Decay Properties: Overview & Prospects in CMS

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Most relevant Run1 measurements to be pursued in Run2:

- $BR(B_{s(d)} \to \mu\mu)$
- $B^0 \to K^*\mu\mu$ angular analysis
- Φ_s, $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$

For each measurement:

- Analysis
- Breakdown of experimental errors in Run1
- Perspectives for Run2

Run 2 Projections & Challenges

- Back of envelope Run2 projection at CMS:
  σ(Run2) = 2 σ(Run1)
  L(Run2) = 100/120 fb^{-1} = 5 L(Run1)
- Total sample (Run1 + Run2) = 11 x Run1
- Expect factor 3.3 improvement in statistical errors & systematic uncertainties scaling with statistics
  (...assuming the same analysis performance...)

But:

- Increased Pile-up: ~ 40 PU @ 13 TeV with L=1.4 10^{34} $cm^{-2}s^{-1}$
- Trigger: stay within the Run1 bandwidth (L1=10 kHz ~ 10% of the total Bandwidth, HLT= 100 Hz) despite the increase of a factor 4 in rate.
  - Trigger selection defined to reduce the rate without affecting too much the signal, path driven by specific analysis

$B \rightarrow \mu^+\mu^-$

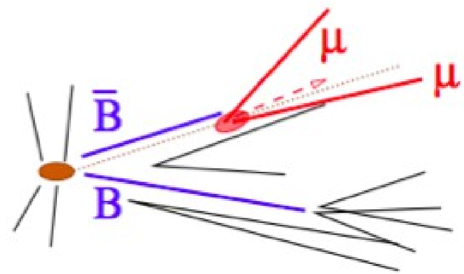
"Measurement of the $B^0_s \rightarrow \mu^+\mu^-$ branching fraction and Search for $B^0 \rightarrow \mu^+\mu^-$ with the CMS Experiment"

[L = 5 fb^{-1} ($\sqrt{S}$=7 TeV)+20 fb^{-1} ($\sqrt{S}$=8 TeV)]

Phys. Rev. Lett. 111, 101804 (2013)

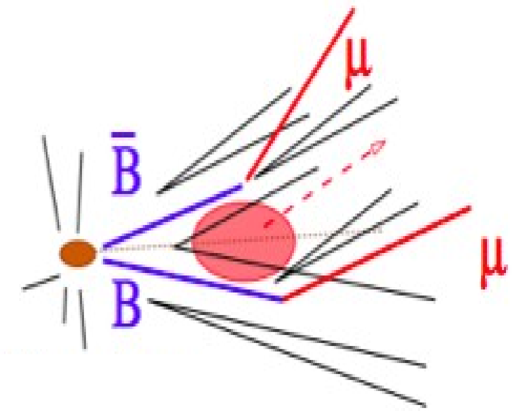
$B \to \mu^+\mu^-$

- Signal: two isolated muons from a secondary vertex



- BKG:
  - Combinatorial
  - Physical:
    - Uncorrelated B semileptonic decays
    - Peaking $B \to hh'$ (h=K, π) (BR~$10^{-7}/10^{-5}$)
    - Non Peaking $B \to h\mu\nu$, $B \to h\mu\mu$, $\Lambda_b \to p\mu\nu$ evaluated normalized to $B^+ \to J/\psi K^+$

Hardware Trigger:
$P_T(\mu)$>3 GeV (few kHz)
High Level Trigger 2011 (2012):
Central region (|η|<1.8): $P_T(\mu)$>4 (3) GeV, $P_T(\mu\mu)$>3.9 (4.9) GeV, 4.8<M(μμ)<6 GeV
Forward region (1.8<|η|<2.2):
$P_T(\mu)$>4 GeV, $P_T(\mu\mu)$>7, Prob(VTX)>0.5%



- Strategy:
  - BDT-based muon (Mis)identification studied on MC/data control samples ($B_s \to KK$, $B^0 \to \pi\pi$, $K^0 \to \pi\pi$, $\Lambda \to p\pi$, $D^* \to D^0\pi$)

$B \to \mu^+\mu^-$

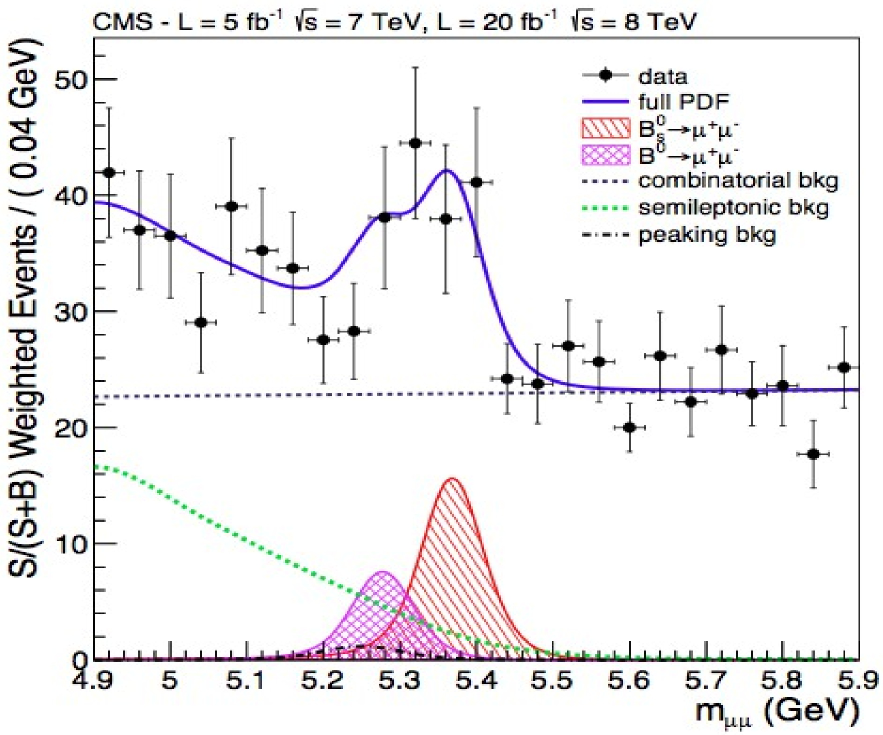
- Strategy:
  - Events selected by means of a MVA exploiting kinematic, vertexing and isolation variables
  - Measure event yields from an unbinned fit to M(μμ)
  - BR obtained relative to the normalization channel $B^+ \to K^+ J/\psi$ to avoid systematics from cross section & luminosity, and reduce efficiency uncertainty:

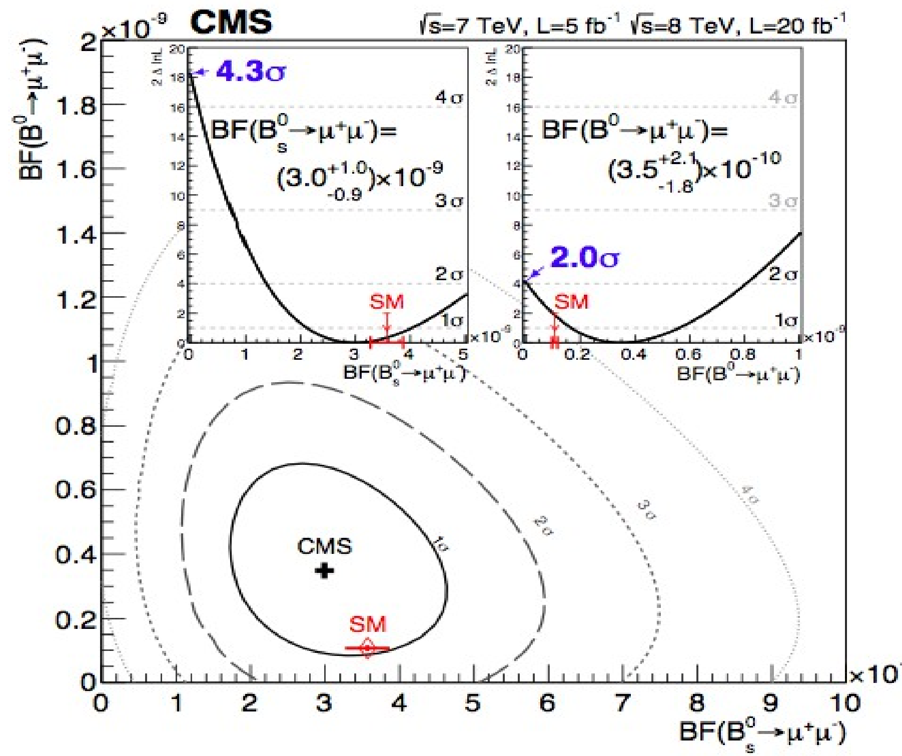
$$B(B_s^0 \to \mu^+\mu^-) = \frac{Y_S}{Y_N}\frac{\epsilon_N}{\epsilon_S}\frac{f_U}{f_S} B(B^+ \to K^+ J/\psi \to K^+\mu^+\mu^-)$$

Y_S, Y_N	Signal and Normalization Yields	$B(B^+) = (6.0 \pm 0.2) 10^{-5}$
ϵ_S, ϵ_N	Signal and Normalization Efficiencies	
$\frac{f_S}{f_U} = 0.256 \pm 0.020$	Ratio between B^+ and B^0_s fragmentation functions [LHCb, JHEP 04 (2013) 001]	

  - Data/MC agreement checked on $B_s \to J/\psi\, \varphi$ control sample

$B \to \mu^+\mu^-$: Results





- Results:

$BR(B_s \to \mu^+\mu^-) = (3.0^{+0.9}_{-0.8}\ (stat)^{+0.6}_{-0.4}\ (syst)\ 10^{-9})$ (4.3 σ significance)

$BR(B^0 \to \mu^+\mu^-) < 1.1 \times 10^{-9}$ @ 95% CL

Combination of BR(B → μμ) from the CMS and LHCb

- CMS Improvements wrt PRL:
  - Input $\tau(B_s)$, f_u/f_s & some BRs from PDG
  - Modeling of the $\Lambda_b \to p\mu\nu$ Background [JHEP 09, 106; PLB 734, 122-130]

$$BR(B_s) = (2.8^{+1.1}_{-0.9}) \times 10^{-9}$$
$$BR(B_d) = (4.4^{+2.2}_{-1.9}) \times 10^{-10}$$

[Nature, 522 (2015) 69]

- Full Likelihood combination of CMS & LHCb results
  - Simultaneous unbinned extended maximum likelihood fit to the mass spectra
  - Take into account correlations/estimate significance

