Low-mass dielectron measurements in pp, p–Pb and Pb–Pb collisions with ALICE at the LHC

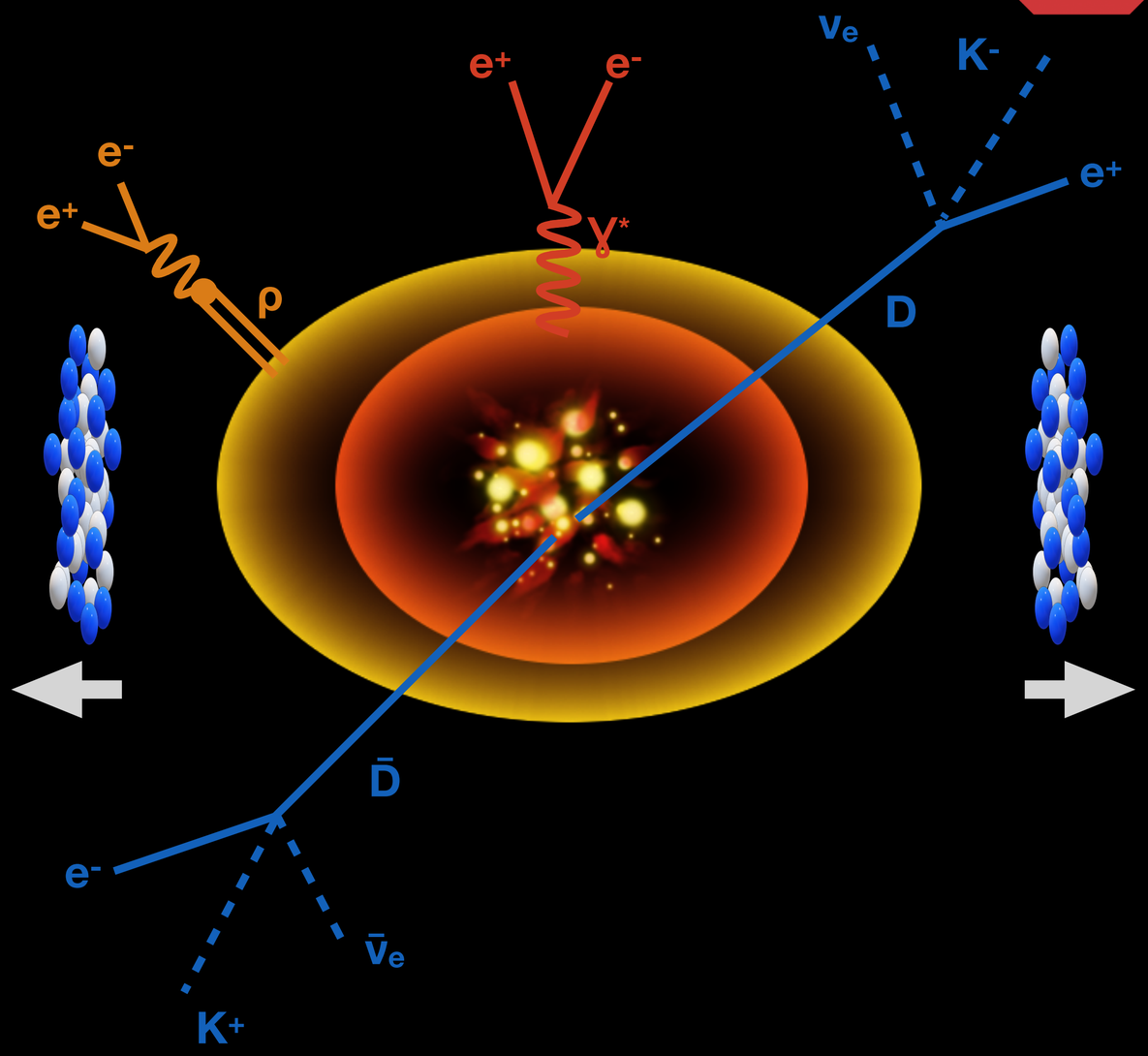
Sebastian Scheid
Goethe University, Frankfurt
on behalf of the ALICE Collaboration

Motivation

Various sources produce correlated pairs of electrons:

- Pseudoscalar and vector mesons (π, η, ρ, ω, ϕ, J/ψ) via direct (e^+e^-) or Dalitz (X e^+e^-) decays
- Semi-leptonic decays of open heavy-flavour hadrons ($c\bar{c} \rightarrow D\bar{D} \rightarrow XY\ e^+e^-$)
- Thermal radiation from QGP and hadronic phase

Excellent probe to study hot and dense hadronic matter as well as QGP properties



Motivation

In pp collisions:

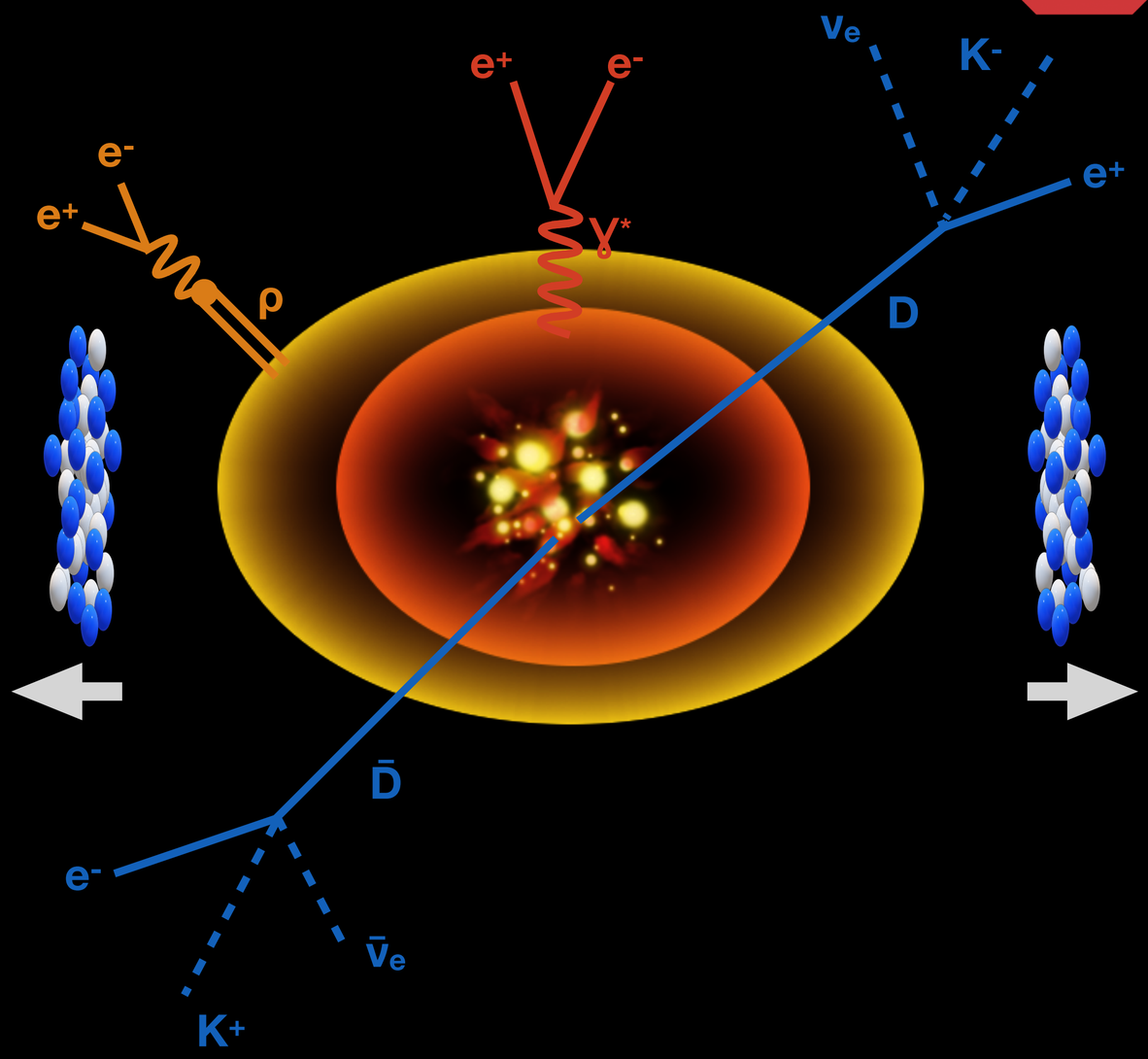
- Vacuum baseline for p–Pb and Pb–Pb collisions
- Study correlations of heavy-quark production

In p–Pb collisions:

- Modifications of heavy-flavour production via CNM effects (e. g. shadowing)
- Possible thermal radiation from QGP droplets

In Pb–Pb collisions:

- Medium modifications of hadronic sources
- Radiation from QGP and hadron gas



ALICE Experiment

Inner Tracking system

- Tracking, Vertexing, and Particle Identification

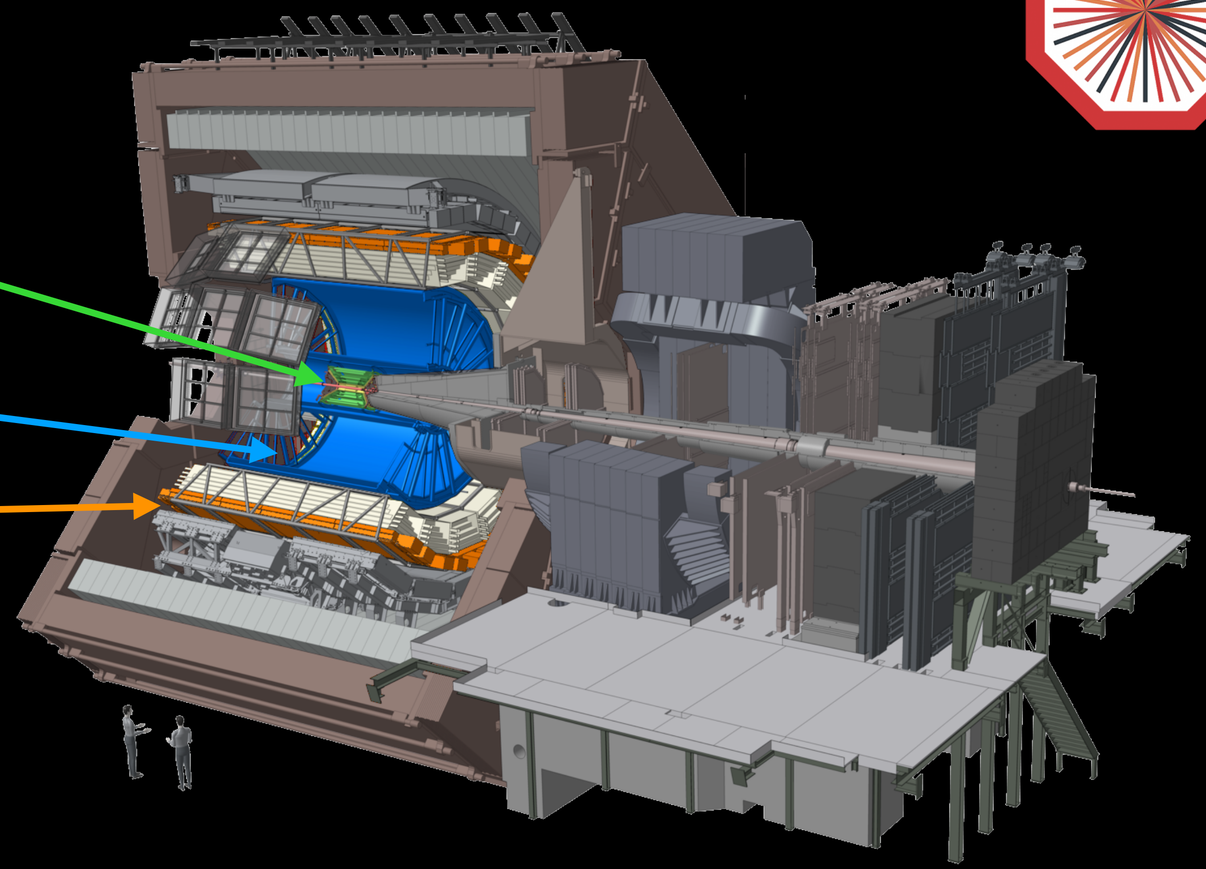
Time Projection Chamber

- Tracking and Particle Identification

Time-Of-Flight

- Particle Identification

V0 for trigger and centrality estimation



Collision system	Number of events	Trigger	
pp at $\sqrt{s}$ = 5.02 TeV	900 M	Minimum-bias	NEW
p–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV	270 M	Minimum-bias	NEW
Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV	80 M	Minimum-bias	
pp at $\sqrt{s}$ = 13 TeV	540 M	Minimum-bias (low B-Field)	

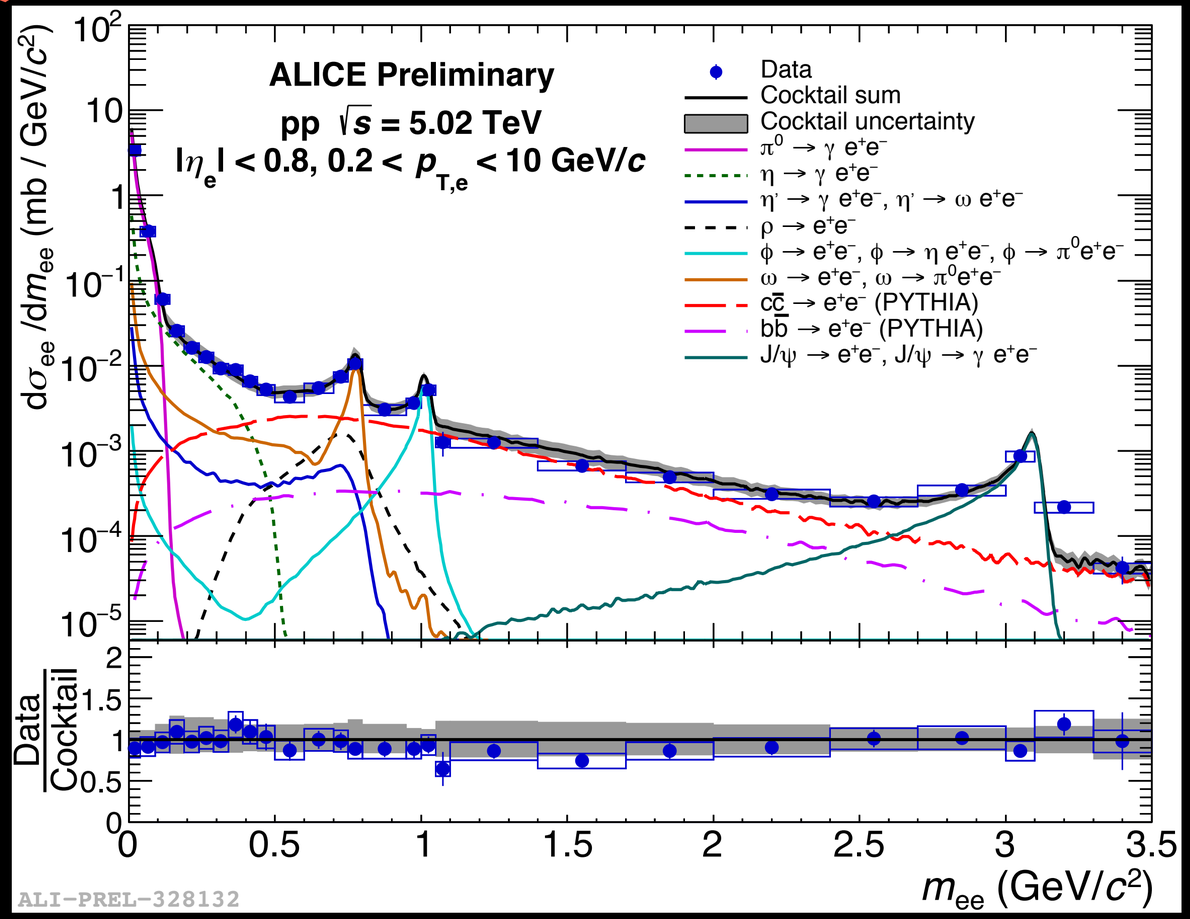
Posters:
HF 55 – A. Capon
HF 50 – H. Degenhardt
EM 05 – E. Meninno
EM 06 – D. Sekihata
EM 07 – L. Viebach

