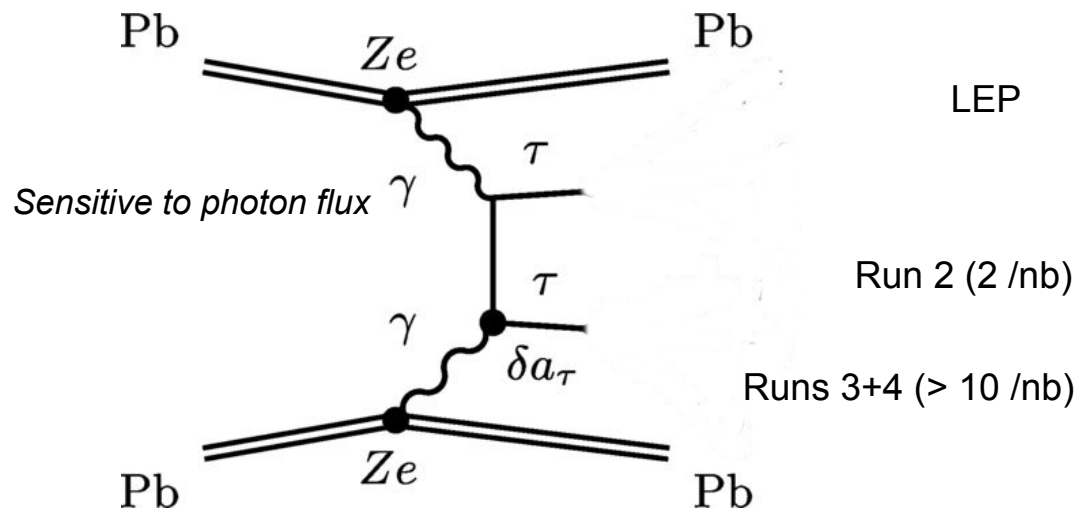


CMS PAS-HIN-21-009
Physics announcement

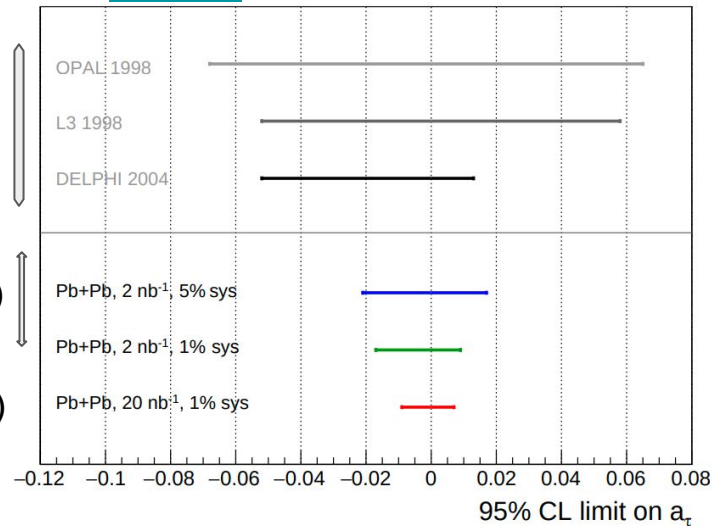
First measurement of the $\gamma\gamma \rightarrow \tau\tau$ production in PbPb collisions with the CMS experiment

Overview of the $\gamma\gamma \rightarrow \tau\tau$ process

- **Promising candidate** for the $a_\tau = (g_\tau - 2)/2$ determination
 - “using a large heavy ion collider” for $g_\tau - 2$ suggested since [90s](#)
 - cross section in UPC receives a **Z^4 enhancement** relative to pp
- LHC could **improve** the sensitivity on a_τ relative to LEP
 - **probe** the anomalous τ lepton **electric moment** too like [BELLE](#)



τ lepton photoproduction in ultraperipheral collisions (UPC)