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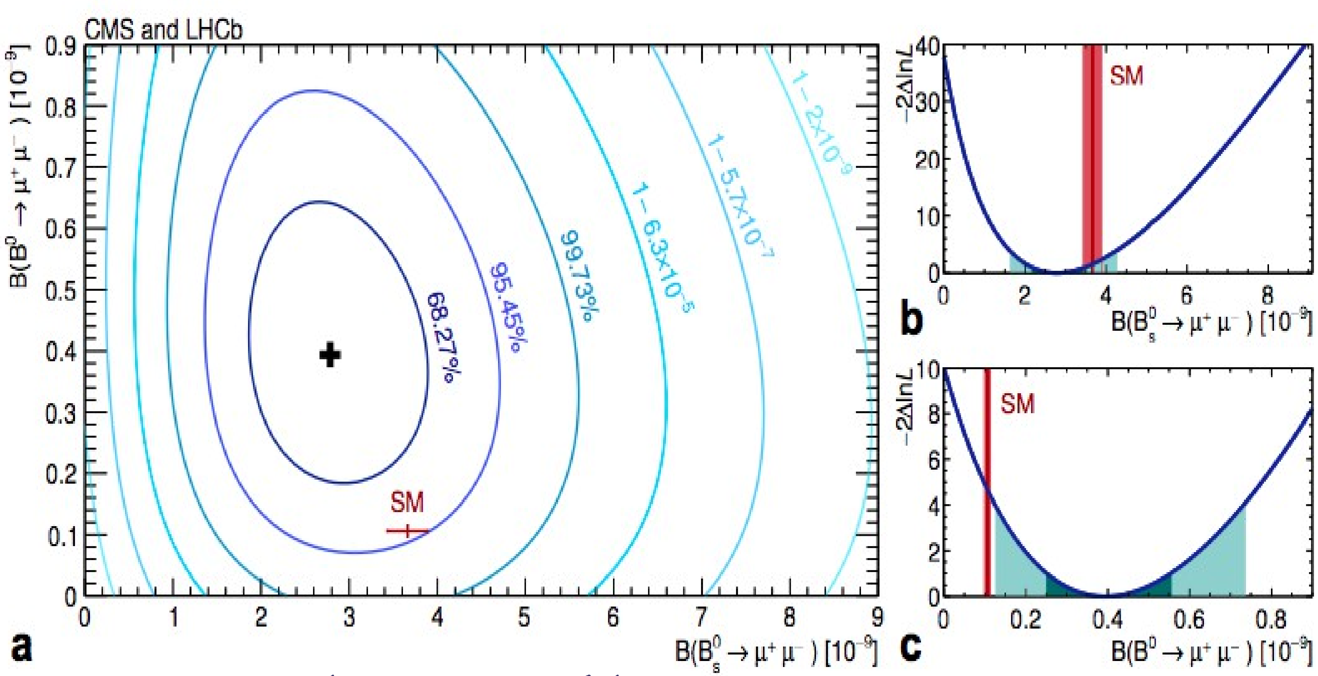

Systematic errors contribute 35% (18%) of the total for B_s (B_d)

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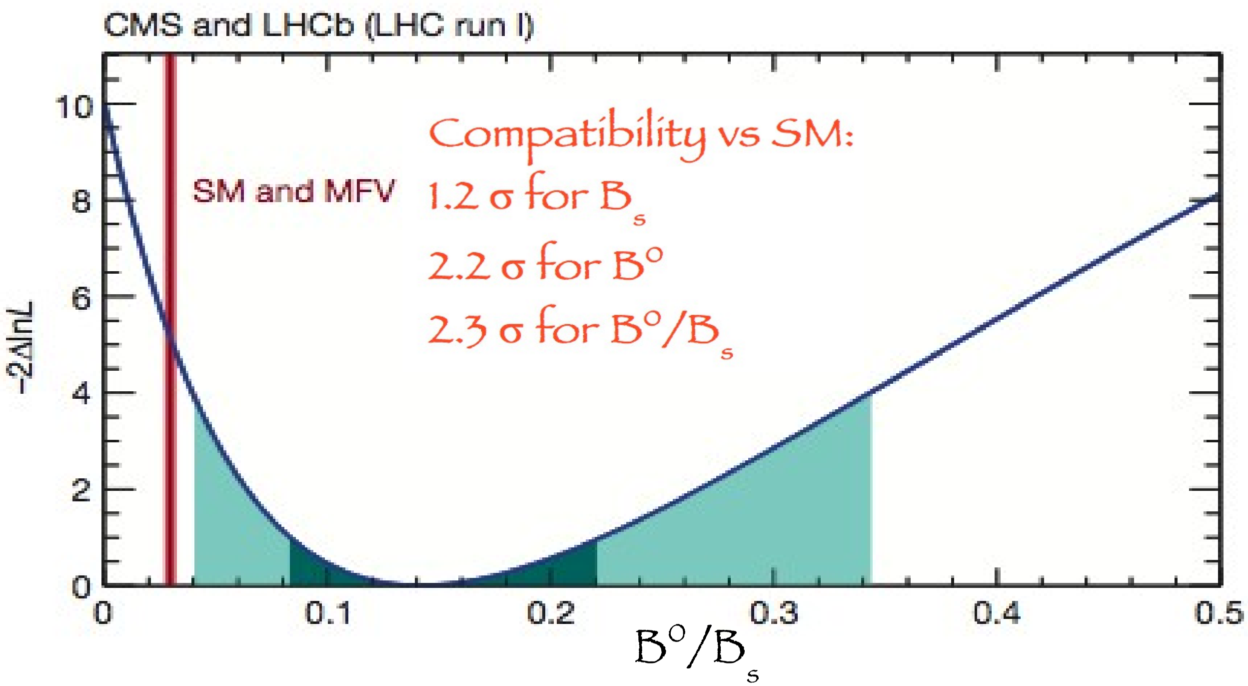

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Breakdown of experimental errors (CMS analysis)

- Measurement dominated by statistical error: wait for new data!
- Main systematics:

  $f_s/f_u = 0.259 \pm 0.015$ [LHCb-CONF-2013-011]

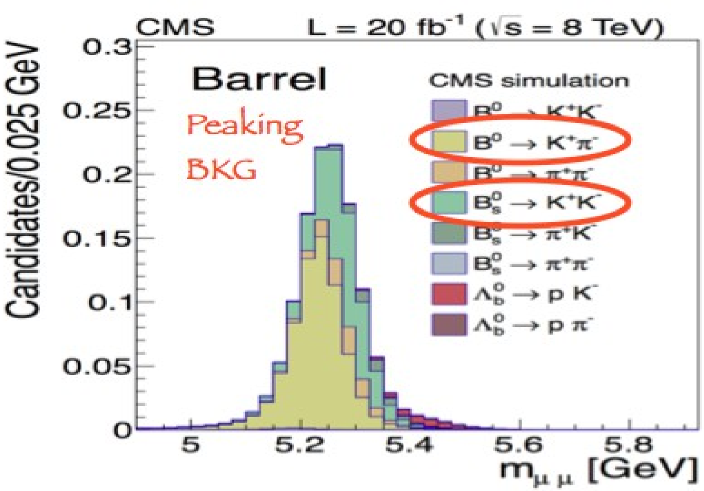
  Muon misidentification w=0.15%/0.22%

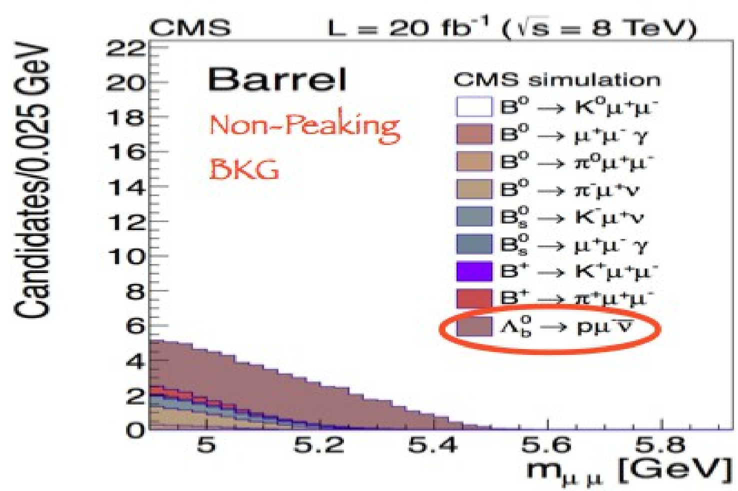
  SL and rare decays: $\delta BR(\Lambda_b \to p\mu\nu)$~40% [PLB 734, 122-130])

  Normalization of SL and peaking BKG to $B^+ \to J/\psi K^+$ (largest syst err.)

$$N(Y\to X) = \frac{B(Y\to X)}{B(B^+\to K^+ J/\psi)} \frac{\epsilon(X)}{\epsilon(B^+)} \frac{f_Y}{f_U} N(B^+\to K^+ J/\psi)$$

Reducible adding more data





Analysis Improvements & Challenges for Run2

- Trigger (rare decays ~12% of BPH rate):
  Use low P_T unprescaled double-muon L1 seed (including muon charge, $|\Delta\eta|$ information), HLT cut on muons P_T>4(3) GeV, use displaced J/ψ for the normalization channel
- Muon identification:
  Further suppress misidentification to reduce peaking & SL BKG
  Study in-flight decays for control samples
- Selection
  Study increased pile-up (spatial separation between PVs and track multiplicity)
  Selection of peaking and rare semileptonic B decays for control samples
- Improve Fit method :
  Move from a categorized 1D fit to $m_{\mu\mu}$ to a 2D (MVA, $m_{\mu\mu}$) one.
  Include nuisance parameters (fake rate, peaking BKG).

