Low-mass dielectron measurements with ALICE at the LHC

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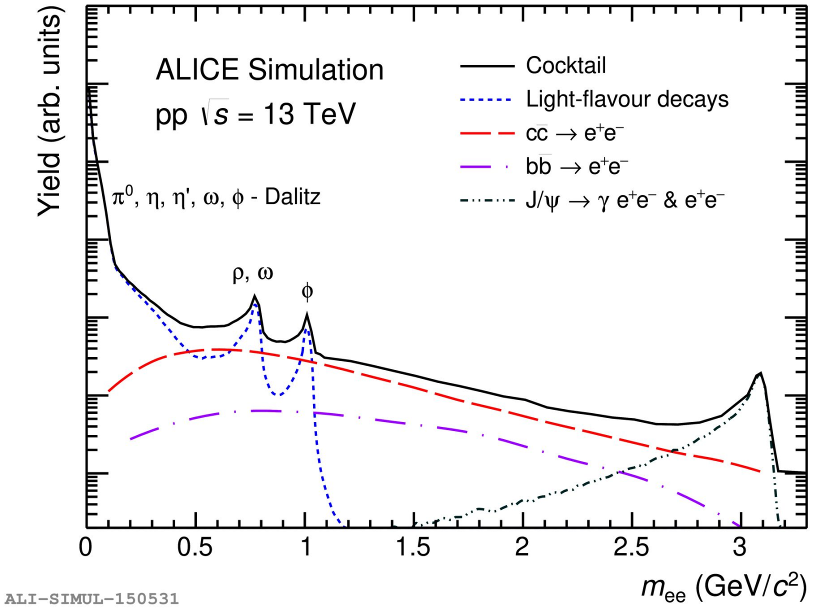
on behalf of the ALICE Collaboration

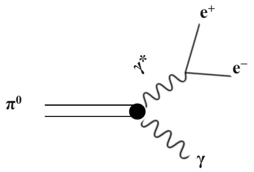
Why dielectrons?

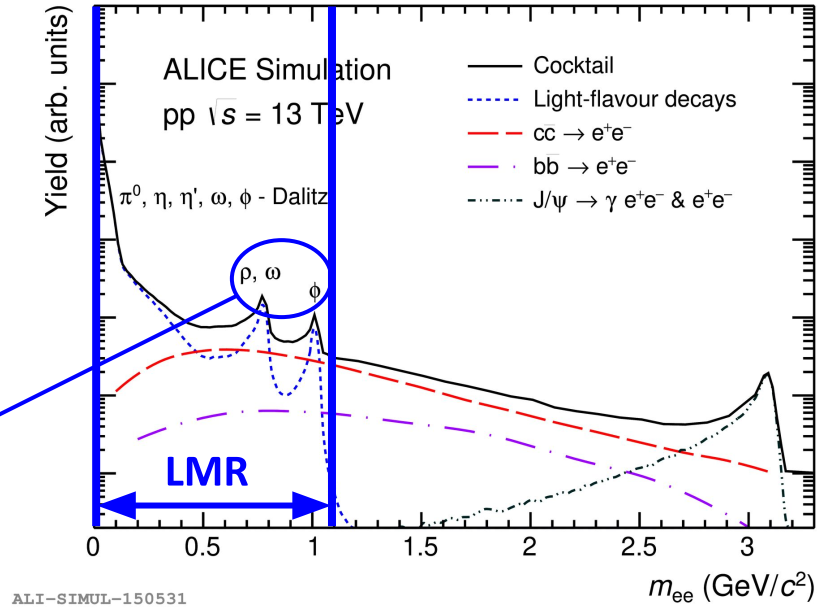
- ➔ Dileptons are a rich source of physical information in all collision systems
  - ⇒ pp: baseline measurements and high-multiplicity phenomena
  - ⇒ p–Pb: cold nuclear matter effects measurements
  - ⇒ Pb–Pb: QGP insights
- ➔ They are produced during all stages from different sources and present negligible final-state interactions
  - ⇒ Allowing to access the whole history of the system created in each type of collision
- ➔ Unique probes of the system



Dielectrons sources

➔ LMR - $m_{ee} < 1.1$ GeV/c^2: Dalitz and resonance decays from light-flavour (LF) mesons and thermal radiation from the medium (Pb–Pb)





ρ - chiral symmetry restoration

Dielectrons sources

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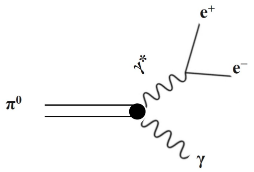
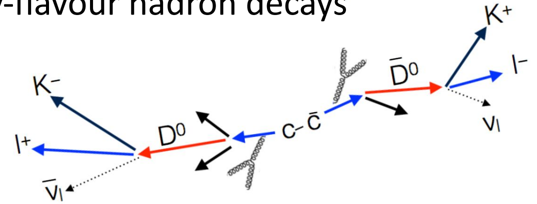
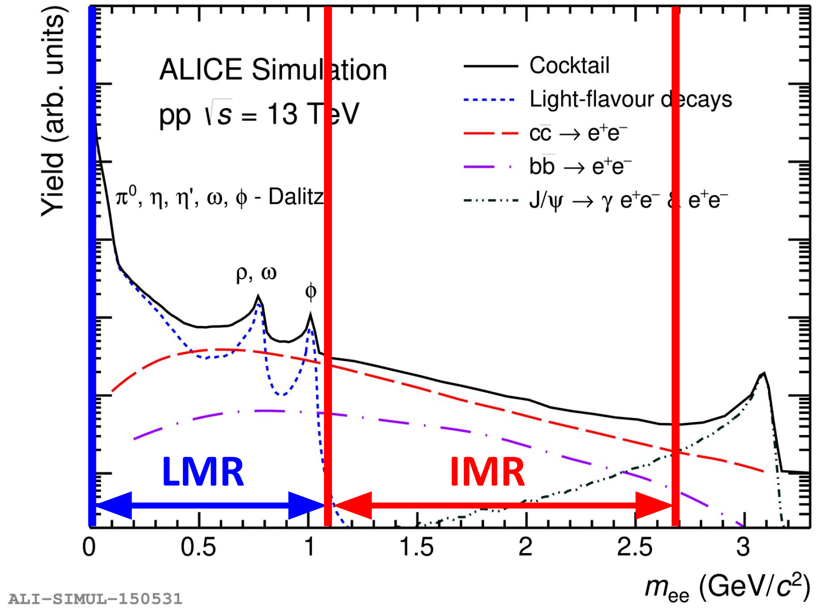


➔ IMR - 1.1 < m_{ee} < 2.7 GeV/c^2: Correlated heavy-flavour hadron decays

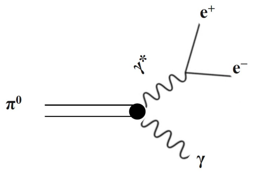


Extraction of HF cross sections: $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$

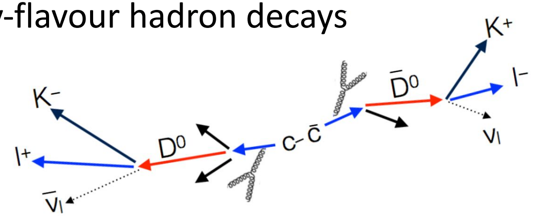


Dielectrons sources

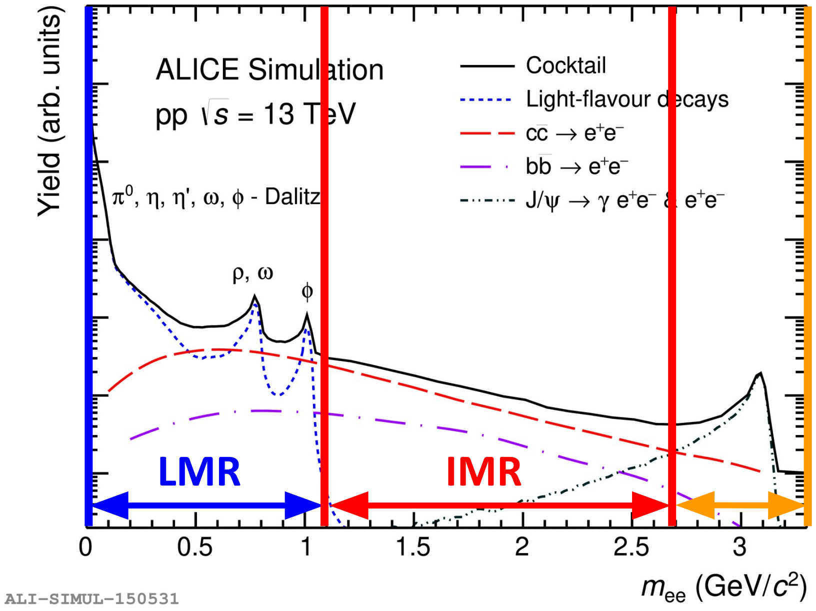
➔ LMR - m_{ee} < 1.1 GeV/c^2: Dalitz and resonance decays from light-flavour (LF) mesons and thermal radiation from the medium (Pb–Pb)



