IS2021

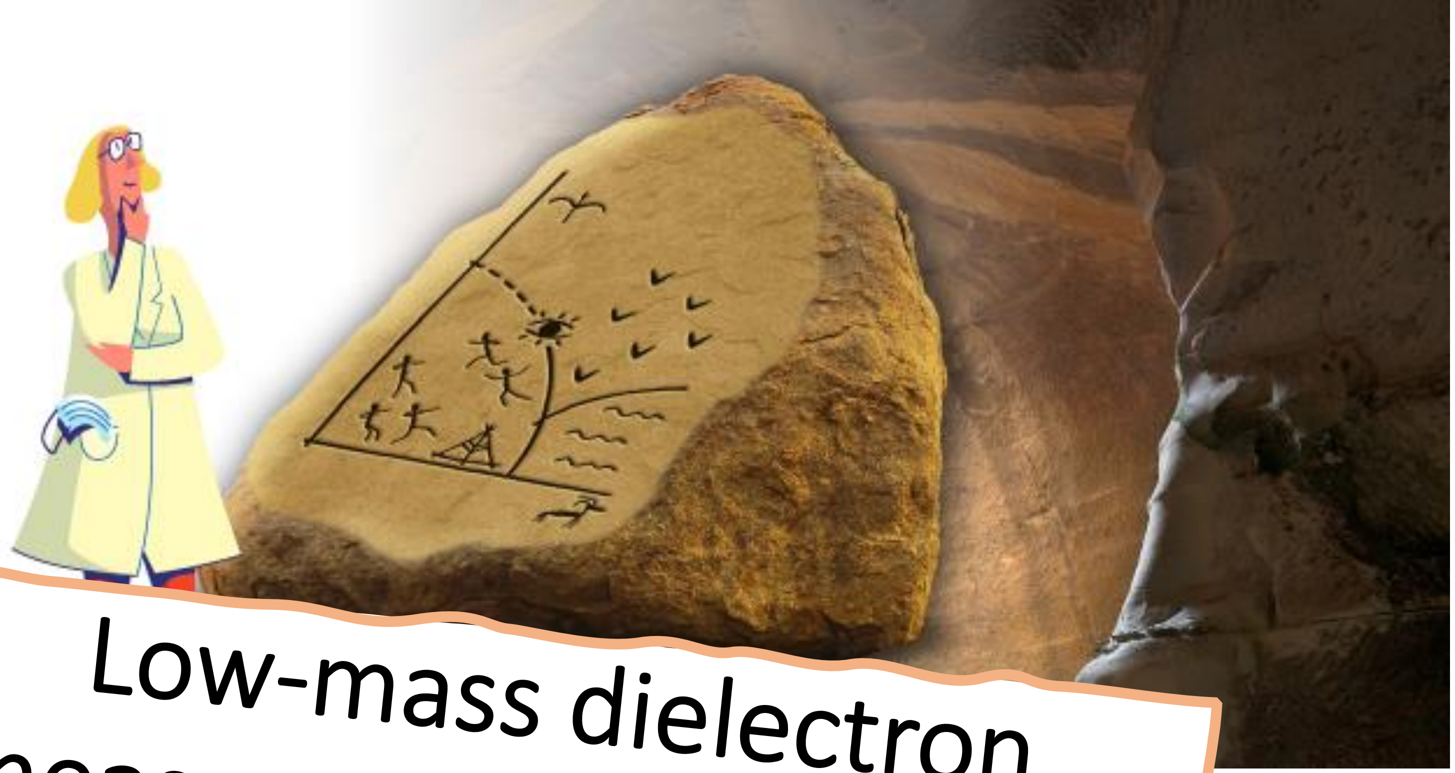
The VI[th] International Conference on the

INITIAL STAGES

OF HIGH-ENERGY NUCLEAR

COLLISIONS

13.01.2021



Low-mass dielectron measurements with ALICE at the LHC

Elisa Meninno on behalf of the ALICE Collaboration

Stefan Meyer Institute for Subatomic Physics, Vienna

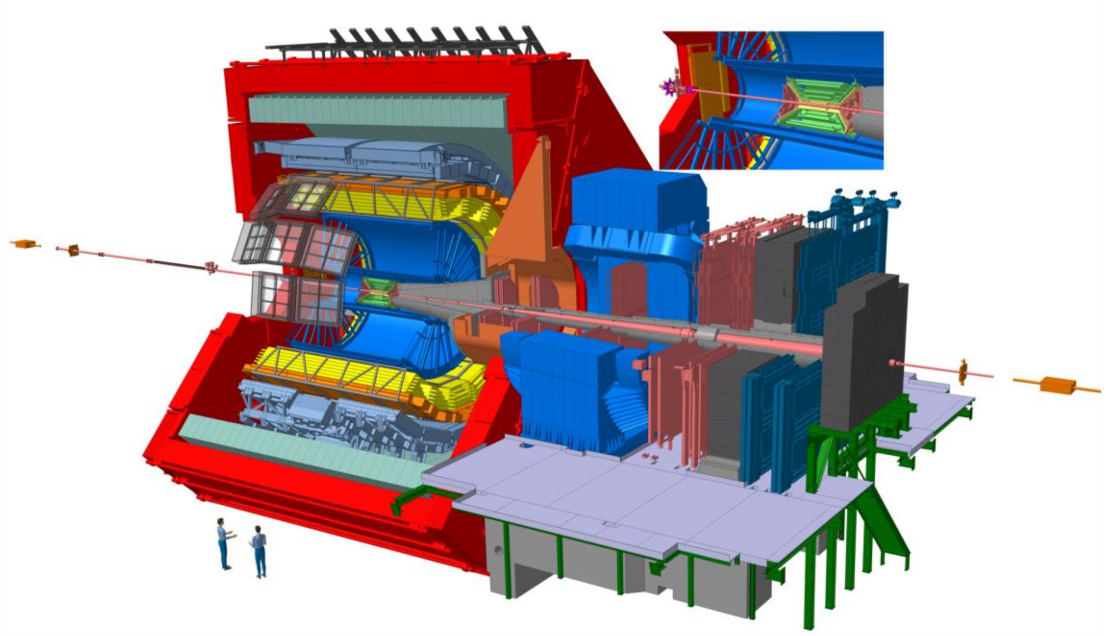
ÖAW FWF Der Wissenschaftsfonds.

Outline

- Physics motivation
- The ALICE experiment
- Low-mass dielectron analyses in ALICE
  - Studies in pp, p–Pb and Pb–Pb collisions
- Outlook

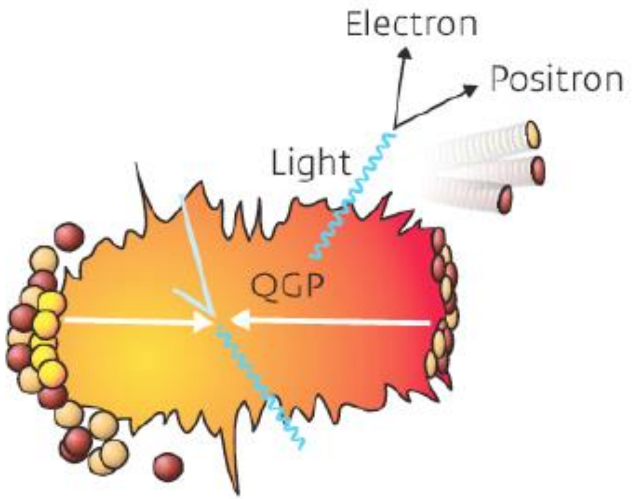
Focus on recent results with LHC Run 2 data in pp and p–Pb collisions @ $\sqrt{s}$ = 5 TeV

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



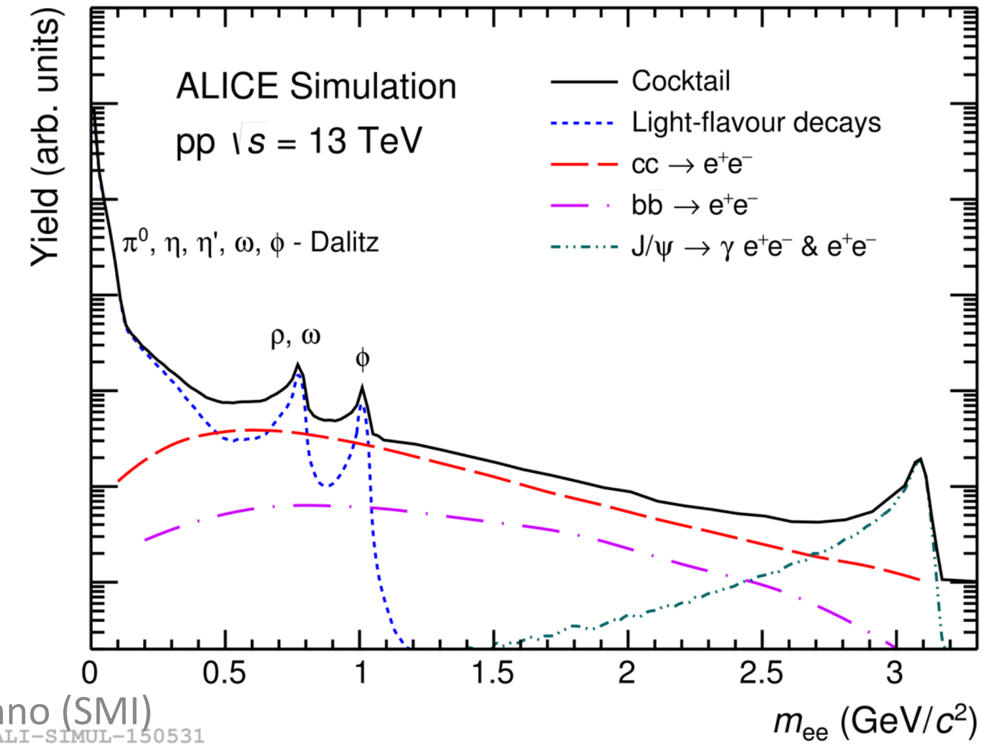
Electromagnetic probes

- Dileptons and photons experience no strong interactions, can therefore directly probe full phase extension of the collisions
  - **Penetrating probes, information from earliest stages well preserved**



- Dileptons emitted from many sources during all stages of the collisions
  - **Investigate the whole history of the medium**

- Measurements in small systems (pp and p–Pb collisions)
  - Crucial reference for Pb-Pb studies
  - Investigate possible cold nuclear matter effects



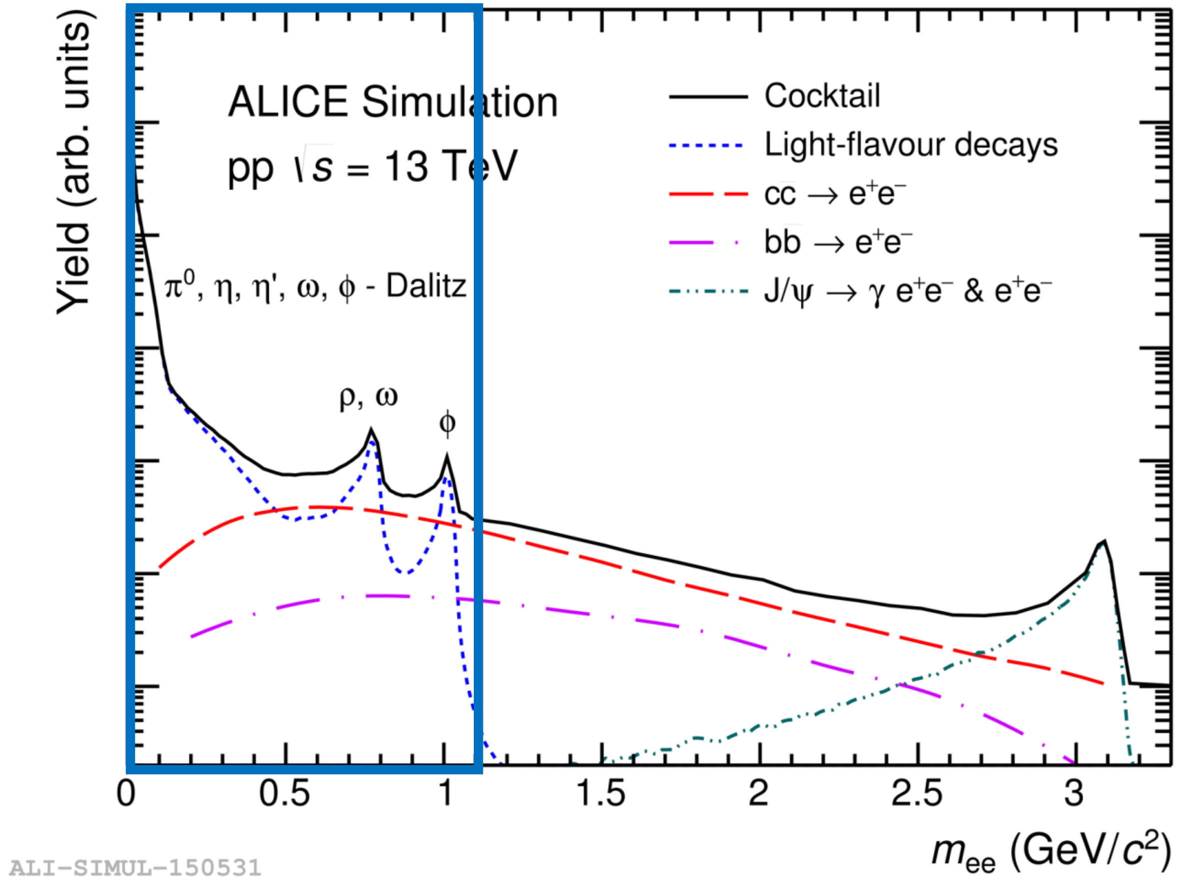
Dielectron mass spectrum

Different sources:

- Dalitz decays (π^0,η,ω,η',ϕ) and 2-body decays (ρ,ω,ϕ) of light-flavour mesons

- ρ: Sensitive to chiral symmetry restoration in the hot hadronic phase

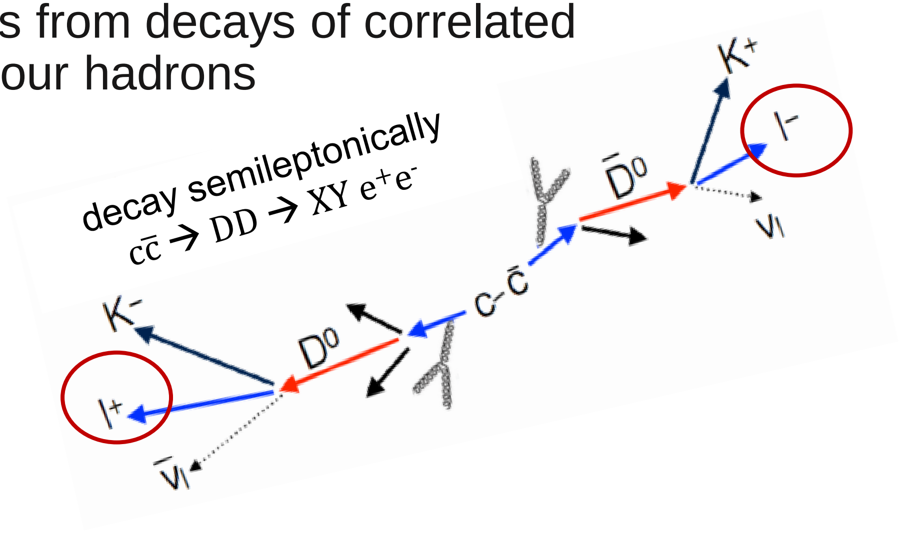
m_{ee} < 1.1 GeV/c^2



Dielectron mass spectrum

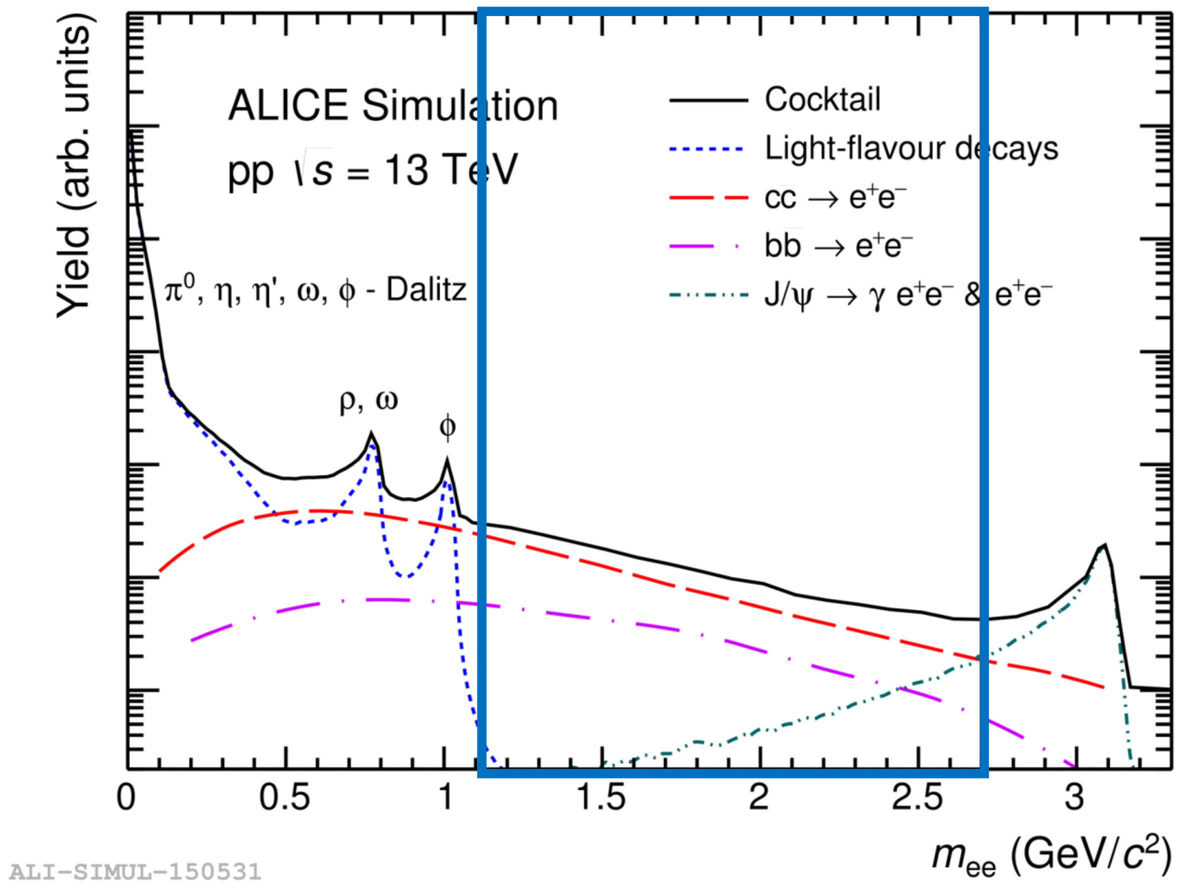
Different sources:

- Dielectrons from decays of correlated heavy-flavour hadrons



  - $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ measurements
  - Nuclear Parton Distribution Functions (nPDFs) in p–Pb and Pb–Pb collisions
  - Energy loss, partial thermalization of correlated charm and beauty quarks

$1.1 < m_{ee} < 2.7$ GeV/c^2

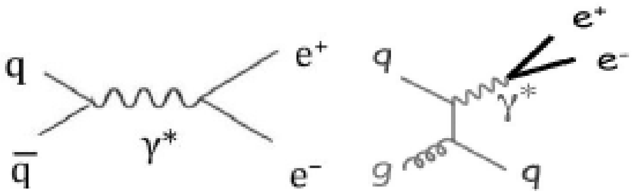


Dilepton mass spectrum

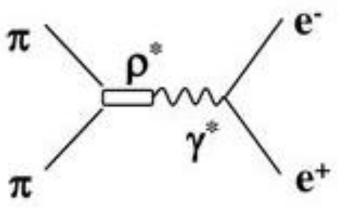
Different sources:

Thermal radiation

- Quark-gluon plasma



- Hadronic gas

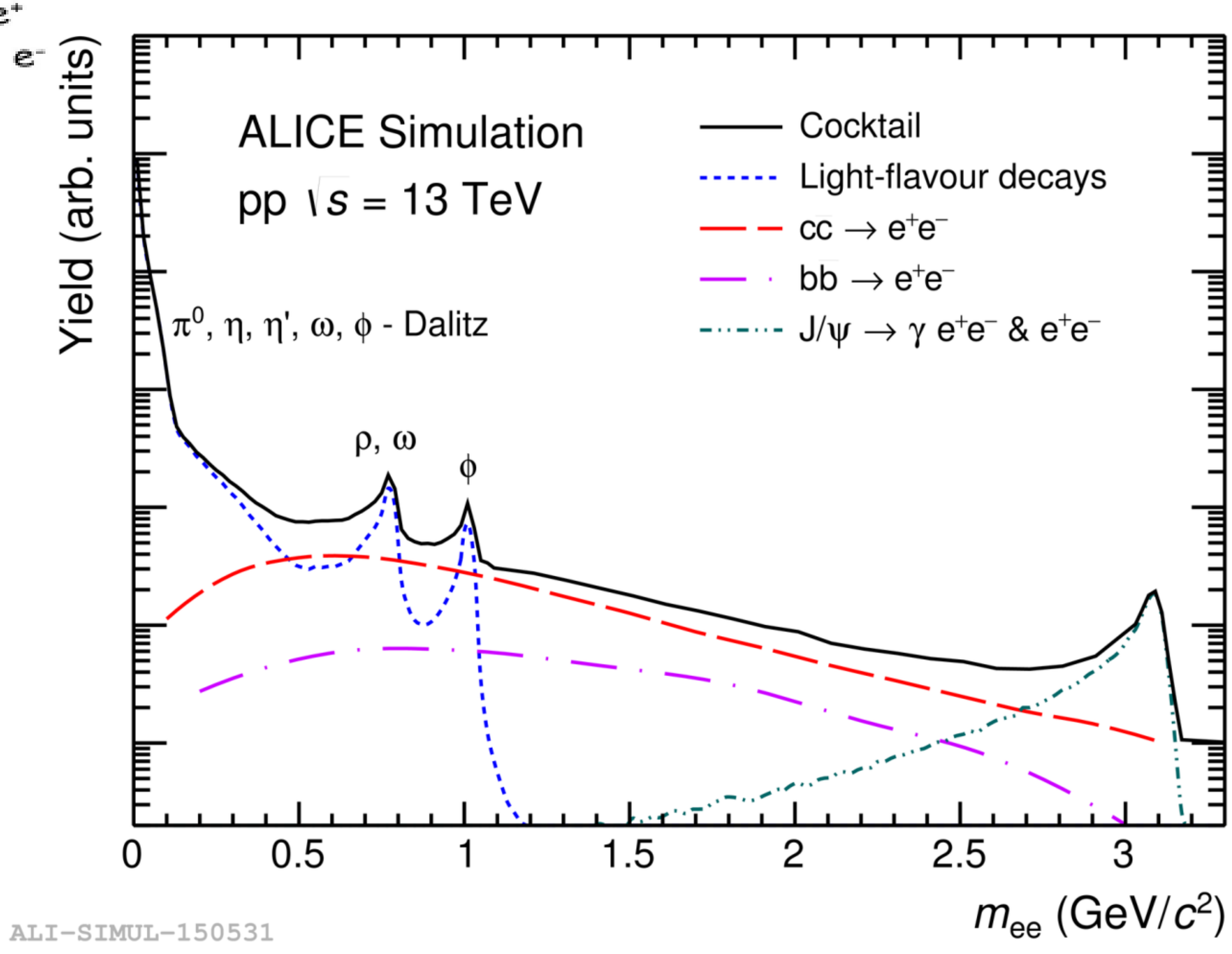


In the intermediate mass region (IMR)

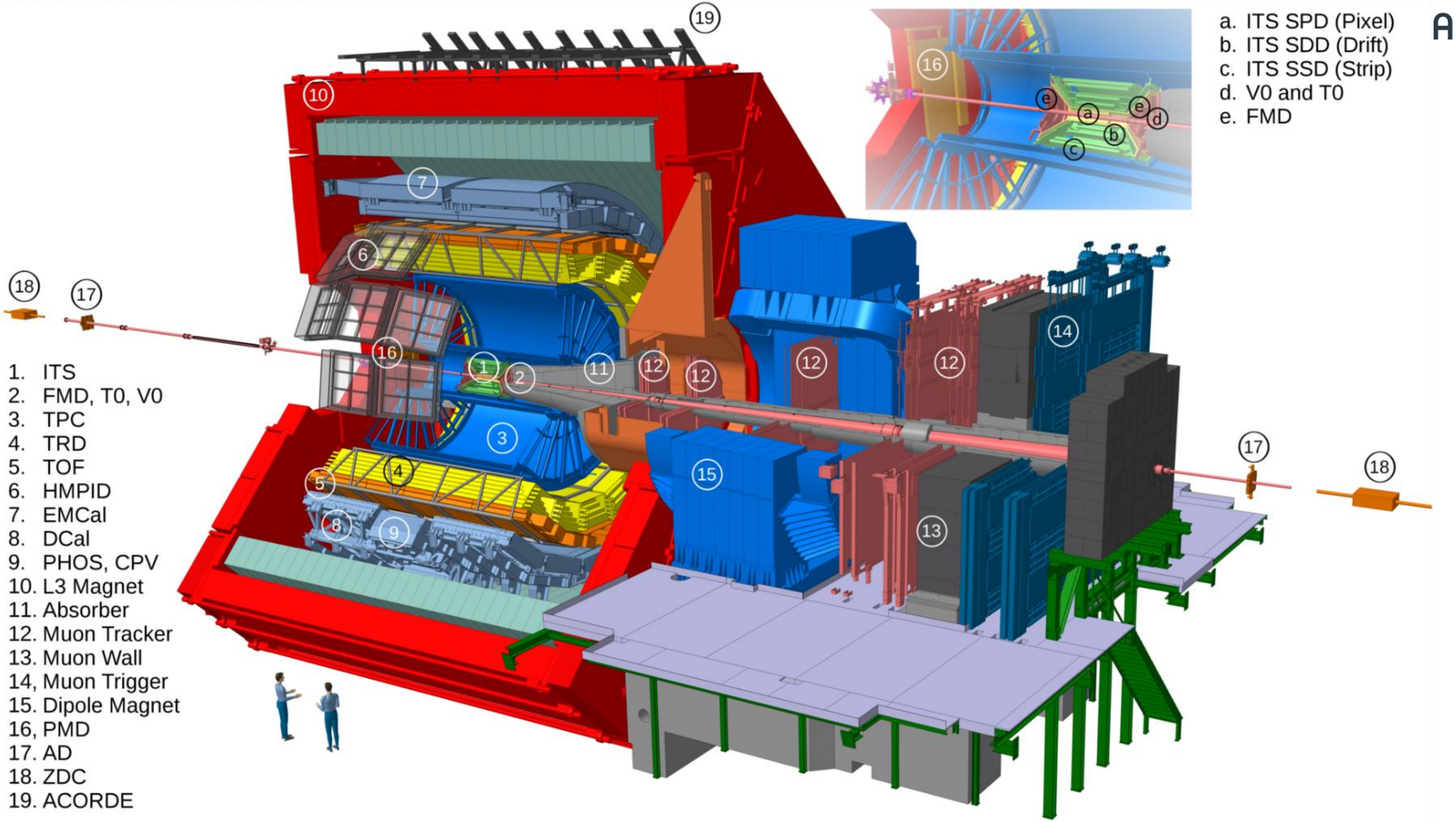
- Thermal radiation from the partonic phase

$$\frac{dN_{ee}}{dm_{ee}} \sim m_{ee}^{3/2} e^{-m_{ee}/T}$$

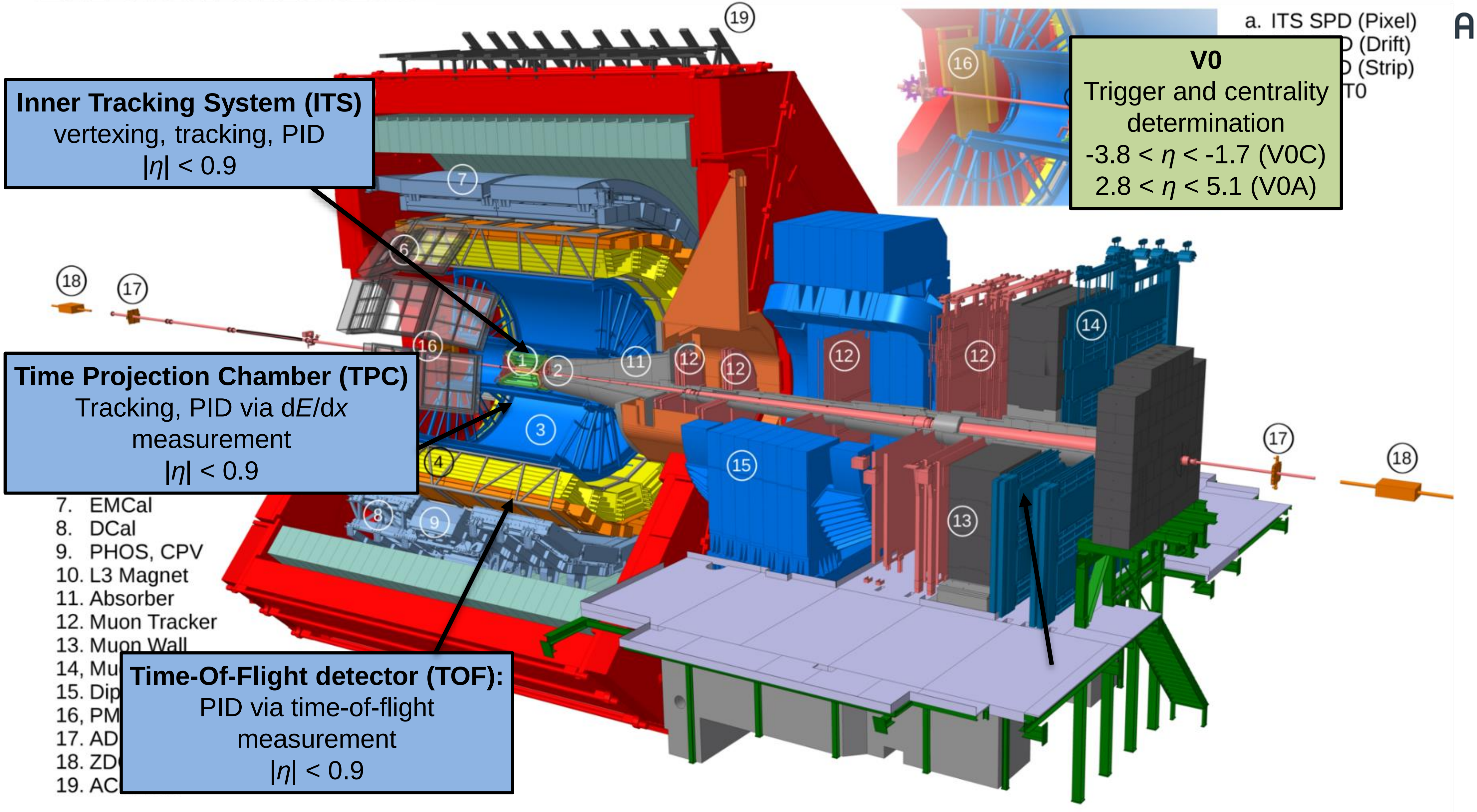
  - Challenging due to the dominant contribution from charm and beauty hadrons



