

Low mass dielectrons in pp, p-Pb and Pb-Pb collisions measured by the ALICE experiment

Ivan Vorobyev
Technische Universität München, Excellence Cluster Universe
on behalf of the ALICE Collaboration

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Low mass dielectron studies

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

High-energy heavy-ion collisions:

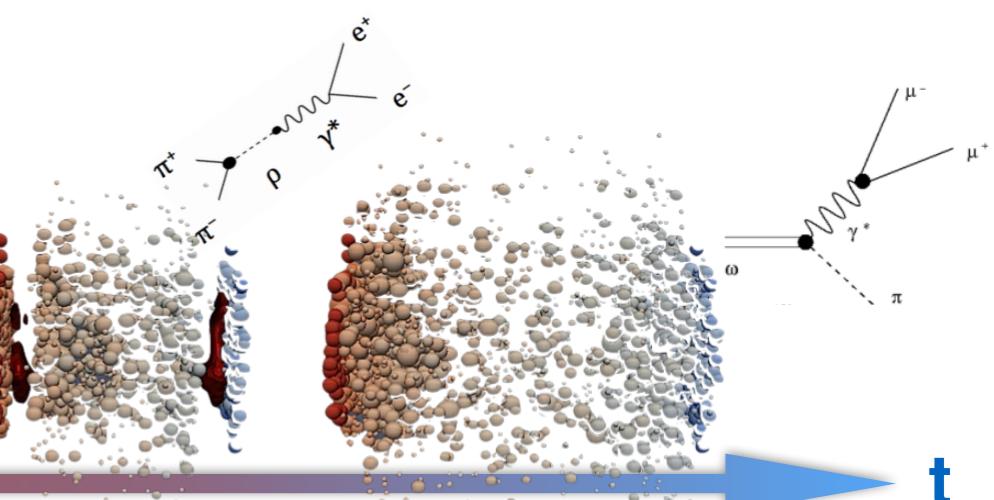
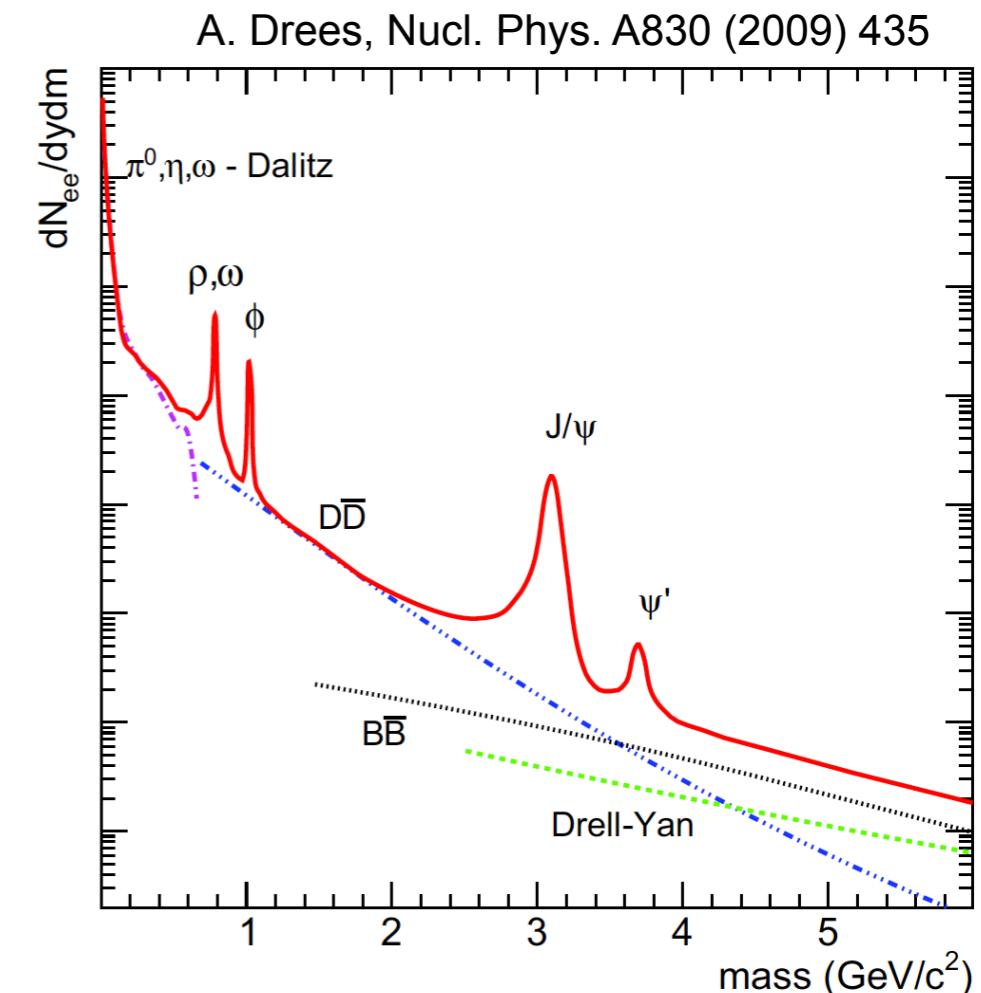
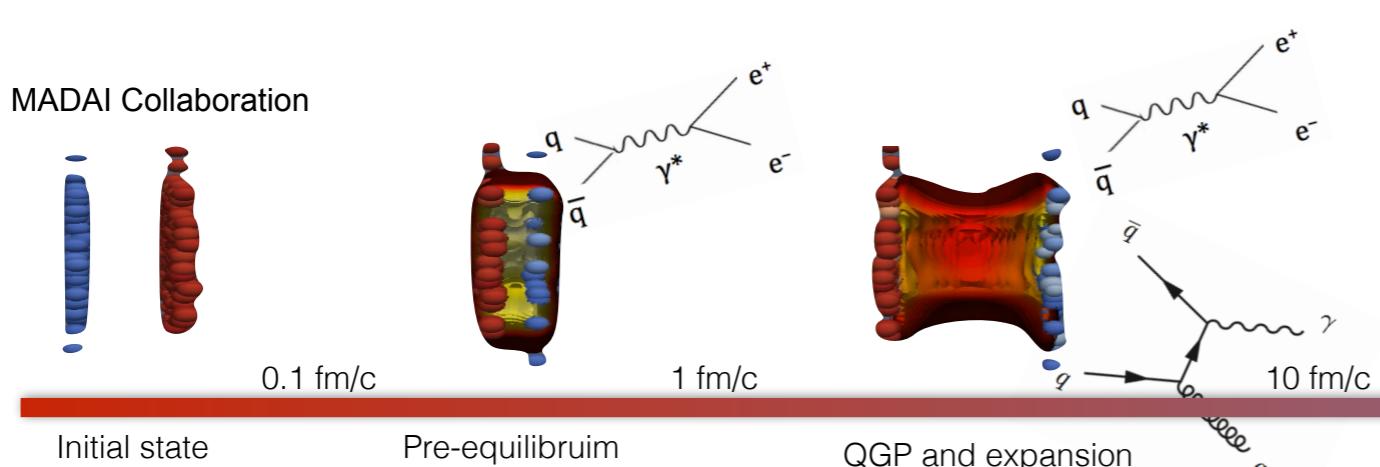
- In-medium modifications of vector mesons
- Thermal radiation from QGP
- Energy loss of correlated heavy flavour quarks

Proton-ion collisions:

- Cold nuclear matter effects

Proton-proton collisions:

- Medium-free reference
- Heavy flavour cross-sections
- New phenomena in high-multiplicity events?



The ALICE Experiment at CERN LHC

Inner Tracking System

- Tracking, vertex, PID (dE/dx)

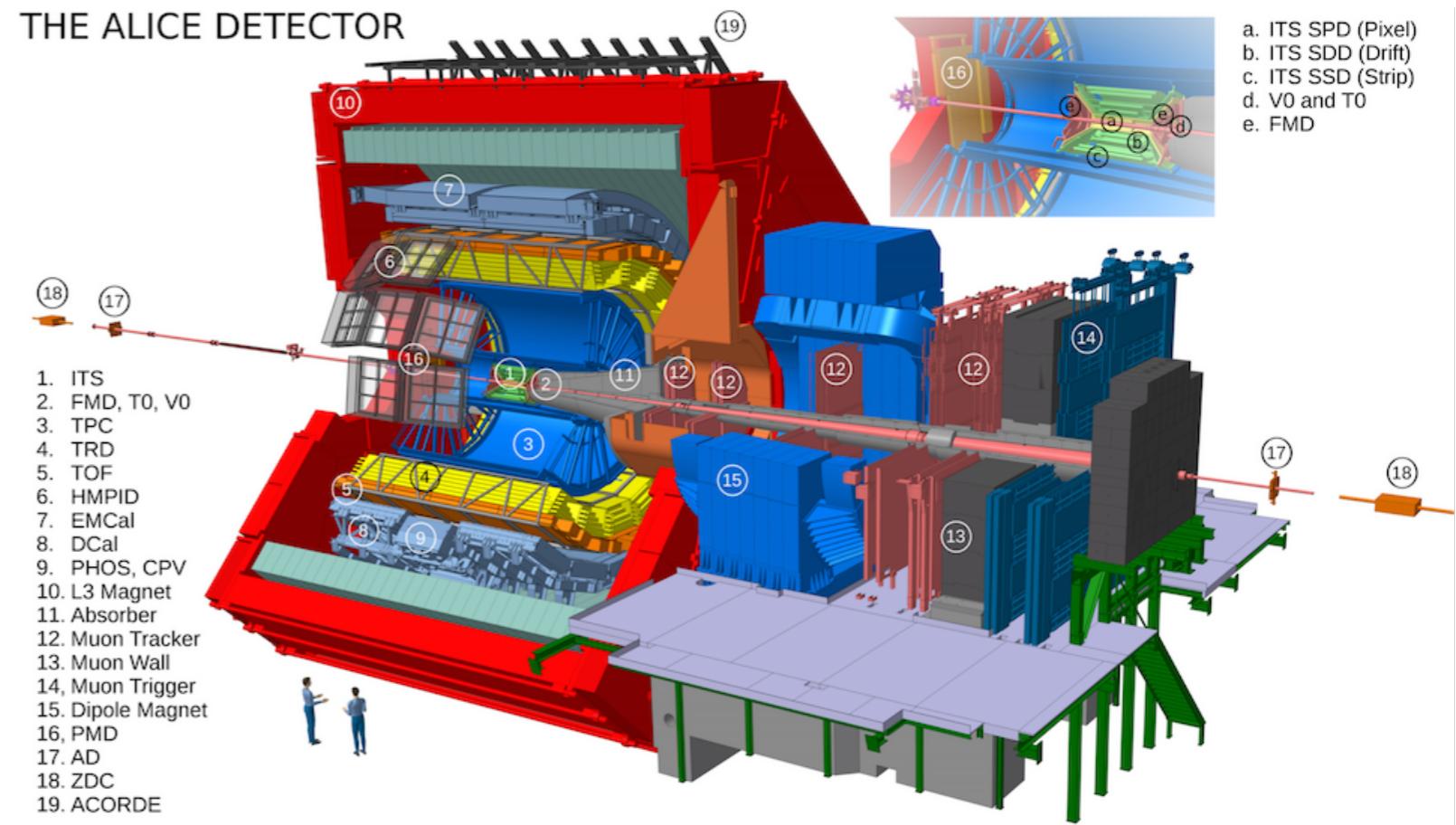
Time Projection Chamber

- Tracking, PID (dE/dx)

Time Of Flight detector

- PID (TOF measurement)

THE ALICE DETECTOR



The ALICE Experiment at CERN LHC

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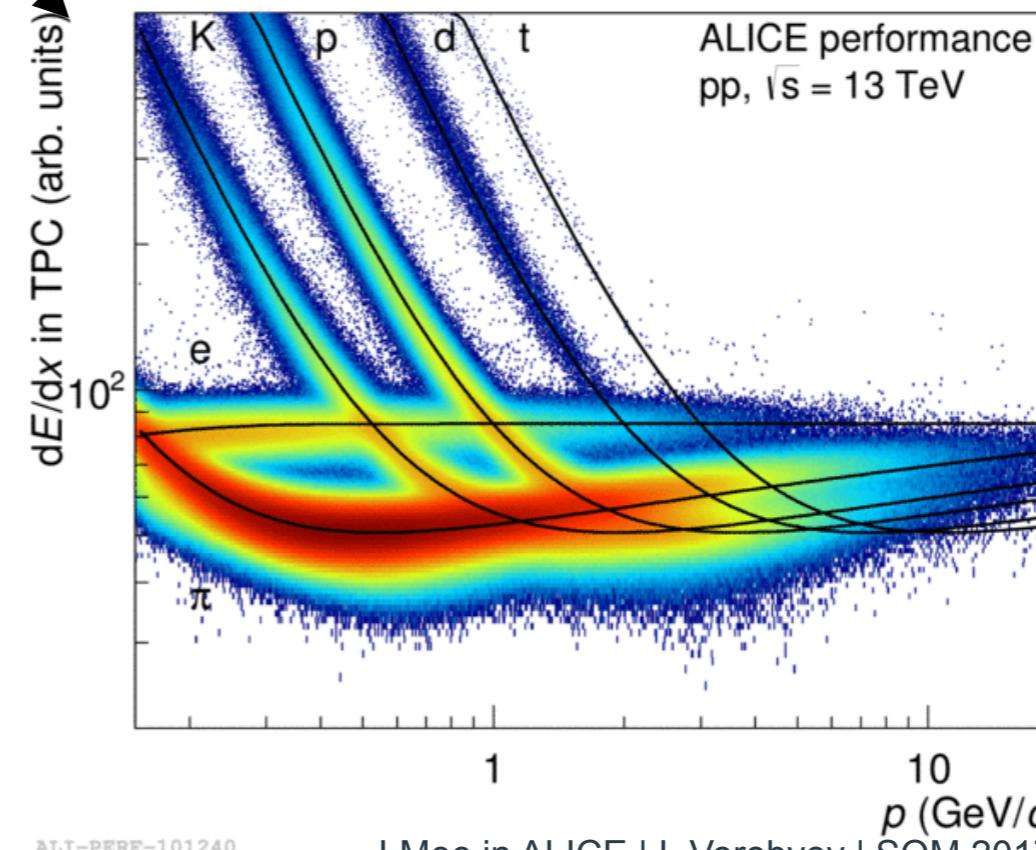
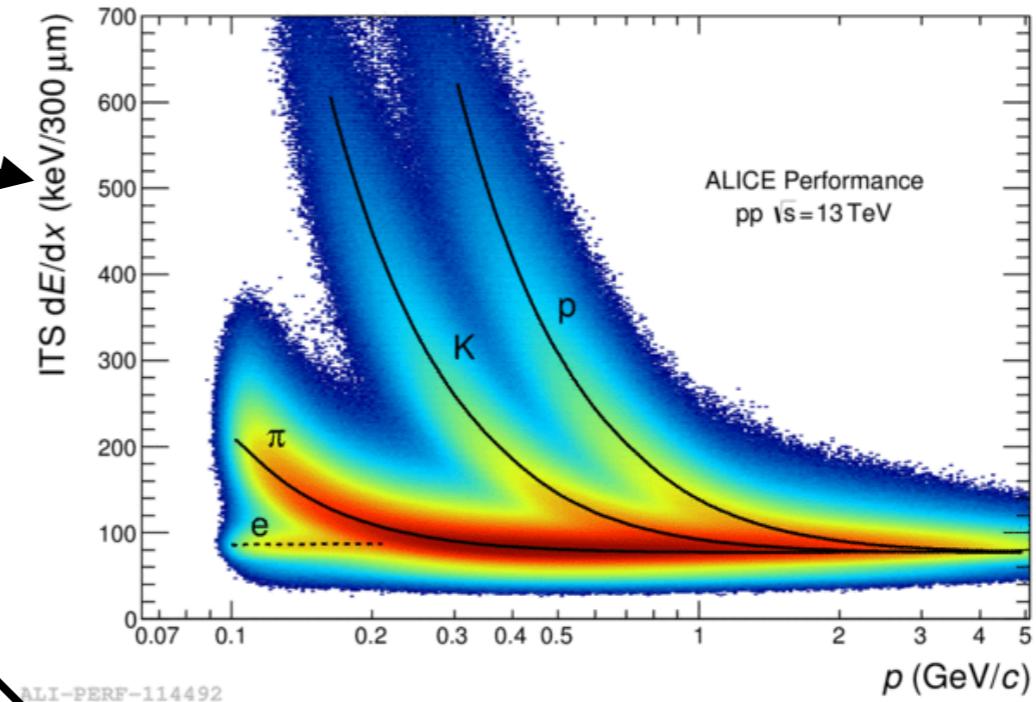
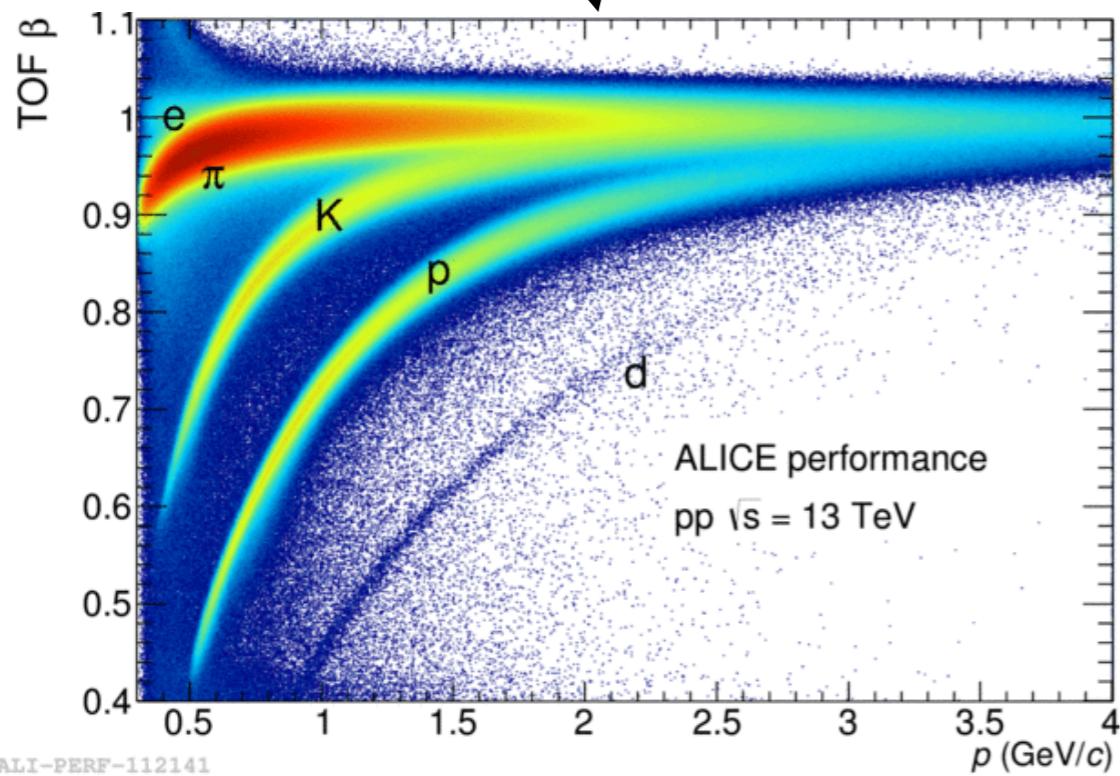
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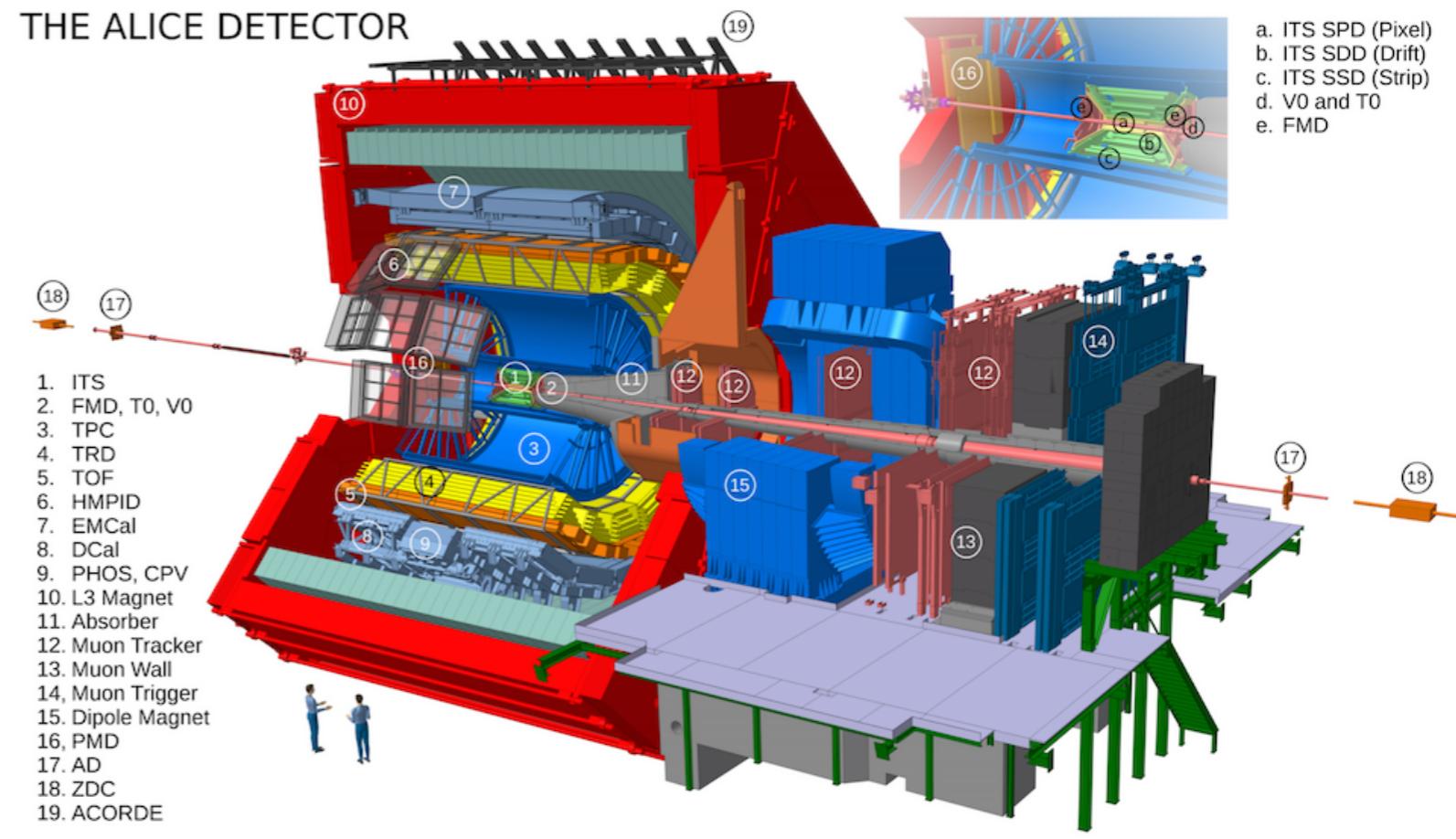
- Tracking, PID (dE/dx)

