

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

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on behalf of the ALICE Collaboration

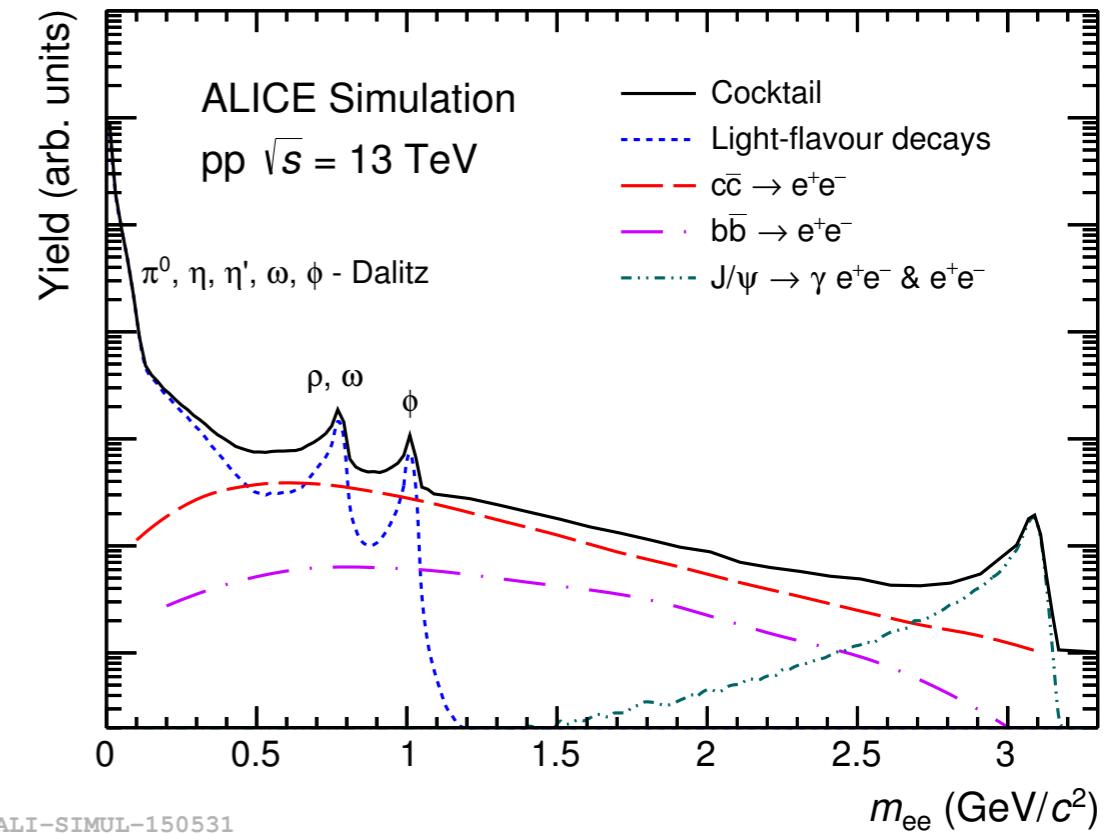


Low mass dielectron studies

Produced during all stages of collisions with negligible final-state interactions

Proton-proton collisions:

- Medium-free reference (min. bias events)
- Heavy-flavour cross sections
- (Virtual) direct photons
- New phenomena in high-multiplicity events?



Low mass dielectron studies

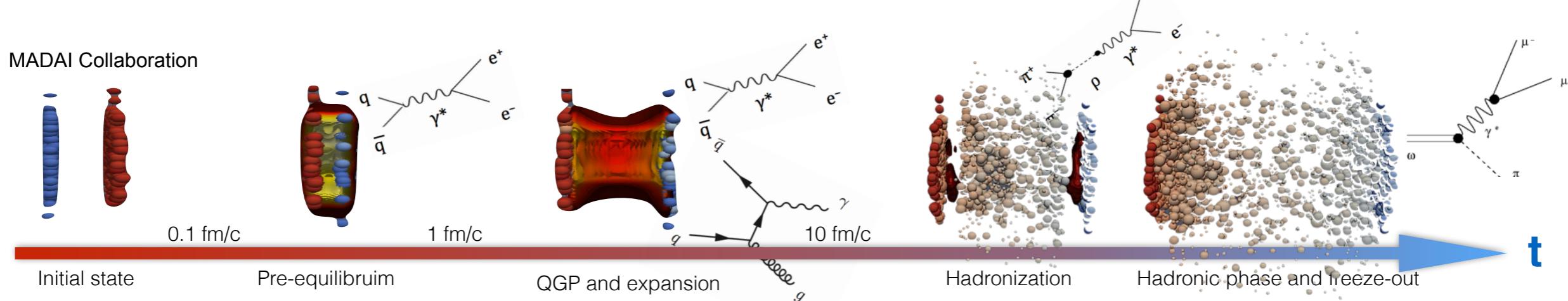
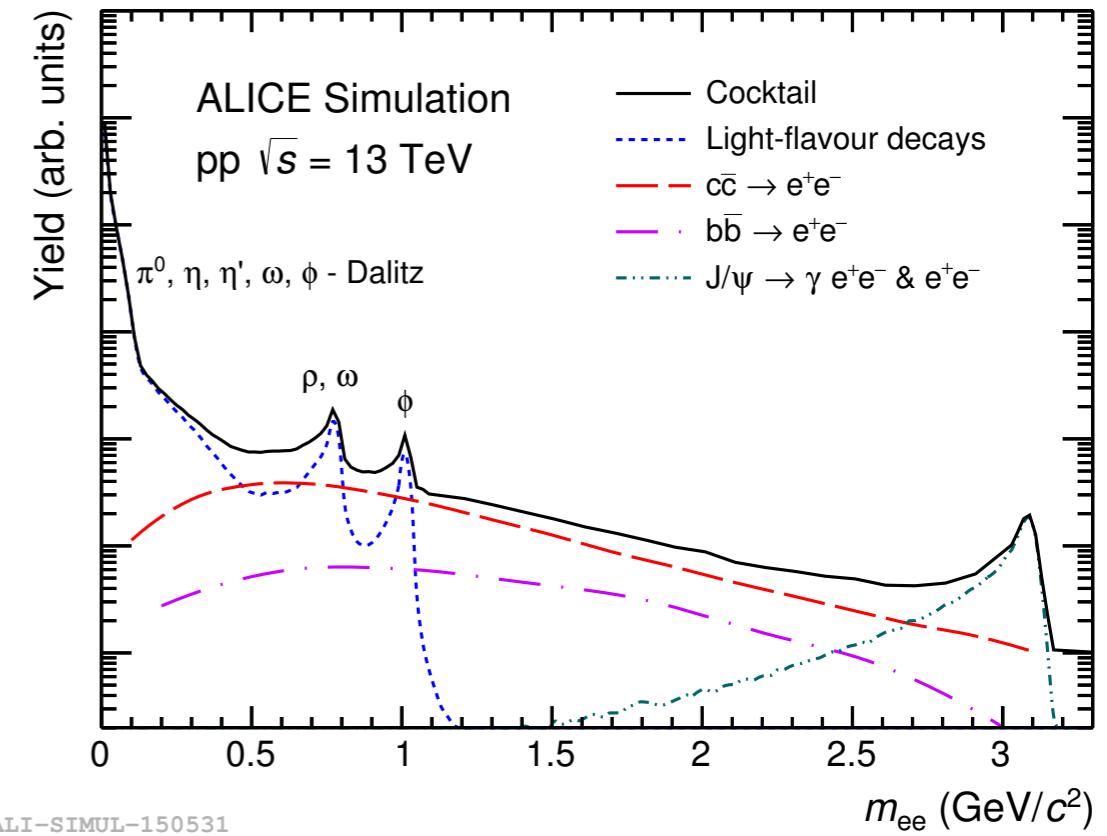
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Proton-proton collisions:

- Medium-free reference (min. bias events)
- Heavy-flavour cross sections
- (Virtual) direct photons
- New phenomena in high-multiplicity events?

High-energy heavy-ion collisions:

- In-medium modifications of vector mesons
- Thermal radiation from QGP
- Energy loss of correlated heavy-flavour quarks



The ALICE Experiment at CERN LHC

Inner Tracking System

- Tracking, vertex, PID (dE/dx)

Time Projection Chamber

- Tracking, PID (dE/dx)

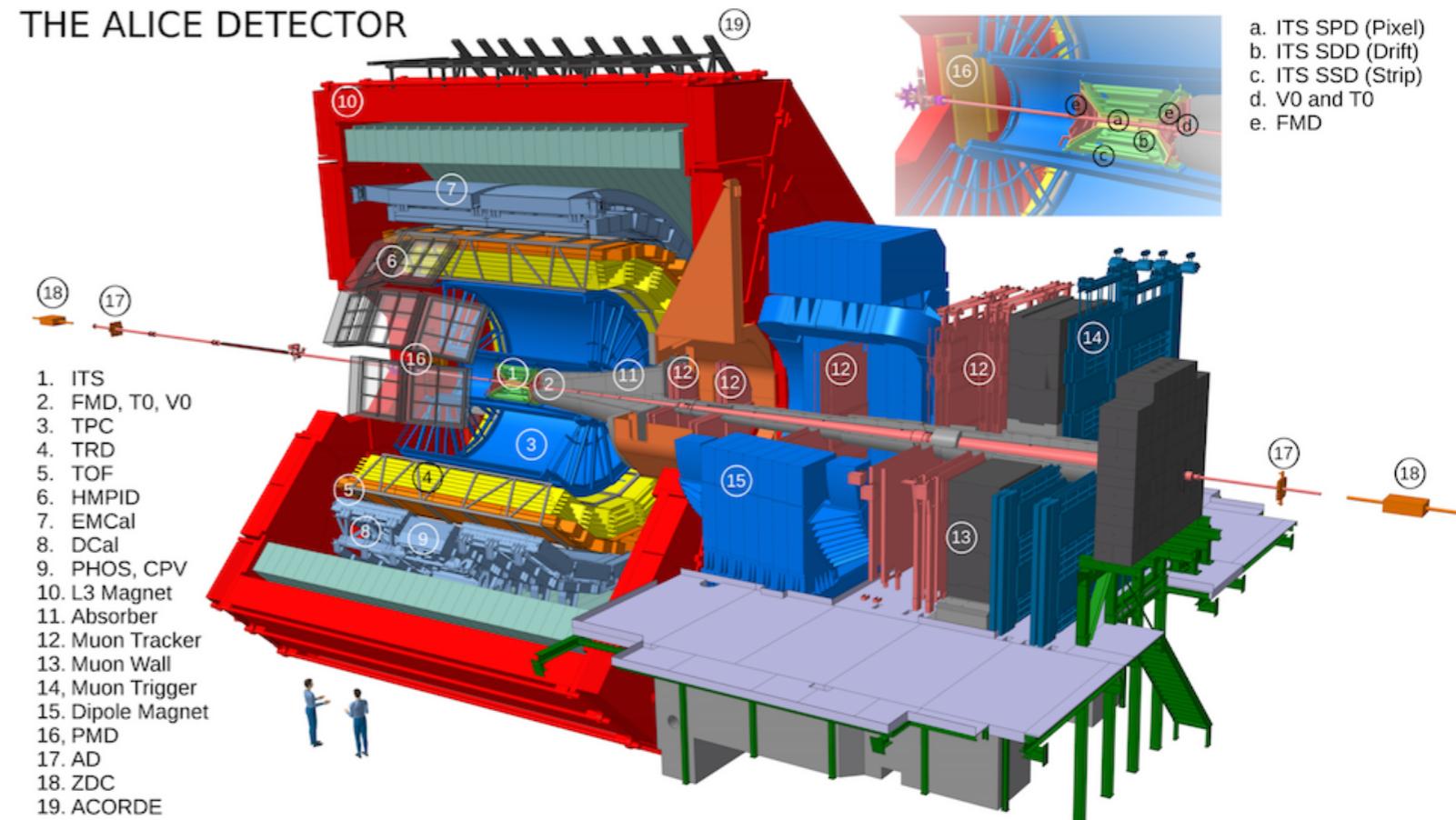
Time Of Flight detector

- PID (TOF measurement)

V0 scintillators

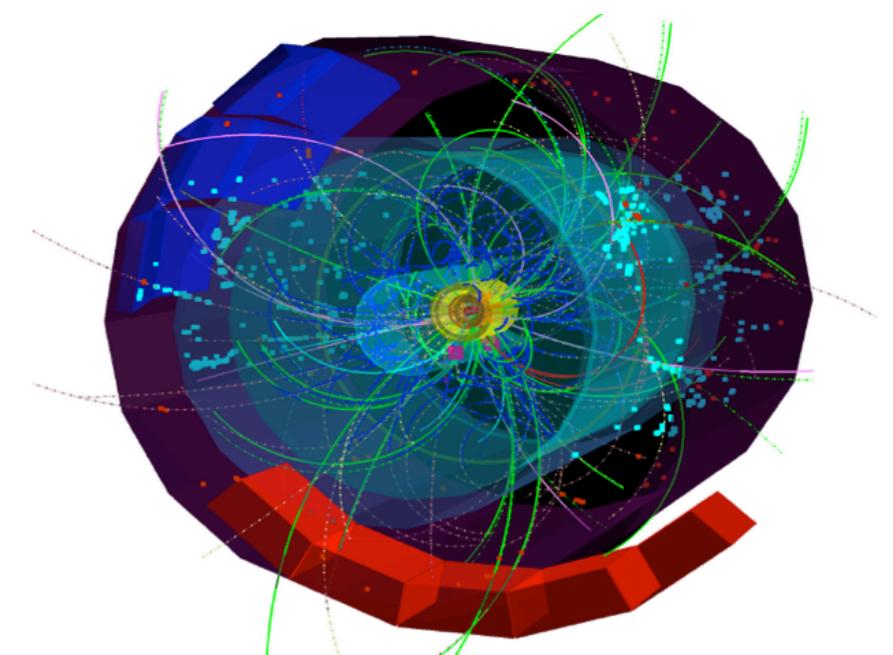
- Trigger, centrality estimation

In this talk:



Collision system	N of events, \mathcal{L}_{int}	Trigger
pp at $\sqrt{s} = 7 \text{ TeV}$	$\sim 370 \text{ M } (\mathcal{L}_{\text{int}} \sim 6 \text{ nb}^{-1})$	min. bias
pp at $\sqrt{s} = 13 \text{ TeV}$	$\sim 440 \text{ M } (\mathcal{L}_{\text{int}} \sim 7.8 \text{ nb}^{-1})$ $\sim 80 \text{ M } (\mathcal{L}_{\text{int}} \sim 2.7 \text{ pb}^{-1})$ $\sim 150 \text{ M } (\mathcal{L}_{\text{int}} \sim 2.7 \text{ nb}^{-1})$	min. bias high mult. (0-0.05% V0M) min. bias (low B-field)
Pb-Pb at $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$	$\sim 20 \text{ M } (\mathcal{L}_{\text{int}} \sim 23 \text{ } \mu\text{b}^{-1})$	0-10% centrality

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



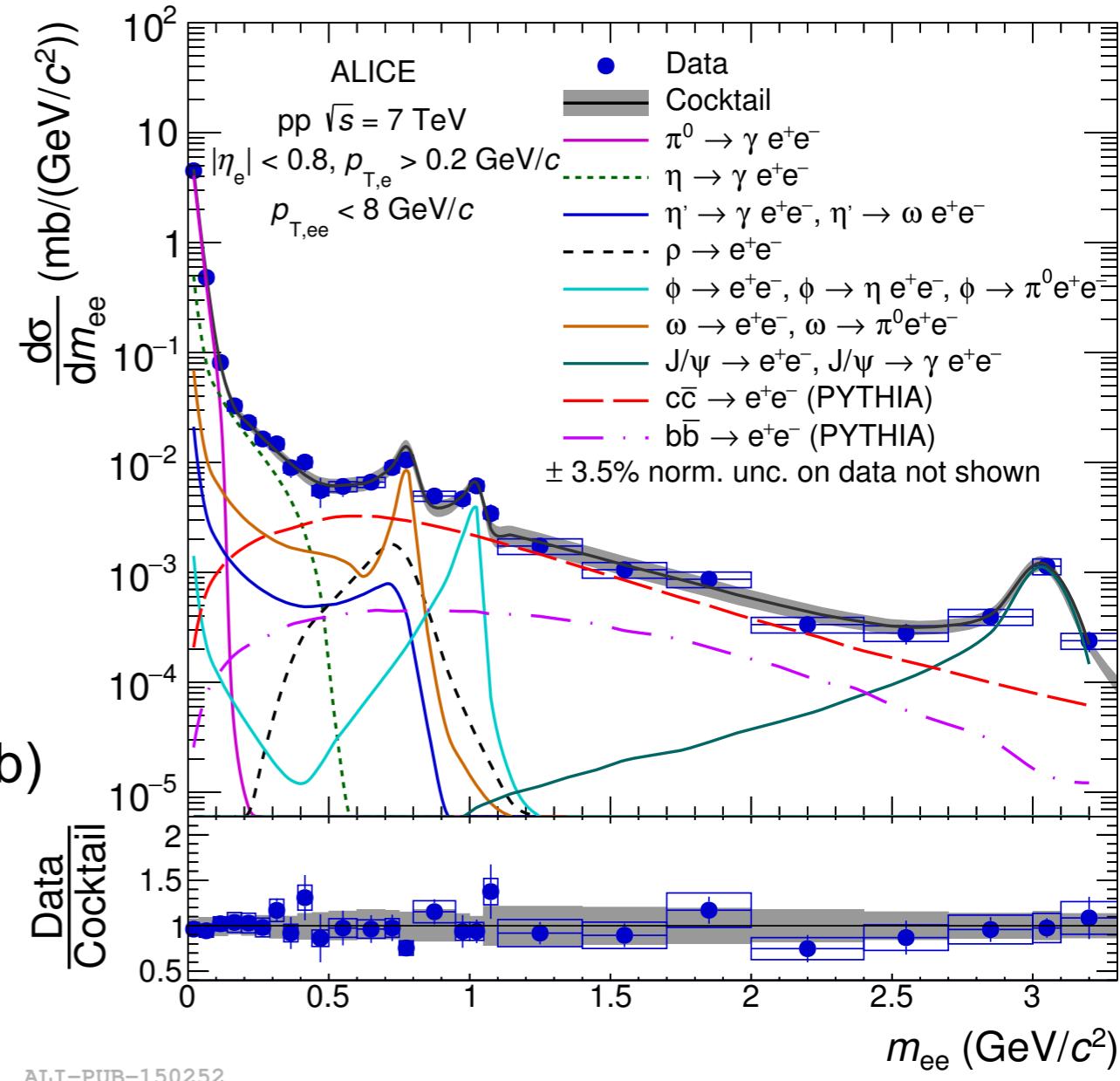
pp $\sqrt{s} = 7$ TeV: invariant mass spectrum

Cocktail of known hadronic sources:

- Resonance and Dalitz decays of light-flavour hadrons
 - measured π^\pm (for π^0), η , ϕ and J/ψ [1-4]
 m_T scaling for η'
 - ω/π^\pm and ρ/π^\pm from PYTHIA 8
 (describes well pp data at $\sqrt{s} = 2.76$ and 7 TeV)
- Correlated HF semi-leptonic decays
 - shape from PYTHIA 6 scaled to measured cross sections [5, 6]
 $(\sigma_{c\bar{c}} = 7.44 \pm 0.60 \text{ mb}, \sigma_{b\bar{b}} = 288 \pm 48 \mu\text{b})$
- Detector acceptance ($p_{T,e} > 0.2 \text{ GeV}/c$, $|\eta_e| < 0.8$) and resolution effects

Analysis is performed as a function of m_{ee} , $p_{T,ee}$ and pair impact parameter DCA_{ee}

arXiv:1805.04391 (submitted to JHEP)



ALI-PUB-150252

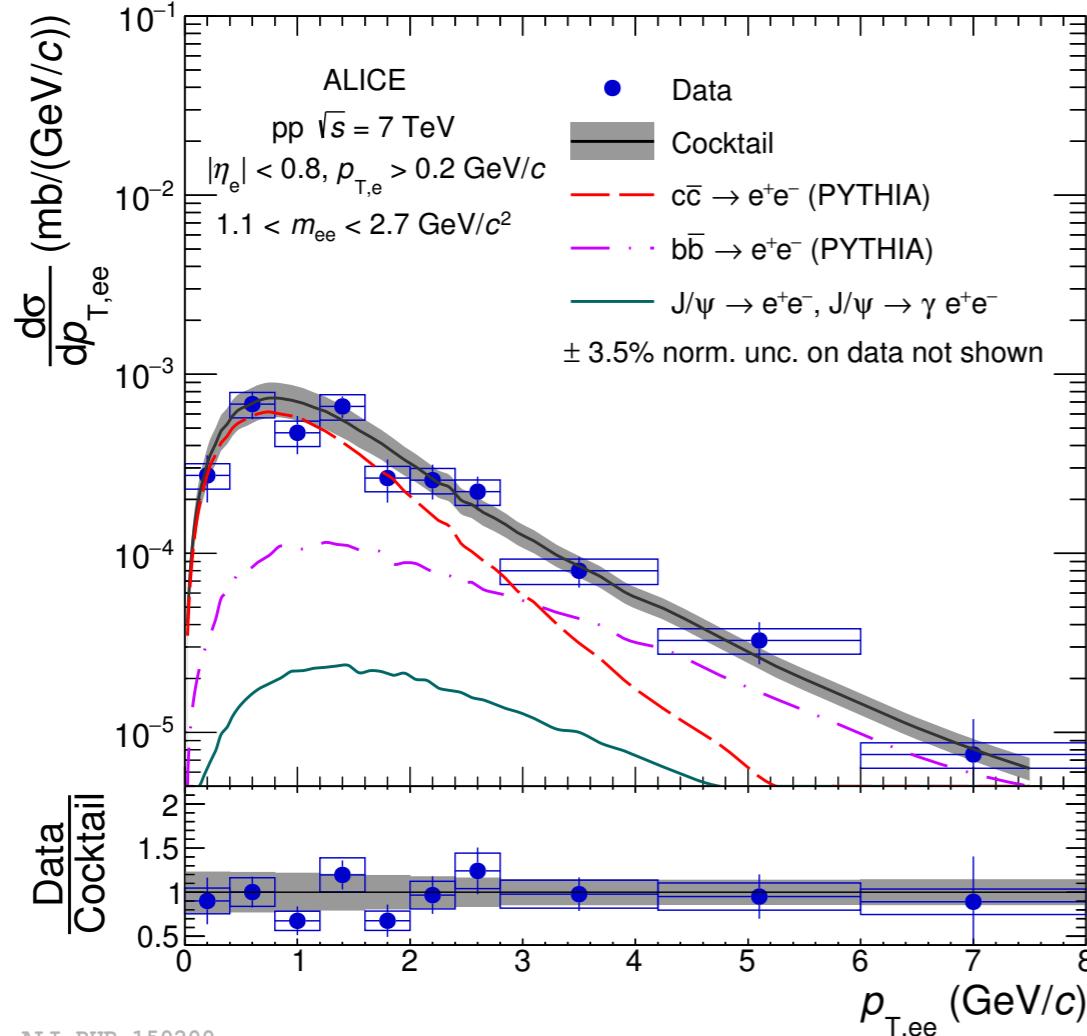
- [1] ALICE Collaboration, Phys. Lett. B 717 (162) 2012
- [2] ALICE Collaboration, Eur. Phys. J. C. 72 (2183) 2012
- [3] ALICE Collaboration, Phys. Lett. B 704 (442) 2011
- [4] ALICE Collaboration, Phys. Lett. B 718 (692) 2012
- [5] ALICE Collaboration, Eur. Phys. J. C77 (2017) 550
- [6] ALICE Collaboration, Eur. Phys. J. C71 (2011) 1645

