Dielectron measurements in Pb-Pb collisions with ALICE at the LHC

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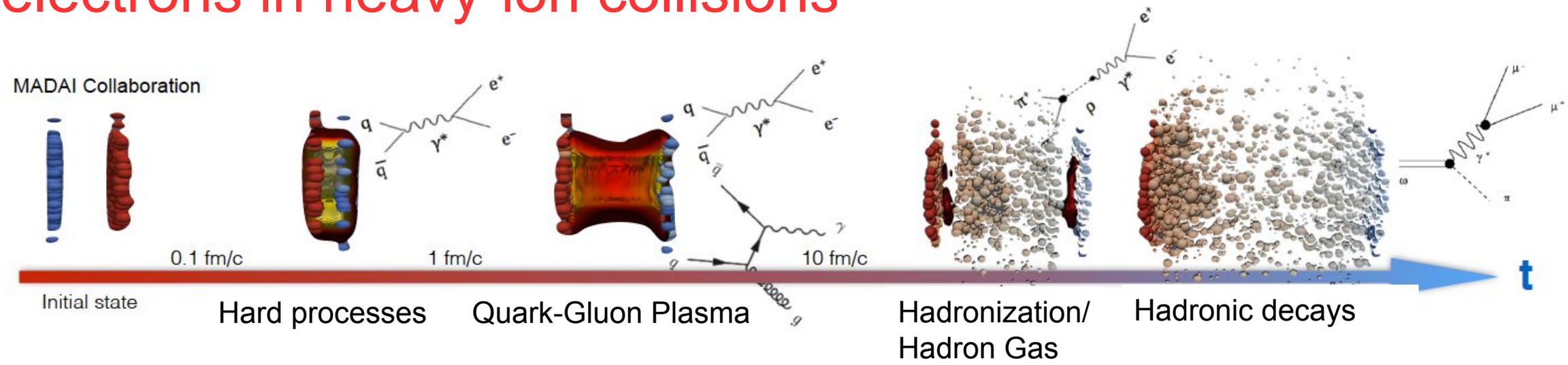
Goethe-University Frankfurt
on behalf of the ALICE Collaboration

Friday 12, 2019, HEP 2019, Ghent, Belgium

Dielectrons in heavy-ion collisions

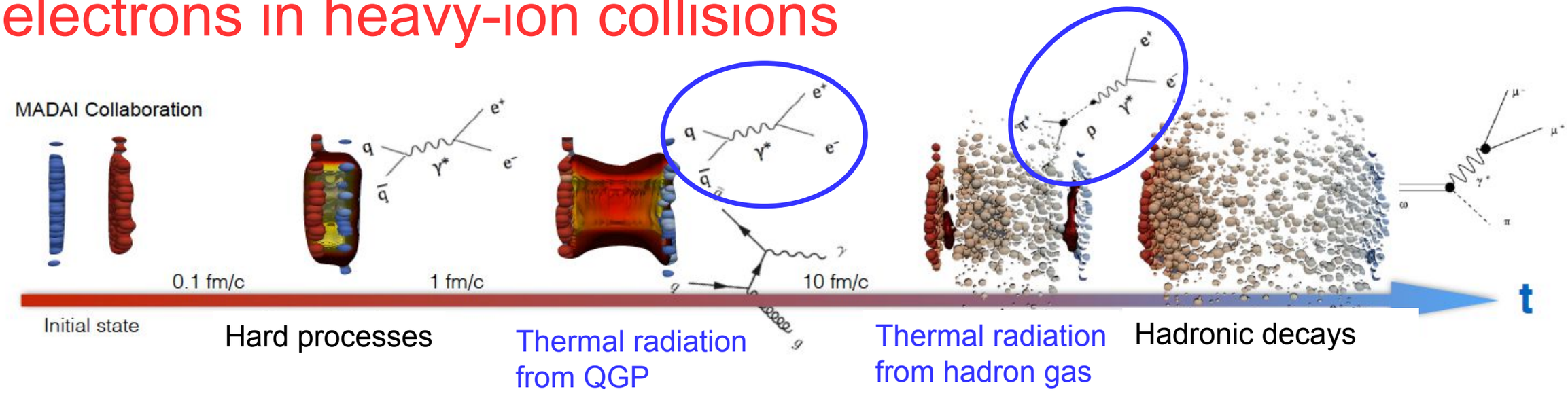


Dielectrons:

- Are produced at all stages of the collision
- Leave the system with small final-state interactions

→ Carry information from the whole space-time evolution of the system

Dielectrons in heavy-ion collisions



Dielectrons:

- Are produced at all stages of the collision
- Leave the system with small final-state interactions

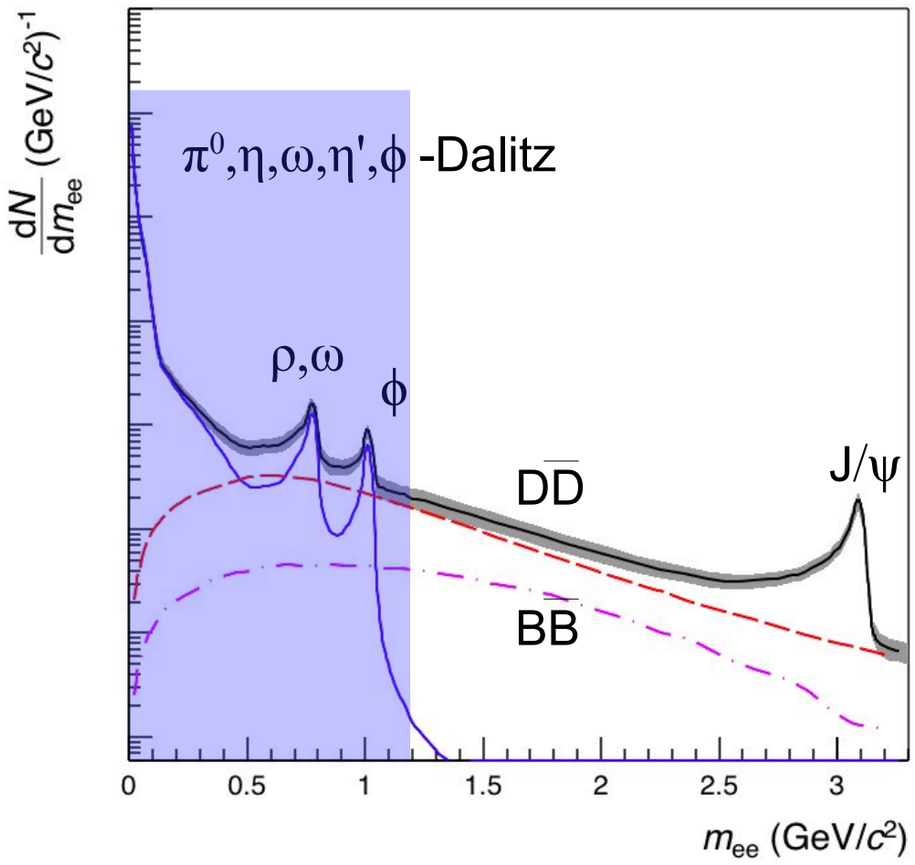
→ Carry information from the whole space-time evolution of the system

Give insight into:

- **Deconfinement with thermal radiation from the Quark-Gluon Plasma**
- **Chiral-phase transition** ($\langle \bar{q}q \rangle$=0) **with modification of the ρ meson/thermal radiation from the hadron gas**

Dielectron sources

Dielectrons come from many different sources



Earlier production time

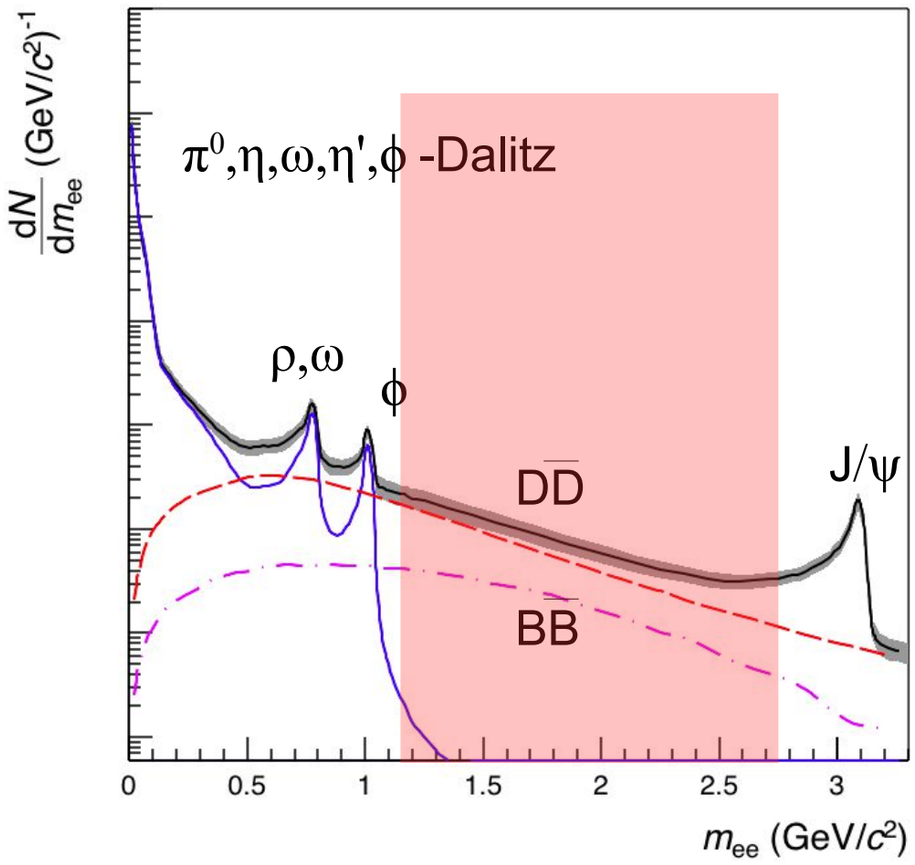
Light-flavour mesons:

