Thermal radiation via dielectrons with ALICE

Ivan Vorobyev for the ALICE Collaboration

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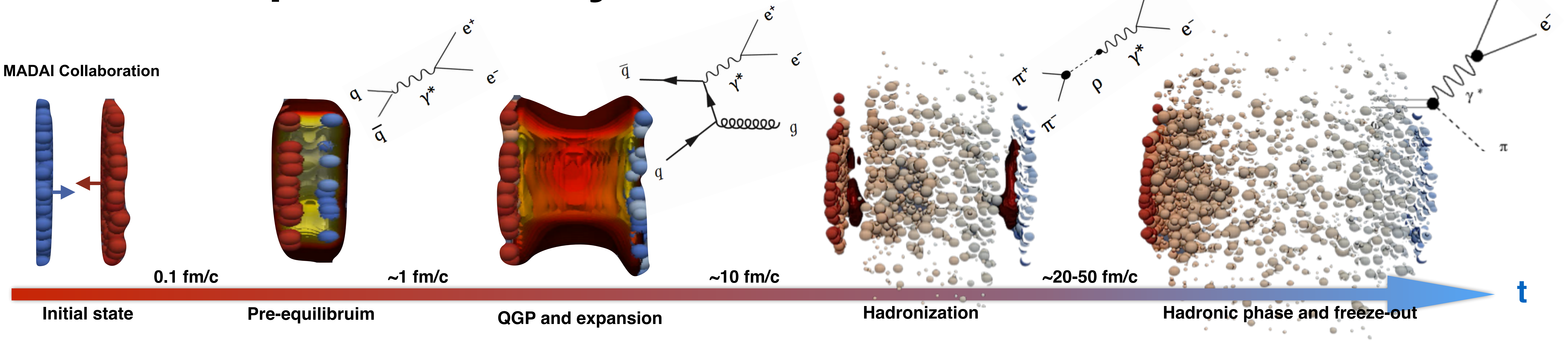
Dielectron pairs in heavy-ion collisions



Dielectrons (e^+e^-) allow one to study the whole space-time evolution of the medium

- Produced during all stages of the collision
- Unaffected by strong final-state interactions

ALICE

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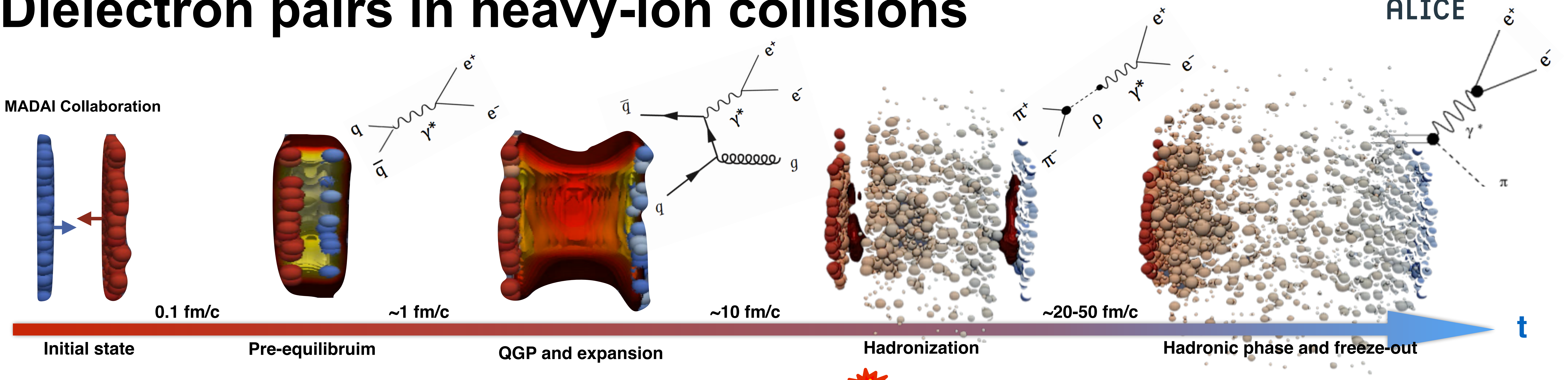

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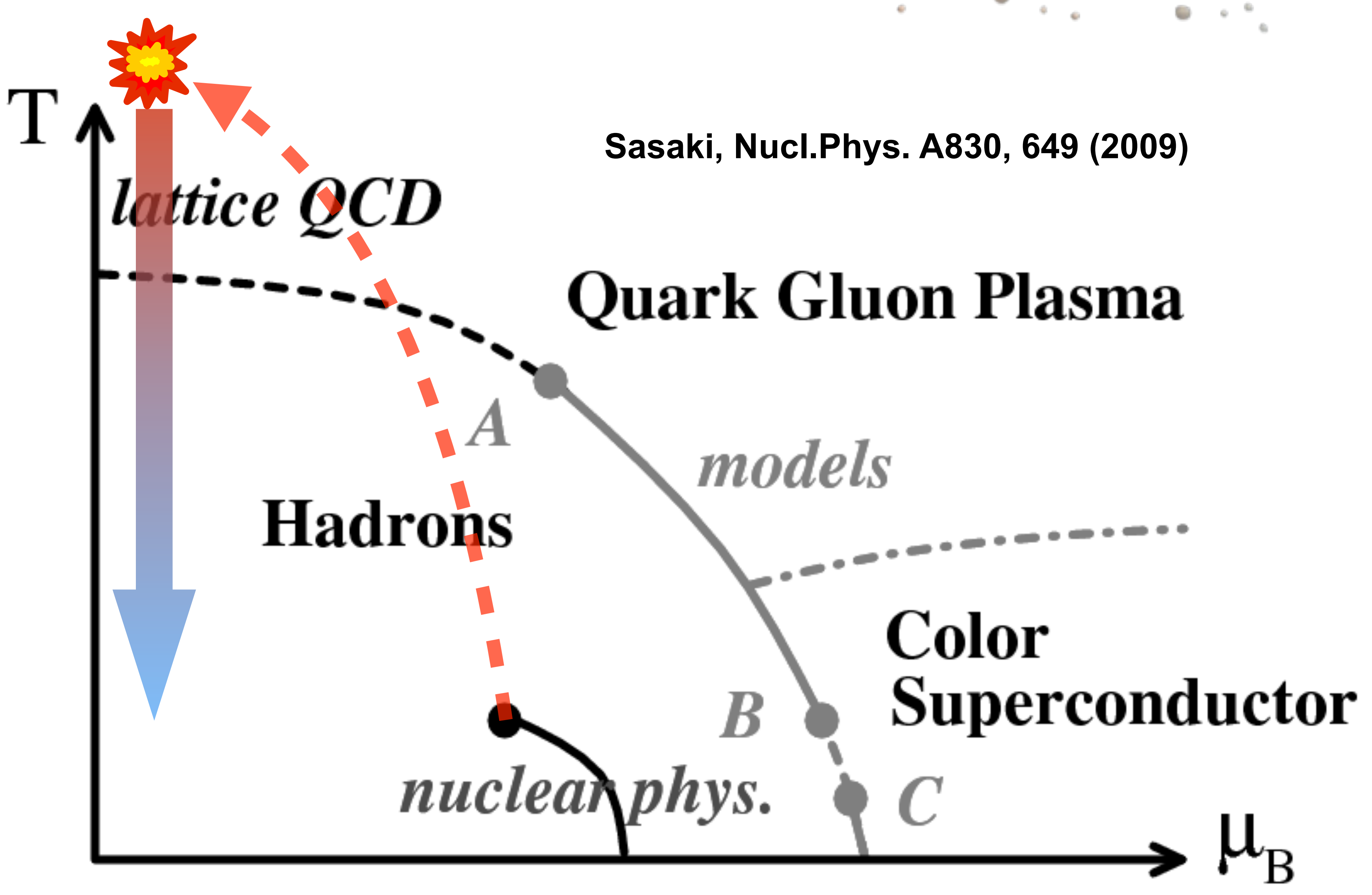
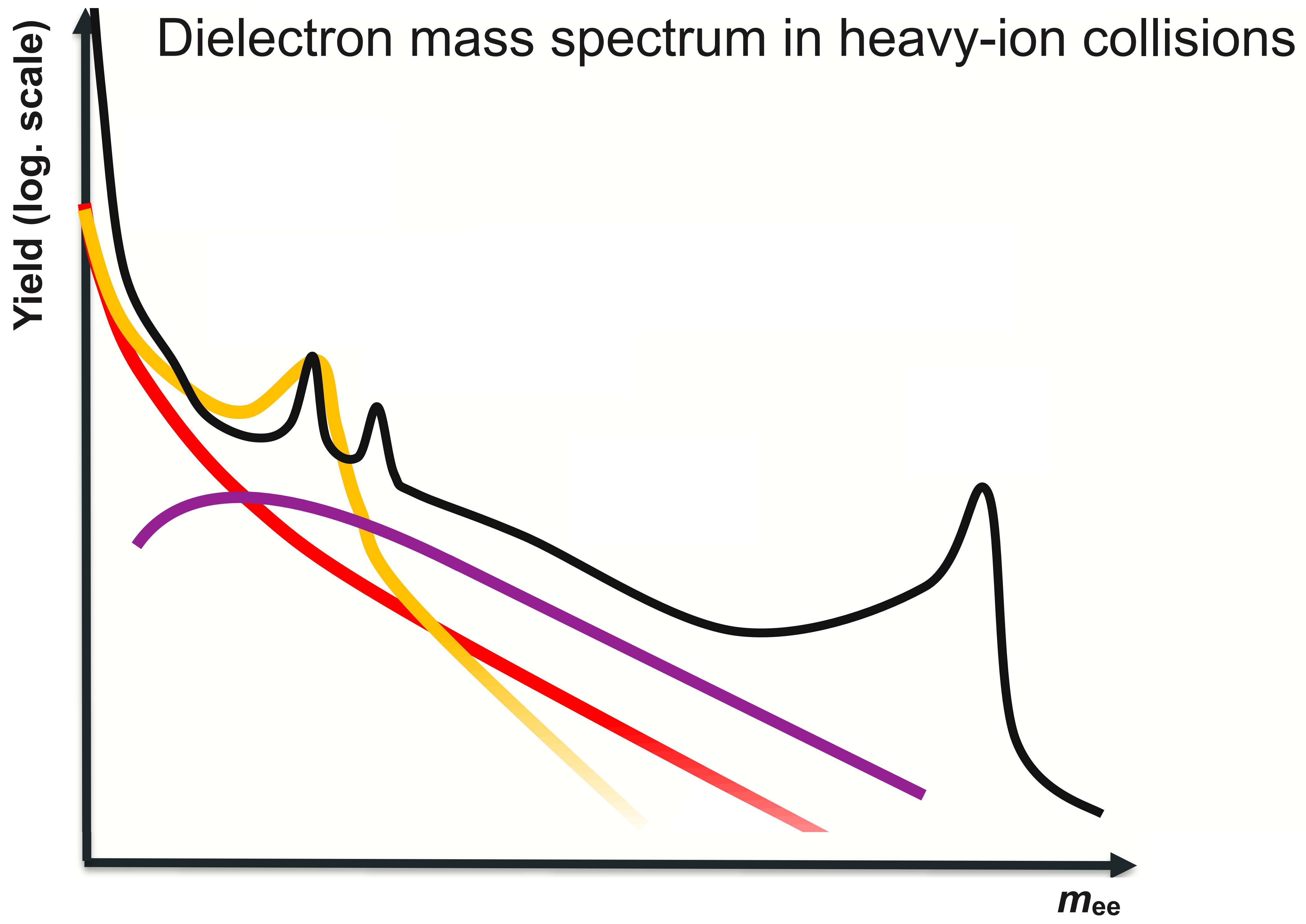
At LHC energies: studies of deconfined phase of matter in the regime of high T and $\mu_B \sim 0$

- Chiral symmetry restoration, *thermal radiation*
- *Need to know the background from hadronic decays!*



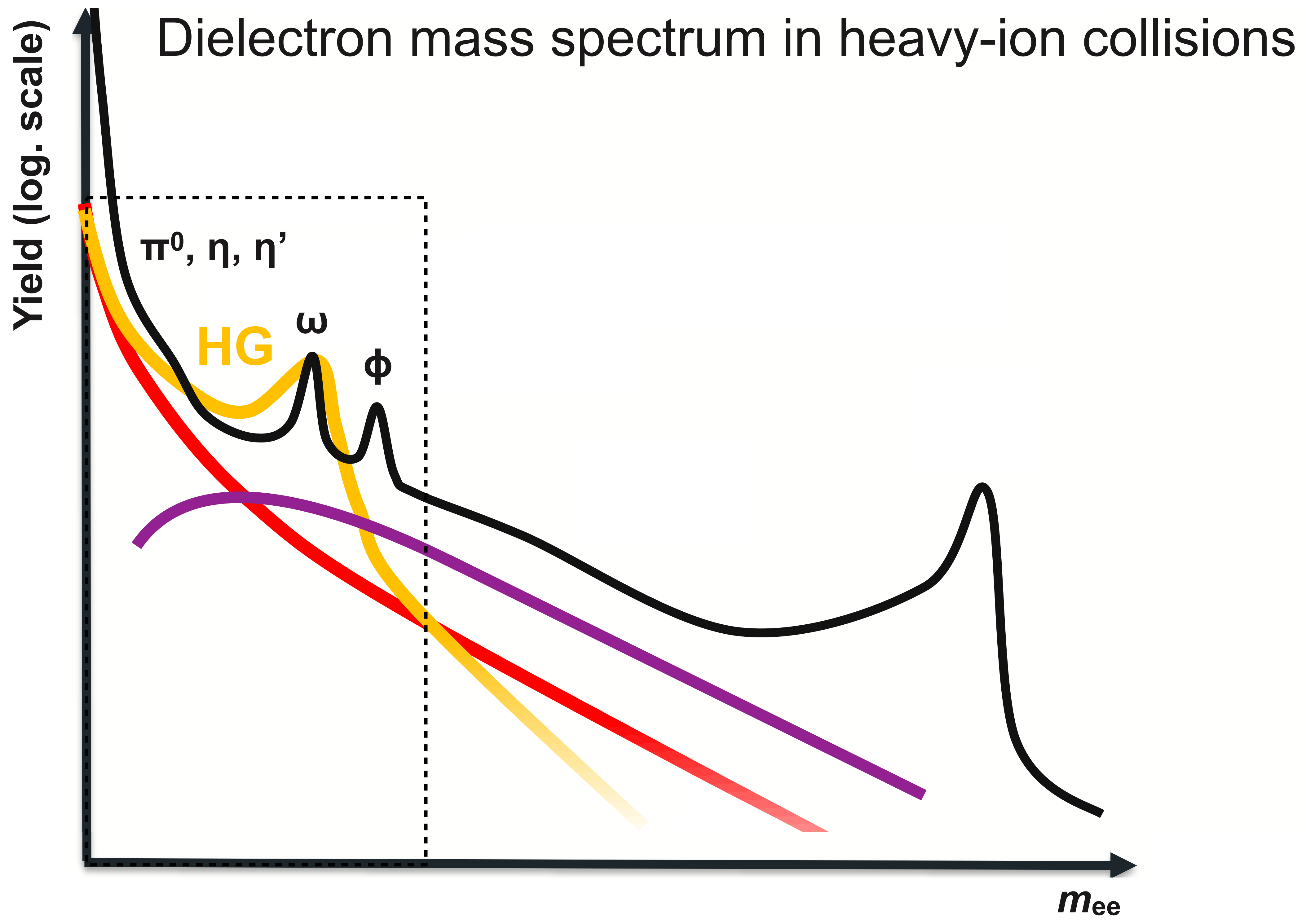
Dielectron mass spectrum



Dielectron mass spectrum

Low mass region (m_{ee} < 1.1 GeV/c^2)

- Thermal radiation from hadron gas (HG) via in-medium ρ
- Pseudoscalar and vector mesons (π^0, η, η', ω, ϕ)



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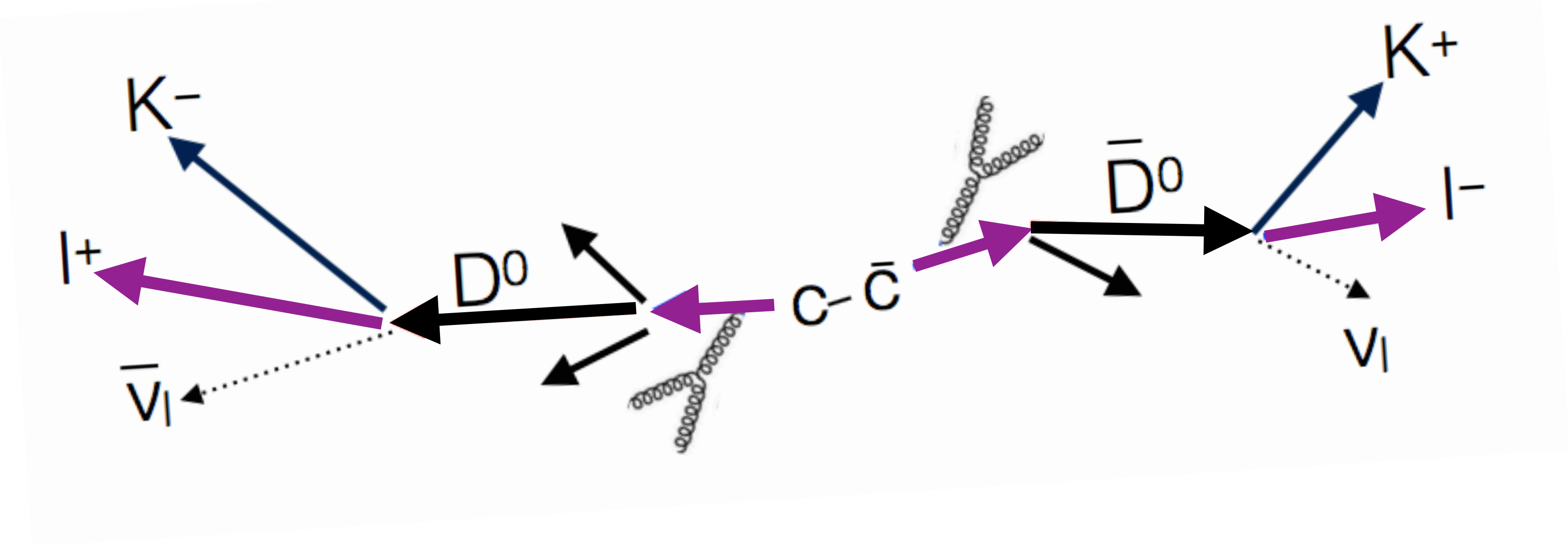
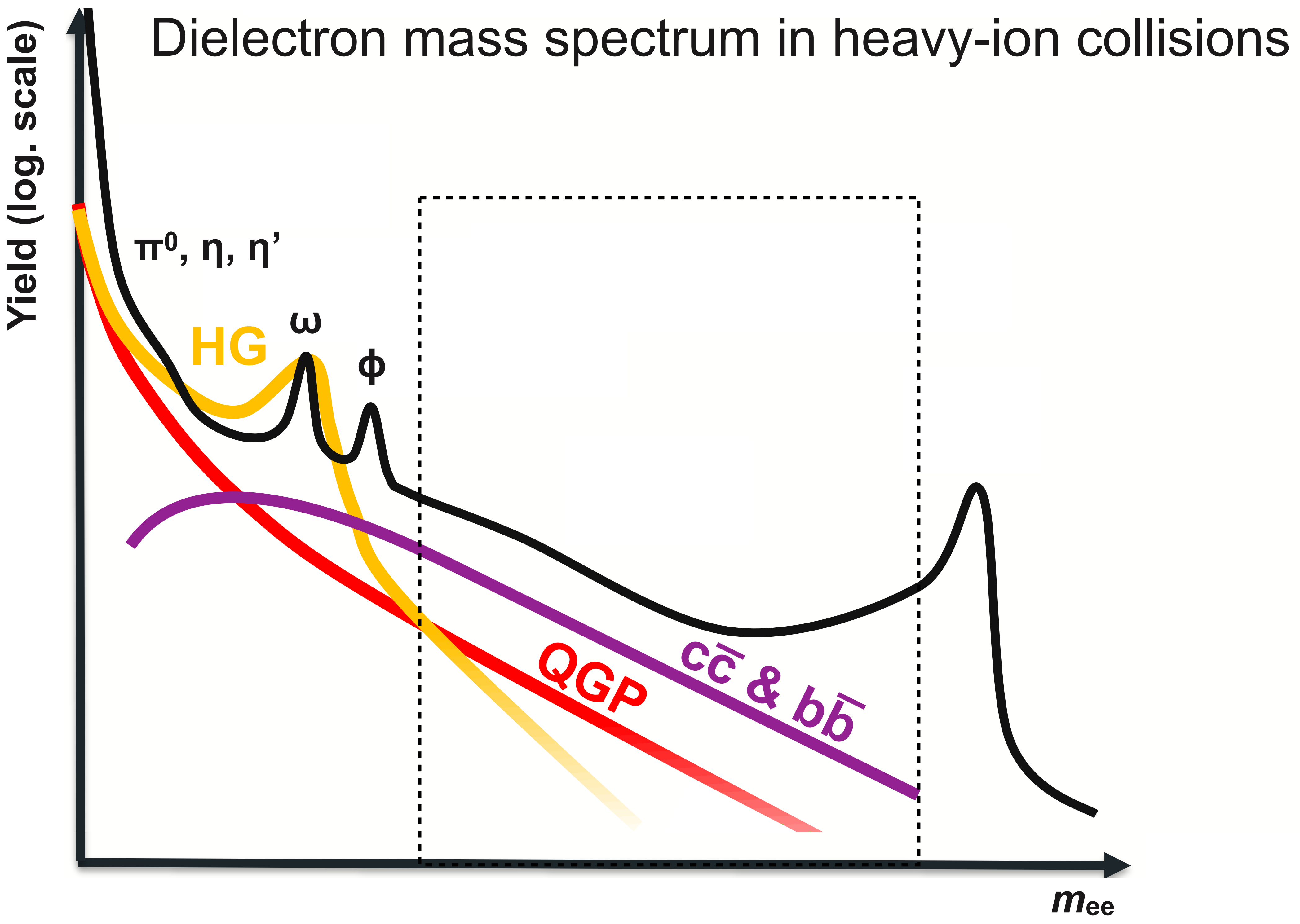
- Thermal radiation from quark-gluon plasma
- Correlated semi-leptonic decays of HF hadrons





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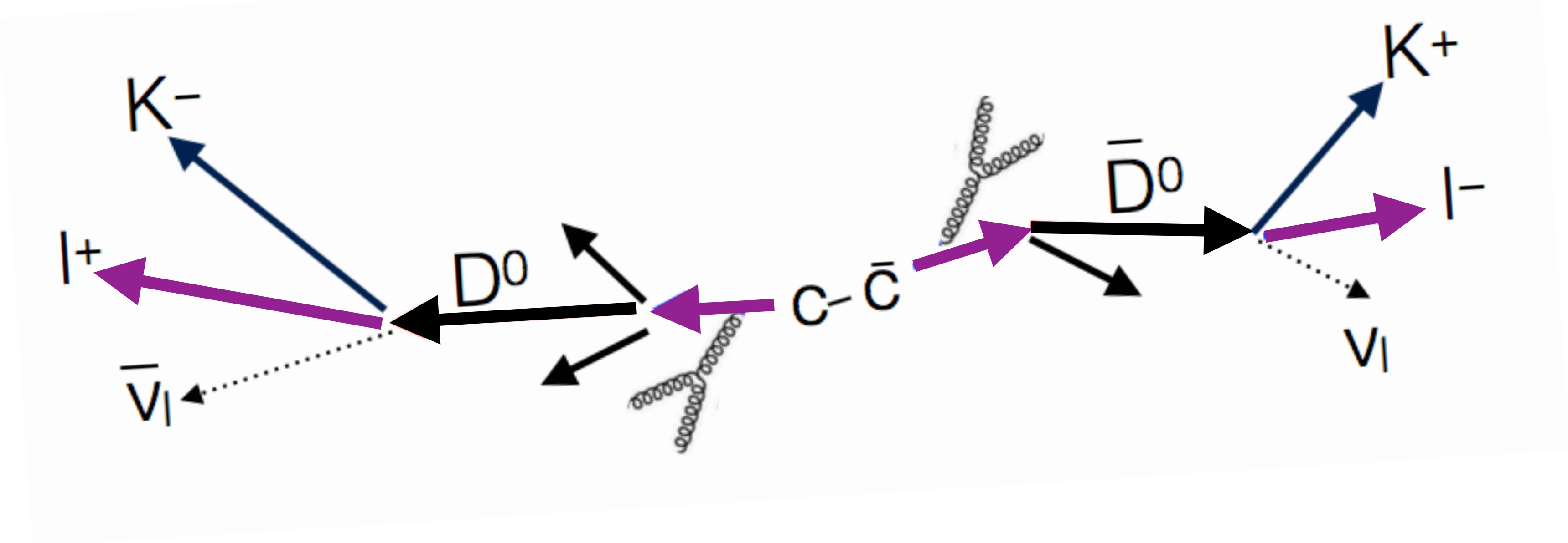

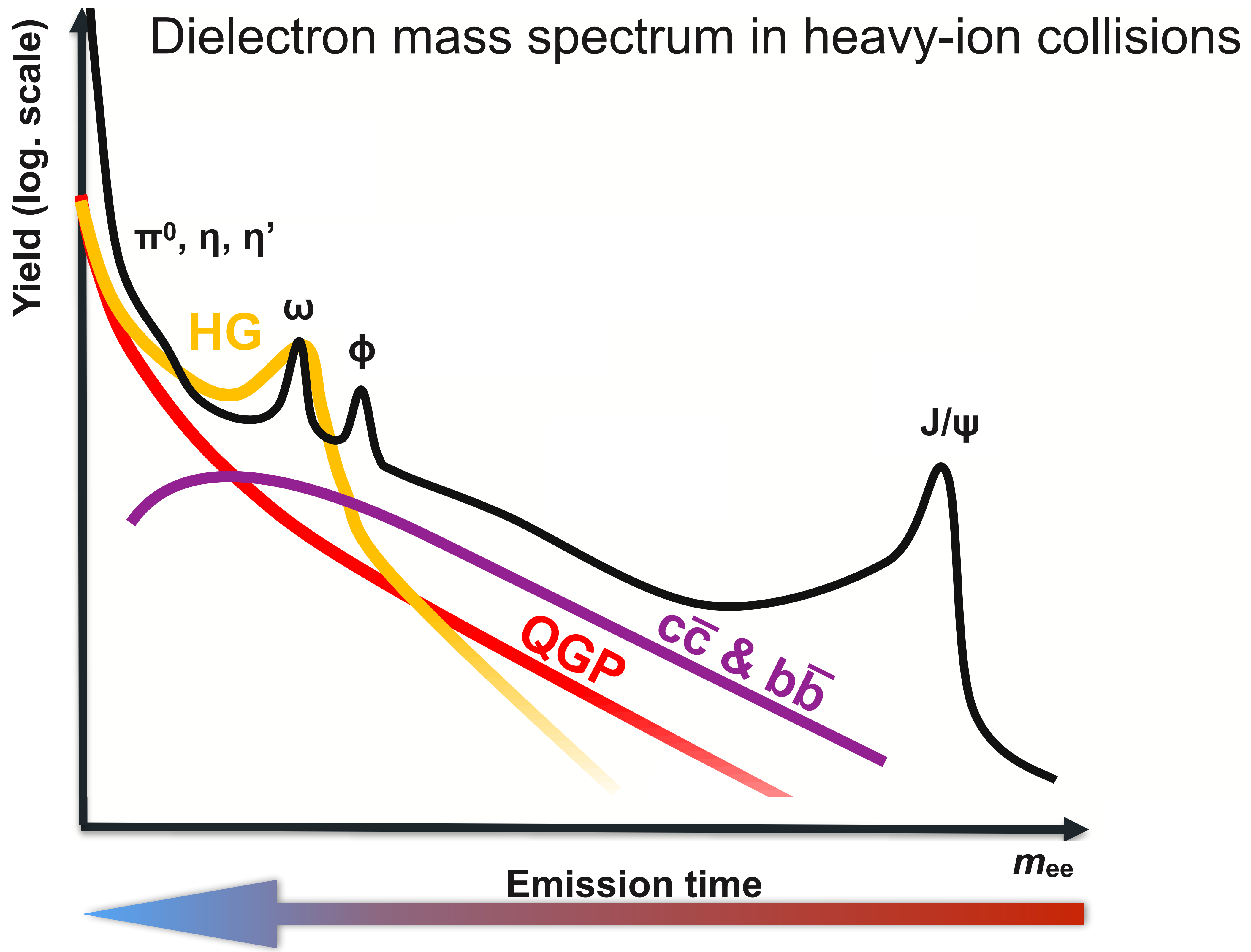

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- Approximate time ordering of the mass spectrum

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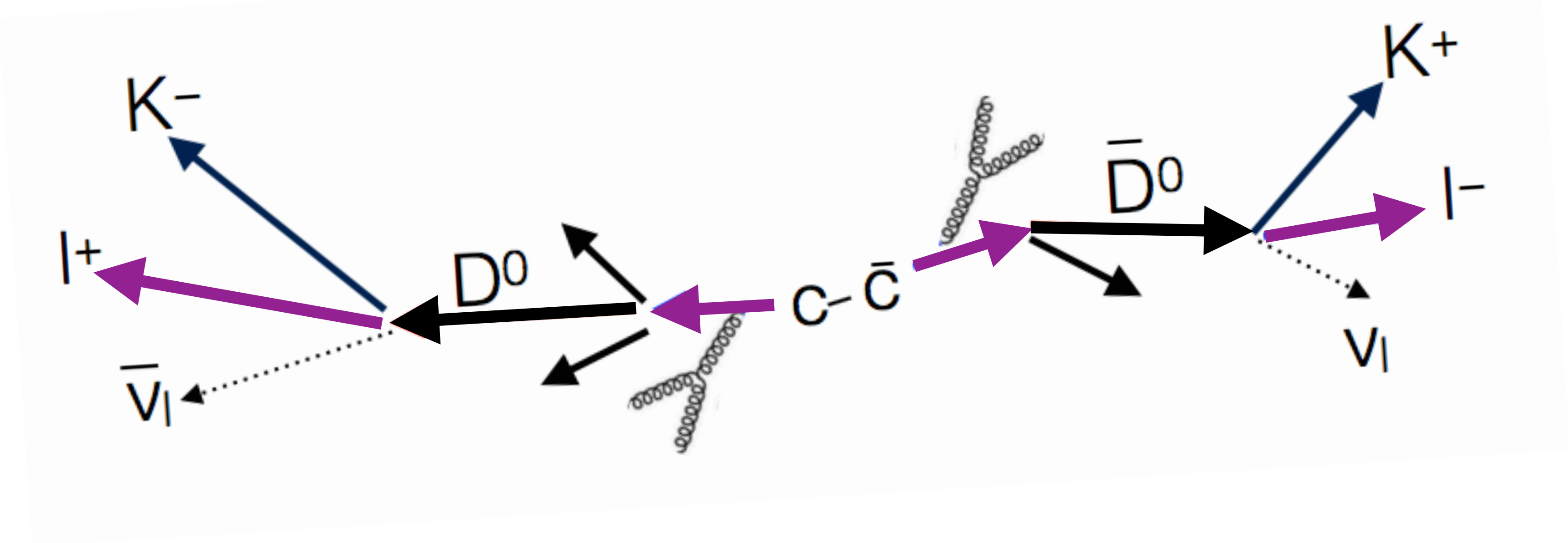

