Low-Mass Dielectron Measurements in pp, p-Pb and Pb-Pb Collisions with ALICE

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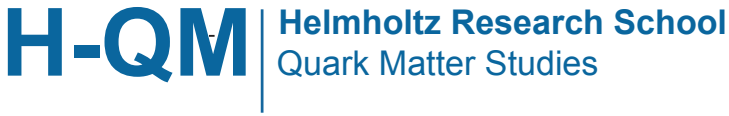
on behalf of the ALICE Collaboration
Institut für Kernphysik, Goethe-Universität Frankfurt
Strangeness in Quark Matter 2015, Dubna
10.07.2015



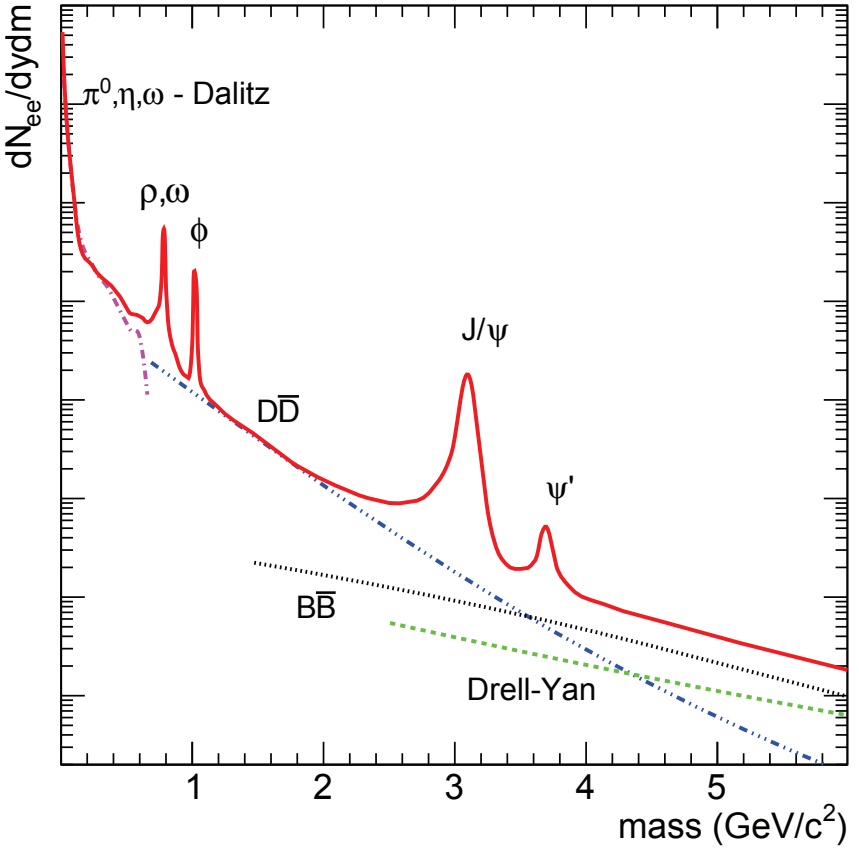
Outline

- Physics Motivation
- The ALICE Detector Setup
- Analysis Techniques
- pp & p-Pb Results
- Status of Pb-Pb Analysis
- Perspectives in Run2 & Run3
- Summary & Outlook

Motivation

Dielectrons in heavy-ion collisions

- emitted throughout the collision
- negligible final-state interaction



A. Drees, Nucl. Phys. A 830, 435c (2009)

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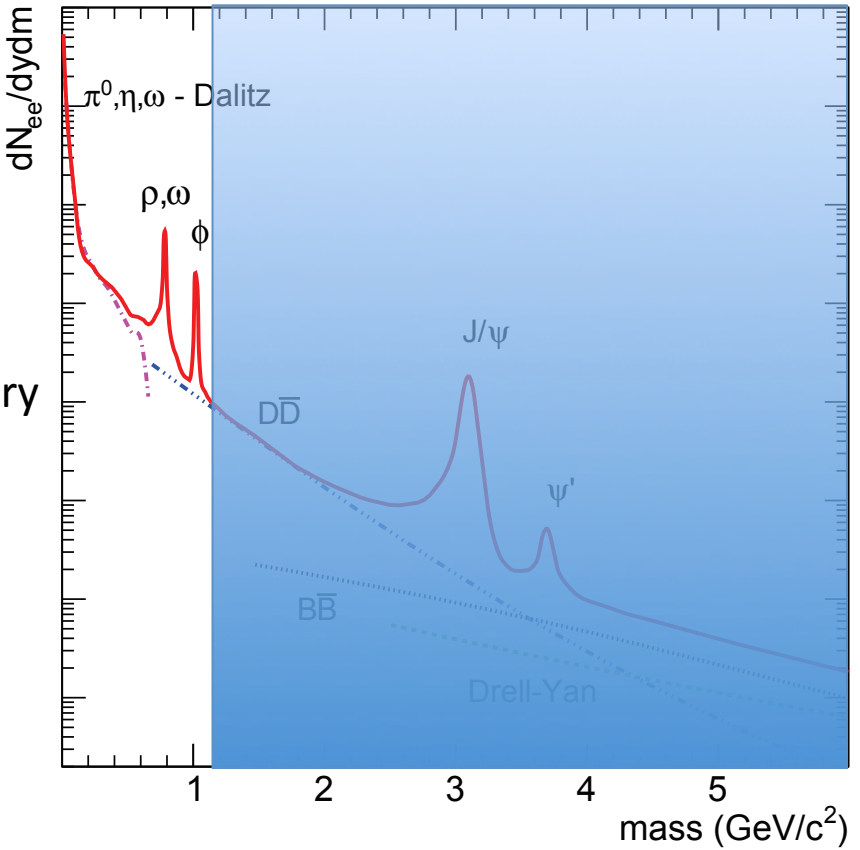
1. **Low-Mass Region (LMR)**

- Dalitz decays (π^0, η, η') & resonances (ρ, ω, ϕ)
- In-medium modifications related to chiral symmetry restoration



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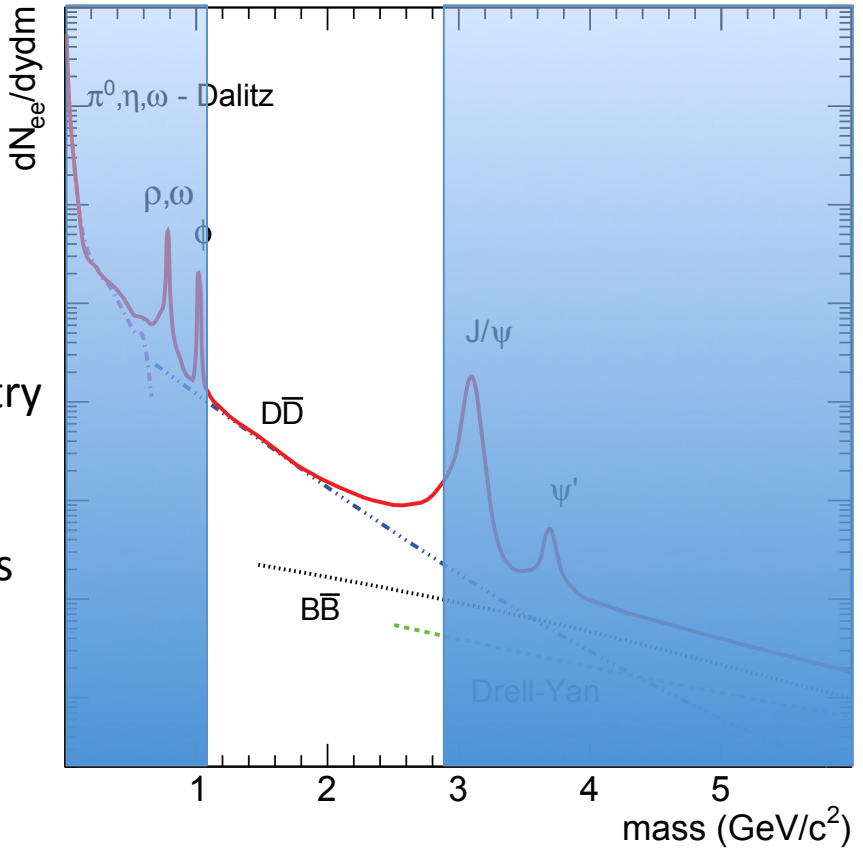
2. **Intermediate-Mass Region (IMR)**
   - Semi-leptonic decays of charm and beauty mesons
   - Thermal radiation of Quark Gluon Plasma (QGP)



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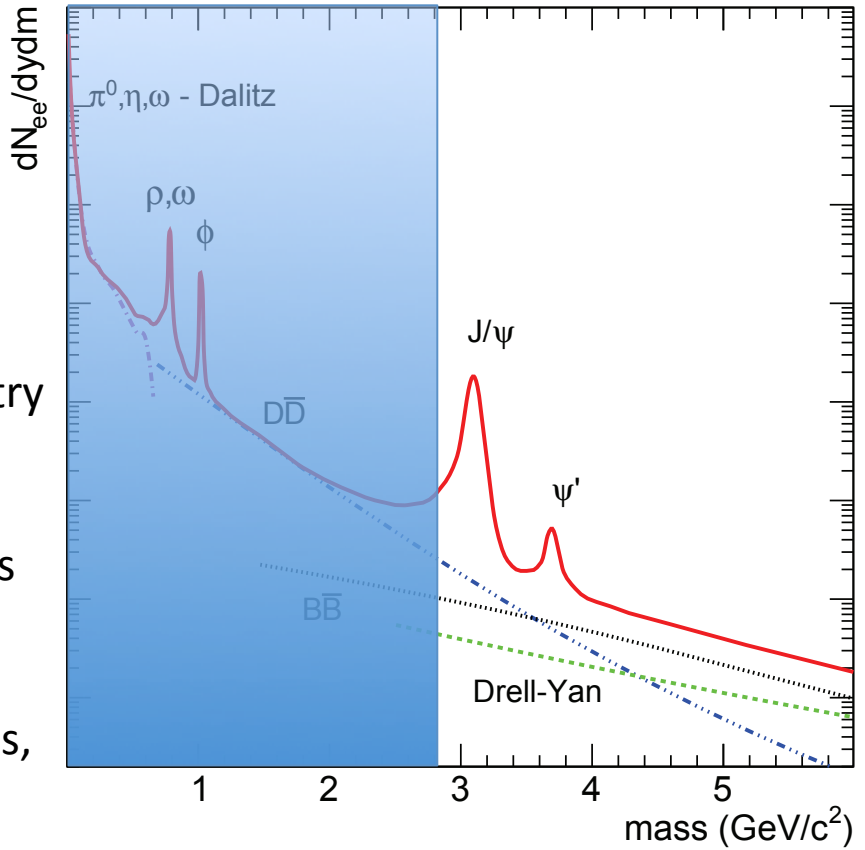
3. **High-Mass Region (HMR)**
- Quarkonia, semi-leptonic decays of beauty mesons, Drell-Yan
- Deconfinement effects in the QGP



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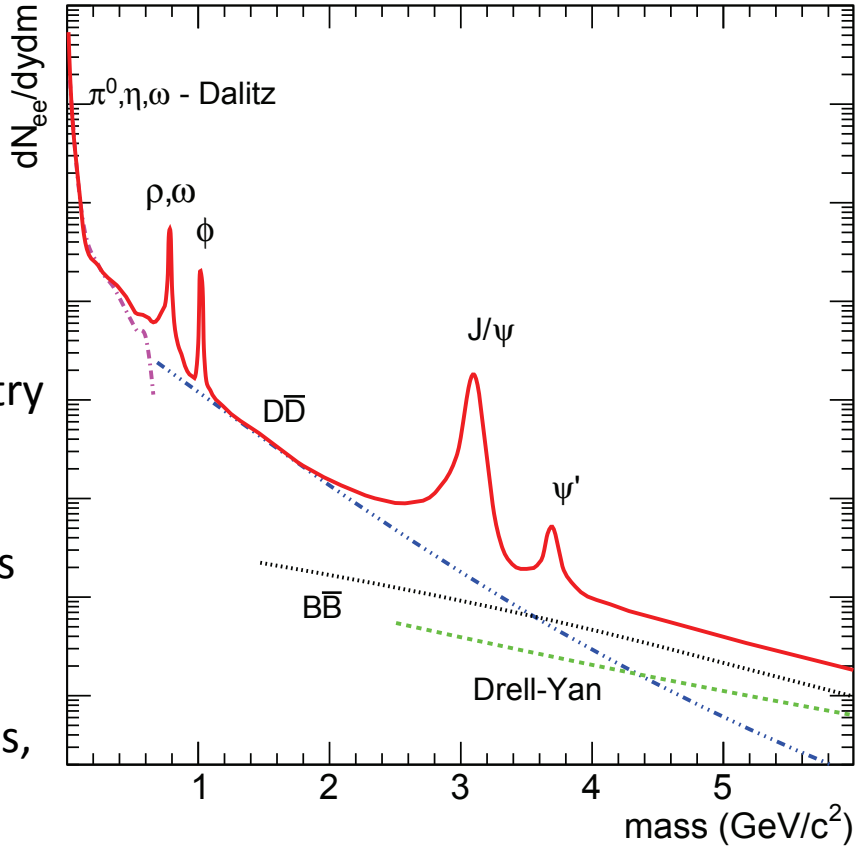


A. Drees, Nucl. Phys. A 830, 435c (2009)

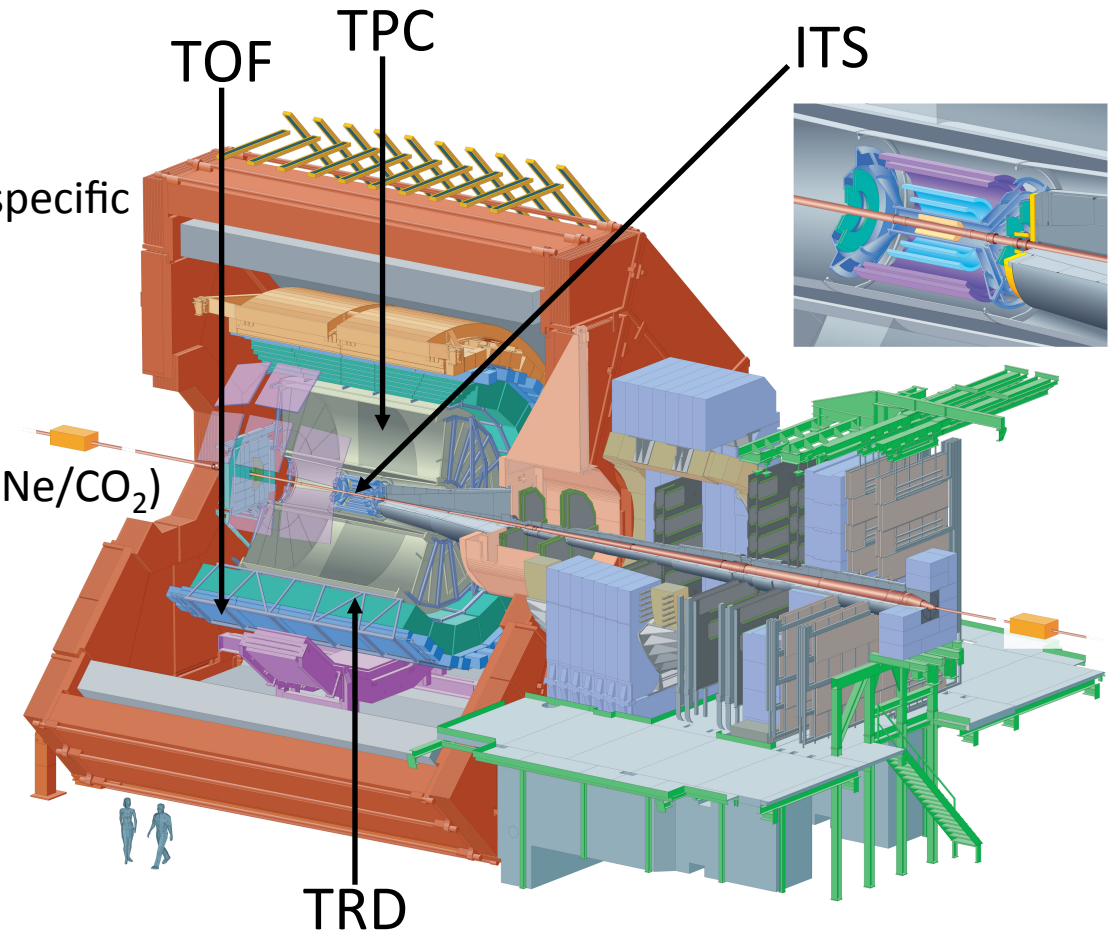
Dielectrons in pp Medium-free baseline

Dielectrons in p-A Initial state effects & modifications from cold nuclear matter effects

