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 with negligible final-state interactions

High-energy heavy-ion collisions:

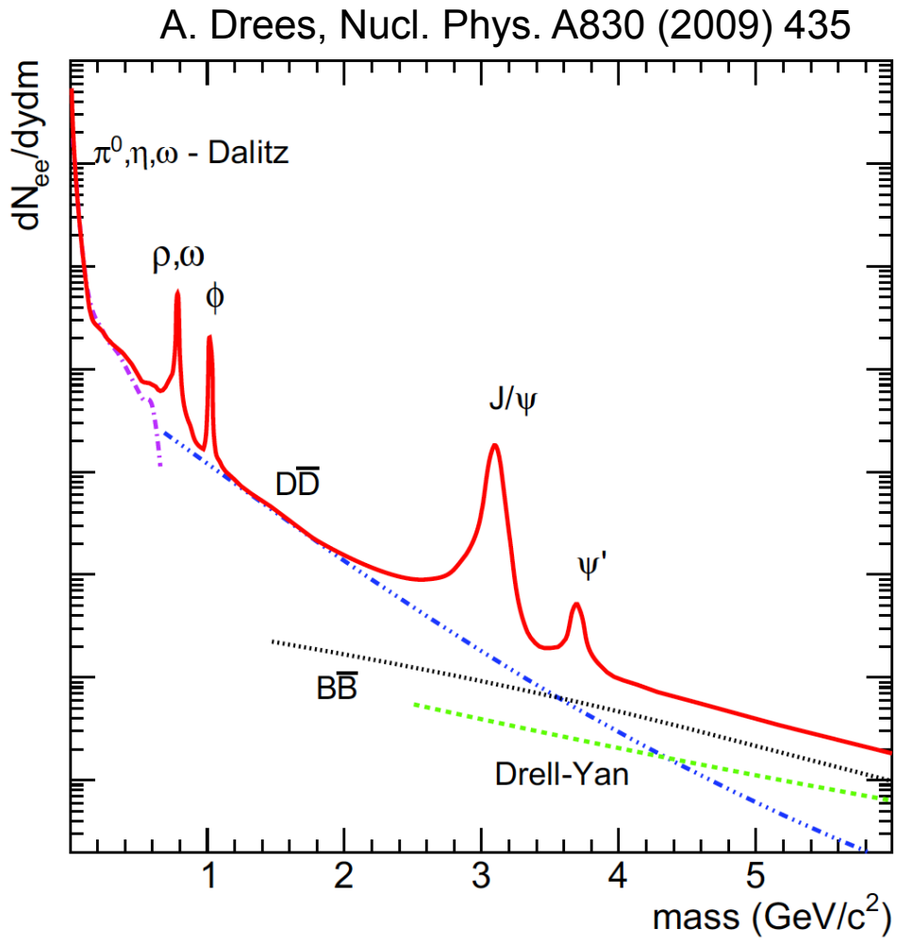
- In-medium modifications of vector mesons
- Thermal radiation from QGP
- Energy loss of correlated heavy flavour quarks

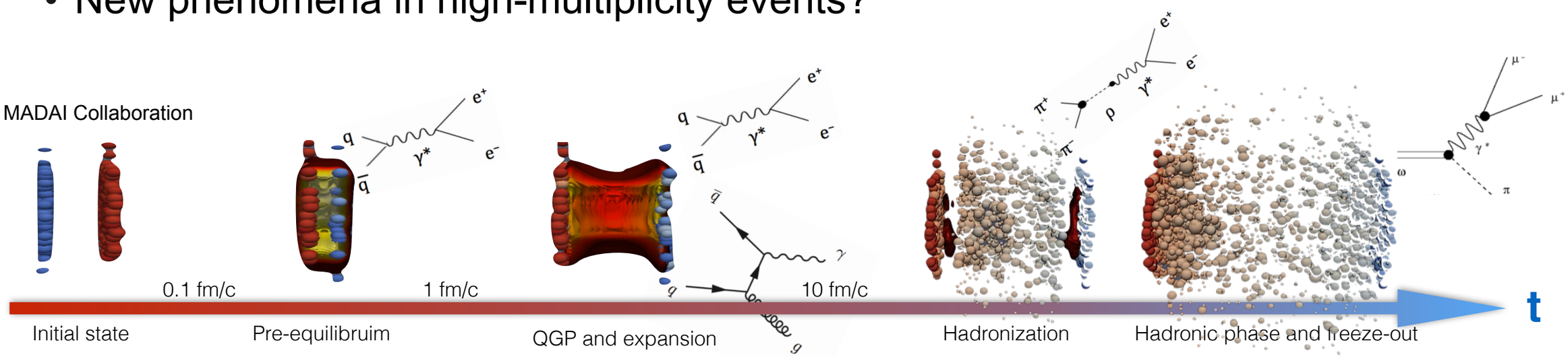
Proton-ion collisions:

- Cold nuclear matter effects

Proton-proton collisions:

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



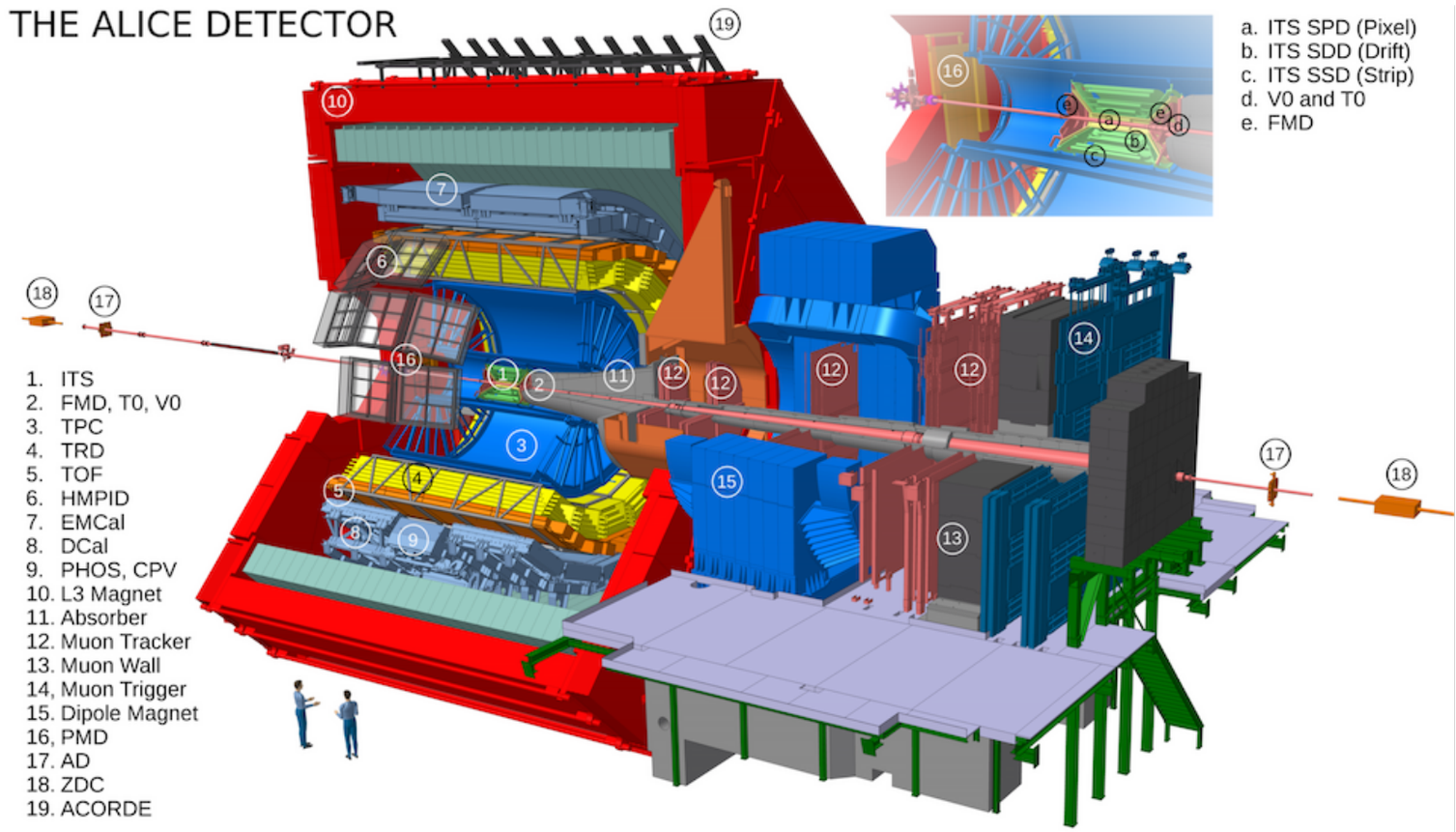


The ALICE Experiment at CERN LHC

Inner **T**racking **S**ystem
- Tracking, vertex, PID (d*E*/d*x*)

Time **P**rojection **C**hamber
- Tracking, PID (d*E*/d*x*)

Time **O**f **F**light detector
- PID (TOF measurement)



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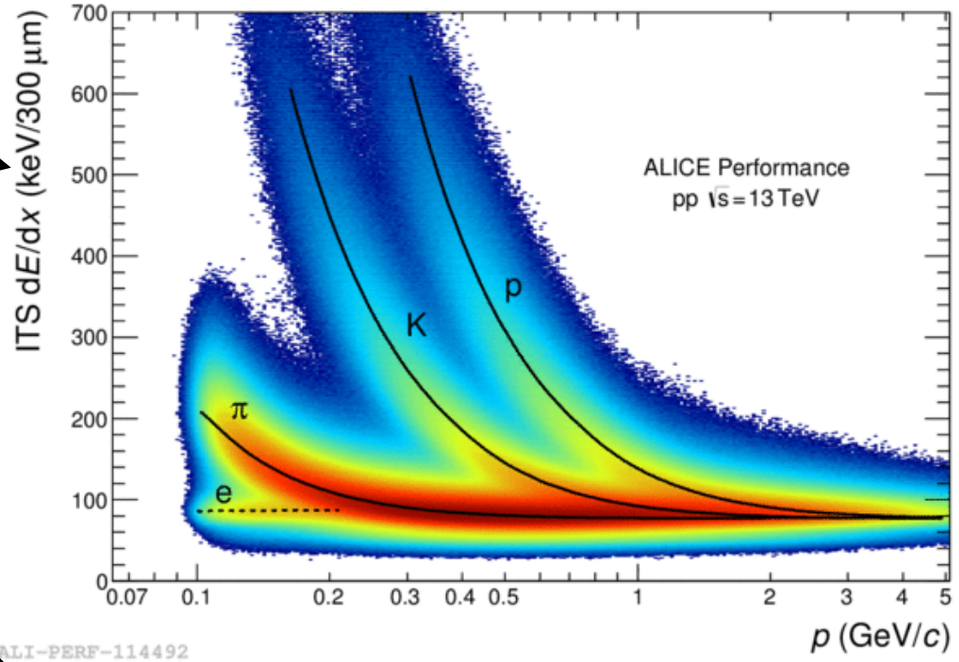

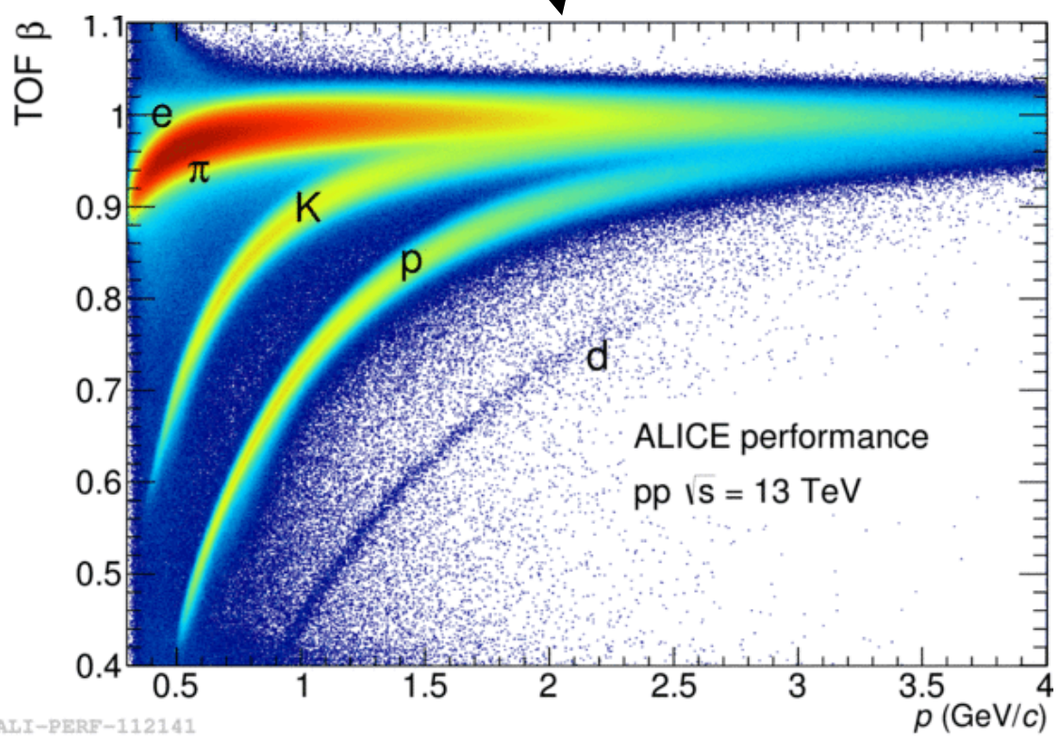

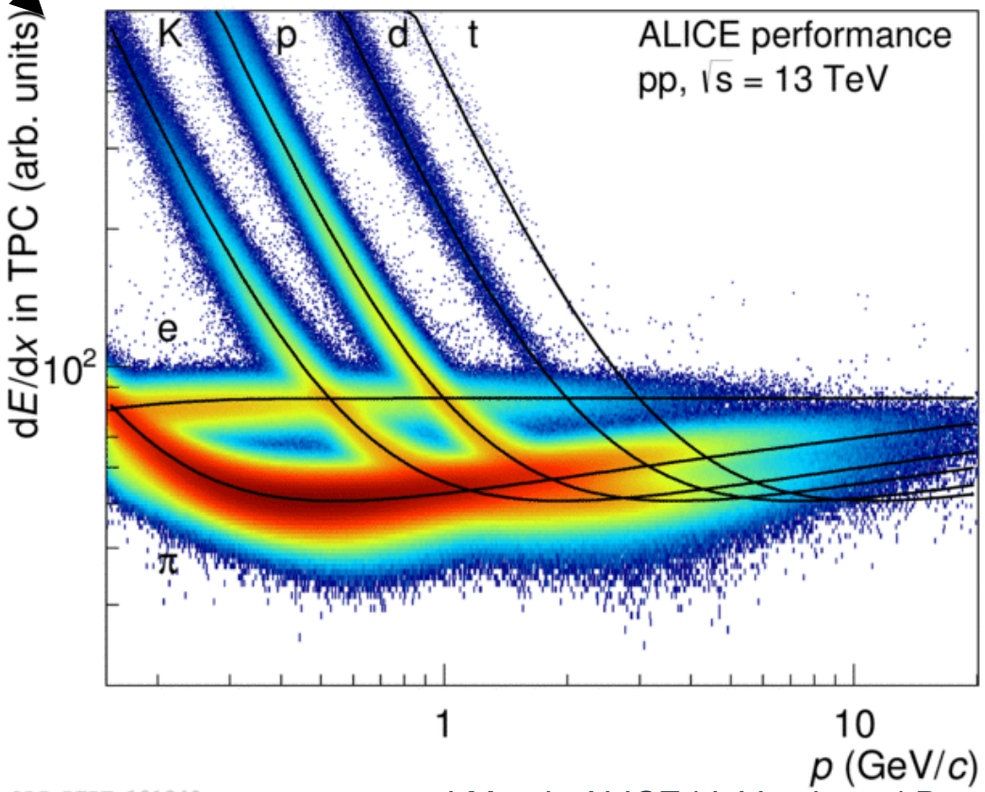

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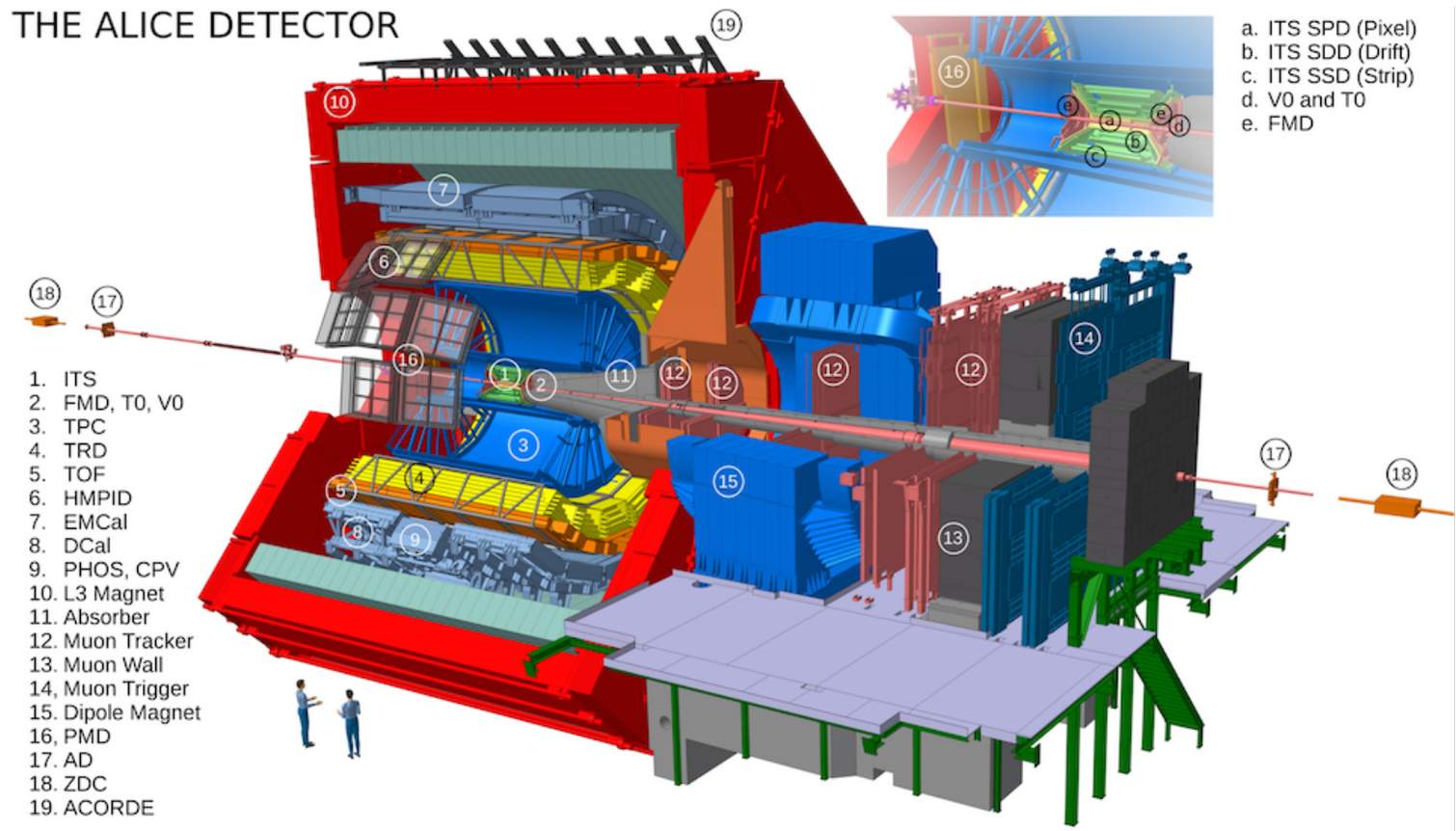
V0 scintillators
- Trigger, centrality estimation



