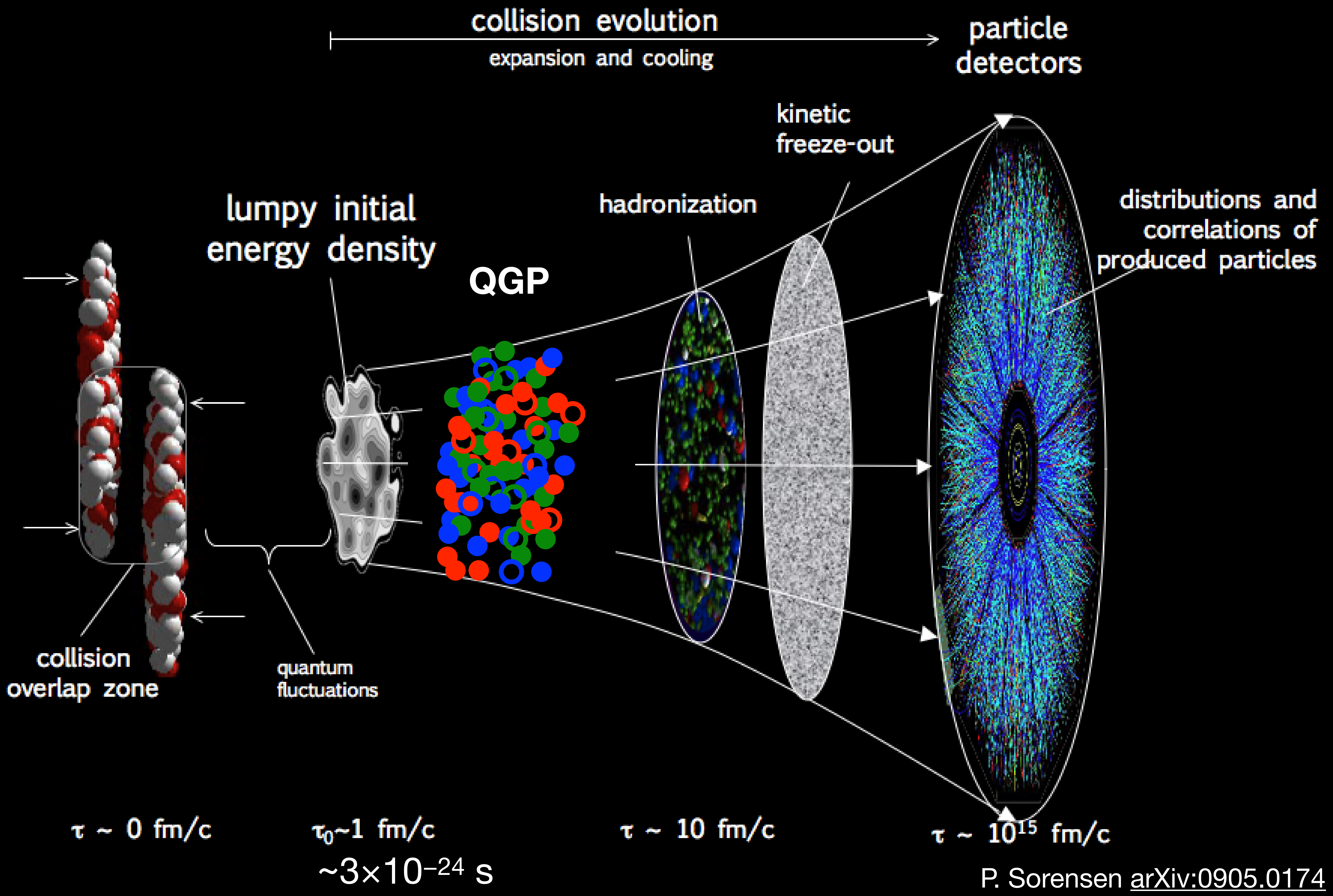
Recent results on low-mass dielectron production in pp and Pb–Pb collisions with ALICE

– Torsten Dahms (on behalf of the ALICE Collaboration) –
Excellence Cluster Universe - Technische Universität München

35th Winter Workshop on Nuclear Dynamics 2019
January, 2019

Nuclear collisions and the QGP expansion



P. Sorensen arXiv:0905.0174

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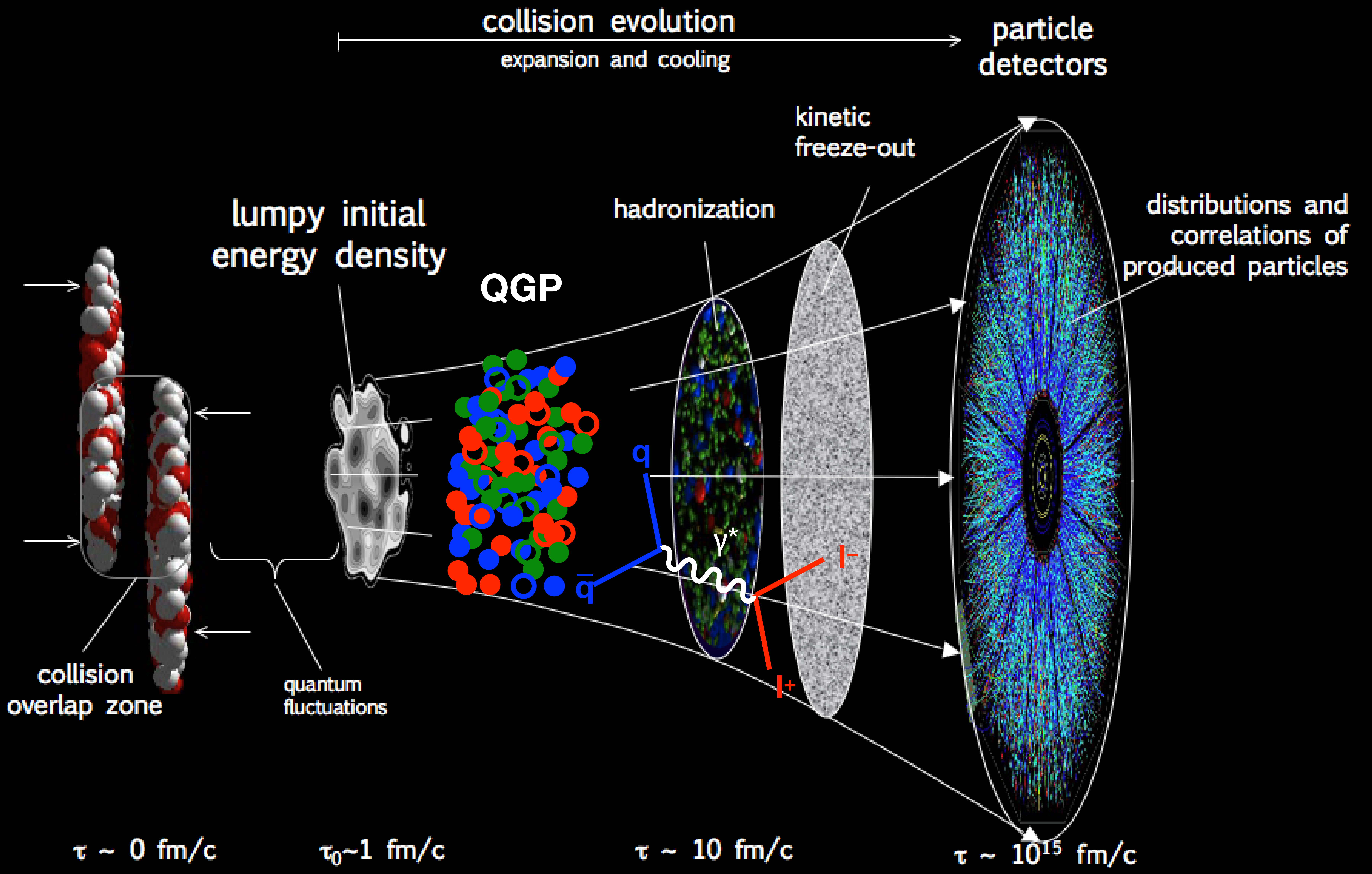

~3×10^{-24} s

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Electromagnetic Radiation

Electromagnetic Radiation

Photons

Electromagnetic Radiation

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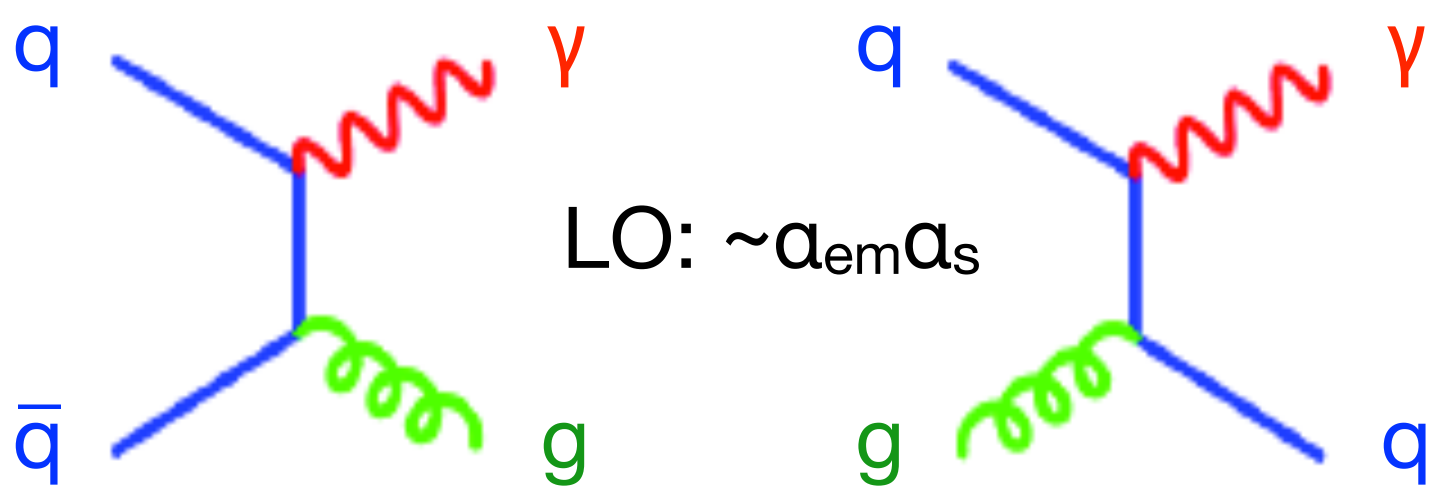
- prompt (pQCD) photons



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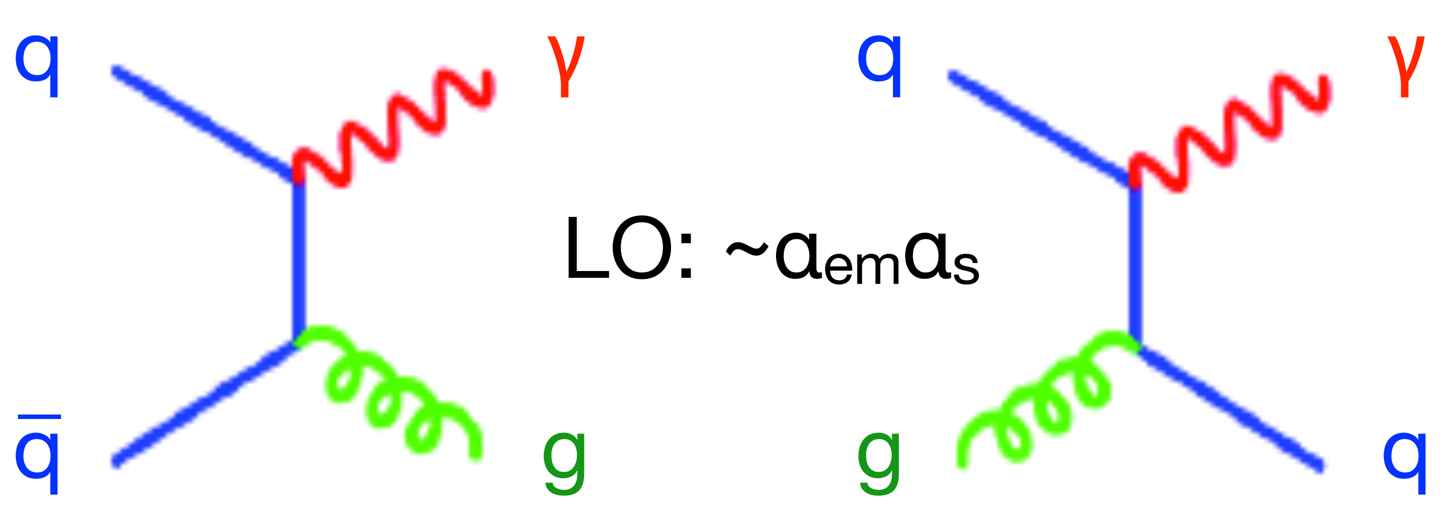

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  - hadron gas, e.g. π ρ → π γ

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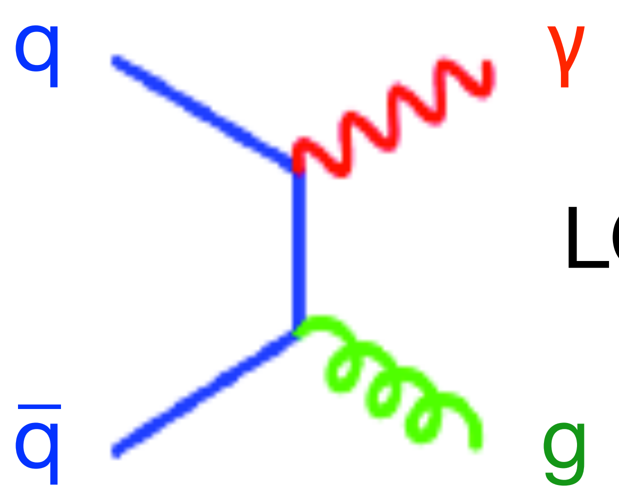

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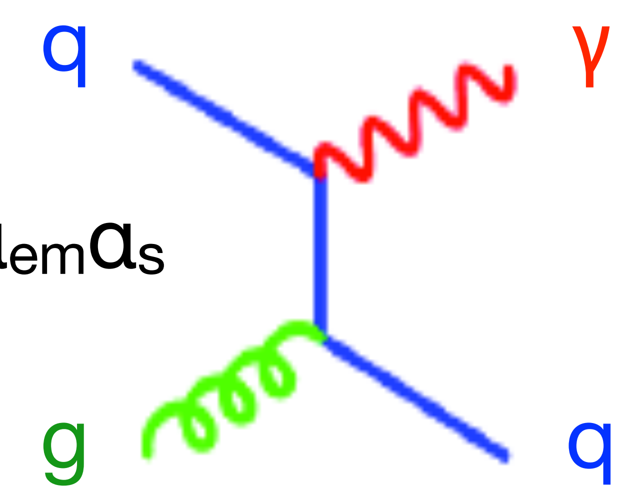

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  - π^0, $\eta \rightarrow \gamma\ \gamma$
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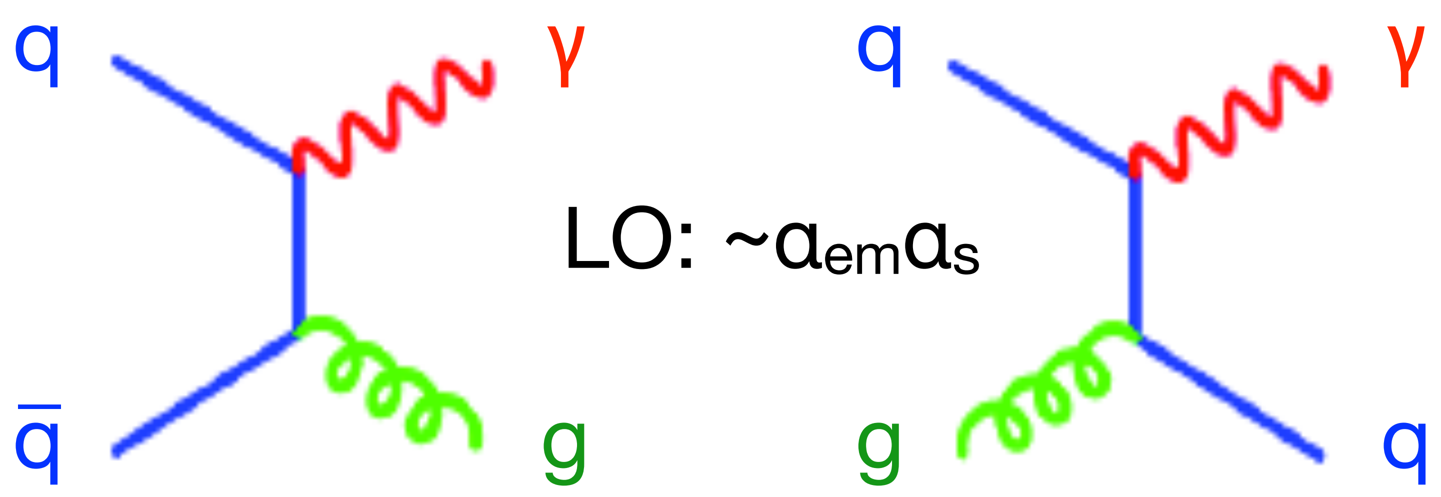