- Dalitz decays ($\pi^0,\eta,\omega,\eta',\Phi$) and 2-body decays ($\rho,\omega,\Phi$) of mesons
- **ρ particularly interesting**:
  - Short lifetime compared to the one of the fireball (≈10 fm at the LHC)
  - Decay (and regeneration) in the hot medium where **chiral symmetry** is predicted to be partially restored

  → Study modification of ρ spectral function and thermal production of ρ
- pp and p-Pb collisions provide crucial baseline measurements

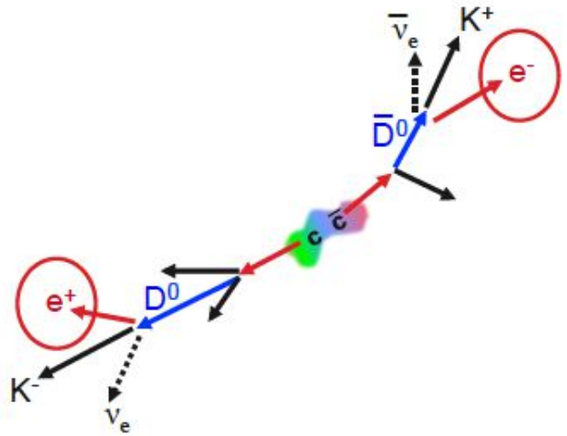
Dielectron sources

Dielectrons come from many different sources



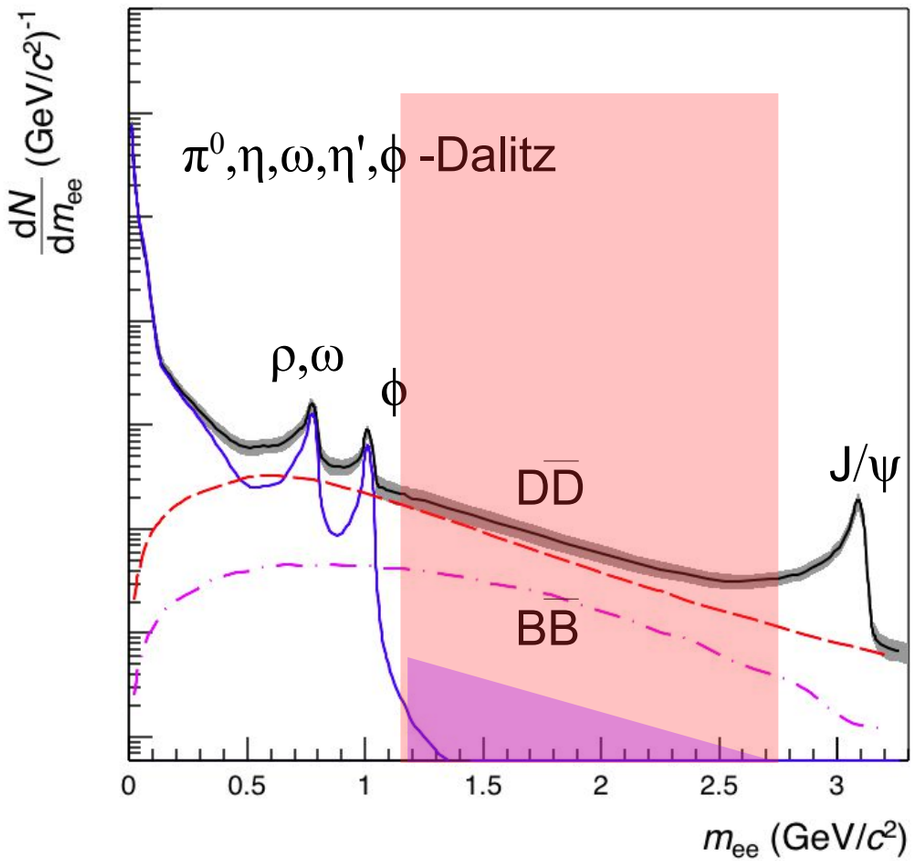
Earlier production time

Heavy-flavour mesons:



- Dielectrons from correlated heavy-flavour hadron decays
- **Complementary to single heavy-flavour hadron measurements**
  Sensitive to kinematical correlation between Q and $\bar{Q}$
- Affected by gluon shadowing, heavy-quark energy loss and thermalization
- **Dominant over a wide invariant mass range at the LHC**
  → need additional experimental means to separate them from prompt sources (thermal radiation)

Dielectron sources

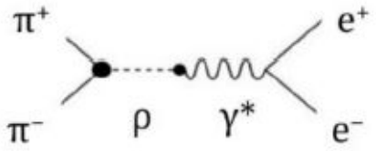


Earlier production time

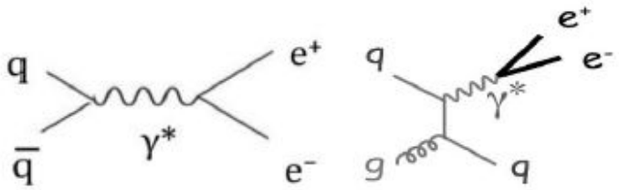
Dielectrons come from many different sources

Thermal radiation:

- Hadronic sources (m_{ee} < 1.2 GeV/c^2):



- **Partonic sources**

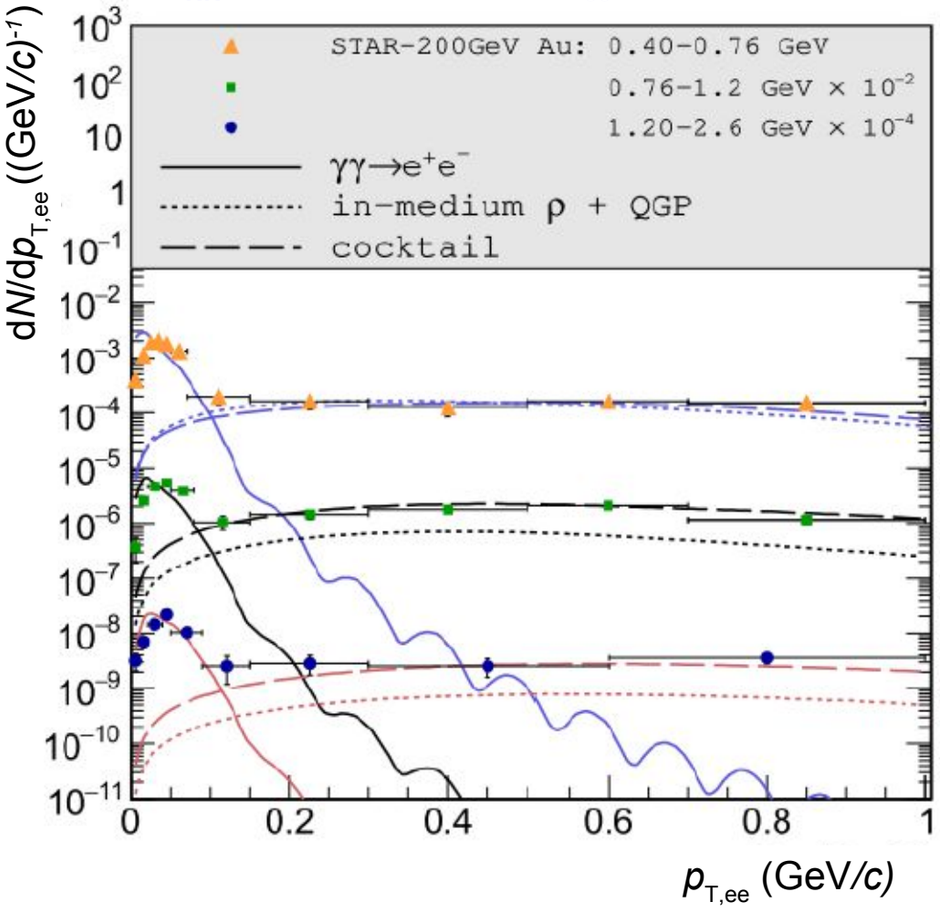


Give acess to QGP temperature
$dN/dm_{ee} \sim \exp(-m_{ee}/T)$ (no Doppler shift)
Measurement challenging due to heavy-flavour background

Dielectron sources

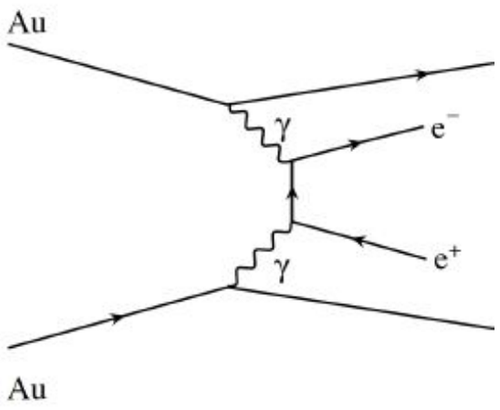
Dielectrons come from many different sources

$p_{T,ee}$ spectra in 60-80% central Au+Au at $\sqrt{s_{NN}}$ = 200 GeV in ≠ m_{ee} regions (STAR)



