

Statistical combination of searches for the $X^\pm(5568)$ state decaying into $B_s^0 \pi^\pm$

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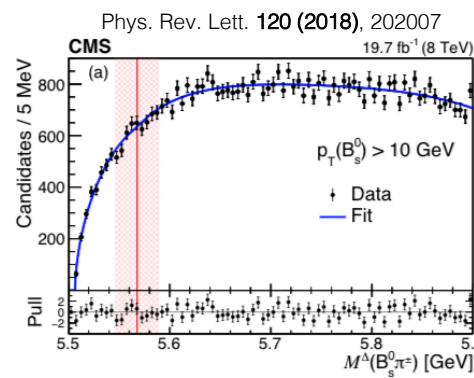
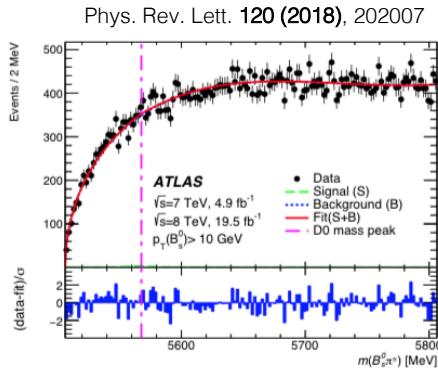


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A decorative banner at the bottom of the slide. It features a colorful, abstract background with streaks of light in shades of orange, red, and blue. Overlaid on this is a white rectangular area containing the text "ICHEP 2020 | PRAGUE" in a bold, sans-serif font. The "I" in "ICHEP" and the "P" in "PRAGUE" are slightly taller than the other letters.

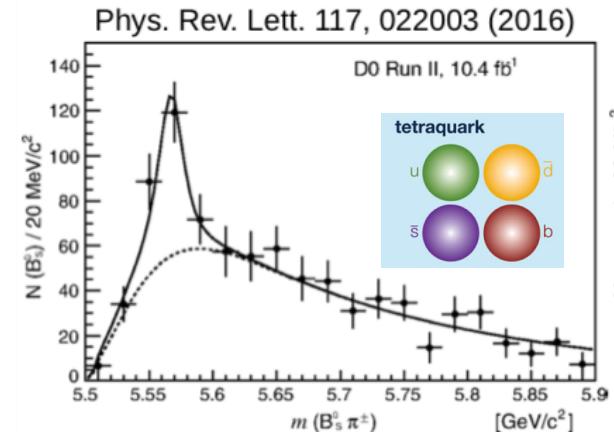
Introduction

- In 2016 D0 published evidence of a state $X^\pm(5568)$ in the $B_s\pi^\pm$ spectrum via $B_s^0 \rightarrow J/\psi \phi$, $J/\psi \rightarrow \mu^+\mu^-$, $\phi \rightarrow K^+K^-$ [1]
- Interpreted as a possible tetraquark *usbd* state
- Also seen in semi-leptonic decays[2]:
 $X^\pm(5568) \rightarrow B_s^0 \pi^\pm$ where $B_s^0 \rightarrow \mu^\pm D_s^\pm X$, $D_s^\pm \rightarrow \phi \pi^\pm$
- Subsequent searches from LHCb[3], CDF[4], ATLAS[5] and CMS[6] did not confirm the D0 observation



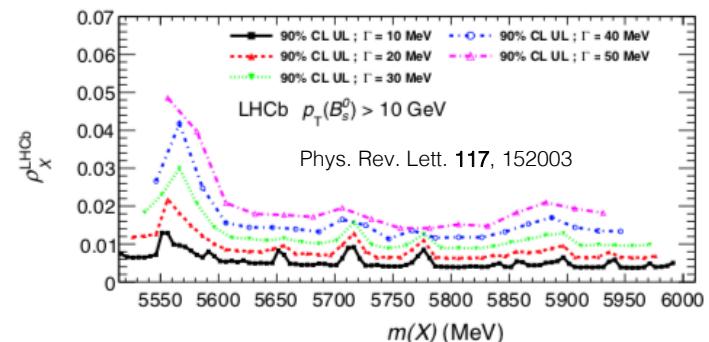
- In absence of a signal the LHC experiments and CDF have set limits on the production cross-section \times branching ratio of the resonance, normalised to the production cross-section of the B_s^0 :

$$\rho_X \equiv \frac{\sigma(\text{pp} \rightarrow X + \text{anything}) \mathcal{B}(X \rightarrow B_s^0 \pi^\pm)}{\sigma(\text{pp} \rightarrow B_s^0 + \text{anything})} = \frac{N_X}{\epsilon_{\text{rel}} N_{B_s^0}}$$



- [1] V.M. Abazov *et. al* (D0 Collaboration) Phys. Rev. Lett. **117**, 022003
- [2] V.M. Abazov *et. al* (D0 Collaboration) Phys. Rev. D **97**, 092004
- [3] R. Aaij *et. al* (LHCb Collaboration) Phys. Rev. Lett. **117**, 152003
- [4] T. Aaltonen *et. al* (CDF Collaboration) Phys. Rev. Lett. **120**, 202006
- [5] G. Aad *et. al* (ATLAS Collaboration) Phys. Rev. Lett. **120** (2018), 202007
- [6] A.M. Sirunyan *et. al* (CMS Collaboration) Phys. Rev. Lett. **120** (2018), 202005

- Asymptotic CLs frequentist method with PDF models for signal and background



Statistical combination

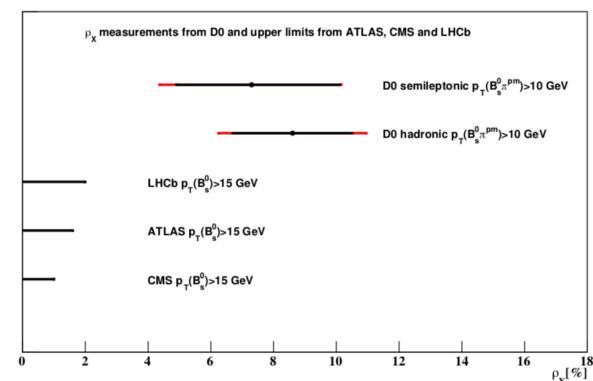
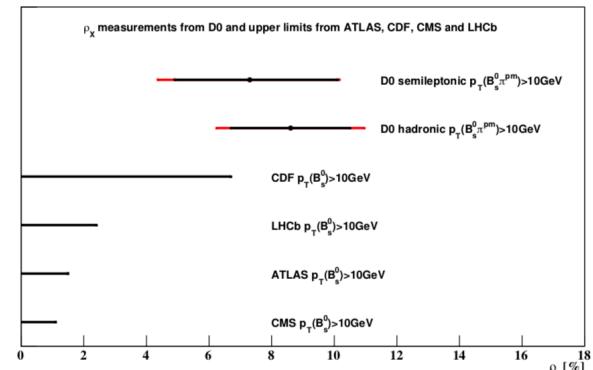
- X \pm (5568) searches have been performed in hadronic/semileptonic decay channels and different $p_T(B_s^0)$ cut ($p_T(B_s^0\pi^\pm)$ for D0)

Experiment	B_s^0 decay channel	p_T cut	$N(B_s^0)/10^3$	$N(X)$
D0	$B_s^0 \rightarrow D_s^- \pi^+$	10 GeV	6222 ± 141	121^{+51}_{-34}
D0	$B_s^0 \rightarrow J/\psi \phi$	10 GeV	5582 ± 100	133 ± 31
LHCb	$B_s^0 \rightarrow D_s^- \pi^+$	5 GeV	62.2 ± 0.3	3 ± 64
LHCb	$B_s^0 \rightarrow D_s^- \pi^+$	10 GeV	28.4 ± 0.2	75 ± 52
LHCb	$B_s^0 \rightarrow D_s^- \pi^+$	15 GeV	8.8 ± 0.1	14 ± 31
LHCb	$B_s^0 \rightarrow J/\psi \phi$	5 GeV	46.3 ± 0.2	-33 ± 43
LHCb	$B_s^0 \rightarrow J/\psi \phi$	10 GeV	13.2 ± 0.1	12 ± 33
LHCb	$B_s^0 \rightarrow J/\psi \phi$	15 GeV	3.7 ± 0.1	-10 ± 17
CDF	$B_s^0 \rightarrow J/\psi \phi$	10 GeV	3.552 ± 0.065	36.0 ± 33
CMS	$B_s^0 \rightarrow J/\psi \phi$	10 GeV	49.277 ± 0.278	-85 ± 160
CMS	$B_s^0 \rightarrow J/\psi \phi$	15 GeV	40.292 ± 0.246	-103.0 ± 230
ATLAS	$B_s^0 \rightarrow J/\psi \phi$	10 GeV	52.75 ± 0.28	60 ± 140
ATLAS	$B_s^0 \rightarrow J/\psi \phi$	15 GeV	43.46 ± 0.24	-30 ± 150

- We have performed a statistical combination of the upper limits on ρ_X based on the CLs method
- Combined PDF:

$$\begin{aligned} \mathcal{L} = & \Pi_i \Pi_j \mathcal{G}[N_{ij}^{\text{obs}}(B_s^0) | N_{ij}^{\text{exp}}(B_s^0), \sigma(N_{ij}(B_s^0))] \times \\ & \mathcal{G}[\epsilon_{ij}^{\text{obs}}(X) | \epsilon_{ij}^{\text{exp}}(X), \sigma(\epsilon_{ij}(X))] \times \\ & \mathcal{G}[N_{ij}^{\text{obs}}(X) | N_{ij}^{\text{exp}}(B_s^0) \cdot \rho_X \cdot \epsilon_{ij}(X), \sigma_{ij}(N_X)] \end{aligned}$$

