SQM2022
The 20th International Conference on Strangeness in Quark Matter
13-17 June 2022 Busan, Republic of Korea

Thermal radiation and direct photon production in Pb–Pb and pp collisions with dielectrons in ALICE

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Introduction

pp

- Vacuum baseline for p—Pb and Pb—Pb
- Search for new phenomena in high-multiplicity events ← **New**

p–Pb

- Cold nuclear matter (CNM) effect

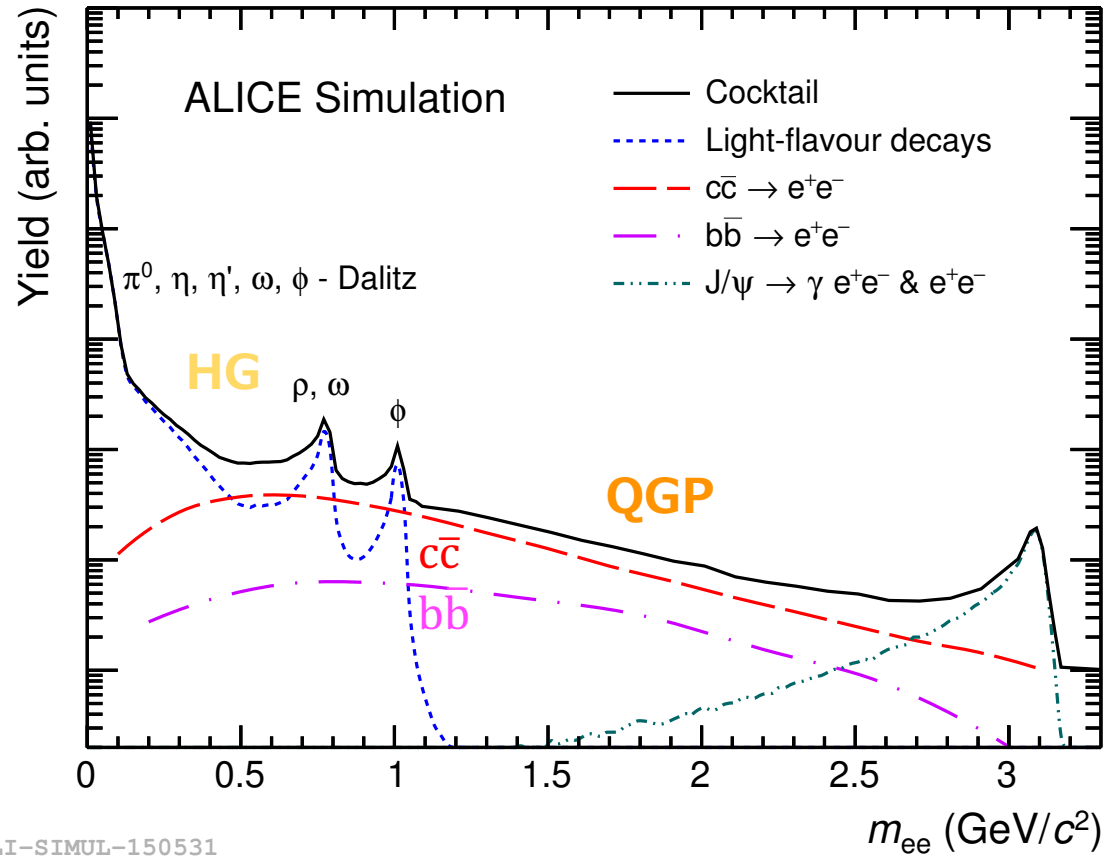
PRC 102 (2020) 055204

- Search for new phenomena in central collisions

Pb–Pb

- Thermal Radiation from QGP and HG ← **New**
- Chiral symmetry restoration via ρ modification
- Coherent photoproduction via $\gamma\gamma \rightarrow e^- e^+$

Parallel talk, Laure Massacrier, 13.Jun



Thermal radiation can be addressed

- m_{ee} and DCA_{ee} analysis at intermediate mass region

(IMR: $1.1 < m_{ee} < 2.7$ GeV/c^2)

- Direct photon analysis via virtual-photon γ^* analysis ($m_{ee} \rightarrow 0$)

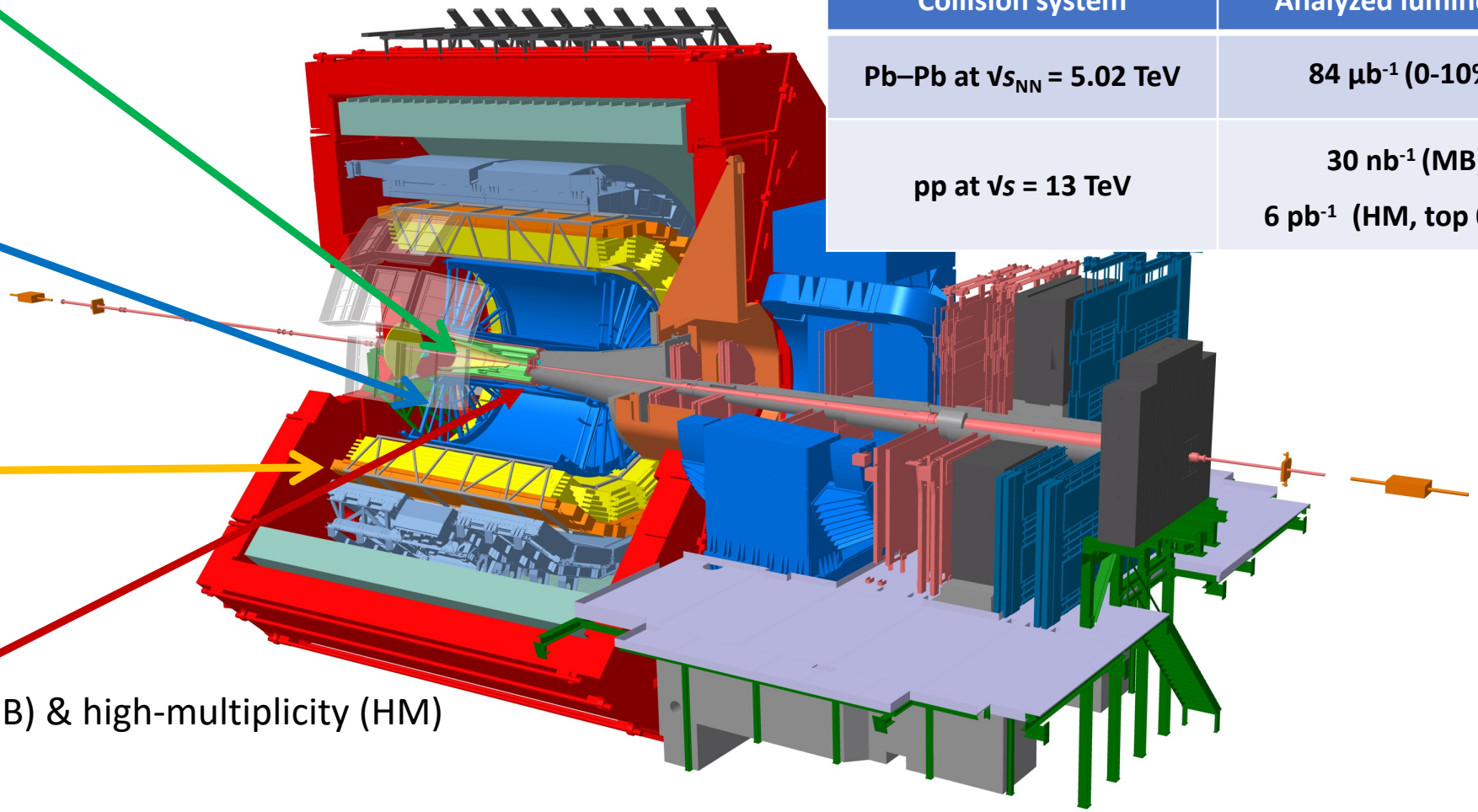
ALICE experiment

Inner Tracking System
- Vertexing
- Tracking
- Particle identification

Time Projection Chamber
- Tracking
- Particle identification

Time-Of-Flight
- Particle identification

V0 scintillation counter
- Trigger : minimum-bias (MB) & high-multiplicity (HM)
- Multiplicity determination
- Centrality estimation



