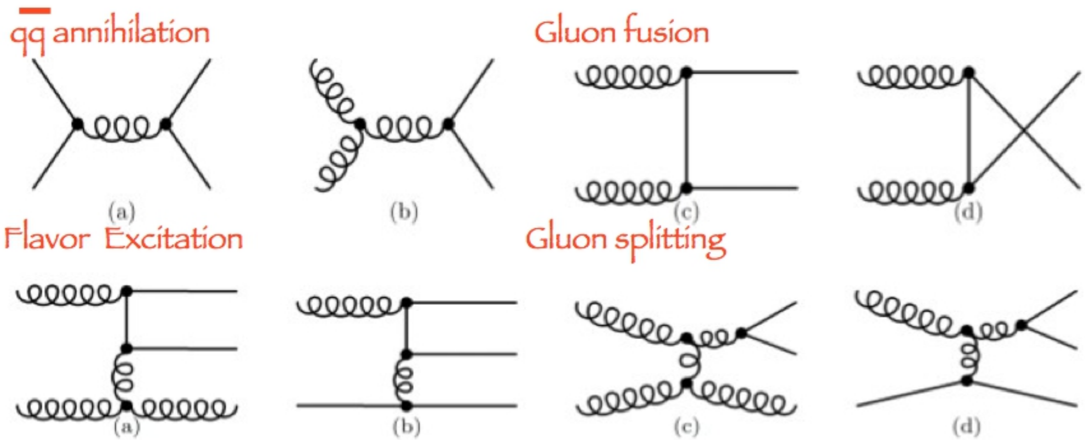
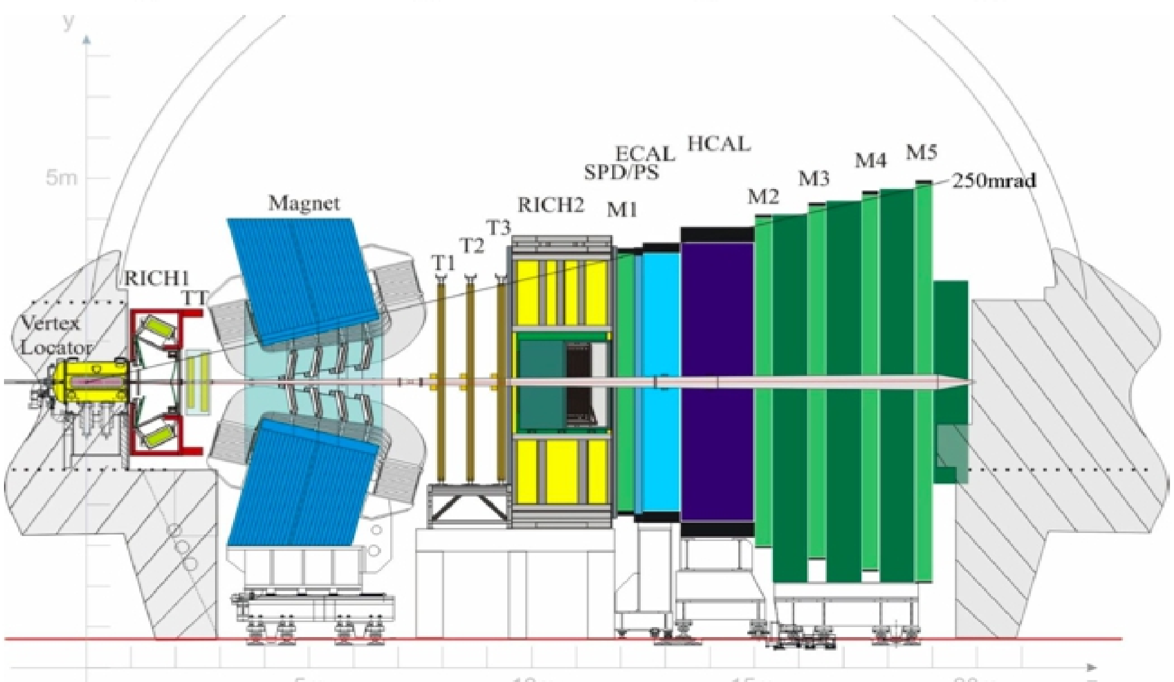
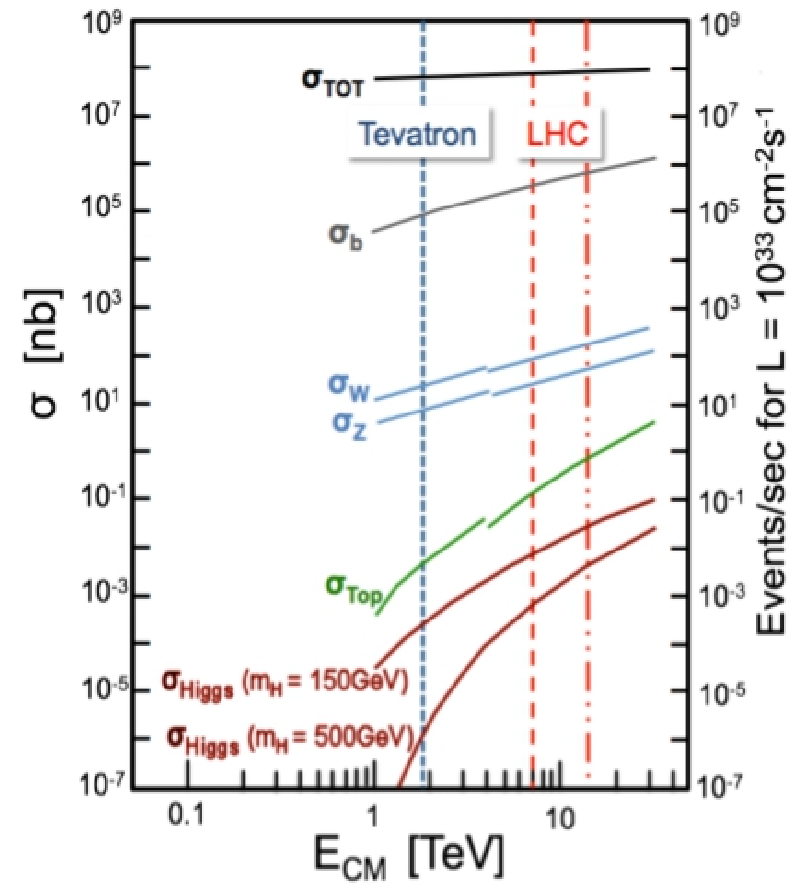
B Physics @ LHC$_b$

- @LHC b quarks are produced in several processes with very high cross section:

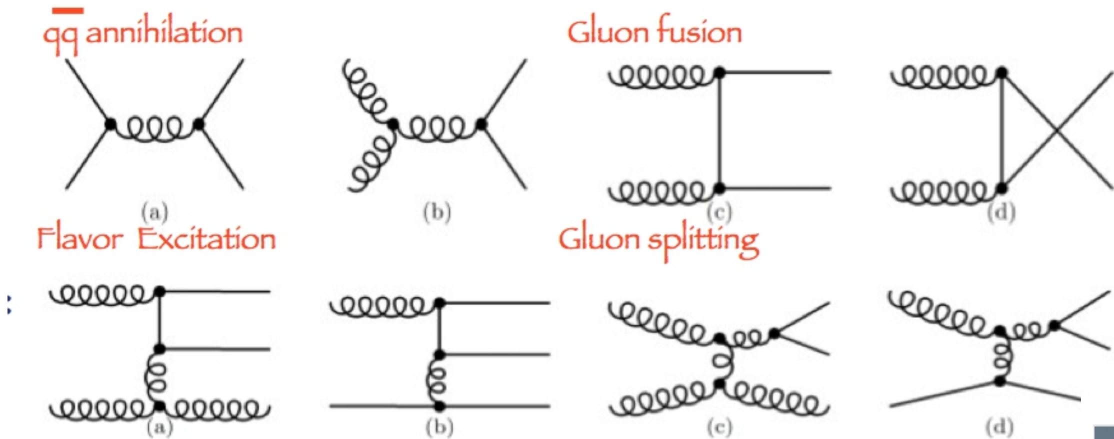






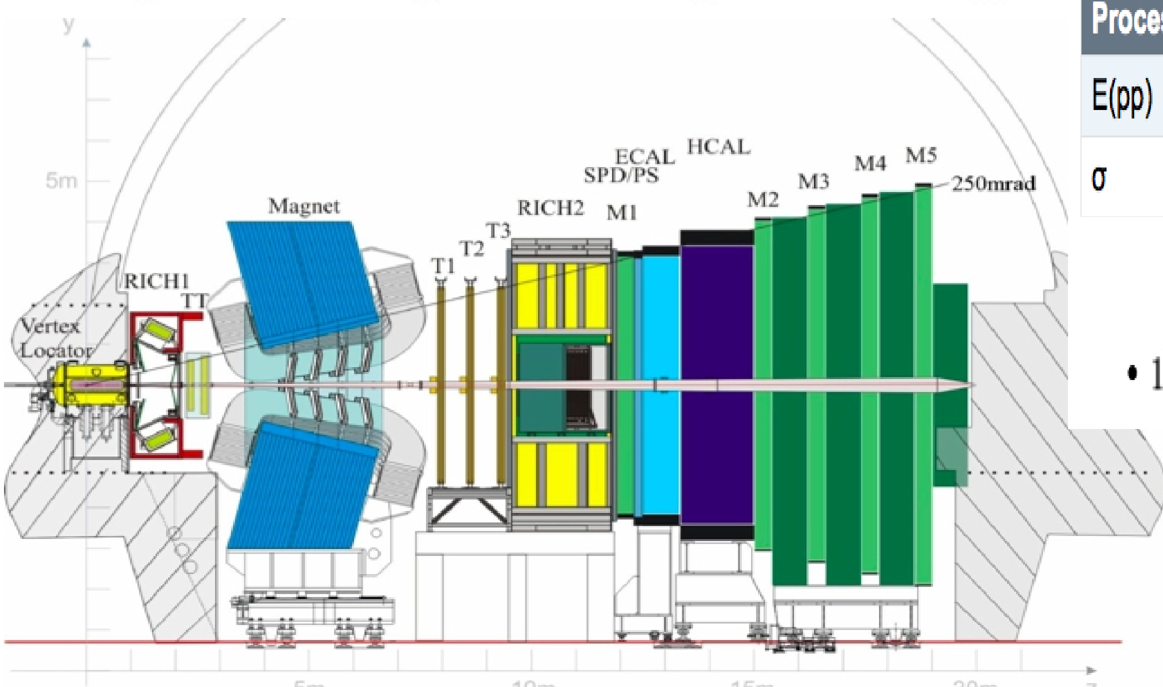
B Physics @ LHC$_b$

- @LHC b quarks are produced in several processes with very high cross section:



pp-collisions				
Year	2010	2011	2012	SUM
L_{int}/fb^{-1}	0.038	1.107	2.082	3.227
E_p/TeV	3.5	3.5	4	-

Process	$pp \to b\bar{b}X$	$pp \to B^{\pm}X$	$pp \to B^0/\bar{B}^0 X$	$pp \to B_s^0/\bar{B}_s^0 X$
E(pp)	7TeV	7TeV	7TeV	7TeV
σ	$(75.3 \pm 14.1)\mu b$	$(38.9 \pm 2.8)\mu b$	$(38.1 \pm 6.0)\mu b$	$(10.5 \pm 1.3)\mu b$

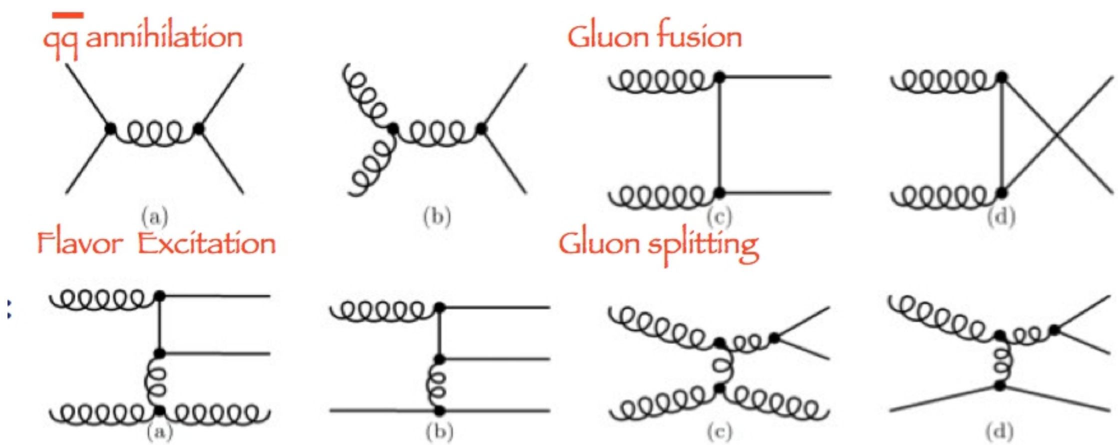


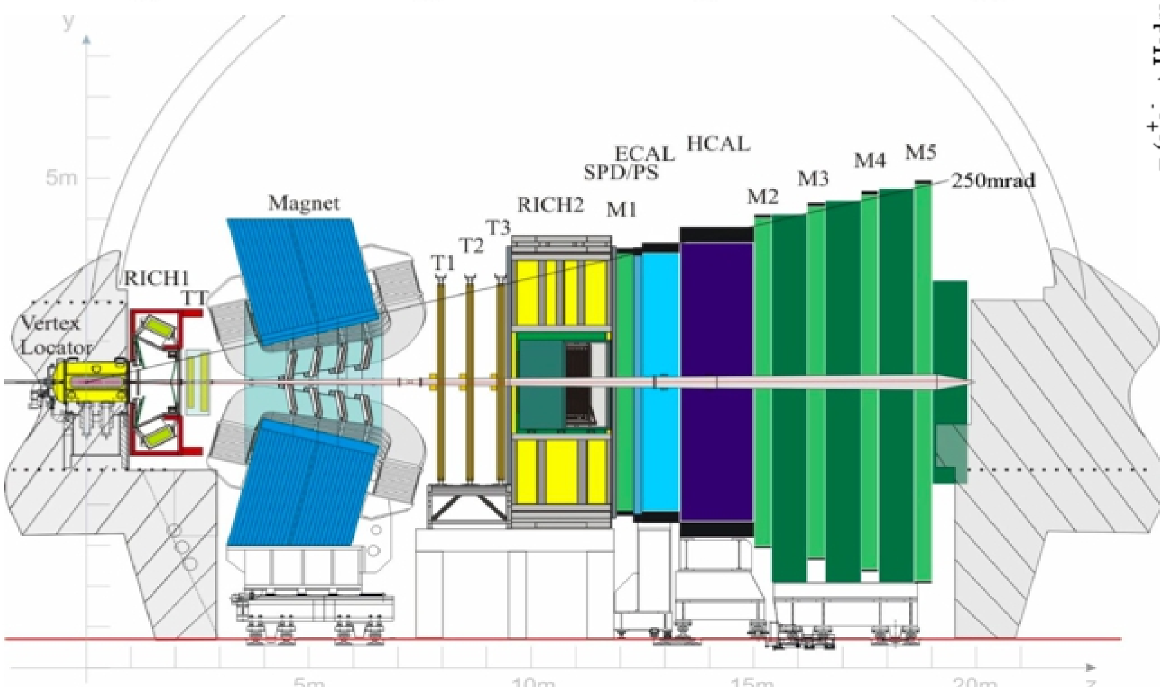
- $1\mu b = 10^9/10^{-15}/b^{-1} = 10^9$ Events$/fb^{-1}$

Nbb(Run1)~3 10^9 (2011-2012)

B Physics @ LHC$_b$

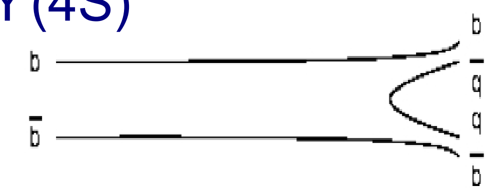
- @LHC b quarks are produced in several processes with very high cross section:

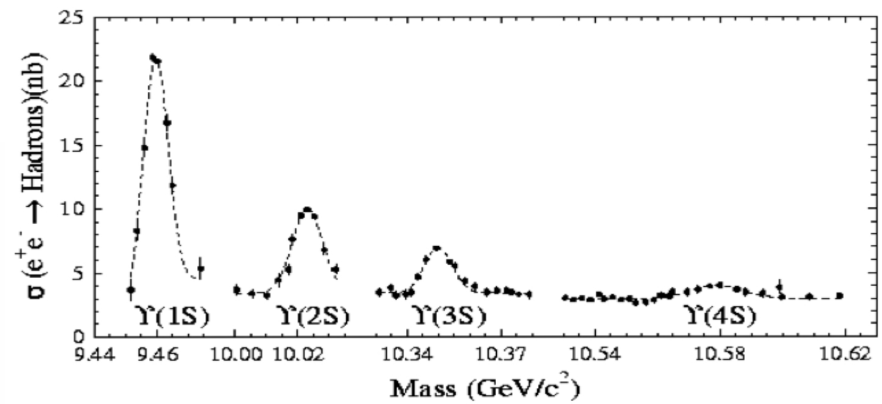




For comparison B-Factories:

Υ(4S)





$\sigma(e^+e^- \rightarrow \Upsilon(4S) \rightarrow BB) = 1.05$ nb

L~ 10^{34} cm^{-2}s^{-1}

Lint~400/700 fb^{-1} (Babar/Belle)

Nbb~420/735 10^6

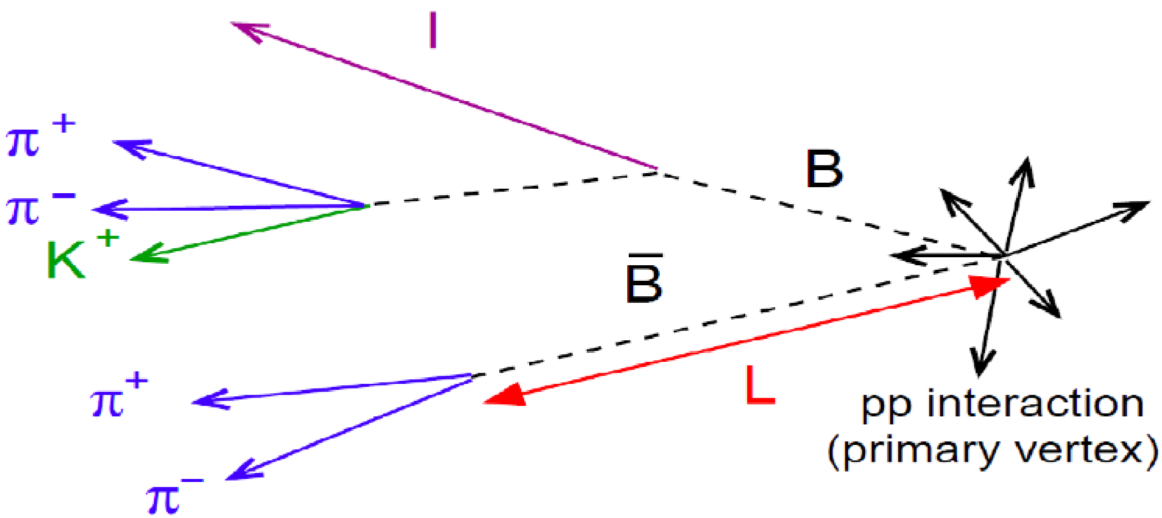
B Physics @ LHC_b

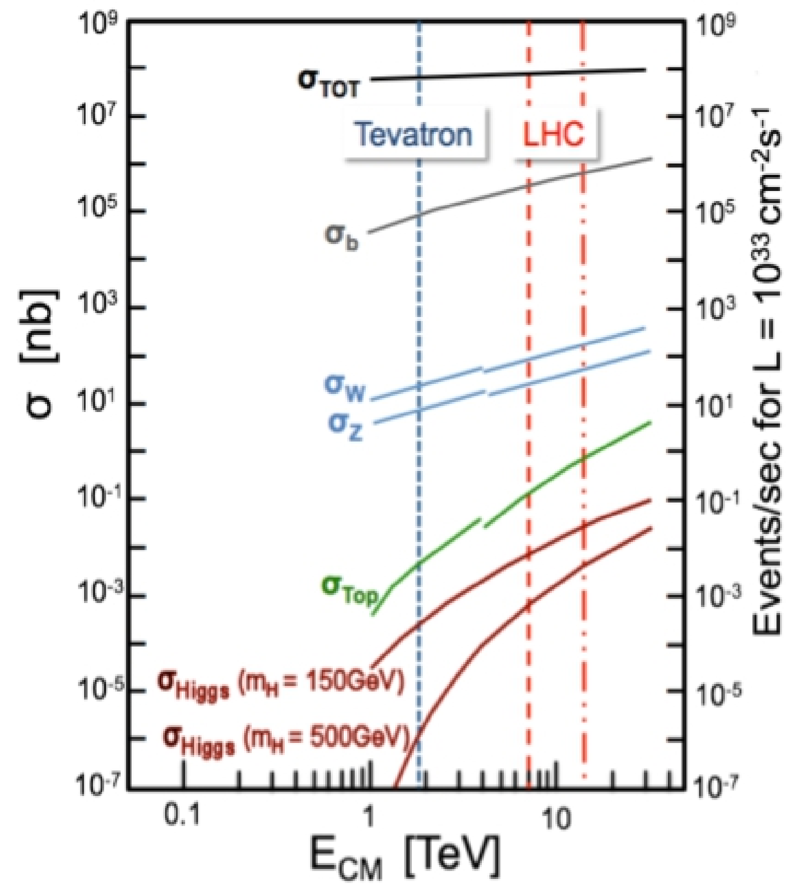
- @LHC b quarks are produced in several processes with very high cross section:

- b quark produced in about 0.5% of pp collisions

- Most B mesons produced forward, average decay lenght L ~ 7 mm

- Momentum p ~ 30 GeV





B Physics @ LHC$_b$

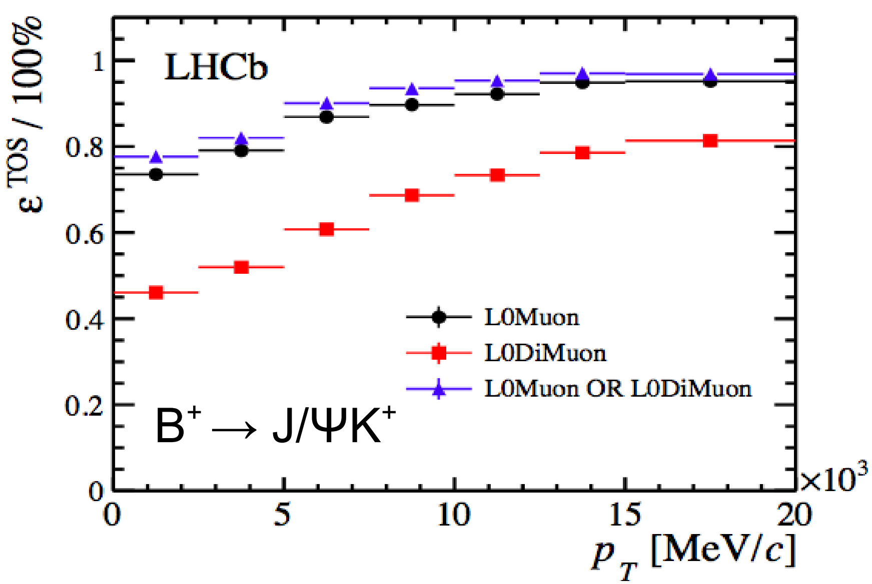
Trigger @ LHCb (Run 1): Level-0, High Level Trigger [arXiv:1412.6352 (2014)]

- Level-0: implemented in hardware, rate < 1 MHz (bunch crossing 40 MHz)
  - L0-Calorimeter, L0-Muon, L0-PileUp
  - Informations from Calorimeters (Scintillator Pad Detector, Preshower, Electromagnetic and Hadronic Calorimenters)

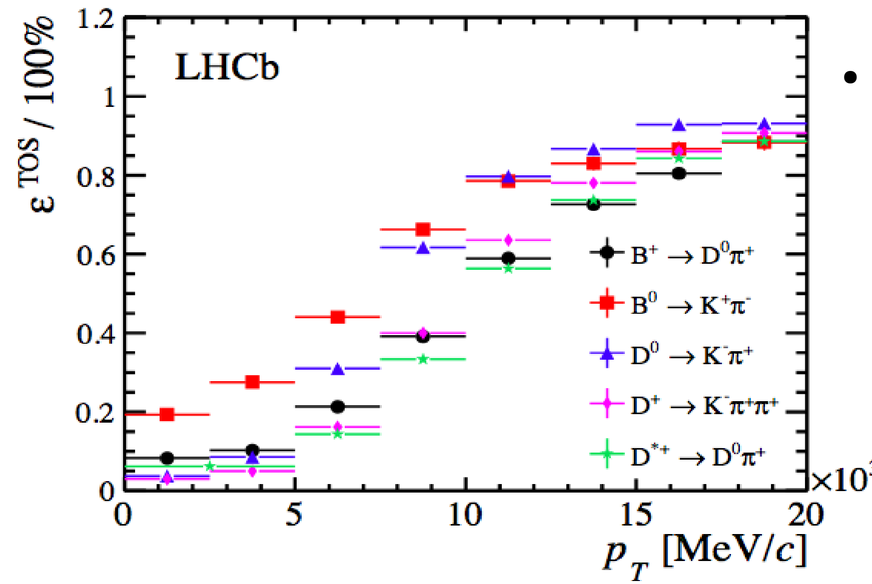
	p_T or E_T 2011	p_T or E_T 2012	SPD 2011 and 2012
single muon	1.48 GeV/c	1.76 GeV/c	600
dimuon $p_{T1} \times p_{T2}$	$(1.30\ \mathrm{GeV}/c)^2$	$(1.60\ \mathrm{GeV}/c)^2$	900
hadron	3.50 GeV	3.70 GeV	600
electron	2.50 GeV	3.00 GeV	600
photon	2.50 GeV	3.00 GeV	600

Scintillator PAD Detector
Number of hit cells

L0 muon trigger



L0 hadron trigger



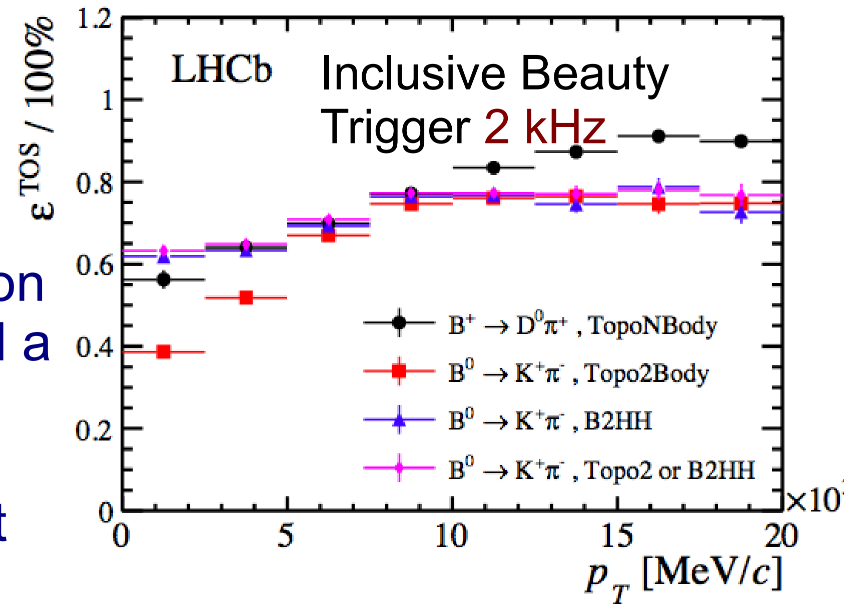
- Efficiency depends on number of prongs

B Physics @ LHC_b

Trigger @ LHCb (Run 1): Level-0, High Level Trigger [arXiv:1412.6352 (2014)]

- High Level Trigger (software, rate < 5 kHz) divided in two levels (partial (80 kHz) and full event reconstruction)

- Beauty Trigger: partially reconstructed b-hadron decays with at least two charged particles and a displaced decay vertex. Track selected based on track fit χ^2, Impact Parameter, muon and electron identification, flight distance, invariant mass



Relative ε

channel	L0	HLT1	HLT2
$B^+ \to J/\psi K^+$, $J/\psi \to \mu^+\mu^-$	89%	92%	87%
$B^0 \to K^+\pi^-$	53%	97%	80%
$B^0 \to D^+\pi^-$, $D^+ \to K^-\pi^+\pi^+$	59%	98%	77%
$D^+ \to K^-\pi^+\pi^+$	44%	89%	91%
$D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+\pi^-\pi^+$	49%	93%	30%

B Physics @ LHC_b

Flavor Tagging @ LHCb [Eur. Phys. J. C 72, 2022 (2012)]

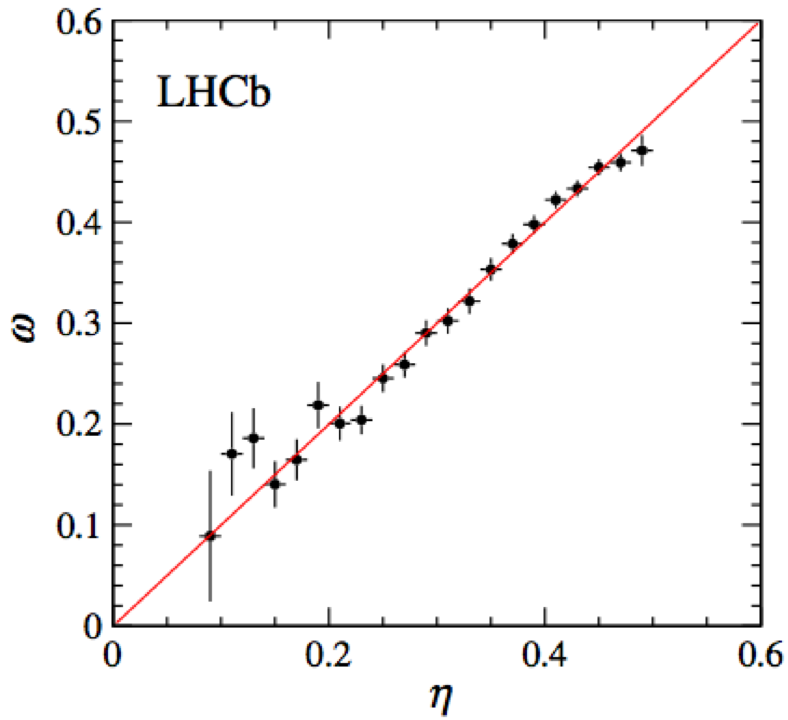
- Flavor of the B_s meson at production determined using Opposite-Side and Same-Side tagging algorithms:

- OS: b quarks are predominantly produced in quark-antiquark pairs.
  - By studying the decay products of the second b-hadron in the event it is possible to tag the flavor of the signal one.
  - OS tagger uses:
    - Charge of leptons (e, μ) from semileptonic b decays
    - Charge of kaons from $b \rightarrow c \rightarrow s$
    - Charge of inclusive secondary vertex from b-hadron decays
    - Optimized on $B^+ \rightarrow J/\Psi K^+$, $B \rightarrow D^{*-} \mu^+ X$, $B^0 \rightarrow D^- \pi^+$

- SS: exploits the hadronization process of the b quark forming the signal B meson
  - Net strangeness of the pp collision is zero: s quark hadronizing in the B_s meson produced in association with a $\bar{s}$ which in 50% of the cases hadronizes in a K^+ which tags the flavor of the B_s at the production
  - Optimized on $B_s \rightarrow D^-_s \pi^+$

Flavor Tagging @ LHCb

- OS & SS algorithms based on Neutal Networks trained on simulated events exploiting several variables
  - Estimated mistag probability η subsequently calibrated with $B^{+/-} \rightarrow J/\Psi K^{+/-}$ data control samples (ω):



$$\omega(\eta) = p_0 + \frac{\Delta p_0}{2} + p_1(\eta - \langle\eta\rangle), \quad (B)$$

$$\bar{\omega}(\eta) = p_0 - \frac{\Delta p_0}{2} + p_1(\eta - \langle\eta\rangle), \quad (\bar{B})$$

Calibration	p_0	p_1	$\langle\eta\rangle$	Δp_0
OS	$0.392 \pm 0.002 \pm 0.008$	$1.000 \pm 0.020 \pm 0.012$	0.392	0.011 ± 0.003
SSK	$0.350 \pm 0.015 \pm 0.007$	$1.000 \pm 0.160 \pm 0.020$	0.350	-0.019 ± 0.005

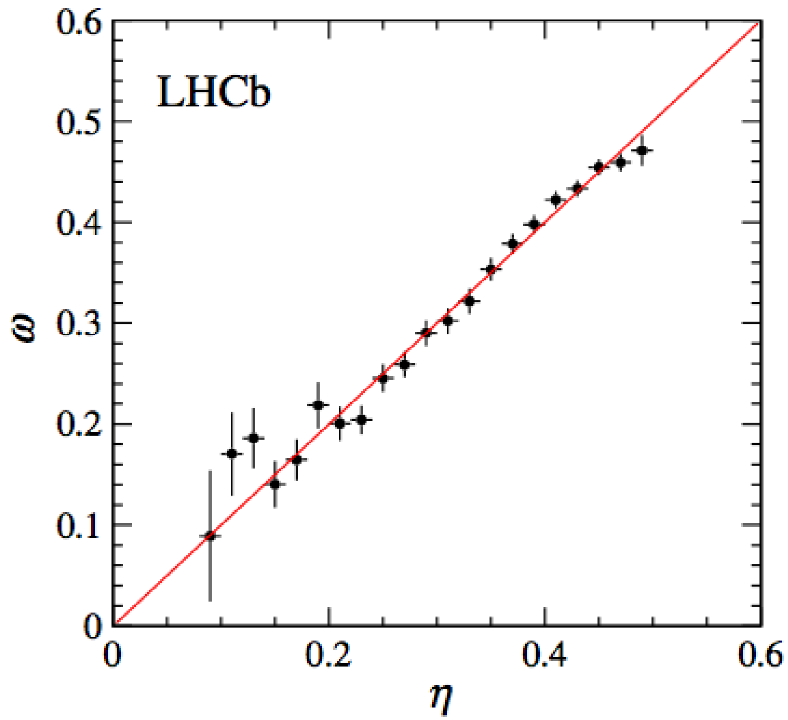
- Parameterization chosen to minimize the correlation between p_0 and p_1

- Systematics from comparison between different channels and data taking periods
- No significant difference between B and $\bar{B}$ observed

B Physics @ LHC_b

Flavor Tagging @ LHCb

- OS & SS algorithms based on Neutal Networks trained on simulated events exploiting several variables
  - Estimated mistag probability η subsequently calibrated with $B^{+/-} \to J/\Psi K^{+/-}$ data control samples:



- By combining the two different taggers, taking into account events with both informations available:

	ω	ε_{tag}	$Q=\varepsilon_{tag}(1-2\omega)^2$
OS	(36.83±0.15)%	(33.00±0.28)%	(2.29±0.06)%
SS	~46%	(10.26±0.18)%	(0.89±0.17)%
OS+SS	35.9%	(39.36±0.32)%	(3.13±0.23)%

To be compared with B-Factories experiments: Q~33%

Measurement of Δm_s @ LHC_b

LHC_b Measurement using $B_s \rightarrow D^-_s \pi^+$ (L=1 fb^{-1}, 3 $x10^{11}$ bb evts)

[New J. Phys. 15, 053021 (2013)]

- Fully reconstruct D_s mesons in five different flavor-specific decay modes $D^-_s \rightarrow \Phi\pi^-$, K^*K^-, $K^+K^-\pi^-$, $K^-\pi^+\pi^-$, $\pi^-\pi^+\pi^-$ (34k signal candidates selected), masses of the intermediate Φ, $K^* \rightarrow K^+\pi^-$ resonances exploited
- B_s meson flavor at production obtained using flavor tagging algorithms
- Signal/BKG separation by means of a Boost Decision Tree using the angle between B_s flight direction and its momentum, B_s and D_s flight distances in the transverse plane, Impact Parameters of daughter tracks
- Simultaneous fit to B_s invariant mass (m) and decay time (t) distributions with PDFs (for signal and BKG in the different five modes):

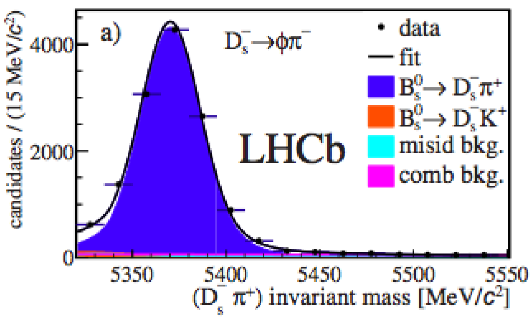
$$\mathcal{P} = \mathcal{P}_m(m)\,\mathcal{P}_t(t, q\,|\sigma_t, \eta)\,\mathcal{P}_{\sigma_t}(\sigma_t)\,\mathcal{P}_\eta(\eta)$$

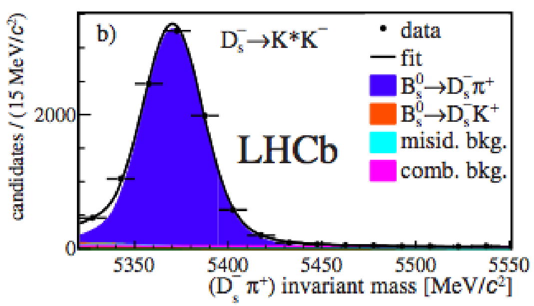
- q = tagging decision (0: no tag info, -1: mixed events, +1: unmixed events),
- η = mistag probability ($0<\eta<0.5$). Last two terms in the PDF (obtained from data using signal band BKG subtracted & side bands) help in the relative normalization for signal and BKG samples.

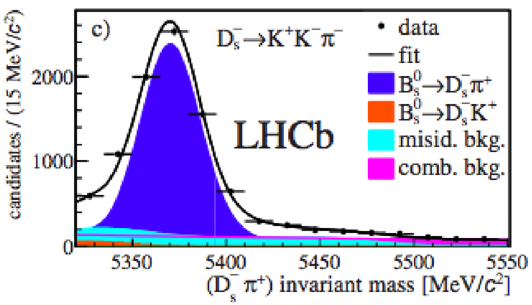
Measurement of Δm_s @ LHC_b

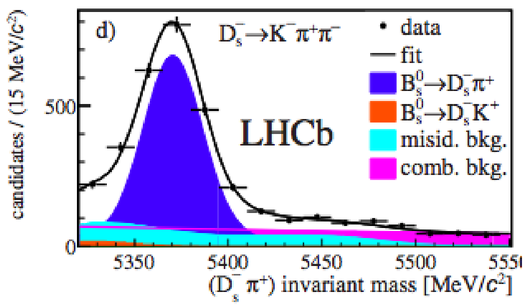
LHC_b Measurement using $B_s \rightarrow D^-_s \pi^+$ (L=1 fb^{-1}, 3 x10^{11} bb evts)

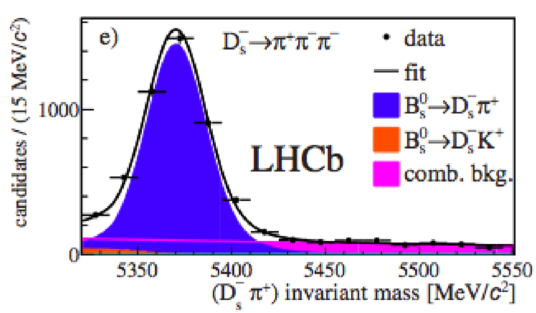
[New J. Phys. 15, 053021 (2013)]











- B_s invariant mass obtained by constraining the D_s mass to PDG
- Mean and width floated, tails from MC

Decay mode	($D_s^-\pi^+$) candidates	$f_{B_s^0 \rightarrow D_s^-\pi^+}$	$f_{B_s^0 \rightarrow D_s^{\mp}K^{\pm}}$
$D_s^- \rightarrow \phi(K^+K^-)\pi^-$	14 691	0.834 ± 0.008	
$D_s^- \rightarrow K^{*0}(K^+\pi^-)K^-$	10 866	0.857 ± 0.009	
$D_s^- \rightarrow K^+K^-\pi^-$ nonresonant	11 262	0.595 ± 0.009	
$D_s^- \rightarrow K^-\pi^+\pi^-$	4288	0.437 ± 0.014	
$D_s^- \rightarrow \pi^-\pi^+\pi^-$	6674	0.599 ± 0.008	0.019 ± 0.010
Total	47 781	0.714 ± 0.004	0.019 ± 0.010

- $B_s \rightarrow D_s K$ with misidentified $K \rightarrow \pi$ treated as signal in the decay time fit

Measurement of Δm_s @ LHC_b

LHC_b Measurement using $B_s \rightarrow D^-_s \pi^+$ ($L=1\ fb^{-1}$, 3×10^{11} bb evts)

[New J. Phys. 15, 053021 (2013)]

Decay time description

- Definition: $t = \frac{Lm}{p}$ (L=decay lenght)

- With no tagging information (i.e. neglecting Oscillation term & taking into account resolution and decay time acceptance:

$$\mathcal{P}_t(t|\sigma_t) \propto \left[\Gamma_s e^{-\Gamma_s t} \cosh\left(\frac{\Delta\Gamma_s}{2} t\right) \theta(t)\right] \otimes G(t; 0, S_{\sigma_t}\sigma_t) \mathcal{E}_t(t)$$

Γs fixed to WA

$\Delta\Gamma_s = 0.106 \pm 0.011 \pm 0.007\ ps^{-1}$

[LHCb, Phys. Rev. D 87, 112010 (2013)]

- Mandatory to obtain a resolution small compared with the B_s oscillation period $T=2\pi/\Delta m_s \sim 350$ fs

- θ(t): Heaviside step function (only positive decay times considered)

Measurement of Δm_s @ LHC_b

LHC_b Measurement using $B_s \to D^-_s \pi^+$ (L=1 fb^{-1}, 3 x10^{11} bb evts)

[New J. Phys. 15, 053021 (2013)]

Decay time description

$$\mathcal{P}_t(t|\sigma_t) \propto \left[\Gamma_s e^{-\Gamma_s t} \cosh\left(\frac{\Delta\Gamma_s}{2}t\right)\theta(t)\right] \otimes G(t;0,S_{\sigma_t}\sigma_t)\mathcal{E}_t(t)$$

Γ_s fixed to WA

$$\Delta\Gamma_s = 0.106 \pm 0.011 \pm 0.007\,\mathrm{ps}^{-1}$$

[LHCb, Phys. Rev. D 87, 112010 (2013)]

- G: Gaussian resolution function:
  - σ_t using event-by-event estimate from the fit to the B_s decay vertex
  - Scaling factor $S_{\sigma t}$ =1.37 ± 0.1 calibrated using fake B_s formed with prompt D_s from primary interaction + random π. Average resolution $S_{\sigma t}$ $<\sigma_t>$=44 x 10^{-15} s

- ε_t(t): Decay time acceptance due to requirement of large track impact parameters
  - Parameterization studied on MC, parameters floated in the fit

- B^0 and Λ_b BKG PDF identical to the signal with ΔΓ=0 and Γ replaced by respective decay widths
- Combinatorial PDF from Side Band: double exponential x polynomial with floating parameters

