

Electromagnetic radiation in pp and Pb-Pb collisions with dielectrons in ALICE

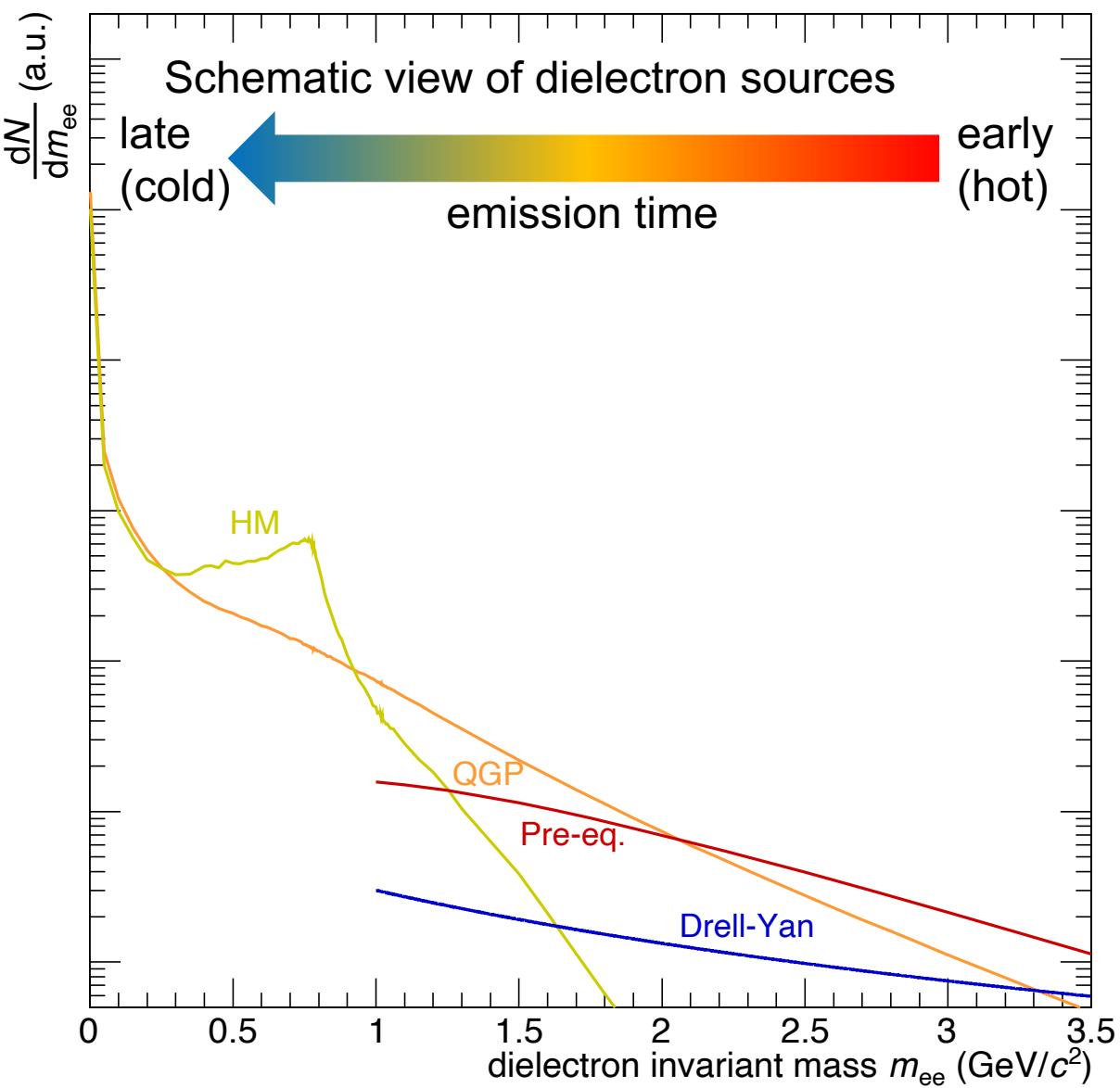
Daiki Sekihata for the ALICE Collaboration

Center for Nuclear Study, the University of Tokyo

Quark Matter 2023, 03-09.Sep.2023

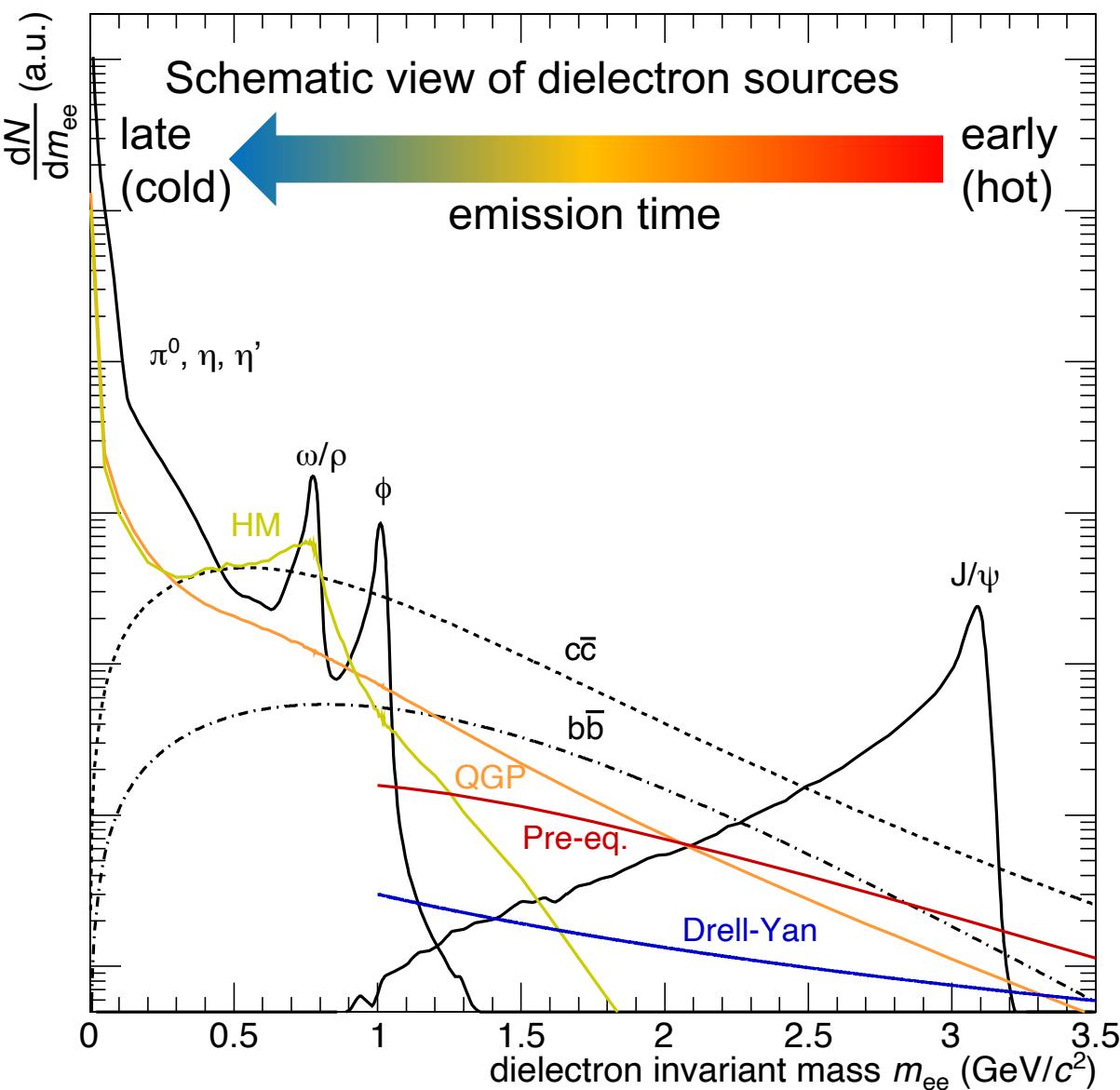


Physics motivation for dielectrons



- Drell-Yan
 - Sensitive to modification of PDF in nuclei
- Pre-equilibrium radiation
 - Reflects parton dynamics in pre-equilibrium and pre-hydro stage
- Thermal radiation
 - Thermodynamical properties and space-time evolution of **hot QCD matter** and **hadronic matter**

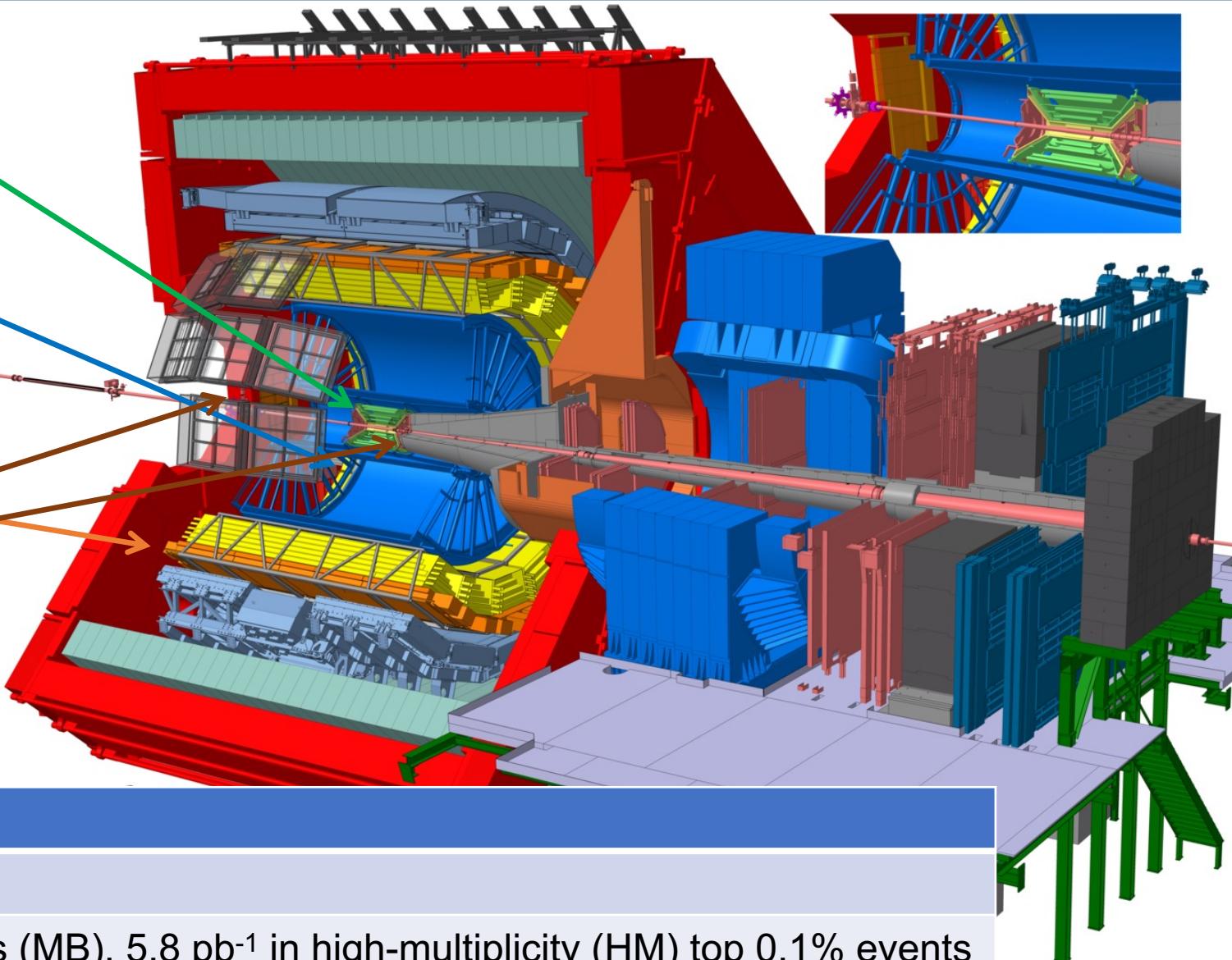
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 - Thermal radiation
 - Thermodynamical properties and space-time evolution of **hot QCD matter** and **hadronic matter**
 - Hadronic decays
 - Space-time evolution and medium interaction
- EM signal \equiv Excess beyond known hadronic sources