Szczurek, A.,arXiv:1903.06080[hep-ph]
STAR Phys. Rev. Lett. 121 (2018) 132301

Photo-production:



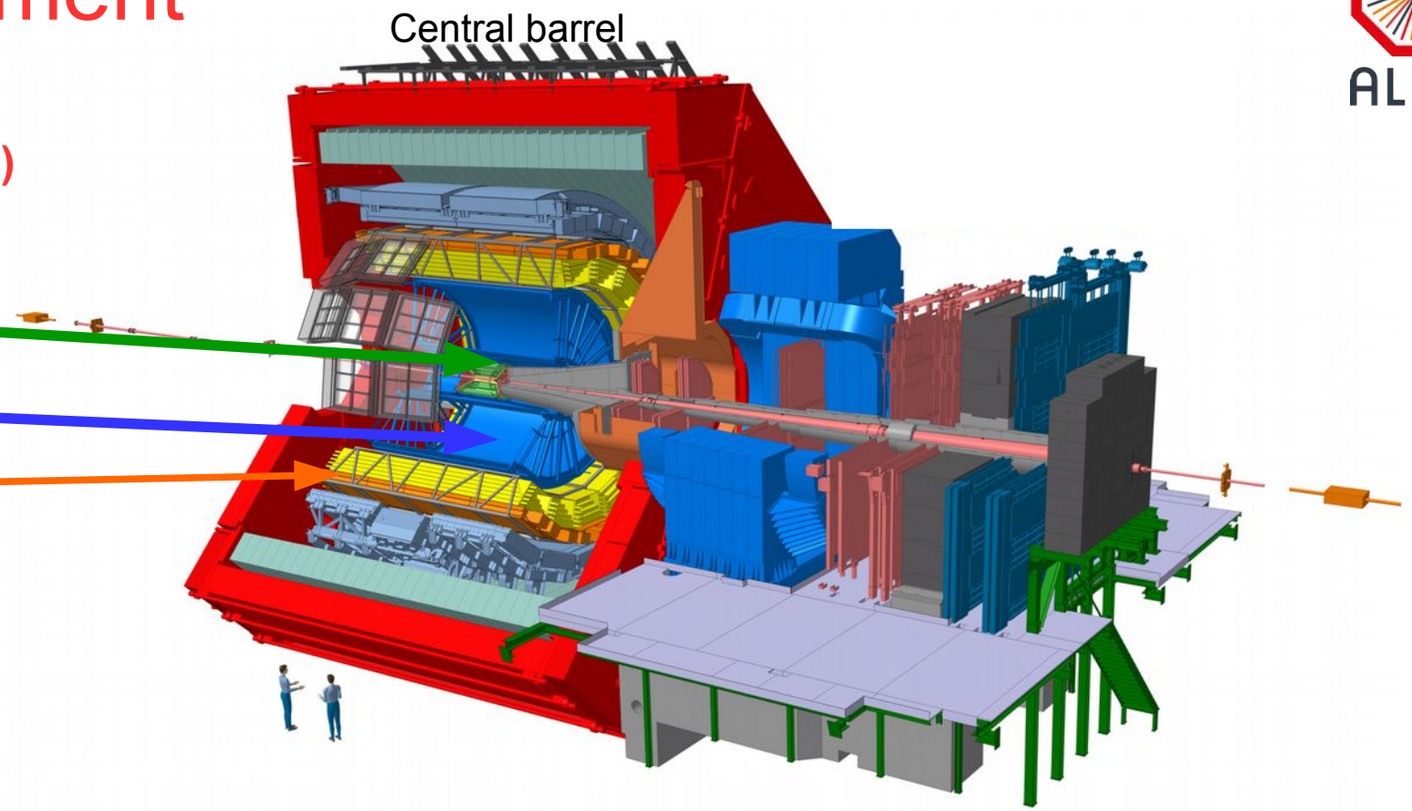
(here ultra-peripheral collisions without hadronic interaction)

- **$\gamma\gamma \rightarrow e^+e^-$** continuum in m_{ee} scaling with Z^4 **from coherent electromagnetic fields of the colliding nuclei**
- **Produce soft e^+e^- pairs** (low $p_{T,ee}$)
- Small centrality dependence compared to that of thermal radiation → **Relative contribution increases in peripheral collisions**

A Large Ion Collider Experiment

Dielectrons measured at mid-rapidity ($|\eta_e| < 0.8$)
in the central barrel

- **Inner Tracking System**
  Tracking, vertexing, particle identification
- **Time Projection Chamber**
  Tracking and particle identification
- **Time-Of-Flight**
  Particle identification
- **V0 hodoscopes**
  Trigger, centrality estimator



Heavy-ion data shown in this talk

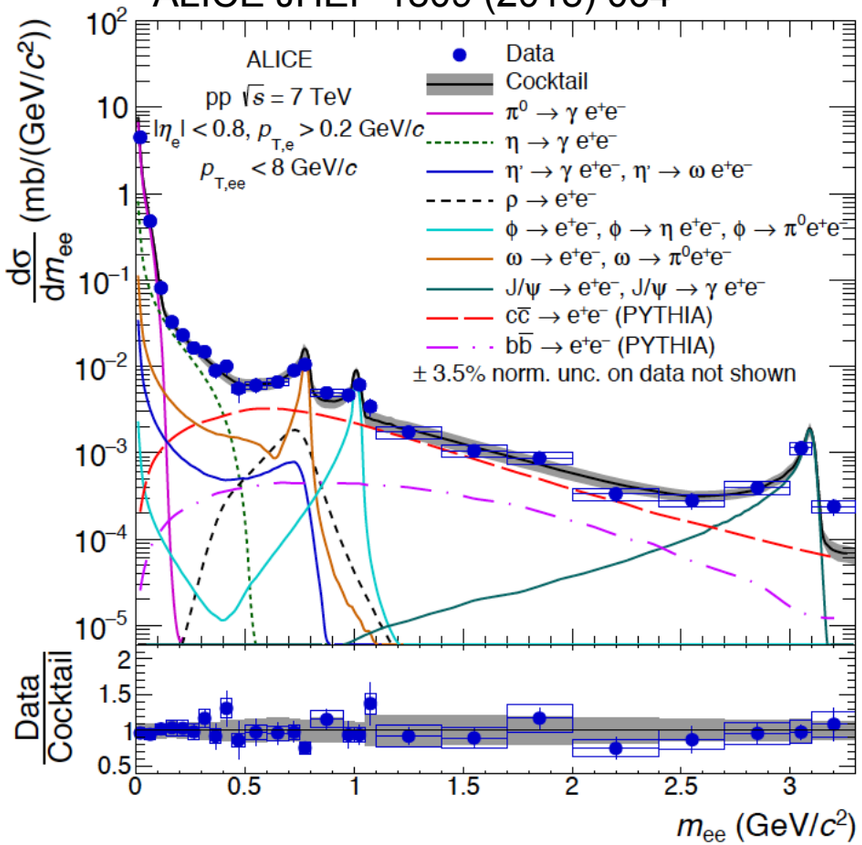
Collision system	Year	Number of events	Trigger
Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV	2011 (Run-1)	≈ 20 M	Centrality trigger 0-10%
Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV	2015 (Run-2)	≈ 80 M	Minimum-bias

Analysis of the **Pb-Pb data at $\sqrt{s_{NN}}$ = 5.02 TeV from 2018** ongoing (expect **~ 9 more statistics in 0-10% centrality**)