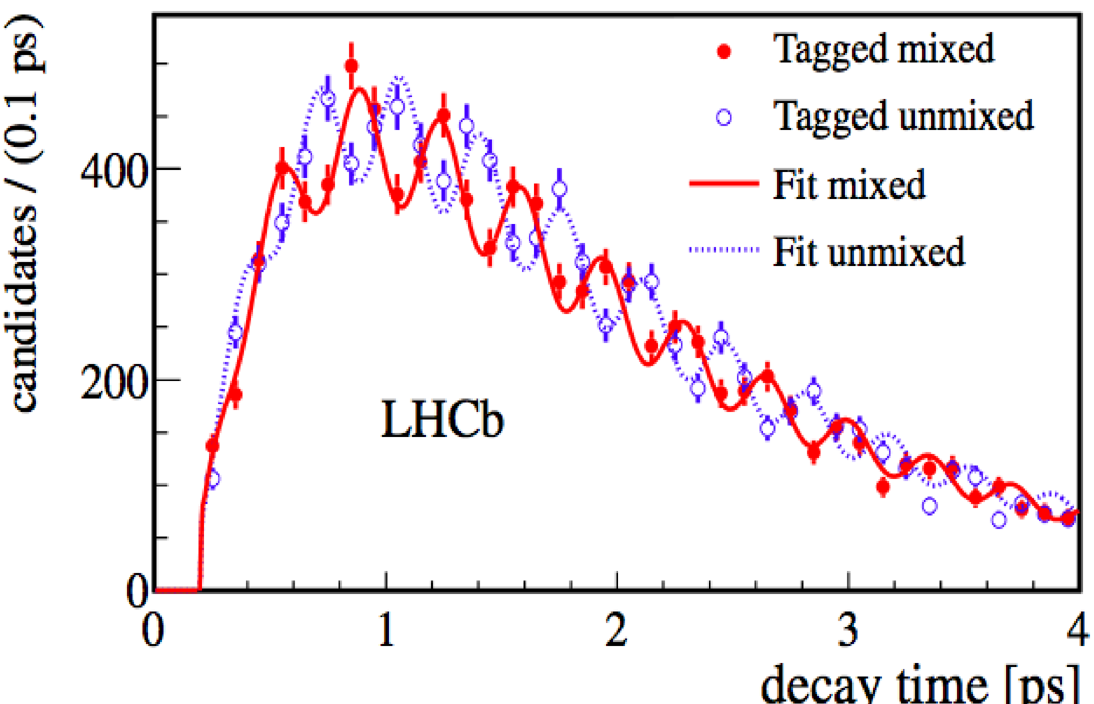
Measurement of Δm_s @ LHC_b

LHC_b Measurement using $B_s \to D^-_s \pi^+$ (L=1 fb^{-1}, 3 x10^{11} bb evts)

[New J. Phys. 15, 053021 (2013)]

- Reconstructed decay time distribution for tagged events (~40%) including detector effects:

$$\mathcal{P}_t(t|\sigma_t) \propto \left\{ \Gamma_s e^{-\Gamma_s t} \frac{1}{2} \left[\cosh\left(\frac{\Delta\Gamma_s}{2} t\right) + q\left[1 - 2\omega(\eta_{OST}, \eta_{SST})\right] \cos(\Delta m_s t) \right] \theta(t) \right\}$$
$$\otimes G(t, S_{\sigma_t} \sigma_t)\, \mathcal{E}_t(t)\, \epsilon,$$



- q: tagging decision from OS-SS (+1: Unmixed, -1: Mixed); Q=(3.8 ± 0.5)%
- $\omega(\eta_{OST}, \eta_{SST})$ mistag probability
- Combinatorial BKG has random tagging
- Tagging parameters and Δm assumed the same for the five decay modes

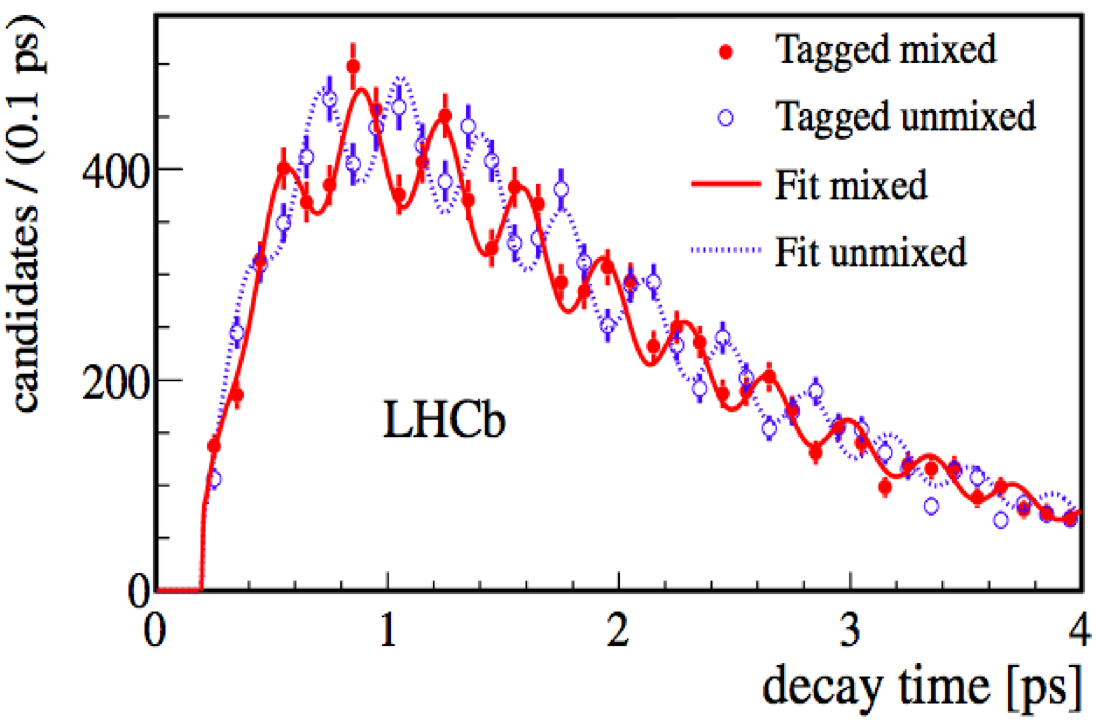
$$\Delta m_s = (17.768 \pm 0.023 \pm 0.006)\, ps^{-1}$$

Measurement of Δm_s @ LHC_b

LHC_b Measurement using $B_s \rightarrow D^-_s \pi^+$ (L=1 fb^{-1}, 3 x10^{11} bb evts)

[New J. Phys. 15, 053021 (2013)]

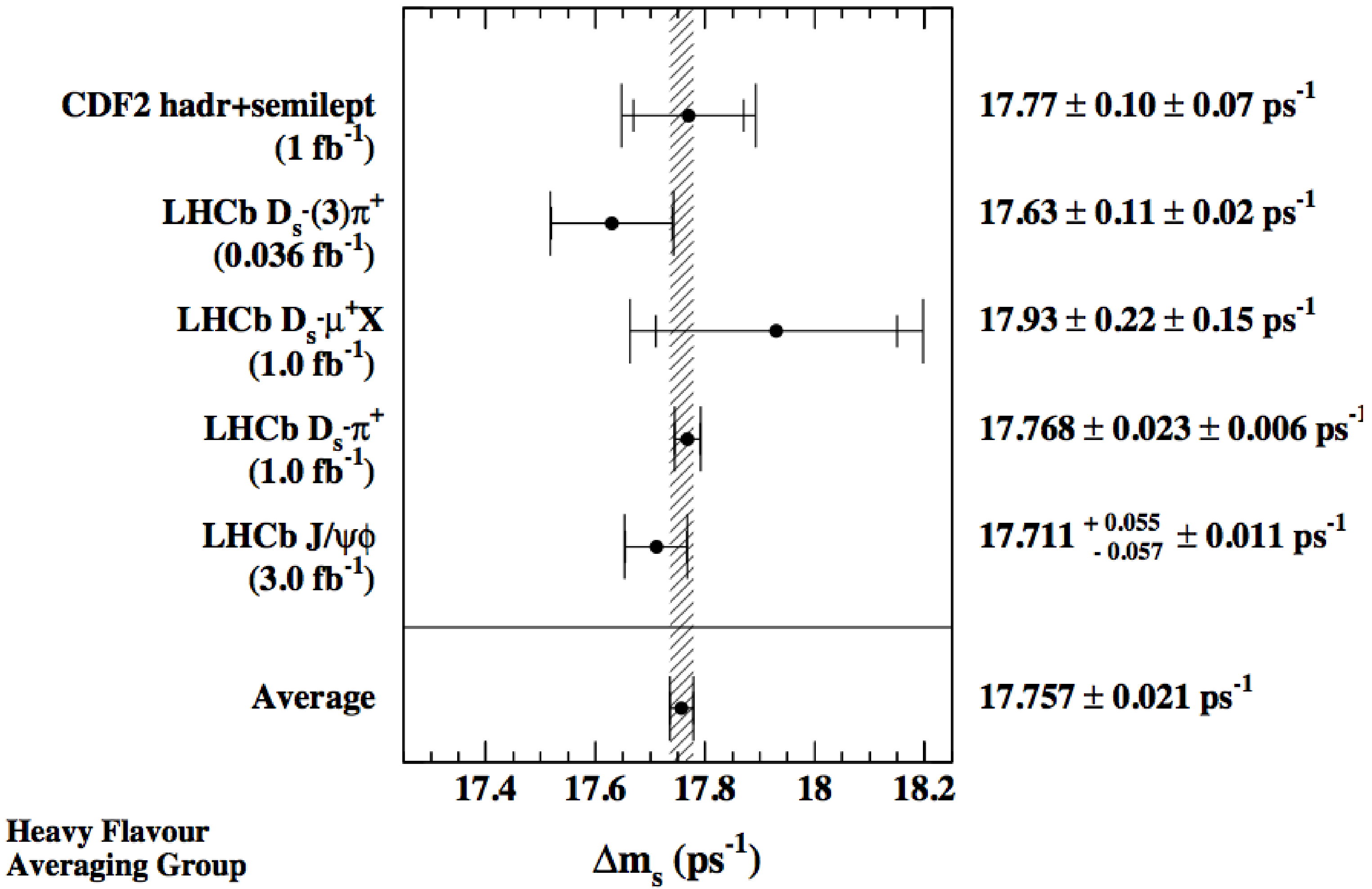
- Systematics dominated by uncertainty on decay time $t = \frac{Lm}{p}$
  - Longit. Detector scale by comparing the track alignment and survey data and evaluating the track distribution in the vertex detector (0.02% on decay time)
  - Time-scale from overall momentum scale from measurement of well known resonances (0.02% effect on decay time)



$$\Delta m_s = (17.768 \pm 0.023 \pm 0.006)\ ps^{-1}$$

Source	Uncertainty (ps^{-1})
z-scale	0.004
Momentum scale	0.004
Decay time bias	0.001
Total systematic uncertainty	0.006

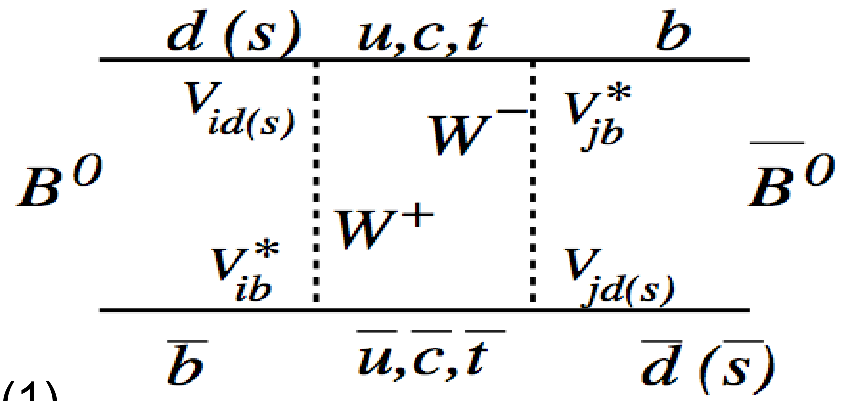
Measurement of Δm_s



- World Average $\Delta m_s = (17.757 \pm 0.021)\, ps^{-1}$

$|V_{td}|/|V_{ts}|$ from B^0 Mixing

- Not measurable in tree-level processes involving top quarks, can be determined using rare radiative B or K decays or B^0 oscillation involving top-quarks in loop/box diagrams
- Theoretical uncertainties in hadronic effects reduced by taking ratios of processes involving B_d and B_s decays
- Using



$$\Delta m_q = \frac{G_F^2}{6\pi^2} f_B^2 m_B M_W^2 \eta_B S_0 |V^*_{tb} V_{tq}|^2 \hat{B}_B$$

$$\Delta m_d = (0.510 \pm 0.003)\,\mathrm{ps}^{-1}$$

$$\Delta m_s = (17.761 \pm 0.022)\,\mathrm{ps}^{-1}$$

S_0: known function

η: QCD corrections O(1)

- f_B: weak decay constant parameterizing matrix elements of axial-vector currents and related to the wave functions overlap
- B_B: bag parameter: operator entering the computation of the box diagrams after integrating out the heavy quarks and W bosons contributions. Responsible of the change in B flavor by 2
- Both calculated with LQCD [S. Aoki et al., arXiv:1310.8555 (2013)]

$$f_{B_d}\sqrt{B_{B_d}} = 216 \pm 15\, MeV\,; \quad f_{B_s}\sqrt{B_{B_s}} = 266 \pm 18\, MeV$$

$|V_{td}|/|V_{ts}|$ from B^0 Mixing

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$$f_{B_d}\sqrt{B_{B_d}} = 216 \pm 15\,MeV\,;\quad f_{B_s}\sqrt{B_{B_s}} = 266 \pm 18\,MeV$$

[S. Aoki et al., arXiv:1310.8555 (2013)]

$$|V_{td}| = (8.4 \pm 0.6) \times 10^{-3}, \qquad |V_{ts}| = (40.0 \pm 2.7) \times 10^{-3}$$

- Error reduced in the ratio

$$\xi = (f_{B_s}\sqrt{\hat{B}_{B_s}})/(f_{B_d}\sqrt{\hat{B}_{B_d}}) = 1.268 \pm 0.063$$

$$|V_{td}/V_{ts}| = 0.216 \pm 0.001 \pm 0.011$$

- In agreement with $B \to \rho\gamma / B \to K^*\gamma$ result from radiative penguins

$$|V_{td}/V_{ts}| = 0.21 \pm 0.04$$

$|V_{td}|/|V_{ts}|$ from B^0 Mixing

- Not measurable in tree-level processes involving top quarks, can be determined using rare radiative B or K decays or B^0 oscillation involving top-quarks in loop/box diagrams
- Theoretical uncertainties in hadronic effects reduced by taking ratios of processes involving B_d and B_s decays
- Using

$$\Delta m_q = \frac{G_F^2}{6\pi^2} f_B^2 m_B M_W^2 \eta_B S_0 |V_{tb}^* V_{tq}|^2 \hat{B}_B$$

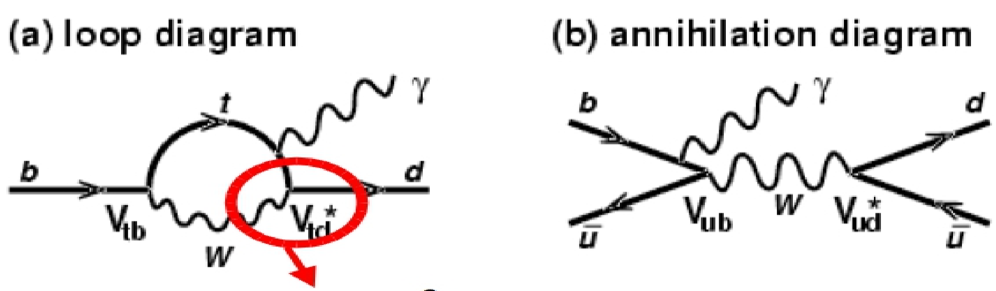
$$f_{B_d}\sqrt{B_{B_d}} = 216 \pm 15\, MeV\,; \quad f_{B_s}\sqrt{B_{B_s}} = 266 \pm 18\, MeV$$

[S. Aoki et al., arXiv:1310.8555 (2013)]

$$\Delta m_d = (0.510 \pm 0.003)\,\mathrm{ps}^{-1}$$

$$\Delta m_s = (17.761 \pm 0.022)\,\mathrm{ps}^{-1}$$

$$|V_{td}| = (8.4 \pm 0.6) \times 10^{-3}, \qquad |V_{ts}| = (40.0 \pm 2.7) \times 10^{-3}$$



$$\left|\frac{V_{td}}{V_{ts}}\right|^2 \sim 0.04$$

- In agreement with B → ργ/B → K*γ result from radiative penguins

$$|V_{td}/V_{ts}| = 0.21 \pm 0.04$$

Measurement of A^q_{CP}

- Two classes of measurements available:

  - Inclusive dilepton asymmetry analyses [Belle, Phys. Rev. D 73, 112002 (2006)], [D0, Phys. Rev. D 89 012002 (2014)], [Babar, Phys. Rev. Lett. 114, 081801 (2015)]:

$$A^q_{CP} = \frac{Prob(\bar{B}^0_q \to B^0_q, t) - Prob(B^0_q \to \bar{B}^0_q, t)}{Prob(\bar{B}^0_q \to B^0_q, t) + Prob(B^0_q \to \bar{B}^0_q, t)} = A^q_{SL} = \frac{N_q(l^+ l^+) - N_q(l^- l^-)}{N_q(l^+ l^+) + N_q(l^- l^-)}$$

    - Hadron Colliders Experiments measure a combination of B^0_d and B^0_s CP parameters: $A^b_{SL} = C_d A^d_{SL} + C_s A^s_{SL}$ $\quad (A^b_{SL}(SM) = (-0.023 \pm 0.004) \times 10^{-2})$ where $C_{d,s}$ depend on $B^0_{d,s}$ production rates and mixing probabilities [D0, Phys. Rev. D 89 012002 (2014)]

  - Flavor specific $B^0_{d,s}$ analyses [D0, Phys. Rev. D 86, 072009 (2012)], [D0, Phys. Rev. Lett. 110, 011801 (2013)], [Babar, Phys. Rev. Lett. 111, 101802 (2013)], [LHCb, Phys. Rev. Lett. 114, 041601 (2015)], [LHCb, Phys. Lett. B 728, 607-615 (2014)]:

    - Reconstruction of $B^0_d \to D^{(*)} l X$, $B^0_s \to D_s l X$
    - Using (or not) flavor tagging information at production

Measurement of A^q_{CP}

Detector-related Asymmetries

- Current statistical precision of the experiments < 0.5% requires very good control of spurious charge asymmetries from:
  - Charge-asymmetric Background: hadrons misidentified as leptons & leptons from light hadron decays (e.g. positive kaons have smaller interactions cross-section than negative kaons in matter reflecting in a higher selection efficiency for K^+ vs K^-)
  - Track reconstruction and lepton identification (detector anisotropy could affect efficiencies)
- Most crucial analysis issue and largest systematic uncertainty
- Effect reduced by inverting magnets polarities (D0, LHCb)
- Estimated on control samples (D0, LHCb) or determined directly in the fit to A_{SL} (Babar)

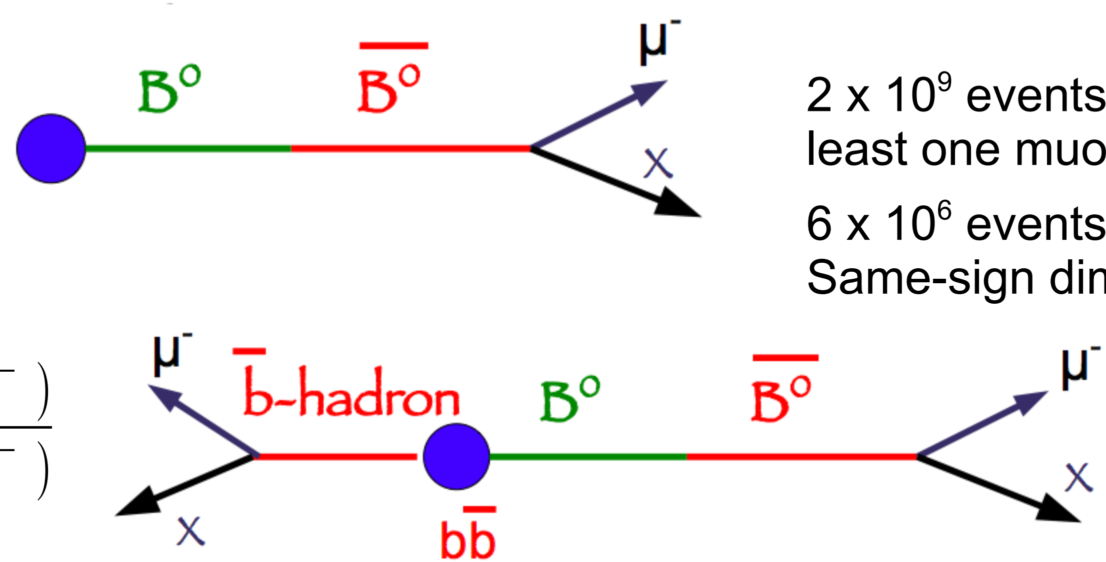
Inclusive dilepton A^b_{SL}

D0 Measurement (L=10.4 fb^{-1}) [D0, Phys. Rev. D 89 012002 (2014)]

- Semileptonic A^b_{SL} measured from inclusive single muon and like-sign dimuon charge asymmetries:

$$a = \frac{n(\mu^+) - n(\mu^-)}{n(\mu^+) + n(\mu^-)}$$

$$A = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)}$$



2 x 10^9 events with at least one muon

6 x 10^6 events with Same-sign dimuons

- Only 3% of single muons come from decays of mixed B^0_q
- Only 30% of equal-charge muons come from decays of mixed B^0_q
- Challenge: understand contributions from:
  - Muons from other b decays, charm and short-lived hadrons
  - Detector-related charge asymmetries
- A^b_{SL} obtained by subtracting the A_{BKG} one from the raw asymmetry A