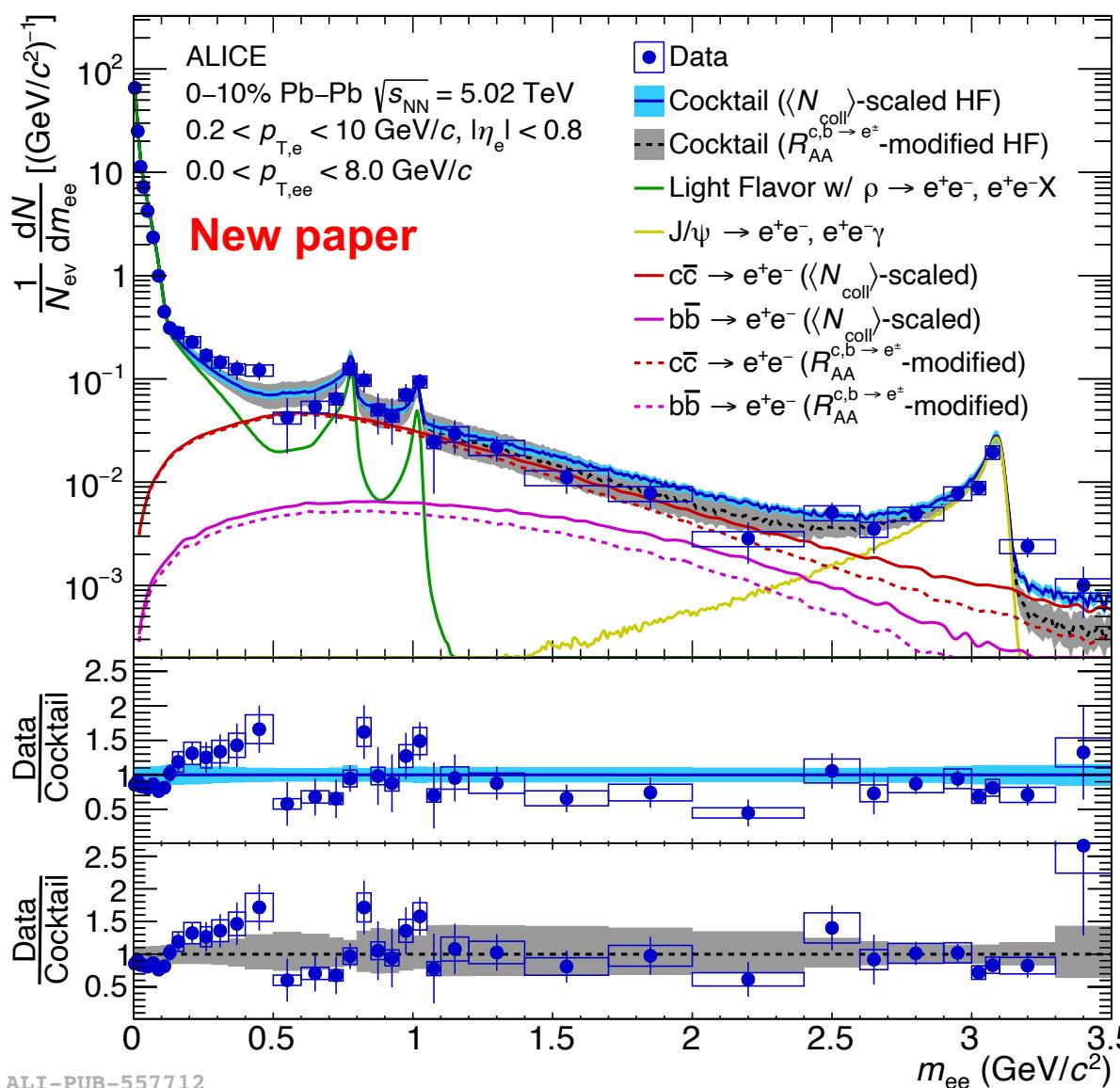
ALICE apparatus at the LHC

- Inner Tracking System (ITS)
 - Vertexing
 - Tracking
- Time Projection Chamber (TPC)
 - Tracking
 - Particle identification
- Time of Flight (TOF)
 - Particle identification
- V0 at forward rapidity
 - Triggering
 - Multiplicity determination

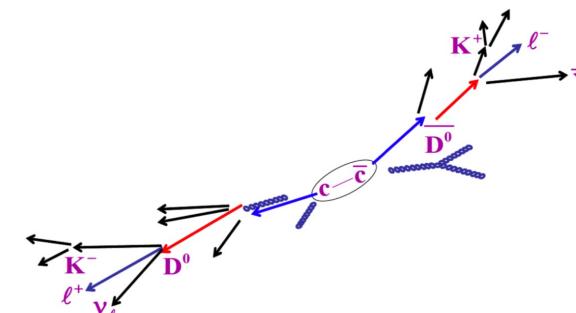


System	Analyzed luminosity
Pb-Pb at 5.02 TeV	$85 \mu b^{-1}$ in 0–10%
pp at 13 TeV	$30 nb^{-1}$ in minimum-bias (MB), $5.8 pb^{-1}$ in high-multiplicity (HM) top 0.1% events

Dielectron production in central Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$

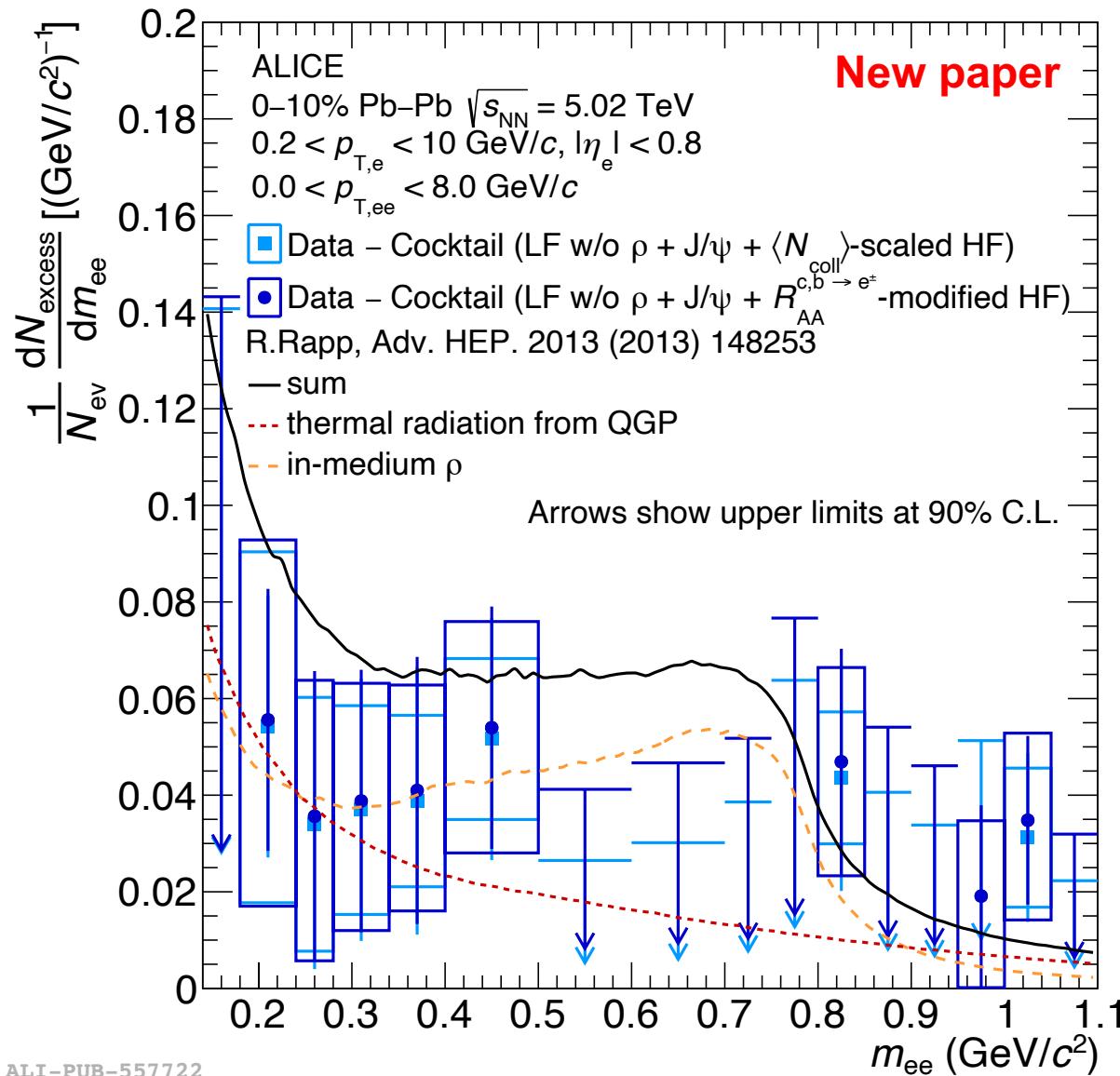


- Comparison to hadronic cocktails
 - N_{coll} -scaled heavy-flavor (HF) (PRC 102 (2020) 055204)
 - Modified HF by R_{AA} of c/b → e (PLB 804 (2020) 135377)



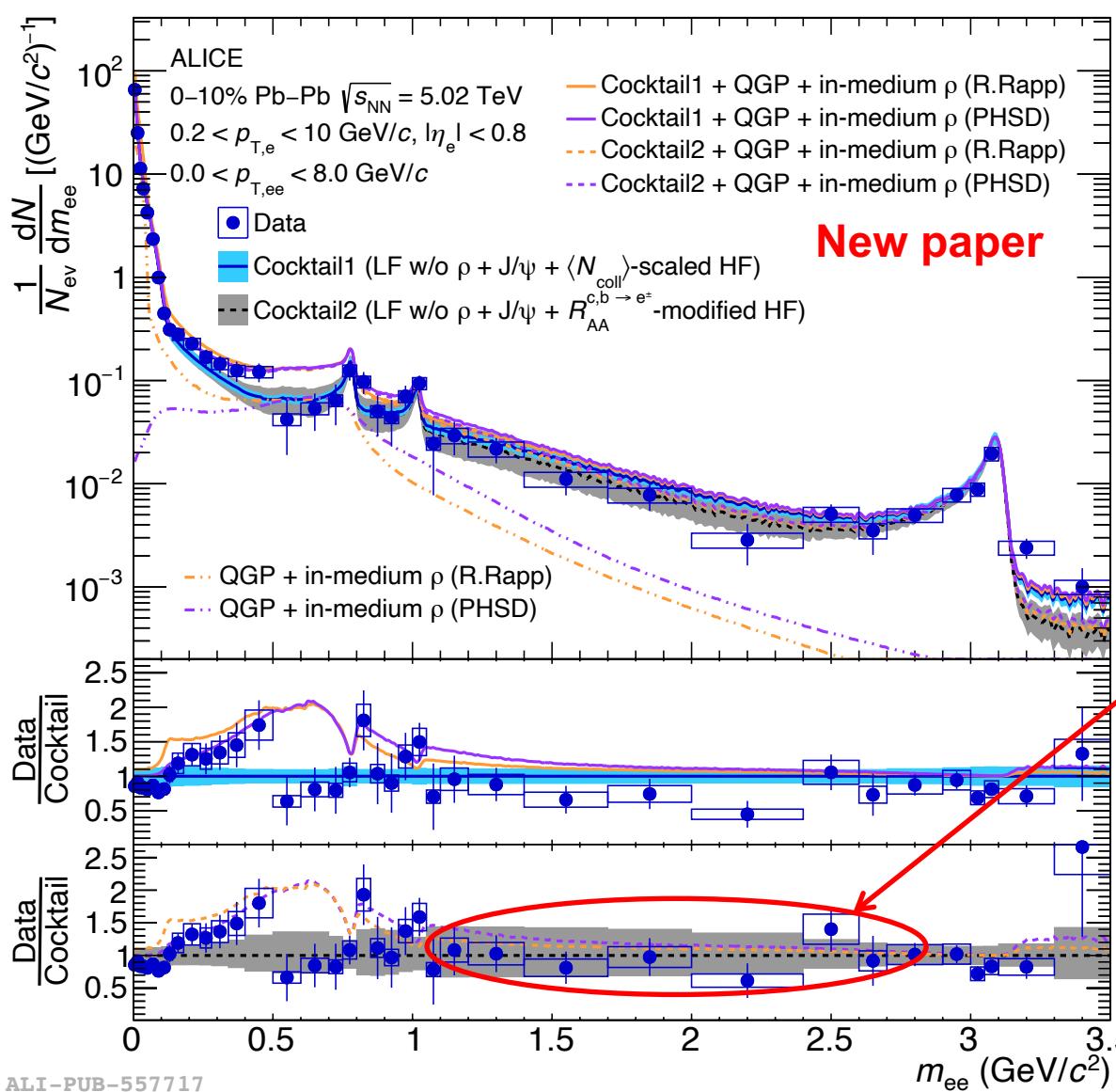
- R_{AA} -modified cocktail can describe data better in the intermediate mass region (IMR: $1.2 < m_{ee} < 2.6 \text{ GeV}/c^2$)
 - Including parton energy loss and shadowing (EPS09) for heavy quarks

Dielectron excess in central Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$