Time Of Flight detector

- PID (TOF measurement)

V0 scintillators

- Trigger, centrality estimation



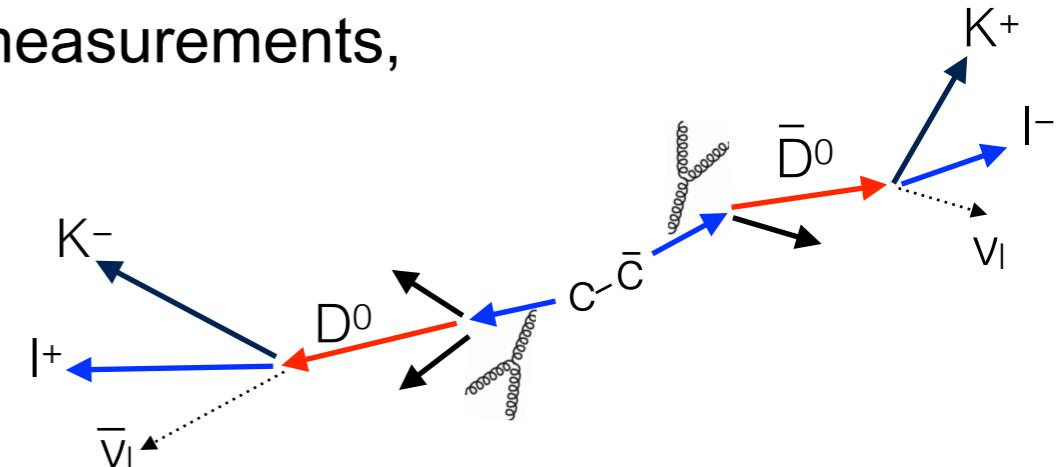
In this talk:

Collision system	N of events	Triggers
pp at $\sqrt{s} = 7$ TeV	~ 370 M	min. bias
pp at $\sqrt{s} = 13$ TeV	~ 104 M + 48 M	min. bias + high mult.
p-Pb at $\sqrt{s_{NN}} = 5.02$ TeV	~ 105 M	min. bias
Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV	~ 20 M	0-10% centrality

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

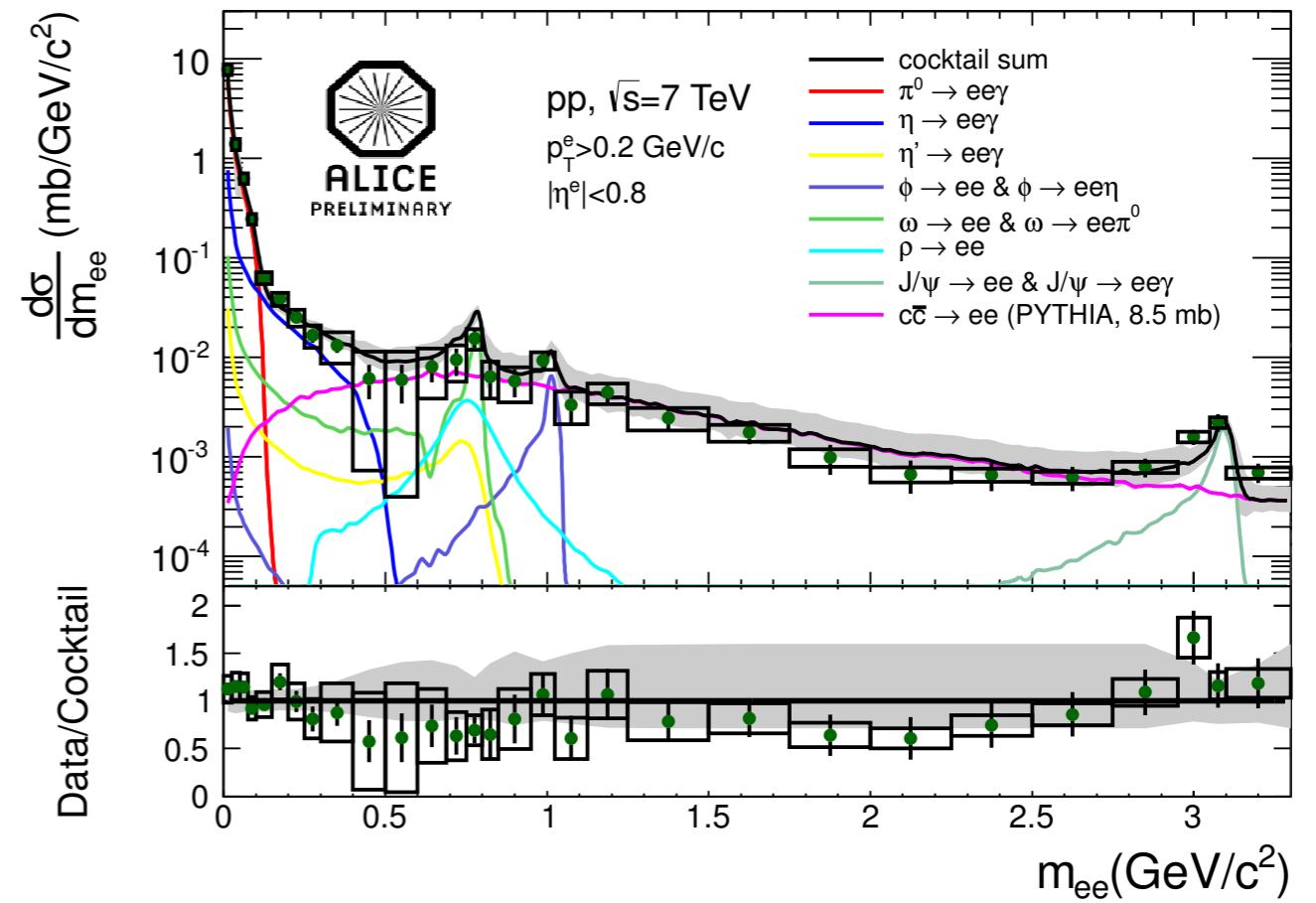
Cocktail of known hadronic sources:

- Resonance and Dalitz decays: π^0 , η , ϕ and J/ψ measurements, other sources (η' , ρ , ω) from m_T scaling
- Heavy-flavour correlated semi-leptonic decays: measured $c\bar{c}$ and $b\bar{b}$ cross sections, shape from PYTHIA simulations
- Detector acceptance and resolution effects



Data in agreement with cocktail calculations within uncertainties

- Finalisation of results is ongoing (heavy-flavour cross section, direct photons, pair DCA analysis)

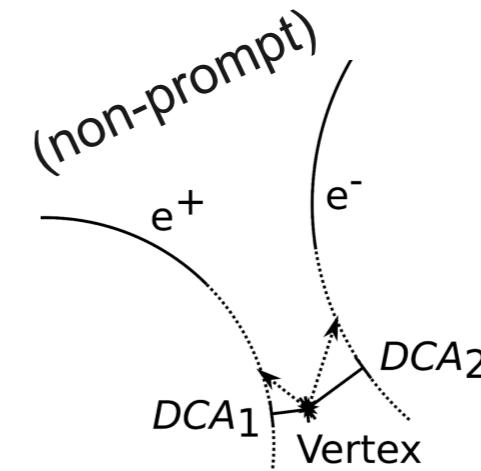


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pp $\sqrt{s} = 7$ TeV: pair DCA analysis

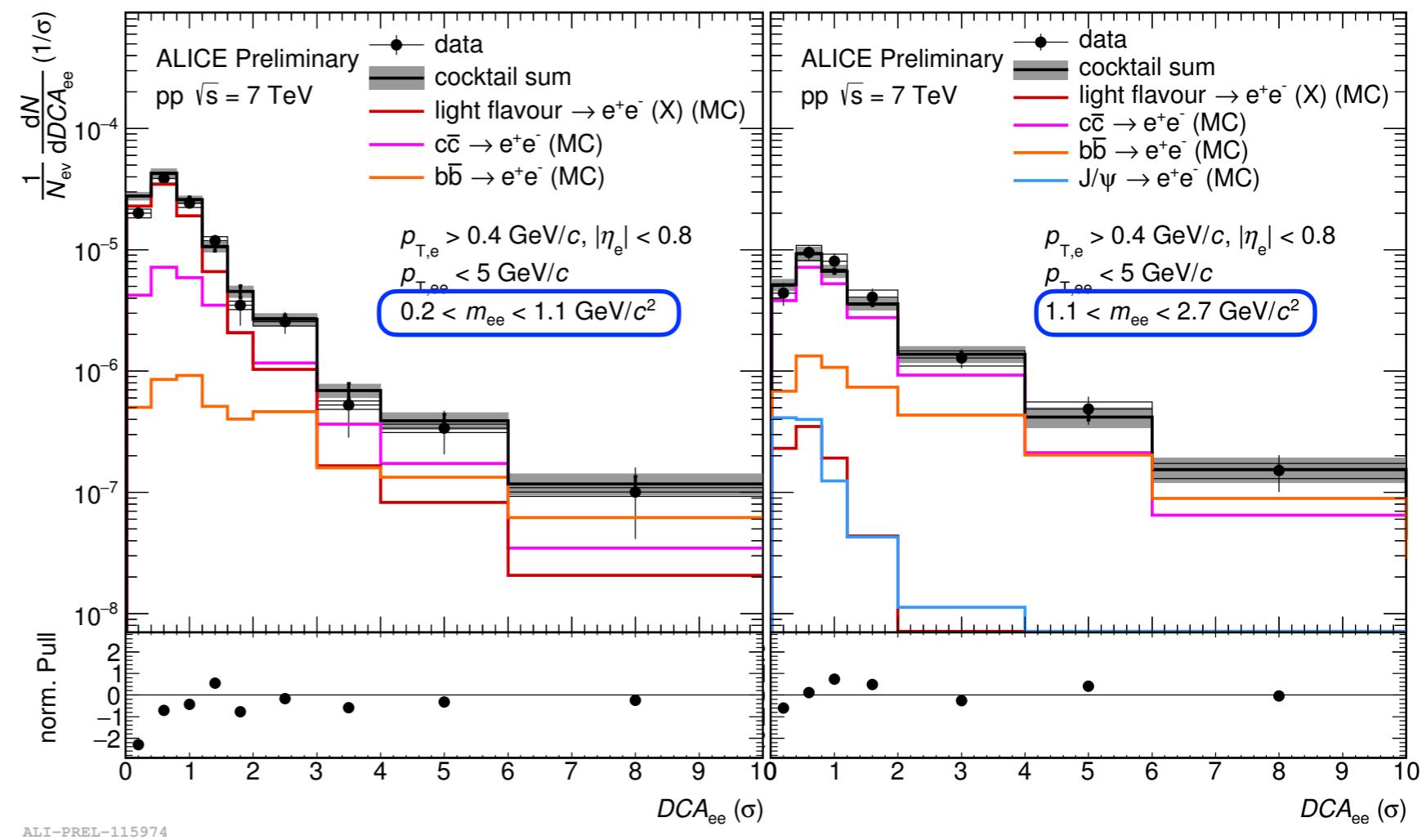
Idea: separate prompt and non-prompt contributions using pair vertex position

- Observable: $DCA_{ee} = \sqrt{\frac{DCA_1^2 + DCA_2^2}{2}}$
- Obtain DCA_{ee} templates from MC, normalise to cocktail and compare with data



Good description of data in all mass regions

- Low-mass region: prompt and non-prompt sources, can separate them
- Intermediate-mass region: non-prompt sources, separation of $c\bar{c}$ and $b\bar{b}$



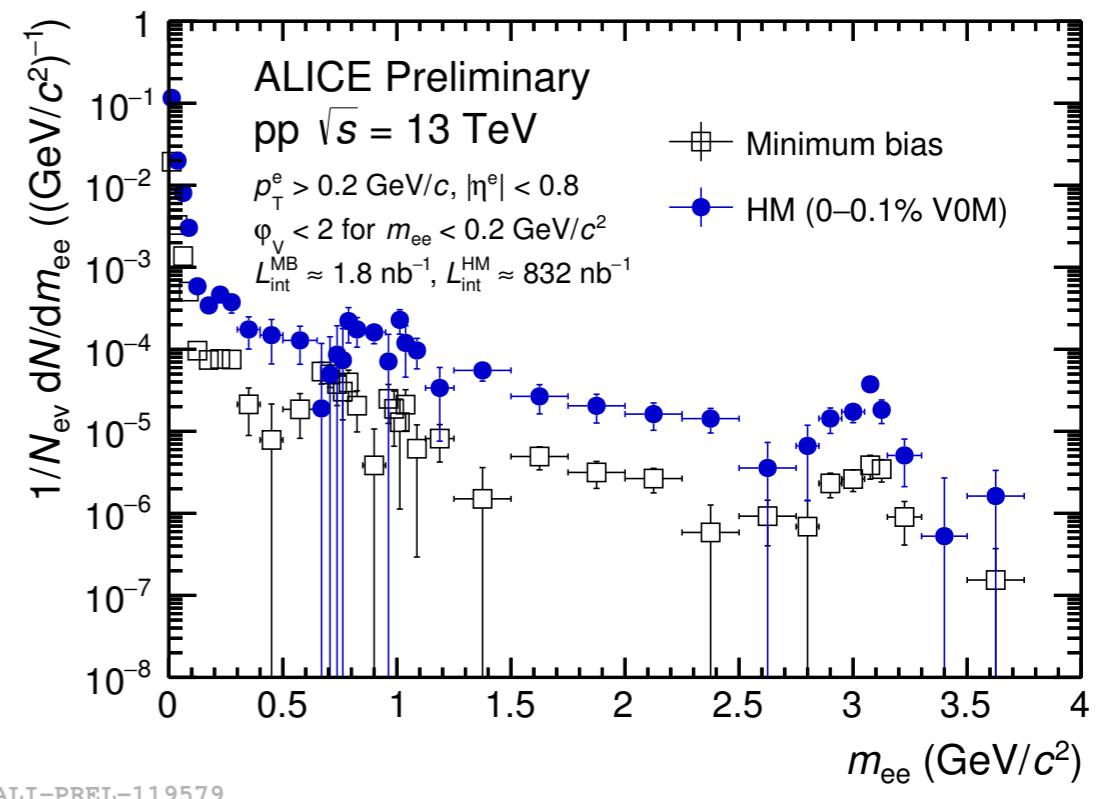
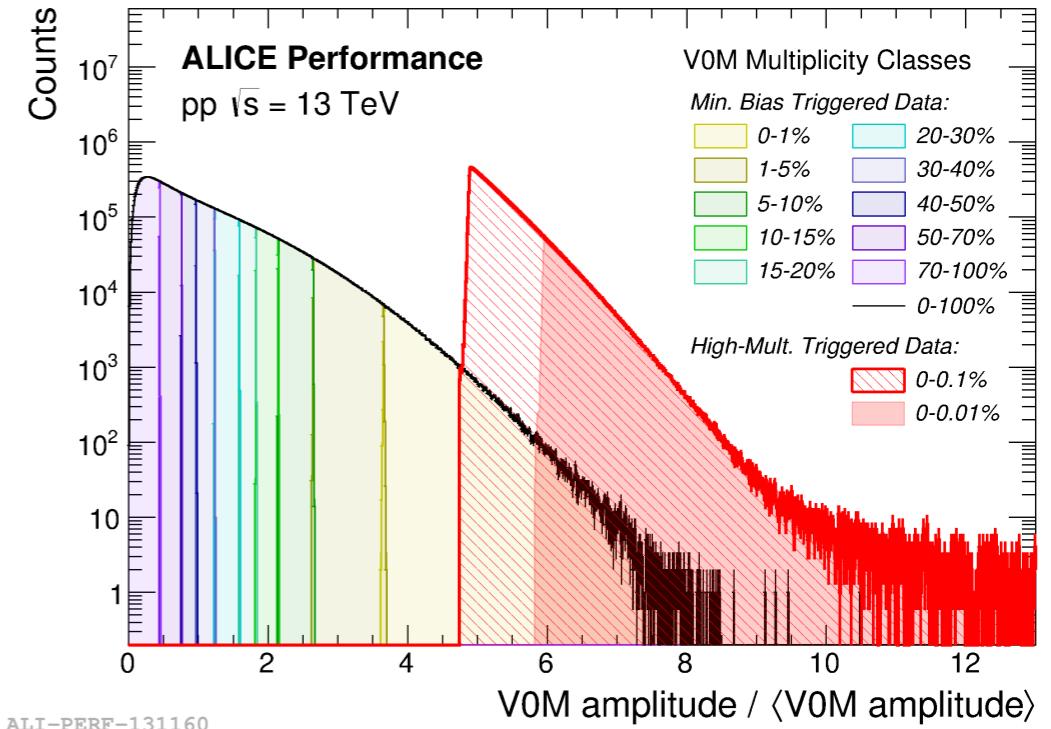
New phenomena in high multiplicity pp events?

Production / destruction of p meson, direct photons, open heavy flavour... ?

Idea: produce a ratio of (uncorrected) dielectron spectra:

$$\frac{N_{ee}(HM)/\langle N_{ch}^{acc}(HM) \rangle}{N_{ee}(MB)/\langle N_{ch}^{acc}(MB) \rangle}$$

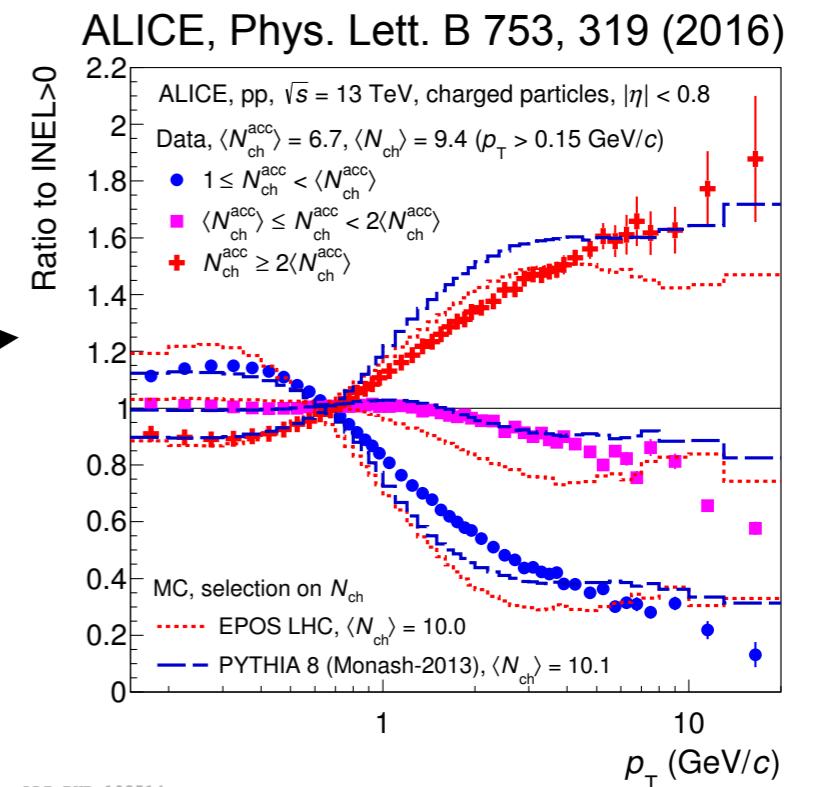
- Min. bias triggered data: coincidence of V0A & V0C signals
- High mult. triggered data: coincidence of V0A & V0C signals, threshold on V0M
- $\langle N_{ch}^{acc}(HM) \rangle / \langle N_{ch}^{acc}(MB) \rangle = 4.36$ (measured at $\eta \sim 0$)
- **Naive expectation** (for light flavour): **signal $\sim N_{ch}$**



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

Light-flavour decays:

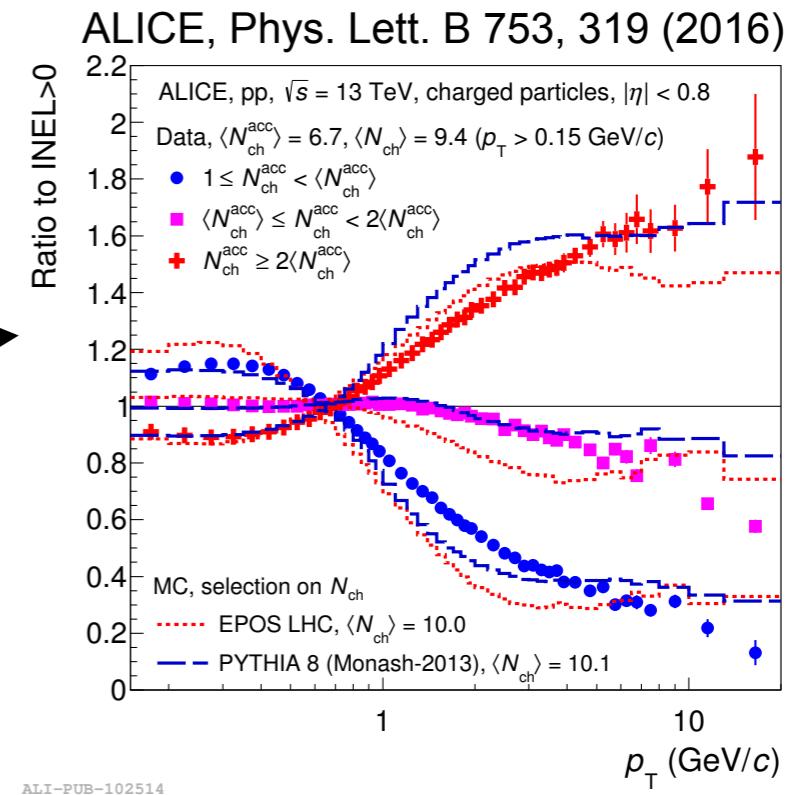
- Preliminary ALICE π^\pm measurements as input, m_T scaling for other hadrons
- Modification of p_T spectrum in events with higher charged particle multiplicities



