technische universität
dortmund

Bundesministerium
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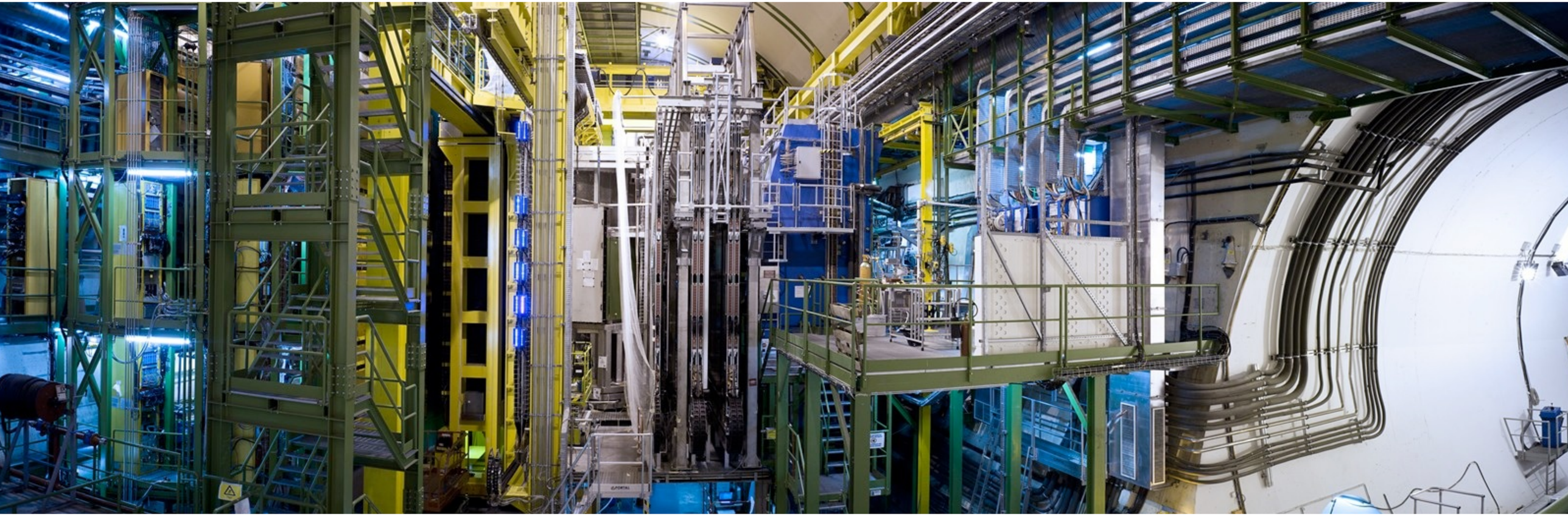
CERN

LHCb

BMBF-Forschungsschwerpunkt FSP-105
LHCb-Experiment
Quark-Flavor-Physik am LHC



Update of sin(2β) from Run I using $B^0 \to [c\bar{c}]K_S$

Patrick Mackowiak, Frank Meier, **Vanessa Müller**, Ramon Niet, Alex Seuthe, Jeroen van Tilburg, Julian Wishahi

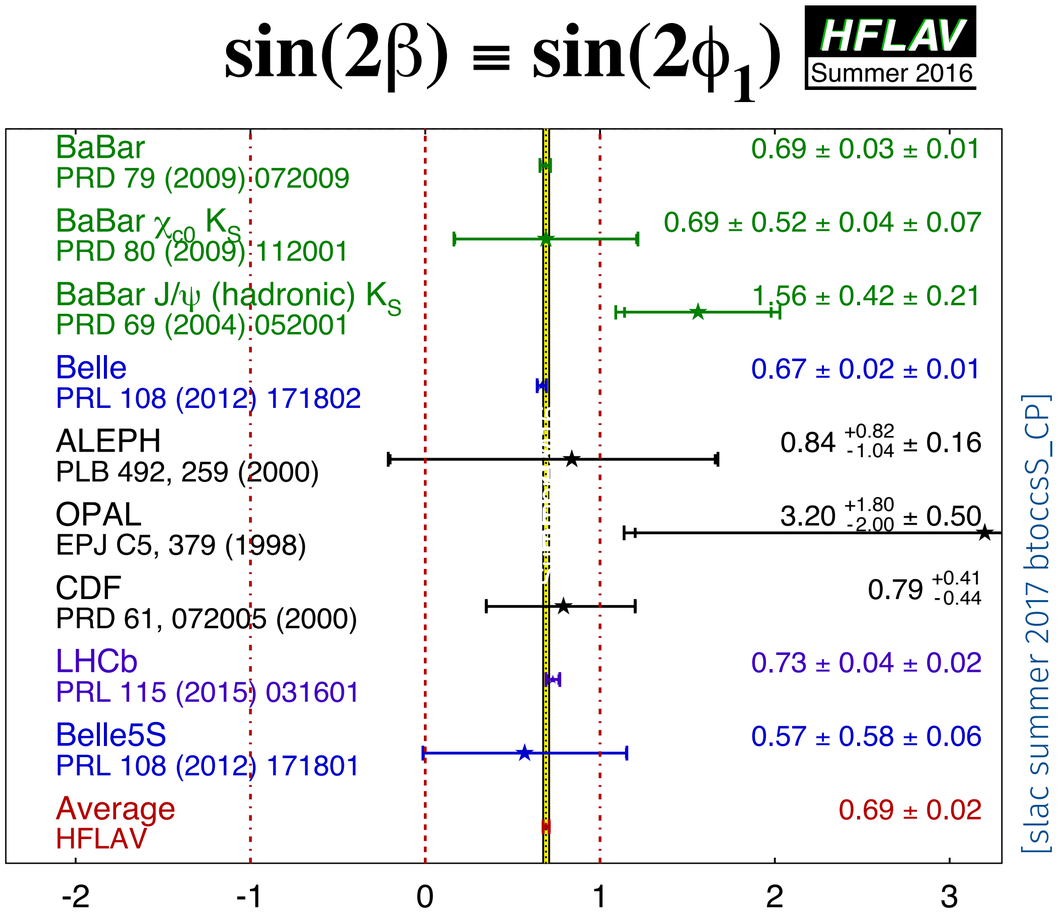
FSP meeting in Siegen, 6th October 2017

Measurements of sin(2β)

- LHCb measurement using $B^0 \to J/\psi(\mu\mu)K_S$ 1 fb^{-1} [PLB721 (2013) 24-31]
- updated on 3 fb^{-1} [PRL 115, 031601 (2015)]
  - S = 0.731 ± 0.035 (stat) ± 0.020 (syst)
  - C = -0.038 ± 0.032 (stat) ± 0.005 (syst)