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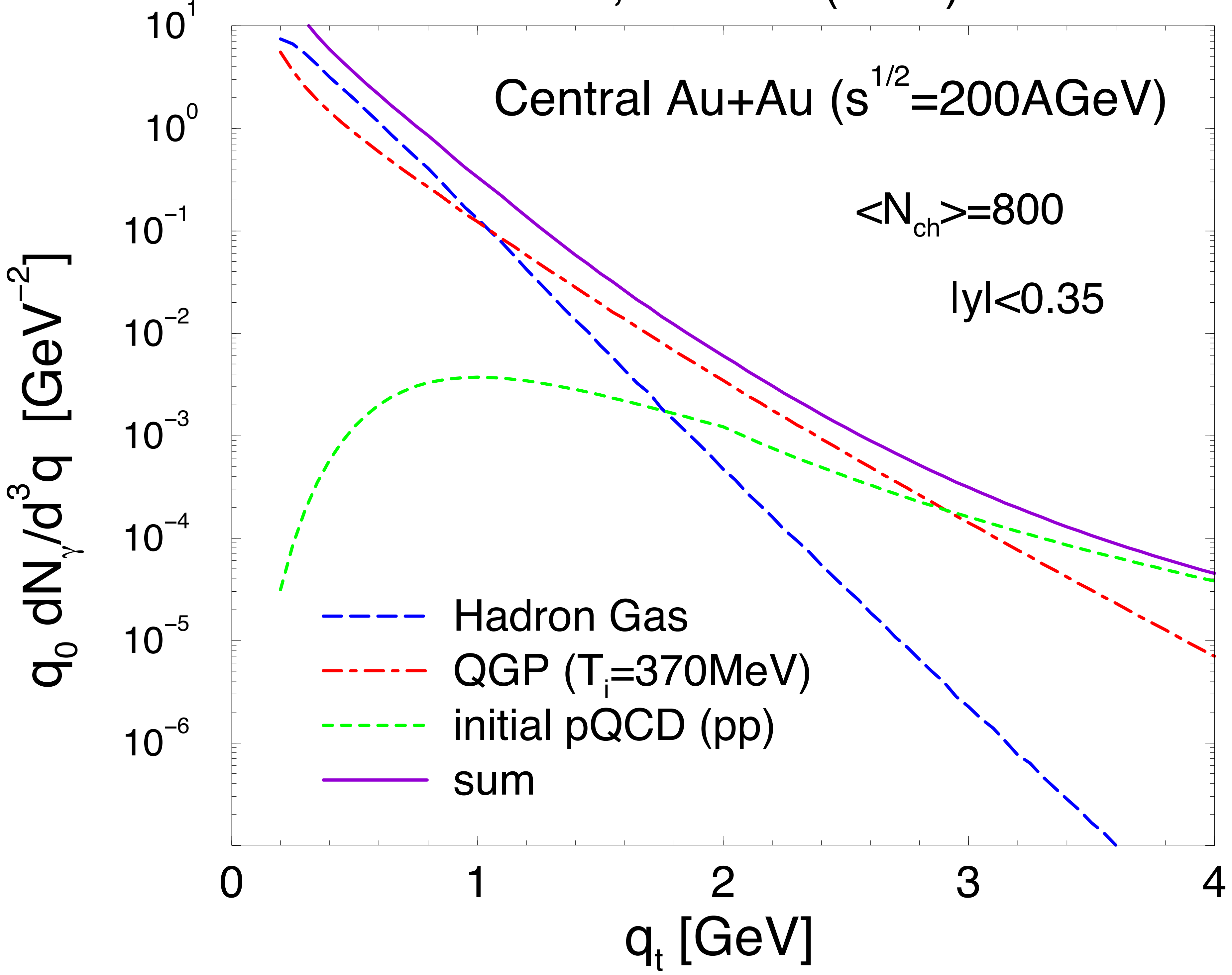
S. Turbide et al., PRC 69 (2004) 014903



- <u>observables:</u> p_T, azimuthal anisotropy

Electromagnetic Radiation

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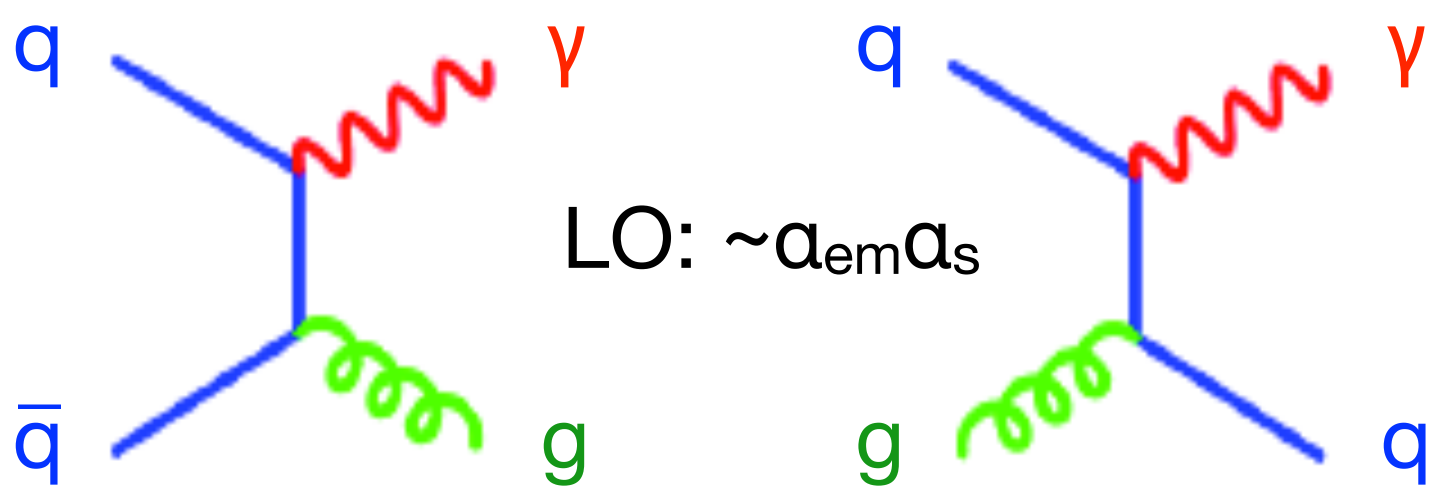

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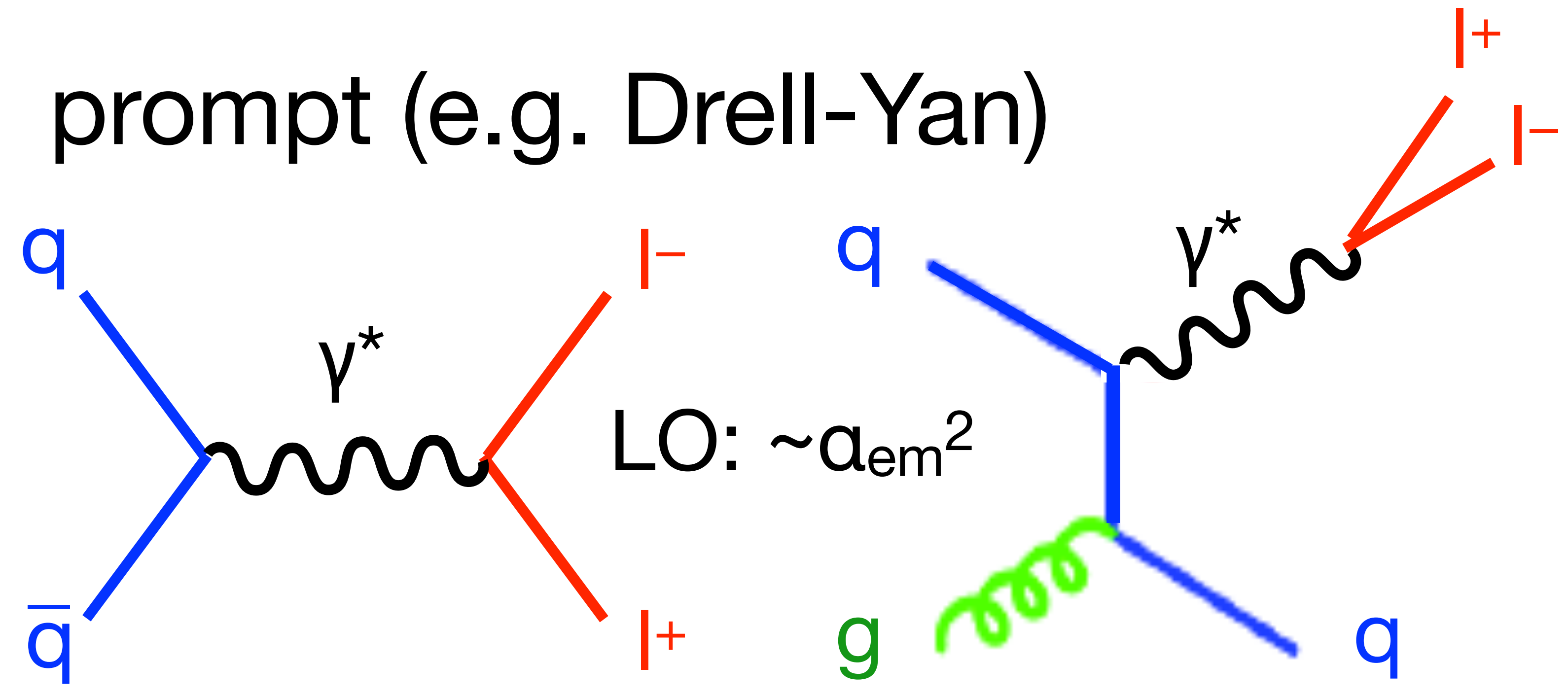

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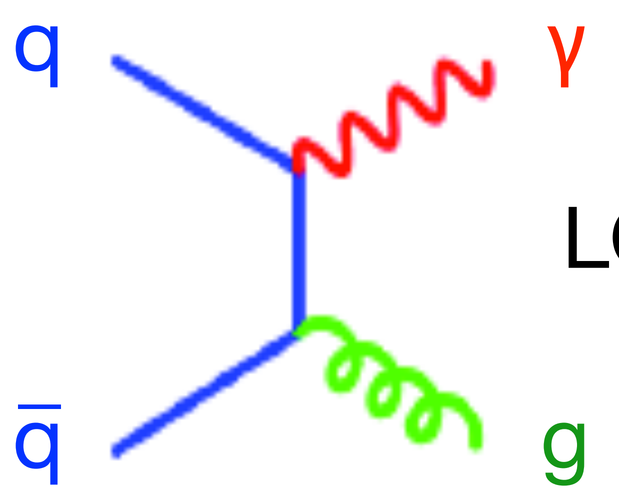

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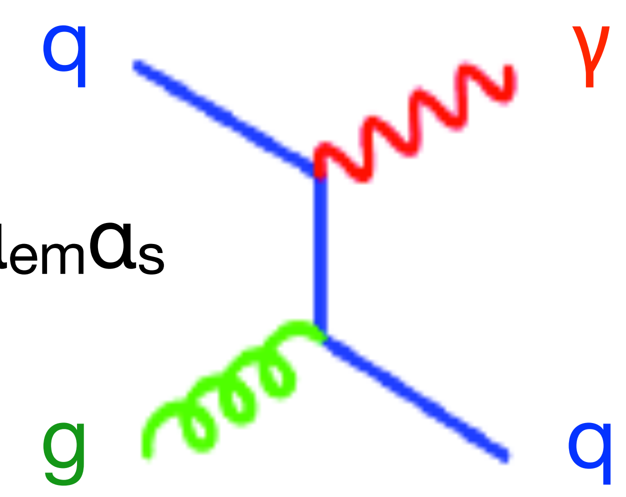

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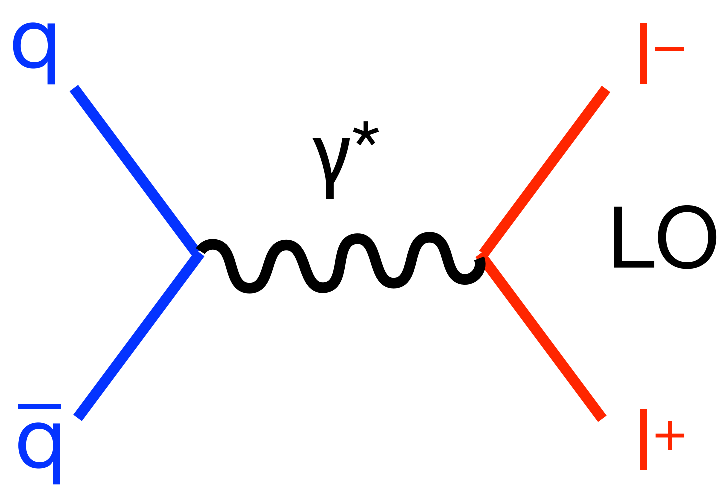

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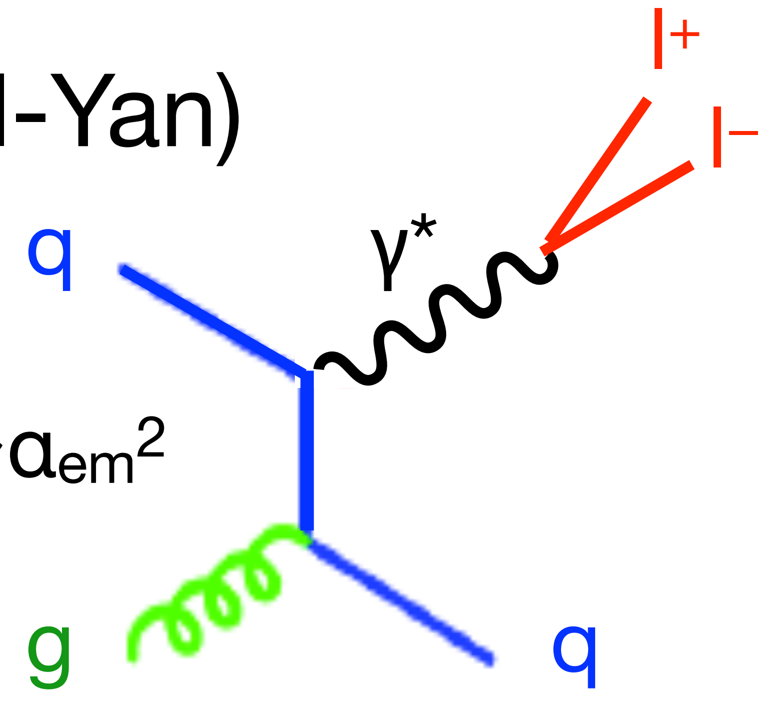

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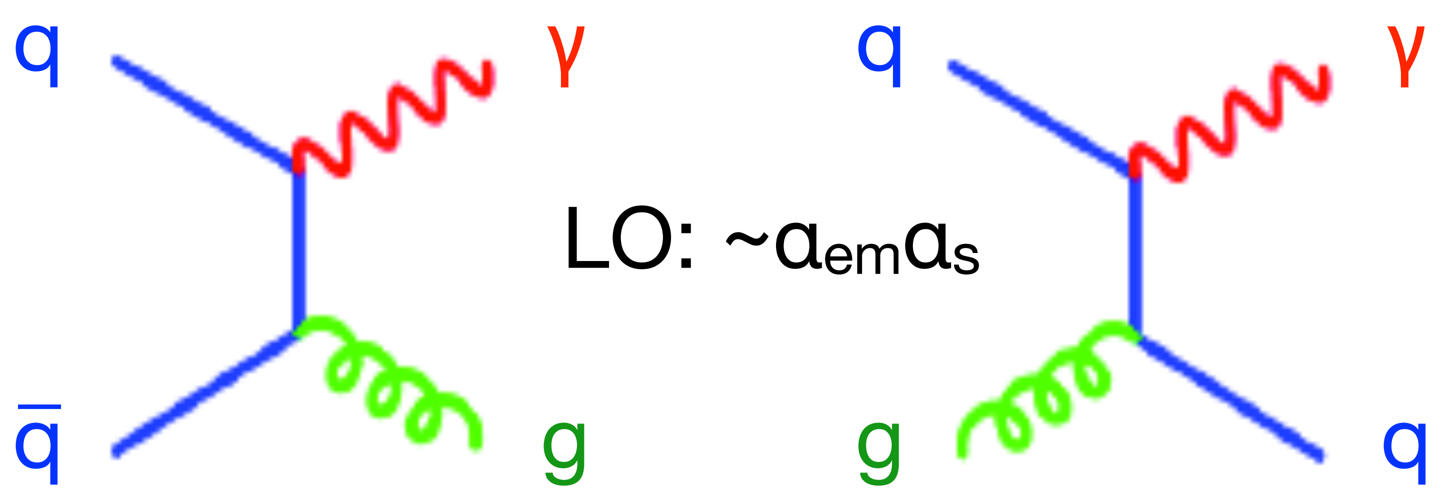

