# Electromagnetic radiation in pp and Pb–Pb collisions with dielectrons in ALICE

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**European Physical Society**
**Conference on High Energy Physics**
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# Motivation

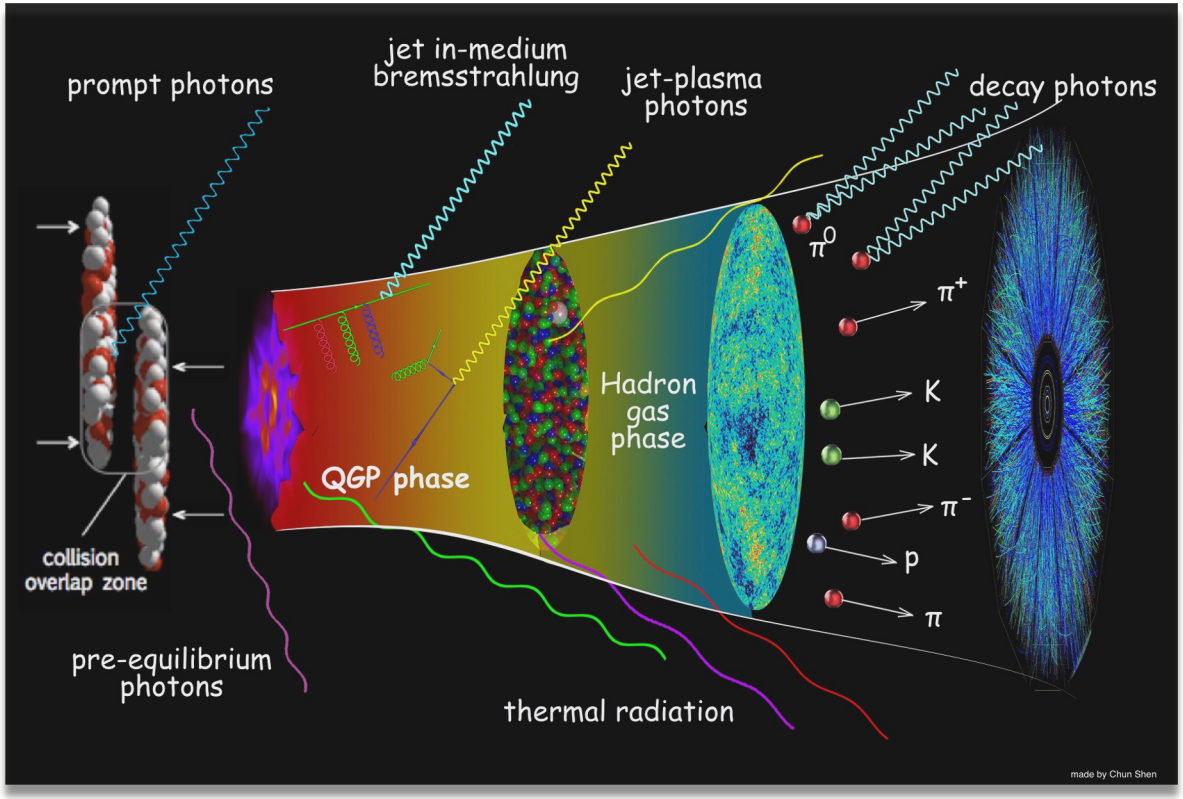
**Direct photons and dileptons**

- Unique probe to study QGP
  - Emitted without final state interactions
  - Take over medium properties

**Sources of direct photons and dileptons**

- Prompt photons (pQCD photons) / Drell-Yan process
- Pre-equilibrium photons and dileptons
- Jet-medium interaction induced photons
- Thermal photons and dileptons from
  - QGP
  - Hot hadronic matter