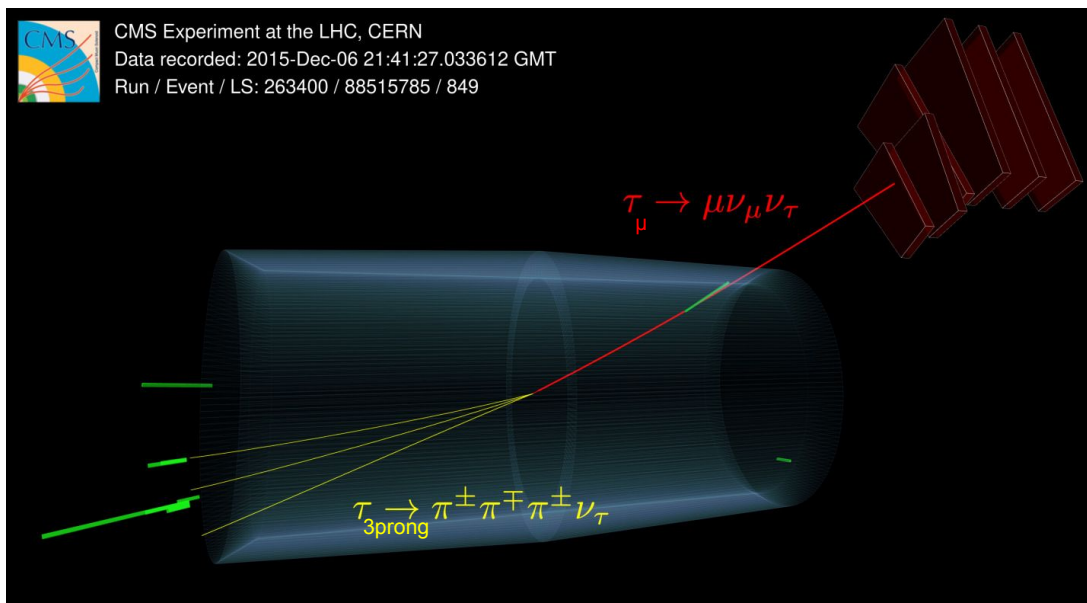


Phys. Lett. B **809** (2020) 135682 (2002.05503)

Phys. Rev. D **102** (2020) 113008 (1908.05180)

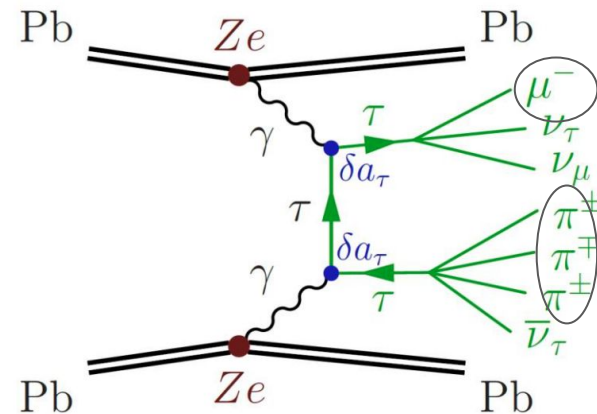
τ 's are multifaceted

- $\tau\tau$ **signal regions** can be then defined based on the lepton and/or hadron **multiplicity**
 - dilepton: the lowest reco efficiency
 - $1\ell + 1$ track: main bkg due to $\mu\mu$, ee
 - **$1\ell + 3$ tracks**: clean with high enough yield
- All channels needed for ultimate precision



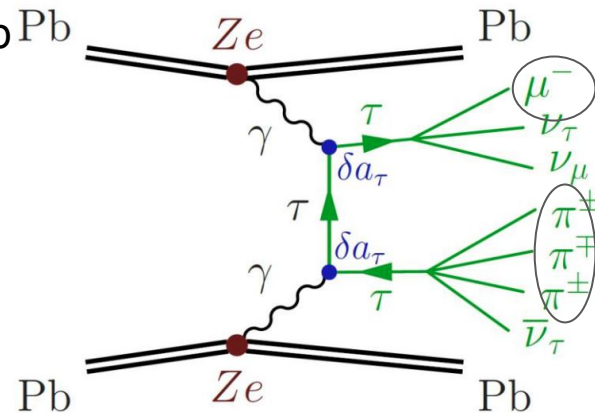
How to observe the $\gamma\gamma \rightarrow \tau\tau$ process at LHC

