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

Daniel Samitz

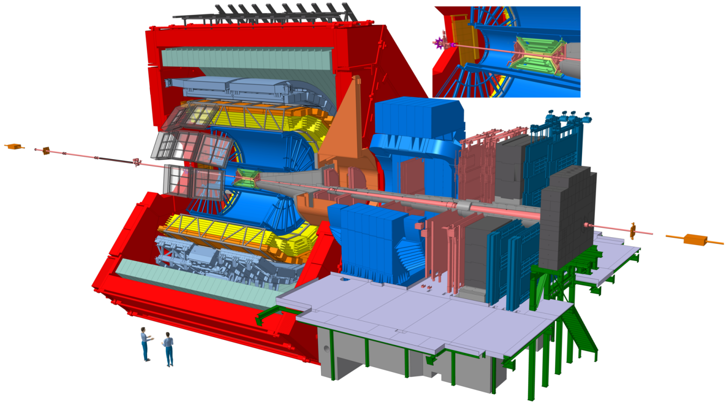
FAKT Workshop 2023
23/02/2023

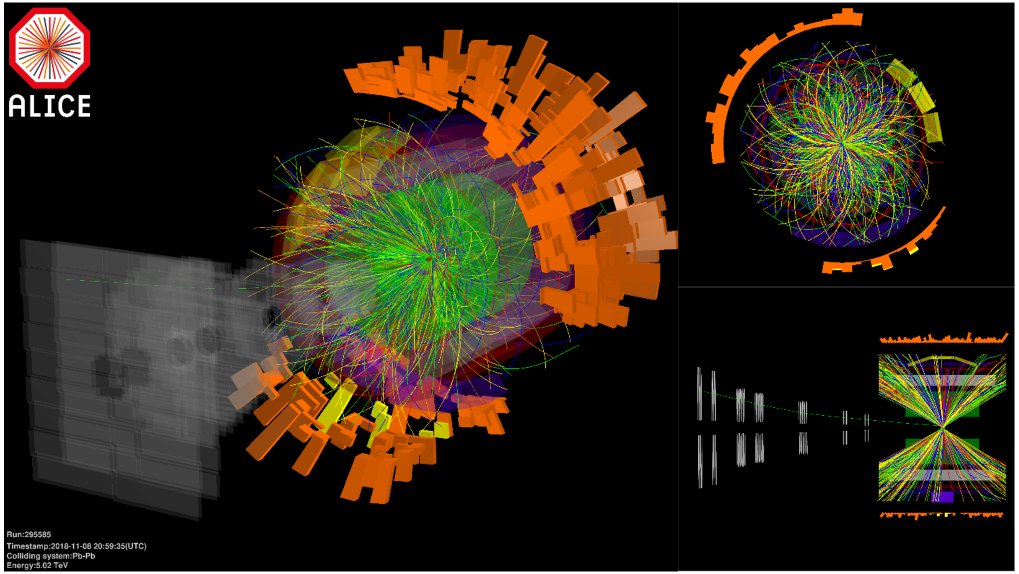
Stefan Meyer Institut für subatomare Physik

Der Wissenschaftsfonds.

Outline

- Low mass dielectron analyses performed in ALICE
  - Studies in pp, p–Pb and Pb–Pb collisions
- Study of $\Lambda_c^+ \rightarrow pK_0^S$ in ALICE





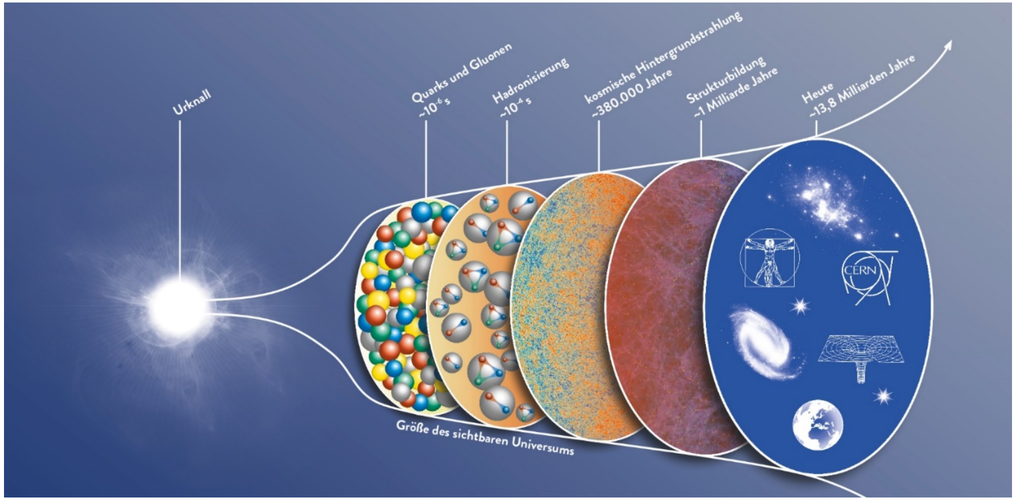
Dielectron production in nuclear collisions
(FWF P 34881)

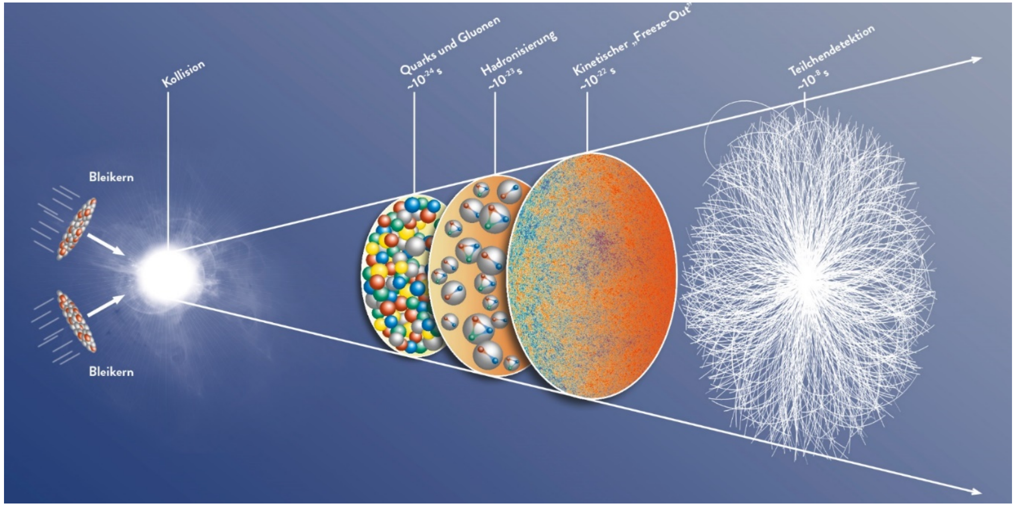
4 years: 10/2021 - 10/2025

Project leader: Elisa Meninno

+ 1 PostDoc

Quark-gluon plasma & heavy-ion collisions





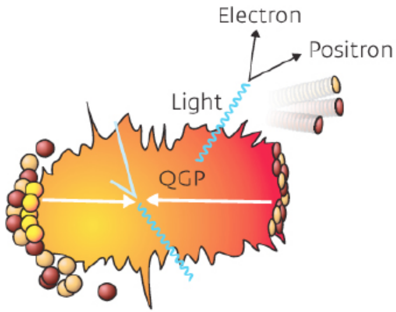
Big Bang

- Shortly after the big bang matter was in a state of plasma of deconfined quarks and gluons (QGP)

