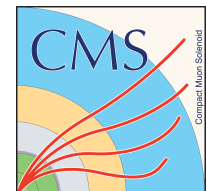


Overview of CMS experimental status quo

With a focus on lifetime measurements

Iakov Andreev (DESY) on behalf of the CMS Collaboration
Workshop “More than a lifetime”, Siegen, 23.09.2025



Contents

- CMS detector and its advantages for beauty and charm studies
- Overview of previous results
- Measurement of the $B_s \rightarrow J/\psi K_S$ effective lifetime
- Measurement of the $B_s \rightarrow \mu\mu$ decay properties
- Future prospects

CMS detector and its advantages

CMS detector

Compact Muon Solenoid

- General-purpose LHC experiment
- Was mainly designed for high- p_T physics
 - Top and Higgs factory
 - Not a dedicated b-factory
- High granularity pixel + strip silicon tracker for excellent track, PV and SV measurements
- External muon chambers outside steel return yoke for a clean muon detection and p_T measurement
- Two level trigger system (hardware + software)



CMS DETECTOR

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm) $\sim 1\text{m}^2$ $\sim 66\text{M}$ channels
Microstrips (80x180 μm) $\sim 200\text{m}^2$ $\sim 9.6\text{M}$ channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying $\sim 18,000\text{A}$

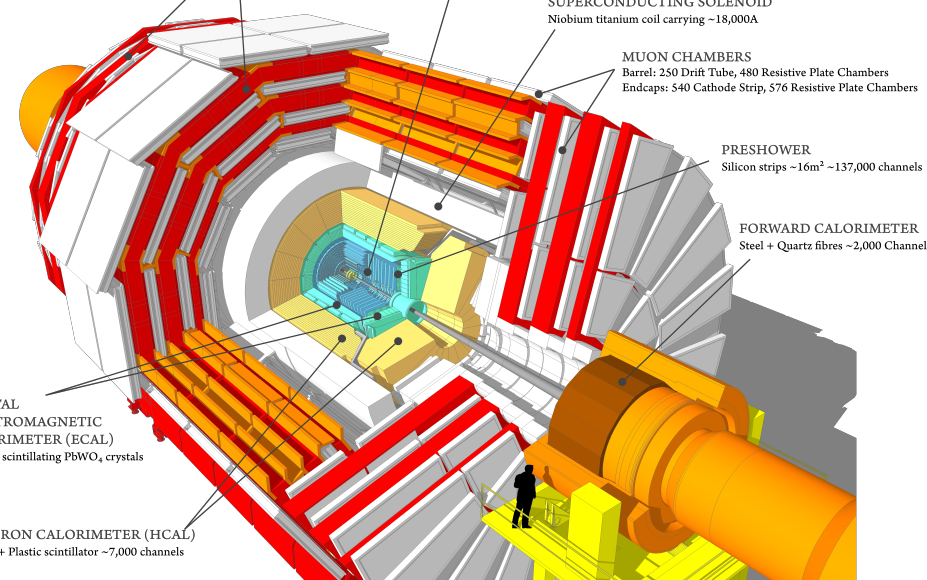
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 540 Cathode Strip, 576 Resistive Plate Chambers

PRESHOWER
Silicon strips $\sim 16\text{m}^2$ $\sim 137,000$ channels

FORWARD CALORIMETER
Steel + Quartz fibres $\sim 2,000$ Channels

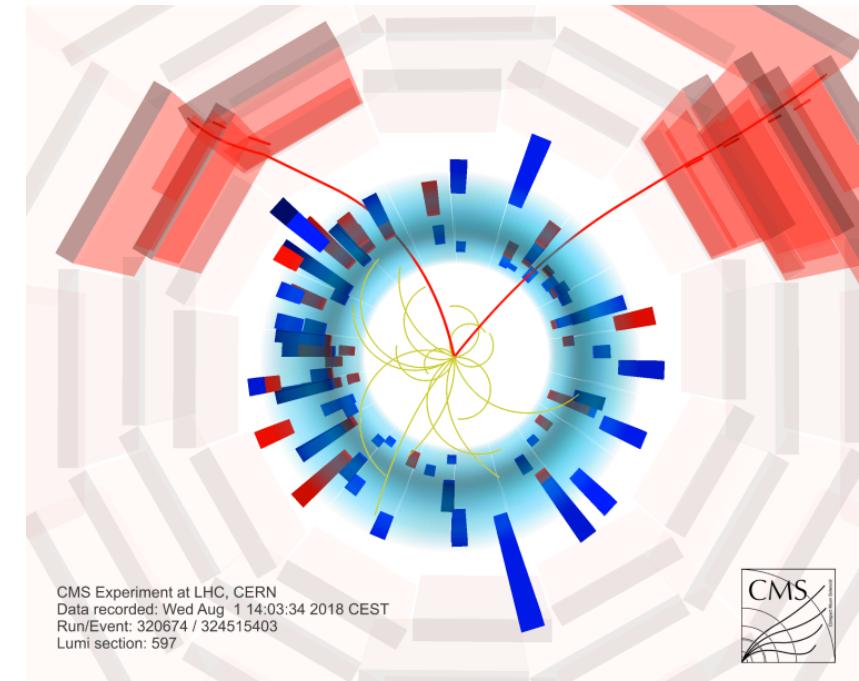
CRYSTAL
ELECTROMAGNETIC
CALORIMETER (ECAL)
 $\sim 76,000$ scintillating PbWO_4 crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator $\sim 7,000$ channels

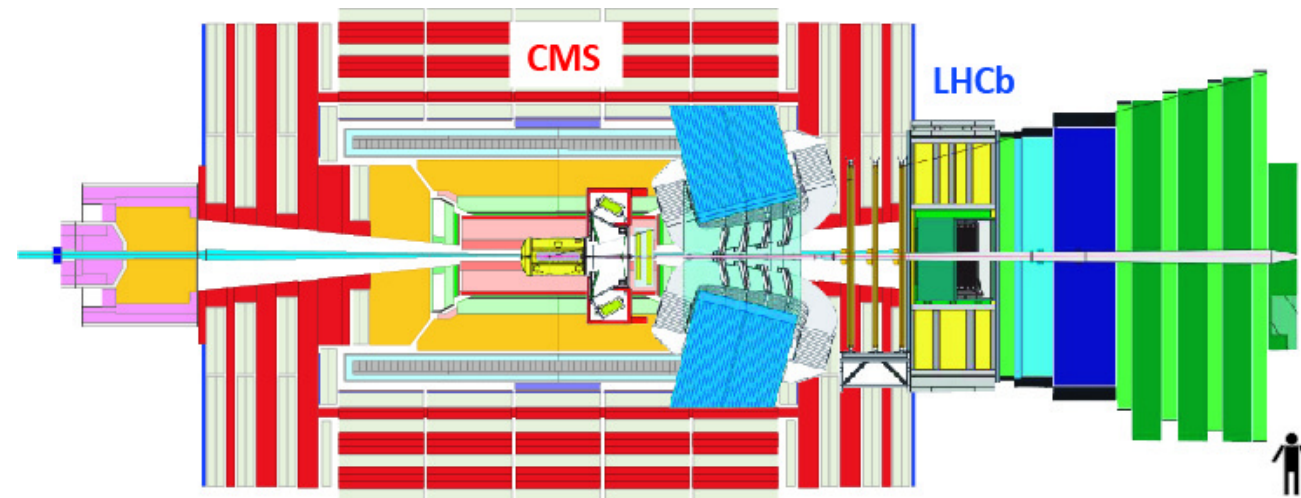


CMS advantages

- ✓ Robust muon system
 - Excellent muon resolution and p_T range ($\geq 3\text{GeV}$), low fake rate
 - For muons up to 100 GeV 1% p_T resolution in barrel, 3% in endcaps
- ✓ Good vertex reconstruction with high decay time resolution
 - e.g., $\sigma_t \sim 65\text{ fs}$ for $B_s^0 \rightarrow J/\psi\phi$
- ✓ Large data samples and novel data taking schemes allow for data taking despite high pileup
 - $\sim O(10^{13})$ $b\bar{b}$ pairs produced at Point 5 during Run 2 (geometric acceptance not considered)
 - Even more in Run3
- ✓ Provides results in $|\eta| < 2.5$
 - Complementary to LHCb $2 < |\eta| < 5$

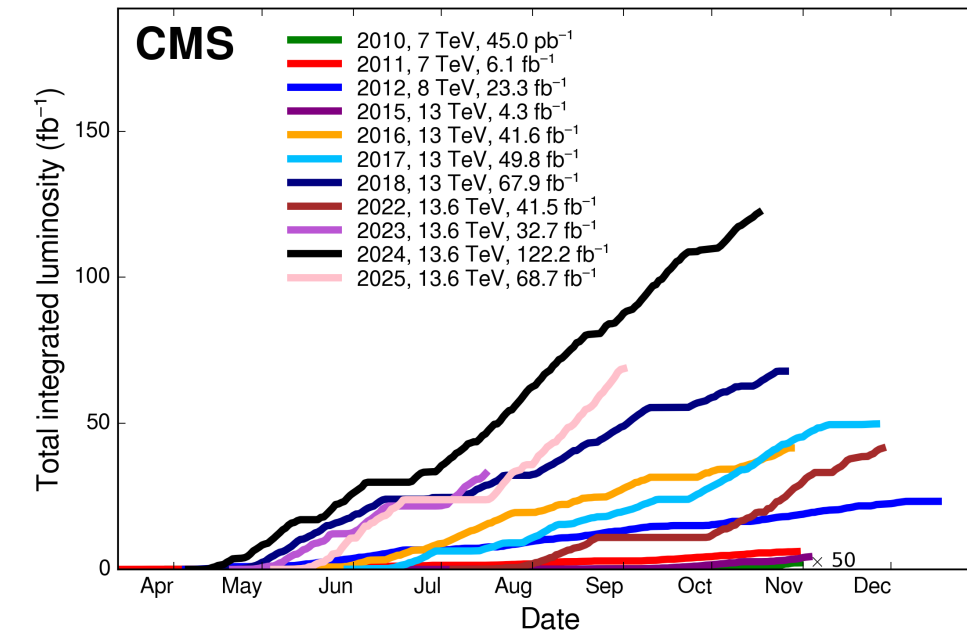
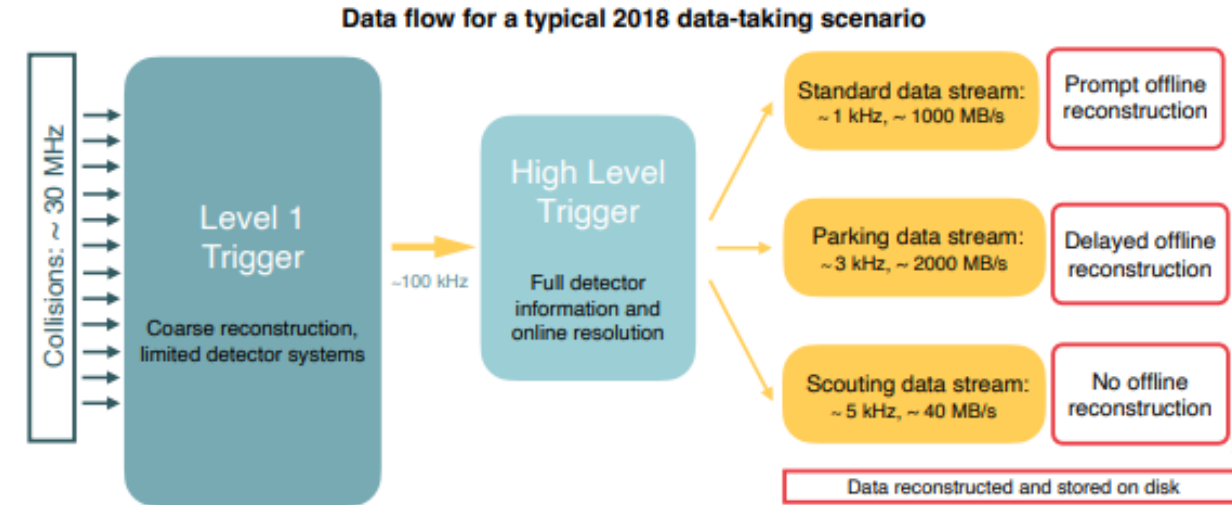