- The total $\gamma\gamma \rightarrow \tau\tau$ cross section is of $O(1 \text{ mb}) \rightarrow O(1 \text{ M})$ with 2 /nb
 - **we expected <100** 1 μ +3 tracks events **within** acceptance
- τ lepton reco **challenging** at low- p_T (<20 GeV)
 - till recently **no** measurement in nuclear collisions
 - indirect presence via Z/ γ^* in top quark [events](#)



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- τ lepton reco **challenging** at low- p_T ($<20 \text{ GeV}$)
 - till recently **no** measurement in nuclear collisions
 - indirect presence via Z/γ^* in top quark [events](#)
- Take advantage of **UPC** events and τ lepton **unique** decay signatures
 - low track multiplicity (N_{ch}), UPC triggers, and “exclusivity” requirements
 - **single lepton** triggers
 - **no activity** in forward hadron (HF) calorimeters above noise threshold
- Aim **to establish** $\gamma\gamma \rightarrow \tau\tau$ at LHC as **the first** crucial step during a dedicated physics program
 - using **PbPb** collisions in 2015 ($\sim 0.5 /nb$)
 - followed by the **inclusion** of 2018 ($\sim 1.5 /nb$)
 - Runs 3+4 **projection** in the realm of the joint ATLAS+CMS [Snowmass22](#) effort



Our event **selection** and MC **simulation**

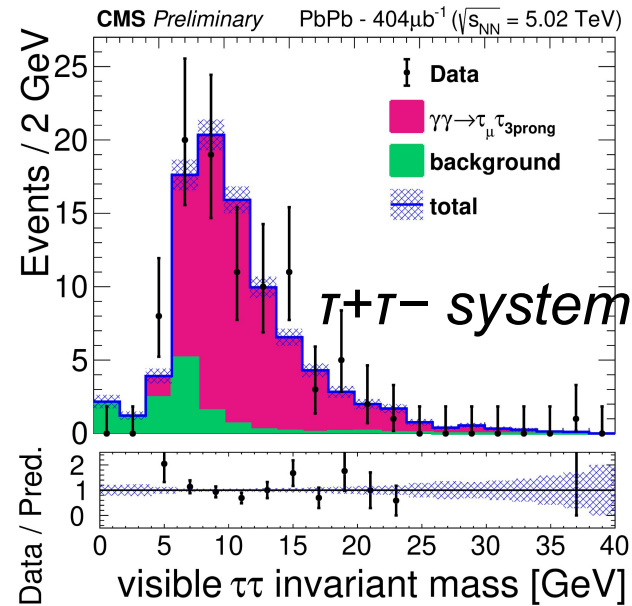
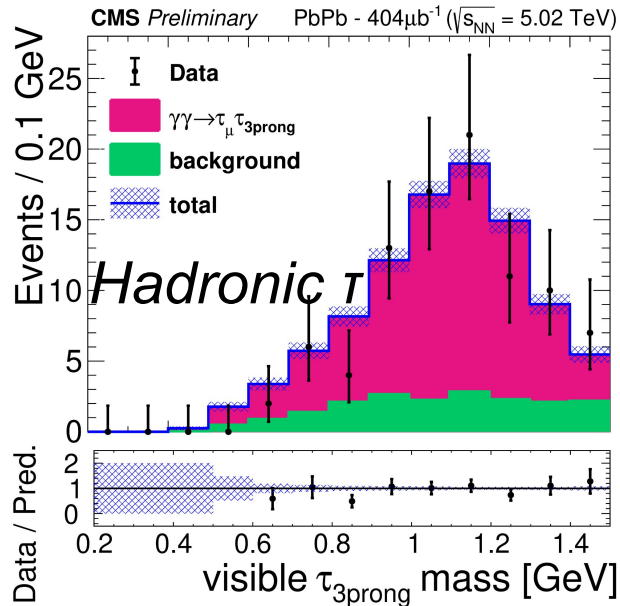
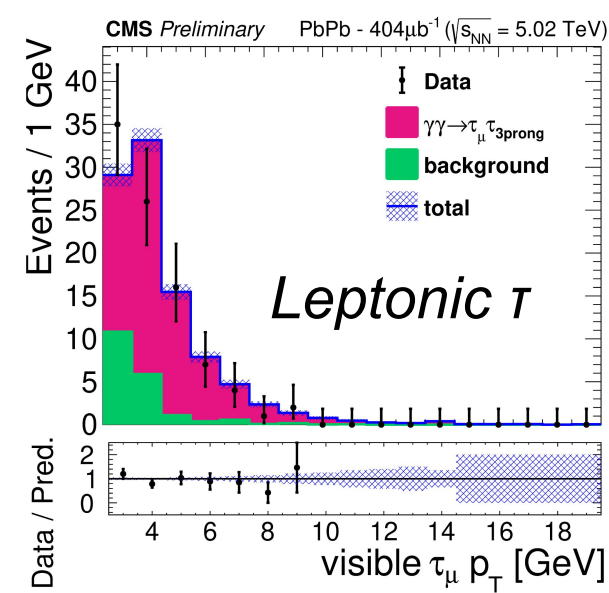
- **Trigger:** 1 muon & + ≥ 1 track in the pixel detector + no HF activity on either side
- **Optimized offline** event selection (cf Table)
- Our **signal region** is 1 muon & $N_{ch}=3$
 - other N_{ch} and HF activity regions used in **bkg estimation**
- MC simulation for **signal and validation** (main bkg, efficiency)

