B-Physics - Rare decays in CMS

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on behalf of the CMS Collaboration

ICNFP2024: XIII International Conference on New Frontiers in Physics
detectors
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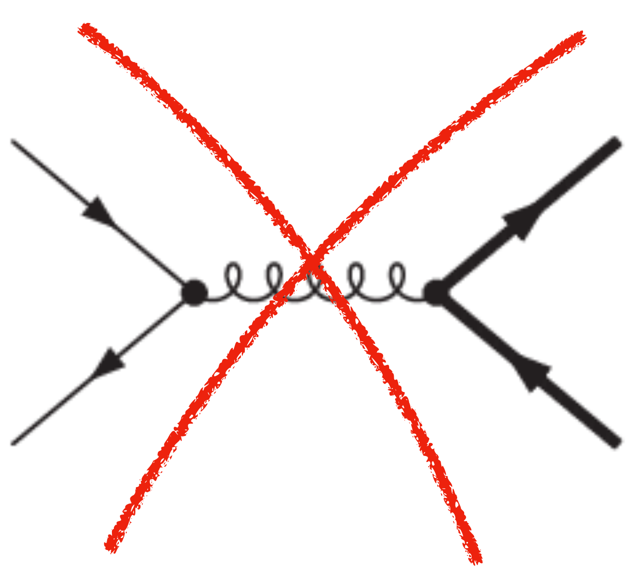
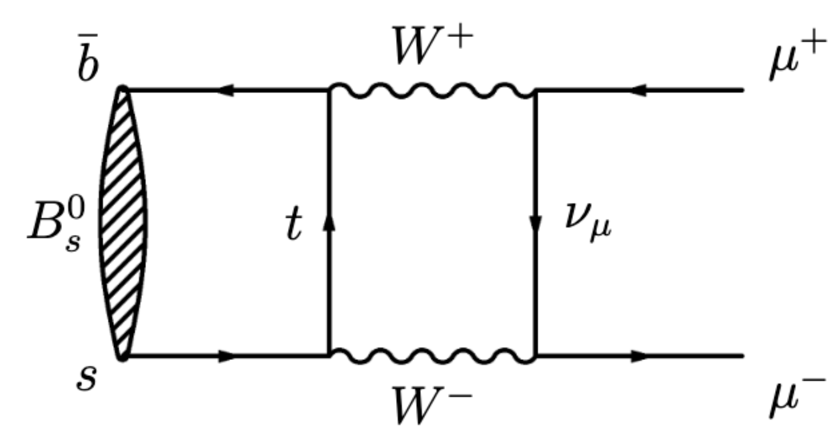
Outline

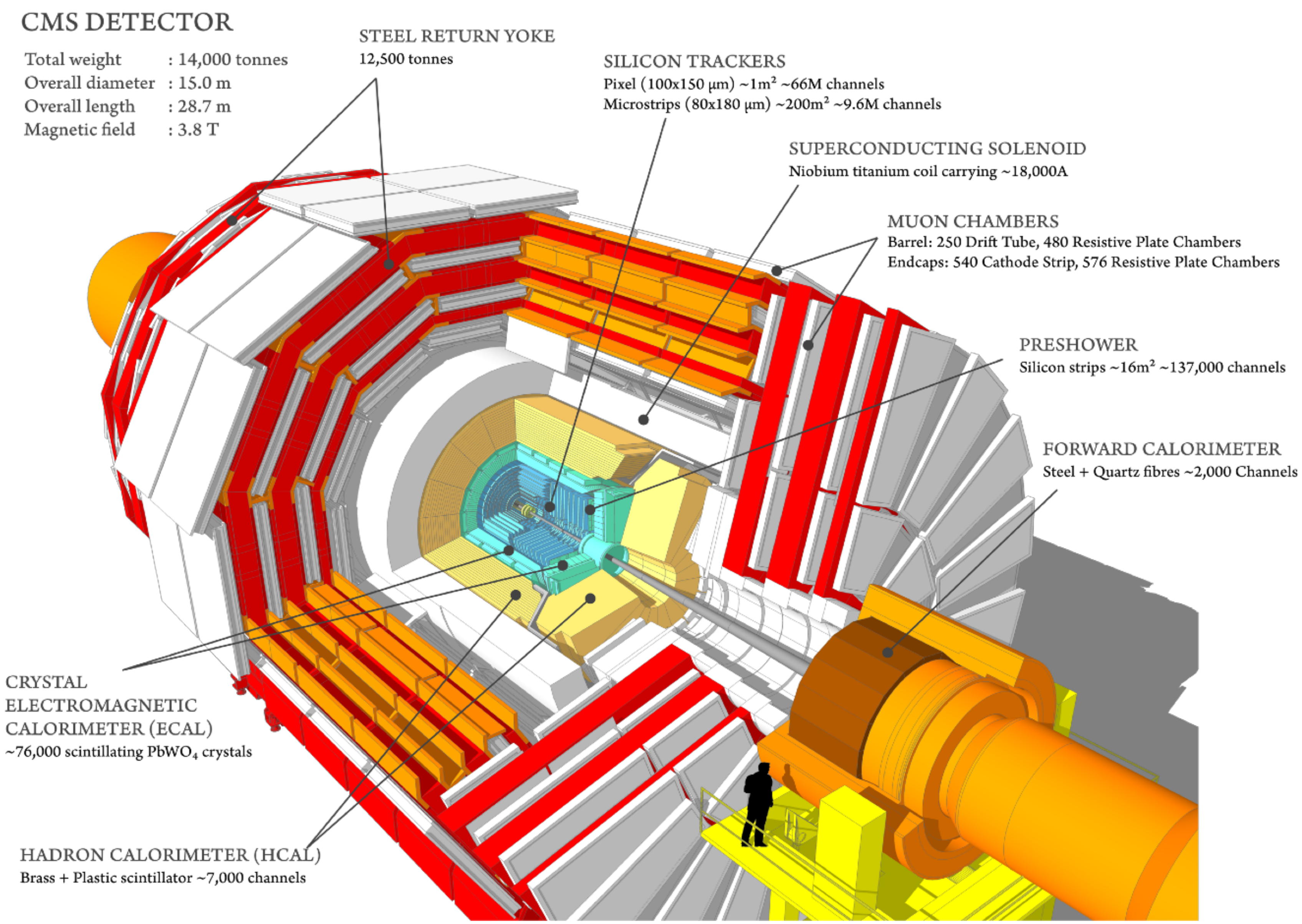
CMS relevant/recent rare decay analyses:

- $B \to \mu\mu$ Branching Fractions and $B_s \to \mu\mu$ Effective Lifetime
- $B^0 \to K^{*0}\mu\mu$ Angular Analysis
- $J/\psi \to \mu\mu\mu\mu$ Decay
- $D^0 \to \mu\mu$ Branching Fraction





