LHCb results on hadronic penguin decays

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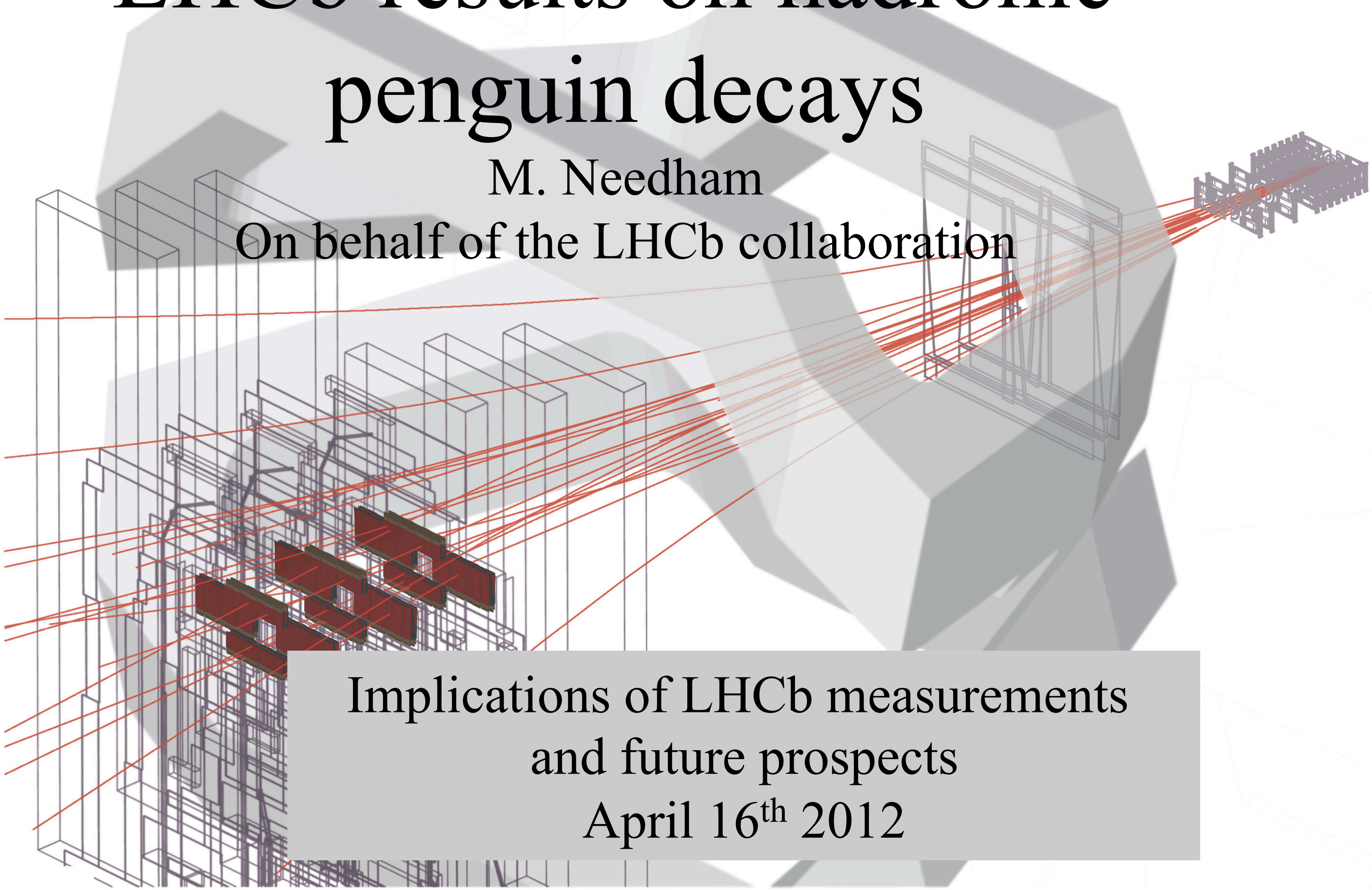
On behalf of the LHCb collaboration



Implications of LHCb measurements and future prospects
April 16th 2012

Outline

- Introduction
- Observation of $B_s \rightarrow K^{*0}\overline{K}^{*0}$
- $B_s \rightarrow \phi\phi$
  - Polarization amplitudes
  - Triple product asymmetries
- Prospects + outlook

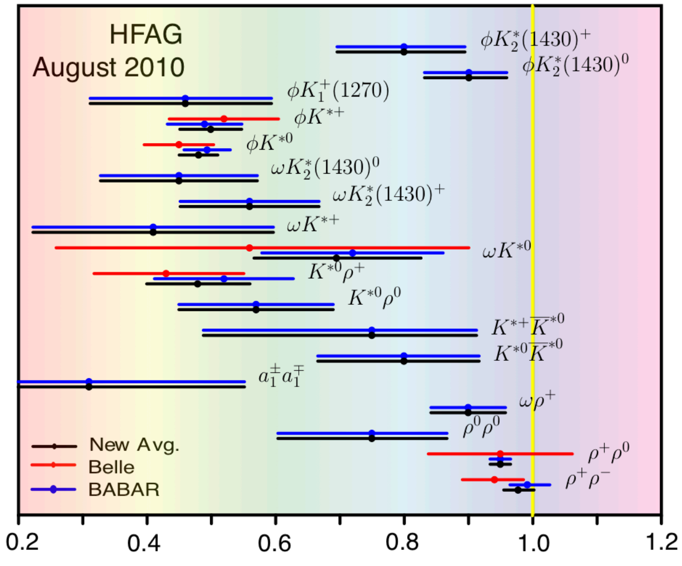
Introduction

B_d hadronic penguin decays studied in several modes at the B-factories

Open issues

- $\sin 2\beta$ in penguin decays (e.g. $B_d \rightarrow \phi K_s$) versus tree (e.g. $B_d \rightarrow J/\psi K_s$)

