# Low-mass dielectrons in ALICE

**Sebastian Scheid**
on behalf of the ALICE Collaboration

Goethe-Universität Frankfurt

# Motivation - Dielectrons

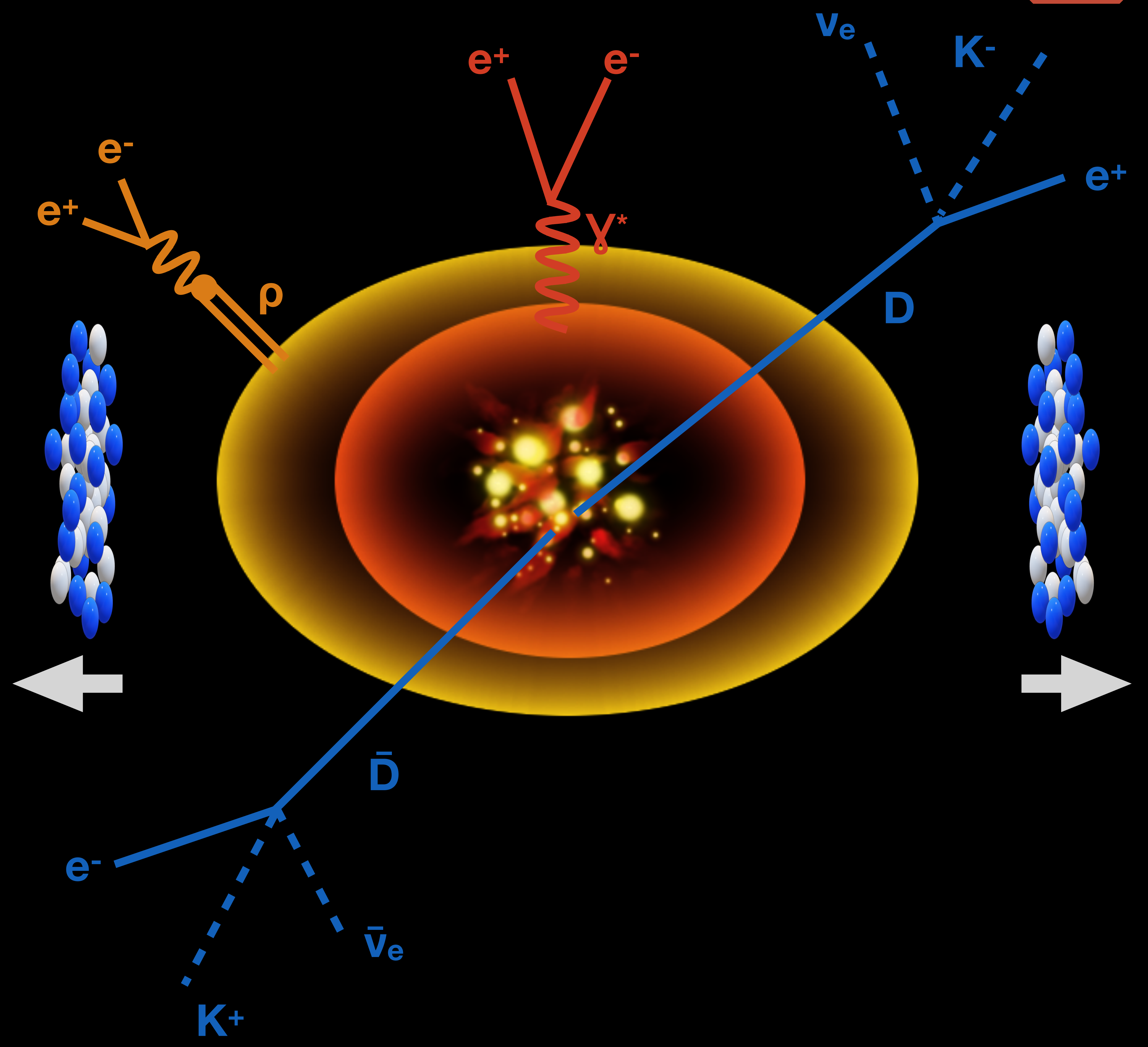
Various sources produce correlated pairs of electrons:

- Pseudoscalar and vector mesons (π, η, ρ, ω, ϕ, J/ψ) via direct ($e^+e^-$) or Dalitz (X $e^+e^-$) decays
- Semi-leptonic decays of open heavy-flavour hadrons ($c\bar{c}$ → DD → XY $e^+e^-$)
- Decays of direct photons via internal conversion

In AA collisions:

- Modification of the hadronic sources
- Additional contribution from QGP and hadron gas radiation
- Produced in all stages of the collision
- Negligible final-state interaction

→ Excellent probe to study QGP properties



# Motivation - Dielectrons

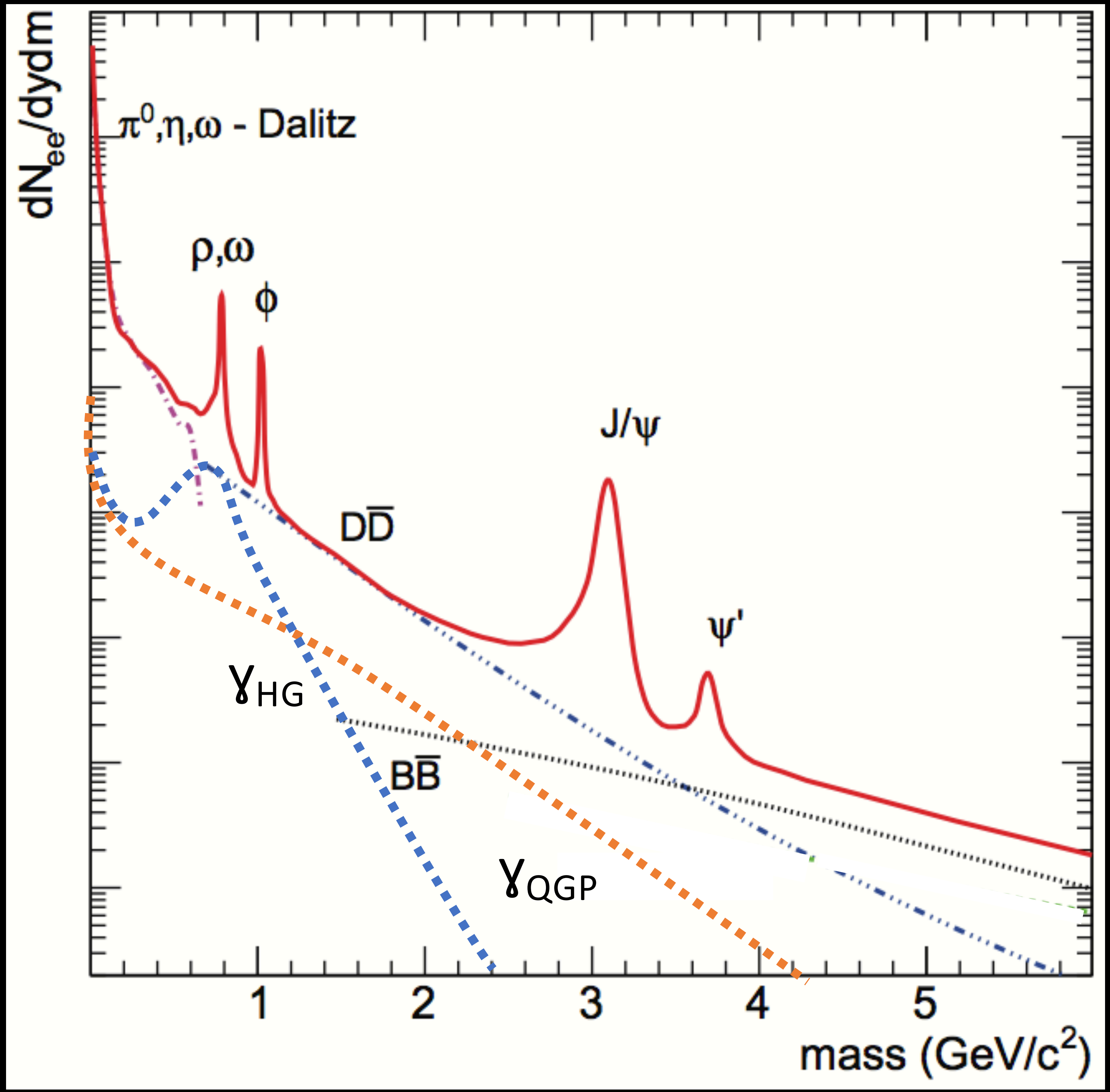
Various sources produce correlated pairs of electrons:

- Pseudoscalar and vector mesons (π, η, ρ, ω, ϕ, J/ψ) via direct ($e^+e^-$) or Dalitz (X $e^+e^-$) decays
- Semi-leptonic decays of open heavy-flavour hadrons ($c\bar{c}$ → DD → XY $e^+e^-$)
- Decays of direct photons via internal conversion

In AA collisions:

- Modification of the hadronic sources
- Additional contribution from QGP and hadron gas radiation
- Produced in all stages of the collision
- Negligible final state interaction

→ Excellent probe to study QGP properties




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

# Motivation - Dielectrons

**pp**

- Vacuum baseline for p–Pb and Pb–Pb
- Heavy-flavour and direct-photon production
- Possible new phenomena

**p–Pb**

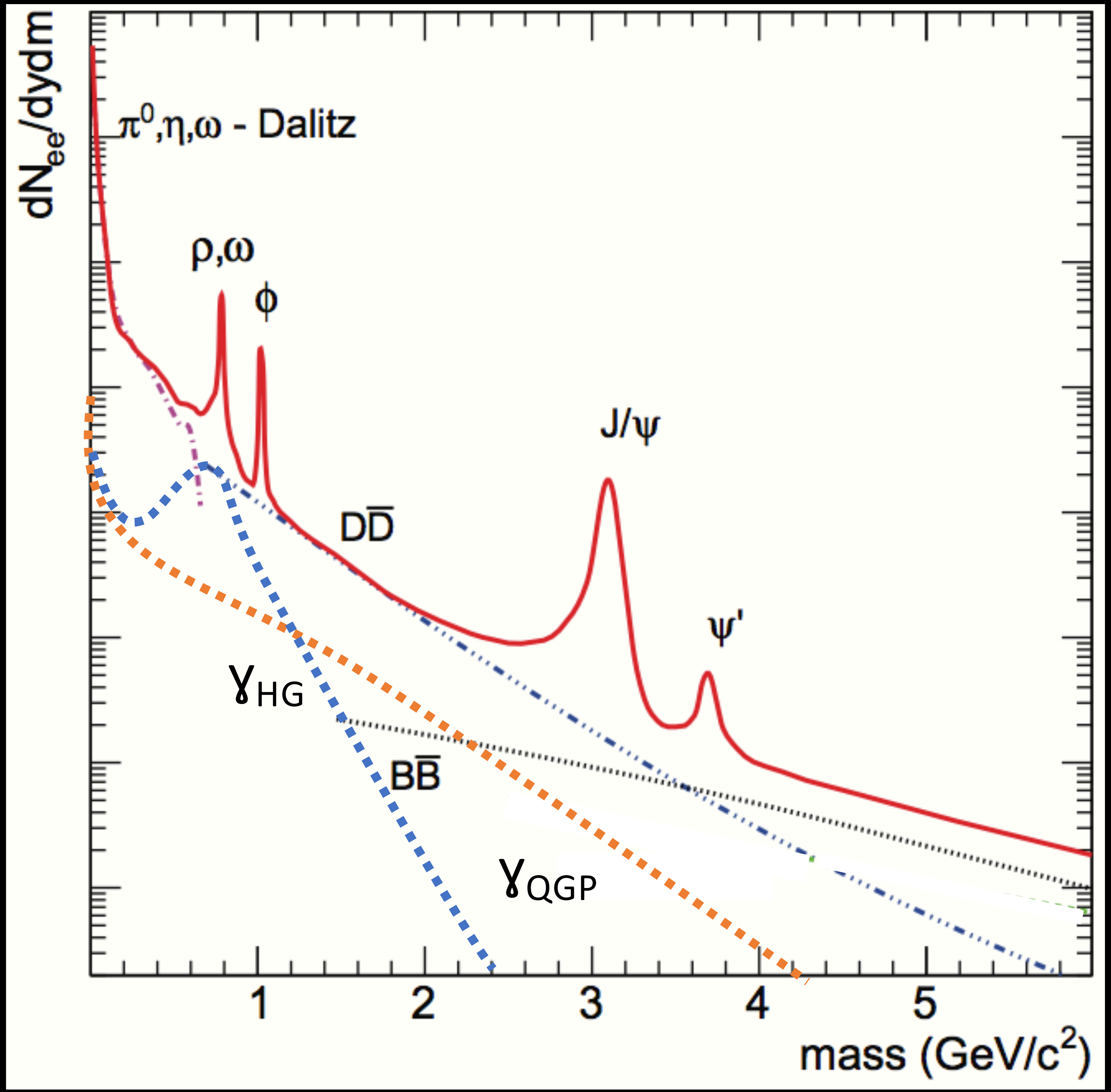
- Cold nuclear matter effects
- Possible thermal radiation