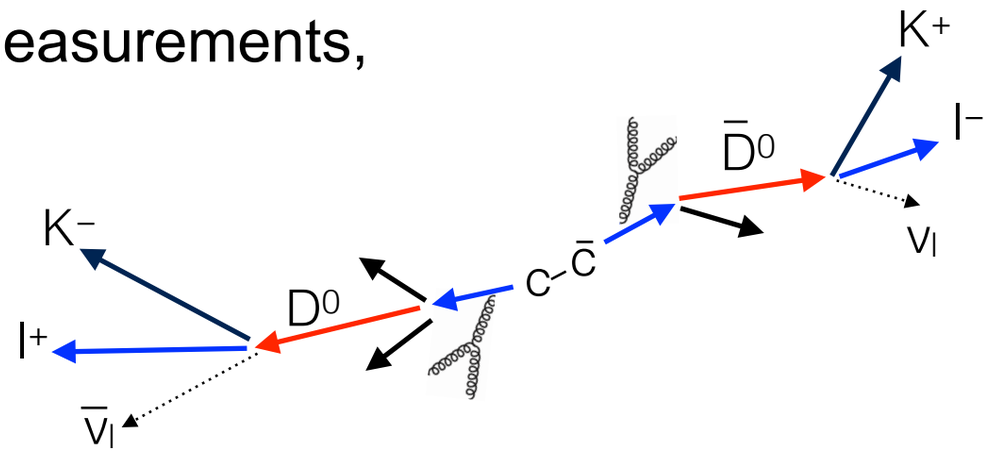
In this talk:

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

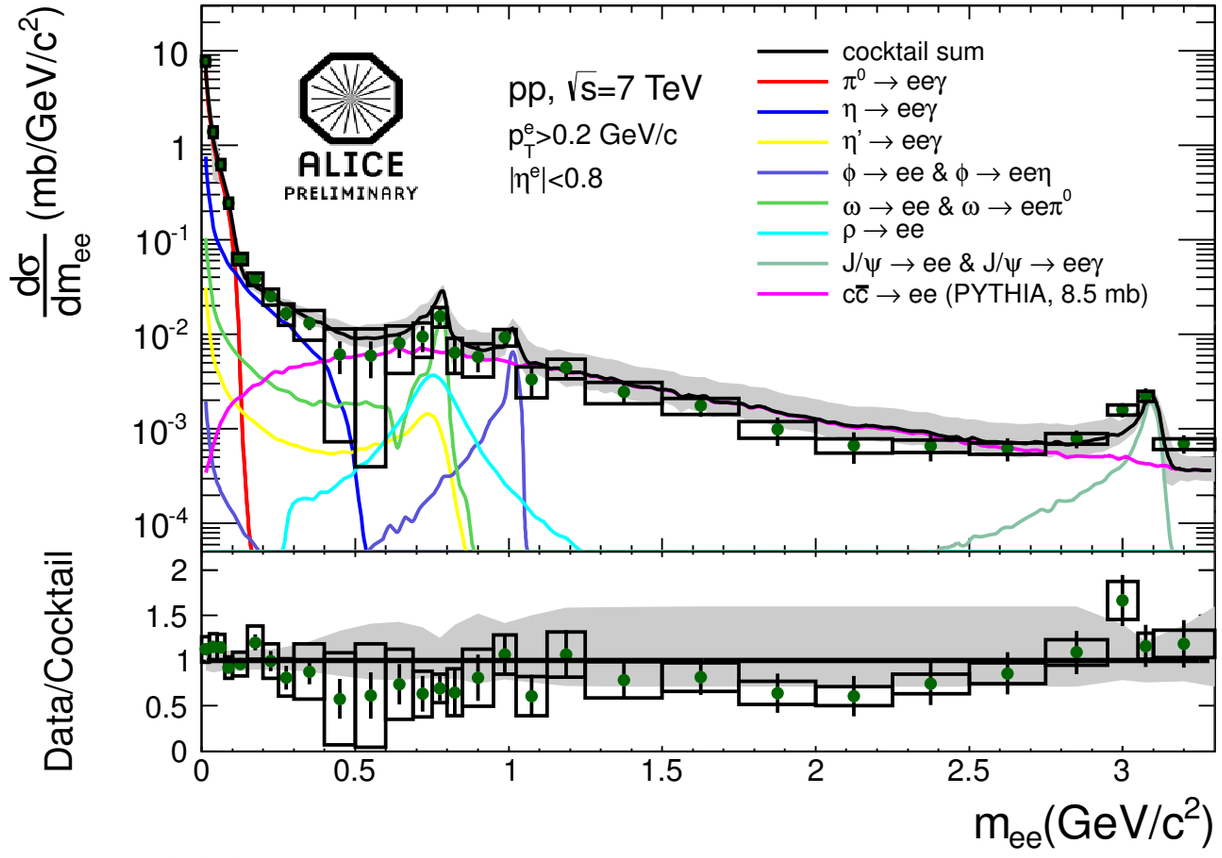
Cocktail of known hadronic sources:

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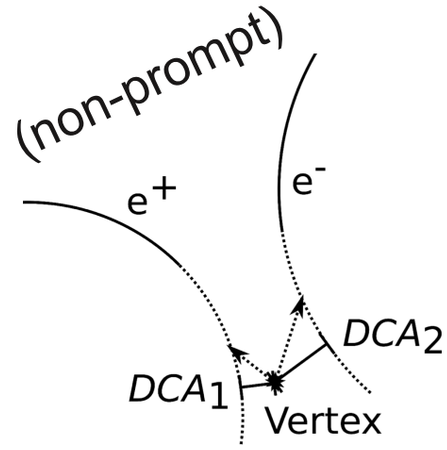
pp $\sqrt{s}$ = 7 TeV: pair DCA analysis

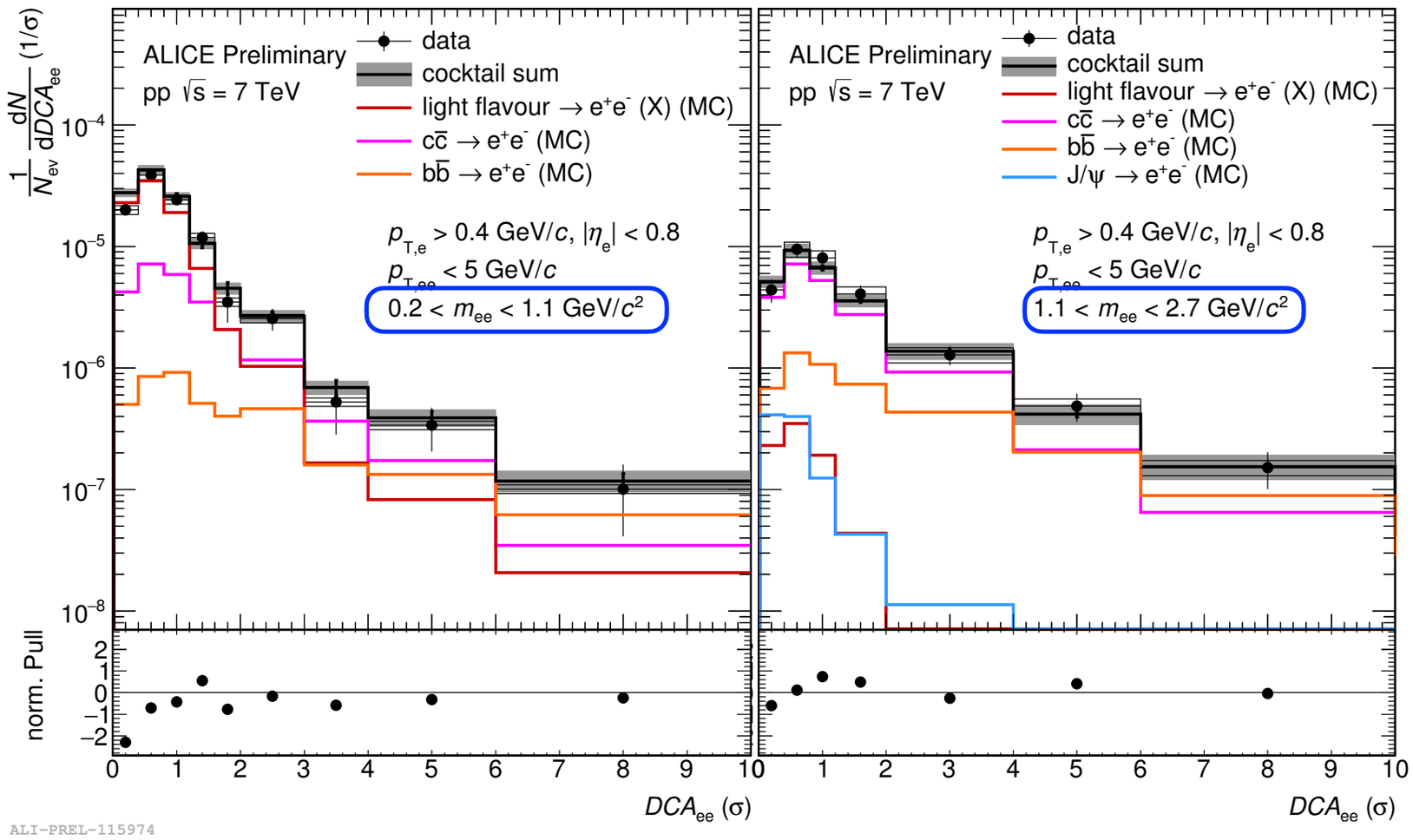
Idea: separate prompt and non-prompt contributions using pair vertex position



- 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 $b\bar{b}$



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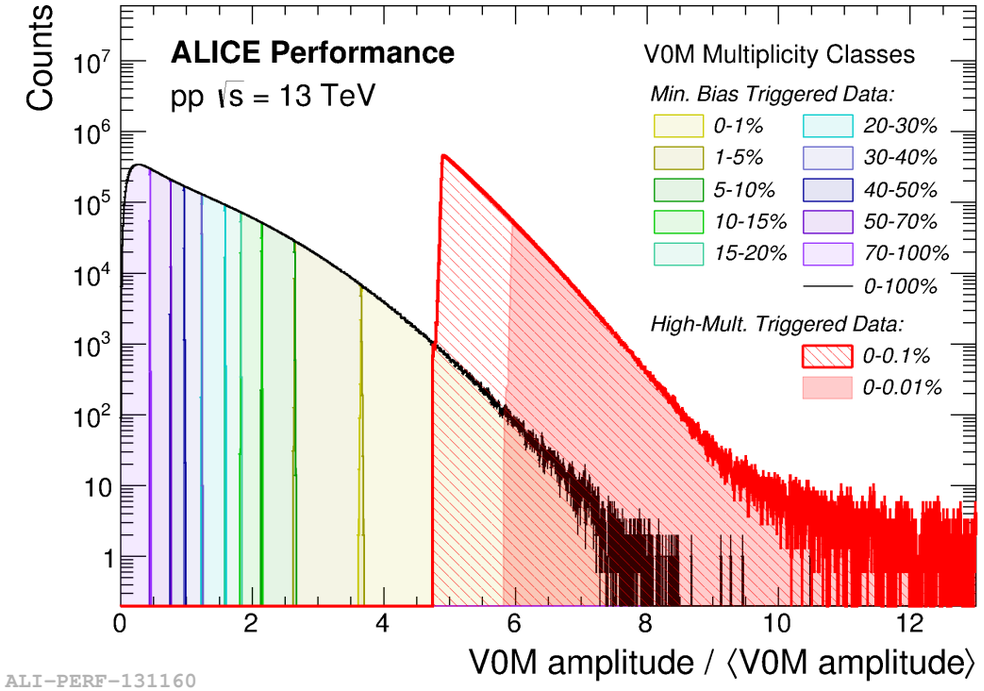
New phenomena in high multiplicity pp events?

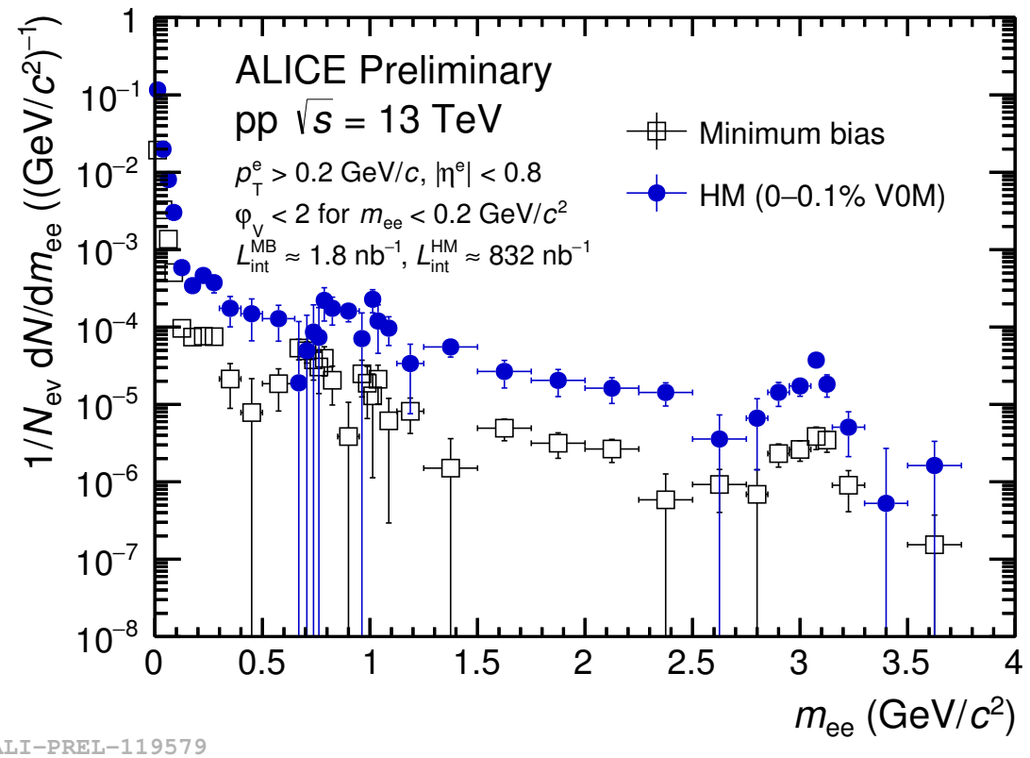
Production / destruction of ρ meson, direct photons, open heavy flavour… ?

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

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

- 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 η ~ 0)
- **Naive expectation** (for light flavour)**: signal ~ N_{ch}**



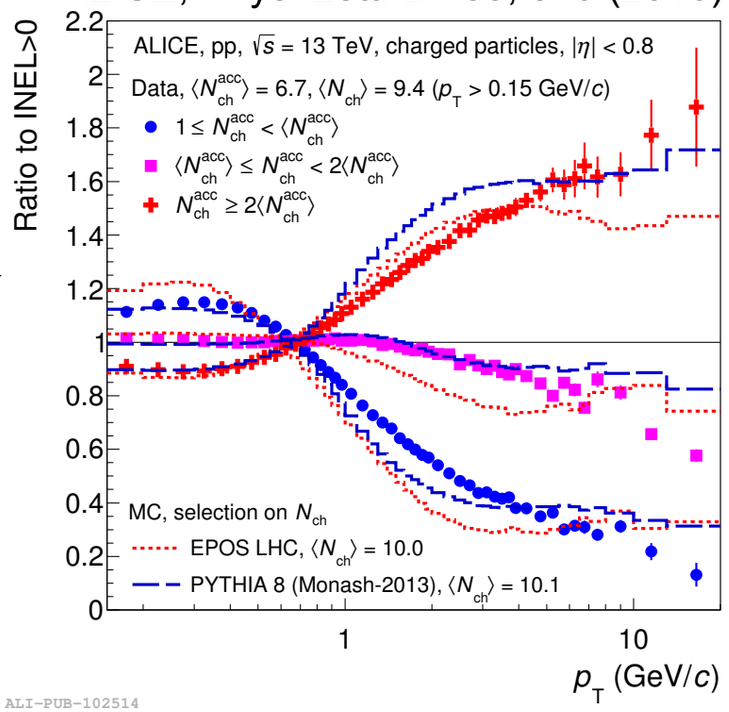


pp $\sqrt{s}$ = 13 TeV: cocktail calculations vs multiplicity

Light-flavour decays:

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

ALICE, Phys. Lett. B 753, 319 (2016)



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

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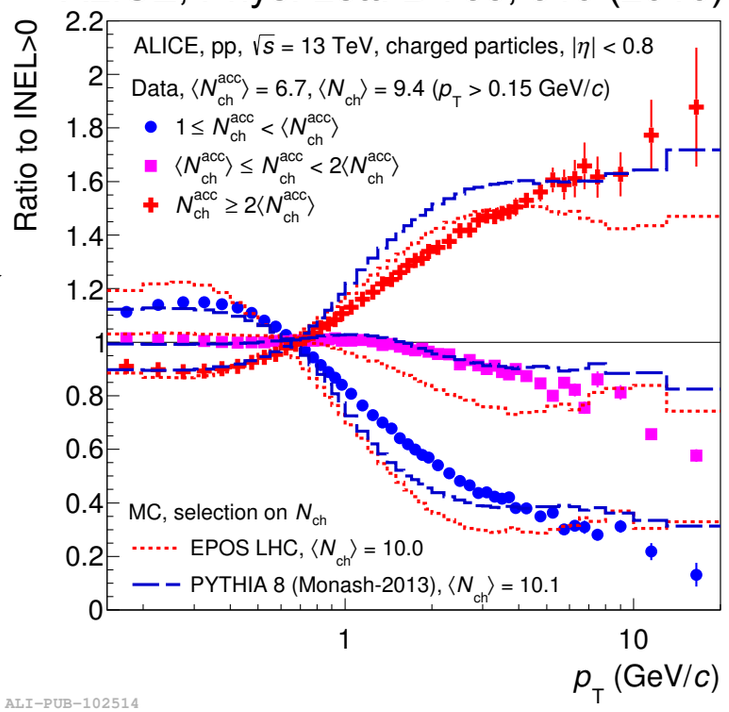
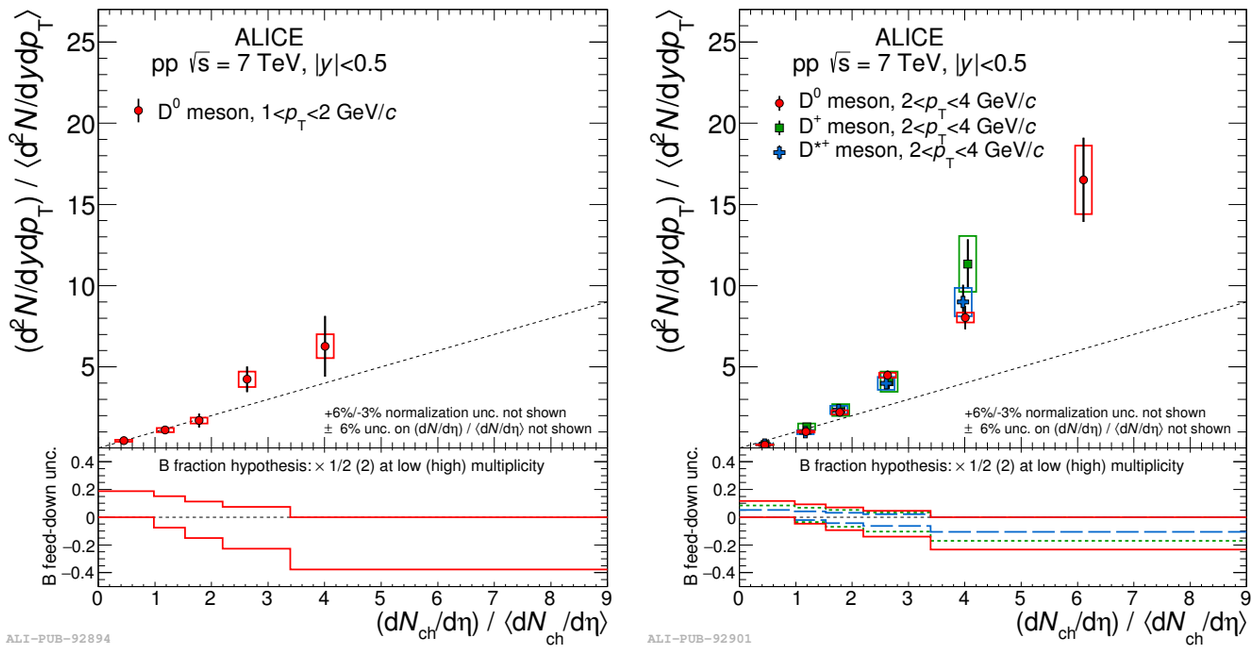


