Electromagnetic probes in ALICE

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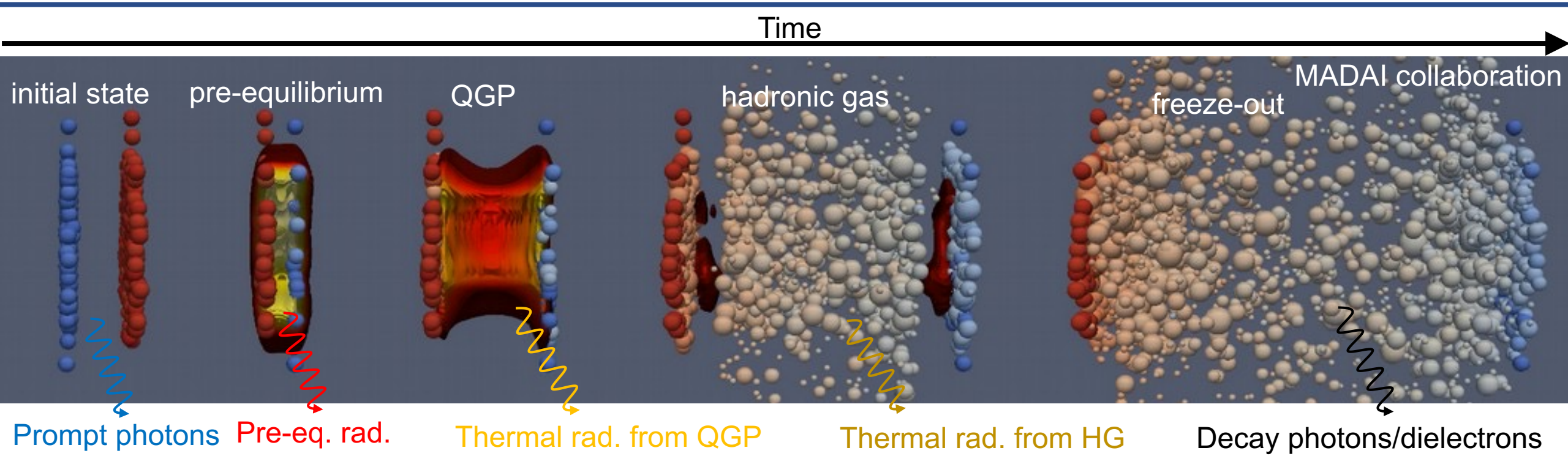
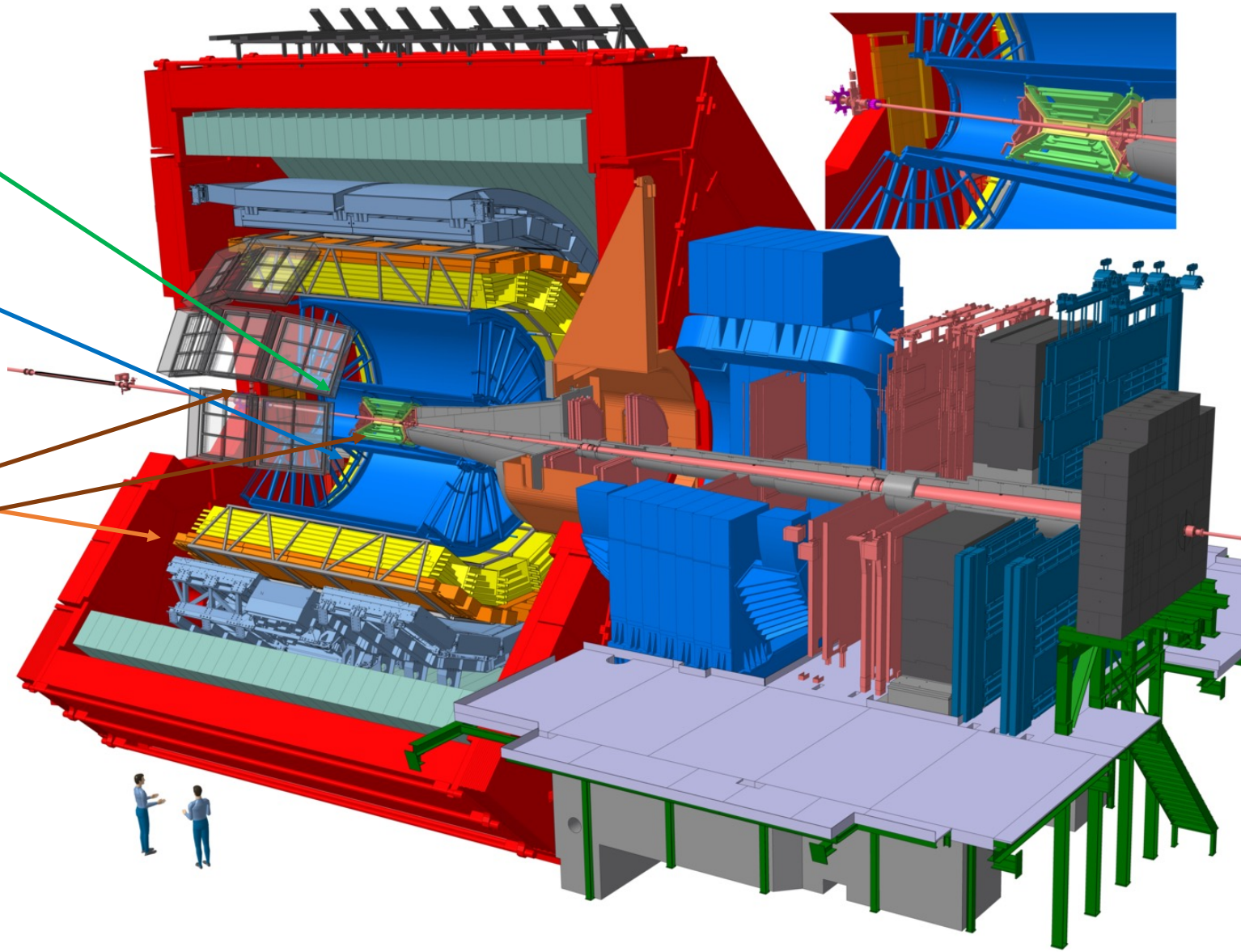
Introduction



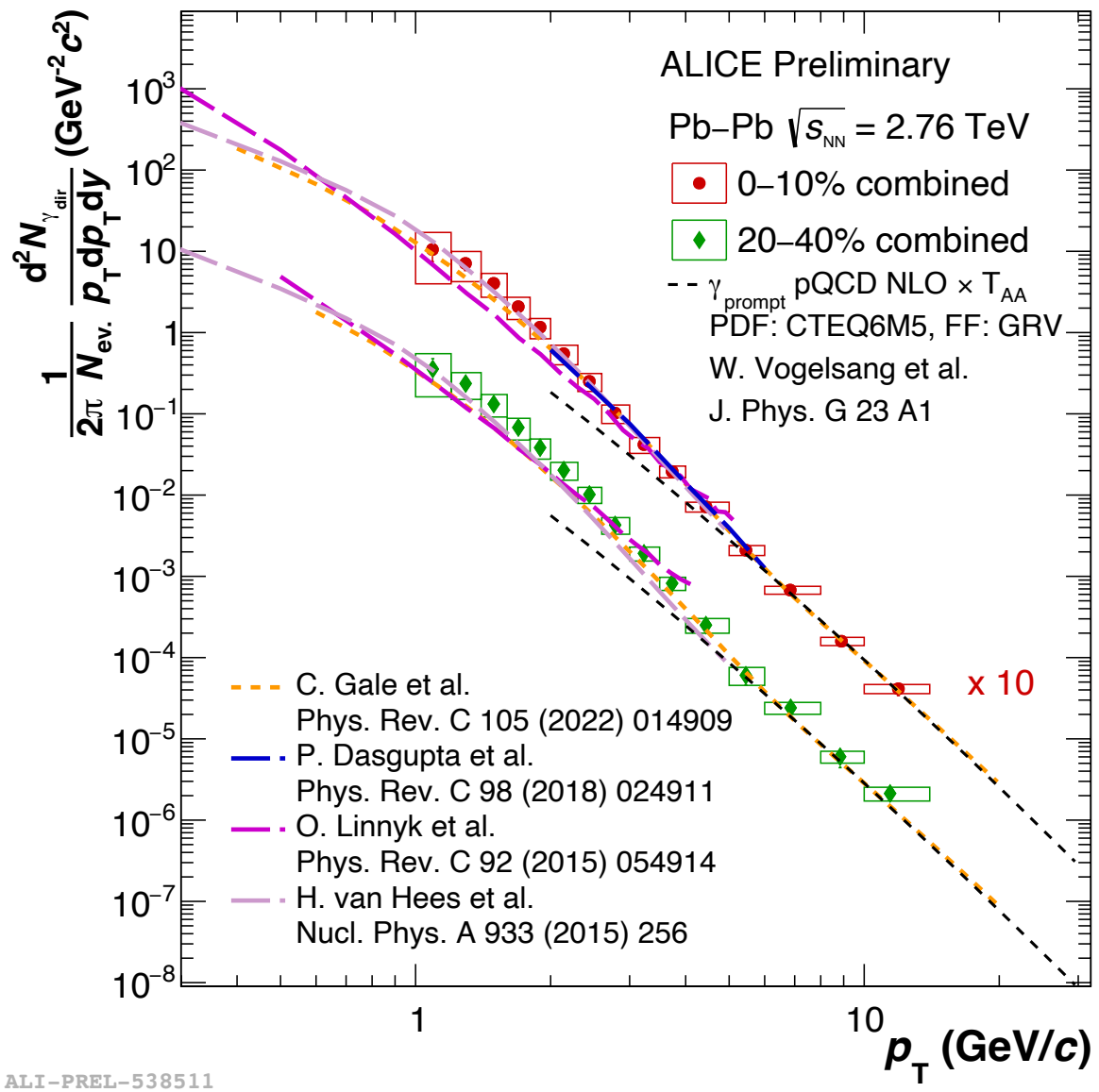
- Unique tools to access early stage of the collision without strong interaction, unlike hadrons.
- Photons and dileptons are emitted from all stages.
- EM signals = excess beyond the known hadronic sources