$B_s \rightarrow \mu\mu$ event example



Data taking schemes

- **Standard DAQ**
 - L1 trigger(hardware) + HLT(computing) triggers
- **Data scouting**
 - Reduced event size by saving HLT information
 - Avoids HLT buffering bottleneck
- **Data parking**
 - Events are saved on tape and reconstructed later
 - Especially relevant now with upcoming LS stop
 - Avoid reconstruction resources bottleneck
 - In 2018 BParking dataset alone $\sim 12\text{B}$ events with about 10^{10} b hadrons (10 times more than overall BaBar/Belle statistics)



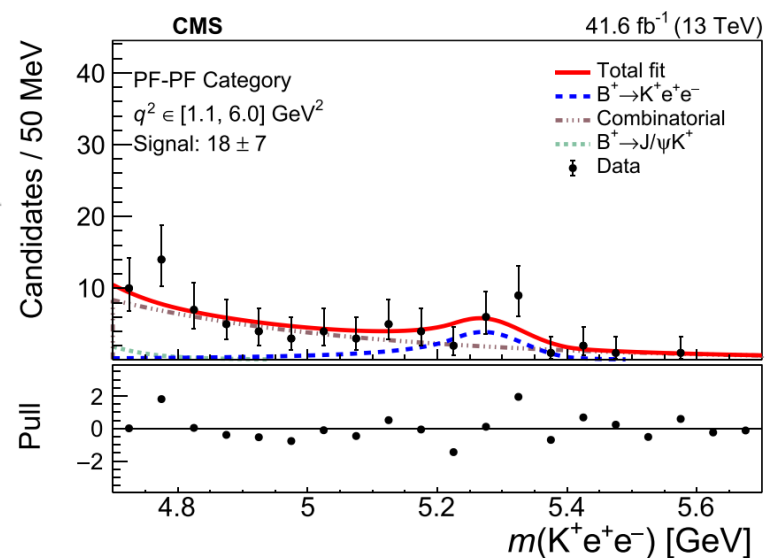
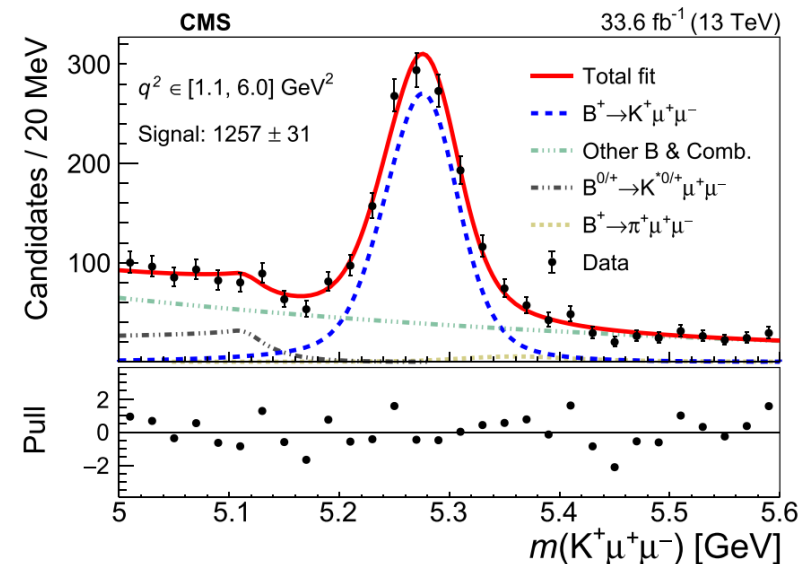
Selected CMS highlights

Test of Lepton Flavor Universality in $B \rightarrow K \ell \ell$

CMS-BPH-22-005

- Fulfills the initial goal of BParking dataset – $R(K)$ measurement
 - Extended ration through J/ψ channel to cancel systematics
 - Muon final state on tag side, electron on probe side
- Despite the huge sample, we still have very low statistics – for electron channel only ~20 events in low- q region

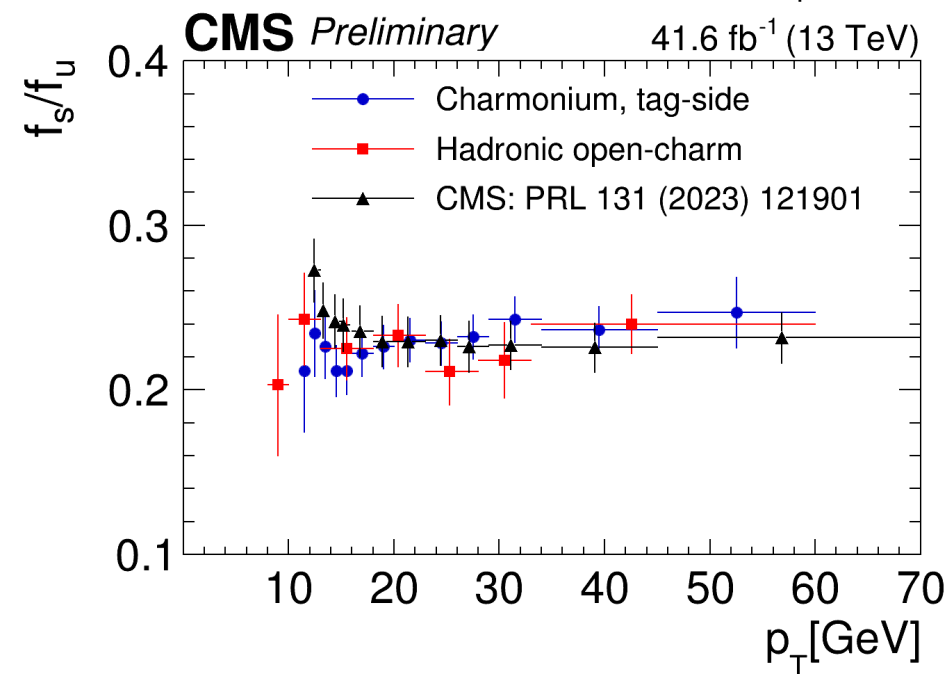
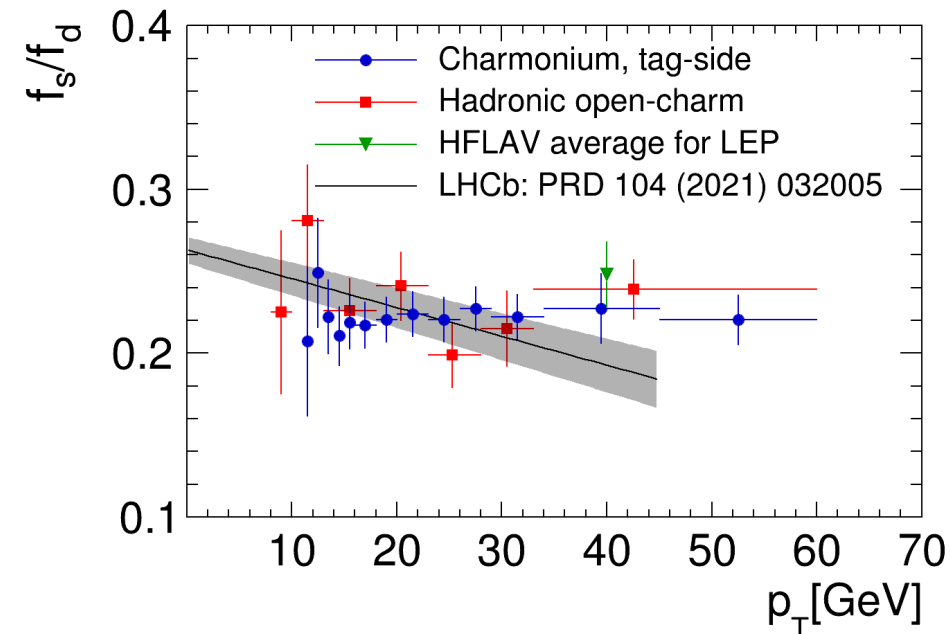
$$R(K)(q^2) = \frac{\mathcal{B}(B^+ \rightarrow K^+ \mu^+ \mu^-)(q^2)}{\mathcal{B}(B^+ \rightarrow J/\psi(\mu^+ \mu^-) K^+)} \bigg/ \frac{\mathcal{B}(B^+ \rightarrow K^+ e^+ e^-)(q^2)}{\mathcal{B}(B^+ \rightarrow J/\psi(e^+ e^-) K^+)}$$
- Measures $R(K) = 0.78^{+0.46}_{-0.23}$
 - In agreement with SM
- Similar to BaBar precision



