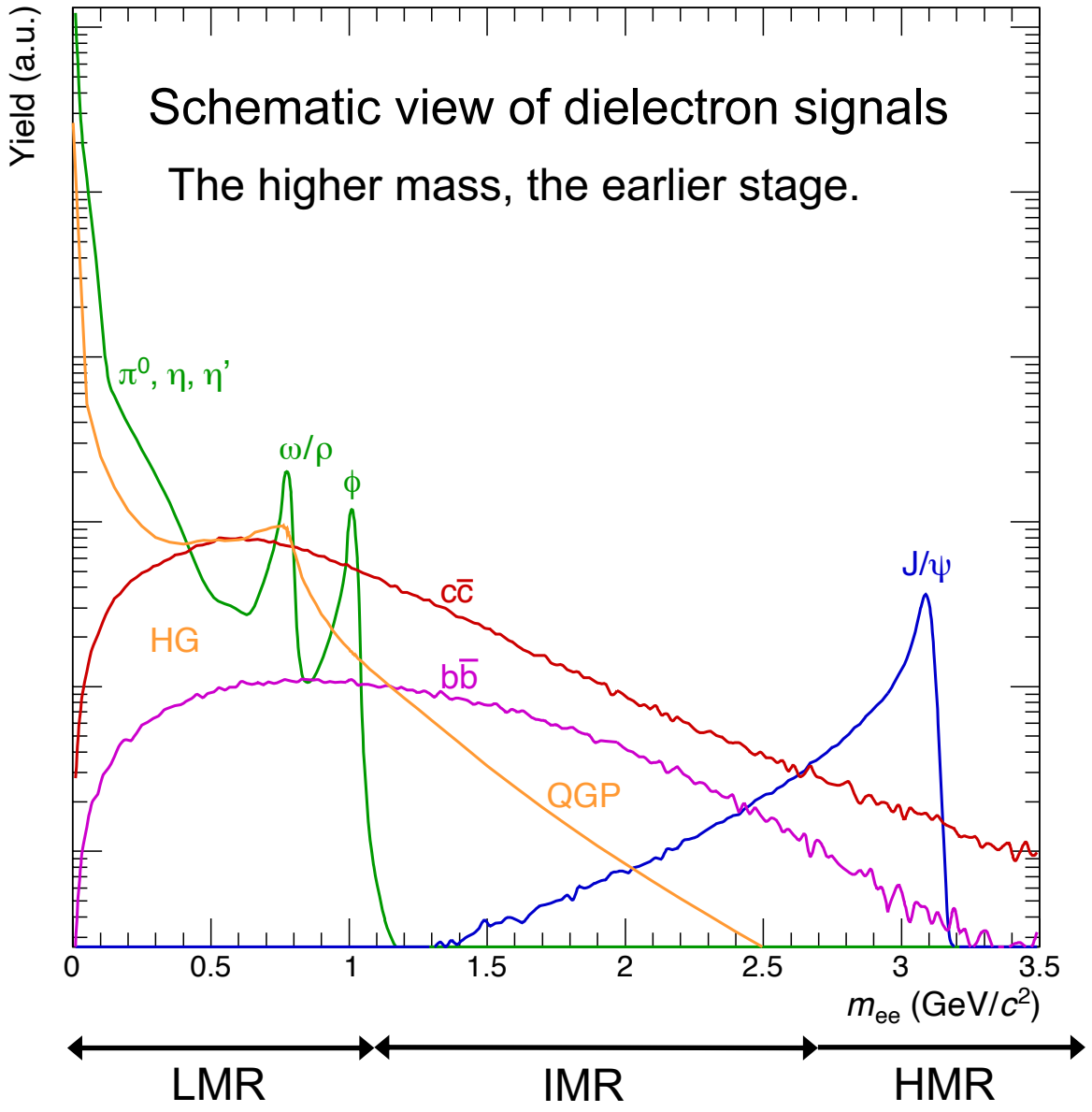
Thermal radiation and direct photon production in Pb-Pb and pp collisions with dielectrons in ALICE

Daiki Sekihata for the ALICE Collaboration
Center for Nuclear Study, the University of Tokyo

ICHEP2022, 06-13.July.2022

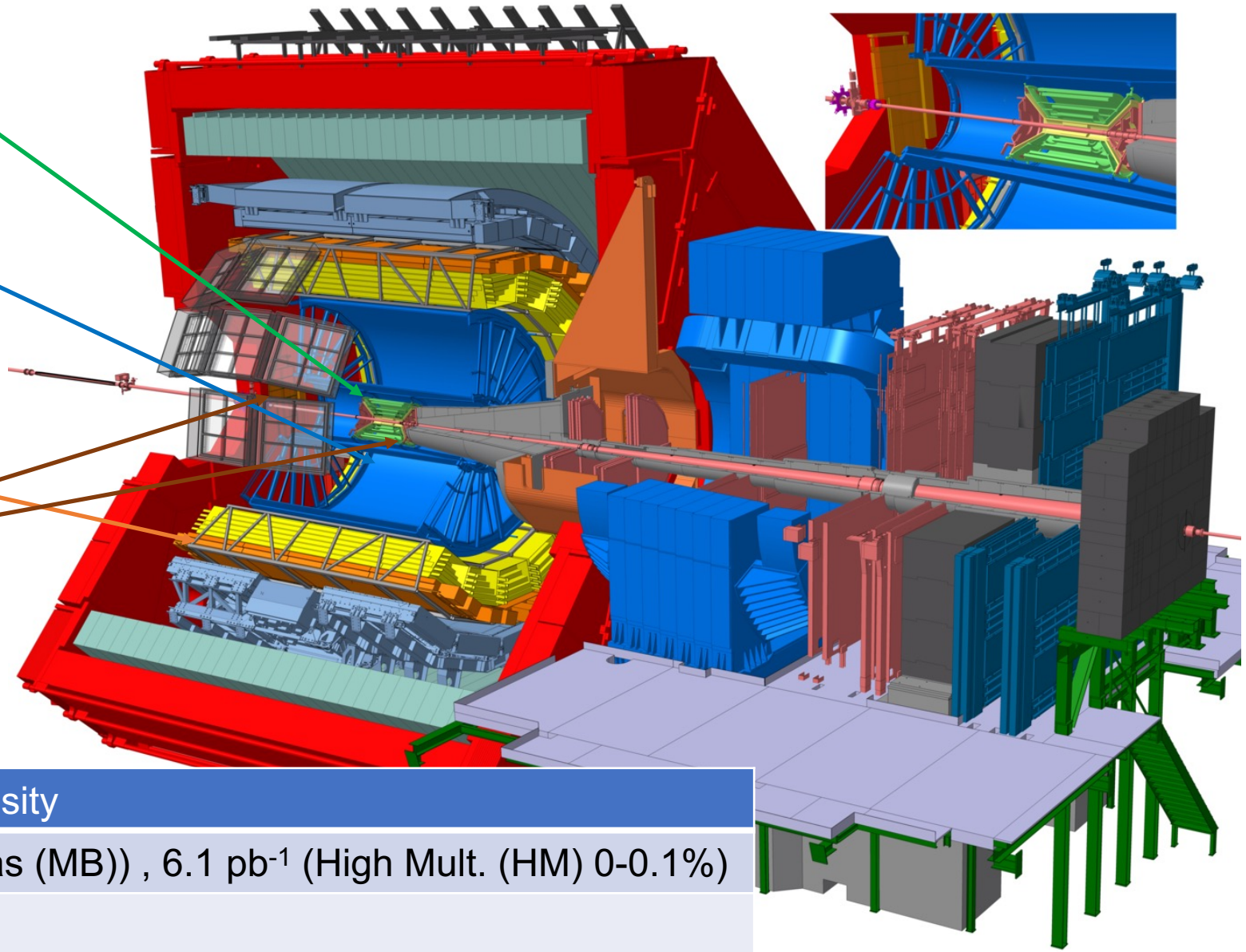
Physics motivations in dielectron measurements



- Low mass region (LMR) : m_{ee} < 1.1 GeV/c^2
  - Modification of spectral function for ρ meson to study chiral symmetry restoration
  - Thermal radiation from QGP and hadronic gas
    -- Virtual direct photons $\gamma^* \rightarrow e^+e^-$ at $m_{ee} \rightarrow 0$
- Intermediate mass region (IMR) : 1.1 < m_{ee} < 2.7 GeV/c^2
  - Semileptonic decays from correlated heavy-flavor hadrons (HF)
  - Thermal radiation from QGP
  - Dielectrons from pre-equilibrium
- High mass region (HMR) : 2.7 GeV/c^2 < m_{ee}
  - Semileptonic decays from correlated heavy-flavor hadrons (HF)
  - Quarkonia
  - Drell-Yan process