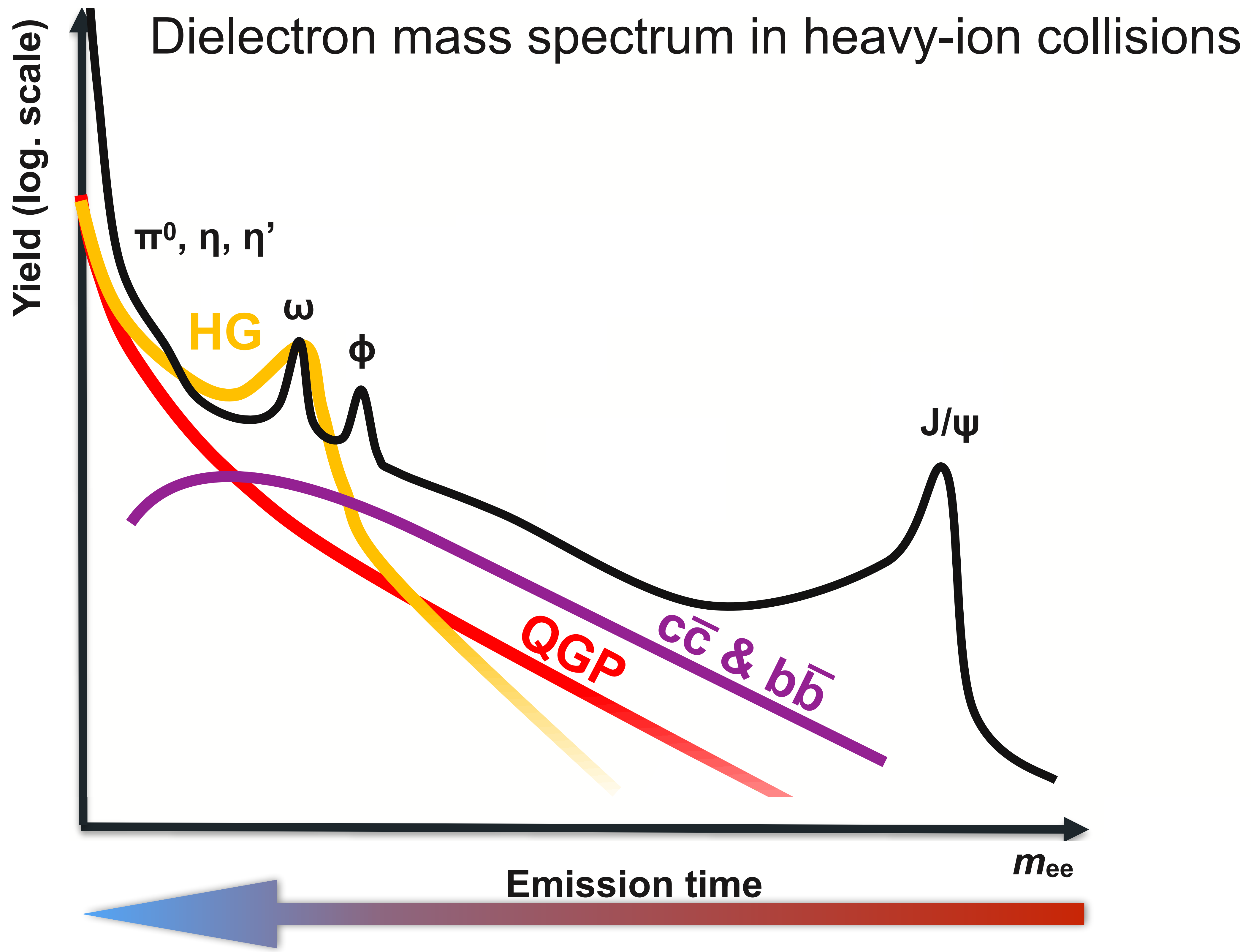

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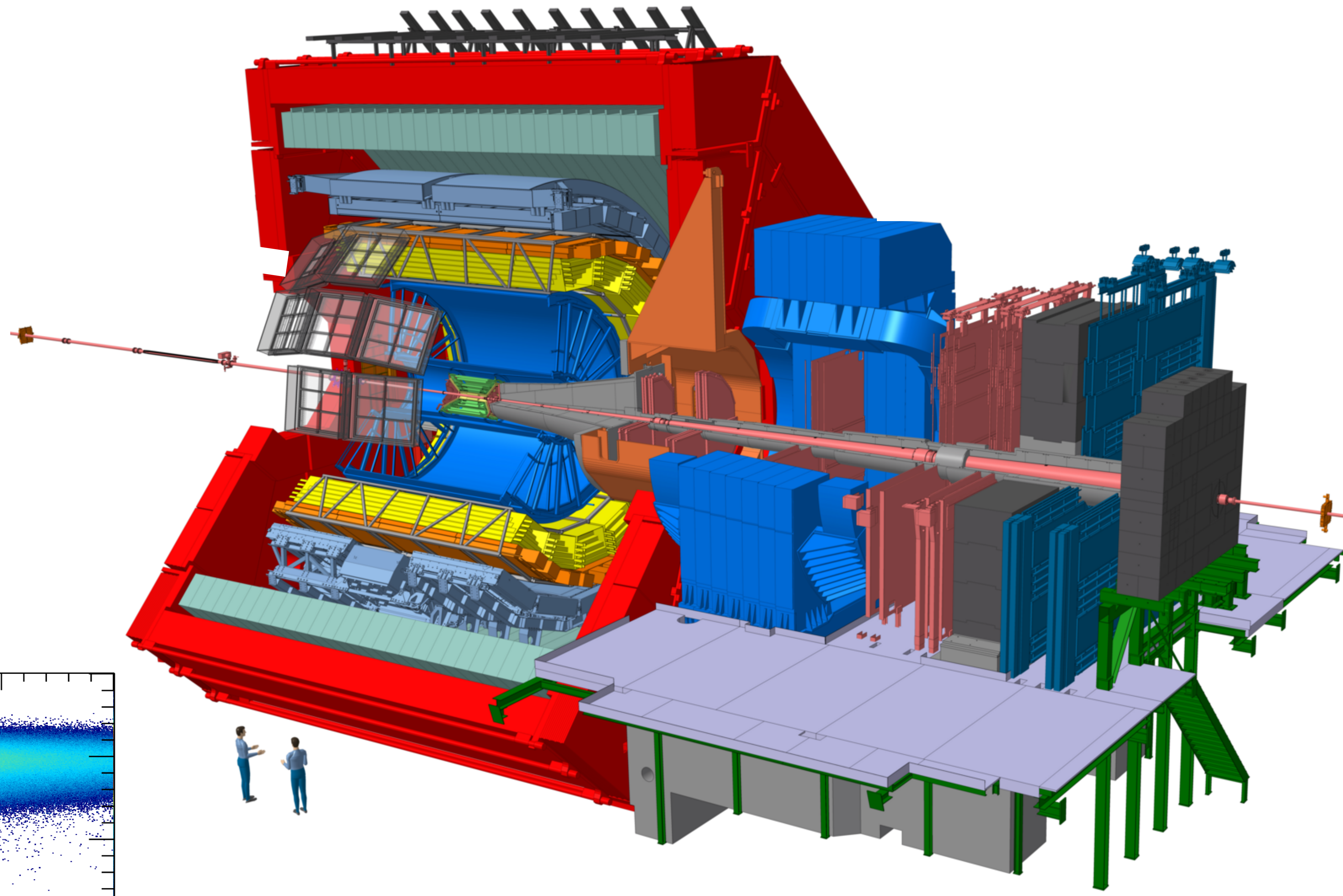
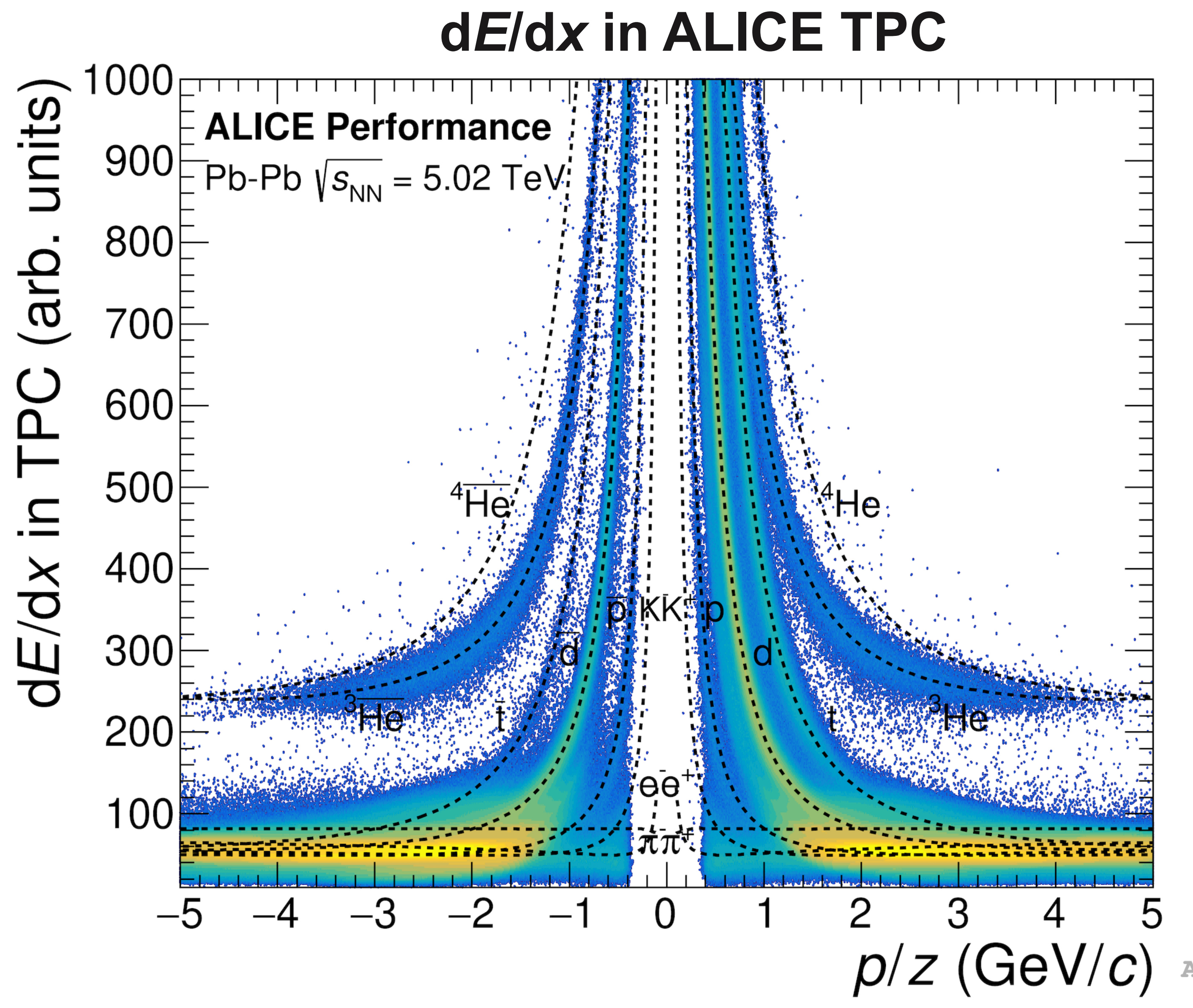
Measurements in pp collisions are crucial to understand this hadronic background!
- Vacuum baseline for the studies in heavy-ion collisions
- Interesting phenomena beyond expected hadronic decays?

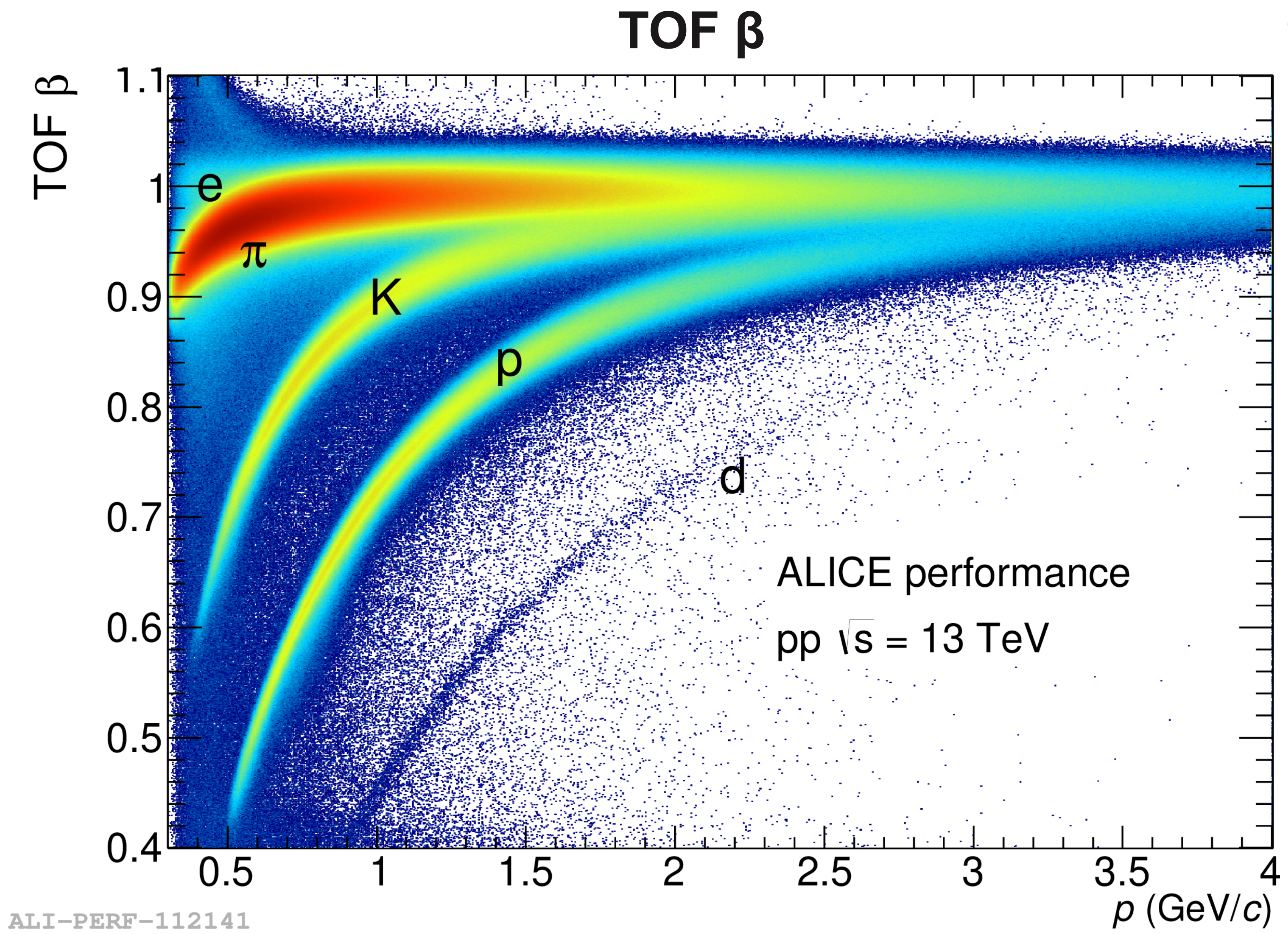
The ALICE apparatus in Run 2 (2015−2018)

Unique tracking and PID capabilities to study the production of low-mass dielectrons at the LHC energies!

- Inner Tracking System: vertex, tracking, PID (dE/dx)
- Time Projection Chamber: tracking, PID (dE/dx in gas)
- Time-of-Flight: PID (via TOF β)
- V0 at forward rapidity: event triggering, multiplicity & centrality determination





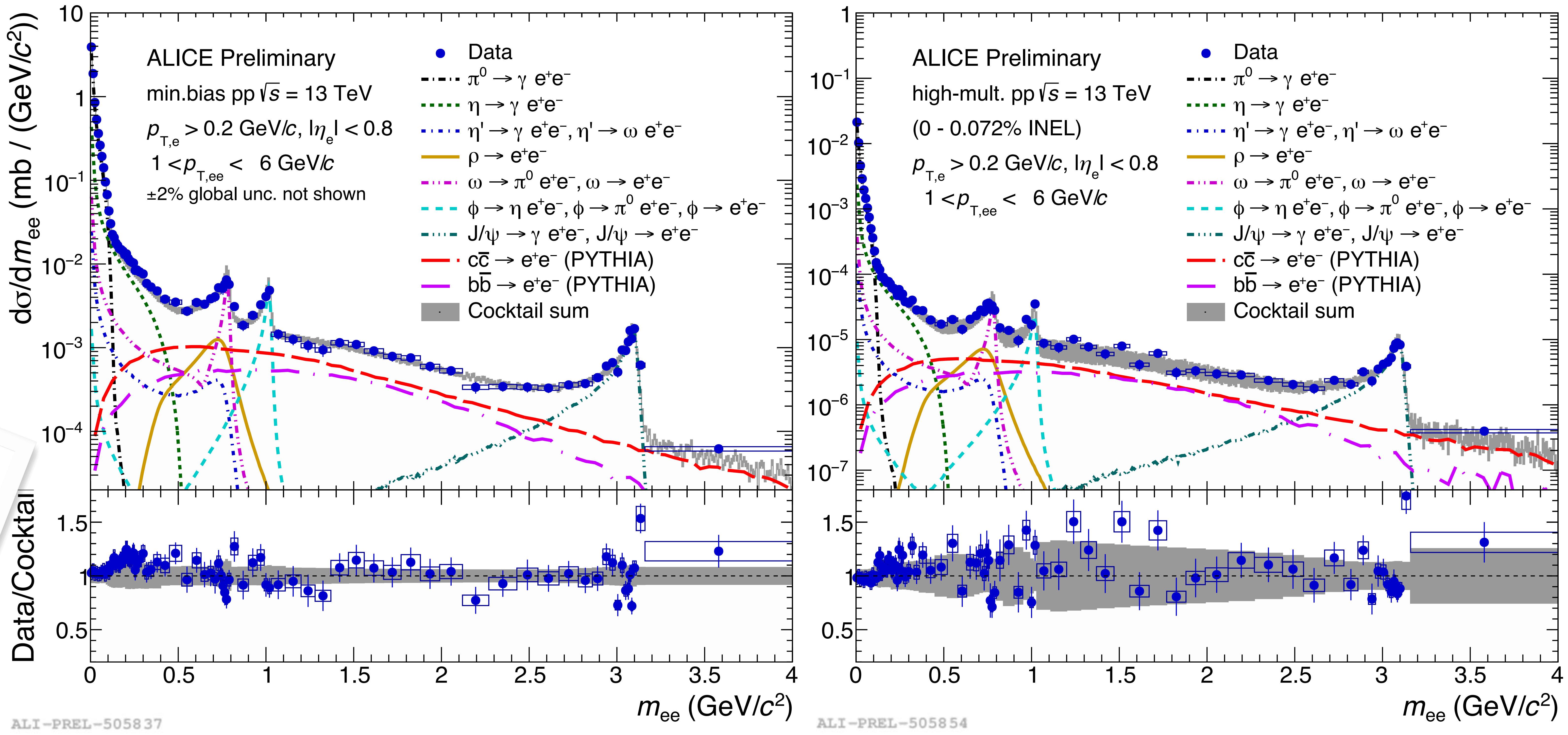


Collision system	Analysed luminosity
Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV	85 μb^{-1} in 0–10%
pp $\sqrt{s}$ = 13 TeV	30 nb^{-1} minimum bias (MB) 5.8 pb^{-1} high multiplicity (HM)

Dielectron spectrum in pp 13 TeV

- Increase of statistics by factor ~ 4 compared to previous publication [1]
- Updated estimation of hadronic decays thanks to independent measurements in pp at $\sqrt{s}$ = 13 TeV

S. Stiefelmaier
18 Jul, 12:00
North Hall



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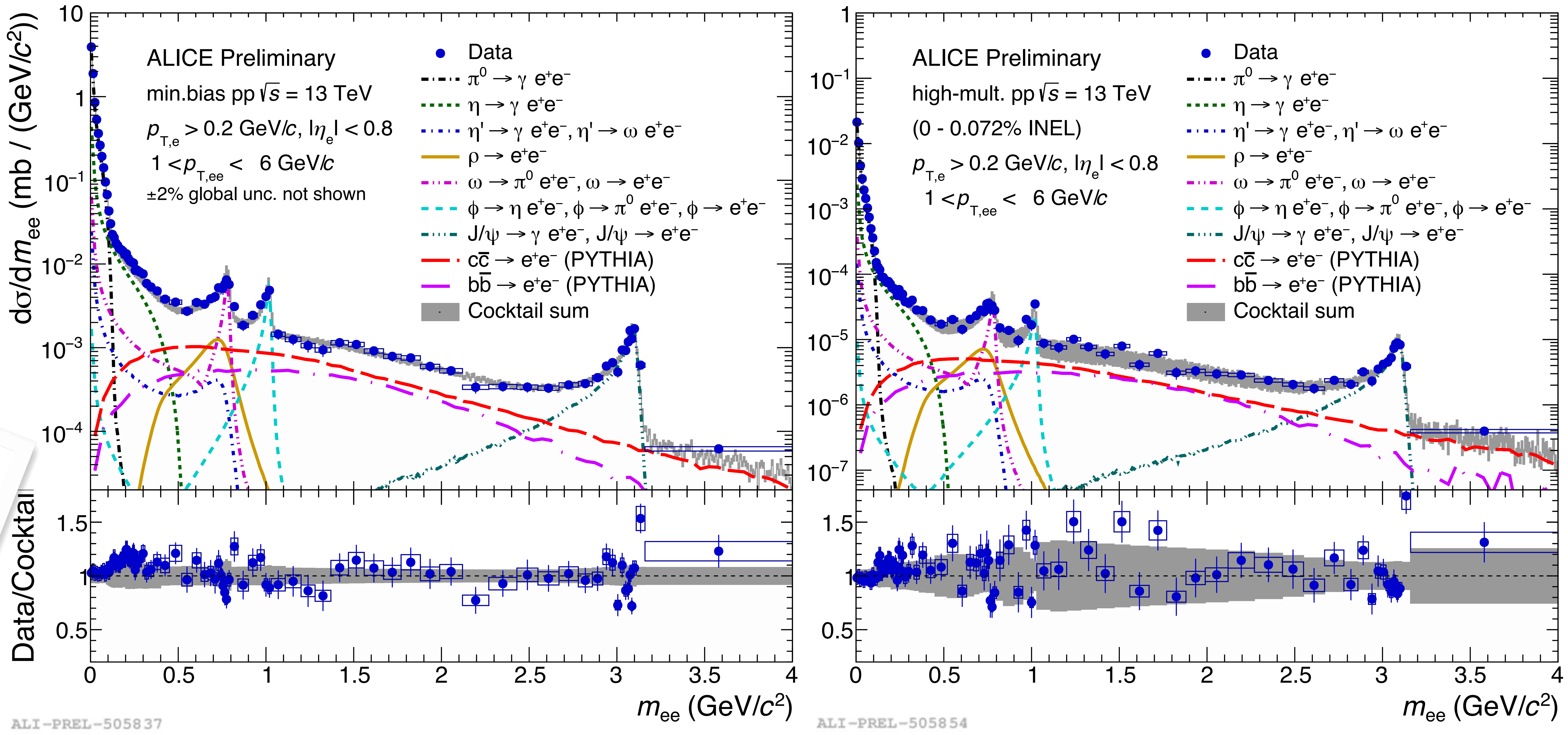


✅ MB data is well described by expected hadronic contributions

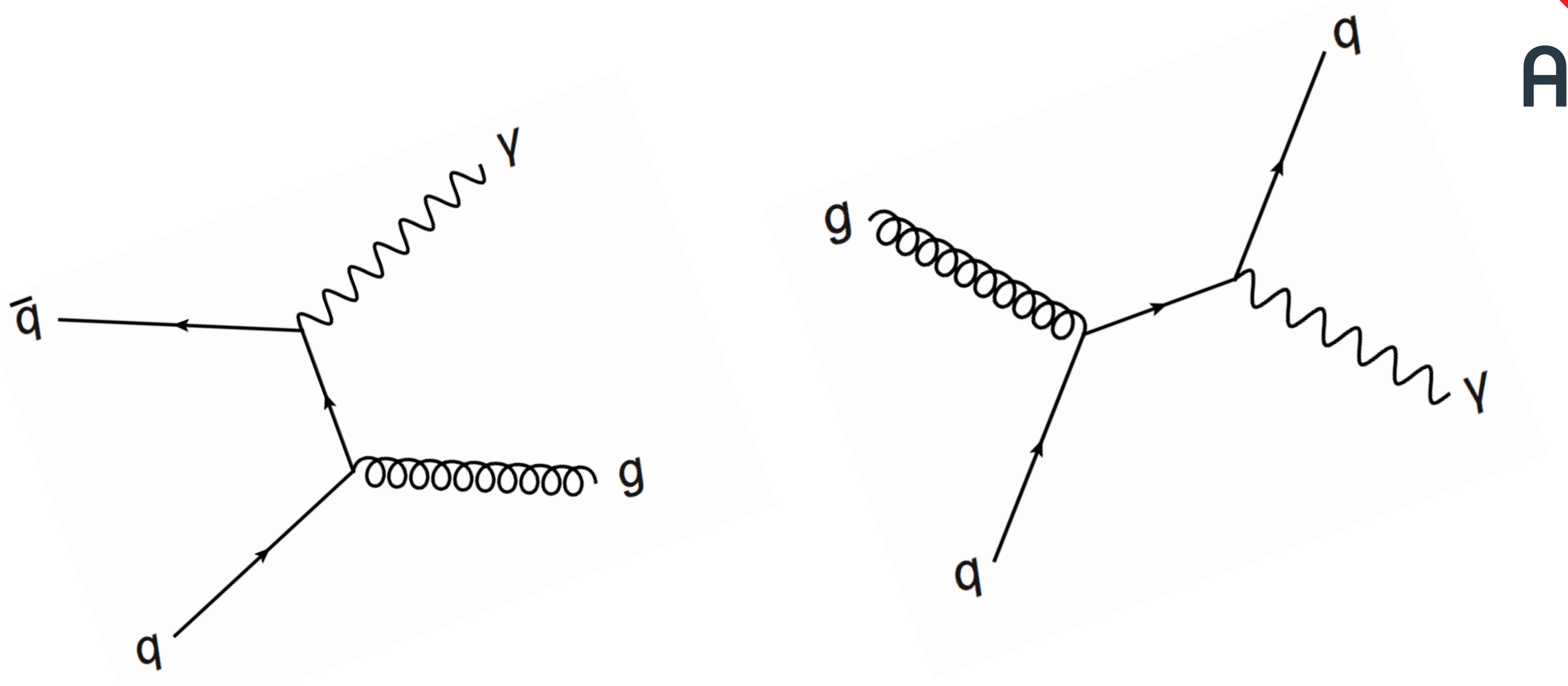
⚠️ Large uncertainties from HF decays for hadronic cocktail in HM events

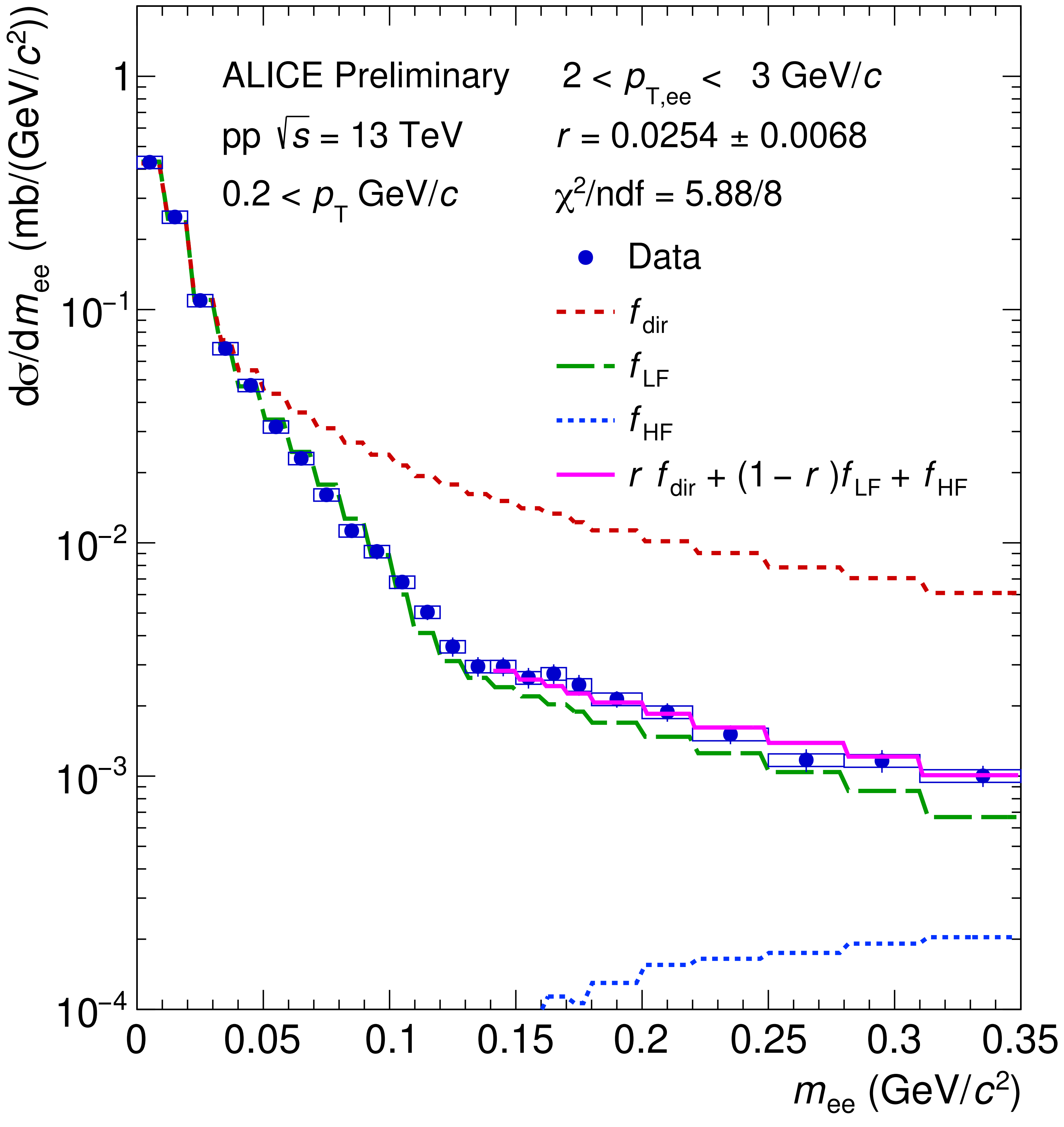
[1] ALICE, Phys. Lett. B 788 (2019) 505

Extraction of direct photons

Any source of real photons can also produce virtual photons (→ e^+e^- pair)

- Additional dimension: invariant mass → can suppress hadronic background by going to $m_{ee} > m_{\pi 0}$





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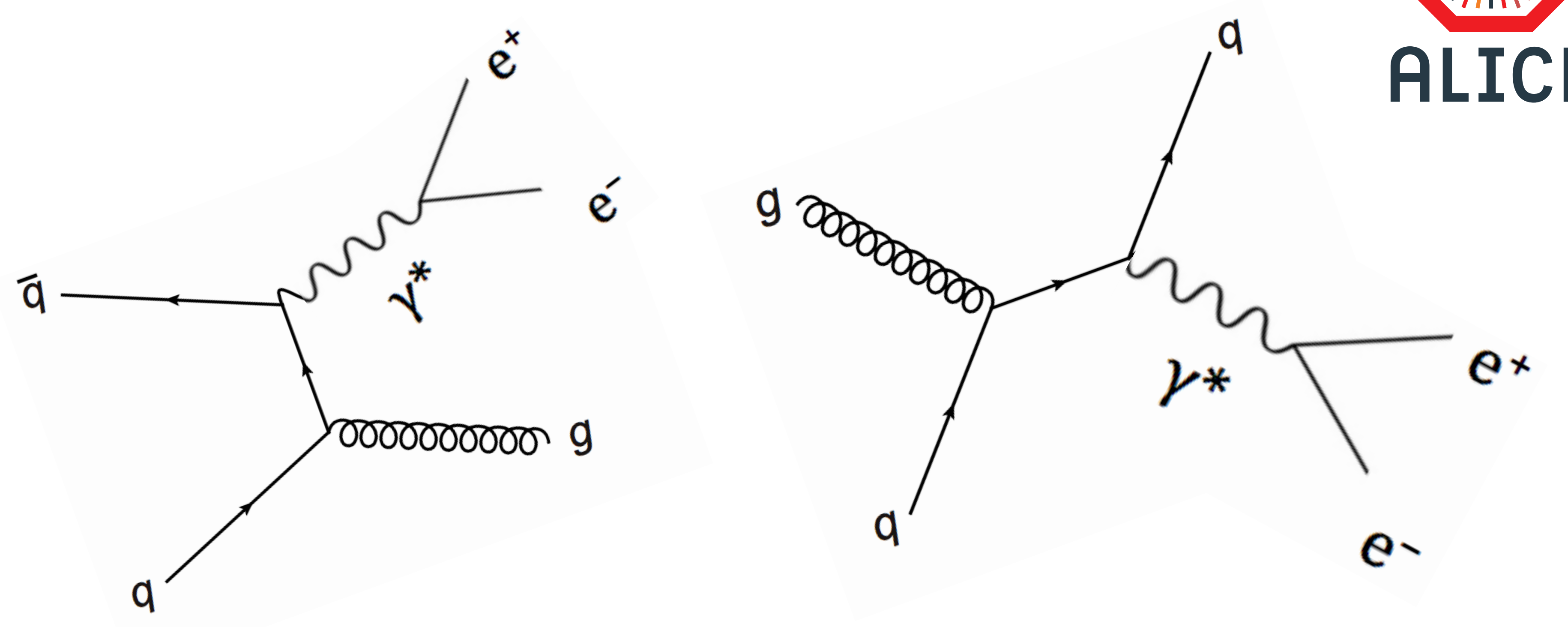

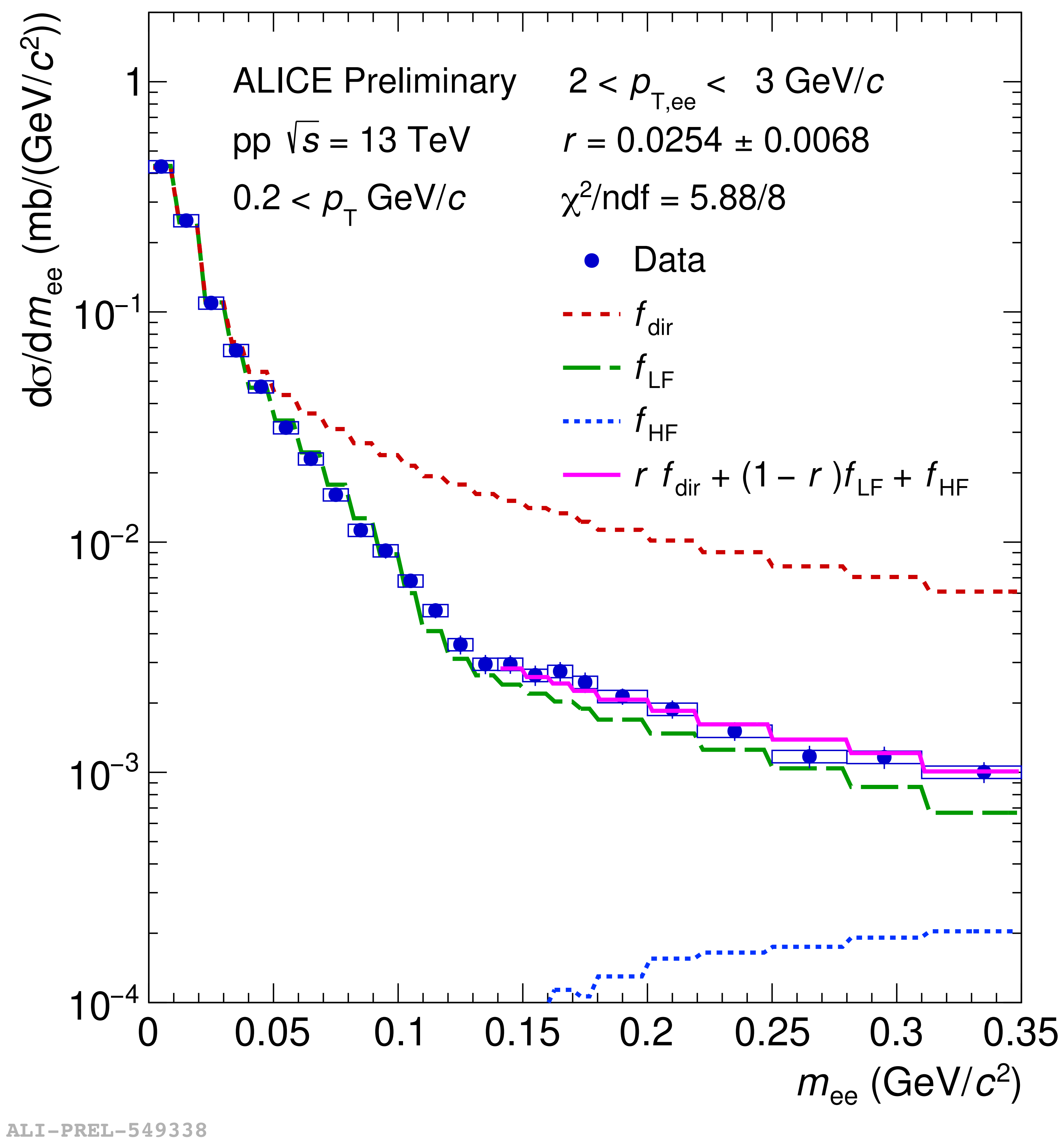

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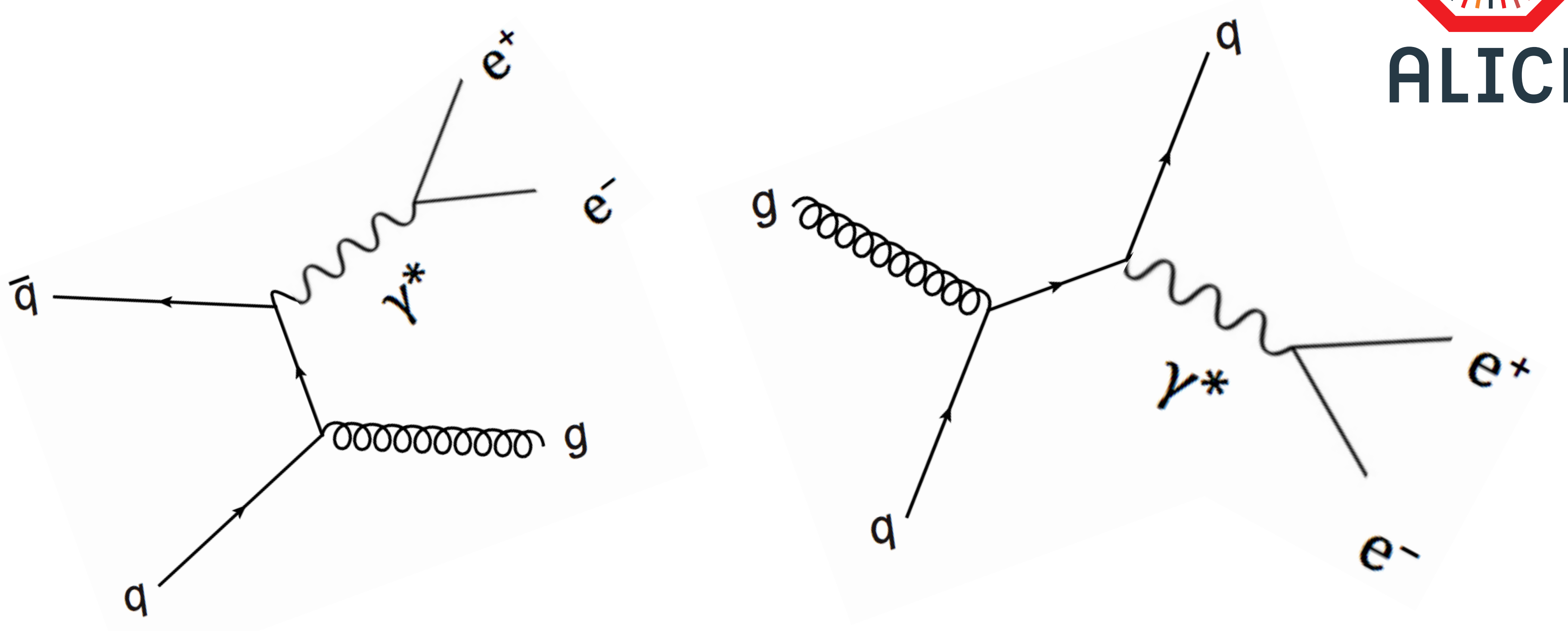
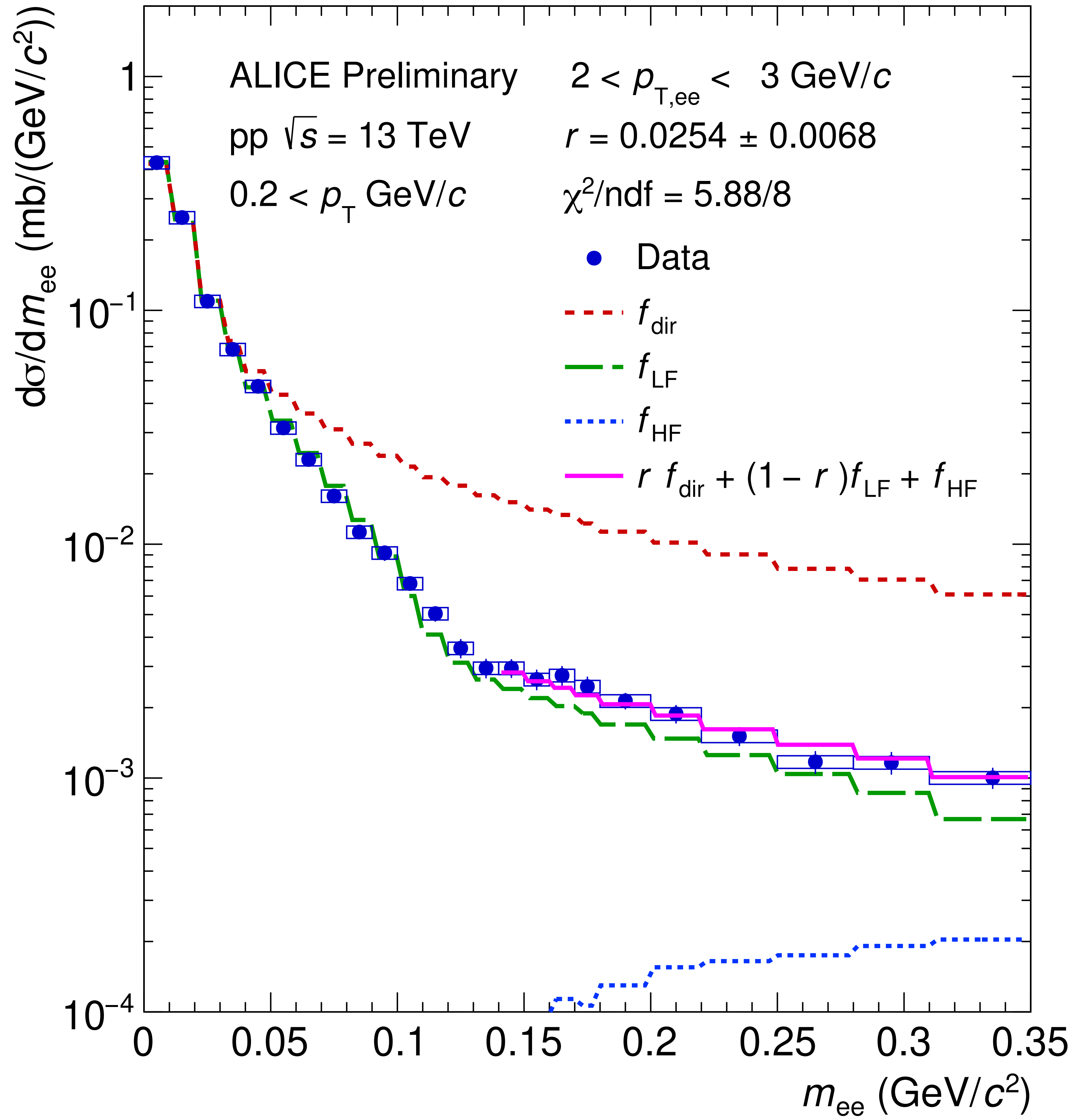
Fit dielecton mass spectrum above π^0 mass with:

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

- f_{dir} and f_{LF} are normalised to data at m_{ee} = 0
- r = (virtual) direct γ / inclusive γ (at m_{ee} = 0)
- γ^*_{dir} from Kroll-Wada: ~1/m_{ee} (for $p_{T,ee} >> m_{ee}$)
- Direct-photon yield: $\gamma_{dir} = r \times \gamma_{incl}$

$$\frac{d^2N}{dm_{ee}dN_\gamma} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)\frac{1}{m_{ee}}S$$





ALI-PREL-549338

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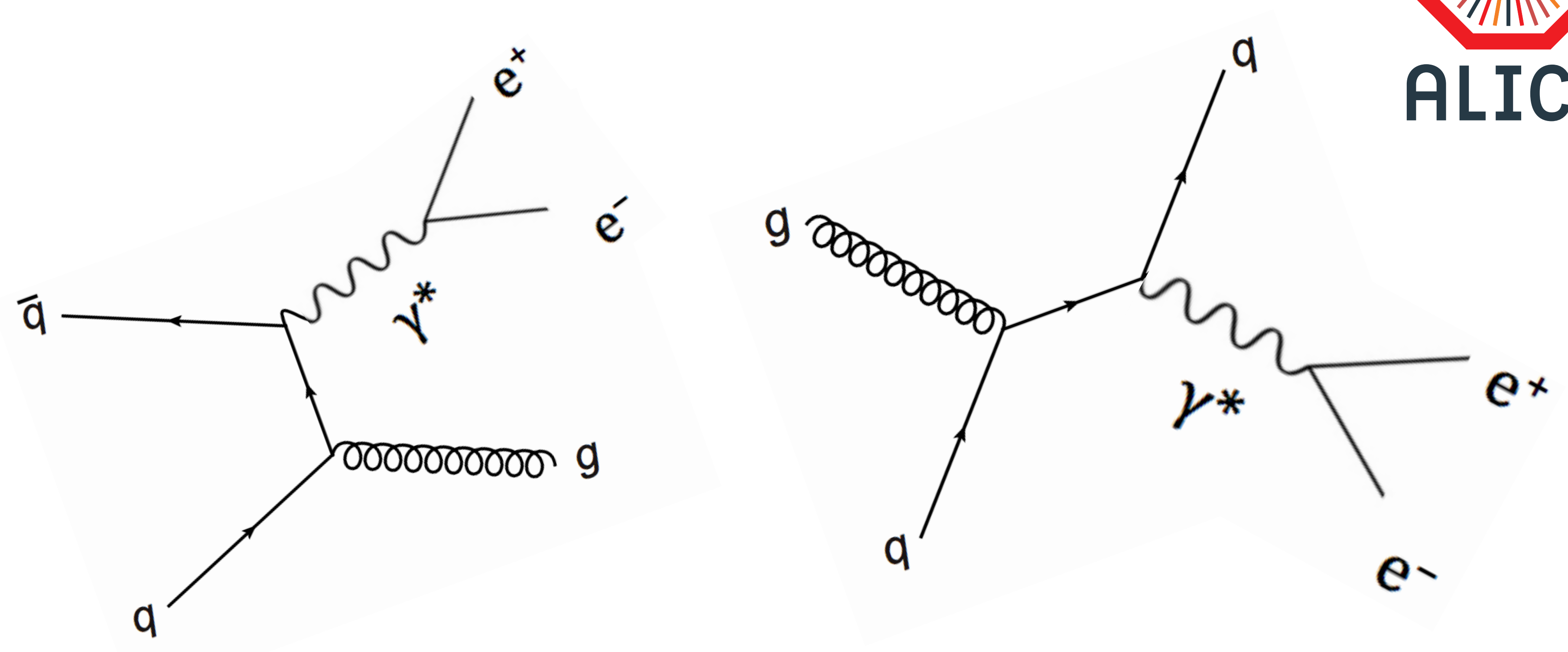

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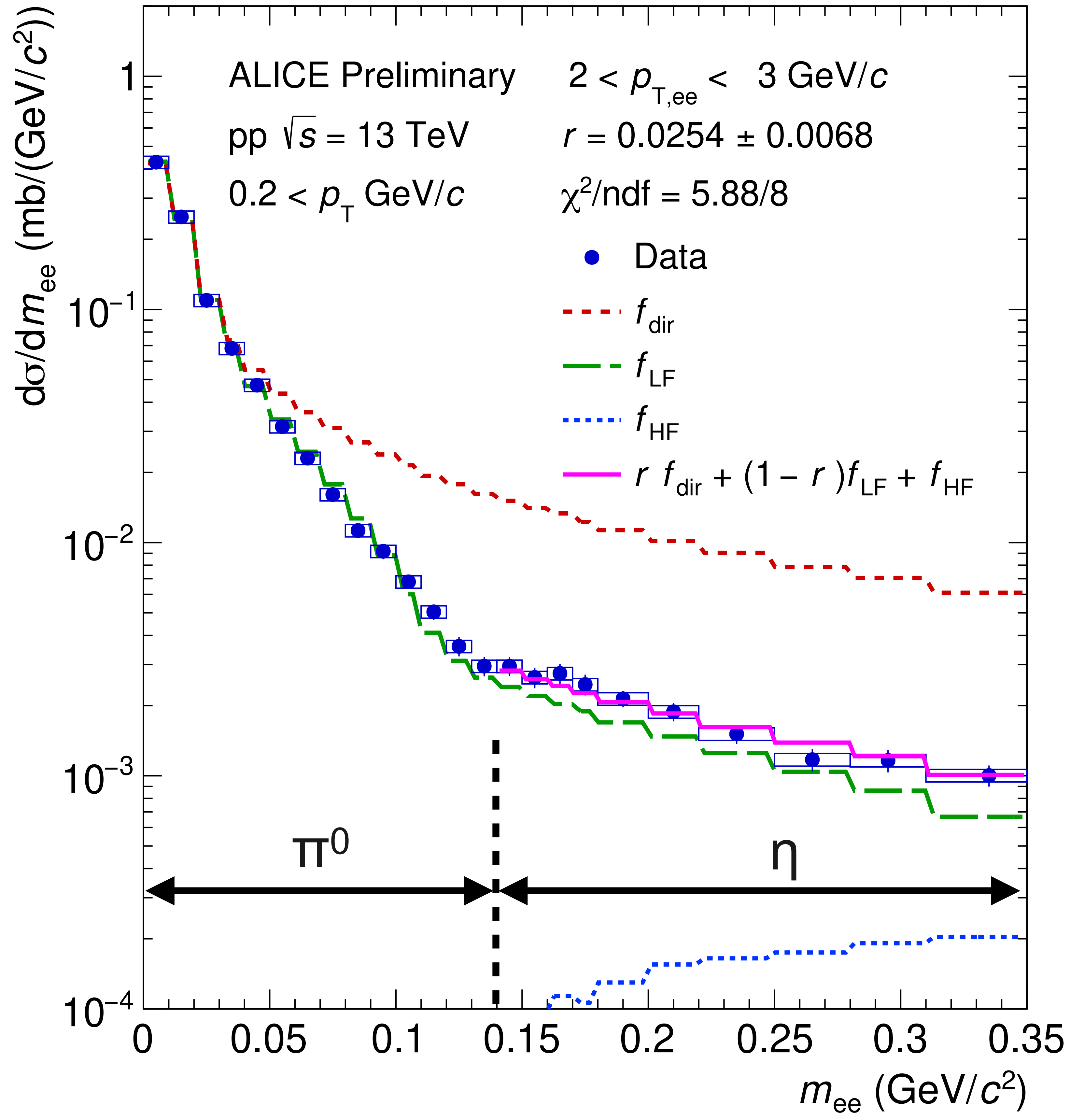

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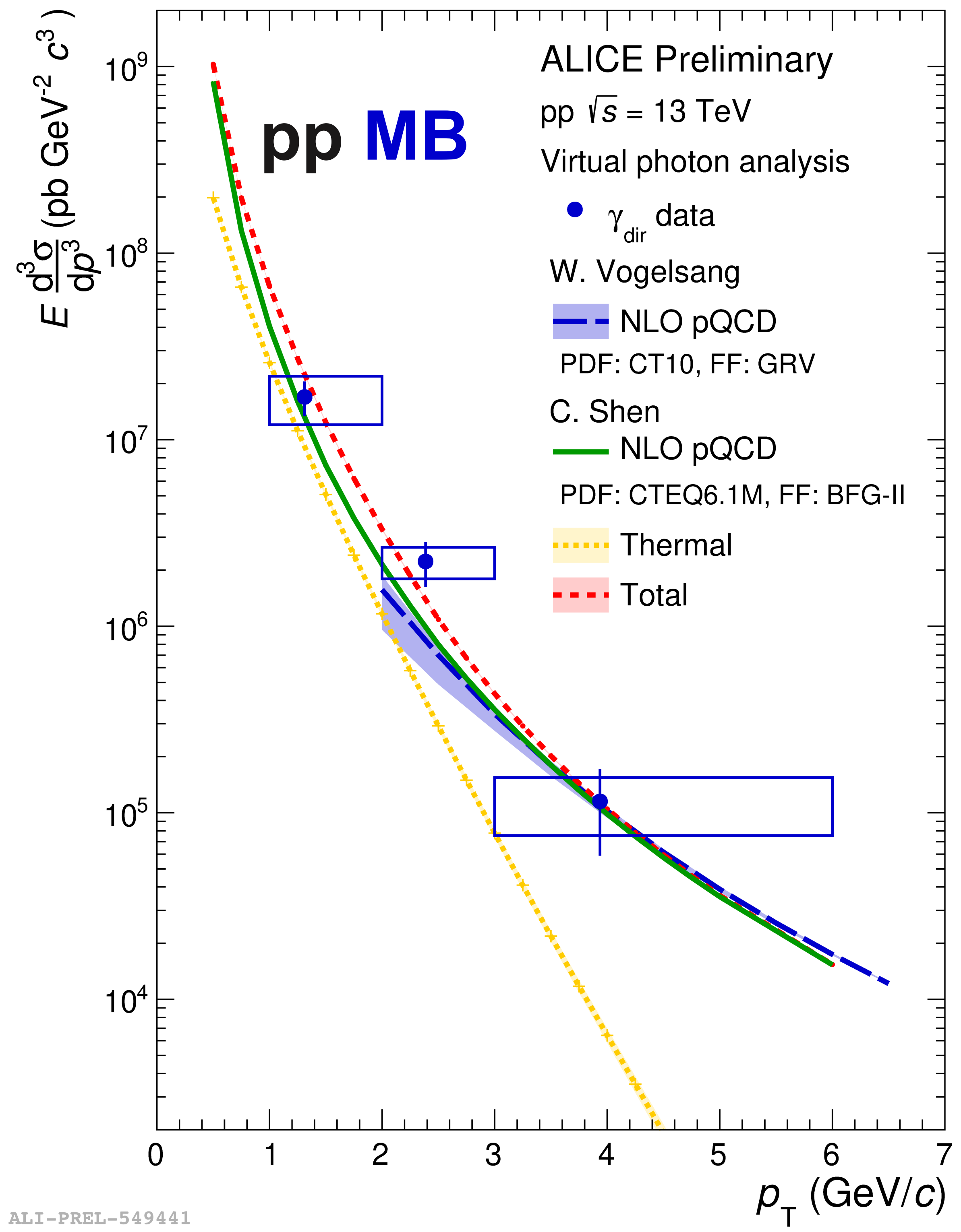
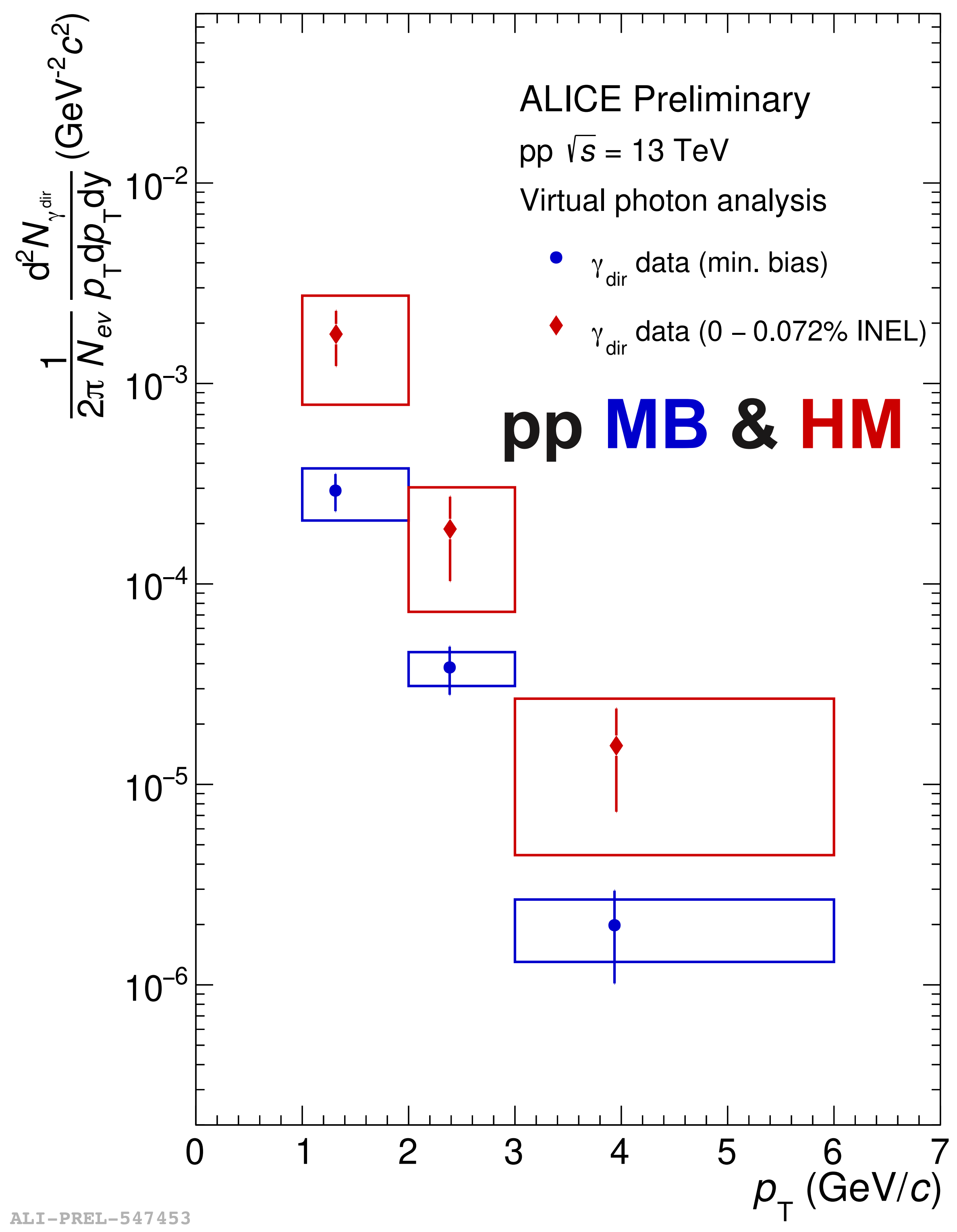
Direct-photon yield in pp and Pb−Pb collisions





First measurement of direct photons in small systems at low p_T at the LHC energies!

🤔 MB pp data can be well reproduced by both prompt or prompt + thermal calculations

🛑 Challenging theoretical calculations of direct-photon yield in HM pp events

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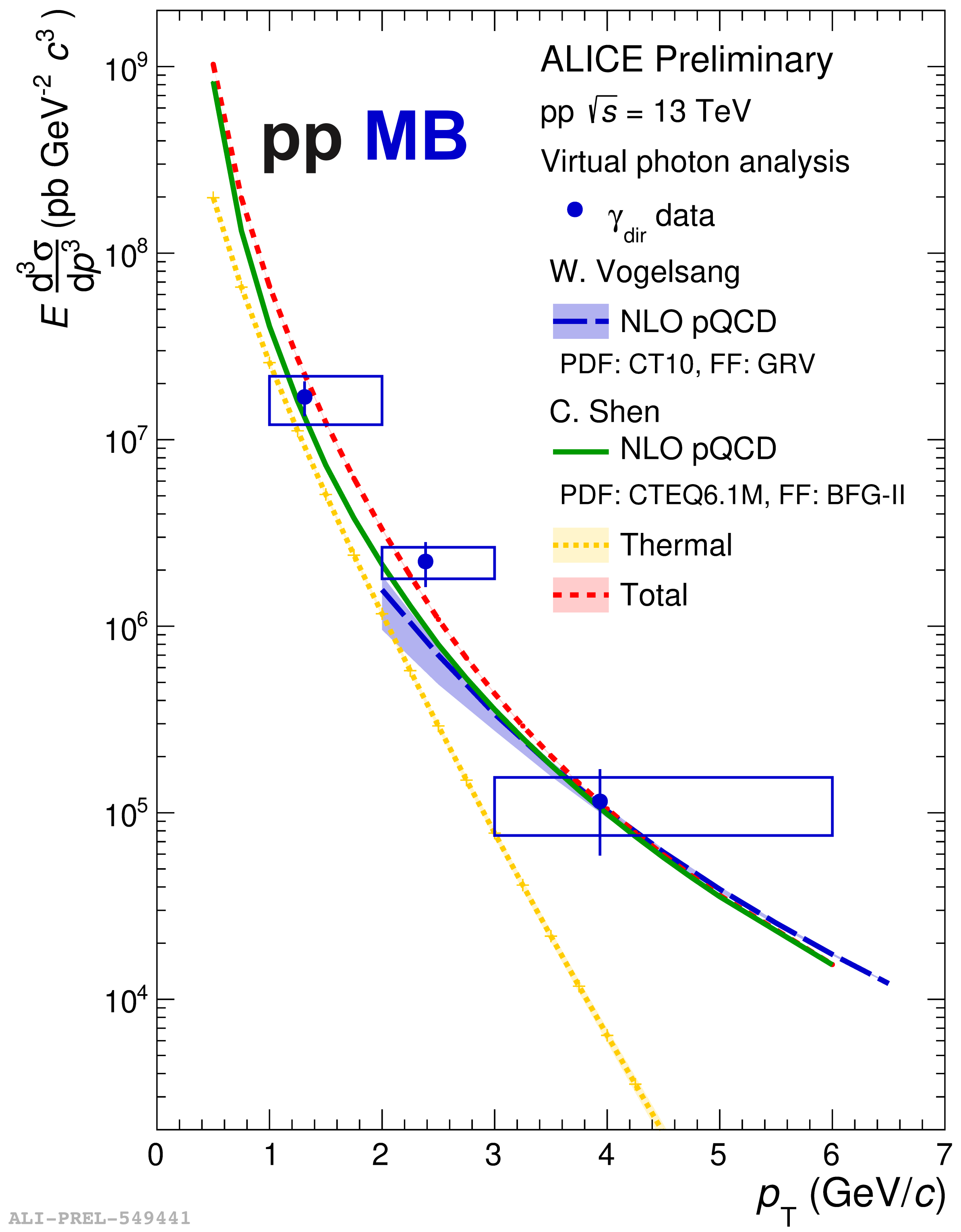

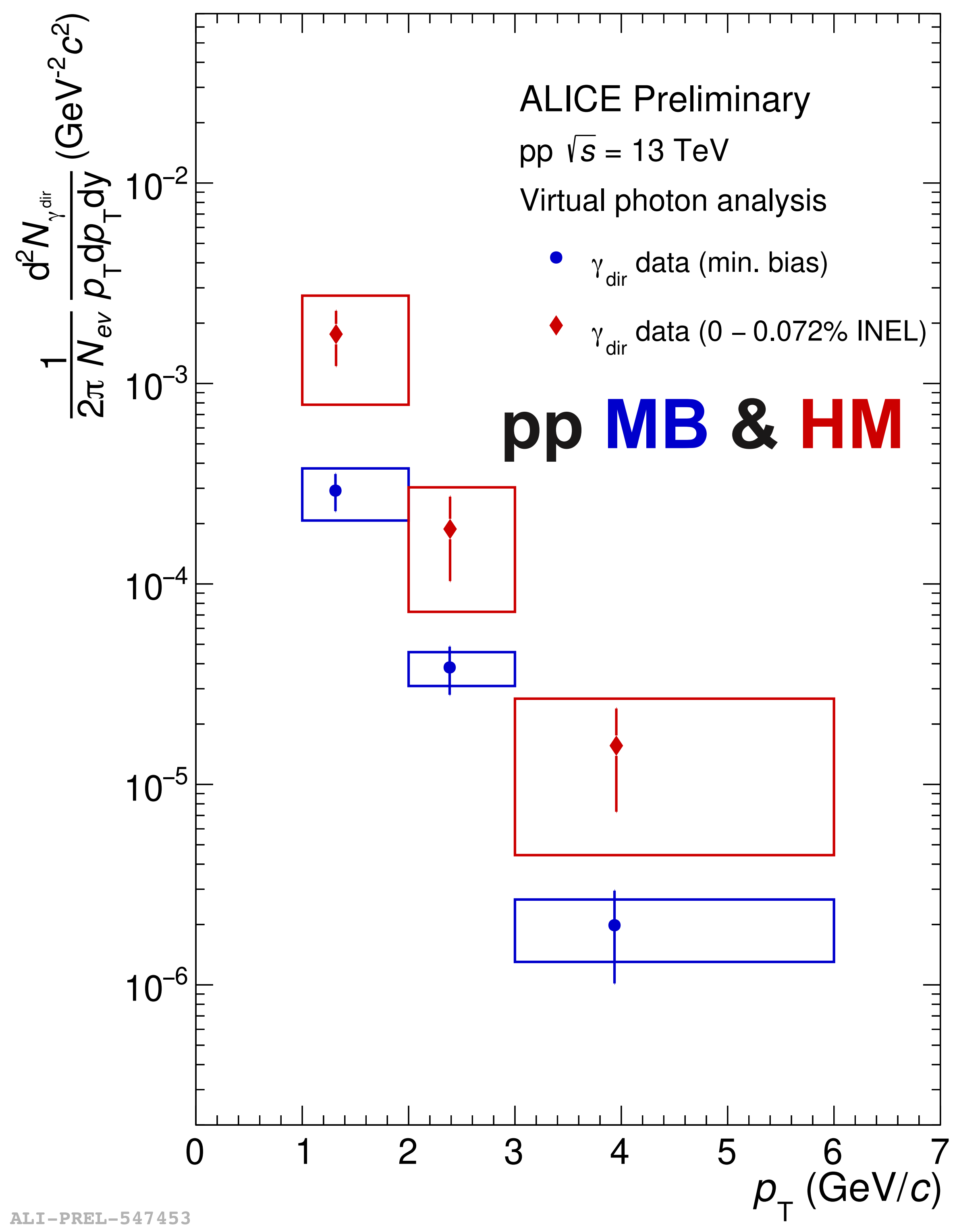

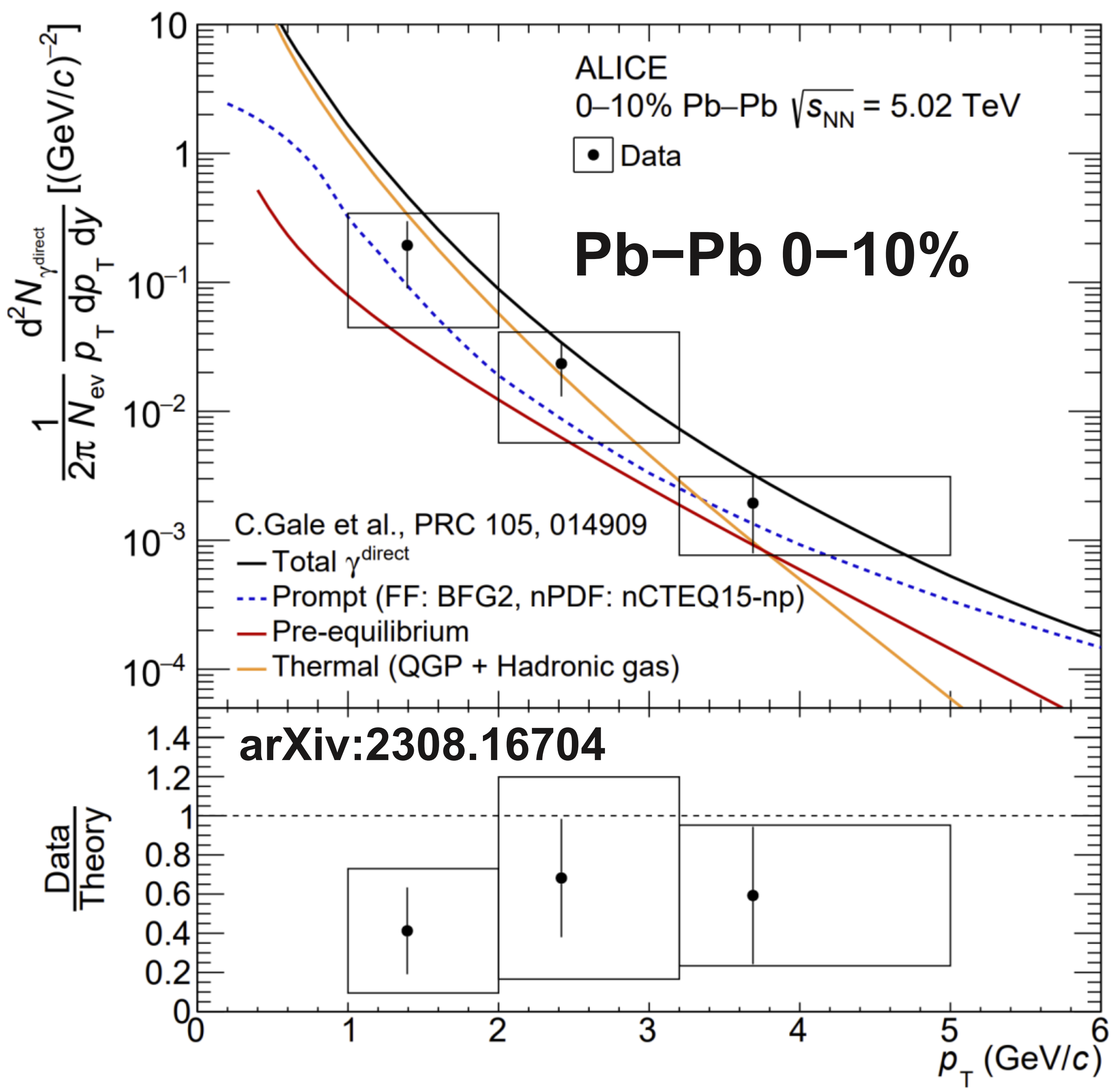

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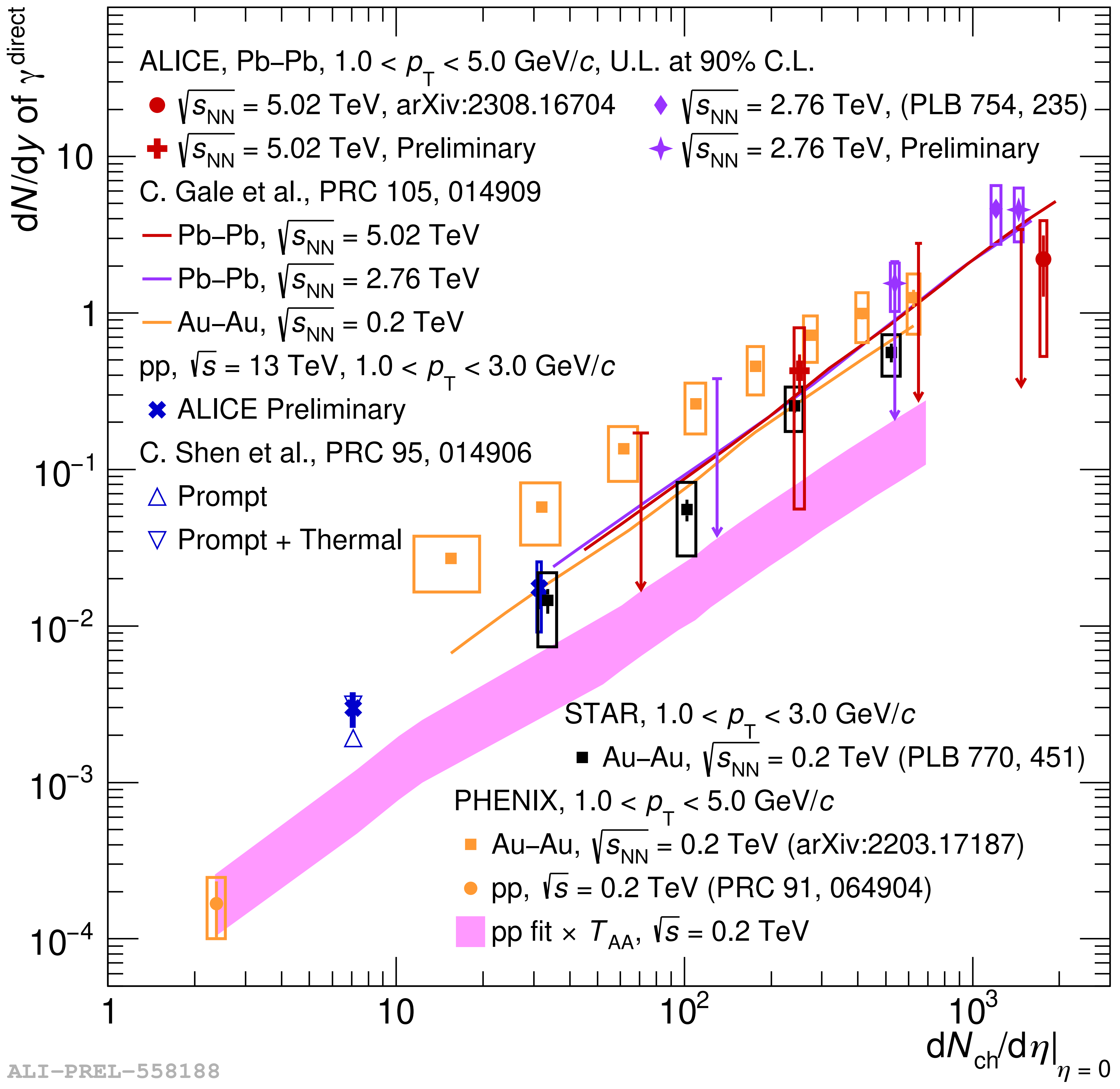
First direct-photon p_T spectrum in Pb−Pb at $\sqrt{s_{NN}}$ = 5.02 TeV!