- aim: increase precision —> idea:
  - include further final states
  - higher charmonium resonances

➡ ***CP*V measurement in $B^0 \to J/\psi(\to ee)K_S$ and $B^0 \to \psi(2S)(\to \mu\mu)K_S$ using 3 fb^{-1}** [arXiv:1709.03944]

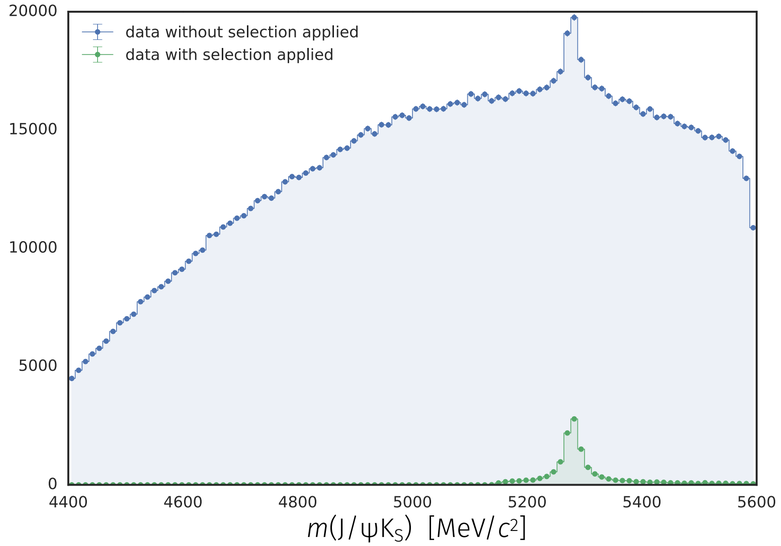


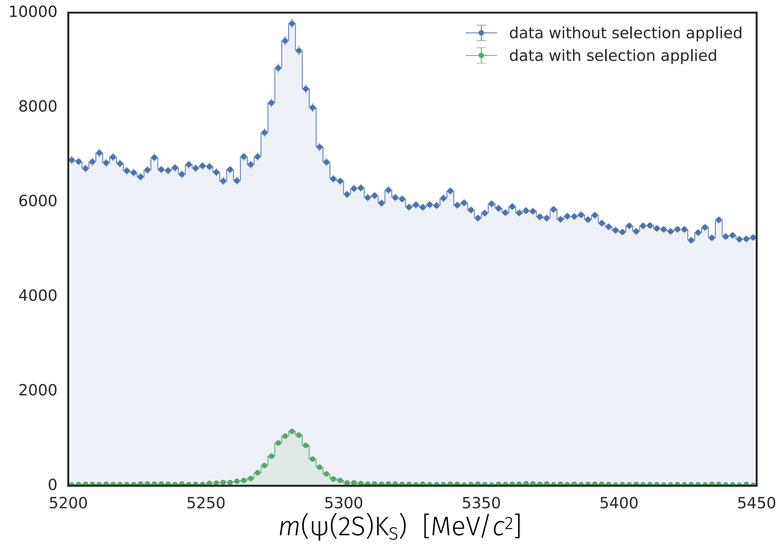
Analysis details

LHCb-ANA-2014-085

Offline Selection Strategy

- preselection
- boosted decision tree,
  features exploit kinematic properties of decay, vertex and track qualities
  - maximise expected sensitivity on *CP* parameter *S*
- veto peaking backgrounds
- remove multiple (B,PV) candidates





Nominal Massfits

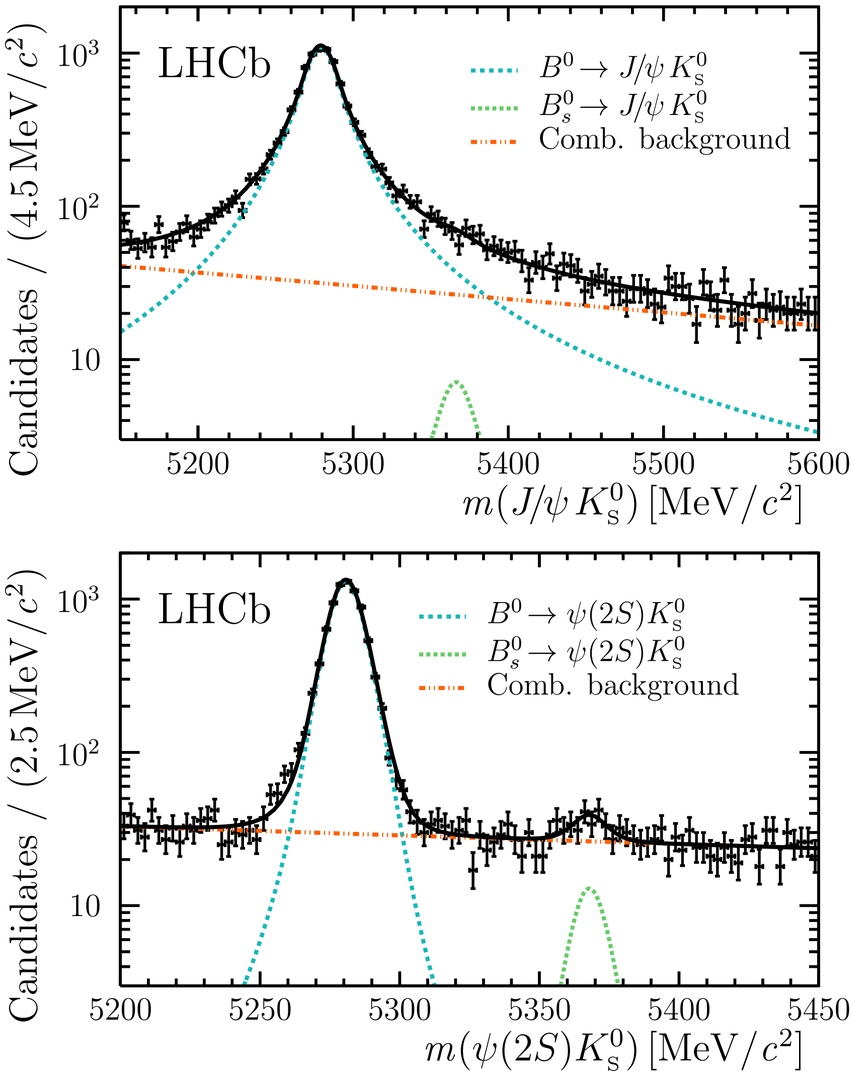
- Hypatia [arXiv:1312.5000] shape parameters fixed to values from MC, except width
- **$N(B^0 \to J/\psi K_S) = 10629 \pm 140$**

