Observation of $B^0_s \to \mu^+\mu^-$ and measurement of its effective lifetime with LHCb Run2 data

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On behalf of the LHCb collaboration
CERN seminar - 14/02/2017

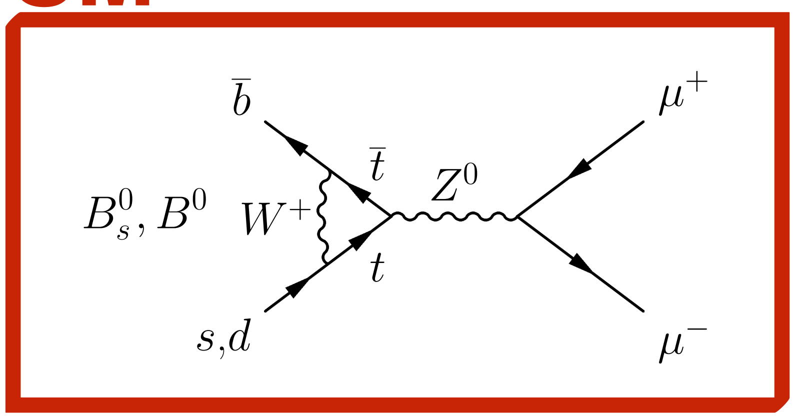
Outline

- Introduction
- Recent results from LHCb:
    - BF($B^0_s \to \mu^+\mu^-$) and search for $B^0 \to \mu^+\mu^-$
    - $B^0_s \to \mu^+\mu^-$ effective lifetime
    - Search for $B^0_{(s)} \to \tau^+\tau^-$
- Prospects
- Conclusions

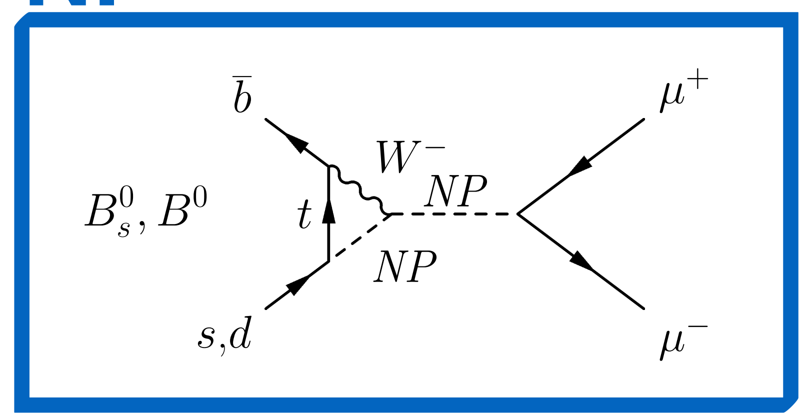
Rare b decays

- Precise measurement sensitive to New Physics effect beyond the SM.
- Flavour Changing Neutral Currents (FCNC) are suppressed at tree level in the **SM**.
- **NP** contributions can arise at the same level of or larger than **SM** one

SM



NP



- FCNC processes can be described by an effective Hamiltonian describing the four fermion interaction

$$\mathcal{H}_{eff} = -\frac{4G_{\mathrm{F}}}{\sqrt{2}\pi} V_{ts}^* V_{tb} \sum_i [C_i \mathcal{O}_i + C'_i \mathcal{O}'_i]$$

- C_i Wilson coefficients
- O_i four-fermion operators

$B^0_{(s)} \to \ell^+\ell^-$

- Pure leptonic decays $B \to \ell^+\ell^-$ are even rarer in the SM due to helicity suppression
- The branching fraction can be written as:

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

- Only C_{10} (vector-axial Wilson coefficient) is non-zero in the SM.
- In case of NP, e.g. model with extended Higgs sectors, contributions also from C_S and C_P are predicted. Large effects already ruled out.
- Extra observables needed to break degeneracy such as:

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

Effective lifetime

- The effective lifetime is defined as

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

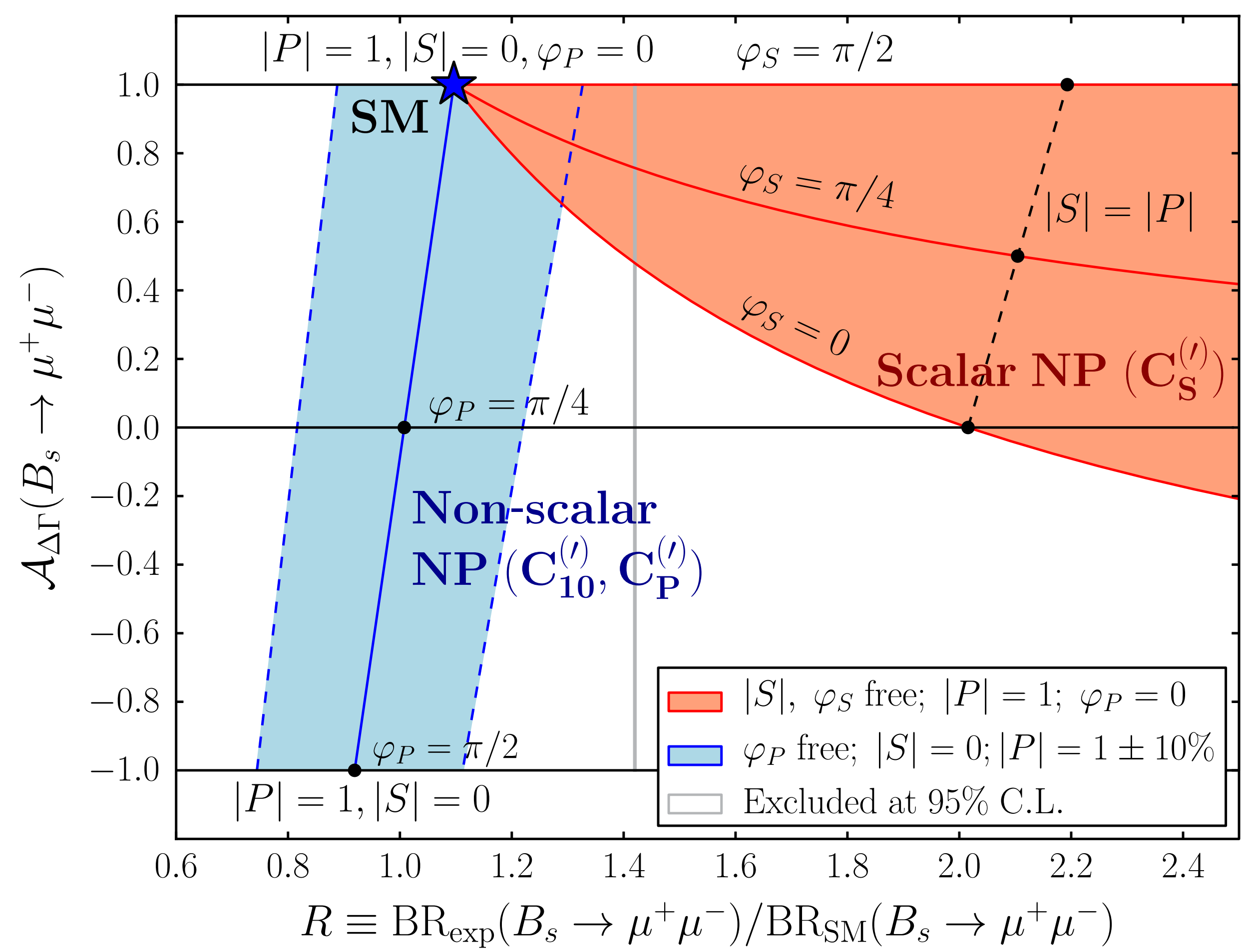
- The following holds

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

- Where:

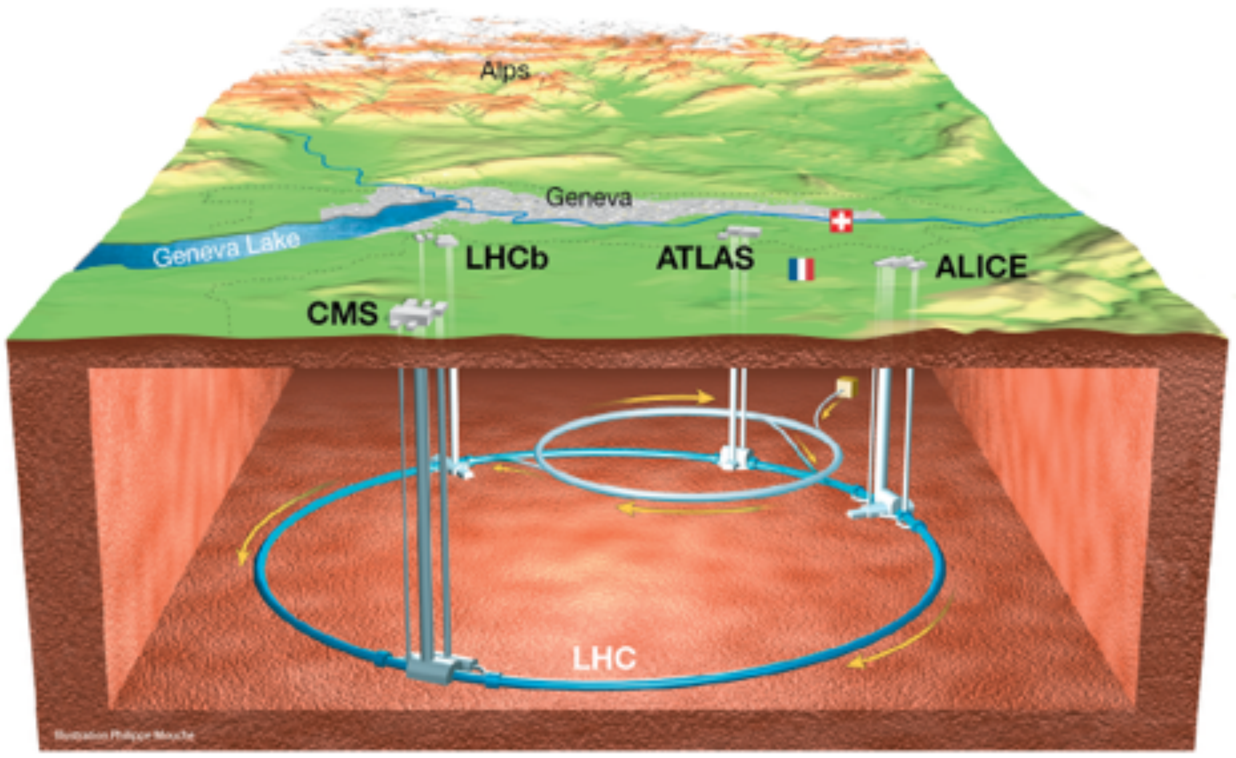
$$y_s \equiv \tau_{B_s}\Delta\Gamma/2 = 0.062 \pm 0.006$$

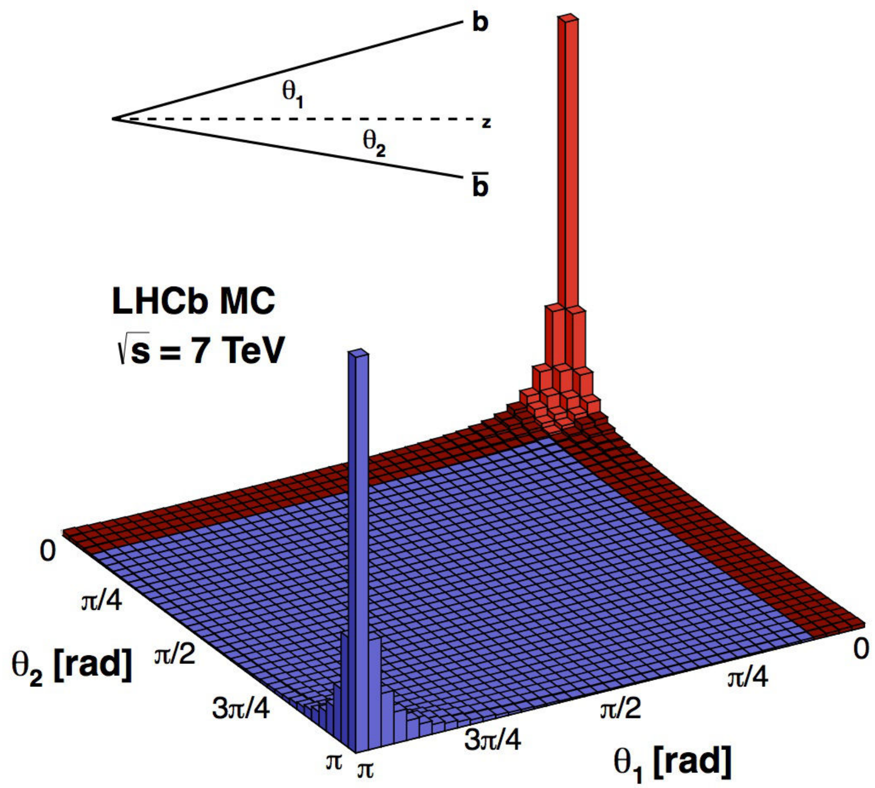
[K. De Bruyn et al. Phys.Rev.Lett. 109 (2012) 041801]



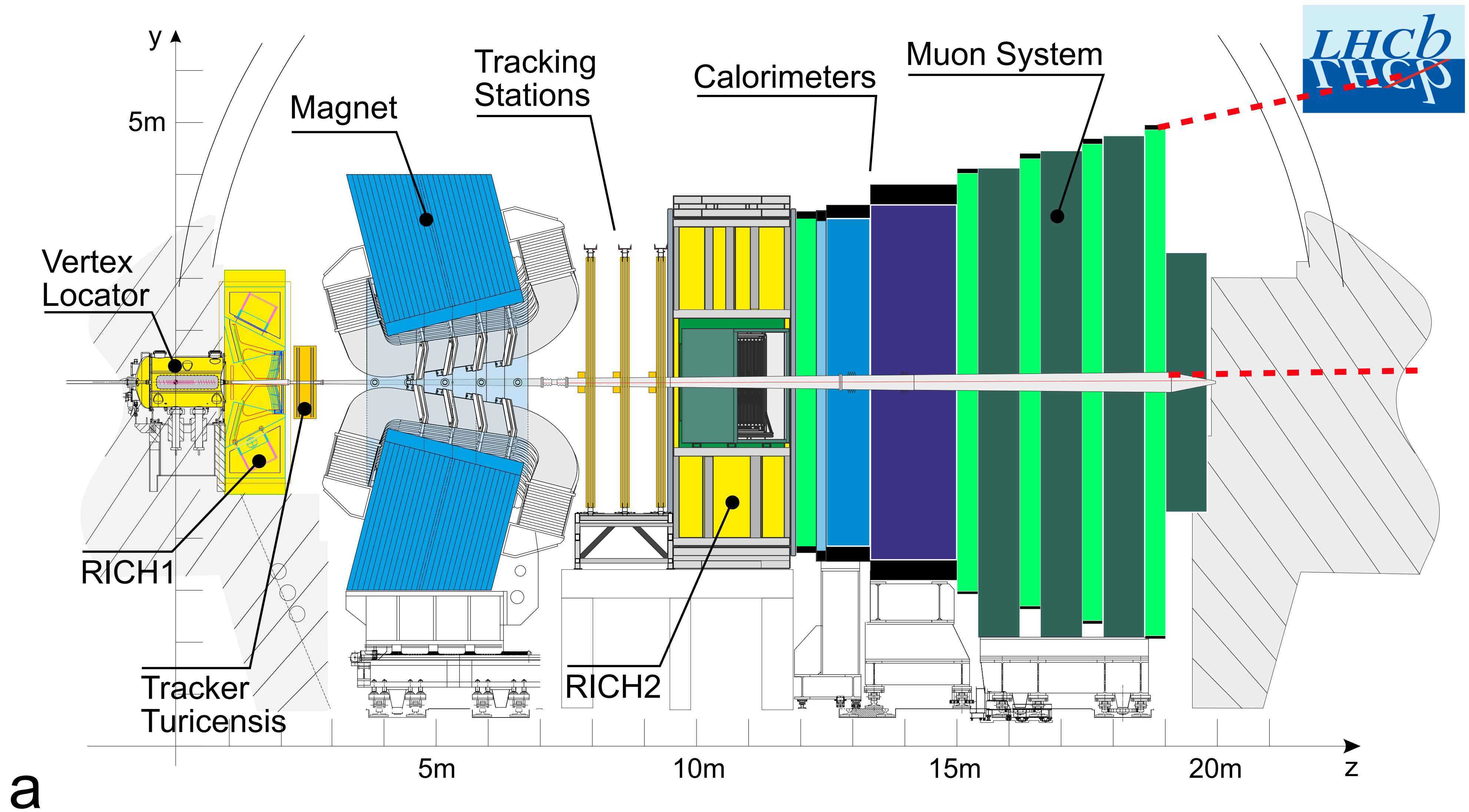
LHCb experiment

- 1225 members, from 71 institutes in 16 countries
- Dedicated experiment for precision measurements of CP violation and rare decays of heavy-flavoured hadrons
- pp collision at $\sqrt{s} = 7, 8, 13$ TeV
- $b\bar{b}$ quark pairs produced predominately in the forward (or backward) region





LHCb Detector



Excellent vertex and IP resolution:

$\sigma(IP) \simeq 24\mu m$ at $p_T = 2GeV$

Good momentum resolution:

$\sigma(p)/p \simeq$ 0.4-0.6% for $p \in (0,100) GeV/c$

Muon identification:

$\varepsilon_\mu = 98\%$, $\varepsilon_{K\to\mu} = 0.6\%$, $\varepsilon_{\pi\to\mu} = 0.3\%$

Trigger efficiency:

$\varepsilon_\mu = 90\%$ for selected B decays

$B^0_{(s)} \to \mu^+\mu^-$

Theoretical expectations

- CP-averaged time integrated branching fraction predictions:

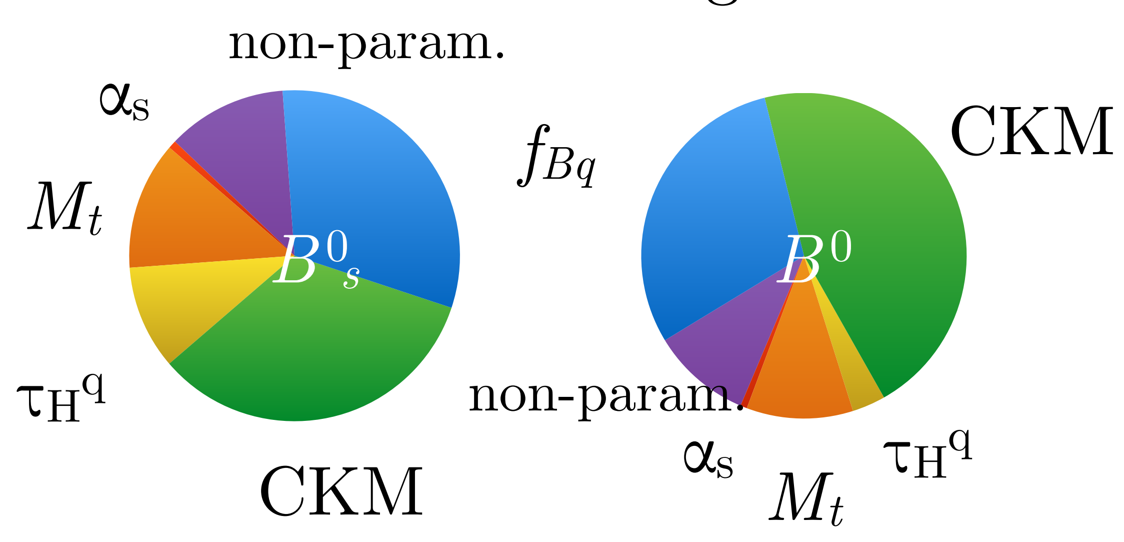
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.66 \pm 0.23) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$$

updated with the latest top mass measurement (Tevatron+LHC combination)

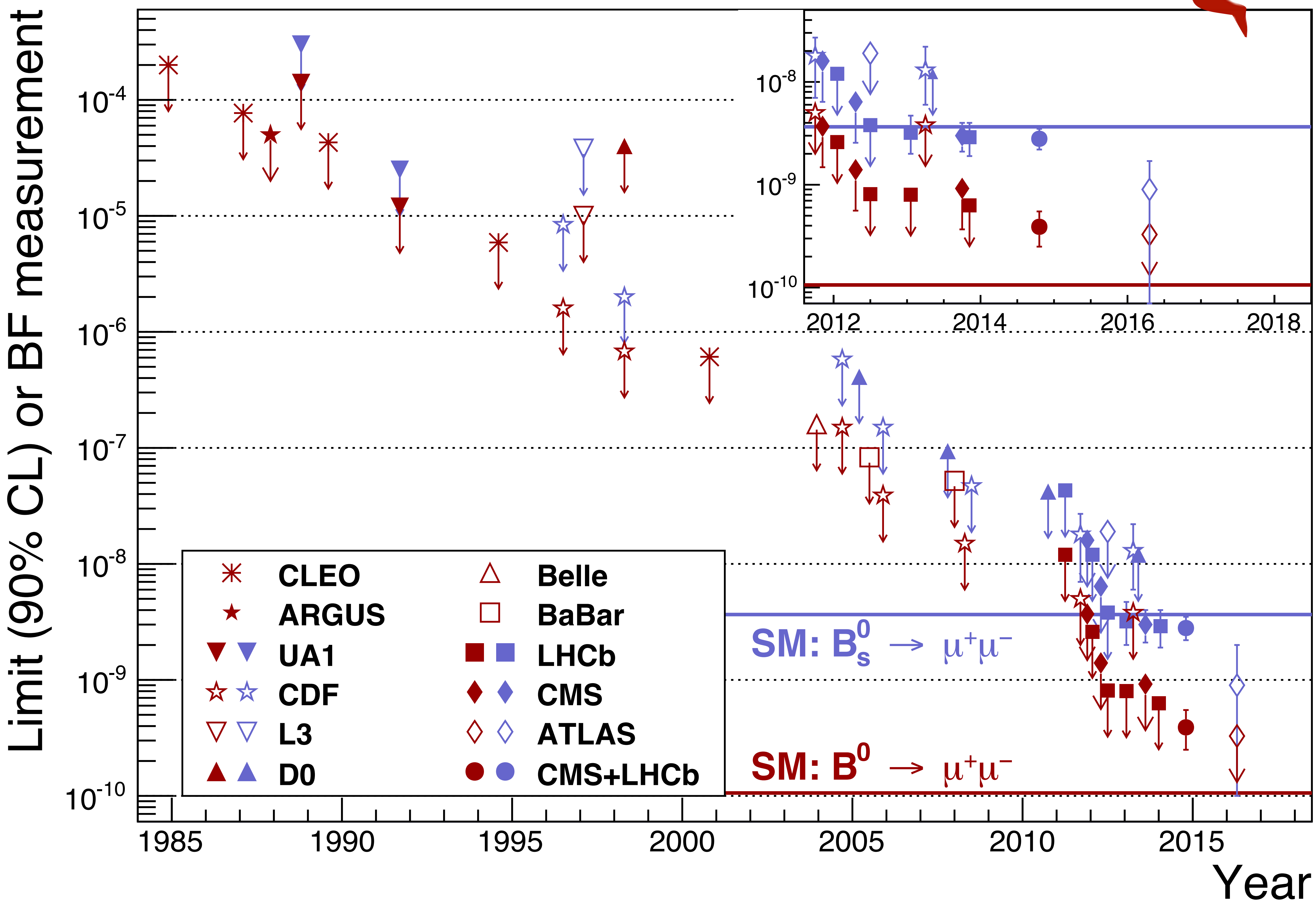
[hep-ex/1403.4427]

Bobeth et al.
[PRL 112 (2014) 101801]

error budgets



Long love story



$B^0_{(s)} \to \mu^+\mu^-$: @ LHC

- CMS-LHCb combined analysis with Run1 data: [Nature 522, 68-72]
  - **Observation of the $B^0_s \to \mu^+\mu^-$**

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = 2.8^{+0.7}_{-0.6} \times 10^{-9}$$