Heavy-flavour contribution:

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

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

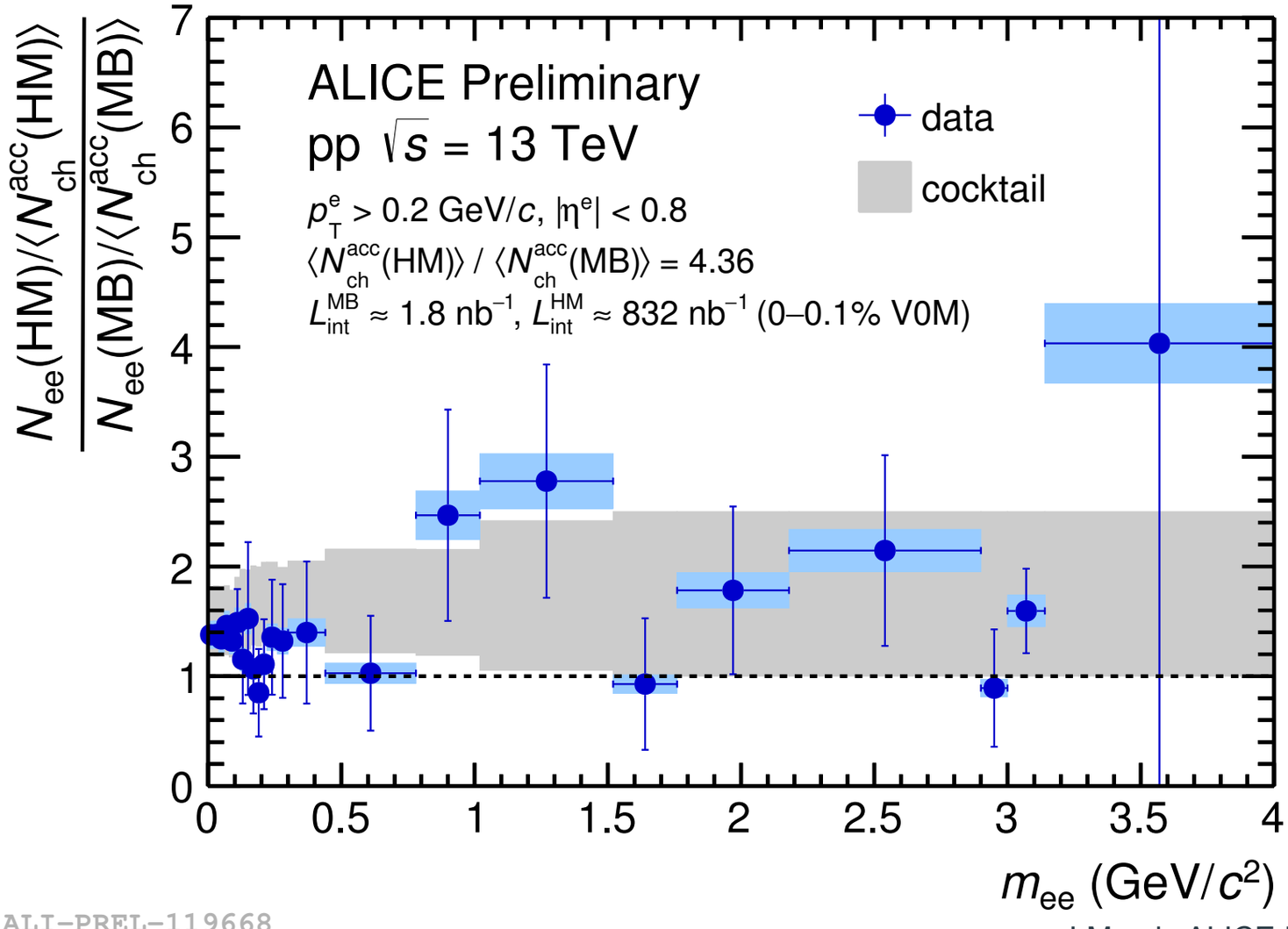
ALICE, JHEP 09, 148 (2015)



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

Results are in agreement with cocktail expectations

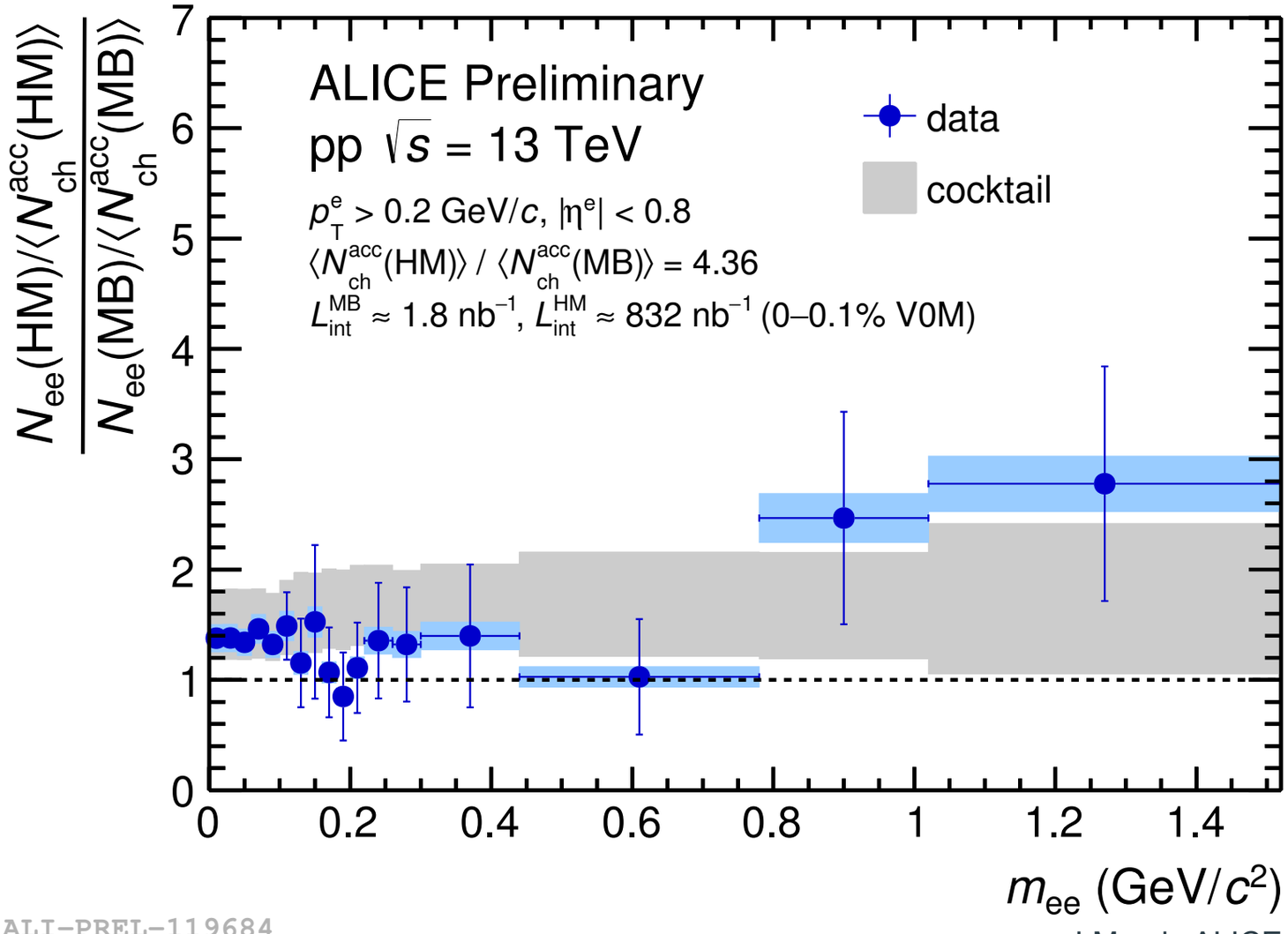
- Intermediate mass: in agreement with D-meson results at 7 TeV



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

Results are in agreement with cocktail expectations

- 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



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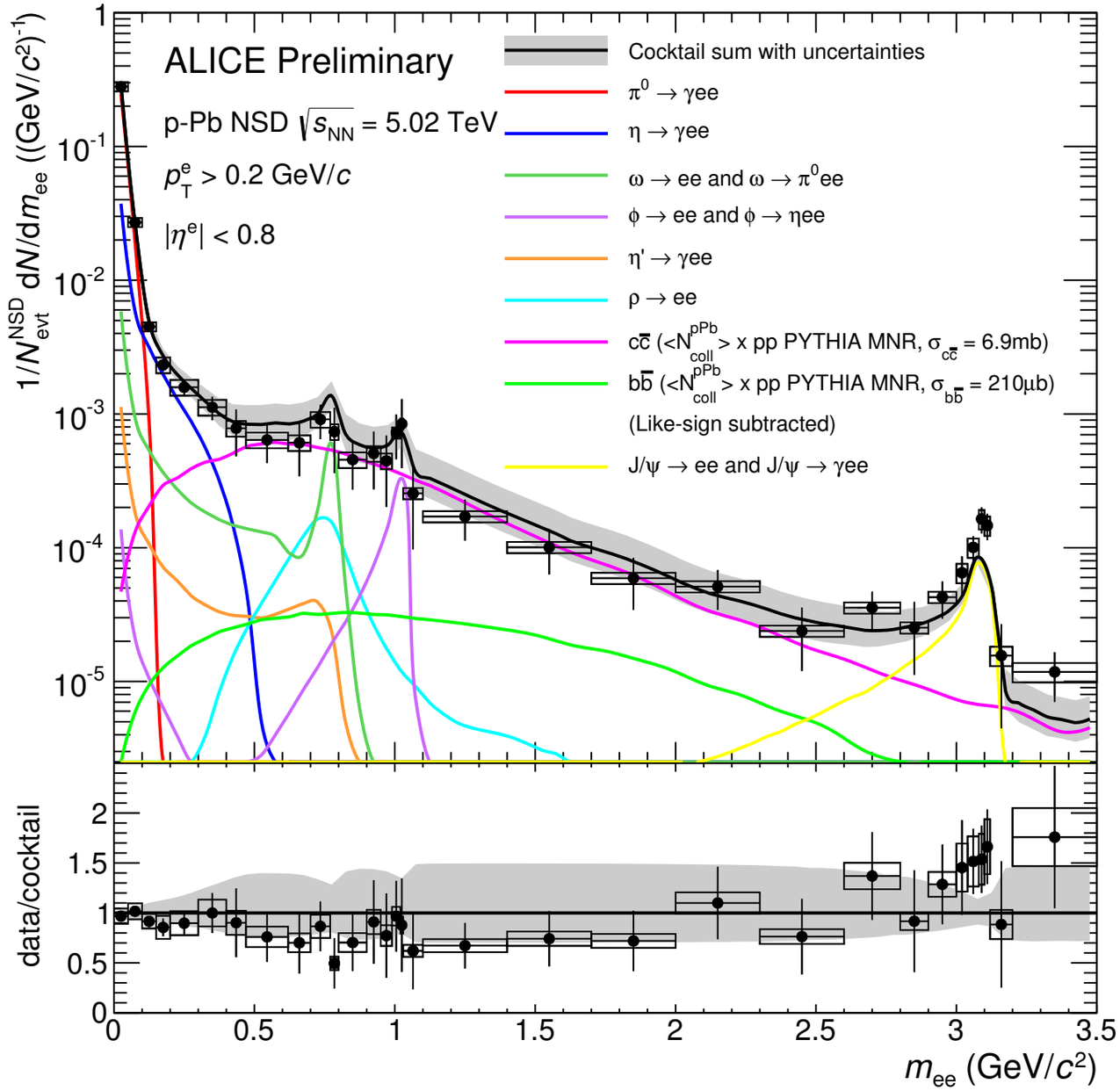
p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV: invariant mass spectrum

Cocktail calculations:

- Resonance and Dalitz decays: $\pi^{\pm}$ 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



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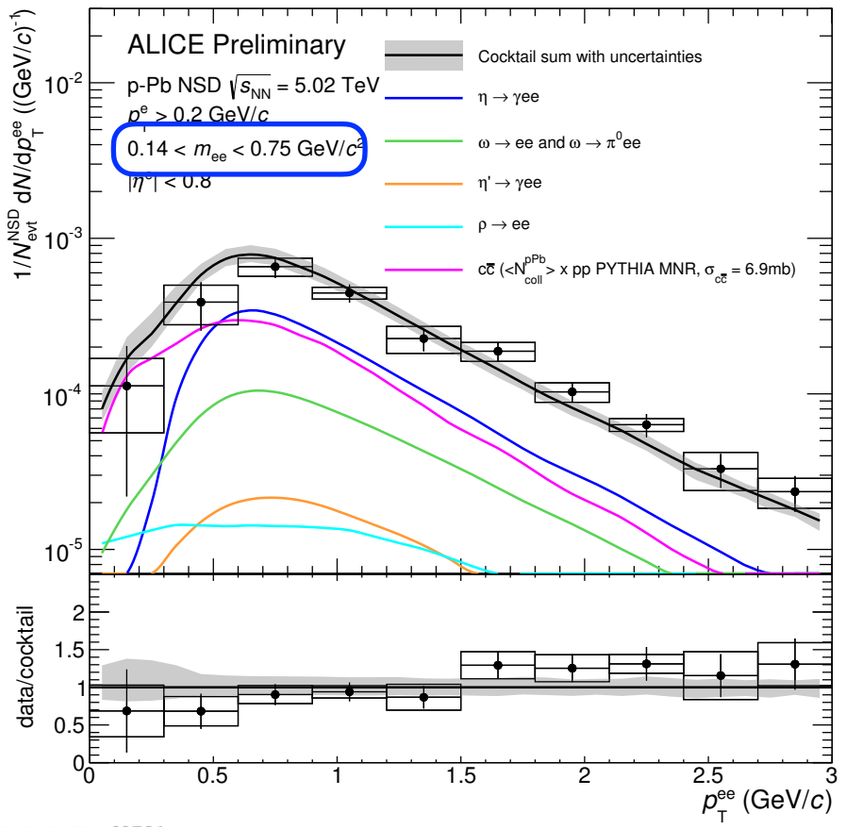
p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV: differential analysis

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

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



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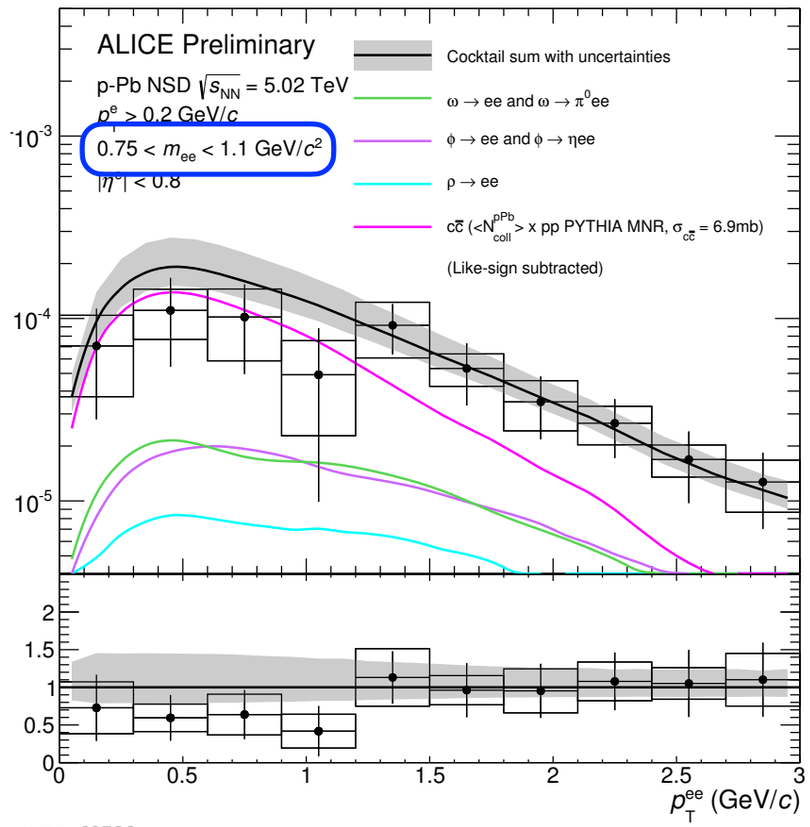
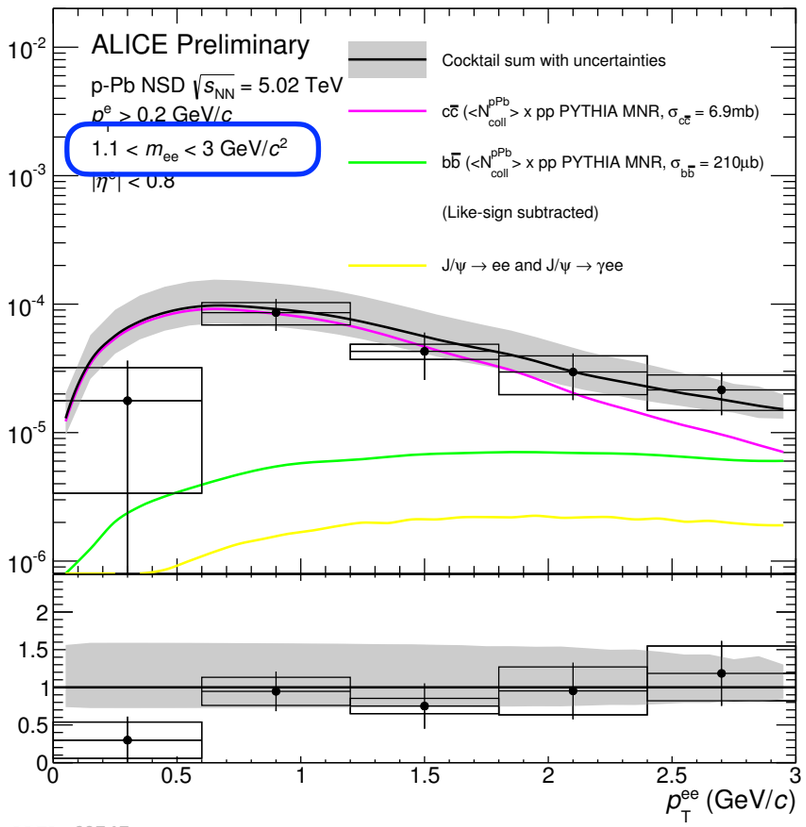