B meson production fractions

CMS-BPH-21-007

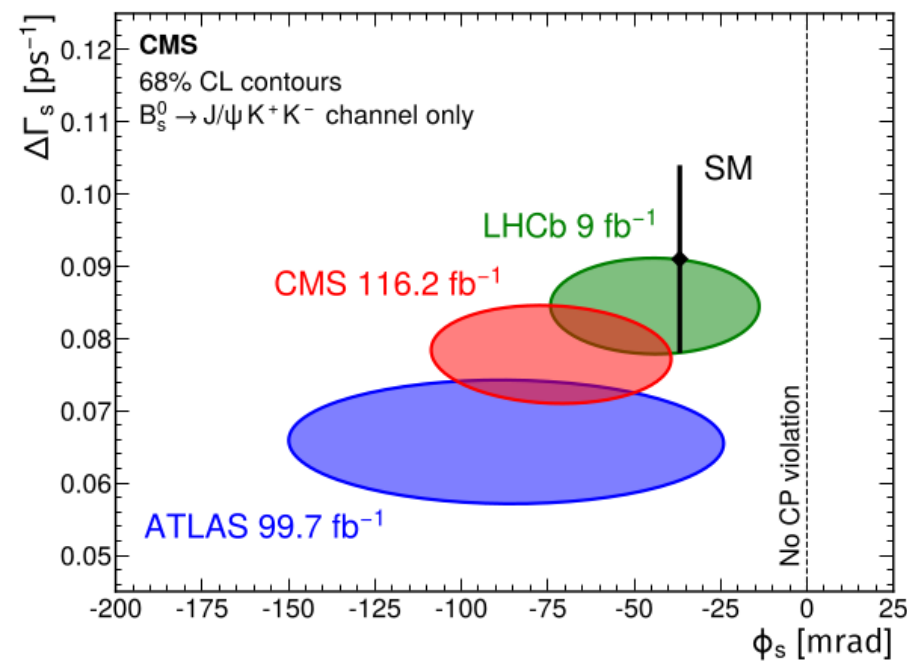
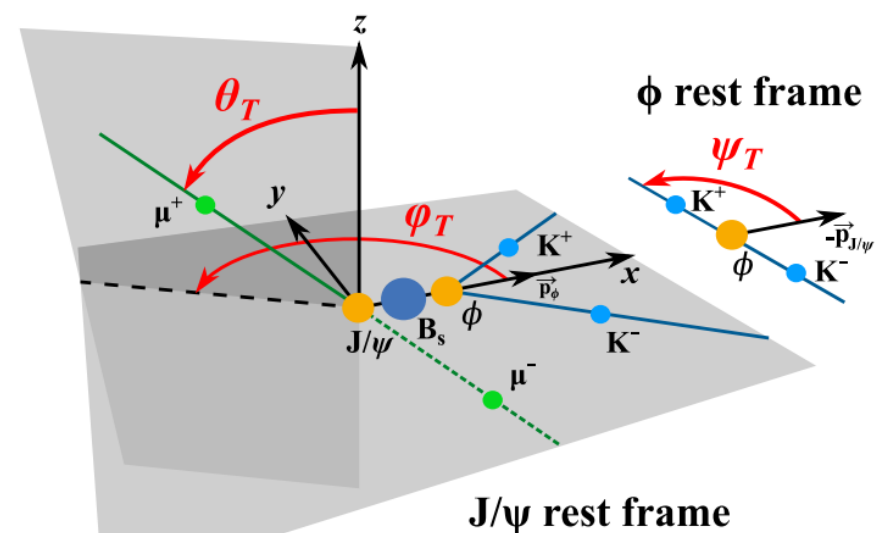
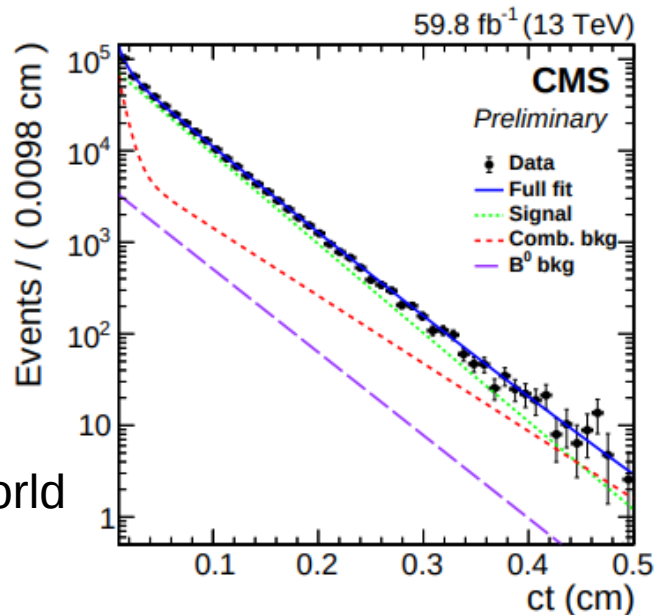
- Heavily utilizes BParking dataset and tag-and-probe method to get decays to hadronic open charm on probe side
 - Charmonium state $B \rightarrow J/\psi K$ or $B_s \rightarrow J/\psi \phi$
 - Open charm state $B_{(s)} \rightarrow \pi^+ D_{(s)}$
 - First time reconstruction** in CMS
- Performing measurements in open charm and charmonium channels simultaneously
 - f_d/f_u can provide a test of isospin invariance – **no significant deviation** observed
 - Still limited** by $p_T > 10$ GeV
 - Clear plateau in B_s/B^+ and B_s/B^0 production ratios above 15 GeV
 - In agreement** with previous results



CP violation in $B_s^0 \rightarrow J/\psi \phi(1020)$

CMS-BPH-23-004

- Performs angular analysis to separate CP eigenstates and flavor analysis to resolve B_s mixing
- Developed DNN based B_s tagger
- Largest ever effective statistics (27.5k events) for a single ϕ_s measurement
- $\Phi_s = -2\beta_s = 73 \pm 23 \pm 7$ mrad
- Precision of ϕ_s is comparable to the world most precise measurement by LHCb
- **First evidence of CPV in $B_s^0 \rightarrow J/\psi \phi(1020)$ decay (3.2 sigma)**



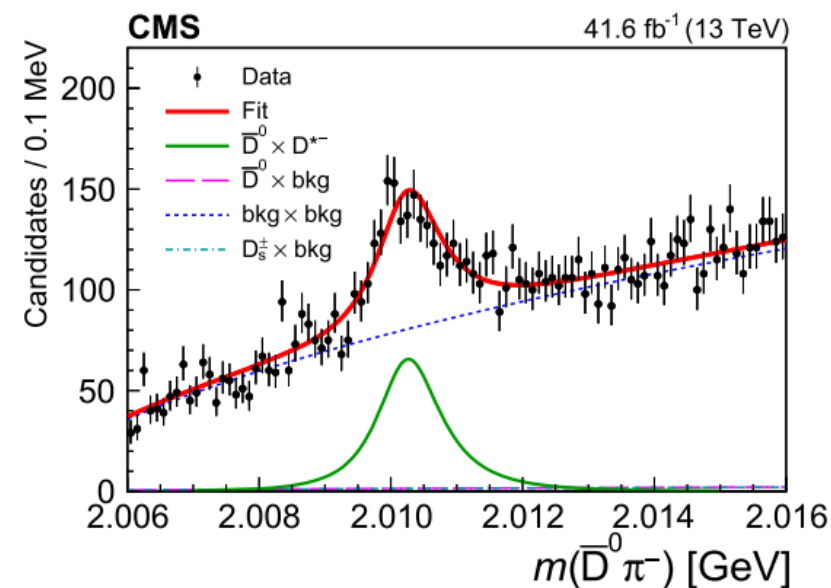
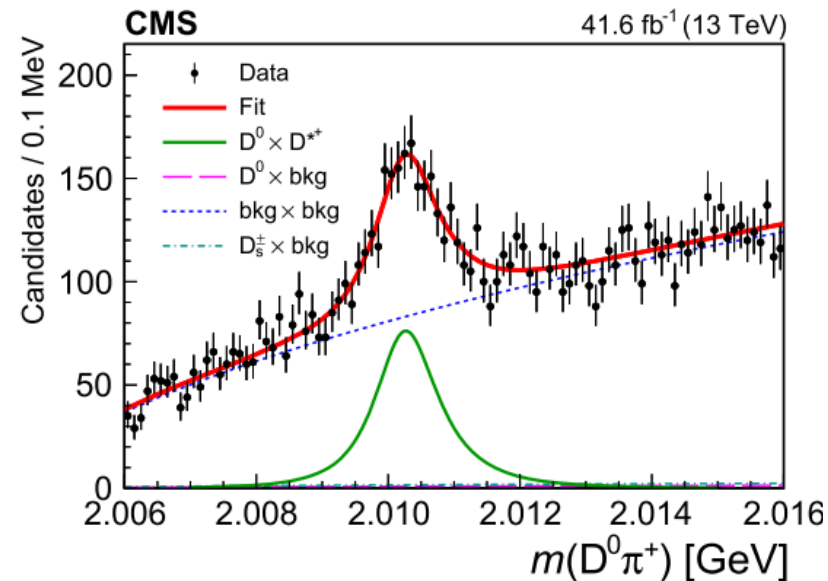
CP violation in $D^0 \rightarrow K_S K_S$

CMS-BPH-23-005

- SM predict CPV in $D^0 \rightarrow K_S K_S$ decay at $O(1\%)$ level
- Use both prompt D^0 and D^0 coming from b decays for data
- Using ΔA_{CP} between two channels ($K_S K_S$ and $K_S \pi \pi$) to cancel out systematics
- Results are based on ~ 2000 events in signal channel
 - For comparison $\sim 2M$ events in $K_S \pi \pi$ channel
- **First measurement** of CP violation in charm in CMS
- Results is consistent with no CPV and with previous results by LHCb and Belle

$$\Delta A_{CP}^{\text{raw}} = (6.3 \pm 3.0 \text{ (stat)} \pm 0.2 \text{ (syst)})\%$$

$$A_{CP}(D^0 \rightarrow K_S^0 K_S^0) = (6.2 \pm 3.0 \text{ (stat)} \pm 0.2 \text{ (syst)} \pm 0.8 (A_{CP}(D^0 \rightarrow K_S^0 \pi^+ \pi^-)))\%$$



Total charm production cross section

CMS-BPH-22-007(7 TeV)

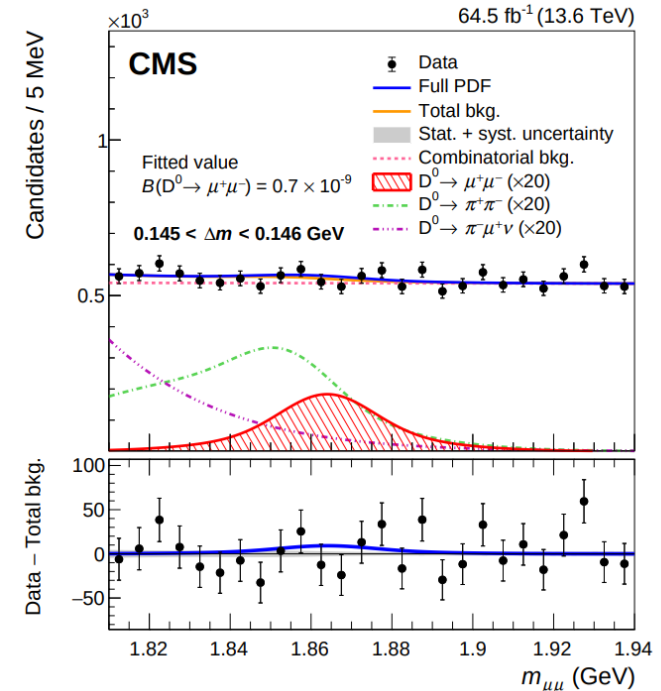
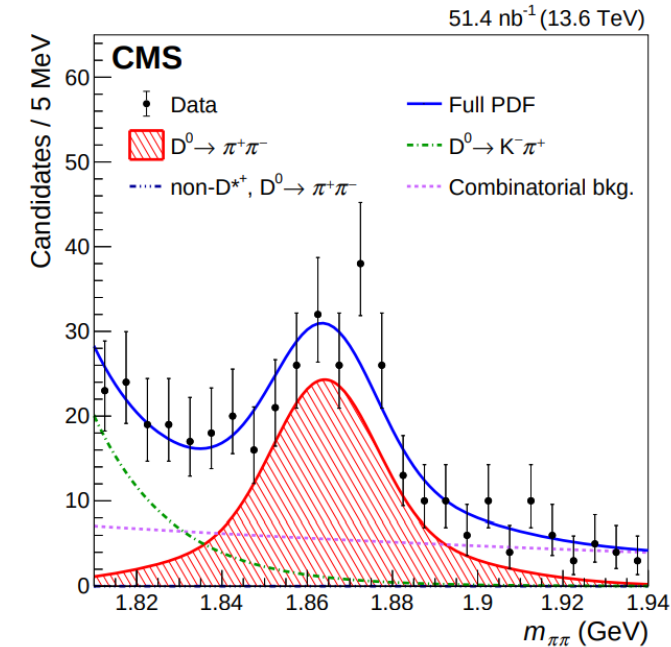
$$\sigma_{c\bar{c},\text{tot}} = 9.39^{+0.74}_{-0.74}(\text{data})^{+0.77}_{-0.73}(\text{ddFONLL})^{+0.83}_{-1.07}(f^{\text{PP}}) \text{ mb}$$

- High charm production cross section and high statistics make possible to search for rare decays

