2023 HARD PROBES Aschaffenburg

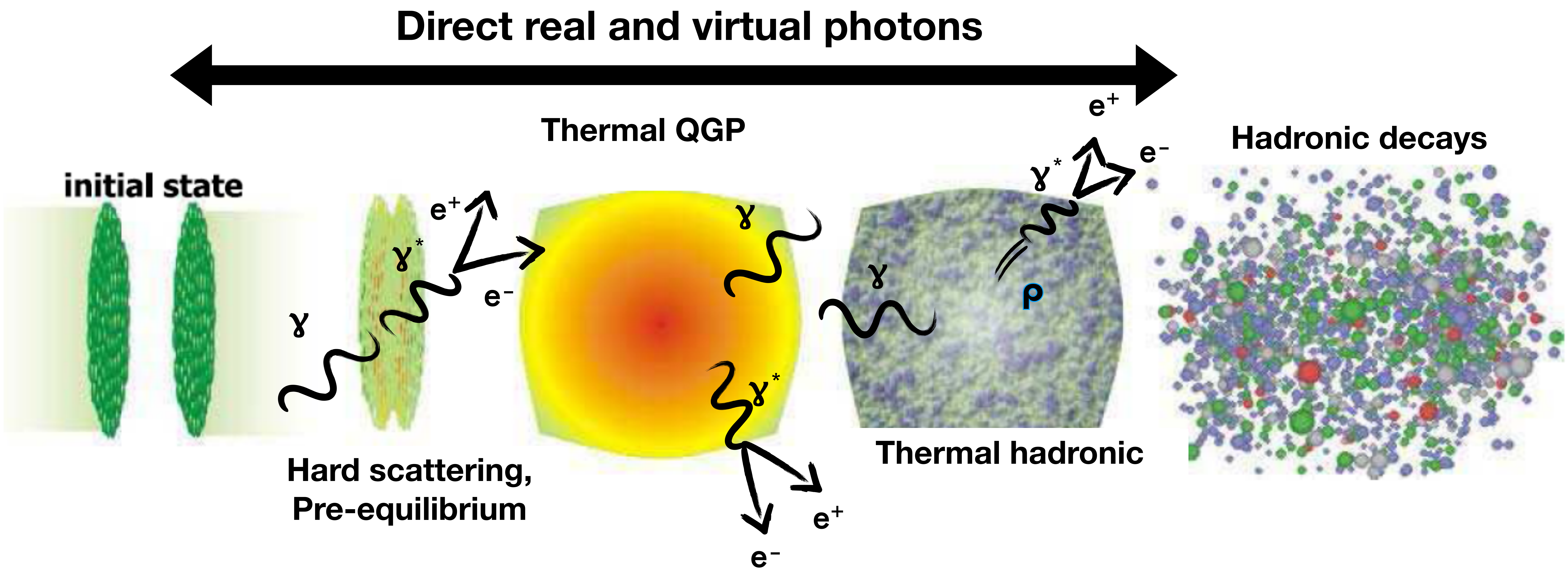
Thermal radiation and direct photon production in Pb—Pb and pp collisions with dielectrons in ALICE

Raphaelle Bailhache for the ALICE Collaboration

ALICE

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Motivation

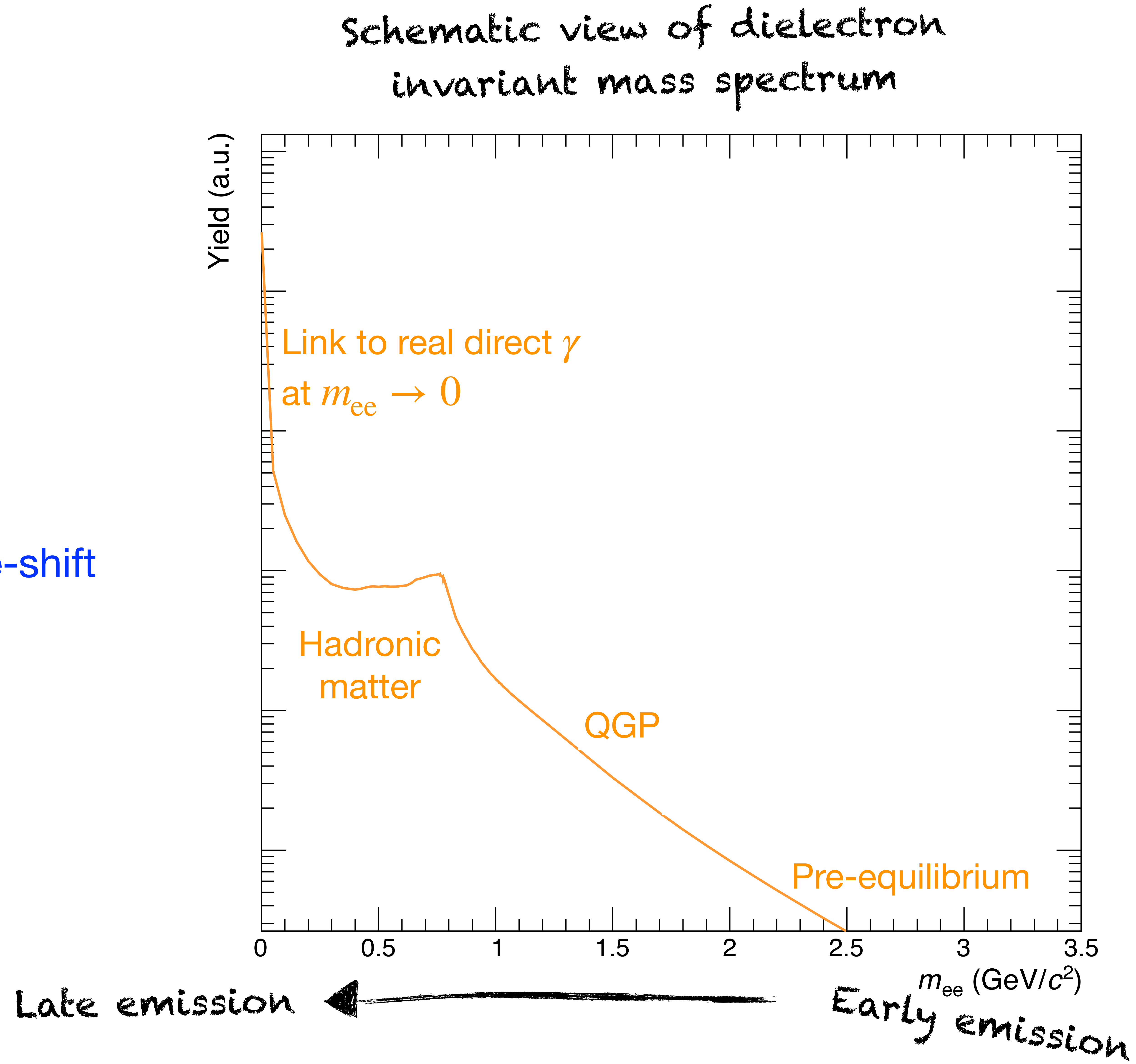


→ **Unique probe of the hot-medium properties**

Motivation for dielectrons

Virtual photons ($\gamma^* \rightarrow e^+e^-$) carry mass ($m_{ee}$):

- Can serve as an approximate clock
  → Separate different stages of the collision
- Radiation from hot-hadronic matter
  Sensitive to in-medium spectral function of ρ meson
- Invariant mass not affected by radial flow
  → Access to average QGP temperatures without blue-shift



Motivation for dielectrons

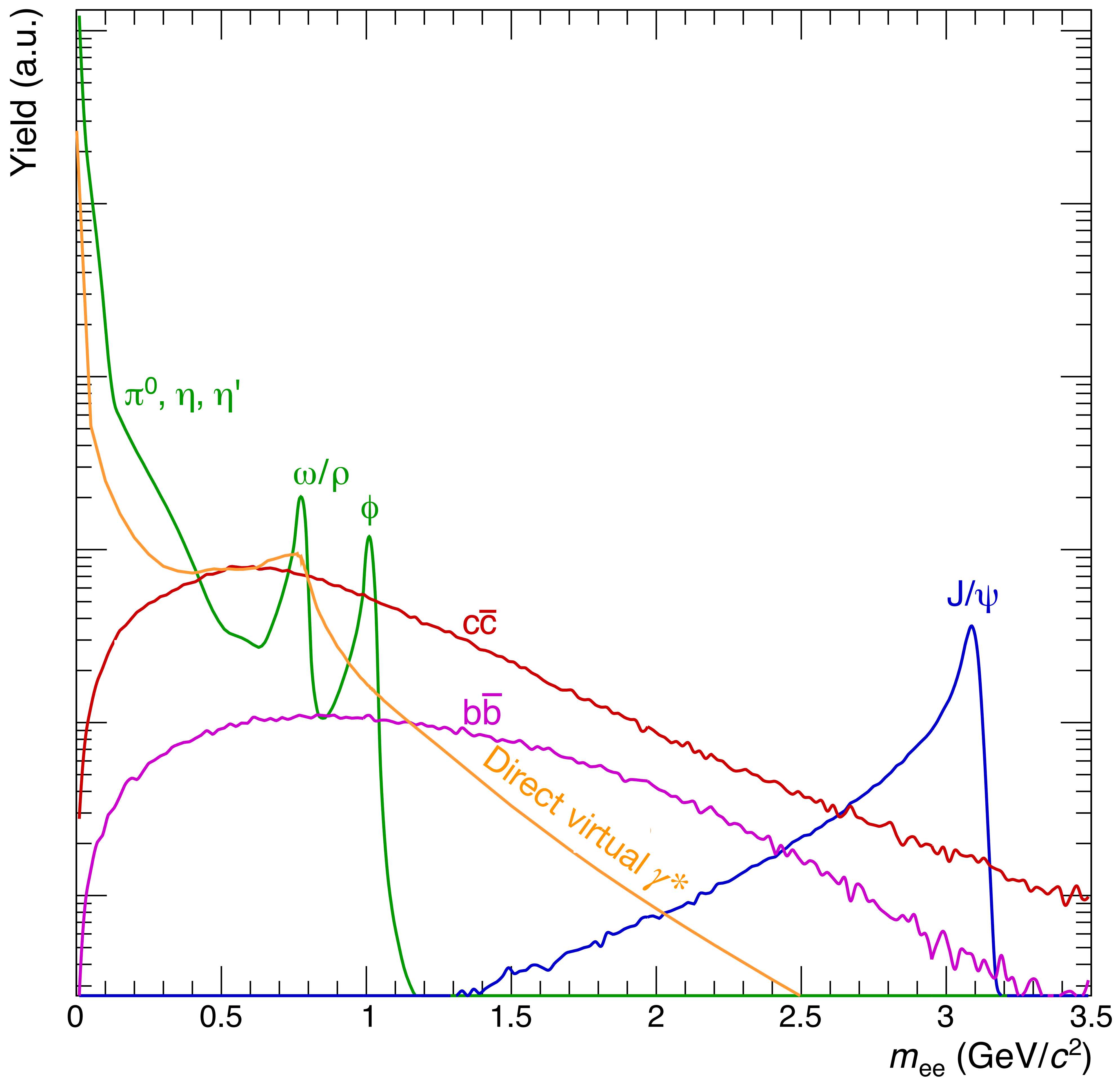
Virtual photons ($\gamma^* \rightarrow e^+e^-$) carry mass ($m_{ee}$):

- Can serve as an approximate clock
  → Separate different stages of the collision
- Radiation from hot-hadronic matter
  Sensitive to in-medium spectral function of ρ meson
- Invariant mass not affected by radial flow
  → Access to average QGP temperatures without blue-shift

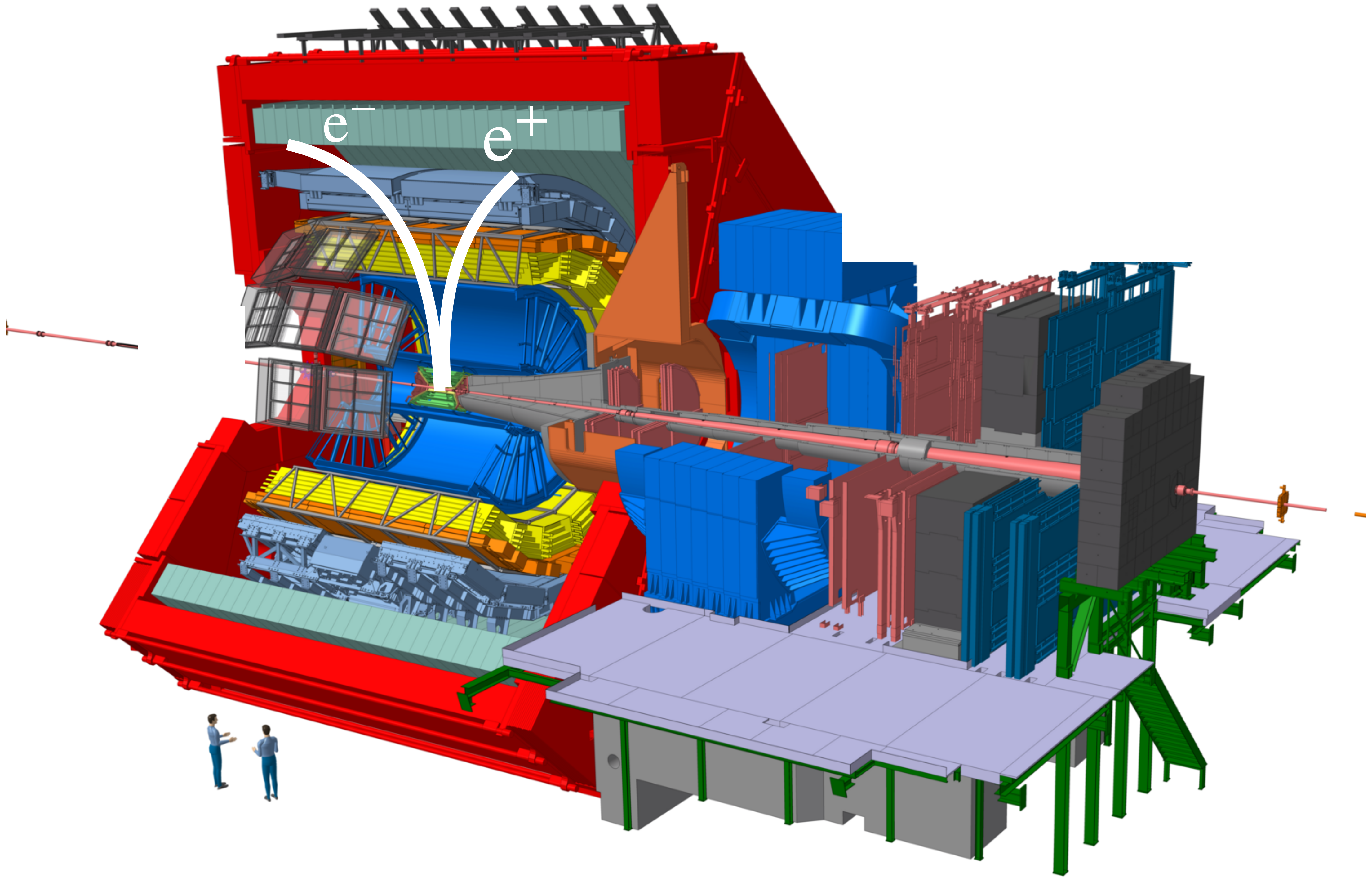
But:

- Small production cross section (additional α_{em} factor)
- Large combinatorial and physical backgrounds
  in particular from correlated heavy-flavour (HF) hadron decays