- Polarization puzzle: Expect from V-A nature of the weak interaction, that $f_L >> f_T$, but observe (e.g. in $B_d \rightarrow \phi K^*$) $f_L \sim f_T$



Hadronic trigger capability at LHCb allows to continue this program + extend to the B_s sector

Observation of $B_s \rightarrow K^{*0}\overline{K}^{*0}$

LHCB-PAPER-2011-012
(arXiv: 1111.4183)

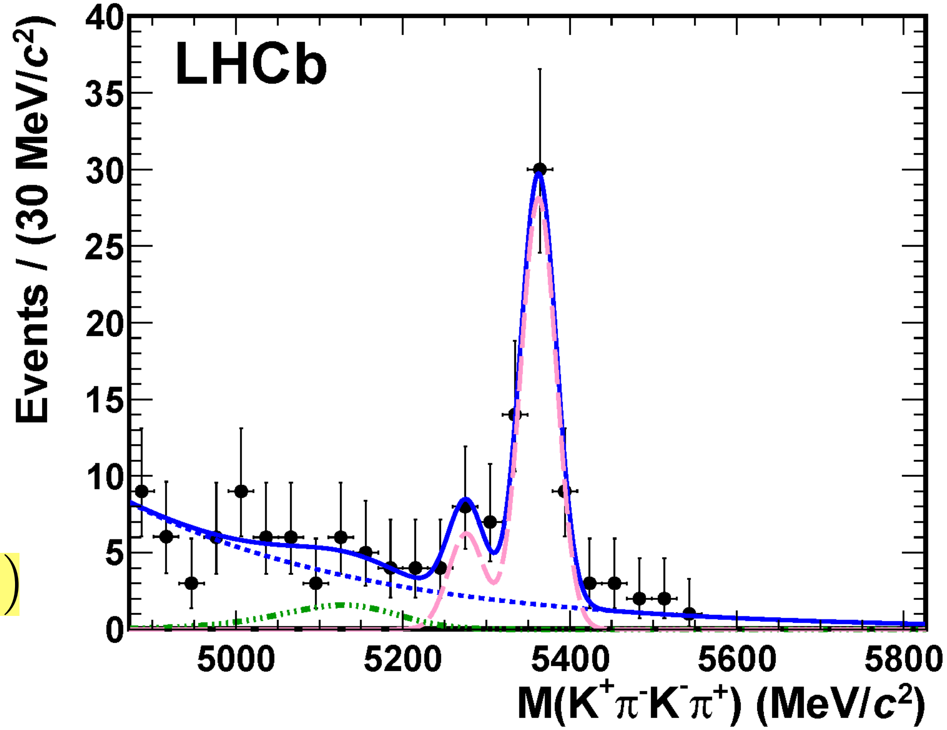
35 pb^{-1} of data taken in 2010

$49.8 \pm 7.5 \ B_s \rightarrow K^+\pi^-K^-\pi^+$ candidates

Dominated by $B_s \rightarrow K^{*0}\overline{K}^{*0}$

Longitudinal polarization fraction

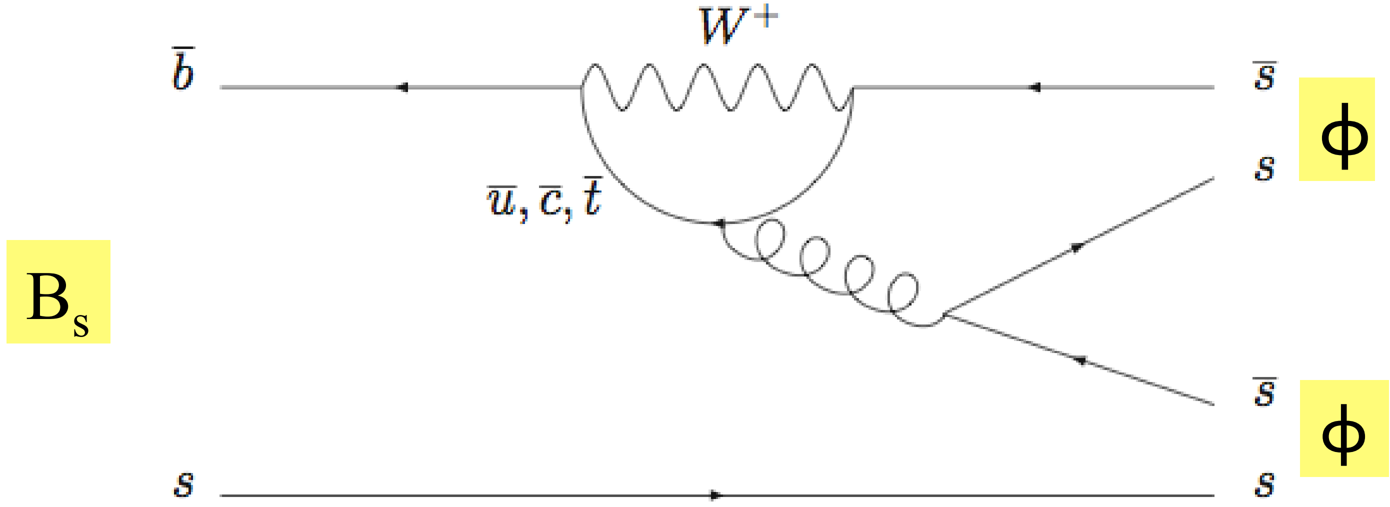
$f_L = 0.31 \pm 0.12(stat) \pm 0.04(syst)$