The vacuum baseline – pp

Dielectron production measured in pp collisions at $\sqrt{s}$ = 5.02 TeV

- Production cross section as function of invariant mass (m_{ee}) well described by expectations from known hadronic sources (hadronic cocktail)
  - Light flavour (LF) from parametrised measurements and particle ratios from PYTHIA
  - Heavy flavour (HF) from PYTHIA or POWHEG, based on measured $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ at $\sqrt{s}$ = 7 TeV, extrapolated with FONLL

NEW

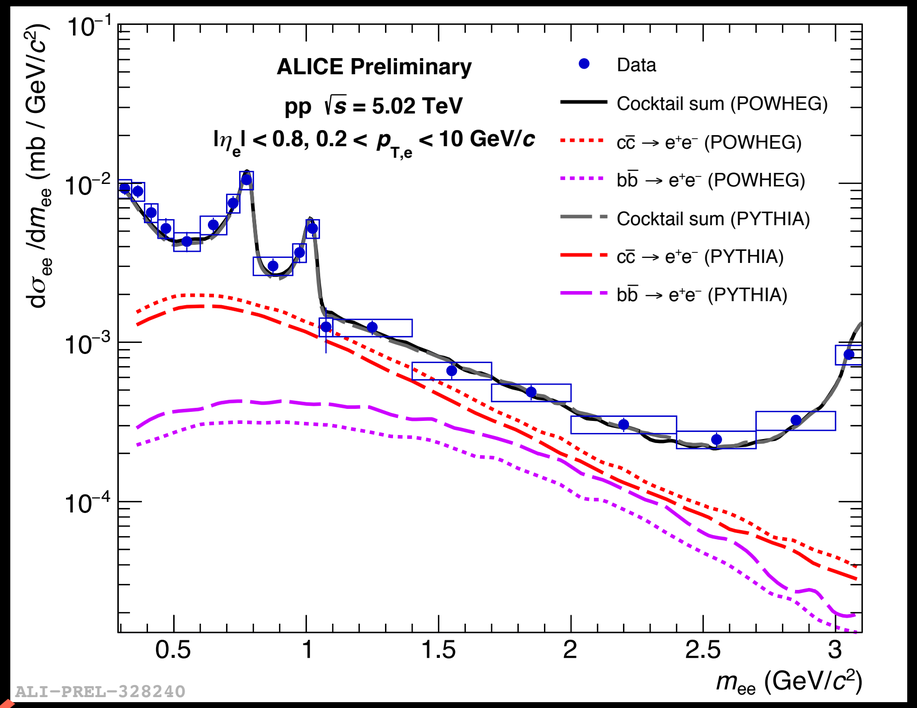


Poster, L. Viebach

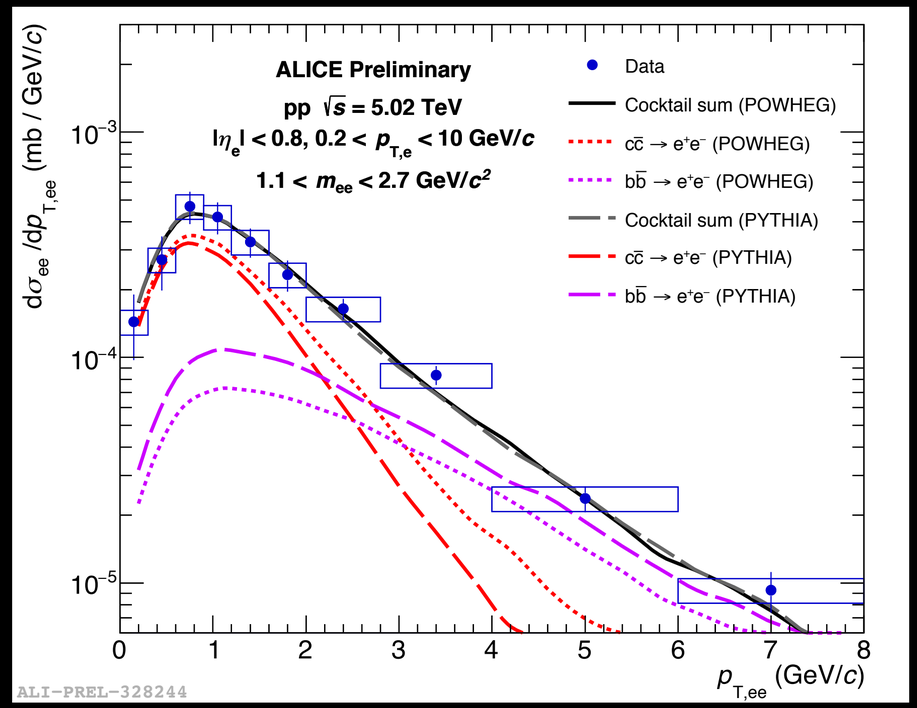
The vacuum baseline – pp

Distinct shape of charm and beauty in m_{ee} and $p_{T,ee}$ can be used to fit cross sections

- Model dependence similar to previous measurements performed at $\sqrt{s}$ = 7 and 13 TeV (Poster, H. Degenhardt)



NEW



Poster, L. Viebach

NEW

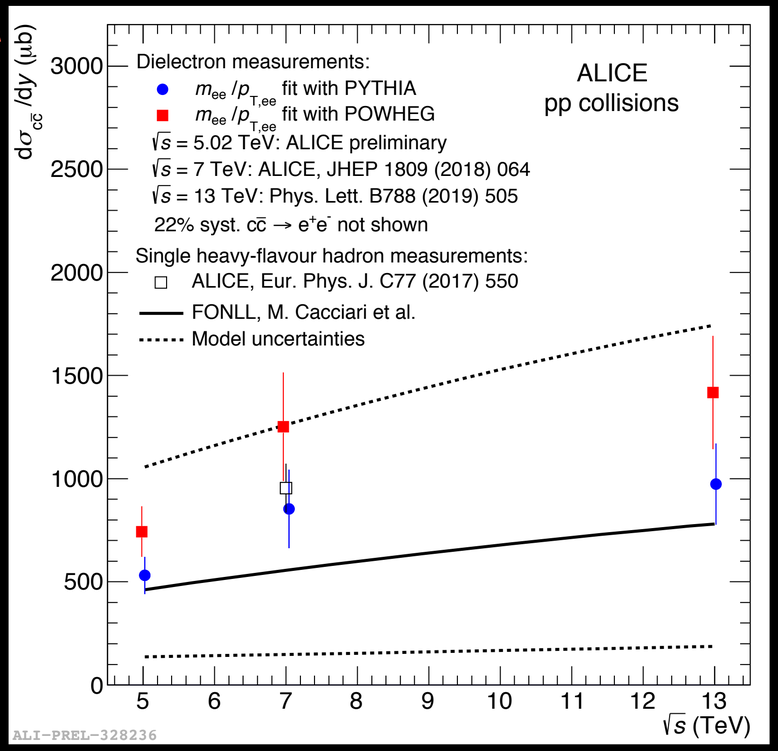
	PYTHIA	POWHEG
$d\sigma_{c\bar{c}}/dy$	0.531 ± 0.062 (stat) ± 0.066 (syst) ± 0.117 (BR)	0.743 ± 0.080 (stat) ± 0.093 (syst) ± 0.163(BR)
$d\sigma_{b\bar{b}}/dy$	0.037 ± 0.004 (stat) ± 0.005 (syst) ± 0.002 (BR)	0.027 ± 0.004 (stat) ± 0.003 (syst) ± 0.002 (BR)

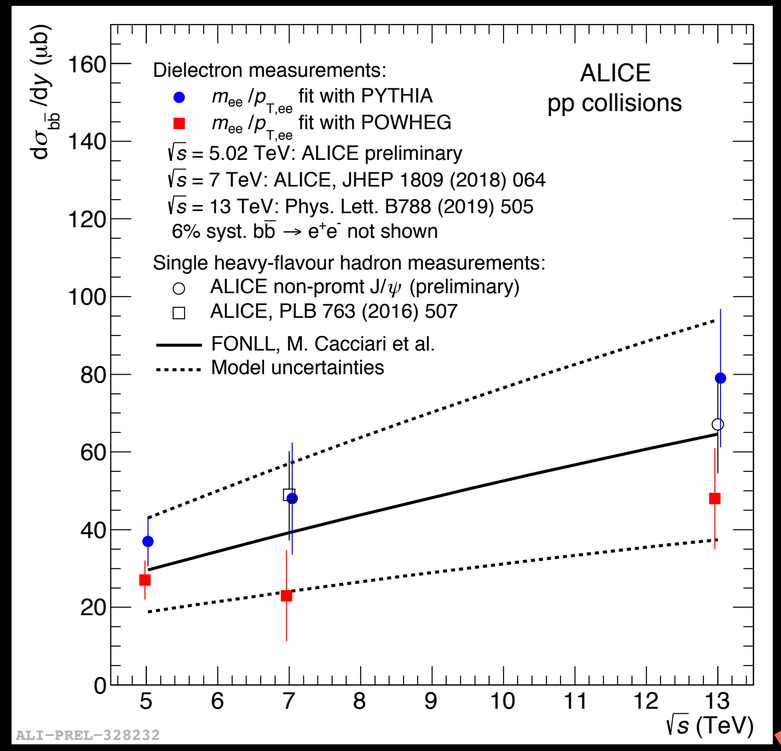
The vacuum baseline – pp

Distinct shape of charm and beauty in m_{ee} and $p_{T,ee}$ can be used to fit cross sections

- Model dependence similar to previous measurements performed at $\sqrt{s}$ = 7 and 13 TeV (Poster, H. Degenhardt)

NEW





Poster, L. Viebach

NEW

First measurement of $d\sigma_{c\bar{c}}/dy$ *and* $d\sigma_{b\bar{b}}/dy$ in pp at $\sqrt{s}$ = 5.02 TeV

Consistent with independent measurements of HF cross sections at mid-rapidity

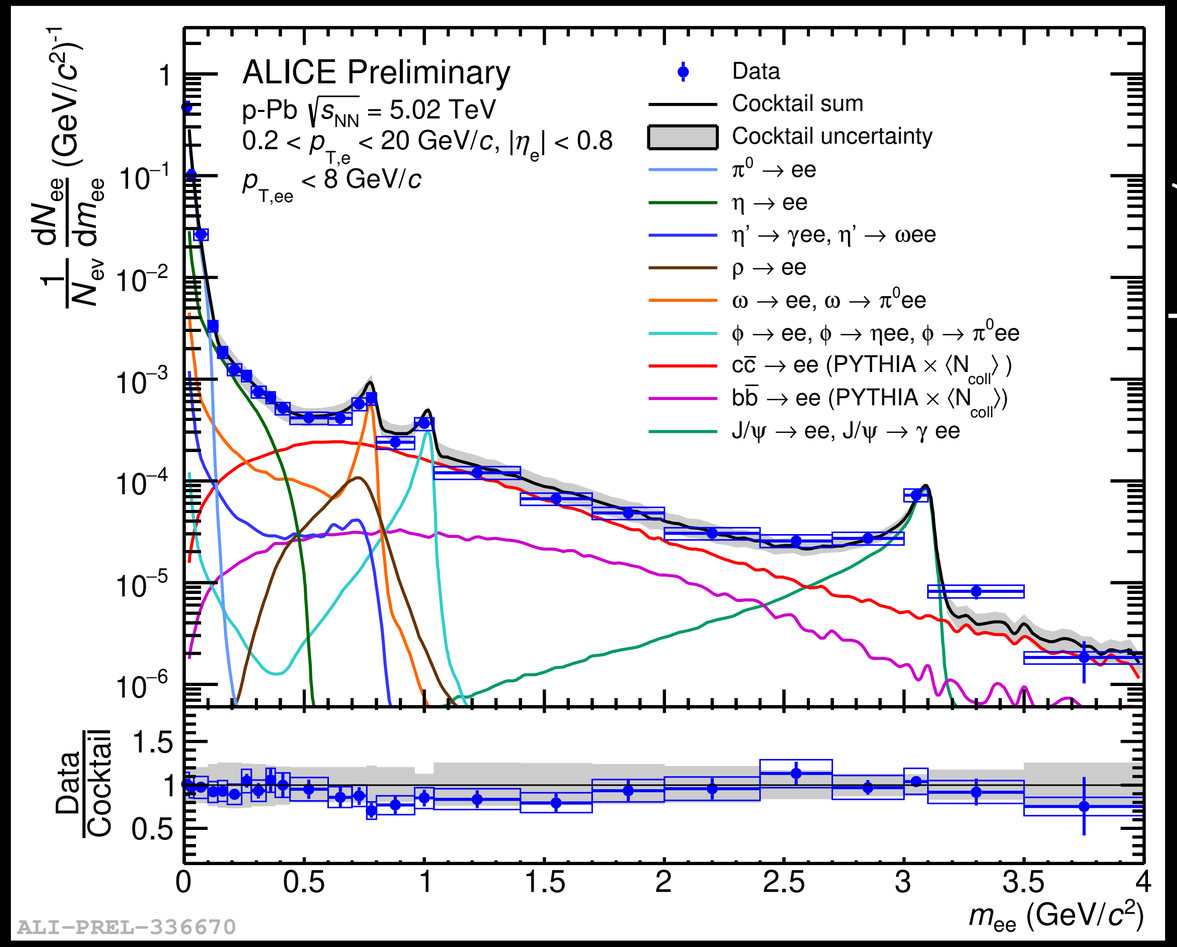
The initial state – p–Pb

NEW

Dielectron production measured in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

- HF from N_{coll} scaling of pp cross section
- Overall good agreement of hadronic cocktail with data
- Systematic uncertainties on cocktail limit interpretation of data