The ALICE Detector Setup

Main detectors for dielectron analysis

- **Inner Tracking System (ITS)**
  - Tracking and vertexing
  - Particle identification (PID) via specific energy loss (d*E*/d*x*) in silicon
- **Time Projection Chamber (TPC)**
  - Main tracking device
  - PID using d*E*/d*x* in gas mixture (Ne/CO_2)
- **Time Of Flight (TOF)**
  - PID for hadron rejection
- **Transition Radiation Detector (TRD)**
  - Online electron trigger

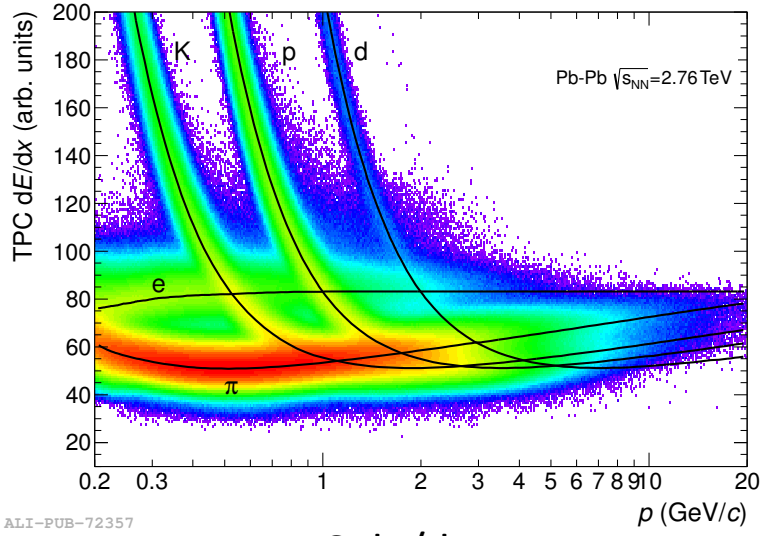


Data samples

- pp at $\sqrt{s}$ = 7 TeV, 300 M minimum bias events
- p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV, 106 M minimum bias events
- Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV, 17 M (0-10 %), 12 M (20-50 %)

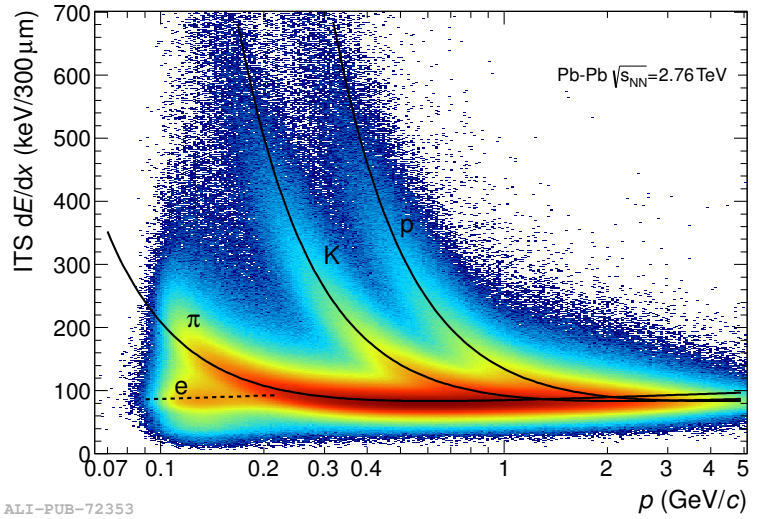
Electron Identification

TPC d*E*/d*x*

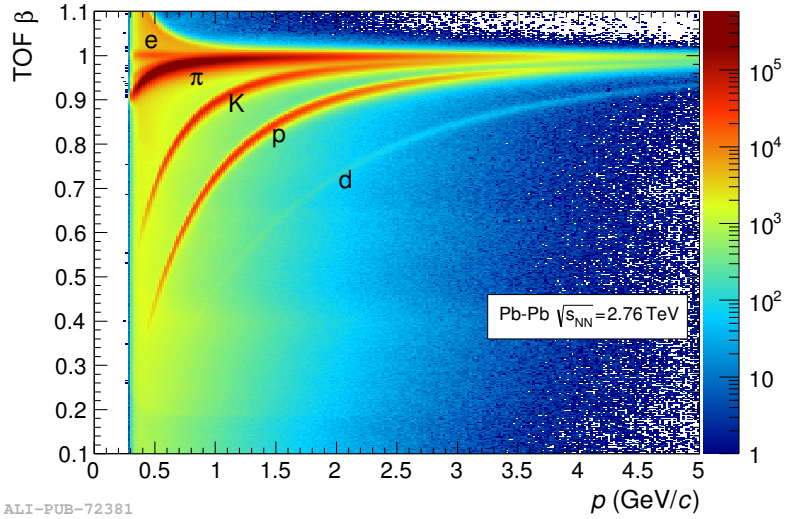


- **TPC**
  - Electron selection, pion rejection (p_T > 0.2 GeV/c)
- **ITS**
  - Electron selection (p_T > 0.2 GeV/c)
- **TOF**
  - Kaon and proton rejection (p_T > 0.4 GeV/c)

ITS d*E*/d*x*

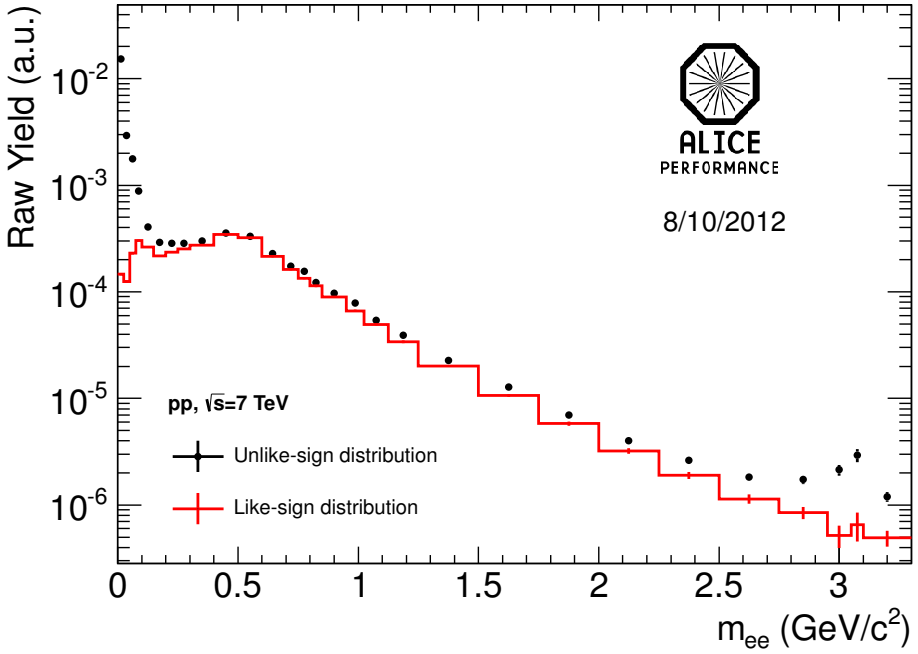


TOF



ALICE Collaboration, Int. J. Mod. Phys. A 29 (2014) 1430044

Signal Extraction



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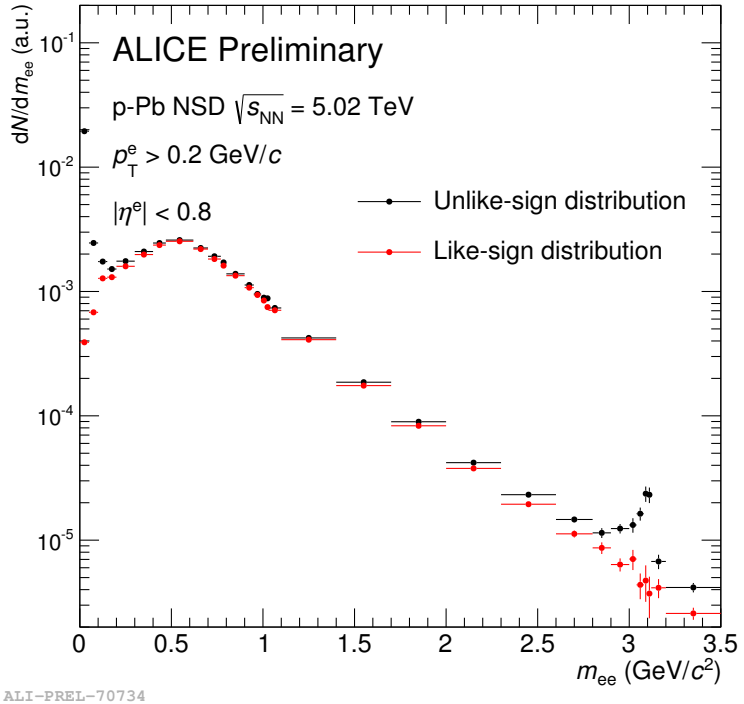

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- **Unlike-sign (ULS) pairs:**

real signal, correlated and combinatorial background

- **Like-sign (LS) pairs:**

corr. and comb. background estimation using

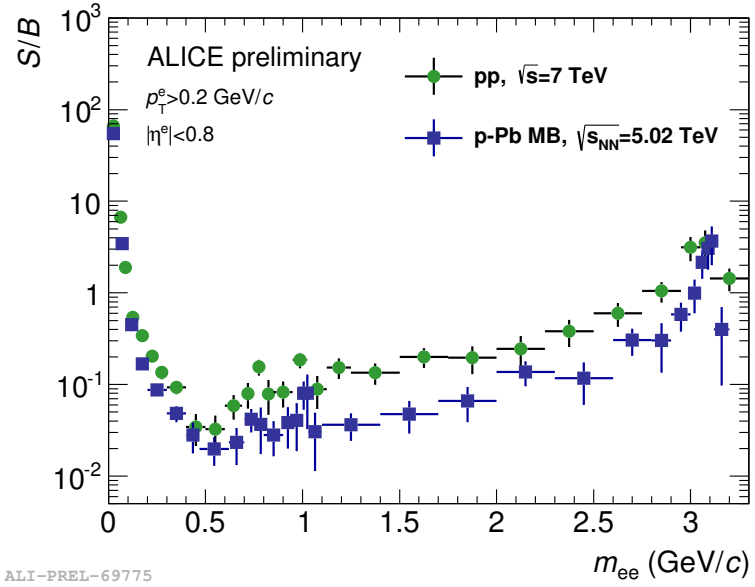
$$2\sqrt{N_{++}N_{--}}$$

Signal = ULS – LS × *R*

R: Acceptance correction factor

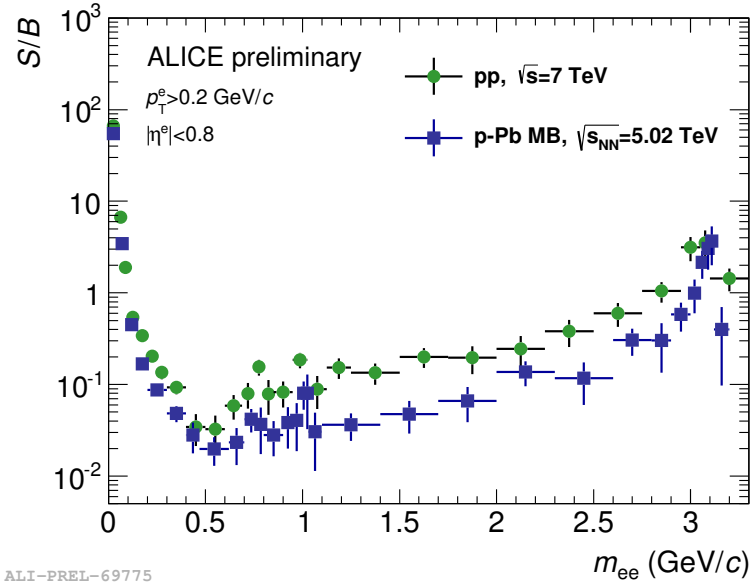
$$R = \frac{\mathrm{ULS}_{\mathrm{mix}}}{\mathrm{LS}_{\mathrm{mix}}}$$

