Low-Mass Dielectron Production in pp, p–Pb and Pb–Pb Collisions with ALICE

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H-QM | Helmholtz Research School
Quark Matter Studies

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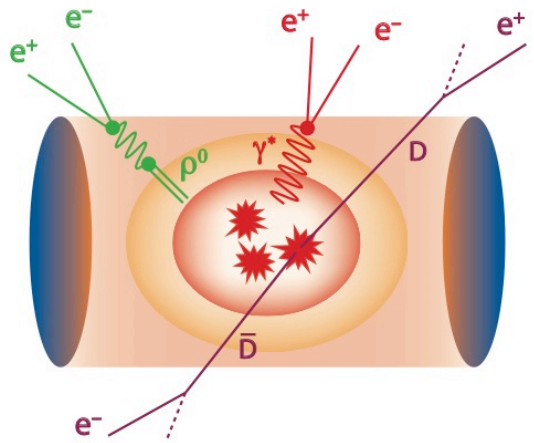
Dielectrons

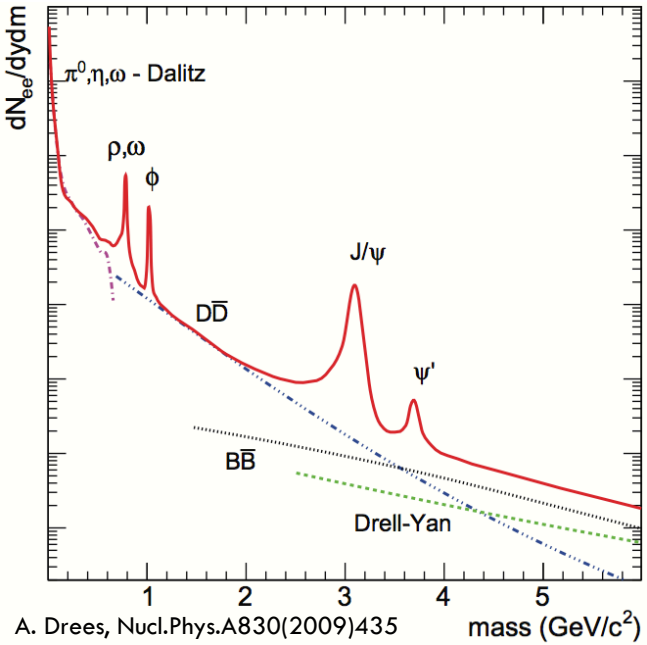
- electromagnetic probe
- no strong final state interaction
- information from all stages of the (HI-)collision



Low and intermediate mass dielectron sources

- in pp collisions:
  - light meson decays
  - correlated open-charm
  - direct photons

  } hadronic "cocktail"
- in Pb–Pb:
  - light mesons (medium-modified)
  - charm (modification of N_{coll} scaling)
  - radiation from hot medium
- in p–Pb: cold nuclear matter effects

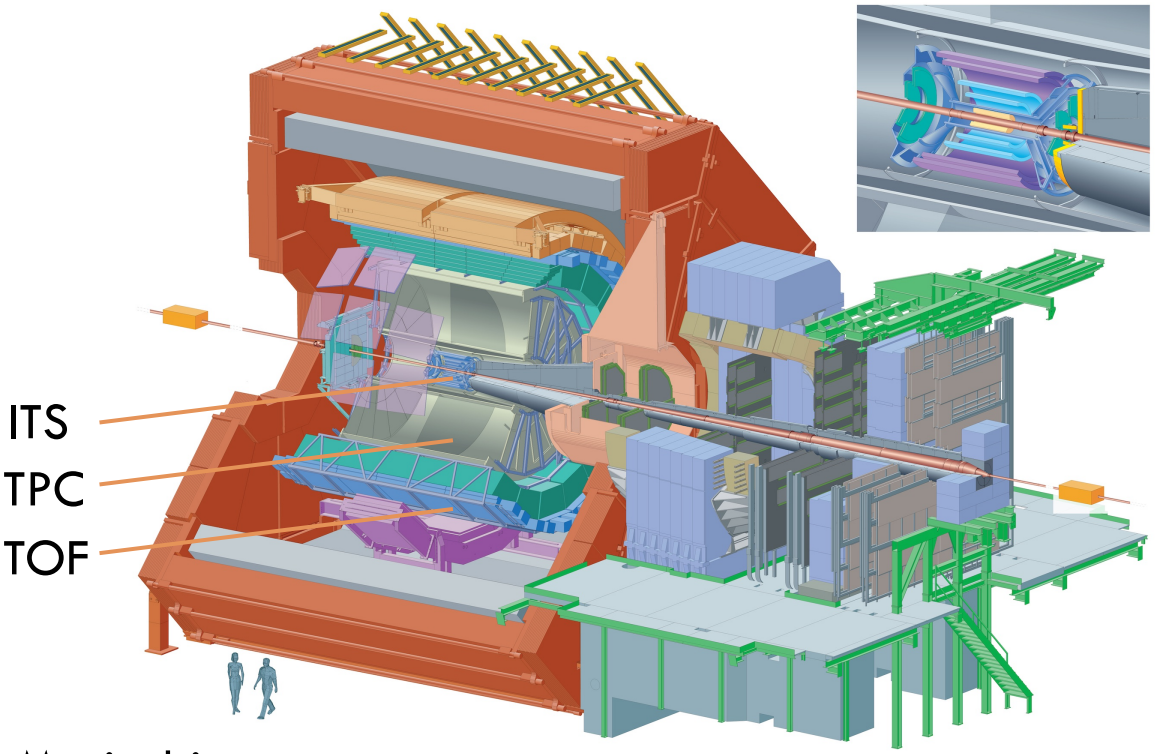


ALICE and the Dielectron Analysis

Involved detectors:

- ITS
  - tracking & vertexing
  - PID (dE/dx in silicon)
- TPC
  - tracking
  - PID (dE/dx in Ne/CO_2)
- TOF
  - PID: hadron rejection