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

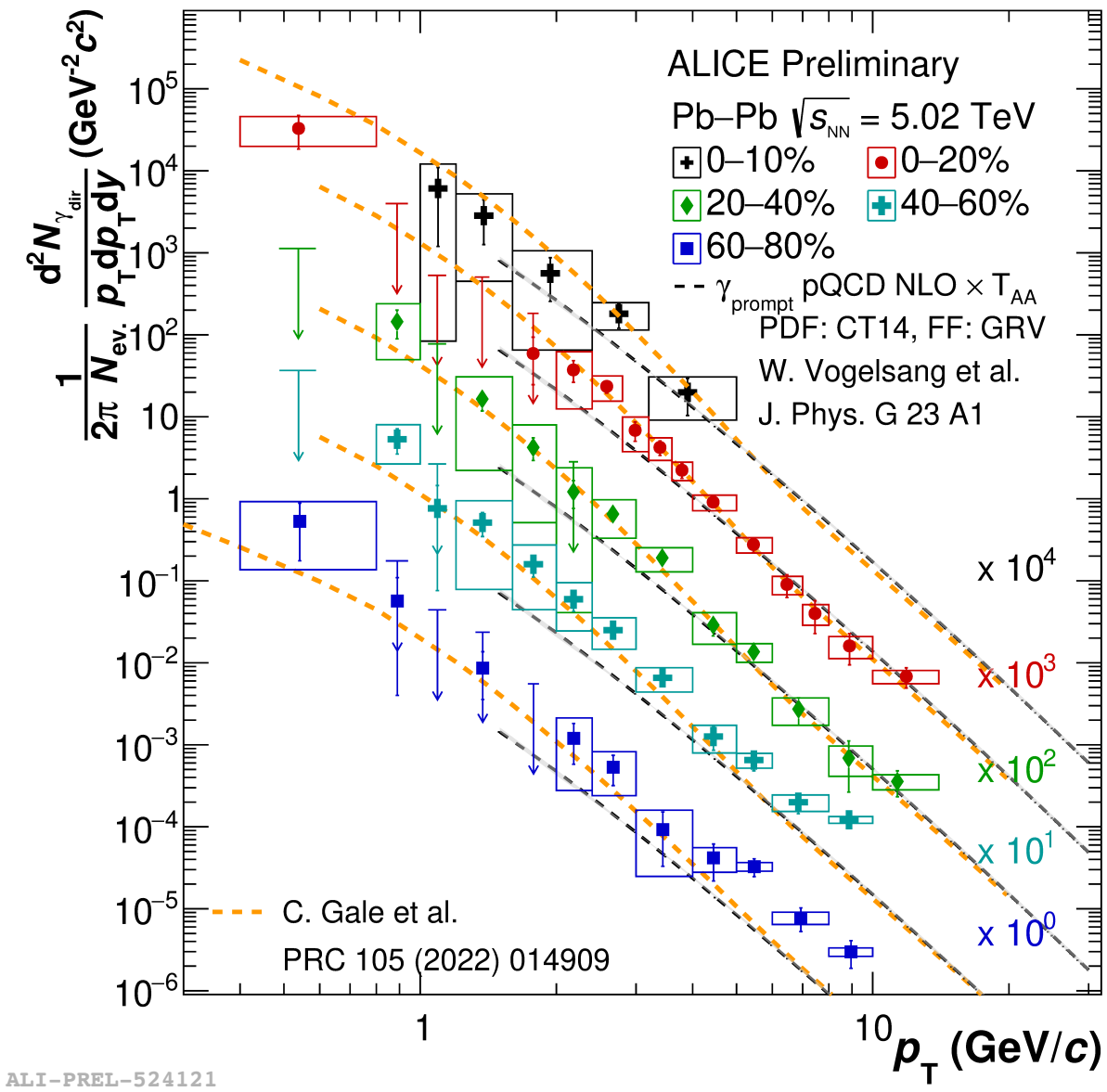


Direct photons in Pb-Pb at 2.76 TeV



- Improved results from the previous publication (PLB 754 (2016) 235-248)
  - Larger statistics : 20M events in 0-10%
  - Data-driven material budget correction (arXiv:2303.15317)
- Most precise direct photon results in ALICE ever
- Consistent with NLO pQCD calculation at high p_T
- Excess of direct photon production beyond pQCD calculation for p_T < 4 GeV/c
  - Thermal + pre-eq. photons

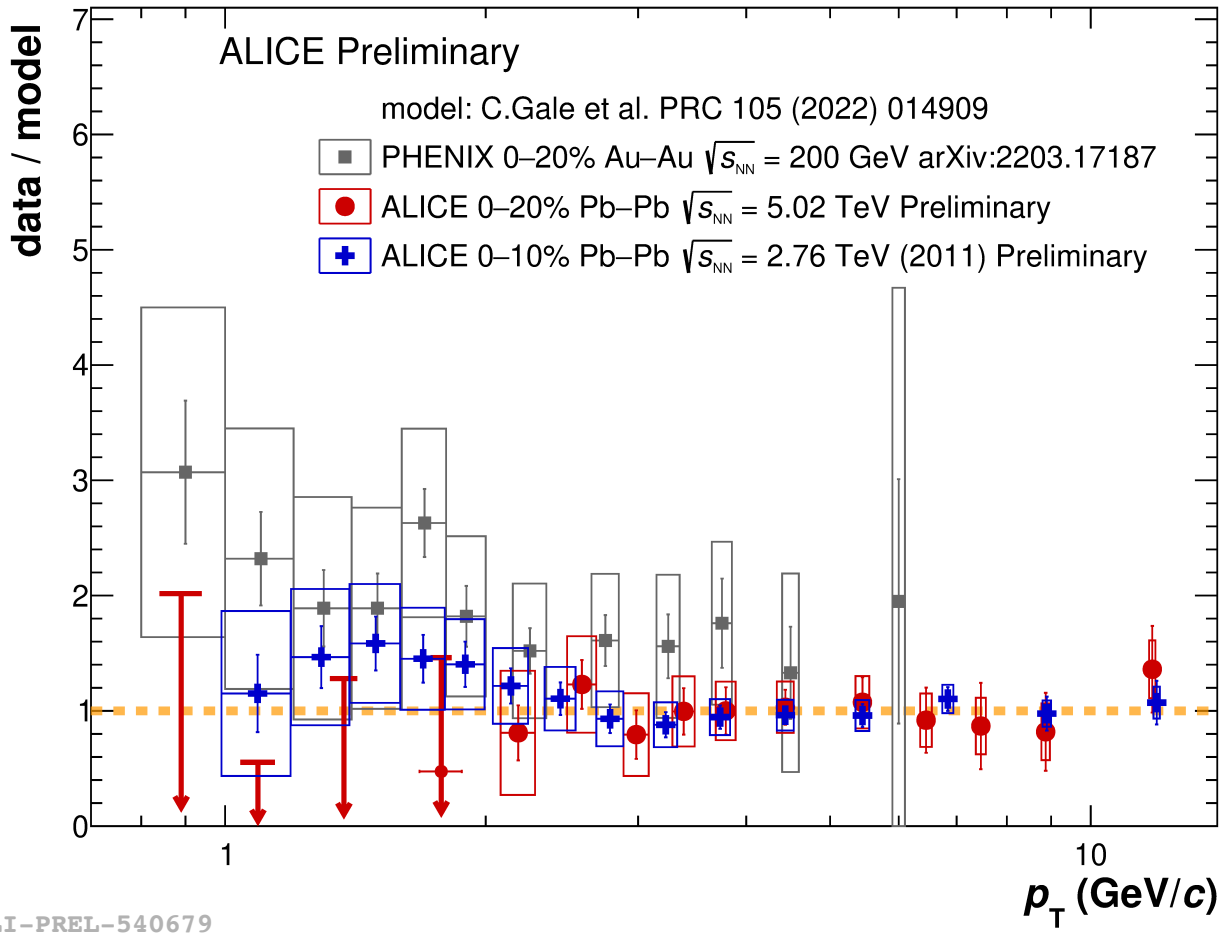
Direct photons in Pb-Pb at 5.02 TeV



ALI-PREL-524121

- Consistent with NLO pQCD calculation at high p_T
- Consistent with the latest model
  PRC 105 (2022) 014909
  - Prompt + pre-eq. + thermal photons
- Outlook: analyzing full statistics in Pb-Pb at 5.02 TeV
  - 100M events in 0-10%
  - 90M events in 30-50%
    -- v_2 measurement