➔ IMR - 1.1 < m_{ee} < 2.7 GeV/c^2: Correlated heavy-flavour hadron decays



➔ J/Ψ mass region - 2.7 < m_{ee} < 3.3 GeV/c^2



The ALICE experiment

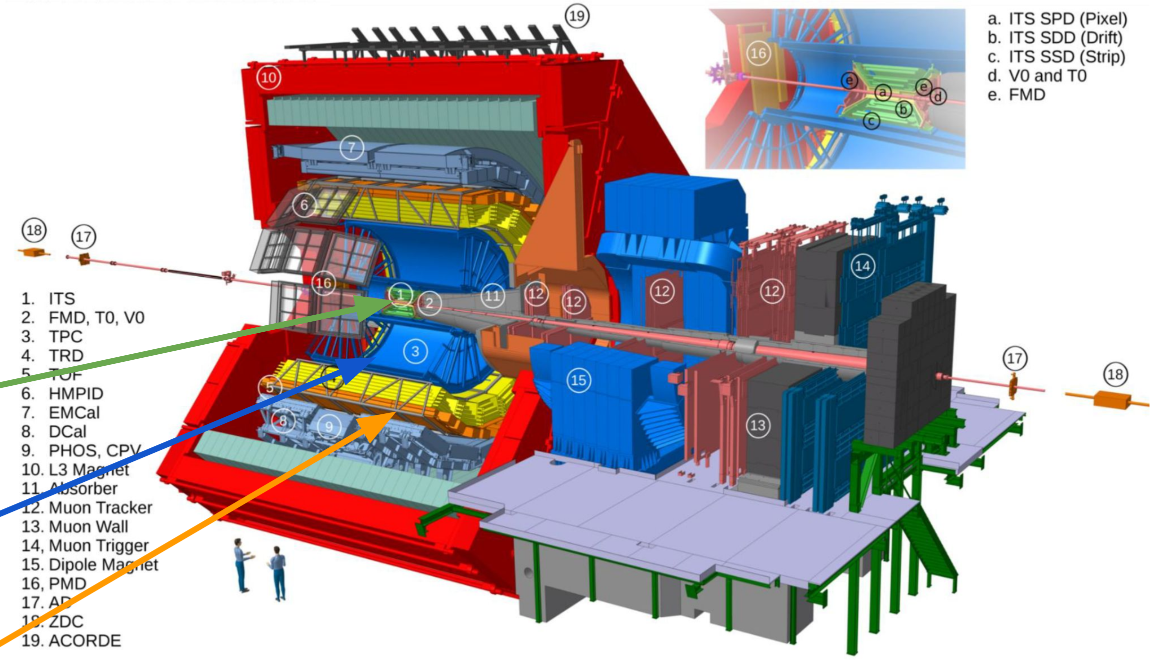
- Dielectrons measured at midrapidity
- In this talk: pp, p–Pb and Pb–Pb at **5 TeV** and soft dielectron production in pp at 13 TeV

V0 scintillators
Trigger and centrality estimator

Inner Tracking System (ITS)
Tracking, vertexing and PID (dE/dx)

Time Projection Chamber (TPC)
Tracking and PID (dE/dx)

Time-Of-Flight (TOF)
Tracking and PID (TOF measurement)



Dielectron production in pp at 5.02 TeV

ALICE

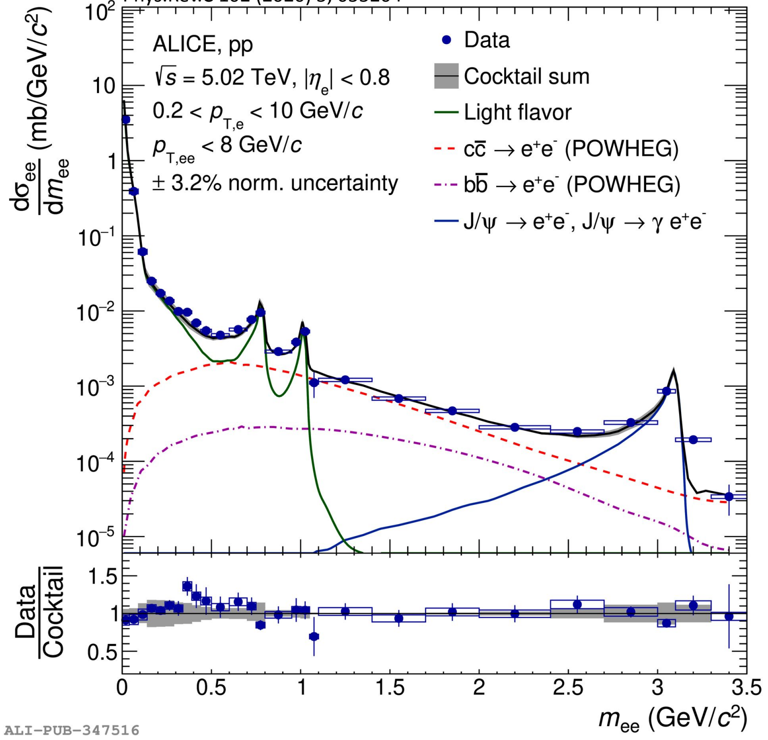
pp 5 TeV

p–Pb 5 TeV

Pb–Pb 5 TeV

Reference

Phys.Rev.C 102 (2020) 5, 055204



- ➔ Dielectron production in pp collisions **is fully described** by hadronic sources
- ➔ LF and J/Ψ from parameterized measurements
- ➔ HF normalized by the cross sections extracted from 2D fits of m_{ee} and $p_{T,ee}$
- ➔ Serves as baseline for p–Pb and Pb–Pb collisions
- ➔ Similar results for other collision energies, and for both PYTHIA and POWHEG generators