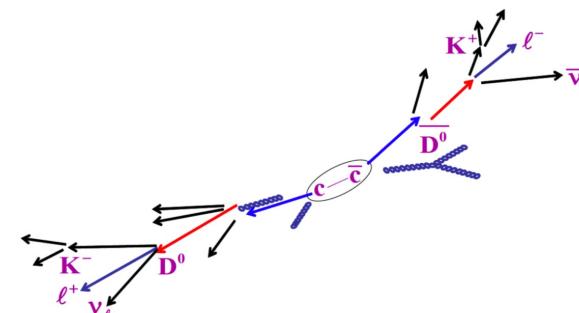


- 2 different HF cocktails subtracted
 - N_{coll} -scaled heavy-flavor (HF) (PRC 102 (2020) 055204)
 - Modified HF by R_{AA} of c/b $\rightarrow e$ (PLB 804 (2020) 135377)
- Significance of excess in $0.18 < m_{ee} < 0.5 \text{ GeV}/c^2$
 - 1.8σ w.r.t. N_{coll} -scaled cocktail
 - 1.5σ w.r.t. R_{AA} -modified cocktail
- Compared with sum of 2 contributions
 - ρ meson produced thermally in hot hadronic matter
 - Thermal radiation from QGP
 - Consistent with thermal radiation from hadronic matter via $\pi^+\pi^- \rightarrow \rho \rightarrow e^+e^-$ in $0.18 < m_{ee} < 0.5 \text{ GeV}/c^2$

Dielectron production in central Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$



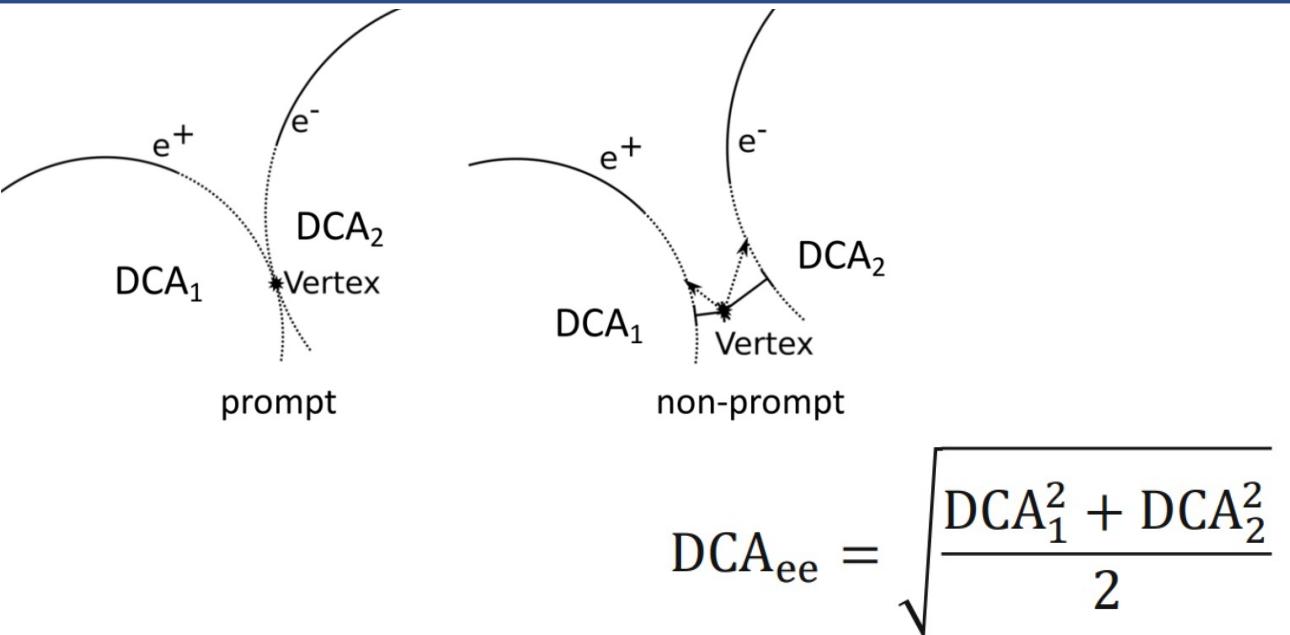
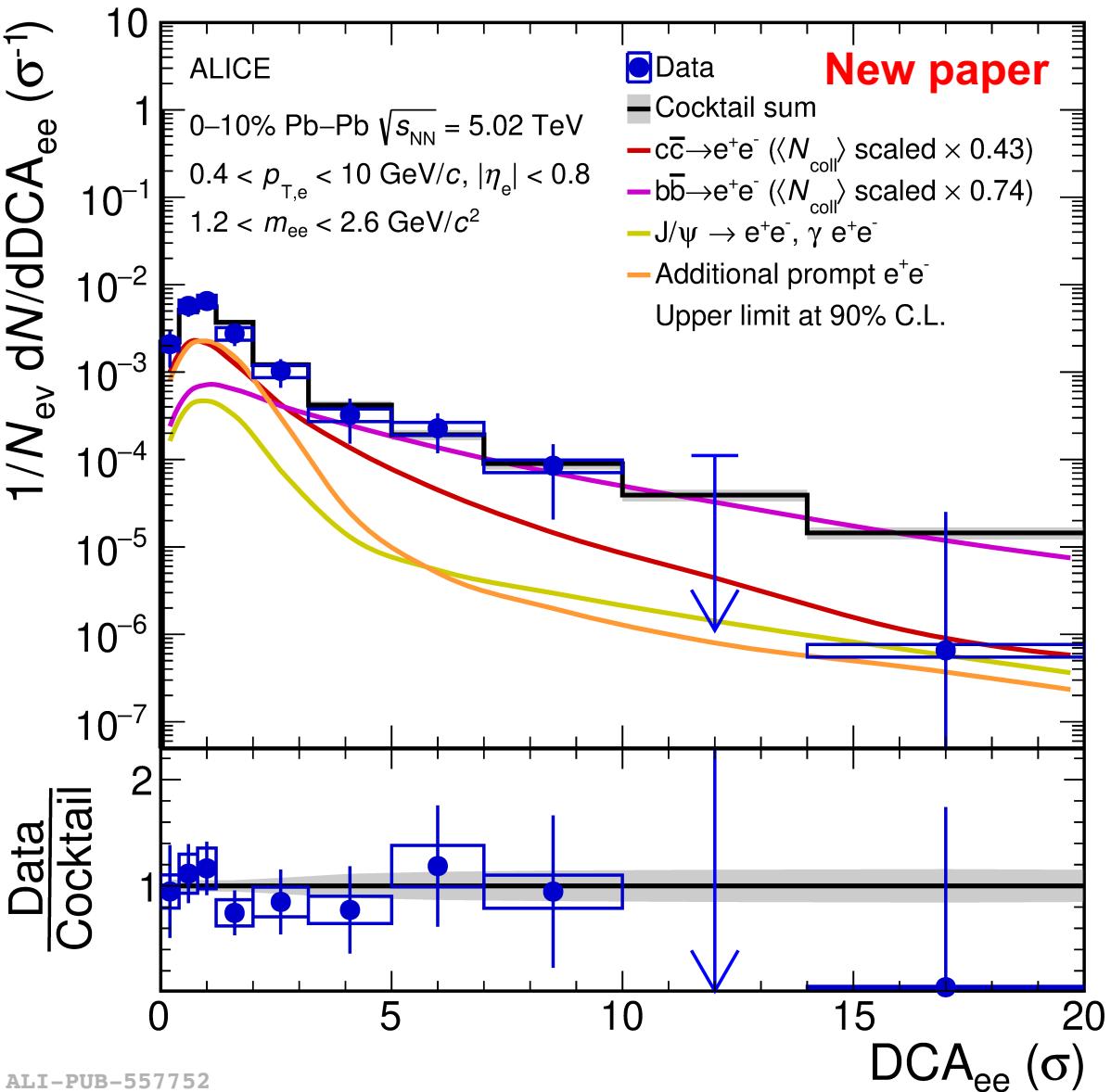
- Comparison to hadronic cocktails without ρ
 - N_{coll} -scaled heavy-flavor (HF) (PRC 102 (2020) 055204)
 - Modified HF by R_{AA} of $c/b \rightarrow e^-$ (PLB 804 (2020) 135377)



Signal region for thermal radiation from QGP
Large cocktail uncertainty due to extra modification
Need cocktail-independent method to extract QGP signal

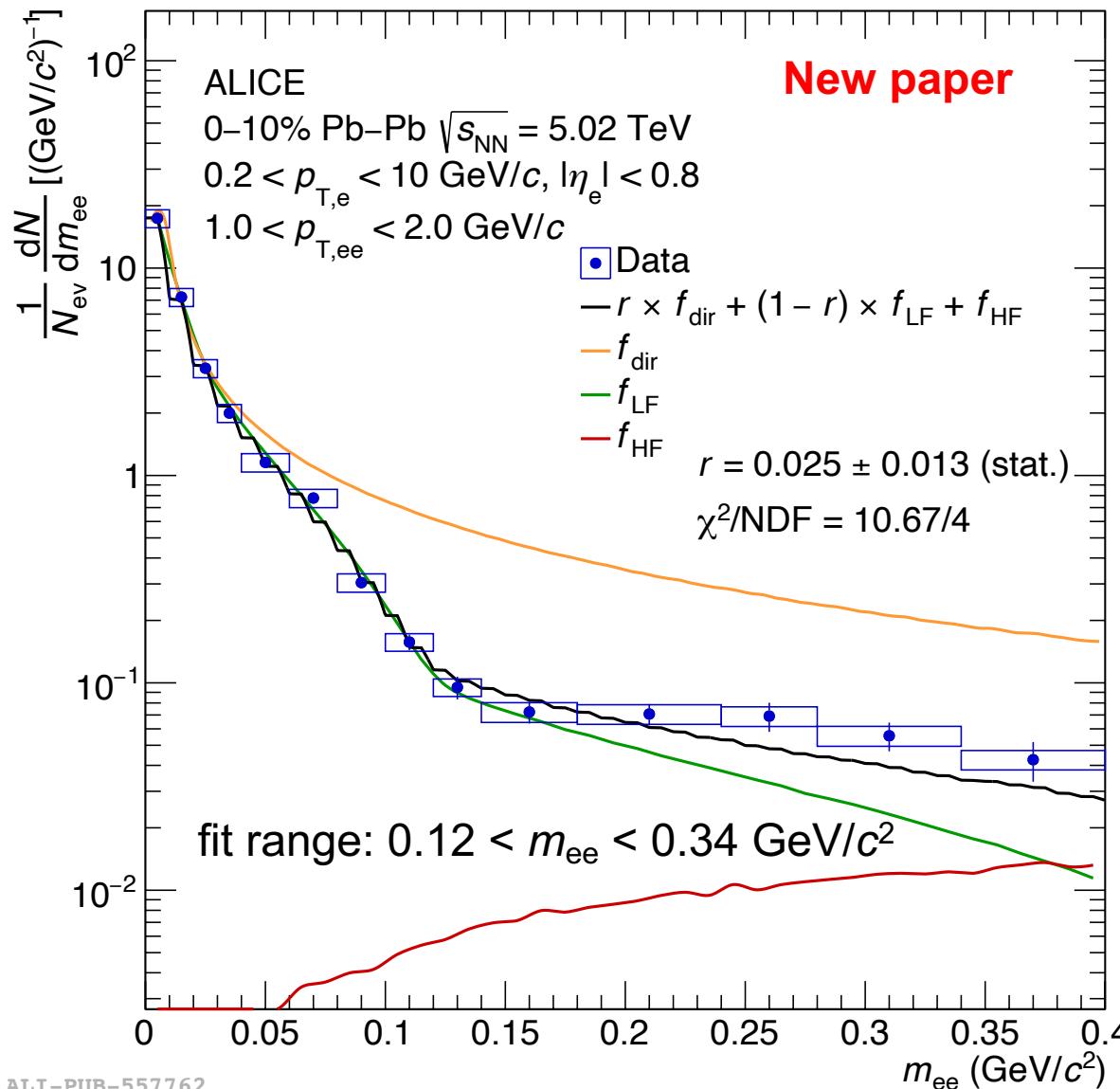
- Topological separation between QGP radiation (prompt) and HF (non-prompt, $c\tau \sim 150 \mu\text{m}$) in the IMR

First DCA_{ee} analysis in central Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$