CMS Detector



Compact Muon Solenoid

General purpose LHC experiment

B-physics: excellent muon resolution and p_T range

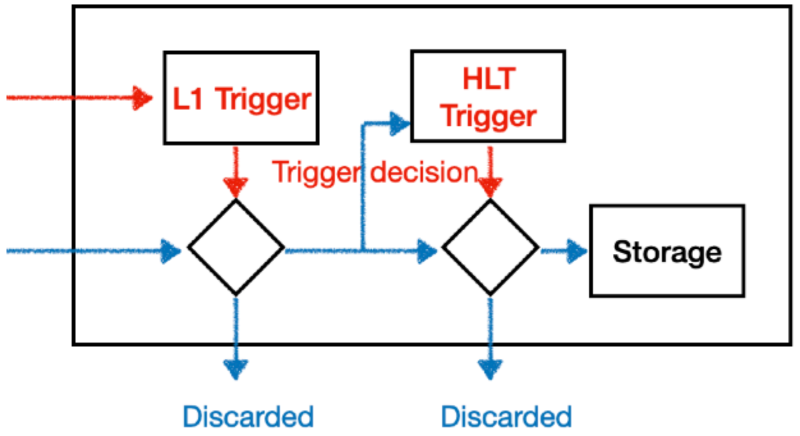
For muons p_T up to 100GeV

1% resolution in the barrel region, 3% in the endcaps

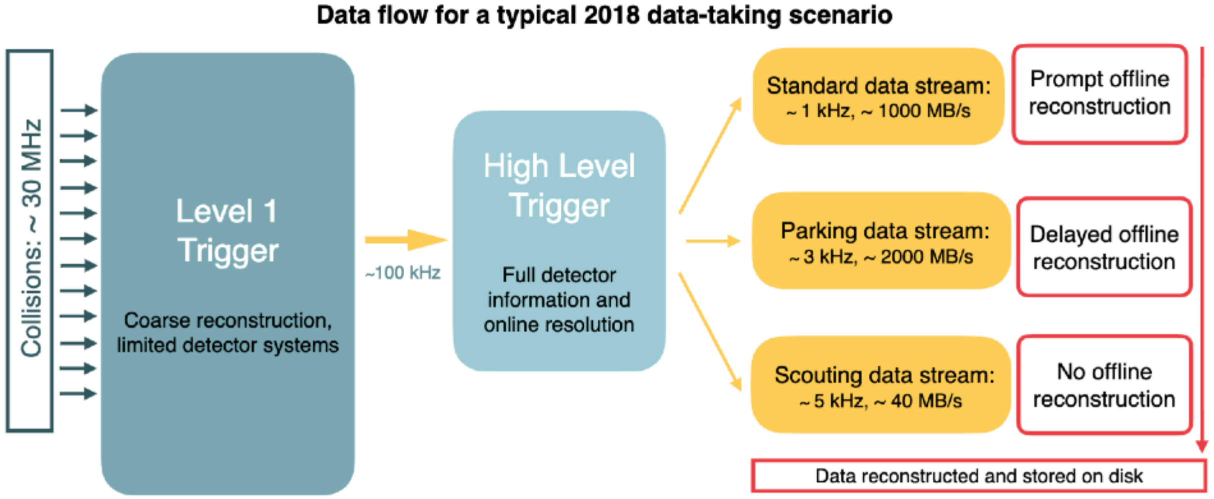
DAQ in CMS

arxiv2403.16134

- **Standard DAQ**
  - L1 Trigger, ASIC/hardware trigger 100kHz
  - HLT Trigger, computer batch 1kHz
- **Data scouting**
  - Reduced the **event size** by saving HLT information
  - Avoids the HLT data buffering bottleneck
  - Analysis example: η→$\mu\mu\mu\mu$ observation [Phys. Rev. Lett. 131, 091903]
- **Data parking**
  - Exploits the computational margin arising from the LHC fill luminosity decay
  - Event are **reconstructed later** in time and saved on **tape**
  - Avoids the reconstruction resources bottleneck
  - During Run2 (2016-2018) recorder 10^{10} B collisions



Data flow for a typical 2018 data-taking scenario



Swagata's talk on Wednesday

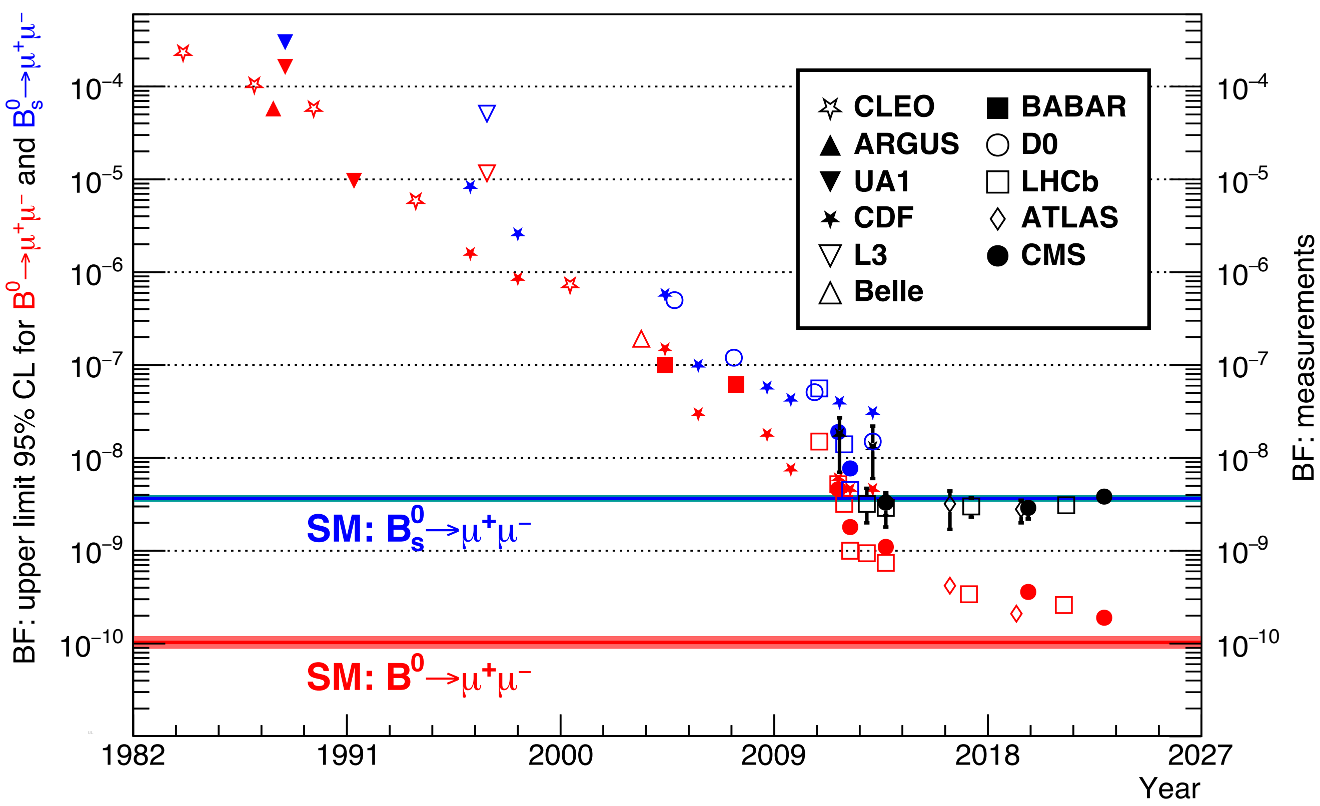
$B \to \mu\mu$

Phys.Lett.B842(2023)137955

$B_s \to \mu\mu$ and $B^0 \to \mu\mu$ decays are highly suppressed in the SM

- Involve flavour-changing neutral current (**FNCN**) transitions
- Helicity suppressed
- Can occur via high-oder EW diagrams (loop)
- **$B^0 \to \mu\mu$** BF further **suppressed** by CKM matrix element by 20x

- Theoretical predictions of the **Branching Fractions** are precise, any deviation might be a hint of NP particles present in the loop diagrams
- **$B_s \to \mu\mu$ effective lifetime** measurement gives another handle to check the presence of NP: the decay is CP-even and without the CP violation the lifetime corresponds to the B_{sH} state