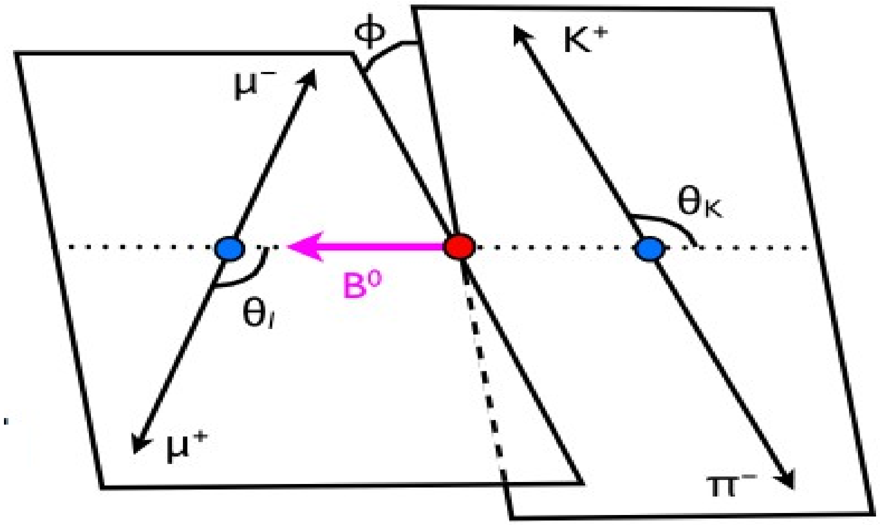
$B^0 \to K^{*0}\mu^+\mu^-$

"Angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$ from pp collisions at $\sqrt{S}$=8 TeV"

[L = 20.5 fb^{-1}]

Submitted to Phys. Lett. B

$B \to K^* \mu^+ \mu^-$



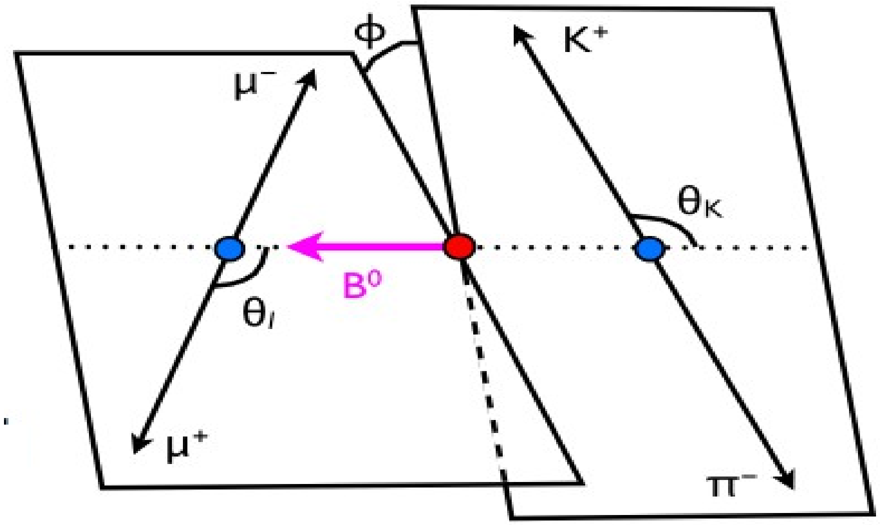
- Kinematics of the decay $B \to V \mu^+ \mu^-$ ($V = K^*$, φ, ρ) determined by three angles:
  - θ_l, θ_K, ϕ
- Event Yields reconstructed in bins of $q^2 = m^2(\mu^+\mu^-)$

- Differential Amplitude:

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_K\, d\cos\theta_l\, dq^2} = \frac{9}{16}\left\{\left[\frac{2}{3}F_S + \frac{4}{3}A_S\cos\theta_K\right](1-\cos^2\theta_l) + (1-F_S)\left[2F_L\cos^2\theta_K(1-\cos^2\theta_l) + \frac{1}{2}(1-F_L)(1-\cos^2\theta_K)(1+\cos^2\theta_l) + \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_l\right]\right\}.$$

- Observables Include:
  - Differential Branching Ratio dB/dq^2
  - A_{FB} (forward-backward muon asymmetry)
  - F_L (fraction of longitudinally polarized K^*)

$B \to K^* \mu^+ \mu^-$



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- F_S: Fraction of spinless $K\pi$ (S-wave) combination
- A_S: Interference amplitude between S-wave and P-wave decays

$B \to K^* \mu^+ \mu^-$

- Strategy:
  - Measure event yields, A_{FB}, F_L, F_S and A_S from an unbinned simultaneous fit to $M(K\pi\mu\mu)$, $\cos(\theta_K)$ and $\cos(\theta_l)$ in bins of q^2
  - dB/dq^2 obtained relative to the normalization channel $B^0 \to K^* J/\psi$:

$$\frac{d\mathcal{B}\left(B^0 \to K^{*0}\mu^+\mu^-\right)}{dq^2} = \left(\frac{Y_S^C}{\epsilon^C} + \frac{Y_S^C f^M}{(1-f^M)\epsilon^M}\right)\left(\frac{Y_N^C}{\epsilon_N^C} + \frac{Y_N^C f_N^M}{(1-f_N^M)\epsilon_N^M}\right)^{-1} \frac{\mathcal{B}\left(B^0 \to K^{*0}J/\psi\right)}{\Delta q^2}$$

S=signal
N=normalization

- Trigger: two OS muons (P_T>3.5 GeV, $|\eta|$<2.2, d_{xy}<2cm from beam axis) forming a displaced vertex. Dimuon: P_T>6.9 GeV, Prob(vtx)>10%, L_{xy}/σ_{Lxy}>3, $\cos(\alpha)$>0.9 [α=angle(P, flight direction)]

$B \to K^* \mu^+ \mu^-$

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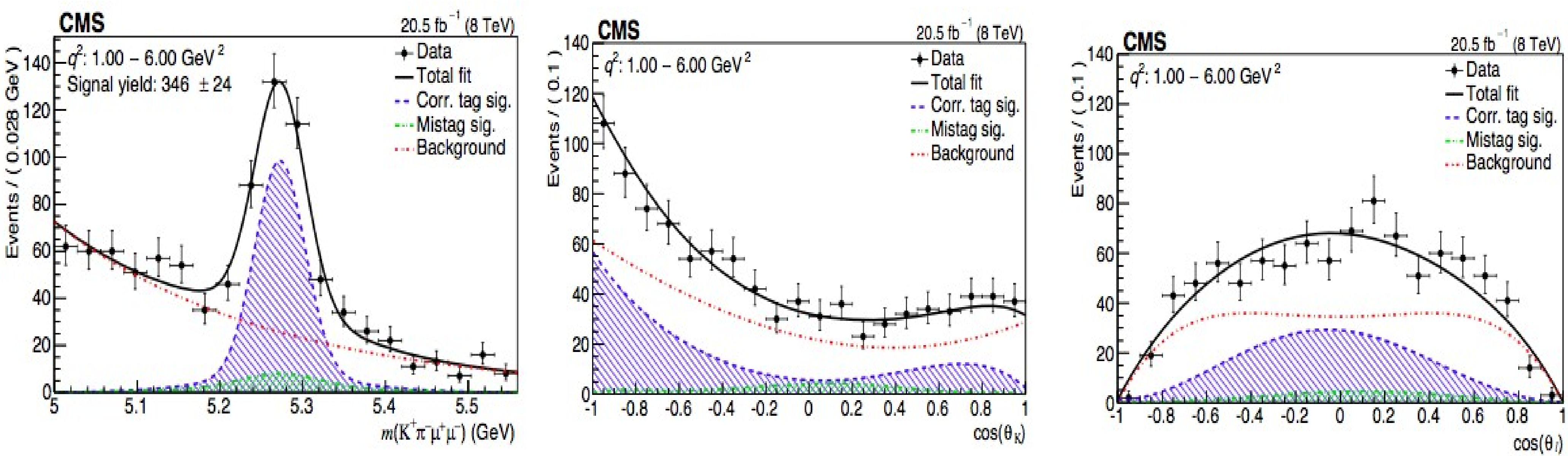
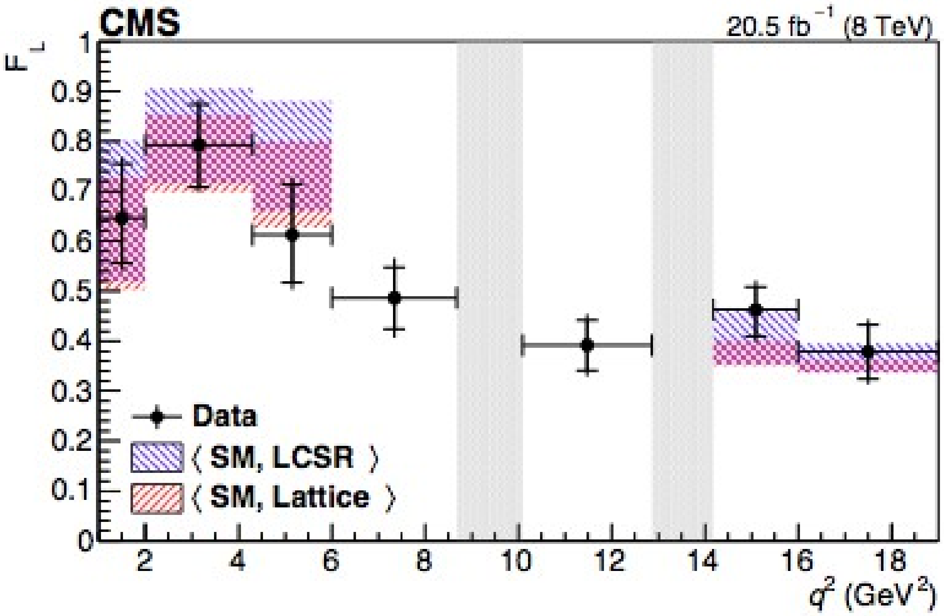
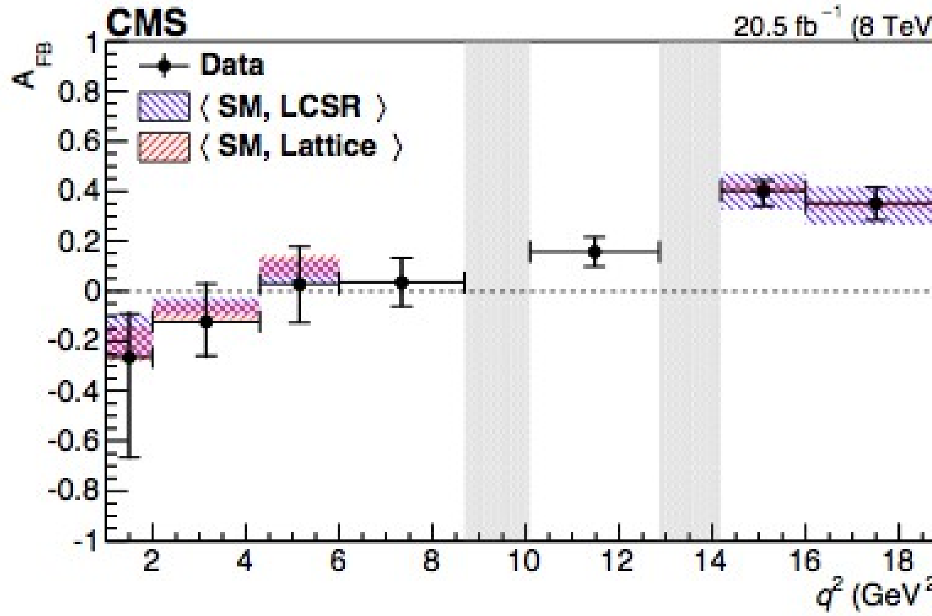
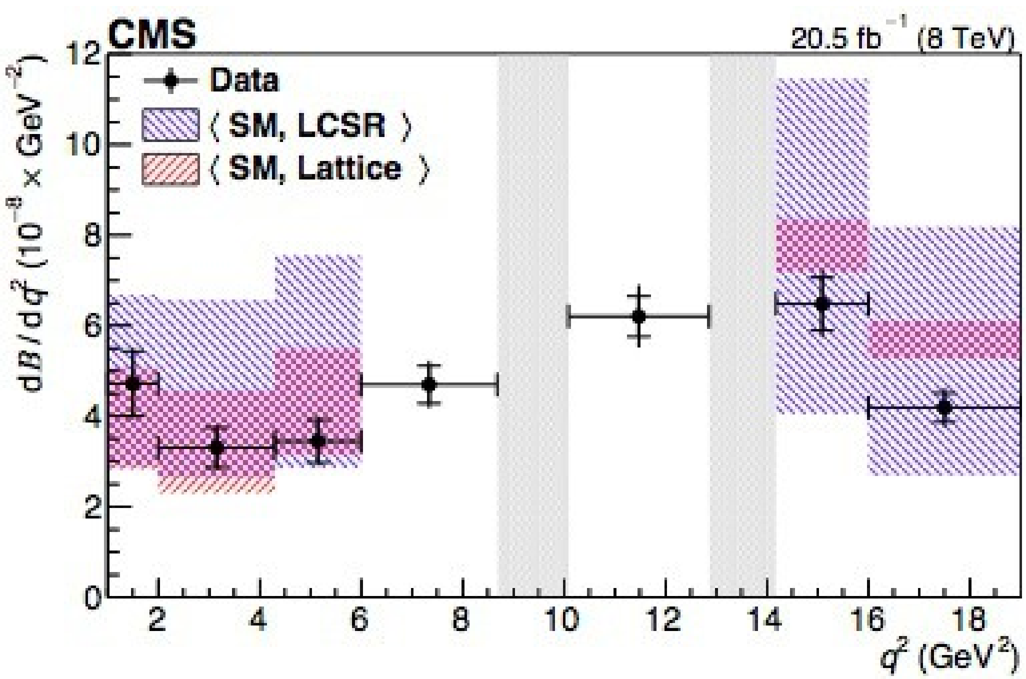