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

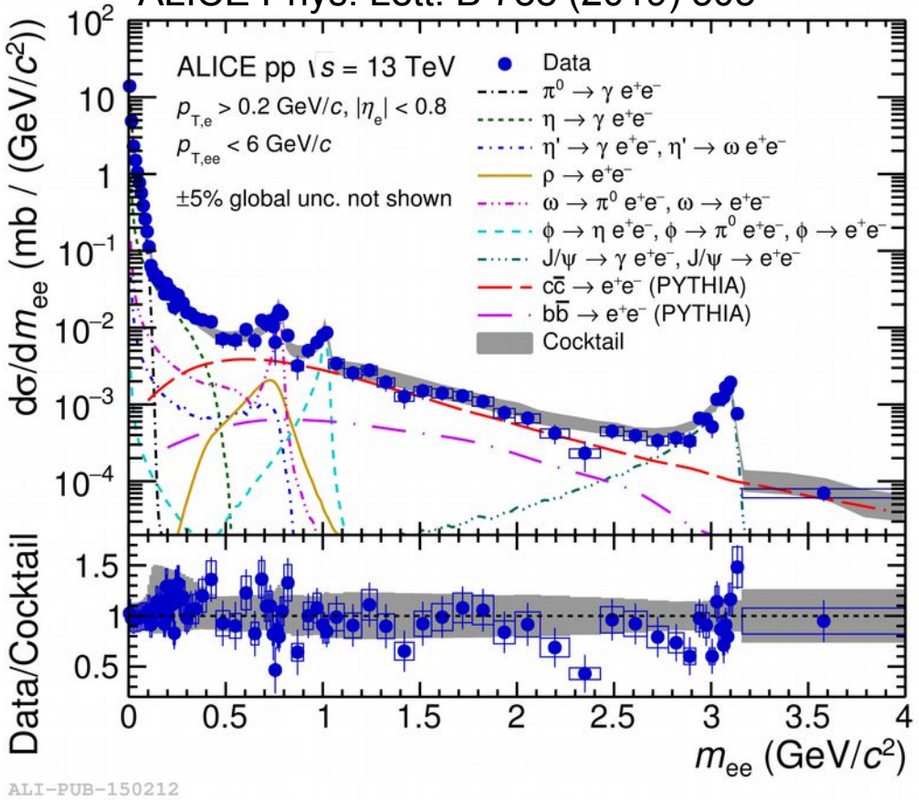
pp $\sqrt{s}$ = 7 TeV

ALICE JHEP 1809 (2018) 064



pp $\sqrt{s}$ = 13 TeV

ALICE Phys. Lett. B 788 (2019) 505



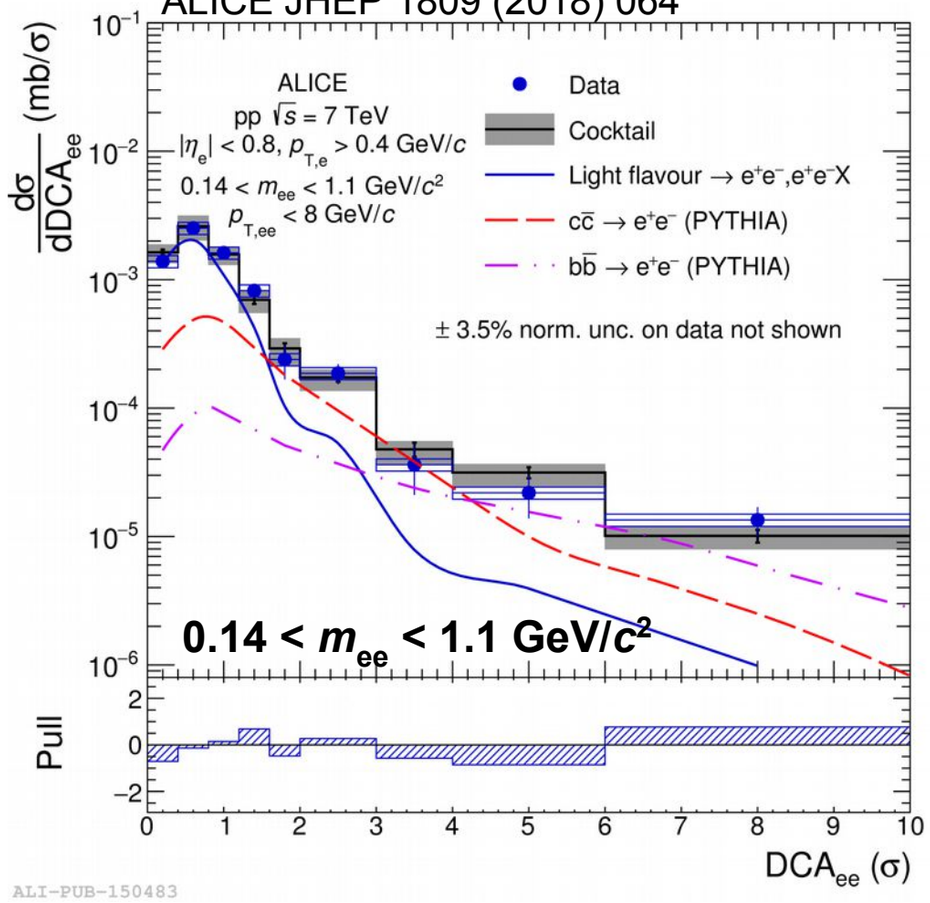
- Dielectron production **well understood** for $p_{T,e}$ > 0.2 GeV/c
- **Heavy-flavour contributions dominate** for m_{ee} > 0.5 GeV/c²

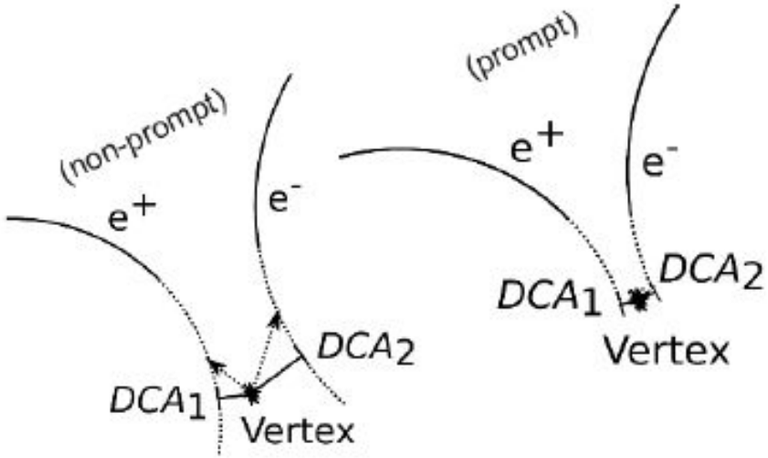
pp and p-Pb results
S. Scheid Sat. 09:45

Topological separation of e^+e^- sources in pp at $\sqrt{s}$ = 7 TeV

pp $\sqrt{s}$ = 7 TeV

ALICE JHEP 1809 (2018) 064





$$\mathrm{DCA_{ee}} = \sqrt{0.5\left(\left(\frac{\mathrm{DCA_1}}{\sigma_1}\right)^2 + \left(\frac{\mathrm{DCA_2}}{\sigma_2}\right)^2\right)}$$

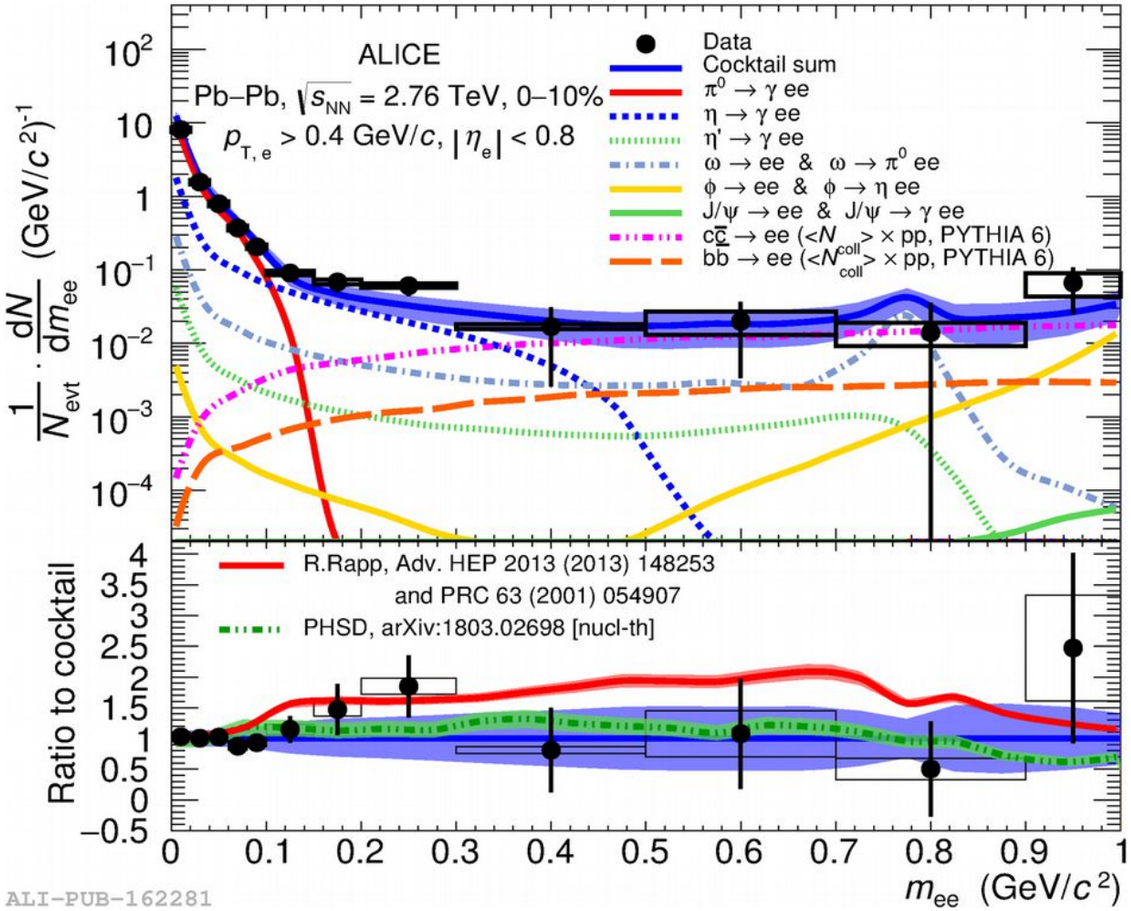
- **Separate non-prompt** (D,B) **from prompt** (light-flavour, thermal) **dielectron sources with Distance of Closest Approach (DCA)**
  D mesons: $c\tau \approx 150$ μm, B mesons: $c\tau \approx 470$ μm
- Not yet used in Pb-Pb analyses