Comparison with theoretical model



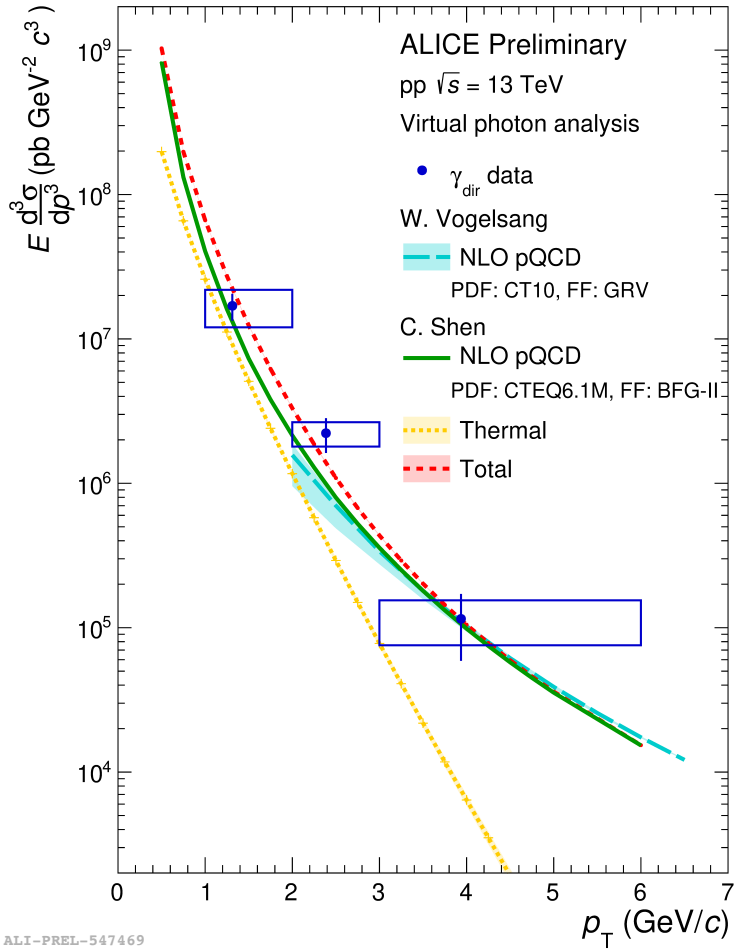
- PRC 105 (2022) 014909, C.Gale et al.
  Prompt + pre-equilibrium + thermal radiation from QGP and hadronic gas

- Good agreement between ALICE data and the model

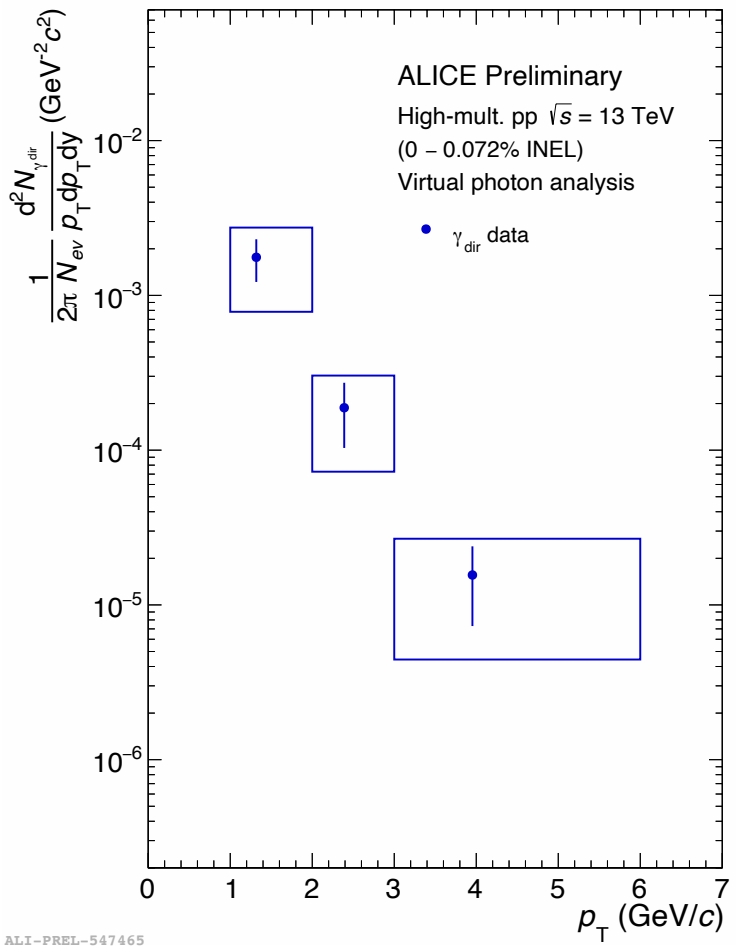
- PHENIX data tend do be higher than the model at low p_T

Direct photon in small system

inelastic pp collisions

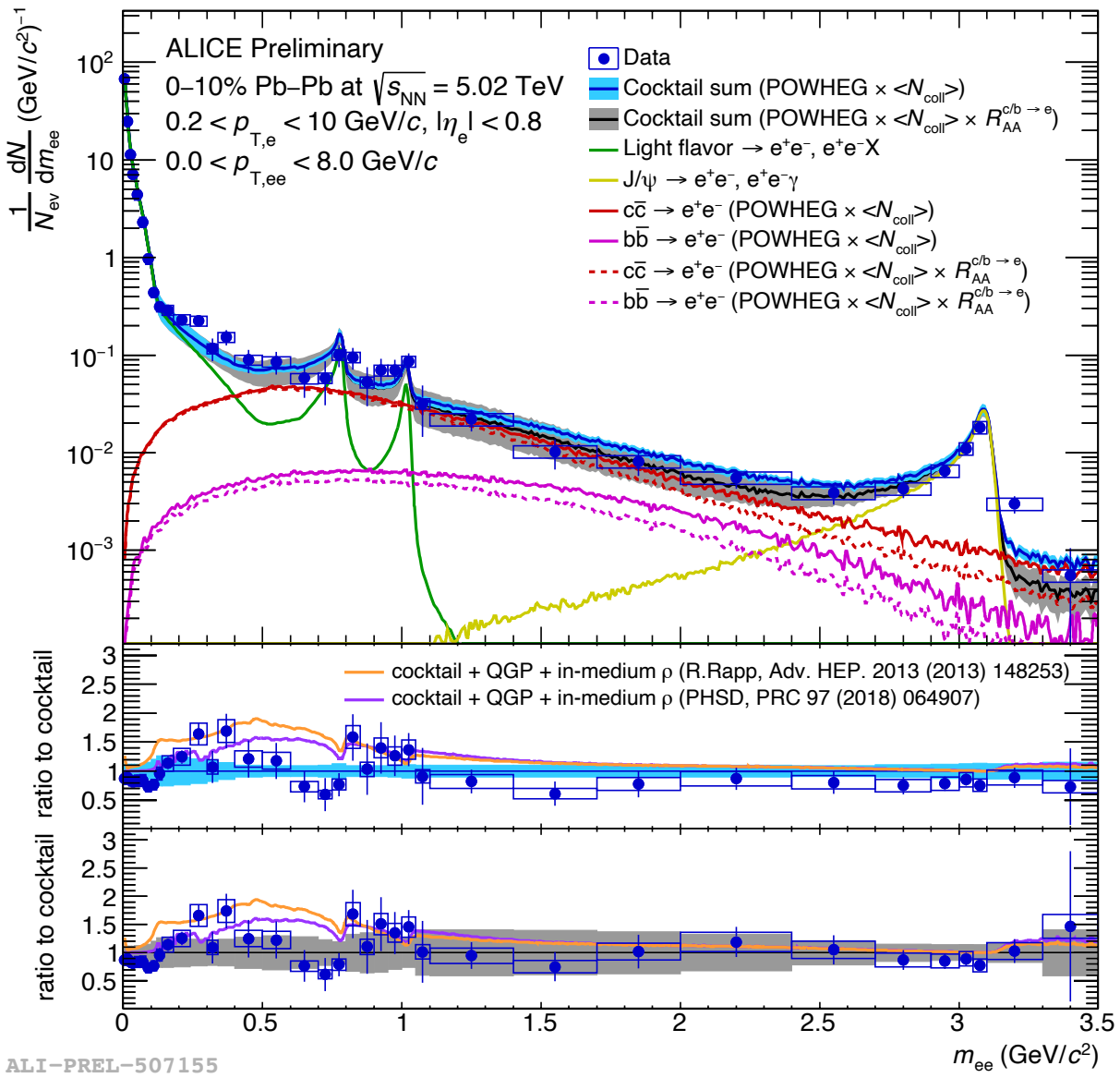


high-multiplicity pp collisions

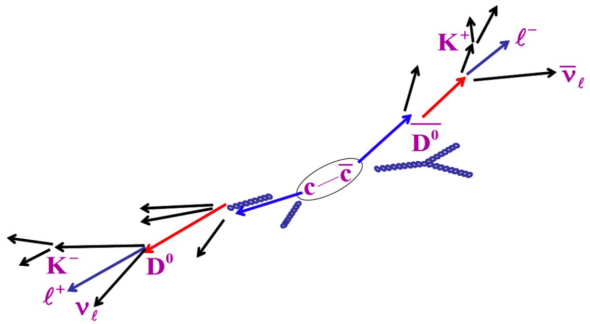


- First measurement of direct photons in small systems at low p_T in ALICE
  - Direct photon fraction ~ 0.01
- Data can be reproduced by the model with and without thermal contribution in inelastic pp collisions.
- Provide constraints to calculations in high-multiplicity pp collisions

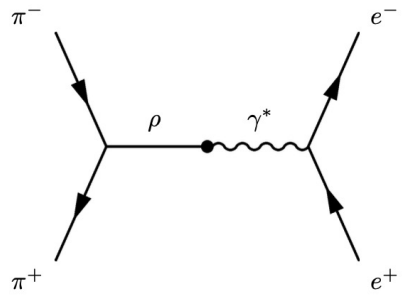
Dielectron production in central Pb-Pb collisions at 5.02 TeV



- 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)