-PREL-69739



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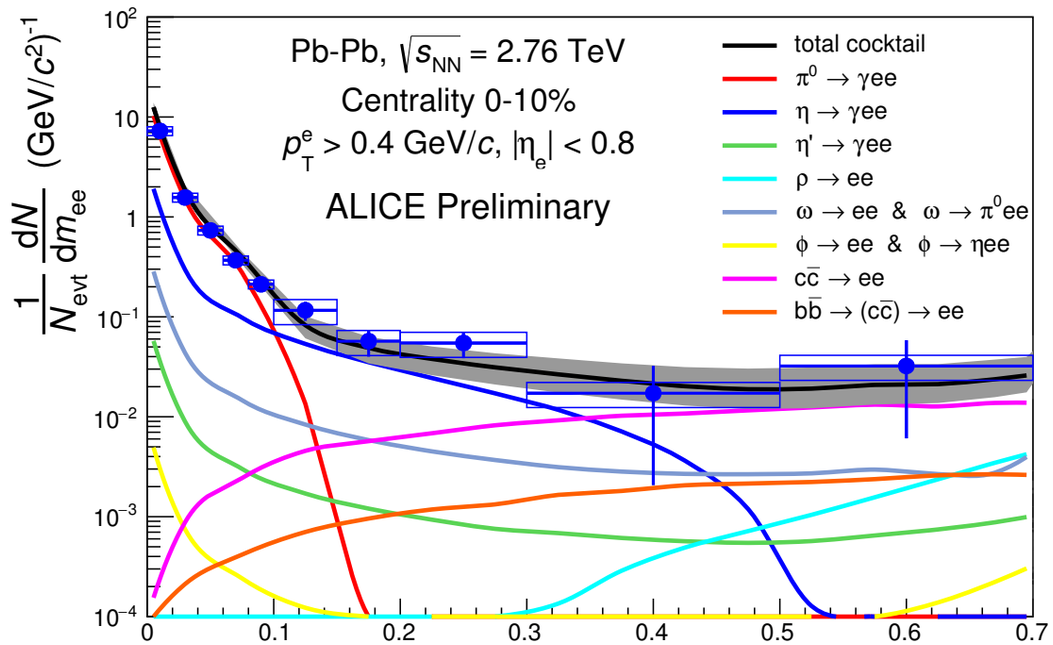
x5 more p-Pb data in Run 2: detailed studies vs m_{ee} and p_T^{ee} are foreseen

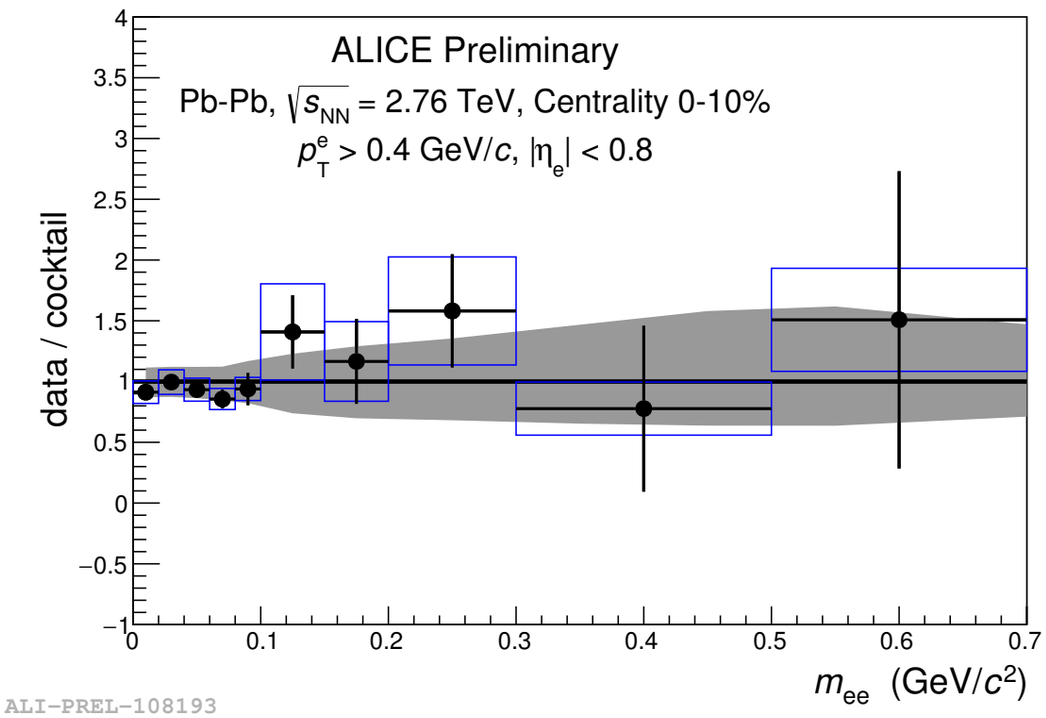
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV: invariant mass spectrum

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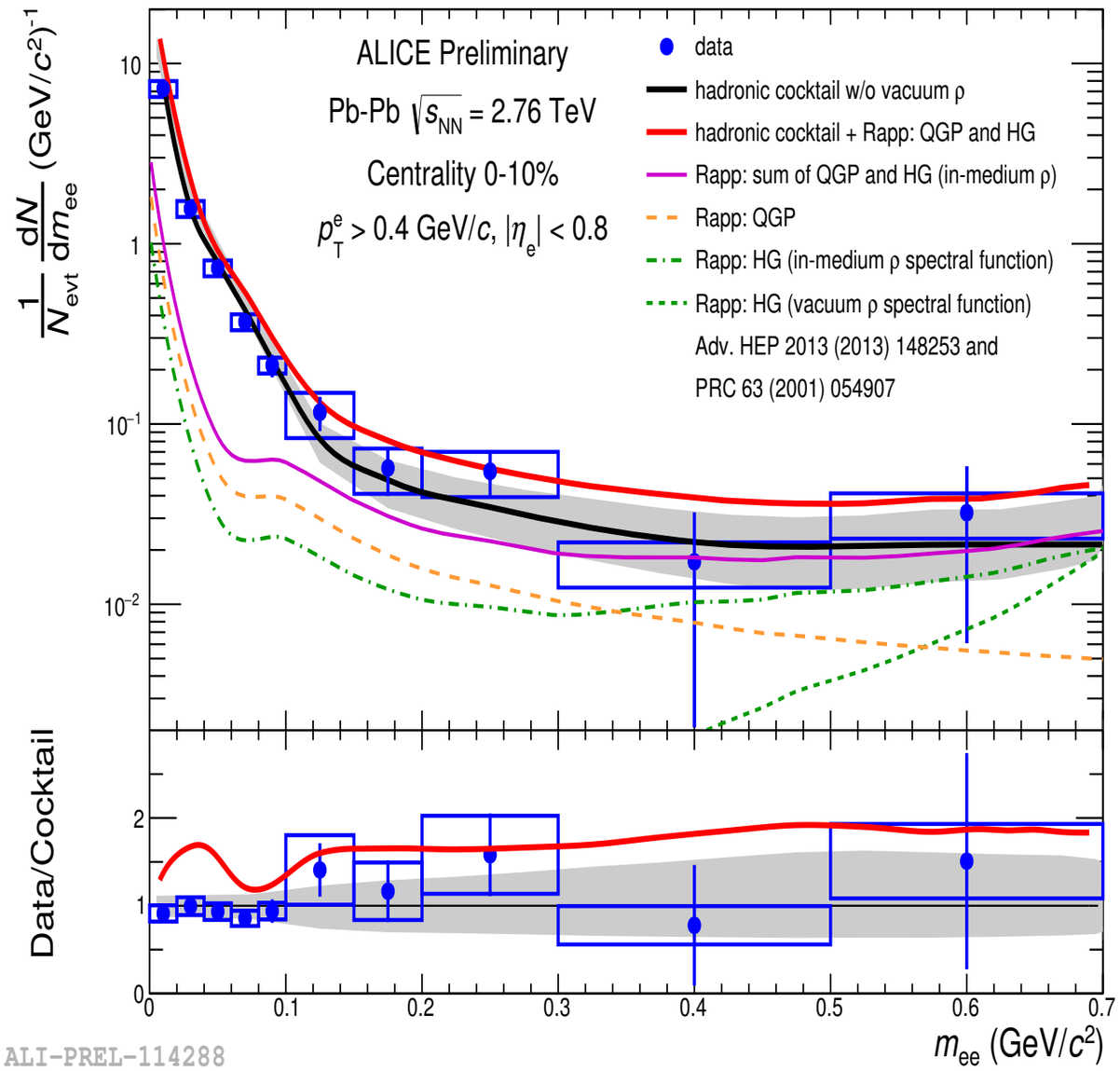
- Light flavour cocktail: π^0 measurements, m_T scaling for other hadrons
- Heavy flavour cocktail: PYTHIA calculations normalised to pp at 7 TeV measurements, extrapolated to 2.76 TeV and scaled with N_{coll}

Data compatible with cocktail within large uncertainties

- Room for additional sources
- **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}



[1] R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253
[2] R. Rapp, Phys. Rev. C63 (2001) 054907

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

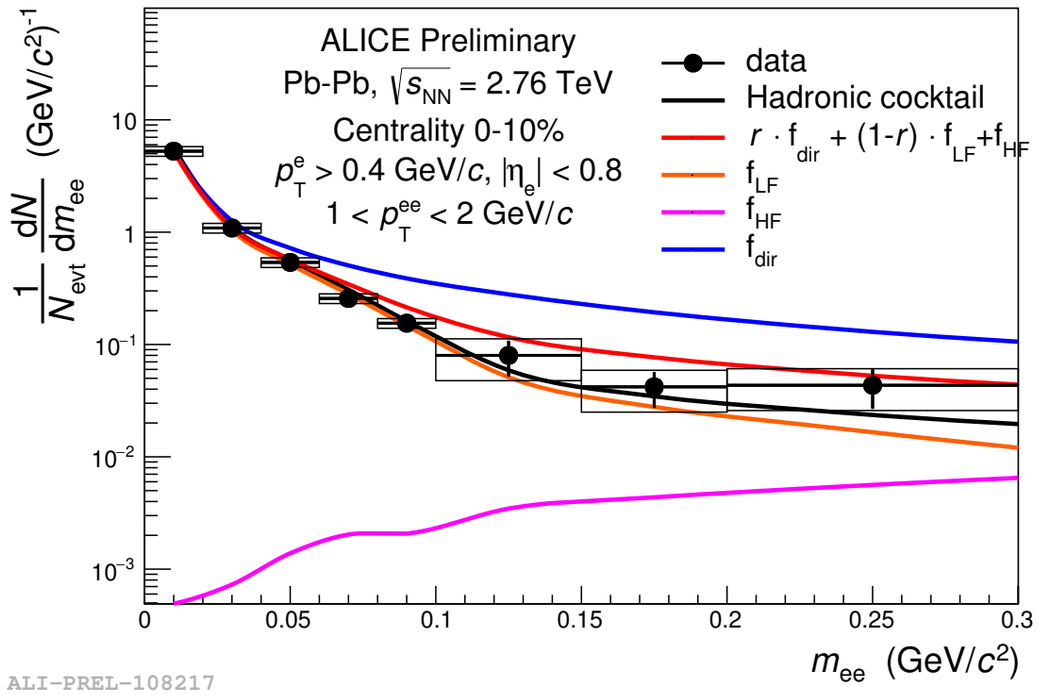
Fit dielecton mass spectrum
(m_{ee} 100-300 MeV/c^2, p_T 1-2 and 2-4 GeV/c)

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

- r = virtual direct γ / inclusive
- Direct virtual photons described by Kroll-Wada (m_{ee} << 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 ~ 0.1 - 0.2** [1, 2]



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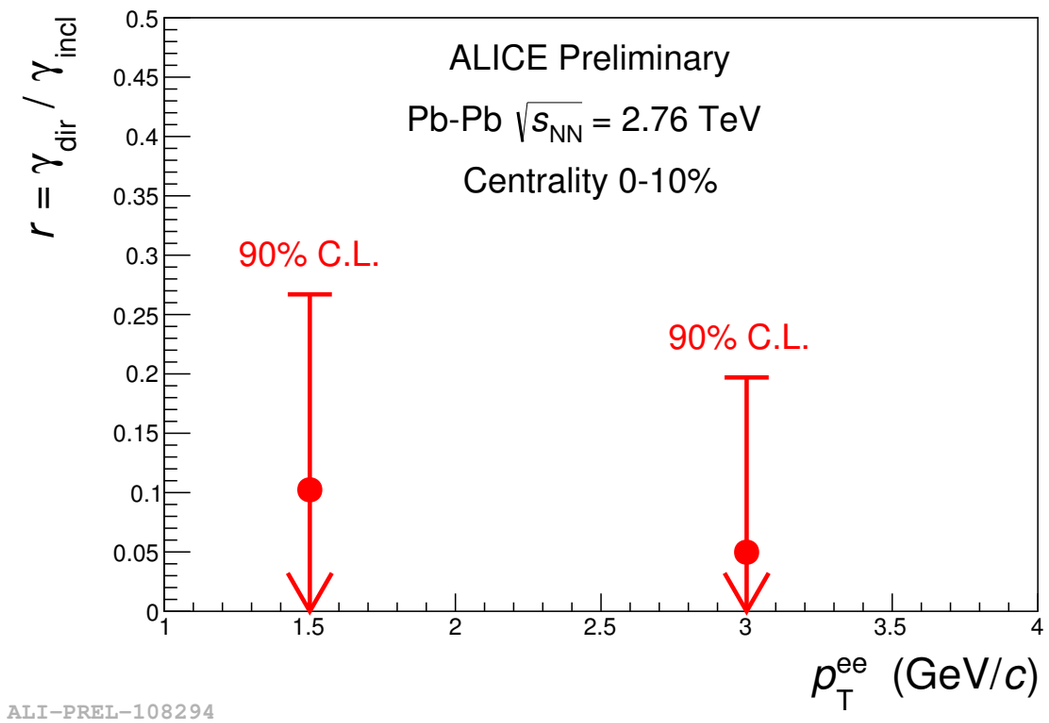


ALI-PREL-108294

[1] ALICE Collaboration, Phys. Lett. B 754 (2016) 235-248
[2] PHENIX Collaboration, Phys. Rev. Lett. 104 (2010) 132301

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

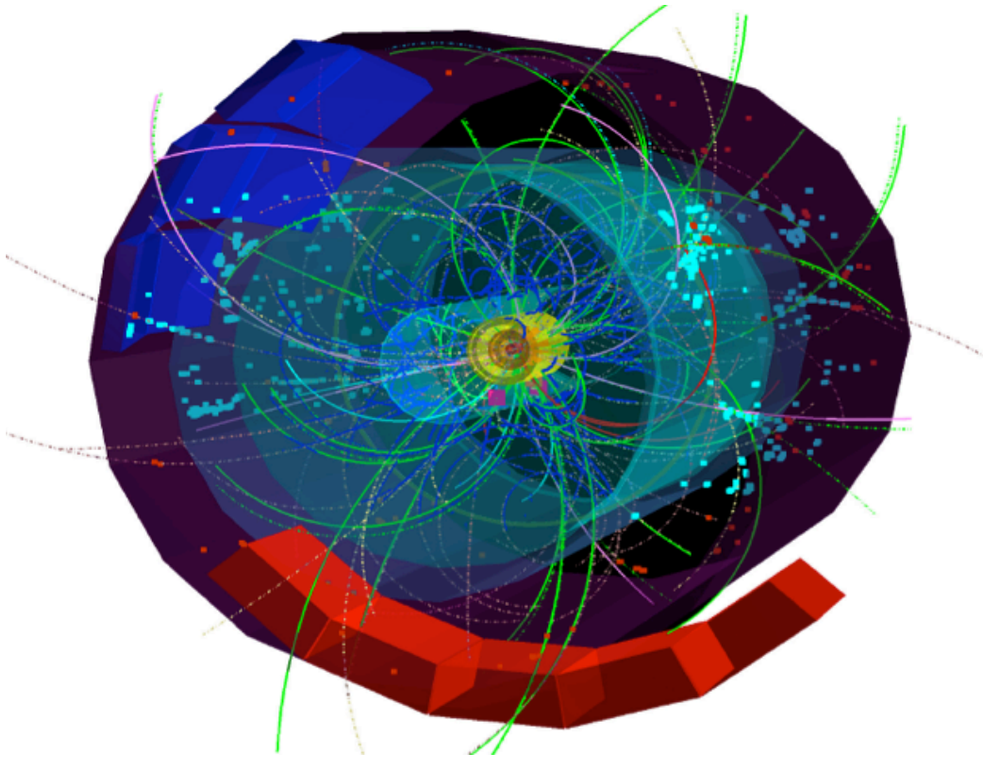
p-Pb collisions

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

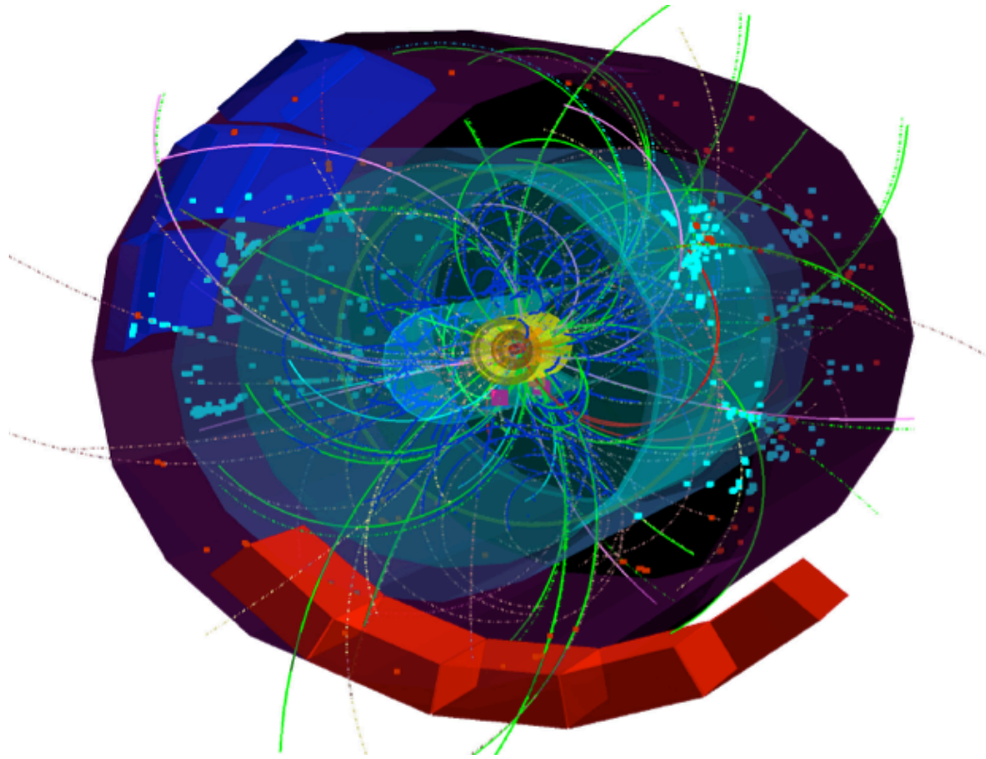
Pb-Pb collisions

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

More results are coming soon!



