Tau g-2 and Heavy Flavor Highlights from ATLAS/CMS

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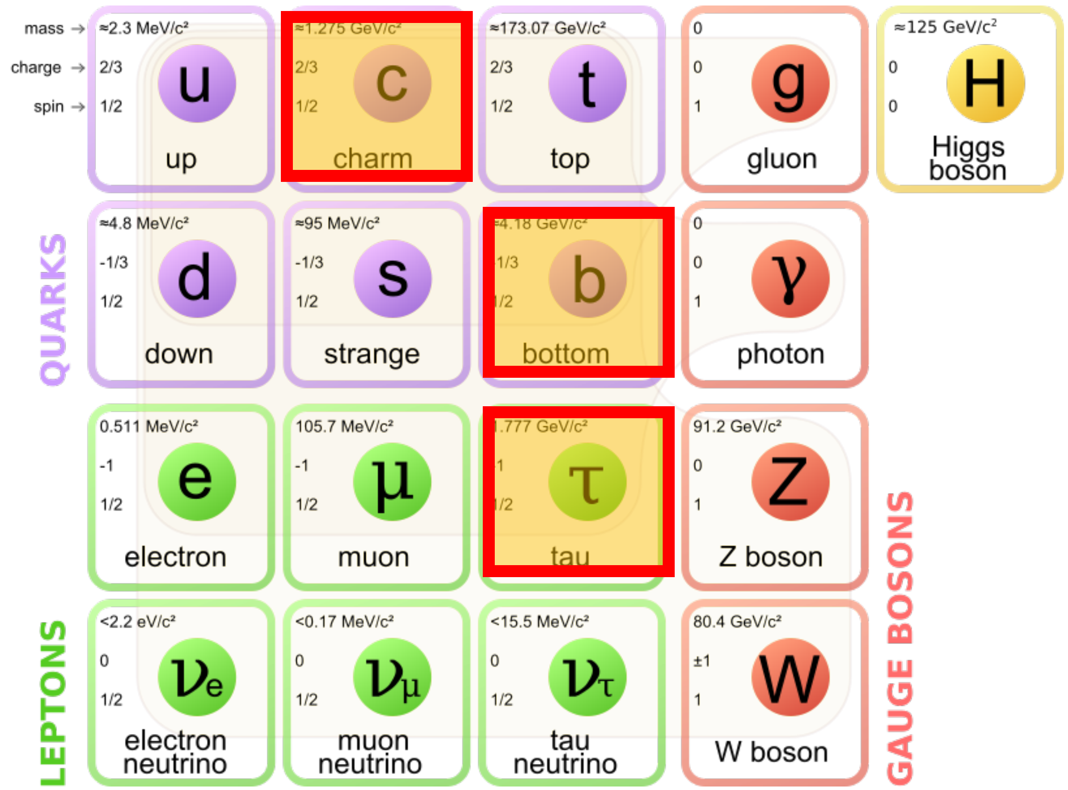
on behalf of ATLAS/CMS Collaborations

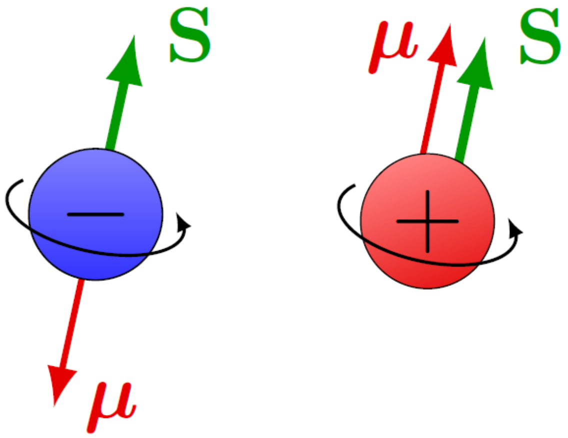
Qingdao, 2024.11.15

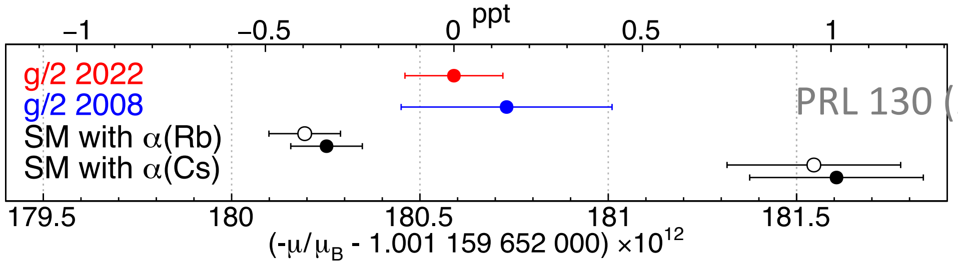
Further probing SM with heavy lepton/quarks

- LHC is also a factory of heavy lepton/quarks
- Heavy lepton/quarks are usually more sensitive to potential NP scenarios
- Testing SM and search for NP indirectly through precision measurement

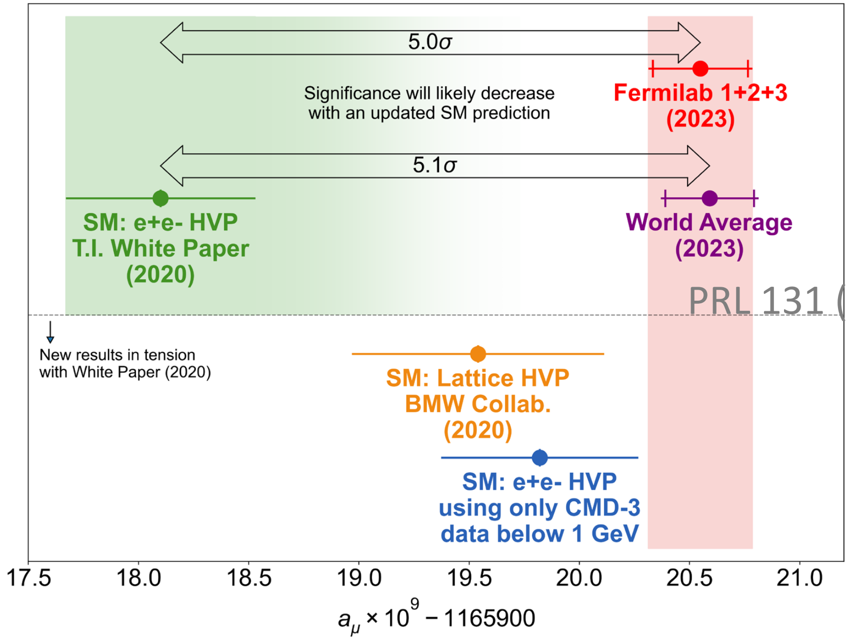


Lepton anomalous magnetic moment a_l





PRL 130 (2023) 071801



PRL 131 (2023) 161802

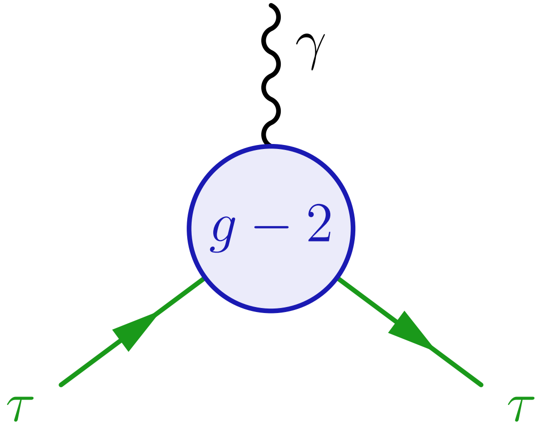
$$\mu = g\frac{e}{2m}\mathbf{S} \qquad a_l = (g-2)/2$$

- measurements of a_e in Penning traps are the "most precise in physics"
- measurements of a_μ in storage rings are in longstanding tension with theoretical computations

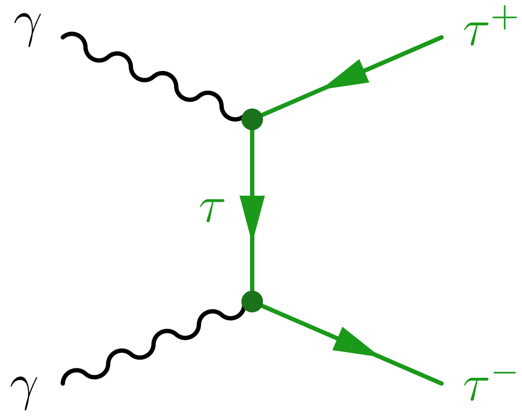
Constrain tau EM moments a_τ & d_τ

If BSM effects scale with the m_l^2, deviations from SM could be 280 times larger than for a_μ

- a_τ & electric dipole moment d_τ can be probed from $\gamma\tau\tau$ **vertex**



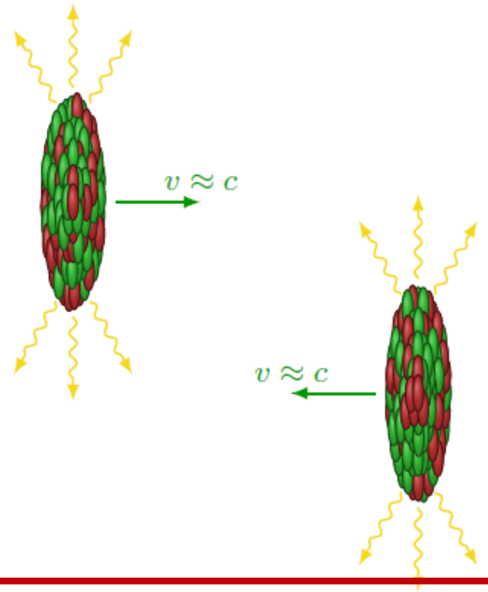
- $\gamma\gamma \rightarrow \tau\tau$ process contains 2 $\gamma\tau\tau$ vertices



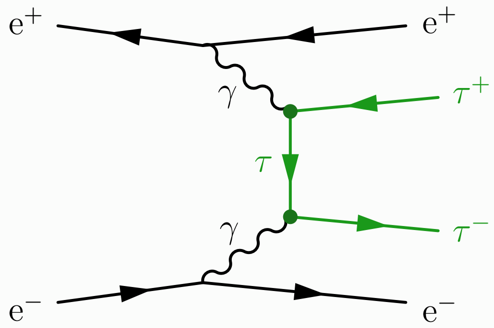
- contraints on electromagnetic moments a_τ & d_τ from *form factors* or *SMEFT*
- in the SM: $d_\tau \sim 10^{-37}$ ecm via CP/T violation in CKM, but could be much larger in BSMs
- Best constraints on a_τ and d_τ are both from e^+e^- collisions:
  - $-0.052 < a_\tau < 0.013$, 95% CL (DELPHI@LEP)
  - $-1.85 < d_\tau < 0.61 \times 10{-}17$ ecm, 95% CL (Belle)

Photon-induced $\tau\tau$ production

Photon-induced process: two charged particles (e.g. protons or ions) pass each other at relativistic velocities, they generate intense electromagnetic fields → **photon-photon collisions** can happen

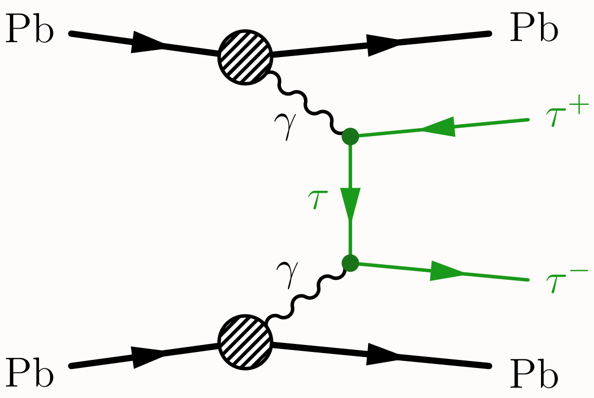


LEP: DELPHI, L3, ...