Schematic overview of ALICE

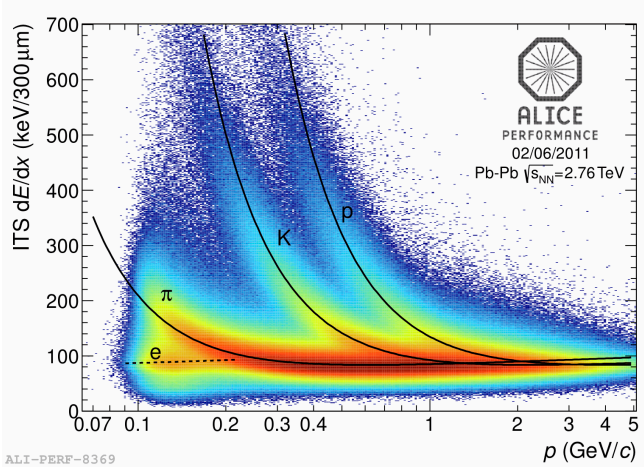


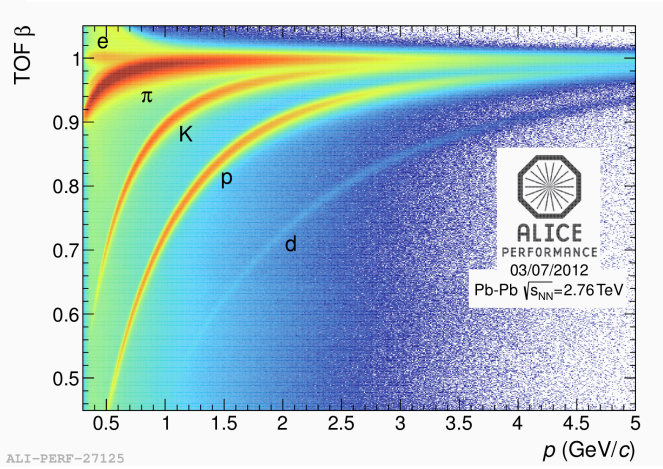
Used datasets:

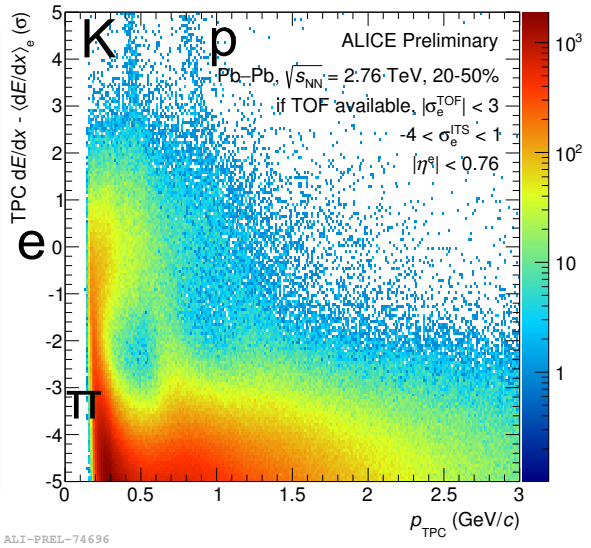
- pp 7 TeV, 2010: ≈ 300 M min. bias events
- p–Pb 5.02 TeV, 2013: ≈ 100 M min. bias events
- Pb–Pb 2.76 TeV, 2011: 17 M (0-10%), 12 M (20-50%)

Electron Selection … in Pb–Pb as example

- ITS dE/dx
- TOF
- TPC dE/dx
  - after ITS and TOF





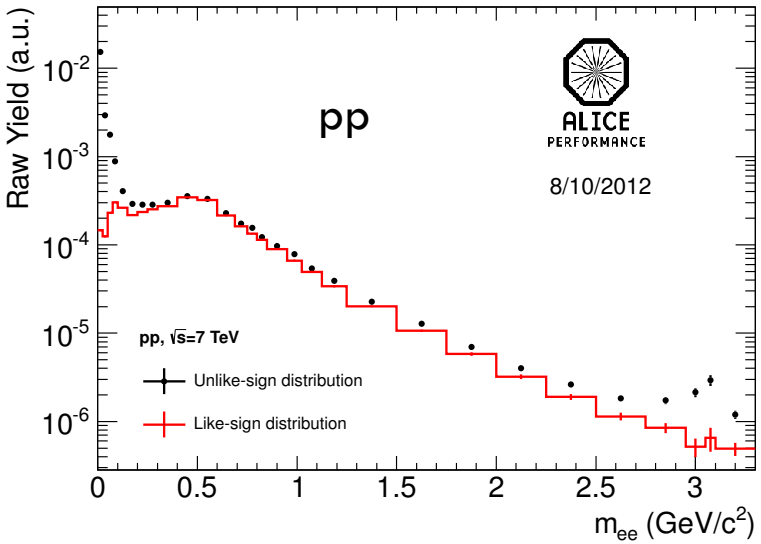


- Cut -4 to +1 sigma outside expected electron signal
- Cut outside ±3 sigma
  - only if good TOF signal available
- Final electron selection
  - -1.5 to +3 sigma
  - p_T = 0.4 – 3.5 GeV/c
  - pion veto ±3 sigma

➡ Hadron contamination ≈ 1-10 % from pp to Pb–Pb

Electron Pair Spectra

- Unlike-sign: sum of real signal and combinatorial background
- Like-sign: combinatorial background estimate
  - using geometric LS = $2 \cdot \sqrt{N_{++} \cdot N_{--}}$



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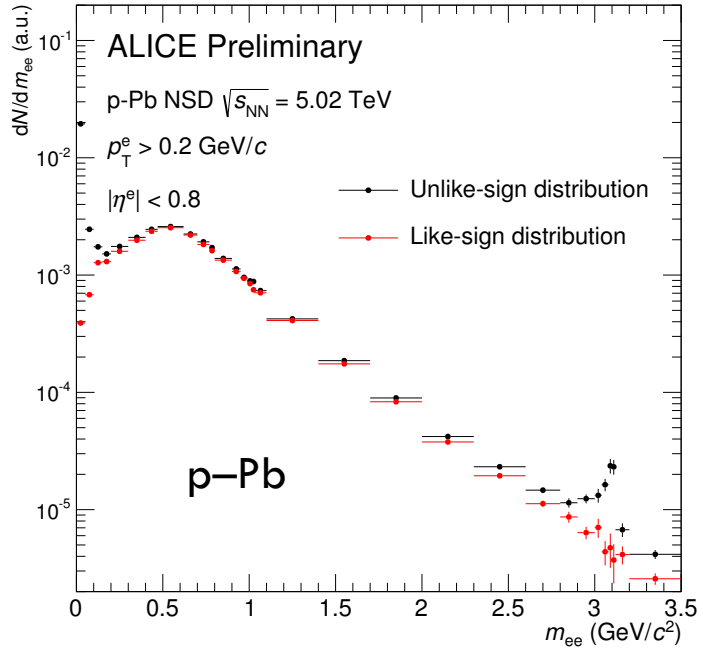