Analyzed datasets in this talk

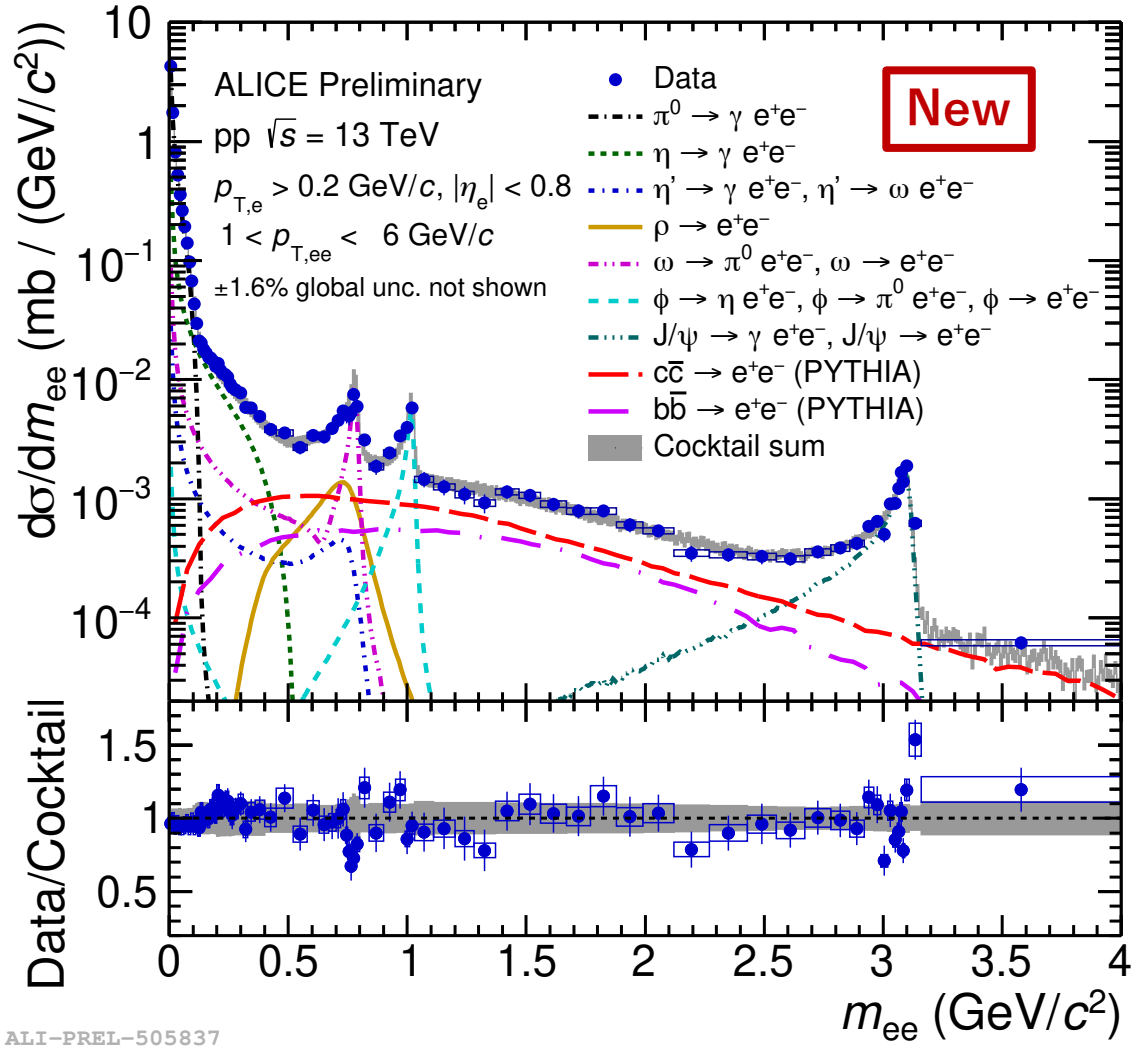
Collision system	Analyzed luminosity
Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV	84 μb^{-1} (0-10%)
pp at $\sqrt{s}$ = 13 TeV	30 nb^{-1} (MB) 6 pb^{-1} (HM, top 0.1%)

pp at √s = 13 TeV in minimum bias events - Invariant mass spectrum

- Full Run 2 datasets analyzed
  - Factor 3.8 in MB compared to previous publication
    Phys. Lett. B 788 (2019) 505
- π^0 and η measured at √s = 13 TeV in MB
  Parallel talk, Adrian Nassirpour 13.Jun

→ Reduced the sys. unc. of the hadronic cocktail

- Cocktail reproduces data $p_{T,ee}$ > 1 GeV/c within uncertainty.