Object	Criteria
μ	$p_T > 3.5 \text{ GeV}$ for $ \eta < 1.2$ $p_T > 2.5 \text{ GeV}$ for $1.2 < \eta < 2.4$
π^\pm	$p_T > 0.5 \text{ GeV}$ for leading π^\pm $p_T > 0.3 \text{ GeV}$ for (sub-)sub-leading π^\pm $ \eta < 2.5$
τ_{3prong}	$p_T^{vis} > 0.2 \text{ GeV}$ $0.2 \text{ GeV} < m_{\pi\pi\pi} < 1.5 \text{ GeV}$

Data-to-exp comparison: control plots in the signal region

7

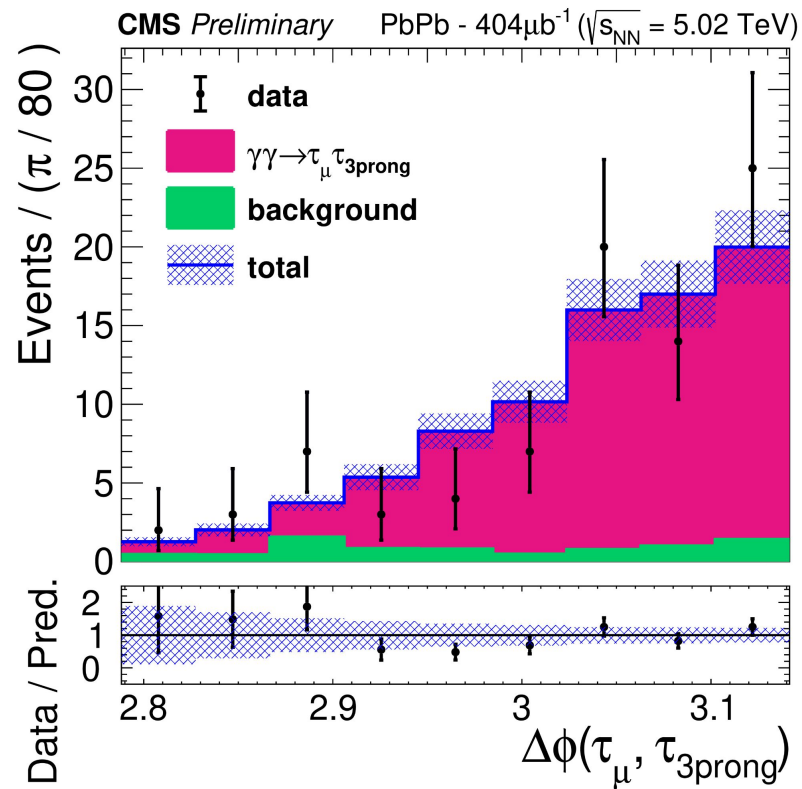
- Very good **agreement** between data & expectations
 - signal MC is scaled to the **integrated luminosity**
 - we're in an almost **bkg-free** phase space region(!)