Data in agreement with cocktail calculations within uncertainties

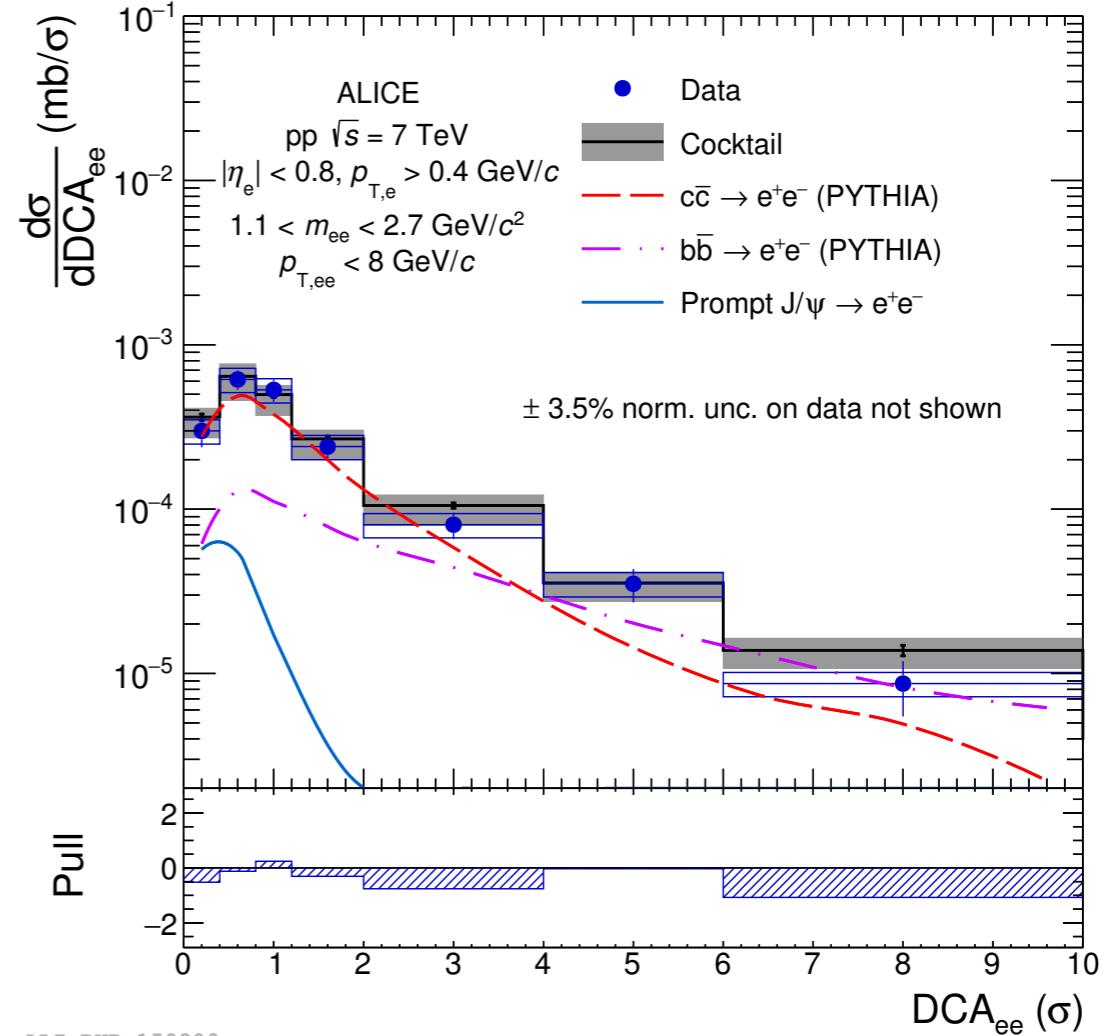
Heavy-flavour cross sections in pp $\sqrt{s} = 7 \text{ TeV}$

Correlated HF decays dominate the intermediate mass region ($1.1 < m_{ee} < 2.7 \text{ GeV}/c^2$)

arXiv:1805.04391 (submitted to JHEP)



ALI-PUB-150200



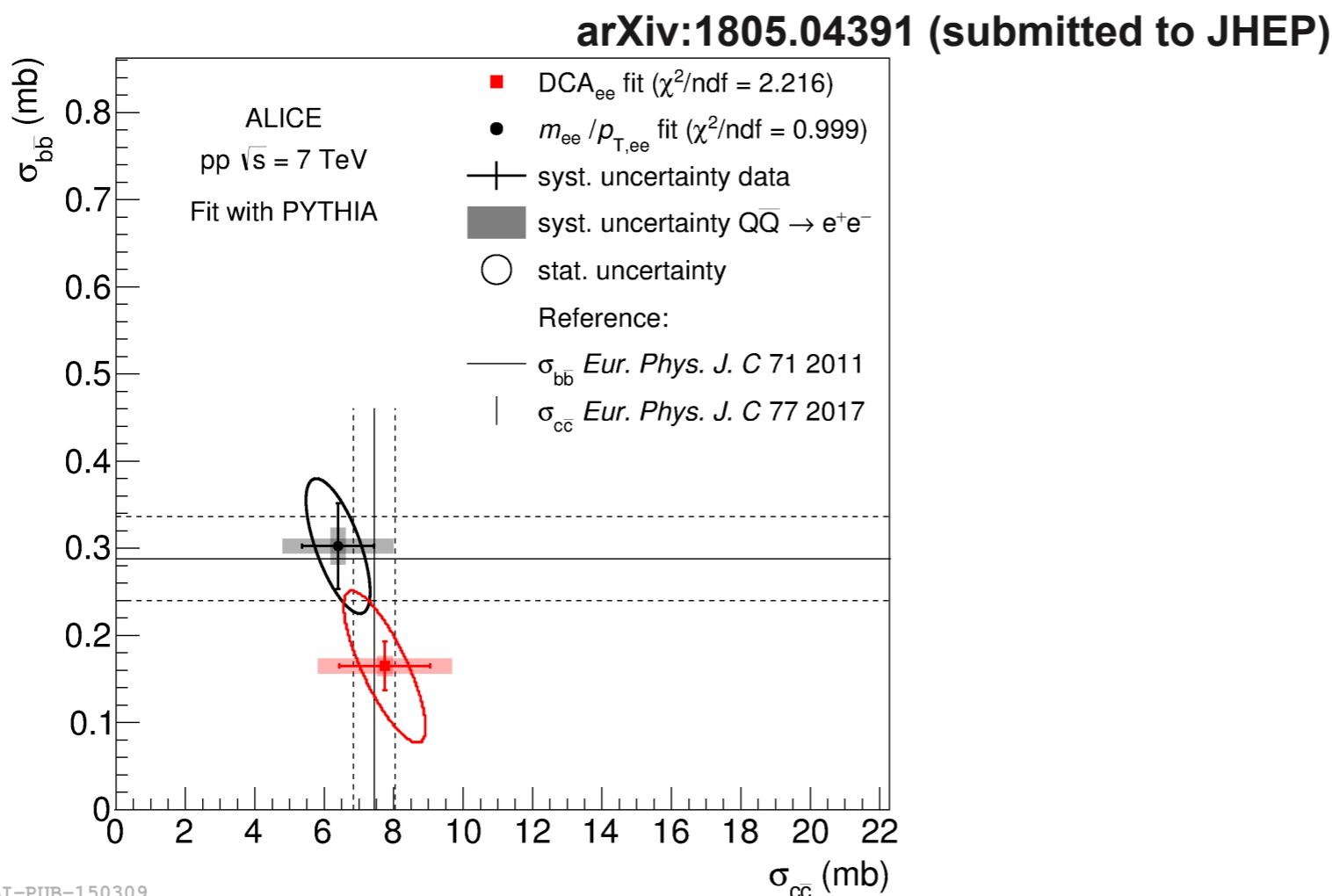
ALI-PUB-150209

- Leave the normalisation free for $c\bar{c}$ and $b\bar{b}$ contributions
- Fit the dielectron spectra in 2D (m_{ee} vs $p_{T,ee}$) or vs DCA_{ee} with MC templates and extract $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$

Heavy-flavour cross sections in pp $\sqrt{s} = 7$ TeV

Results agree between two methods

- Sensitive to predicted acceptance and $m_{ee}/p_{T,ee}$ spectra ($m_{ee}/p_{T,ee}$ fit)
- In good agreement with previous independent measurements of single HF hadrons



Heavy-flavour cross sections in pp $\sqrt{s} = 7$ TeV

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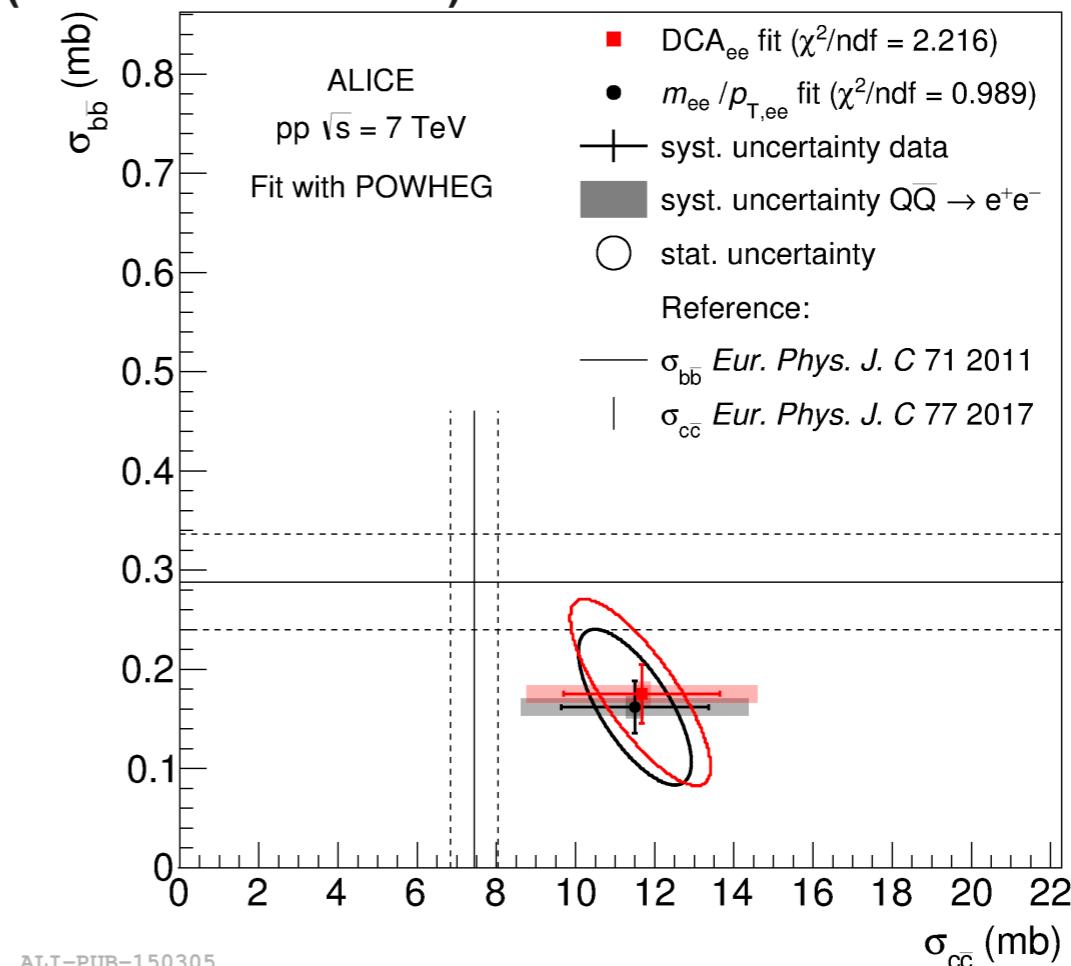
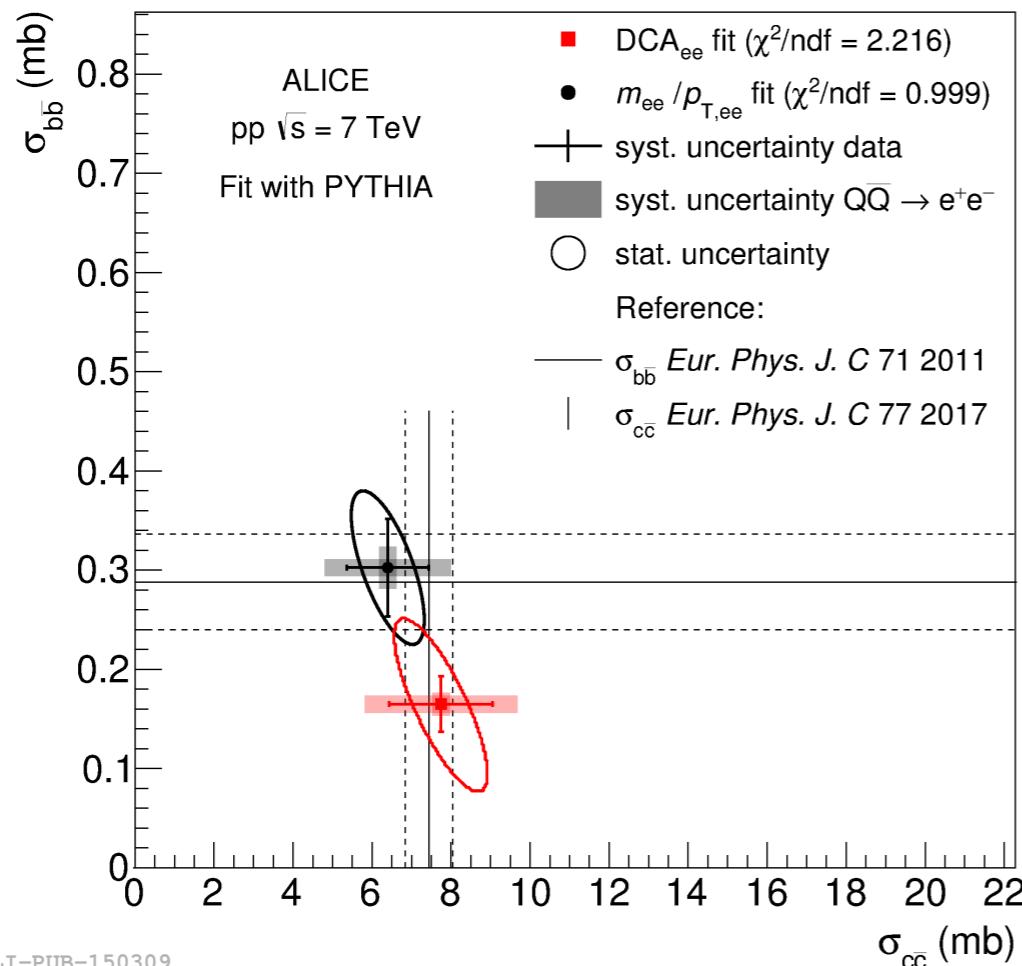
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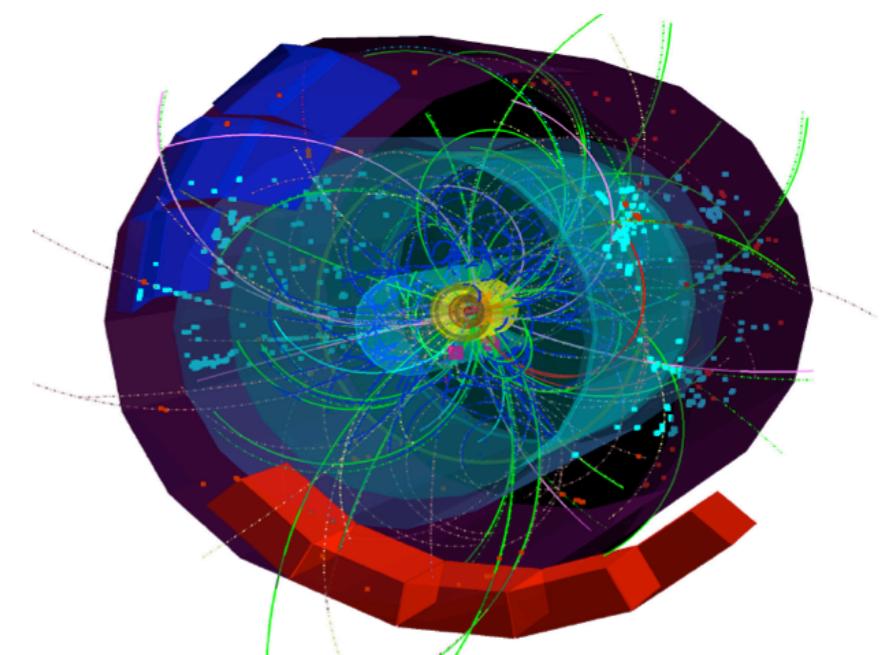
Model dependence: implementation of heavy-quark production mechanism

- PYTHIA 6: leading order with parton shower
- POWHEG: NLO, PYTHIA 6 for parton shower

[arXiv:1805.04391](#) (submitted to JHEP)



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

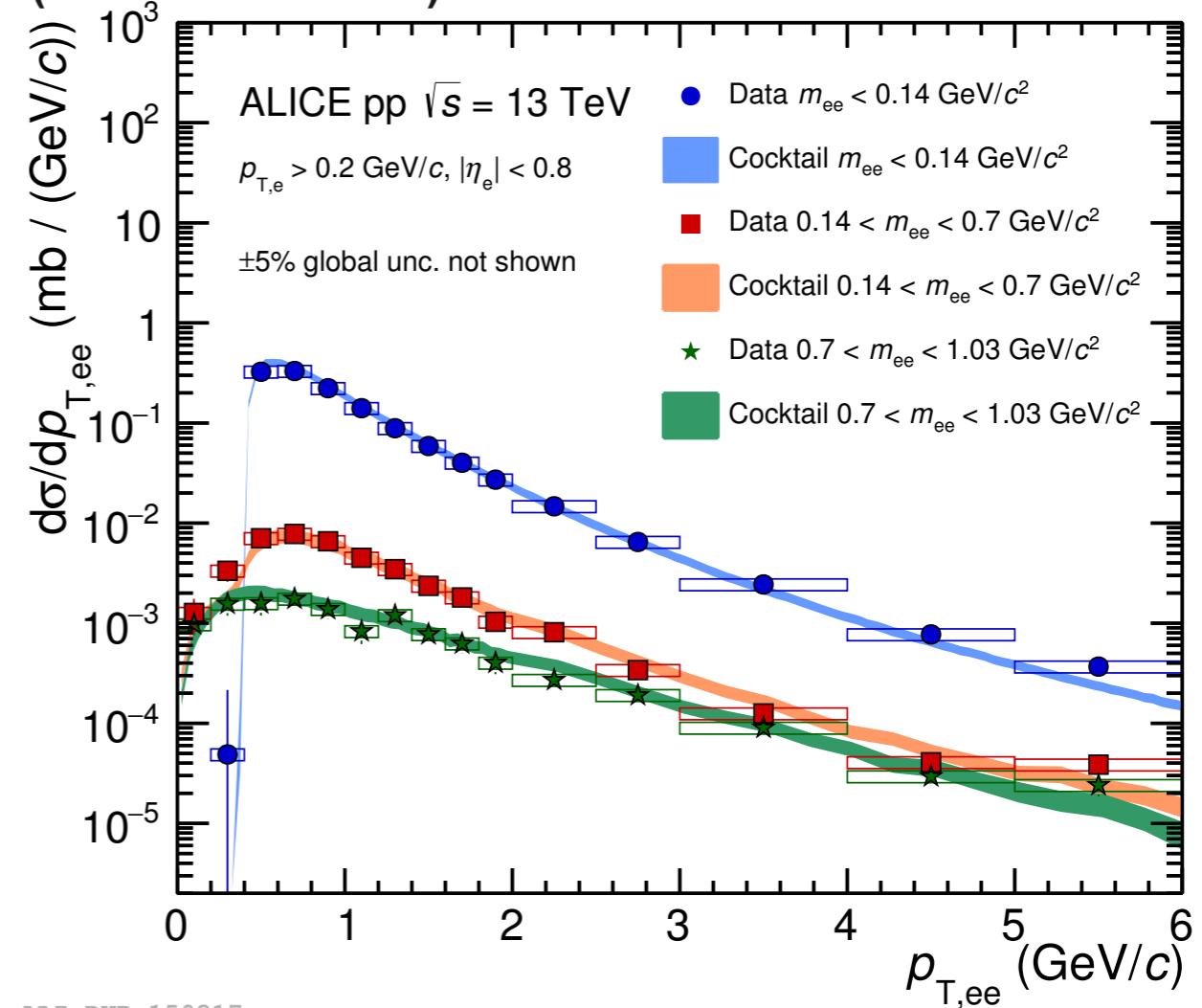
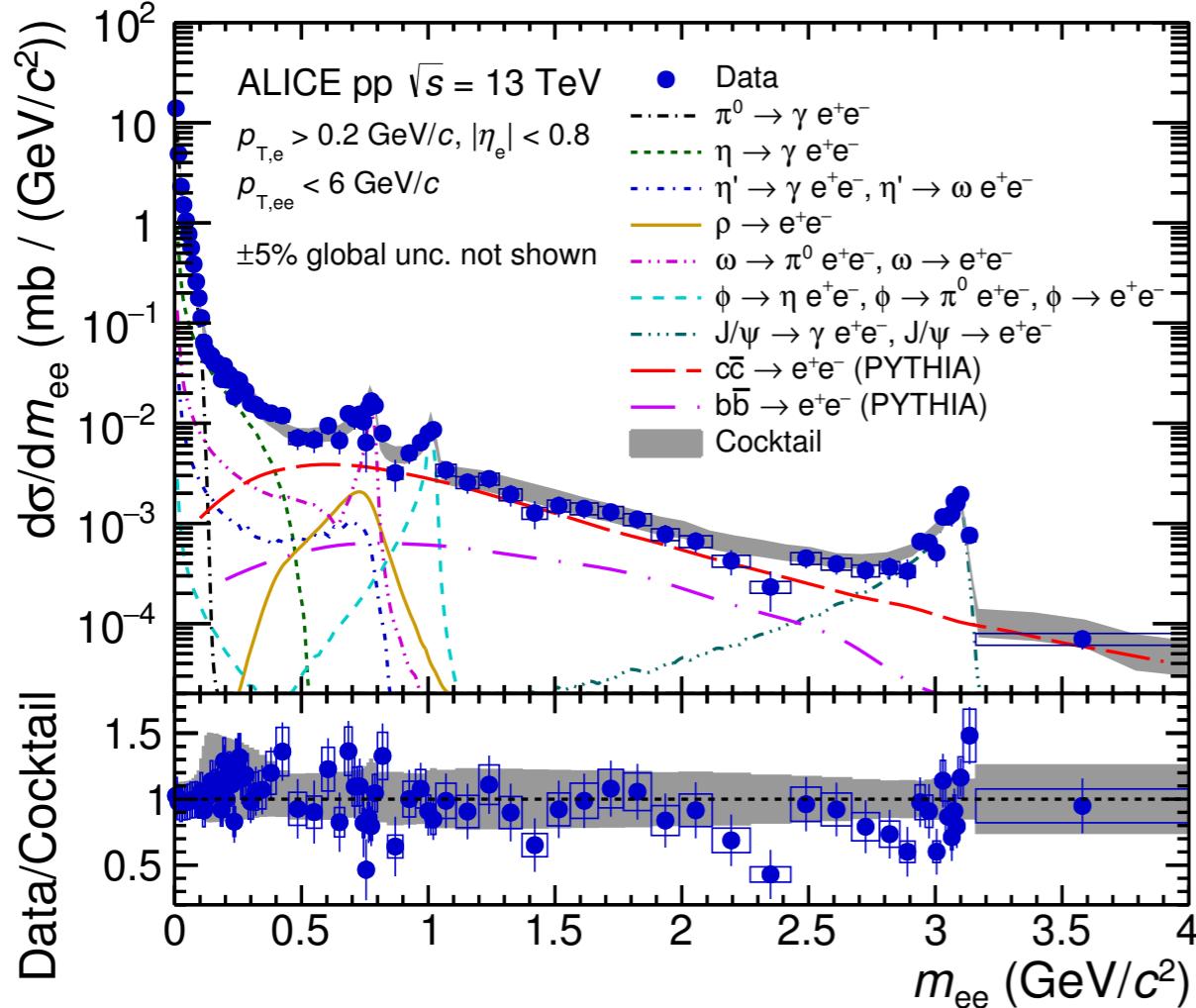


pp $\sqrt{s} = 13$ TeV: invariant mass and $p_{T,ee}$ spectra

Cocktail of known hadronic sources similar to 7 TeV data analysis

- π^\pm from data, PYTHIA 8 for ρ/π and ω/π , m_T scaling for η' and ϕ
- PYTHIA 6 for correlated HF semi-leptonic decays

arXiv:1805.04407 (submitted to PLB)