Schematic view of dielectron invariant mass spectrum

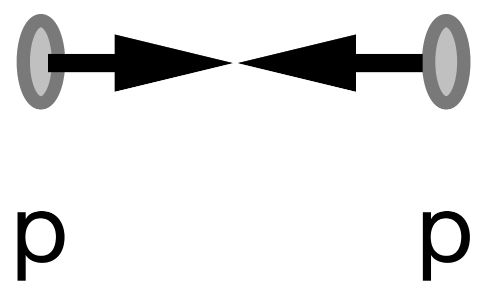


ALICE results from Run 2



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

ALICE



- **Full statistics of Run 2 data**
  - 30 nb^{-1} minimum bias (MB) collisions
  - 6.1 pb^{-1} high multiplicity 0-0.1% (HM) collisions

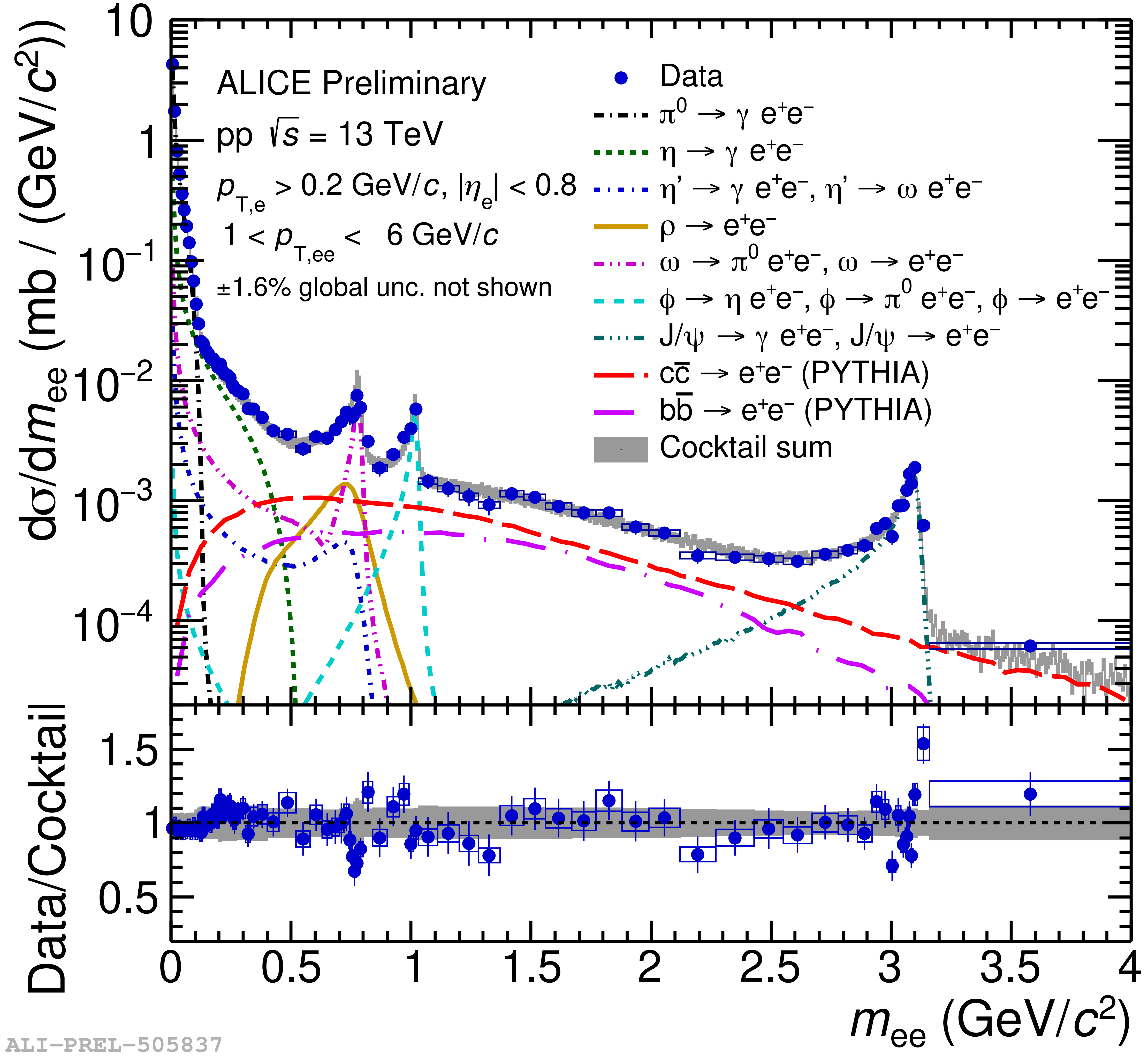
→ 4 times more data compared to previous publication

PLB 788 (2019) 505

- **Described by cocktail of known hadron decays** based on measured neutral mesons
  - At the same energy
  - In the same multiplicity class

See poster 109. by Joshua Koenig

Minimum bias pp collisions



Extraction of direct-photon fraction r

- **Direct photons in pp collisions**
  - Important baseline for Pb—Pb studies
  - Search for possible thermal radiation in HM pp events

- **Extract direct-photon fraction *r*** $\left(= \frac{\gamma^*_{\rm dir}}{\gamma^*_{\rm inc}} \Big|_{m_{\rm ee}\to 0} = \frac{\gamma_{\rm dir}}{\gamma_{\rm inc}} \right)$

by fitting the $m_{\rm ee}$ distribution above the pion mass:

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

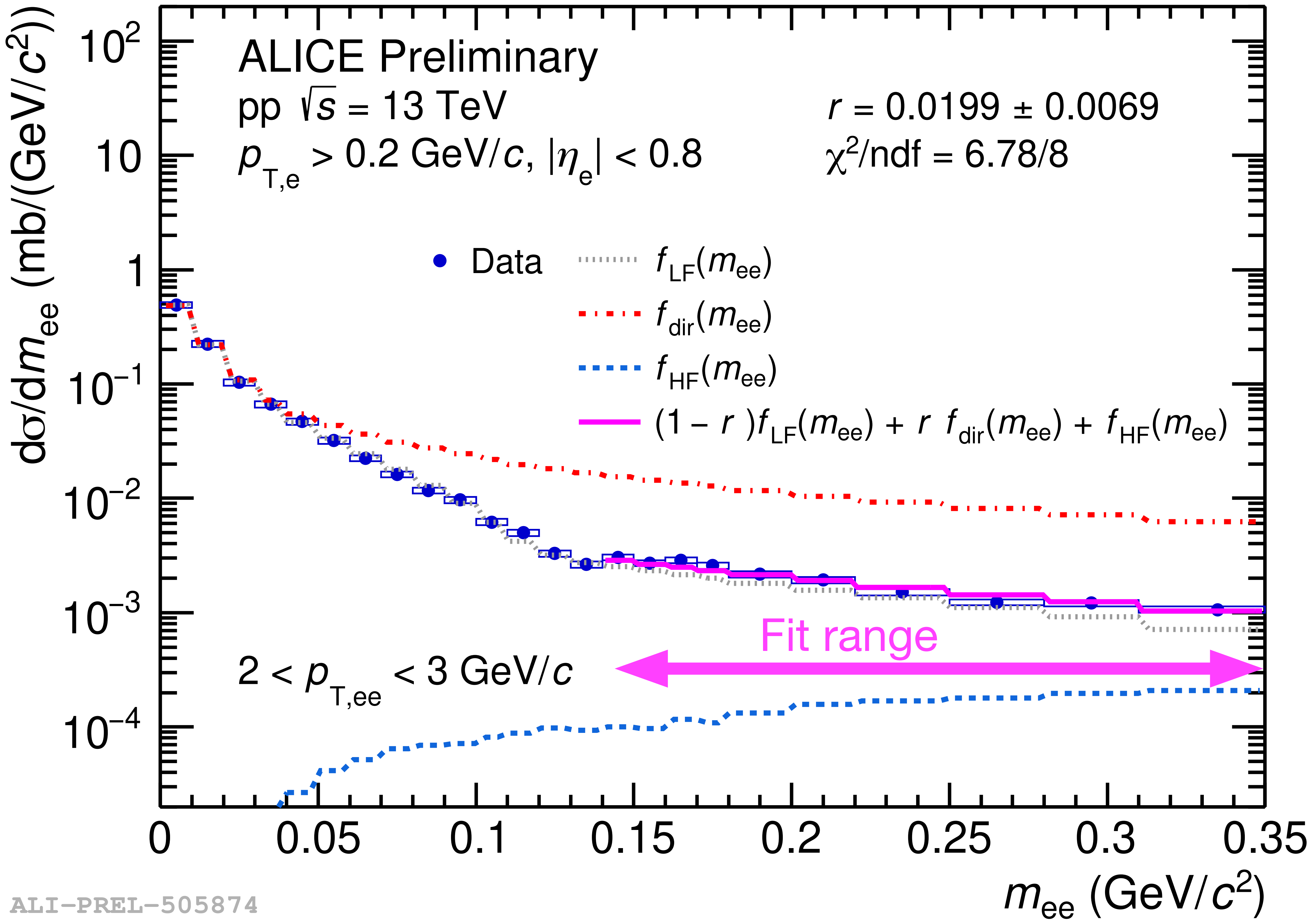
Light flavour

Direct γ^*

Heavy flavour

→ Suppress π^0 background compared to real γ

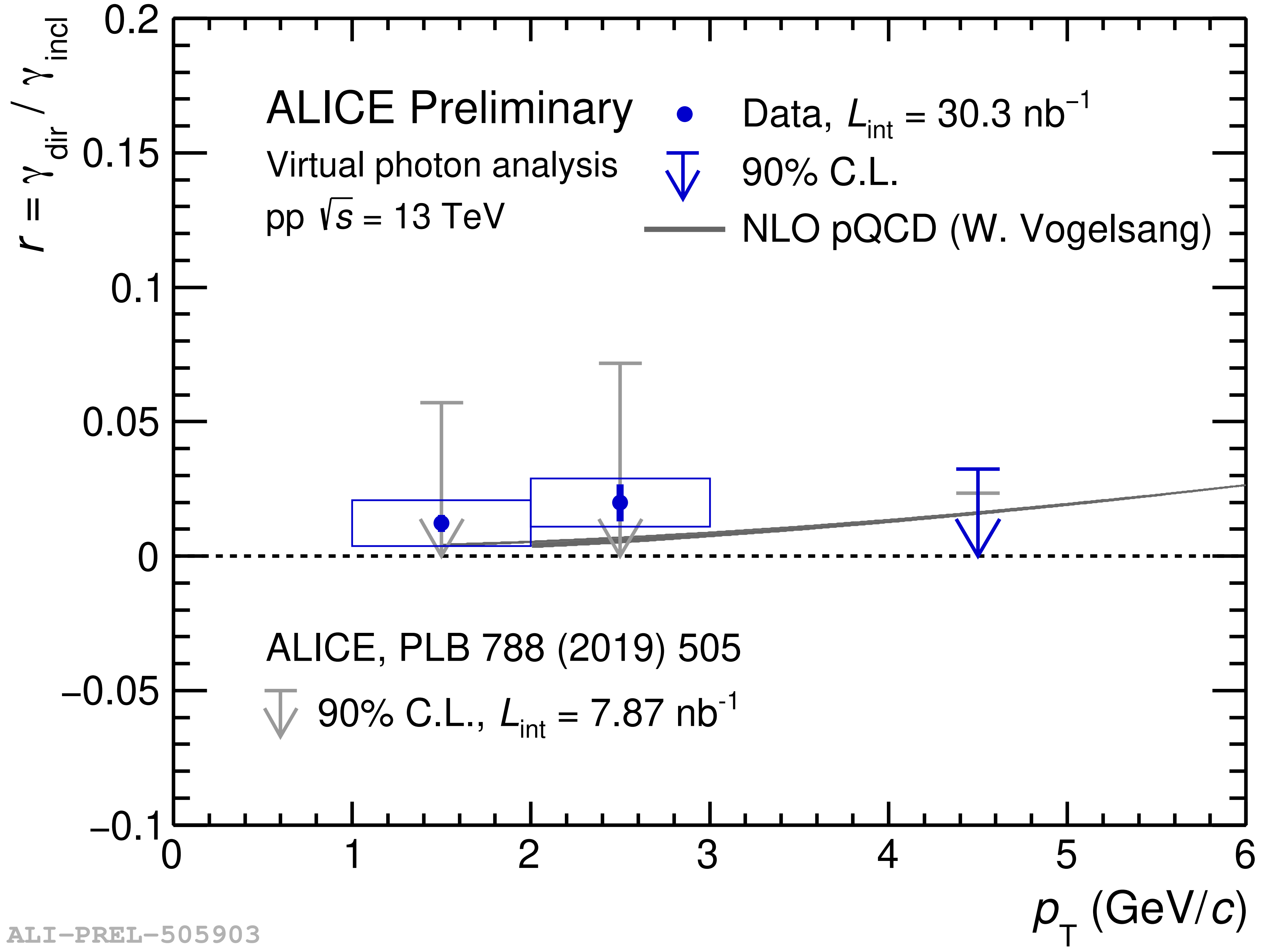
Fit of $m_{\rm ee}$ spectra



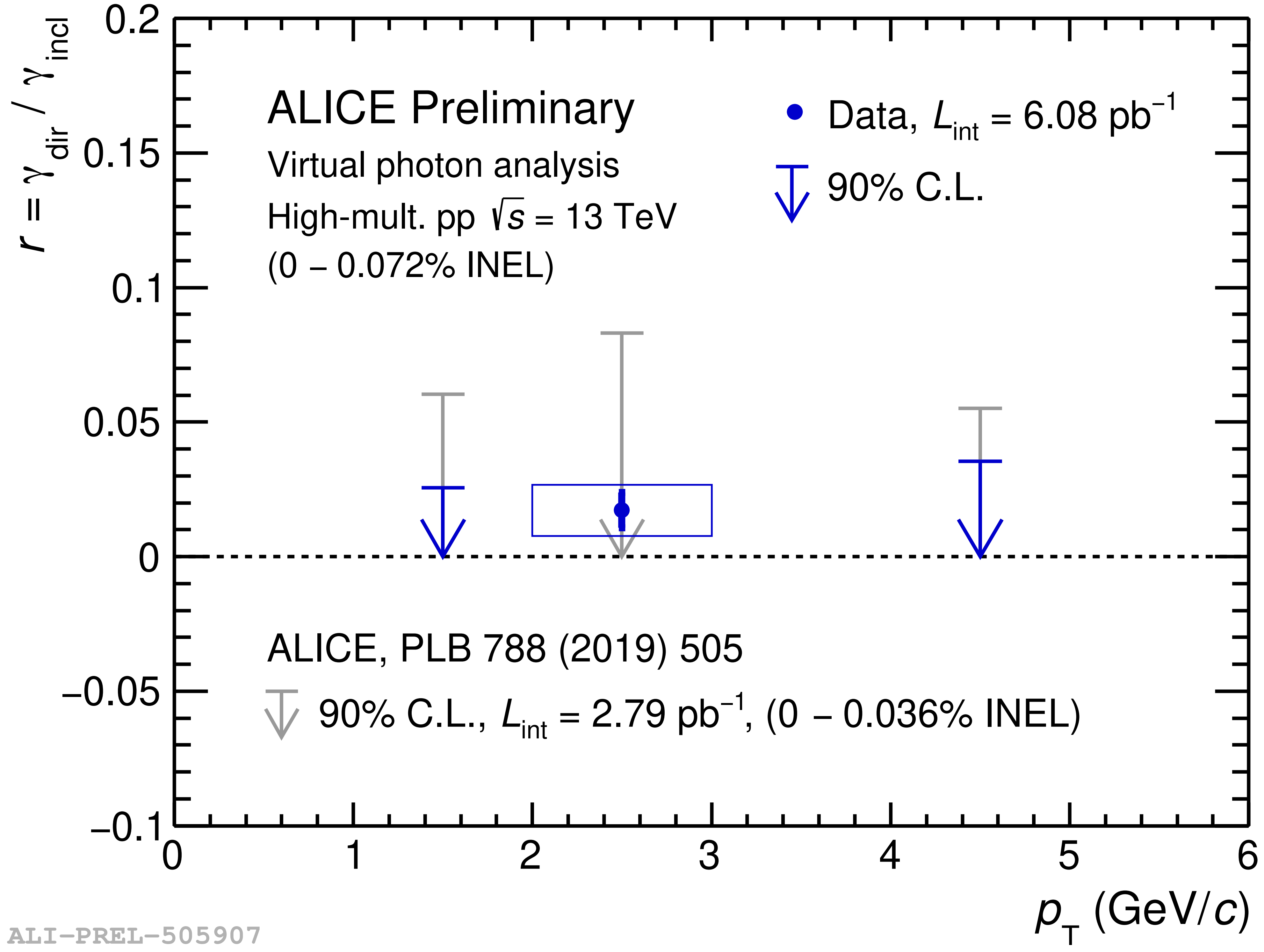
Kroll-Wada formula for direct γ^* contributions:
N.M. Kroll and Walter Wada, Phys. Rev. 98 (1955) 1355