  $N(B_S \to J/\psi K_S) = 70 \pm 41$

  $N(BKG) = 2696 \pm 109$
- **$N(B^0 \to \Psi(2S) K_S) = 7970 \pm 100$**

  $N(B_S \to \Psi(2S) K_S) = 79 \pm 19$

  $N(BKG) = 2797 \pm 69$
- *sWeights* are used in the *CP* fit



[arXiv:1709.03944]

Decay Time Fit — "*CP* PDF"

$$\mathcal{P}(t, \vec{d}\,|\sigma_t, \vec{\eta}) \propto \underbrace{\varepsilon(t)}_{\text{acceptance}} \cdot \left(\underbrace{\mathcal{P}(t', \vec{d}\,|\vec{\eta})}_{CP\text{ PDF}} \otimes \underbrace{\mathcal{R}(t - t'|\sigma_t)}_{\text{resolution}} \right)$$

- including
  - true decay time t', reconstructed decay time t
  - tag decision $\vec{d} = (d_{OS}, d_{SS})$ and per-event mistag $\vec{\eta} = (\eta_{OS}, \eta_{SS})$
  - decay-time acceptance $\varepsilon(t)$ described by cubic splines
  - decay-time resolution $R(t–t'|\sigma_t)$ described by triple Gaussian model

Flavour Tagging Strategy & Performance

- using
  - OS combination:
    OSe, OSμ, OSK, OSVtxCh, OSc
  - SS combination:
    SSπBDT, SSp
- calibration channels
  - $B^+ \to J/\psi(\to ee/\mu\mu)K^+$ (OS)
  - $B^0 \to J/\psi(\to ee/\mu\mu)K^*$ (SS)

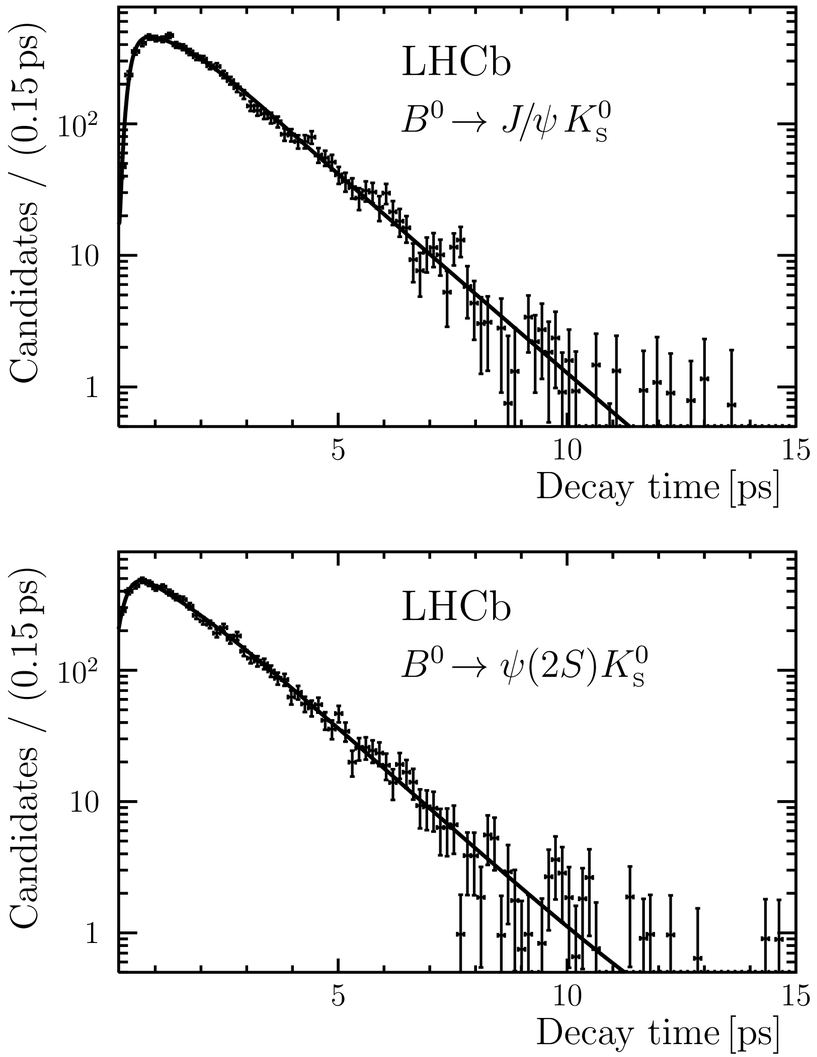
Run I $B^0 \to J/\psi(\mu\mu)K_S$ had total of 3.02 %

	$B^0 \to J/\psi K_S$	$B^0 \to \psi(2S)K_S$
OS inclusive	3.60 %	2.46 %
SS inclusive	2.40 %	1.07 %
OS+SS	**5.93 %**	**3.42 %**

CP fit

- simultaneous maximum likelihood fit
- constrained τ_d, Δm_d, A_P, FT calibration
- A_P computed using arXiv:1703.08464
- fixed decay-time resolution
- float acceptance parameters & S, C

$$
\begin{aligned}
C\left(B^0 \to J/\psi K^0_S\right) &= 0.12 \pm 0.07 \\
S\left(B^0 \to J/\psi K^0_S\right) &= 0.83 \pm 0.08 \\
C\left(B^0 \to \psi(2S) K^0_S\right) &= -0.05 \pm 0.10 \\
S\left(B^0 \to \psi(2S) K^0_S\right) &= 0.84 \pm 0.10
\end{aligned}
$$



[arXiv:1709.03944]