$B \to K^* \mu^+ \mu^-$ Results







Results consistent with SM

- CMS Experimental errors comparable with theoretical for F_L and A_{FB}, smaller for dB/dq^2

Measurement dominated by statistical error

Breakdown of experimental errors

- Error range between the different q^2 bins

Systematic uncertainty	$F_L (10^{-3})$	$A_{FB} (10^{-3})$	$d\mathcal{B}/dq^2$ (%)
Simulation mismodeling	1–17	0–37	1.0–5.5
Fit bias	0–34	2–42	—
MC statistical uncertainty	3–10	5–18	0.5–2.0
Efficiency	34	5	—
$K\pi$ mistagging	1–4	0–7	0.1–4.1
Background distribution	1–9	0–6	0.0–1.2
Mass distribution	3	1	3.2
Feed-through background	0–27	0–5	0.0–4.0
Angular resolution	6–24	0–5	0.2–2.1
Normalization to $B^0 \to K^{*0} J/\psi$	—	—	4.6
Total systematic uncertainty	36–54	10–68	6.4–8.6

- → : Systematics reducible with statistics increasing
- Main systematics:
- Closure test on simulation: MC **statistics**, Toy MC, fit on MC subsamples
- Efficiency computed on MC: error includes **statistics** and different functions choice. Efficiency dependence on angles and q^2 from the comparison of the fitted parameters on $B^0 \to K^* J/\psi$, $B^0 \to K^* \psi'$ with the PDG

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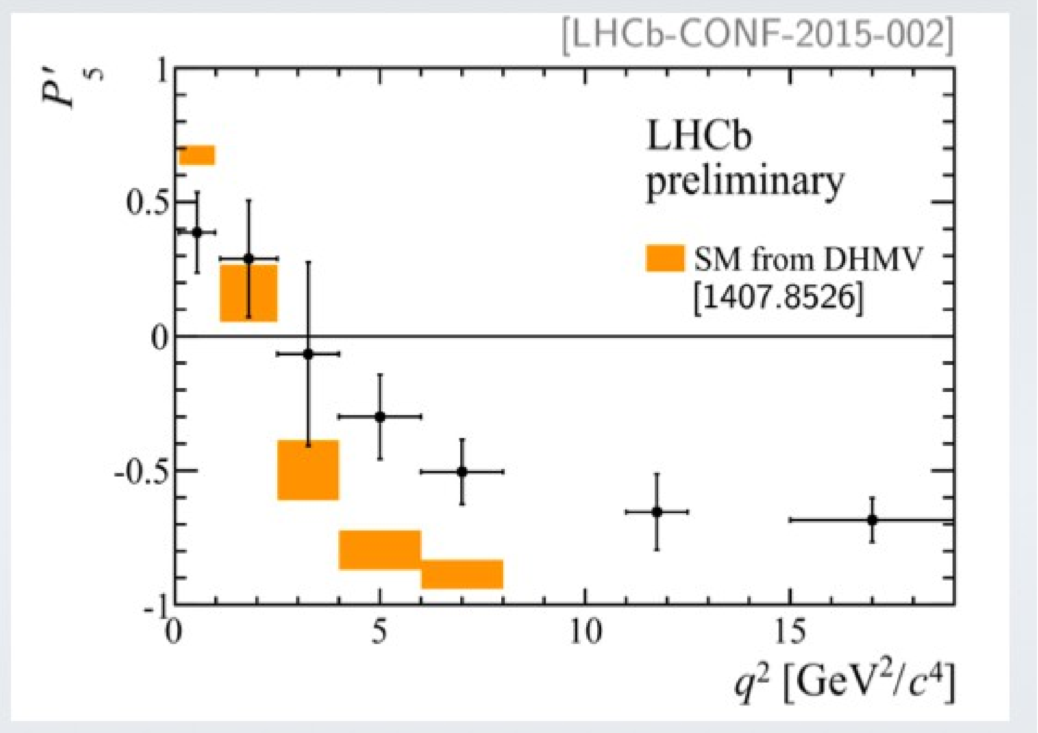
- → : Systematics reducible with statistics increasing
- Double-Gaussian mass distributions (different for correctly tagged and mistagged evts) fitted to data with widths constrained to MC, checked on control samples
- Feed-through error from fit in bins neighbour to the excluded resonances. Can be reduced by enlarging the vetoed resonances mass region
- Angular resolution effect from fit using generated vs reconstructed quantities

Analysis Improvements & Challenges for Run2

- Already ongoing on Run1 dataset:
    - Study of the P'_5 parameterization as LHCb
    - Analysis of other channels: $B^+ \rightarrow K^{*+} \mu\mu$, $K^+ \mu\mu$, ($\Lambda_b \rightarrow \Lambda\mu\mu$)



- Future: include additional physics observables: Isospin & CP Asymmetries

$$A_I = \frac{\Gamma(B^0 \rightarrow K^{(*)0}\mu^+\mu^-) - \Gamma(B^+ \rightarrow K^{(*)+}\mu^+\mu^-)}{\Gamma(B^0 \rightarrow K^{(*)0}\mu^+\mu^-) + \Gamma(B^+ \rightarrow K^{(*)+}\mu^+\mu^-)}$$

$$\mathcal{A}_{CP} = \frac{\Gamma(\overline{B}^0 \rightarrow \overline{K}^{*0}\mu^+\mu^-) - \Gamma(B^0 \rightarrow K^{*0}\mu^+\mu^-)}{\Gamma(\overline{B}^0 \rightarrow \overline{K}^{*0}\mu^+\mu^-) + \Gamma(B^0 \rightarrow K^{*0}\mu^+\mu^-)}$$

Analysis Improvements & Challenges for Run2

- Trigger: low P_T muons are mandatory!
  Rate reduced by a harder cut on each muon $P_T>4$ GeV (current analysis uses $P_T>3.5$ GeV) & including an additional displaced hadron track (cut on P_T and IP/σ), plus dimuon cuts on Prob(VTX), L_{xy}/σ_{Lxy}, cos(α)
  - Considering only the variation in the muon P_T cut from 3.5 GeV to 4 GeV, & assuming L=100 fb^{-1} @ 13 TeV:
    ~10500 evts (to be compared with the ~1400 evts of the current statistics): enough for a full angular analysis with a statistical error reduction ~ 3

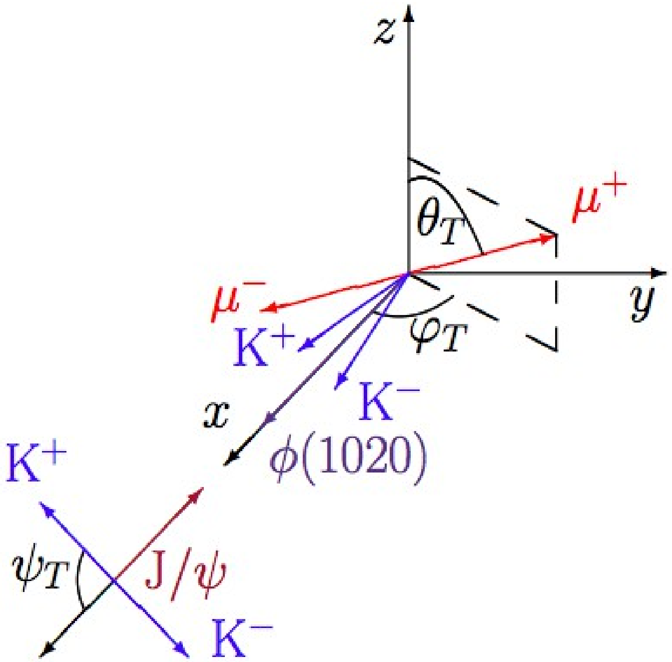
$B_s \rightarrow J/\Psi\phi$

"Measurement of the CP-violating weak phase Φ_s and the decay width difference $\Delta\Gamma_s$ using the $B_s \rightarrow J/\Psi\phi$ decay channel in pp collision at $\sqrt{S}=8$ TeV"