Search for charm decay in two muons

CMS-BPH-23-008

- Predicted branching ratio is around 3×10^{-13}
- Utilizes new **Run3** low p_T dimuon trigger
 - Run3 BParking analysis, data from 2022-2023
- Tags D^0 through D^* decay $D^{*+} \rightarrow D^0 \pi$
- Uses peaking background $D^0 \rightarrow \pi\pi$ as normalization channel via zero bias trigger
- No signal observed**
 - $B(D^0 \rightarrow \mu\mu) < 2.4 \times 10^{-9}$ at 95% Conf. level
 - 50% improvement w.r.t. to previous LHCb measurement

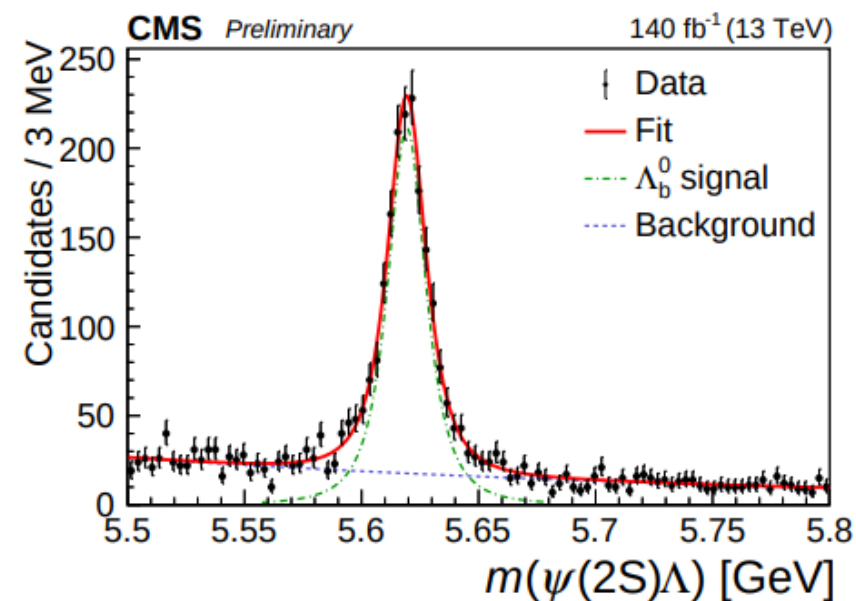
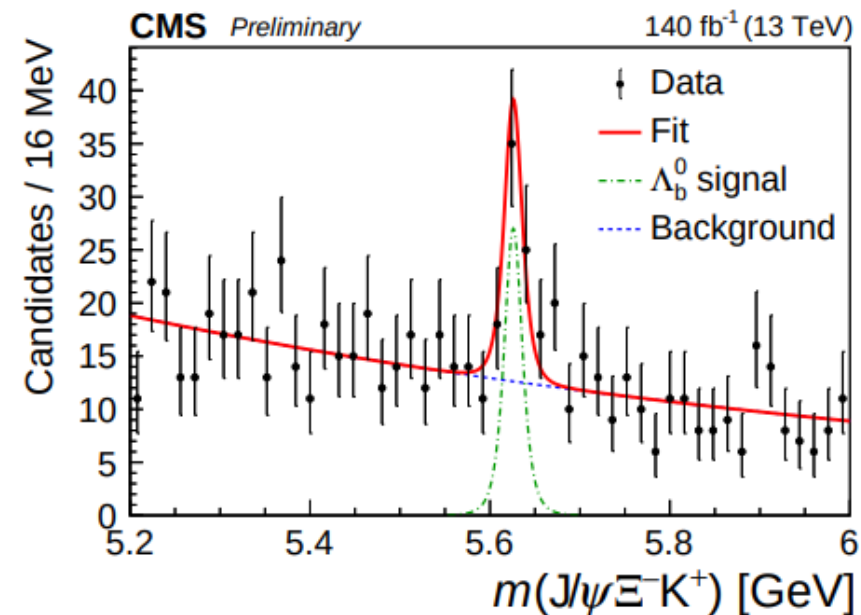


Observation of the $\Lambda_b^0 \rightarrow J/\psi \Xi^- K^+$ decay

CMS-BPH-22-002

- CMS very well suited for spectroscopy due to the good SV and track resolutions
- Uses channel $\Lambda_b^0 \rightarrow \psi(2S)\Lambda$ for normalization and for branching ratio calculation
 - Similar topology – reduced systematics
- Signal is extracted using UML fit
- **5.8 sigma significance** in 46 ± 11 events

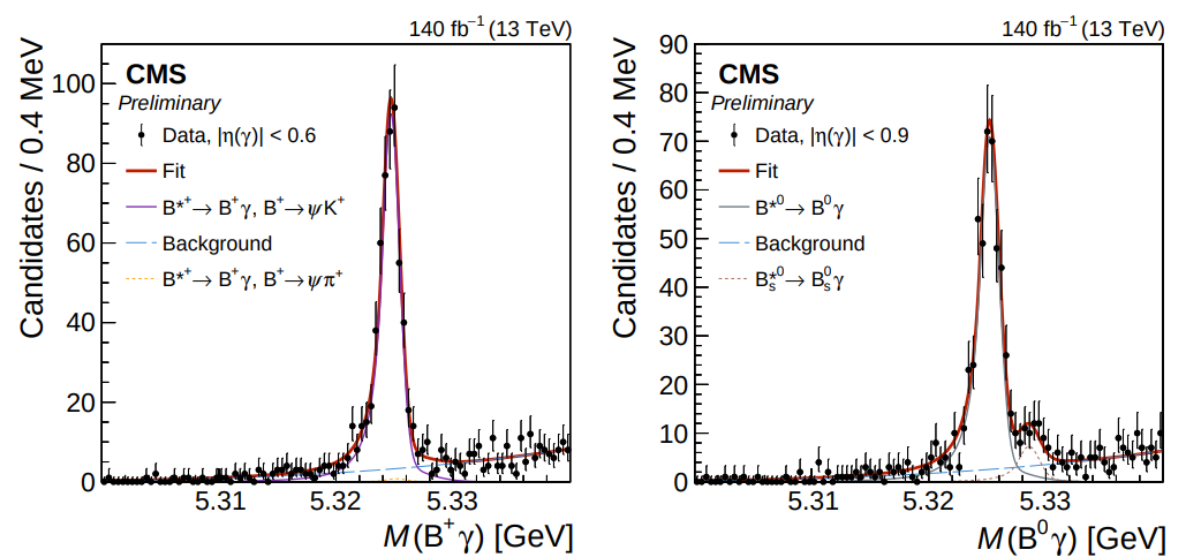
$$\mathcal{R} \equiv \frac{\mathcal{B}(\Lambda_b^0 \rightarrow J/\psi \Xi^- K^+)}{\mathcal{B}(\Lambda_b^0 \rightarrow \psi(2S)\Lambda)} = [2.5 \pm 0.8 (\text{stat}) \pm 0.9 (\text{syst})]\%,$$



First full B* reconstruction

CMS-BPH-24-011

- First full reconstruction of B* meson family through radiative decays and photon conversions
- Can detect photons **as low as 300MeV**
- Photon selection technique was calibrated using $\pi^0 \rightarrow \gamma\gamma$ decays
 - Measured energy is lower due to bremsstrahlung, need scale factors
- Plethora of **new measurements**



	Parameter	Value
1	$\Delta m(B^{*+}) \equiv m(B^{*+}) - m(B^+)$	$45.277 \pm 0.039 \pm 0.021 \text{ MeV}$
2	$\Delta m(B^{*0}) \equiv m(B^{*0}) - m(B^0)$	$45.471 \pm 0.056 \pm 0.024 \text{ MeV}$
3	$\Delta m(B_s^{*0}) \equiv m(B_s^{*0}) - m(B_s^0)$	$49.407 \pm 0.132 \pm 0.034 \text{ MeV}$
4	$m(B^{*+})$	$5324.69 \pm 0.04 \pm 0.02 \pm 0.07 \text{ MeV}$
5	$m(B^{*0})$	$5325.19 \pm 0.06 \pm 0.02 \pm 0.08 \text{ MeV}$
6	$m(B_s^{*0})$	$5416.34 \pm 0.13 \pm 0.03 \pm 0.10 \text{ MeV}$
7	$m(B^{*0}) - m(B^{*+})$	$0.50 \pm 0.07 \pm 0.01 \pm 0.05 \text{ MeV}$
8	$m(B_s^{*0}) - m(B^{*+})$	$91.66 \pm 0.14 \pm 0.03 \pm 0.12 \text{ MeV}$
9	$m(B_s^{*0}) - m(B^{*0})$	$91.15 \pm 0.14 \pm 0.03 \pm 0.12 \text{ MeV}$
10	$m(B_s^{*0}) - \frac{m(B^{*0}) + m(B^{*+})}{2}$	$91.40 \pm 0.13 \pm 0.03 \pm 0.12 \text{ MeV}$
1	$\Delta m(B^{*0}) - \Delta m(B^{*+})$	$0.19 \pm 0.07 \pm 0.01 \text{ MeV}$
2	$\Delta m(B_s^{*0}) - \Delta m(B^{*+})$	$4.13 \pm 0.14 \pm 0.03 \text{ MeV}$
3	$\Delta m(B_s^{*0}) - \Delta m(B^{*0})$	$3.94 \pm 0.14 \pm 0.03 \text{ MeV}$
4	$\Delta m(B_s^{*0}) - \frac{\Delta m(B^{*0}) + \Delta m(B^{*+})}{2}$	$4.03 \pm 0.13 \pm 0.03 \text{ MeV}$
5	$\Delta m(B^{*0}) / \Delta m(B^{*+})$	$1.0043 \pm 0.0015 \pm 0.0002$
6	$\Delta m(B_s^{*0}) / \Delta m(B^{*+})$	$1.0912 \pm 0.0031 \pm 0.0007$
7	$\Delta m(B_s^{*0}) / \Delta m(B^{*0})$	$1.0866 \pm 0.0031 \pm 0.0007$
8	$\frac{2 \cdot \Delta m(B_s^{*0})}{\Delta m(B^{*+}) + \Delta m(B^{*0})}$	$1.0889 \pm 0.0030 \pm 0.0007$

Order of magnitude improvement in precision

CMS results on lifetime

Compilation of CMS results on lifetime

Particle	Channel	Analysis
B^0	$J/\psi K^*(892)$	BPH-13-008
	$J/\psi K_s$	BPH-13-008
B_s^0	$J/\psi \pi \pi$	BPH-13-008
	$J/\psi \phi(1020)$	BPH-13-008
	$\mu\mu$	BPH-16-004 BPH-21-006
	$J/\psi K_s$	BPH-22-001
Λ_b	$J/\psi \Lambda$	BPH-13-008 BPH-11-013
B_c	$J/\psi \pi$	BPH-13-008

Measurement of the $B_s \rightarrow J/\psi K_s$ effective lifetime

CMS-BPH-22-001

Dataset 2016-2018 (140 fb^{-1})