Good description of data with hadronic cocktail expectations

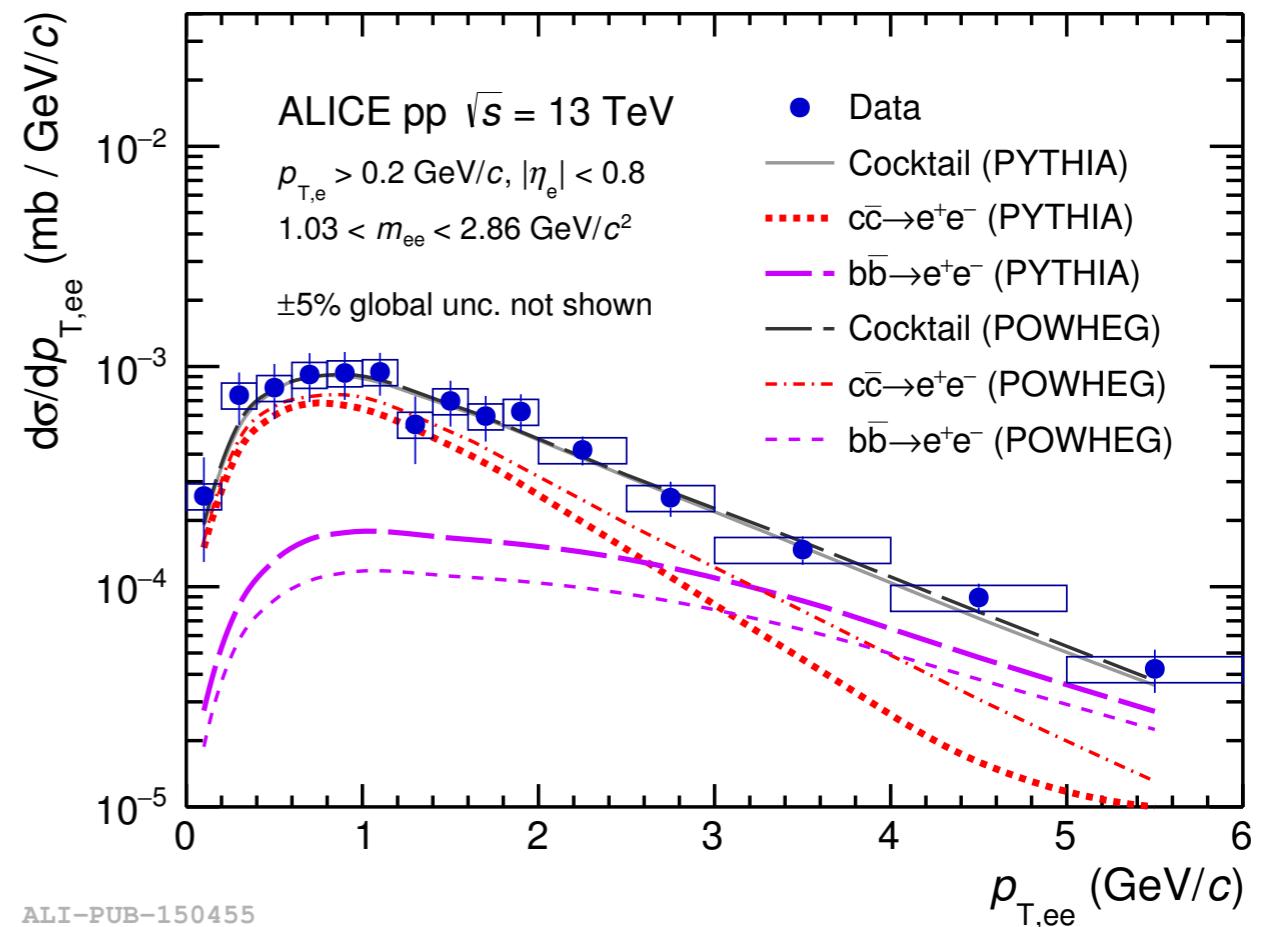
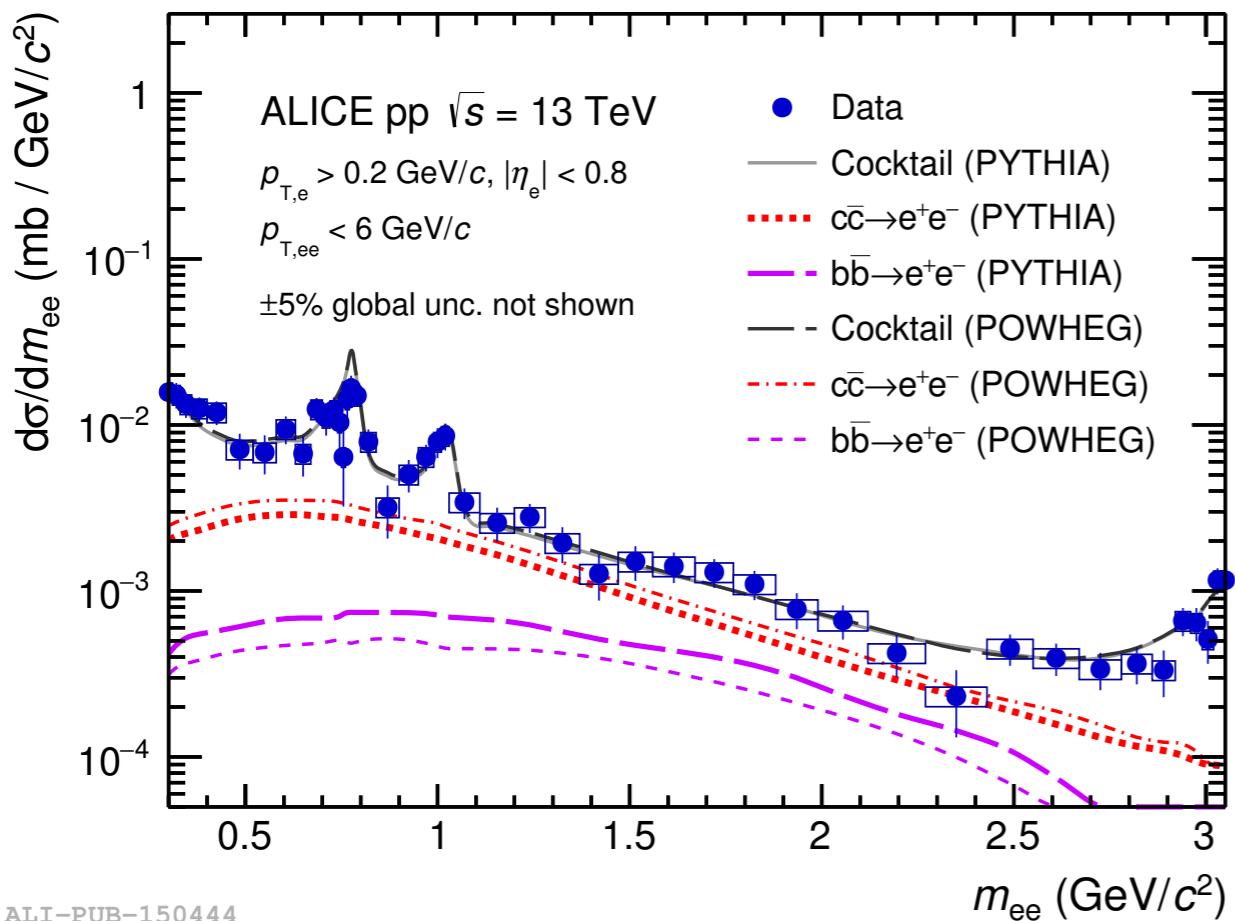
- e^+e^- production in min. bias pp collisions is well understood for $p_{T,e} > 0.2 \text{ GeV}/c$

pp $\sqrt{s} = 13$ TeV: heavy-flavour cross sections

Fit the dielectron spectra in 2D (m_{ee} vs $p_{T,ee}$) in intermediate mass region

- Similar model dependence is observed as for results in pp at $\sqrt{s} = 7$ TeV

arXiv:1805.04407 (submitted to PLB)



ALI-PUB-150444

ALI-PUB-150455

PYTHIA

POWHEG

$d\sigma_{c\bar{c}}/dy _{y=0}$	$974 \pm 138 \text{ (stat.)} \pm 140 \text{ (syst.) } \mu\text{b}$	$1417 \pm 184 \text{ (stat.)} \pm 204 \text{ (syst.) } \mu\text{b}$
$d\sigma_{b\bar{b}}/dy _{y=0}$	$79 \pm 14 \text{ (stat.)} \pm 11 \text{ (syst.) } \mu\text{b}$	$48 \pm 14 \text{ (stat.)} \pm 7 \text{ (syst.) } \mu\text{b}$

Ratio of dielectron spectra in HM over INEL events

New phenomena in high-multiplicity events?

Idea: produce a ratio of dielectron spectra

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

Cocktail calculations take into account expected modifications:

- Hardening of $h^\pm p_T$ spectrum [1], same mult. scaling for LF hadrons at the same m_T
- D and J/ ψ production vs mult. [2,3], same enhancement for beauty as for open charm

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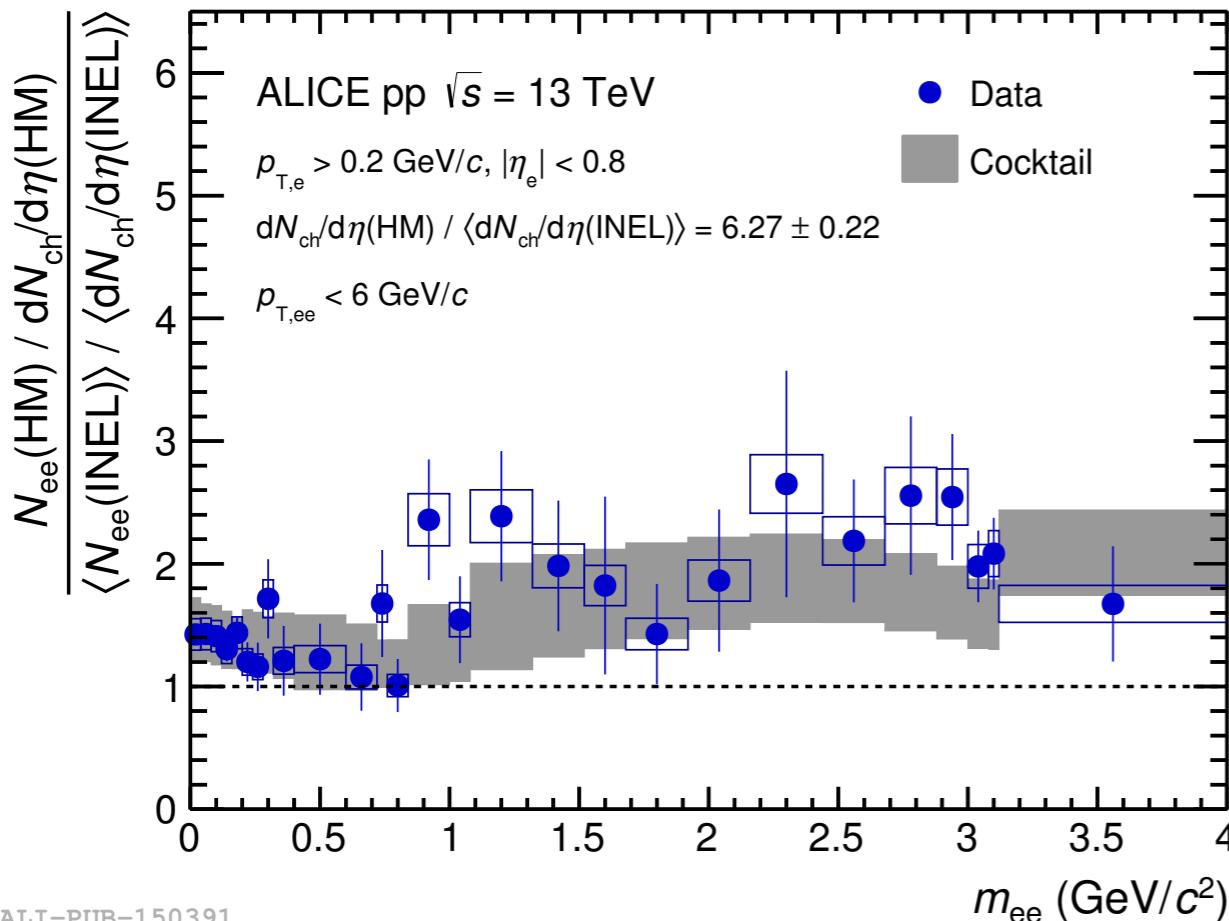
$$\frac{N_{ee}(HM)}{\langle N_{ee}(INEL) \rangle} \times \frac{\langle dN_{ch}/d\eta(INEL) \rangle}{dN_{ch}/d\eta(HM)}$$

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Good agreement with cocktail expectations over whole measured range

arXiv:1805.04407 (submitted to PLB)



ALI-PUB-150391

- [1] ALICE Collaboration, Phys. Lett. B 753, 319 (2016)
- [2] ALICE Collaboration, JHEP 09, 148 (2015)
- [3] ALICE Collaboration, Phys. Lett. B 712 (2012) 165

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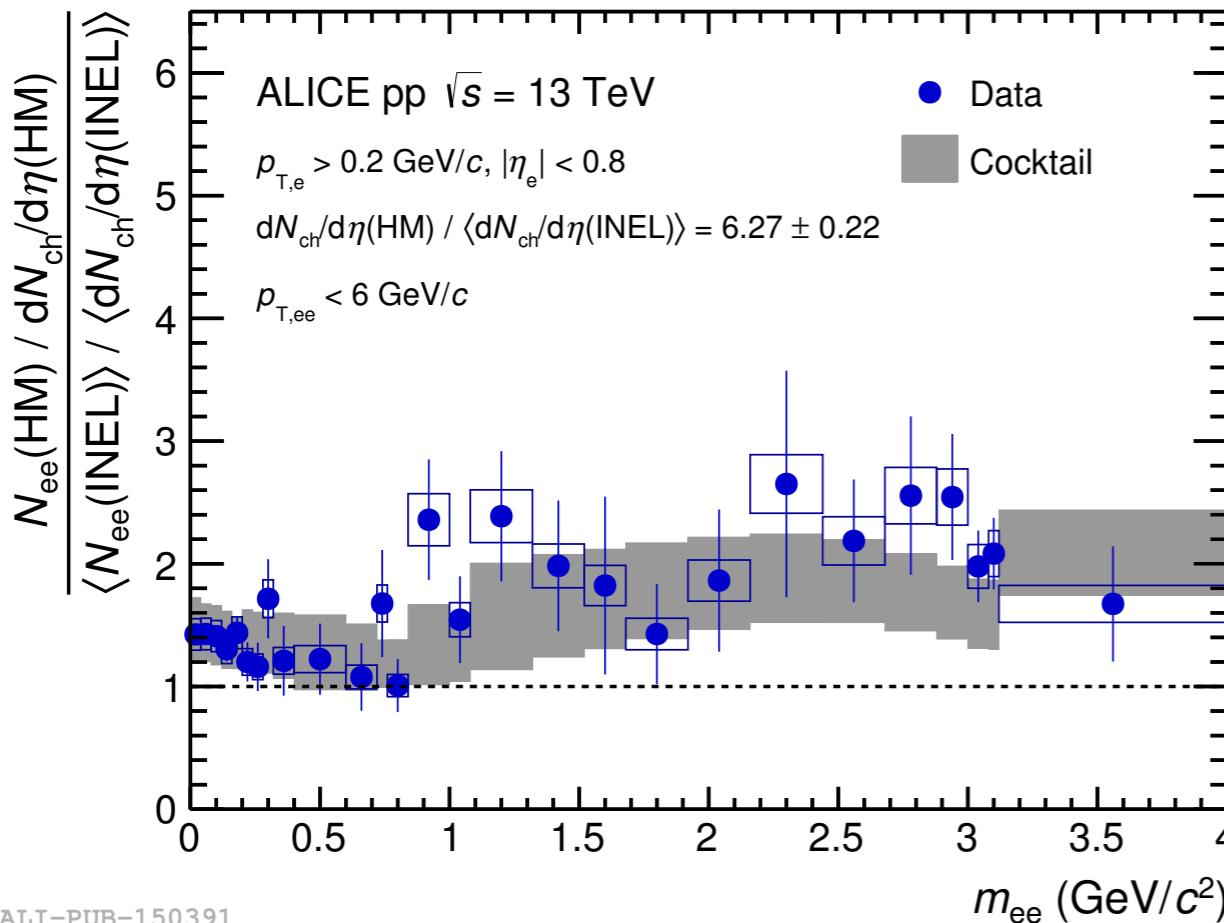
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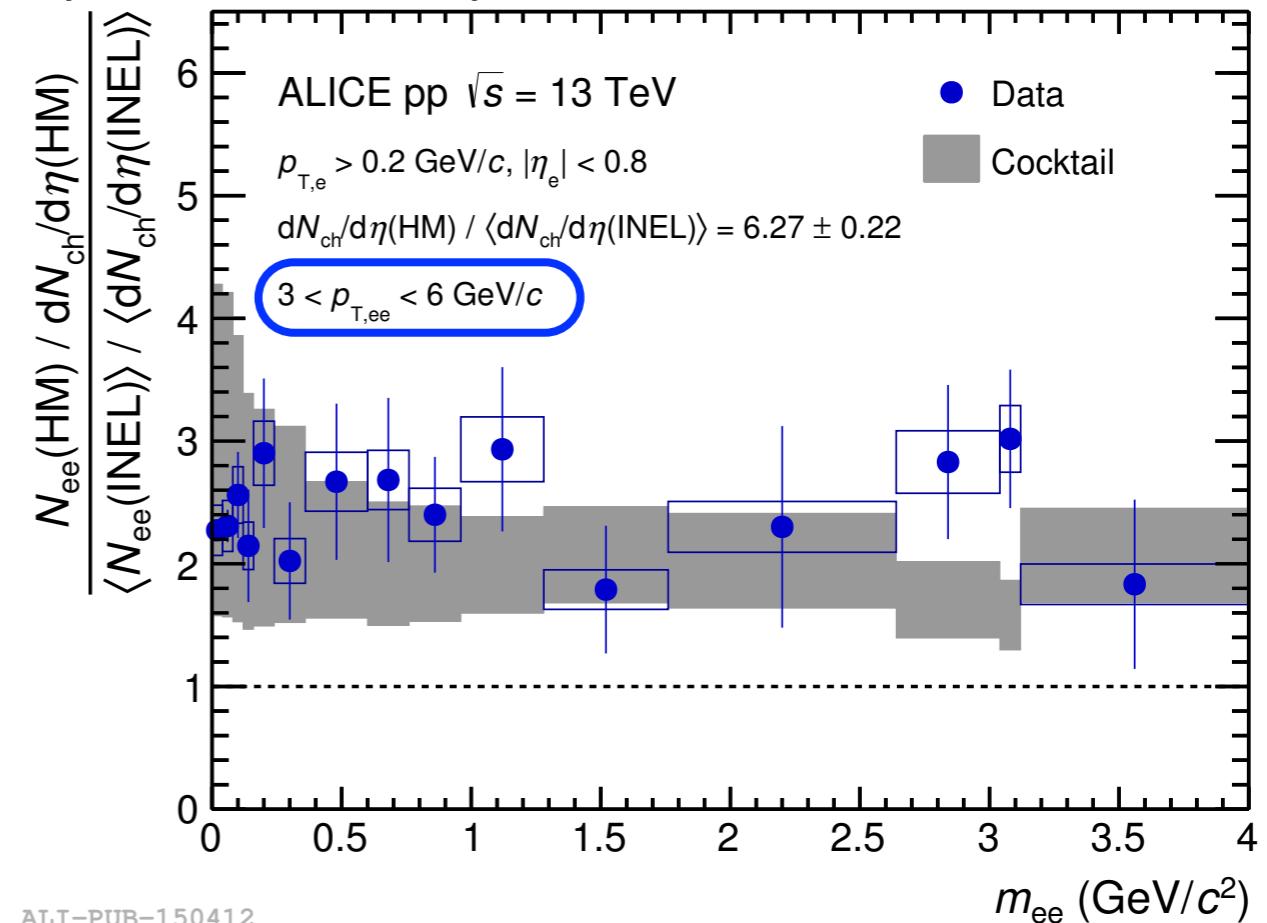


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[1] ALICE Collaboration, Phys. Lett. B 753, 319 (2016)

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[3] ALICE Collaboration, Phys. Lett. B 712 (2012) 165



ALI-PUB-150412

Virtual direct photons

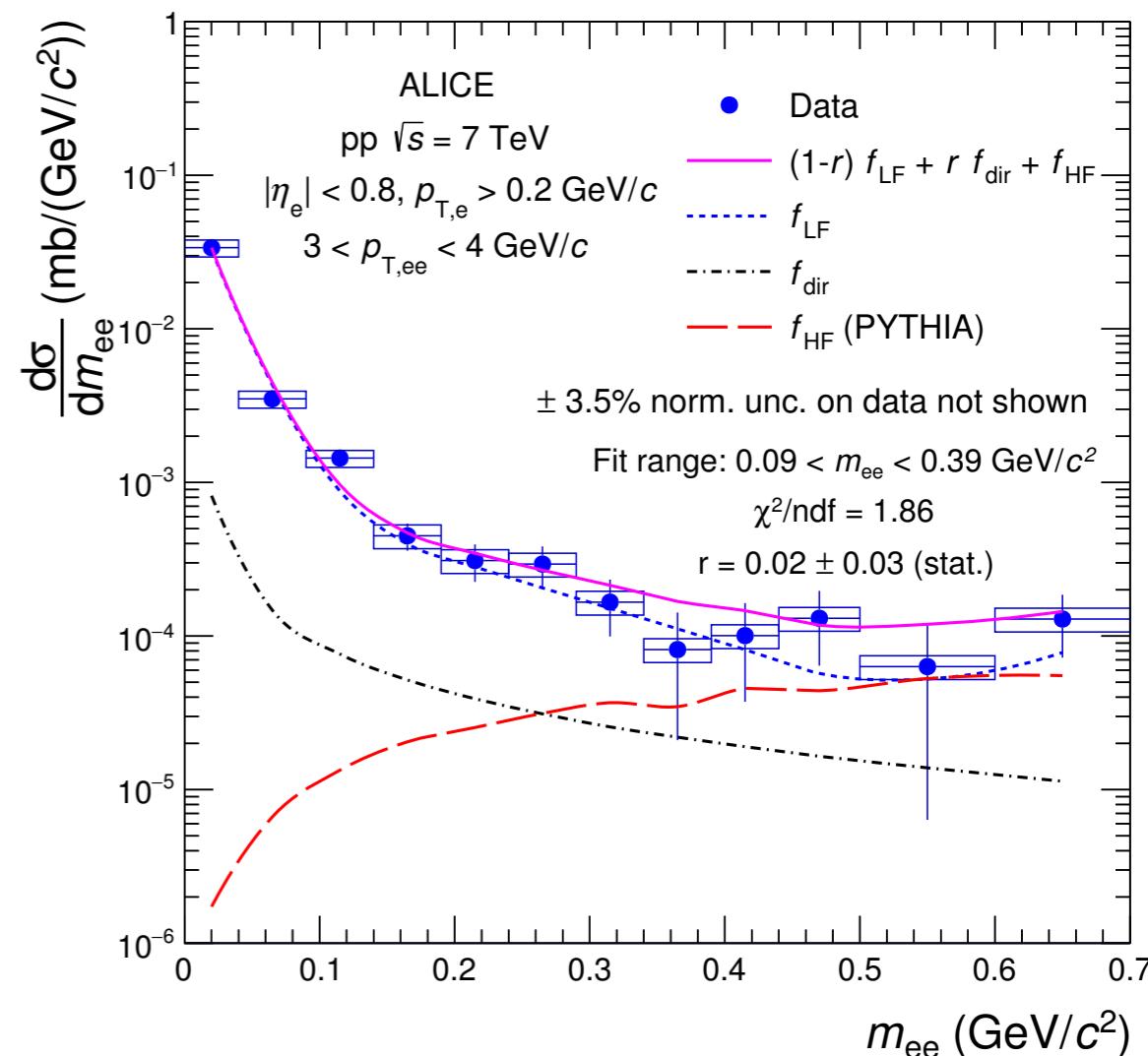
Any source of real photons can also produce virtual photons ($\rightarrow e^+e^-$ pair)