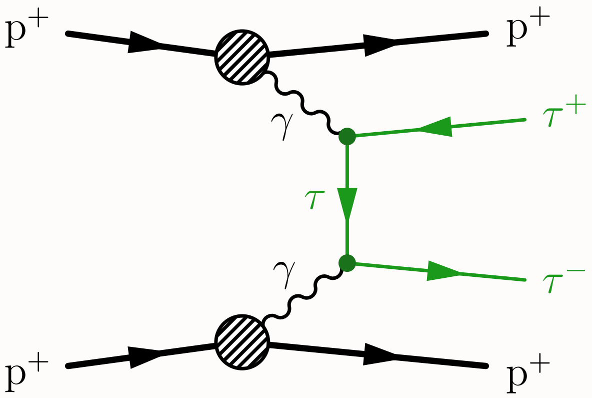


$e^+e^- \to e^+e^- \tau^+\tau^-$

LHC: CMS, ATLAS, ...



PbPb → PbPb $\tau^+\tau^-$



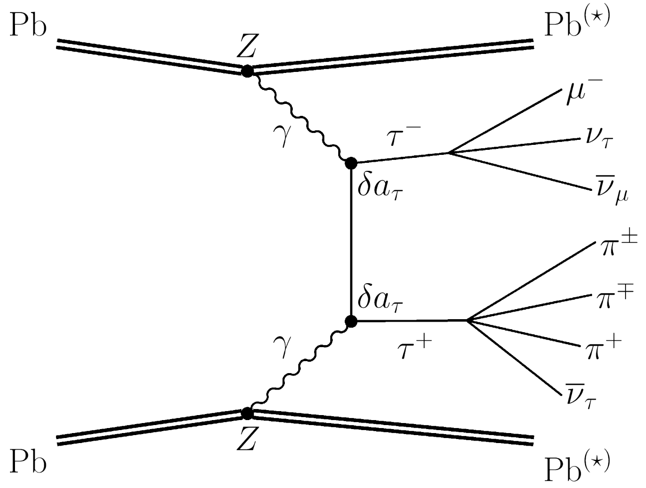
pp → pp $\tau^+\tau^-$

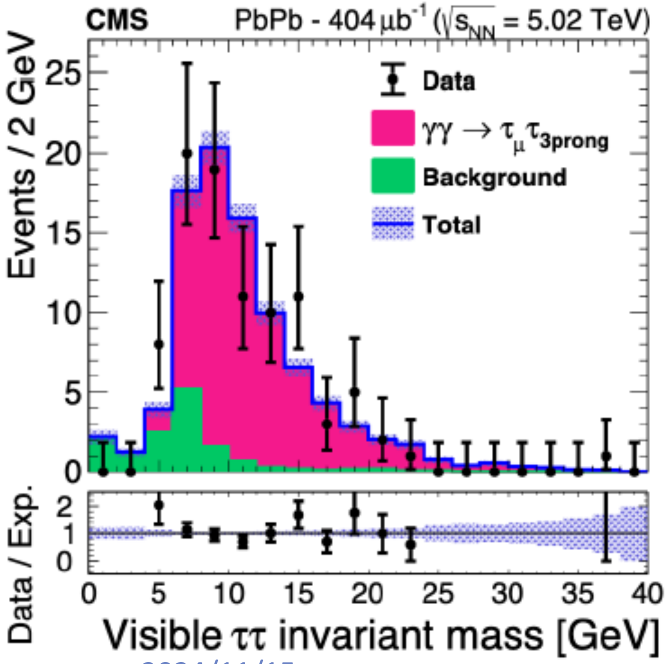
EPJC 35 (2004) 159
PLB 407 (1997) 341

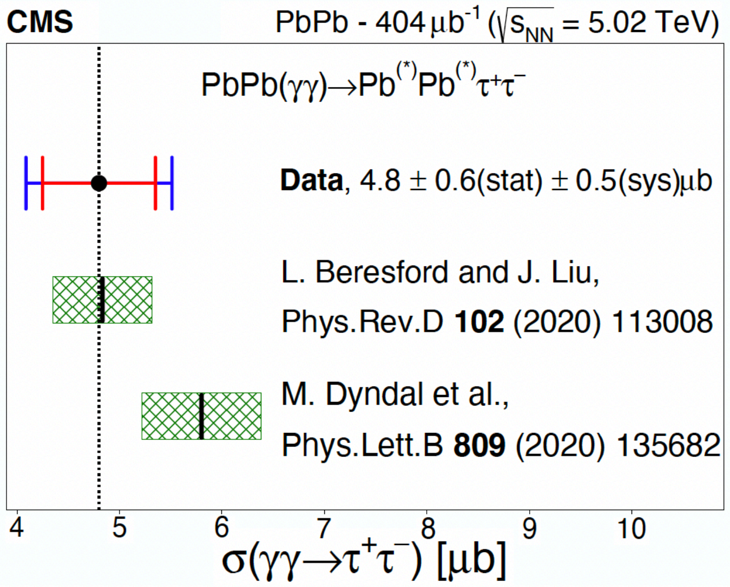
$\gamma\gamma \to \tau\tau$ measurements in PbPb collisions:CMS22

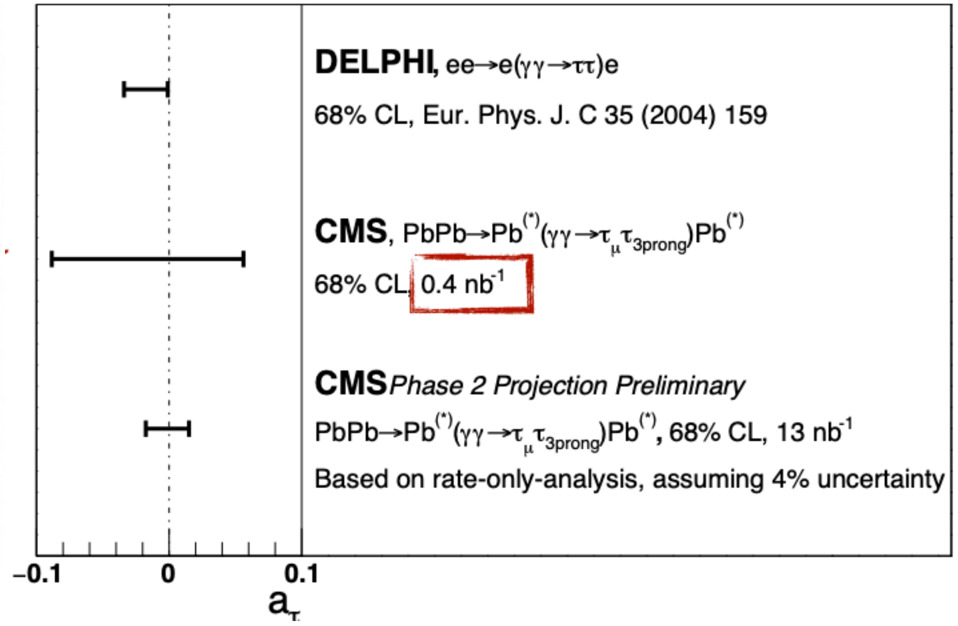
- first observed of $\gamma\gamma \to \tau\tau$ in PbPb by CMS & ATLAS in 2022
- $\sigma \propto Z^4$ enhancement
- clean channel: small backgrounds
- phase space $m_{\tau\tau} < 40$ GeV