Signal yield estimation

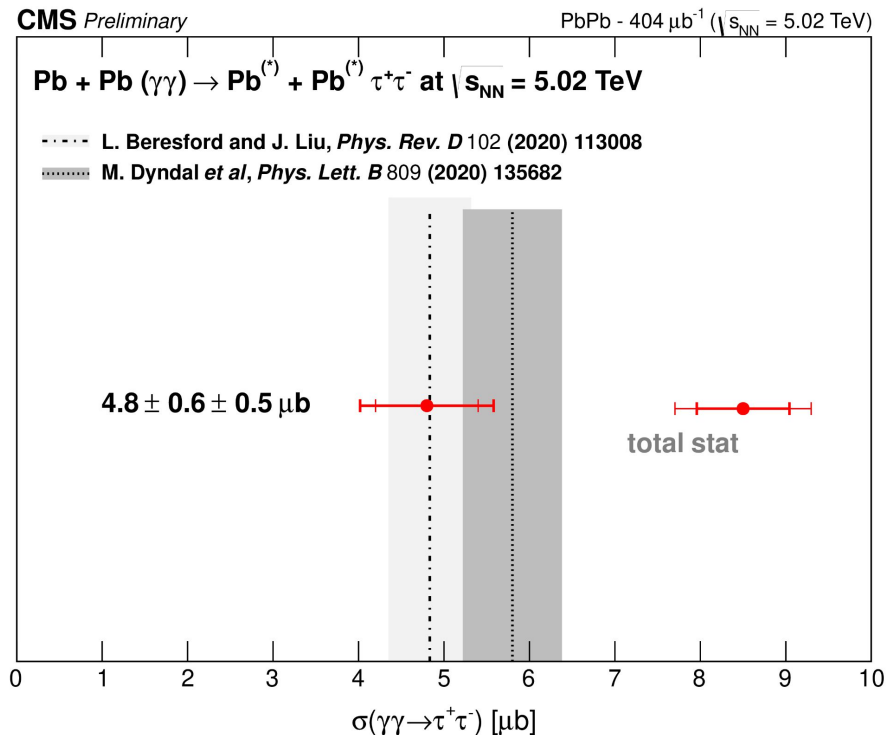
- Binned likelihood fit to a discriminating variable
- **Angular separation** ($\Delta\phi$) between leptonic and hadronic candidates
 - MC signal (peaky) and bkg template (flat) from data
- Number of observed post-fit **signal events**: 77 ± 12
- Observed significance is **more than 5σ**
 - **taking into account** systematic uncertainties
 - affecting the rate with log-normal priors
 - affecting the shape with Gaussian prior



Cross section measurement

- Extra ingredients needed
 - $L = 404 \text{ } \mu\text{b}$
 - $BR_{u-3prong} = 5.06\%$
 - efficiency** (ϵ) from MC = 78.5%