Inclusive dilepton A^b_{SL}

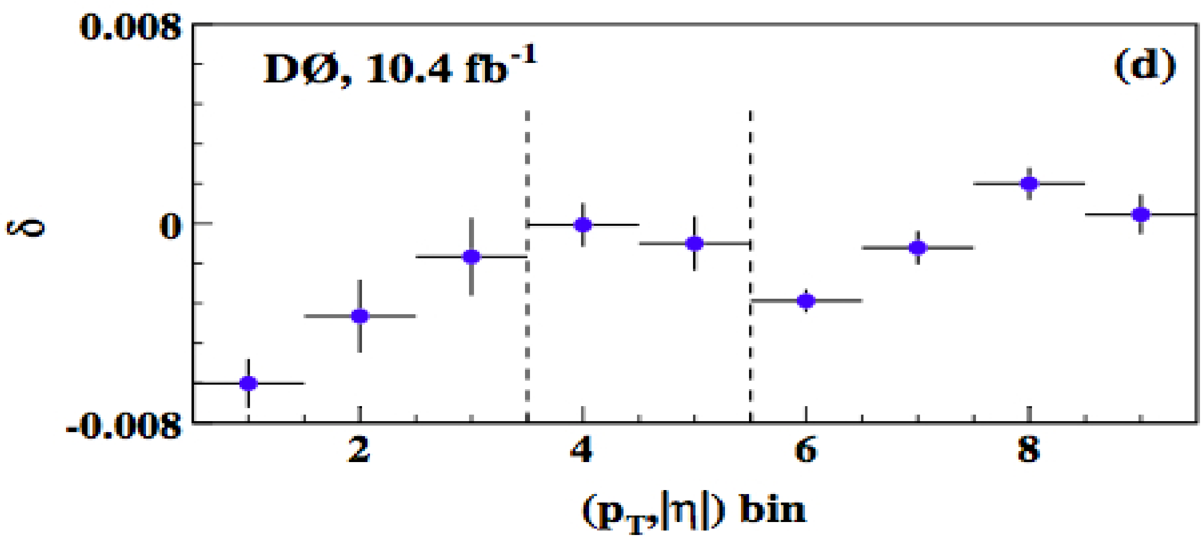
D0 Measurement (L=10.4 fb^{-1}) [D0, Phys. Rev. D 89 012002 (2014)]

- Dominant contribution to the inclusive and like-sign dimuon BKG asymmetries comes from the charge asymmetry of muons produced in decay in flight of $K \to \mu\nu$, $\pi \to \mu$ and misidentified K, π and p:

- Single muon asymmetry in bin i of (p_T, |η|), ($\eta = -\ln\tan\left(\frac{\theta}{2}\right)$ pseudorapidity)

$$a^i = a^i_{CP} + a^i_{\text{bkg}} \qquad a^i_{\text{bkg}} = a^i_\mu + f^i_K a^i_K + f^i_\pi a^i_\pi + f^i_p a^i_p \qquad a^i_\mu \equiv (1 - f^i_{\text{bkg}})\delta_i$$

δ_i=charge asymmetry in single μ detection & identification



$$\delta = -0.0013 \pm 0.0002.$$

From $J/\Psi \to \mu^+\mu^-$ using track info only and counting the tracks identified as muons

Inclusive dilepton A^b_{SL}

D0 Measurement (L=10.4 fb^{-1}) [D0, Phys. Rev. D 89 012002 (2014)]

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δ_i=charge asymmetry in single μ detection & identification

- Fractions of Background K, π and p is obtained taking into account:
  - Measured misidentification rate in the decays $K^{*0} \to K^+\pi^-$ ($K \to \mu$), $K_s \to \pi\pi$ ($\pi \to \mu$), $\Lambda \to \pi p$ ($p \to \mu$)
  - Fractions R^i of K, π and p in the inclusive sample coming from the specific processes
  - Isospin invariance to costrain R^i fractions e.g. $R^i(K^{*0} \to K^+ \pi^-)=R^i(K^{*+} \to K_s \pi^+)$
  - Ratio of the efficiencies to reconstruct the same charged particles in different decays

Inclusive dilepton A^b_{SL}

D0 Measurement (L=10.4 fb^{-1}) [D0, Phys. Rev. D 89 012002 (2014)]

- Dominant contribution to the inclusive and like-sign dimuon BKG asymmetries comes from the charge asymmetry of muons produced in decay in flight of $K \to \mu\nu$, $\pi \to \mu$ and misidentified K, π and p:

  - Dimuon asymmetry in bin i of (p_T, |η|), ($\eta = -\ln\tan\left(\frac{\theta}{2}\right)$ pseudorapidity):

$$A^i \equiv \frac{N_i^+ - N_i^-}{N_i^+ + N_i^-} = A^i_{CP} + A^i_{\rm bkg} \qquad N_i^{\pm} = N_{ii}^{\pm\pm} + \sum_{j=1}^{9} N_{ij}^{\pm\pm} \qquad A^i_{\rm bkg} = \frac{2N_{ii}a^i_{\rm bkg} + \sum_j N_{ij}(a^i_{\rm bkg} + a^j_{\rm bkg})}{N_{ii} + \sum_{j=1}^{9} N_{ij}}$$

- Fractions of Background K, π and p is obtained taking into account:
  - Measured misidentification rate in the decays $K^{*0} \to K^+\pi^-$ ($K \to \mu$), $K_s \to \pi\pi$ ($\pi \to \mu$), $\Lambda \to \pi p$ ($p \to \mu$)
  - Fractions R^i of K, π and p in the inclusive sample coming from the specific processes
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Inclusive dilepton A^b_{SL}

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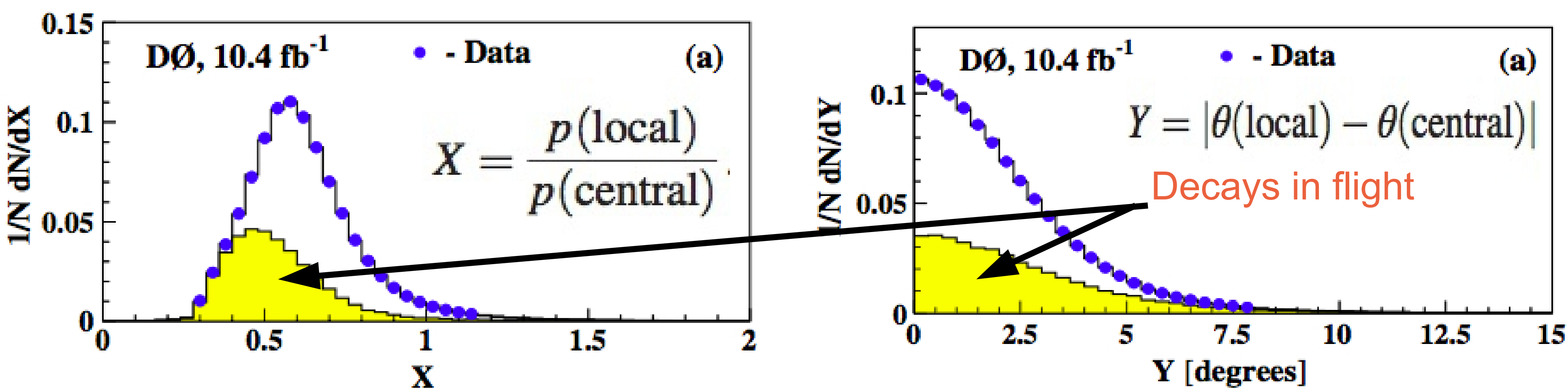
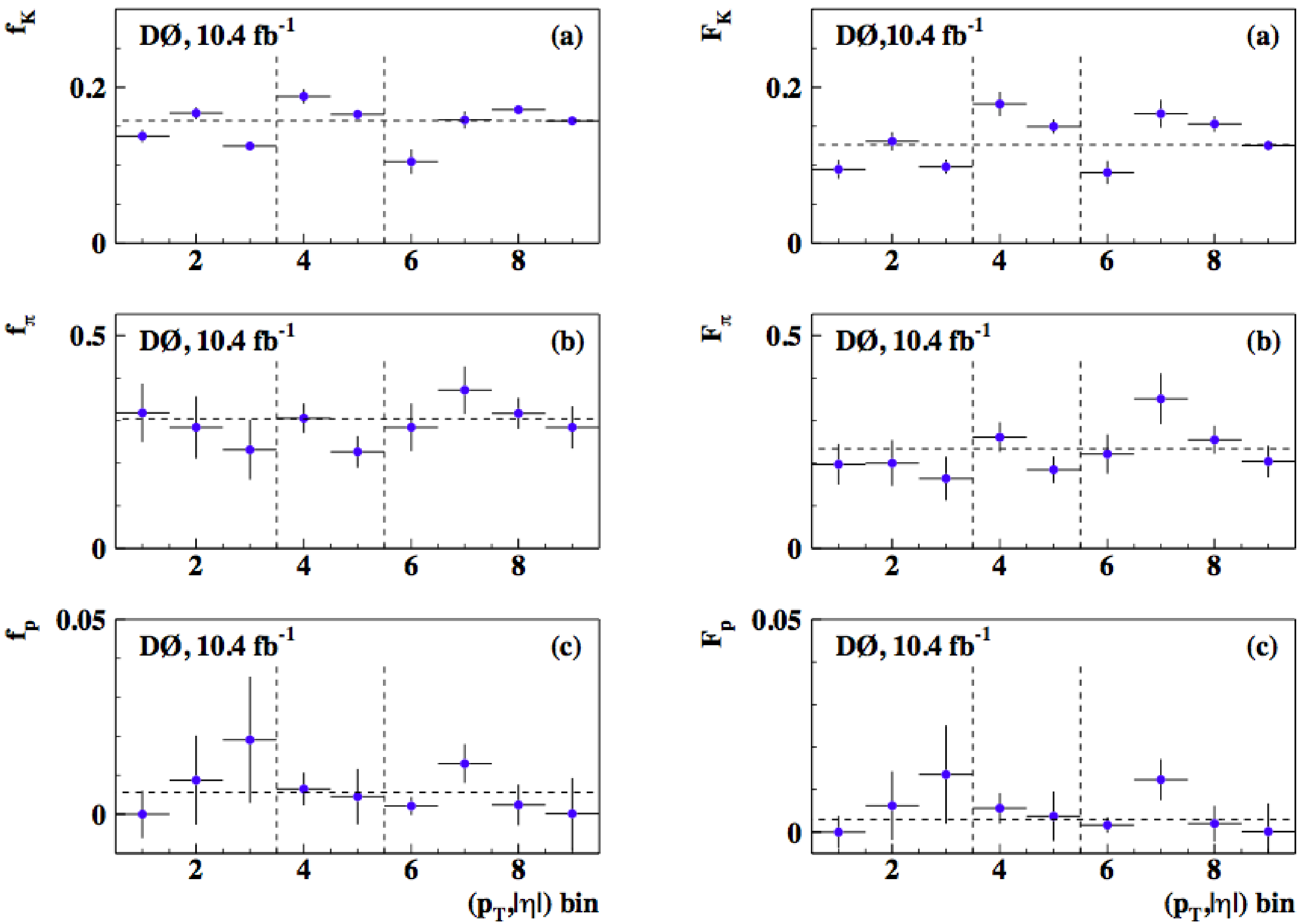
- BKG Fractions checked using comparison of central tracking and local reconstruction for muons: difference in P and angle sensitive to fraction of decays in flight



Inclusive dilepton A^{b}_{SL}

D0 Measurement (L=10.4 fb^{-1}) [D0, Phys. Rev. D 89 012002 (2014)]



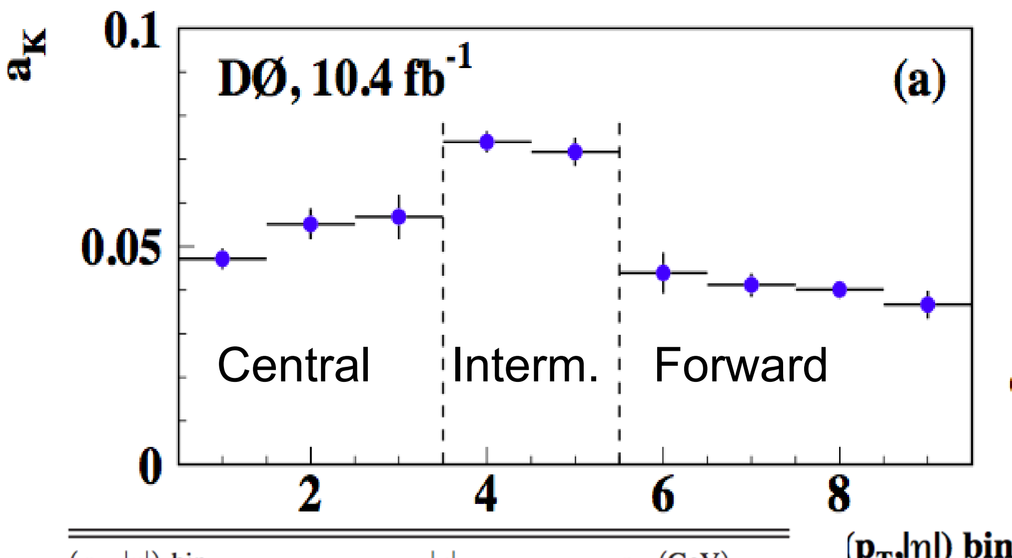
Inclusive muon sample | Like-sign dimuon sample

Inclusive dilepton A^b_{SL}

- Background asymmetries measured using $K^{*0} \to K^+\pi^-$, $\Phi \to KK$ with $K \to \mu$, $K_s \to \pi\pi$ with $\pi \to \mu$, $\Lambda \to p\pi$ with $p \to \mu$

$$a^X \equiv \frac{\varepsilon^{X^+} - \varepsilon^{X^-}}{\varepsilon^{X^+} + \varepsilon^{X^-}}.$$

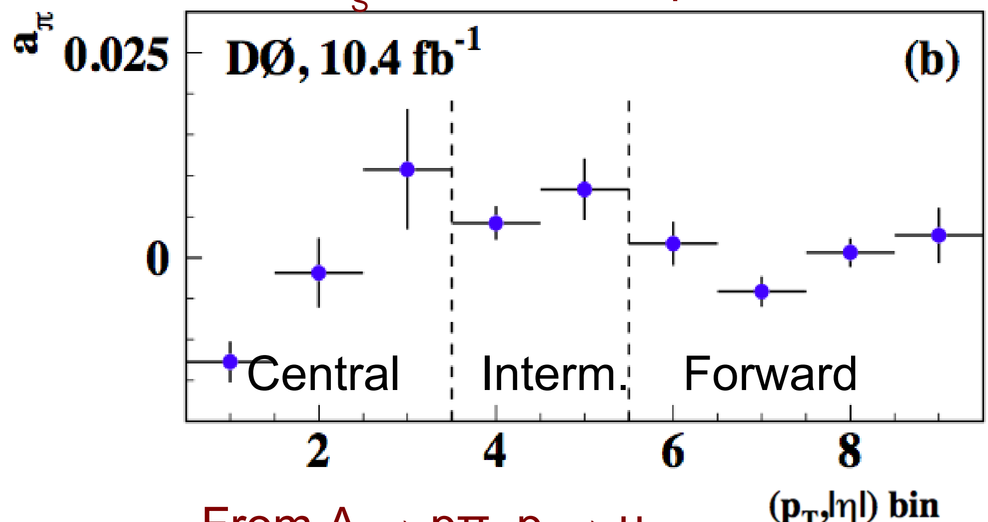
From $K^* \to K^+\pi^-$, $\Phi \to KK$, $K \to \mu$



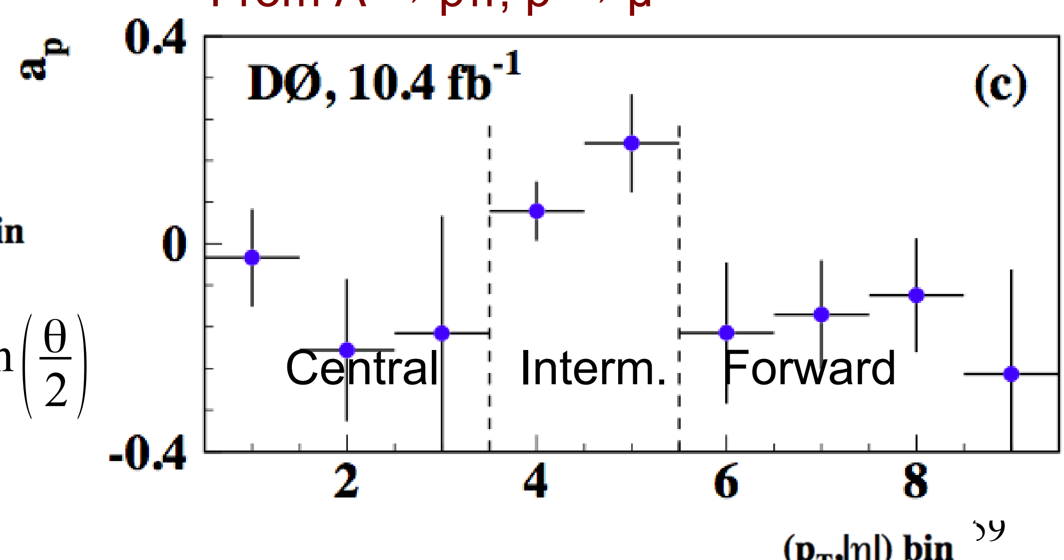
$(p_T, \|\eta\|)$ bin	$\|\eta\|$	p_T (GeV)
1	<0.7	<5.6
2	<0.7	5.6 to 7.0
3	<0.7	>7.0
4	0.7 to 1.2	<5.6
5	0.7 to 1.2	>5.6
6	>1.2	<3.5
7	>1.2	3.5 to 4.2
8	>1.2	4.2 to 5.6
9	>1.2	>5.6

$$\eta = -\ln \tan\left(\frac{\theta}{2}\right)$$

From $K_S \to \pi^+\pi^-$, $\pi \to \mu$



From $\Lambda \to p\pi$, $p \to \mu$

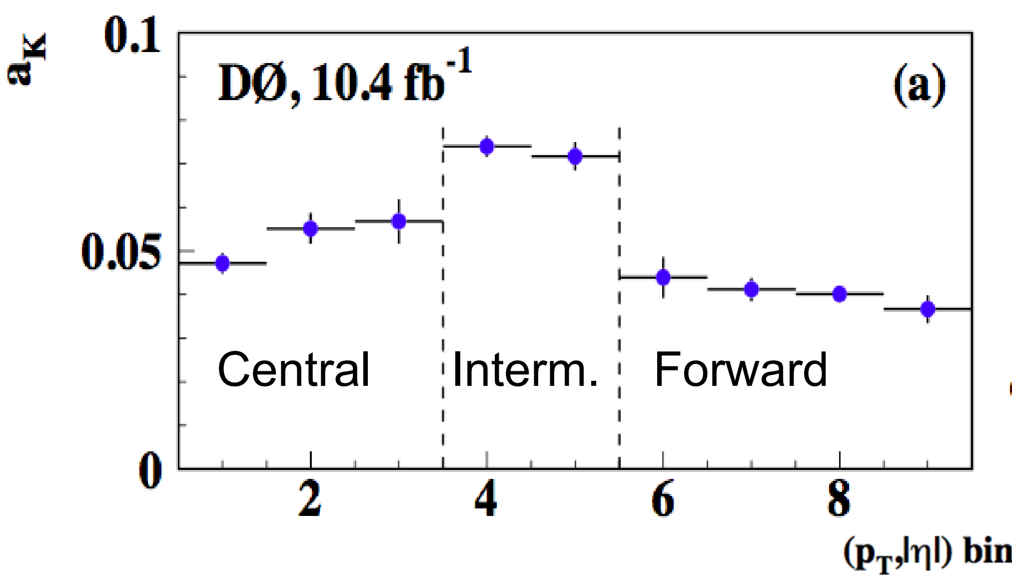


Inclusive dilepton A^b_{SL}

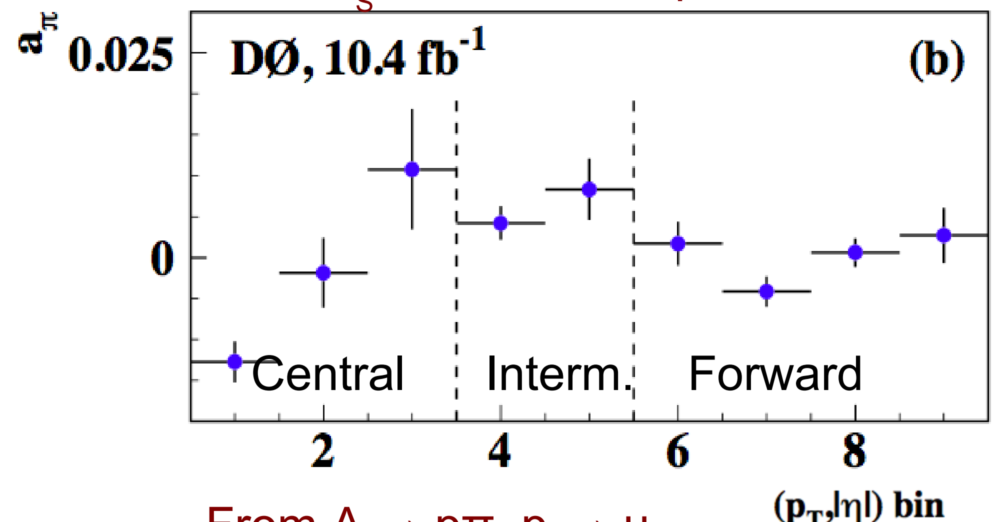
- Background asymmetries measured using $K^{*0} \to K^+\pi^-$, $\Phi \to KK$ with $K \to \mu$, $K_s \to \pi\pi$ with $\pi \to \mu$, $\Lambda \to p\pi$ with $p \to \mu$

$$a^X \equiv \frac{\varepsilon^{X^+} - \varepsilon^{X^-}}{\varepsilon^{X^+} + \varepsilon^{X^-}}.$$