Branching ratio measured to be

$BR(B_s \rightarrow K^{*0}\overline{K}^{*0}) = (2.81 \pm 0.46(stat) \pm 0.45(syst) \pm 0.34(f_s/f_d)) \times 10^{-5}$

$B_s \rightarrow \phi\phi$



- Golden mode for measurement of ‘ϕ_s’ in hadronic penguin decays (e.g. see Raidal, arXiv, hep-ph/0209091)

  - In Standard Model cancellation between decay + mixing phases ‘ϕ_s’ is negligible. Non zero measurement ➔ New Physics

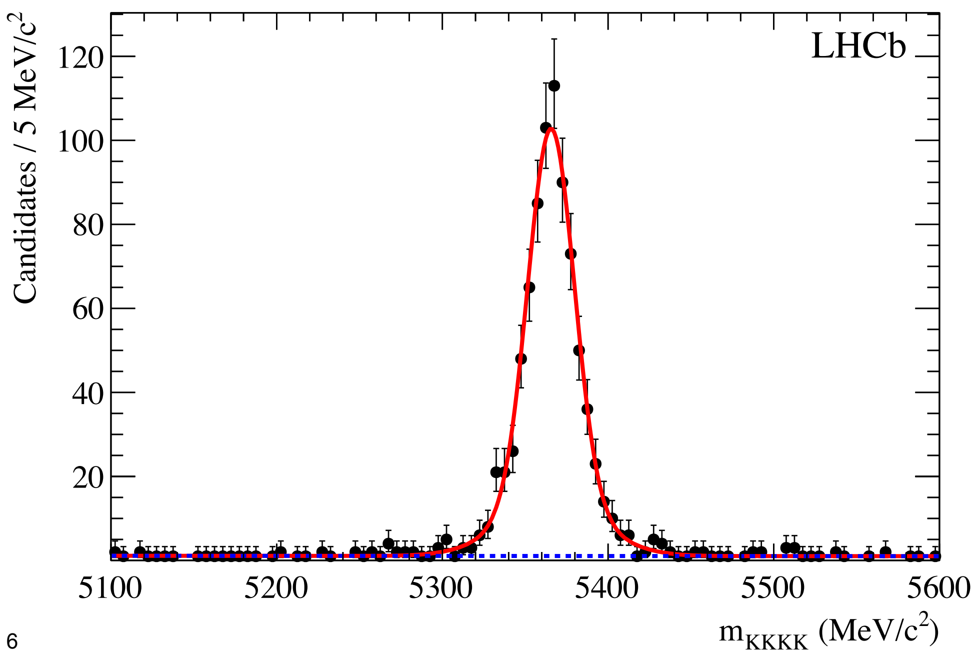
- Long term goal time dependent angular fit to measure ‘ϕ_s’

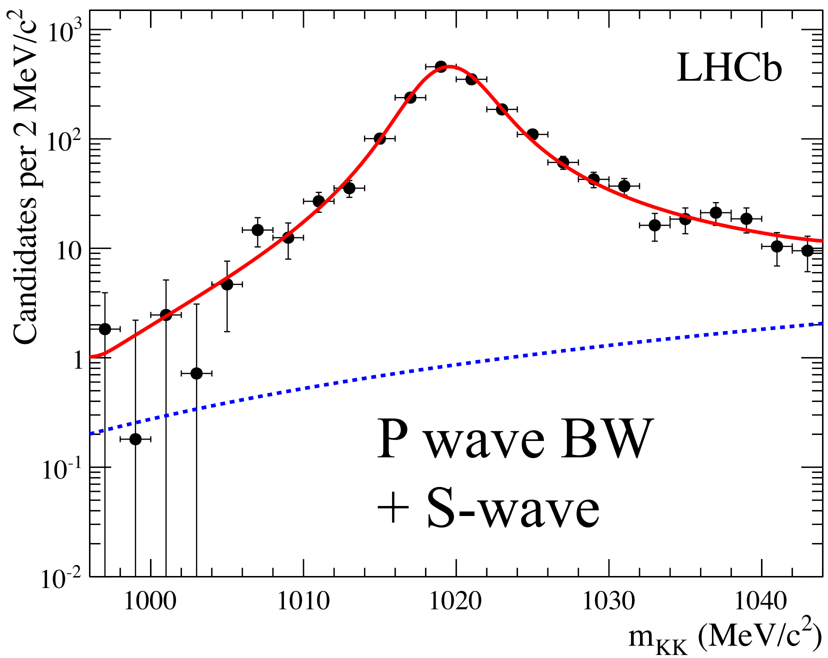
- First studies: untagged time integrated angular analysis to extract polarization amplitudes and triple product asymmetries