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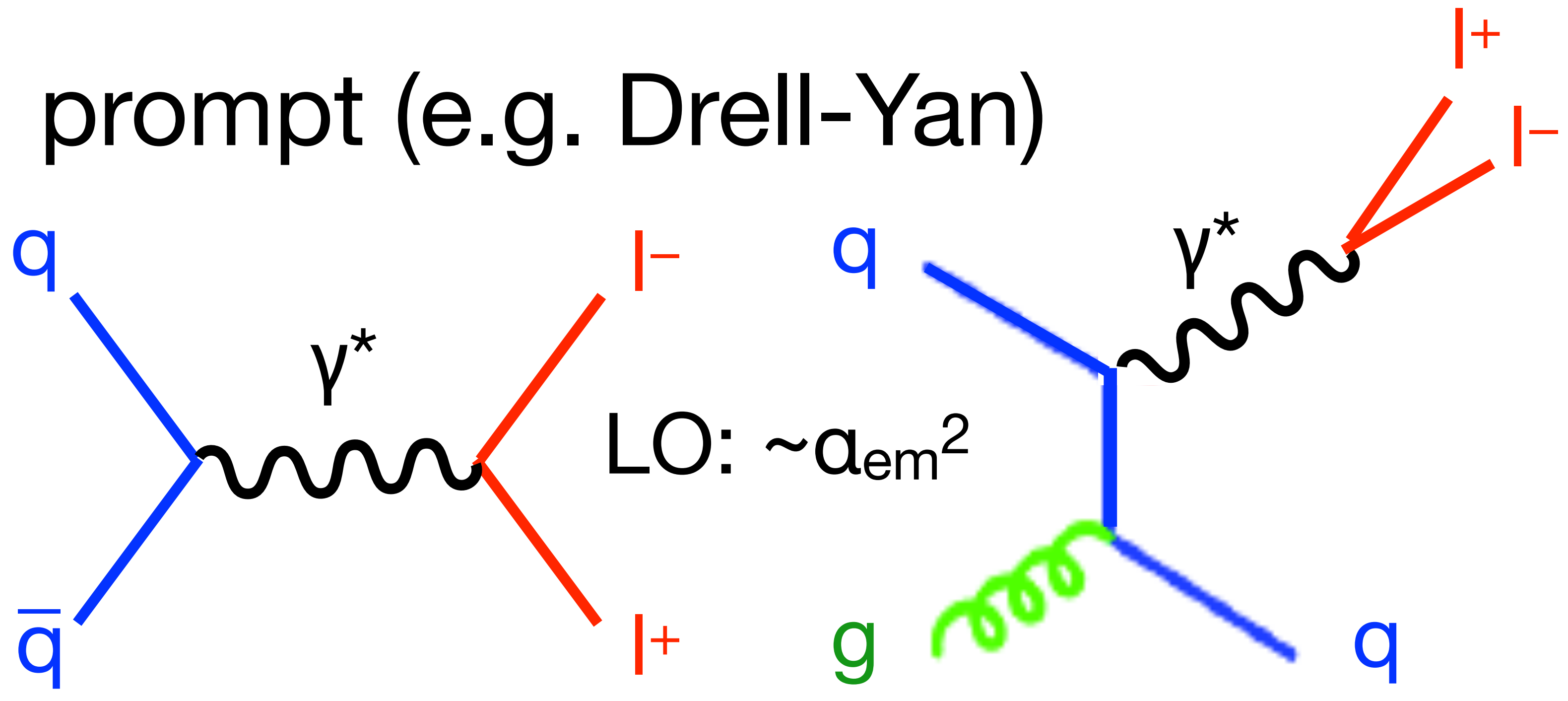

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  - Dalitz: $\pi^0 \rightarrow \gamma\,e^+e^-$, $\eta \rightarrow \gamma\,l^+l^-$, …
  - semileptonic heavy-flavour meson decays

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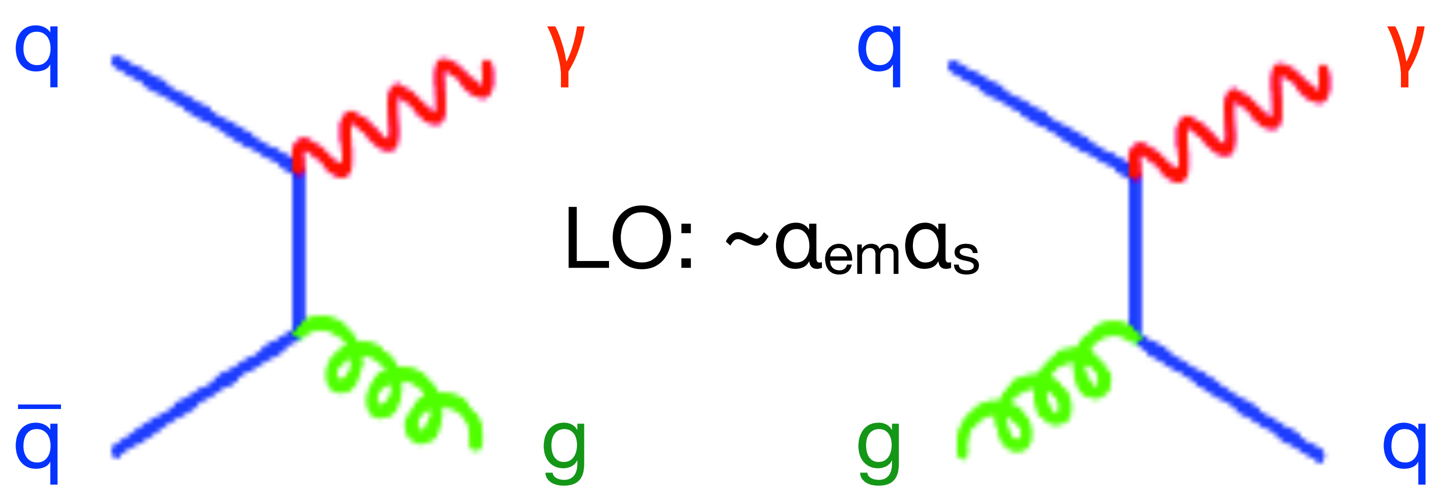

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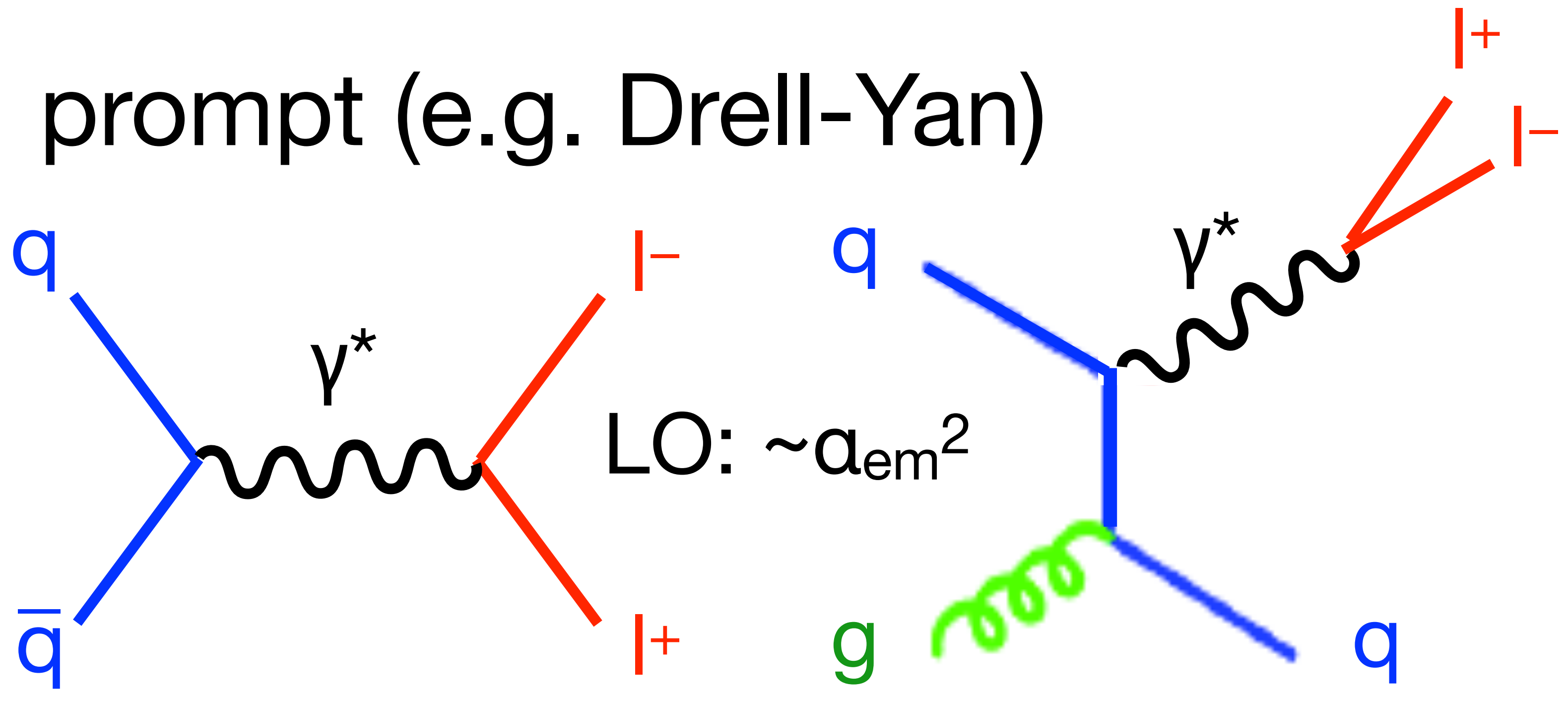

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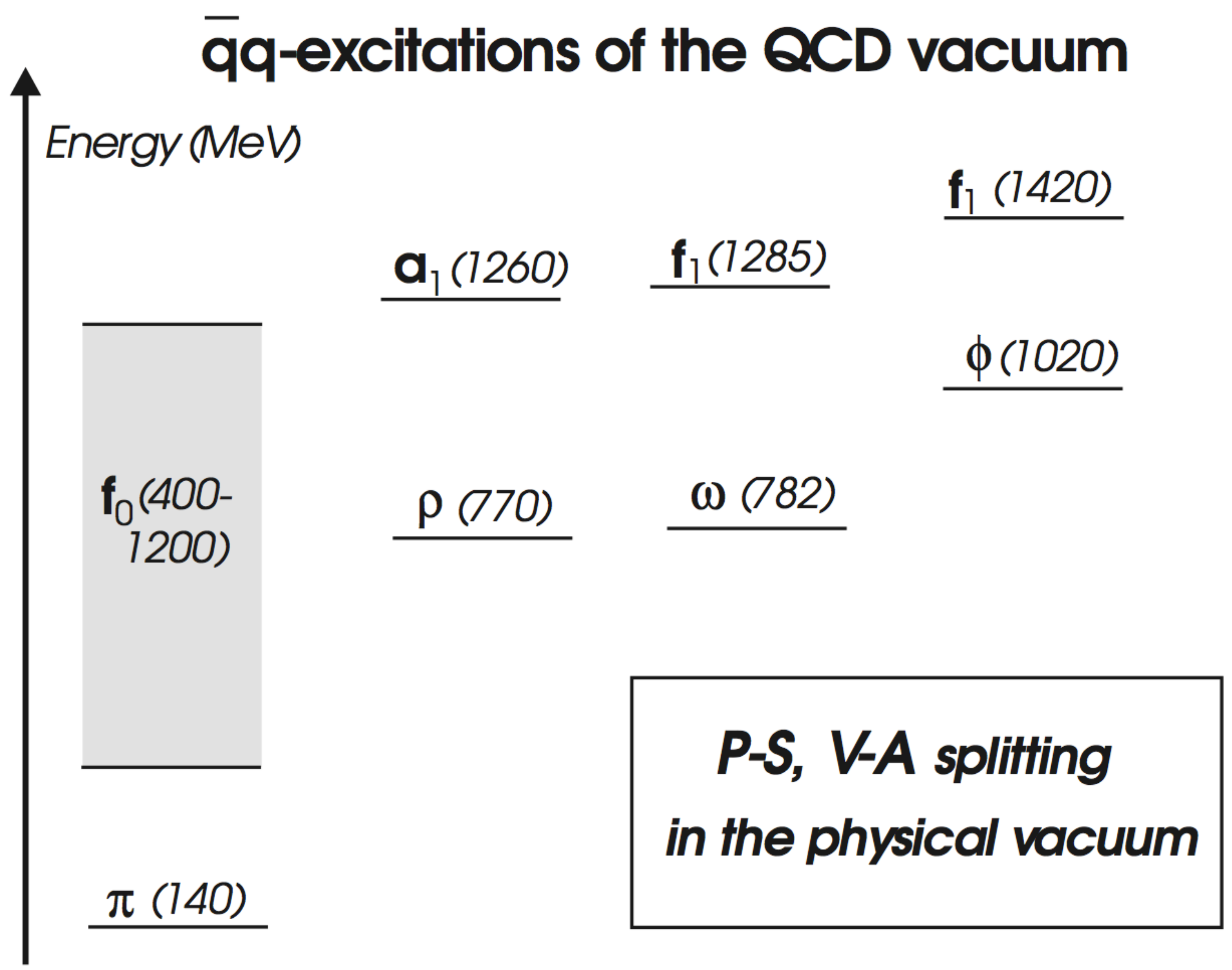
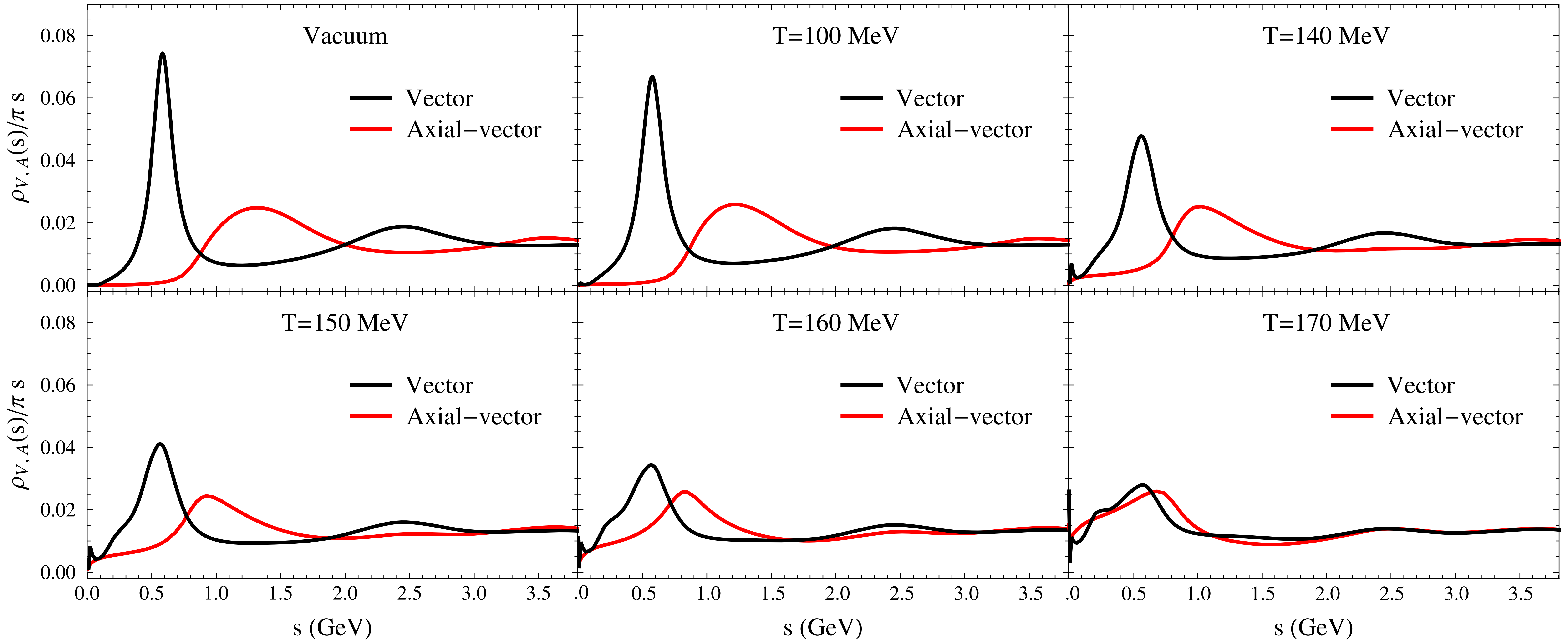
- <u>observables:</u> p_T, azimuthal anisotropy, mass, polarisation