- Summary of the experimental results on ρ_X

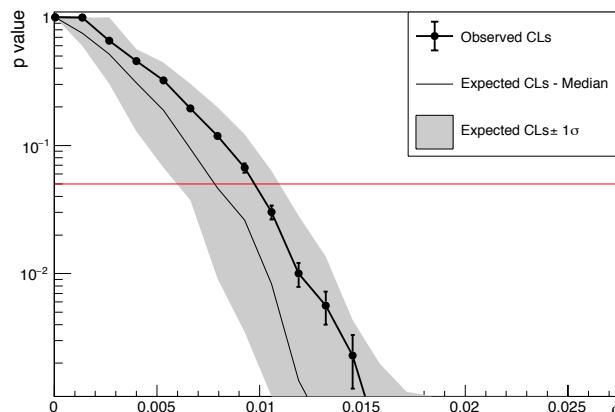


- N_{ij}^{obs} = Number of observed (B_s^0 or X) candidate events
- N_{ij}^{exp} = Number of expected (B_s^0 or X) candidate events
- $\sigma_{ij}(N)$ = uncertainty on N
- ϵ_{ij} = relative reconstruction efficiency
- i = {ATLAS, CDF, CMS, LHCb}
- j = {hadronic, semileptonic}

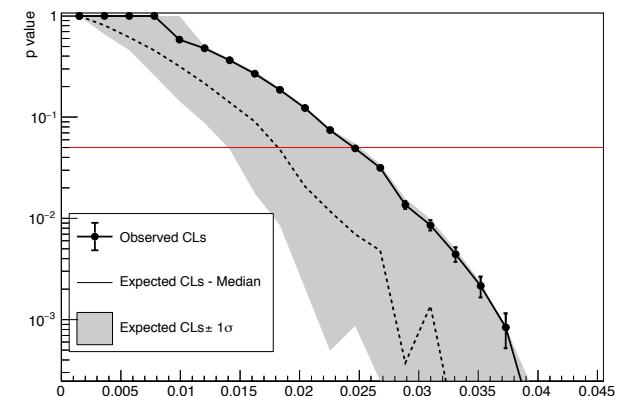
Results & Conclusions

- Consistency check: reproduction of upper limit results of the single experiments

Experiment	p_T cut	Measured upper limit on ρ_X (%)	Upper limit on ρ_X (%) obtained in this work
ATLAS	10 GeV	1.5	1.48 ± 0.04
ATLAS	15 GeV	1.6	1.70 ± 0.07
CDF	10 GeV	6.7	6.69 ± 0.12
CMS	10 GeV	1.1	1.15 ± 0.04
CMS	15 GeV	1.0	1.04 ± 0.05
LHCb	10 GeV	2.4	2.45 ± 0.04
LHCb	15 GeV	2.0	2.19 ± 0.05



CLs vs ρ_x obtained using the input values of ATLAS, CDF, CMS and LHCb for the $p_T(B_s^0) > 10$ GeV bin



CLs vs ρ_x obtained using the input values of LHCb for the $p_T(B_s^0) > 10$ GeV bin

Inputs for combination	$p_T(B_s^0) > 10$	$p_T(B_s^0) > 15$
ATLAS, CMS, LHCb	$\rho_X < 0.915\%$	$\rho_X < 0.909\%$
ATLAS, CDF, CMS, LHCb	$\rho_X < 0.961\%$	--

Upper limit on ρ_X at 95% CL obtained from the inputs of the three LHC experiments and, separately, with the inclusion of CDF for the two analysis bins $p_T(B_s^0) > 10$ and 15 GeV

- The statistical combination on the exclusion of the $X^\pm(5568)$ from the LHC experiments brings for the first time the upper limit at 95% CL on ρ_X below 1% in both analysis bins:

$$\rho_X(p_T(B_s^0) > 10 \text{ GeV}) < 0.915\%; \rho_X(p_T(B_s^0) > 15 \text{ GeV}) < 0.909\%$$

The study of the rare decays $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ at $\sqrt{s} = 13$ TeV with the ATLAS detector



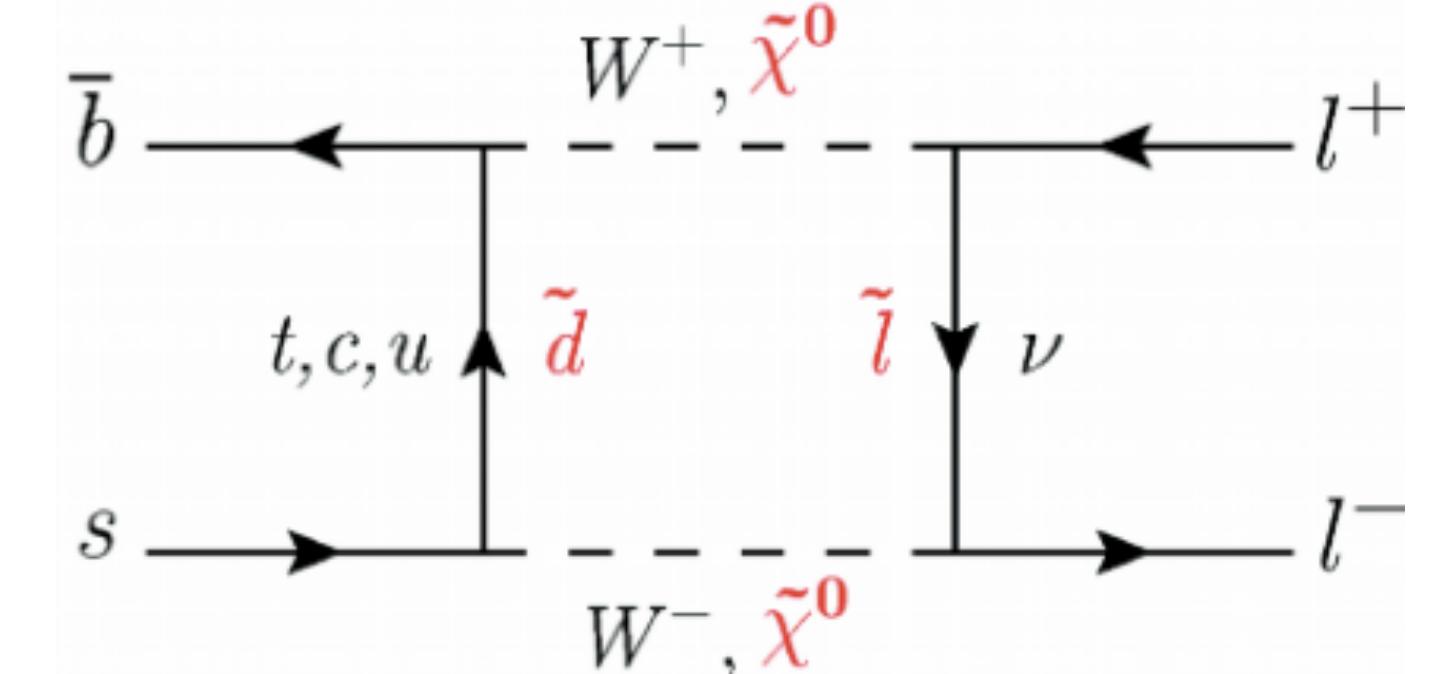
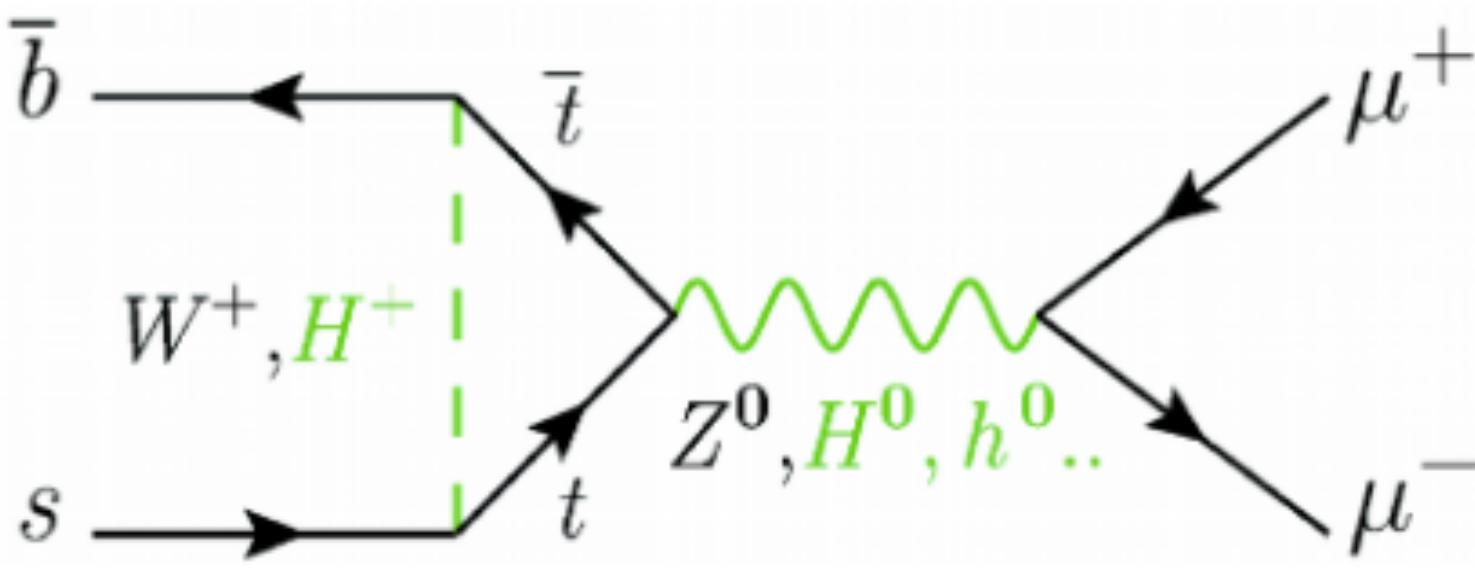
Mazuza Ghneimat for the ATLAS Collaboration
JHEP04(2019)098



► Strongly suppressed flavour-changing neutral-current processes, predicted in the Standard Model (SM)

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.66 \pm 0.14) \times 10^{-9}$$

$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) = (1.03 \pm 0.05) \times 10^{-10}$$



► Deviations from the SM prediction may indicate new physics that involves non-SM heavy particles.