6.2σ significance observed
compatibility with SM at 1.2σ level

  - **Evidence of $B^0 \to \mu^+\mu^-$**

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = 3.9^{+1.6}_{-1.4} \times 10^{-10}$$

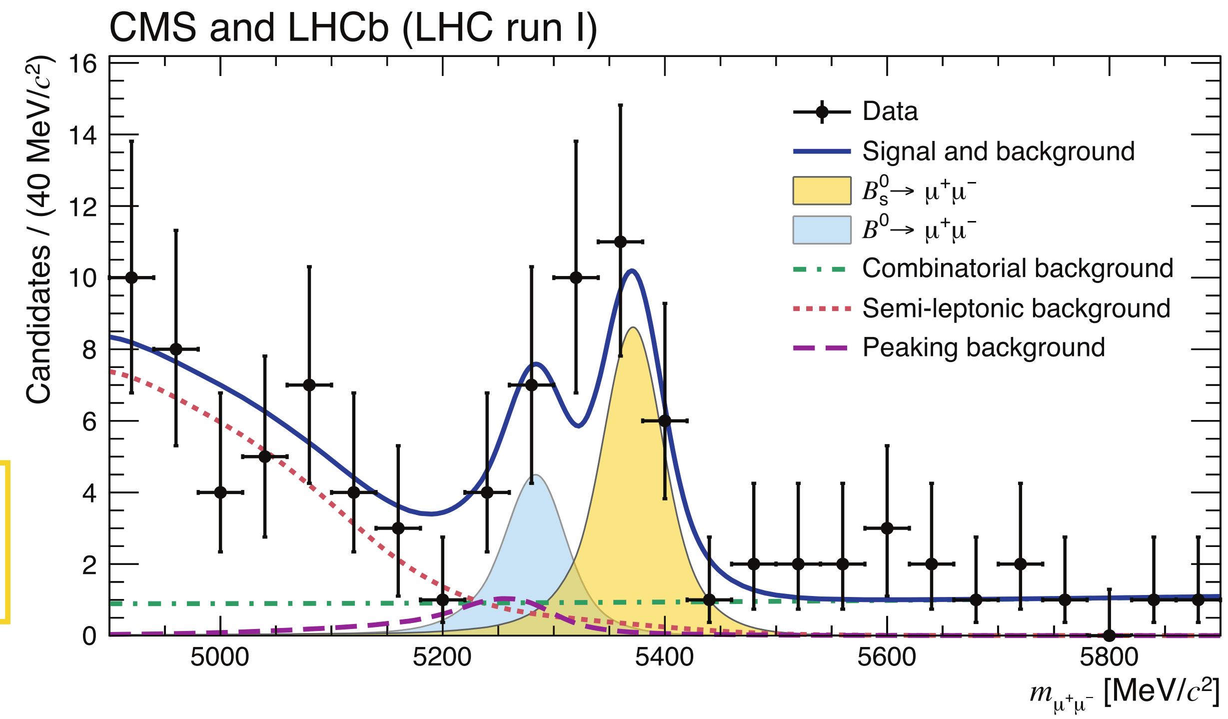
3.0 σ stat. significance
compatibility with SM at 2.2σ level

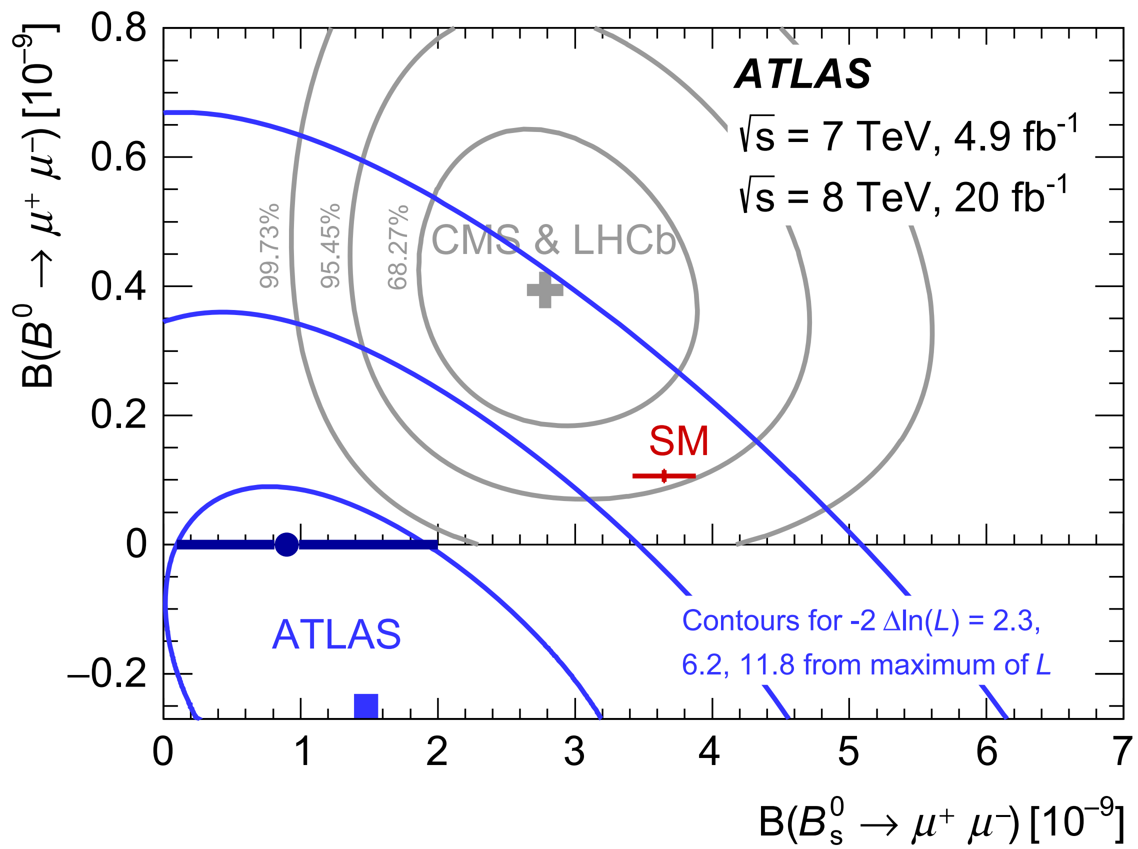
- **ATLAS:** [EPJ C76 (2016) 9, 513]

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

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 4.2 \times 10^{-10} \text{ at } 95\% \text{ C.L.}$$

Mild tension among experimental results.
Excess on B^0 intriguing, to be investigated



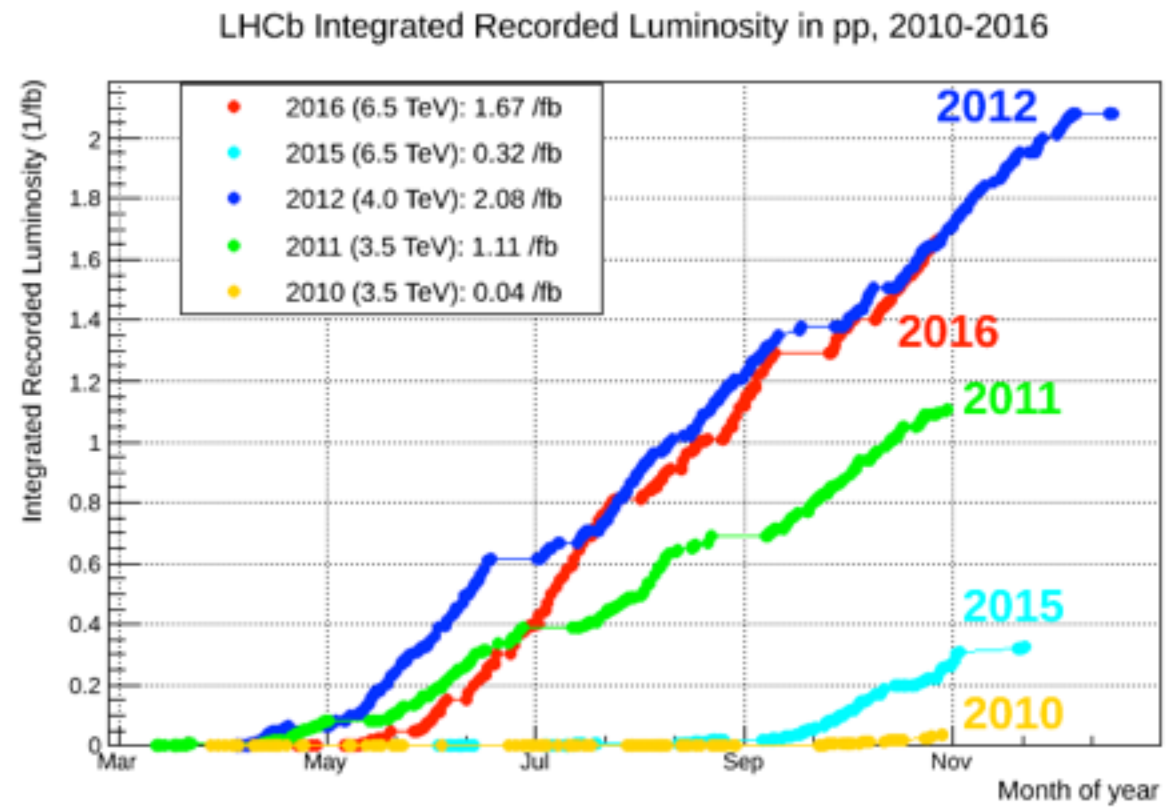


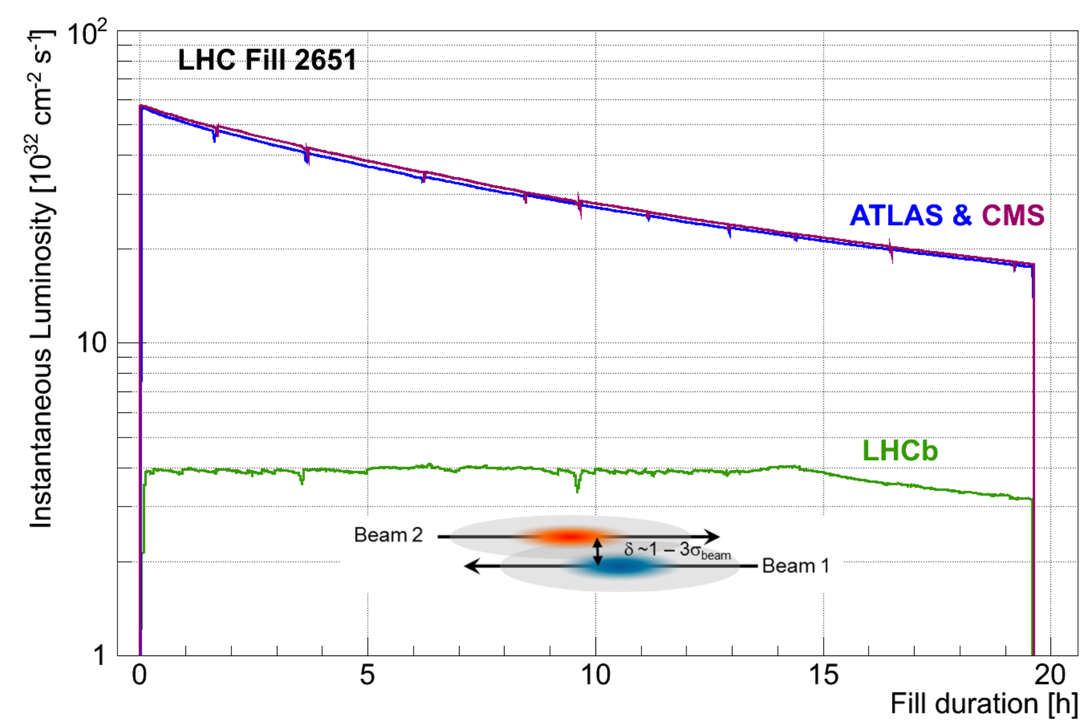
Dataset

- Thanks to the performance of LHC, in 2015-2016 we had another great data-taking period

- The $B^0_{(s)} \to \mu^+\mu^-$ analysis presented today is performed on Run1 data + 1.4fb^{-1} of Run2 data. note that $b\bar{b}$ cross section roughly grows linearly from 7 to 13 TeV/c^2

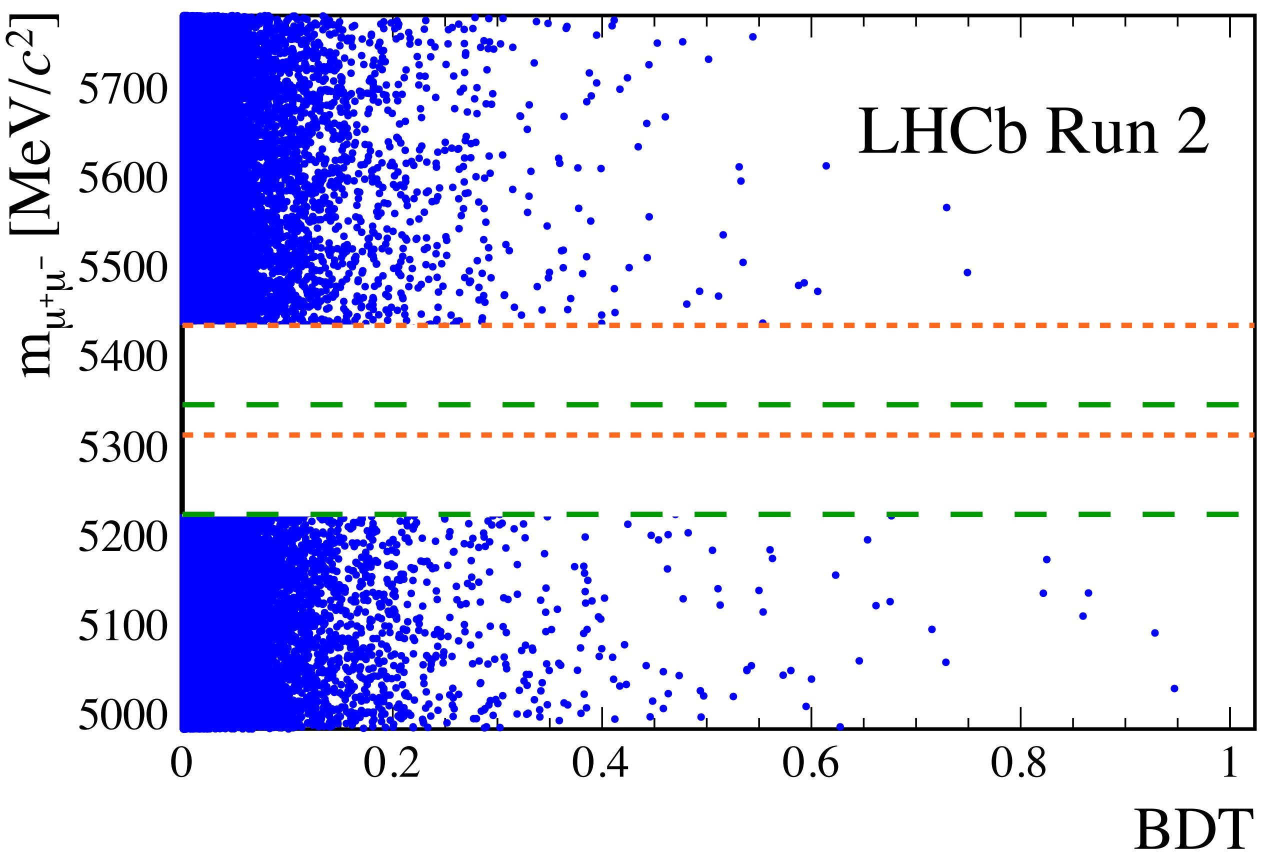
- Luminosity levelled at ~4×10^{32} $cm^{-2}s^{-1}$





$B^0_{(s)}\to\mu^+\mu^-$: strategy (1)

- Significant improvements introduced in the analysis with 13 TeV data.
- A pair of opposite charged muons with and $m_{\mu\mu} \in [4900,6000]$ MeV/c^2 forming good vertex displaced w.r.t. the interaction point; loose MVA selection applied
- **Signal/Background classification in $m_{\mu\mu}$ vs MVA classifier (BDT) plane:**
  - BDT based on kinematic and geometrical variables, trained with MC; calibration for signal with $B^0_{(s)}\to h^+h'^-$ exclusive channels. **Improved in the new analysis, much better BDT performance for combinatorial bkg rejection and tighter PID selection to reject exclusive bkg (optimised for Bd)**



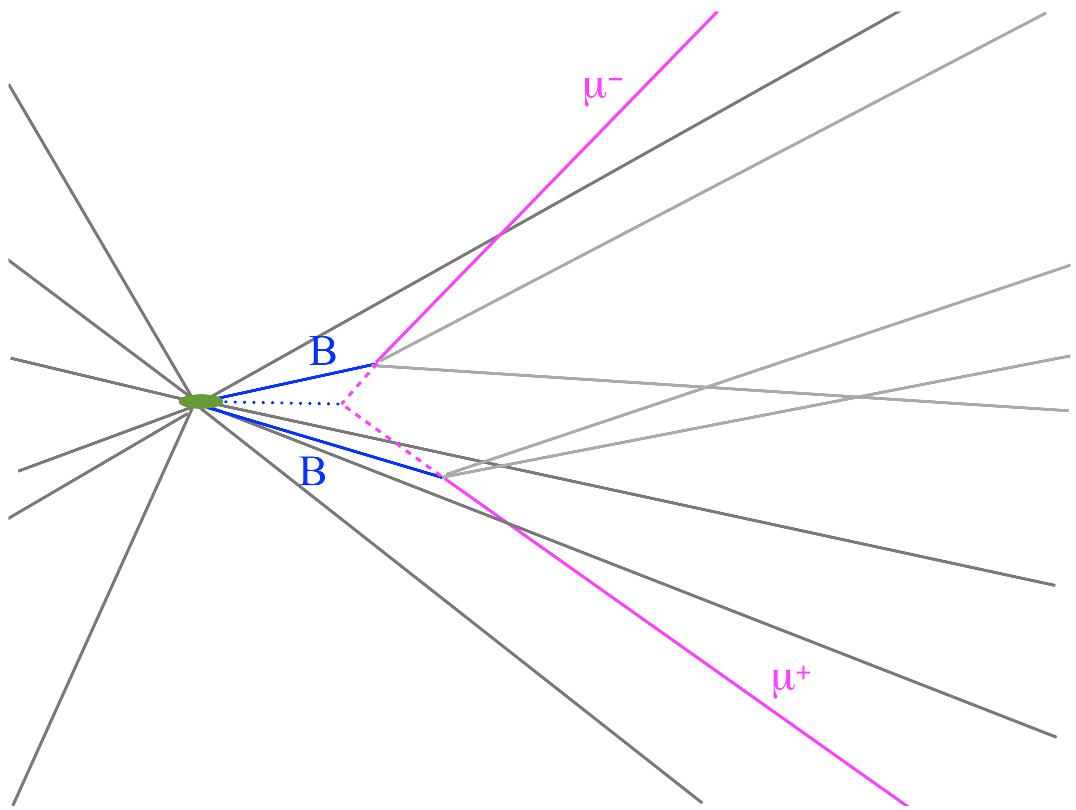
- Search window kept blind until analysis optimised

$B^0_{(s)} \to \mu^+\mu^-$: strategy (2)

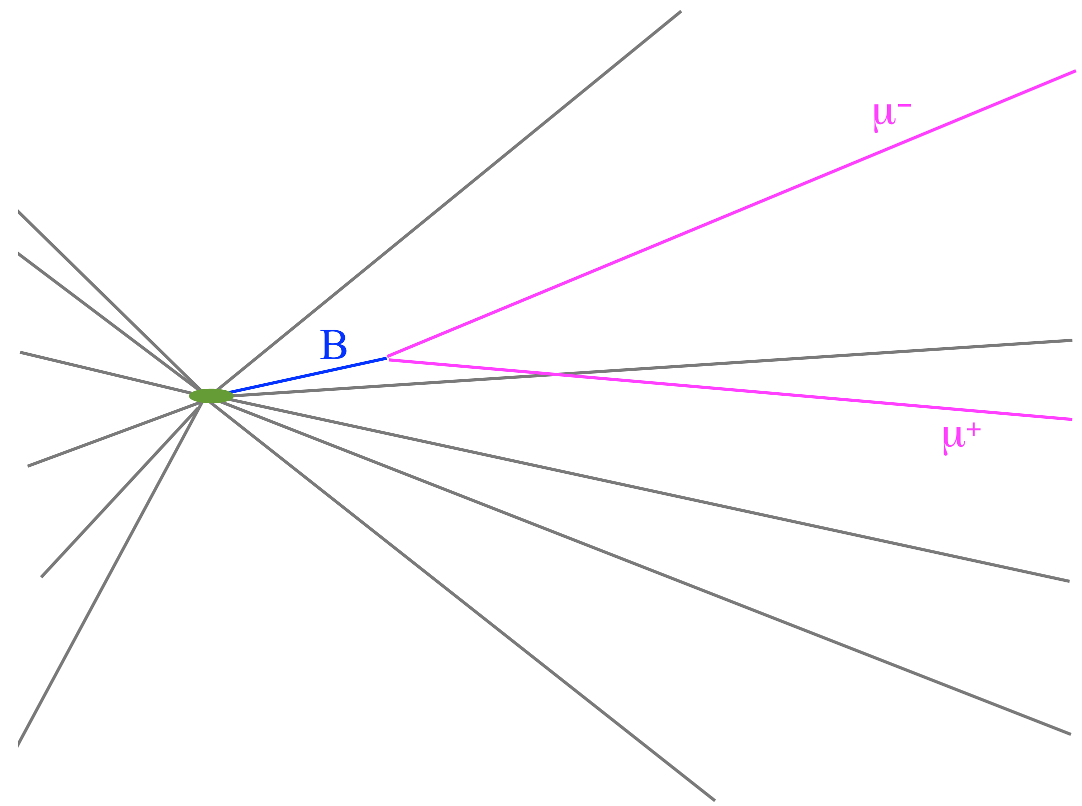
- **Normalisation:**
  - $B^0 \to K\pi$ and $B^+ \to J/\psi K^+$ used as normalisation channels; hadronisation fraction dependence on $\sqrt{s}$ evaluated using $B^+ \to J/\psi K^+$ and $B^0_s \to J/\psi\varphi$
- **Background estimation:**
  - Exclusive background evaluated through a combination of data driven methods, MC and theoretical inputs
- **Results:**
  - Branching fraction from unbinned likelihood fit
  - Upper limit from CLs method
  - Effective lifetime measurement:
    - First measurement, performed from signal weighted decay time fit