[L = 19.7 fb^{-1}]

Submitted to Phys. Lett. B

$B_s \to J/\Psi\varphi$



- Kinematics of the decay determined by three angles:
  - θ_T, φ_T, ψ_T in the transversity basis
- Differential decay rate

$$\frac{d^4\Gamma(B_s^0)}{d\Theta\, d(ct)} = f(\Theta,\alpha,ct) \propto \sum_{i=1}^{10} O_i(\alpha,ct)\, g_i(\Theta).$$

- Time dependent angular analysis needed to disentangle CP-odd and CP-event eigenstates

$$O_i(\alpha,ct) = N_i e^{-ct/c\tau}\left[a_i \cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + b_i \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + c_i \cos(\Delta m_s t) + d_i \sin(\Delta m_s t)\right]$$

α=Physics parameters: ΔΓ, Φ, ct, decay amplitudes and phases

- b_i and d_i depend on Φ_s

$B_s \to J/\Psi\varphi$

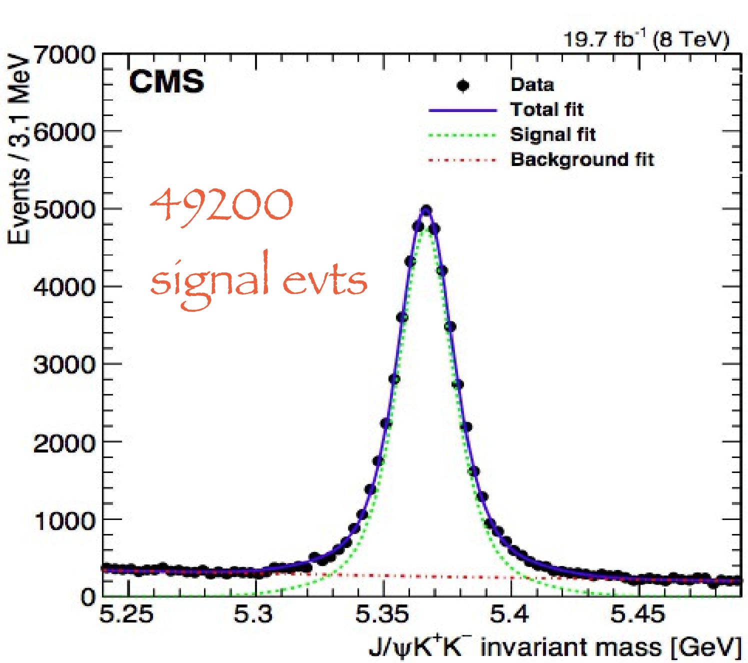
- Strategy:
  - Exclusive reconstruction of events
  - Opposide-Side lepton flavor tagging of the B_s
  - Multidimensional fit on $m(B_s)$, θ_T, φ_T, ψ_T, ct, δct
  - Trigger: two OS muons (P_T>4 GeV, $|\eta|$<2.1) forming a displaced vertex.
    Dimuon: P_T>6.9 GeV, $DOCA_{\mu\mu}$(3D)<5cm, Prob(vtx)>10%, L_{xy}/σ_{Lxy}>3, $\cos(\alpha)$>0.9, 2.9<$m(\mu\mu)$<3.3 GeV