**Pb–Pb**

- QGP radiation
- Chiral-symmetry restoration

**At LHC energies:**

**Hottest and longest living QGP ever created**




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

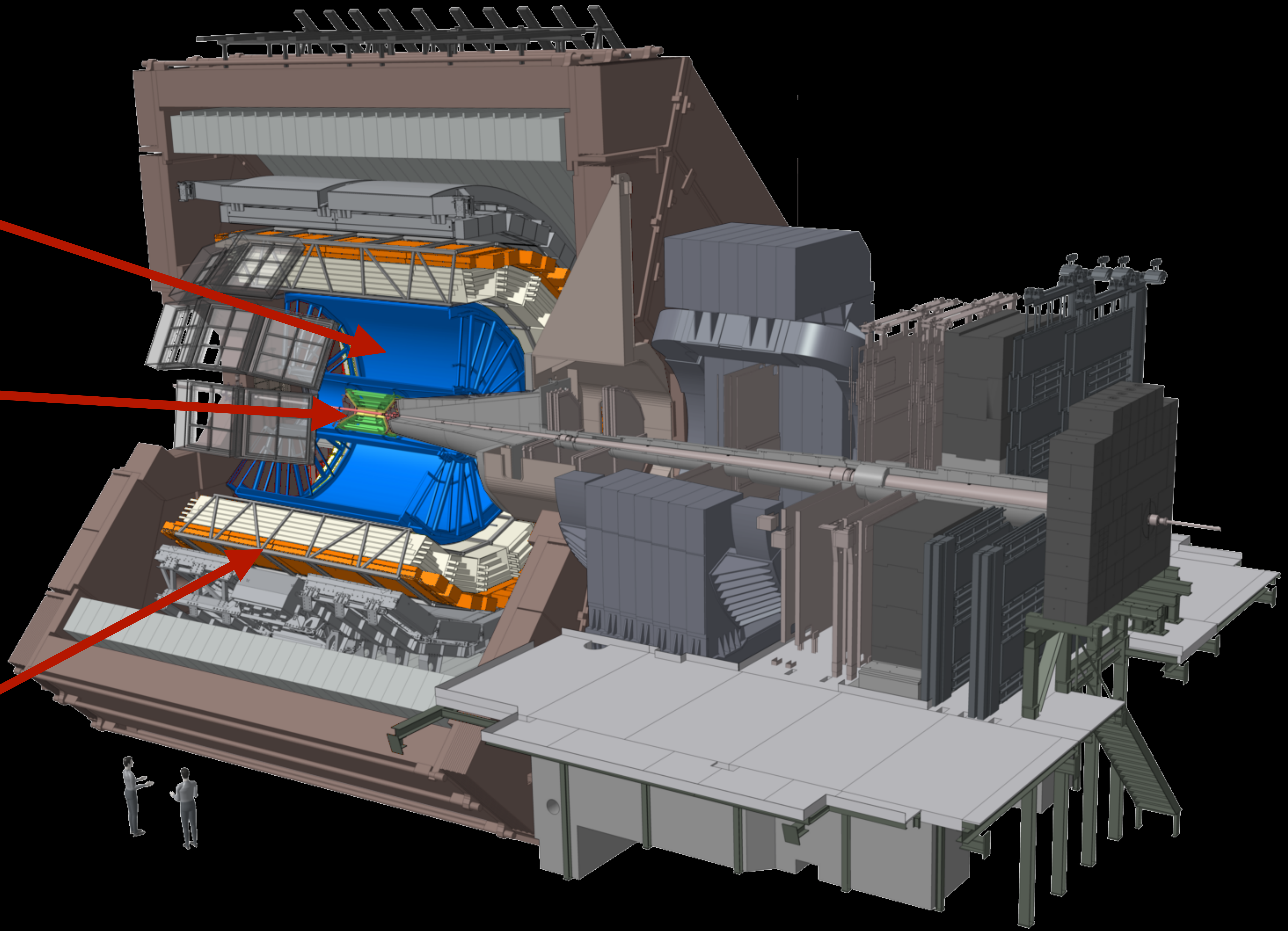
# The ALICE Detector

**Time Projection Chamber**
- Particle identification via d$E$/dx
- Tracking

**Inner Tracking System**
- Particle identification via d$E$/dx
- Tracking
- Vertex determination

**V0**
- Centrality estimation
- Trigger

**Time Of Flight**
- Particle identification via Time-Of-Flight



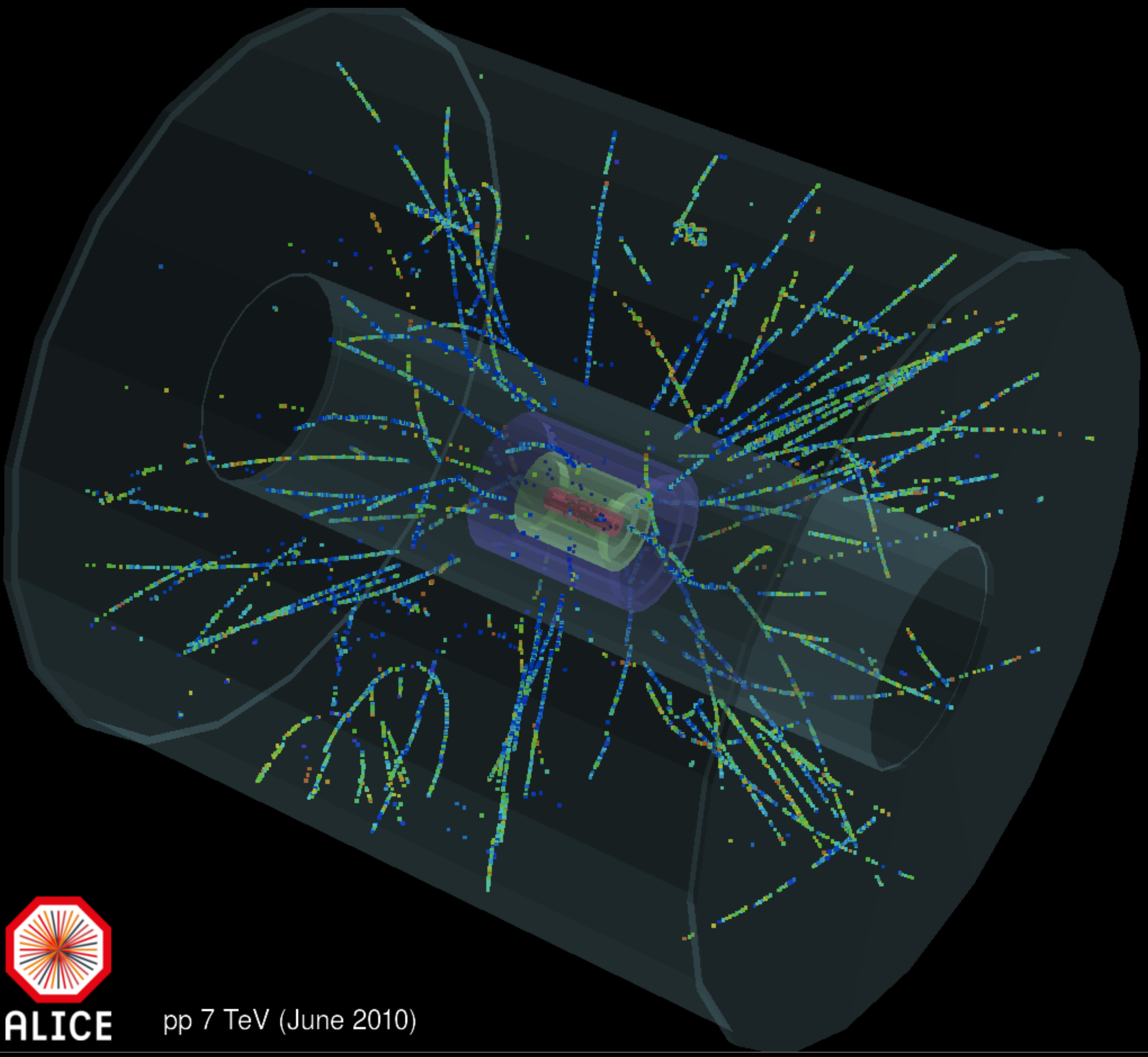
# pp Collisions

Run 1

- $\sqrt{s}$ = 7 TeV (min bias)
  JHEP 1809 (2018) 064

Run 2

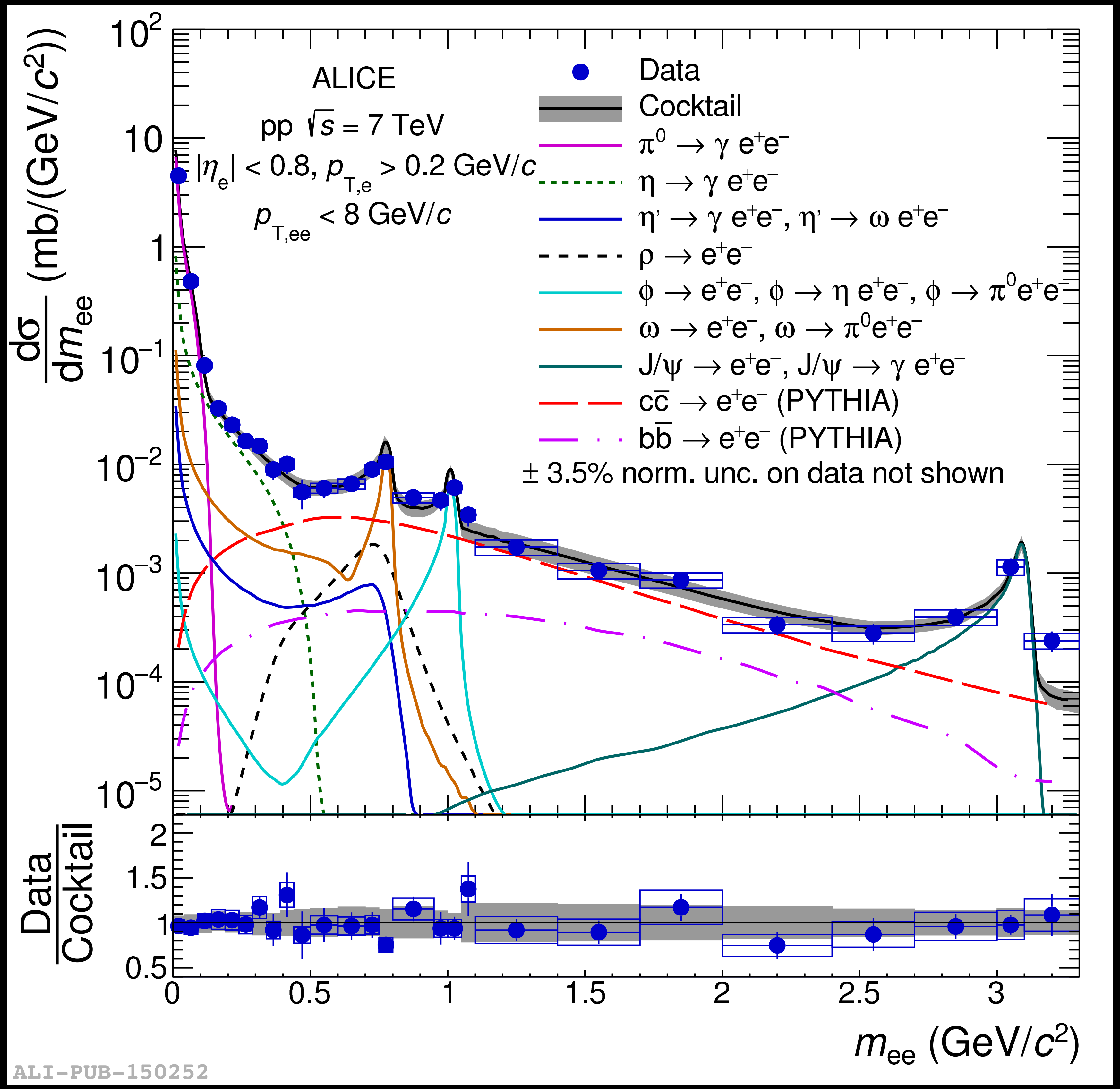
- $\sqrt{s}$ = 13 TeV (min bias and HM)
  PLB 788 (2019) 505
- $\sqrt{s}$ = 13 TeV (min bias at B = 0.2 T)
  preliminary
- $\sqrt{s}$ = 5.02 TeV (min bias)
  analysis ongoing

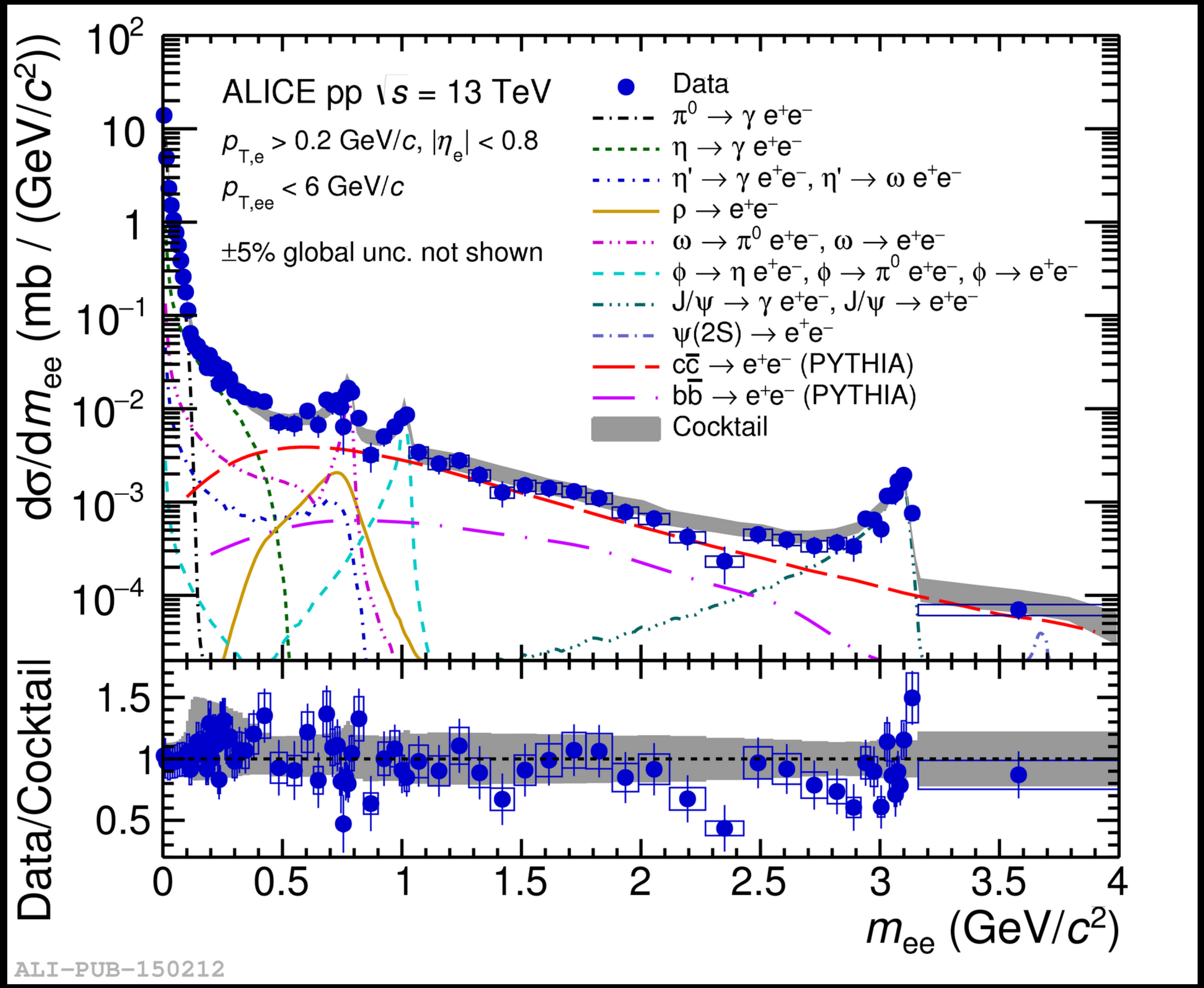


ALICE pp 7 TeV (June 2010)

# Dielectron mass spectra

JHEP 1809 (2018) 064



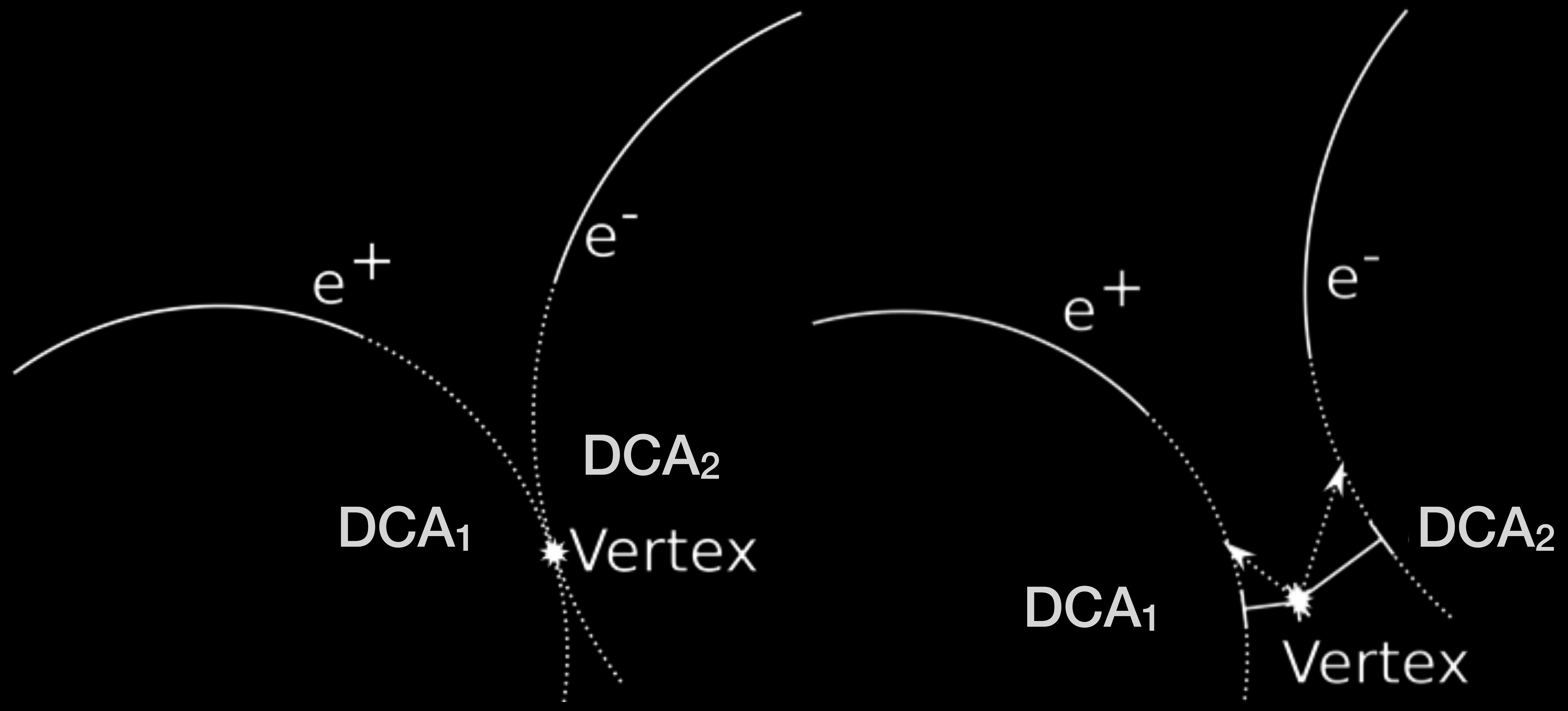




PLB 788 (2019) 505

- Dielectron production well understood
- Heavy flavour dominates for $m_{ee}$ > 0.5 GeV/$c^2$
  → Very large background for thermal-radiation studies in Pb—Pb

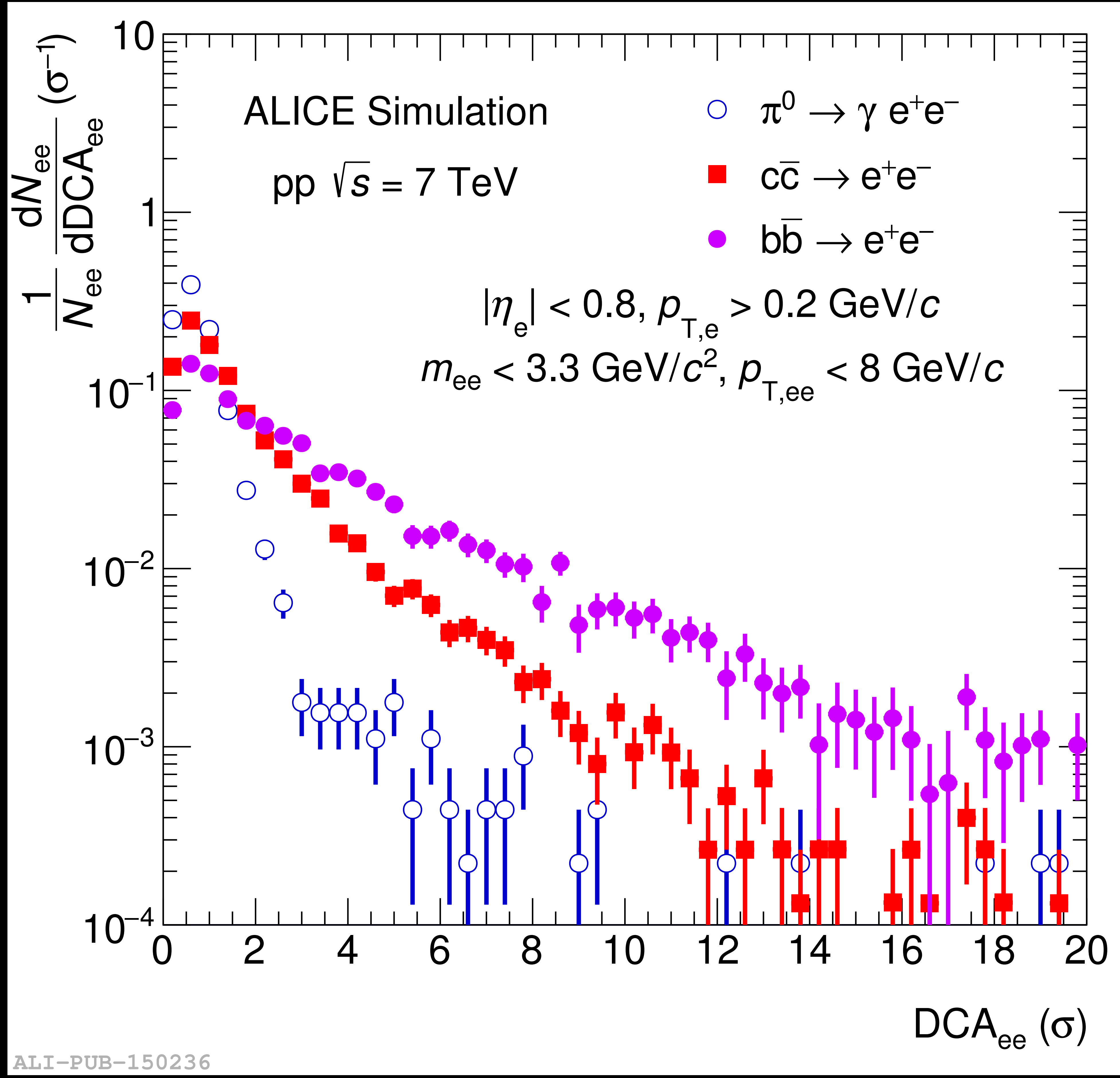
# Topological separation of e+e- sources