**Evolution of heavy-ion collisions**

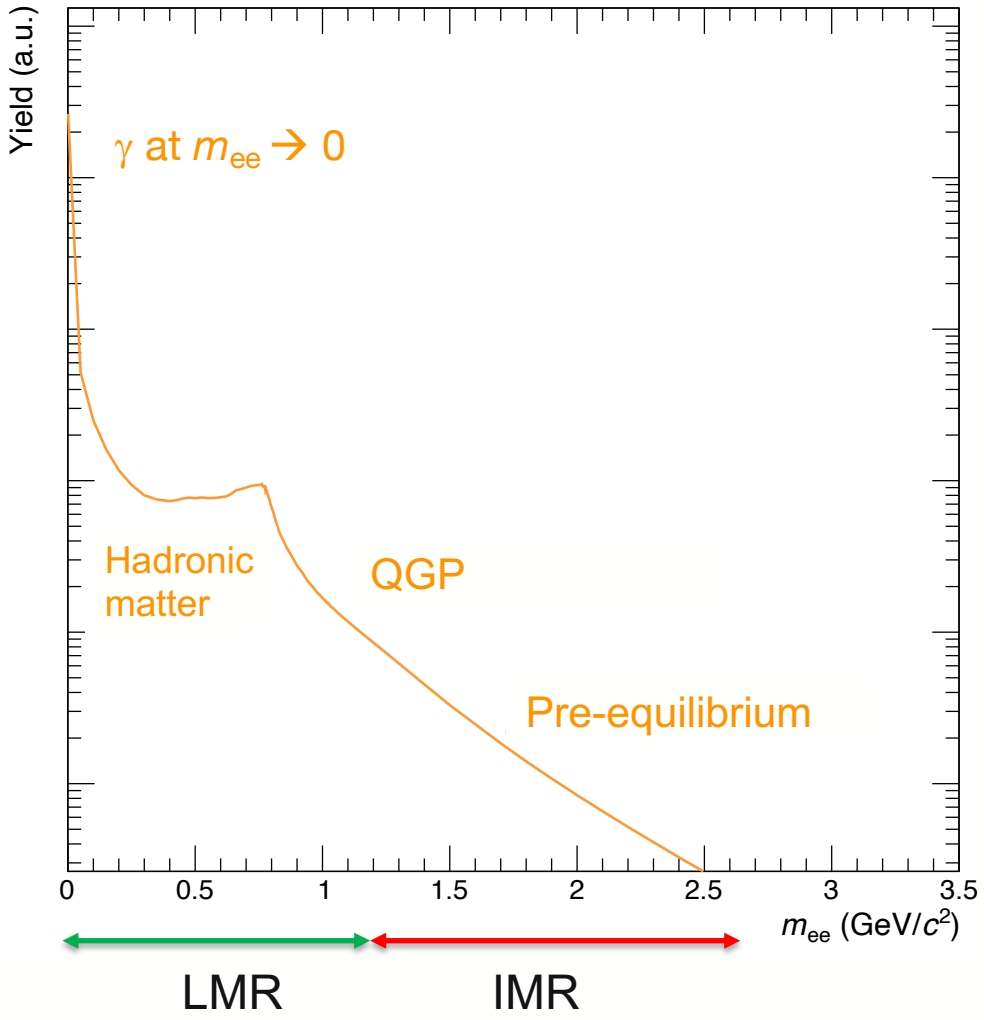



made by Chun Shen

# Dielectrons and heavy-ion collisions

- Dielectron carries invariant mass
- Access to thermal radiation
  - Low Mass Region ( $m_{ee} < 1.1$ GeV/$c^2$)
    - Radiation from Hadronic phase
    - Sensitive to in-medium spectral function of ρ meson
  - Intermediate Mass Region ($1.1 < m_{ee} < 2.6$ GeV/$c^2$ )
    - Radiation from QGP
  - $m_{ee} \rightarrow 0$
    - Link to real direct photon

**Sketch of invariant mass spectrum in heavy-ion Collisions**



# Dielectrons in heavy-ion collisions

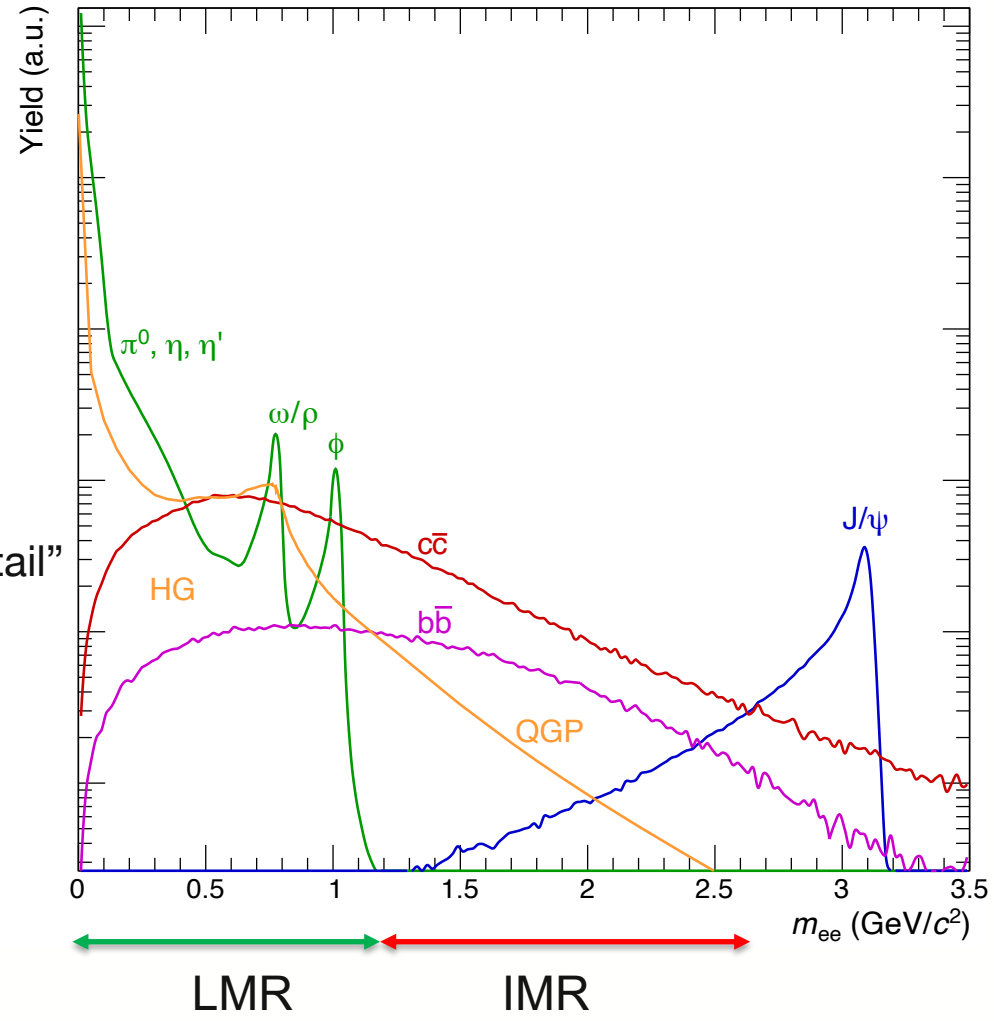
**Dielectron measurement is a big challenge**

- Small production rate ~ ($\alpha_{EM}$) and steeply falling spectrum
- Large background at LHC energies
  - Combinatorial pairs
  - Physical origins
    - Light-flavour (LF) hadron decays and J/$\psi$
      - LF : $\pi^0$ , $\eta$ , $\eta'$ , $\rho$ , $\omega$ , $\phi$
    - Heavy-flavour (HF) hadron decays
      - $c\bar{c}$ and $b\bar{b}$

→ Dielectron yield from known hadron decays : “Hadronic cocktail”