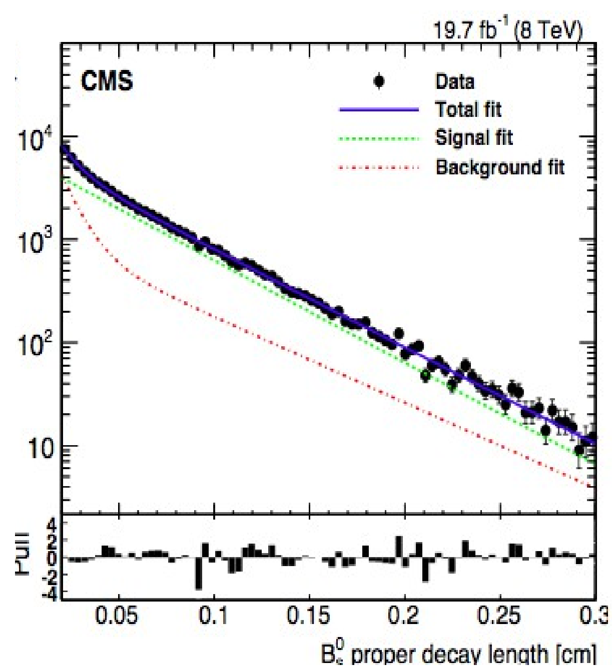
ω=30.17± 0.24 ±0.05%

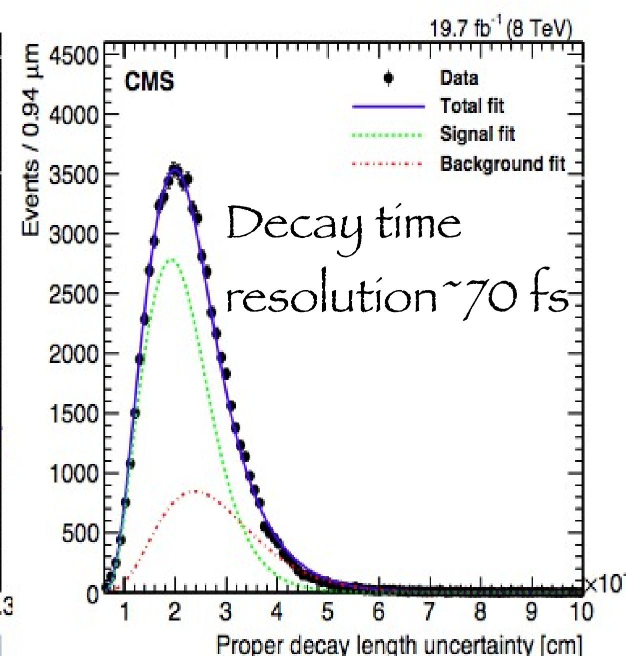
ε=8.31± 0.03%

$P=\varepsilon(1-2\omega)^2$

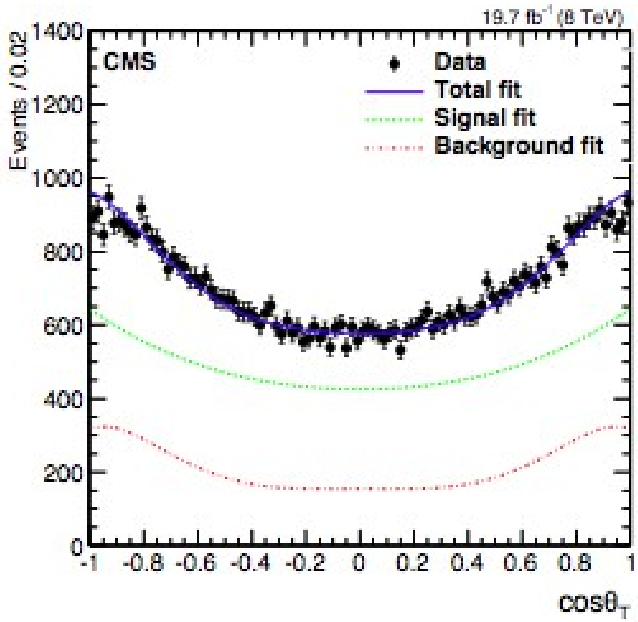
P=1.307 ± 0.031 ±0.007%

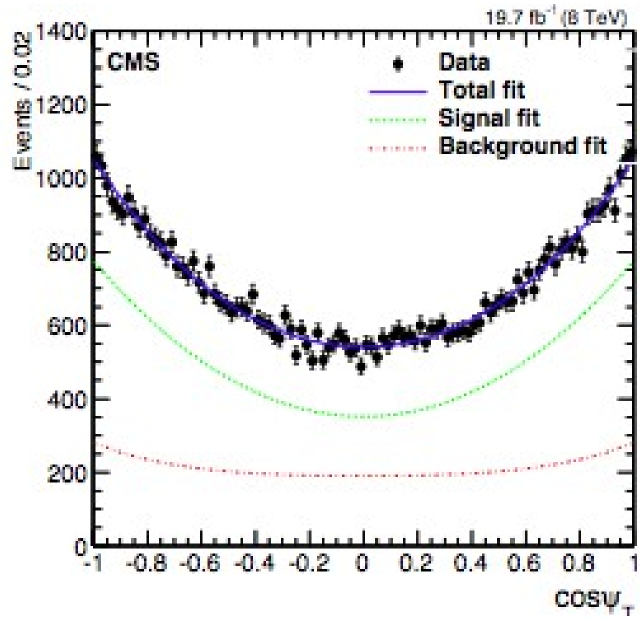


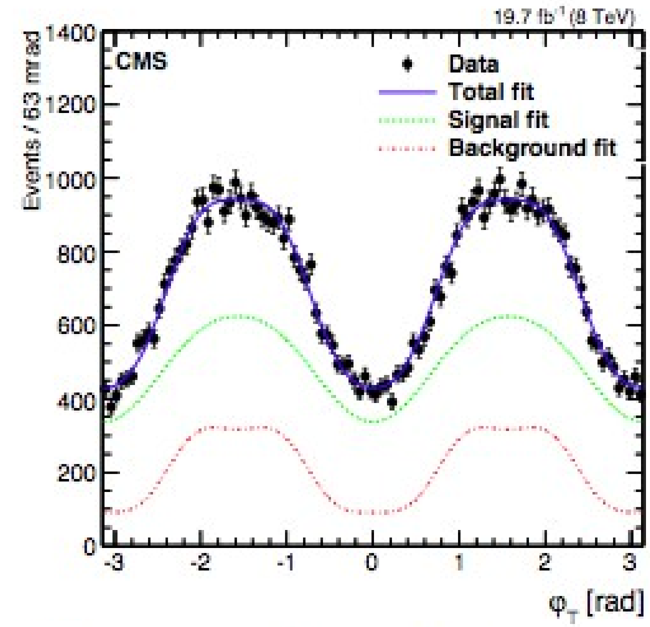


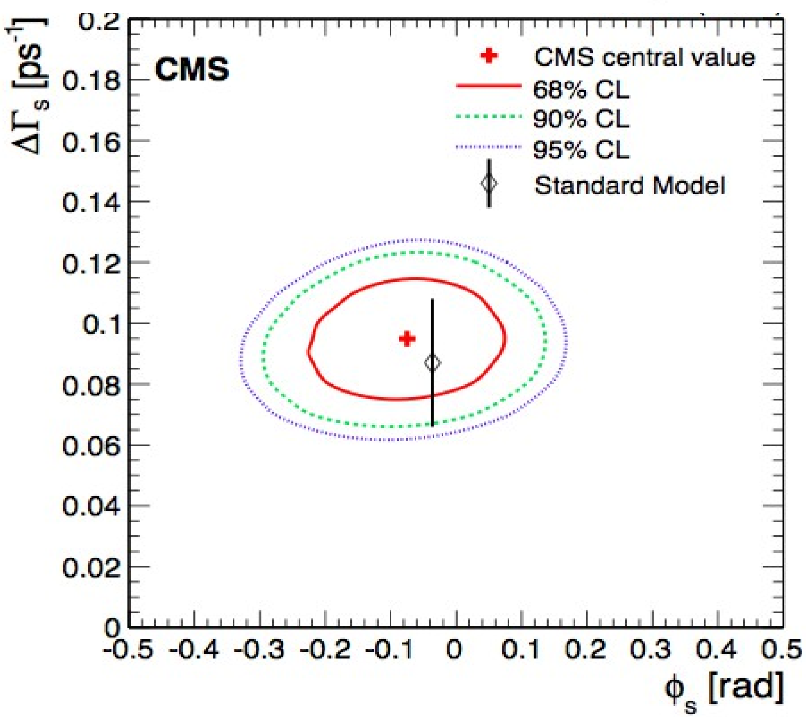


$B_s \to J/\Psi\phi$ Results









Statistical error only

Parameter	Fit result
ϕ_s [rad]	-0.075 ± 0.097
$\Delta\Gamma_s$ [ps^{-1}]	0.095 ± 0.013
$\lvert A_0\rvert^2$	0.510 ± 0.005
$\lvert A_S\rvert^2$	$0.012^{+0.009}_{-0.007}$
$\lvert A_\perp\rvert^2$	0.243 ± 0.008
$\delta_\parallel$ [rad]	$3.48^{+0.07}_{-0.09}$
$\delta_{S\perp}$ [rad]	$0.37^{+0.28}_{-0.12}$
$\delta_\perp$ [rad]	2.98 ± 0.36
$c\tau$ [μm]	447.2 ± 2.9

Breakdown of experimental errors

Source of uncertainty	ϕ_s [rad]	$\Delta\Gamma_s$ [ps^{-1}]	$\|A_0\|^2$	$\|A_S\|^2$	$\|A_\perp\|^2$	$\delta_\parallel$ [rad]	$\delta_{S\perp}$ [rad]	$\delta_\perp$ [rad]	$c\tau$ [μm]
ct efficiency	0.002	0.0057	0.0015	—	0.0023	—	—	—	1.0
Angular efficiency	0.016	0.0021	0.0060	0.008	0.0104	0.674	0.14	0.66	0.8
Kaon p_T weighting	0.014	0.0015	0.0094	0.020	0.0041	0.085	0.11	0.02	1.1
ct resolution	0.006	0.0021	0.0009	—	0.0008	0.004	—	0.02	2.9
Flavour tagging	0.003	0.0003	—	—	—	0.006	0.02	—	—
Model bias	0.015	0.0012	0.0008	—	—	0.025	0.03	—	0.4
Mistag distribution modelling	0.004	0.0003	0.0006	—	—	0.008	0.01	—	0.1
pdf modelling assumptions	0.006	0.0021	0.0016	0.002	0.0021	0.010	0.03	0.04	0.2
$\|\lambda\|$ as a free parameter	0.015	0.0003	0.0001	0.005	0.0001	0.002	0.01	0.03	—
Total systematic uncertainty	0.031	0.0070	0.0114	0.022	0.0116	0.680	0.18	0.66	3.4
Statistical uncertainty	0.097	0.0134	0.0053	0.008	0.0075	0.081	0.17	0.36	2.9

- Measurement dominated by statistical error: wait for new data!
- → : Systematics reducible with statistics increasing
- Main systematics:
  - ct efficiency: flat or taking into account turn-on due to significance requirement
  - Angular efficiency: variation of the corresponding parameters according to statistical error

Breakdown of experimental errors

Source of uncertainty	ϕ_s [rad]	$\Delta\Gamma_s$ [ps^{-1}]	$\lvert A_0\rvert^2$	$\lvert A_S\rvert^2$	$\lvert A_\perp\rvert^2$	$\delta_\parallel$ [rad]	$\delta_{S\perp}$ [rad]	$\delta_\perp$ [rad]	$c\tau$ [μm]
ct efficiency	0.002	0.0057	0.0015	—	0.0023	—	—	—	1.0
Angular efficiency →	0.016	0.0021	0.0060	0.008	0.0104	0.674	0.14	0.66	0.8
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Flavour tagging	0.003	0.0003	—	—	—	0.006	0.02	—	—
Model bias	0.015	0.0012	0.0008	—	—	0.025	0.03	—	0.4
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$\lvert\lambda\rvert$ as a free parameter	0.015	0.0003	0.0001	0.005	0.0001	0.002	0.01	0.03	—
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Statistical uncertainty	0.097	0.0134	0.0053	0.008	0.0075	0.081	0.17	0.36	2.9

- → : Systematics reducible with statistics increasing
- Kaon P_T weighting: different MC vs Data K spectrum
- ct resolution: scale factor k(ct) of the Gaussian resolution function obtained from MC and calibrated using simulated and real prompt J/ψ
- Possible model bias checked with Toy MC

Analysis Improvements & Challenges for Run2

- Trigger:
  - Need to maximize the Φ_s significance. Require two muons with P_T>4 GeV with an additional displaced track (as for K*μμ).

- Improve fit method: mass fit with per-event error, fit of the CPV parameter $\lambda = (q/p)\left|\frac{A}{\bar{A}}\right|$

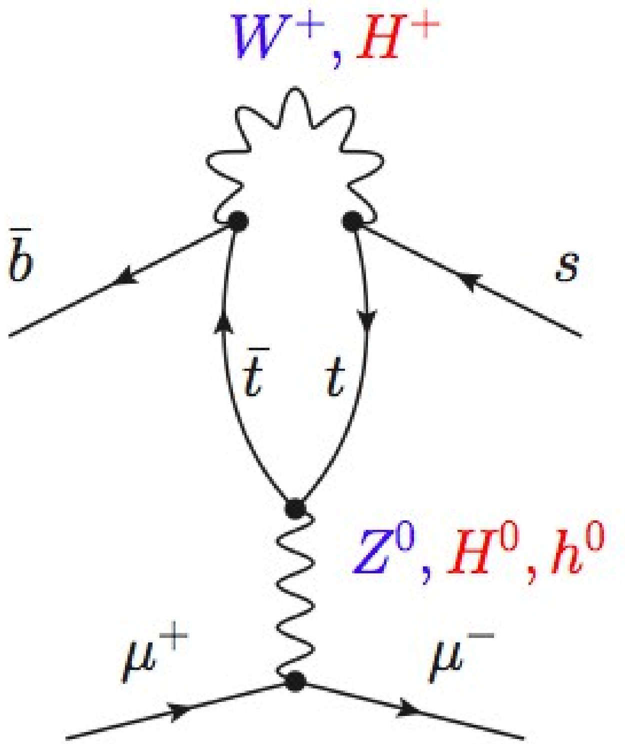
- Flavor tagging: include more variables, and use same-side informations

Conclusions

- CMS will pursue several competitive analyses on B decays Properties using Run2 dataset
- Main topics:
  - Rare decays: $B \to \mu\mu$, $\tau \to 3\mu$
  - CP-Violation: $B_s \to J/\Psi\phi$, $B_s \to J/\Psi\pi\pi$, $B_s \to J/\Psi f_0$, $B^0 \to J/\Psi Ks$
  - B-hadrons lifetimes (B^0, B^+, B_s, B_c, Λ_b, Ξ_b,..)
  - $B \to X_s\mu\mu$ (X_s=K^{*0}, K^{*+}, K^+): new parameterizations, include other observables (A_I, A_{CP})
  - B mixing and A_{SL}
- Expected factor ~ 10 in statistics increasing
- Increased rate and pile-up require improvements of trigger strategy (path analysis-driven) and development of smart techniques

Backup

$B \to \mu^+\mu^-$



- Golden mode to test New Physics with scalar/pseudo-scalar interactions
- Suppression of B_d over B_s ~$|V_{td}|/|V_{ts}|$ in SM:

  $BR(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2)\ 10^{-9}$

  $BR(B_d \to \mu^+\mu^-) = (0.11 \pm 0.01)\ 10^{-9}$

  [Buras et al. Eur. Phys. J C72, 2172 (2012)]

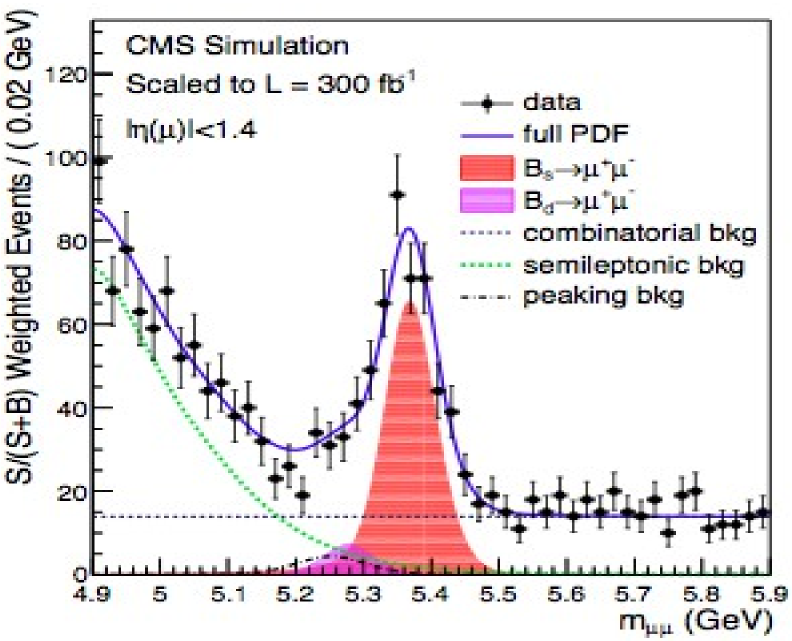
  [Uncertainties from f_{Bs} (lattice), $V_{tb}V_{ts}$, m_t, τ_{Bs}]