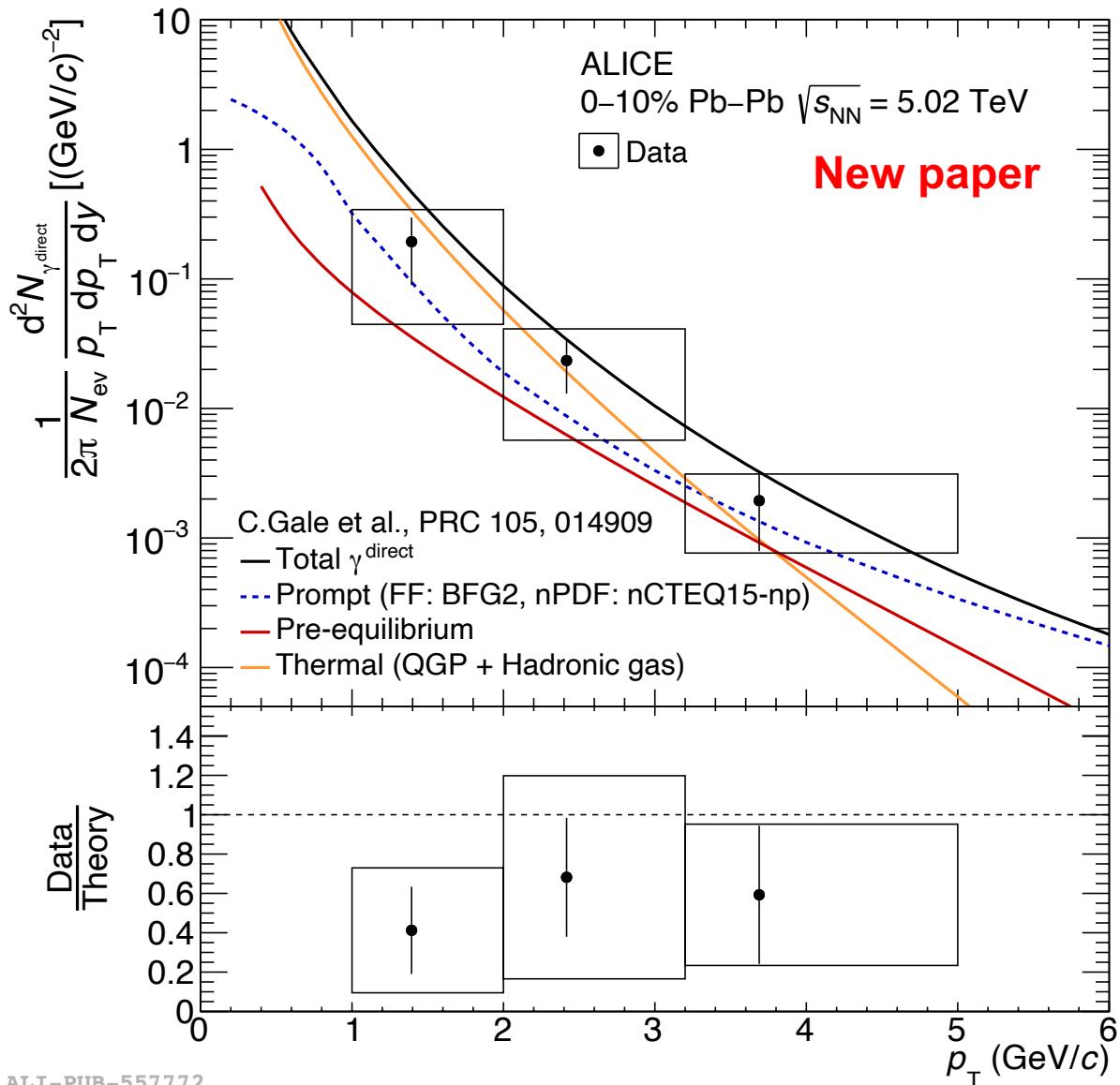
- First DCA_{ee} analysis in Pb-Pb collisions
 - Template fit in $1.2 < m_{ee} < 2.6 \text{ GeV}/c^2$
- Scaling factors to obtain the best fit are:
 - **Beauty:** $[0.74 \pm 0.24 \text{ (stat.)} \pm 0.12 \text{ (syst.)}] \times \langle N_{\text{coll}} \rangle$
 - **Charm:** $[0.43 \pm 0.40 \text{ (stat.)} \pm 0.22 \text{ (syst.)}] \times \langle N_{\text{coll}} \rangle$
 - **Thermal:** $3.17 \pm 3.81 \text{ (stat.)} \pm 0.35 \text{ (syst.)}$ w.r.t. Rapp model

Extracting direct photon signal from dielectron m_{ee} spectrum



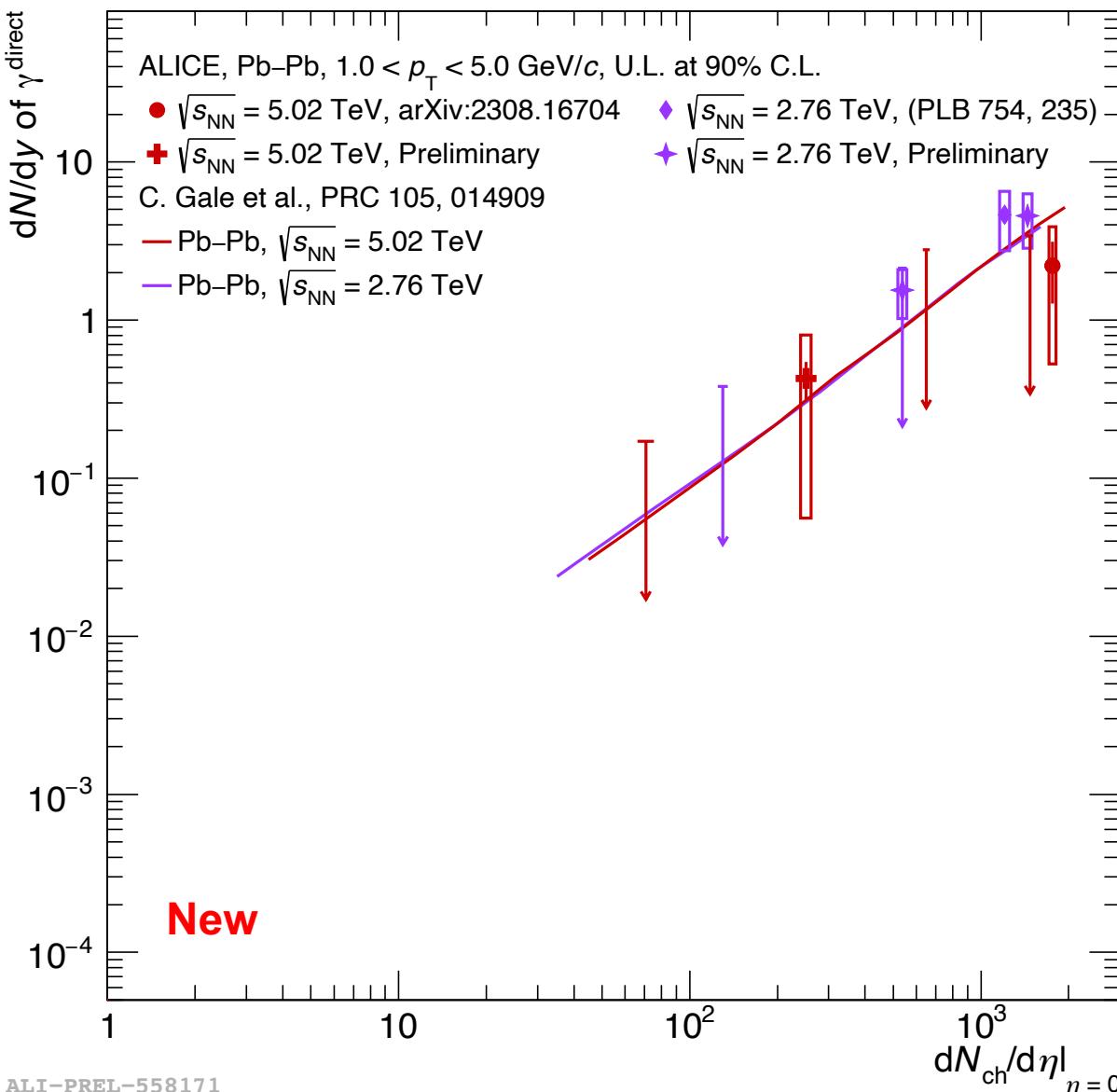
- Template fit with 3 components
 - Light-flavor (measured p_T spectra in ALICE and decayer)
 - Heavy-flavor (fixed to measured m_{ee} and $p_{T,ee}$ spectra)
 - Dielectrons associated with real photons by Kroll-Wada
- $$\frac{d^2N}{dm_{ee}dp_T} = \frac{2\alpha}{3\pi} \frac{1}{m_{ee}} \sqrt{1 - \frac{4m_e^2}{m_{ee}^2}} \left(1 + \frac{2m_e^2}{m_{ee}^2}\right) \frac{dN}{dp_T}$$
N.M. Kroll and Walter Wada, Phys. Rev. 98, 1355
- $dN/dm_{ee} = r \times f_{\text{dir}} + (1 - r) \times f_{\text{LF}} + f_{\text{HF}}$
- r : only free parameter for direct photon fraction
- Advantage : select m_{ee} window above π^0 mass
 - 85% of decay photons is from π^0 .
 - Main background for direct photons: $\eta \rightarrow ee\gamma$

Direct photon production in central Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$



- First direct photon measurement via dielectrons in Pb–Pb collisions with ALICE
- Compared with the latest model
 - Including photons from all stages:
Prompt + **pre-equilibrium** + **thermal photons**
 - Describes ALICE data within experimental uncertainties
 - Tend to be upper edge of uncertainty

Direct photon dN/dy vs. charged-particle multiplicity

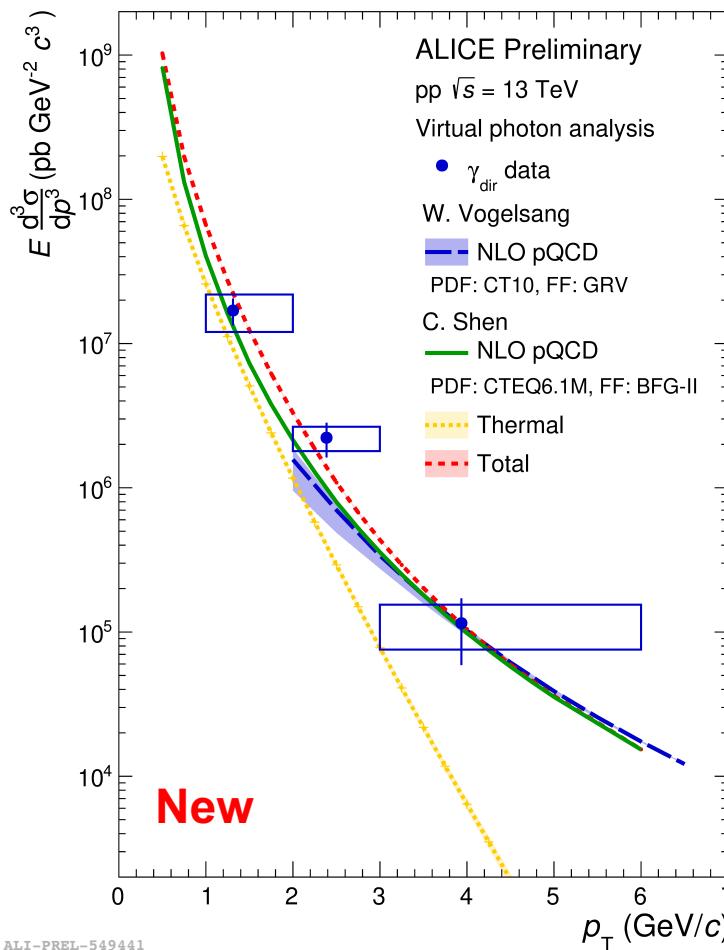


- Latest model describes multiplicity dependence of direct photon yields within experimental uncertainties.
 - Photons from all stages (PRC 105 014909)
See [real direct photon productions in ALICE](#) by Carolina Arata on Sep.5th

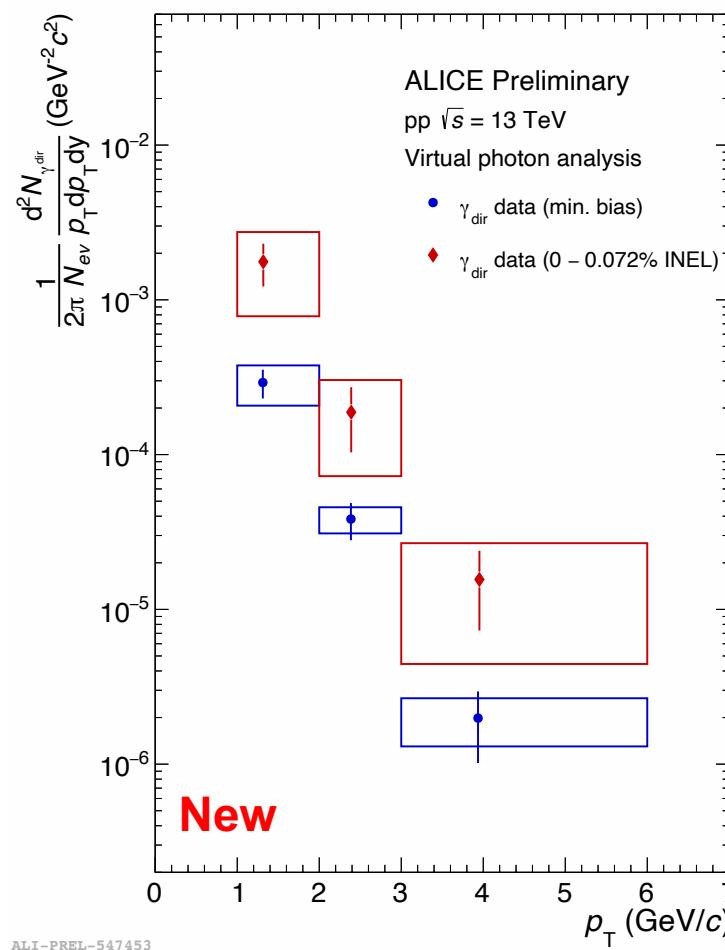
What about smaller colliding systems?
ALICE also measured direct photons in pp at 13 TeV.