Compare data to data to circumvent dependence on cocktail uncertainties



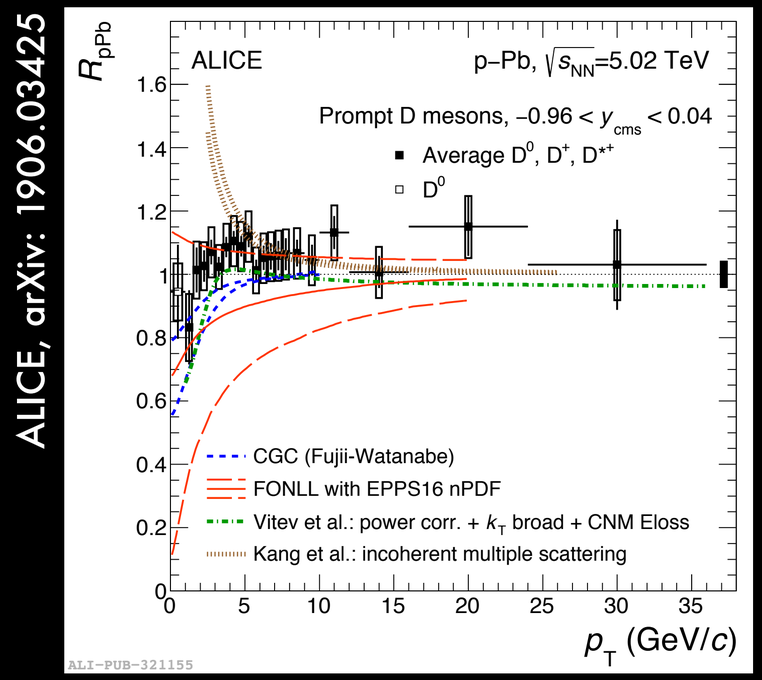
Poster, A. Capon

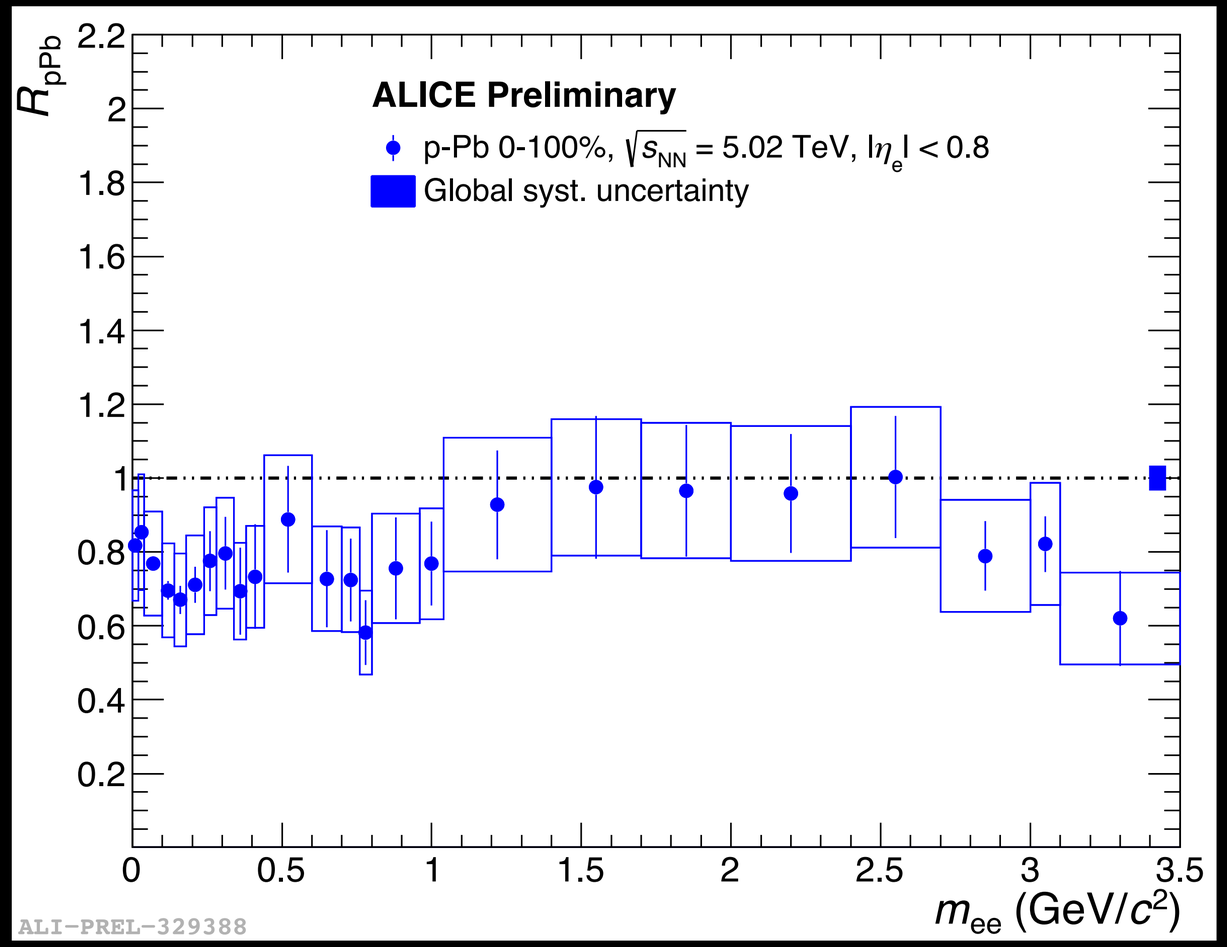
The initial state – nuclear modification

$$R_{\mathrm{pPb}} = \frac{1}{\langle N_{\mathrm{coll}} \rangle} \frac{\mathrm{d}N/\mathrm{d}m_{\mathrm{ee}}|_{\mathrm{pPb}}}{\mathrm{d}N/\mathrm{d}m_{\mathrm{ee}}|_{\mathrm{pp}}}$$

No significant modification of HF in IMR (1.1 – 2.7 GeV/c^2)

- In line with previous ALICE measurements of D-meson R_{pPb}





NEW

The initial state – nuclear modification

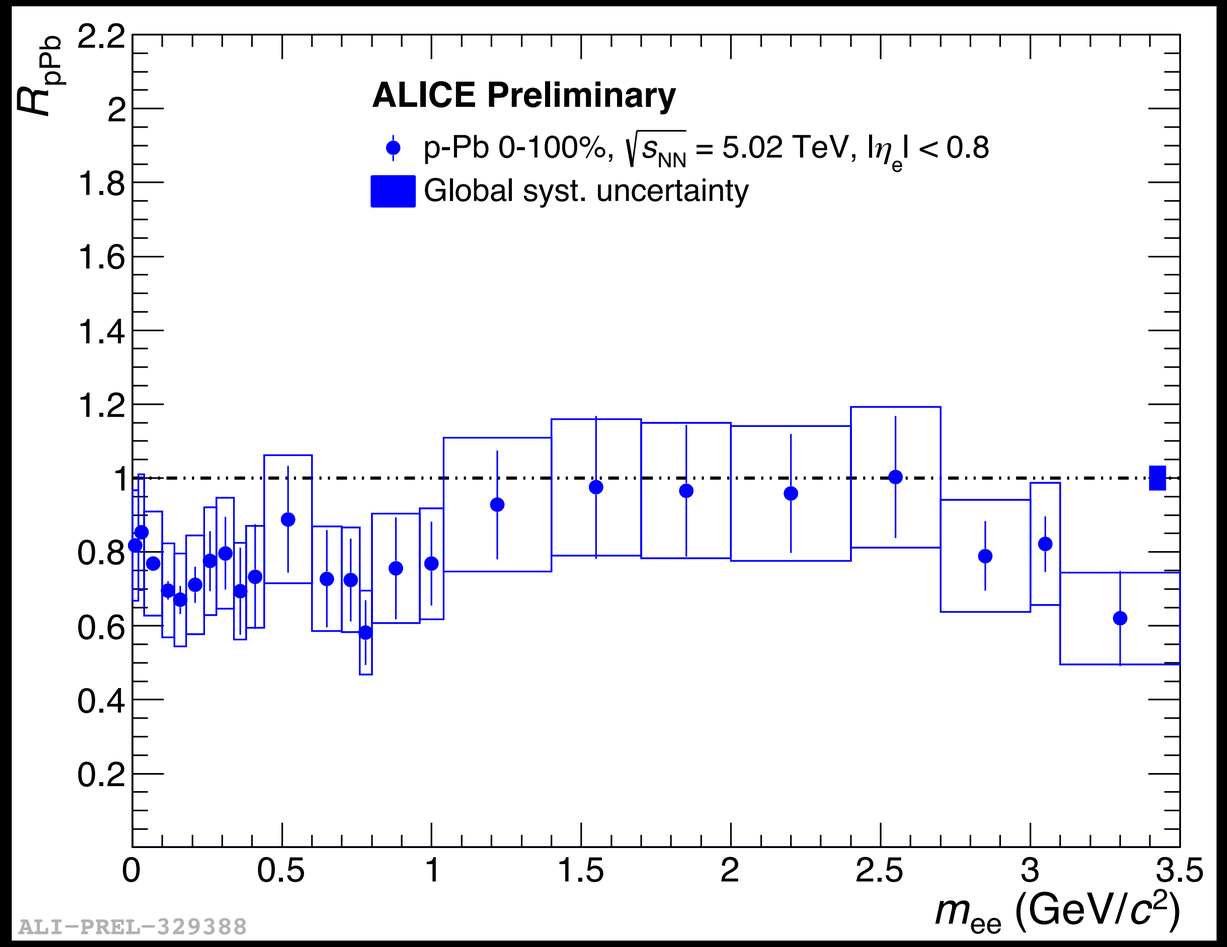
$$R_{\mathrm{pPb}} = \frac{1}{\langle N_{\mathrm{coll}} \rangle} \frac{\mathrm{d}N/\mathrm{d}m_{\mathrm{ee}}|_{\mathrm{pPb}}}{\mathrm{d}N/\mathrm{d}m_{\mathrm{ee}}|_{\mathrm{pp}}}$$

No significant modification of HF in IMR (1.1 – 2.7 GeV/c^2)

- In line with previous ALICE measurements of D-meson R_{pPb}

Deviation from unity for m_{ee} < 1 GeV/c^2

- Light flavour does not scale with N_{coll} at low p_{T}



NEW

The initial state – nuclear modification

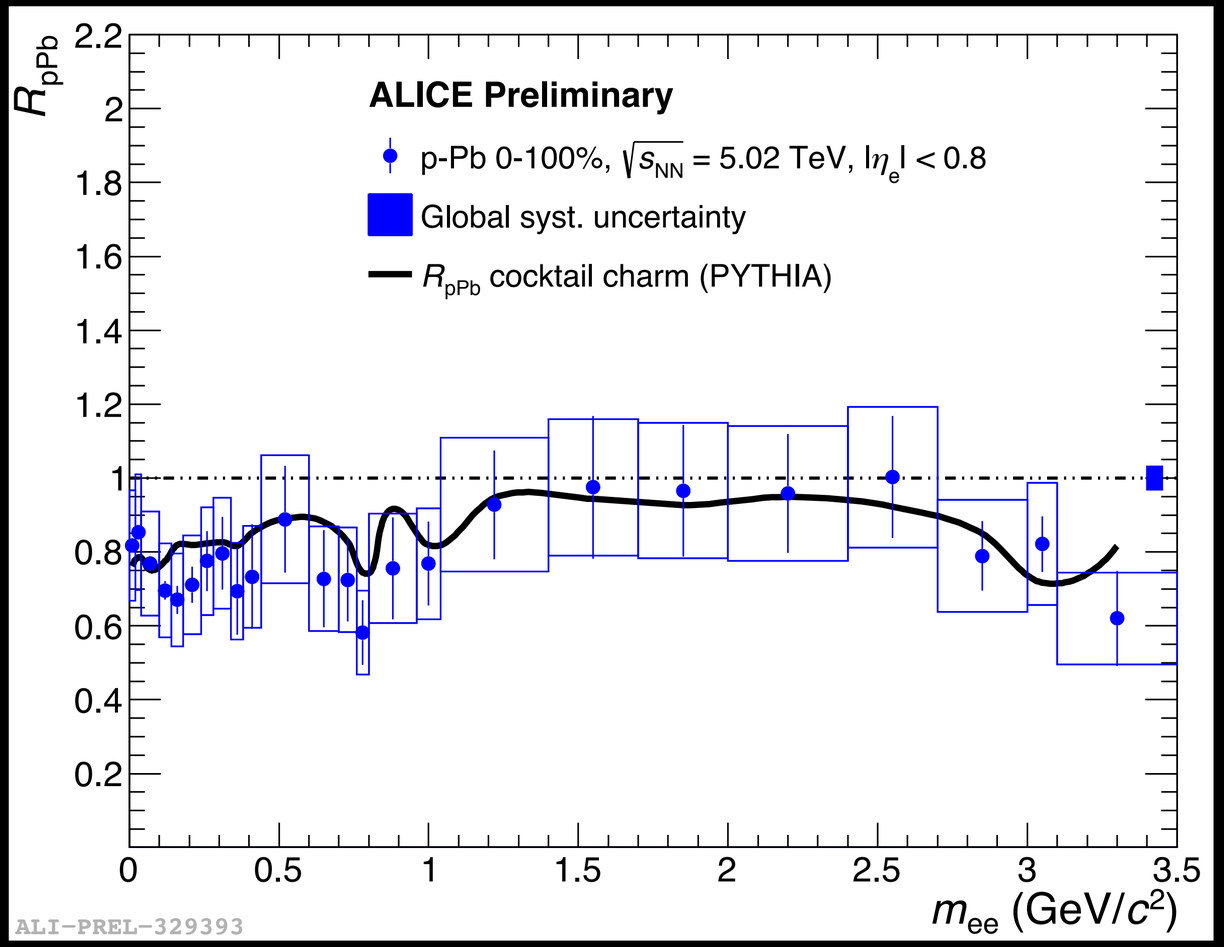
$$R_{\mathrm{pPb}} = \frac{1}{\langle N_{\mathrm{coll}} \rangle} \frac{\mathrm{d}N/\mathrm{d}m_{\mathrm{ee}}|_{\mathrm{pPb}}}{\mathrm{d}N/\mathrm{d}m_{\mathrm{ee}}|_{\mathrm{pp}}}$$

No significant modification of HF in IMR (1.1 – 2.7 GeV/c^2)

- In line with previous ALICE measurements of D-meson R_{pPb}

Deviation from unity for m_{ee} < 1 GeV/c^2

- Light flavour does not scale with N_{coll} at low p_{T}
- Compare to cocktail ratios which include scaling effects
  - Deviation from unity in line with scaling of light flavour production in p–Pb



NEW

The initial state – nuclear modification

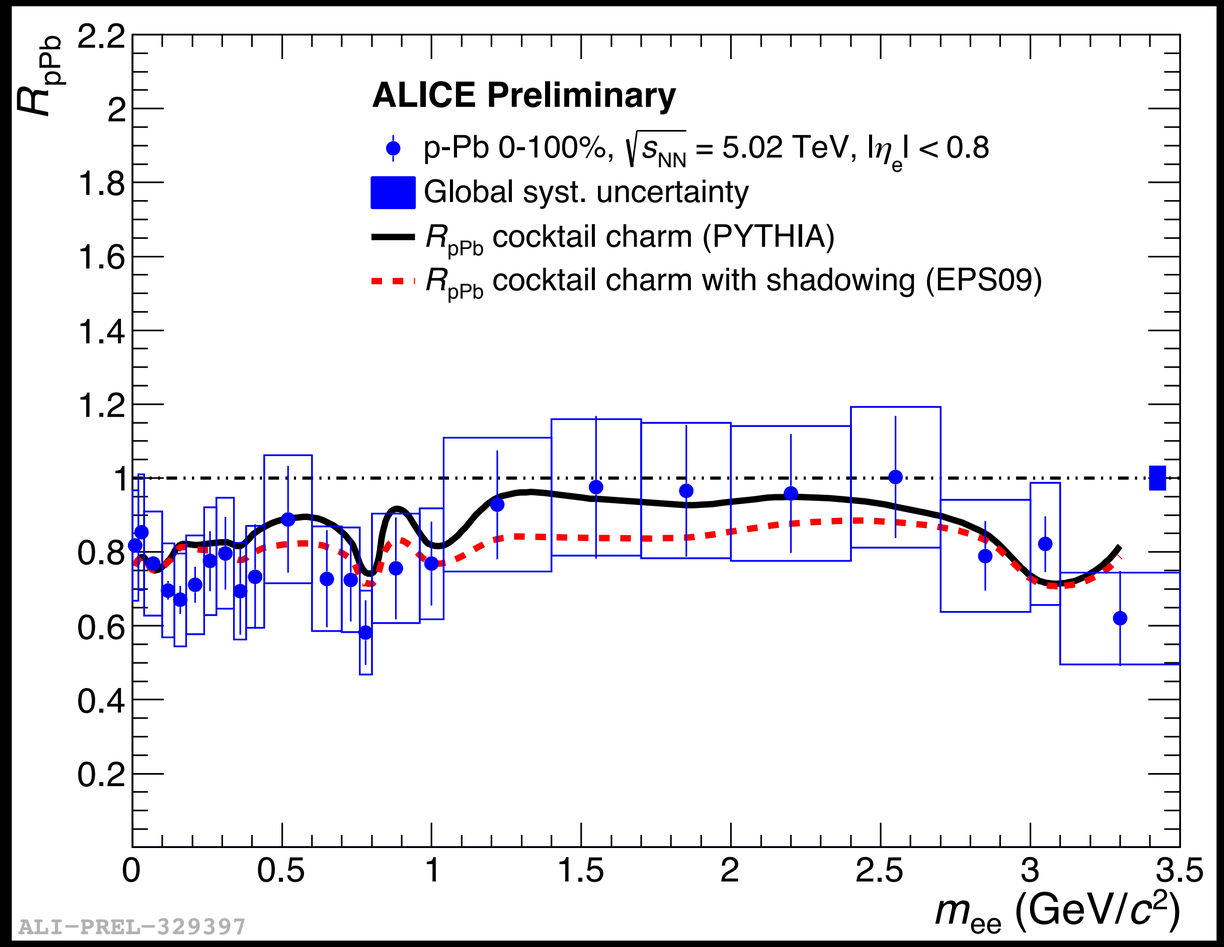
$$R_{\mathrm{pPb}} = \frac{1}{\langle N_{\mathrm{coll}} \rangle} \frac{\mathrm{d}N/\mathrm{d}m_{\mathrm{ee}}|_{\mathrm{pPb}}}{\mathrm{d}N/\mathrm{d}m_{\mathrm{ee}}|_{\mathrm{pp}}}$$