Chiral Symmetry and Hadron Masses

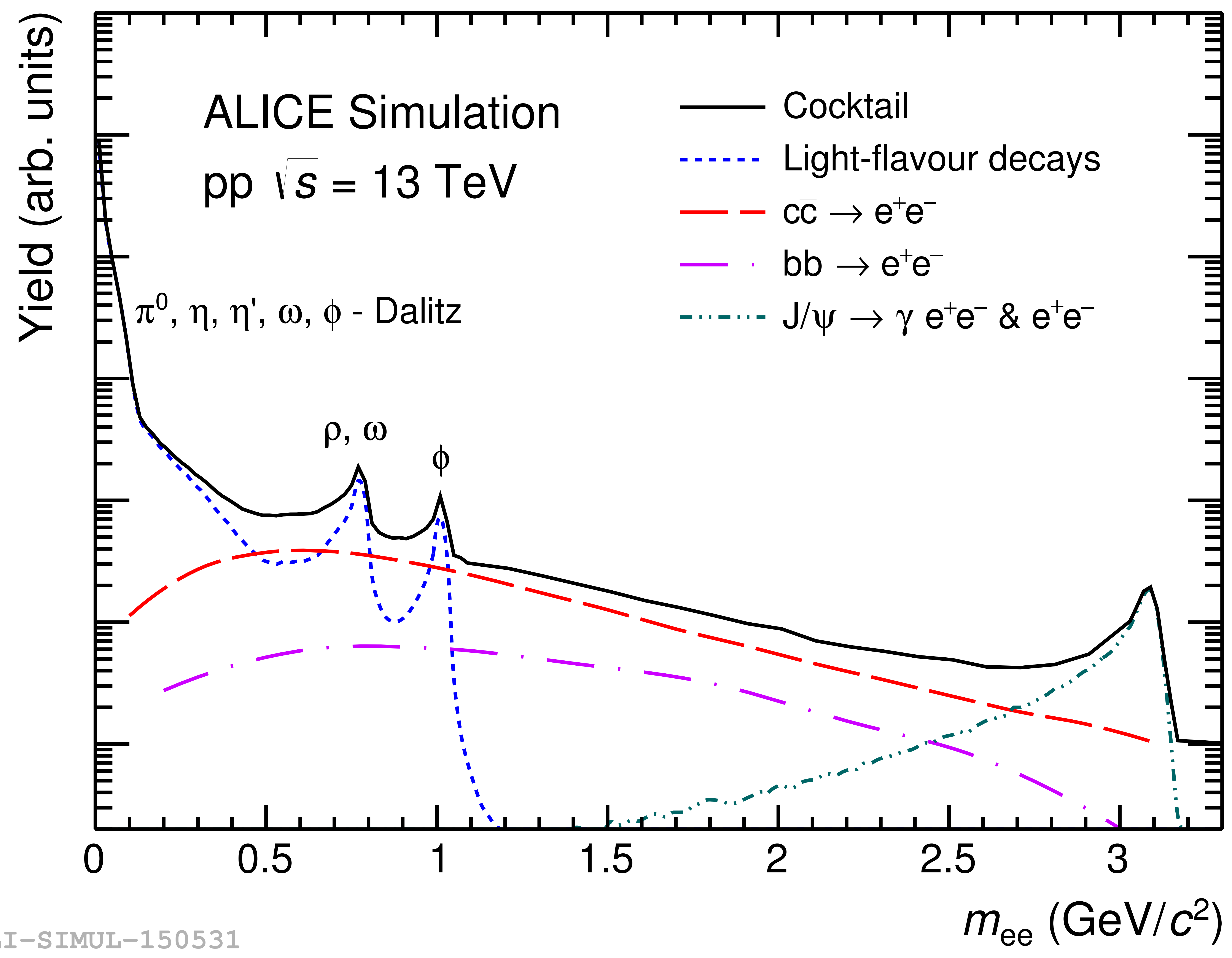




P. M. Hohler, R. Rapp, PLB 731 (2014) 103

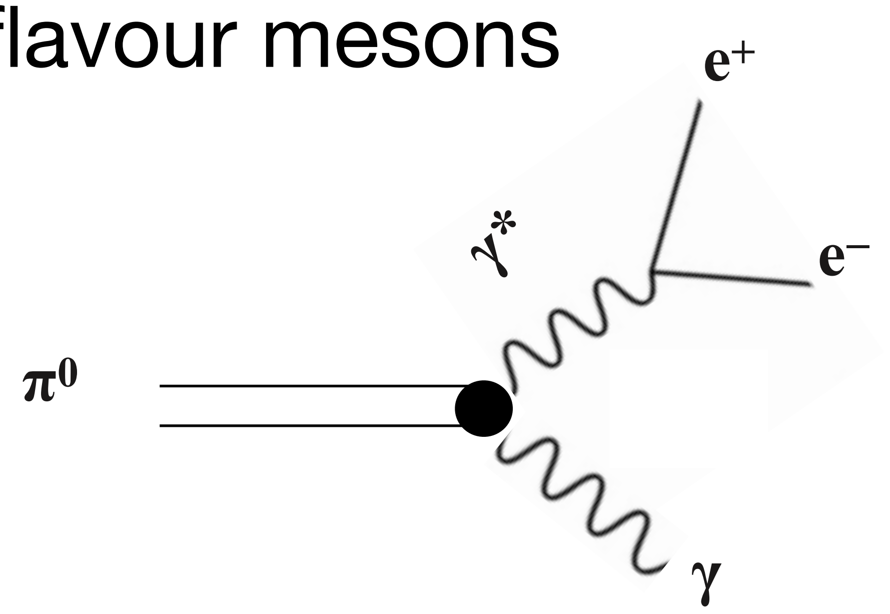
- Mass splitting of chiral partners generated by spontaneous chiral symmetry breaking
- **Chiral symmetry restoration at high *T*: spectral functions of chiral partners degenerate**
  - experimentally accessible only via short-lived $\rho \rightarrow e^+e^-$ decays inside the hot medium

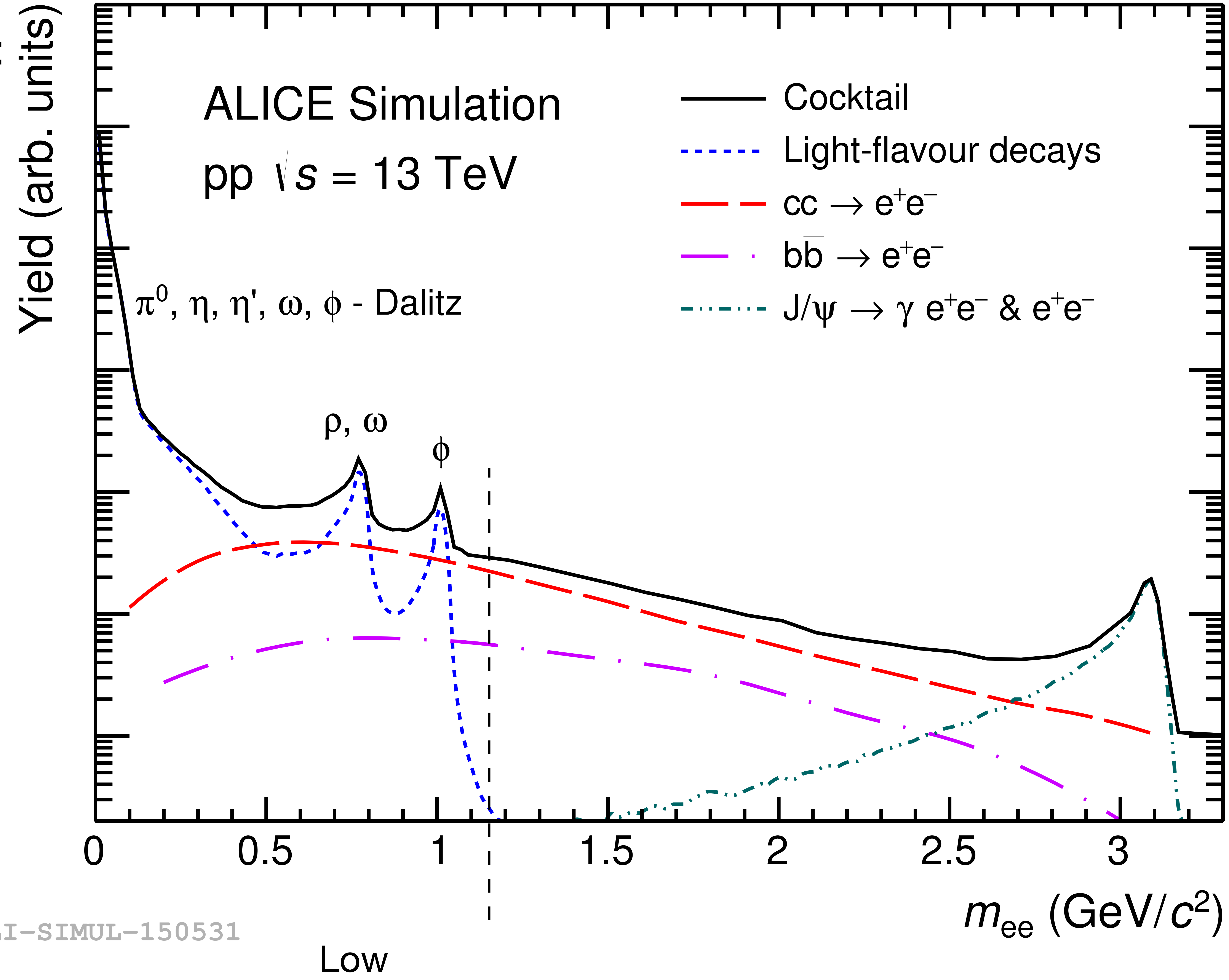
Typical Dilepton Mass Spectrum



Typical Dilepton Mass Spectrum

- Low mass range (m_{ee} < 1 GeV/c^2):
  - resonance and Dalitz decays of light-flavour mesons





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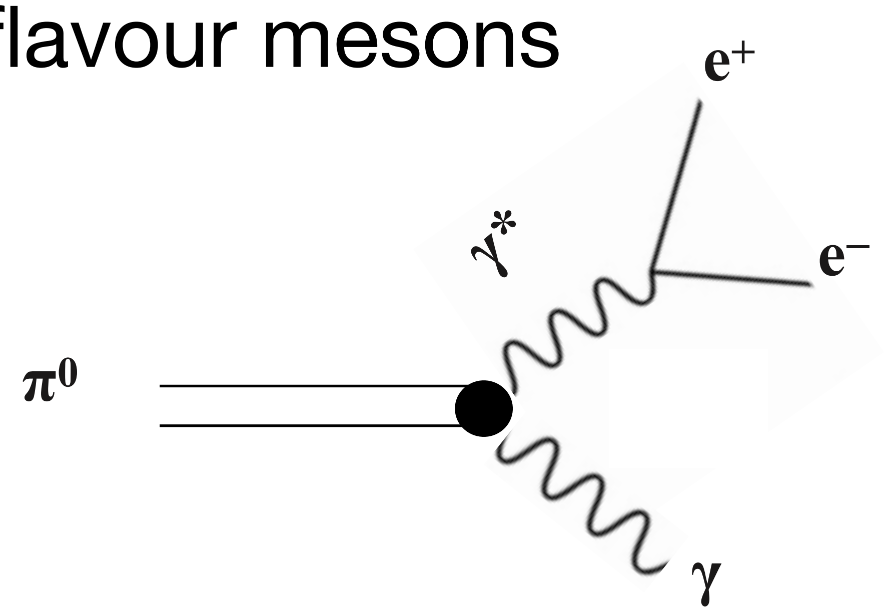

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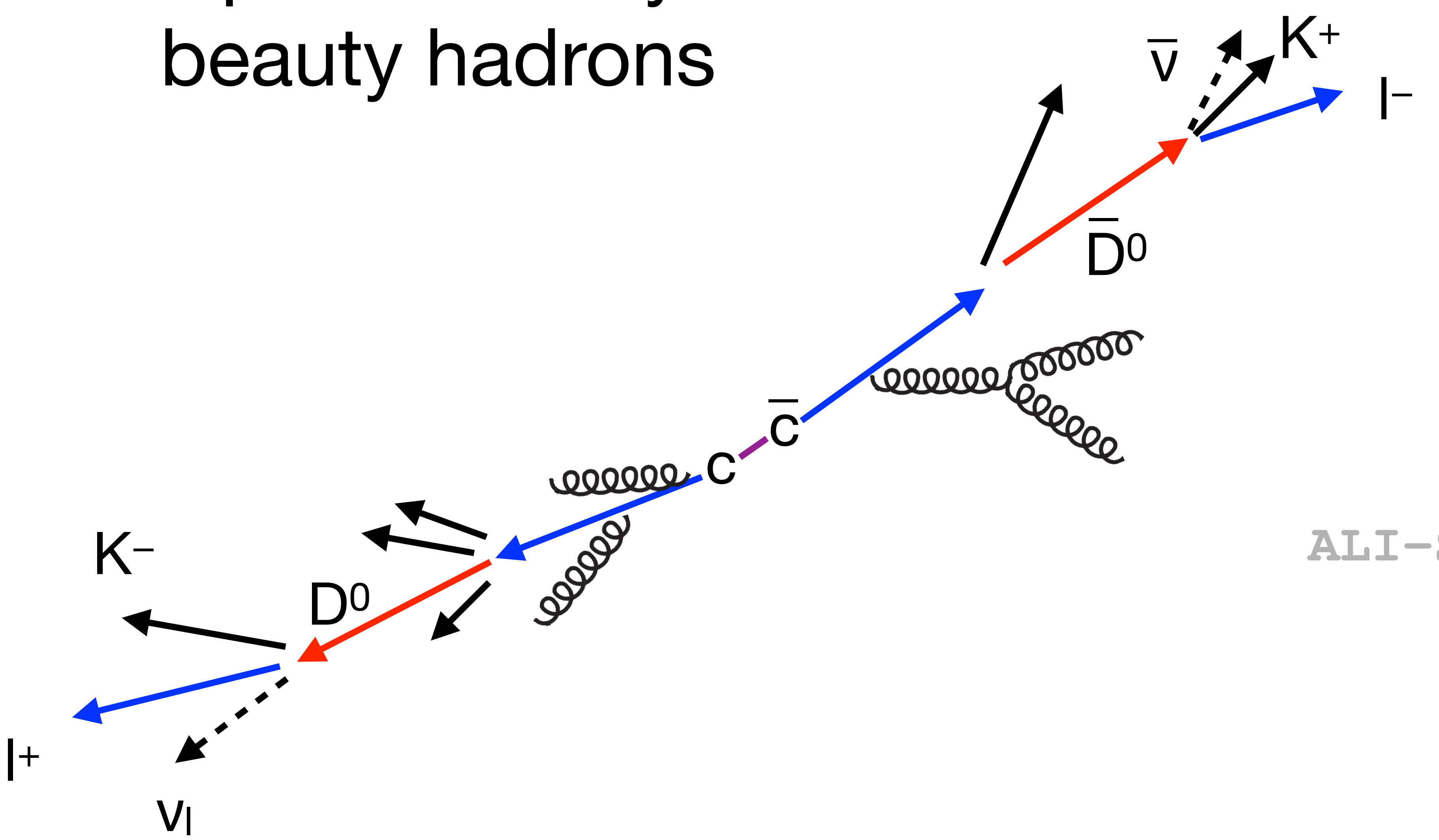

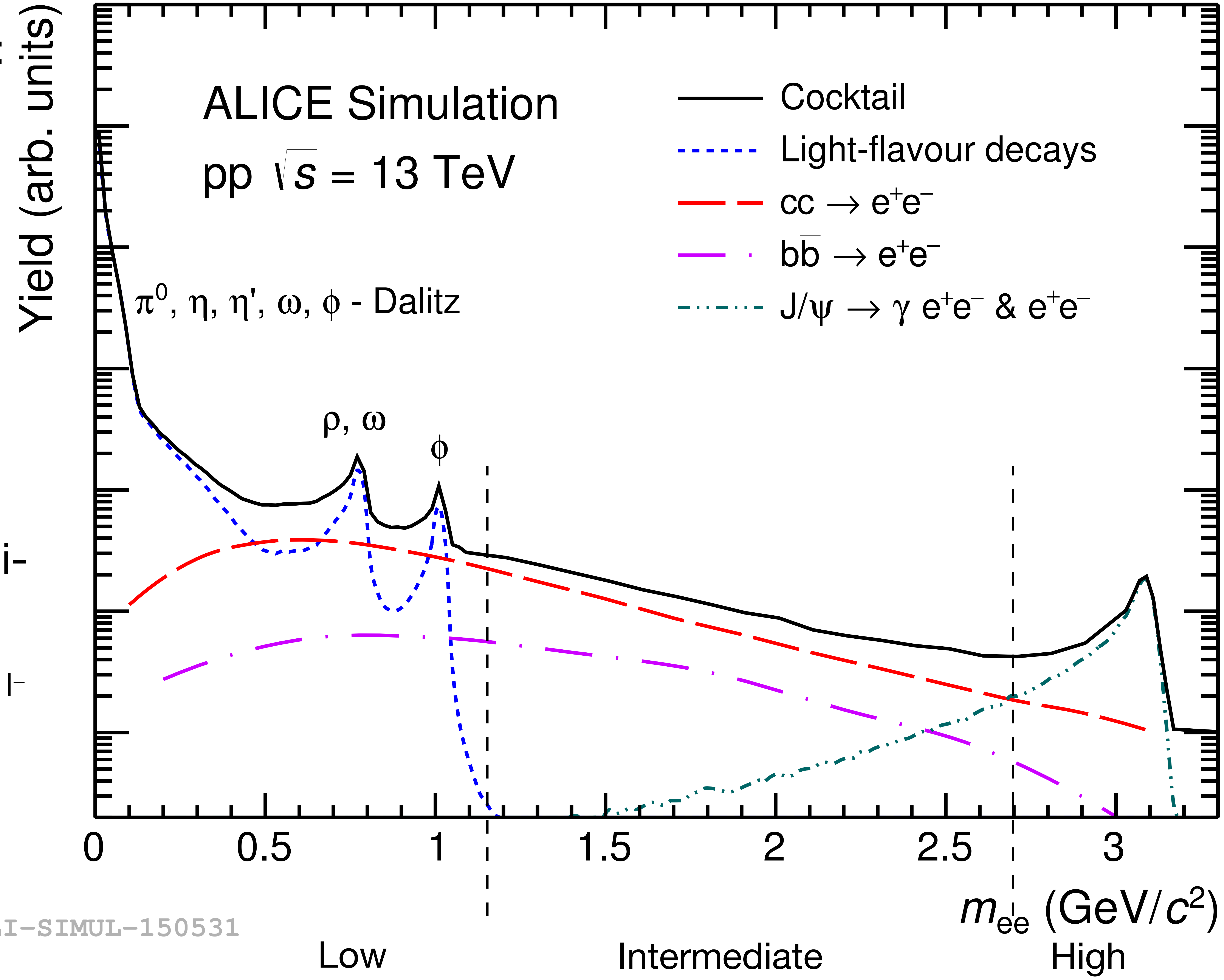

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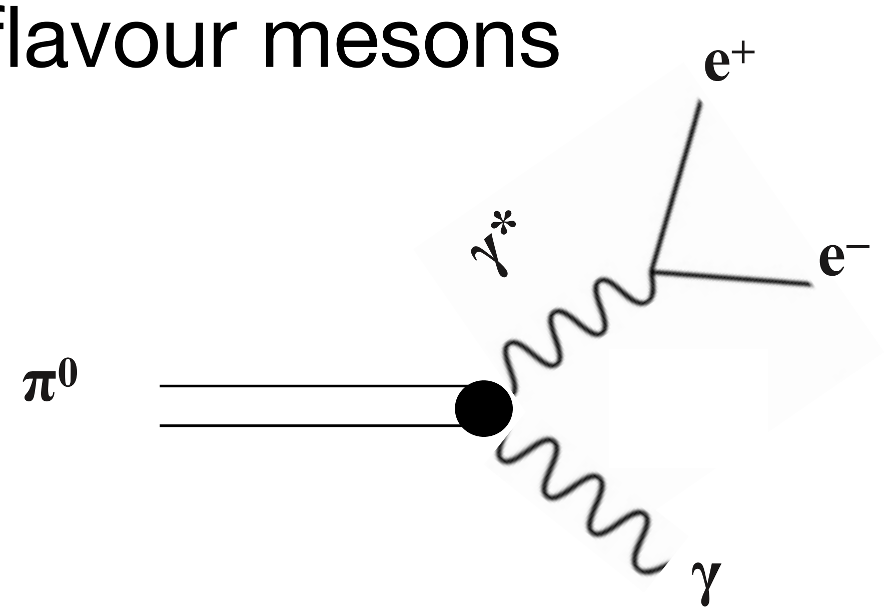