The ALICE apparatus

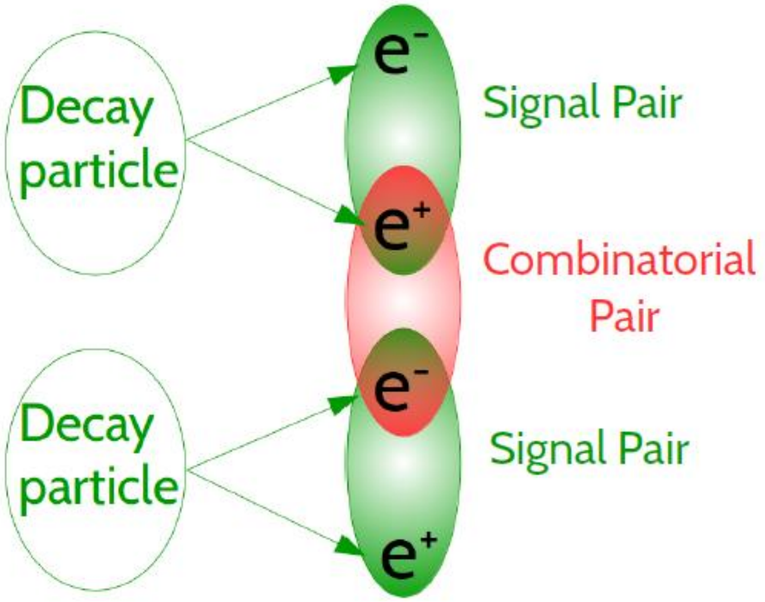


The ALICE apparatus



Obtaining the dielectron spectrum

- Track quality cuts applied to ensure only "good" quality tracks are used
- Particle identification performed
  - TPC, TOF used
- Photon conversion into dielectrons needs to be removed



- Subtract combinatorial background via like-sign subtraction:

$$LS_{all} = \boxed{R} \cdot \sqrt{N_{++} \cdot N_{--}}$$

$$US_{signal} = US_{all} - LS_{all}$$

Additional factor to account for different acceptances between ++ and – pairs

- S/B ~ 10^{-2} in pp and p–Pb collisions

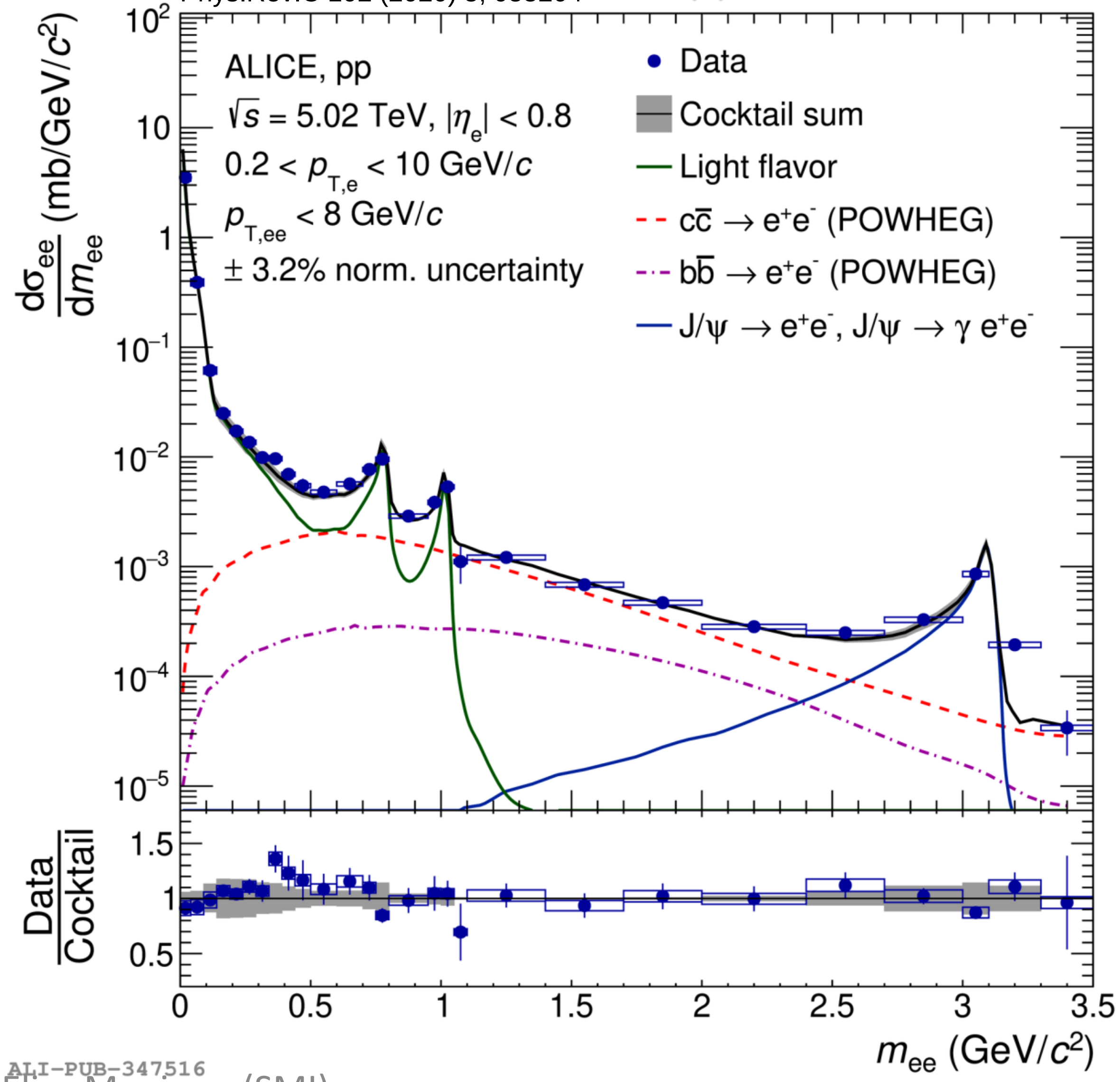
Dielectron measurements in pp collisions

- Spectrum compared with cocktail of known hadronic sources
  - **Data well described by cocktail within uncertainties**
  - Similar results in pp collisions at $\sqrt{s}$ = 7 TeV and 13 TeV

- Light flavour and J/ψ from parametrized measurements and particle ratios
- Heavy flavour from POWHEG or PYTHIA, m_{ee} and $p_{T,ee}$ shapes normalized to our own measurements of $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$

pp@$\sqrt{s}$ = 5 TeV

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

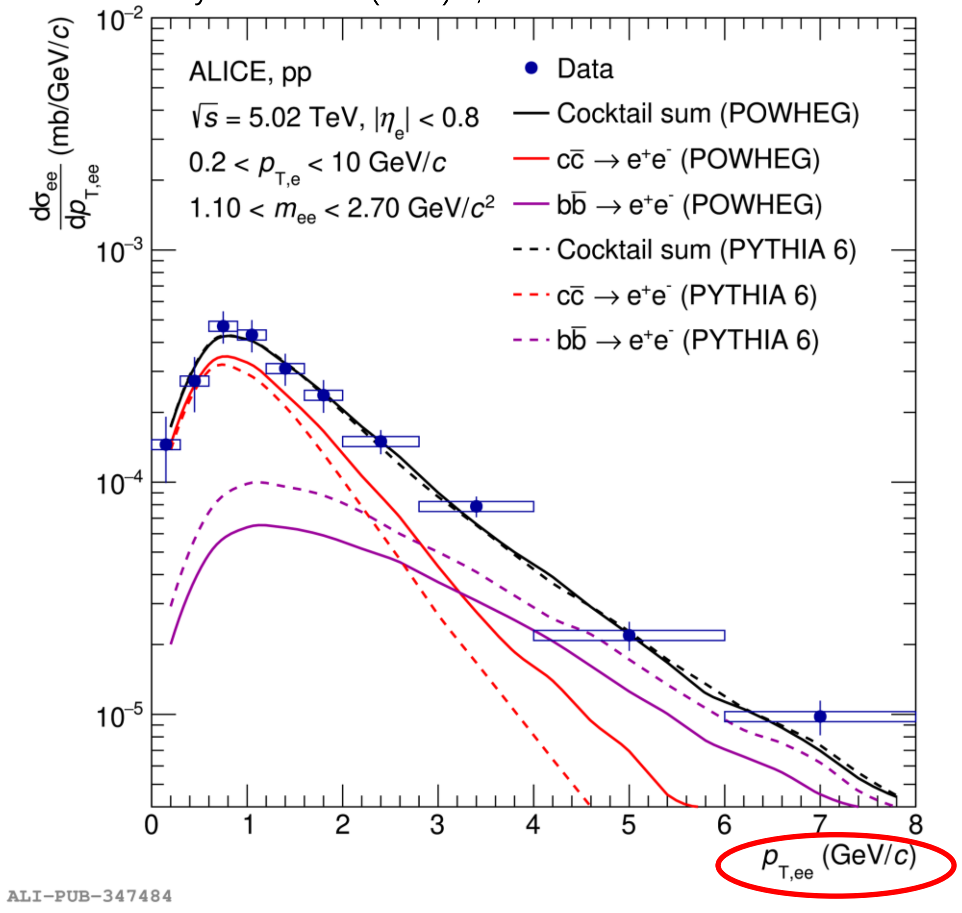


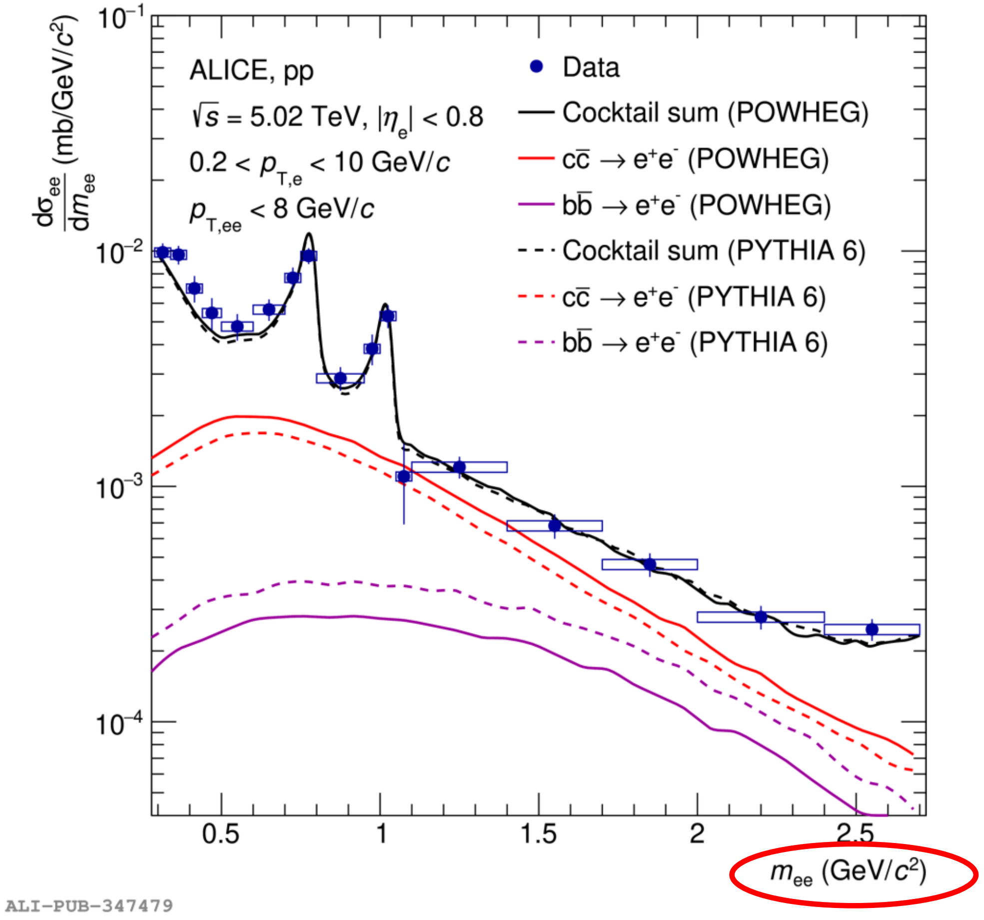
Dielectron measurements in pp collisions

- HF cross sections extracted with a 2D m_{ee} $p_{T,ee}$ fit (pp@5,7,13 TeV)

pp@$\sqrt{s}$ = 5 TeV

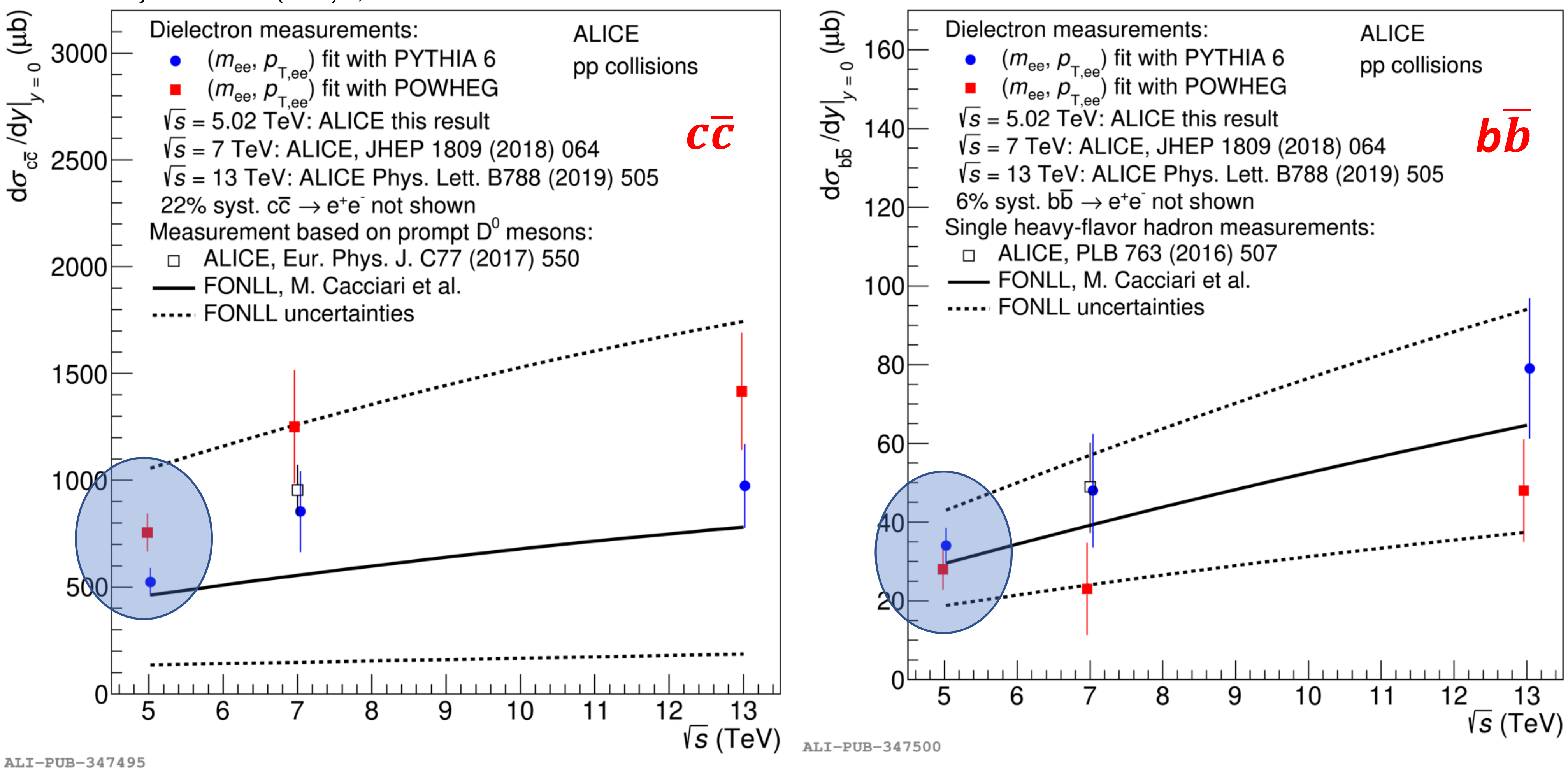
Phys.Rev.C 102 (2020) 5, 055204





Dielectron measurements in pp collisions

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



- MC (PYTHIA and POWHEG) generator dependence observed in all available energies
- Charm and beauty cross sections compatible with previous measurements of HF hadron decays

