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

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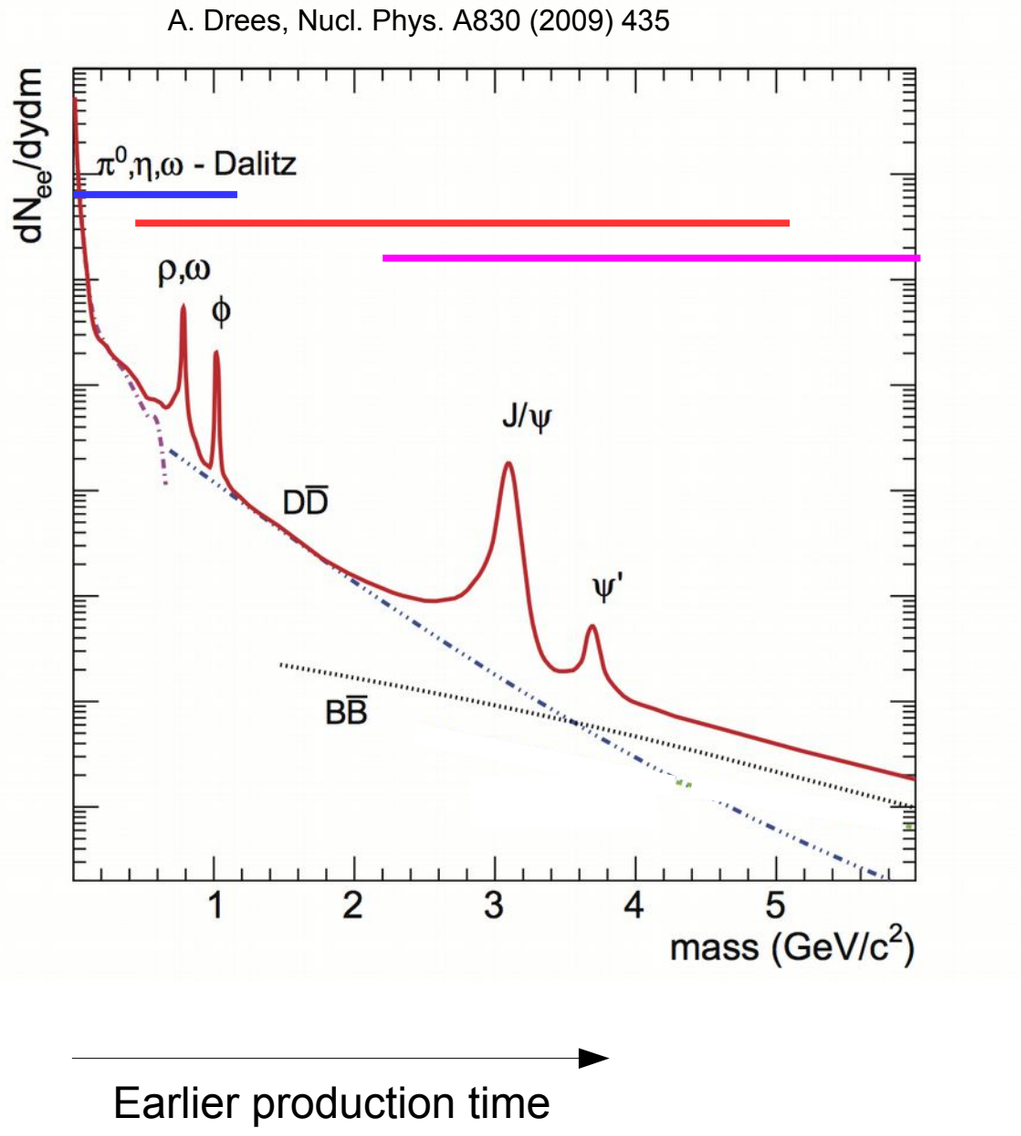
on behalf of the ALICE Collaboration

July 6, 2017, EPS Conference on High Energy Physics, Venice, Italy

Dielectrons

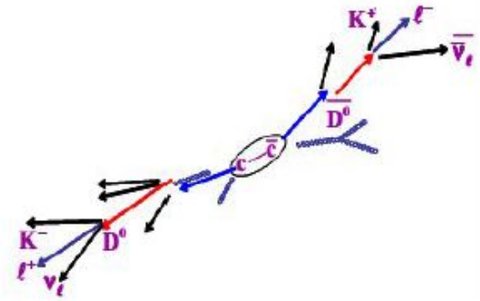


- Unaffected by strong interactions
- Produced during all stages of the collisions

→ Approximate mass ordering of the production time

pp collisions (vacuum baseline for Pb-Pb studies):

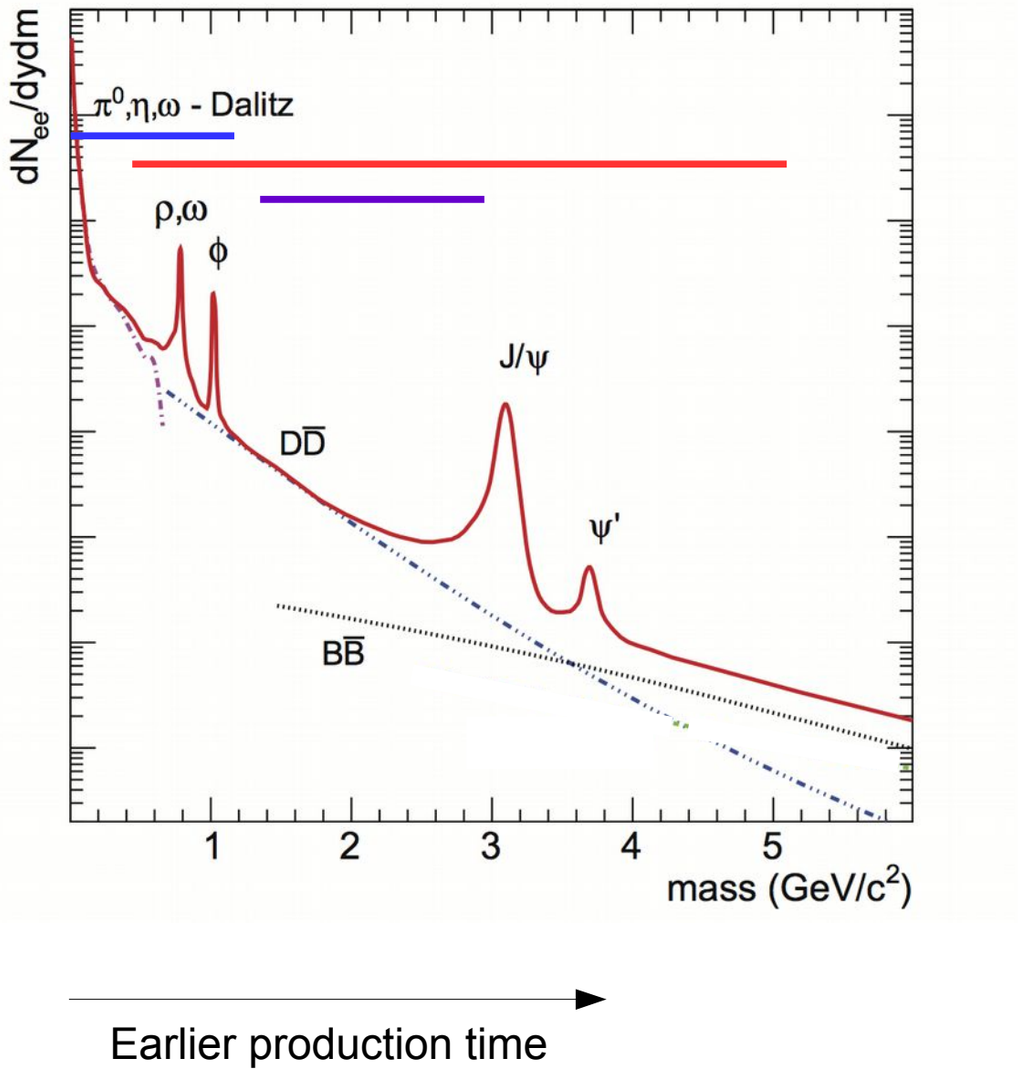
- Measure Dalitz decay of mesons (π^0,η,ω,η',Φ) and 2-body resonance decays (ρ,ω,Φ)
- Study virtual direct photons ($\Upsilon_{dir}^{*} \rightarrow e^+e^-$)
  - Complementary to real photon measurements
  - Test pQCD
- Heavy-Flavour production via $c\bar{c}$ and $b\bar{b}$ decays (complementary to other HF analyses)



- Quarkonia (not the subject of this talk)

Dielectrons

A. Drees, Nucl. Phys. A830 (2009) 435



Earlier production time

p-Pb collisions: study cold nuclear matter effects

Pb-Pb collisions:

- In-medium modification of vector mesons (connected to chiral symmetry restoration? P.M. Hohler and R. Rapp, Phys. Lett. B 731 (2014) 103)
- Virtual direct photons and contribution from thermal radiation from the medium at low p_T

- Energy loss of correlated charm and beauty quarks

- Thermal radiation from the Quark-Gluon Plasma: $dN/dm_{ee} \sim \exp(-m_{ee}/T)$ (no Doppler shift)

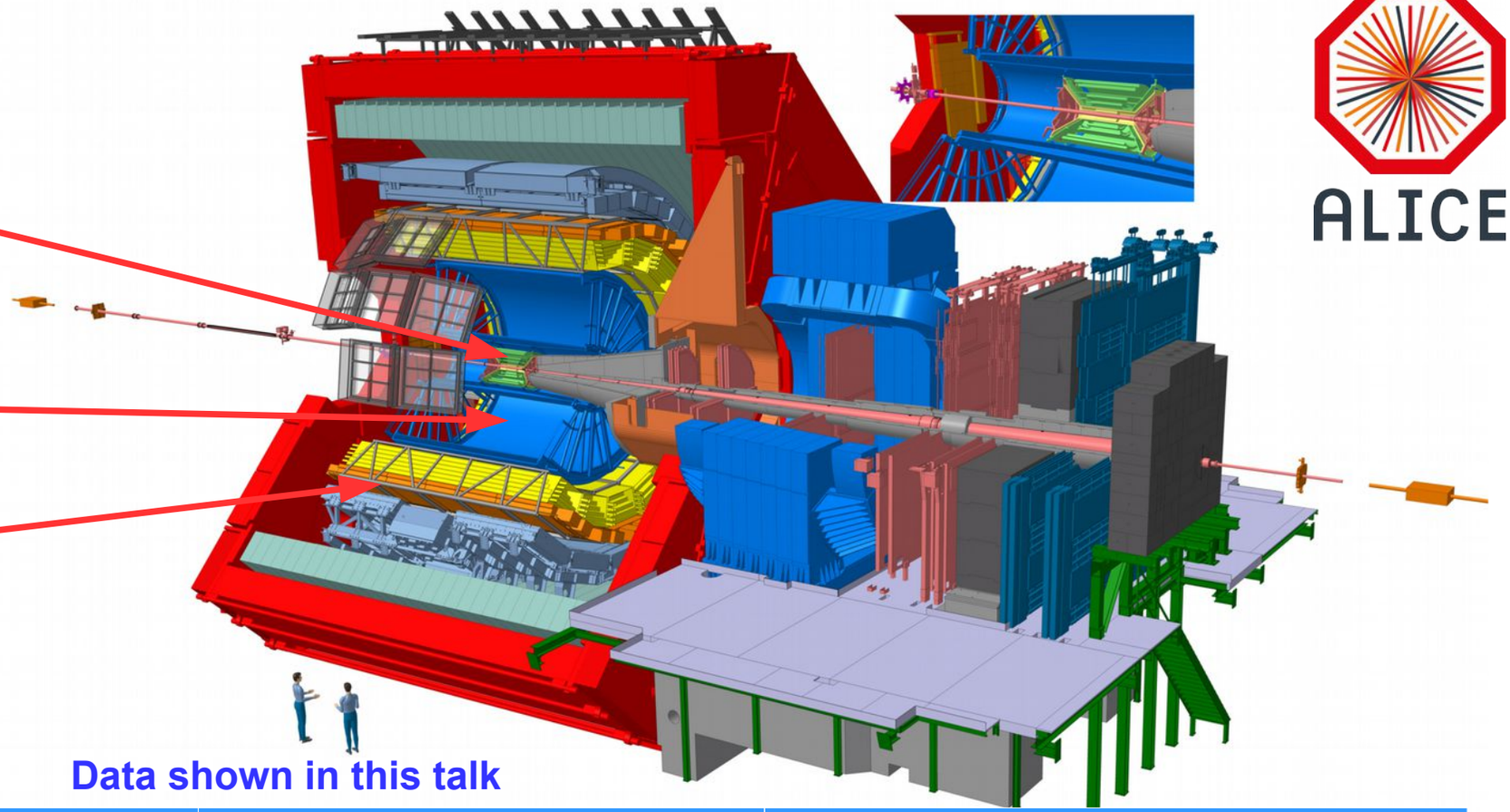
ALICE experiment

Inner Tracking System
- Tracking
- Vertexing
- Particle IDentification
  (via d*E*/d*x* in silicon layers)