Ultra-relativistic heavy-ion (Pb–Pb) collisions at the LHC

- QGP recreated in laboratory

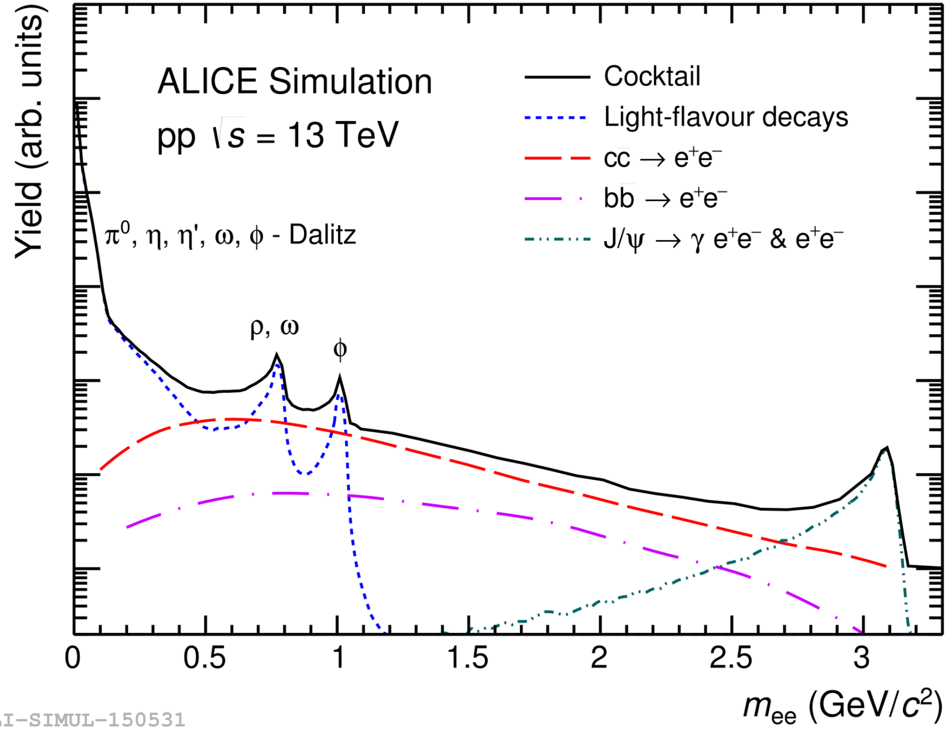
Electromagnetic probes



Photons and leptons experience no strong interactions, can therefore directly probe the inner regions of collision
→ penetrating probes, information from earliest stages well preserved

- Dielectrons emitted from many sources during all stages of the collisions
  → investigate the whole history of the medium

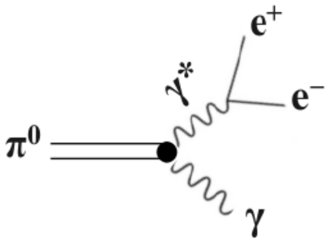
- Small systems (pp and p–Pb) used as reference measurements
  - crucial reference for Pb–Pb studies
  - investigate possible cold nuclear matter effects

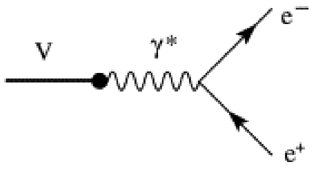


Dielectron mass spectrum

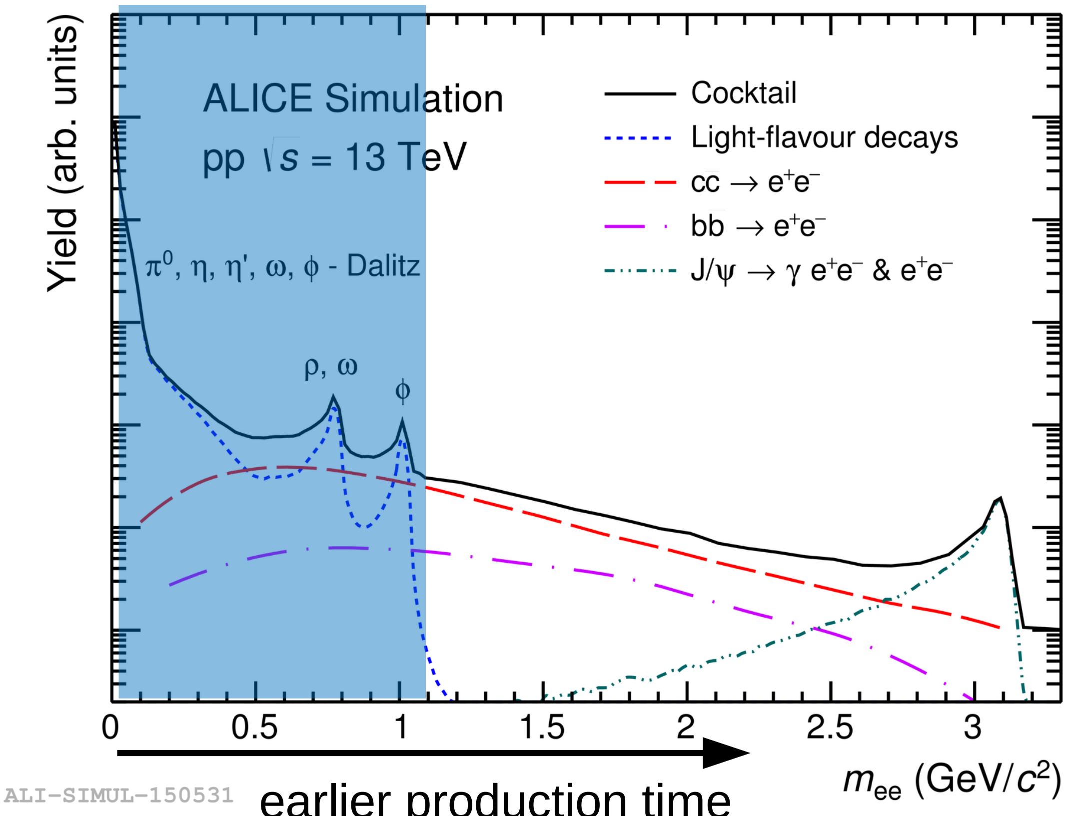
Different sources:

- Decays of light-flavor mesons
  - Dalitz decays $(\pi^0, \eta, \omega, \eta', \Phi)$
  - 2-body decays (ρ, ω, Φ)