Back-up slides



Dielectron pair analysis

- Physics signal:

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

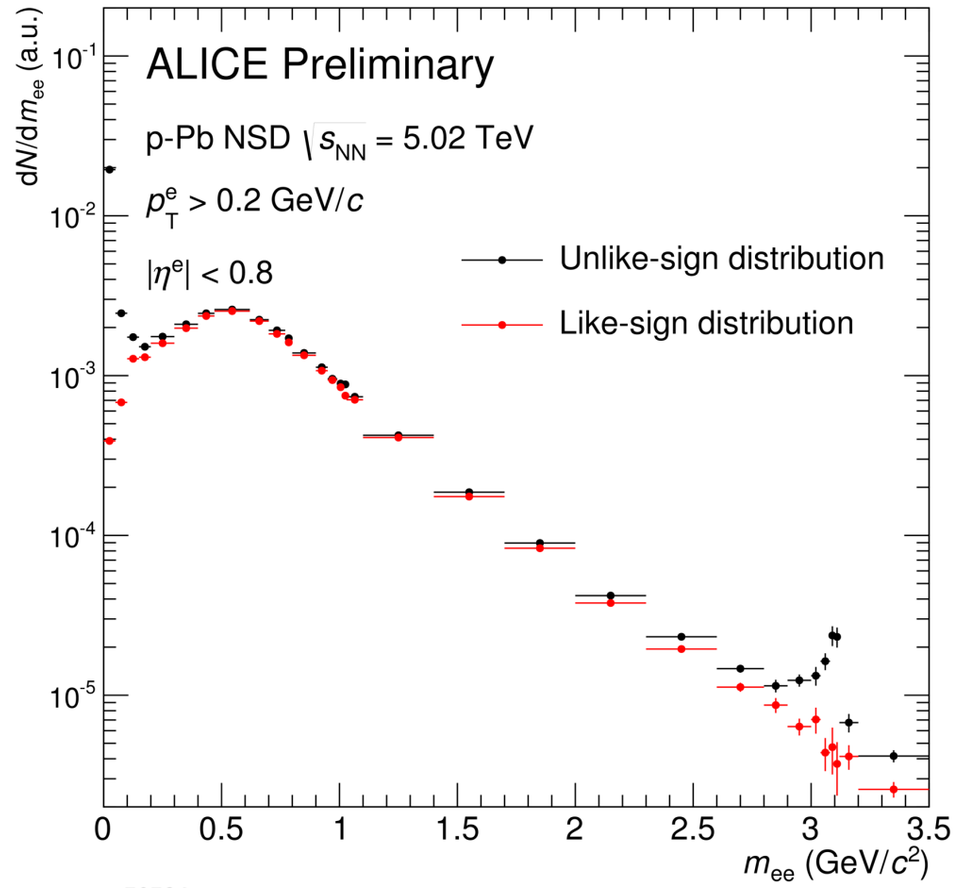
- Combinatorial background: geometric mean of like-sign pairs from same event

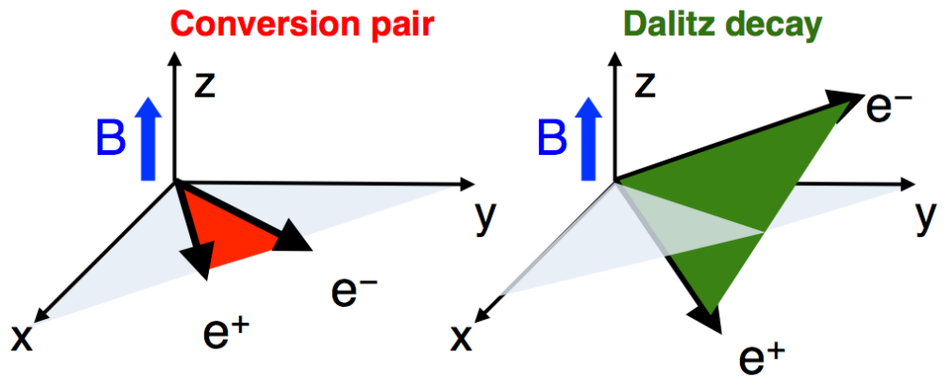
$$B = 2\sqrt{N_{++} \cdot N_{--}}$$

- 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





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

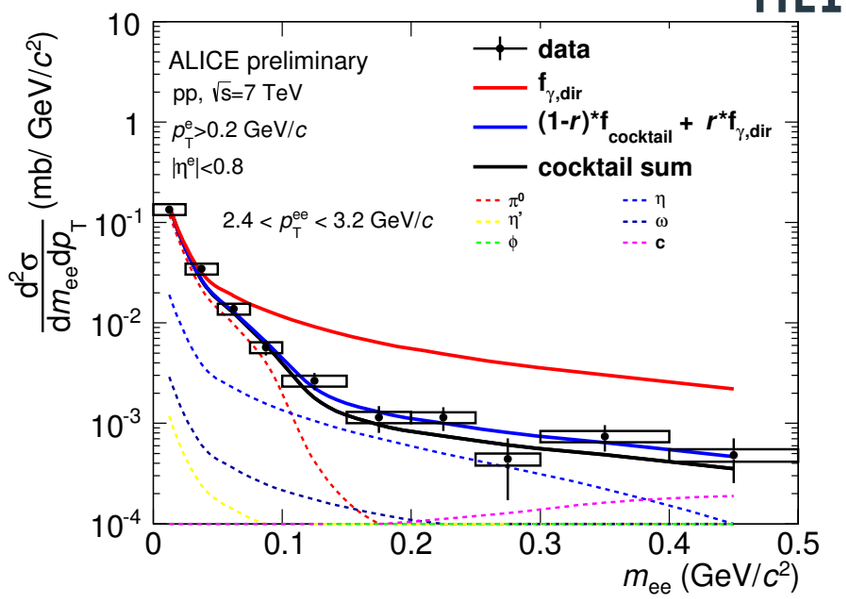
Fit dielecton mass spectrum (m_{ee} 100-400 MeV/c^2, p_T > 1 GeV/c) with

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

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

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

- **Results compatible with NLO pQCD calculations**



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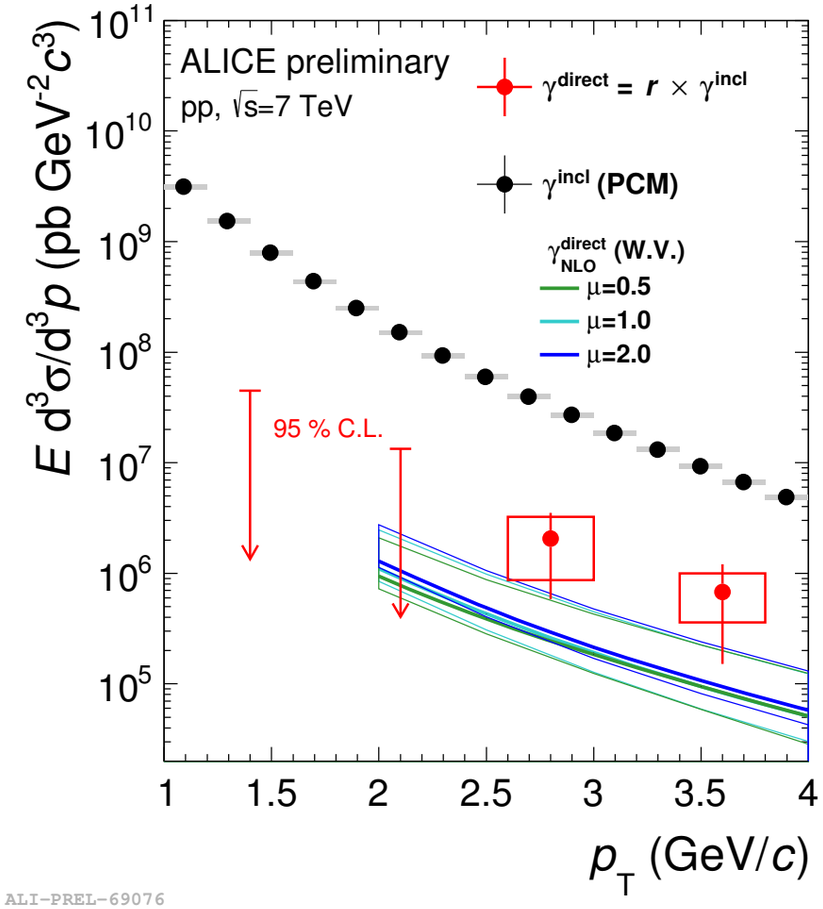

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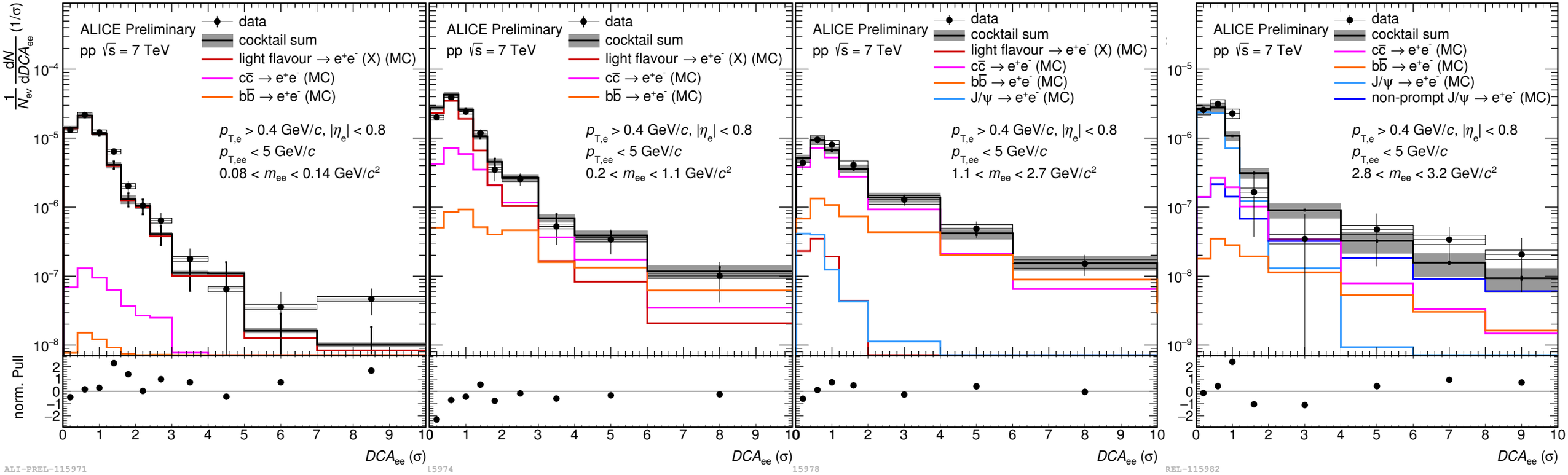
pp $\sqrt{s}$ = 7 TeV: pair DCA analysis

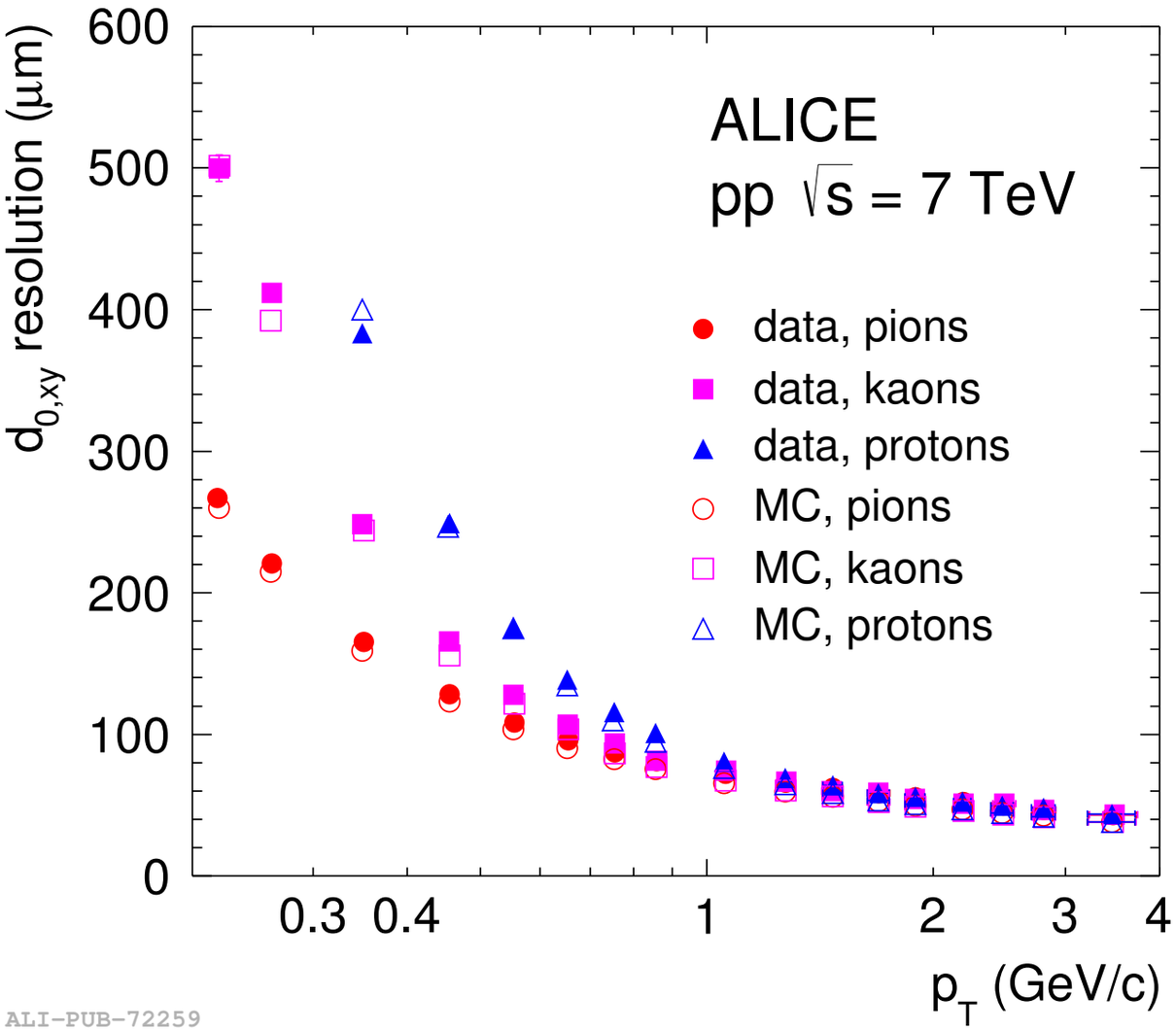
Idea: separate prompt and non-prompt contributions using pair vertex position

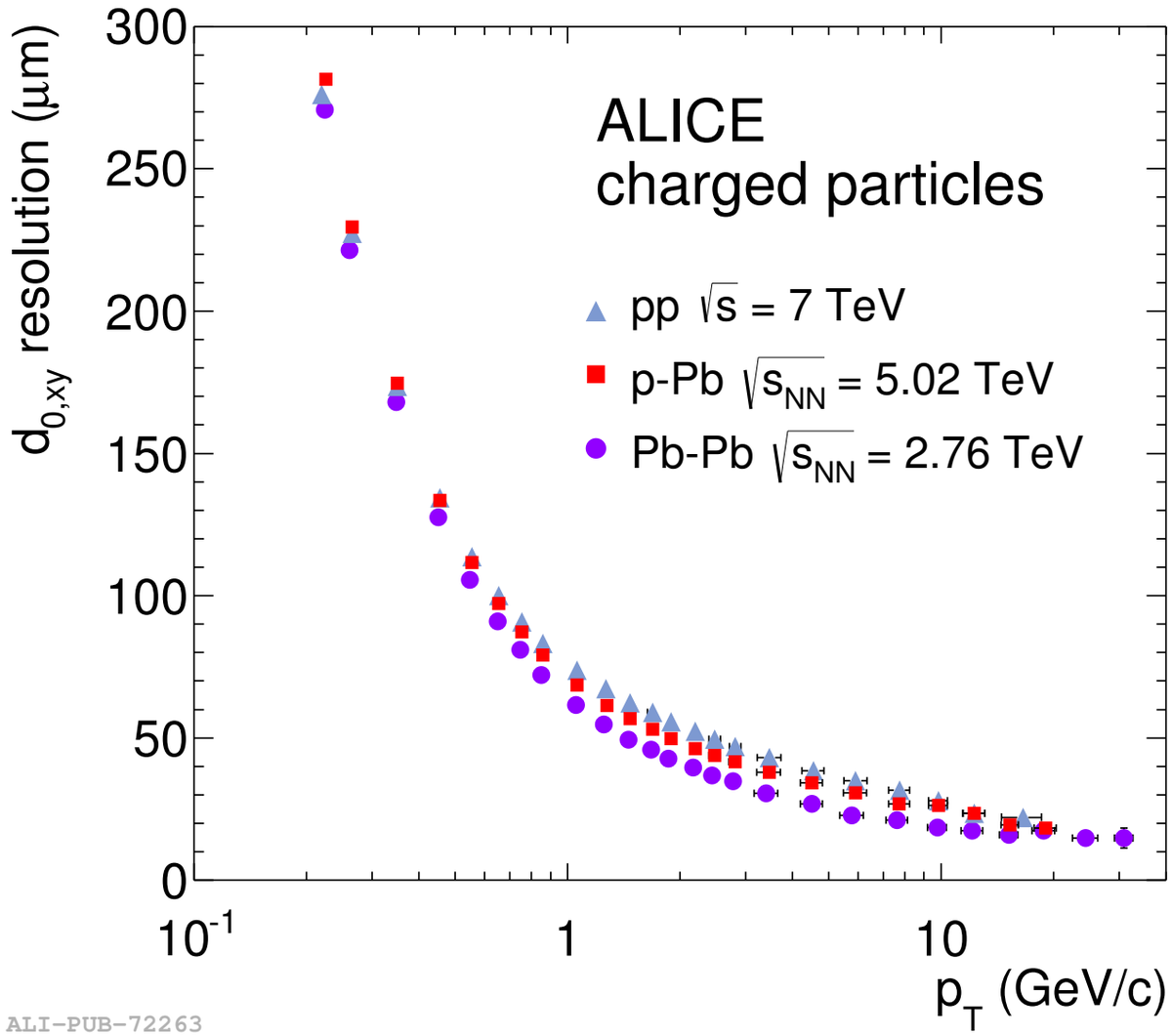
- Tracks from D or B decays ($c\tau$ ~ 100-500 μm) do not point back to event vertex
- Observable: $DCA_{ee} = \sqrt{\frac{DCA_1^2 + DCA_2^2}{2}}$ (DCA_i - **D**istance of **C**losest **A**pproach of track i)
- Obtain DCA_{ee} templates from MC, normalise to cocktail and compare with data