- Small internal conversion probability $O(10^{-2})$, cross section decreases as $\sim 1/m_{ee}$
- Additional dimension: invariant mass \rightarrow can suppress hadronic background by going to $m_{ee} > m_{\pi^0}$

Fit dielectron mass spectrum above π^0 mass with:

$$f(m_{ee}) = r \cdot f_{dir}(m_{ee}) + (1-r)f_{LF}(m_{ee}) + f_{HF}(m_{ee})$$

- f_{dir} and f_{LF} are normalised to data at $m_{ee} = 0$
- $r = (\text{virtual}) \text{ direct } \gamma / \text{inclusive } \gamma$ (at $m_{ee} = 0$)
- γ^*_{dir} from Kroll-Wada ($m_{ee} \ll p_T$), $\sim 1/m_{ee}$



ALI-PUB-150496

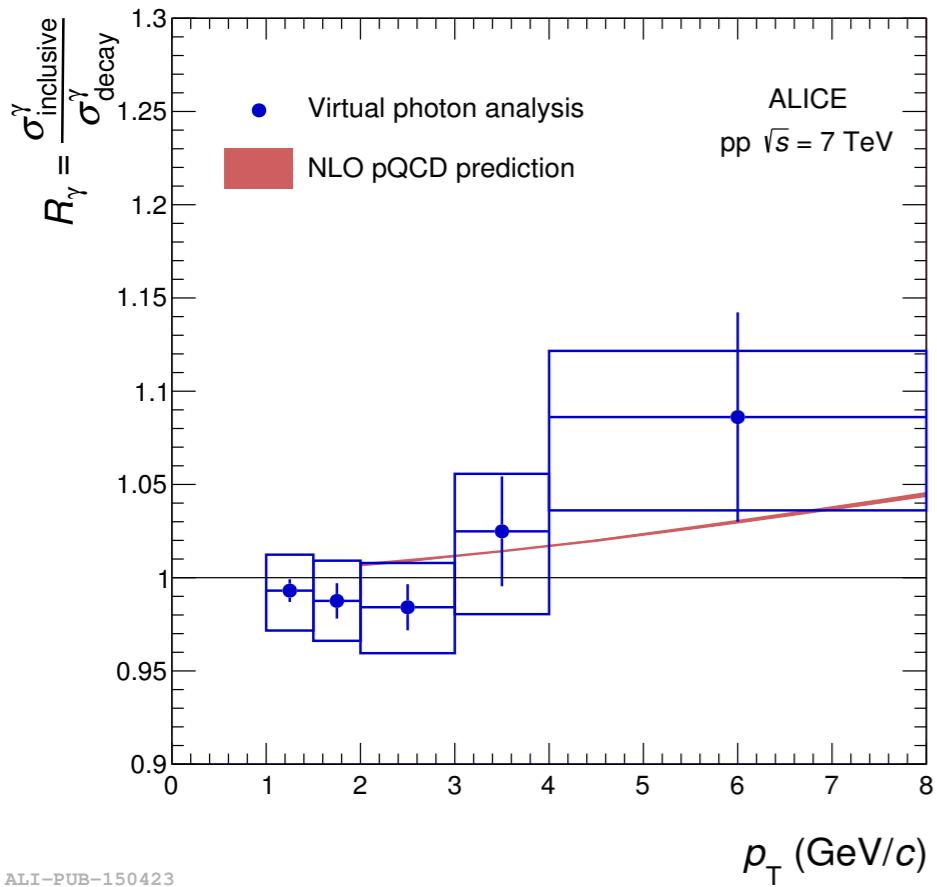
Virtual direct photons: results in pp collisions

No significant direct photon contribution is observed

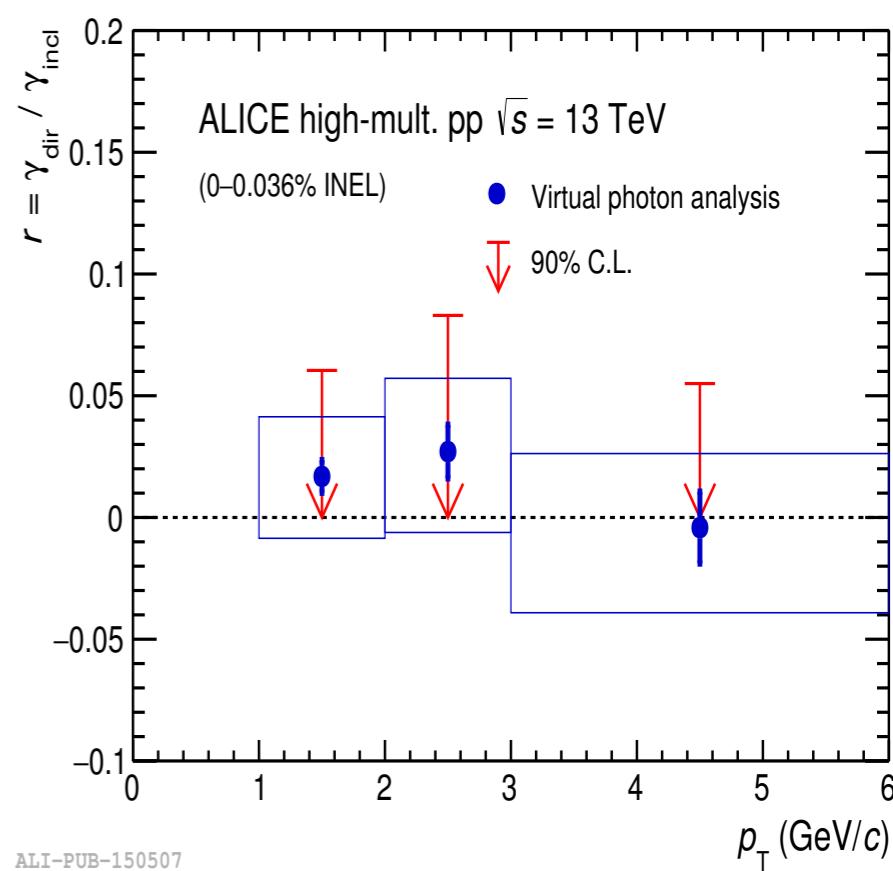
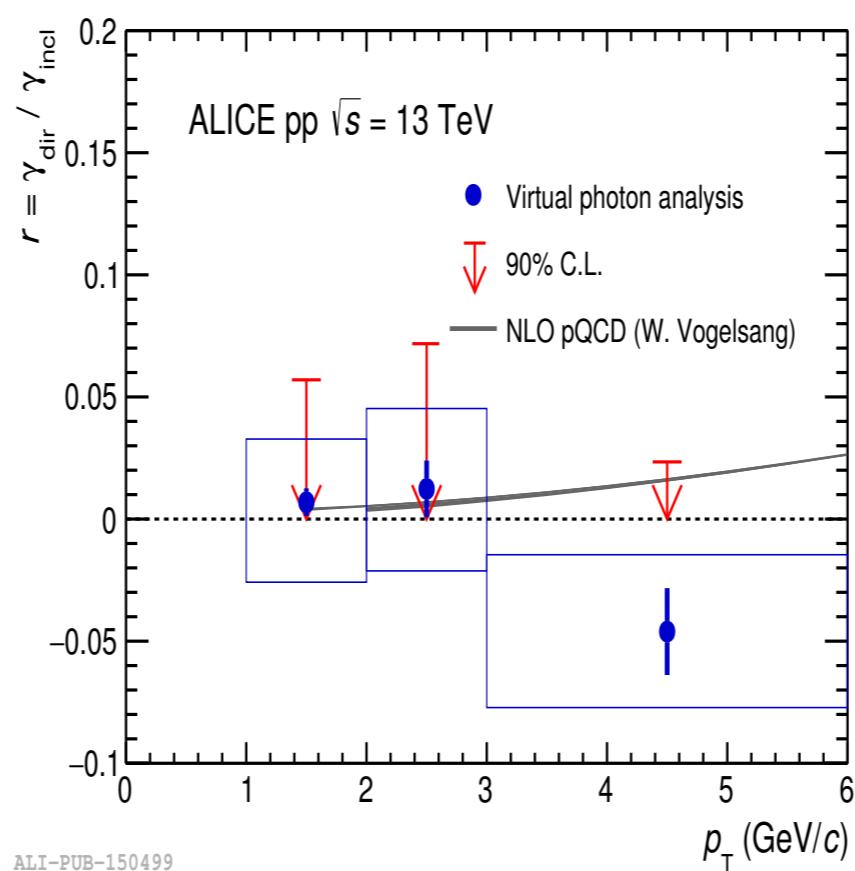
- Results in inelastic events are consistent with pQCD NLO calculations [1]
- Upper limits at 90% C.L. are extracted with the Feldman-Cousins method [2]

Extend the measurements of direct photons in pp collisions at different energies [3]

[arXiv:1805.04391](#) (submitted to JHEP)



[arXiv:1805.04407](#) (submitted to PLB)



[1] L. E. Gordon and W. Vogelsang, Phys. Rev. D 48, 3136 (1993)

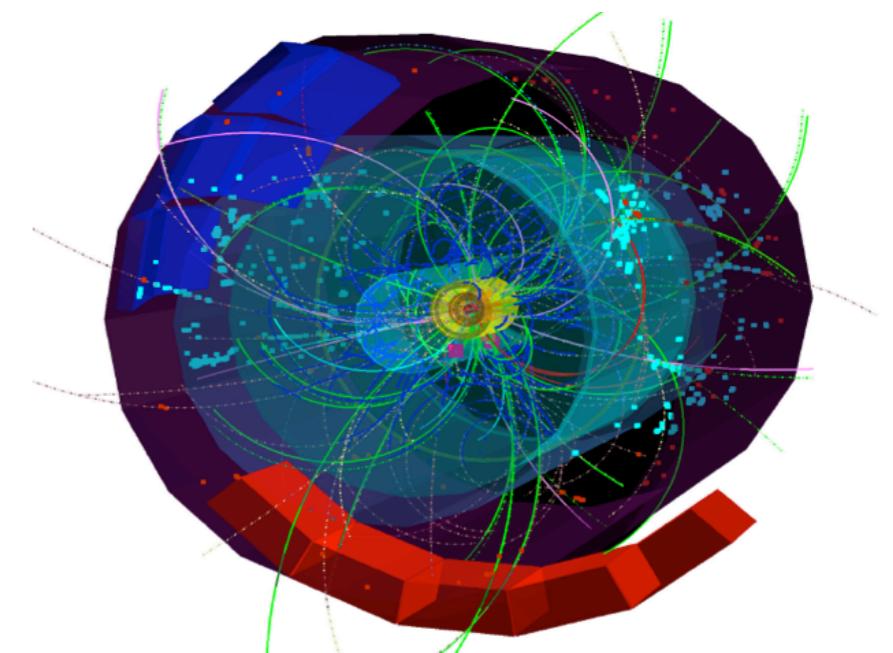
[2] G. Feldman and R. Cousins, Phys. Rev. D 57, 3873 (1998)

[3] ALICE Collaboration, arXiv:1803.09857

New!



Central Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$



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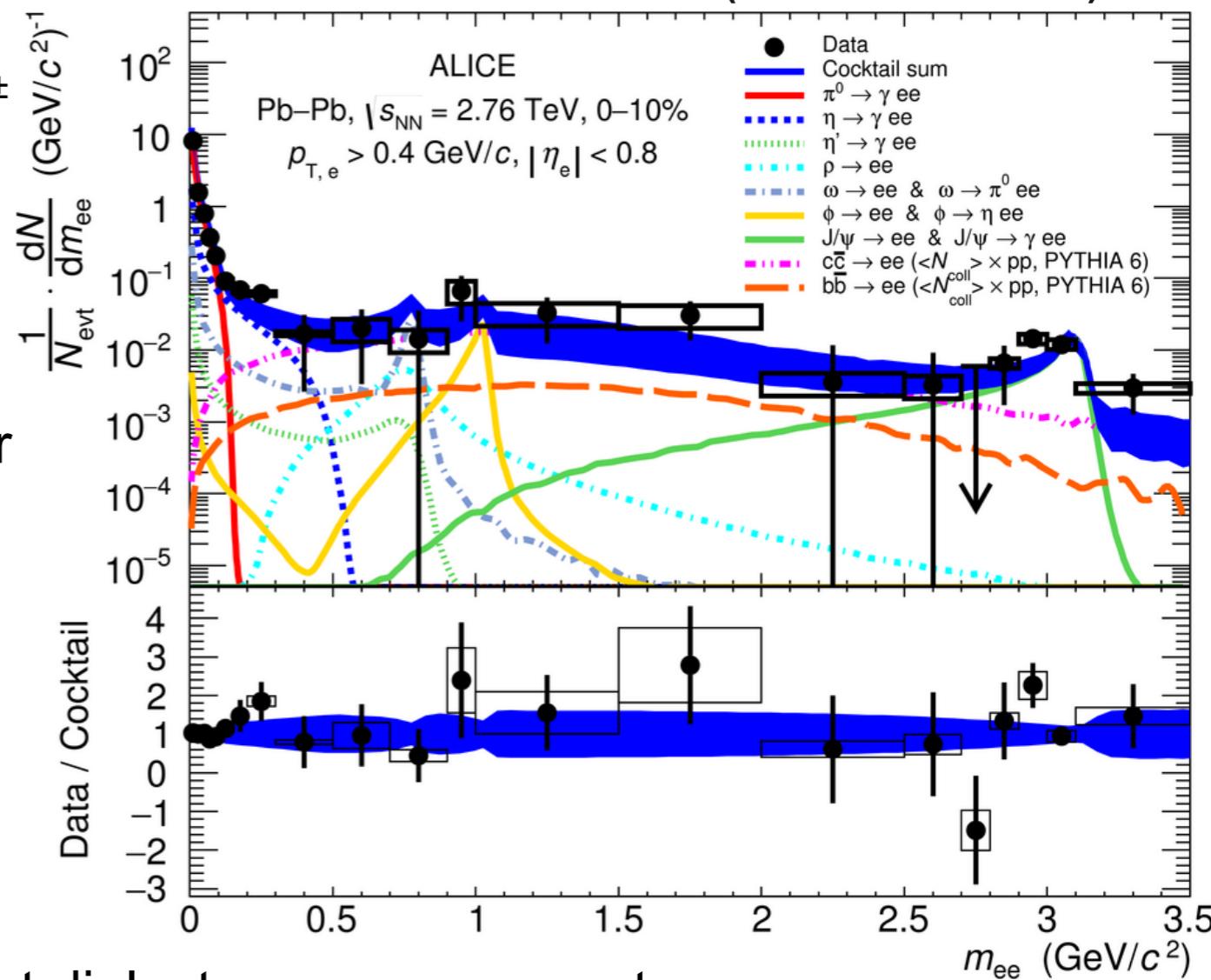
arXiv:1807.00923 (submitted to PRC)

Light-flavour cocktail sources:

- Measured π^0 spectrum, η/π and K^\pm/π^\pm ratios for η [1-3]
- m_T scaling for other hadrons

Heavy-flavour cocktail:

- PYTHIA calculations for pp at 2.76 TeV scaled with N_{coll} from MC Glauber (no medium and shadowing effects)



Data compatible with cocktail within uncertainties

- Statistically limited sensitivity of current dielectron measurement
- Data/cocktail (excluding vacuum ρ^0) in $0.15 < m_{ee} < 0.7 \text{ GeV}/c^2$:
 $R = 1.38 \pm 0.28 \text{ (stat.)} \pm 0.08 \text{ (syst.)} \pm 0.27 \text{ (cocktail)}$

[1] ALICE Collaboration, Eur. Phys. J. C74, 10, 3108 (2014)

[2] ALICE Collaboration, Phys. Lett. B717, 162 (2012)

[3] ALICE Collaboration, Phys. Lett. B736, 196 (2014)



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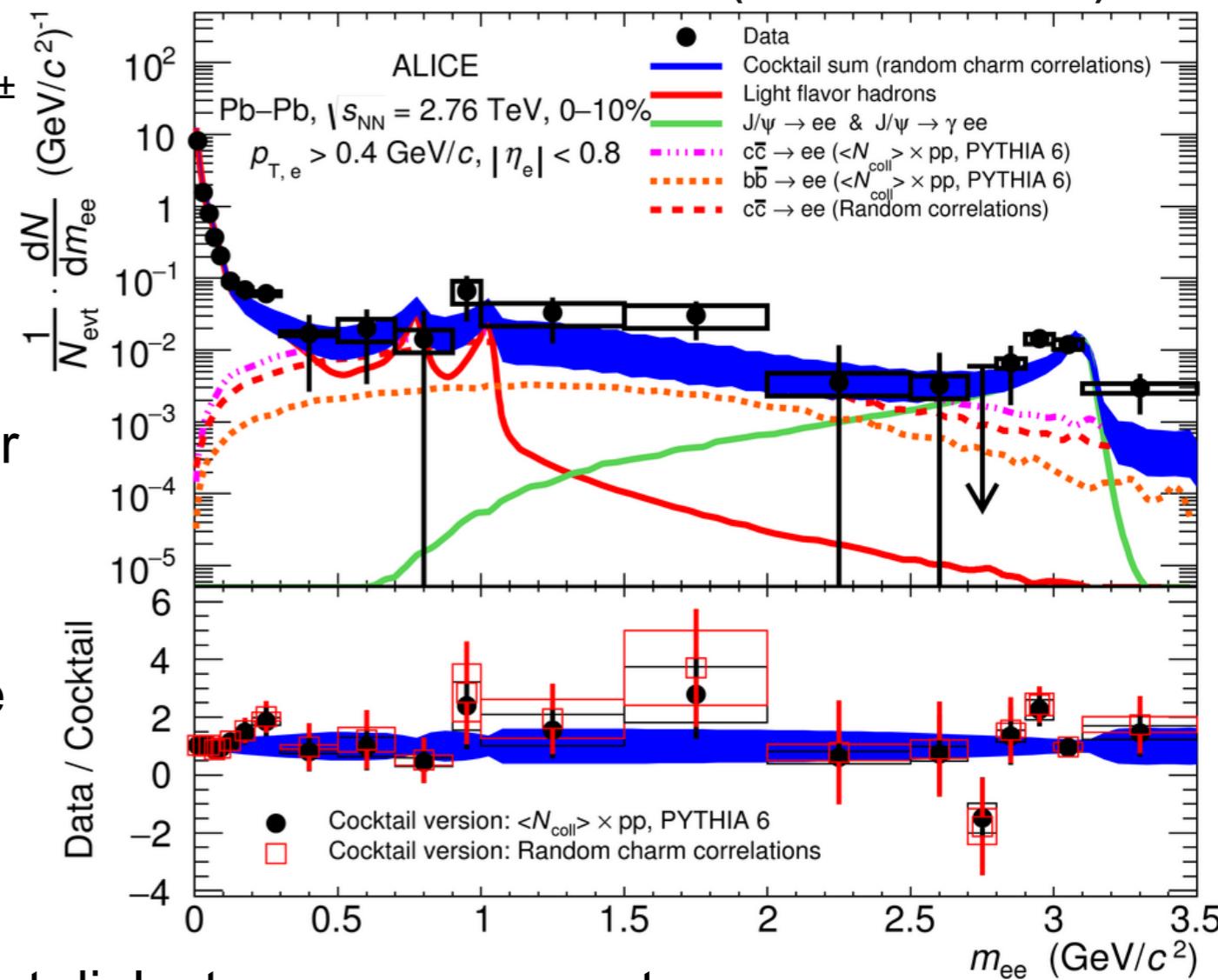
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Heavy-flavour cocktail:

- PYTHIA calculations for pp at 2.76 TeV scaled with N_{coll} from MC Glauber (no medium and shadowing effects)
- Alternative method: complete randomisation of initial angular correlations of $c\bar{c}$ pairs (extreme case of medium effects)

Data compatible with cocktail within uncertainties

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- Intermediate mass range compatible with both approaches for HF cocktail



[1] ALICE Collaboration, Eur. Phys. J. C74, 10, 3108 (2014)

[2] ALICE Collaboration, Phys. Lett. B717, 162 (2012)

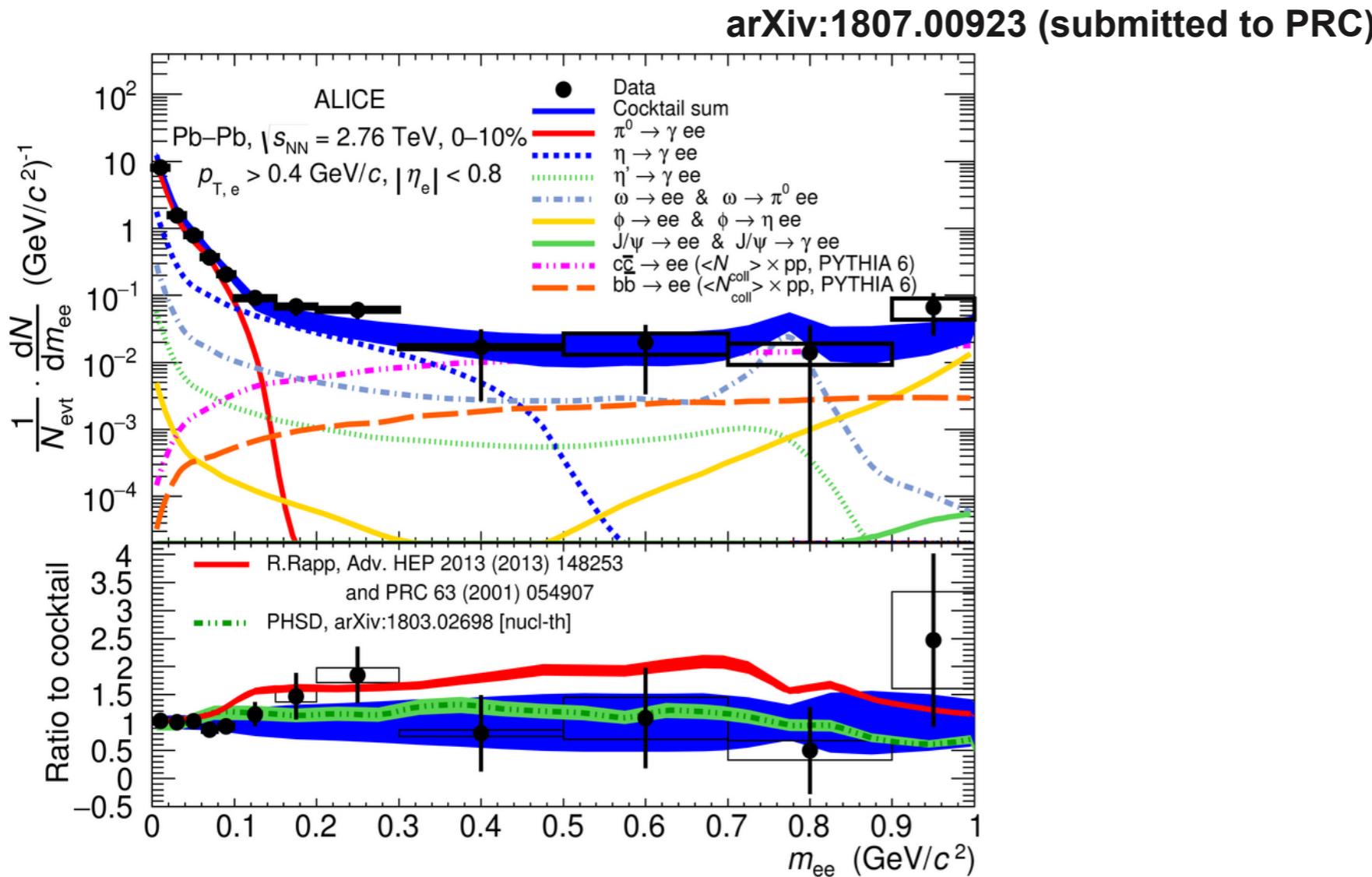
[3] ALICE Collaboration, Phys. Lett. B736, 196 (2014)

New!

Thermal dielectrons and direct photons

Data compared to hadronic cocktail + thermal dielectrons from two models:

- **Expanding fireball model** [Adv. HEP 2013 (2013) 148253, PRC 63 (2001) 054907]
- **Parton-Hadron-String Dynamics transport approach** [arXiv:1803.02698]



New!