S/B Ratio



- Signal-to-background ratios:
  - **pp:** S/B > 4%
  - **p-Pb:** S/B > 2%

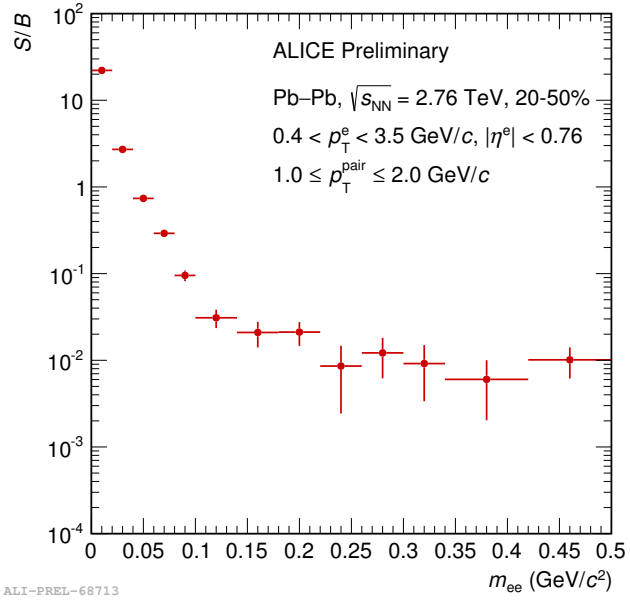
S/B Ratio

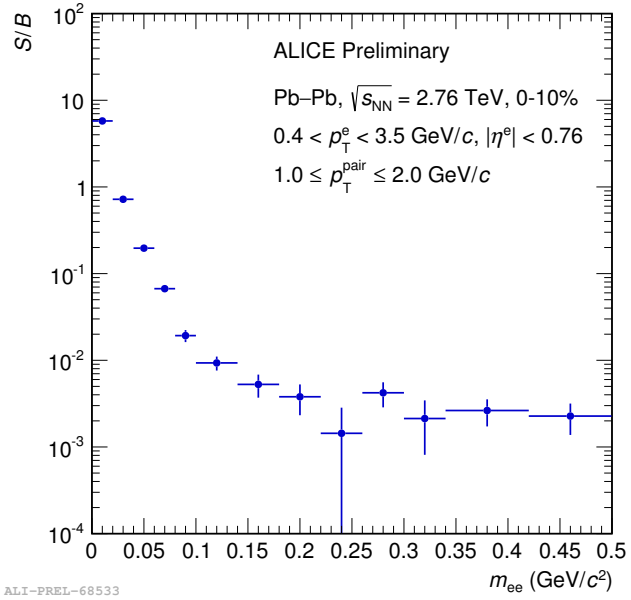


- Signal-to-background ratios:
  - **pp:** S/B > 4%
  - **p-Pb:** S/B > 2%

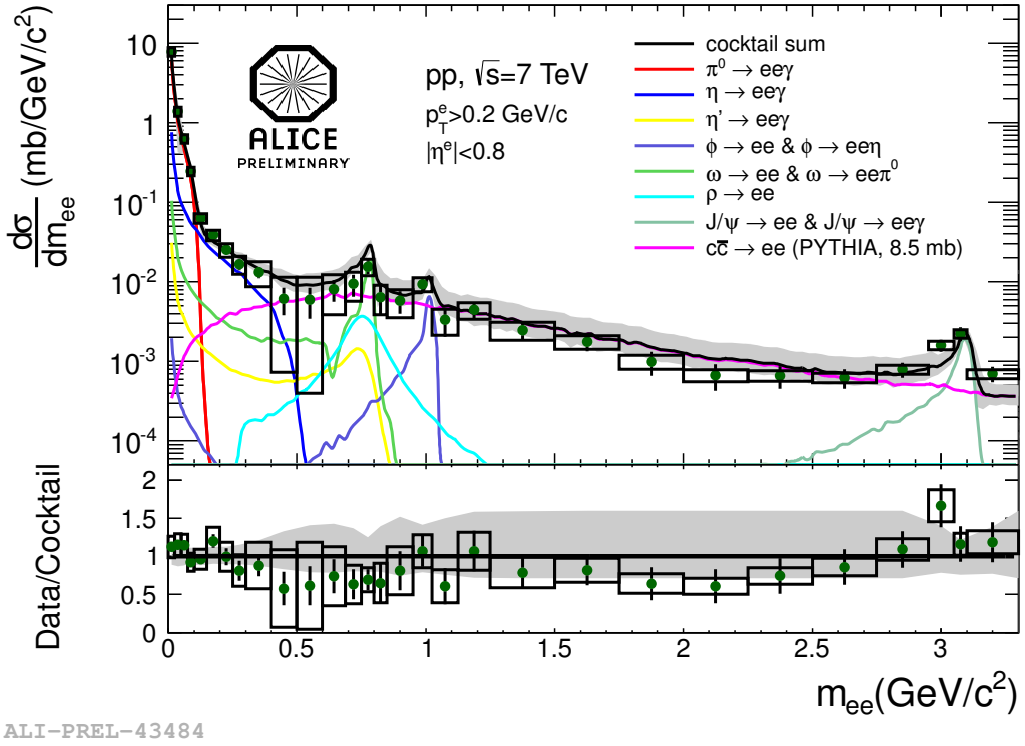
Challenging analysis

- **Semi-central Pb-Pb:** S/B > 1%
- **Central Pb-Pb:** S/B > 0.2%





Mass Spectrum in pp Collisions



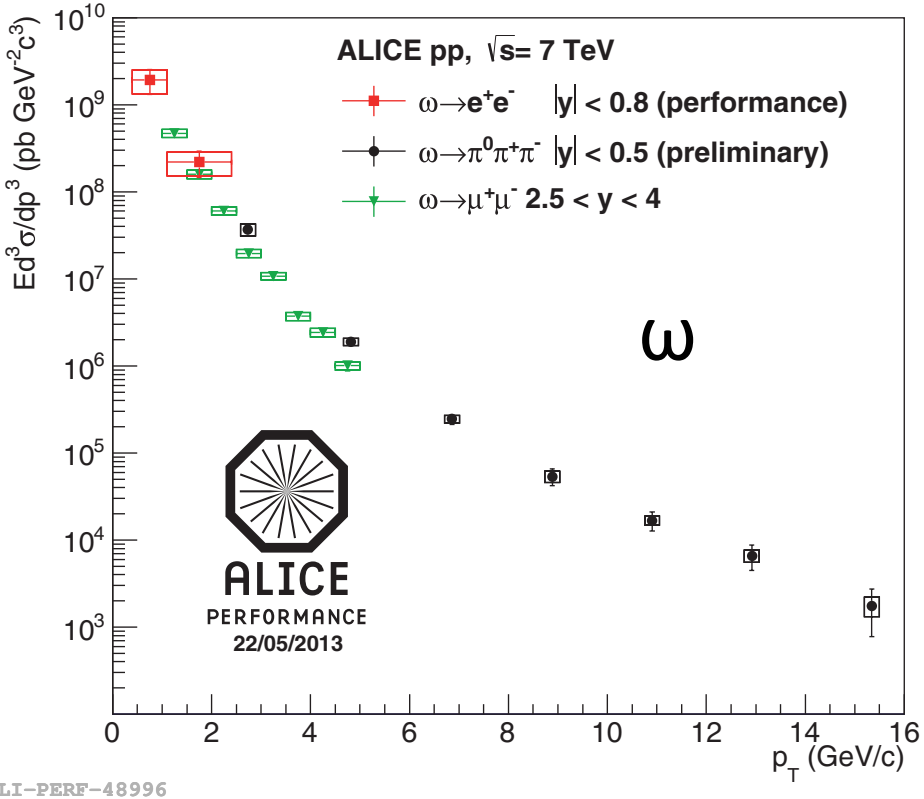
- Hadronic cocktail
  - Hybrid cocktail framework for ALICE based on PYTHIA and EXODUS
    PHENIX, Phys. Rev. C 81, 034911 (2010)
- Cocktail inputs in pp collisions:
  - measured p_T spectra of π^0, η, ϕ, J/ψ
  - other mesons obtained from m_T scaling
  - semi-leptonic decays of charm mesons from PYTHIA based on cross section measured in pp collisions at 7 TeV

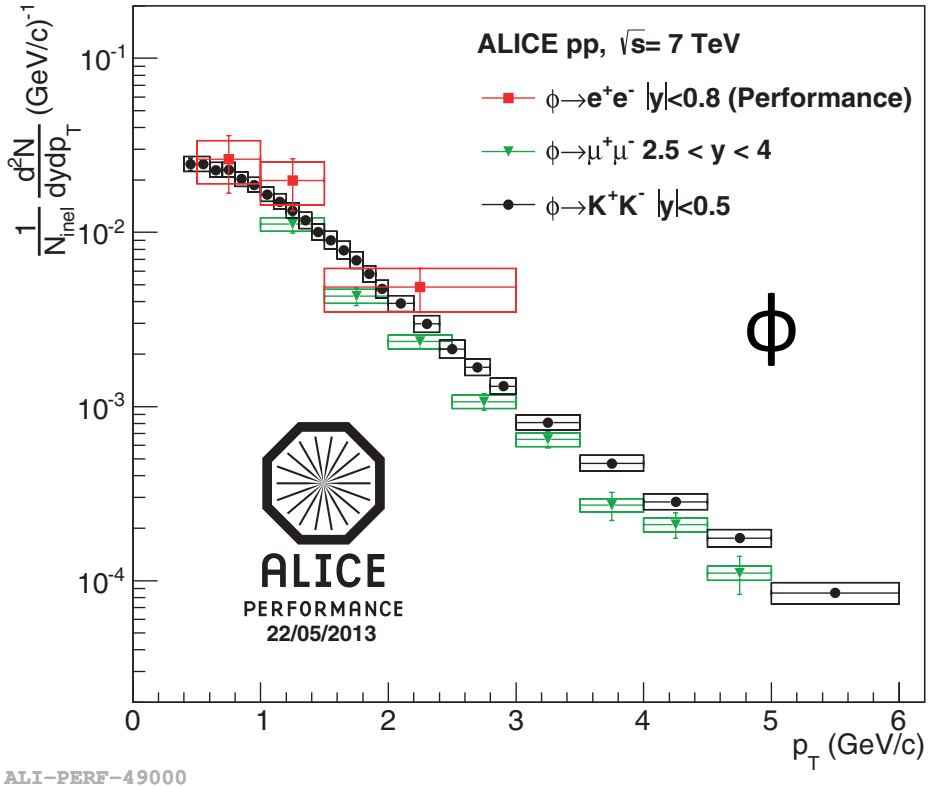
- Data and cocktail in agreement
- Syst. uncertainties of the data: mainly from background subtraction
- Syst. uncertainties of the cocktail (for m_{ee} > 0.5 GeV/c^2): mainly from charm cross section

Resonances in pp Collisions

- ω and ϕ resonance cross sections obtained from the e^+e^- channel for pp collisions at $\sqrt{s}$ = 7 TeV
- The results compared to measurements in hadronic and $\mu^+\mu^-$ decay channels
- **ω:** p_T spectra in the e^+e^- channel and in the $\pi^0\,\pi^+\,\pi^-$ decay channel complement each other
- **ϕ:** p_T spectrum in the e^+e^- channel agrees with the p_T spectrum in the K^+K^- decay channel

Muon channel: ALICE Collaboration, Phys. Lett. B710 (2012)
Kaon channel: ALICE Collaboration, Eur. Phys. J. C72, 2183 (2012)





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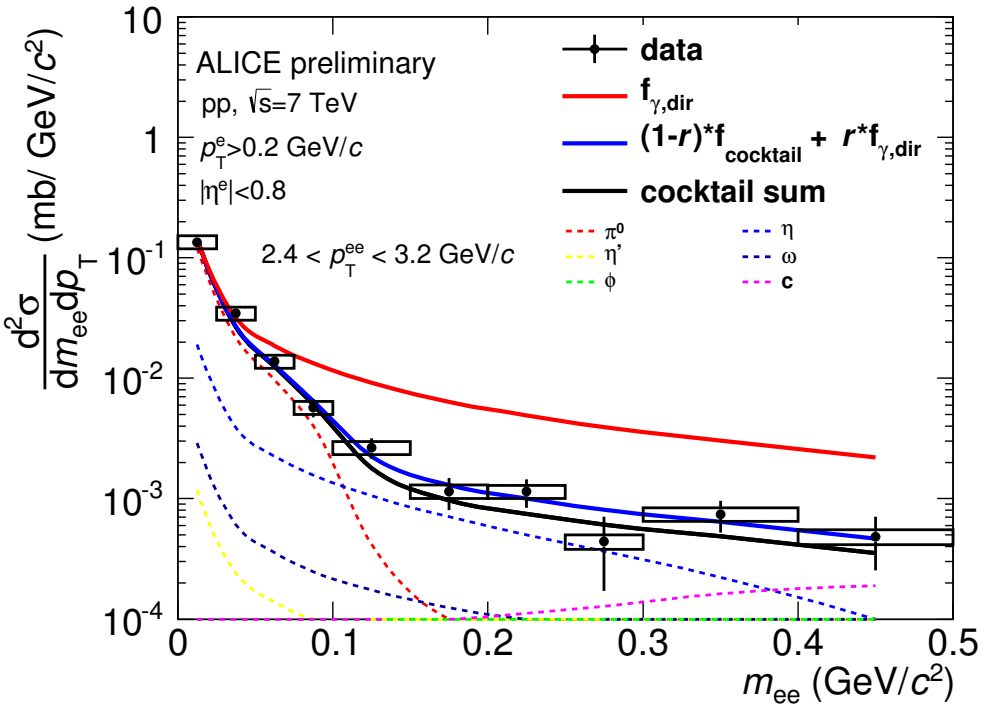
Virtual Direct Photons in pp Collisions

- Aim: direct photon cross section in pp collisions at $\sqrt{s}$ = 7 TeV
- Number of virtual photons per real photon calculated by Kroll-Wada equation

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



- Fit function:

  $f_{comb} = (1\text{-}r) \times f_{cocktail} + r \times f_{\gamma,dir}$

- f_{comb} : combined fit function
- $f_{cocktail}$: cocktail sum
- $f_{\gamma,dir}$: photon input from Kroll-Wada

- Fit parameter *r* reflects the ratio of direct over inclusive photons

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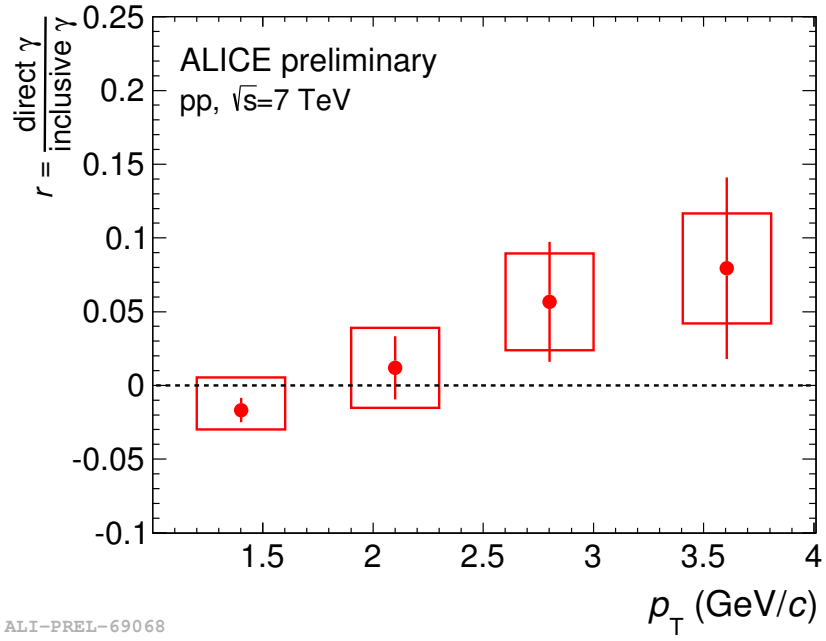
Direct Photon Fraction vs. p_T

- Extraction of fit parameter r in various p_T ranges
- Assumption: $r = \gamma_{direct}/\gamma_{inclusive}$



- Direct photon spectrum can be calculated:

$$\gamma_{direct} = r \times \gamma_{inclusive}$$

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- Extraction of fit parameter r in various p_T ranges
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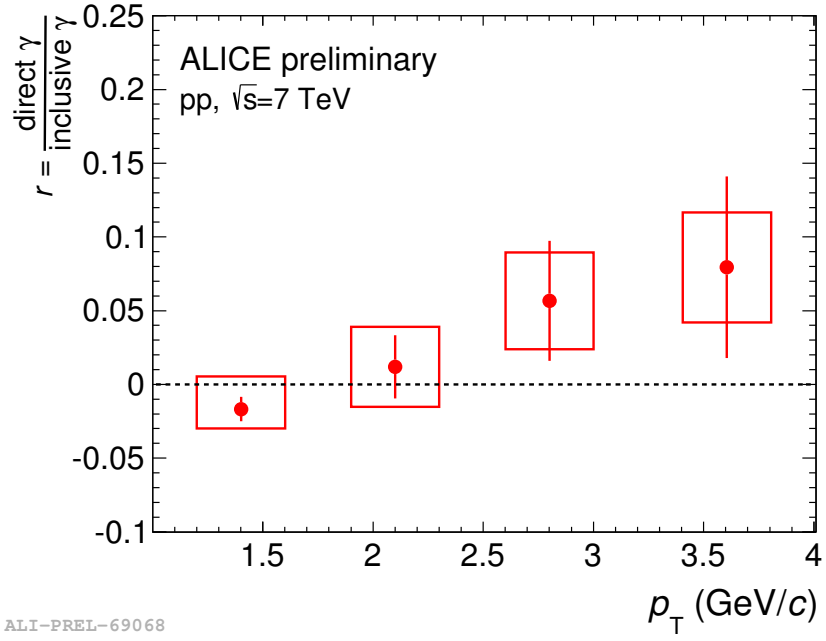
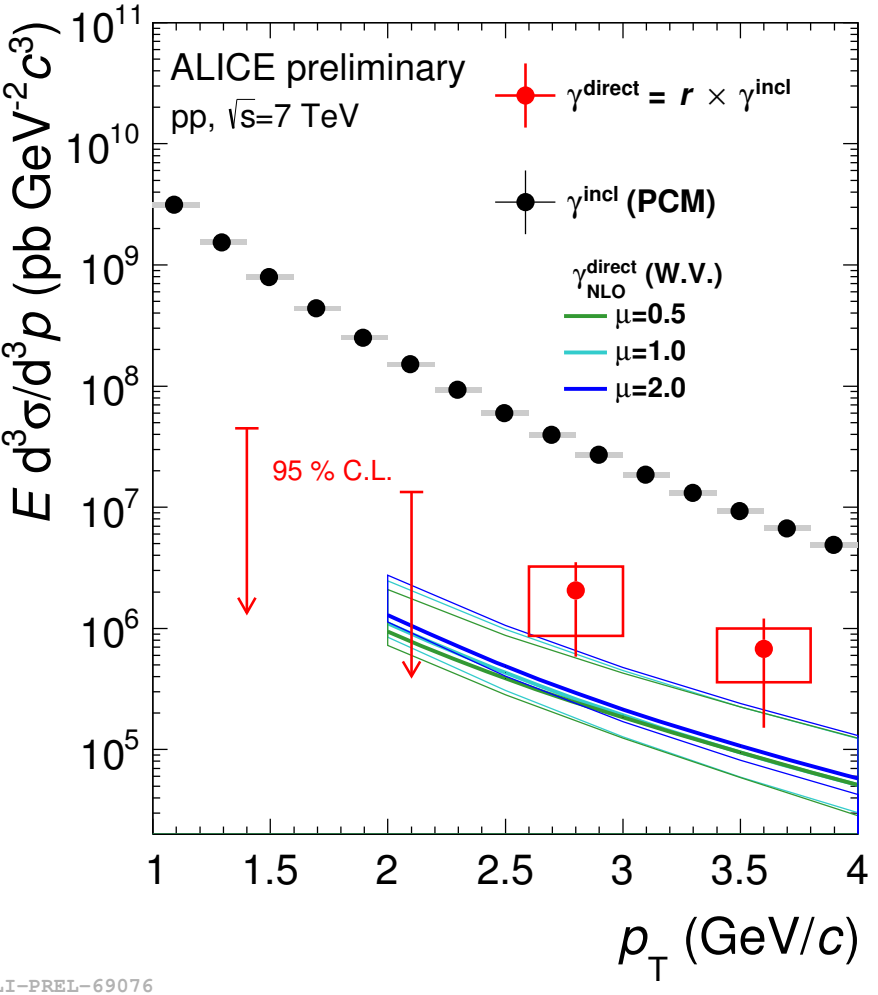