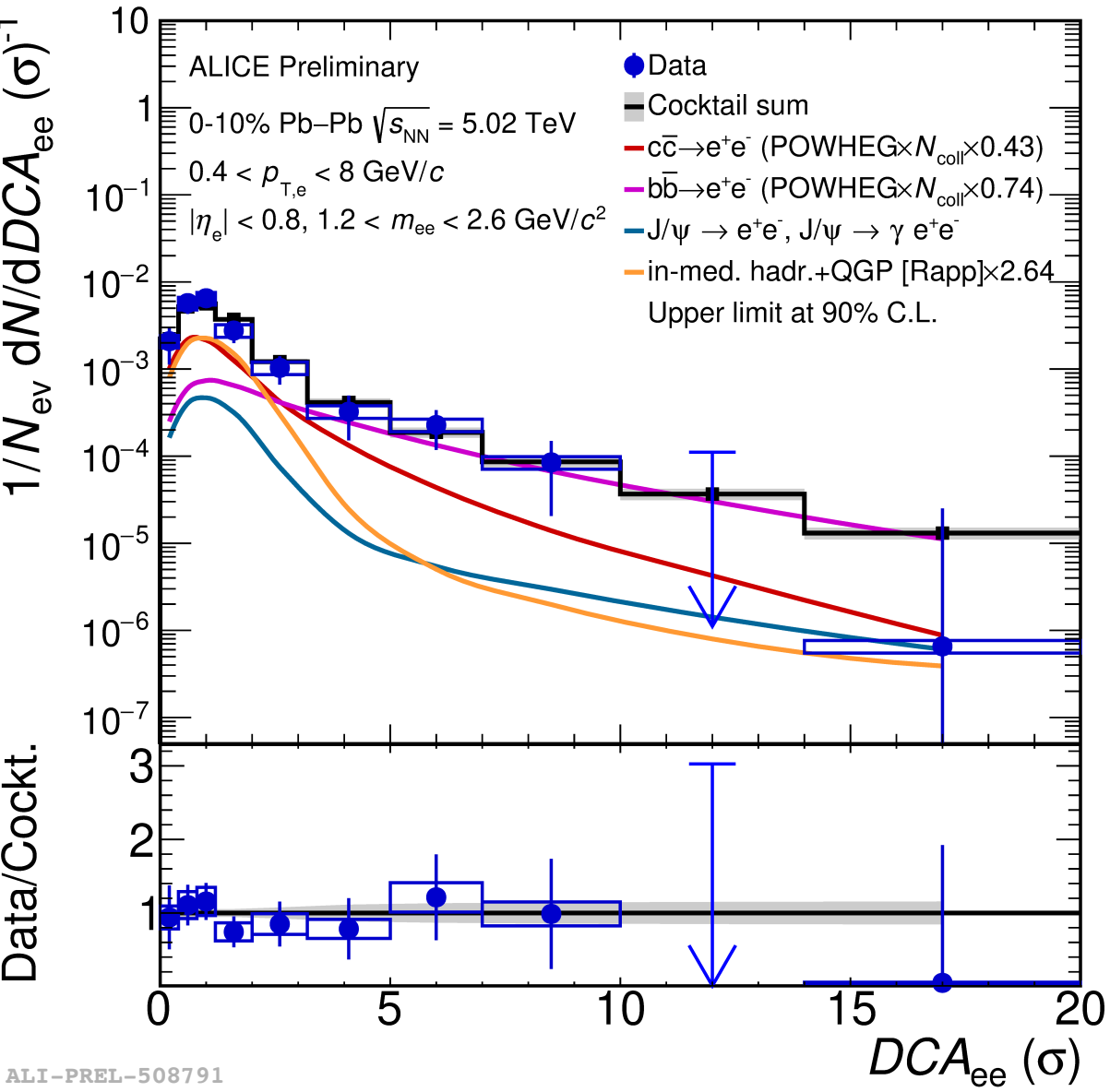
- Hint of an excess at m_{ee} < 0.5 GeV/c^2
  - Consistent with thermal radiation from hadronic gas



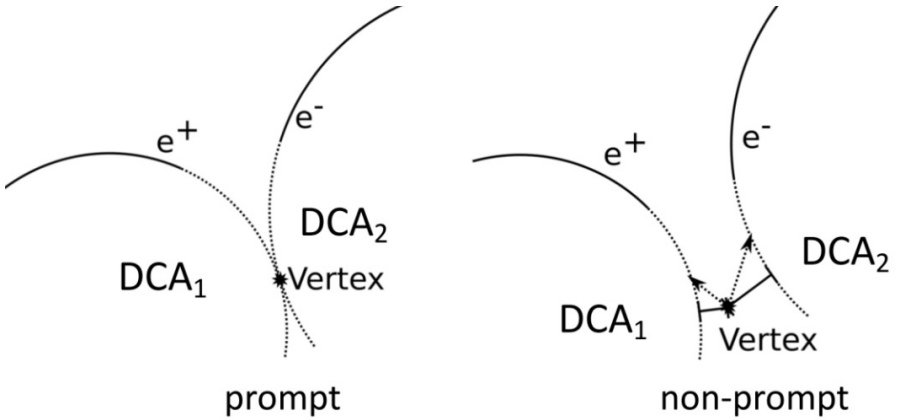
- Need topological separation between QGP radiation (prompt) and HF (non-prompt, $c\tau$~150 μm) in the IMR

  IMR: 1.2 < m_{ee} < 2.6 GeV/c^2

Dielectron DCA_{ee} spectrum in central Pb-Pb collisions at 5.02 TeV



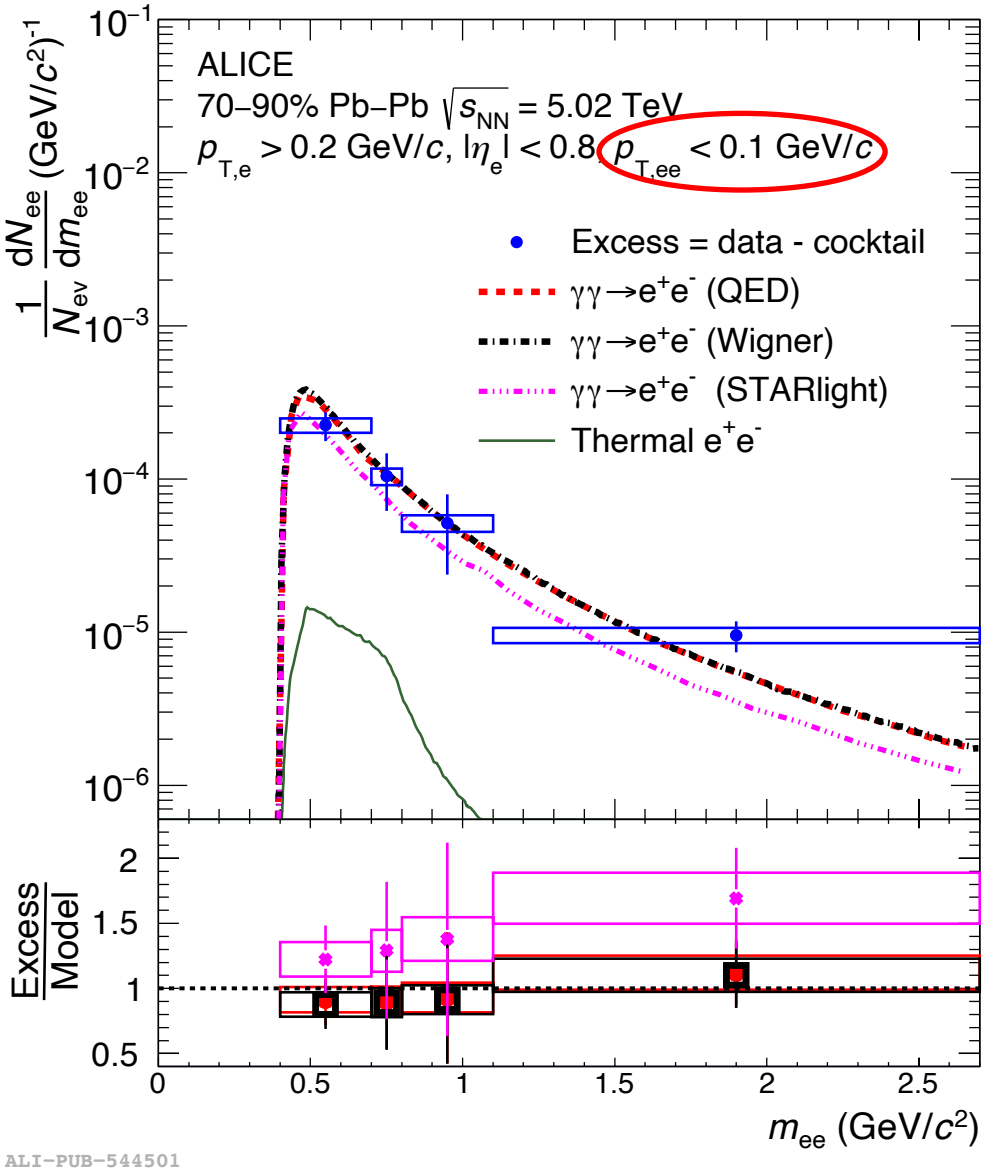
- First DCA_{ee} analysis in Pb-Pb collisions
  - Template fit in 1.2 < m_{ee} < 2.6 GeV/c^2
- Scaling factors to obtain the best fit are:
  - Beauty: 0.74 ± 0.24 (stat.) ± 0.12 (syst.) x $\langle N_{coll} \rangle$
  - Charm: 0.43 ± 0.40 (stat.) ± 0.22 (syst.) x $\langle N_{coll} \rangle$
  - Thermal: 2.64 ± 3.18 (stat.) ± 0.29 (syst.) (w.r.t. R.Rapp)