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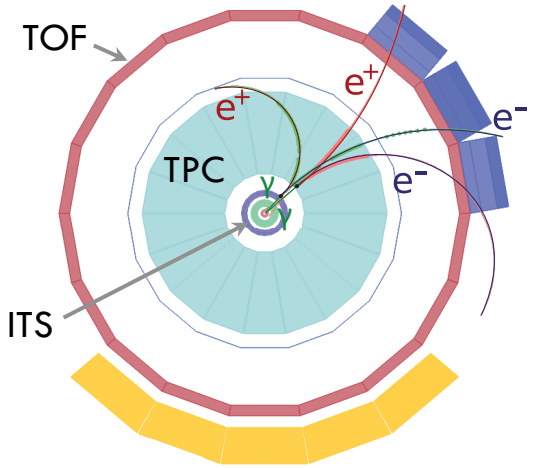
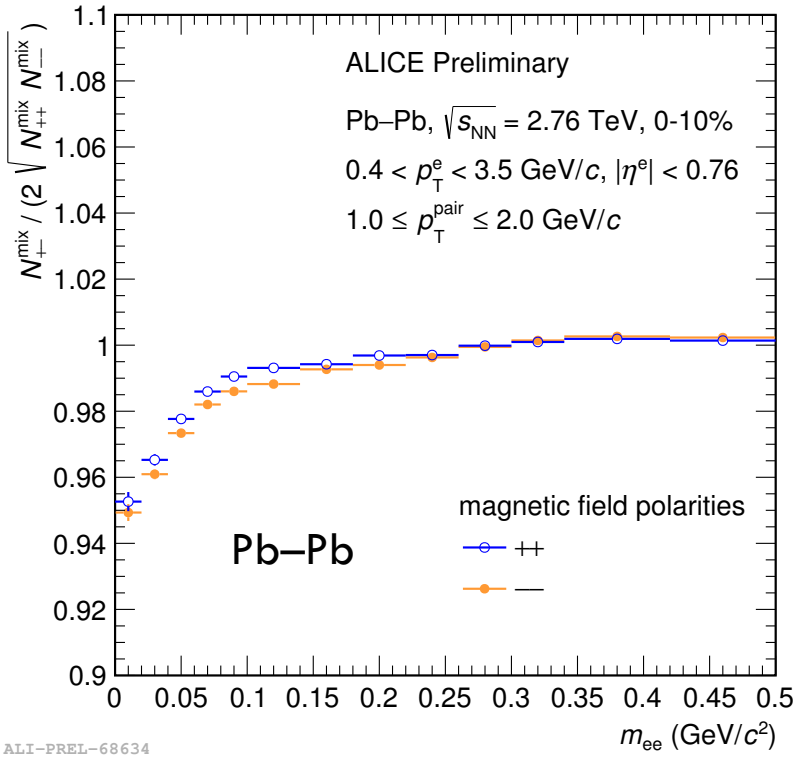
- Subtracted signal = ULS – LS • R
  - contains all correlated dielectron pairs

R : Pair Acceptance Correction



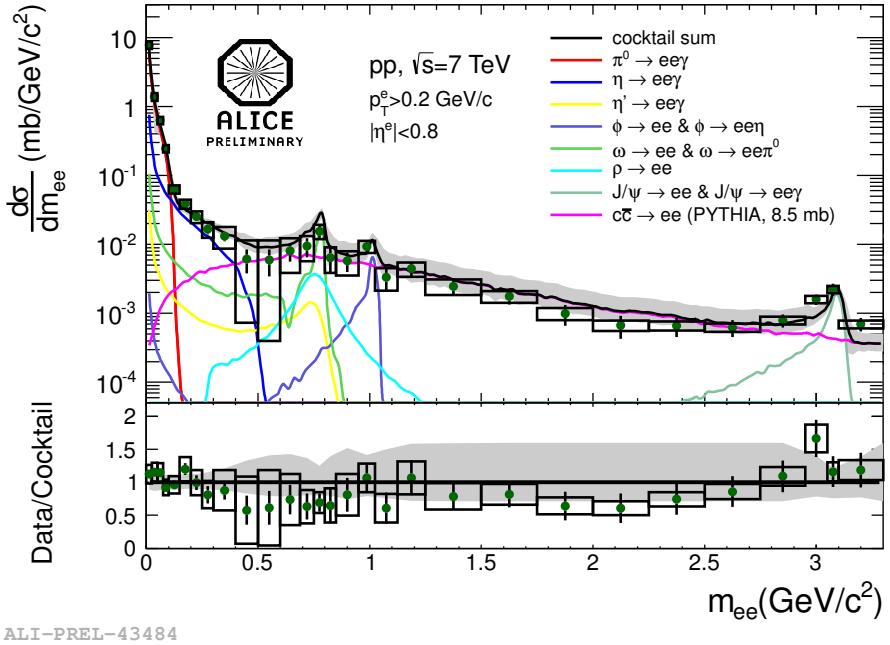
- Correction factor $R = \frac{ULS_{mix}}{LS_{mix}}$
  - ➡ apply to like-sign background



- Different acceptance for ULS and LS pairs
- Estimated via event mixing
  - only detector effects
  - no correlations between particles

Dielectrons in pp collisions at $\sqrt{s}$ = 7 TeV

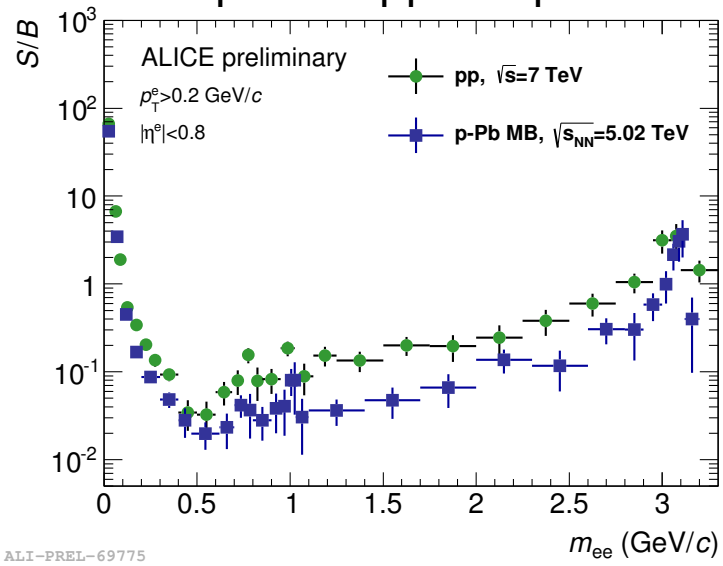
- Subtracted yield (≡ combinatorial-background-subtracted signal)
  - neutral mesons
  - correlated open heavy-flavour
  - virtual direct photons
- Hadronic cocktail
  - based on ALICE measurements for π^0, η, ϕ, J/ψ
    – other sources from m_T scaling
  - $c\bar{c}$ cross-section from ALICE