**Pair distance-of-closest-approach (DCA$_{ee}$)**




$$\mathrm{DCA}_{ee} = \sqrt{\frac{\mathrm{DCA}_1^2 + \mathrm{DCA}_2^2}{2}}$$

→ **Normalise track DCA to resolution**



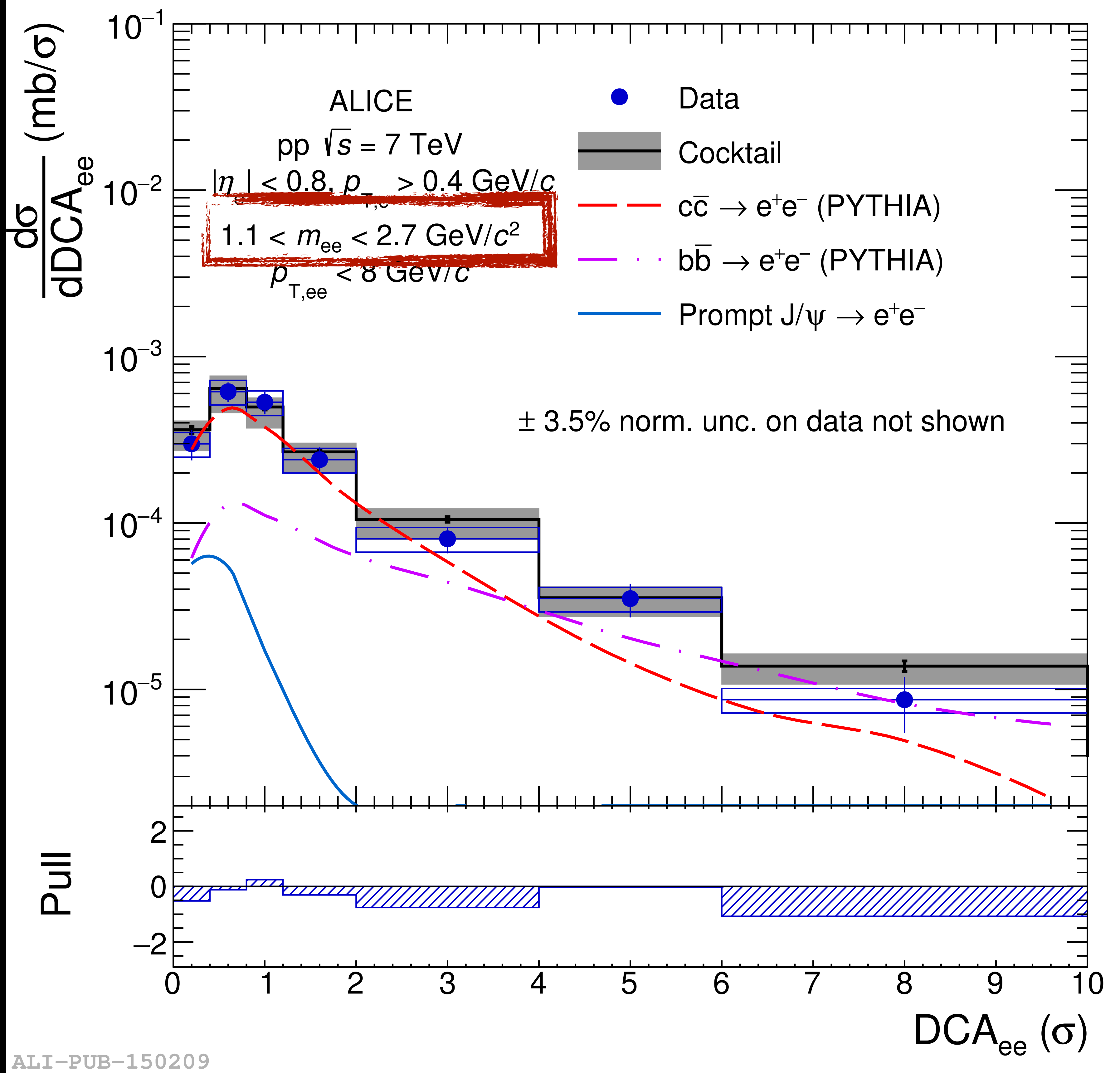

JHEP 1809 (2018) 064

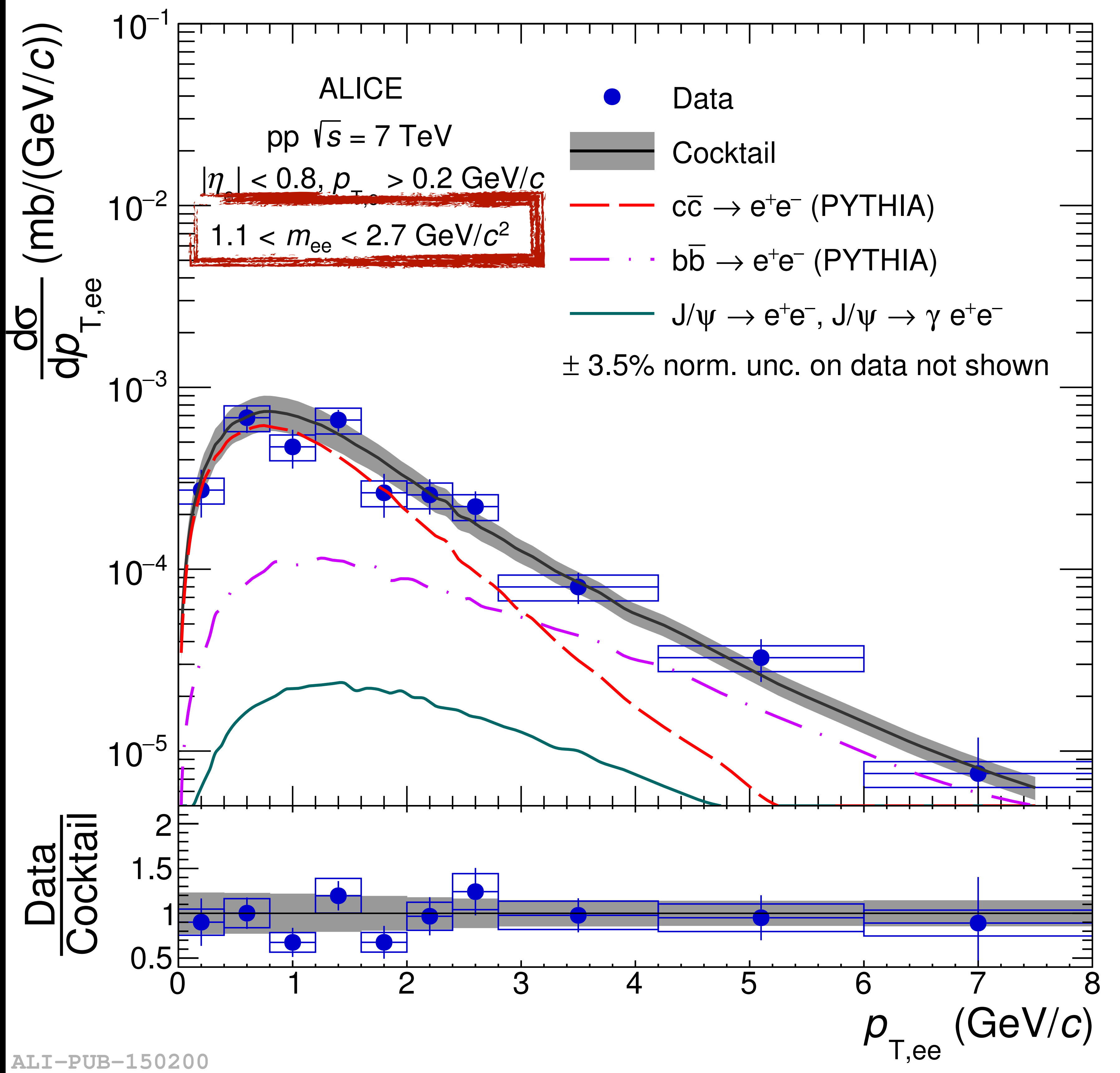
DCA$_{ee}$ allows us to **separate prompt from delayed dielectron sources:**

**DCA$_{ee}$(prompt) < DCA$_{ee}$(charm) < DCA$_{ee}$(beauty)**

# Heavy flavour in pp at √s = 7 TeV

**HF dominated mass region**

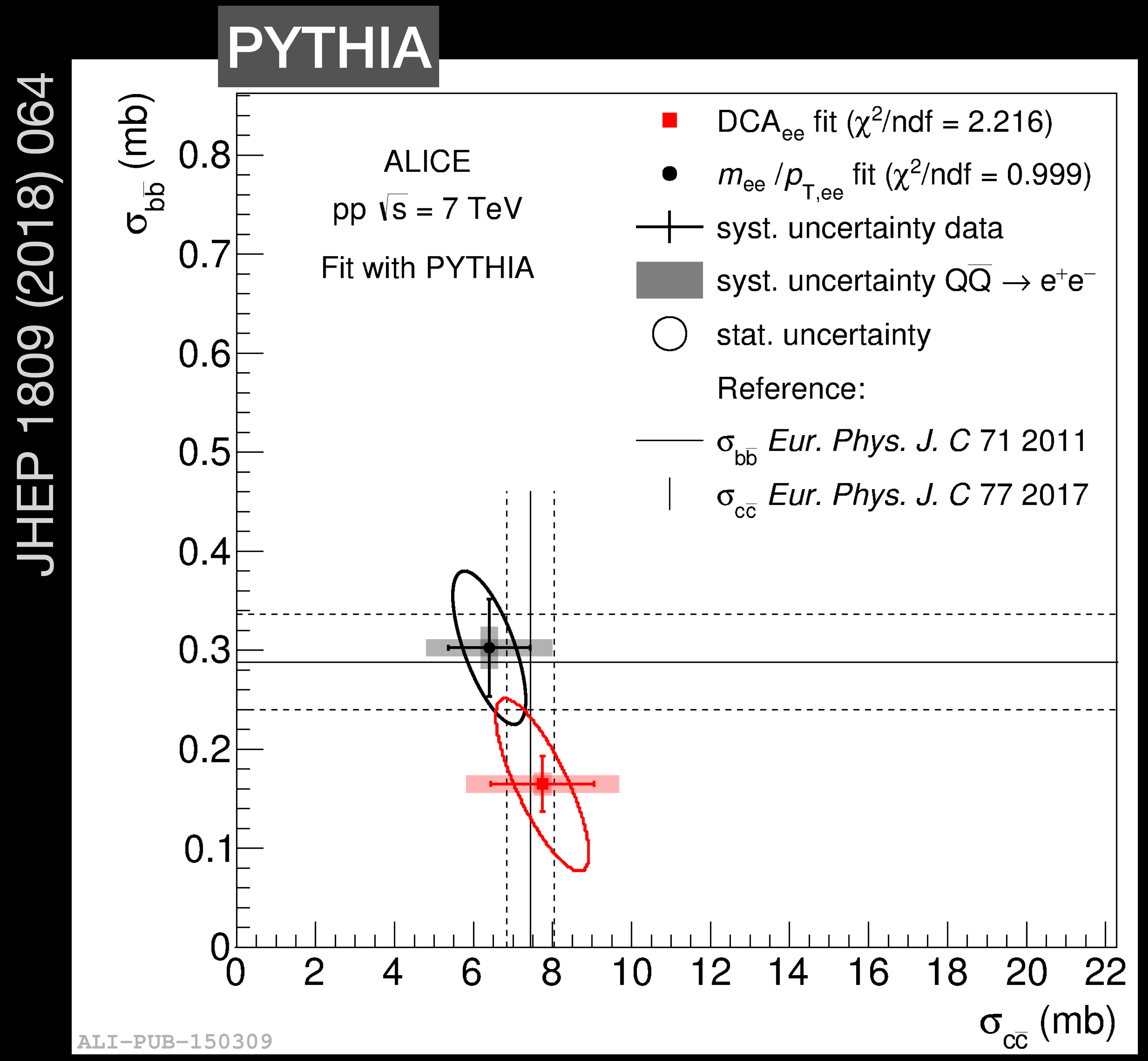



JHEP 1809 (2018) 064

- No indication of prompt source — as expected in pp
- Extract heavy-flavour cross sections from fits of MC templates to either $DCA_{ee}$ or $m_{ee}/p_{T,ee}$ distributions

# Heavy-flavour in pp at $\sqrt{s}$ = 7 TeV

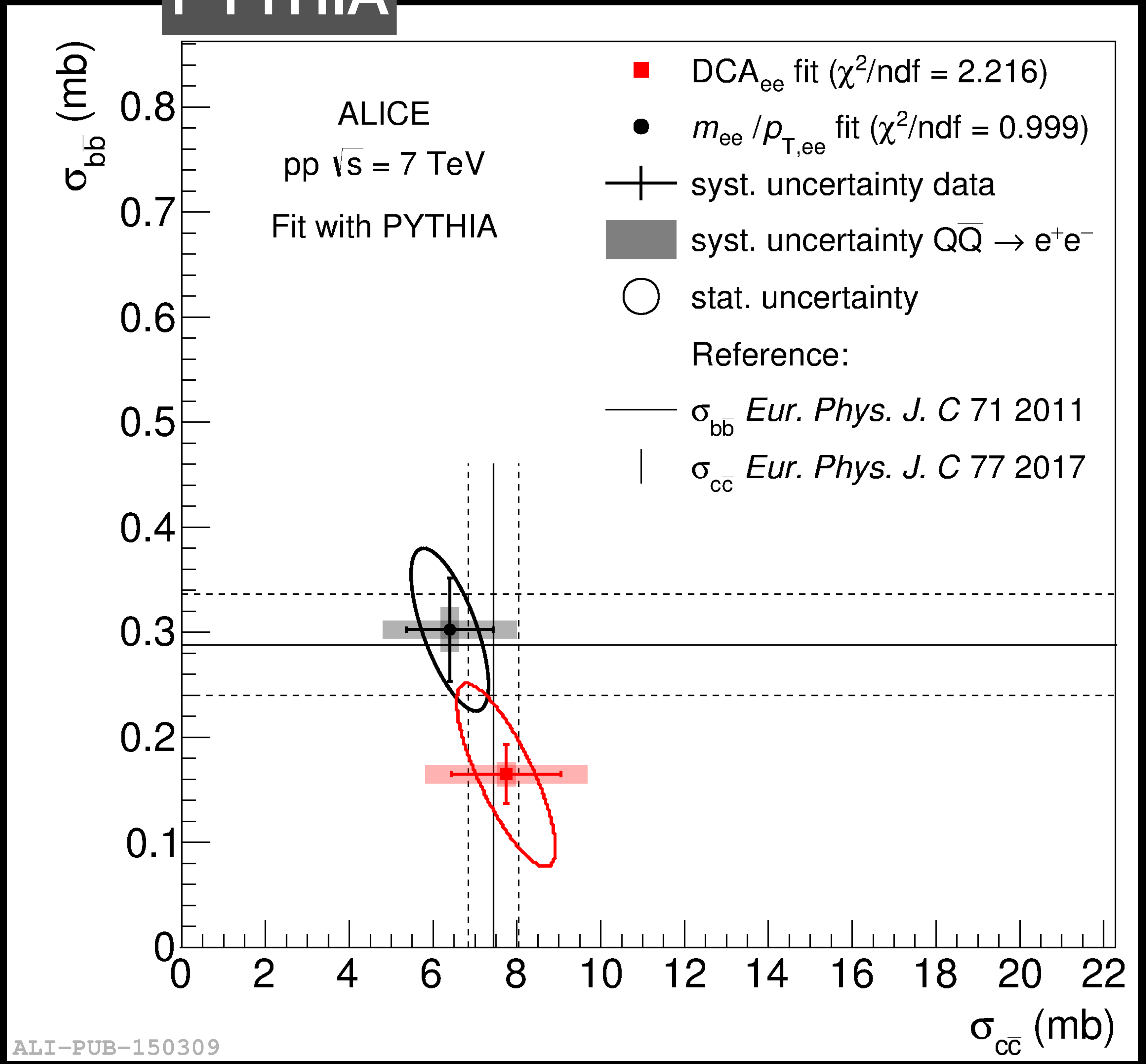



- DCA$_{ee}$ and $m_{ee}/p_{T,ee}$ fits in agreement
- $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ consistent with independent measurement using single-HF hadrons
- Dominant systematic uncertainty: 22% from $c\bar{c}\rightarrow ee$ branching ratio

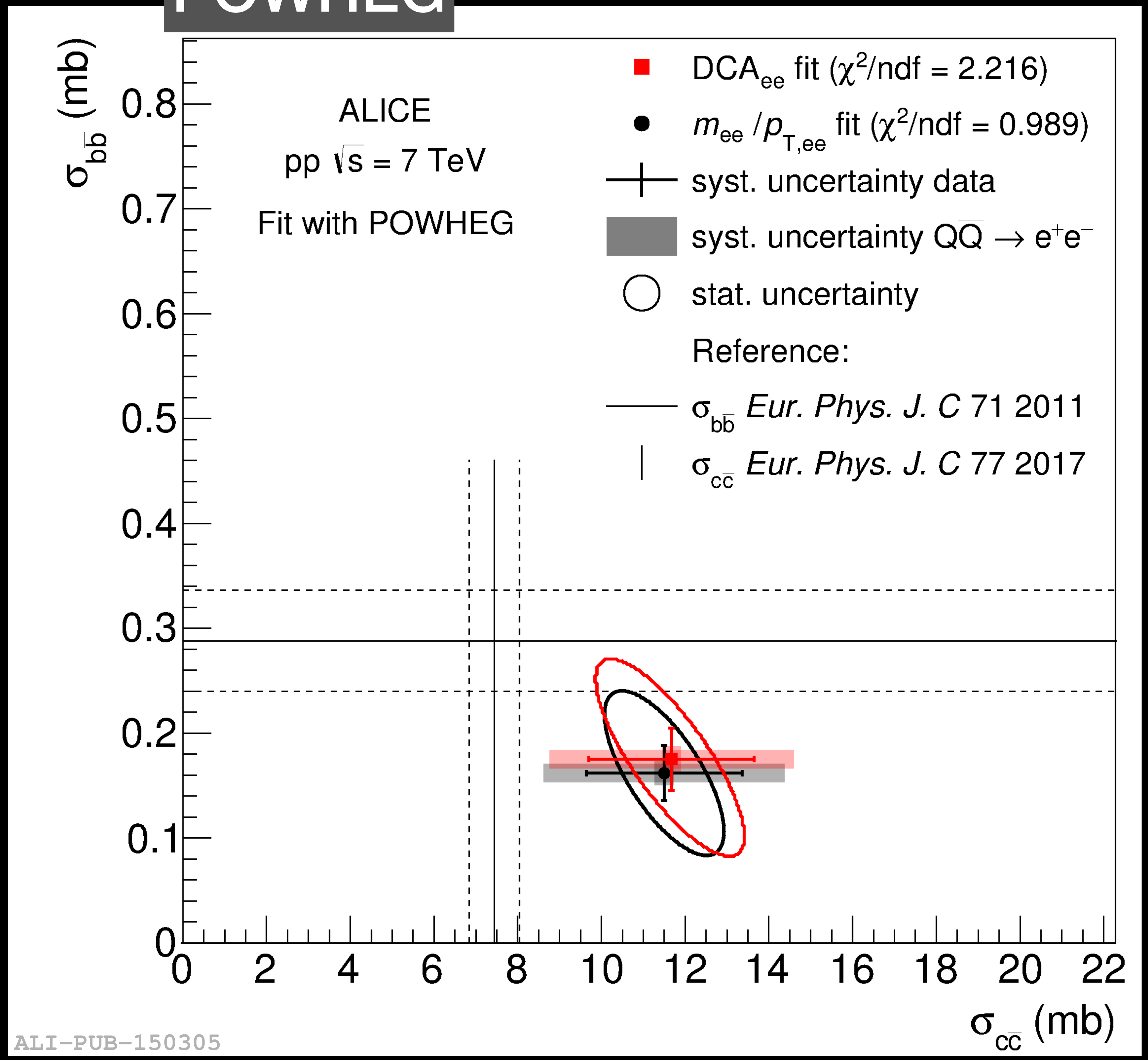
# Heavy-flavour in pp at $\sqrt{s}$ = 7 TeV