$B^0_{(s)} \to \mu^+\mu^-$ discrimination

Dominant combinatorial background from $b\bar{b} \to \mu^+\mu^- X$ decays

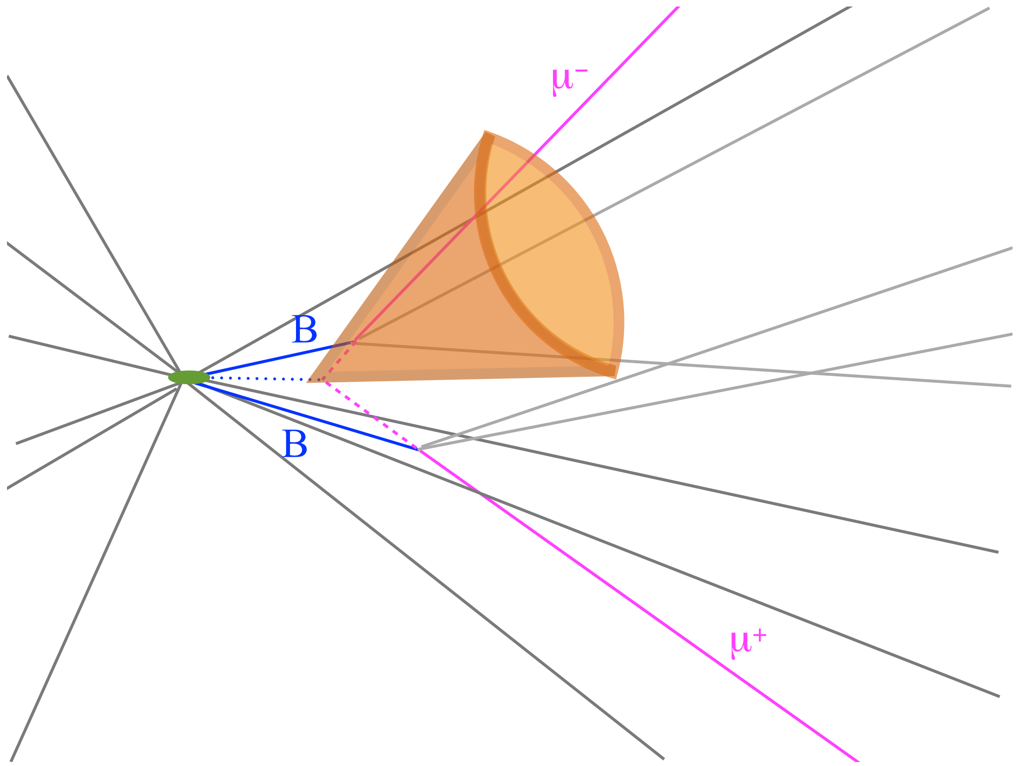


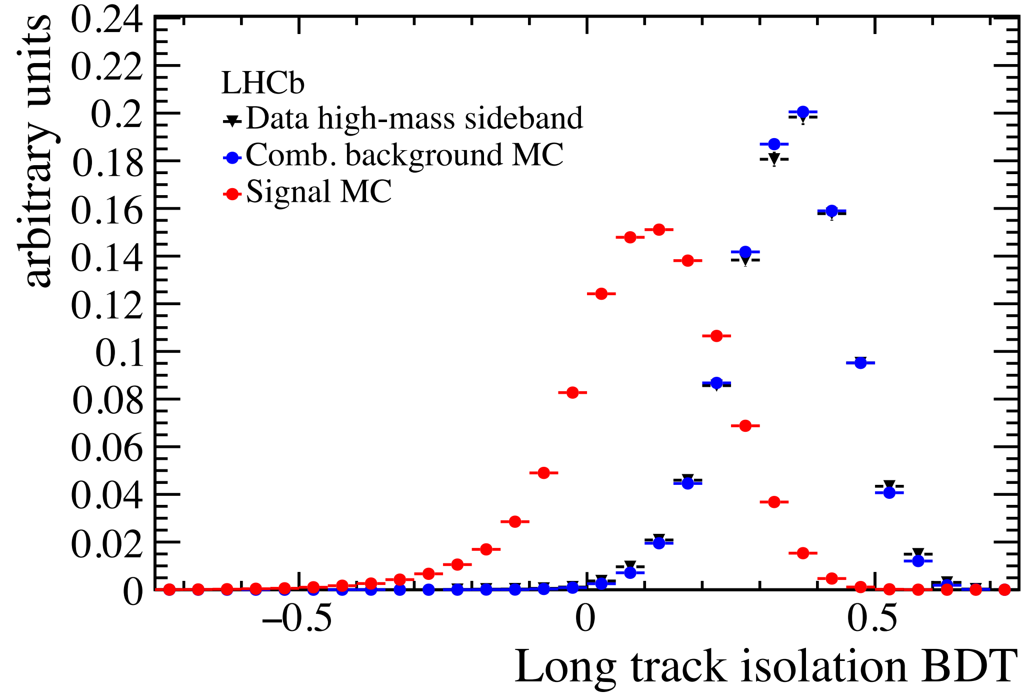
Signal: 2 muons from a single well reconstructed background



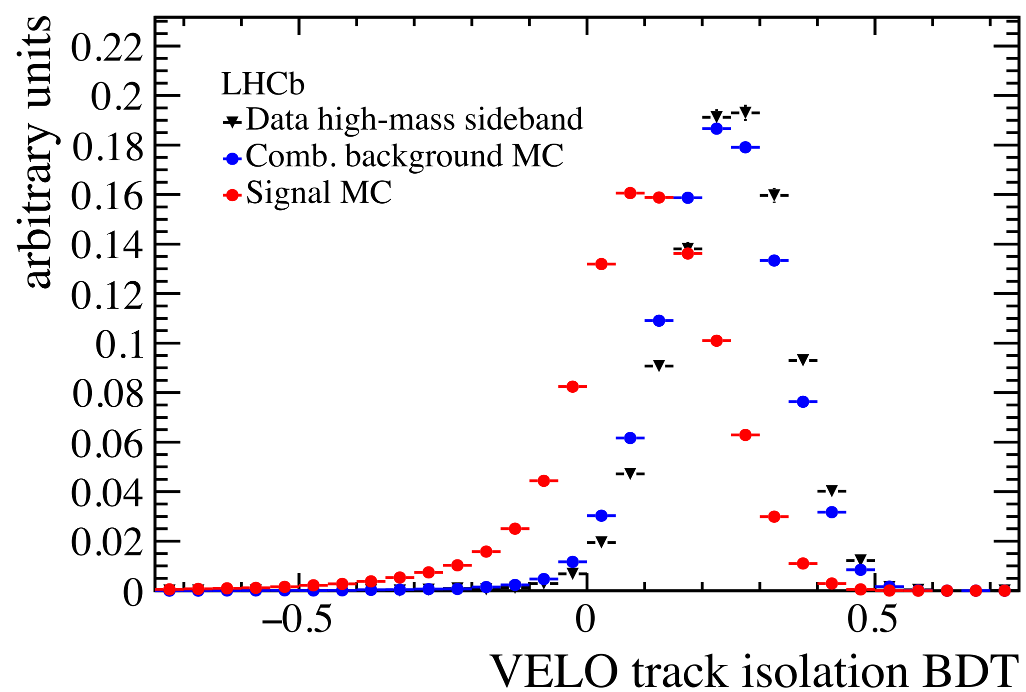
New multivariate classifier trained on simulated events using 7 variables including 2 new isolation variables.

New isolation



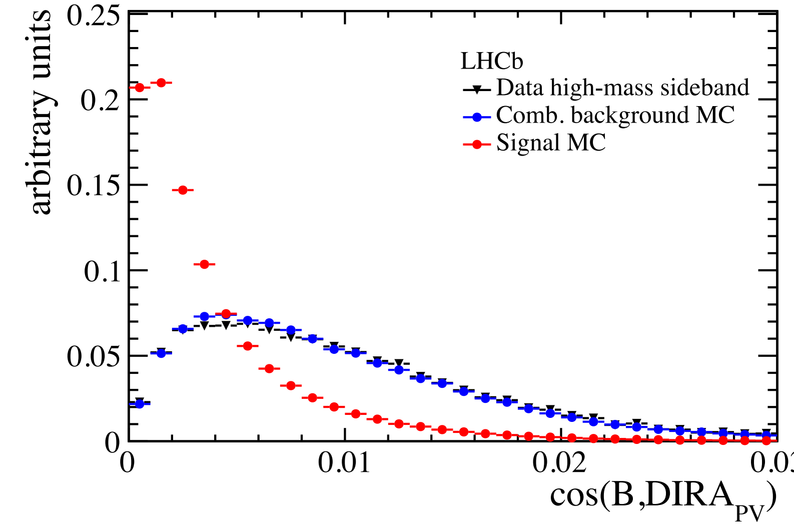


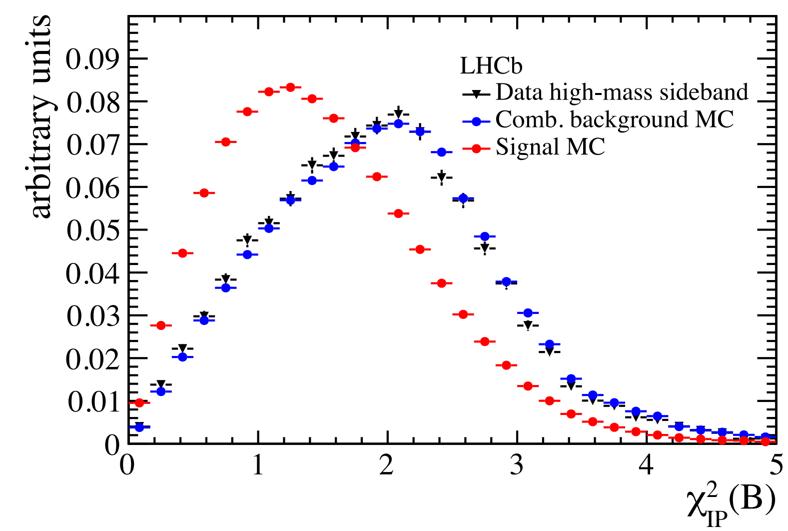
- Previous muon isolation based on rectangular cuts on variables related to the track information
- 2 multivariate classifiers are now used, one with tracks passing through all tracking stations, another with just tracks reconstructed only by the vertex detector.

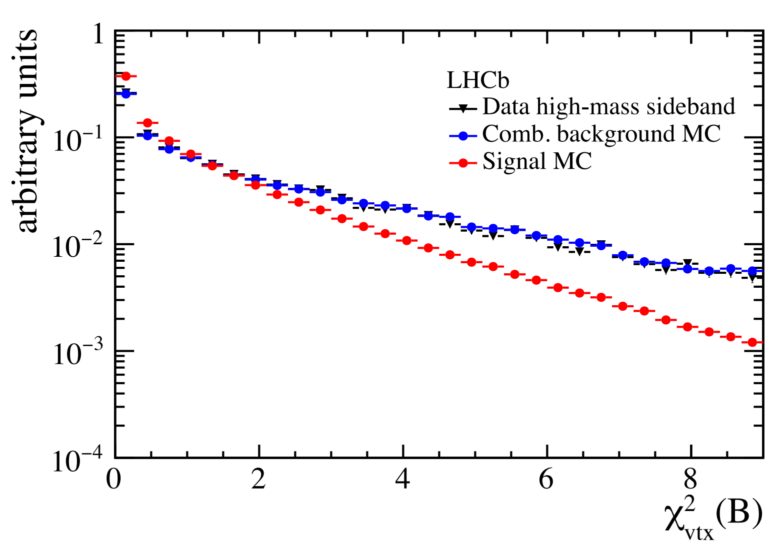


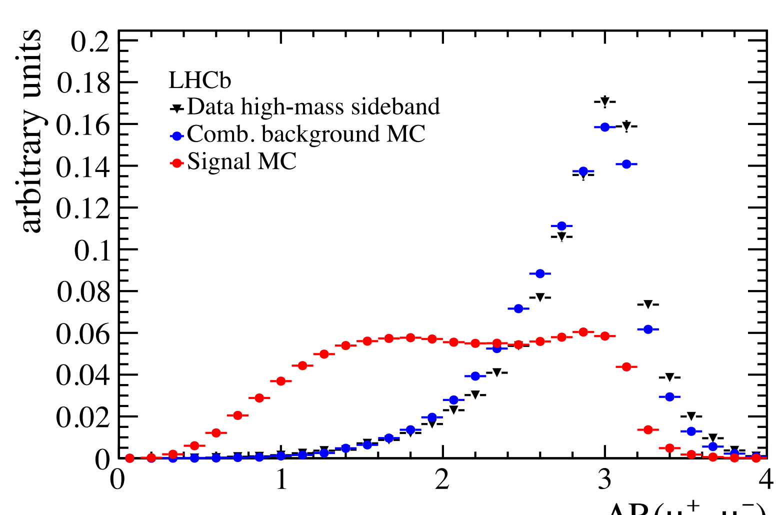
Multivariate classifier

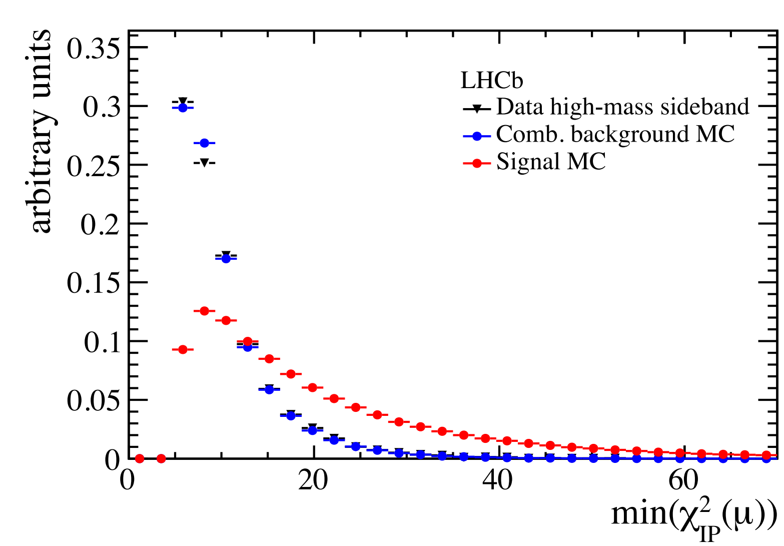
- Isolation variables taken as starting point to train the BDT classifier.
- Optimisation and training on simulated events
- Correlation with invariant mass negligible (below 5%)
- Same definition of the BDT used for Run1 and Run2 datasets while calibration performed independently





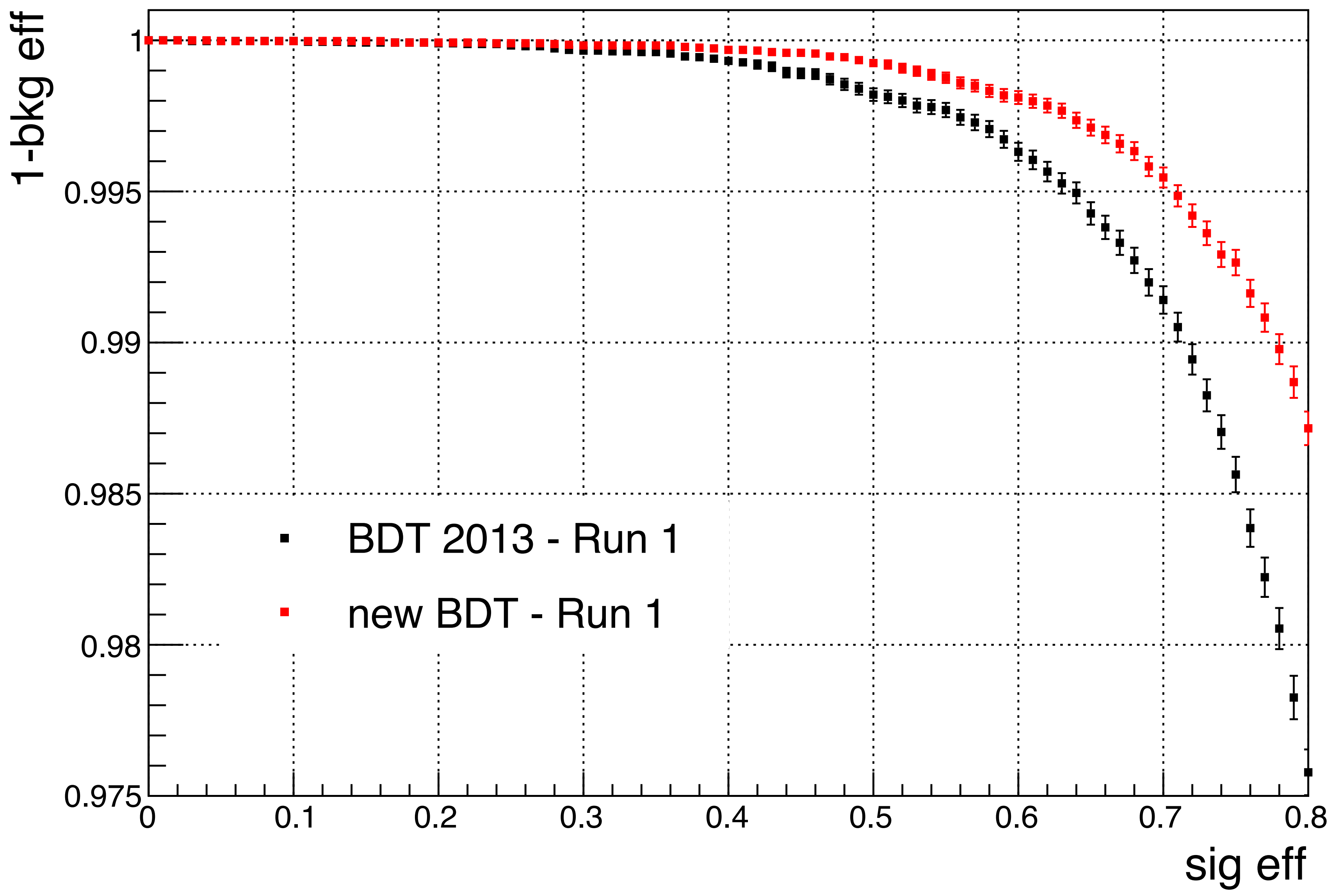






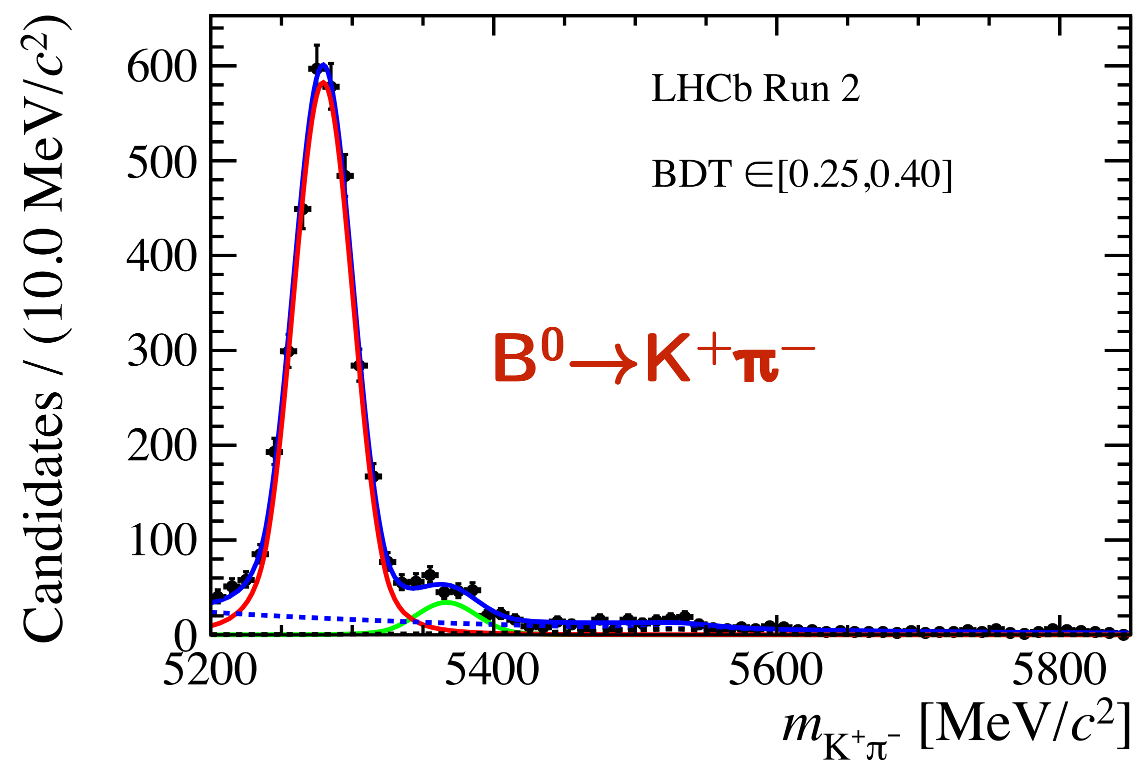
BDT performances

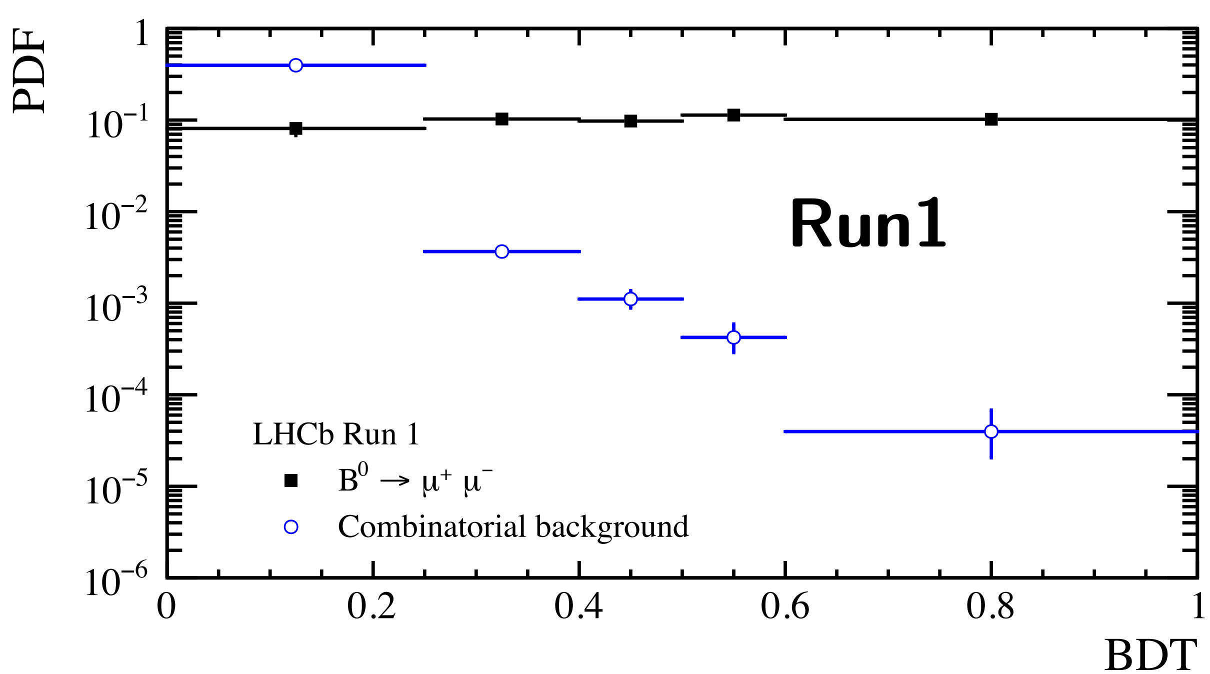
Significant improvement w.r.t. previous classifier observed with simulated events.