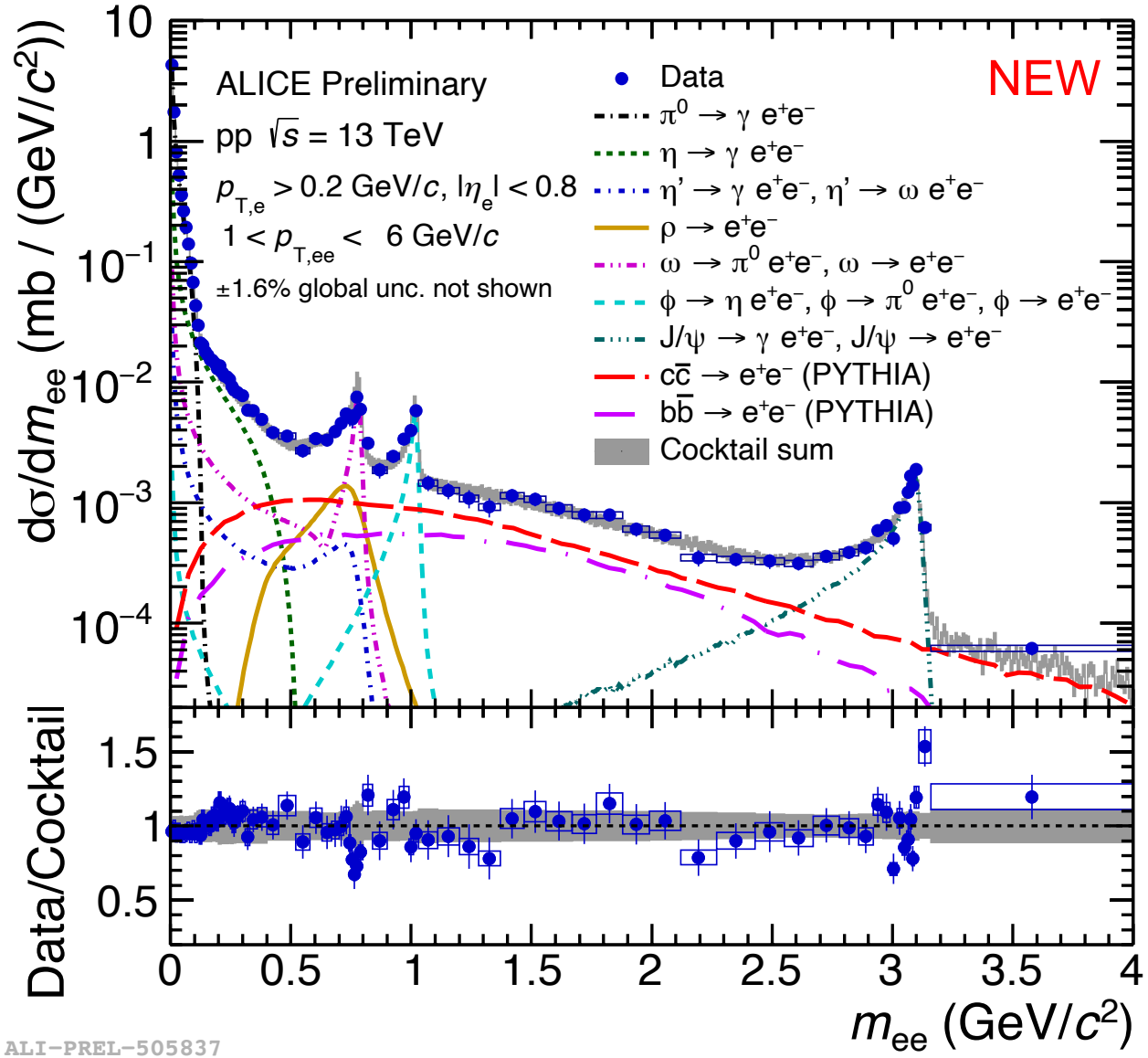
ALICE apparatus at the LHC

- 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 estimation



collision system	analyzed luminosity
pp at $\sqrt{s}$ = 13 TeV	30 nb^{-1} (Min. Bias (MB)) , 6.1 pb^{-1} (High Mult. (HM) 0-0.1%)
Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV	84 μb^{-1} (0-10%)

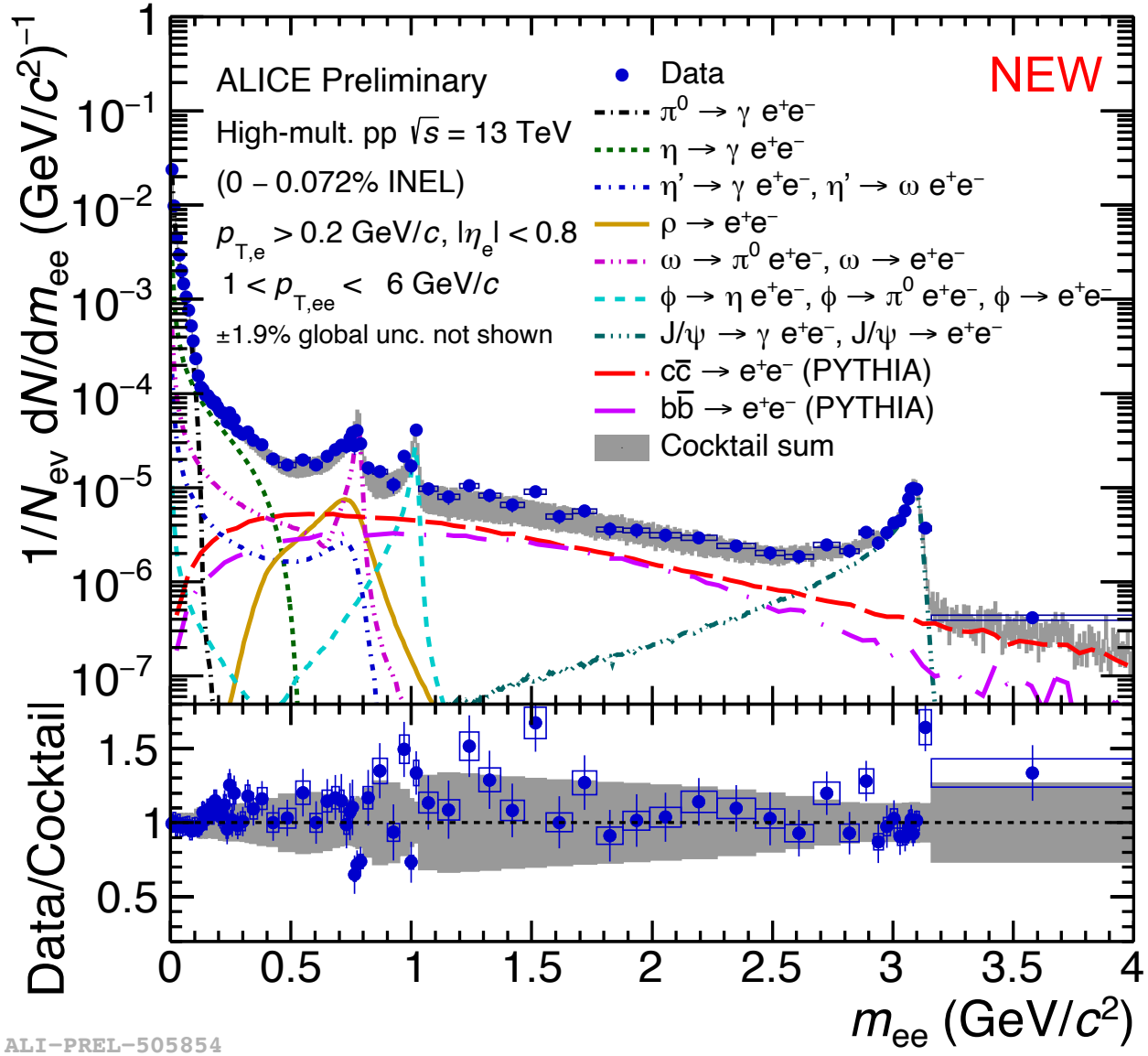
Dielectron production in MB pp at $\sqrt{s}$ = 13 TeV



- Full statistics in Run 2 data
  - 4 times more data compared to previous publication. PLB 788 (2019) 505
- Described by hadronic cocktail.
- The hadronic cocktail updated with measured neutral mesons
  - at the same energy
  - in the same multiplicity class

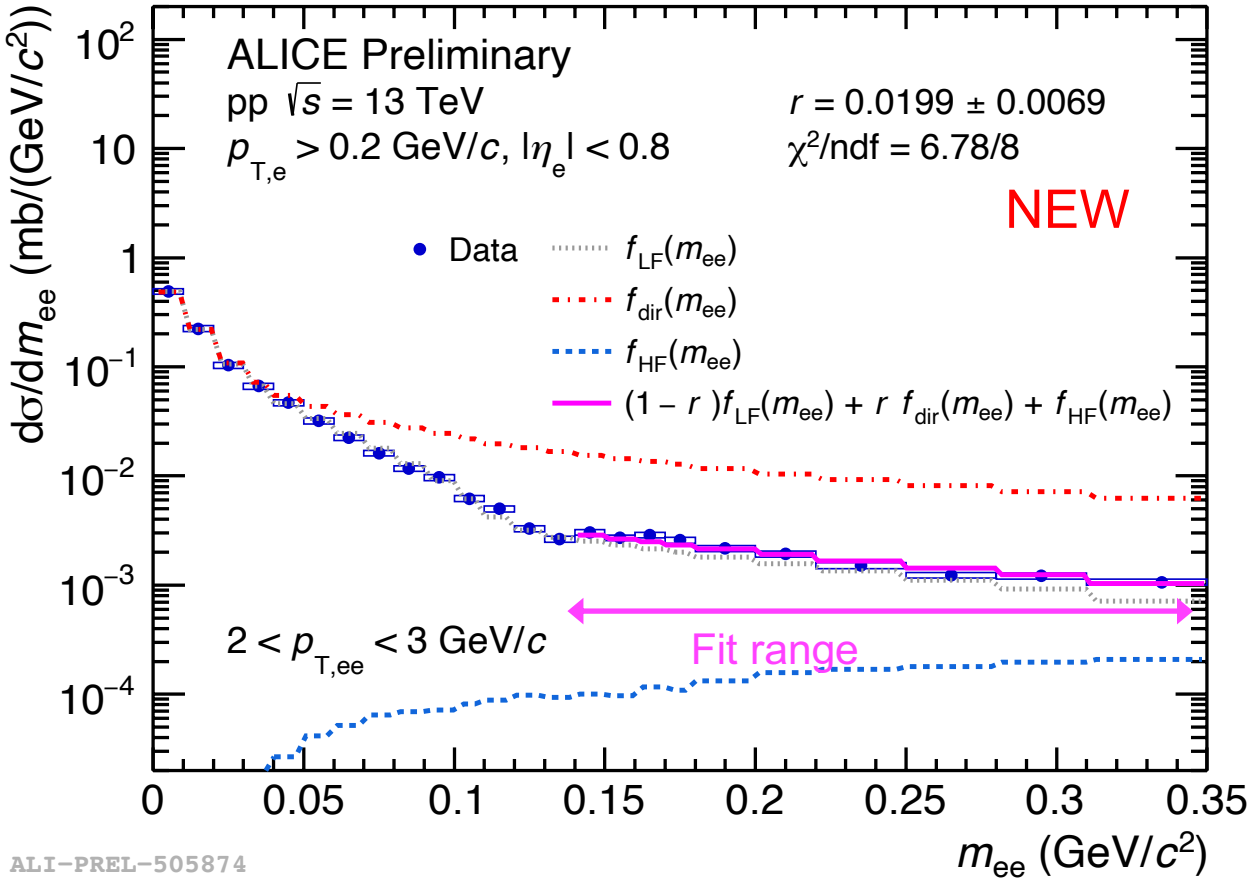
Joshua Koenig (neutral mesons)
07.July.2022 at 11:30, Strong interactions and Hadron Physics

Dielectron production in HM pp at $\sqrt{s}$ = 13 TeV



- Full statistics in Run 2 data
  - 4 times more data compared to previous publication. PLB 788 (2019) 505
- Described by hadronic cocktail.
- The hadronic cocktail updated with measured neutral mesons
  - at the same energy
  - in the same multiplicity class
- No excess of thermal radiation in HM pp at the IMR within uncertainty.
  - Large syst. unc. due to multiplicity dependence of HF production.