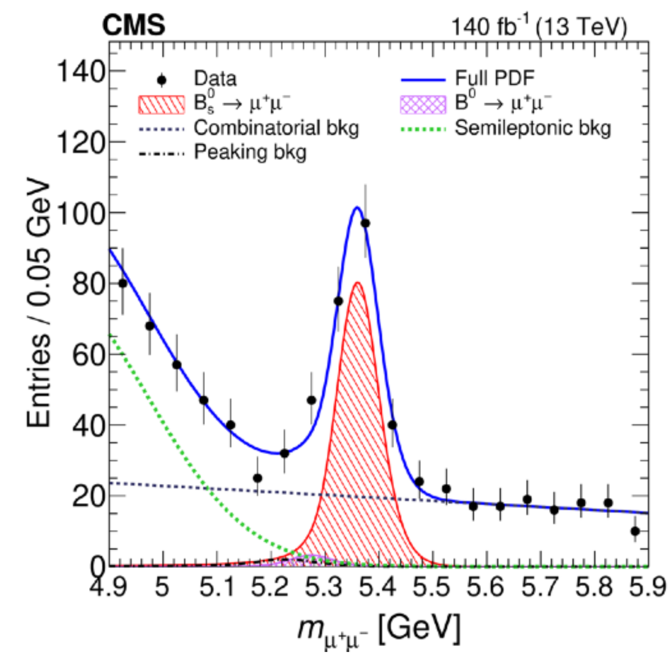


B→$\mu\mu$ Branching Fractions

Phys.Lett.B842(2023)137955

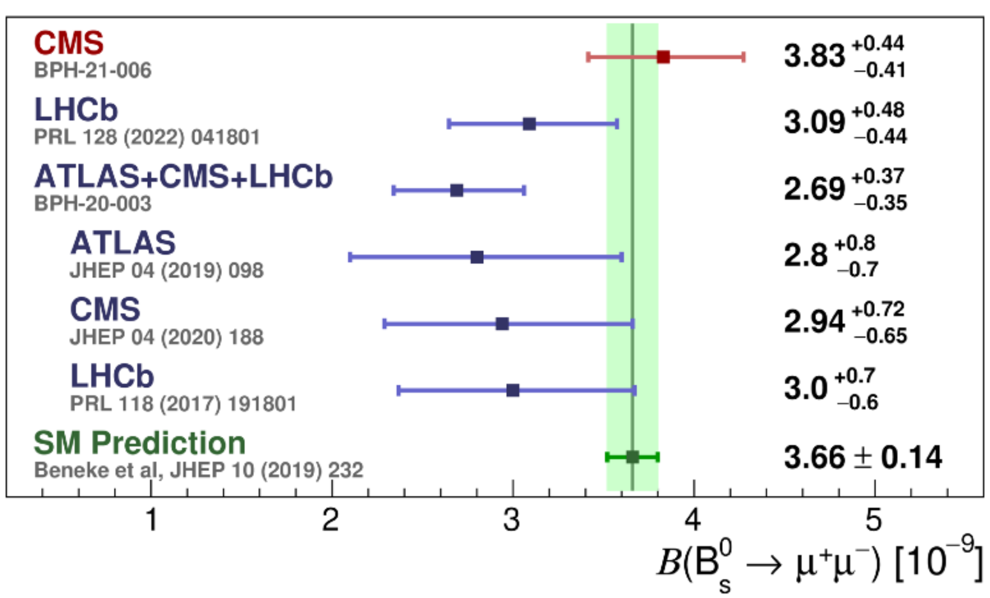
Analysis details

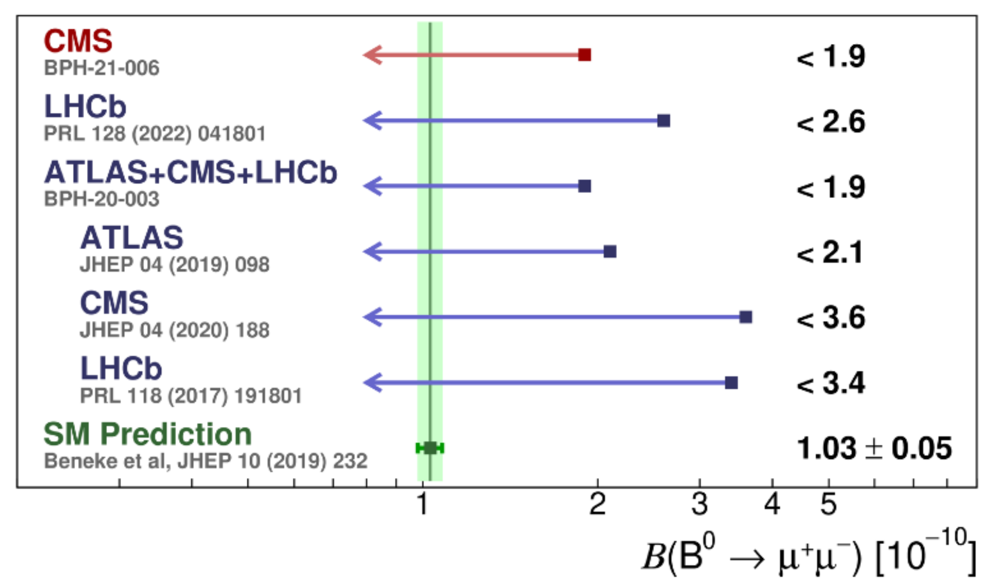
- **Standard DAQ**, dimuon trigger
- Extensive use **BDTs** for muon identification (fake reduction) and signal selection
- 2016→2018 data at $\sqrt{s}$ = 13TeV
- BFs **normalised** with respect to **B^+→J/ψK^+** channel
- UML fit (mass, mass uncertainty) on 16 categories
  - Rapidity, data taking period, BDT output



$$\mathcal{B}(\mathrm{B}^0_s \to \mu^+\mu^-) = \left[3.83^{+0.38}_{-0.36}(stat)^{+0.19}_{-0.16}(syst)^{+0.14}_{-0.13}(f_s/f_u)\right] \times 10^{-9}$$

$$\mathcal{B}(\mathrm{B}^0 \to \mu^+\mu^-) < 1.9 \times 10^{-10} \text{ @ 95\% CL}$$





$B_s \to \mu\mu$ Effective Lifetime

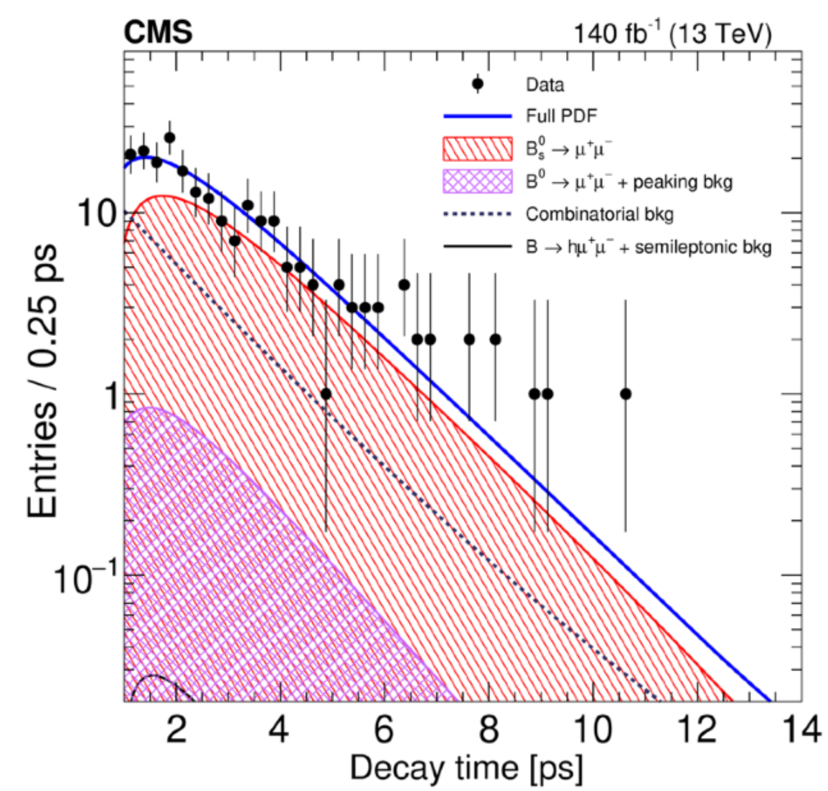
Phys.Lett.B842(2023)137955

Analysis details

- Lifetime efficiency derived from simulation
- Main systematics due to the correlation of between the BDT and the decay time
- Result:

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

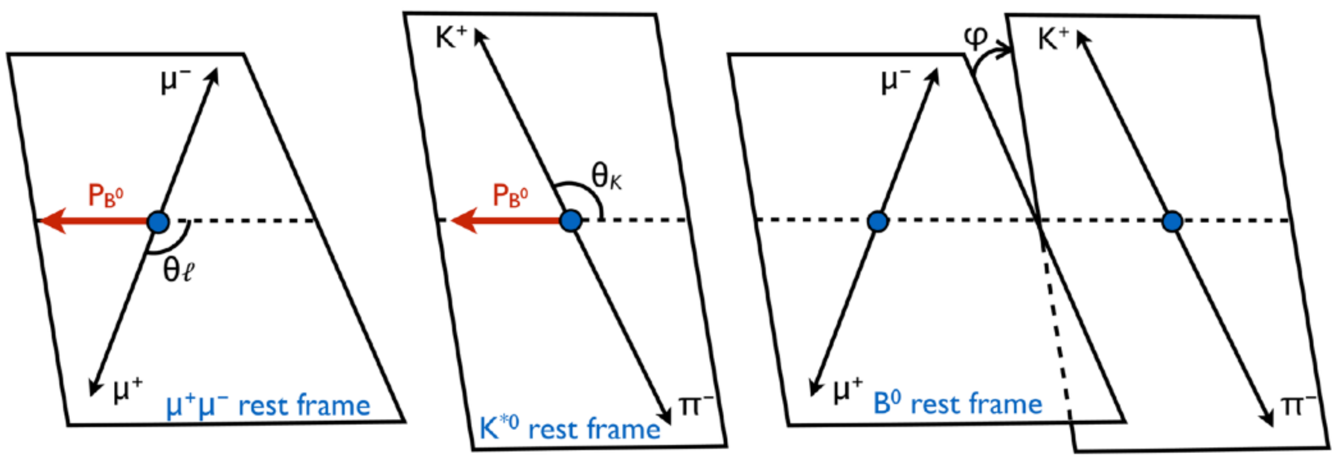
- In **agreement with the SM** [τ_H=1.62 ps]
- Needs more data to be able to discriminate between B_{sH} and B_{sL} states



$B^0 \to K^{*0}\mu\mu$ introduction

Angular analysis of the decay channel $B^0 \to K^{*0}\mu^+\mu^-$ with K^{*0} decaying into $K\pi$

- Motivation: angular distributions can be defined as function of Wilson coefficients.
- **Angular variables**: θ_K, θ_l, ϕ
- Distribution measured in q^2 bins: invariant mass squared of the dimuon system



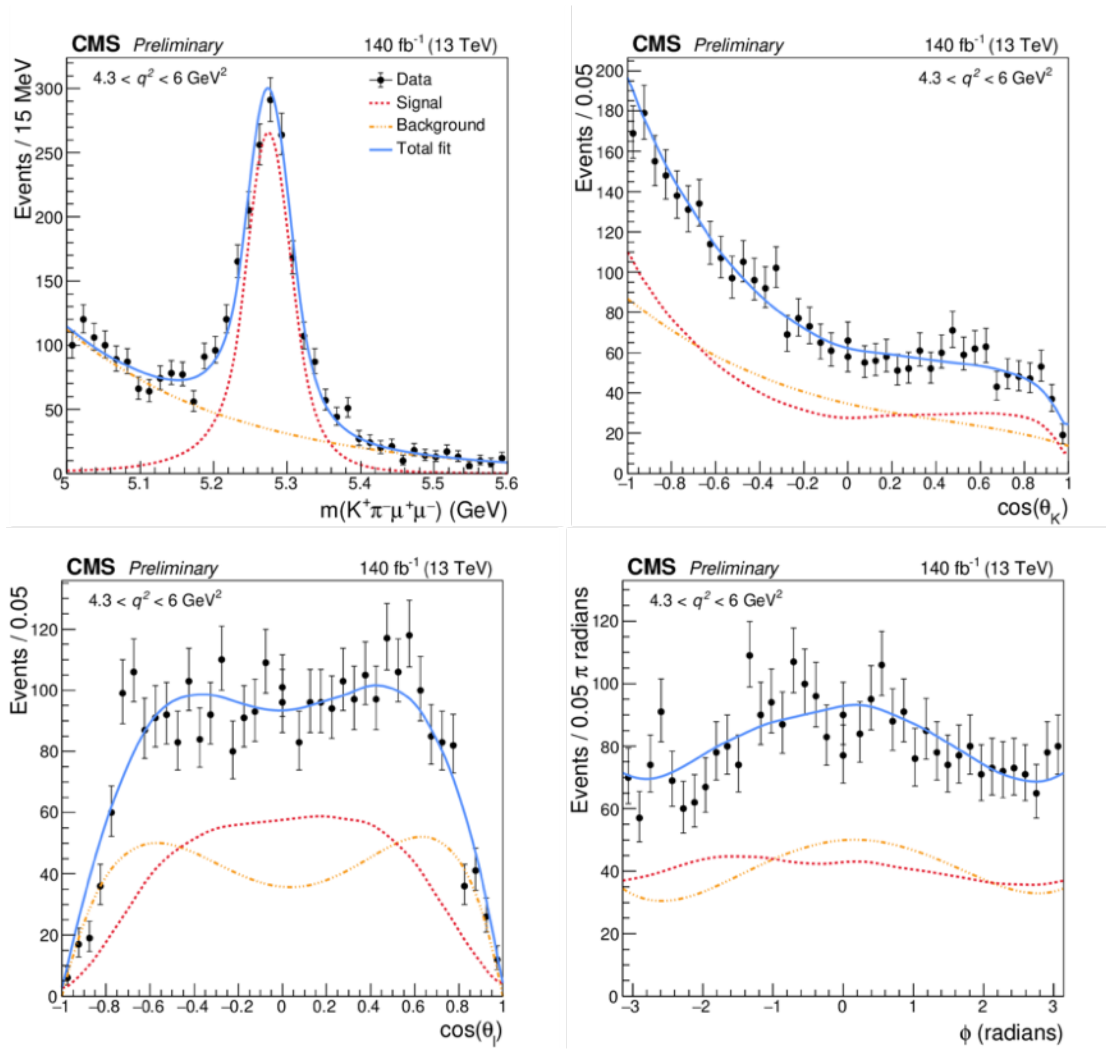
- **CP-averaged observables**: F_L, P_i, P_j'

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_l\mathrm{d}\cos\theta_K\mathrm{d}\phi} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K$$
$$+ (\frac{1}{4}(1-F_L)\sin^2\theta_K - F_L\cos^2\theta_K)\cos 2\theta_l$$
$$+ \frac{1}{2}P_1(1-F_L)\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$
$$+ \sqrt{(1-F_L)F_L}(\frac{1}{2}P_4'\sin 2\theta_K\sin 2\theta_l\cos\phi + P_5'\sin 2\theta_K\sin\theta_l\cos\phi)$$
$$- \sqrt{(1-F_L)F_L}(P_6'\sin 2\theta_K\sin\theta_l\sin\phi - \frac{1}{2}P_8'\sin 2\theta_K\sin 2\theta_l\sin\phi)$$
$$+2P_2(1-F_L)\sin^2\theta_K\cos\theta_l - P_3(1-F_L)\sin^2\theta_K\sin^2\theta_l\sin 2\phi)\Big]$$