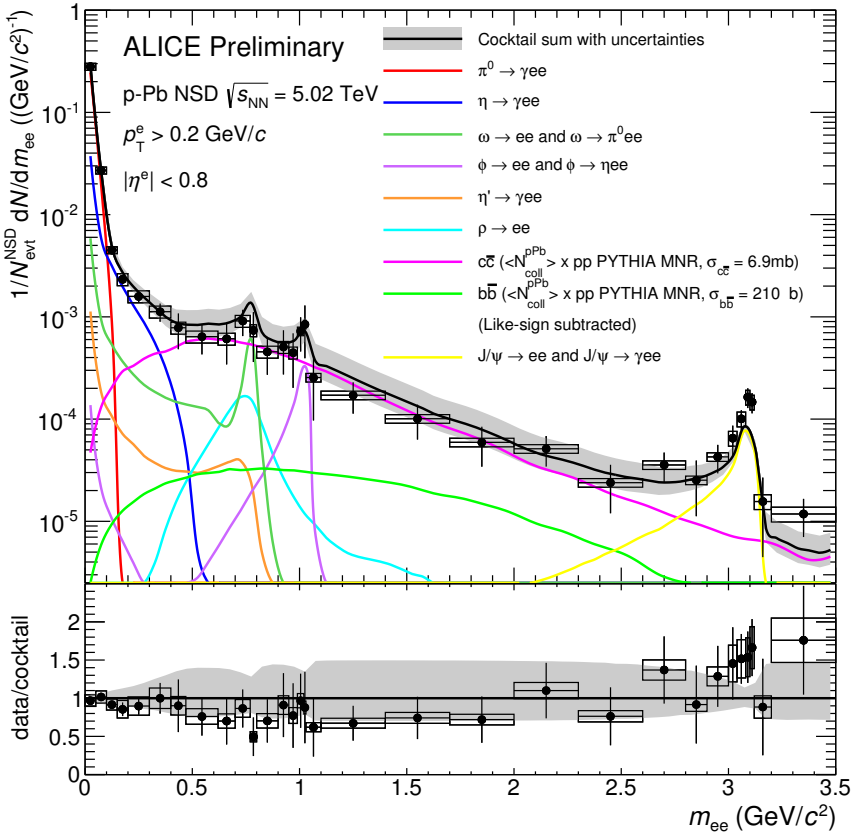


- Data and cocktail in agreement
  - systematic uncertainties in cocktail from input spectra (mainly charm)

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

Signal-to-background ratio comparison: pp and p–Pb

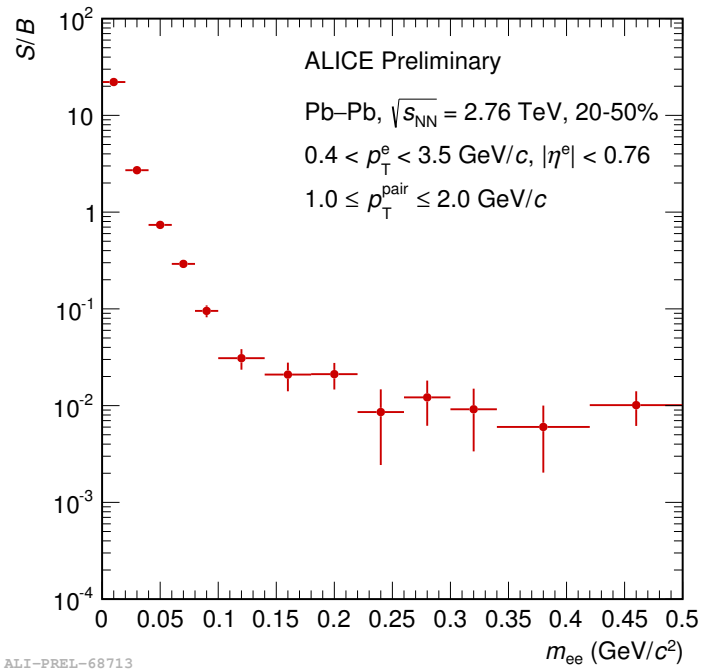




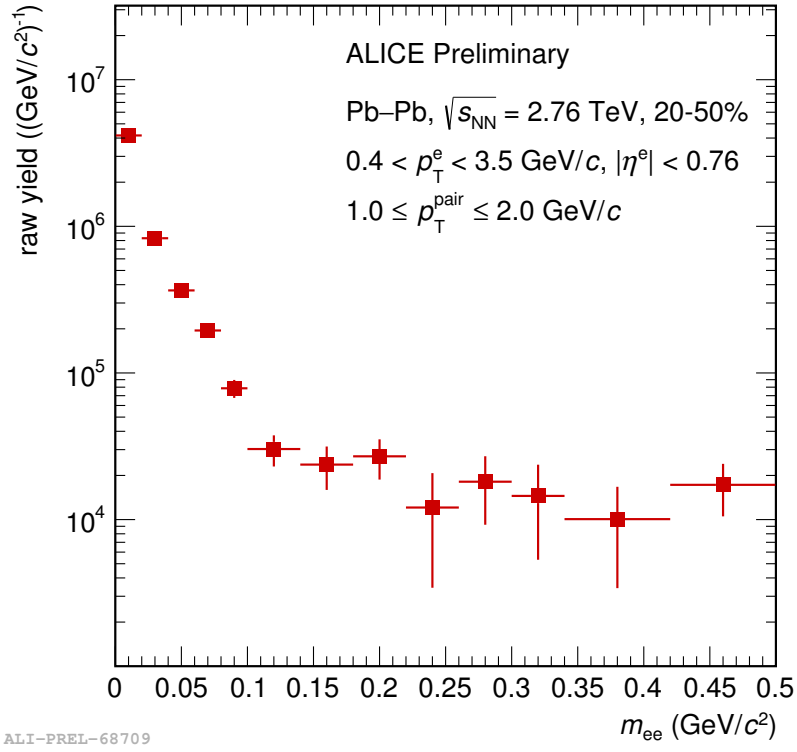
- More challenging S/B (½ - ¼ of pp)
- Good agreement between data and cocktail expectation
- Consistent results for electron p_T > 0.2 GeV/c and p_T > 0.4 GeV/c

