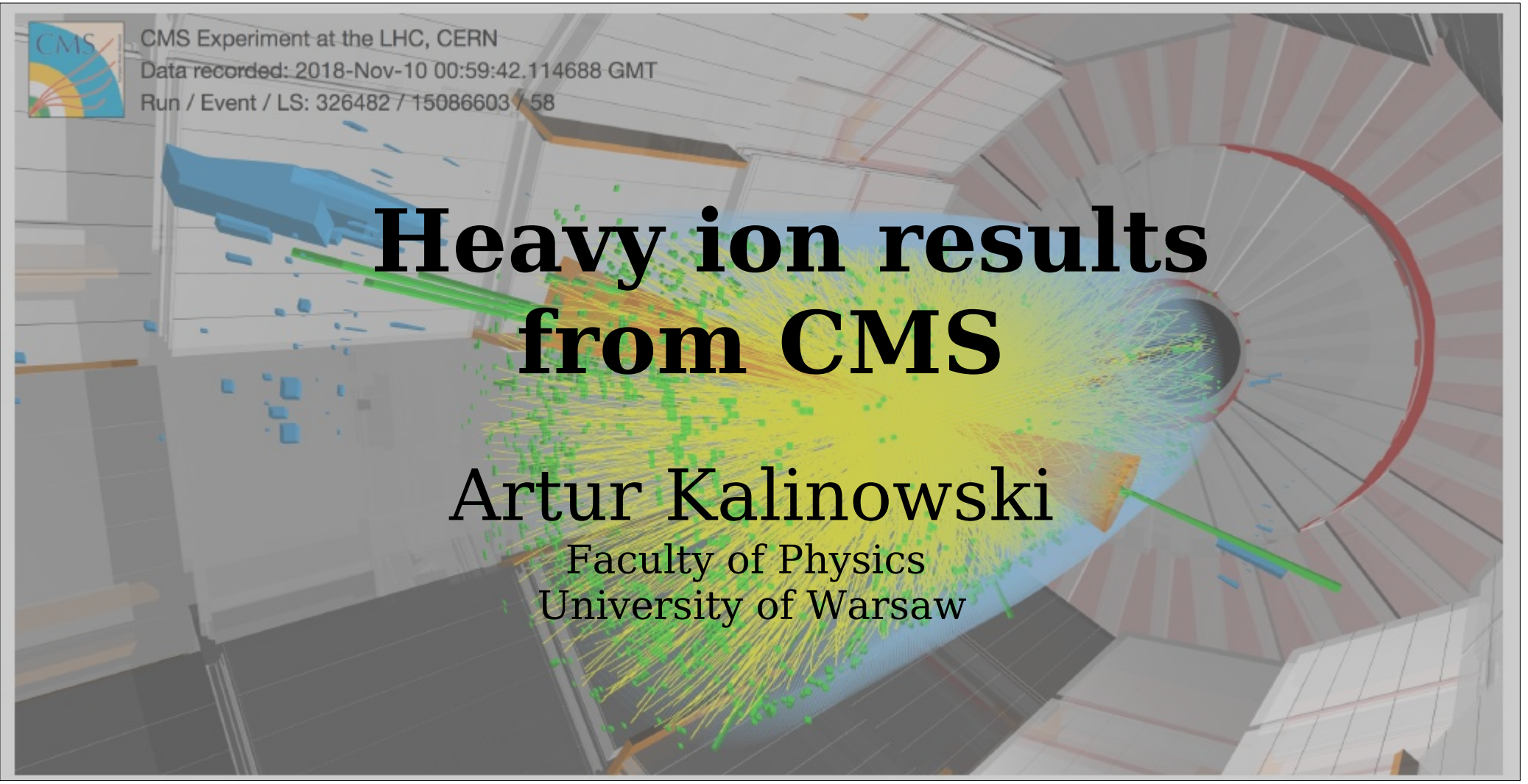


Heavy ion results from CMS

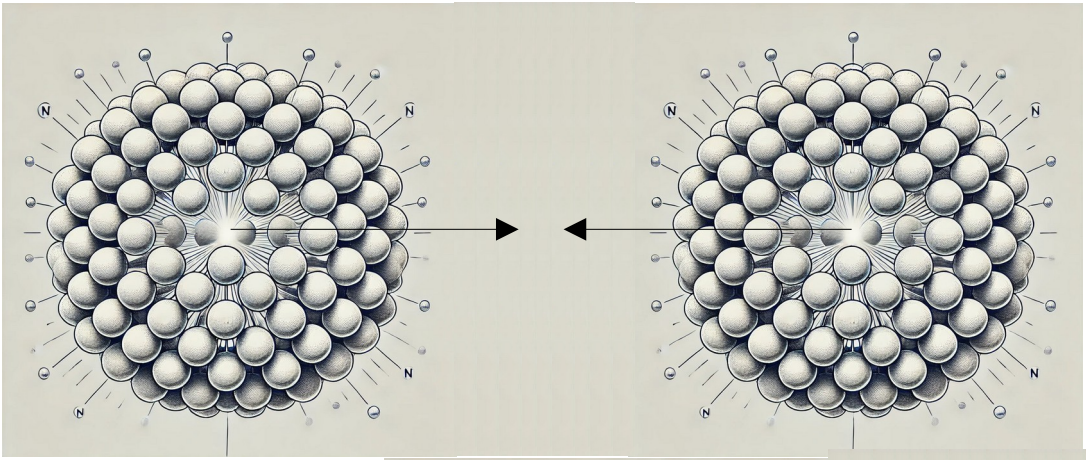
Artur Kalinowski

Faculty of Physics
University of Warsaw

Heavy ion laboratory: a 2in1 set

$b<2R_A$ - central collisions

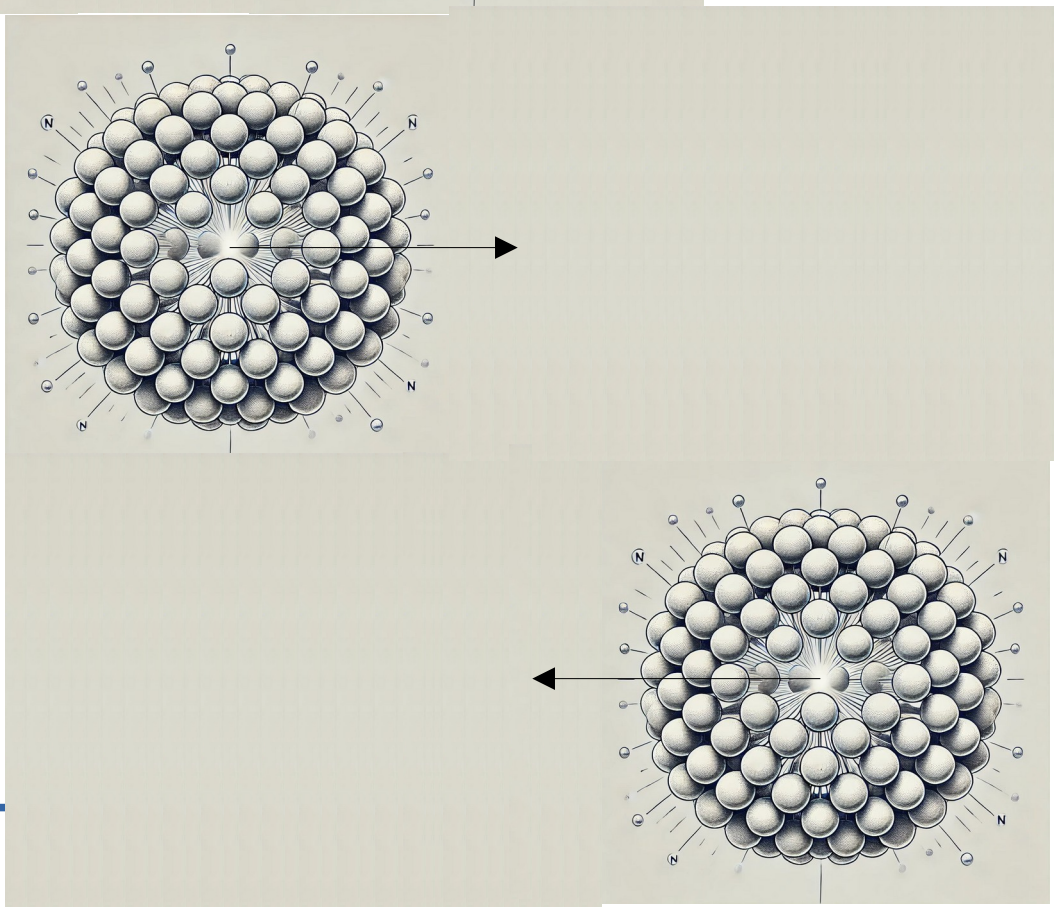
- dense colored matter (QGP) laboratory



ChatGPT generated drawing

$b>2R_A$ - ultra peripheral collisions

- high intensity photon beam laboratory



Bottom quark energy loss and hadronization in QGP

arXiv:2409.07258 [nucl-ex]