Extraction of direct photon fraction *r* via internal conversion



- $\gamma^{direct} = \gamma^{inc} - \gamma^{decay}$
  Photons not originating from hadron decays

- Template fit with light-, heavy-flavor hadrons and direct photons.
  - $d\sigma/dm_{ee} = r \times f_{dir} + (1-r) \times f_{LF} + f_{HF}$
  - r is the only free parameter.

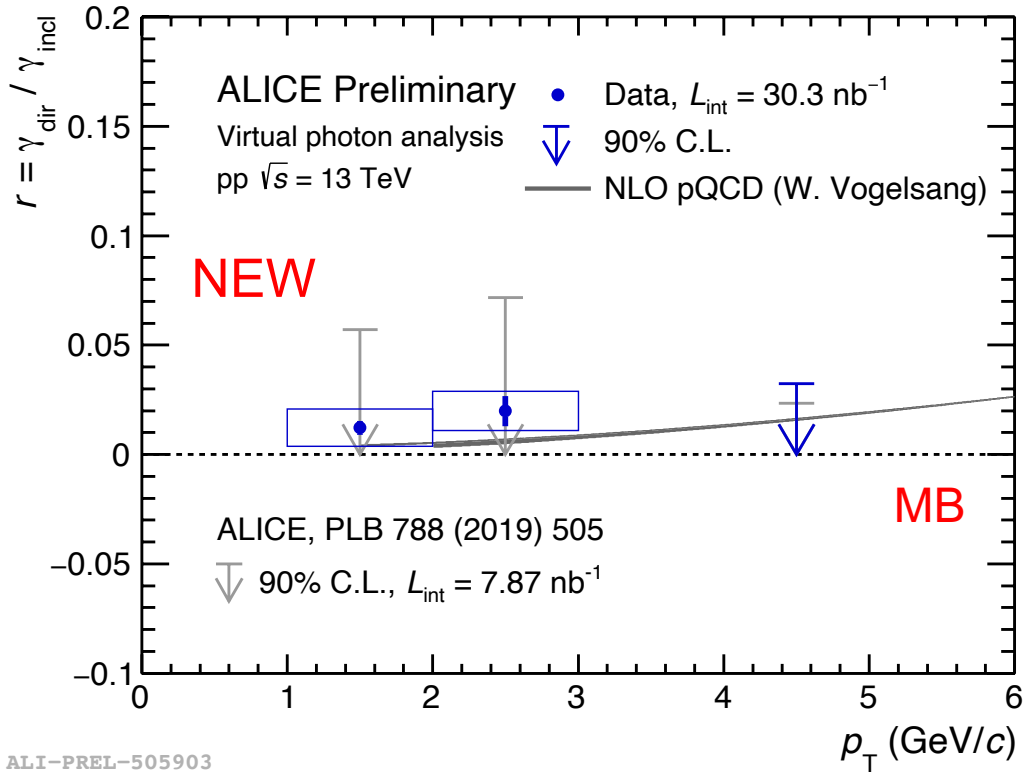
- r is extracted from m_{ee} > 140 MeV/c^2 to suppress π^0 background.

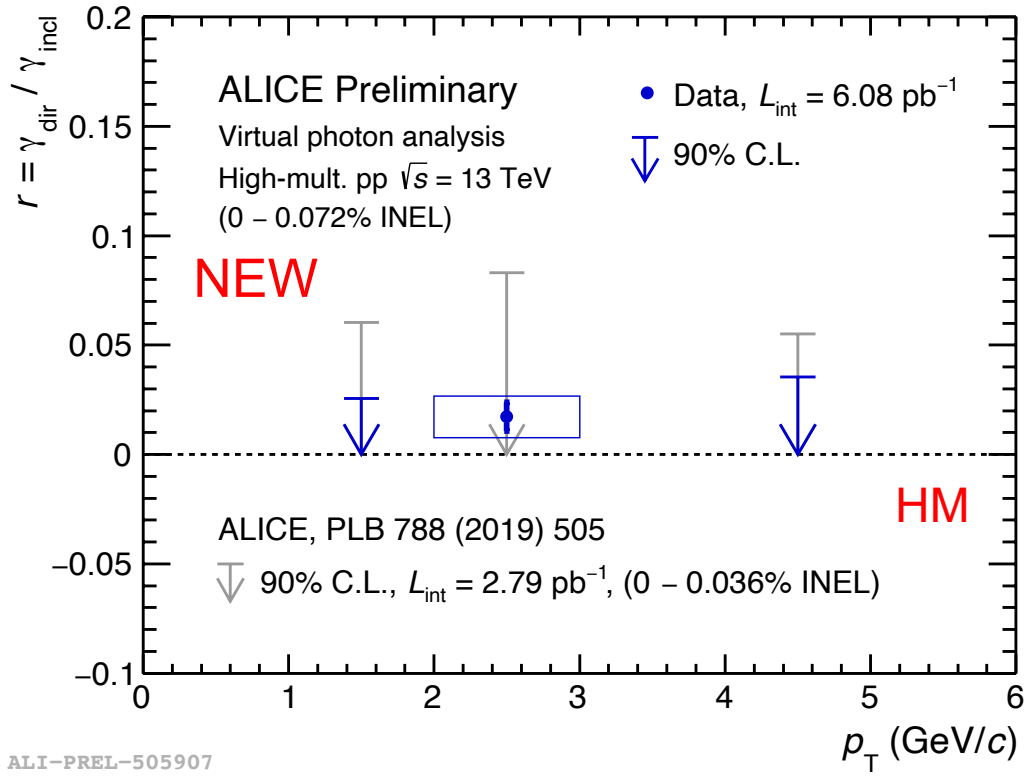
$$\frac{d^2N}{dm_{ee}dp_T} = \frac{2\alpha}{3\pi}\frac{1}{m_{ee}}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)\frac{dN}{dp_T}$$

N.M. Kroll and Walter Wada , Phys. Rev. 98, 1355

Direct photon template f_{dir} is described by KW formula.

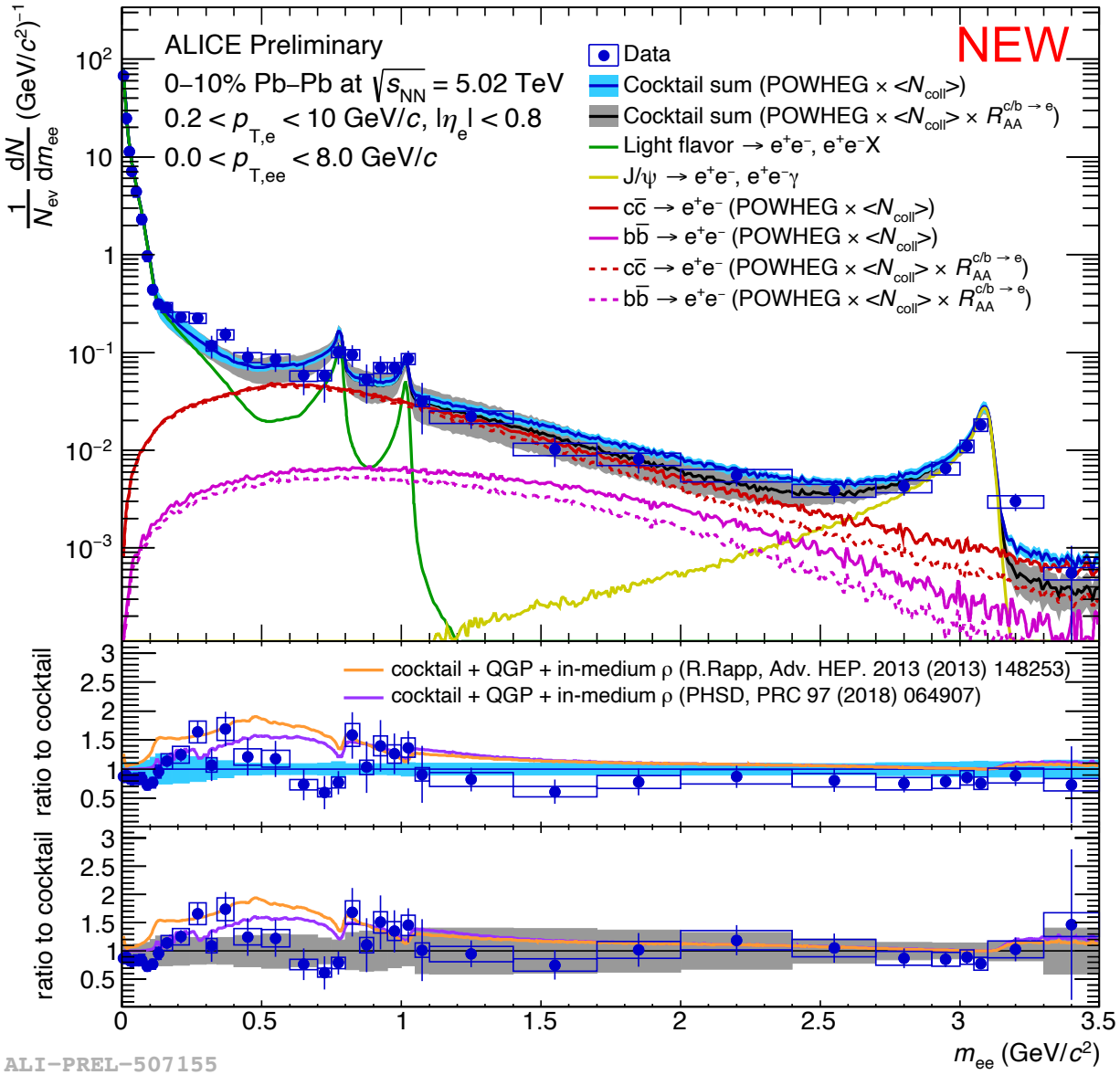
Direct photon fraction in pp at $\sqrt{s}$ = 13 TeV





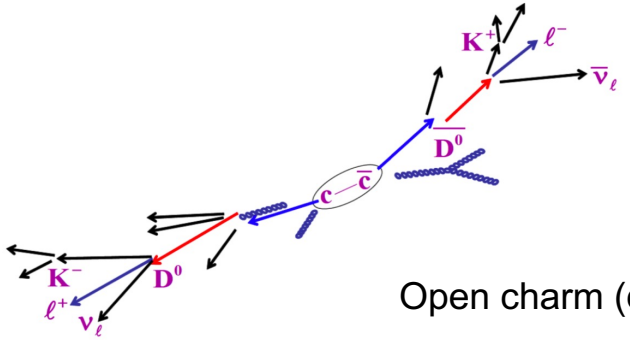
- Significant reduction of both stat. and syst. unc., compared to the previous ALICE paper
- Similar direct photon fraction in MB and HM pp collisions
  - understand the direct photon yield vs. dN_{ch}/dη from small to large systems
  - search for onset of thermal radiations in small system

