Low-mass dilepton measurements with ALICE at the LHC

Hard Probes 2018: International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions

Aix-Les-Bains, Savoie, France

Alberto Calivà for
the ALICE Collaboration

GSI Helmholtzzentrum für
Schwerionenforschung GmbH

Outline

Introduction & physics motivation

Dimuon measurements:

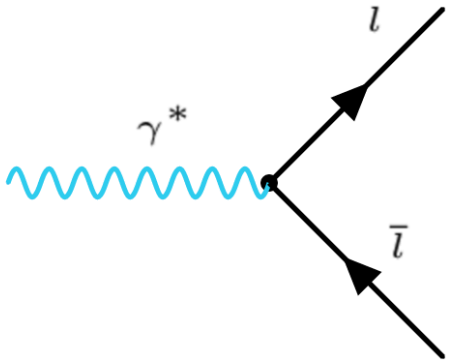
- ϕ meson production in pp and Pb-Pb collisions
  - ➢ Improved precision of the measurement in pp collisions at $\sqrt{s}$ = 5.02 TeV (preliminary)

Dielectron measurements:

- Published results in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- Preliminary results in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
- Dielectron invariant-mass spectra & heavy-flavor cross sections in pp collisions

Introduction & physics motivation

Dileptons are produced continuously during the space-time evolution of nucleus-nucleus collisions



Negligible final state interaction:

- Unperturbed signals on production process

Low-mass vector-meson production:

- Input for phenomenological models that describe particle production in a non-perturbative QCD regime
- Strangeness production via the ϕ meson measurement

Dilepton continuum:

- In-medium effects of low-mass vector mesons (broadening)
- Thermal radiation from virtual component of direct photons
- Measurement of charm and bottom production & modification

Measurements in pp collisions ⟶ fundamental baseline for AA collisions

The ALICE setup

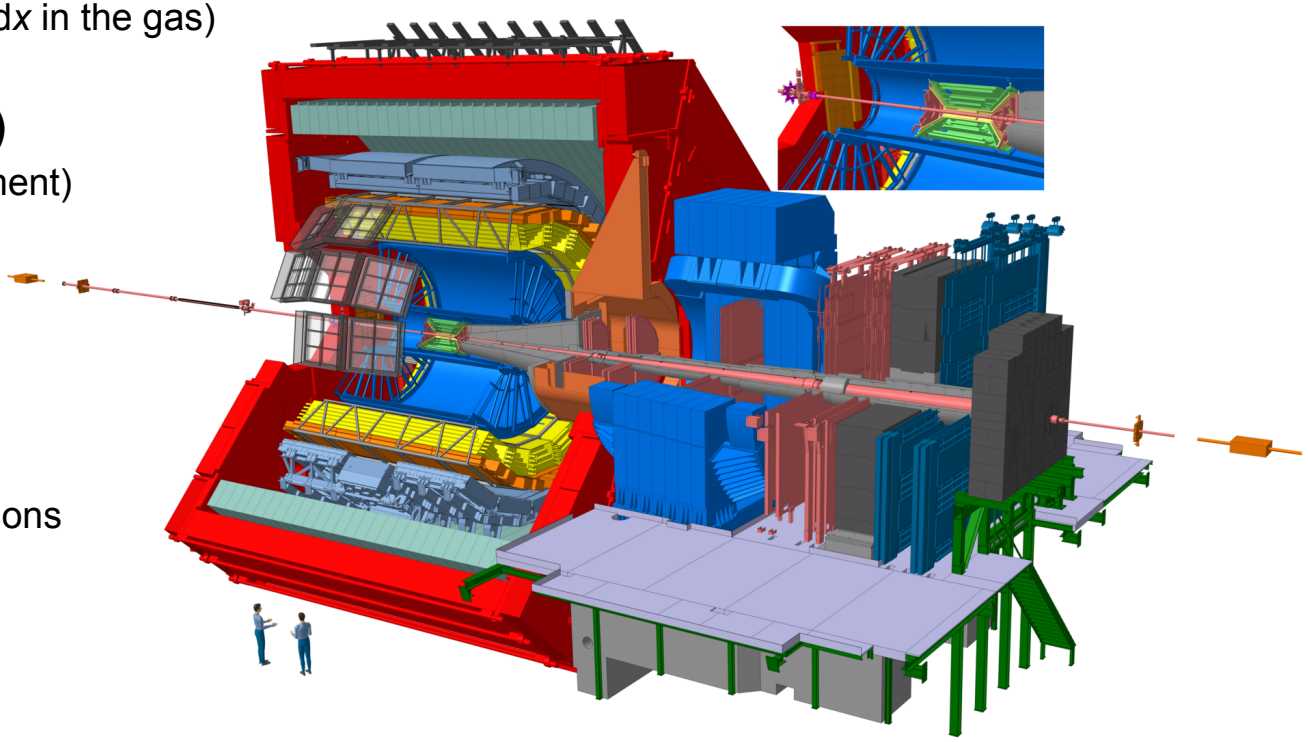
ITS (Inner Tracking System)
- Tracking, vertexing & PID (via d*E*/d*x* in silicon layers)

TPC (Time Projection Chamber)
- Tracking & PID (via d*E*/d*x* in the gas)

TOF (Time Of Flight)
- PID (via TOF measurement)

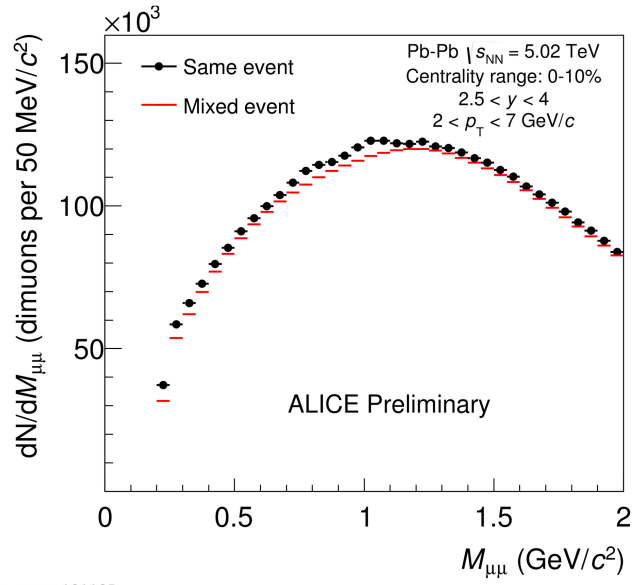
V0
- Centrality estimator

Muon spectrometer
- Trigger & tracking of muons



Dimuon measurements

Signal extraction of ϕ meson



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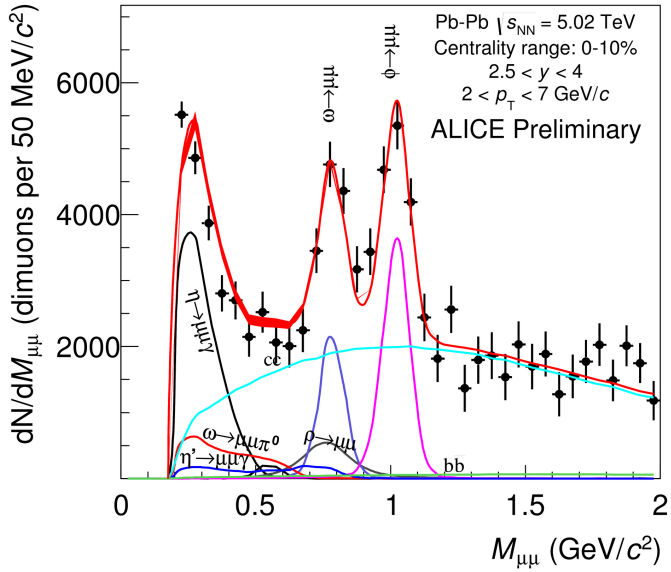


ALI-PREL-121162

Single muons are selected with $-4 < \eta_\mu < -2.5$

Minimum p_T for dimuon pairs:

- 2 GeV/*c* in Pb-Pb collisions
- ≈ 0 GeV/*c* in pp collisions for most forward rapidity

Combinatorial background:

Unlike-sign invariant-mass distribution from mixed events normalized to $2R\sqrt{N_{++} \cdot N_{--}}$

$$R = N_{+-}^{\text{mixed}} \Big/ \left[2\sqrt{N_{++}^{\text{mixed}} \cdot N_{--}^{\text{mixed}}}\right]$$

correction for geometrical asymmetry of the detector

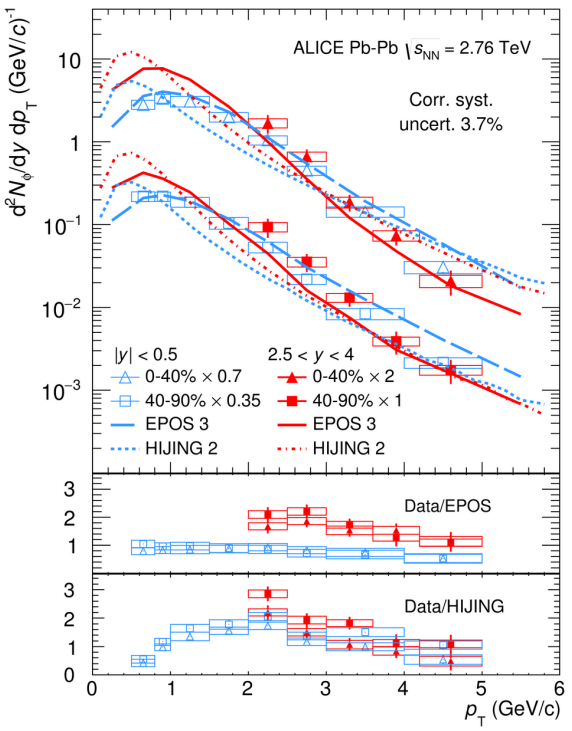
Contribution from light-meson decays estimated from a fit with mass shapes given by simulations

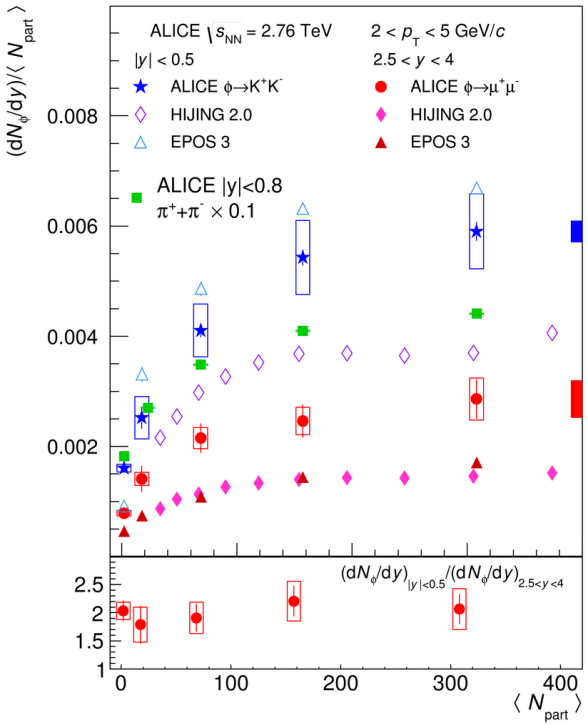
Continuum background from open charm and bottom "regularized" to describe the residual contribution from correlated background