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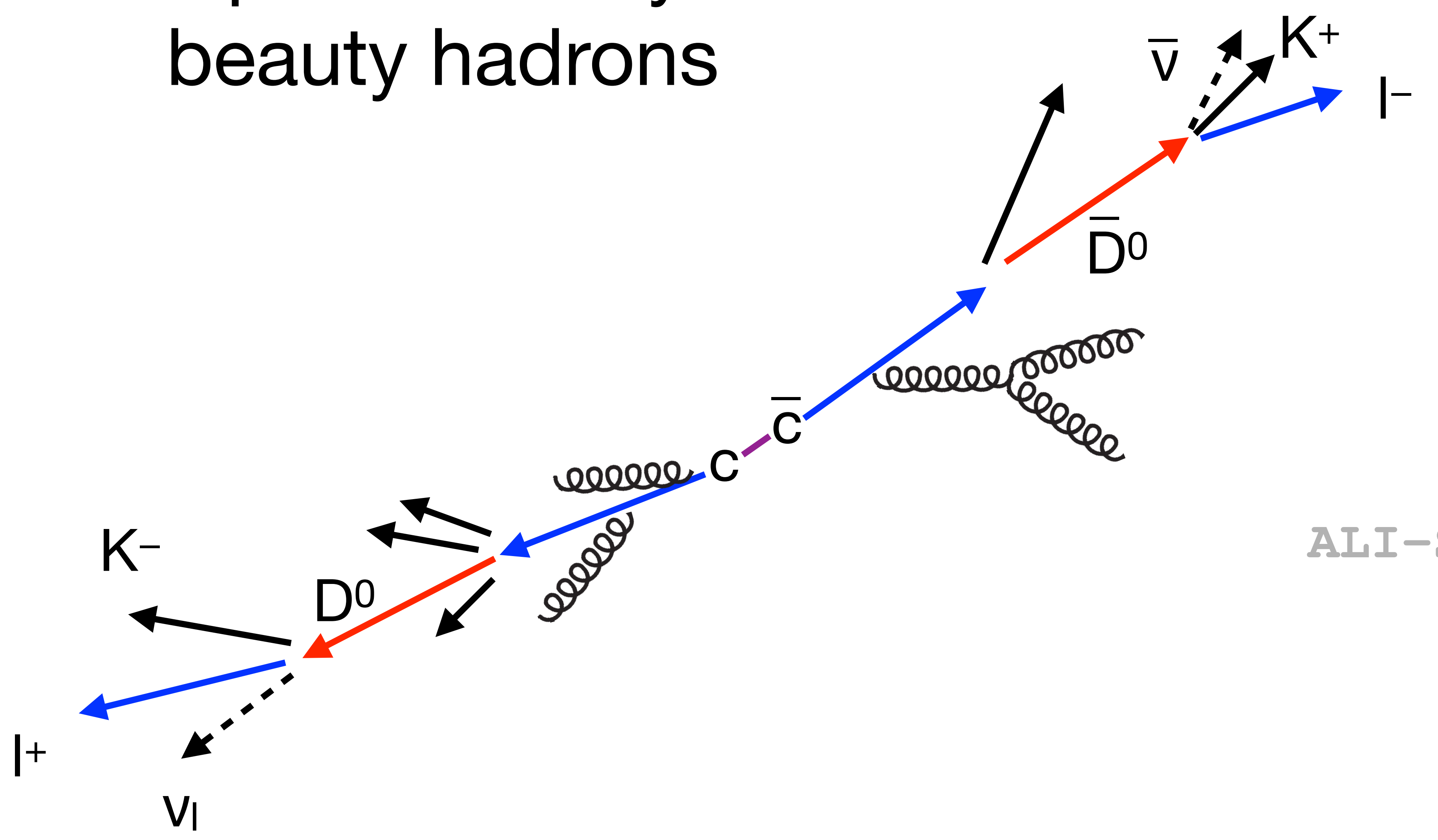

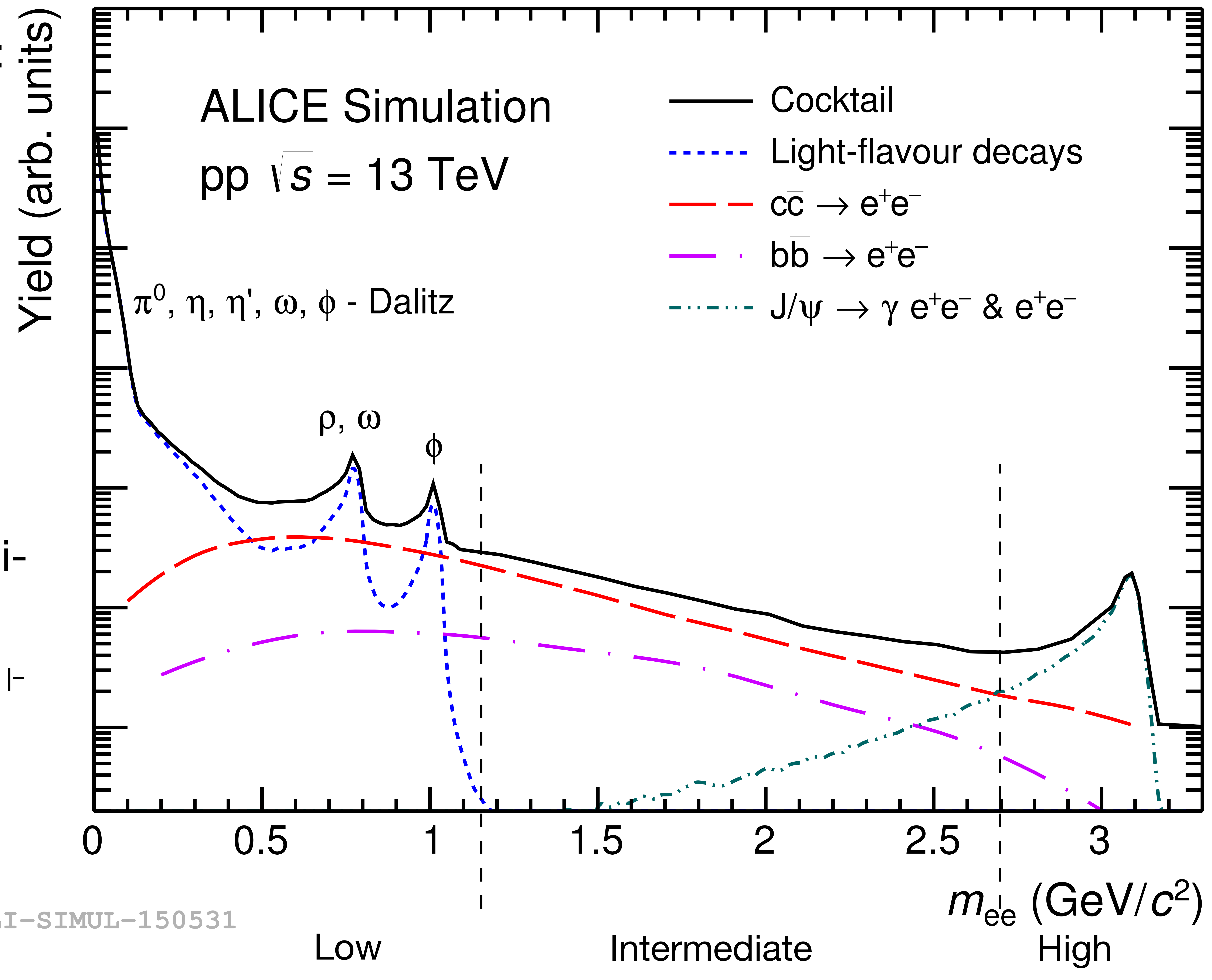

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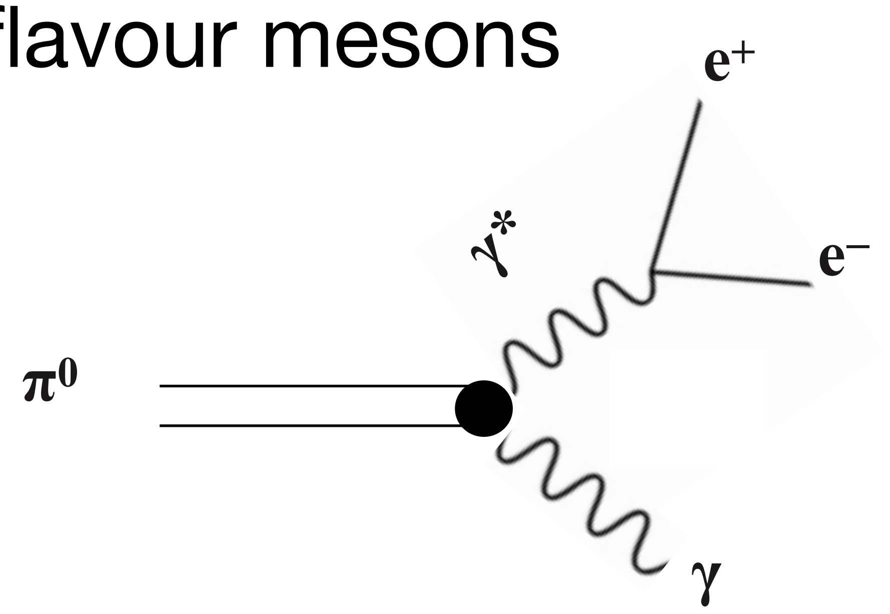

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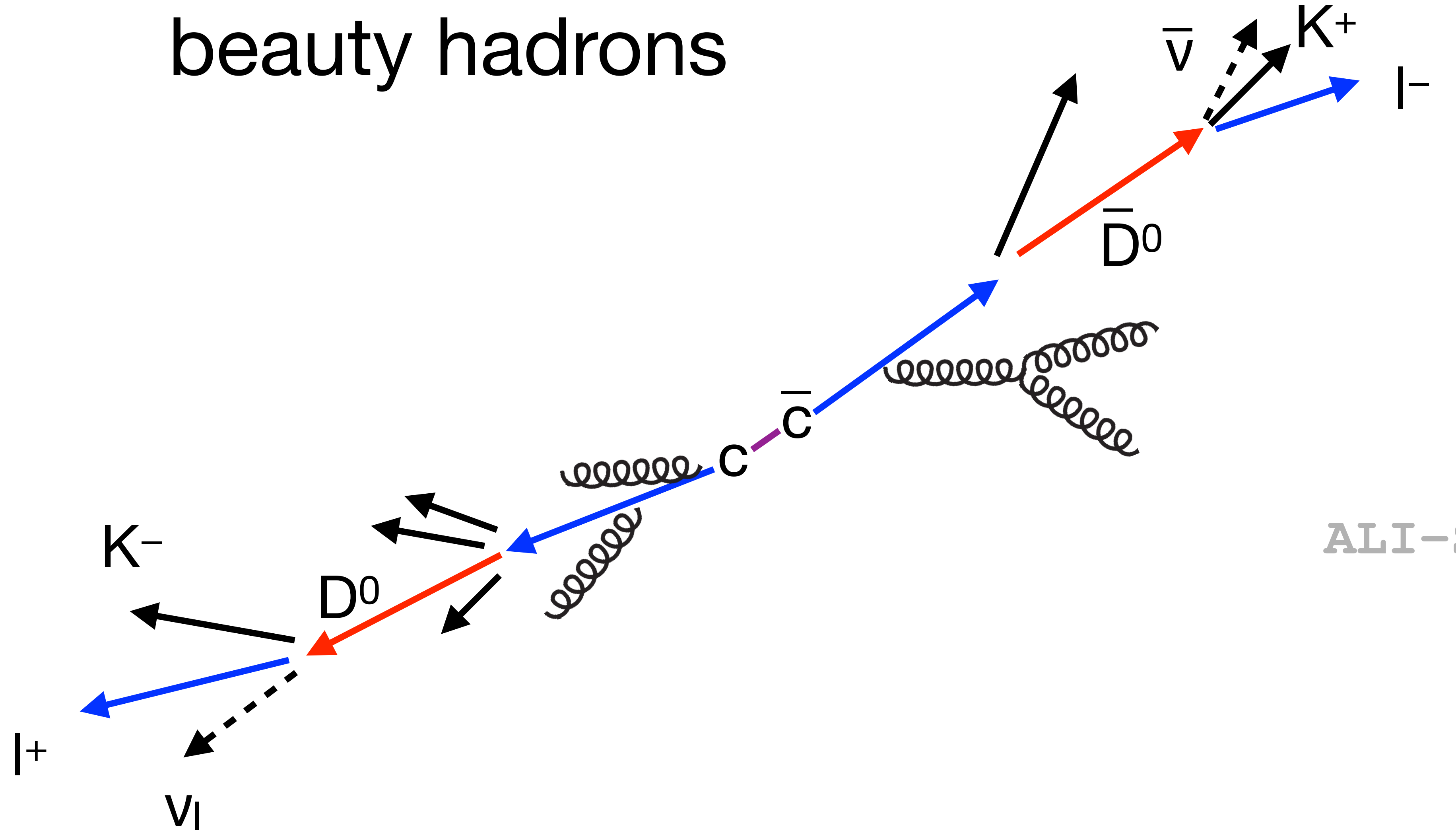

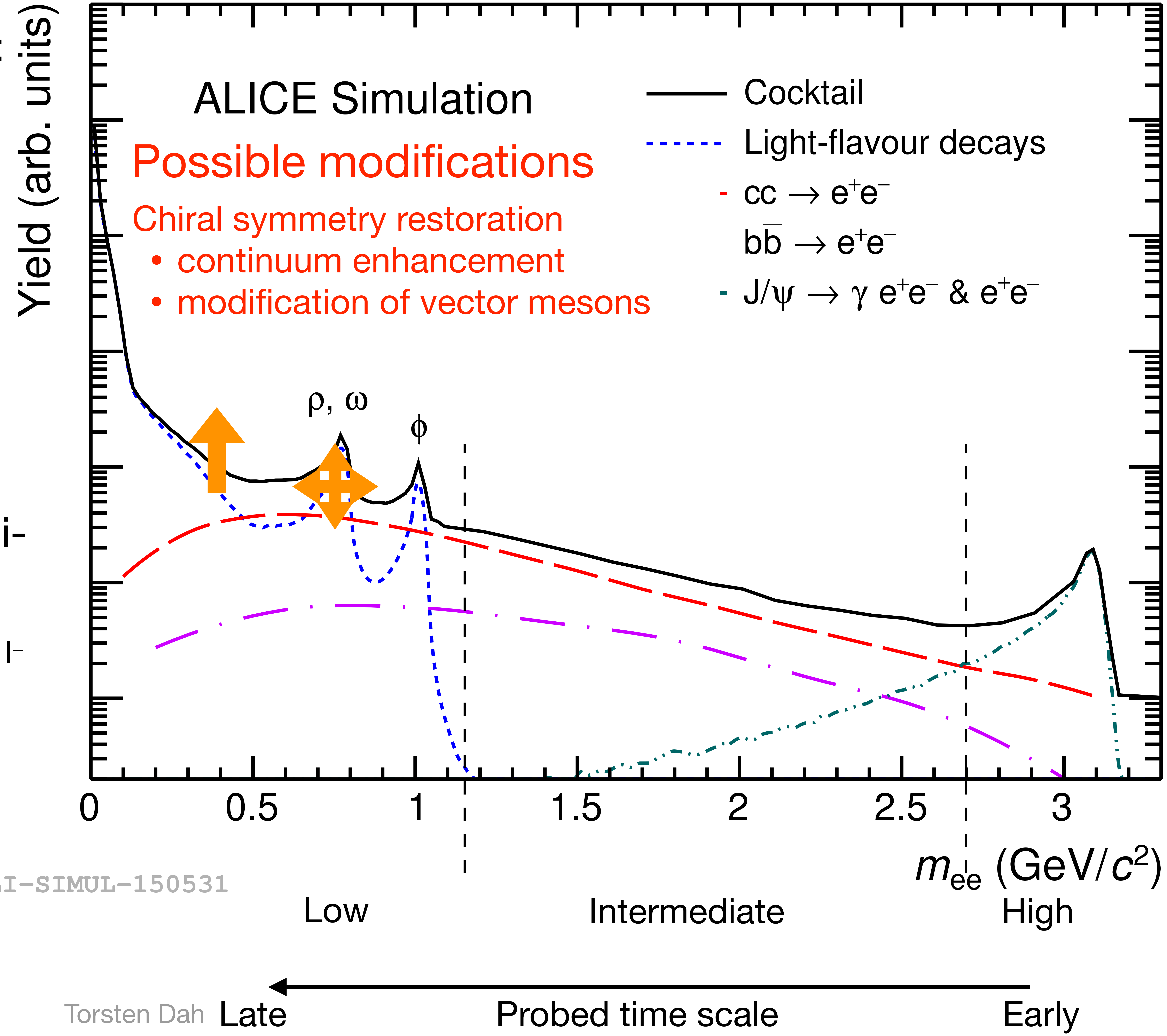

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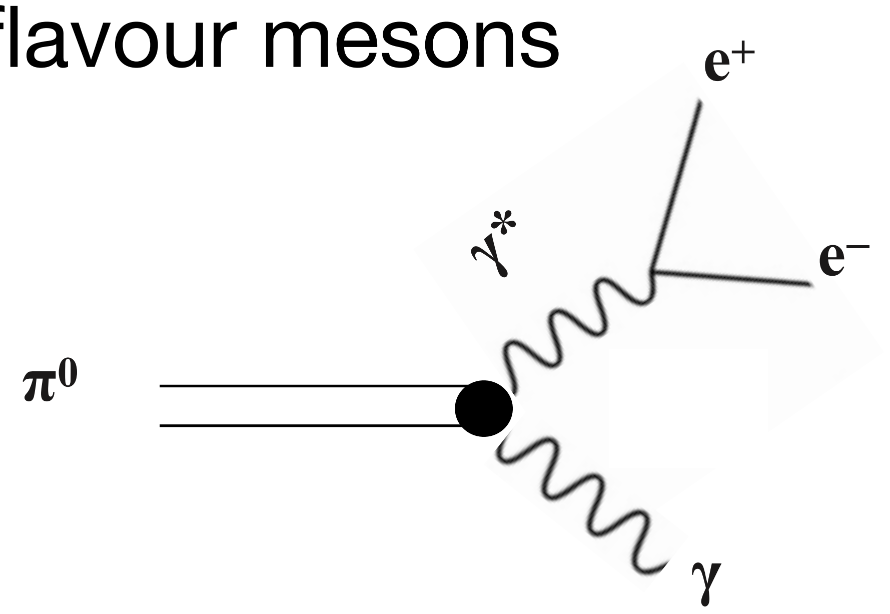