Search for thermal radiation in small systems

minimum-bias pp collisions

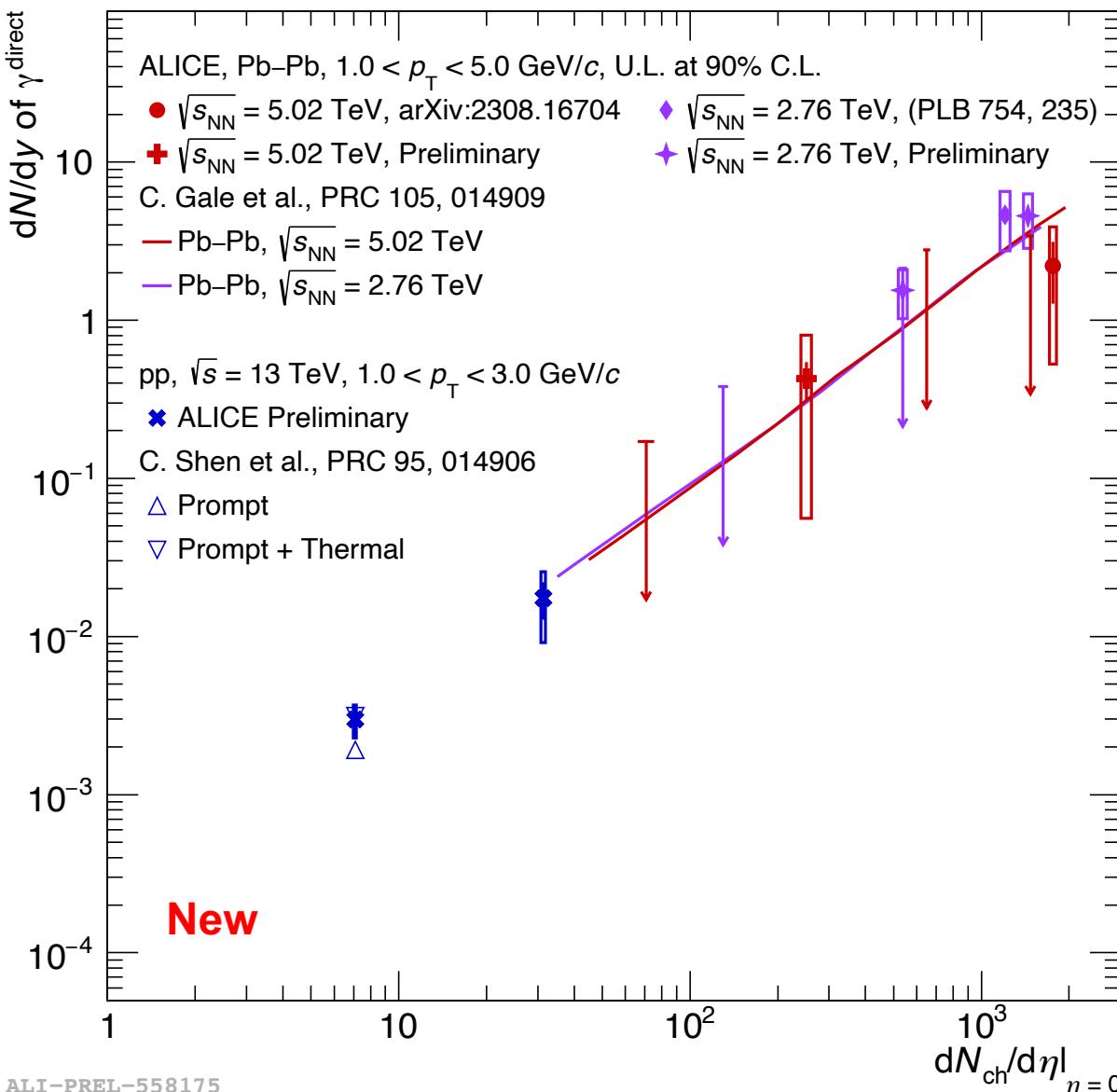


minimum-bias pp collisions high-multiplicity pp collisions



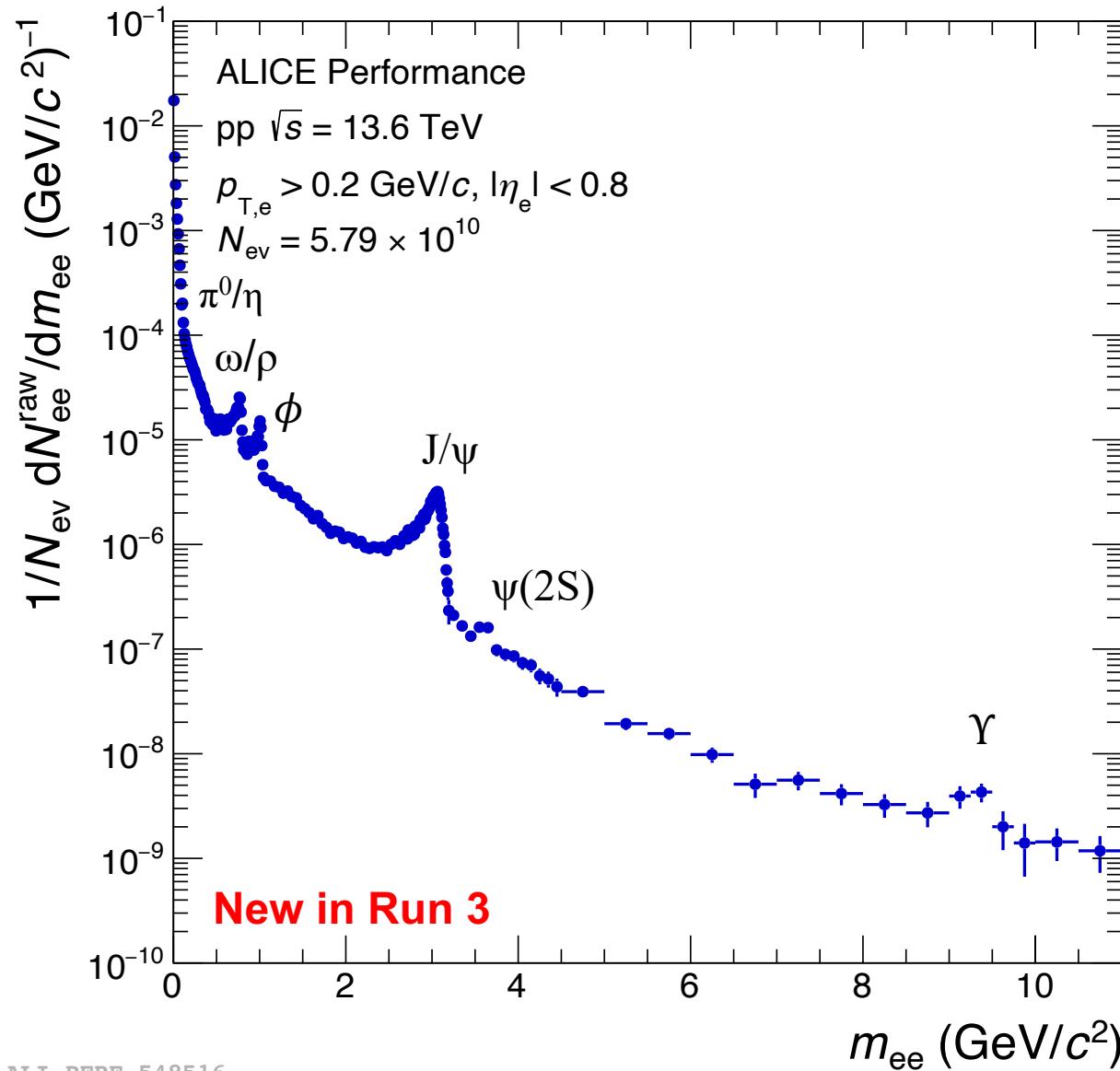
- First measurement of direct photons in small systems at low p_T in ALICE
 - Direct photon fraction $r = 0.01 \sim 0.03$
- Data can be reproduced by both **prompt only** and **prompt + thermal radiation** in MB pp collisions.
- Significant increase of direct photon yields in high-multiplicity pp collisions
 - Challenging to calculate photon productions in HM pp collisions

Direct photon dN/dy vs. charged-particle multiplicity



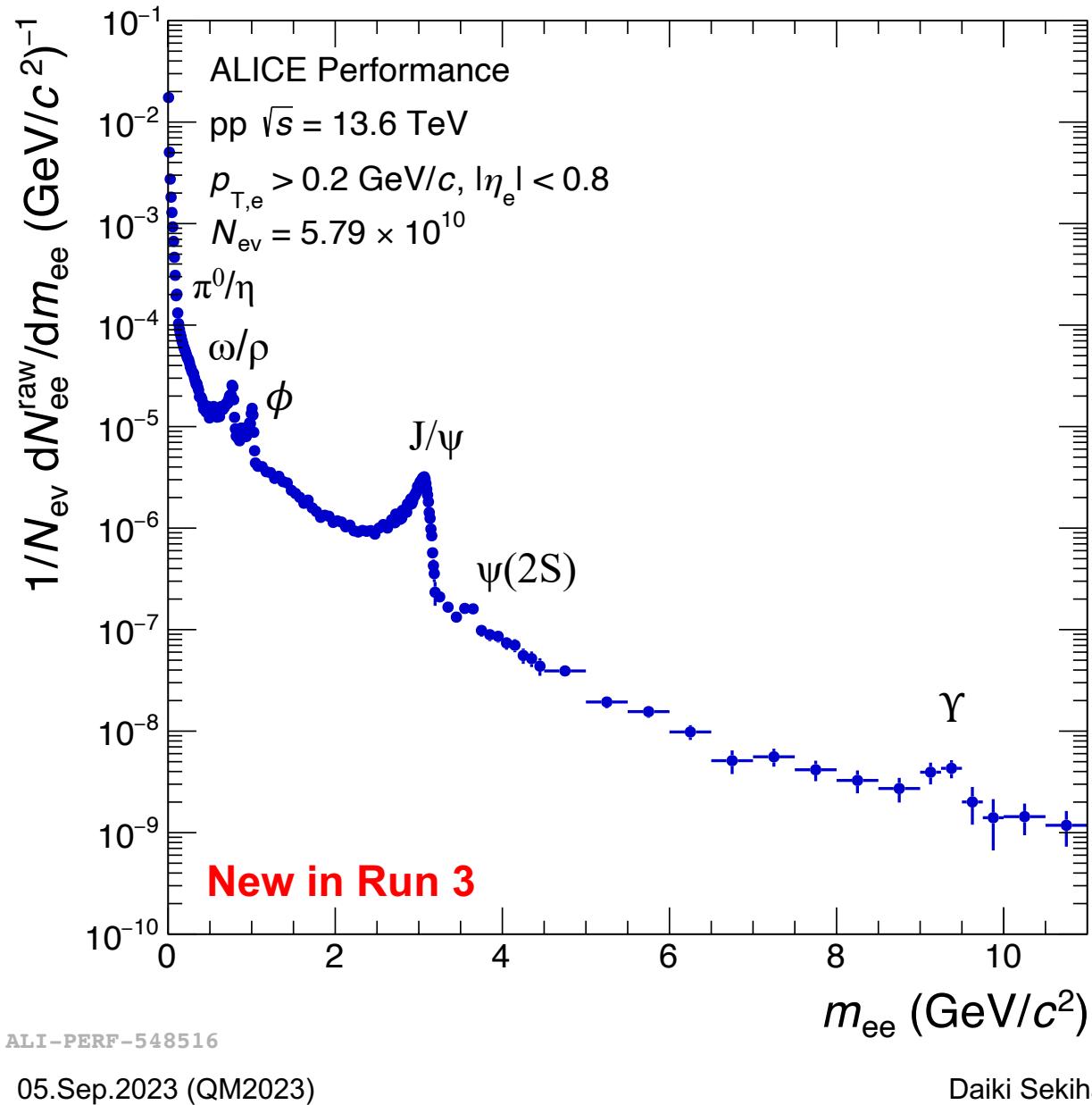
- Latest model describes multiplicity dependence of direct photon yields within experimental uncertainties.
 - Photons from all stages (PRC 105 014909)
- New data points in pp at 13 TeV via dielectrons
 - $dN_{\text{ch}}/\text{d}\eta = 7$ (MB) and 30 (HM)
 - Crucial inputs for theoretical developments