Impact of QGP on b-quark hadronization:

• b-quarks interacts with QGP via elastic collisions and QGP induced radiation →

details of b quark transport in QGP need deeper understanding

• QGP has large component of strange quarks →

B_s mesons are frequently produced

$$R_{AA}(p_T) = \frac{1}{T_{AA}} \frac{dN_{PbPb}^{B^+,B_s^0}}{dp_T} \Big/ \frac{d\sigma_{pp}^{B^+,B_s^0}}{dp_T}$$

Datasets:

• PbPb, 2018 run, 1.7 nb^{-1} @ 5.02 TeV

• pp, 2017 run, 302 pb^{-1} @ 5.02 TeV

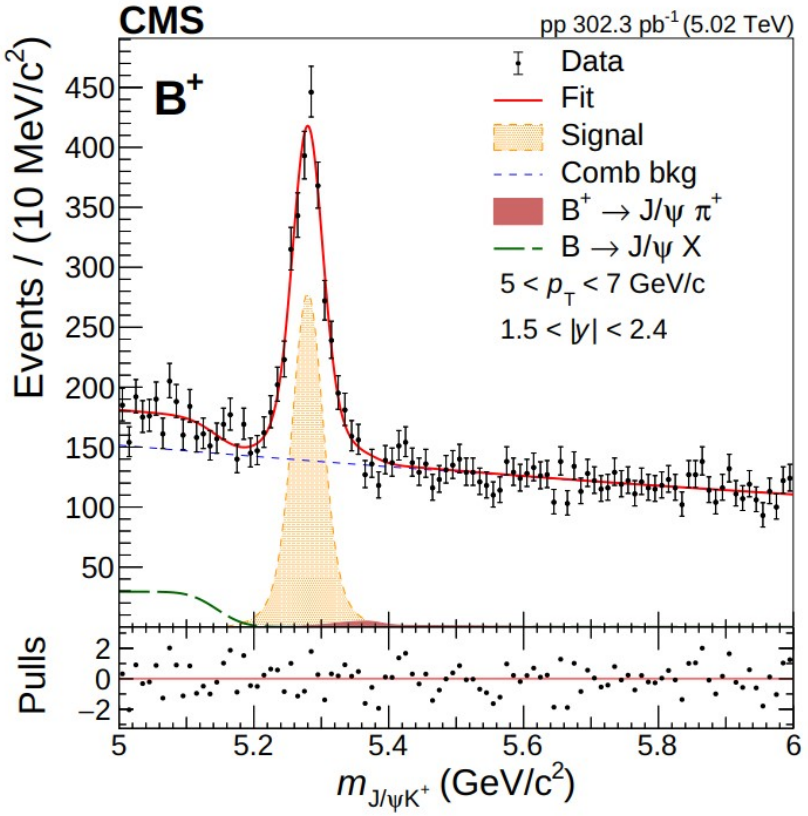
Bottom quark energy loss and hadronization in QGP

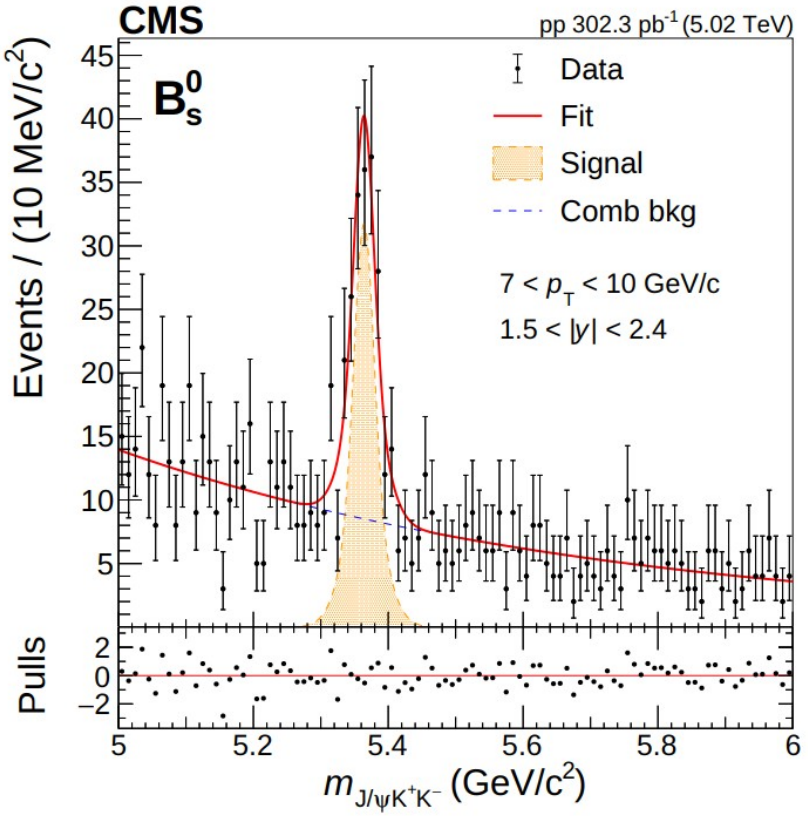
arXiv:2409.07258 [nucl-ex]

B^0_s identification: $B^0_s \rightarrow J/\psi\,\phi(1020)$

B^+ identification: $B^+ \rightarrow J/\psi\,K^+$

$J/\psi \rightarrow \mu^+\mu^-$ $\quad$ $\phi(1020) \rightarrow K^+K^-$





Bottom quark energy loss and hadronization in QGP

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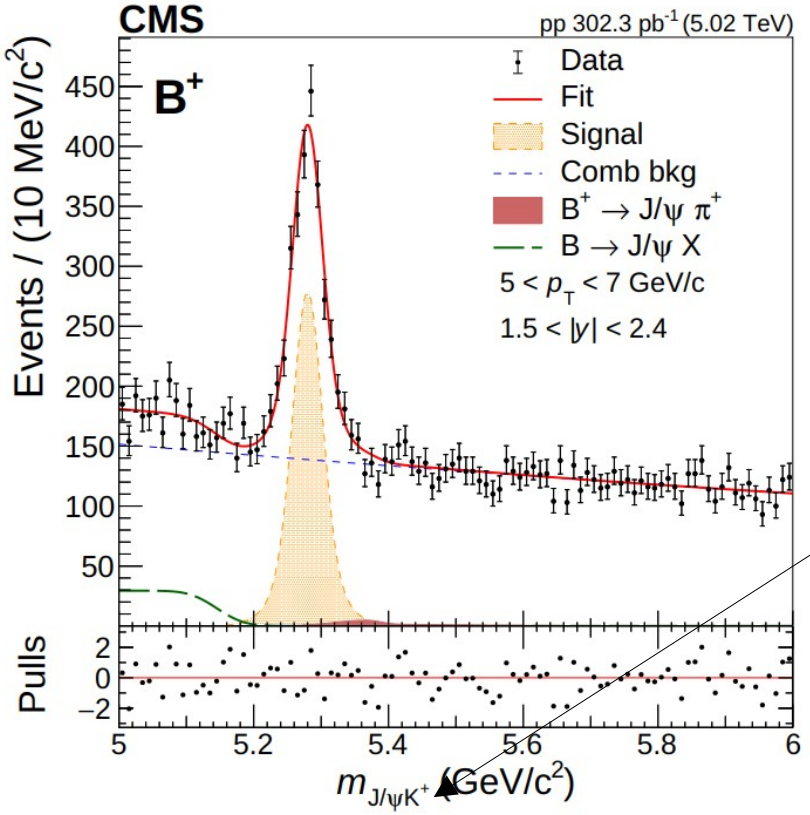
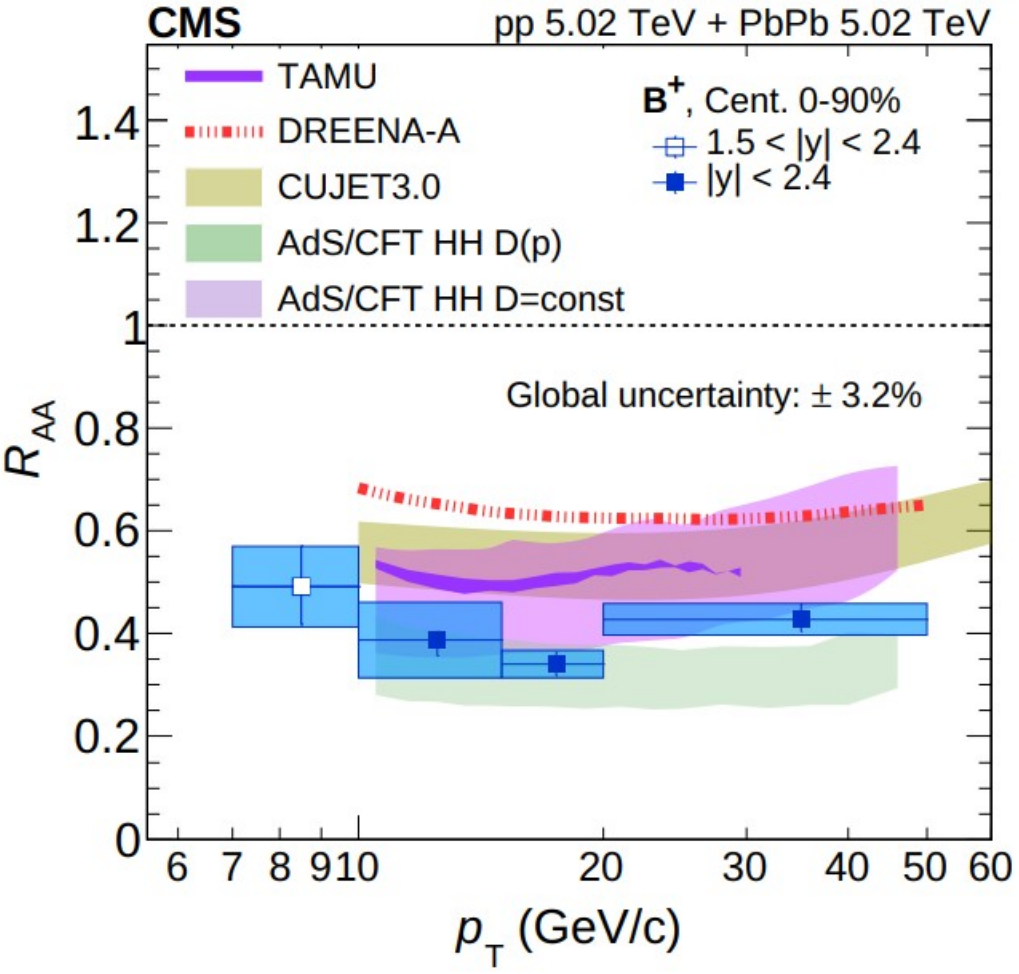