$$\sigma_{fiducial} = \frac{N_{signal}}{L \times BR \times \epsilon}$$



$$\sigma_{fiducial} = 4.8 \pm 0.6(stat) \pm 0.5(sys) \mu\text{b}$$

Overview of uncertainties

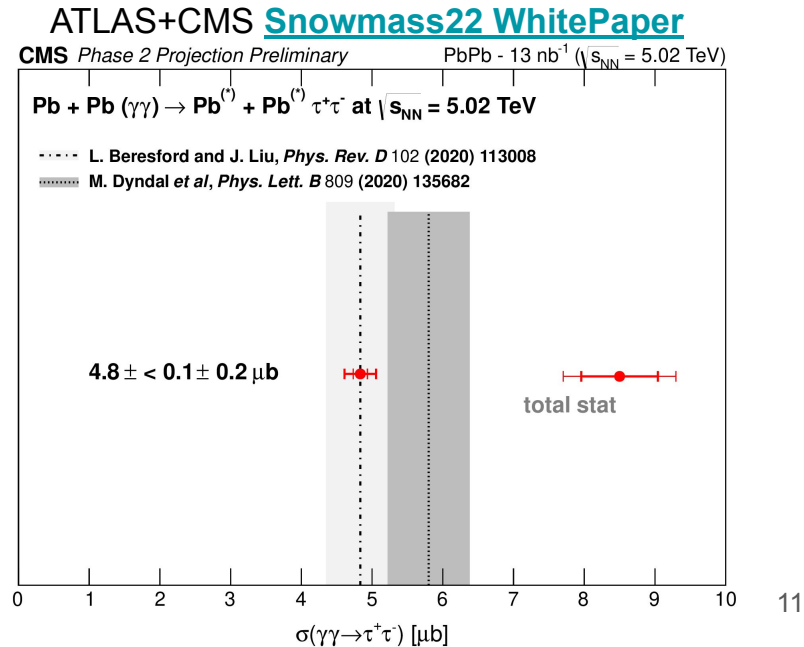
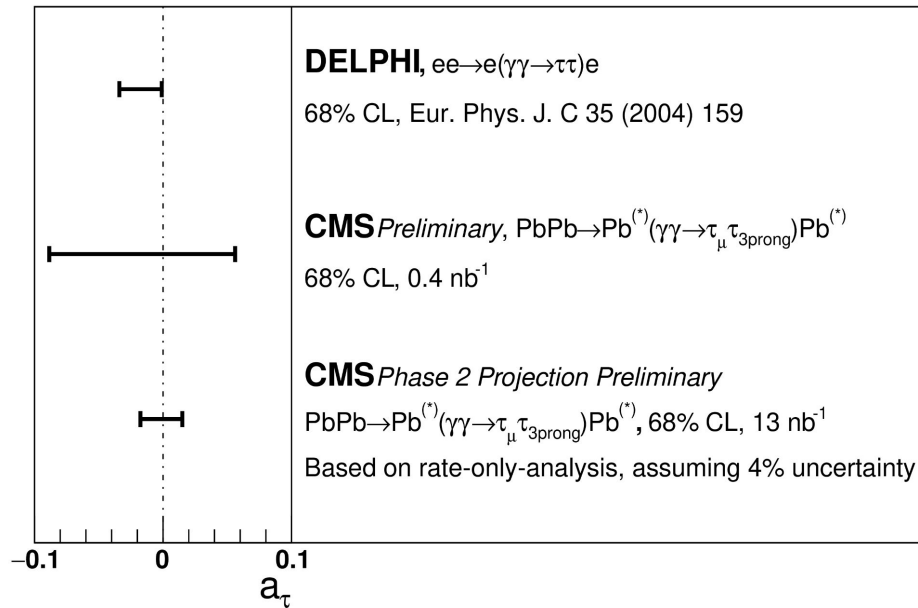
- **Statistically dominated** (13%)
- Systematic wise the **dominant sources** are related to
 - muons (trigger efficiency)
 - tracking efficiency
 - luminosity
- Total uncertainty (16%) comparable to the current theory uncertainty (10%)
 - difficult to **discriminate** between existing models
 - **model-dependent** limits on anomalous moments can be set

Source	Relative uncertainty (%)
Muon scale factor	6.7
Luminosity measurement	5.0
Pion scale factor	3.6
MC sample size (bin by bin)	3.0
MC sample size (efficiency)	1.1
HF scale effect on background shape	0.9
τ lepton branching fraction measurement	0.6
Effect of N_{ch} on background shape	0.2
Total	9.7

Constraints on a_τ and expected performance at HL-LHC



- Using the [theo calculation](#) of $\sigma(\gamma\gamma \rightarrow \tau\tau)$ as a function of a_τ —scale only
 - first limits** at LHC can be obtained
- We expect a total uncertainty well below the current theory uncertainty
 - we can discriminate** between existing models
 - projected limit at HL-LHC **competing with LEP**