No significant modification of HF in IMR (1.1 – 2.7 GeV/c^2)

- In line with previous ALICE measurements of D-meson R_{pPb}

Deviation from unity for m_{ee} < 1 GeV/c^2

- Light flavour does not scale with N_{coll} at low p_{T}
- Compare to cocktail ratios which include scaling effects
  - Deviation from unity in line with scaling of light flavour production in p–Pb
- Compare to model including nuclear shadowing (EPS09)
  - m_{ee} < 1 GeV/c^2 cocktail including shadowing improves description of data
  - m_{ee} > 1 GeV/c^2 shadowing (EPS09) on uncertainty edge

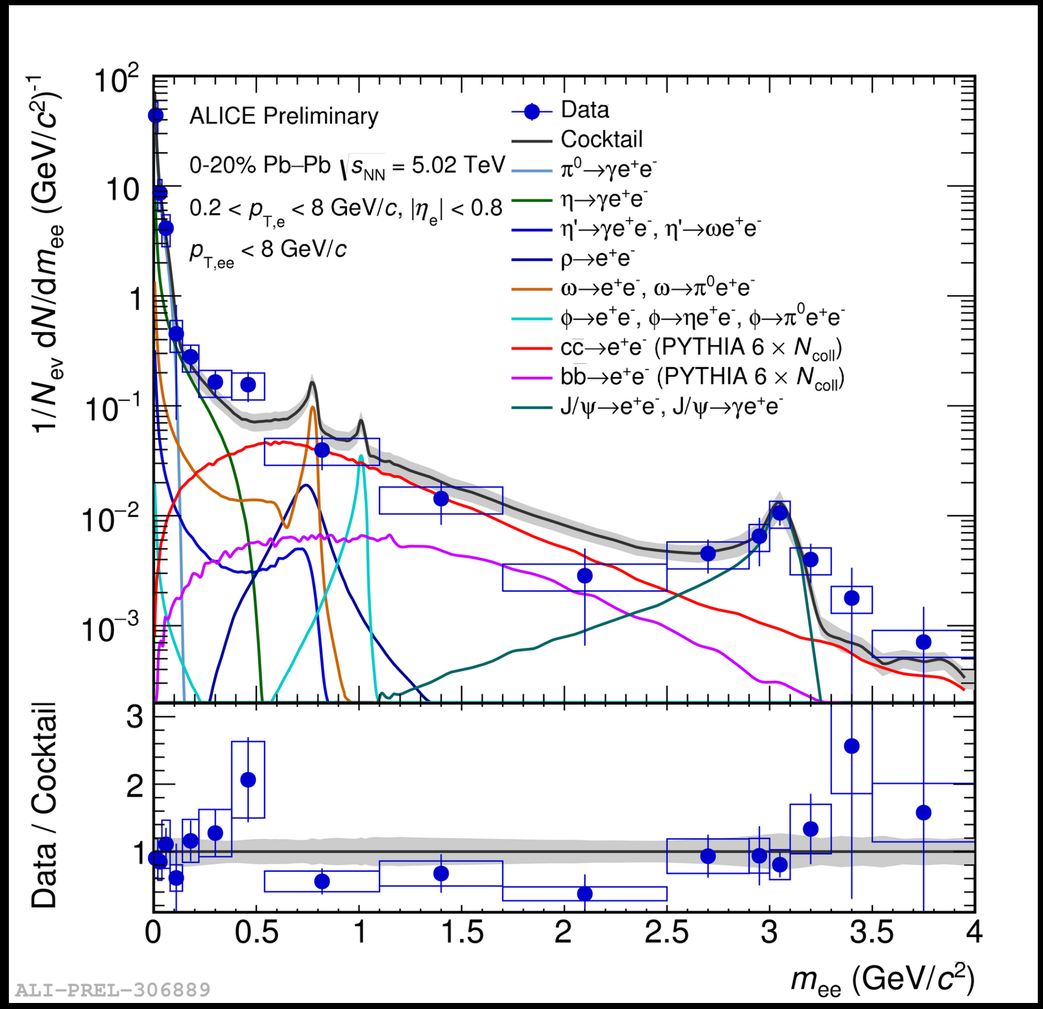


NEW

Pb–Pb

Corrected dielectron yield measured at $\sqrt{s_{NN}}$ = 5.02 TeV as function of m_{ee}

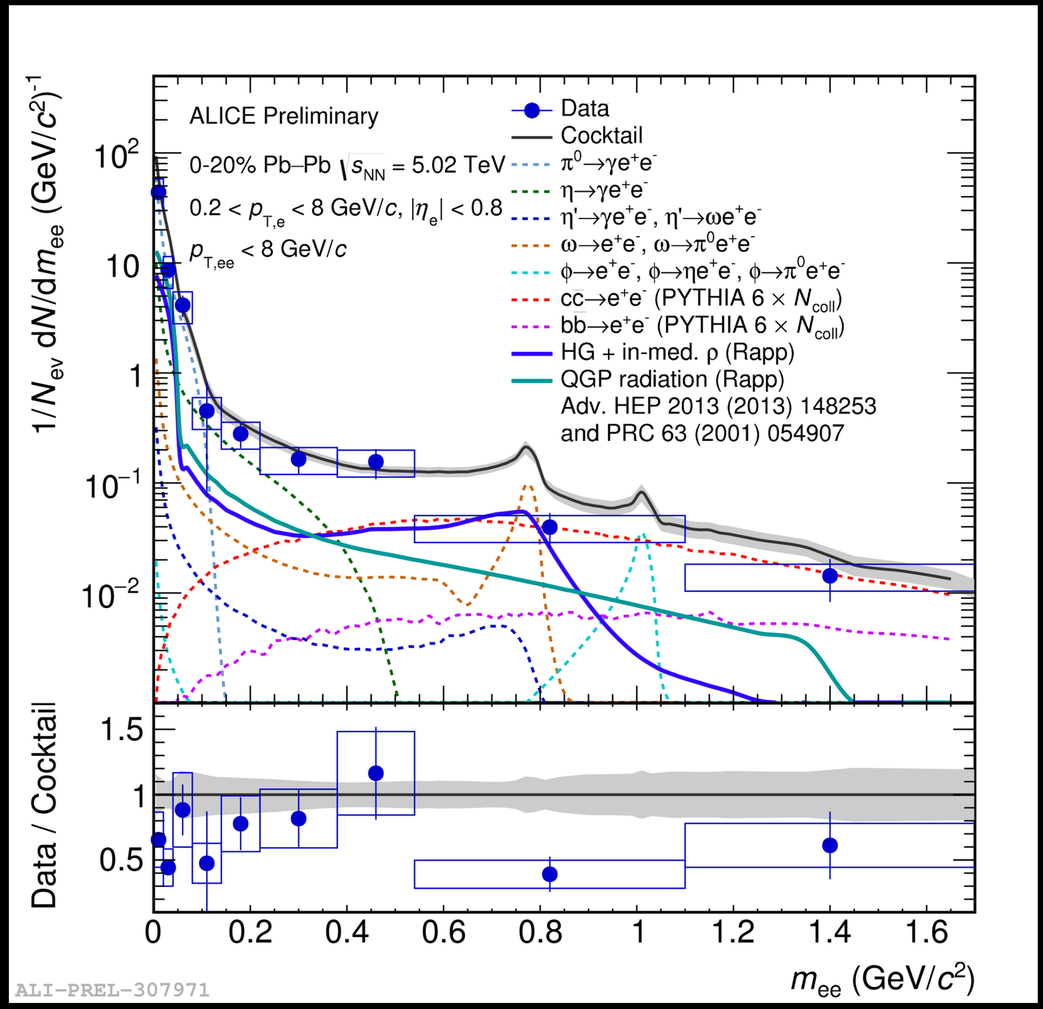
- Hint for enhancement (?) in low-mass region ~0.5 GeV/c^2



Pb–Pb

Corrected dielectron yield measured at $\sqrt{s_{NN}}$ = 5.02 TeV as function of m_{ee}

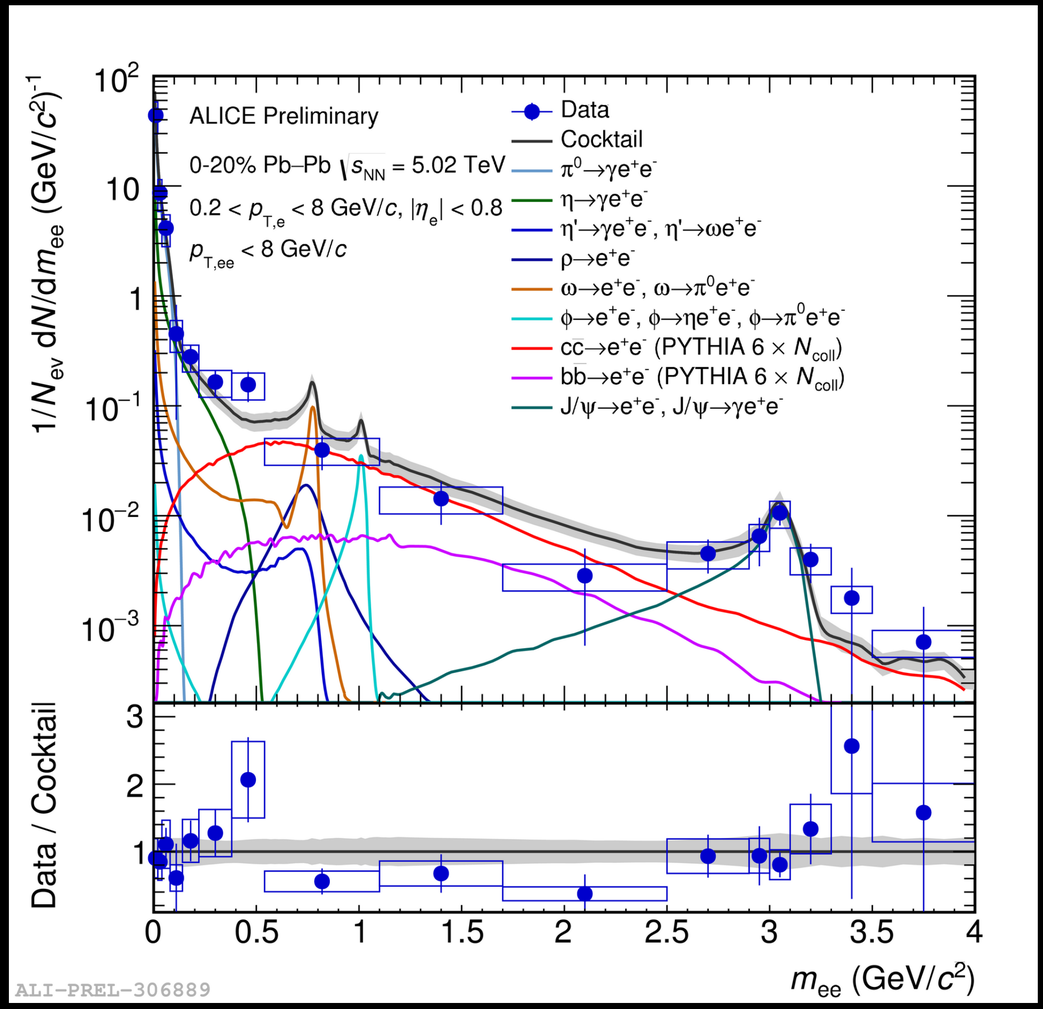
- Hint for enhancement (?) in low-mass region ~0.5 GeV/c^2
  - Consistent with thermal model calculations (R. Rapp)



Pb–Pb

Corrected dielectron yield measured at $\sqrt{s_{NN}}$ = 5.02 TeV as function of m_{ee}

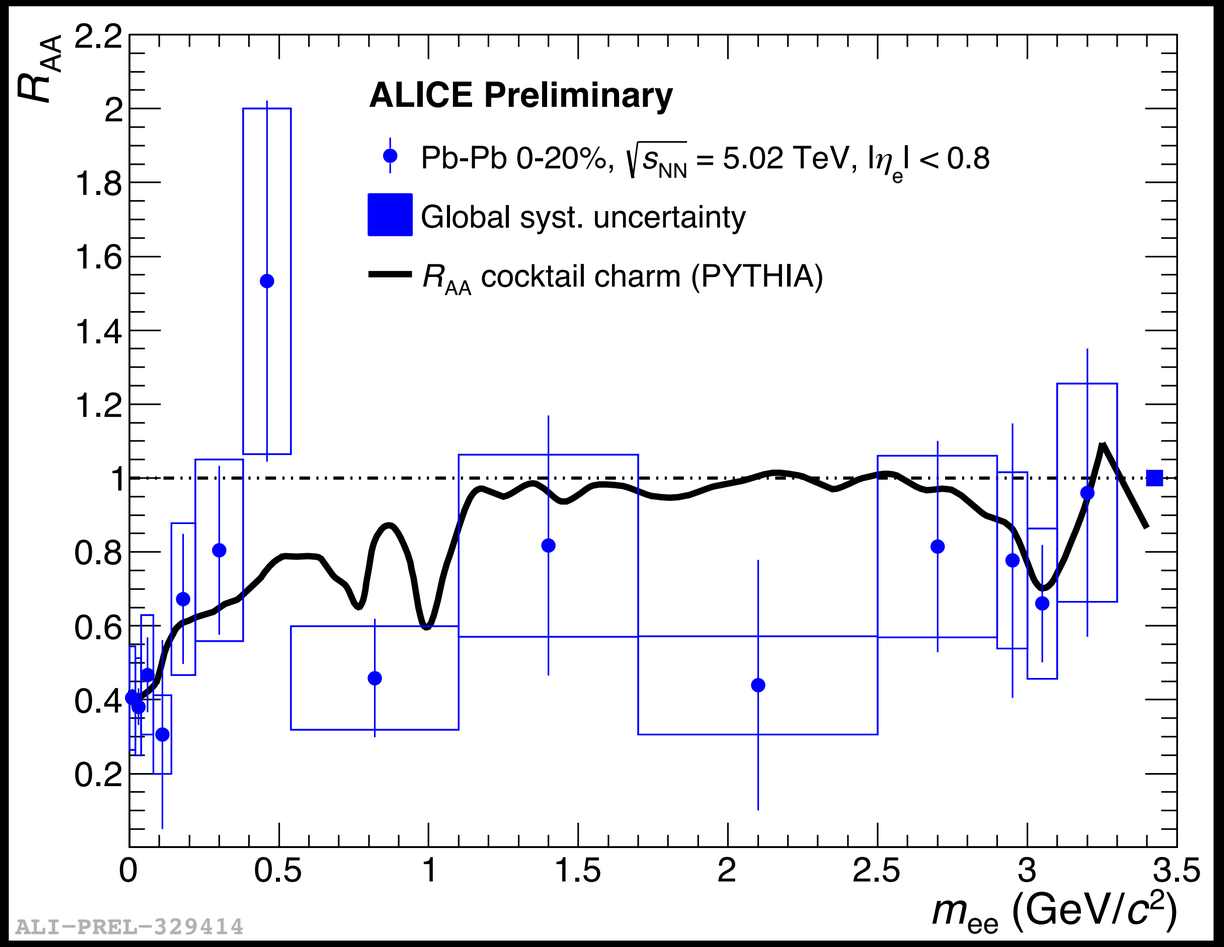
- Hint for enhancement (?) in low-mass region ~0.5 GeV/c^2
  - Consistent with thermal model calculations (R. Rapp)
- Suppression below vacuum baseline in HF dominated region