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

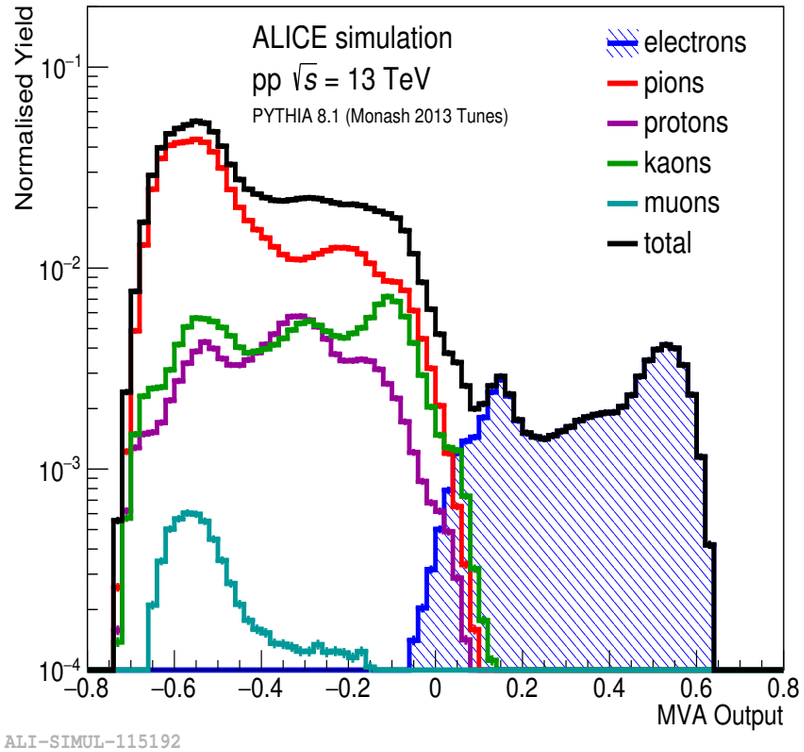
- DCA resolution should be smaller than observable ($c\tau$ of D meson ~ 150 μm)
- Pair DCA analysis is done for p_T > 0.4 GeV/c

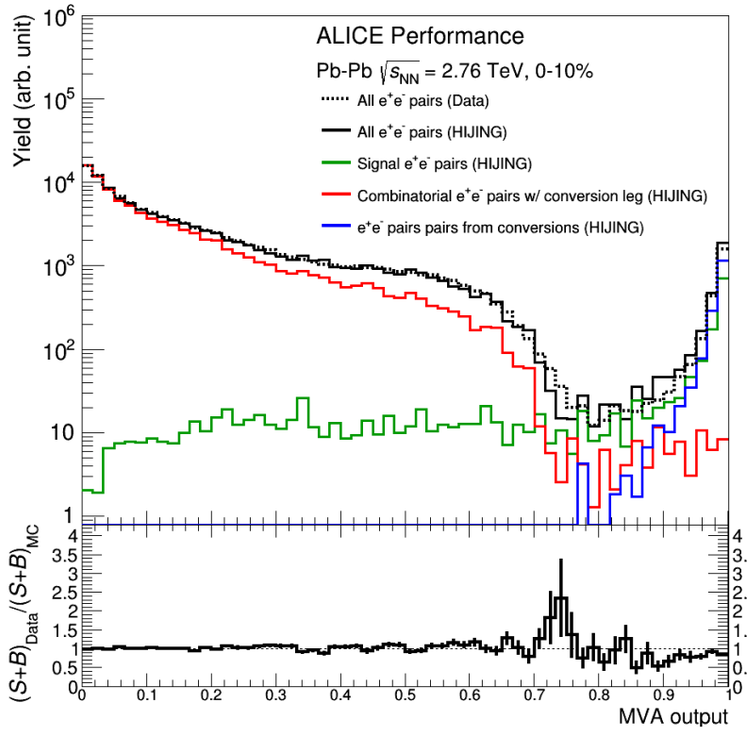


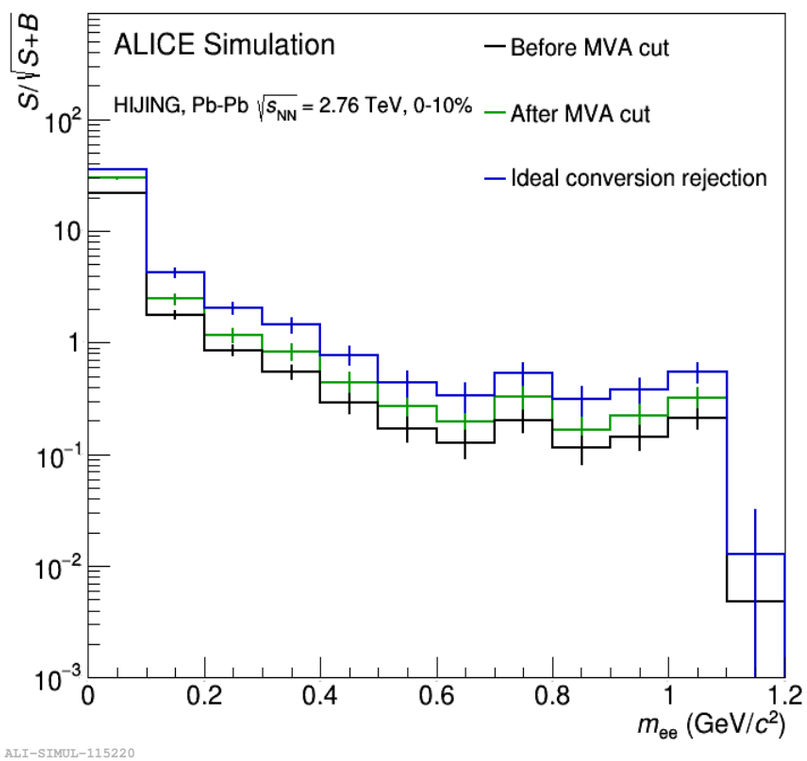


New developments: machine learning methods

- 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





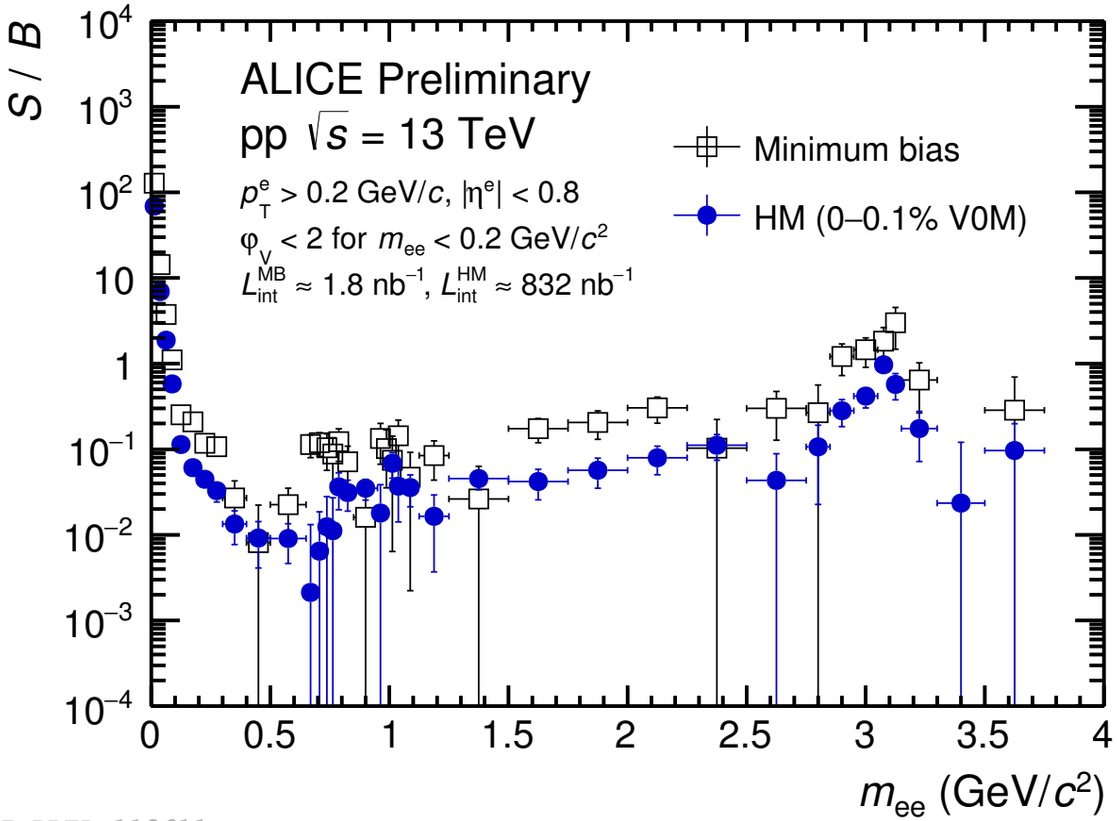


pp $\sqrt{s}$ = 13 TeV: S / B and significance

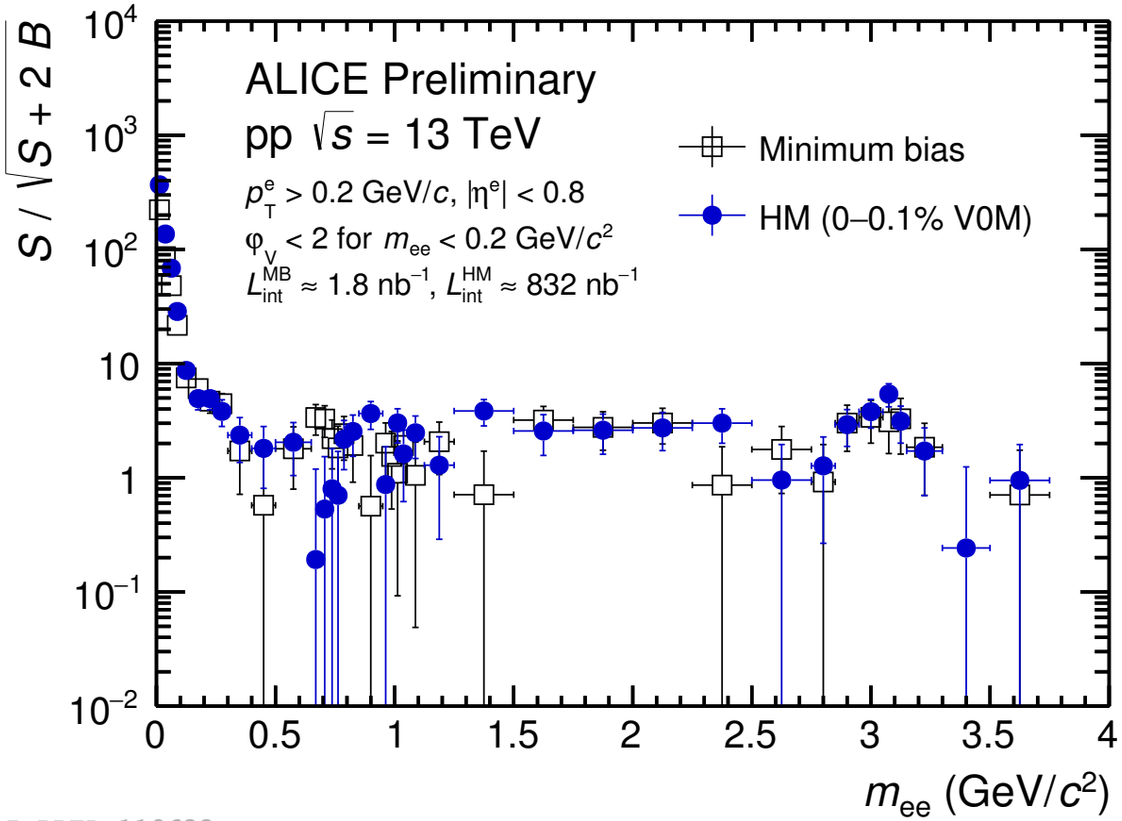
Naive expectation: signal is proportional to N_{ch}, combinatorial background grows like N_{ch}^2

→ Signal / background ratio is lower for high multiplicity events

→ Significance is comparable in background-dominated mass region



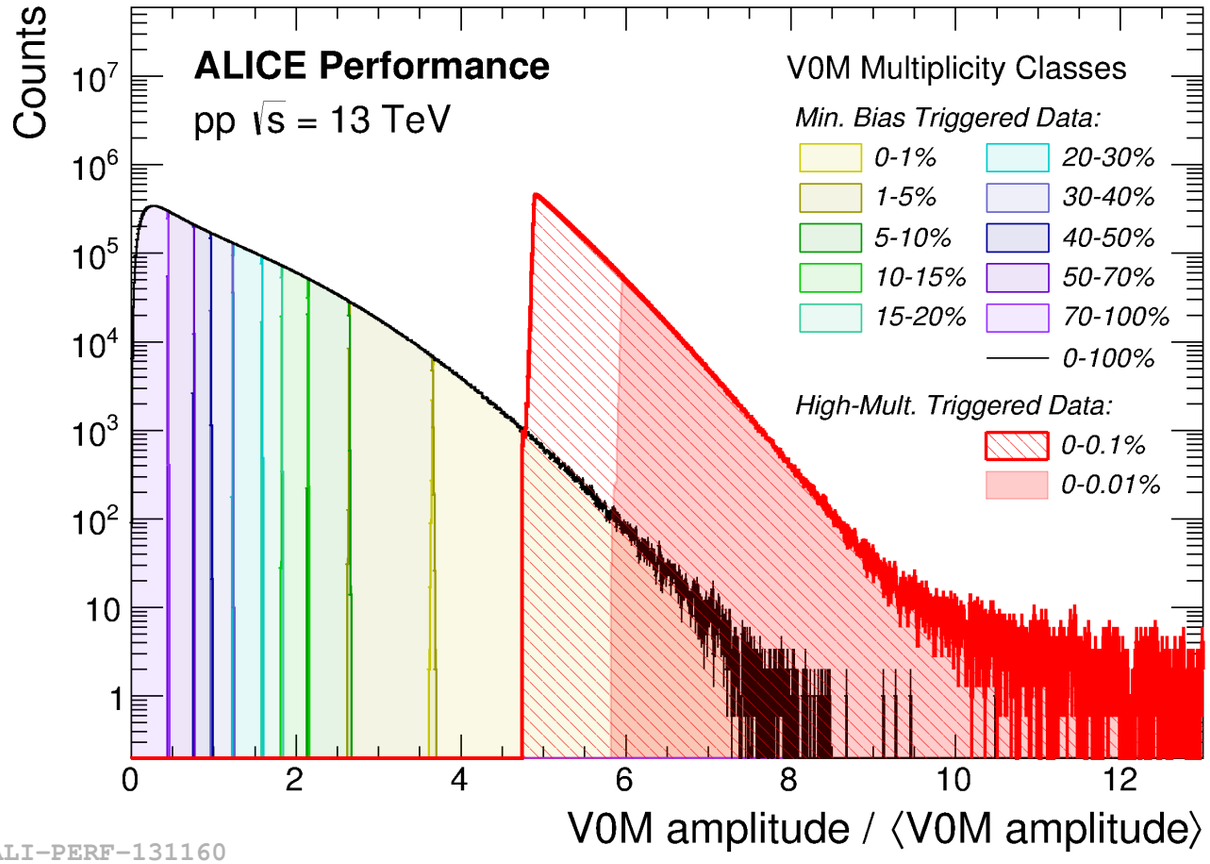
ALI-PREL-119611



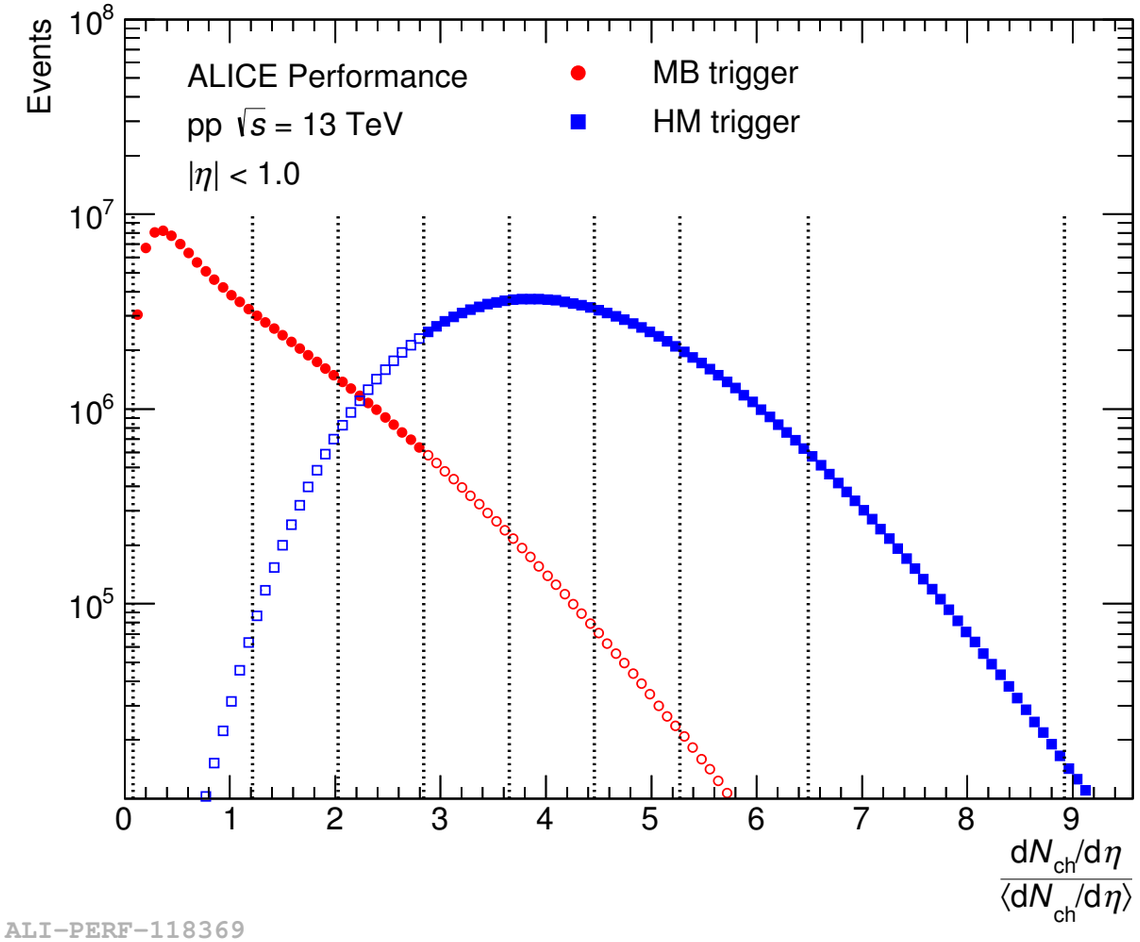
ALI-PREL-119633

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
- $\langle N_{ch}^{acc}(HM) \rangle / \langle N_{ch}^{acc}(MB) \rangle$ = 4.36 (measured at η ~ 0)