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



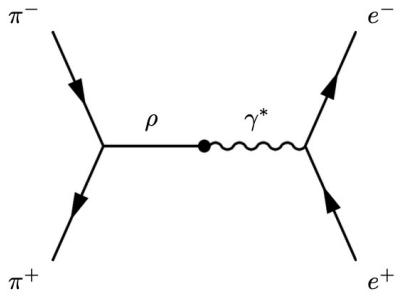
- Comparison to hadronic cocktails
  - N_{coll}-scaled HF (PRC 102 (2020) 055204)
  - Modified HF by R_{AA} of c/b→e (PLB 804 (2020) 135377)

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

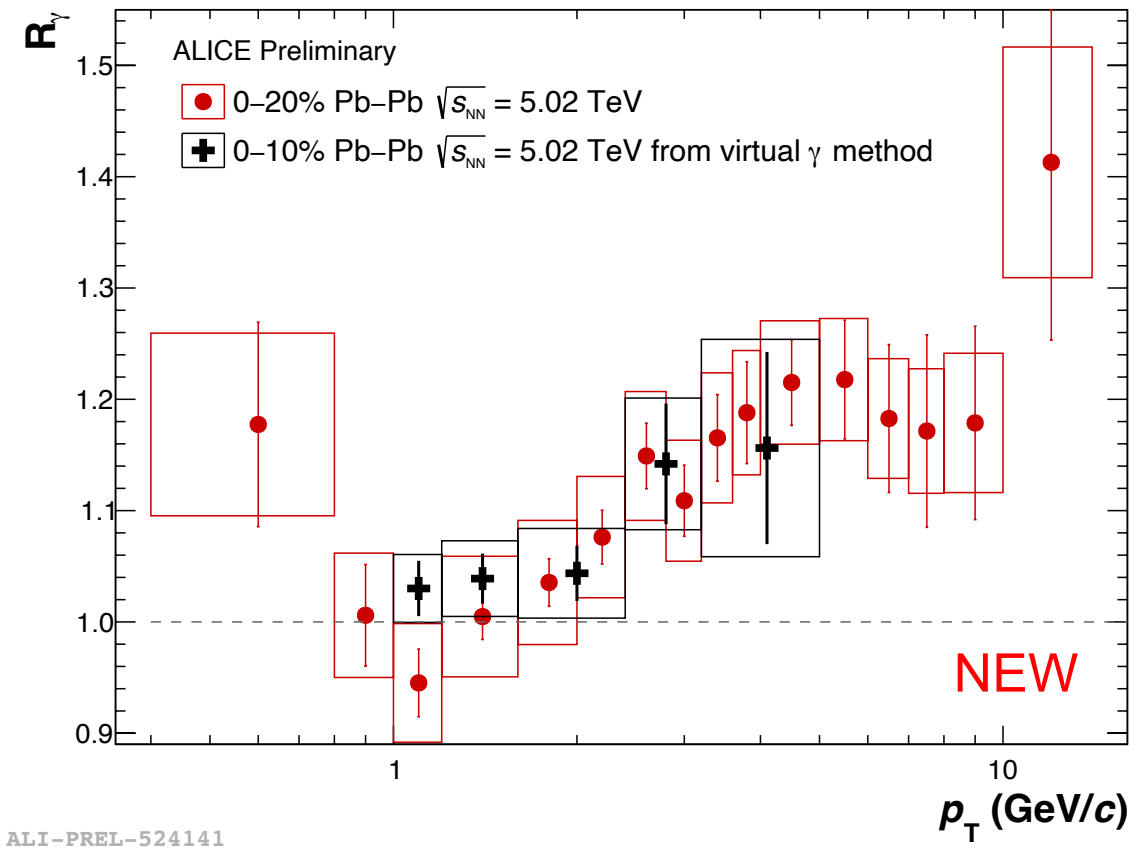


Open charm (de)correlation

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



Direct photon excess ratio in central Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

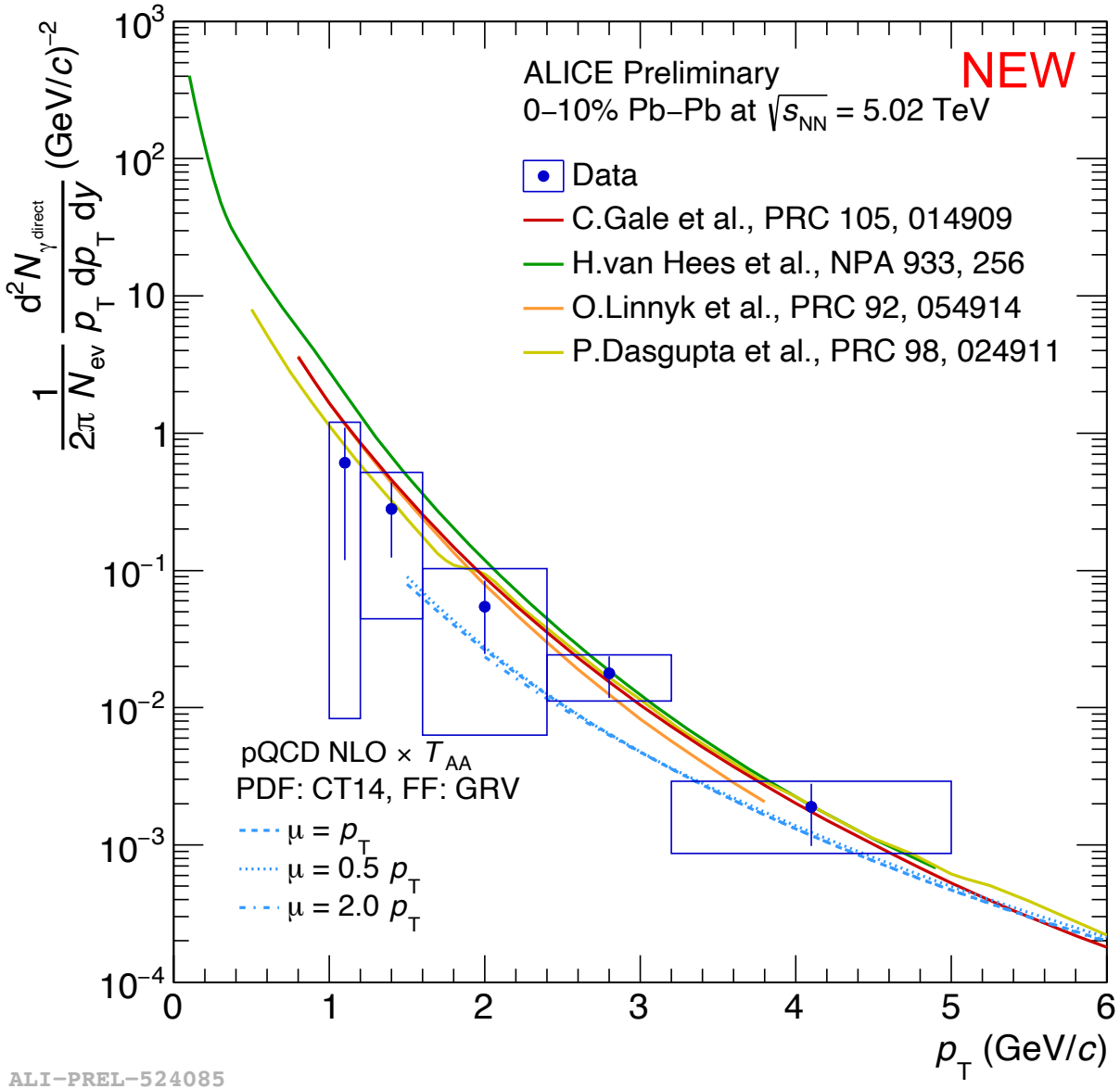


$$R_\gamma = \frac{\gamma_{\mathrm{inc}}}{\gamma_{\mathrm{decay}}} = 1 + \frac{\gamma_{\mathrm{direct}}}{\gamma_{\mathrm{decay}}} = \frac{1}{1 - r}$$

Mike Sas (real direct photons)
07.July.2022 at 18:40, Heavy Ions

- Good agreement between real and virtual direct photons
- First measurement in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
  - Smaller systematic uncertainty compared to real photons at low p_T.
  - Systematic uncertainty dominated by η/π^0.
  - Statistically hungry

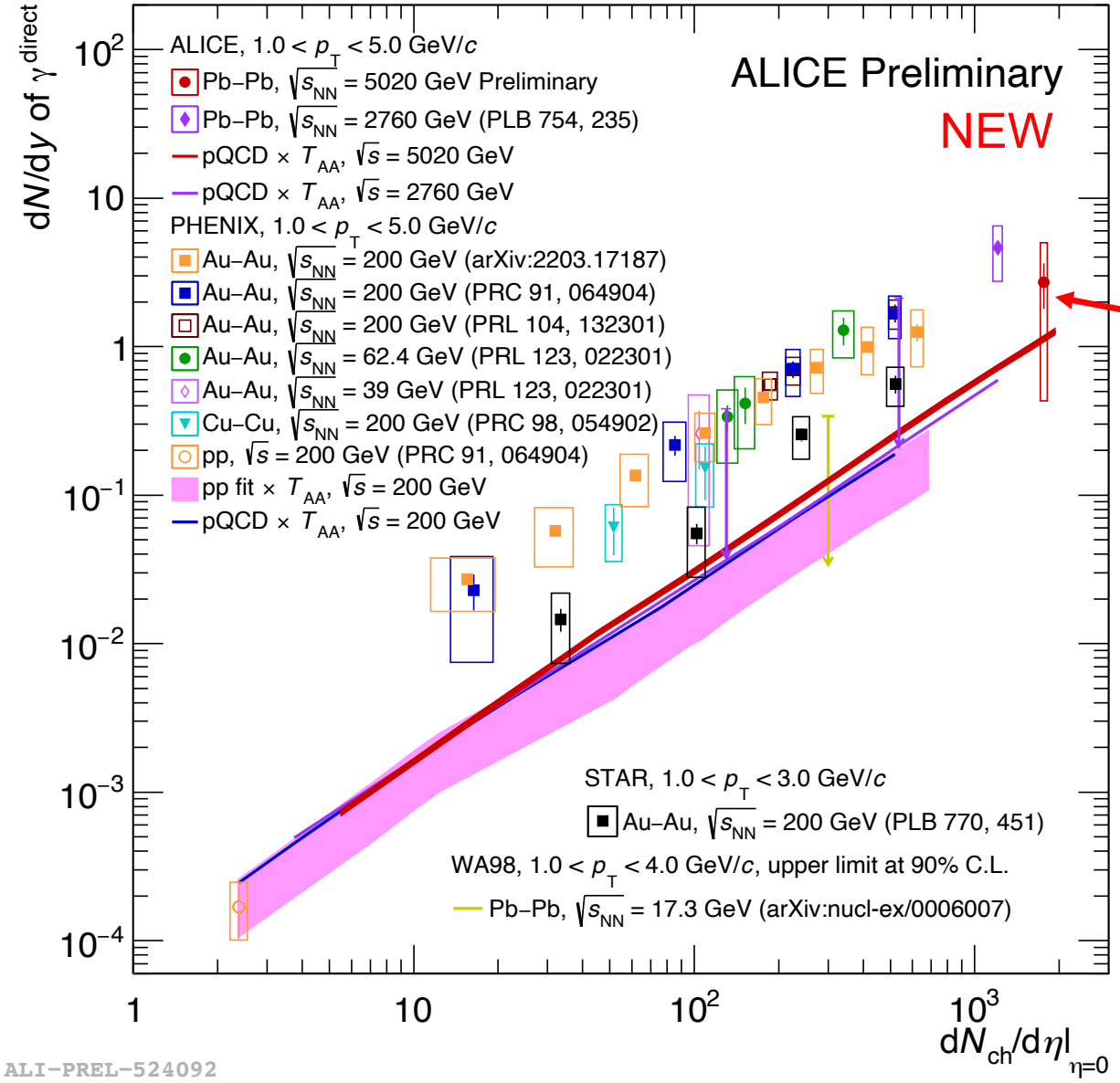
Direct photon spectrum with theory curves