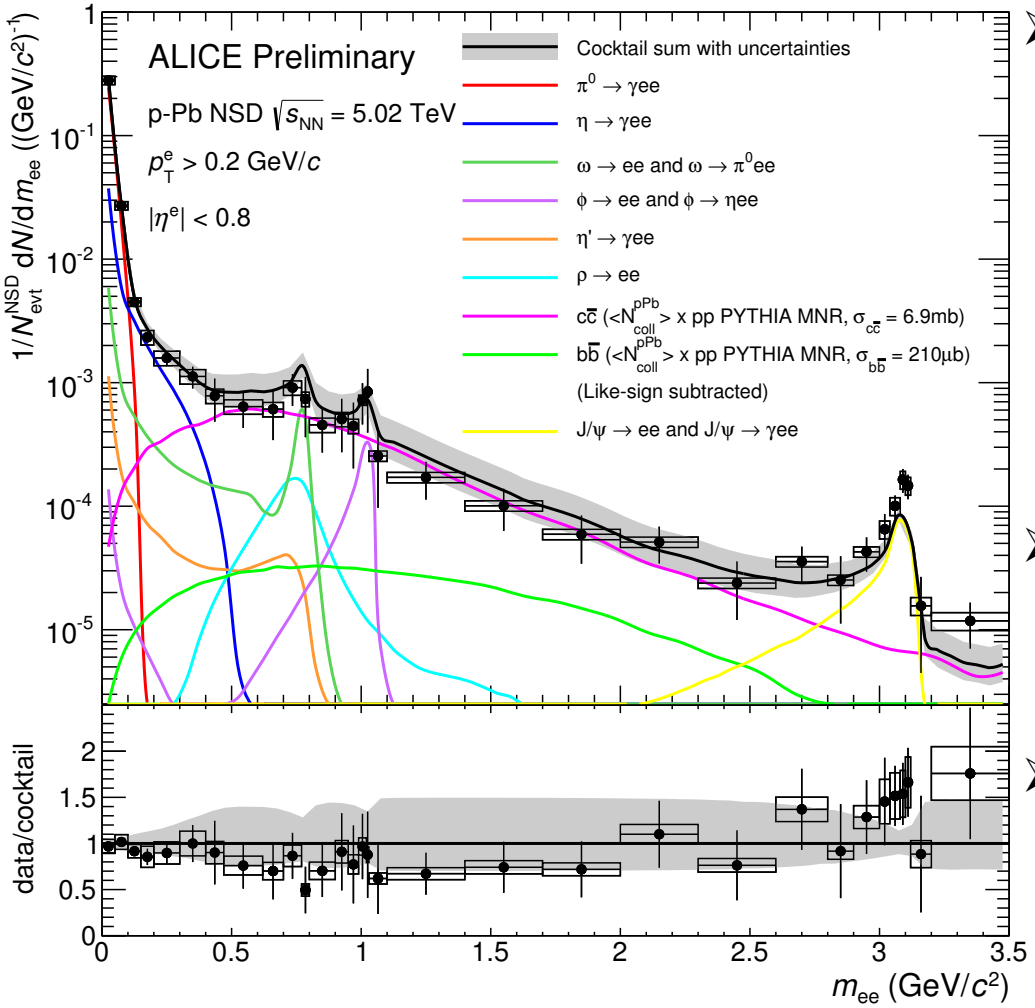
- Direct photon spectrum can be calculated:

$$\gamma_{direct} = r \times \gamma_{inclusive}$$

- Inclusive photon spectrum measured via photon conversion method (PCM)
- pQCD NLO calculations consistent with direct photon spectrum



Mass Spectrum in p-Pb Collisions



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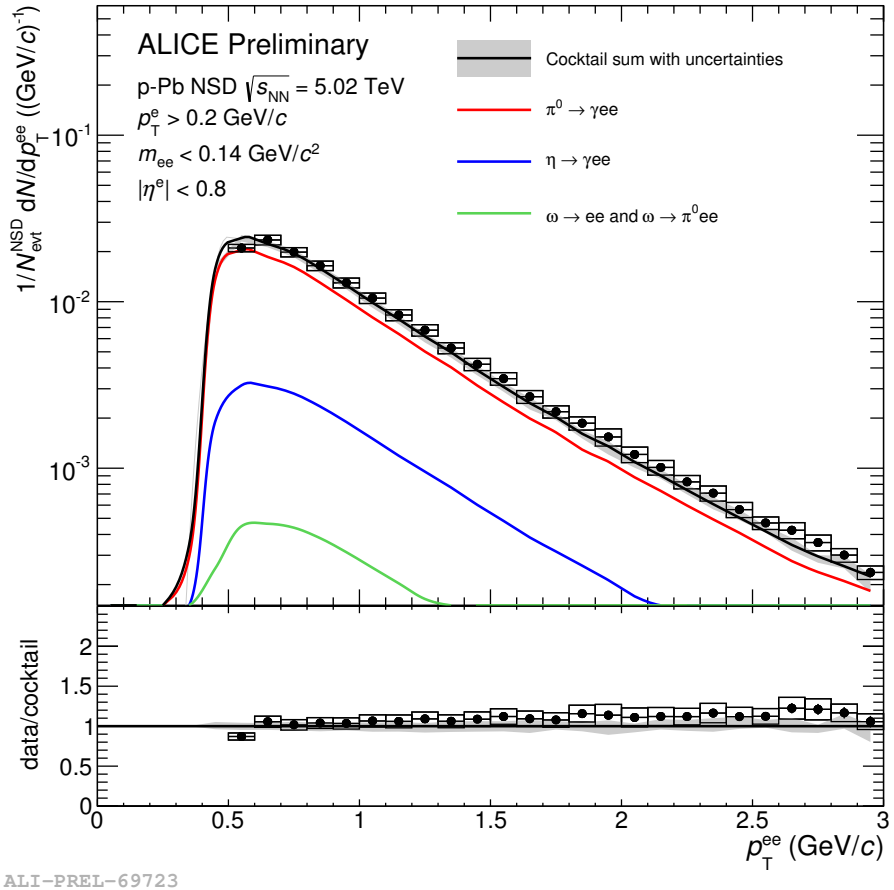
- Hadronic cocktail inputs in p-Pb collisions:
  - measured p_T spectra of $\pi^{\pm}$
  - other mesons obtained from m_T scaling
  - semi-leptonic decays of charm and beauty mesons from PYTHIA in pp collisions scaled by number of binary collisions $<N_{coll}>$
- Measurement and cocktail in agreement within systematic uncertainties (mainly from charm contribution)
- No strong conclusion on cold nuclear matter effects, also no evidence for charm suppression due to the large systematic uncertainties

p_T Spectra in p-Pb Collisions

- $m_{ee} < 0.14$ GeV/c^2
- dominated by π^0



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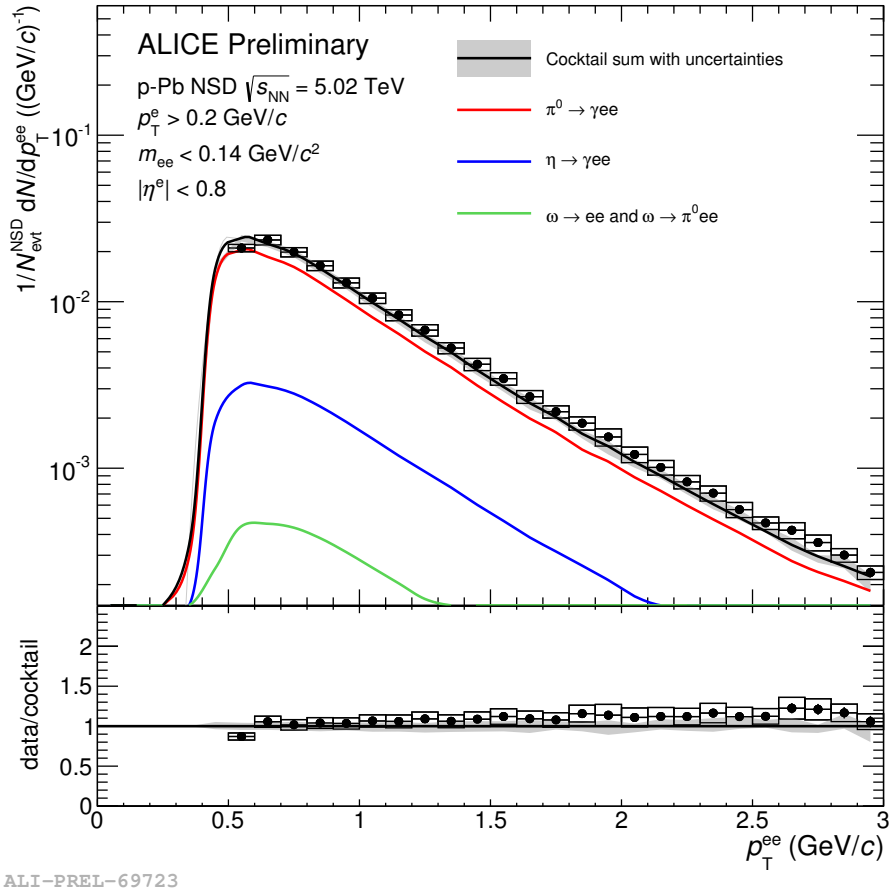
p_T Spectra in p-Pb Collisions

- $m_{ee} < 0.14$ GeV/c^2
- dominated by π^0

- $0.14 < m_{ee} < 0.75$ GeV/c^2
- dominated by η and charm



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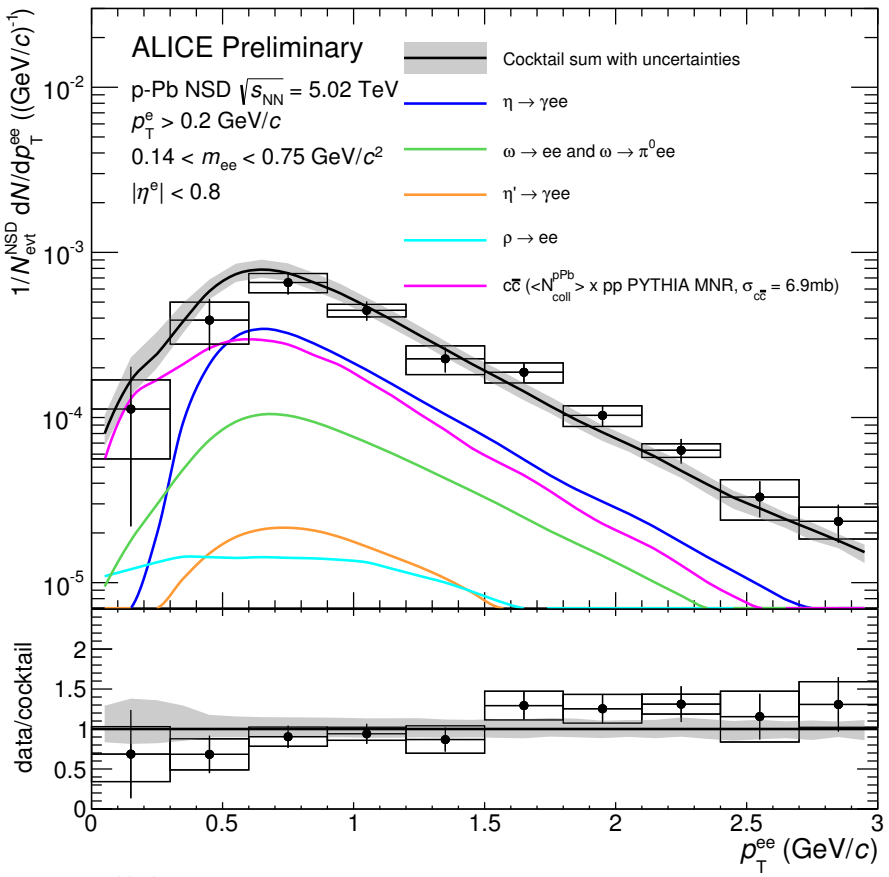

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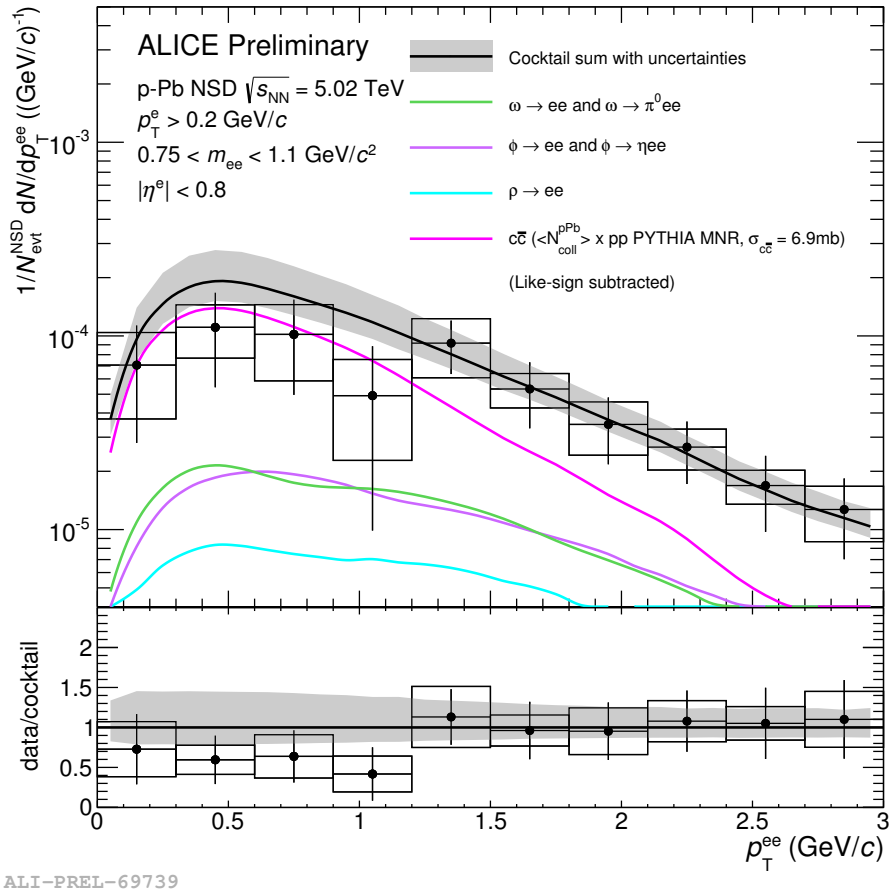
p_T Spectra in p-Pb Collisions

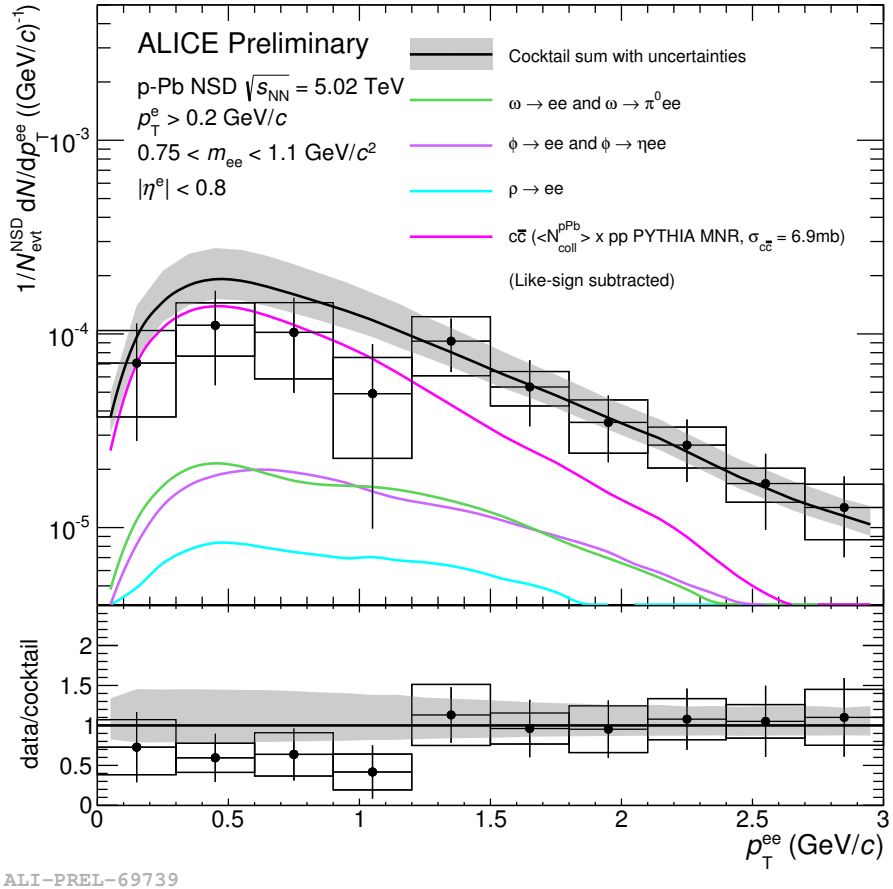
- $0.75 < m_{ee} < 1.1$ GeV/c^2 (resonance region)
- dominated by charm