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

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

V0: centrality estimator and trigger

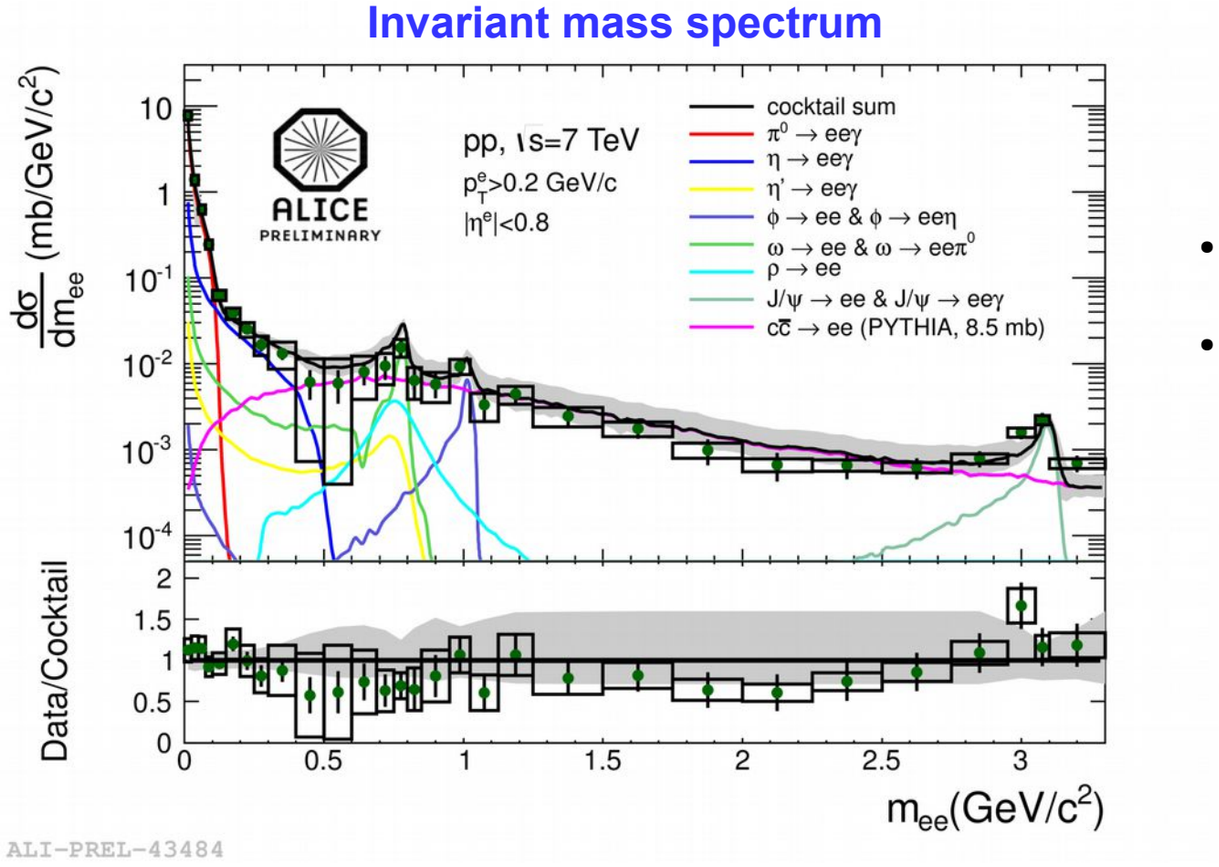


Data shown in this talk

Collision system	Year	Number of events	Trigger
pp at $\sqrt{s}$ = 7 TeV	2010 (Run-1)	≈ 370 M (L_{int} ≈ 6 nb^{-1})	Minimum bias
pp at $\sqrt{s}$ = 13 TeV	2016 (Run-2)	≈ 104 M (L_{int} ≈ 1.8 nb^{-1}) ≈ 48 M (L_{int} ≈ 832 nb^{-1})	Minimum bias high-multiplicity trigger
p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV	2013 (Run-1)	≈ 105 M (L_{int} ≈ 48 μb^{-1})	Minimum bias
Pb-Pb at $\sqrt{s}$ = 2.76 TeV	2011 (Run-1)	≈ 20 M (L_{int} ≈ 23 μb^{-1})	Centrality trigger 0-10%

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

Invariant mass spectrum



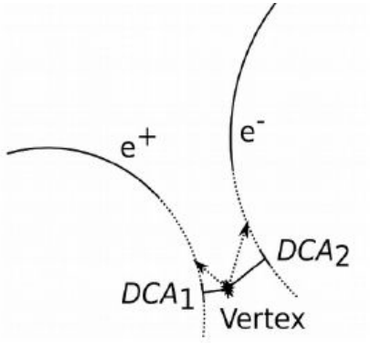
- **Corrected e^+e^- spectrum in the ALICE acceptance**
- **Cocktail of known hadronic sources:**
  - Measured π^0,η,η',ρ,ω,Φ,J/ψ spectra taken as input.
  - Other light contributions: m_T scaling
  - $c\bar{c}$ and $b\bar{b}$: PYTHIA 6 scaled to measured $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$
    ALICE Collaboration, arXiv:1702.00766 to be published in EPJC
    LHCb Collaboration, Eur. Phys. J. C71 (2011) 1645

- **Cocktail** of known hadronic sources **consistent with data within uncertainties**
  (Same analysis ongoing in pp collisions at $\sqrt{s}$ = 13 TeV)
- **More differential studies** as a function p_T^{ee} and DCA_{ee} ongoing

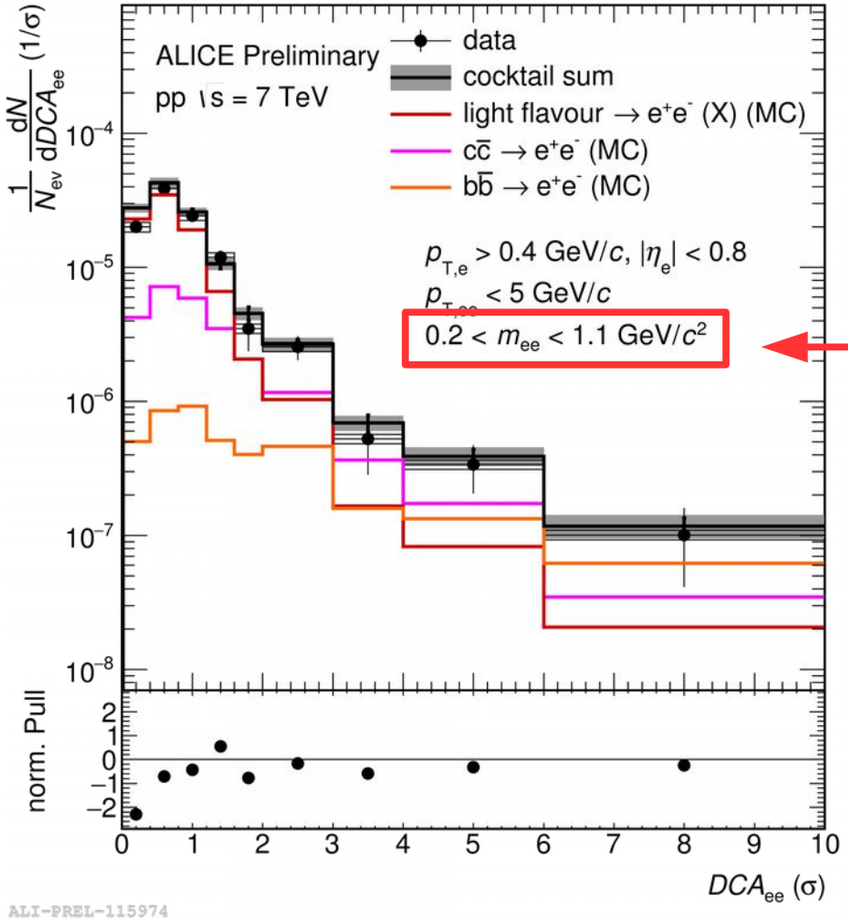
DCA_{ee} analysis in pp at $\sqrt{s}$ = 7 TeV

Observable: $DCA_{ee} = \sqrt{\frac{DCA_1^2 + DCA_2^2}{2}}$

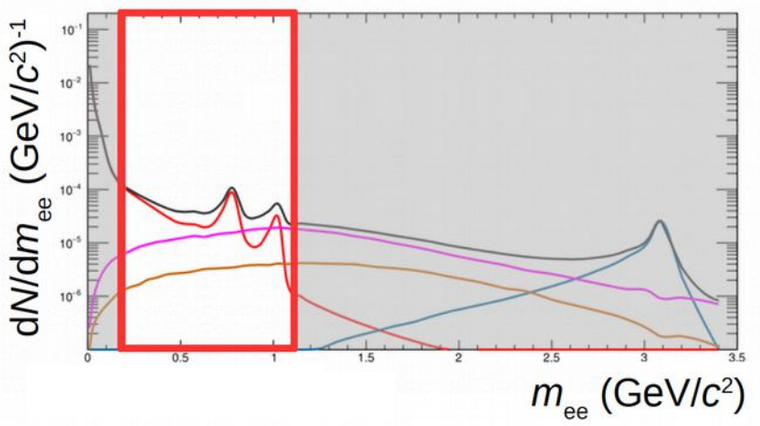
DCA_i=Distance-Of-Closest-Approach to primary vertex of electron *i*



non-prompt



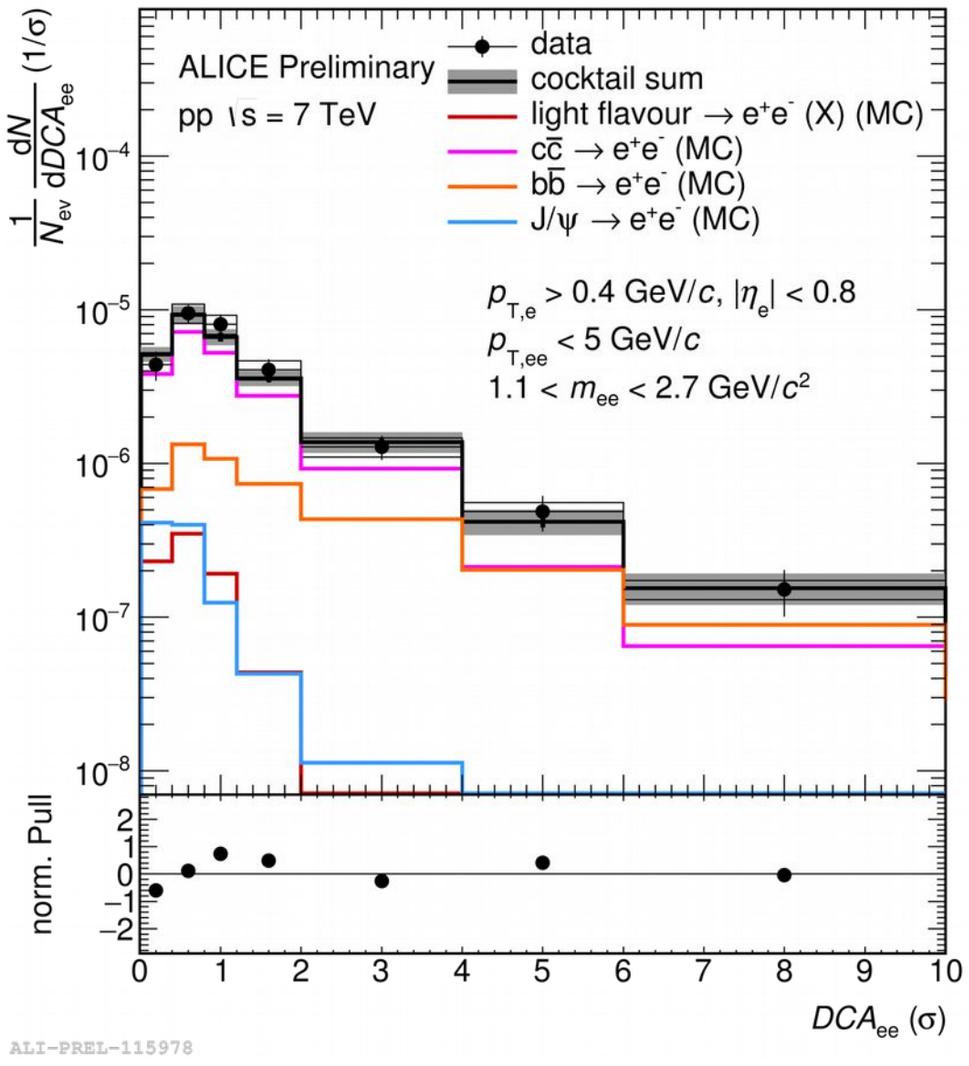
- **Compare measured DCA_{ee}** distributions **with DCA_{ee}** templates **from full MC simulations** normalized to the cocktail

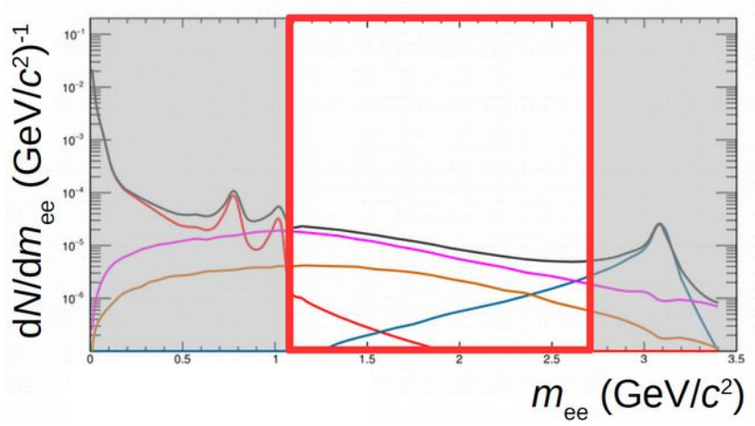


- **Low mass region** (**0.2< m_{ee}<1.1 GeV/c^2**)
  = mixture of prompt and non-prompt sources
  - **Need heavy flavour** ($c\tau \approx$ 100-500 μm) **to describe the tail of the distribution**