$B^0 \to K^{*0}\mu\mu$ angular analysis

Analysis details CMS-PAS-BPH-21-002

- 2016 to 2018 standard DAQ data
- Signal from resonant K^{*0} and non resonant $K\pi$ (S-wave)
- KDE angular efficiencies modelled on simulated events
- **Maximum likelihood fit in bins of q^2** of the signal and background pdf
- Fit validated in control regions J/ψ and $\psi(2S)$

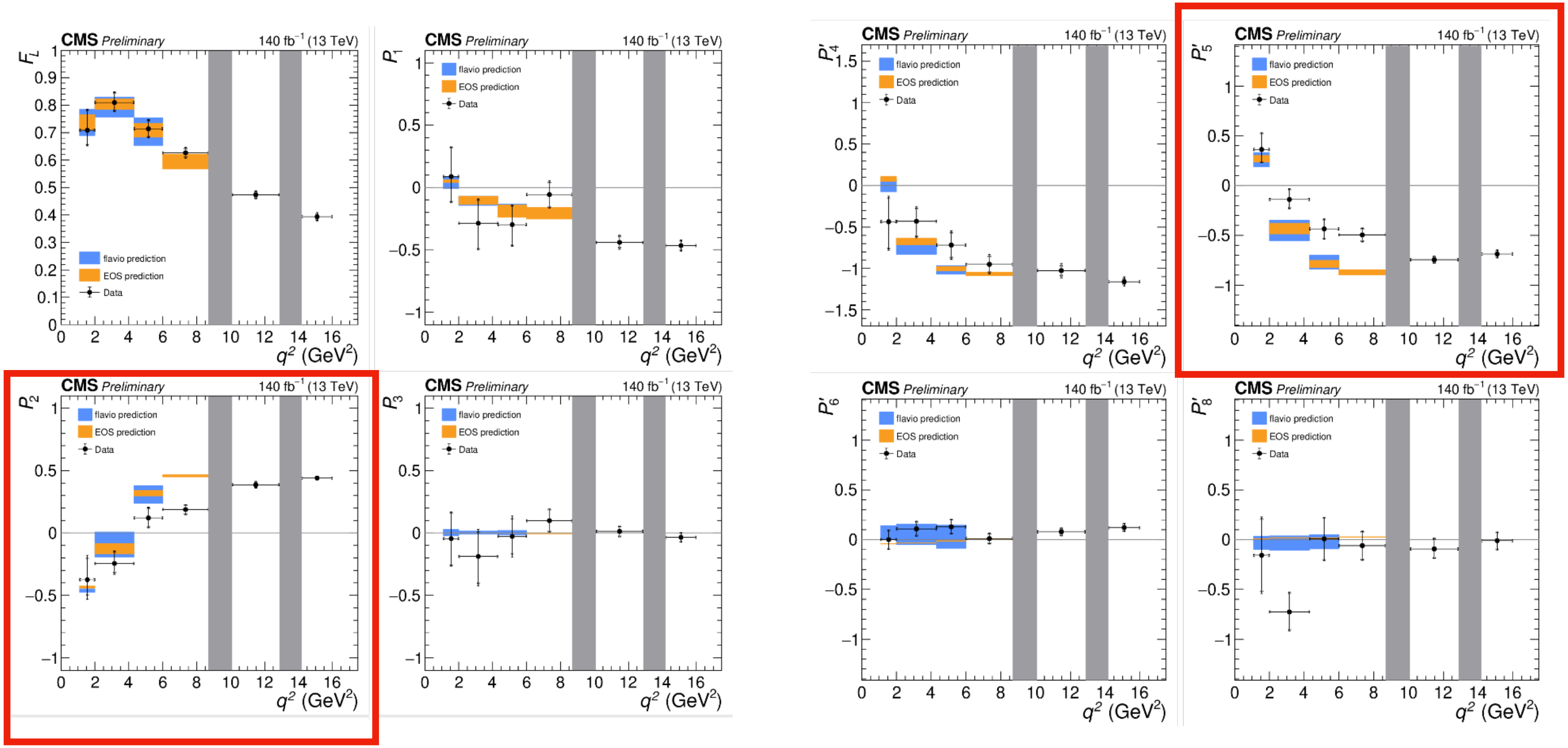


$B^0 \to K^{*0}\mu\mu$ results 1/2

Results

CMS-PAS-BPH-21-002

- **Tensions** in some bins of **P_5' and P_2**
  - Flavio: local form-factors (LQCD and Light-Cone Sum Rule) + non-local form-factors (QCDF)
  - EOS: local form-factors (LQCD and LCSR), novel parametrisation of non-local form-factors