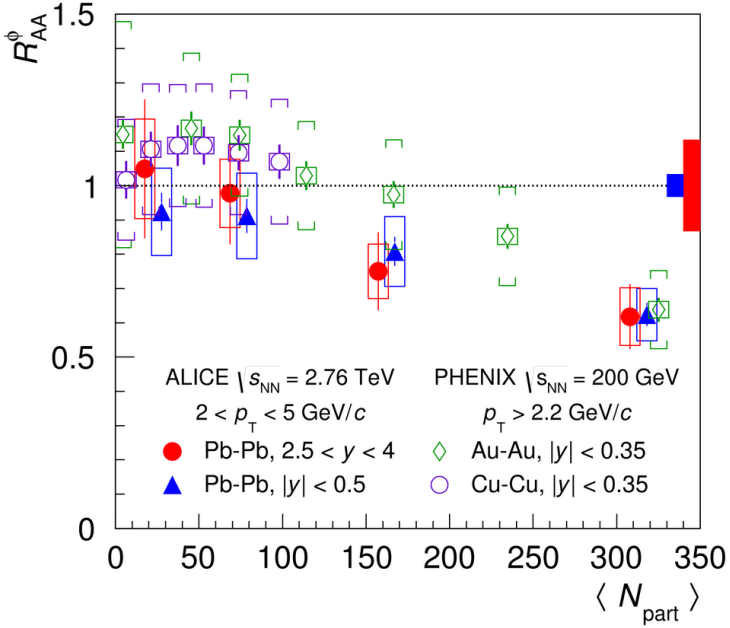
ϕ meson in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

arXiv:1804.08906 [nucl-ex]

Poster by **A. Uras**







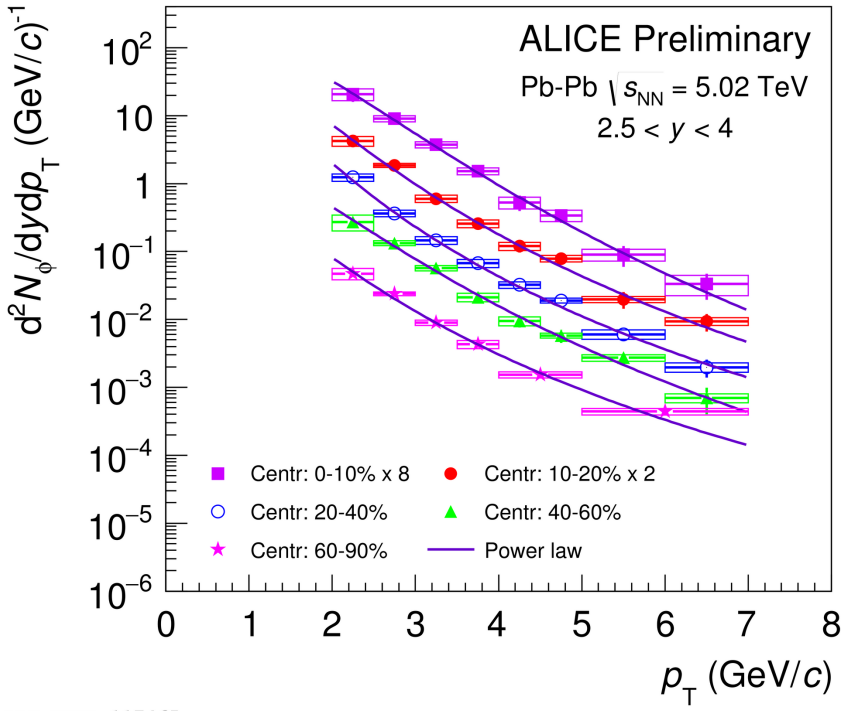
EPOS 3 and HIJING 2 underestimate the ϕ meson yield by a factor ~2 at low p_T

dN_ϕ/dy per participant: increasing trend vs. $\langle N_{part} \rangle$ followed by saturation

- Constant ratio (~2) between production at mid-rapidity and forward

R_{AA} at forward and mid-rapidity are consistent: similar interaction with the bulk

ϕ meson in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV



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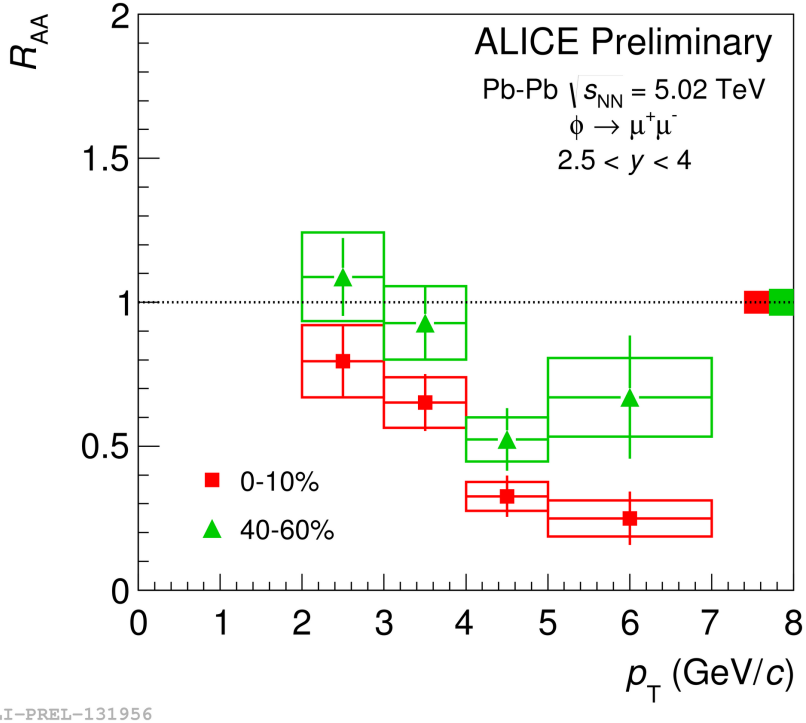


ALI-PREL-131956

p_T spectrum described by power-law function in all centralities

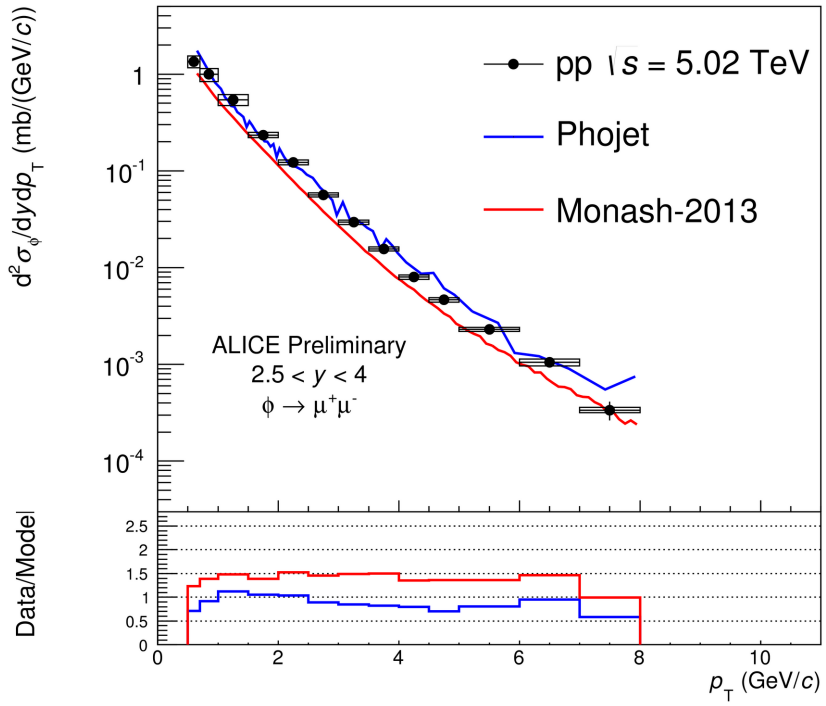
Tails become harder going from central to more peripheral collisions

- Consistent with previous results from ALICE and PHENIX

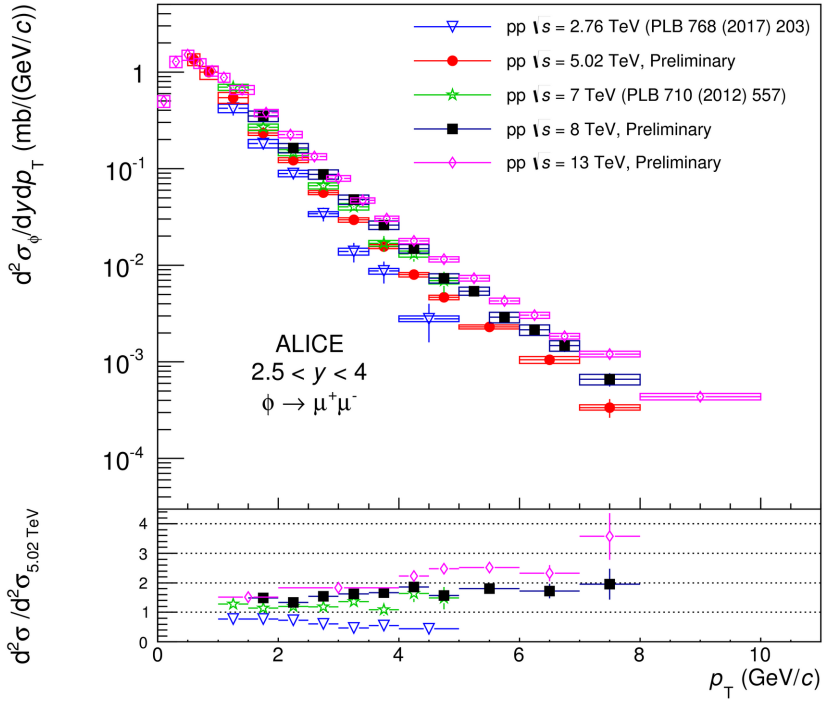
p_T-dependent R_{AA}: stronger suppression in central collisions