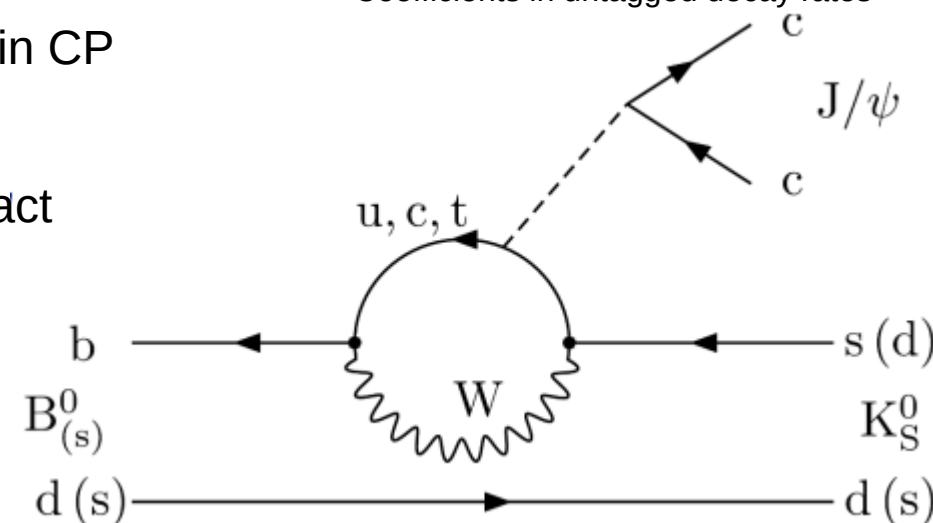
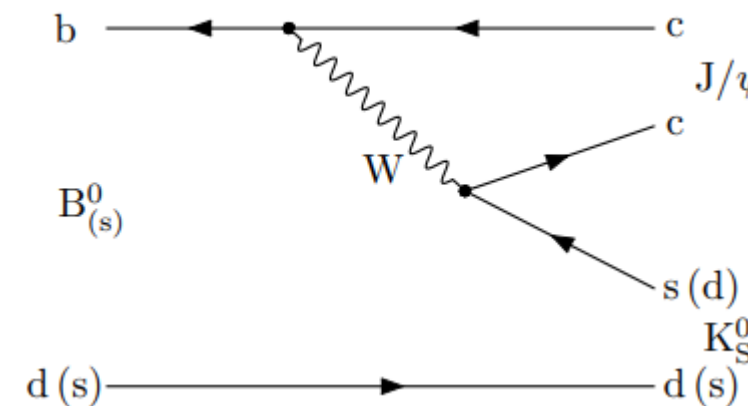
Analysis introduction

- B_s mesons are produced as flavor eigenstates but propagate as mass eigenstates. If there is no CP mixing these mass states coincide with CP-eigenstates

- Two eigenstates for B_s have different lifetimes and in that case we can extract mass eigenstates rates asymmetry using observable λ

$$A_{\Delta\Gamma} = \frac{R_H - R_L}{R_H + R_L} = \frac{-2\mathcal{R}(\lambda)}{1 + |\lambda|^2} \quad \text{where} \quad \Gamma(B_s \rightarrow f) + \Gamma(\bar{B}_s \rightarrow f) = R_H e^{-\Gamma_H t} + R_L e^{-\Gamma_L t}$$

- Result of this analysis is a measurement of B_s **effective lifetime** τ in CP odd final state $J/\psi K_S$ in CMS Run2 dataset
- Analysis uses $J/\psi K_S$ invariant mass and proper decay time to extract effective lifetime
 - $B^0 \rightarrow J/\psi K_S$ is used as control channel



Effective lifetime predictions

- Effective lifetime can be defined and expressed as

$$\tau(B_s^0 \rightarrow J/\psi K_S^0) \equiv \frac{\int_0^\infty t \{ \Gamma[B_s^0(t) \rightarrow J/\psi K_S^0] + \Gamma[\bar{B}_s^0(t) \rightarrow J/\psi K_S^0] \} dt}{\int_0^\infty \{ \Gamma[B_s^0(t) \rightarrow J/\psi K_S^0] + \Gamma[\bar{B}_s^0(t) \rightarrow J/\psi K_S^0] \} dt} = \frac{\tau_{B_s^0}}{1 - y_s^2} \left(\frac{1 + 2 y_s A_{\Delta\Gamma} + y_s^2}{1 + y_s A_{\Delta\Gamma}} \right)$$

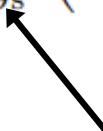
- Using the latest measurements and assuming SM ($A_{\Delta\Gamma} = 0.94 \pm 0.07$, $\tau_{B_s} = 1.520 \pm 0.005$ ps, $\Delta\Gamma = 0.084 \pm 0.005$ ps⁻¹)

- $\tau(J/\psi K_S)_{\text{SM}} = 1.62 \pm 0.02$ ps
- $\tau(J/\psi K_S) = 1.75 \pm 0.12 \pm 0.07$ ps – result from [LHCb](#)

Average lifetime

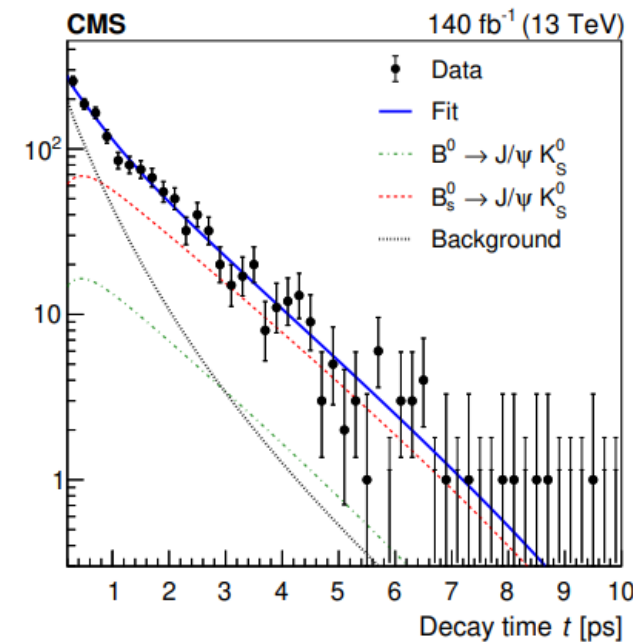
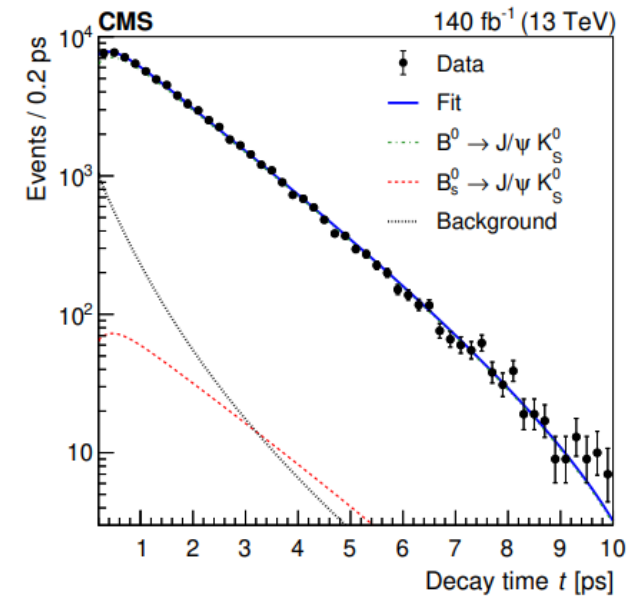
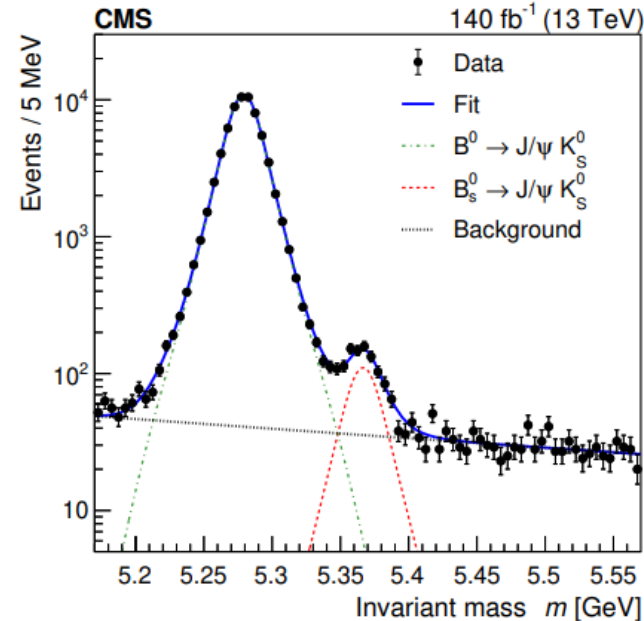


Normalized decay width difference
 $y_s = \tau_{B_s} \Delta\Gamma/2$



Fit and results

- The effective lifetime is measured with a 2D Unbinned Maximum Likelihood (UML) fit to the invariant mass and proper decay time. The decay time uncertainty is used as a conditional parameter
 - Both B^0 and B_s signals are fitted
 - Control channel is used for validation of measurement components
- Results (using 727 ± 35 B_s signal candidates):
 - $\tau(J/\psi K_S) = 1.59 \pm 0.07$ (stat) ± 0.03 (syst) ps
- Good agreement with world average value in control channel B^0
- The measured value is in agreement with the SM prediction, compatible with the previous LHCb results at 2.1σ and is twice more precise



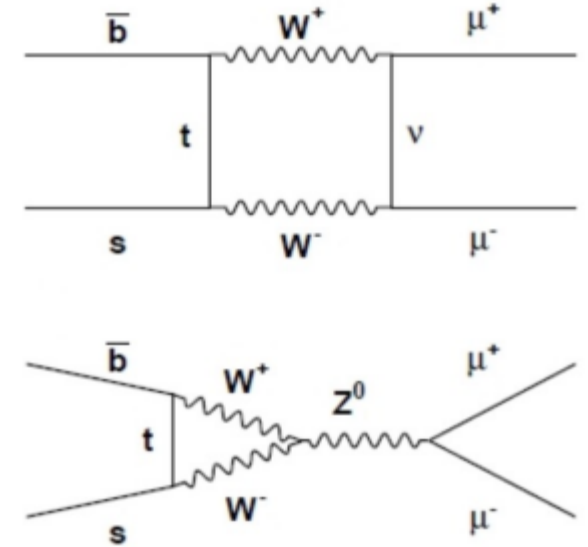
Measurement of the $B_s \rightarrow \mu\mu$ decay properties

CMS-BPH-21-006

Dataset 2016-2018 (140 fb^{-1})

