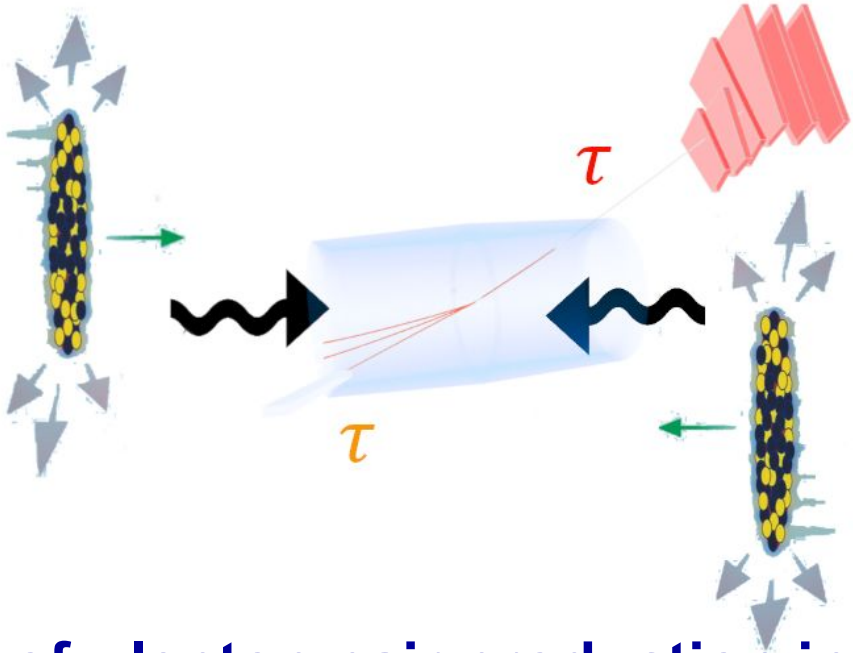


Observation of τ lepton pair production in ultraperipheral lead-lead collisions at 5.02 TeV

arXiv:2206.05192

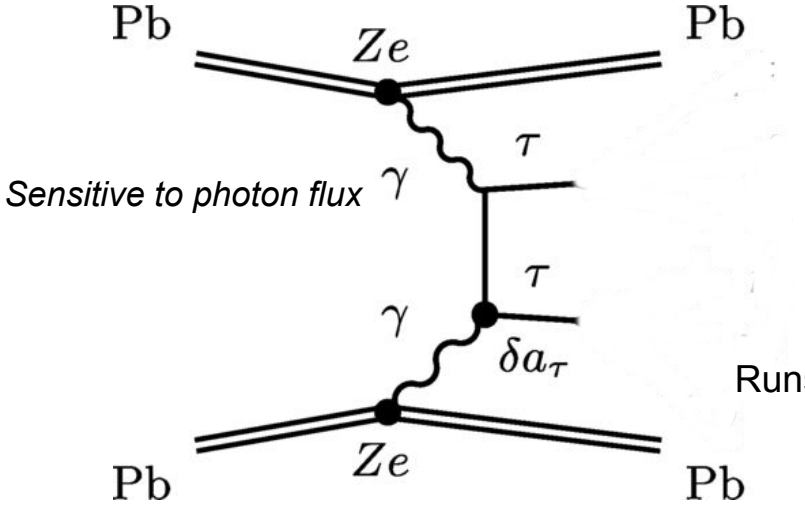
(submitted to PRL)