Energy dependence of ϕ meson production

NEW



ALI-PREL-308109



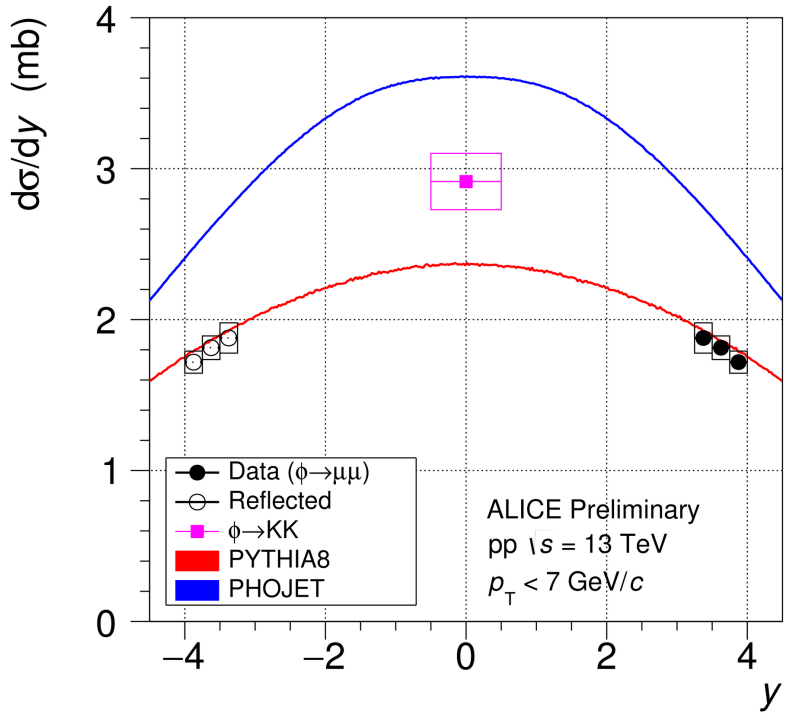
ALI-PREL-308099

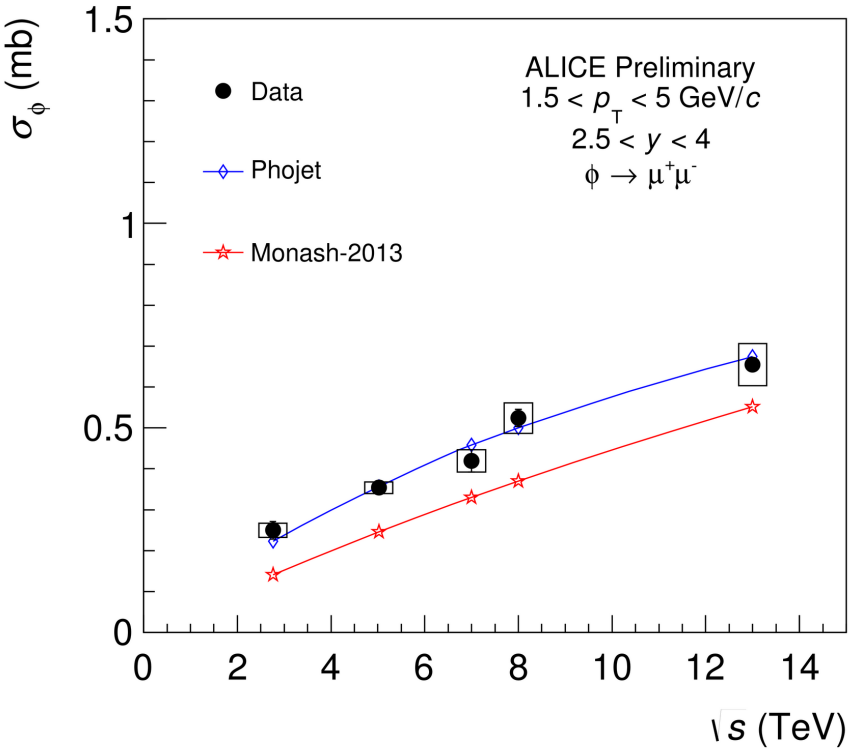
New measurement of the ϕ meson spectrum in pp collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

- Improved statistical precision and wider p_T range
- Smaller systematic uncertainties

p_T spectrum of ϕ meson becomes harder for increasing center-of-mass energy

ϕ meson production vs. *y* and energy





The full rapidity dependence of the ϕ meson p_T-integrated production cross section is not reproduced by the models

- PYTHIA 8 consistent with the data only at forward rapidity

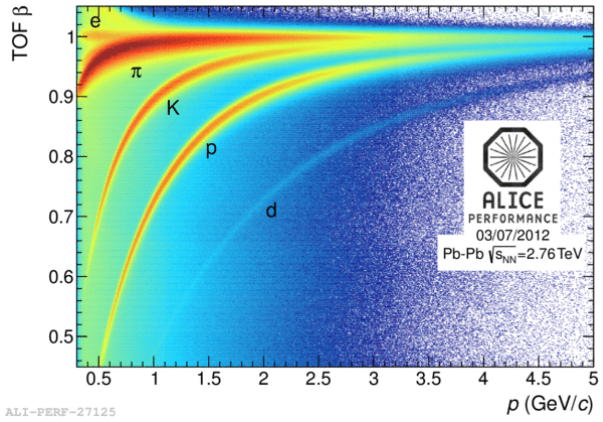
The $\sqrt{s}$ dependence of the ϕ meson cross section, integrated over common phase space of the measurements, is described by PHOJET

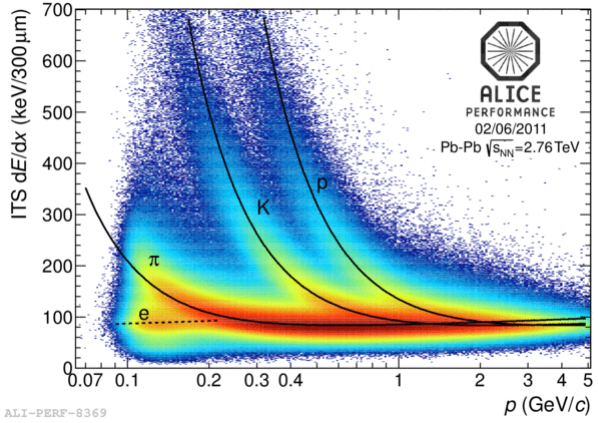
Dielectron measurements

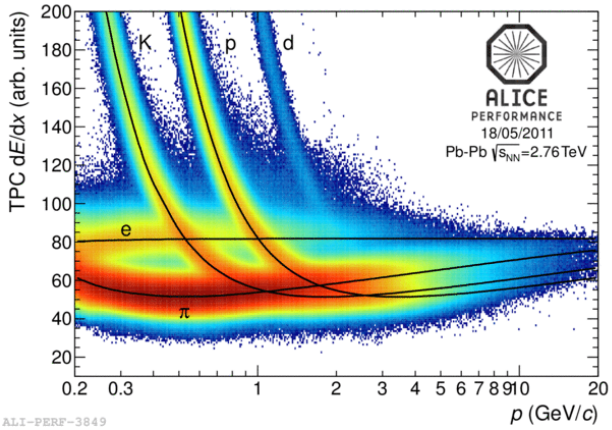
Electron identification & signal extraction

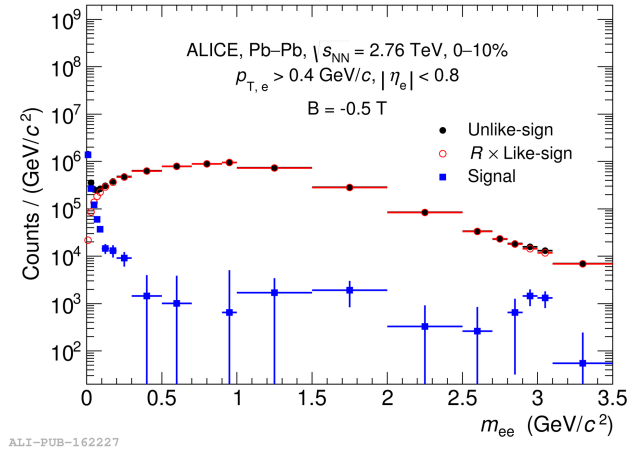
Electron candidates are selected in the pseudorapidity range $|\eta_e|<0.8$

Particle identification based on dE/dx measured by ITS and TPC and time-of-flight measured by TOF









Combinatorial background described by like-sign invariant-mass spectrum:

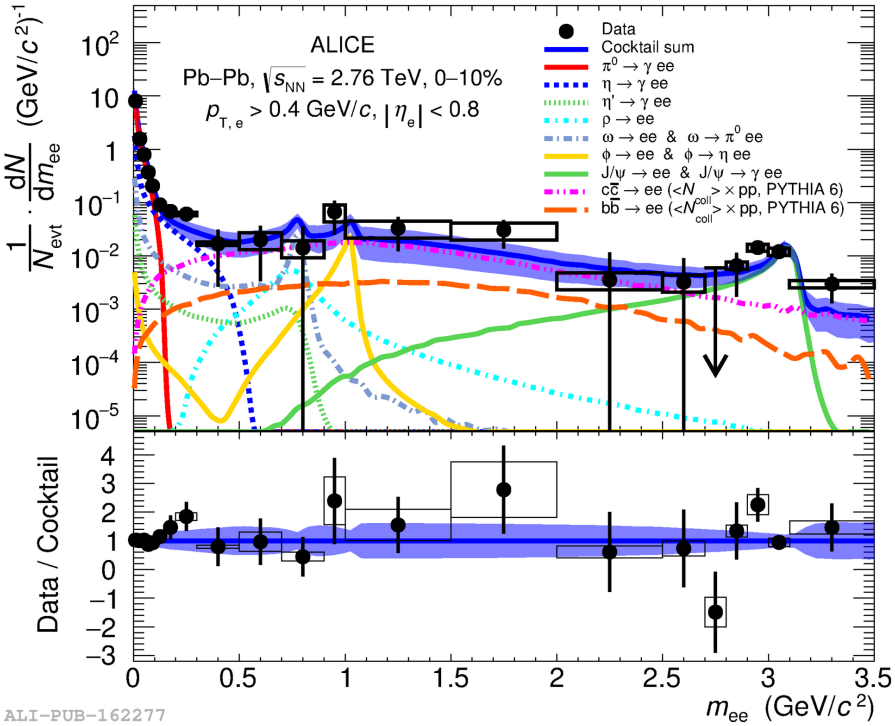
$$2R\sqrt{N_{++}\cdot N_{--}}$$

correlated & uncorrelated background

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

NEW

arXiv:1807.00923 [nucl-ex]
Submitted to PRC



Cocktail of known hadronic sources:

- π^0 from ALICE measurement
- η from K/π ratio in Pb-Pb and η/π ratio in pp collisions
- Other mesons from m_T scaling

Dielectrons from charm and bottom decays obtained as $\langle N_{coll} \rangle \times (dN/dm_{ee})_{pp}$

From PYTHIA 6 scaled to $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ cross-sections measured in pp collisions

Data are consistent with the cocktail within the uncertainties

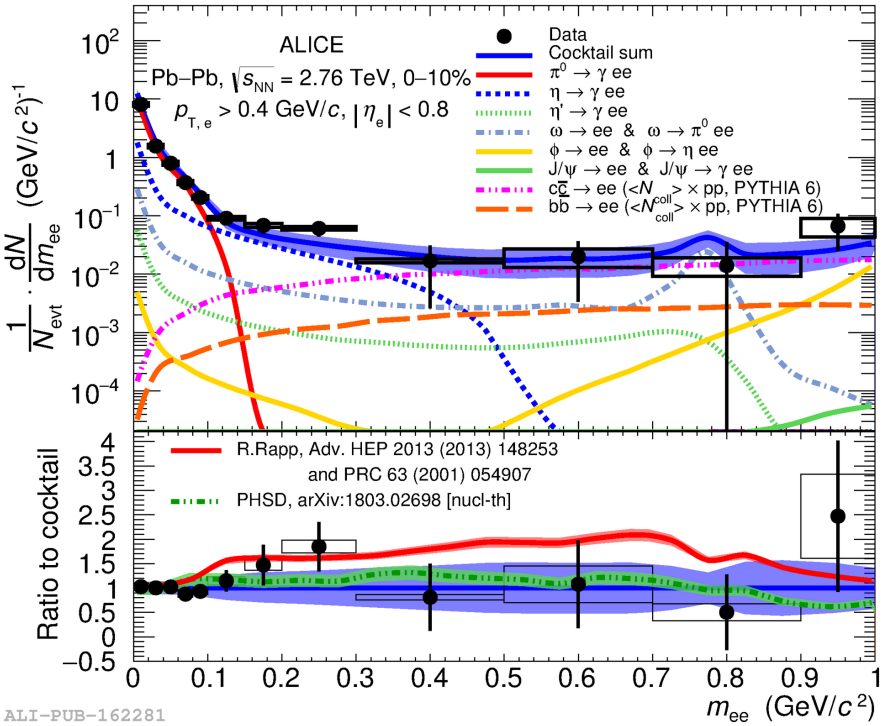
Data / cocktail (w/o vacuum ρ^0) in 150 < m_{ee} < 700 MeV/c^2:
1.40 ± 0.28 (stat.) ± 0.08 (syst.) ± 0.27 (cocktail)

→ Limited sensitivity to low-mass excess due to low statistics

Thermal dielectrons

NEW

arXiv:1807.00923 [nucl-ex]
Submitted to PRC



Theoretical model calculations:

R. Rapp:

Thermal dielectrons from expanding fireball model and in-medium broadening of ρ^0 from hadronic many-body theory

PHSD:

Thermal dielectrons from QGP assuming that quarks are massive off-shell quasi particles. Collision broadening of ρ^0 spectral function

The two models are consistent with the data within the uncertainties

Virtual direct photons

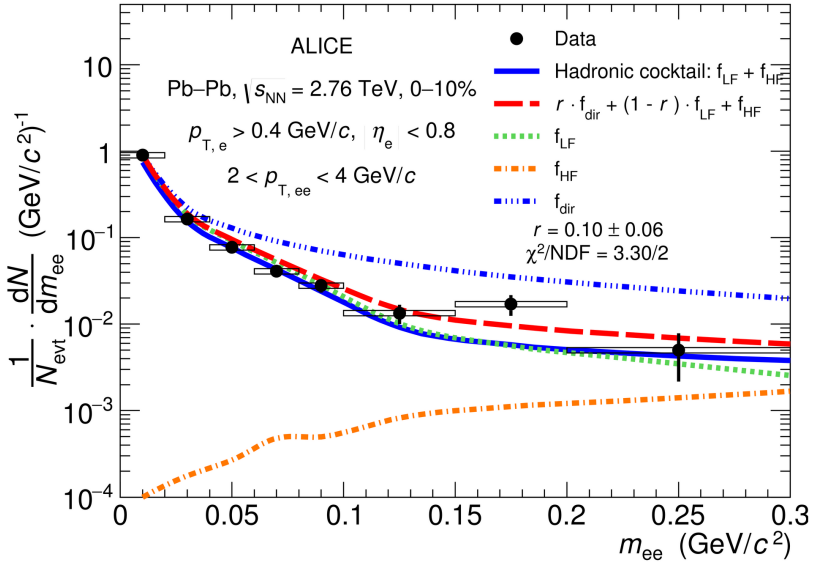
Contribution from virtual direct photons measured from minimized χ^2 fit of data in the mass range $100 < m_{ee} < 300$ MeV/c^2:

$$f(m_{ee}) = r \cdot \underbrace{f_{dir}(m_{ee})}_{\text{Virtual photon mass shape (Kroll-Wada eq.)}} + (1-r) \cdot \underbrace{f_{LF}(m_{ee})}_{\text{Light-flavor cocktail}} + \underbrace{f_{HF}(m_{ee})}_{\text{Heavy-flavor contribution}}$$

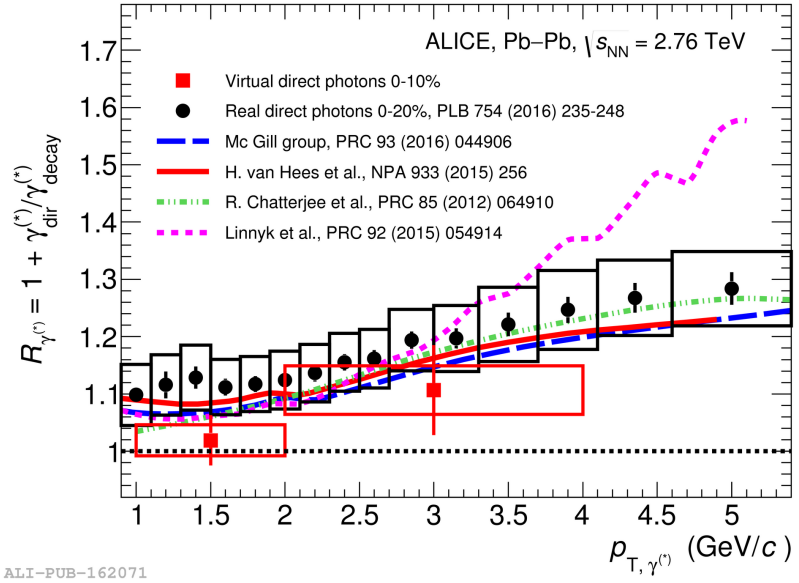
Fraction of virtual direct photons extrapolated for $m_{ee} \rightarrow 0$ GeVc^2

NEW

arXiv:1807.00923 [nucl-ex], Submitted to PRC



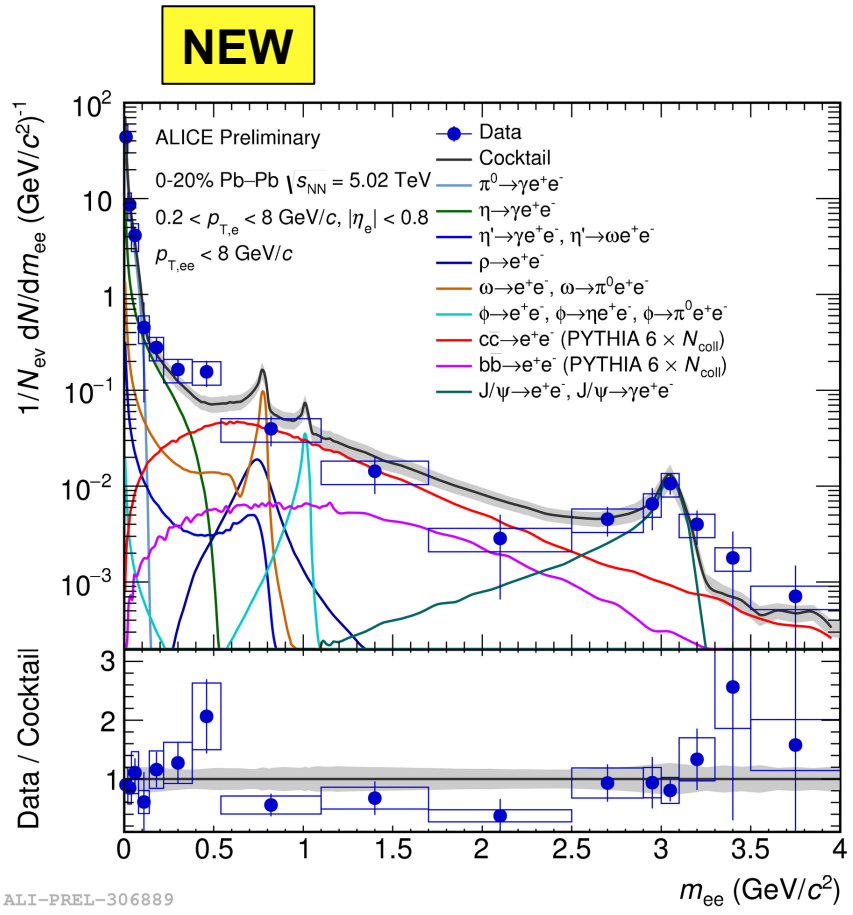
ALI-PUB-162179



ALI-PUB-162071

Virtual direct photon measurement is at lower edge of real photon measurement remaining consistent with it within the uncertainties

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



Hadronic cocktail parametrization:

- Charged pions as proxy for π^0
- η from K/π ratio in Pb-Pb
- Other mesons from m_T scaling
- J/ψ from ALICE measurement in Pb-Pb collisions at 5.02 TeV

Dielectrons from charm and bottom decays obtained as $\langle N_{coll} \rangle \times (dN/dm_{ee})_{pp}$

From PYTHIA 6

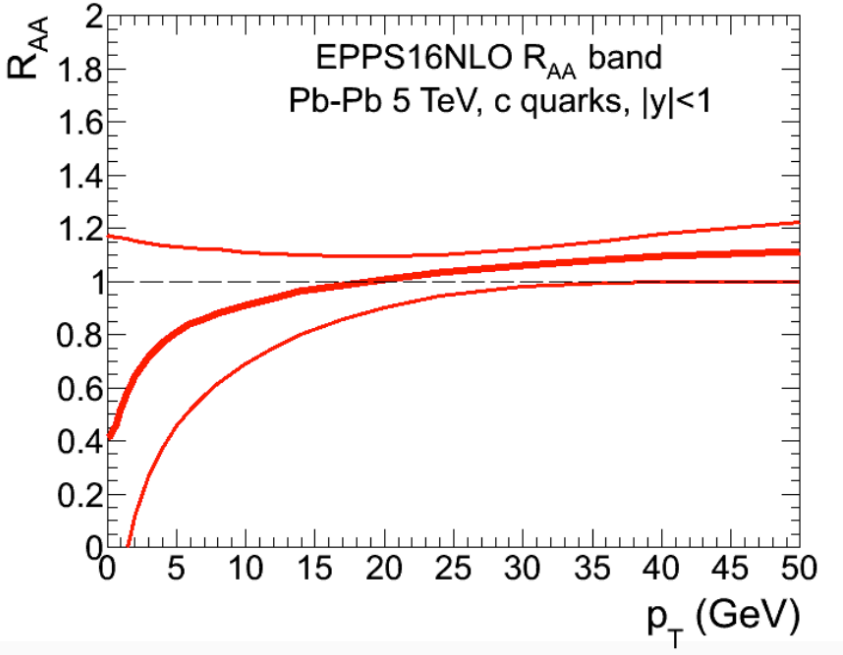
First evidence of **charm modification** as compared to N_{coll} scaling from PYTHIA from the comparison to hadronic cocktail in 1.1 < m_{ee} < 2.5 GeV/c^2:

➢ data / cocktail = 0.53 ± 0.19 (stat) ± 0.12 (syst) ± 0.13 (cocktail)

Cold nuclear matter effects

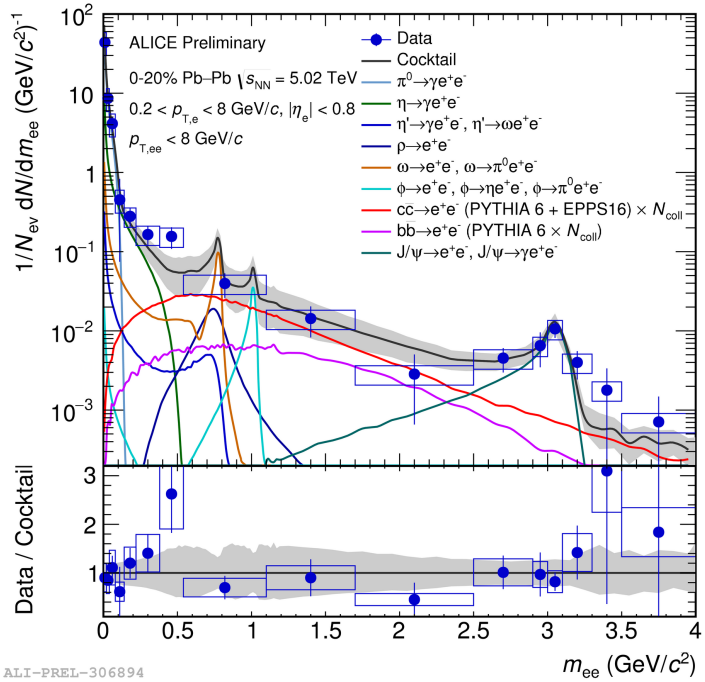
R_{AA} of charm quarks including only shadowing effects (EPPS16NLO)

R. Rapp et al., NPA 979 (2018) 21



Simulation of charm suppression:

Electrons from charm decays in PYTHIA are weighted using the p_T-dependent R_{AA}:



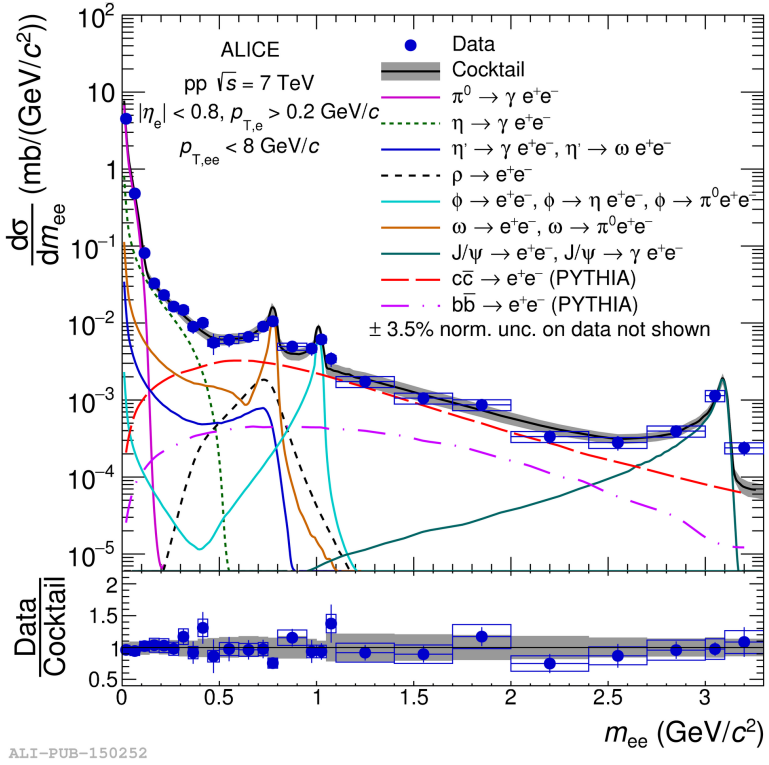
NEW

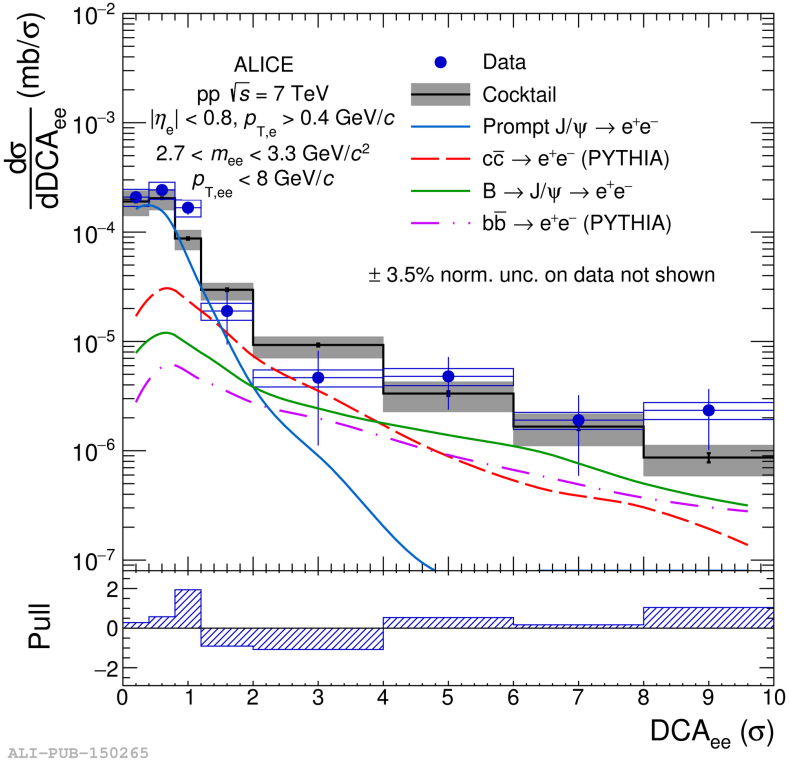
Data are consistent with the cocktail with modified charm in the mass range $1.1 < m_{ee} < 2.5$ GeV/c^2:

- Data/cocktail = 0.82 ± 0.26 (stat.) ± 0.18 (syst.) ± 0.29 (cocktail)

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

JHEP 09 (2018) 64





Dielectron spectrum consistent with the cocktail within uncertainties

DCA_{ee} is a powerful tool to separate prompt and non-prompt dielectron sources

➢ improved resolution in Run 3 with upgraded ITS

$$\mathrm{DCA_{ee}}\,(\sigma) = \sqrt{\mathrm{DCA_{e^+}^2}/\sigma^2 + \mathrm{DCA_{e^-}^2}/\sigma^2}$$

$DCA_e(\sigma)$: Distance-of-closest approach to the vertex in unit of DCA resolution (σ)

Charm & bottom cross sections at $\sqrt{s}$ = 7 TeV

Charm & bottom cross sections extracted from a double-differential (m_{ee}, p_T) fit of data in the intermediate mass region ($1.1 < m_{ee} < 2.7$ GeV/c^2)

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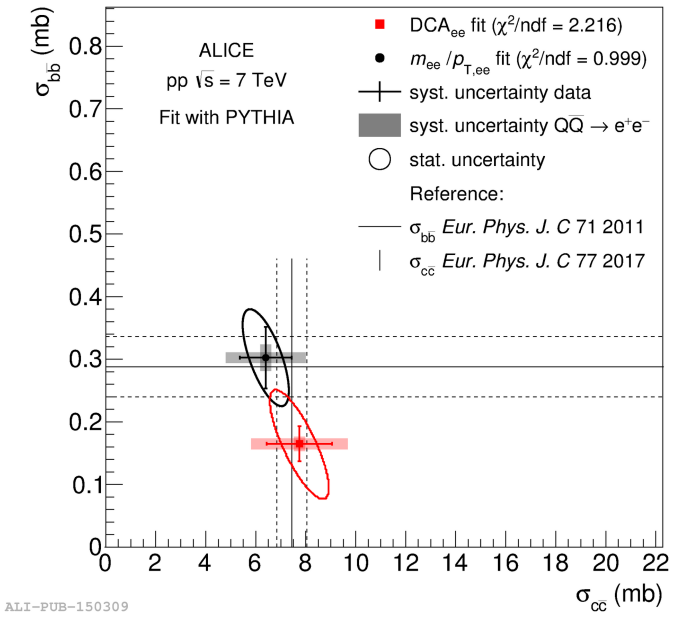
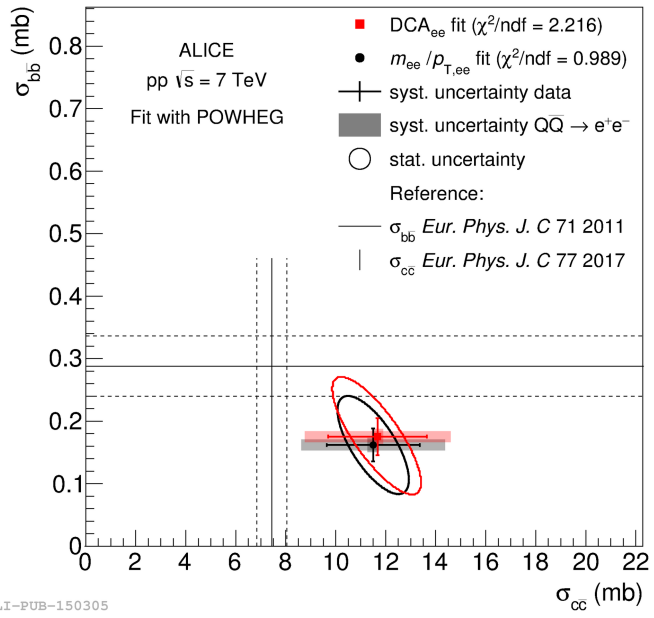




Poster by **S. Scheid**

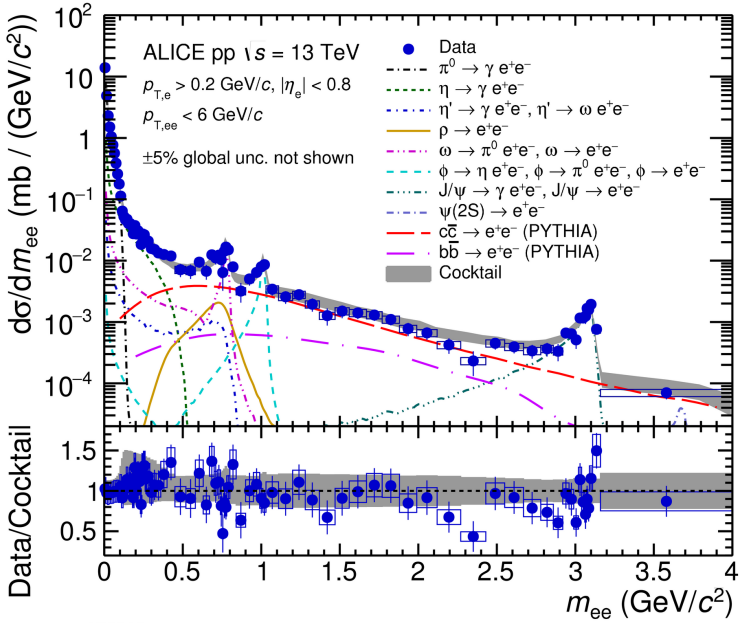
Measured cross sections are consistent with independent measurements

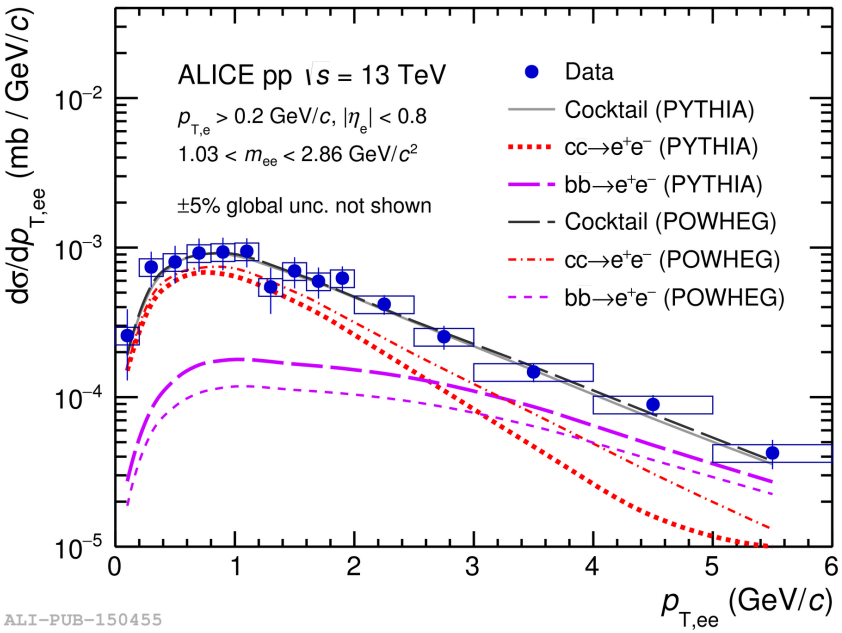
Model dependence (PYTHIA vs. POWHEG):

- Dielectrons are sensitive to charm production mechanism and angular correlations

Dielectrons in pp collisions at $\sqrt{s}$ = 13 TeV

arXiv:1805.04407 [hep-ex], submitted to PLB





Good understanding of hadronic component in pp collisions

First measurement of $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ in pp collisions at $\sqrt{s}$ = 13 TeV from 2D fit in intermediate-mass region (1.03 < m_{ee} < 2.86 GeV/c):