- Need precise knowledge of these backgrounds

**Dielectron continuum in heavy-ion collisions**



# Dielectron invariant mass spectrum

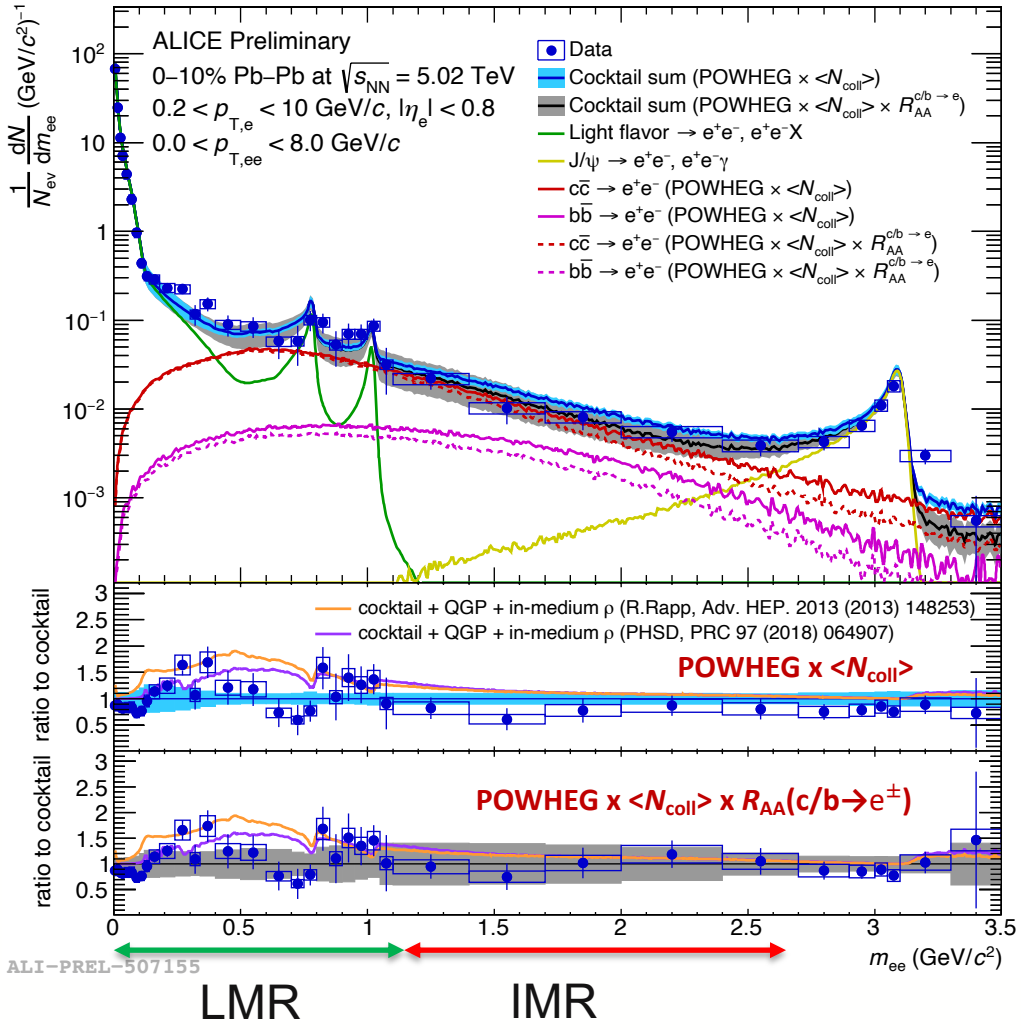
- Data compared with hadronic cocktail

- At low $m_{ee}$
  - Data consistent with predictions for additional thermal radiation contributions ( $m_{ee} < 0.5$ GeV/$c$ )
    - Fireball model using hadronic many-body theory
    - Transport model PHSD

- At IMR ($1.1 < m_{ee} < 2.7$ GeV/$c^2$)
  - $\langle N_{coll} \rangle$ scaled heavy-flavor (HF) (Vacuum baseline)

    Phys. Rev. C 102 (2020) 055204
  - HF cocktail modified by $R_{AA}$(c/b → e$^{\pm}$)

    Phys. Lett. B 804 (2020) 135377
  - Data is consistent with
    - HF suppression & thermal radiation from QGP



# Direct virtual photon method

- Direct virtual photon fraction

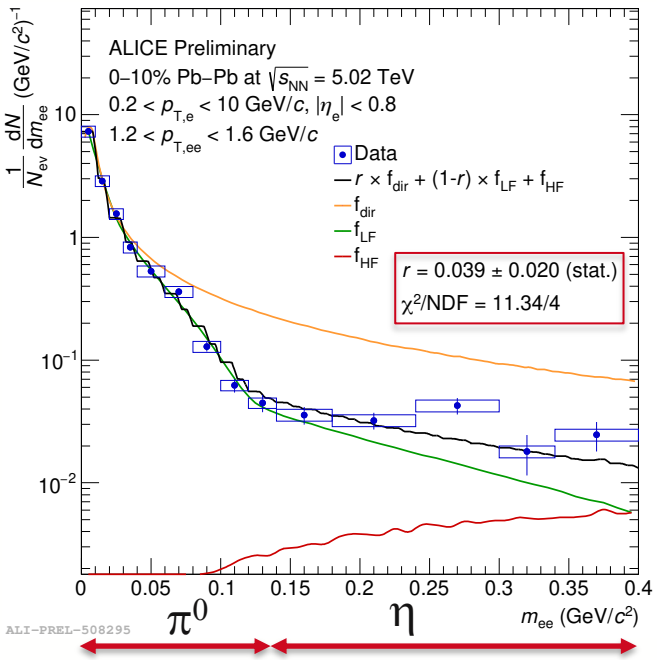
$$r = (\gamma^*_{\mathrm{dir}}/\gamma^*_{\mathrm{incl}})_{m_{\mathrm{ee}}\to 0} = (\gamma_{\mathrm{dir}}/\gamma_{\mathrm{incl}})$$