pp at √*s* = 13 TeV in high-multiplicity events - Invariant mass spectrum

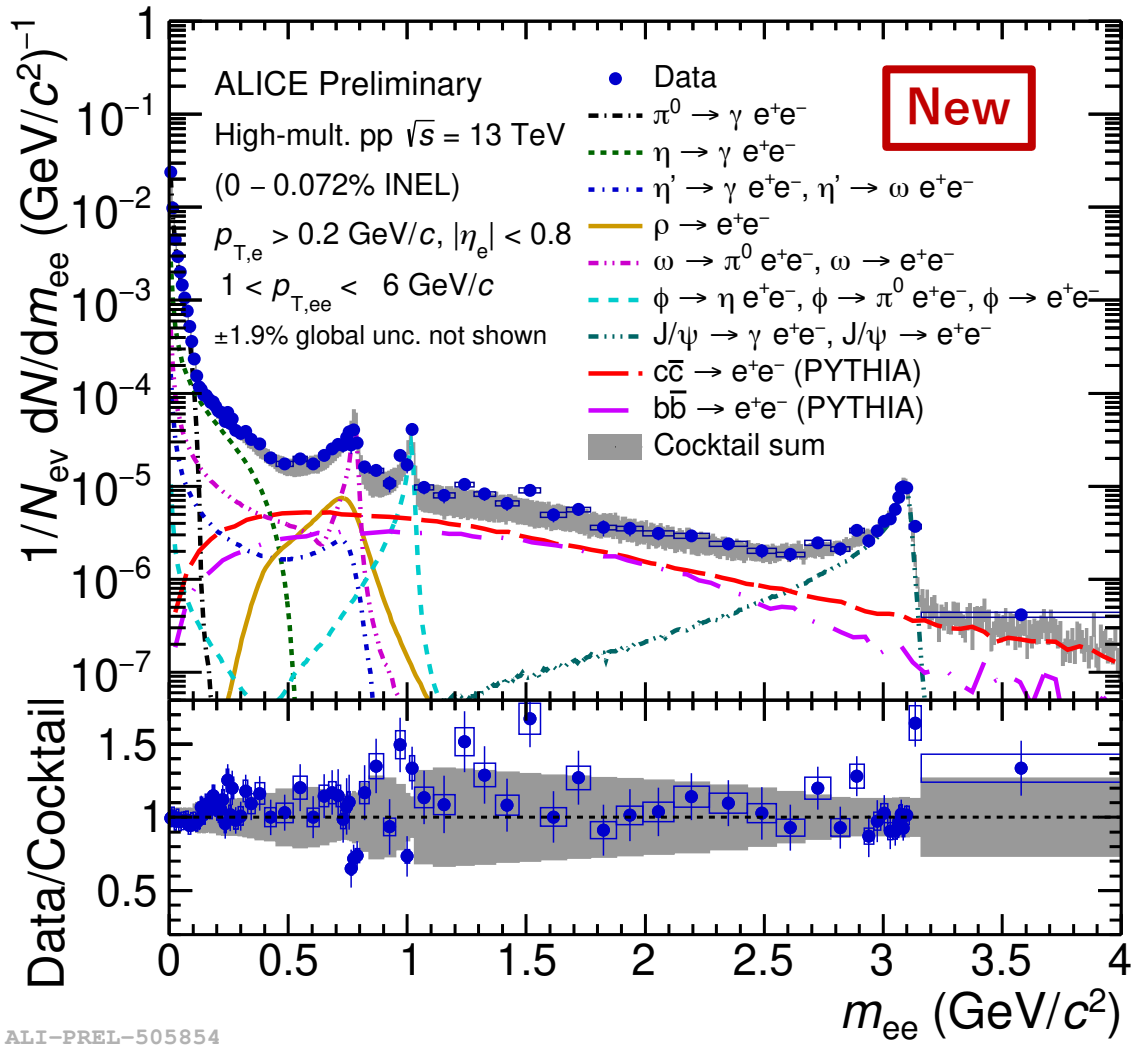
- Full Run 2 datasets analyzed
  - Factor 4.4 in HM compared to previous publication
    Phys. Lett. B 788 (2019) 505
- π^0 and η measured at √*s* = 13 TeV in the same multiplicity class
  Parallel talk, Adrian Nassirpour 13.Jun

→ Reduced the sys. unc. of the hadronic cocktail

- HF cocktail: applied p_T dependent multiplicity scaling factor
  JHEP **2015,** 148 (2015)

→ The scaling factor dominates the cocktail unc. at IMR

- Within uncertainty, no excess w. r. t. data



Extraction of direct photon fraction *r*

- Relation is given by Kroll-Wada formula

N.M. Kroll and W. Wada PR 98 (1955) 1355

$$\frac{d^2N_{ee}}{dm_{ee}} = \frac{2\alpha}{3\pi}\frac{1}{m_{ee}}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)|F(m_{ee}^2)|^2\left(1-\frac{m_{ee}^2}{M_h^2}\right)^3 dn_\gamma$$

Process dependent form factor

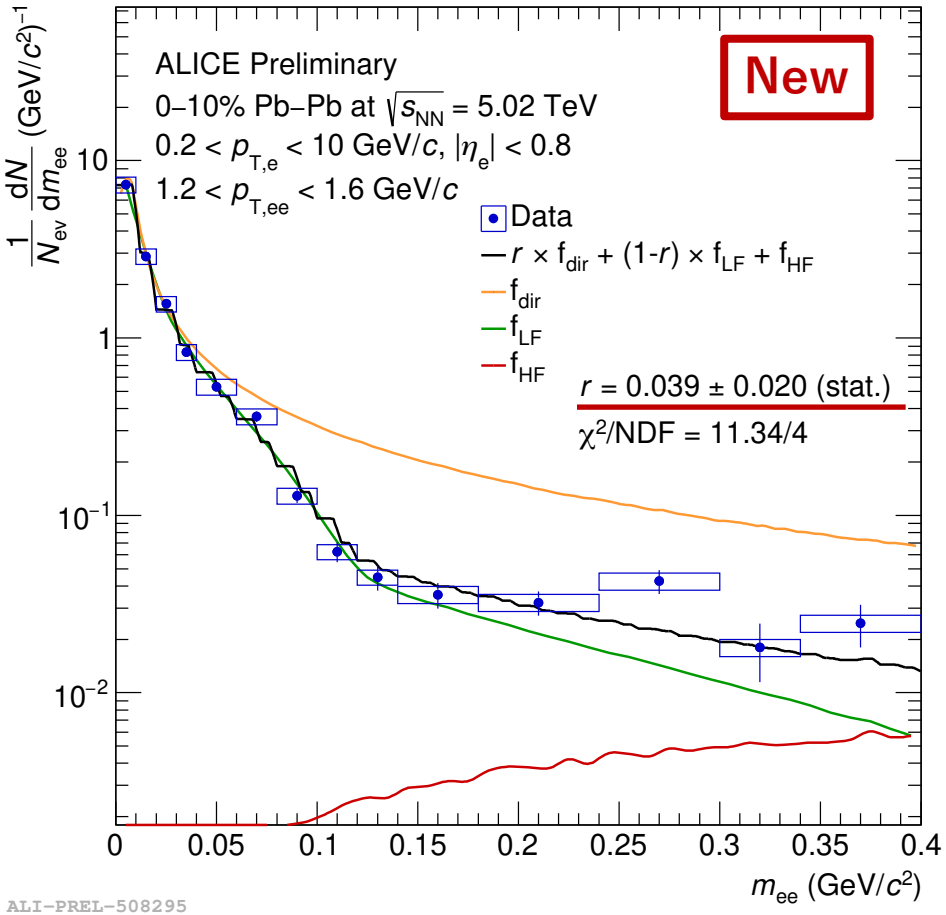
→ Hadrons : 0, Virtual photons : 1

- Exploit the difference to separate virtual photon and dielectron from Dalitz decay
- Yield fitted with : $f = r \times f_{\mathrm{dir}} + (1-r) \times f_{\mathrm{LF}} + f_{\mathrm{HF}}$