HF cross sections via dielectron

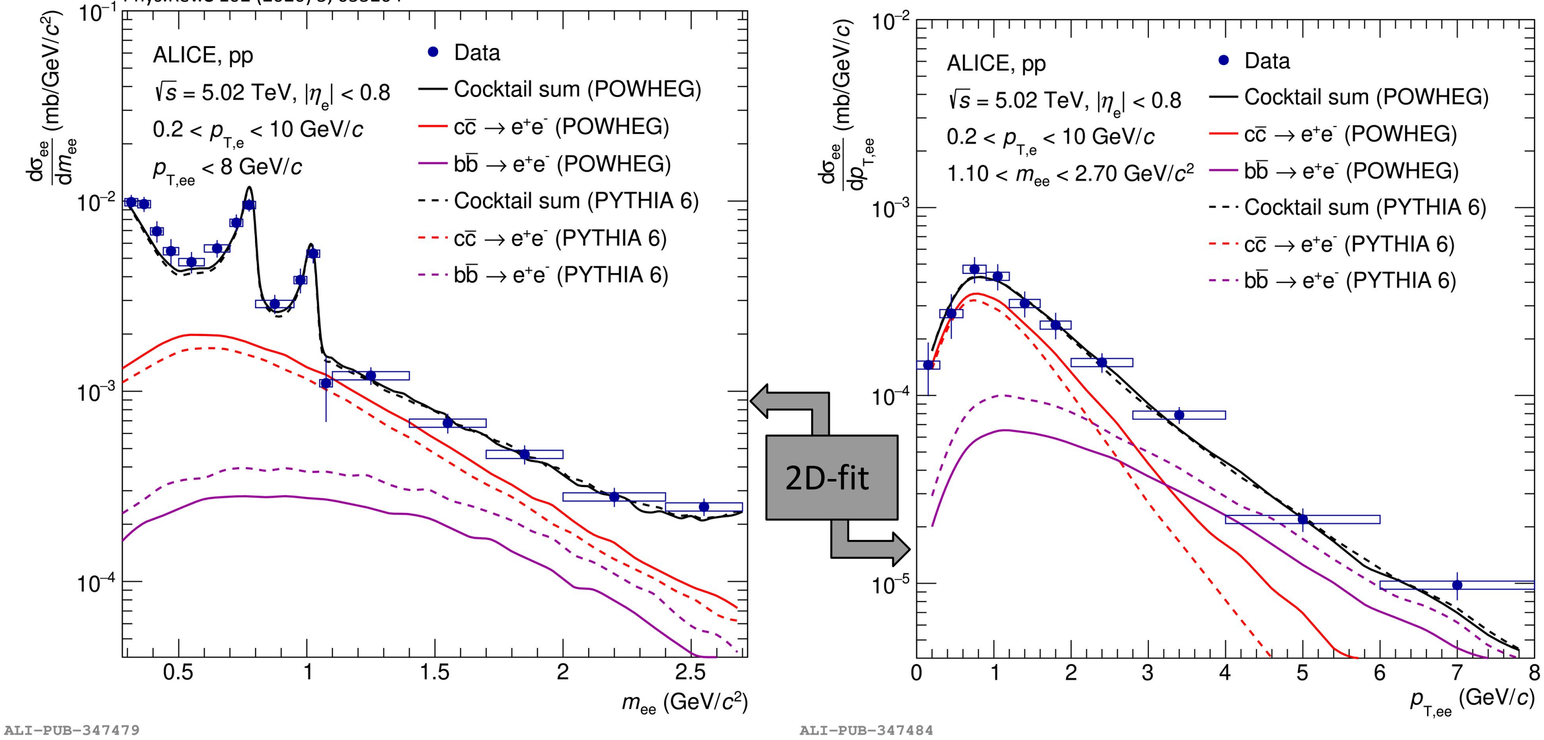
pp 5 TeV

p–Pb 5 TeV

Pb–Pb 5 TeV

➔ HF cross sections extraction for both PYTHIA and POWHEG generators

Phys.Rev.C 102 (2020) 5, 055204



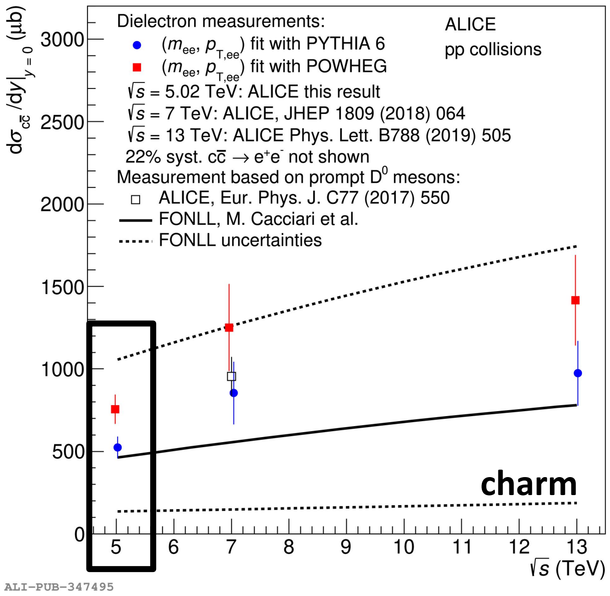
HF cross sections at different energies

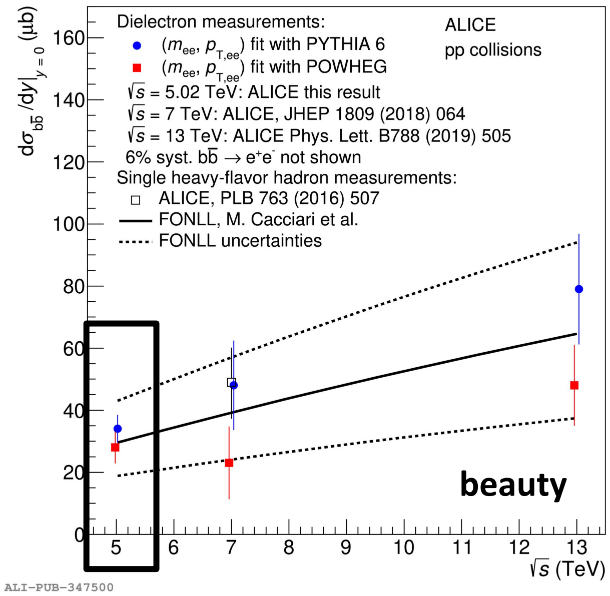
pp 5 TeV

p–Pb 5 TeV

Pb–Pb 5 TeV

Phys.Rev.C 102 (2020) 5, 055204





Parallel Talk:
Charm cross section and fragmentation fractions in pp collisions with ALICE
27 Jul 2021, 10:15
T06: QCD and Hadronic Physics

- ➔ Extracted HF cross sections depend on the event generator
- ➔ Similar results from measurements in different energies of pp collisions
- ➔ Energy dependence described by FONLL within large model uncertainty
- ➔ Measurements will be updated by the new ALICE results showing larger baryon fraction than assumed

Dielectron production in p–Pb at 5.02 TeV

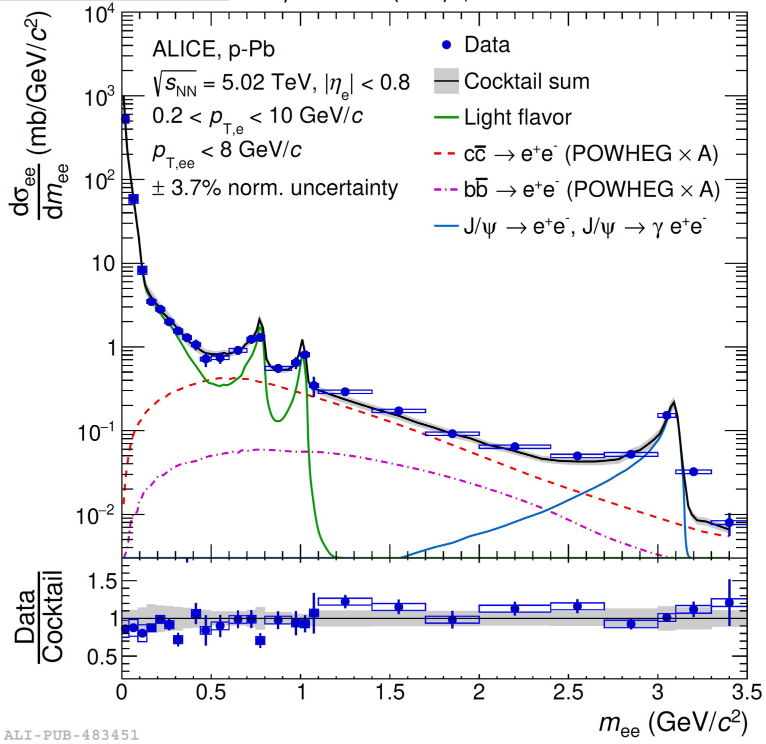
pp 5 TeV

p–Pb 5 TeV

Pb–Pb 5 TeV

Modifications not related to QGP

Phys.Rev.C 102 (2020) 5, 055204



- ➔ LF and J/Ψ from parameterized measurements
- ➔ HF normalized by the cross sections extracted from 2D fits of m_{ee} and $p_{T,ee}$ in pp collisions scaled by atomic mass number (A)
- ➔ No significant deviation from vacuum expectation
- ➔ Possible data-to-data comparison to pp collisions

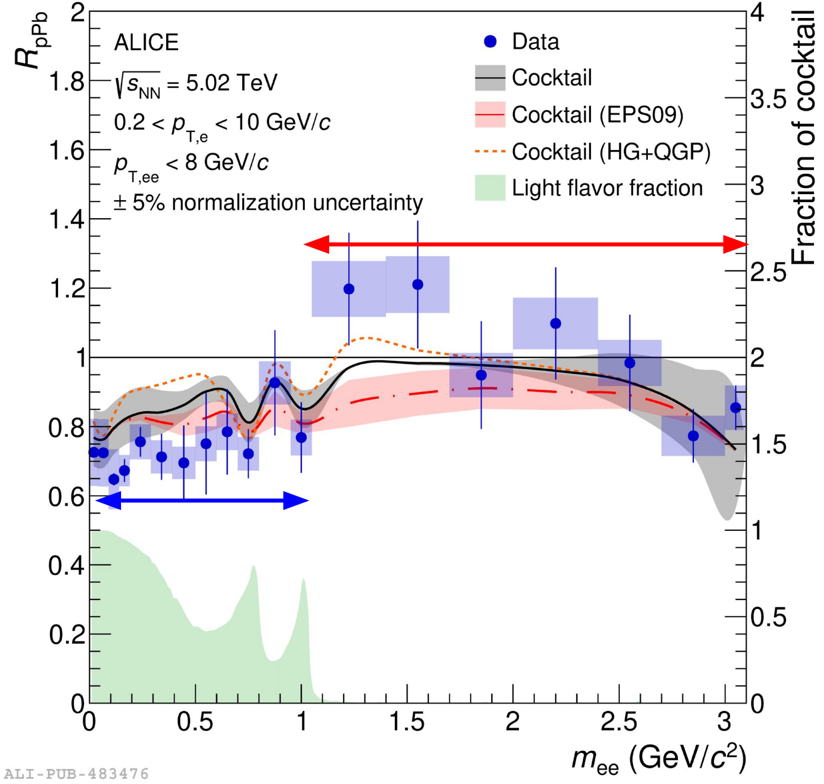
R_{pPb} of dielectron

pp
5 TeV

p–Pb
5 TeV

Pb–Pb
5 TeV

Phys.Rev.C 102 (2020) 5, 055204



➔ Nuclear modification factor R_{pPb}:

$$R_{pPb}(m_{ee}) = \frac{1}{A}\frac{d\sigma_{ee}^{pPb}/dm_{ee}}{d\sigma_{ee}^{pp}/dm_{ee}}$$

