$B_{d,s} \rightarrow \mu^+\mu^-$ at the LHC

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On behalf of ATLAS, CMS & LHCb collaborations at the LHC

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HEP is knocking at the heaven's door

- Direct searches at the LHC has not yielded any positive indication for existence of beyond Standard Model (SM) physics at TeV energy scale or higher.

- The search for *New Physics* (NP) at the LHC has become a marathon from an anticipated sprint game.

- Surely with only about few % of data delivered till now, ***THERE IS HOPE .***

- This hope is sustained by the exciting deviations from SM in B-physics in several measurements .

  → These could be hints for NP at much higher energy scale than accessible directly at colliders.

- NP can contribute to

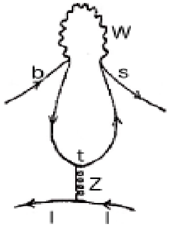
→ Enhancement or suppression of decay rates

→ Introduction of new source of CP violation

→ Modification of angular distribution of final state particles.

$B_s \rightarrow \mu^+\mu^-$ can be a subtle player in this game!

$B_{d,s} \rightarrow \mu^+\mu^-$



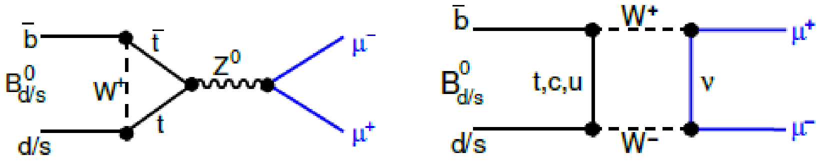
- Orthogonal to NP searches via $b \rightarrow s\gamma$, $\mu \rightarrow e\gamma$,..

- Extremely rare decay due to loop level processes

i) FCNC via Z penguin and box diagram

ii) Very clean experimental signatures

iii) Helicity suppression: m_l^2 / M_B^2



- Predicted branching ratios (time integrated) in SM

→ with latest value to top mass, higher order effects of electroweak and strong interactions

Bobeth et al,
PRL 112, (2014) 101801

$$\mathcal{B}_{SM}(B_s \rightarrow \mu^+\mu^-) = (3.65 \pm 0.23) * 10^{-9}$$

$$\mathcal{B}_{SM}(B_d \rightarrow \mu^+\mu^-) = (1.06 \pm 0.09) * 10^{-10}$$

Ratio R= $0.0295^{+0.0028}_{-0.0025}$

Note ($V_{ts} > V_{td}$)

- Small theoretical uncertainties (mainly due to CKM matrix elements & decay constants f_d, , f_s) ➔ excellent probe for new physics

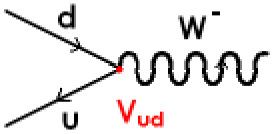
What does data say?

- **Branching ratio measurements are in agreement with SM!**
- However NP may still be playing a role in the process without affecting the BR.
- But deviations are seen in other processes involving b→ s $\mu\mu$ transitions: (angular analysis, lepton flavour universality, ..)
  → cannot be just experimental effects
  → cannot be explained theoretically in terms of QCD.
- In effective theory formalism, via, operator product expansion formalism, one tries to decipher the nature of new interaction.
  → The Wilson coefficients corresponding to perturbative, short distance physics, sensitive to physics at energy scale higher than electroweak scale.
  → Operators indicating non-perturbative, long distance aspects of QCD.
- NP can modify Wilson coefficients, as well as induce new operators.

New Physics effect on decays

The decay amplitude can be described by effective field theories;

$$\boxed{A(M \to F) = \langle F|\mathcal{H}_{eff}|M\rangle = \frac{G_F}{\sqrt{2}} \sum_i V^i_{CKM} C_i(\mu) \langle F|Q_i(\mu)|M\rangle}$$



$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \leftarrow$$

CKM
Couplings

Wilson Coeff.
μ =energy scale

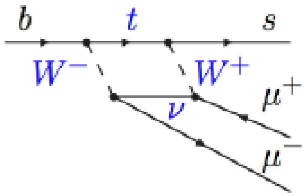
Hadronic matrix
elements

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V^*_{ts} \sum_i [\underbrace{\mathcal{C}_i(\mu)\mathcal{O}_i(\mu)}_{\text{left handed}} + \underbrace{\mathcal{C}'_i(\mu)\mathcal{O}'_i(\mu)}_{\text{right handed (suppressed in the SM)}}]$$

i=1, 2	Tree
i=3-6, 8	Gluon penguin
i=7	Photon penguin
i=9, 10	Electroweak penguin
i=S	Higgs (scalar) penguin
i=P	Pseudoscalar penguin

- Only C_{10} (axial-vector) contributes to $B_{d,s} \to \mu^+\mu^-$ in SM

O_{10}



New Physics effect on $B_{d,s} \to \mu^+\mu^-$ branching fraction

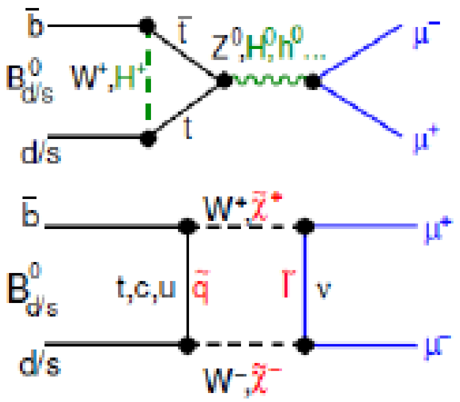
$$\Gamma\left(B_s^0 \to \mu^+\mu^-\right) \sim \frac{G_F^2\alpha^2}{64\pi^3} m_{Bs}^2 f_{Bs}^2 \left|V_{tb}V_{ts}\right|^2 \left|2m_\mu C_{10}\right|^2$$

From lattice calculations

to be determined experimentally

- In presence of NP (eg., extended Higgs sector) C_s, C_p contributes

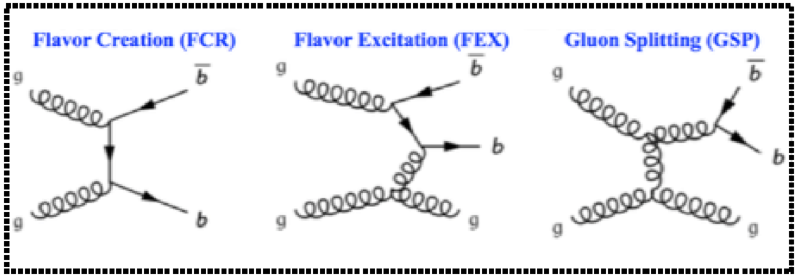
$$\mathcal{B} \propto |V_{tb}V_{tq}| \left[\left(1-\frac{4m_\ell^2}{M_B^2}\right)|C_S - C'_S|^2 + |(C_P - C'_P) + \frac{2m_\ell}{M_B}(C_{10}-C'_{10})|^2\right]$$



- Similar considerations for $B_{d,s} \to \tau^+\tau^-$ but less suppressed from helicity
- Further Minimal Flavour Violation (MFV) models, accommodating violation of lepton flavour universality, may enhance the rate significantly.

B-physics at the LHC

- Large cross section: 300 μb @ √s = 7 TeV
  600 μb @ √s = 13 TeV



- Experiments at LHC are very suitable for detailed studies in heavy flavour sector.

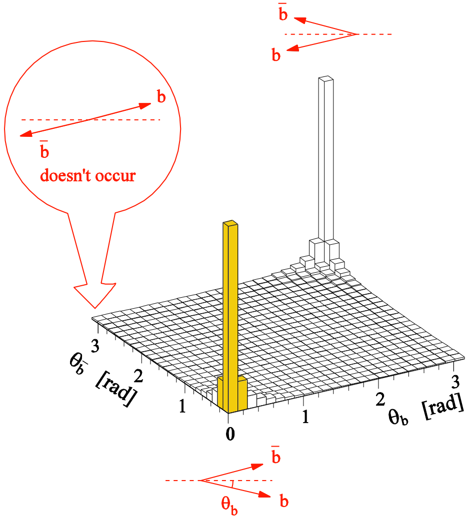
- b-quark life time ~ 1.6 ps (transitions between quarks via CKM matrix)

→ Important to measure secondary vertex with precision

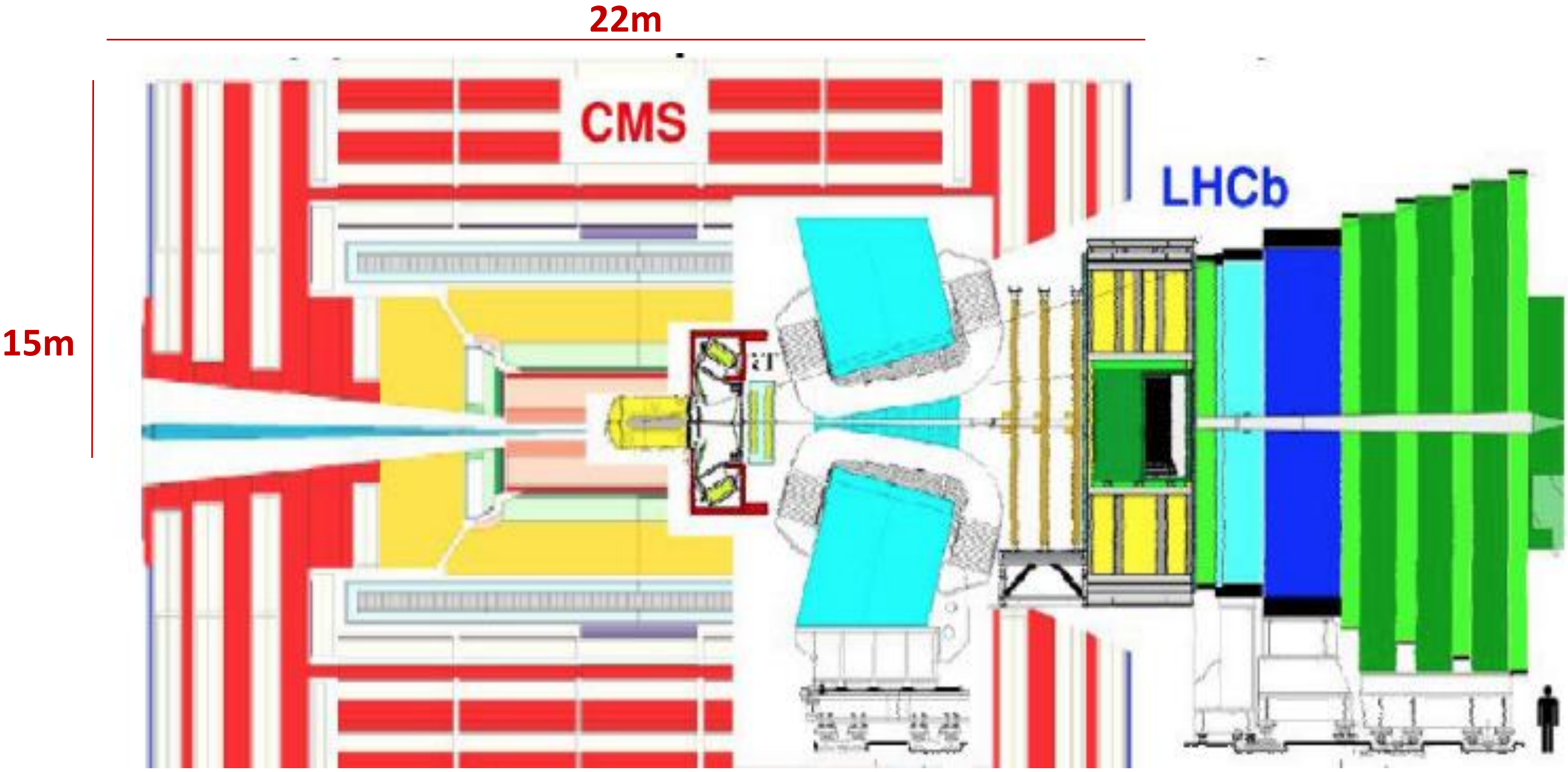
- Hadronization of b :
  B^0 (40%), B^+ (40%), Bs (10%), b-baryons Λ_b etc: (10%)

- Average momentum of B-meson: ~ 100 GeV @ √s = 13 TeV

- In a large fraction of events, b & $\bar{b}$ are back to back.