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

MB pp collisions



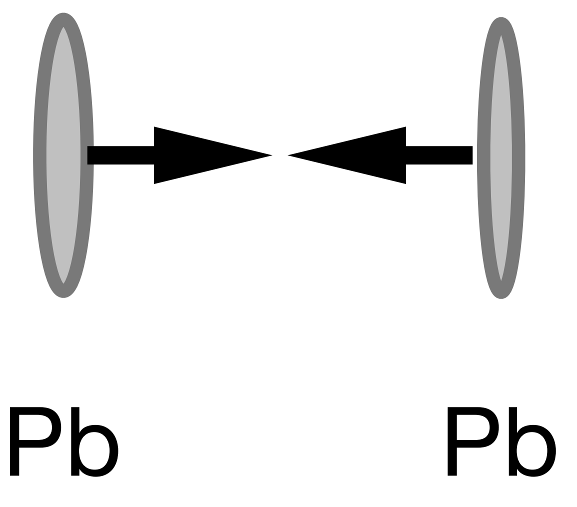
HM pp collisions



- Significant reduction of both stat. and syst. uncertainties compared to previous ALICE paper [1]
- **Similar direct photon fraction in MB and HM pp collisions**
  - **Understand the direct-photon yield** vs $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ **from small to large systems**
  - Search for onset of thermal radiations in small systems

[1] PLB 788 (2019) 505

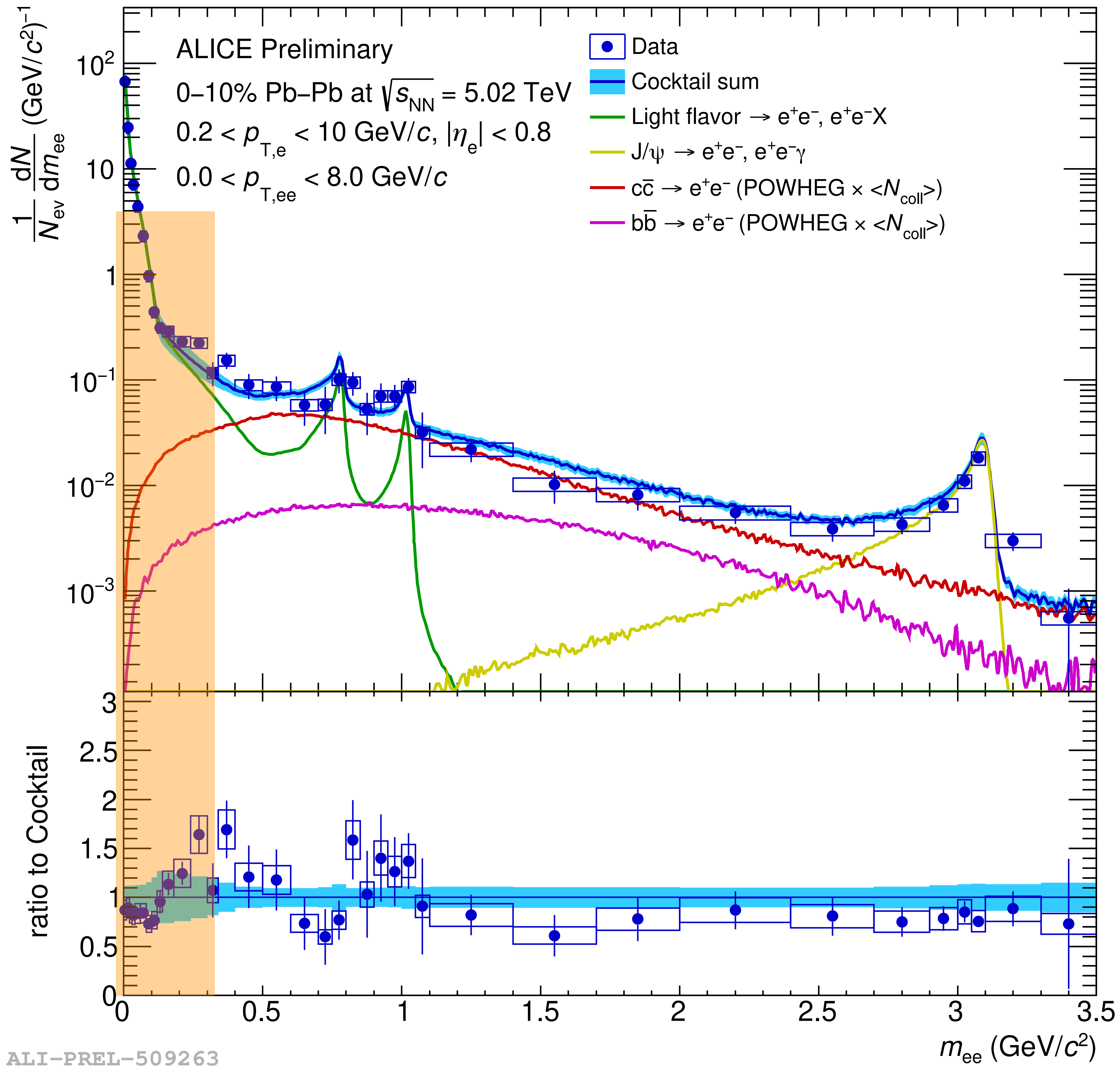
Dielectron production in central Pb—Pb at $\sqrt{s_{NN}} = 5.02\,\mathrm{TeV}$



Data compared to hadronic cocktail based on N_{coll} -scaled heavy-flavour (HF) measurement in pp [1]

- Hint for an excess at $m_{\mathrm{ee}} < 0.5\,\mathrm{GeV}/c^2$

- Extract direct-photon fraction r as in pp at very low m_{ee}

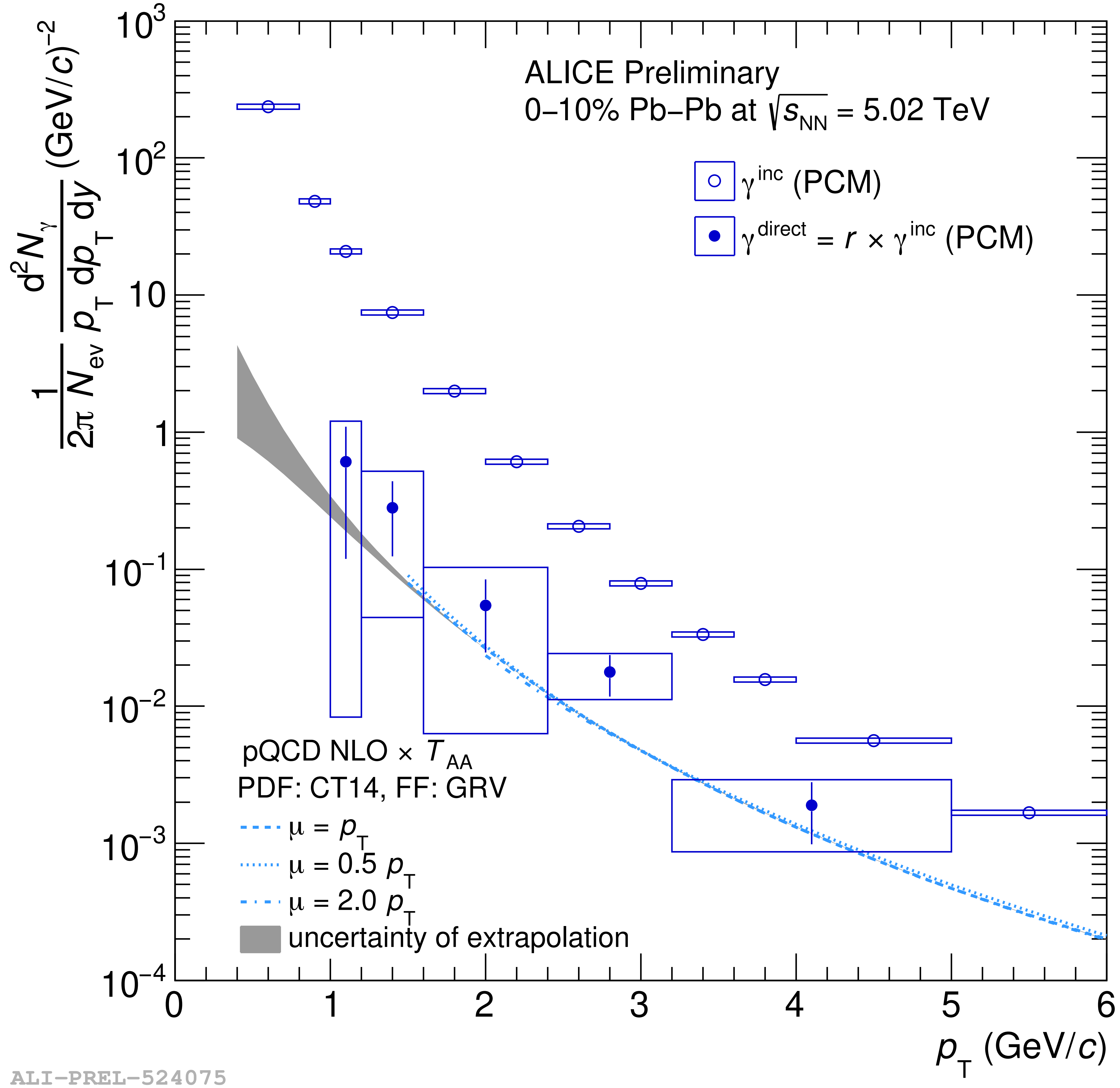


[1] PRC 102 (2020) 055204

Direct photon in central Pb—Pb at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$

- First **direct γ measurement** in 0—10% Pb—Pb collisions at 5.02 TeV
  - γ^{inc} measured with photon conversion method
  - $\gamma^{direct} = r \times \gamma^{inc}$, r from dielectron analysis

- **A hint of an excess above pQCD**



ALI-PREL-524075

See talk 46. by Ana Marín for real γ

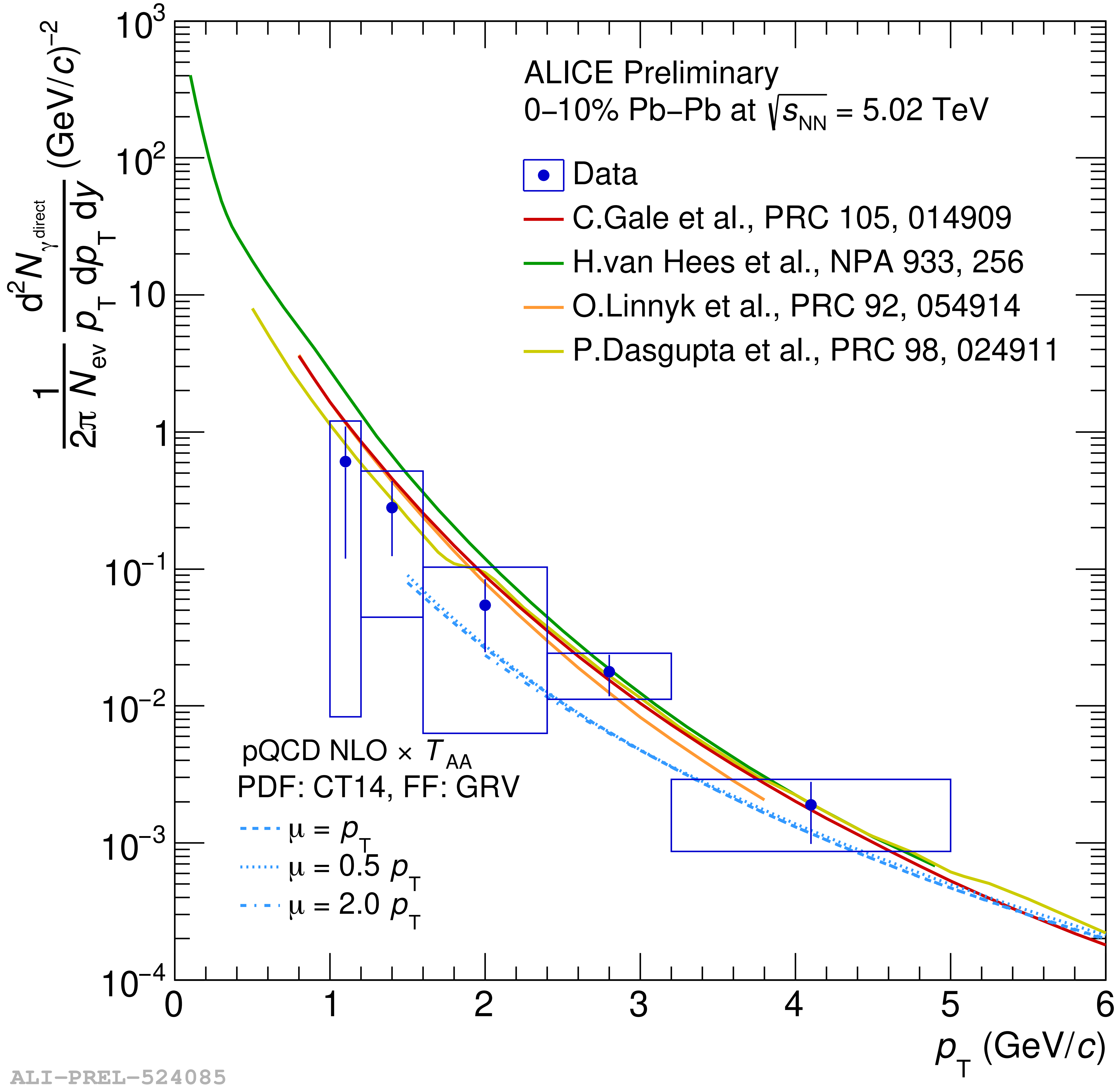
Direct photon in central Pb—Pb at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$

- First **direct γ measurement** in 0—10% Pb—Pb collisions at 5.02 TeV
  - γ^{inc} measured with photon conversion method
  - $\gamma^{direct} = r \times \gamma^{inc}$, r from dielectron analysis