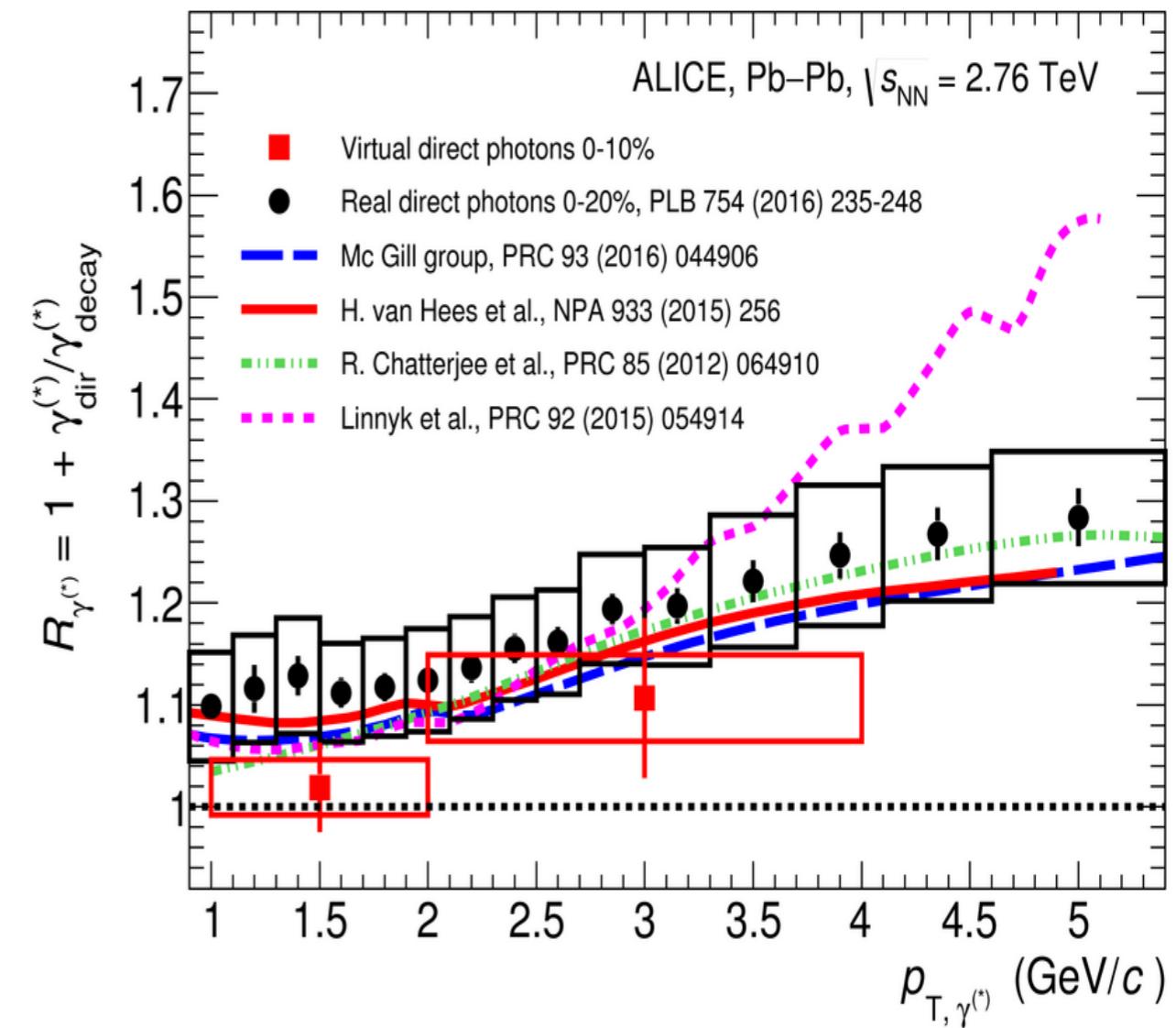
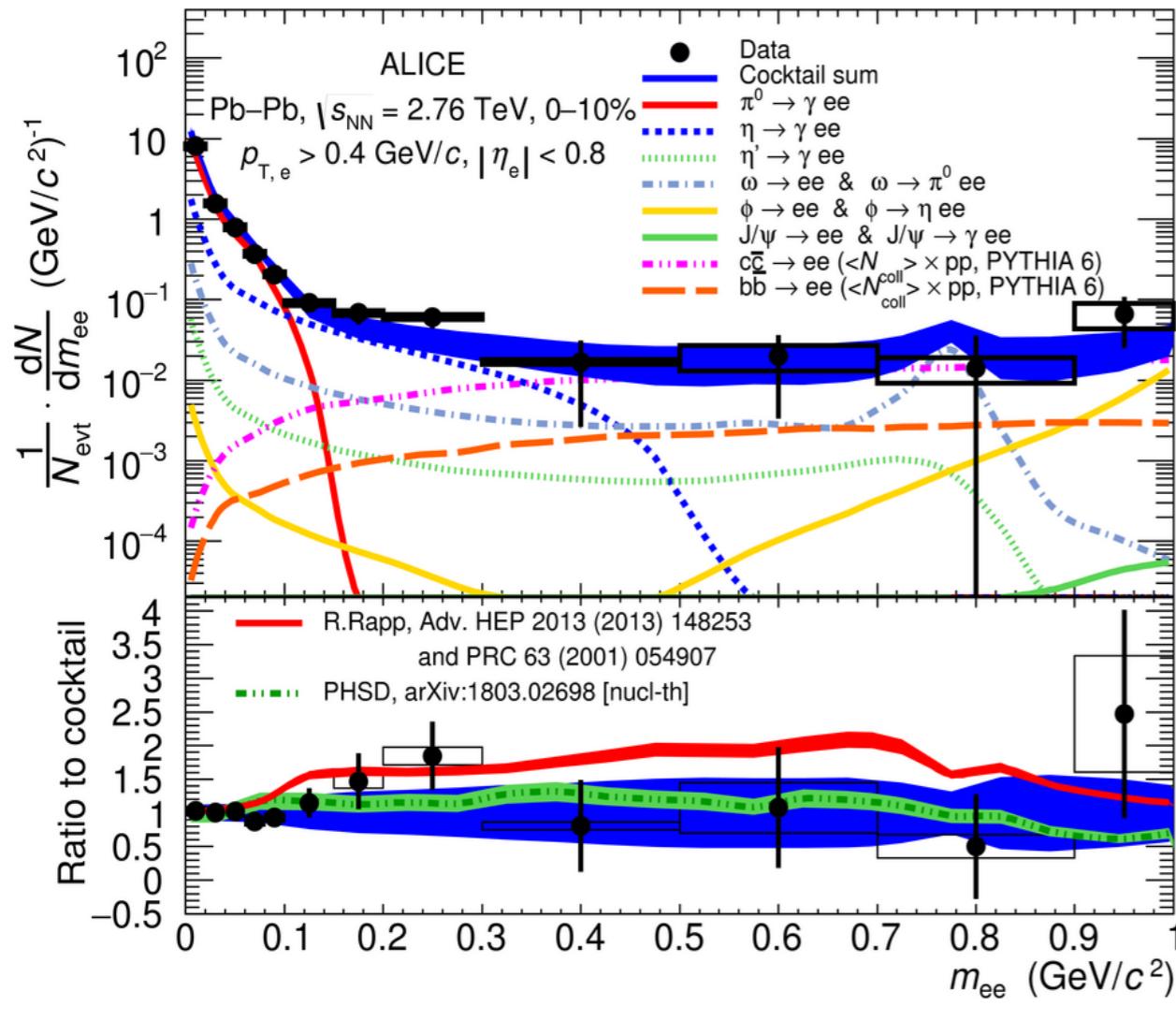
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Virtual direct photon results in agreement with real direct photon measurements

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Summary and outlook

pp collisions

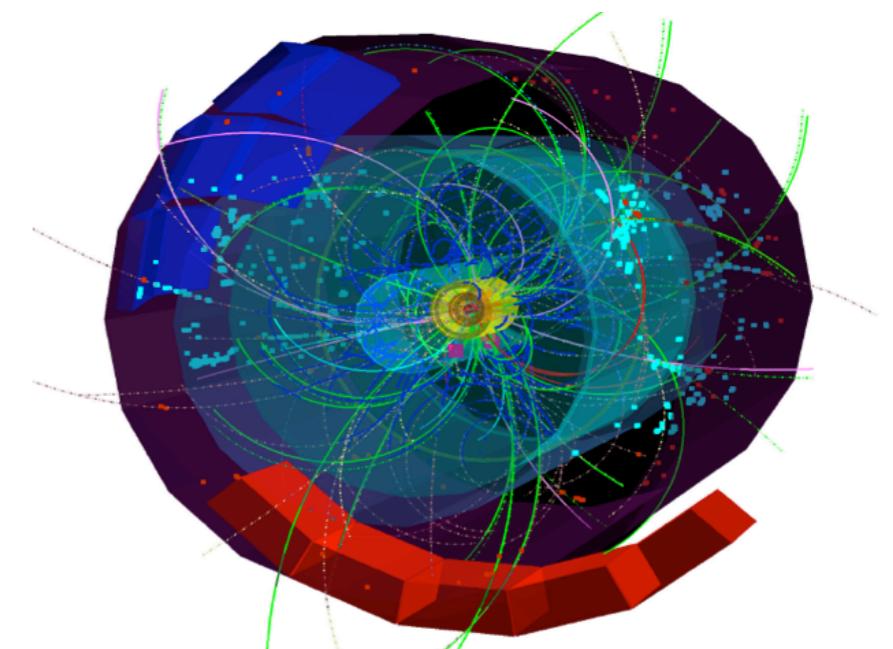
- Results are described with cocktail calculations of known hadronic sources
- Measurement of heavy-flavour production cross-sections and direct photons
- First low-mass dielectron analysis of high-multiplicity events

Pb-Pb collisions

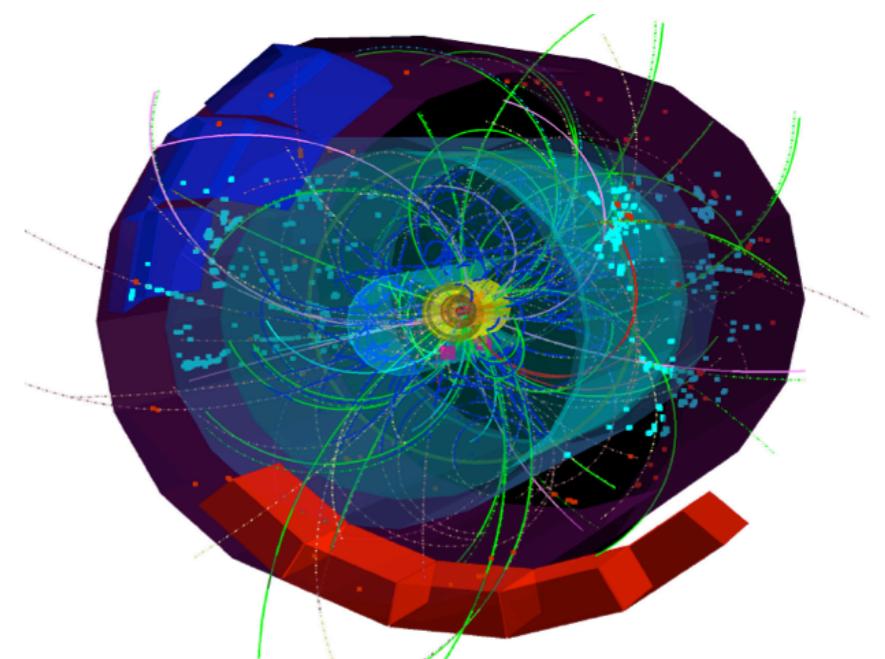
- Challenging analysis, limited sensitivity for detailed studies
- Results compatible with hadronic cocktail within uncertainties, room for additional contributions
- Plan to collect ~ 100 x more central Pb-Pb events in Run 3 after detector upgrade: precise studies, access to T_{init}

***First results from Run 1 and Run 2 data
are submitted for publication***

***More Run 2 results are on their way
(p -Pb and Pb-Pb at $\sqrt{s_{NN}} = 5.02$ TeV)***



Back-up slides



Dielectron pair analysis

- Physics signal:

$$S = N_{+-} - B \cdot R$$

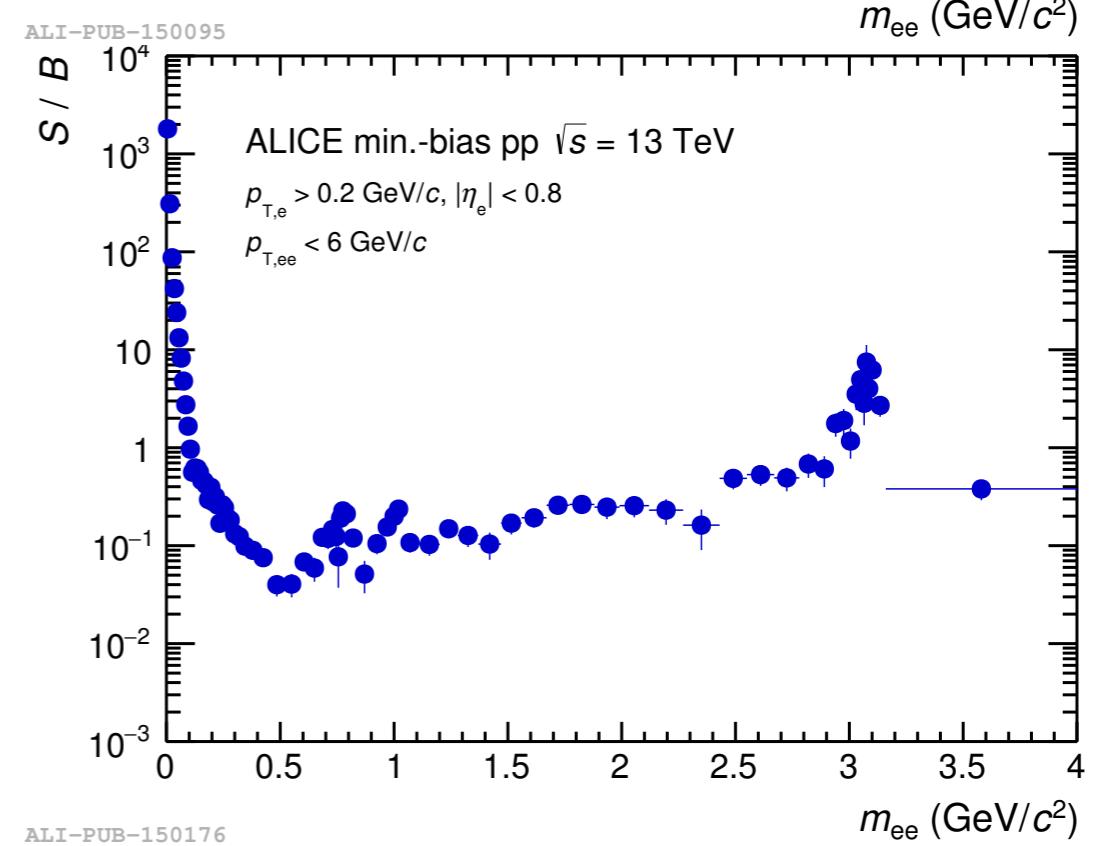
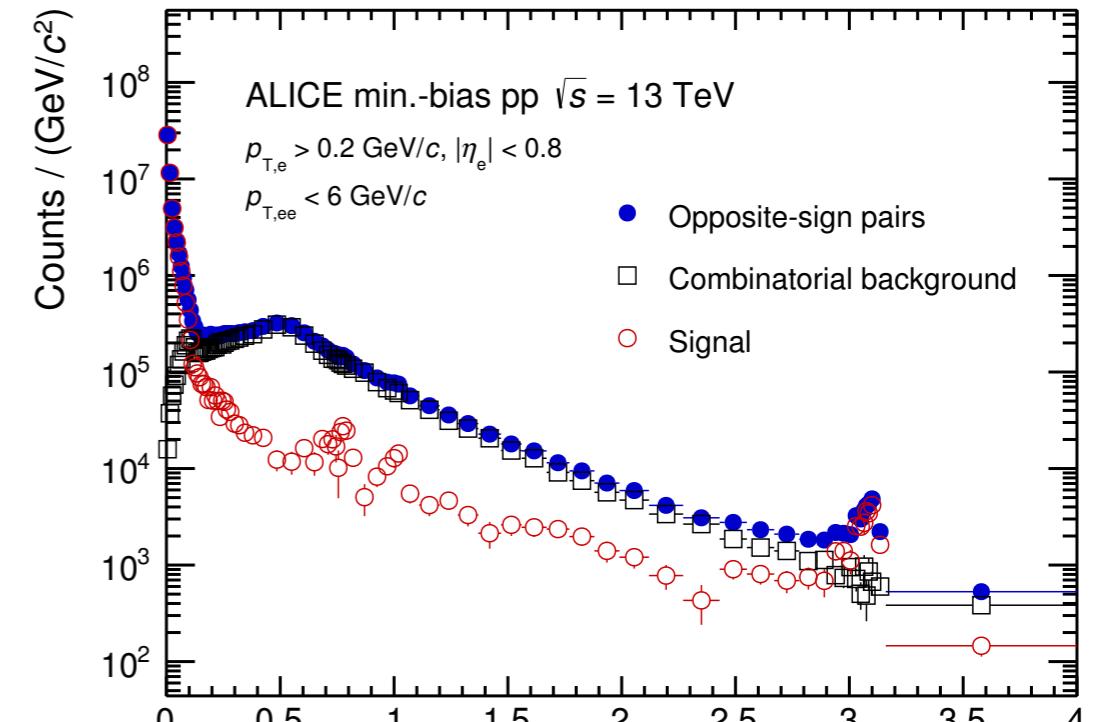
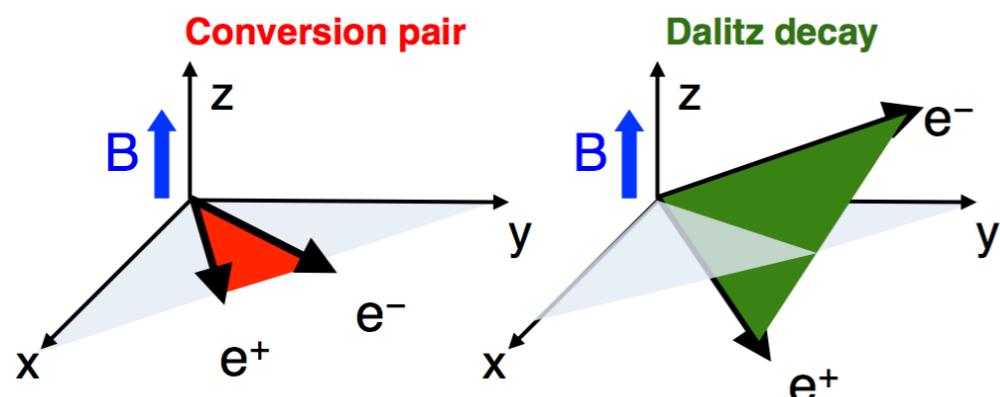
- Combinatorial background: geometric mean of like-sign pairs from same event

$$B = 2\sqrt{N_{++} \cdot N_{--}}$$

- Pair acceptance correction factor (from mixed events)

$$R = \frac{N_{+-MIX}}{2\sqrt{N_{++MIX} \cdot N_{--MIX}}}$$

- Conversion rejection techniques: V0 tagging, pair orientation relative to the magnetic field



The ALICE Experiment at CERN LHC: PID

Inner Tracking System

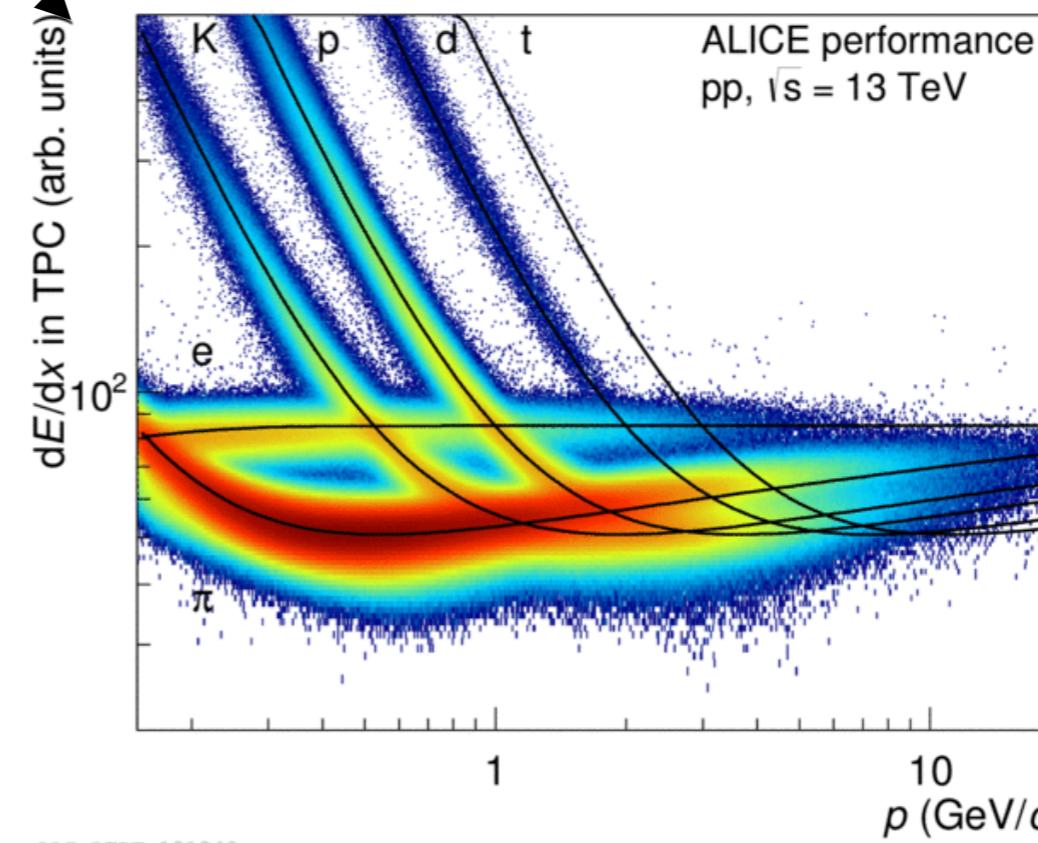
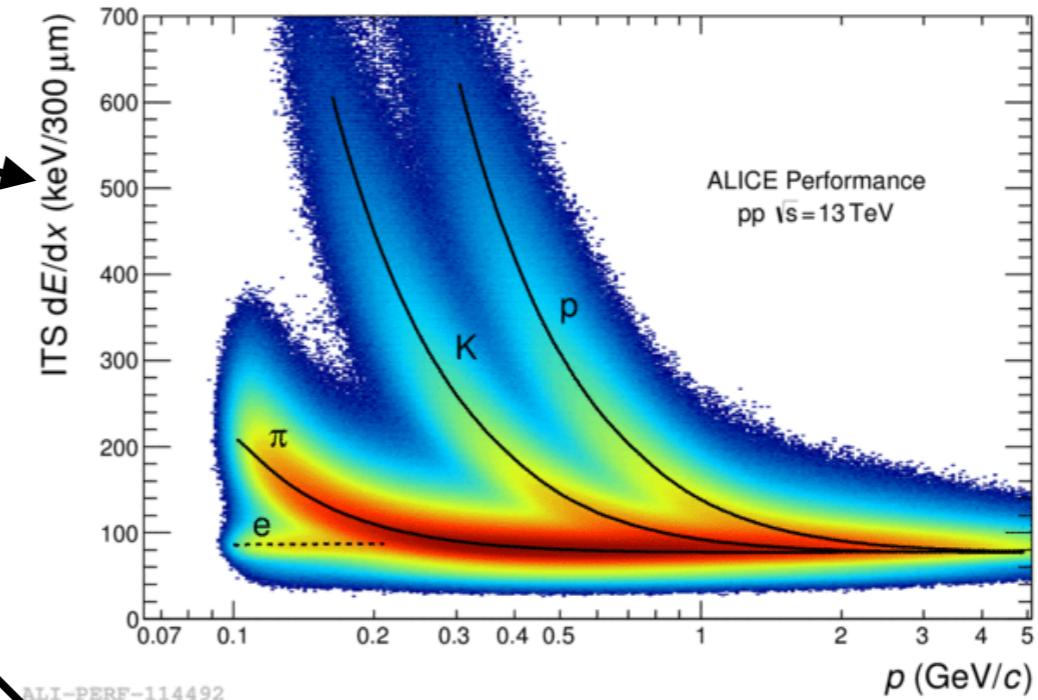
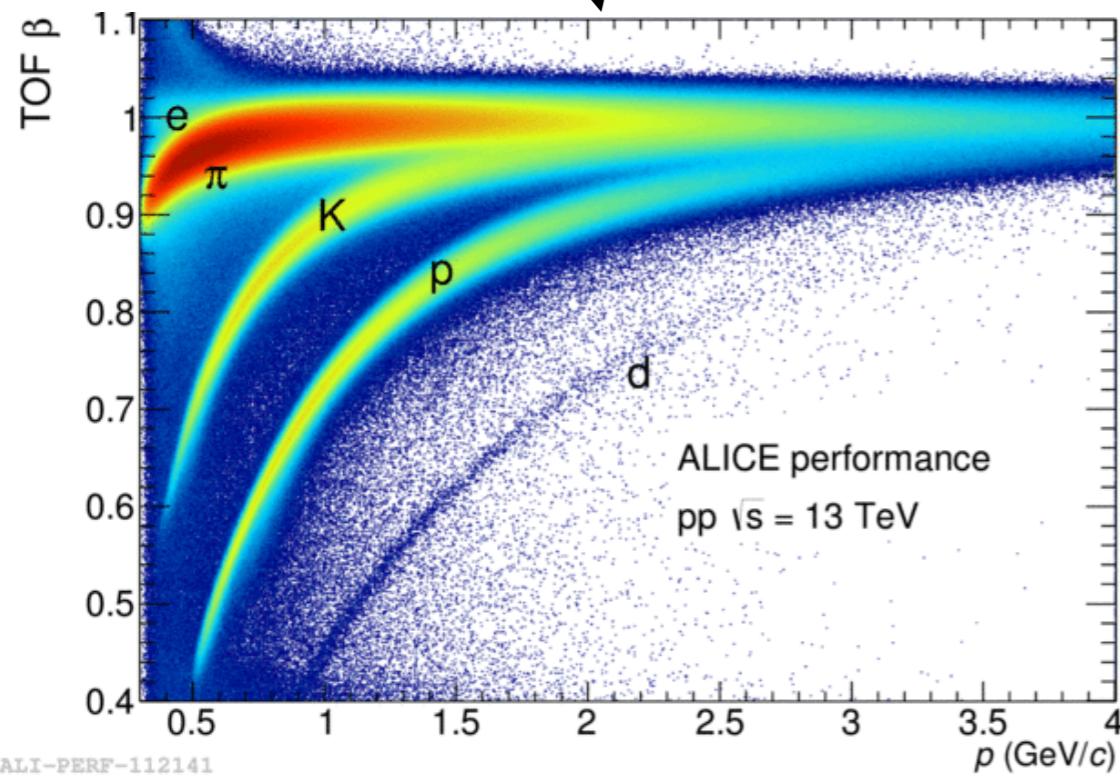
- Tracking, vertex, PID (dE/dx)