➔ LF (m_{ee} < 1 GeV/c^2) and HF (m_{ee} > 1 GeV/c^2) present different scaling behaviours - dependence of the LF fraction

➔ Theory calculations compatible with both models:

⇒ charm shadowing (EPS09) - disfavoured in IMR

⇒ thermal radiation (HG+QGP) - disfavoured in m_{ee} < 0.5 GeV/c^2

⇒ Important to separate thermal radiation from HF in the IMR

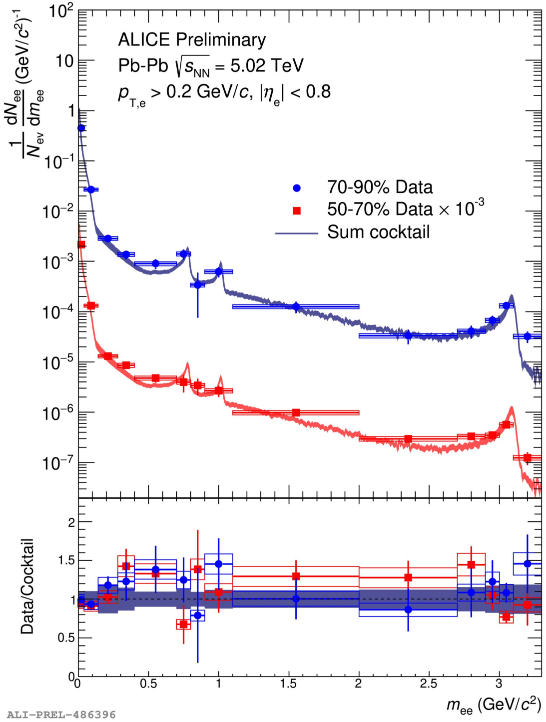
Dielectron production in peripheral Pb–Pb collisions at 5.02 TeV

ALICE

pp 5 TeV	p–Pb 5 TeV	Pb–Pb 5 TeV

Peripheral collisions

Preliminary results of dielectron production in 50-70 % and 70-90 % central Pb–Pb collisions (2015 + 2018)



- ➔ HF normalized by the cross sections obtained in pp collisions scaled by binary nucleon-nucleon collisions
- ➔ **No significant excess observed when compared to vacuum cocktails**

Dielectron production in peripheral Pb–Pb collisions at 5.02 TeV

ALICE

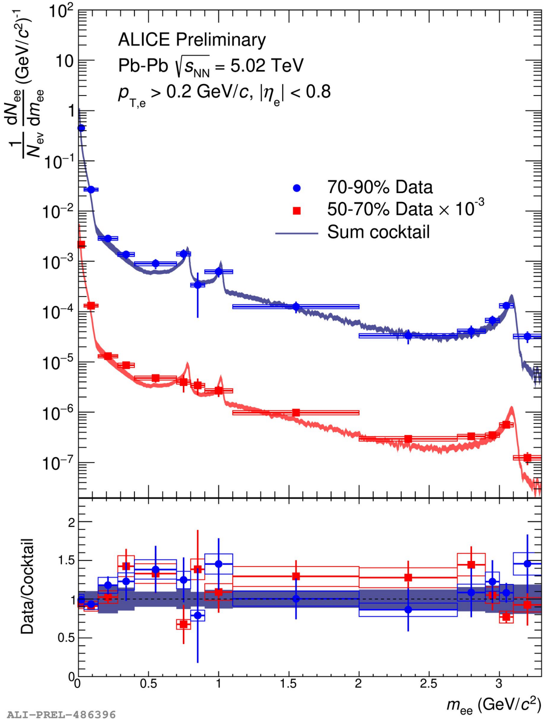
pp
5 TeV

p–Pb
5 TeV

Pb–Pb
5 TeV

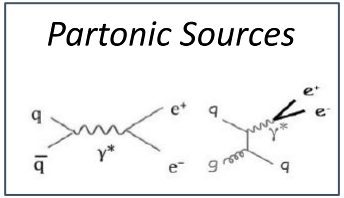
Peripheral collisions

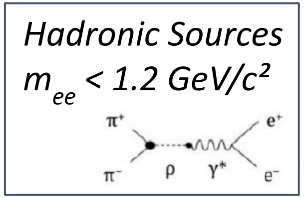
Preliminary results of dielectron production in 50-70 % and 70-90 % central Pb–Pb collisions (2015 + 2018)

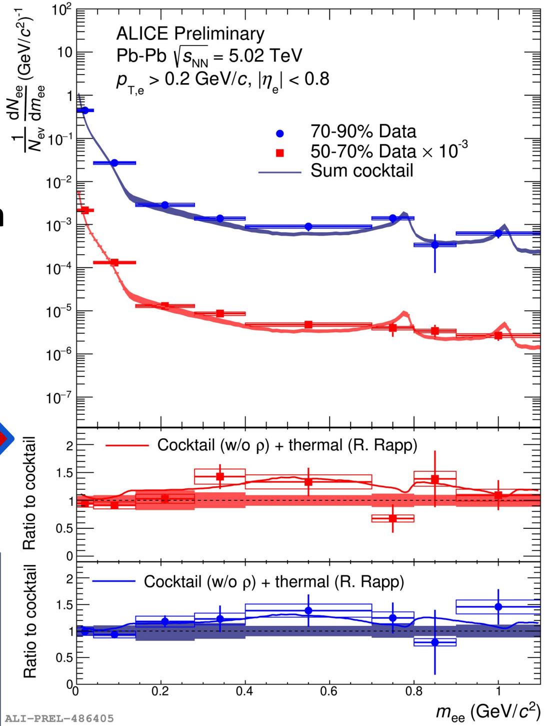


- ➔ HF normalized by the cross sections obtained in pp collisions scaled by binary nucleon-nucleon collisions
- ➔ **No significant excess observed when compared to vacuum cocktails**
- ➔ Data is fairly well compatible with additional sources of thermal radiation

R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253







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

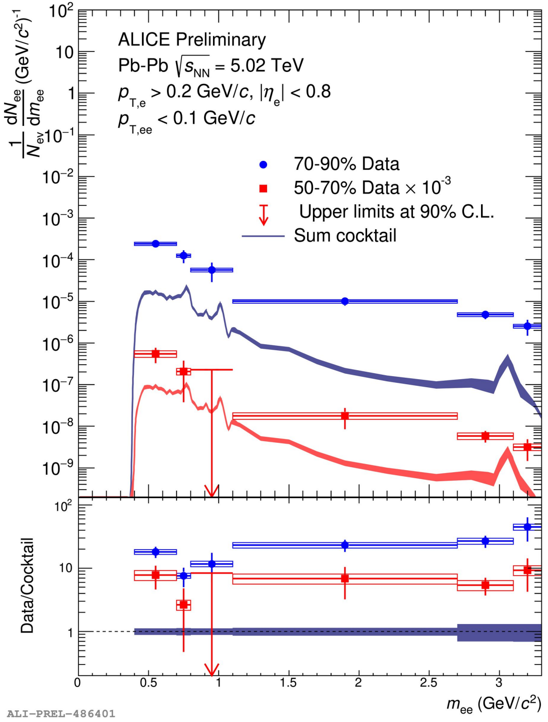
pp 5 TeV

p–Pb 5 TeV

Pb–Pb 5 TeV

Peripheral collisions

Preliminary results of dielectron production in 50-70 % and 70-90 % central Pb–Pb collisions (2015 + 2018)



- ➔ Significant excess for $p_{T,ee}$ < 0.1 GeV/c in a wide m_{ee} range
- ➔ The effect is larger for more peripheral collisions