$m_{ee} < 1.1\,\mathrm{GeV/c^2}$

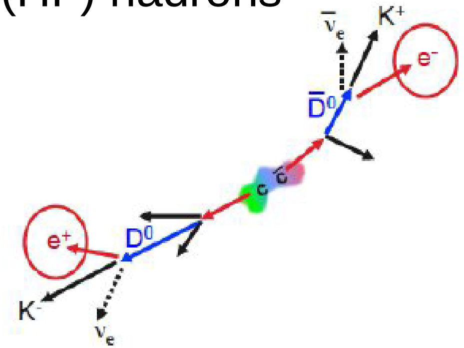


earlier production time

Dielectron mass spectrum

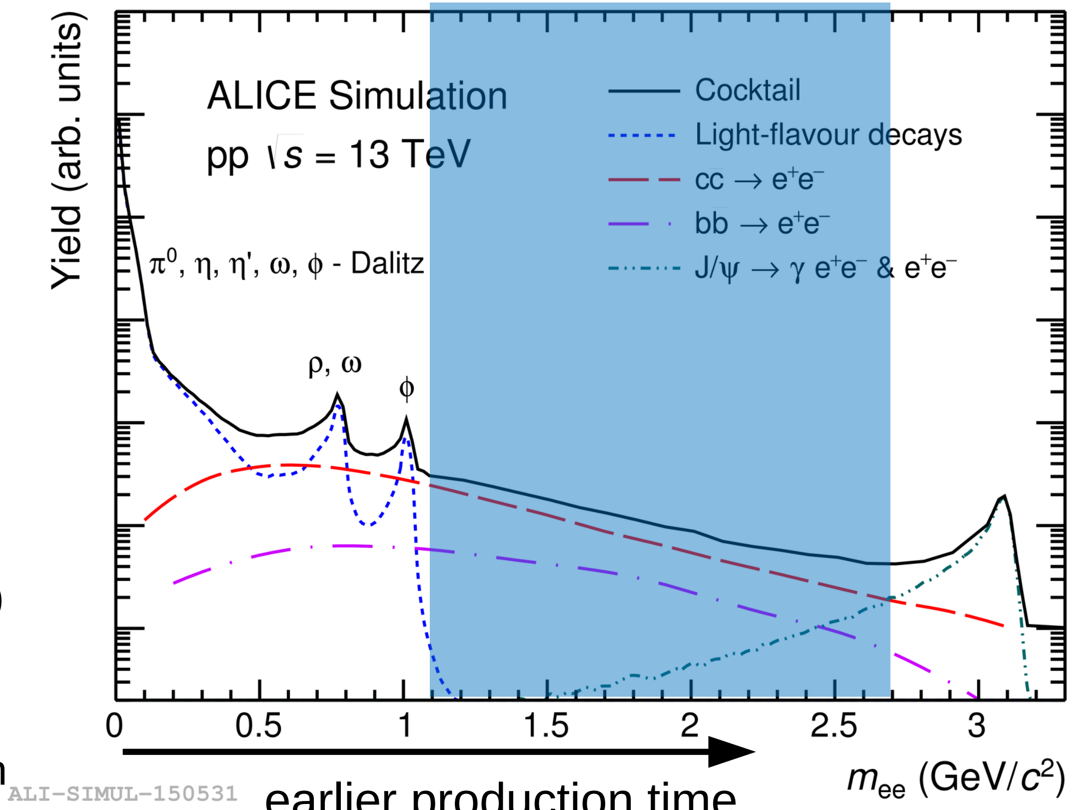
Different sources:

- Dielectrons from decays of correlated heavy-flavor (HF) hadrons



  - $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ complementary to direct heavy-flavor hadron measurments
  - Nuclear parton distribution function (PDF) in p–Pb and Pb–Pb collisions
  - Pb–Pb: energy loss, partial thermalization of correlated charm and beauty quarks

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

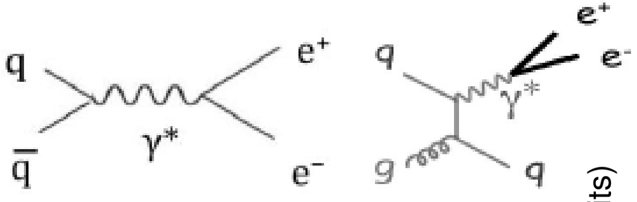


earlier production time

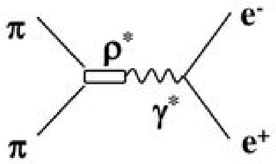
Dielectron mass spectrum

Different sources:

- Thermal radiation
  - Quark-gluon plasma



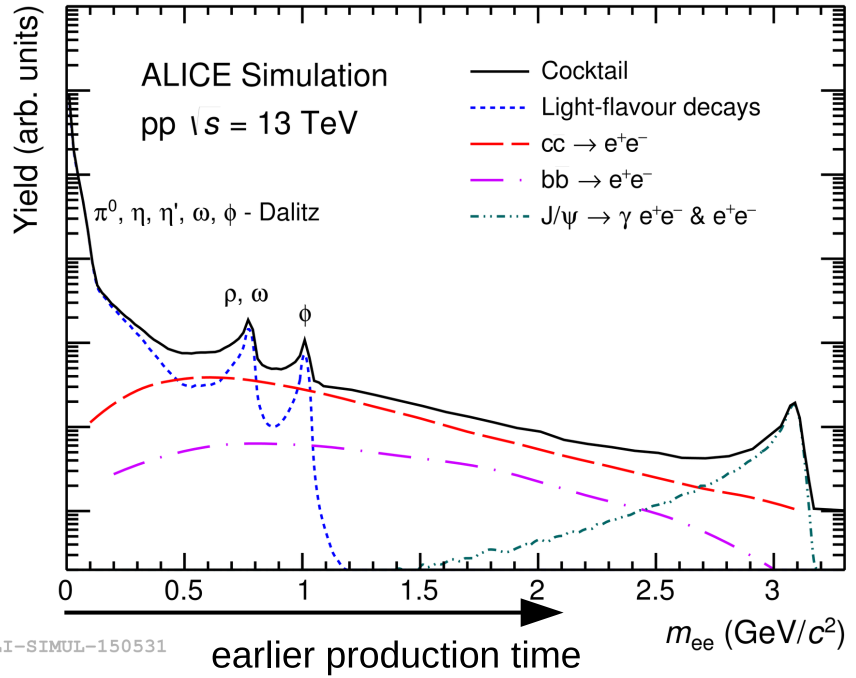
  - Hot hadronic matter



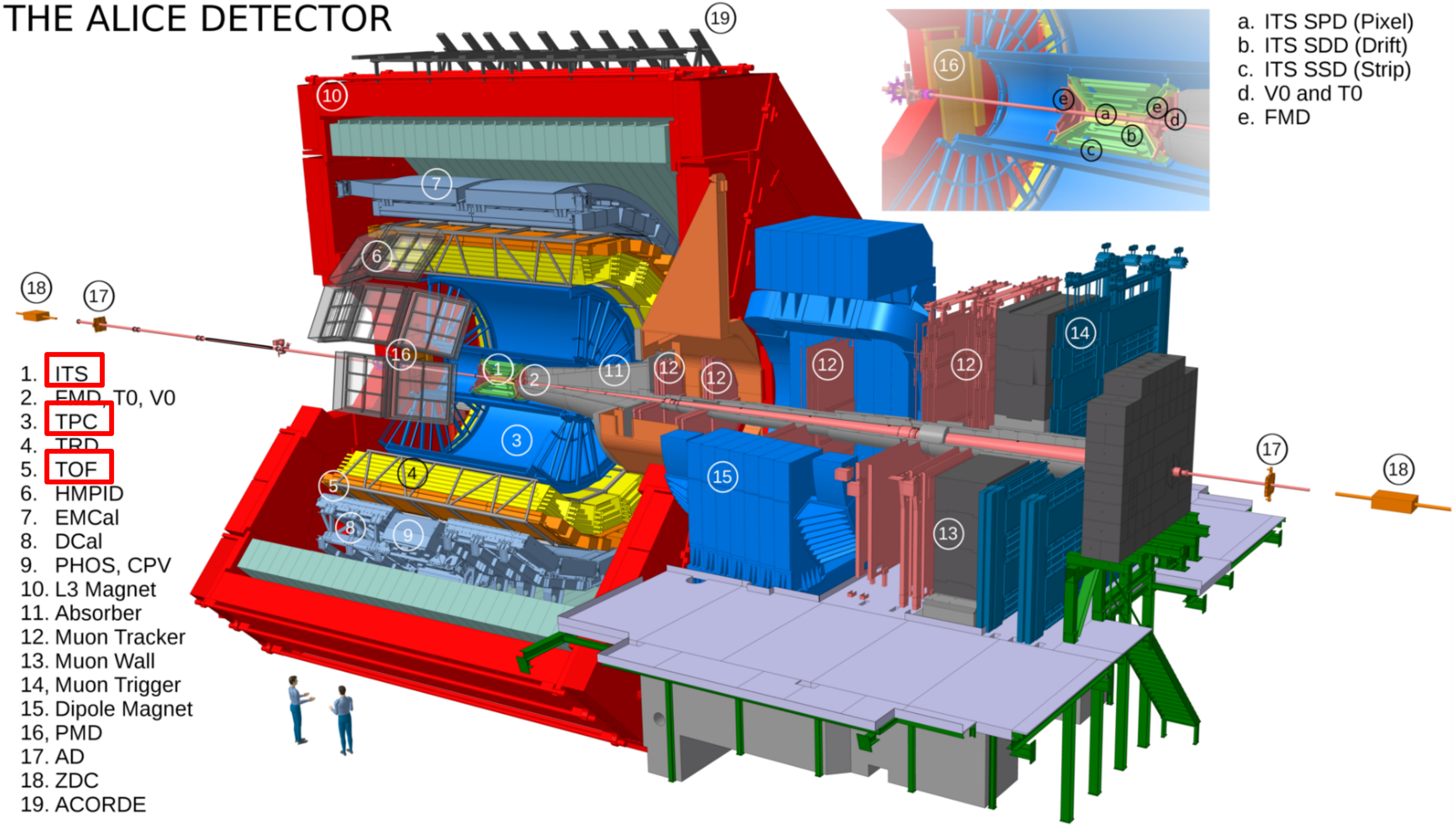
  - In the intermediate mass region:
    thermal radiation from partonic phase