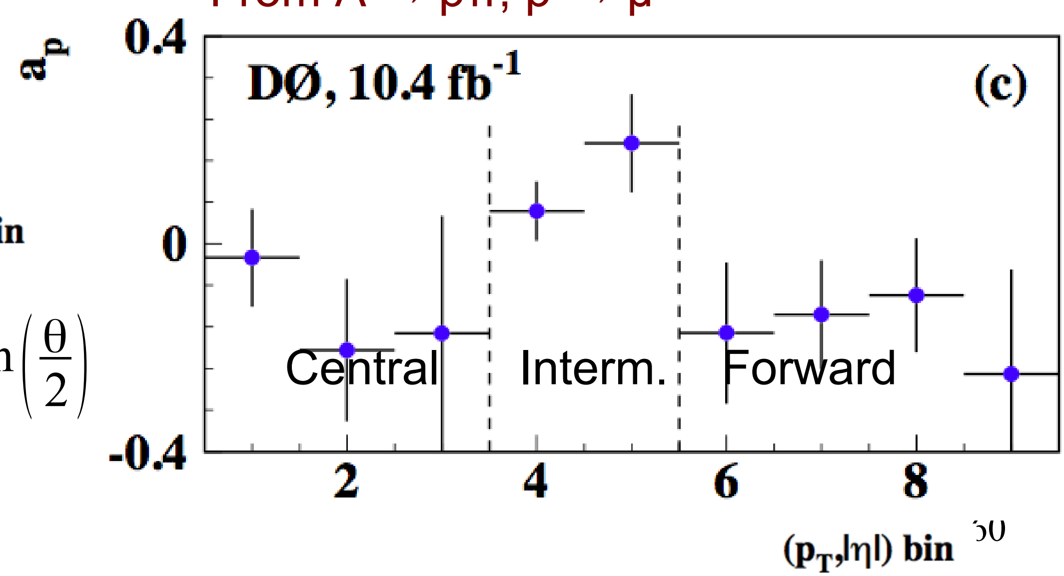
From $K^* \to K^+\pi^-$, $\Phi \to KK$, $K \to \mu$



From $K_s \to \pi^+\pi^-$, $\pi \to \mu$



From $\Lambda \to p\pi$, $p \to \mu$



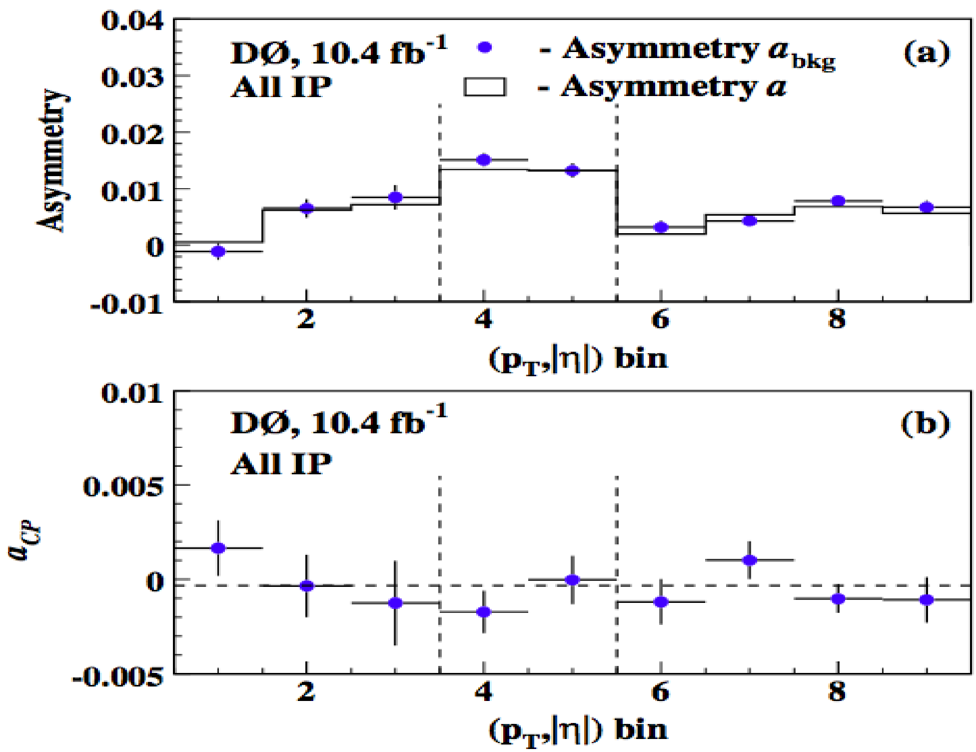
$$a_K = +0.0510 \pm 0.0010$$
$$a_\pi = -0.0006 \pm 0.0008$$
$$a_p = -0.0143 \pm 0.0342$$

$$\eta = -\ln \tan\left(\frac{\theta}{2}\right)$$

Inclusive dilepton A^b_{SL}

D0 Measurement ($L=10.4\ fb^{-1}$) [D0, Phys. Rev. D 89 012002 (2014)]

- Observed single muon asymmetry agrees with Background expectations



$$a^i = a^i_{CP} + a^i_{\text{bkg}}$$

$(p_T, \lvert\eta\rvert)$ bin	$\lvert\eta\rvert$	p_T (GeV)
1	<0.7	<5.6
2	<0.7	5.6 to 7.0
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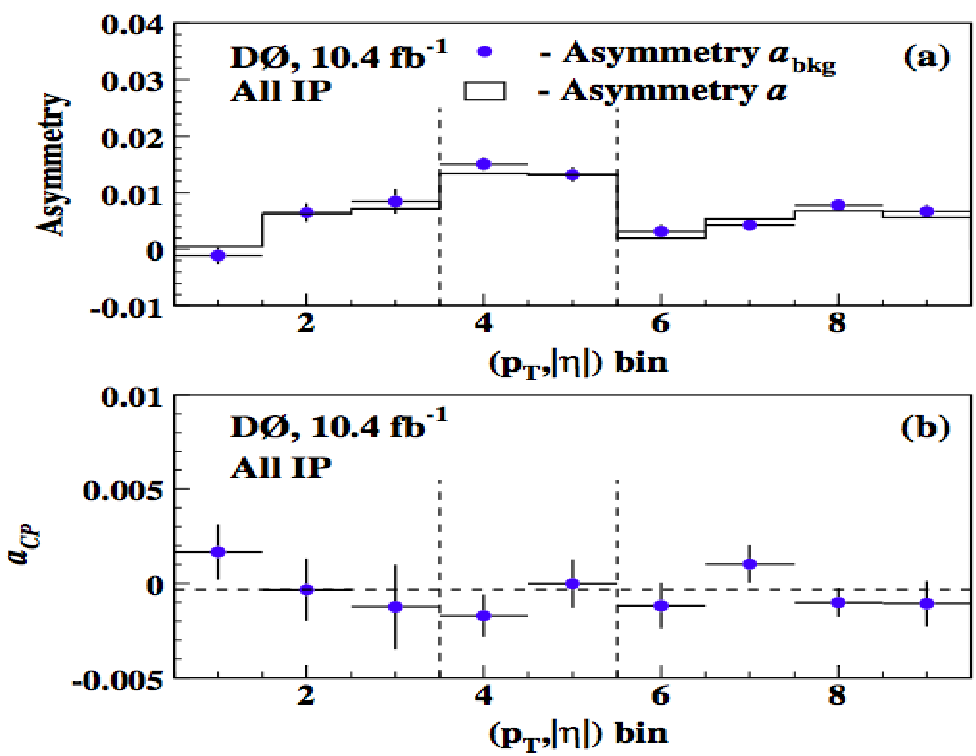
7	>1.2	3.5 to 4.2
8	>1.2	4.2 to 5.6
9	>1.2	>5.6

- From the inclusive single muon sample: a_{CP}=(-0.032 ± 0.042 ± 0.061)%
- In agreement with SM
- Systematics from BKG fraction and asymmetries

Inclusive dilepton A^b_{SL}

D0 Measurement (L=10.4 fb^{-1}) [D0, Phys. Rev. D 89 012002 (2014)]

- Observed single muon asymmetry agrees with Background expectations



$$a^i = a^i_{CP} + a^i_{\text{bkg}}$$

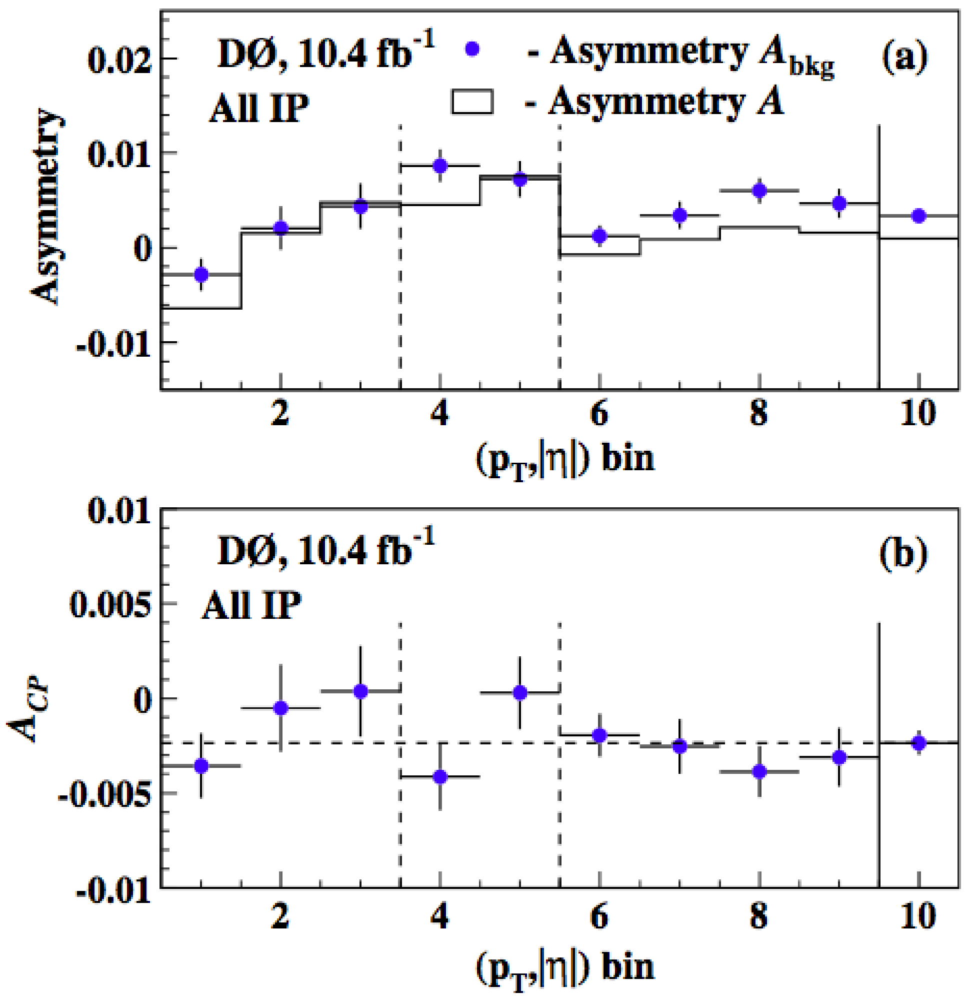
Quantity	All IP
$f_K a_K \times 10^3$	7.99 ± 0.21
$f_\pi a_\pi \times 10^3$	-0.19 ± 0.31
$f_p a_p \times 10^3$	-0.08 ± 0.09
$a_\mu \times 10^3$	-0.70 ± 0.12
$a \times 10^3$	6.70 ± 0.02
$a_{\text{bkg}} \times 10^3$	7.02 ± 0.42
$a_{CP} \times 10^3$	-0.32 ± 0.42

- From the inclusive single muon sample: a_{CP}=(-0.032 ± 0.042 ± 0.061)%
- In agreement with SM
- Systematics from BKG fraction and asymmetries

Inclusive dilepton A^b_{SL}

D0 Measurement (L=10.4 fb^{-1}) [D0, Phys. Rev. D 89 012002 (2014)]

- Dimuon asymmetry



Quantity	All IP
$F_K a_K \times 10^3$	6.25 ± 0.29
$F_\pi a_\pi \times 10^3$	0.04 ± 0.25
$F_p a_p \times 10^3$	-0.06 ± 0.07
$A_\mu \times 10^3$	-2.88 ± 0.30
$A \times 10^3$	1.01 ± 0.40
$A_{\rm bkg} \times 10^3$	3.36 ± 0.50
$A_{CP} \times 10^3$	-2.35 ± 0.64

$$A_{CP} = A - A_{bkg}$$

- From the inclusive dimuon sample: A_{CP}=(-0.235 ± 0.064 ± 0.055)%
- Systematics from BKG fraction and asymmetries
- Significant deviation wrt SM

Inclusive dilepton A^b_{SL}

D0 Measurement ($L=10.4\ fb^{-1}$) [D0, Phys. Rev. D 89 012002 (2014)]

- Several sources of CPV
- Single muon asymmetry depends only on CPV in mixing:

$$a_{CP}=c_b A^b_{SL};\quad A^b_{SL}=C_d A^d_{SL}+C_s A^s_{SL};\quad C_d=f_d\chi_d/(f_d\chi_d+f_s\chi_s);\quad C_s=1-C_d$$

- c_b=(3-11)% varying with IP: fraction of muons in inclusive sample which have oscillated (from MC)

- Effective X_d increases with proper decay time (muon IP), X_s =0.5
- Dimuon asymmetry depends on CPV in mixing and in interference between mixing and decay amplitude in the process B^0 ($\overline{B}^0$) → $c\overline{c}d\overline{d}$ (e.g. D^{*+} D^{*-}, accessible both to B^0 and $\overline{B}^0$, see later):

$$A_{CP}=A^{mix}+A^{inter};\quad A^{mix}=C_b A^b_{SL};\quad C_b=0.45-0.58$$ (depending on IP)

- Interference contribution present only in the dimuon asymmetry

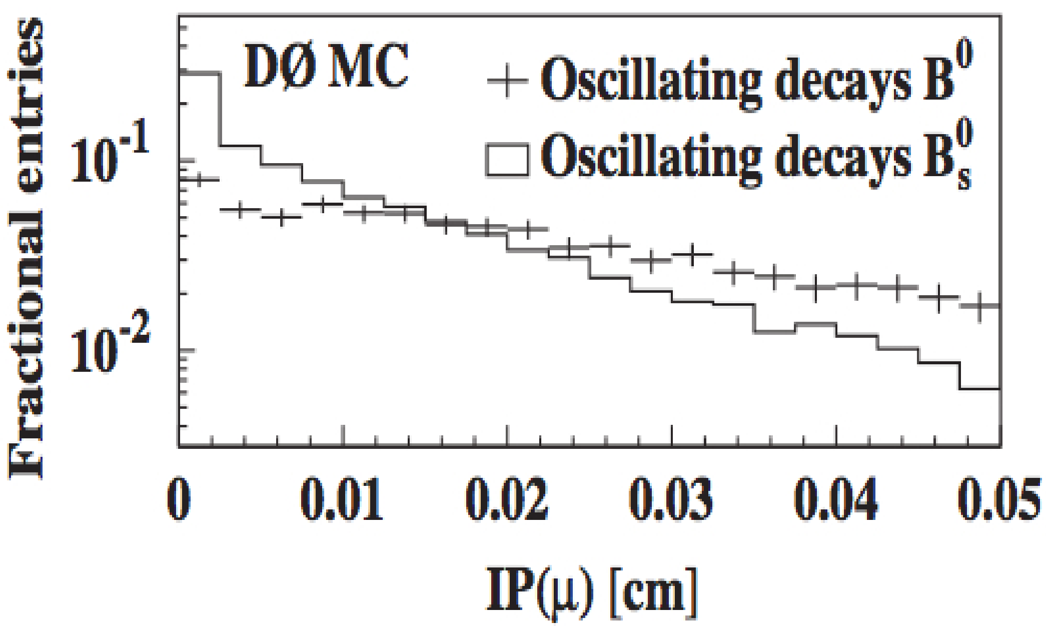
$$A^{inter}=-\sin(2\beta)\frac{x_d}{1+x_d^2}\frac{\Delta\Gamma_d}{\Gamma_d}\omega(c\bar{c}d\bar{d})=(-0.050\pm0.012)\%\ ;\quad x_d=\frac{\Delta m_d}{\Gamma_d}$$

$\omega(c\bar{c}d\bar{d})$: Contribution of $c\overline{c}d\overline{d}$ channels in the inclusive sample

Inclusive dilepton A^b_{SL}

D0 Measurement (L=10.4 fb^{-1}) [D0, Phys. Rev. D 89 012002 (2014)]

- By subtracting the interference term and correctig for the fraction of signal muons in the inclusive sample:
  A^b_{SL}=(-0.496 ± 0.153 ± 0.072)%
  differs from SM expectation by 2.8 σ
- Measurement performed in three different muon Impact Parameter regions (different BKG fraction):
  χ^2/dof=31/9 gives probability p(SM)=3 x 10^{-4} corresponding to 3.6 σ discrepancy
- Mixed B^0 fractions depend on muon IP: separation of contributions gives



$$a^d_{sl} = (-0.62 \pm 0.42) \times 10^{-2}$$
$$a^s_{sl} = (-0.86 \pm 0.74) \times 10^{-2}$$

χ^2/dof=10/7, ρ=-79%
3.4 σ from SM expectations

Inclusive dilepton A^b_{SL}

D0 Measurement (L=10.4 fb^{-1}) [D0, Phys. Rev. D 89 012002 (2014)]

- By subtracting the interference term and correctig for the fraction of signal muons in the inclusive sample:

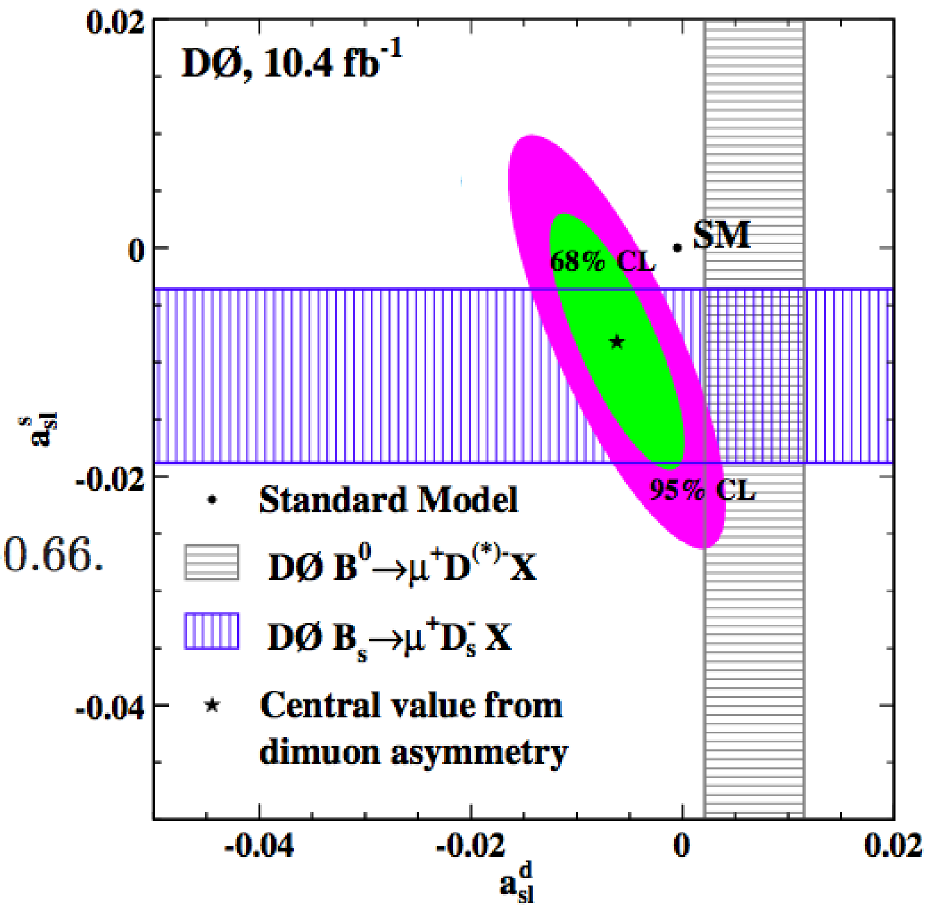
  A^b_{SL}=(-0.496 ± 0.153 ± 0.072)%

  differs from SM expectation by 2.8 σ
- By fitting ΔΓ/Γ on A^{inter}:

$$a^d_{sl} = (-0.62 \pm 0.43) \times 10^{-2}$$
$$a^s_{sl} = (-0.82 \pm 0.99) \times 10^{-2}$$
$$\frac{\Delta\Gamma_d}{\Gamma_d} = (0.50 \pm 1.38) \times 10^{-2}$$

$$\rho_{d,s} = -0.61, \quad \rho_{d,\Delta\Gamma} = -0.03, \quad \rho_{s,\Delta\Gamma} = +0.66.$$

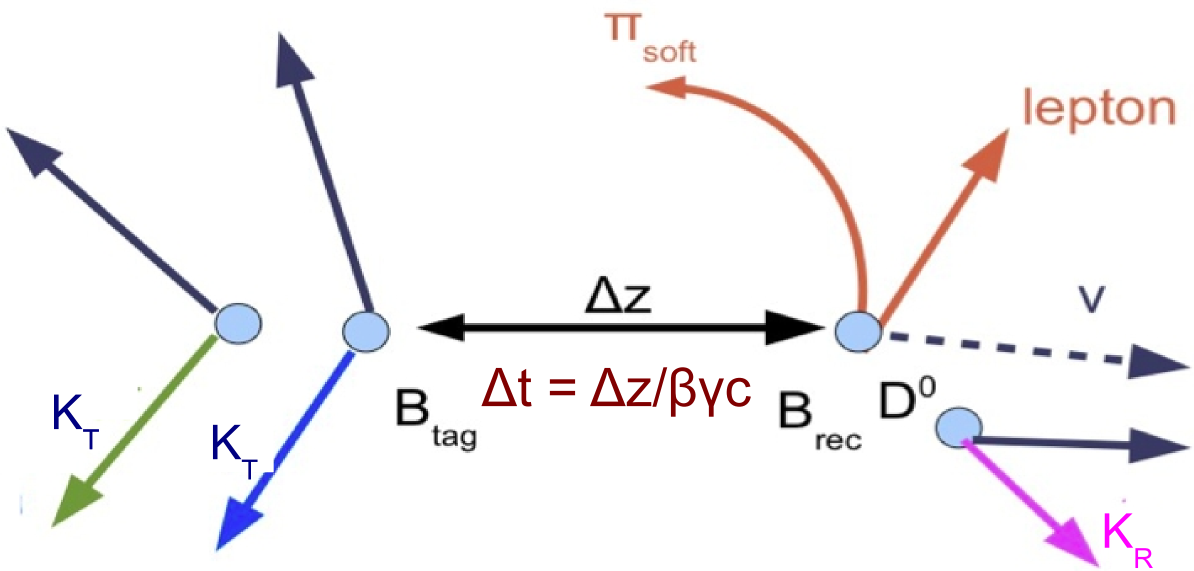
3.0 σ from SM expectations



Flavor Specific A^d_{SL}

Babar Measurement (L=425.7 fb^{-1})[Phys. Rev. Lett. 111 101802 (2013)] [Phys. Rev. D 93, 032001 (2016)]