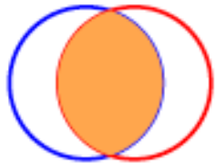
$\mathrm{DCA_{ee}}$(prompt) < $\mathrm{DCA_{ee}}$(charm) < $\mathrm{DCA_{ee}}$(beauty)

pp and p-Pb results
S. Scheid Sat. 09:45

0-10% central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

ALICE Phys. Rev. C 99, 024002



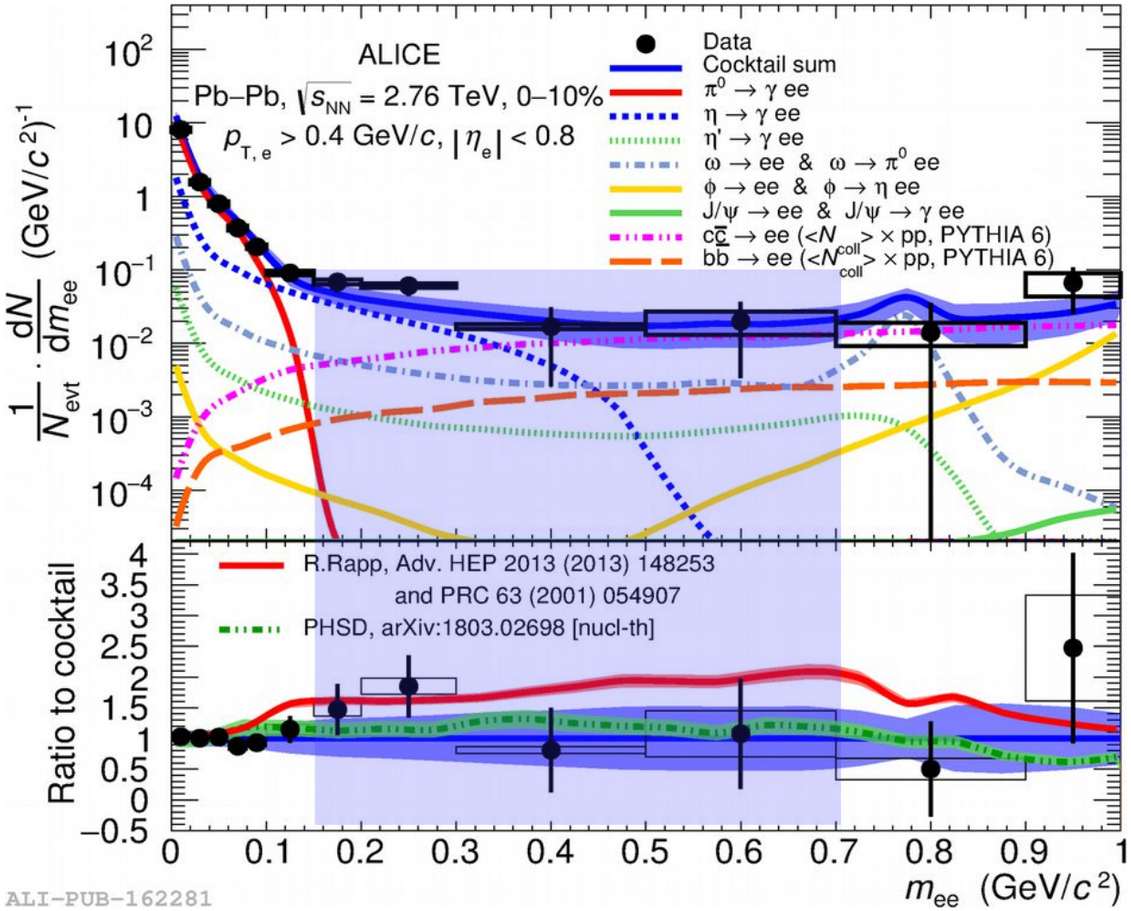


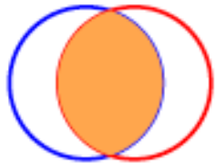
Run 1 (2011 data): pioneering study in Pb-Pb collisions
no use of DCA_{ee} yet

- **Corrected e^+e^- yield in the ALICE acceptance**
- ***Vacuum* cocktail of known hadronic sources based on:**
  - Measured π^0 spectrum
  - Measured K/π^0 ratio in Pb-Pb and η/π^0 ratio in pp for η
  - m_T scaling for other hadrons
  - $c\bar{c}$ and $b\bar{b}$ contributions from PYTHIA normalized to pp x N_{coll}

0-10% central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

ALICE Phys. Rev. C 99, 024002





Run 1 (2011 data): pioneering study in Pb-Pb collisions
no use of DCA_{ee} yet

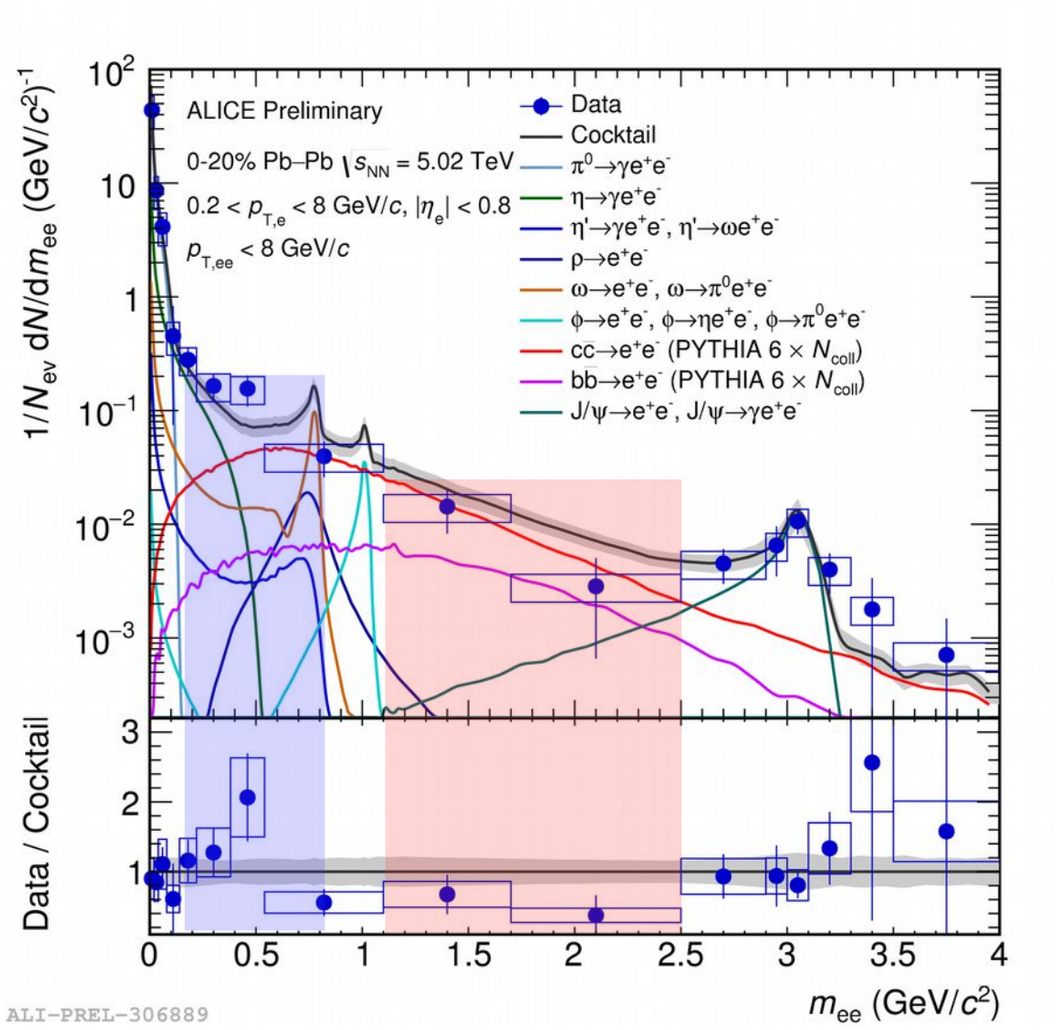
- **Data/*vacuum* cocktail ratio in low mass region:**
  1.40 ± 0.28 (stat.) ± 0.08 (syst.) ± 0.27 (cocktail)
  in 0.15 < m_{ee} < 0.7 GeV/c^2

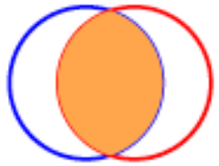
- Models including **thermal dielectron production:**
  - **Expanding fireball model: R.Rapp [1]**
  - **Transport approach: PHSD [2]**

Data consistent with thermal dielectron production
Reduced sensitivity (stats., $c\bar{c}$ background)

[1] R.Rapp, Adv. HEP 2013 (2013) 148253, Phys. Rev. C63 (2001) 054907
[2] T.Song, W.Cassing, P.Moreau, E.Bratkovskaya arXiv:1803.02698 [nucl-th]