No hadron PID @CMS
K is any charged particle track with K mass assumed

Bottom quark energy loss and hadronization in QGP

arXiv:2409.07258 [nucl-ex]

B^+ mesons



TAMU ← transport model. No radiative energy loss.

DREENA-A, CUJET3.0 } pQCD models

AdS/CFT HH D(p), AdS/CFT HH D=const

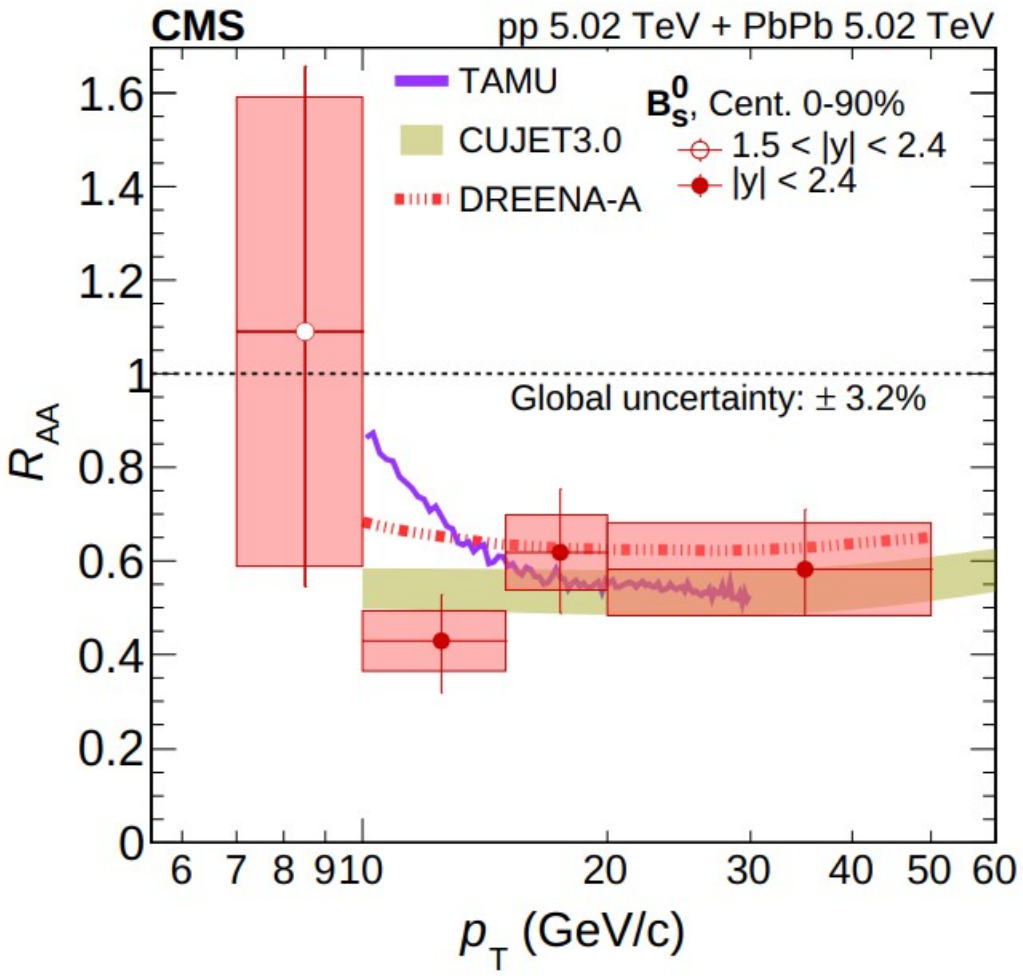
anti-de-Sitter/conformal field theory correspondence

D - diffusion coefficient heavy-quark propagation through the medium

Bottom quark energy loss and hadronization in QGP

arXiv:2409.07258 [nucl-ex]

B^0_s mesons



TAMU ← transport model. No radiative energy loss.

CUJET3.0, DREENA-A } pQCD models

QGP medium response to hard probes

Charged particle correlation with Z boson direction.

CMS-PAS-HIN-23-006

- hard scattering occurs before QGP formation →
  Z p_T boson indicates hard probe energy before interaction with QGP

- hard scattered quark interacts with QGP medium →
  induces medium response and recoil

Datasets:

- PbPb, 2018 run, 1.7 nb^{-1} @ 5.02 TeV
- pp, 2017 run, 302 pb^{-1} @ 5.02 TeV

QGP medium response to hard probes

Event selection:

CMS-PAS-HIN-23-006

- at least two μ with p_T>20 GeV/c
  60<m$\mu\mu$<120 GeV/c^2

- Z boson 40<p_T<350 GeV/c

- charged particle track
  p_T> 300 GeV

- multi parton interaction and underlying event contributions subtracted

QGP medium response to hard probes

CMS-PAS-HIN-23-006

$$\frac{1}{N_Z}\Delta\langle N_{ch}\rangle(\Delta\phi_{ch,Z},\Delta y_{ch,Z}) = \frac{N_{ch}(\Delta\phi_{ch,Z},\Delta y_{ch,Z}) - \langle N_{ch}\rangle}{N_Z}$$