$B_s \rightarrow \phi\phi$

LHCb-PAPER-2012-004
arXiv:1204.1620

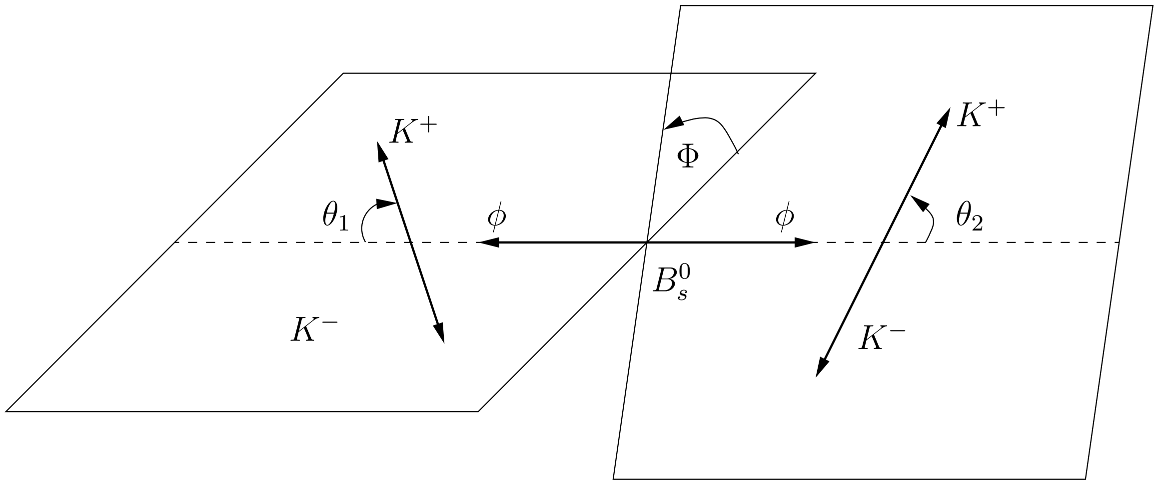
- Full 2011 dataset (~1 fb^{-1})
- 801 ± 29 candidates with excellent signal to background ratio
- S- wave component in +/- 25 MeV window around ϕ mass ~ 1.3 %





Polarization Amplitudes

- Three polarization amplitudes $A_{0,}$ $A_{//}$ (CP-even), $A_{\perp}$ (CP-odd)
- Measure using untagged time-integrated angular fit to helicity angles: kaon decay angles (θ_1,θ_2) and the angle between the two decay planes (ϕ)



- Assume $\phi_s = 0$ is zero
- Γ_s and $\Delta\Gamma_s$ from LHCb B_s ➔J/ψϕ measurement (PRL.108 101803 2012) input as Gaussian constraints

Polarization Amplitudes

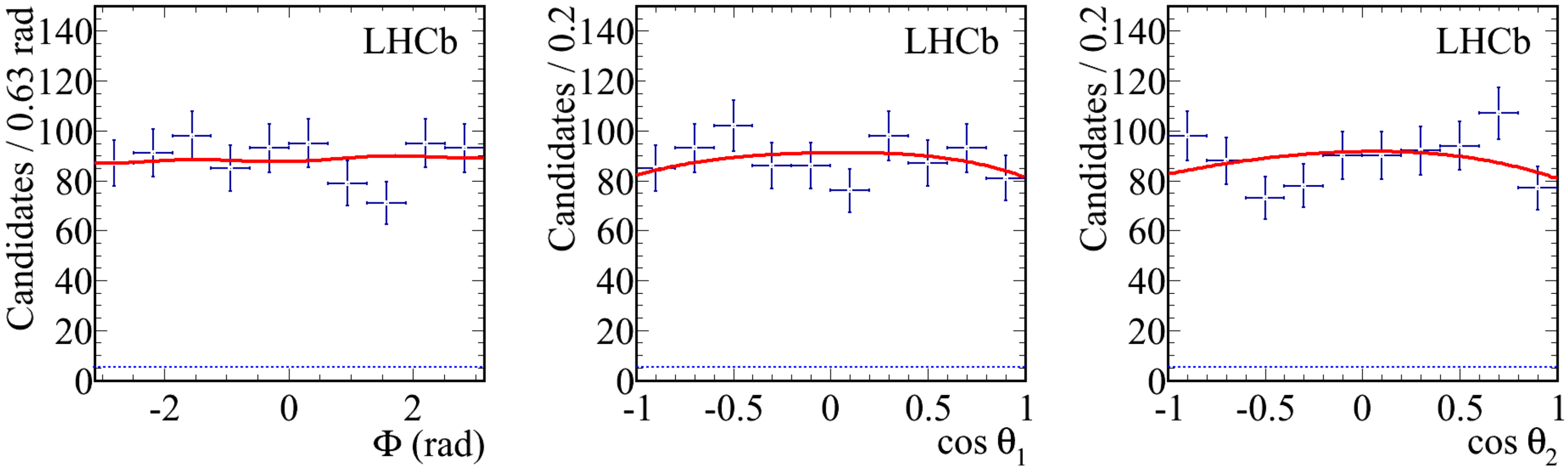
Untagged, time integrated angular fit to helicity angles (Φ, $\cos\theta_1$, $\cos\theta_2$) to extract polarization amplitudes + strong phase