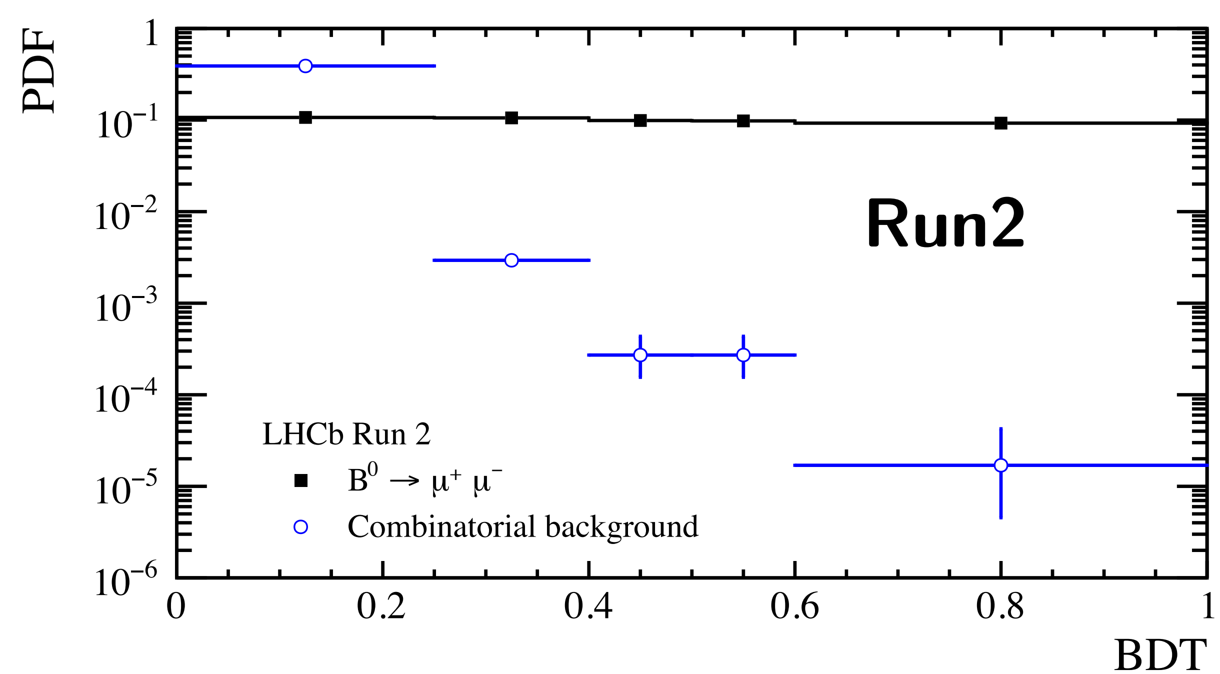


$B^0_{(s)} \to \mu^+\mu^-$: BDT calibration

- BDT output defined to be **flat for signal**, and peaking at zero for background
- Signal BDT shape from $B^0 \to K^+\pi^-$ events, which have same topology as the signal
- Background BDT shape is evaluated on the di-muon mass sidebands







Background sources

- In addition to the main combinatorial background source described by an **exponential shape,** other two categories populate the lower mass range:

  - **Decays with one or two hadrons misidentified as a muon.**
    - $B \to h^+h'^-$
    - $B^0 \to \pi^-\mu^+\nu_\mu$
    - $B^0_s \to K^-\mu^+\nu_\mu$
    - $\Lambda^0_b \to p\mu^-\overline{\nu}_\mu$

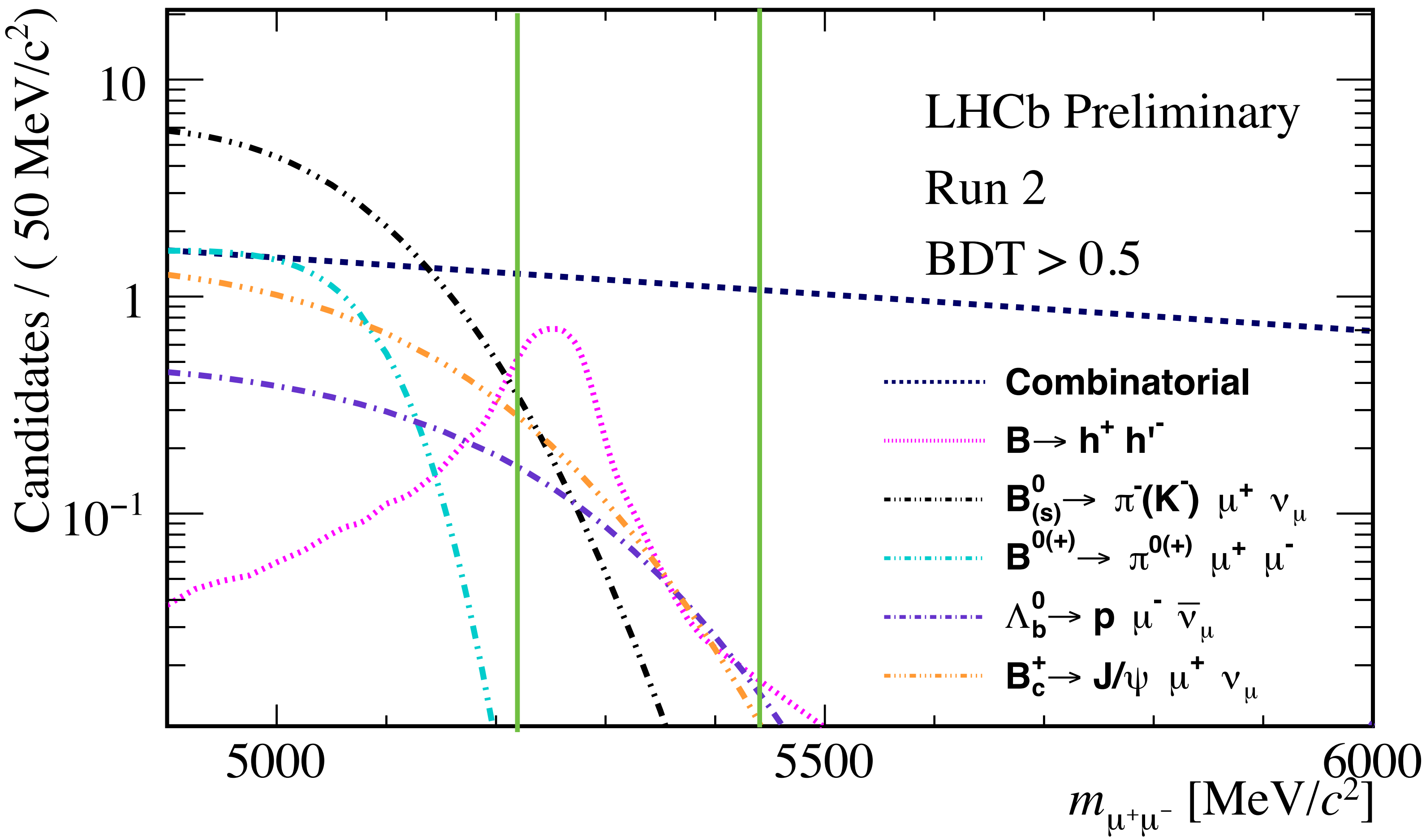
  - **Decays with two real muons.**
    - $B_c^+ \to J/\psi(\to\mu^+\mu^-)\mu^+\nu_\mu$
    - $B^{0(+)} \to \pi^{0(+)}\mu^+\mu^-$

- Mass and BDT pdfs determined from simulated samples with misID probability calibrated on data.
- Expected yields evaluated by normalising on control channels
- Background x-check from independent fits to $K\mu$ and $\pi\mu$ mass spectrum

Exclusive backgrounds

Dominant channels in **signal region** and BDT>0.5:

$B \to h^+ h'^-$	2.9 ± 0.3
$B_c^+ \to J/\psi \mu^+ \nu_\mu$	1.2 ± 0.2
$\Lambda^0_b \to p \mu^- \overline{\nu}_\mu$	0.7 ± 0.1
$B^0 \to h^- \mu^+ \nu_\mu$	0.80 ± 0.06



- $B \to h^+ h'^-$ peaking in the signal region. Factor ~2 reduction w.r.t. previous analysis
- $B^{0(+)} \to \pi^{0(+)} \mu^+ \mu^-$ interplay with combinatorial background.
- All these decays taken into account in the final fit.
- Contribution from $B^0_s \to \mu^+ \mu^- \gamma$ and $B^0_s \to \mu^+ \mu^- \nu_\mu \overline{\nu}_\mu$ decays negligible.

$B^0_{(s)} \rightarrow \mu^+\mu^-$: new performances

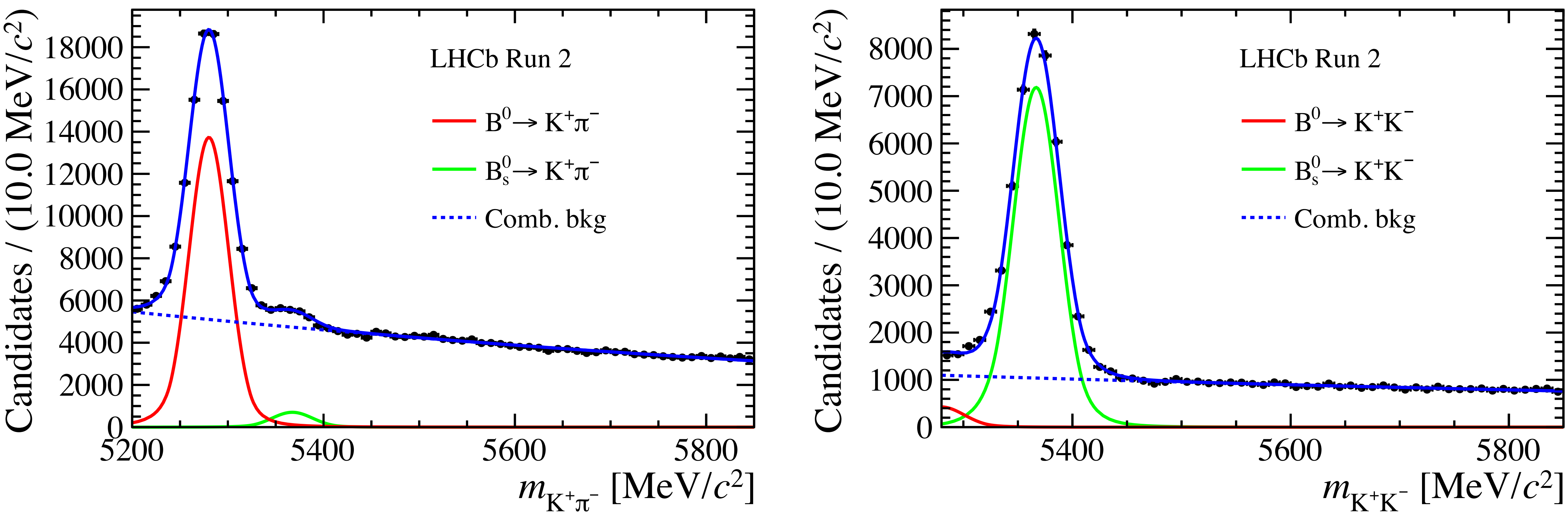
- Yields from Run1 mass sidebands ($5447 < m_{\mu\mu} < 6500$ MeV/c^2)

Selection	0.0-0.25	0.25-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0
old BDT + DLL	37442	403	76	41	11	9	3	0
new BDT + DLL	37701	213	46	16	4	3	2	0
new BDT + ProbNN	30631	172	34	13	3	2	0	0

- significant improvement w.r.t. the previous analysis $\rightarrow$ 50% in background reduction due to improved BDT

- Additional improvements ~20% due to new PID selection

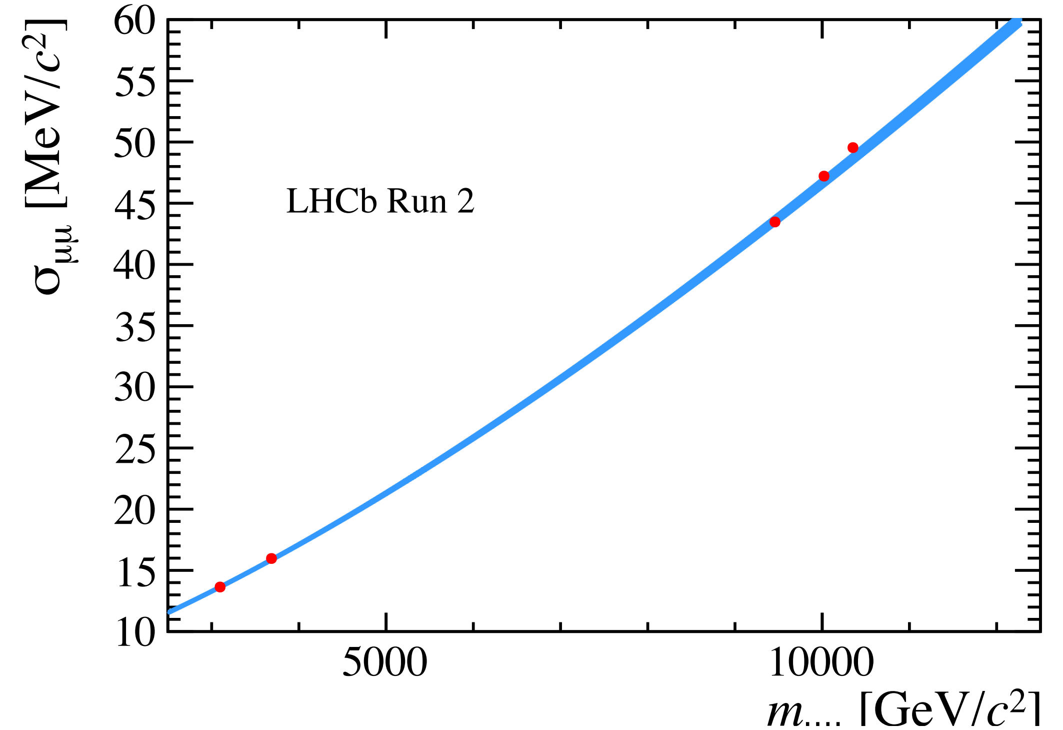
$B^0_{(s)} \to \mu^+\mu^-$: mass calibration

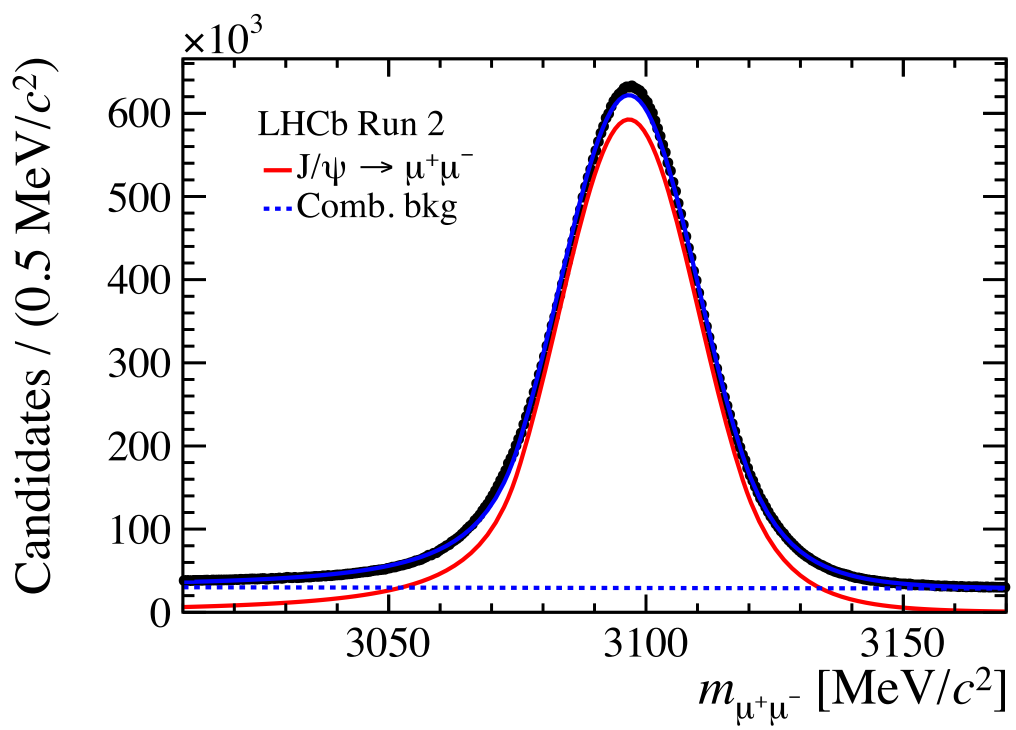


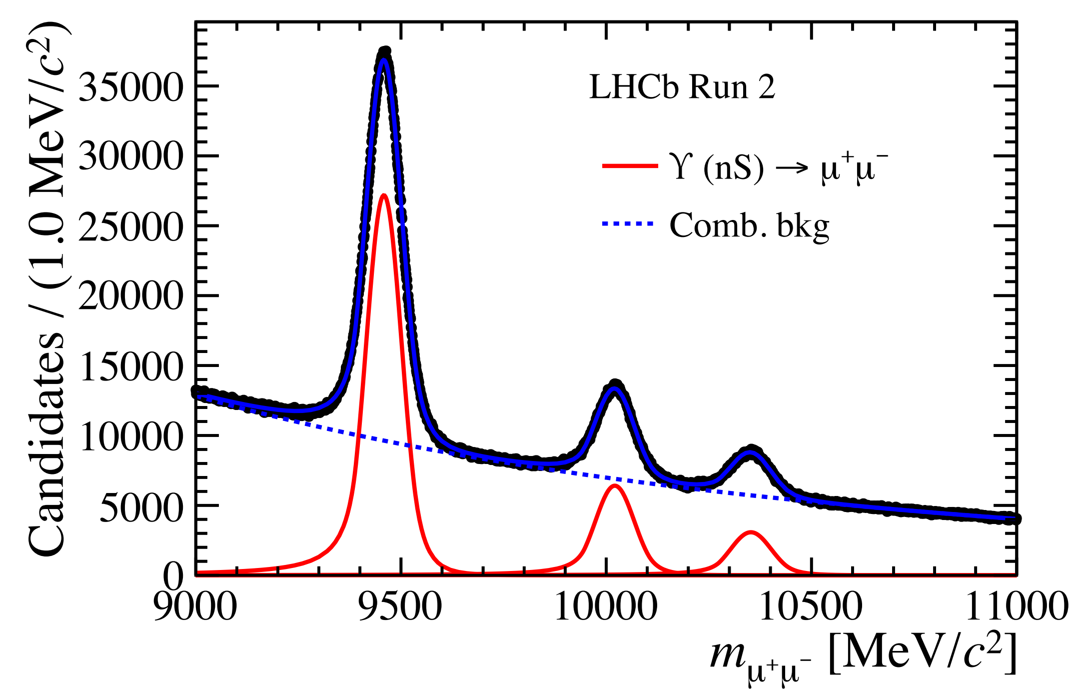
- Determination of mass peak position with well visible exclusive $B \to hh'$ decays

$B^0_{(s)} \to \mu^+\mu^-$: mass resolution

- Resolution determination from **power law interpolation** of dimuon resonances: J/ψ, $\psi(2S)$, $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$
- Mass resolution ~23MeV/c^2
- 1% difference between Run1 and Run2 data



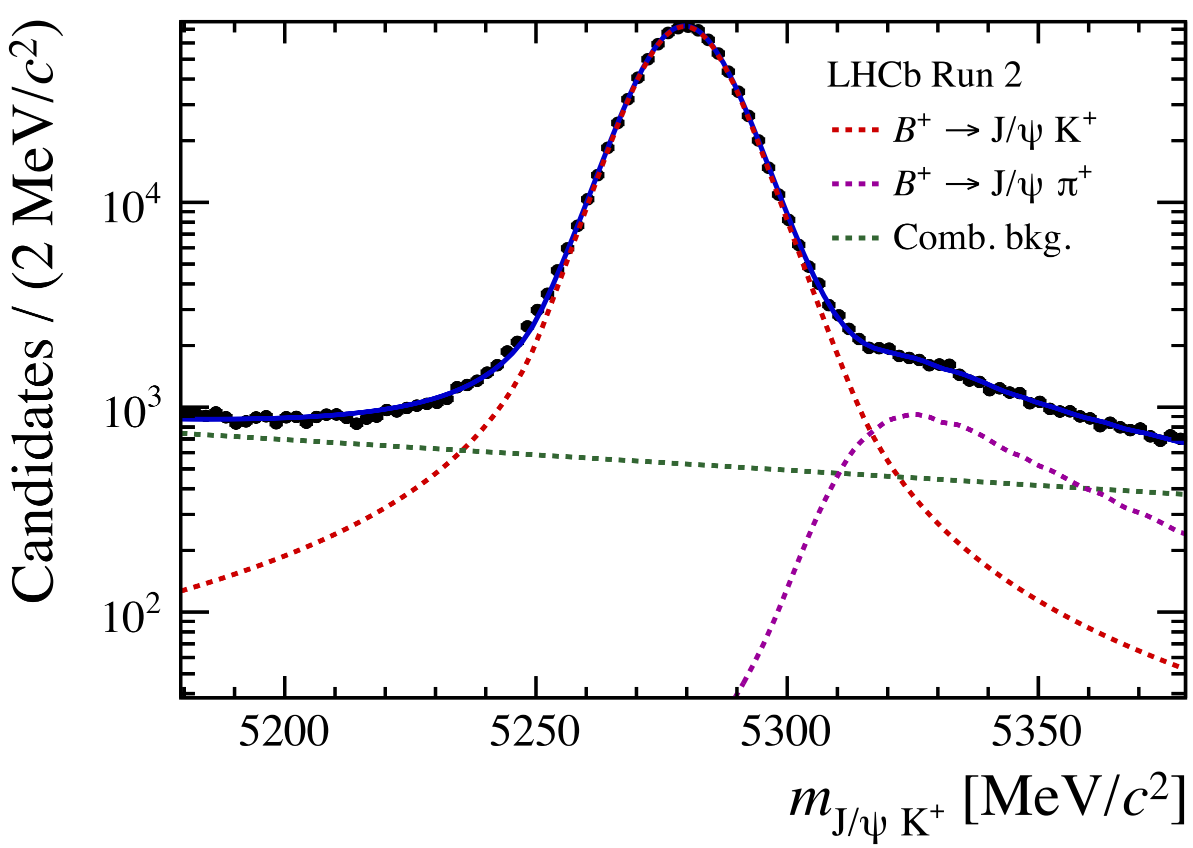


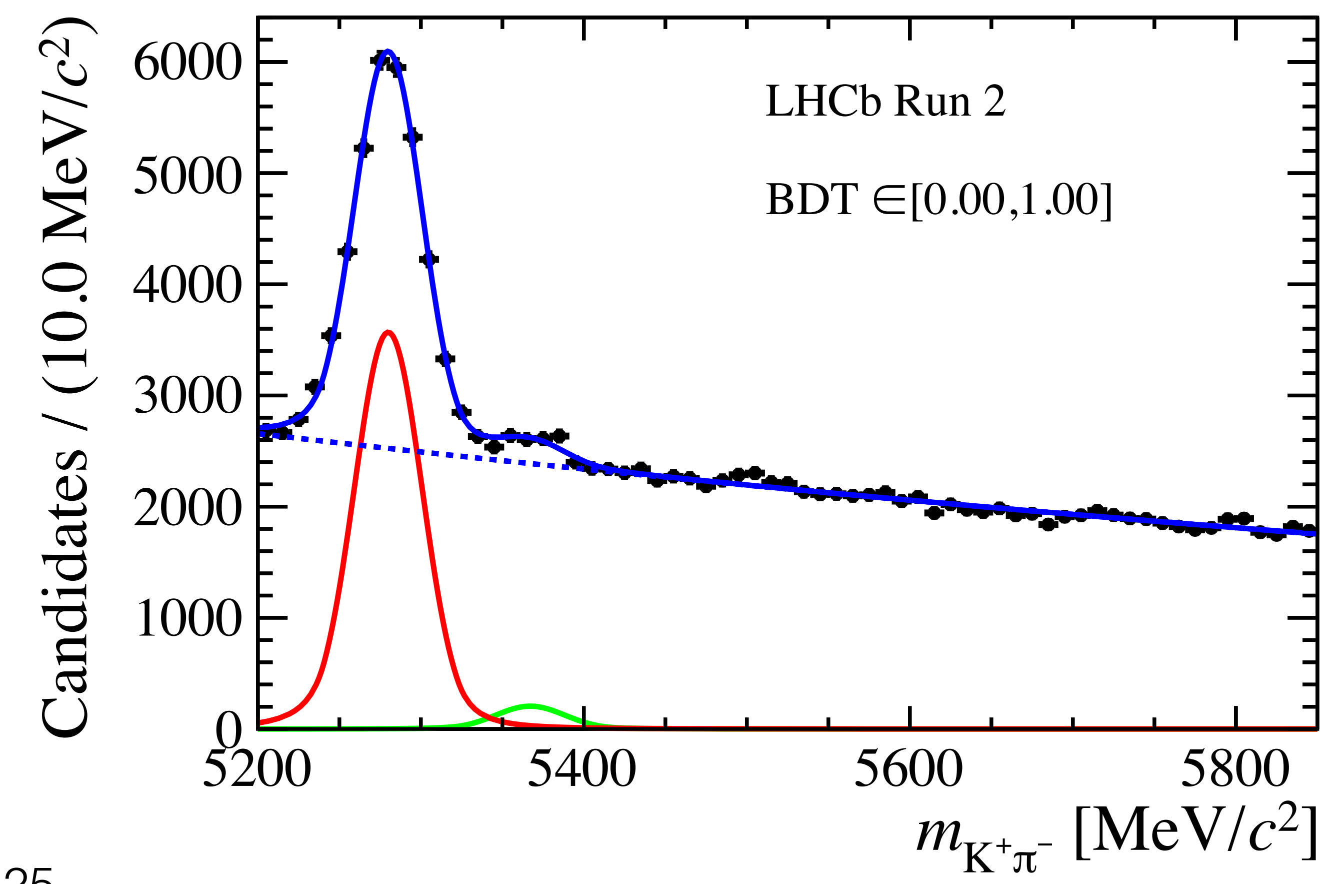


$B^0_{(s)} \to \mu^+\mu^-$: normalisation

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

- Two control channels used for the normalization: $B^+ \to J/\psi K^+$ and $B^0 \to K^+\pi^-$
- Evaluated from simulated events and x-checked on data
- Trigger efficiency from data-driven technique