→ fit dielectron mass spectrum above $\pi^0$ mass with

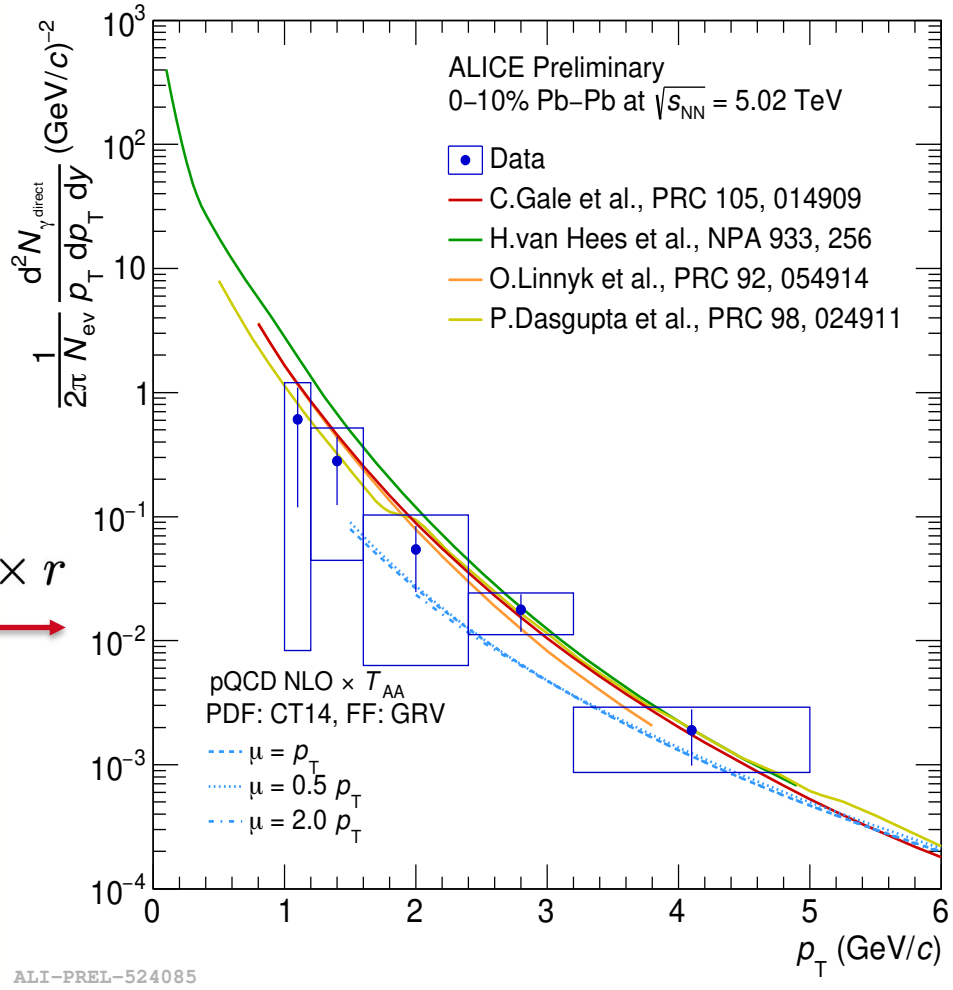
$$f = r \times f_{\mathrm{dir}} + (1-r) \times f_{\mathrm{LF}} + f_{\mathrm{HF}}$$

- $f_{\mathrm{dir}}$ and $f_{\mathrm{LF}}$ are normalised to data at $m_{\mathrm{ee}} < 40$ MeV/$c^2$
- $f_{\mathrm{dir}}$ described by Kroll-Wada formula

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




$$\gamma^{\mathrm{dir}} = \gamma^{\mathrm{incl}} \times r$$




- All models agree with the data
- Some tends to overestimate them at low $p_{\mathrm{T}}$

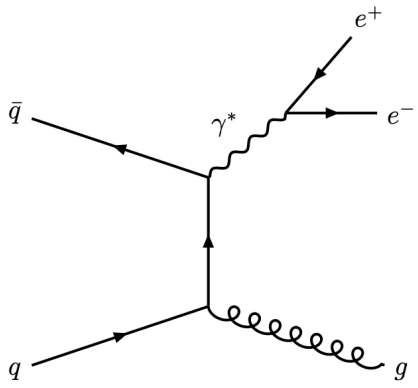
# Motivation for direct photon in pp collisions

**QGP in small systems**

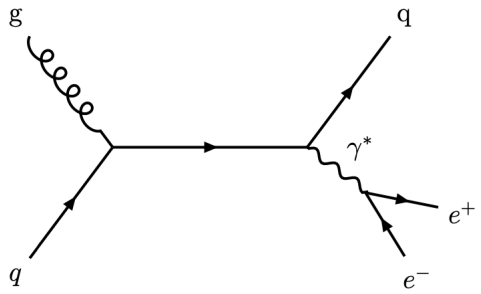
- Collectivity in small systems observed at RHIC and LHC
- No energy loss observed in $R_{AA}$ measurements
- *Does the system thermalize or not ?*
  - Onset of thermal photon production at $dN_{ch}/d\eta \sim 10$ ?