Dielectron measurements in p–Pb collisions

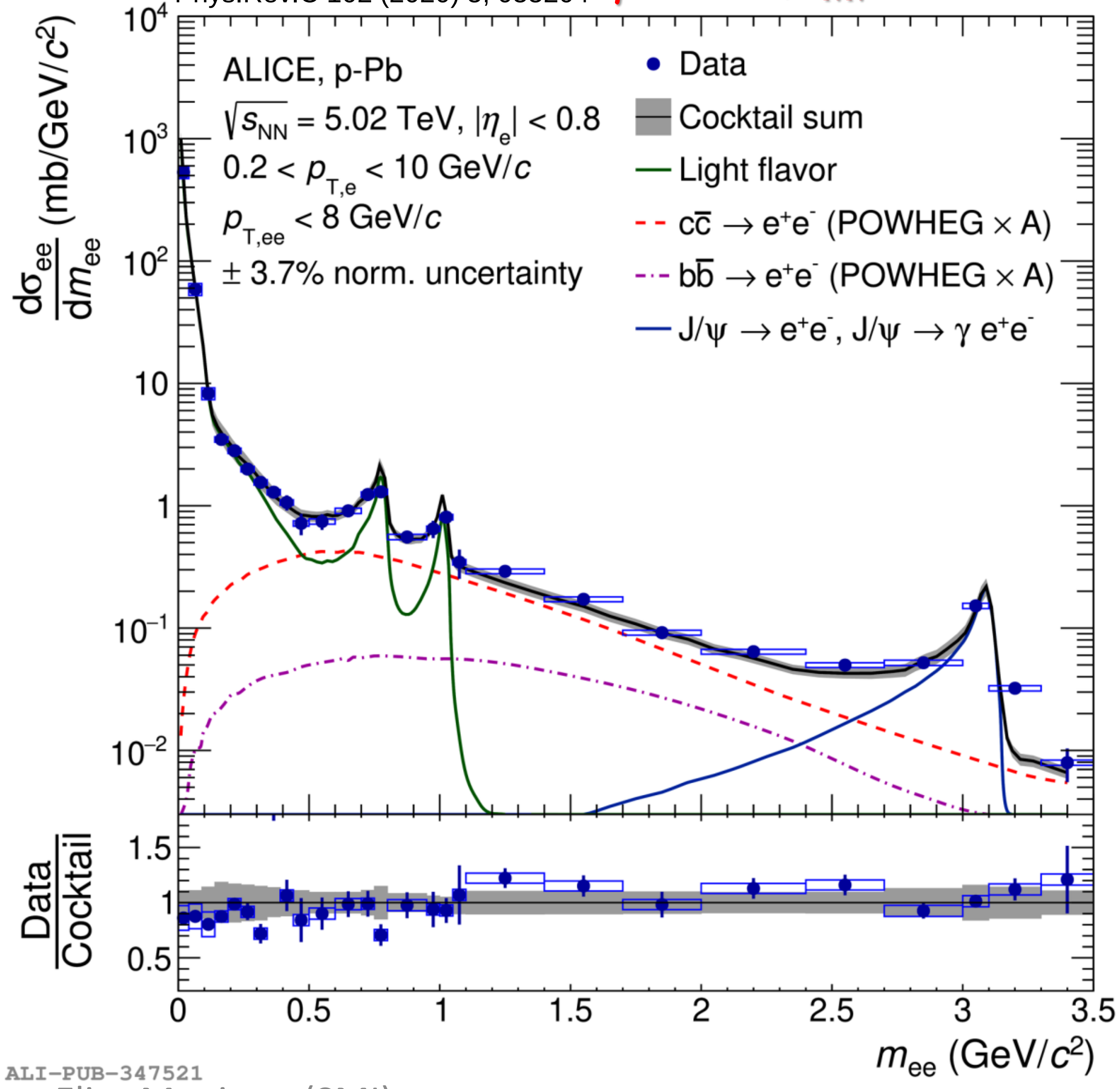
Understand modification not related to hot QCD matter

- Spectrum in good agreement with cocktail of known hadronic sources
  - Heavy flavour from PYTHIA or POWHEG based on binary NN collision scaled measured $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ in pp collisions at 5.02 TeV

- No significant deviation from vacuum expectation
  - cold nuclear matter effects seem small compared to current measurement uncertainties.

p–Pb@$\sqrt{s_{NN}}$ = 5 TeV

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



R_{pPb}

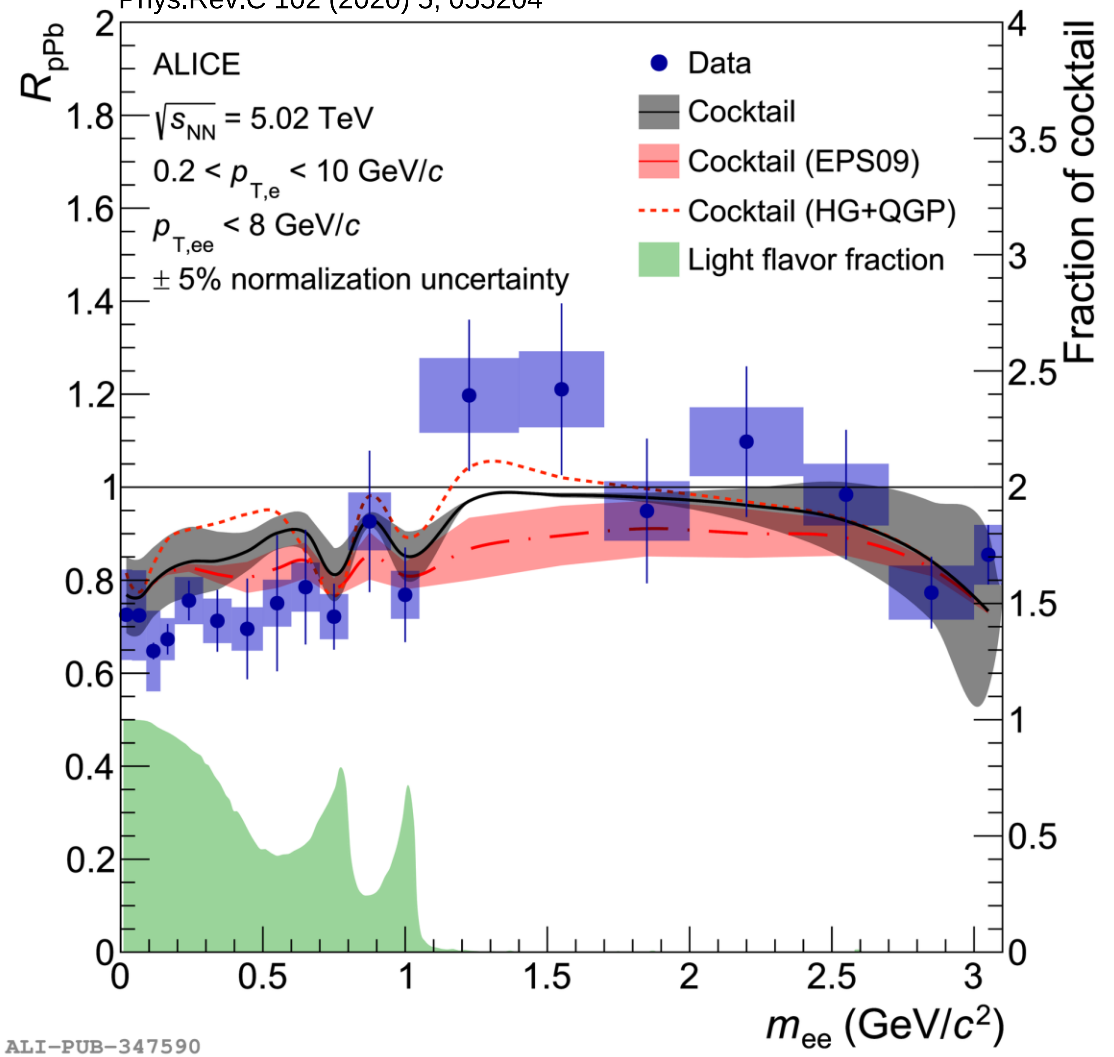
$$R_{\mathrm{pPb}} = \frac{1}{A}\frac{\mathrm{d}\sigma_{\mathrm{ee}}^{\mathrm{pPb}}/dm_{\mathrm{ee}}}{\mathrm{d}\sigma_{\mathrm{ee}}^{\mathrm{pp}}/dm_{\mathrm{ee}}}$$

- Comparison to models including only scaling effects or nuclear shadowing (EPS09):
  - Data compatible with both models within uncertainties
  - EPS09 seem disfavored in IMR

- Thermal radiation can not be excluded by the data.
  - Important to separate dielectrons from HF and from thermal radiation

Thermal radiation in small systems?

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

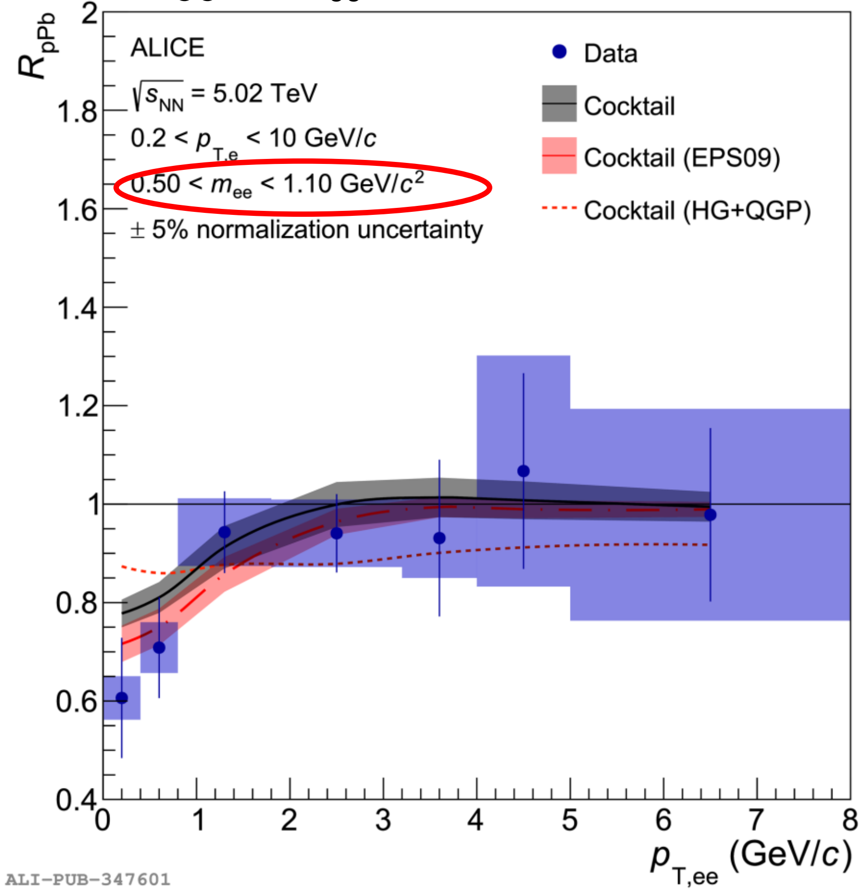


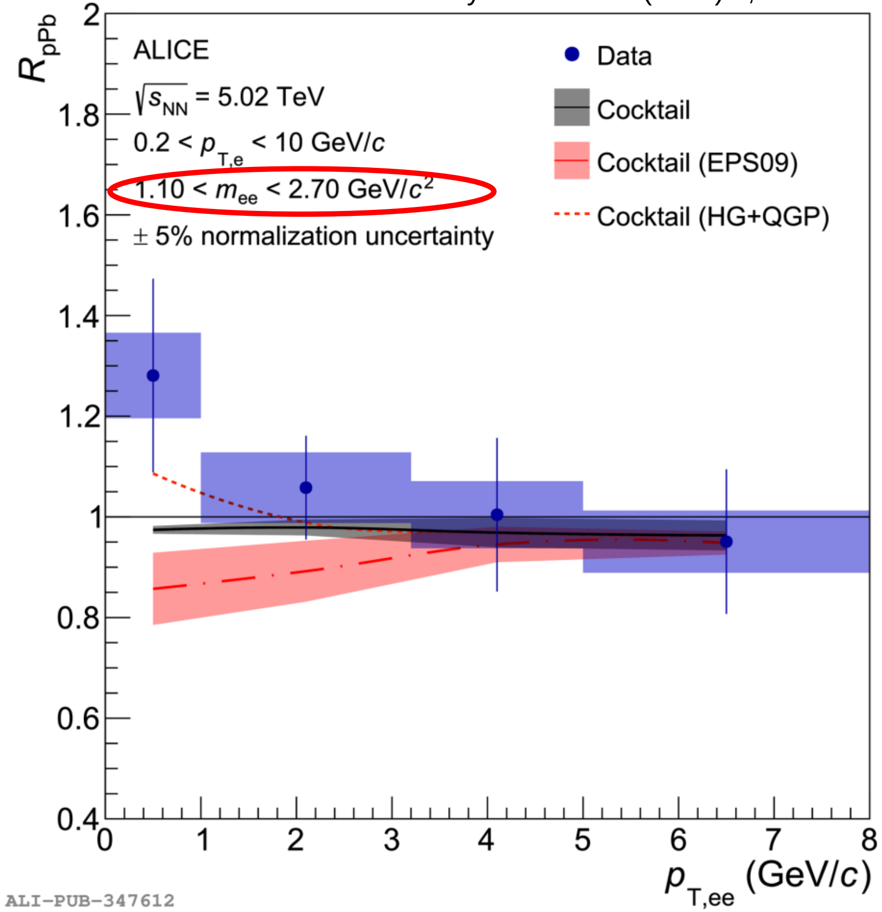
Thermal radiation model by R. Rapp:
Physics Letters B473no. 1, (2000) 13 – 19

R_{pPb}

$$R_{\mathrm{pPb}} = \frac{1}{A}\frac{\mathrm{d}\sigma^{\mathrm{pPb}}_{\mathrm{ee}}/dm_{\mathrm{ee}}}{\mathrm{d}\sigma^{\mathrm{pp}}_{\mathrm{ee}}/dm_{\mathrm{ee}}}$$

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





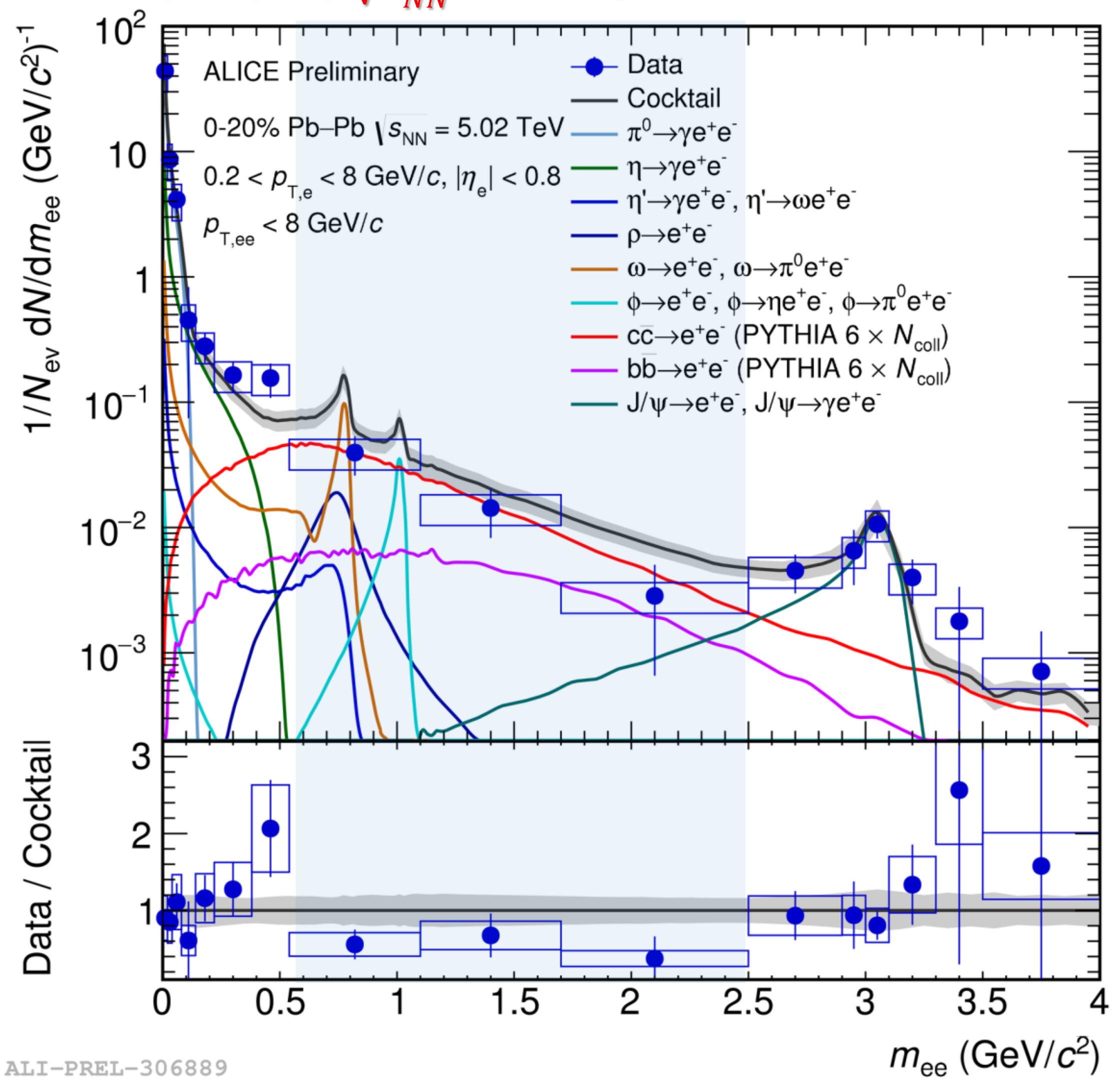
- Above 1 GeV/c LF sources scale with binary NN collisions
- Deviation from unity for $p_{\mathrm{T,ee}}$ < 1 GeV/c
  - Can be described by hadronic cocktail