Pb–Pb

Corrected dielectron yield measured at $\sqrt{s_{NN}}$ = 5.02 TeV as function of m_{ee}

- Hint for enhancement (?) in low-mass region ~0.5 GeV/c^2
  - Consistent with thermal model calculations (R. Rapp)
- Suppression below vacuum baseline in HF dominated region
  - Most probably final state effects (e. g. Energy loss)



Pb–Pb

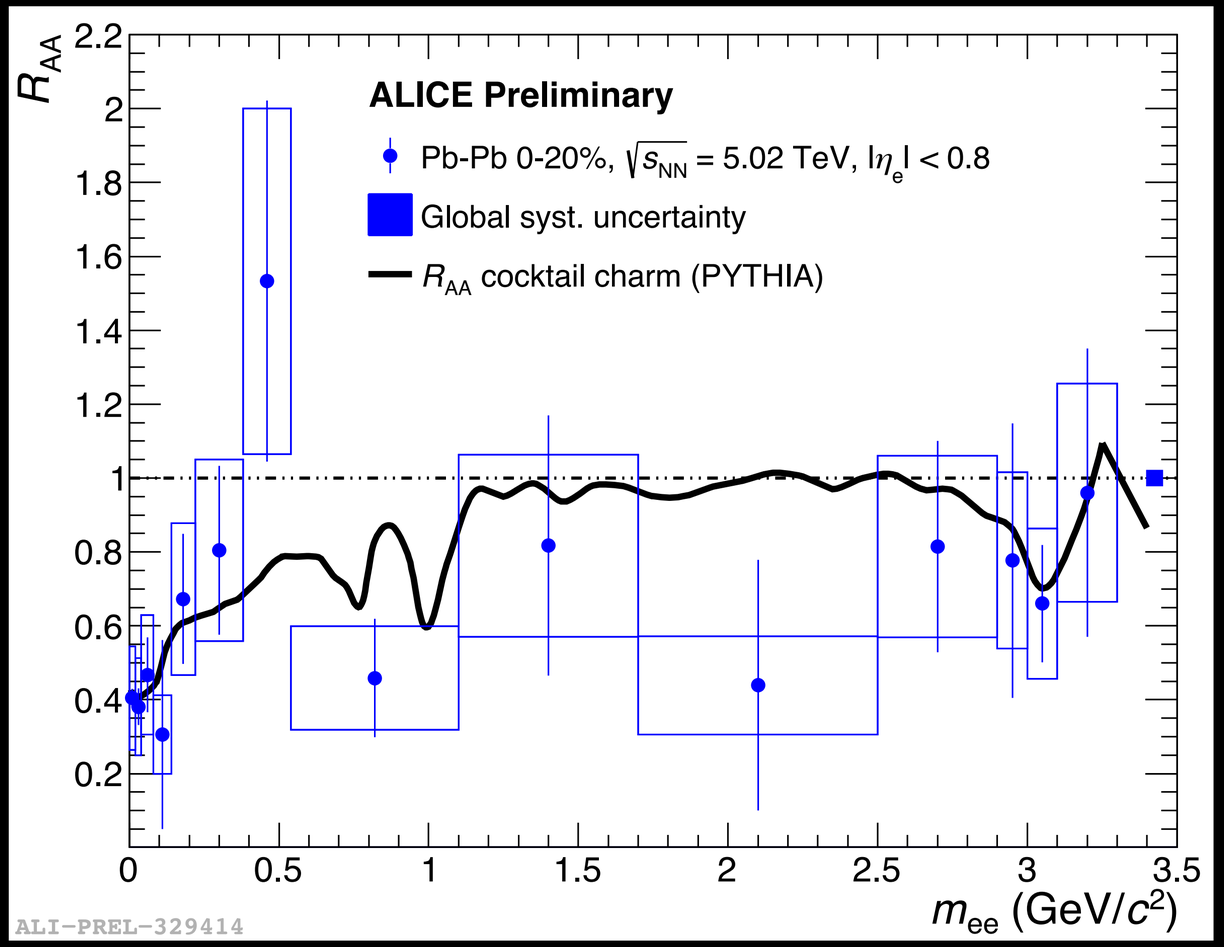
Corrected dielectron yield measured at $\sqrt{s_{NN}}$ = 5.02 TeV as function of m_{ee}

- Hint for enhancement (?) in low-mass region ~0.5 GeV/c^2
  - Consistent with thermal model calculations (R. Rapp)
- Suppression below vacuum baseline in HF dominated region
  - Most probably final state effects (e. g. Energy loss)
  - Taking this into account → Stronger enhancement than over vacuum

Perspectives to measure thermal radiation in IMR

- Complexity of interplay between initial and final state effects on charm production complicate construction of a baseline
- Topological separation of thermal radiation and heavy-flavour sources necessary (Poster: E. Meninno)

NEW



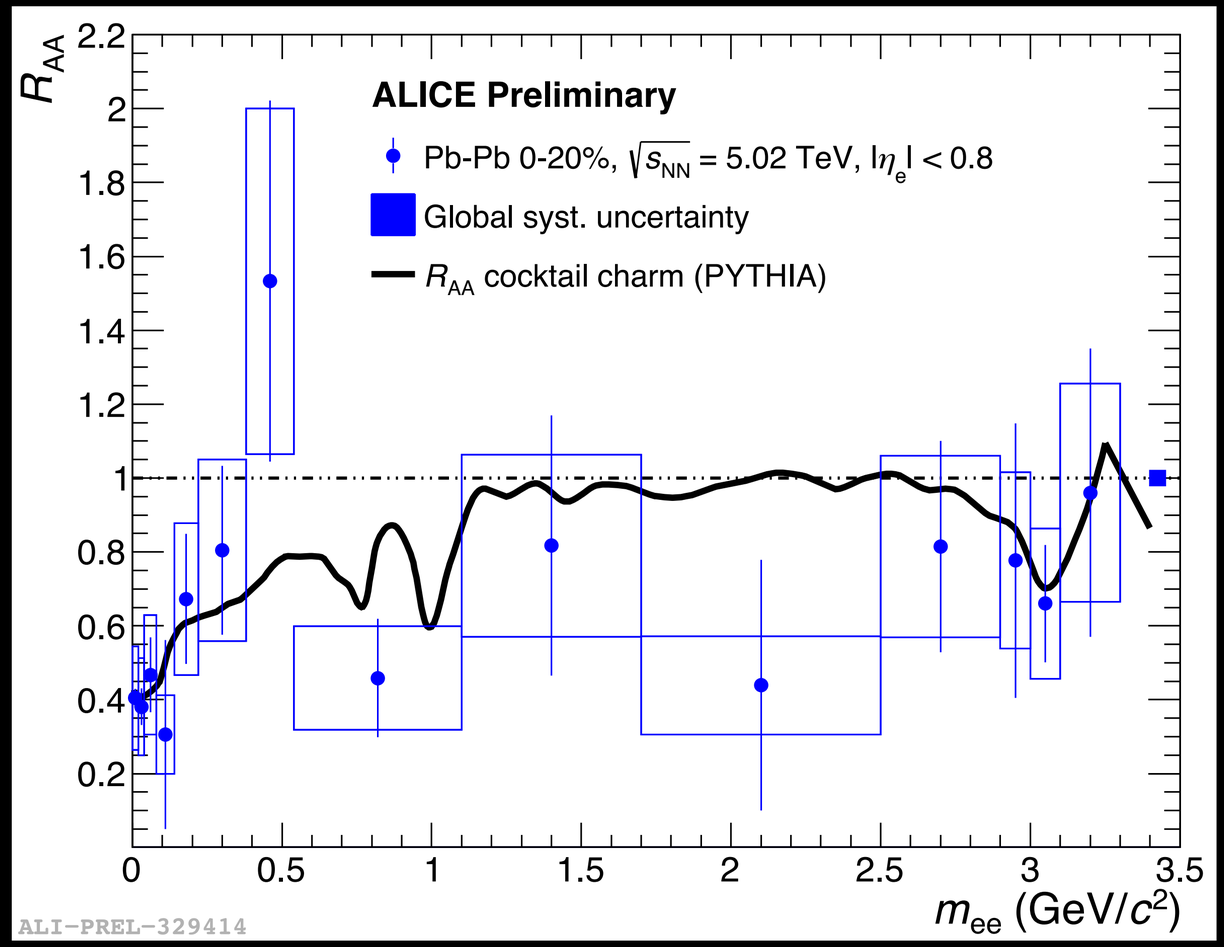
Pb–Pb

Corrected dielectron yield measured at $\sqrt{s_{NN}}$ = 5.02 TeV as function of m_{ee}

- Hint for enhancement (?) in low-mass region ~0.5 GeV/c^2
  - Consistent with thermal model calculations (R. Rapp)
- Suppression below vacuum baseline in HF dominated region
  - Most probably final state effects (e. g. Energy loss)
  - Taking this into account → Stronger enhancement than over vacuum

Perspectives to measure thermal radiation in IMR

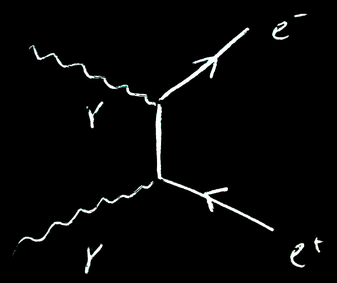
- Complexity of interplay between initial and final state effects on charm production complicate construction of a baseline
- Topological separation of thermal radiation and heavy-flavour sources necessary (Poster: E. Meninno)
- Analysis of high-statistics Pb–Pb data set from 2018 ongoing (Poster: D. Sekihata)



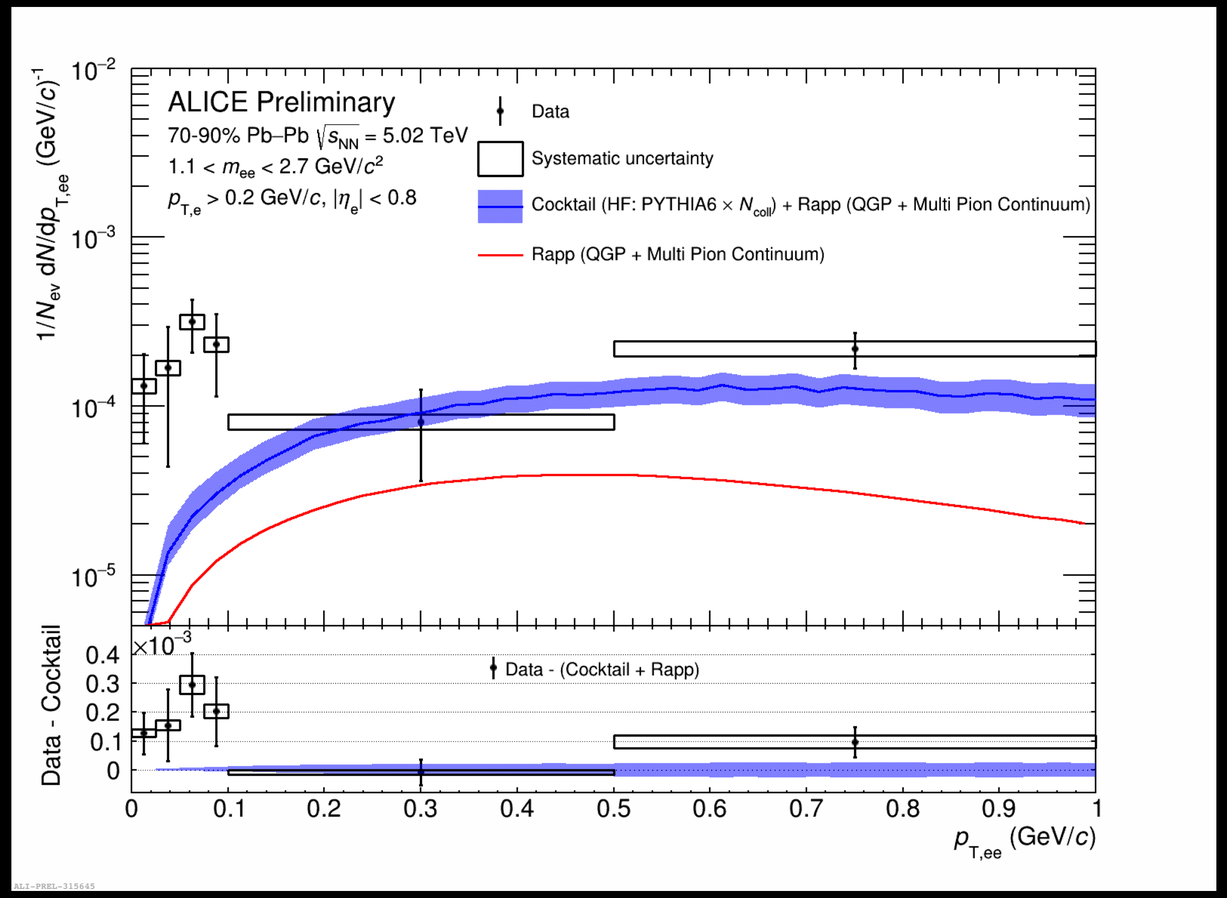
Low p_T in peripheral Pb–Pb

Enhancement measured by STAR [*Phys. Rev. Lett.* **121** (2018)]
Similar effects seen in ALICE

Can be explained by coherent photo production



More differential studies needed to understand modification of UPC physics with nuclear overlap (e. g. Event plane dependence)



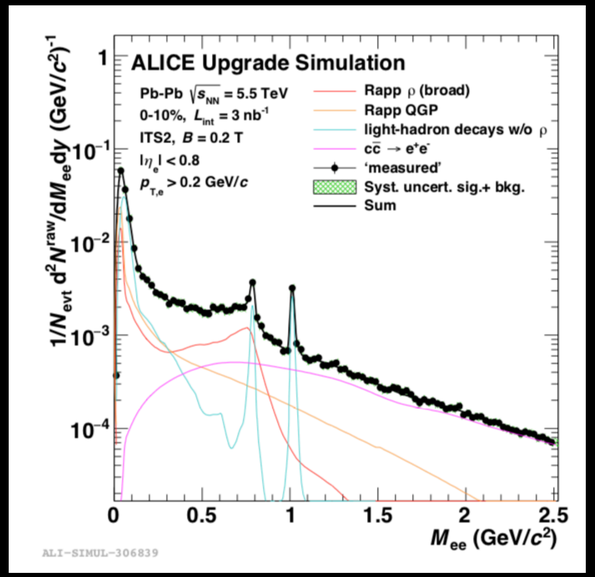
Future e^+e^- measurements with ALICE

Talk by F. Reidt
Tue, 18:20

New ITS and upgrade of TPC readout system will improve the vertex pointing resolution by a factor 3-6 and enhance the readout rate in Pb–Pb by a factor 100 [CERN-LHCC-2013-13,CERN-LHCC-2013-23]