Analysis introduction

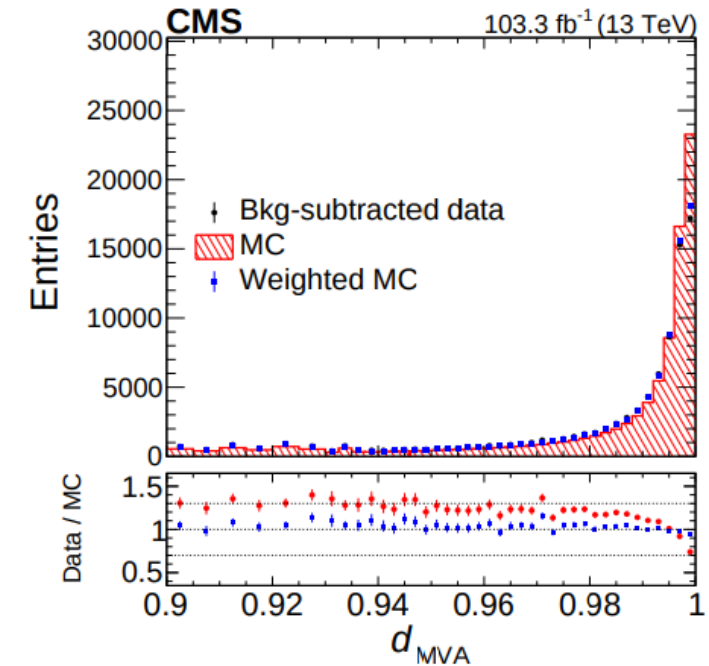
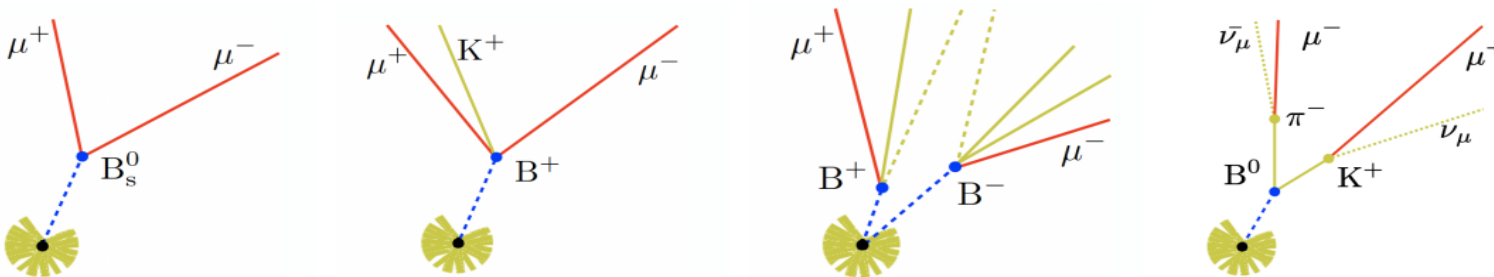
- $B_{(s)} \rightarrow \mu\mu$ are strongly suppressed in SM (FCNC and Helicity)
 - Theoretically very easy to calculate and experimentally has a very clean signature
- Some hints of deviation from SM have been observed in $b \rightarrow s$ ll processes
- $B_s \rightarrow \mu\mu$ is CP even therefore only $B_{s,H}$ lifetime is measured without CP violation
 - Any significant deviation from the expected value will hint at BSM physics
- SM expectations are very small – need **high statistics**
- Normalization to well known decay channels $B \rightarrow J/\psi K$ and $B \rightarrow J/\psi \phi$
 - Cancellation on systematics
 - No reliance on $b\bar{b}$ production cross section



$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.66 \pm 0.14) \times 10^{-9}$$
$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) = (1.03 \pm 0.05) \times 10^{-10}$$

Event selection

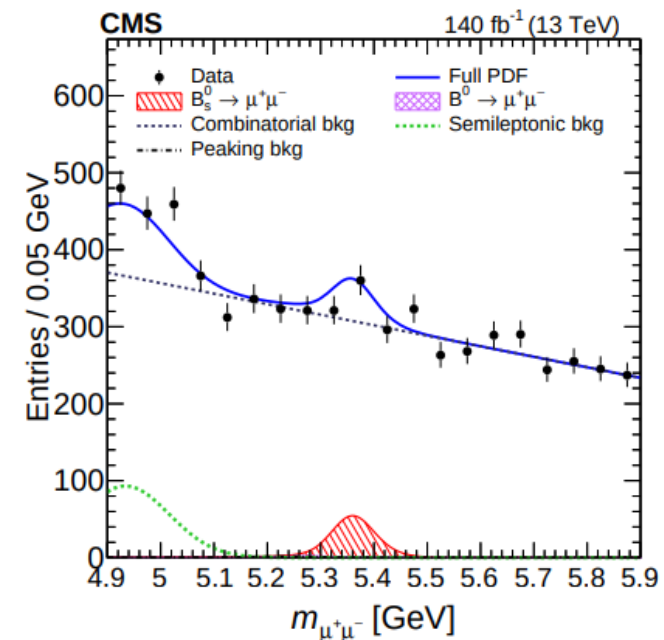
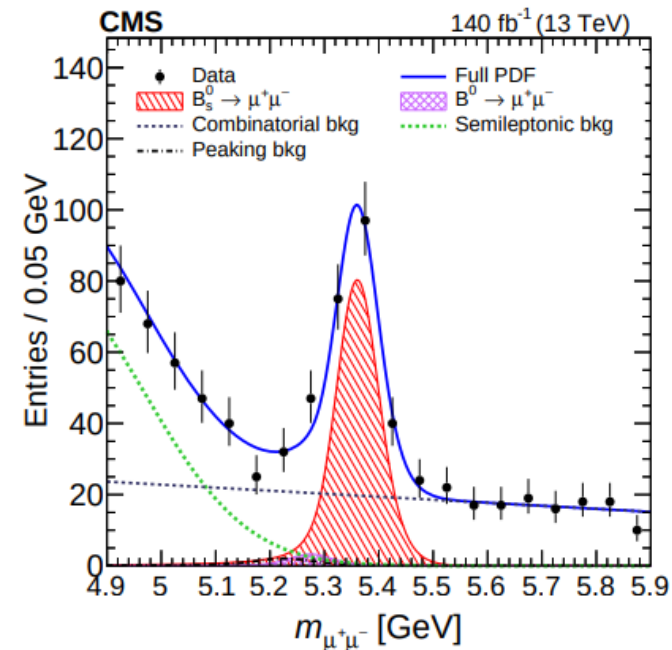
- Use control channels $B \rightarrow J/\psi K$ and $B \rightarrow J/\psi \phi$
- Dimuon trigger with tight quality tracks and a valid secondary vertex
- Decay vertex of b meson – done via kinematic refit of muon tracks with SV constraints
- Backgrounds
 - Charmless hadronic two body decays – negligible after selection
 - Combinatorial BB events $\rightarrow$ MVA reduction
 - Partially reconstructed semileptonic decays $\rightarrow$ MVA reduction
- 16 fit categories – 4 years X 2 BDT bins X 2 eta regions



MVA analysis

- Uses several weak discrimination variables with a BDT (XGBoost)
 - Pointing angles (2D and 3D)
 - Suppressing all non-two-body backgrounds
 - Quality and displacement of SV
 - Suppressing combinatorial background
 - Particle isolation
 - Suppressing semileptonic decays
- Trained on MC and signal sidebands
 - Validated on $B \rightarrow J/\psi K$ events

$$I = \frac{p_T}{p_T + \sum_{\text{trk}} p_T(\text{trk})},$$



Branching fractions

- 2D UML fit to dimuon mass and its uncertainty
- Two strategies for normalization
 - J/ψK – relies on knowledge f_s/f_u (derived from [LHCb measurement](#))
 - J/ψφ – adds higher systematics (additional kaon)

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = \mathcal{B}(B^+ \rightarrow J/\psi K^+) \frac{N_{B_s^0 \rightarrow \mu^+ \mu^-}}{N_{B^+ \rightarrow J/\psi K^+}} \frac{\epsilon_{B^+ \rightarrow J/\psi K^+}}{\epsilon_{B_s^0 \rightarrow \mu^+ \mu^-}} \frac{f_u}{f_s} = \left[3.83_{-0.36}^{+0.38} \text{ (stat)}_{-0.16}^{+0.19} \text{ (syst)}_{-0.13}^{+0.14} (f_s/f_u) \right] \times 10^{-9},$$

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = \mathcal{B}(B_s^0 \rightarrow J/\psi \phi(1020)) \frac{N_{B_s^0 \rightarrow \mu^+ \mu^-}}{N_{B_s^0 \rightarrow J/\psi \phi(1020)}} \frac{\epsilon_{B_s^0 \rightarrow J/\psi \phi(1020)}}{\epsilon_{B_s^0 \rightarrow \mu^+ \mu^-}} = \left[4.02_{-0.38}^{+0.40} \text{ (stat)}_{-0.23}^{+0.28} \text{ (syst)}_{-0.15}^{+0.18} (\mathcal{B}) \right] \times 10^{-9}.$$

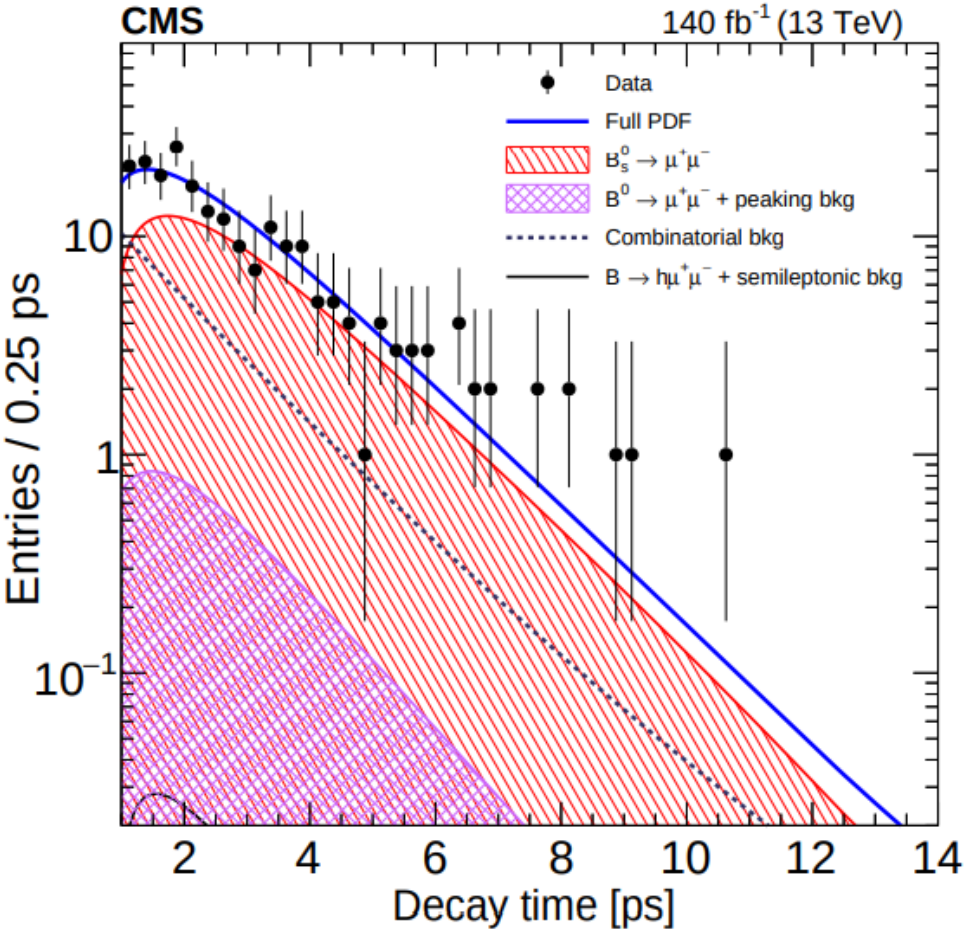
$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) = \mathcal{B}(B^+ \rightarrow J/\psi K^+) \frac{N_{B^0 \rightarrow \mu^+ \mu^-}}{N_{B^+ \rightarrow J/\psi K^+}} \frac{\epsilon_{B^+ \rightarrow J/\psi K^+}}{\epsilon_{B^0 \rightarrow \mu^+ \mu^-}} \frac{f_u}{f_d}, \quad \mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 1.5 \times 10^{-10} \text{ at 90\% CL,}$$

$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 1.9 \times 10^{-10} \text{ at 95\% CL,}$$

- All UML fit results are **comparable with SM predictions**

Lifetime measurement

- 3D UML fit to dimuon mass, its uncertainty and decay time
- Efficiency is derived by simulations and corrected using J/ψ K control channel to mitigate MVA bias
- Combinatorial background distribution is derived from sidebands
- Main systematic due to the correlation between MVA and decay time
- Good agreement with SM
- Need more data to be able to discriminate between mass eigenstates