U.S. DEPARTMENT OF ENERGY | Office of Science

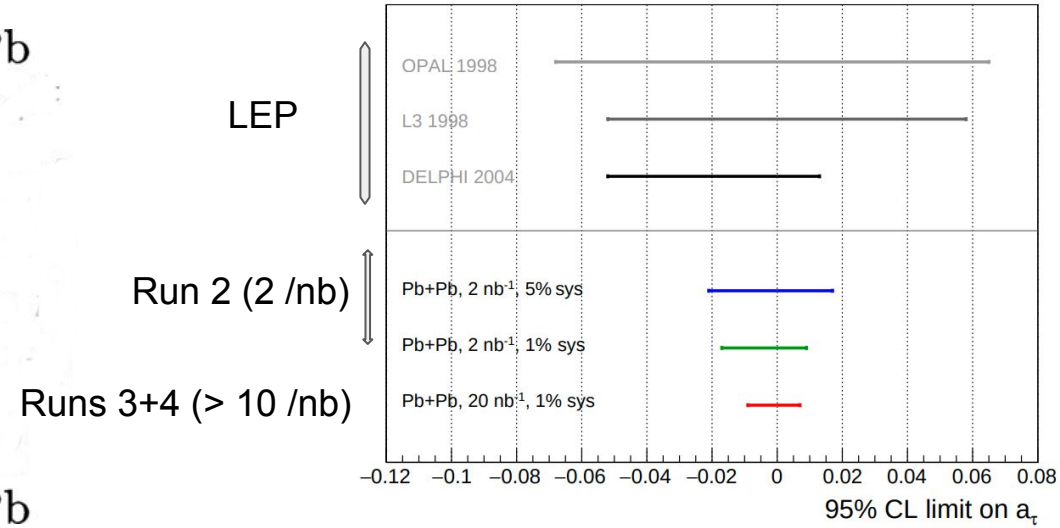
GK Krintiras (cern.ch/gkrintir) for the CMS Collaboration

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

- **Promising candidate** for the a_τ = (g_τ -2)/2 determination
  - "using a large heavy ion collider" for g_τ-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)



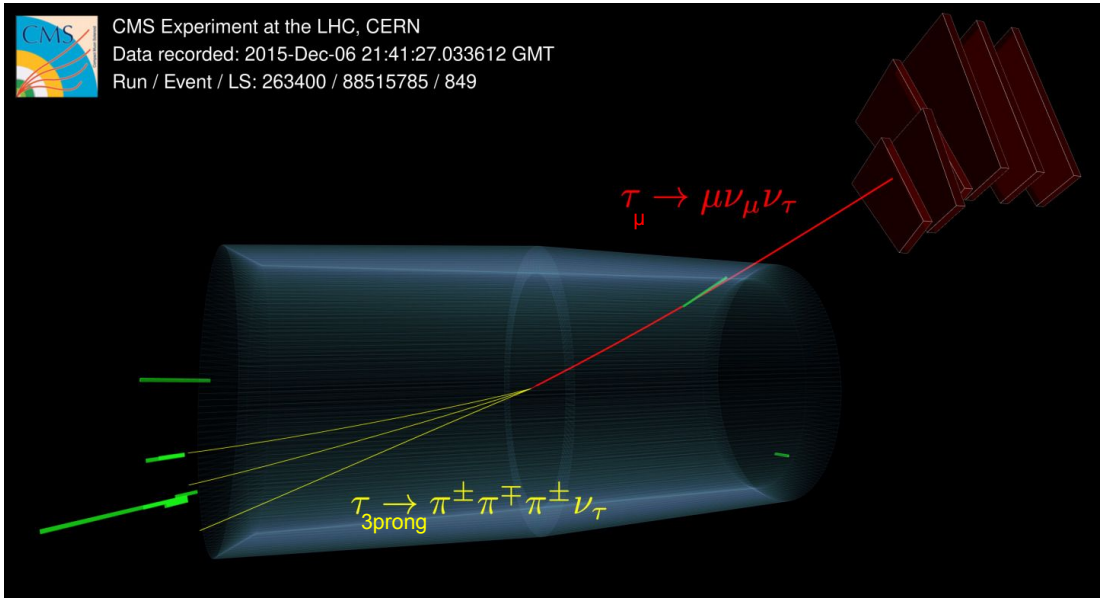
Phys. Lett .B **809** (2020) 135682 (2002.05503)
Phys. Rev. D **102** (2020) 113008 (1908.05180)