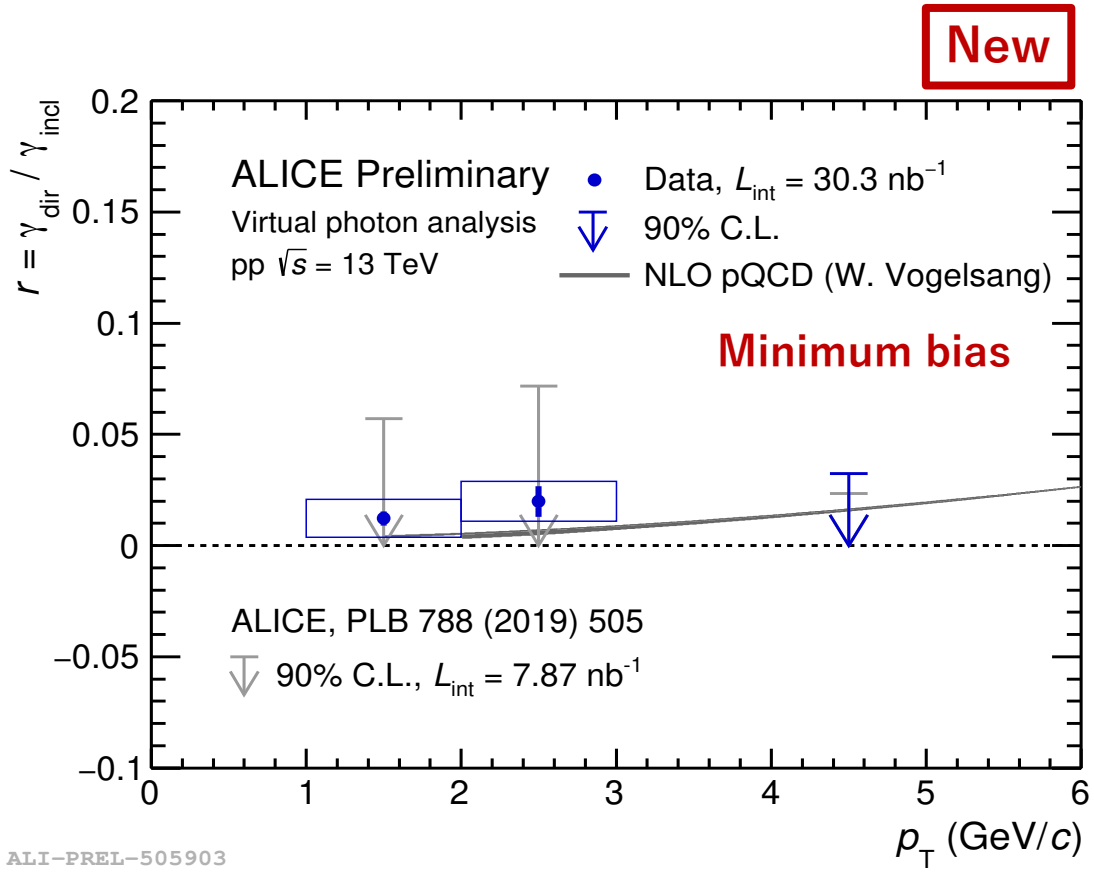
Virtual-photon template | Light flavor | and | heavy flavor

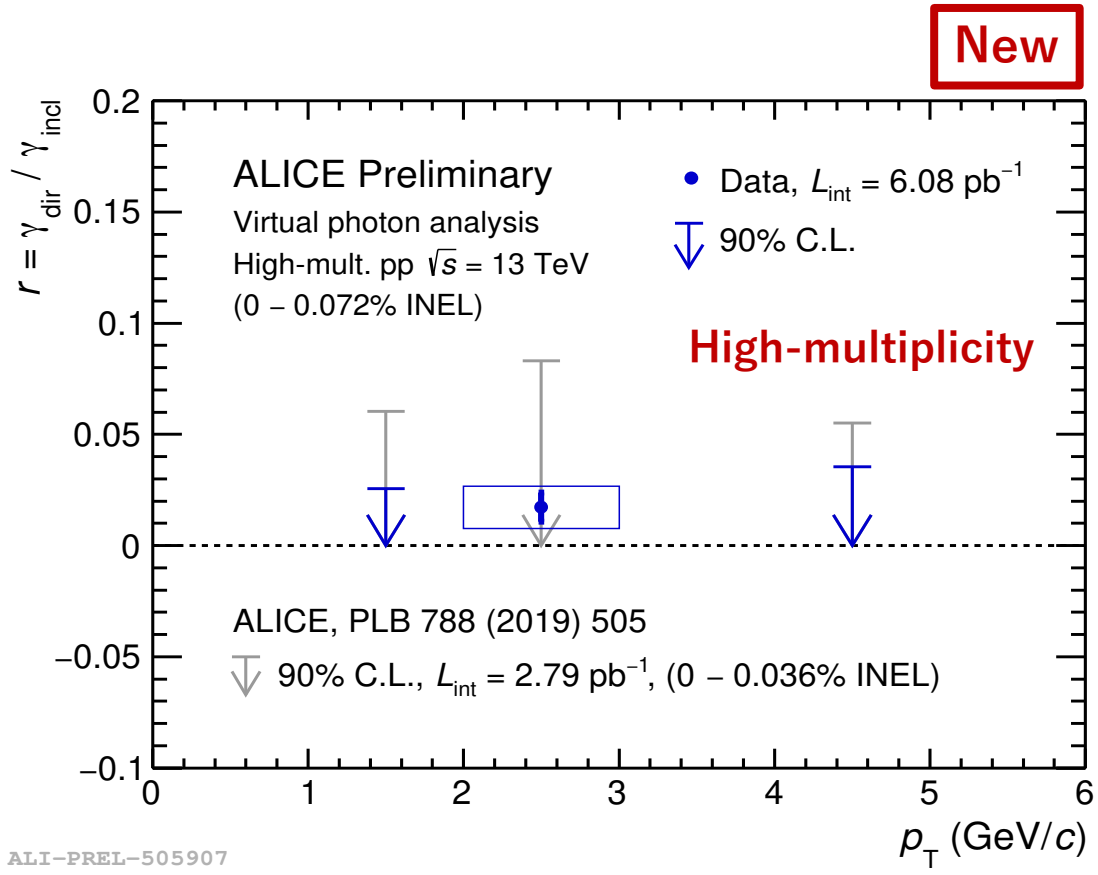
where $r = (\gamma^*_{\mathrm{dir}}/\gamma^*_{\mathrm{incl}})_{m_{\mathrm{ee}}\to 0} = (\gamma_{\mathrm{dir}}/\gamma_{\mathrm{incl}})$

- Assumption only valid for $p_{\mathrm{T,ee}} \gg m_{\mathrm{ee}}$ → Extract r at $p_{\mathrm{T,ee}} > 1\,\mathrm{GeV}/c$



Direct photon fraction in pp collisions at √s = 13 TeV





- Much smaller statistical and systematic uncertainties compared with previous publication
- No significant increase with respect to pQCD photons in MB
- No sign of increase direct photon fraction in HM w. r. t. MB

Central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV - Invariant mass spectrum

- Data compared with hadronic cocktail with $\langle N_{coll} \rangle$ scaled heavy flavor (HF) measured in pp at $\sqrt{s}$ = 5.02 TeV