- **A hint of an excess above pQCD**

- Theoretical **models** consistent with data although **at the upper edge of the syst. unc. at low p_T**

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



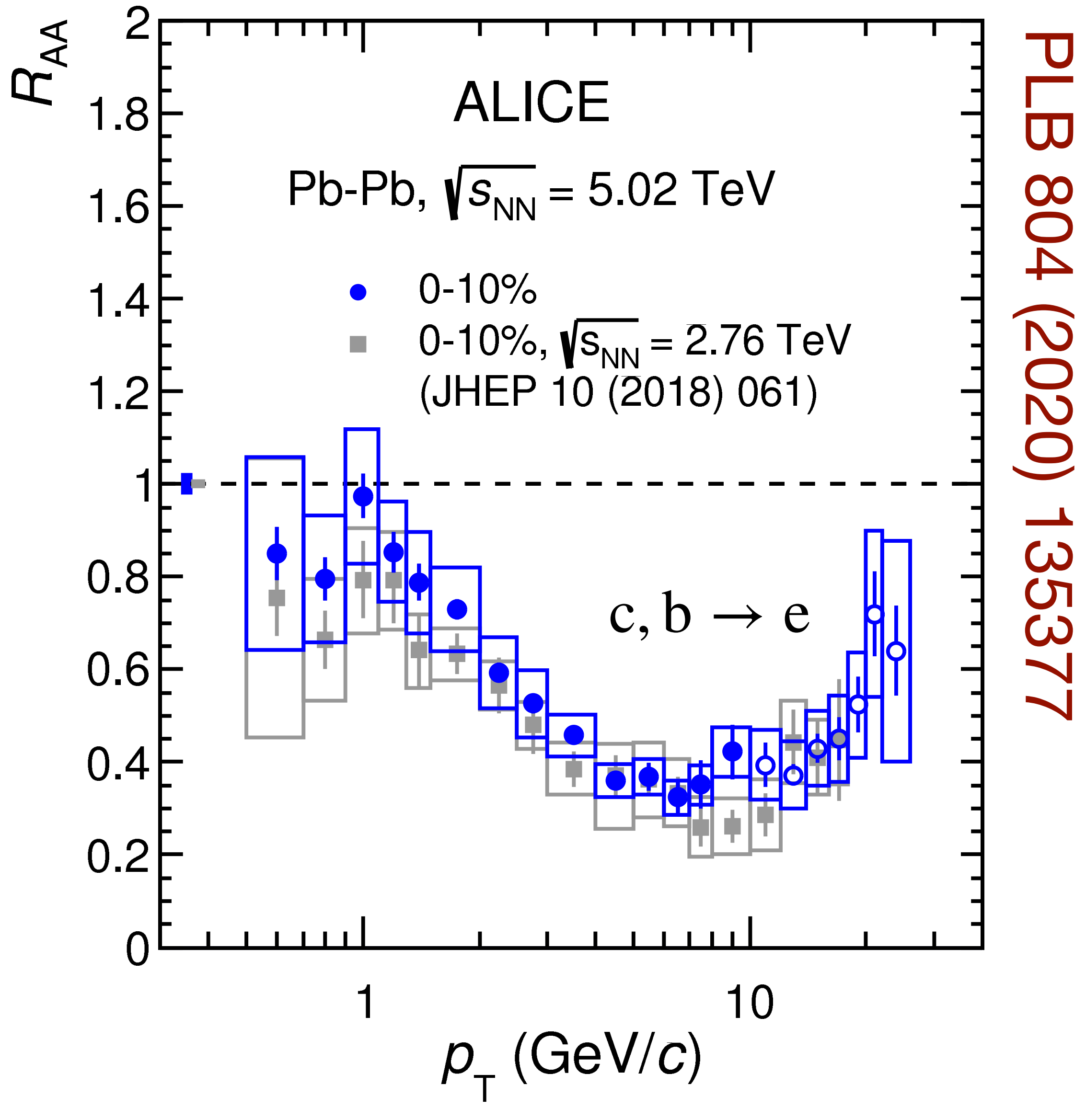
See talk 46. by Ana Marin for real γ

Dielectron in Pb—Pb: modified heavy-flavour contribution

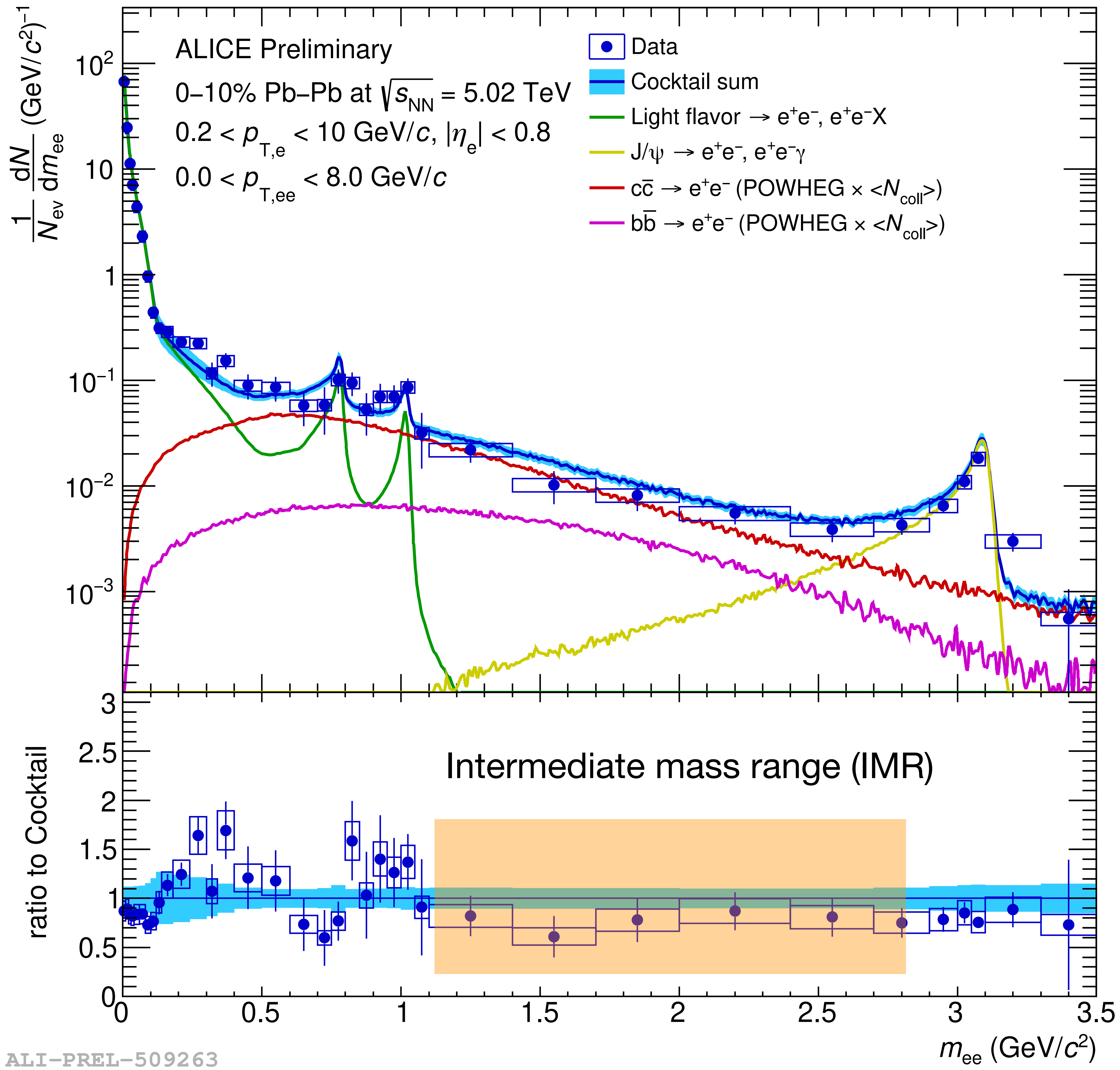
Dielectron studies at higher m_{ee}

N_{coll}-scaled HF cocktail at the upper edge of the data syst. unc. in the IMR
→ **HF known to be modified in Pb—Pb**

Construct modified heavy-flavour cocktail based on measurements of single heavy-flavour hadron decay electrons



ALI-PUB-327779



ALI-PREL-509263

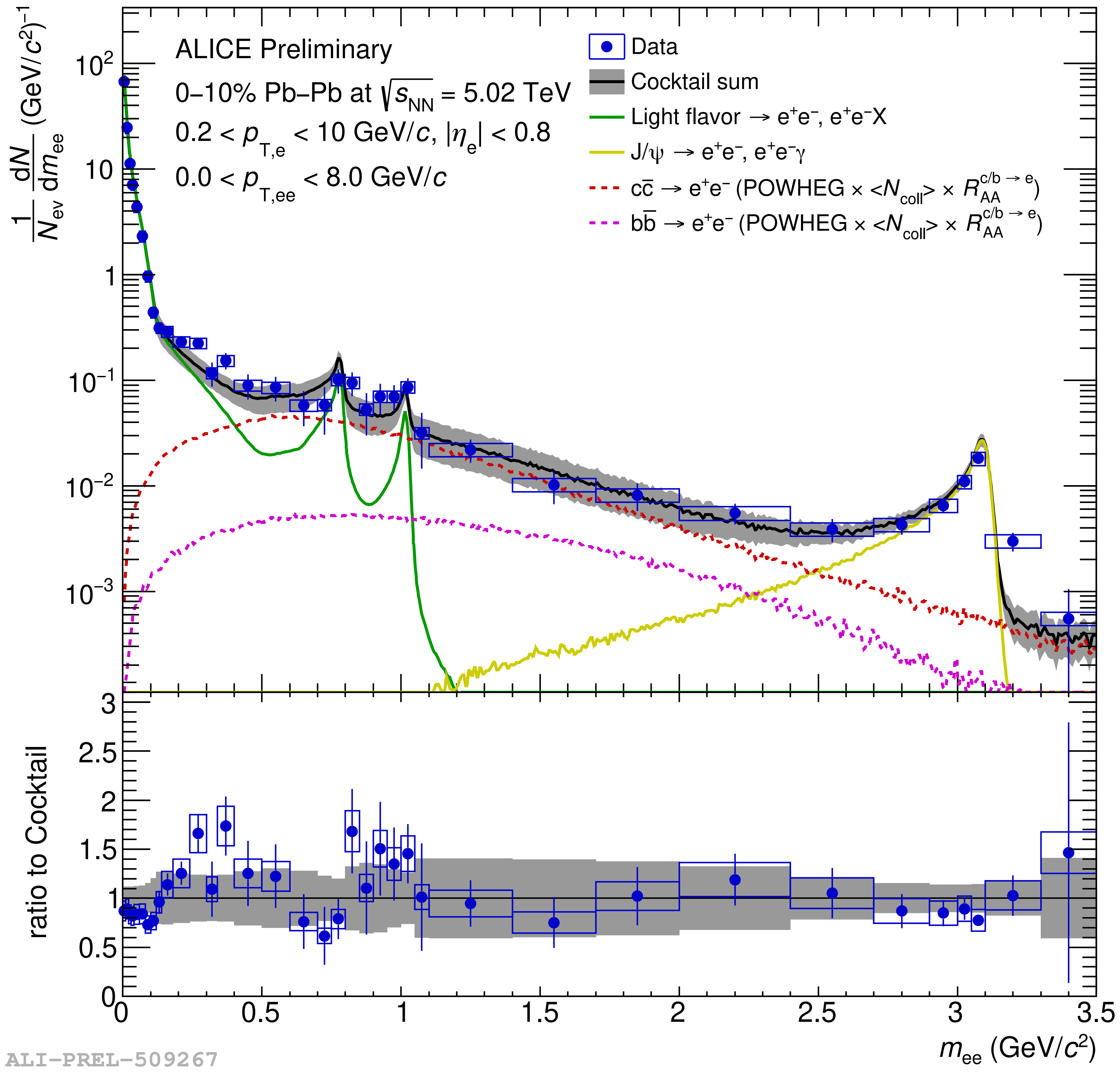
Dielectron in Pb—Pb: modified heavy-flavour contribution

Dielectron studies at higher m_{ee}

N_{coll}-scaled HF cocktail at the upper edge of the data syst. unc. in the IMR
→ **HF known to be modified in Pb—Pb**

Construct modified heavy-flavour cocktail based on measurements of single heavy-flavour hadron decay electrons

→ **Description of the data improved** but additional uncertainties introduced



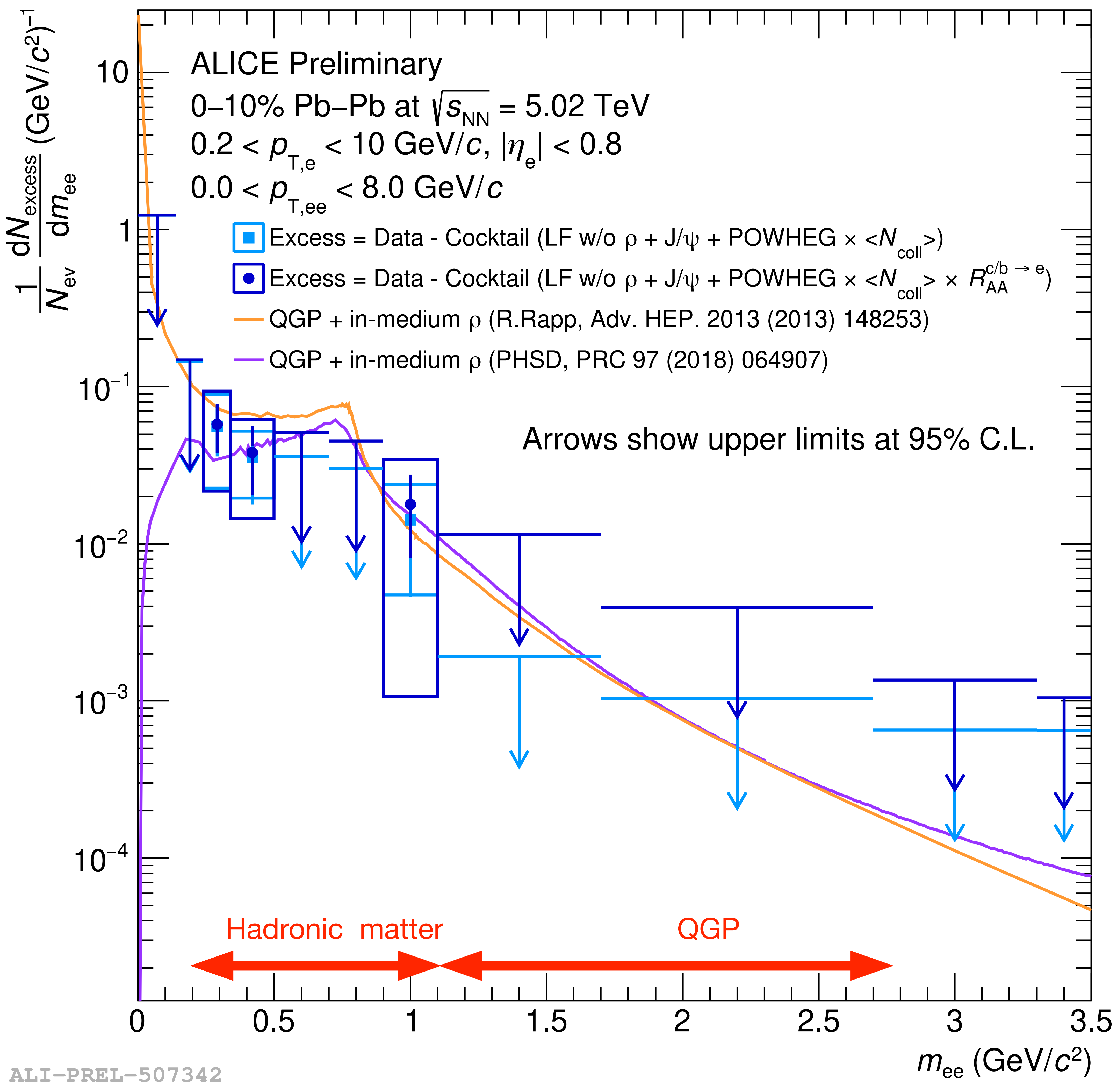
Dielectron excess in Pb—Pb

Dielectron excess (data - cocktail)
using N_{coll}-scaled or modified HF contribution