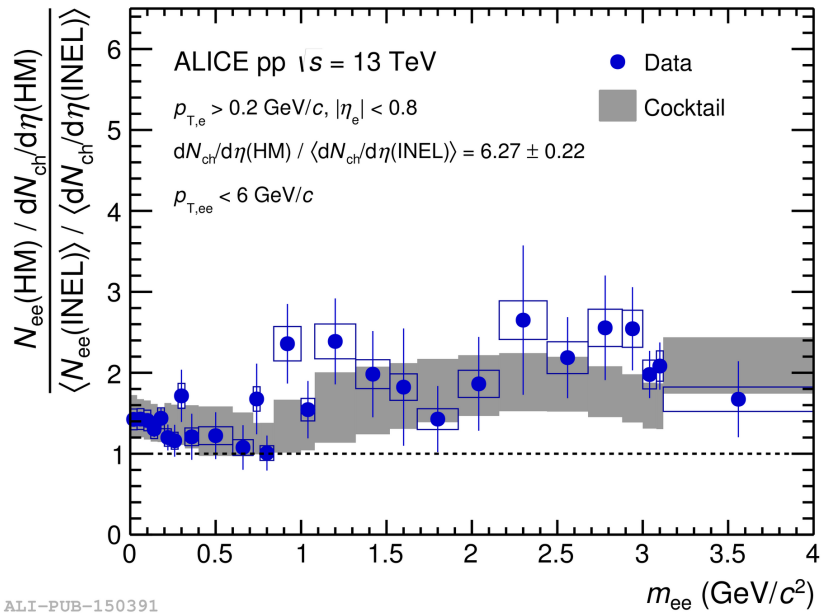
$d\sigma_{c\bar{c}}/dy\|_{y=0}$ = 974 ± 138 (stat.) ± 140 (syst.) µb $d\sigma_{b\bar{b}}/dy\|_{y=0}$ = 79 ± 14 (stat.) ± 11 (syst.) µb	using PYTHIA
$d\sigma_{c\bar{c}}/dy\|_{y=0}$ = 1417 ± 184 (stat.) ± 204 (syst.) µb $d\sigma_{b\bar{b}}/dy\|_{y=0}$ = 48 ± 14 (stat.) ± 7 (syst.) µb	using POWHEG

Consistent with extrapolations from lower energies

Similar model dependence as for pp collisions at 7 TeV

Dielectrons in high-multiplicity pp collisions

arXiv:1805.04407 [hep-ex], submitted to PLB



Observable: $\dfrac{N_{ee}(\mathrm{HM})}{\langle N_{ee}(\mathrm{INEL})\rangle} \times \dfrac{\langle dN_{ch}/d\eta(\mathrm{INEL})\rangle}{dN_{ch}/d\eta(\mathrm{HM})}$

account for trivial scaling with charged-particle multiplicity

Ratio is in good agreement with hadronic cocktail in all p_T ranges

Dielectrons in high-multiplicity pp collisions

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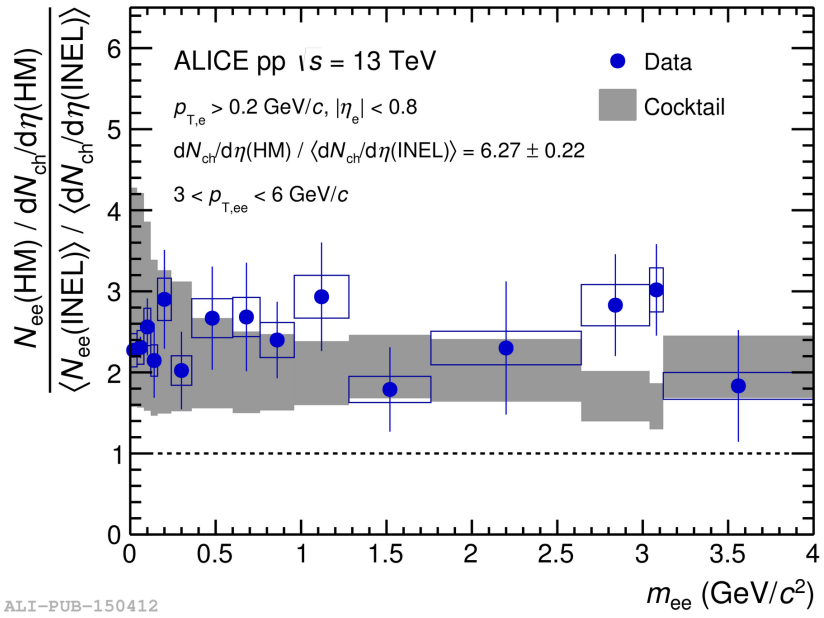

Observable: $\frac{N_{ee}(HM)}{\langle N_{ee}(INEL)\rangle} \times \frac{\langle dN_{ch}/d\eta(INEL)\rangle}{dN_{ch}/d\eta(HM)}$

account for trivial scaling with charged-particle multiplicity

Ratio is in good agreement with hadronic cocktail in all p_T ranges

High p_T ($3 < p_T < 6$ GeV/c) dominated by bottom:

- multiplicity dependence similar to that of open charm (**first clear evidence**)

Dielectrons in high-multiplicity pp collisions

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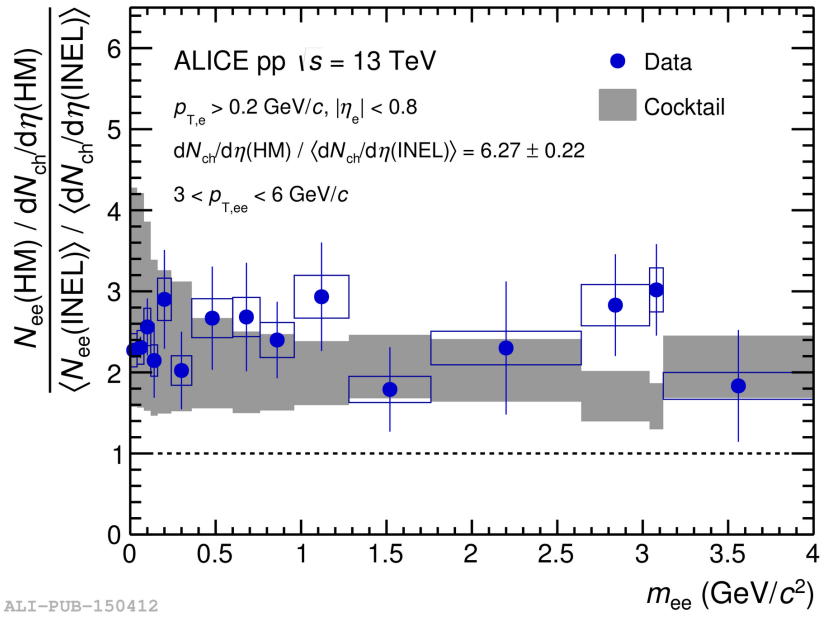

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account for trivial scaling with charged-particle multiplicity

Ratio is in good agreement with hadronic cocktail in all p_T ranges

High p_T ($3 < p_T < 6$ GeV/c) dominated by bottom:

- multiplicity dependence similar to that of open charm (**first clear evidence**)

Virtual direct-photon measurement:

No significant direct-photon contribution is observed: upper limits at 90% C.L. are set

- Consistent with pQCD calculations

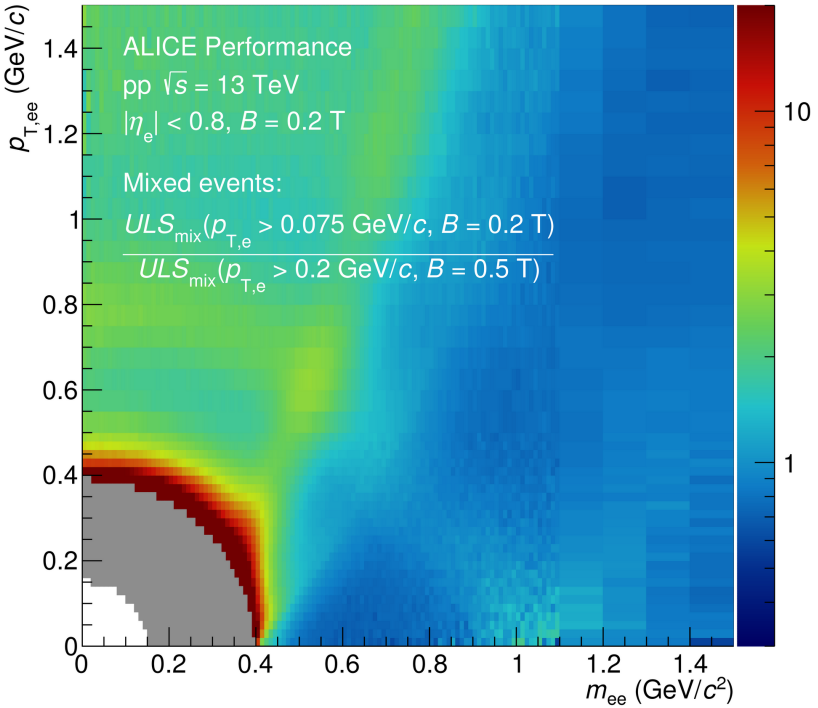
Data sample	$1 < p_{T,ee} < 2$ GeV/c	$2 < p_{T,ee} < 3$ GeV/c	$3 < p_{T,ee} < 6$ GeV/c
Minimum bias	0.057	0.072	0.023
High multiplicity	0.060	0.083	0.055
pQCD	0.003	0.007	0.013

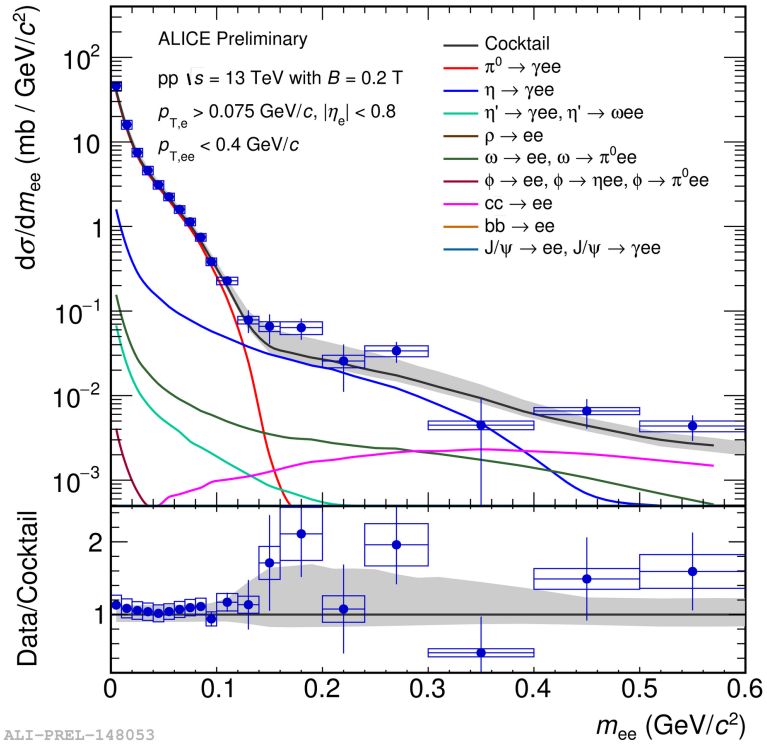
Low-*B* field results

Pilot runs of pp collisions at $\sqrt{s}$ = 13 TeV with reduced magnetic field

➢ **Performance test for Run 3 after the upgrade**

Talk by **C. Bedda** on Th. 04/10 (9:00 AM)





Larger efficiency due to higher TOF acceptance at the same p_T

Measurement extended to lower p_T: 200 MeV/c ⟶ 75 MeV/c

Summary

ϕ meson production:

- No consistent description by the models in pp collisions
- Yield underestimated by HIJING and EPOS in Pb-Pb collisions

Dielectron measurements:

- Limited sensitivity to low-mass excess in Pb-Pb collisions
  - Precision measurement is expected after the upgrade
- First indication of deviation of charm yields from binary scaling at $\sqrt{s_{NN}}$ = 5.02 TeV
- Sensitivity to charm and bottom production in pp collisions

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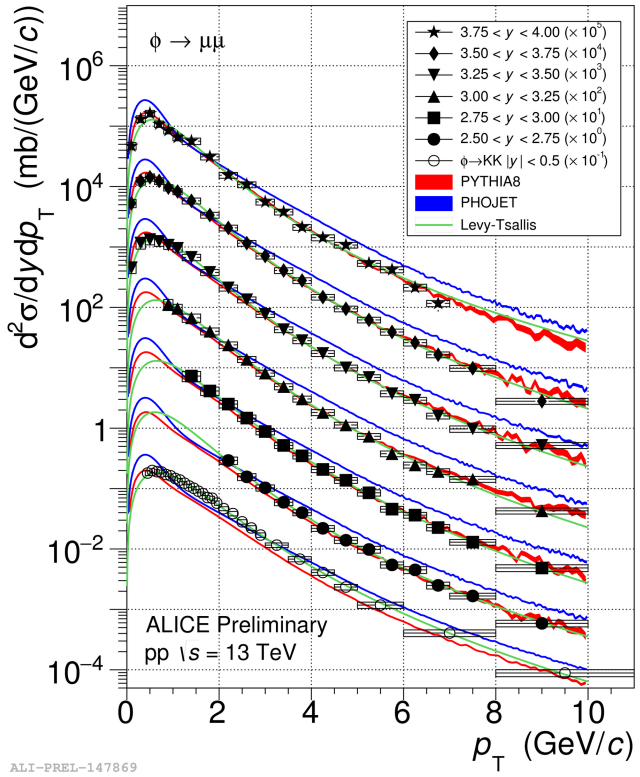
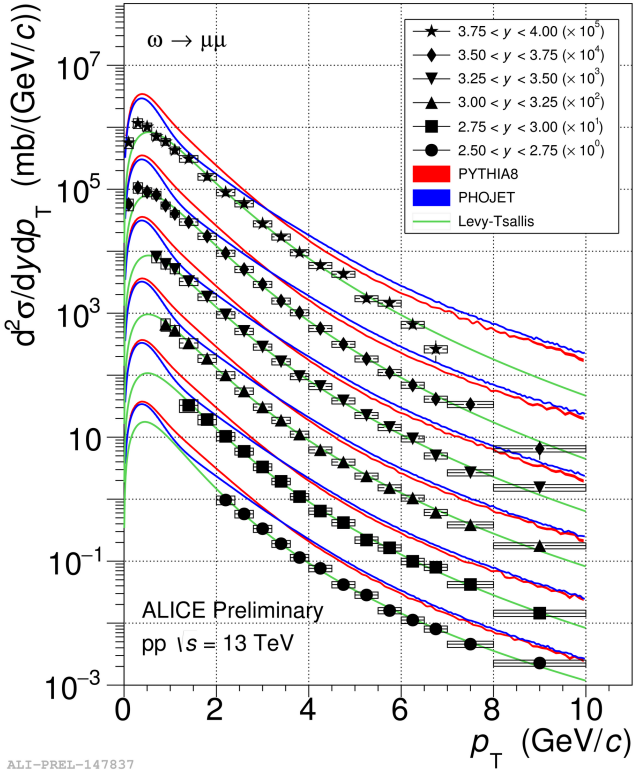
- First indication of deviation of charm yields from binary scaling at $\sqrt{s_{NN}}$ = 5.02 TeV
- Sensitivity to charm and bottom production in pp collisions

Thank you for your attention

Backup slides

ω and ϕ mesons in pp collisions at $\sqrt{s_{NN}}$ = 13 TeV





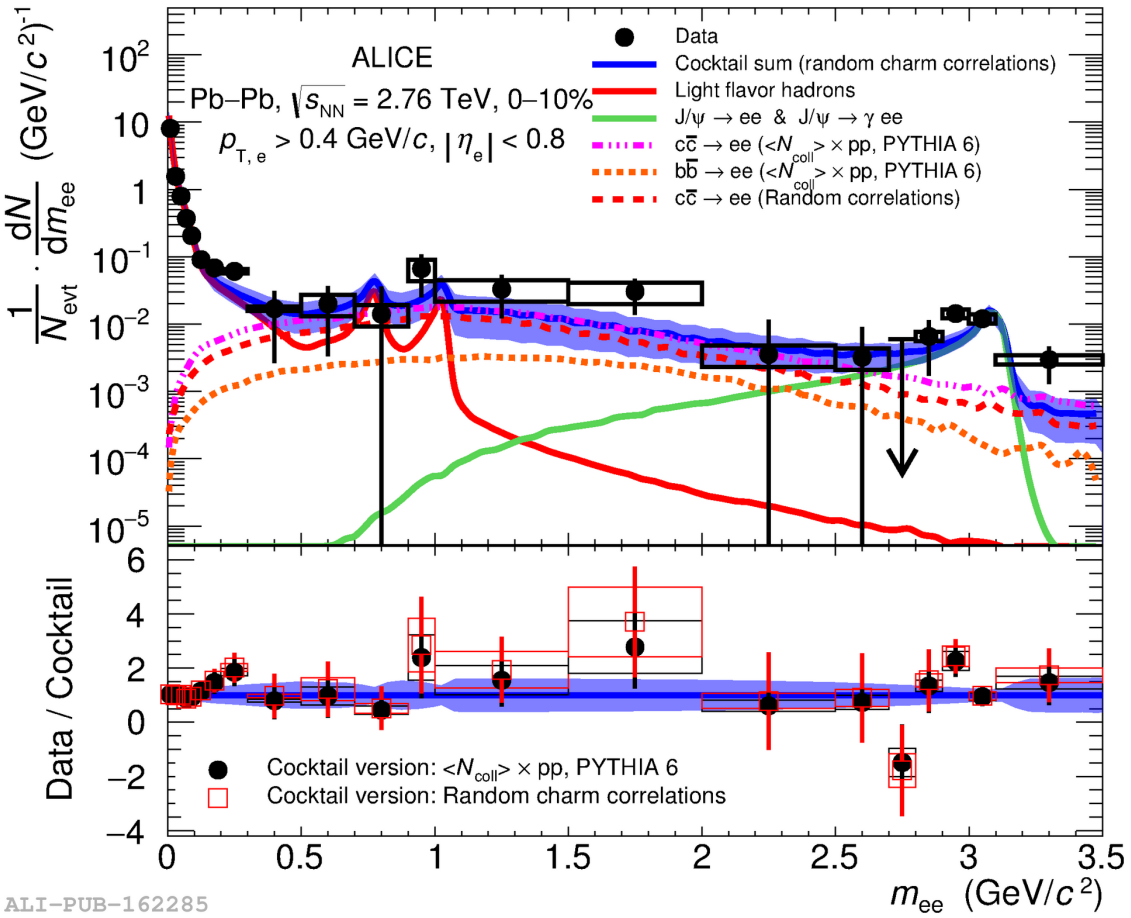
Large data sample of pp collisions at $\sqrt{s_{NN}}$ = 13 TeV:

- double-differential (p_T,y) production cross-sections of ω and ϕ mesons

PYTHIA 8 fairly describes the ϕ meson spectrum over the measured p_T range

PHOJET overestimates the production cross-section of both the ω and ϕ mesons

Charm in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

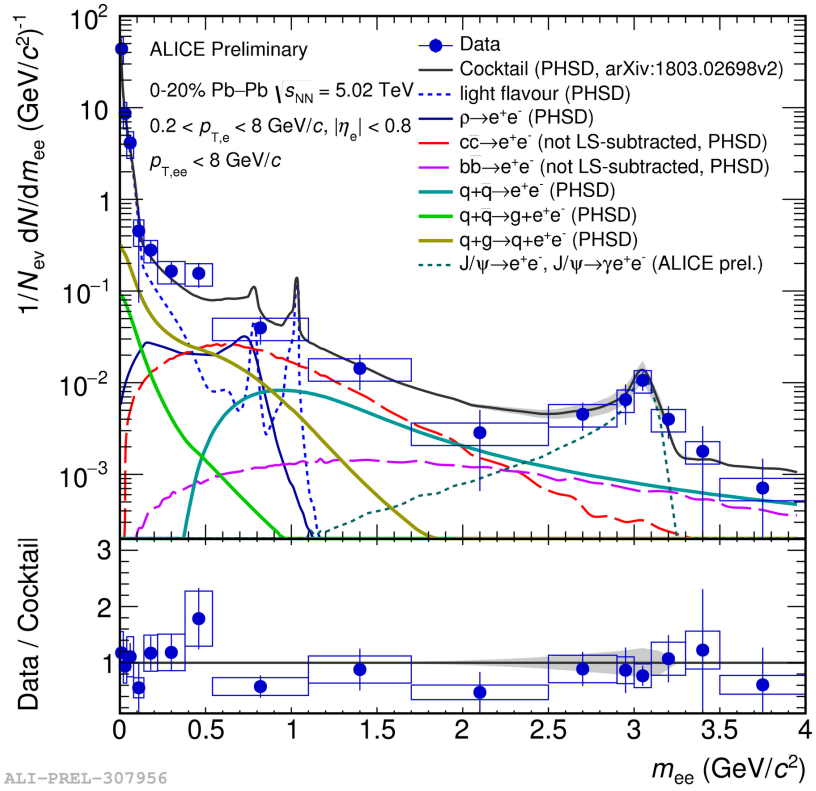


Random angular correlations of dielectrons from charm decays:

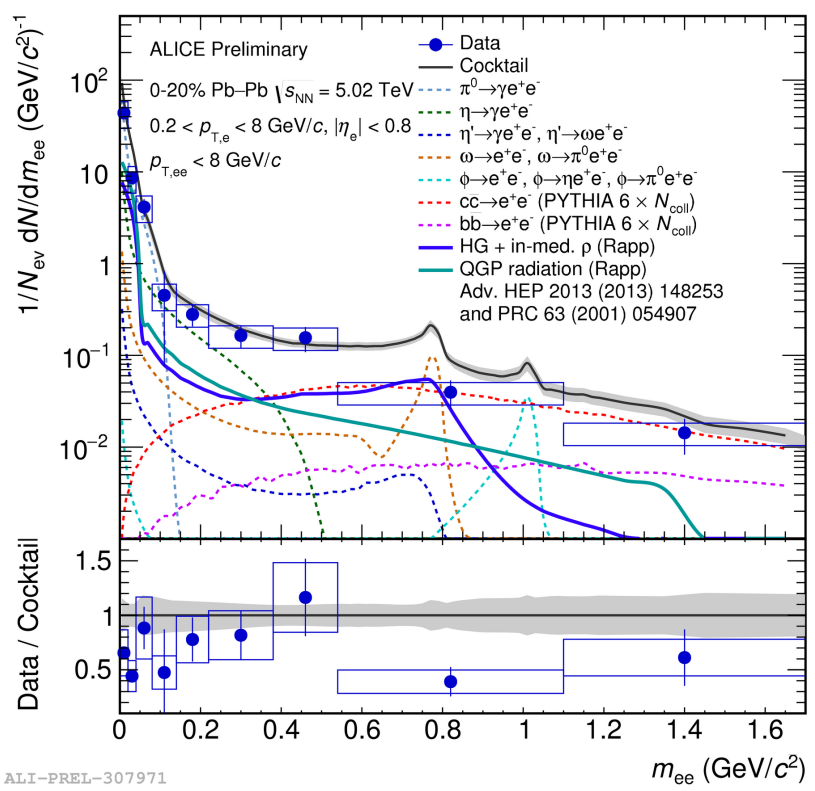
- Charm contribution suppressed by a factor ~2