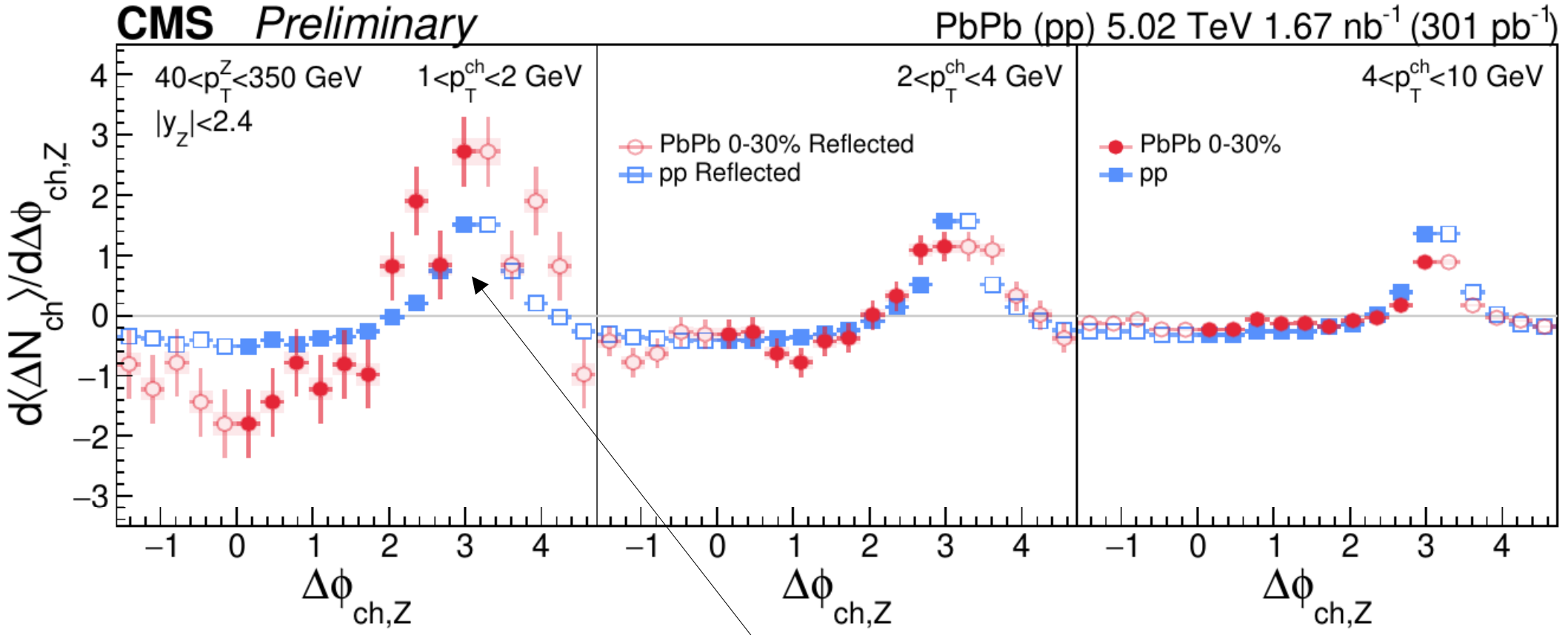
$$\frac{1}{N_Z}\Delta\langle N_{ch}\rangle(\Delta\phi_{ch,Z},\Delta y_{ch,Z}) = S(\Delta\phi_{ch,Z},\Delta y_{ch,Z}) - B(\Delta\phi_{ch,Z},\Delta y_{ch,Z})$$

"same event" – contain real and random correlations

"mixed events" – contain random correlations only

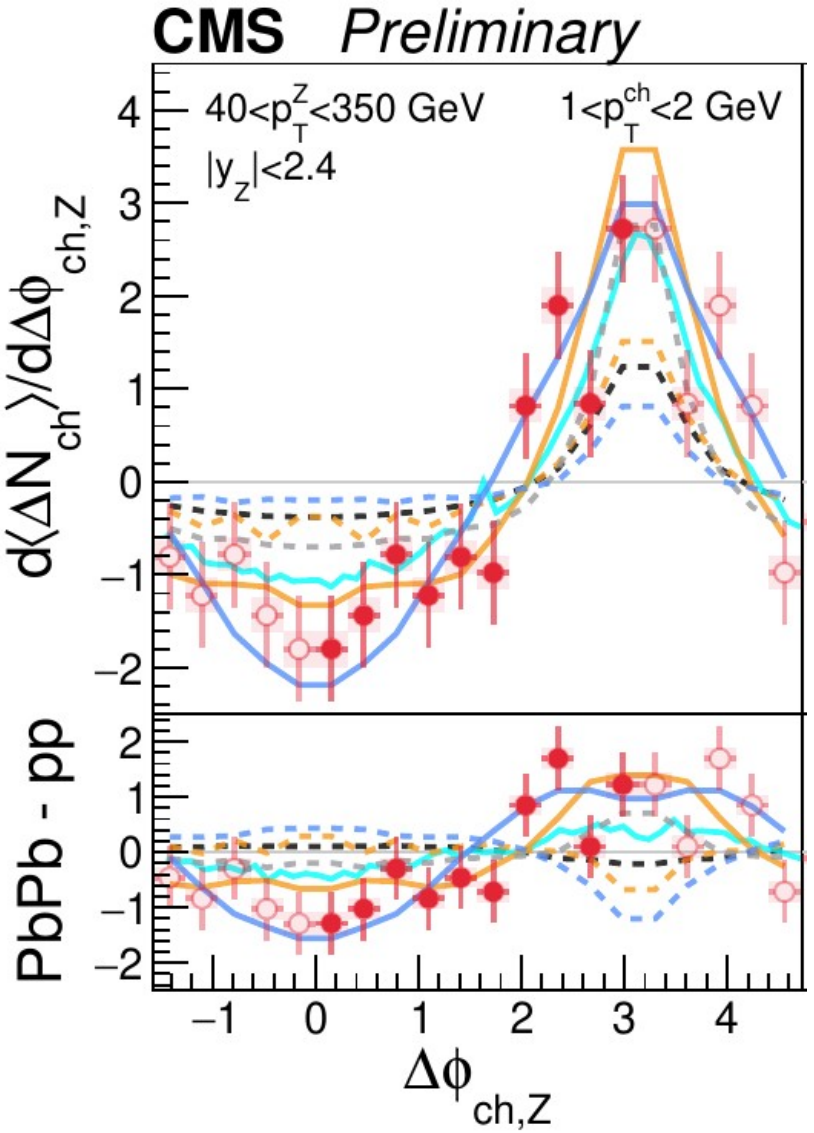
QGP medium response to hard probes

CMS-PAS-HIN-23-006



low p_T tracks sensitive to medium reaction to hard scattered parton traversing medium around $\Delta\varphi \sim\pi$ wrt. Z boson

QGP medium response to hard probes



CMS-PAS-HIN-23-006

- PbPb 0-30%
- Hybrid
- Hybrid No wake
- PYQUEN
- Jewel v2.2.0
- Jewel No recoil
- CoLBT
- PYTHIA8 p_T^Z>20 GeV

Phenomenological jet quenching model. No local four-momentum conservation.

Interaction of jets with a QGP with pQCD based calculations, incorporating both radiative and collisional energy losses

Pythia8 tuned to high p_T yield distribution. Discrepancy shows jest in QGP are not vacuum-like.

γ-γ laboratory

High intensity "photon beam":

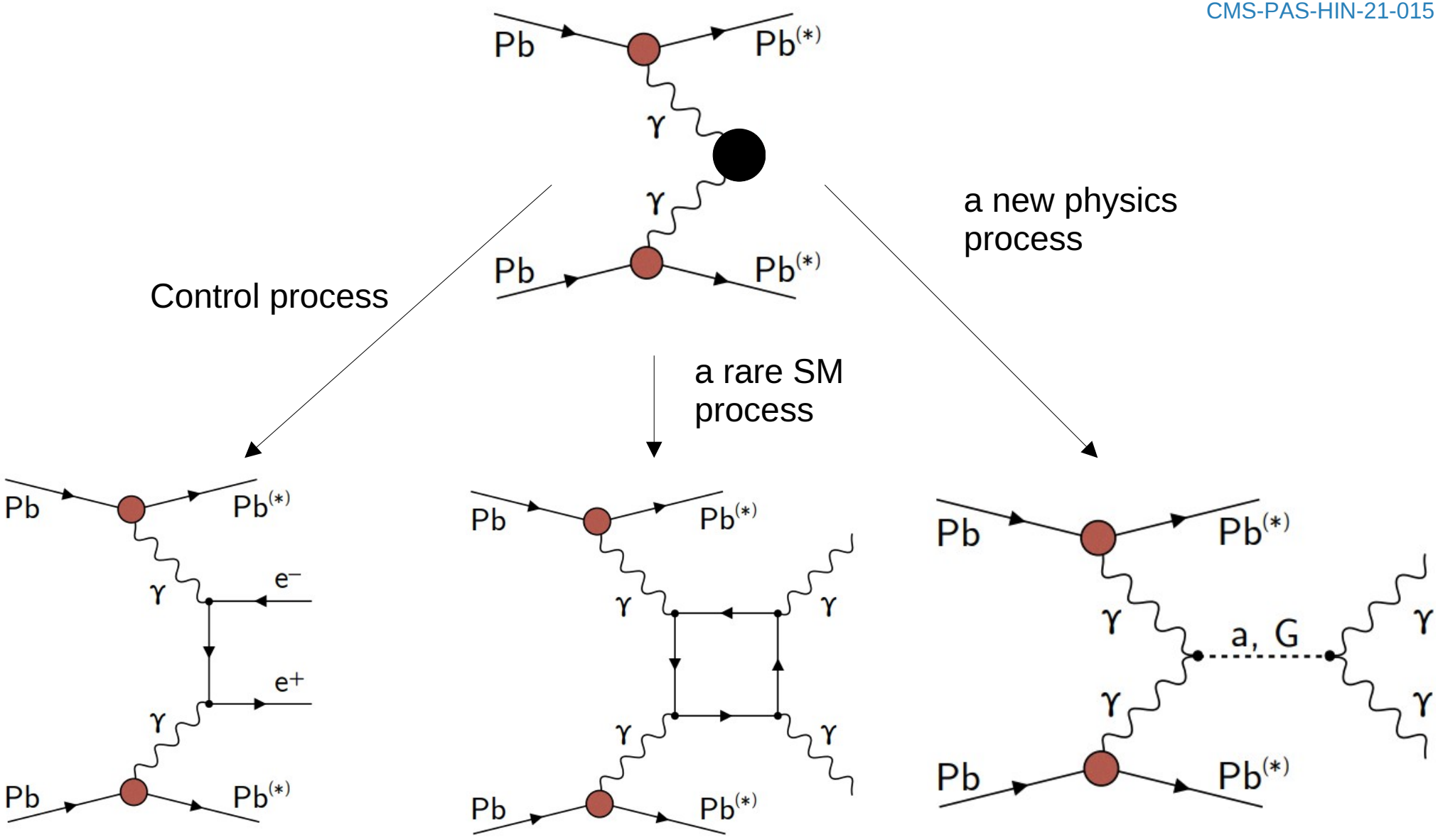
- energy: $E_\gamma = \gamma_{ion\,Lorentz} / R_{ion} \simeq 100\,\mathrm{GeV}$