Dielectrons in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

- 20-50% centrality
- Signal extraction focused on very low-mass region
- S/B ≈ $\frac{1}{2} - \frac{1}{5}$ of p–Pb

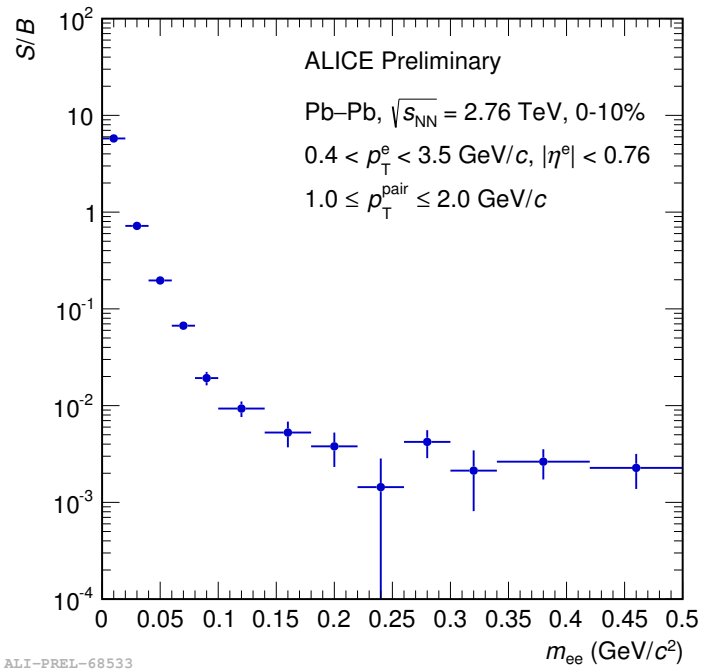


- Subtracted signal
  - No efficiency correction applied yet
  - Cocktail comparison coming



Dielectrons in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

- 0-10% centrality
- Signal extraction focused on very low-mass region
- S/B ≈ $1/10 - 1/30$ of p–Pb



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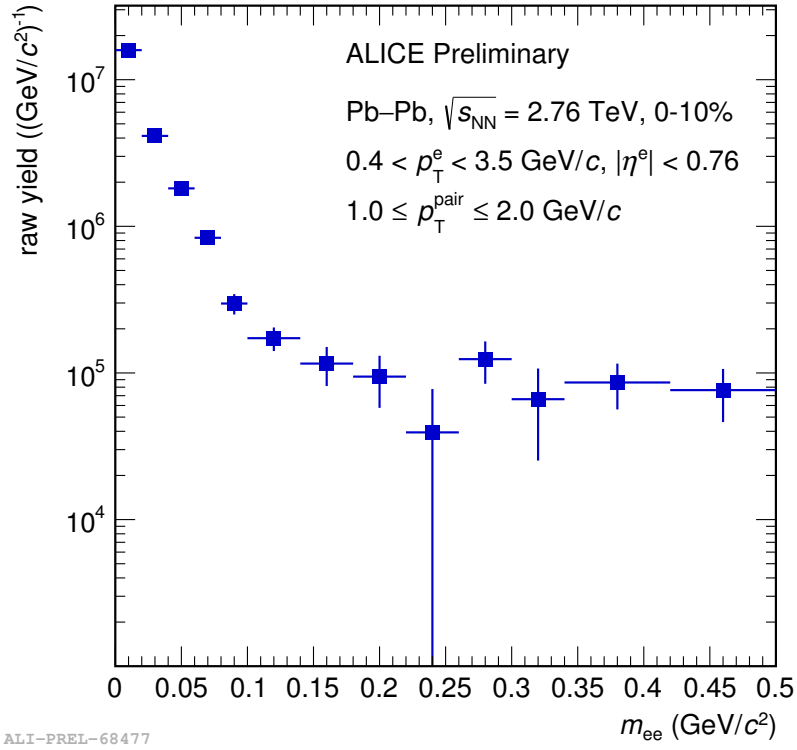
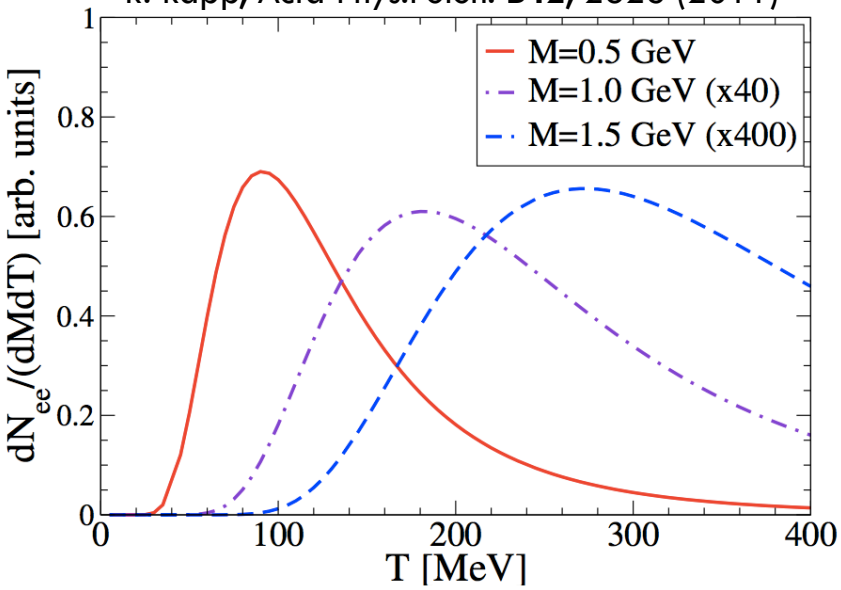


Temperature Measurements

- With real photons
  - average over collision evolution
  - blue-shift due to collective effects
- With virtual photons (→dielectrons)
  - m_{ee} as extra dimension
    - selective in time
  - no blue-shift in invariant mass

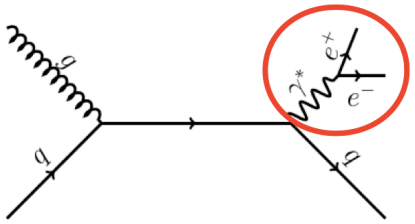
R. Rapp, Acta Phys.Polon. **B42**, 2823 (2011)



- At low mass
  - done in pp collisions, analysis ongoing in p–Pb, statistics limited in Pb–Pb
- At intermediate mass
  - planned in Pb–Pb collisions during LHC run 3, after major detector upgrade