ALI-PREL-69739

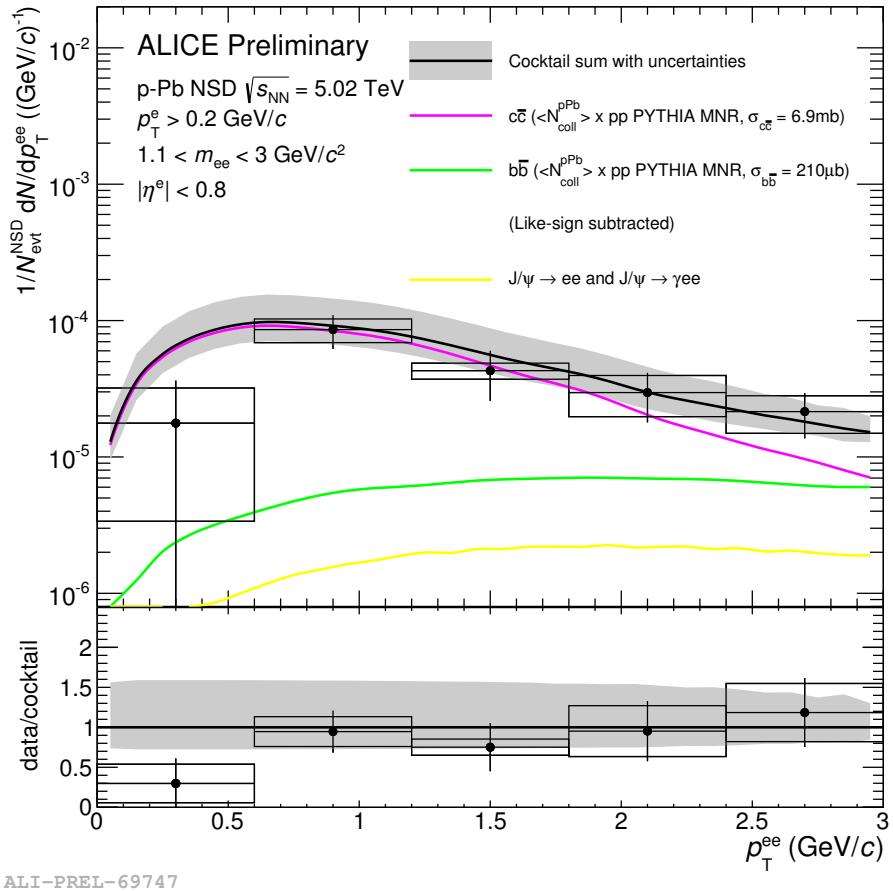
p_T Spectra in p-Pb Collisions

- $0.75 < m_{ee} < 1.1$ GeV/c^2 (resonance region)
- dominated by charm



ALI-PREL-69739

- $1.1 < m_{ee} < 3.0$ GeV/c^2
- dominated by charm
- Data and cocktail in agreement



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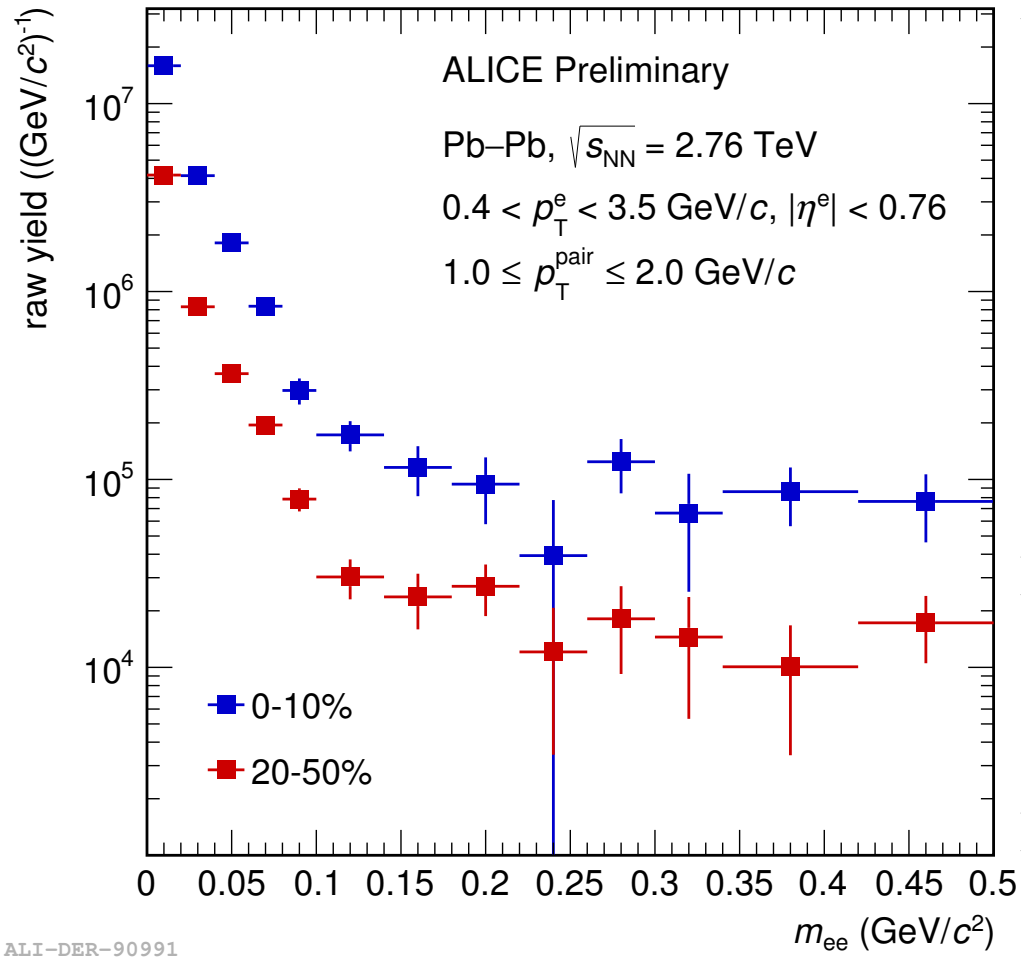
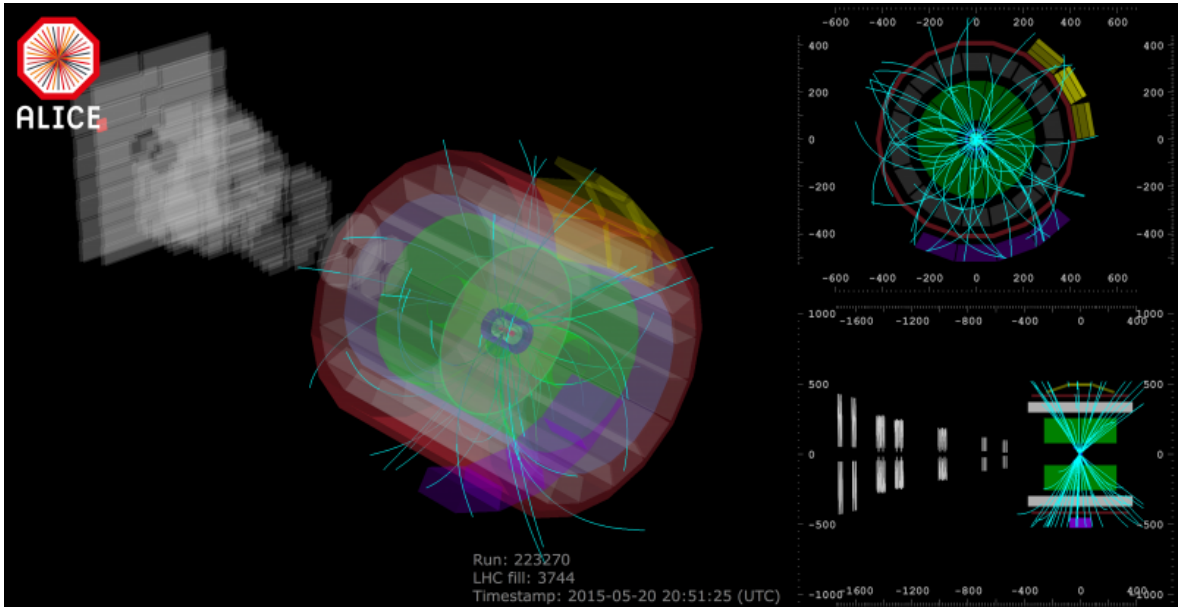
Mass Spectrum in Pb-Pb Collisions



- Uncorrected invariant mass spectrum measured in **central (0-10 %)** and **semi-central (20-50 %)** Pb-Pb collisions
  - Track p_T cut > 0.4 GeV/c
  - Pair transverse momentum $1.0 < p_T < 2.0$ GeV/c
- Signal-to-background ratios
  - **Central Pb-Pb:** S/B > 0.2%
  - **Semi-central Pb-Pb:** S/B > 1%
- Small S/B requires precise determination of the background shape (work in progress)

Run2

- After a successful running period from Nov. 2009 to Jan. 2013 (Run1), the new data taking period (Run2) started in June 2015
- First pp collisions at 13 TeV



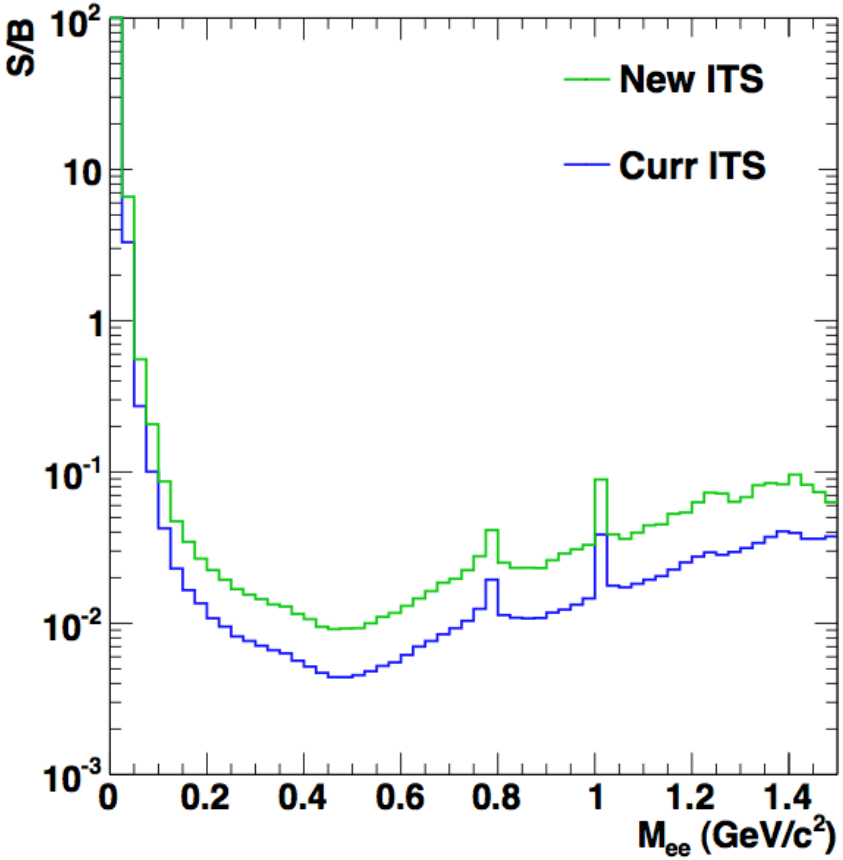
http://alicematters.web.cern.ch/?q=content/node/838

- Dielectron measurements are challenging, we will benefit from more statistics
- ALICE Transition Radiation Detector (TRD) completed
- Major upgrades will be done for Run3 (starts ~2020)

ALICE Upgrade for Run3

- **ITS and TPC** will be upgraded for **Run3** during the **Long Shutdown 2 (2018-2019)**

- With **new ITS** (7 layers totally), more precise measurement of displaced vertices will be possible ➔ advantage for heavy-flavor decays



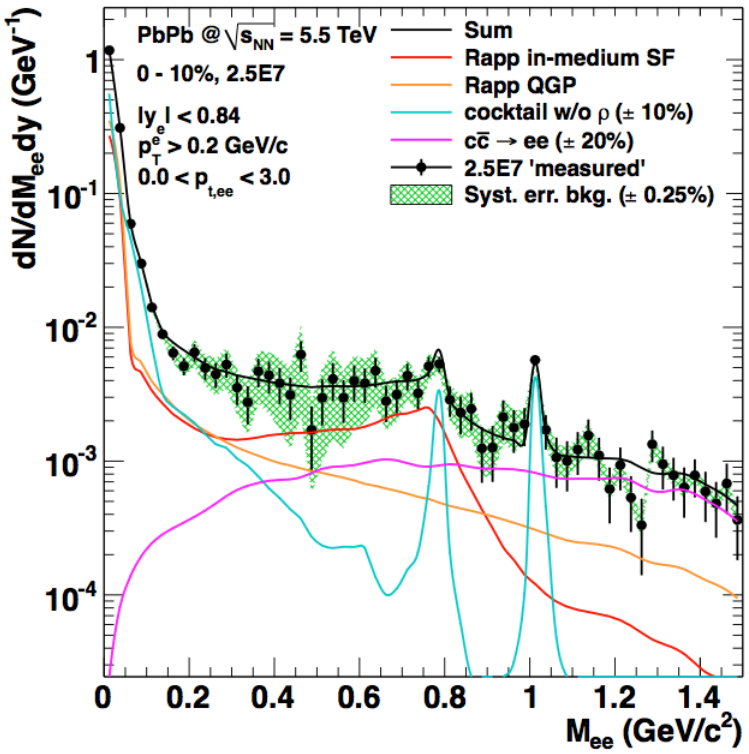
- With **upgraded ITS (better tracking capability at low p_T)**, factor 2 improvement for **signal-to-background ratio (S/B)** achieved

- **Current readout chambers** of **TPC** will be replaced with **GEM (Gas Electron Multiplier)** foils in order to provide **continuous readout of TPC at 50 kHz interaction rate (100x higher data taking rate)**

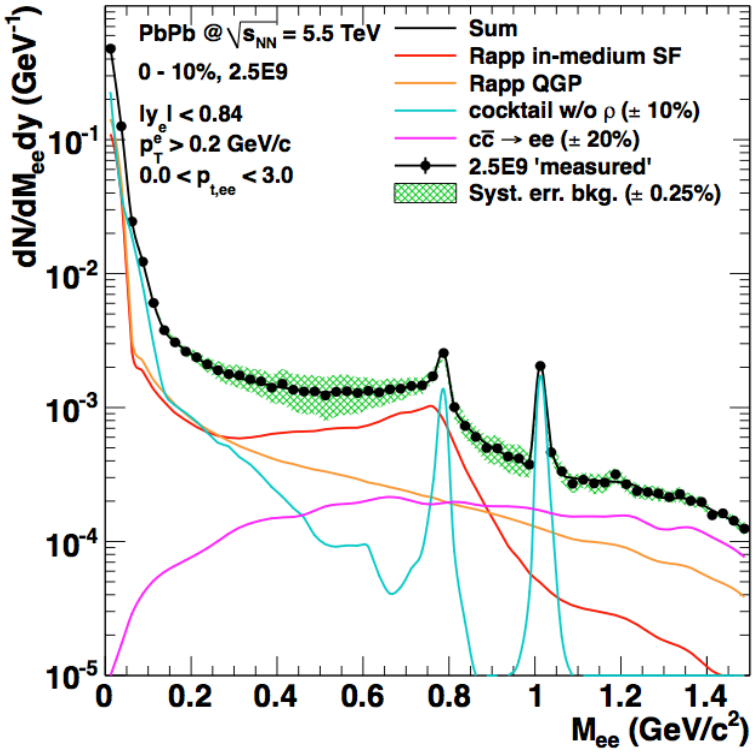
ALICE Collaboration, J. Phys. G41 (2014) 087001