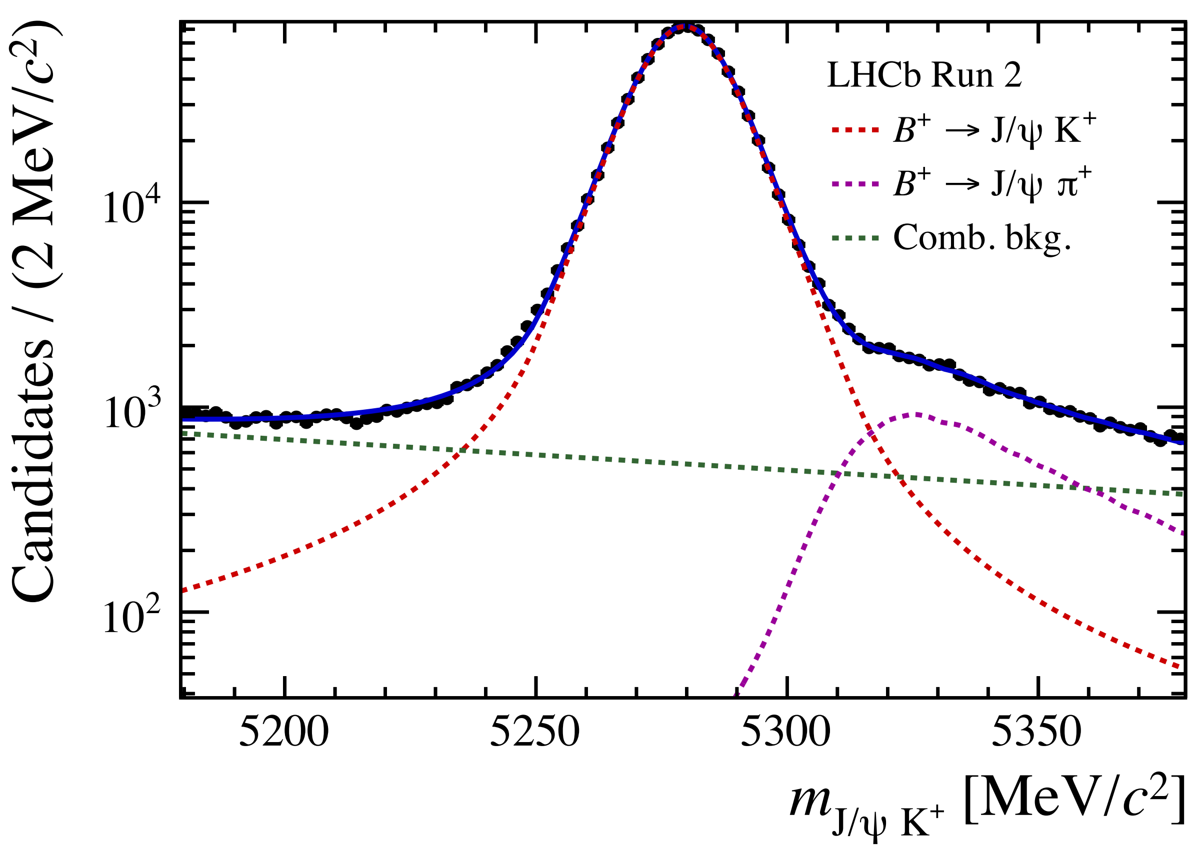
$B^0_{(s)} \to \mu^+\mu^-$: normalisation

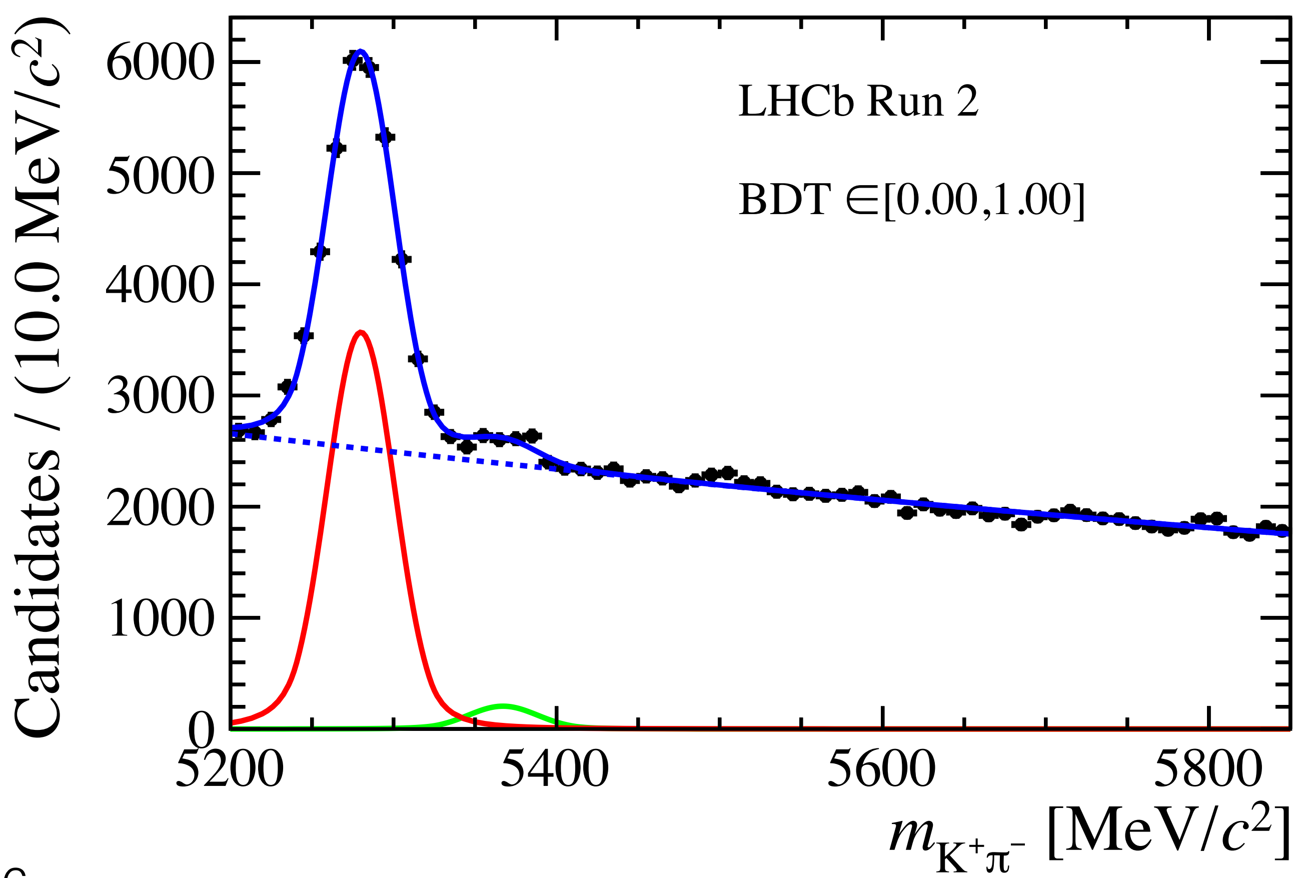
$$\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon^{Acc}_{norm}}{\epsilon^{Acc}_{sig}} \times \frac{\epsilon^{RecSel|Acc}_{norm}}{\epsilon^{RecSel|Acc}_{sig}} \times \frac{\epsilon^{Trig|RecSel}_{norm}}{\epsilon^{Trig|RecSel}_{sig}} \times \frac{f_{\mathrm{cal}}}{f_{d(s)}} \times \frac{N_{B^0_{(s)}\to\mu^+\mu^-}}{N_{\mathrm{cal}}}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

[LHCb-CONF-2013-011]

- Hadronisation fraction from LHCb measurement $f_s / f_d = 0.259 \pm 0.015$
- Values at $\sqrt{s} = 13$TeV scaled according to $B^0_s \to J/\psi\varphi$ and $B^+ \to J/\psi K^+$ ratio

$$C^{Run2}_{fsfd} = (f_s/f_d)_{13TeV}/(f_s/f_d)_{7+8TeV} = 1.068(46)$$





$B^0_{(s)} \to \mu^+\mu^-$: normalisation

$B^0_s \to \mu^+\mu^-$	$\alpha^{B^+\to J/\psi K^+} \times 10^{10}$	$\alpha^{B^0\to K^+\pi^-} \times 10^{10}$	$\alpha^{comb.} \times 10^{10}$
Run 1	1.099(78)	1.060(94)	1.088(74)
Run 2	1.352(103)	1.210(126)	1.313(95)
		Total:	0.595(38)

$B^0 \to \mu^+\mu^-$	$\alpha^{B^+\to J/\psi K^+} \times 10^{11}$	$\alpha^{B^0\to K^+\pi^-} \times 10^{11}$	$\alpha^{comb.} \times 10^{11}$
Run 1	2.952(12)	2.847(19)	2.923(10)
Run 2	3.646(18)	3.262(28)	3.541(16)
		Total:	1.601(44)

- Measured $(1964\pm1)\times10^3$ $B^+\to J/\psi K^+$ and $(62\pm3)\times10^3$ $B^0\to K^+\pi^-$ decays
- Assuming the SM rates, after the selection we expect:
  - **~62 $B^0_s\to\mu^+\mu^-$ events and ~7 $B^0\to\mu^+\mu^-$ events in the whole BDT range**

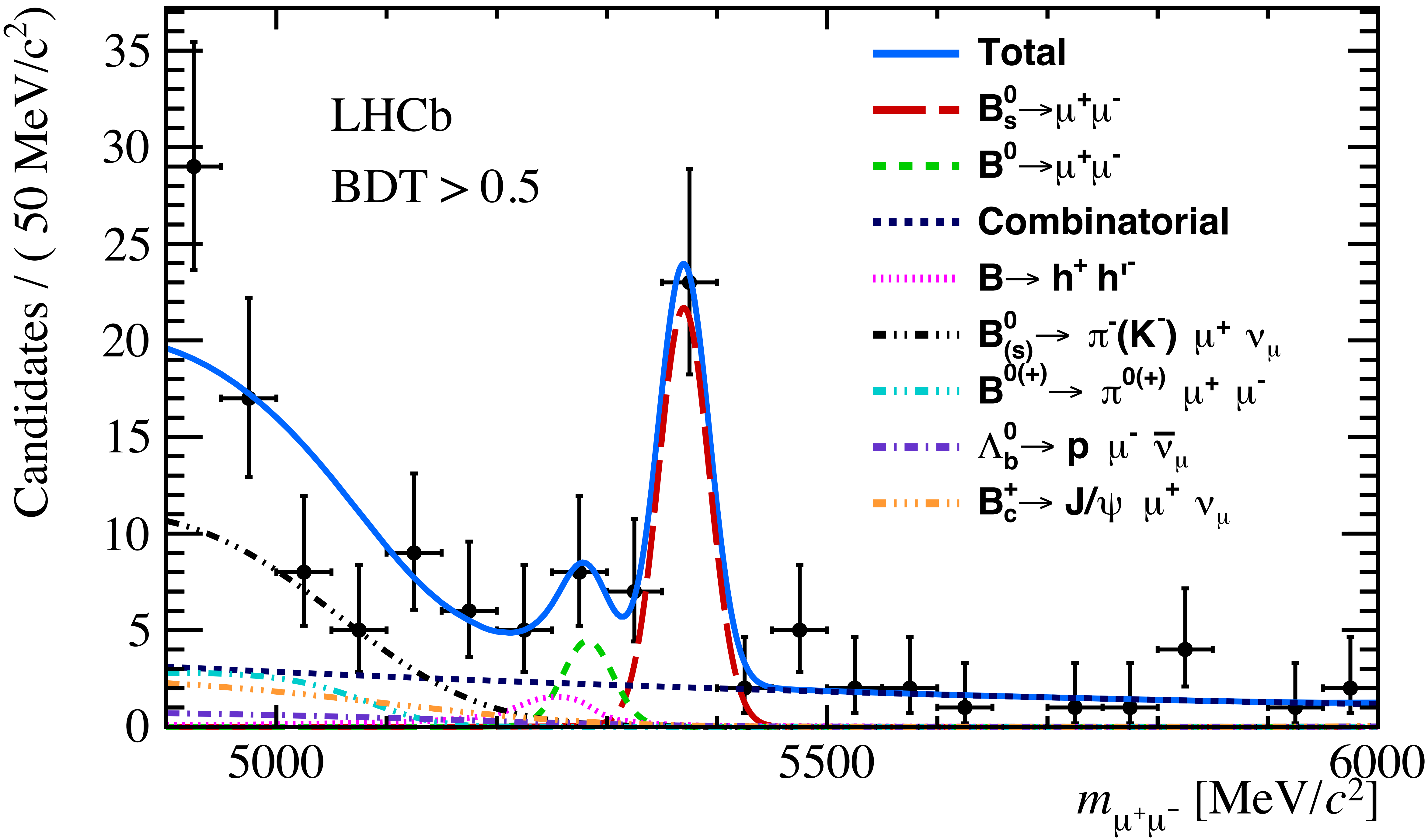
$B^0_{(s)} \to \mu^+\mu^-$: branching fraction fit

- Unbinned maximum likelihood fit on BDT binned di-muon mass spectra:
  - 4 BDT bins in Run1 and 4 BDT bins in Run2 simultaneously considered
    - background dominated region BDT $\in [0,0.25]$ excluded in the final fit
  - mass range [4900,6000] MeV/c^2
- Free parameters: BF($B^0 \to \mu^+\mu^-$) and BF($B^0_s \to \mu^+\mu^-$) and combinatorial background
- Signal fractions constrained in each BDT bin to expectations
- Exclusive background yields constrained to their expectations

It’s time to show the peak

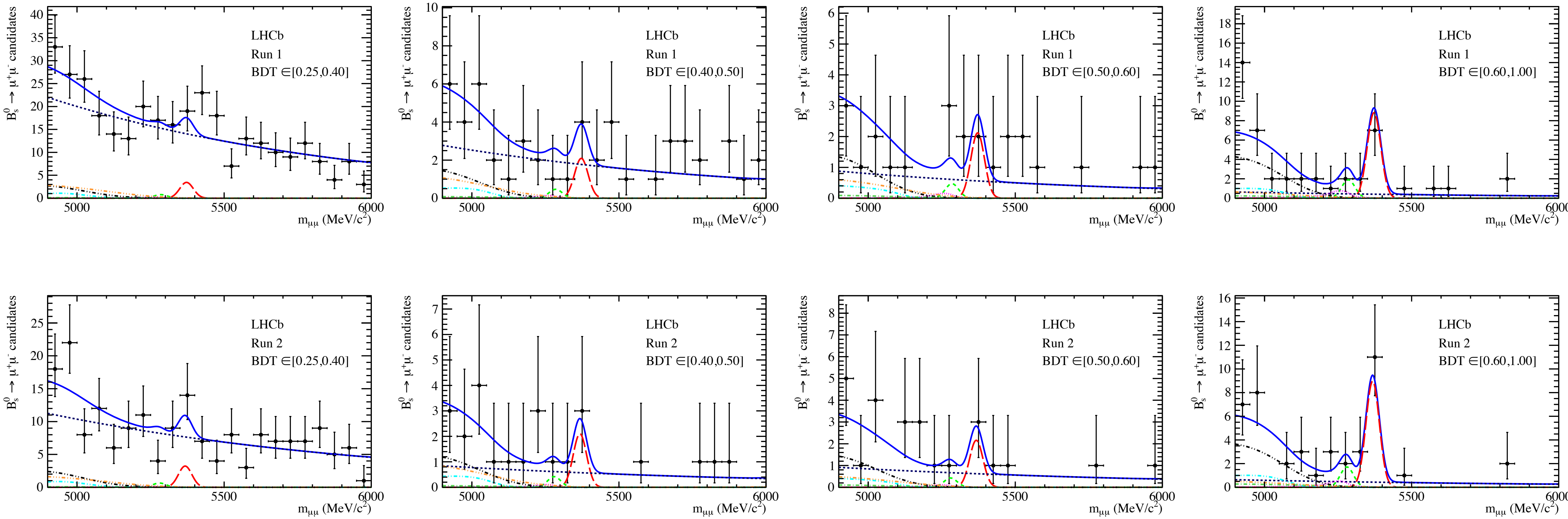
In the most sensitive region

[LHCB-PAPER-2017-001]



$B^0_s \to \mu^+\mu^-$: fit slices

[LHCB-PAPER-2017-001]

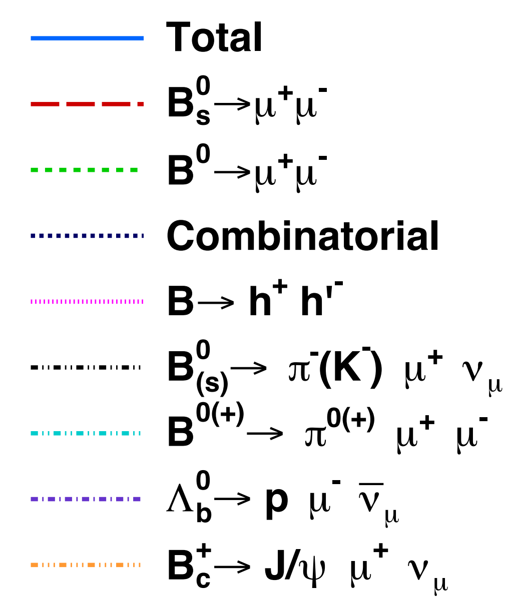


- Fit results:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.8 \pm 0.6) \times 10^{-9} \quad \mathbf{7.8\sigma}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.6^{+1.1}_{-0.9}) \times 10^{-10} \quad \mathbf{1.9\sigma}$$

- Systematics from nuisance parameters and background model
- Given no evidence of $B^0 \to \mu^+\mu^-$, upper limit has been evaluated



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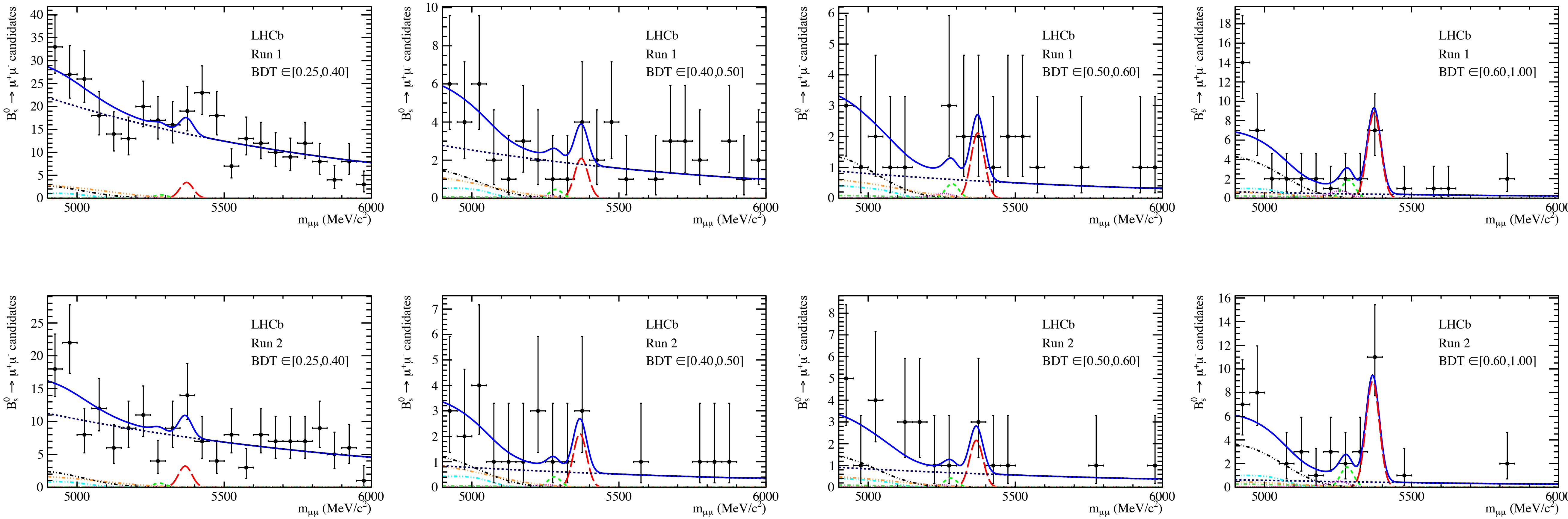

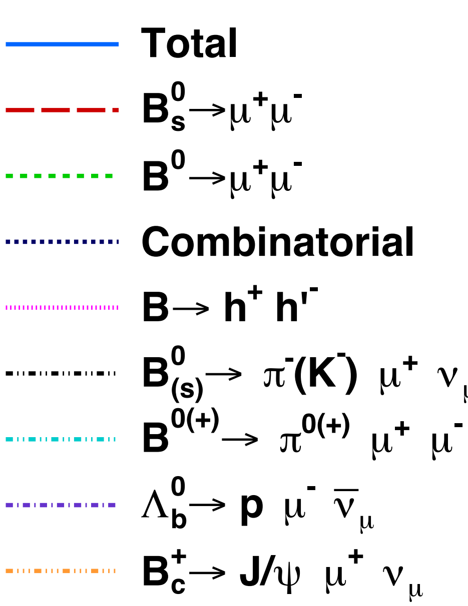

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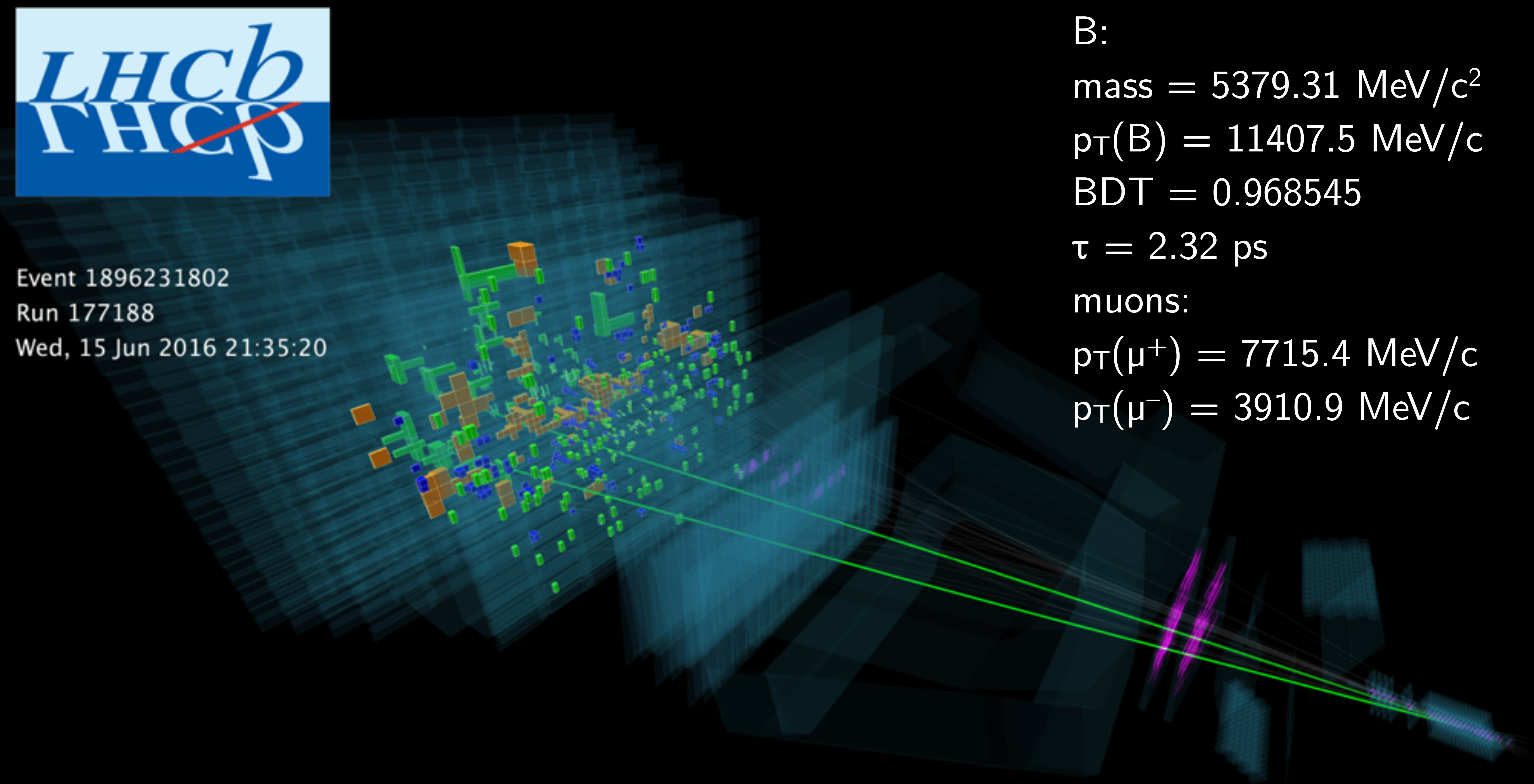
- Selection efficiency dependency on lifetime evaluated repeating the fit under the $A_{\Delta\Gamma} = 0$ and -1 hypotheses. Increase respect to the SM assumption of 4.6 % and 10.9 %, respectively