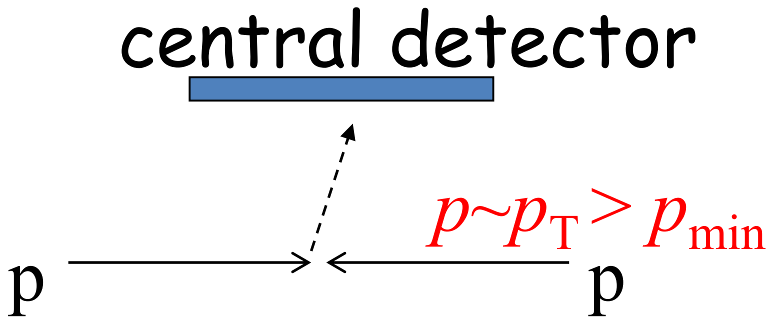
Complementarity of CMS and LHCb experiments



Innermost detector plays key role providing high resolution of

i) Impact parameter to resolve secondary vertices
ii) Dimuon invariant mass, ….

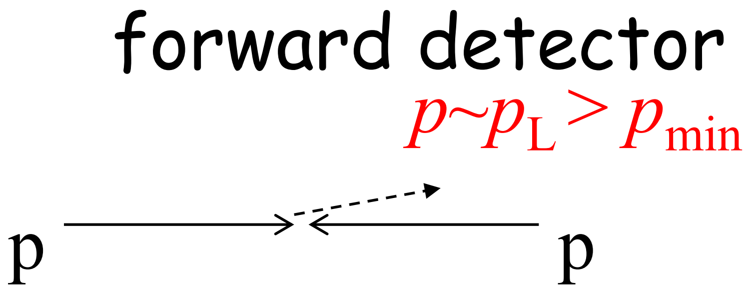
CMS/ATLAS vs. LHCb



central detector

p $\quad$ p

$p \sim p_T > p_{min}$



forward detector

$p \sim p_L > p_{min}$

p $\quad$ p

➔ ***p_T* threshold can be set low for high b-efficiency**

Rough comparison

Experiment (Run2 scenario)	ATLAS/CMS	LHCb
Instantaneous luminosity	$1 * 10^{34}$ /cm^2 /s	$2 * 10^{32}$ /cm^2 /s
Avg. interactions /crossing	50	0.5
bb events /10^7s	$5 * 10^{13}$ * accept.	$1 * 10^{12}$ * accept.
Track measurement	ϑ >220 mrad	10 < ϑ < 300 mrad
p_T threshold for trigger (GeV)	4(3)	1.5
$m_{\mu\mu}$ mass resolution (MeV)	32 - 75	25
Proper time resolution (fs)	77	36
capability for measuring μ	excellent	excellent

Measurement of $B_s \to \mu^+\mu^-$

CMS: 25/fb
LHCb: 3/fb

- Searched during last 30 years
- Combined measurement by CMS and LHCb using **Run1 data**

→ **$B_s \to \mu^+\mu^-$ observed with 6.2 σ significance**

→ **Evidence of $B_d \to \mu^+\mu^-$ with 3.0 σ significance**

Nature 522 (2015) 68

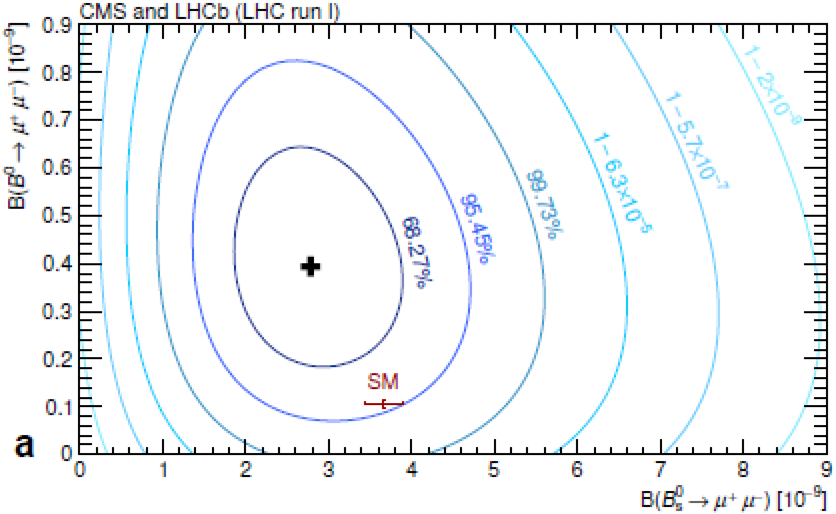
$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.8\,^{+0.7}_{-0.6}) \times 10^{-9}$ → within 1.2σ of SM

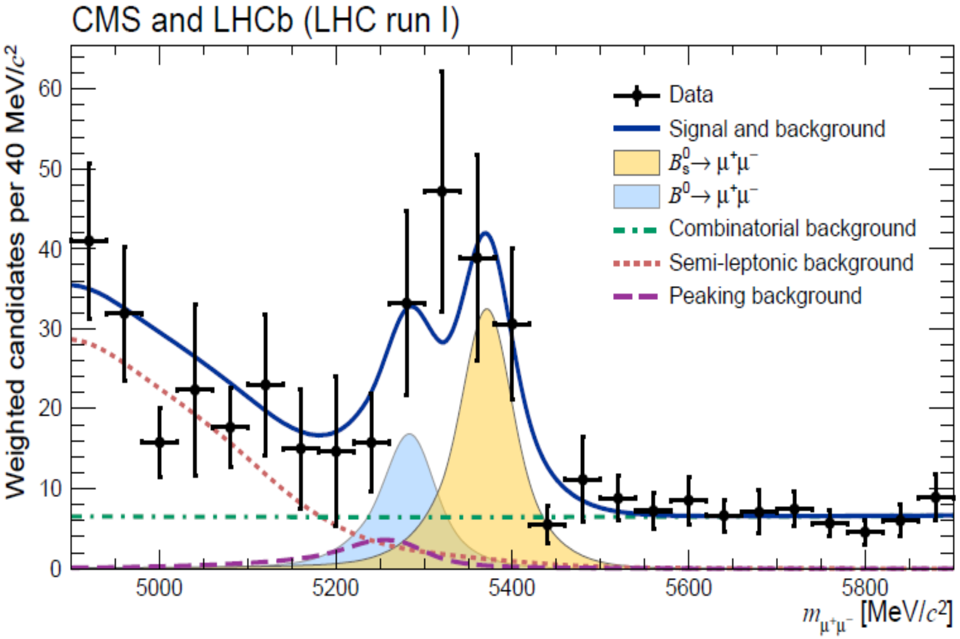
$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.9\,^{+1.6}_{-1.4}) \times 10^{-10}$ → within 2.2σ of SM

Ratio : R = 0.14 +0.06 -0.08
→ within 2.3 σ of SM

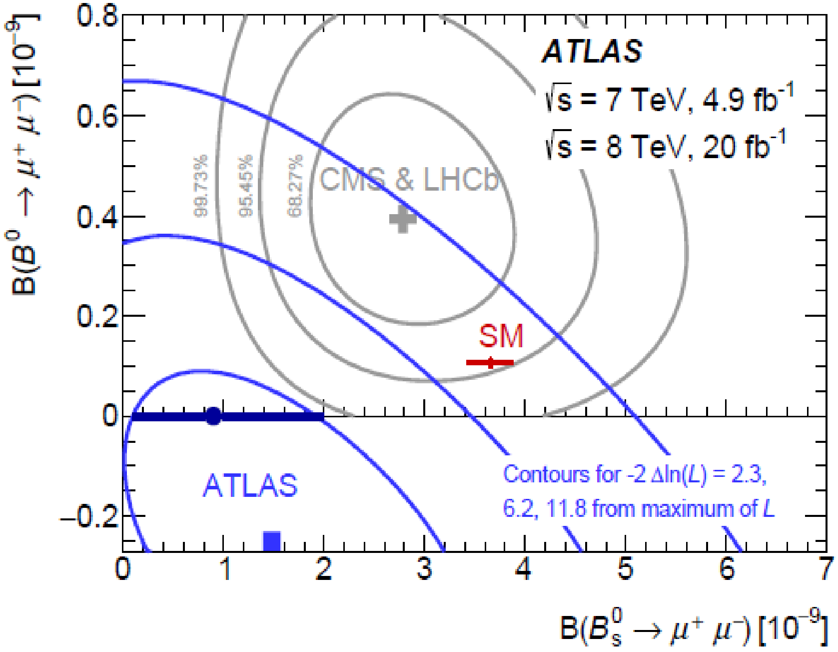
Ratio of observation wrt SM

$\mathcal{S}^{B^0_s}_{\mathrm{SM}} = 0.76\,^{+0.20}_{-0.18}$ and $\mathcal{S}^{B^0}_{\mathrm{SM}} = 3.7\,^{+1.6}_{-1.4}$





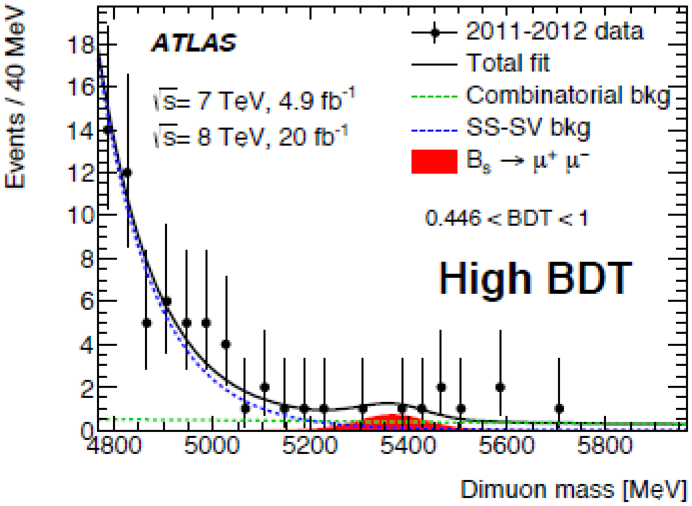
Measurement by ATLAS experiment: Run1 data