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
  - 1ℓ +1 track: main bkg due to μμ, ee
  - 1ℓ **+3 tracks: clean with high enough yield**

All channels needed for **ultimate precision**

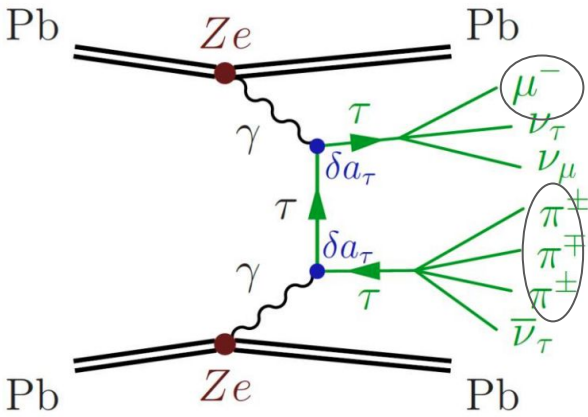
CMS-PHO-EVENTS-2022-003-2



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 mb) → O(1 M) with 2 /nb
  - **we expected <100** 1μ+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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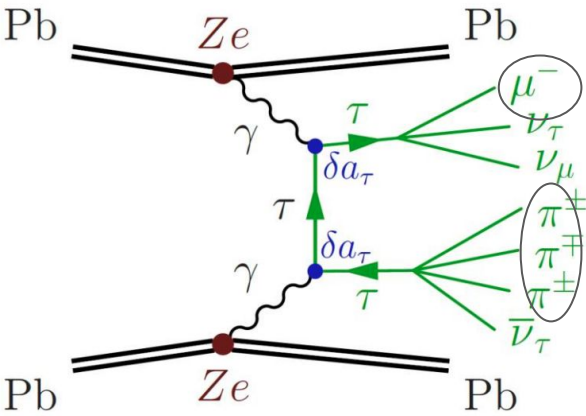


- Take advantage of **UPC** events and τ lepton **unique** decay signatures
  - low track multiplicity (N_{ch}), UPC triggers, and "exclusivity" requirements
    - **single lepton** triggers
    - **no activity** in forward hadron (HF) calorimeters above noise threshold

- 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 (~0.5 /nb)
  - followed by the **inclusion** of 2018 (~1.5 /nb)
  - Runs 3+4 **projection** in the realm of the joint ATLAS+CMS **Snowmass22** effort

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

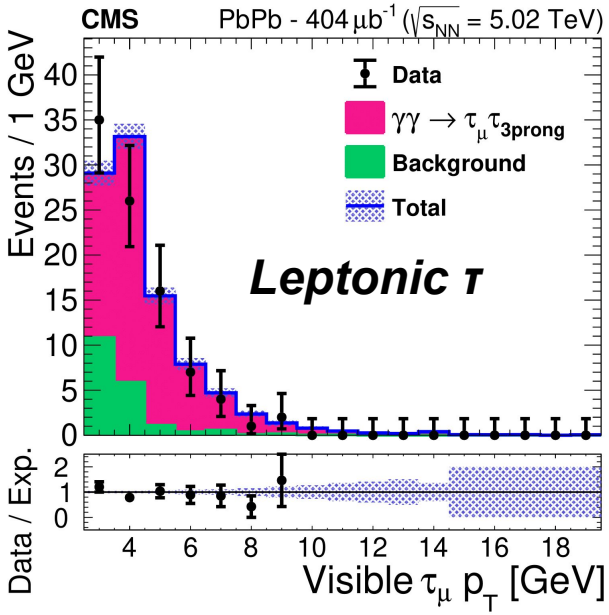
- **Trigger:** 1 muon & + >=1 track in the pixel detector + no HF activity on either side
- **Optimized offline** event selection (cf Table)
- Our **signal region** is 1 muon & N_{ch}=3
  - other N_{ch} and HF activity regions used in **bkg estimation**
- MC simulation for **signal and validation** (main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