→ Can separate prompt and non-prompt sources

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





Intermediate-mass region (IMR, 1.1< m_{ee}<2.7 GeV/c^2)

Dominated by heavy-flavour contributions

- No hint of prompt sources
- **$b\bar{b}$** contribution dominates **at large DCA_{ee}**

($c\tau$(B)≈ 470 μm, $c\tau$(D)≈ 150 μm)

→ Separate $c\bar{c}$ and $b\bar{b}$

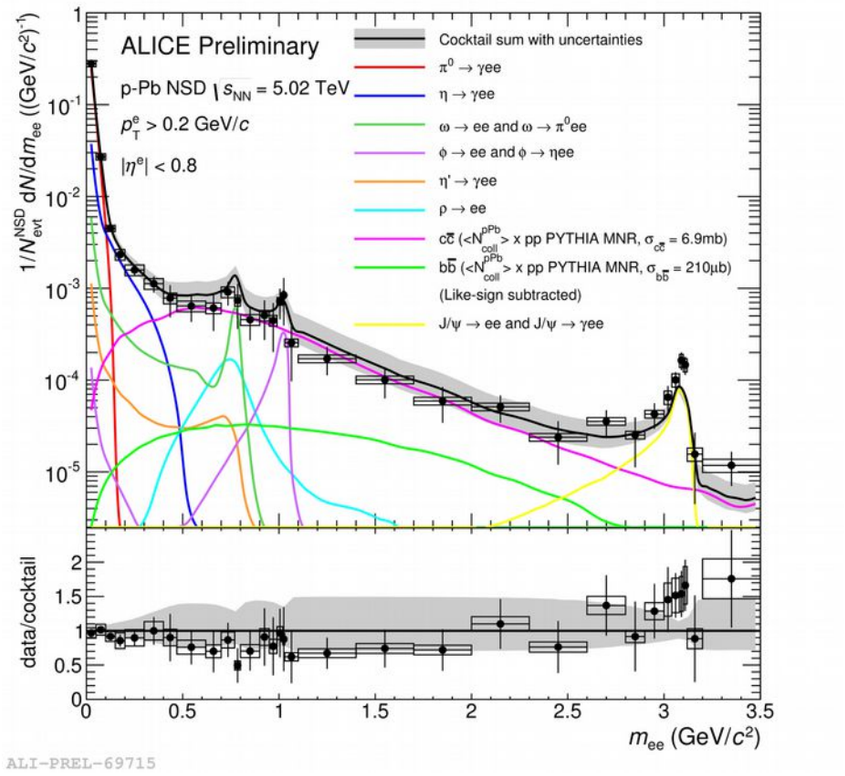
Paper in preparation:

- e^+e^- production as a function of m_{ee}, p_T^{ee} and DCA_{ee}
- Study of heavy-flavour production
- Direct virtual photon study

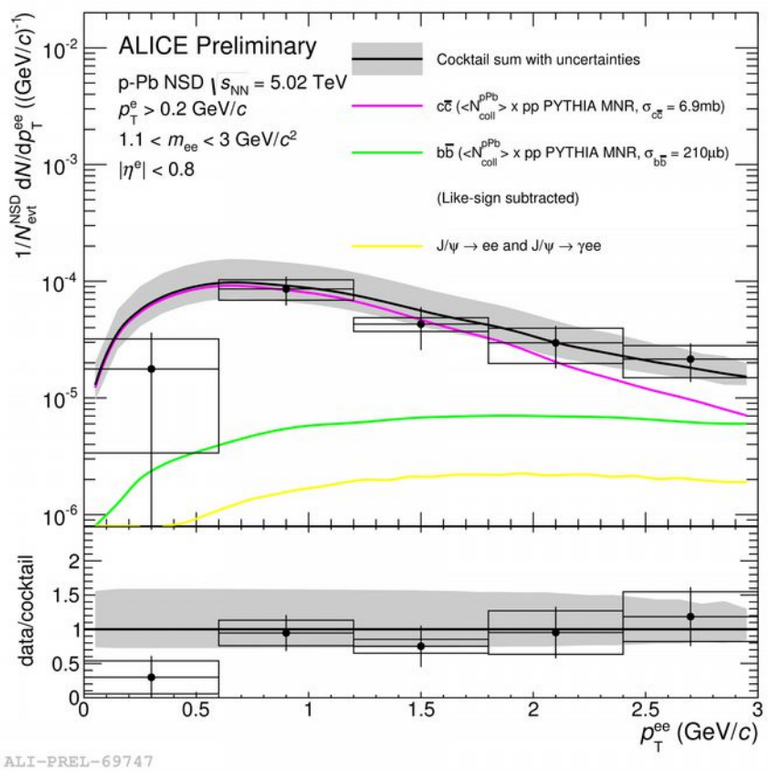
p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

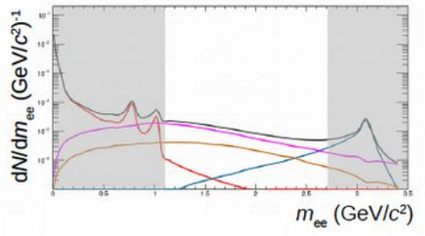
Differential analysis in m_{ee} and p_T^{ee} with Run-1 data:

Invariant mass spectrum



p_T^{ee} spectrum in the Intermediate Mass Region





$b\bar{b}$ increases with p_T^{ee}

→ **Disentangle $c\bar{c}$ and $b\bar{b}$**

- **Data consistent with cocktail** within uncertainties
- **Hint for smaller charm production** (compared to N_{coll} scaling): **cold nuclear matter effect ?**

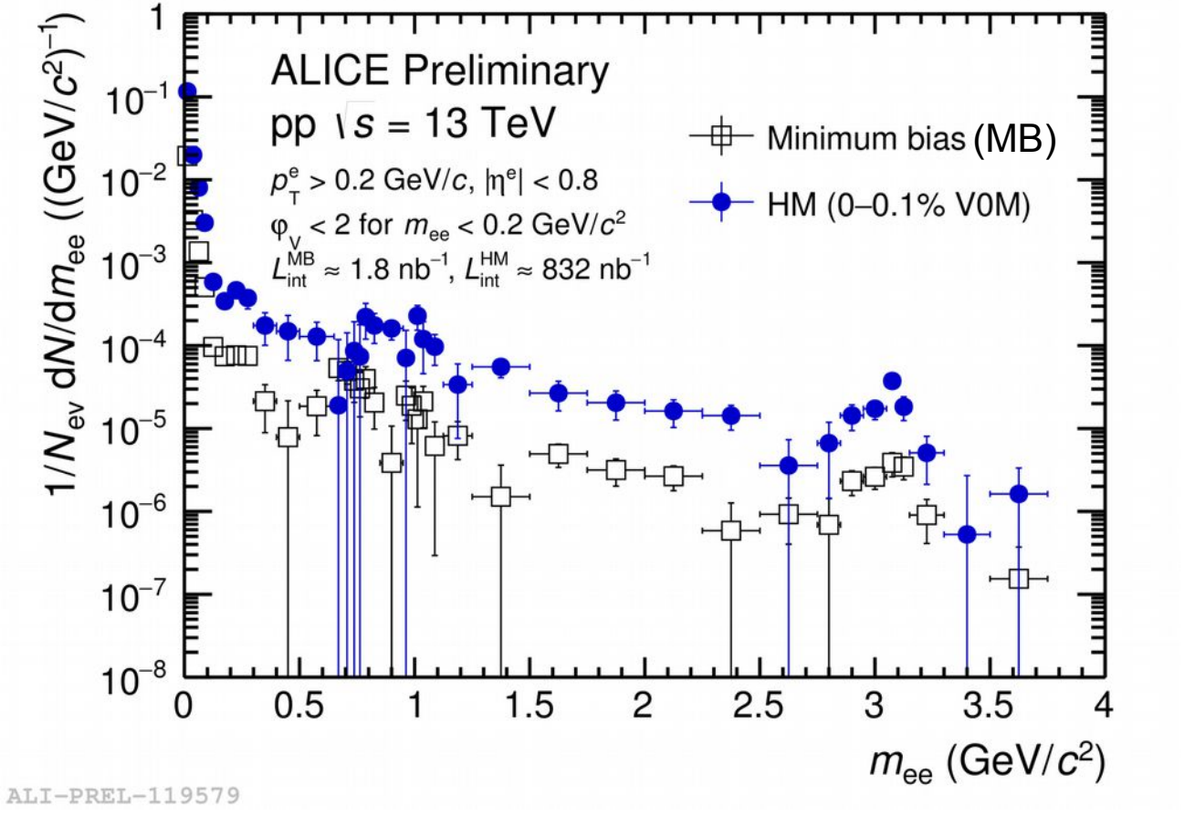
About **5 times more statistics in Run 2** data: m_{ee}, p_T^{ee} and DCA_{ee} studies going to higher p_T^{ee}

pp at $\sqrt{s}$ = 13 TeV: High-Multiplicity studies

New (or heavy-ion like) phenomena in High-Multiplicity (HM) pp events:

- **Production/destruction of ρ mesons**
- Multiplicity scaling of light hadrons, open heavy flavours and direct photons: understanding of **Multiple Parton Interactions**
- **Thermal radiation (if any)** in HM events

→ **Compare dielectron yield** (uncorrected) **in MB and HM pp collisions**



Charged-particle multiplicity at mid-rapidity (|y|<0.5):

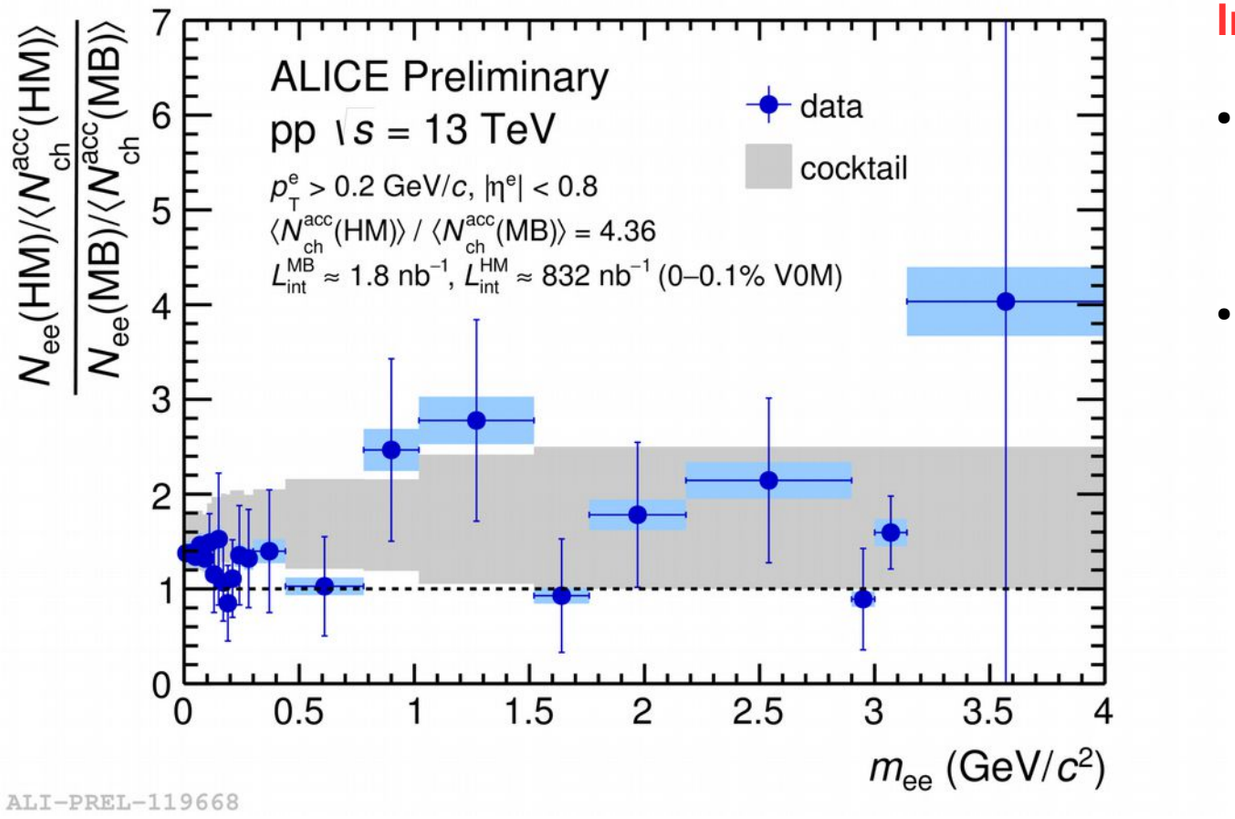
$\langle N_{ch}^{acc}(MB)\rangle$ = 7.3

$\langle N_{ch}^{acc}(HM)\rangle$ = 32 ($\langle N_{ch}^{acc}(MB)\rangle$ x 4.36)

Run-2 data

Ratio of dielectron mass spectra

Observable: $\dfrac{N_{ee}(\mathrm{HM}) \,/\, \langle N_{ch}^{acc}(\mathrm{HM})\rangle}{N_{ee}(\mathrm{MB}) \,/\, \langle N_{ch}^{acc}(\mathrm{MB})\rangle}$



Run-2 data

In agreement with cocktail expectations

- **J/Ψ mass region**:
  consistent with parallel J/Ψ analysis
  Talk by J.Crkovska 06.07 at 11:30