$$\frac{\mathrm{d}N_{ee}}{\mathrm{d}m_{ee}} \sim m_{ee}^{3/2}\,\mathrm{e}^{-m_{ee}/T}$$

    challenging due to dominant contribution from charm and beauty hadrons



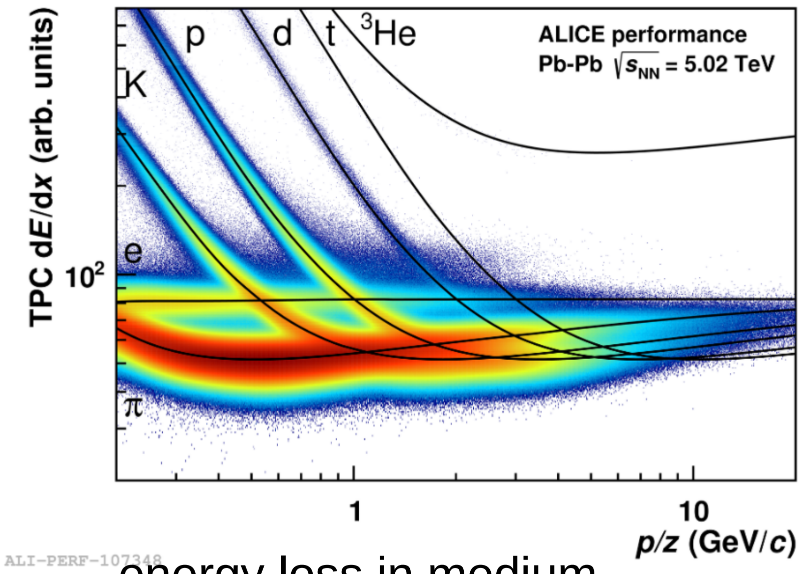
THE ALICE DETECTOR



ALICE

Particle Identification

Time Projection Chamber (TPC)

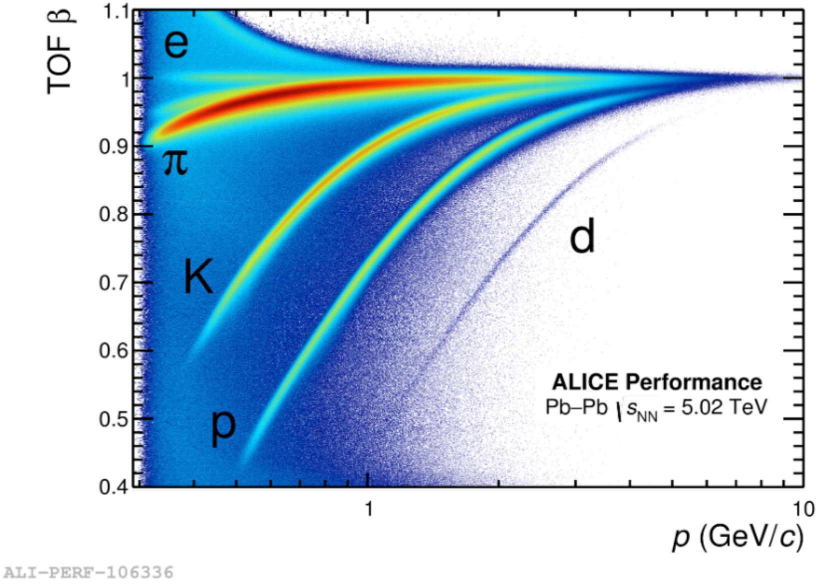


energy loss in medium
(Bethe-Bloch formula)

$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1-\beta^2)}\right) - \beta^2\right]$$

$$\beta = \frac{v}{c}$$

Time of Flight (TOF)

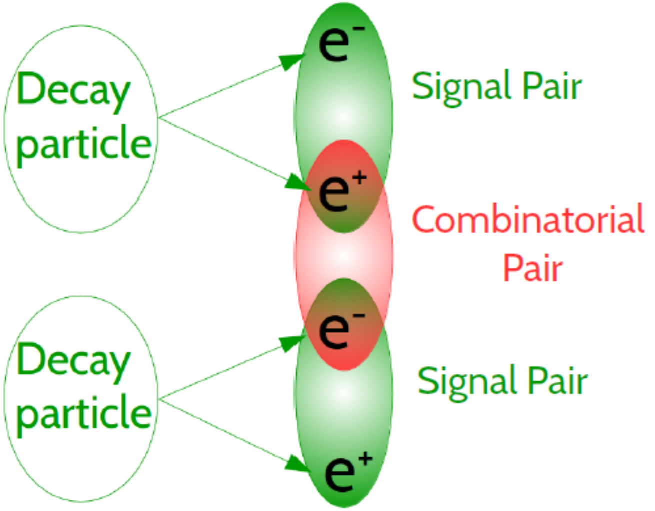


time resolution ~50 ps

$$p = \frac{mc\beta}{\sqrt{1-\beta^2}} \Rightarrow \beta = \frac{p}{\sqrt{(mc)^2 + p^2}}$$

Obtaining the spectrum

- Track quality cuts applied to ensure only “good” quality tracks are used
- Electron particle identification performed
- Real photons converting into electrons in the detector material need to be removed
  ⟶ conversion rejection cuts (hit in first ITS layer)



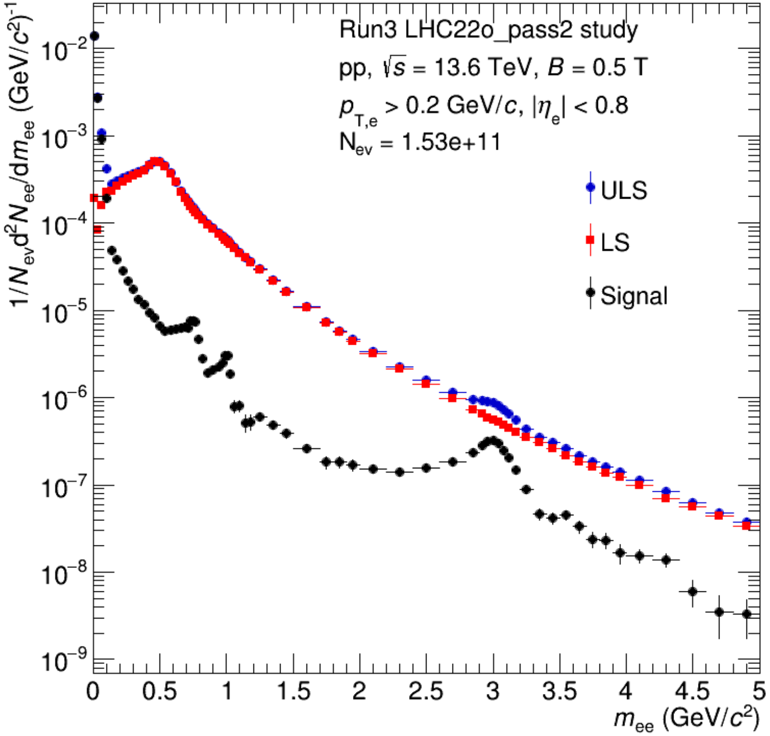
- Obtain spectrum via like-sign (LS) subtraction from unlike-sign (US) pairs

$$LS_{\mathrm{all}} = R \times 2\sqrt{N_{++} \cdot N_{--}}$$

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

additional factor to account for different acceptances for like- and unlike-sign pairs