CMS(2022)
PRL 131(2023) 151803

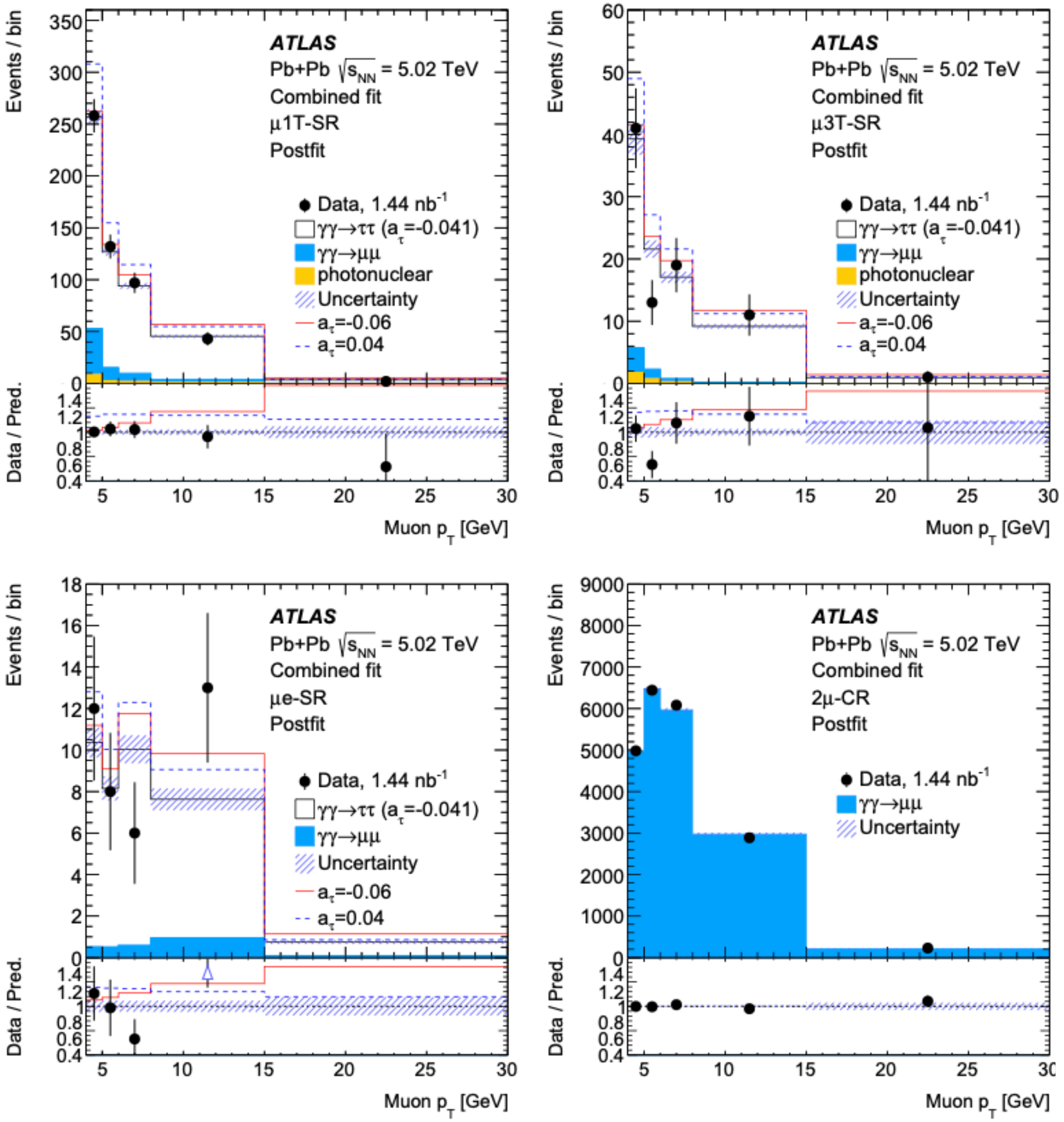


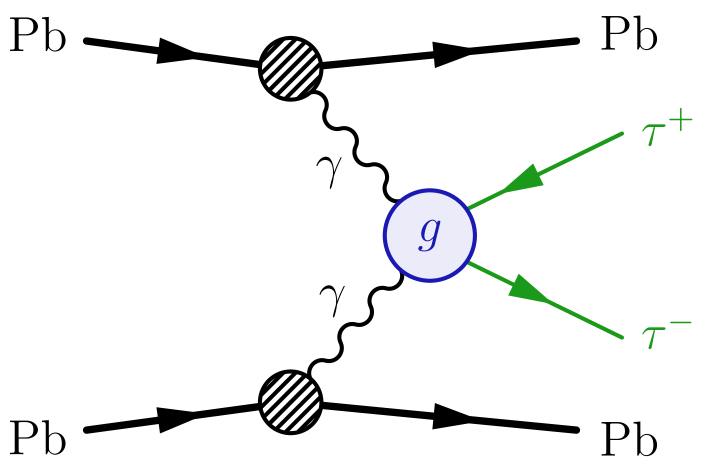


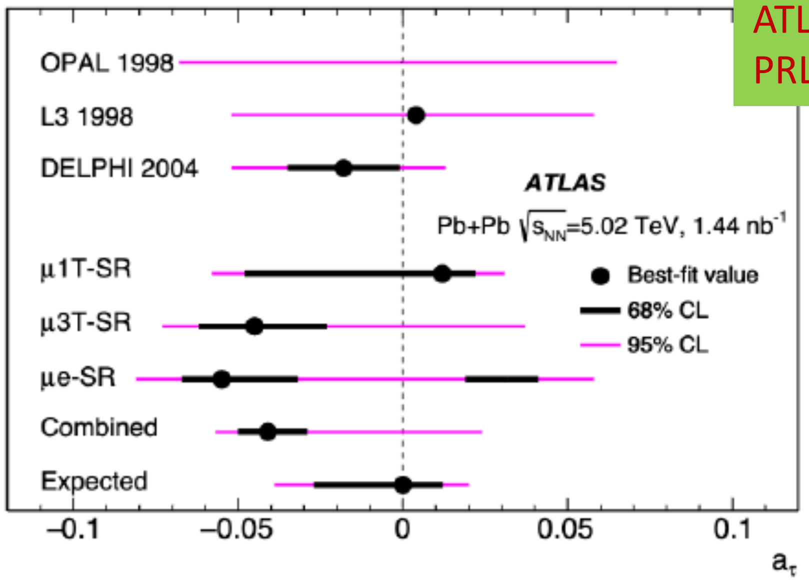




$\gamma\gamma \to \tau\tau$ measurements in PbPb collisions: ATLAS



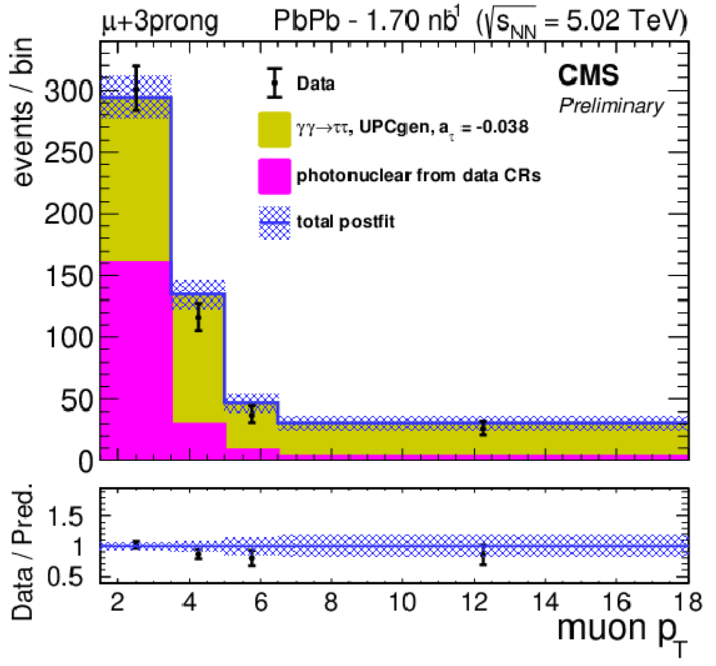


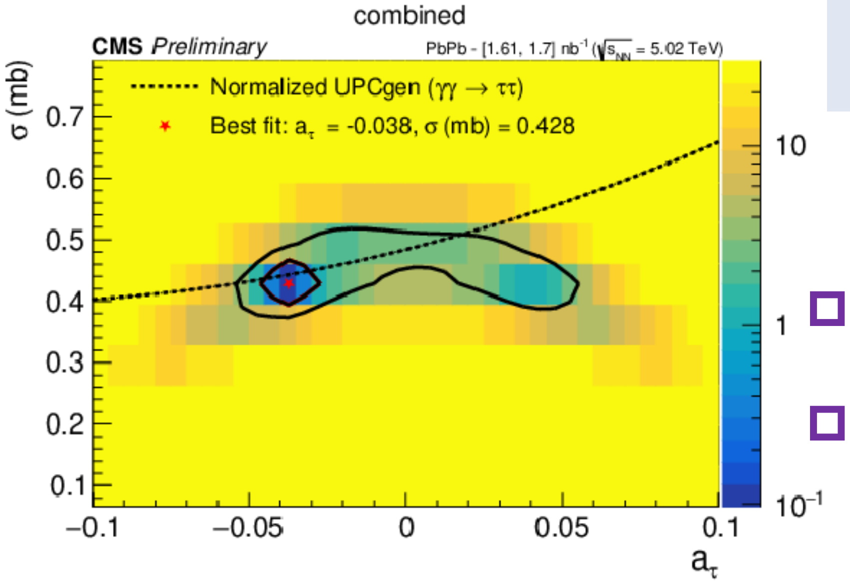


ATLAS(2022)
PRL 131(2023) 151802

Set constraints on a_τ close to best result from DELPHI

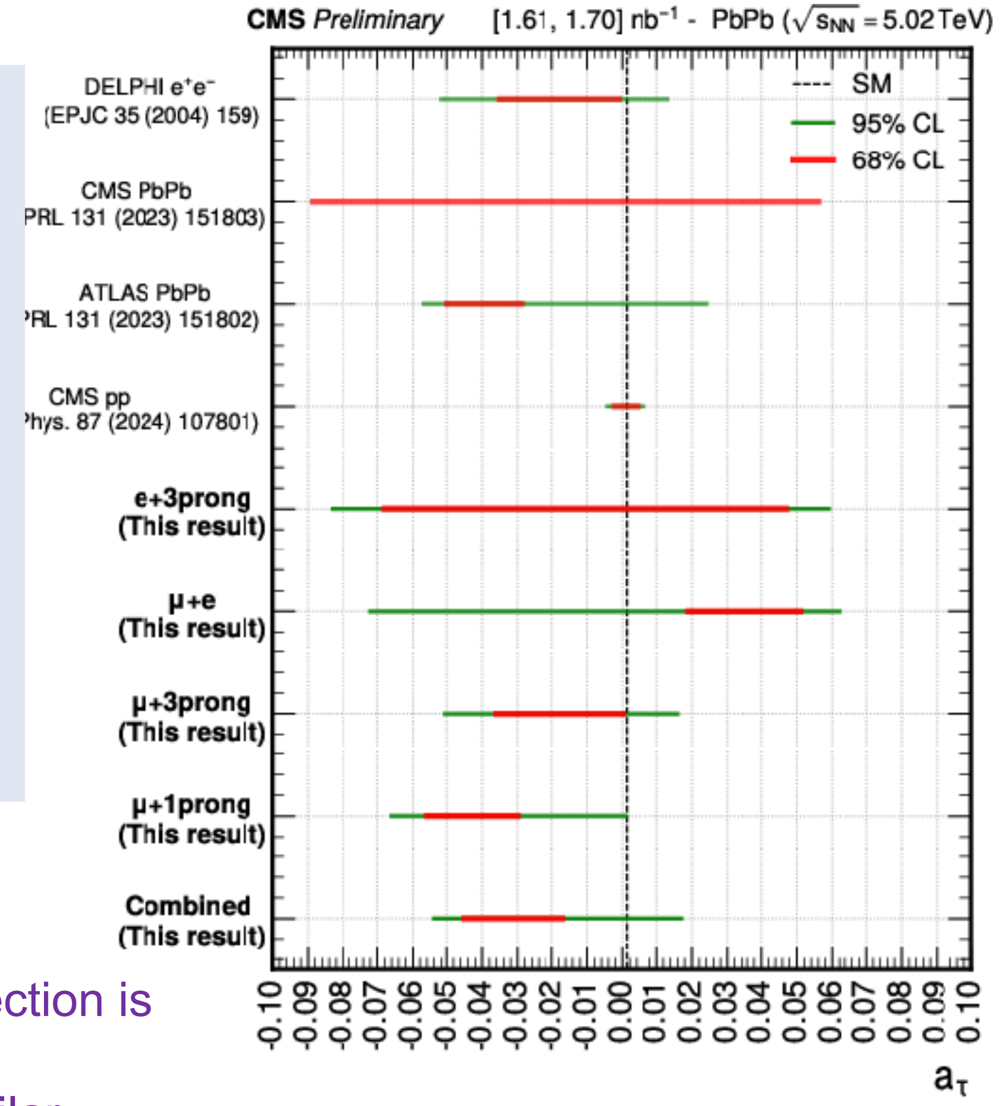
$\gamma\gamma \to \tau\tau$ measurements in PbPb collisions:CMS(new)





Major updates

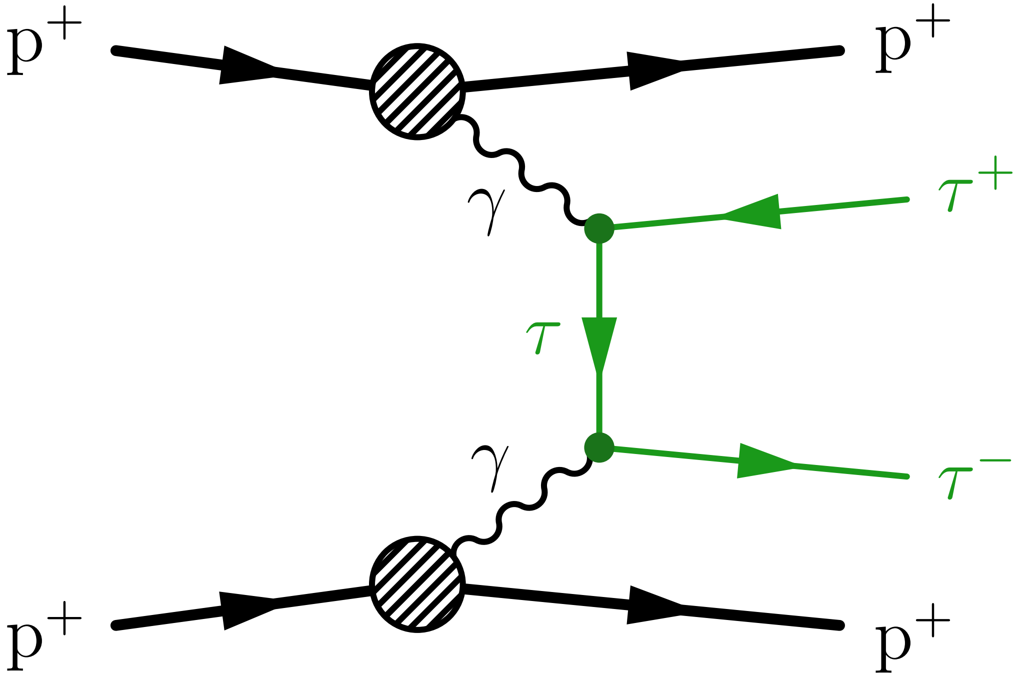
- ✓ With 2018 data, integrated lumi up to 1.70 nb^{-1} (x4)
- ✓ addition of three tau pair decay modes
- ✓ incorporation of both cross section and kinematic distributions



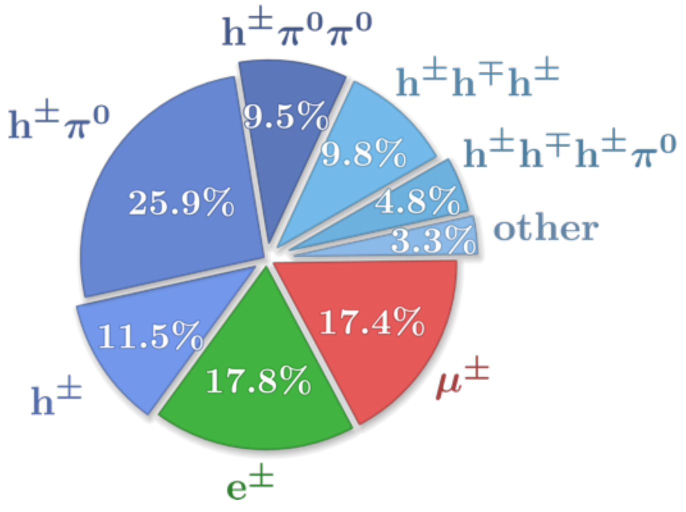
- ☐ The measured fiducial cross section is the most precise to date
- ☐ the g−2 measurement is of similar sensitivity to DELPHI and ATLAS