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

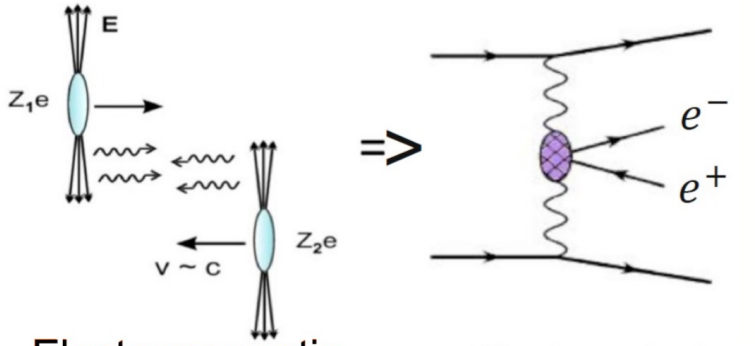
Low-$p_{T,ee}$ dielectron excess in peripheral Pb-Pb collisions

JHEP 06 (2023) 024



- 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

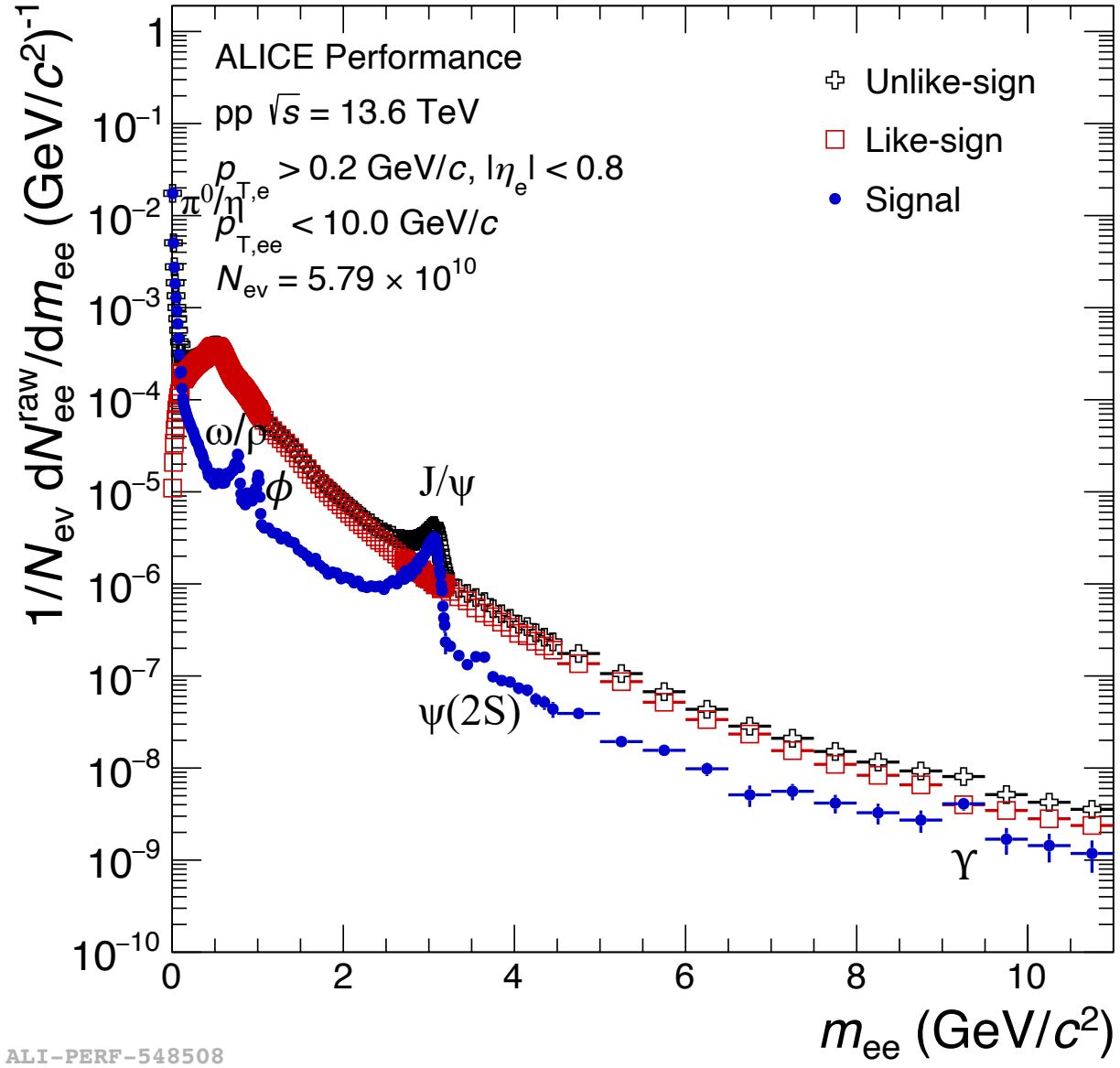
QED : leading-order QED
Wigner : Wigner functions in momentum and impact-parameter space
STARlight : equivalent photon approximation approach