- **Intermediate mass region:**
  agrees with D meson results at 7 TeV
  Talk by A. De Caro 06.07 at 11:45
  ALICE Collaboration, JHEP 09 (2015) 148

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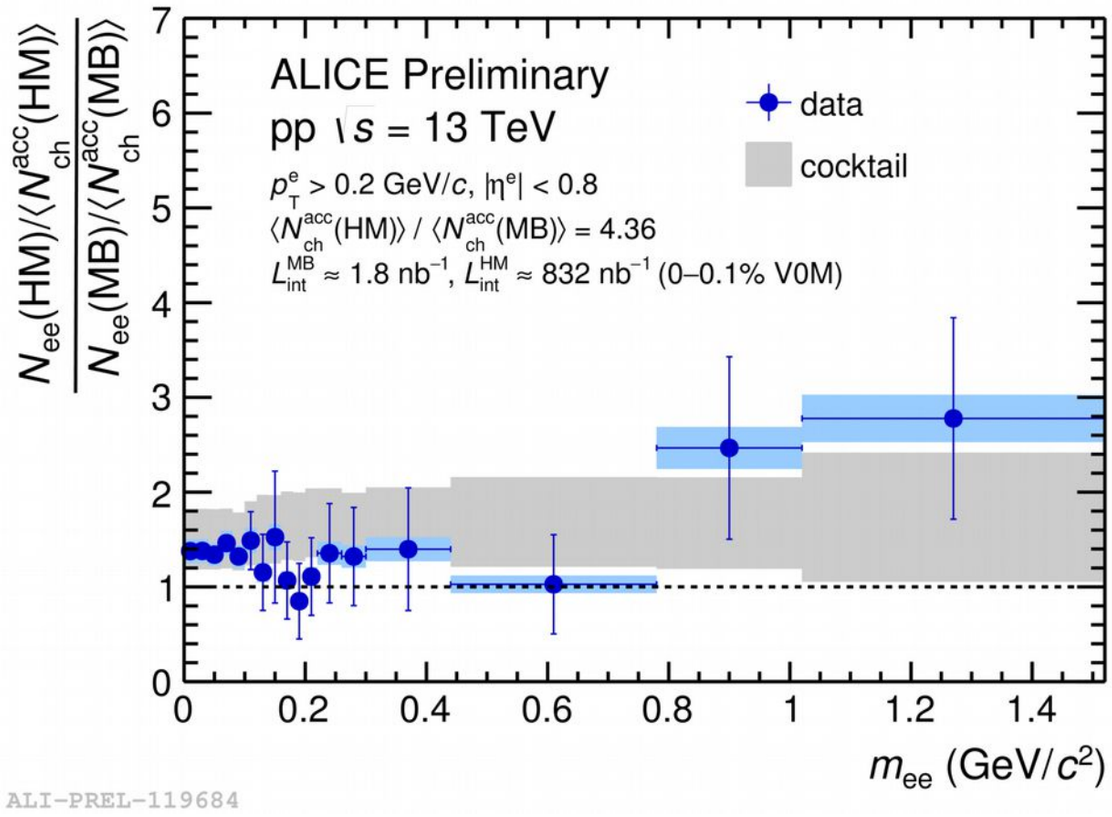

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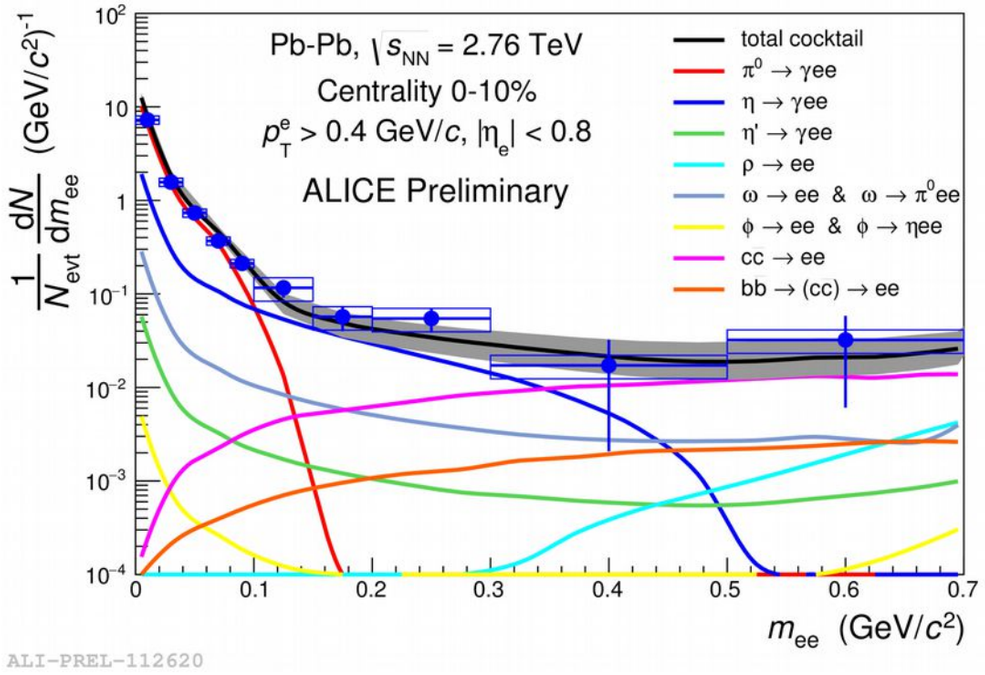
  ALICE Collaboration, JHEP 09 (2015) 148

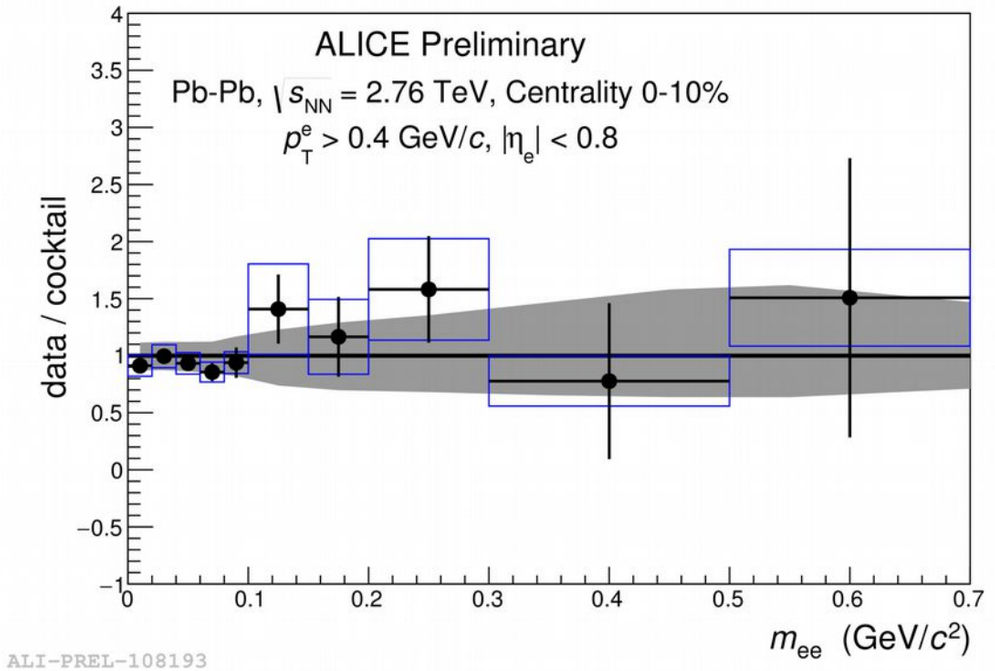
- **π^0 mass region:**
  Ratio > 1, change of hadron p_T spectrum
  ALICE Collaboration, Phys. Lett. B 753 (2016) 319-329

- **Low mass region:**
  More data needed to investigate the spectrum modification in details
  x 5 more pp data recorded in 2016

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

Invariant mass spectrum in 0-10% central Pb-Pb collisions (m_{ee} < 0.7 GeV/c^2)

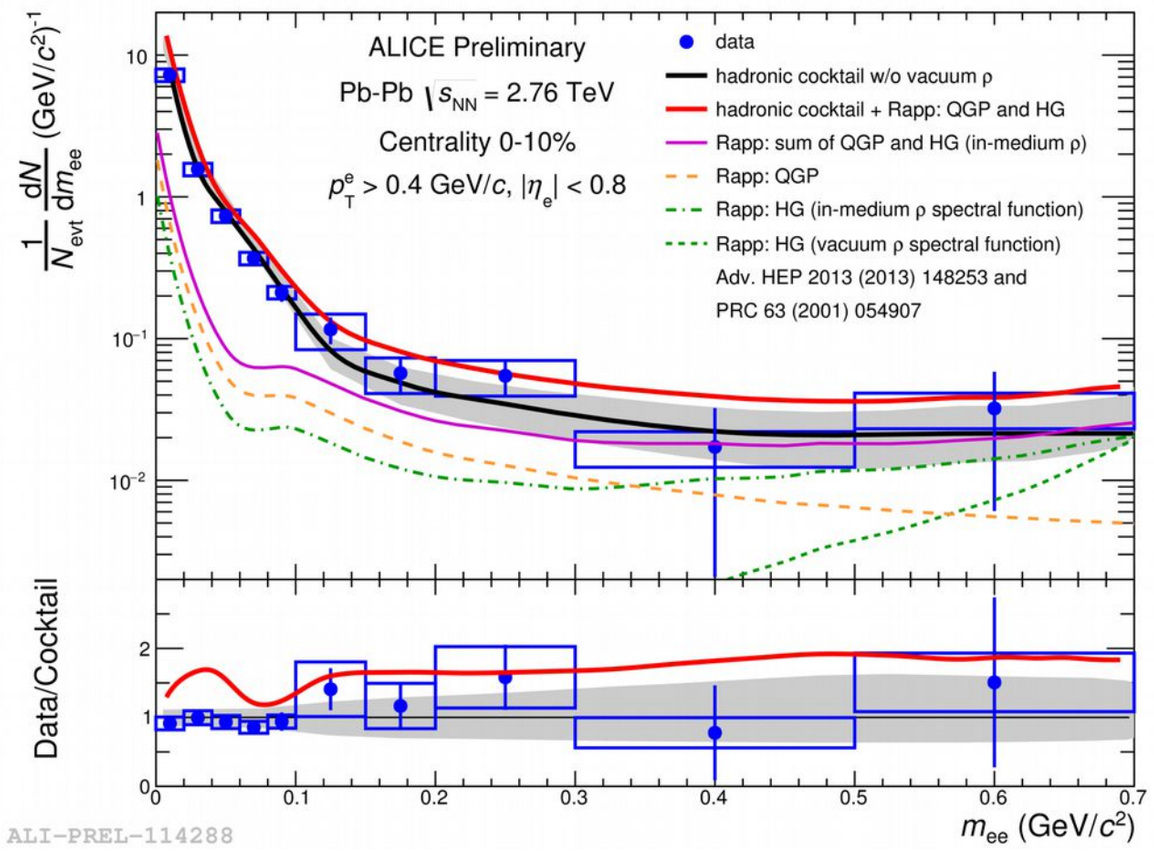




- **Corrected e^+e^- yield in the ALICE acceptance**
- **Cocktail of known hadronic sources:**
  - Measured π^0 spectrum taken as input
  - Other hadrons from m_T scaling
  - Heavy-flavour contributions estimated with PYTHIA normalized to pp measurements x N_{coll}

- **Data compatible with cocktail** within uncertainties
- Is there **room for additional contributions ?**

Theoretical predictions



Data compared to:

- **Cocktail** without vacuum ρ
- **Thermal dielectrons:**
  - from **QGP** (expanding fireball model with T_C = 170 MeV)
  - from **hadron gas** (include in-medium ρ and ω from hadronic many-body theory)

→ **Sum of expected e^+e^- yield in red**

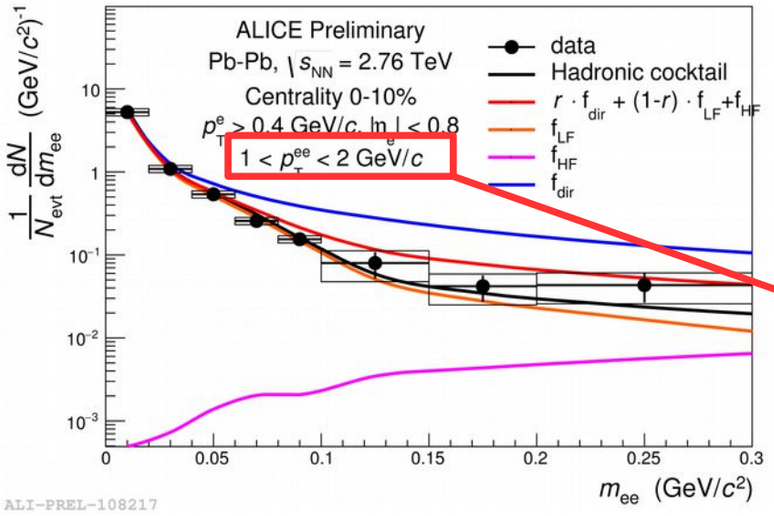
R.Rapp, Adv. High Energy Phys. 2013 (2013) 148253
R.Rapp, Phys. Rev. C63 (2001) 054907

- **No sensitivity yet** for possible thermal radiations from QGP and hadron gas
- **Run-3 (upgrades)** will allow more significant measurements