- intensity: $I \sim Z^5 = 5 \cdot 10^7 I_{p-p}$

- allows to study rare, photon induced, processes in particular light-by-light (LbL) scattering

Light-by-light scattering

CMS-PAS-HIN-21-015



Light-by-light scattering

CMS-PAS-HIN-21-015

Event selection:

- exactly two γ or two e
- $p_{T\gamma\gamma/ee} < 1$ GeV, $|\Delta\varphi_{\gamma\gamma/ee} - \pi| < 0.01$
- no charged particle track with $p_T > 300$ MeV
- no neutral particle deposits in ECAL and HCAL
- no large deposit in the Zero Degree Calorimeter (ZDC)

Overall efficiency:

$$C^{\gamma\gamma} = (8.0 \pm 1.1)\%$$
$$C^{ee} = (4.4 \pm 0.3)\%$$

$\gamma\gamma \to ee$

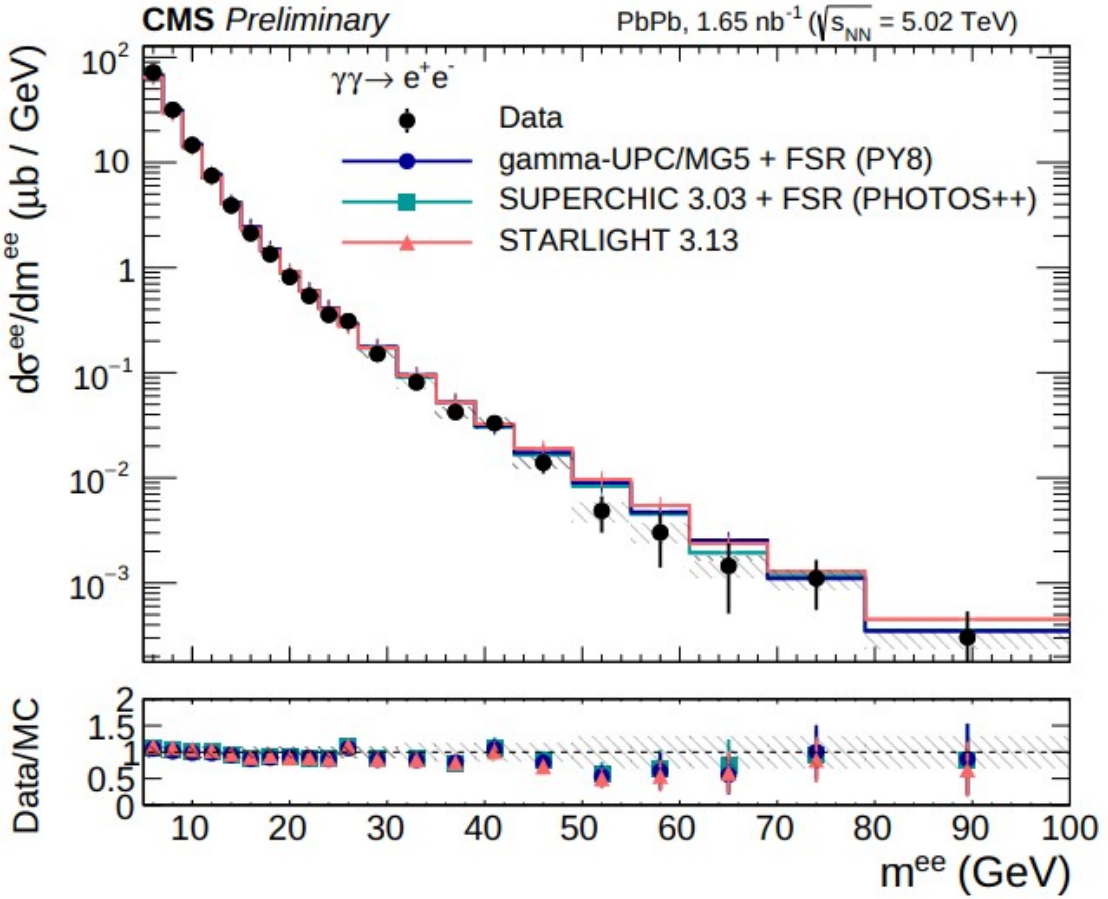
CMS-PAS-HIN-21-015

Dataset: PbPb, 2018 run, 1.65 nb^{-1} @ 5.02 TeV

$N_{ee}^{DATA} \simeq 20\,000$

$$\sigma_{fid}(\gamma\gamma \to e^+e^-) = \frac{N^{ee,data}}{C^{ee}\mathcal{L}_{int}} = 271.5 \pm 1.9\,(stat) \pm 18.3\,(syst)\ \mu b$$

- virtually background free process
- very good data description by Monte Carlo generators



$\gamma\gamma \to ee$

CMS-PAS-HIN-21-015

Dataset: PbPb, 2018 run, 1.65 nb^{-1} @ 5.02 TeV

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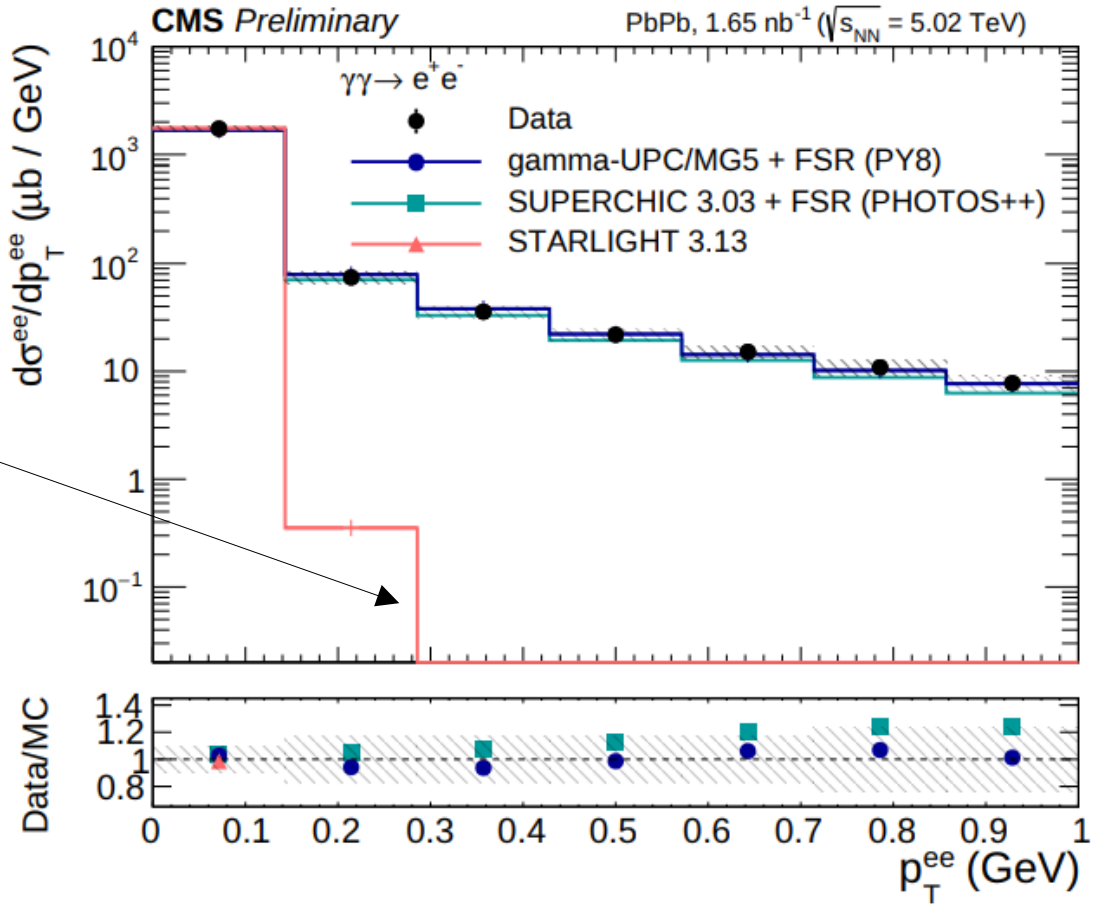
- STARLIGHT generator does not include final state photon radiation correction