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

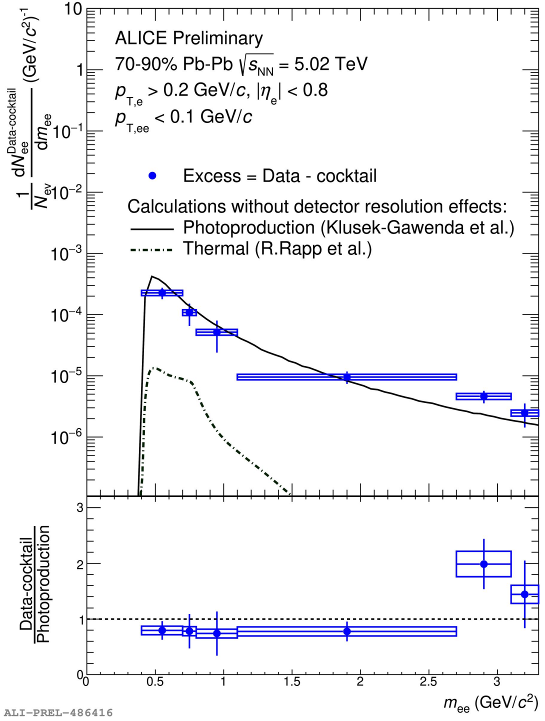
pp 5 TeV

p–Pb 5 TeV

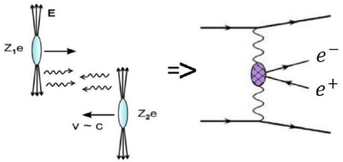
Pb–Pb 5 TeV

Peripheral collisions

Preliminary results of dielectron production in 50-70 % and 70-90 % central Pb–Pb collisions (2015 + 2018)



➔ **Consistent with photoproduction calculations**



➔ $\gamma\gamma \rightarrow e^+e^-$ continuum in m_{ee} scaling with Z^4 from coherent electromagnetic field of the colliding nuclei

➔ Present some centrality dependence

M. Klusek-Gawenda, W. Schaefer, A. Szczurek, PLB 814 (2021) 136114
R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253

Dielectron production in central Pb–Pb collisions

ALICE

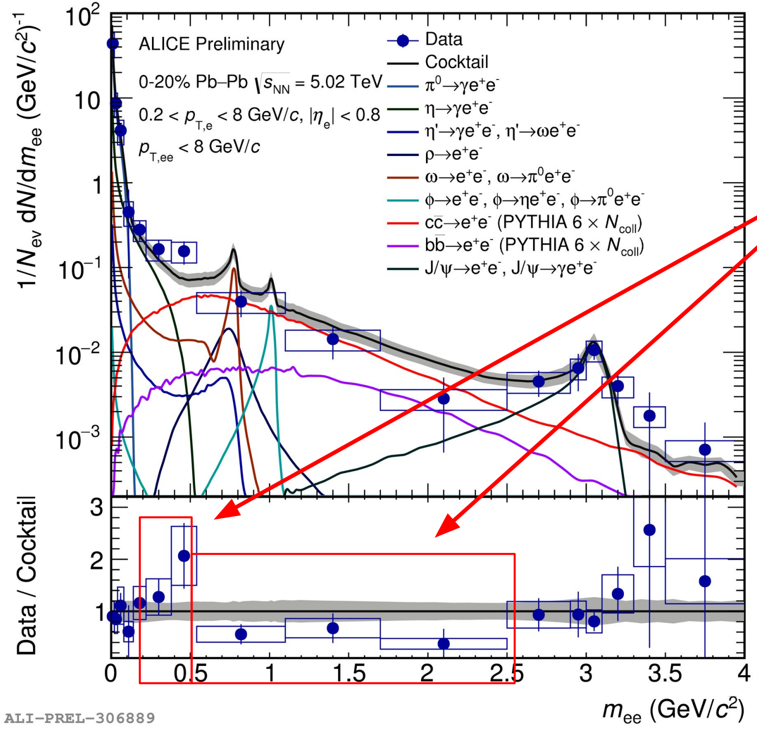
pp 5 TeV

p–Pb 5 TeV

Pb–Pb 5 TeV

Central collisions

Preliminary results of dielectron production in 0-20 % central Pb–Pb collisions (2015)



➔ HF: PYTHIA6 binary nucleon-nucleon collisions scaling

➔ Differences between data and cocktail observed in some regions of the invariant mass yield

Dielectron production in central Pb–Pb collisions

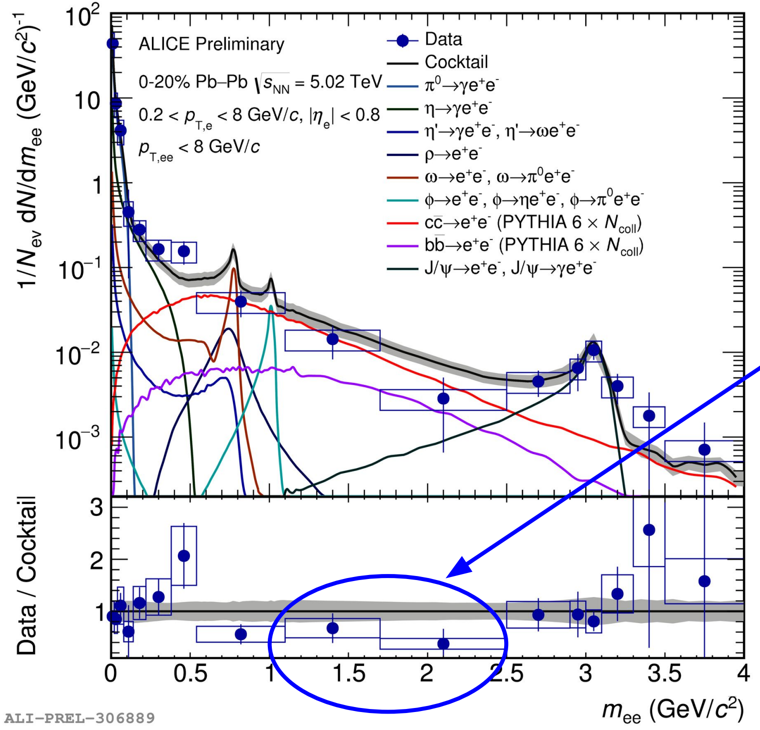
pp 5 TeV

p–Pb 5 TeV

Pb–Pb 5 TeV

Central collisions

Preliminary results of dielectron production in 0-20 % central Pb–Pb collisions (2015)



- ➔ HF: PYTHIA6 binary nucleon-nucleon collisions scaling
- ➔ Differences between data and cocktail observed in some regions of the invariant mass yield
- ➔ Heavy-flavour suppression observed

Dielectron production in central Pb–Pb collisions

ALICE

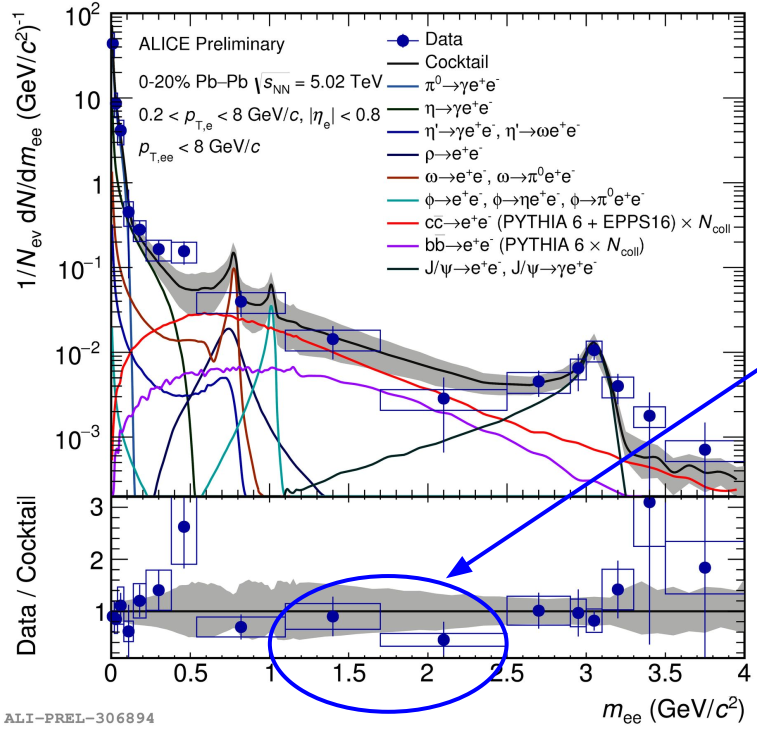
pp
5 TeV

p–Pb
5 TeV

Pb–Pb
5 TeV

Central collisions

Preliminary results of dielectron production in 0-20 % central Pb–Pb collisions (2015)