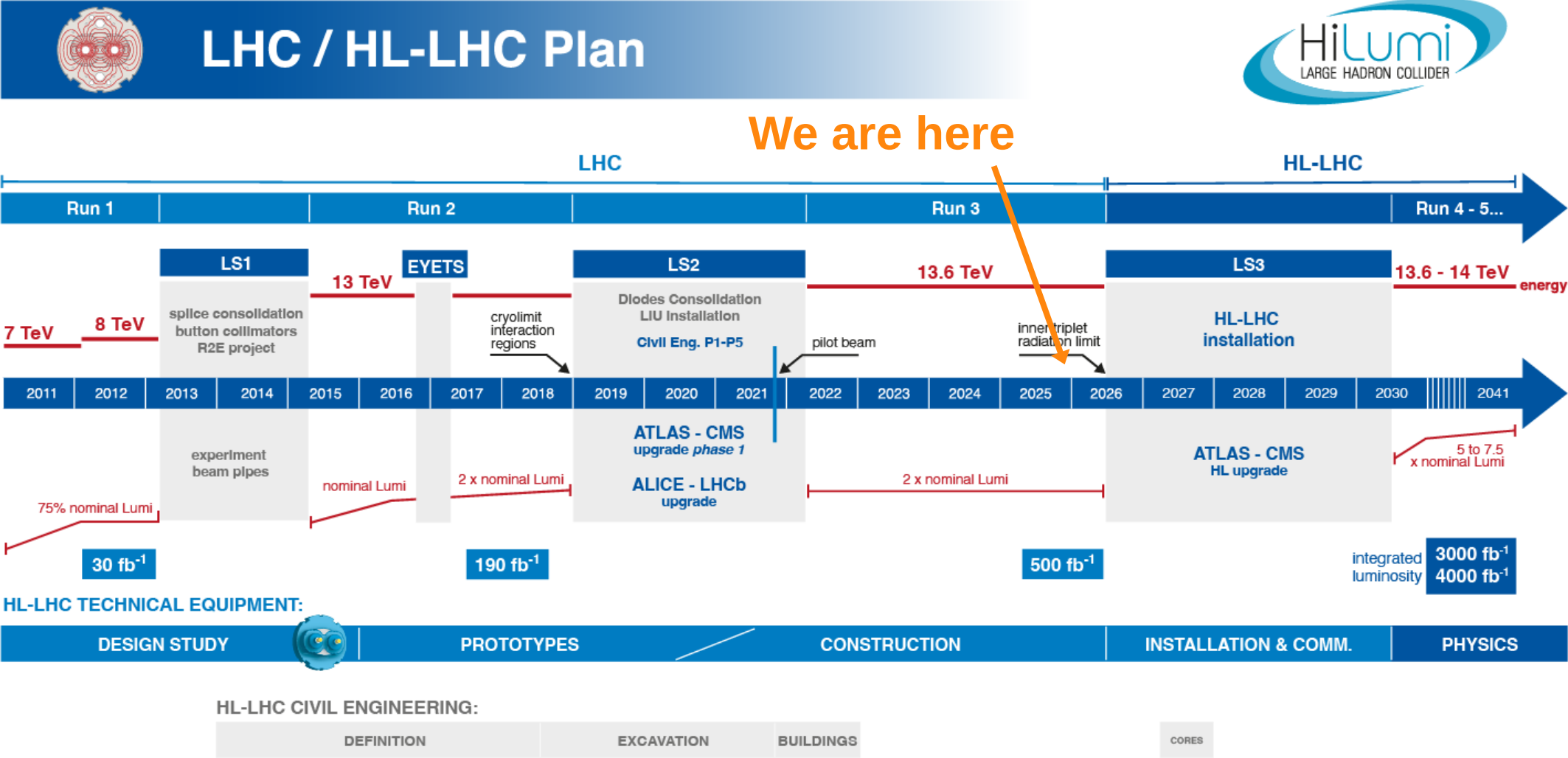
$$\tau = 1.83^{+0.23}_{-0.20} \text{ (stat)}^{+0.04}_{-0.04} \text{ (syst) ps.}$$

Effect	2016a	2016b	2017	2018
Lifetime fit bias	0.04	0.04	0.05	0.04
Decay time distribution mismodeling	0.10	0.06	0.02	0.02
Efficiency modeling		0.01		
Lifetime dependence		0.01		
Total	0.11	0.07	0.05	0.04

Projections for the future

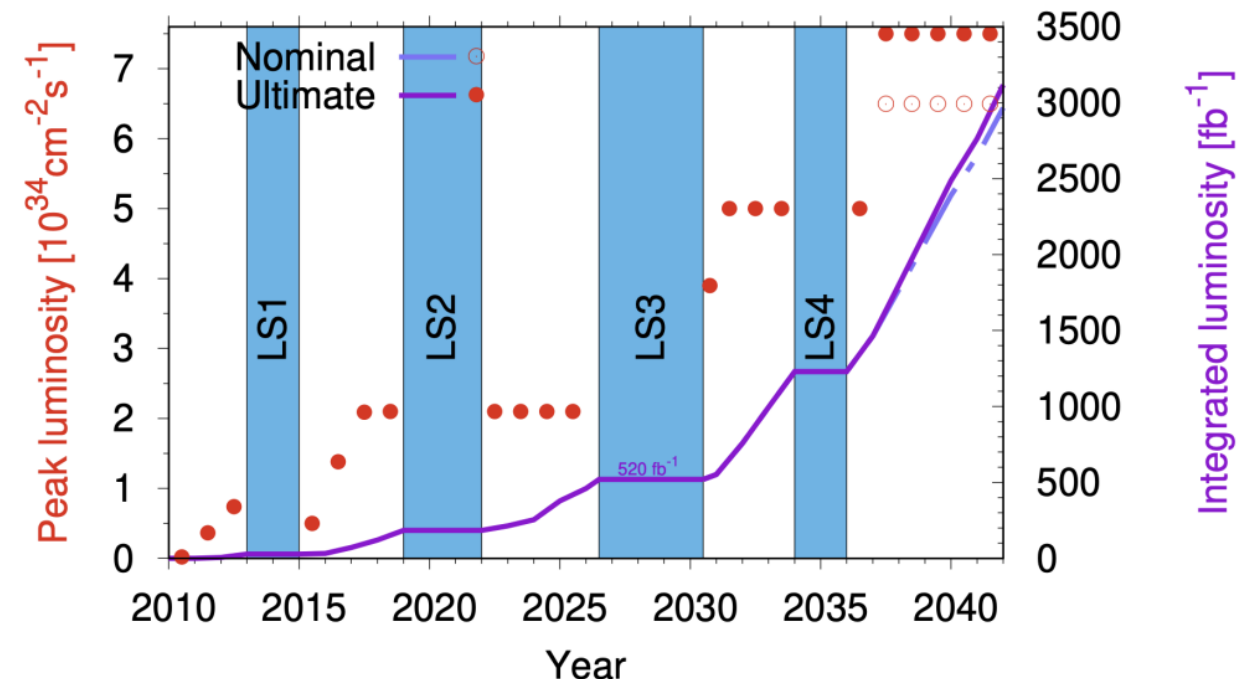
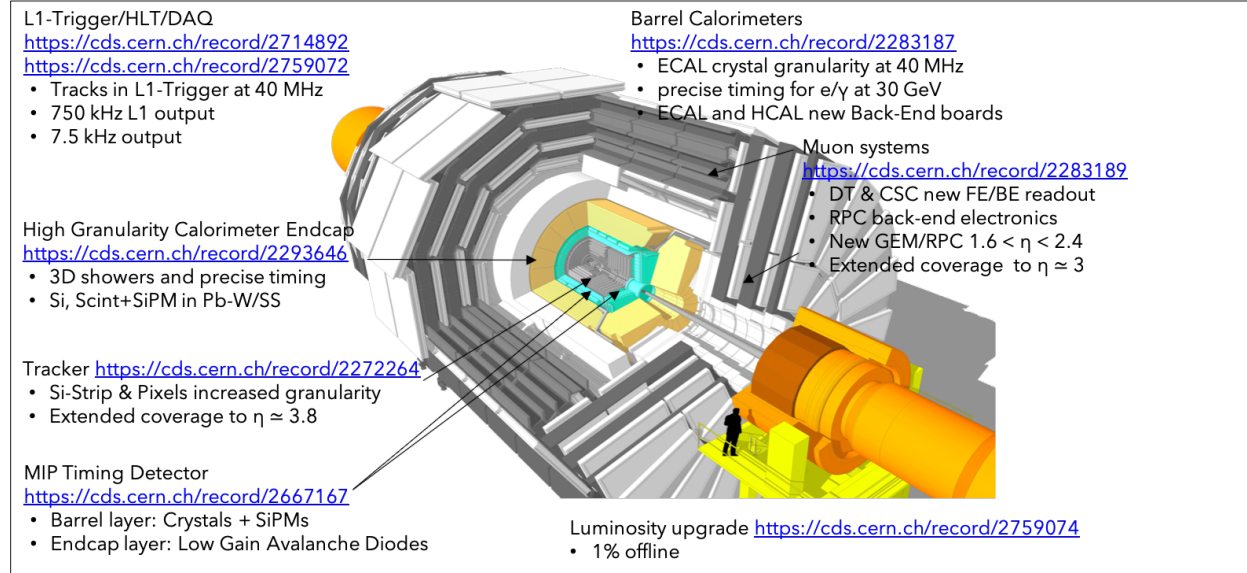
CMS-FTR-18-013 and CMS-BPH-25-001

HL-LHC plan



HL-LHC and CMS upgrade

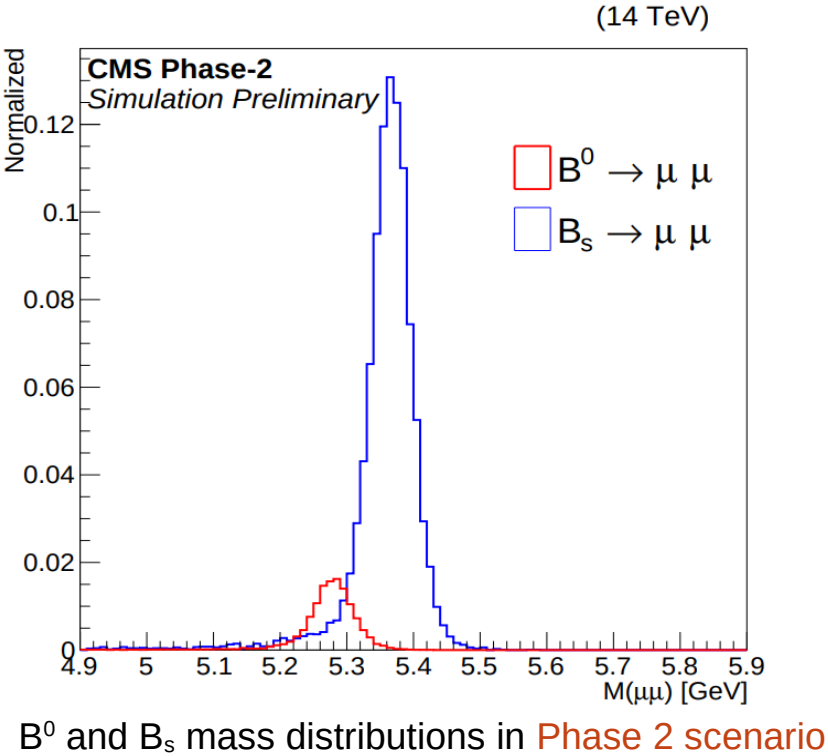
- HL-LHC will feature significantly more collisions both in terms of instantaneous ($5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$) and integrated luminosity (3000 fb^{-1})
- Improvements and/or replacement of several key systems: calorimeters, muon systems, tracker
- New MIP timing detector
- Muon will increase coverage to $|\eta| < 3$ and tracks to $|\eta| < 4$
- Enhanced timing and granularity will enable better purity in low momentum electrons and muons and will also allow for triggers on hadronic final states