EPJ C76 (2016) 9, 513

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (0.9^{+1.1}_{-0.8}) \times 10^{-9}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 4.2 \times 10^{-10} \text{ @ 95\% CL}$$



Significance of B_s signal 1.6σ

2d likelihood compatible with SM at 2σ

Recent results from LHCb

PRL 118 (2017) 191801

- Updated analysis using combination of **Run2 data (1.4 /fb) & Run1 data (3/fb)**

→ new signal isolation

→ better rejection of di-hadron background due to better particle ID

→ Background rejection improved using new multivariate analysis (BDT)

- **Theoretical uncertainties (on V_{CKM}, f_{Bs}) well below statistical error**

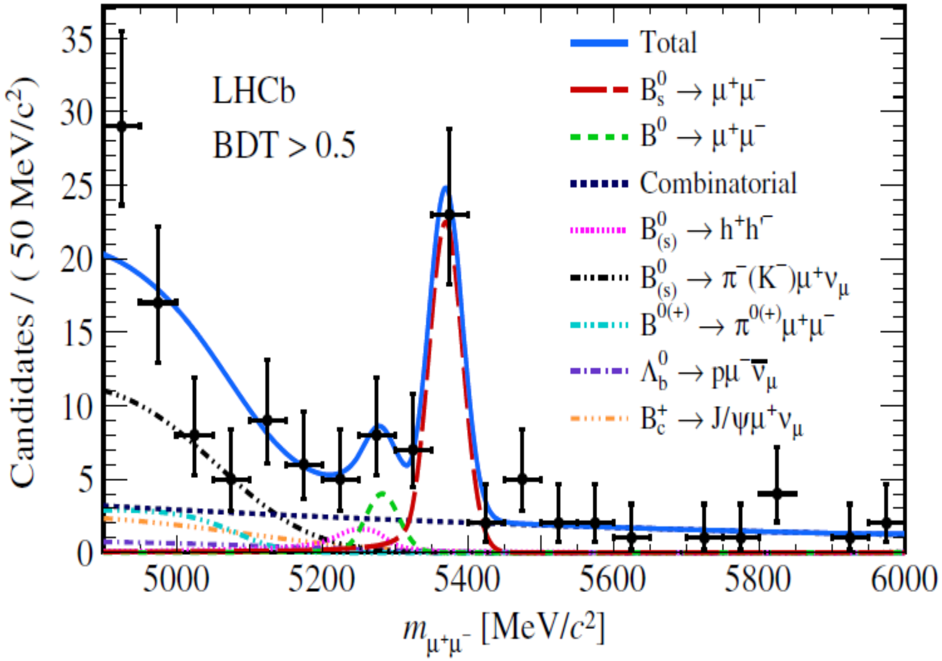
$$\boxed{\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}}$$

First observation by a single experiment with 7.8 σ significance

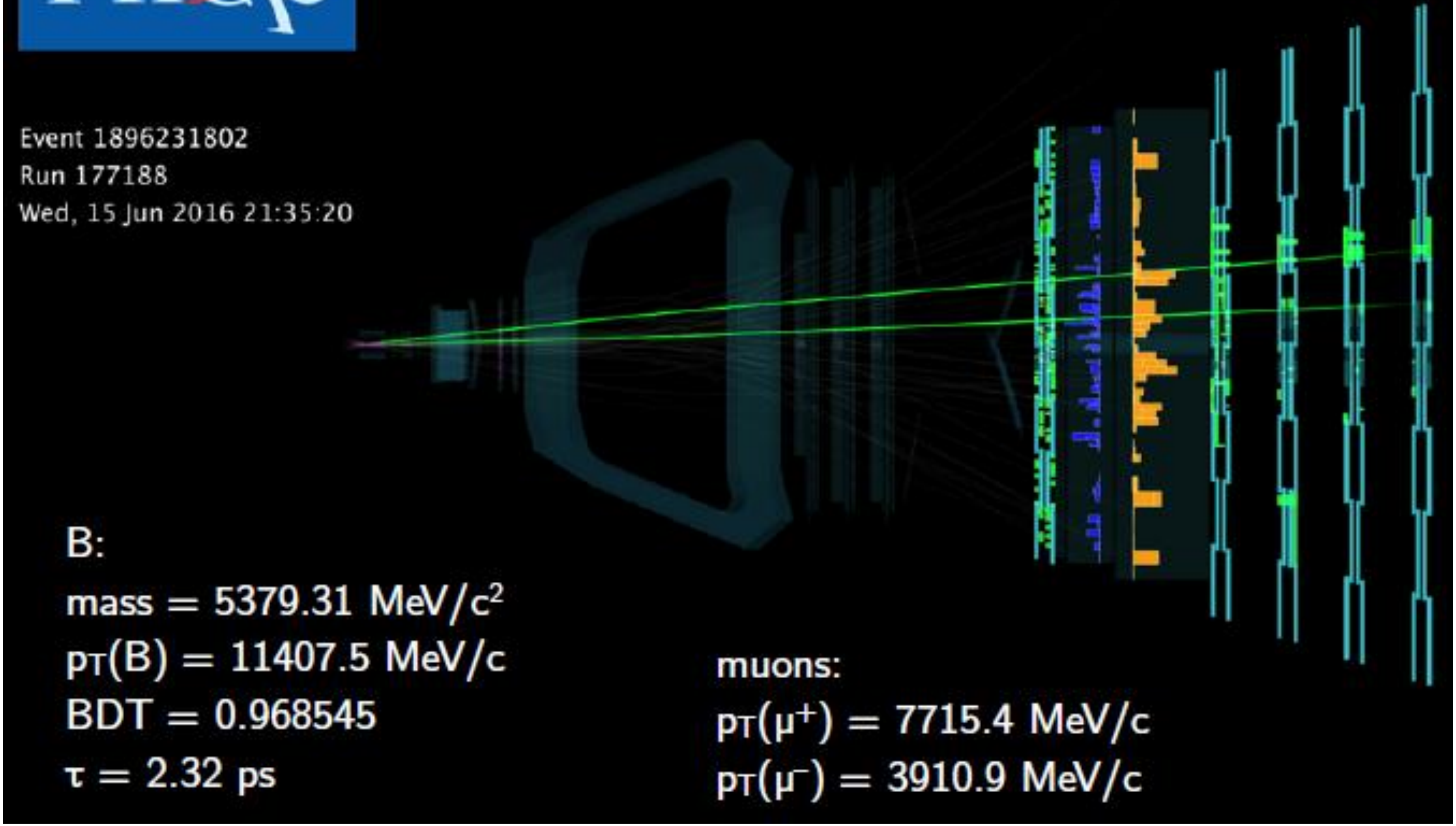
$$\boxed{\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10}}$$

No evidence

Smaller compared to Run1 measurement



Candidate event

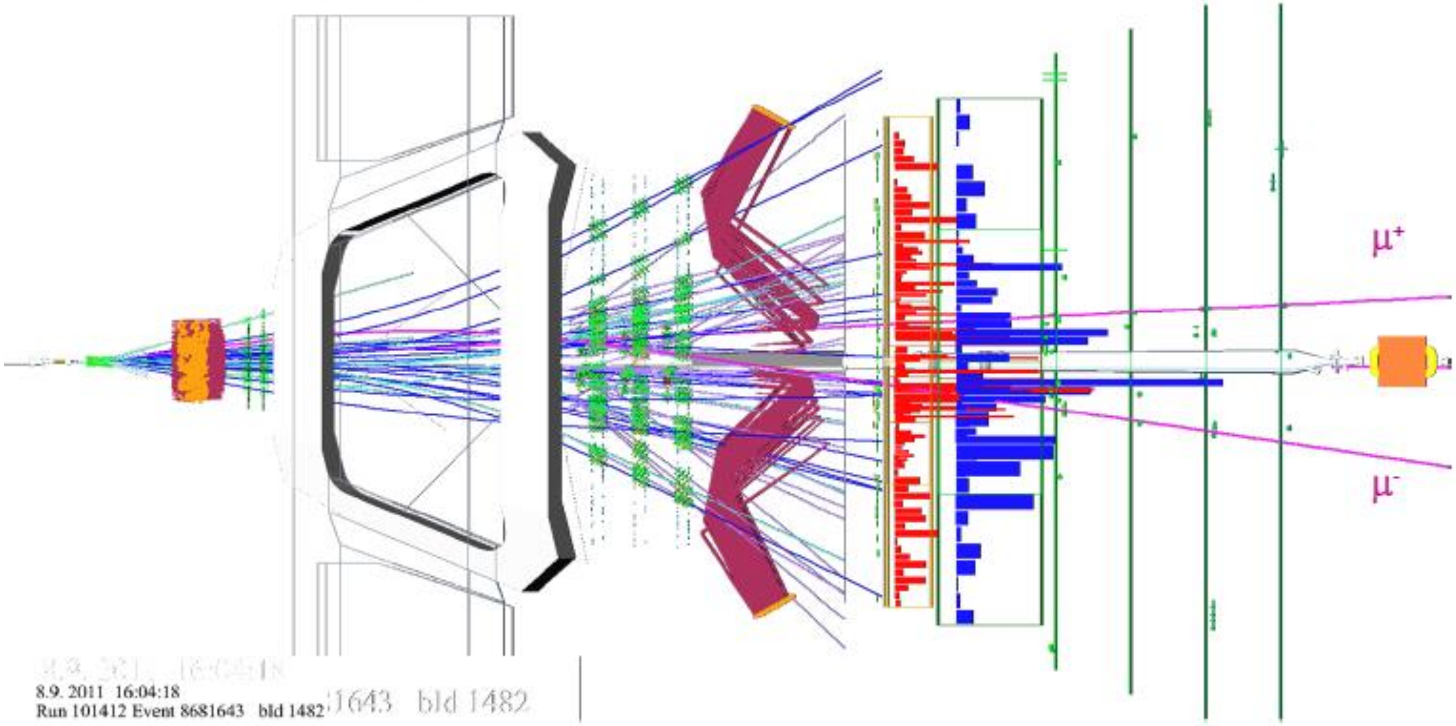


Event 1896231802
Run 177188
Wed, 15 Jun 2016 21:35:20

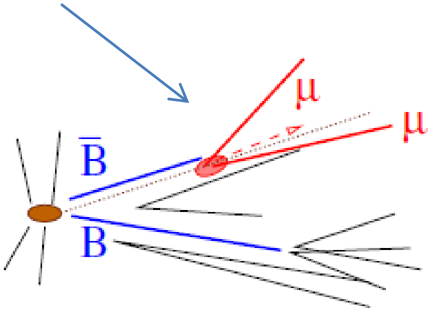
B:
mass = 5379.31 MeV/c^2
$p_T(B)$ = 11407.5 MeV/c
BDT = 0.968545
τ = 2.32 ps