  → Search for thermal photons in small systems at LHC energies

**Measure direct virtual photon γ***
**in inelastic and high-multiplicity (HM) pp at $\sqrt{s}$ = 13 TeV**

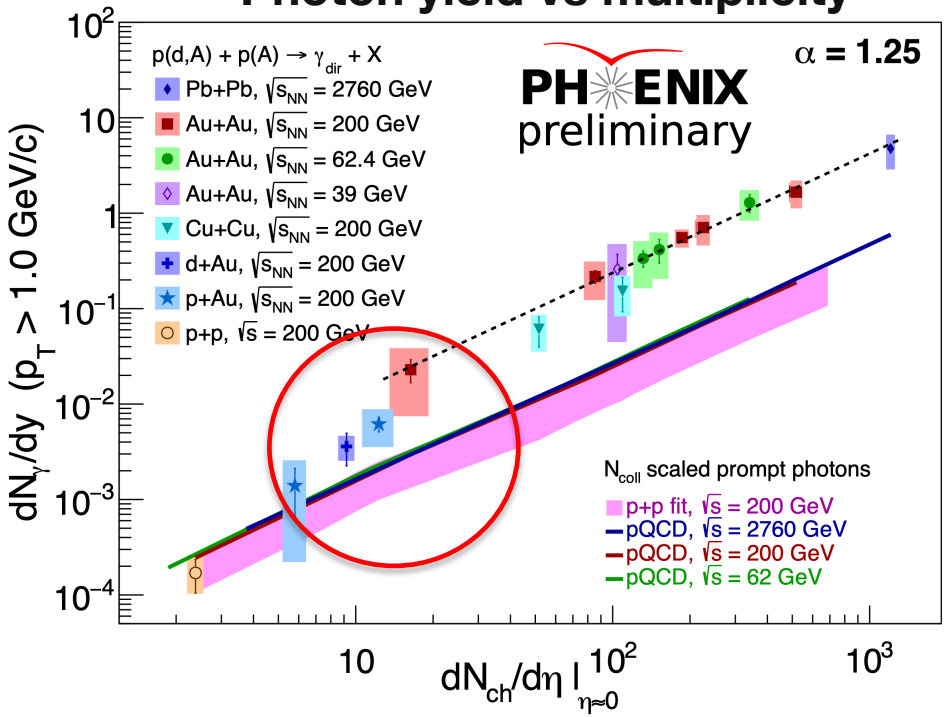



quark-gluon Compton




quark-antiquark annihilation

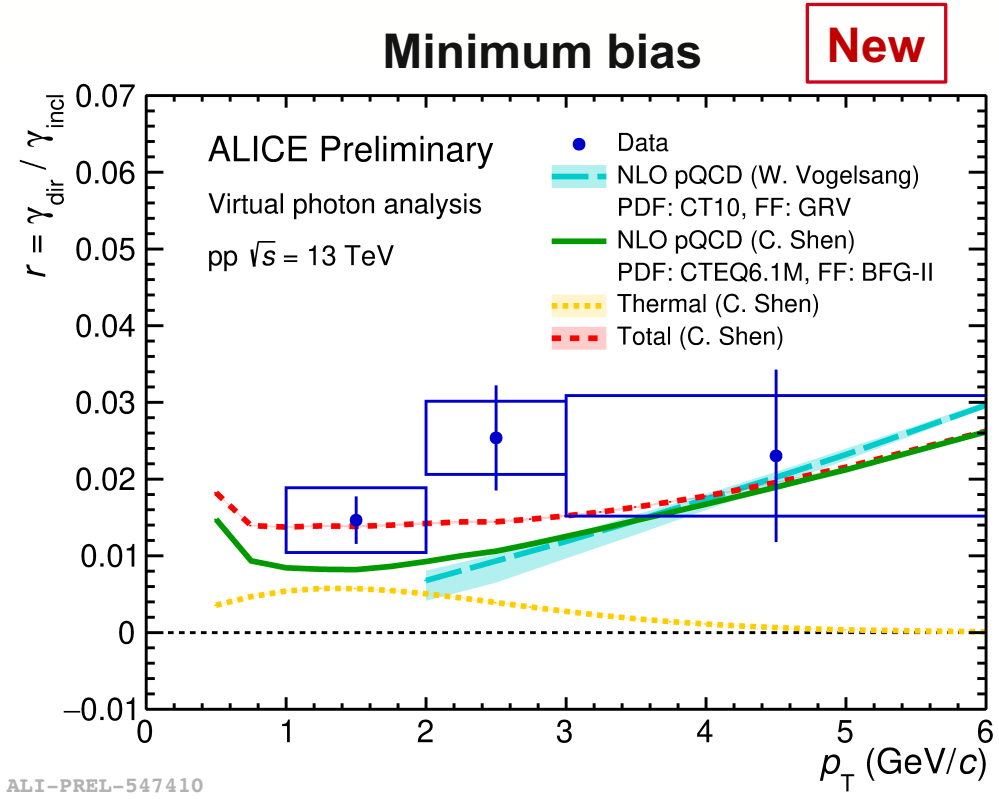
**Photon yield vs multiplicity**

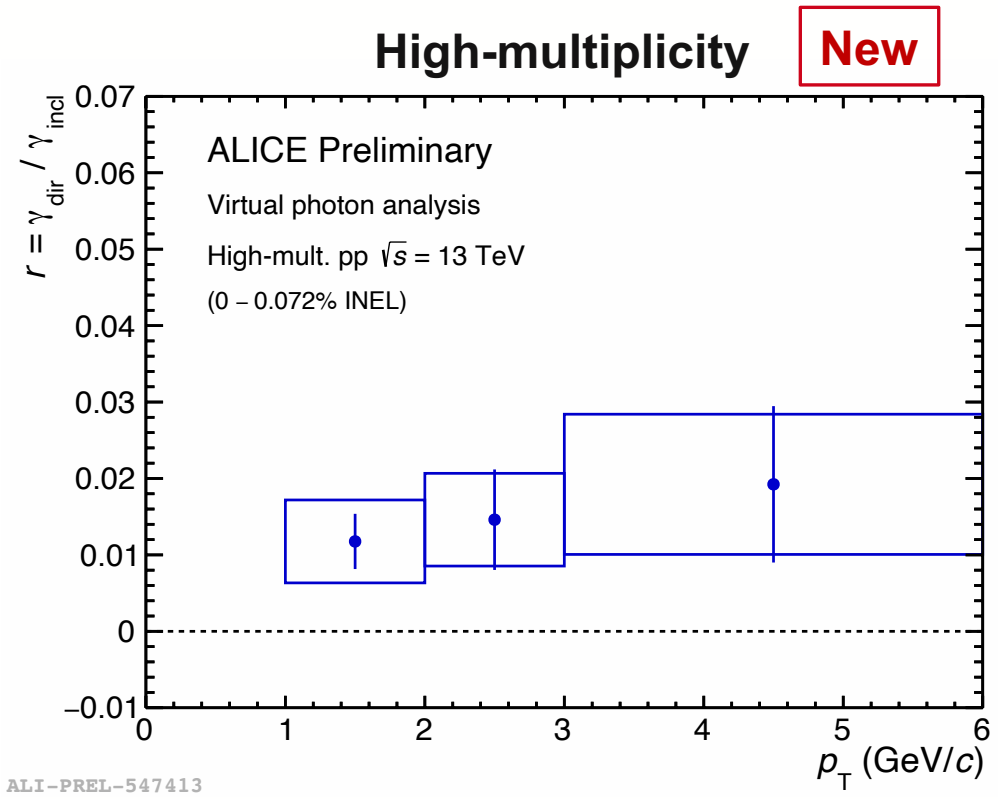



pp collisions at $\sqrt{s}$ = 13 TeV

- $dN_{ch}/d\eta \sim 7$ (MB)
- $dN_{ch}/d\eta \sim 30$ (HM, top 0.1%)

# Direct photon fraction $r$ vs $p_T$




- Significant yield of direct photons in all analysed momentum bins.
- Results compared with theoretical prediction (MB only)
  - NLO pQCD by W. Vogelsang [1]
  - Viscous hydrodynamical (QGP-like) model (on top of NLO pQCD $\gamma$ ) by C.Shen [2]
- Calculations for prompt photons in HM not yet available

Significance for $1 < p_T < 6$ GeV/$c$
- 3.2 σ (Min.bias)
- 1.9 σ (High-mult.)