► The branching fractions are measured relative to the reference decay mode $B^\pm \rightarrow J/\psi (\rightarrow \mu^+ \mu^-) K^\pm$.

world averages, PDG: $(1.010 \pm 0.029) \times 10^{-3} \times (5.961 \pm 0.033) \times 10^{-2}$

$$\mathcal{B}(B_{(s)}^0 \rightarrow \mu^+ \mu^-) = N_{d(s)} \frac{\mathcal{B}(B^+ \rightarrow J/\psi K^+) \times \mathcal{B}(J/\psi \rightarrow \mu^+ \mu^-)}{\mathcal{D}_{\text{ref}}} \times \frac{f_u}{f_{d(s)}}$$

$N_{d(s)}$ yield from UML fit to $m_{\mu\mu}$ data

$\mathcal{D}_{\text{ref}} = N_{J/\psi K^+} \times (\varepsilon_{\mu^+ \mu^-} / \varepsilon_{J/\psi K^+})$

Reference channel yield from UML fit to $m_{J/\psi K^+}$

Ratio of efficiencies evaluated on MC tuned to data

HFLAV average: $f_u/f_d = 0.256 \pm 0.013; f_u/f_d = 1$
the ratio of the hadronisation probabilities of a b -quark into B^+ and $B_{(s)}^0$

► Blinded dimuon invariant mass region [5166 MeV, 5526 MeV].

Background processes

Continuum background

- consists of muons from uncorrelated hadron decays.
- Boosted Decision Tree (BDT) to reject this background is trained on sideband data.

Partially reconstructed B decays

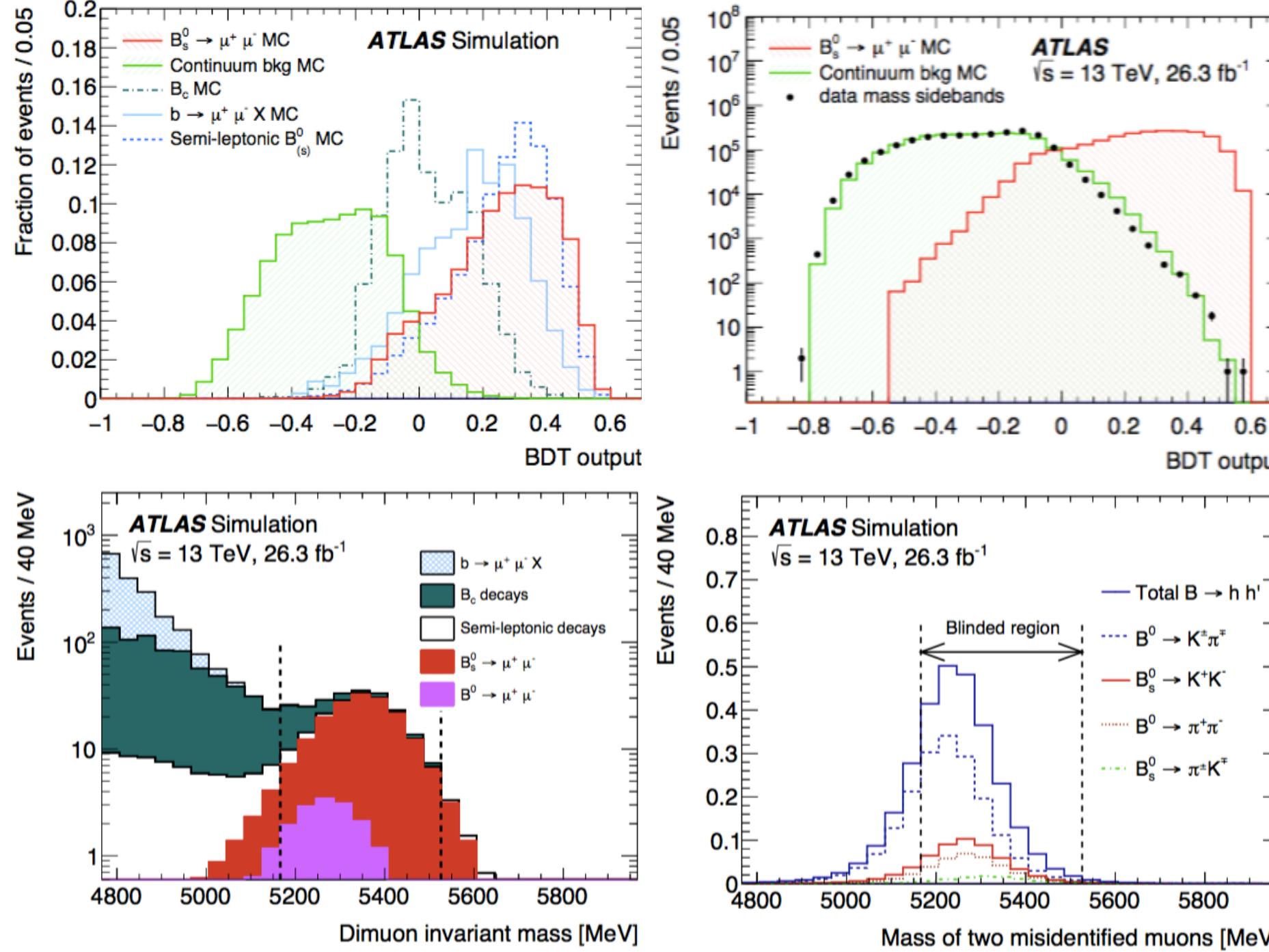
- same-vertex ($B \rightarrow \mu^+ \mu^- X$), same-side ($b \rightarrow c \bar{p} \nu \rightarrow s(d) \mu \mu \bar{v}$) and B_c decays.
- exponential in the low mass sideband.

Semi-leptonic B decays

- $B^0 \rightarrow \pi^- \mu^+ \nu$, $B_s^0 \rightarrow K^- \mu^+ \nu$, $\Lambda^0_b \rightarrow p \mu^- \bar{\nu}$
- charged hadron misidentified as muon.

Peaking background $B \rightarrow hh'$

- both hadrons misidentified as muons.
- presents in the $m_{\mu\mu}$ -signal region.



Results

Branching fractions using 2015+2016 data

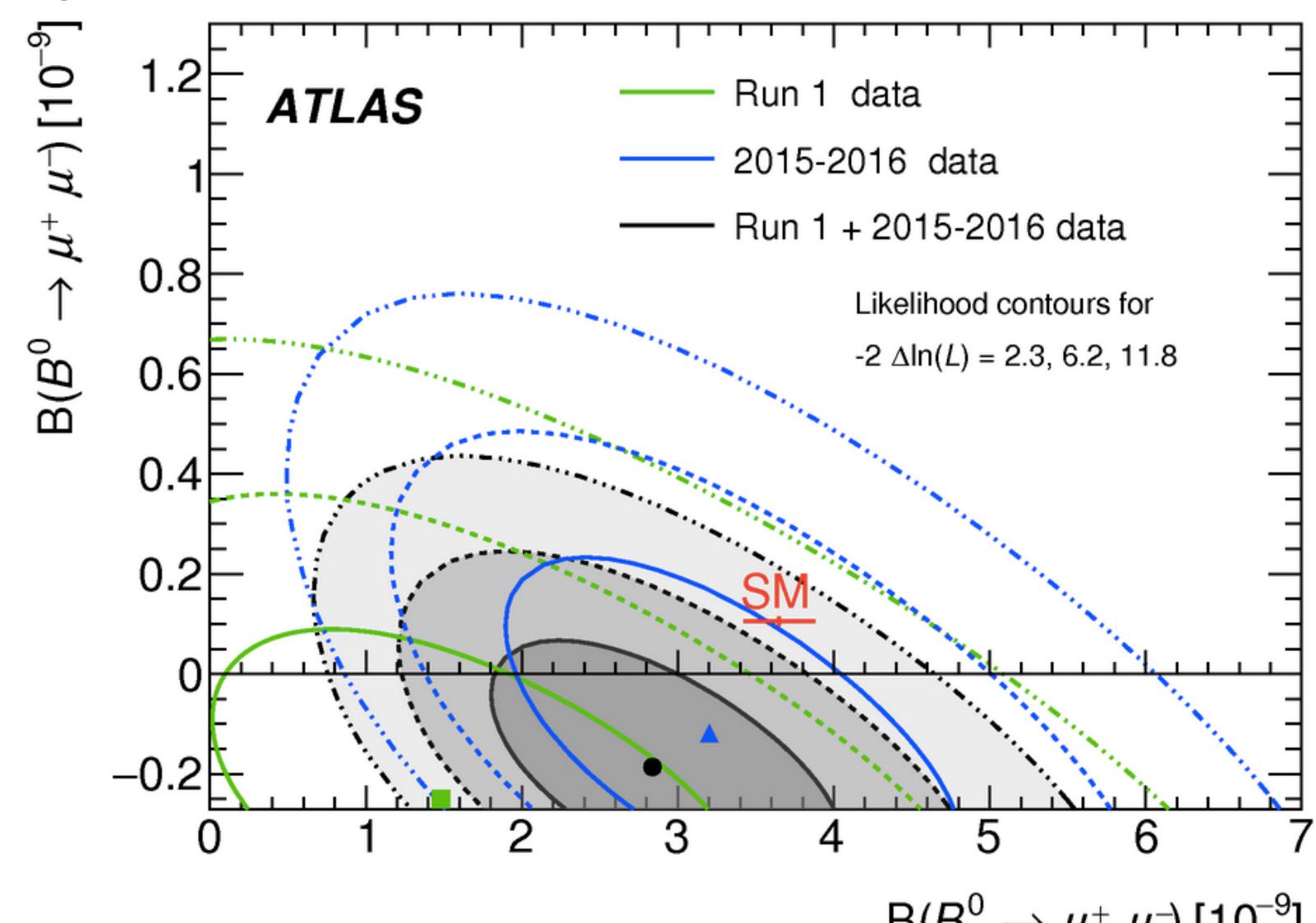
$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.21^{+0.96+0.49}_{-0.91-0.30}) \times 10^{-9}$$

$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 4.3 \times 10^{-10} \text{ @ 95% CL}$$

Combination with Run1

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (2.8^{+0.8}_{-0.7}) \times 10^{-9}$$

$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 2.1 \times 10^{-10} \text{ @ 95% CL}$$