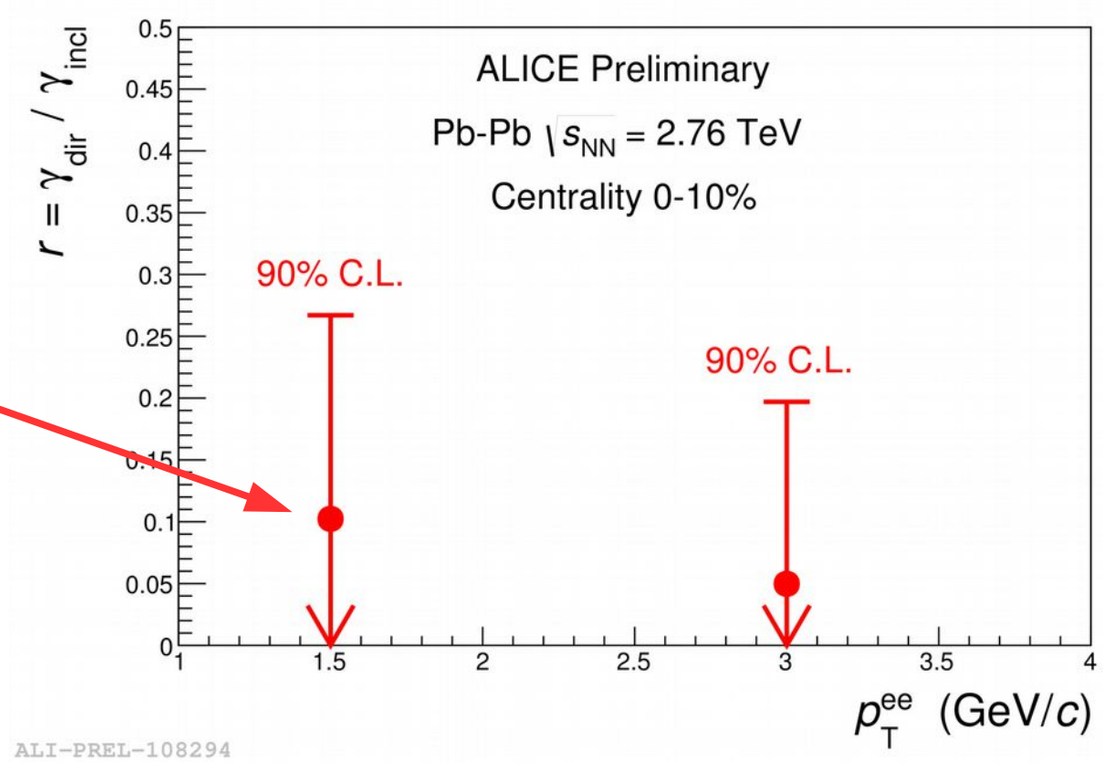
Virtual direct photons

Paper in preparation

Fit the mass spectrum in the mass range [0.1,0.3] GeV/c^2 with :
$f(m_{ee}) = r \cdot f_{dir}(m_{ee}) + (1-r) \cdot f_{LF}(m_{ee}) + f_{HF}(m_{ee})$



r = fraction of direct photons (Y_{dir}^{*} / Y_{incl}^{*})



Direct virtual photons described by the Kroll-Wada equation for $p_T^{ee} >> m_{ee}$:

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

- **Compatible with ALICE real photon** measurements
- **Fraction of direct photons similar to STAR and PHENIX results** ($r \approx 0.1$-0.2) in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

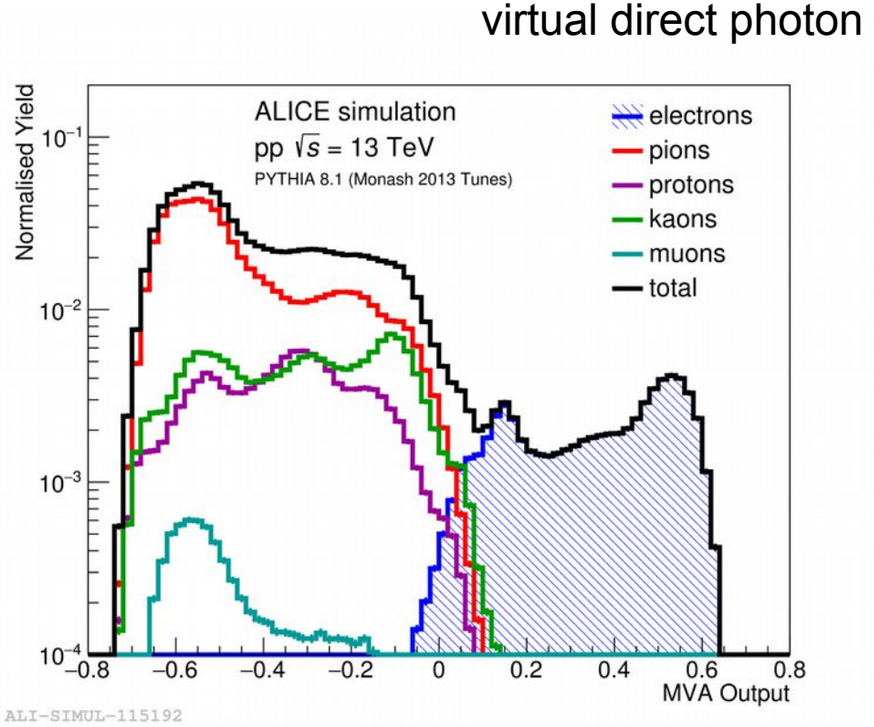
ALICE: Phys. Lett. B 754 (2016) 235-248; PHENIX: Phys. Rev. Lett. 104 (2010) 132301; STAR: Nuclear Physics A 931 (2014) 691-695

Summary and Outlook

pp collisions: results at $\sqrt{s}$ = 7 &13 TeV described by cocktail of known hadronic sources
virtual direct photon, heavy-flavour, MB and HM studies ongoing

p-Pb collisions: results at $\sqrt{s_{NN}}$ = 5.02 TeV compatible with hadronic cocktail within uncertainties
x 5 more data recorded in Run-2 (study cold nuclear matter effects)

Pb-Pb collisions: results at $\sqrt{s_{NN}}$ = 2.76 TeV compatible with hadronic cocktail within uncertainties
no sensitivity yet for excess in the ρ region → Run-2&3 data
virtual direct photon studies in agreement with real photon measurements



Talk of R. Haake 06.07 at 18:00

PID with multivariate analysis

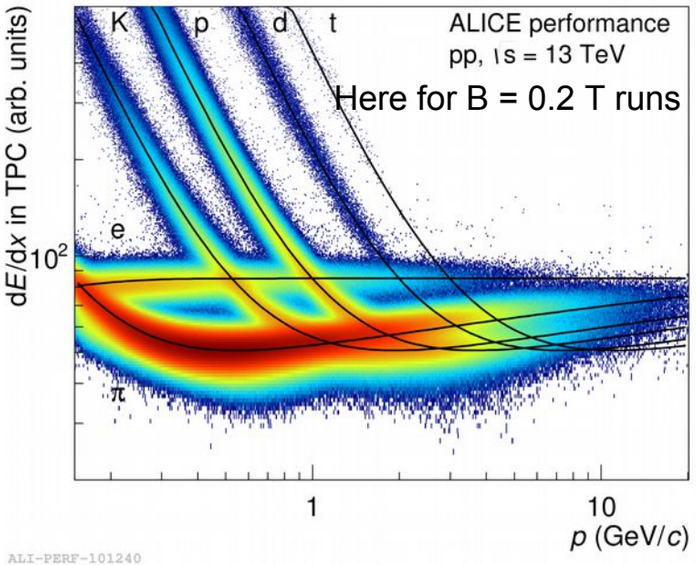
	Efficiency (%)	Purity (%)
Cut Method Efficiency Prioritised	70	91
Cut Method Purity Prioritised	13	99
Multivariate Method	95	96
Momentum integrated (0.2 < p_T < 10 GeV/c)		

- Employ **machine learning methods** to identify $e^{\pm}$ and remove conversion
- **Run-3** after ITS & TPC upgrades: higher rate & background rejection power
  → **measure thermal radiation & ρ in-medium spectral function**
  Talk of C. Lippmann 08.07 at 10:00 and of P. Camerini 08.07 at 9:45

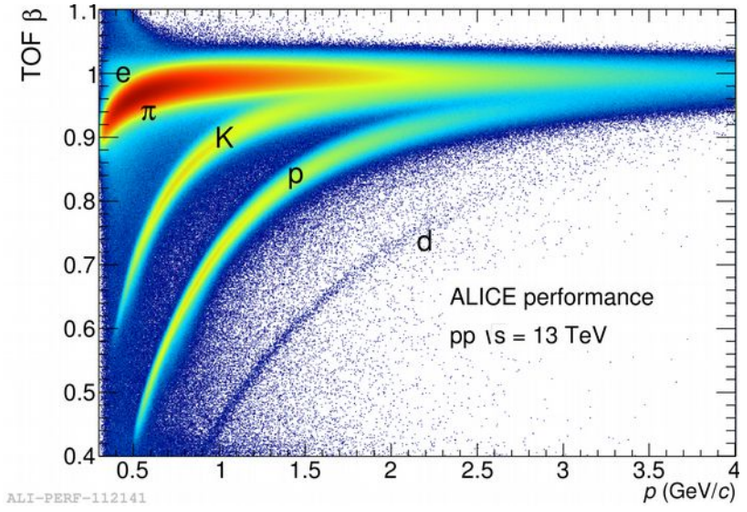
Back-up

Electron Identification

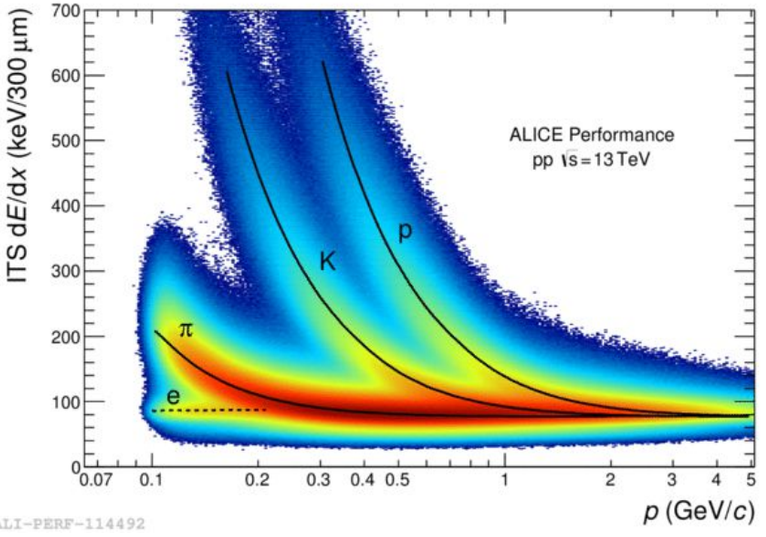
Time Projection Chamber



Time-Of-Flight

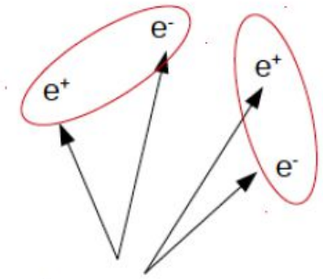


Inner Tracking System

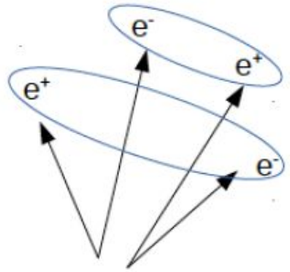


Signal extraction

- Unlike-sign (*ULS*) pairs:
  contains real signal,
  correlated and combinatorial background



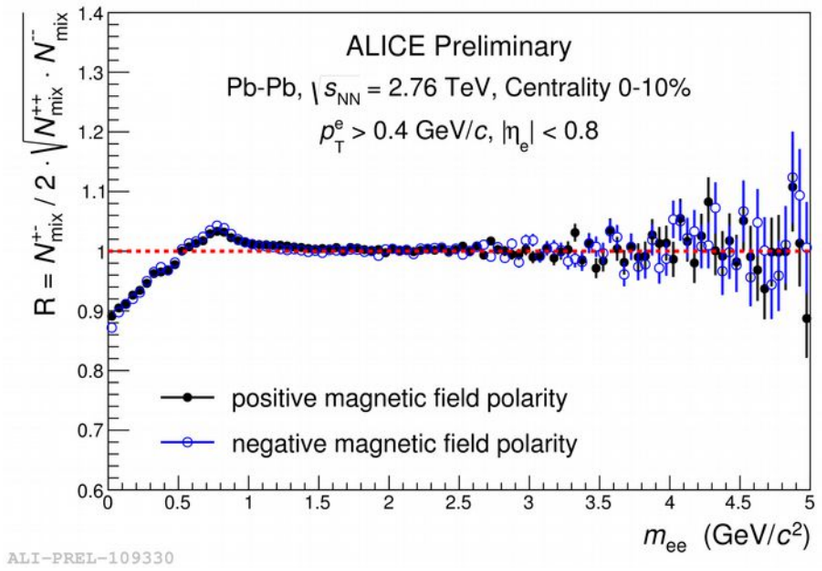
Signal

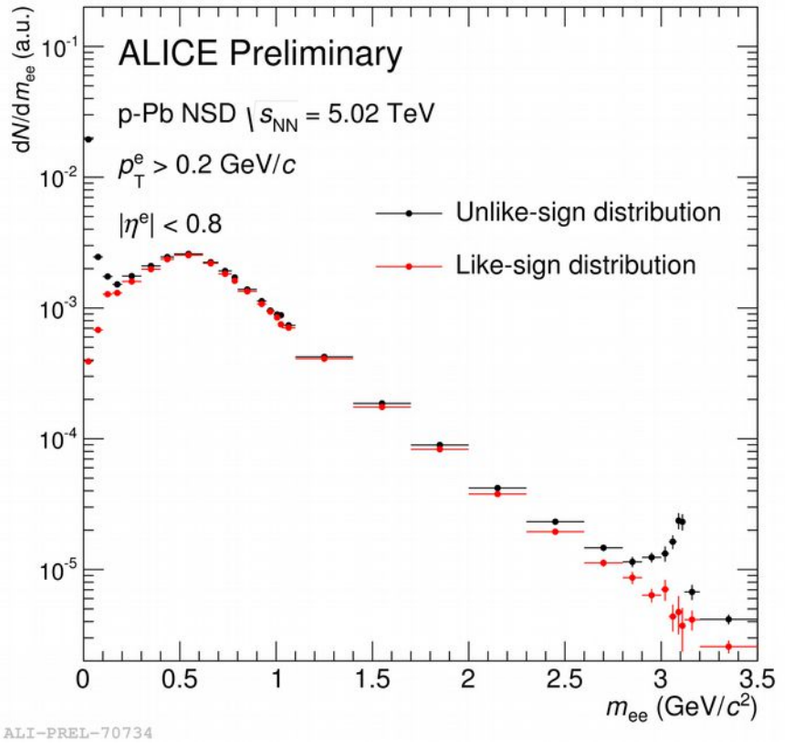


Background

- Like-sign (*LS*) pairs: $2\sqrt{N_{++}.N_{--}}$
  Estimation of correlated and combinatorial background