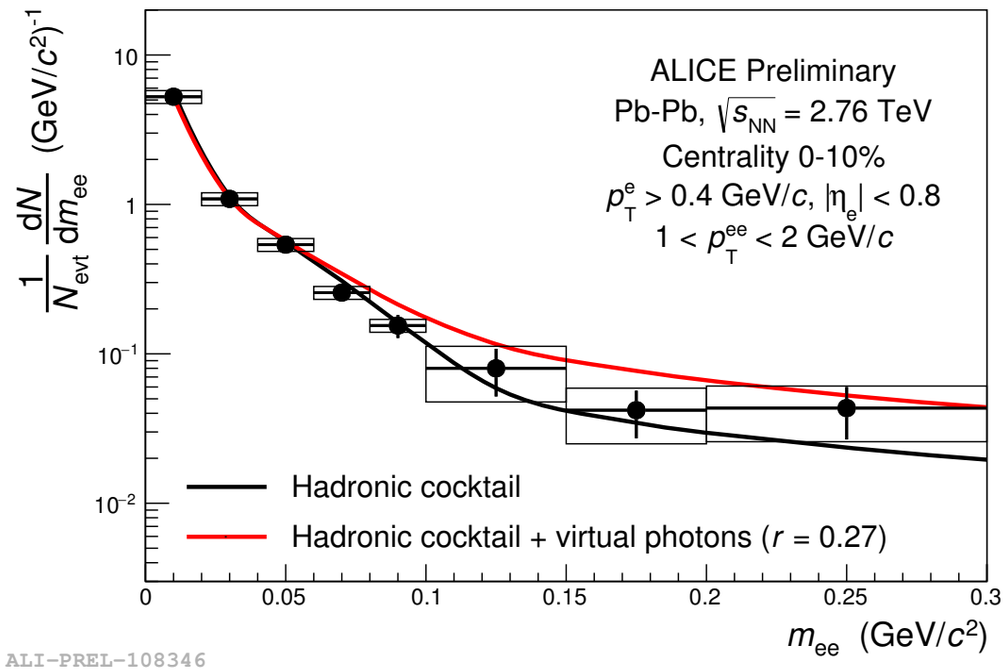


ALI-PERF-131160

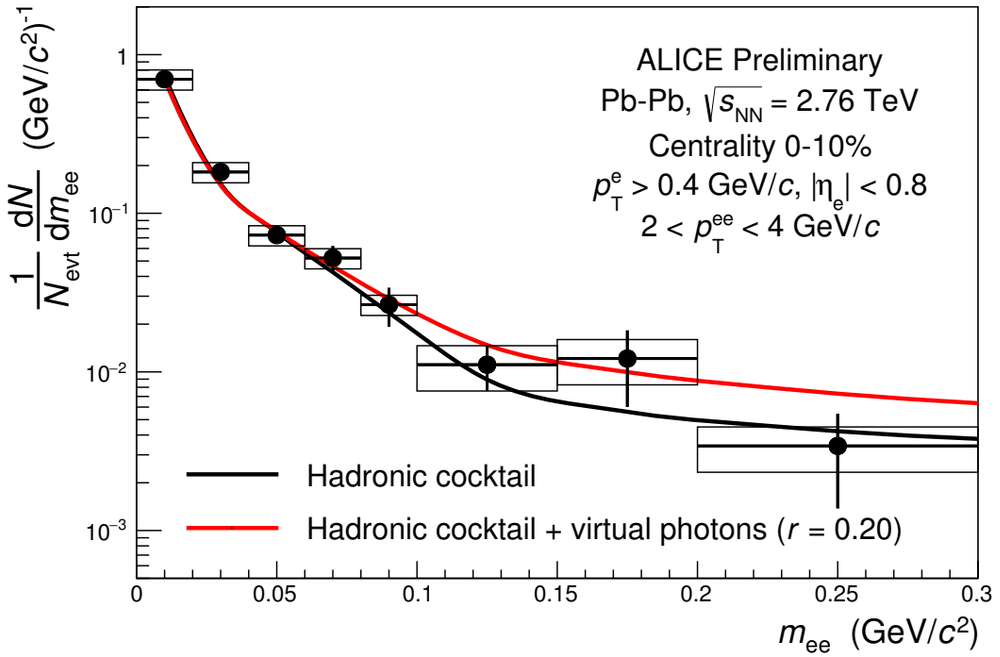


ALI-PERF-118369

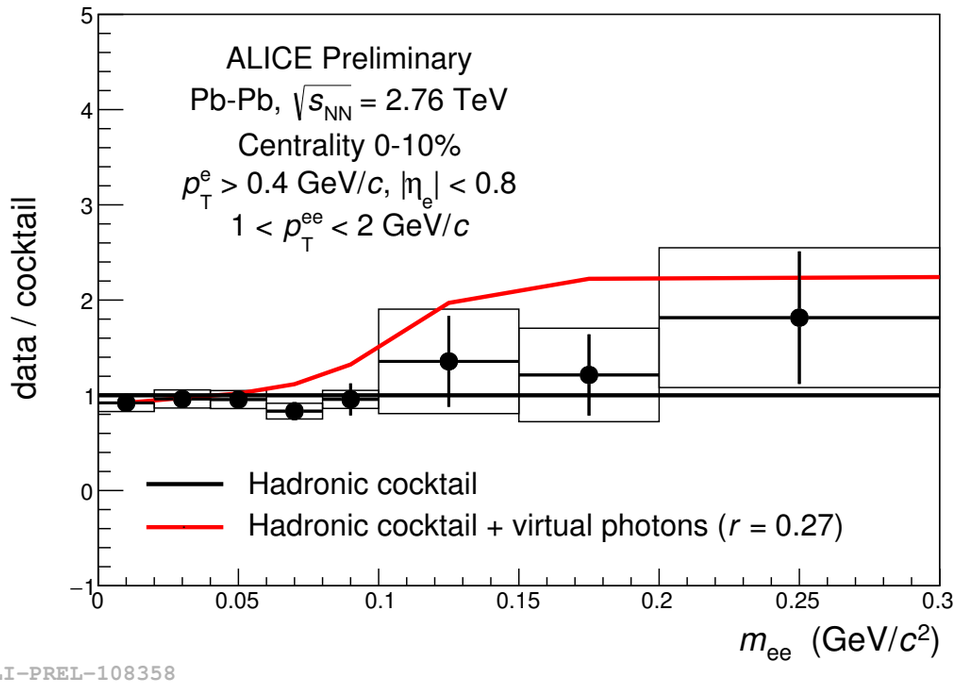
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV: virtual direct photons