⚠️ Sum of all contributions (prompt, pre-equilibrium, thermal) overestimates data by ~1σ

Direct-photon yield vs mult

- *Is there a universal scaling of direct-photon yield with multiplicity?*
- *Where is the onset of thermal radiation?*



[1] ALICE, Phys. Lett. B 754 (2016) 235
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ALICE

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✅ Recent measurements by ALICE in Pb−Pb are in agreement with model predictions:

- Real photons in 0−20% Pb−Pb at $\sqrt{s_{NN}}$ = 2.76 TeV [1]
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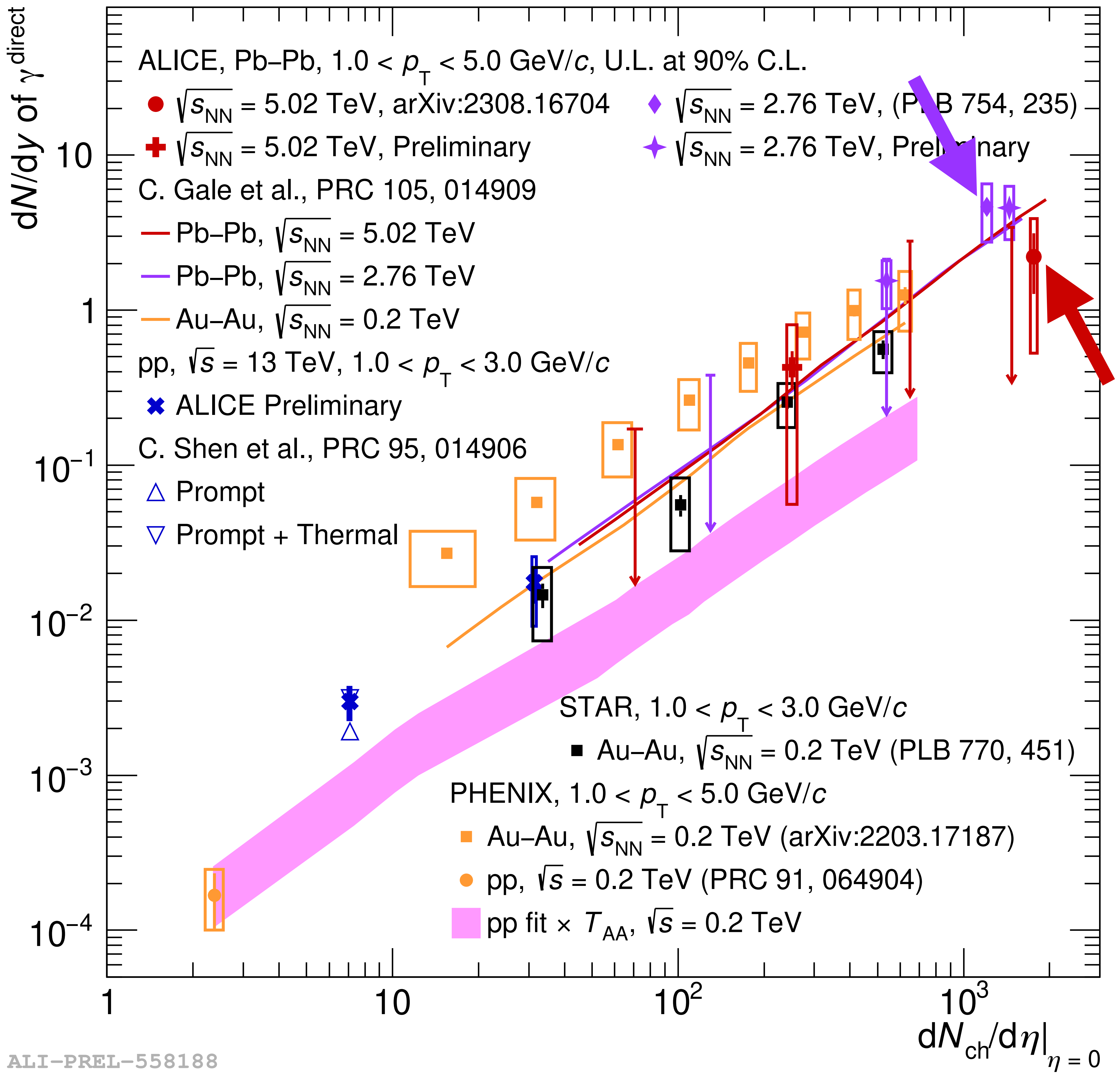

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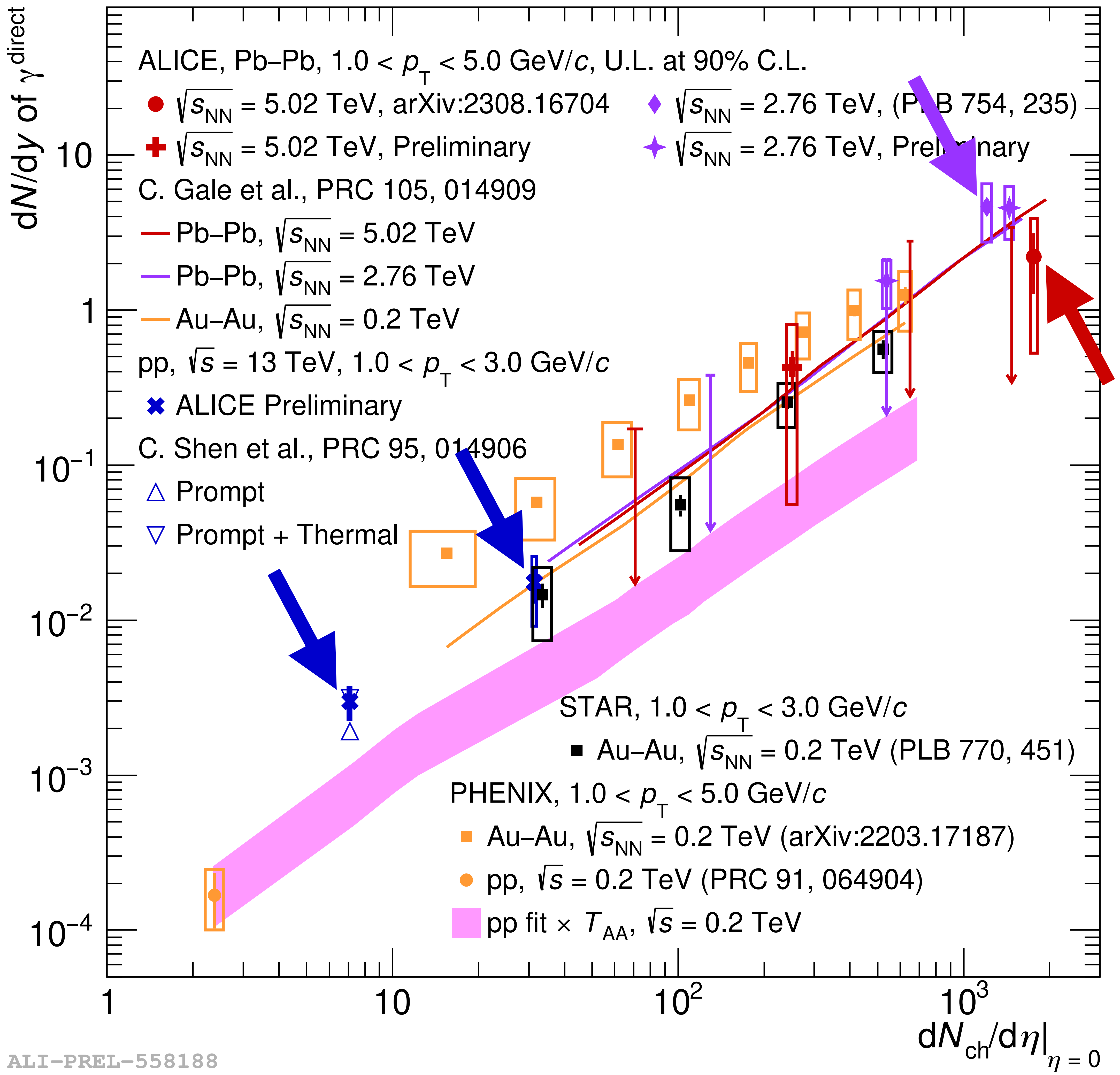
❗ Measurements in small systems are a crucial input for theoretical models!

- Virtual photons in pp at $\sqrt{s}$ = 13 TeV vs multiplicity



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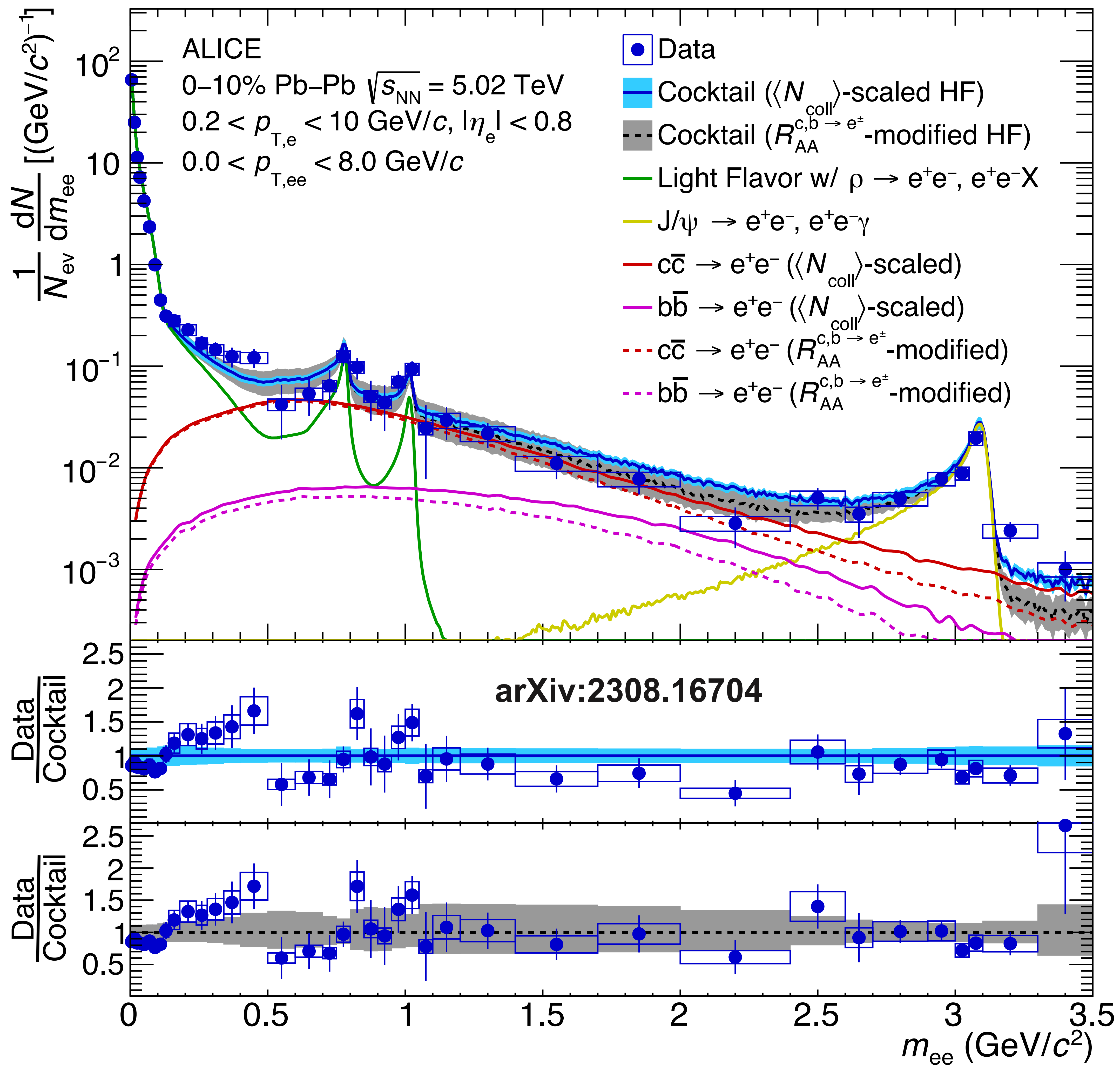
Dielectron mass spectrum in central Pb−Pb events

Hadronic decay cocktail is implemented using:

- HF cross section measured in pp at $\sqrt{s}$ = 5.02 TeV and scaled with N_{coll}
  - Indication of HF suppression compared to pp
- Modified HF production, including measurement of R_{AA} for c / b → e±
  - Better overall description of the data



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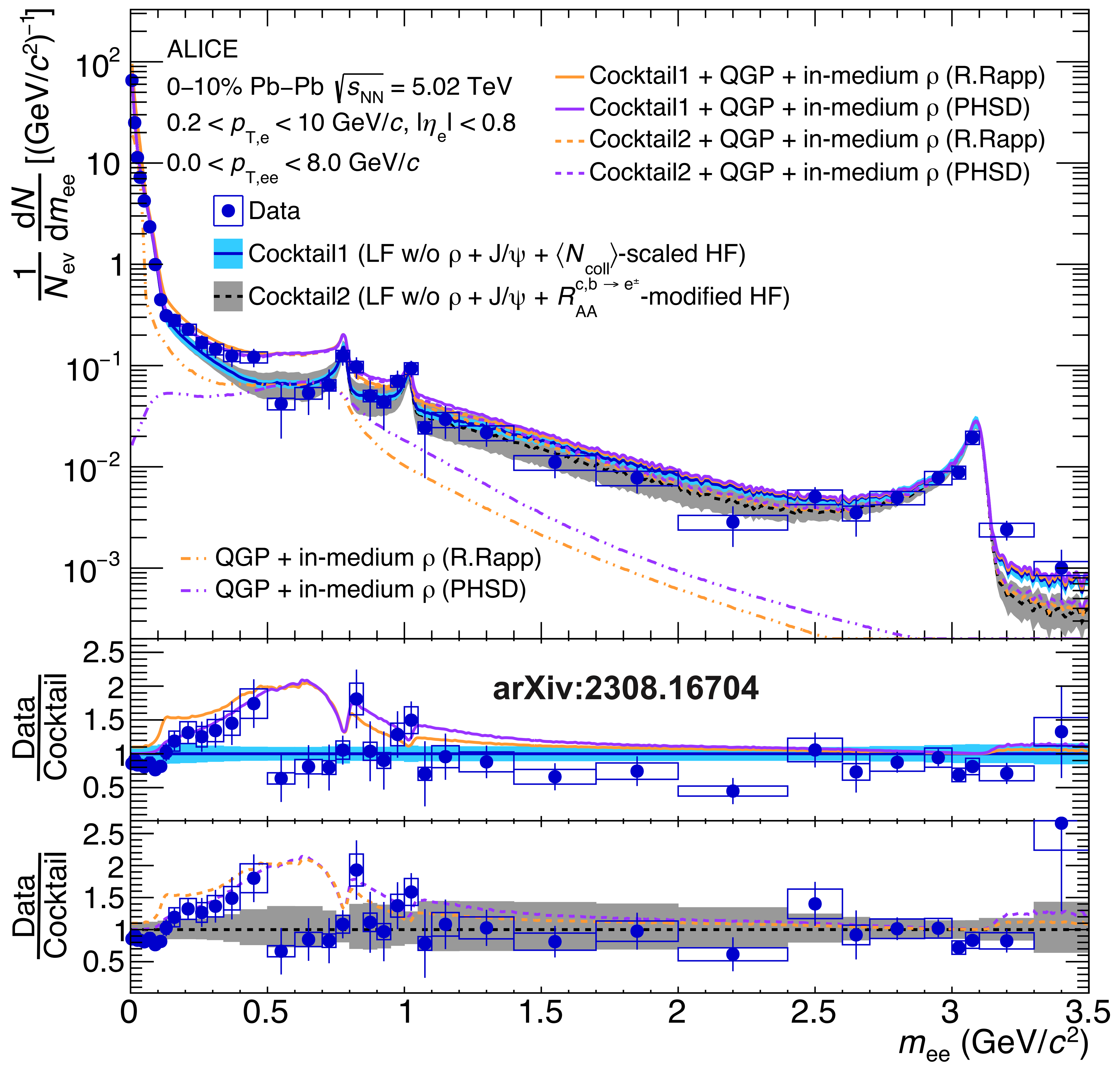
🧐 *A hint for low-mass excess with ~1.3σ significance*

- Contribution from ρ meson produced thermally via $\pi^+\pi^- \rightarrow \rho \rightarrow e^+e^-$

✅ *Both theoretical models (R. Rapp [1], PHSD [2]) can describe the data well*

❗ *QGP radiation in the IMR is absorbed by HF cocktail uncertainty!*



[1] Rapp, Adv. HEP . 2013 (2013) 148253
[2] Song et al., PRC 97 (2018) 064907

Excess spectrum in central Pb–Pb events

ALICE

Subtraction of all known hadronic sources except ρ meson

Data compared to the sum of:
- Thermal radiation from QGP
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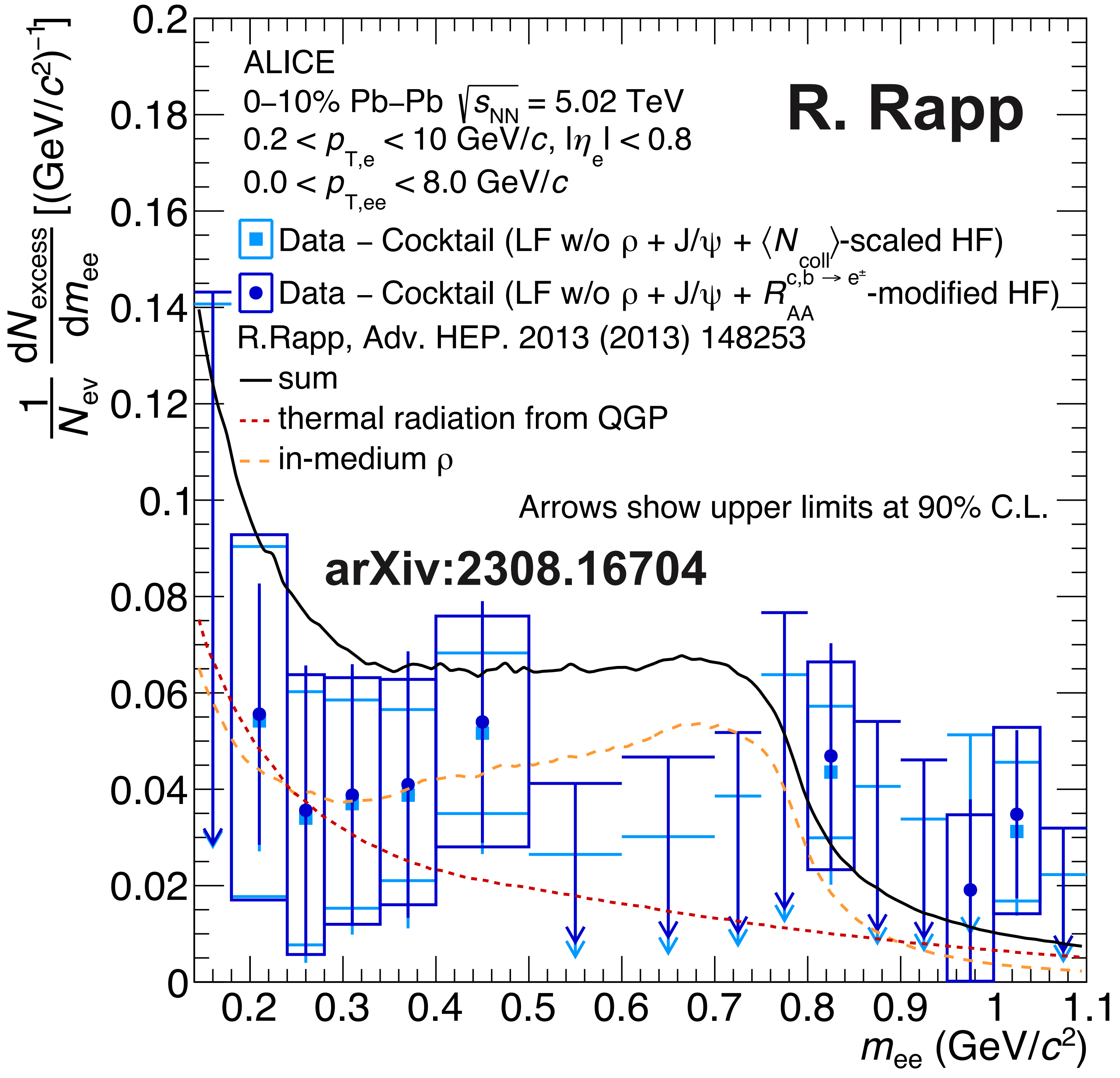

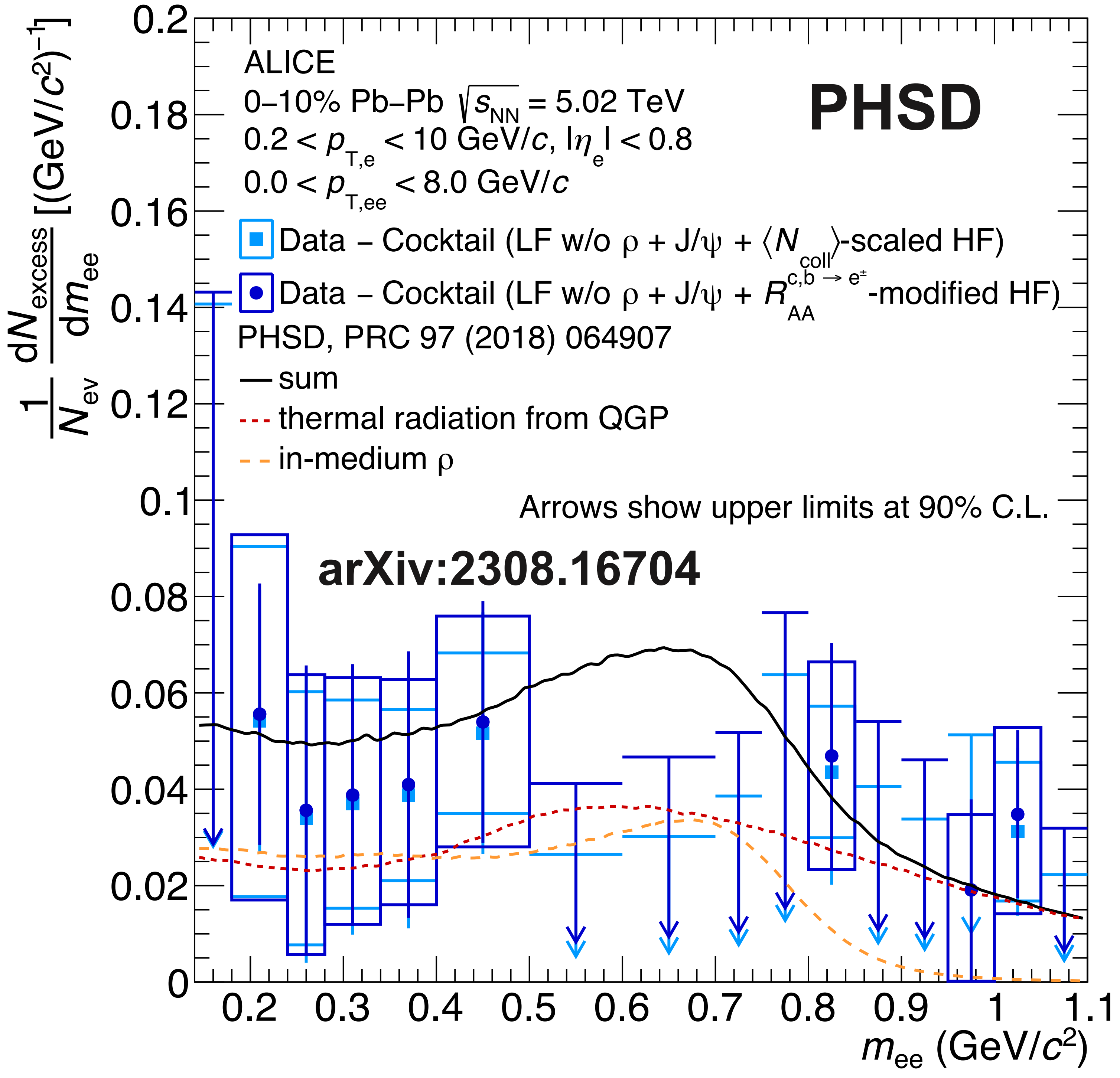

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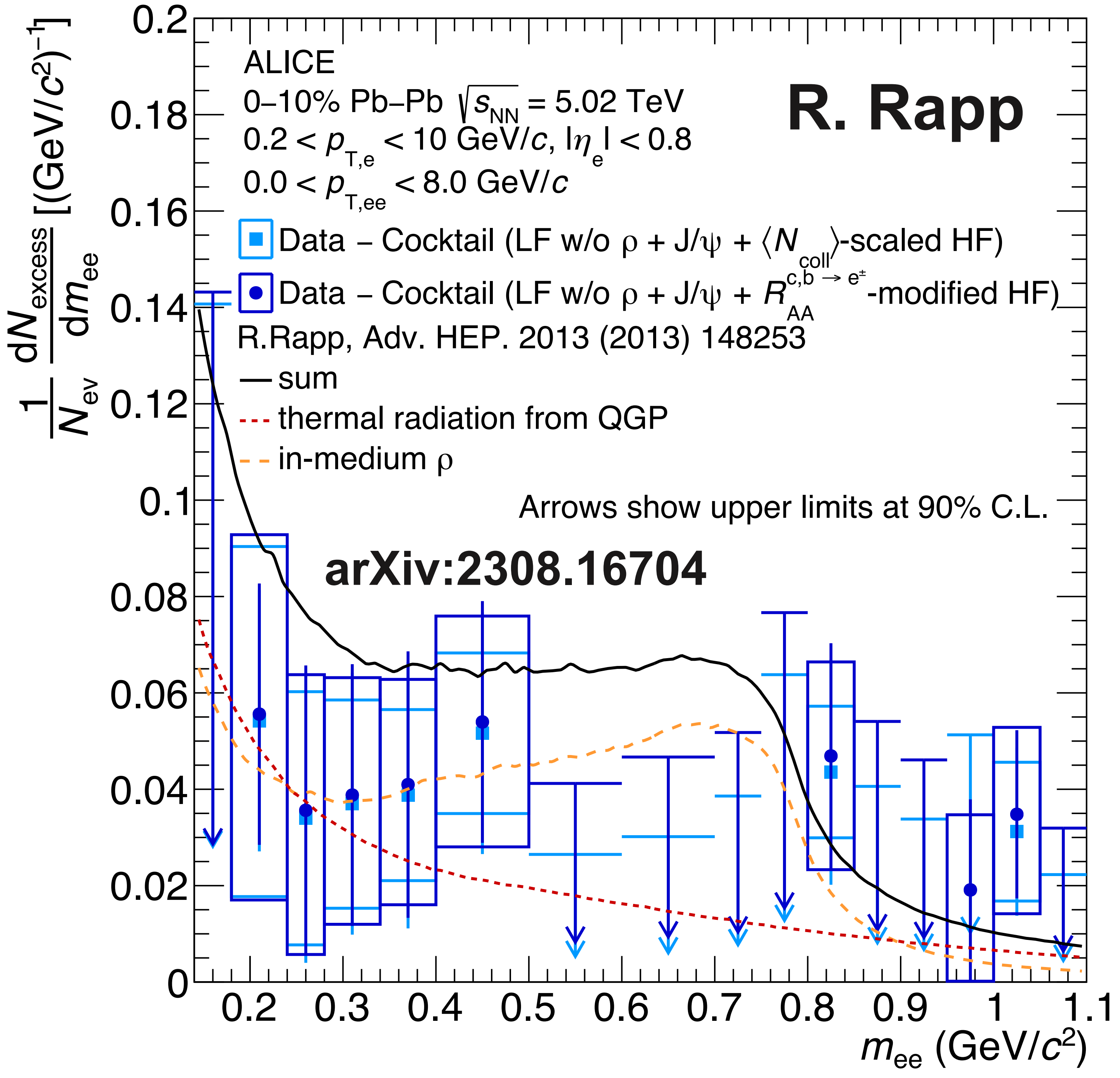
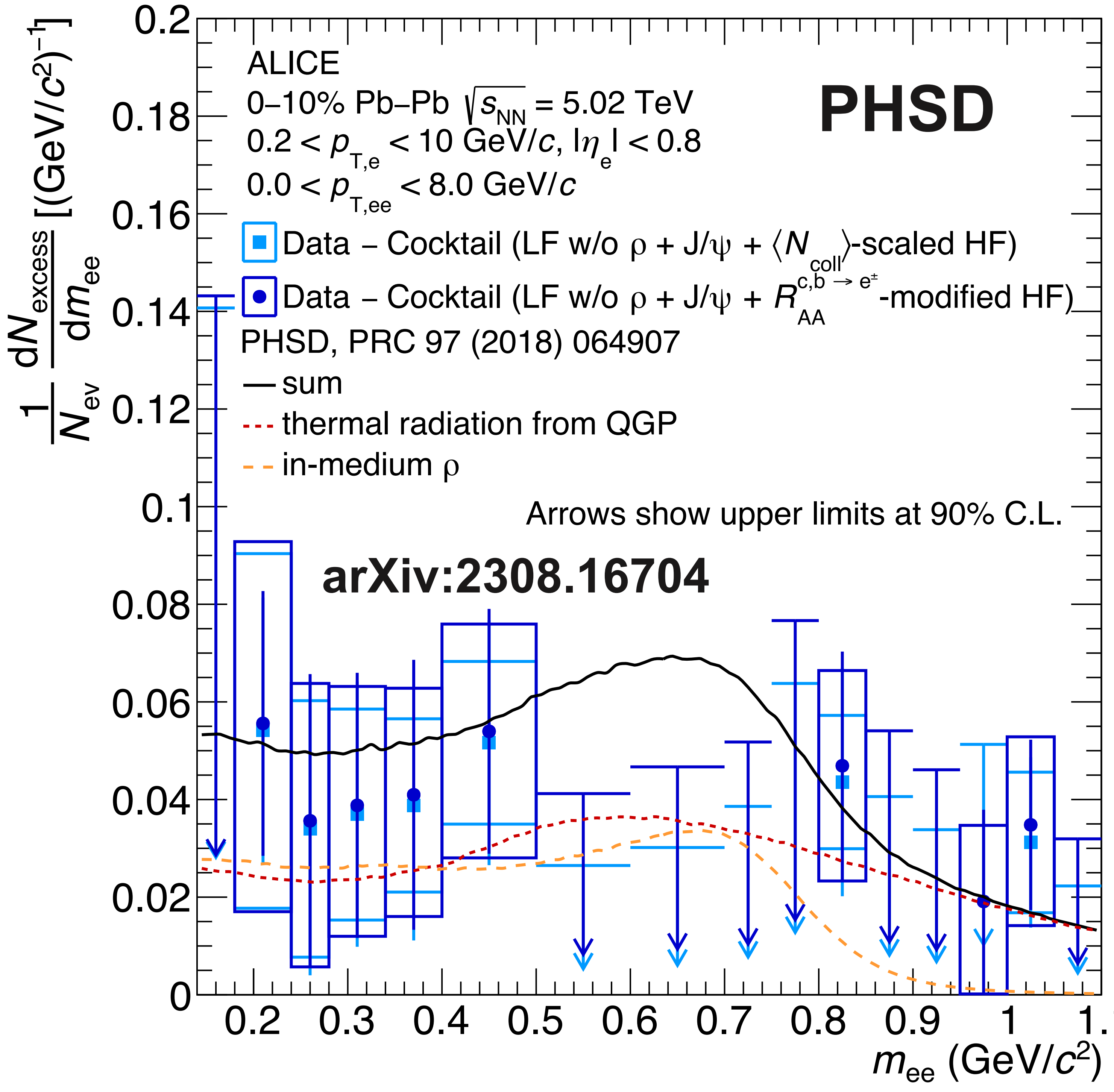
✅ Overall in a good agreement with theoretical models:

- Expanding fireball [1]
- Parton-Hadron-String Dynamics [2]





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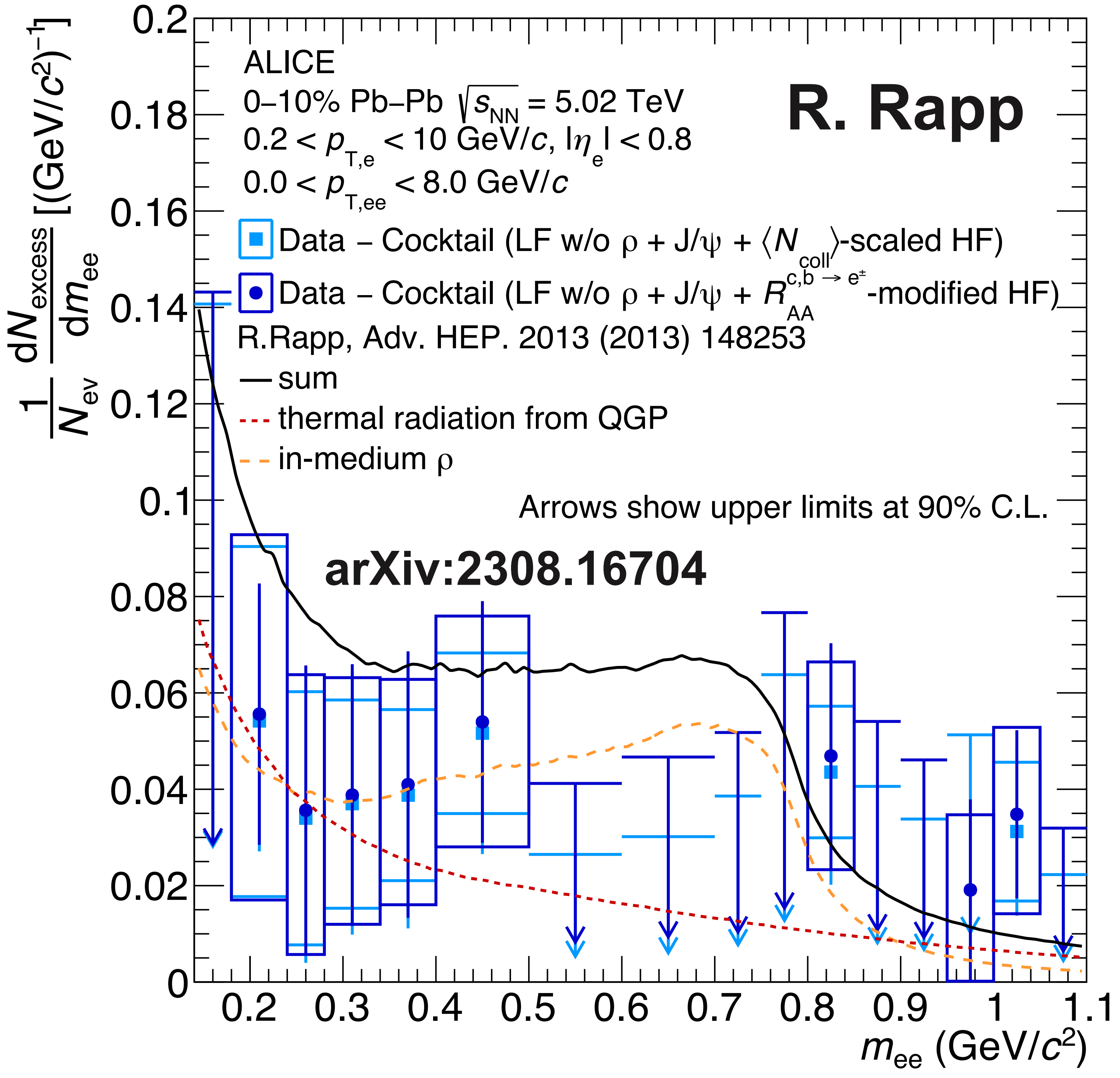