Time Projection Chamber

- Tracking, PID (dE/dx)

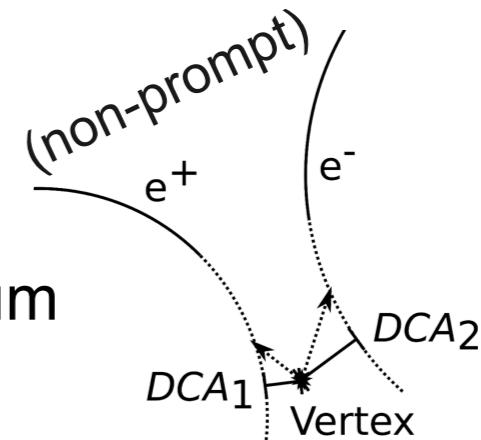
Time Of Flight detector

- PID (TOF measurement)



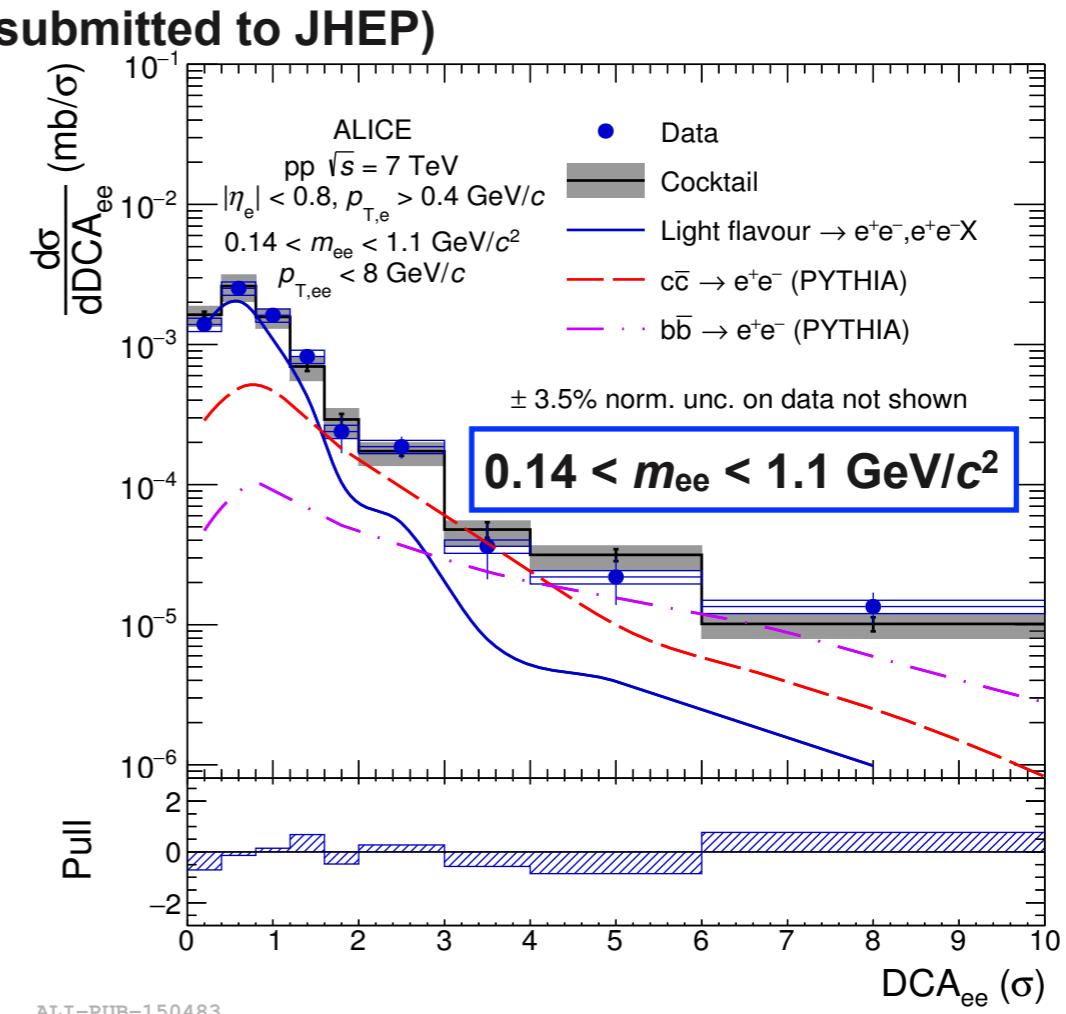
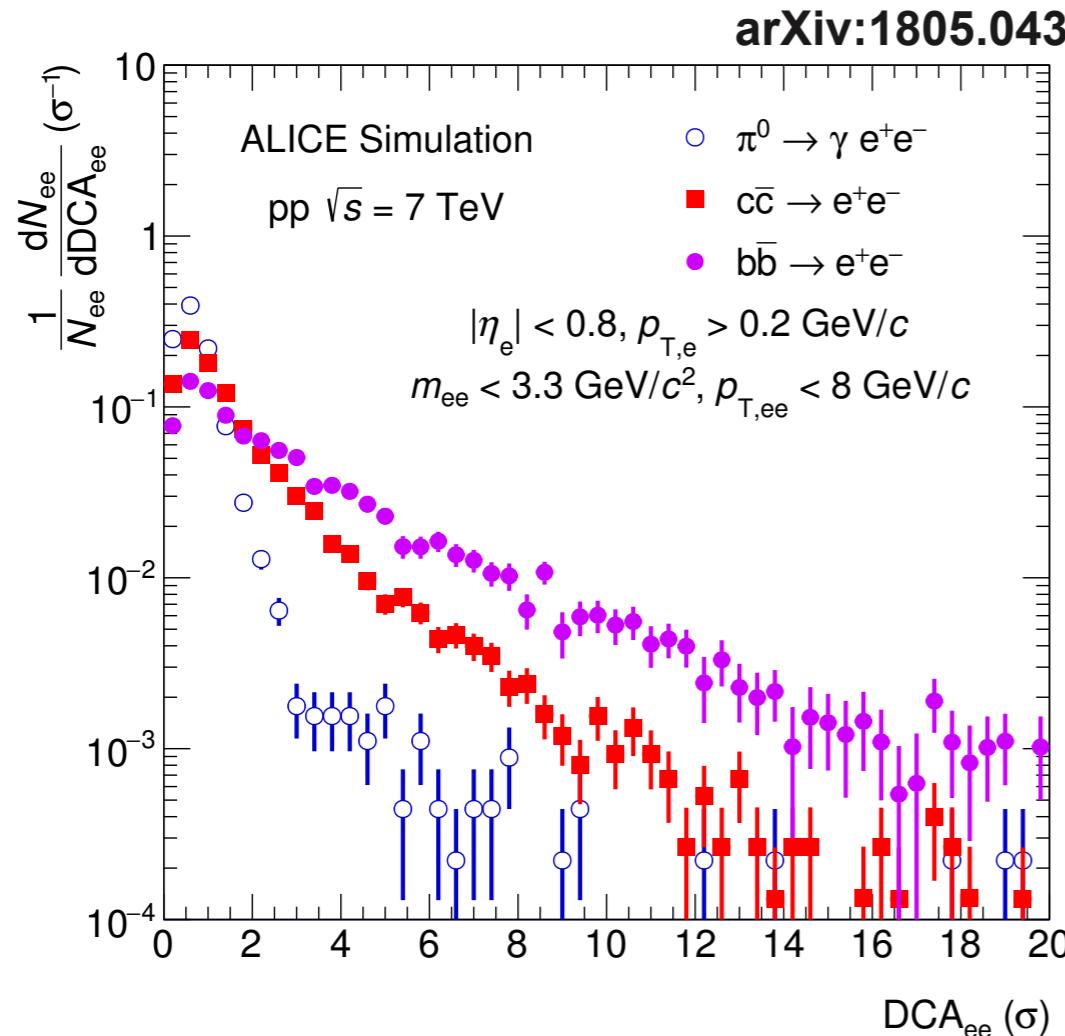
pp $\sqrt{s} = 7$ TeV: DCA_{ee} analysis

- Observable: $DCA_{ee} = \sqrt{\frac{(DCA_{xy,1}/\sigma_{xy,1})^2 + (DCA_{xy,2}/\sigma_{xy,2})^2}{2}}$
- HF decays: D mesons $c\tau \sim 150$ μm, B mesons $c\tau \sim 470$ μm
 - Daughter tracks do not point to vertex
- Obtain DCA_{ee} templates from MC, normalise to cocktail and compare with data



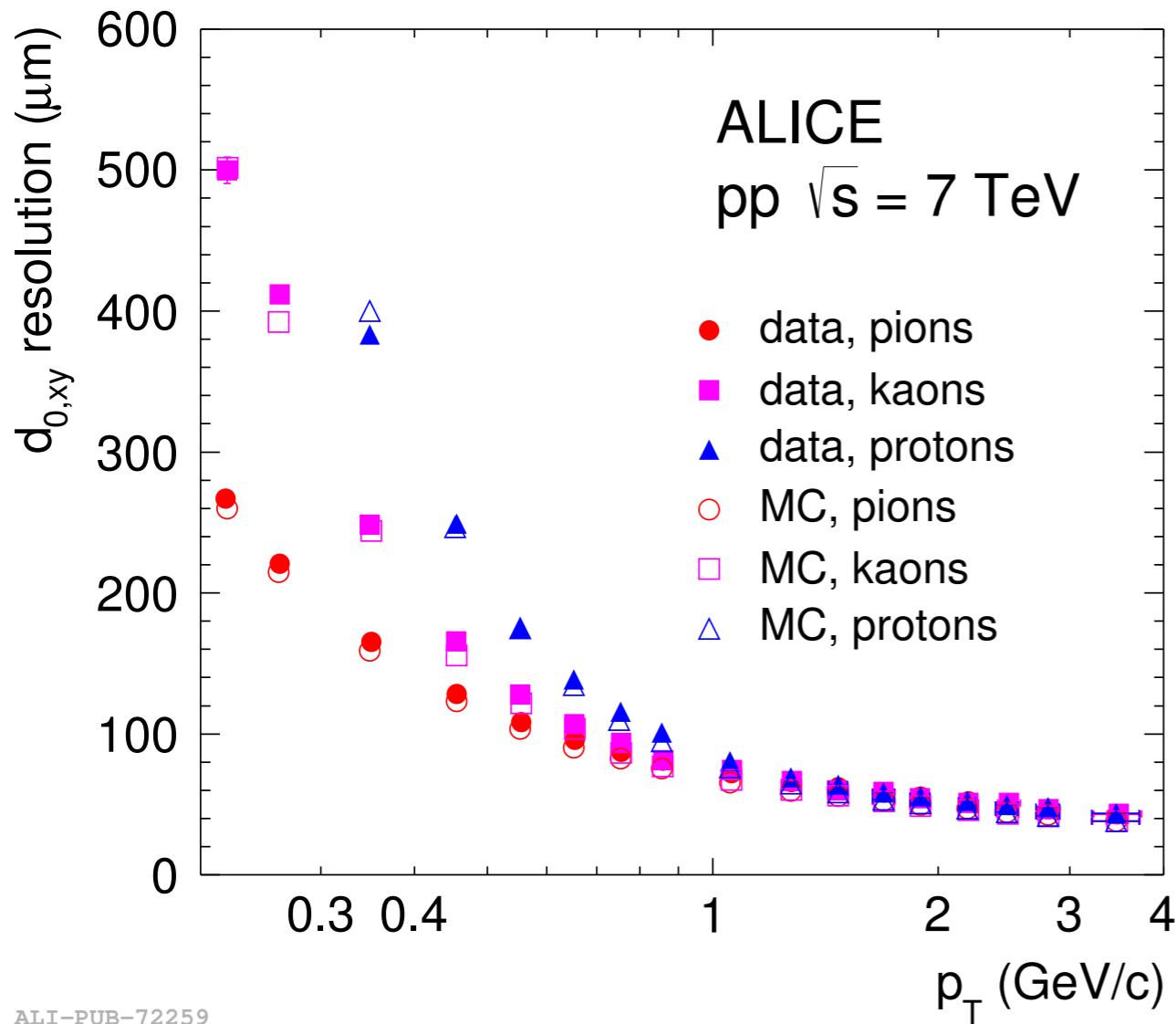
Good description of data in all observed mass regions

- Separation of prompt and non-prompt sources with DCA_{ee}

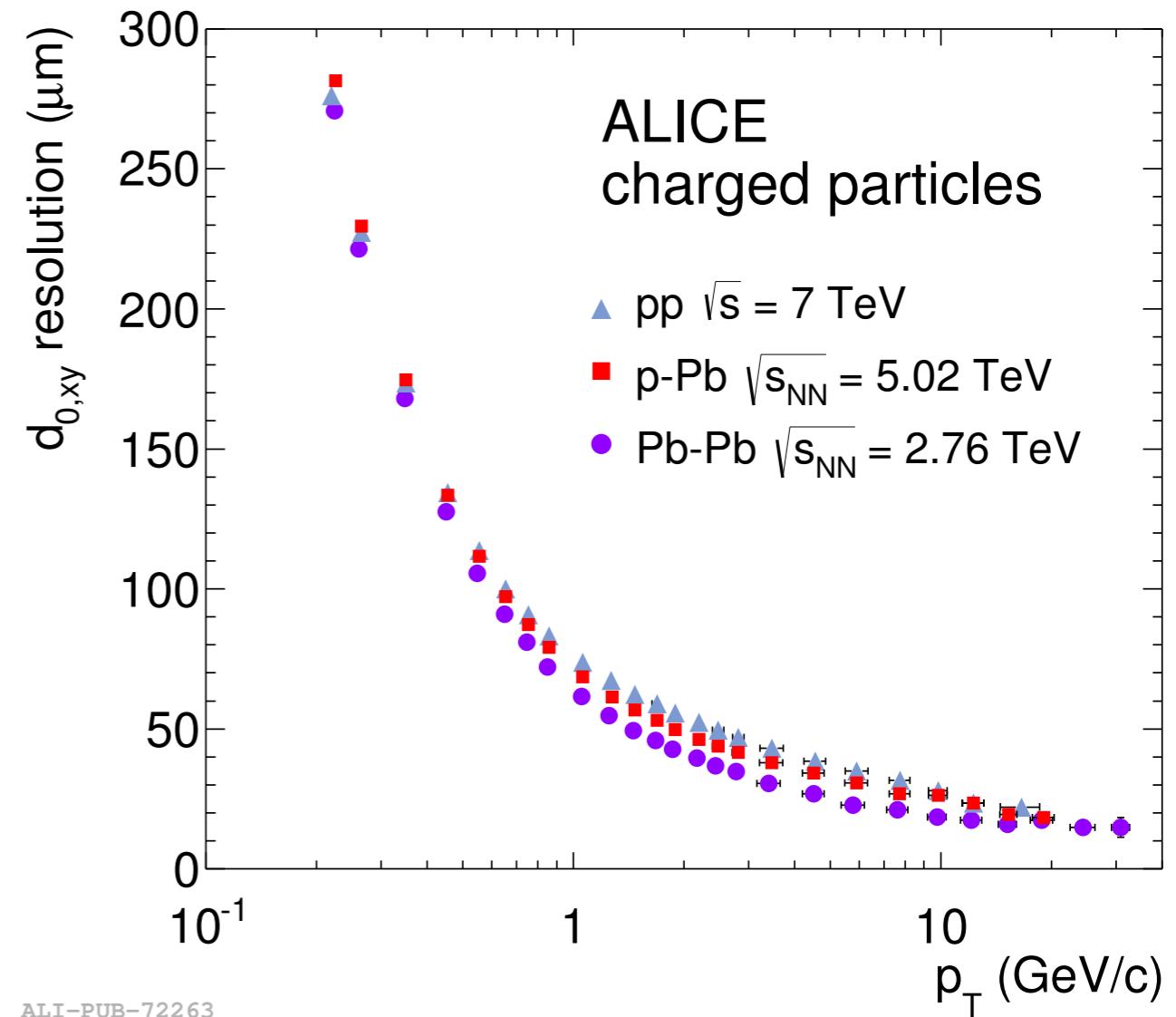


pp $\sqrt{s} = 7$ TeV: DCA resolution

- DCA resolution should be smaller than observable ($c\tau$ of D meson ~ 150 μm)
- Pair DCA analysis is done for $p_T > 0.4$ GeV/c



ALI-PUB-72259

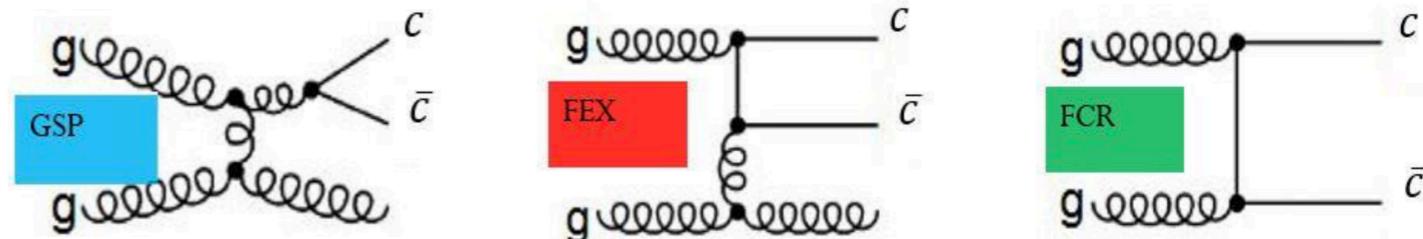


ALI-PUB-72263

HF production mechanisms

Idea: study different charm production processes using PYTHIA 6 simulations

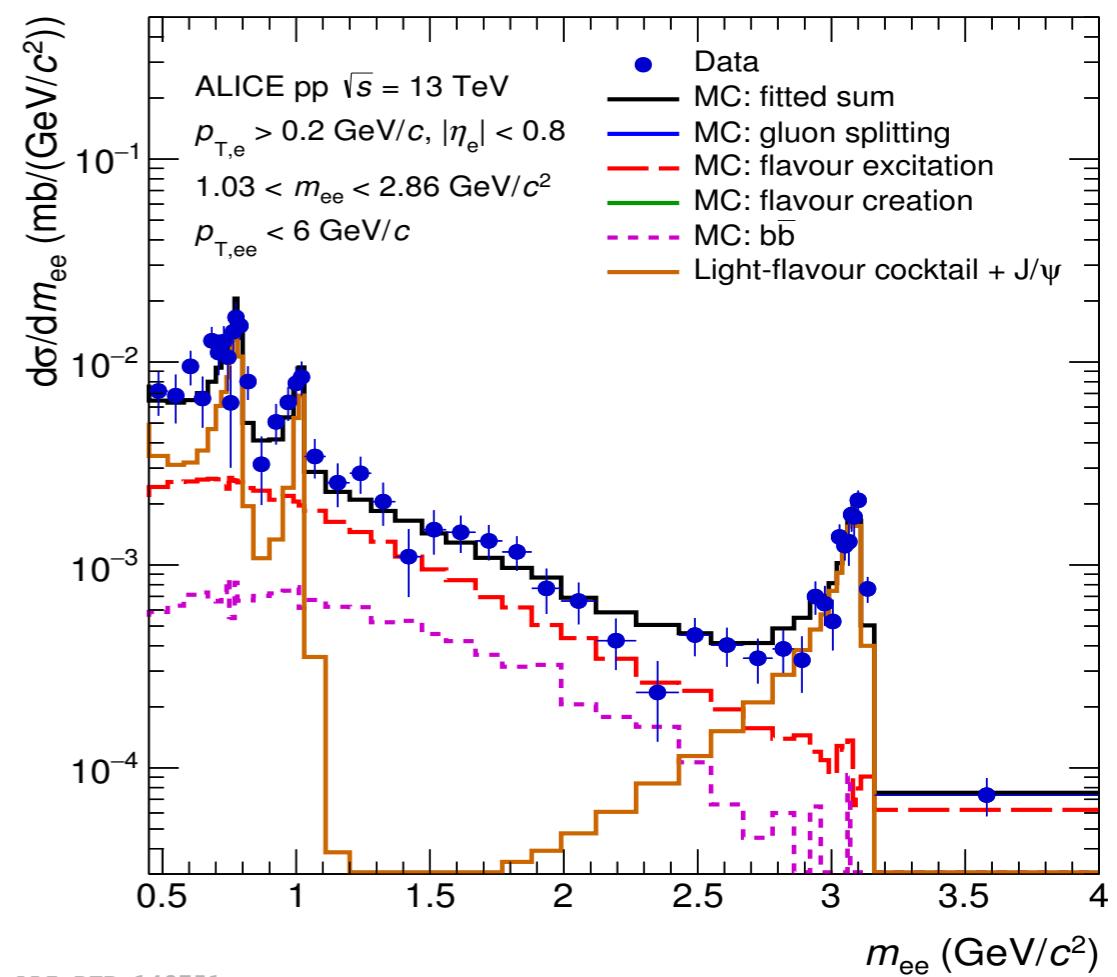
- Gluon splitting (GSP) (default fraction 55%)
- Flavour excitation (FEX) (20%)
- Flavour creation (FCR) (10%)
- e^+e^- from $b\bar{b}$ (15%)