  Phys. Rev. C 102 (2020) 055204

  → Vacuum baseline

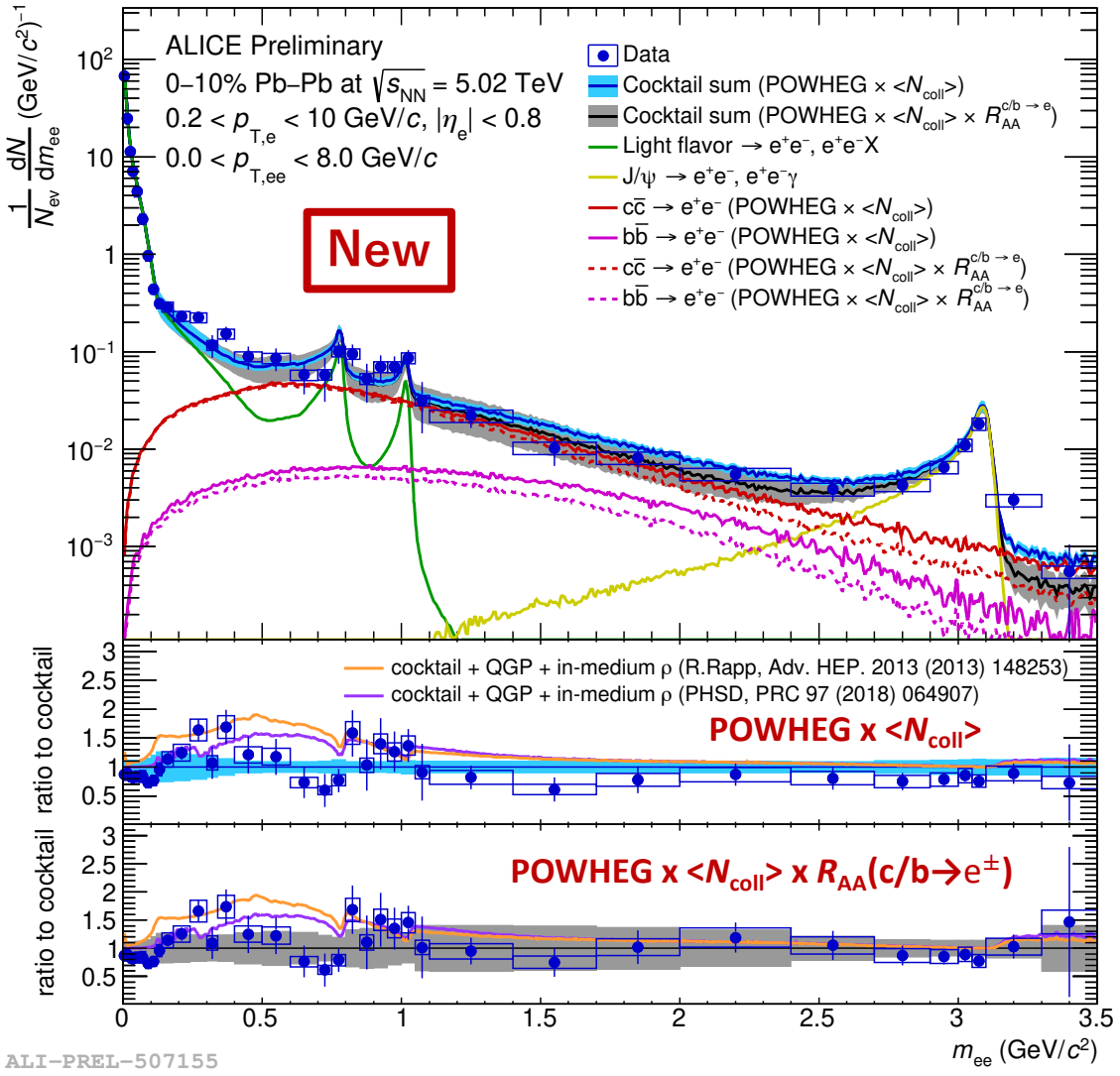
- Cocktail underestimates data slightly at IMR

  → HF cocktail modified by CNM and hot medium effect

  - Vacuum baseline x R_{AA}(c/b → e$^{\pm}$)

    Phys. Lett. B 804 (2020) 135377

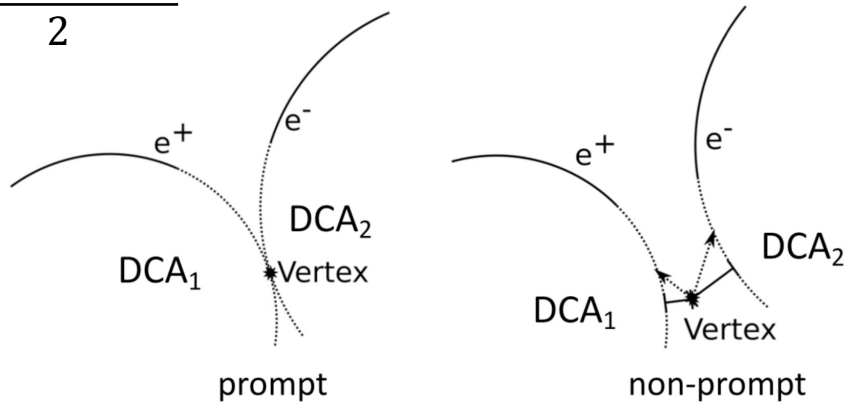
- Data is consistent with HF suppression & thermal radiation from QGP



Central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV – Extraction of prompt thermal signal

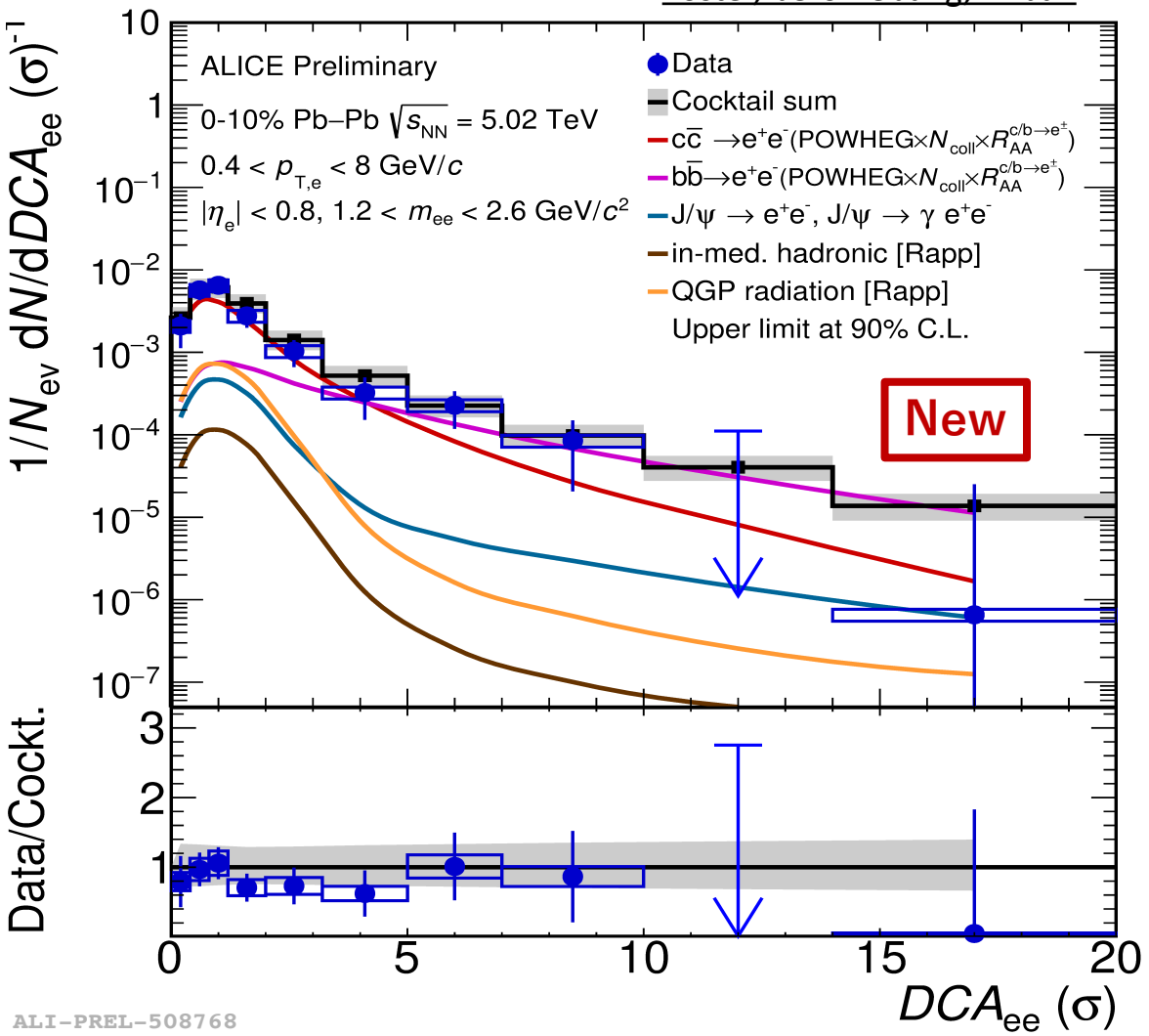
- Difficulty in extraction of prompt thermal e^+e^- from QGP at IMR due to huge non-prompt correlated HF background
- Separate prompt and non-prompt sources via impact parameter