Obtaining the spectrum



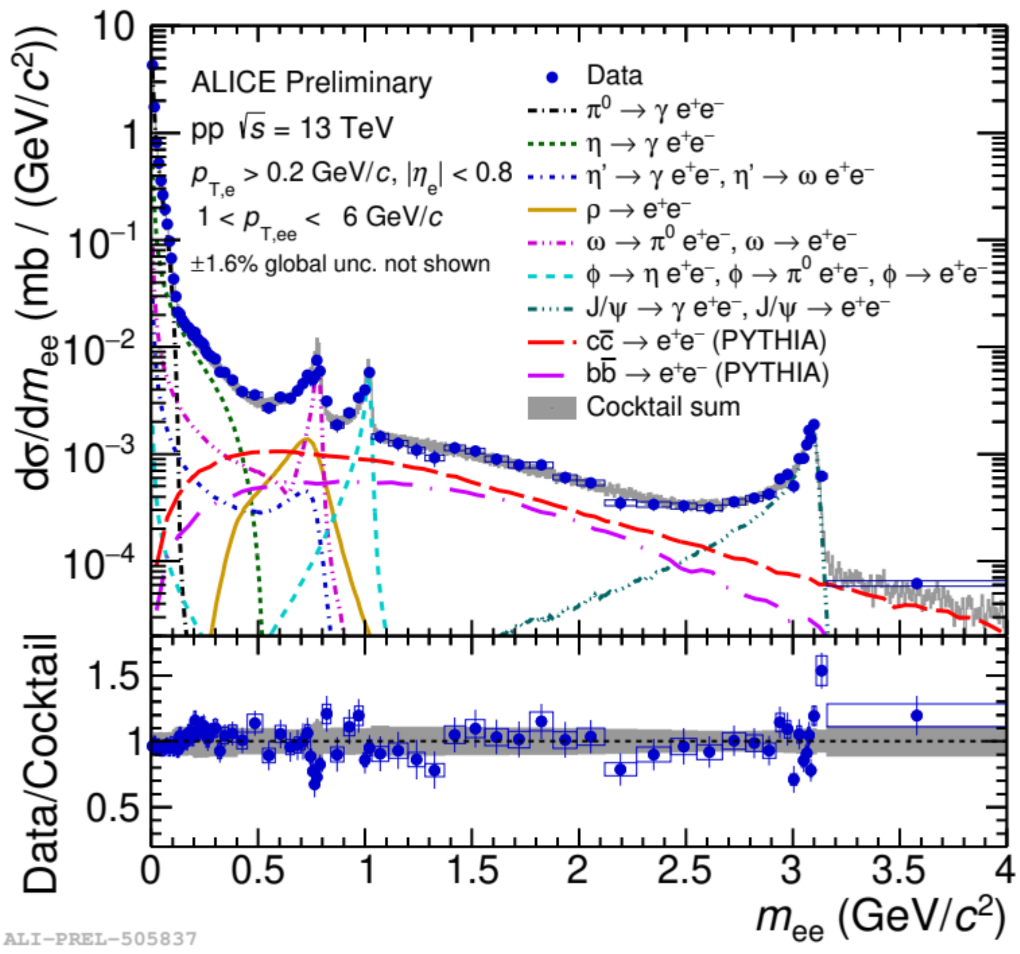
- Track quality cuts applied to ensure only “good” quality tracks are used
- Electron particle identification performed
- Real photons converting into electrons in the detector material need to be removed
  ⟶ conversion rejection cuts (hit in first ITS layer)
- Obtain spectrum via like-sign (LS) subtraction from unlike-sign (US) pairs

$$LS_{\text{all}} = R \times 2\sqrt{N_{++} \cdot N_{--}}$$

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

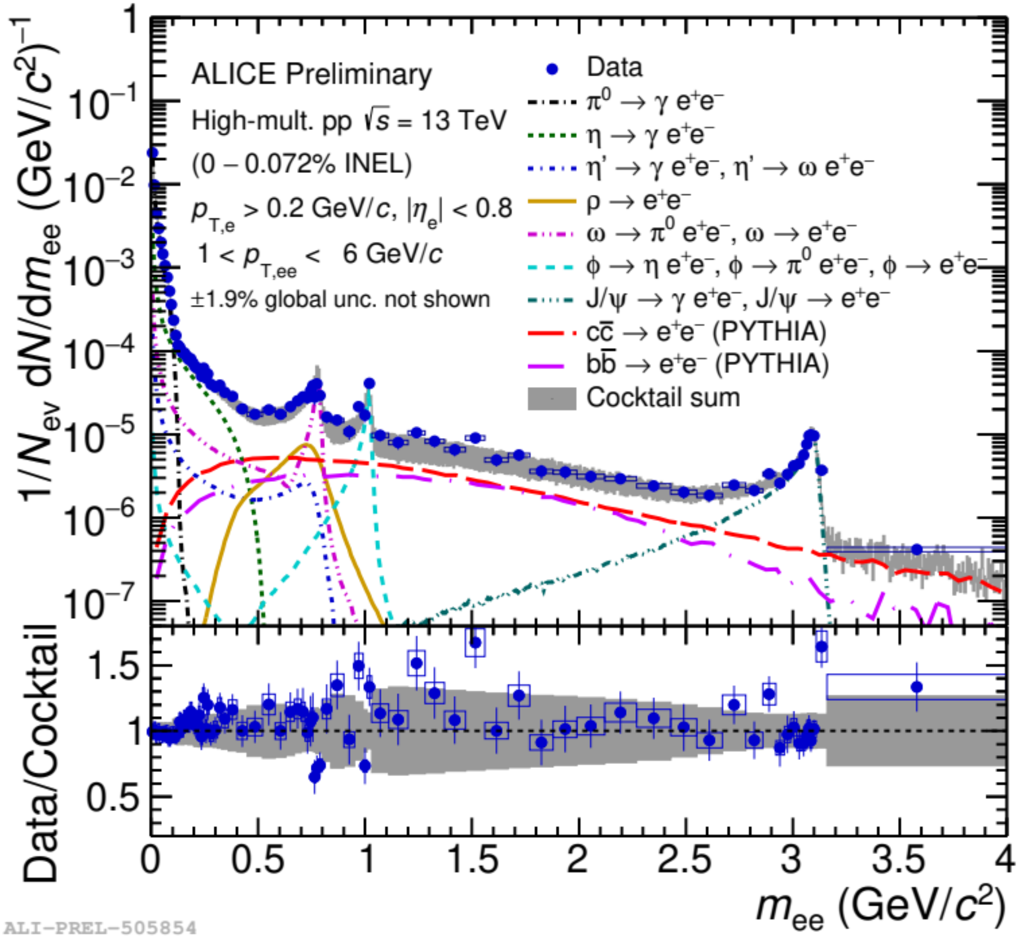
additional factor to account for different acceptances for like- and unlike-sign pairs

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



- Well described by hadronic sources
  - also seen in pp at $\sqrt{s} = 5.02\,\mathrm{TeV}$ (Phys. Rev. C 102 (2020) 055204)
- Within uncertainties no excess of thermal radiation in high particle multiplicity pp events