Compared with two different predictions for thermal radiation
R.Rapp: fireball and hadronic many body system
pHSD: transport model

Possible QGP contribution not resolvable
within systematic (and statistical) uncertainties

→ **Require a cocktail-independent approach !**



Topological separation of dielectron sources

Distance-of-closest approach to primary vertex

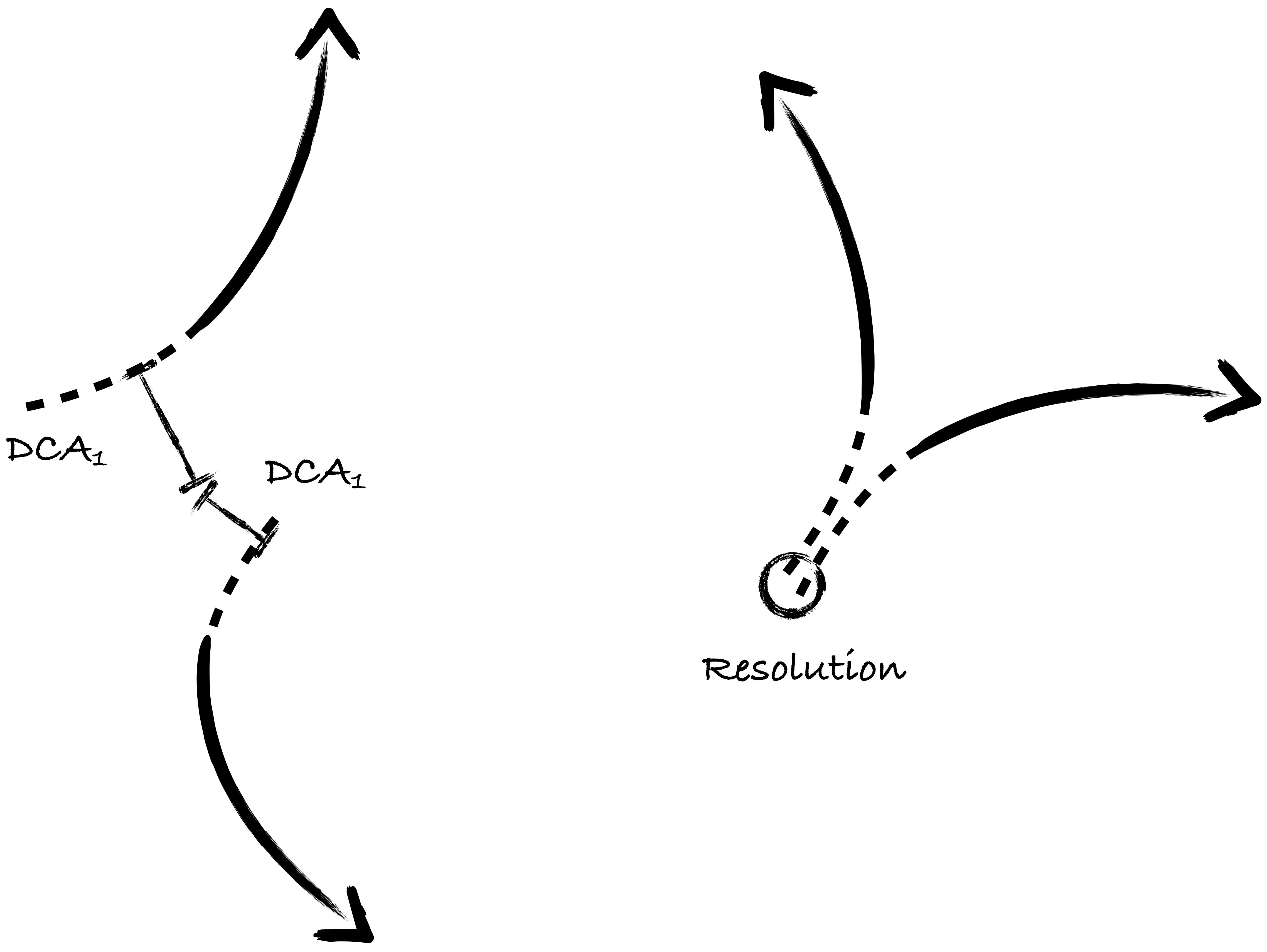
$$\mathrm{DCA}_{\mathrm{ee}} = \sqrt{\frac{\mathrm{DCA}_1^2 + \mathrm{DCA}_2^2}{2}}$$

$\mathrm{DCA}_{\mathrm{i}}$ normalised to its resolution

Allow separation of prompt and delayed e^+e^- sources

$\mathrm{DCA}_{\mathrm{ee}}$(prompt) < $\mathrm{DCA}_{\mathrm{ee}}(c\bar{c} \rightarrow e^+e^-)$ < $\mathrm{DCA}_{\mathrm{ee}}(b\bar{b} \rightarrow e^+e^-)$

Non-prompt (heavy-flavour)   Prompt (thermal)



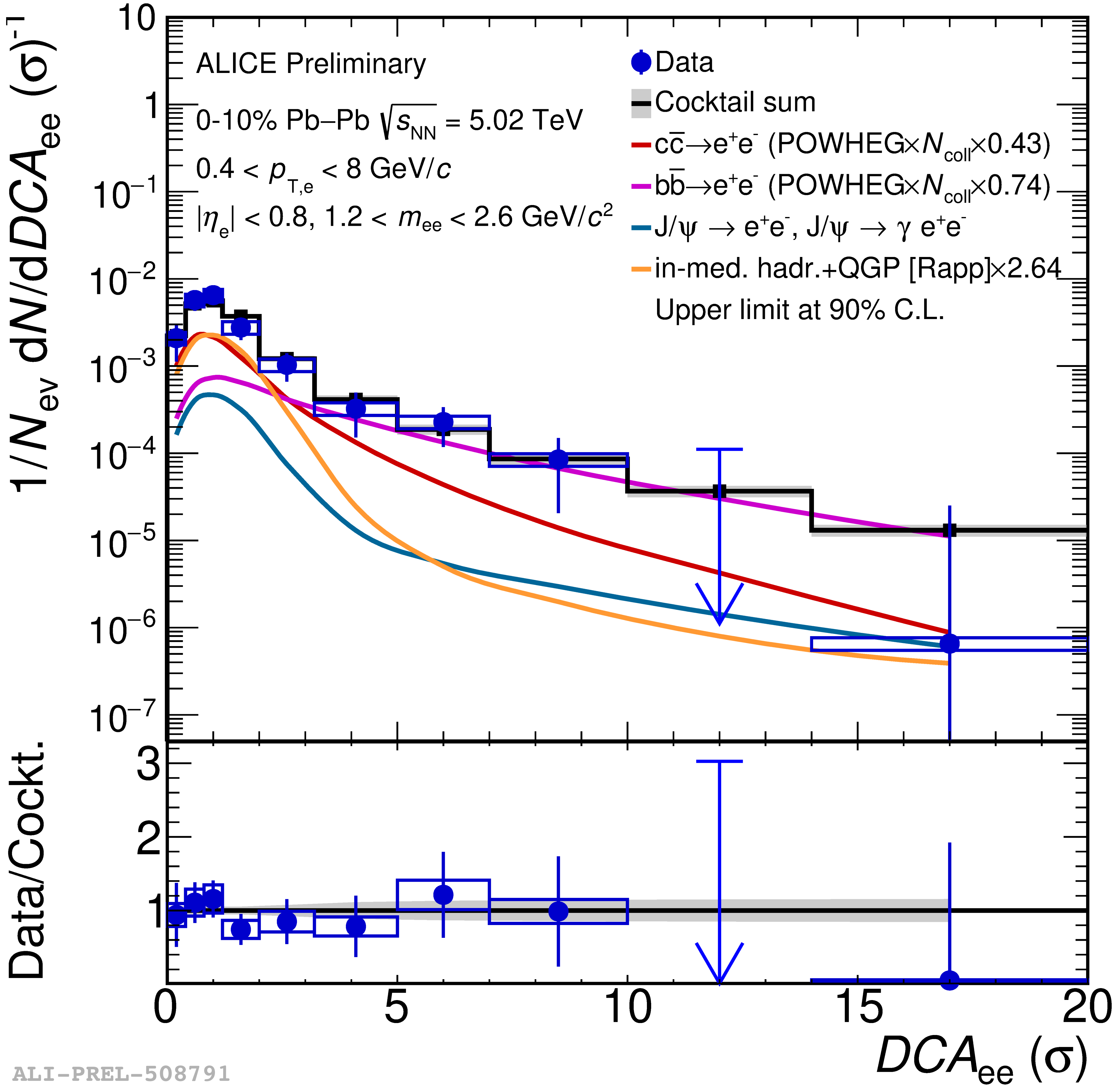
$c\tau \approx$ 150 (450) μm
for charm (beauty) hadrons

First $\mathrm{DCA_{ee}}$ analysis in Pb—Pb

Extraction of **prompt thermal** signal via fits of measured $\mathrm{DCA_{ee}}$ distributions in the IMR

- Beauty contribution fixed via separate fit at high $\mathrm{DCA_{ee}}$
  $\mathrm{b\bar{b}}$: $0.74 \pm 0.24\,(\mathrm{stat.}) \pm 0.12\,(\mathrm{syst.})$ x N_{coll} scaling
- Simultaneous fit of charm and prompt contribution:
  $\mathrm{c\bar{c}}$: $0.43 \pm 0.40\,(\mathrm{stat.}) \pm 0.22\,(\mathrm{syst.})$ x N_{coll} scaling
  prompt: $2.64 \pm 3.18\,(\mathrm{stat.}) \pm 0.29\,(\mathrm{syst.})$ x thermal R. Rapp

Fit of $\mathrm{DCA_{ee}}$ spectrum in the IMR



See poster 270. by Jerome Jung

First DCA_{ee} analysis in Pb—Pb

Extraction of **prompt thermal** signal via fits of measured DCA_{ee} distributions in the IMR

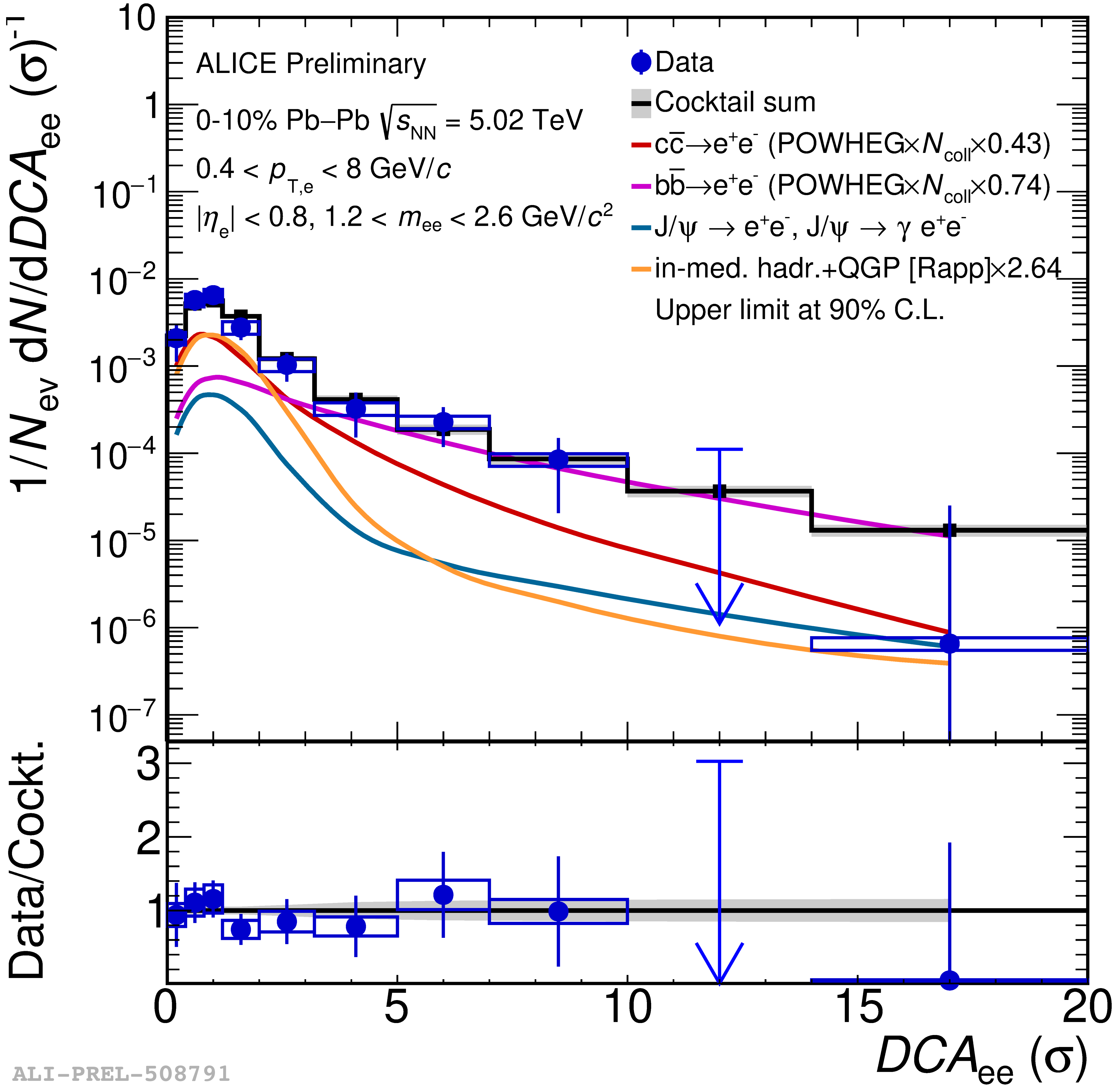
- Beauty contribution fixed via separate fit at high DCA_{ee}
  $b\bar{b}$: $0.74 \pm 0.24\,(\mathrm{stat.}) \pm 0.12\,(\mathrm{syst.})$ x N_{coll} scaling

- Simultaneous fit of charm and prompt contribution:
  $c\bar{c}$: $0.43 \pm 0.40\,(\mathrm{stat.}) \pm 0.22\,(\mathrm{syst.})$ x N_{coll} scaling
  prompt: $2.64 \pm 3.18\,(\mathrm{stat.}) \pm 0.29\,(\mathrm{syst.})$ x thermal R. Rapp

- **Results in agreement with:**
  - **Heavy-flavour suppression**
  - **Thermal contribution in the order of R. Rapp predictions**