muons:
$p_T(\mu^+)$ = 7715.4 MeV/c
$p_T(\mu^-)$ = 3910.9 MeV/c

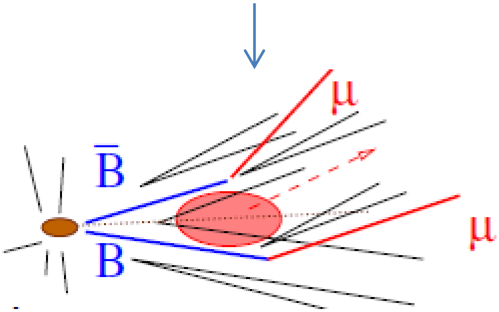
$B_s \to \mu^+\mu^-$ event in LHCb



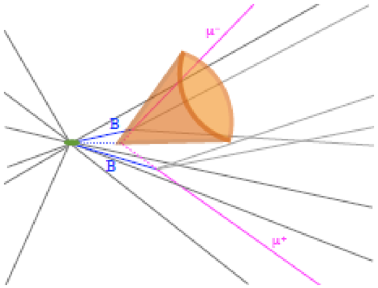
Signal



Combinatorial background

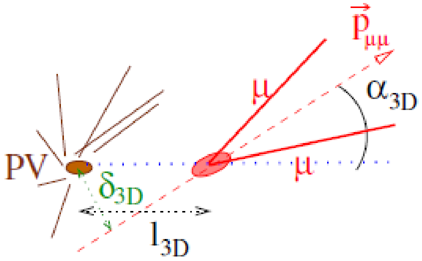


Discriminated via isolation variable



LHCb: latest analysis strategy

- Opposite sign muon pair: $m_{\mu\mu}$: [4900, 6000] MeV
- Signal/background classification in $m_{\mu\mu}$ vs. BDT plane
- Inputs to BDT: kinematics, geometrical and isolation variables
- Background discrimination using BDT much better compared to performance of Run1 MVA.
- Categorization by $m_{\mu\mu}$ and BDT score



- Calibration of signal peak position with $B_s \rightarrow h^+ h^-$ (KK, Kπ)
- Normalization channels: (signal-like topology), $B^+ \rightarrow J/\Psi K^+$
- Fraction of hadronization (f_d / f_s) √s –dependent

→ 3.86± 0.22 at 13 TeV, 6.8% increase for Run2

→ estimated from ratio of $B^+ \rightarrow J/\Psi K^+$ to $B^0_s \rightarrow J/\Psi \phi$

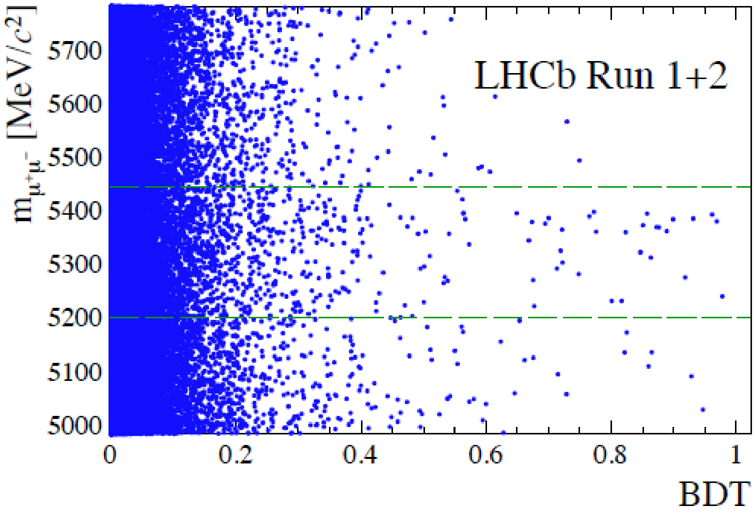
- Background estimation: using data-driven methods, MC samples, theoretical inputs.

Phys. Rev. lett 118 (2017) 191801

for the full dataset used in Run 1 and Run 2. The BDT variable is shown on the x-axis and the invariant mass of the two muons is shown on the y-axis. The dashed green line indicates the signal mass region, for which $m_{\mu^+\mu^-} \in [5200, 5445]\ \mathrm{MeV}/c^2$.

LHCb: results

- Yields: $B^+ \rightarrow J/\Psi K^+$: $(1964 \pm 1) \times 10^3$, $B^0 \rightarrow K\pi$: $(62 \pm 3) \times 10^3$
- Expect ~ 62 events of $B_s \rightarrow \mu^+\mu^-$, ~ 7 events of $B_d \rightarrow \mu^+\mu^-$ in whole BDT range
- Branching fraction from unbinned maximum likelihood fit, in high BDT region (signal and exclusive bkg. fractions constrained to expectations)
- Upper limit on $\mathcal{B}(B_d \rightarrow \mu^+\mu^-)$ from CL_s ($=CL_{S+B}/CL_s = 0.5$) method
- Compatibility with background hypothesis: $1 - CL_b = 0.05$
- Effective lifetime from signal weighted decay time fit.



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LHCb: results

Upper limit on $\mathcal{B}(B_d \rightarrow \mu^+\mu^-)$

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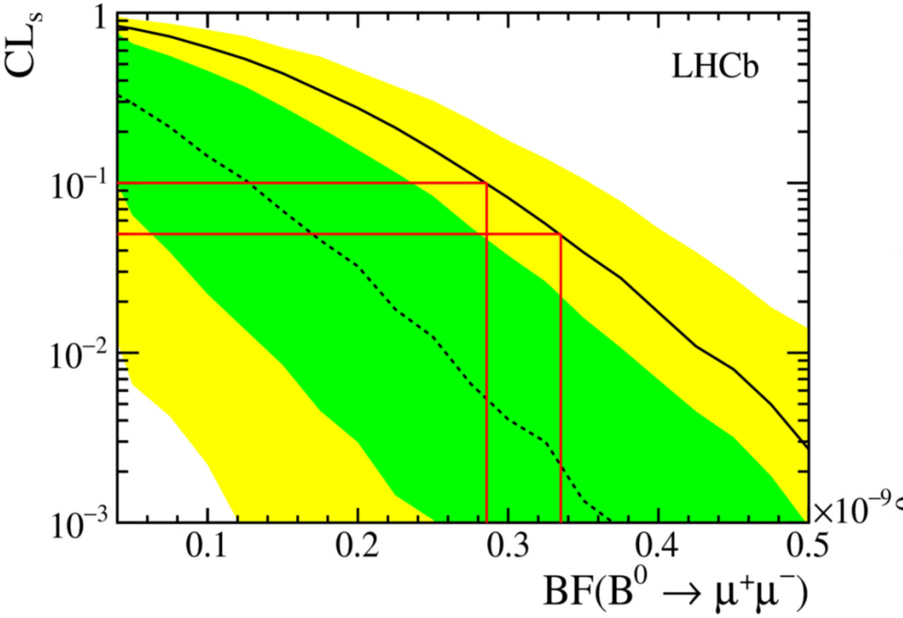
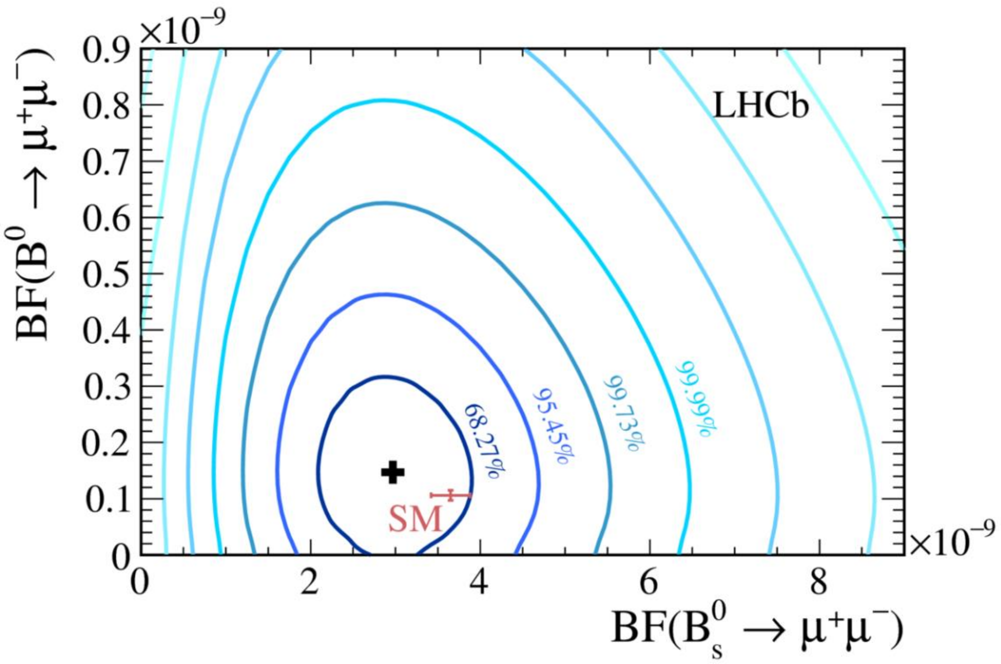
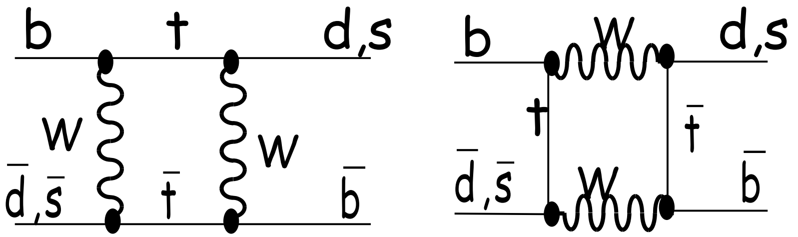


2D likelihood profile



Effective lifetime



- Oscillation leads to CP even and odd mass eigenstates with different decay widths: Γ_H, Γ_L and $\Delta\Gamma = 0.082 \pm 0.007$ /ps

- In SM only the heavy state decays to dimuon final state

→ NOT the case if new physics leads to large CP violation in Bs system.