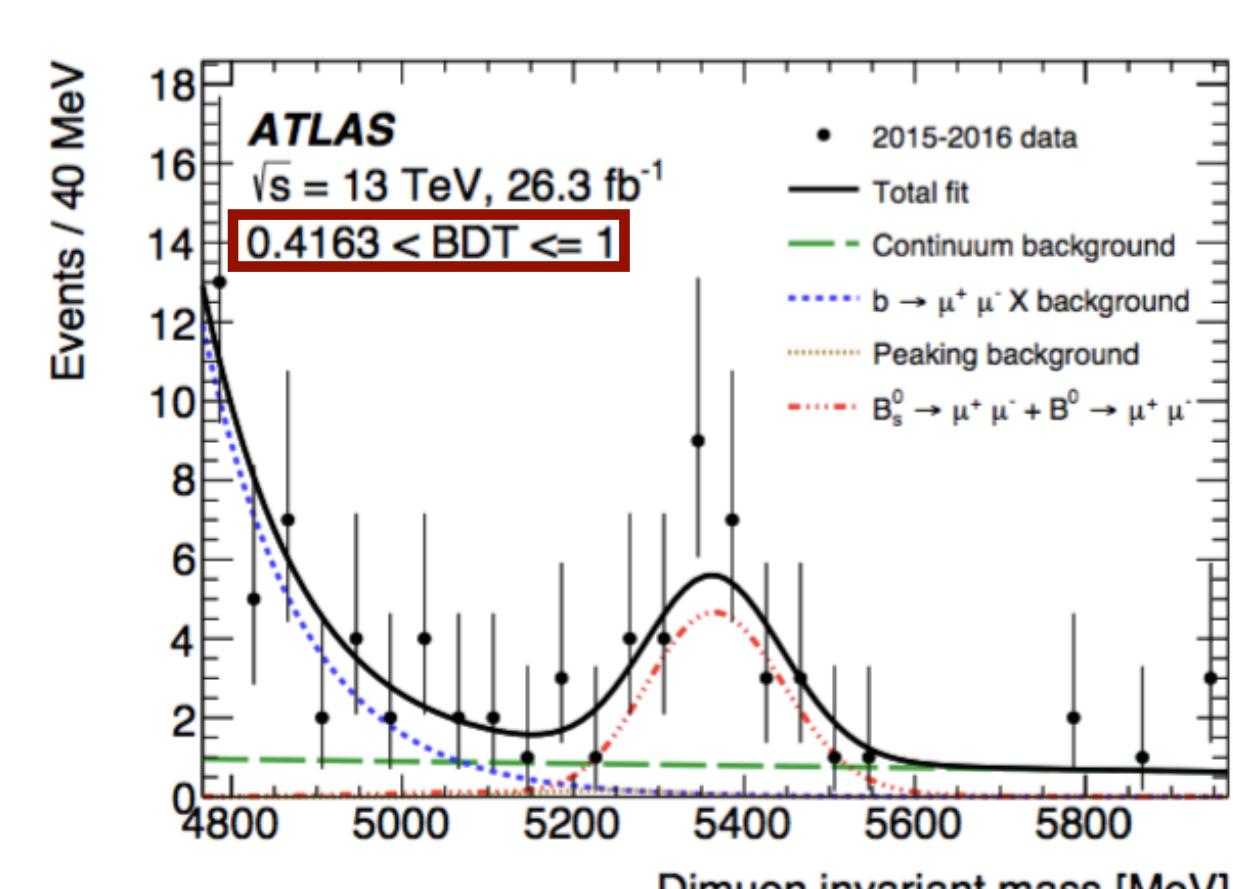
Signal yield

- Extracted with unbinned maximum-likelihood fit to $m_{\mu\mu}$ simultaneously across four intervals of BDT
- each of 18% of signal MC events.

- BDT boundaries: 0.1439, 0.2455, 0.3312, 0.4163, 1.

Extracted (expected) yields

$$N_s = 80 \pm 22 (91), N_d = -12 \pm 20 (10)$$



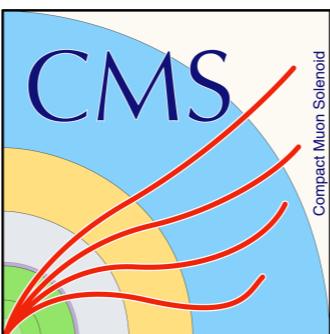
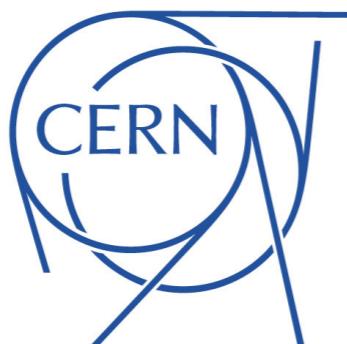
Measurement of the CP violating weak phase ϕ_s in the
 $B_s^0 \rightarrow J/\psi\phi \rightarrow \mu^+\mu^-K^+K^-$ decay process using the data collected by
CMS in proton-proton collision at $\sqrt{s} = 13$ TeV

Muhammad Alibordi

On behalf of CMS collaboration

28 JULY - 6 AUGUST 2020

PRAGUE, CZECH REPUBLIC



CMS public result : [here](#)
e-Print : [here](#)

Motivation (Rev. Mod. Phys., 88, 045002)

The source of CP violation in the Yukawa sector of SM:

- complex phase in CKM matrix, sensitive to new physics
- **overconstrain** the CKM unitarity triangle as many way as possible to look for new physics.
- the $B_s^0 \rightarrow J/\psi\phi \rightarrow \mu^+\mu^-K^+K^-$ comprises $b \rightarrow c\bar{c}s$ transition, and the resulting weak phase is given by,

$$\phi_s \simeq -2\beta_s, \quad \beta_s = \arg \left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*} \right)$$

Current status of the precise values obtained from global fit,

$$\phi_s = -36.98^{+0.81}_{-0.70} \text{ mrad}, \quad \Delta\Gamma_s = 0.091 \pm 0.013 \text{ ps}^{-1}$$

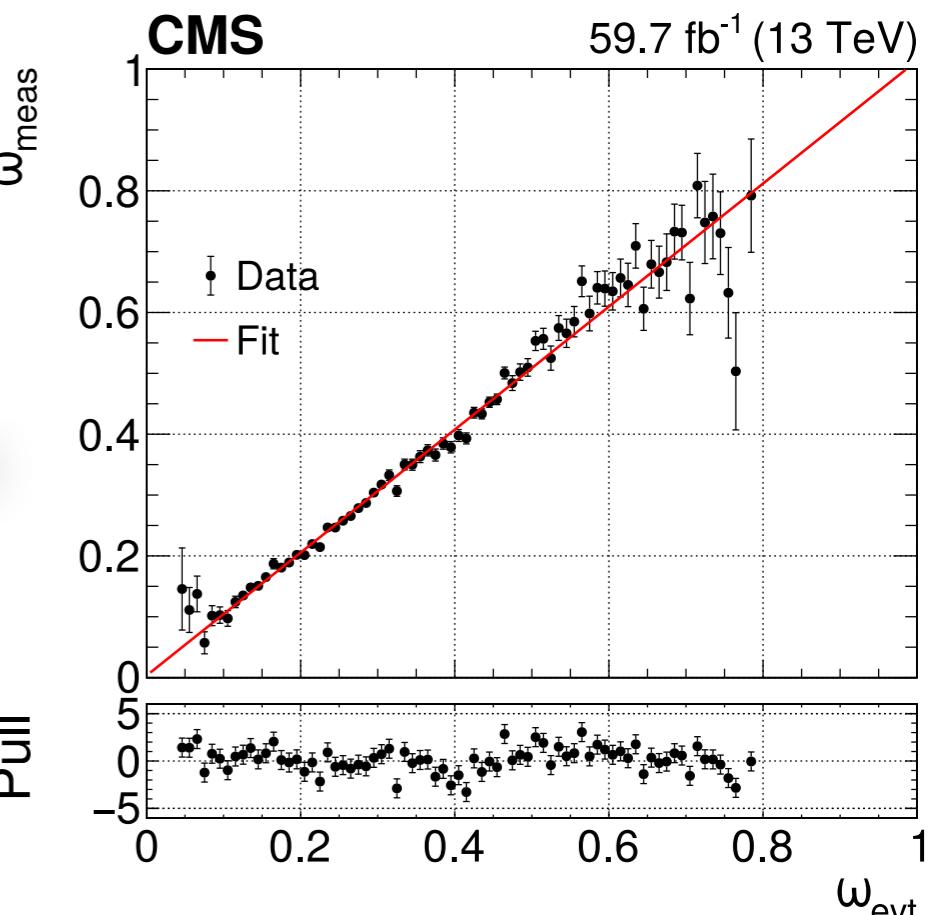
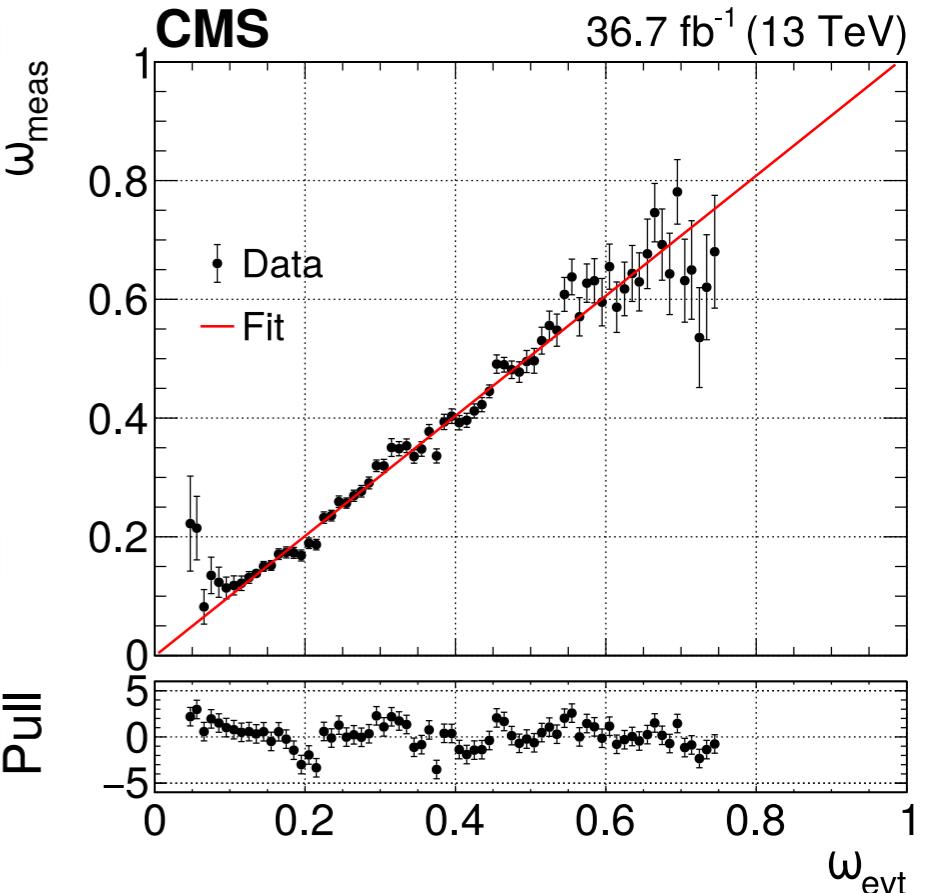
Identification of flavor specific modes