→ Looking forward to Run 3 to improve precision

Fit of DCA_{ee} spectrum in the IMR



ALI-PREL-508791

See poster 270. by Jerome Jung

Run 3 started already…

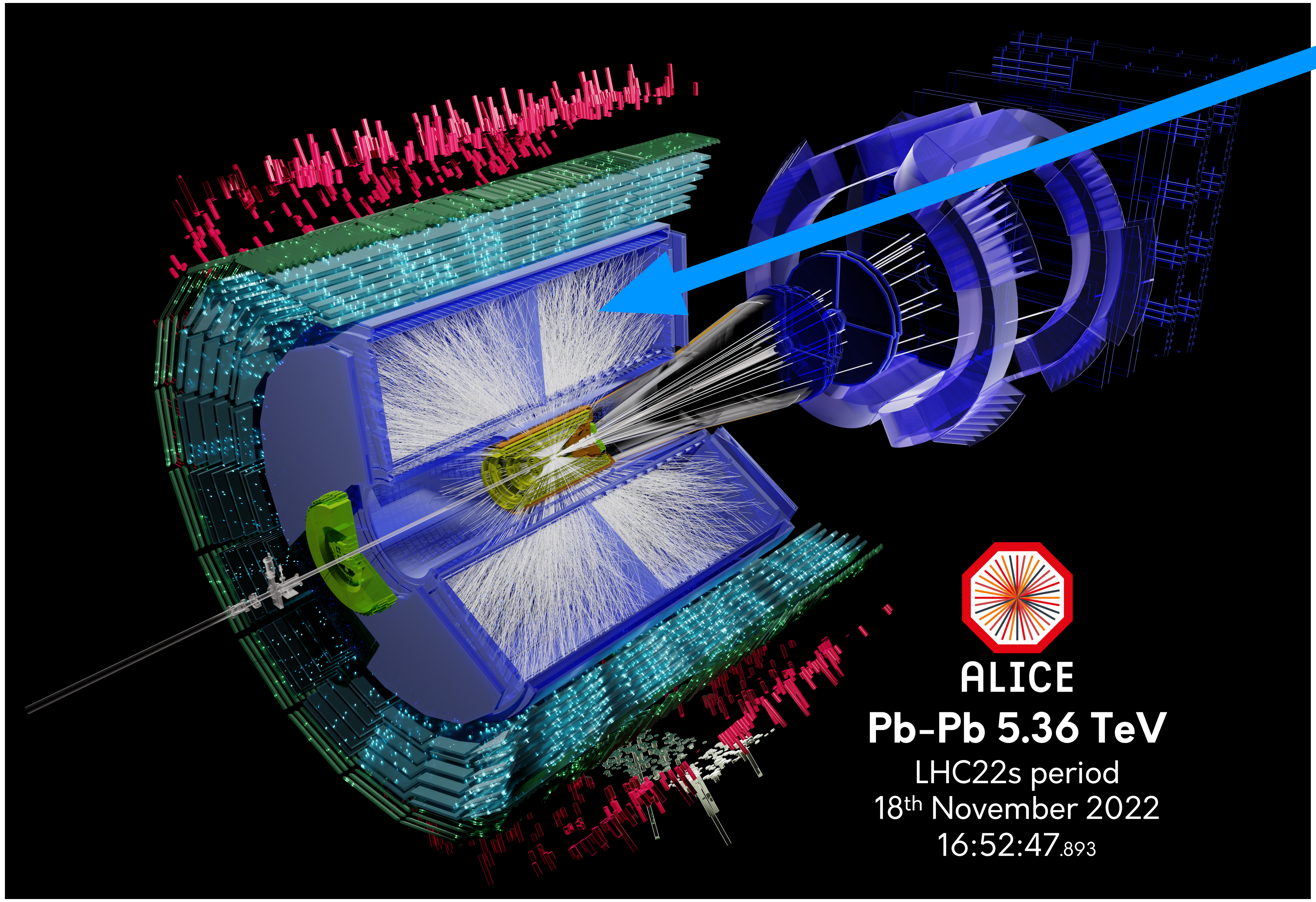
ALICE in Run 3

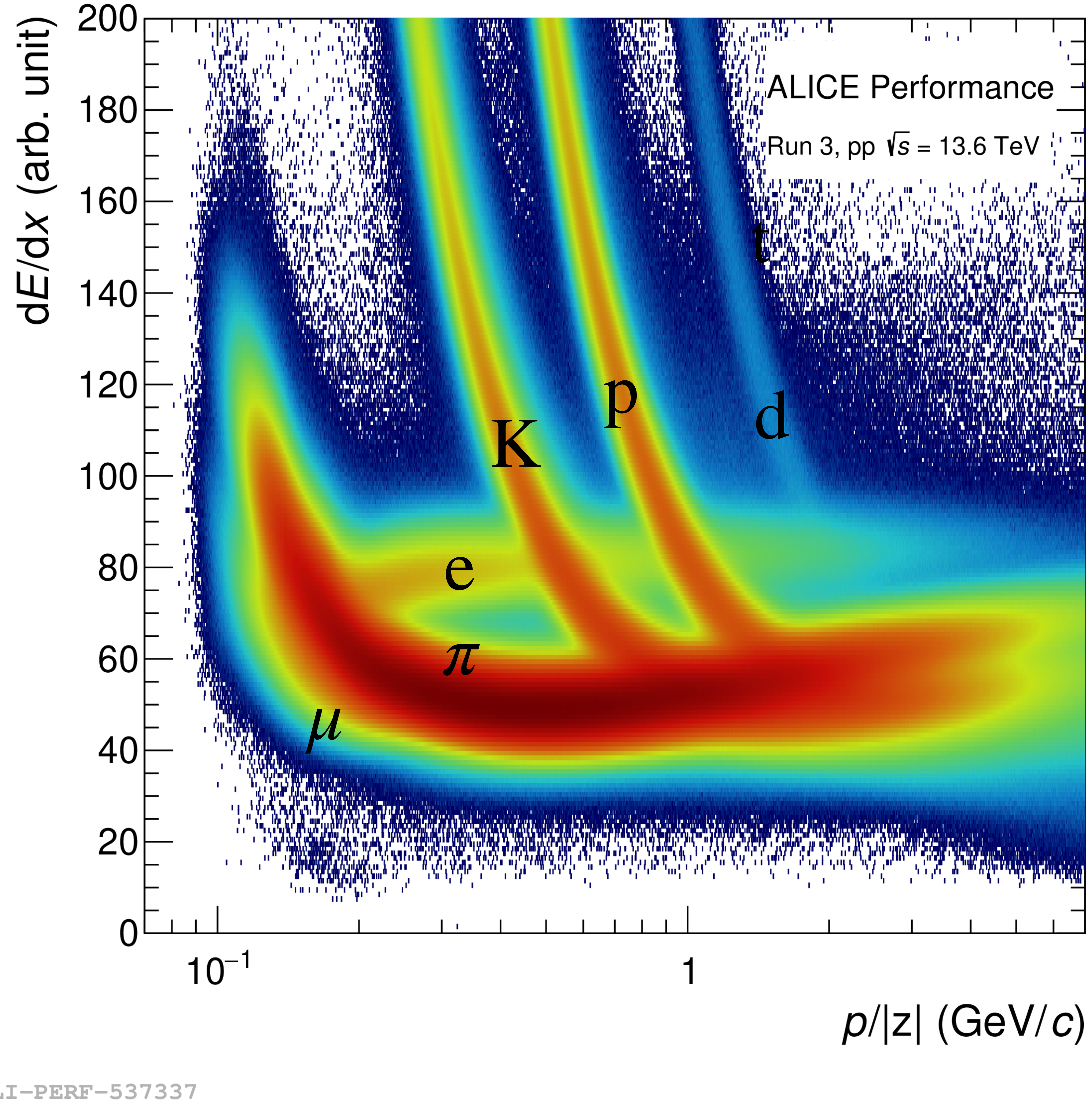
New !

New GEM based TPC read-out chambers [1]

→ Continuous read-out

→ Larger data acquisition rate
(up to 1000 in pp and 100 in Pb—Pb)





[1] CERN-LHCC-2013-020, CERN-LHCC-2015-002

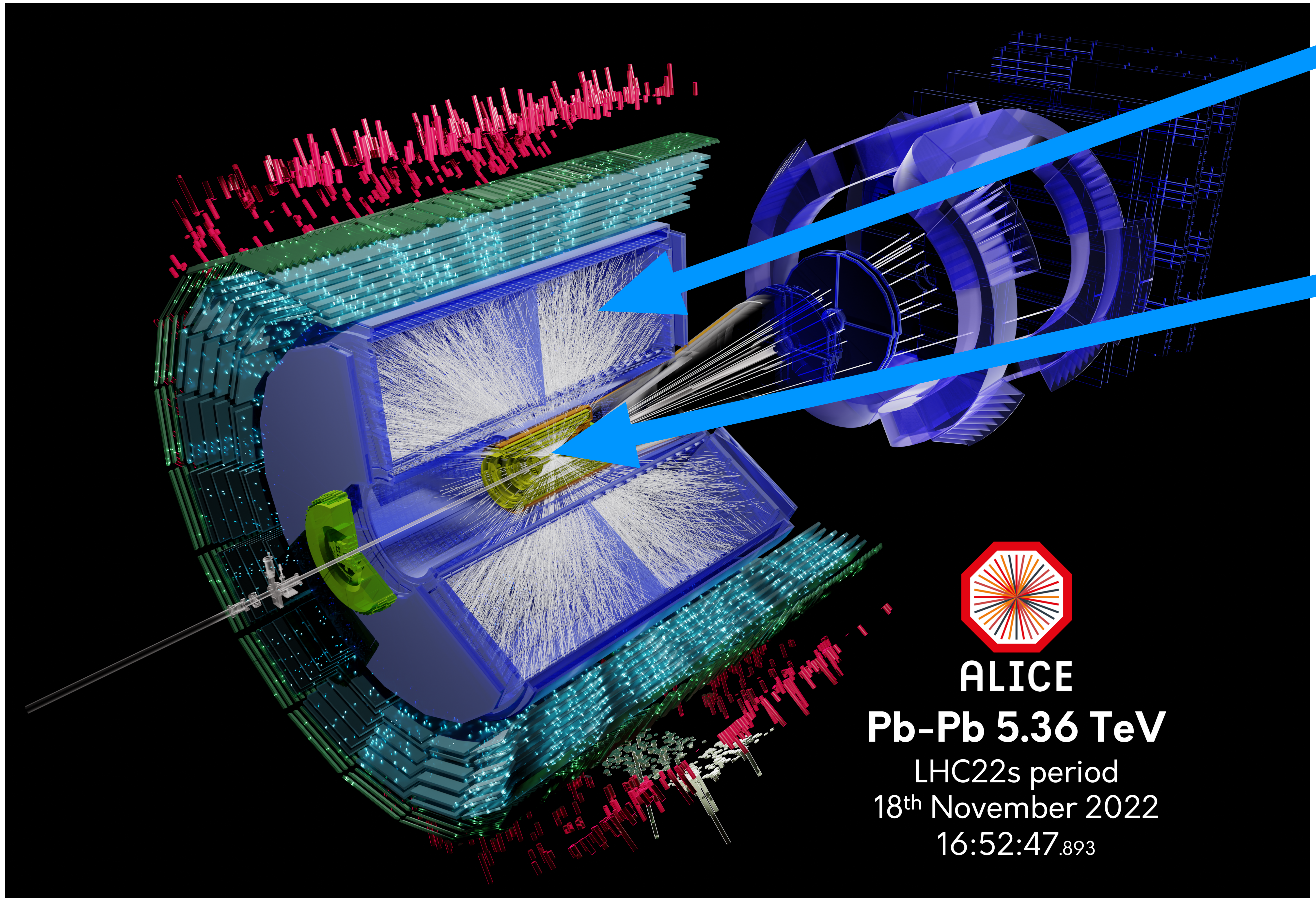
ALICE in Run 3

New !

New GEM based TPC read-out chambers [1]

→ Continuous read-out

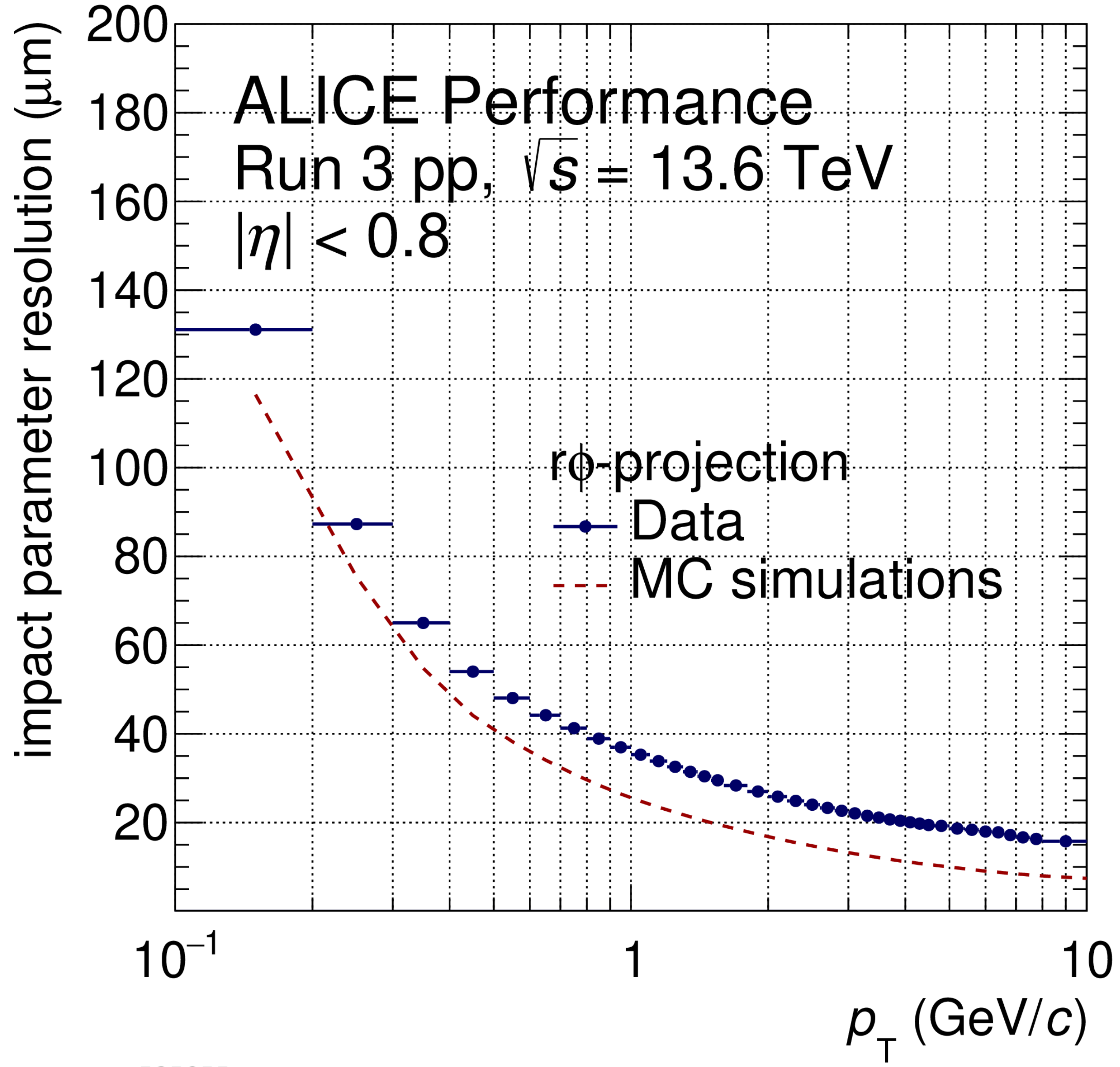
→ Larger data acquisition rate
(up to 1000 in pp and 100 in Pb—Pb)



New Inner Tracking System (ITS2) [2]

→ Less material

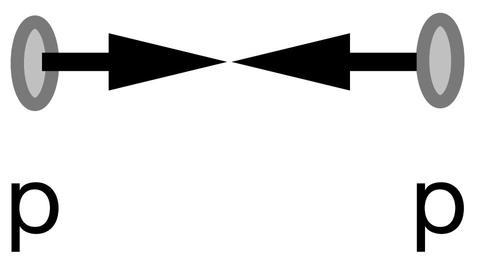
→ Better pointing resolution (x 3 in $r\varphi$, x 6 in z)



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

First look at dielectron with Run 3

New !