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



- Expectations : prompt + non-prompt ($c\bar{c}$ and $b\bar{b}$)
  - DCA_{ee} (prompt) < DCA_{ee} ($c\bar{c}$) < DCA_{ee} ($b\bar{b}$)

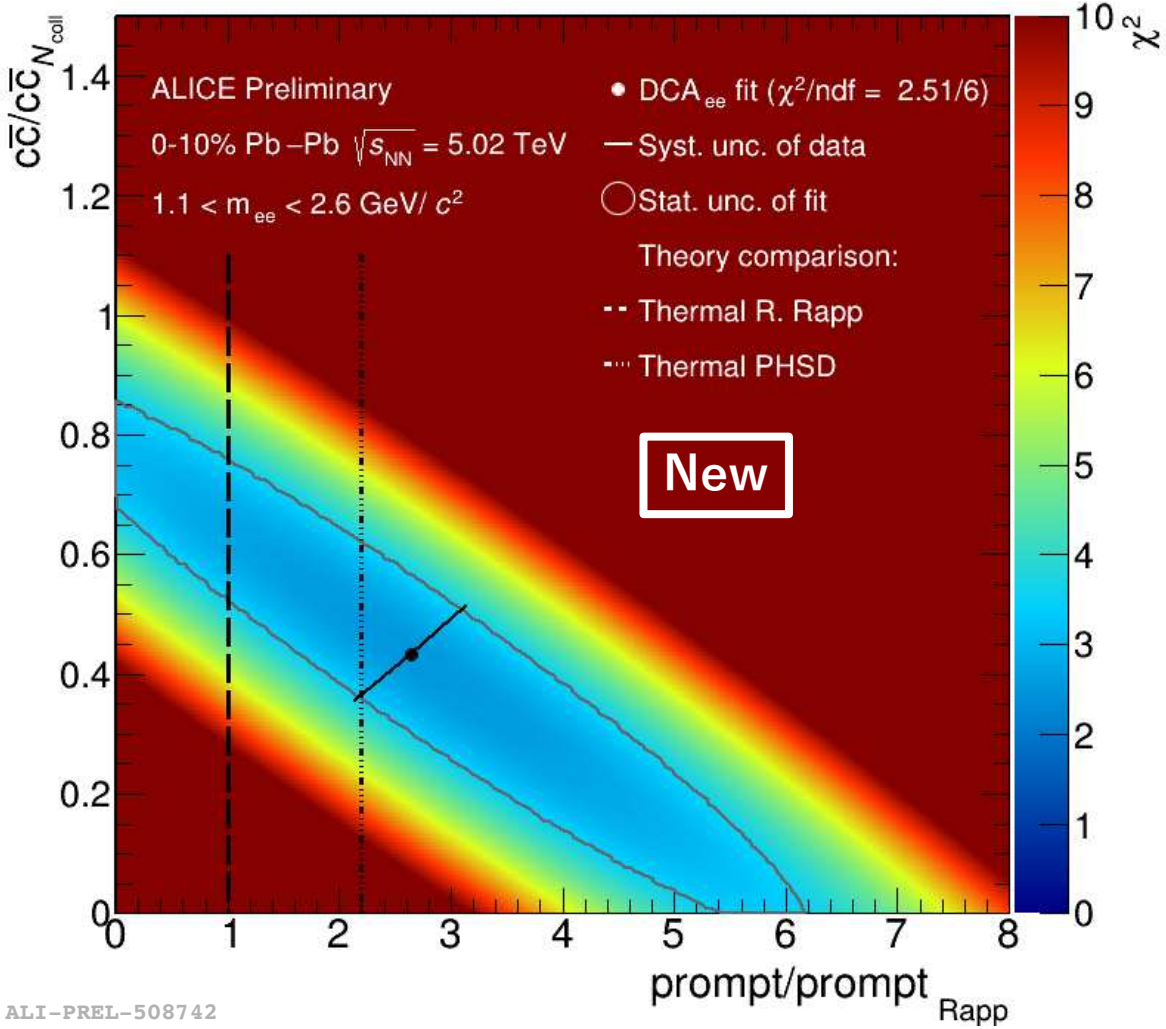
Poster, Jerome Jung, 14.Jun



Central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV – Extraction of prompt thermal signal

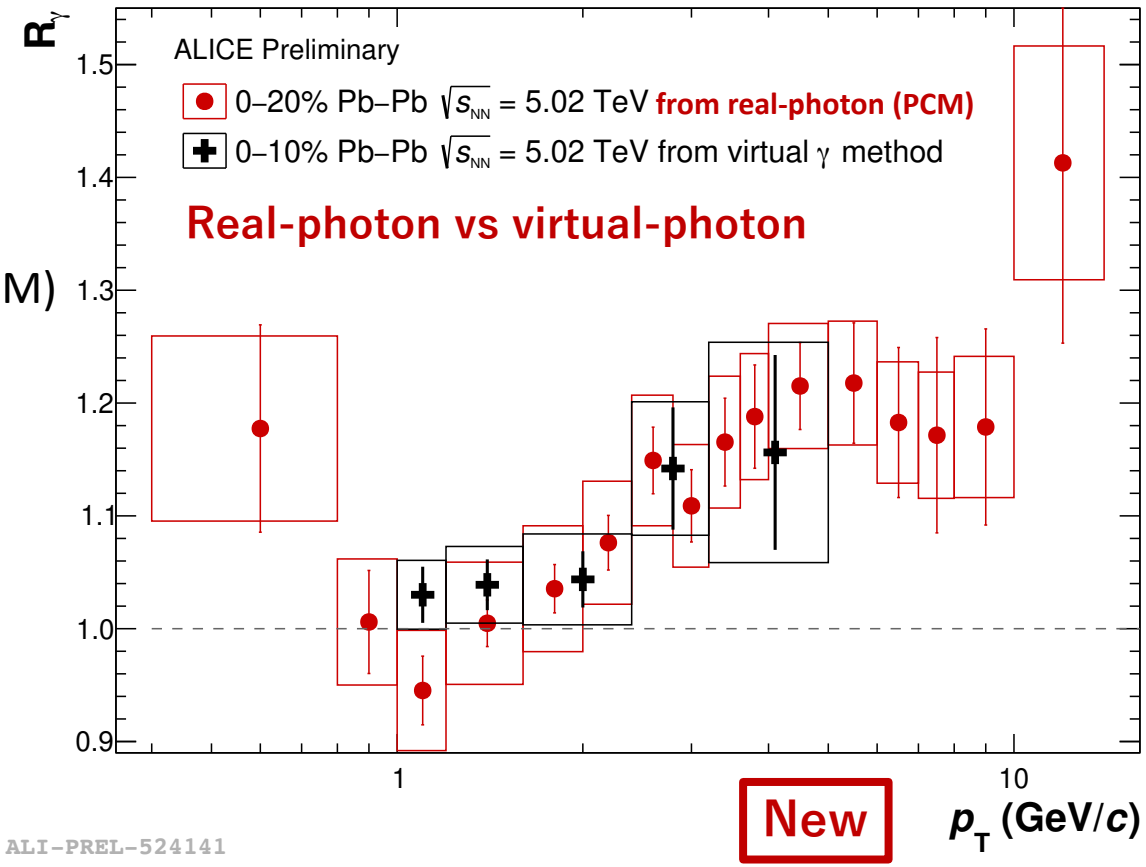
- Fix $b\bar{b}$ contribution via fit at high DCA_{ee}
  - $b\bar{b} = 0.74 \pm 0.24\,(\text{stat.}) \pm 0.12\,(\text{syst.})$
    w.r.t. N_{coll} scaling
- Simultaneous fit $c\bar{c}$ and prompt contributions
  - $c\bar{c} = 0.43 \pm 0.40\,(\text{stat.}) \pm 0.12\,(\text{syst.})$
    w.r.t. N_{coll} scaling
  - $\text{prompt} = 2.64 \pm 3.18\,(\text{stat.}) \pm 0.29\,(\text{syst.})$
    w.r.t. R. Rapp
- Results agree with:
  - Charm suppression
  - Thermal contribution in the order of Rapp/PHSD