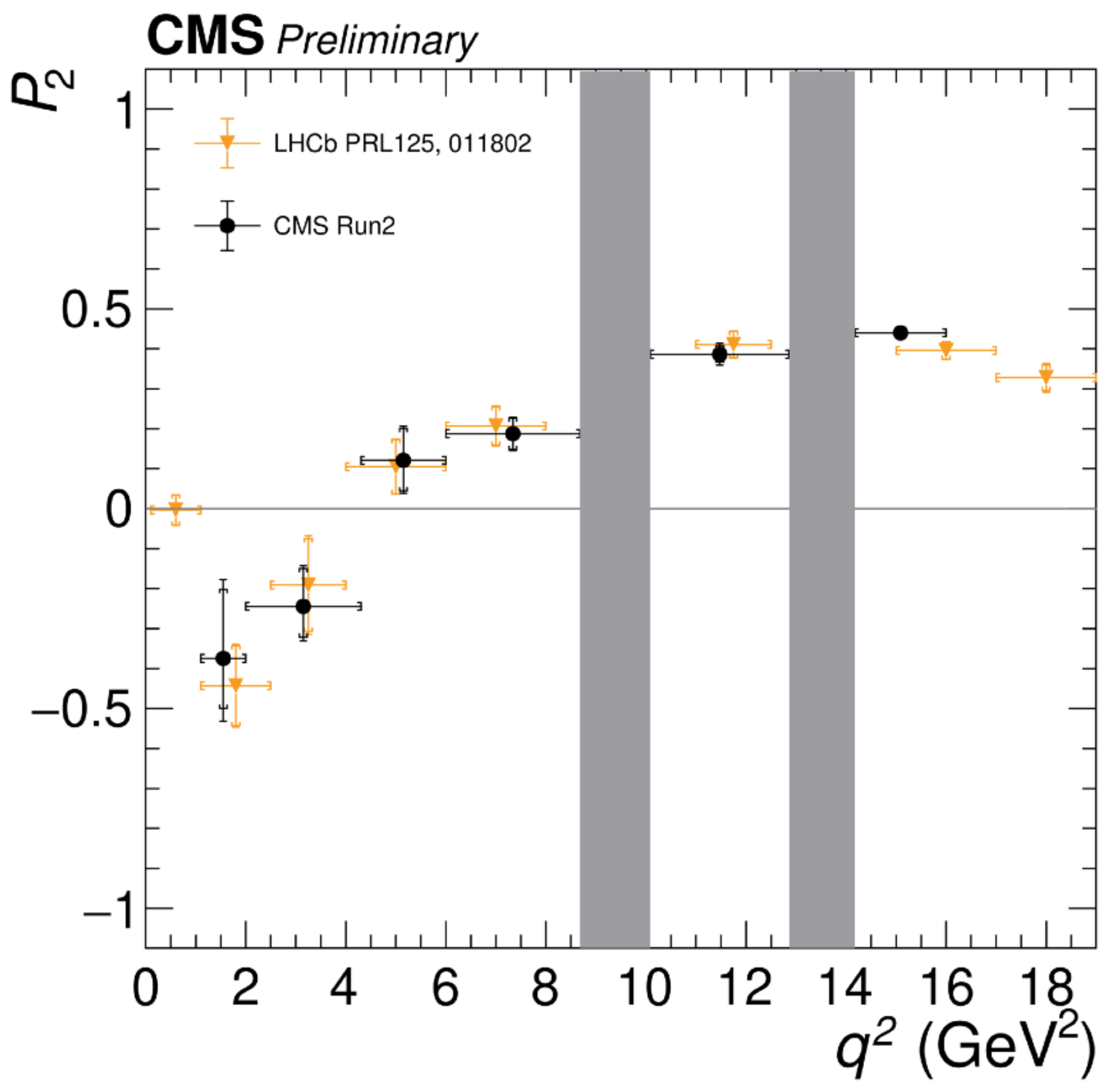


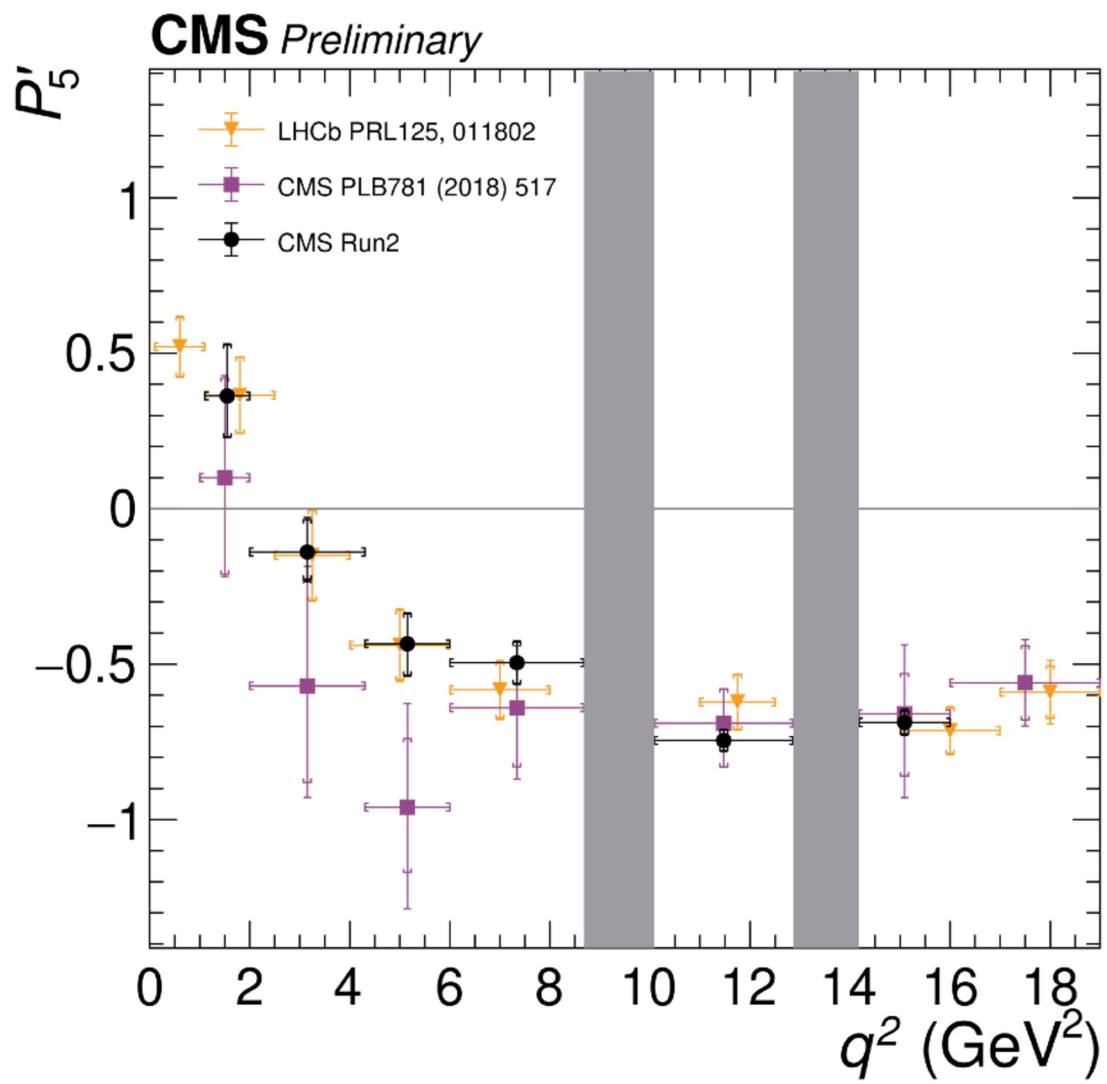
$B^0 \to K^{*0} \mu\mu$ results 2/2

CMS-PAS-BPH-21-002

Results

- Statistical **agreement** with previous **measurements**





$J/\psi \to \mu\mu\mu\mu$ introduction

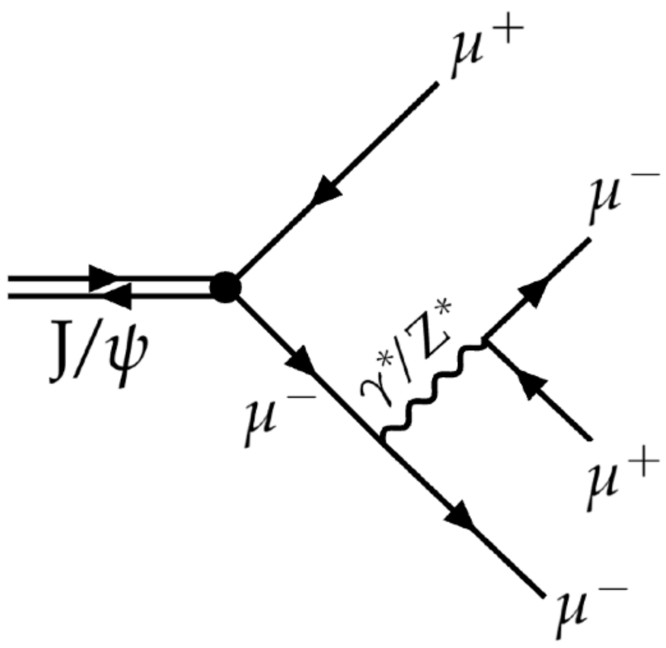
Phys. Rev. D 109

Motivations

- BESII already reported the observation of $J/\psi \to ee\mu\mu$ and $J/\psi \to eeee$, setting an upper limit for the $J/\psi \to \mu\mu\mu\mu$ decay channel. [Phys. Rev. D 109, 052006]
- **Very clean and precise** theoretical BF prediction $\mathcal{B}(J/\psi \to \mu\mu\mu\mu) = (9.74 \pm 0.05) \times 10^{-7}$ [Phys. Rev. D 104, 094023]

Analysis details

- Use of B parked Run2 data taken in 2008
- Efficiency measured on simulations
- BF measured relative to the $J/\psi \to \mu\mu$ BF
- ML fit of the 4-muon and di-muon invariant mass



$$\frac{\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-)}{\mathcal{B}(J/\psi \to \mu^+\mu^-)} = \frac{N(J/\psi \to \mu^+\mu^-\mu^+\mu^-)}{N(J/\psi \to \mu^+\mu^-)} \Big/ \frac{\epsilon_{J/\psi \to \mu^+\mu^-\mu^+\mu^-}}{\epsilon_{J/\psi \to \mu^+\mu^-}},$$