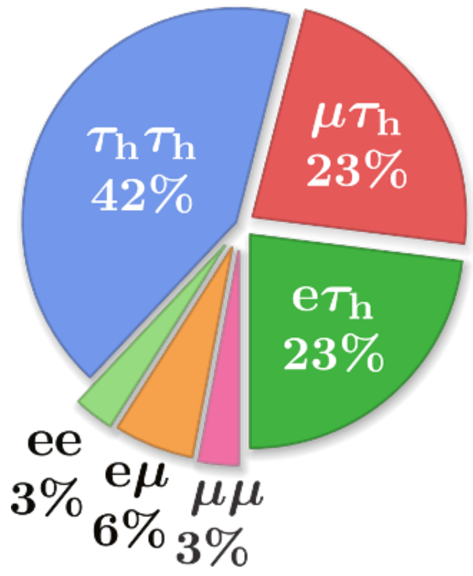
CMS-HIN-24-011

$\gamma\gamma \rightarrow \tau\tau$ signature in pp collisions



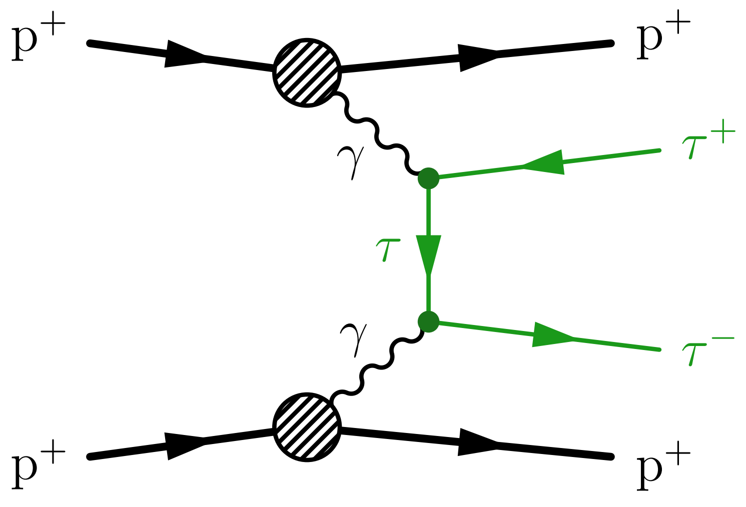
- **2 τ leptons**
  - opposite charge sign
  - back-to-back: $|\Delta\phi| \approx \pi$
  - τ decays: $\tau\tau$ decays:



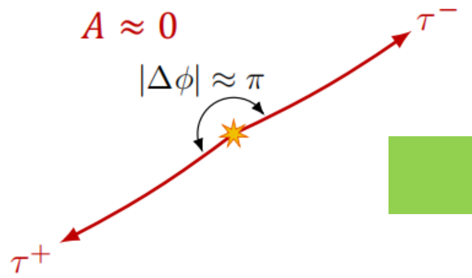


- **2 diffracted protons**
  - no hadronic activity close to $\tau\tau$ vertex

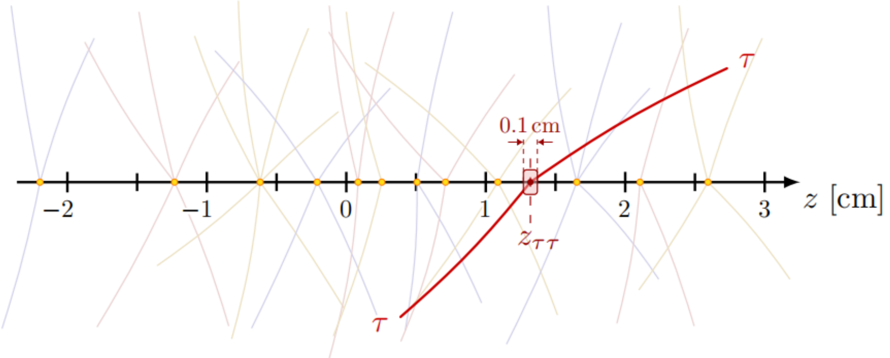
CMS $\gamma\gamma \to \tau\tau$ in pp: Strategy



- select events with opposite sign $\tau^{+}\tau^{-}$
  - combine 4 $\boldsymbol{\tau\tau}$ final states: eμ, e$\tau_{\rm h}$, $\mu\tau_{\rm h}$, $\tau_{\rm h}\tau_{\rm h}$
  - **exclusivity cuts**:
    - back-to-back: $\boldsymbol{A = 1 - \frac{|\Delta\phi|}{\pi} < 0.015}$
    - low activity around $\tau\tau$ vertex: **$\mathbf{N_{tracks}}$=0 or 1** in 0.1 cm window



ROPP 87 (2024) 107801



- use $\mu\mu$ events (Z → $\mu\mu$, $\gamma\gamma$ → $\mu\mu$) to measure corrections to simulation
- measure $\gamma\gamma \to \tau\tau$ from observed $m_{\tau\tau}$ shape & yield in **50 < $\boldsymbol{m_{\tau\tau}^{\rm vis}}$ < 500 GeV**:
  - above e+e− & PbPb ($m_{\tau\tau} \lesssim$ 50 GeV)
  - $m_{\tau\tau}^{\rm vis} \lesssim$ 500 GeV to ensure unitarity in signal samples

More details:
Zongsheng He's talk@
EW+top session

First observation of $\gamma\gamma \to \tau\tau$ in pp collisions

- combined **observed significance of 5.3σ (6.5σ expected)** assuming SM a_τ

  ⇒ **first observation of $\gamma\gamma \rightarrow \tau\tau$ in pp** !

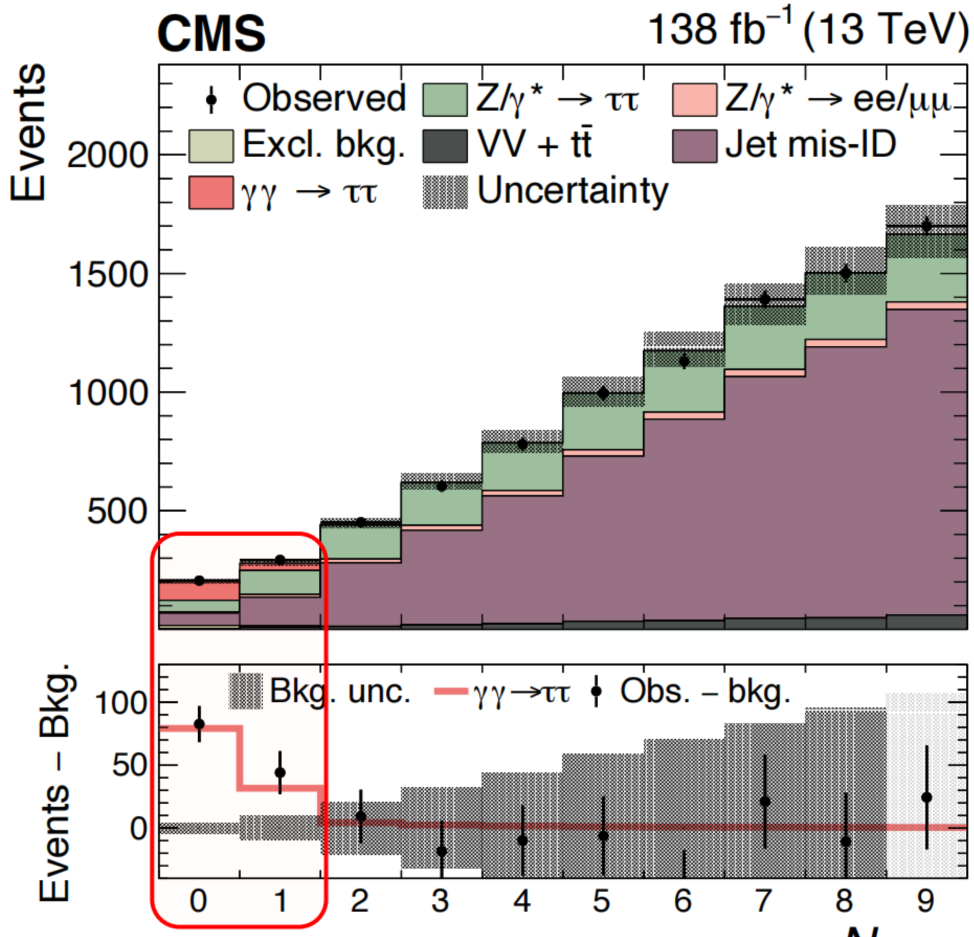
- combined **signal strength**

  $r = 0.75 +0.21 -0.18$

  w.r.t. gammaUPC elastic prediction

  × rescaling measured in $\mu\mu$ data

- Fiducial cross section: $12.4^{+3.8}_{-3.1}$ fb
- dominant systematic uncertainties:
  - elastic rescaling to $\gamma\gamma \rightarrow \tau\tau$
  - N^{HS}_{tracks} corrections to Drell–Yan



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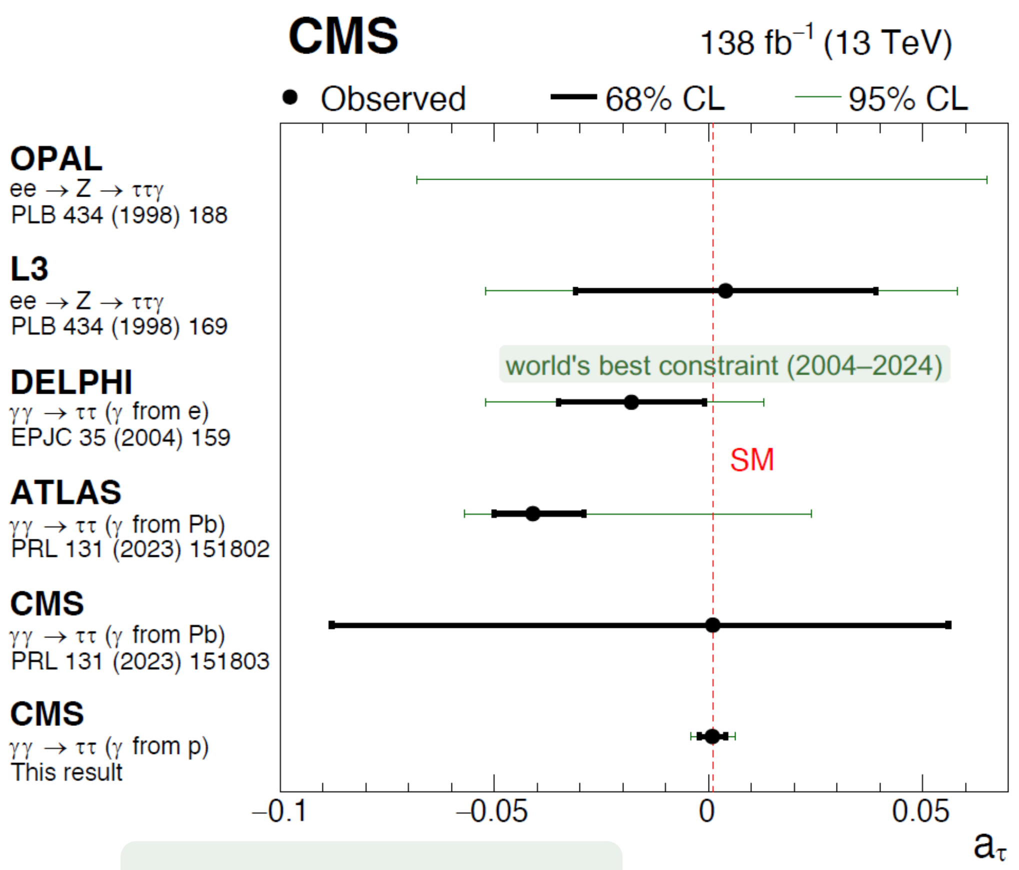
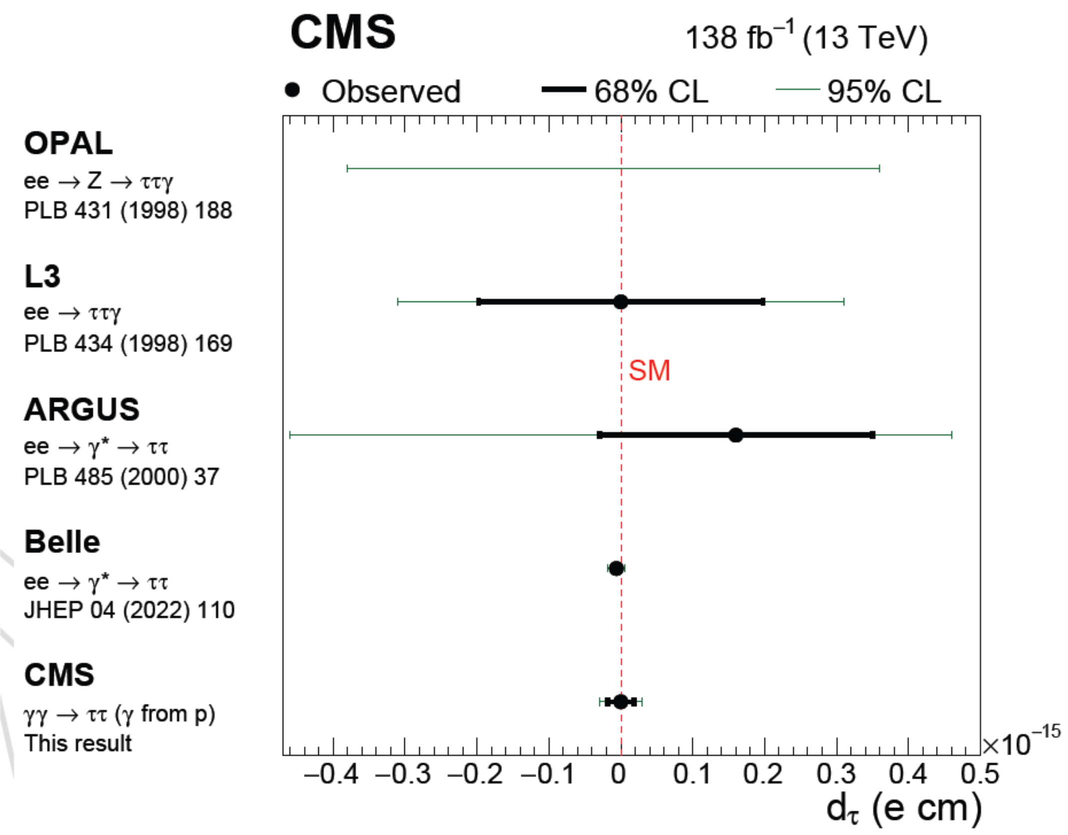
Constraints on a_τ and d_τ