ALICE Upgrade for Run3

Current ITS+TPC



Upgraded ITS+TPC



ALICE Collaboration, J. Phys. G41 (2014) 087001

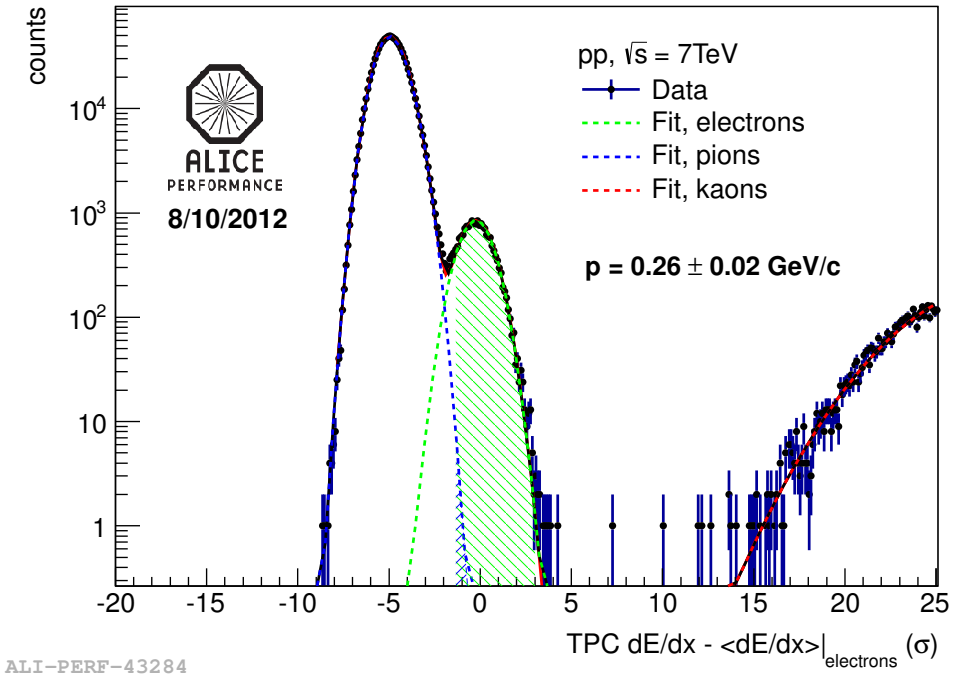
- Comparison of current ITS+TPC to upgraded ITS+TPC
- **Current ITS+TPC:** 25 M central (0-10 %) Pb-Pb events at $\sqrt{s_{NN}}$ = 5.5 TeV (current readout rate)
- **Upgraded ITS+TPC:** 2.5 G Pb-Pb events at $\sqrt{s_{NN}}$ = 5.5 TeV (continuous readout)
- **New ITS & TPC:** smaller systematic uncertainty on the background and charm, improved statistical precision

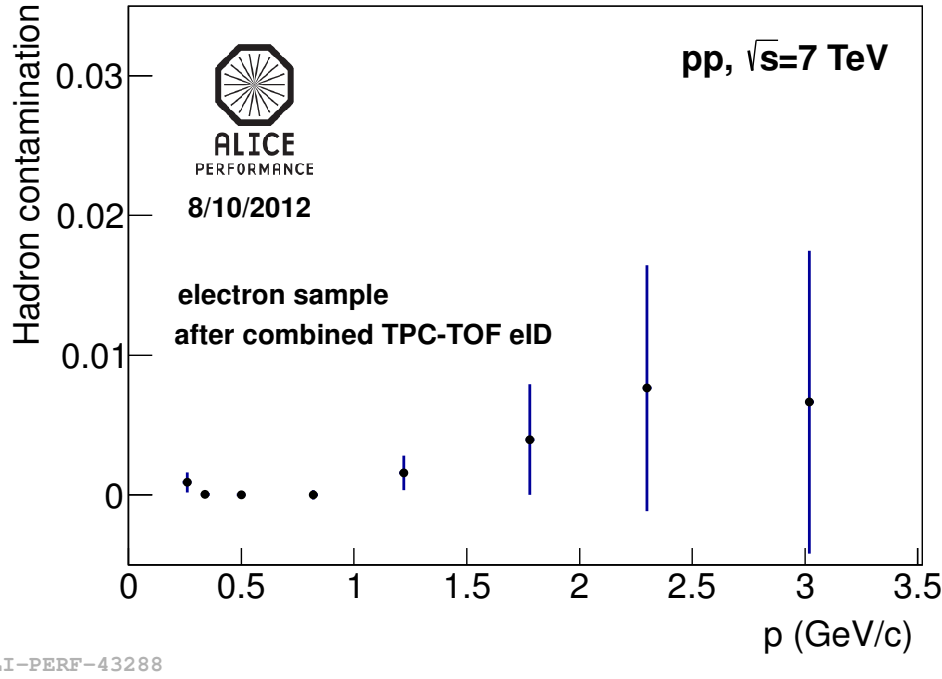
Summary & Outlook

- Invariant mass spectrum in pp collisions consistent with cocktail calculations
- pQCD NLO calculations consistent with direct photon spectrum in pp collisions
- Preliminary p-Pb results (invariant mass and p_T spectra) in agreement with cocktail calculations
- Pb-Pb analysis ongoing
- Run1 analysis is being finalized
  - Improved hadronic cocktail
- Run2 started in June 2015
  - will benefit from more statistics
- Major upgrades of ITS and TPC will be implemented for Run3
  - Significant increase of data taking rate and S/B ratio
  - Improvement of statistical and systematic uncertainties

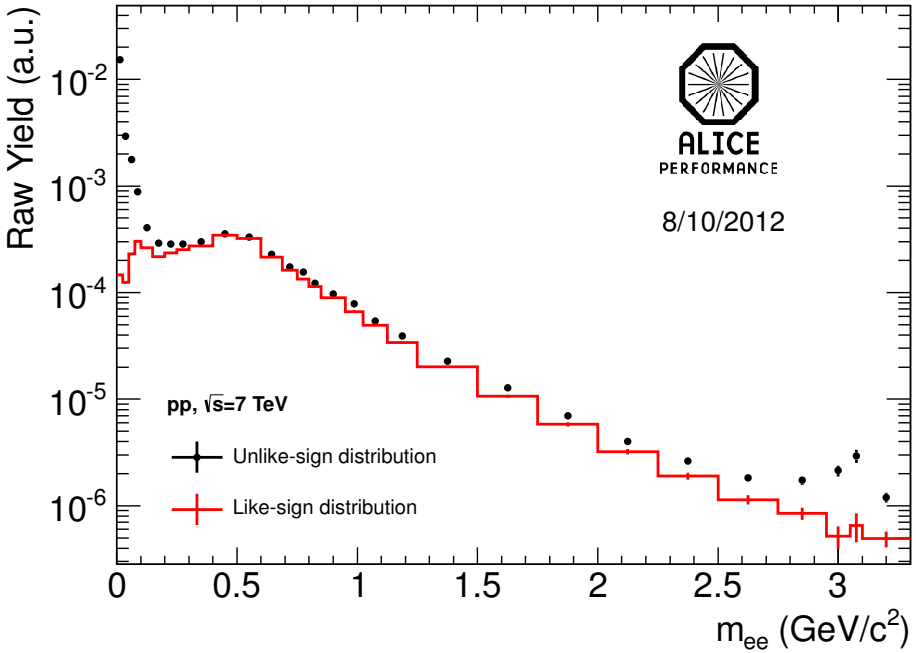
Backup

Hadron Contamination in pp Collisions

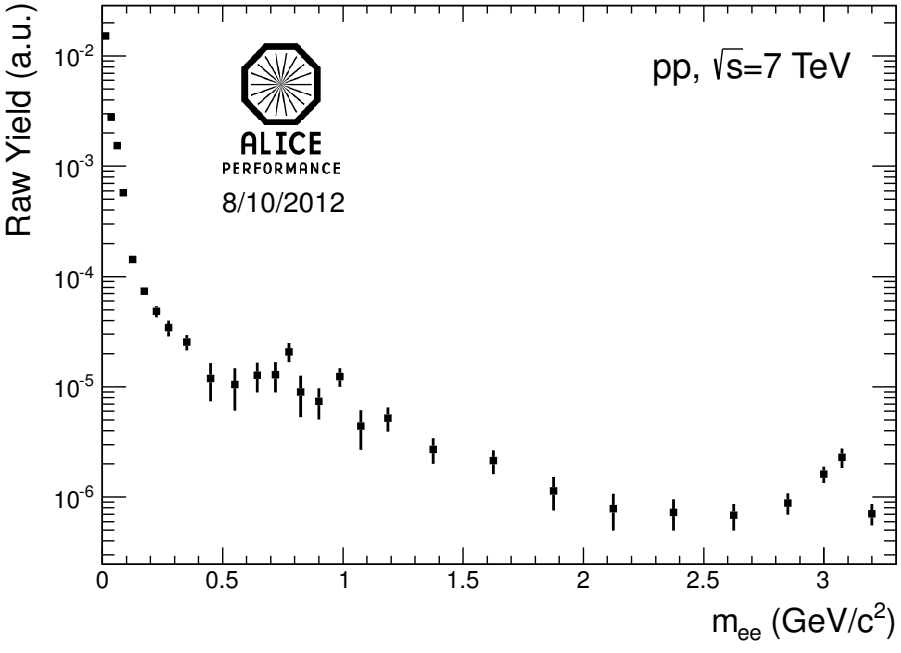




Uncorrected Mass Spectrum in pp Collisions

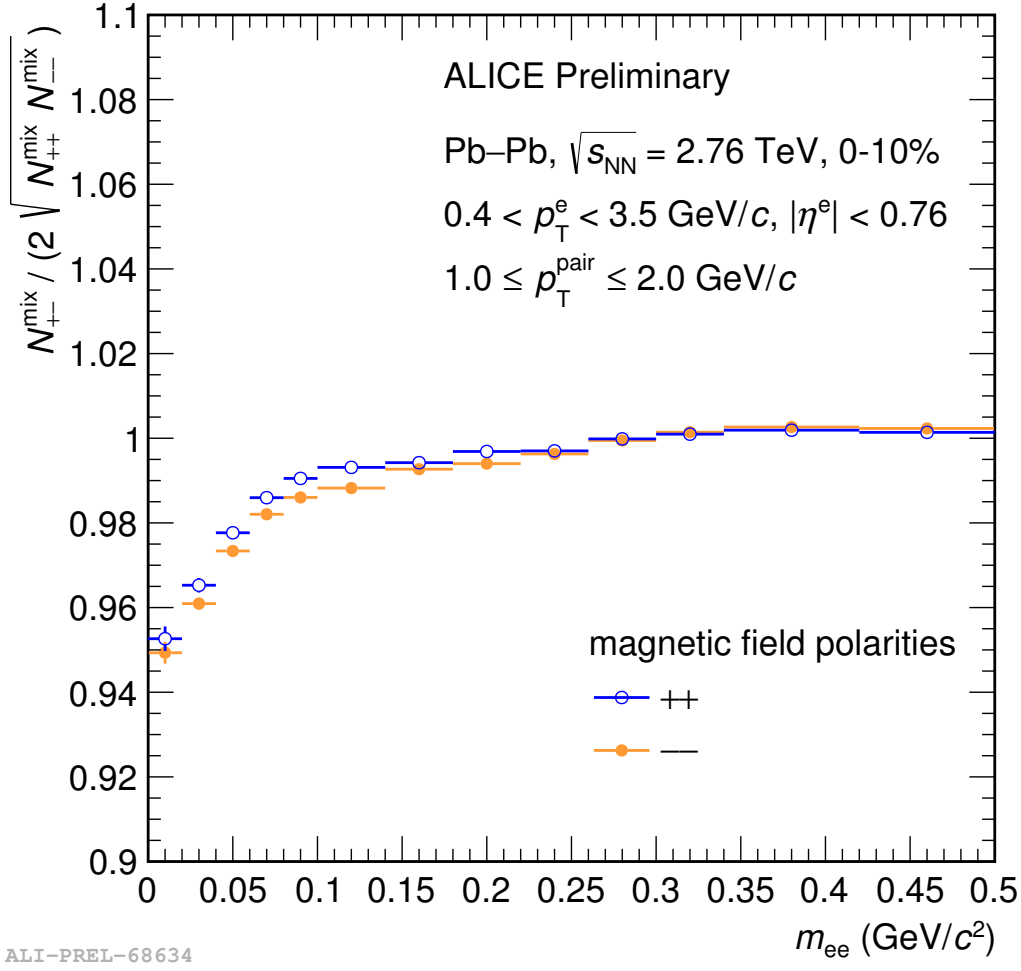


ALI-PERF-43276



ALI-PERF-43272

Acceptance Correction Factor

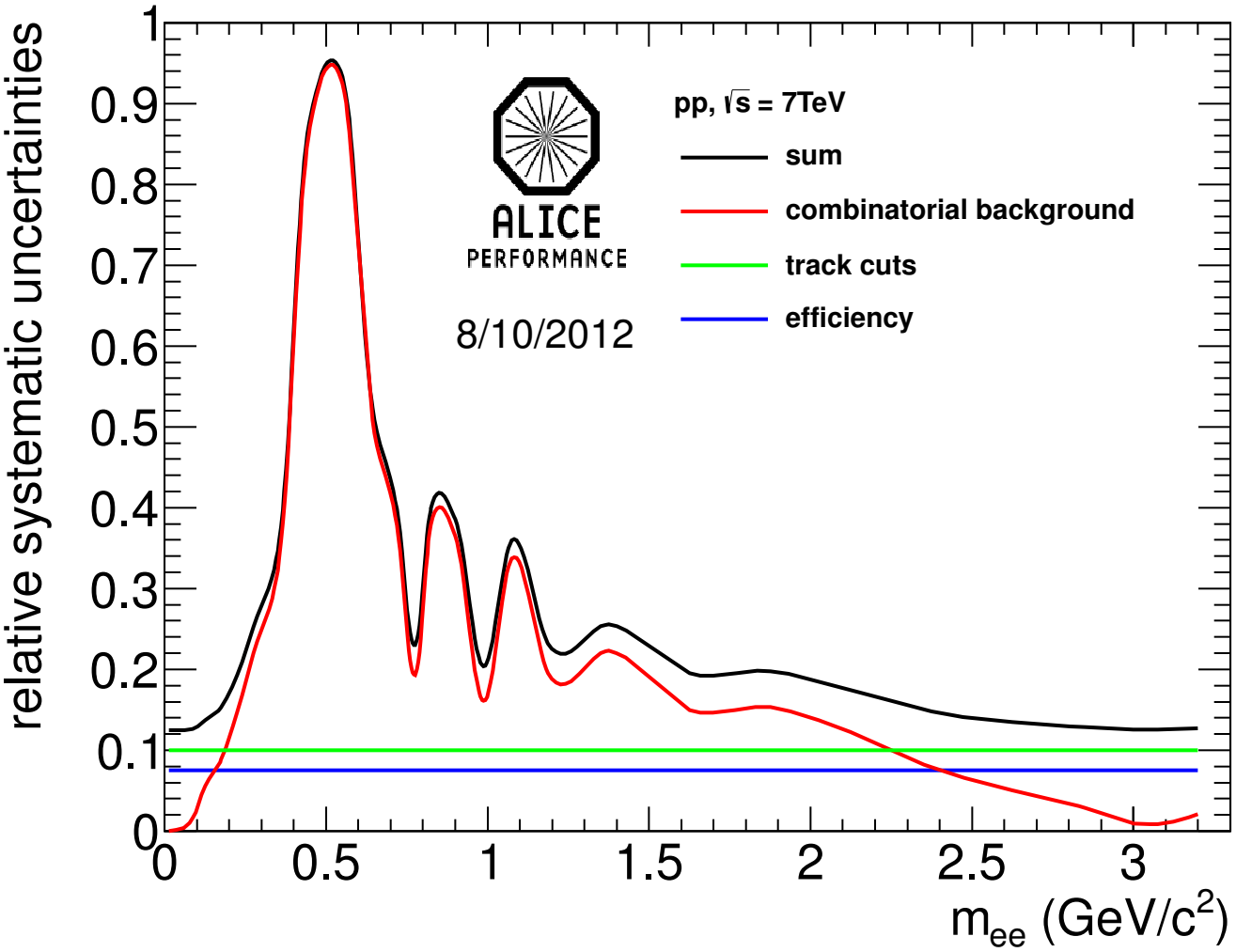


- ULS and LS pairs have different acceptances
- Estimated via event mixing technique:

$$R = \frac{\mathrm{ULS}_{\mathrm{mix}}}{\mathrm{LS}_{\mathrm{mix}}}$$

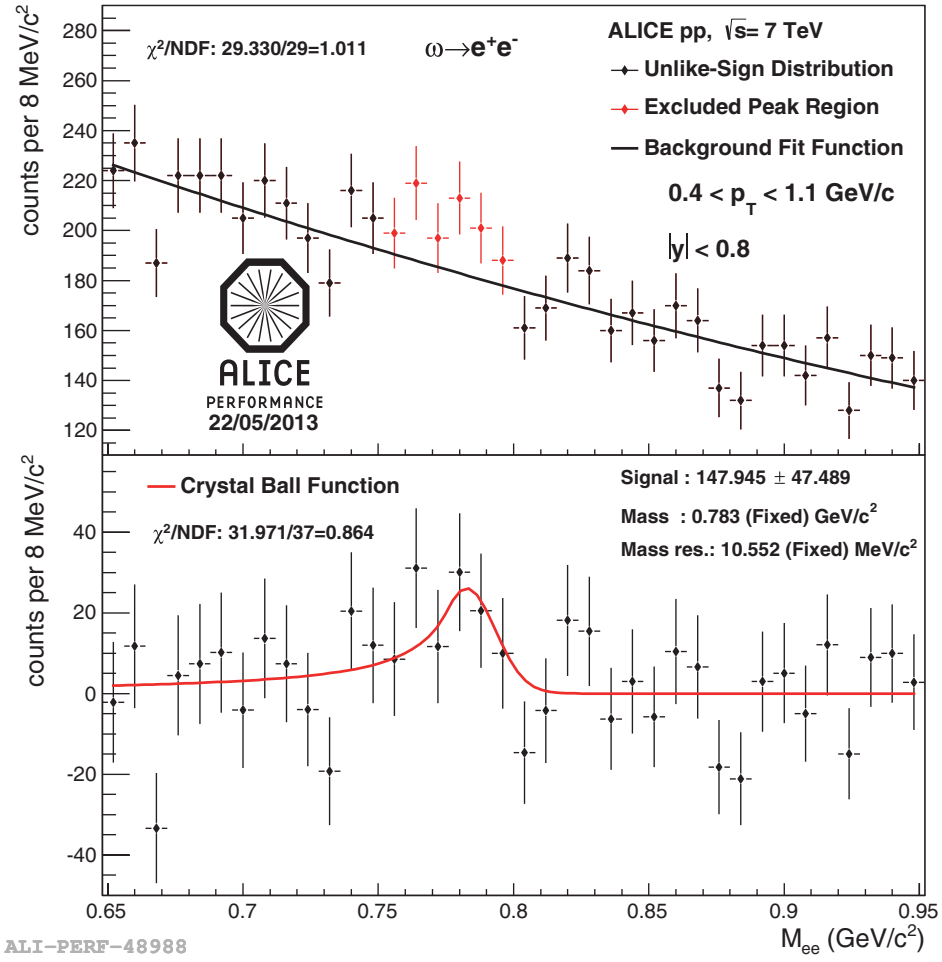
- $R < 1$: In the very low-mass region

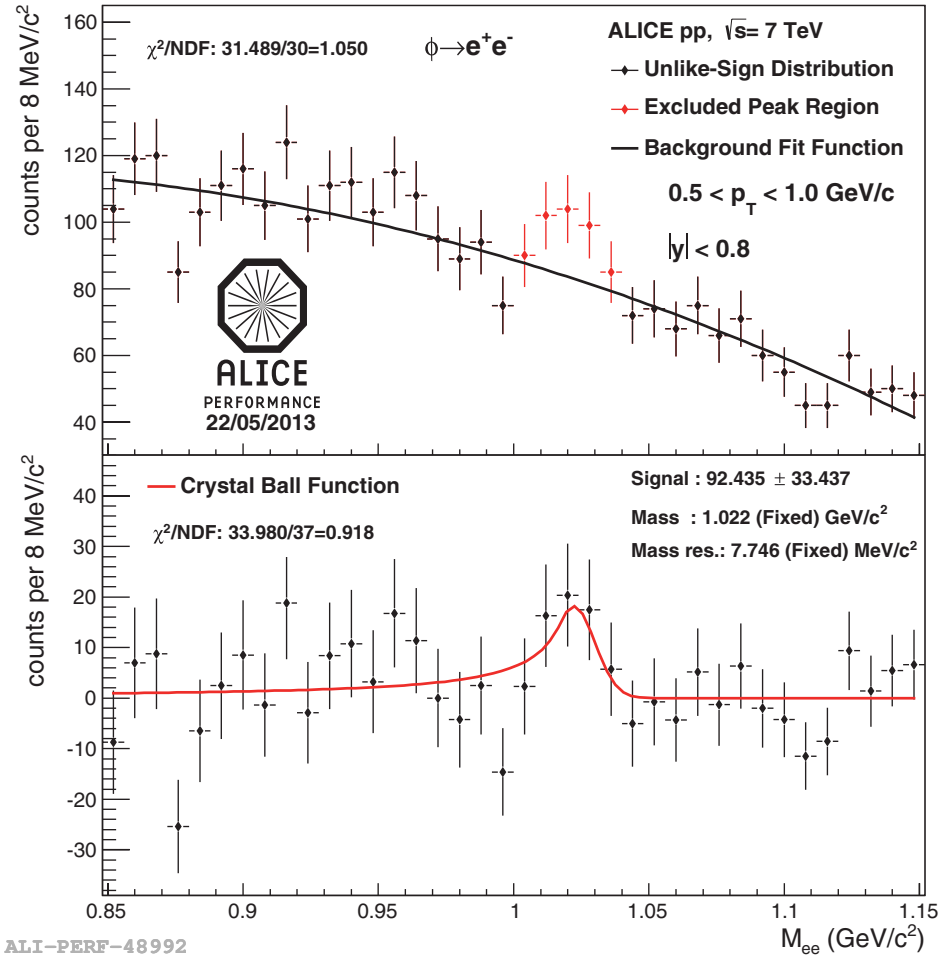
Systematics in pp Collisions



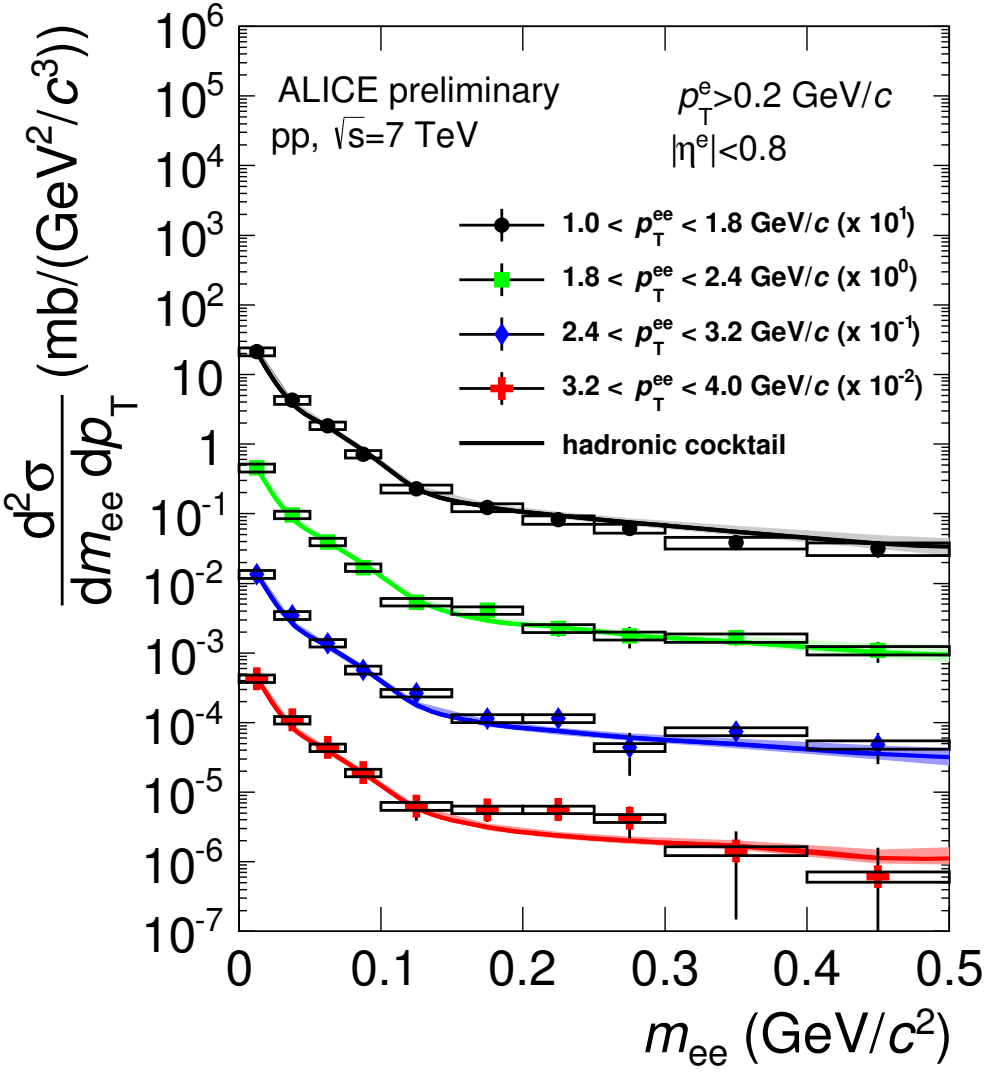
ALI-PERF-43375

ω & ϕ in pp Collisions

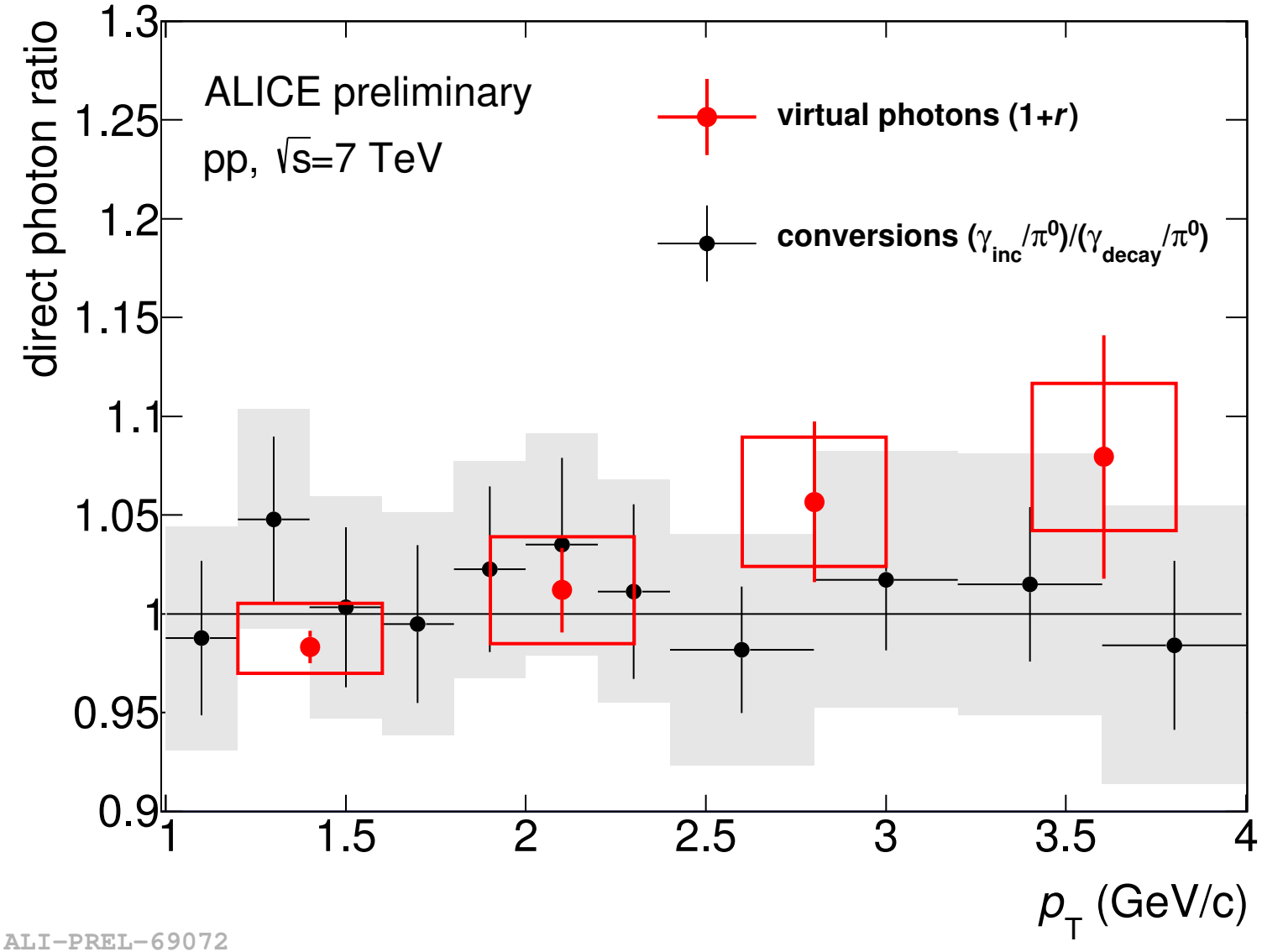




Mass Spectrum for different p_T

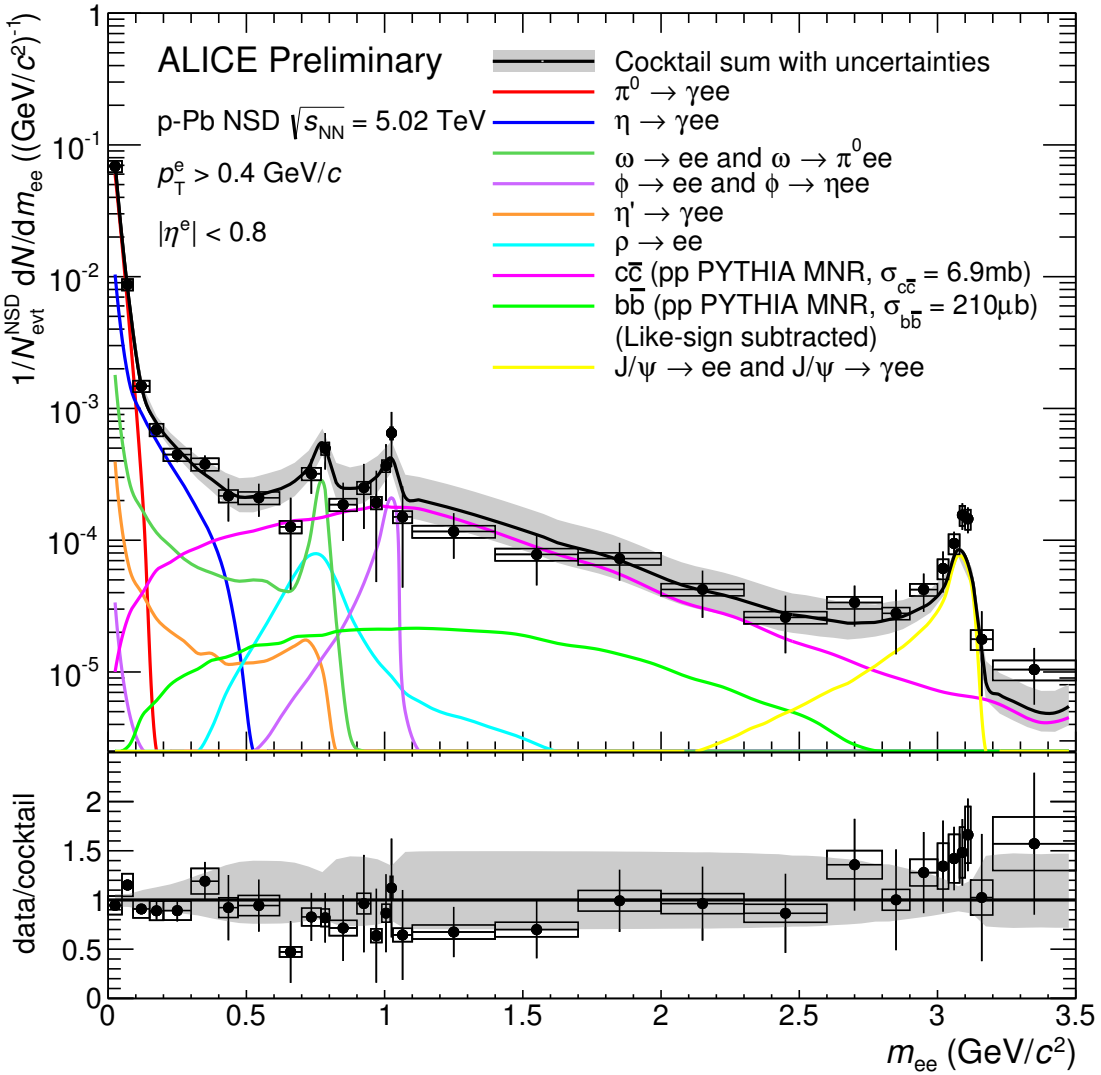


Direct Photon Ratio in pp Collisions



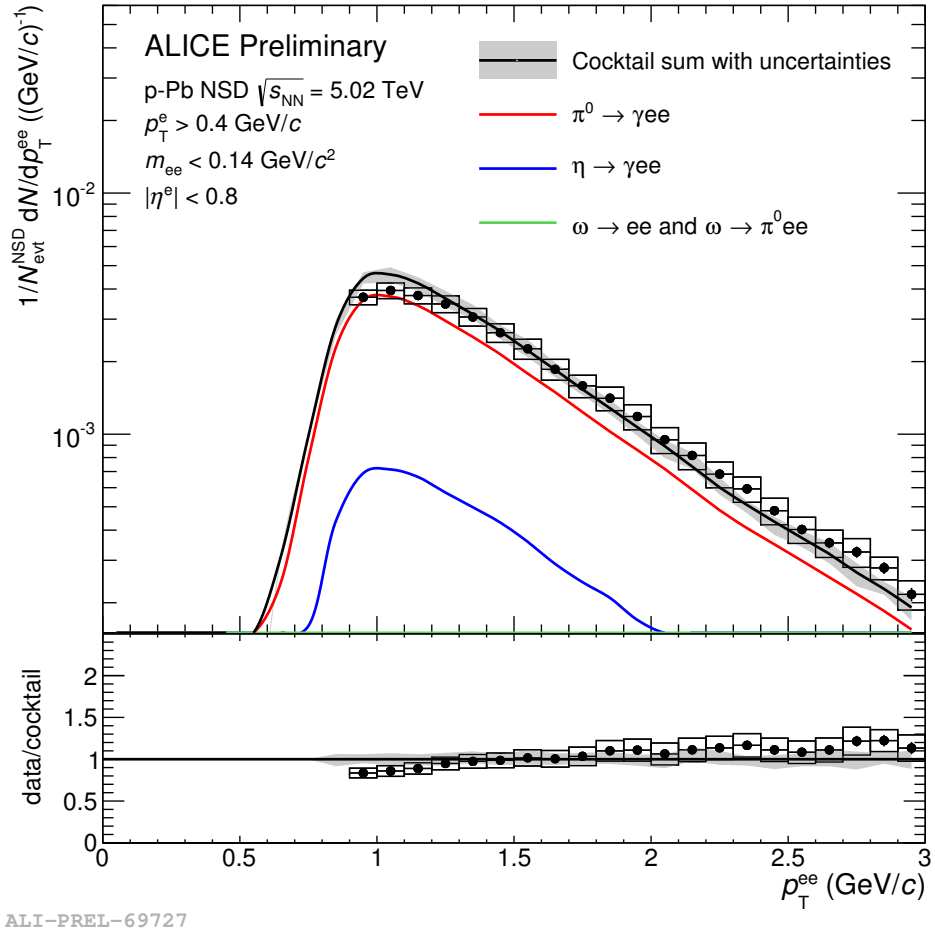
ALI-PREL-69072

Mass Spectrum in p-Pb ($p_T > 0.4$ GeV/c)



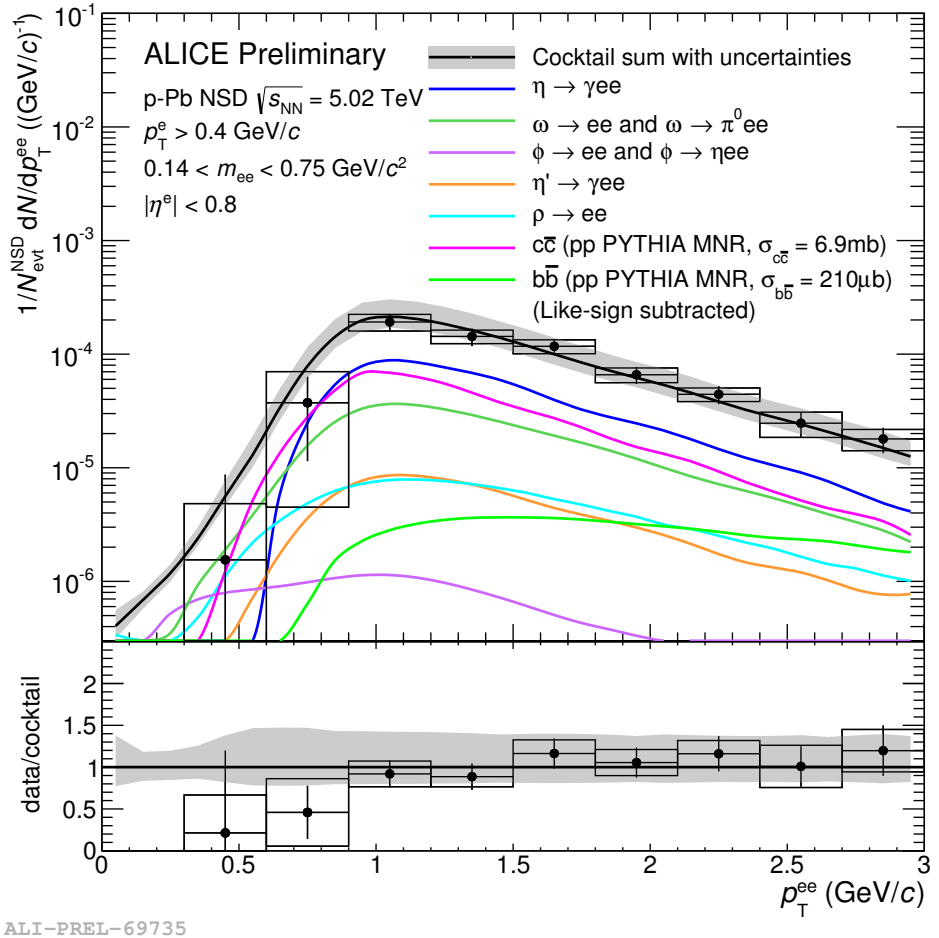
p_T Spectra in p-Pb (p_T > 0.4 GeV/c)

- m_{ee} < 0.14 GeV/c^2
- dominated by π^0



ALI-PREL-69727

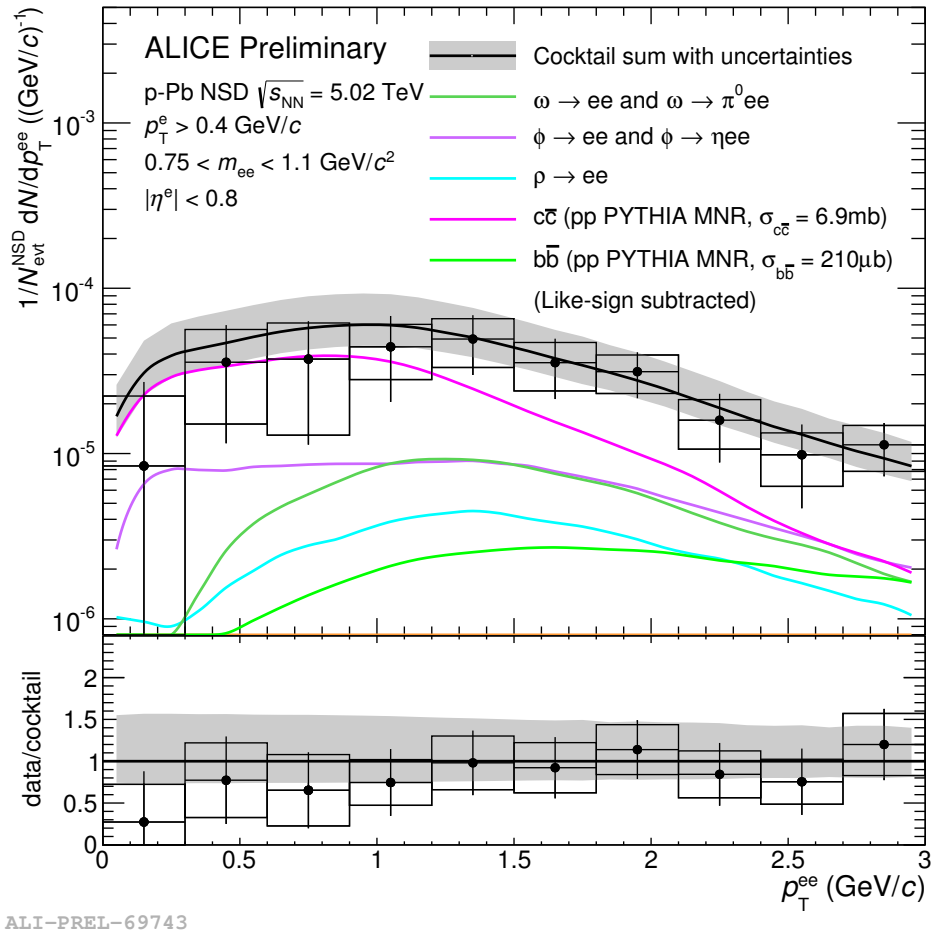
- 0.14 < m_{ee} < 0.75 GeV/c^2
- dominated by η and charm



ALI-PREL-69735

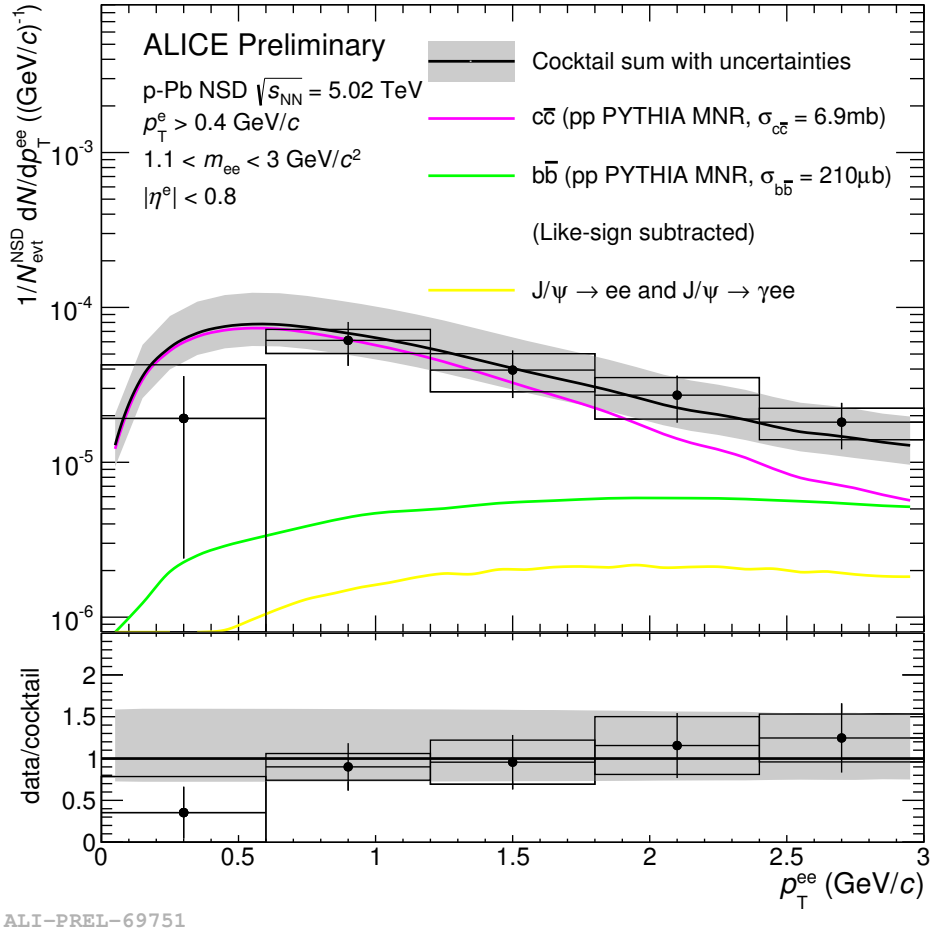
p_T Spectra in p-Pb (p_T > 0.4 GeV/c)