J/ψ→$\mu\mu\mu\mu$ results

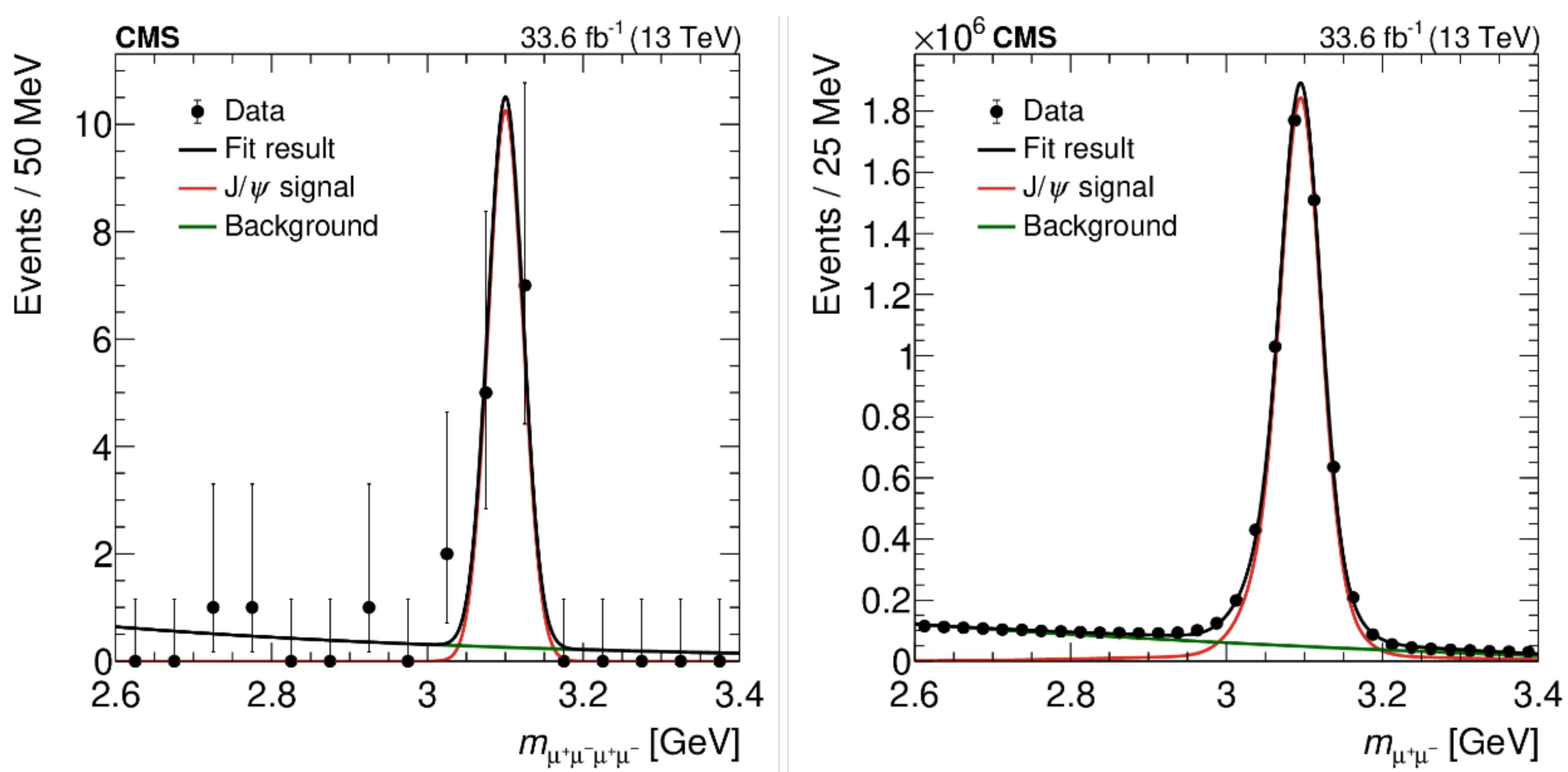
Phys. Rev. D 109

Results

- **Observation** of the J/ψ→$\mu\mu\mu\mu$ decay
- Results consistent with the SM predictions

$$\frac{\mathcal{B}(\mathrm{J}/\psi \to \mu^+\mu^-\mu^+\mu^-)}{\mathcal{B}(\mathrm{J}/\psi \to \mu^+\mu^-)} = [16.9^{+5.5}_{-4.6}\,(\mathrm{stat}) \pm 0.6\,(\mathrm{syst})] \times 10^{-6}.$$

$$\mathcal{B}(\mathrm{J}/\psi \to \mu^+\mu^-\mu^+\mu^-) = [10.1^{+3.3}_{-2.7}\,(\mathrm{stat}) \pm 0.4\,(\mathrm{syst})] \times 10^{-7},$$



$D^0 \to \mu\mu$ introduction

Motivations

- Particular attention has been put on the b→s transition, see $B \to \mu\mu$, while c→u transitions are less studied at LHC
- $D^0 \to \mu\mu$ decay channel is suppressed as it is a **FCNC process**
- SM predictions not particularly reliable, but **expected to be very small** $\mathcal{B}(D^0 \to \mu\mu) = 3 \times 10^{-13}$
- New Physics can increase the BF

Analysis details

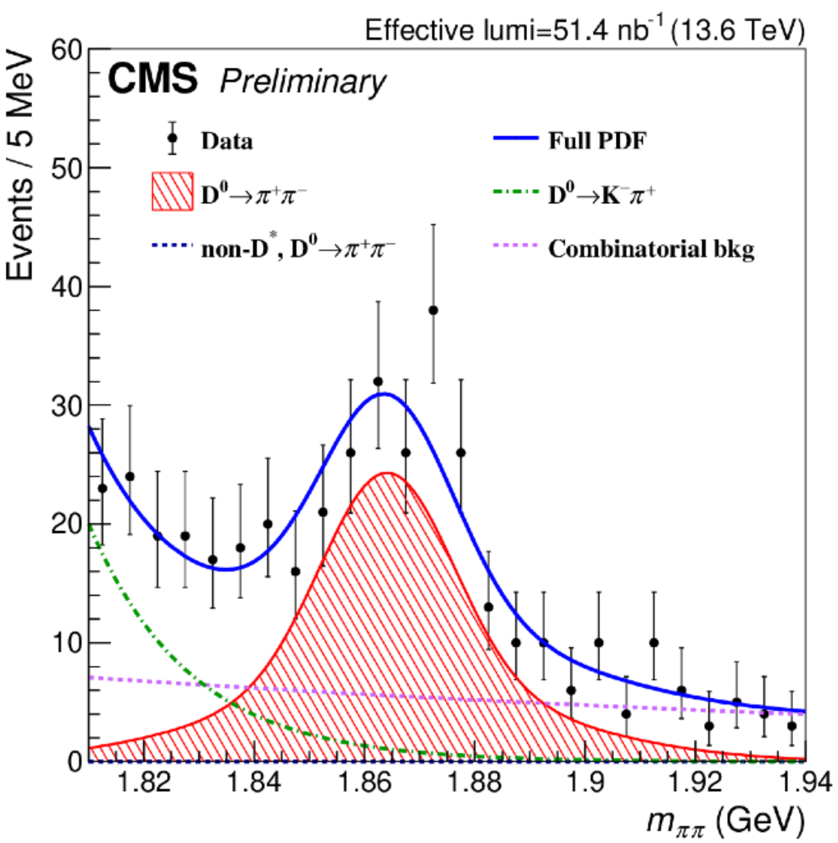
- Based on data collected using the **B parking DAQ in 2022-2023**
- $D^0 \to \mu\mu$ reconstructed from $D^{*+} \to D^0 \pi^+$ for BG reduction
- After basic preselection (+dimoun trigger) a selection based on BDT output is applied
- BF measured fitting the D^0 peak and the difference of mass between D^{*+} and D^0 (Δm)
- BF normalised with respect to the $D^0 \to \pi\pi$ decay