JHEP 1809 (2018) 064

PYTHIA




POWHEG




- $DCA_{ee}$ and $m_{ee}/p_{T,ee}$ fits in agreement
- $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ consistent with independent measurement using single-HF hadrons
- Dominant systematic uncertainty: 22% from $c\bar{c} \rightarrow ee$ branching ratio

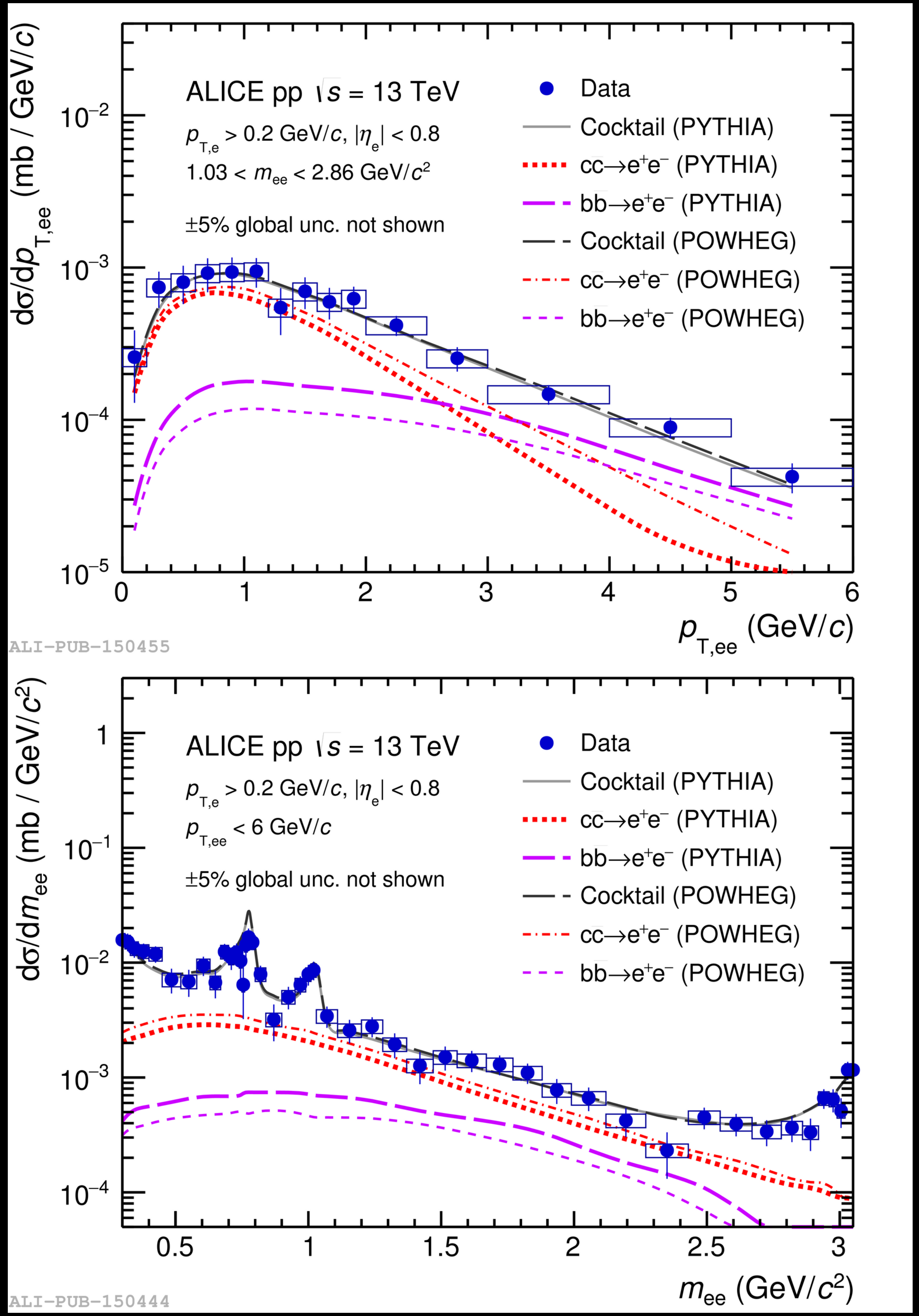
- $DCA_{ee}$ and $m_{ee}/p_{T,ee}$ fits in agreement
- Tension between $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ from PYTHIA and POWHEG
  → Sensitivity on different production mechanisms for heavy-flavour quarks

# Heavy flavour in pp at √s = 13 TeV

Similar findings in 13 TeV min bias and high-multiplicity analysis

| | PYTHIA | POWHEG |
|---|---|---|
| $d\sigma_{c\bar{c}}/dy\|_{y=0}$ | $974 \pm 138\,(\text{stat.}) \pm 140\,(\text{syst.})$ μb | $1417 \pm 184\,(\text{stat.}) \pm 204\,(\text{syst.})$ μb |
| $d\sigma_{b\bar{b}}/dy\|_{y=0}$ | $79 \pm 14\,(\text{stat.}) \pm 11\,(\text{syst.})$ μb | $48 \pm 14\,(\text{stat.}) \pm 7\,(\text{syst.})$ μb |
| $d\sigma_{c\bar{c}}/dy\|^{HM}_{y=0}$ | $4.14 \pm 0.67\,(\text{stat.}) \pm 0.66\,(\text{syst.})$ μb | $5.95 \pm 0.91\,(\text{stat.}) \pm 0.95\,(\text{syst.})$ μb |
| $d\sigma_{b\bar{b}}/dy\|^{HM}_{y=0}$ | $0.29 \pm 0.07\,(\text{stat.}) \pm 0.05\,(\text{syst.})$ μb | $0.17 \pm 0.07\,(\text{stat.}) \pm 0.03\,(\text{syst.})$ μb |

**First measurement of charm and beauty cross sections at mid rapidity in pp at √s = 13 TeV**



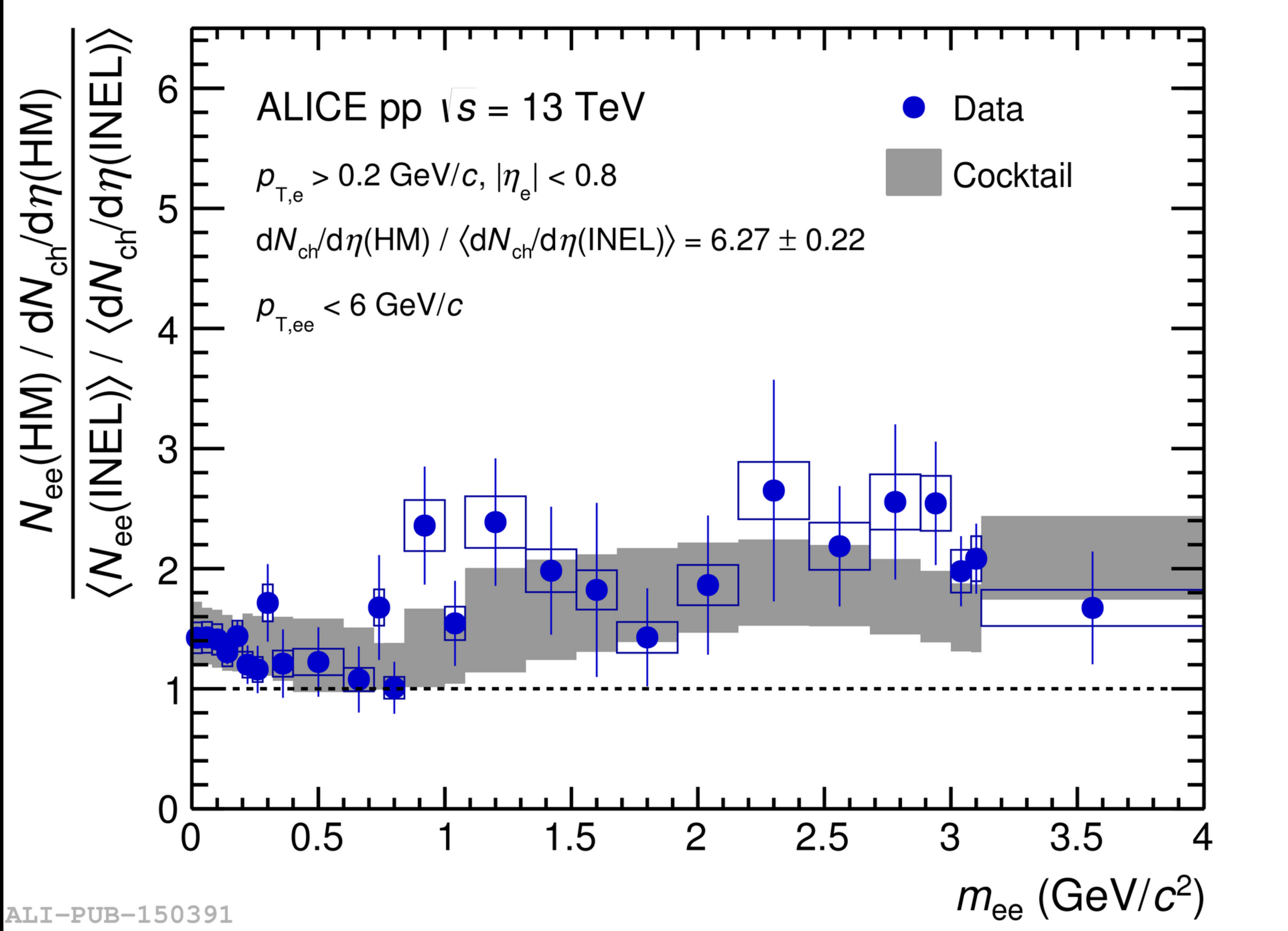

PLB 788 (2019) 505

# High multiplicity in pp at $\sqrt{s}$ = 13 TeV

**Medium effects in HM pp collisions?**

- Selection of HM events i. e. 0.036% with the highest multiplicity
- Ratio of HM to inelastic pp collisions to cancel some uncertainties (scaled by multiplicity)
- Cocktail reflects stronger than linear increase in HF production with multiplicity (from D-meson measurement) and hardening of $p_T$ spectra

**→No sensitivity (yet) for medium radiation in HM pp data**




PLB 788 (2019) 505

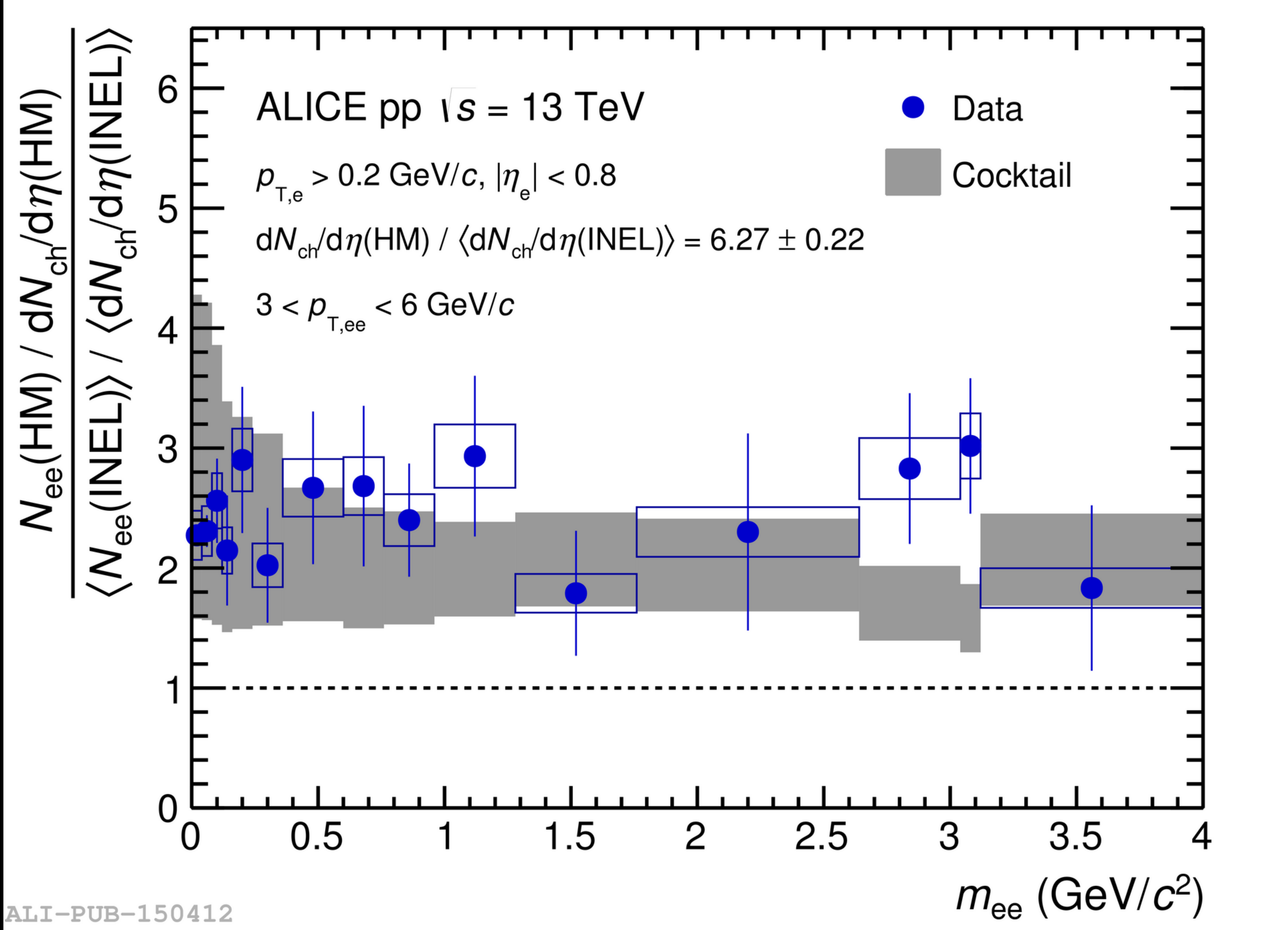
# High multiplicity in pp at $\sqrt{s}$ = 13 TeV

**Medium effects in HM pp collisions?**

- Selection of HM events i. e. 0.036% with the highest multiplicity
- Ratio of HM to inelastic pp collisions to cancel some uncertainties (scaled by multiplicity)
- Cocktail reflects stronger than linear increase in HF production with multiplicity (from D-meson measurement) and hardening of $p_T$ spectra

**→No sensitivity (yet) for medium radiation in HM pp data**

**→Scaling of beauty similar to charm at high $p_{T,ee}$**



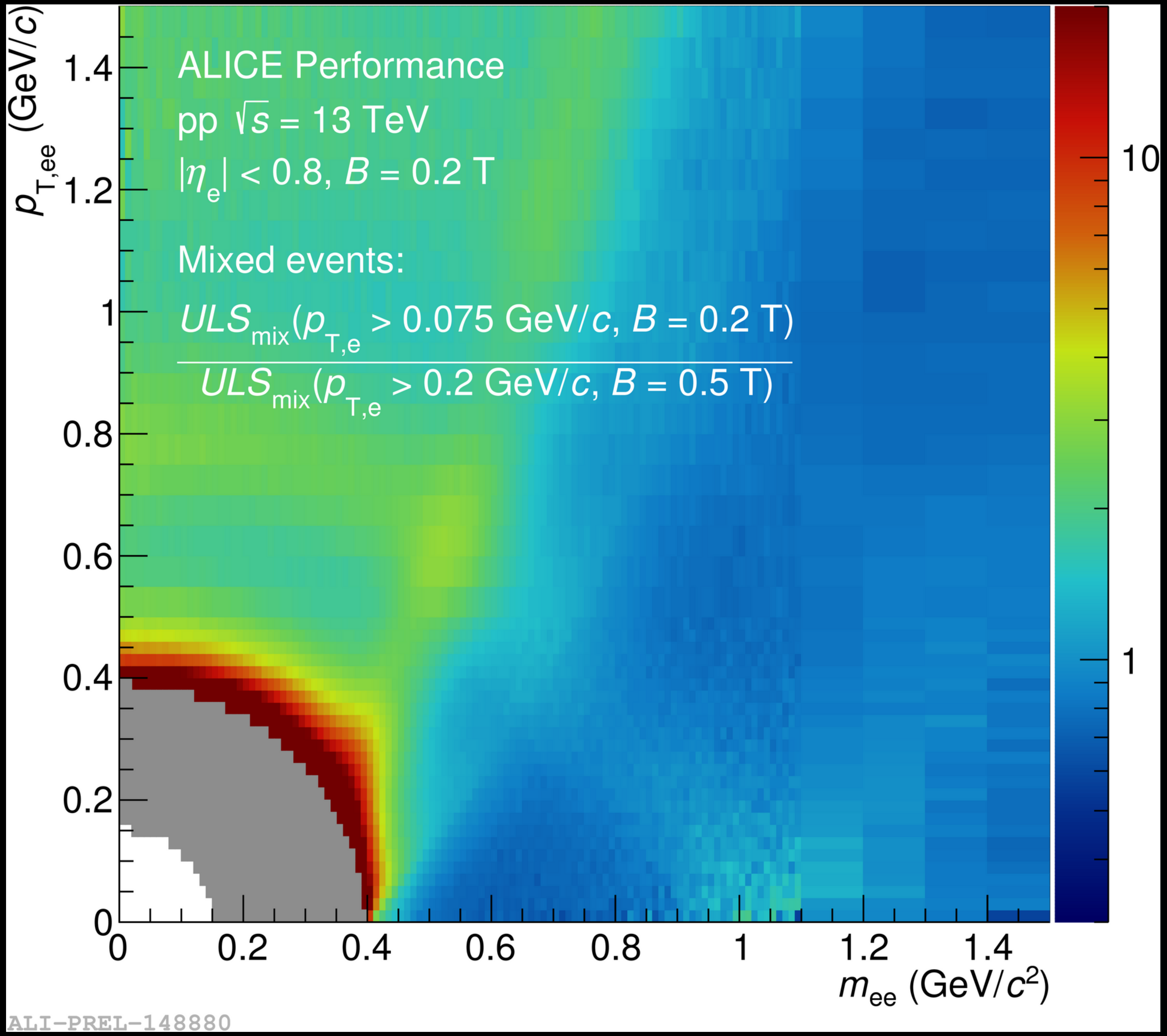

PLB 788 (2019) 505

# Soft dielectrons in pp at $\sqrt{s}$ = 13 TeV

Dedicated campaigns in Run 2 with reduced magnetic field (0.5 T → 0.2 T)