Results

Combinations

Conclusion

Results

- systematic uncertainties:
  evaluated using pseudoexperiments
  with alternative assumptions
- to account for:
  - influence of constrained parameters
  - MC-data differences
- results:

$$C\left(B^0 \to J/\psi K^0_S\right) = \quad 0.12 \pm 0.07 \pm 0.02$$
$$S\left(B^0 \to J/\psi K^0_S\right) = \quad 0.83 \pm 0.08 \pm 0.01$$
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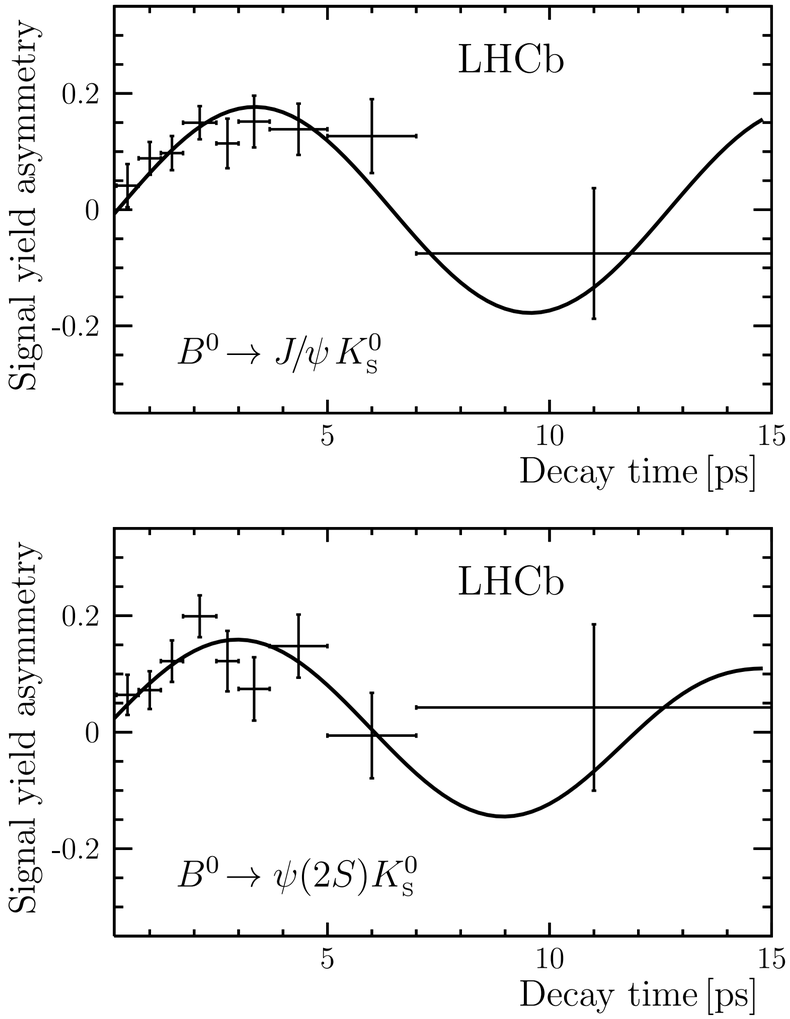


[arXiv:1709.03944]

Combinations

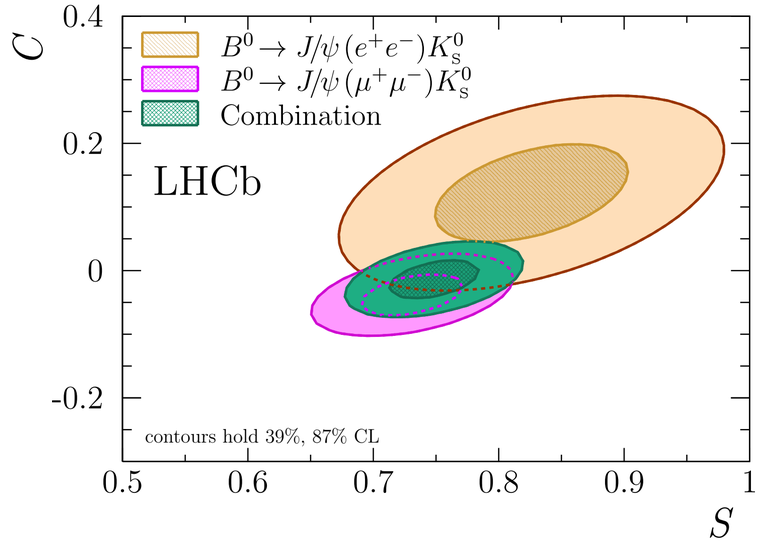
- used GammaCombo framework for 2D likelihood scans
- two combinations are published
  - $B^0 \to J/\psi K_S^0$ combination from μμ and ee mode:

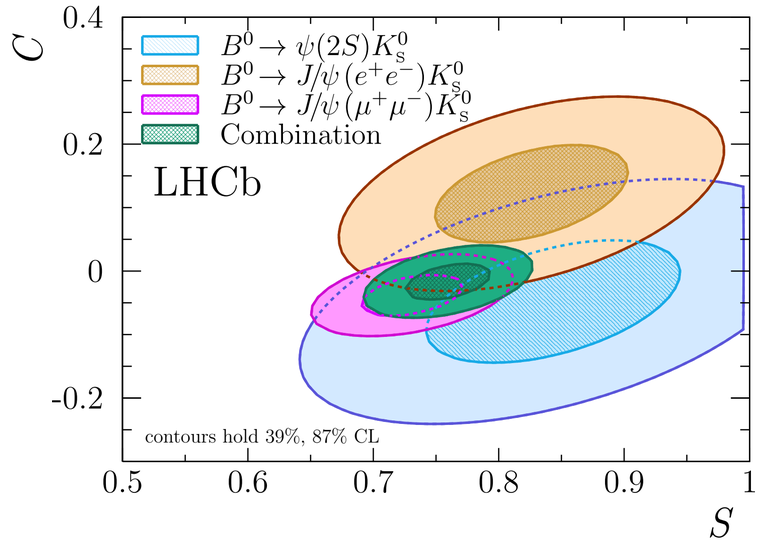
$$C\left(B^0 \to J/\psi K_S^0\right) = -0.014 \pm 0.030$$
$$S\left(B^0 \to J/\psi K_S^0\right) = \quad 0.75 \quad \pm 0.04$$

  - LHCb average of all charmonium modes, i.e. J/ψ(μμ,ee), ψ(2S)(μμ):

$$C\left(B^0 \to [c\bar{c}]K_S^0\right) = -0.017 \pm 0.029$$
$$S\left(B^0 \to [c\bar{c}]K_S^0\right) = \quad 0.760 \pm 0.034$$

- consistent with indirect measurements by the
  - CKMfitter group $S = 0.740\,^{+0.020}_{-0.025}$
  - UTfit collaboration $S = 0.73 \pm 0.04$





[arXiv:1709.03944]

Conclusion

- successfully performed first time-dependent measurement of *CP*V in an electron channel at a hadron collider
- LHCb is working at the "precision frontier"
- measurement improves precision at LHCb by 20%
- measurement will improve precision of the world average
  - current WA: $S(B^0 \to [c\bar{c}]K_S) = 0.69 \pm 0.02$ [HFLAV]
- published on arXiv, submitted to JHEP