A nice candidate



B:

mass = 5379.31 MeV/c^2

$p_T(B)$ = 11407.5 MeV/c

BDT = 0.968545

τ = 2.32 ps

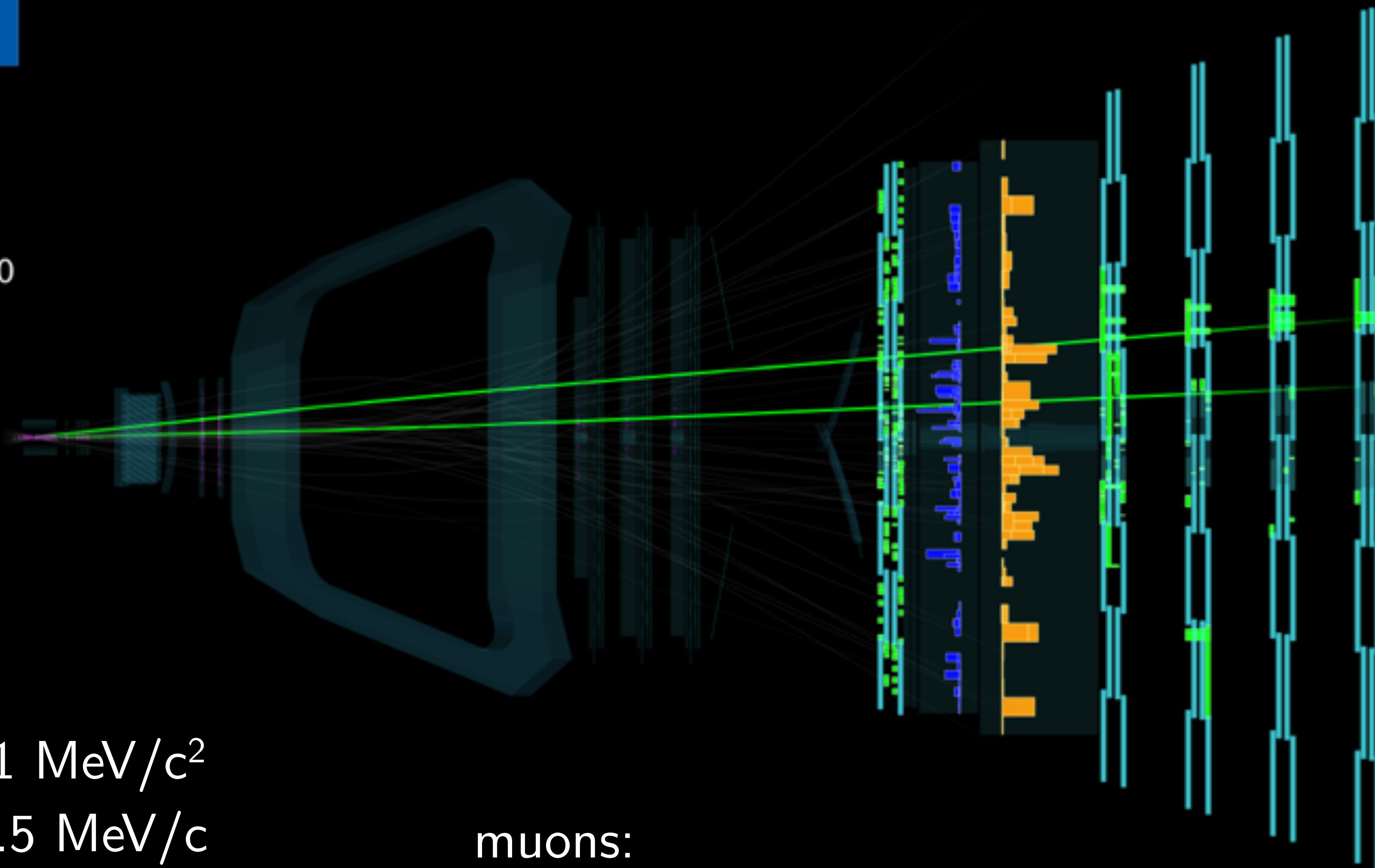
muons:

$p_T(\mu^+)$ = 7715.4 MeV/c

$p_T(\mu^-)$ = 3910.9 MeV/c

A nice candidate

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



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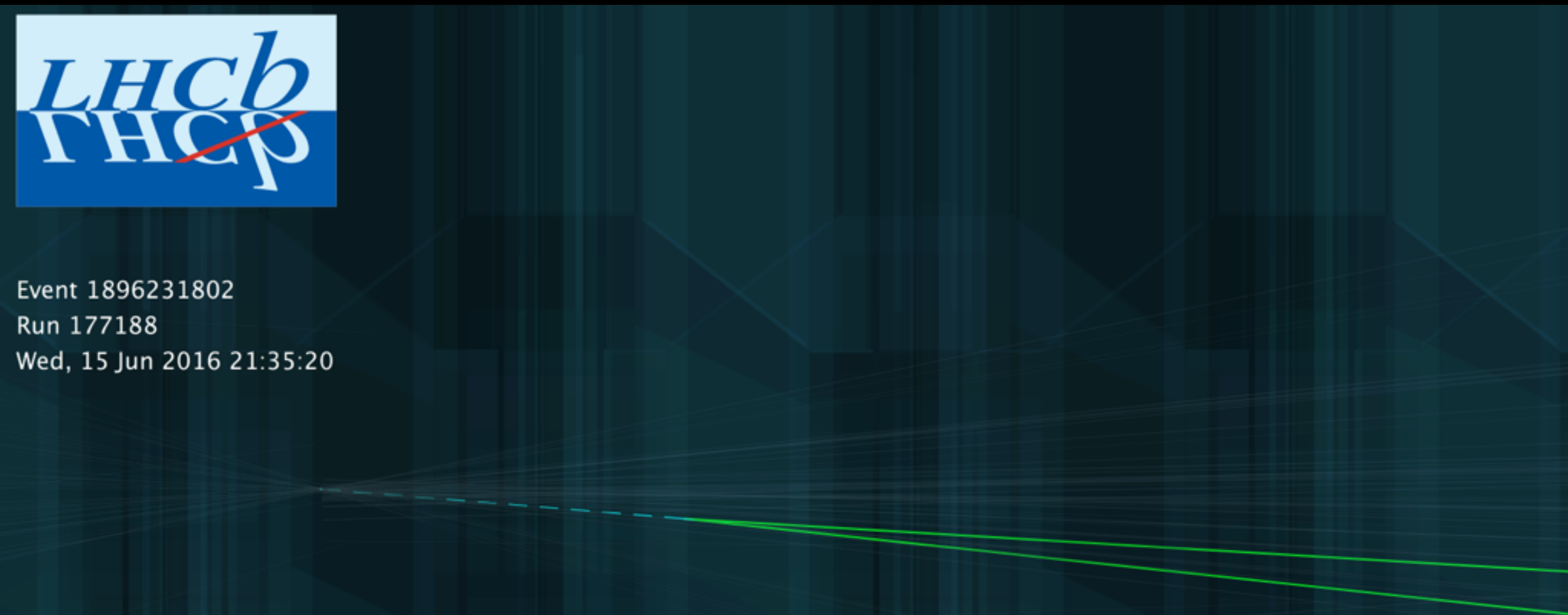

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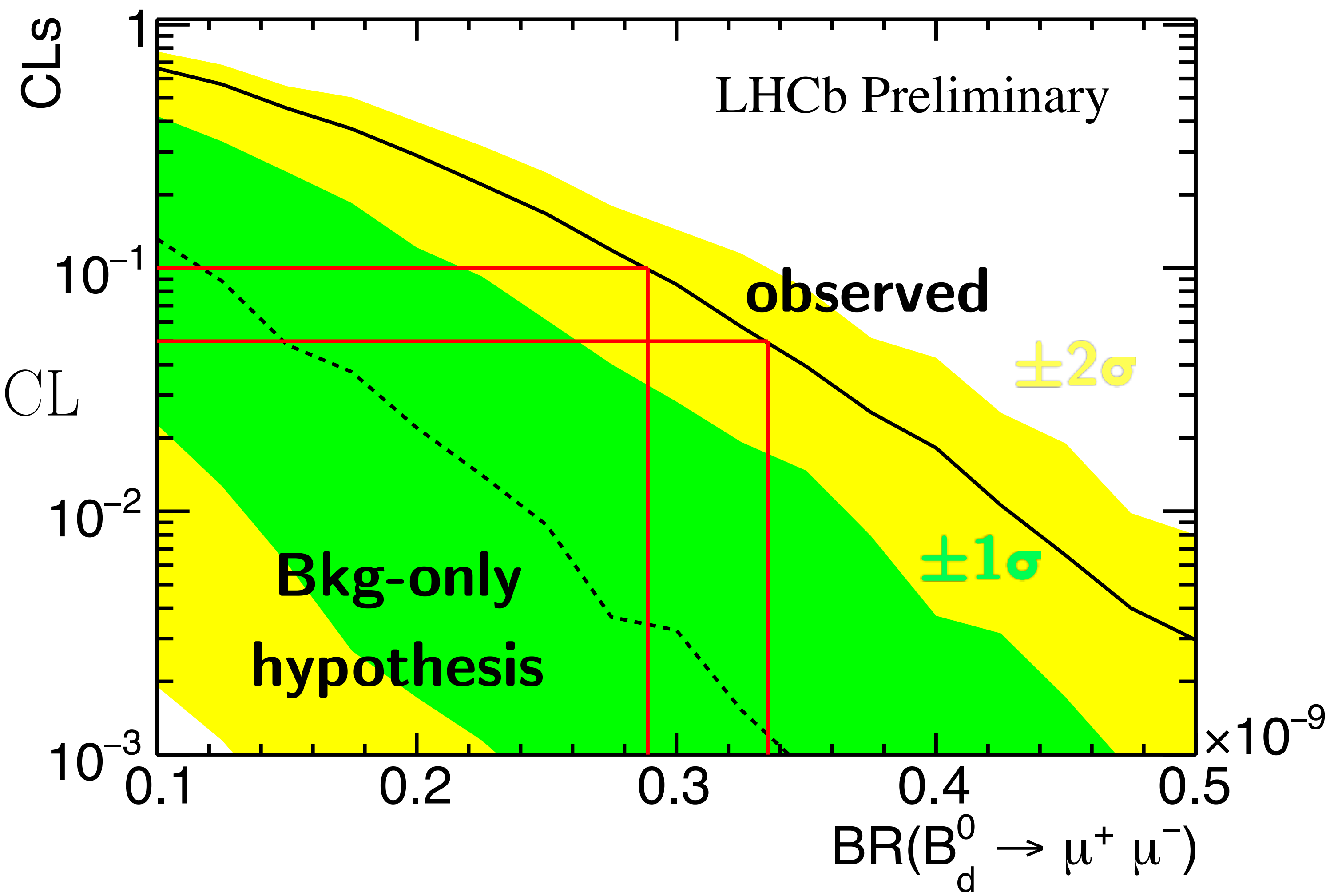
$B^0 \to \mu^+\mu^-$: upper limit

[LHCB-PAPER-2017-001]

- Use CL_s method: evaluate compatibility with background only (CL_b) and signal + background hypotheses (CL_{s+b}); the 95%CL upper limit is defined at $CL_s = CL_{s+b}/CL_b = 0.05$
- Observed upper limit:

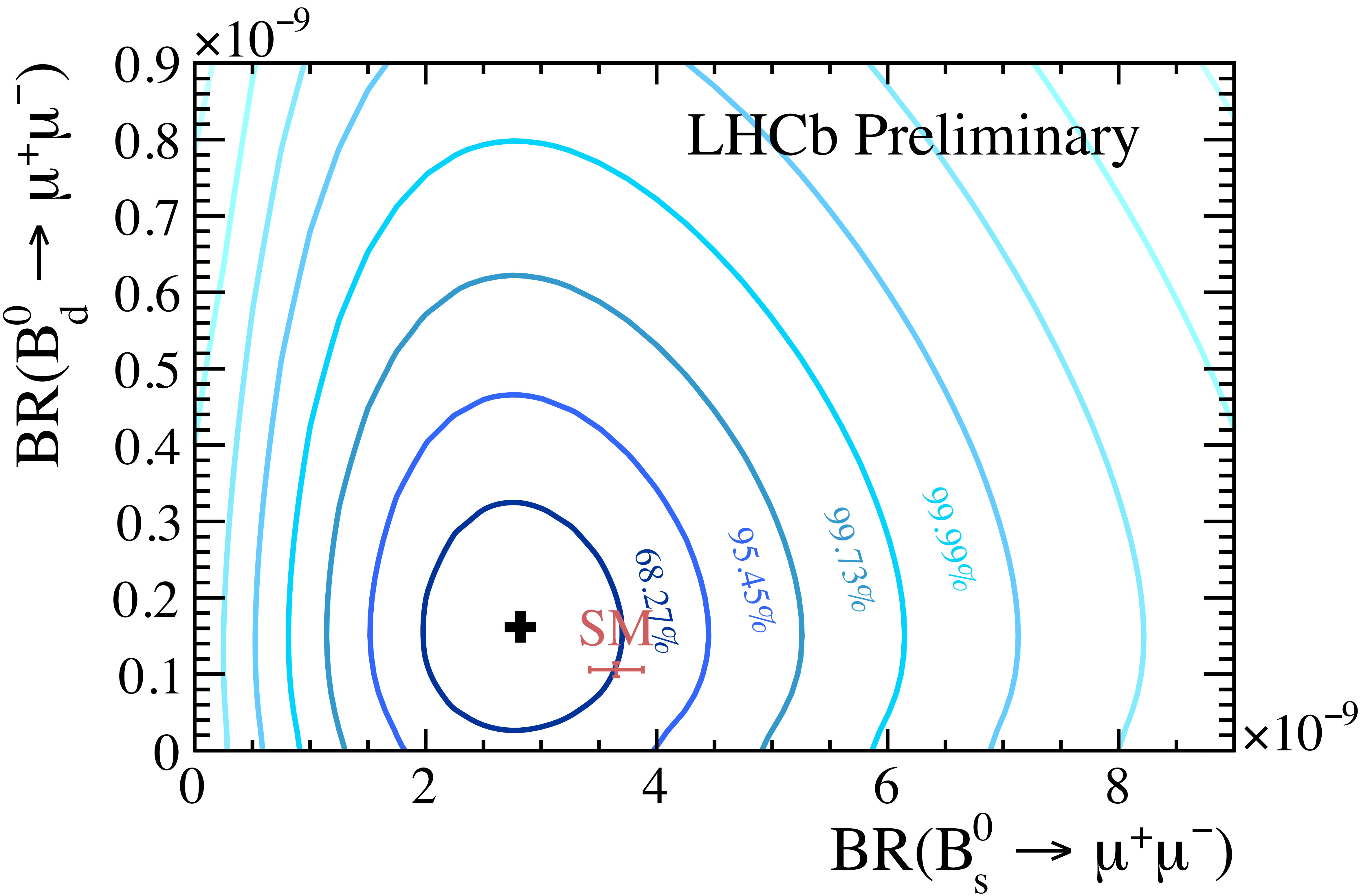
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \cdot 10^{-10} \text{ @ } 95\% \text{ CL}$$

- Compatibility with bkg only hypothesis $1\text{-}CL_b = 0.05$

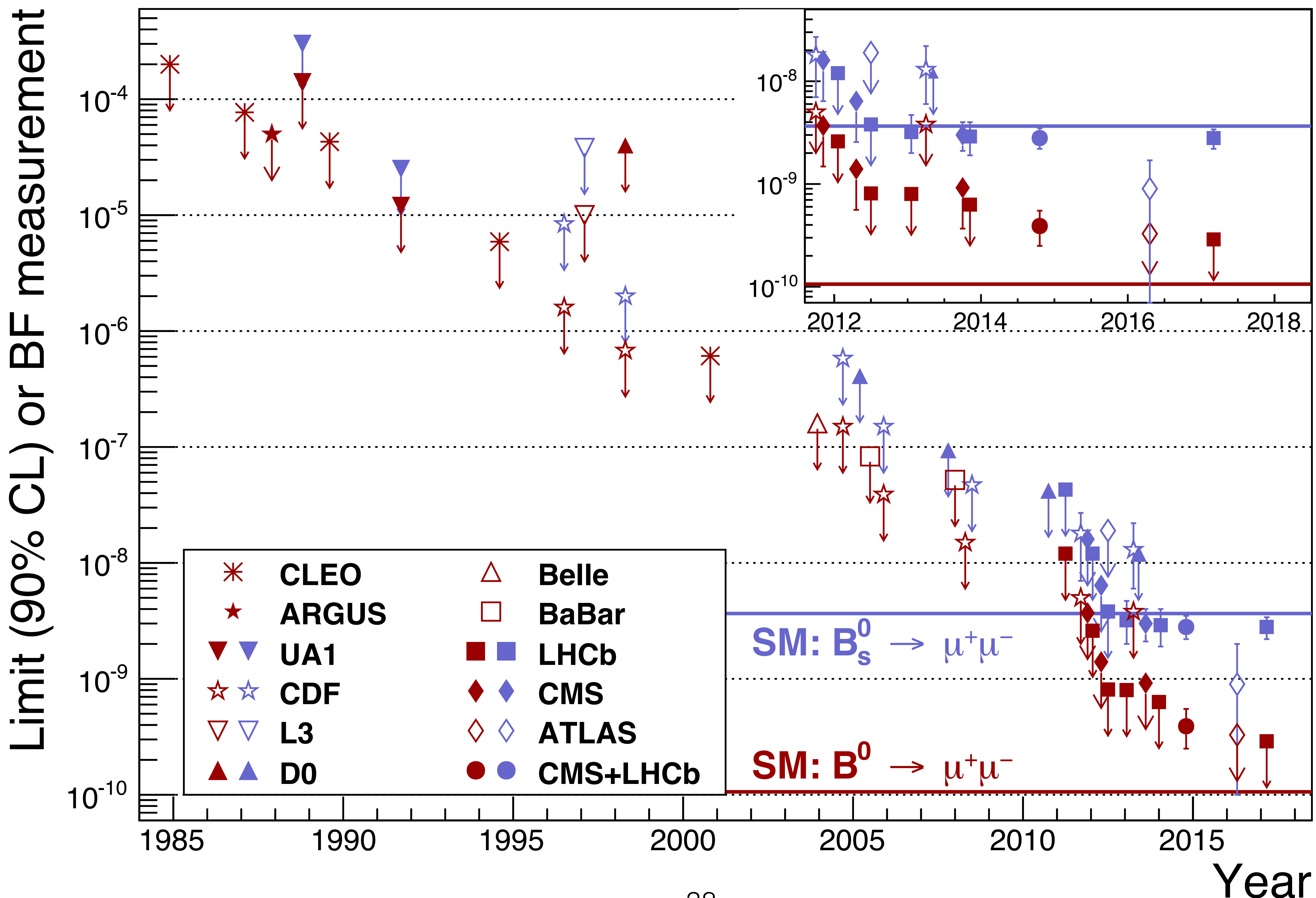


2D likelihood profile

[LHCB-PAPER-2017-001]