- Test scenario for Run 3
- Gain in phase space
  - Larger acceptance in $p_{T,e}$ (0.2 GeV/$c$ → 0.075 GeV/$c$)
  - Higher efficiency in TOF

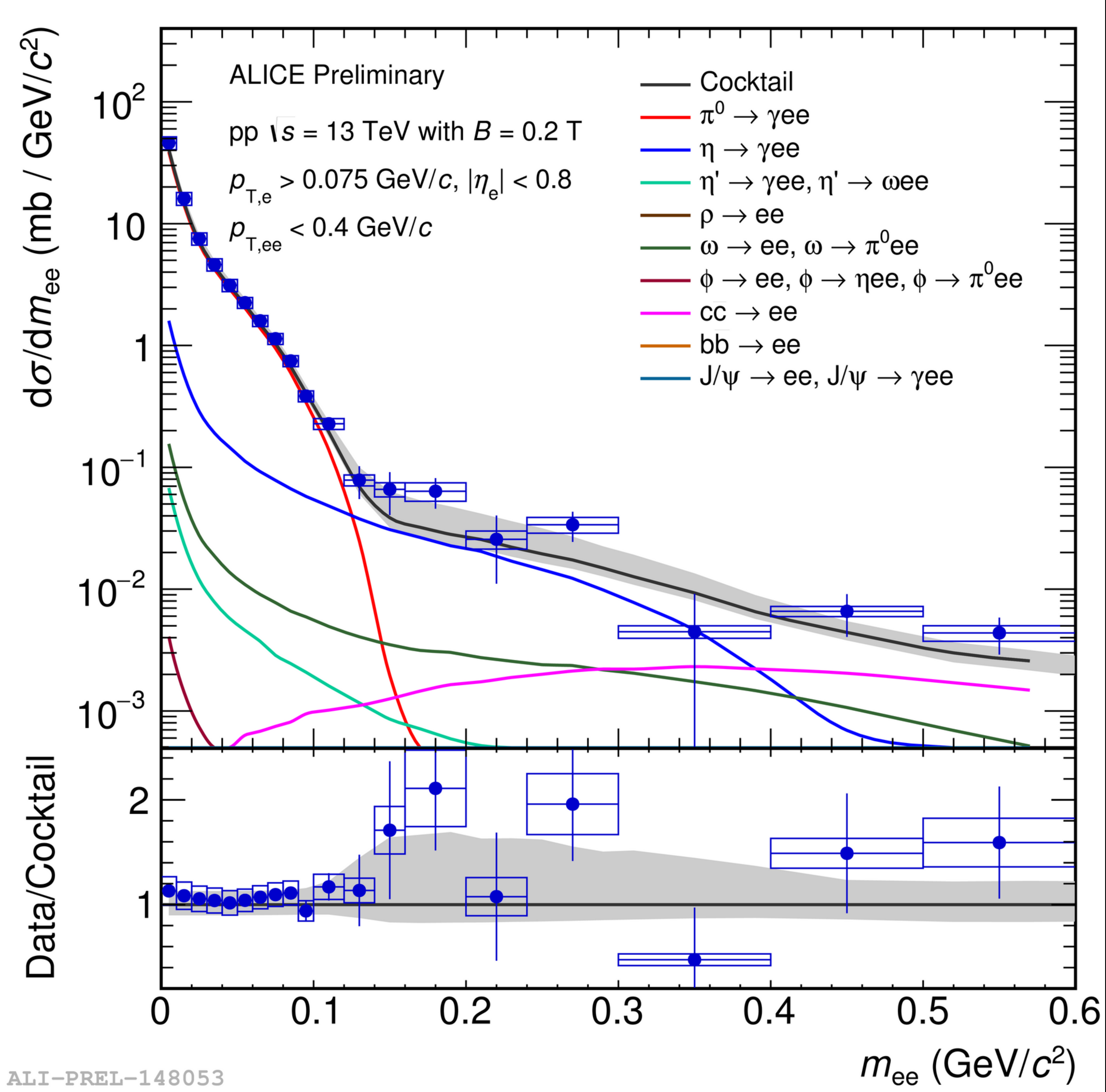
→ Sensitivity for soft dielectron production

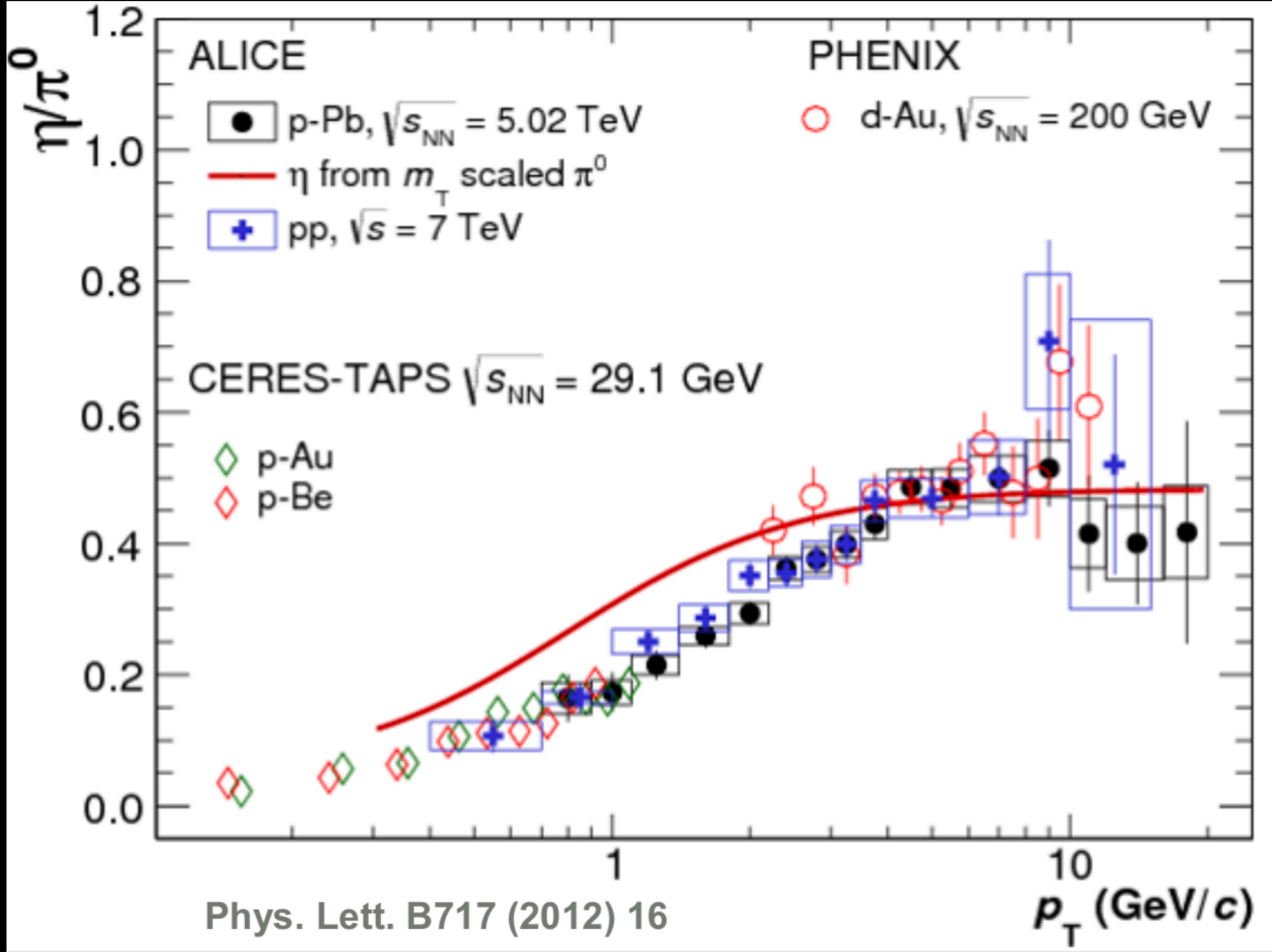


# Soft dielectrons in pp at $\sqrt{s}$ = 13 TeV

Hint for enhancement at LHC energies

- 2.2σ stat. significance over central value ($0.14 < m_{ee}$ 0.6 GeV/$c^2$) more data on tape
- Main cocktail uncertainties from $m_T$-scaling
  - Overpredicts η at low $p_T$

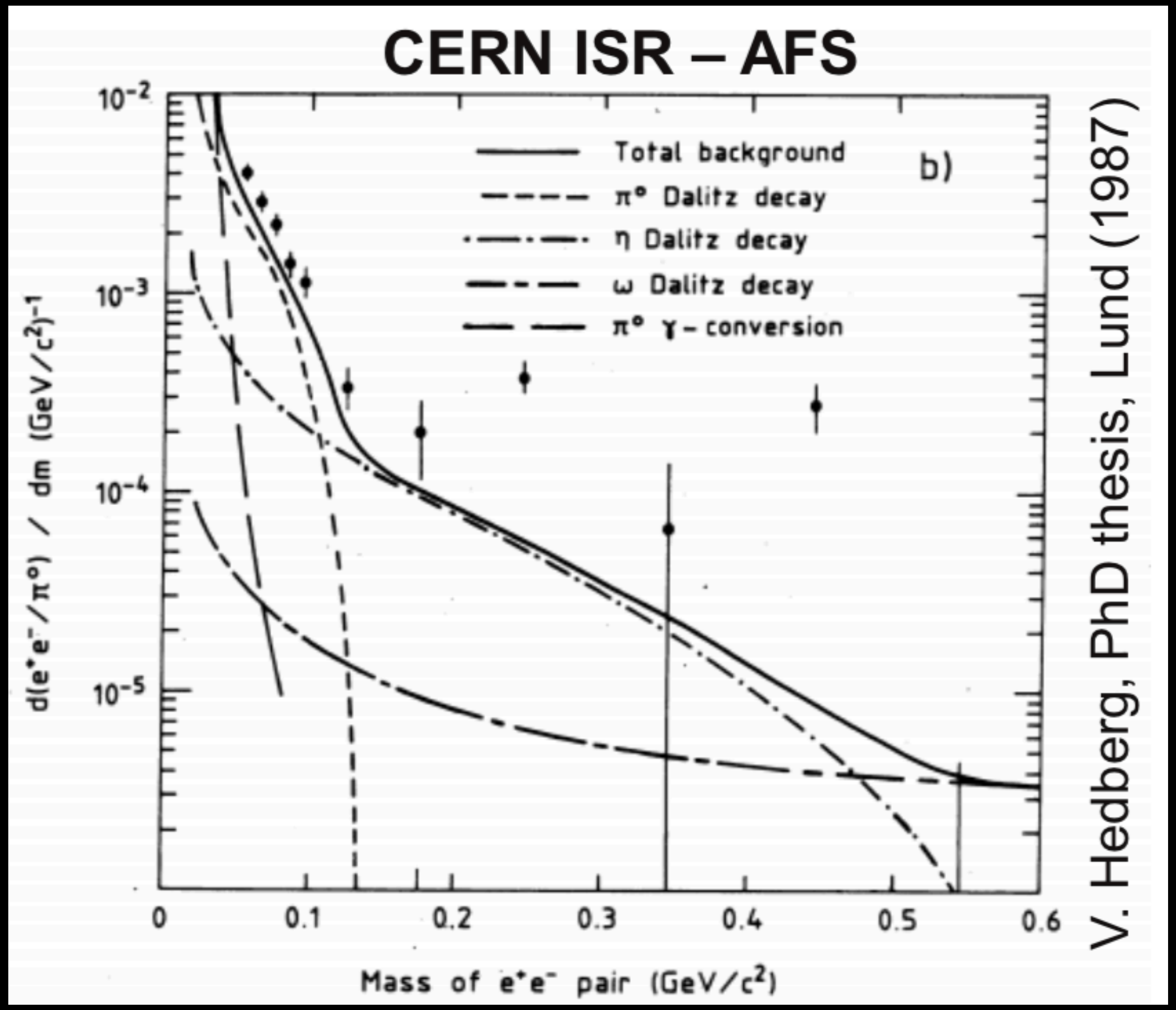


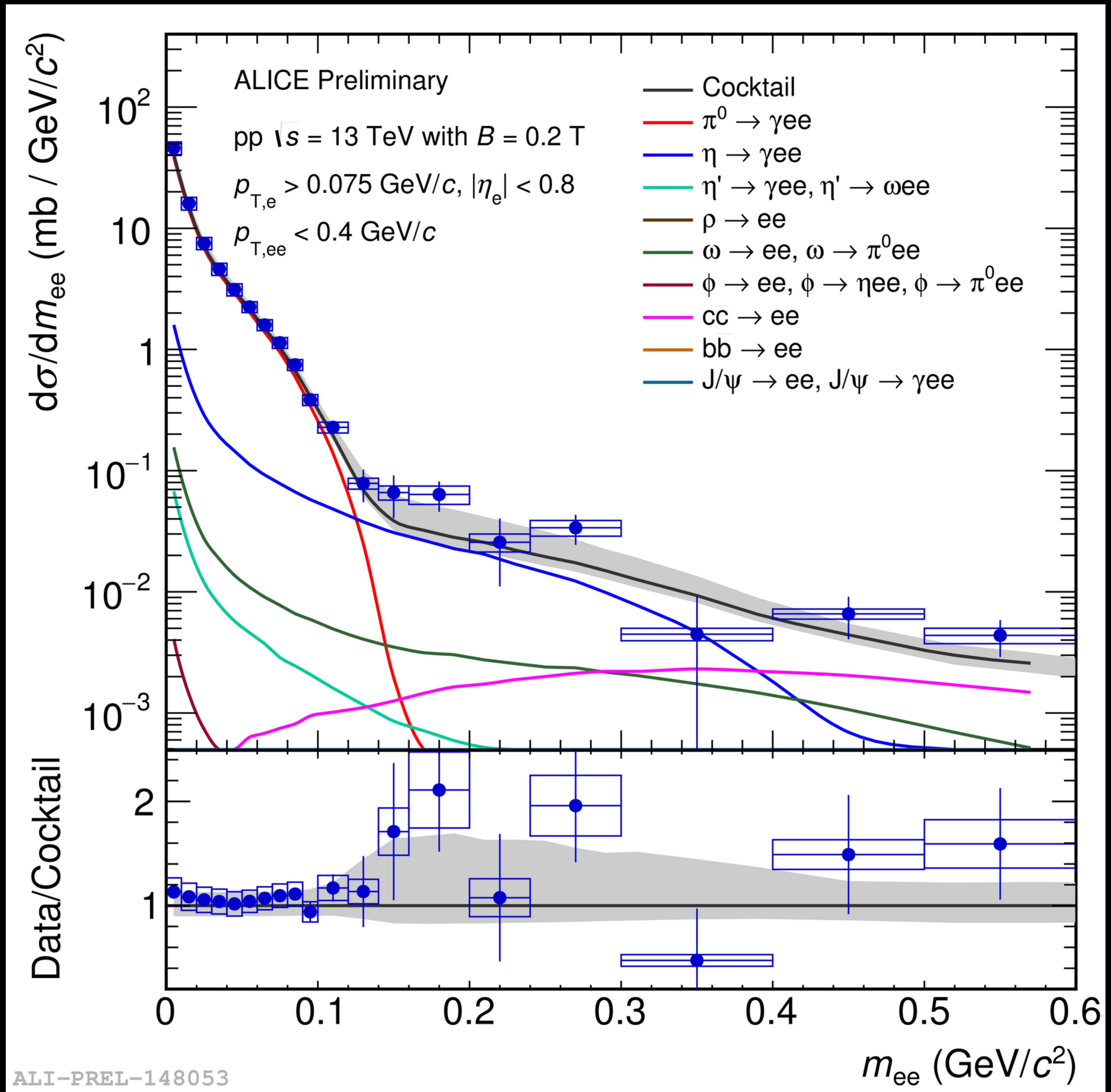



# Soft dielectrons in pp at $\sqrt{s}$ = 13 TeV

Hint for enhancement at LHC energies

- 2.2σ stat. significance over central value ($0.14 < m_{ee}$ 0.6 GeV/$c^2$) more data on tape
- Main cocktail uncertainties from $m_T$-scaling
  - Overpredicts η at low $p_T$
- Open question since ISR times