Electromagnetic interaction

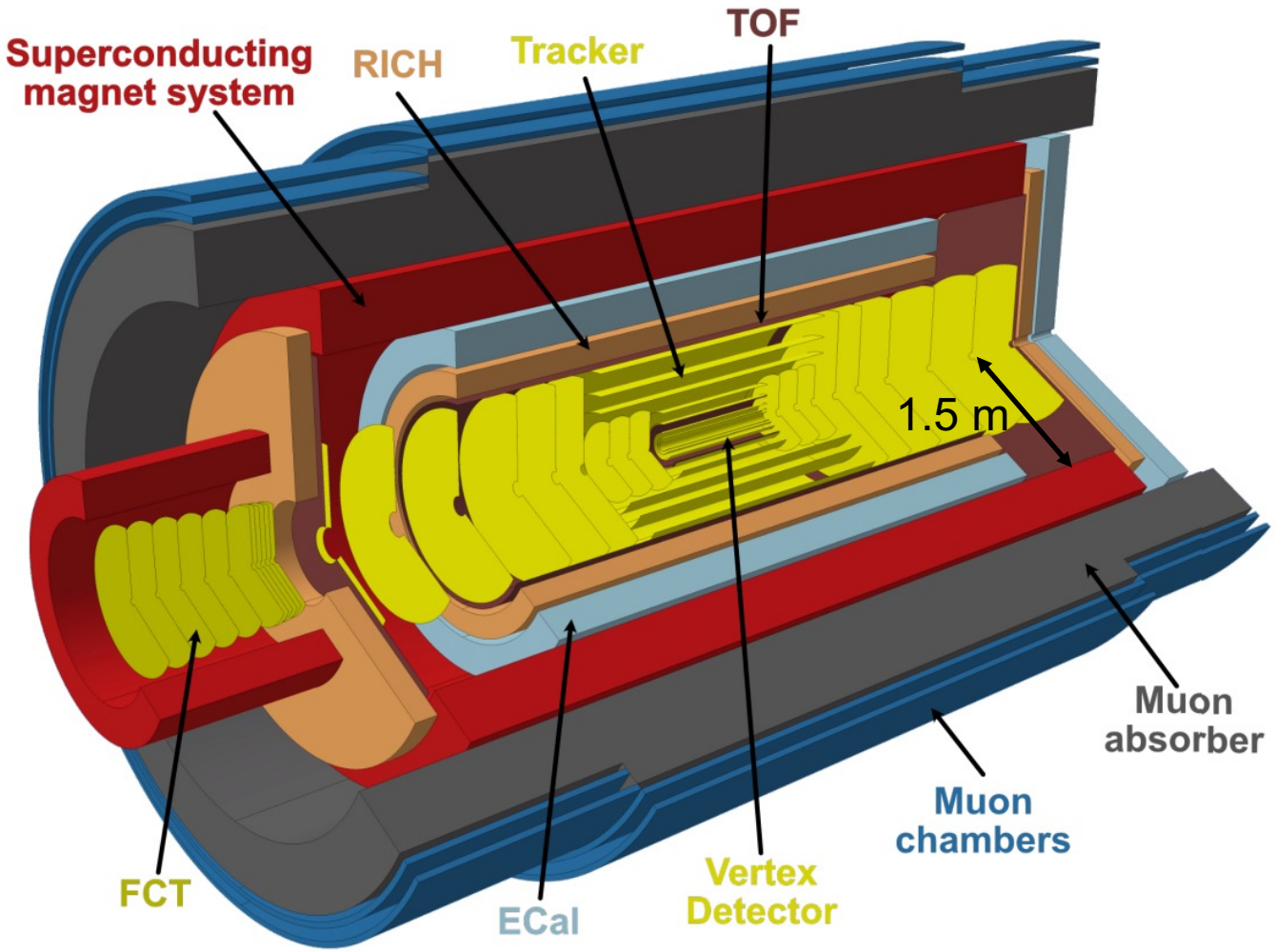
Photon-photon interactions

ALICE Run 3

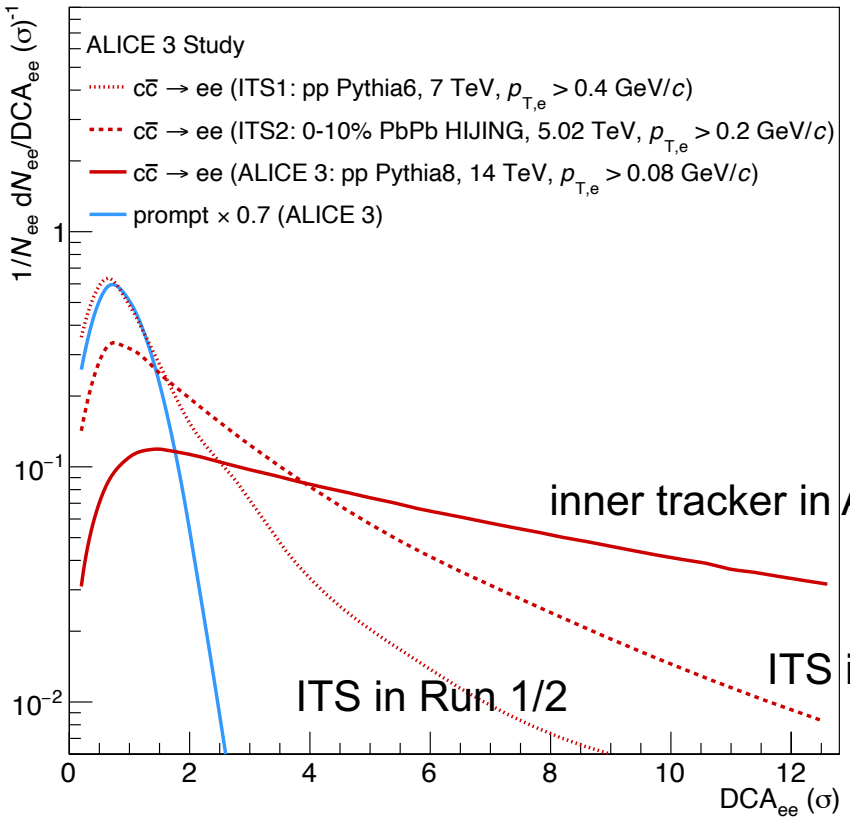


- ALICE recorded huge statistics in 2022 and 2023.
  - Already 10 times larger than that in Run 2
- Clear dielectron signals in pp at 13.6 TeV
  - π^0 and η Dalitz decays
  - $\omega/\rho/\phi$ peak
  - J/ψ and $\psi(2S)$ peak
  - Υ peak
  - HF continuum in the intermediate and high mass regions

Future plan : ALICE 3



- Advanced silicon technology
  - High-rate data acquisition
  - Precise vertexing with retractable inner tracker
  - Particle identification down to low p_T



Summary

- ALICE measured both real and virtual photons to study early stage of hot and dense QCD matter.
  - Direct photons from small to large systems
  - DCA_{ee} analysis to separate heavy-flavor and thermal radiation
  - Dielectron excess at very low $p_{T,ee}$ in peripheral collisions with hadronic overlap

- EM probes become even more exciting in Run 3, 4 and ALICE 3.
  - High-rate data acquisition
  - Precise vertexing with retractable inner tracker
  - Particle identification down to low p_T

Low-$p_{T,ee}$ dielectron excess in peripheral Pb-Pb collisions

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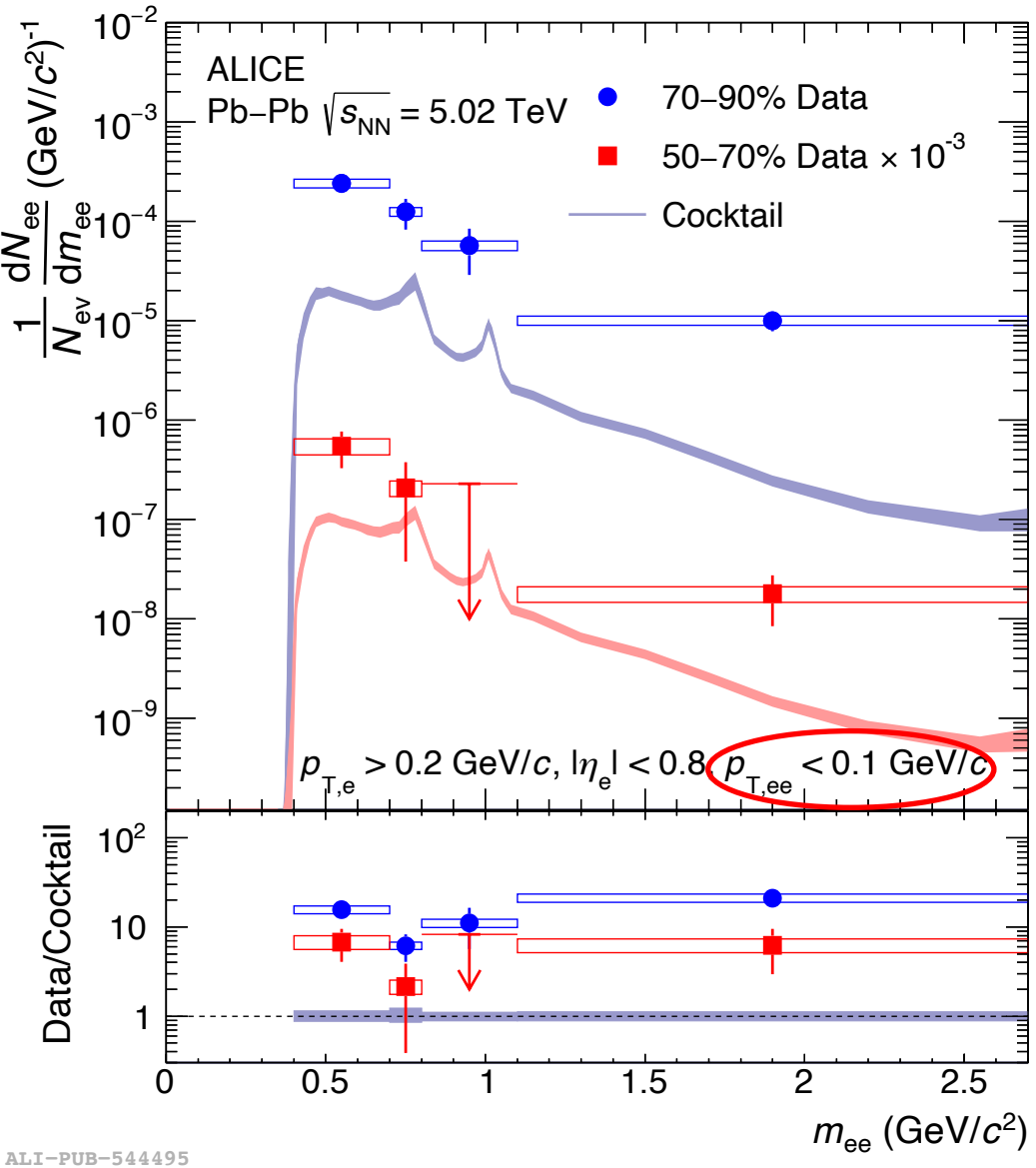

- An excess beyond hadronic cocktail
  - larger significance in peripheral collisions