- ➔ HF: PYTHIA6 binary nucleon-nucleon collisions scaling
- ➔ Differences between data and cocktail observed in some regions of the invariant mass yield
- ➔ Heavy-flavour suppression observed (reduced when including nPDF - EPPS16)

Eskola, K.J., Paakkinen, P., Paukkunen, H. *et al. Eur. Phys. J. C* **77,** 163 (2017)

Dielectron production in central Pb–Pb collisions

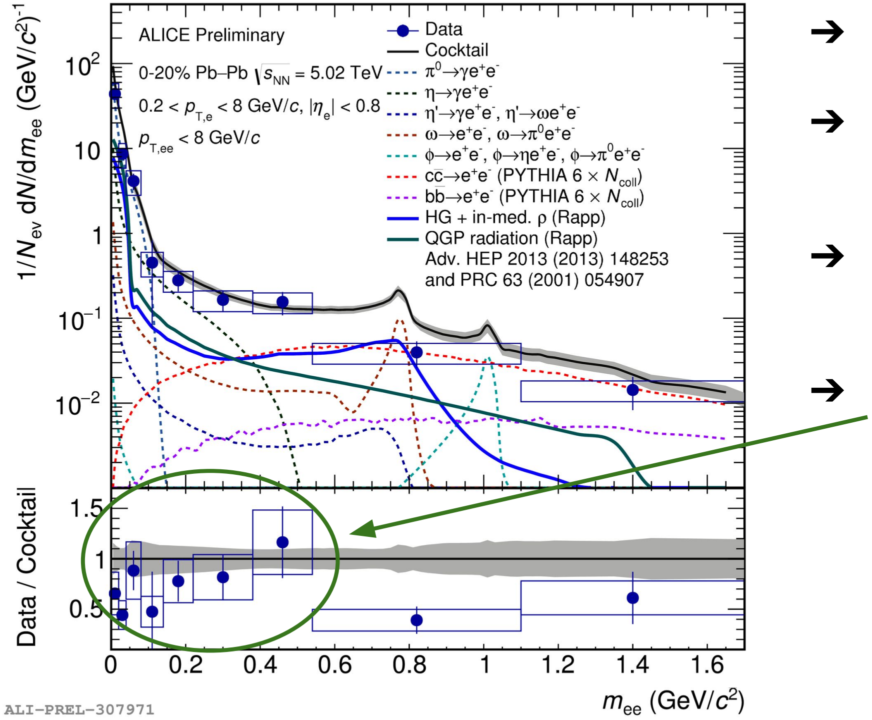
pp 5 TeV

p–Pb 5 TeV

Pb–Pb 5 TeV

Central collisions

Preliminary results of dielectron production in 0-20 % central Pb–Pb collisions (2015)



➔ HF: PYTHIA6 binary nucleon-nucleon collisions scaling

➔ Differences between data and cocktail observed in some regions of the invariant mass yield

➔ Heavy-flavour suppression observed (reduced when including nPDF - EPPS16)

➔ Low m_{ee} is described by models including thermal radiation

Dielectron production in central Pb–Pb collisions

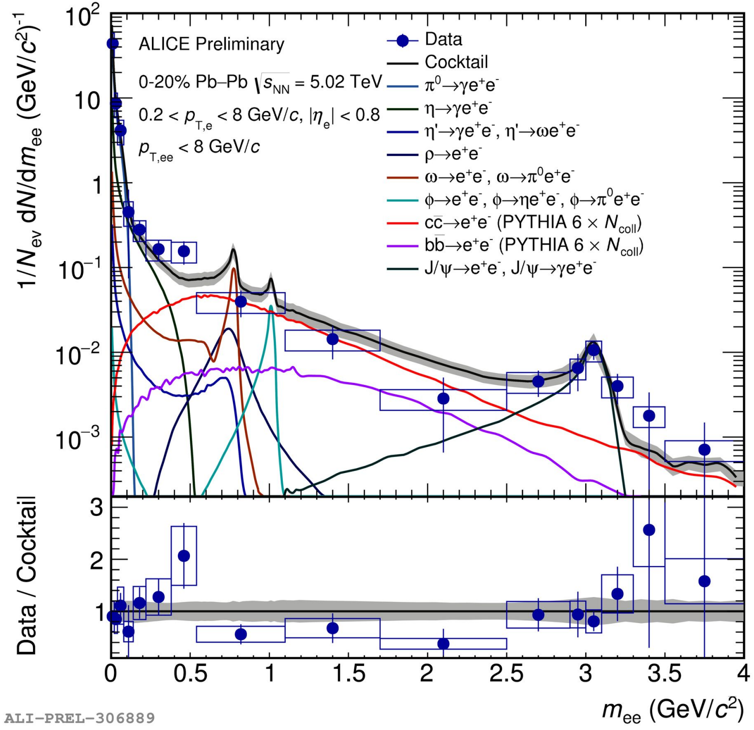
Central collisions

pp
5 TeV

p–Pb
5 TeV

Pb–Pb
5 TeV

Preliminary results of dielectron production in 0-20 % central Pb–Pb collisions (2015)

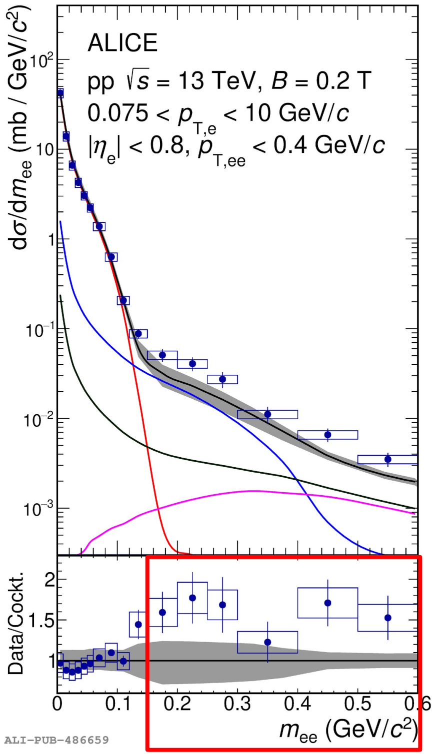


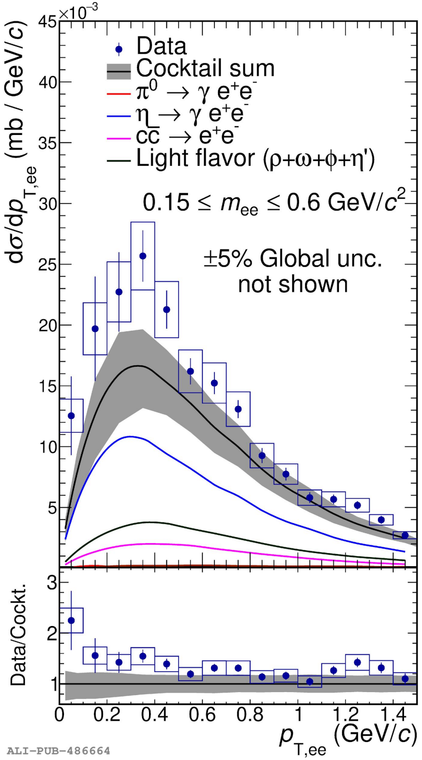
- ➔ HF: PYTHIA6 binary nucleon-nucleon collisions scaling
- ➔ Differences between data and cocktail observed in some regions of the invariant mass yield
- ➔ Heavy-flavour suppression observed (reduced when including nPDF - EPPS16)
- ➔ Low m_{ee} is described by models including thermal radiation
- ➔ Analysis in central Pb–Pb using 2018 data (higher statistics) ongoing! - 10x in 0-10% centrality

Soft dielectron production in pp at 13 TeV

ALICE

arXiv: 2005.14522 (PRL)