$$|A_0|^2 = 0.365 \pm 0.022\,(\text{stat}) \pm 0.012\,(\text{syst})$$

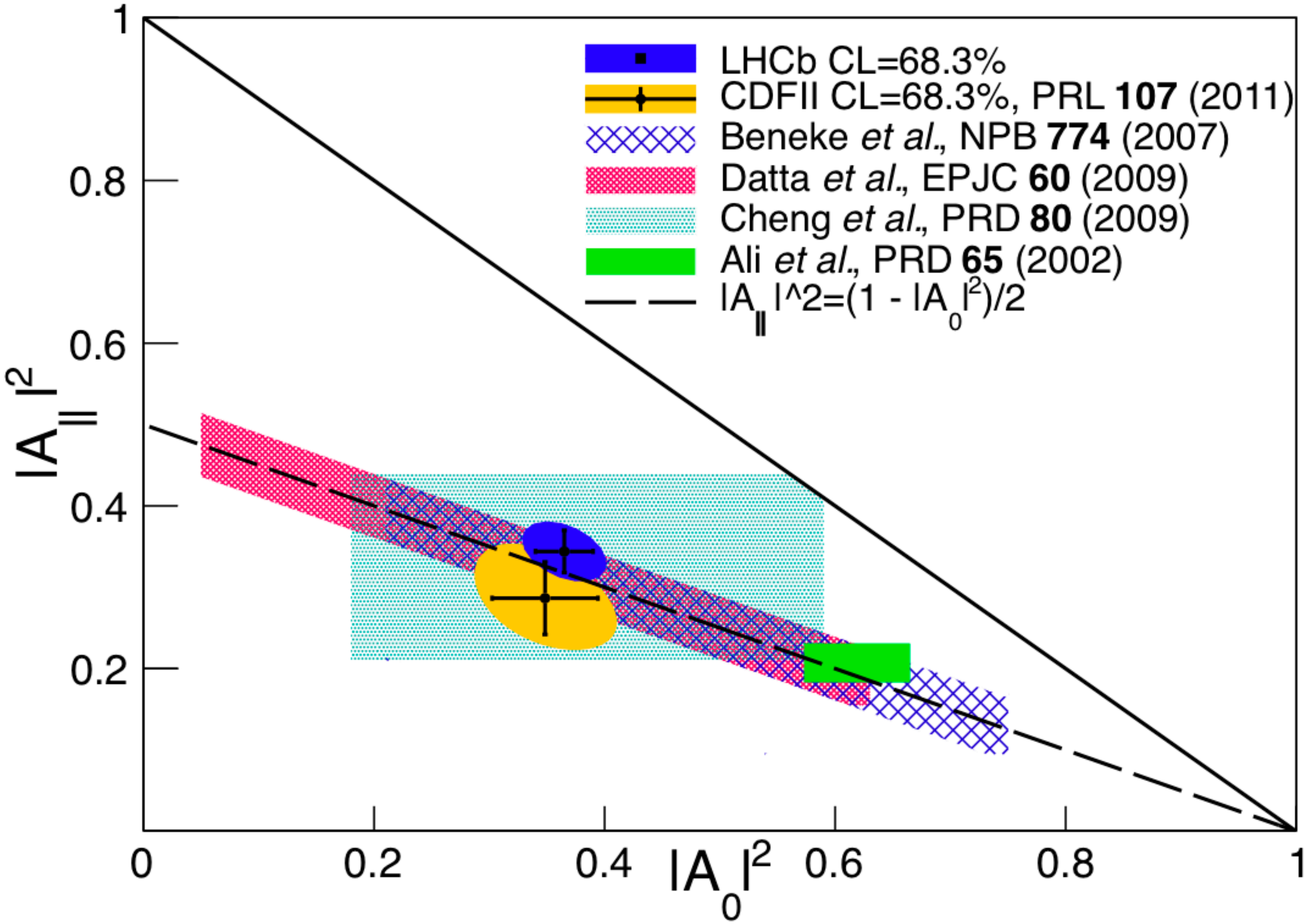
$$|A_\perp|^2 = 0.291 \pm 0.024\,(\text{stat}) \pm 0.010\,(\text{syst})$$

+ strong phase $\delta_\parallel \equiv \delta_2 - \delta_1 = \arg(A_\parallel / A_0)$

$$\cos(\delta_\parallel) = -0.844 \pm 0.068\,(\text{stat}) \pm 0.029\,(\text{syst})$$