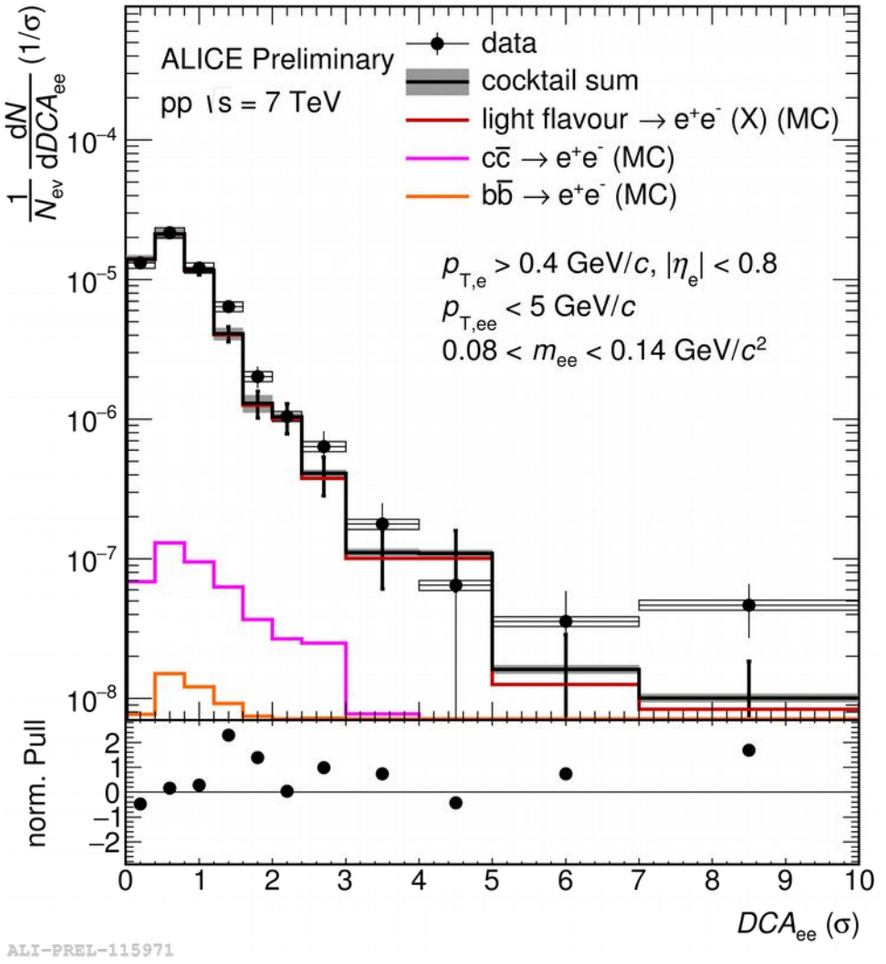
Signal = *ULS* – *LS* . *R*
R: acceptance correction factor
$R = ULS_{mix} / LS_{mix}$