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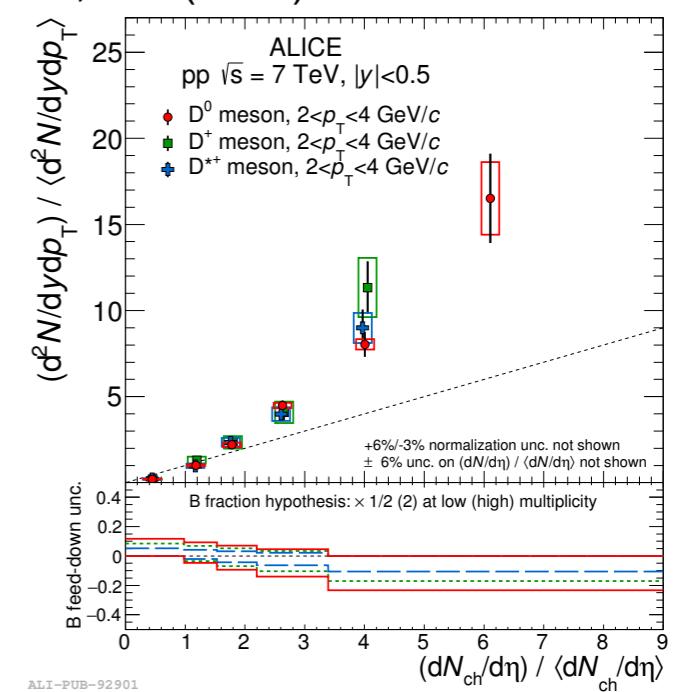
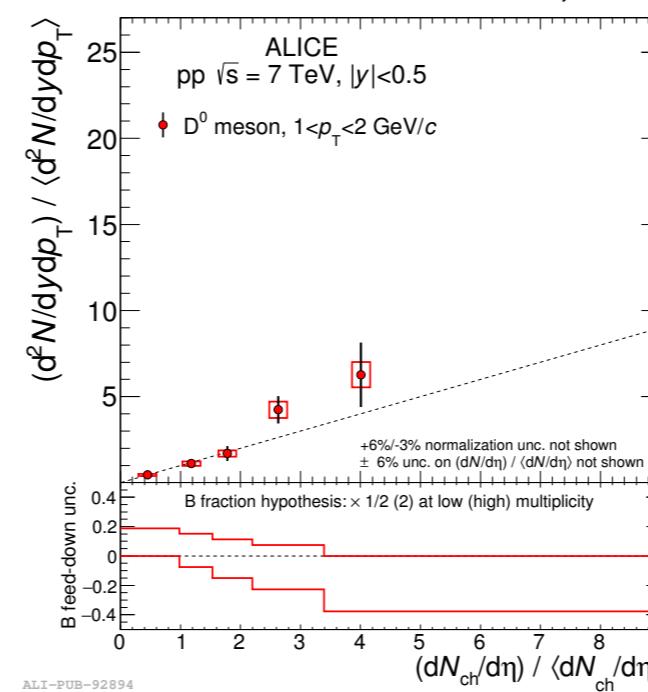
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Heavy-flavour contribution:

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

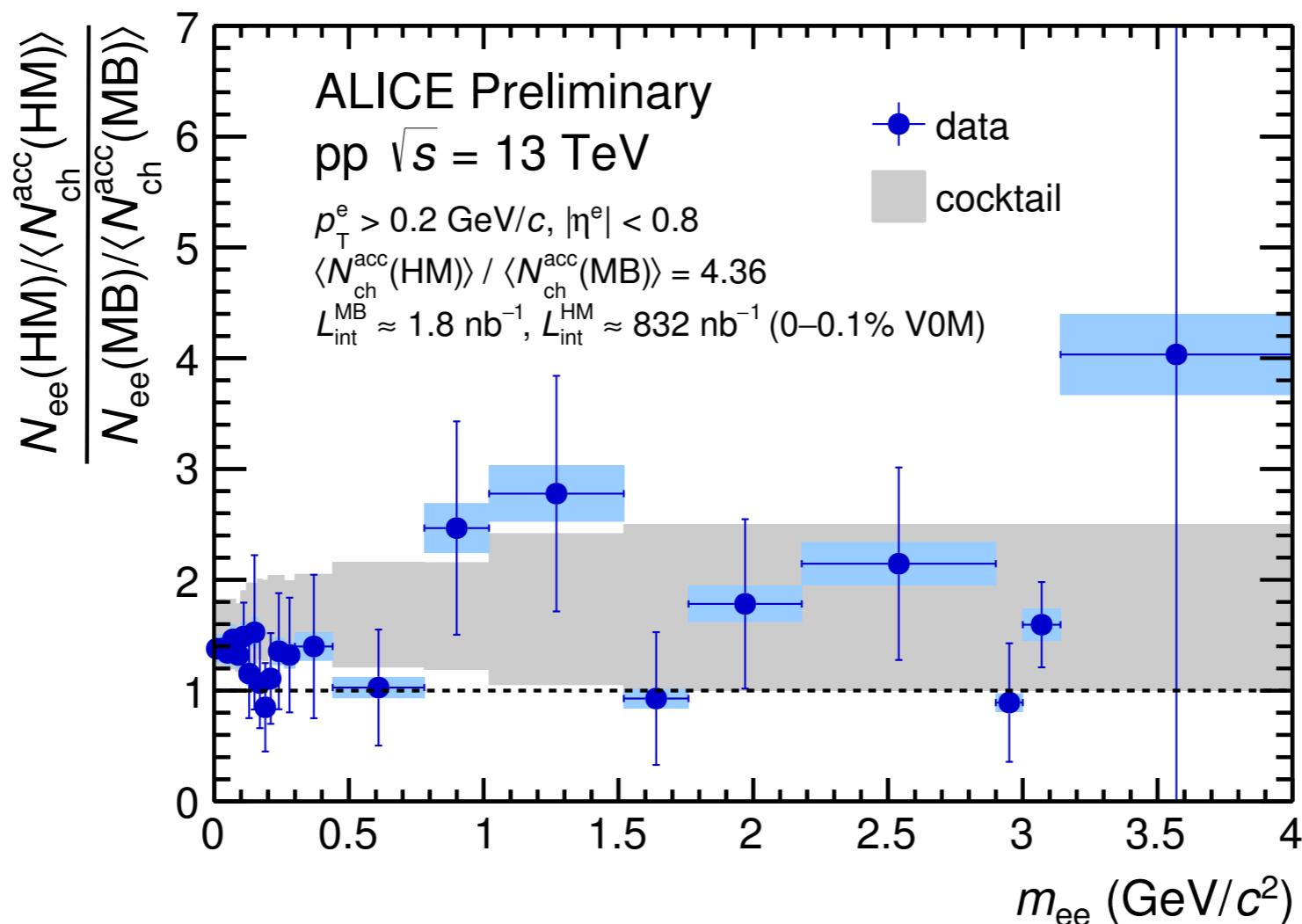
$$\frac{N_{c\bar{c} \rightarrow ee}(\text{HM}) / \langle N_{ch}(\text{HM}) \rangle}{N_{c\bar{c} \rightarrow ee}(\text{MB}) / \langle N_{ch}(\text{MB}) \rangle} \approx 1 - 2.5$$



pp $\sqrt{s} = 13$ TeV: high multiplicity data analysis

Results are in agreement with cocktail expectations

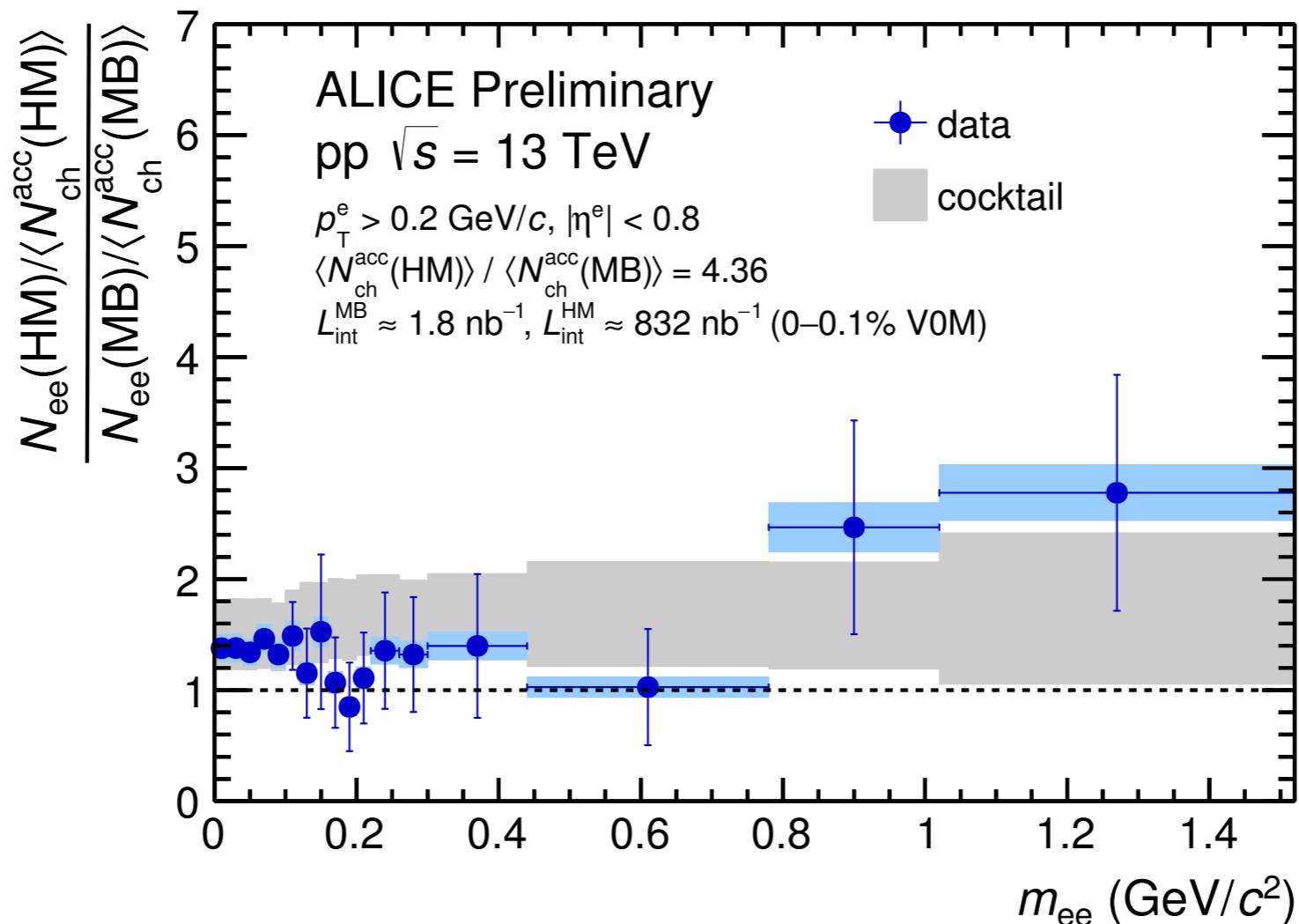
- J/ ψ consistent with dedicated analysis [I. Arsene, Small systems, Thu 10:00]
- Intermediate mass: in agreement with D-meson results at 7 TeV



pp $\sqrt{s} = 13$ TeV: high multiplicity data analysis

Results are in agreement with cocktail expectations

- J/ ψ consistent with dedicated analysis [I. Arsene, Small systems, Thu 10:00]
- Intermediate mass: in agreement with D-meson results at 7 TeV
- Low mass: ratio > 1 due to change of hadron p_T spectrum and acceptance cut
- Analysis of more data (x5) is ongoing

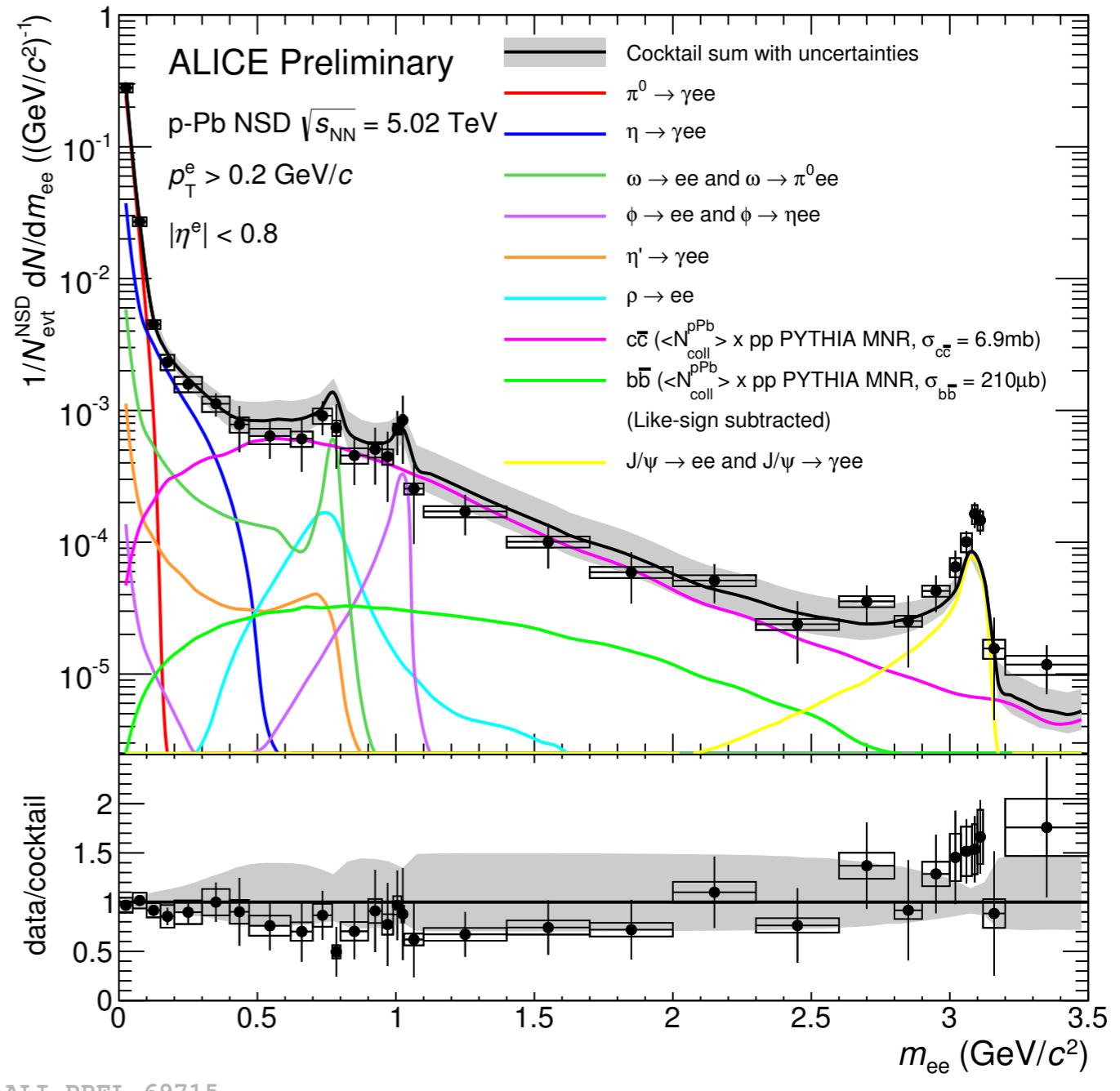


p-Pb $\sqrt{s_{NN}} = 5.02$ TeV: invariant mass spectrum

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

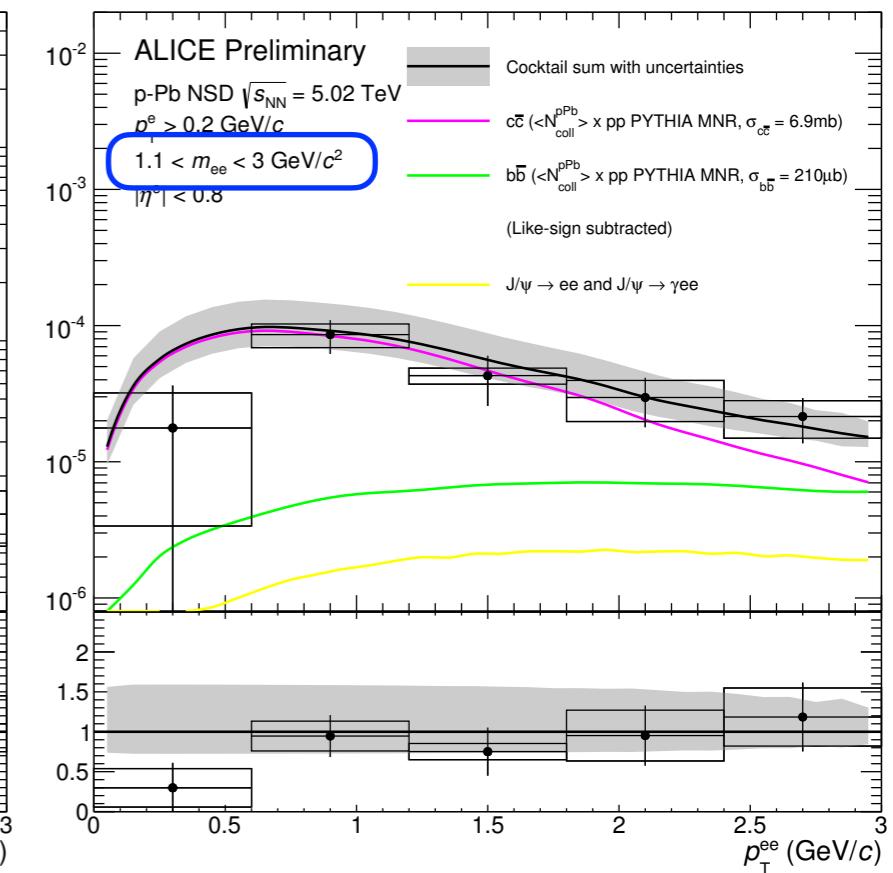
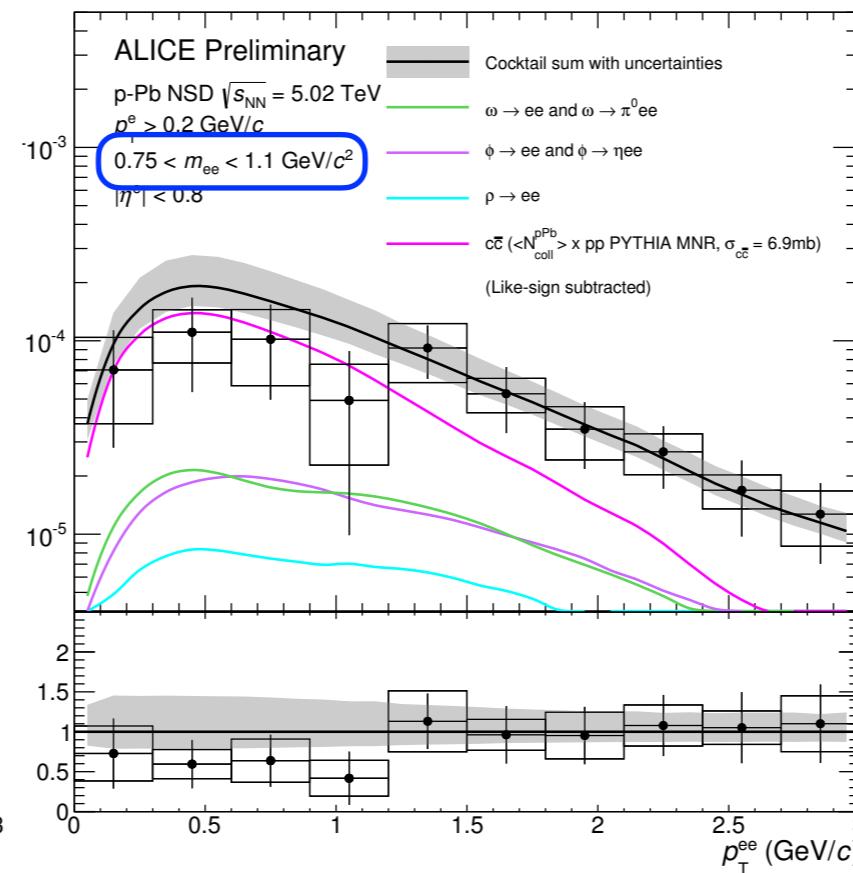
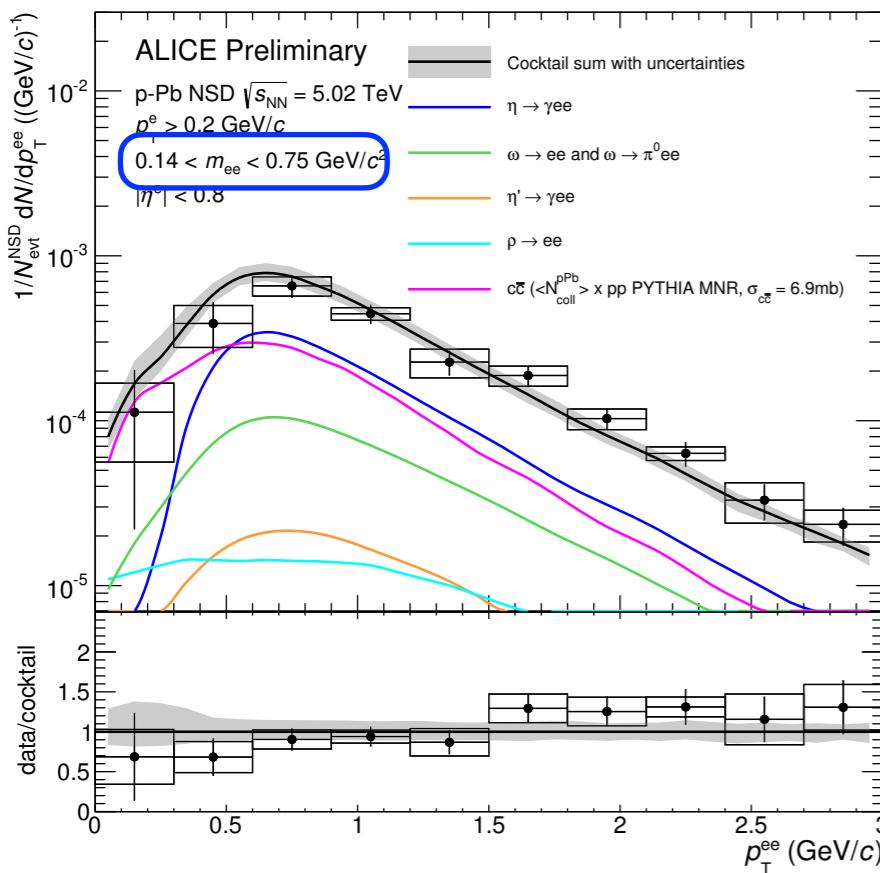
**Data consistent with cocktail
within uncertainties**



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?