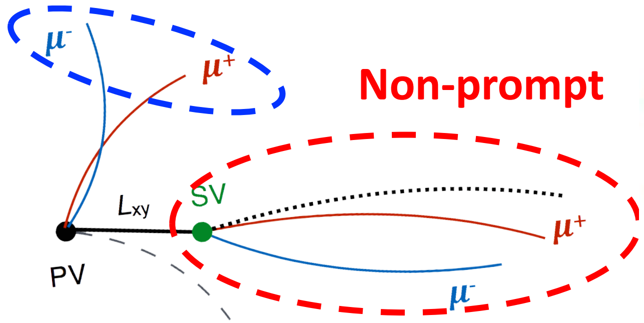


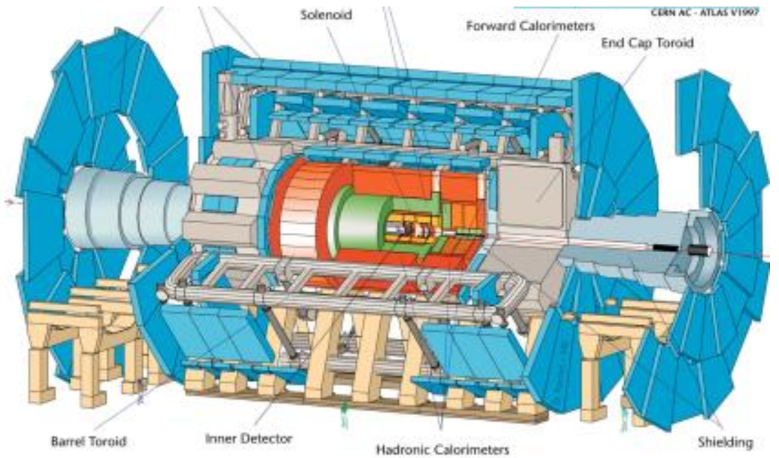
>5x better than LEP !

approaching Belle !

ROPP 87 (2024) 107801

ATLAS and CMS for HF studies



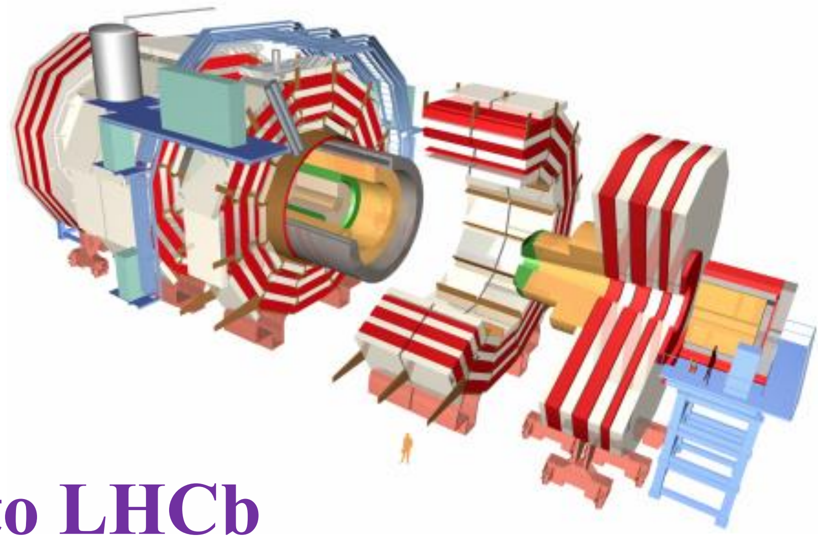


- Large silicon tracker
- Strong magnetic field
- Broad acceptance
- Superb muon systems

(CMS parameters, ATLAS similar)

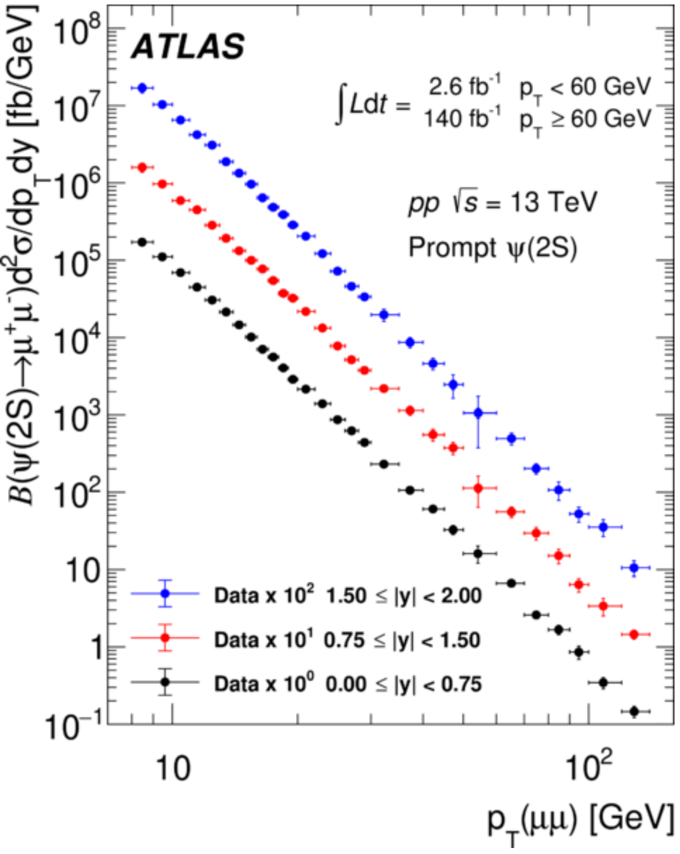
  - Three different devices, coverage up to $|\eta|<2.4$
  - Dimuon mass resolution ~0.6-1.5% (depending on $|y|$).
  - Fake rate ≤0.1% for pi,K; ≤0.05% for proton, with very tight ID

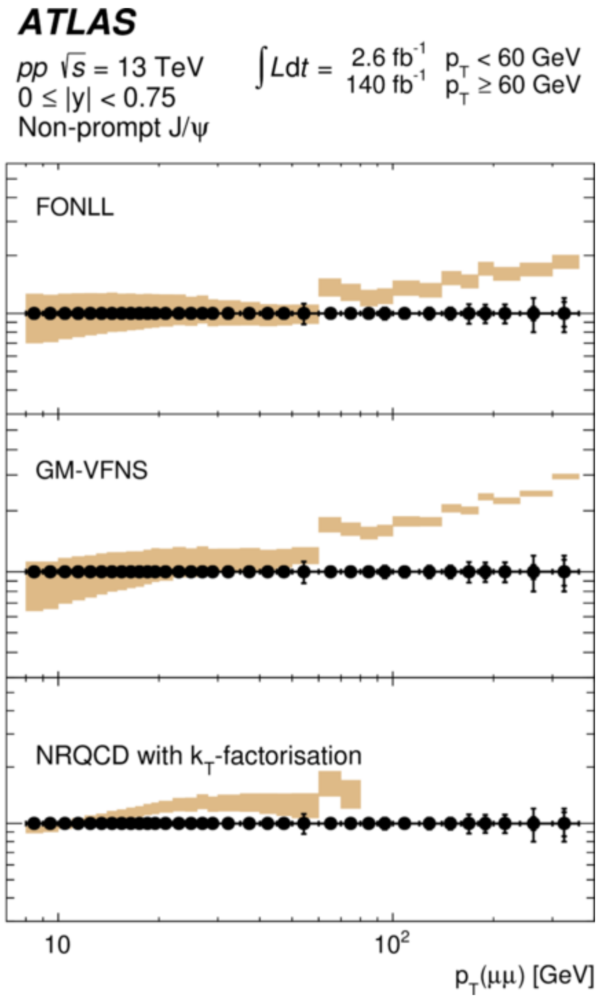
- Flexible triggers, novel & dedicated data-taking approaches