→ effective lifetime for dimuon decay is a complementary probe for new physics

$$\tau_{\ell^+\ell^-} = \frac{\int_0^\infty t\langle\Gamma(B_s(t)\to\ell^+\ell^-)\rangle dt}{\int_0^\infty \langle\Gamma(B_s(t)\to\ell^+\ell^-)\rangle dt}$$

$$\Gamma(B_s(t)\to\mu^+\mu^-)\equiv\Gamma(B_s^0(t)\to\mu^+\mu^-)+\Gamma(\bar{B}_s^0(t)\to\mu^+\mu^-)$$

- NP effect shows up in asymmetry →

$A_{\Delta\Gamma}$ can be anything between -1 to +1

$$A_{\Delta\Gamma}^{\ell^+\ell^-} = \frac{\Gamma_{B_{s,H}\to\ell^+\ell^-}-\Gamma_{B_{s,L}\to\ell^+\ell^-}}{\Gamma_{B_{s,H}\to\ell^+\ell^-}+\Gamma_{B_{s,L}\to\ell^+\ell^-}} \overset{SM}{=} 1$$

Effective lifetime

- Accurate measurement of τ potentially indicate nature of new physics, if any.

$$\boxed{\tau_{\ell^+\ell^-} = \frac{\tau_{B_s}}{1-y_s^2}\left[\frac{1+2A_{\Delta\Gamma}^{\ell^+\ell^-}\, y_s + y_s^2}{1+A_{\Delta\Gamma}^{\ell^+\ell^-}\, y_s}\right]}$$

$$\boxed{y_s \equiv \tau_{B_s}\Delta\Gamma/2 = 0.062 \pm 0.006}$$

LHCb measurement:

$$\boxed{\tau(B_s^0 \to \mu^+\mu^-) = 2.04 \pm 0.44 \pm 0.05 \text{ ps}}$$

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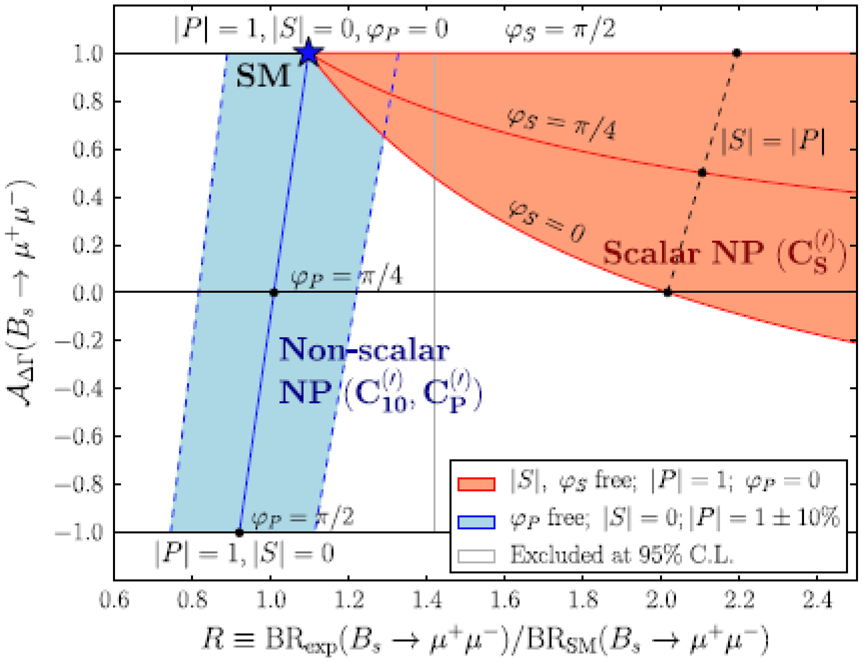
Compare with SM: 1.510 ± 0.005 ps

Consistent with $A_{\Delta\Gamma}$ =1(-1) at 1.0(1.4)σ level

Bruyn et. al.
Phys. Rev. lett 109(2015) 041801



Effect of NP on Asymmetry is orthogonal to BR

- 5% precision on τ can be achieved with data corr integrated luminosity of ~ 50 /fb

LHCb: Measurement of effective lifetime

PRL 118 (2017) 191801

- Fit performed in 2 steps:

i) To dimuon invariant mass distribution in range [5320,6000] MeV .

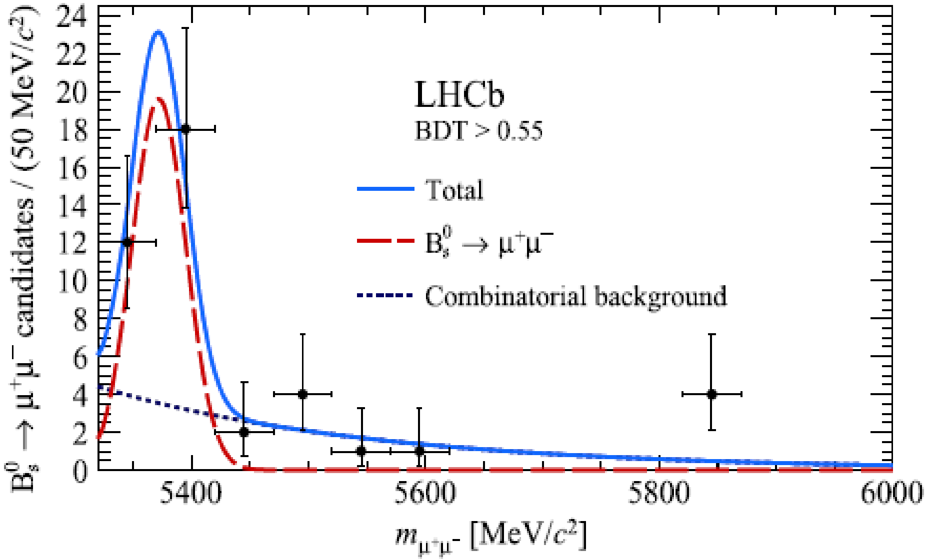
→ exclude $B_d \to \mu^+\mu^-$ region.

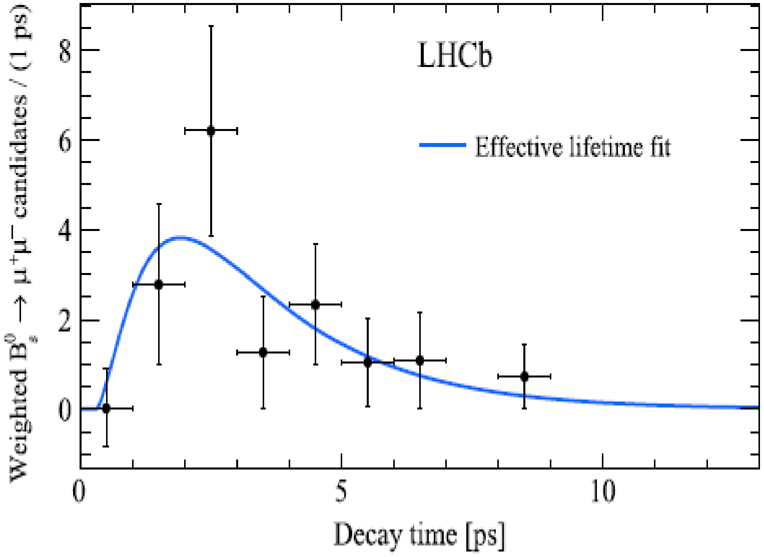
→ Data is background-subtracted by using event weights in *sPlot* technique

ii) To weighted decay time distribution

→ decay time acceptance fn. validated with $B^0 \to K^+\pi^-$

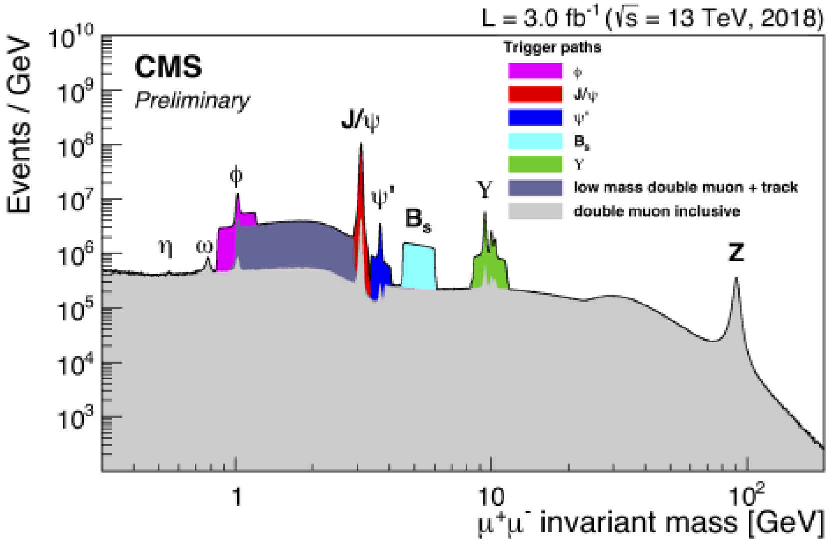
- Unlike BF measurement, use single BDT cut and looser PID
- Acceptance function modeled on simulated events of $B_s \to \mu^+\mu^-$





CMS analysis with Run2 data

CMS-DP-2018-036



- New 4-layer pixel detector since 2017

- More than 4 times larger data volume already on tape

  Run1: 25/fb, 2016: 35/fb, 2017: 40/fb

- Trigger strategy:

  → dimuon invariant mass around resonances, dimuon p_T, prompt & displaced vertices