- First measurement in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
  - γ^{inc} constructed with photon conversion method.
  - $\gamma^{direct} = r \times \gamma^{inc}$
- A hint of an excess above pQCD
- Theoretical models with thermal radiation tend to predict higher yields than data at low p_T.

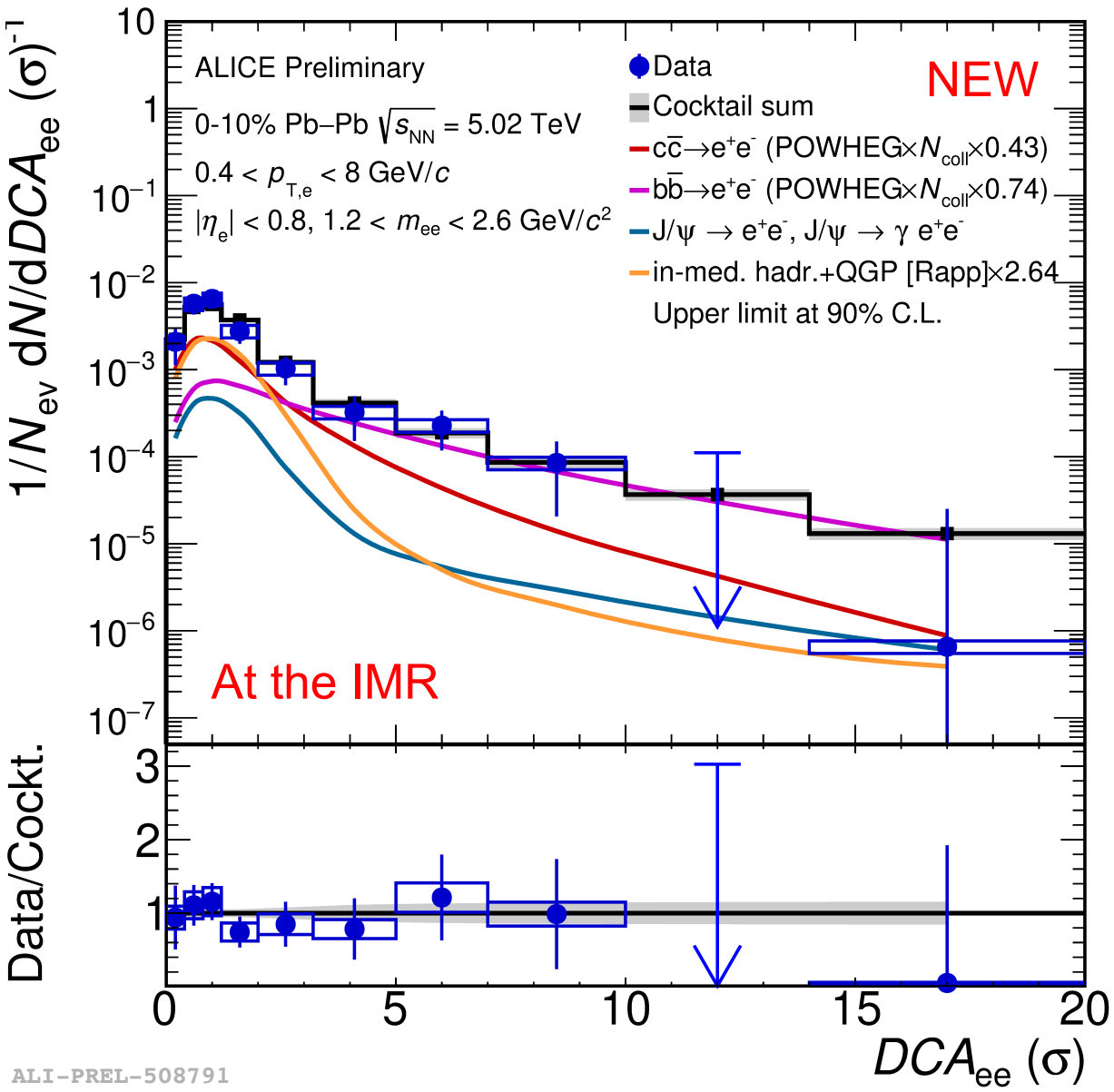
- C.Gale : EM radiation from all stages including pre-equilibrium
- H.van Hees : Thermal radiation from QGP
  + hadronic many body system
- O.Linnyk : Direct photons in microscopic transport model
- P.Dasgupta : Thermal photons with fluctuations in the initial stage

d*N*/d*y* of direct photon vs. multiplicity

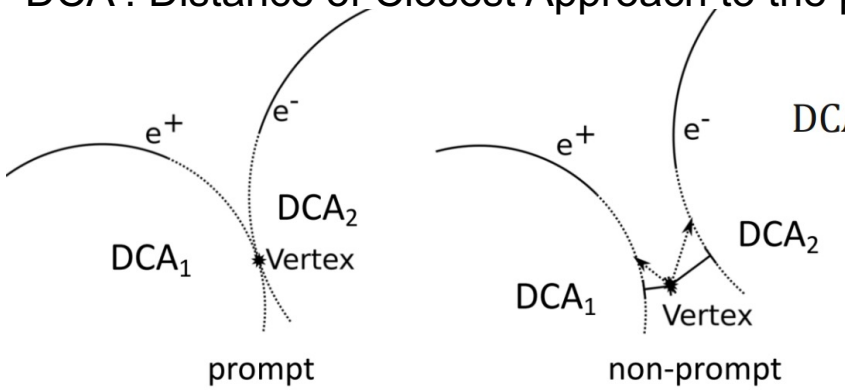


- First measurement in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
- A hint of an excess above pQCD
- Universal scaling suggested by PHENIX still holds with the new ALICE data.
  - Consistent with extrapolation from both PHENIX and STAR.

First DCA_{ee} analysis in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV



DCA : Distance of Closest Approach to the primary vertex



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

topological separation : DCA_{ee} (thermal rad.) < DCA_{ee} (HF)

- First attempt to extract scaling factor for HF and thermal radiation (R.Rapp) from DCA_{ee} template
  - fix $b\bar{b}$ component at large DCA_{ee}
  - free param. : $c\bar{c}$ and thermal radiation

$b\bar{b}$: 0.74 ±0.24 (stat.) ±0.12 (syst.) (w.r.t. N_{coll} scaling)

$c\bar{c}$: 0.43 ±0.40 (stat.) ±0.22 (syst.) (w.r.t. N_{coll} scaling)

thermal: 2.64 ±3.18 (stat.) ±0.29 (syst.) (w.r.t. R. Rapp)

Larger statistics (x100) and better vertexing resolution will give us strong separation power in Run 3 and beyond.

Summary

- In pp collisions at $\sqrt{s}$ = 13 TeV :
  - Direct photon fraction measured with full statistics of Run 2 data
  - Similar direct photon fraction in MB and HM events

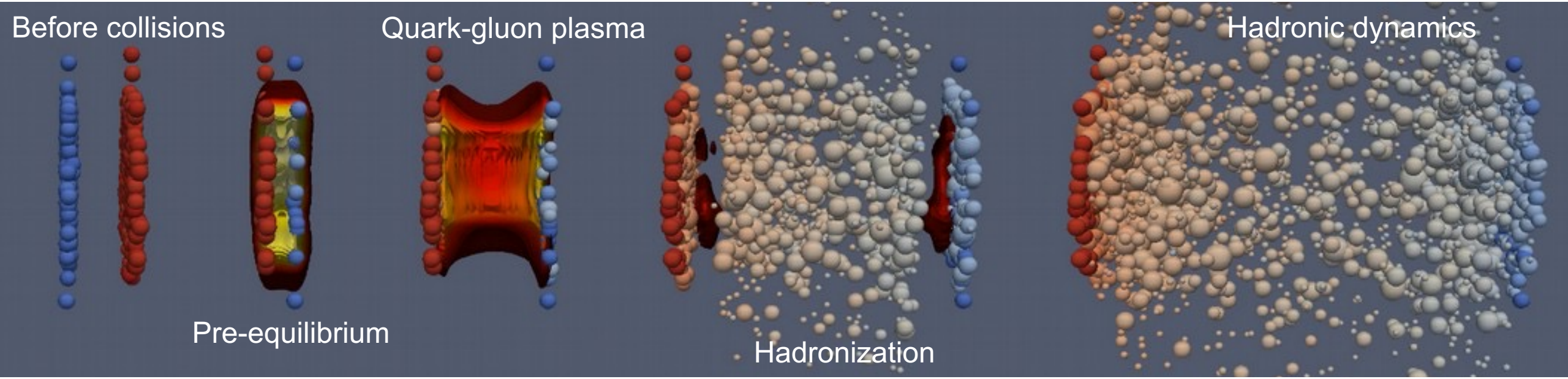
- In central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV :
  - First measurement of virtual direct photon via dielectron with ALICE
  - A hint of direct photon excess above pQCD at low p_T
  - State-of-the-art model tends to predict higher direct photon yields.
  - Universal scaling of dN/dy of direct photon vs. $dN_{ch}/d\eta$ holds within large uncertainty
  - Need topological selection with DCA_{ee} to separate thermal radiation and HF suppression in Run 3 and beyond

backup

- backup

Physics motivation of photon/dielectron measurements

Emitted from all stages of the collision without final state interactions
- A unique tool to study space-time evolution of heavy-ion collisions and medium properties