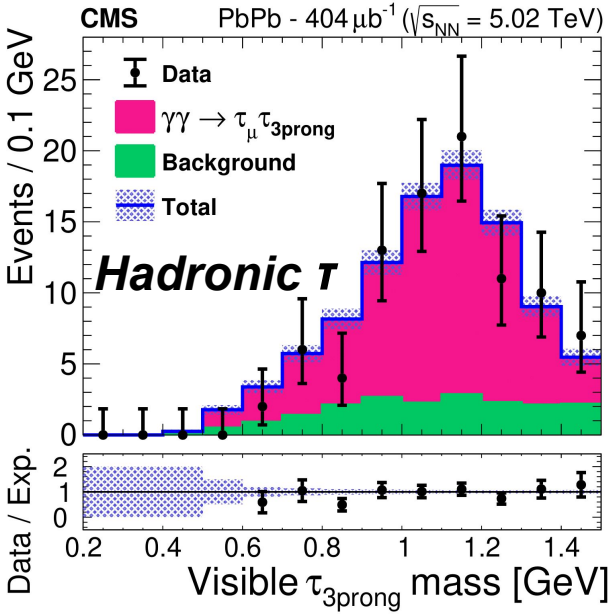
Object	Criteria
μ	$p_T > 3.5$ GeV for $\|\eta\| < 1.2$ $p_T > 2.5$ GeV for $1.2 < \|\eta\| < 2.4$
$\pi^{\pm}$	$p_T > 0.5$ GeV for leading $\pi^{\pm}$ $p_T > 0.3$ GeV for (sub-)sub-leading $\pi^{\pm}$ $\|\eta\| < 2.5$
τ_{3prong}	$p_T^{vis} > 0.2$ GeV 0.2 GeV $< m_{\pi\pi\pi} < 1.5$ GeV

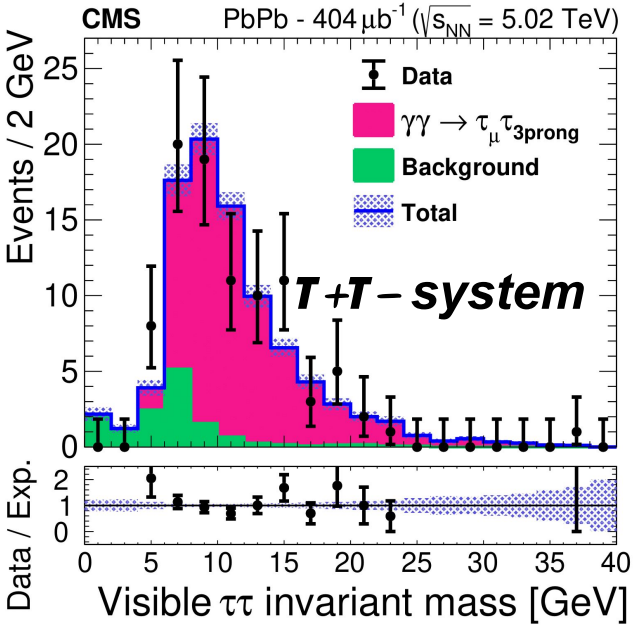
→ **Low-p_T** muons

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

- Very good **agreement** between data & expectations
  - signal MC is scaled to the **integrated luminosity**
  - we're in an almost **bkg-free** phase space region(!)
  - **unambiguous reconstruction** of the $\tau^+\tau^-$ system