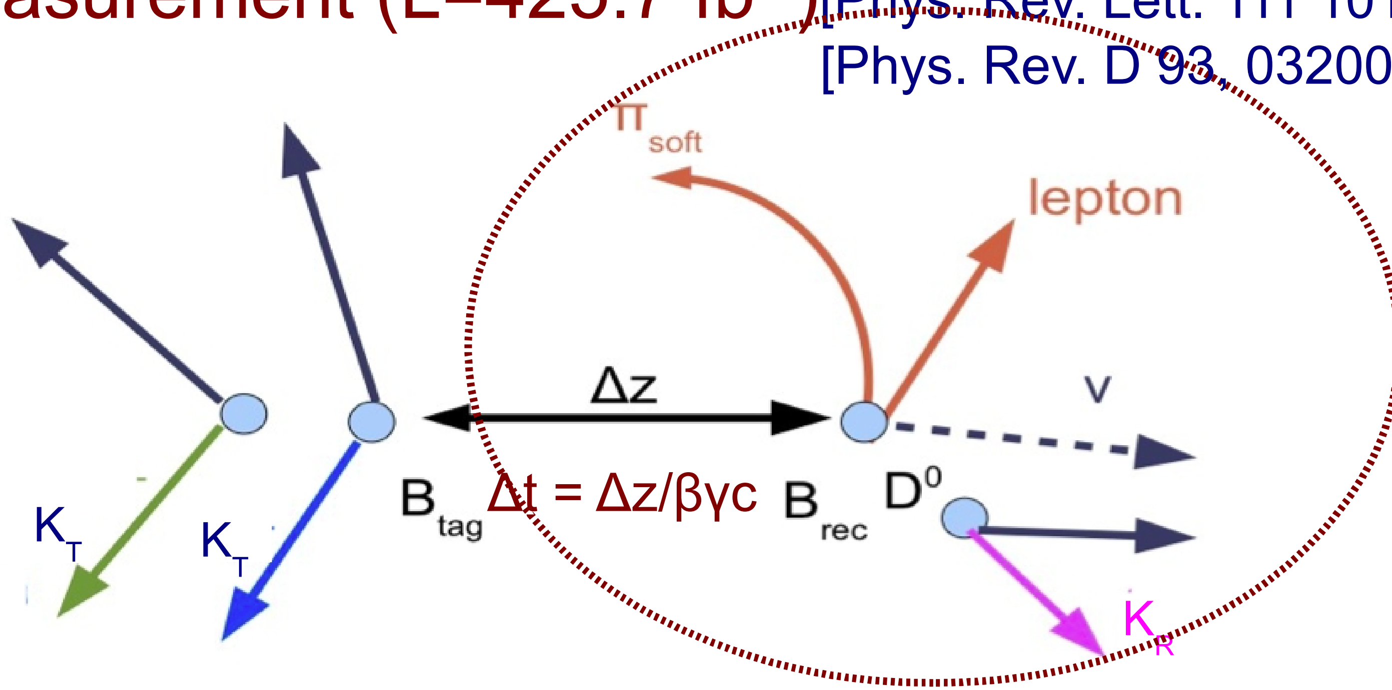
- A^d_{SL} measured from Partially Reconstructed $B^0 \to D^* X l \nu$, $D^* \to D^0 \pi$ using a tagging algorithm based on charged K identification from the other B^0 meson decay:



- Flavor of the partially reconstructed B^0 from the lepton & pion charges
- Flavor of the tag B^0 using events with a charged kaon K_T:
  - K^+ (K^-) come usually from B^0 ($\overline{B}^0$) decays

Flavor Specific A^d_{SL}

Babar Measurement ($L=425.7\ fb^{-1}$) [Phys. Rev. Lett. 111 101802 (2013)]
[Phys. Rev. D 93, 032001 (2016)]



- Observed asymmetry between tagged+untagged events with l^+ and l^-:

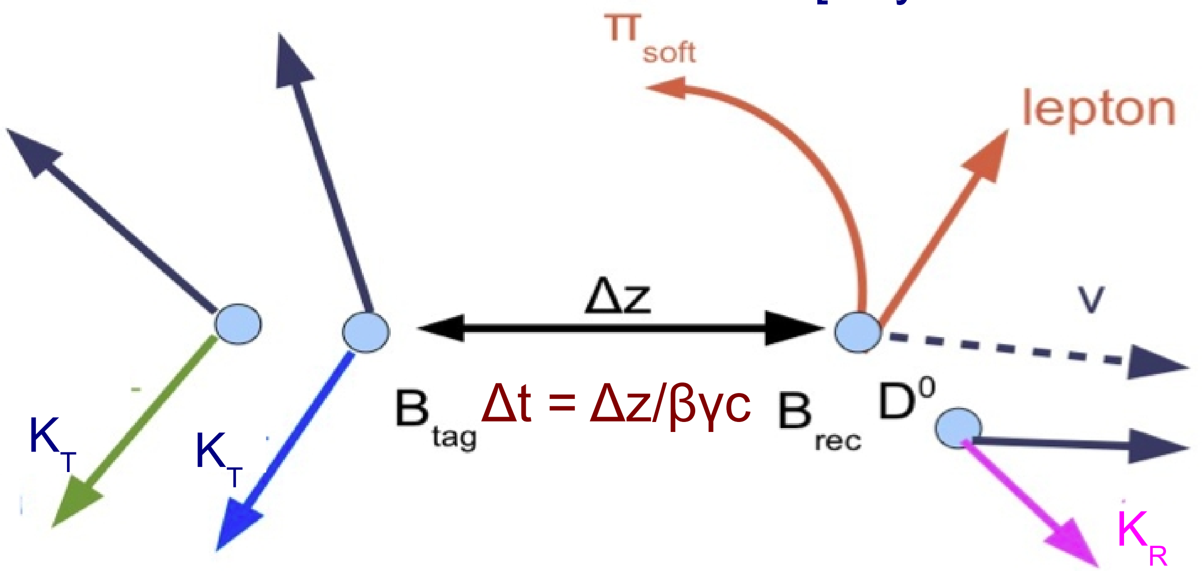
$$A_l = \frac{N(l^+) - N(l^-)}{N(l^+) + N(l^-)} \approx \mathcal{A}_{r\ell} + \mathcal{A}_{CP}\chi_d$$

  - A_{rl}: detector induced charge asymmetry for the Reconstructed-Side
  - A_{CP} asymmetry diluted by integrated mixing probability (only mixed events affected by A_{CP}: i.e. more B^0B^0 than $\bar{B}^0\bar{B}^0$ reflects in more B^0 than $\bar{B}^0$)

Flavor Specific A^d_{SL}

Babar Measurement (L=425.7 fb^{-1})

[Phys. Rev. Lett. 111 101802 (2013)]
[Phys. Rev. D 93, 032001 (2016)]



- Observed asymmetry in mixed events:

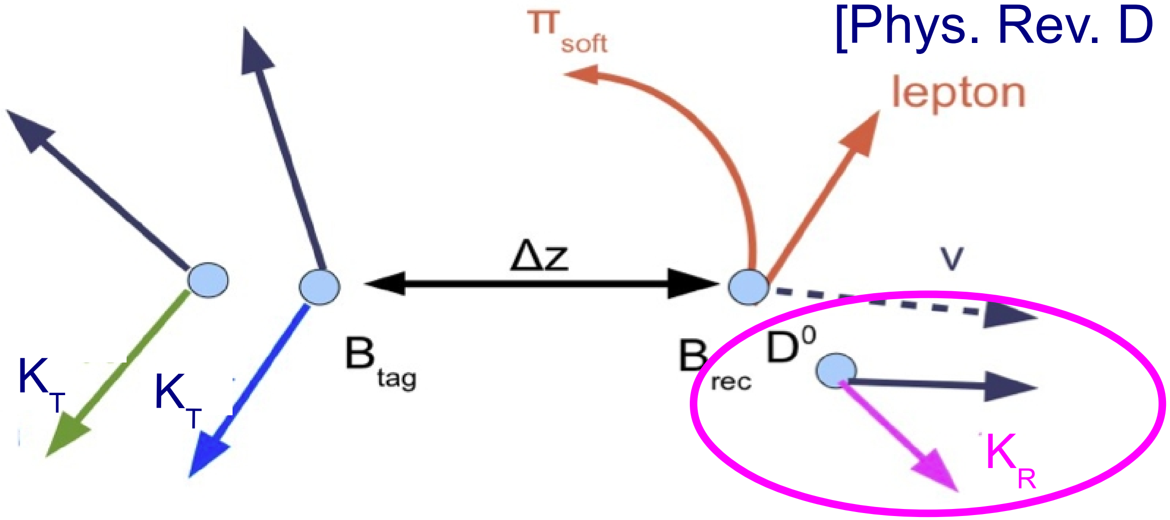
$$A_T = \frac{N(\ell^+ K_T^+) - N(\ell^- K_T^-)}{N(\ell^+ K_T^+) + N(\ell^- K_T^-)} \approx \mathcal{A}_{r\ell} + \mathcal{A}_K + \mathcal{A}_{CP}$$

  - A_K: detector charge asymmetry in kaon reconstruction for the Tag-Side (different K^+/K^- interaction cross sections in the detector material)

Flavor Specific A^d_{SL}

Babar Measurement ($L=425.7\ fb^{-1}$) [Phys. Rev. Lett. 111 101802 (2013)]

[Phys. Rev. D 93, 032001 (2016)]



- Kaons with the same charge as the lepton could arise from Cabibbo-favored decays of the D^0 in the PR side (K_R)
- Observed asymmetry for these events:

$$A_R = \frac{N(\ell^+ K_R^+) - N(\ell^- K_R^-)}{N(\ell^+ K_R^+) + N(\ell^- K_R^-)} \approx \mathcal{A}_{r\ell} + \mathcal{A}_K + \mathcal{A}_{CP}\chi_d$$

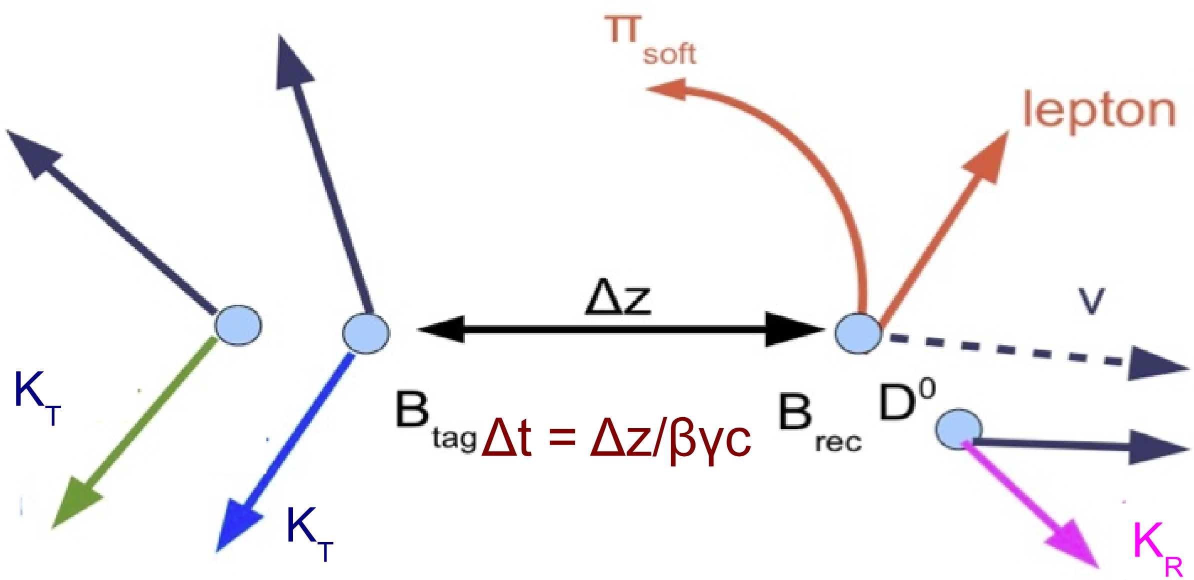
  - A_{CP} asymmetry diluted by integrated mixing probability (only mixed events affected by A_{CP}: i.e. more B^0B^0 than B^0B^0 reflects in more B^0 than B^0)

- A_{CP}, A_K, A_{rl} obtained by using the three equations in a global ML fit

Flavor Specific A^d_{SL}

Babar Measurement (L=425.7 fb^{-1}) [Phys. Rev. Lett. 111 101802 (2013)] [Phys. Rev. D 93, 032001 (2016)]

- Tagging Kaon sample:



- K_T: Tag Kaon Tag Side
- K_R: Tag Kaon Decay Side

  95% of K_R populate the “Mixed” event sample due to K-l same-sign charge correlation

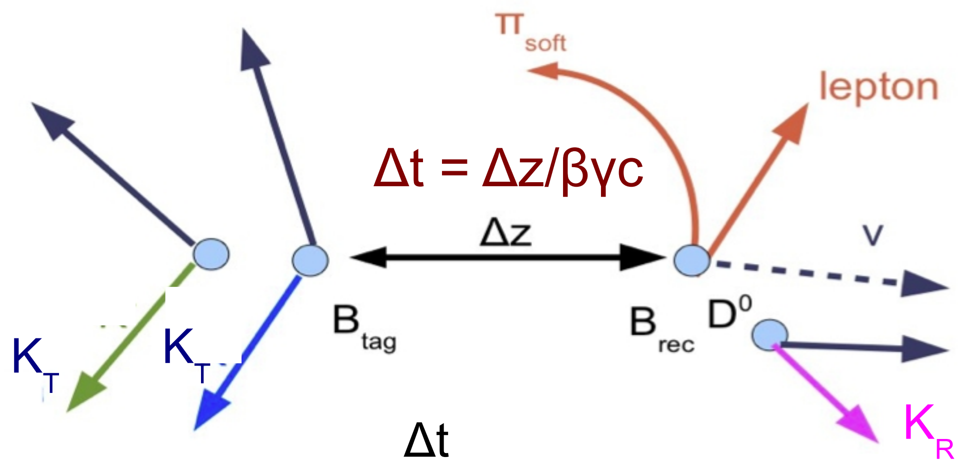
  - Constitute 75% of the Mixed sample
  - Separated using angle between K & l and Δt
  - Characterized by different mistag wrt K_T

Flavor Specific A^{d}_{SL}

Babar Measurement (L=425.7 fb^{-1})

[Phys. Rev. Lett. 111 101802 (2013)]

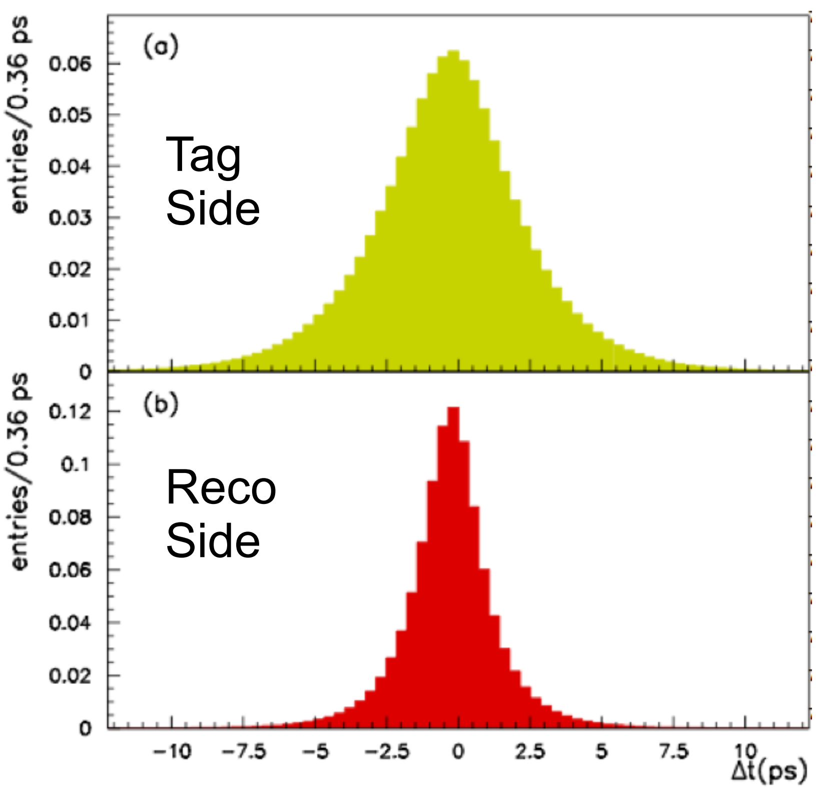
[Phys. Rev. D 93, 032001 (2016)]



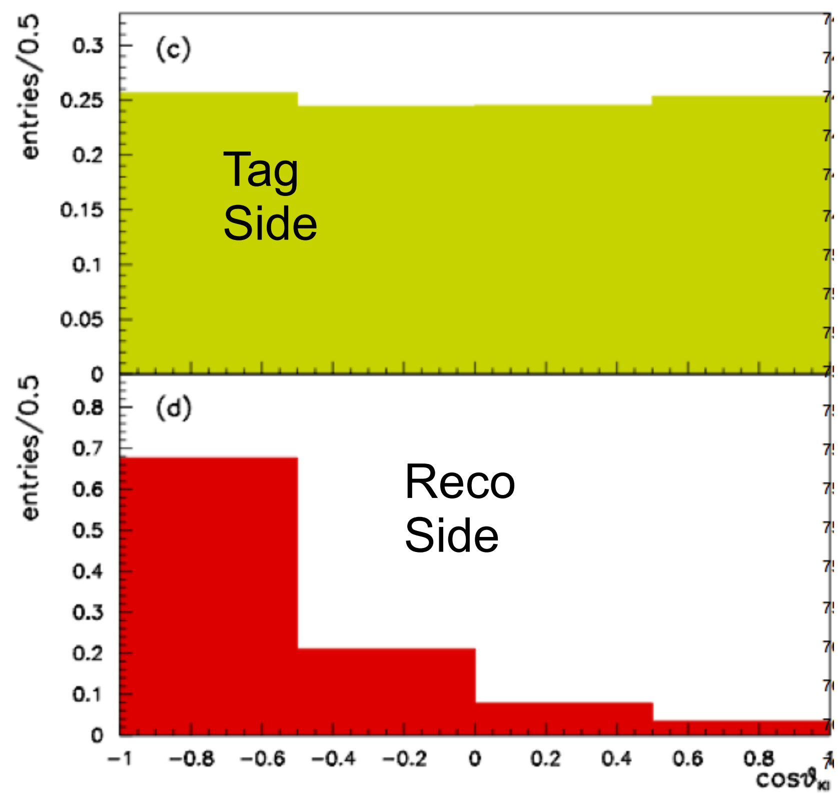
- K_T: Tag Kaon Tag Side
- K_R: Tag Kaon Decay Side

K_R Δt shape from a Data driven reconstruction

Δt



$\cos\theta_{Kl}$



Flavor Specific A^d_{SL}

Babar Measurement (L=425.7 fb^{-1})

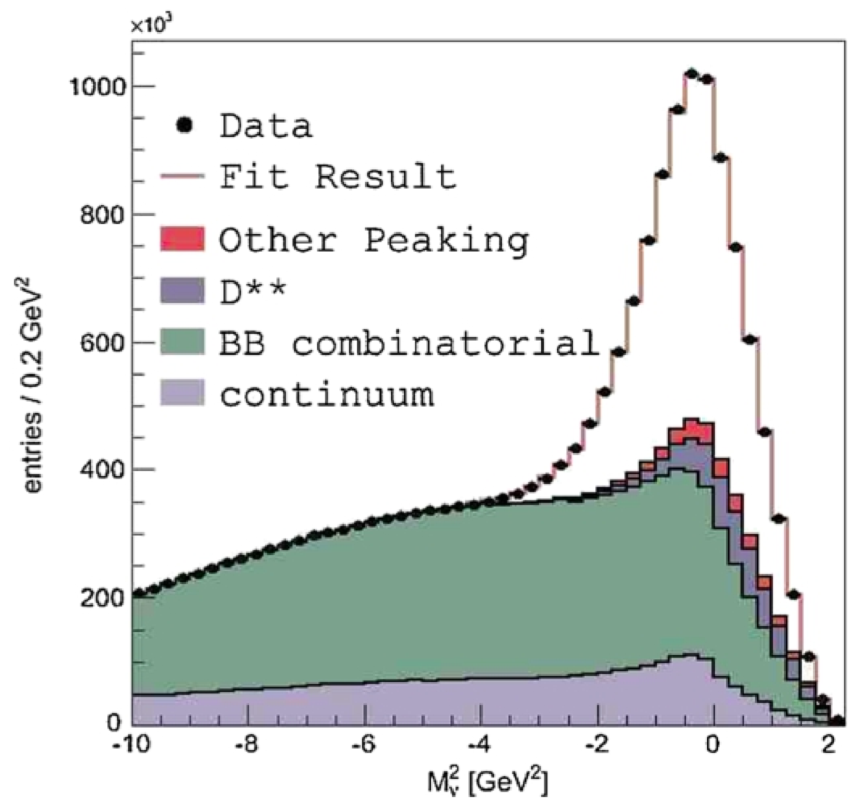
[Phys. Rev. Lett. 111 101802 (2013)]
[Phys. Rev. D 93, 032001 (2016)]