$\gamma\gamma \to \gamma\gamma$

CMS-PAS-HIN-21-015

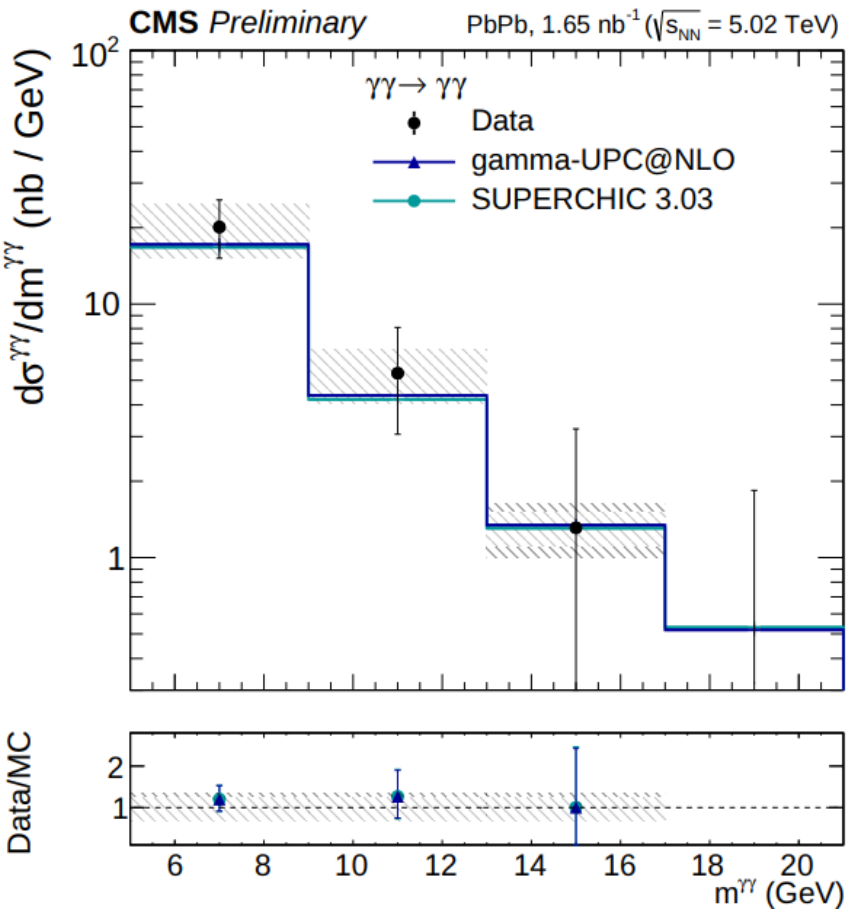
Dataset: PbPb, 2018 run, 1.65 nb^{-1} @ 5.02 TeV

$N_{\gamma\gamma}^{DATA} \simeq 26$

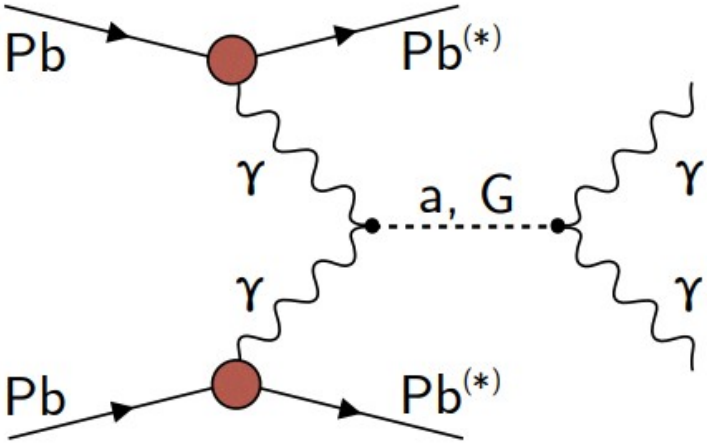
$$\sigma_{fid}(\gamma\gamma \to \gamma\gamma) = \frac{N^{\gamma\gamma,data} - N^{\gamma\gamma,bkg}}{C^{\gamma\gamma}\mathcal{L}_{int}} = 107 \pm 33\,(stat) \pm 20\,(syst)\,nb$$