Thermal e^+e^- in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

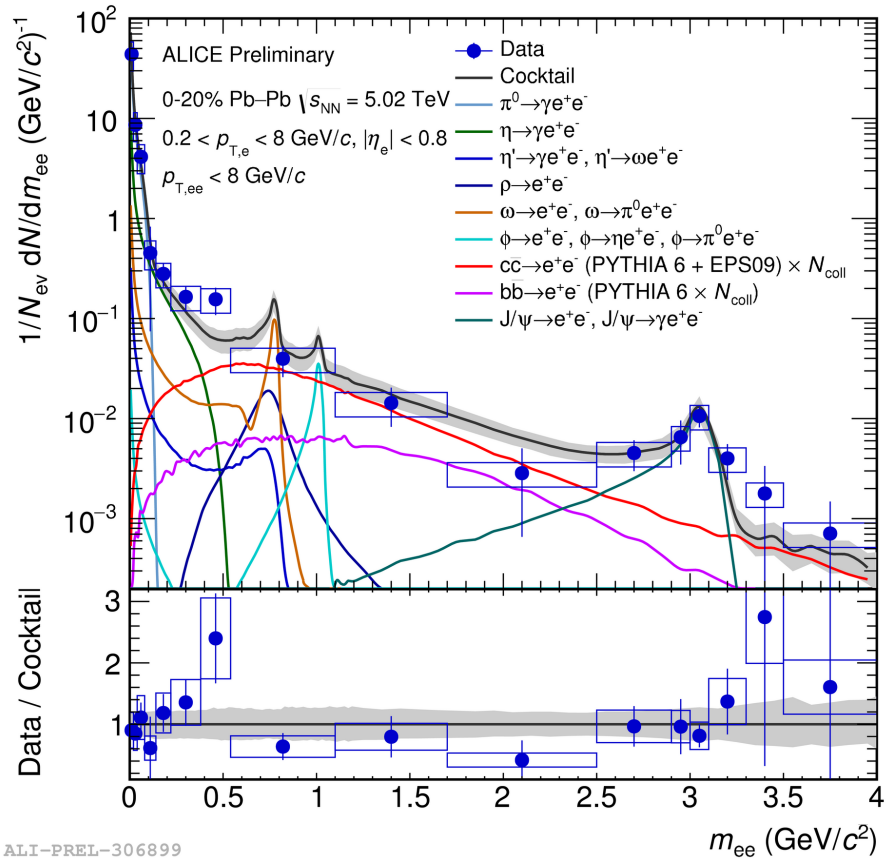
PHSD



R.Rapp



Charm modification from EPS09

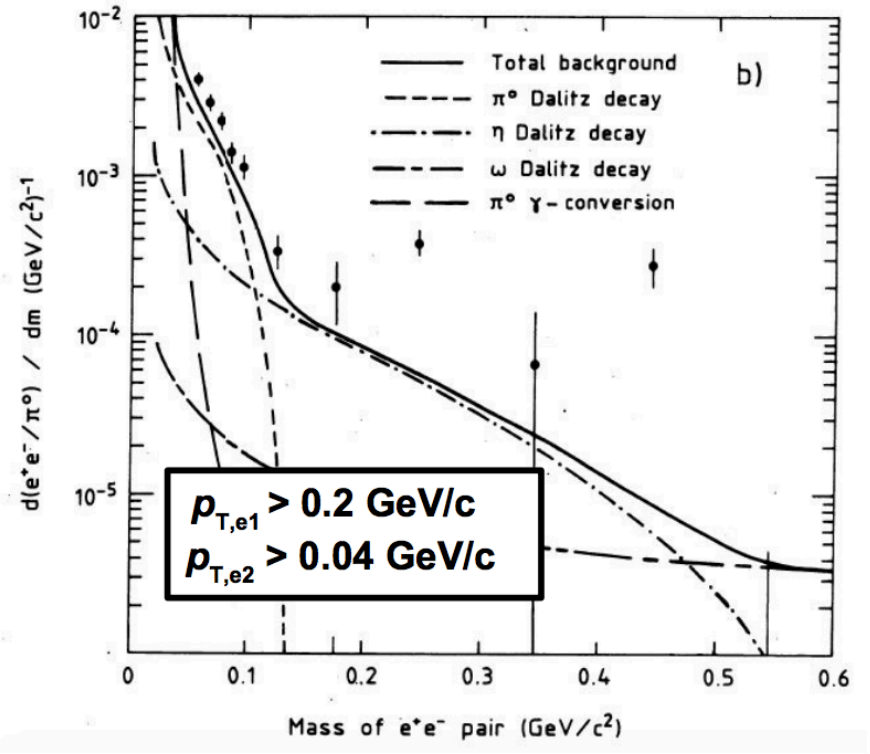


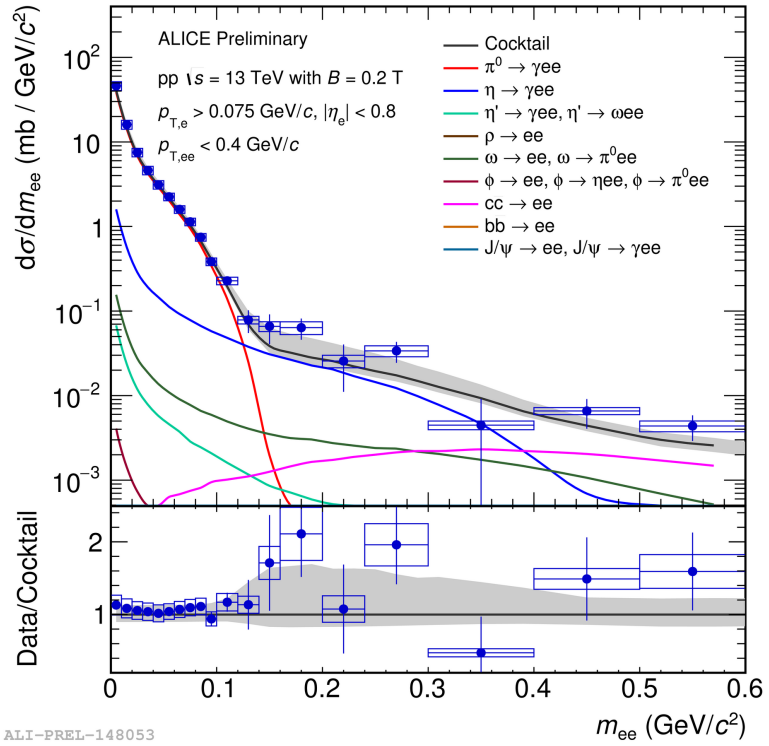
Modified charm from EPS09 calculation

Anomalous dielectron pairs

Excess of dielectrons observed by the AFS experiment at the ISR for $0.05 < m_{ee} < 0.6$ GeV/c^2 and very low pair-p_T

Ph. D. thesis of V.Hedberg, Lund University (1987)





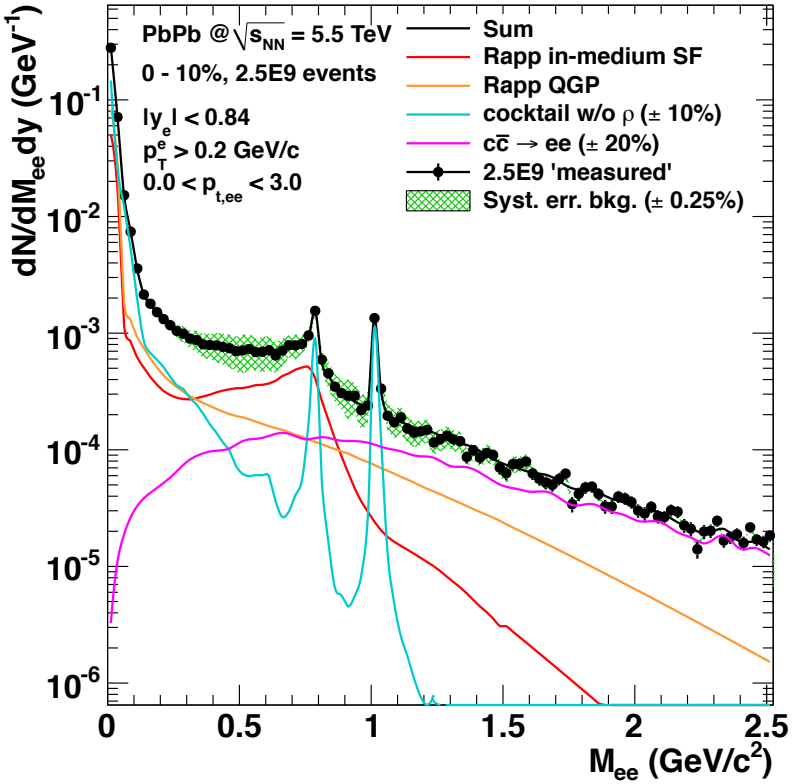
Probe similar kinematic region at the LHC

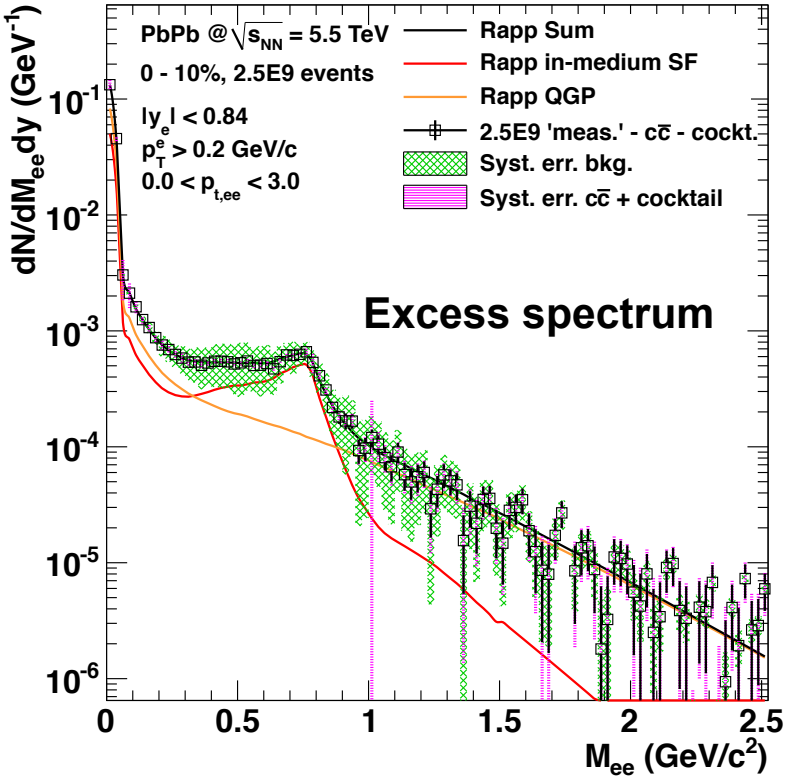
More data and precise η measurement at low p_T are needed

Perspectives after the ALICE upgrade

J. Phys. G 41 (2014) 087002

new ITS, 2.5x10^9 events with DCA cuts





- New ITS: suppression of main background sources (Dalitz, conversion & charm)
- Continuous TPC readout will increase event rate by a factor ~100
  - ➢ Detailed measurement of in-medium modification & thermal radiation