$p^2_{T,ee}$ spectra in peripheral Pb-Pb collisions

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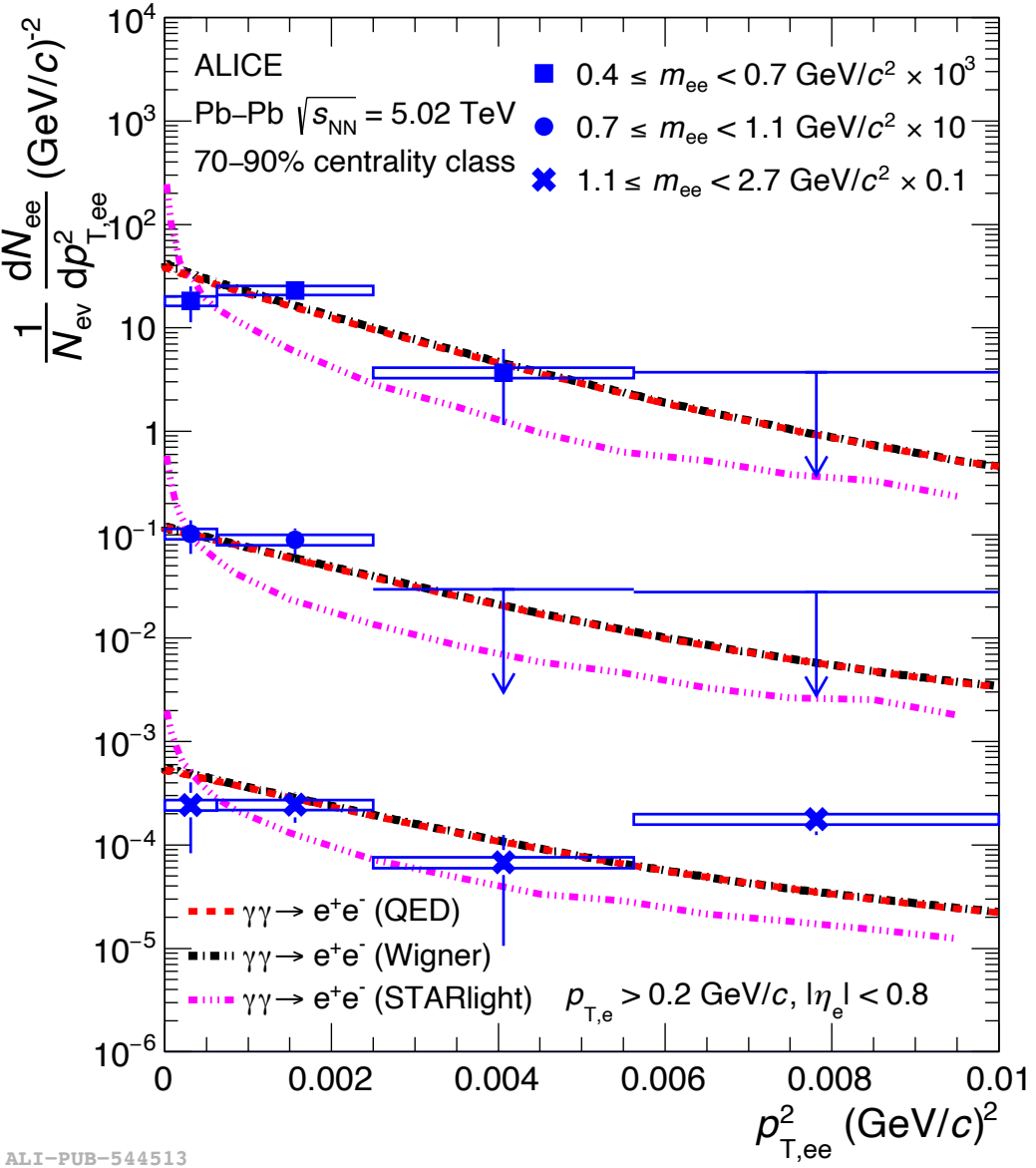
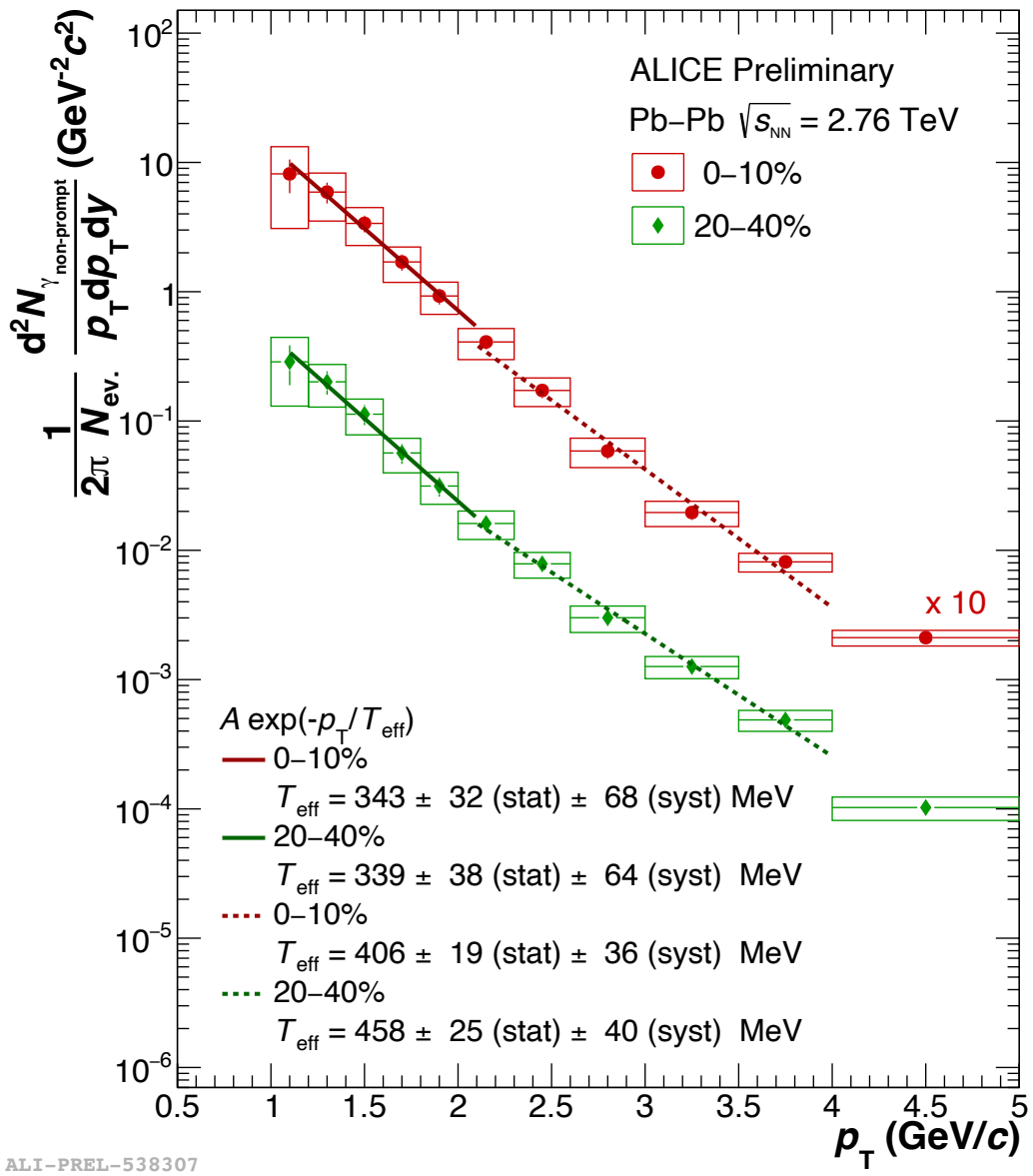


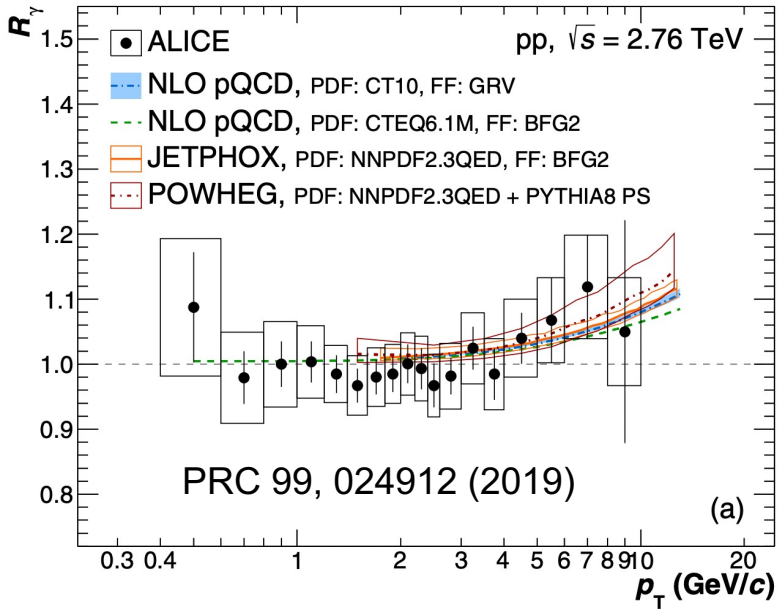
- The lowest-order QED and Wigner formalism can produce the excess yields.
- STARlight falls below data point $p^2_{T,ee}$ > 6.25e-4 (GeV/c)^2
  - k_T-factorization approach used in STARlight lacks impact parameter dependences which is clearly visible in the experimental measurements
- The data support the statement that the $p_{T,ee}$ broadening observed in hadronic heavy-ion collisions, in comparison to those in UPC, originates predominantly from the initial EM field strength that varies significantly with impact parameter.

Inverse slope T_{eff} of Nonprompt direct photon $\gamma_{\mathrm{AA}}^{\mathrm{Nonprompt}} = \gamma_{\mathrm{AA}}^{\mathrm{direct}} - \langle \mathrm{N_{coll}} \rangle \times \gamma_{\mathrm{pp}}^{\mathrm{direct}}$

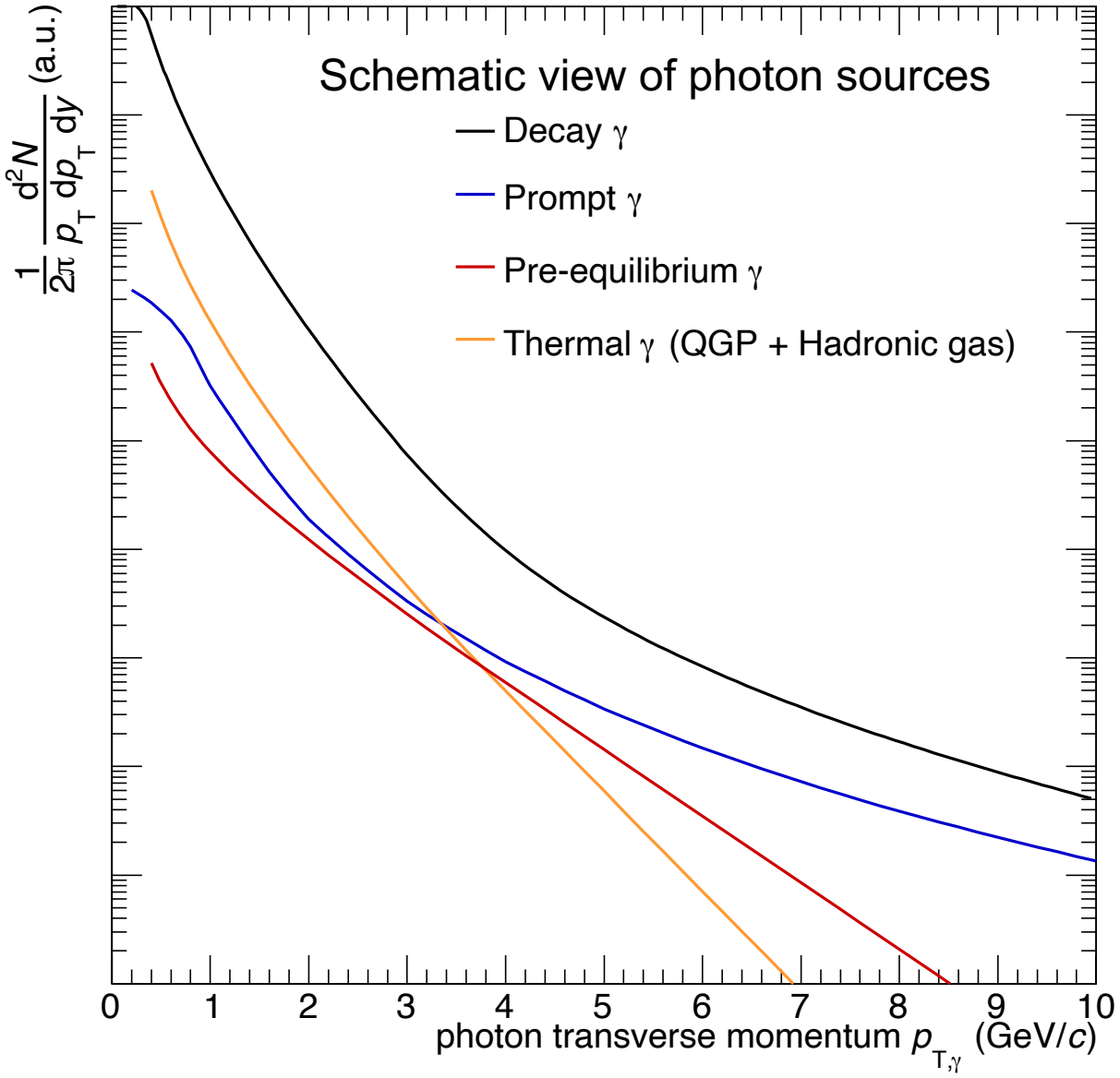


- Averaged temperature over space-time evolution
  - early temperature
  - expansion velocity (i.e. blue shift)