[1] PRD 48 (1993)
[2] PRC 95 (2017) 014906

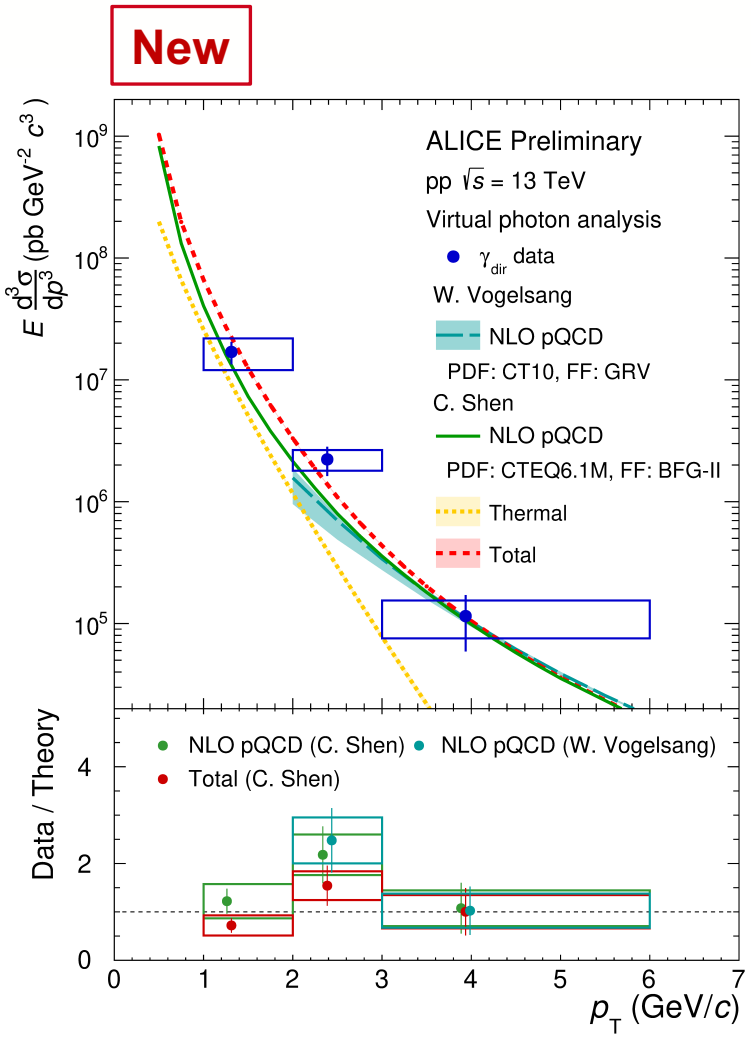
# Direct photon spectrum

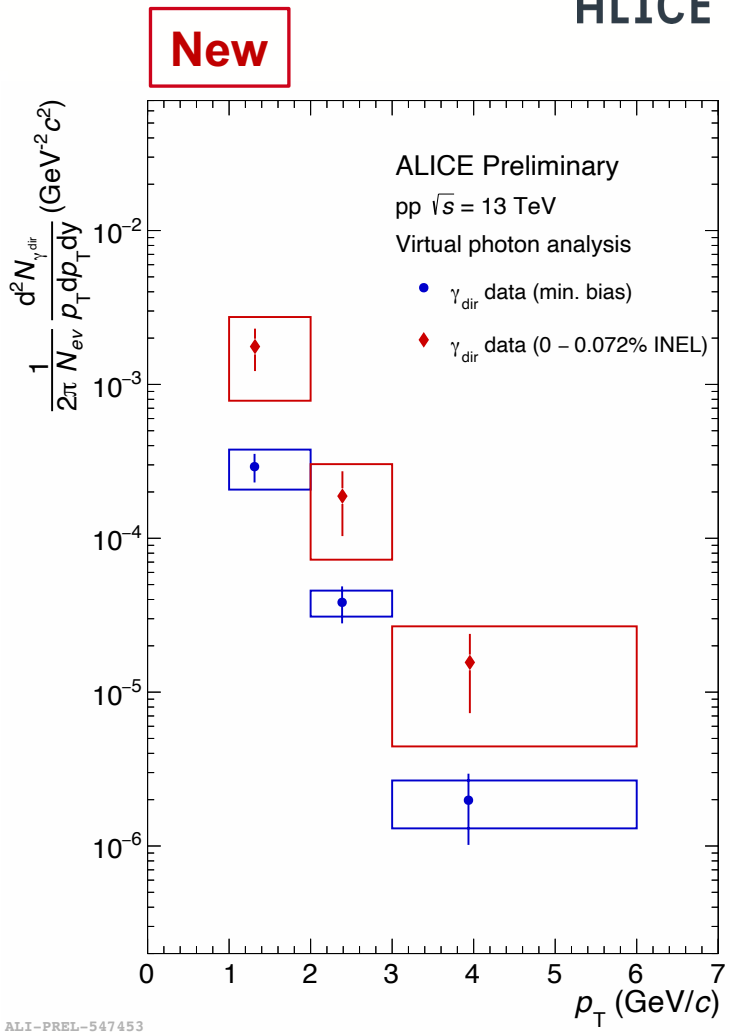
- MB compared with theoretical predictions
  - NLO pQCD above $p_T$ = 2 GeV/$c$ (W. Vogelsang)