Polarization Amplitudes



$f_L \sim |A_0|^2$

Good agreement with CDF measurements and Latest pQCD predictions

Triple Product Asymmetries

Datta + London: arXiv:hep-ph/0303159
Gronau + Rosner: arXiv:hep-ph/11071232v2

CP-odd/CP-even interference terms $\mathrm{Im}(A_0^{*} A_\perp)$ + $\mathrm{Im}(A_{//}^{*} A_\perp)$ are proportional to Triple products + are odd under time reversal

Sign according to $\cos\theta_1 \cos\theta_2$

$$
\begin{array}{lrcl}
\mathrm{V} & \sin\Phi & = & (\hat{n}_{V_1} \times \hat{n}_{V_2}) \cdot \hat{p}_{V_1} \\
\mathrm{U} & \sin 2\Phi & = & 2(\hat{n}_{V_1} \cdot \hat{n}_{V_2})(\hat{n}_{V_1} \times \hat{n}_{V_2}) \cdot \hat{p}_{V_1}
\end{array}
$$

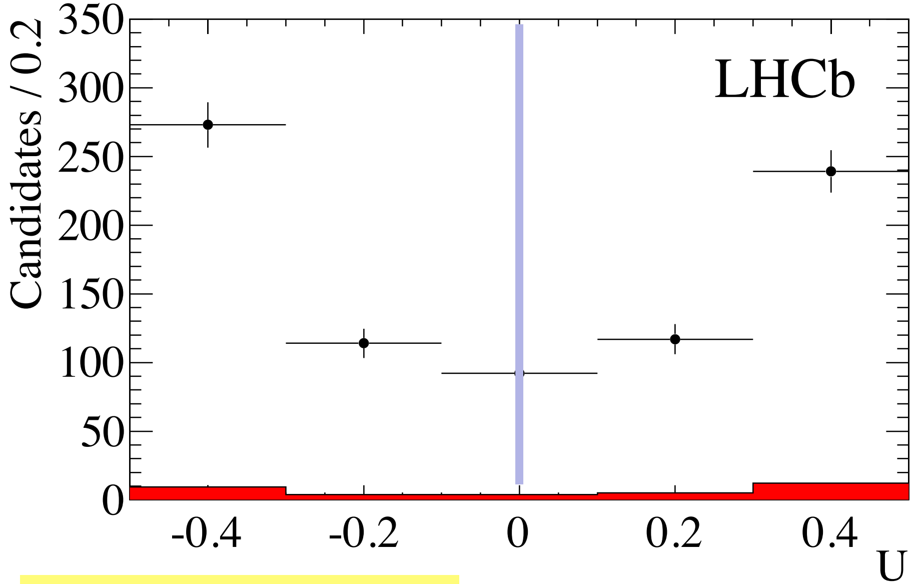
- Non-zero TPs: T violation + hence CP violation

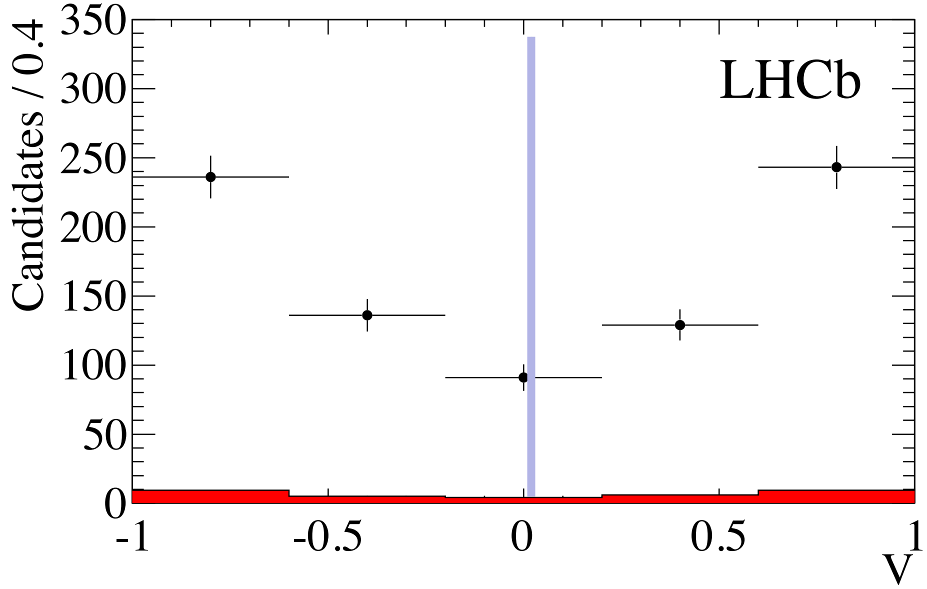
- Extraction of TP asymmetries simple counting exercise:

$$
A_U = \frac{\Gamma(U>0) - \Gamma(U<0)}{\Gamma(U>0) + \Gamma(U<0)} \qquad A_V = \frac{\Gamma(V>0) - \Gamma(V<0)}{\Gamma(V>0) + \Gamma(V<0)}
$$