First raw m_{ee} spectrum in Run 3



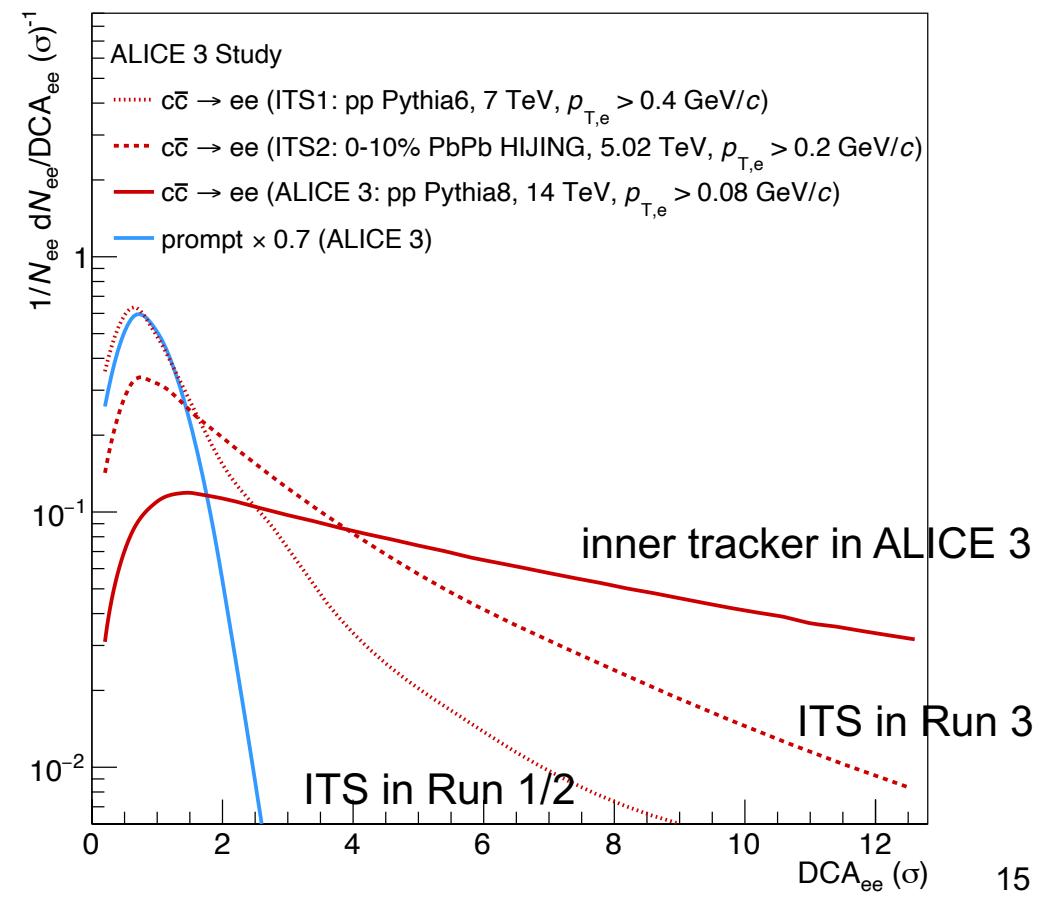
- ALICE recorded huge statistics in 2022 and 2023.
 - 0.97 pb^{-1} analyzed for the left plot
 - 0.03 pb^{-1} in Run 2
- Clear dielectron signals in pp at 13.6 TeV
 - π^0 and η Dalitz decays
 - $\omega/\rho/\phi$ peak
 - J/ψ and $\psi(2S)$ peak
 - γ peak
 - HF continuum in the intermediate and high mass regions

First raw m_{ee} spectrum in Run 3

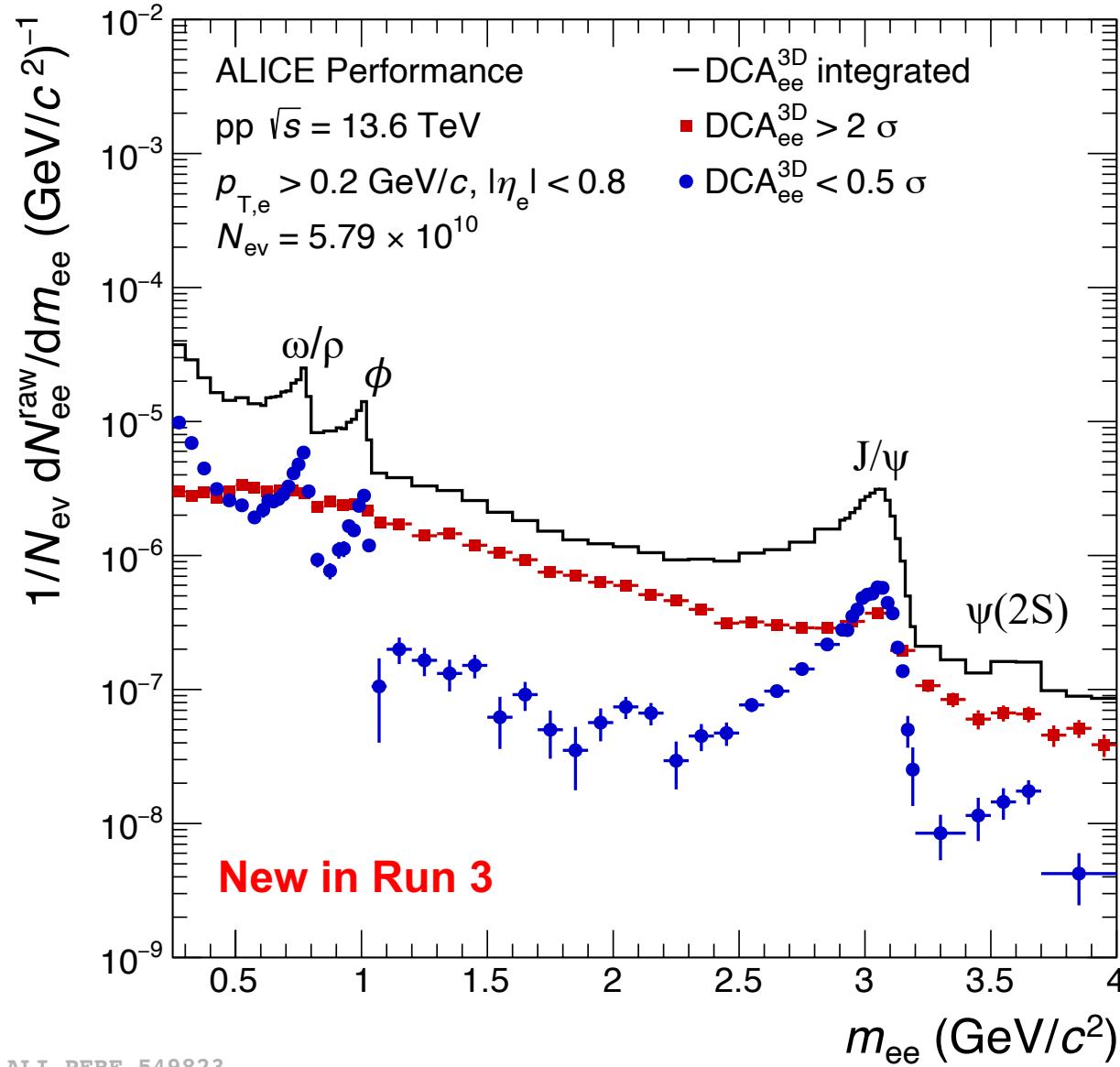


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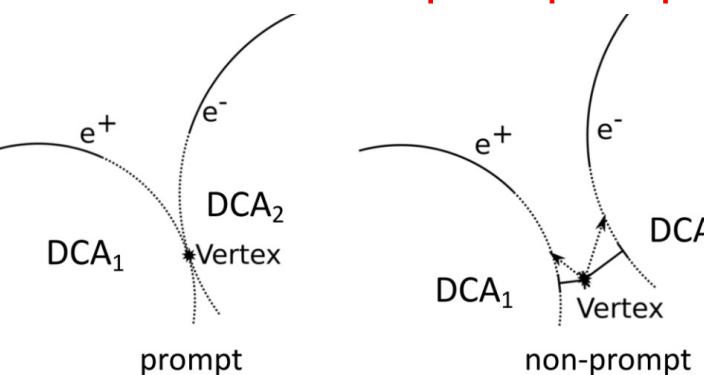
DCA_{ee} spectra with new ITS



Separation power with DCA_{ee} in Run 3



- ALICE recorded huge statistics in 2022 and 2023.
 - 0.97 pb⁻¹ analyzed for the left plot
 - 0.03 pb⁻¹ in Run 2
- Strong separation power of DCA_{ee}
 - Prompt dielectrons with DCA_{ee} < 0.5 σ
 - LF + prompt J/ ψ + possible thermal radiation
 - Non-prompt dielectrons with DCA_{ee} > 2.0 σ
 - HF + non-prompt J/ ψ



$$DCA_{ee} = \sqrt{\frac{DCA_1^2 + DCA_2^2}{2}}$$

Summary

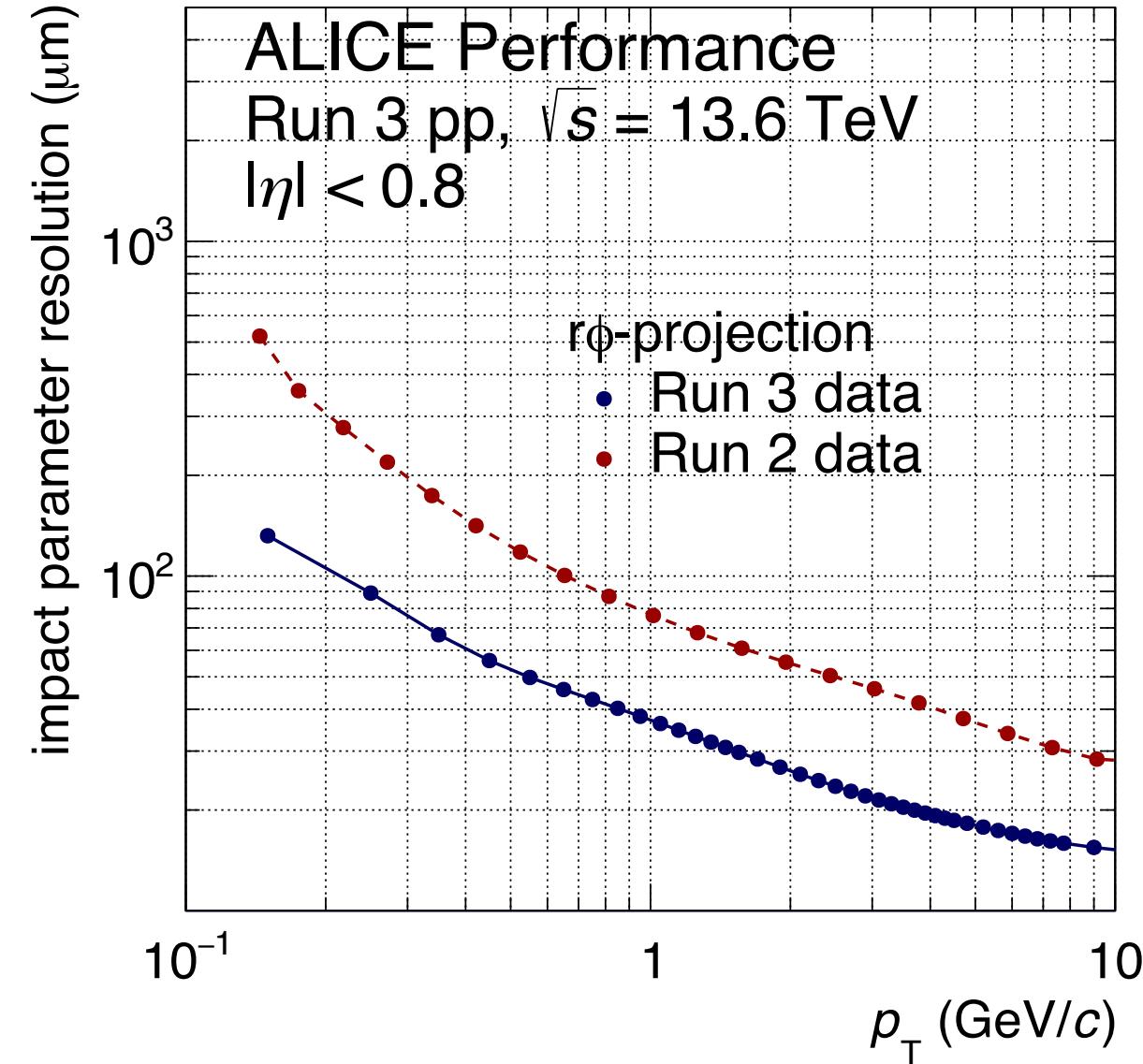
- ALICE measured $\gamma^* \rightarrow e^+e^-$ to study early stage of hot and dense QCD matter.
 - First direct photon results from small to large systems via dielectrons in ALICE
 - Crucial inputs for theoretical developments in HM pp collisions
 - The latest model including photons from all stages describes Pb–Pb data.
 - First DCA_{ee} analysis to separate dielectrons from heavy-flavor and thermal radiation
- Dielectron results become even more exciting in Run 3, 4 and beyond.
 - Expected 200 pb⁻¹ in pp at $\sqrt{s} = 13.6$ TeV and 7 nb⁻¹ in Pb–Pb at $\sqrt{s_{NN}} = 5.36$ TeV in Run 3
 - Precise vertexing to separate electrons from heavy-flavor hadrons and thermal radiation