0-20% central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV



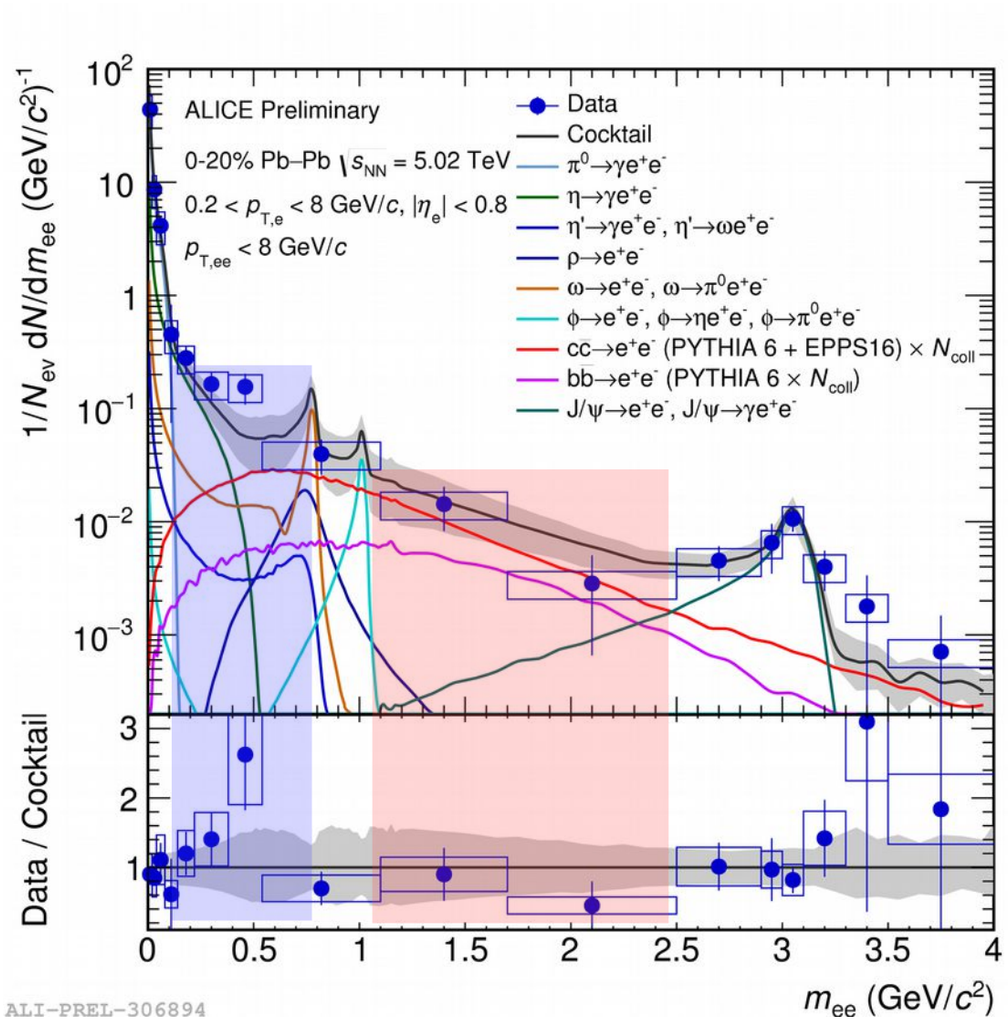


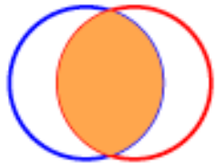
Run 2 (2015 data): data compared to *vacuum* cocktail:

- **Results also compatible with low-mass enhancement**
  Factor 1.15 ± 0.18 (stat.) ± 0.31 (syst.) ± 0.17 (cocktail)
  in $0.15 < m_{ee} < 0.7$ GeV/c^2

- **Indication for charm suppression**
  at intermediate mass ($1.1 < m_{ee} < 2.5$ GeV/c^2)

0-20% central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV





Run 2 (2015 data): data compared to *vacuum* cocktail:

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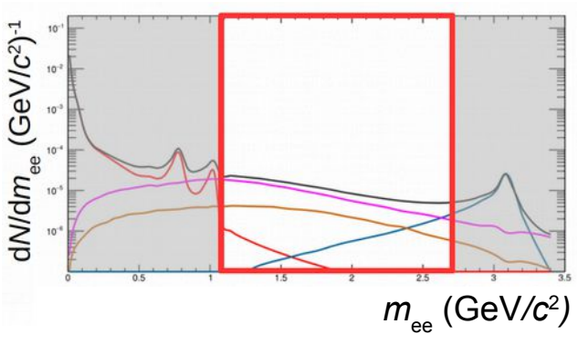
  Factor 1.15 ± 0.18 (stat.) ± 0.31 (syst.) ± 0.17 (cocktail)
  in $0.15 < m_{ee} < 0.7$ GeV/c^2

- **Indication for charm suppression**
  Better description if **cold-nuclear matter effects** are taken into account for charm (EPPS16 nPDF)
  → **Reduce the cocktail yield slightly**
  → **Increase cocktail systematic uncertainties**

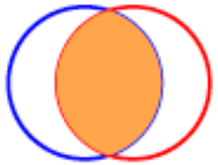
Peripheral Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

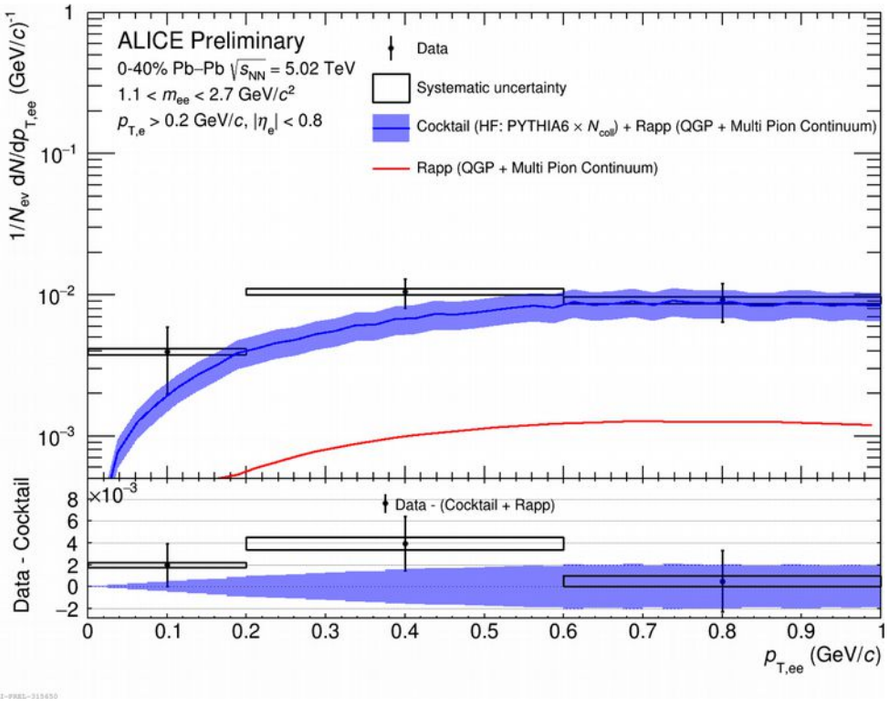
- **Excess observed at low $p_{T,ee}$ in peripheral Pb-Pb collisions in $1.1 < m_{ee} < 2.7$ GeV/c^2**
  - No significant excess observed in 0-40% central Pb-Pb collisions
  - **3.6 σ excess in 70-90%** central Pb-Pb collisions

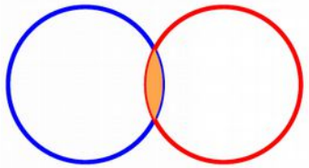
→ **Could be related to photo-production of e^+e^-** (no prediction available so far)

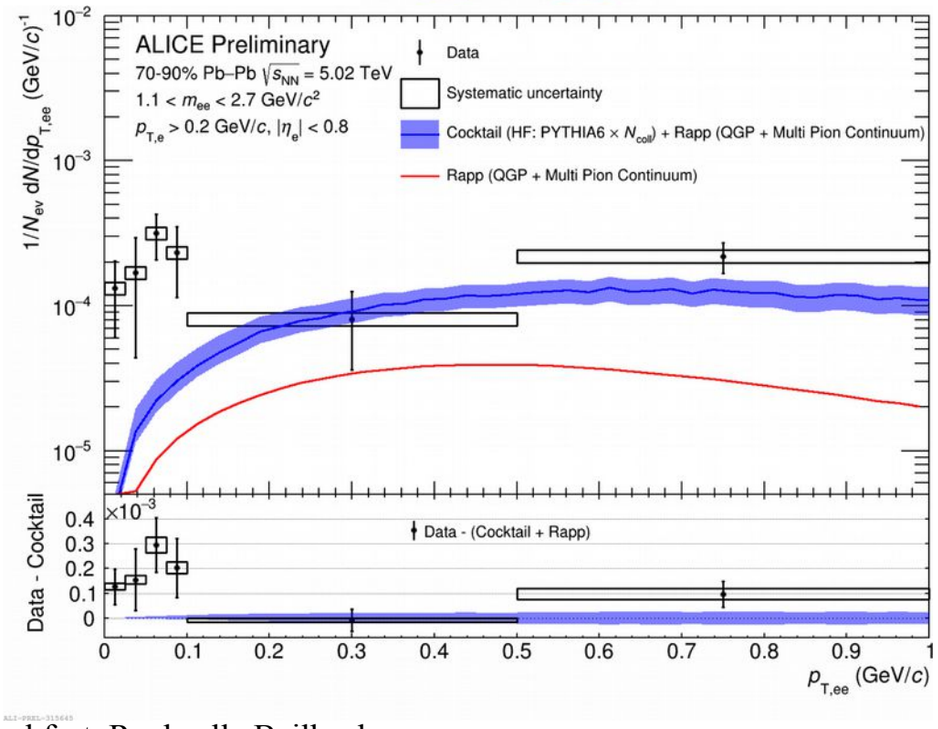


Dielectron $p_{T,ee}$ spectra









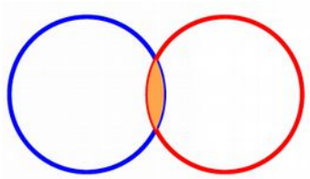
Peripheral heavy-ion collisions: from RHIC to LHC

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

→ also observed by the STAR Collaboration at RHIC:

- In the same $p_{T,ee}$ range
- With a relative excess slightly larger than at LHC