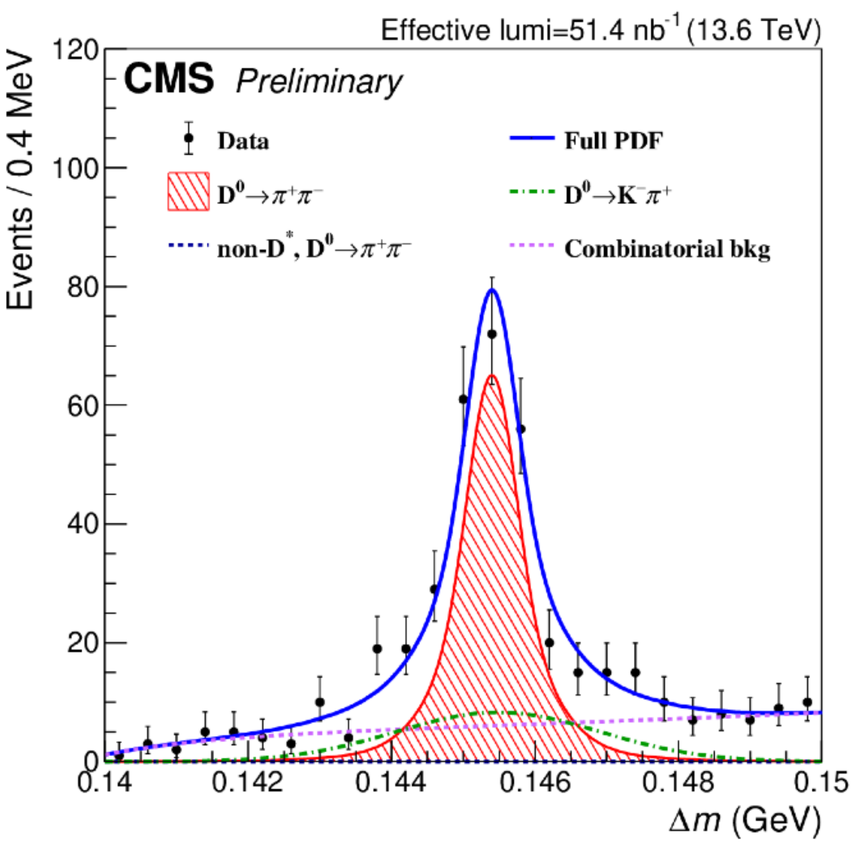
$D^0 \to \mu\mu$ normalisation channel

$$\mathcal{B}(D^0 \to \mu^+\mu^-) = \mathcal{B}(D^0 \to \pi^+\pi^-)\frac{N_{D^0\to\mu^+\mu^-}}{N_{D^0\to\pi^+\pi^-}}\frac{\varepsilon_{D^0\to\pi^+\pi^-}}{\varepsilon_{D^0\to\mu^+\mu^-}}$$

Normalisation channel

- 195 signal events extracted





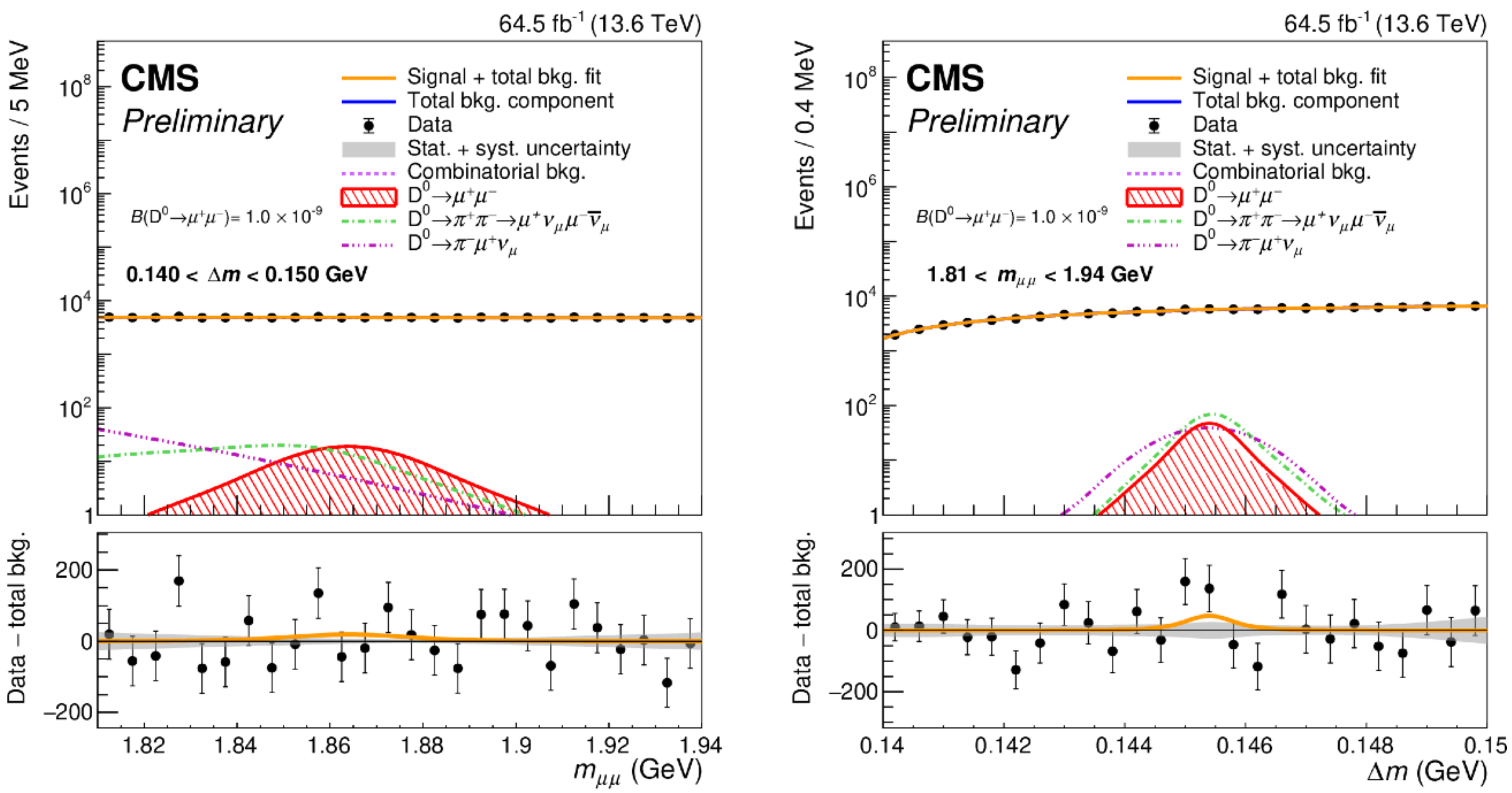
$D^0 \to \mu\mu$ results

Results

- **Best upper limit** to date
- Compatible with the SM

$$\mathcal{B}(D^0 \to \mu^+\mu^-) < 2.6 \times 10^{-9} \text{ at 95\% CL.}$$

$$\mathcal{B}(D^0 \to \mu^+\mu^-) = (1.0 \pm 0.9) \times 10^{-9},$$



Conclusions

CMS pretty competitive experiment for B-physics rare search decays in muons:

- $B \to \mu\mu$ Branching Fractions and $B_s \to \mu\mu$ Effective Lifetime
  - Best single measurement
- $B^0 \to K^{*0}\mu\mu$ angular analysis
  - Best measurement to date
- $J/\psi \to \mu\mu\mu\mu$
  - First observation
- $D^0 \to \mu\mu$
  - Best upper limit to date