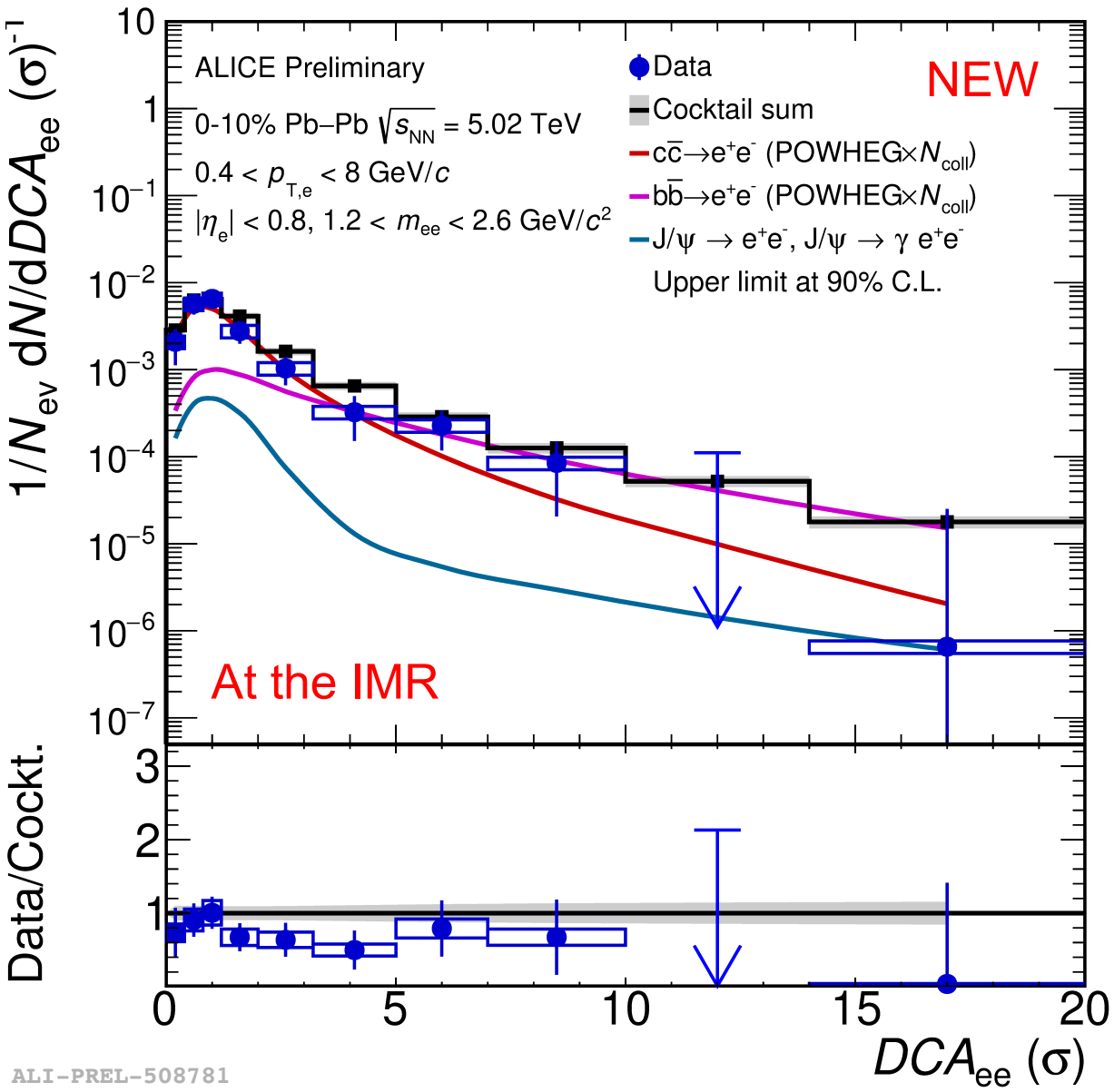


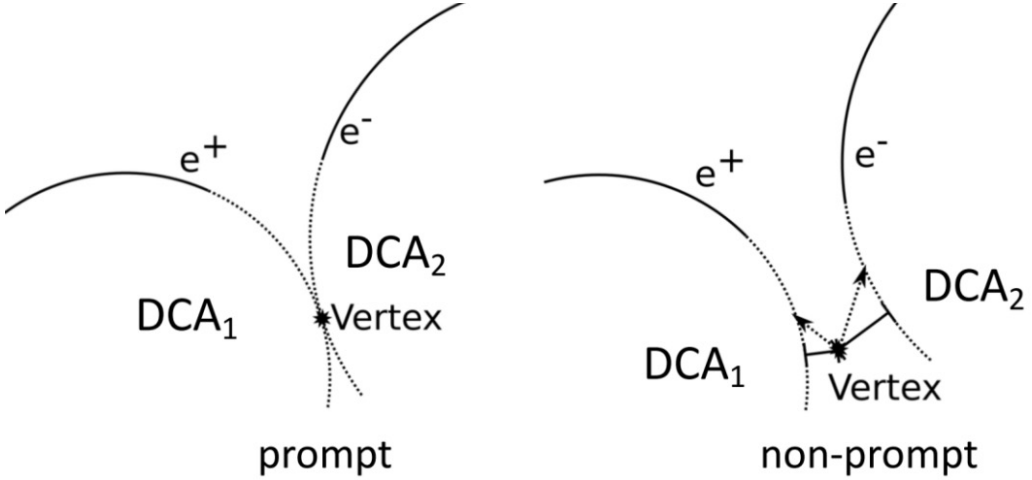
MADAI collaboration

- Prompt photons/dileptons via hard scatterings of in-coming partons
- Electromagnetic radiation from pre-equilibrium stage
- Thermal radiation from QGP
- Thermal radiation from hadronic gas
- Decay photons/dielectrons from hadrons

} main topics in this presentation

First DCA_{ee} analysis in Pb-Pb at 5.02 TeV

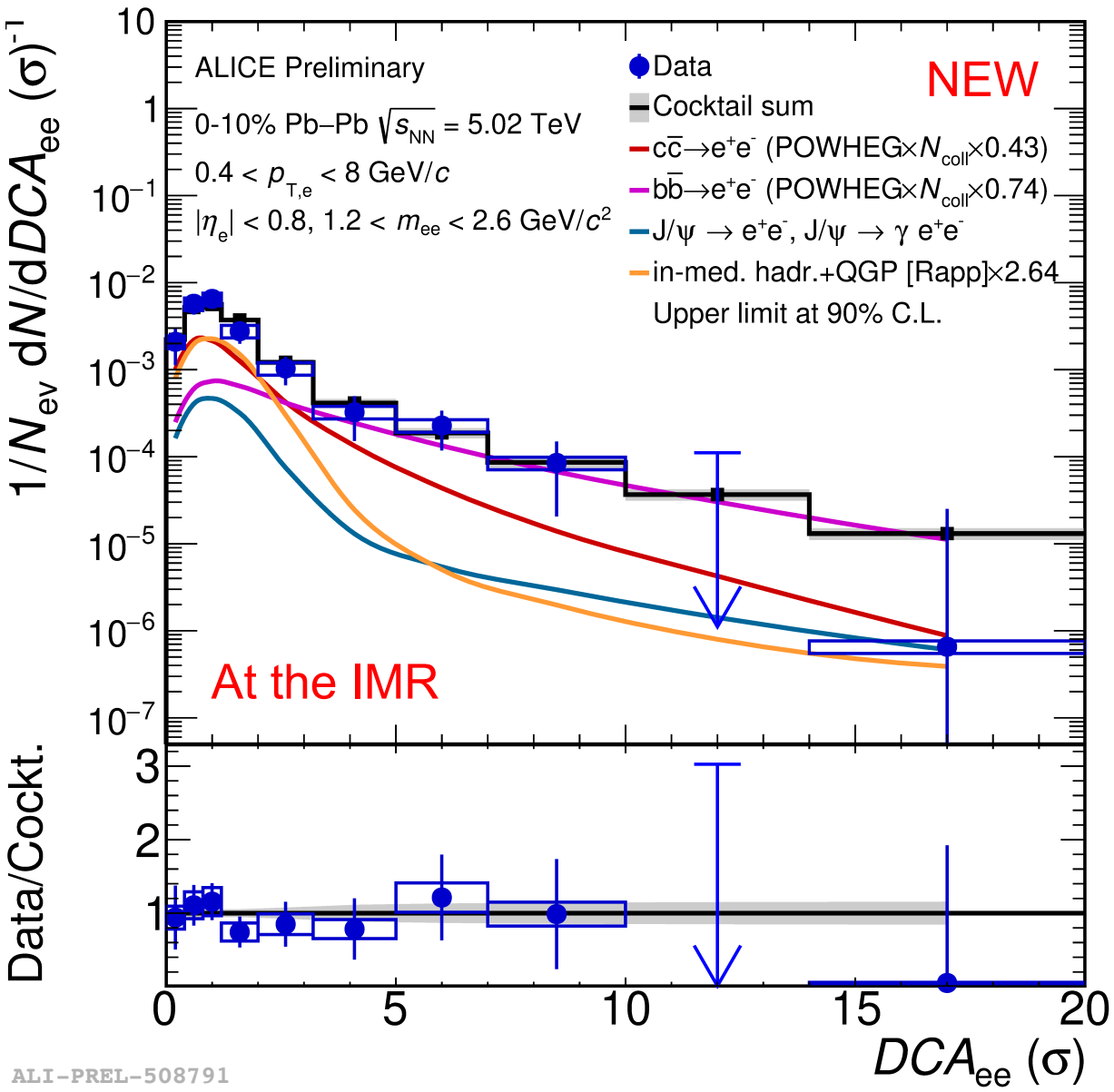




DCA_{ee} (thermal rad.) < DCA_{ee} (HF)

- A hint of HF suppression
  - $b\bar{b}$ dominates large DCA_{ee}

First DCA_{ee} analysis in Pb-Pb at 5.02 TeV



- First attempt to extract scaling factor for HF and thermal radiation (R.Rapp) from DCA_{ee} template
  - fix $b\bar{b}$ component at large DCA_{ee}
  - free param. : $c\bar{c}$ and thermal radiation