Virtual direct photons

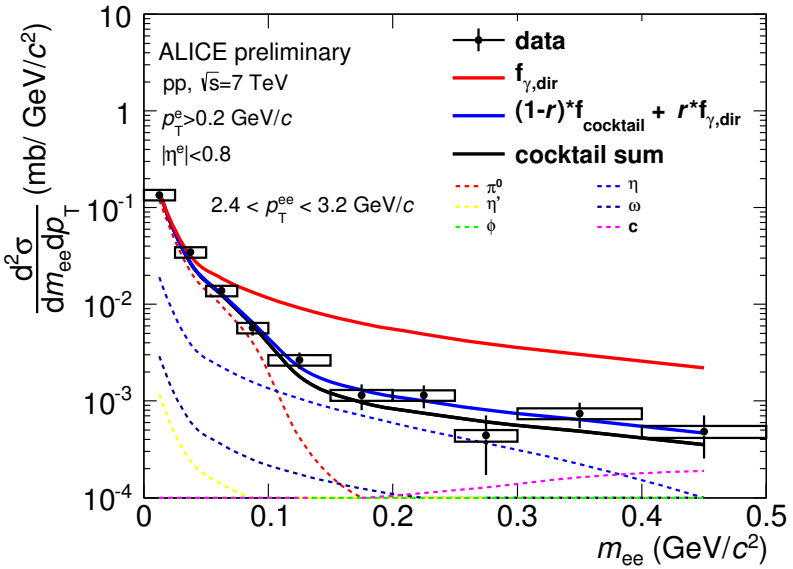
- Production processes
  - Quark-gluon Compton scattering →
  - Quark-antiquark annihilation



- Description via Kroll-Wada equation
  - $$\frac{d^2 n_{ee}}{dm_{ee}} = \frac{2\alpha}{3\pi}\frac{1}{m_{ee}}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right) S dn_\gamma$$
    - kinematic region: $p_T^{ee} \gg m_{ee}$
    - 1/m shape

→ … in pp collisions at ALICE:

- Focus on $m_{ee} < 0.5$ GeV/c^2 & $p_{T,ee} > 2.4$ GeV/c
- Combined fit = (1-*r*)•cocktail + *r*•γ^*_{direct}
  - ***r*** : ratio of direct over inclusive photons



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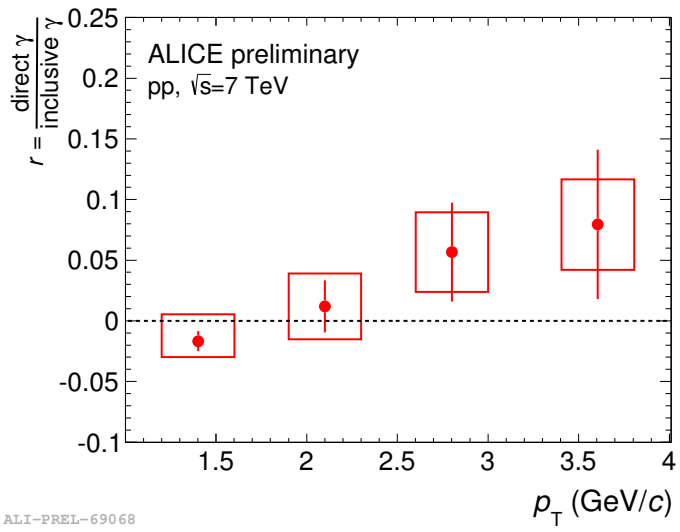
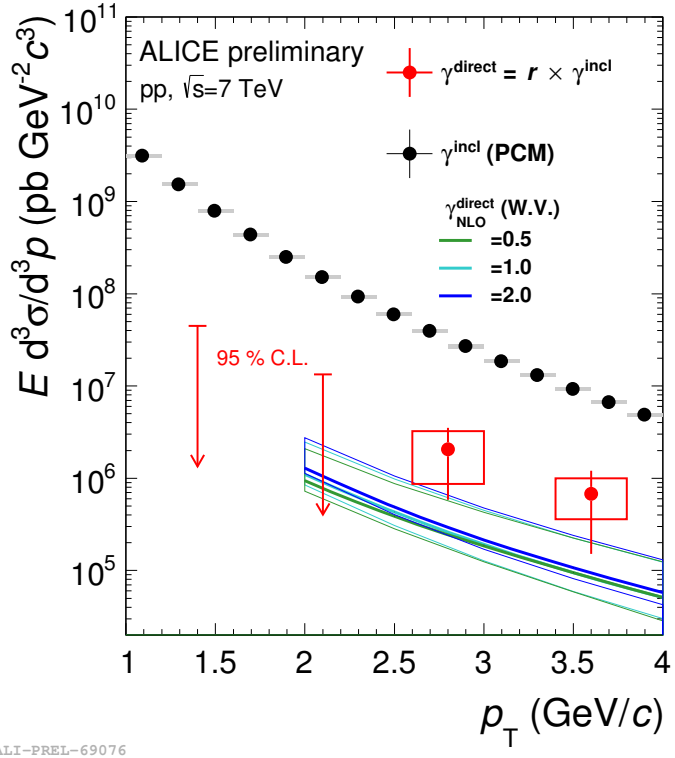
Direct photon spectrum in pp

- Assumption: $r = \frac{\gamma_{direct}}{\gamma_{inclusive}} = \frac{\gamma^{*}_{direct}}{\gamma^{*}_{inclusive}} \rightarrow \gamma_{direct} = r \cdot \gamma_{inclusive}$
- Extraction of r in different pair-p_T bins
- $\gamma_{inclusive}$ measured with Photon Conversion Method (PCM)

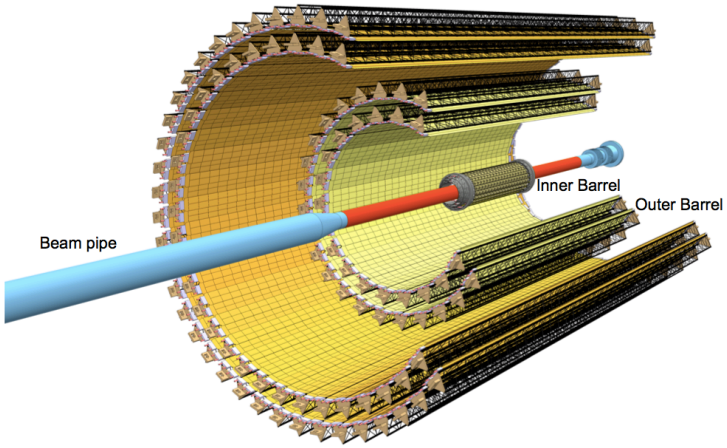




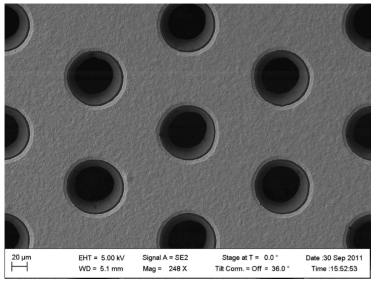
Direct γ spectrum consistent with NLO pQCD calculations within uncertainties