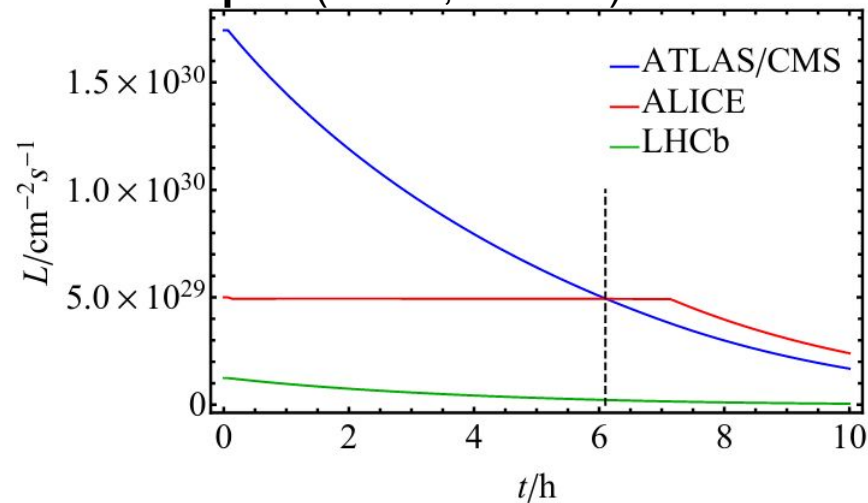
Outlook

- LHC heavy ion collision (HIC) data are a **gamechanger**
 - accelerator performance well **surpassed** any initial expectations
 - exploiting HIC is a unique and complementary means to **search for BSM phenomena**
 - but also **improve** existing models
- A **dedicated physics program** for studying a_τ is initiated in CMS
 - with 2015 CMS data we **establish** the signal
 - $\gamma\gamma \rightarrow \tau\tau$ signal region defined based on **lepton** and **track** multiplicity
 - **1 μ + 3 tracks**
 - **further improvements** with inclusion of existing/upcoming data & improved techniques
 - HL-LHC **baseline projection** done for the expected limits on a_τ
- Ample room for **cross-experiment collaboration**
 - existing measurements can be used for further **combinations** of HIC data at LHC

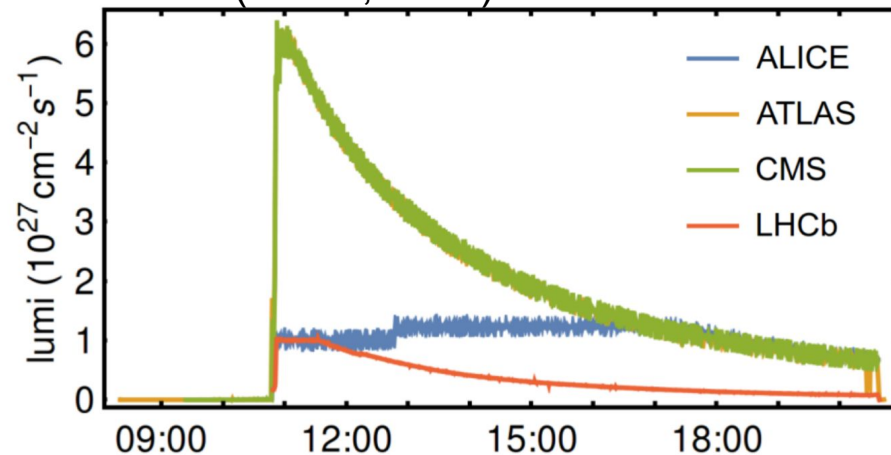


Heavy ion collisions (HIC) at LHC

pPb (Run 2, 200 /nb)



PbPb (Run 2, 2 /nb)



- LHC collided **more** types of beam, than originally foreseen, with **better** than expected performance
 - In practice, we've come close to the “**HL-LHC**” **performance** with pPb and PbPb collisions
- Opens up **further opportunities** for probes not accessible so far due to lower luminosity and/or energy
 - two one-month runs would be needed to reach the Runs 3+4 target of **1200 /nb** in pPb
 - five one-month runs would be needed to reach the Runs 3+4 target of **13 /nb** in PbPb
 - **all 4** experiments participate
 - makes luminosity sharing far **more challenging** than high-pileup pp running
 - **complementary** phase space regions, cross checks