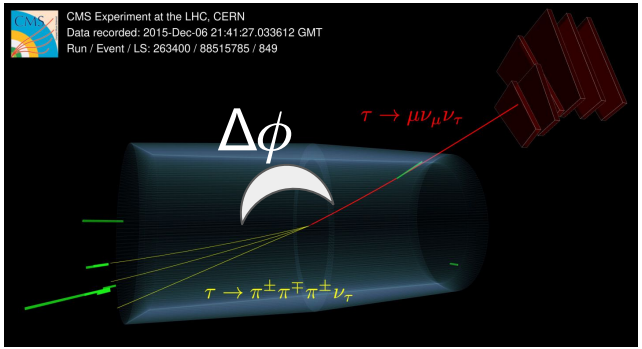


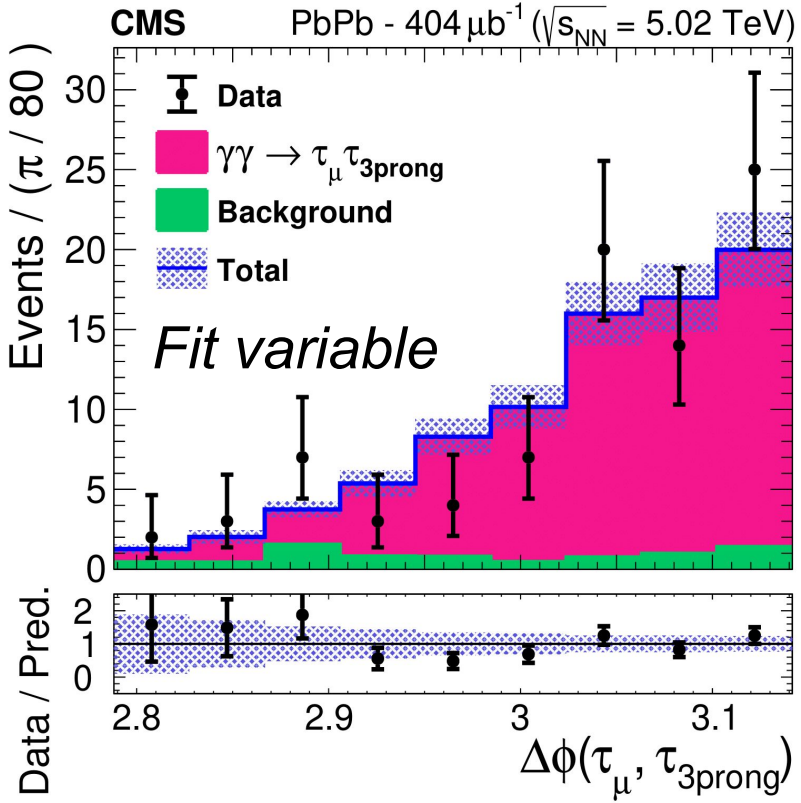




Signal yield estimation

- 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

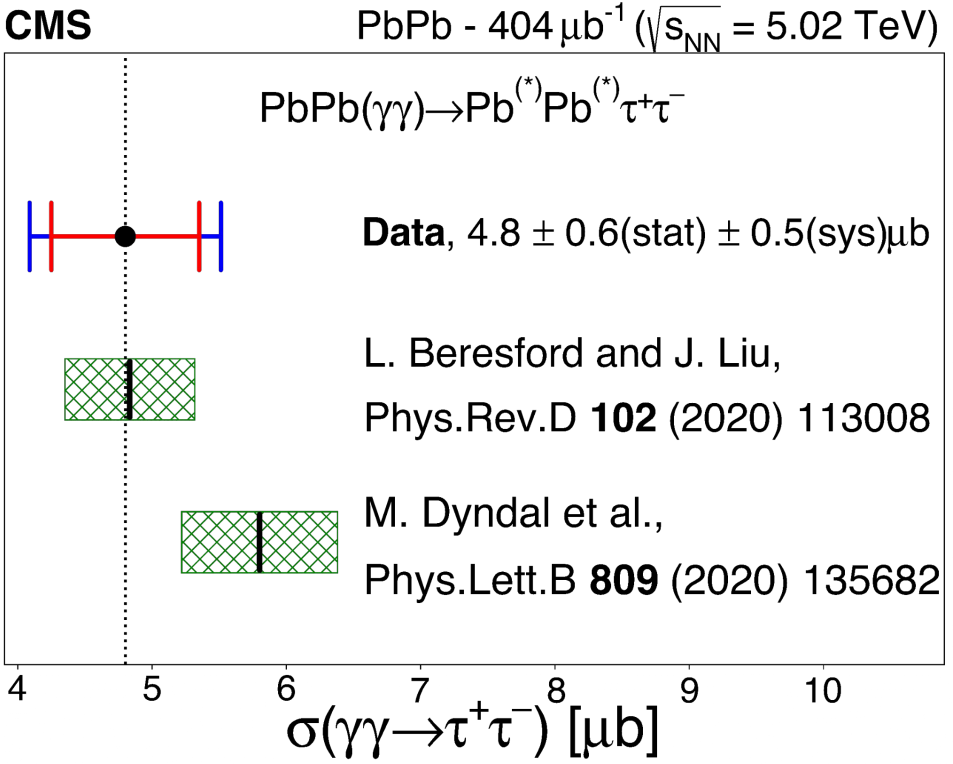




Cross section **measurement**

- Extra ingredients needed
  - **L** = 404 $/\mu b$
  - Bτ_{μ} = 17.39%
  - B$\tau_{3\,\text{prong}}$=14.55%
  - **efficiency** (ϵ) from MC = 78.5%

$$\sigma(\gamma\gamma \rightarrow \tau^{+}\tau^{-}) = N_{\text{sig}} / (2\epsilon\, \mathcal{L}_{\text{int}}\, \mathcal{B}_{\tau_{\mu}}\, \mathcal{B}_{\tau_{3\text{prong}}})$$