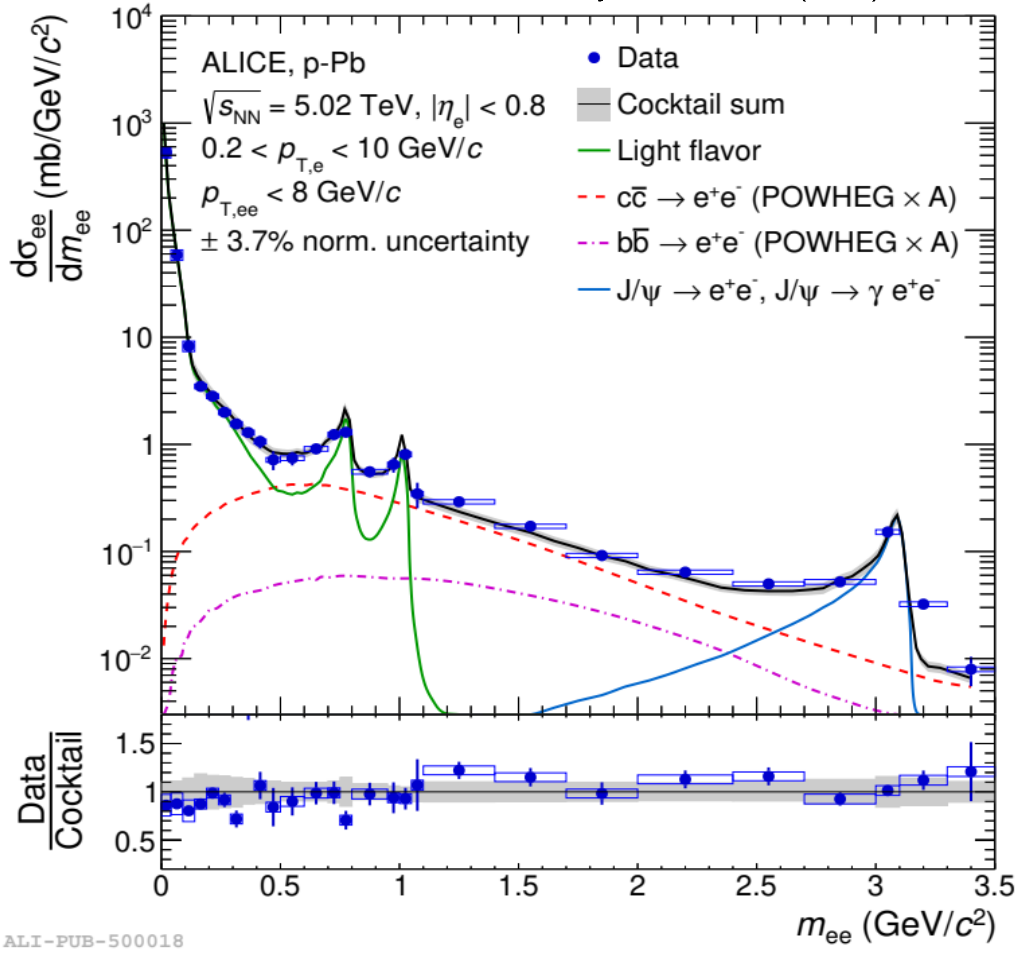
Dielectron production in pp at $\sqrt{s} = 13\,\text{TeV}$ in high multiplicity



- Well described by hadronic sources
  - also seen in pp at $\sqrt{s} = 5.02\,\text{TeV}$ (Phys. Rev. C 102 (2020) 055204)
- Within uncertainties no excess of thermal radiation in high particle multiplicity pp events

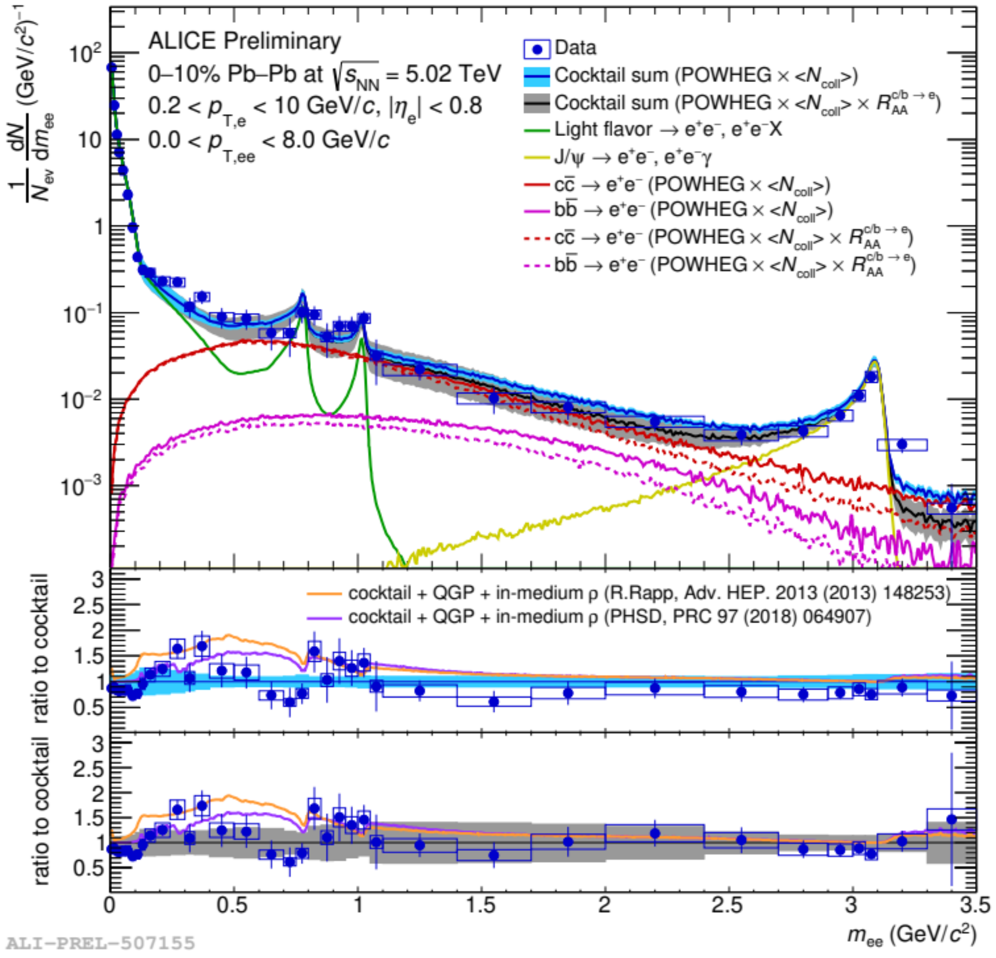
Dielectron production in p–Pb at $\sqrt{s_{NN}} = 5.02\,\mathrm{TeV}$

Phys. Rev. C 102 (2020) 055204



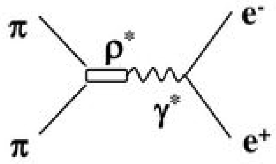
- Heavy flavor cocktail from binary NN collisions scaled with atomic mass number (A=208)
- In good agreement with known hadronic sources
- No significant deviations from vacuum expectations
  - Cold nuclear matter effects seem to be small compared to current measurement uncertainty

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



- Comparison to hadronic cocktail
  - N_{coll}-scaled HF (PRC 102 (2020) 055204)
  - modified HF by R_{AA} of $c/b \to e$ (PLB 804 (2020) 135377)

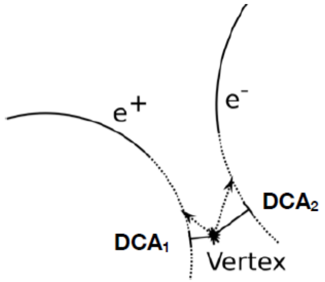
- Hint of an excess at $m_{ee} < 0.5\,\mathrm{GeV/c^2}$
  - consistent with thermal radiation from hot hadronic matter