  - Viscous hydrodynamical model (C. Shen *et al.*)
    QGP-like

  → Result is consistent with both calculations

- Larger direct photon yield observed in HM pp collisions



# ALICE in Run 3

New

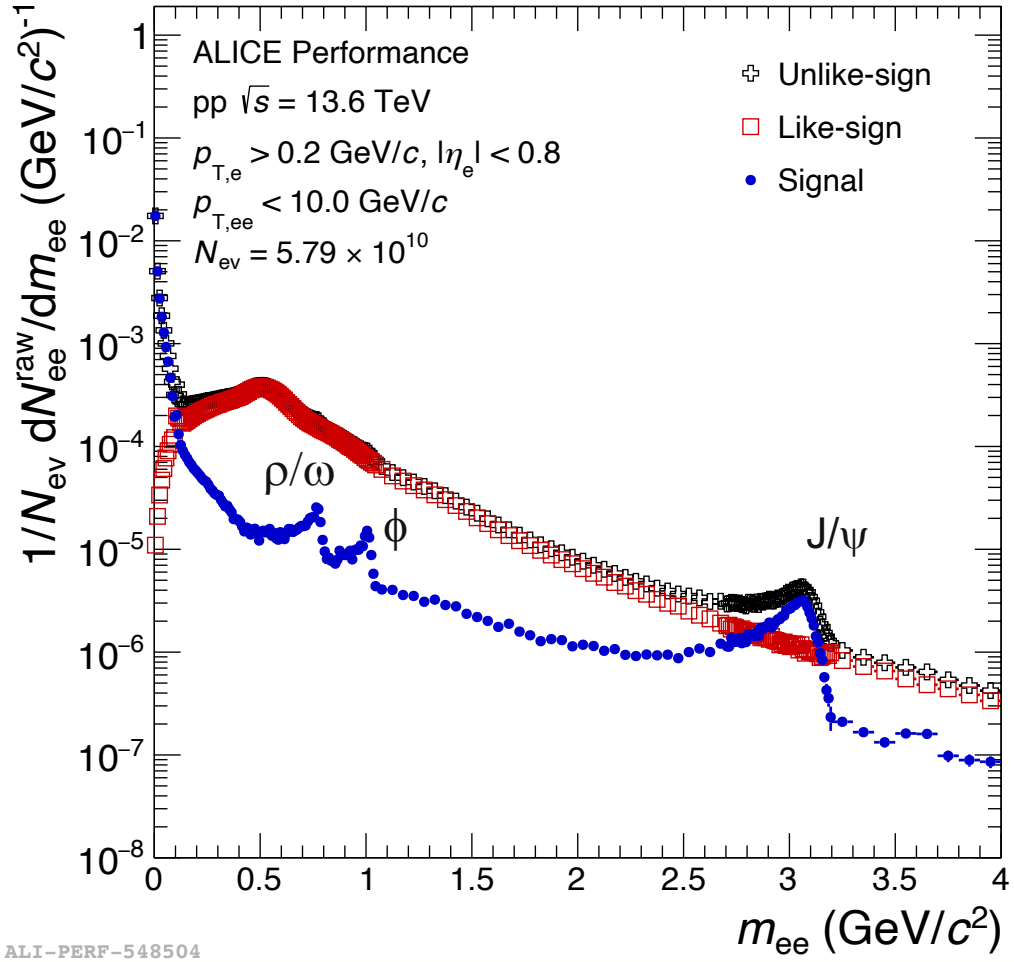
**ALICE upgrade during LS2**

- ITS Upgrade [1]
  → better vertex resolution
- New GEM-based TPC [2]
  → continuous readout mode, much larger IR/statistics

**Run 3** (2022-)

- pp collisions $\sqrt{s}$ = 13.6 TeV
  – First look is very promising !

**Raw dielectron spectrum in Run 3**



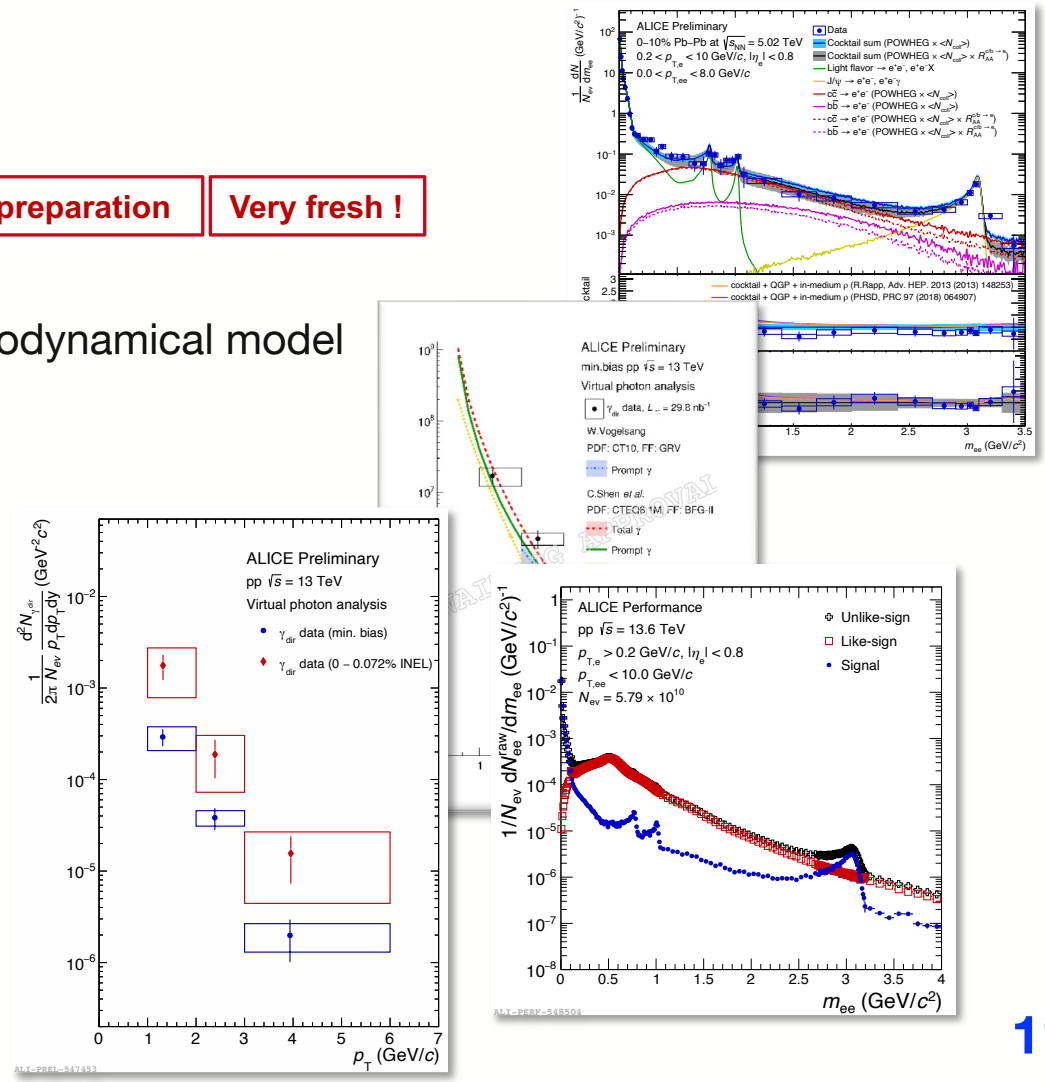

[1] CERN-LHCC-2012-013
[2] CERN-LHCC-2013-020, CERN-LHCC-2015-002

# Summary

- Dielectron production in central Pb--Pb collisions **Paper in preparation**
  - Dielectron invariant mass
  - Direct virtual photon