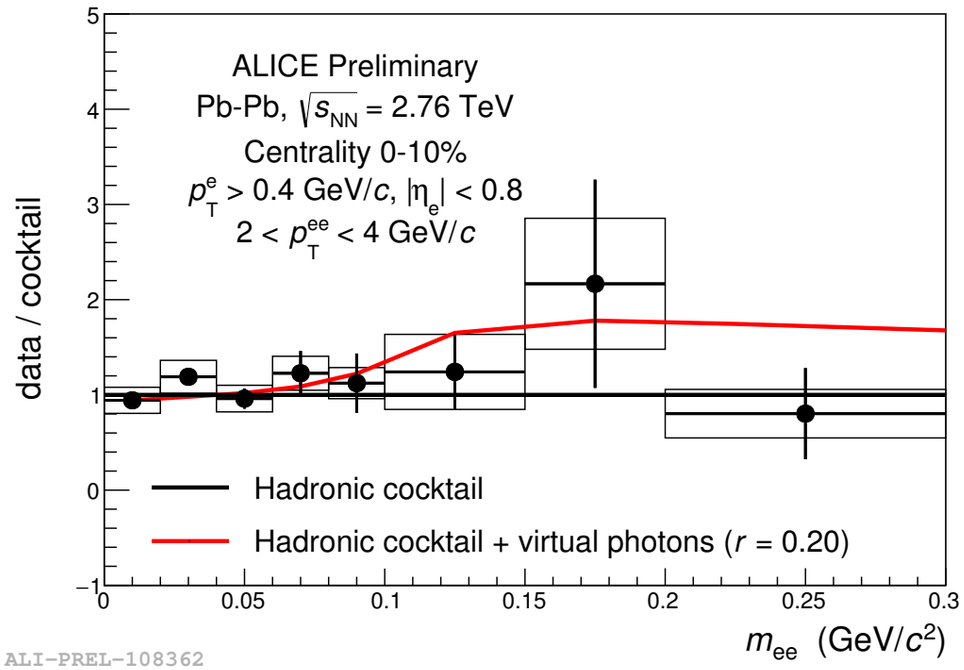
ALI-PREL-108346



ALI-PREL-108350



ALI-PREL-108358

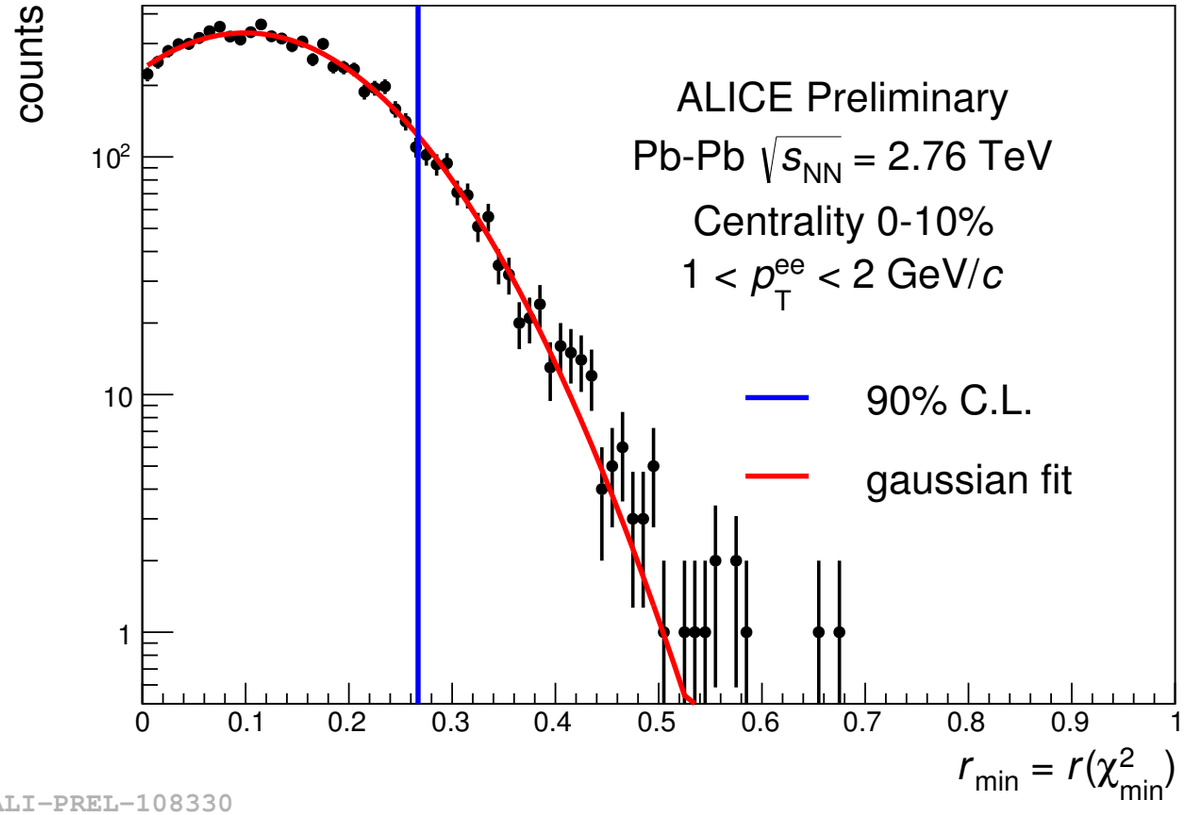


ALI-PREL-108362

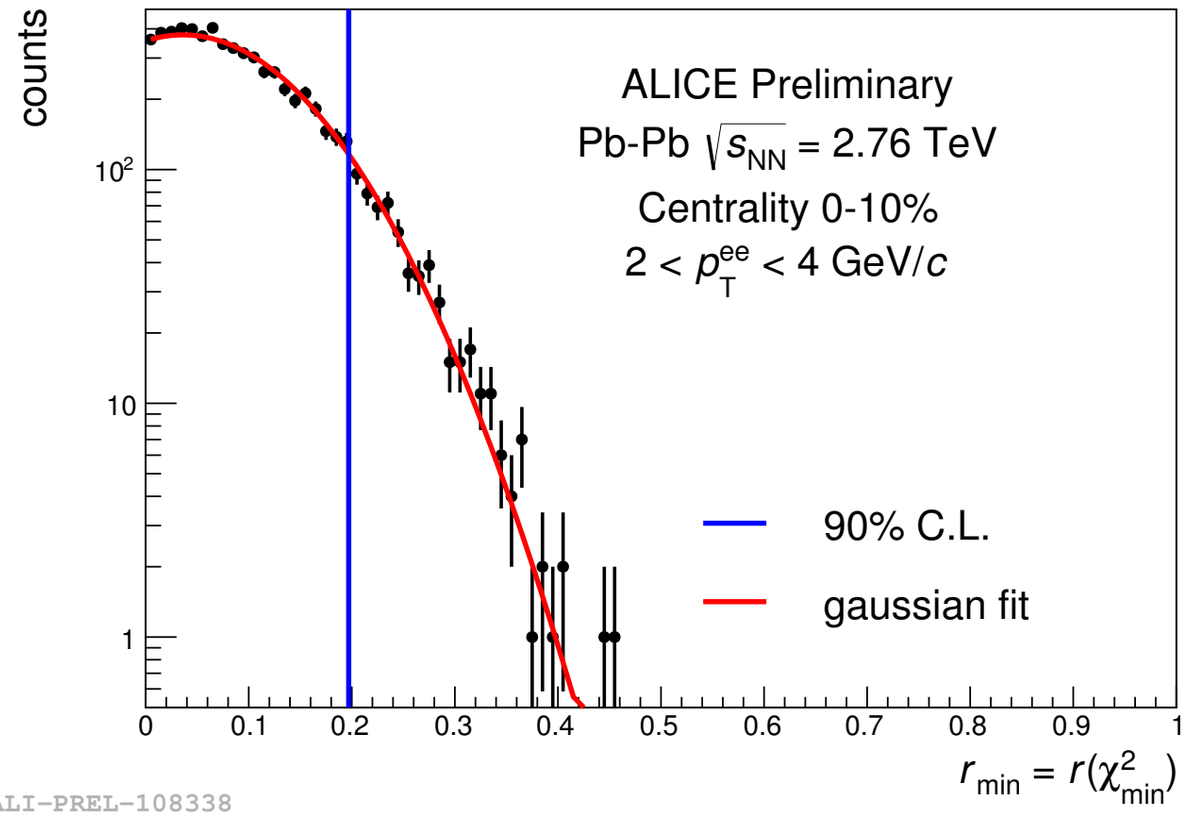
Upper limit on virtual direct photons

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



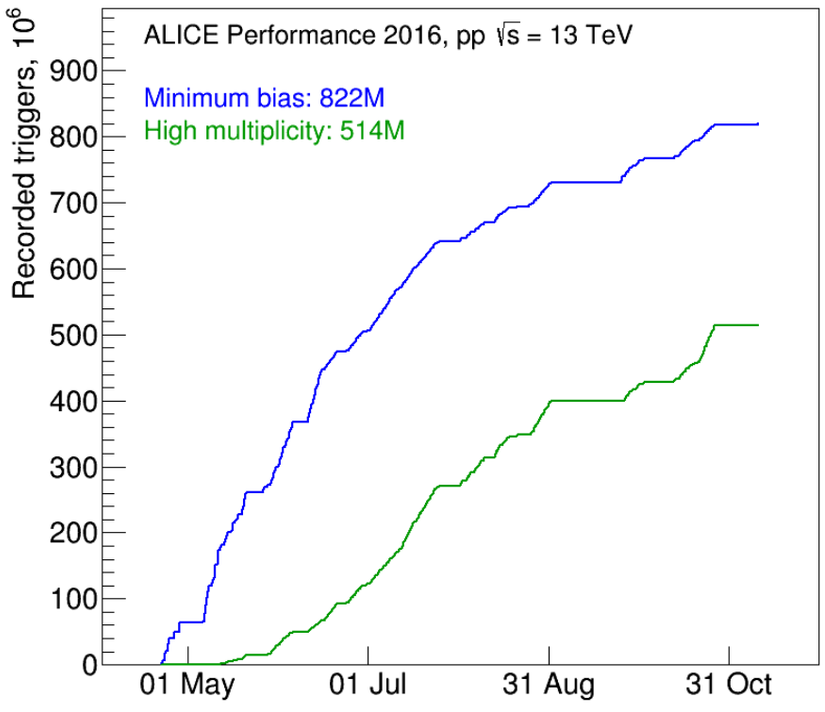
ALI-PREL-108330

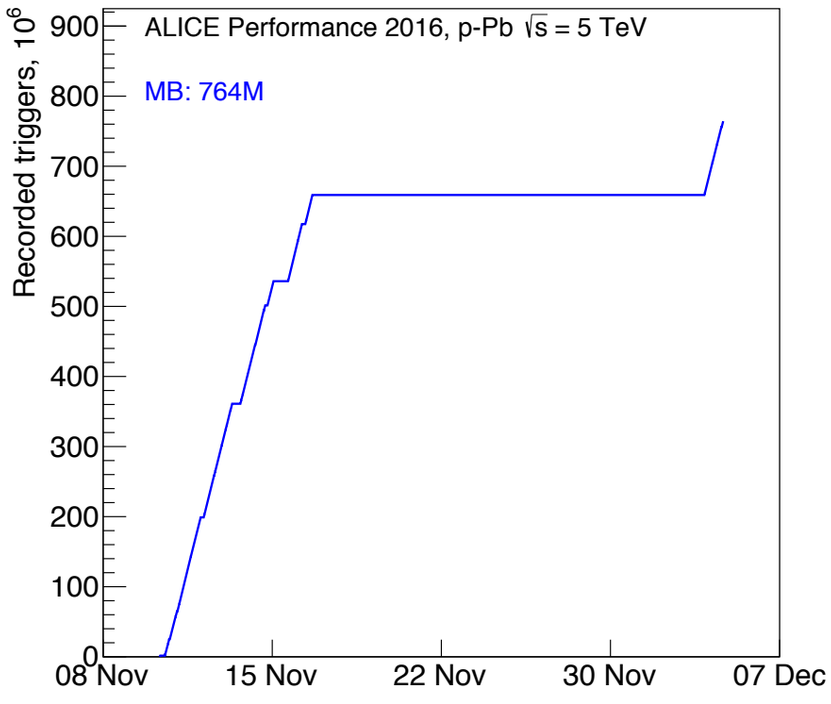


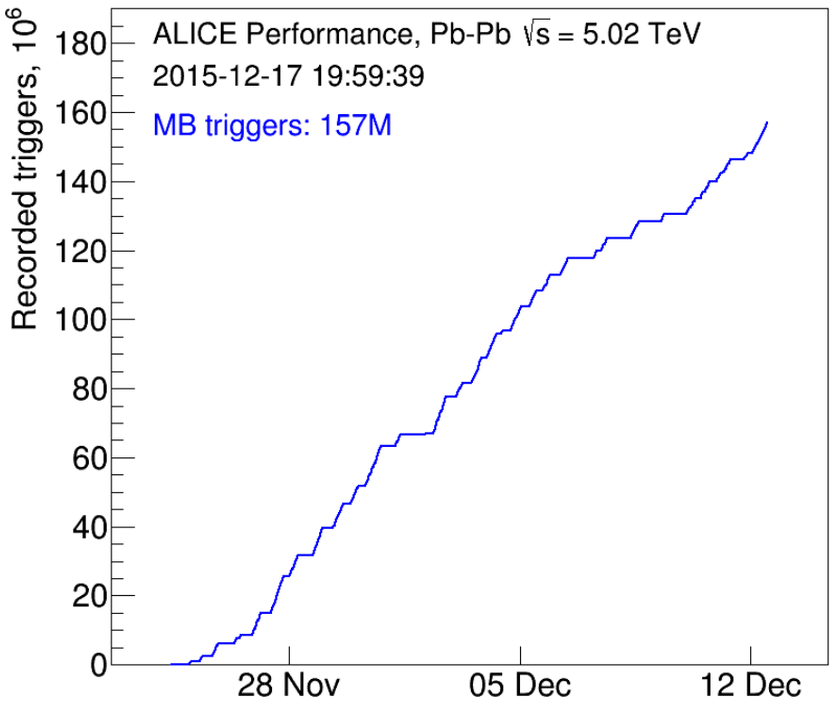
ALI-PREL-108338

Run 2 collected data

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

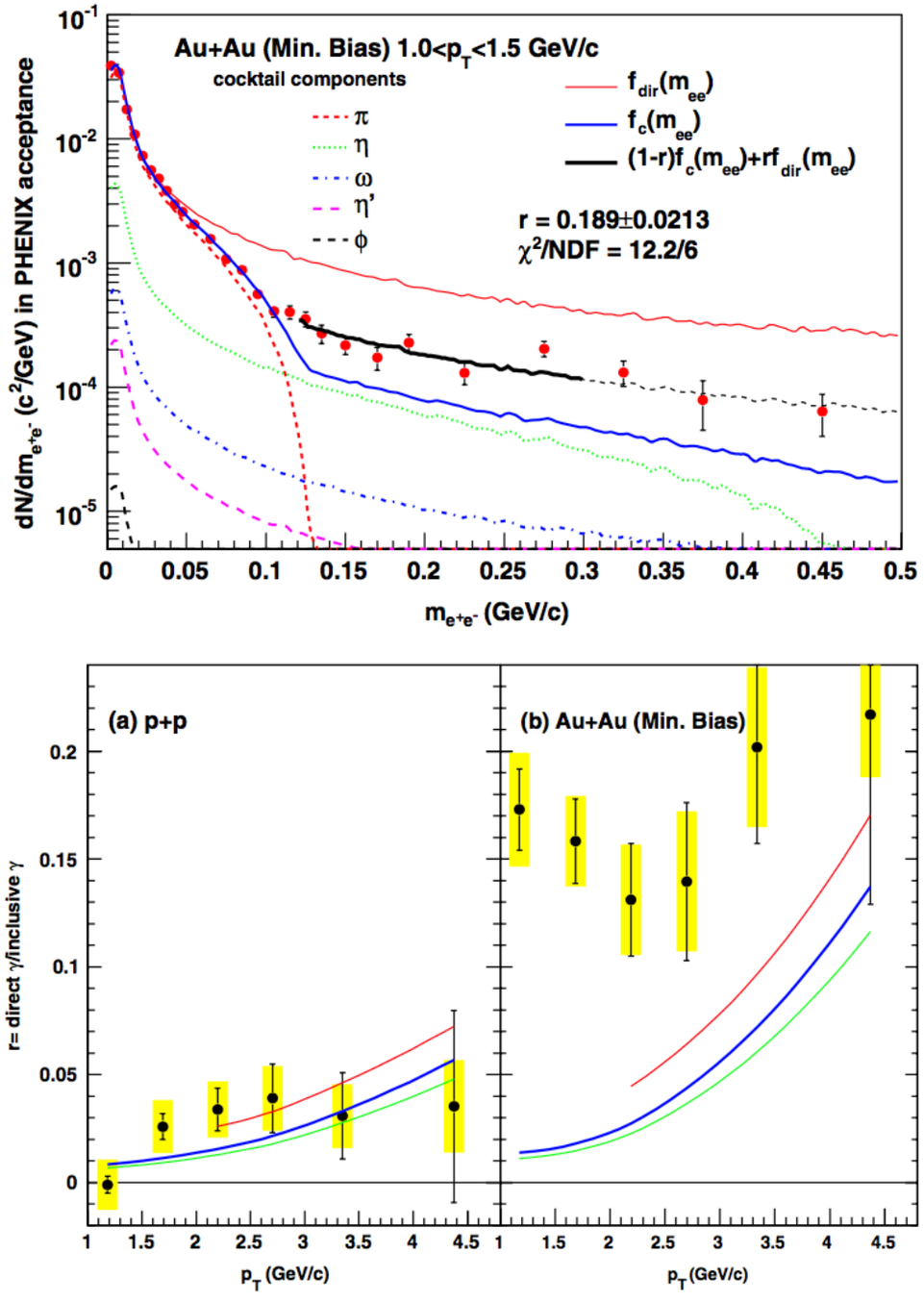




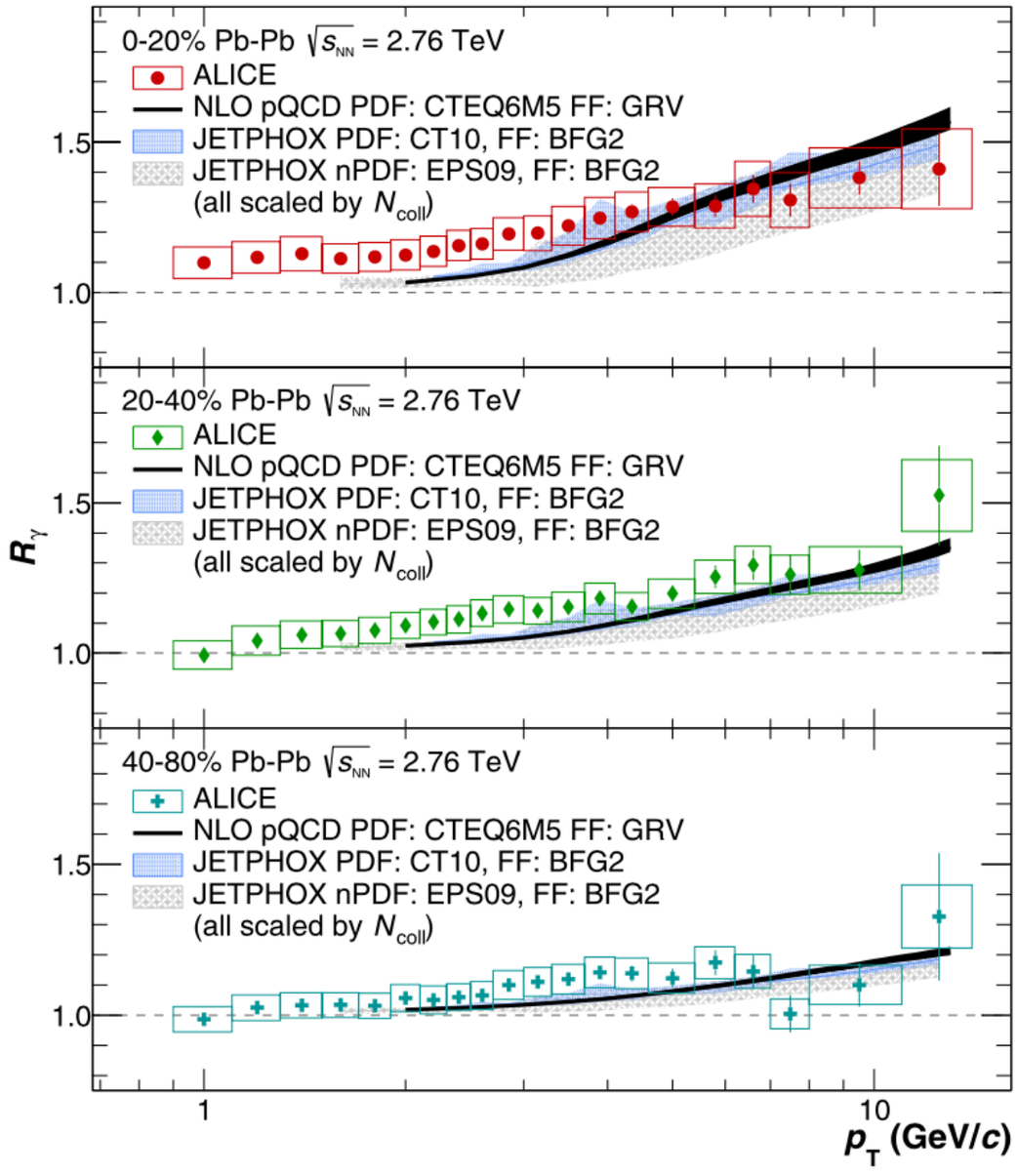


Direct photon results

PHENIX Au-Au 200 GeV [2]



ALICE Pb-Pb 2.76 TeV [1]

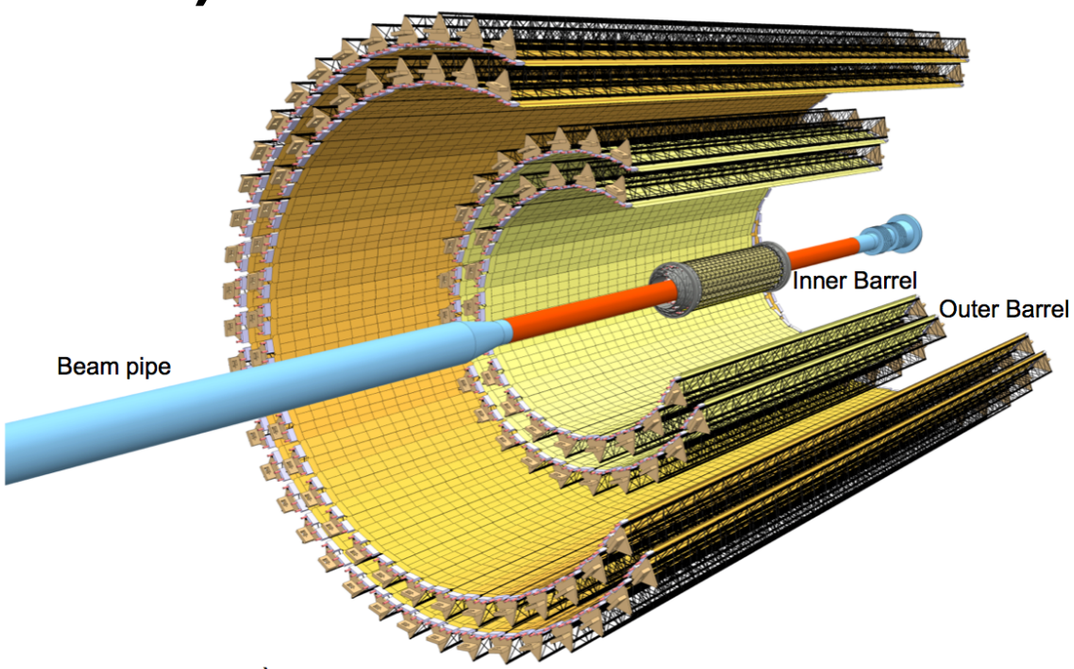


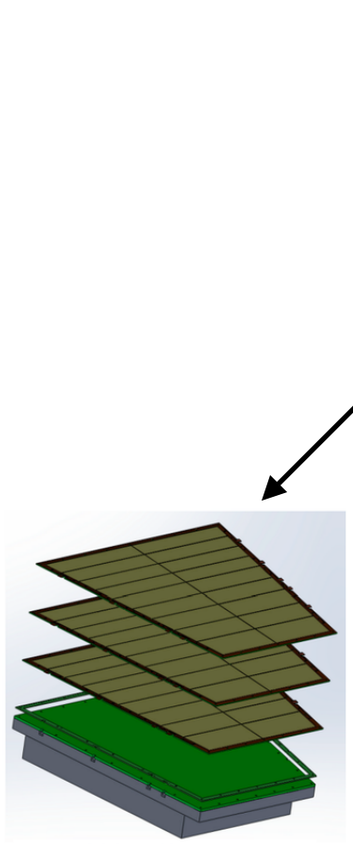
[1] ALICE Collaboration, Phys. Lett. B 754 (2016) 235-248
[2] PHENIX Collaboration, Phys. Rev. Lett. 104 (2010) 132301

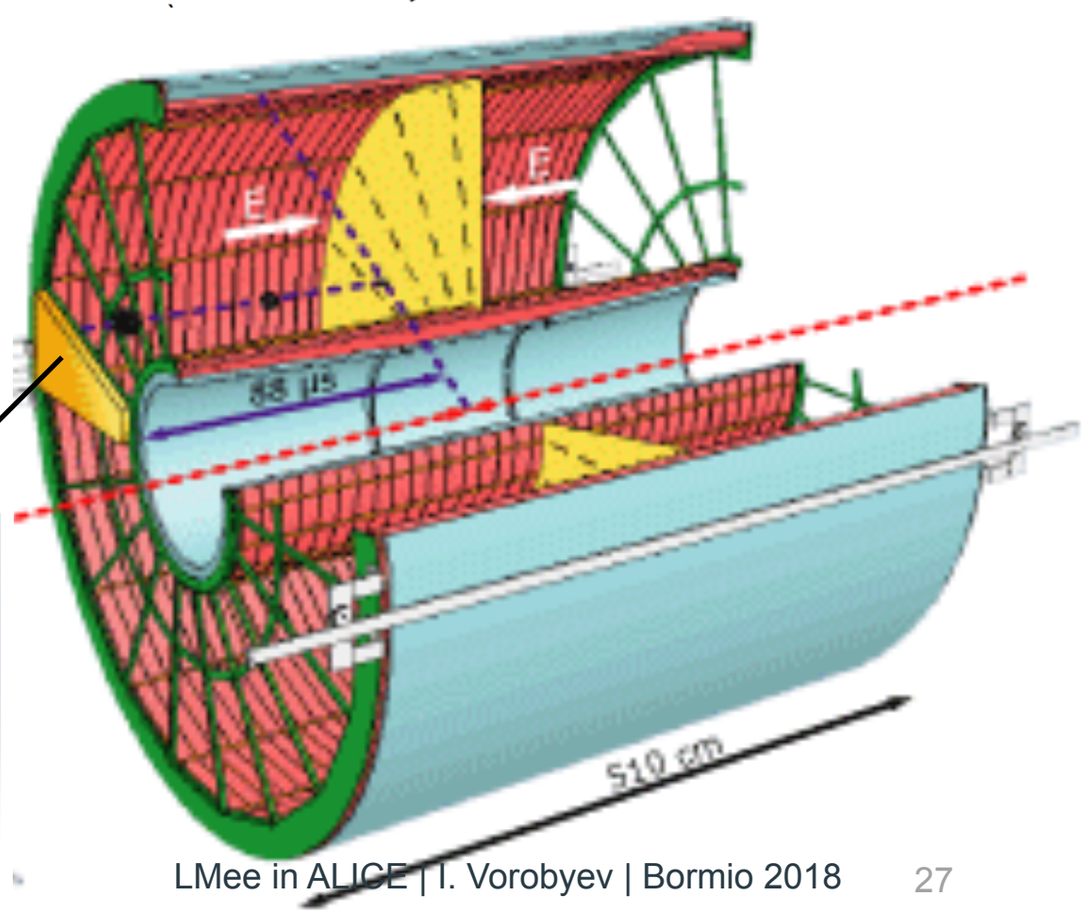
ALICE Upgrade for Run 3 (2020-2022)

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)

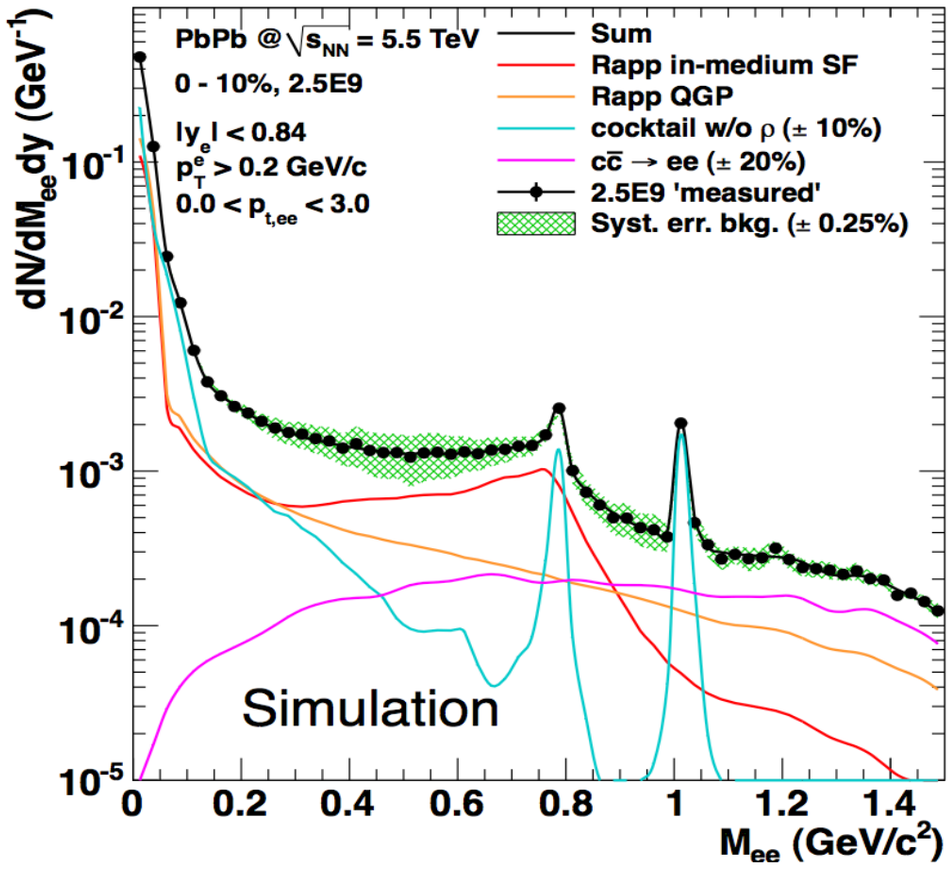


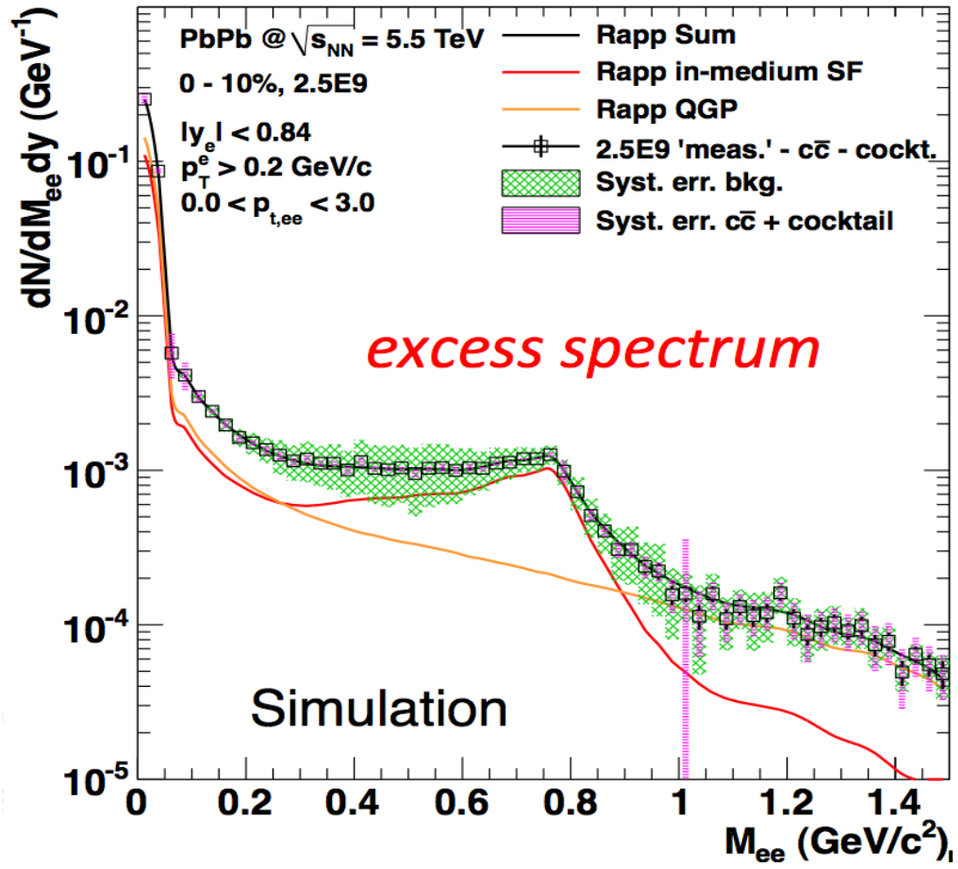




ALICE Upgrade for Run 3 (2020-2022)

- Dedicated low B field = 0.2 T to increase acceptance of low p_T & mass pairs
- Expected statistics: 2.5 x 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