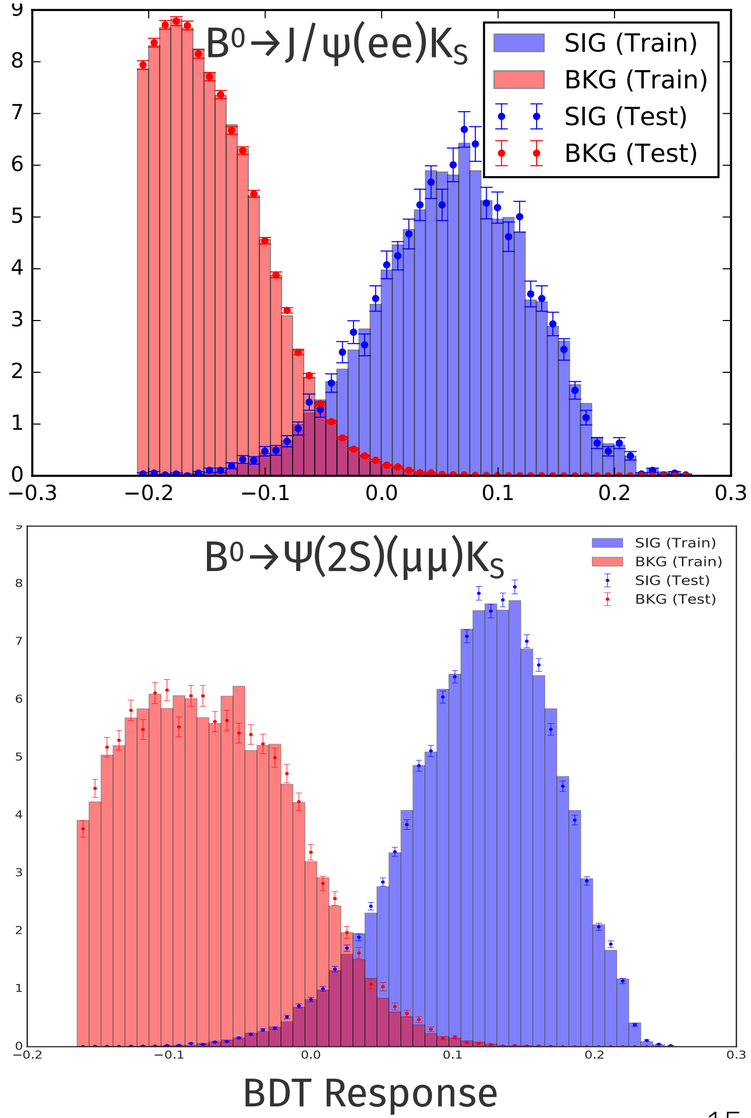
- Run II will be very promising, stay tuned!

Backup

Selection

Selection (BDT)

- BDT features contain:
  - minimum IP χ^2 of e, π, K_S, J/ψ, $\Psi(2S)$ and B
  - K_S decay time significance
  - p_T of B, K_S, J/Ψ
  - χ^2 of DTF and vertices
- Training sample consists of
  - Data upper mass sideband >5600MeV / >5450MeV for $B^0 \to J/\psi(ee)K_S$ / $B^0 \to \psi(2S)(\mu\mu)K_S$
  - Simulated data



BDT Cutpoint Optimization

- Perform scans in BDT response
- Fit reconstructed B mass for *sWeights*
  - Ipatia for Signal (Shape from MC)
  - Exponential for Background
- Use *sWeights* to compute FOM Q_{mod}

$$Q_{\mathrm{mod}} = \frac{\left(\sum_i s_{w_i}\right)^2}{\sum_i {s_{w_i}}^2} \bar{D}^{\mathrm{mod}}$$

Effective Signal Size

Tagging Power

Resolution Power

$$N_{\mathrm{EffSig}} = \frac{\left(\sum_i s_{w_i}\right)^2}{\sum_i {s_{w_i}}^2}$$

$$\bar{D}^{\mathrm{mod}} = \frac{1}{\sum_i s_{w_i}} \sum_i (1-2\omega_i)^2 e^{-(\Delta m_d \sigma(t_l))^2} \cdot X_i \cdot s_{w_i}$$

$$X_i = \left[\frac{\sin(\Delta m_d \cdot t_i)}{1 + q_i(1-2\omega_i) \cdot S \cdot e^{-(\Delta m_d \sigma(t_i))^2/2} \cdot \sin \Delta m_d t_i} \right]^2$$

sin(2β) Term (“X”)

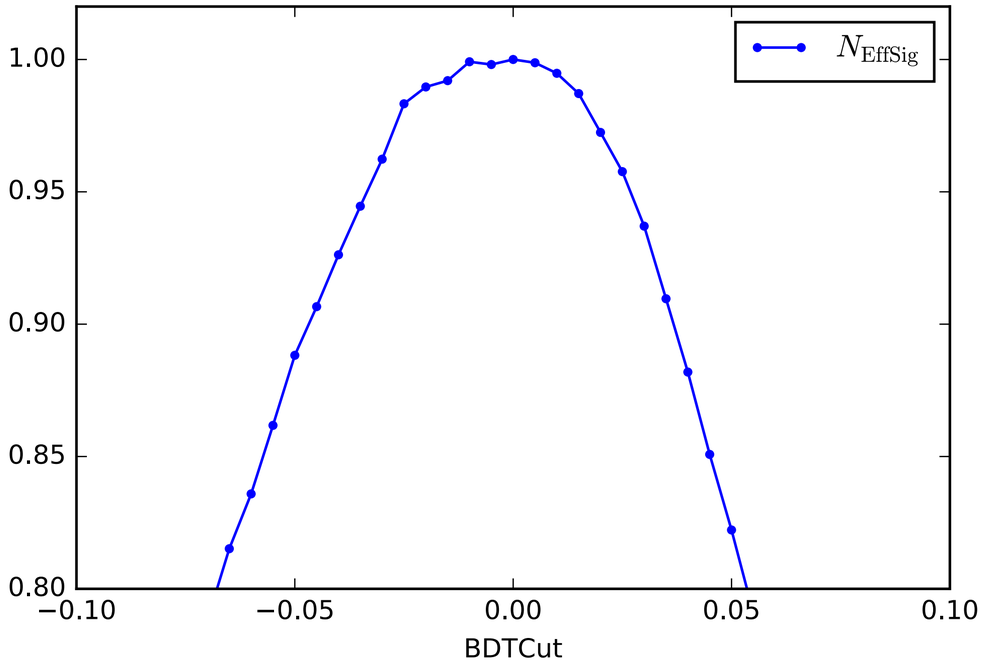
based on LHCb-INT-2009-12, extended by *sWeights*, 1bin only

Selection Optimization (FOM)

- Maximum effective signal size of 7825 @BDTCut 0.0

  N_{sig} = 11267

  N_{bkg} = 5001



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Selection Optimization (FOM)