Dedicated dielectron runs with low magnetic fields (B = 0.2T) planned to increase acceptance to low p_T

Low-field pilot runs were performed to explore potential for such a configuration



Citron, Z. et al, 1812.06772

Soft dielectrons in pp

Enhancement was reported at the ISR

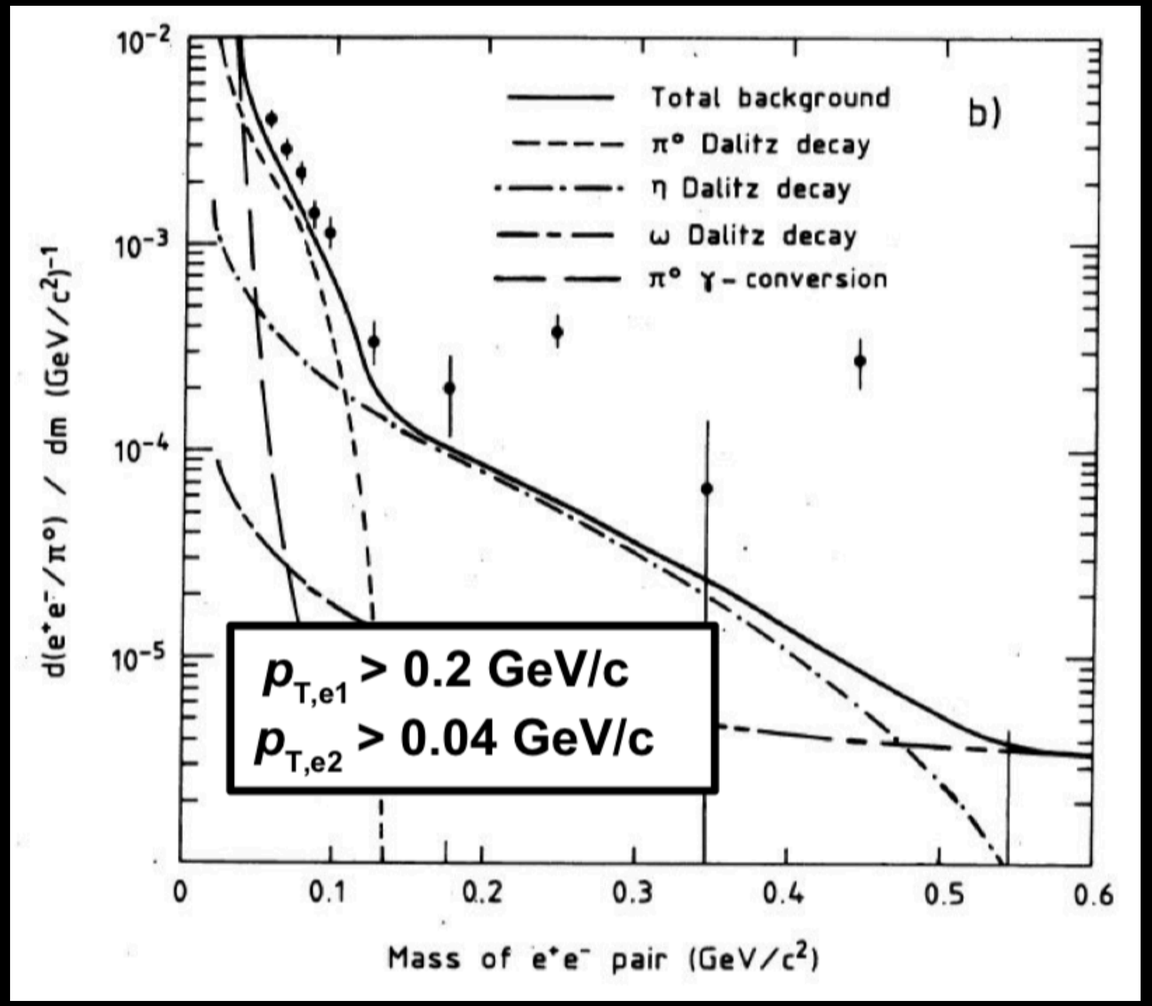
- Never confirmed nor disproven

Reduced magnetic field in the ALICE solenoid (0.5T→0.2T) extends low-p_T reach to 75 MeV/c for single electrons

Access to very low mass and pair p_T

Preliminary results shown at QM18

- Hint for excess in the soft η region
- Qualitatively consistent with ISR data
- Limited statistical precision
- Large uncertainty on η cocktail contribution, constrained by m_T-scaling



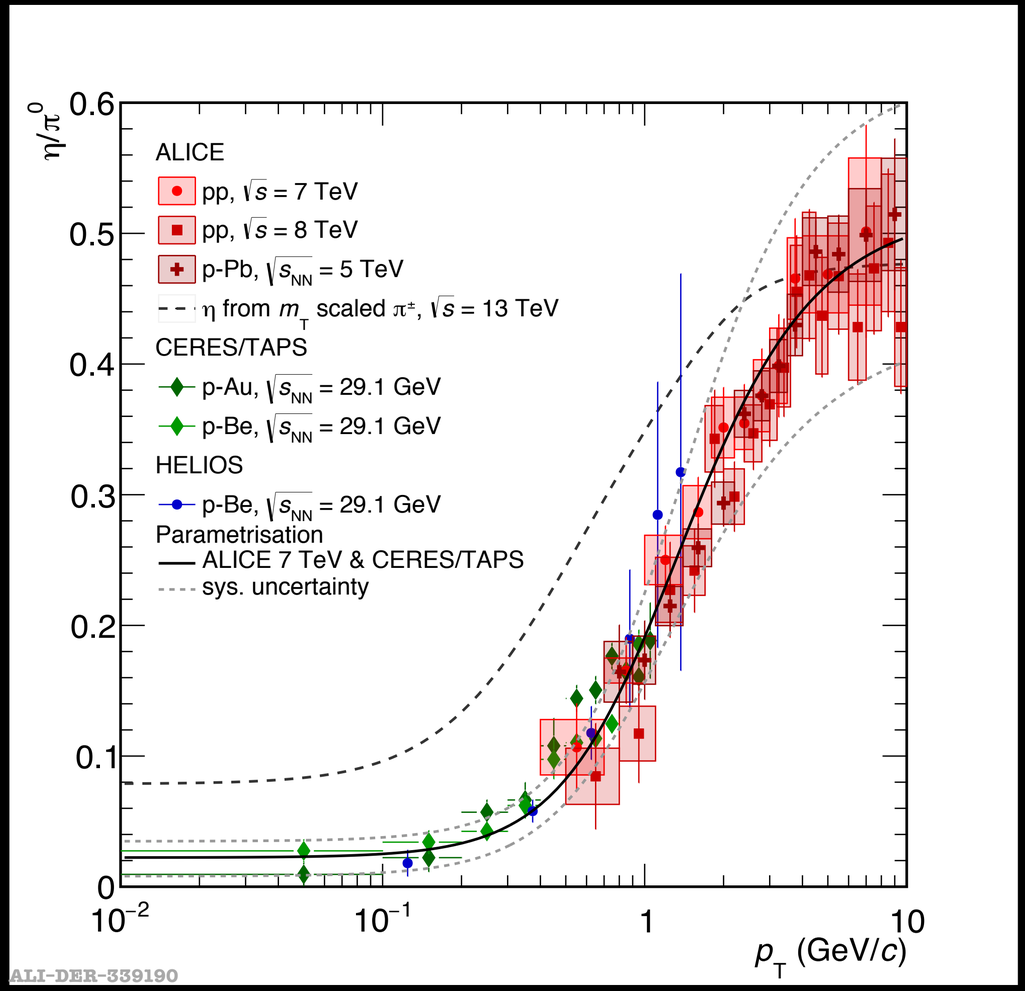
V. Hedberg, PhD Thesis, Lund University (1987)

Dielectron production in pp at $\sqrt{s}$ = 63 GeV

Soft dielectrons in pp at 13 TeV

Reevaluate η cocktail contribution and uncertainties

- New parametrisation of η
- Discard m_T-scaling as upper uncertainty constraint



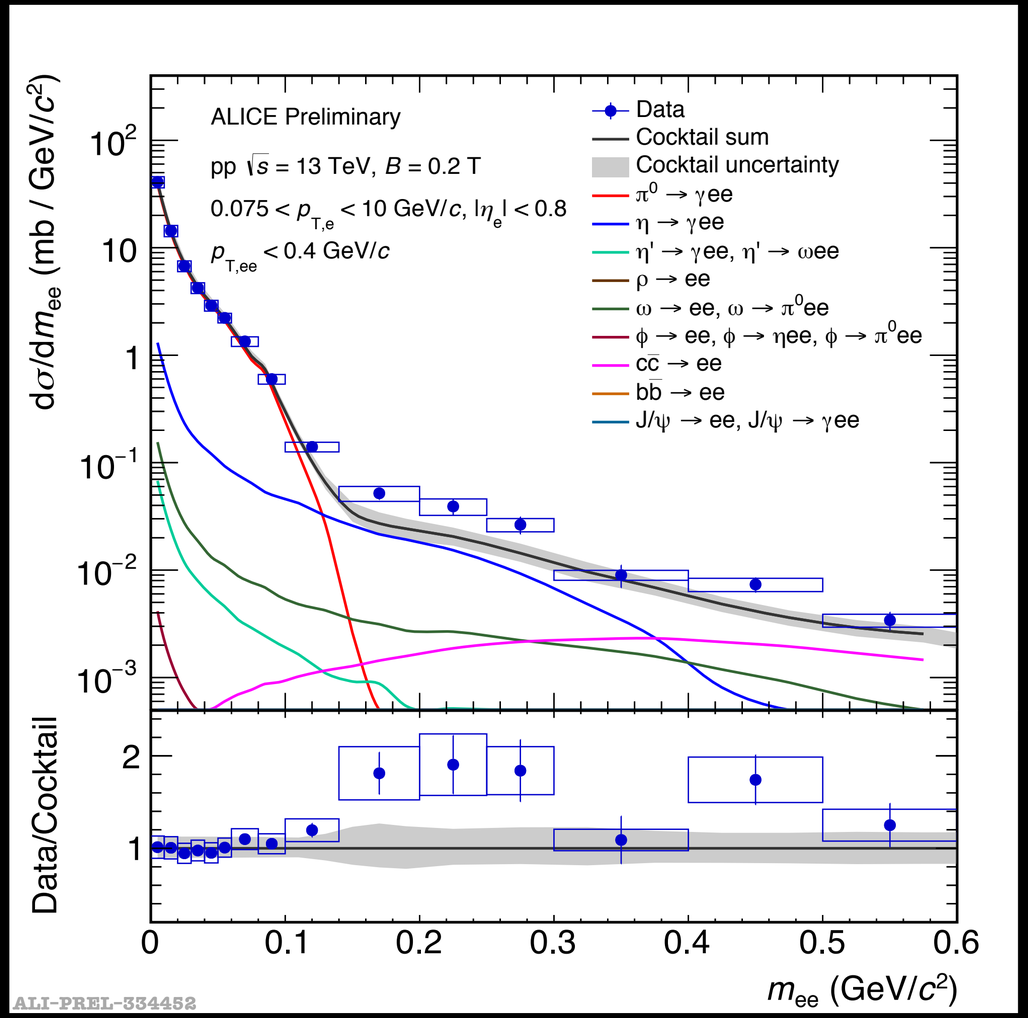
Soft dielectrons in pp at 13 TeV

Reevaluate η cocktail contribution and uncertainties

- New parametrisation of η
- Discard m_T-scaling as upper uncertainty constraint

Include more low-field data from 2018

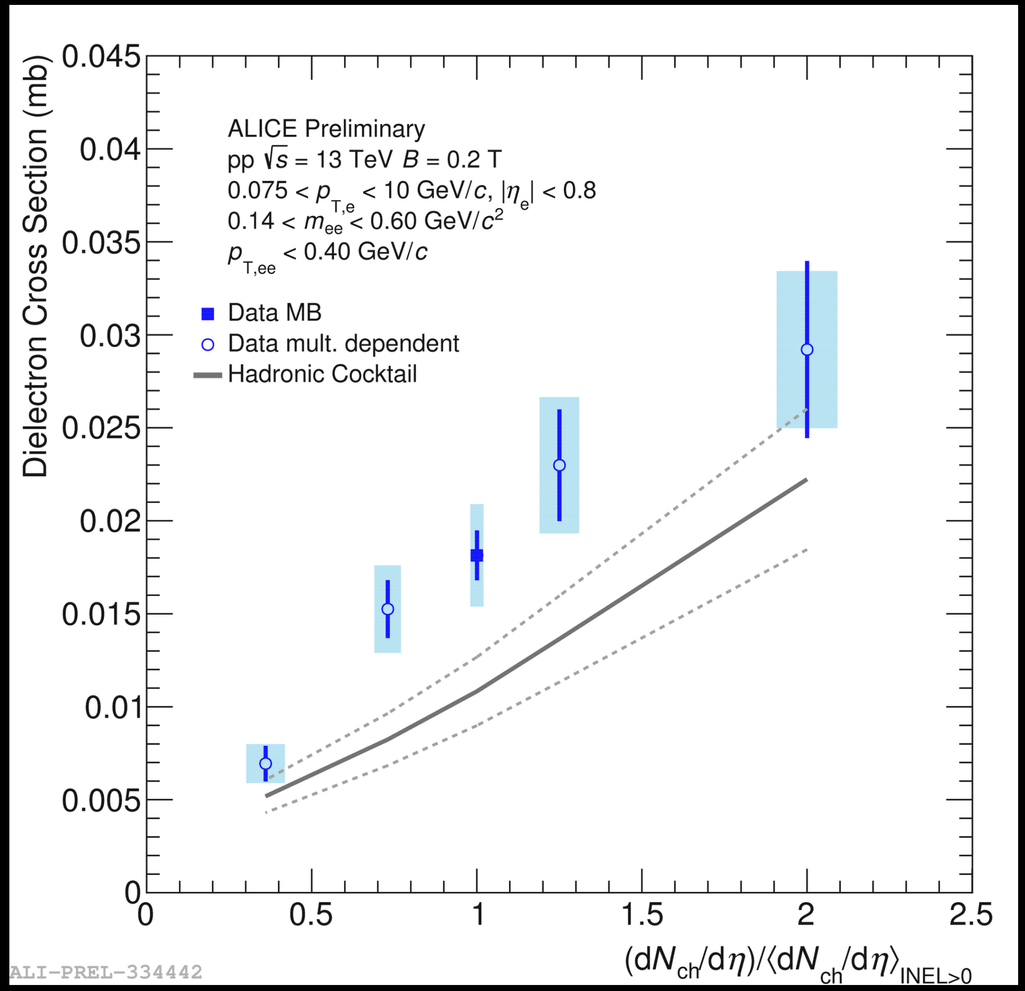
- Statistical significance of enhancement increased