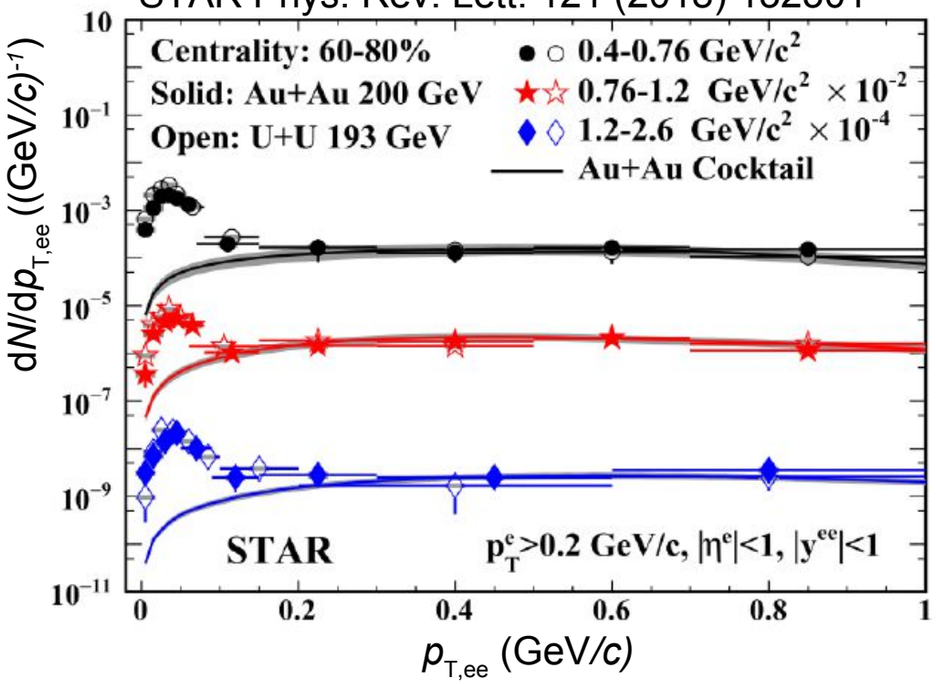
→ Can be described at RHIC by calculations for coherent photo-production of e^+e^-



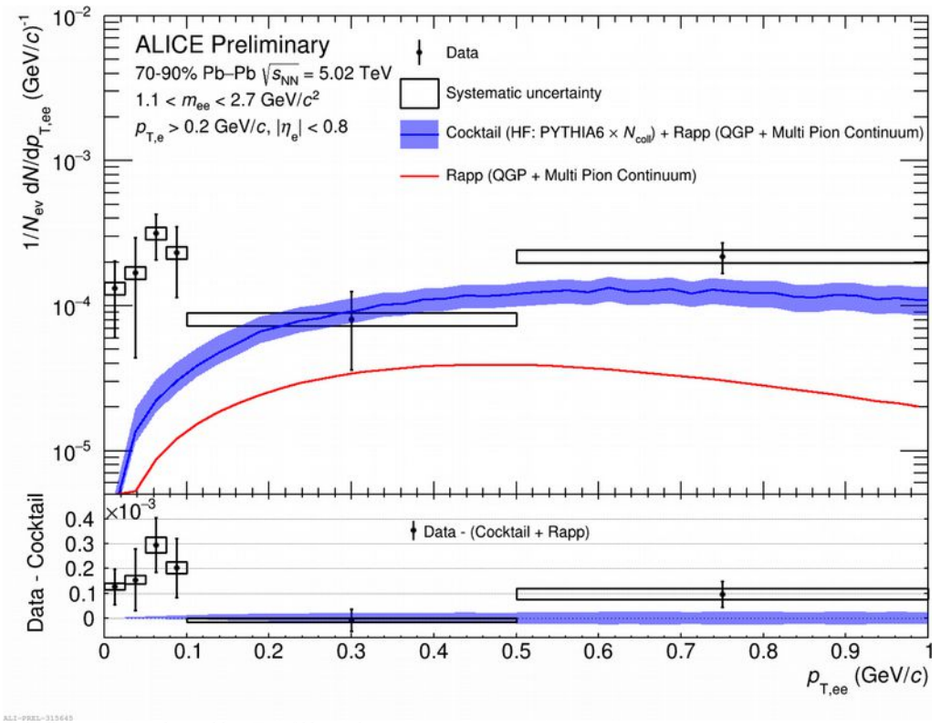
Dielectron $p_{T,ee}$ spectra

RHIC

STAR Phys. Rev. Lett. 121 (2018) 132301



LHC



Summary and Outlook

- **Low-$p_{T,ee}$ dielectron production:**
  - **Excess of 3.6σ in 70-90% central Pb-Pb collisions** (data compatible with expectation in 0-40% centrality)

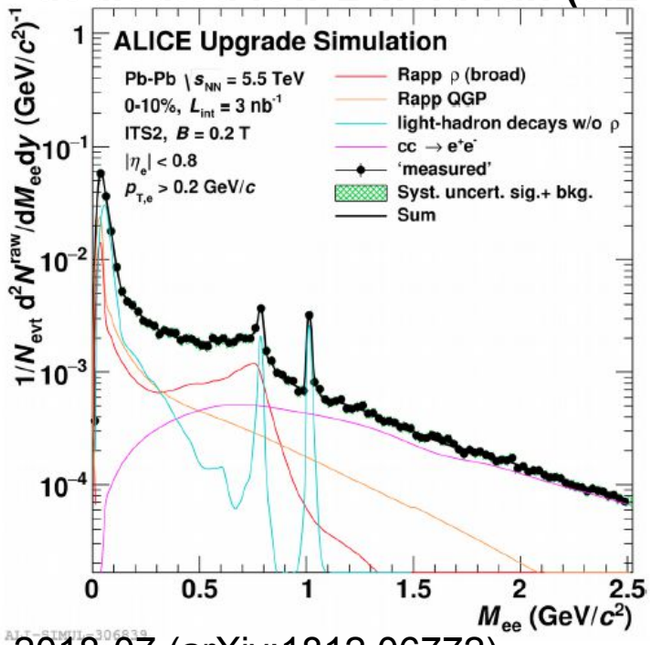
  → **Photo-production $\gamma\gamma \rightarrow e^+e^-$ not included in the cocktail yet**

  → **Outlook: study B field effects**
- **Study of ρ spectral function modification and thermal radiation from the medium:**
  - **Limited by statistics and heavy-flavour background** (no use yet of DCA_{ee})

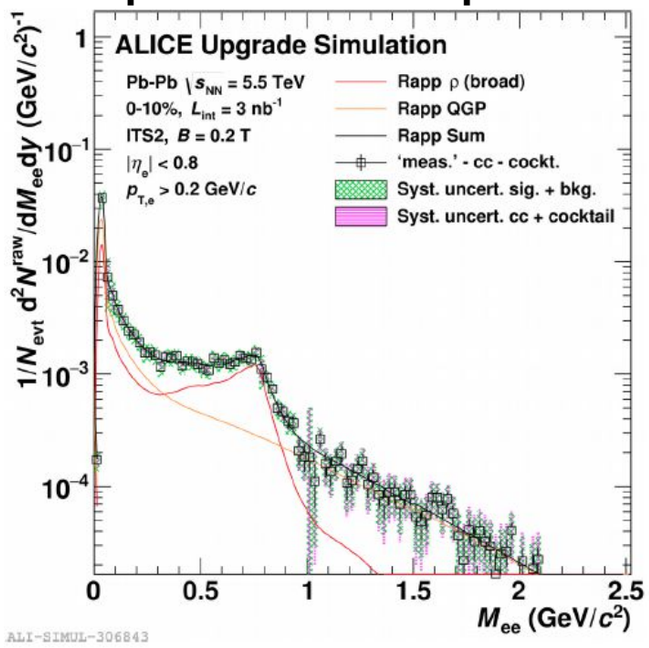
  → **Analysis of 2018 Pb-Pb data on going** (x9 more stats in 0-10%)

  → Major upgrades of ITS and TPC **for Run3**: better DCA resolution (x3 in xy and x5 in z), higher acquisition rate (x100)

Feasibility study with 3nb^{-1} dedicated low B field run (0.2 T)



Expected excess spectrum



→ **ρ spectral function with ~15% unc.**

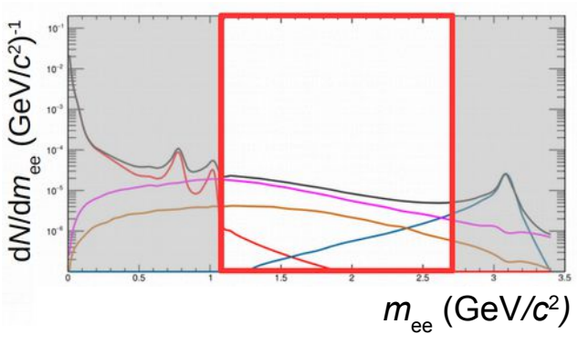
→ **Early *T* of the medium with ~20% unc.**

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

Thank you

Peripheral Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

- **Excess observed at low $p_{T,ee}$ in peripheral Pb-Pb collisions in 1.1 < m_{ee} < 2.7 GeV/c^2**
  Including shadowing for cc (**EPS09** & **EPPS16** nPDFs)
  → **Reduce the cocktail yield slightly**
  → **Increase cocktail systematic uncertainties**