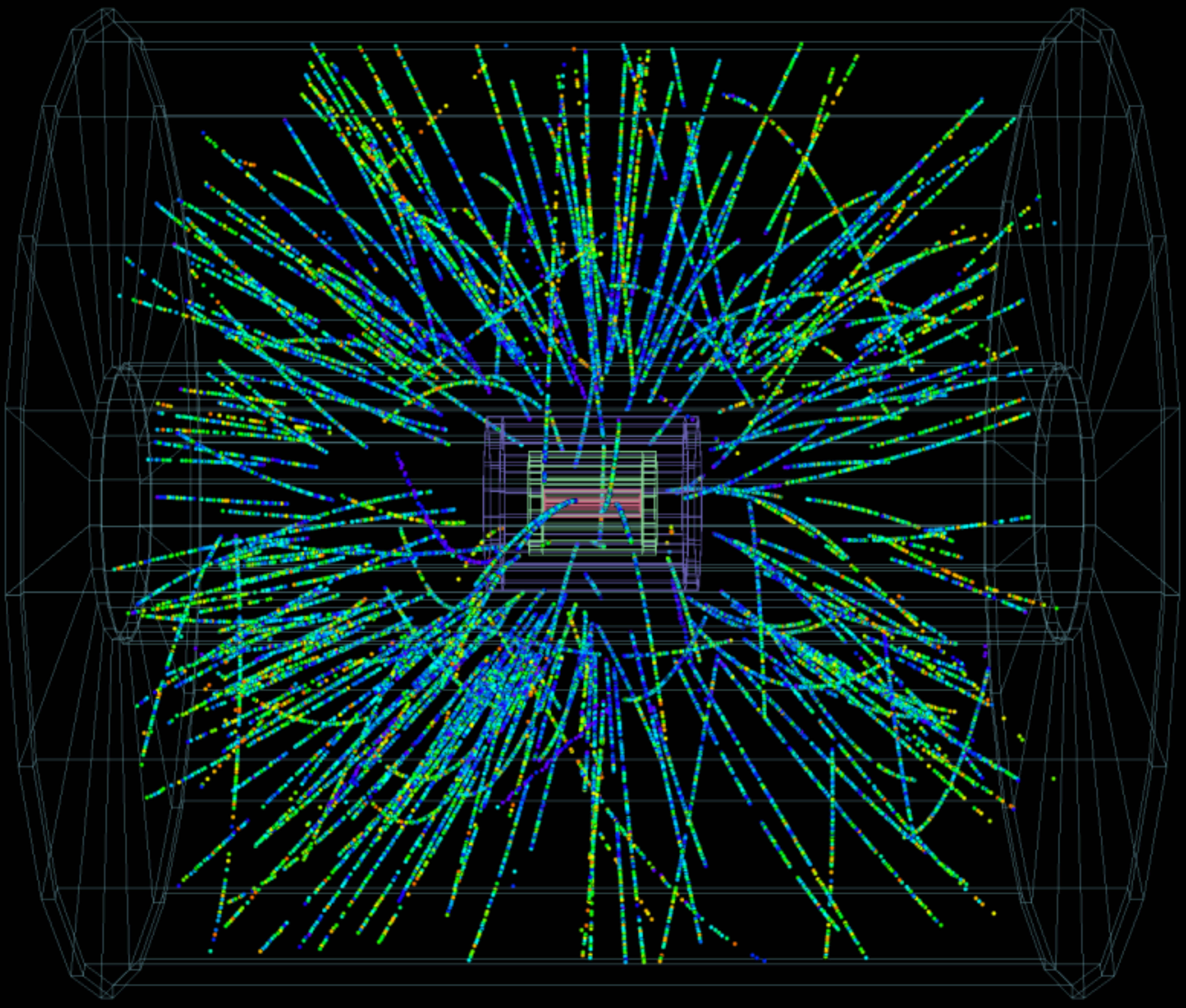
# p–Pb Collisions

Run 1

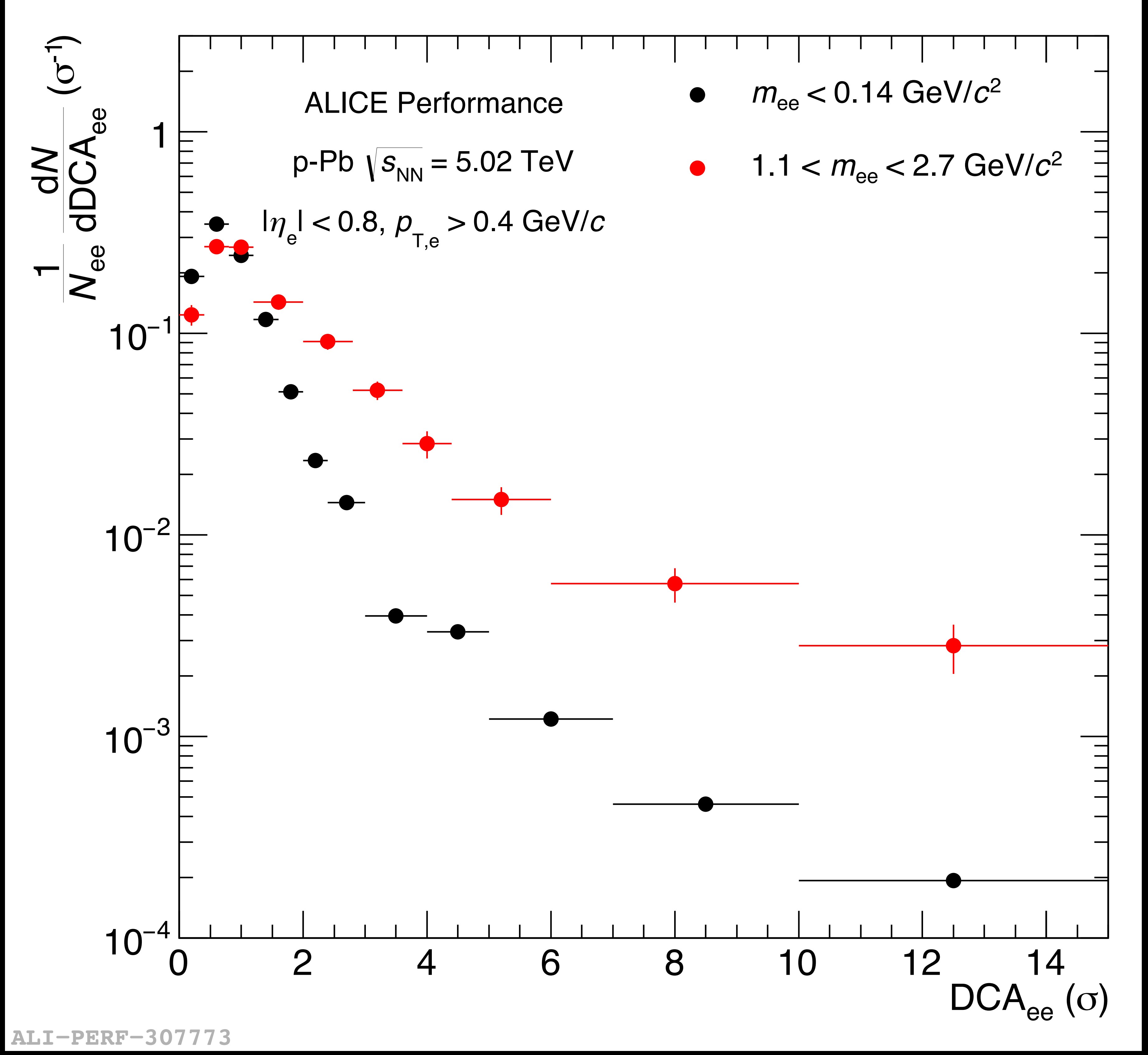
- $\sqrt{s_{NN}}$ = 5.02 TeV (min bias)
  preliminary

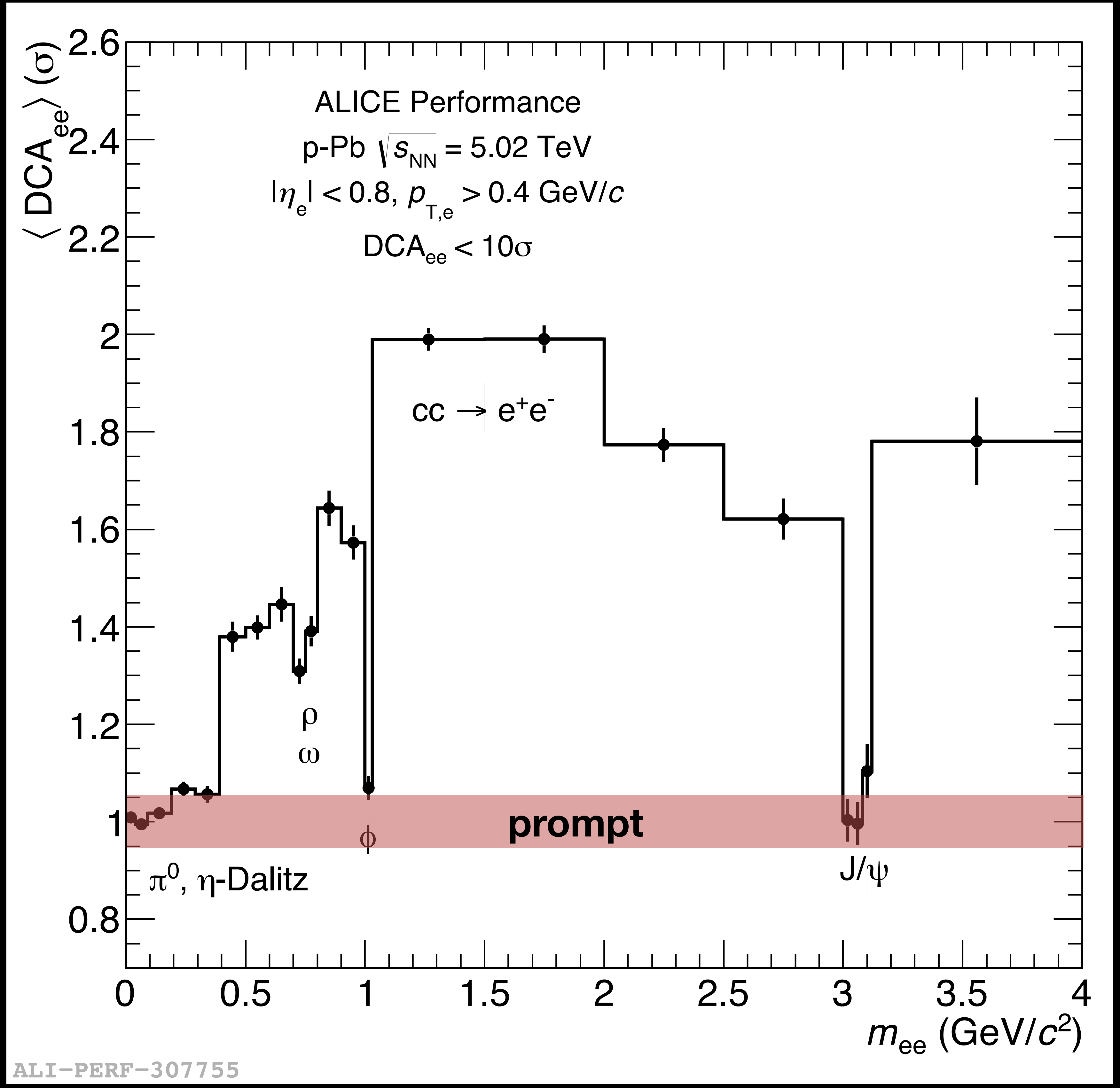
Run 2

- $\sqrt{s_{NN}}$ = 5.02 TeV (min bias)
  Factor 5 more statistics than Run 1
  analysis ongoing



# p–Pb in $\sqrt{s_{NN}}$ = 5.02 TeV (Run 2)




**$DCA_{ee}$ analysis**

- Study Cold Nuclear Matter effects on HF production
- Multiplicity dependent analysis: Possible thermal radiation in high-multiplicity p-Pb collisions

Ongoing analysis employing machine learning for electron identification

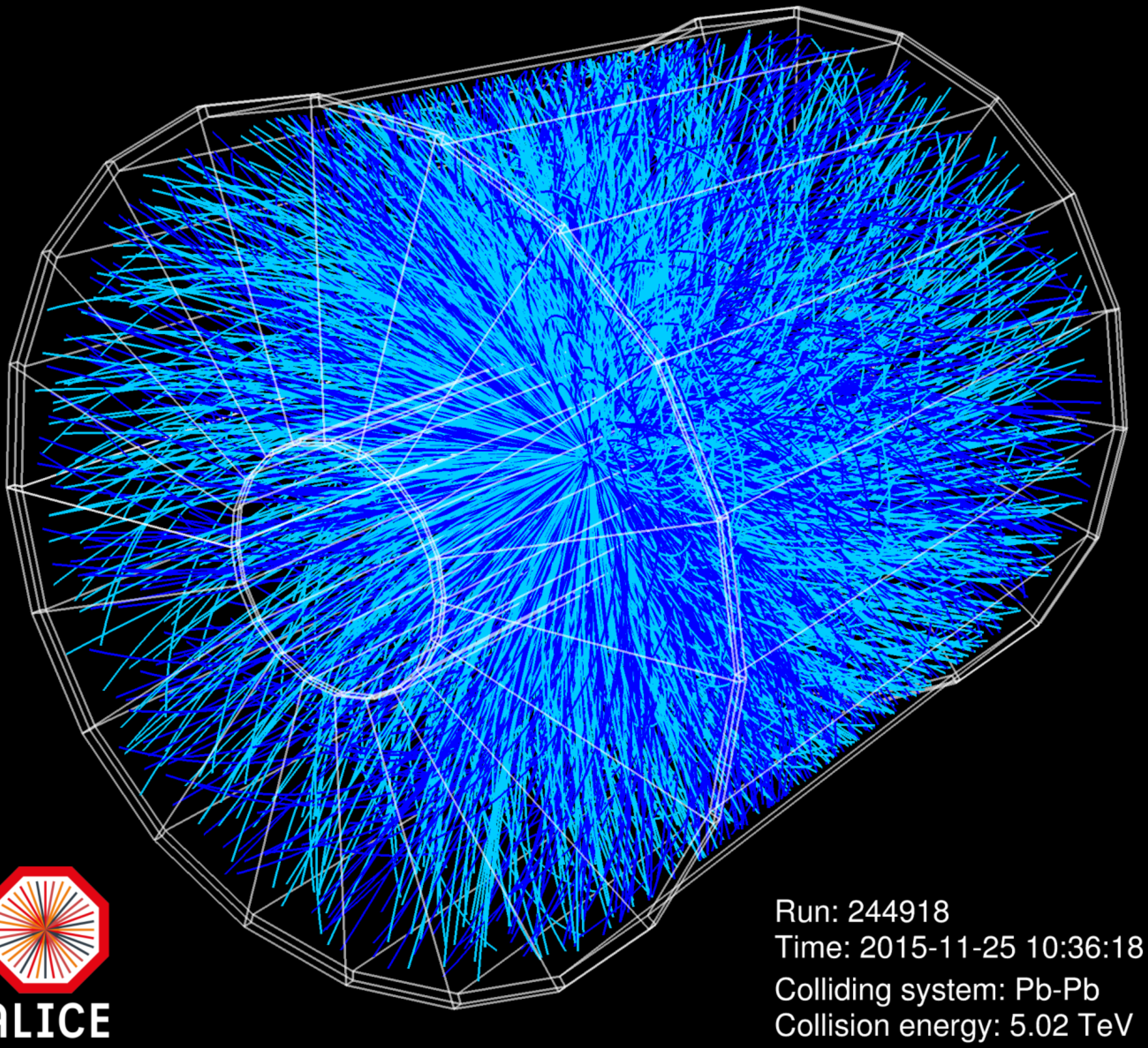
# Pb–Pb Collisions

Run 1

- $\sqrt{s_{NN}}$ = 2.76 TeV (0-10% central)
  1807.00923 (PRC acc.)