- Maximum effective signal size
  of 7825 @BDTCut 0.0
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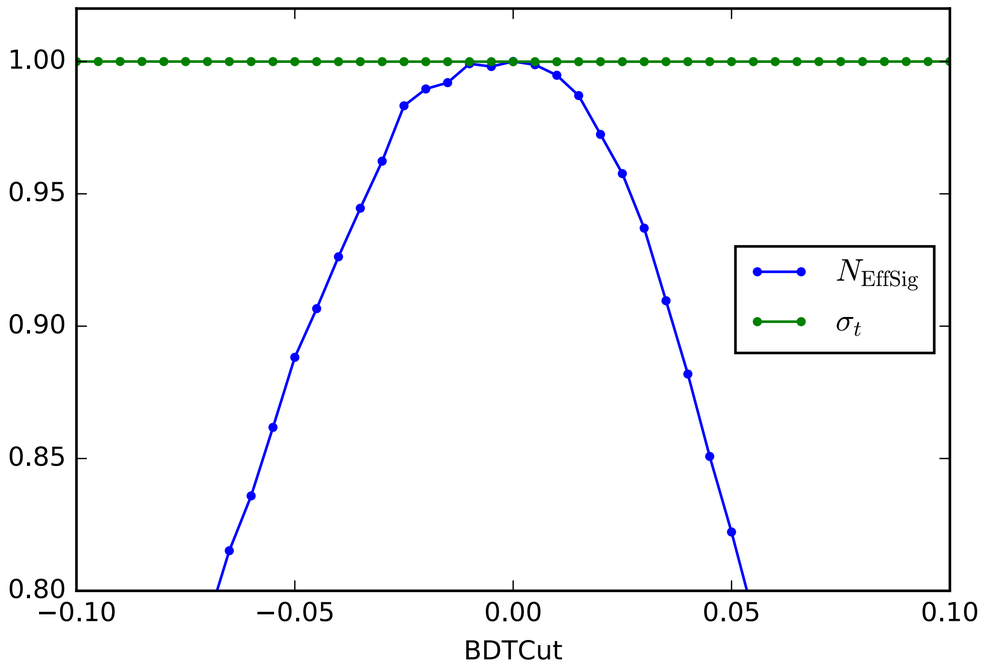
- Resolution of no importance



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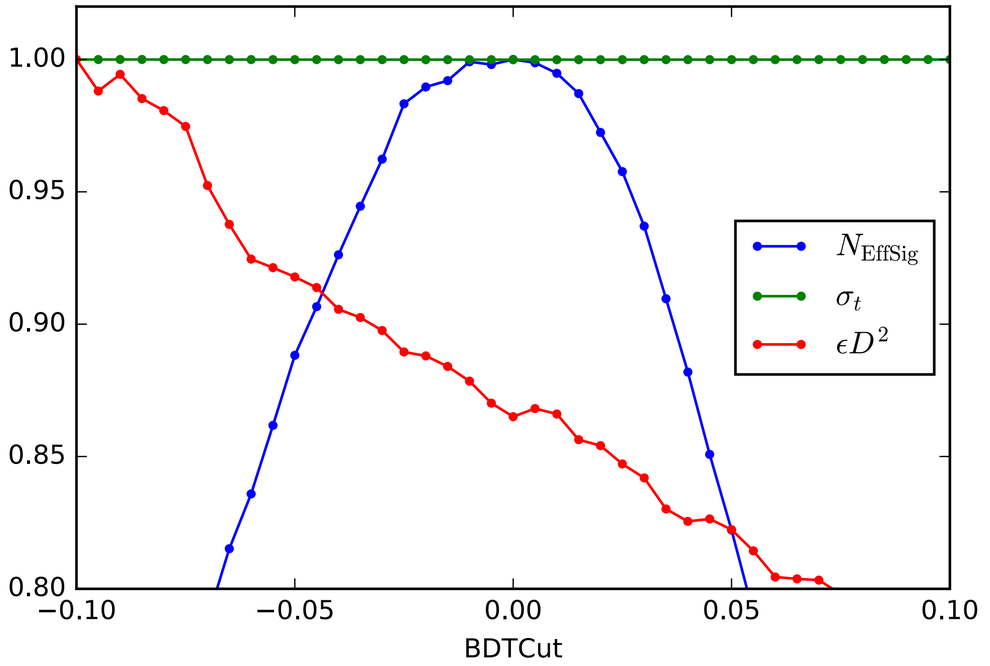
- Tagging Power decreases
  (OS standard combination, uncalibrated)



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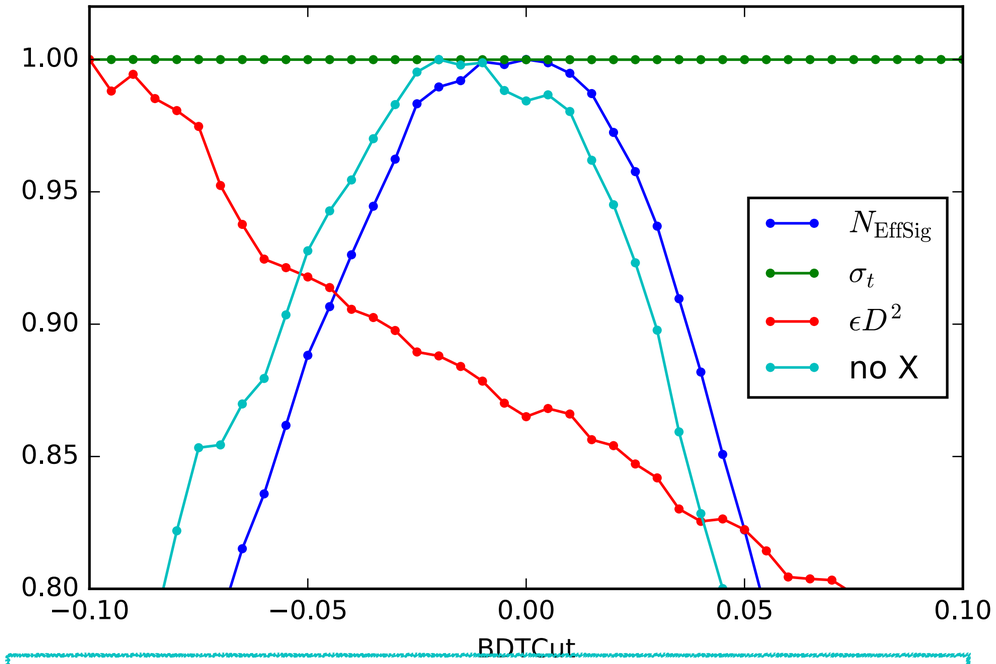
- Sophisticated FOM accounts for this loss