- First nonprompt direct photon at the LHC
  - $\gamma^{\mathrm{nonprompt}} = \gamma^{\mathrm{direct}} - \gamma^{\mathrm{pQCD}}$



Direct photons

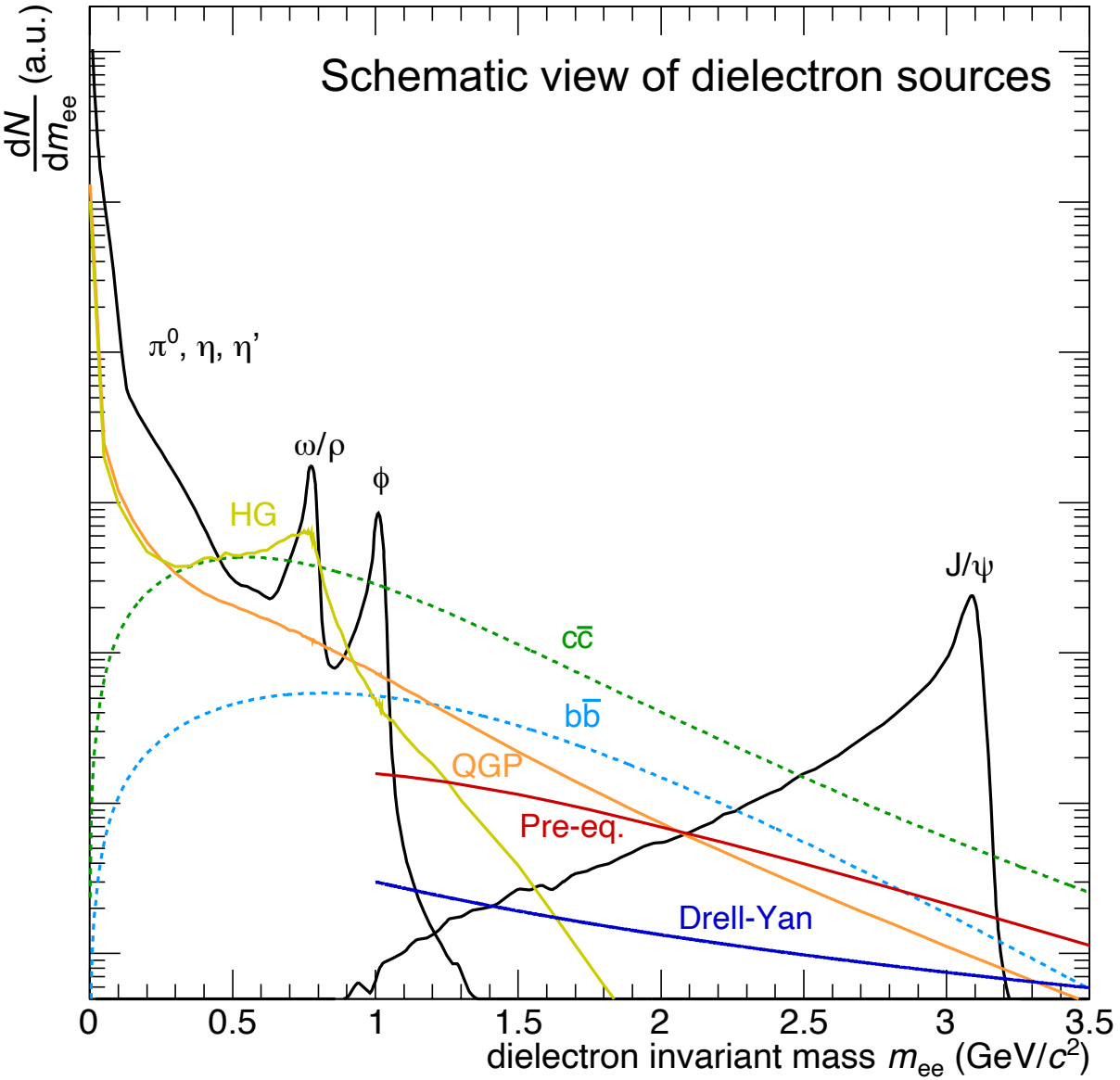


- Prompt photon from initially hard scatterings
- Pre-equilibrium photon
- Thermal photon from QGP + hadronic gas
- Large background from hadronic decays

Sources are distinguishable by different p_T ranges:

yield, v_2 and inverse slope with blueshift provide information on early stages + models

Dielectrons ($\gamma^* \rightarrow e^+e^-$)



- Invariant mass not affected by radial flow of expanding medium

→ accessible to early stage of QGP without blueshift

- Thermal radiation from hadronic gas

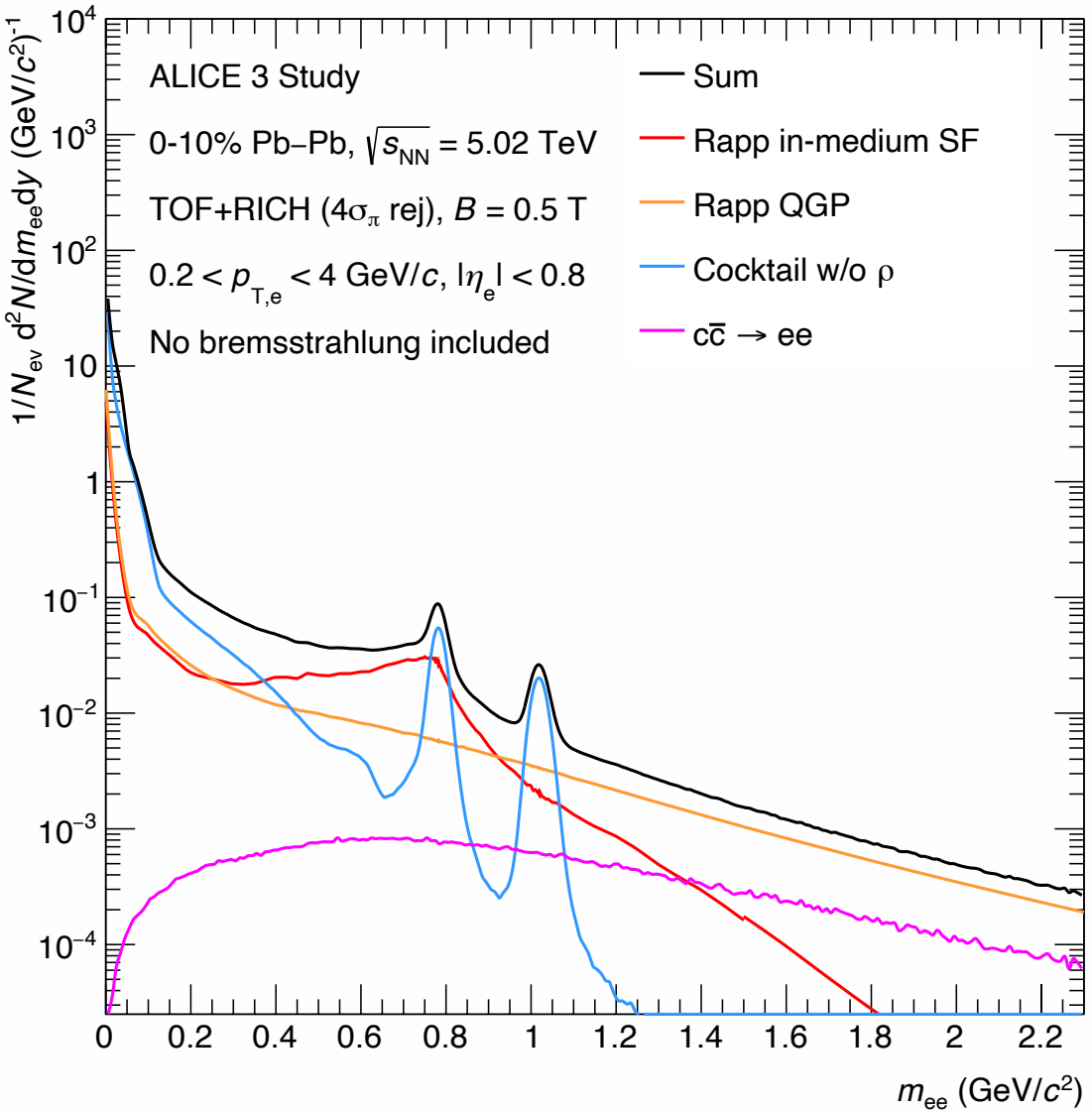
→ sensitive to in-medium spectral function of ρ meson

- Smaller production yield than that of real photon
- Large backgrounds from:

  - light-flavor hadrons

  - semileptonic decays of correlated heavy-flavor hadrons

Future plan : ALICE3



- Strong charm rejection thanks to silicon technique
- Accessible to in-medium SF of ρ meson
  - study chiral symmetry restoration
- Thermal radiation from early stage of QGP
  - determine QGP properties at early stage
- Pre-equilibrium radiation
  - how equilibrated system is formed from purely gluonic system