- Expect to be zero in the Standard Model

Triple Product Asymmetries





LHCb-PAPER-2012-004
arXiv:1204.1620

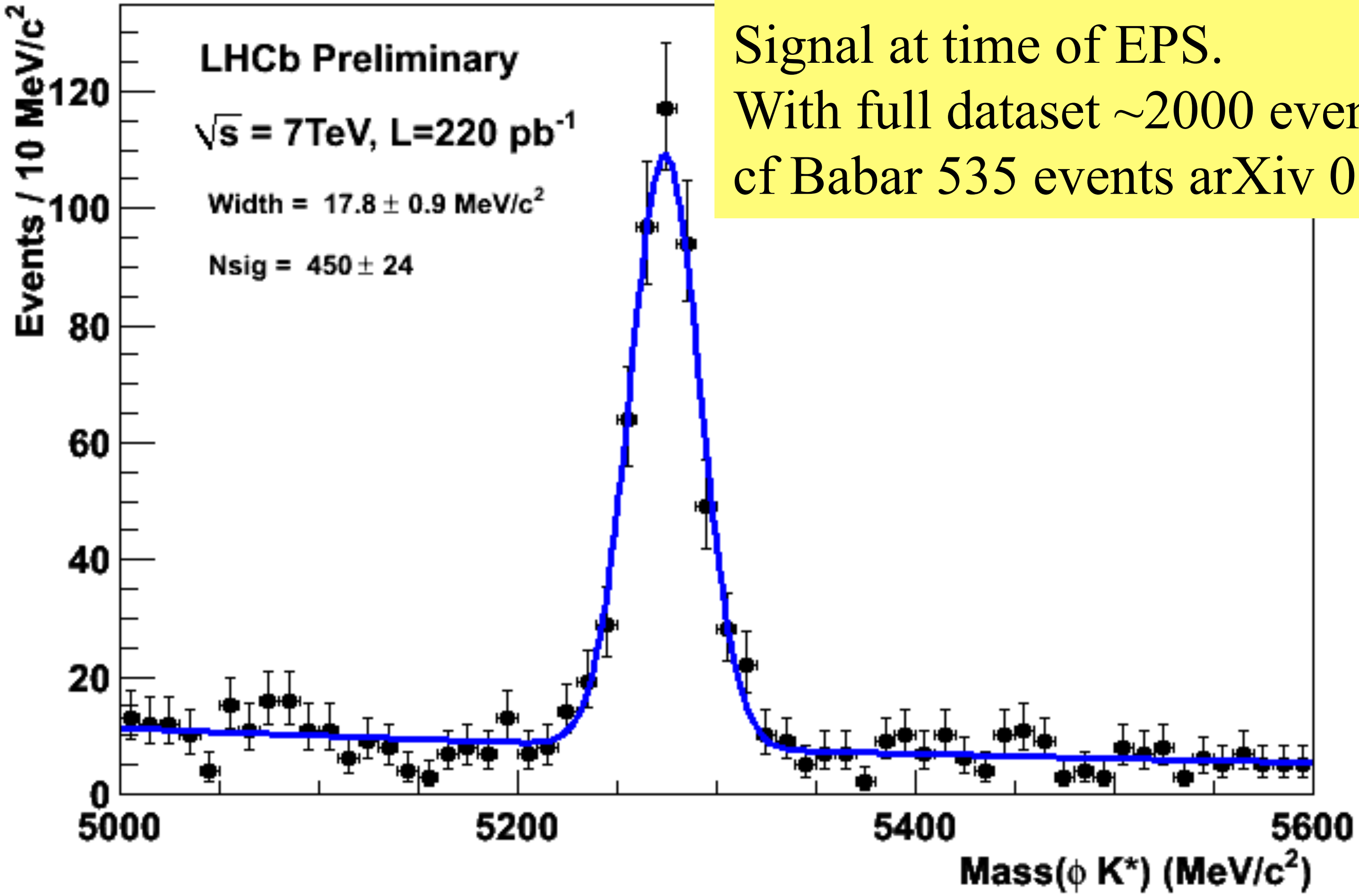
	A_u	A_v
LHCb	**-0.055 ± 0.036 ± 0.018**	**0.01 ± 0.036 ± 0.018**
CDF	-0.007 ± 0.064 ± 0.018	-0.12 ± 0.064 ± 0.016
My average	-0.042 ± 0.034	-0.025 ± 0.034

Results are consistent with CDF and zero CP violation

Outlook

- Those are our public results on hadronic penguins
- With the 2011+2012 dataset many more analyses going on and there is a lot more to come in the next months:
  - Generic trigger lines that pick up hadronic B decays with good efficiency
  - Offline streaming selecting B^+, B_d, B_s decays to two light resonances η, η’, K*, ρ, ω f^0, ϕ
- For the ϕX family we can know explore similar modes to those studied for the J/ψX family with 2010 data

$B_d \rightarrow \phi K^*$



Signal at time of EPS.
With full dataset ~2000 events
cf Babar 535 events arXiv 0808.3586

Ongoing: measurements of the polarization amplitudes, Triple Products and CP asymmetries , …