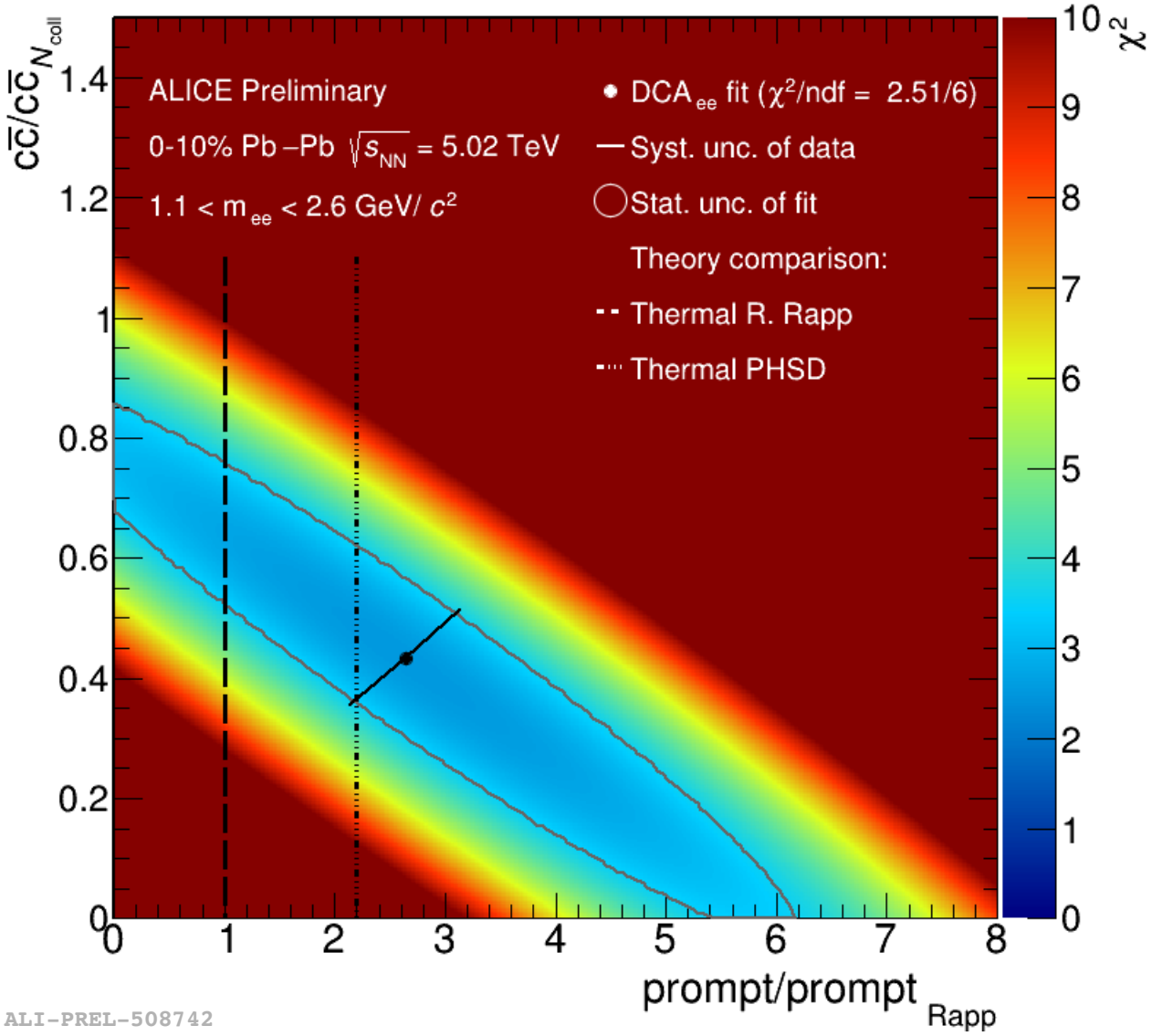
$b\bar{b}$: 0.74 ±0.24 (stat.) ±0.12 (syst.) (w.r.t. N_{coll} scaling)

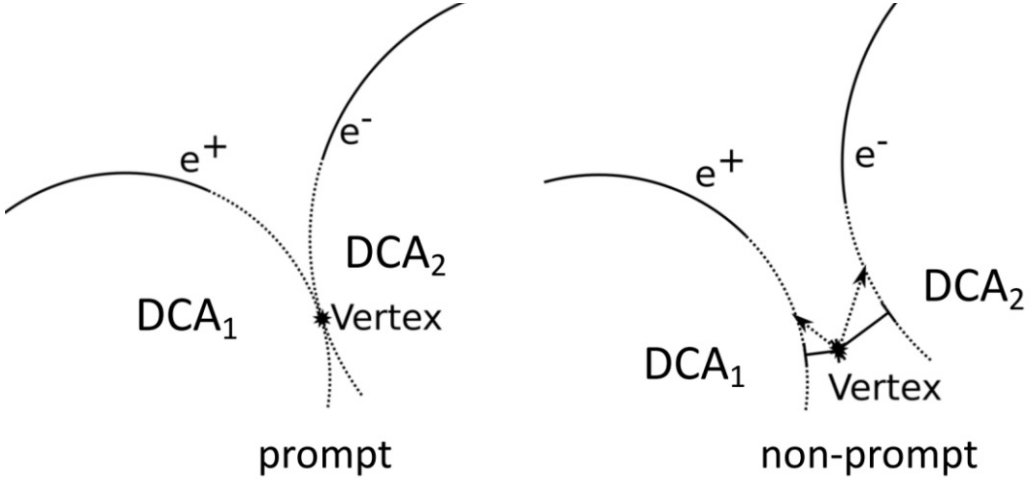
$c\bar{c}$: 0.43 ±0.40 (stat.) ±0.22 (syst.) (w.r.t. N_{coll} scaling)

thermal: 2.64 ±3.18 (stat.) ±0.29 (syst.) (w.r.t. R.Rapp)

Larger statistics and better vertexing resolution will give us strong separation power in Run 3 and beyond.

First DCA_{ee} analysis in Pb-Pb at 5.02 TeV

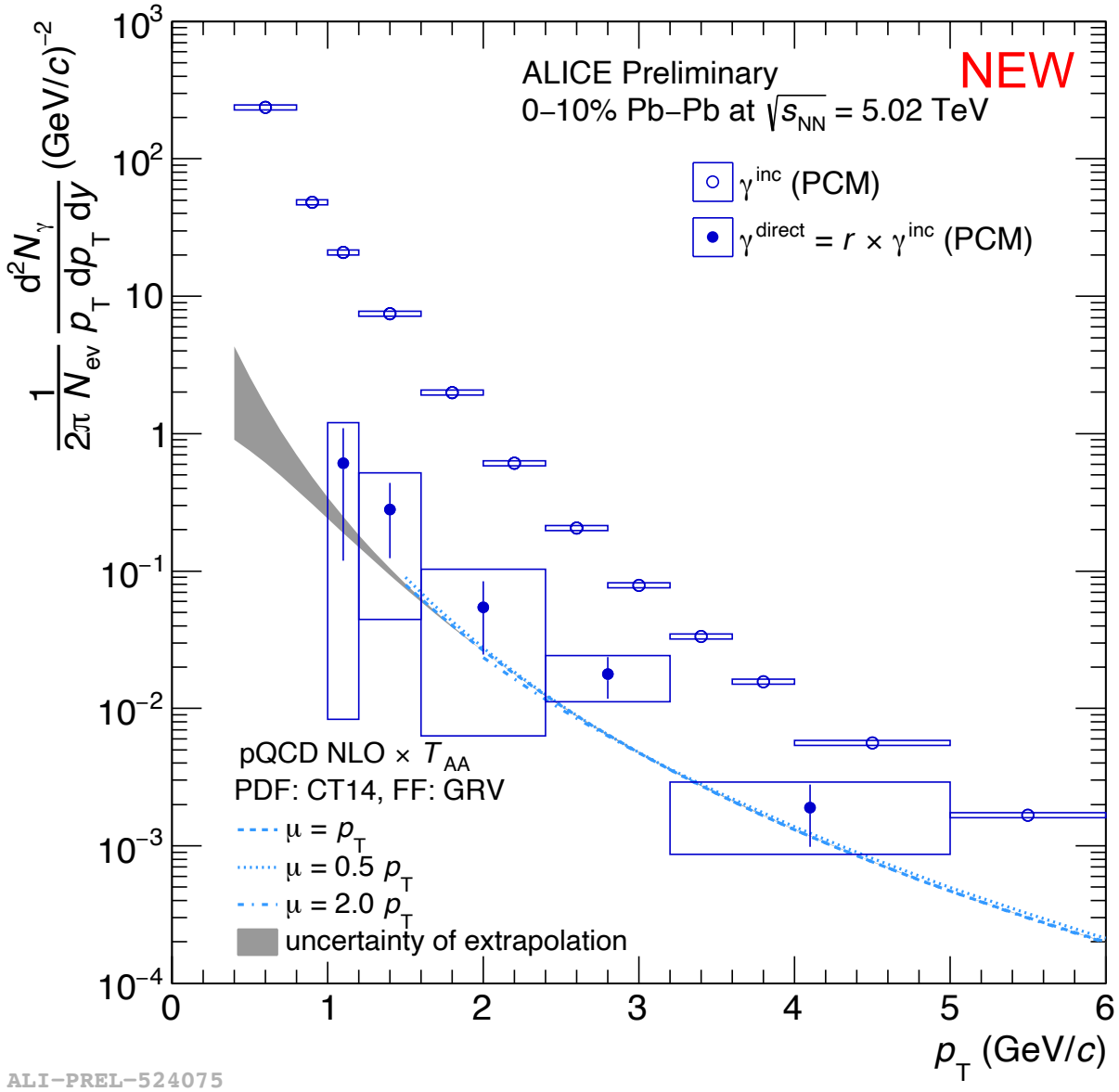




DCA_{ee} (thermal rad.) < DCA_{ee} (HF)