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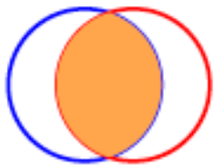
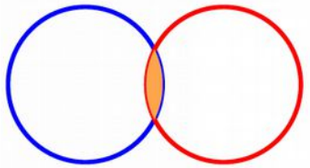
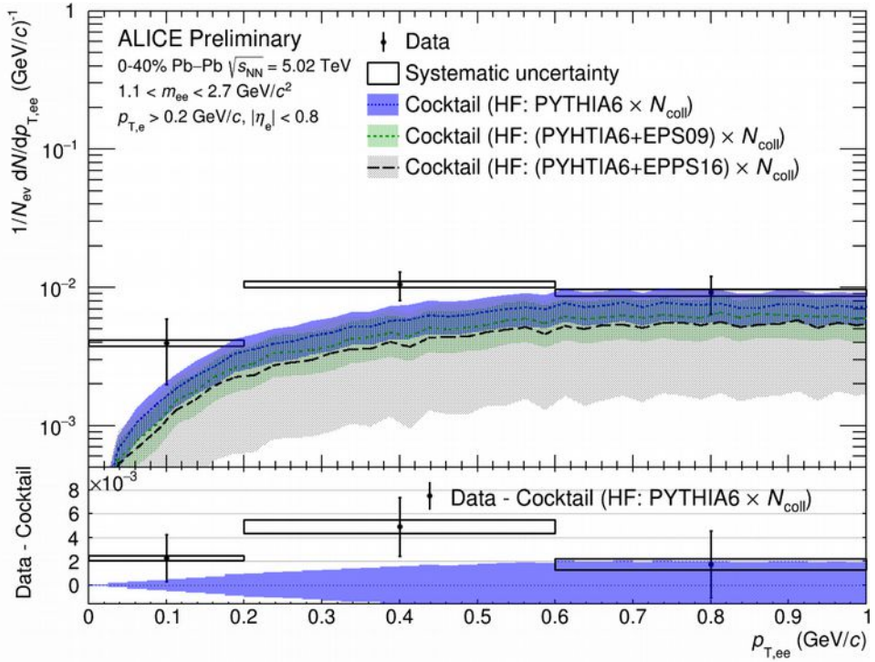
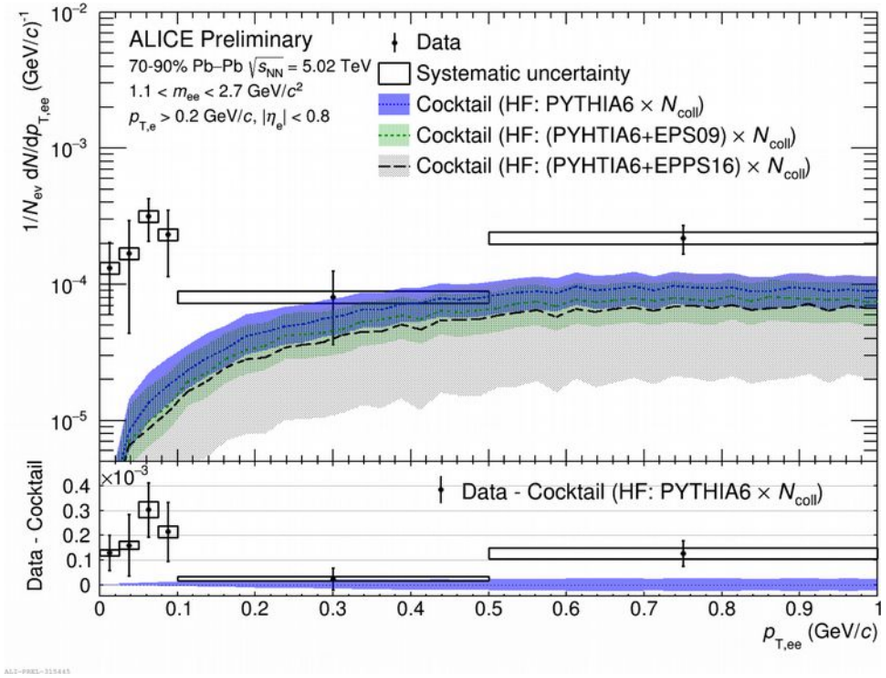
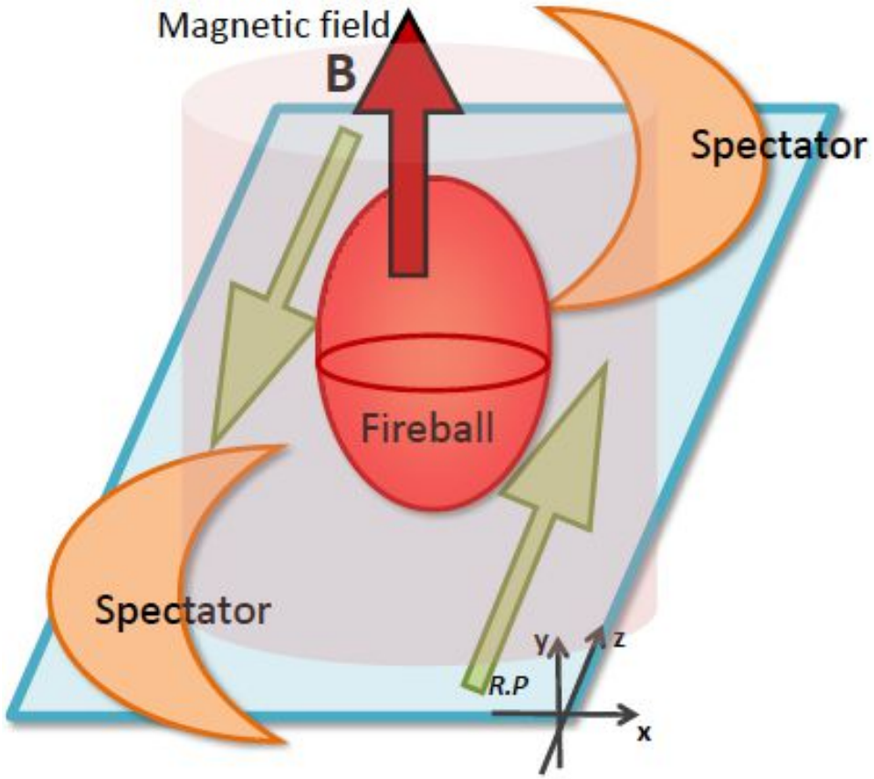




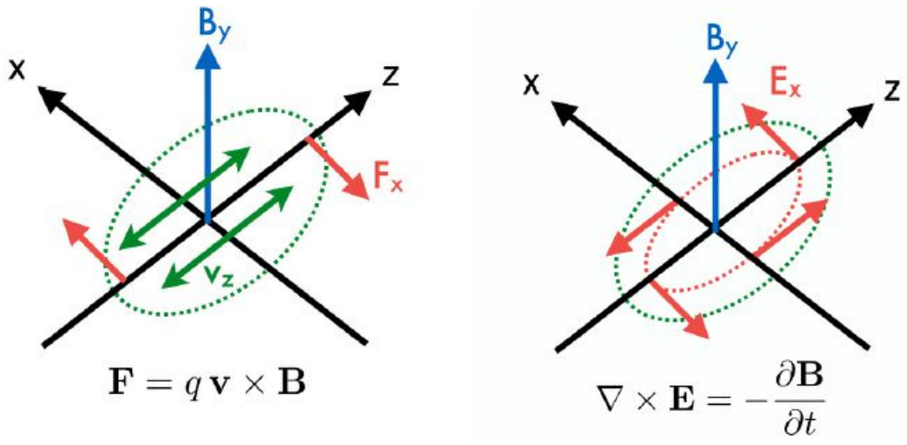




Intense magnetic field created in heavy-ion collisions



Maximum strength ~ 10^{15} Teslas at the LHC



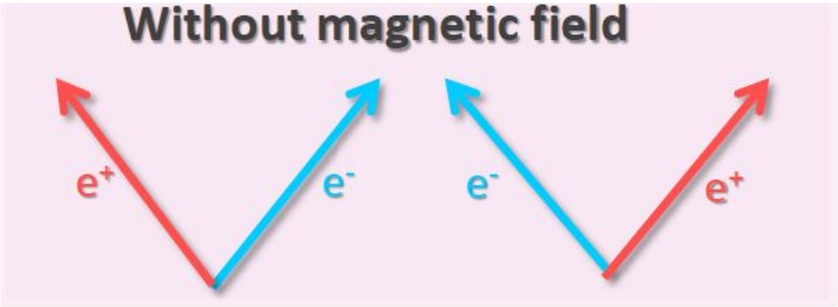
$$\mathbf{F} = q\,\mathbf{v} \times \mathbf{B}$$

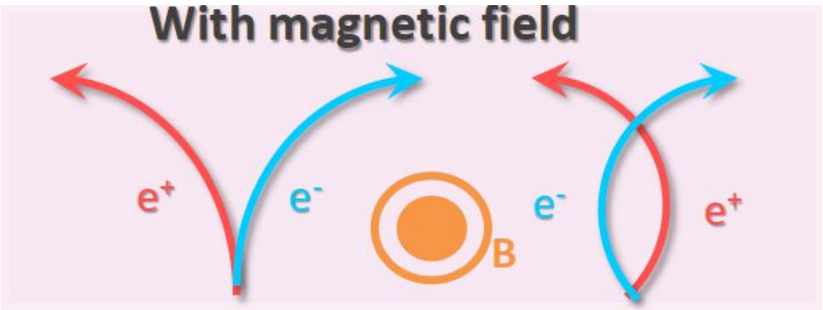
Lorentz force → Hall current

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Faraday efffect

Deflection of e^+e^- pairs





$$\cos\alpha \equiv \frac{\vec{p}_{e^-} \times \vec{p}_{e^+}}{|\vec{p}_{e^-} \times \vec{p}_{e^+}|} \cdot \frac{\vec{B}}{|\vec{B}|}$$