- Compatible with unity in the IMR
  - EPS09 parametrization disfavored by data

Measurements in Pb–Pb

- HF: PYTHIA6 binary NN collision scaling
- Deviation from cocktail for m_{ee} in **0.5 – 2.5** GeV/c^2
  - Suppression observed in HF region

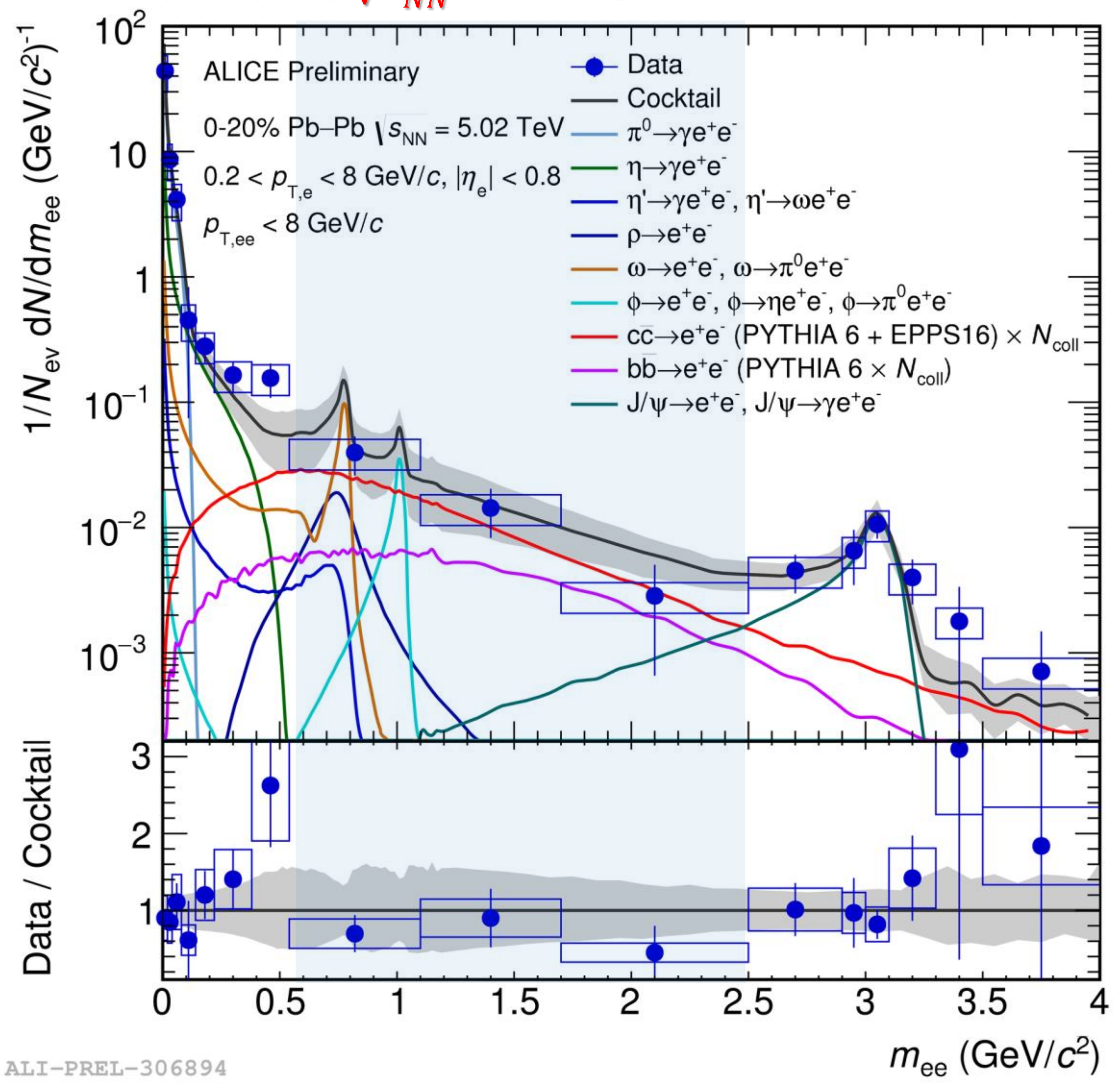
Pb–Pb@$\sqrt{s_{NN}}$ = 5 TeV central collisions



Measurements in Pb–Pb

- HF: PYTHIA6 binary NN collision scaling
- Deviation from cocktail for m_{ee} in **0.5 – 2.5** GeV/c^2
  - Suppression observed in HF region
- Discrepancy reduced when nPDF included

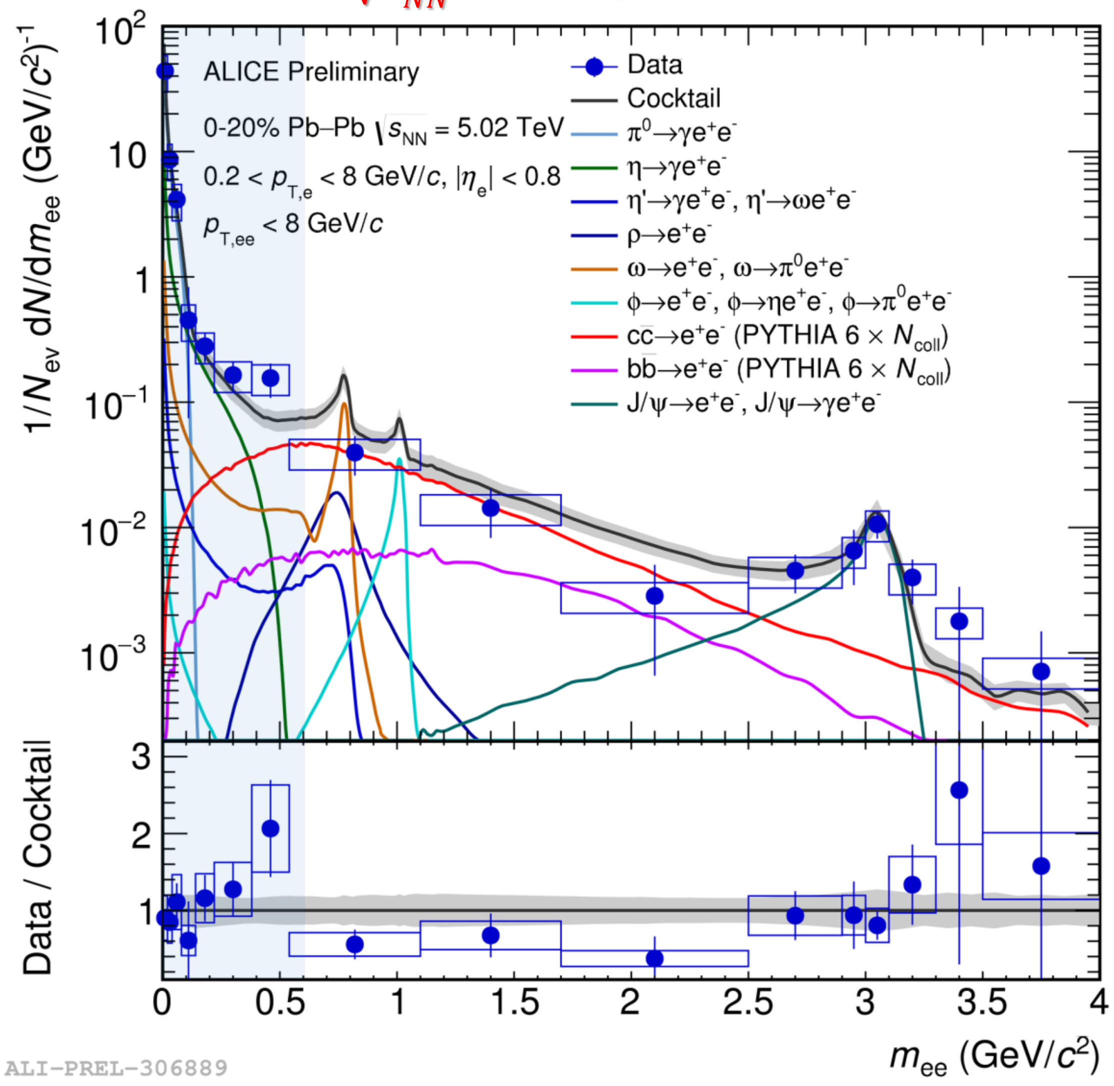
Pb–Pb@$\sqrt{s_{NN}}$ = 5 TeV central collisions



Measurements in Pb–Pb

- HF: PYTHIA6 binary NN collision scaling
- Deviation from cocktail for m_{ee} in **0.5 – 2.5** GeV/c^2
  - Suppression observed in HF region
- Discrepancy reduced when nPDF included
- Hint for enhancement at **low m_{ee}**?

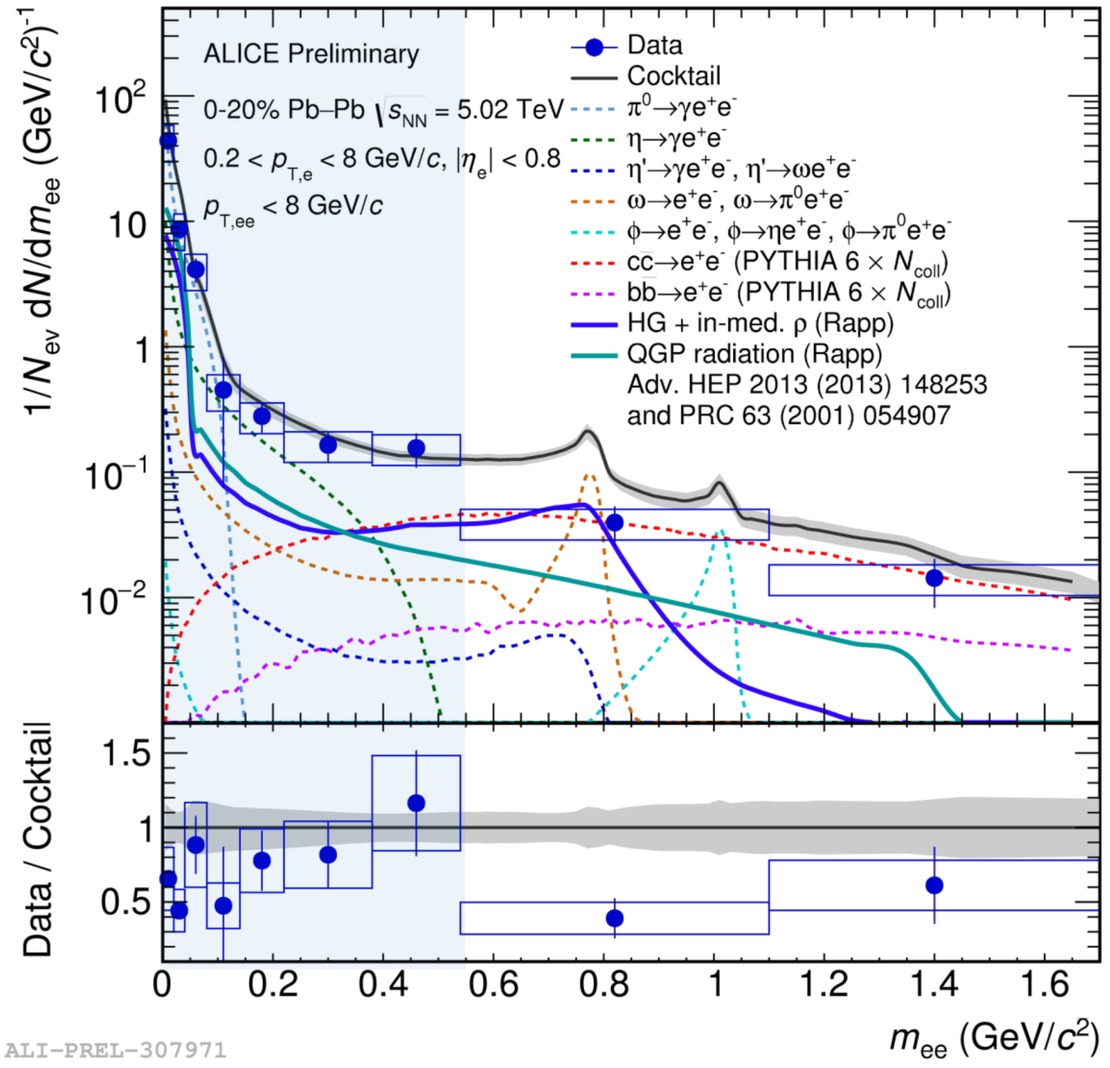
Pb–Pb@$\sqrt{s_{NN}}$ = 5 TeV central collisions



Measurements in Pb–Pb

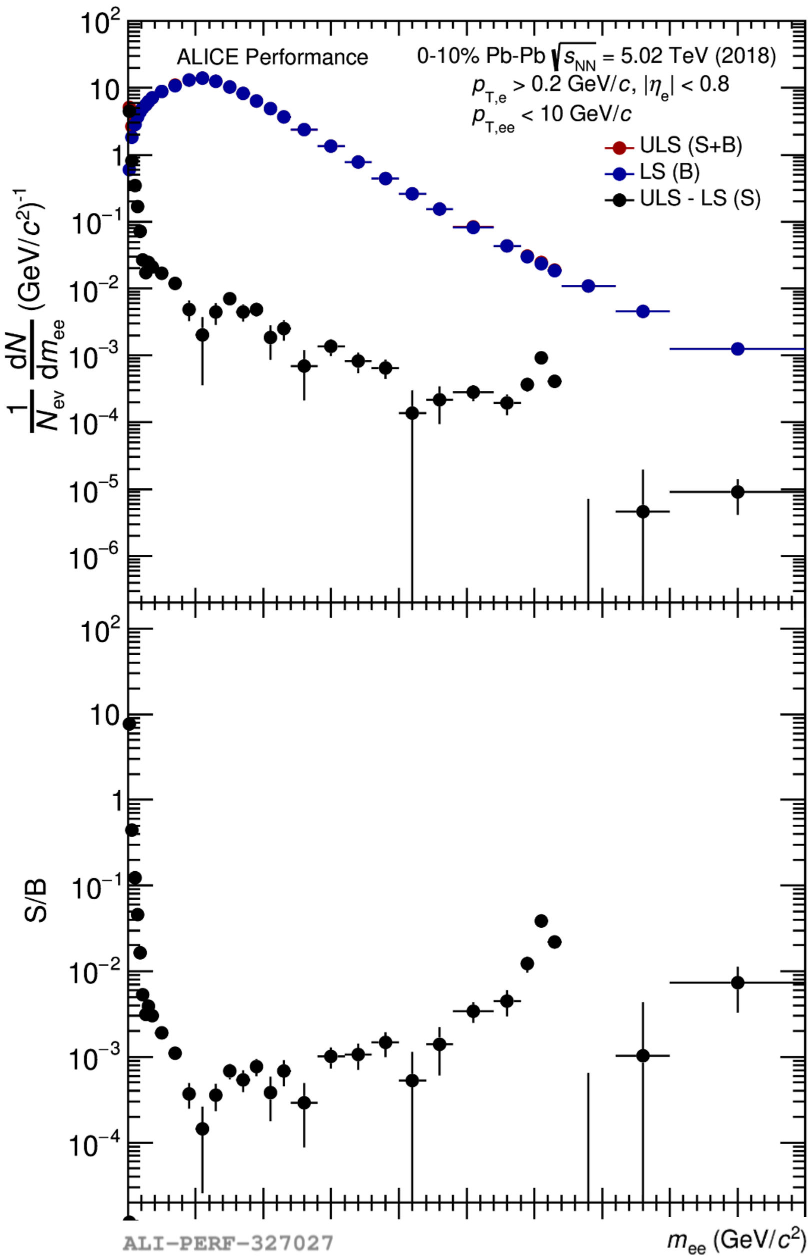
- HF: PYTHIA6 binary NN collision scaling
- Deviation from cocktail for m_{ee} in **0.5 – 2.5** GeV/c^2
  - Suppression observed in HF region
- Discrepancy reduced when nPDF included
- Hint for enhancement at **low** $\boldsymbol{m_{ee}}$?
  - Compatible with thermal radiation models