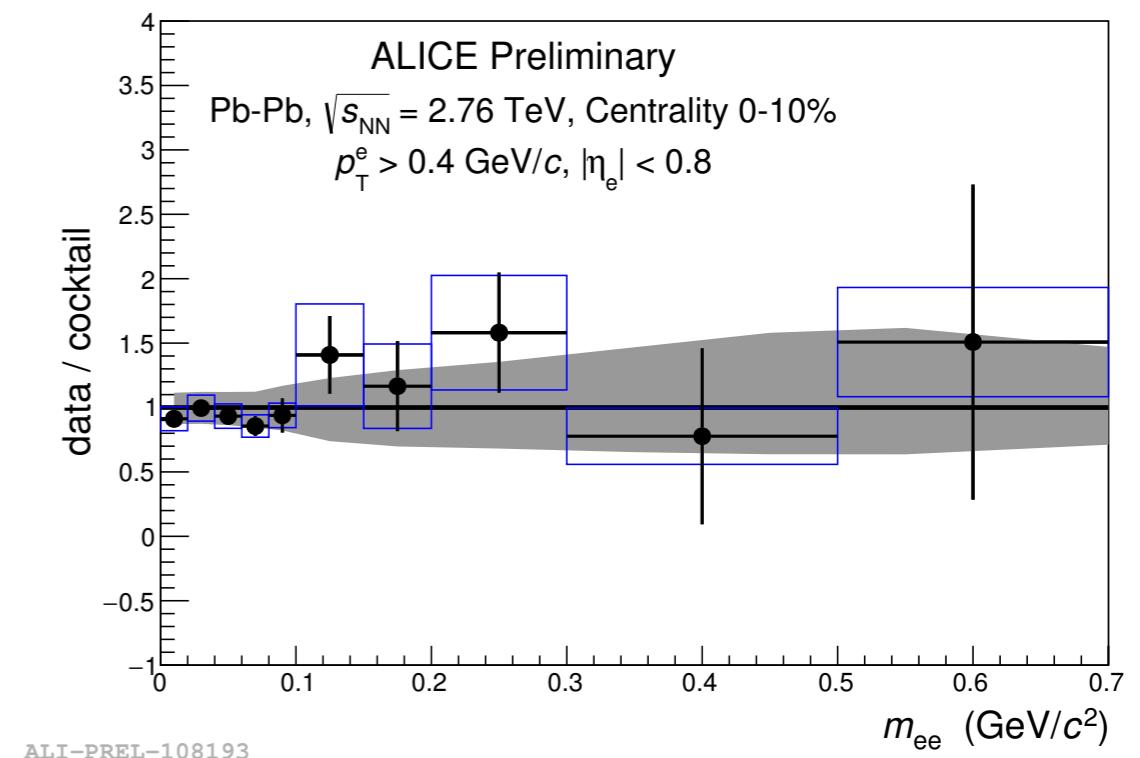
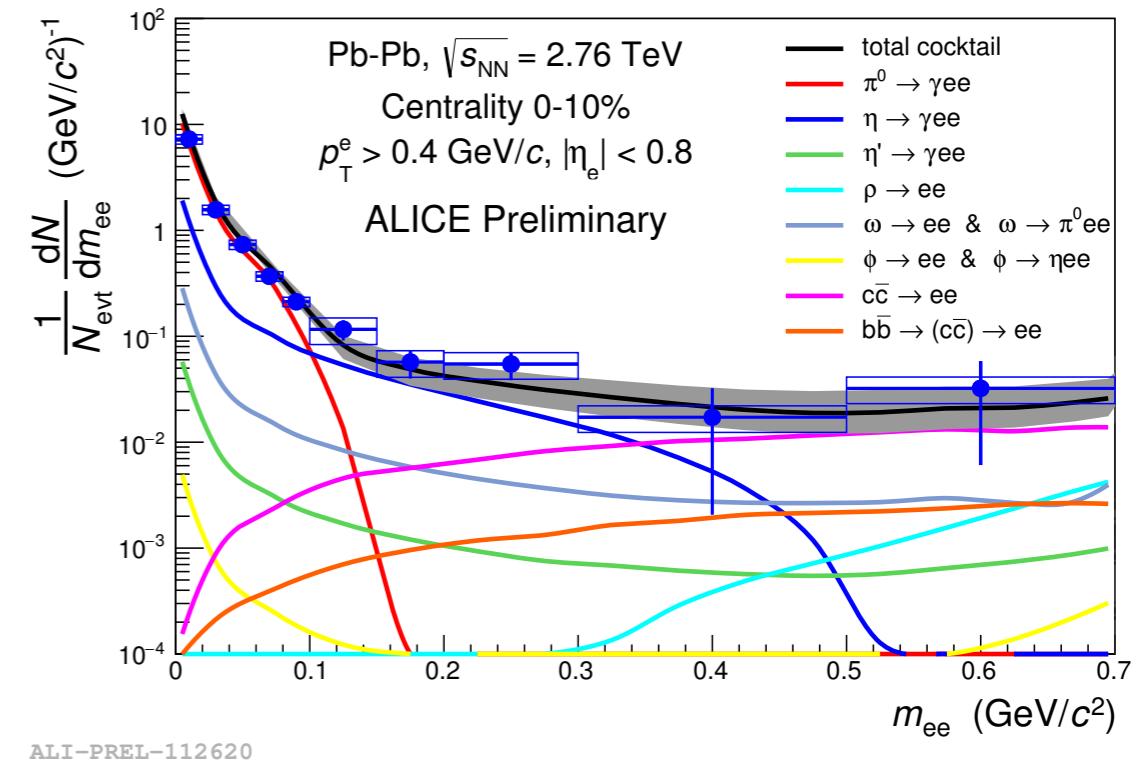
x5 more p-Pb data in Run 2: detailed studies vs m_{ee} and p_T^{ee} are foreseen

Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV: invariant mass spectrum

- Light flavour cocktail: π^0 measurements, m_T scaling for other hadrons
- Heavy flavour cocktail: PYTHIA calculations normalised to pp at 7 TeV measurements, extrapolated to 2.76 TeV and scaled with N_{coll}

Data compatible with cocktail within large uncertainties

- Room for additional sources

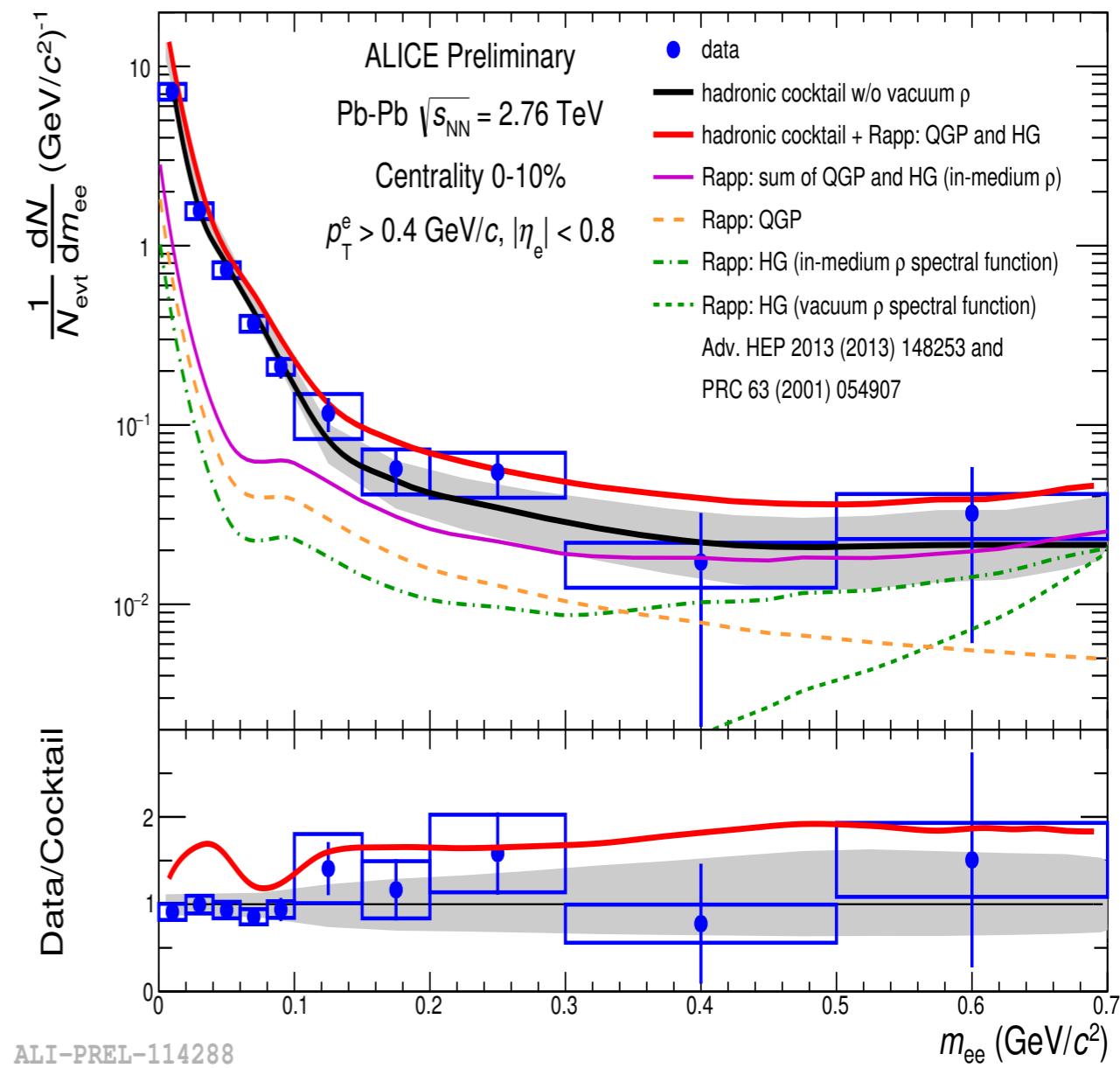


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Data compatible with cocktail within large uncertainties

- Room for additional sources
- **Data** compared to **hadronic cocktail + QGP** and **HG** radiation with modified ρ and ω in-medium spectral functions [1, 2]
- Reduced sensitivity to measure thermal radiation
- Run 3 data (after detector upgrade): more precise studies, access to T_{init}
[G. Martinez-Garcia, Det. Upgrades, Fri 11:10]



Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV: virtual direct photons

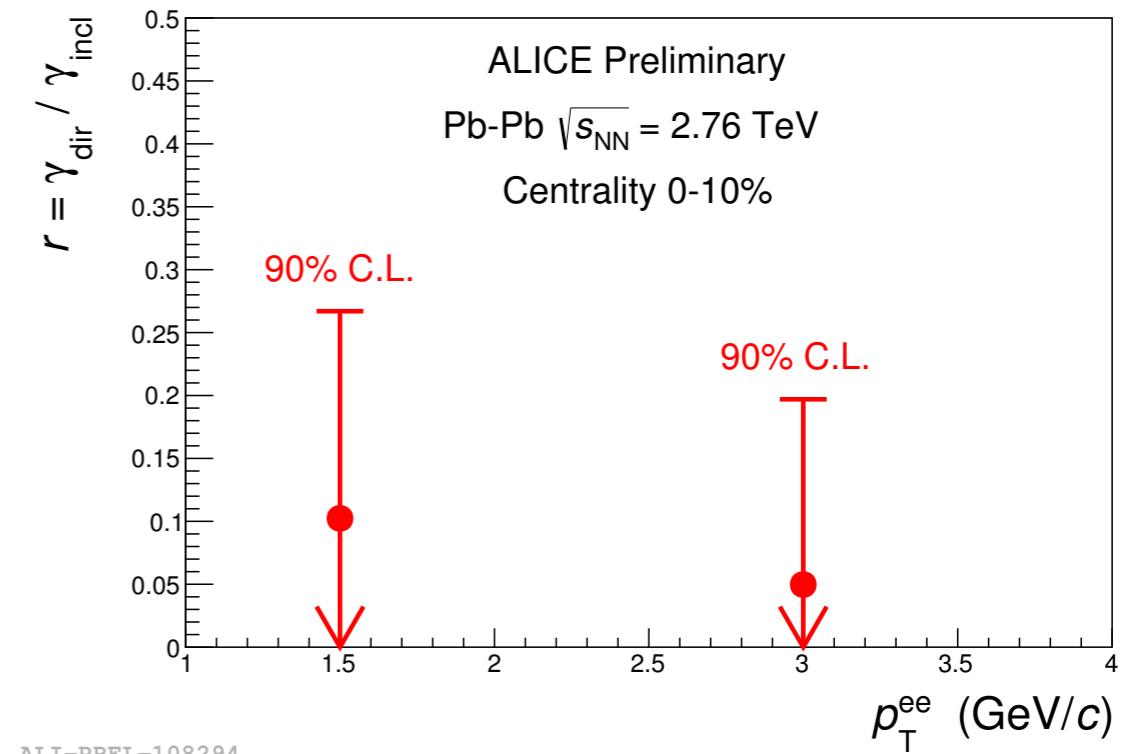
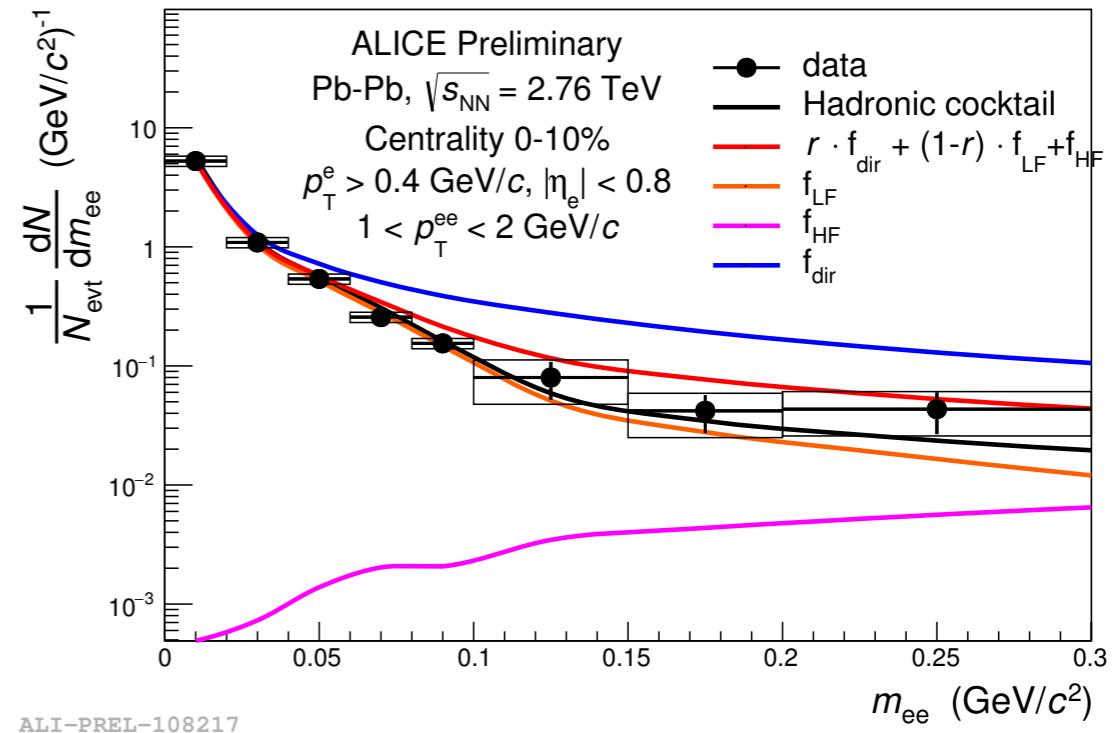
Fit dielectron mass spectrum (m_{ee}
 100-300 MeV/c 2 , p_T 1-2 and 2-4 GeV/c)

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

- r = virtual direct γ / inclusive
- Direct virtual photons described by Kroll-Wada ($m_{ee} \ll p_T$)

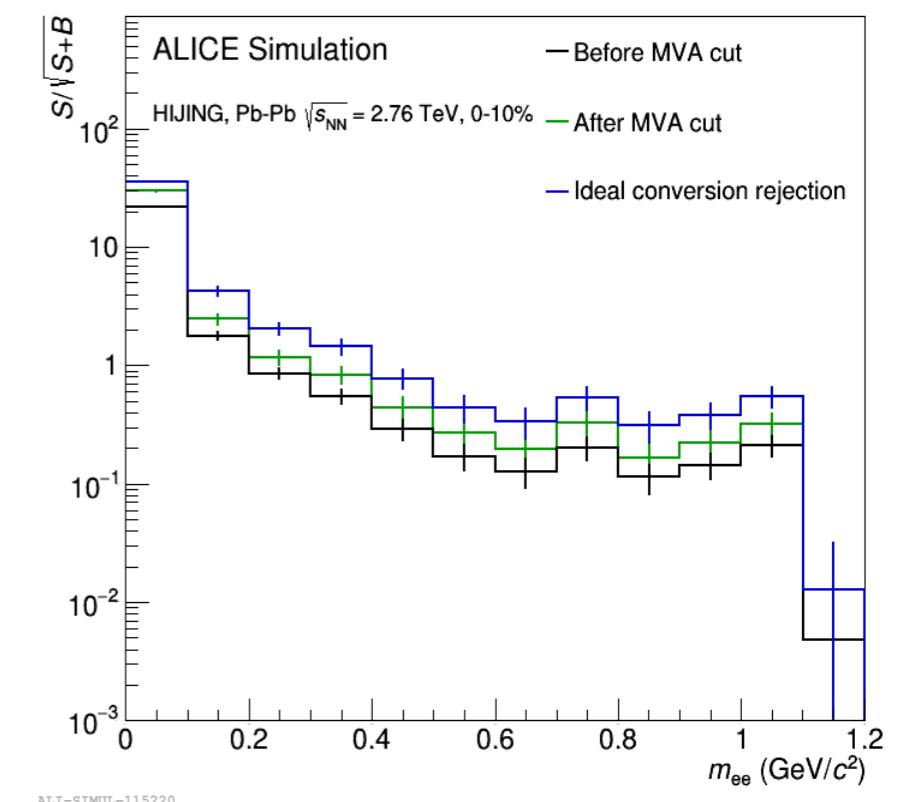
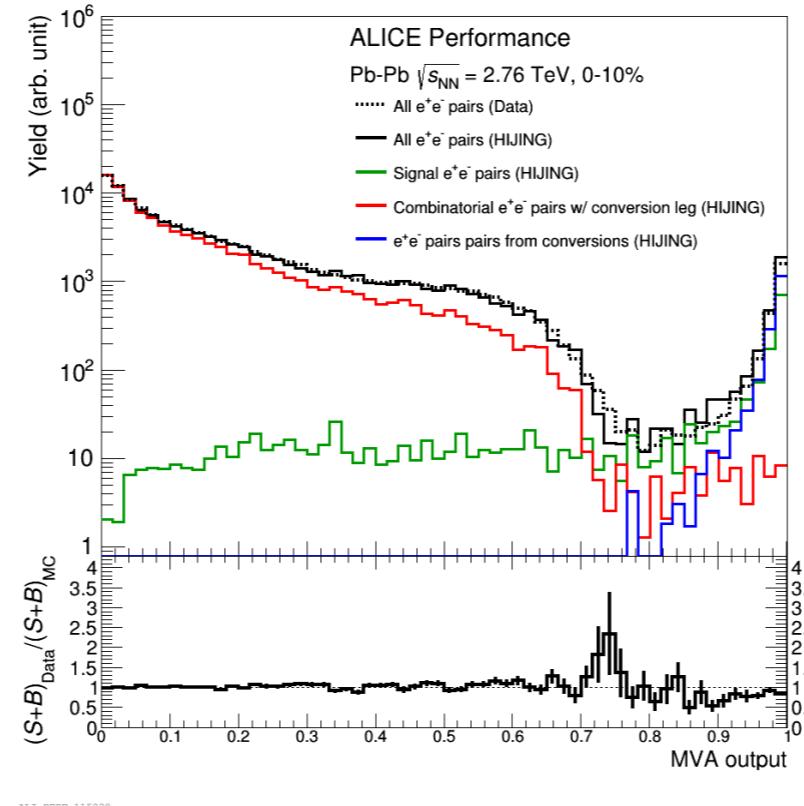
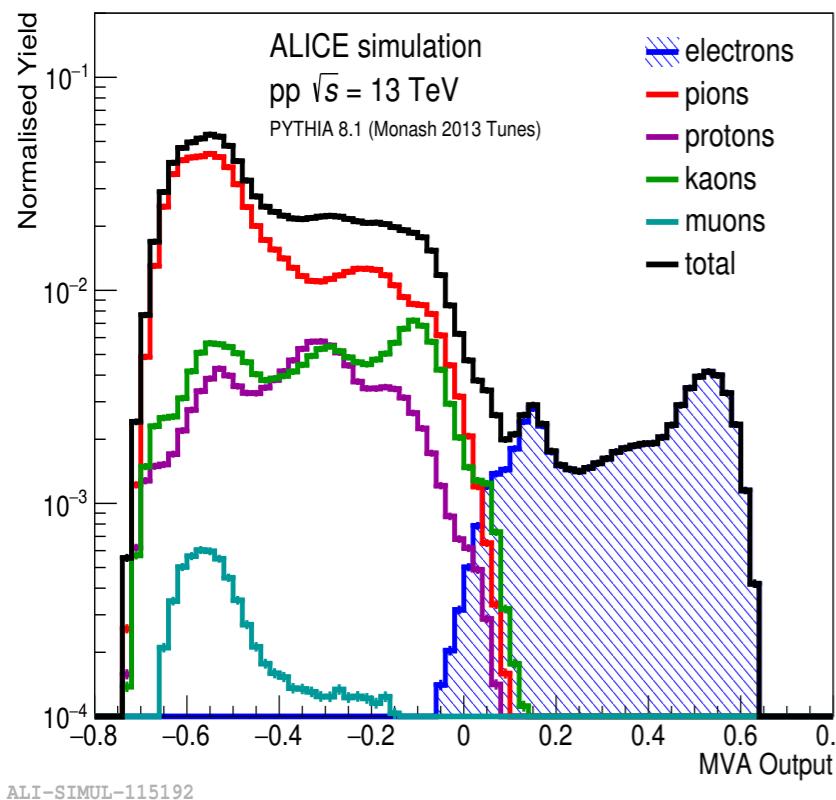
$$\frac{1}{N_\gamma} \frac{dN_{ee}}{dm_{ee}} = \frac{2\alpha_{e.m.}}{3\pi} \sqrt{1 - \frac{4m_e^2}{m_{ee}^2}} \left(1 + \frac{2m_e^2}{m_{ee}^2}\right) \times \frac{1}{m_{ee}}$$