Poster, Jerome Jung, 14.Jun



Central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV - Direct photon excess ratio R_γ

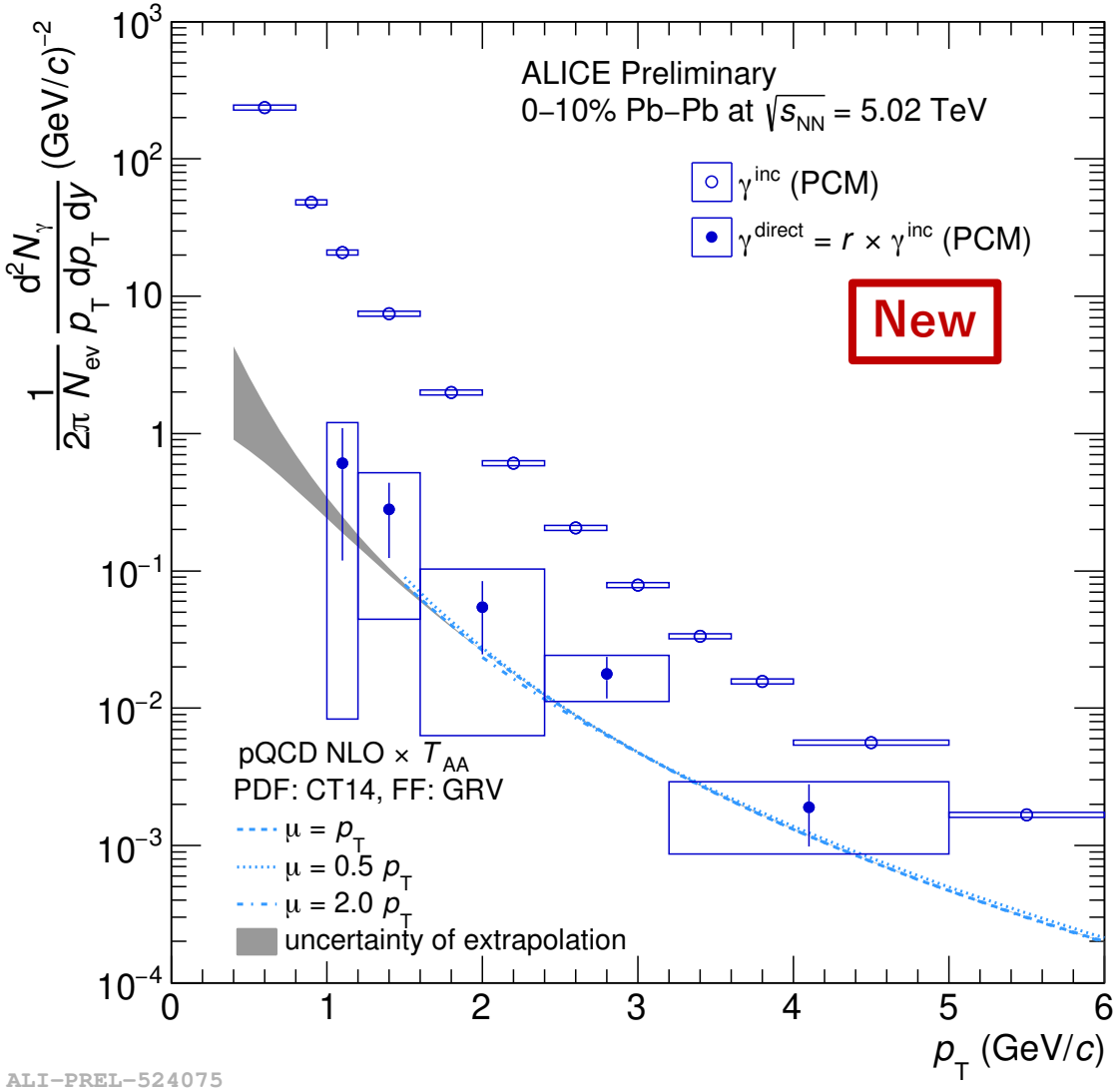
- Direct photon excess ratio: $R_\gamma = \gamma_{\mathrm{incl}}/\gamma_{\mathrm{decay}}$
- Two methods: real photon analysis via gamma conversion (PCM) in the detector, virtual photon analysis (dielectron)
- Both analyses are in good agreement.



Central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV - Direct photon spectrum

- Direct photon excess ratio: $R_\gamma = \gamma_{\mathrm{incl}}/\gamma_{\mathrm{decay}}$
- Two methods: real photon analysis via gamma conversion (PCM) in the detector, virtual photon analysis (dielectron)
- Both analyses are in good agreement.
- Direct photon yield constructed as $\gamma^{\mathrm{dir}} = \gamma^{\mathrm{incl}} \times r$