Run 2

- $\sqrt{s_{NN}}$ = 5.02 TeV (0-20% central)
  preliminary (2015 data)
  Factor > 5 data on tape from 2018
  data taking campaign



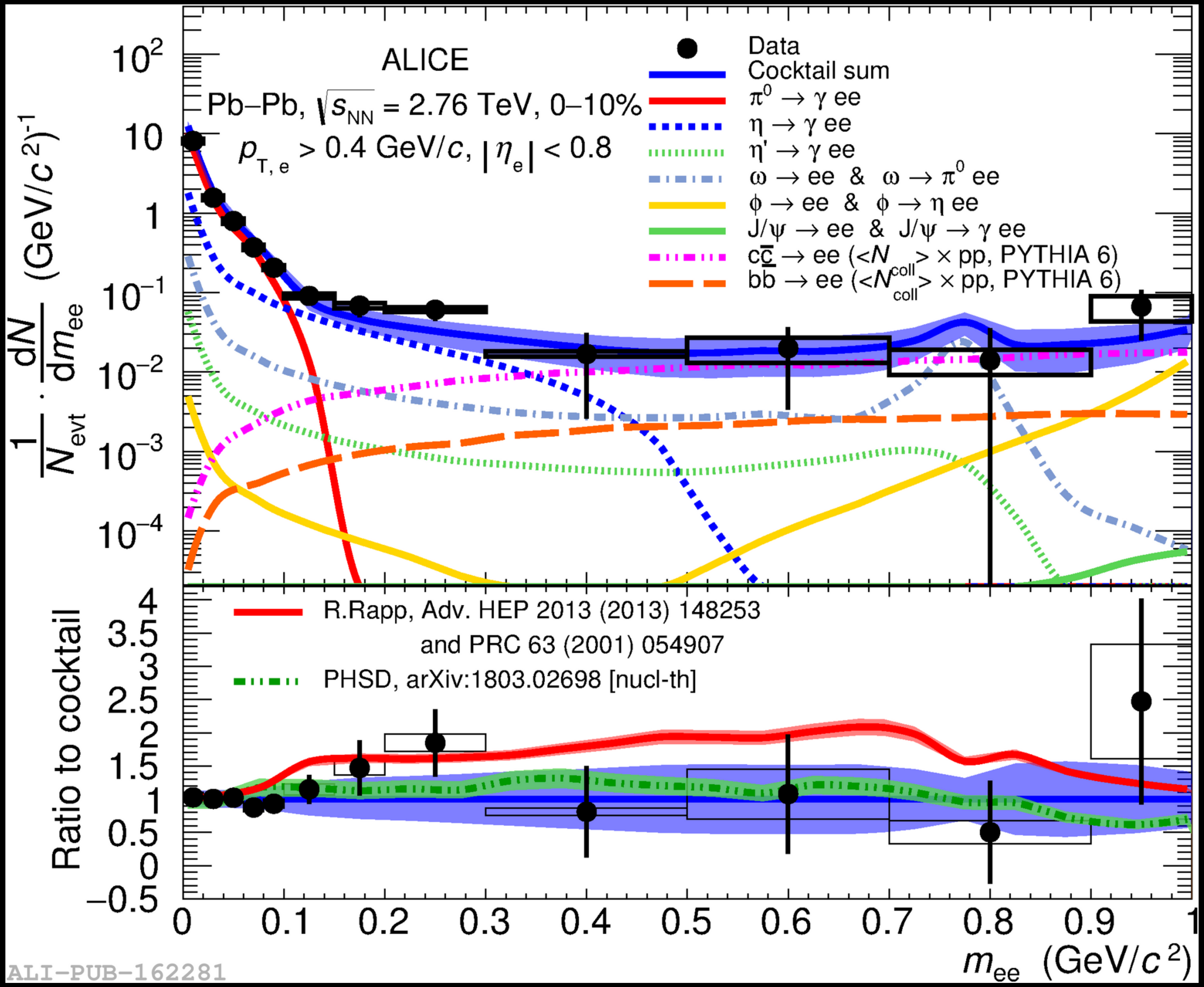
# Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV

Pioneering study in Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV

- Indication of enhancement over cocktail

1.38 ± 0.28 (stat.) ± 0.08 (syst.) ± 0.27 (cocktail)
($0.15 < m_{ee} < 0.7$ GeV/$c^2$)

- In agreement with models including thermal radiation
- **No CNM effects included in HF cocktail**

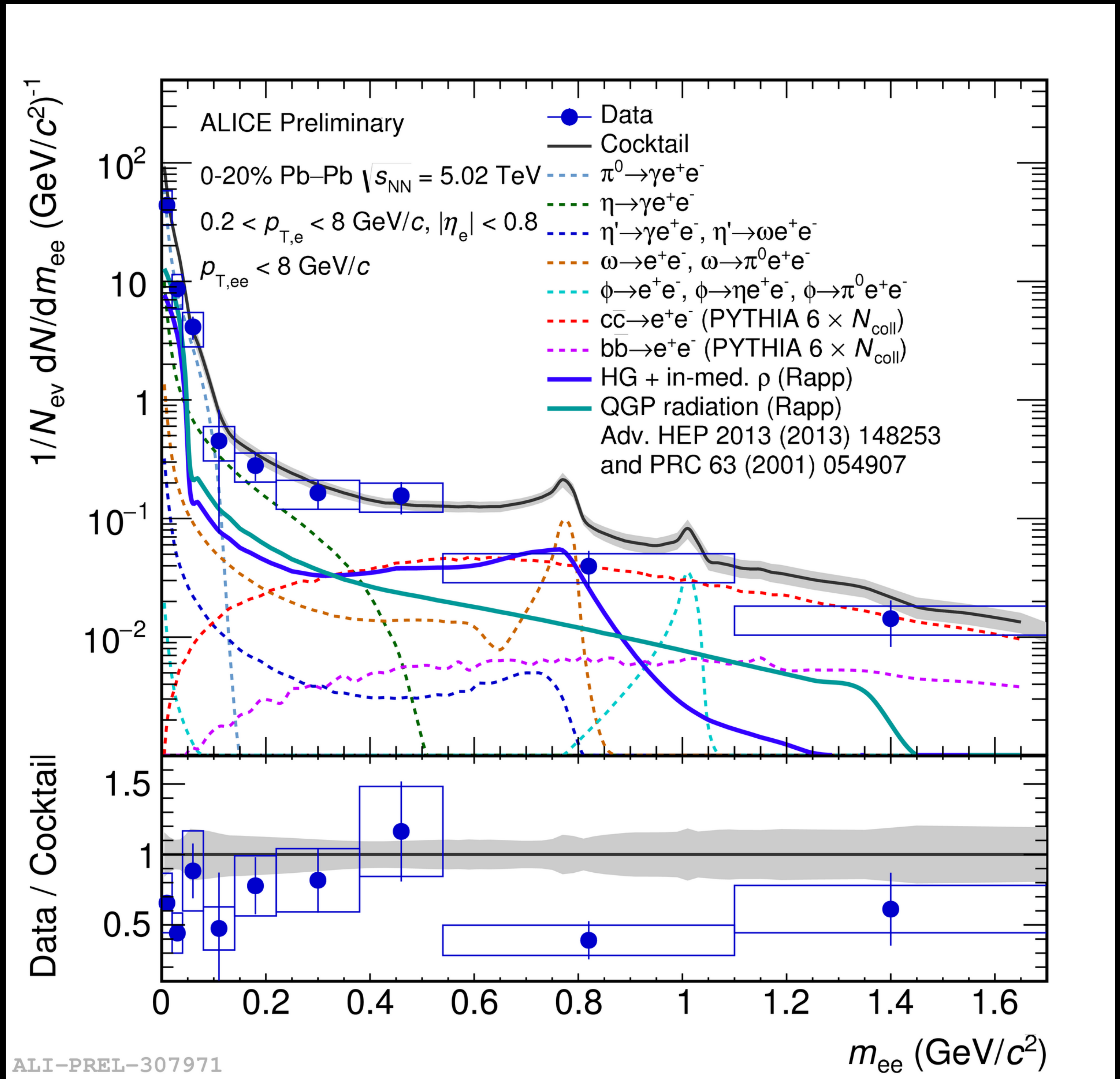



1807.00923 (PRC acc.)

# Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

**Run 2 Pb–Pb data from 2015**

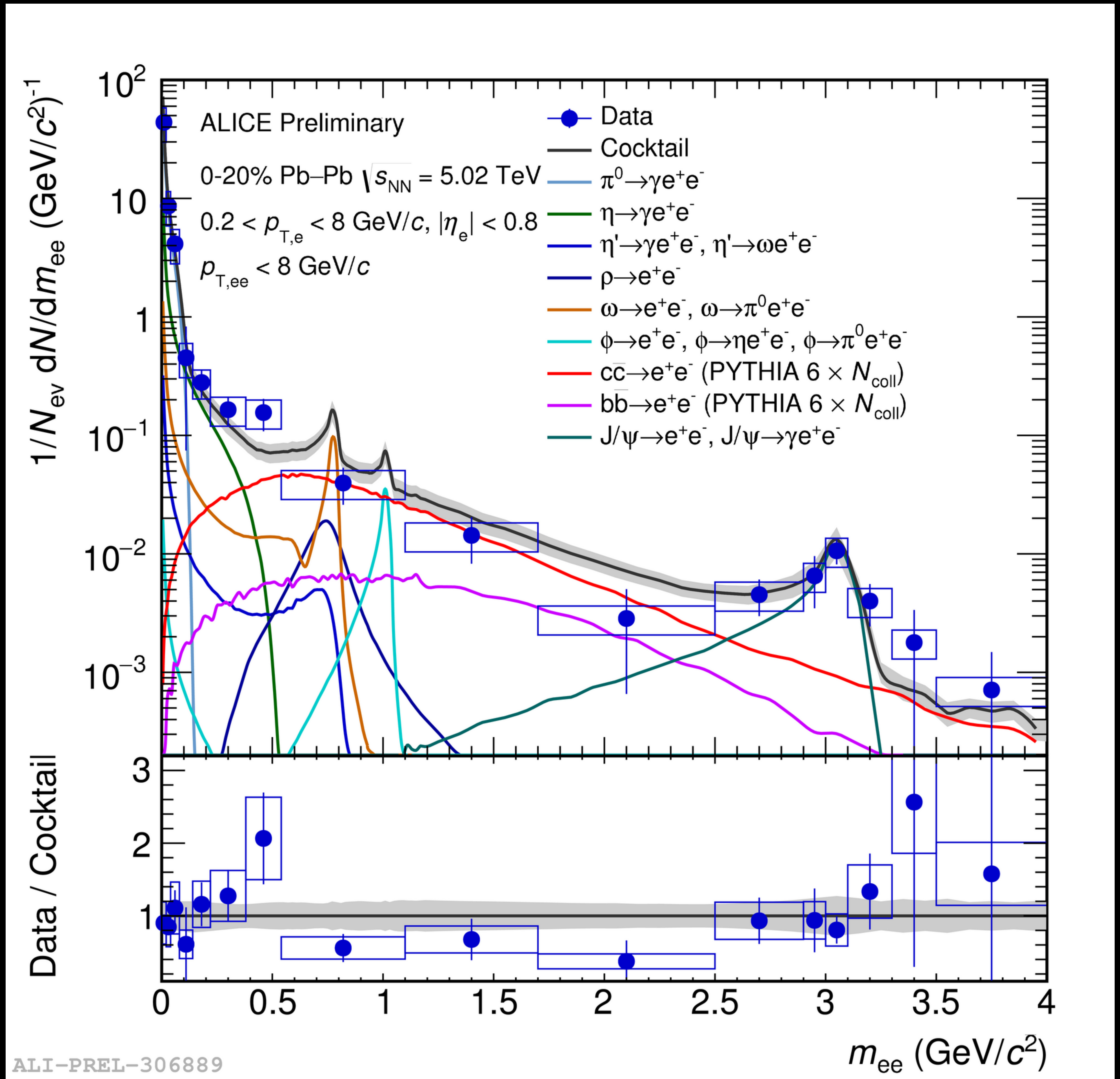
- Higher collision energy
- Better detector performance
- Improved analysis techniques
- Acceptance gain by lowering $p_{T,e}$ cut (0.4 GeV/*c* → 0.2 GeV/*c*)
- Preliminary result also compatible with low-mass enhancement and thermal dielectron production
- **No CNM effects included in HF cocktail**
  - **Indication for charm suppression**



# Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

**Run 2 Pb–Pb data from 2015**

- Higher collision energy
- Better detector performance
- Improved analysis techniques
- Acceptance gain by lowering $p_{T,e}$ cut (0.4 GeV/$c$ → 0.2 GeV/$c$)
- Preliminary result also compatible with low-mass enhancement and thermal dielectron production
- **No CNM effects included in HF cocktail**
  - **Indication for charm suppression**



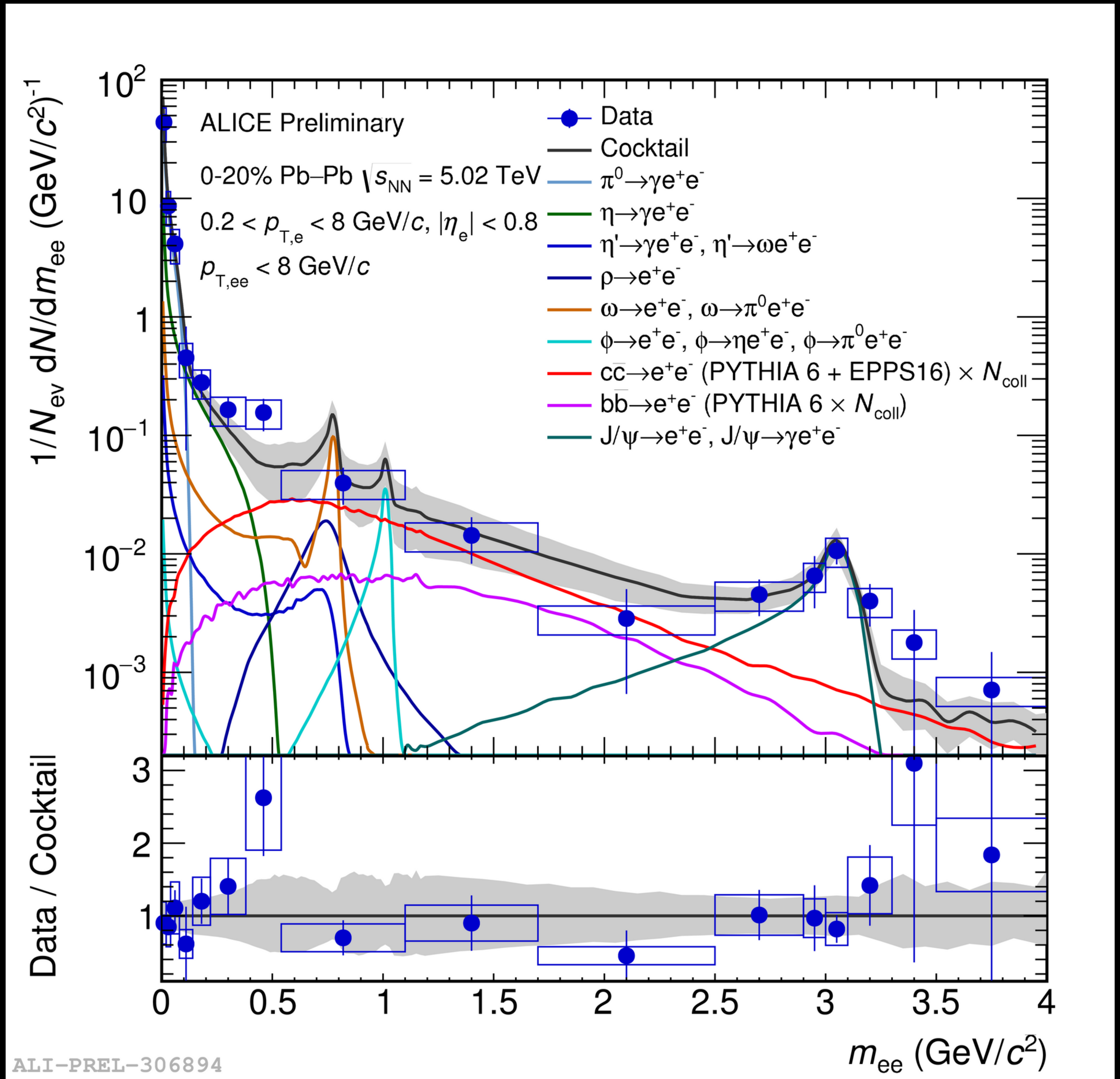
# Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

**Run 2 Pb–Pb data from 2015**

- Higher collision energy
- Better detector performance
- Improved analysis techniques
- Acceptance gain by lowering $p_{T,e}$ cut (0.4 GeV/$c$ → 0.2 GeV/$c$)
- Preliminary result also compatible with low-mass enhancement and thermal dielectron production
- **No CNM effects included in HF cocktail**
  - **Indication for charm suppression**

**→ Better description of the data if CNM effects (EPPS16) taken into account**

Efforts to apply machine learning techniques for conversion rejection ongoing



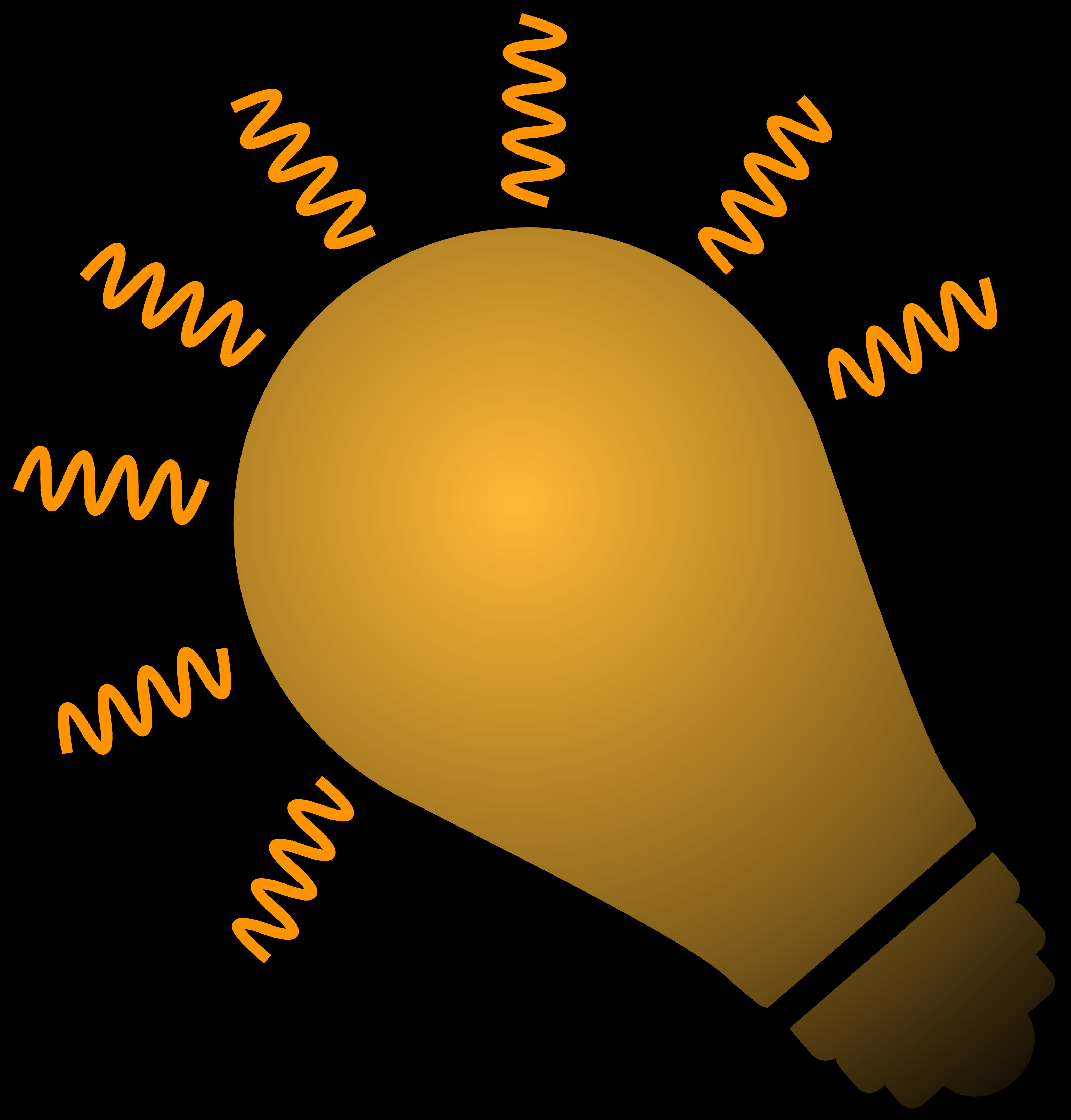
# Direct photons

Run 1

- pp $\sqrt{s}$ = 7 TeV (min bias)
  JHEP 1809 (2018) 064
- Pb–Pb $\sqrt{s_{NN}}$ = 2.76 TeV
  (0-10% central)
  1807.00923 (PRC acc.)