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=1

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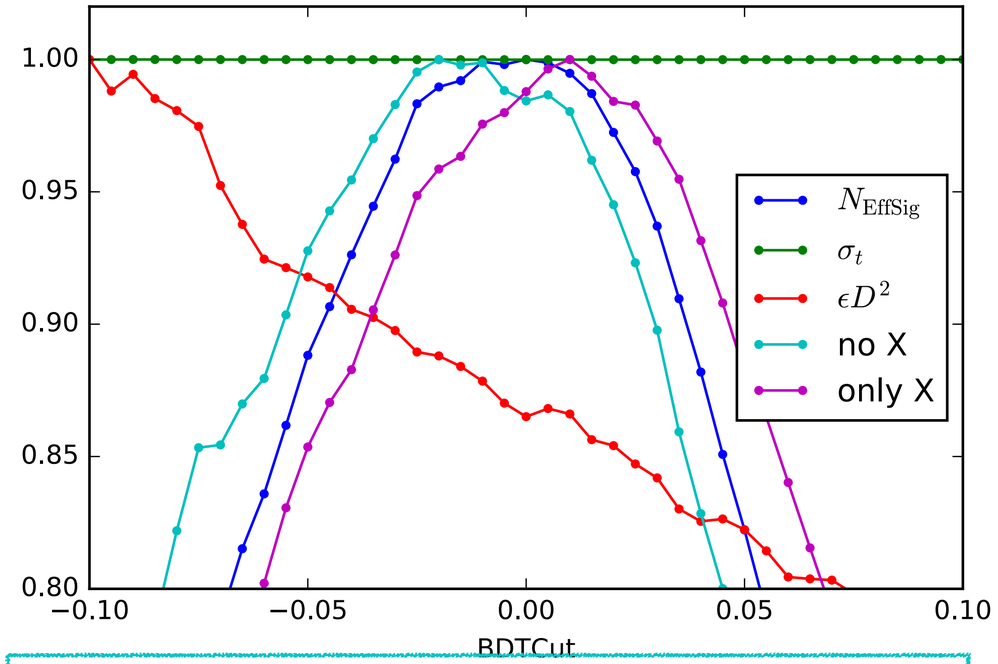
- Sophisticated FOM accounts for this loss
- X term cuts harder
  due to decay-time bias of BDT



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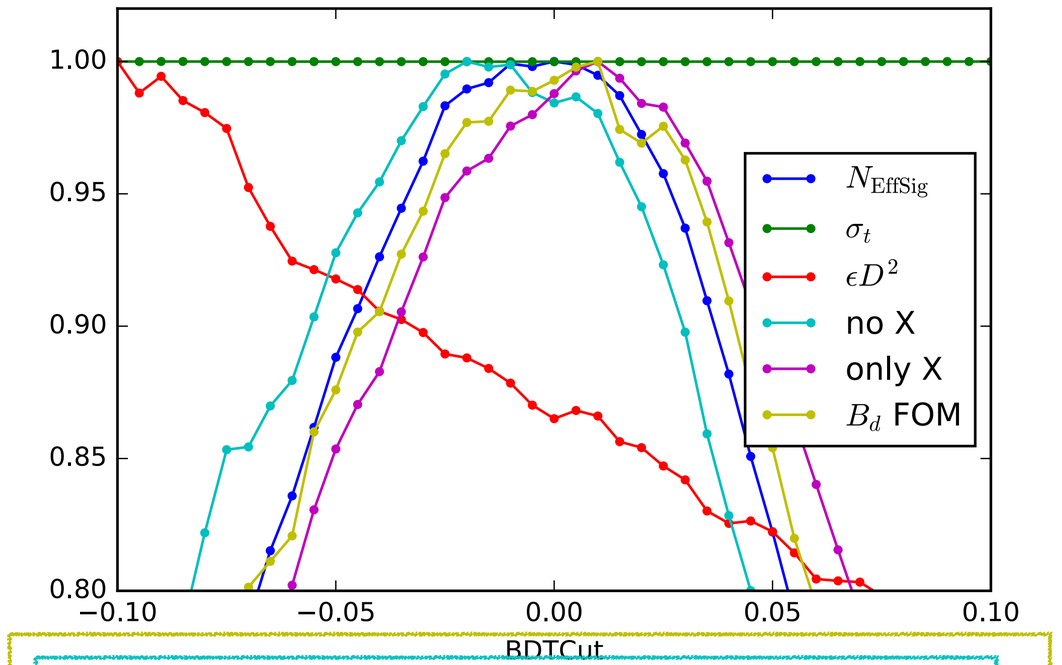
  (OS standard combination, uncalibrated)
- Sophisticated FOM accounts for this loss
- X term cuts harder
  due to decay-time bias of BDT
- B_d FOM dominated by X → Cut 0.01