Distinguish B_s^0 and \bar{B}_s^0 at the time of production

Opposite Side taggers: exploit the decay products of the other b quark produced in the event with some figures of merit

- $\epsilon_{\text{tag}} = N_{\text{tag}}/N_{\text{total}}$: tagging efficiency;
- $\omega_{\text{tag}} = N_{\text{tag,wrong}}/N_{\text{tag}}$: per-event mistag probability evaluated with a DNN;
- $P_{\text{tag}} = \epsilon_{\text{tag}}(1 - 2\omega_{\text{tag}})^2$: tagging power.

Dataset	$\epsilon_{\text{tag}}(\%)$	$\omega_{\text{tag}}(\%)$	$P_{\text{tag}}(\%)$
2017	$(45.7 \pm 0.1)\%$	$(27.1 \pm 0.1)\%$	$(9.6 \pm 0.1)\%$
2018	$(50.9 \pm 0.1)\%$	$(27.3 \pm 0.1)\%$	$(10.5 \pm 0.1)\%$



Analysis

- The best B_s^0 vertex is obtained from a **Kalman Vertex** fit with the four tracks (μ^+, μ^-, K^+, K^-), and a biological evolution inspired Genetic Algorithm is used to optimize the physics selections.
- To extract the weak phase and decay width difference a multidimensional fit is employed to perform the time dependent angular analysis with three angles ($\cos\theta_T, \cos\psi_T, \phi_T$) defined in the transversity basis.
- The negative log likelihood of the unbinned multidimensional extended maximum-likelihood fitter is,

$$-\ln \mathcal{L} = - \sum_{i=0}^{N_{\text{evt}}} \ln P_i + N_{\text{tot}} - N_{\text{evt}} \ln N_{\text{tot}}, \quad P_i : \text{event pdf}, \quad N_{\text{evt}} = 65500$$

.

- P_i includes signal model, background model and the proper time and angular efficiencies.

$$P_{\text{sig}} = \epsilon(ct) \epsilon(\Theta) [\tilde{\mathcal{F}}(\Theta, ct, \alpha) \otimes G(ct, \sigma_{ct})] P_{\text{sgn}}(m_{B_s^0}) P_{\text{sig}}(\sigma_{ct}) P(\xi)_{\text{sig}}$$

$$P_{\text{bkg}} = P_{\text{bkg}}(\cos\theta_T, \phi_T) P_{\text{bkg}}(\cos\psi_T) P_{\text{bkg}}(ct) P_{\text{bkg}}(m_{B_s^0}) P_{\text{bkg}}(\sigma_{ct}) P(\xi)_{\text{bkg}}$$

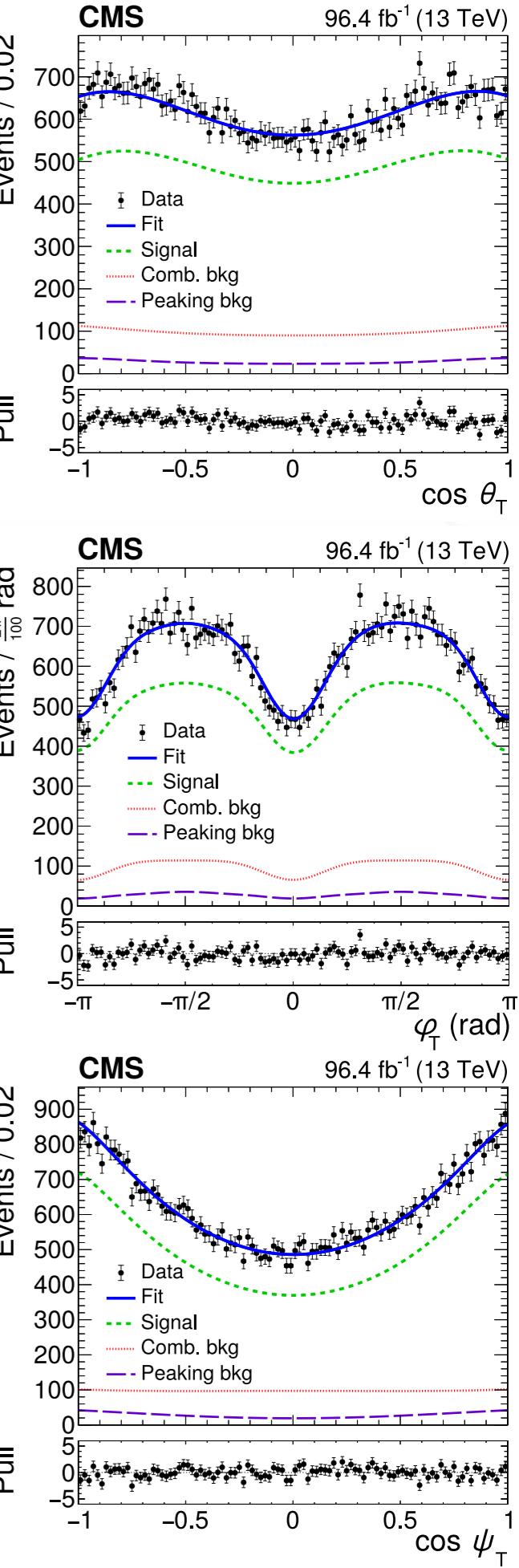


Table of systematic uncertainties

	ϕ_s [mrad]	$\Delta\Gamma_s$ [ps $^{-1}$]	Δm_s [\hbar ps $^{-1}$]	$ \lambda $	Γ_s [ps $^{-1}$]	$ A_0 ^2$	$ A_\perp ^2$	$ A_s ^2$	$\delta_{ }$ [rad]	δ_\perp [rad]	$\delta_{s\perp}$ [rad]
Statistical uncertainty	50	0.014	0.10	0.026	0.0042	0.0047	0.0063	0.0077	0.12	0.16	0.083
Model bias	7.9	0.0019	—	0.0035	0.0005	0.0002	0.0012	0.001	0.020	0.016	0.006
Angular efficiency	3.8	0.0006	0.007	0.0057	0.0002	0.0008	0.0010	0.002	0.006	0.015	0.015
Proper decay length efficiency	0.3	0.0062	0.001	0.0002	0.0022	0.0014	0.0023	0.001	0.001	0.002	0.002
Proper decay length resolution	2.5	0.0008	0.015	0.0009	0.0005	0.0007	0.0009	0.007	0.006	0.025	0.022
Data/simulation difference	0.6	0.0008	0.004	0.0003	0.0003	0.0044	0.0029	0.007	0.007	0.007	0.028
Flavor tagging	0.1	$<10^{-4}$	0.001	0.0002	$<10^{-4}$	0.0003	$<10^{-4}$	$<10^{-3}$	0.001	0.003	0.001
Sig./bkg. ω_{evt} difference	3.0	—	—	—	0.0005	—	0.0008	—	—	—	0.006
Model assumptions	—	0.0008	—	0.0046	0.0003	—	0.0013	0.001	0.017	0.019	0.011
Peaking background	0.3	0.0008	0.011	$<10^{-4}$	0.0002	0.0005	0.0002	0.003	0.005	0.007	0.011
<i>S-P</i> wave interference	—	0.0010	0.019	—	0.0005	0.0005	—	0.013	—	0.019	0.019
Total systematic uncertainty	9.6	0.0067	0.028	0.0082	0.0024	0.0048	0.0044	0.016	0.028	0.045	0.047

Results

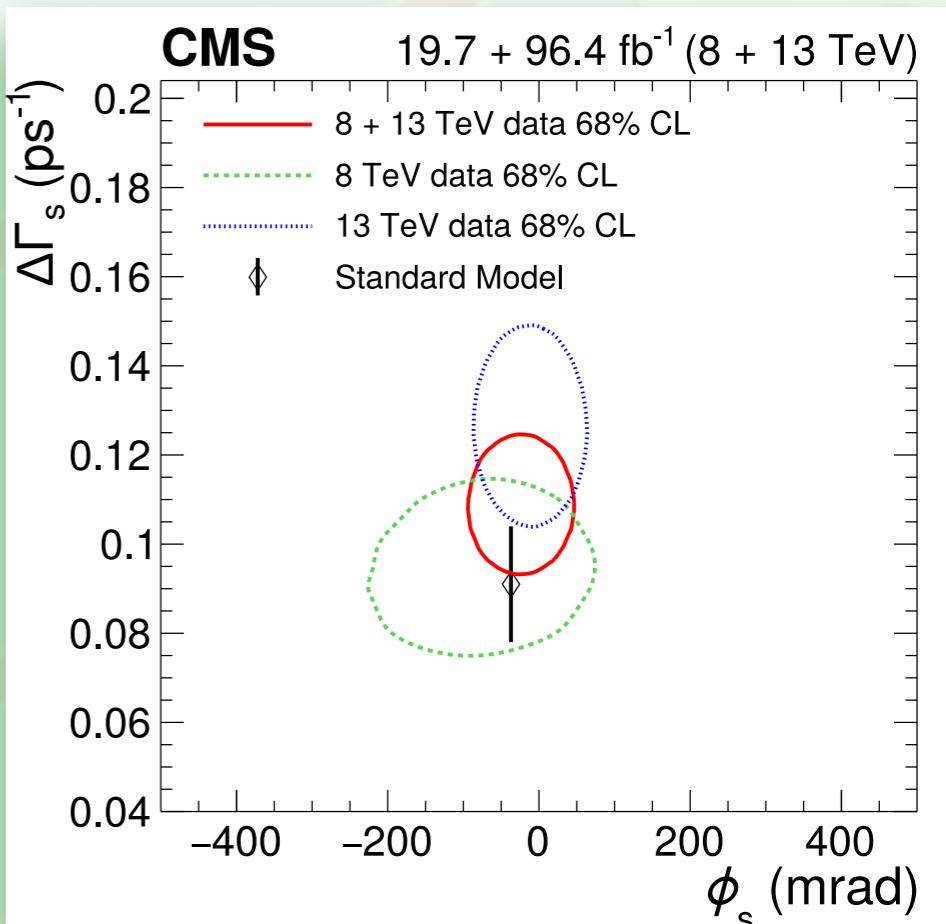
The obtained final results at $\sqrt{s} = 13 \text{ TeV}$ are,