[Dielectron in ALICE 3](#)
Poster by Horst Sebastian Scheid

[Topological separation of dielectron signals with machine learning](#)
Poster by Jerome Jung

backup

Impact parameter resolution



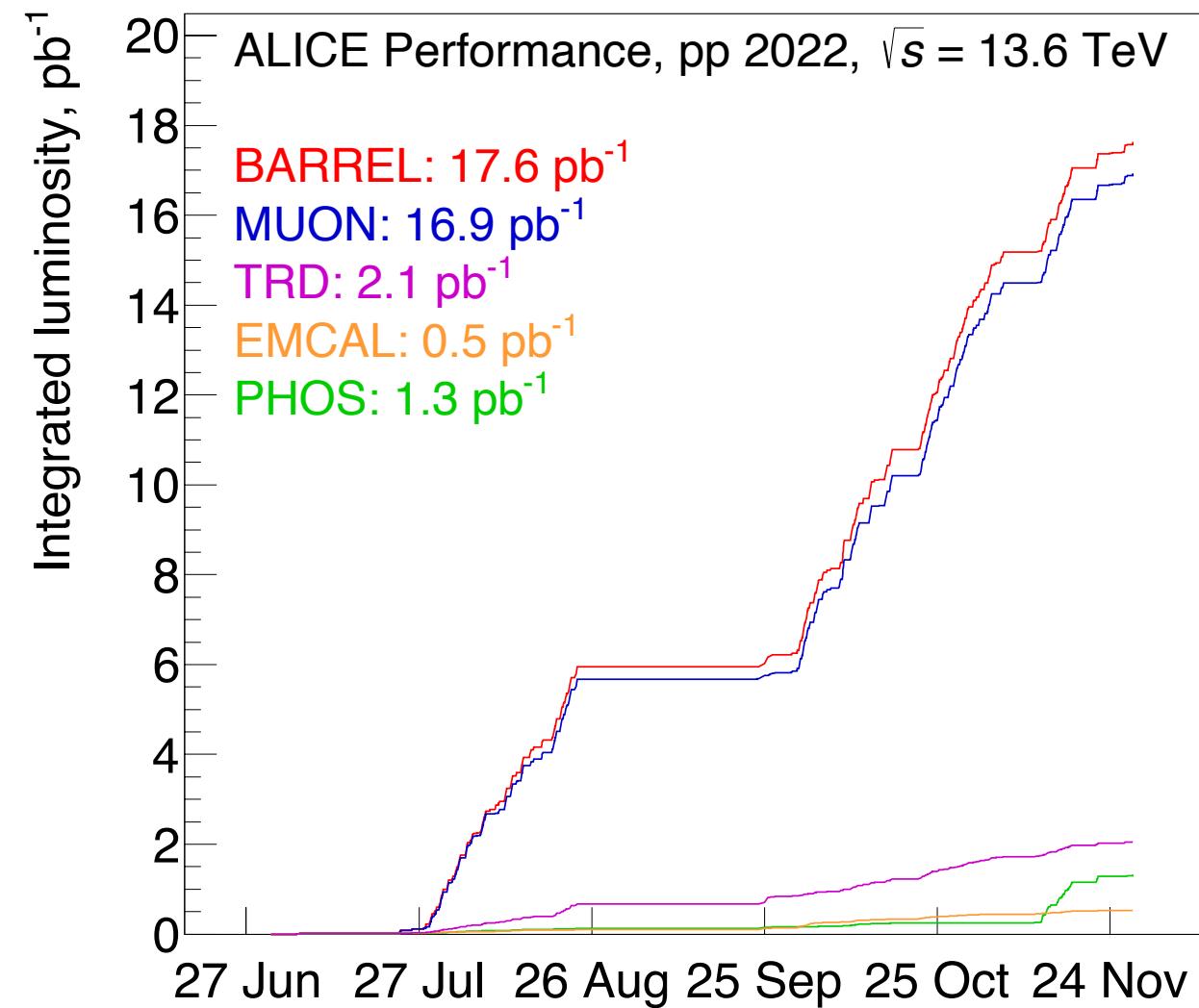
ALI-PERF-558822

05.Sep.2023 (QM2023)

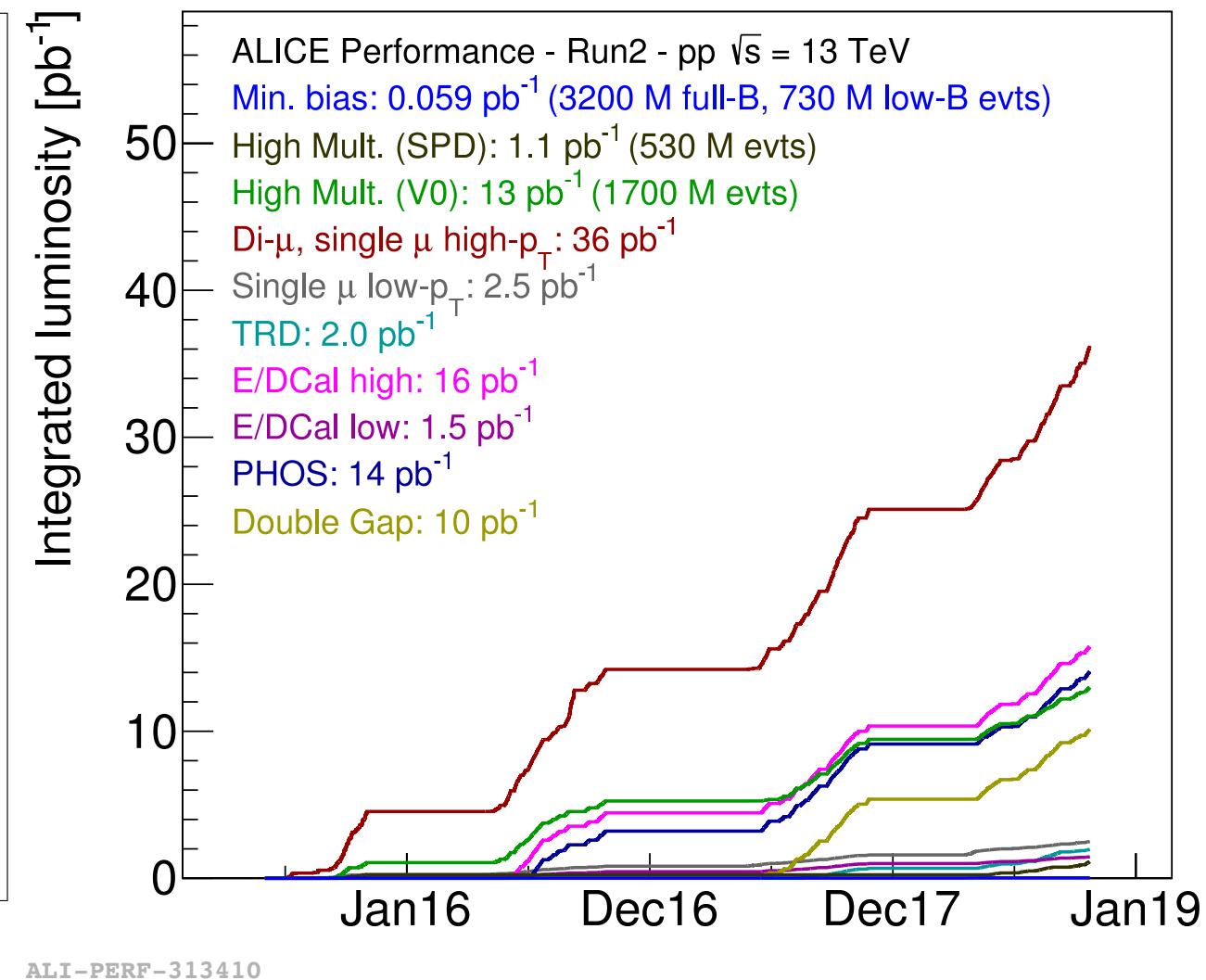
Daiki Sekihata (CNS, U.Tokyo)