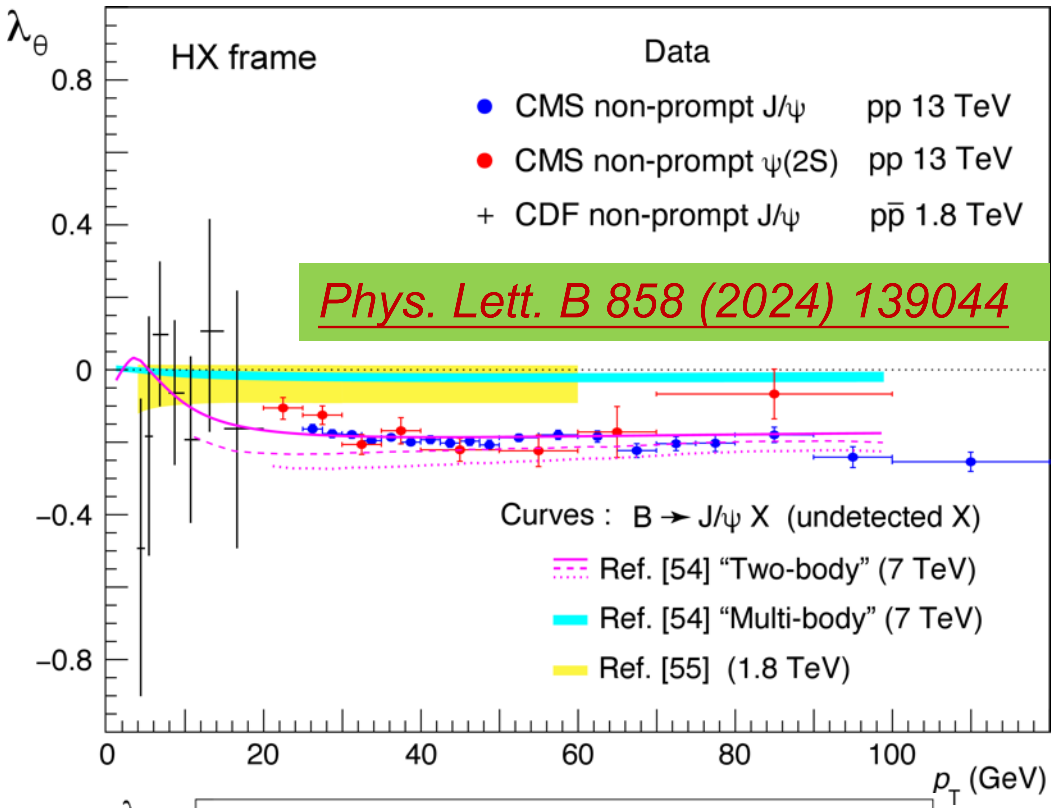
Complementary to LHCb

J/ψ & ψ(2S) xsec and polarization@13TeV

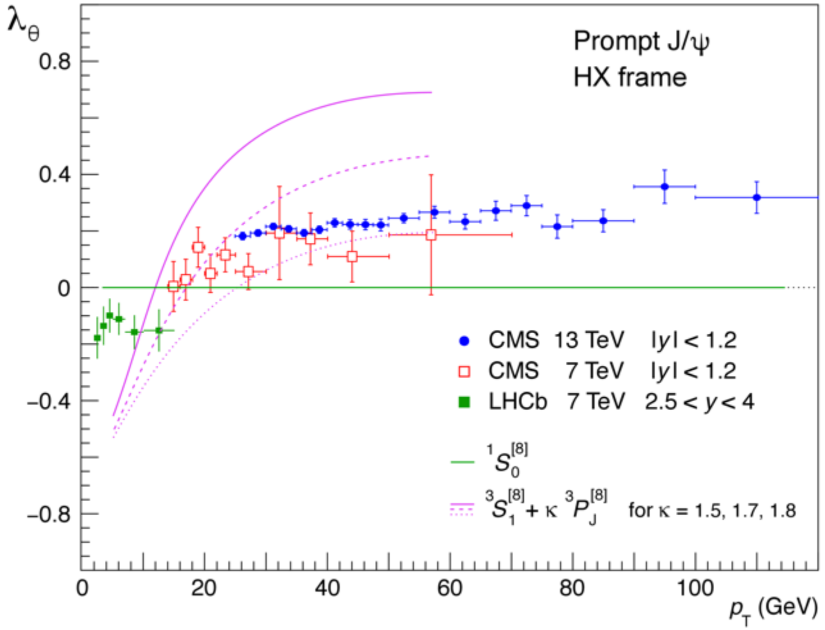




Eur. Phys. J. C 84 (2024) 169



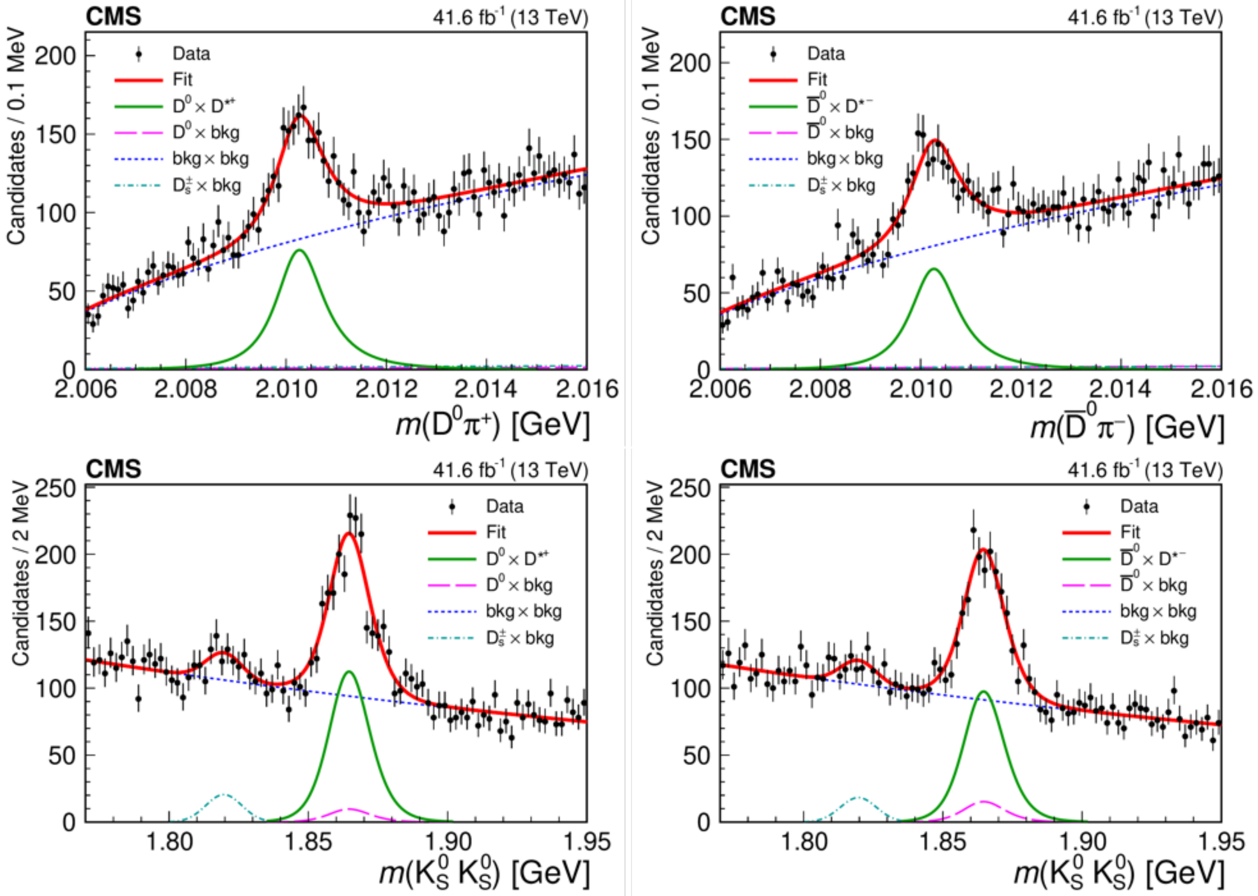
Phys. Lett. B 858 (2024) 139044



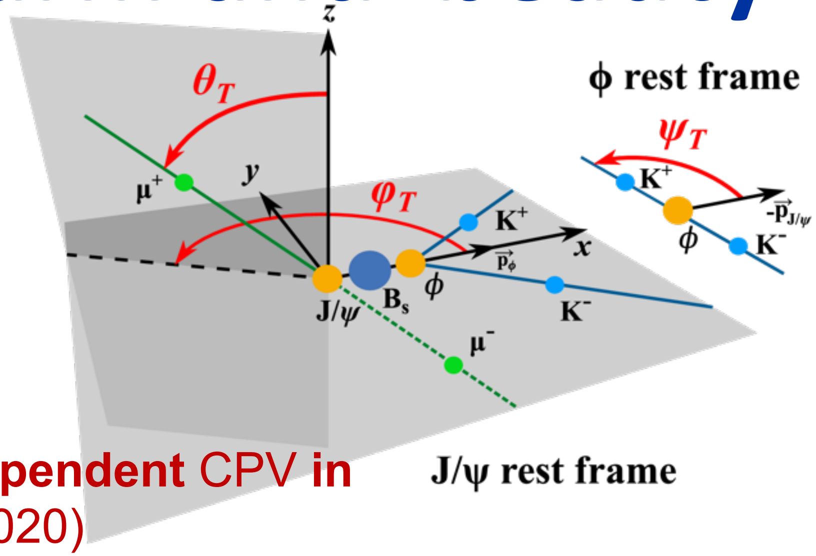
Studies of CP violation in charm and beauty

$D^0 \to K_S^0 K_S^0$

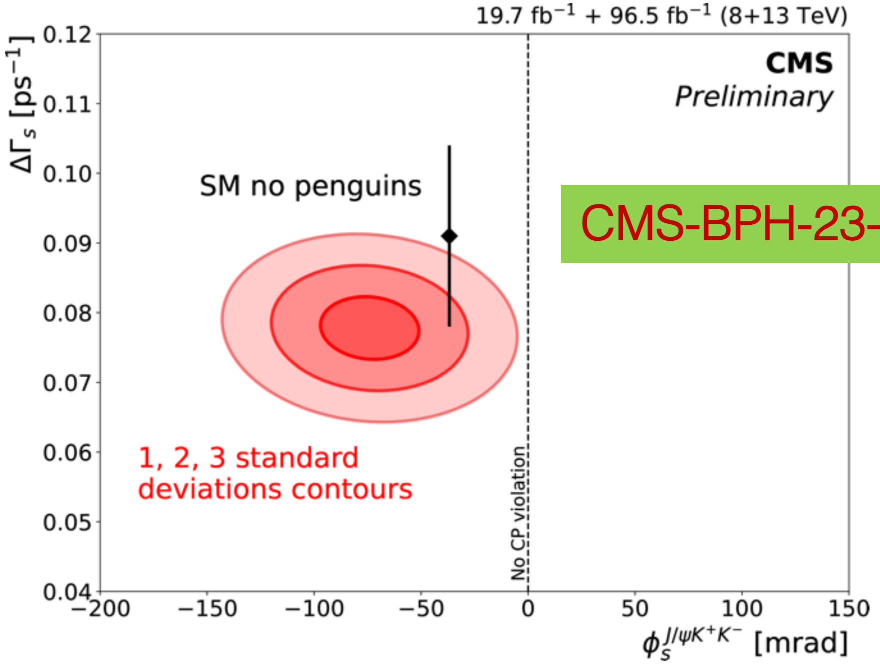
CMS-BPH-23-005, arXiv:2405.11606, EPJC(2024)