- 0.75 < m_{ee} < 1.1 GeV/c^2 (resonance region)
- dominated by charm



ALI-PREL-69743

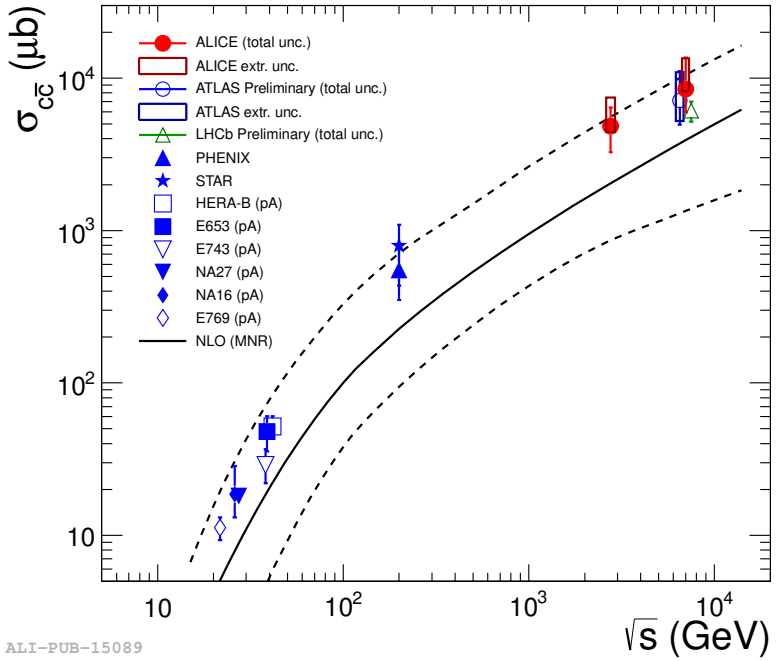
- 1.1 < m_{ee} < 3.0 GeV/c^2
- dominated by charm
- Data and cocktail in agreement



ALI-PREL-69751

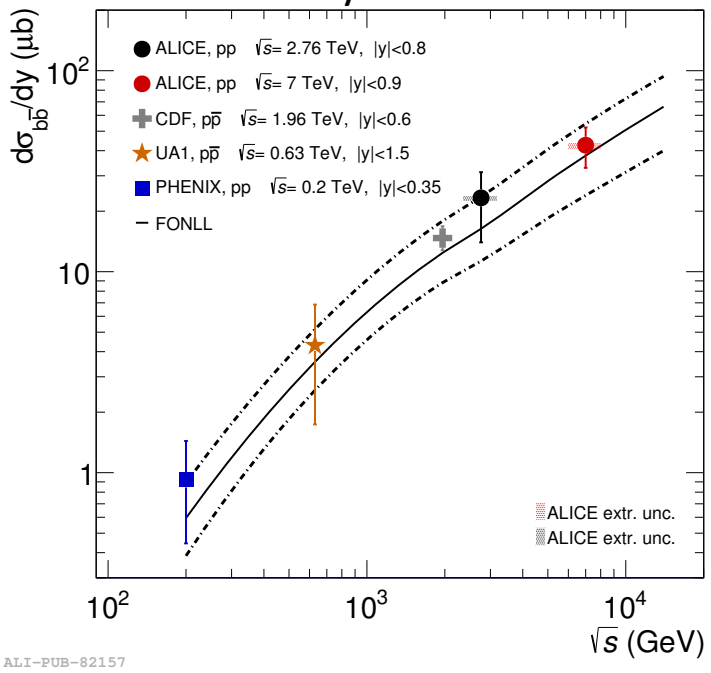
Hadronic Cocktail (Heavy-Flavor)

Charm cross section



ALICE Collaboration, arXiv:hep-ex/1205.4007

Beauty cross section



ALICE Collaboration, arXiv:nucl-ex/1405.4144

- Contributions of **the semi-leptonic heavy-flavor decays** based on cross sections measured in pp at $\sqrt{s}$ = 2.76 and 7 TeV
- For contributions in p-Pb and Pb-Pb collisions, pp expectations scaled by number of binary collisions $\langle N_{coll} \rangle$
- Cross sections at $\sqrt{s}$ = 5.02 TeV estimated by interpolation from FONLL (Fixed Order + Next-to-Leading Log) M. Cacciari, S. Frixione and P. Nason arXiv:hep-ph/0102134
- ***J/Ψ*** based on pp calculations (scaled to p-Pb measurements)