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

Overview of **uncertainties**

- **Statistically dominated** (13%)
- Systematic wise (9.7%) the **dominant sources** are related to
  - muons (trigger efficiency)
  - pion efficiency
  - luminosity

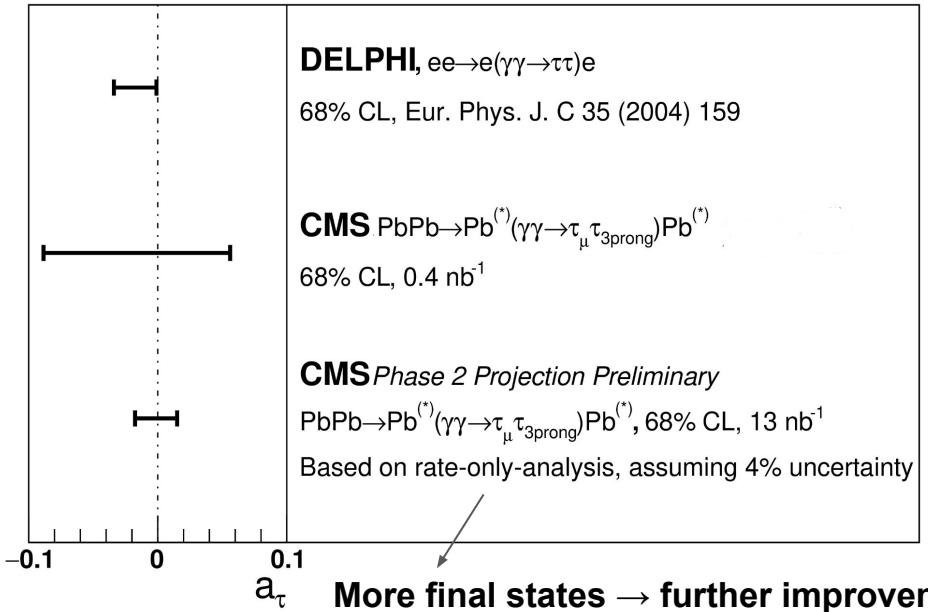
- Total uncertainty comparable to the current theory uncertainty
  - difficult to **discriminate** between existing models
  - **model-dependent** limits on anomalous moments can be set