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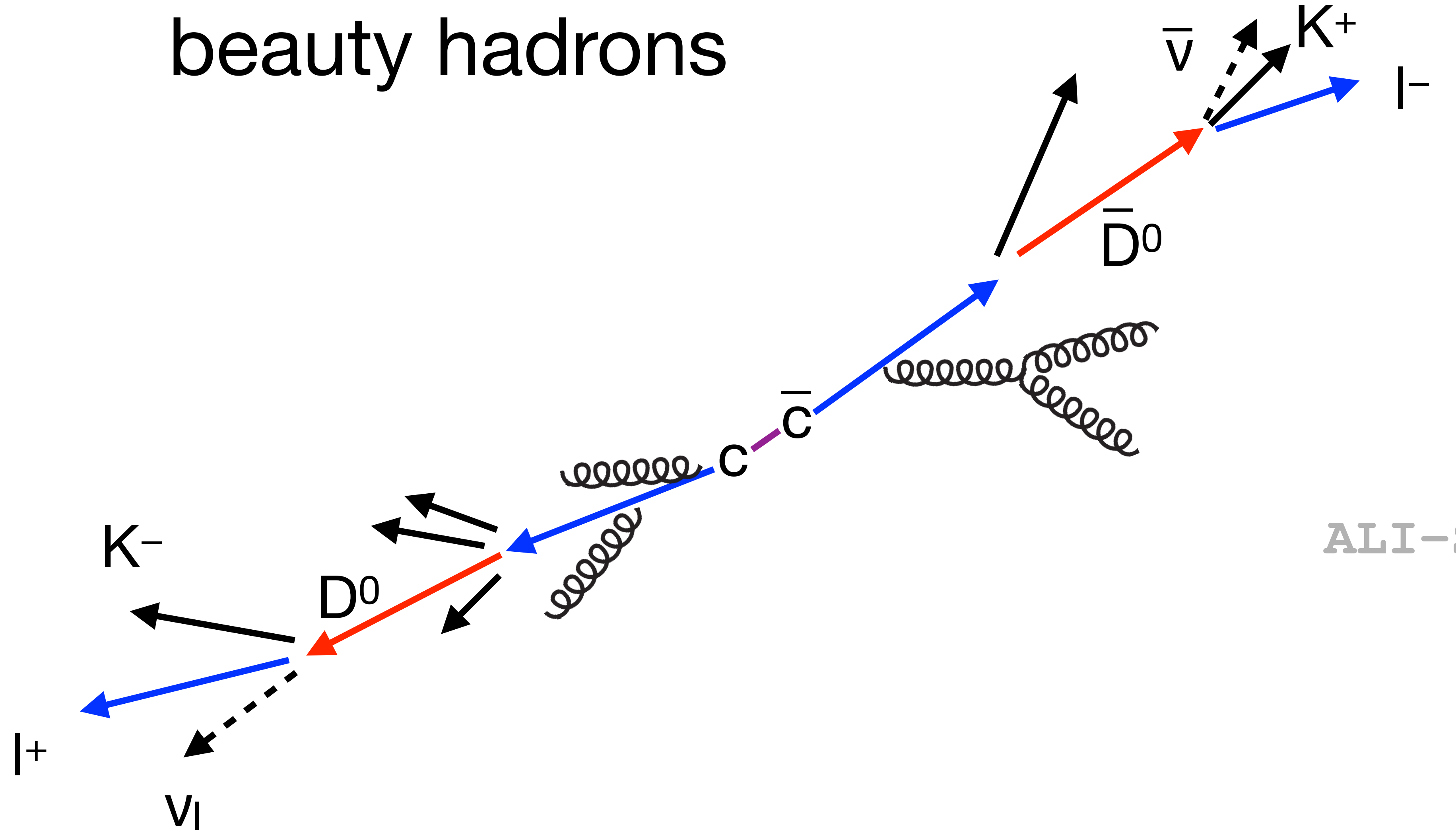

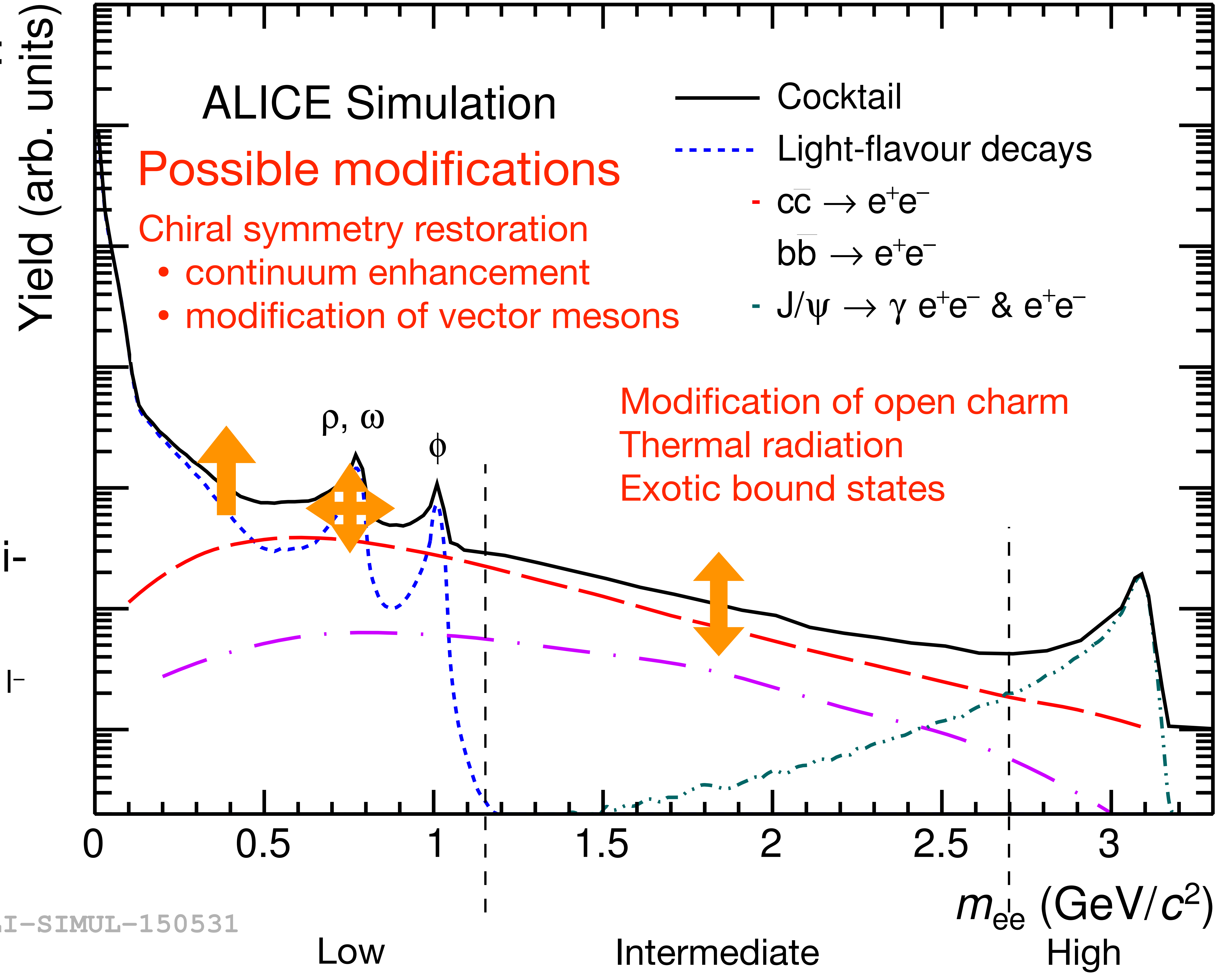

Late ← Probed time scale — Early

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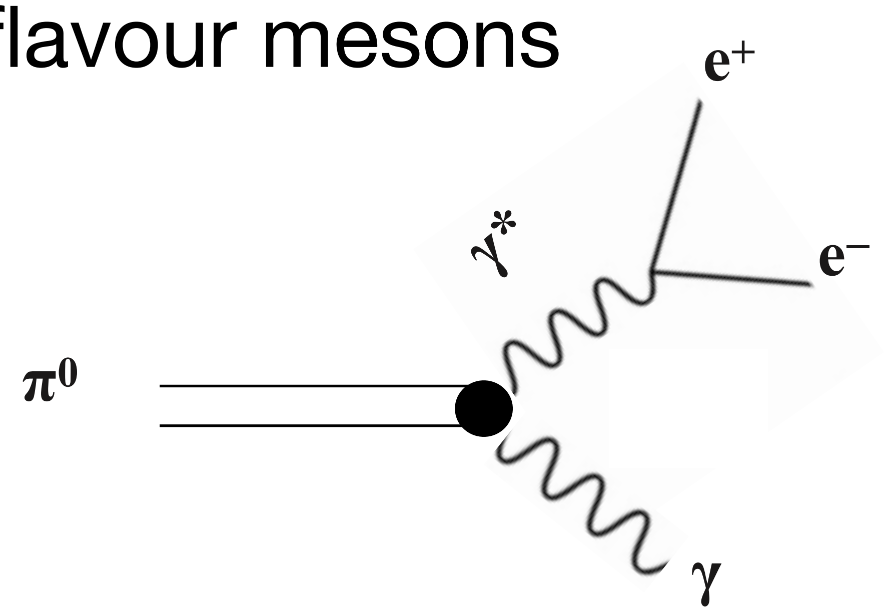

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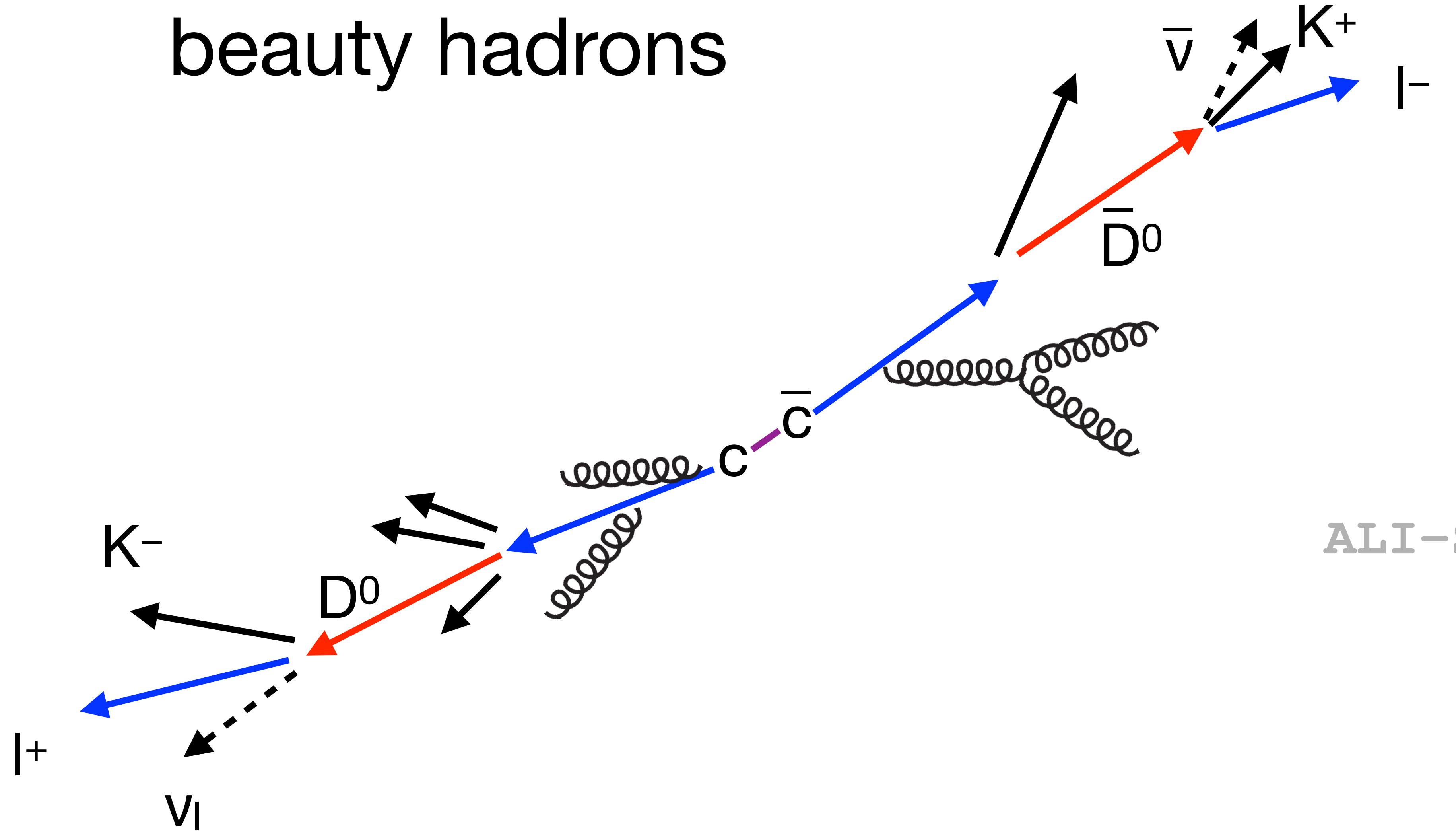
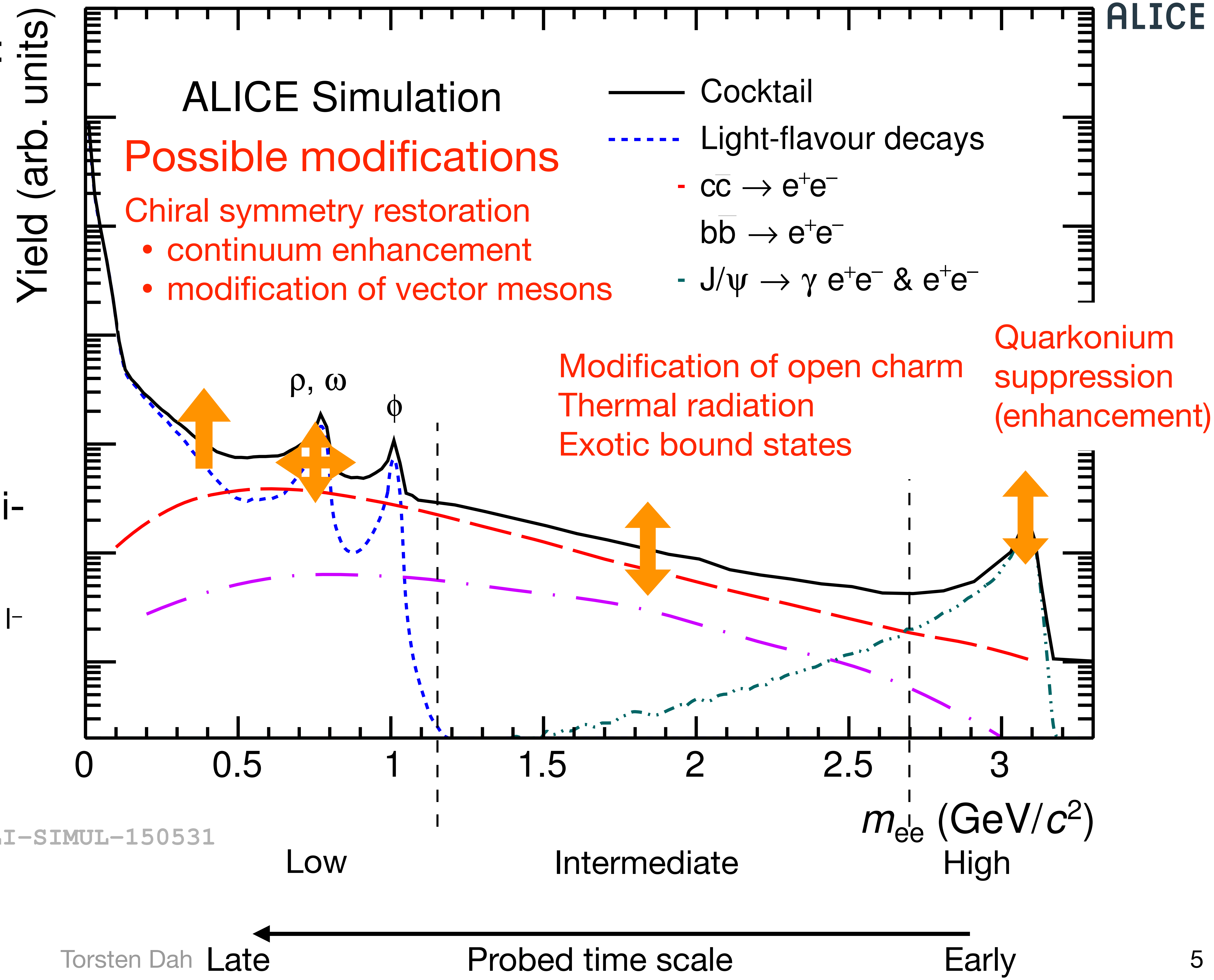
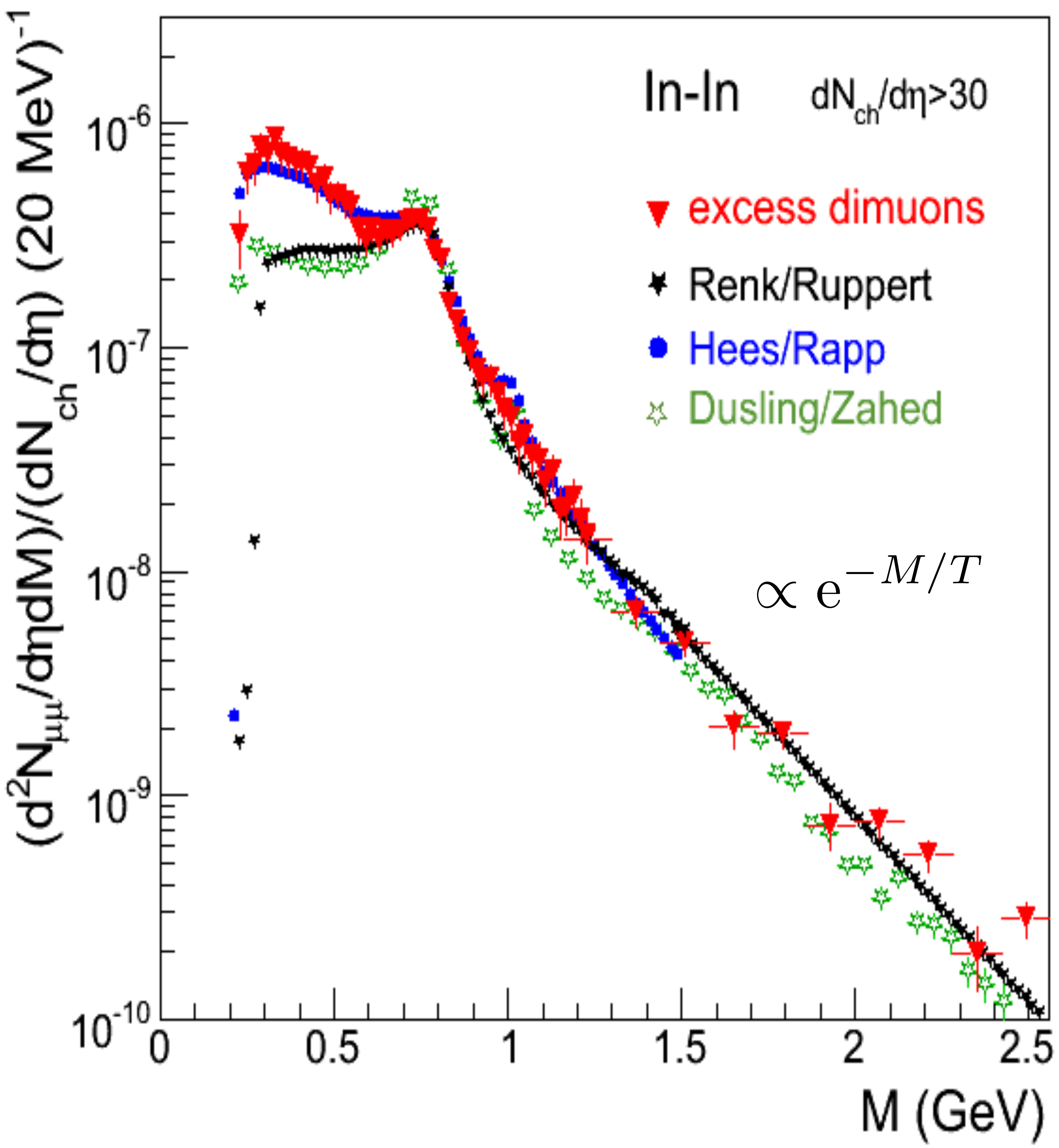