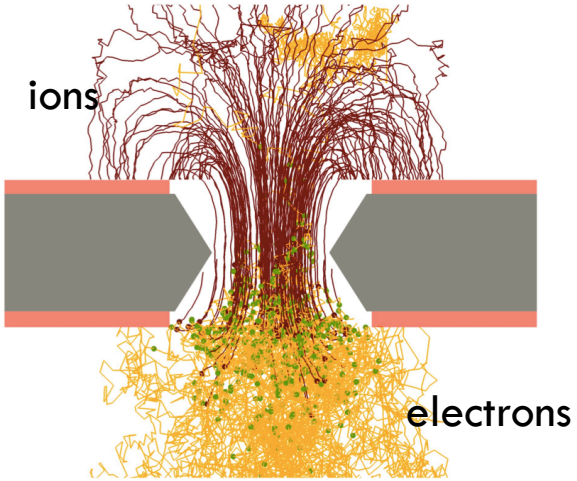
ALICE Upgrade

- New ITS
  - 7 Layers of Silicon Detectors (MAPS)
  - reduced material budget
  - precise measurement of displaced vertices (heavy-flavour decays)



- New readout chambers for the TPC
  - signal amplification based on GEM foils
  - continuous readout without gating grid
    - up to 100x higher data taking rate

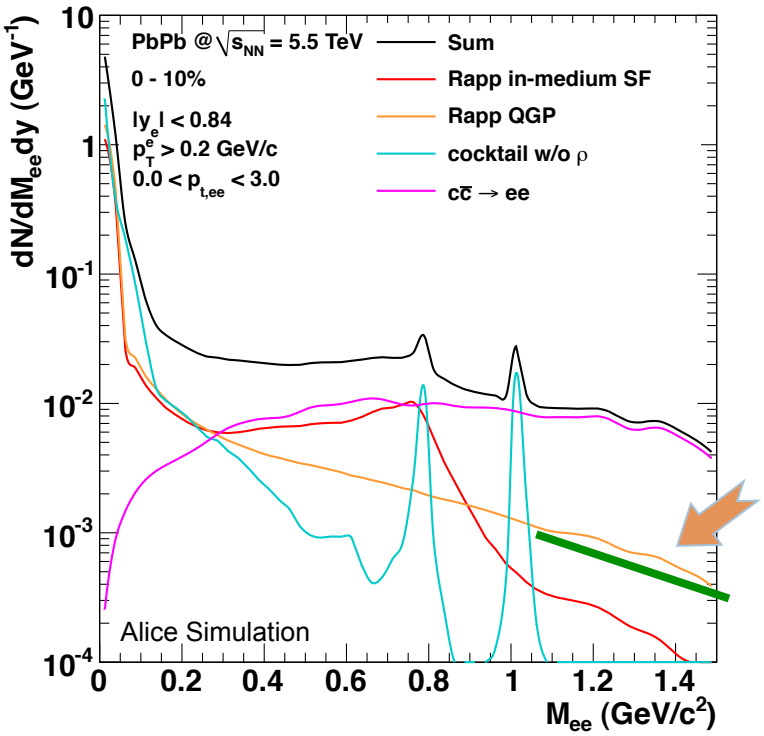




Study of early Temperature Measurement

- Goal: extract slope of QGP radiation in intermediate mass region

Predicted composition of invariant mass distribution at $\sqrt{s_{NN}} = 5.5$ TeV



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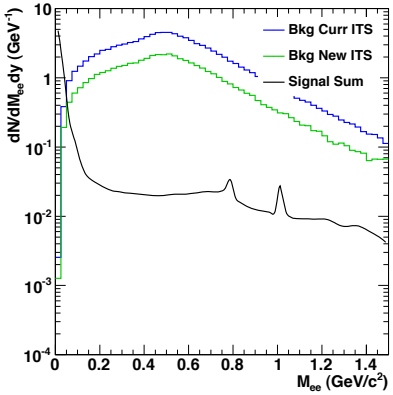
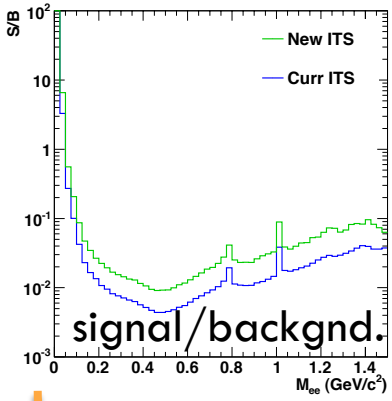
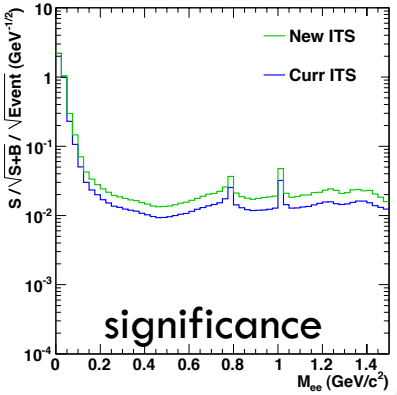


background estimates from ALICE simulations

total predicted signal



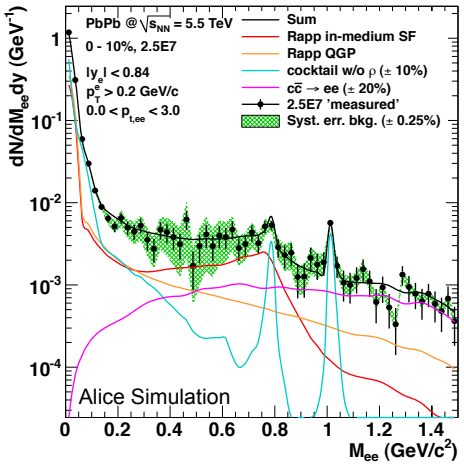


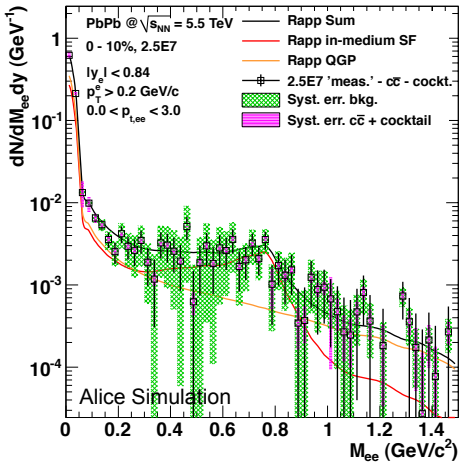
input for signal sampling using Poisson statistics!