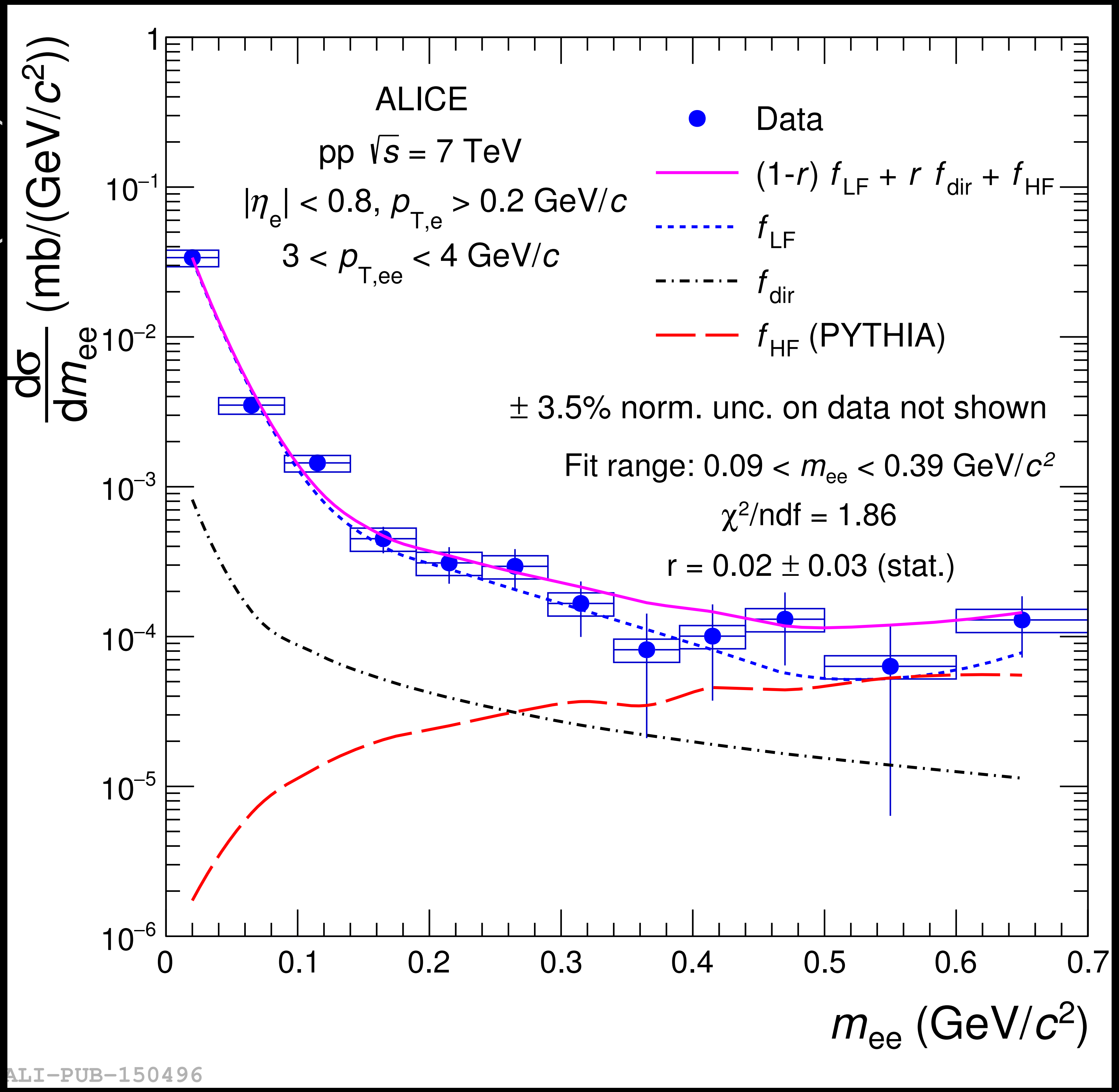
Run 2

- pp $\sqrt{s}$ = 13 TeV (min bias and HM)
  PLB 788 (2019) 505



# Virtual direct photons

JHEP 1809 (2018) 064



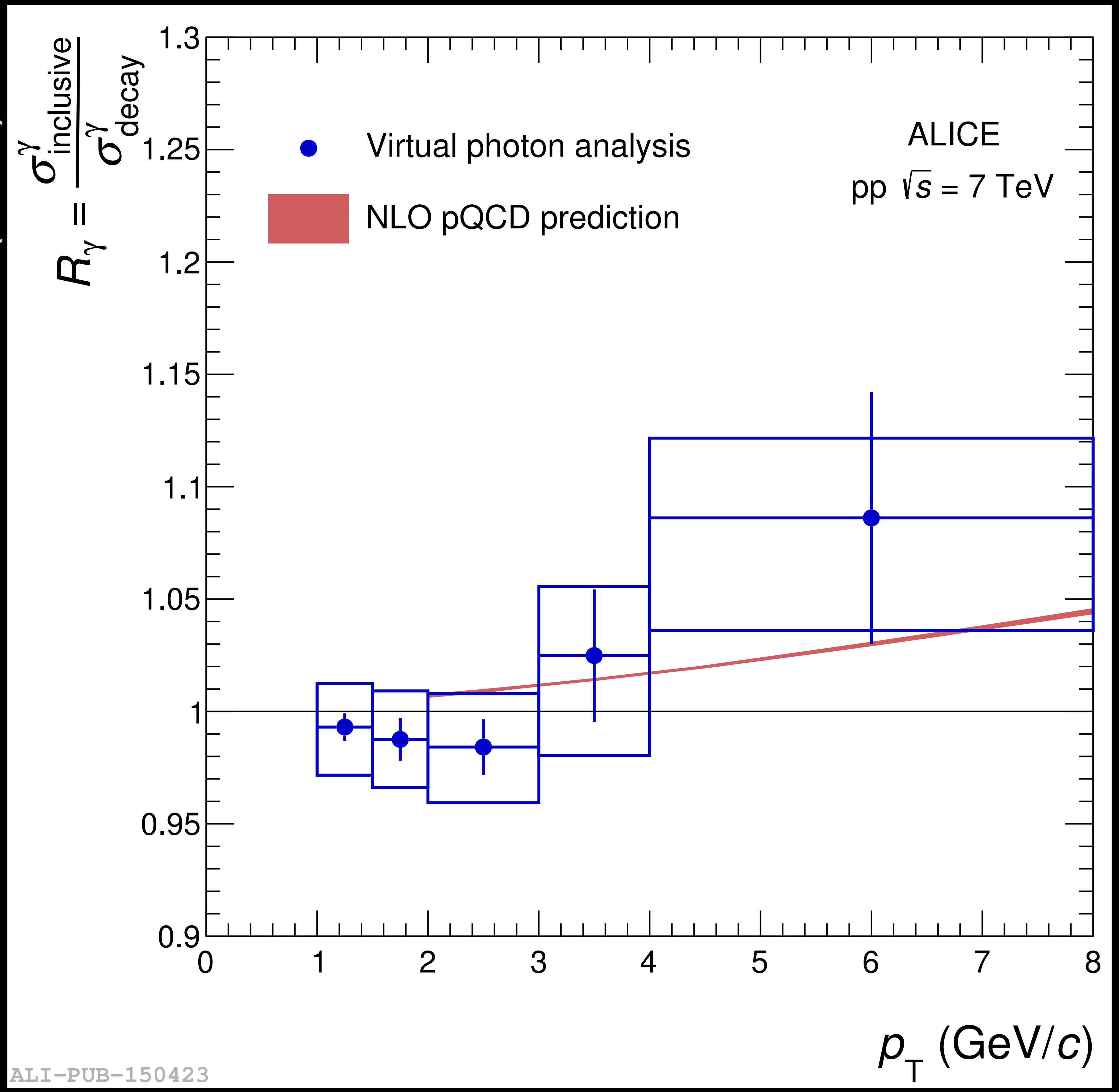

**Real and virtual-photon yield connected by the Kroll-Wada equation ($p_{T,ee}$>$m_{ee}$)**

$$\frac{d^2 N_{ee}}{dm_{ee}dp_{T,ee}} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\cdot\left(1+\frac{2m_e^2}{m_{ee}^2}\right)\cdot\frac{1}{m_{ee}}\frac{dN_\gamma}{dp_T}$$

Extract virtual direct photon yield with three-component fit to $m_{ee}$ spectrum ($m_{ee} > m_\pi$)
→ Extrapolate to $m_{ee}$ = 0 for real-photon yield

# Virtual direct photons

JHEP 1809 (2018) 064




**Real and virtual-photon yield connected by the Kroll-Wada equation ($p_{\rm T,ee}$>$m_{\rm ee}$)**

$$\frac{{\rm d}^2 N_{\rm ee}}{{\rm d}m_{\rm ee}{\rm d}p_{\rm T,ee}} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_{\rm e}^2}{m_{\rm ee}^2}} \cdot \left(1+\frac{2m_{\rm e}^2}{m_{\rm ee}^2}\right) \cdot \frac{1}{m_{\rm ee}} \frac{{\rm d}N_\gamma}{{\rm d}p_{\rm T}}$$

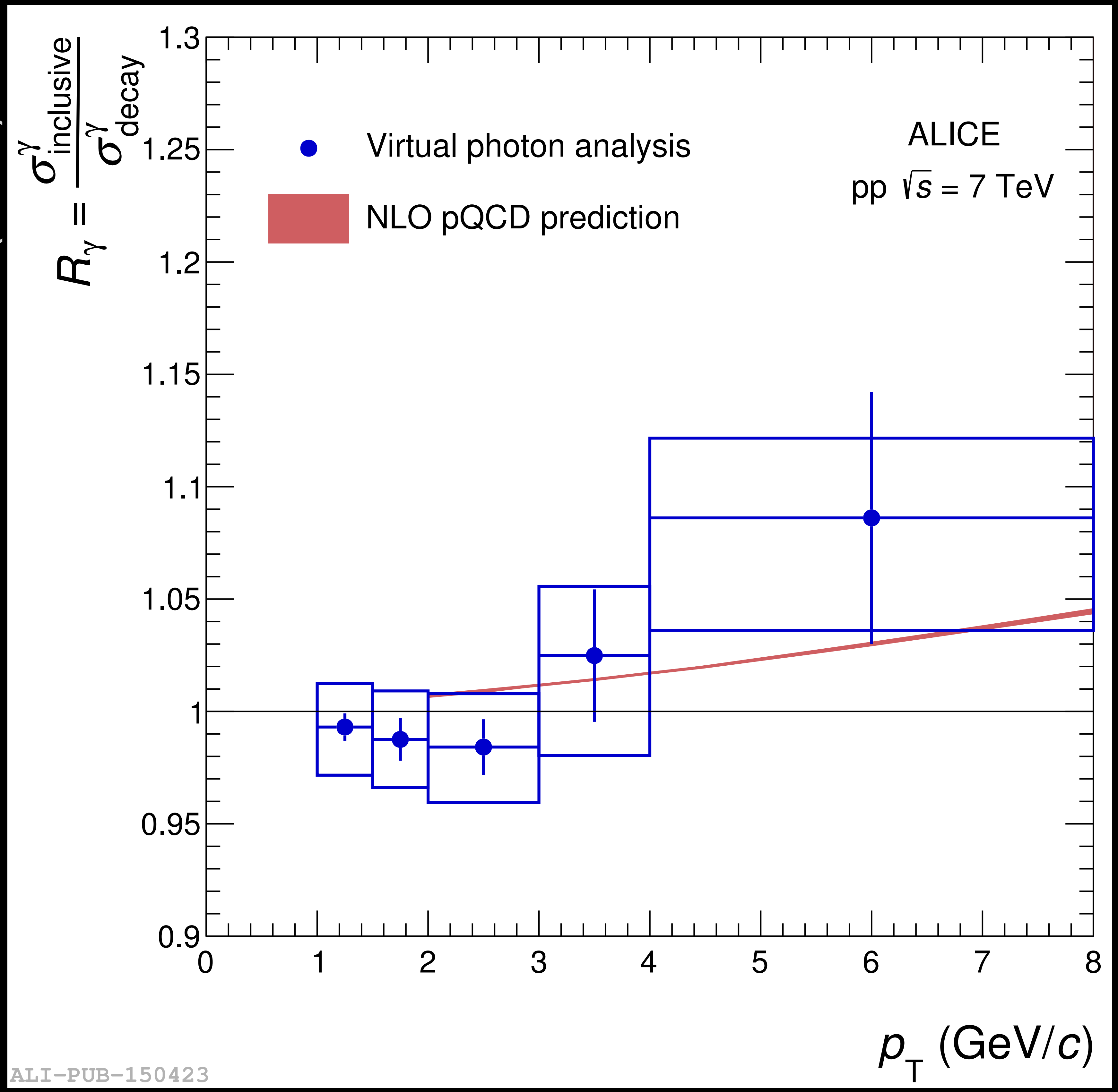
Extract virtual direct photon yield with three-component fit to $m_{\rm ee}$ spectrum ($m_{\rm ee} > m_\pi$)
→ Extrapolate to $m_{\rm ee}$ = 0 for real-photon yield

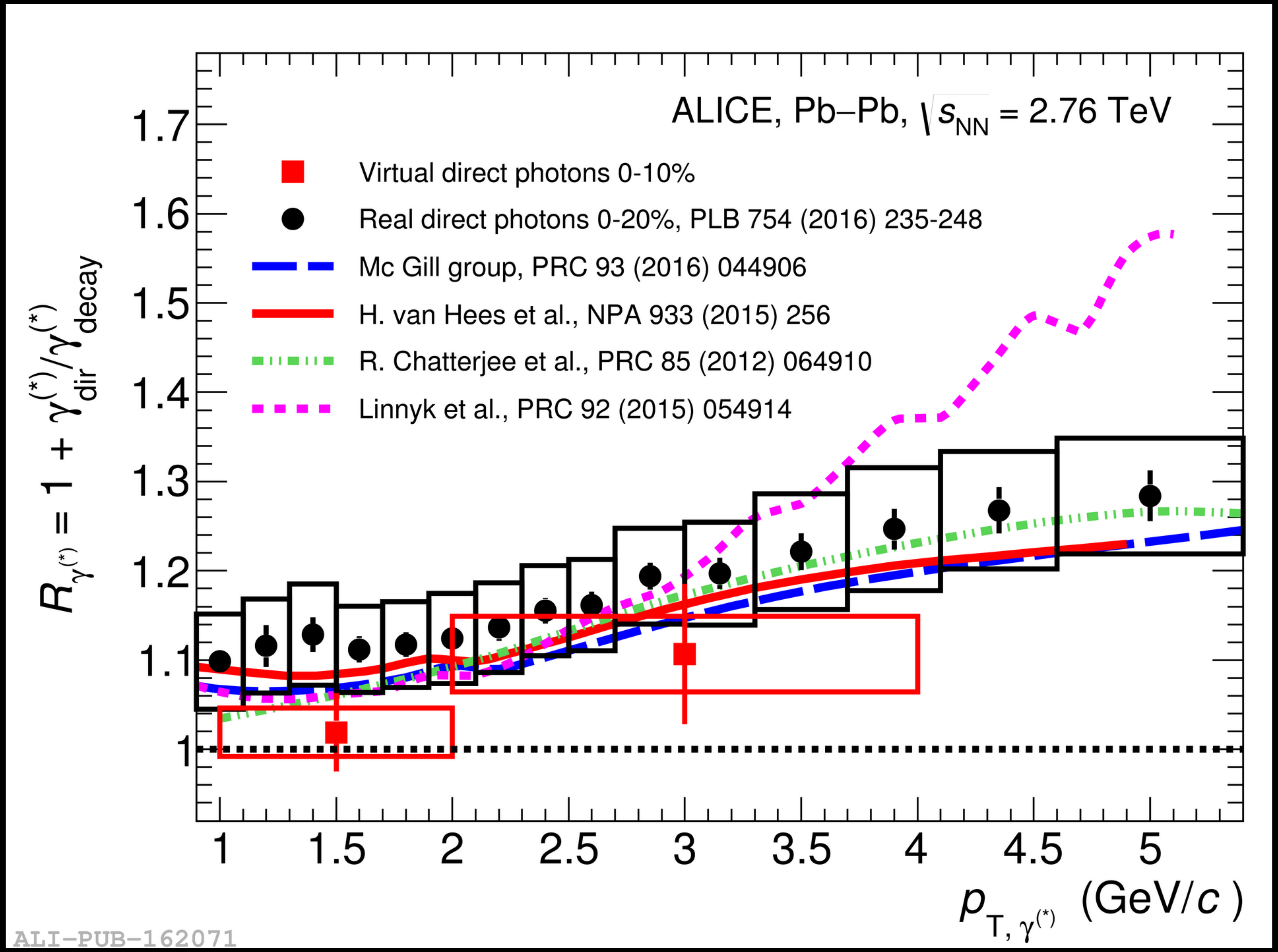
$$R_\gamma = \frac{N_{\gamma,incl}}{N_{\gamma,decay}}$$

- $R_\gamma$ in pp at $\sqrt{s}$ = 7 TeV virtual-photon analysis compatible with NLO pQCD calculations

# Virtual direct photons

JHEP 1809 (2018) 064




1807.00923 (PRC acc.)

- $R_\gamma$ in pp at $\sqrt{s}$ = 7 TeV virtual-photon analysis compatible with NLO pQCD calculations
- $R_\gamma$ in Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV compatible with real-photon analysis

# Summary

- Dielectron analysis in ALICE well underway
- First results from Run 1 and Run 2 available:

*Dielectron production in proton-proton collisions at $\sqrt{s}$ = 7 TeV*
ALICE Collaboration, JHEP 1809 (2018) 064

*Dielectron and heavy-quark production in inelastic and high-multiplicity pp collisions at $\sqrt{s}$ = 13 TeV*
ALICE Collaboration, PLB 788 (2019) 505

*Measurement of dielectron production in central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV*
ALICE Collaboration, 1807.00923 (PRC acc.)

- High-statistics data sets for pp, p–Pb and Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV available from Run 2
- Benefits of machine learning techniques under revision

# Outlook

Major upgrades under construction for Run 3 and 4

- Higher data acquisition rate (x100) and reduced ITS material budget (x4) with better DCA resolution (x3)
  → More statistics and better background rejection

*Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams*
Citron, Z. *et al,* 1812.06772