Source	Uncertainty (%)
Muon efficiency	6.7
Integrated luminosity measurement	5
Pion efficiency	3.6
Simulation sample size (bin-by-bin)	3.0
Simulation sample size (efficiency)	1.1
HF scale effect on background shape	0.9
τ lepton branching fraction	0.6
Effect of n_{ch} on background shape	0.2
Total (systematic)	9.7

Constraints on a_T and **expected performance** at HL-LHC

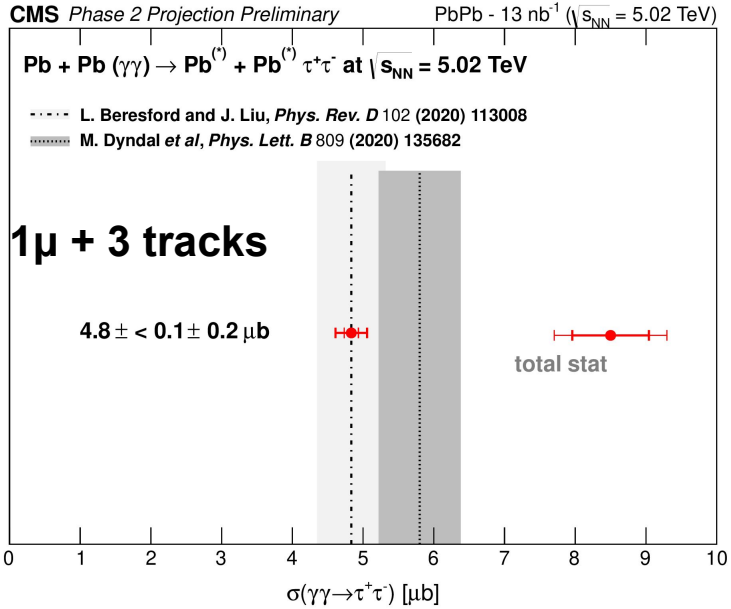
- Using the theo calculation of $\sigma(\gamma\gamma\to\tau\tau)$ as a function of a_T –scale only
  - **model-dependent measurements** at LHC can be obtained

- 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



More final states → further improvements

ATLAS+CMS Snowmass22 WhitePaper



Outlook

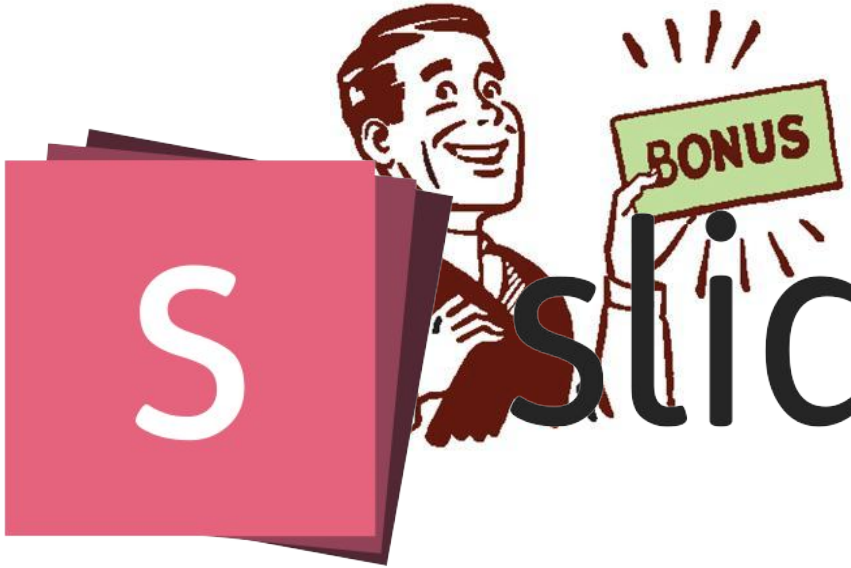
- LHC heavy ion collision (HIC) data are a **gamechanger**
  - accelerator performance well **surpassed** any initial expectations
  - exploiting HIC is a **unique and complementary means** to **search for BSM phenomena**
    - but also to **improve** existing models