Pb–Pb@$\sqrt{s_{NN}}$ = 5 TeV central collisions



First studies in 2018 Pb-Pb collisions

- Ongoing studies look very promising!
- Higher statistics (9 times more data in 0-10% centrality) reduce statistical fluctuations, mainly in the low-mass region

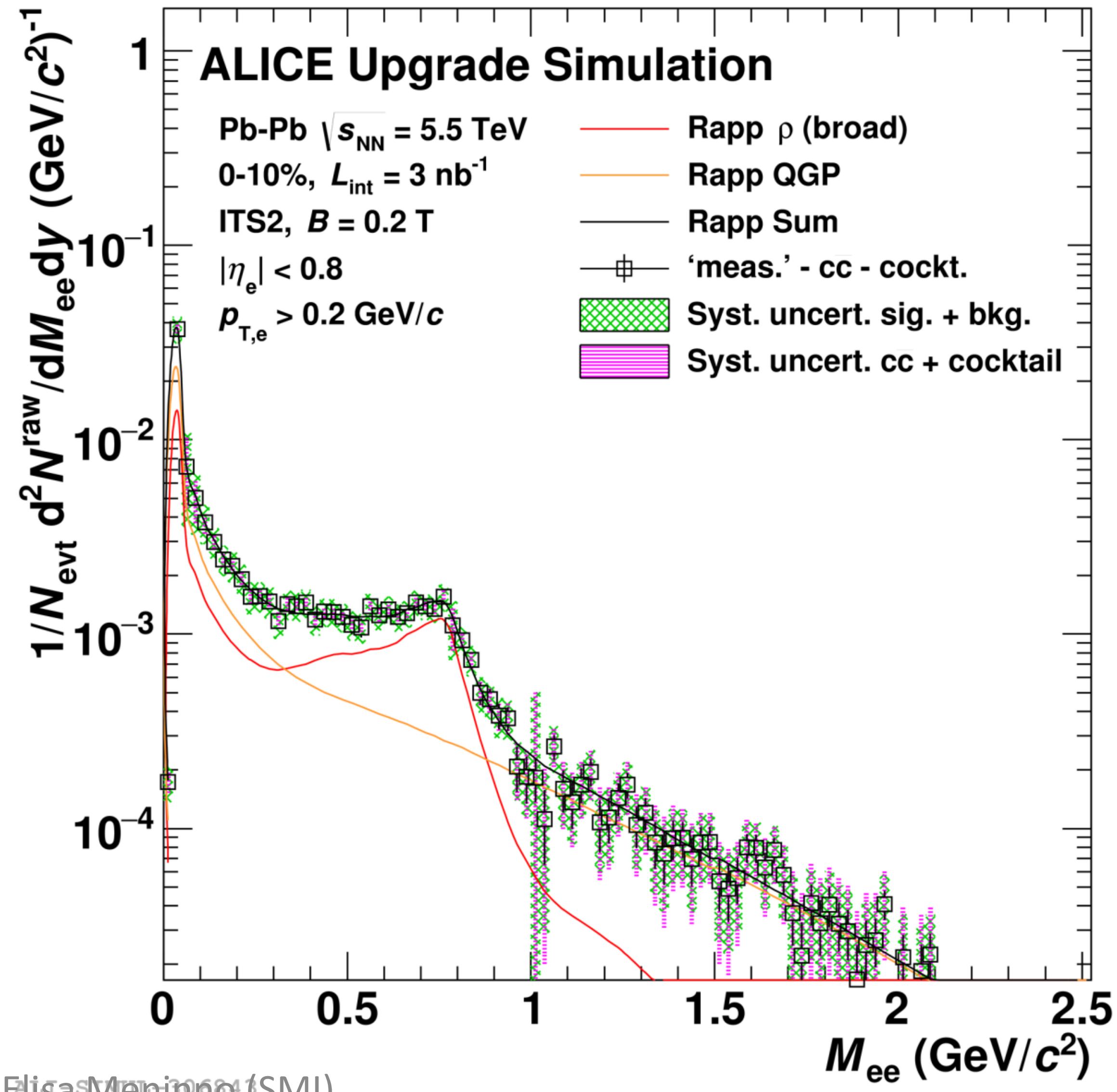


Future dielectron measurements

Upgrade of ITS and TPC:

- improved vertex resolution, reduced material budget, 50 times higher acquisition rate
  - Better separation of prompt sources (thermal radiation) from HF electrons, via DCA studies
  - Sensitivity to in-medium modified ρ spectral function

CERN-LPCC-2018-07 (arXiv:1812.06772)



Summary

Dielectron measurements in pp, p–Pb and Pb–Pb collisions

pp

- Measurement of charm and beauty cross sections
- Model dependence of heavy-flavour production

p–Pb

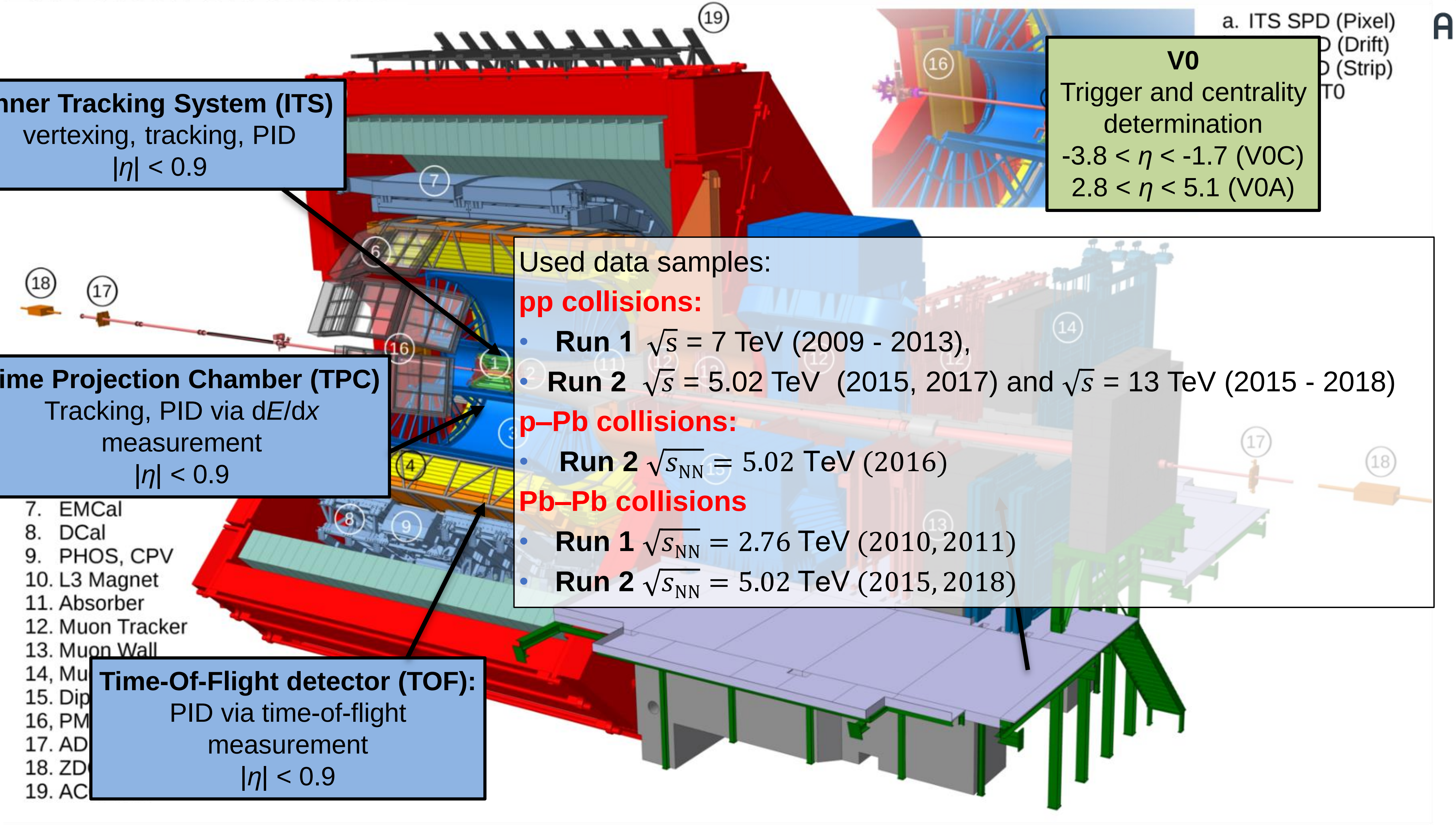
- No significant modification of heavy-flavour production in IMR, hint of $R_{\mathrm{pPb}} < 1$ for smaller masses
- Important to separate thermal radiation and HF in the IMR

Pb–Pb

- Possible excess from thermal radiation ~ 0.5 GeV/c^2 ?
- Suppression of heavy flavour from final state effects
- Very promising first studies in 2018 Pb-Pb collisions

Backup

The ALICE apparatus



Inner Tracking System (ITS)
vertexing, tracking, PID
$|\eta| < 0.9$

Time Projection Chamber (TPC)
Tracking, PID via dE/dx measurement
$|\eta| < 0.9$

Time-Of-Flight detector (TOF):
PID via time-of-flight measurement
$|\eta| < 0.9$

V0
Trigger and centrality determination
$-3.8 < \eta < -1.7$ (V0C)
$2.8 < \eta < 5.1$ (V0A)

Used data samples:

pp collisions:

- **Run 1** $\sqrt{s}$ = 7 TeV (2009 - 2013),
- **Run 2** $\sqrt{s}$ = 5.02 TeV (2015, 2017) and $\sqrt{s}$ = 13 TeV (2015 - 2018)

p–Pb collisions:

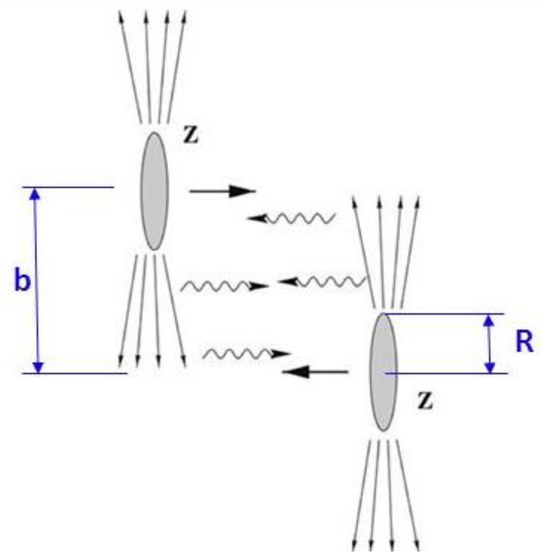
- **Run 2** $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV (2016)

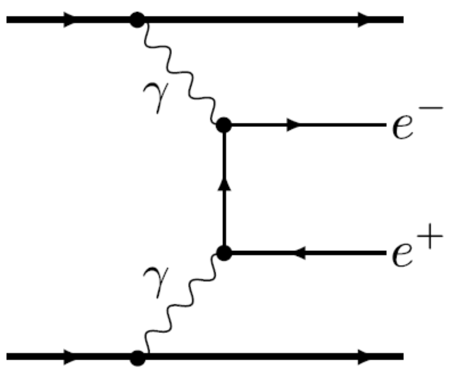
Pb–Pb collisions

- **Run 1** $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV (2010, 2011)
- **Run 2** $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV (2015, 2018)