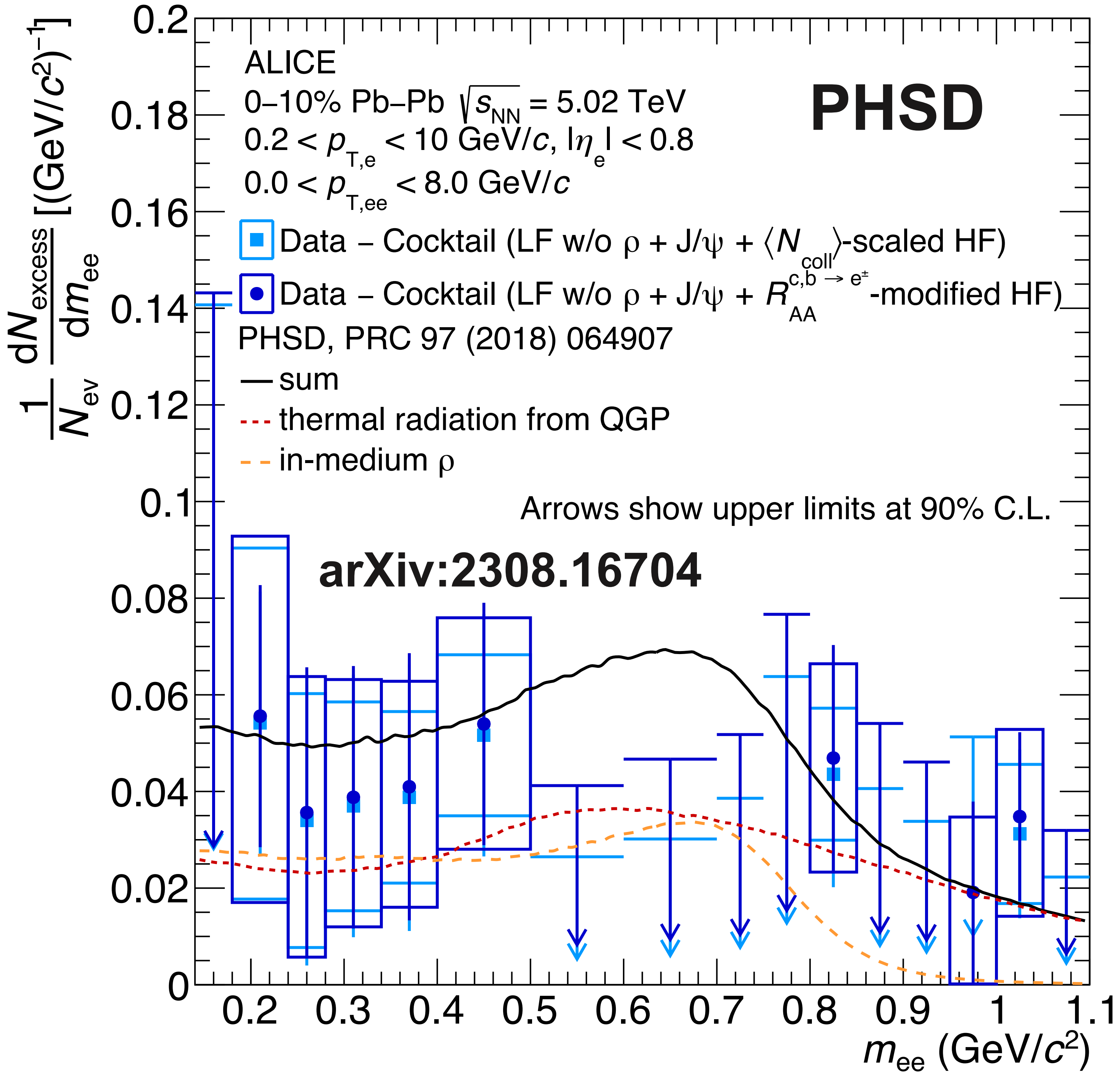

⚠️ Tension between data and theory in $0.5 < m_{ee} < 0.7$ GeV/c^2 mass range
- 4.0σ (2.7σ) using N_{coll}-scaled (modified) HF cocktail
- *More data is needed to investigate this discrepancy!*

[1] Rapp, Adv. HEP . 2013 (2013) 148253
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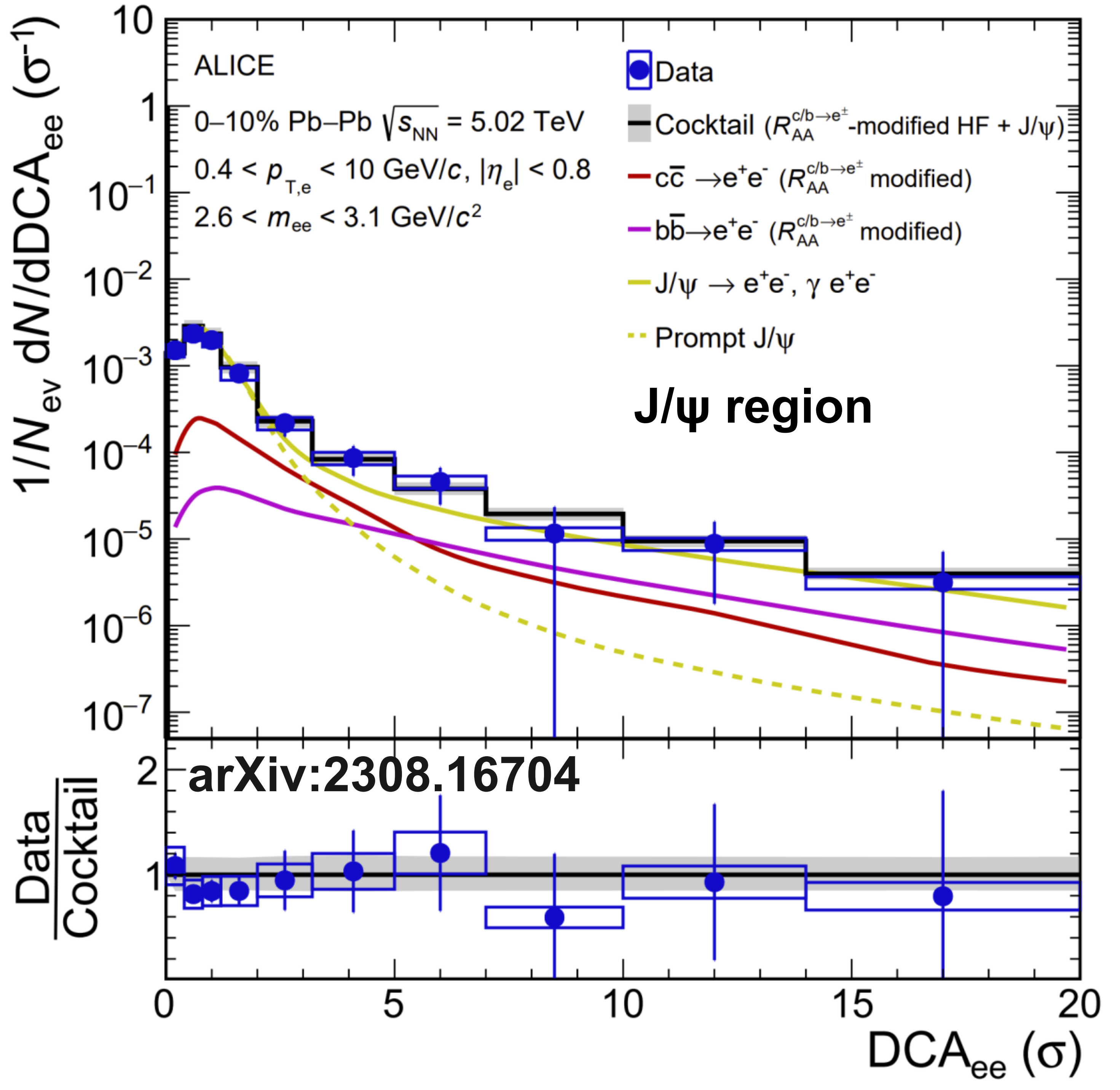
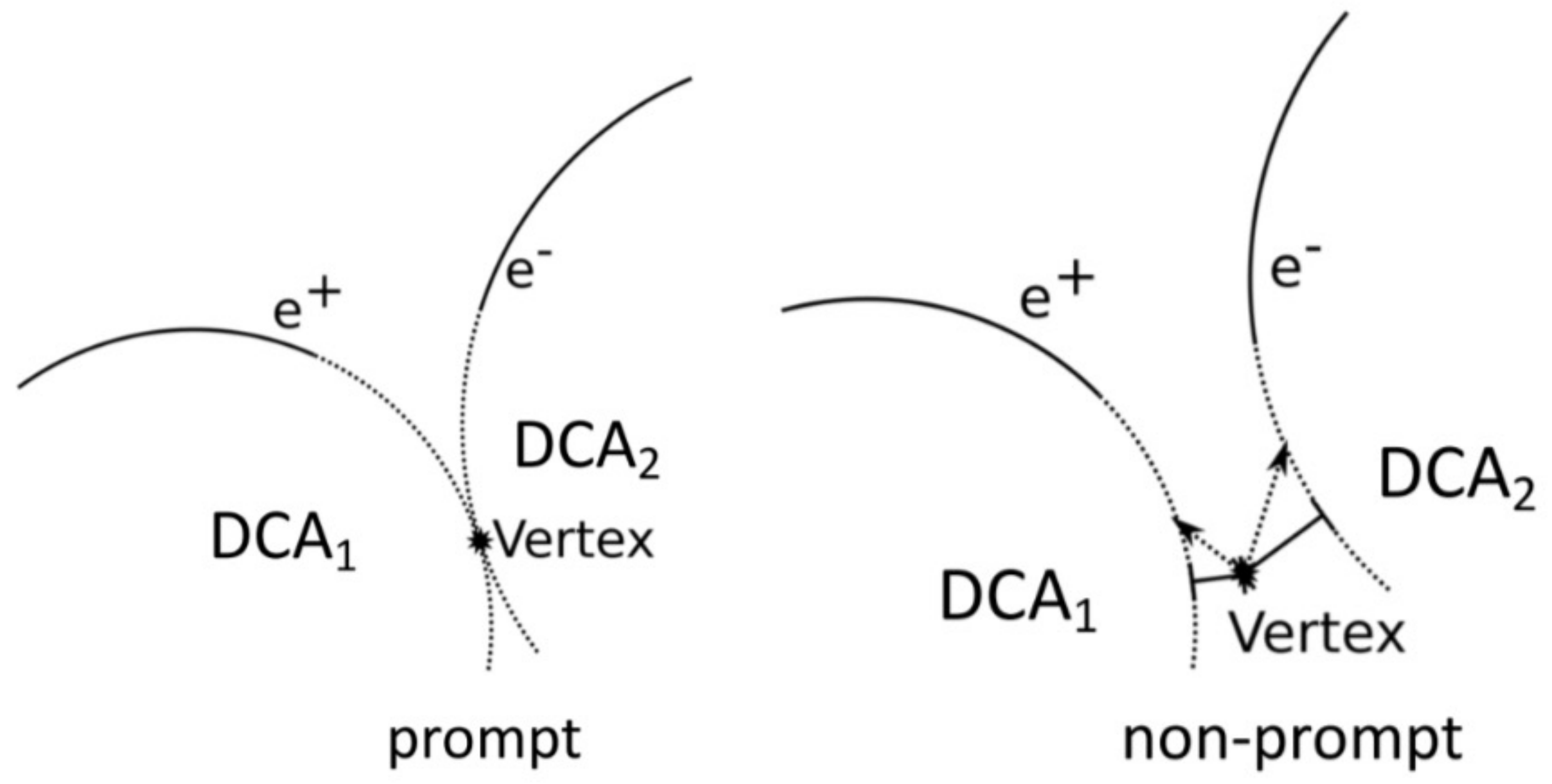
Separation of prompt / non-prompt sources

Test of the topological separation with DCA_{ee} in J/ψ region

- J/ψ is well known, charm and beauty scaled by modified HF cocktail
- Data well described by *sum* of all templates

$$DCA_{ee} = \sqrt{0.5\left(\left(\frac{DCA_1}{\sigma_1}\right)^2 + \left(\frac{DCA_2}{\sigma_2}\right)^2\right)}$$





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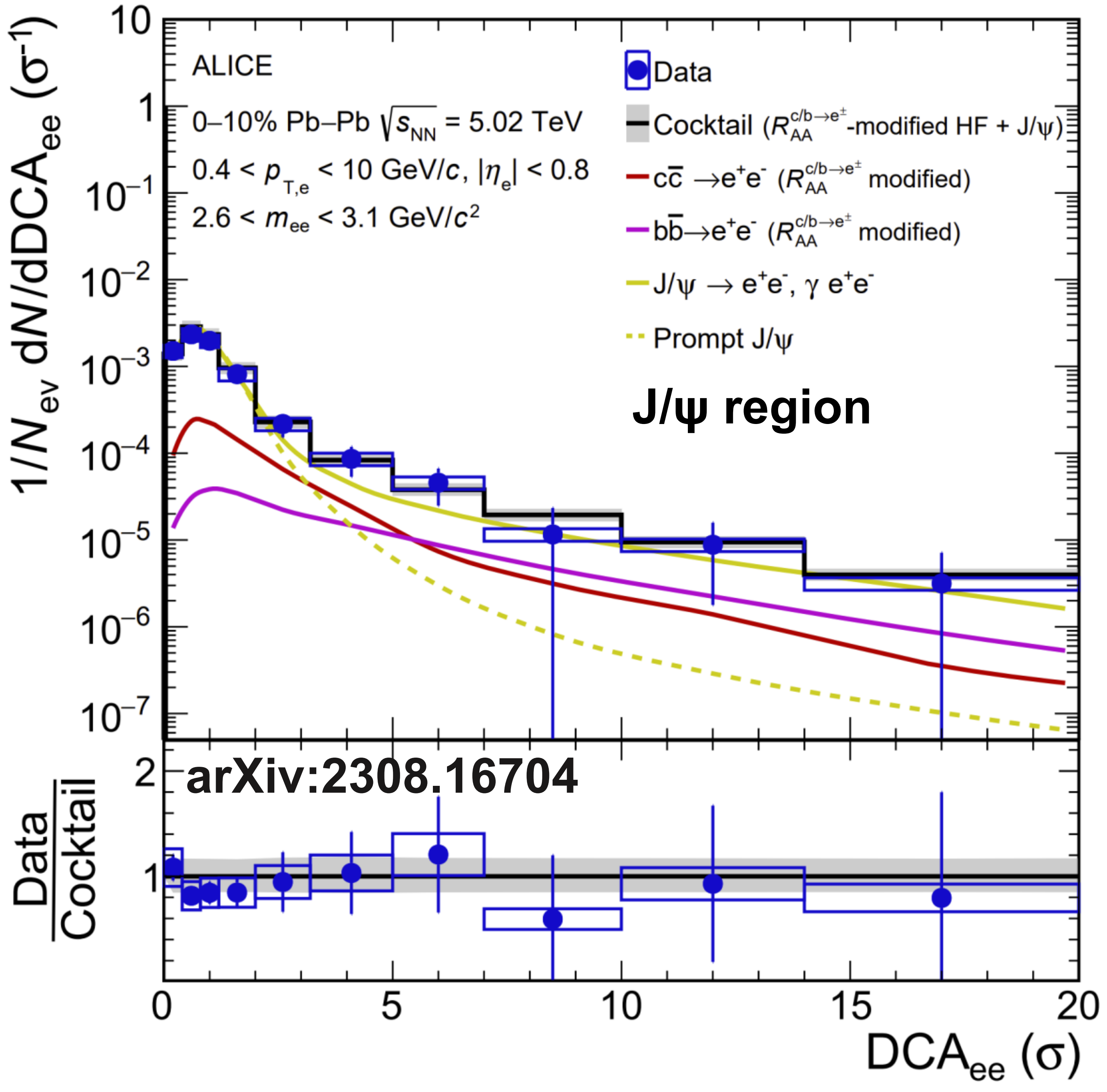
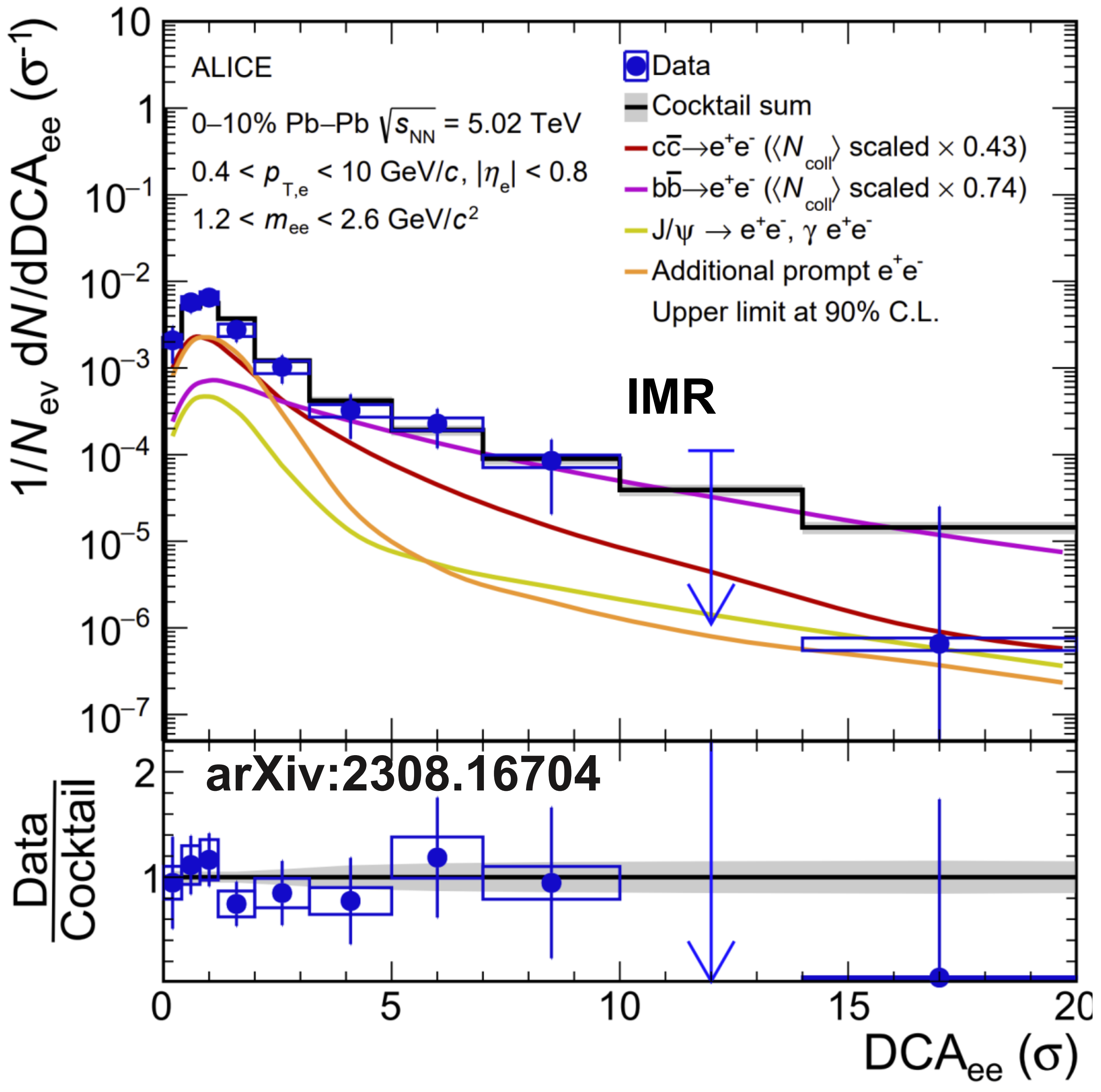
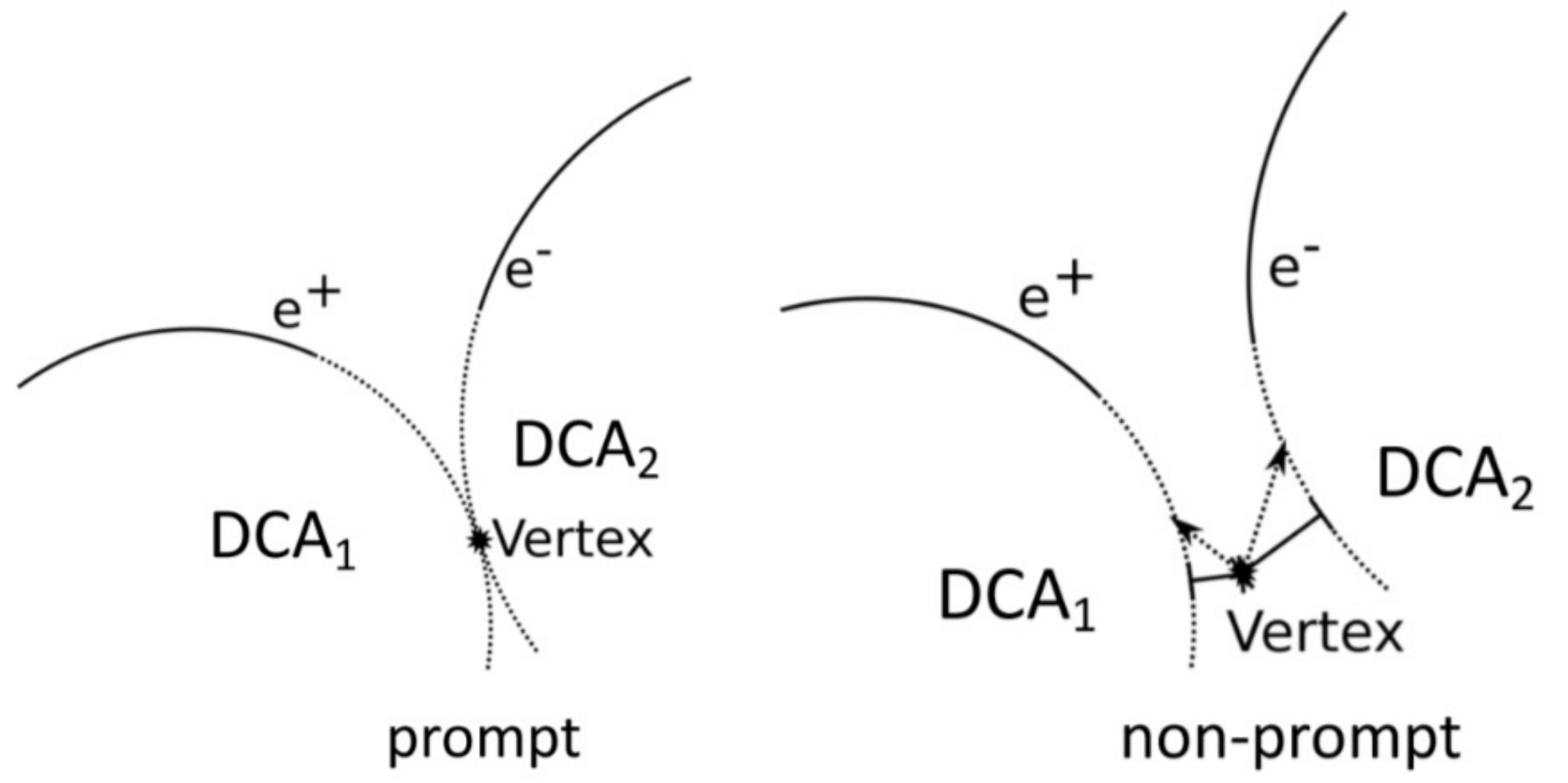
Extraction of prompt thermal signal with DCA_{ee} template *fit* in IMR:

- charm: **0.43 ± 0.40 (stat.) ± 0.22 (syst.) w.r.t. N_{coll} scaling**
- prompt: **2.64 ± 3.18 (stat.) ± 0.29 (syst.) w.r.t. Rapp's model**





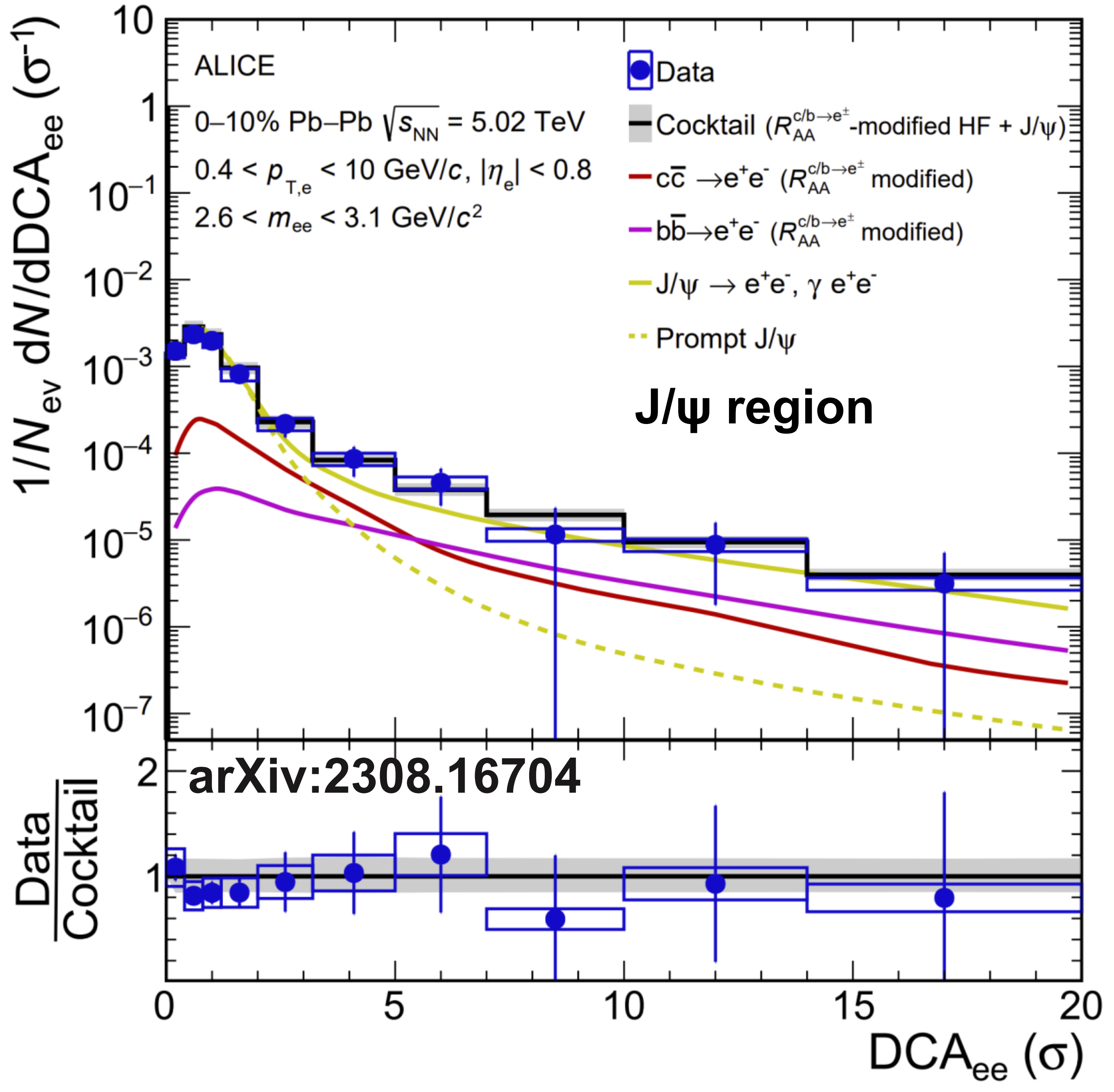


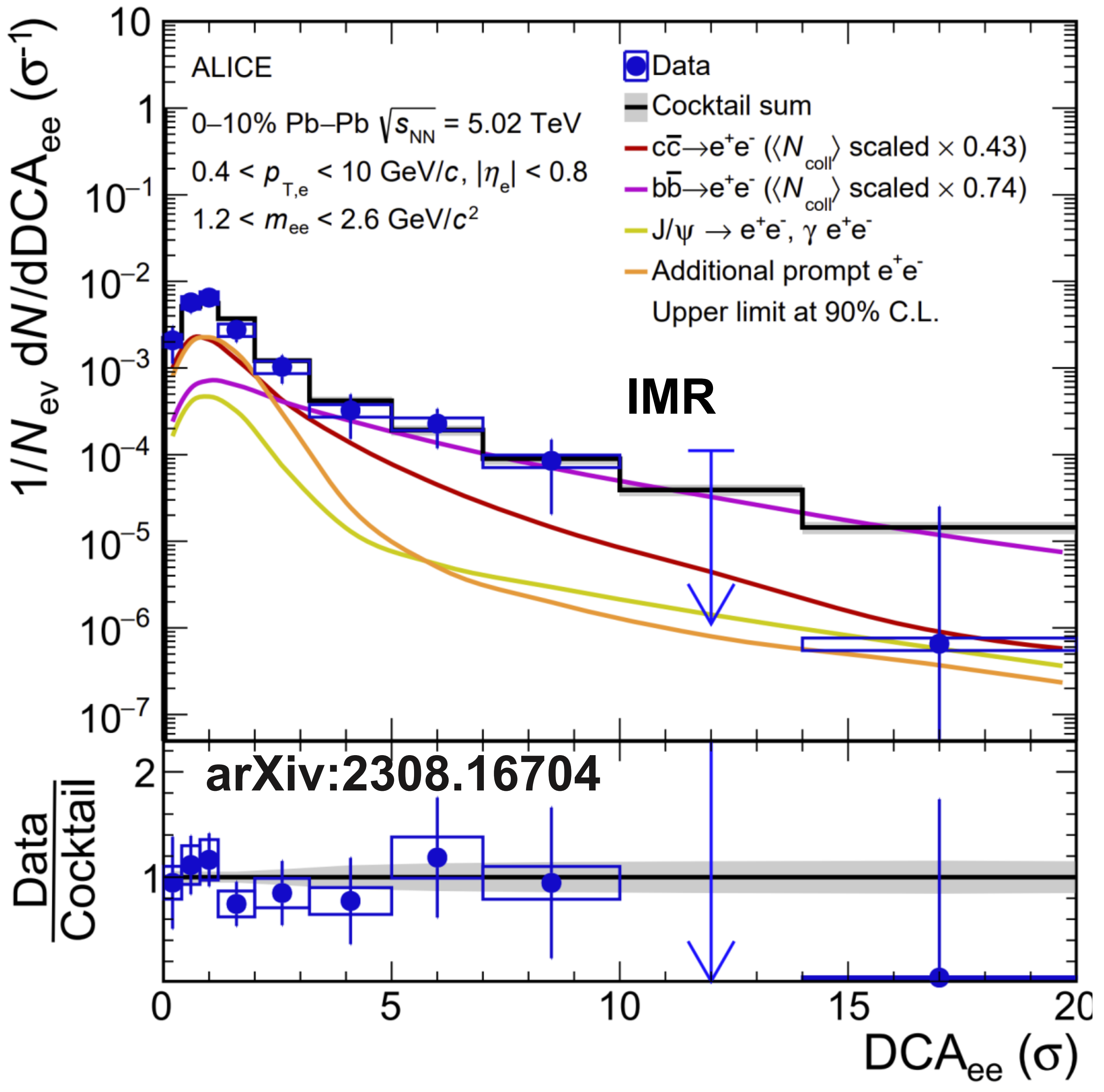
Separation of prompt / non-prompt sources

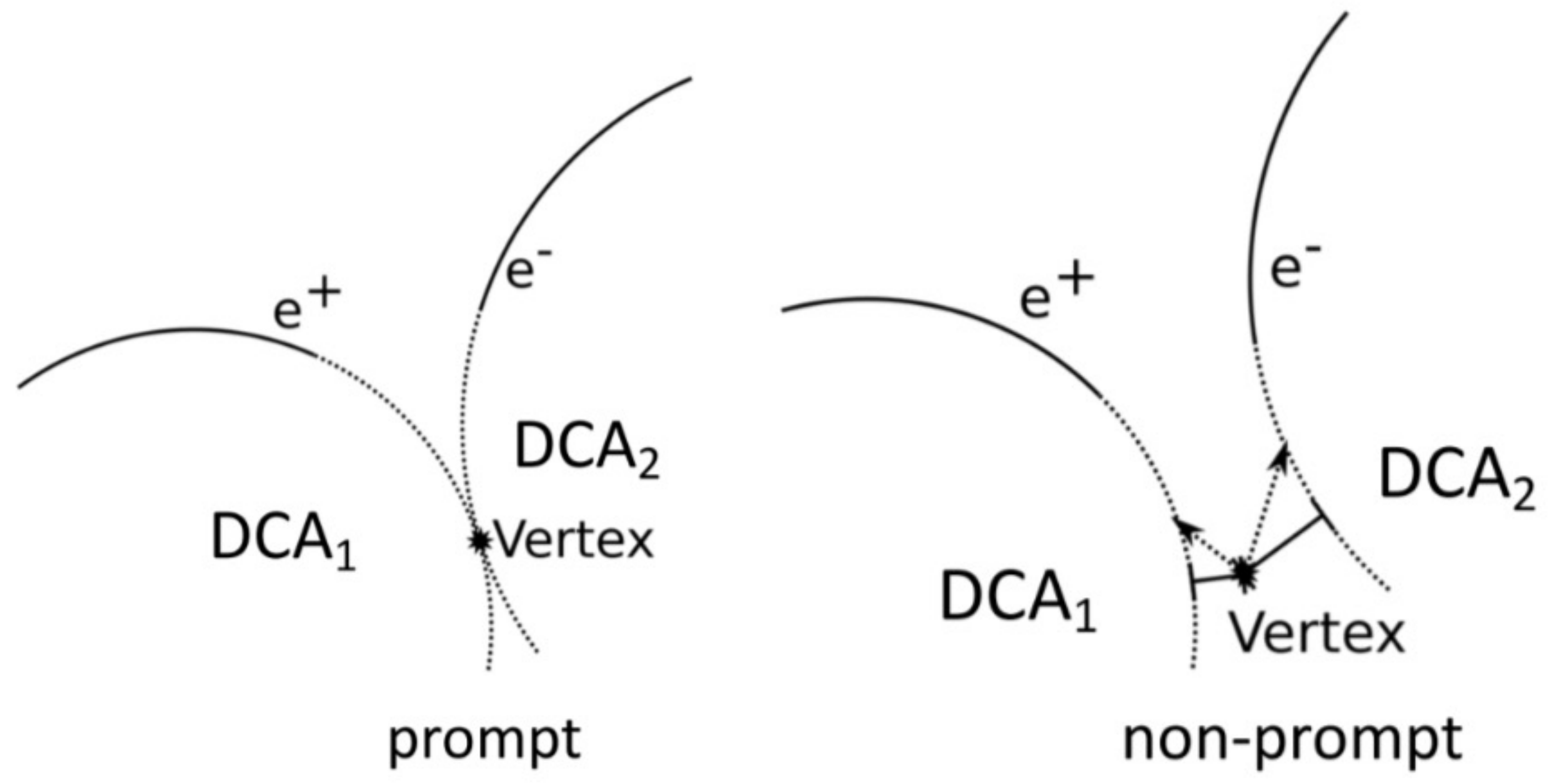
Test of the topological separation with DCA_{ee} in J/ψ region
- J/ψ is well known, charm and beauty scaled by modified HF cocktail
- Data well described by *sum* of all templates

Extraction of prompt thermal signal with DCA_{ee} template *fit* in IMR:
- charm: **0.43 ± 0.40 (stat.) ± 0.22 (syst.) w.r.t. N_{coll} scaling**
- prompt: **2.64 ± 3.18 (stat.) ± 0.29 (syst.) w.r.t. Rapp's model**

$$DCA_{ee} = \sqrt{0.5\left(\left(\frac{DCA_1}{\sigma_1}\right)^2 + \left(\frac{DCA_2}{\sigma_2}\right)^2\right)}$$







❗ Independent of hadronic cocktail!
- More statistics and better topological separation will enable the extraction of thermal contribution