- large background from mismeasured $\gamma\gamma \to ee$

- good data description by Monte Carlo generators

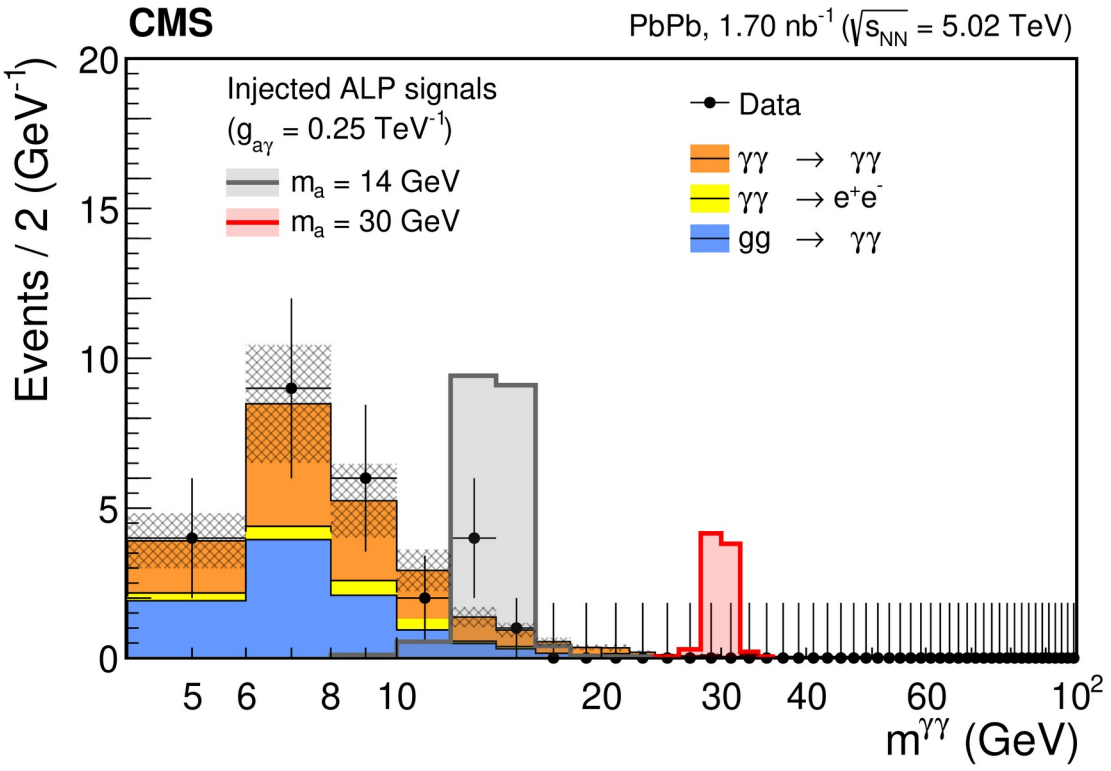


$\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$

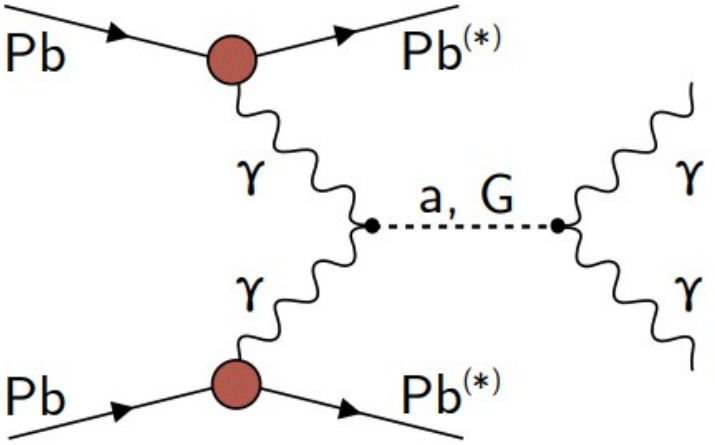


CMS-PAS-HIN-21-015

- no axion like events excess observed



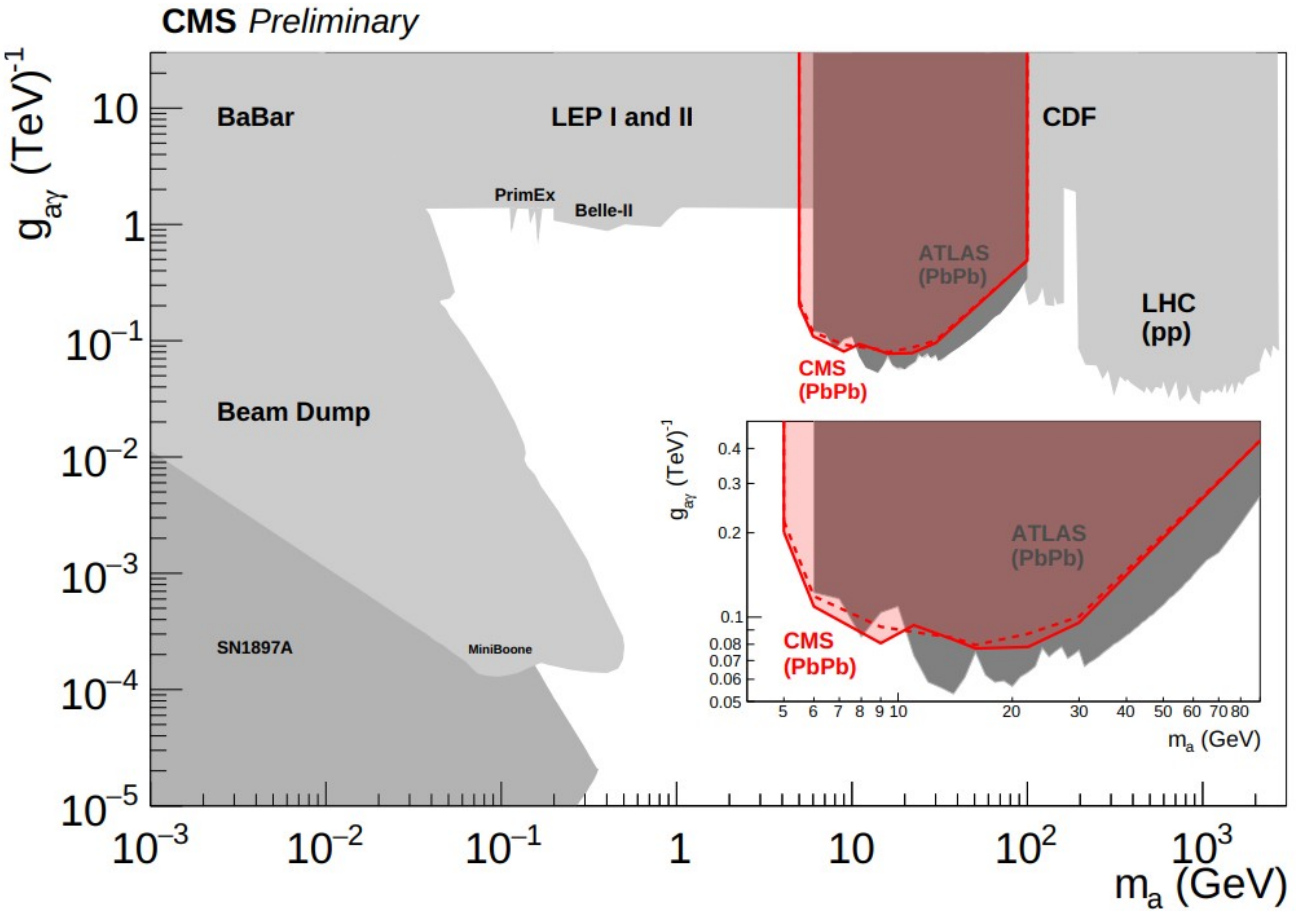
$\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$



CMS-PAS-HIN-21-015

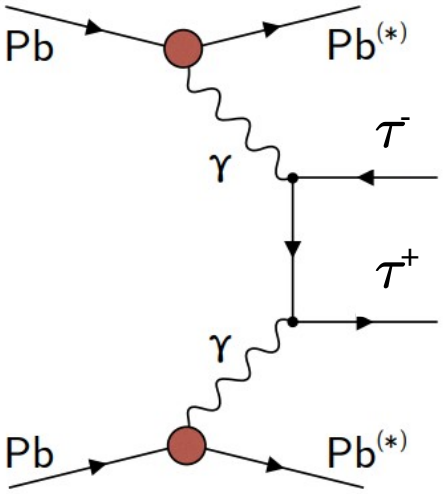
- limits on axion-γ coupling consistent with previous results

- some improvement is achieved for m_a<10 GeV/c^2



$\gamma\gamma \to \tau\tau$

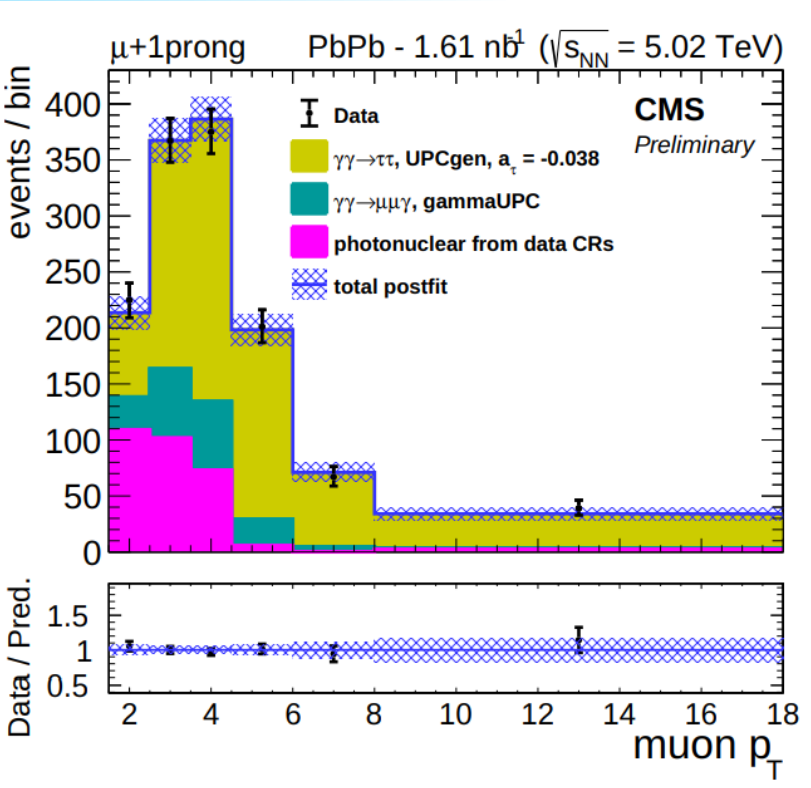
CMS-PAS-HIN-24-011

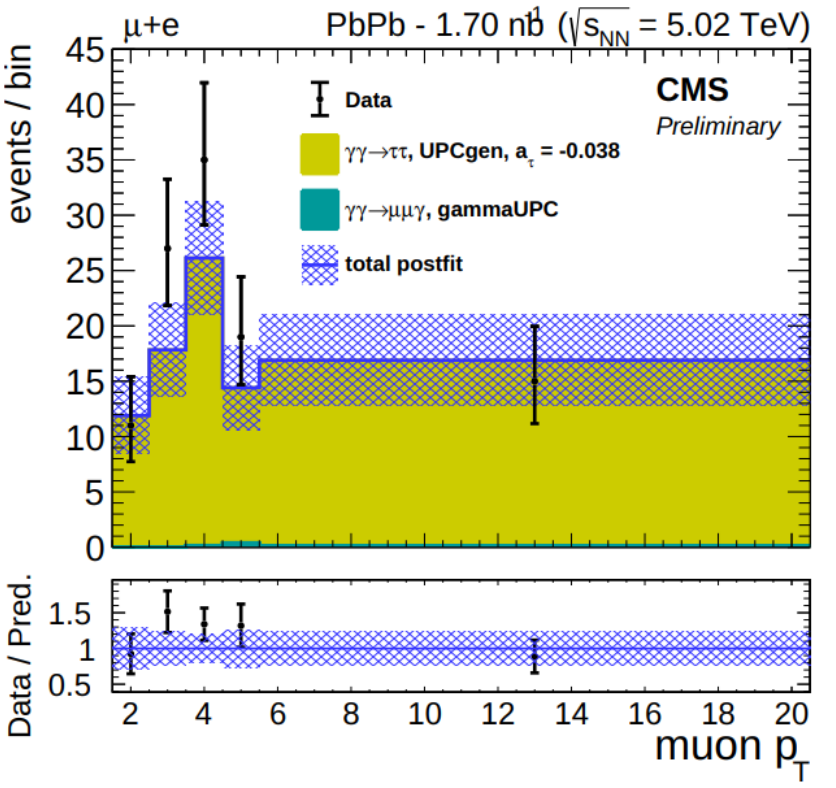


- $\tau\tau \to \mu$ + hadrons (1,3 prong) + υ
  $\tau\tau \to$ e + hadrons (3 prong) + υ
  $\tau\tau \to \mu$ + e + υ