NA60: Thermal Dilepton Spectrum

- Acceptance corrected mass spectrum
- Hadron contributions subtracted
  - except the ρ
- *M*<1 GeV/*c*²:
  - dominated by broadened ρ from scattering with baryons
- *M*>1 GeV/*c*²:
  - Planck-like exponential shape
  - **fit yields *T* ~ 205–230 MeV**
  - above T_c → partonic production
  - Mass spectrum unaffected by radial flow (Lorenz invariant)



H. Specht, AIP Conf.Proc. 1322 (2010) 1

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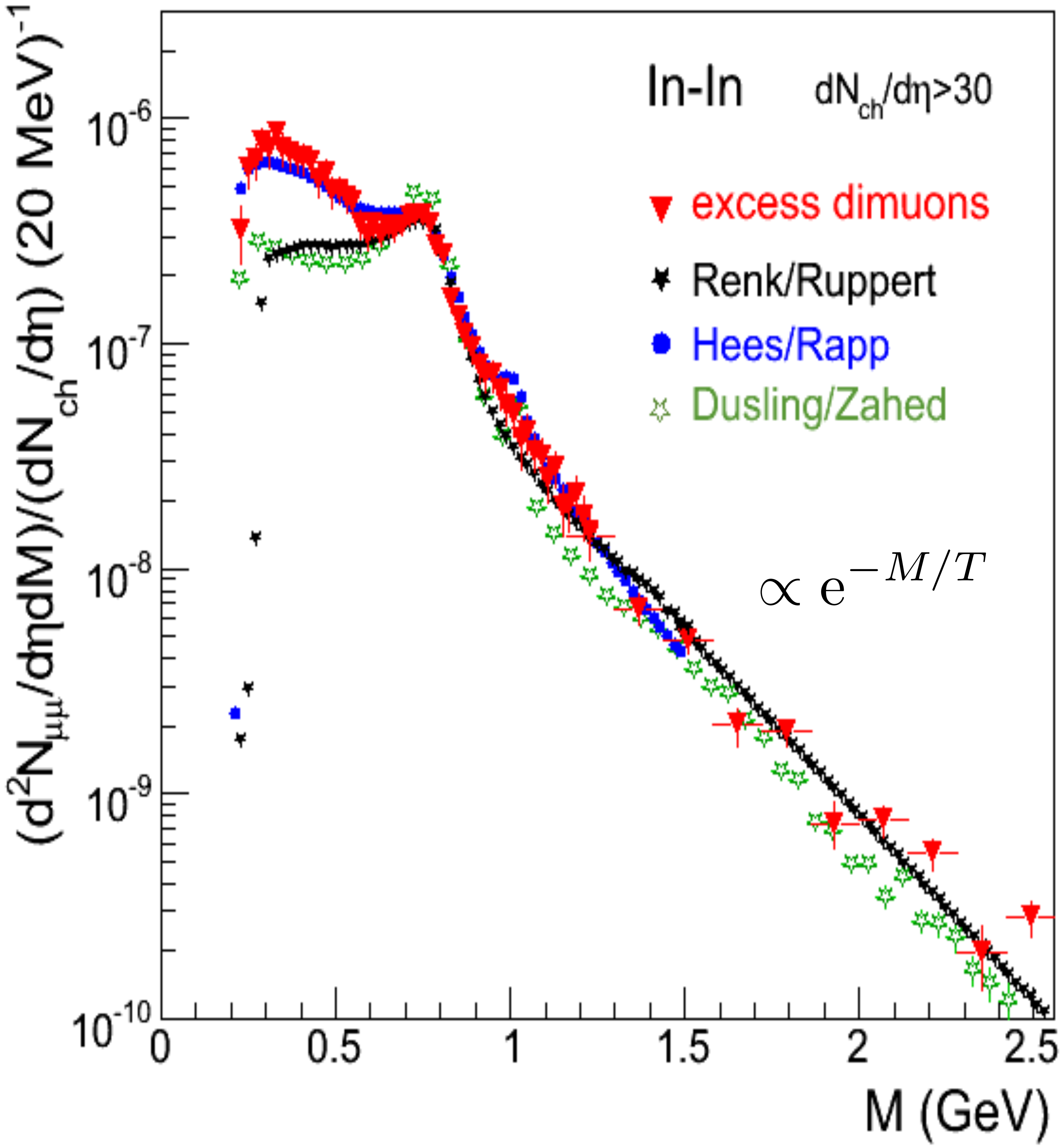
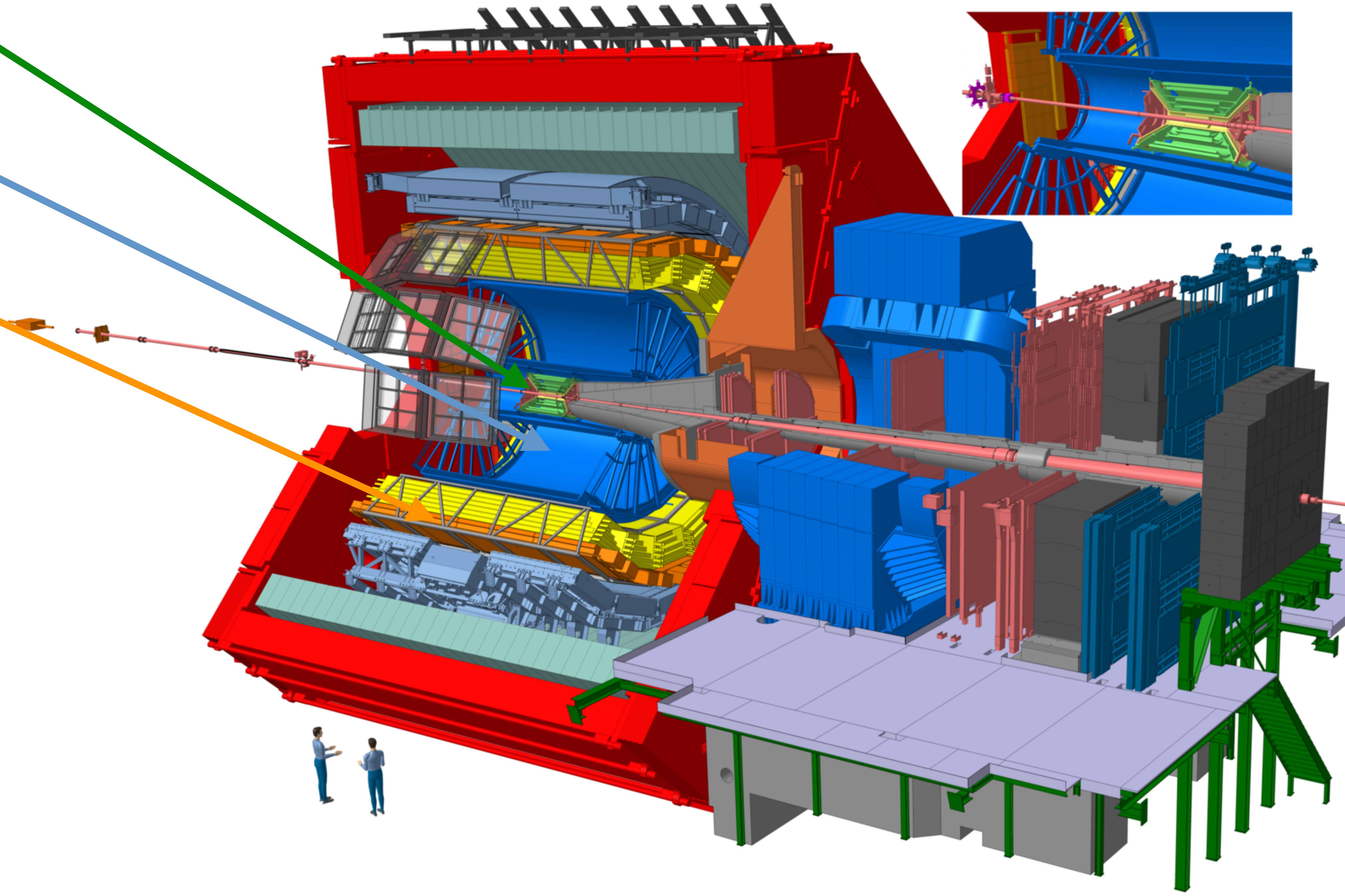


H. Specht, AIP Conf.Proc. 1322 (2010) 1

- SPS energies: non-vanishing net-baryon density
- **LHC energies: zero net baryon density → lattice QCD applicable, test EOS**

A Large Ion Collider Experiment

- **Inner Tracking System:**
  - Tracking, vertex, PID (d*E*/dx)
- **Time Projection Chamber**
  - Tracking, PID (d*E*/dx)
- **Time Of Flight detector**
  - PID (TOF measurement)
- **V0 scintillators**
  - Trigger, centrality estimation



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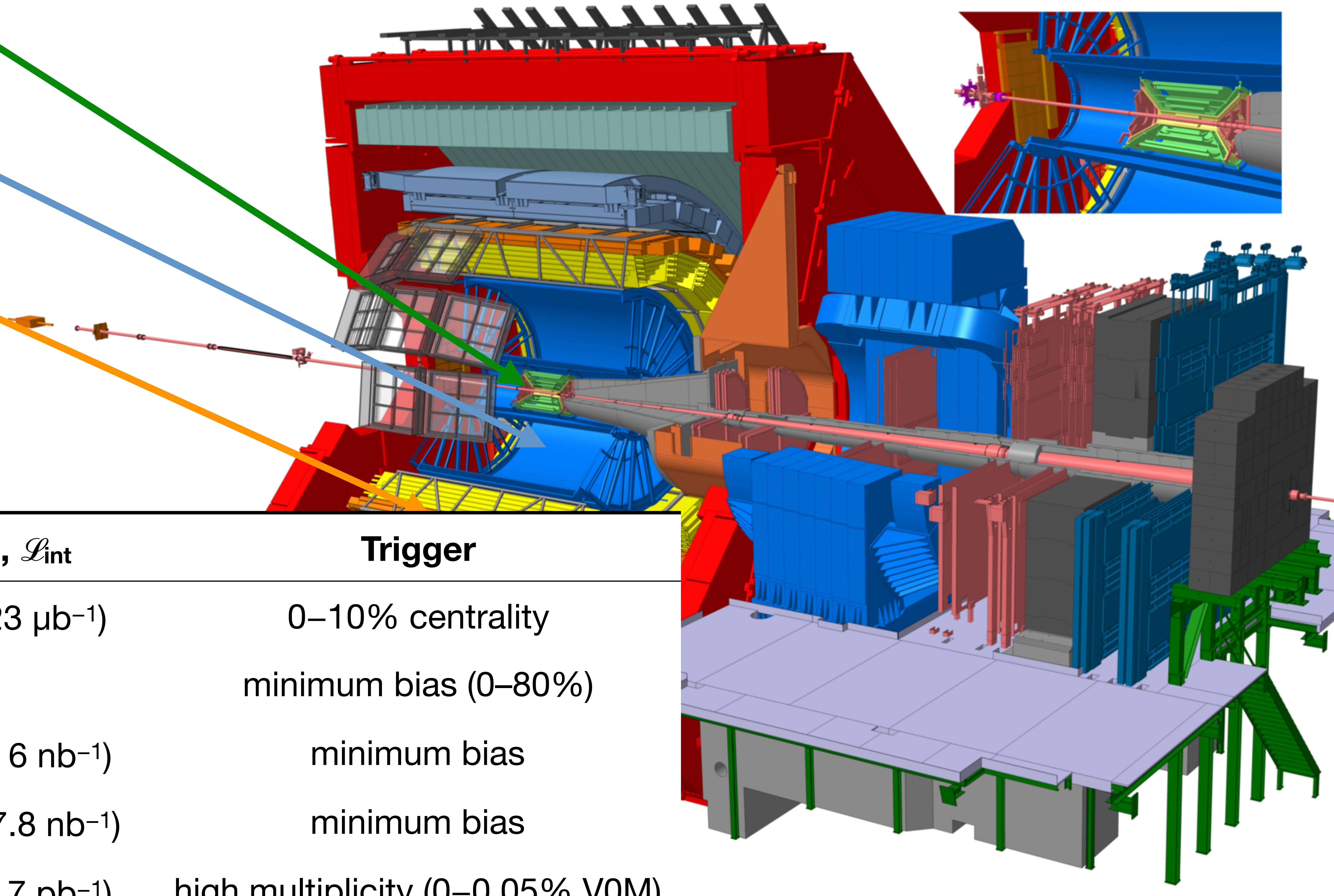