Soft dielectrons in pp at 13 TeV

Soft dielectron production as function of relative charged particle density

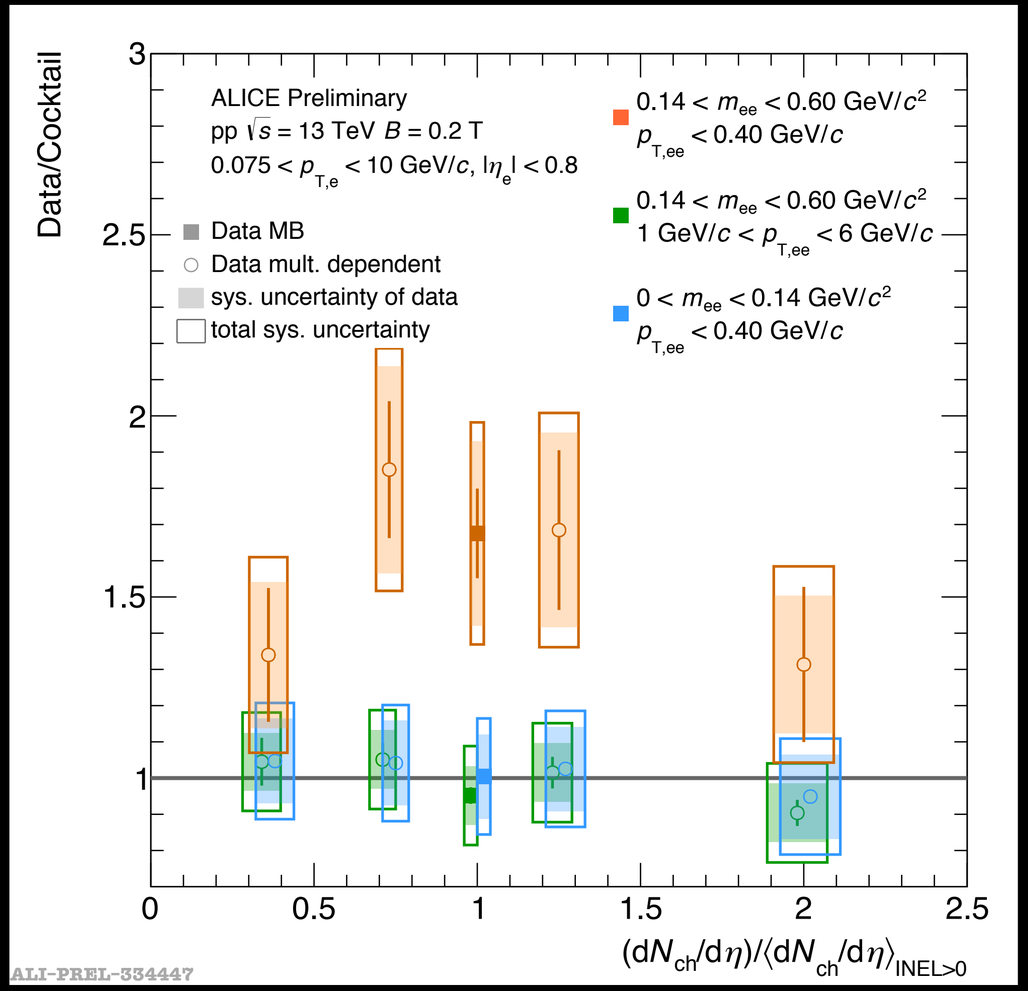
- Data consistently over cocktail prediction in η mass region and $p_{T,ee}$ < 0.4 GeV/c



Soft dielectrons in pp at 13 TeV

Soft dielectron production as function of relative charged particle density

- Data consistently over cocktail prediction in η mass region and $p_{T,ee} < 0.4$ GeV/c
- Enhancement compatible with linear scaling with multiplicity
- π^0 mass region at $p_{T,ee} < 0.4$ GeV/c or
  η mass for $1 < p_{T,ee} < 6$ GeV/c consistent with cocktail



Summary

Dielectron measurements in pp, p–Pb and Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

pp collisions

- Baseline for p–Pb and Pb–Pb established
- Model dependence of heavy-flavour production and first measurement of $d\sigma_{c\bar{c}}/dy$ and $d\sigma_{b\bar{b}}/dy$ in pp collisions at $\sqrt{s}$ = 5.02 TeV

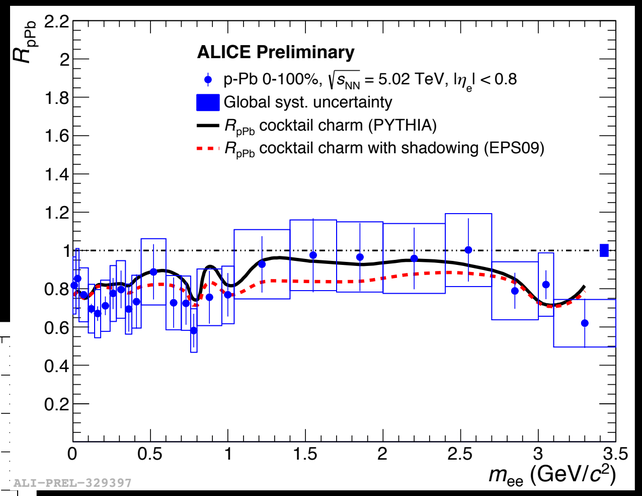
p–Pb collisions

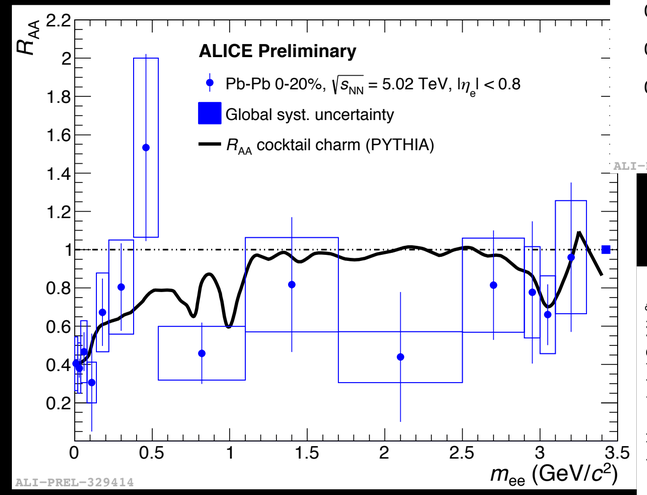
- No significant modification of heavy-flavour production in IMR
- Hint for suppression at smaller masses
- Model comparison expects larger suppression

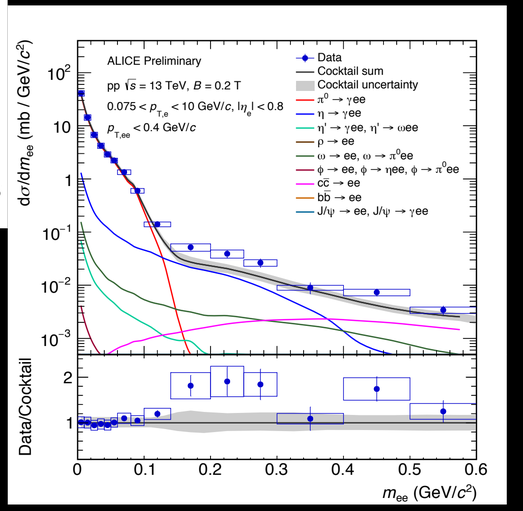
Pb–Pb collisions

- Possible excess from thermal radiation ~0.5 GeV/c^2
- Suppression of heavy flavour from final state effects
- Low $p_{T,ee}$ excess observed

Soft dielectron production in pp shows enhancement over cocktail as function of multiplicity