- Results compatible with ALICE and RHIC direct photon measurements of $r \sim 0.1 - 0.2$ [1, 2]



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



Summary and outlook

pp collisions

- Medium-free baseline for heavy ions studies
- First low-mass dielectron analysis of high-multiplicity events
- Results are described with cocktail calculations of known hadronic sources

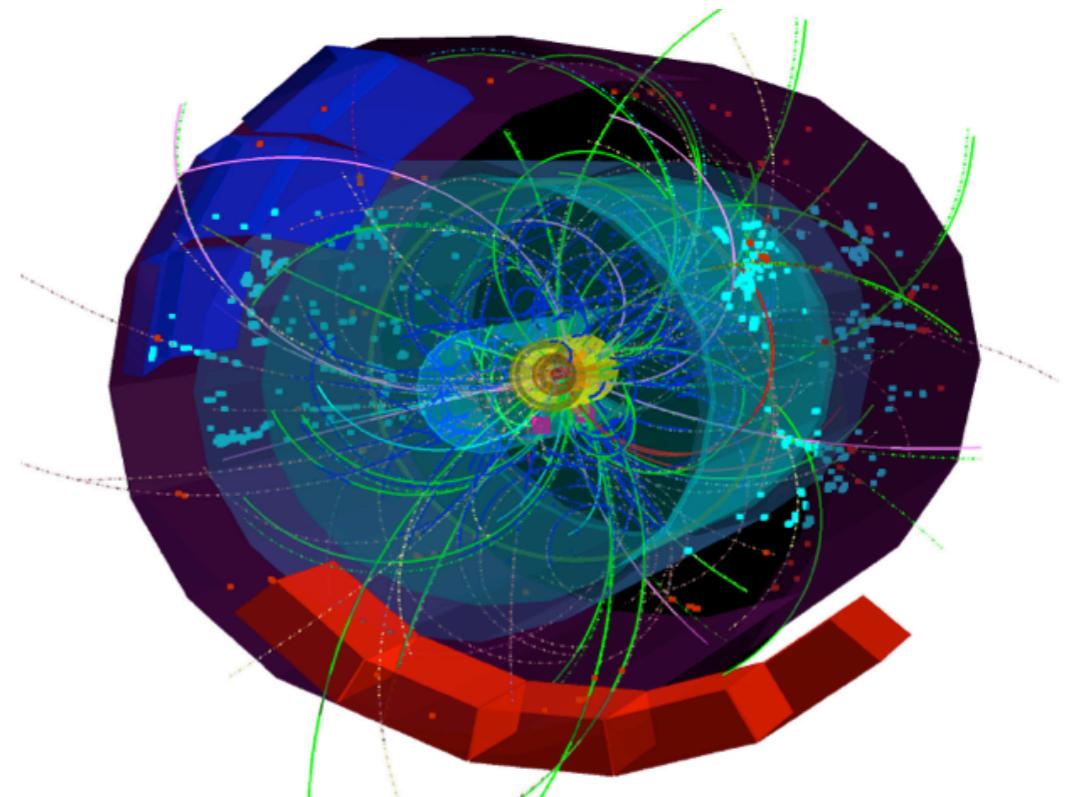
p-Pb collisions

- Studies of possible cold nuclear matter effects
- Compatible with hadronic cocktail within uncertainties

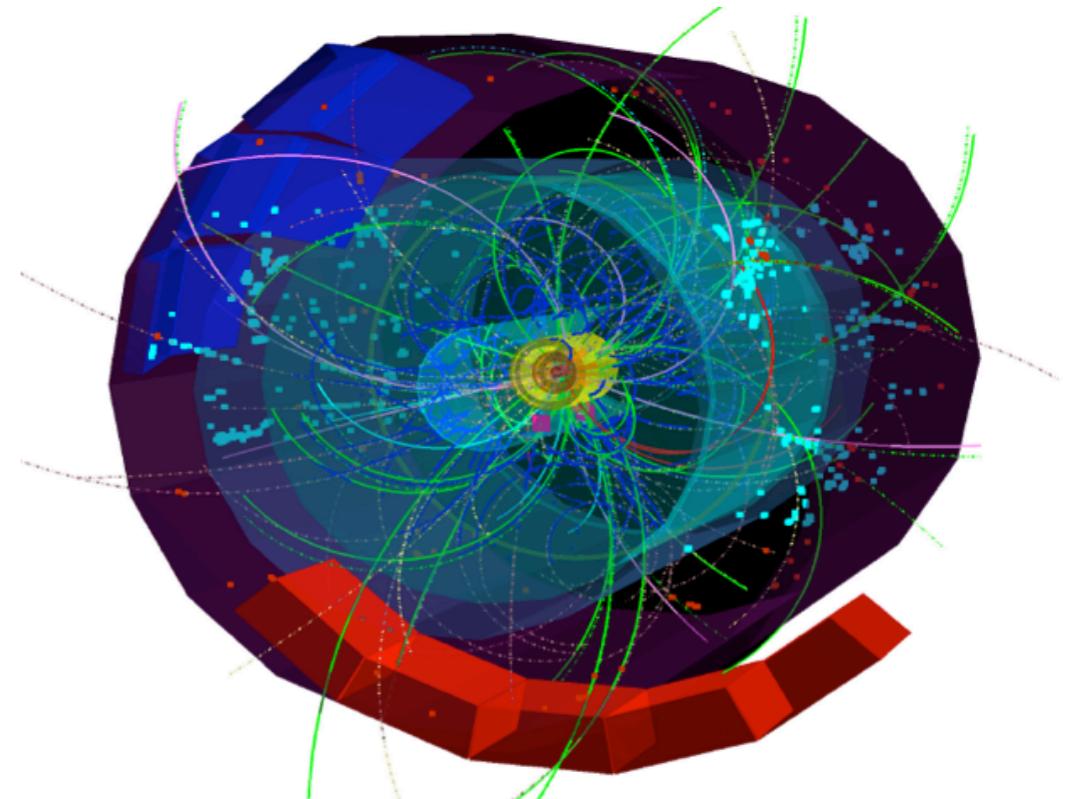
Pb-Pb collisions

- Challenging analysis, results compatible with hadronic cocktail within uncertainties
- Room for additional contributions

***More Run 2 results are coming soon,
so stay tuned!***



Back-up slides



Dielectron pair analysis

- Physics signal:

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

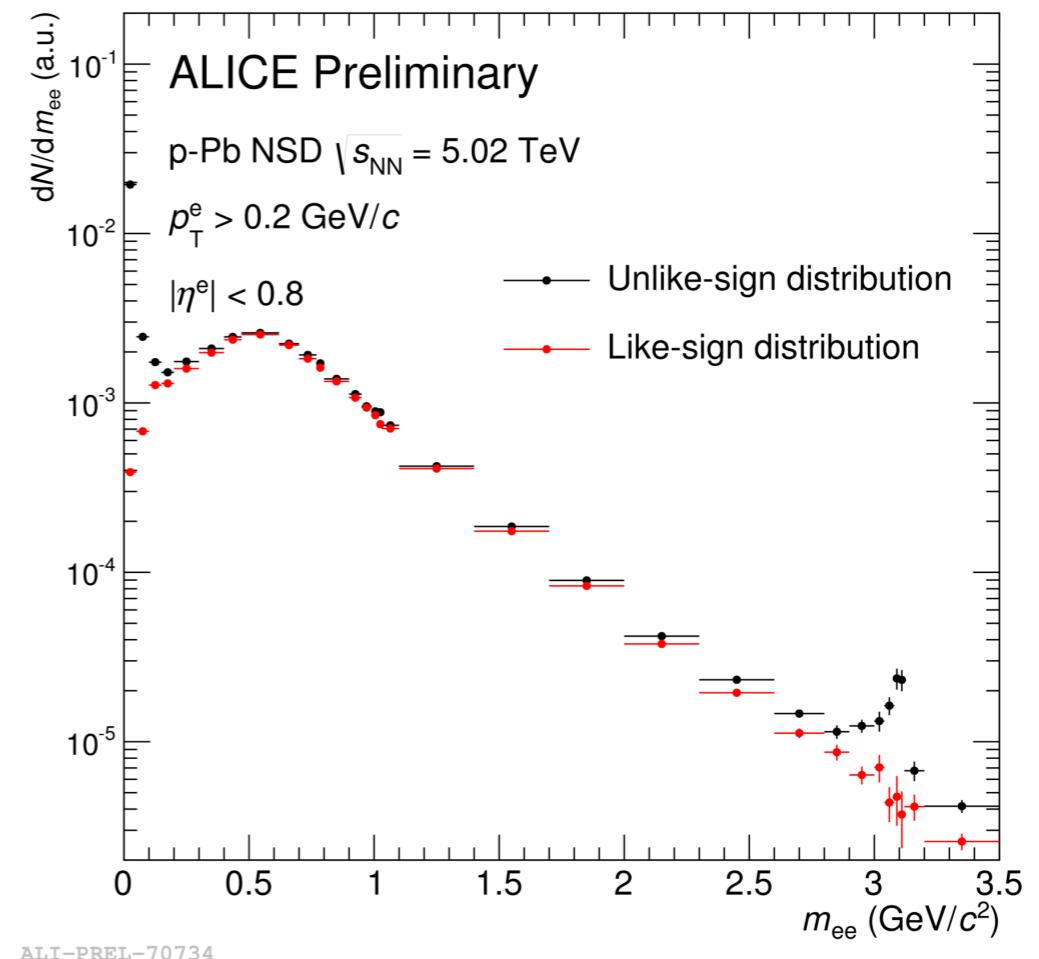
- Combinatorial background: geometric mean of like-sign pairs from same event

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

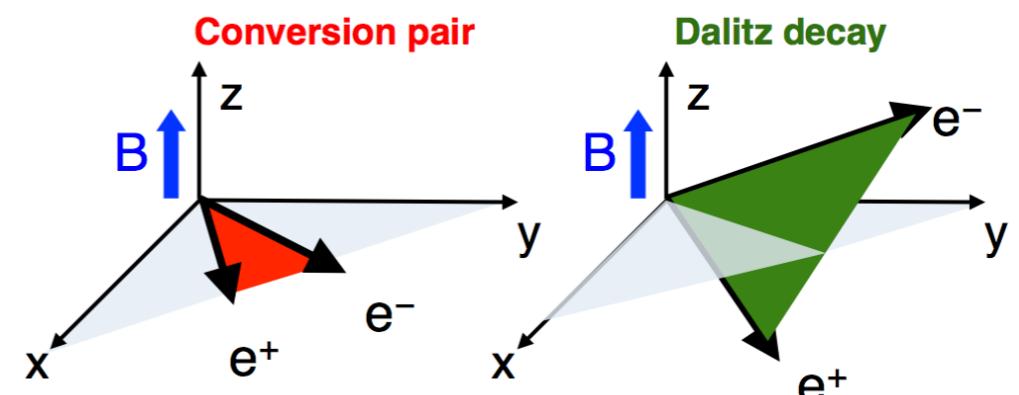
- Pair acceptance correction factor (from mixed events)

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

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



ALI-PREL-70734



pp $\sqrt{s} = 7$ TeV: direct photons

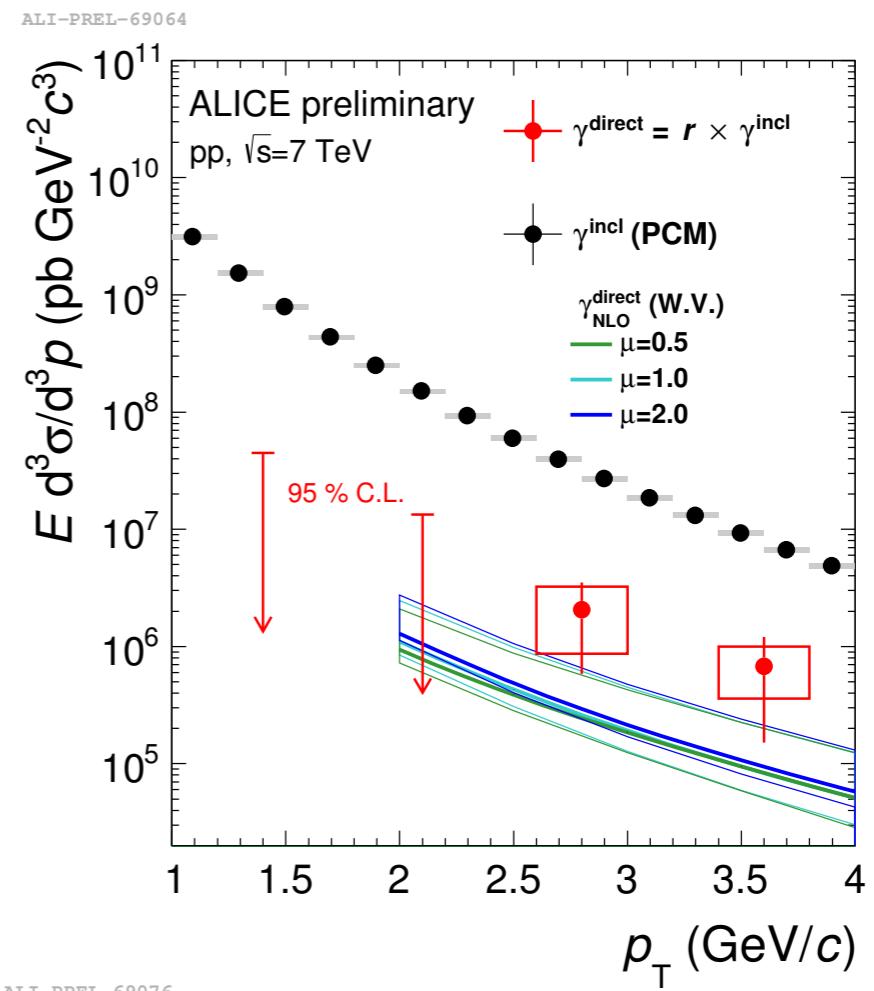
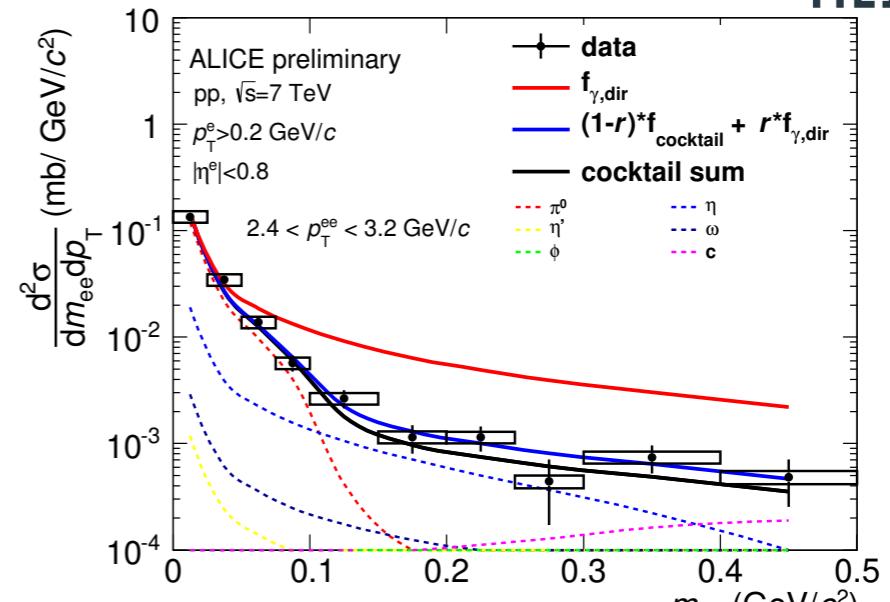
Fit dielectron mass spectrum (m_{ee} 100-400 MeV/c 2 , $p_T > 1$ GeV/c) with

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

- r = virtual direct γ / inclusive
- Direct virtual photons described by Kroll-Wada ($m_{ee} \ll p_T$)

$$\frac{1}{N_\gamma} \frac{dN_{ee}}{dm_{ee}} = \frac{2\alpha_{e.m.}}{3\pi} \sqrt{1 - \frac{4m_e^2}{m_{ee}^2}} \left(1 + \frac{2m_e^2}{m_{ee}^2}\right) \times \frac{1}{m_{ee}}$$

- Results compatible with NLO pQCD calculations

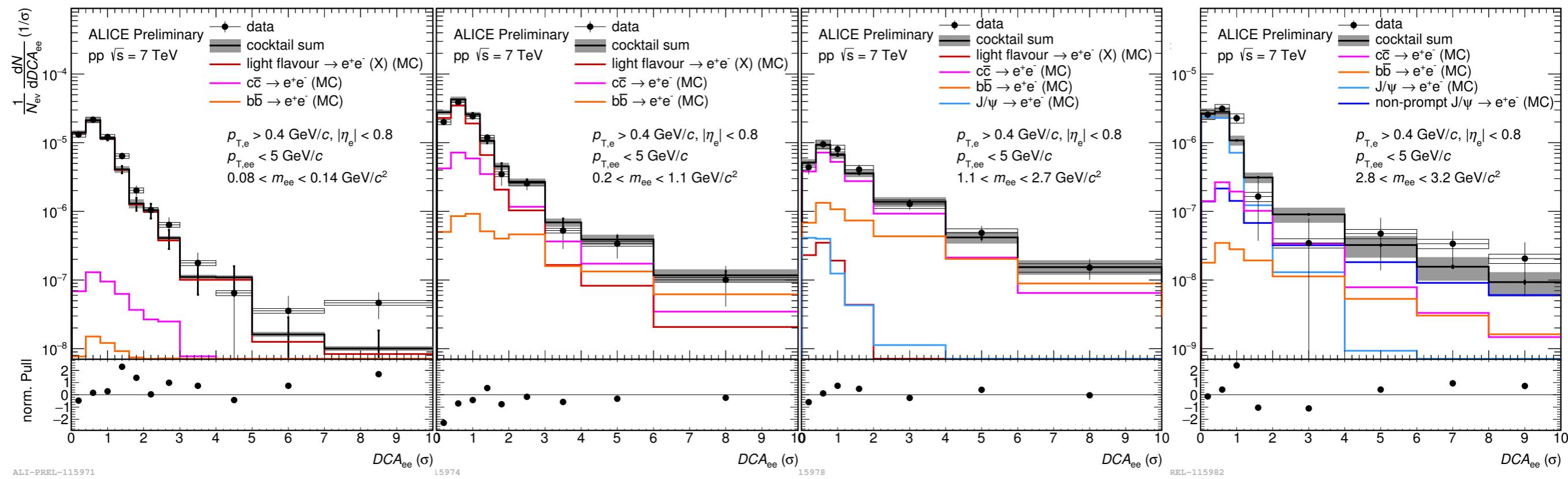


ALI-PREL-69076

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

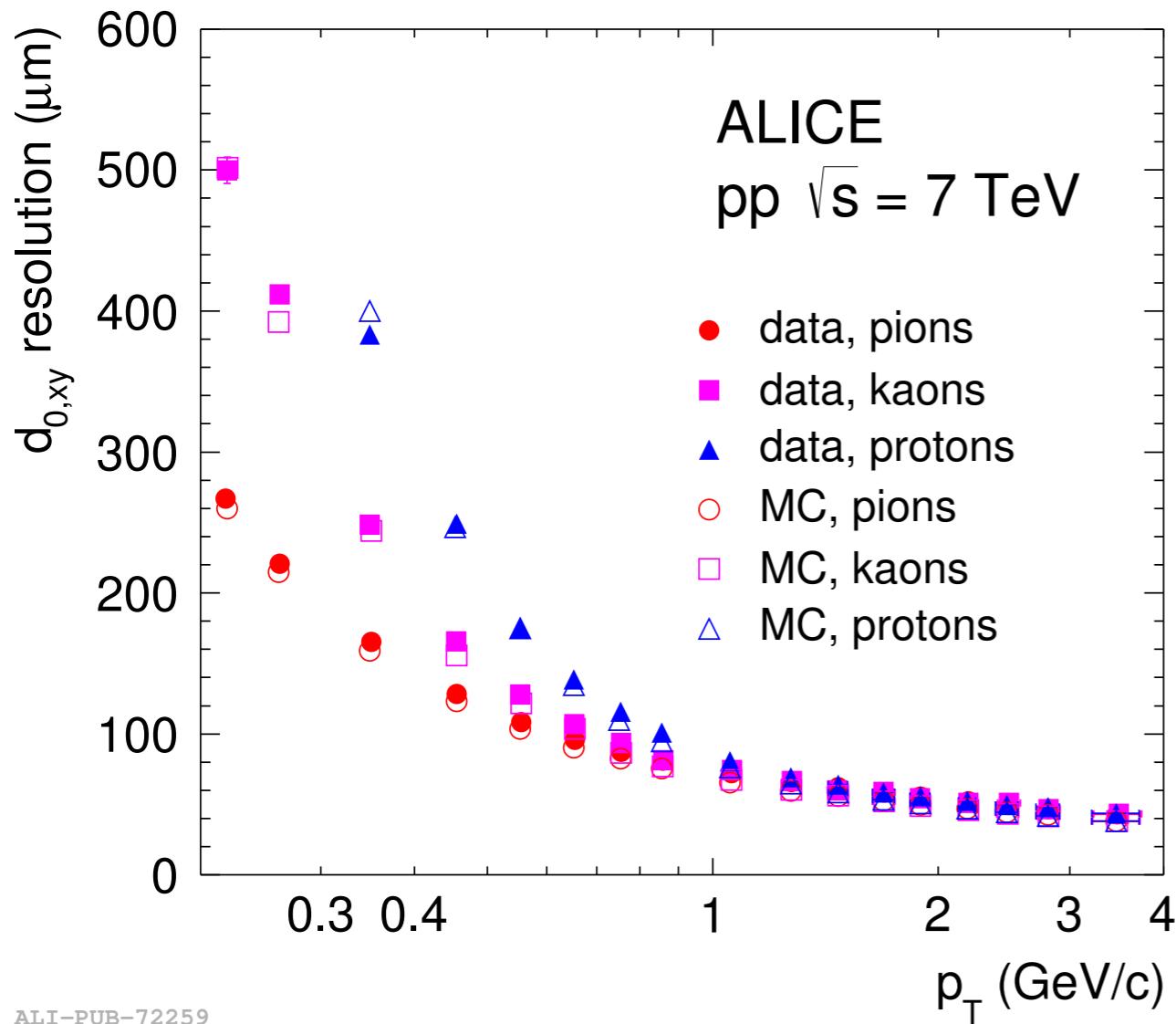
Idea: separate prompt and non-prompt contributions using pair vertex position