Inclusive photon spectrum from PCM



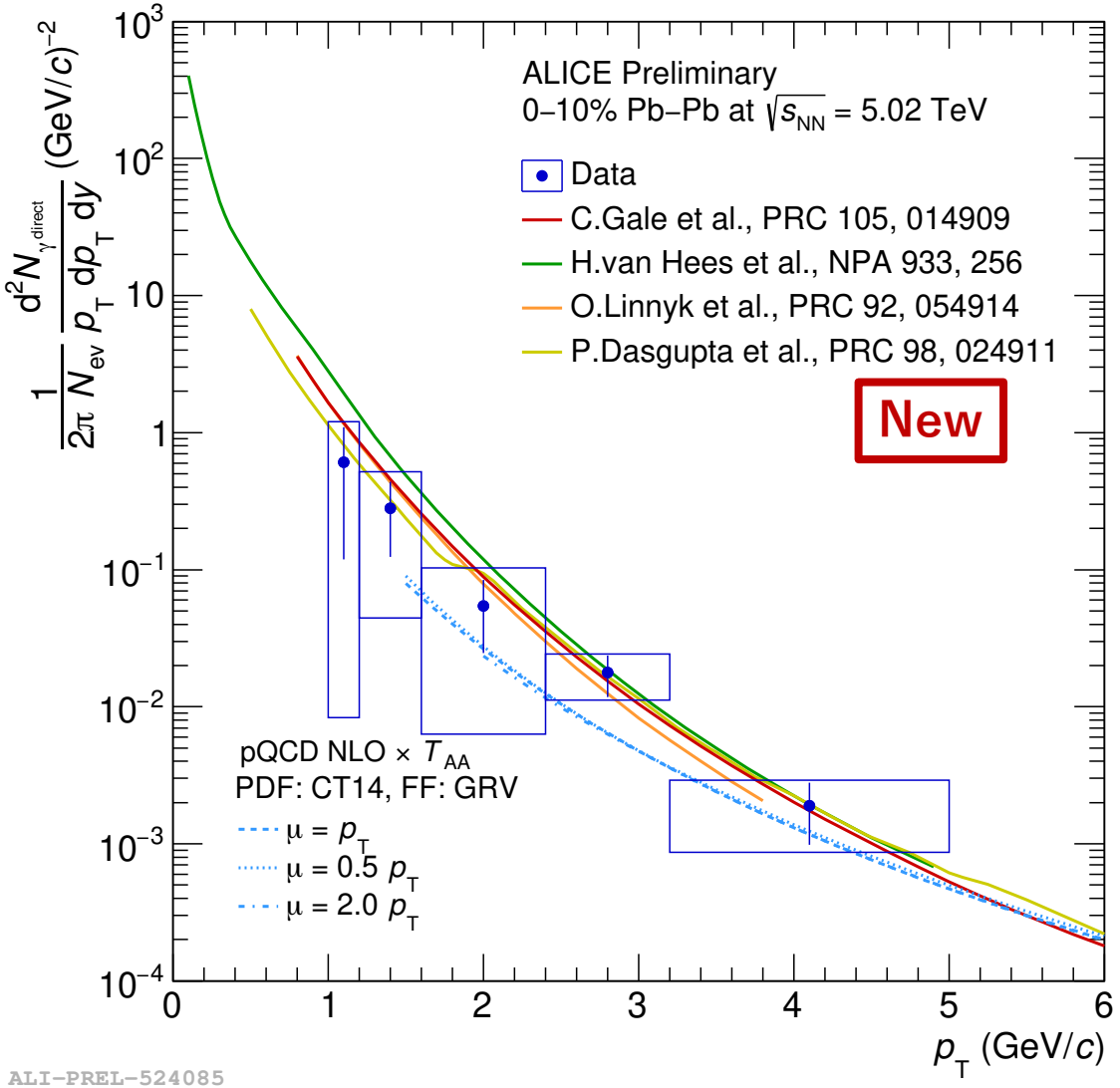
Central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV - Direct photon spectrum

- Direct photon yield compared to theoretical models

  Thermodynamic models : C.Gale/H.vanHees/P.Dasgupta

  Microscopic transport model (PHSD) : O. Linnyk

- All models agree with the data but some tends to overestimate them at low p_T



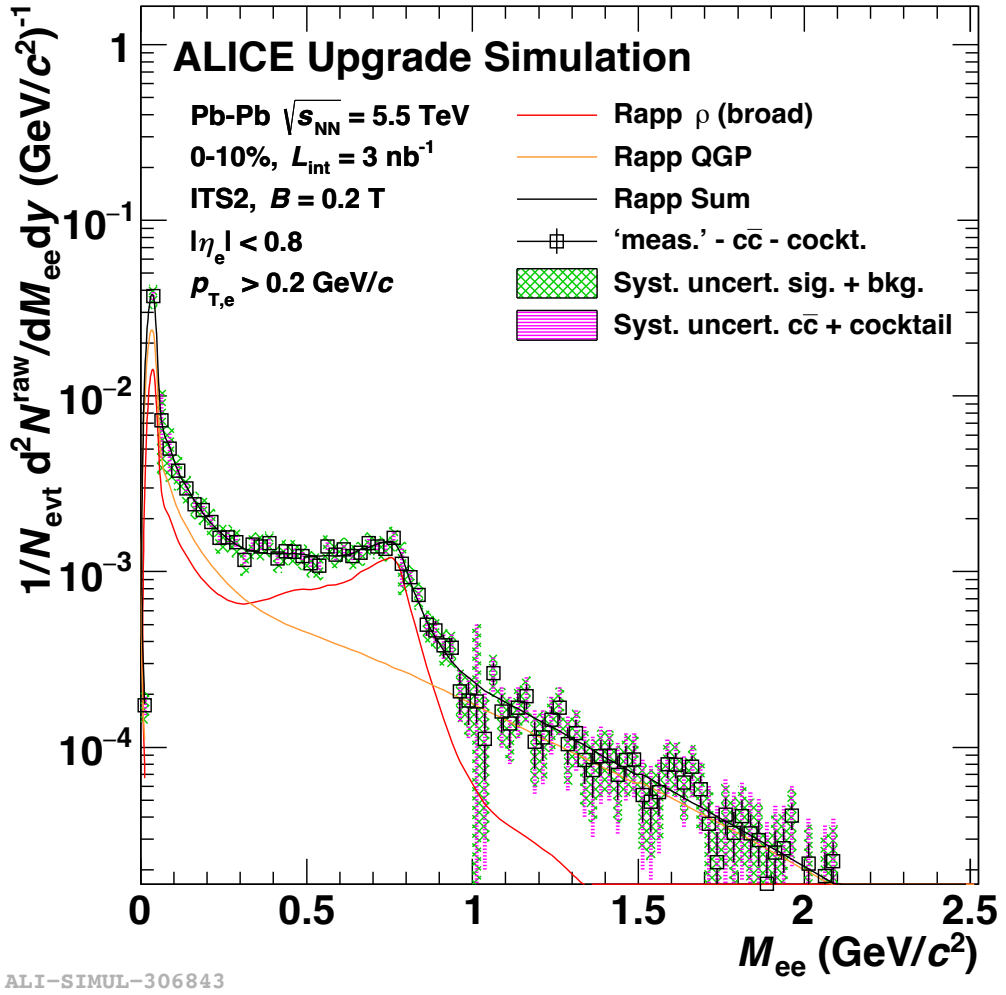
Future prospects

Run 3 and Run 4

- New ITS
  - Improved vertex resolution
  - Separate HF from prompt e^+e^- sources
- TPC upgrade
  - GEM-based readout
  - Continuous readout in Pb–Pb ~ 50 kHz
- Pb–Pb
  - Increase factor 100 ~ 13 nb^{-1} from entire Run 3 + Run 4

    Z.Citron et al., CERN-LPCC-2018-07, arXiv:1812.06772
- pp
  - Future High-energy pp program (2022 -)

    ALICE-PUBLIC-2020-005 CERN-LHCC-2020-018; LHCC-G-179
    - Min. bias pp ~ 200 pb^{-1}
    - High mult pp ~ 3 pb^{-1}



Summary

- **pp at $\sqrt{s}$ = 13 TeV in MB and HM events**
  - Within uncertainty no excess w.r.t. cocktail at IMR in HM
  - No significant increase with respect to pQCD photons in MB
  - No sign of increase direct photon fraction in HM w.r.t MB
- **Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV in central collision**
  - First DCA_{ee} analysis to separate thermal radiation & HF background
  - First measurement of direct photon spectrum with virtual photon method
- **Run 3 & Run 4 and beyond**
  - With upgraded ITS and TPC, much more statistics will be expected

    Plenary talk, Sarah Porteboeuf, 16.Jun

    Plenary talk, Raphaelle Bailhache, 16.Jun
  - ALICE enters Quantitative/Precision era