Outlook: dielectron production in Run 3 and 4

J. Liu
18 Jul, 10:45
Terrace 2B

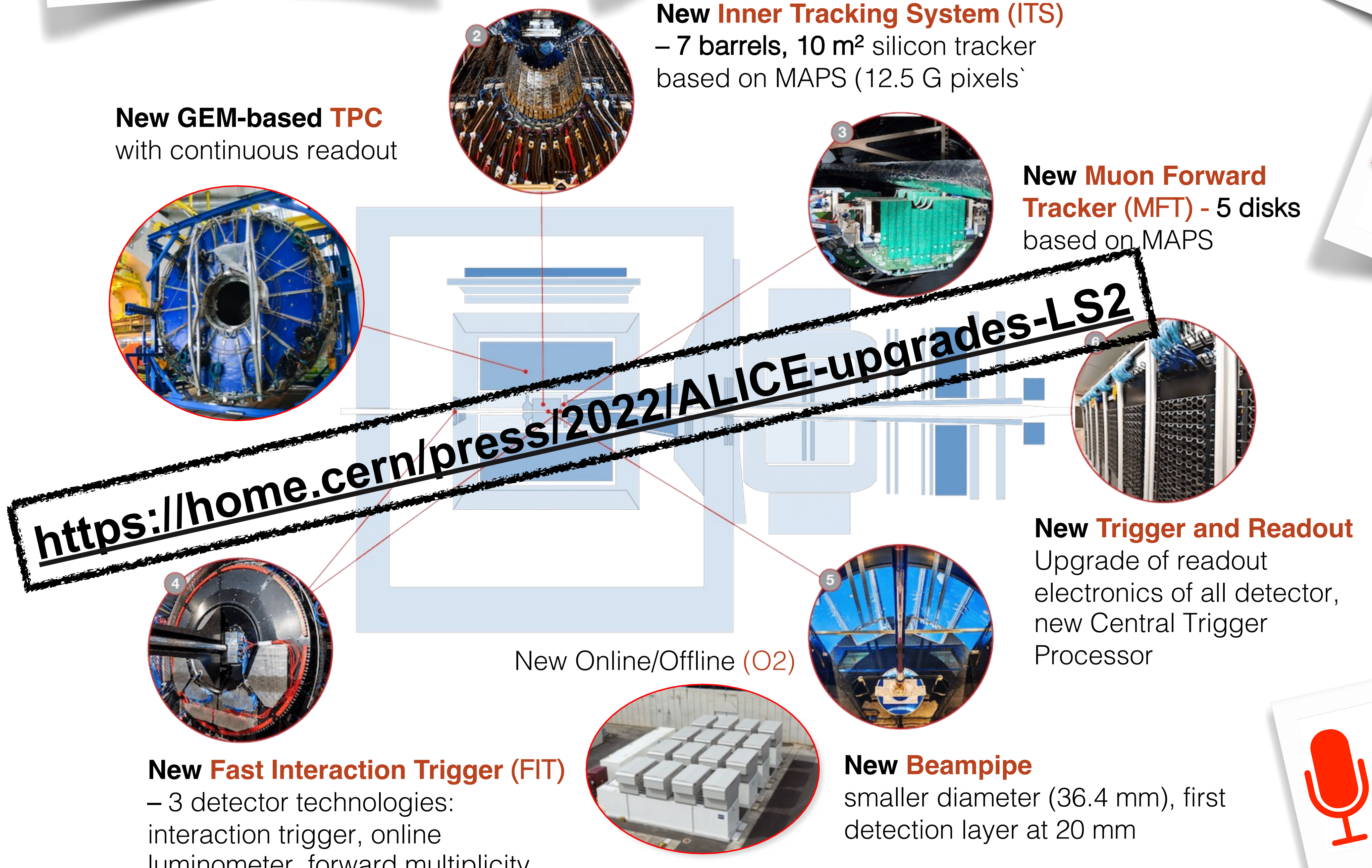
G. Batigne
20 Jul, 16:45
Terrace 2B

F. Schlepper
18 Jul, 09:42
Terrace 2B

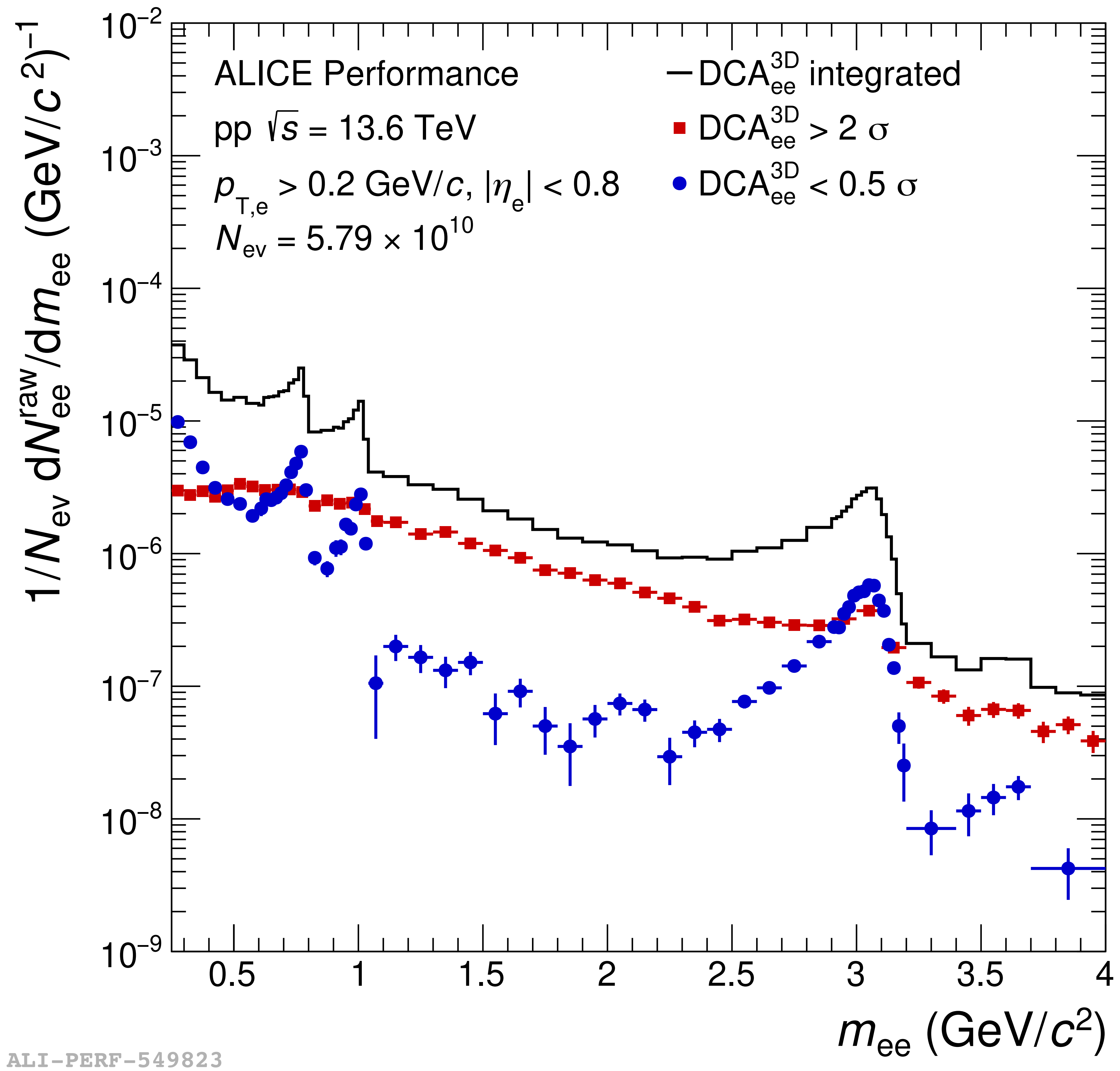
S. Kushpil
19 Jul, 19:00
Foyer Floor 2

Y. Melikyan
19 Jul, 08:48
Terrace 2B

D. Rohr
19 Jul, 09:21
Club A



Outlook: dielectron production in Run 3 and 4



- Continuous readout at IR in Pb−Pb up to 50 kHz
- Factor 3−6 better vertex pointing resolution → separation of prompt & non-prompt sources
- Expected statistics in Run 3 & 4: >200 pb^{-1} in pp at $\sqrt{s}$ = 13.6 TeV, ~13 nb^{-1} in Pb−Pb at $\sqrt{s_{NN}}$ = 5.36 TeV

Summary

Measurements of low-mass dielectrons allow for versatile studies of heavy-ion collisions

Analysis of full Run 2 ALICE data yielded plenty of interesting results:

☝️ First direct-photon signal at low p_T in pp collisions at the LHC energies

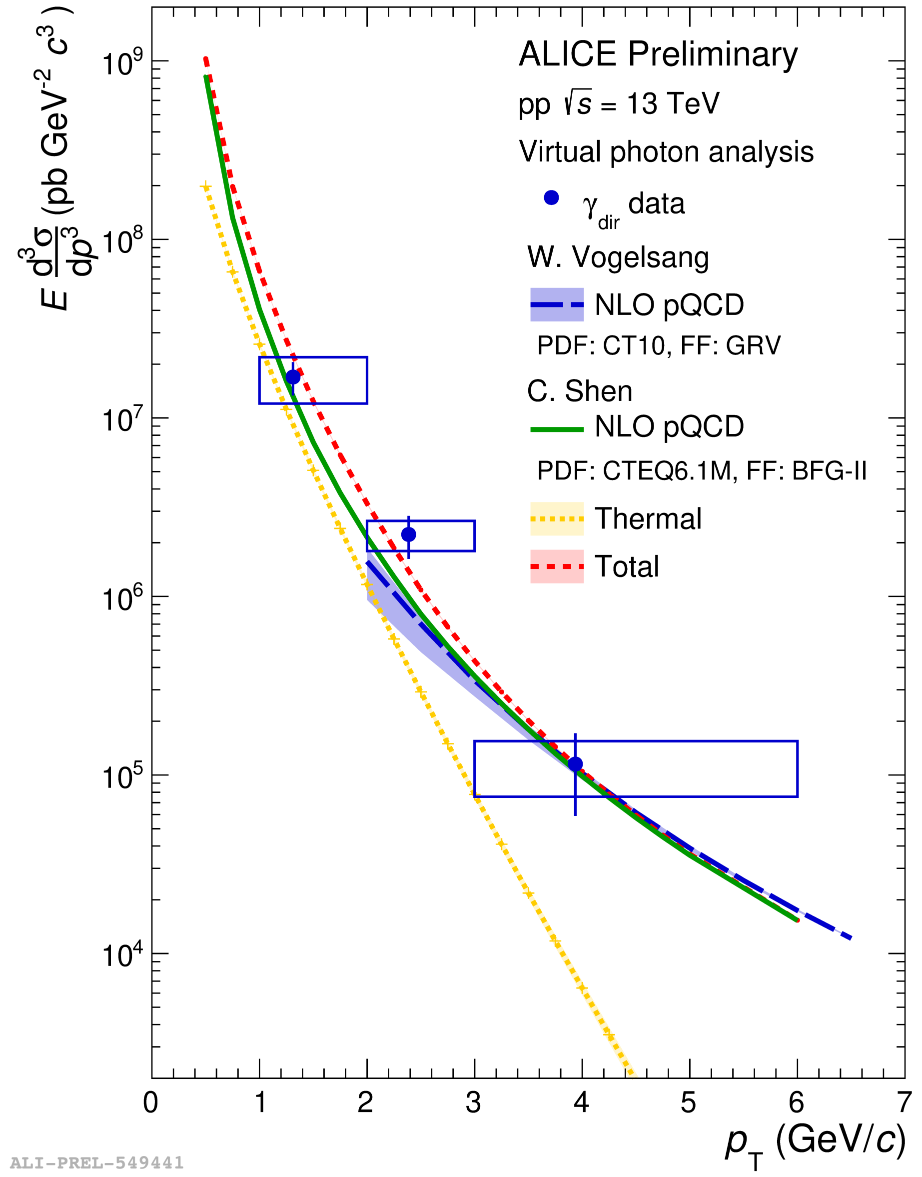
- Input for the search of thermal radiation onset

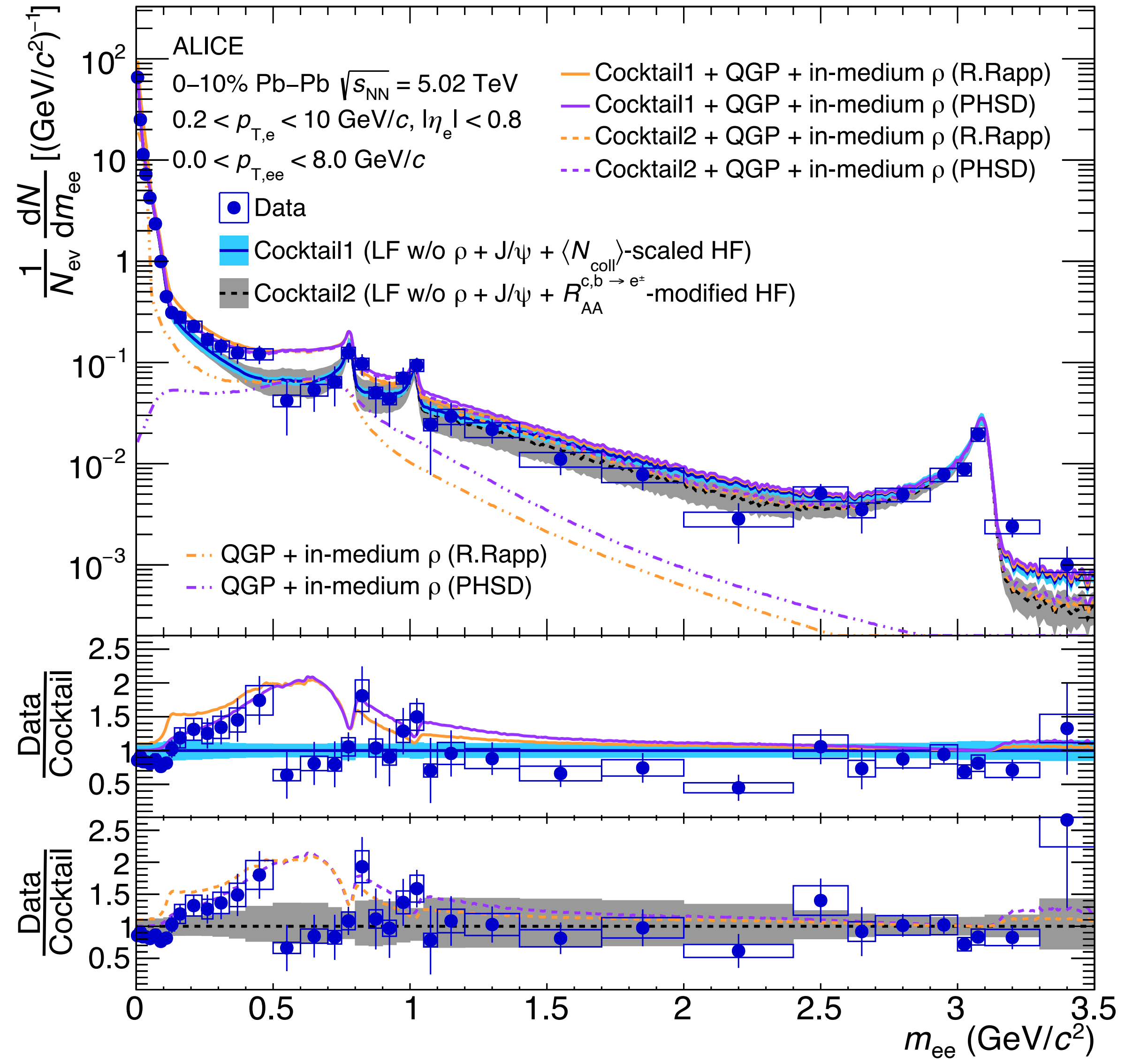
☝️ First measurement of direct-photon p_T spectrum in Pb−Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

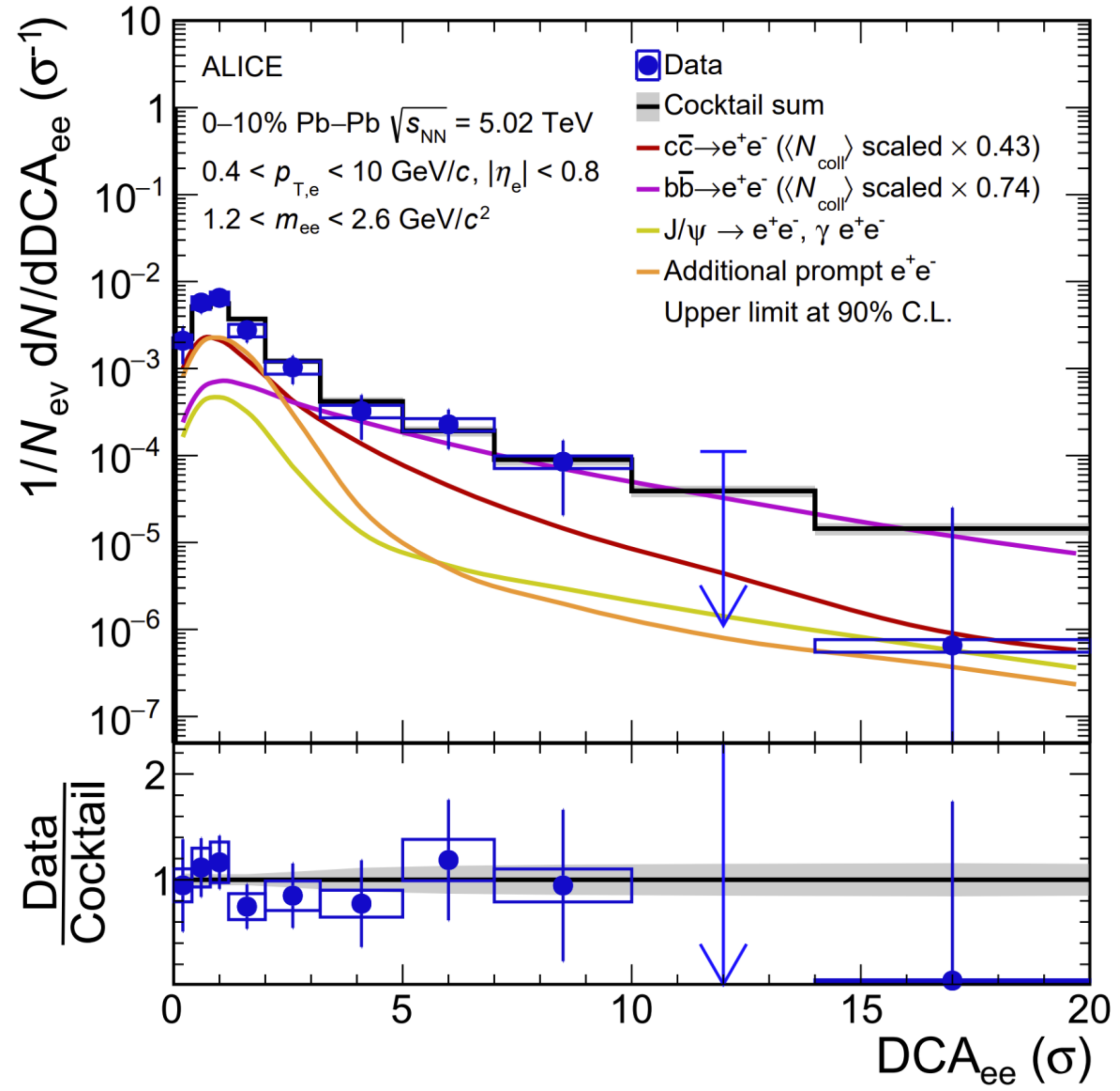
- Limits for thermal radiation predicted by models

☝️ First DCA_{ee} analysis in Pb−Pb to test topological separation of thermal radiation and HF background

Much better precision is expected from Run 3 and 4 data!







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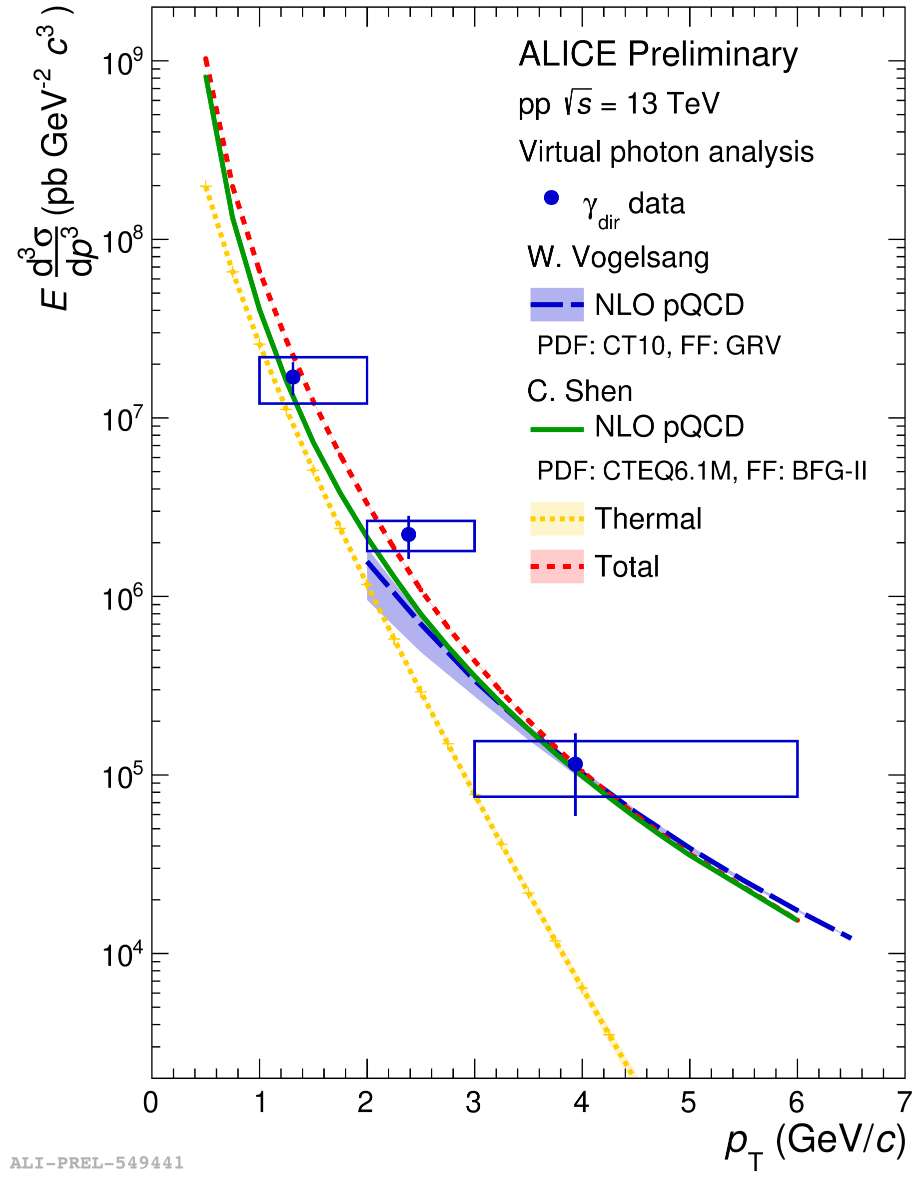
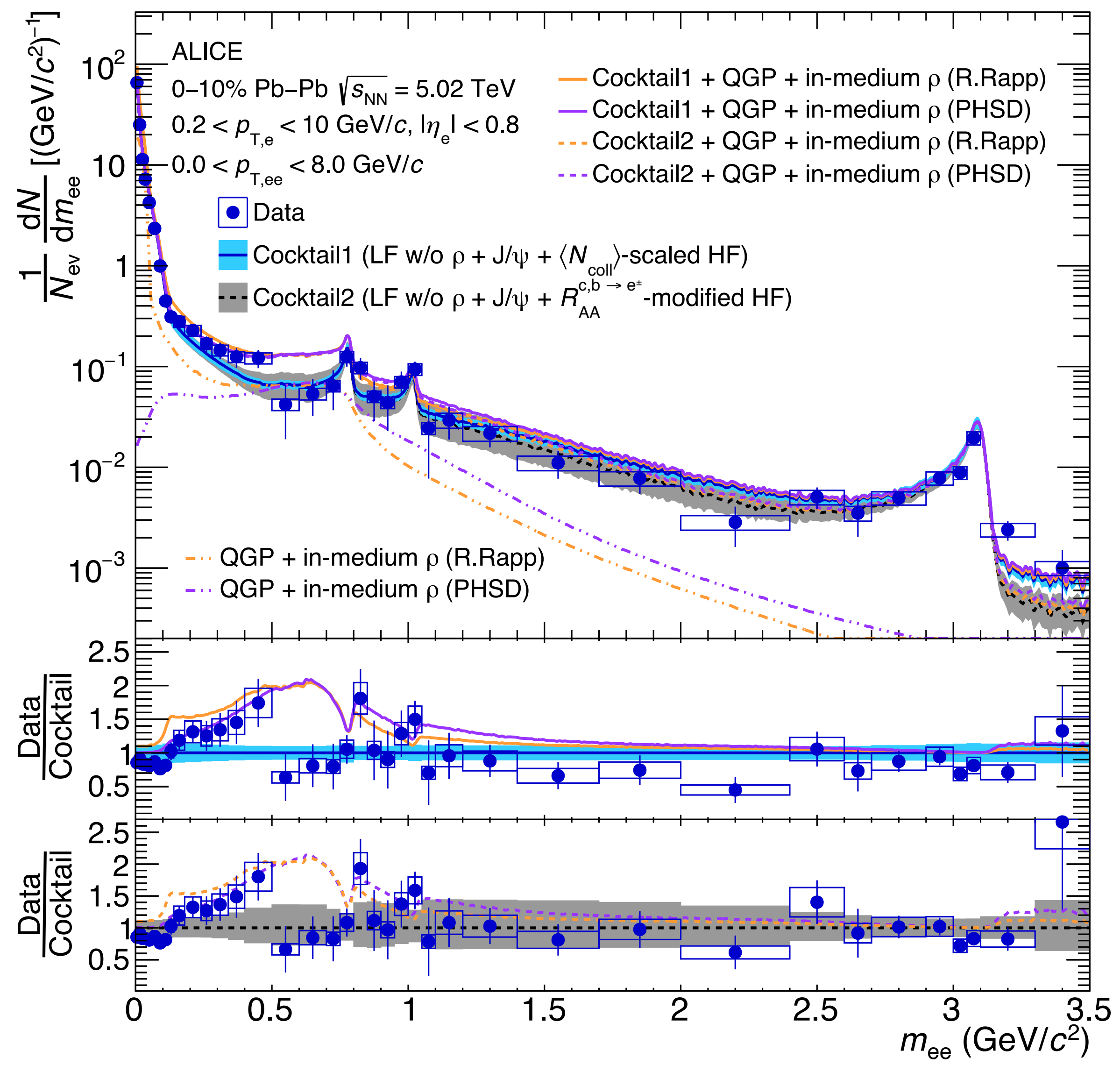
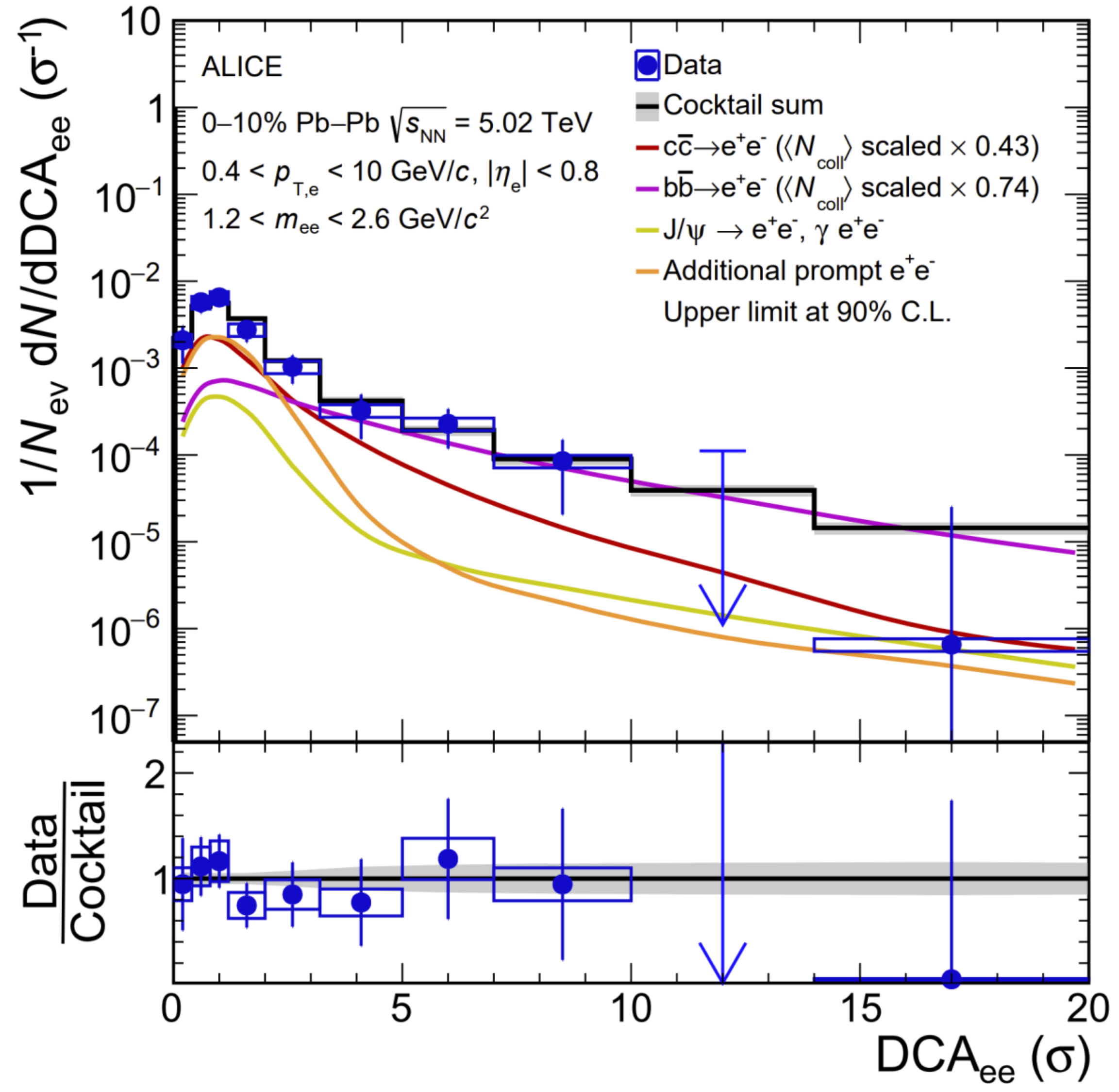
Thank you for your attention!





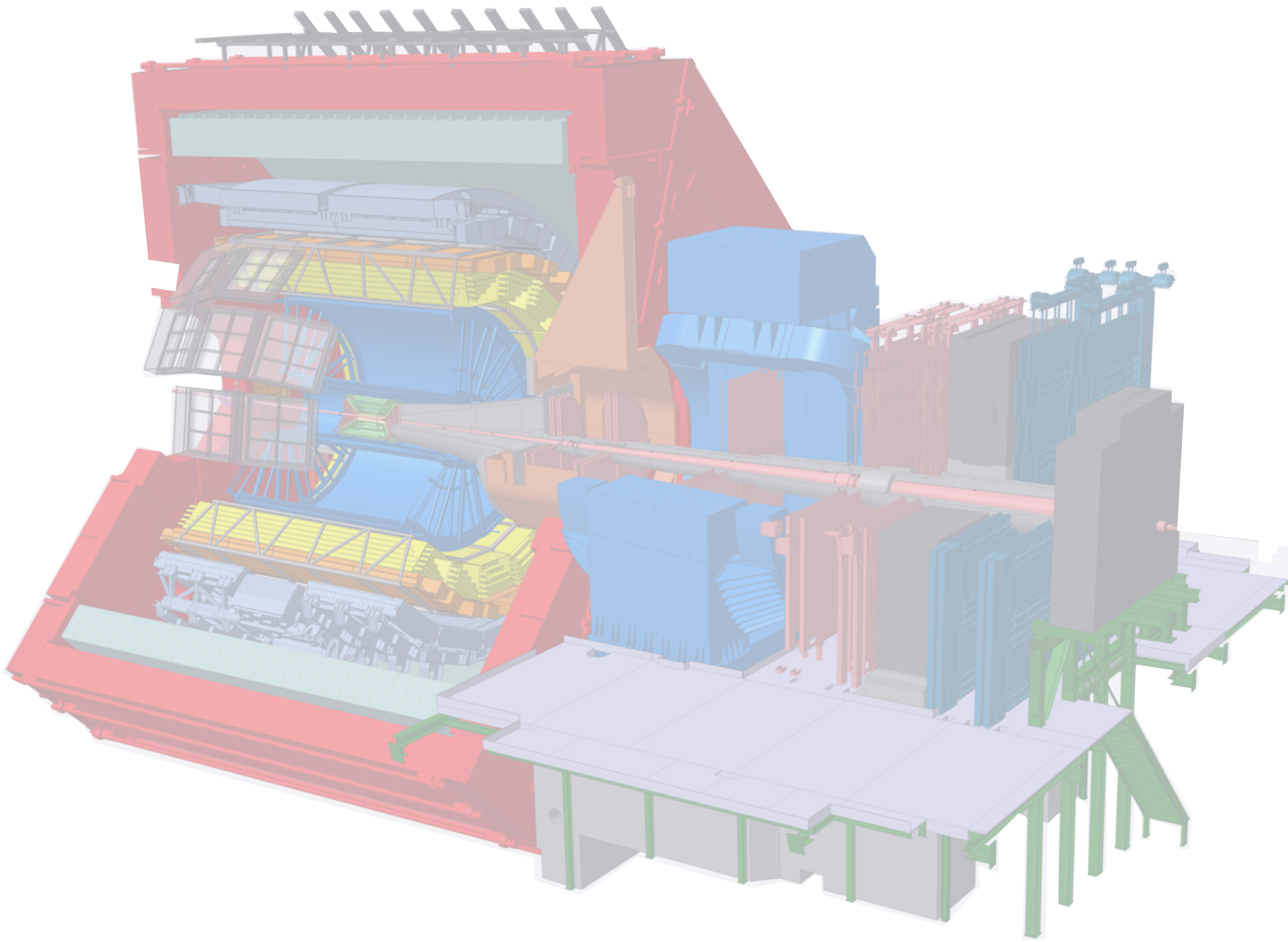


Back-up slides

The ALICE apparatus in Run 2 (2015−2018)

Unique tracking and PID capabilities to study the production of low-mass dielectrons at the LHC energies!