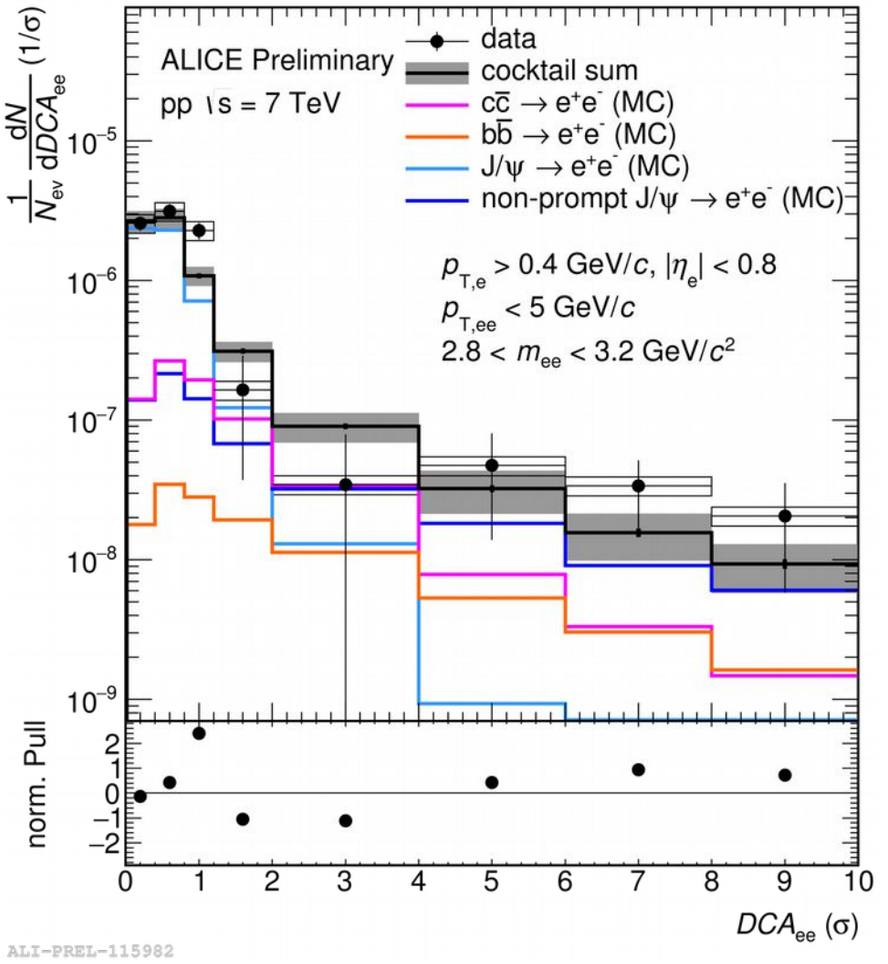


DCA analysis

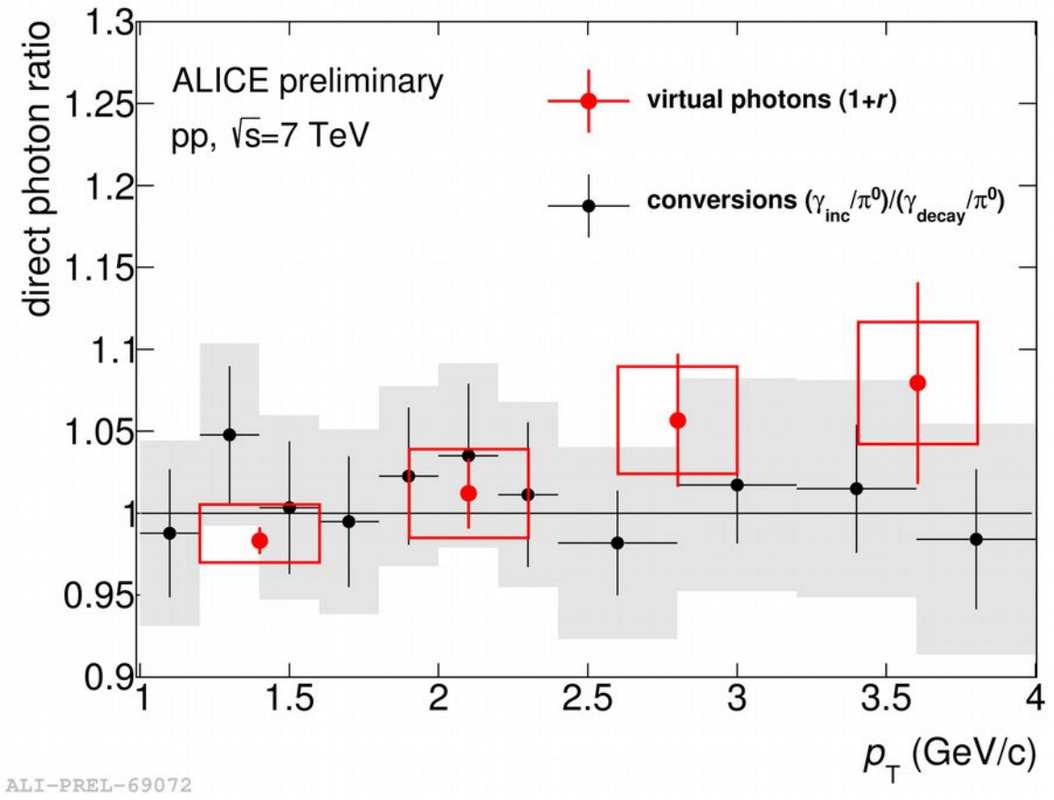
π^0 mass region

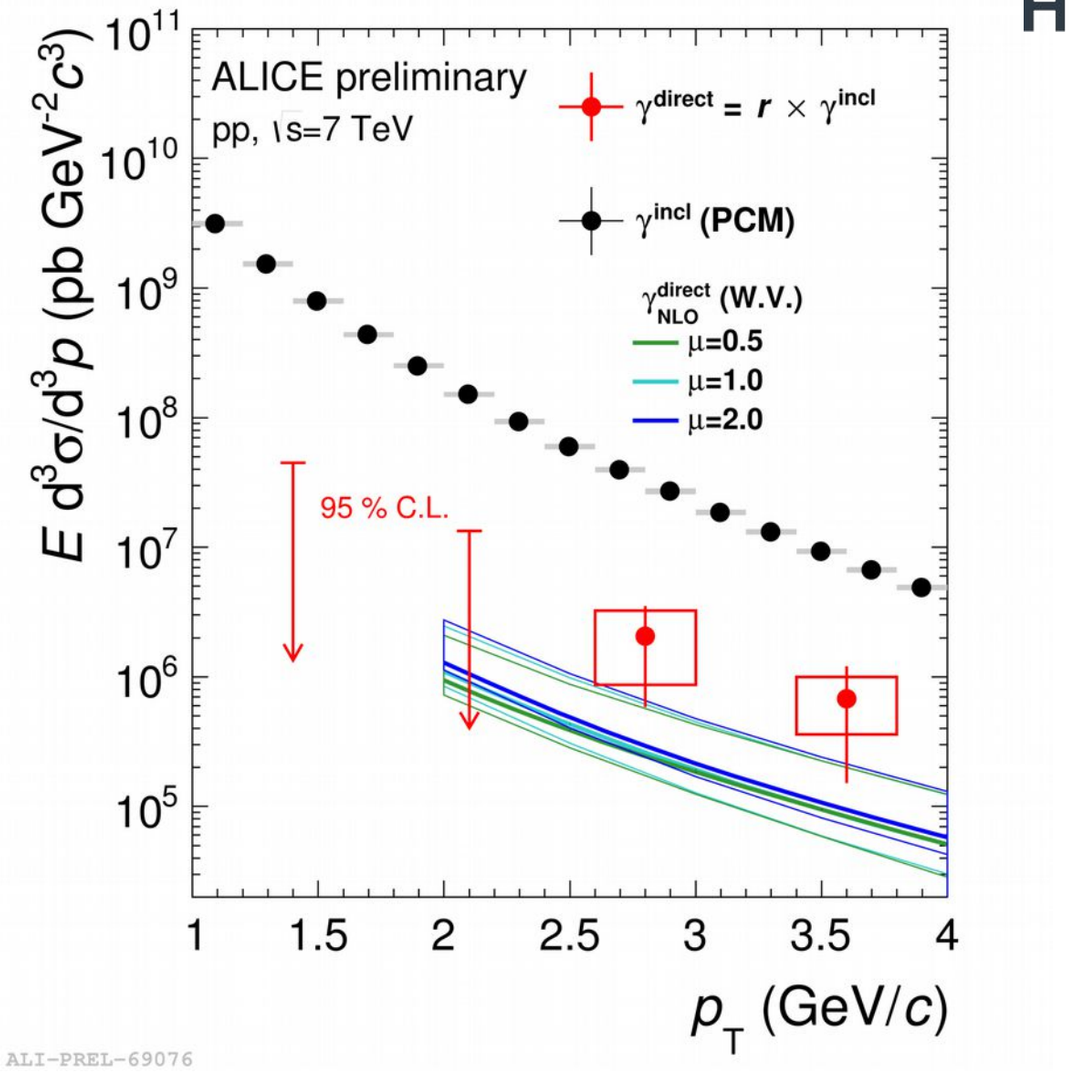


J/ψ mass region

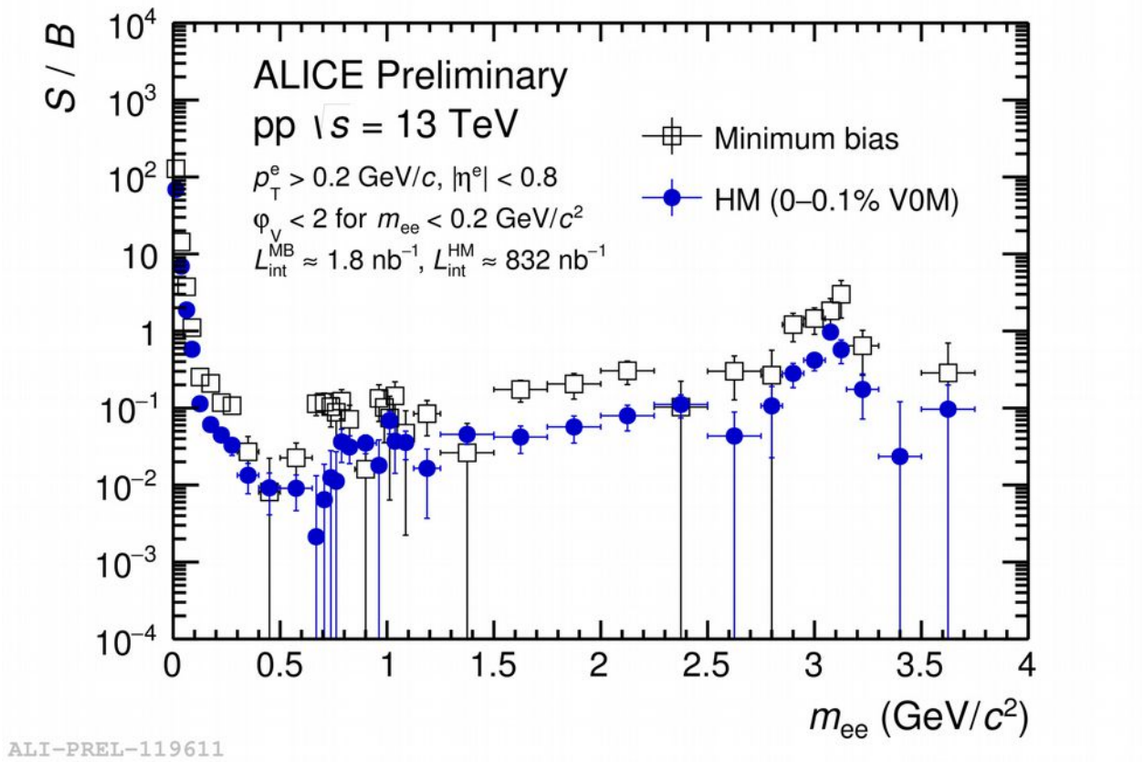


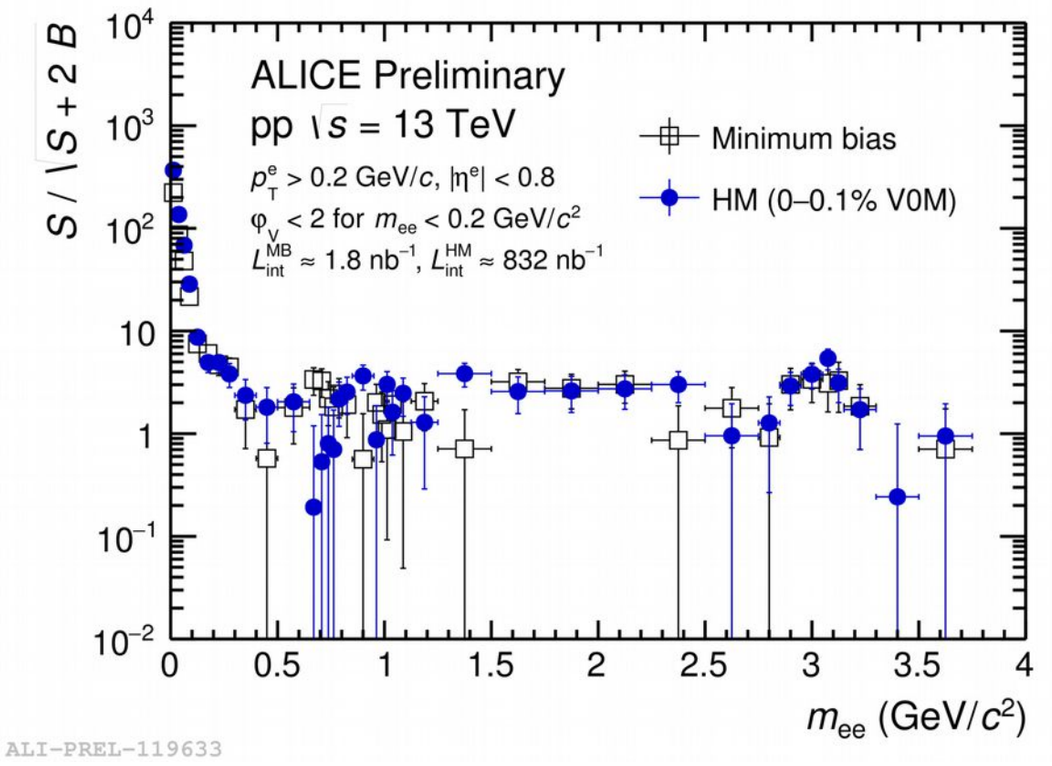
Direct Virtual Photon in pp at $\sqrt{s}$ = 7 TeV





High-multiplicity studies



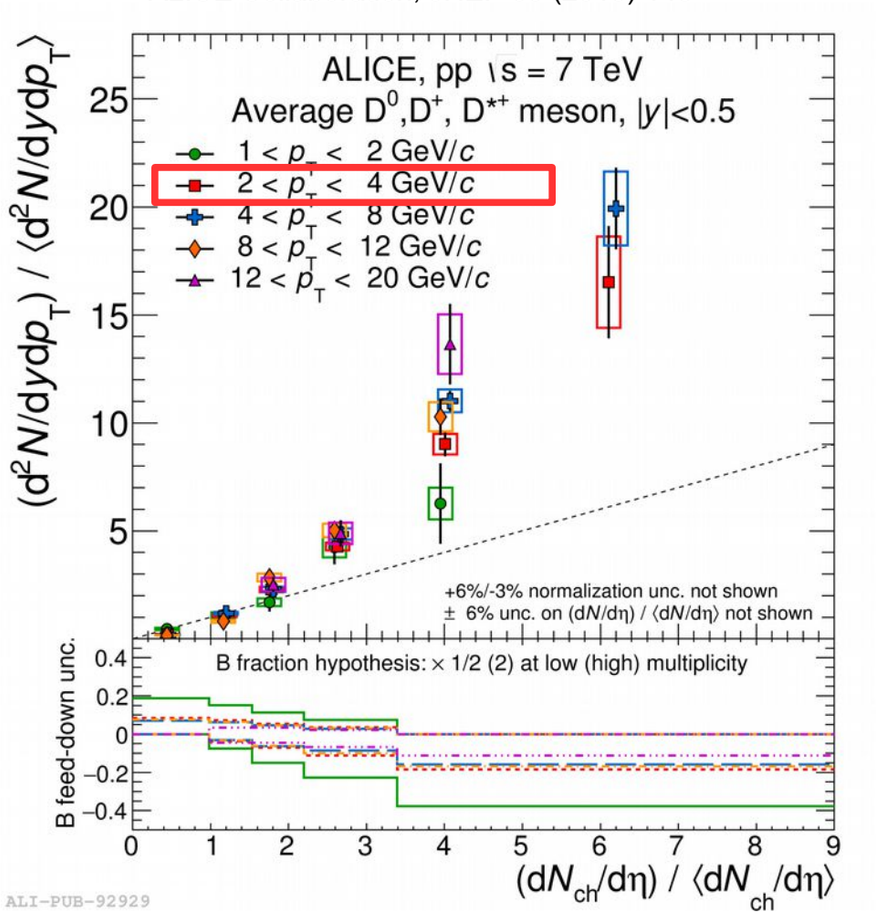


Naive expectation: signal is proportinal to N_{ch}^{acc} and combinatorial background grows like N_{ch}^{2}

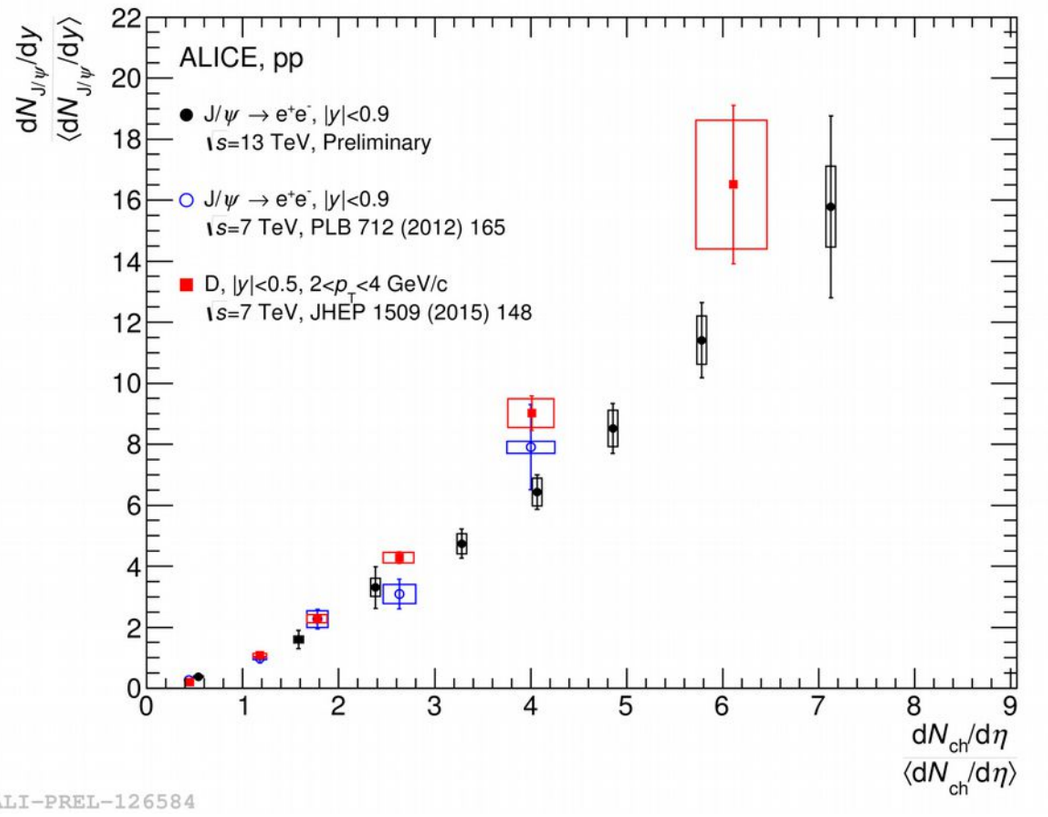
- Signal/background ratio lower for high multiplicity events
- Statistical significance comparable in background-dominated region