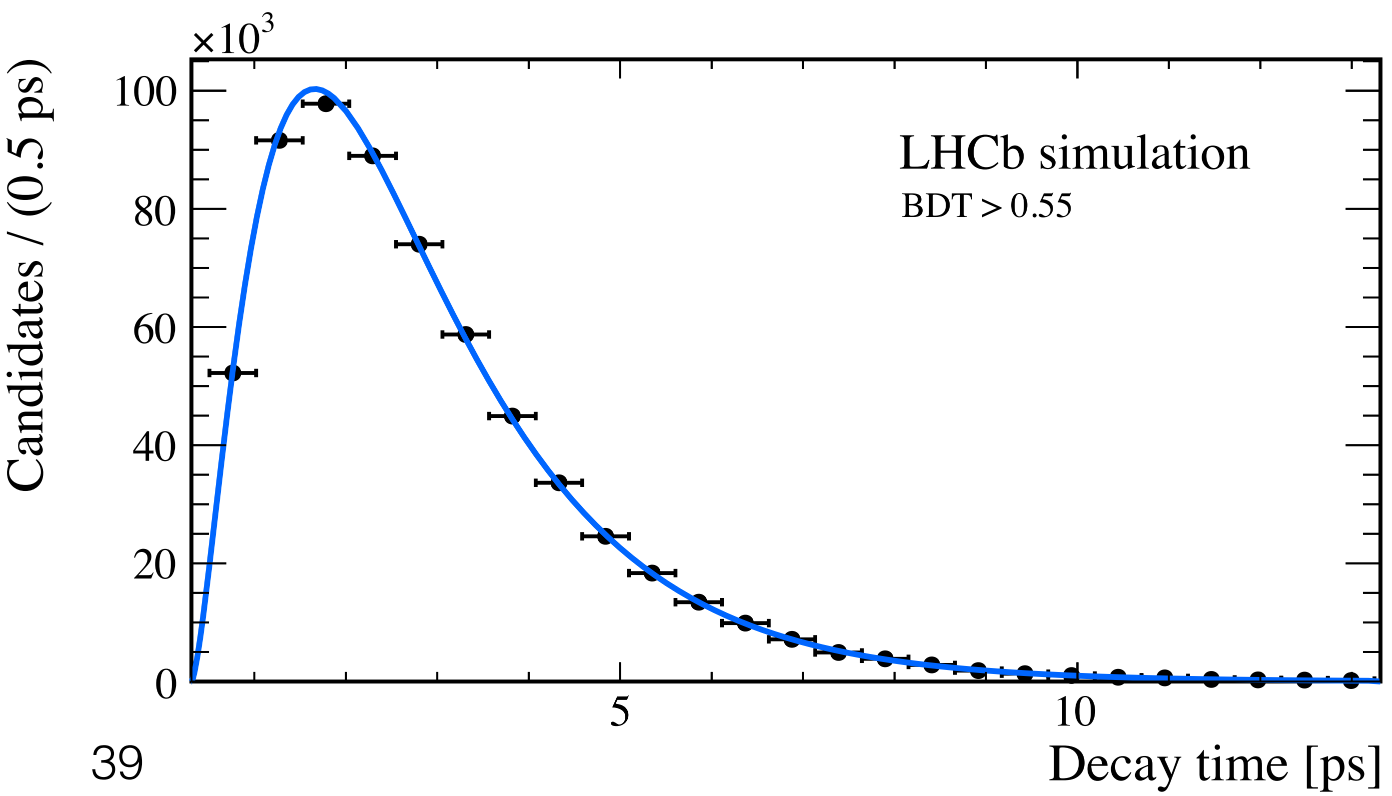
Another chapter in our story



Effective lifetime analysis strategy

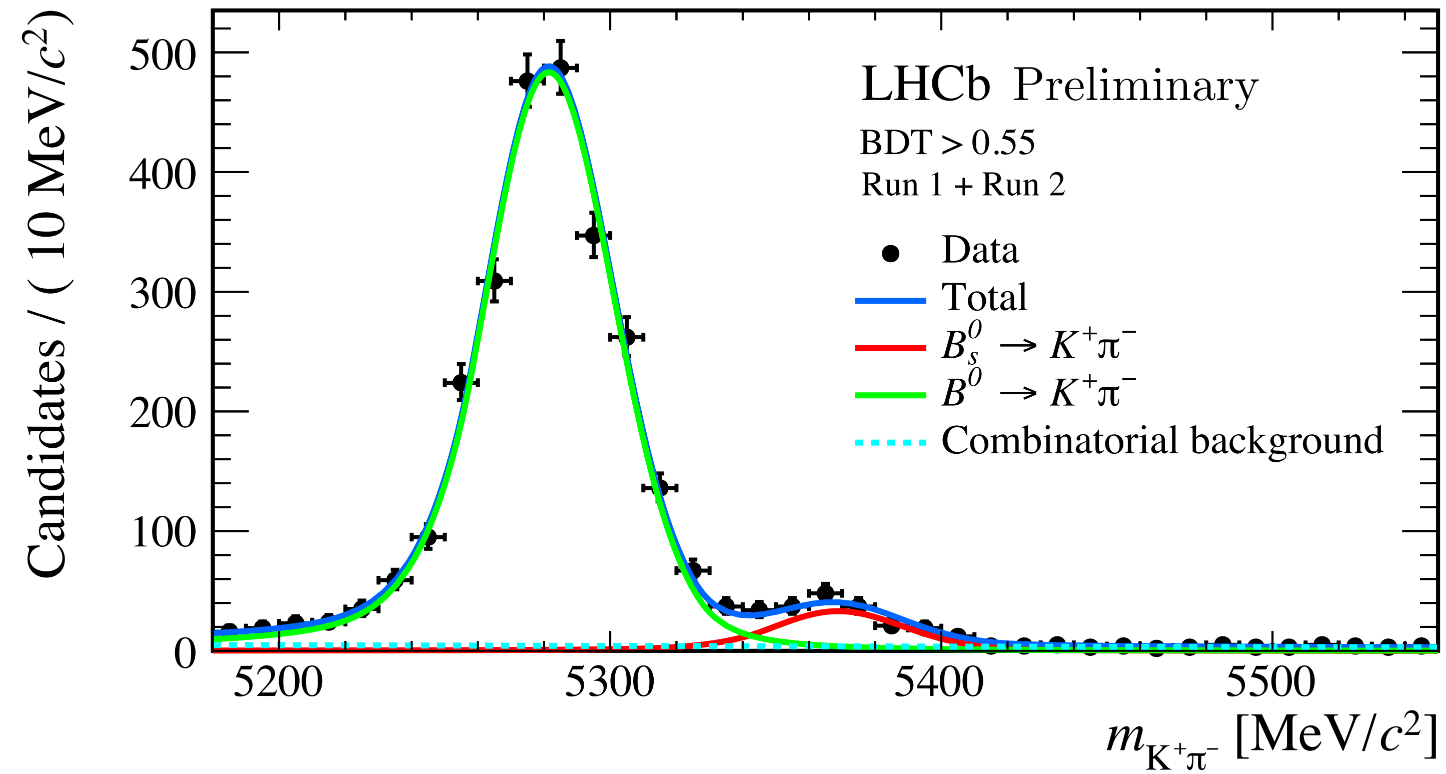
- Same pre-selection, BDT classifier and PID selection as for the BF measurement
- Fit performed in 2 stages:
  - Fit to the invariant mass distribution in [5320,6000] MeV/c^2 to evaluate weights according to sPlot technique.
  - Fit to the weighted decay time distribution
- Looser PID requirements and single BDT cut applied. Cut optimised to minimise the statistical uncertainty
- Acceptance function modelled on simulated $B^0_s \to \mu^+\mu^-$ events

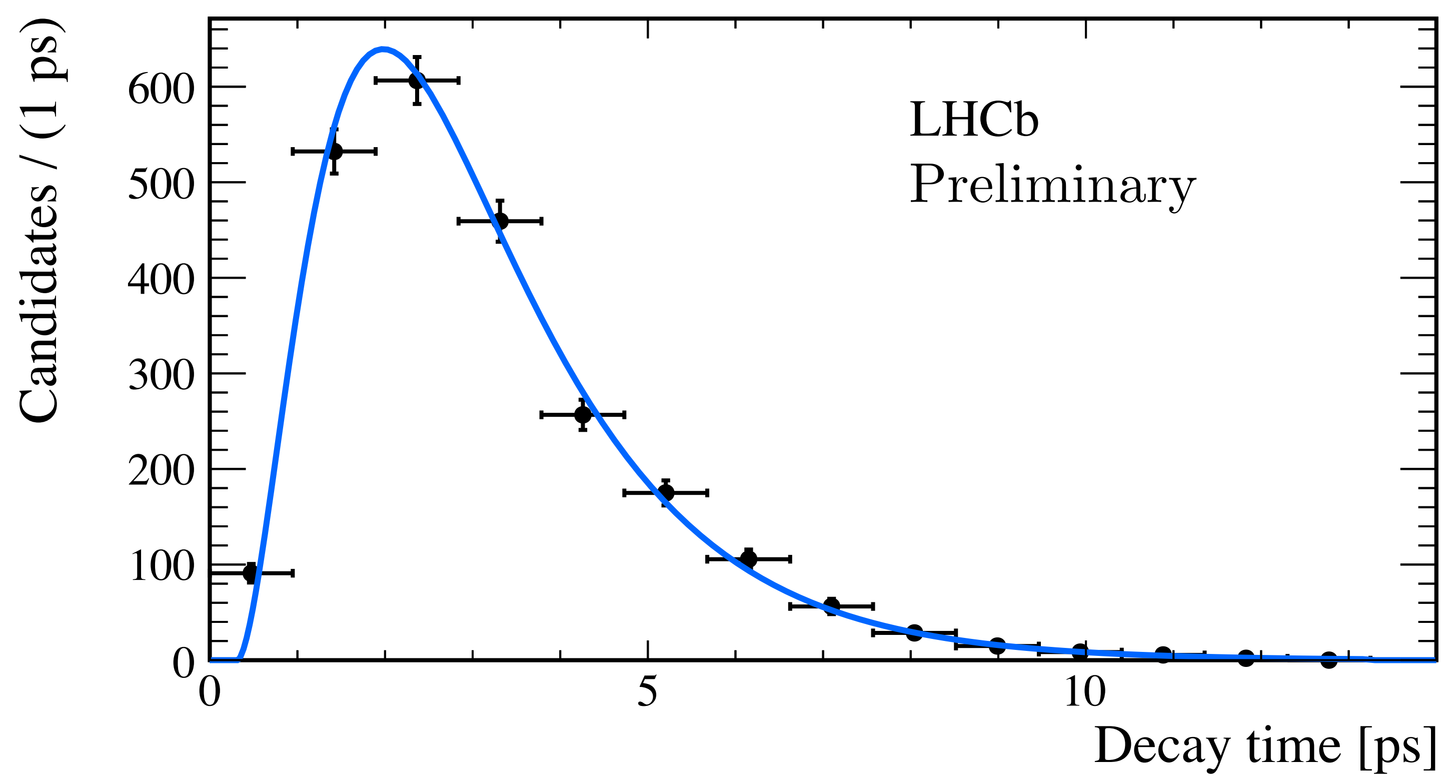
$$\epsilon(t) = \frac{[a\,(t - t_0)]^n}{1 + [a\,(t - t_0)]^n}$$



Effective lifetime x-checks

- Acceptance function validated by measuring $B^0 \to K^+\pi^-$ effective lifetime
- Measured effective lifetime is $\tau = 1.52 \pm 0.03_{stat}$ ps consistent with the world average (PDG value of $\tau = 1.520 \pm 0.004$ ps)
- Uncertainty taken as systematics on acceptance function





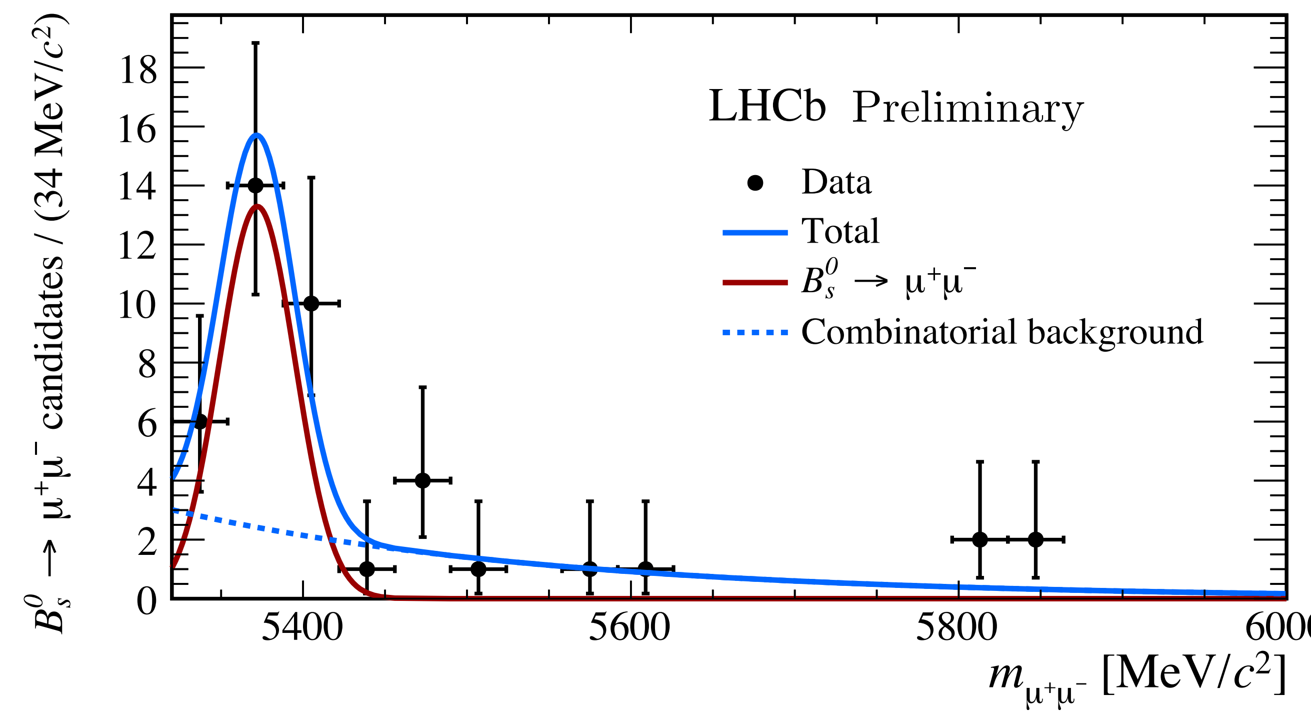
Effective lifetime result

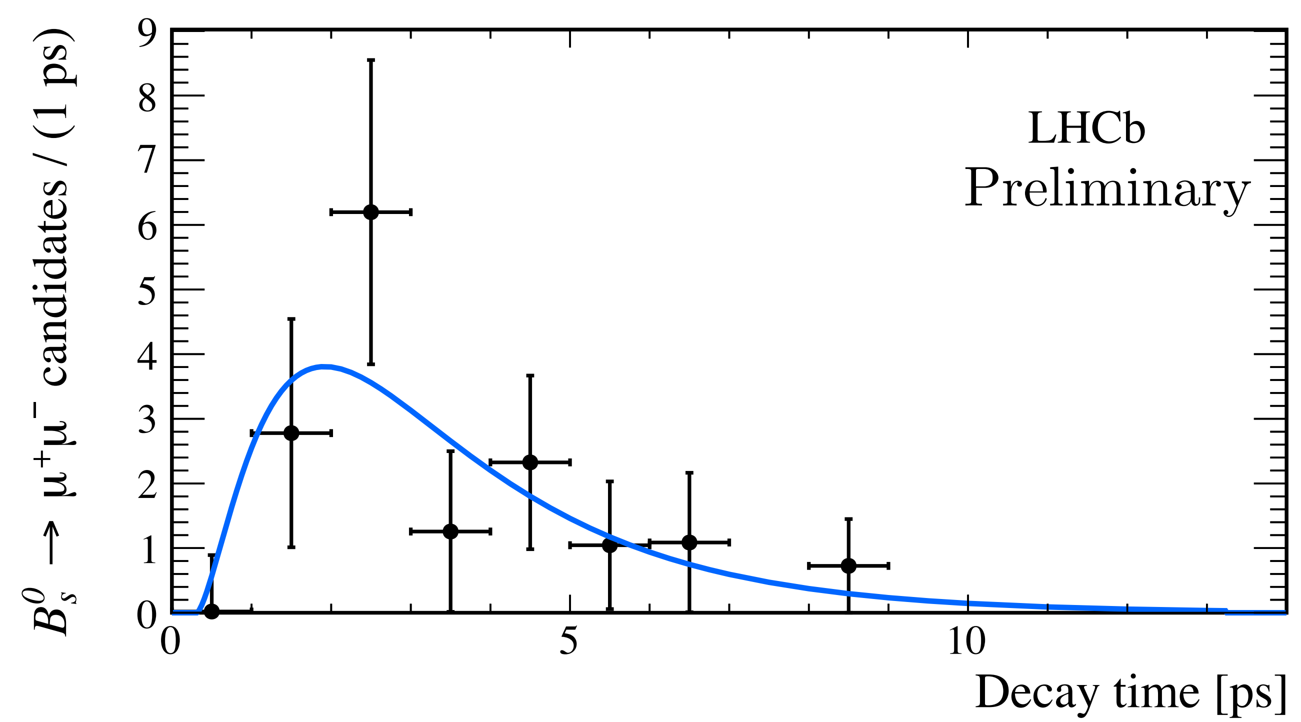
[LHCB-PAPER-2017-001]

The fit results for $B^0_s \to \mu^+\mu^-$:

$$\tau(B^0 \to \mu^+\mu^-) = 2.04 \pm 0.44_{(\mathrm{stat})} \pm 0.05_{(\mathrm{syst})}\ \mathrm{ps}$$

- Consistent with $A_{\Delta\Gamma} = 1\ (-1)$ hypothesis at the 1.0σ (1.4σ) level.
- Contamination from $B^0 \to \mu^+\mu^-$, $B \to h^+h'^-$ and semileptonic decays negligible and not included.
- Effect due to different fractions of light and heavy mass eigenstate and production asymmetry included as systematics





$B^0_s \to \tau^+\tau^-$

$B^0_s \to \tau^+\tau^-$: motivation

[LHCb-CONF-2016-011]

- FCNC analogous to $B^0_{(s)} \to \mu^+\mu^-$ but less helicity-suppressed
- Test lepton flavour universality together with $B^0_{(s)} \to \mu^+\mu^-$
- SM prediction for time integrated branching fractions:

$$\mathcal{B}(B_s^0 \to \tau^+\tau^-)^{\langle t \rangle} = (7.73 \pm 0.49) \cdot 10^{-7}$$
$$\mathcal{B}(B^0 \to \tau^+\tau^-)^{\langle t \rangle} = (2.22 \pm 0.19) \cdot 10^{-8}$$

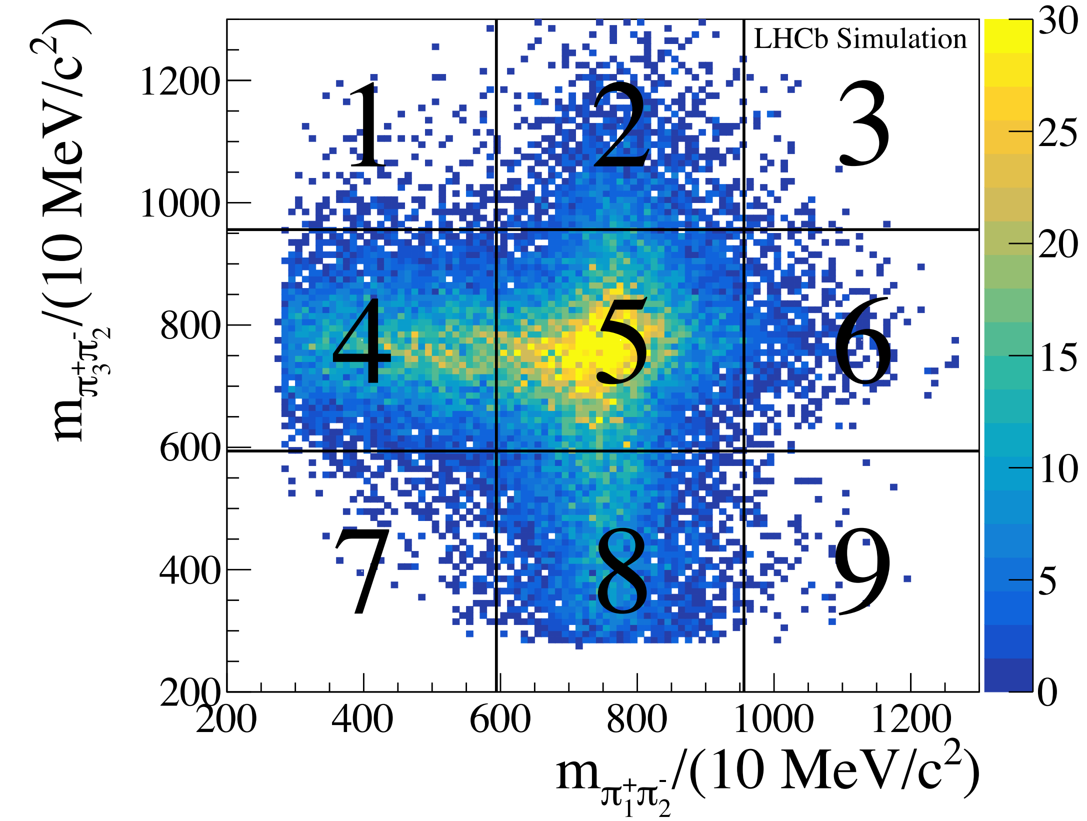
[Bobeth et al, PRL 112 (2014), 101801]

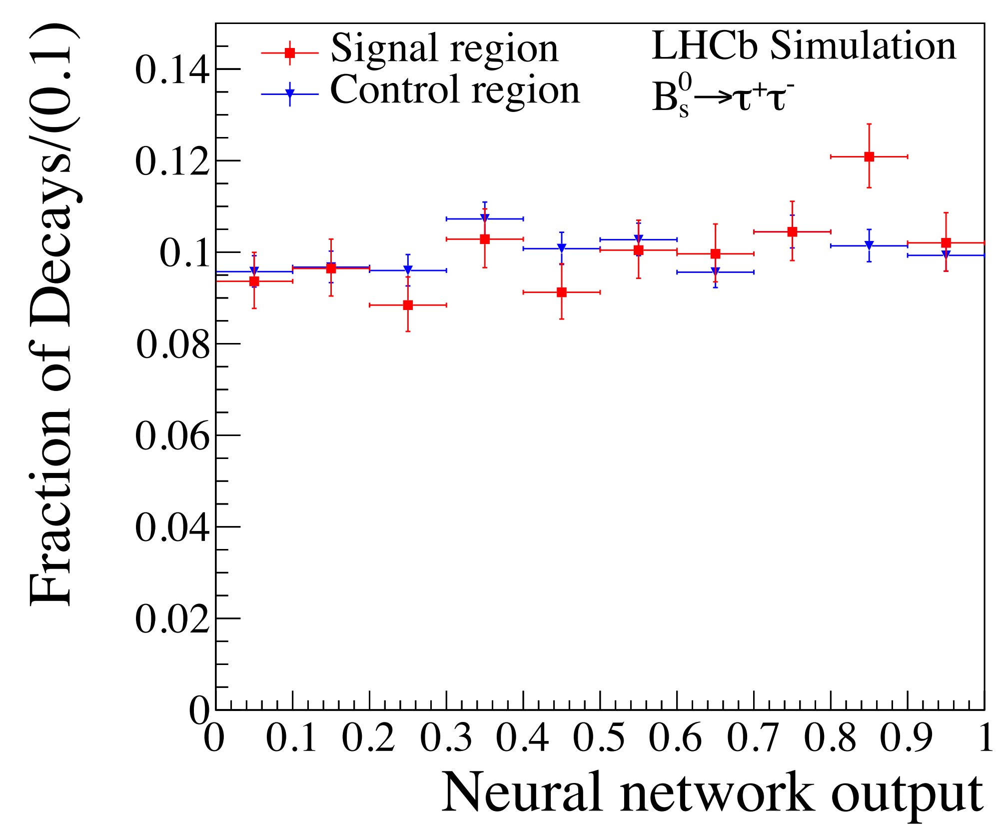
- τ selected through the $\tau^+ \to \pi^+\pi^+\pi^-\overline{\nu}_\tau$ decay.
- Challenging search due to the presence of at least 2 neutrinos in the final state
  - B^0_s and B^0 peaks unresolvable in mass; analysis optimised for B^0_s. Assumption on one decay to extract limit on the other.
- Previous result only on B^0 from BaBar: $BF(B^0 \to \tau^+\tau^-) < 4.1 \times 10^{-3}$ at 90% CL
- Analysis performed on Run1 data

[PRL 96 (2006) 241802]

Intermediate resonances

- Exploited intermediate $\rho^0(770)$ resonance to tag candidates.
- Definition of *signal*, *background* and *control region* based on $m_{\pi_1\pi_2}$ and $m_{\pi_3\pi_2}$:
  - signal: both τ in region 5
  - control region: one τ in 4 or 8 & the other in 4,5 or 8
- Selection:
  - cut based loose selection
  - 2 stage Neural Network based on kinematics, geometry and isolation.