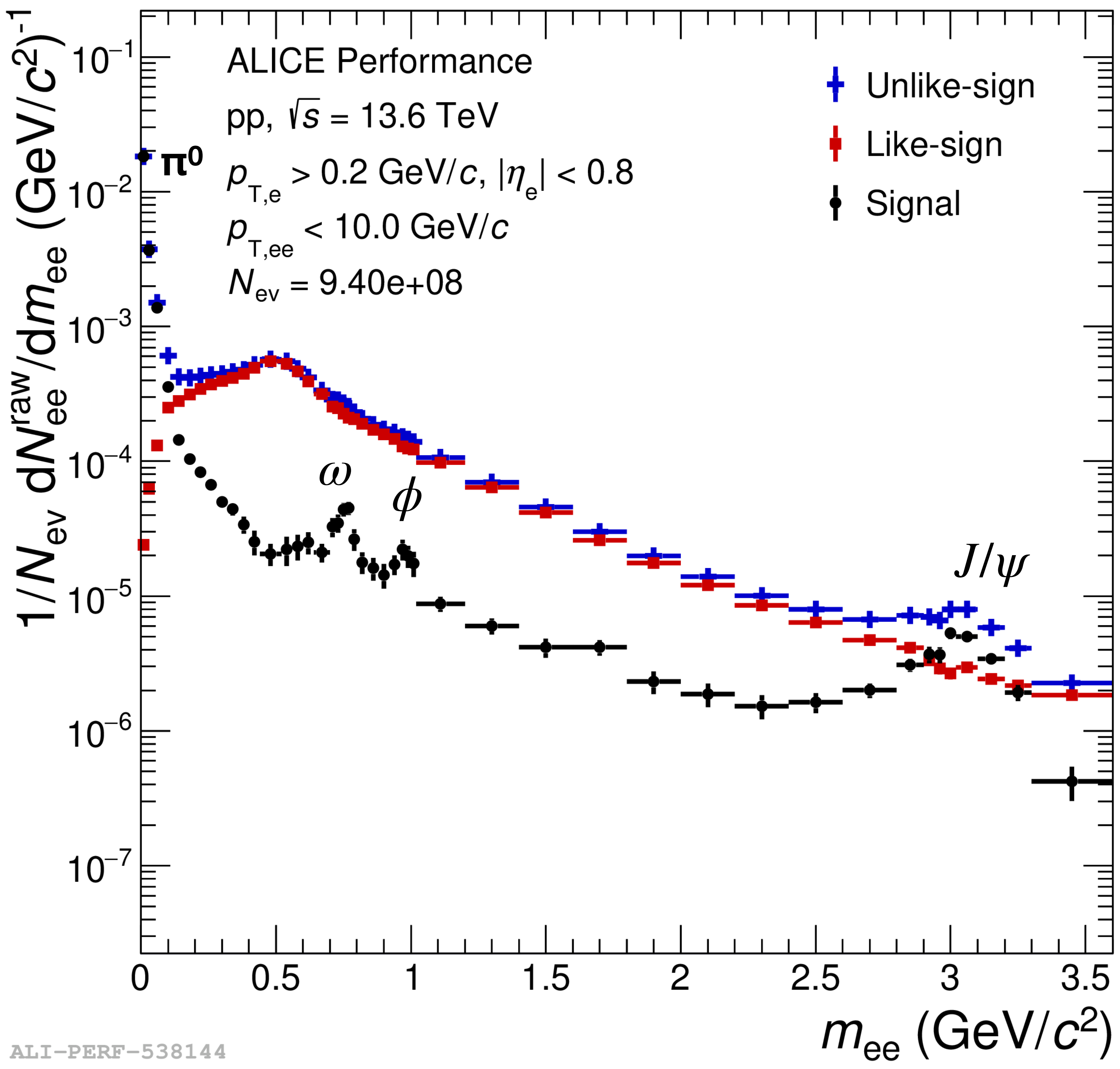


- **Raw dielectron m_{ee} spectrum**
  in pp collisions at $\sqrt{s} = 13.6\,\text{TeV}$
  → Clear $\omega, \phi, J/\psi$ peaks

- **Data collected in two days**
  Similar number of events as for full Run 2 data set

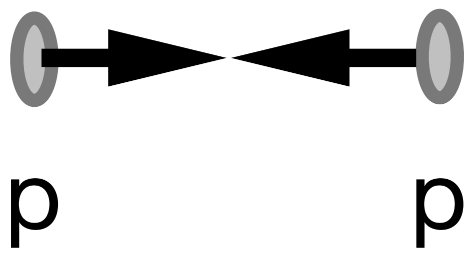
- Similar signal-to-background as in Run 2

See poster 84. by Florian Eisenhut



First look at dielectron with Run 3

New !

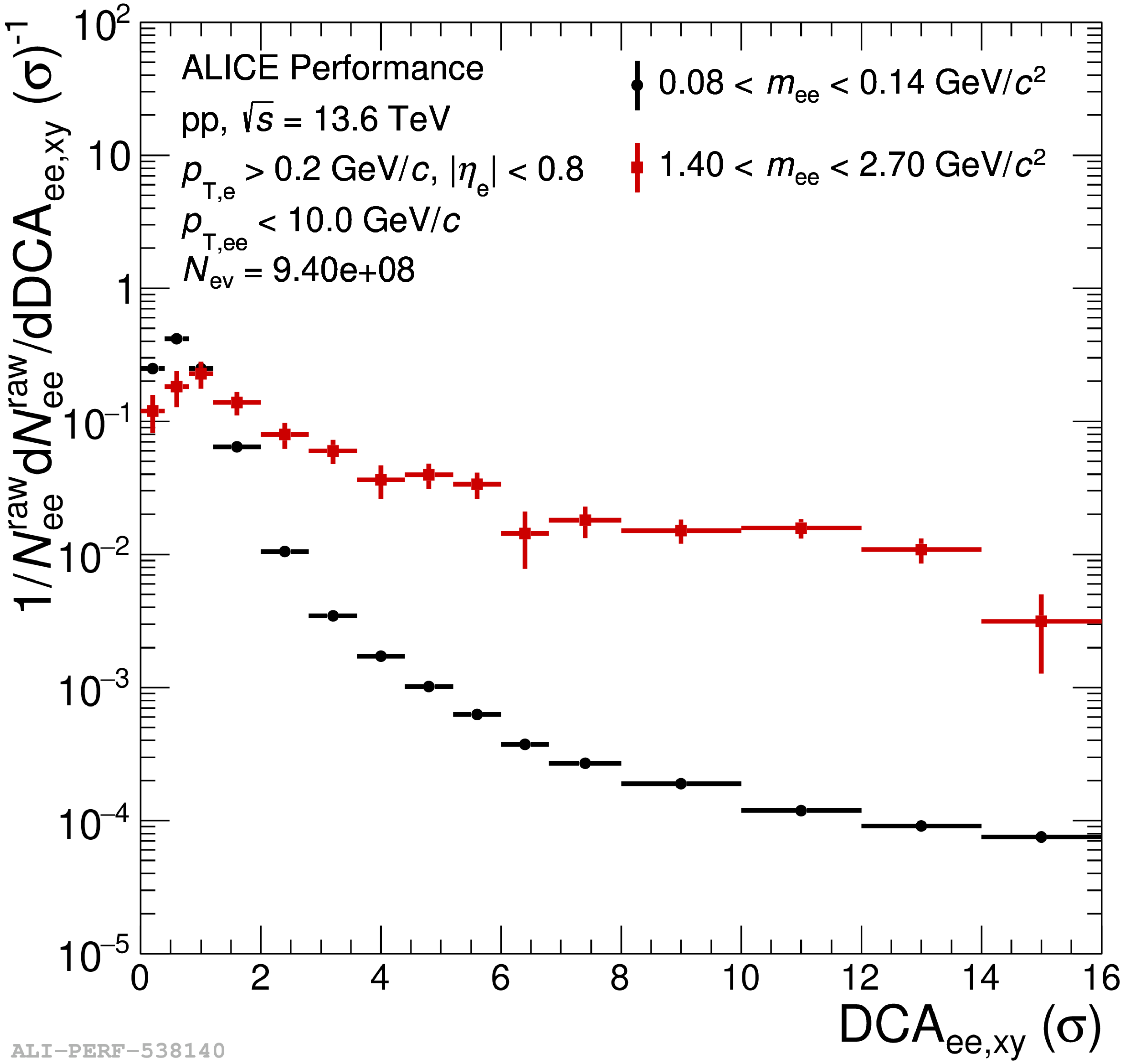


- **Normalised raw dielectron $\mathrm{DCA_{ee}}$ spectra** in pp collisions at $\sqrt{s} = 13.6\,\mathrm{TeV}$
- **Low m_{ee}: dominated by prompt π^0 dalitz decays**
- **Intermediate m_{ee}**: dominated by **non-prompt** HF decays

→ **Improved separation power compared to Run 2**

→ Work on going to include DCA in z direction

See poster 84. by Florian Eisenhut



Summary

Dielectron measurements with full Run 2 statistics:

- Similar direct-photon fraction observed in MB and HM pp collisions at $\sqrt{s} = 13\,\mathrm{TeV}$
- In central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV:
  - Direct-photon measurement described by state-of-the-art models although at the upper edge of the syst. unc.
  - Understanding of heavy-flavour background crucial at the LHC

  → Tools developed to allow measurement of thermal radiation from the QGP

First look into Run 3 data promising

See talk 46. by Ana Marín for ALICE real γ results

See posters 109. by Joshua Koenig, 270. by Jerome Jung and 84. by Florian Eisenhut

Back-up

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

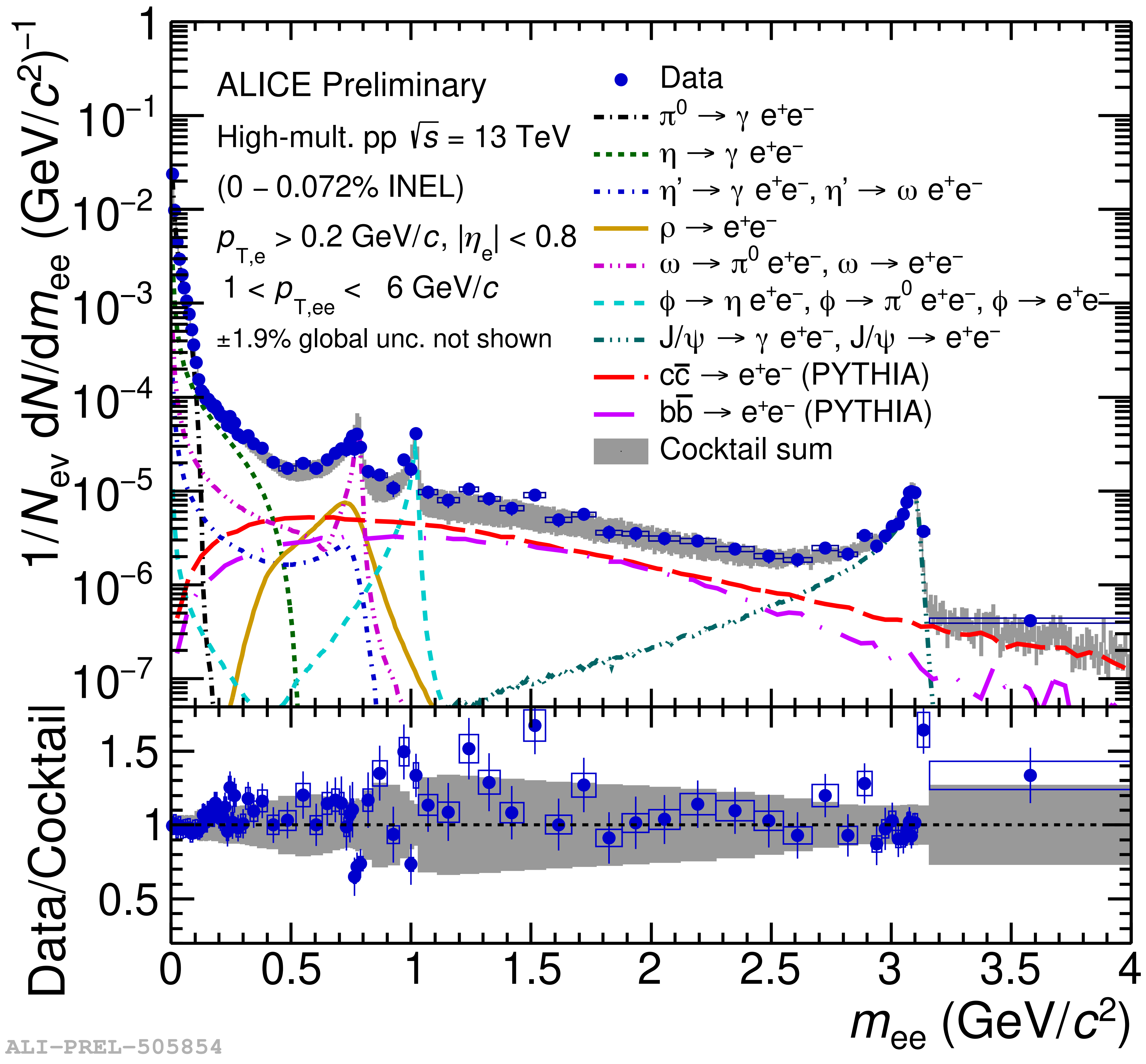
- **Full statistics of Run 2 data**
  - 30 nb^{-1} minimum bias (MB)
  - 6.1 pb^{-1} high multiplicity 0-0.1% (HM)

  → 4 times more data compared to previous publication

- **Described by cocktail of known hadron decays** based on measured neutral mesons
  - At the same energy
  - In the same multiplicity class