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=1

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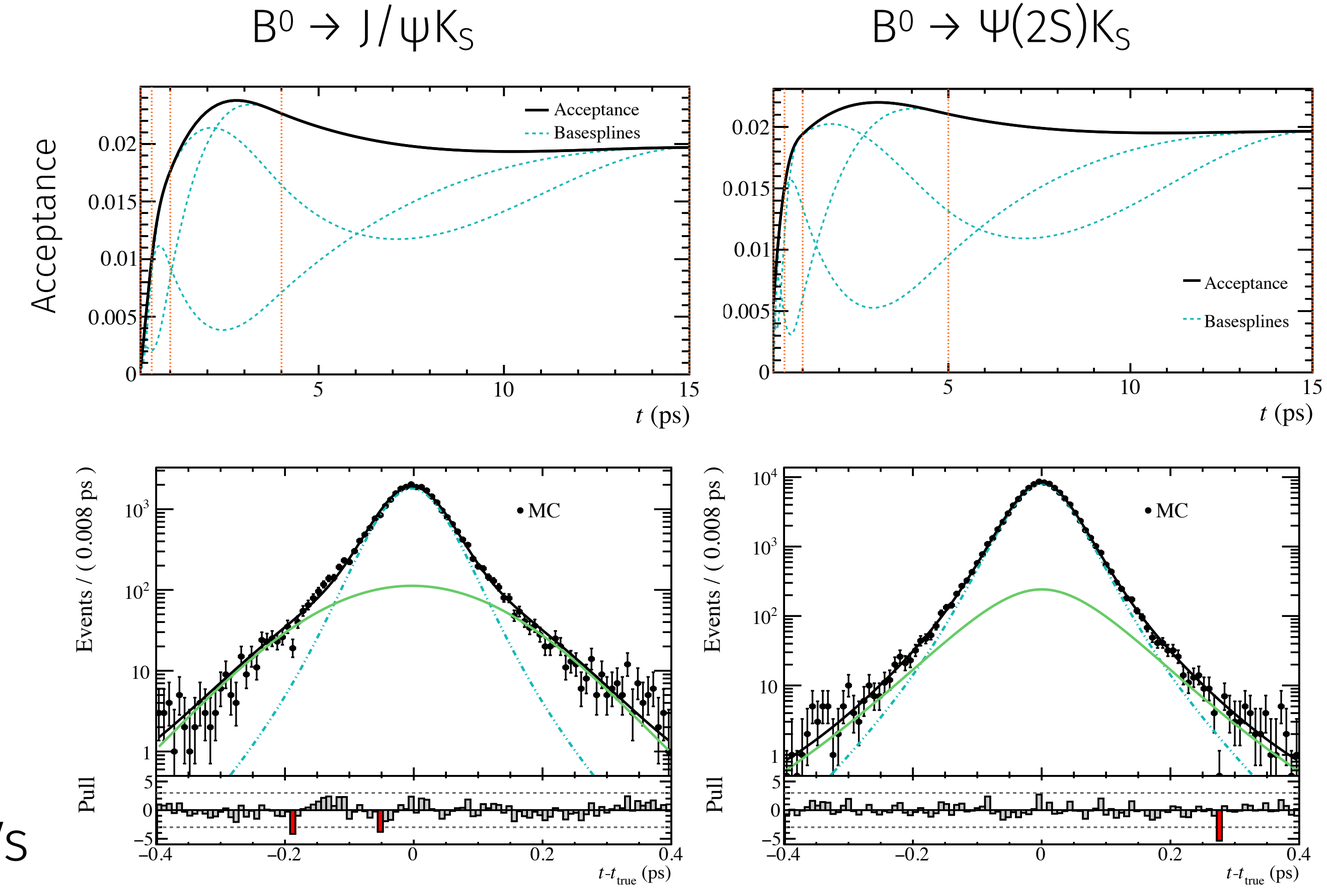
Decay-time Description

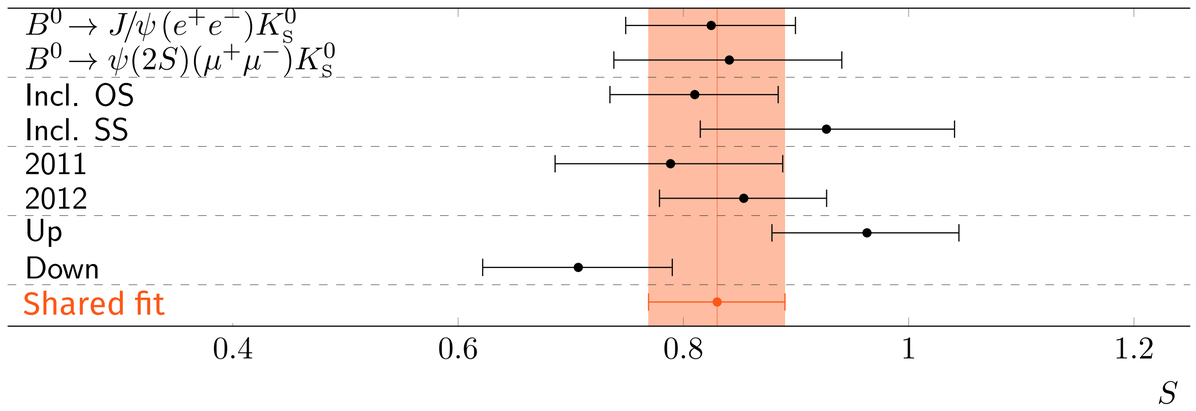
Decay Time Acceptance and Resolution

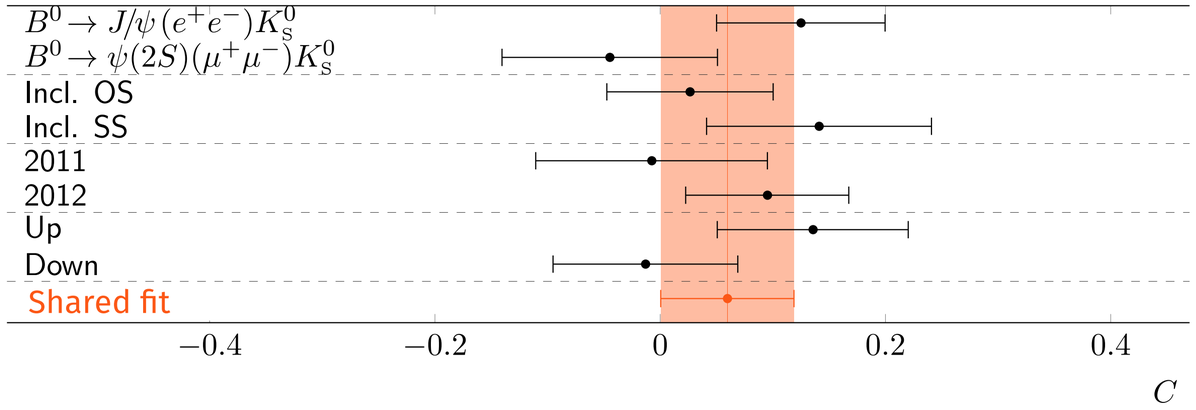
- acceptance
  - use cubic-splines
  - knots determined on MC
  - parameters left floating in *CP*-fit
- resolution
  - dependent on the per-event decay time error estimate σ_t
  - triple Gaussian model, including Gaussian for wrongly associated PVs



Crosschecks

- *CP* fit on various subsets:
  - split decay channels
  - OS tags only vs. SS tags only
  - split years 2011 vs. 2012
  - mag up vs. mag down
- everything is perfectly consistent with fit with shared *CP* coefficients





Systematic Uncertainties

- evaluated using pseudoexperiments with alternative assumptions

	$B^0 \to J/\psi K_S$		$B^0 \to \psi(2S) K_S$	
source	σ_S	σ_C	σ_S	σ_C
$\Delta\Gamma$	0.003	0.007	0.007	0.003
Δm	0.004	0.004	0.004	0.004
A_P	0.004	0.009	0.007	0.005
FT calib	0.002	0.005	0.005	0.002
decay-time bias	0.006	0.006	0.006	0.004
σ_t scaling	0.003	0.005	0.002	0.002
decay-time efficiency	0.006	0.004	0.006	0.004
total	**0.011**	**0.016**	**0.014**	**0.010**