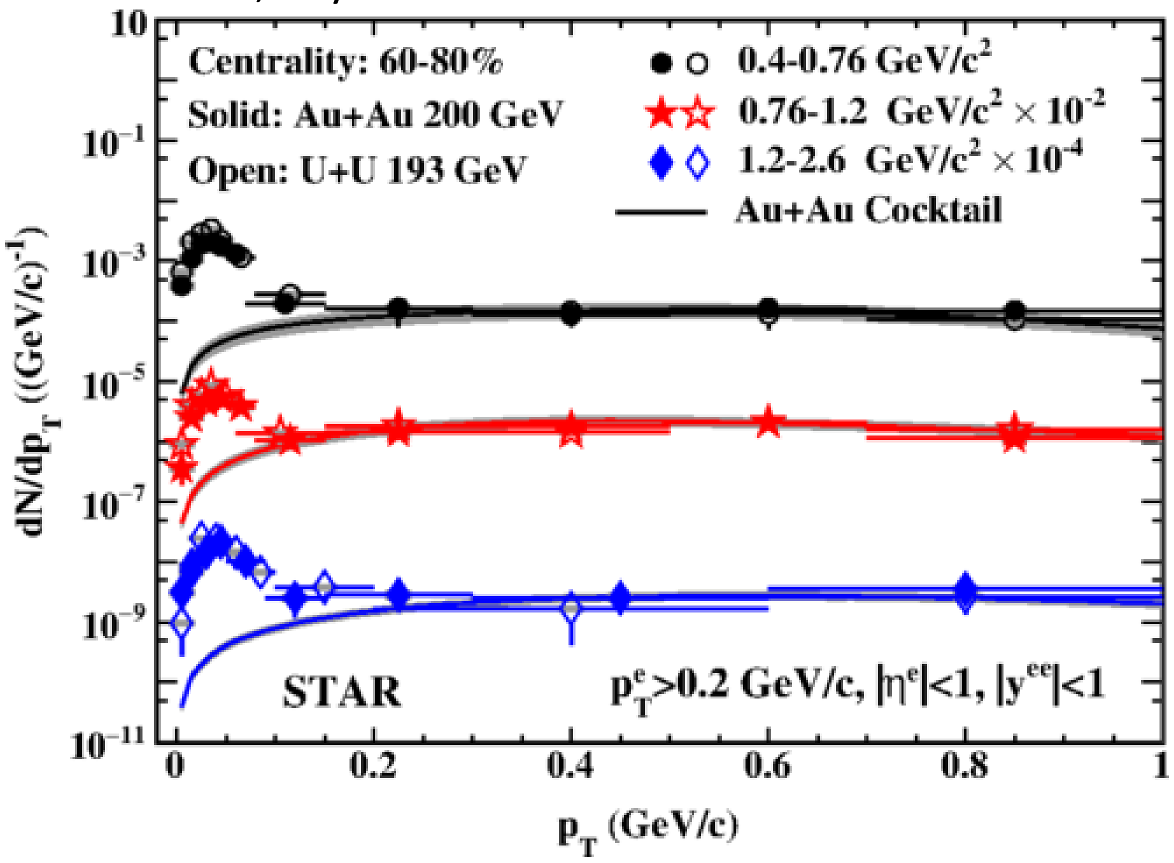
Dilepton photo production

- Photo-Production





STAR, Phys. Rev. Lett. 121. 132301



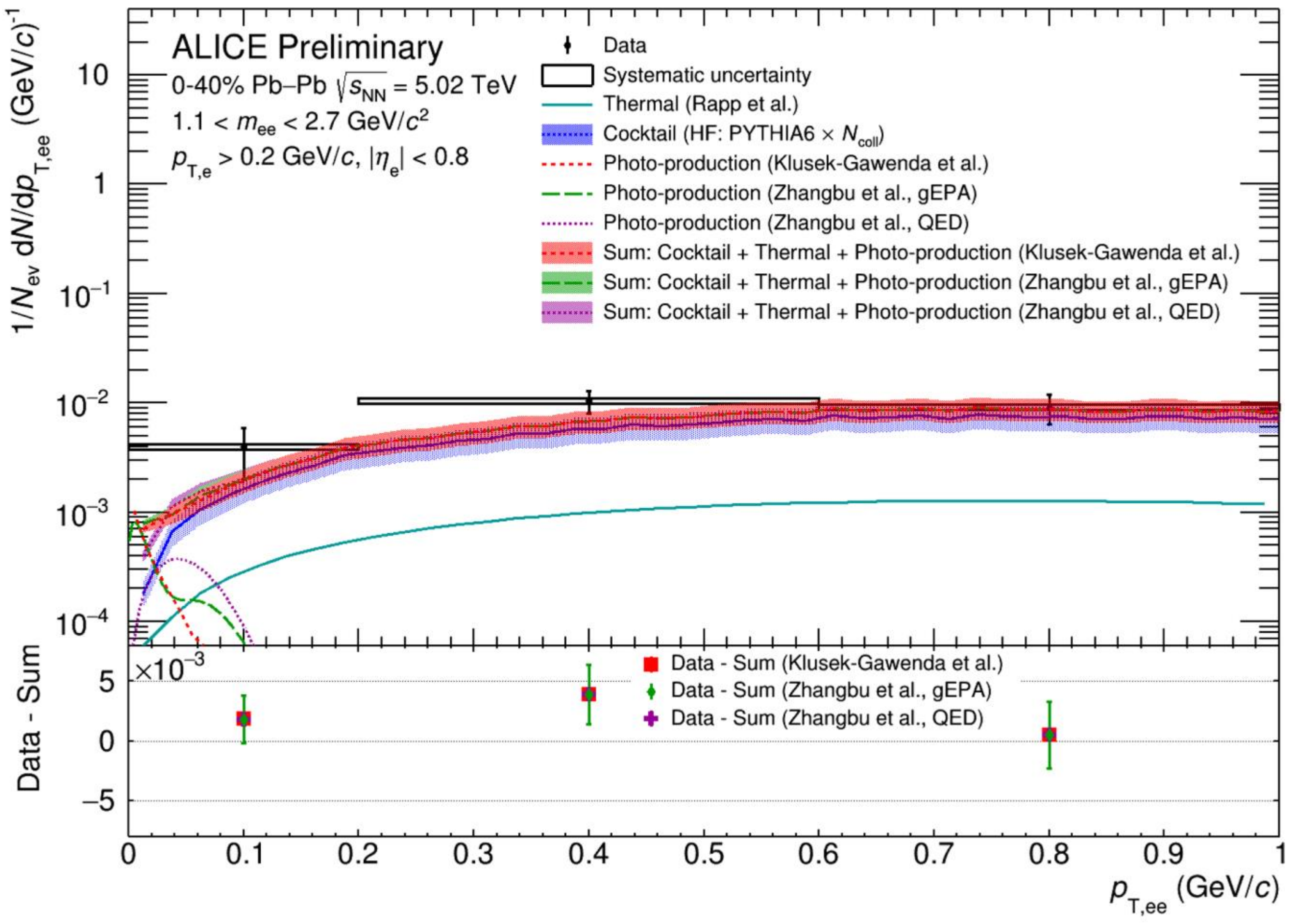
- Excess with respect to hadronic and thermal sources in peripheral collisions
  - Compatible with calculations for dielectron production from coherent photon-photon interactions

Low p_T analysis in Pb–Pb

Photo-Production in Pb-Pb

- Analysis performed in the mass range dominated by HF, $1.1 < m_{ee} < 2.7$ GeV/c^2

Pb–Pb@$\sqrt{s_{NN}}$ = 5 TeV



- No significant discrepancy observed in **0-40% centrality**

Low p_T analysis in Pb–Pb

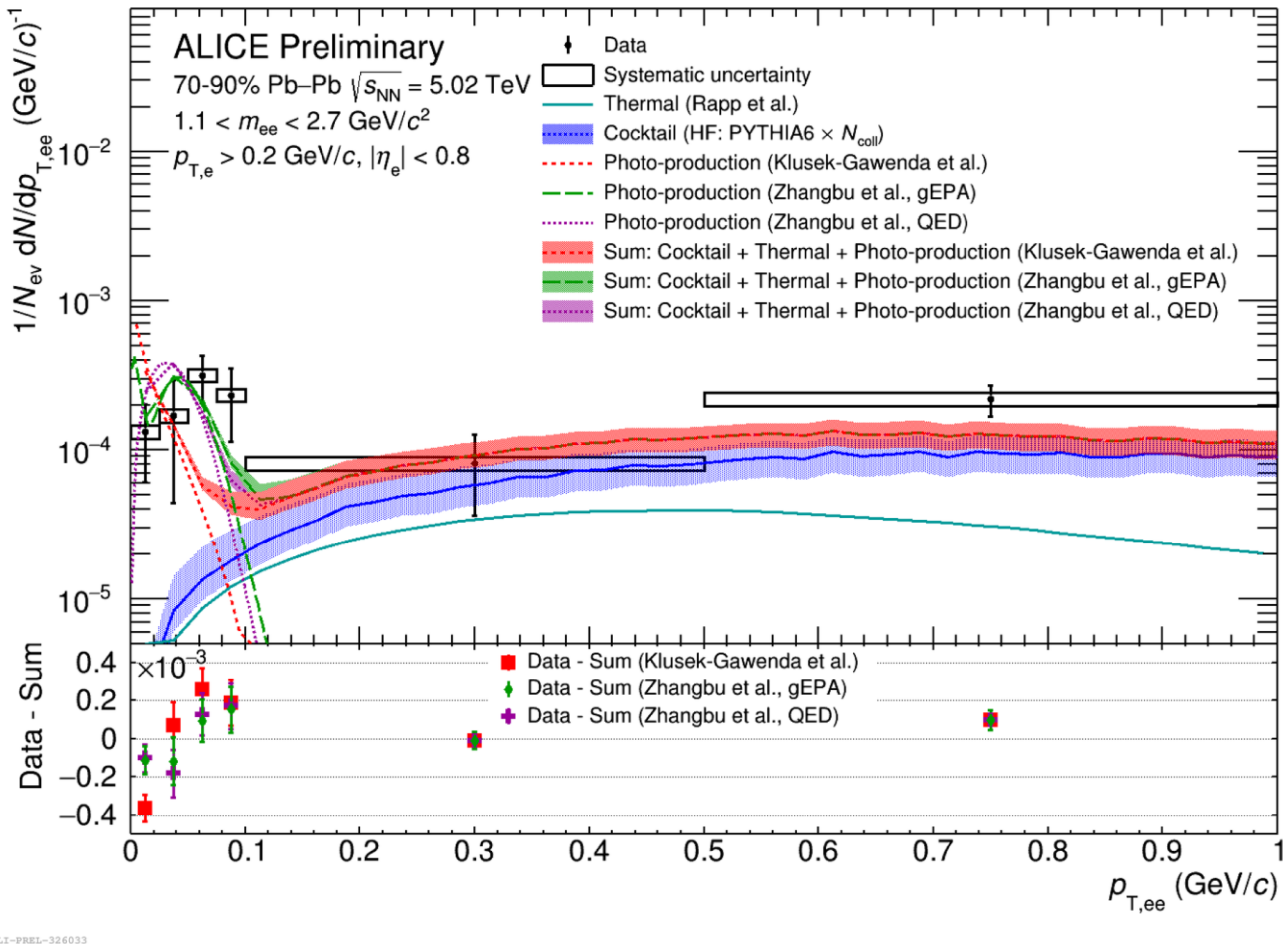
ALICE

Photo-Production in Pb-Pb

- Analysis performed in the mass range dominated by HF, $1.1 < m_{ee} < 2.7$ GeV/c^2

- Centrality class **70-90%** more sensitive to the photo-production than 0-40%
  - Excess w.r.t. cocktail and thermal sources at $p_{T,ee} < 0.1$ GeV/c
  - Compatible with photo-production models
  - Excess observed at the same $p_{T,ee}$ range as at STAR STAR, Phys. Rev. Lett. 121. 132301

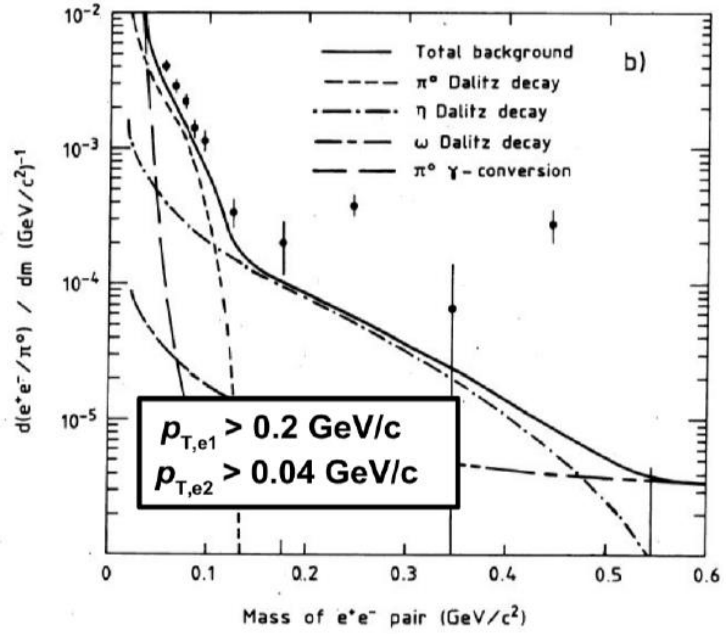
Pb–Pb@$\sqrt{s_{NN}}$ = 5 TeV



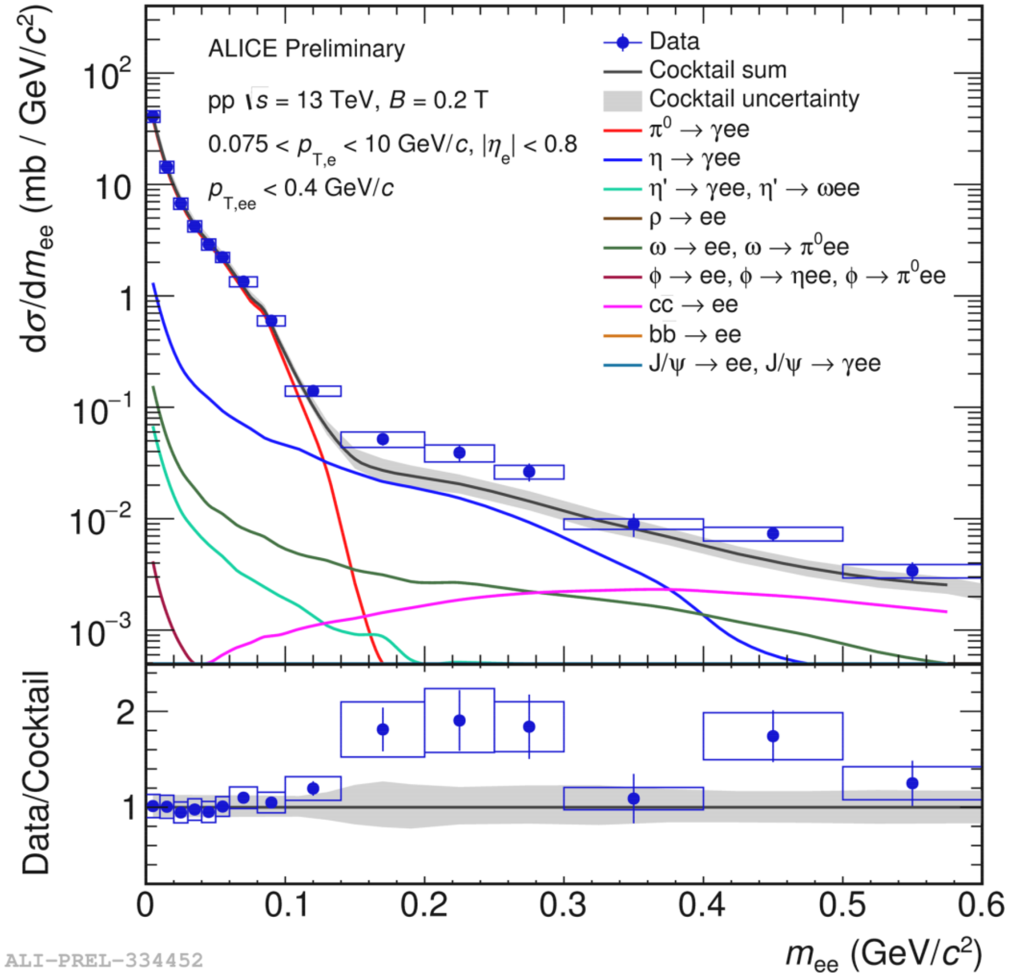
Outlook:
2018 data: **2 times more statistics** in 70-90% centrality!

Soft dielectrons in in pp 13 TeV

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



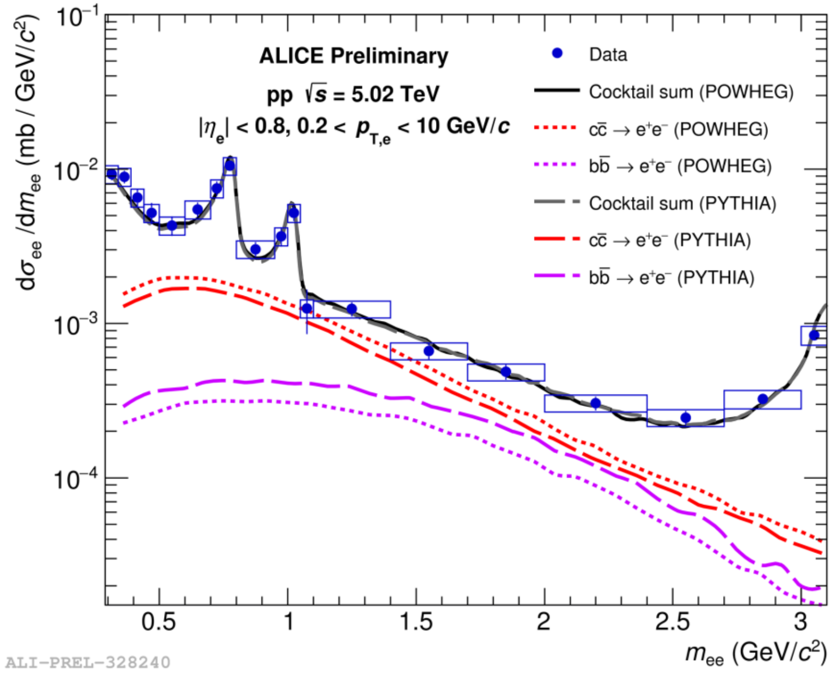
pp@√s = 13 TeV

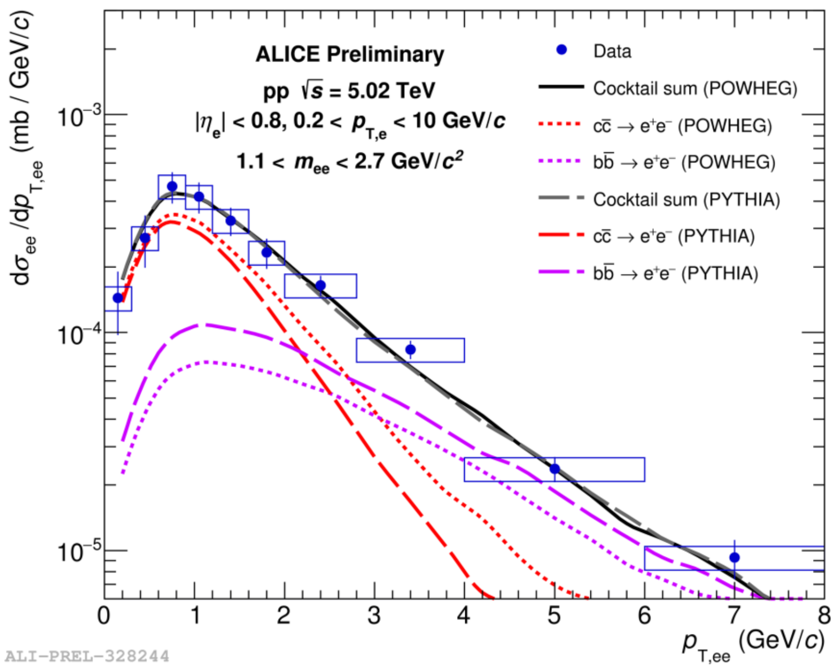


- Low-mass region (LMR) excess:
- Not explainable with contribution of known hadronic decays