  See poster 109 by Joshua Koenig

High multiplicity pp collisions



$\mathrm{DCA_{ee}}$ analysis in Pb—Pb

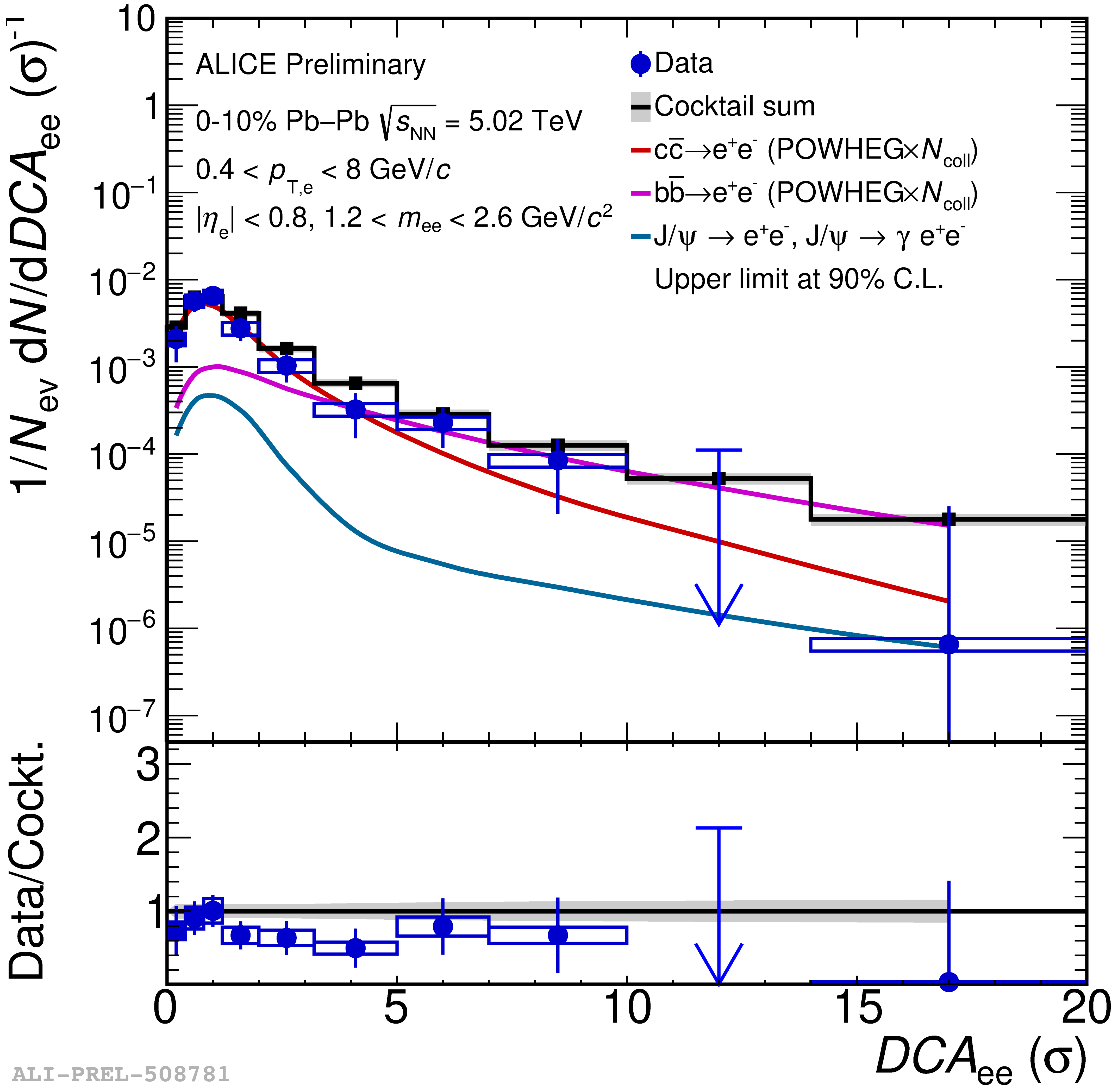
First $\mathrm{DCA_{ee}}$ analysis in Pb–Pb at $\sqrt{s_{NN}} = 5.02$ TeV

Comparison to N_{coll}-scaled cocktail:

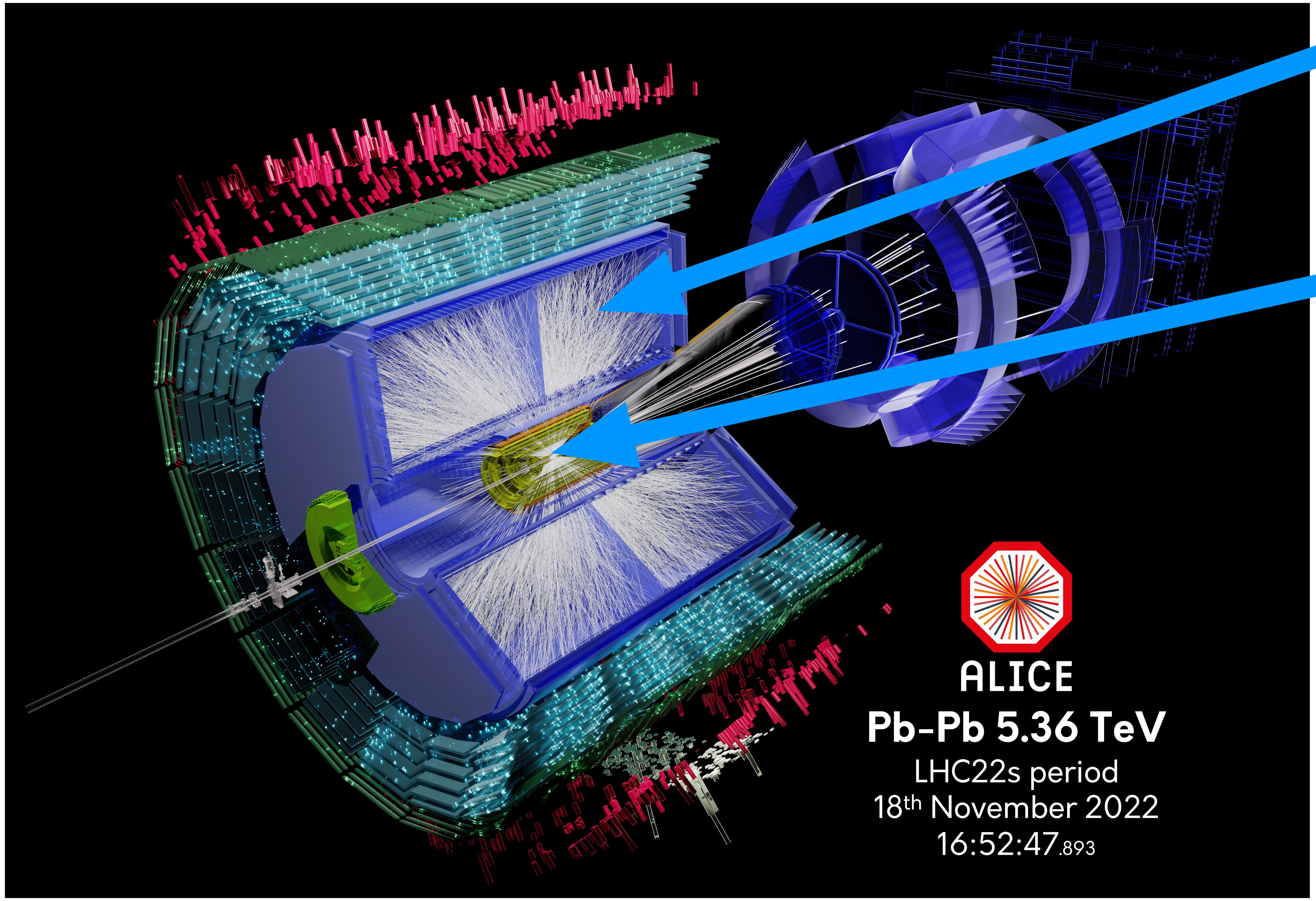
- Beauty dominates the spectrum at high $\mathrm{DCA_{ee}}$
- Charm more prominent at low $\mathrm{DCA_{ee}}$

→ Data below HF expectation

→ Clear indication of HF suppression



ALICE in Run 3



New GEM based TPC read-out chambers [1]

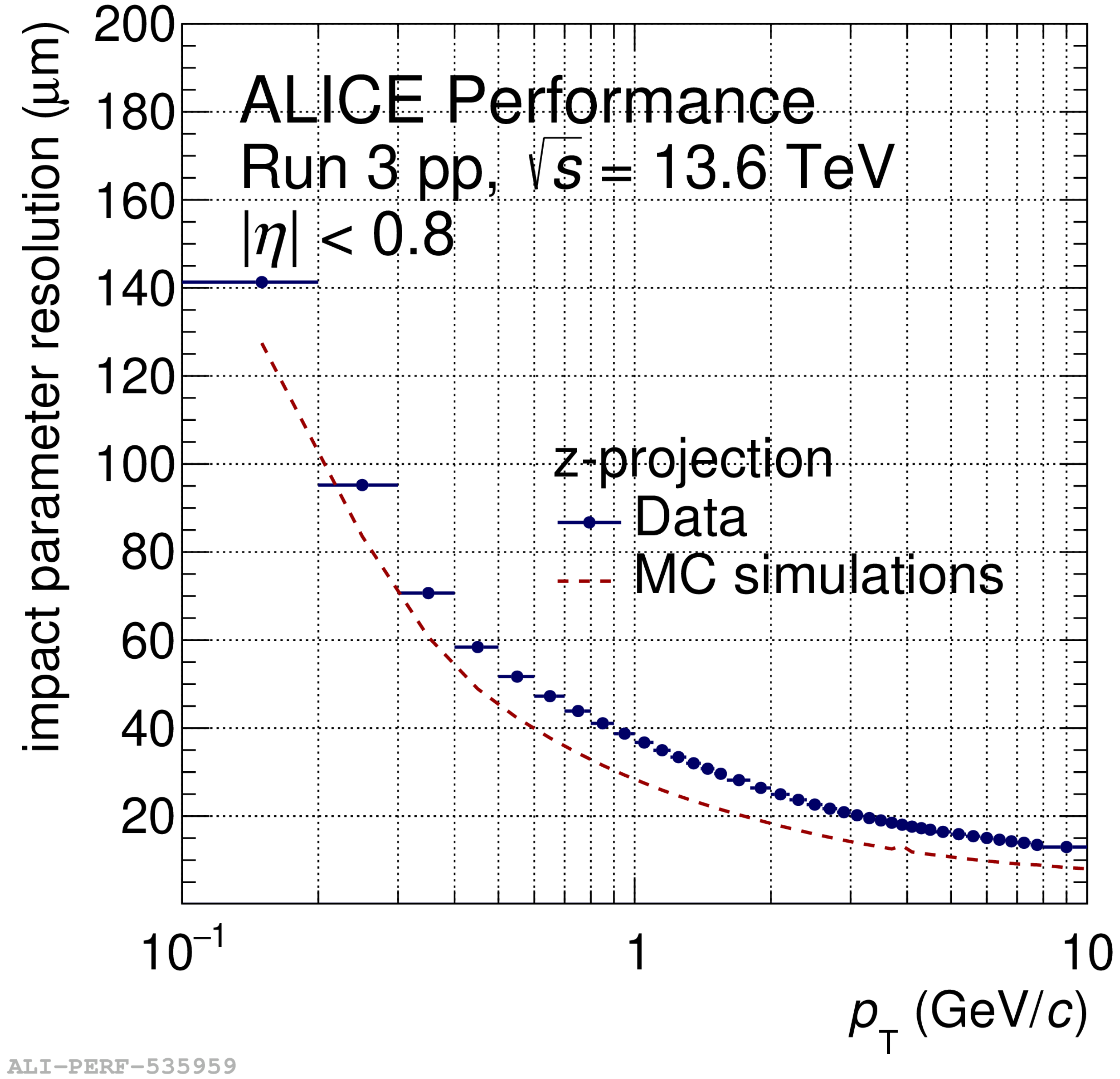
→ Continuous read-out

→ Larger data acquisition rate (up to 1000 in pp and 100 in Pb—Pb)

New Inner Tracking System (ITS2) [2]

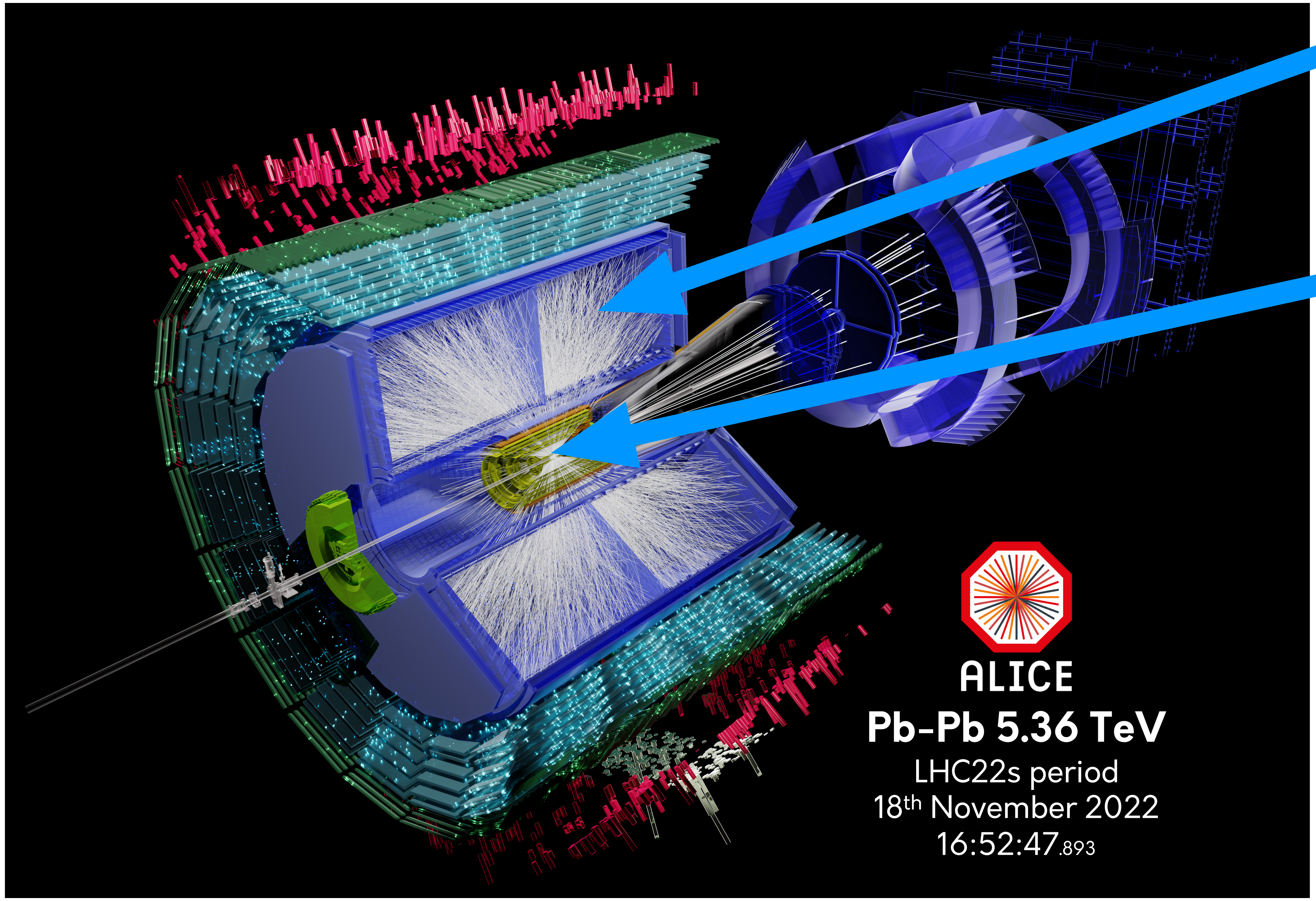
→ Less material

→ Better pointing resolution (x 3 in $r\varphi$, x 6 in z)



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

ALICE in Run 3



New GEM based TPC read-out chambers

→ Continuous read-out

→ Larger data acquisition rate (up to 1000 in pp and 100 in Pb—Pb)

New Inner Tracking System (ITS2)

→ Less material

→ Better pointing resolution (x 3 in $r\varphi$, x 5 in z)

New online-offline system (O2)

→ Online Processing of all events