- Reconstruct only lepton and soft π with opposite charge
- Signal selected exploiting the neutrino missing squared mass with the approximation of B^0 at rest in the ϒ(4S) frame:

$$\mathcal{M}_\nu^2 = (E_{\text{beam}} - E_{D^*} - E_\ell)^2 - (\mathbf{p}_{D^*} + \mathbf{p}_\ell)^2,$$

$N_{peak} = (5.945 \pm 0.007) \times 10^6$

- D* 4-momentum estimated from π kinematics using simulation
- Signal includes $B^0 \to D^{*-} X^0 l^+ \nu$, $D^{*-} X^0 \tau\nu$, ($\tau \to l\nu\nu$), $D^{*-}h^+$ (misidentified hadron)
- Peaking BKG from flavor-insensitive CP eigenstates, D*DX, ($D \to lX$), $B^+ \to D^{*-} X^+ l^+ \nu$
- Sample composition extracted from a fit to M^2_ν by floating the D*, D** and Combinatorial components using MC shape and Continuum shape from Off-Peak events



Flavor Specific A^d_{SL}

Babar Measurement ($L=425.7\ fb^{-1}$) [Phys. Rev. Lett. 111 101802 (2013)] [Phys. Rev. D 93, 032001 (2016)]

- A_{CP} measured with a binned four-dimensional fit to Δt, $\sigma_{\Delta t}$, $\cos\theta_{lK}$ and p_K
- Parameters describing Δt resolution and mistag, Δm, B^0 lifetime, and the interference between Cabibbo-favored and doubly Cabibbo-suppressed decays in the B_{tag} side floated in the fit (r' ~ O(1%): amplitude ratio, b & c: CPV from interference)

$$\mathcal{F}_{\bar{B}^0B^0}(\Delta t) = \frac{\Gamma_0 e^{-\Gamma_0|\Delta t|}}{2(1+r'^2)}\left[\left(1+\left|\frac{q}{p}\right|^2 r'^2\right)\cosh(\Delta\Gamma\Delta t/2) + \left(1-\left|\frac{q}{p}\right|^2 r'^2\right)\cos(\Delta m_d\Delta t) - \left|\frac{q}{p}\right|(b+c)\sin(\Delta m_d\Delta t)\right],$$

$$\mathcal{F}_{B^0\bar{B}^0}(\Delta t) = \frac{\Gamma_0 e^{-\Gamma_0|\Delta t|}}{2(1+r'^2)}\left[\left(1+\left|\frac{p}{q}\right|^2 r'^2\right)\cosh(\Delta\Gamma\Delta t/2) + \left(1-\left|\frac{p}{q}\right|^2 r'^2\right)\cos(\Delta m_d\Delta t) + \left|\frac{p}{q}\right|(b-c)\sin(\Delta m_d\Delta t)\right],$$

$$\mathcal{F}_{\bar{B}^0\bar{B}^0}(\Delta t) = \frac{\Gamma_0 e^{-\Gamma_0|\Delta t|}}{2(1+r'^2)}\left[\left(1+\left|\frac{p}{q}\right|^2 r'^2\right)\cosh(\Delta\Gamma\Delta t/2) - \left(1-\left|\frac{p}{q}\right|^2 r'^2\right)\cos(\Delta m_d\Delta t) - \left|\frac{p}{q}\right|(b-c)\sin(\Delta m_d\Delta t)\right] \times \left|\frac{q}{p}\right|^2,$$

$$\mathcal{F}_{B^0B^0}(\Delta t) = \frac{\Gamma_0 e^{-\Gamma_0|\Delta t|}}{2(1+r'^2)}\left[\left(1+\left|\frac{q}{p}\right|^2 r'^2\right)\cosh(\Delta\Gamma\Delta t/2) - \left(1-\left|\frac{q}{p}\right|^2 r'^2\right)\cos(\Delta m_d\Delta t) + \left|\frac{q}{p}\right|(b+c)\sin(\Delta m_d\Delta t)\right] \times \left|\frac{p}{q}\right|^2,$$

Flavor Specific A^d_{SL}

Babar Measurement ($L=425.7\ fb^{-1}$) [Phys. Rev. Lett. 111 101802 (2013)] [Phys. Rev. D 93, 032001 (2016)]

- If K_T comes from decay of CP eigenstate in tag side ($B^0 \to D^{(*)}D^{(*)}$) ~ 1% total sample (+: B^0 in reco side, -: $\overline{B^0}$ in reco side, S, C from MC):

$$\mathcal{F}_{CPe}(\Delta t') = \frac{\Gamma_0}{4} e^{-\Gamma_0|\Delta t'|}(1 \pm S\sin(\Delta m_d \Delta t') \pm C\cos(\Delta m_d \Delta t'),$$

- Due to different charge asymmetry of the K_T and K_R, the fractions of K_R tags in each of the four sample (l^+K^+, l^-K^-, l^+K^-, l^-K^+) is correlated with A_{CP}

$$f^{\pm\pm}_{K_R}(|q/p|) = f^{\pm\pm}_{K_R}(|q/p| = 1) \times g^{\pm\pm}(|q/p|)$$

- $f_{KR}(|q/p|=1)$ free in the fit, $g(|q/p|)$ analytical functions absorbing the $|q/p|$ dependence during the fit minimization

- In a subsample of the combinatorial BKG from B^0, reco-side lepton paired with a soft pion from the tag side D* decay. Due to charge correlation, the effective mixed event fraction is higher in the combinatorial wrt signal: effective BKG Δm & τ_{B0} floated

$$\chi_d^{\text{comb}} = \chi_0^{\text{comb}}(a + b \cdot p_K) \qquad \chi_0^{\text{comb}} = \frac{x^2_{\text{comb}}}{2(1 + x^2_{\text{comb}})}$$

Flavor Specific A^d_{SL}

Babar Measurement (L=425.7 fb^{-1})

[Phys. Rev. Lett. 111 101802 (2013)]
[Phys. Rev. D 93, 032001 (2016)]

- Sample divided in bins of Δt, $\sigma\Delta t$, $\cos\theta_{lK}$, p_K, M^2_ν
- Rate of events for each tagged sample:

$$\begin{aligned}
&\mathcal{F}^{\ell K}(\Delta t, \sigma_{\Delta t}, \mathcal{M}_{\text{miss}}{}^2, \cos\theta_{\ell,K}, p_K | \tau_{B^0}, \Delta m, |q/p|) \\
&\quad = (1 - f_{B^+}(\mathcal{M}_{\text{miss}}{}^2) - f_{CP}(\mathcal{M}_{\text{miss}}{}^2) - f_{\text{comb}}(\mathcal{M}_{\text{miss}}{}^2) - f_{\text{cont}}(\mathcal{M}_{\text{miss}}{}^2))\mathcal{G}^{B^0}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) \\
&\qquad + f_{B^+}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{B^+}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) + f_{CP}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{CP}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) \\
&\qquad + f^0_{\text{comb}}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{B^0\text{comb}}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) + f^+_{\text{comb}}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{B^+\text{comb}}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) \\
&\qquad + f_{\text{cont}}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{\text{cont}}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K)
\end{aligned}$$

- Expected fraction of mixed events computed in terms of Δm, τ_{B0} and mistag, and constrained to the observed one (separately for signal and combinatorial BKG)

$$P^{\text{exp}}_m = \frac{\mathcal{G}^{B^0_T}_{\ell^+K^+} + \mathcal{G}^{B^0_T}_{\ell^-K^-}}{\mathcal{G}^{B^0_T}_{\ell^+K^+} + \mathcal{G}^{B^0_T}_{\ell^-K^-} + \mathcal{G}^{B^0_T}_{\ell^+K^-} + \mathcal{G}^{B^0_T}_{\ell^-K^+}} \qquad C^{B^0_T}_m = \frac{N!}{N_m!N_u!}(P^{\text{exp}}_m)^{N_m}(1 - P^{\text{exp}}_m)^{N_u},$$

Flavor Specific A^{d}_{SL}

Babar Measurement (L=425.7 fb^{-1})

[Phys. Rev. Lett. 111 101802 (2013)]
[Phys. Rev. D 93, 032001 (2016)]

- Sample divided in bins of Δt, $\sigma\Delta t$, $\cos\theta_{lK}$, p_K, M^2_ν
- Rate of events for each tagged sample:

$$\begin{aligned}
&\mathcal{F}^{\ell K}(\Delta t, \sigma_{\Delta t}, \mathcal{M}_{\text{miss}}{}^2, \cos\theta_{\ell,K}, p_K | \tau_{B^0}, \Delta m, |q/p|) \\
&\quad = (1 - f_{B^+}(\mathcal{M}_{\text{miss}}{}^2) - f_{CP}(\mathcal{M}_{\text{miss}}{}^2) - f_{\text{comb}}(\mathcal{M}_{\text{miss}}{}^2) - f_{\text{cont}}(\mathcal{M}_{\text{miss}}{}^2))\mathcal{G}^{B^0}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) \\
&\qquad + f_{B^+}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{B^+}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) + f_{CP}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{CP}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) \\
&\qquad + f^0_{\text{comb}}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{B^0\text{comb}}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) + f^+_{\text{comb}}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{B^+\text{comb}}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) \\
&\qquad + f_{\text{cont}}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{\text{cont}}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K)
\end{aligned}$$

- Expected fraction of mixed (unmixed) events tagged by a positive K, computed in terms of A_{CP} and detector related asymetries, and constrained to the observed one

$$P^{\text{exp}}_{m(u),K^+} = \frac{\mathcal{G}^{B^0_T}_{\ell^+(\ell^-)K^+}}{\mathcal{G}^{B^0_T}_{\ell^+(\ell^-)K^+} + \mathcal{G}^{B^0_T}_{\ell^-(\ell^+)K^-}}.$$

$$\begin{aligned}
C^{B^0_T}_{m(u),K^+} &= \frac{N_{m(u)}!}{N_{m(u),K^+}!N_{m(u),K^-}!} \\
&\quad \times (P^{\text{exp}}_{m(u)K^+})^{N_{m(u)K^+}} \\
&\quad \times (1 - P^{\text{exp}}_{m(u)K^+})^{N_{m(u)K^-}}.
\end{aligned}$$

Flavor Specific A^d_{SL}

Babar Measurement (L=425.7 fb^{-1}) [Phys. Rev. Lett. 111 101802 (2013)] [Phys. Rev. D 93, 032001 (2016)]

- Sample divided in bins of Δt, $\sigma\Delta t$, $\cos\theta_{lK}$, p_K, M^2_ν
- Rate of events for each tagged sample:

$$
\begin{aligned}
&\mathcal{F}^{\ell K}(\Delta t, \sigma_{\Delta t}, \mathcal{M}_{\text{miss}}{}^2, \cos\theta_{\ell,K}, p_K | \tau_{B^0}, \Delta m, |q/p|) \\
&\quad = (1 - f_{B^+}(\mathcal{M}_{\text{miss}}{}^2) - f_{CP}(\mathcal{M}_{\text{miss}}{}^2) - f_{\text{comb}}(\mathcal{M}_{\text{miss}}{}^2) - f_{\text{cont}}(\mathcal{M}_{\text{miss}}{}^2))\mathcal{G}^{B^0}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) \\
&\qquad + f_{B^+}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{B^+}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) + f_{CP}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{CP}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) \\
&\qquad + f^0_{\text{comb}}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{B^0\text{comb}}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) + f^+_{\text{comb}}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{B^+\text{comb}}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K) \\
&\qquad + f_{\text{cont}}(\mathcal{M}_{\text{miss}}{}^2)\mathcal{G}^{\text{cont}}_{\ell K}(\Delta t, \sigma_{\Delta t}, \cos\theta_{\ell,K}, p_K)
\end{aligned}
$$

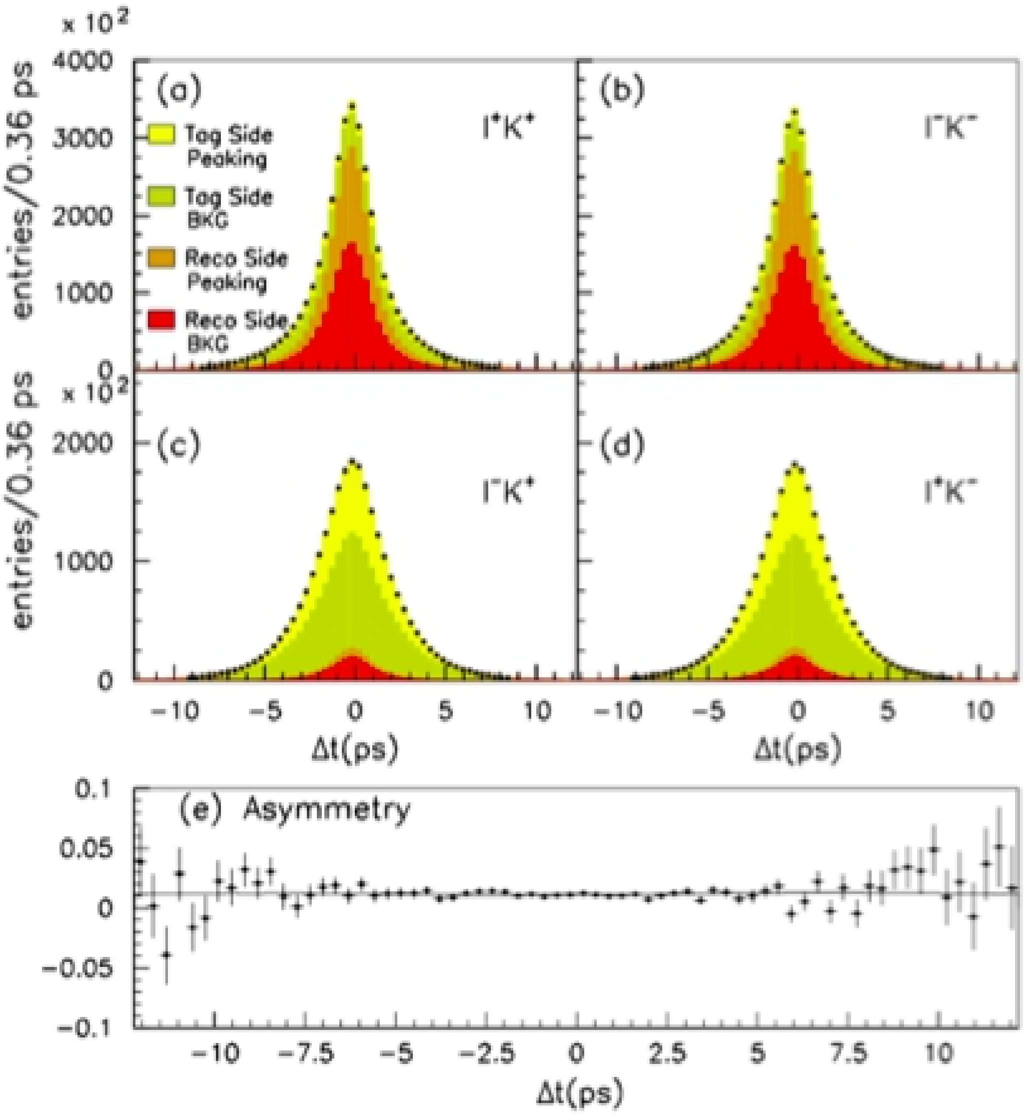
- Statistical precision comes mostly from time-integrated fractions

- Time dependence measures mistag parameters and discriminate between different sample components

Flavor Specific A^d_{SL}

Babar Measurement ($L=425.7\ fb^{-1}$)

[Phys. Rev. Lett. 111 101802 (2013)]
[Phys. Rev. D 93, 032001 (2016)]



- A_{CP} measured with a binned four-dimensional fit to Δt, $\sigma_{\Delta t}$, $\cos\theta_{lK}$ and p_K
- Parameters describing Δt resolution and mistag, Δm, B^0 lifetime, and the interference between Cabibbo-favored and doubly Cabibbo-suppressed decays in the B_{tag} side floated in the fit
- 168 parameters determined in the fit

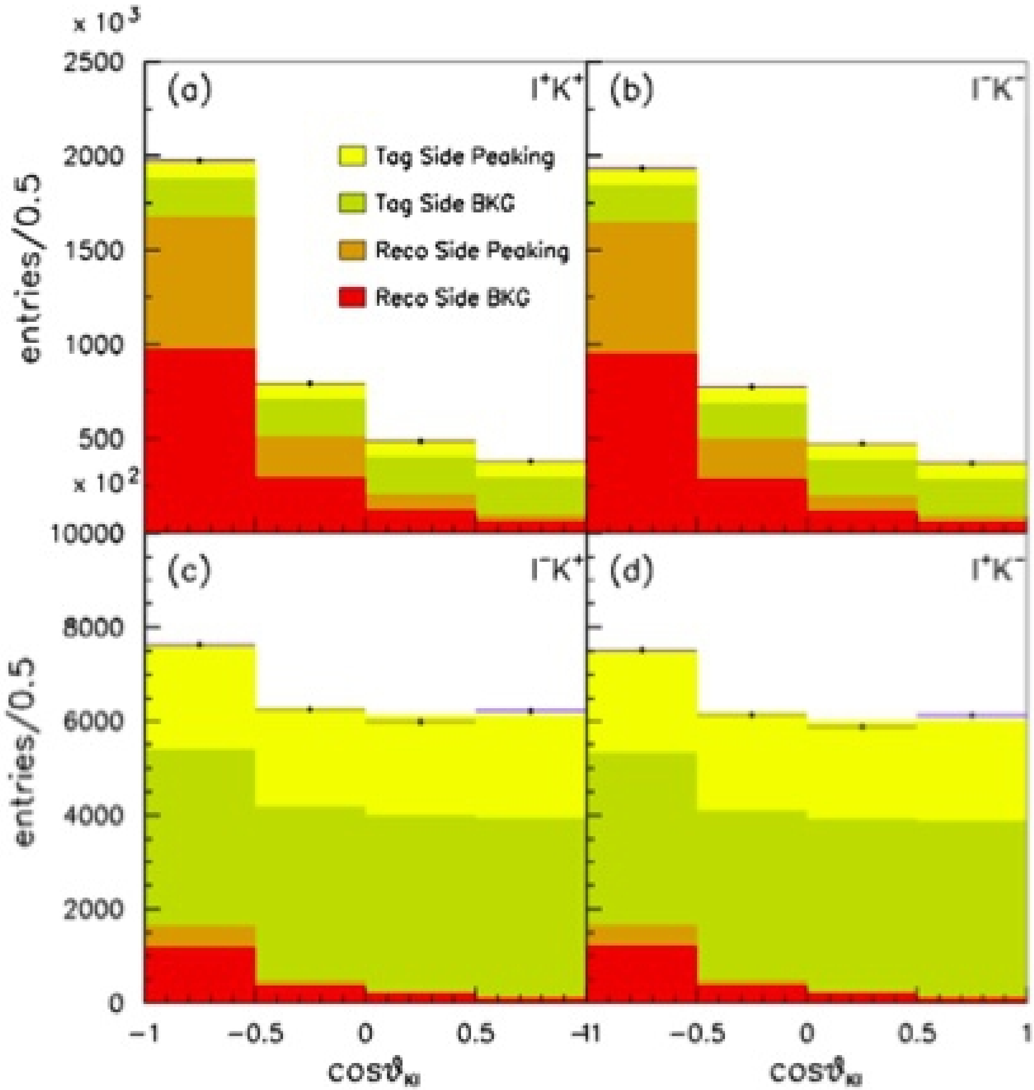
$$A_{CP} = (0.06 \pm 0.17^{+0.32}_{-0.38}) \times 10^{-2}$$

In agreement with SM

Flavor Specific A^d_{SL}

Babar Measurement ($L=425.7\ fb^{-1}$)

[Phys. Rev. Lett. 111 101802 (2013)]
[Phys. Rev. D 93, 032001 (2016)]



- Systematics from
  - Sample composition
  - Δt resolution model
  - K_R Δt shape and fraction

$$A_{CP} = (0.06 \pm 0.17^{+0.32}_{-0.38}) \times 10^{-2}$$

In agreement with SM

Flavor Specific A^d_{SL}

Babar Measurement (L=425.7 fb^{-1})

[Phys. Rev. Lett. 111 101802 (2013)]
[Phys. Rev. D 93, 032001 (2016)]

Source	$\delta\Delta_{CP}(10^{-3})$
Peaking sample composition	$^{+1.50}_{-1.17}$
Combinatorial sample composition	± 0.39
Δt resolution model	± 0.60
K_R fraction	± 0.11
K_R Δt distribution	± 0.65
Fit bias	$^{+0.58}_{-0.46}$
CP eigenstate description	0
Physical parameters	$^{+0}_{-0.28}$
Total	$^{+1.88}_{-1.61}$

- Systematics from
  - Sample composition
  - Δt resolution model
  - K_R Δt shape and fraction

$$A_{CP} = (0.06 \pm 0.17^{+0.32}_{-0.38}) \times 10^{-2}$$

In agreement with SM

Flavor Specific A^s_{SL}

LHCb Measurement (L=1.0 fb^{-1}) [Phys. Lett. B728 607-615 (2014)]

- Given the D0 and B-Factories result, it is important to understand if physics beyond the SM is present in the B^0_s sector
- A^s_{SL} measured from exclusive decays $B^0_s \to D^-_s X \mu^+ \nu$ ($D^-_s \to \Phi\pi^-$, $\Phi \to KK$)
- Particle-antiparticle production asymmetries a_P may bias the measured value at hadronic colliders:

$$a_P \equiv \frac{N(B) - N(\bar{B})}{N(B) + N(\bar{B})}$$ (few percent, B($\bar{B}$): produced mesons)

- Measured time-integrated charge asymmetry after correction for detector effects:
  - Neglecting detector & production asymmetries:

$$f_{mix} = 2\chi(1-\chi); \quad f_{unmix} = 1 - f_{mix}; \quad A_{CP} = \frac{N_{BB} - N_{\bar{B}\bar{B}}}{N_{BB} + N_{\bar{B}\bar{B}}}$$

$$N_B = N f_{unmix} + 2N \frac{f_{mix}}{2}(1 + A_{CP}); \quad N_{\bar{B}} = N f_{unmix} + 2N \frac{f_{mix}}{2}(1 - A_{CP})$$

$$A_{meas} = \frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}} = \frac{2N\chi(1-\chi)2A}{2N} = \chi(1-\chi)2A_{CP} = A_{CP}/2; \quad (\chi_s = 0.5)$$