- Inner Tracking System: vertex, tracking, PID (d*E*/d*x*)



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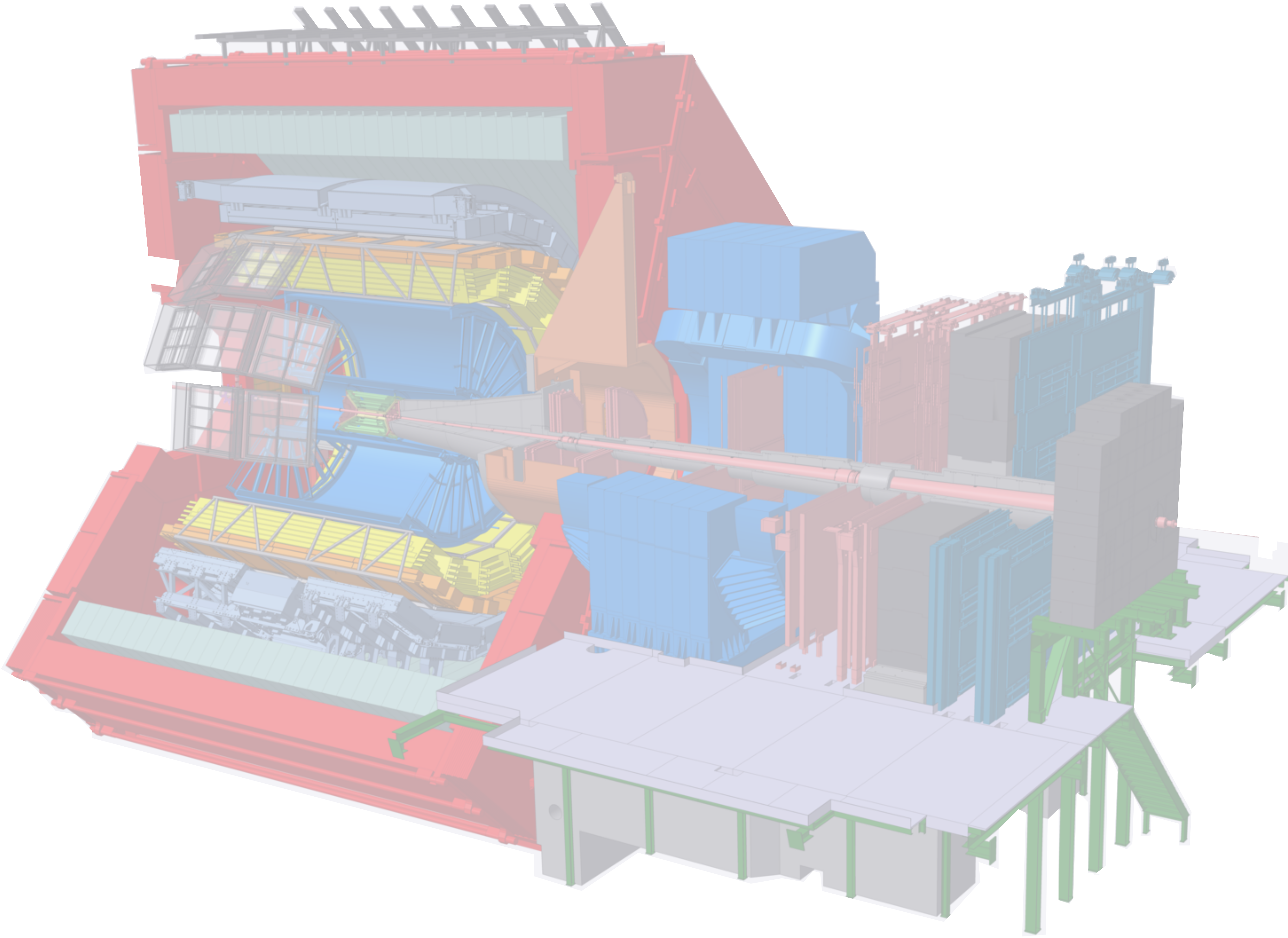

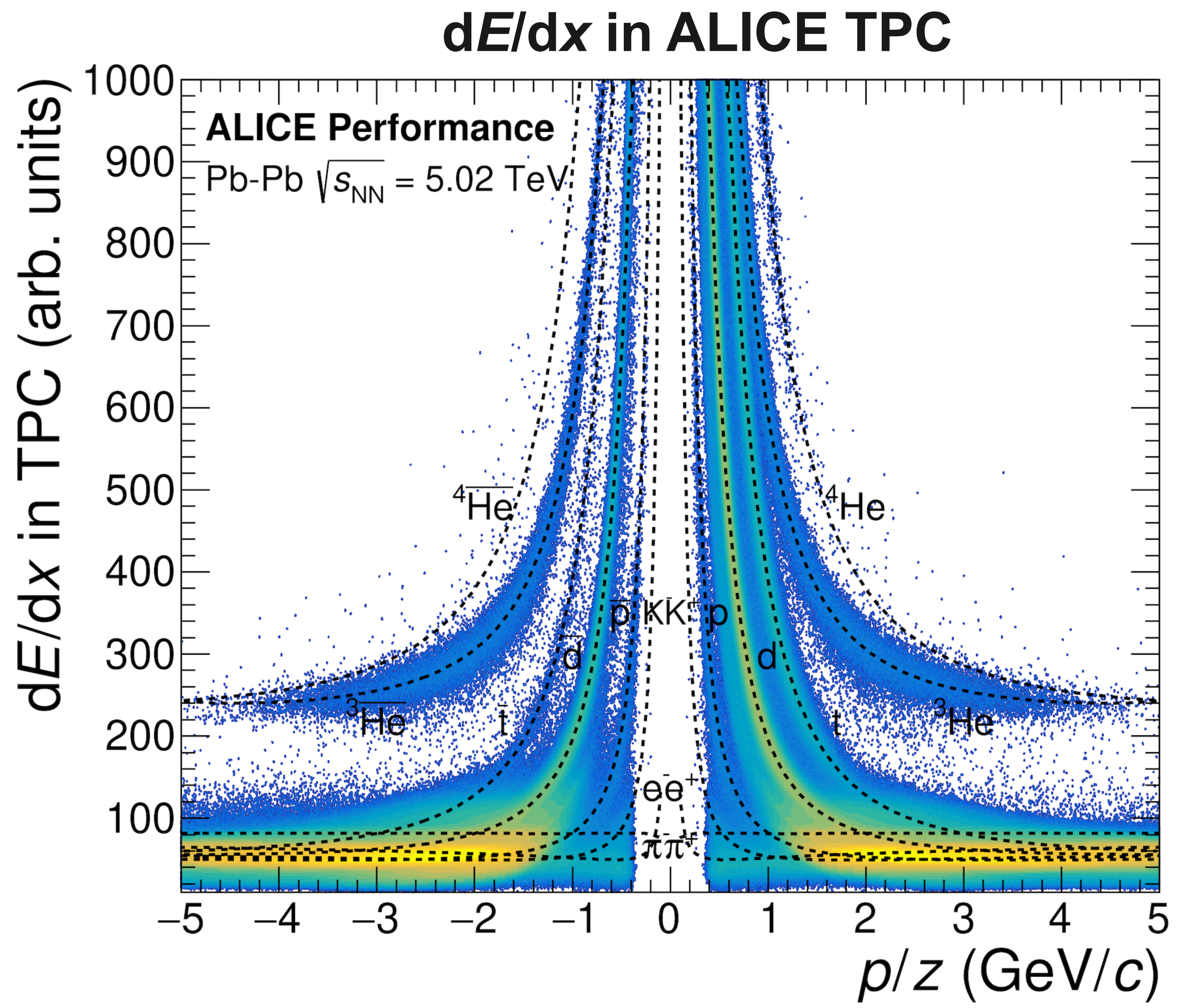

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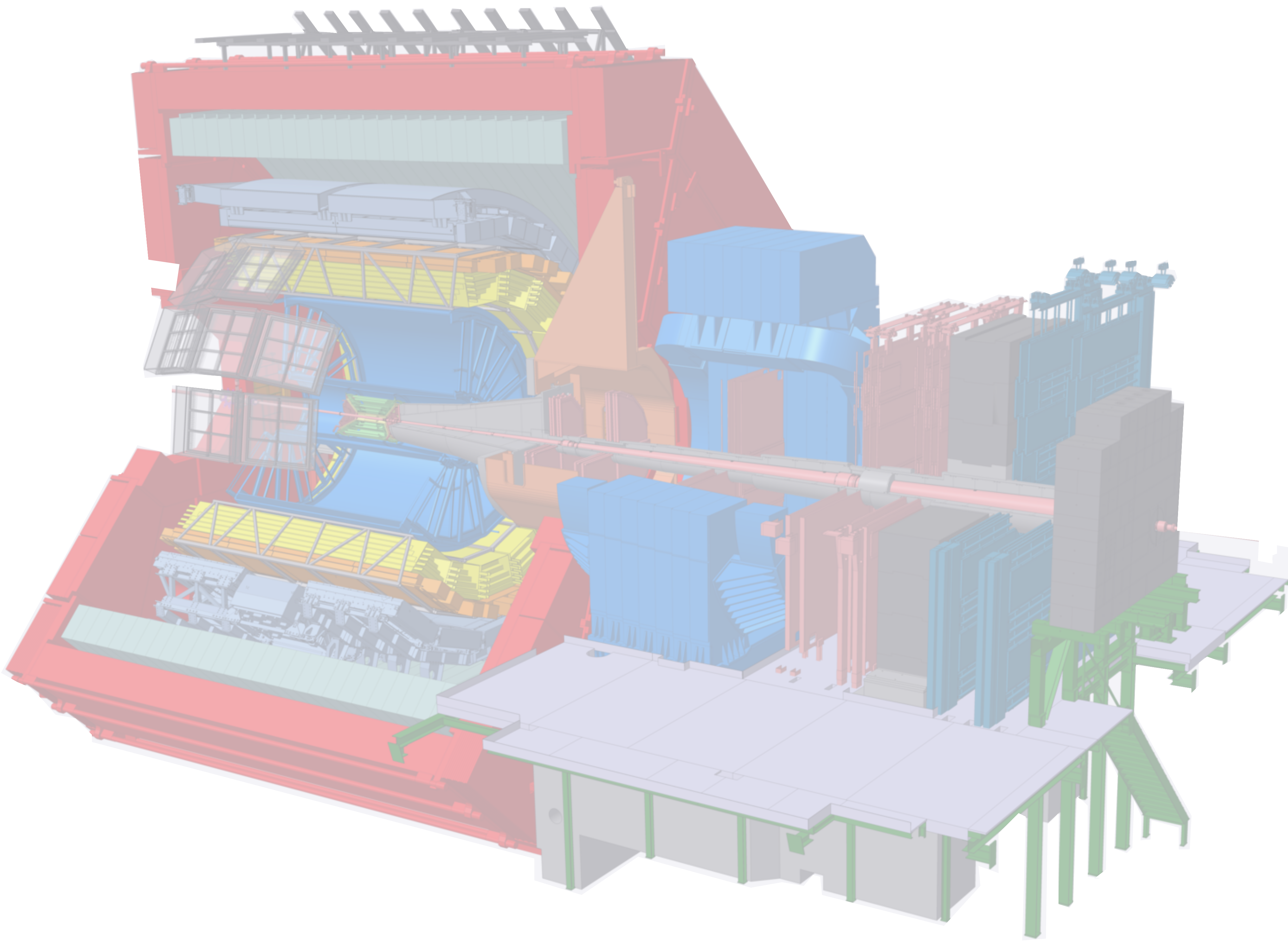
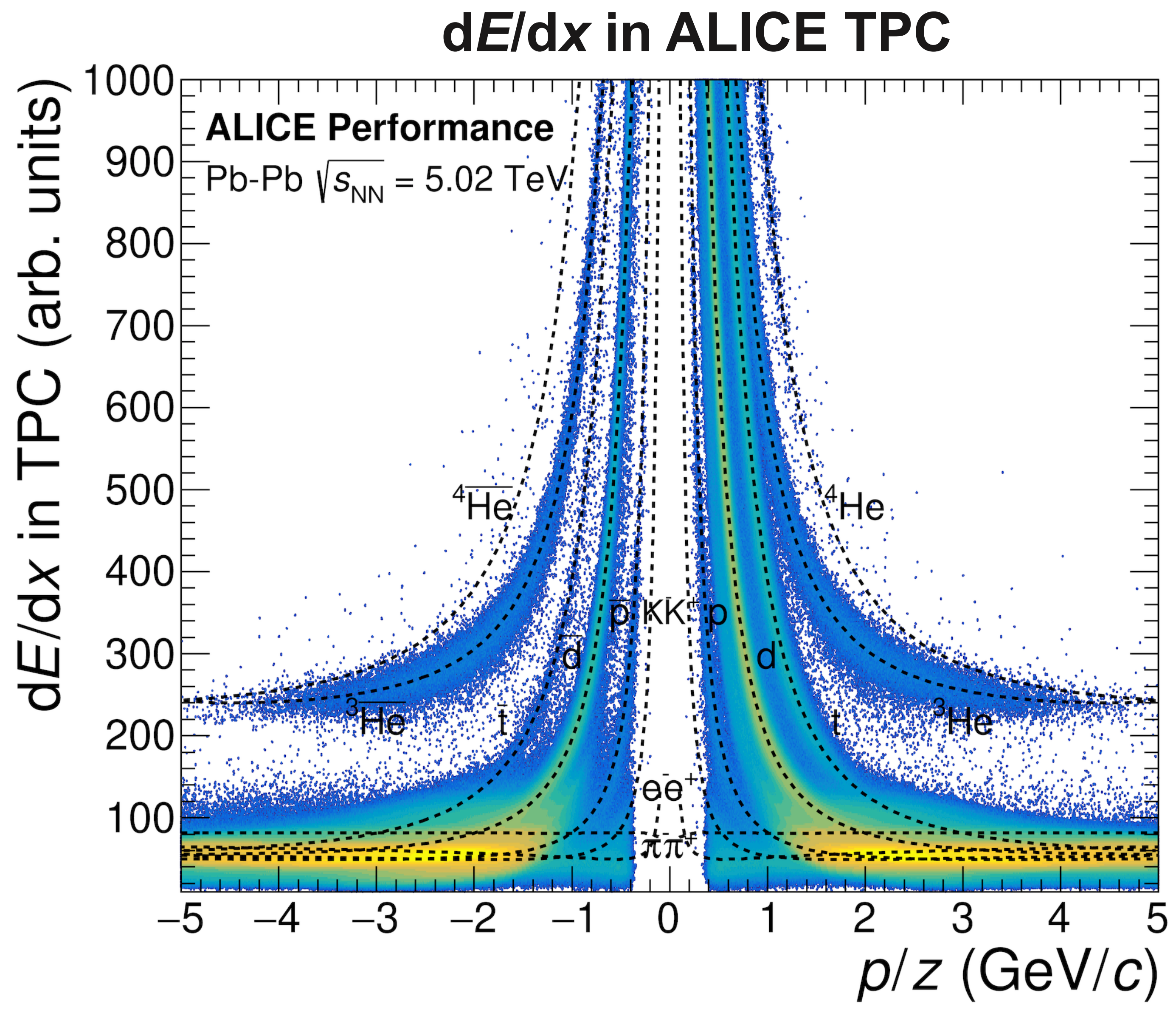
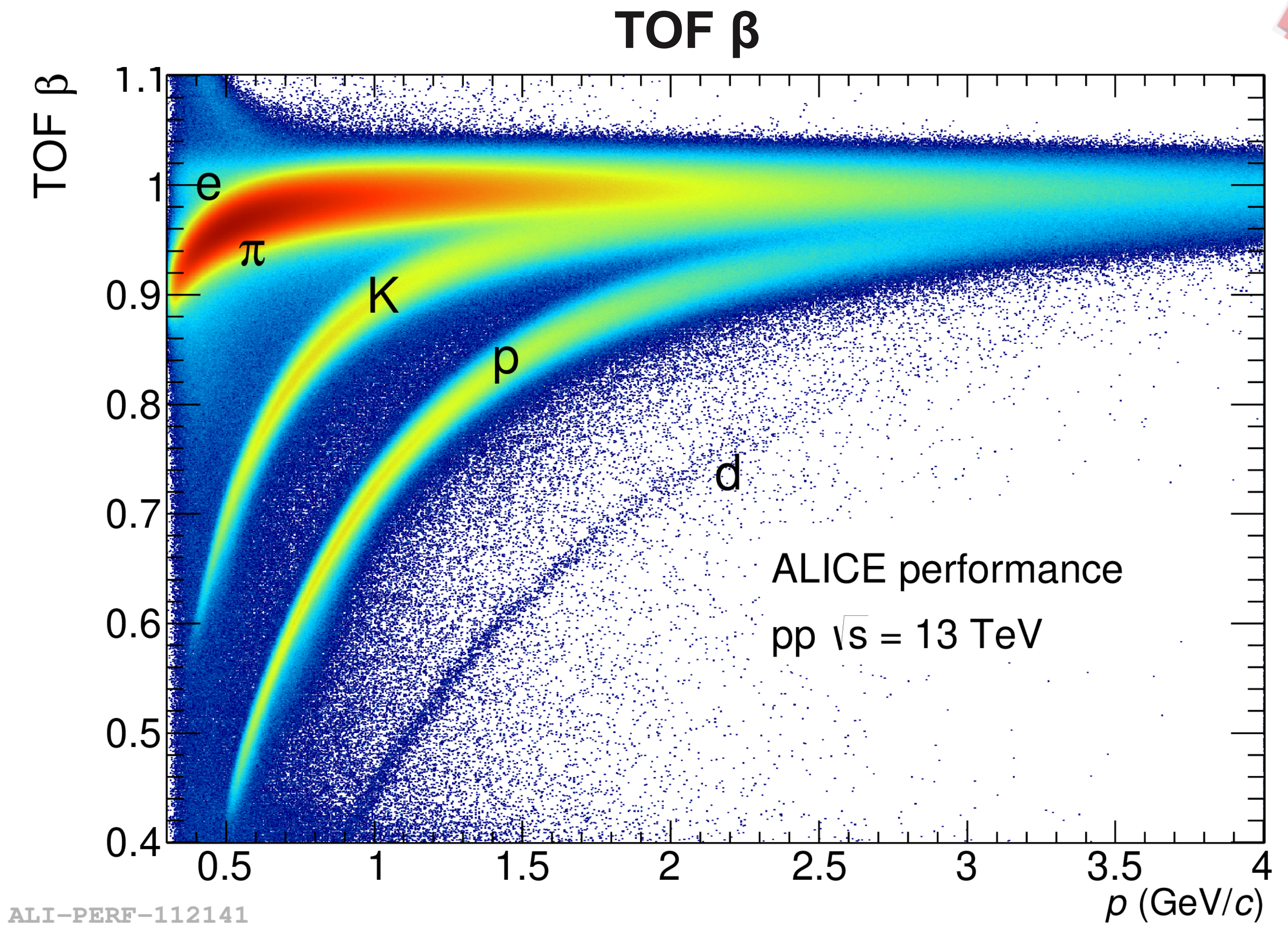
- Time Projection Chamber: tracking, PID (d*E*/dx in gas)
- Time-of-Flight: PID (via TOF β)







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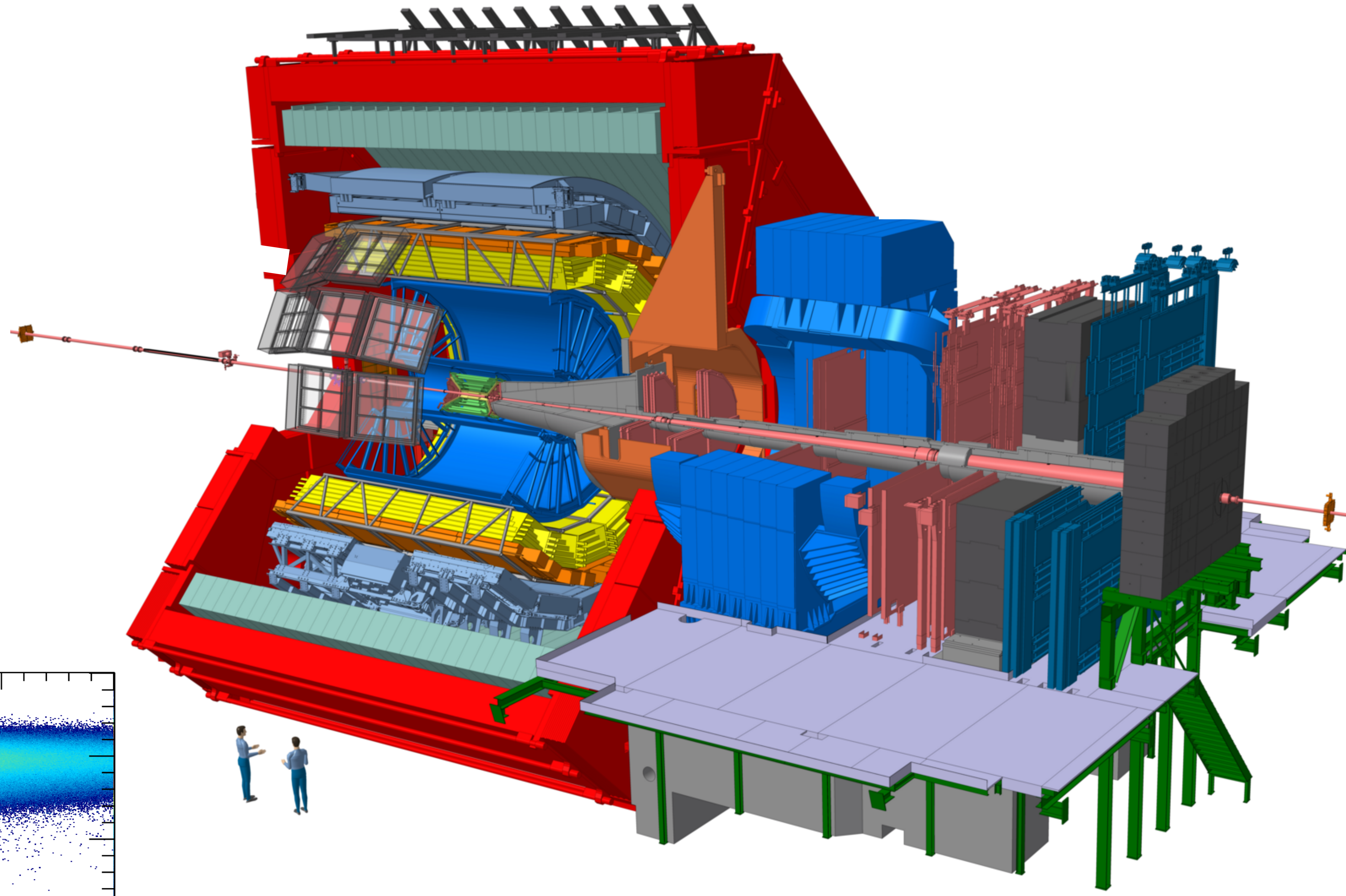
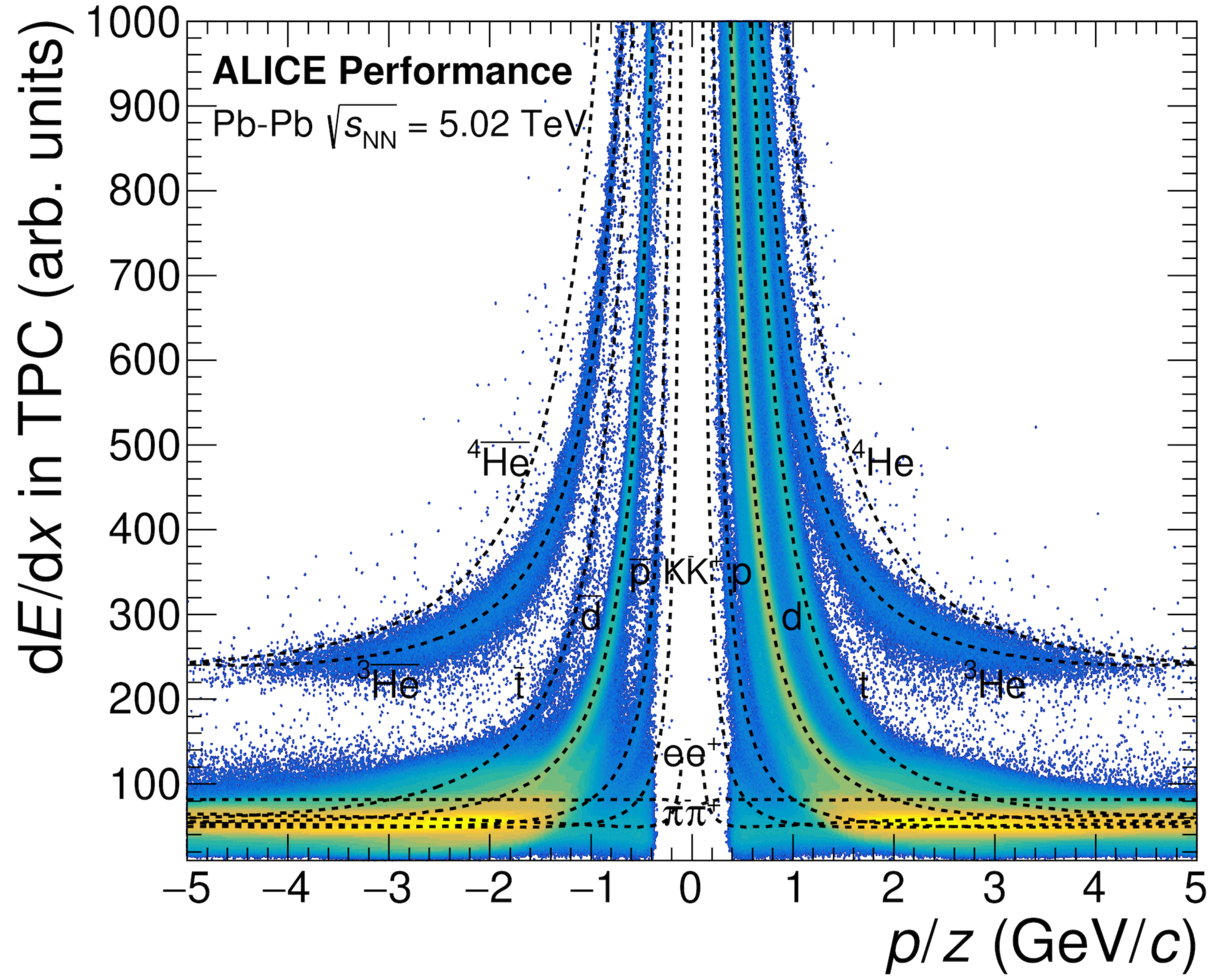
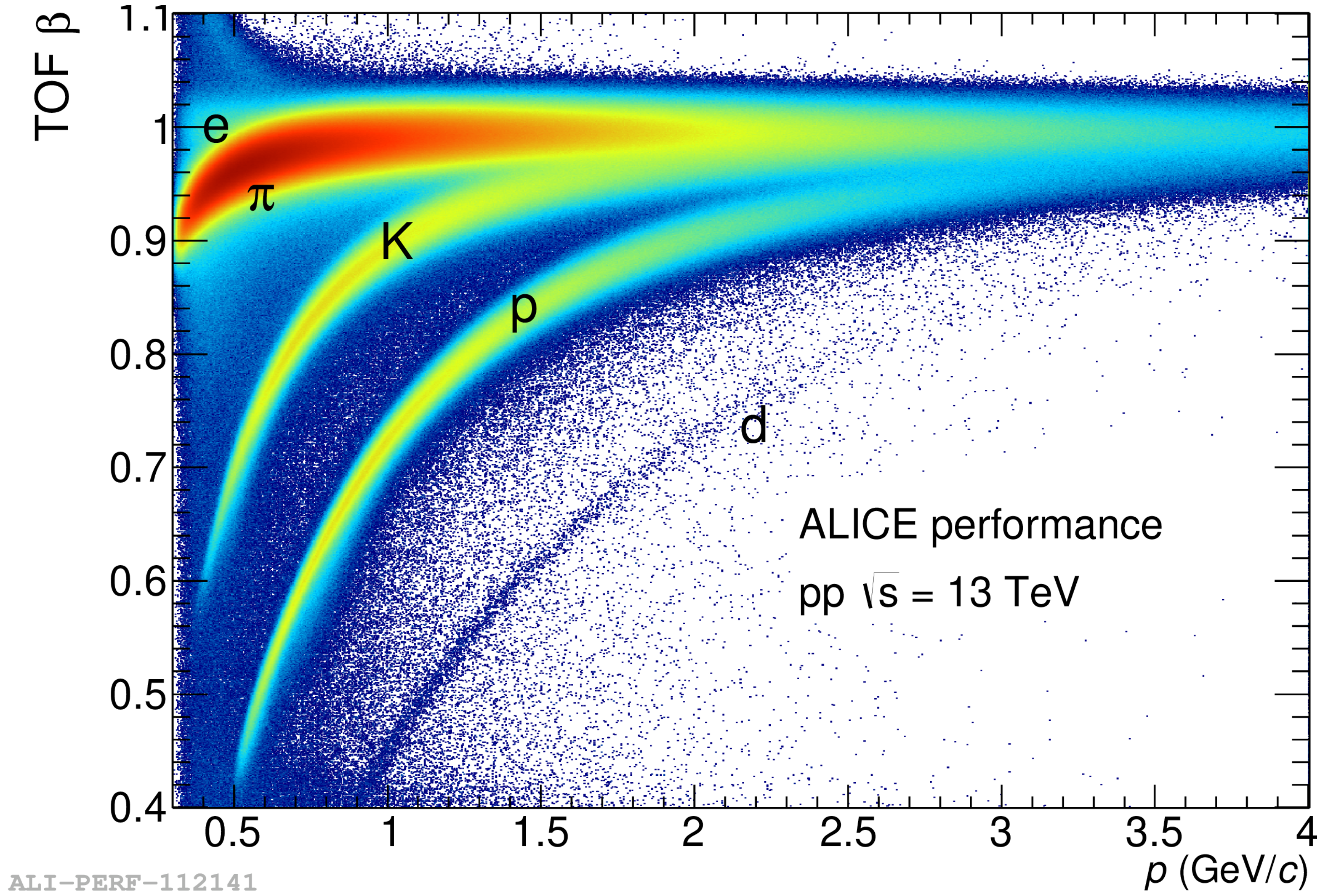
- Time Projection Chamber: tracking, PID (d*E*/dx in gas)
- Time-of-Flight: PID (via TOF β)
- V0 at forward rapidity: event triggering, multiplicity & centrality determination



d*E*/dx in ALICE TPC

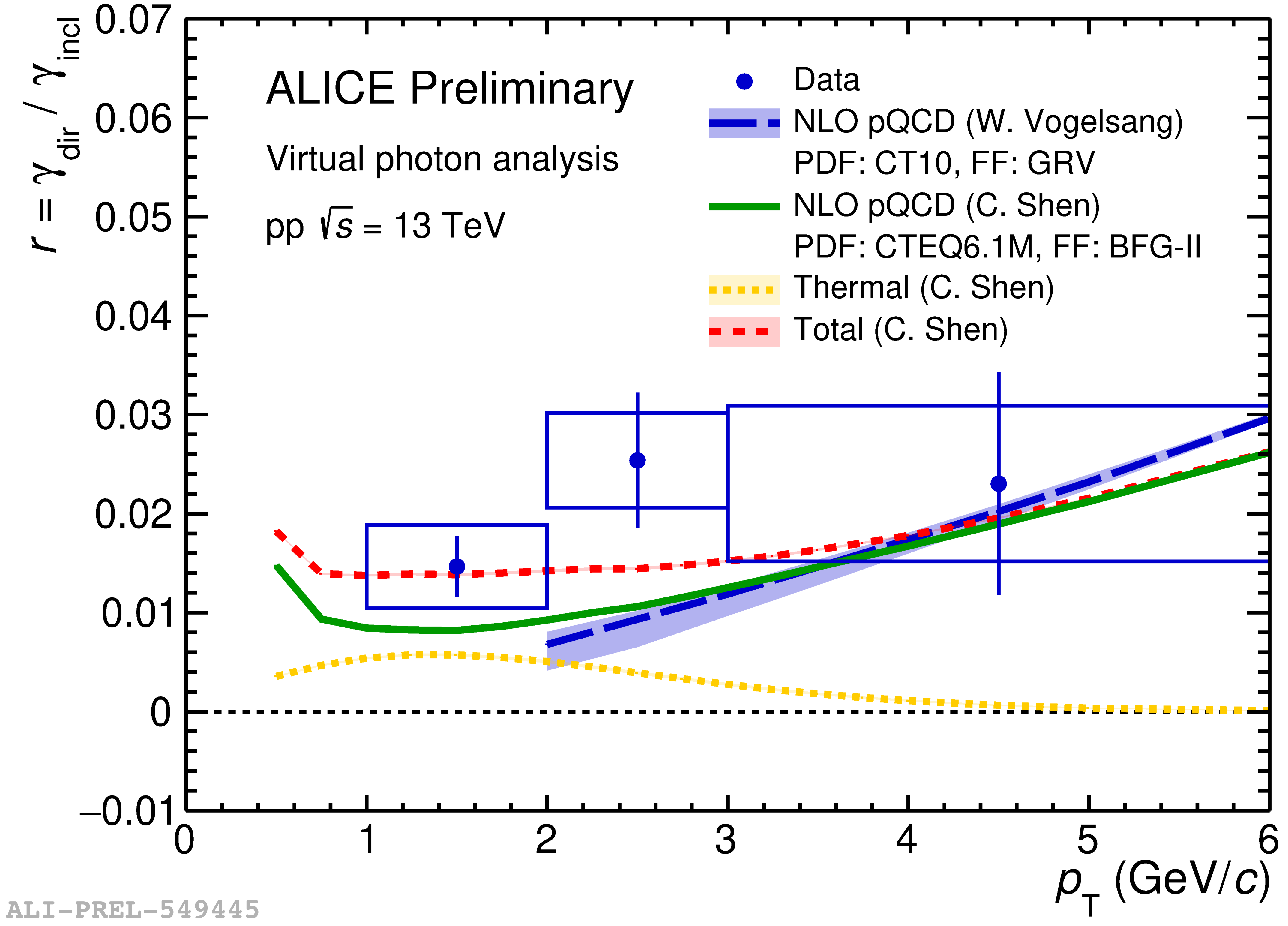


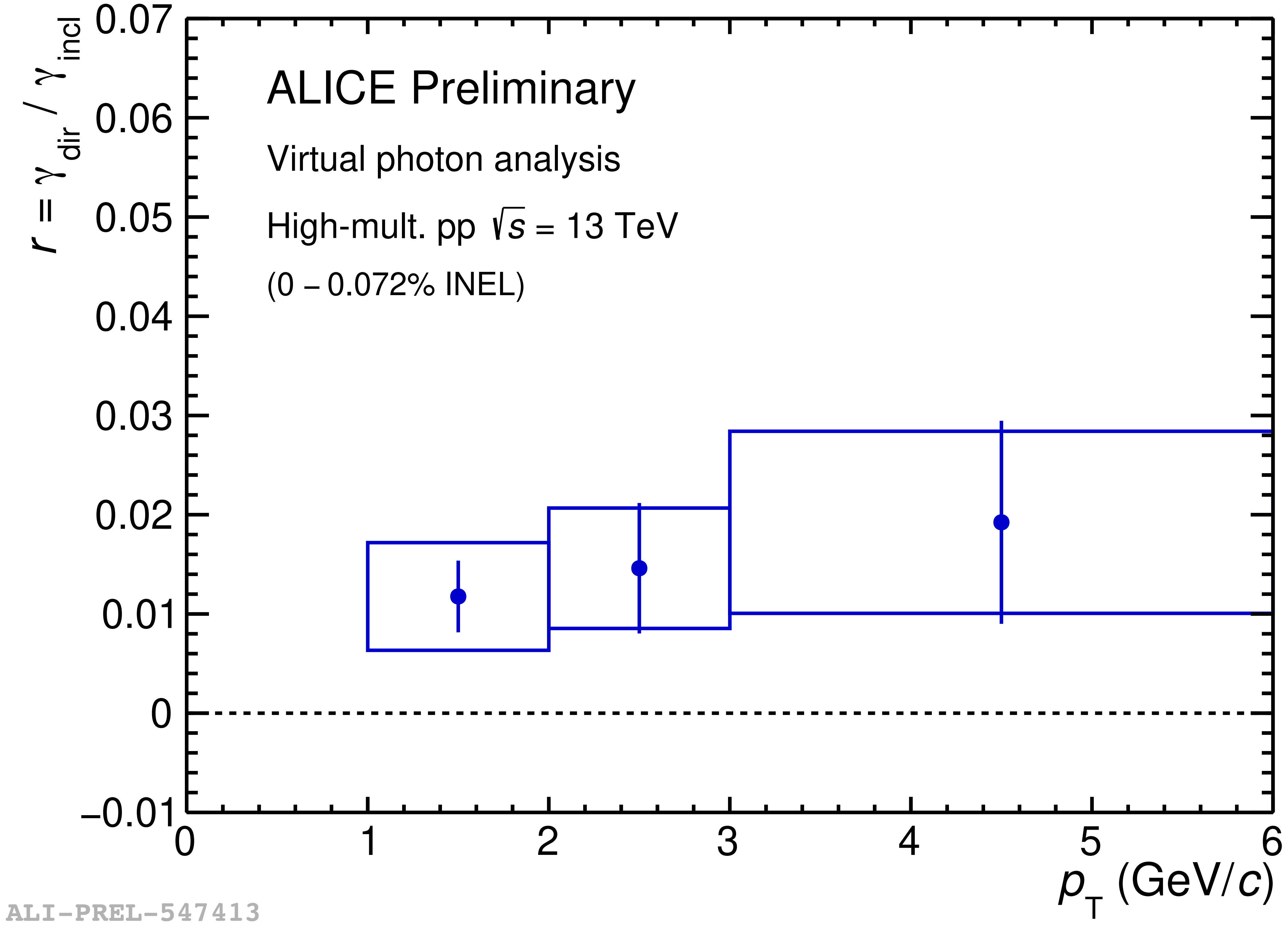
TOF β



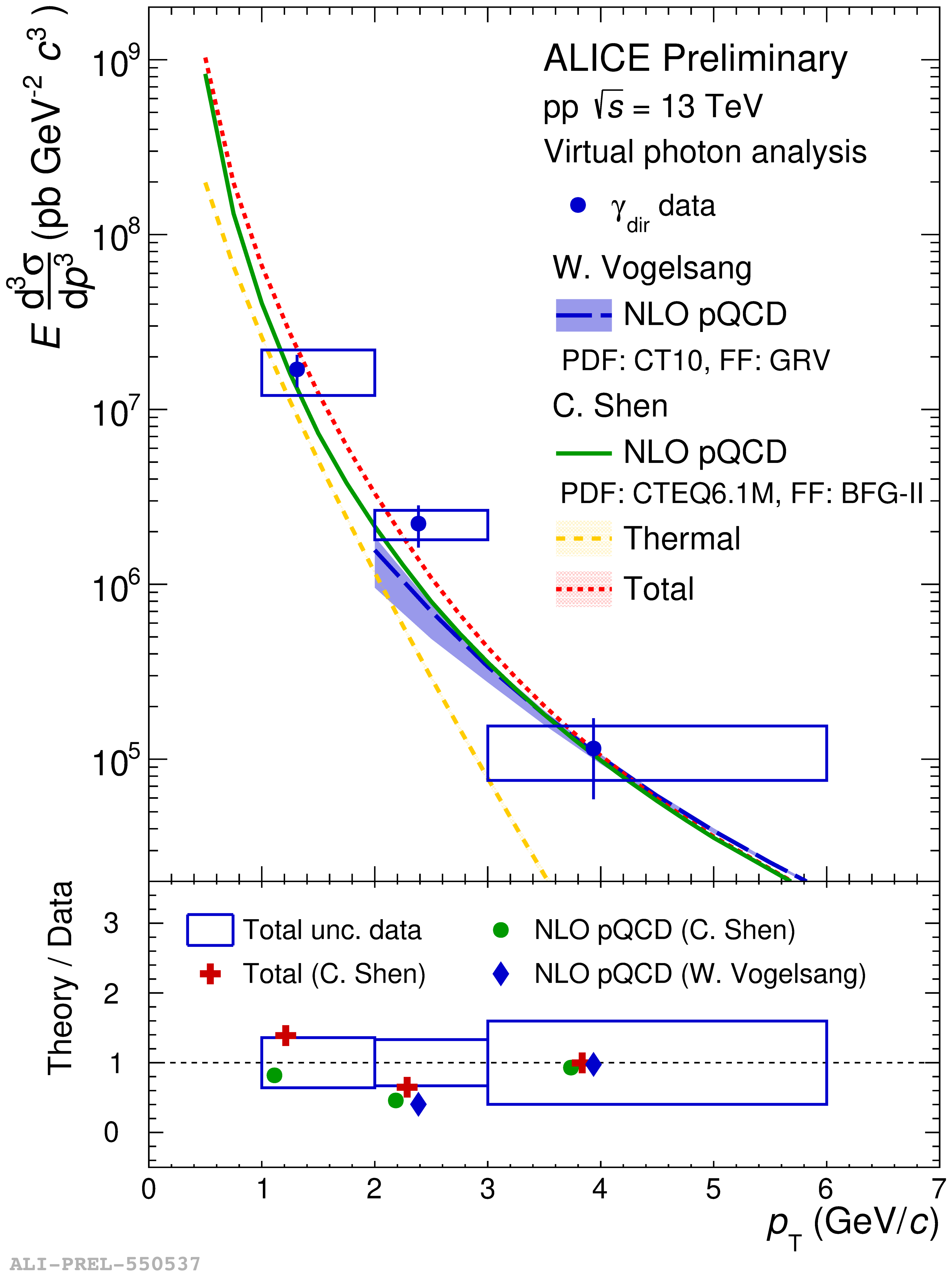
Collision system	Analysed luminosity
Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV	85 μb^{-1} in 0–10%
pp $\sqrt{s}$ = 13 TeV	30 nb^{-1} minimum bias (MB) 5.8 pb^{-1} high multiplicity (HM)