$$\begin{aligned}\phi_s &= -11 \pm 50 \text{ (stat)} \pm 10 \text{ (syst) mrad} \\ \Delta\Gamma_s &= 0.114 \pm 0.014 \text{ (stat)} \pm 0.007 \text{ (syst) ps}^{-1}\end{aligned}$$

consistent with the absence of CP violation in the mixing-decay interference. The $\sqrt{s} = 13 \text{ TeV}$ results are further combined with $\sqrt{s} = 8 \text{ TeV}$ results, the obtained combined results are,

$$\begin{aligned}\phi_s &= -21 \pm 45 \text{ mrad} \\ \Delta\Gamma_s &= 0.1073 \pm 0.0097 \text{ ps}^{-1}\end{aligned}$$

The two-dimensional likelihood contours at 68% CL in the ϕ_s - $\Delta\Gamma_s$ plane is consistent with current SM prediction.



Discriminating New Physics in $b \rightarrow s \mu \bar{\mu}$ via Transverse Polarization Asymmetry of K^* in $B \rightarrow K^* \mu \bar{\mu}$ decay

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With A. K. Alok (IIT Jodhpur) and S. Uma Sankar (IIT
Bombay)

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Anomalies in $b \rightarrow s\mu\mu$ and Global Fits

Main Discrepancies

Measurements of 120+ observables

$R_K, R_{K^*}, \text{Br}(B_s \rightarrow \mu\mu),$

$B \rightarrow K\mu\mu:$ Br and ang-obs,

$B \rightarrow K^*\mu\mu:$ Br and ang-obs,

$\text{Br}(B \rightarrow X_s \mu\mu), \text{ Br}(B_s \rightarrow \phi\mu\mu)$

A) The measured values of the ratios R_K and R_{K^*} disagree with their SM predictions at the level of $\sim 2.5\sigma$. [LHCb, arXiv:1705.05802; LHCb, arXiv:1903.09252]

$$R_{K^{(*)}} = \frac{\text{Br}(B \rightarrow K^{(*)}\mu\mu)}{\text{Br}(B \rightarrow K^{(*)}ee)}$$

Violation of Lepton Flavor Universality

B) The measurement of $\text{Br}(B_s \rightarrow \phi\mu\mu)$ is $\sim 3.5\sigma$ away from the SM predictions. [LHCb, arXiv:1506.08777]

C) Measurement of angular observable P'_5 is $\sim 3\sigma$ away from its SM value. [LHCb, arXiv:2003.04831]

New Physics in the form of vector and axial vector in $b \rightarrow s\mu\mu$ transitions.

$$\begin{aligned} \mathcal{H}_{\text{NP}} = & -\frac{\alpha_{\text{em}} G_F}{\sqrt{2}\pi} V_{ts}^* V_{tb} \left[C_9^{\text{NP}} (\bar{s}\gamma^\mu P_L b)(\bar{\mu}\gamma_\mu \mu) + C_{10}^{\text{NP}} (\bar{s}\gamma^\mu P_L b)(\bar{\mu}\gamma_\mu \gamma_5 \mu) \right. \\ & \left. C_9'^{\text{NP}} (\bar{s}\gamma^\mu P_R b)(\bar{\mu}\gamma_\mu \mu) + C_{10}'^{\text{NP}} (\bar{s}\gamma^\mu P_R b)(\bar{\mu}\gamma_\mu \gamma_5 \mu) \right] \end{aligned}$$

Several Global fits are performed. Some are

Alguer et al, arXiv:1903.09578

Alok et al, arXiv:1903.09617

Ciuchini et al, arXiv:1903.09632

Aebischer et al, arXiv:1903.10434

Kowalska et al, arXiv:1903.10932

Arbey et al, arXiv:1904.08399

A common Result (arXiv:1903.09617)

NP scenarios	Best fit value	pull
(I) C_9^{NP}	-1.09 ± 0.18	6.24
(II) $C_9^{\text{NP}} = -C_{10}^{\text{NP}}$	-0.53 ± 0.09	6.40
(III) $C_9^{\text{NP}} = -C_9'^{\text{NP}}$	-1.12 ± 0.17	6.43

Transverse Polarization Asymmetry of K* Meson

The vector meson K^* has three polarizations

1. one longitudinal $\lambda_{K^*} = 0$ and 2. two transverse $\lambda_{K^*} = +1, -1$

A completeness relation between polarization fractions

Two are independent

$$F_L + F_T^+ + F_T^- = \frac{\Gamma(\lambda_{K^*} = 0)}{\Gamma_{\text{Tot}}} + \frac{\Gamma(\lambda_{K^*} = +1)}{\Gamma_{\text{Tot}}} + \frac{\Gamma(\lambda_{K^*} = -1)}{\Gamma_{\text{Tot}}} = 1$$

F_L is only sensitive to scalar and tensor interactions. It does not help us in this case.

Take asymmetry between two transverse components

$$A_T = F_T^+ - F_T^- = \frac{|H_+|^2 - |H_-|^2}{|H_0|^2 + |H_+|^2 + |H_-|^2}$$

Transforming helicity amplitudes H 's to transversity amplitudes using relations

$$A_{\perp,\parallel} = (H_+ \mp H_-) / \sqrt{2}, \quad A_0 = H_0$$

[Altmannshofer et al, JHEP 0901, 019 (2009)]

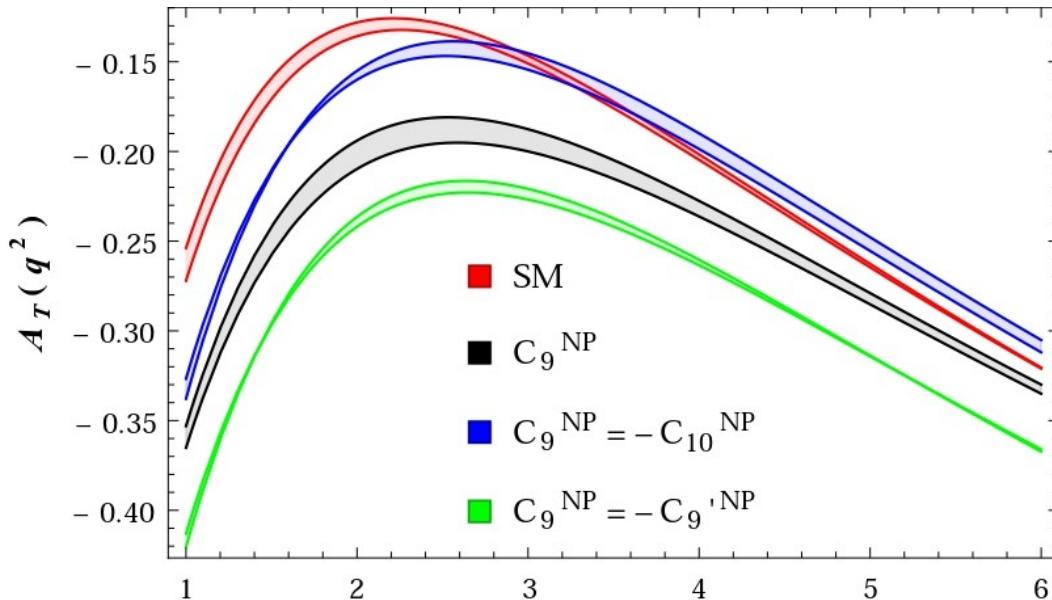
The asymmetry takes the form

$$A_T = \frac{2 \operatorname{Re}(A_{\parallel} A_{\perp}^*)}{|A_{\parallel}|^2 + |A_{\perp}|^2 + |A_0|^2}$$

Where $A_i A_j^* = A_{iL} A_{jL}^* + A_{iR} A_{jR}^*$, ($i, j = 0, \perp, \parallel$).

Papers on Transverse asymmetry in different perspectives: Melikhov et al, PLB 442, 381 (1998); Kruger, Matias, PRD 71, 094009 (2005); Becirevic, Schneider, NPB 854, 321 (2012)

Predictions and Distinguishing Ability



NP scenarios	$\langle A_T \rangle_{[1,6]} \text{ in \%}$
SM	20.7 ± 0.48
(I) C_9^{NP}	24.9 ± 0.57
(II) $C_9^{NP} = -C_{10}^{NP}$	21.3 ± 0.50
(III) $C_9^{NP} = -C_9'^{NP}$	28.4 ± 0.66

- Asymmetry is negative in the entire low- q^2 range for all cases. The peak value of SM prediction is -0.13 at $q^2 = 2.2 \text{ GeV}^2$.
- The peak values for NP scenarios I and III are -0.19 and -0.22 respectively. The deviation is largest for the scenario III.
- For NP scenario II, the prediction is similar to that of SM for $q^2 > 3 \text{ GeV}^2$ whereas the prediction is suppressed for $q^2 < 3 \text{ GeV}^2$.
- From the table, it is also evident that prediction of the asymmetry for each NP scenario is substantially different from each other. Hence an accurate measurement of this asymmetry can lead to a clear distinction between three NP scenarios.