- Direct photon production in pp collisions at √s = 13 TeV **Paper in preparation** **Very fresh !**
  - Significant yield
  - MB result is consistent with NLO pQCD calculation and Hydrodynamical model
  - HM result shows multiplicity dependence
    - Missing calculation for NLO pQCD photons in HM

- Detailed differential studies in reach with Run 3 data **Very fresh !**



# Backup

# Dielectron $DCA_{ee}$ spectrum

- First attempt to extract prompt thermal $e^+e^-$ via template fit
- Expectations : prompt + non-prompt ($c\bar{c}$ and $b\bar{b}$)
  - $DCA_{ee}$ (prompt) < $DCA_{ee}$ ($c\bar{c}$) < $DCA_{ee}$ ($b\bar{b}$)
- Template consists of prompt + HFs
  - Fixed $b\bar{b}$ contribution to reproduce data at high $DCA_{ee}$
  - Simultaneous fit to $DCA_{ee}$ in $1.2 < m_{ee} < 2.6$ GeV/$c^2$

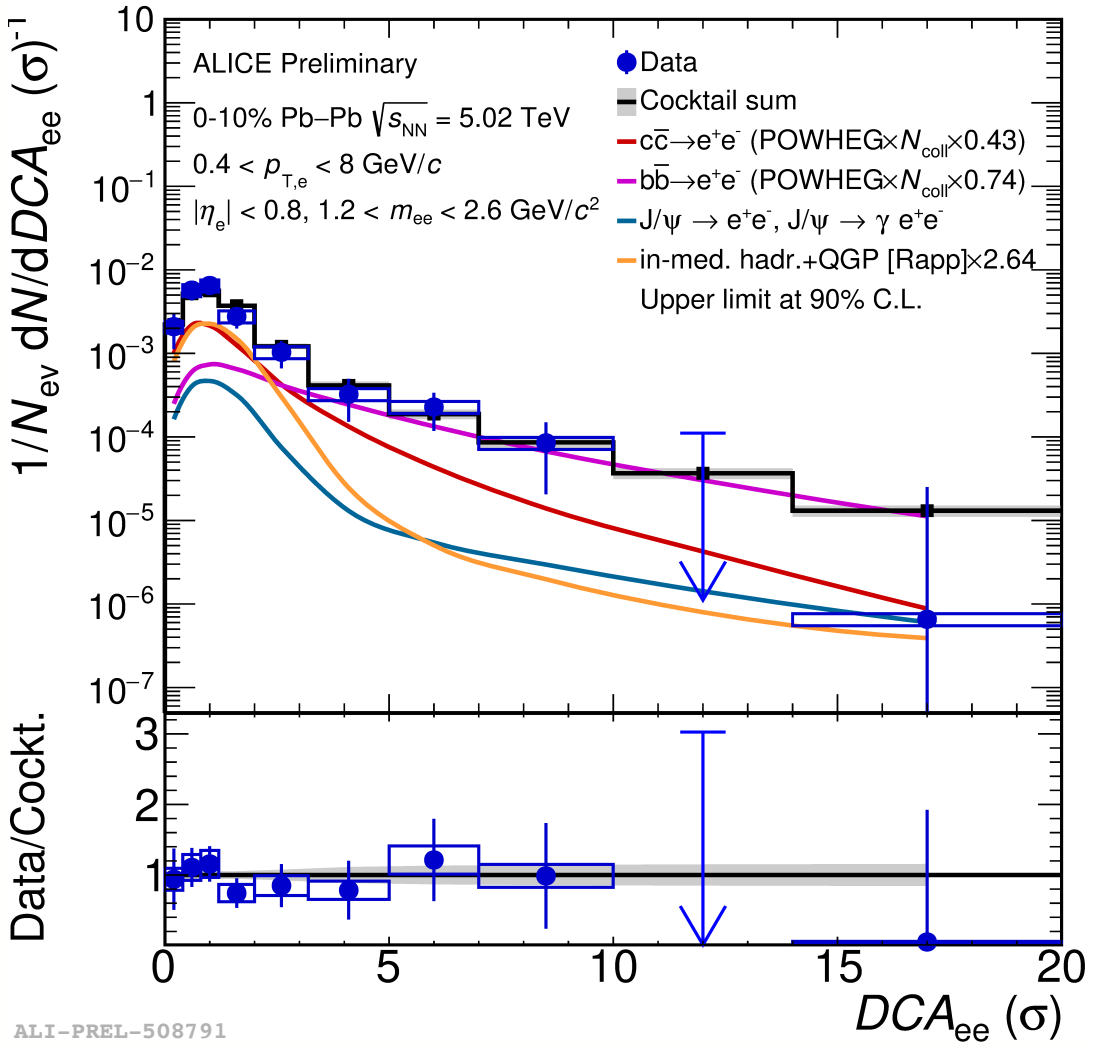
  → Determine prompt and $c\bar{c}$ contribution
- Results
  - $c\bar{c}$ contribution:

    0.43±0.40 (stat.)±0.22 (syst.) x $\langle N_{coll} \rangle$

    → Charm suppression
  - thermal contribution:

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

    → Thermal contribution in the order of Rapp/PHSD



# Photon yield vs $dN_{ch}/d\eta$

- Photon integrated at low $p_T$
  - $1 < p_T < 3$ GeV/$c$ *:* sensitive to thermal radiation
- Comparison : Shen's MB prediction
  - Result agrees Prompt + Thermal contribution
- Result shows clear multiplicity dependence