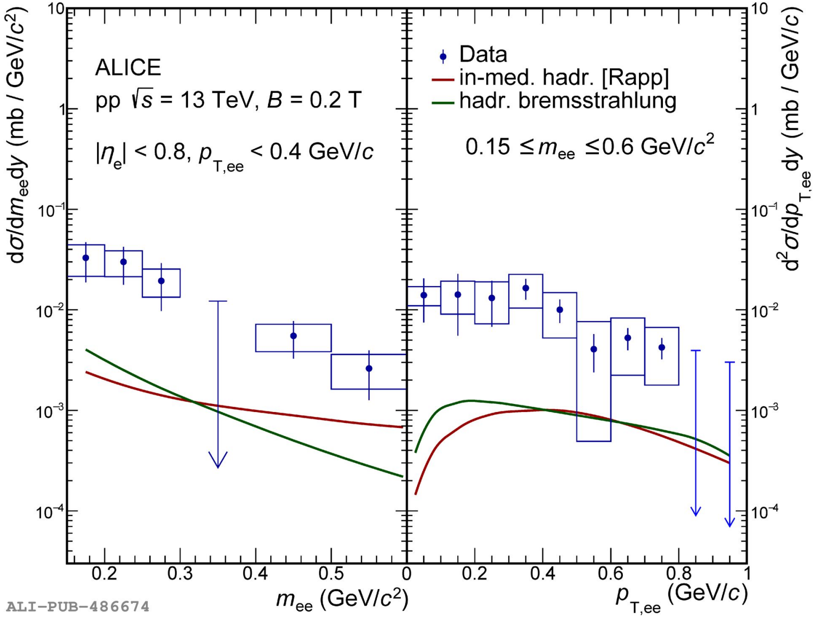


- ➔ Anomalous soft-dilepton and -photon excess already reported by other experiments
- ➔ Special data taking with reduced magnetic field of 0.2 T in ALICE allows to access electrons with $p_{T,e}$ down to 0.075 GeV/c for this purpose
- ➔ Cocktail underpredicts data by a factor of 1.61 ± 0.13 (stat.) ± 0.17 (syst.) ± 0.34 (cocktail) in:
  - ⇒ $p_{T,ee}$ < 0.4 GeV/c
  - ⇒ 0.15 < m_{ee} < 0.6 GeV/c^2
- ➔ No excess observed in different regions as lower m_{ee} or higher $p_{T,ee}$
- ➔ No multiplicity dependence observed

V. Hedberg PhD thesis, Lund (1987); DLS Collaboration,Phys. Rev. Lett. 61 (1988) 1069-1072; M.R.Adams *et al.* Phys. Rev. D27 (1983) 1977-1998; K.J. Anderson *et al.* Phys. Rev. Lett. 37 (1976) 700-802; A.Belogianni *et al.* Phys.Lett.B548 n 3 (2002) 122-128, 129-130; J.Antos *et al.* Z. Phys. C59 (1993) 547-554

Soft dielectron production in pp at 13 TeV

arXiv: 2005.14522 (PRL)



➔ Excess yield cannot be reproduced by calculations of initial- and final-state hadrons bremsstrahlung or by thermal dielectron production predictions

➔ Possible mechanism:

⇒ The radiation comes from a back-reaction of the vacuum to a non-perturbative back-to-back $q\bar{q}$ pair (charge oscillation arising from leading quarks ripping meson-like fermions from the Dirac sea)

⇒ Strong non-perturbative phenomena only seen with e^+e^- or γ

O. Garcia-Montero, ArXiv:2104.07050v1; D. E. Kharzeev and F. Loshaj, Phys. Rev. D89, 074053(2014), arXiv:1308.2716

Summary

pp 5 TeV	➔ Reference measurement for p-Pb and Pb-Pb ➔ Charm and beauty cross sections measured
p–Pb 5 TeV	➔ No significant modification of heavy-flavour production ➔ Separation of dielectron sources and multiplicity studies ongoing
Pb–Pb 5 TeV	➔ No significant excess observed compared to vacuum cocktails for $p_{T,e} > 0.2$ GeV/c in peripheral collisions ➔ Low-$p_{T,ee}$ excess compatible with coherent photoproduction in peripheral collisions ➔ Possible excess from thermal radiation in low m_{ee} in central collisions ➔ Heavy-flavour suppression in central collisions
pp 13TeV	➔ Significant excess in soft dielectron production ➔ Current theoretical models can not reproduce the excess, although recent calculations aim to ➔ No significant multiplicity dependence
Outlook	➔ **ITS** and **TPC** upgrade for Run 3 and Run 4: Improved resolution, faster readout, continuous readout ➔ Better vertex pointing resolution - Better separation of HF from prompt sources via DCA ➔ Higher acquisition rate: gain by a factor 100 in Pb–Pb statistics in Run 3 and Run 4

Summary

pp 5 TeV

- ➔ Reference measurement for p-Pb and Pb-Pb
- ➔ Charm and beauty cross sections measured

p–Pb 5 TeV

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- ➔ Separation of dielectron

Pb–Pb 5 TeV

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- ➔ Low-$p_{T,ee}$ excess compat ripheral collisions
- ➔ Possible excess from the ons
- ➔ Heavy-flavour suppressi

Parallel Talks (T12: Detector R&D and Data Handling):

- ***First results of the newly installed, MAPS based, ALICE Inner Tracking System*** **- 26 Jul 2021, 10:30**
- ***Preparation for ALICE data processing and analysis in LHC Run 3*** **- 28 Jul 2021, 10:00**
- ***Future upgrades of ALICE for Run 4*** **- 29 Jul 2021, 10:00**
- ***ALICE 3*** **- 29 Jul 2021, 11:15**

pp 13TeV

- ➔ Significant excess in soft dielectron product n
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Outlook

- ➔ **ITS** and **TPC** upgrade for Run 3 and Run 4: Improved resolution, faster readout, continuous readout
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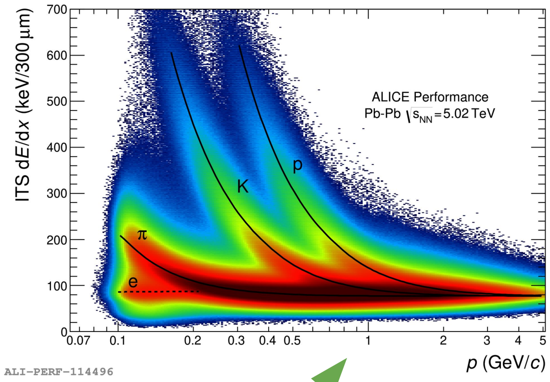
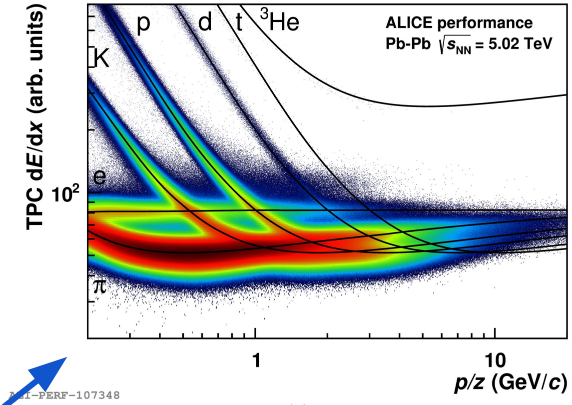
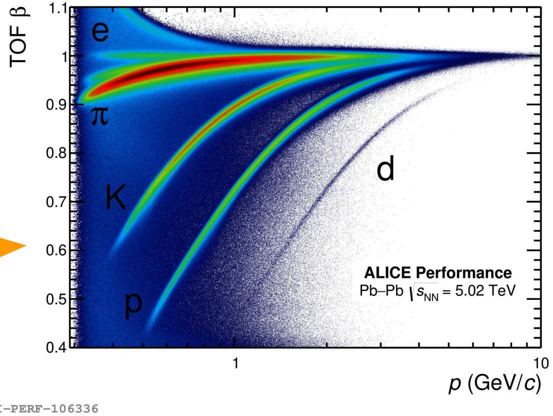
Thank you!

Electron identification







Inner Tracking System (ITS)
Particle Identification via dE/dx

Time Projection Chamber (TPC)
Particle Identification via dE/dx

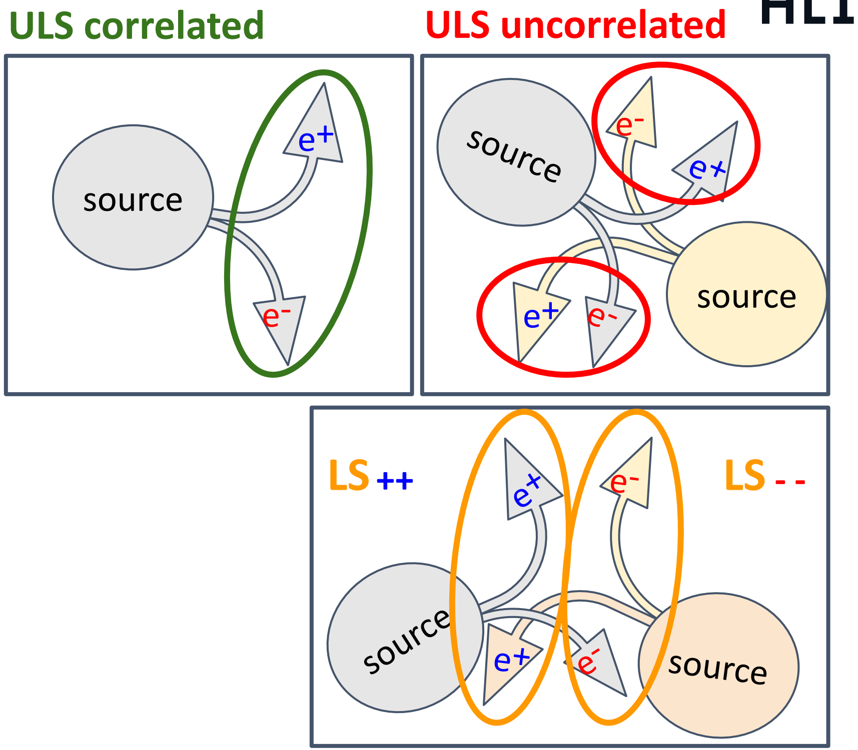
Time-Of-Flight (TOF)
Particle Identification via TOF measurement