Fit the data in 2d (m_{ee} vs $p_{T,ee}$) allowing each fractional contribution to be between 0 and 1

Fit results:

- GSP: (0.00 ± 0.67)
- FEX: (0.68 ± 0.06)
- FCR: (0.00 ± 0.99)
- e^+e^- from $b\bar{b}$: (0.32 ± 0.06)
- Fit prefers larger FEX contribution than predicted by PYTHIA
- Poor constraint on FCR and GSP contributions: more data needed

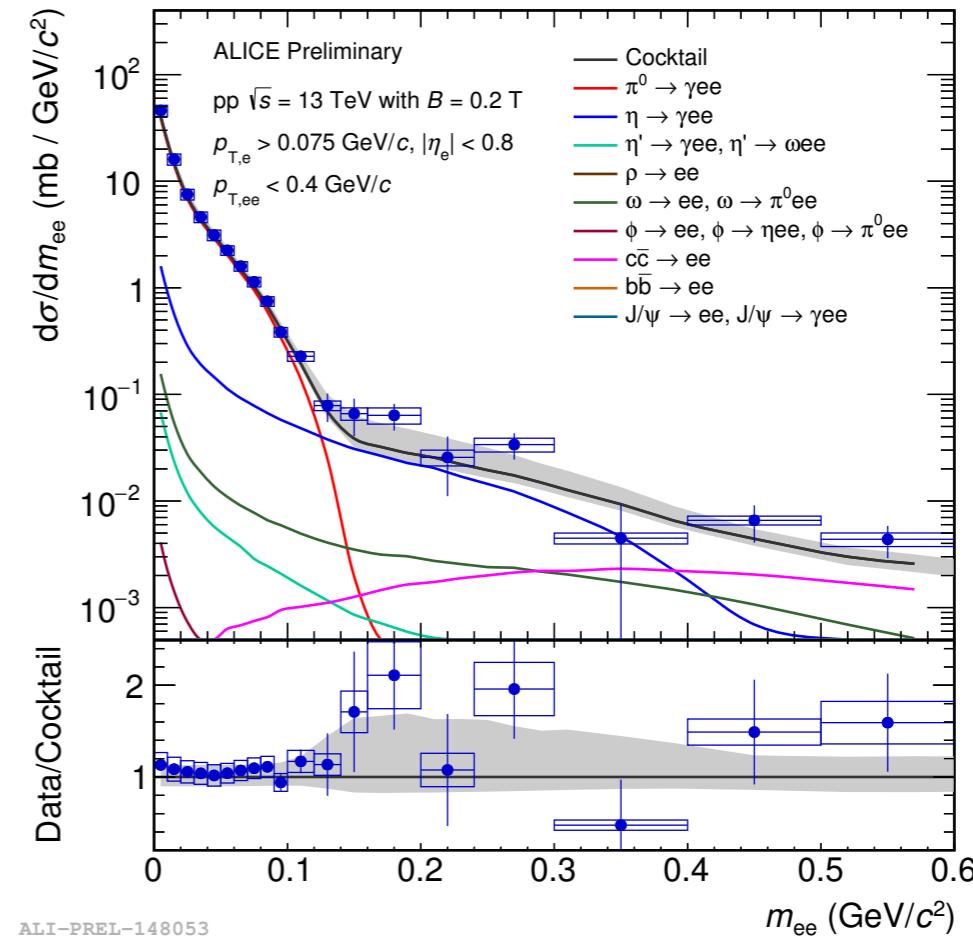
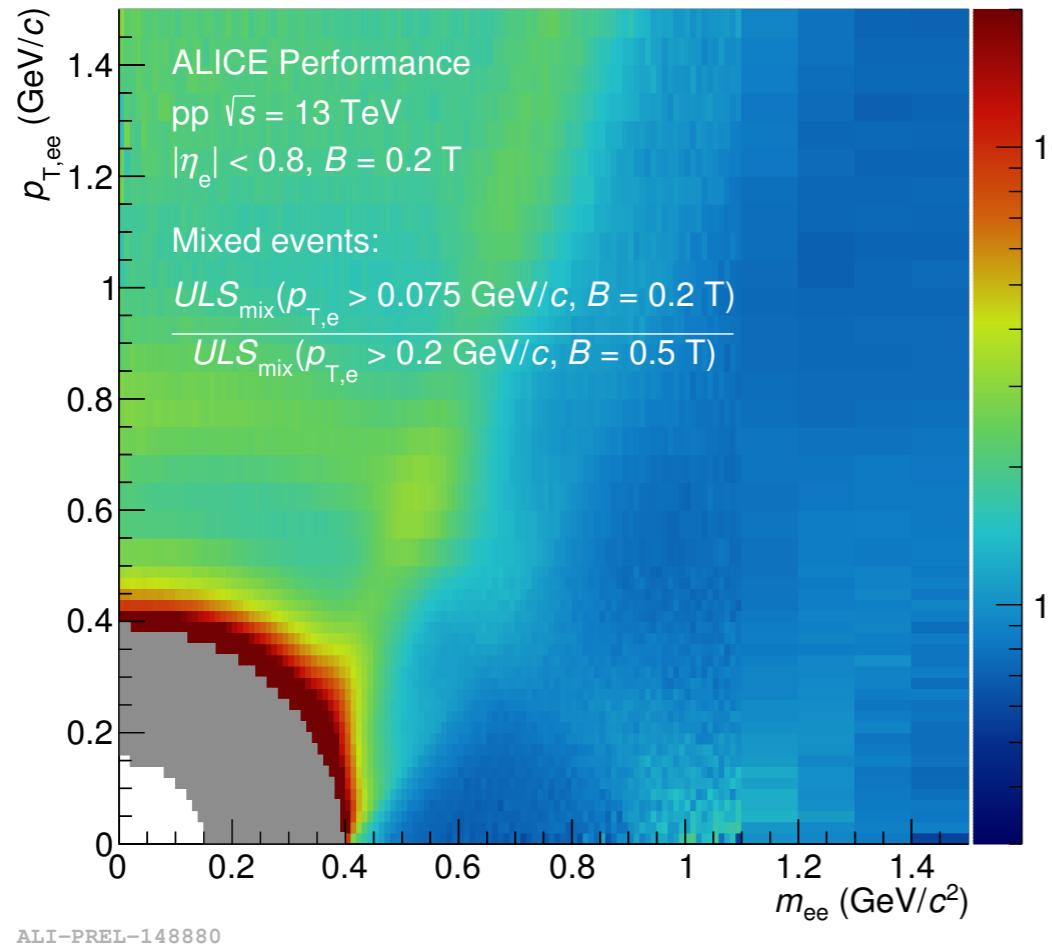


ALI-DER-148751

pp $\sqrt{s} = 13$ TeV: low B -field studies

Run 3: major experiment upgrade (ITS, TPC), dedicated run for low-mass dielectrons with reduced magnetic field of the ALICE solenoid

- Increased charged-particle acceptance, access to low- p_T /low- m_{ee} pairs
- Improved background rejection capabilities



Results from pilot runs in 2016 and 2017: data on the upper edge of the cocktail unc.

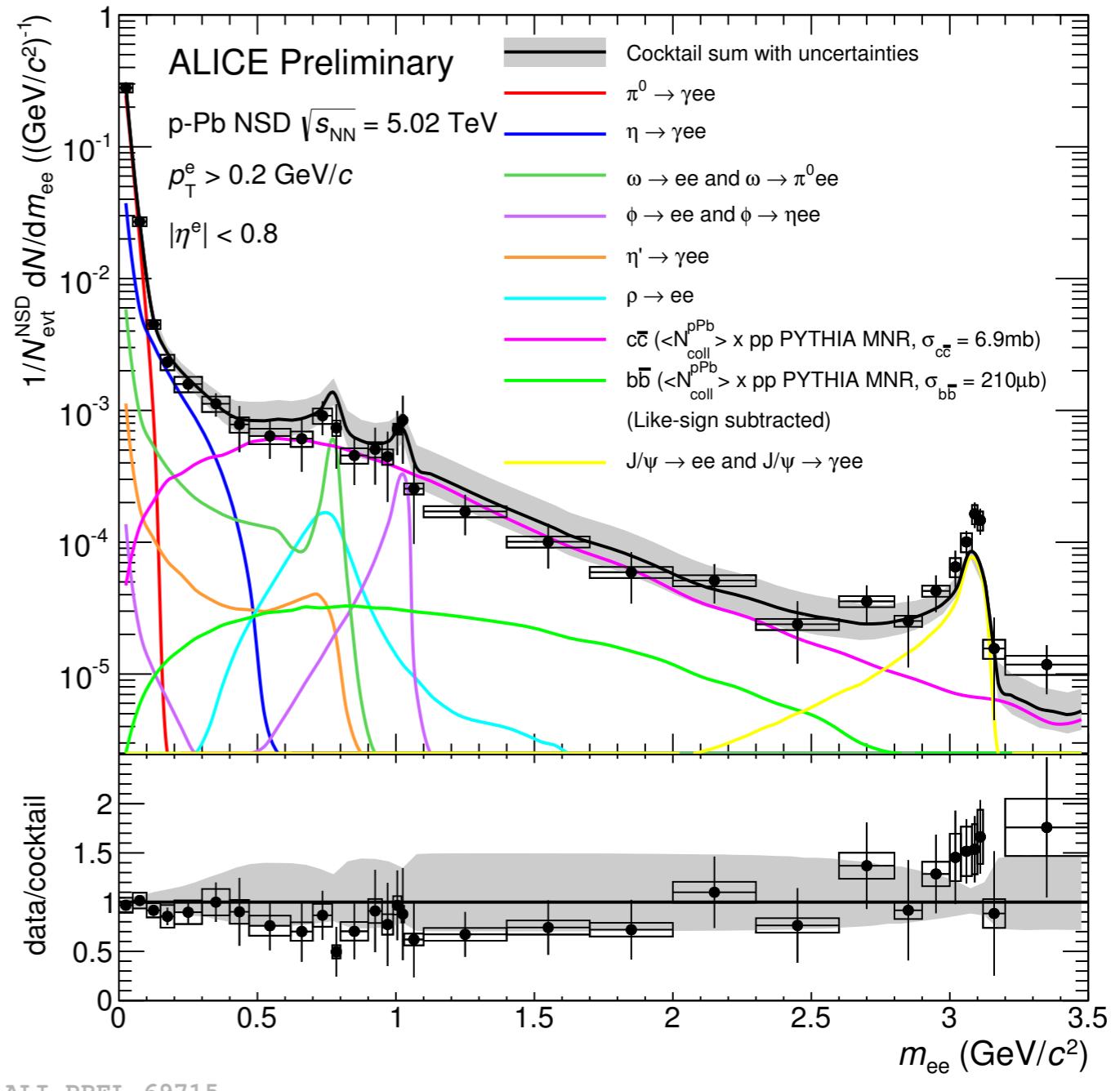
- Need more data and η measurements at very low p_T
- Will help to understand the excess of dielectrons observed by the AFS experiment [1]

p-Pb $\sqrt{s_{NN}} = 5.02$ TeV: invariant mass spectrum

Cocktail calculations:

- Resonance and Dalitz decays:
 π^\pm and J/ψ measurements,
 m_T scaling for other hadrons
- Heavy flavour contributions:
cross section extrapolated from
pp at 7 TeV measurements

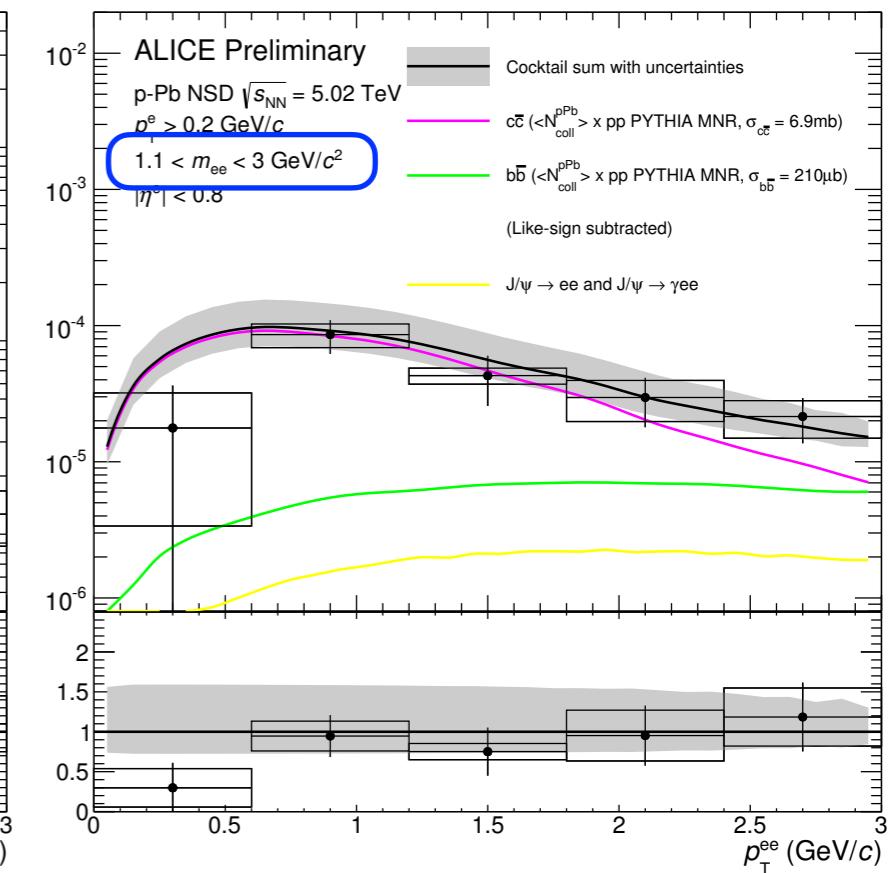
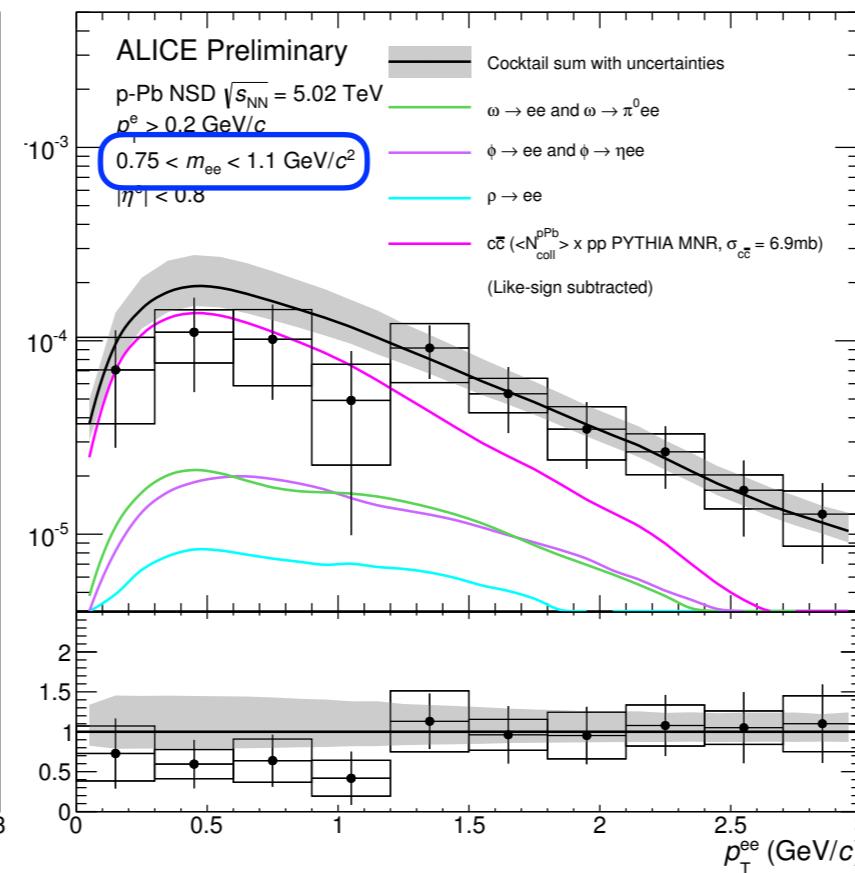
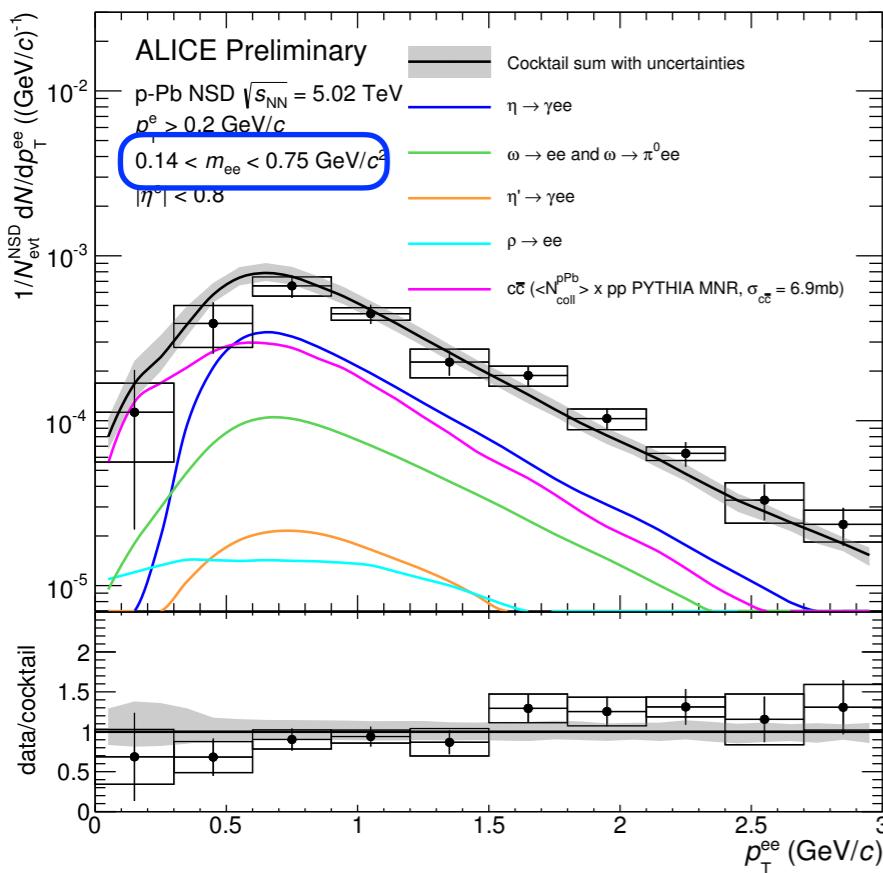
**Data consistent with cocktail
within uncertainties**



p-Pb $\sqrt{s_{NN}} = 5.02$ TeV: differential analysis

Differential analysis in m_{ee} - p_T^{ee} :

- Sensitive to $c\bar{c}$ and $b\bar{b}$ cross sections
- Cold nuclear matter effects?

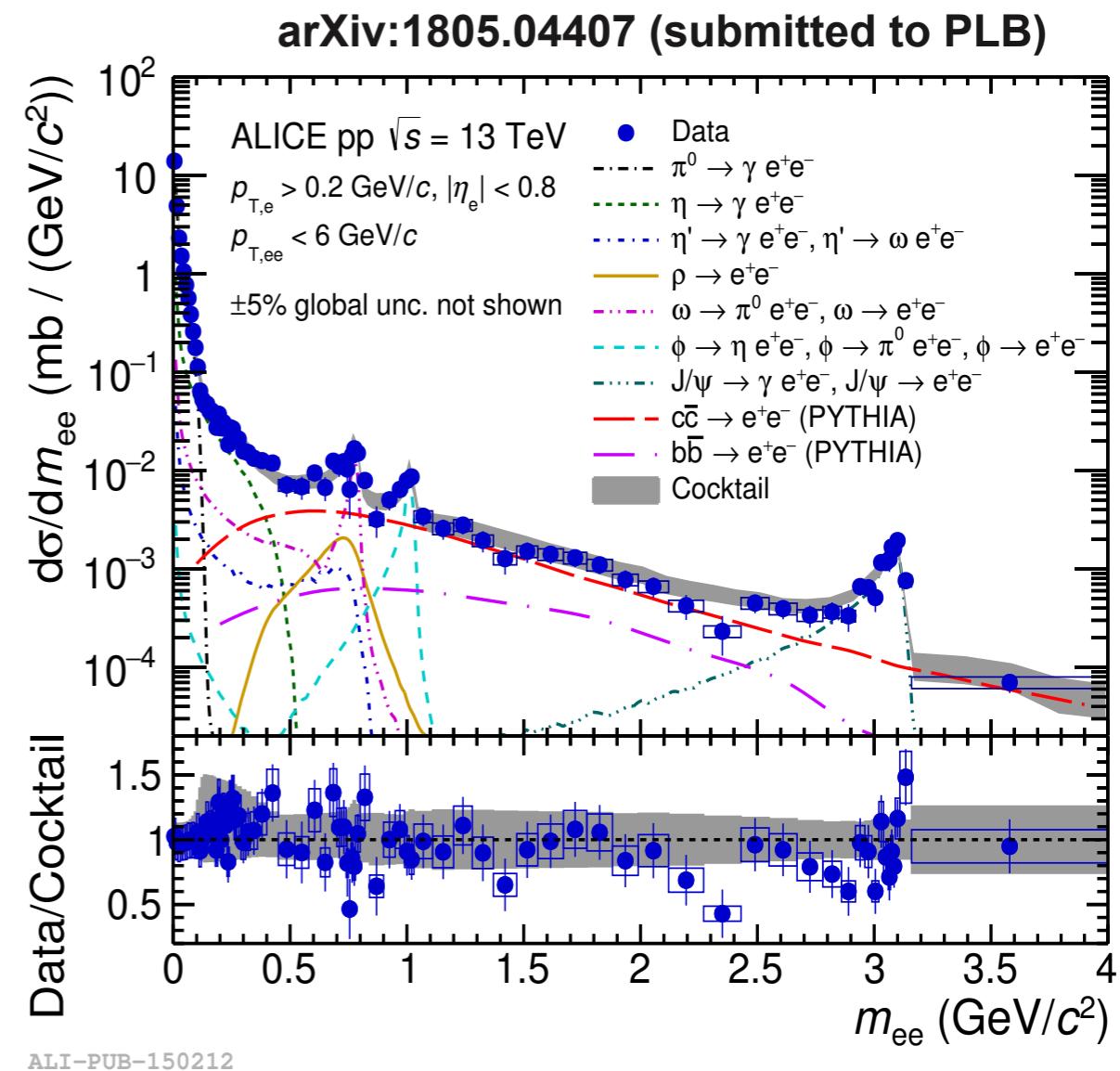


x5 more p-Pb data in Run 2: detailed studies vs m_{ee} and p_T^{ee} are ongoing

pp $\sqrt{s} = 13$ TeV: cocktail details

Cocktail of known hadronic sources:

- Resonance and Dalitz decays of light-flavour hadrons
 - h^\pm at 13 TeV [1], h^\pm/π^\pm at 7 TeV [2] for π^\pm
 - PYTHIA 8 (Monash 2013) for ρ/π and ω/π ratios (good description of data [3, 4])
 - m_T scaling for other hadrons (η' and ϕ)
- Correlated HF semi-leptonic decays
 - PYTHIA 6 scaled to FONLL extrapolated cross-sections from 7 TeV [5, 6]
 - $d\sigma_{c\bar{c}}/dy|_{y=0} = 1296^{+172}_{-162} \mu\text{b}$
 - $d\sigma_{b\bar{b}}/dy|_{y=0} = 68^{+15}_{-16} \mu\text{b}$
- Detector acceptance ($p_{T,e} > 0.2 \text{ GeV}/c$, $|\eta_e| < 0.8$) and resolution effects



Good description of data with hadronic cocktail expectations

- e^+e^- production in min. bias pp collisions is well understood for $p_{T,e} > 0.2 \text{ GeV}/c$

- [1] ALICE Collaboration, Phys. Lett. B 753 (2016) 319
- [2] ALICE Collaboration, Eur. Phys. J. C 73 (2013) 2662
- [3] ALICE Collaboration, arXiv:1805.04365
- [4] ALICE Collaboration, ALICE-PUBLIC-2018-004
- [5] ALICE Collaboration, Eur. Phys. J. C77 (2017) 550
- [6] ALICE Collaboration, JHEP 11 (2012) 065

New phenomena in high multiplicity pp events?