Hadronic cocktail in HM pp events

D mesons in pp at $\sqrt{s}$ = 7 TeV
ALICE Collaboration, JHEP 09 (2015) 148

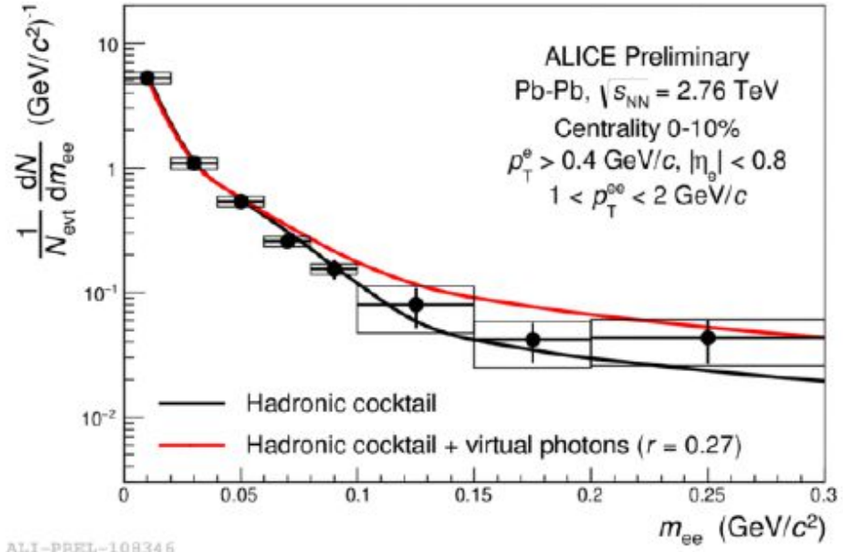


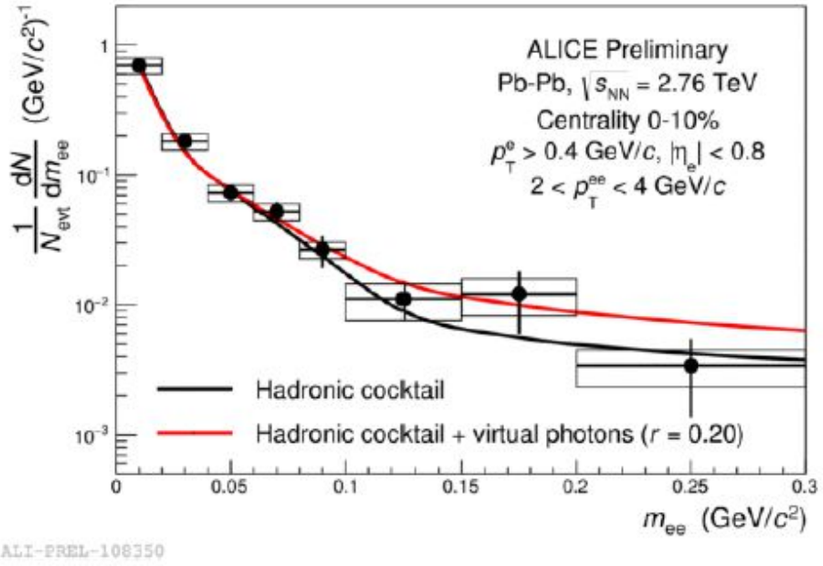
J/Ψ similar to D mesons

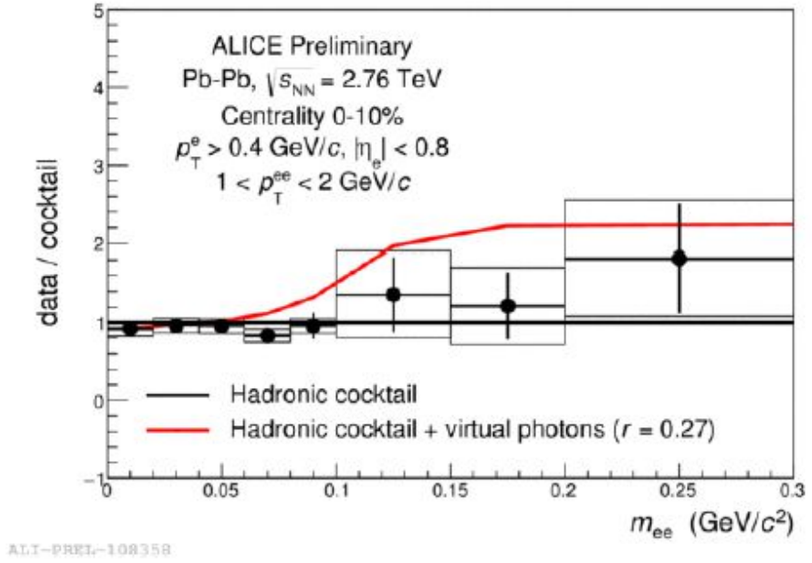


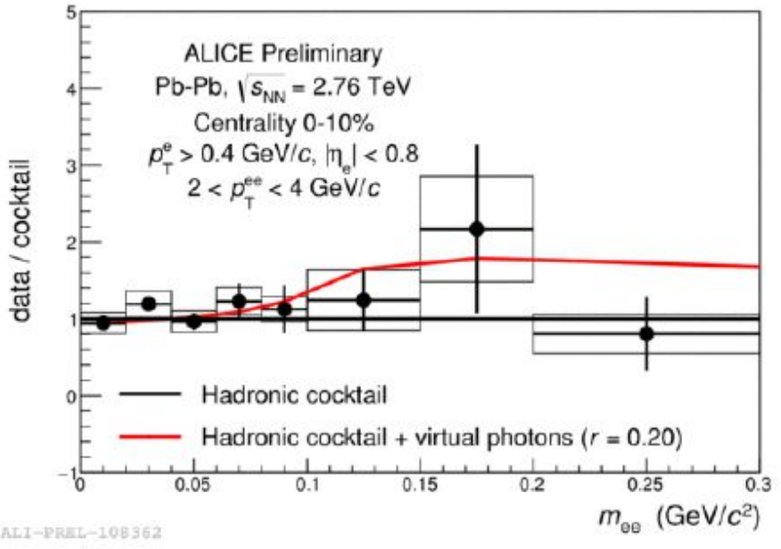
Enhanced factor between 1.2 and 2 for the mean p_T of D mesons observed as function of m_{ee} in PYTHIA and the D meson multiplicity measurements in pp at $\sqrt{s}$ = 7 TeV

Upper Limit on direct virtual photons





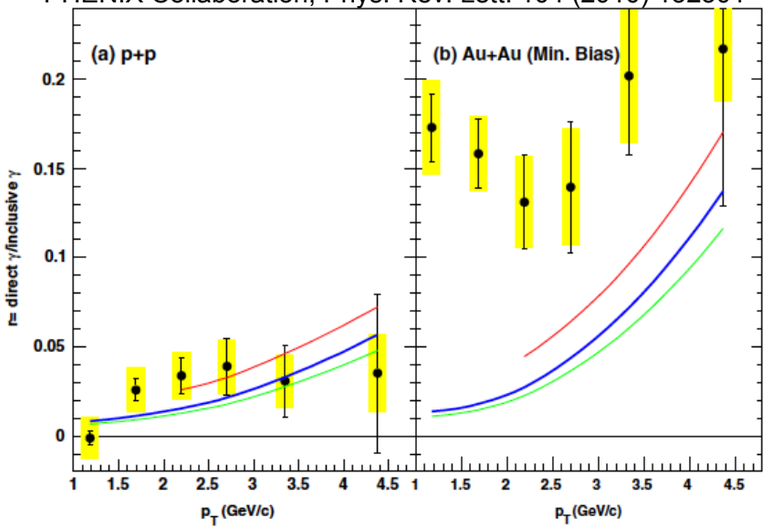




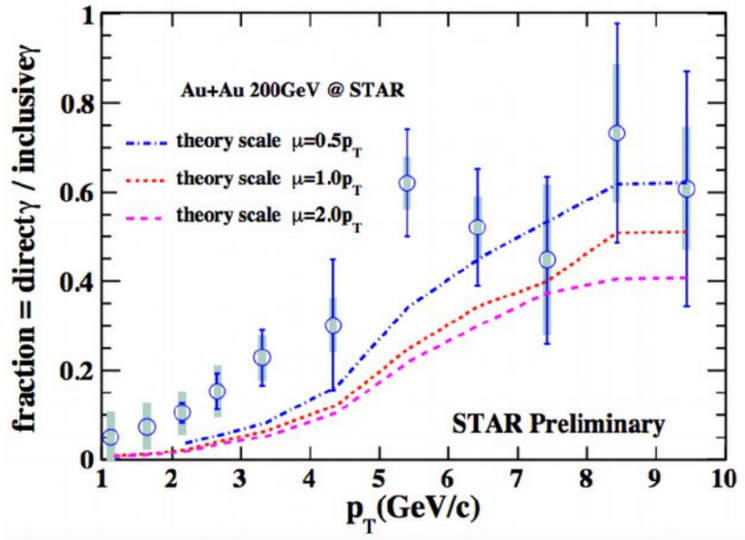
Fraction of direct virtual photons

RHIC

PHENIX Collaboration, Phys. Rev. Lett. 104 (2010) 132301

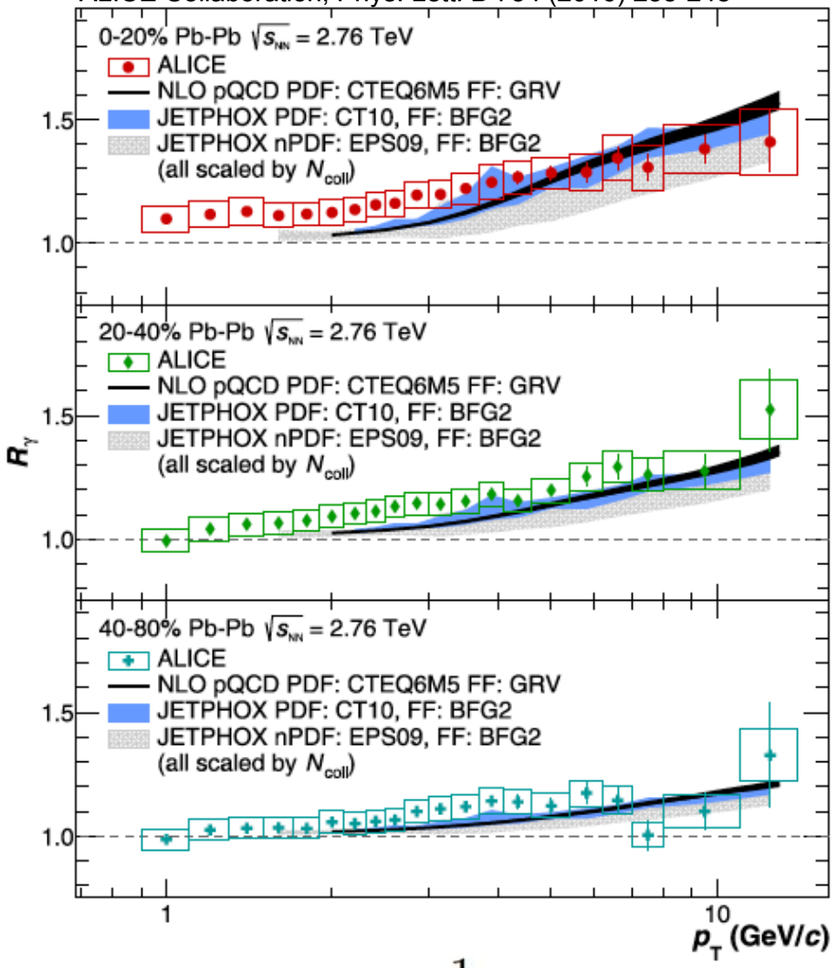


STAR Collaboration, Nuclear Physics A 931 (2014) 691-695



LHC

ALICE Collaboration, Phys. Lett. B 754 (2016) 235-248

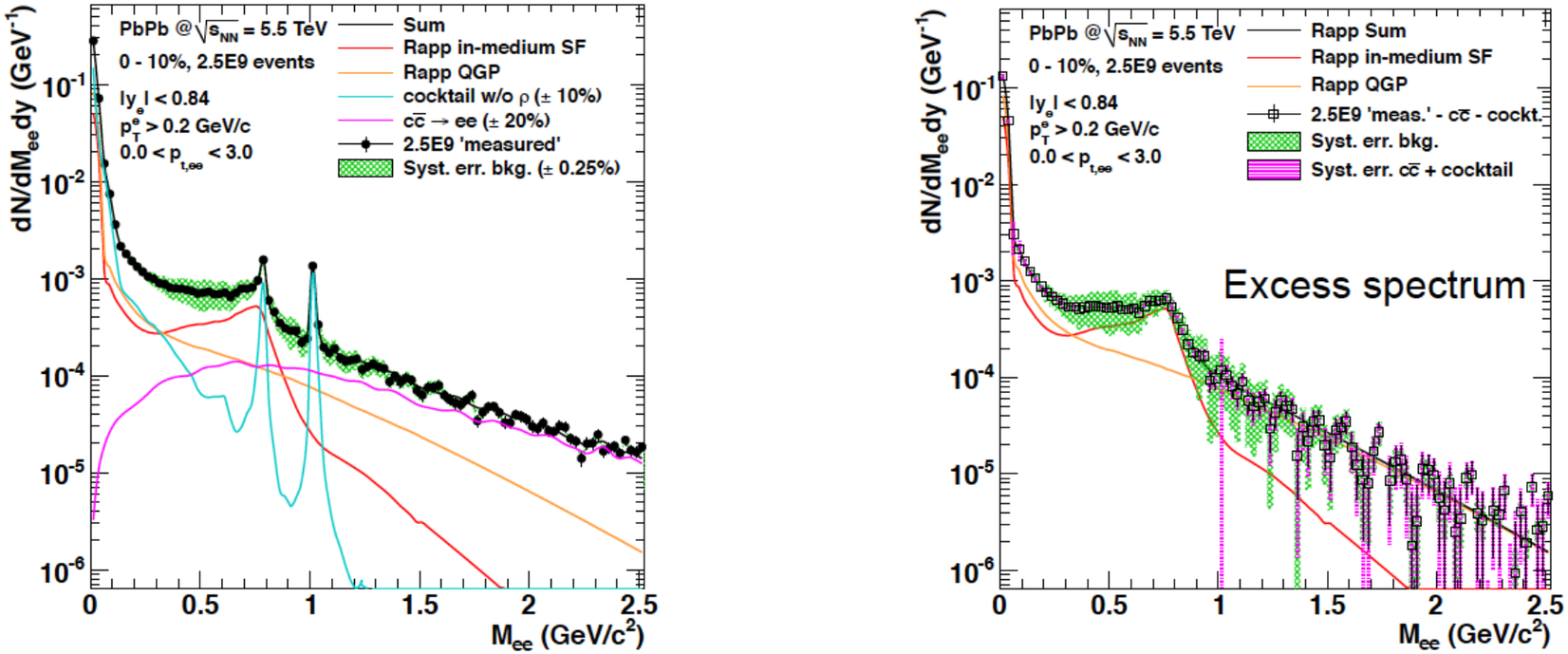


$$r = 1 - \frac{1}{R_\gamma} \approx 0.1$$

Run-3 after upgrades

- **ITS upgrade:**
  - Reduced material budget **(x4)** and improved vertex resolution **(x3)**
- **TPC upgrade:**
  - New readout chamber with GEM foils for continuous readout
  - High acquisition rate up to 50 kHz for Pb-Pb **(x100)**

J. Phys. G 41 (2014) 087002



New ITS, 2.5x10^9 events with *DCA* cuts

Fit for m_{ee}>1.1 GeV/c^2: dN/dm_{ee}~exp(-m_{ee}/T) → slope presicion ±10% stat ±10-20% syst