Flavor Specific A^s_{SL}

LHCb Measurement (L=1.0 fb^{-1}) [Phys. Lett. B728 607-615 (2014)]

- Given the D0 and B-Factories result, it is important to understand if physics beyond the SM is present in the B^0_s sector
- A^s_{SL} measured from exclusive decays $B^0_s \to D^-_s X \mu^+ \nu$ ($D^-_s \to \Phi\pi^-$, $\Phi \to KK$)
- Particle-antiparticle production asymmetries a_P may bias the measured value at hadronic colliders:

$$a_P \equiv \frac{N(B) - N(\bar{B})}{N(B) + N(\bar{B})}$$

(few percent, B($\bar{B}$): produced mesons)

- Measured time-integrated charge asymmetry after correction for detector effects:
  - Taking into account the oscillation probability:

$$|g_\pm(t)|^2 = \frac{e^{-\Gamma_q t}}{2}\left[\cosh\left(\frac{\Delta\Gamma_q}{2}t\right) \pm \cos(\Delta m_q t)\right]$$

- ε(t): decay time acceptance function for B_s mesons

$$N_B = N f_{unmix} \frac{\int e^{-\Gamma t}}{2}\left(\cosh\left(\frac{\Delta\Gamma t}{2}\right) + \cos(\Delta m t)\right)\epsilon(t)\,dt + 2N\frac{f_{mix}}{2}(1 + A_{CP})\frac{\int e^{-\Gamma t}}{2}\left(\cosh\left(\frac{\Delta\Gamma t}{2}\right) - \cos(\Delta m t)\right)\epsilon(t)\,dt$$

$$N_{\bar{B}} = N f_{unmix} \frac{\int e^{-\Gamma t}}{2}\left(\cosh\left(\frac{\Delta\Gamma t}{2}\right) + \cos(\Delta m t)\right)\epsilon(t)\,dt + 2N\frac{f_{mix}}{2}(1 - A_{CP})\frac{\int e^{-\Gamma t}}{2}\left(\cosh\left(\frac{\Delta\Gamma t}{2}\right) - \cos(\Delta m t)\right)\epsilon(t)\,dt$$

Flavor Specific A^s_{SL}

LHCb Measurement (L=1.0 fb^{-1}) [Phys. Lett. B728 607-615 (2014)]

- Given the D0 and B-Factories result, it is important to understand if physics beyond the SM is present in the B^0_s sector
- A^s_{SL} measured from exclusive decays $B^0_s \to D^-_s X \mu^+ \nu$ ($D^-_s \to \Phi\pi^-$, $\Phi \to KK$)
- Particle-antiparticle production asymmetries a_P may bias the measured value at hadronic colliders:

$$a_P \equiv \frac{N(B) - N(\bar{B})}{N(B) + N(\bar{B})}$$ (few percent, B($\bar{B}$): producted mesons)

- Measured time-integrated charge asymmetry after correction for detector effects:

$$A_{\text{meas}} \equiv \frac{\Gamma[D_s^- \mu^+] - \Gamma[D_s^+ \mu^-]}{\Gamma[D_s^- \mu^+] + \Gamma[D_s^+ \mu^-]}$$

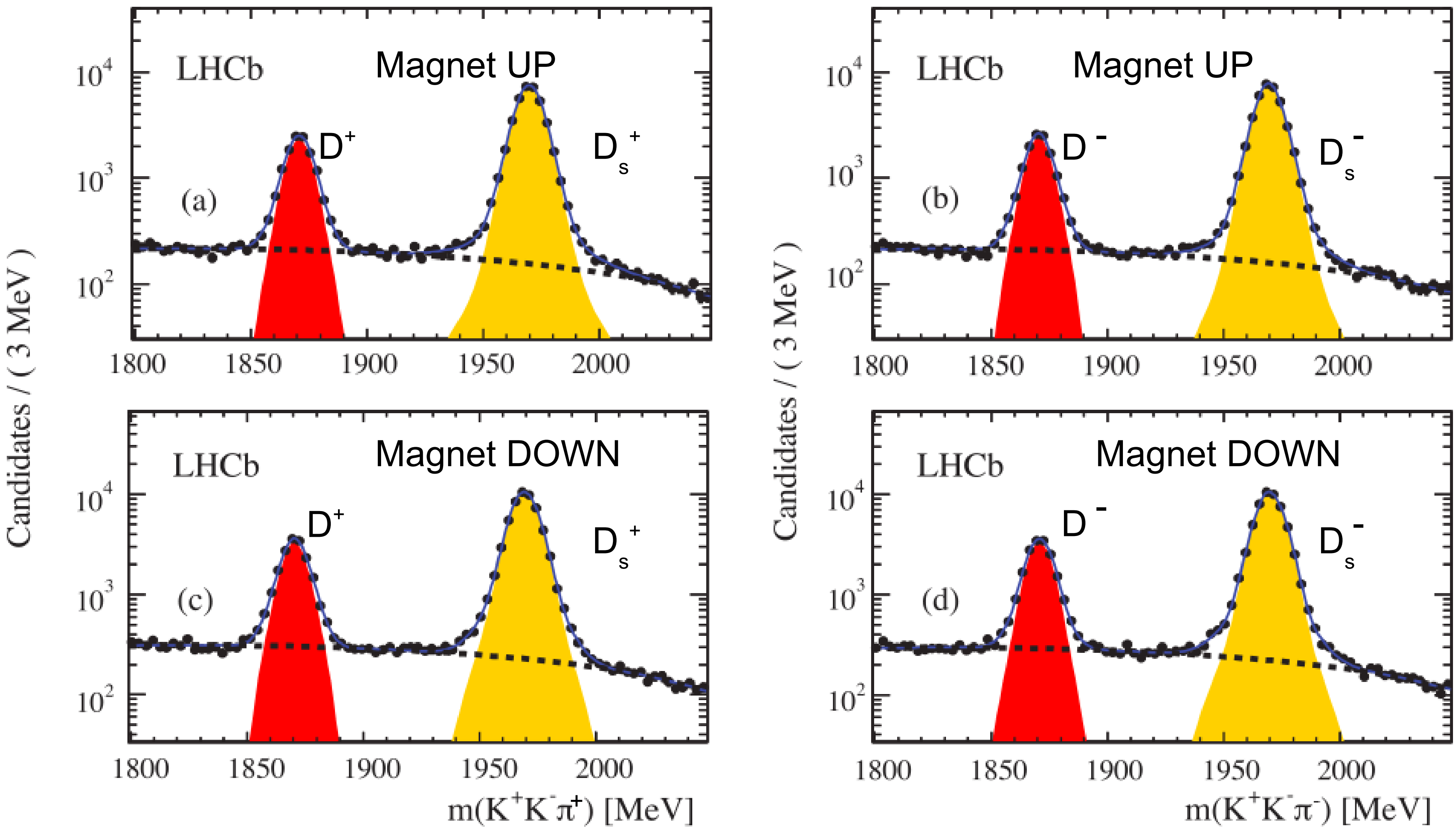
$$= \frac{a^s_{sl}}{2} + \left[a_P - \frac{a^s_{sl}}{2}\right] \frac{\int_{t=0}^{\infty} e^{-\Gamma_s t} \cos(\Delta M_s t)\epsilon(t)\,dt}{\int_{t=0}^{\infty} e^{-\Gamma_s t} \cosh(\frac{\Delta\Gamma_s t}{2})\epsilon(t)\,dt}$$

- ε(t): decay time acceptance function for B_s mesons
- Acceptance integral ratio ~ 0.2% → negligible
  - → $A_{meas} = a^s_{sl}/2$

Flavor Specific A^s_{SL}

LHCb Measurement ($L=1.0\ fb^{-1}$) [Phys. Lett. B728 607-615 (2014)]

- Signal yields extracted from KKπ invariant mass distributions



Flavor Specific A^s_{SL}

LHCb Measurement (L=1.0 fb^{-1}) [Phys. Lett. B728 607-615 (2014)]

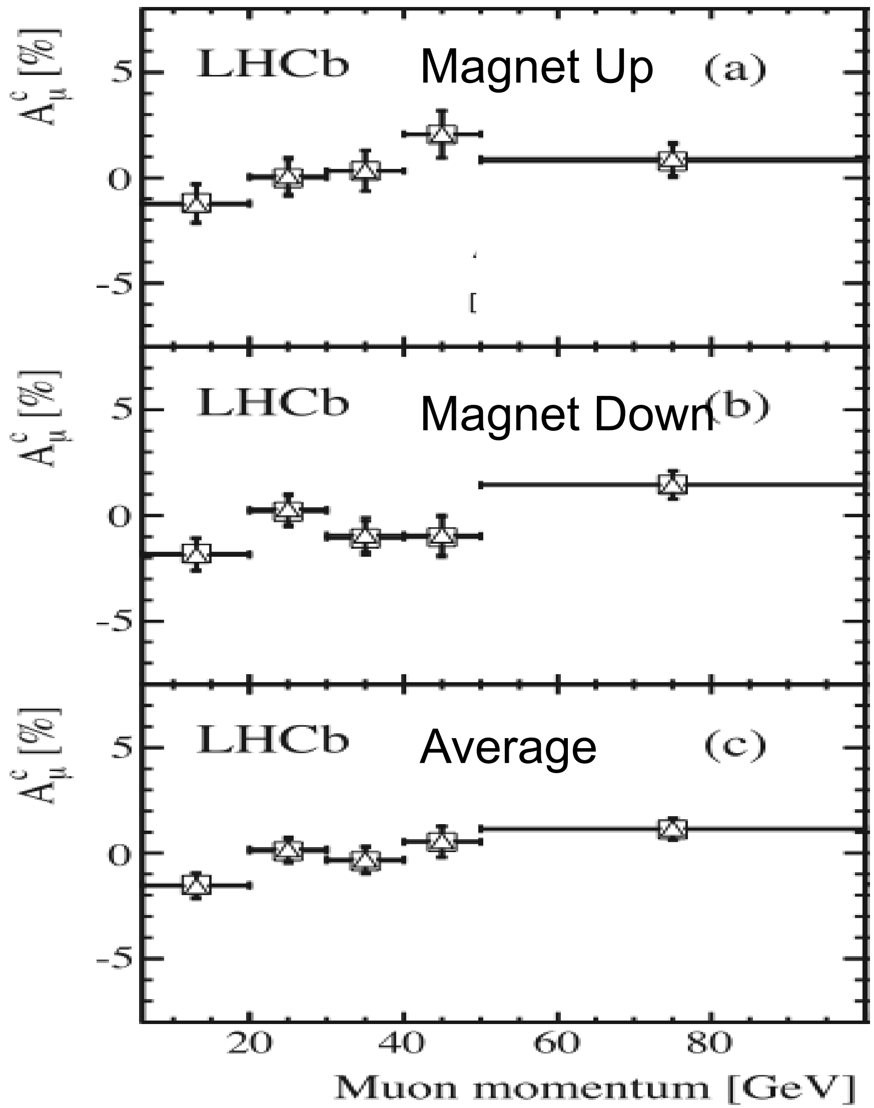
- Corrected measured time-integrated charge asymmetry:

$$A_{\rm meas} = A^{\rm c}_{\mu} - A_{\rm track} - A_{\rm bkg}$$

$$A^{\rm c}_{\mu} = \frac{N(D_s^- \mu^+) - N(D_s^+ \mu^-) \times \frac{\epsilon(\mu^+)}{\epsilon(\mu^-)}}{N(D_s^- \mu^+) + N(D_s^+ \mu^-) \times \frac{\epsilon(\mu^+)}{\epsilon(\mu^-)}}$$

- Muon efficiency ratio $\varepsilon(\mu^+)/\varepsilon(\mu^-)$ from $J/\Psi \to \mu\mu$ reconstructed by requiring pairs of opposite-charge tracks consistent with the J/Ψ invariant mass and then applying the muon selection

- A^c_μ=(+0.04 ± 0.25)%



Flavor Specific A^s_{SL}

LHCb Measurement ($L=1.0\ fb^{-1}$) [Phys. Lett. B728 607-615 (2014)]

- Corrected measured time-integrated charge asymmetry:

$$A_{\text{meas}} = A^c_{\mu} - A_{\text{track}} - A_{\text{bkg}}$$

$$A^c_{\mu} = \frac{N(D_s^- \mu^+) - N(D_s^+ \mu^-) \times \frac{\epsilon(\mu^+)}{\epsilon(\mu^-)}}{N(D_s^- \mu^+) + N(D_s^+ \mu^-) \times \frac{\epsilon(\mu^+)}{\epsilon(\mu^-)}}$$

Raw asymmetry corrected for muon efficiencies charge dependence

- Tracking asymmetry mostly cancels between π and μ in the $\Phi\pi^-\mu^+$ sample (π and μ have opposite charge).

- Track efficiency ratio $\varepsilon(\pi^+)/\varepsilon(\pi^-)$ from comparison of fully and partially reconstructed $D^{*+} \rightarrow D^0 \pi^+$, $D^0 \rightarrow K^-\pi^+\pi^+(\pi^-)$ and charge conjugated mode. For both the states, the efficiency is obtained from the ratio of fully and partially reconstructed evts without requiring explicit reconstruction of the π^-.

- Detector effects reduced by periodically reversing magnets polarities

  - $A_{\text{track}} = (+0.02 \pm 0.13)\%$: track-reconstruction asymmetry

Flavor Specific A^s_{SL}

LHCb Measurement ($L=1.0\ fb^{-1}$) [Phys. Lett. B728 607-615 (2014)]

- Corrected measured time-integrated charge asymmetry:

$$A_{\rm meas} = A^c_\mu - A_{\rm track} - A_{\rm bkg}$$

- BKG from prompt charm production, fake muons and real D_s, $B \to D_s D$, $D \to l X$
- A_{BKG} computed using control samples:
  - $D^+_s \pi^- (K^-) X$ with $\pi^- (K^-)$ misidentified as muons, $b \to c\bar{c}s$ with $W \to D_s$, $D \to \mu$
  - $A_{bkg} = (+0.05 \pm 0.05)\%$

- After the corrections:

$$A_{meas} = (-0.03 \pm 0.25 \pm 0.18) \times 10^{-2} \to a^s_{SL} = (-0.06 \pm 0.50 \pm 0.36) \times 10^{-2}$$

Flavor Specific A^s_{SL}

LHCb Measurement (L=1.0 fb^{-1}) [Phys. Lett. B728 607-615 (2014)]

$$a^s_{SL} = (-0.06 \pm 0.50 \pm 0.36) \times 10^{-2}$$

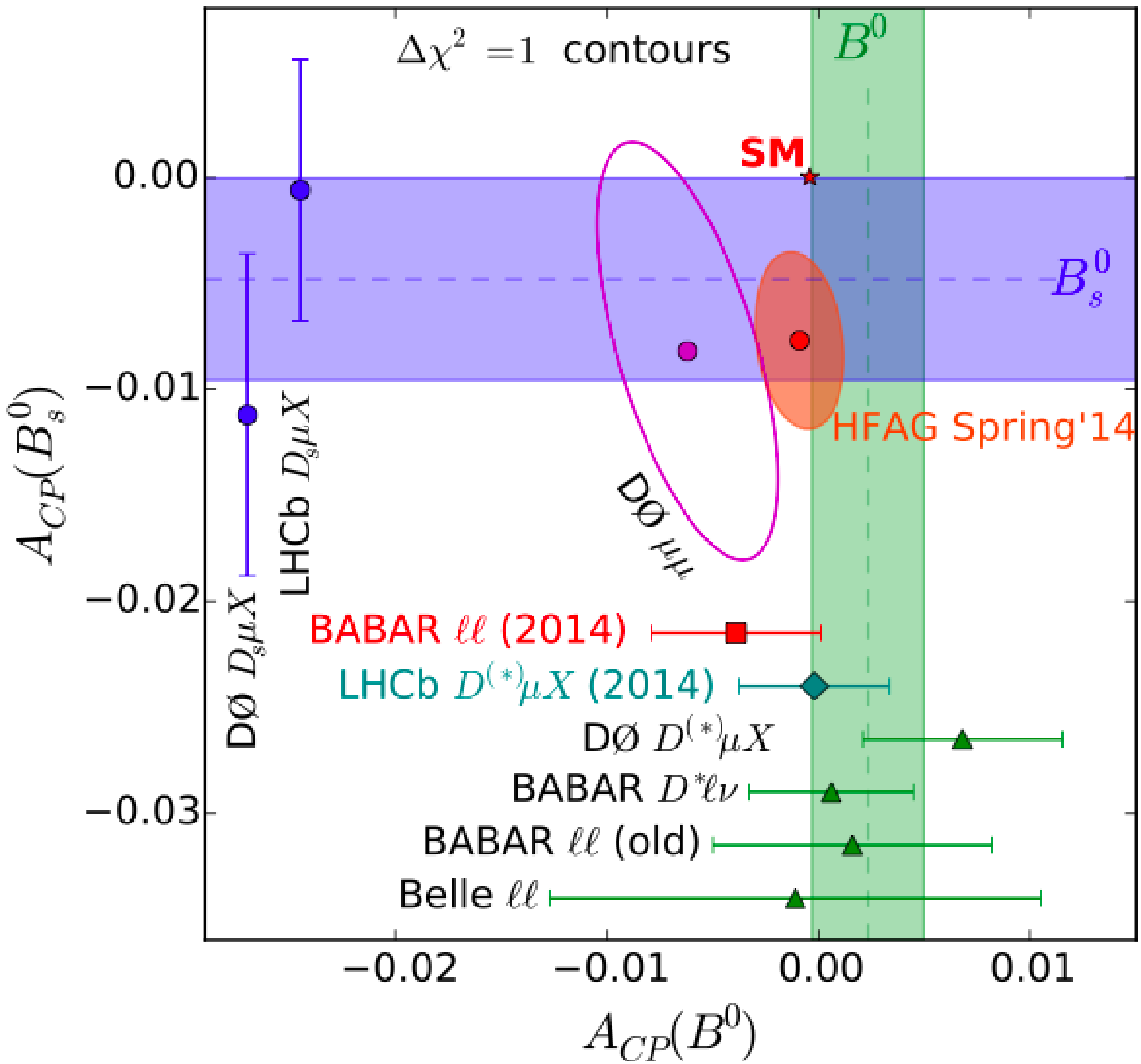
- Most precise measurement, in agreement with SM
- Systematics from tracking asymmetry, efficiency ratios, signal shape and binning

Sources of systematic uncertainty on $A_{\rm meas}$.

Source	$\sigma(A_{\rm meas})$ [%]
Signal modelling and muon correction	0.07
Statistical uncertainty on the efficiency ratios	0.08
Background asymmetry	0.05
Asymmetry in track reconstruction	0.13
Field-up and field-down run conditions	0.01
Software trigger bias (topological trigger)	0.05
Total	0.18

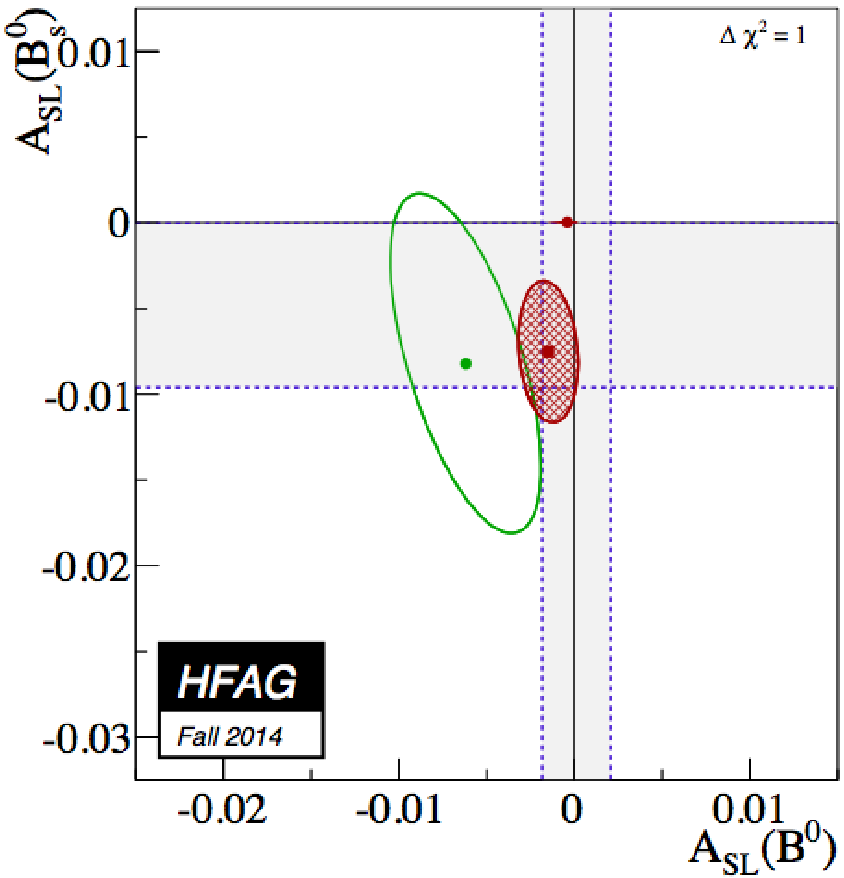
Summary on A^q_{SL}

- Various measurements compared with the HFAG spring 2014 average



Summary on A^q_{SL}

- Result from Flavor-Specific measurements from HFAG Fall 2014 [arXiv:1412.7515]
  - A^d_{SL}:
    - Υ(4S): -0.0019 ± 0.0027
    - All: +0.0001 ± 0.0020
  - A^s_{SL}:
    - World Alverage: -0.0048 ± 0.0048



- World Average of flavor specific measurements agree with SM

- Total World Average computed using a 2D fit (ρ=-0.158):
  - A^d_{SL}:-0.0015 ± 0.0017
    $|q/p|_d$=1.0007 ±0.0009
  - A^s_{SL}:-0.0075 ± 0.0041
    $|q/p|_s$=1.0038 ±0.0021
- Global WA shows agrees with SM at ~ 1.5 σ
- Only tension in the D0 inclusive measurement