- Tracks from D or B decays ($c\tau \sim 100-500$ μm) do not point back to event vertex
- Observable: $DCA_{ee} = \sqrt{\frac{DCA_1^2 + DCA_2^2}{2}}$ (DCA_i - Distance of Closest Approach of track i)
- Obtain DCA_{ee} templates from MC, normalise to cocktail and compare with data

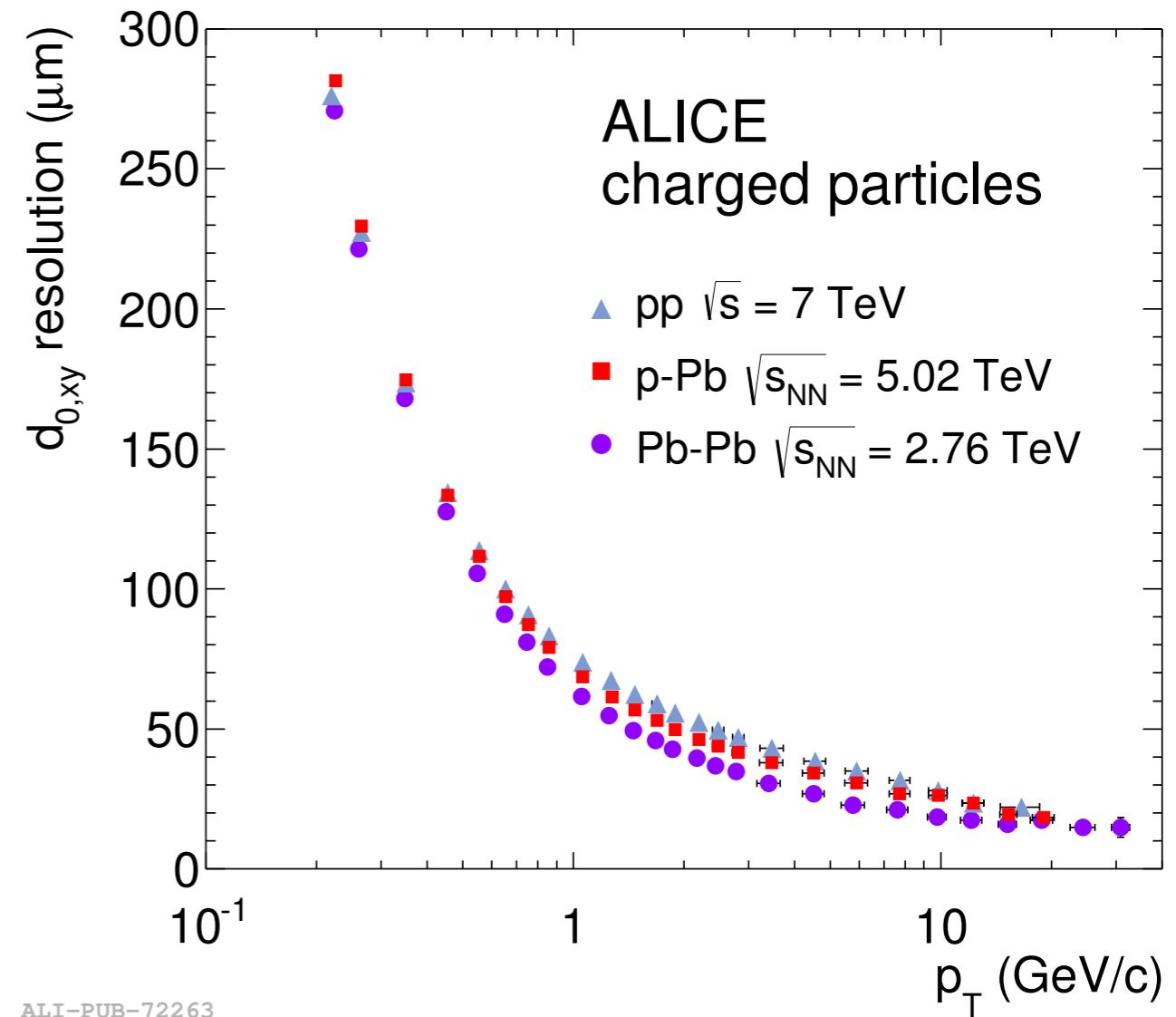


pp $\sqrt{s} = 7$ TeV: DCA resolution

- 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

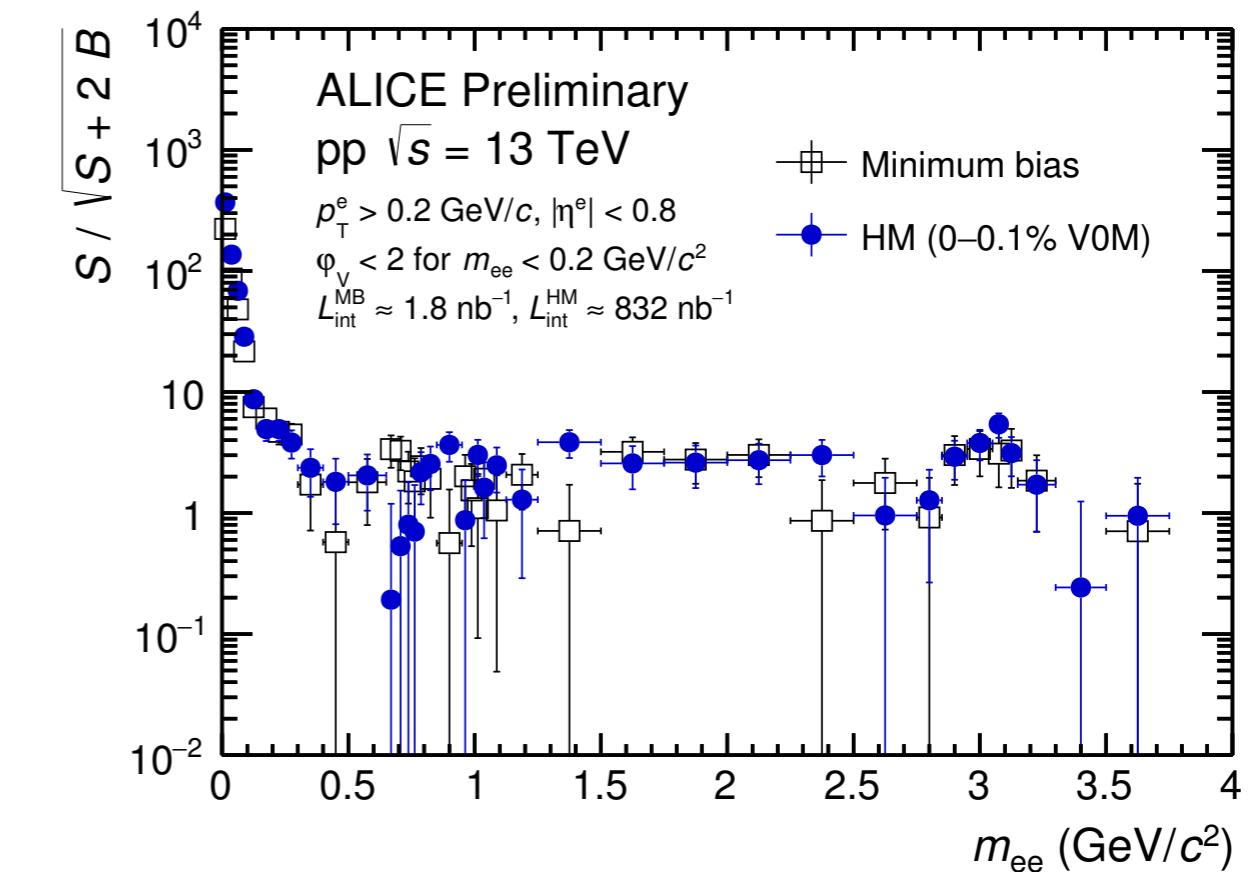
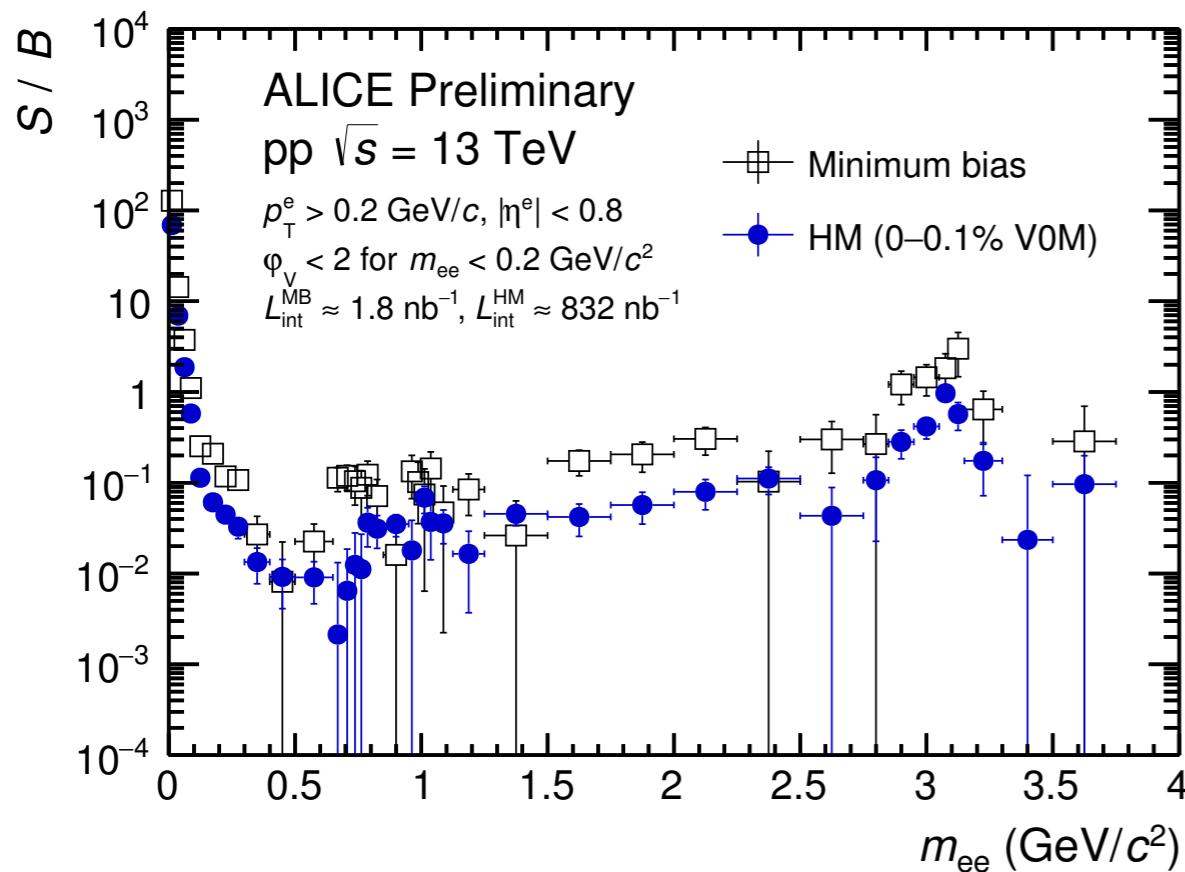


ALI-PUB-72263

pp $\sqrt{s} = 13$ TeV: S / B and significance

Naive expectation: signal is proportional to N_{ch} , combinatorial background grows like N_{ch}^2

- Signal / background ratio is lower for high multiplicity events
- Significance is comparable in background-dominated mass region

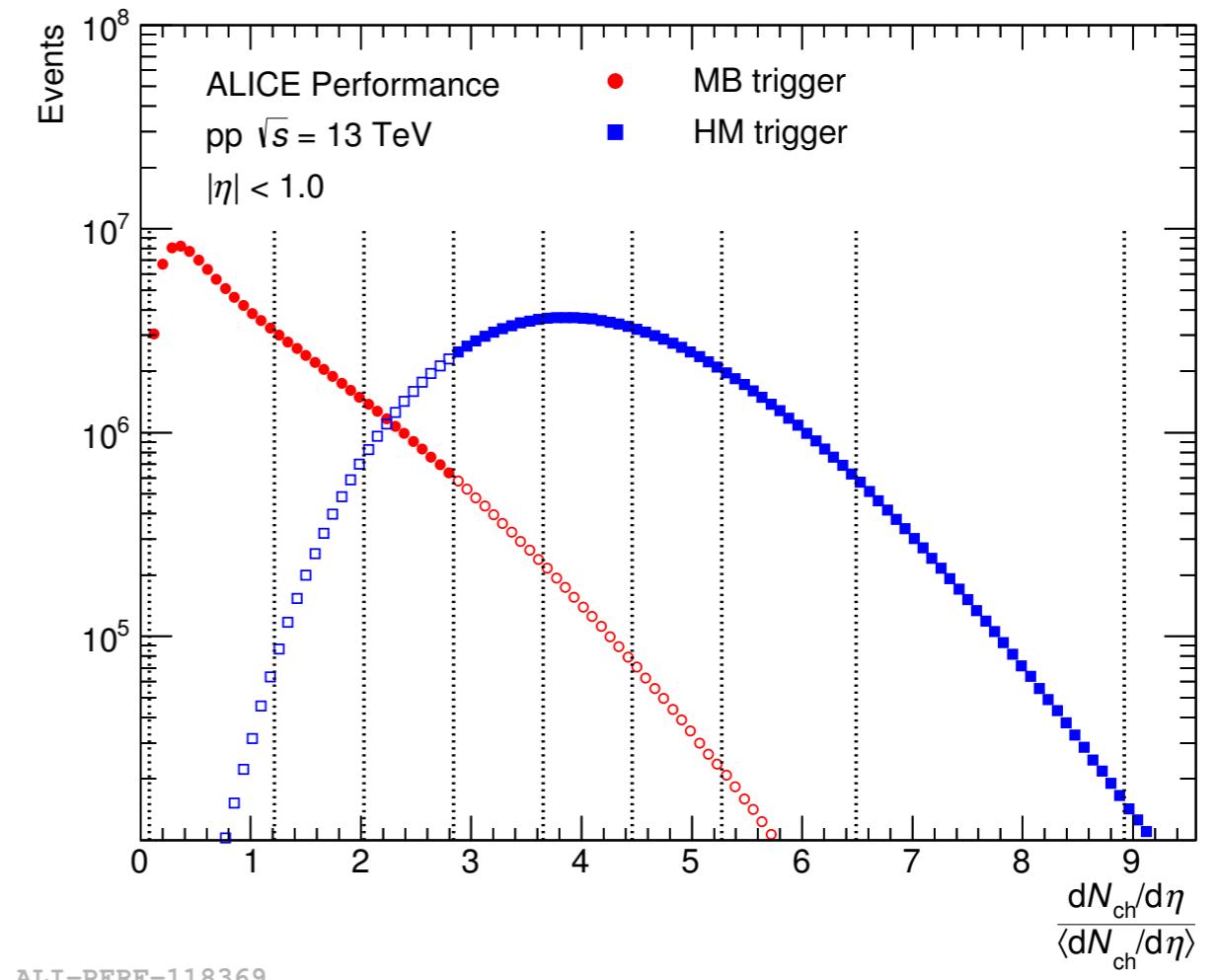
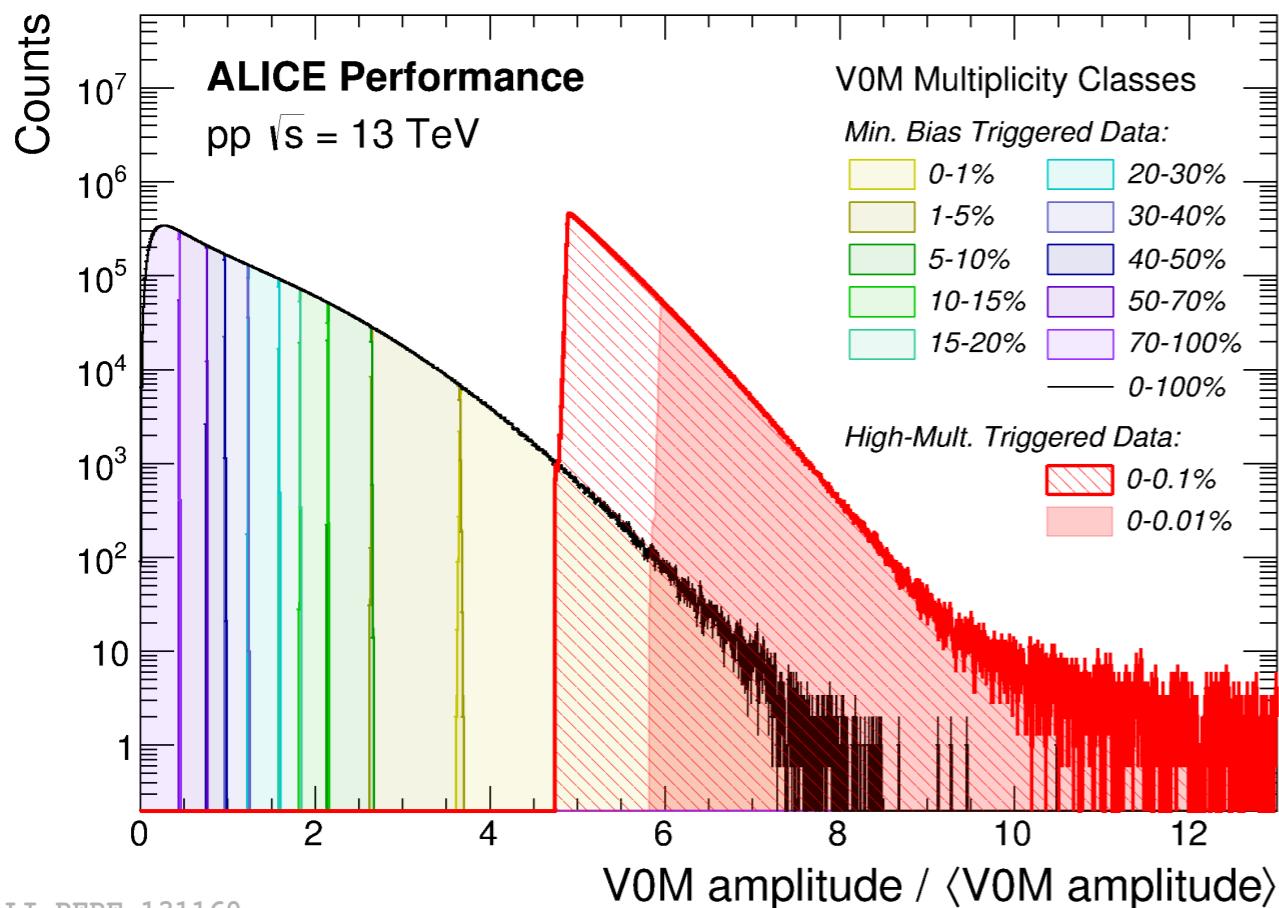