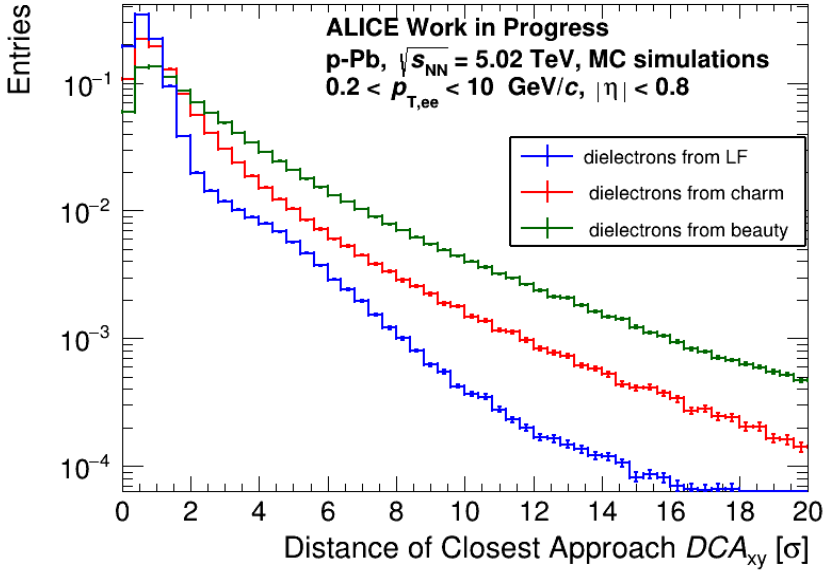
Outlook: DCA studies

- Heavy-flavour hadrons have a delayed decay
  D-mesons: $c\tau = 150 - 300\,\mu\mathrm{m}$ B-mesons: $c\tau = 450\,\mu\mathrm{m}$

- Can use distance of closest approach (DCA) as discriminating variable to separate elctrons form charm and bottom decays



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



- Already promising studies in Run2

- Run3 with upgraded tracking system
  → 3 – 6 times better vertexing resolution

Summary & outlook

- Interesting results for low-mass dielectron production achieved in pp, p–Pb and Pb–Pb
  - only some of the most recent results shown here

- Run 3+4 see also: CERN-LPCC-2018-07
  - higher statistics (factor 100)
  - better vertex pointing resolution (factor 3-6)

  → will allow for better separation of thermal radiation and HF background

upgrades:
TPC: CERN-LHCC-2013-020, CERN-LHCC-2015-002
ITS: CERN-LHCC-2012-013

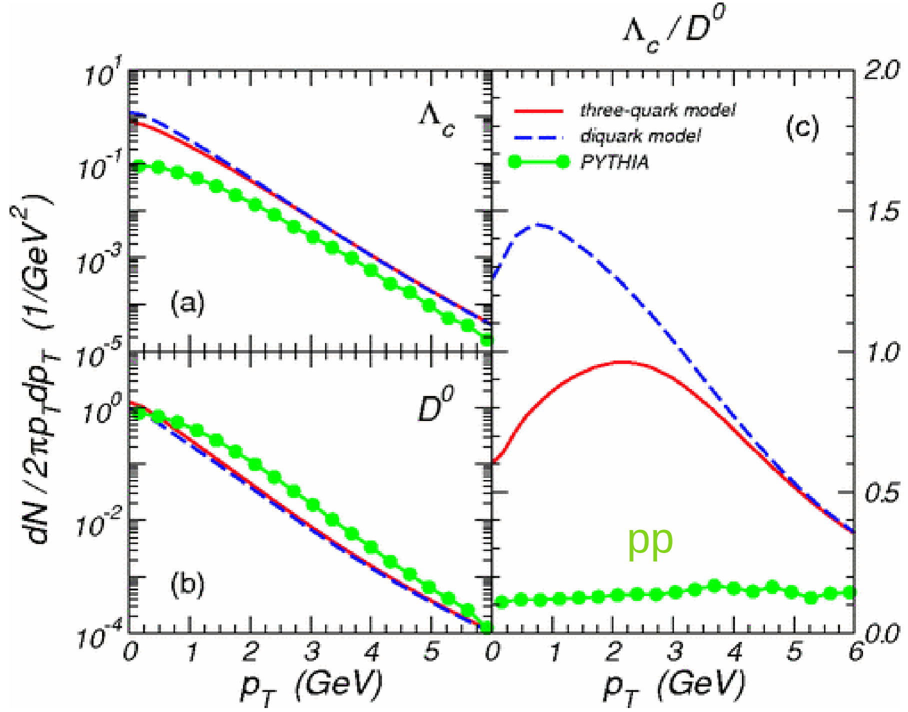
- Vienna group: ongoing studies using machine learning techniques for background rejection

$\Lambda_c^+ \to pK_S^0$ in pp collisions in ALICE

(Elisa Meninno, Daniel Samitz, Paul Bühler)

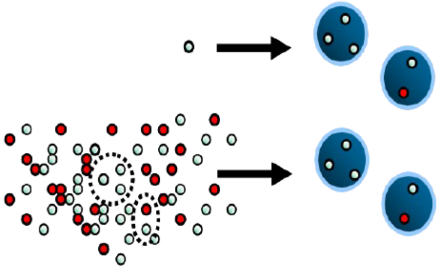
Motivation

- Understand hadronisation processes in the QGP: measuring the baryon/meson ratio



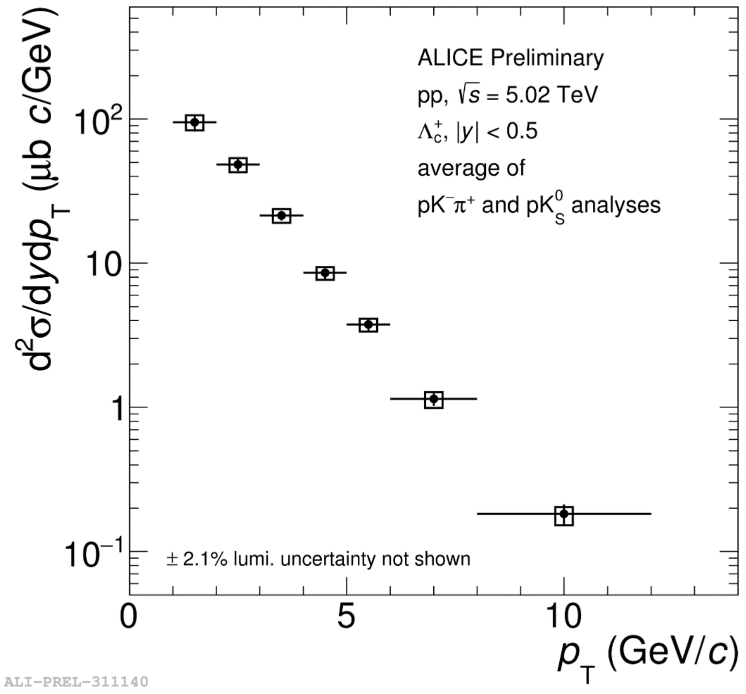
Fragmentation:

Coalescence:

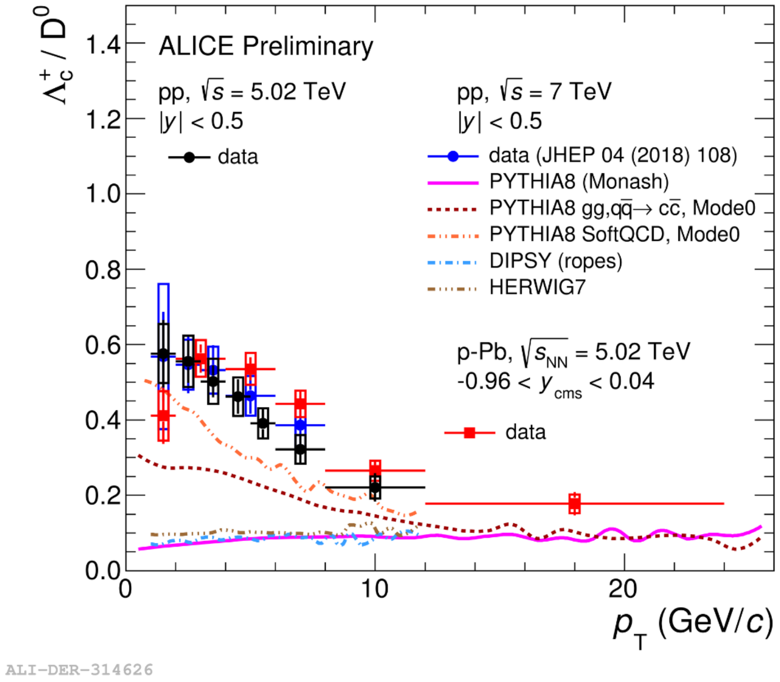


- Enhancement of Λ_c^+ / D^0 ratio predicted in coalescence models.
- Further enhancement expected if thermalised light diquark states exist in the QGP.