- A **dedicated physics program** for studying a_T is initiated in CMS
  - with 2015 CMS data we **establish** the signal
    - $\gamma\gamma \to \tau\tau$ signal region defined based on **lepton** and **track** multiplicity
      - **1μ + 3 tracks**
  - **further improvements** with inclusion of more data, final states, & improved techniques
    - HL-LHC **baseline projection** done for the expected limits on a_T

- Ample room for **cross-experiment collaboration**
  - existing measurements can be used for further **combinations** of HIC data at LHC

arXiv:2206.05192 (submitted to PRL)

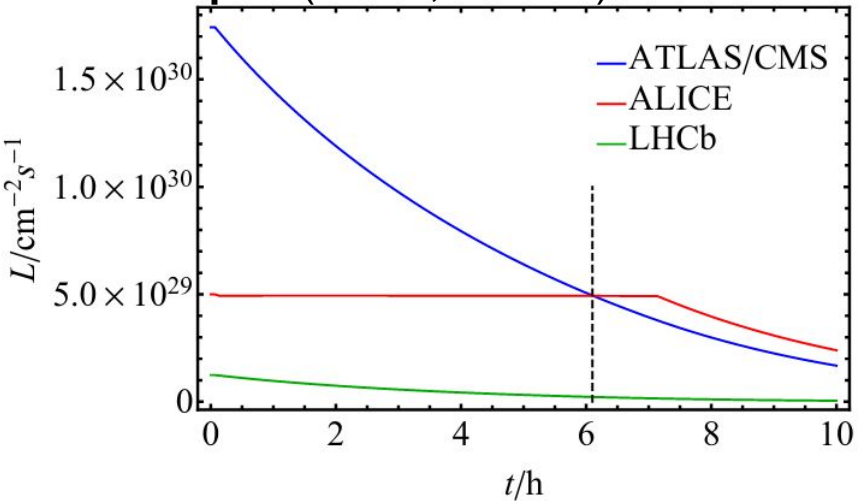
Physics announcement



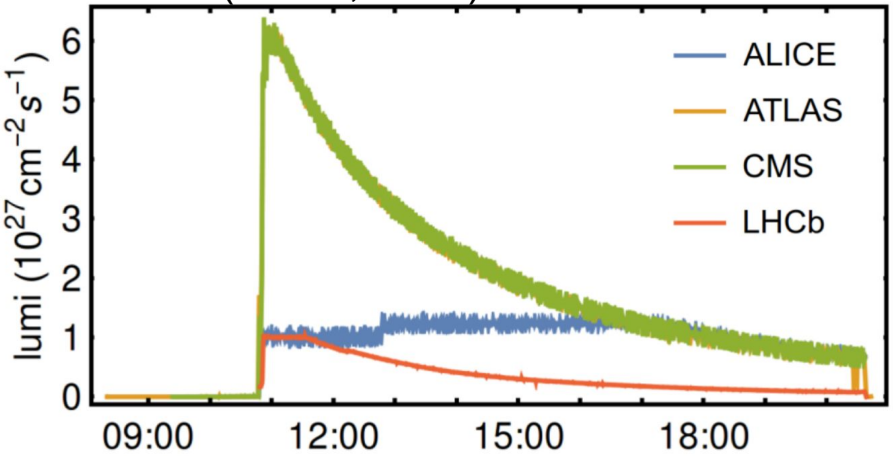
slides

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