Dielectron signal

- ➔ Electrons are separated as like-sign (LS) and unlike-sign (ULS) charged pairs
- ➔ ULS carries both correlated (signal) and uncorrelated (background - combinatorial effect of the method) physical information
- ➔ LS carries uncorrelated (mostly) physical information
- ➔ The dielectron signal is obtained by the subtraction of the identified background (LS) from the ULS pairs:

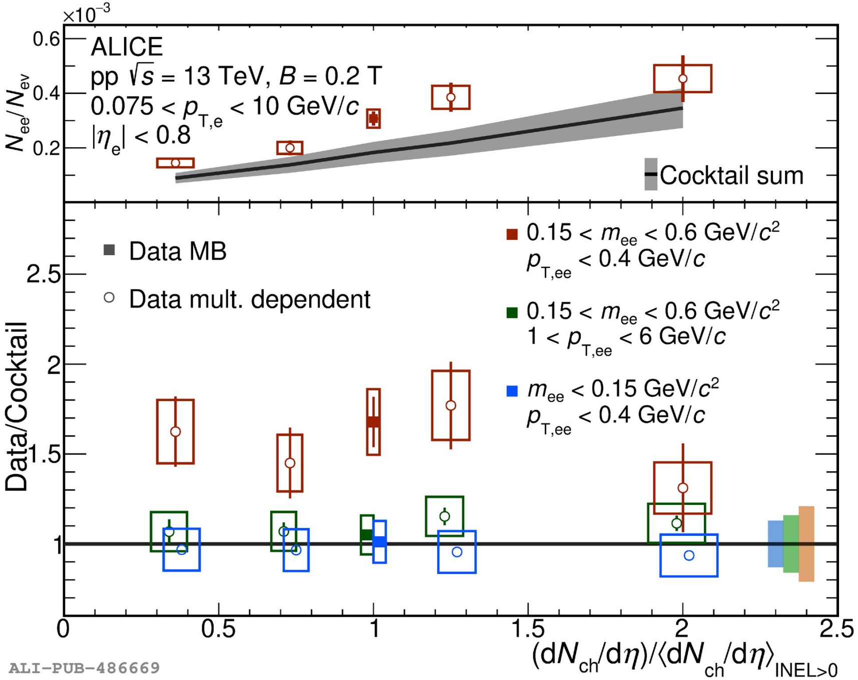
$$Signal = ULS - R \cdot \sqrt{N_{++} \cdot N_{--}}$$

Additional factor to take into account acceptance differences between different LS charged pairs



Soft dielectron production in pp at 13 TeV

ArXiv: 2005.14522 (PRL)



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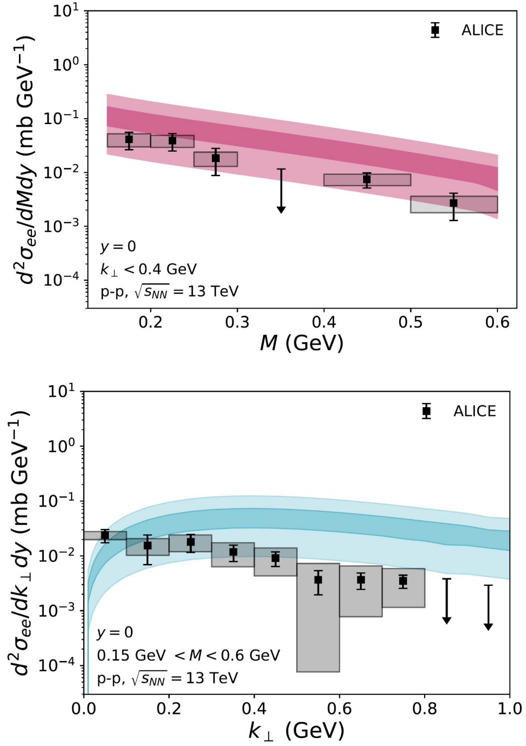
- ➔ Low magnetic field of 0.2 T in ALICE allows to access electrons with $p_{T,e}$ down to 0.075 GeV/c for this purpose
- ➔ Cocktail underpredicts data by a factor of 1.6 in:
  - ⇒ $p_{T,ee} < 0.4$ GeV/c
  - ⇒ $0.15 < m_{ee} < 0.6$ GeV/c^2
- ➔ No multiplicity dependence observed
- ➔ No excess observed in different regions as lower m_{ee} or higher $p_{T,ee}$

V. Hedberg PhD thesis, Lund (1987); DLS Collaboration,Phys. Rev. Lett. 61 (1988) 1069-1072; M.R.Adams *et al.* Phys. Rev. D27 (1983) 1977-1998; K.J. Anderson *et al.* Phys. Rev. Lett. 37 (1976) 700-802; A.Belogianni *et al.* Phys.Lett.B548 n 3 (2002) 122-128, 129-130; J.Antos *et al.* Z. Phys. C59 (1993) 547-554

Soft dielectron production in pp at 13 TeV

ArXiv: 2104.07050v1



➔ **Qualitative study by now, lacking the quark mass - limiting lighter quarks calculations**

➔ Recently calculated possible mechanism:

- ⇒ The radiation comes from a back-reaction of the vacuum to a non-perturbative back-to-back $q\bar{q}$ pair, triggering meson-like excitations that couples to photons
- ⇒ Charge oscillation arising from leading quarks ripping meson-like fermions from the Dirac sea

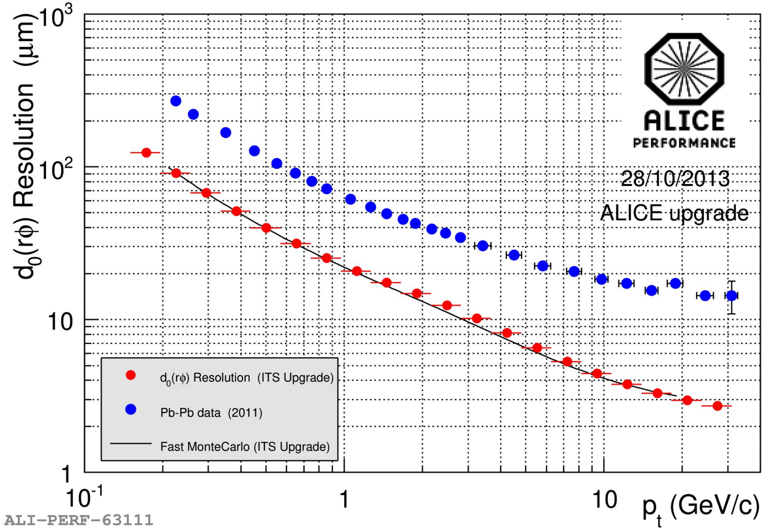
- Proposed Model: D. E. Kharzeev and F. Loshaj, Phys. Rev. D89, 074053(2014), arXiv:1308.2716
- Calculation by: O. Garcia-Montero, ArXiv:2104.07050v1

Outlook

ALICE

- ➔ **ITS** and **TPC** upgrade for Run 3 and Run 4
- ➔ Improved resolution, faster readout
- ➔ New readout chambers (GEM's and SAMPA), continuous readout

- ➔ Better vertex pointing resolution
  - ⇒ Allowing to access electrons with smaller p_T
  - ⇒ Better separation of HF from prompt sources via DCA
- ➔ Higher acquisition rate
  - ⇒ Drastically increasing the luminosity



Parallel Talks (T12: Detector R&D and Data Handling):

- ***First results of the newly installed, MAPS based, ALICE Inner Tracking System* - 26 Jul 2021, 10:30**
- ***Preparation for ALICE data processing and analysis in LHC Run 3* - 28 Jul 2021, 10:00**
- ***Future upgrades of ALICE for Run 4* - 29 Jul 2021, 10:00**
- ***ALICE 3* - 29 Jul 2021, 11:15**