Results (Run2): pp and p-Pb



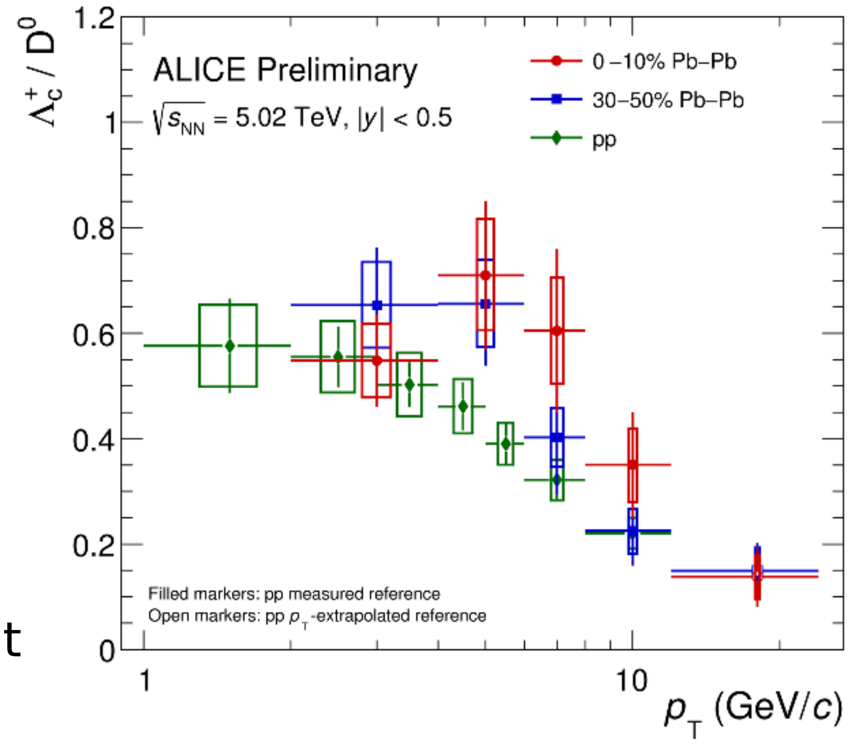
- Λ_c cross section in pp collisions

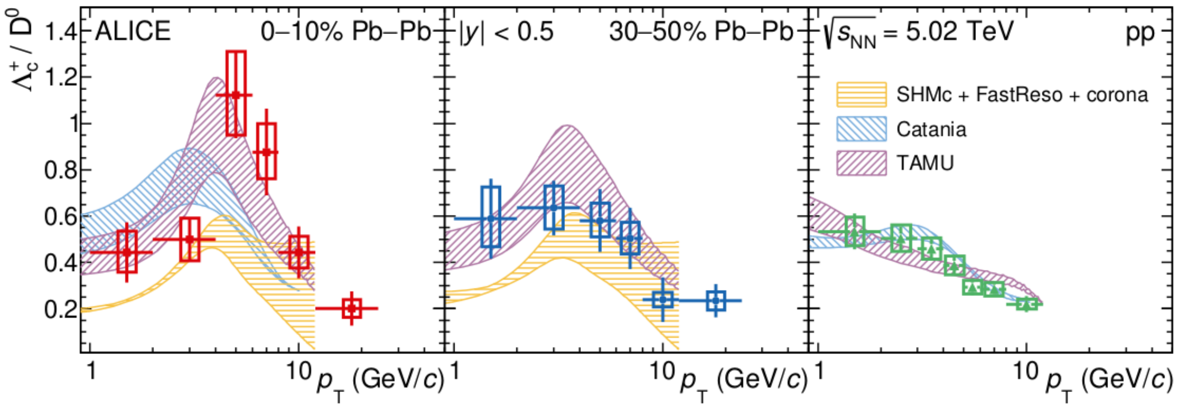


- Λ_c/D^0 ratio in pp collisions
- All the MC underestimate the data
- Pp and p-Pb compatible within uncertainties

Results (Run2): Pb-Pb

- Hint of higher Λ_c/D^0 than in pp collisions.
- Λ_c/D^0 ratio in central collisions higher than in peripheral collisions
- Qualitatively similar to Λ/K_S^0 and p/π
- Can be explained by models taking into account coalescence and QGP effects





Outlook Run3

- Detector upgrades and higher statistics will allow for unprecedented precision for baryon/meson ratio in pp, p-Pb and Pb-Pb collisions

- Analysis of Run3 data (pp) is just beginning (many workflows still under development)

- D^0 peak is already visible in the data

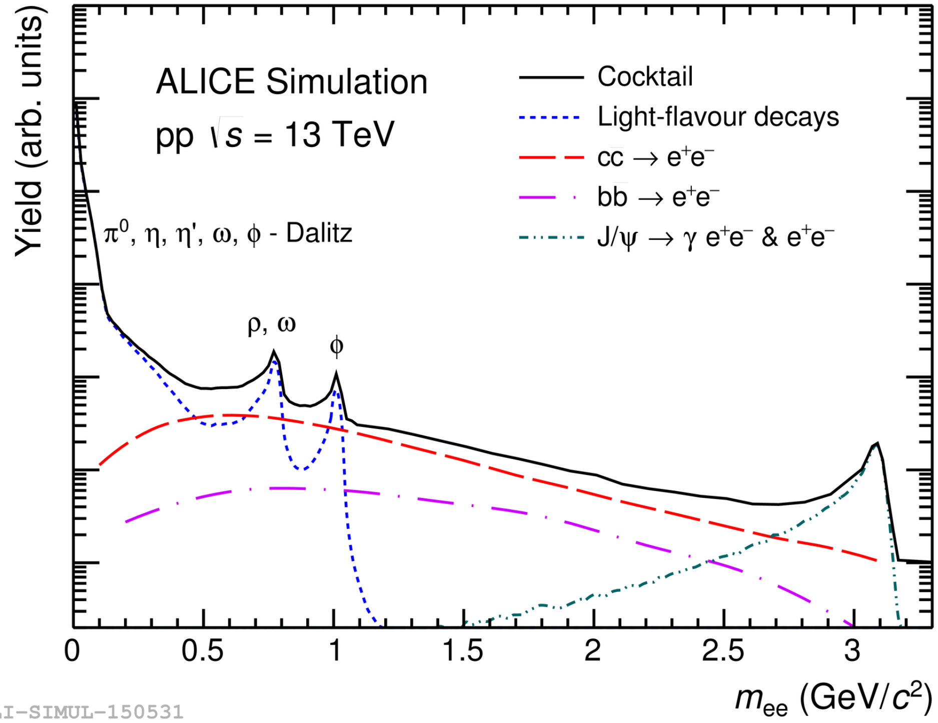
- Λ_c^+ not seen yet….

Thank you for your attention

Hadronic cocktail

- Data compared to simulations referred to as “hadronic cocktail”

- Known source of dielectrons
  - Light mesons
    - mesons generated from parametrized pT and rapidity distributions
    - Distributions either from experiment or from scaling arguments from other mesons
    - Forced to decay into dielectrons ($\mathrm{BR}(\pi^0 \to \mathrm{e}^+\mathrm{e}^-\gamma) \sim 1\,\%$



  - Correlated decays of heavy flavour hadrons
    - Use standard event generator (PYTHIA) to simulate $c\bar{c}$ and $b\bar{b}$ creation
    - Force the resulting hadrons to decay semi-leptonically

Electron identification

- Track quality cuts applied to ensure only “good” quality tracks are used

- Electron particle identification performed
  - $-1.5 < \sigma_e^{\mathrm{TPC}} < 4$
  - $3.5 < \sigma_\pi^{\mathrm{TPC}}$
  - $-3 < \sigma_e^{\mathrm{TOF}} < 3$

- Real photons converting into electrons in the detector material need to be removed:
  - Demand hit in first ITS layer