Dielectron measurements in pp collisions

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





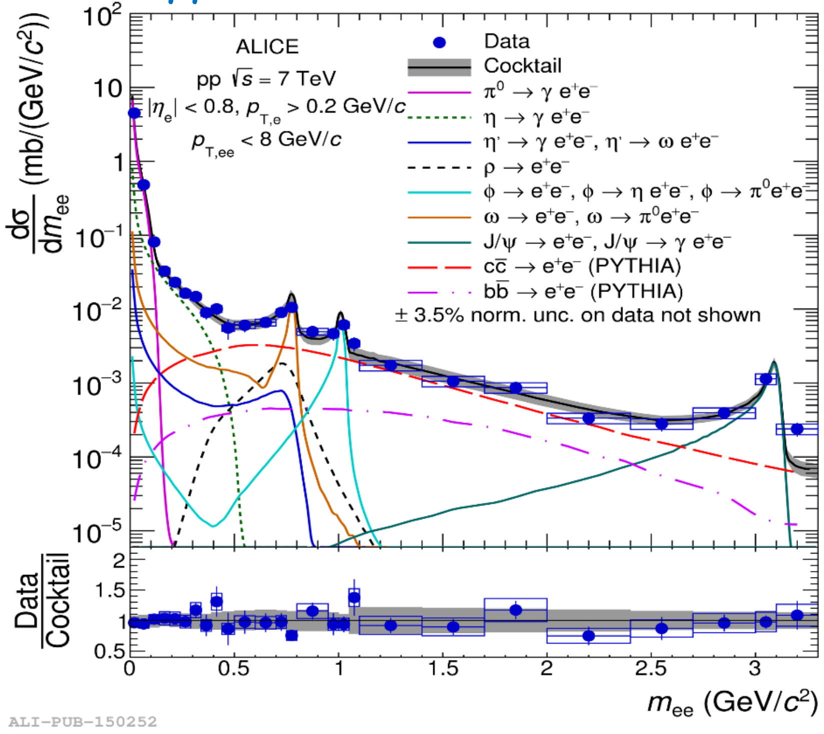
pp@$\sqrt{s}$ = 5 TeV

- Model dependence observed, similar to what observed in pp collisions at $\sqrt{s}$ = 7 TeV and 13 TeV

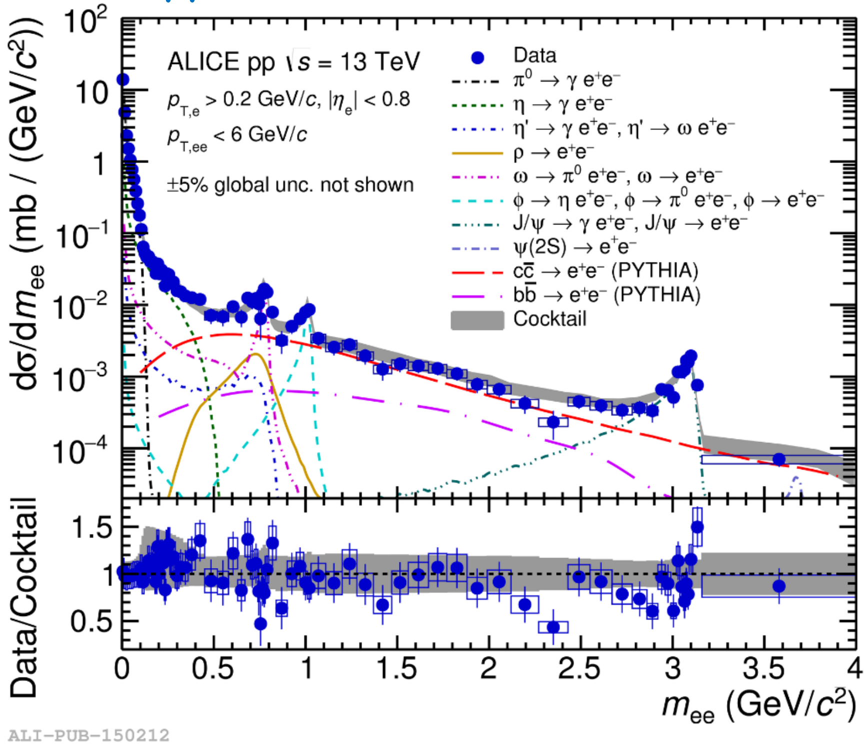
	$d\sigma_{c\bar{c}}/dy$	$d\sigma_{b\bar{b}}/dy$
PYTHIA	0.531 ± 0.062 (stat.) ± 0.066 (syst.) mb	0.037 ± 0.004 (stat.) ± 0.005 (syst.) mb
POWHEG	0.743 ± 0.080 (stat.) ± 0.093 (syst.) mb	0.027 ± 0.004 (stat.) ± 0.003 (syst.) mb

pp reference measurements @ $\sqrt{s}$ = 7 TeV and 13 TeV

pp @ 7 TeV



pp @ 13 TeV

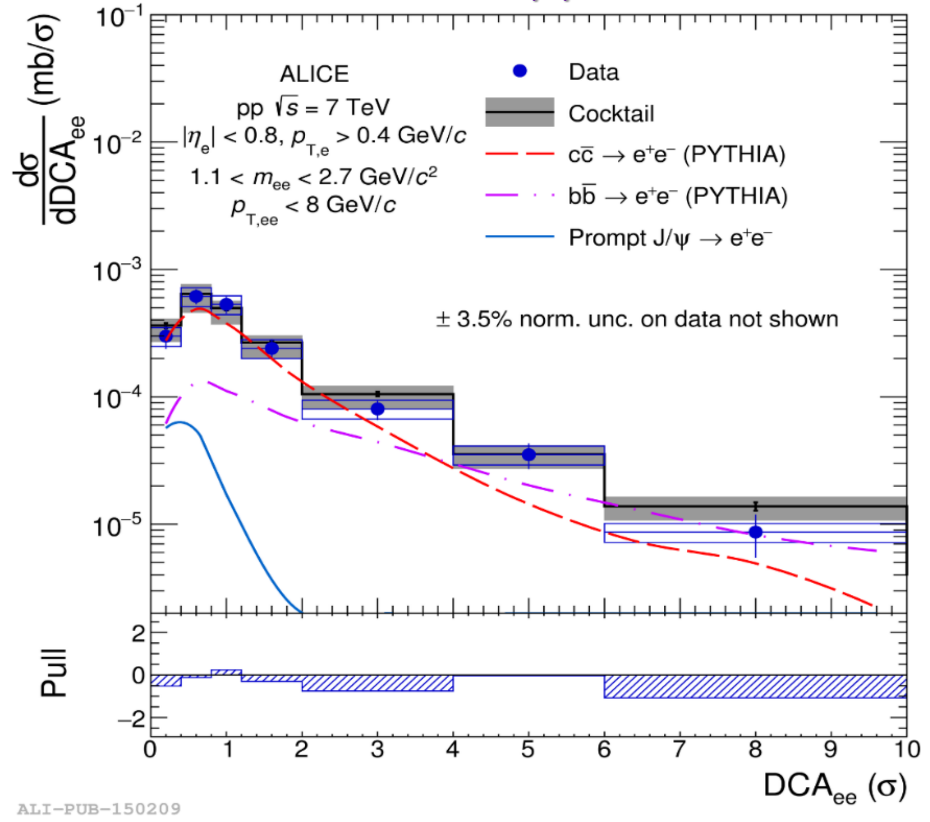


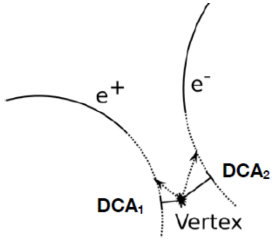
- Spectrum compared with cocktail of known hadronic sources
  - Data described by cocktail within uncertainties
- Dielectron production well understood for $p_{T,e} > 0.2$ GeV/c
- Heavy-flavour contributions dominate for $m_{ee} > 1.1$ GeV/c^2
- Complementary (w.r.t. heavy-flavour hadron measurements) $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ measurements

Dielectron measurements in pp collisions

- DCA dielectron spectra in IMR used to extract charm and beauty cross section

$pp@\sqrt{s} = 7$ TeV





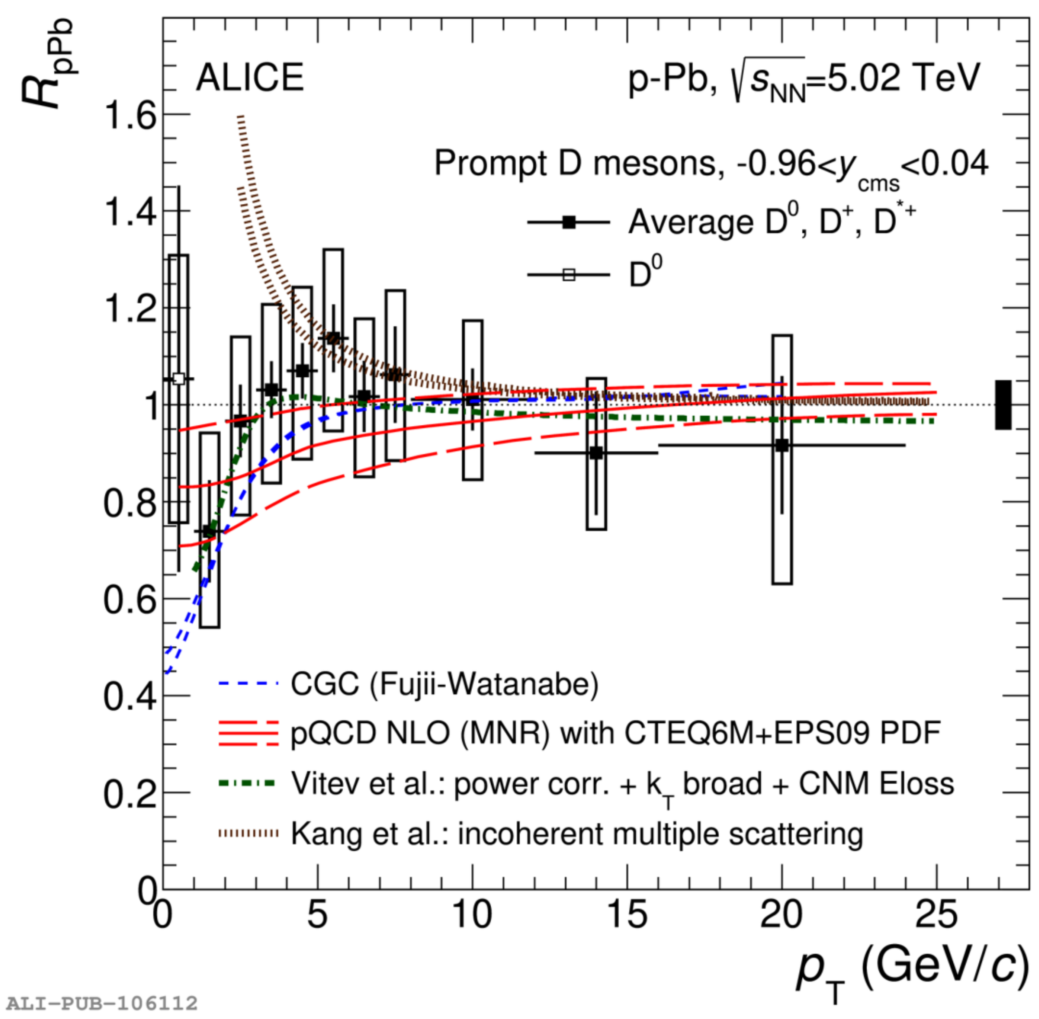
$$DCA_{ee} = \sqrt{\frac{DCA_1^2 + DCA_2^2}{2}}$$

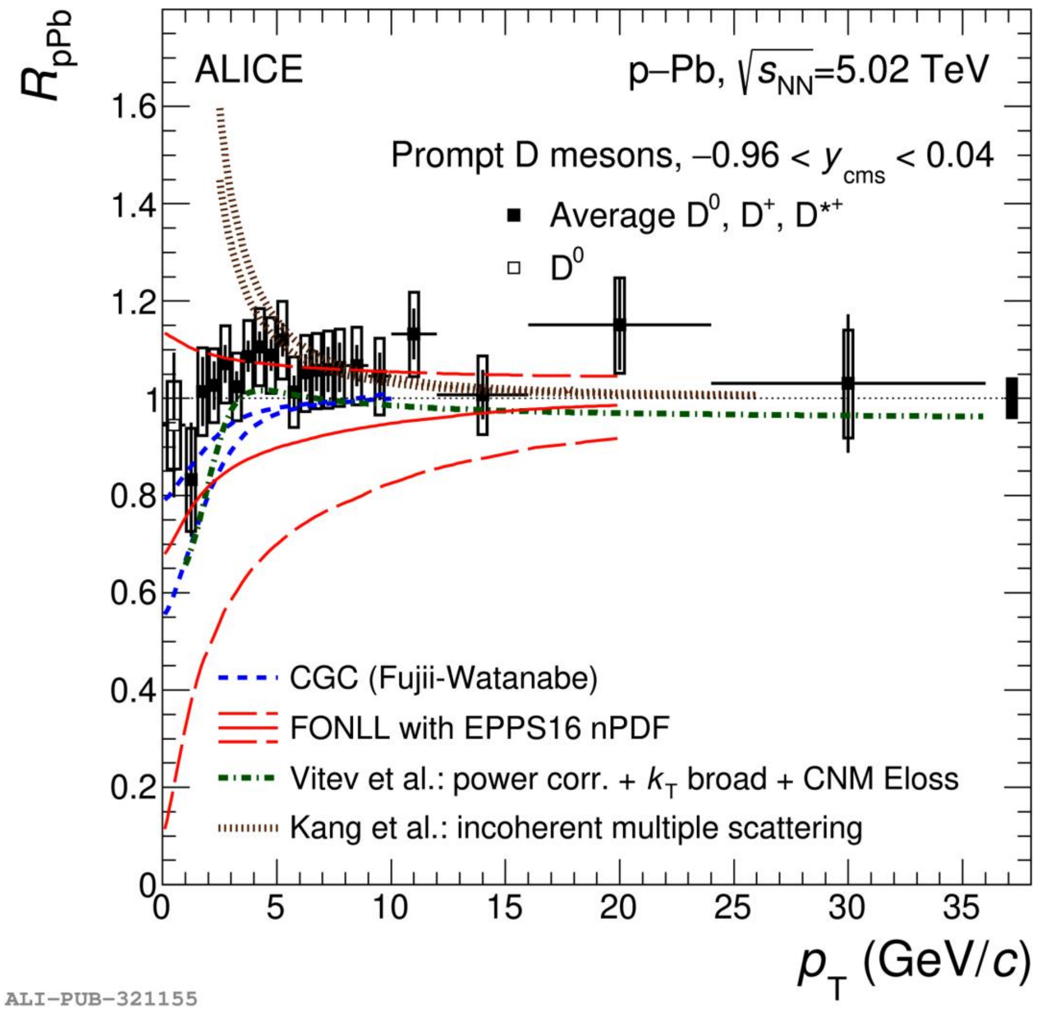
- Heavy-flavour hadrons have a delayed decay
- D-meson $c\tau$ = 150-300 μm, B-meson $c\tau$ = 450 μm

DCA_{ee}(prompt) < DCA_{ee}(charm) < DCA_{ee}(beauty)

DCA useful variable to discriminate charm and beauty hadron decay electrons

- Additional fit with *DCA* (in pp collisions at $\sqrt{s}$ = 7 TeV)





EPPS16/EPS09 for nPDF