Future measurements

CMS-FTR-18-013 and CMS-BPH-25-001

- We expect future triggers to be no worse than the existing ones
- Also assumed that benefits from detector upgrades will at the very least compensate for the increased pile up
- Still a lot of projects that can be done with Run3 data
 - CMS B-physics program was revitalized in the last ~7 years – only in the late Run2
 - Plethora of results and updates can be expected from Run3 studies
- Concrete calculations were performed only for a handful of results – we can expect the same order effects in majority of other results



	CMS 116-140 fb ⁻¹	CMS 3000 fb ⁻¹
$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)$ [10 ⁻⁹]	0.45	0.22
$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)$ [10 ⁻¹⁰]	< 1.5	0.12
$\tau_{\text{eff}}(B_s^0 \rightarrow \mu^+ \mu^-)$ [ps]	0.23	0.05
ϕ_s [mrad]	23	3

Current experimental uncertainties for several variables and expected sensitivity for them by the early 2040

Summary

- Despite not being a b-factory CMS is capable of producing cutting edge measurements in beauty and charm physics
 - This became possible with new trigger strategies and refined flavor tagging
- Can compete with dedicated experiments in wide range of possible topics
- Lifetime $B_s \rightarrow \mu\mu$ is currently the most precise measurement of this value to date
 - $\tau = 1.83^{+0.23}_{-0.20} \text{ (stat)}^{+0.04}_{-0.04} \text{ (syst) ps.}$
- Lifetime $B_s \rightarrow J/\psi K_S$ measurement is also the most precise measurement of this value
 - $\tau(B_s^0 \rightarrow J/\psi K_S^0) = 1.59 \pm 0.07 \text{ (stat)} \pm 0.03 \text{ (syst) ps.}$
- Run 3 takes full advantage of revised trigger strategies developed in 2018
 - Expect a wide range of exciting results from us!

Thank you

Backup slides

CP violation in $B_s^0 \rightarrow J/\psi \phi(1020)$

CMS-BPH-23-004

- Performs angular analysis to separate CP eigenstates and flavor analysis to resolve B_s mixing

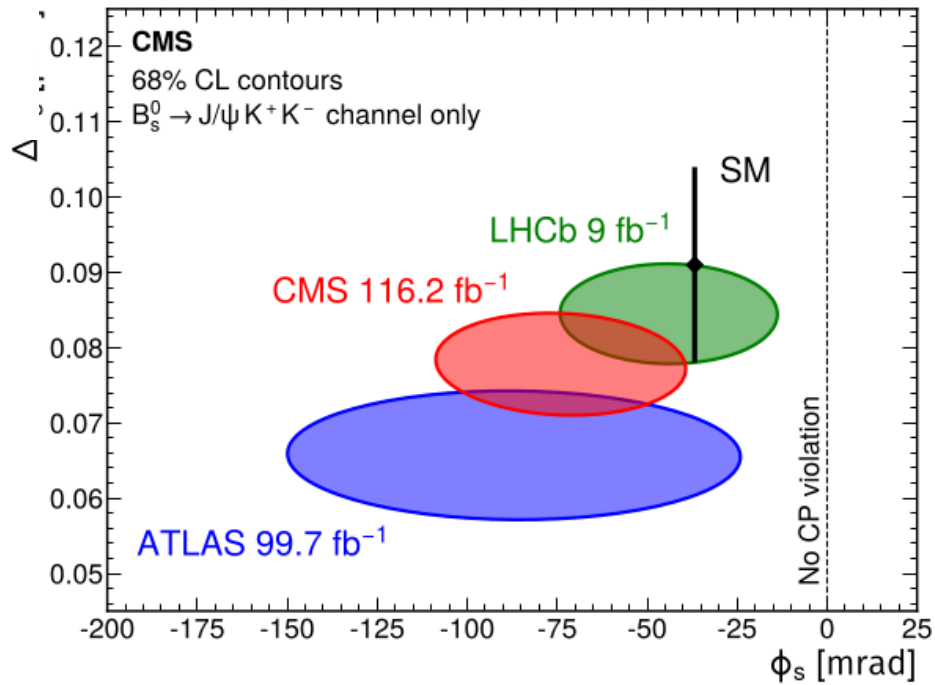
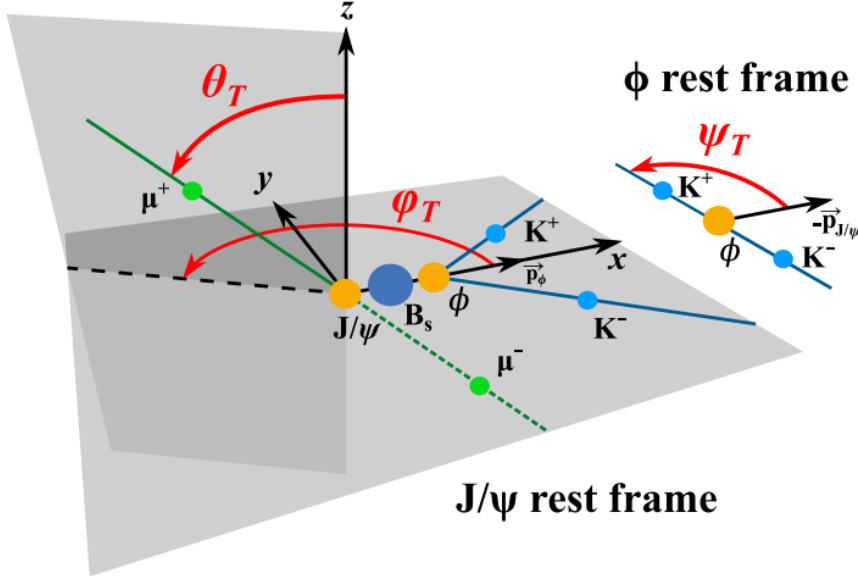
- Developed DNN based B_s tagger

- Tagging efficiency 55.9%
- Dilution power 10%
- Tagging power 5.6%

$$P_{\text{tag}} \equiv \epsilon_{\text{tag}} \mathcal{D}^2$$

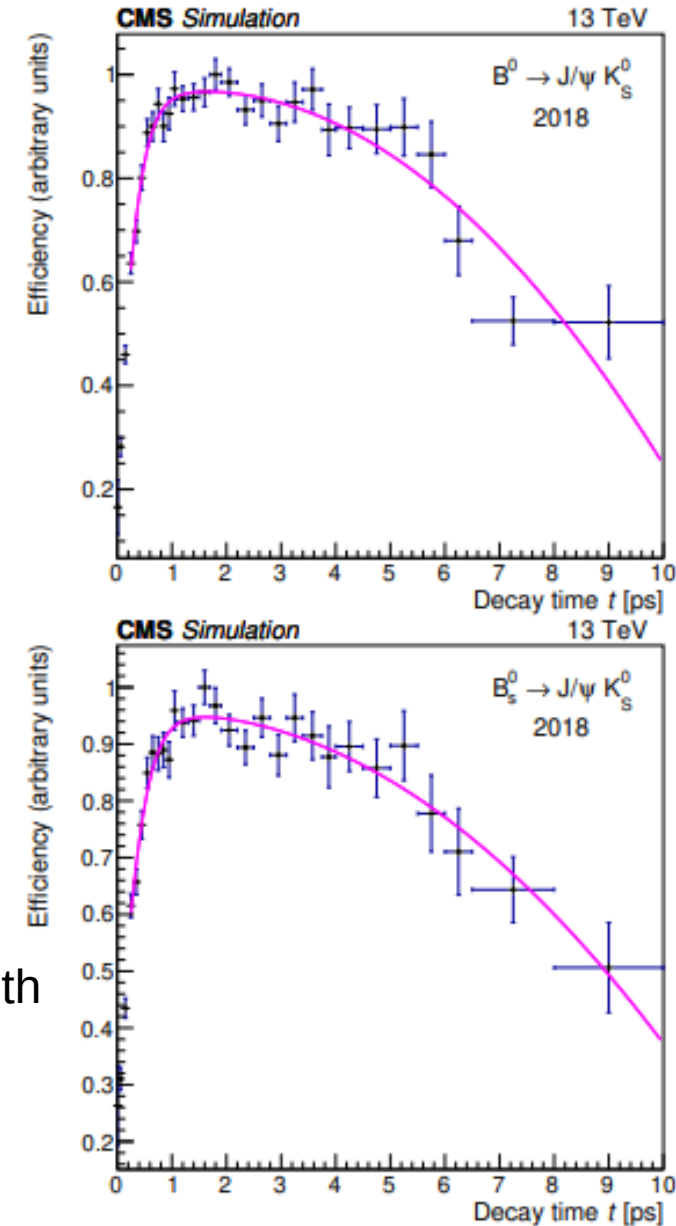
Parameter	Fit value	Stat. uncer.	Syst. uncer.
ϕ_s [mrad]	-73	± 23	± 7
$\Delta\Gamma_s$ [ps^{-1}]	0.0761	± 0.0043	± 0.0019
Γ_s [ps^{-1}]	0.6613	± 0.0015	± 0.0028
Δm_s [$\hbar\text{ps}^{-1}$]	17.757	± 0.035	± 0.017
$ \lambda $	1.011	± 0.014	± 0.012
$ A_0 ^2$	0.5300	± 0.0016	± 0.0044
$ A_{\perp} ^2$	0.2409	± 0.0021	± 0.0030
$ A_S ^2$	0.0067	± 0.0033	± 0.0009
$\delta_{\parallel}$	3.145	± 0.074	± 0.025
$\delta_{\perp}$	2.931	± 0.089	± 0.050
$\delta_{S\perp}$	0.48	± 0.15	± 0.05

- Largest ever effective statistics (27.5k events) for a single ϕ_s measurement
- Precision of ϕ_s is comparable to the world most precise measurement by LHCb
- First evidence of CPV in $B_s^0 \rightarrow J/\psi \phi(1020)$ decay (3.2 sigma)**



Event selection and efficiencies

- Trigger: $J/\psi \rightarrow \mu\mu$ candidate with dimuon $p_T > 20(25)$ GeV for 2016(2017/2018)
- Offline $K_S \rightarrow \pi^+\pi^-$ selection:
 - Displaced by $>15\sigma$ from the beamline and $>5\sigma$ from the B_s vertex
 - Invariant mass within 70 MeV from world-average value
- Background sources
 - $\Lambda \rightarrow p\pi^-$ suppressed with constraints on the decay kinematics
 - $B^0 \rightarrow J/\psi K_S$ – control channel, irreducible
 - $B^0 \rightarrow J/\psi K^{*0}$ -negligible, suppressed by displacement requirement
 - Combinatorial: suppressed with dedicated BDT selection using variables with minimal correlation to the proper decay time
- Time efficiency is measured in simulations for B_s and B^0
 - Modeled via
$$\varepsilon(t; p_0, p_1, p_2, p_3, p_4) = p_0 + p_1 t + p_2 t^2 + \frac{p_3}{1 + \exp(-p_4 t)}$$



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