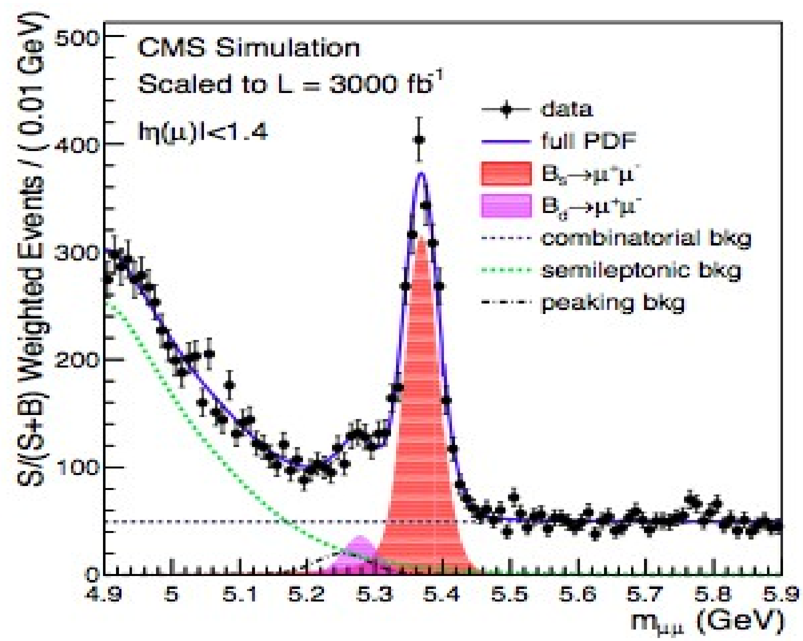
  - Test of Minimal Flavor Violation: general structure of SM FCNC is preserved, flavor violation depends only on CKM
- Check New Physics scenarios in the extended Higgs sector:
  - MSSM: BR ~ $\tan^6\beta/M^4_A$
  - 2 Higgs Doublet Models: BR ~ $\tan^4\beta$

Upgrade performance for $B \to \mu\mu$ after Run2

- CMS Upgrades more affecting the result:
  - L1 Trigger: new track trigger (necessary to reduce the rate)
  - Tracker: reduced material budget & increased resolution

CMS-PAS FTR-14-015

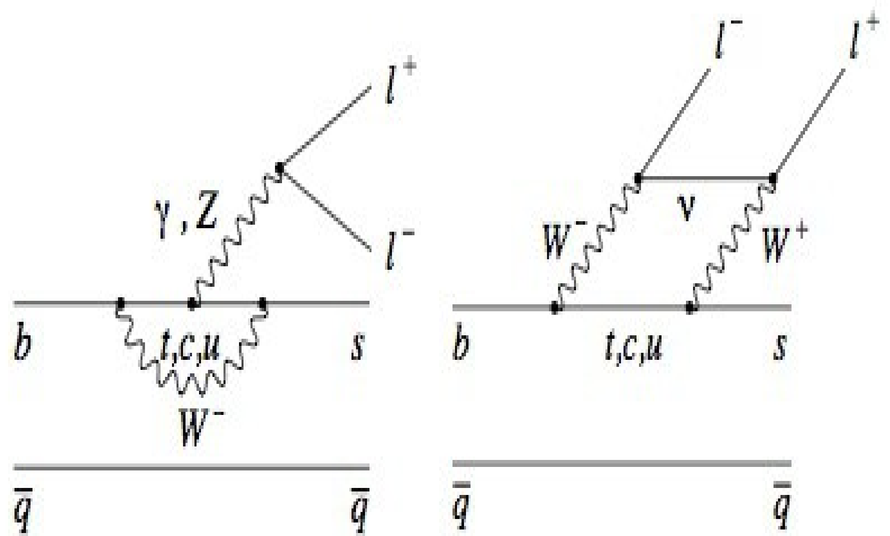




Estimate of analysis sensitivity

$\mathcal{L}$ (fb^{-1})	$N(B_s^0)$	$N(B^0)$	$\delta\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	$\delta\mathcal{B}(B^0 \to \mu^+\mu^-)$	B^0 sign.	$\delta\frac{\mathcal{B}(B^0\to\mu^+\mu^-)}{\mathcal{B}(B_s^0\to\mu^+\mu^-)}$
20	18.2	2.2	35%	> 100%	$0.0 - 1.5\,\sigma$	> 100%
100	159	19	14%	63%	$0.6 - 2.5\,\sigma$	66% Run2
300	478	57	12%	41%	$1.5 - 3.5\,\sigma$	43%
300 (barrel)	346	42	13%	48%	$1.2 - 3.3\,\sigma$	50%
3000 (barrel)	2250	271	11%	18%	$5.6 - 8.0\,\sigma$	21%

$B \to K^* \mu^+ \mu^-$



FCNC process forbidden at tree level, BR~10^{-6}: Probe the SM!

- Sensitive to the effects of NP in photon, vector and axial-vector couplings which can enter at the same order as SM contributions
- Complementary information to $B \to \mu^+\mu^-$

- Amplitudes expressed using OPE in terms of:
  - Hadronic Form Factors (accuracy ~20%) [A. Barucha et al. arXiv 1004.3249]
  - Wilson coefficients C^{eff}_7, C^{eff}_9, C^{eff}_{10} [A. Ali et al.,PRD 61 074024, Z. Phys. C 67 417]
  - Clean theoretical predictions expecially at low $q^2=m^2(\mu^+\mu^-)$
  - Experimentally clean signature

$B \to K^{*}\mu^{+}\mu^{-}$

- Strategy:
  - Measure event yields, A_{FB} and F_L from an unbinned simultaneous fit to $M(K\pi\mu\mu)$, $\cos(\theta_K)$ and $\cos(\theta_l)$ in bins of q^2

$$PDF(M,\theta_K,\theta_l)=Y_S^C S^C(m) S^a(\theta_K,\theta_l)\epsilon^C(\theta_K,\theta_l)$$

Right tag Signal

$$+Y_S^C \frac{f^M}{1-f^M} S^M(m) S^a(-\theta_K,-\theta_l)\epsilon^M(\theta_K,\theta_l)$$

Wrong tag Signal

$$+Y_B B^m(m) B^{\theta_K}(\theta_K) B^{\theta_l}(\theta_l)$$

BKG

Y_S^C, Y_B	Event Yields
$S^a(\theta_K,\theta_l), \epsilon^C(\theta_K,\theta_l)$, $S^a(-\theta_K,-\theta_l), \epsilon^M(\theta_K,\theta_l)$	Signal 2D angular shape and efficiency
$S^C(m), S^M(m), B(m)$	Mass PDFs
$B^{\theta_K}(\theta_K)$, $B^{\theta_l}(\theta_l)$	Angular BKG PDFs

  - dB/dq^2 obtained relative to the normalization channel $B^0 \to K^{*}J/\psi$:

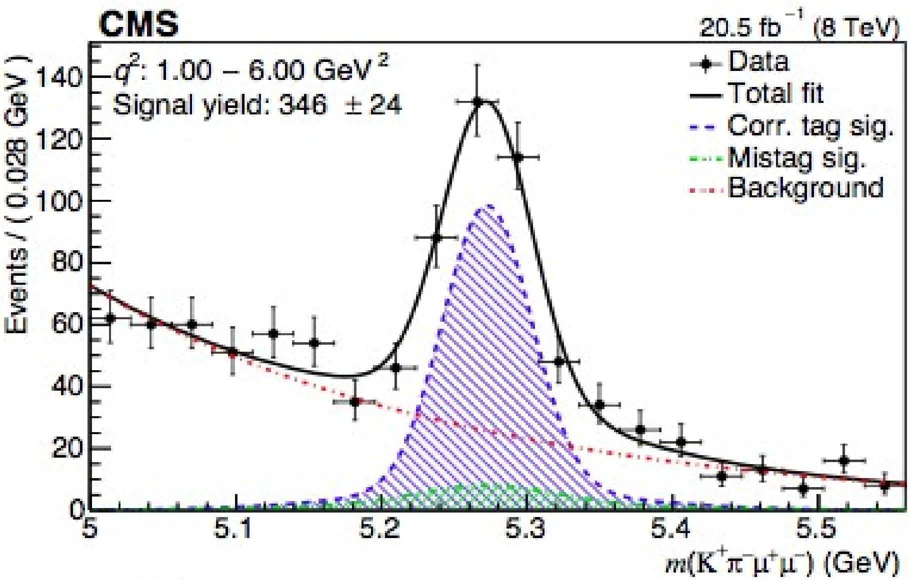
$$\frac{d\mathcal{B}(B^0\to K^{*0}\mu^+\mu^-)}{dq^2}=\left(\frac{Y_S^C}{\epsilon^C}+\frac{Y_S^C f^M}{(1-f^M)\epsilon^M}\right)\left(\frac{Y_N^C}{\epsilon_N^C}+\frac{Y_N^C f_N^M}{(1-f_N^M)\epsilon_N^M}\right)^{-1}\frac{\mathcal{B}(B^0\to K^{*0}J/\psi)}{\Delta q^2}$$