- Production / destruction of ρ meson
- Thermal radiation in small systems
- Understanding of Multiple Parton Interactions

Idea: produce a ratio of dielectron spectra in high-multiplicity over inelastic events:

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

- $dN_{ch}/d\eta(\text{HM}) / \langle dN_{ch}/d\eta(\text{INEL}) \rangle = 6.27 \pm 0.22$
(measured at $\eta \sim 0$)

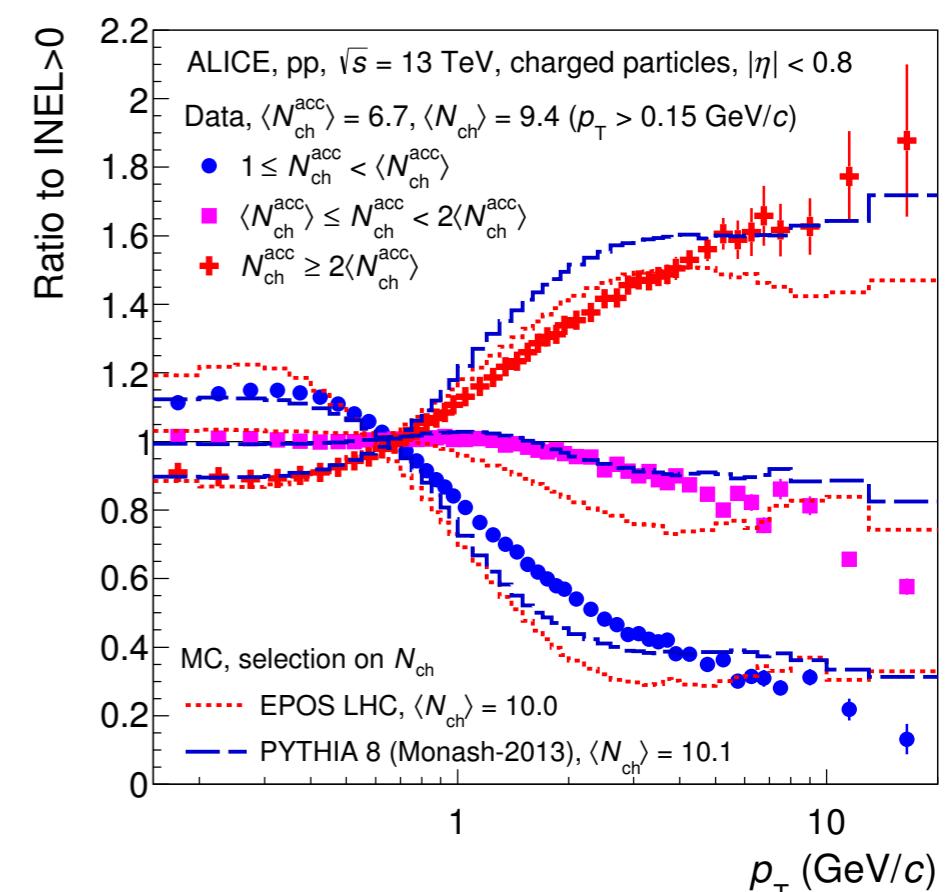
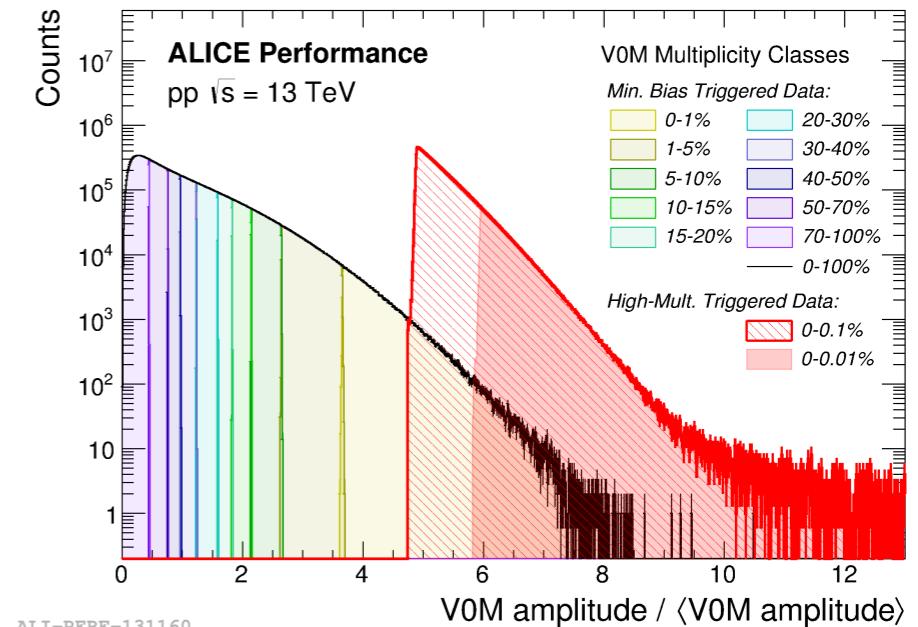
Input for high-multiplicity cocktail calculations:

- LF: modification of p_T spectrum of charged particles in events with higher multiplicities [1]
 - Assume same scaling with multiplicity for all LF hadrons at the same m_T
- HF: multiplicity dependent production of D meson [2] and inclusive J/ ψ [3] in pp at $\sqrt{s} = 7$ TeV
 - Same enhancement for beauty is assumed as for open charm

[1] ALICE Collaboration, Phys. Lett. B 753, 319 (2016)

[2] ALICE Collaboration, JHEP 09, 148 (2015)

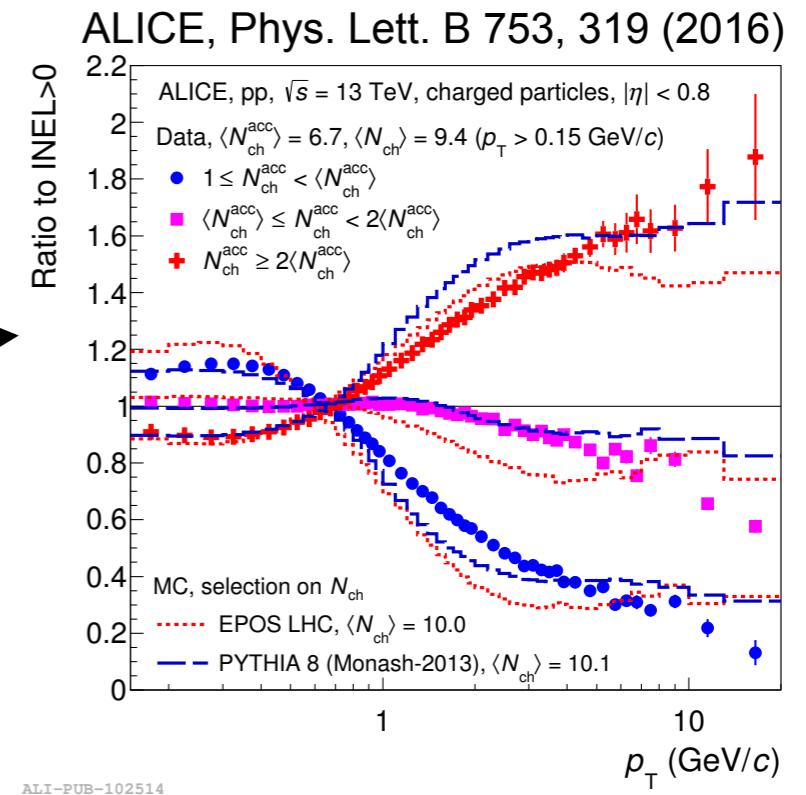
[3] ALICE Collaboration, Phys. Lett. B 712 (2012) 165



pp $\sqrt{s} = 13$ TeV: cocktail calculations vs multiplicity

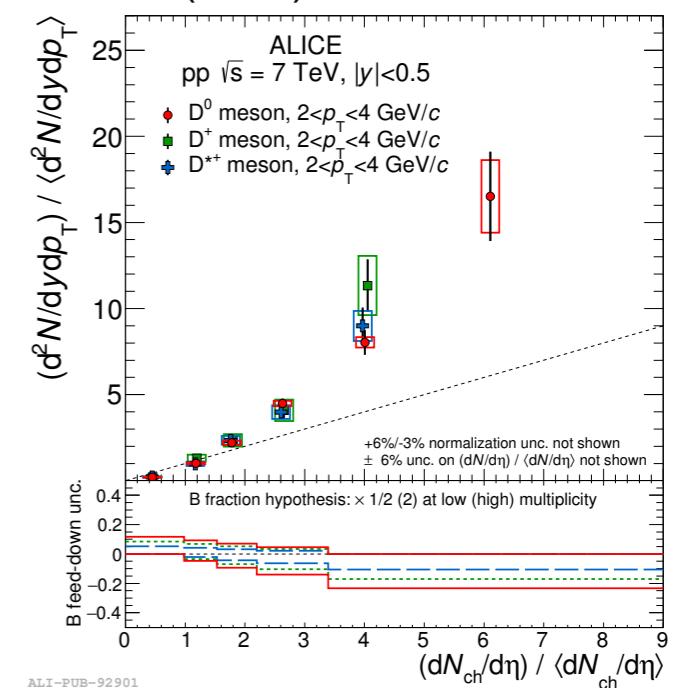
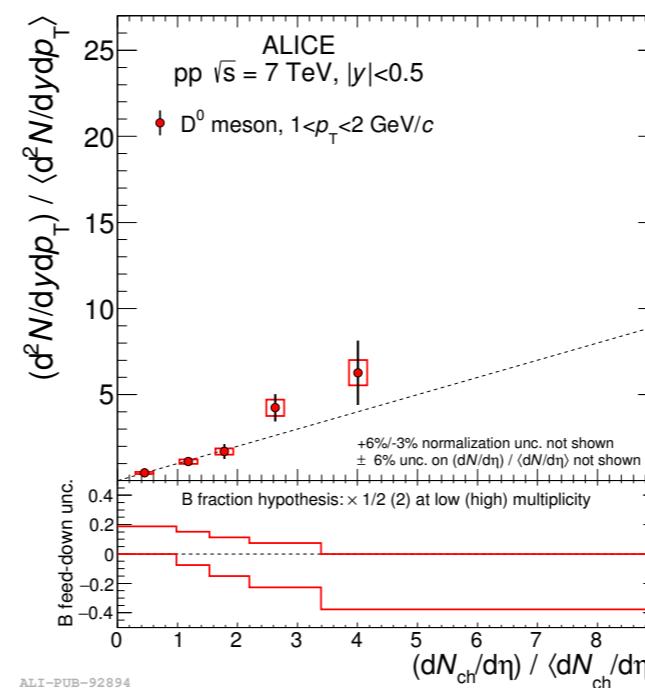
Light-flavour decays:

- ALICE π^\pm measurements as input, m_T scaling for other hadrons
- Modification of p_T spectrum in events with higher charged particle multiplicities



Heavy-flavour contribution:

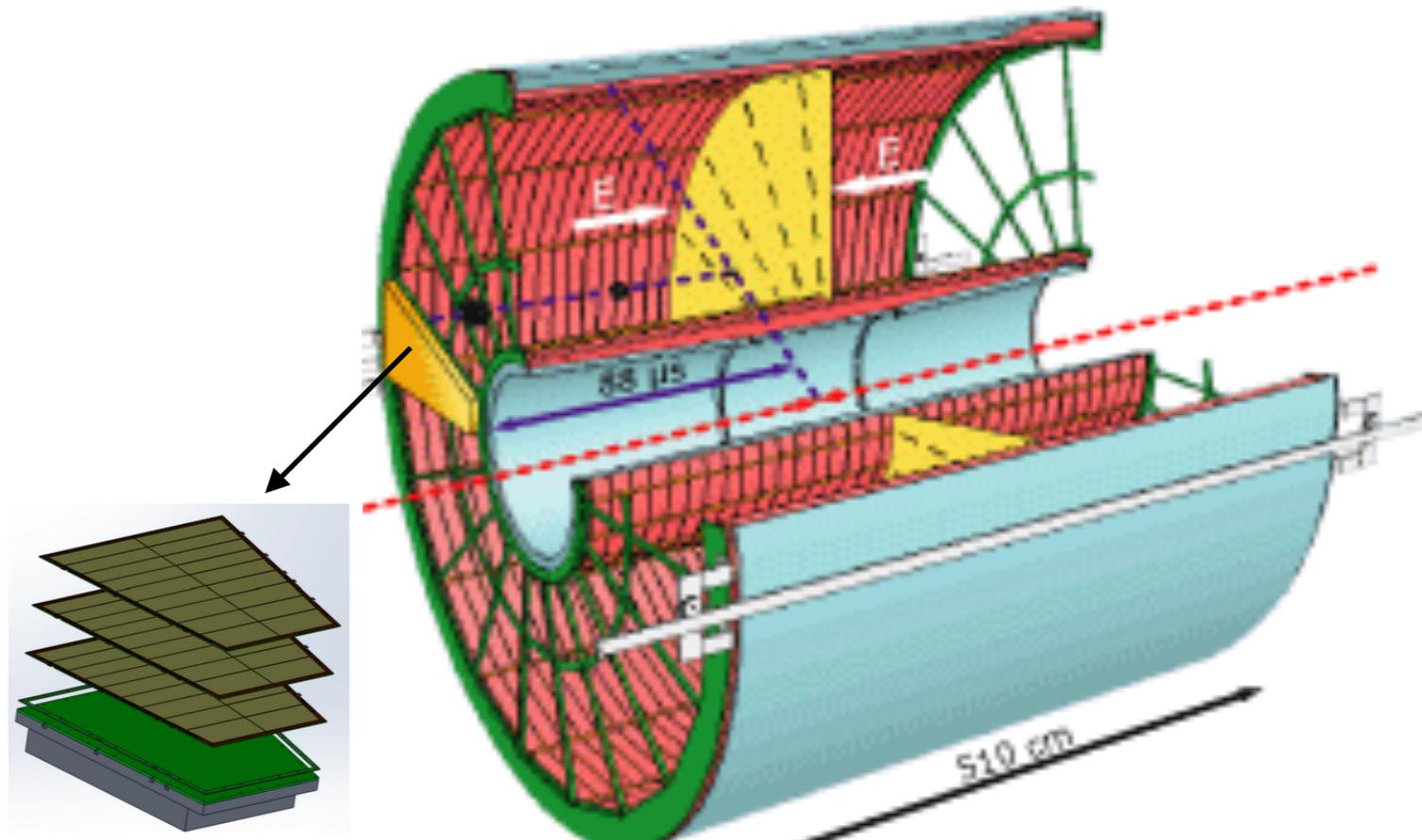
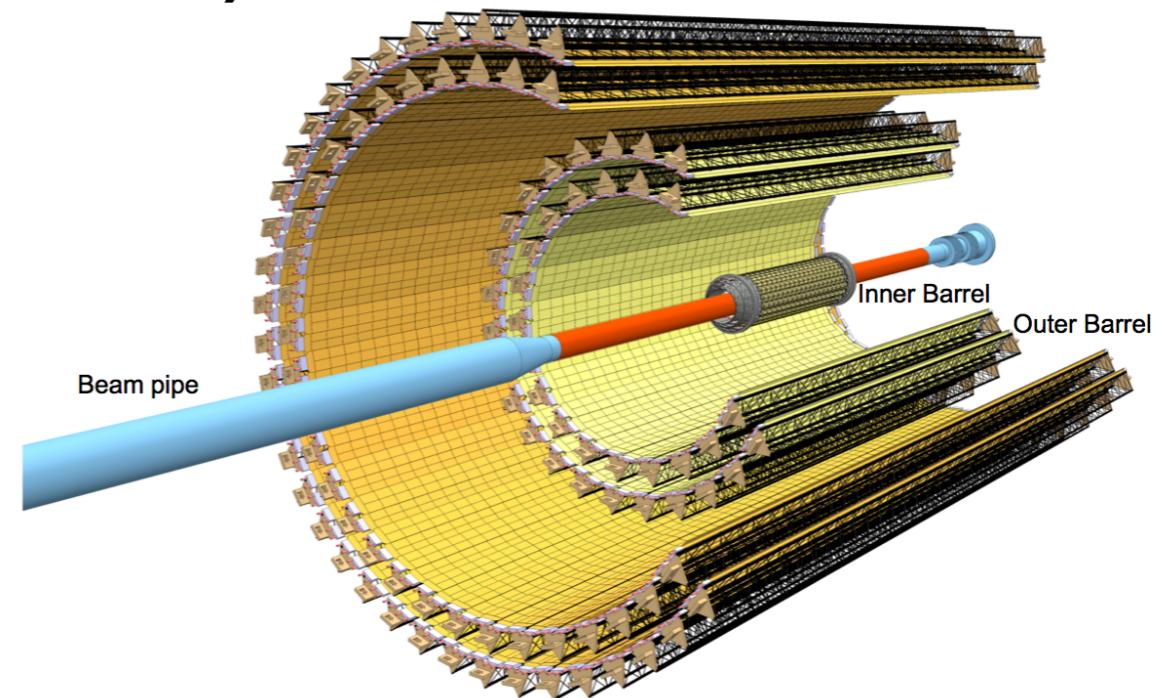
- PYTHIA simulation of open charm production
- Multiplicity dependent production of D meson in pp at $\sqrt{s} = 7$ TeV



ALICE Upgrade for Run 3 (2020-2022)

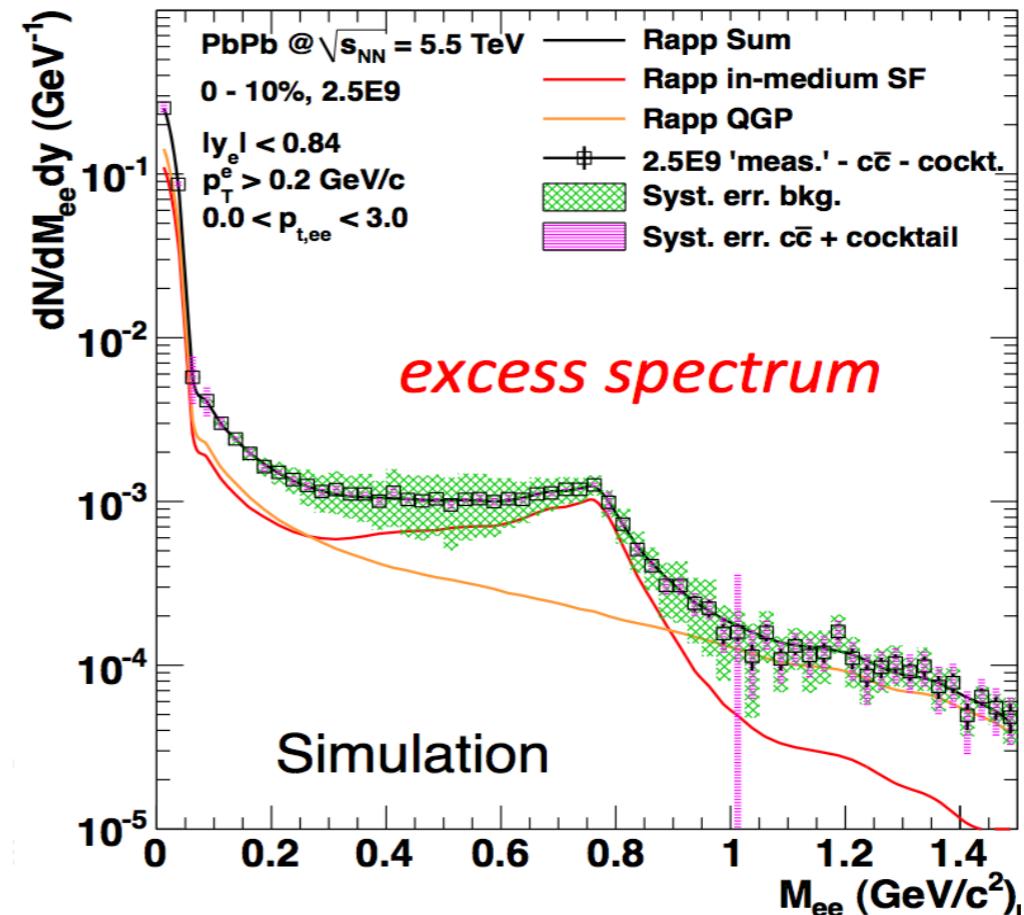
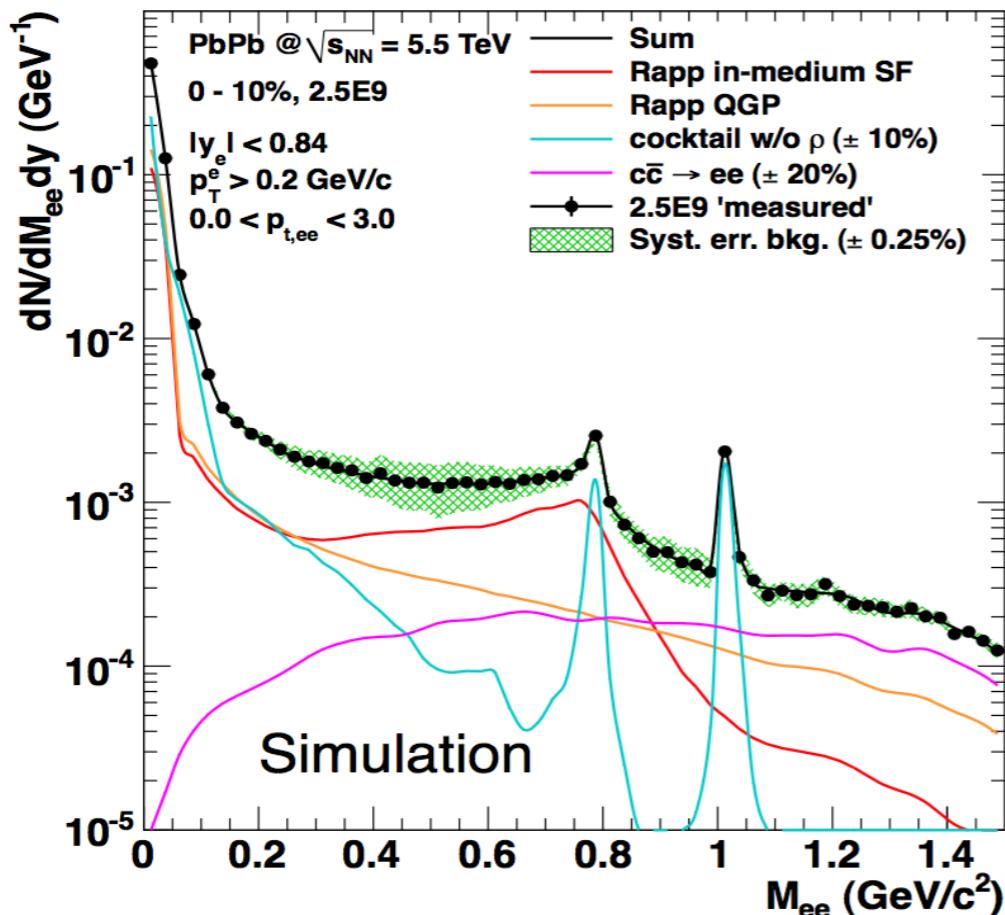
Major upgrades of main tracking systems

- Completely new 7-layer ITS detector
- New TPC GEM-based readout chambers
- Higher readout rate up to 50 kHz in PbPb (x50 compared to Run 2)



ALICE Upgrade for Run 3 (2020-2022)

- Dedicated low B field = 0.2 T to increase acceptance of low p_T & mass pairs
- Expected statistics: 2.5×10^9 PbPb events in 4 weeks of PbPb data taking



Excess above 1 GeV is dominated by thermal QGP radiation

- T of early stages without blue shift
- 10% statistical and 10-20% systematic uncertainties in IMR

New developments: machine learning methods

- Electron identification: **improves efficiency while keeping hadron contamination low**
- Dielectron signal: **suppress conversions, reduce combinatorial background**
- Usage of the methods are foreseen in the dielectron analysis of pp, p-Pb and Pb-Pb Run 2 data