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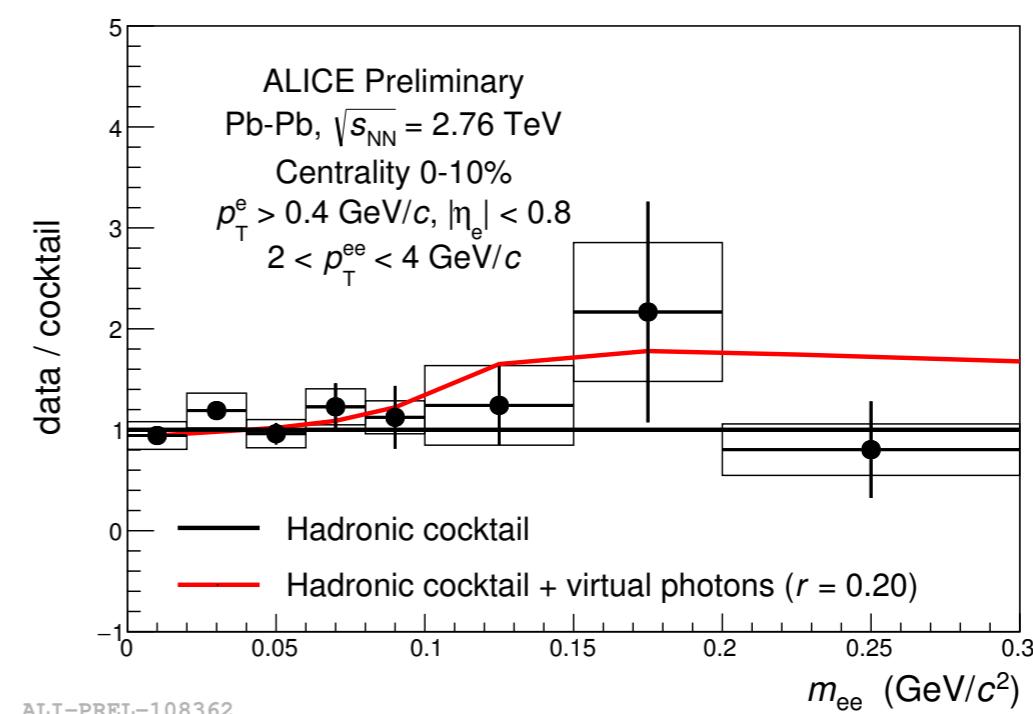
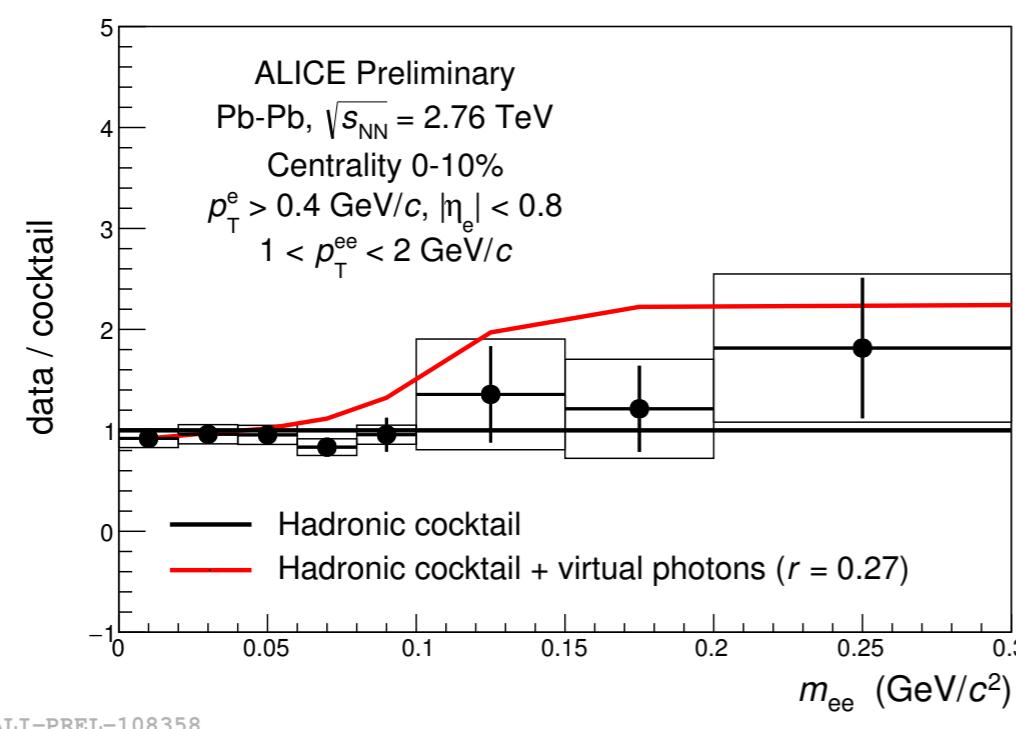
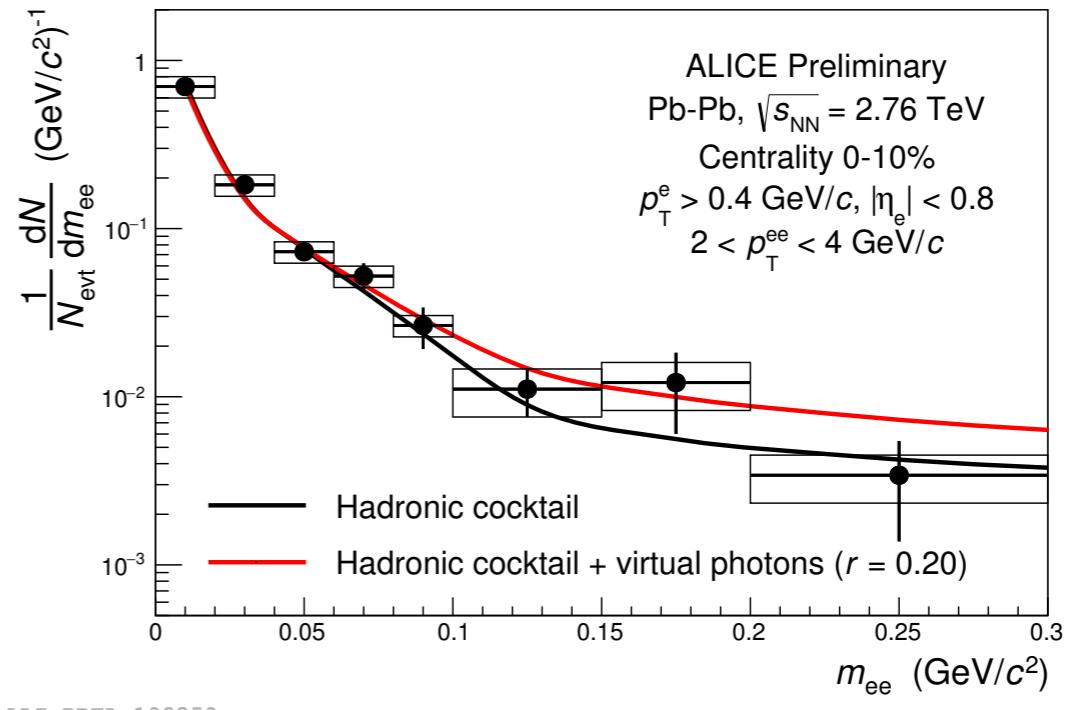
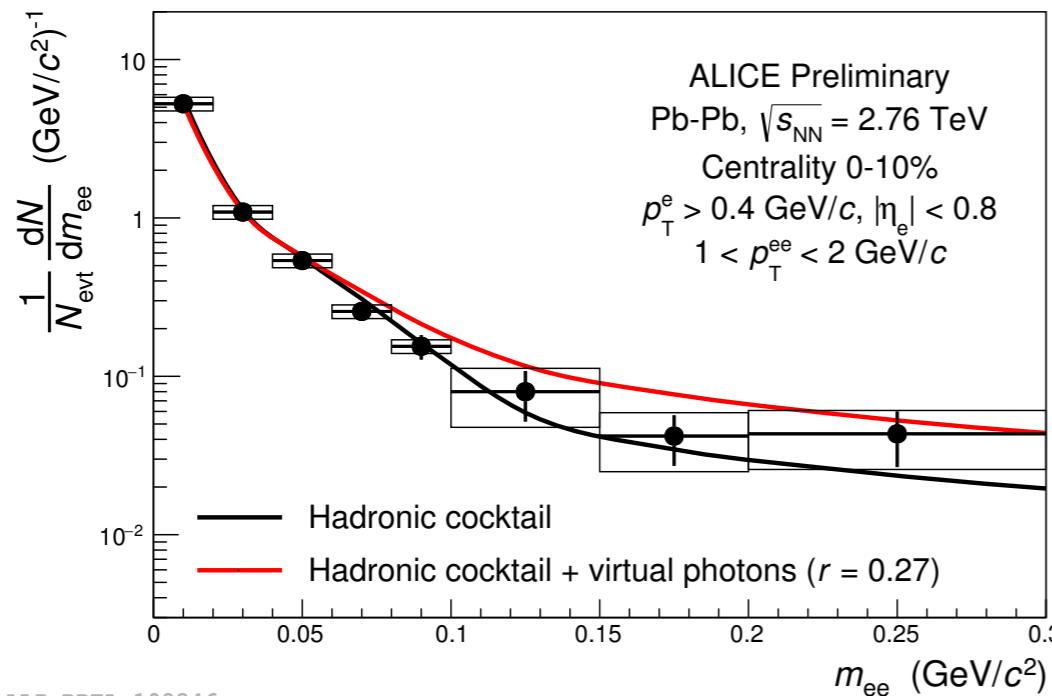
ALI-PREL-119633

pp $\sqrt{s} = 13$ TeV: MB and HM triggers

- Min. bias trigger: coincidence of V0A & V0C signals (forward rapidity)
- High mult. trigger: coincidence of V0A & V0C signals, threshold on V0M
- $\langle N_{\text{ch}}^{\text{acc}}(\text{HM}) \rangle / \langle N_{\text{ch}}^{\text{acc}}(\text{MB}) \rangle = 4.36$ (measured at $\eta \sim 0$)



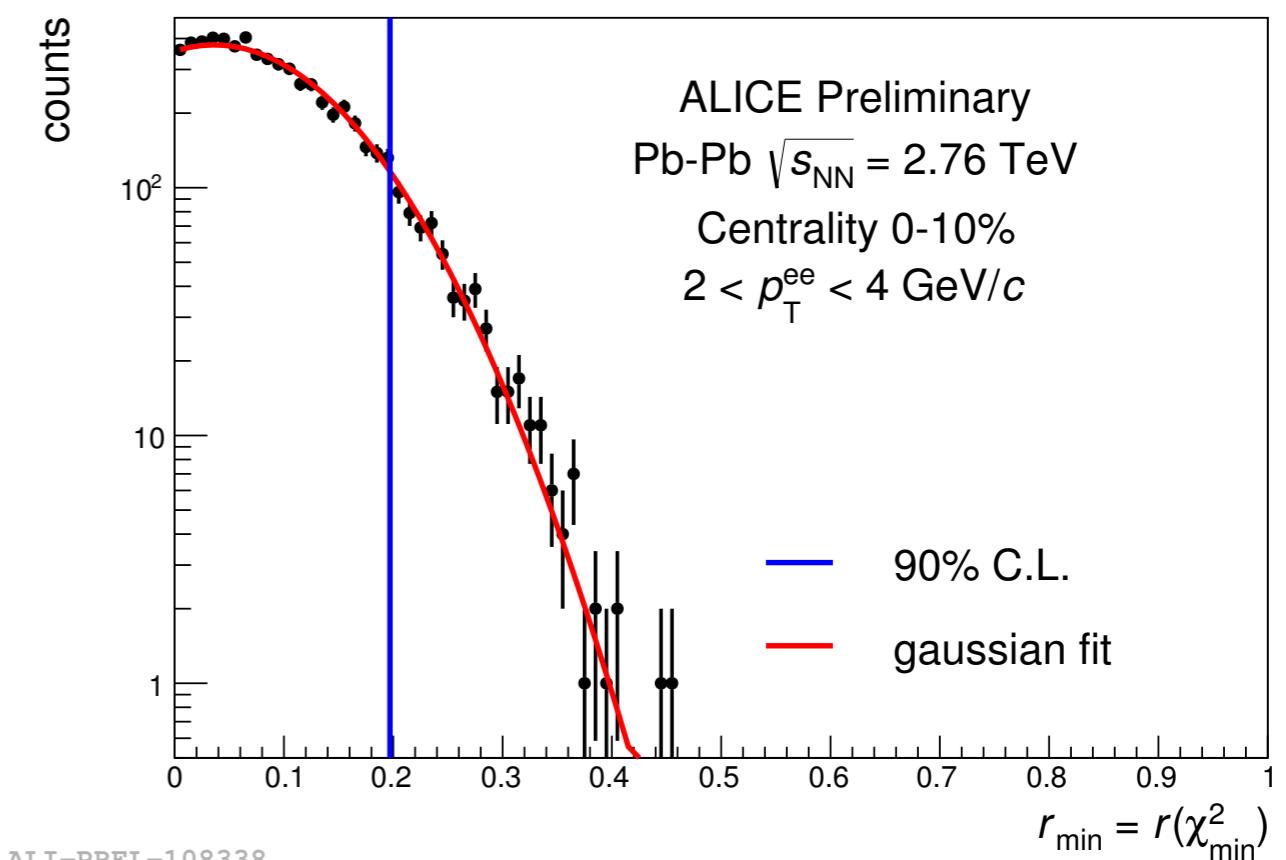
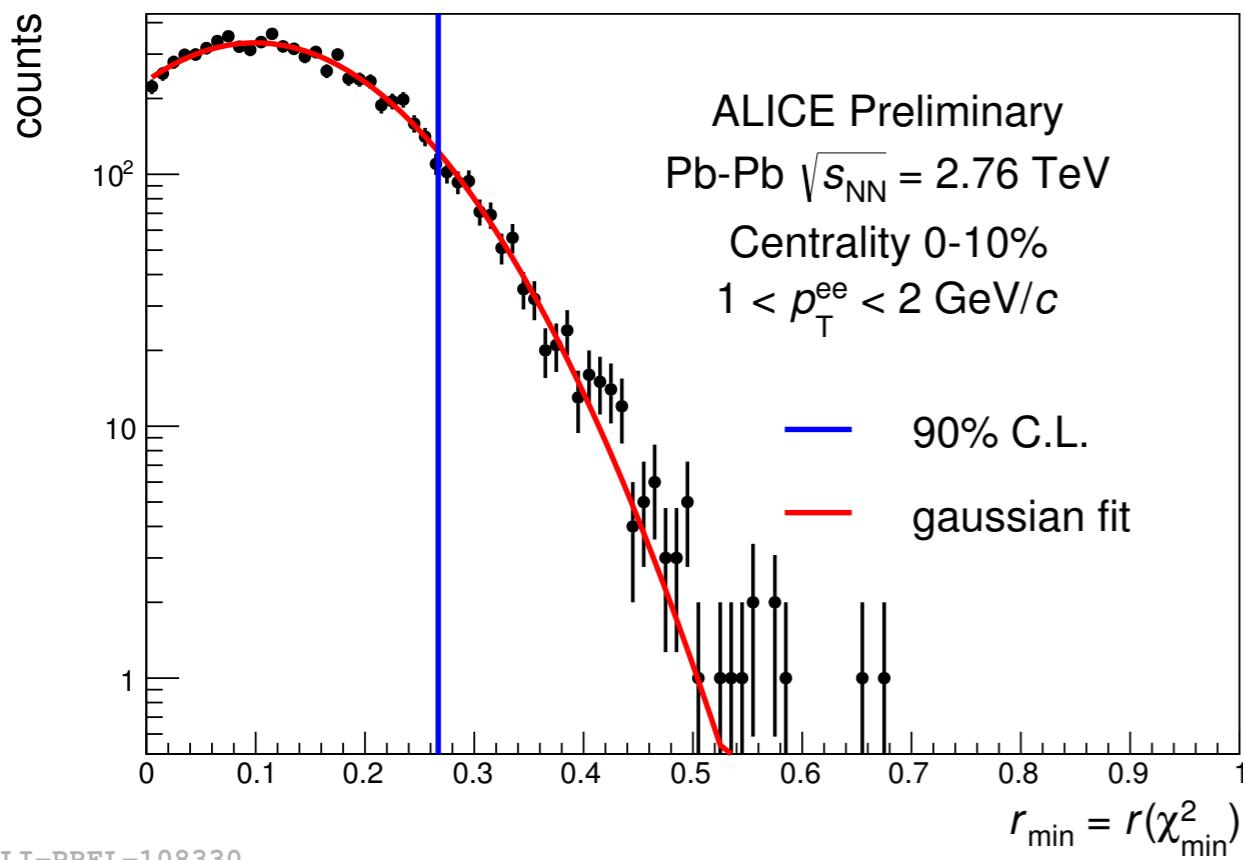
Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV: virtual direct photons



Upper limit on virtual direct photons

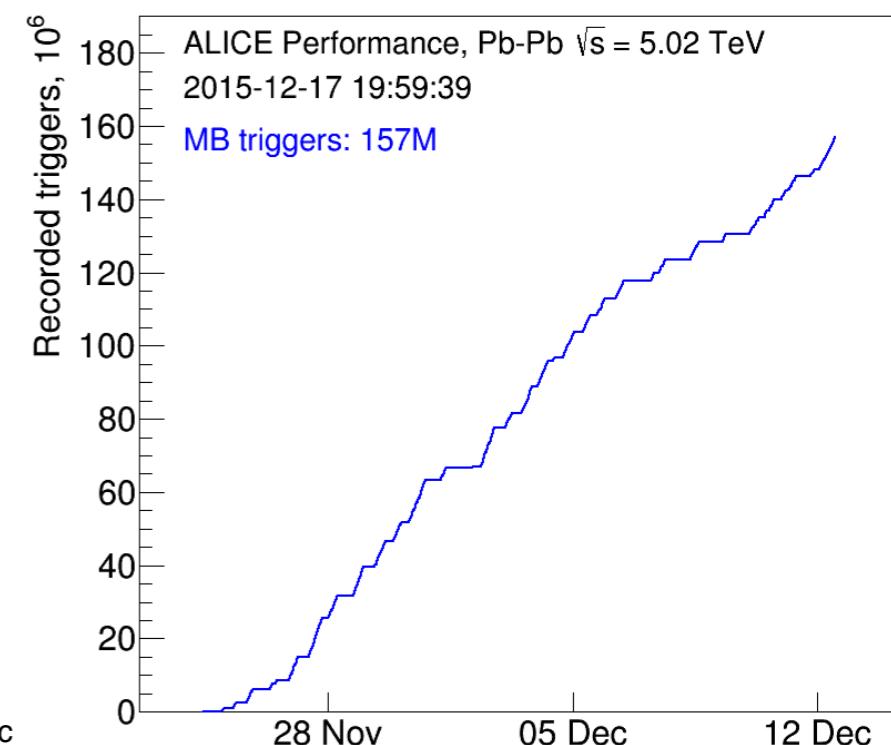
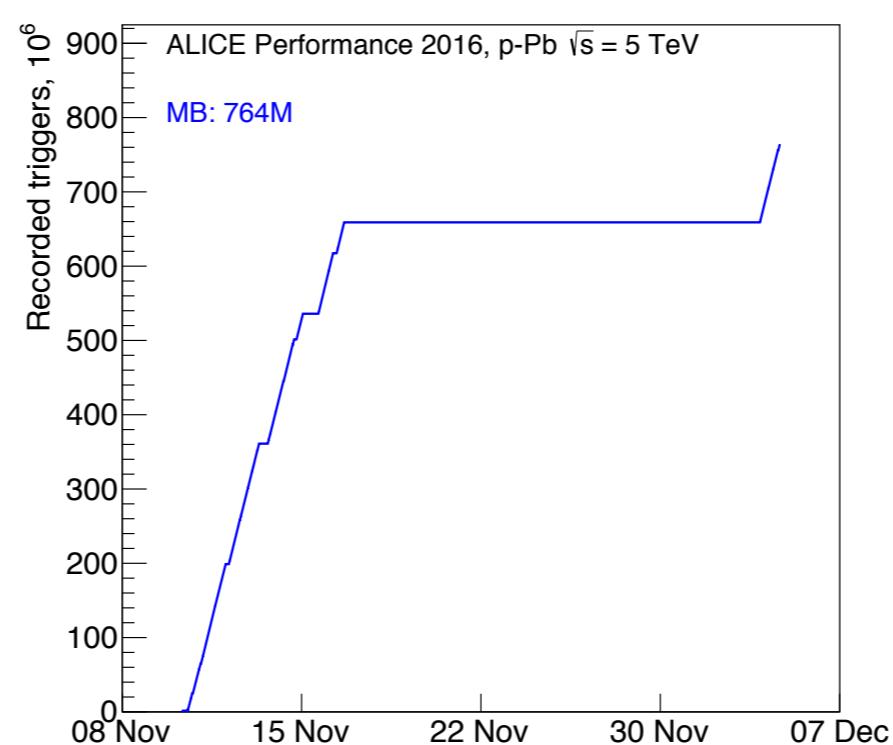
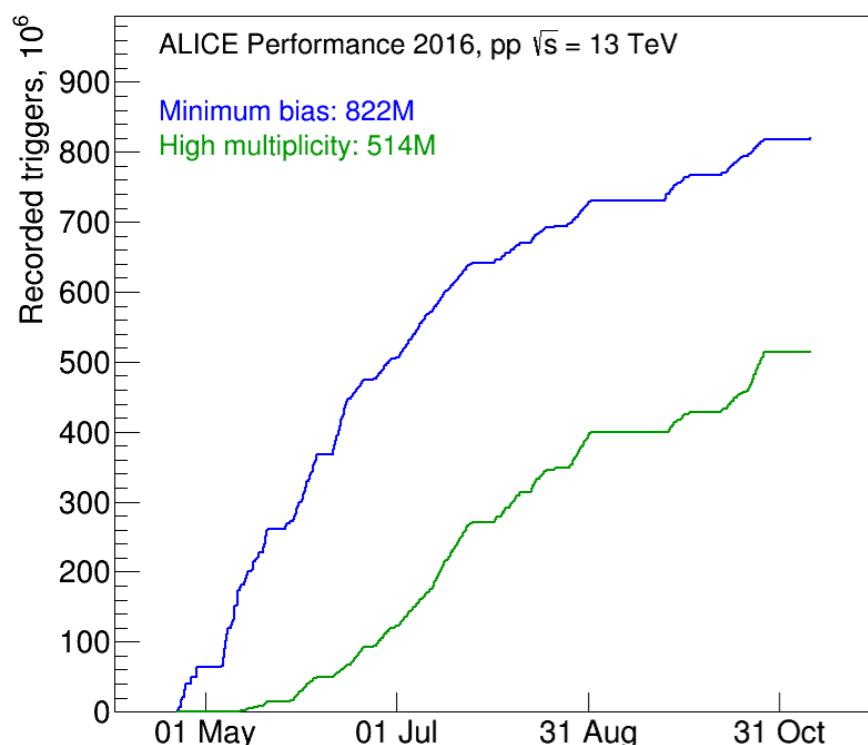
Measure fraction of virtual photons in $N = 10^4$ simulated experiments