ϕ_s in $B_s \rightarrow \phi\phi$

- Most of the tools to perform first measurement of in place and we are ‘almost’ ready to go:
  - Simulation + upgrade studies before first data-taking
  - Experience from $B_s \rightarrow J/\psi\ \phi$
  - $B_s \rightarrow \phi\phi$ PDFs, fitters exercised with untagged studies for amplitudes
- First measurement will be proof of principle. With 2011 + 2012 data precision of ~ 0.3 rad can be achieved
  - Similar precision likely for $B_s \rightarrow K^{*0}\overline{K^{*0}}$
- With ~5 fb^{-1} collected with current LHCb up to 2018 expect precision of 0.08 rad
- Key channel for the upgrade: 50 fb^{-1} +improved hadron trigger, precision of 0.02 rad

CERN-LHCC-2011-001

Summary

- With 2010 dataset made first observation of $B_s \rightarrow K^{*0}\overline{K}^{*0}$
  - Similar studies to $B_s \rightarrow \phi\phi$ possible for this channel with 2011 dataset
- 2011 dataset world's most precise measurements of polarization amplitudes and Triple Product asymmetries in $B_s \rightarrow \phi\phi$
- Expect many more measurements to come with 2011 (+2012) dataset
- Hadronic penguin decays (e.g. $B_s \rightarrow \phi\phi$) key measurements for the LHCb upgrade
- New ideas/predictions to exploit our large dataset welcome !

Backup

Polarization Systematics

Source	$\lvert A_0\rvert^2$	$\lvert A_\perp\rvert^2$	$\lvert A_\parallel\rvert^2$	$\cos\delta_\parallel$
S-wave	0.007	0.005	0.012	0.001
Time Acceptance	0.006	0.006	0.002	0.007
Angular Acceptance	0.007	0.006	0.006	0.028
Trigger category	0.003	0.002	0.001	0.004
Background model	0.001	-	0.001	0.003
Total	0.012	0.010	0.014	0.029

Triple Product Systematics

Source	A_U	A_V	Chosen uncertainty
Angular acceptance	0.009	0.006	0.009
Decay time acceptance	0.006	0.014	0.014
Fit model	0.004	0.005	0.005
Total			0.018

Decay Rate

$$\frac{d^4\Gamma}{d\cos\theta_1 d\cos\theta_2 d\Phi dt} \propto \sum_{n=1}^{6} K_n(t) f_n(\theta_1,\theta_2,\Phi)$$

$$\begin{aligned}
f_1(\theta_1,\theta_2,\Phi) &= 4\cos^2\theta_1\cos^2\theta_2 \\
f_2(\theta_1,\theta_2,\Phi) &= \sin^2\theta_1\sin^2\theta_2(1+\cos 2\Phi) \\
f_3(\theta_1,\theta_2,\Phi) &= \sin^2\theta_1\sin^2\theta_2(1-\cos 2\Phi) \\
f_4(\theta_1,\theta_2,\Phi) &= -2\sin^2\theta_1\sin^2\theta_2\sin 2\Phi \\
f_5(\theta_1,\theta_2,\Phi) &= \sqrt{2}\sin 2\theta_1\sin 2\theta_2\cos\Phi \\
f_6(\theta_1,\theta_2,\Phi) &= -\sqrt{2}\sin 2\theta_1\sin 2\theta_2\sin\Phi.
\end{aligned}$$

$$\begin{aligned}
K_1(t) &= \frac{1}{2}A_0^2[(1+\cos\phi_s)e^{-\Gamma_L t} + (1-\cos\phi_s)e^{-\Gamma_H t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s] \\
K_2(t) &= \frac{1}{2}A_\parallel^2[(1+\cos\phi_s)e^{-\Gamma_L t} + (1-\cos\phi_s)e^{-\Gamma_H t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s] \\
K_3(t) &= \frac{1}{2}A_\perp^2[(1-\cos\phi_s)e^{-\Gamma_L t} + (1+\cos\phi_s)e^{-\Gamma_H t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s] \\
K_4(t) &= |A\parallel||A_\perp|[\pm e^{-\Gamma_s t}\{\sin\delta_1\cos(\Delta m_s t) - \cos\delta_1\sin(\Delta m_s t)\cos\phi_s\} \\
&\quad -\frac{1}{2}(e^{-\Gamma_H t} - e^{-\Gamma_L t})\cos\delta_1\sin\phi_s] \\
K_5(t) &= \frac{1}{2}|A_0||A_\parallel|\cos(\delta_2-\delta_1) \\
&\quad [(1+\cos\phi_s)e^{-\Gamma_L t} + (1-\cos\phi_s)e^{-\Gamma_H t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s] \\
K_6(t) &= |A_0||A_\perp|[\pm e^{-\Gamma_s t}\{\sin\delta_2\cos(\Delta m_s t) - \cos\delta_2\sin(\Delta m_s t)\cos\phi_s\} \\
&\quad -\frac{1}{2}(e^{-\Gamma_H t} - e^{-\Gamma_L t})\cos\delta_2\sin\phi_s]
\end{aligned}$$

Decay Rate

$$
\begin{aligned}
K_1 &= A_0^2 \tau_L \\
K_2 &= A_\|^2 \tau_L \\
K_3 &= A_\perp^2 \tau_H \\
K_4 &= 0 \\
K_5 &= |A_0||A_\perp| \cos(\delta_\|) \tau_L \\
K_6 &= 0
\end{aligned}
$$