- final state lepton p_T distribution is sensitivity to a_τ used to construct likelihood

$$\mathscr{L}\left(p_T | a_\tau\right)$$



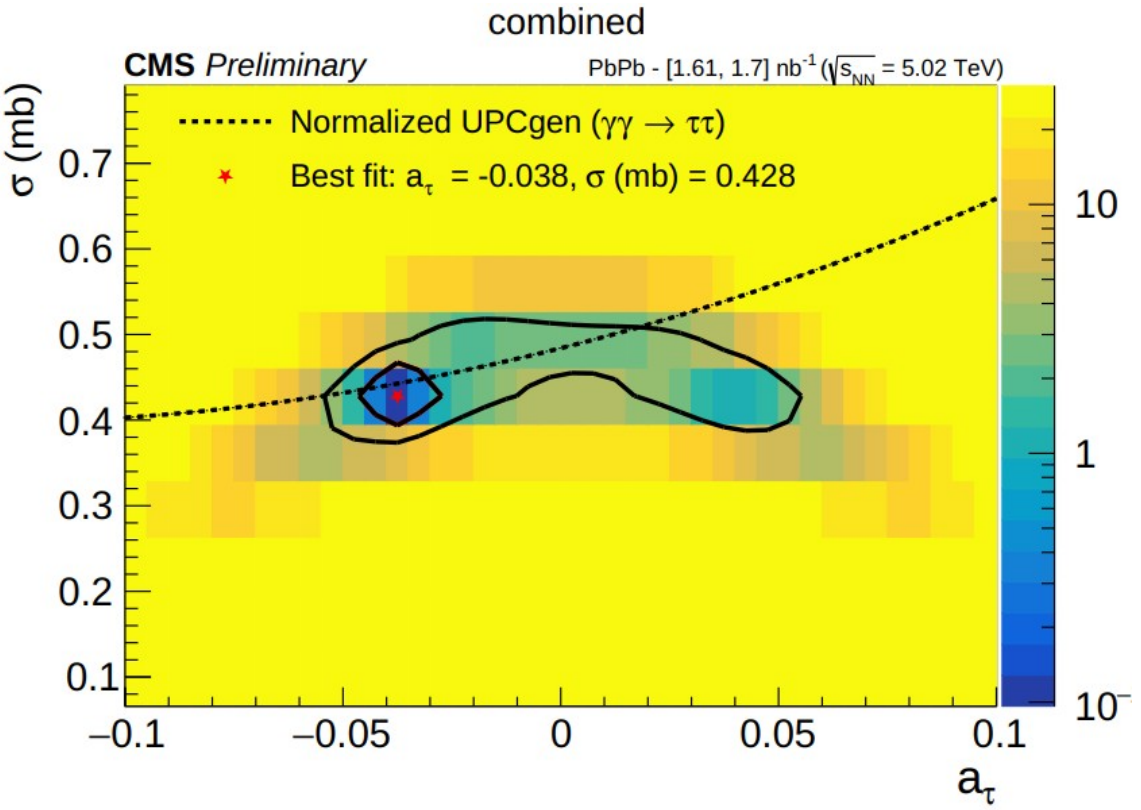


$\gamma\gamma \to \tau\tau$

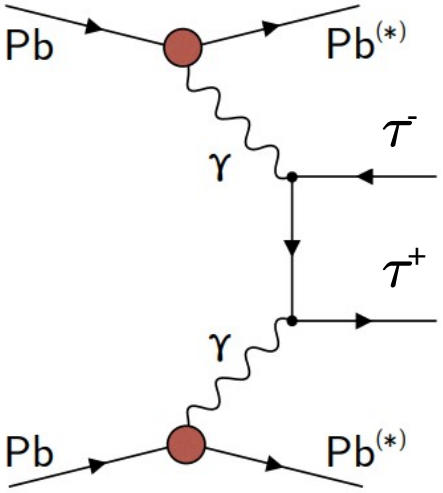
CMS-PAS-HIN-24-011

- $\mathscr{L}\left(p_T | a_\tau\right)$ is not sensitive to a_τ sign

- $\gamma\gamma \to \tau\tau$ cross section is monotonously correlated with τ anomalous magnetic moment



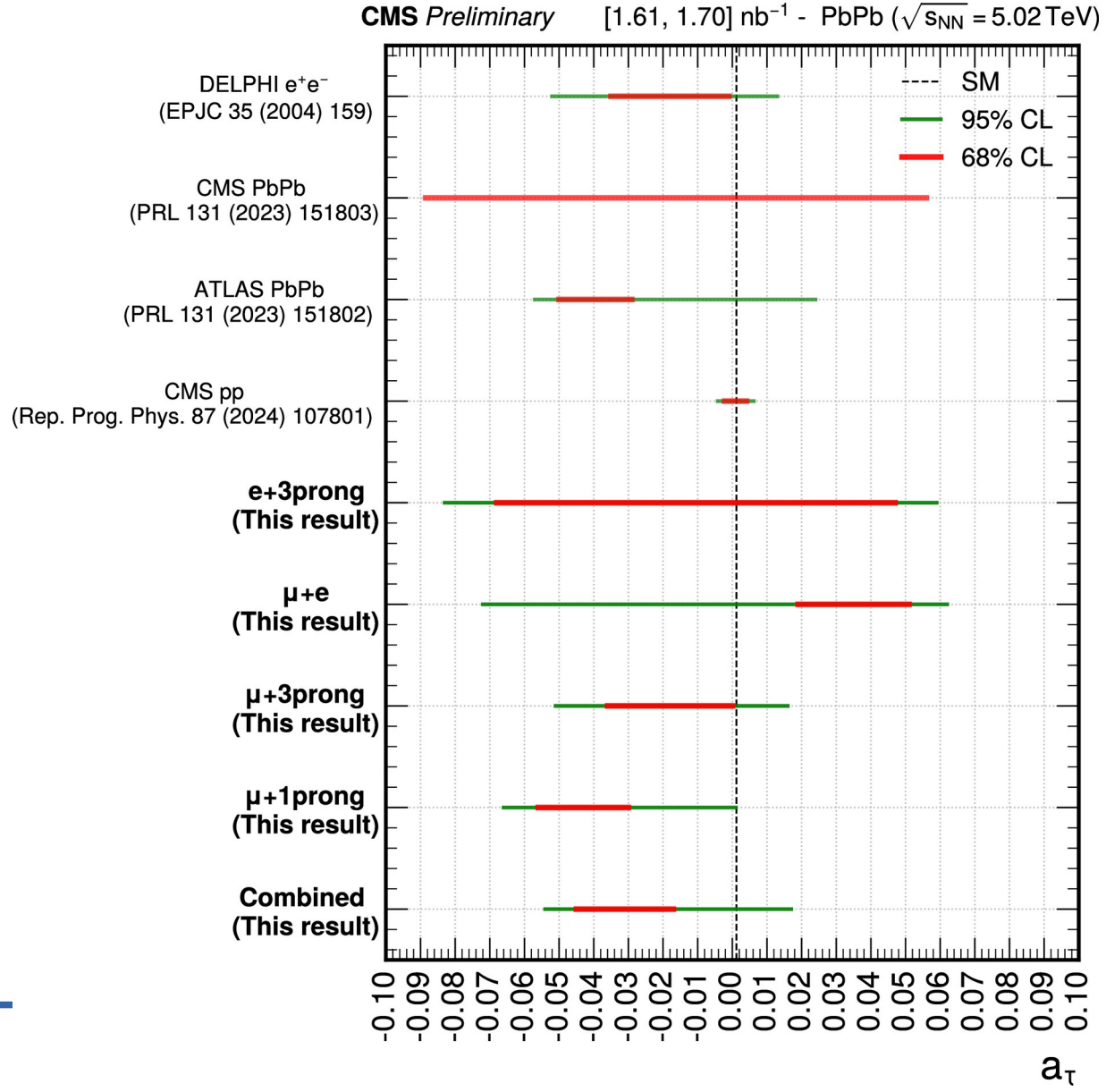
$\gamma\gamma \to \tau\tau$



- a_τ is probed in low ττ invariant mass system probed in opposite to result from p-p

- result consistent with previous measurements

CMS-PAS-HIN-24-011



Conclusions

• Heavy ion and proton-ion collisions provide unique opportunity for QCD and QED studies

• Heavy ion physics is like a Darwin's voyage on board the Beagle – a long trip of accumulation of evidences and hints for a complicated structure of low momentum, many body, QCD.

• An exhaustive diary of the observations collected so far is given in a recent

Overview of high-density QCD studies with the CMS experiment at the LHC

arXiv:2405.10785 [nucl-ex]