Normalisation and Fit

[LHCb-CONF-2016-011]

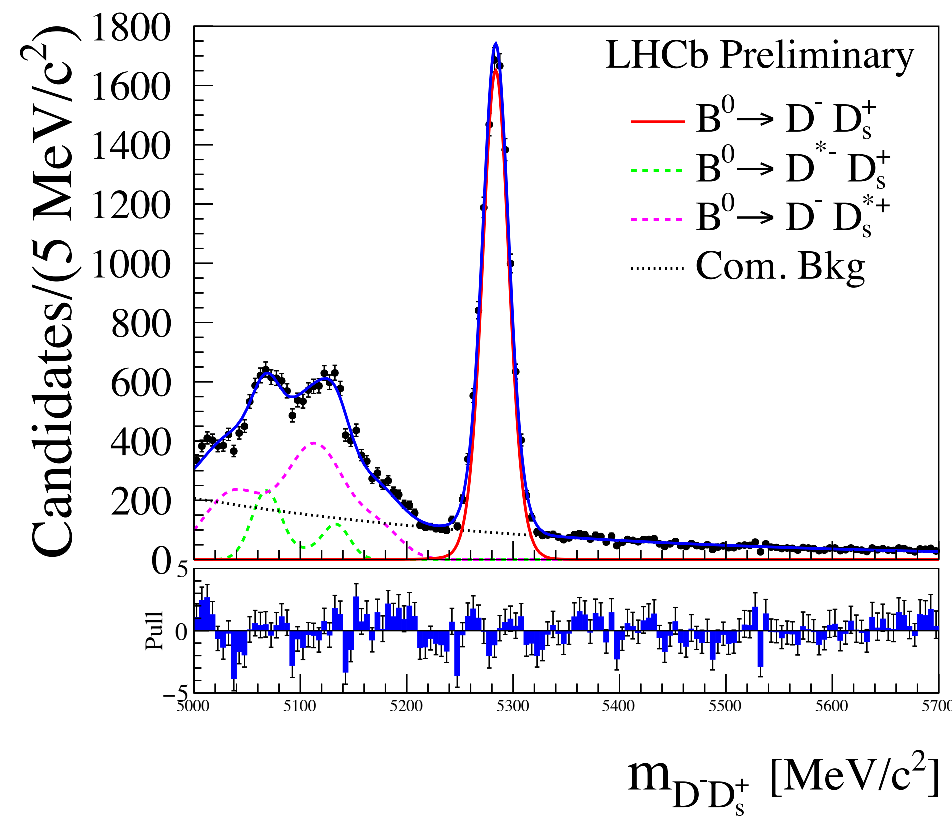
- $B^0 \to D^+(K^-\pi^+\pi^+)D^-_s(K^-K^+\pi^+)$ used as normalisation channel; N^{obs}_{D-D+s}=10629±114
- Signal extracted from NN fit in the signal region:
  - $N_{Bs\to\tau\tau}$ = -46±51
- Compatible with the background only hypothesis → upper limit with CLs method
- Observed upper limit:

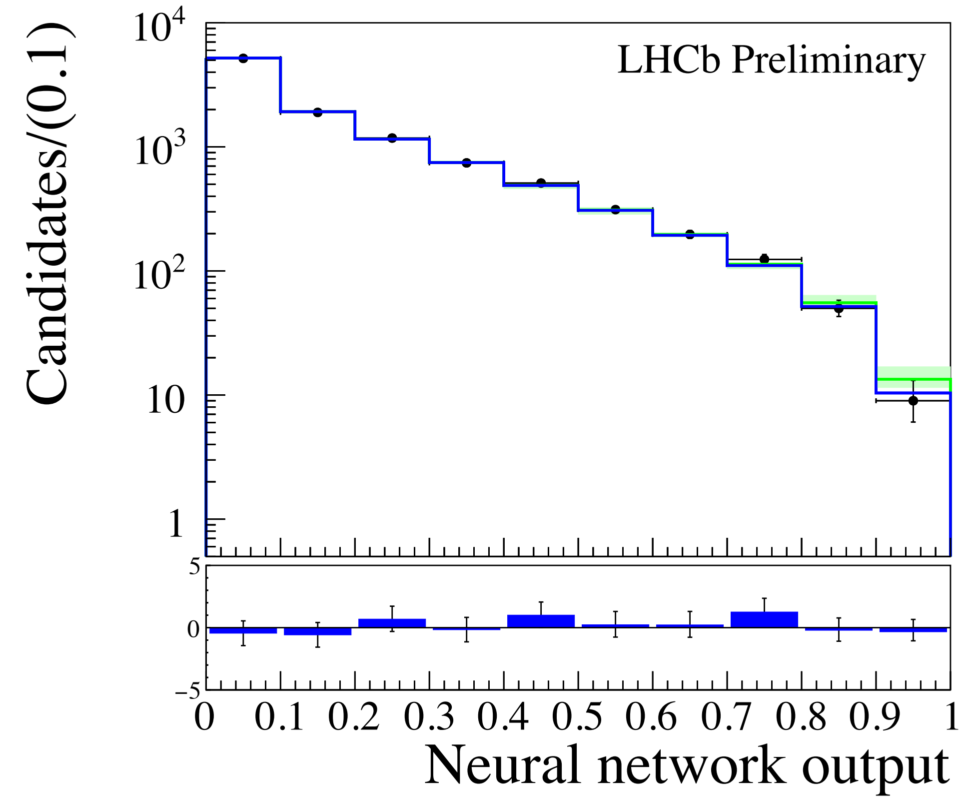
$$\mathcal{B}(B_s^0 \to \tau^+\tau^-) < 2.4(3.0) \times 10^{-3} \text{ at } 90(95)\% \text{ C.L.}$$

- Assuming signal fully dominated by B^0:

$$\mathcal{B}(B^0 \to \tau^+\tau^-) < 1.0(1.3) \times 10^{-3} \text{ at } 90(95)\% \text{ C.L.}$$

- x4 improvements w.r.t. previous result from BaBar
- Note: Preliminary result has strong dependence on the decay model of the τ → new analysis ready soon with improved decay model.





Prospects

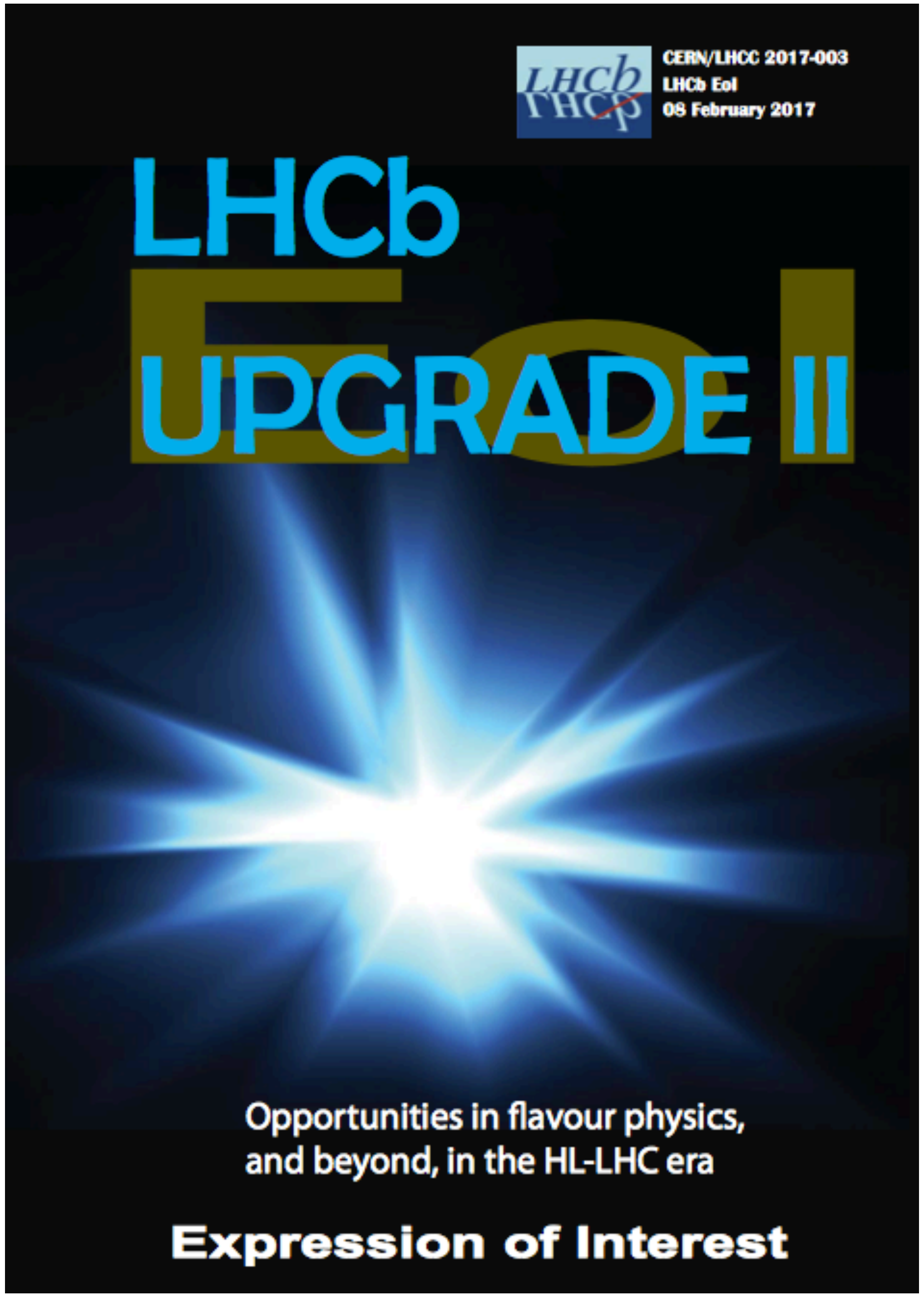
LHCb luminosity prospects

LHC era			HL-LHC era	
Run1 (2010-12)	Run2 (2015-18)	Run3 (2021-23)	Run4 (2026-29)	Run5+ (2032+)
$3fb^{-1}$	**$8fb^{-1}$**	**→**	**$50fb^{-1}$**	**$*300fb^{-1}$**

* assumes a Phase-II LHCb upgrade to raise the instantaneous luminosity to $2x10^{34}$ $cm^{-2}s^{-1}$

- Remember that beauty production cross section roughly doubles passing from 7 to 13-14 TeV *pp* collisions
- LHCb Phase-I upgrade comes after Run-2
  - Raising the instantaneous luminosity from $4x10^{32}$ to $2x10^{33}$ $cm^{-2}s^{-1}$ commencing in Run-3
- LHCb has just submitted to the LHCC an Expression of Interest for a Phase-2 upgrade for Run 5+

LHCb Expression of Interest for a Phase-II upgrade



- By the end of Run 4, and assuming the SM predictions, LHCb will reach a 40% precision on the ratio $BF(B^0 \to \mu\mu)/BF(B^0_s \to \mu\mu)$
  - very powerful observable to constrain the flavour structure of models beyond the SM
- After Phase-II of LHCb the precision on the ratio will be 20% or better, putting strong constraints on viable NP models
- The large B_s yield will allow a precise measurement of the $B_s \to \mu\mu$ effective lifetime, with a precision at the level of 30 fs, as well as of CP-violating observables
- These measurements will be particularly important for discriminating between NP models in the event that effects beyond the SM are observed

https://cds.cern.ch/record/2244311

Conclusions (1)

- We presented today an updated analysis on $B^0_{(s)} \to \mu^+\mu^-$ combining Run1 and first part of Run2 data.

- We observe the $B^0_s \to \mu^+\mu^-$ decay with a branching fraction compatible with the SM:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.8 \pm 0.6) \times 10^{-9}$$

  - This is the first single experiment observation with a statistical significance of 7.8σ

- No evidence for the $B^0 \to \mu^+\mu^-$ decay is found, stringent constraint to NP approaching the SM prediction.

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \cdot 10^{-10} \text{ @ } 95\% \text{ CL}$$

Conclusions (2)

- First measurement of the $B^0_s \to \mu^+\mu^-$ effective lifetime is presented

$$\tau(B^0 \to \mu^+\mu^-) = 2.04 \pm 0.44_{(\mathrm{stat})} \pm 0.05_{(\mathrm{syst})}\,\mathrm{ps}$$

- World's best limit on BF($B^0_s \to \tau^+\tau^-$)

$$\mathcal{B}(B^0_s \to \tau^+\tau^-) < 2.4(3.0) \times 10^{-3} \text{ at } 90(95)\%\text{ C.L.}$$

$$\mathcal{B}(B^0 \to \tau^+\tau^-) < 1.0(1.3) \times 10^{-3} \text{ at } 90(95)\%\text{ C.L.}$$

We warmly thank our colleagues in the CERN accelerator departments for the excellent performance of the LHC!!

backup

Indirect searches

- The Standard Model has been a spectacularly successful theory with many measurements confirming
- However some phenomena imply SM is an incomplete model:
  - dominance of matter over antimatter
  - evidence of dark matter from cosmological observation
  - neutrino oscillation
  - gravity not included
- Search of new particles and interactions that can explain the deviations observed.
- Precise measurements of known hadron properties are the most powerful tool to probe energy scales not accessible with direct searches

Time effect

- The selection efficiency and BDT distribution of $B^0_s \rightarrow \mu^+\mu^-$ depend on the lifetime, further dependence in the time integrated BF

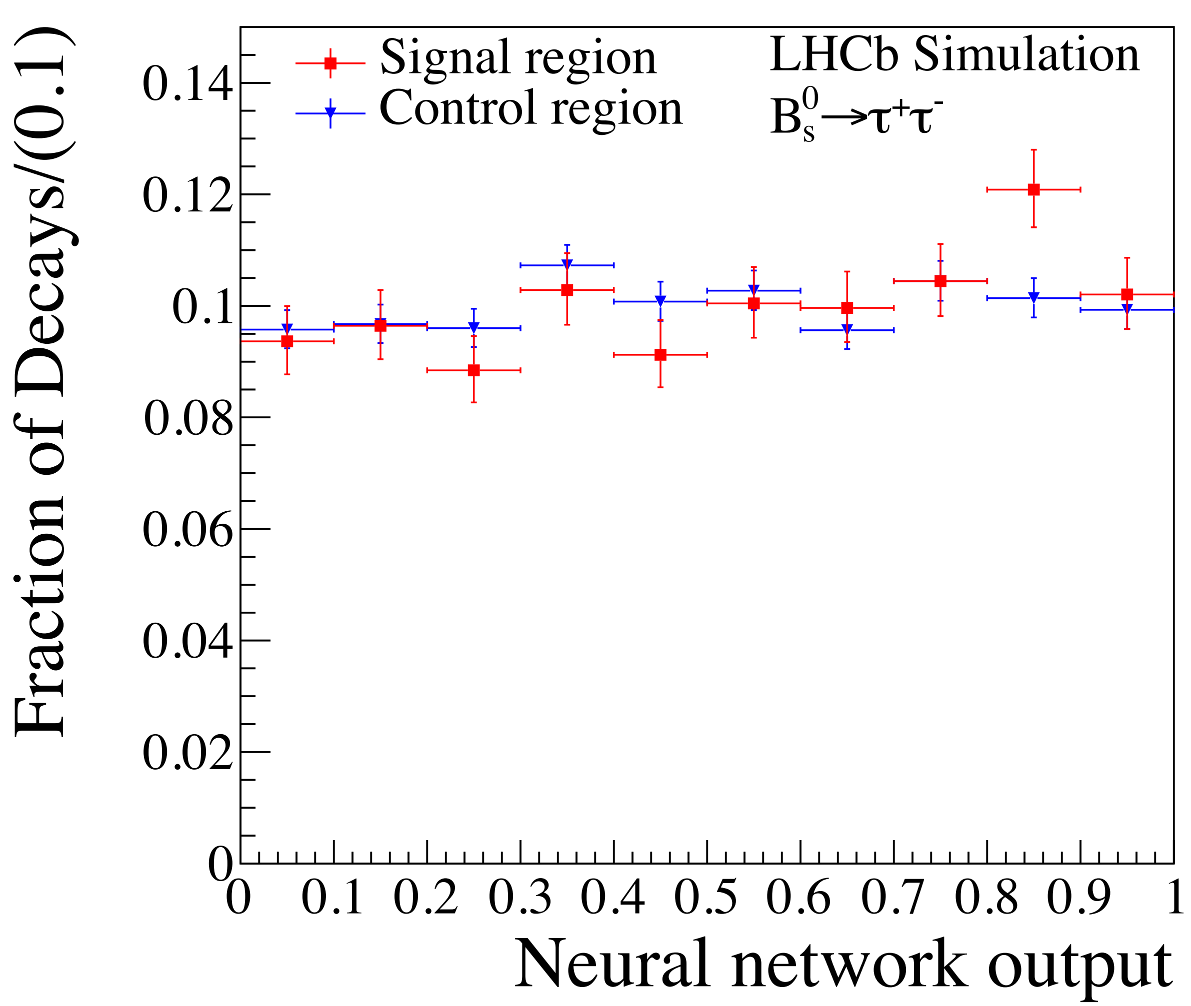
- SM value assumed for $\tau(B^0_s \rightarrow \mu^+\mu^-)$ corresponding to $A_{\Delta\Gamma} = 1$.

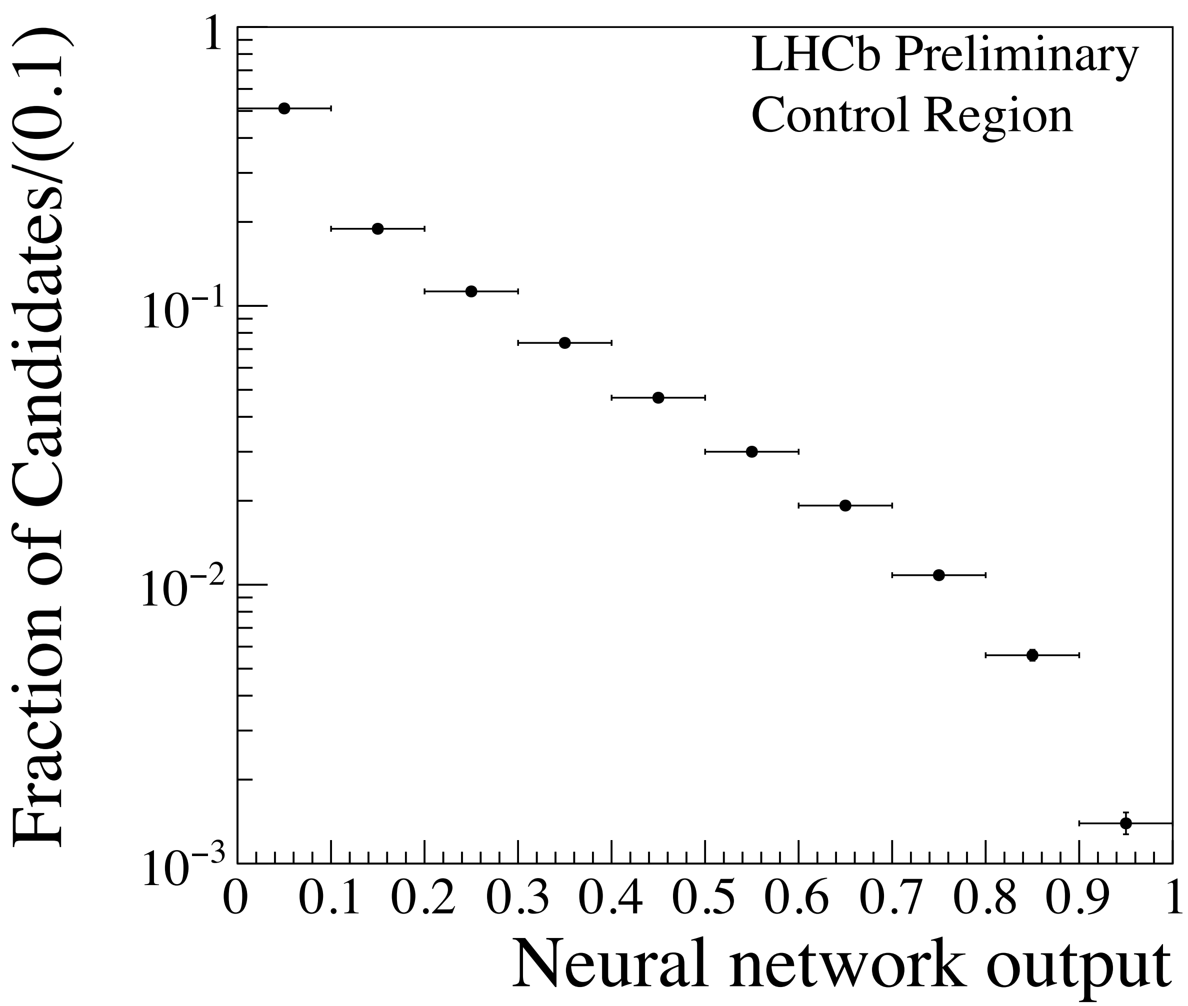
- The model dependence is evaluated by repeating the fit under the $A_{\Delta\Gamma} = 0$ and -1 hypotheses

- An increase of the branching fraction with respect to the SM assumption of 4.6 % and 10.9 %, respectively. The dependence is to a good approximation linear in the physically allowed $A_{\Delta\Gamma}$ range.

Fit Strategy

- Fit to the NN output distribution preformed
- Output remapped such that the **signal** is flat while the **background** peaks at 0
- Signal template from simulated events, background from data control region





Upper Limit

- Observed upper limit:

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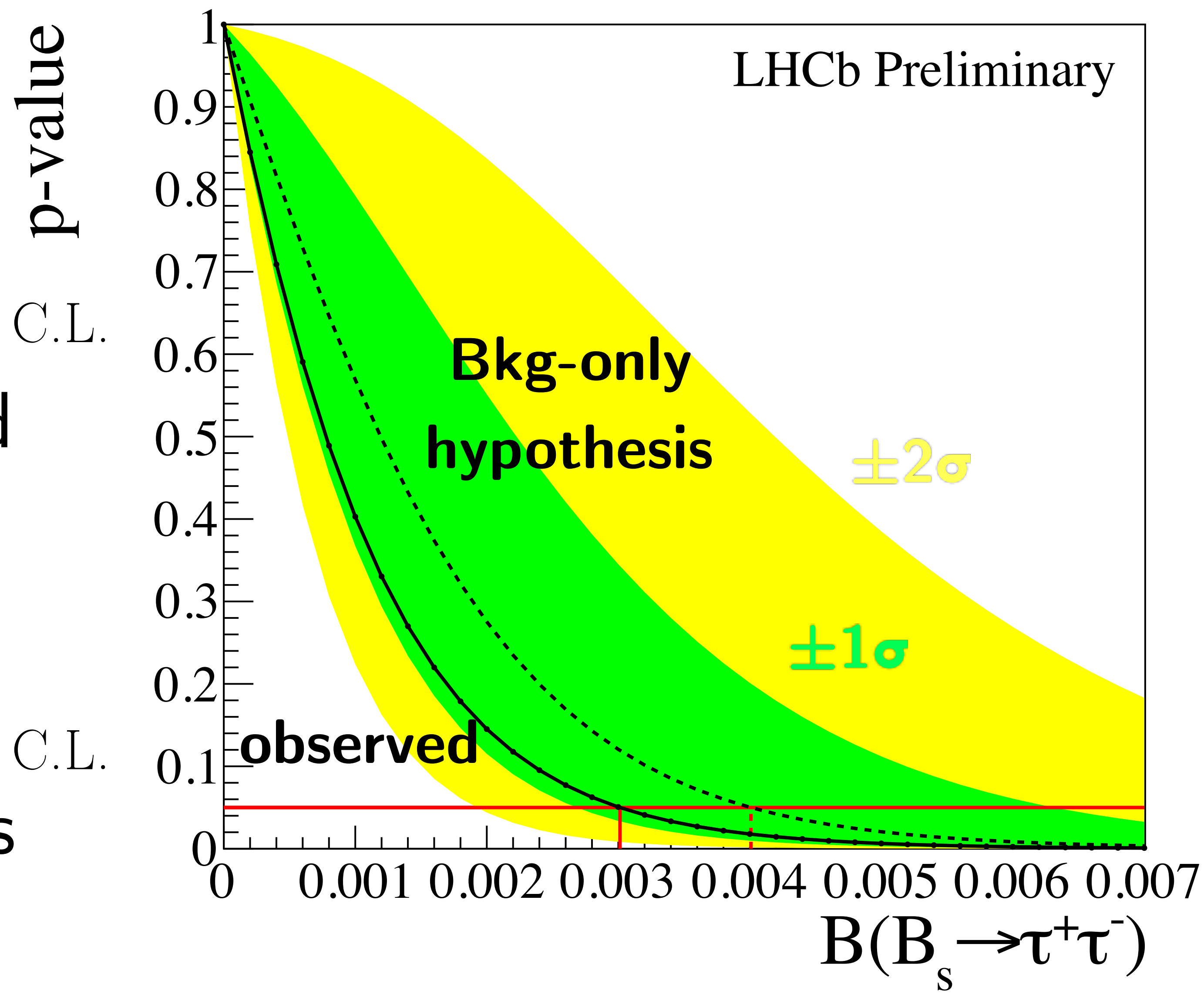
[PRL 96 (2006) 241802]



b fragmentation f_s/f_d

[arXiv:1307.5024]

- LHCb used semileptonic decays: ratio of $B^0_s \to D_s \mu X$ to $B \to D^+ \mu X$
- Combined with hadronic results: ratio of $B^0_s \to D^-_s \pi^+$ to $B^0 \to D^- K^+$

- Recently updated using new $BF(D_s \to K^+ K^- \pi^+)$ from CLEO, BaBar and Belle
- Updated B lifetime measurements

New

$$\frac{f_s}{f_d} = 0.259 \pm 0.015$$

- PT dependence negligible for $B^0_{(s)} \to \mu^+ \mu^-$. Checked the variation as a function of $\sqrt{s}$ with $B^+ \to J/\psi K^+$ and $B^0_s \to J/\psi \phi$