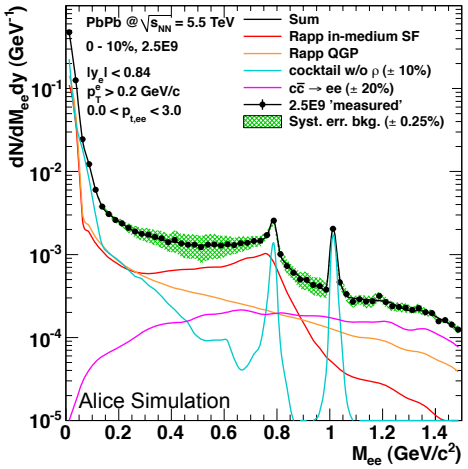
Expected Spectra

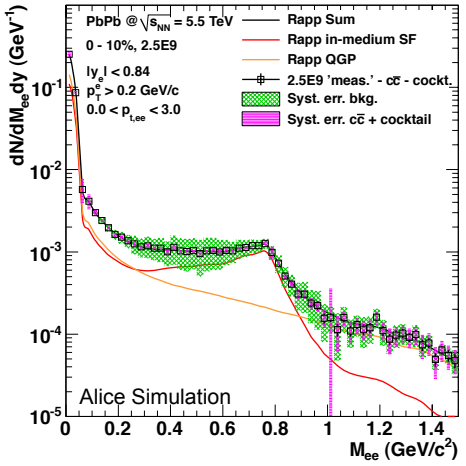
Signal – cocktail & charm = Excess

- Current ITS
  - DCA cut to reduce charm contribution
  - 25 M events within 0-10% centrality (curr. readout rate)
- New ITS & TPC
  - tighter DCA cut
  - 2.5 G events (continuous TPC readout)





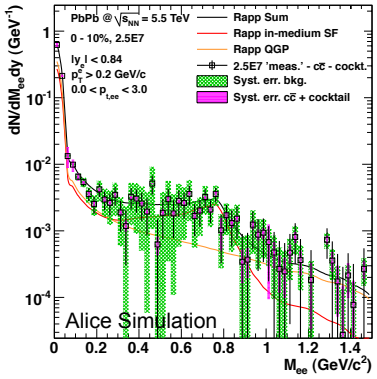




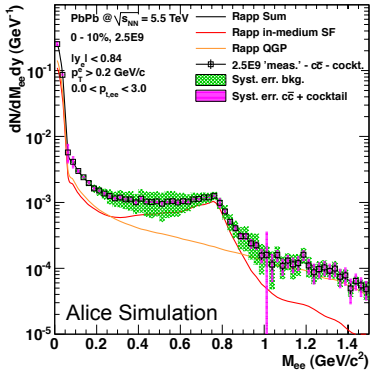
Extraction of Medium Temperature

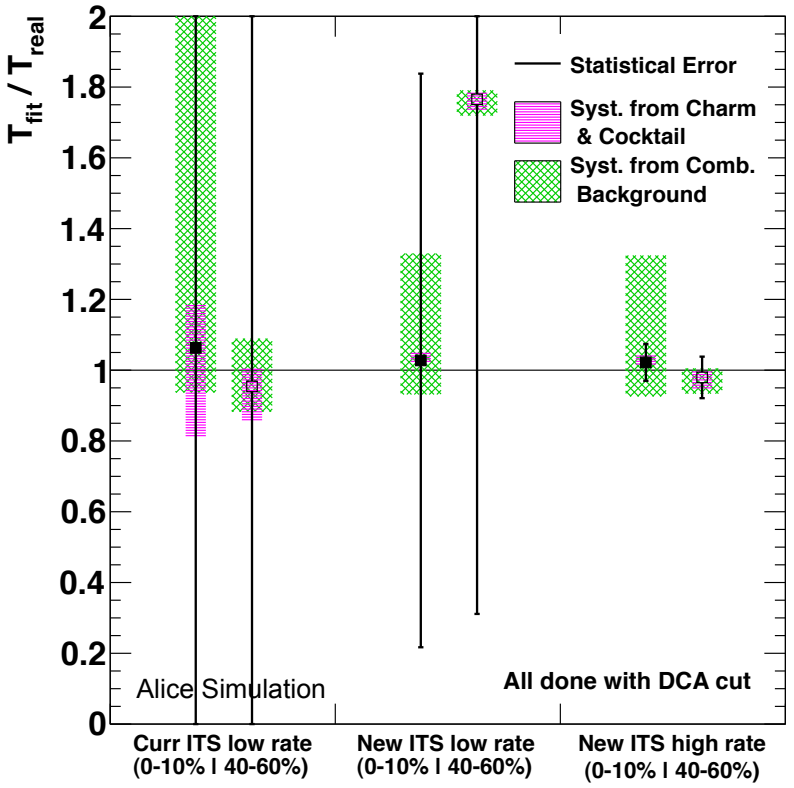
- Thermal radiation: $dN/dM_{ee} \sim \exp(-M_{ee}/T)$
- Exponential fit for $M_{ee} > 0.9$ GeV/c^2 gives effective temperature

Excess Current ITS, with DCA cut



Excess New ITS, DCA cut, high rate





➡ New ITS

- reduction of charm and background uncertainties

➡ New TPC readout

- improvement of statistical precision

Summary

- Electromagnetic probes are a good tool to study the evolution of high-energy collisions
- Electrons and positrons with low momenta can be reconstructed with the ITS, TPC and TOF detectors in ALICE
- Low-mass dielectrons have been measured in all collision systems at the LHC
  - they show good agreement with expectations in pp and p–Pb collisions
  - measurement in Pb–Pb is challenging, will benefit from more statistics in future
- e^+e^- pairs can be used for temperature measurements
  - the selection of invariant mass regions gives access to different collision phases

- ALICE will implement major upgrades of the ITS and TPC for LHC run 3
  - The performance of the dielectron measurement in Pb–Pb was studied
  - With the upgraded ALICE detector, a precise measurement of the early effective temperature is expected to become feasible