- Random sampling of data around best fit curve and moving of data coherently by fraction of their systematic uncertainties
- Upper limit (90% CL) extracted from integration of obtained r distributions



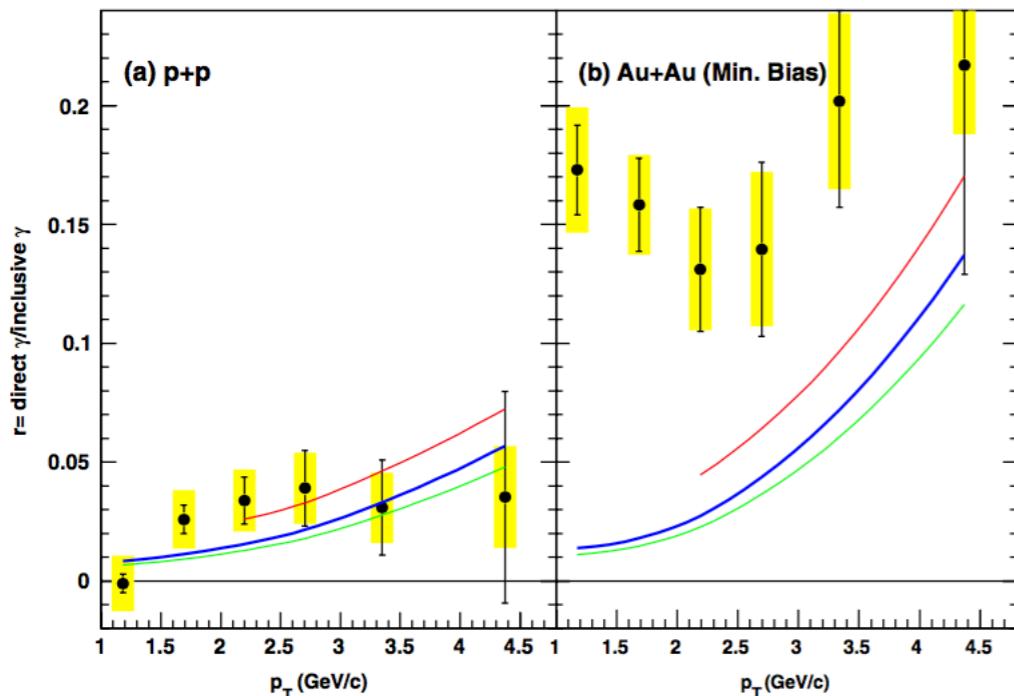
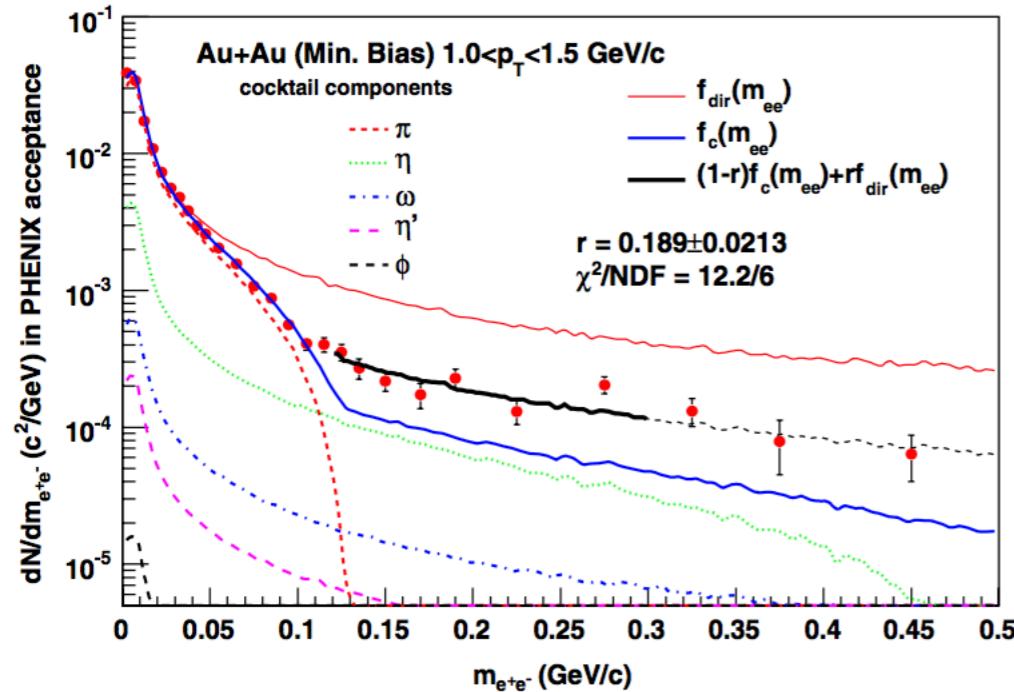
Run 2 collected data

Statistics collected in pp 2016 (13 TeV), p-Pb 2016 (5 TeV) and Pb-Pb 2015 (5 TeV)

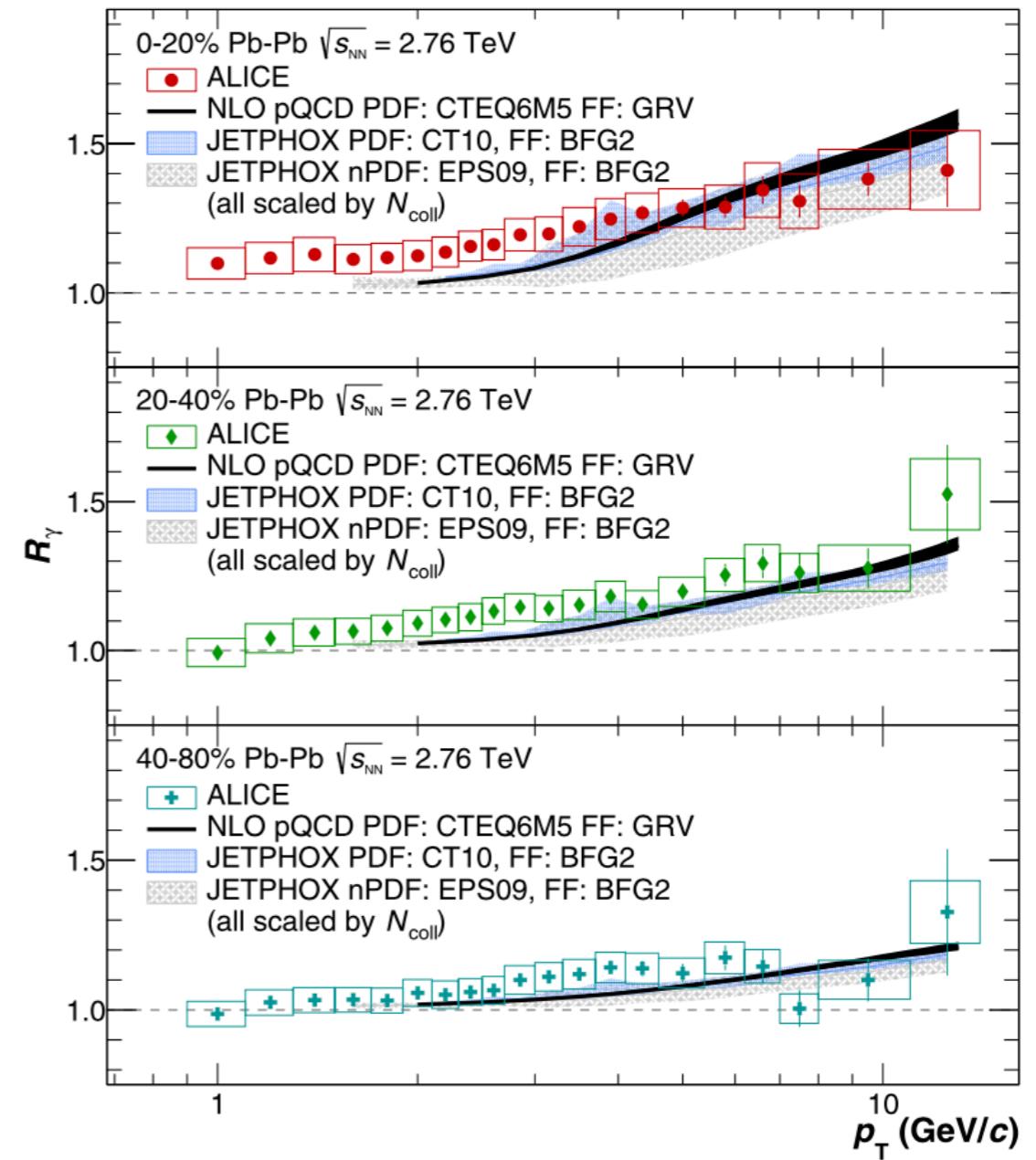


Direct photon results

PHENIX Au-Au 200 GeV [2]



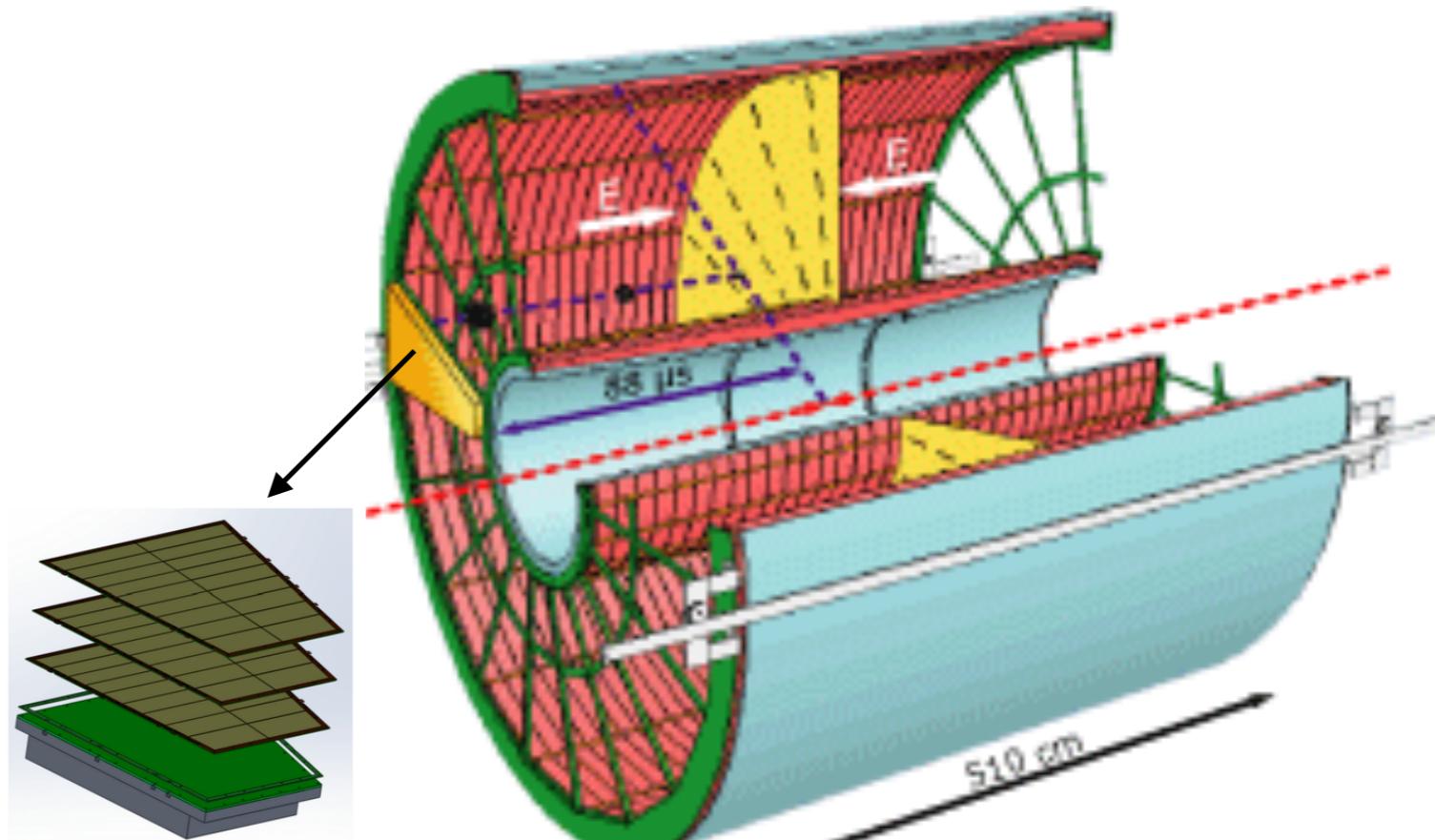
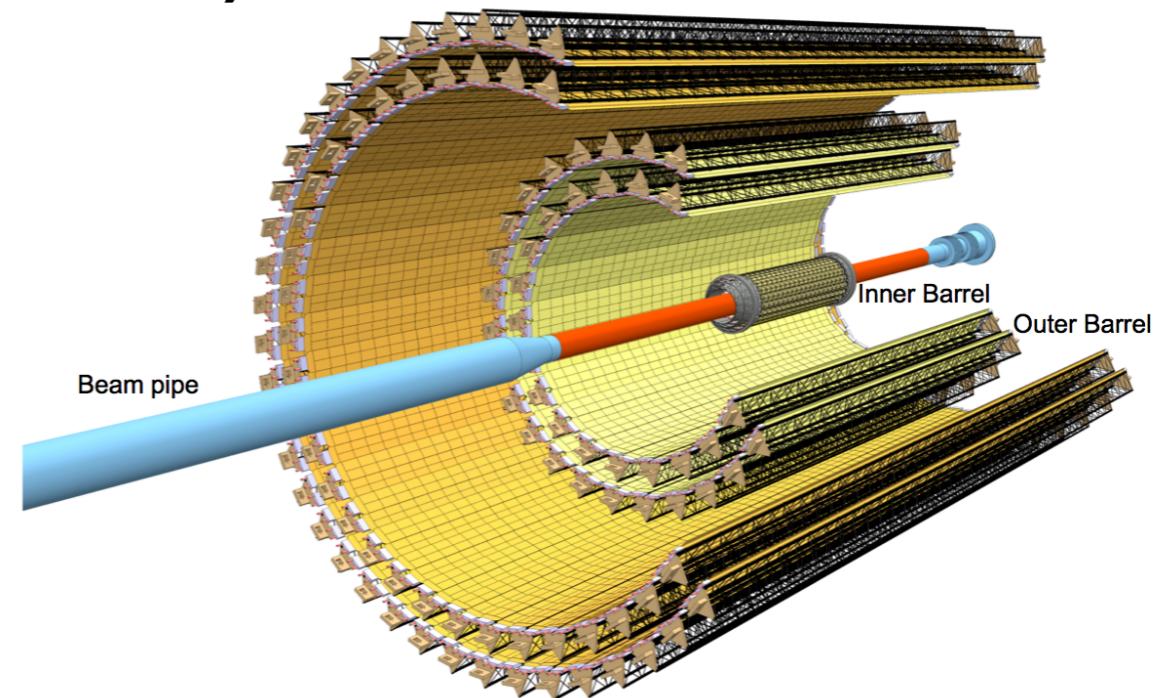
ALICE Pb-Pb 2.76 TeV [1]



ALICE Upgrade for Run 3 (2020-2022)

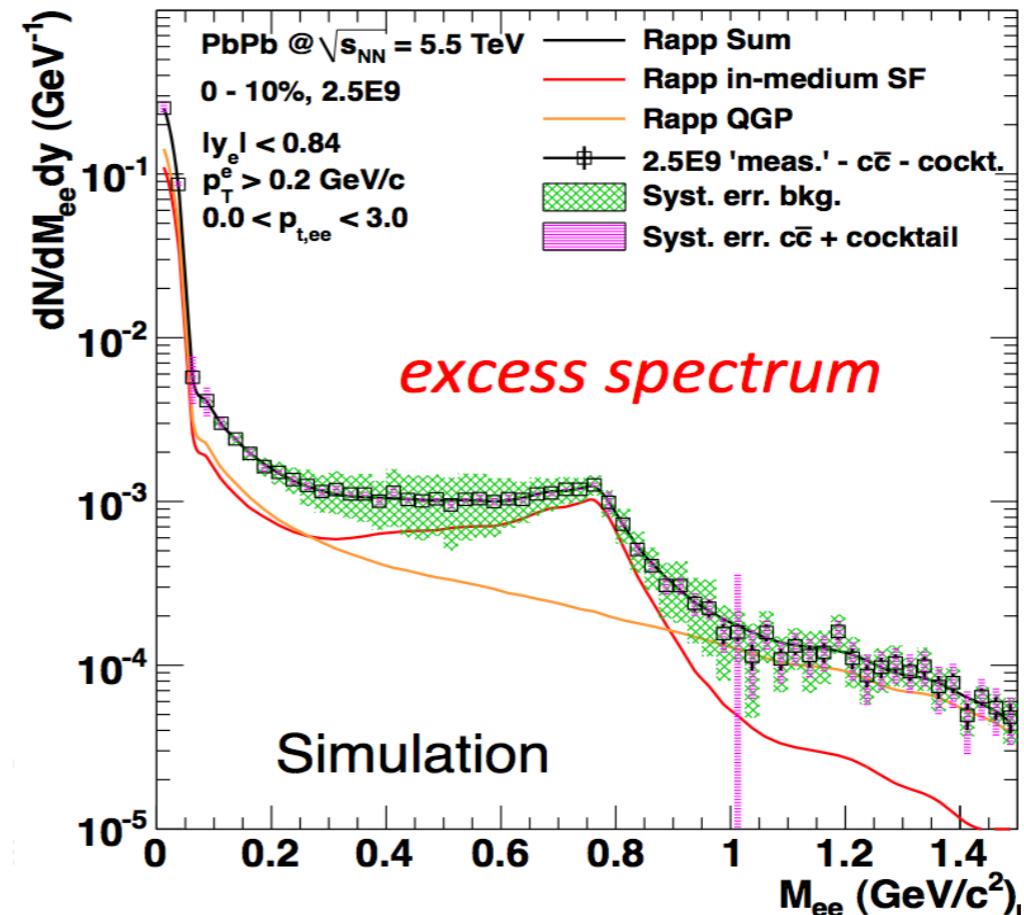
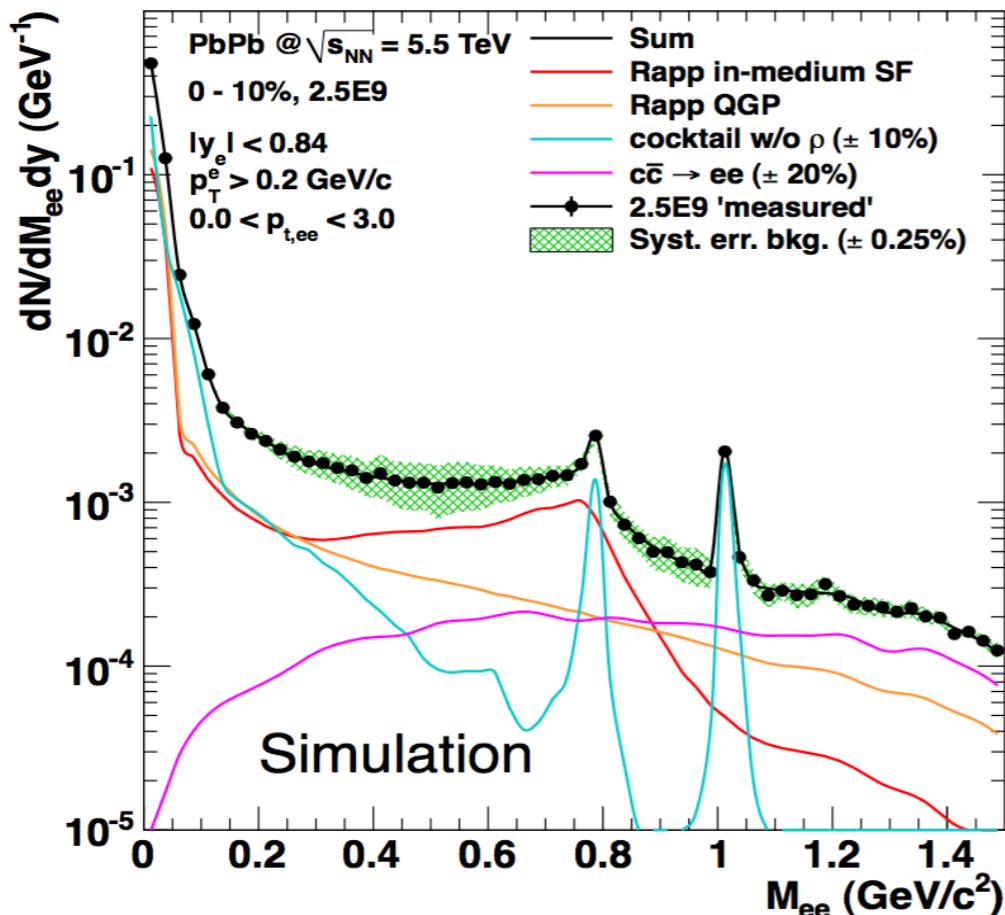
Major upgrades of main tracking systems

- 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