$$A_{CP}(\mathrm{K_S^0K_S^0}) = (6.2 \pm 3.0 \pm 0.2 \pm 0.8)\%,$$

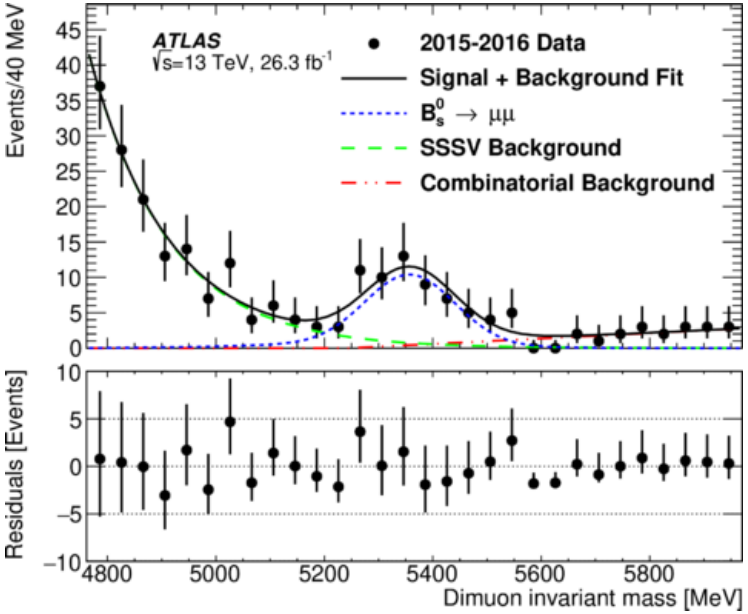


3.2σ time-dependent CPV **in**
$B_s^0 \to J/\psi\ \phi(1020)$

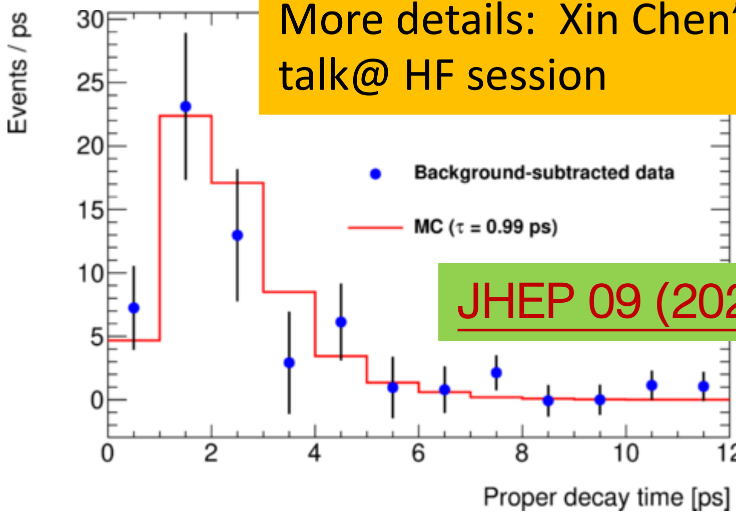


CMS-BPH-23-004

Effective lifetime measurement with neutral $B_{(s)}$ meson



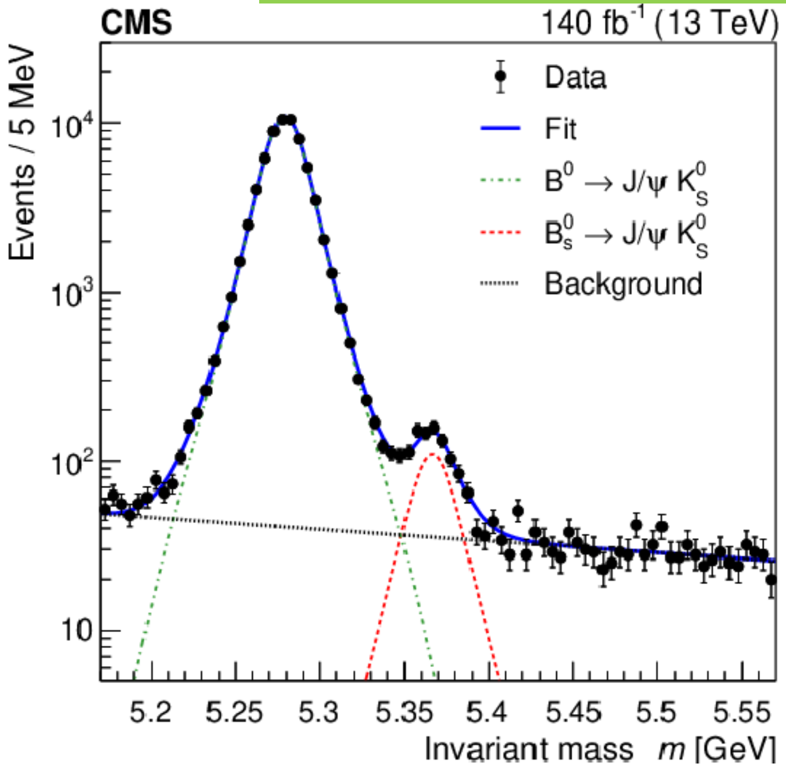
$$\tau_{\mu\mu}^{\mathrm{Obs}} = 0.99^{+0.42}_{-0.07}\,(\mathrm{stat.}) \pm 0.17\,(\mathrm{syst.})\,\mathrm{ps}.$$

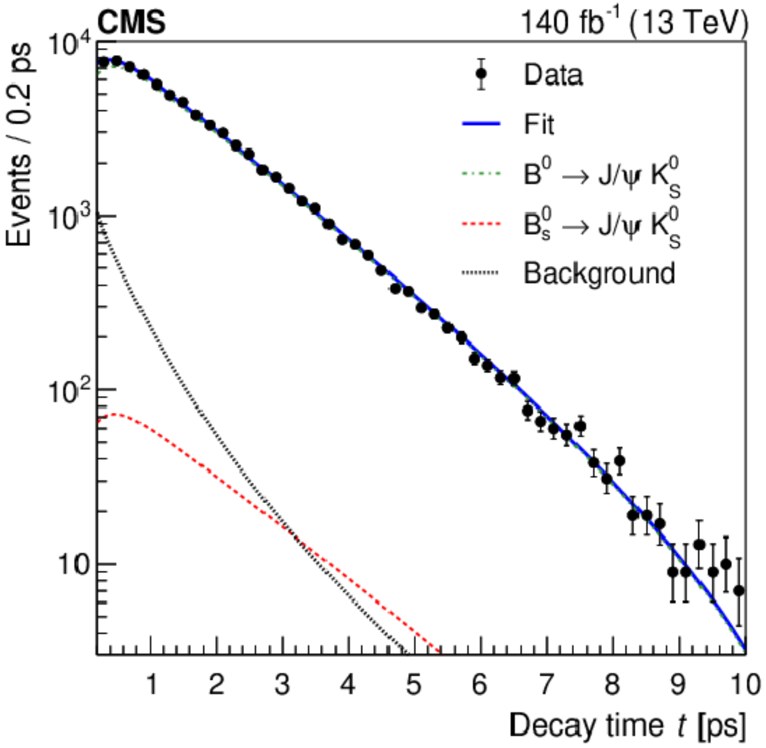


More details: Xin Chen's talk@ HF session

JHEP 09 (2023) 199

CMS-BPH-22-001,arxiv: 2407.13441, JHEP(2024)





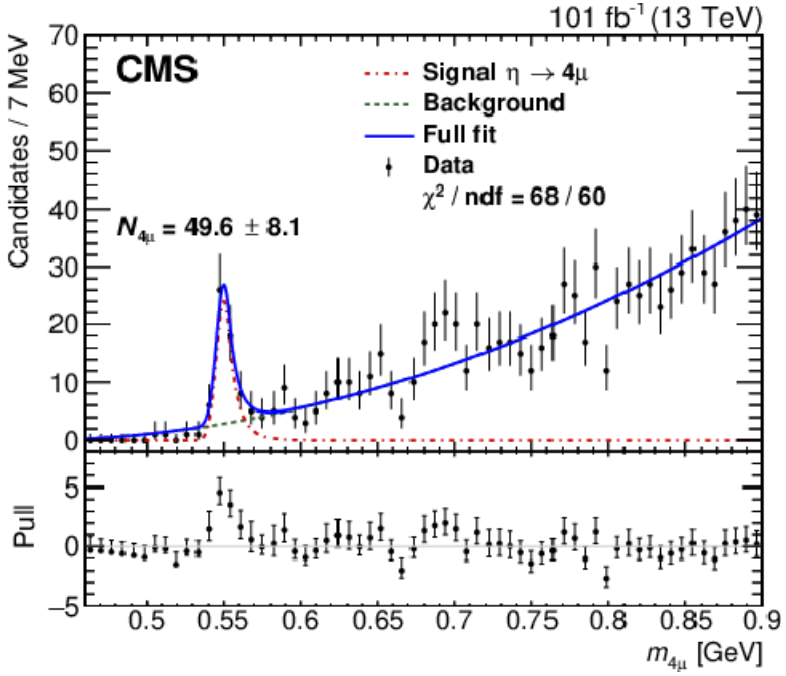
$$\tau(B_s^0 \to J/\psi K_S^0) \equiv \frac{\int_0^\infty t\,\{\Gamma[B_s^0(t) \to J/\psi K_S^0] + \Gamma[\overline{B}_s^0(t) \to J/\psi K_S^0]\}\,dt}{\int_0^\infty \{\Gamma[B_s^0(t) \to J/\psi K_S^0] + \Gamma[\overline{B}_s^0(t) \to J/\psi K_S^0]\}\,dt}$$

$$\tau(B_s^0 \to J/\psi K_S^0) = 1.59 \pm 0.07\,(\mathrm{stat}) \pm 0.03\,(\mathrm{syst})\,\mathrm{ps}$$

ATLAS: B0-> J/psi K*0, CERN seminar 11/19

Rare decays into muons

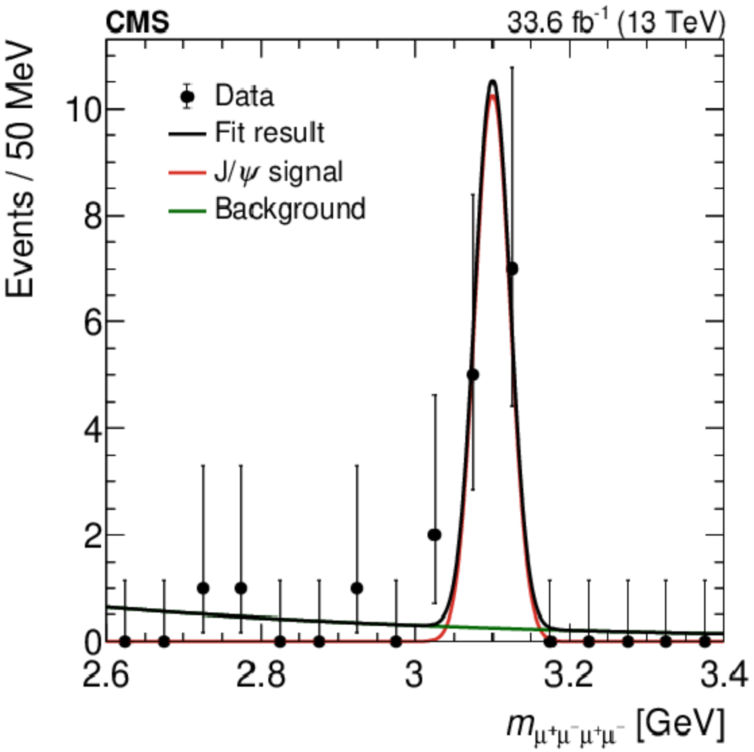
PRL131, 091903 (2023)



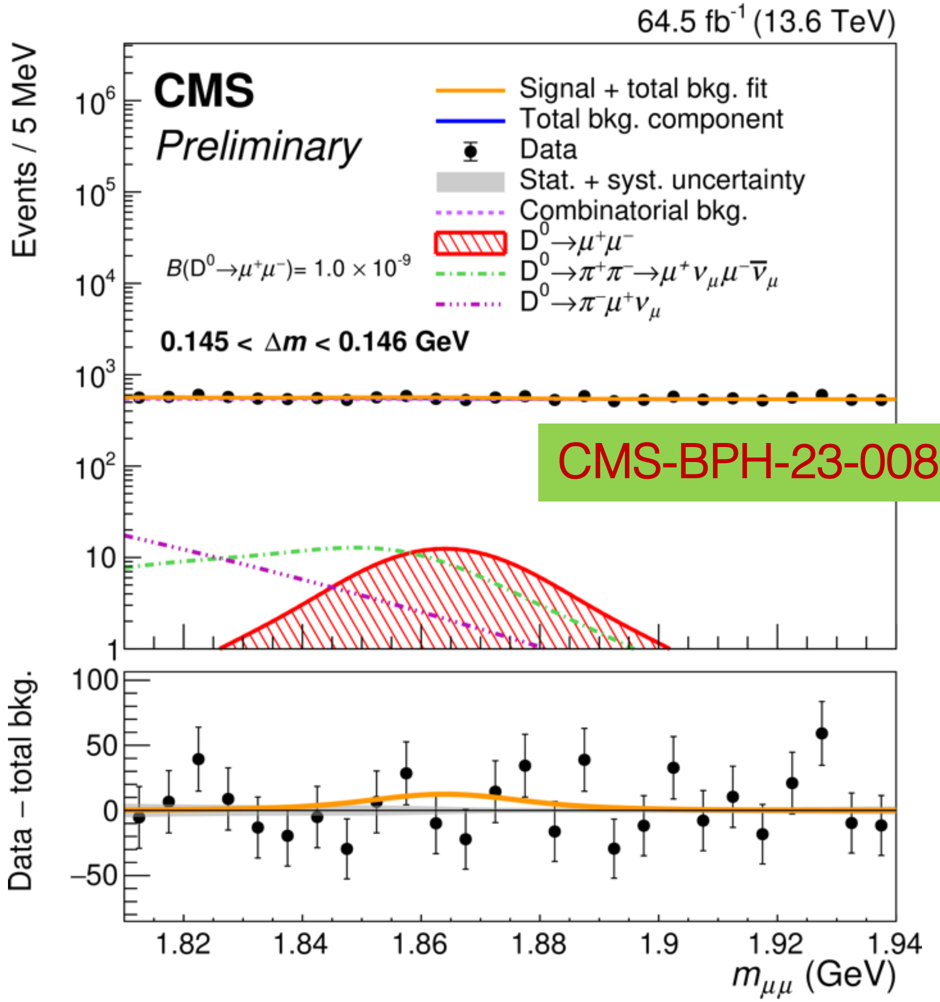
$$\mathcal{B}(\eta \to \mu^+\mu^-\mu^+\mu^-) =$$

$$(5.0 \pm 0.8\ (\text{stat}) \pm 0.7\ (\text{syst}) \pm 0.7\ (\mathcal{B}_{2\mu})) \times 10^{-9}$$