→ Increased instantaneous luminosity → more stringent criteria

- Analysis much improved → no more a search BUT precise measurement

→ Dedicated trigger in central region~ 15% bandwidth for flavour physics

→ Improved muon identification

→ In-situ dimuon trigger and reconstruction bias estimate

→ Improved pile-up studies

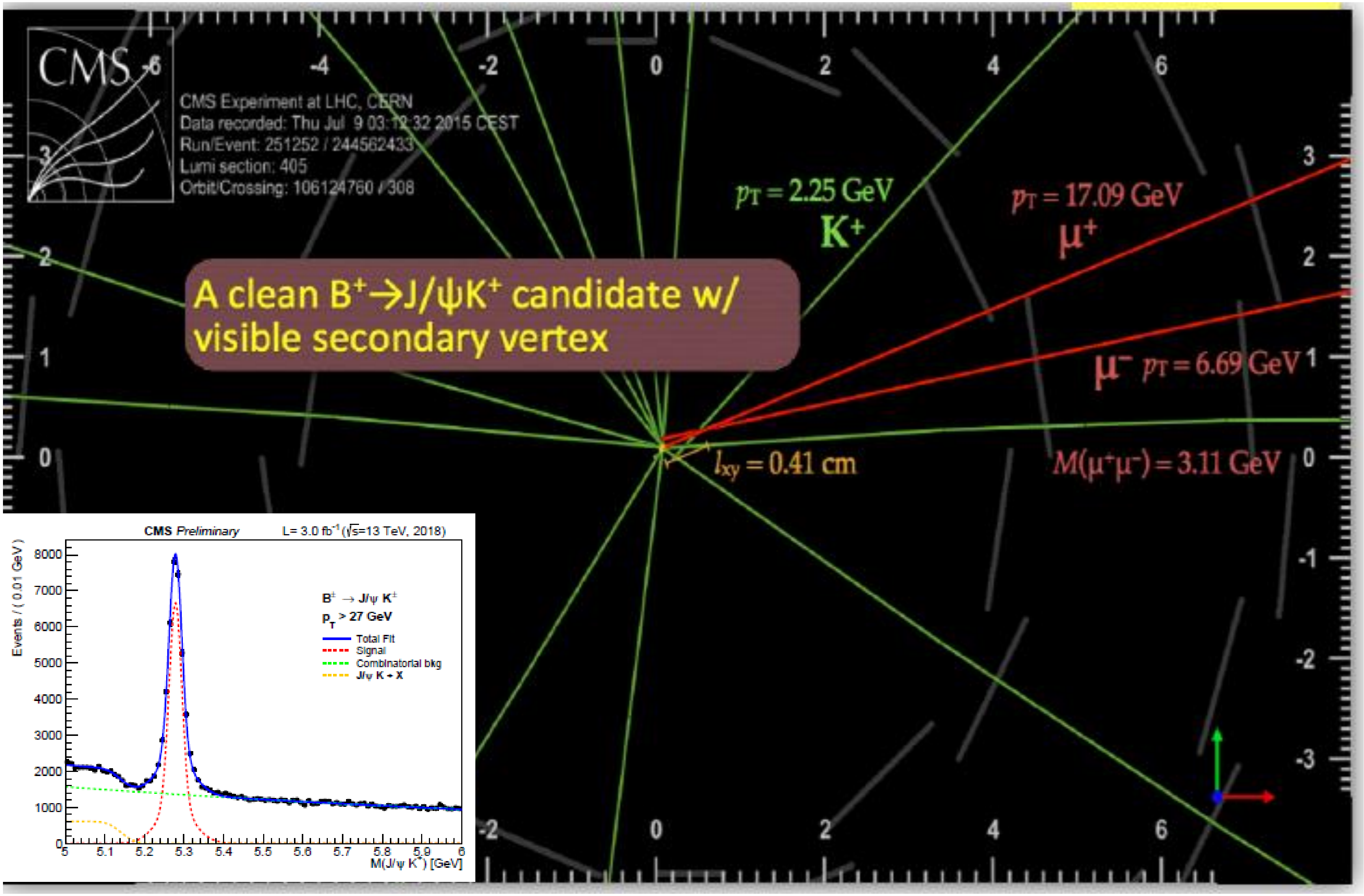
More discussion
In talk by D.Sahoo

- identification of primary vertex independent of pile up

$B_s \to \mu^+\mu^-$ ***result in near future***

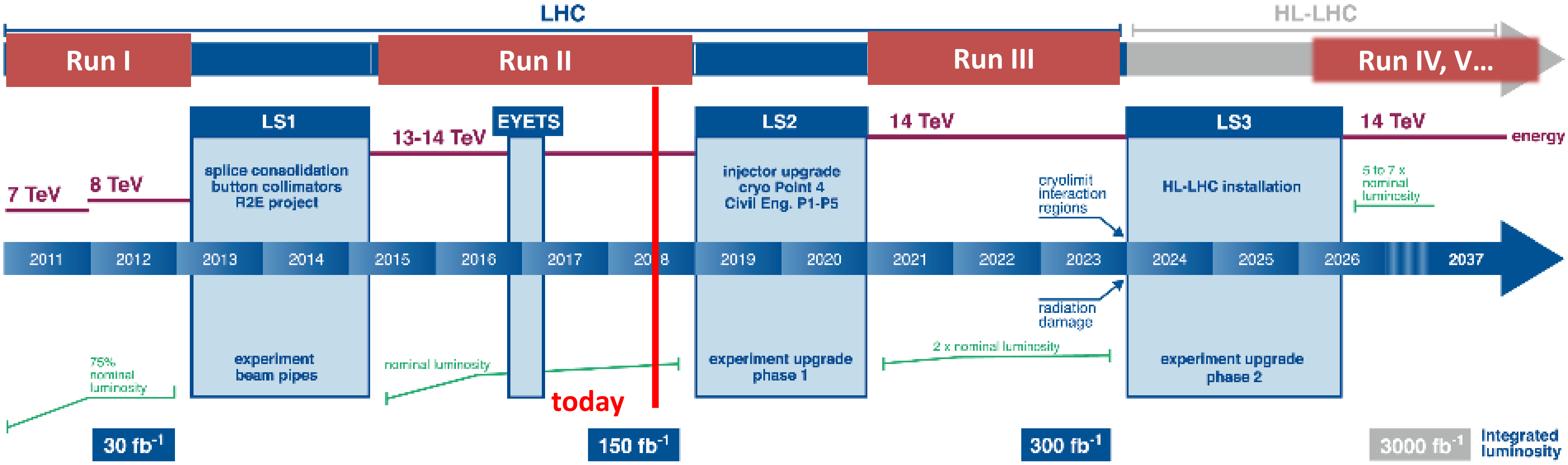
Dimuon event in CMS at 13 TeV

CMS-DP-2015-018



A clean $B^+ \to J/\psi K^+$ candidate w/ visible secondary vertex

LHC plan and HL-LHC (High Luminosity LHC)



The HL-LHC Project: *300 fb^{-1} → 3000 fb^{-1}*

Major intervention on more than 1.2 km of the LHC

#enabling a total integrated luminosity of **3000 to 6000 fb^{-1}**

#implying an integrated luminosity of **250-300 fb^{-1} per year,**

#design for μ ~ **140 (~ 200)** ➔ peak luminosity of **5 (7.5) 10^{34} cm^{-2} s^{-1}**

=> Ten times the luminosity reach of first 10 years of LHC operation

CMS projection for future

FTR-13-022
TDR-15-002
TDR-17-001

Considered simple scaling of current analysis

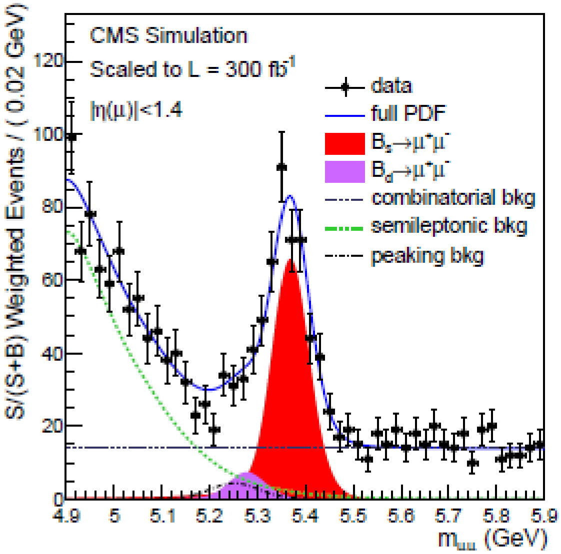
→ NOT including as yet better features of detector and methodology of future.

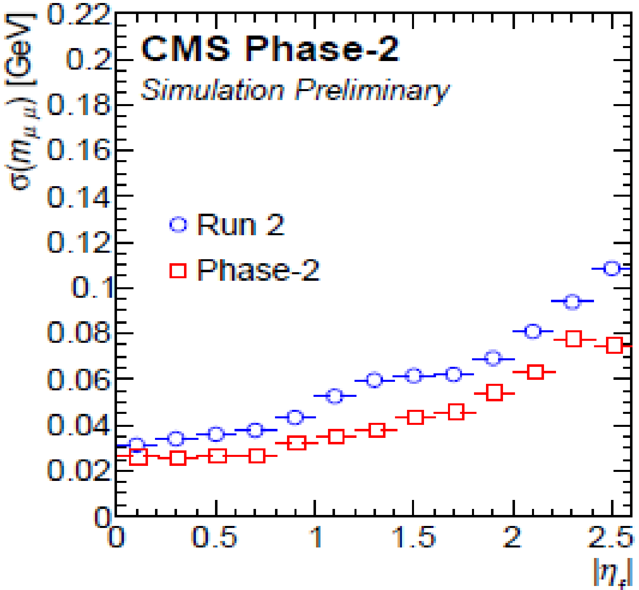
L (fb^{-1})	No. of B_s^0	No. of B^0	$\delta\mathcal{B}/\mathcal{B}(B_s{}^0 \to \mu^+\mu^-)$	$\delta\mathcal{B}/\mathcal{B}(B^0 \to \mu^+\mu^-)$	B^0 sign.	$\delta\frac{\mathcal{B}(B^0\to\mu^+\mu^-)}{\mathcal{B}(B_s^0\to\mu^+\mu^-)}$
20	16.5	2.0	35%	>100%	0.0–1.5 σ	>100%
100	144	18	15%	66%	0.5–2.4 σ	71%
300	433	54	12%	45%	1.3–3.3 σ	47%
3000	2096	256	12%	18%	5.4–7.6 σ	21%

Crucial improvement in trigger capability for Phase-2 upgraded detector

→ Tracking information in level1 trigger (decision in 12 μs)

→ P_T resolution of dimuon system

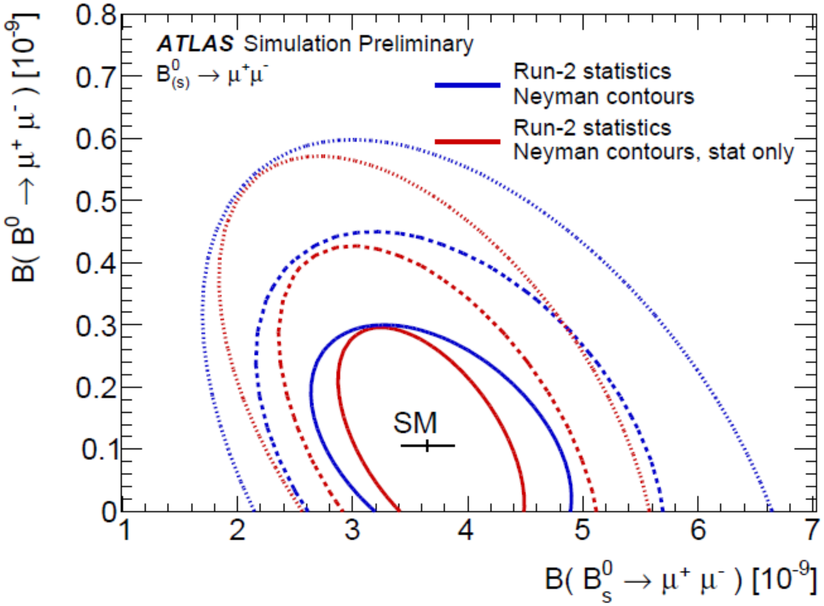


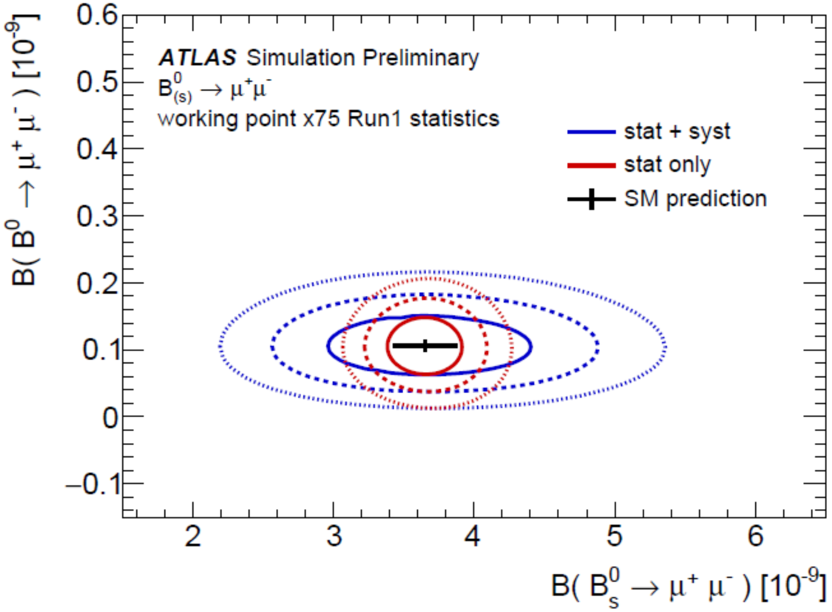


ATLAS Projection for the future

Extrapolated from Run1 measurement

	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$		$\mathcal{B}(B^0 \to \mu^+\mu^-)$	
	stat $[10^{-10}]$	stat + syst $[10^{-10}]$	stat $[10^{-10}]$	stat + syst $[10^{-10}]$
Run 2	7.0	8.3	1.42	1.43
HL-LHC: Conservative	3.2	5.5	0.53	0.54
HL-LHC: Intermediate	1.9	4.7	0.30	0.31
HL-LHC: High-yield	1.8	4.6	0.27	0.28





Conclusion

- LHC experiments have been painstakingly improving their measurements of the process $B_s \rightarrow \mu^+\mu^-$.
- Results are in agreement with Standard Model.
  But beyond SM physics may be lurking behind!
  ➔ need precise measurement of related observables, like, effective lifetime.
- LHCb has combined Run1 and part of the Run2 data to achieve 7σ observation of $B_s \rightarrow \mu^+\mu^-$ by a single experiment.
- LHCb has also measure effective lifetime which agrees with Standard Model.
- No new result, based on Run2 data (13 TeV) from ATLAS and CMS as yet.
- With analysis of more data on-going, expect exciting results in near future from LHC experiments.
- Coming decade will see improved detectors and hence higher potential.