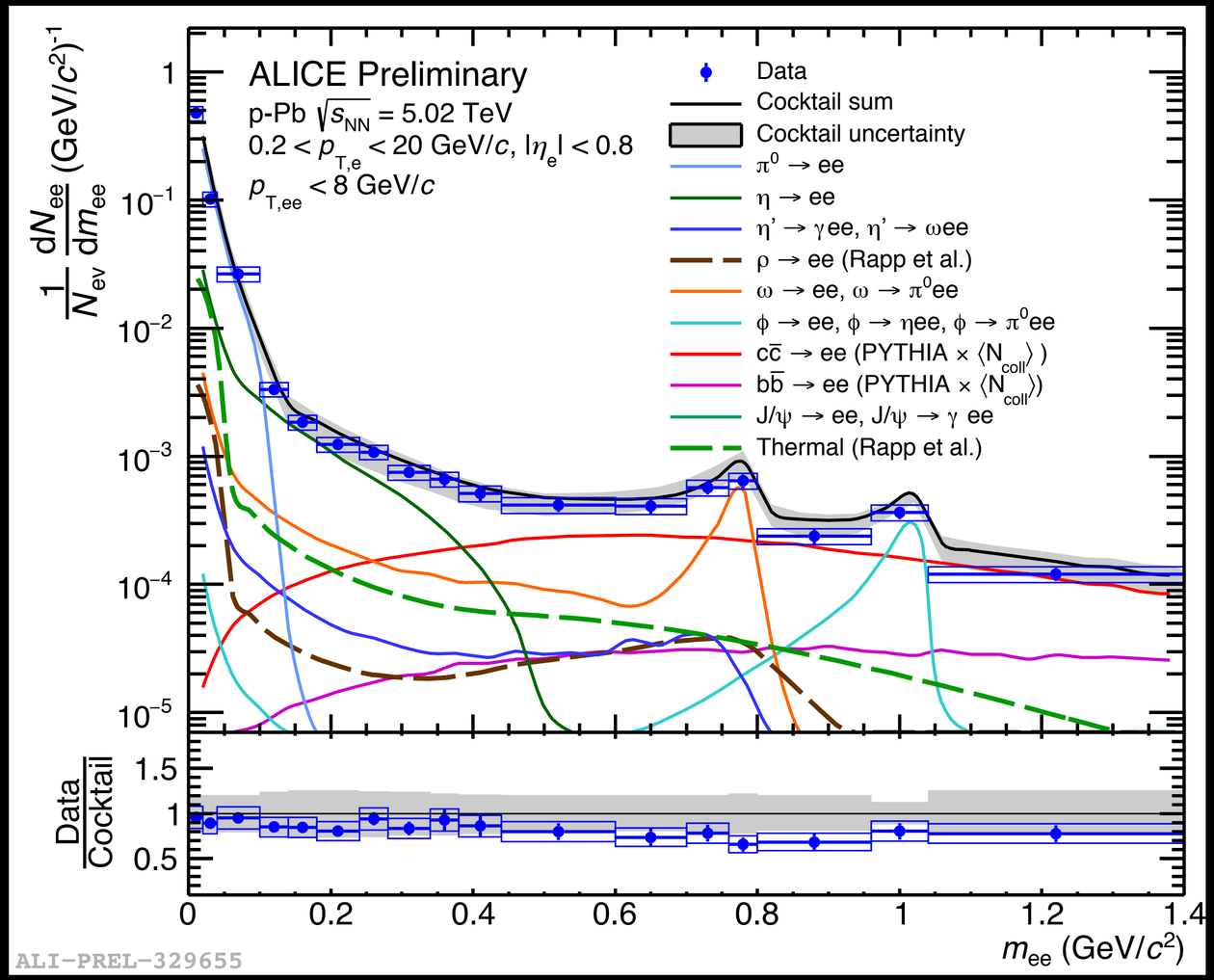


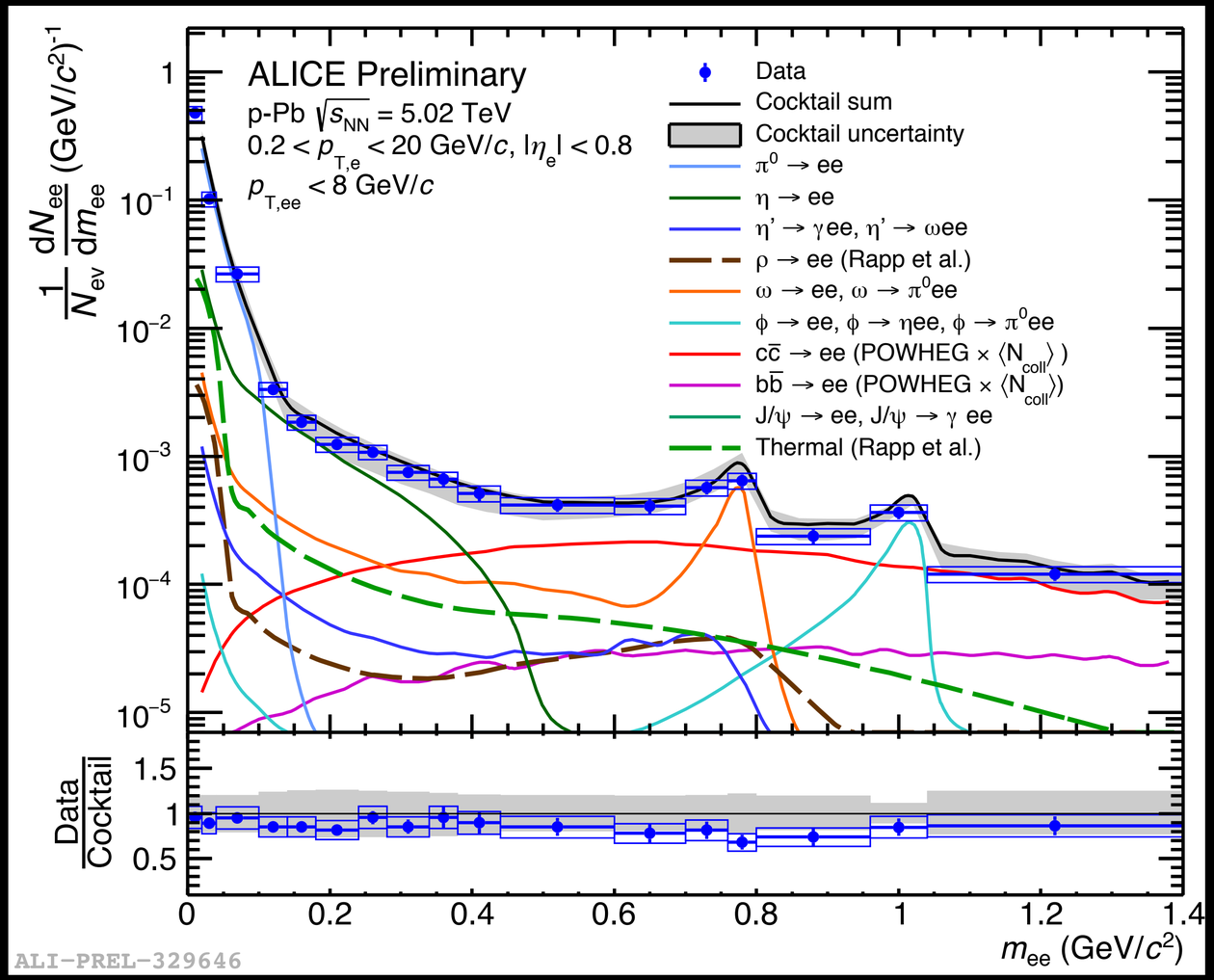




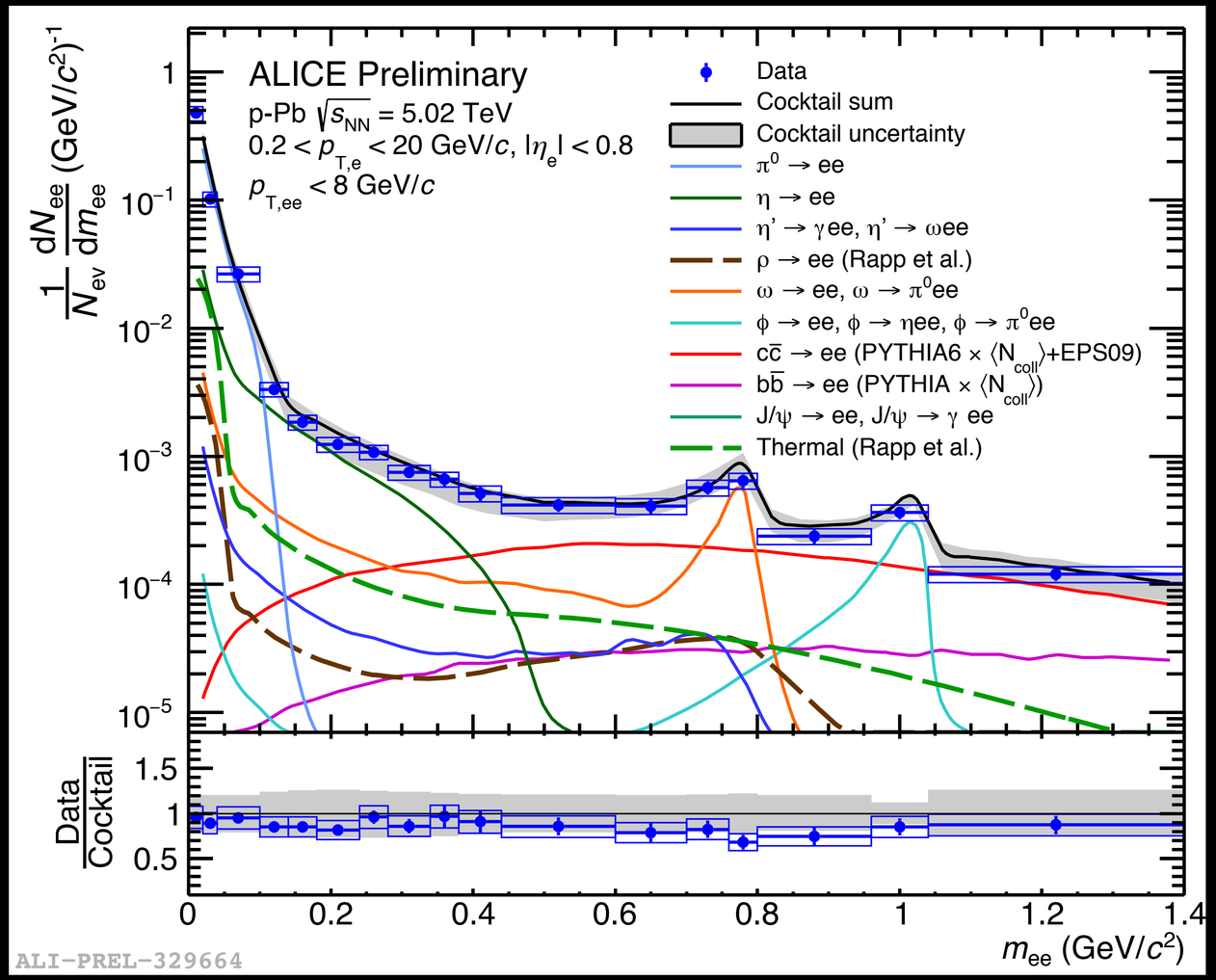
Backup

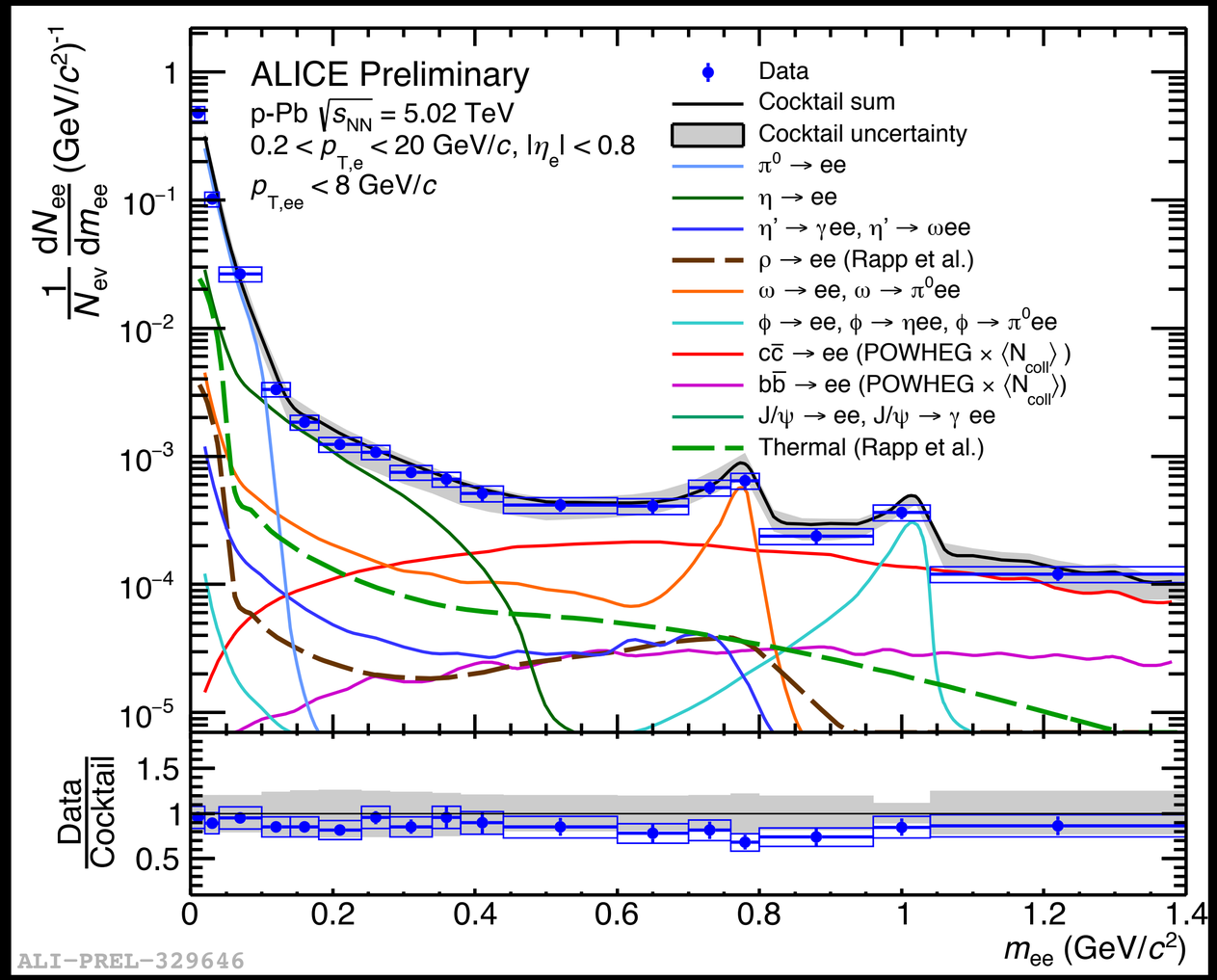
Backup


ALICE Preliminary
p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
$0.2 < p_{T,e} < 20$ GeV/c, $|\eta_e| < 0.8$
$p_{T,ee} < 8$ GeV/c
Data
Cocktail sum
Cocktail uncertainty
$\pi^0 \rightarrow ee$
$\eta \rightarrow ee$
$\eta' \rightarrow \gamma ee$, $\eta' \rightarrow \omega ee$
$\rho \rightarrow ee$ (Rapp et al.)
$\omega \rightarrow ee$, $\omega \rightarrow \pi^0 ee$
$\phi \rightarrow ee$, $\phi \rightarrow \eta ee$, $\phi \rightarrow \pi^0 ee$
$c\bar{c} \rightarrow ee$ (PYTHIA $\times \langle N_{coll} \rangle$)
$b\bar{b} \rightarrow ee$ (PYTHIA $\times \langle N_{coll} \rangle$)
$J/\psi \rightarrow ee$, $J/\psi \rightarrow \gamma$ ee
Thermal (Rapp et al.)
$\frac{1}{N_{ev}} \frac{dN_{ee}}{dm_{ee}}$ (GeV/c^2)$^{-1}$
Data / Cocktail
m_{ee} (GeV/c^2)
ALI-PREL-329655

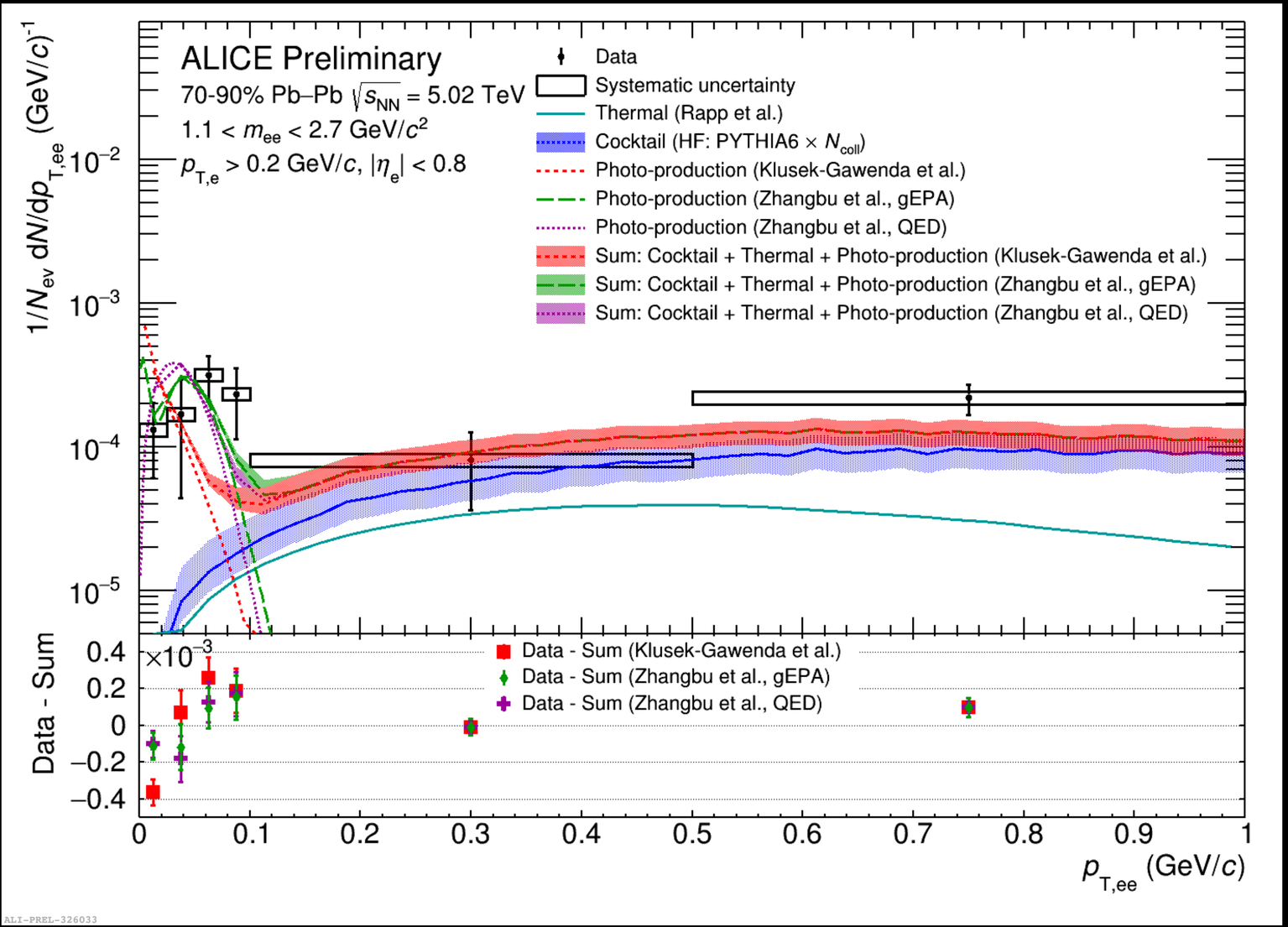

ALICE Preliminary
p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
$0.2 < p_{T,e} < 20$ GeV/c, $|\eta_e| < 0.8$
$p_{T,ee} < 8$ GeV/c
Data
Cocktail sum
Cocktail uncertainty
$\pi^0 \rightarrow ee$
$\eta \rightarrow ee$
$\eta' \rightarrow \gamma ee$, $\eta' \rightarrow \omega ee$
$\rho \rightarrow ee$ (Rapp et al.)
$\omega \rightarrow ee$, $\omega \rightarrow \pi^0 ee$
$\phi \rightarrow ee$, $\phi \rightarrow \eta ee$, $\phi \rightarrow \pi^0 ee$
$c\bar{c} \rightarrow ee$ (POWHEG $\times \langle N_{coll} \rangle$)
$b\bar{b} \rightarrow ee$ (POWHEG $\times \langle N_{coll} \rangle$)
$J/\psi \rightarrow ee$, $J/\psi \rightarrow \gamma$ ee
Thermal (Rapp et al.)
$\frac{1}{N_{ev}} \frac{dN_{ee}}{dm_{ee}}$ (GeV/c^2)$^{-1}$
Data / Cocktail
m_{ee} (GeV/c^2)
ALI-PREL-329646

Backup


ALICE Preliminary
p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
$0.2 < p_{T,e} < 20$ GeV/c, $|\eta_e| < 0.8$
$p_{T,ee} < 8$ GeV/c
Data
Cocktail sum
Cocktail uncertainty
$\pi^0 \rightarrow ee$
$\eta \rightarrow ee$
$\eta' \rightarrow \gamma ee$, $\eta' \rightarrow \omega ee$
$\rho \rightarrow ee$ (Rapp et al.)
$\omega \rightarrow ee$, $\omega \rightarrow \pi^0 ee$
$\phi \rightarrow ee$, $\phi \rightarrow \eta ee$, $\phi \rightarrow \pi^0 ee$
$c\bar{c} \rightarrow ee$ (PYTHIA6 × $\langle N_{coll} \rangle$+EPS09)
$b\bar{b} \rightarrow ee$ (PYTHIA × $\langle N_{coll} \rangle$)
$J/\psi \rightarrow ee$, $J/\psi \rightarrow \gamma$ ee
Thermal (Rapp et al.)
$\frac{1}{N_{ev}} \frac{dN_{ee}}{dm_{ee}}$ (GeV/c^2)$^{-1}$
Data / Cocktail
m_{ee} (GeV/c^2)
ALI-PREL-329664


ALICE Preliminary
p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
$0.2 < p_{T,e} < 20$ GeV/c, $|\eta_e| < 0.8$
$p_{T,ee} < 8$ GeV/c
Data
Cocktail sum
Cocktail uncertainty
$\pi^0 \rightarrow ee$
$\eta \rightarrow ee$
$\eta' \rightarrow \gamma ee$, $\eta' \rightarrow \omega ee$
$\rho \rightarrow ee$ (Rapp et al.)
$\omega \rightarrow ee$, $\omega \rightarrow \pi^0 ee$
$\phi \rightarrow ee$, $\phi \rightarrow \eta ee$, $\phi \rightarrow \pi^0 ee$
$c\bar{c} \rightarrow ee$ (POWHEG × $\langle N_{coll} \rangle$)
$b\bar{b} \rightarrow ee$ (POWHEG × $\langle N_{coll} \rangle$)
$J/\psi \rightarrow ee$, $J/\psi \rightarrow \gamma$ ee
Thermal (Rapp et al.)
$\frac{1}{N_{ev}} \frac{dN_{ee}}{dm_{ee}}$ (GeV/c^2)$^{-1}$
Data / Cocktail
m_{ee} (GeV/c^2)
ALI-PREL-329646

Backup


ALICE Preliminary
70-90% Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV
1.1 < m_{ee} < 2.7 GeV/c^2
$p_{T,e}$ > 0.2 GeV/c, $|\eta_e|$ < 0.8
Data
Systematic uncertainty
Thermal (Rapp et al.)
Cocktail (HF: PYTHIA6 × N_{coll})
Photo-production (Klusek-Gawenda et al.)
Photo-production (Zhangbu et al., gEPA)
Photo-production (Zhangbu et al., QED)
Sum: Cocktail + Thermal + Photo-production (Klusek-Gawenda et al.)
Sum: Cocktail + Thermal + Photo-production (Zhangbu et al., gEPA)
Sum: Cocktail + Thermal + Photo-production (Zhangbu et al., QED)
$1/N_{ev}\ dN/dp_{T,ee}$ (GeV/c)$^{-1}$
Data - Sum
×10^{-3}
Data - Sum (Klusek-Gawenda et al.)
Data - Sum (Zhangbu et al., gEPA)
Data - Sum (Zhangbu et al., QED)
$p_{T,ee}$ (GeV/c)
ALI-PREL-326033