Improved determination of $|V_{us}|$ from tau decays



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ICHEP 2020 | PRAGUE

40th INTERNATIONAL CONFERENCE
ON HIGH ENERGY PHYSICS

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$|V_{us}|$ determinations using tau decays

- ▶
$$\frac{R(\tau \rightarrow X_{\text{strange}} \nu)}{|V_{us}|^2} = \frac{R(\tau \rightarrow X_{\text{non-strange}} \nu)}{|V_{ud}|^2} - \delta R_{\tau, \text{SU3 breaking}},$$
 $\tau \rightarrow X_s \nu$
- ▶
$$\frac{\Gamma(\tau^- \rightarrow K^- \nu_\tau)}{\Gamma(\tau^- \rightarrow \pi^- \nu_\tau)} = \frac{|V_{us}|^2}{|V_{ud}|^2} \left(\frac{f_{K\pm}}{f_{\pi\pm}} \right)^2 \frac{\left(1 - m_K^2/m_\tau^2\right)^2}{\left(1 - m_\pi^2/m_\tau^2\right)^2} \frac{R_{\tau/K}}{R_{\tau/\pi}} R_{K/\pi}$$
 $\tau \rightarrow K/\tau \rightarrow \pi$
- ▶
$$\Gamma(\tau^- \rightarrow K^- \nu_\tau) = \frac{G_F^2}{16\pi\hbar} f_{K\pm}^2 |V_{us}|^2 m_\tau^3 \left(1 - \frac{m_K^2}{m_\tau^2}\right)^2 R_{\tau/K} R_{K\mu 2}$$
 $\tau \rightarrow K$

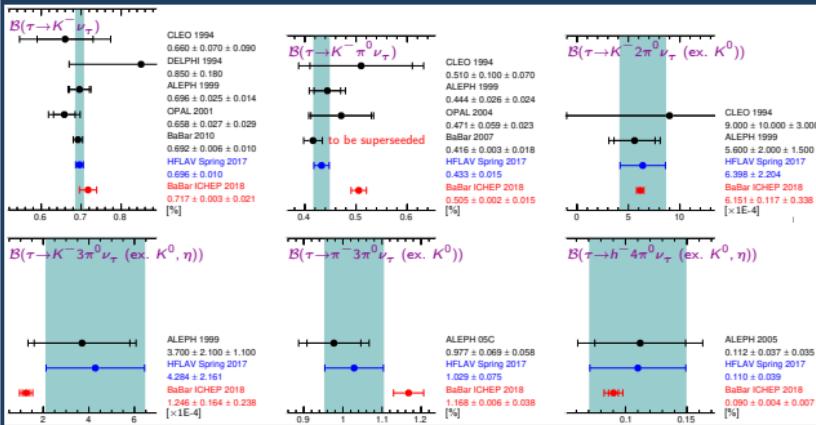
- ▶ $\Gamma(\tau^- \rightarrow X)$, $R(\tau \rightarrow X) = \Gamma(\tau \rightarrow X) / \Gamma(\tau \rightarrow e\nu\bar{\nu})$ from HFLAV tau branching ratio fit 2018
- ▶ $\delta R_{\tau, \text{SU3 breaking}}$ from Gamiz et al. JHEP 01 (2003) 06, PRL 94 (2005) 011803
 - ▶ perturbative QCD (OPE, finite energy sum rules), requires m_s value (lattice QCD)
- ▶ $(f_{K\pm}/f_{\pi\pm})$, $f_{K\pm}$ from lattice QCD, FLAG 2019
- ▶ $R_{K\mu 2}$, $R_{K/\pi}$ from Cirigliano & Neufeld 2011, Di Carlo et al. 2019
- ▶ $R_{\tau/K}/R_{\tau/\pi}$ from Decker & Finkemeier 1995
- ▶ remaining inputs are very precisely known

Updates and on-going work since EPS-HEP 2019

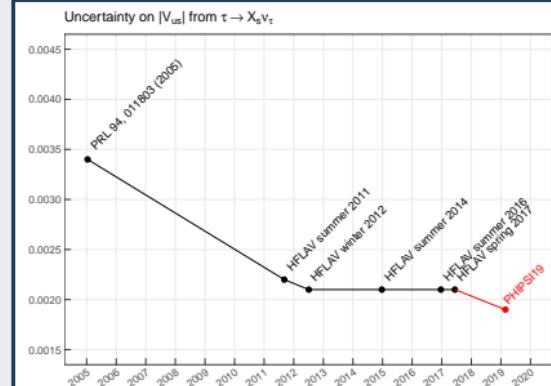
BABAR 2018 prelim. results on $\mathcal{B}(\tau \rightarrow K n\pi^0\nu)$ paper in preparation (not yet ready unfortunately)

► $|V_{us}|$ from tau decays is limited by experimental precision on tau branching fractions

BABAR $\mathcal{B}(\tau \rightarrow K, \pi n\pi^0\nu)$ ICHEP 2018 prelim.



Uncertainty on $|V_{us}|$ ($\tau \rightarrow X_s \nu$)



QCD+QED lattice determinations of pseudoscalar decay radiative corrections

chiral pert. th.
QCD+QED lattice

Cirigliano & Neufeld 2011
Di Carlo *et al.* [RM123 collab.] 2019

	$\delta R_{\pi\ell 2}$	$\delta R_{K\ell 2}$
chiral pert. th.	1.76(21)%	0.64(24)%
QCD+QED lattice	1.53(19)%	0.24(10)%

new

Updated $|V_{us}|$ from tau decays

$|V_{ud}|$ updates

- PDG 2018 → 2020
 $|V_{ud}|$: new estimates of universal electroweak radiative corrections to superallowed nuclear beta decays [Seng *et al.* 2018, Czarnecki *et al.* 2019, Seng *et al.* 2019]
 \Rightarrow tension in CKM first row unitarity

Other updates since EPS-HEP 2019

- FLAG 2016 → FLAG 2019 lattice QCD averages
- HFLAV 2018 report accepted by EPJC Jun 2020

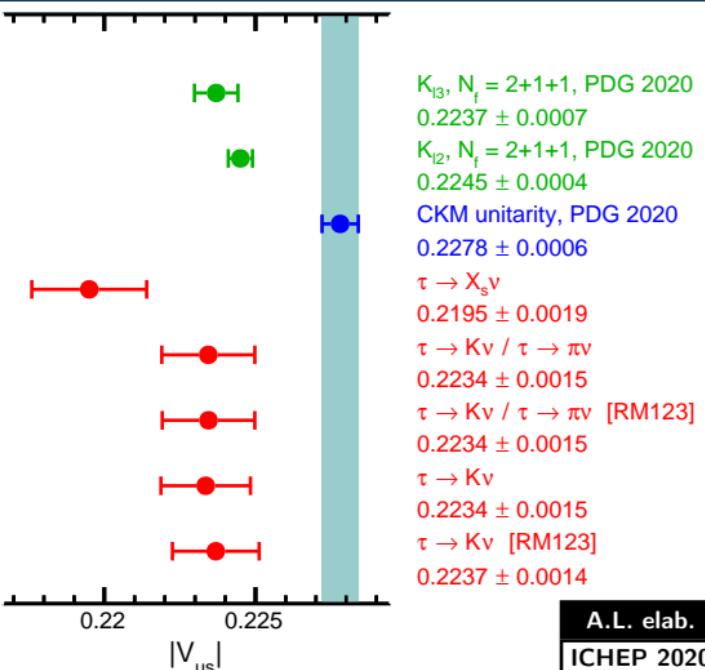
$|V_{us}|$ from tau status at ICHEP 2020

- $|V_{us}|_{\tau \rightarrow X_s \nu} - |V_{us}|_{\text{uni}} = -4.2\sigma$ (was -2.9σ)
- other $|V_{us}|$ from tau more than -2σ apart

Alternative $|V_{us}| (\tau \rightarrow X_s \nu)$ determinations

- R.J.Hudspith *et al.*, PLB 781 (2018) 206,
 P.Boyle *et al.*, PRL 121/20 (2018) 202003
 are consistent with kaon $|V_{us}|$ values

$|V_{us}|$ from tau decays, ICHEP 2020



A.L. elab.
ICHEP 2020

- RM123 determinations use Di Carlo 2019 isospin-limit f_K/f_π and f_K elaborations based on FLAG 2019

UNTAGGED MEASUREMENT OF $B \rightarrow \pi l \nu$ AT BELLE II

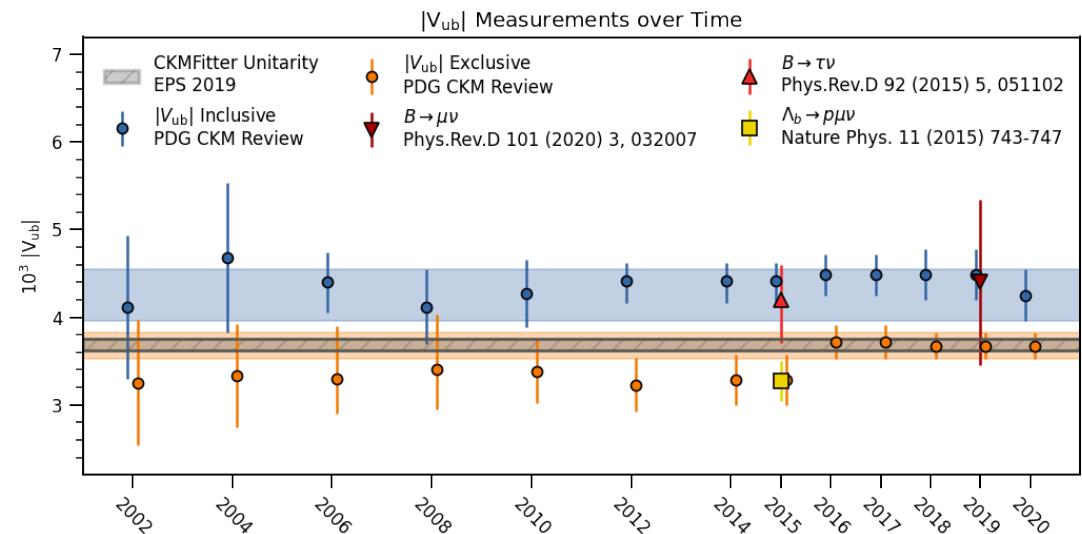
Florian Bernlochner, Jochen Dingfelder,
Svenja Granderath, Peter Lewis