Stay tuned!

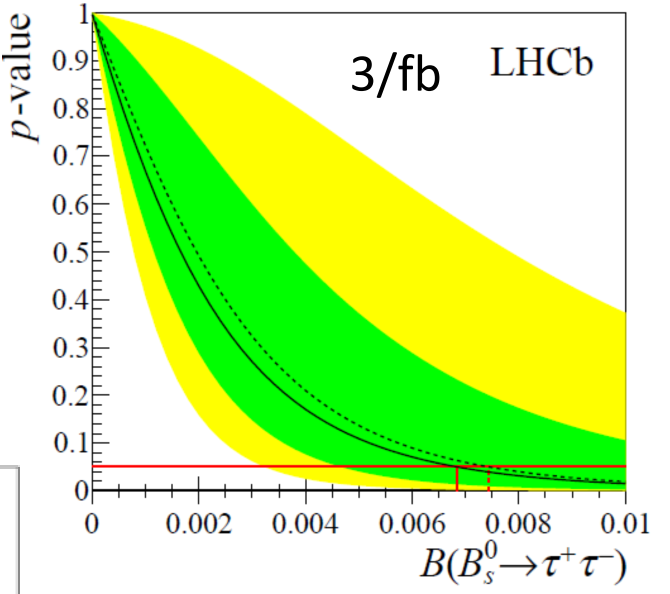
BACKUP

$B_s \to \tau^+\tau^-$

- Measurement has become more important in view of possible violation of lepton flavour universality in recent measurement of R(D*) etc..
- Extremely challenging due to presence of νs in the final state
- LHCb analysis cannot distinguish between B_d & B_s
- Control channel: $B^0 \to D^+(K^-\pi^+\pi^+)\, D_s^-\,(K^+K^-\pi^-)$

$$\boxed{\mathcal{B}(B_s^0 \to \tau^+\tau^-) < 5.7\,(7.4) \times 10^{-3} \text{ at } 90\,(95)\%\text{ CL}}$$

- Currently the best limit
- Factor of 2.6 improvement compared to Babar

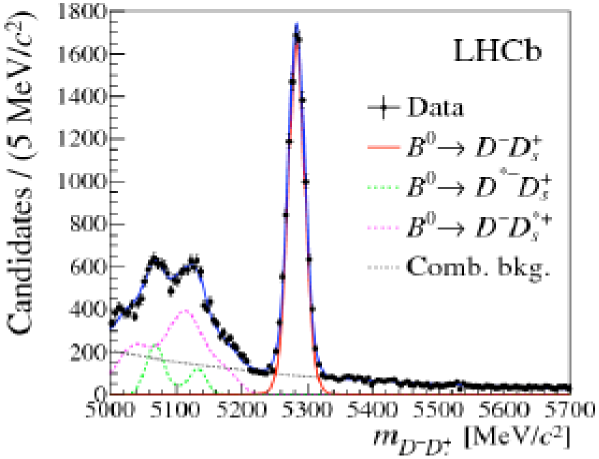


$$\mathcal{B}(B^0 \to \tau^+\tau^-)_{\rm SM} = (2.22 \pm 0.19) \times 10^{-8}$$
$$\mathcal{B}(B_s^0 \to \tau^+\tau^-)_{\rm SM} = (7.73 \pm 0.49) \times 10^{-7}$$

SM prediction:

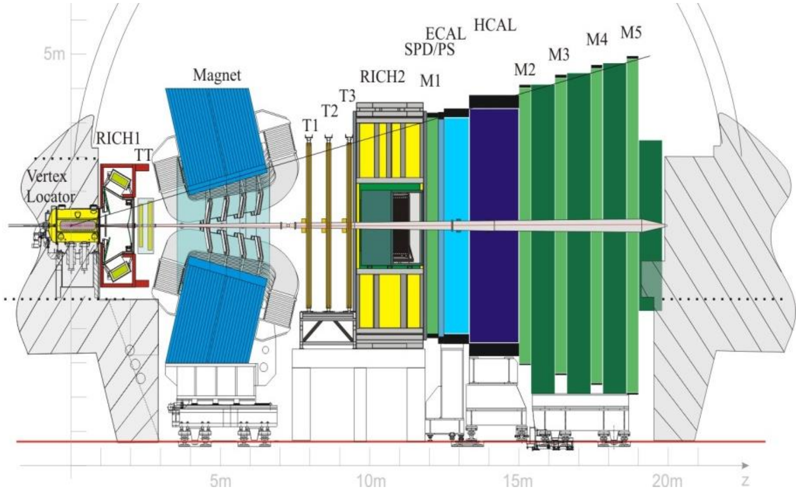
Bobeth et.al PRL 112, 101801

Phys. Rev. lett 118 (2017) 191801



LHCb detector

- Single-arm forward spectrometer
- ~ 4% of solid angle coverage ($2 < \eta < 5$)
- accepts ~ 30% of b-hadrons
- bb pairs in 1 /fb data: ~ $1.8*10^{11}$



✓ Excellent tracking, particle identification, efficient trigger

✓ Two RICH detectors for particle identification

✓ Hadronic & electromagnetic calorimeters

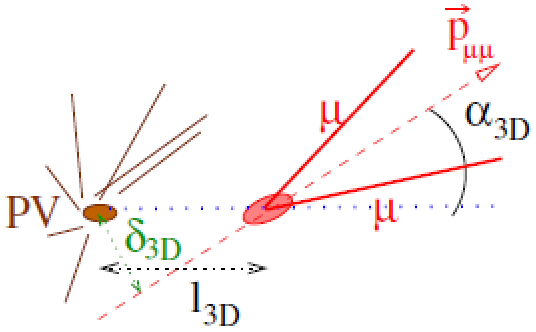
✓ Precision silicon vertex locator (VELO)

Designed to run at low instantaneous luminosity ($2x10^{32}$ cm^{-2} s^{-1})
→ Maximum luminosity levelled to $4x10^{32}$ cm^{-2} s^{-1}

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \frac{N_{B_s^0\to\mu^+\mu^-}}{N_{\text{norm.}}} \times \frac{f_d}{f_s} \times \frac{\varepsilon_{\text{norm.}}}{\varepsilon_{B_s^0\to\mu^+\mu^-}} \times \mathcal{B}_{\text{norm.}} = \alpha_{\text{norm.}} \times N_{B_s^0\to\mu^+\mu^-}$$

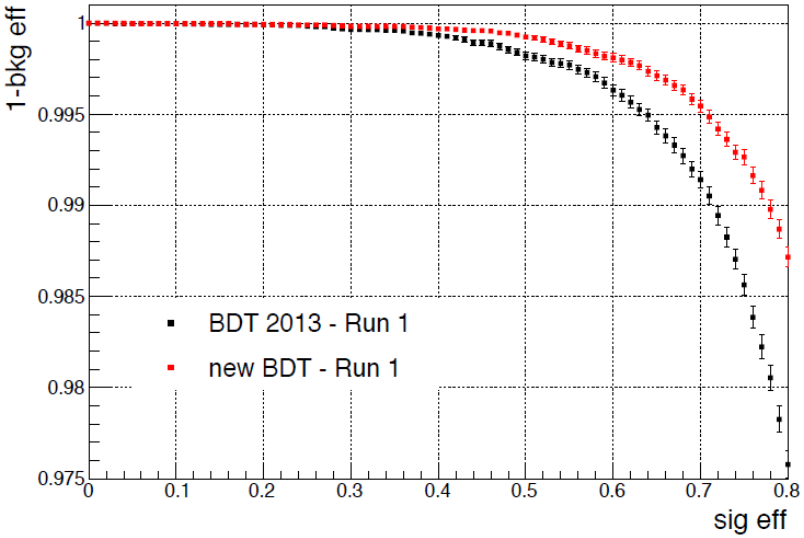
fd/fs = 3.86± 0.22

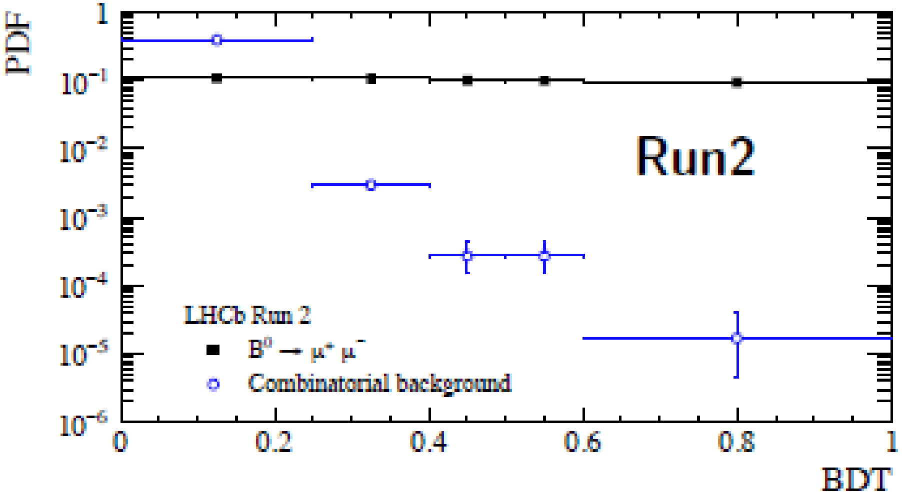
$$\begin{aligned}\mathcal{B}(B_s^0 \to \mu^+\mu^-) &= \frac{n^{\text{obs}}_{B_s^0}}{\varepsilon_{B_s^0}\, N_{B_s^0}} = \frac{n^{\text{obs}}_{B_s^0}}{\varepsilon_{B_s^0}\, \mathcal{L}\, \sigma(pp \to B_s^0)} \\ &= \frac{n^{\text{obs}}_{B_s^0}}{N(B^+ \to J/\psi\, K^+)} \frac{A_{B+}}{A_{B_s^0}} \frac{\varepsilon^{ana}_{B+}}{\varepsilon^{ana}_{B_s^0}} \frac{\varepsilon^{\mu}_{B+}}{\varepsilon^{\mu}_{B_s^0}} \frac{\varepsilon^{trig}_{B+}}{\varepsilon^{trig}_{B_s^0}} \frac{f_u}{f_s} \mathcal{B}(B^+ \to J/\psi\, [\mu^+\mu^-] K)\end{aligned}$$