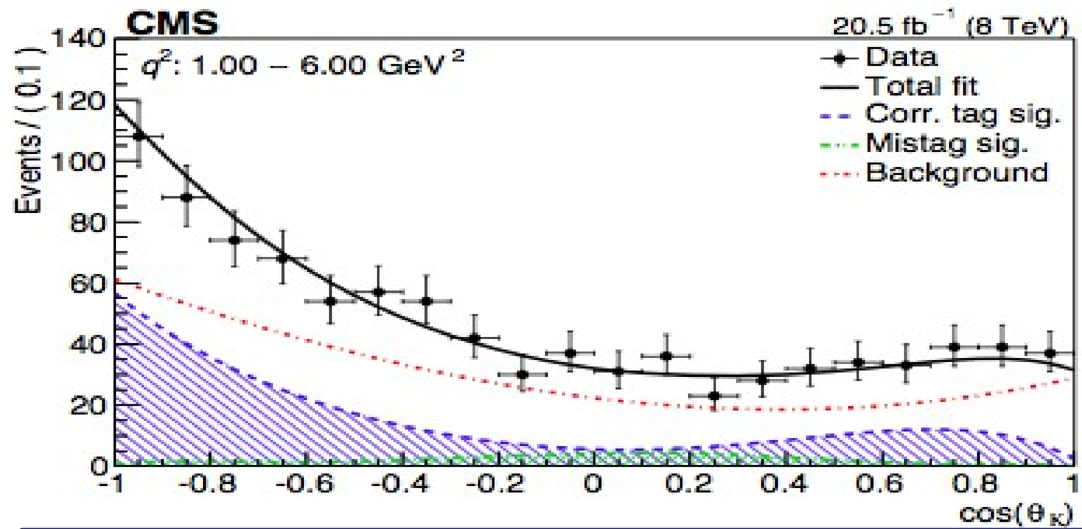
S=signal

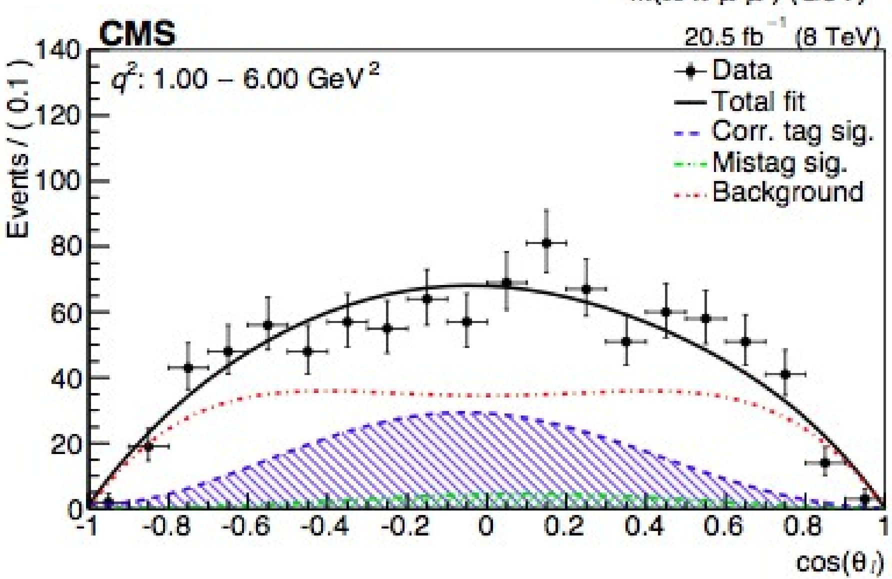
N=normalization

$B \rightarrow K^{*}\mu^{+}\mu^{-}$

- Strategy:
  - Measure event yields, A_{FB} and F_L from an unbinned simultaneous fit to $M(K\pi\mu\mu)$, $\cos(\theta_K)$ and $\cos(\theta_l)$ in bins of q^2







- B flavor tagging from $K\pi$ charge
- BKG PDFs:

  Combinatorial from MC

  Peaking parameterized on MC

  $B \rightarrow K^{*}J/\psi(\psi')$

Breakdown of experimental errors

- Results in the range $1<q^2<6$ GeV^2 (best theoretical error)

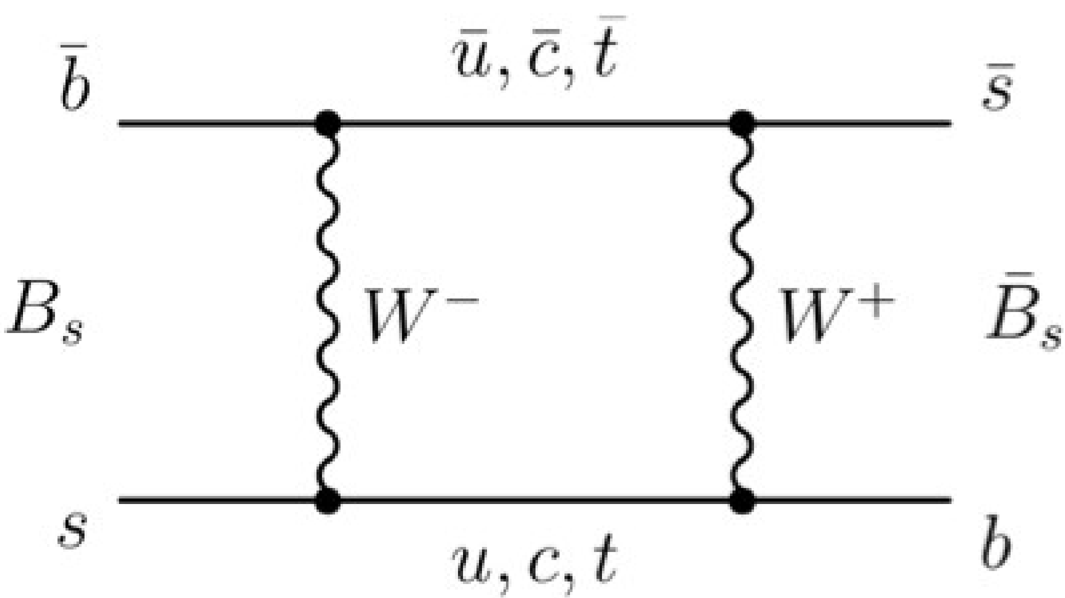
Experiment	F_L	A_{FB}	$d\mathcal{B}/dq^2$ $(10^{-8}\,\mathrm{GeV}^{-2})$
CMS (7 TeV)	$0.68 \pm 0.10 \pm 0.02$	$-0.07 \pm 0.12 \pm 0.01$	$4.4 \pm 0.6 \pm 0.4$
CMS (8 TeV, this analysis)	$0.72 \pm 0.05 \pm 0.04$	$-0.15\,^{+0.10}_{-0.08} \pm 0.03$	$3.6 \pm 0.3 \pm 0.3$
CMS (7 TeV + 8 TeV)	0.71 ± 0.06	$-0.12\,^{+0.07}_{-0.08}$	3.8 ± 0.4
LHCb	$0.65\,^{+0.08}_{-0.07} \pm 0.03$	$-0.17 \pm 0.06 \pm 0.01$	$3.4 \pm 0.3\,^{+0.4}_{-0.5}$
BaBar	—	—	$4.1\,^{+1.1}_{-1.0} \pm 0.1$
CDF	$0.69\,^{+0.19}_{-0.21} \pm 0.08$	$0.29\,^{+0.20}_{-0.23} \pm 0.07$	$3.2 \pm 1.1 \pm 0.3$
Belle	$0.67 \pm 0.23 \pm 0.05$	$0.26\,^{+0.27}_{-0.32} \pm 0.07$	$3.0\,^{+0.9}_{-0.8} \pm 0.2$
SM (LCSR)	$0.79\,^{+0.09}_{-0.12}$	$-0.02\,^{+0.03}_{-0.02}$	$4.6\,^{+2.3}_{-1.7}$
SM (Lattice)	$0.73\,^{+0.08}_{-0.10}$	$-0.03\,^{+0.04}_{-0.03}$	$3.8\,^{+1.2}_{-1.0}$

Results consistent with SM

- Measurement dominated by statistical error: wait for new data!

$B_s \to J/\Psi\varphi$

- CP violating phase Φ_s originated from interference between:
  - Direct $B_s \to J/\Psi\varphi$
  - Decay via mixing $B_s \to \overline{B}_s \to J/\Psi\varphi$
- In the SM:
  - $\Phi_s = -2\beta_s = 0.0363^{+0.0016}_{-0.0015}$ with $\beta_s = \arg(-V_{ts} V^*_{tb} / V_{cs} V^*_{cb})$



New Physics in B mixing could modify the phase

$B_s \to J/\Psi\varphi$

- Strategy:
  - Exclusive reconstruction of events
  - Flavor tagging of the B_s at the production time
  - Multidimensional fit on $m(B_s)$, θ_T, φ_T, ψ_T, ct, δct
  - Likelihood:

$$\mathcal{L} = L_s + L_{bkg},$$

$$L_s = N_s \cdot \left[\tilde{f}(\Theta, \alpha, ct) \otimes G(ct, \sigma_{ct}) \cdot \epsilon(\Theta)\right] \cdot P_s\left(m_{B_s^0}\right) \cdot P_s(\sigma_{ct}) \cdot P_s(\xi),$$

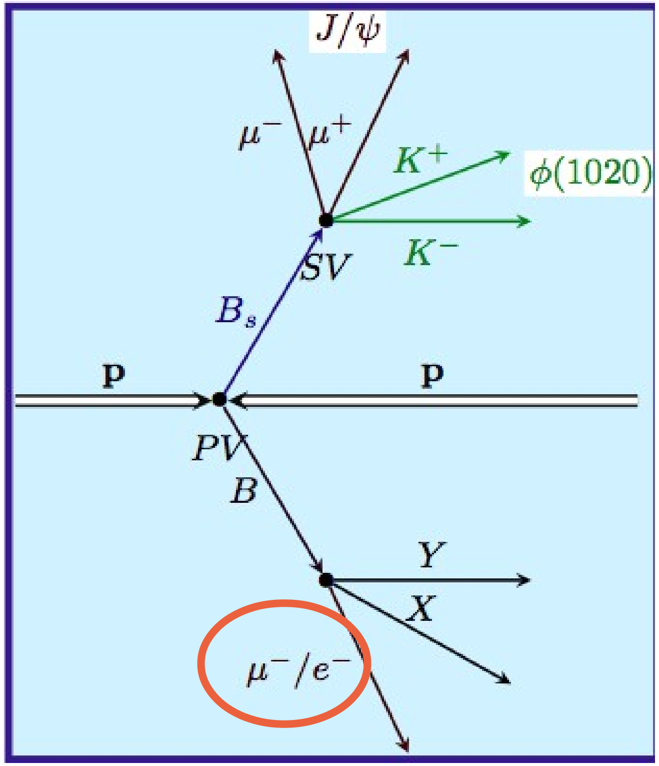
$$L_{bkg} = N_{bkg} \cdot P_{bkg}(\cos\theta_T, \varphi_T) \cdot P_{bkg}(\cos\psi_T) \cdot P_{bkg}(ct) \cdot P_{bkg}\left(m_{B_s^0}\right) \cdot P_{bkg}(\sigma_{ct}) \cdot P_{bkg}(\xi)$$

- $\tilde{f}(\Theta, \alpha, ct)$ signal PDF
- $G(ct, \sigma_{ct})$ Gaussian proper decay time resolution, per-event
- $\varepsilon(\Theta) = \varepsilon(\cos\theta_T, \cos\psi_T, \varphi_T)$ angular efficiencies
- $P_S(m_{Bs})$ signal mass PDF, triple-Gaussian with a common mean
- $P_S(\sigma_{ct})$ proper time uncertainty (Γ functions)
- $P_S(\xi)$ tag decision, per-event
- P_{bkg} background PDFs

P. Eerola

$B_s \to J/\Psi\varphi$

- Opposite side lepton (e, μ) Flavor Tagging using a MultiLayer Perceptron NN optimized to maximize $P=\varepsilon(1-2\omega)^2$ based on lepton P_T, η, isolation, IP(3D), charge in a ΔR cone



- Ptag=1.307 ± 0.031 ±0.007%
  ω=30.17± 0.24 ±0.05%
  ε=8.31± 0.03%