ICHEP 2020, 29.07.20

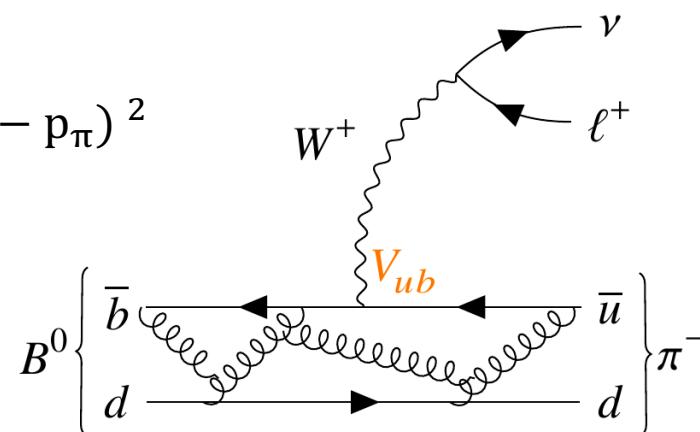


INTRODUCTION AND METHOD

- Belle II is e^+e^- collider producing $B\bar{B}$ pairs
- The B mesons can decay semileptonically
- Allows measurement of $|V_{ub}|$, where tension between $|V_{ub}|$ measured exclusively and inclusively persists
- $B \rightarrow \pi l\nu$ most accessible channel
- $\text{BF} \propto |V_{ub}|^2 f(q^2)$
- Determine ΔBF in five q^2 bins
- Form factor fit to the ΔBF spectrum

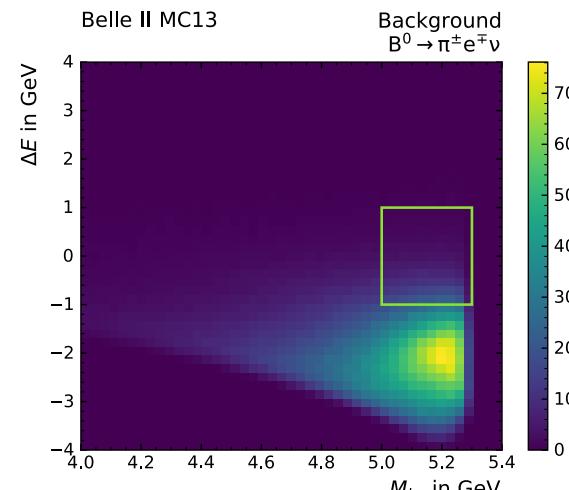
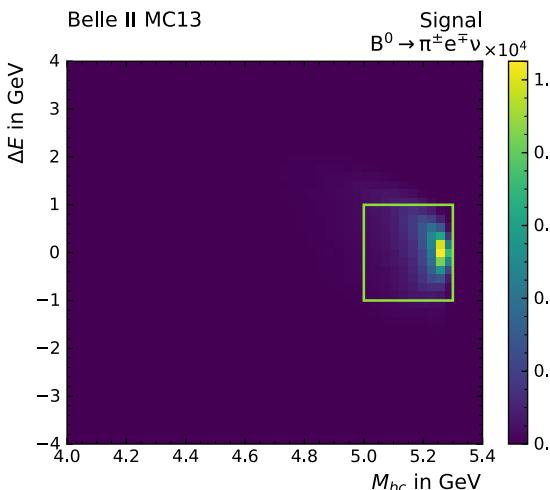


$$q^2 = (p_B - p_\pi)^2$$

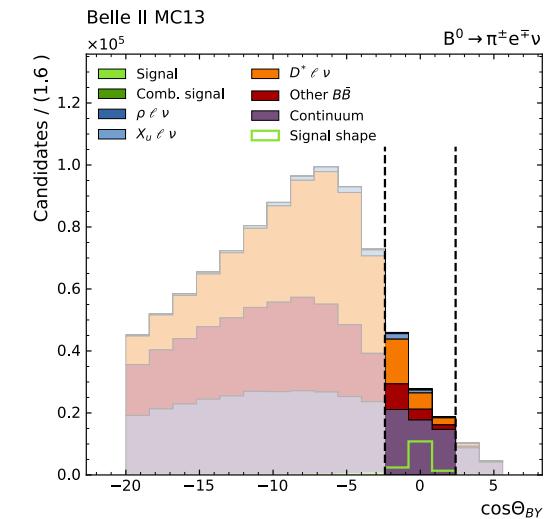


SIGNAL SELECTION + BACKGROUND SUPPRESSION

- Call combination of lepton and pion candidate a Y candidate
- Select on cosine of the angle between B and Y candidate: $\cos\theta_{BY}$
- Define: $\Delta E = E_B - E_{\text{beam}}$ $M_{bc} = \sqrt{E_{\text{beam}}^2 - |\vec{p}_B|^2}$
- Select 2D region:

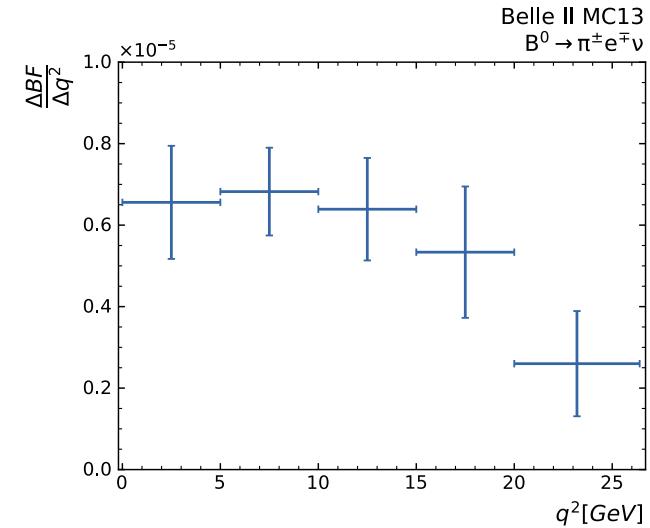
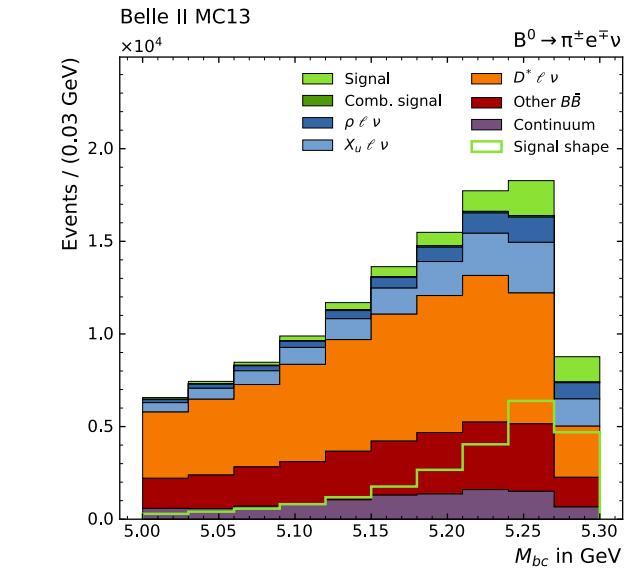
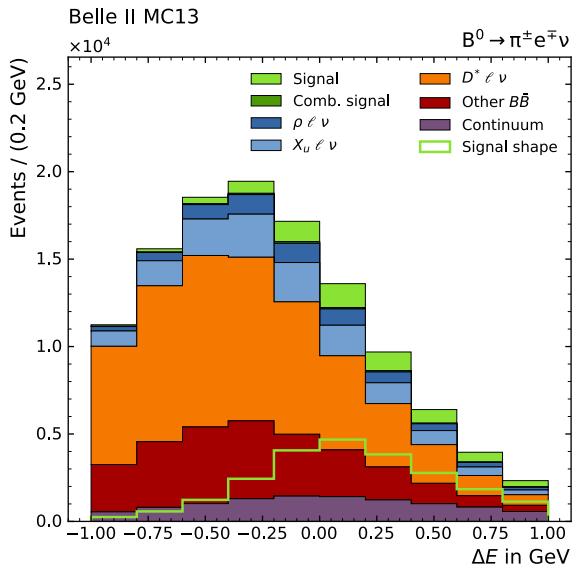
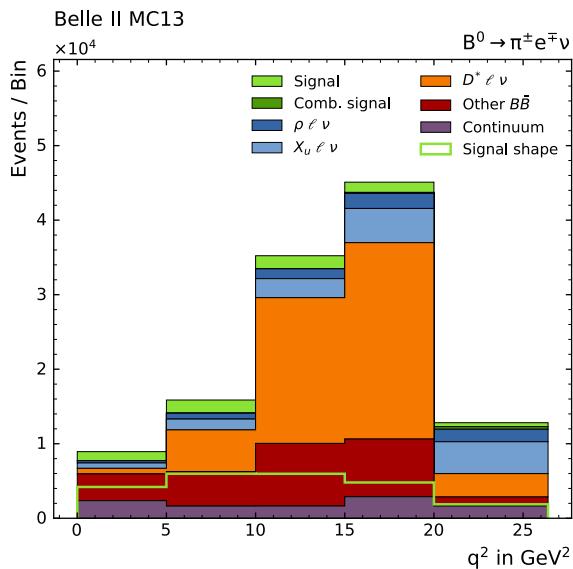


- Event shape for continuum and $B\bar{B}$ events different
- Use ten training variables to train a continuum suppression BDT in each q^2 bin



SIGNAL EXTRACTION

- Simultaneous extended binned maximum likelihood fit of the 2D distributions of ΔE and M_{bc}
- Signal to background ratio in the q^2 bins:



Calculate partial BF from:

$$BF = \frac{N}{2\epsilon_{rec} f \times N_{BB}}$$