19

Integrated luminosity in 2022

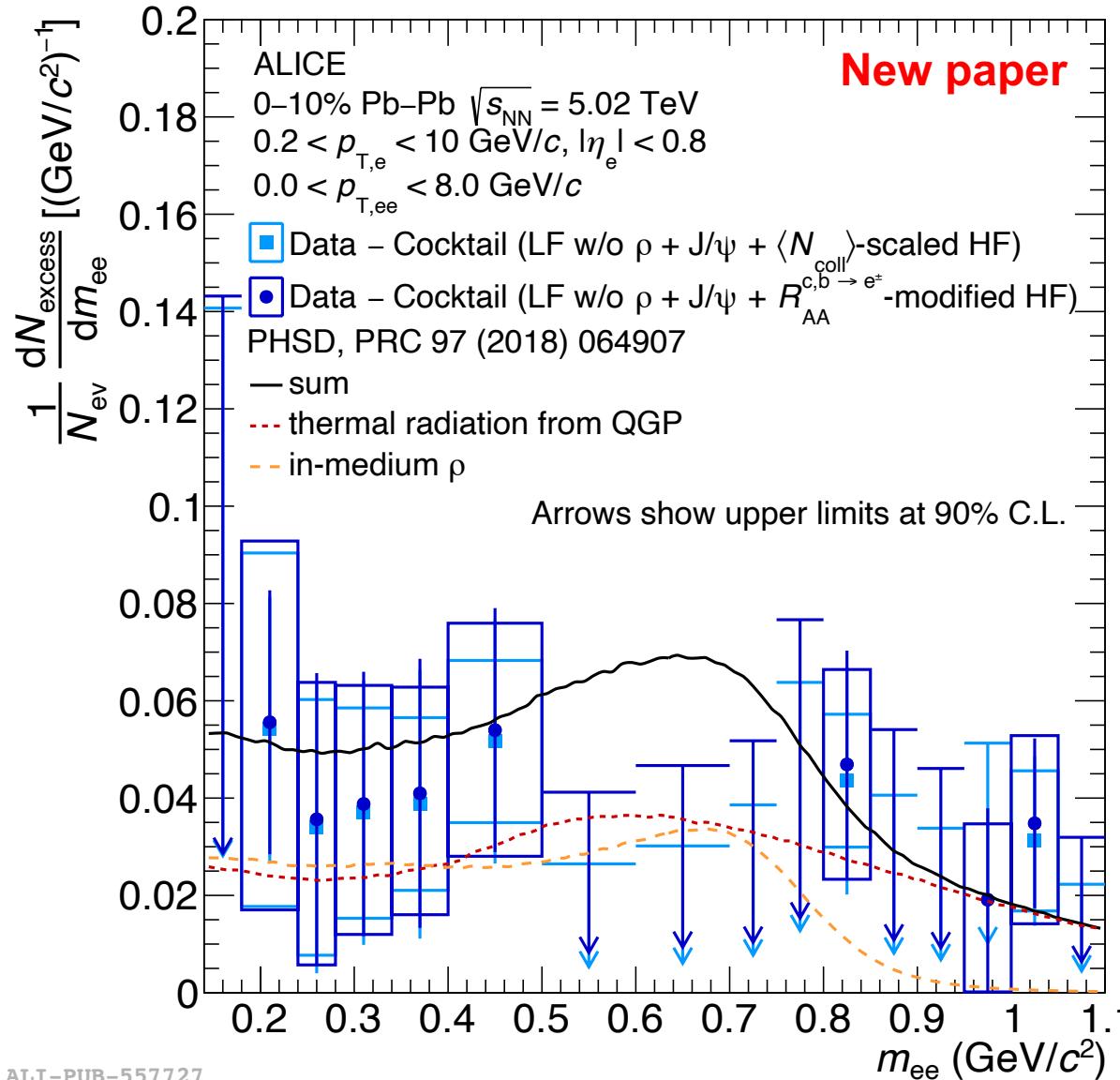


ALI-PERF-542867



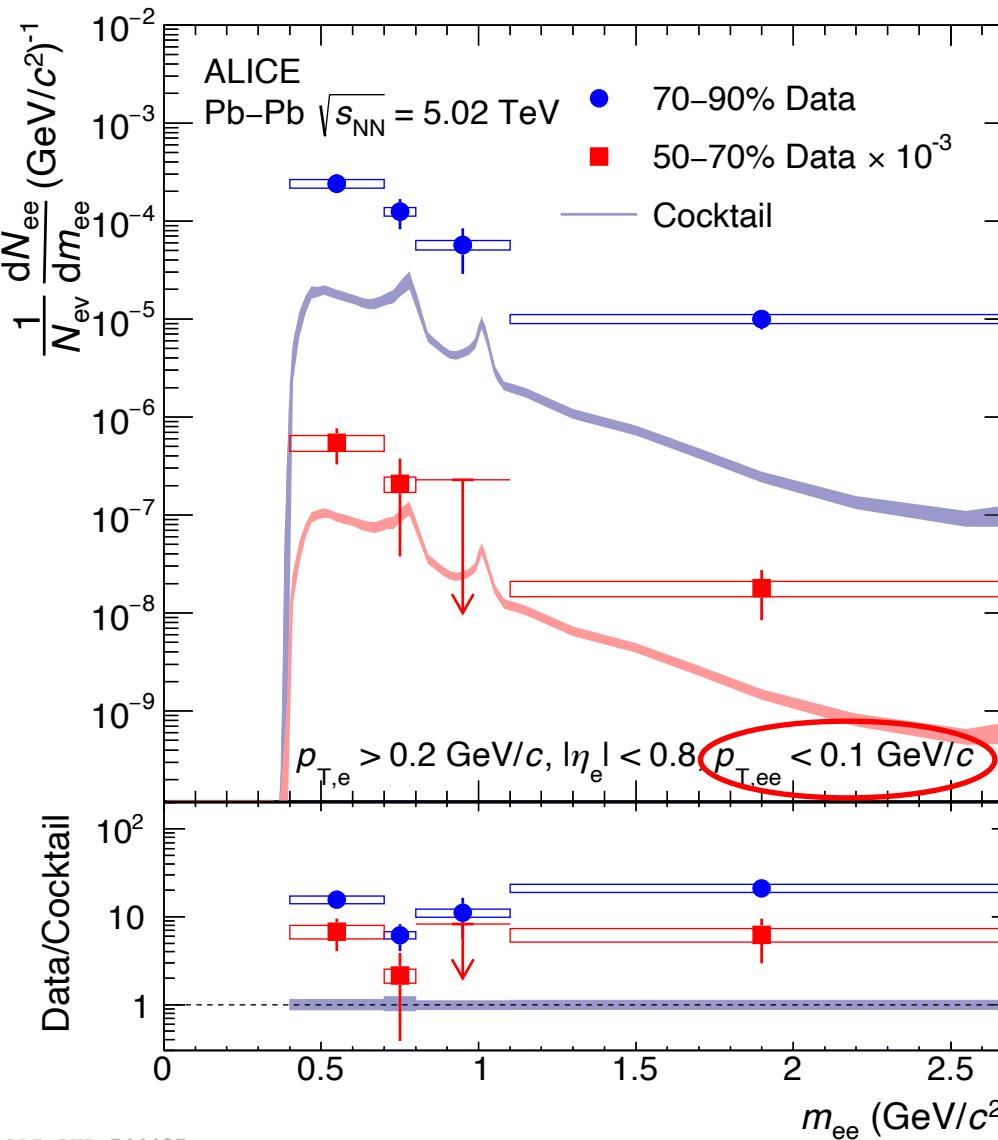
ALI-PERF-313410

Dielectron excess in central Pb-Pb collisions at 5.02 TeV



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Soft dielectron excess in peripheral Pb-Pb collisions at 5.02 TeV



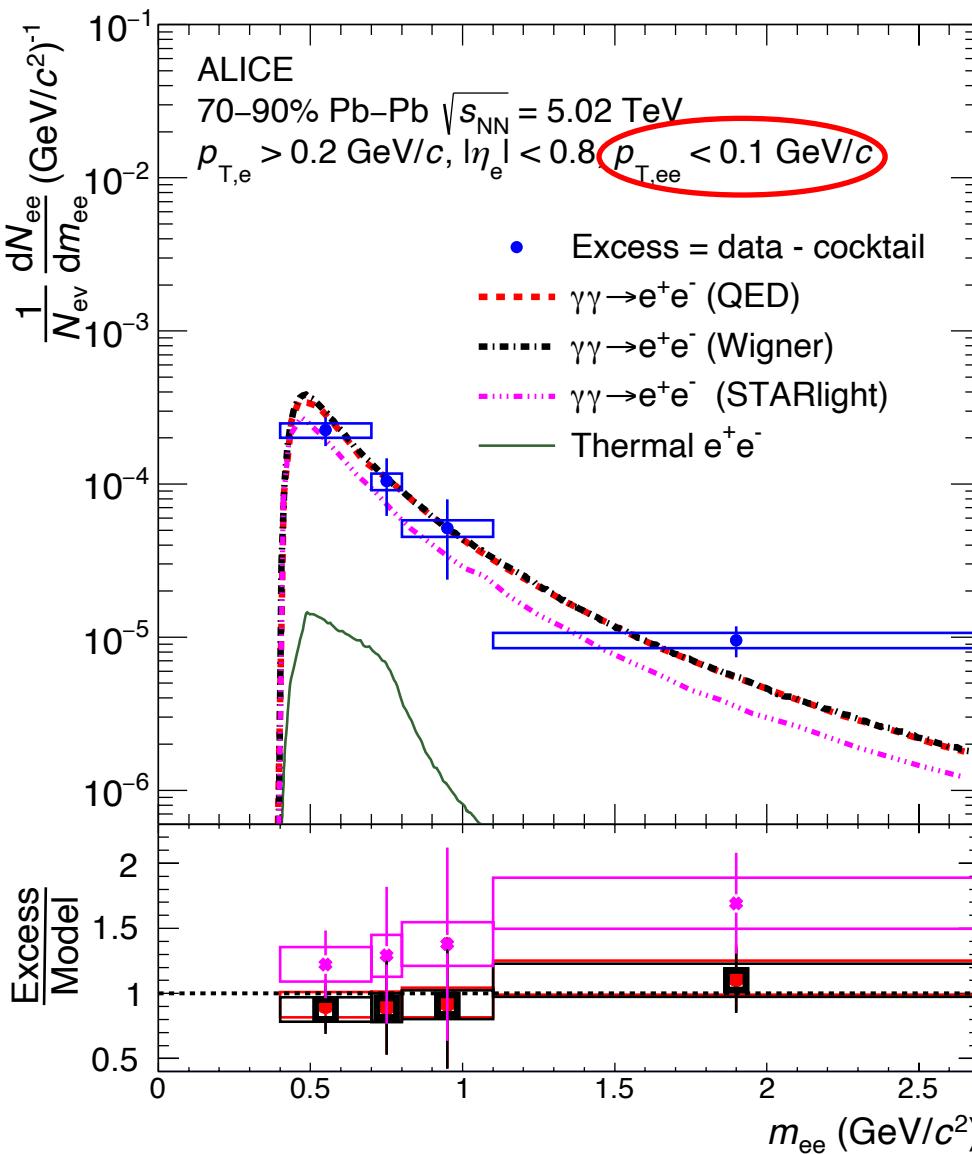
- Excess beyond hadronic cocktail

- Larger significance in **peripheral** collisions

[JHEP 06 \(2023\) 024](#)

ALI-PUB-544495

Soft dielectron excess in peripheral Pb-Pb collisions at 5.02 TeV



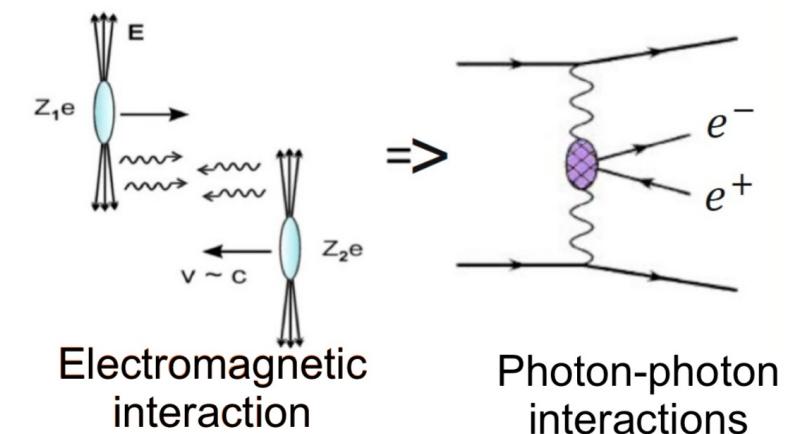
- Excess beyond hadronic cocktail
 - Larger significance in peripheral collisions
- Excess compared with photon-photon interaction
 - All models can reproduce the data within uncertainties.
 - STARlight tends to underestimate the data

[JHEP 06 \(2023\) 024](#)

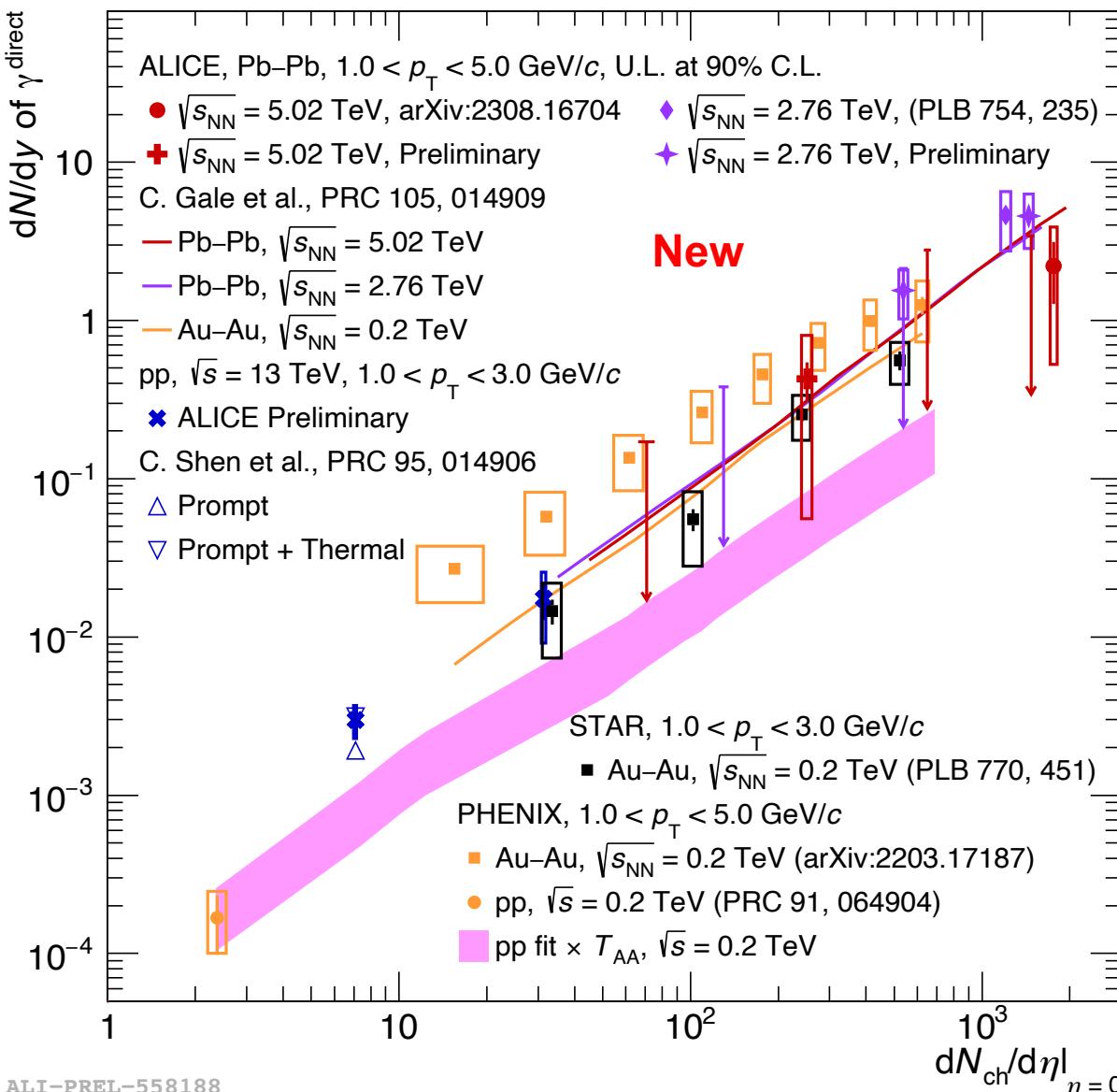
QED : Leading-order QED

Wigner : Wigner functions in momentum and impact-parameter space

STARlight : Equivalent photon approximation approach



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