Direct-photon fraction in pp MB and HM events

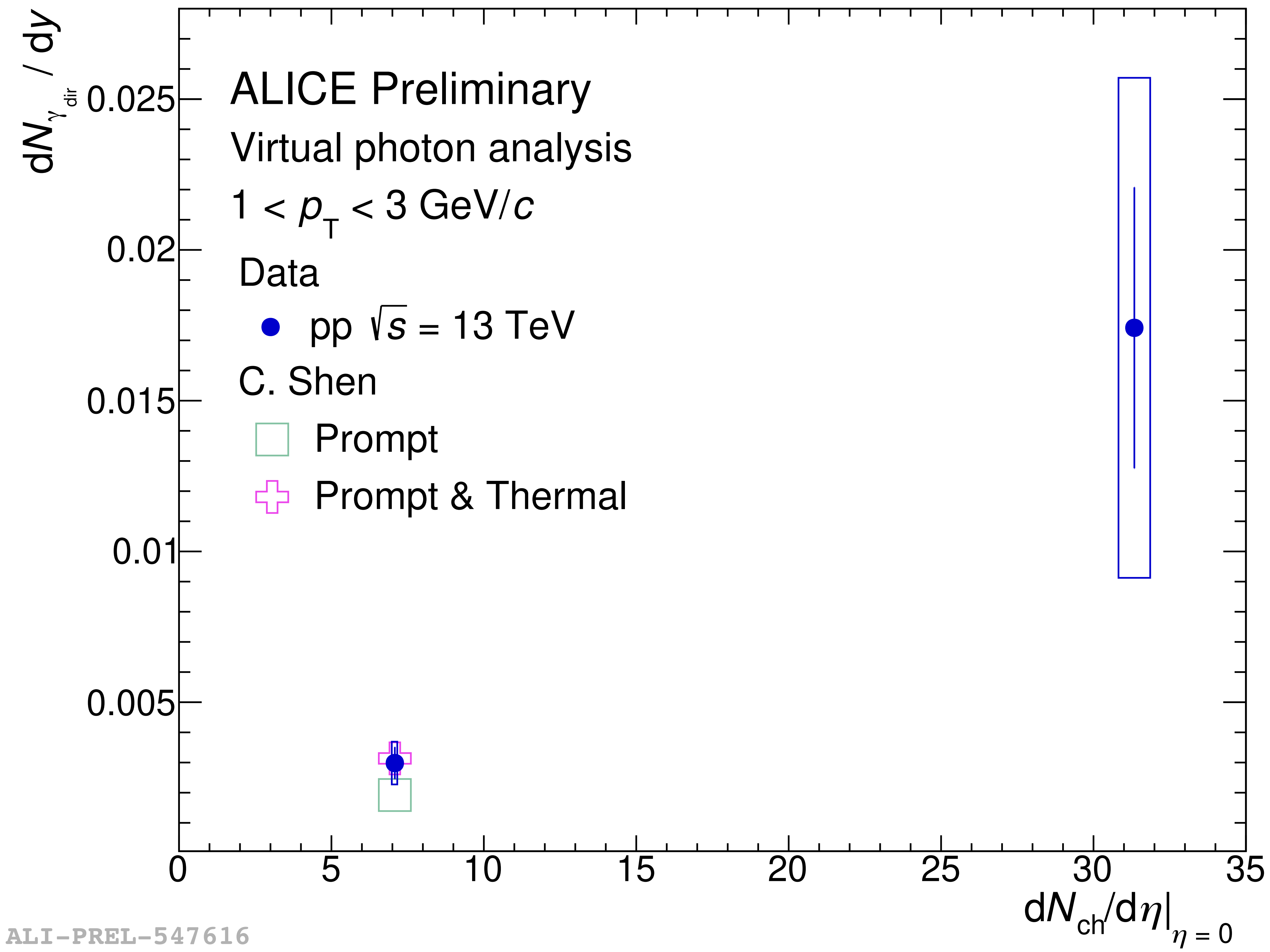




Direct-photon yield in pp MB events and vs multiplicity

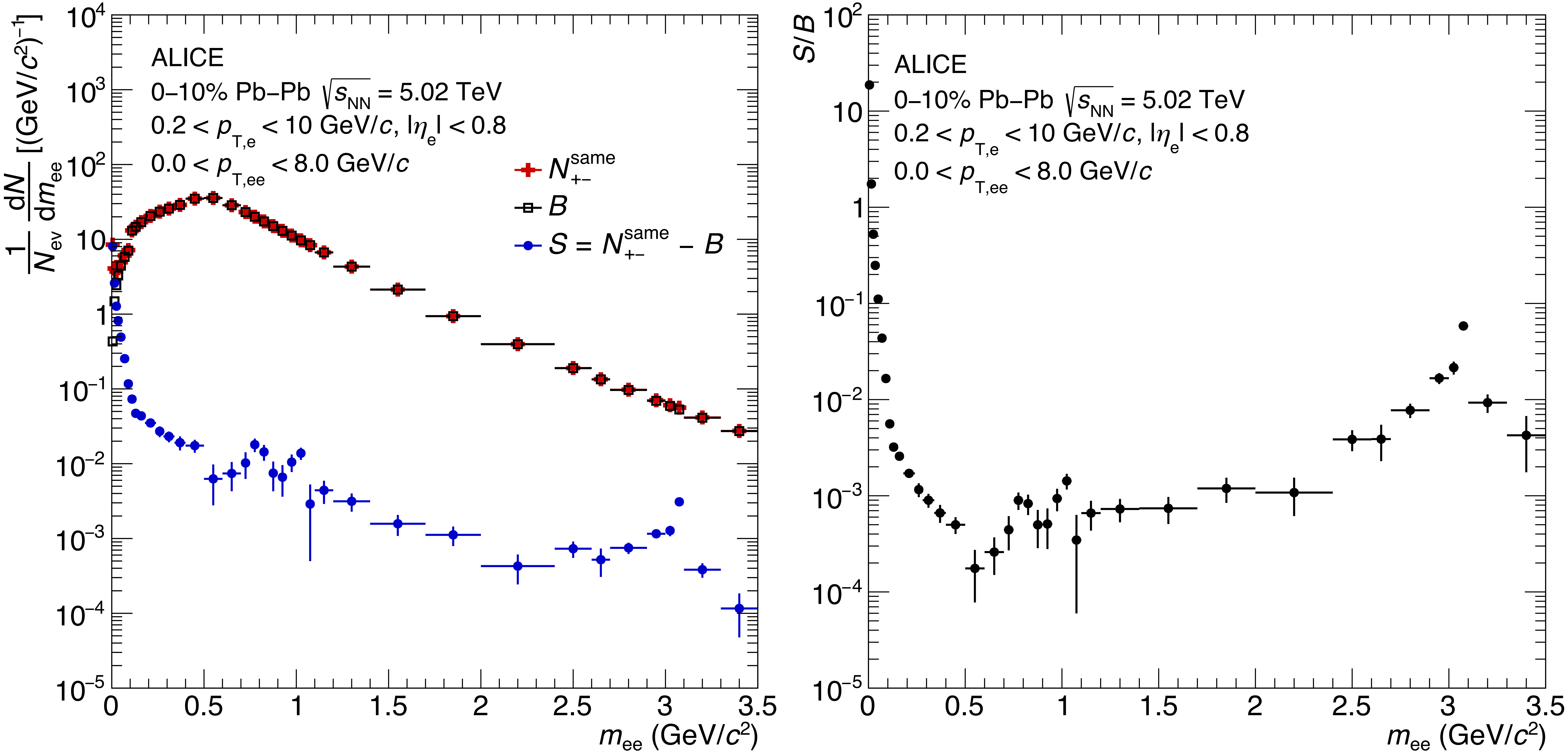


ALI-PREL-550537



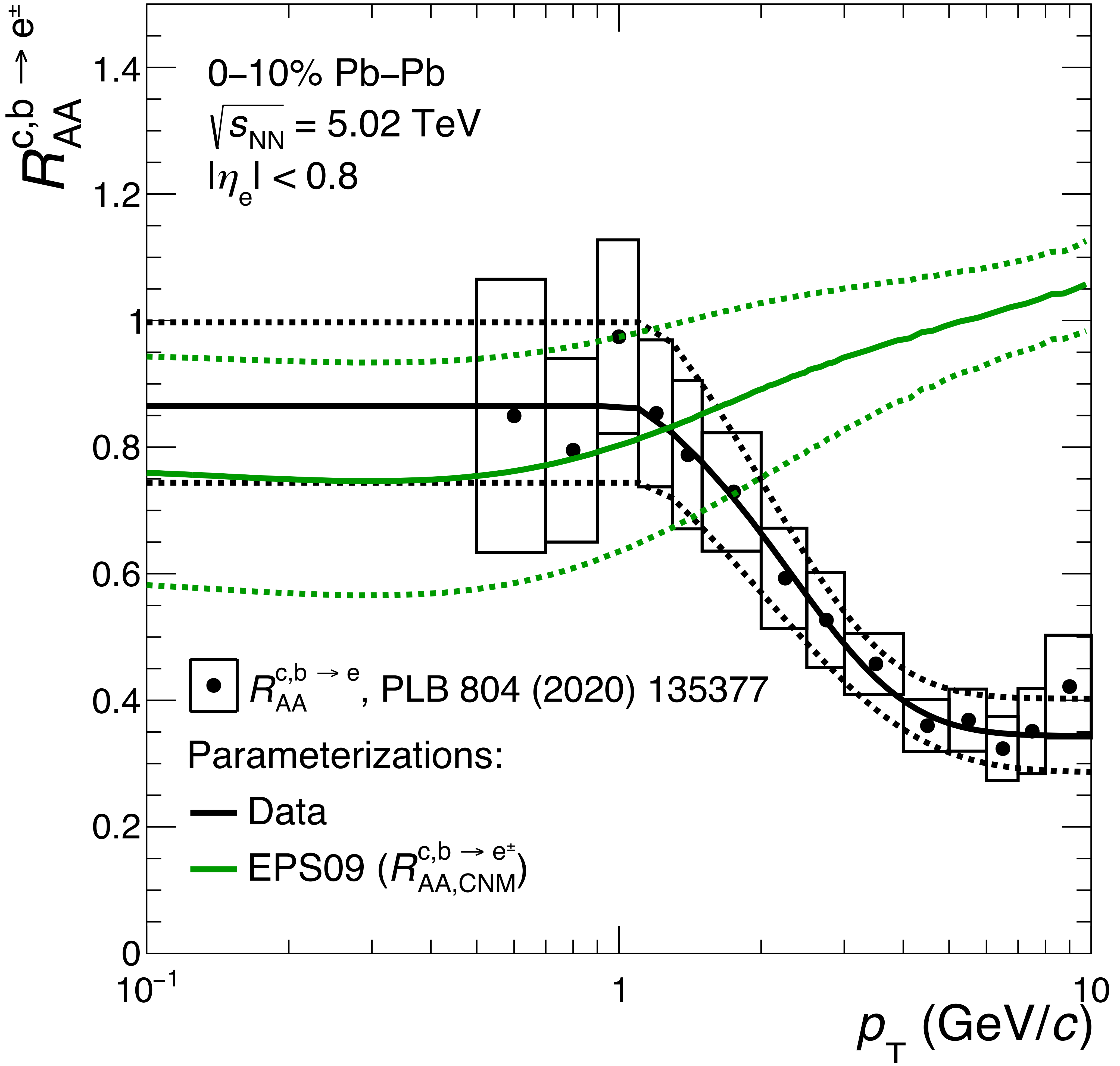
ALI-PREL-547616

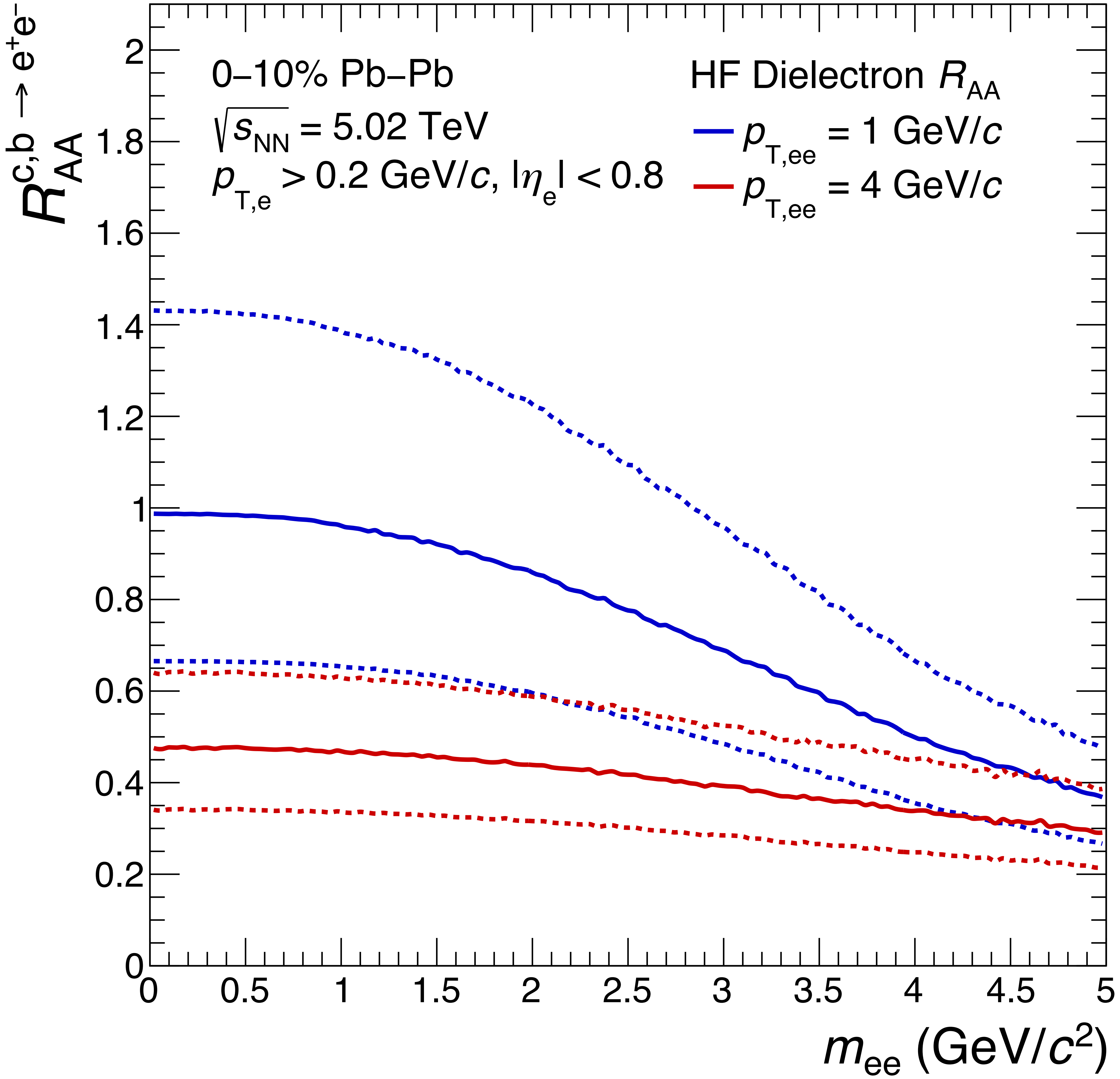
Raw yield and *S*/*B* ratio in central Pb−Pb [1]



[1] ALICE, arXiv:2308.16704

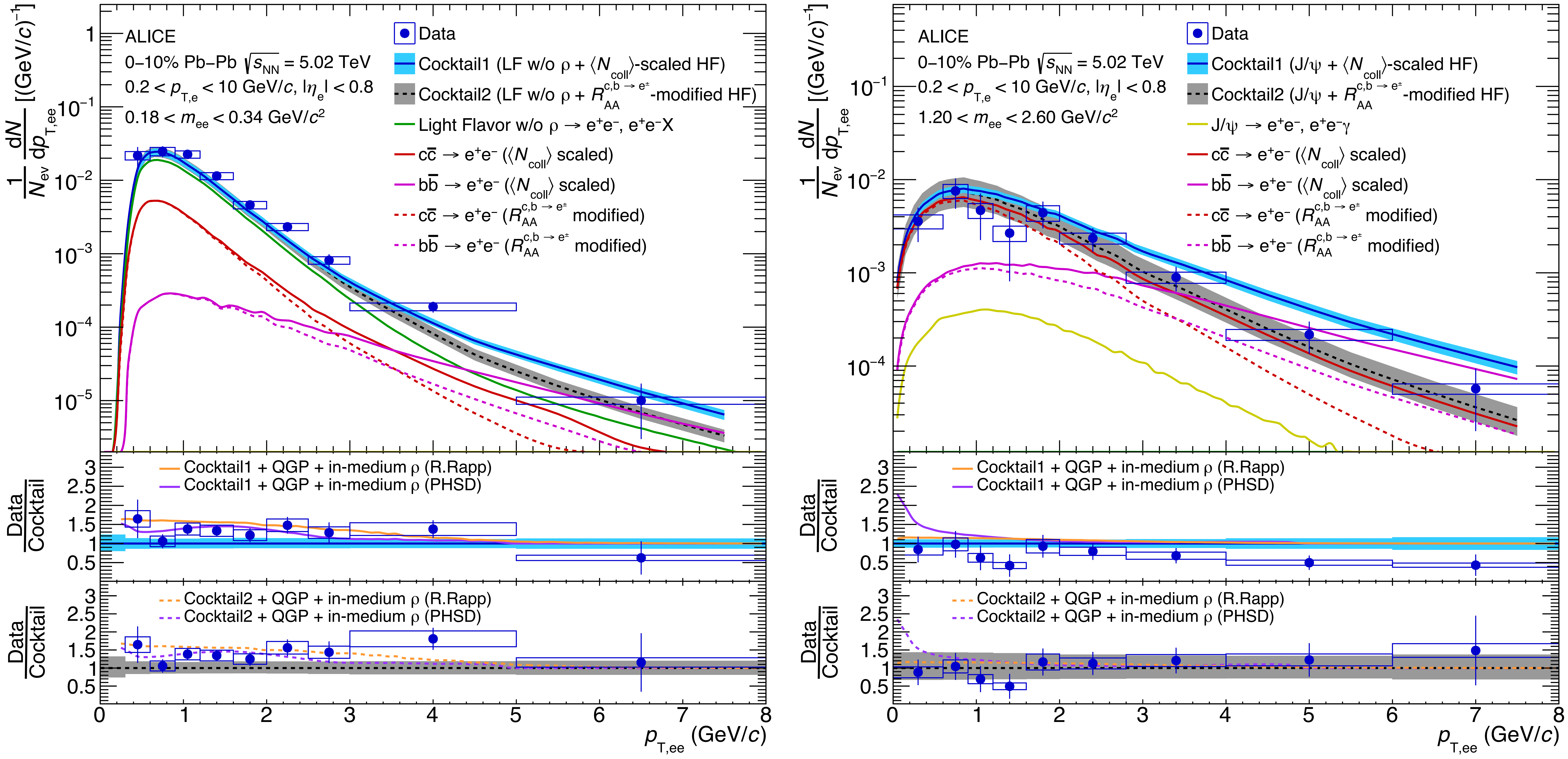
R_{AA} of (di)electrons from HF in central Pb–Pb [1]





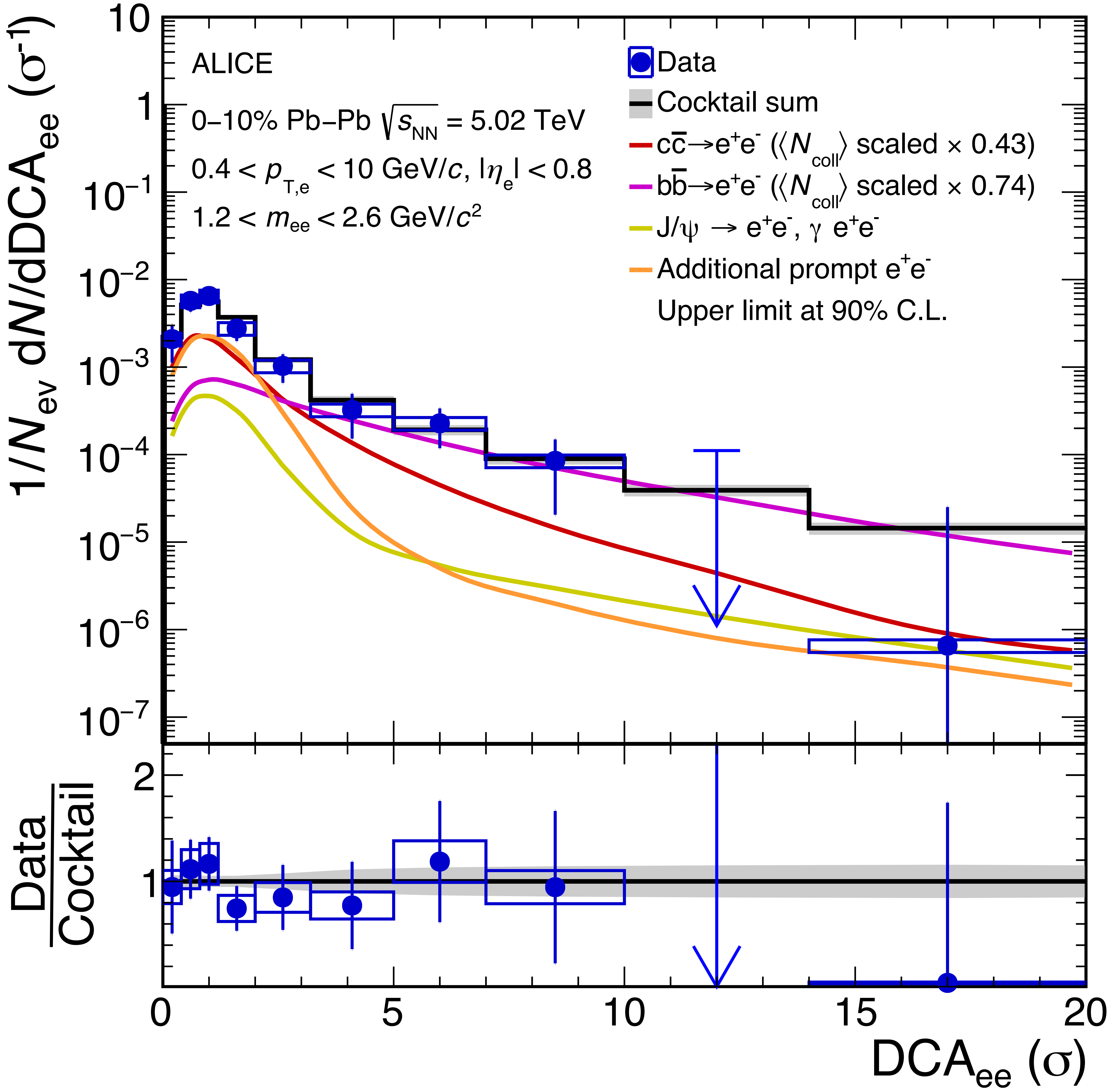
[1] ALICE, arXiv:2308.16704

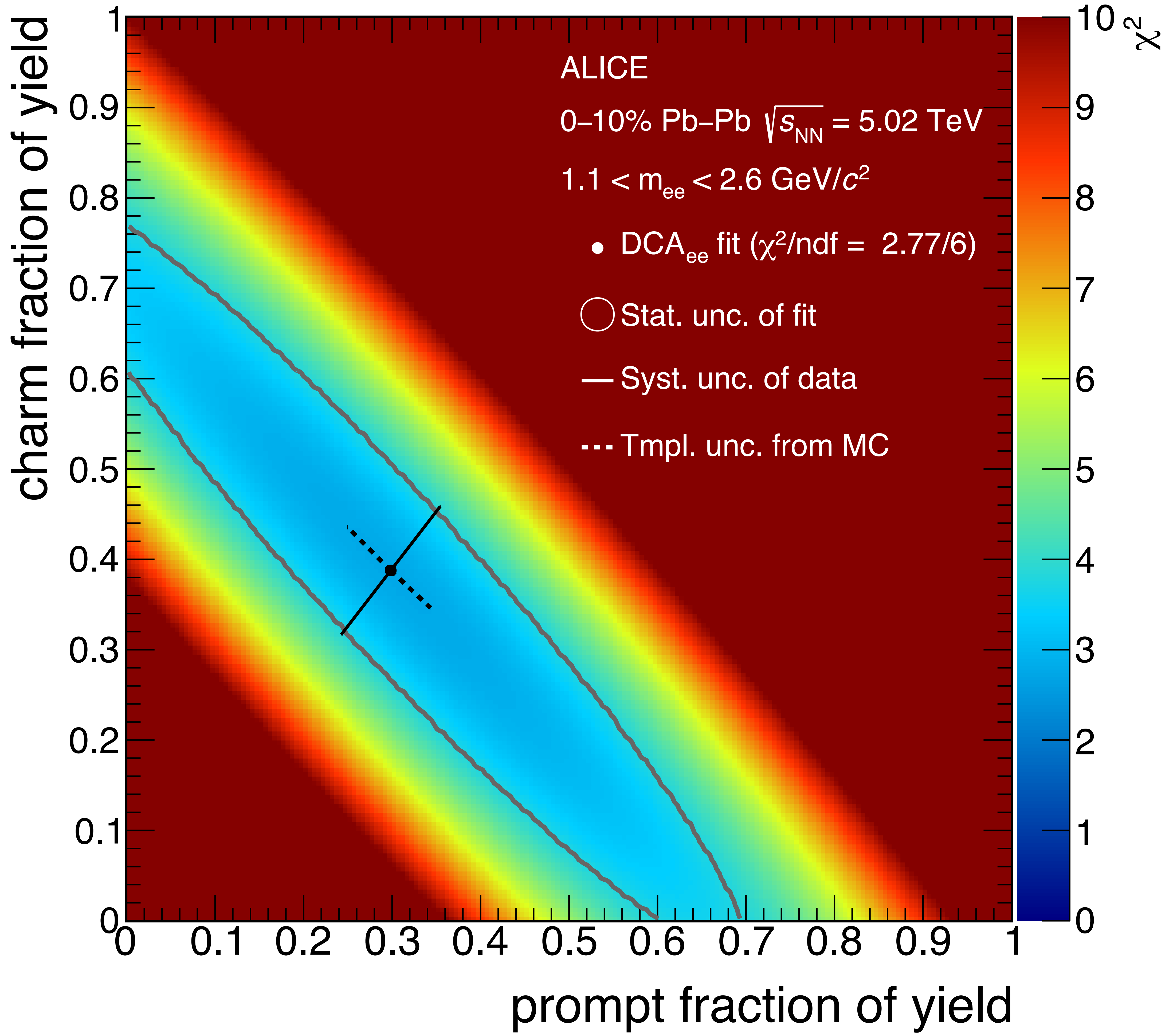
$p_{T,ee}$ differential yields in central Pb–Pb [1]



[1] ALICE, arXiv:2308.16704

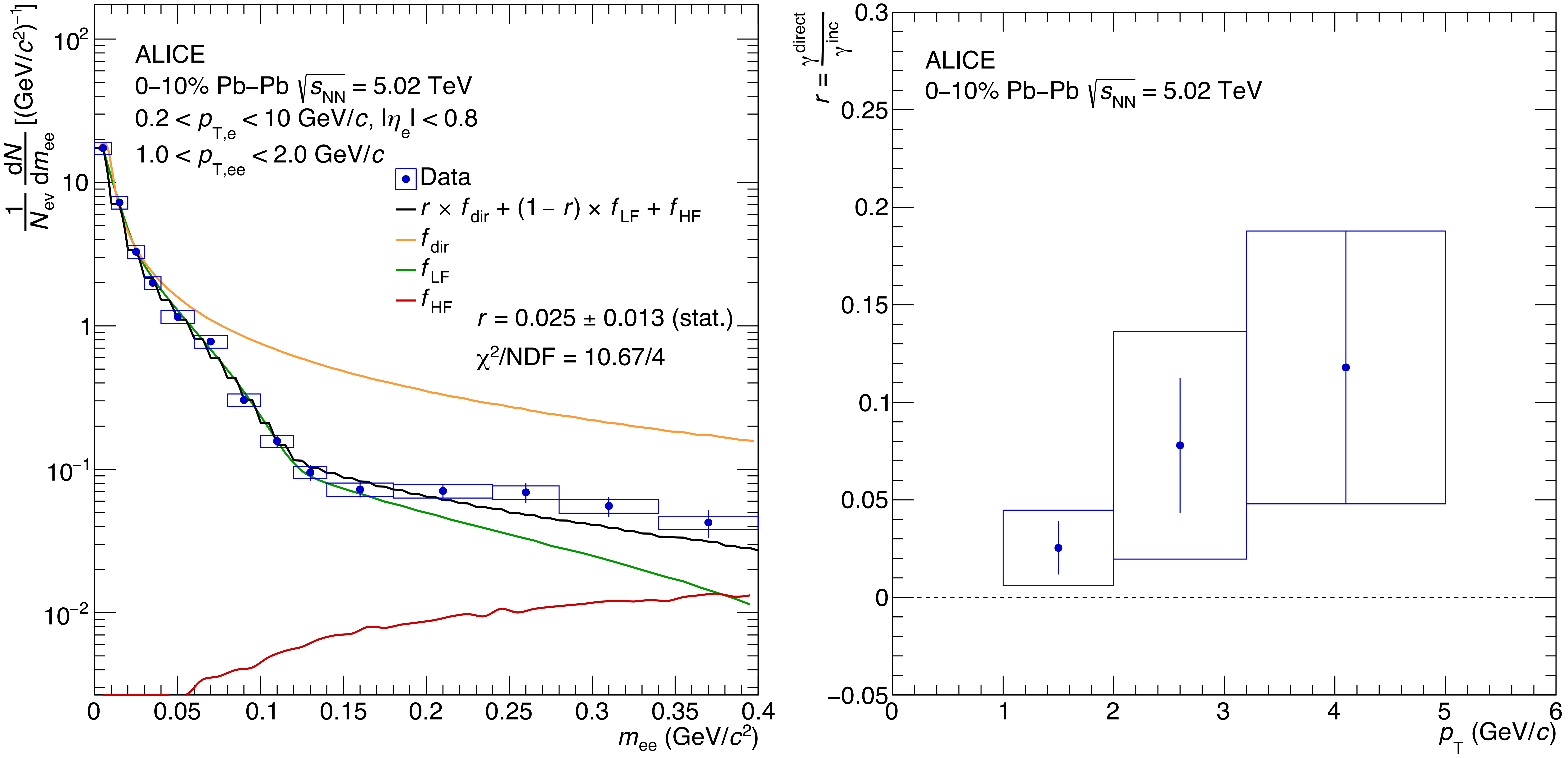
DCA_{ee} template fit in IMR in central Pb–Pb [1]





[1] ALICE, arXiv:2308.16704

Direct-photon fraction in central Pb–Pb [1]



[1] ALICE, arXiv:2308.16704