Improvements in LHCb : Run2 wrt Run1

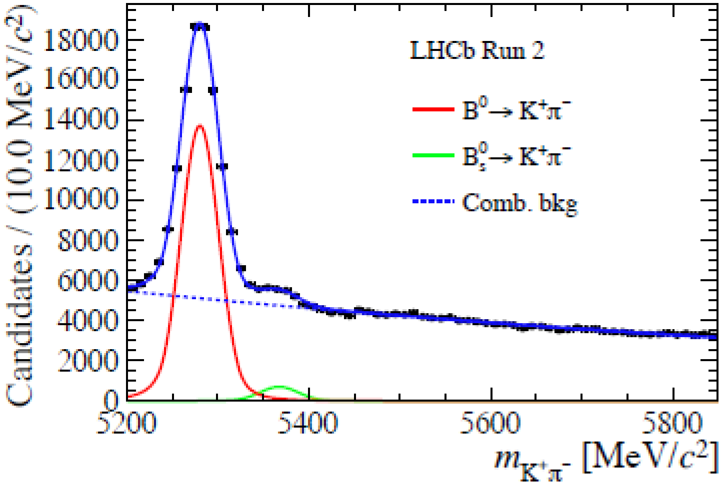
BDT-based isolation





- Signal BDT shape from B → Kπ,
- Background: di-muon mass sidebands

Aspects of LHCb analysis



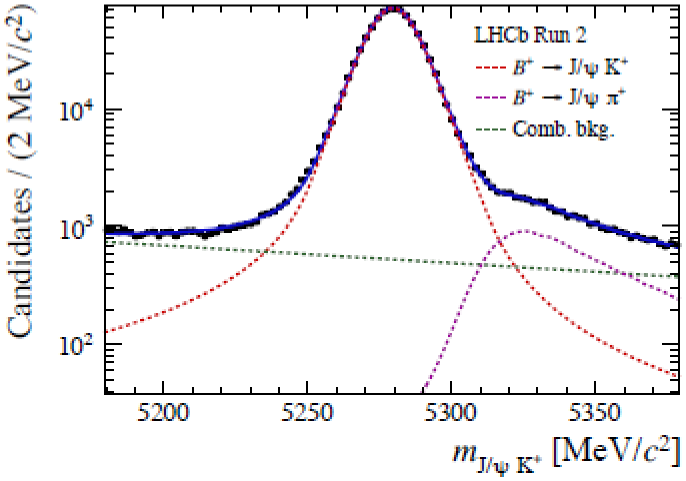
- Background: Combinatorial + Exclusive

→Decays with one or 2 hadrons (identified as μ):

$B_s \to h^+ h^-$, $B^0_{d/s} \to \pi^- / K^- \mu^+ \nu$, $\Lambda^0_b \to p\, \mu^+ \nu$,

$B^+c \to J/\Psi(\to \mu\mu^-)\mu^+ \nu$, $B^+ \to \pi^- \mu^+ \nu$

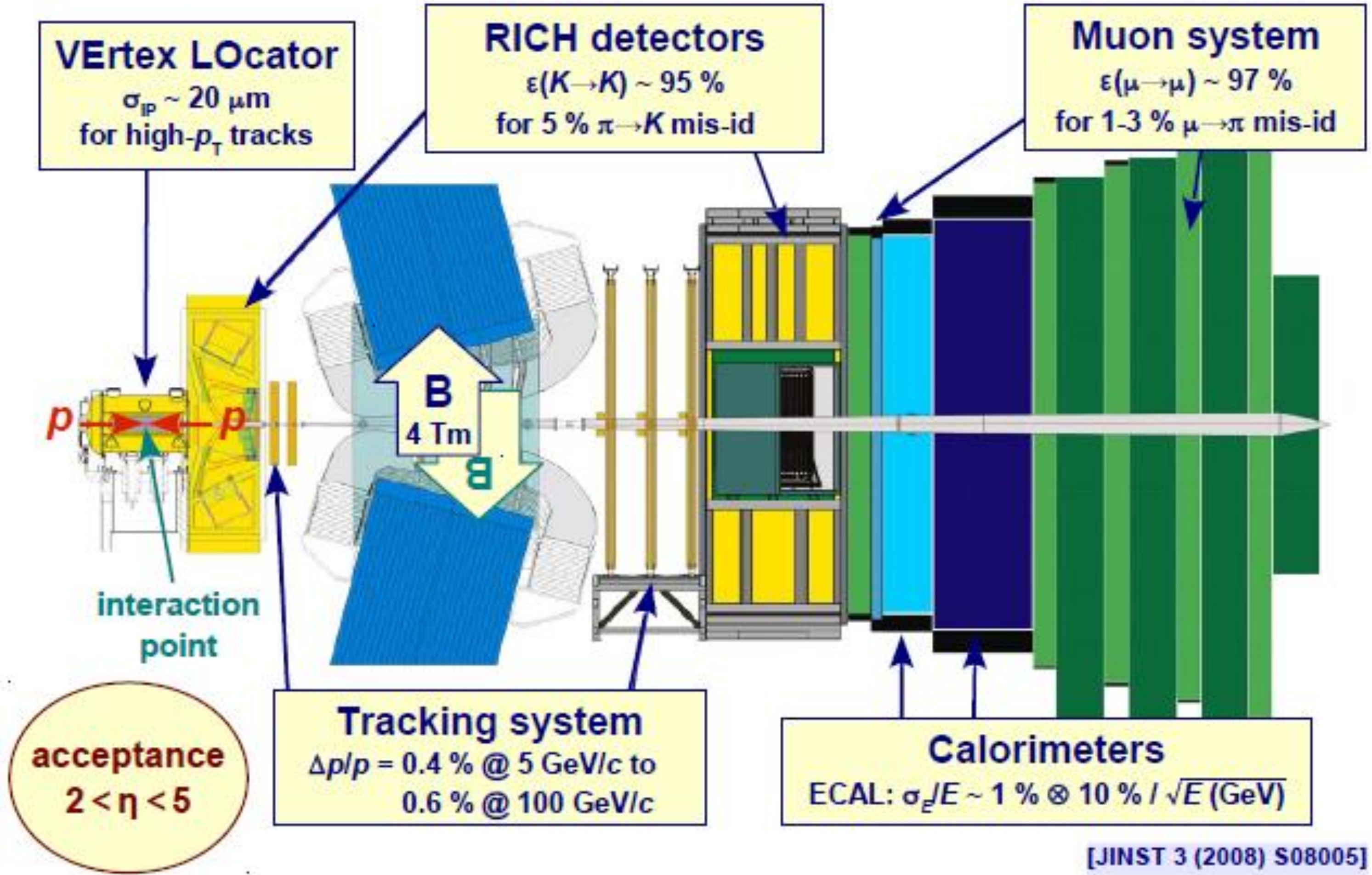
Negligible: $B^0s \to \mu^-\mu^+ \gamma$, $B^0s \to \mu^-\mu^+ \nu\nu$



$$\mathrm{BR} = \mathrm{BR_{cal}} \times \frac{\epsilon^{Acc}_{norm}}{\epsilon^{Acc}_{sig}} \times \frac{\epsilon^{RecSel|Acc}_{norm}}{\epsilon^{RecSel|Acc}_{sig}} \times \frac{\epsilon^{Trig|RecSel}_{norm}}{\epsilon^{Trig|RecSel}_{sig}} \times \frac{f_{\mathrm{cal}}}{f_{d(s)}} \times \frac{N_{B^0_{(s)} \to \mu^+\mu^-}}{N_{\mathrm{cal}}} = \alpha_{(s)} \times N_{B^0_{(s)} \to \mu^+\mu^-}$$

LHCb-CONF-2013-011

LHCb Apparatus



VErtex LOcator
$\sigma_{IP} \sim 20\ \mu m$
for high-p_T tracks

RICH detectors
$\varepsilon(K \rightarrow K) \sim 95\ \%$
for 5 % $\pi \rightarrow K$ mis-id

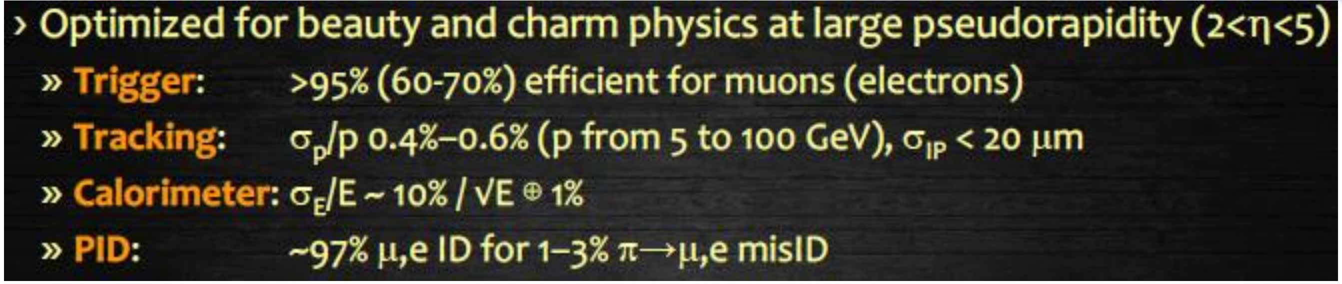
Muon system
$\varepsilon(\mu \rightarrow \mu) \sim 97\ \%$
for 1-3 % $\mu \rightarrow \pi$ mis-id

acceptance
$2 < \eta < 5$

Tracking system
$\Delta p/p = 0.4\ \%$ @ 5 GeV/c to
0.6 % @ 100 GeV/c

Calorimeters
ECAL: $\sigma_E/E \sim 1\ \% \otimes 10\ \% / \sqrt{E}$ (GeV)

[JINST 3 (2008) S08005]



› Optimized for beauty and charm physics at large pseudorapidity ($2<\eta<5$)
  - **Trigger:** >95% (60-70%) efficient for muons (electrons)
  - **Tracking:** σ_p/p 0.4%–0.6% (p from 5 to 100 GeV), $\sigma_{IP} < 20\ \mu m$
  - **Calorimeter:** $\sigma_E/E \sim 10\% / \sqrt{E} \oplus 1\%$
  - **PID:** ~97% μ,e ID for 1–3% $\pi \rightarrow \mu$,e misID

Experimental issues in general

- ATLAS, CMS and LHCb all have far better measurement capability for measuring μ than e

- Trigger, reconstruction, selection, particle identification are more difficult for e (trigger eff. For CMS: 50 -80 %)

- Mass resolution is affected by bremsstrahlung for e

→ Need energy recovery

→ Mass shape modeled according to the number of brem-photon recovered

- Blind analysis ➔ optimized selection, muon misidentification probability, resilience with event pileup.

  ➔ categorized multivariate analysis essential

No new result, based on Run2 data (13 TeV) from ATLAS and CMS as yet.