PRD109, L111101 (2024)



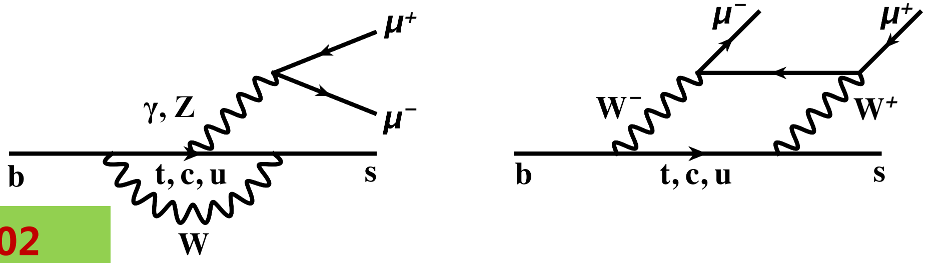
$$\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-) =[\,10.1\,^{+3.3}_{-2.7}\ (\text{stat}) \pm 0.4\ (\text{syst})\,] \times 10^{-7}$$



CMS-BPH-23-008

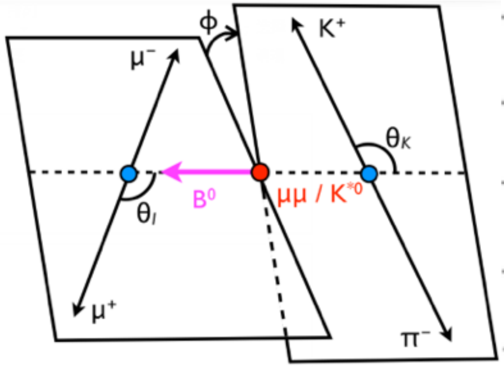
B(D^0-> μ+μ-) < 2.6x10^{-9} at 95%CL, upper limit improved by 35%

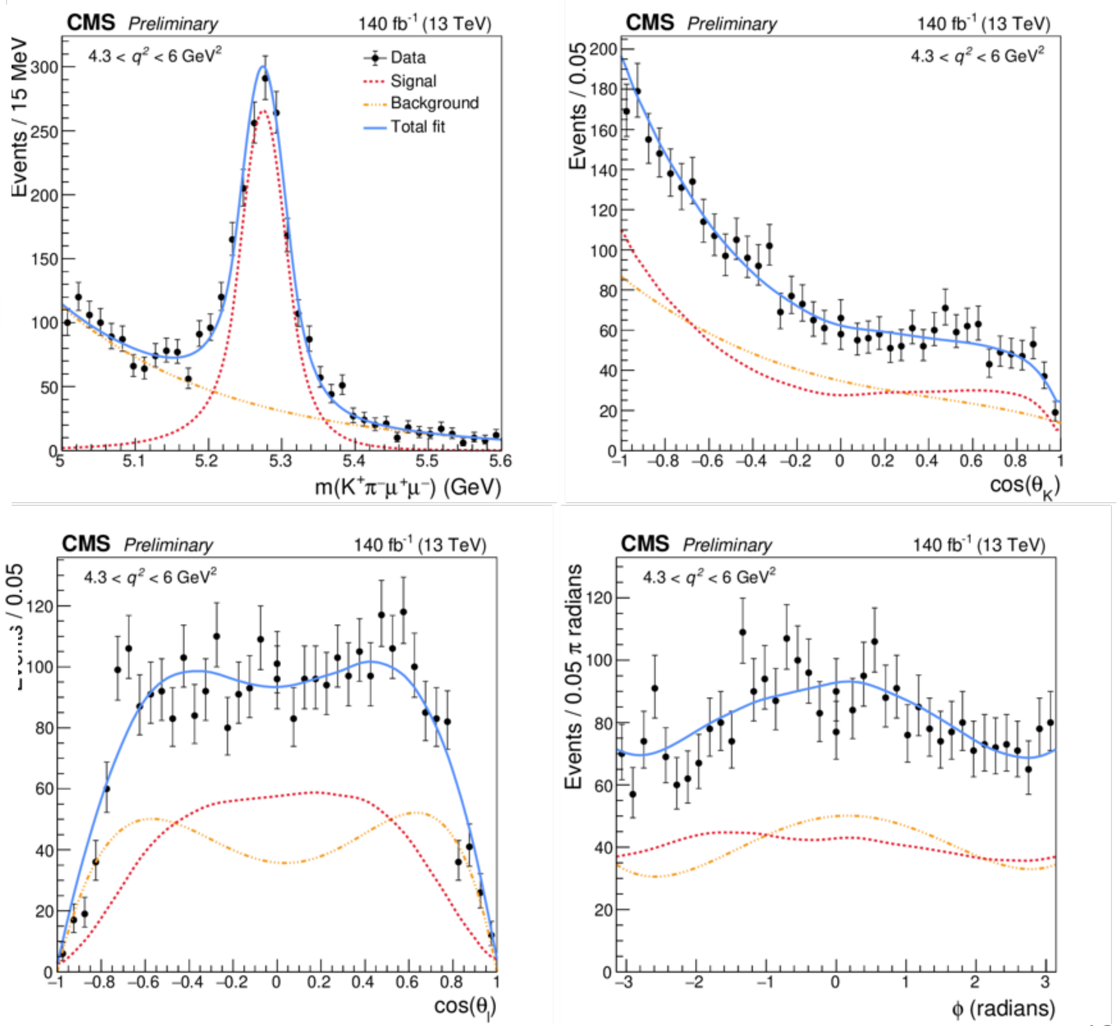
Full angular analysis of $B^0 \to K^{*0}\mu\mu$



CMS-BPH-21-002

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





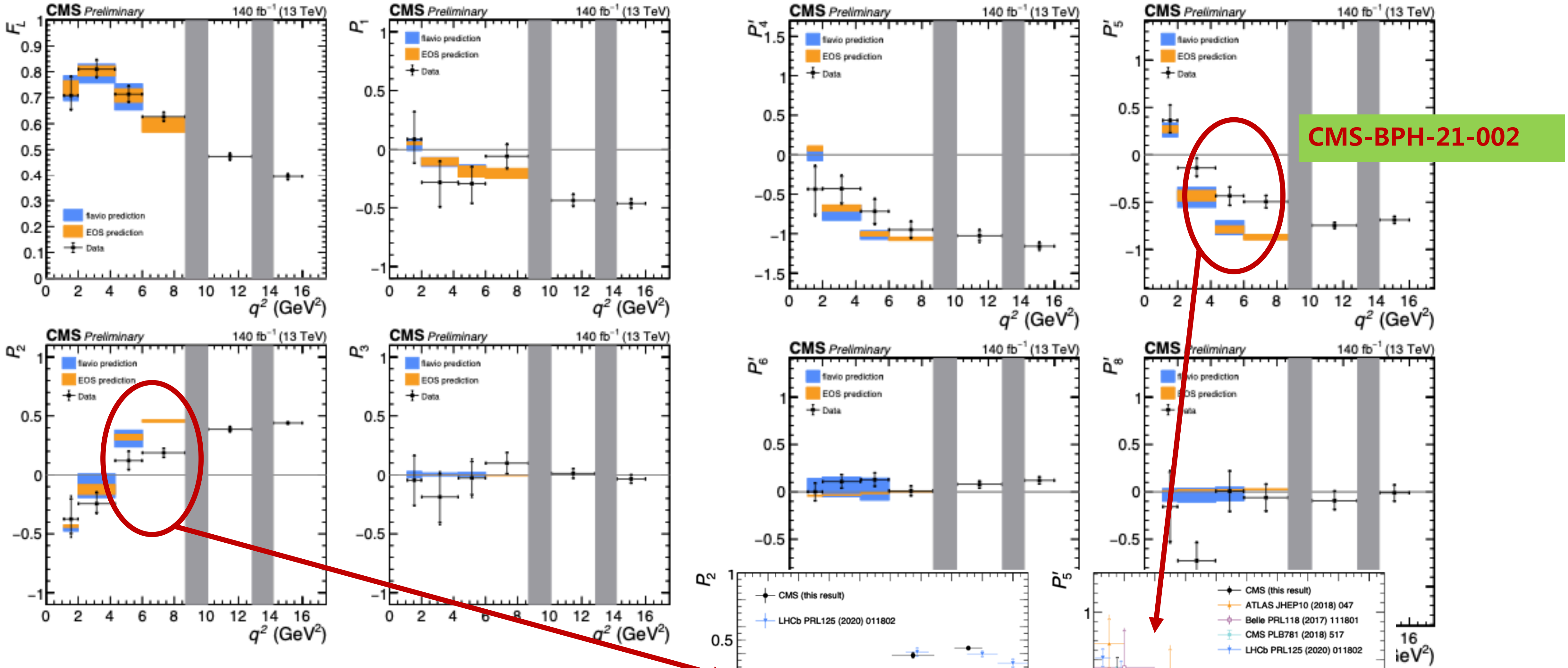
$$\mathrm{pdf}(m,\cos\theta_K,\cos\theta_l,\phi) = Y_S\Big[S^C(m)\,S^a(\cos\theta_K,\cos\theta_l,\phi)\,\epsilon^C(\cos\theta_K,\cos\theta_l,\phi)$$
$$+R\cdot S^M(m)\,S^a(-\cos\theta_K,-\cos\theta_l,-\phi)\,\epsilon^M(\cos\theta_K,\cos\theta_l,\phi)\Big]$$
$$+Y_B B^m(m)\,B^a(\cos\theta_K,\cos\theta_l,\phi)$$

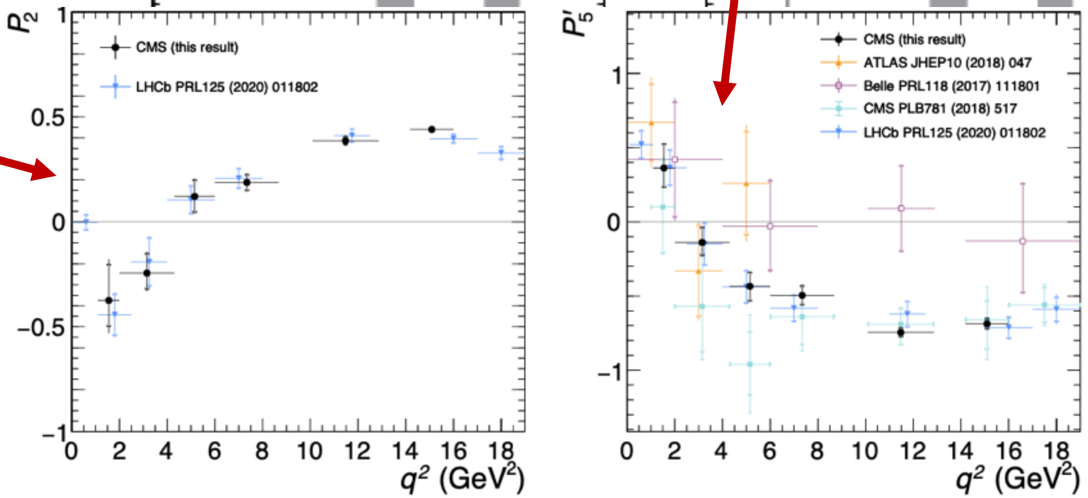
Angular rate

Signal and bkg mass shapes

KDE efficiency

Bkg angular shape





- ✓ among the most precise measurements of the angular observables of this decay
- ✓ valuable contribution to the understanding of the b → sl^+l^-

Summary

- LHC is probing SM with heavy lepton/quarks extensively
- ATLAS/CMS observed $\gamma\gamma \rightarrow \tau\tau$ in both PbPb and pp collisions
  - also used to constrain the tau electromagnetic moments
  - pp result gains large improvement on tau g-2
  - Tau EDM result is at the same order as the best measurement
- Many results on heavy flavor physics from ATLAS/CMS
  - Charmonium production and polarization
  - CKM triangle and CP violation
  - Neutral $B_{(s)}$ effective life time
  - Multi-lepton rare decays
  - FCNC b->s l l processes
  - Spectroscopy, exotic hadrons, LFU test …

More results:
ATLAS Public Results Link
CMS Public Results Link