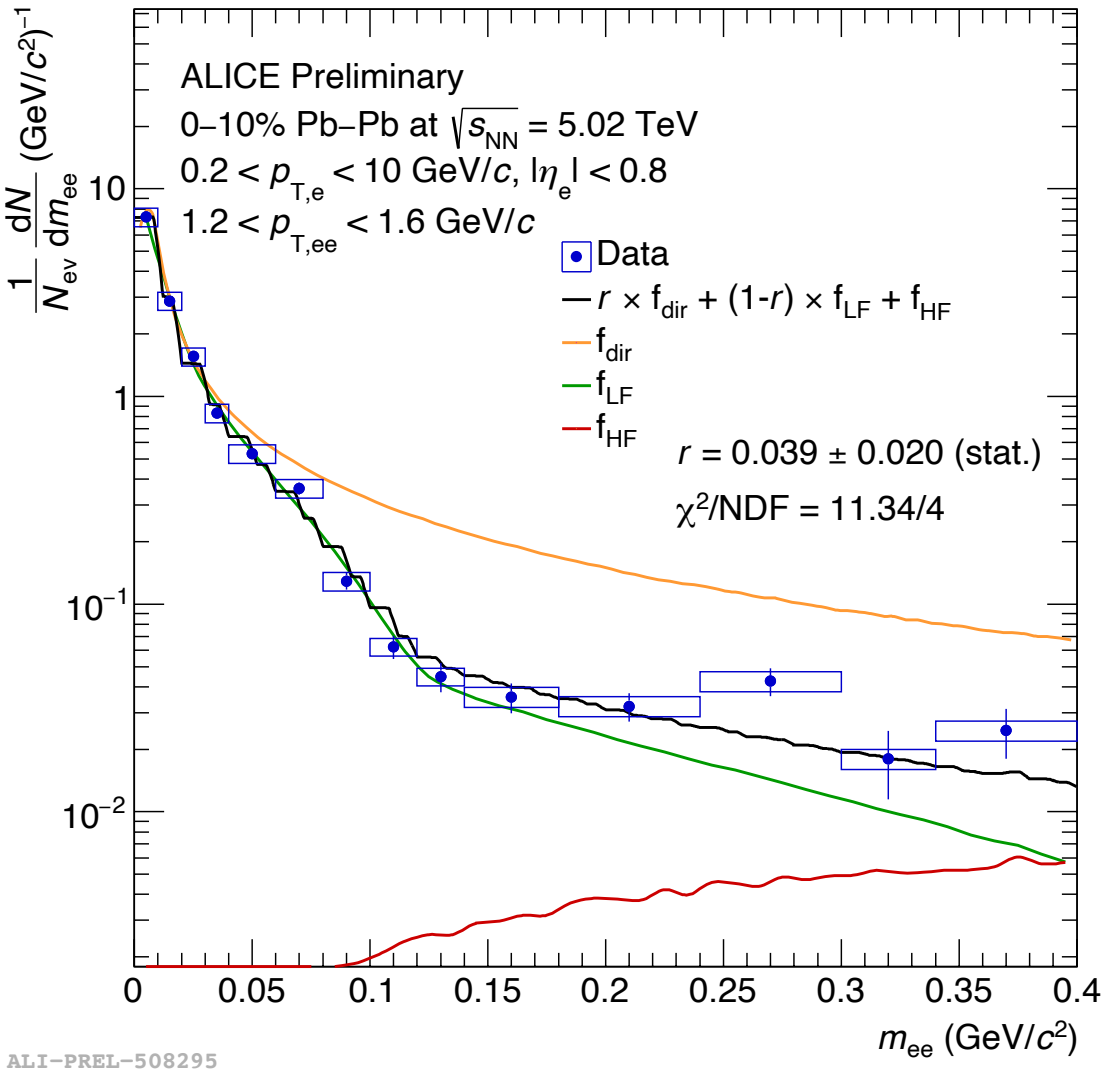
- A hint of HF suppression

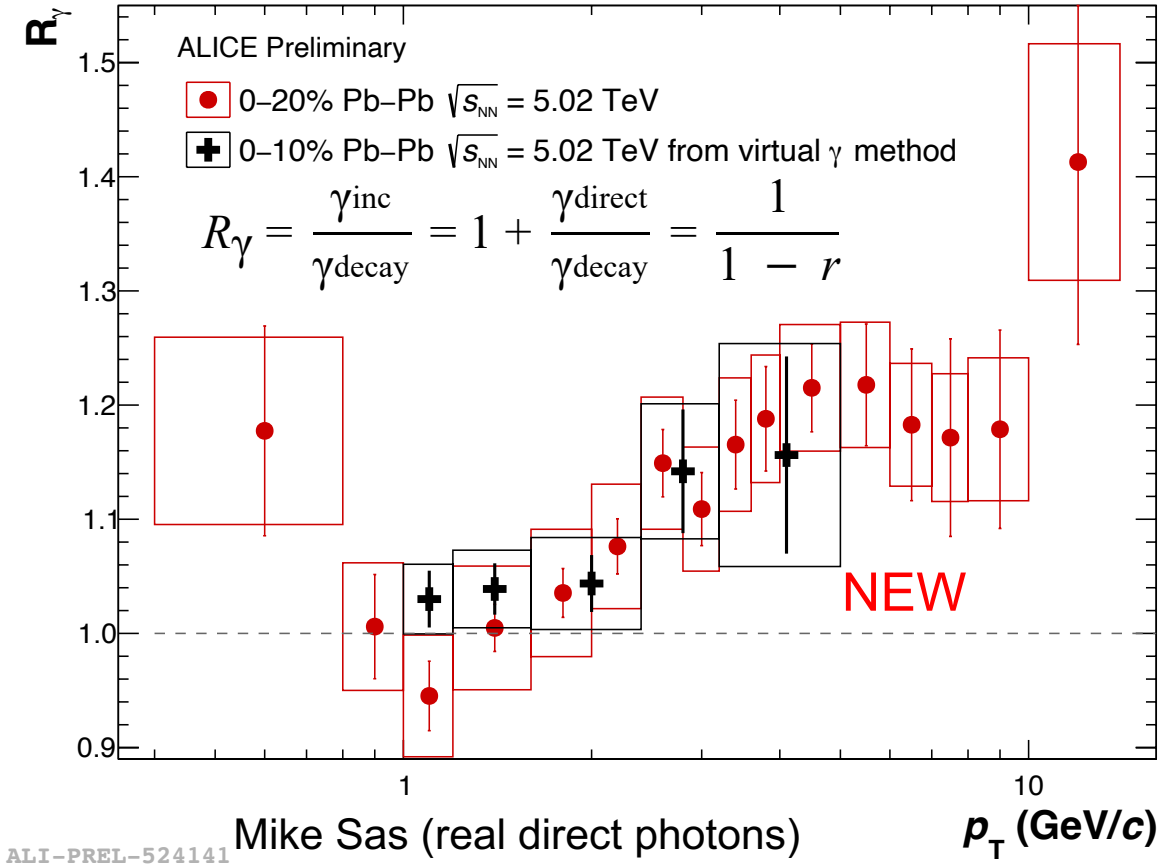
Direct photon spectrum in central Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV



- First measurement in Pb-Pb at 5.02 TeV
  - γ^{inc} constructed with photon conversion method.
- A hint of an excess above pQCD

Direct photon excess ratio in central Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

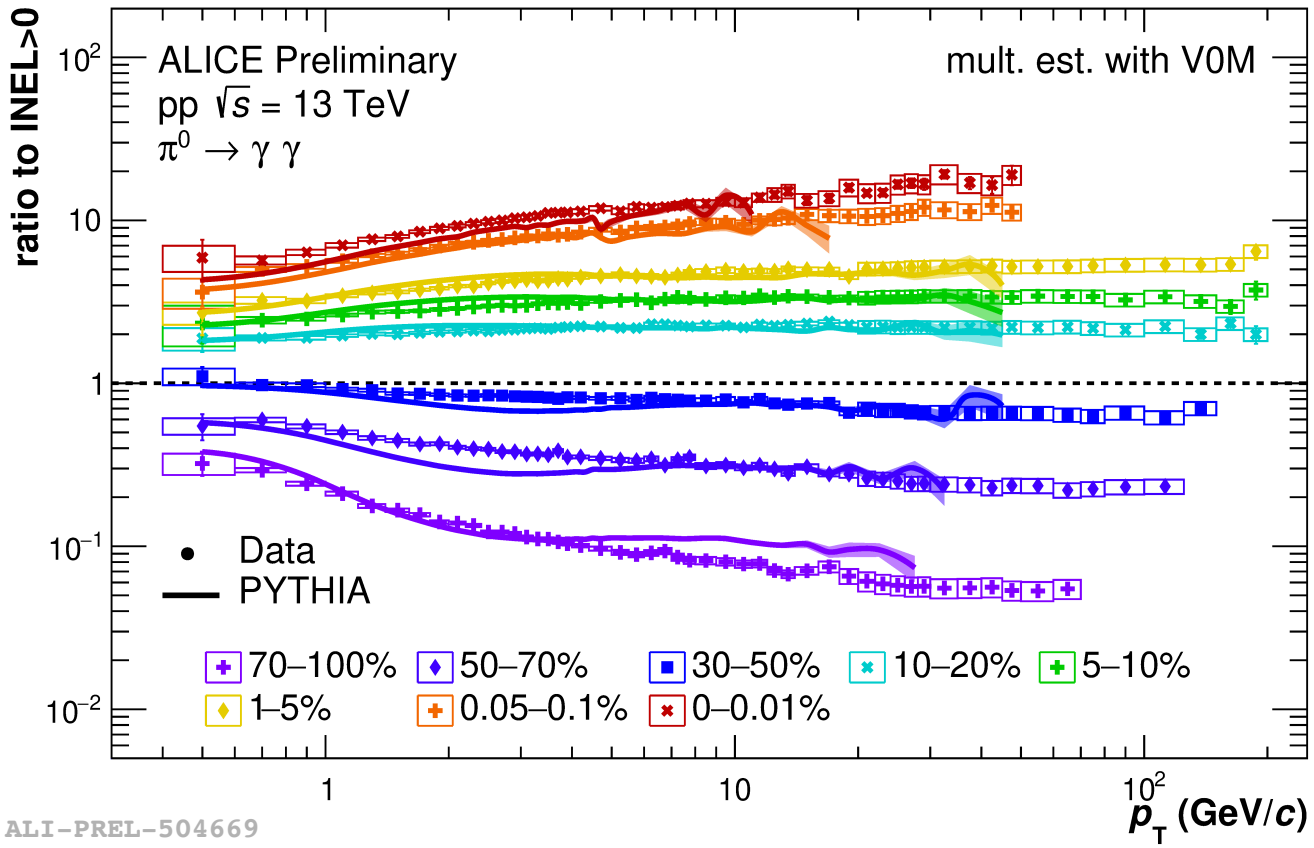




Mike Sas (real direct photons)
https://agenda.infn.it/event/28874/contributions/171015/

- Good agreement between real and virtual direct photons
- First measurement in Pb-Pb at 5.02 TeV
  - smaller syst. unc. compared to real photons at low p_T
  - syst. unc. is dominated by η/π^0.

Neutral mesons yields vs. multiplicity in pp at $\sqrt{s}$ = 13 TeV



- Similar direct photon fraction in MB and HM pp collisions
- Neutral mesons yields increase with N_{ch}. (i.e. large inclusive photon yields in HM events)

  → Indicating that direct photons yields increase with N_{ch}, too.