Collision system	Year	N of events, $\mathscr{L}_{int}$	Trigger
Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV	2011	~20 M ($\mathscr{L}_{int}$ ~ 23 μb^{-1})	0–10% centrality
Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV	2015	~80 M	minimum bias (0–80%)
pp at $\sqrt{s}$ = 7 TeV	2010	~370 M ($\mathscr{L}_{int}$ ~ 6 nb^{-1})	minimum bias
pp at $\sqrt{s}$ = 13 TeV	2016	~440 M ($\mathscr{L}_{int}$ ~ 7.8 nb^{-1})	minimum bias
pp at $\sqrt{s}$ = 13 TeV	2016	~80 M ($\mathscr{L}_{int}$ ~ 2.7 pb^{-1})	high multiplicity (0–0.05% V0M)
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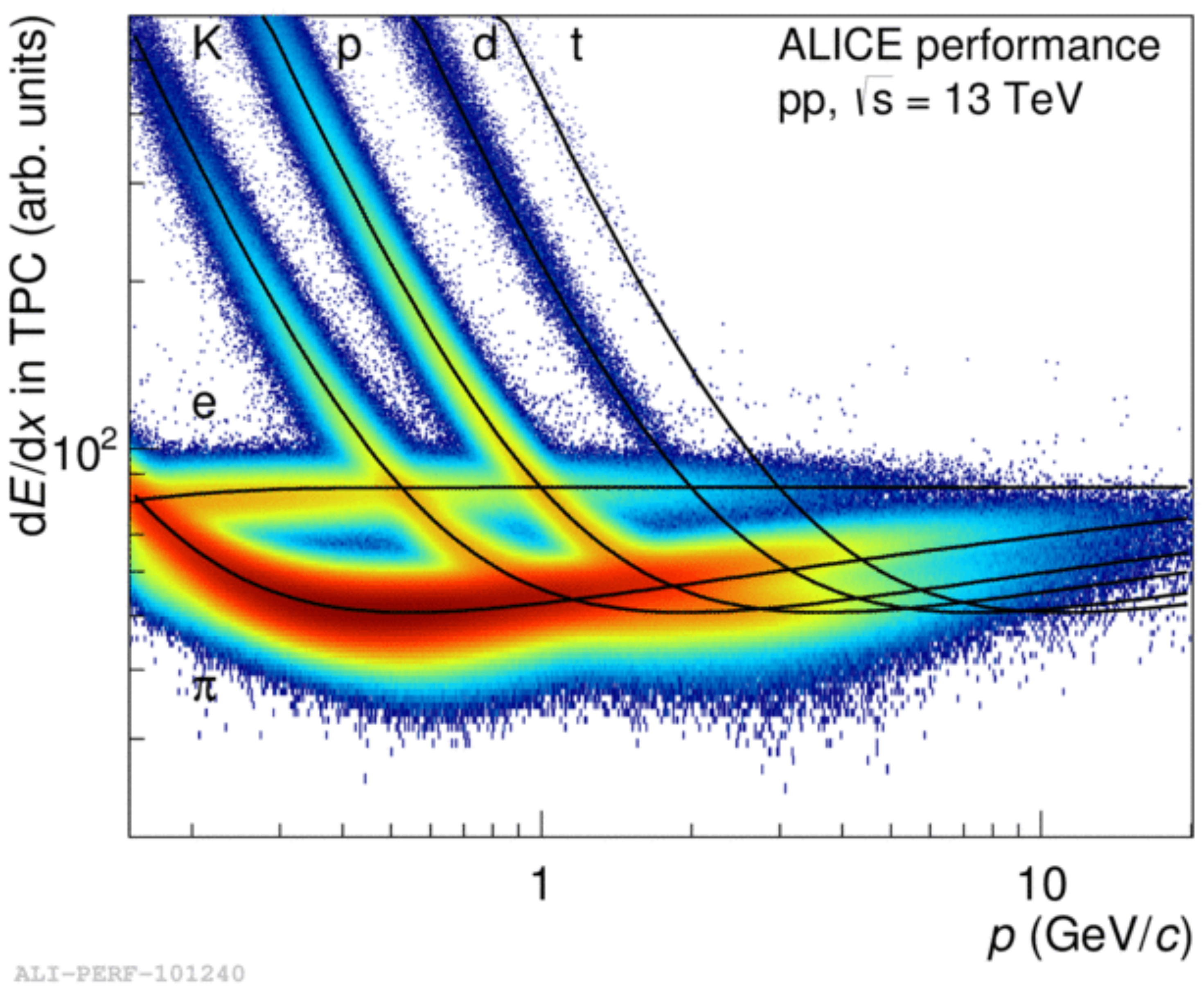

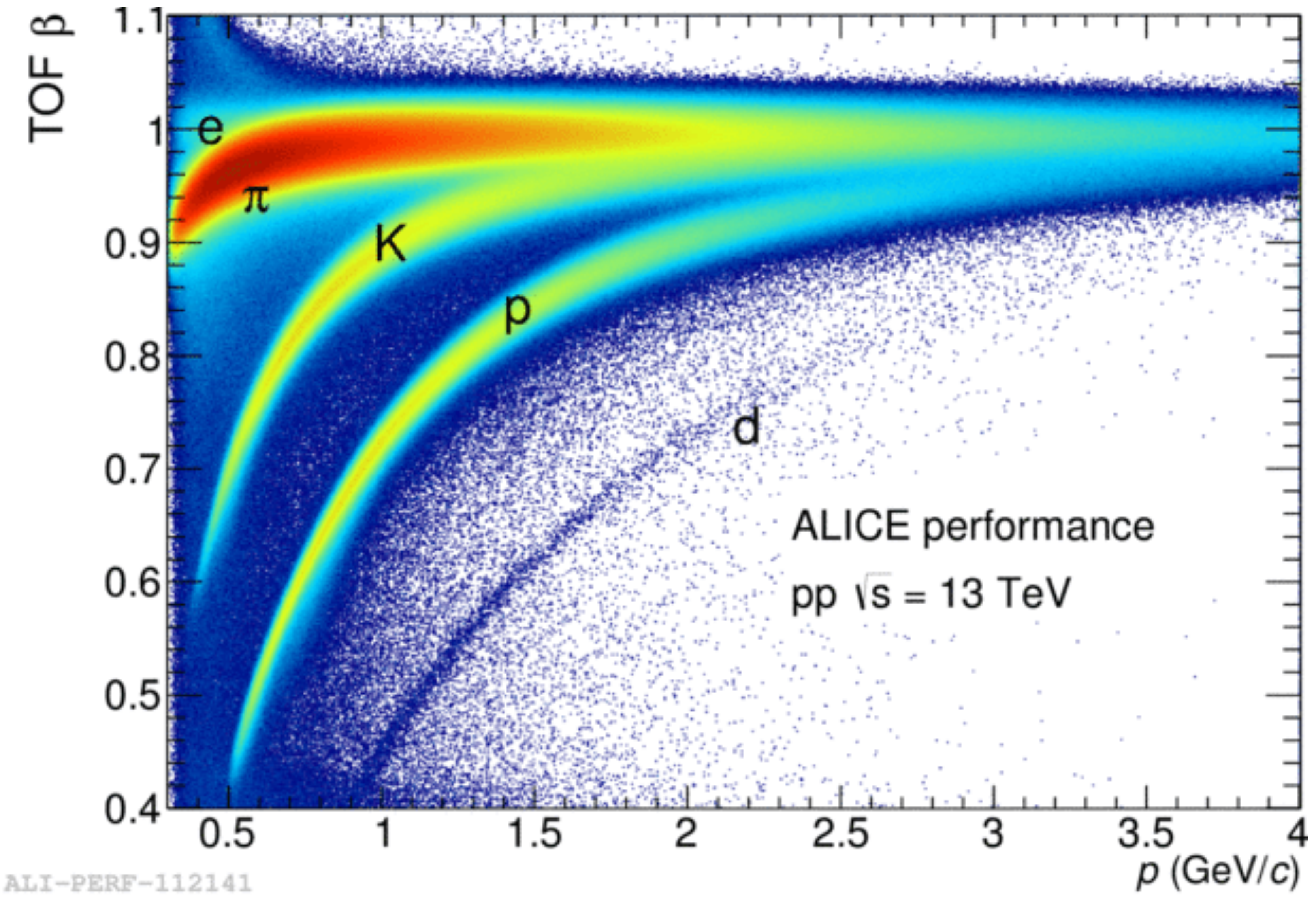

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Dielectron Signal Extraction in ALICE

- Physics signal: $S = N_{+-} - B$
- Combinatorial background: $B = R \cdot 2\sqrt{N_{++} \cdot N_{--}}$ geometric mean of same-sign pairs
- Pair acceptance correction factor (from mixed events)

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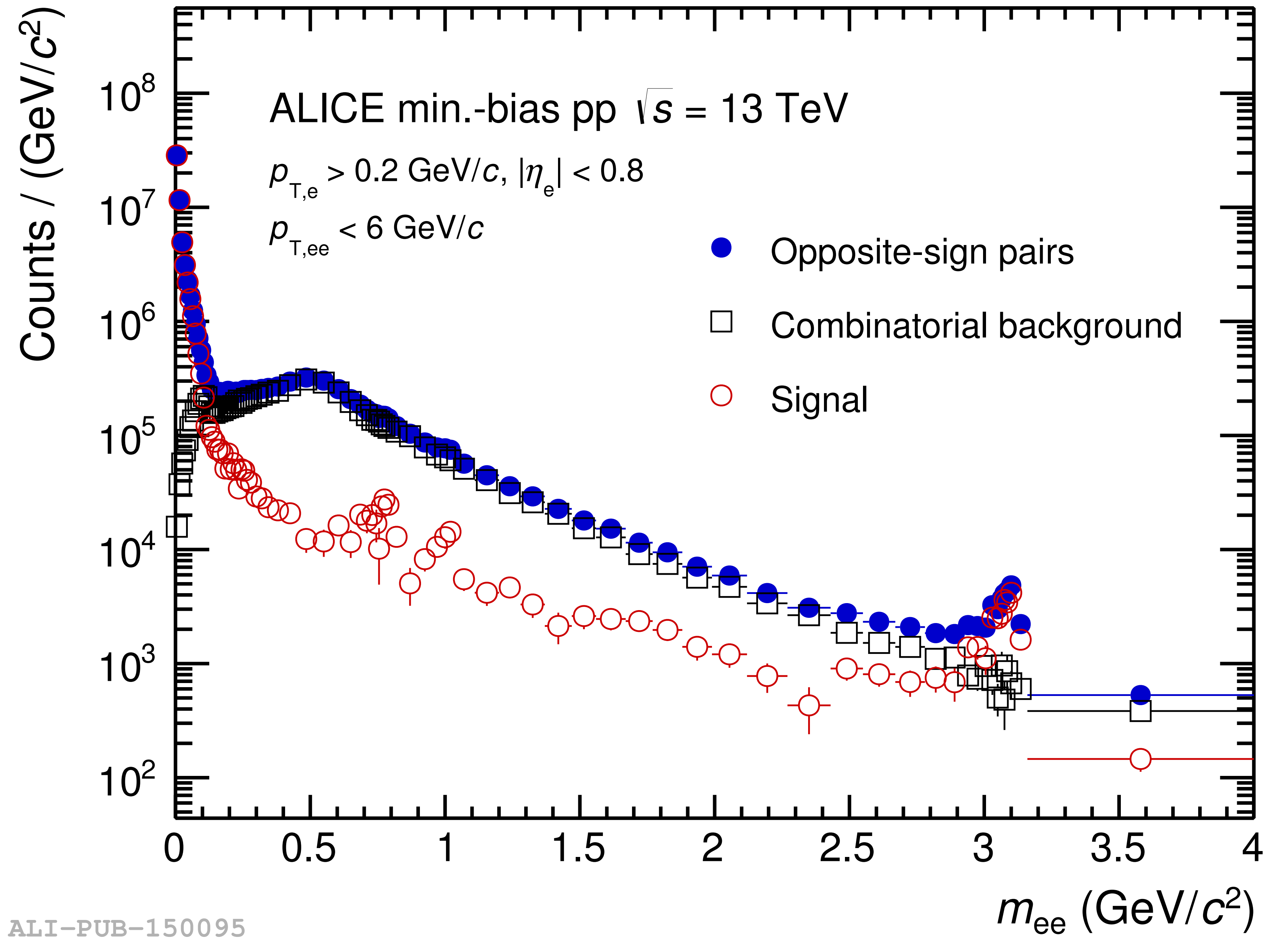

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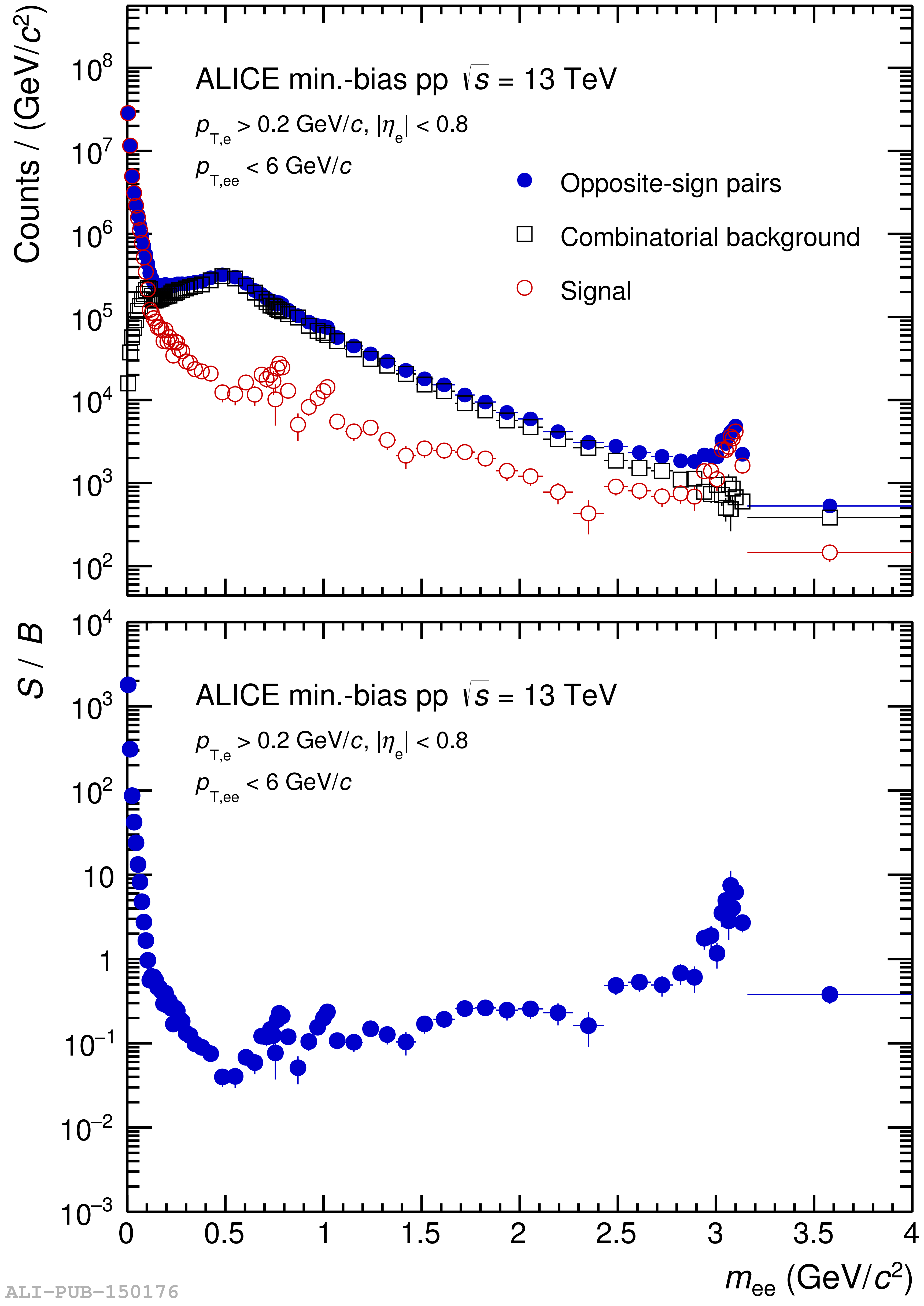
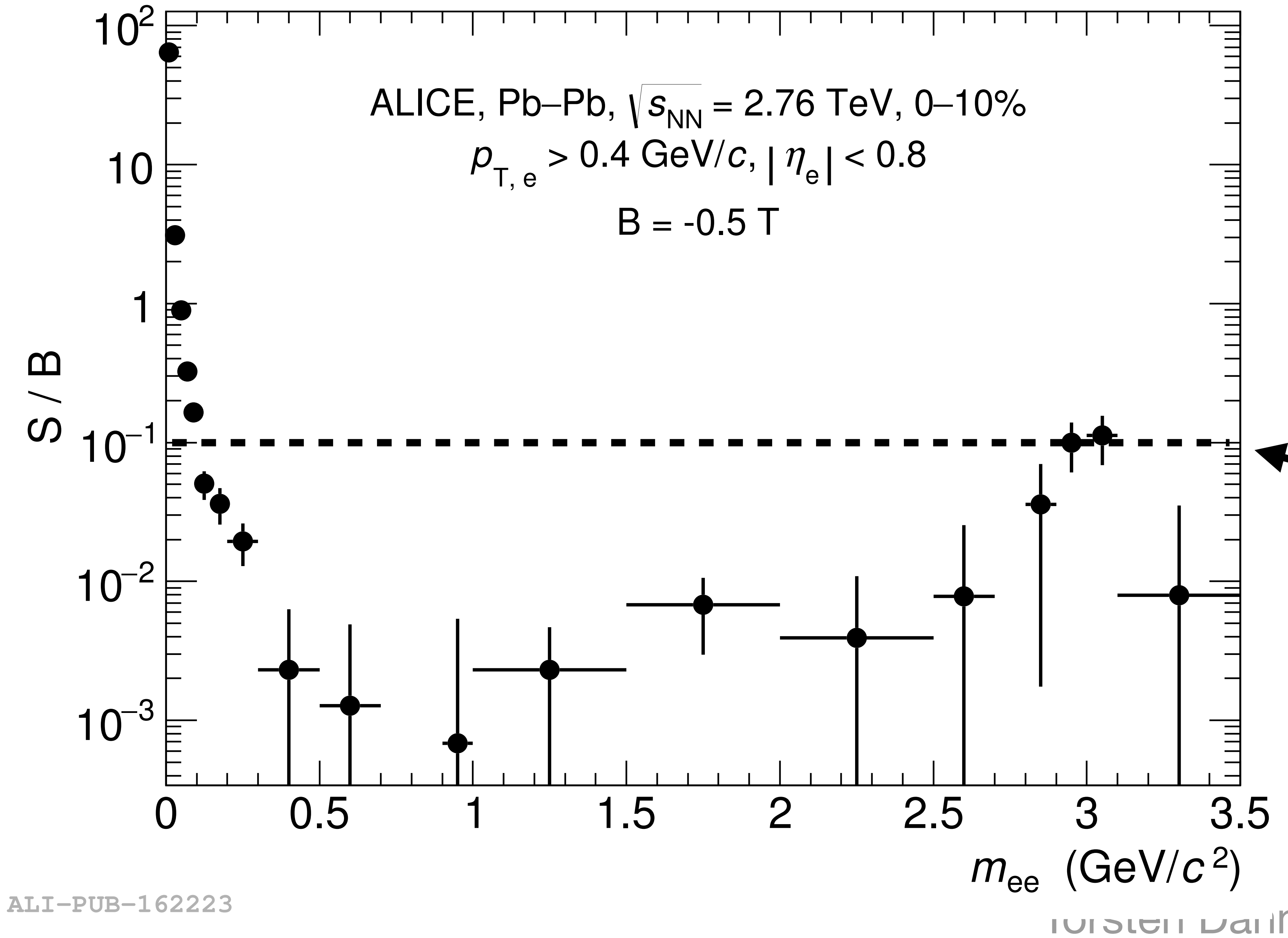
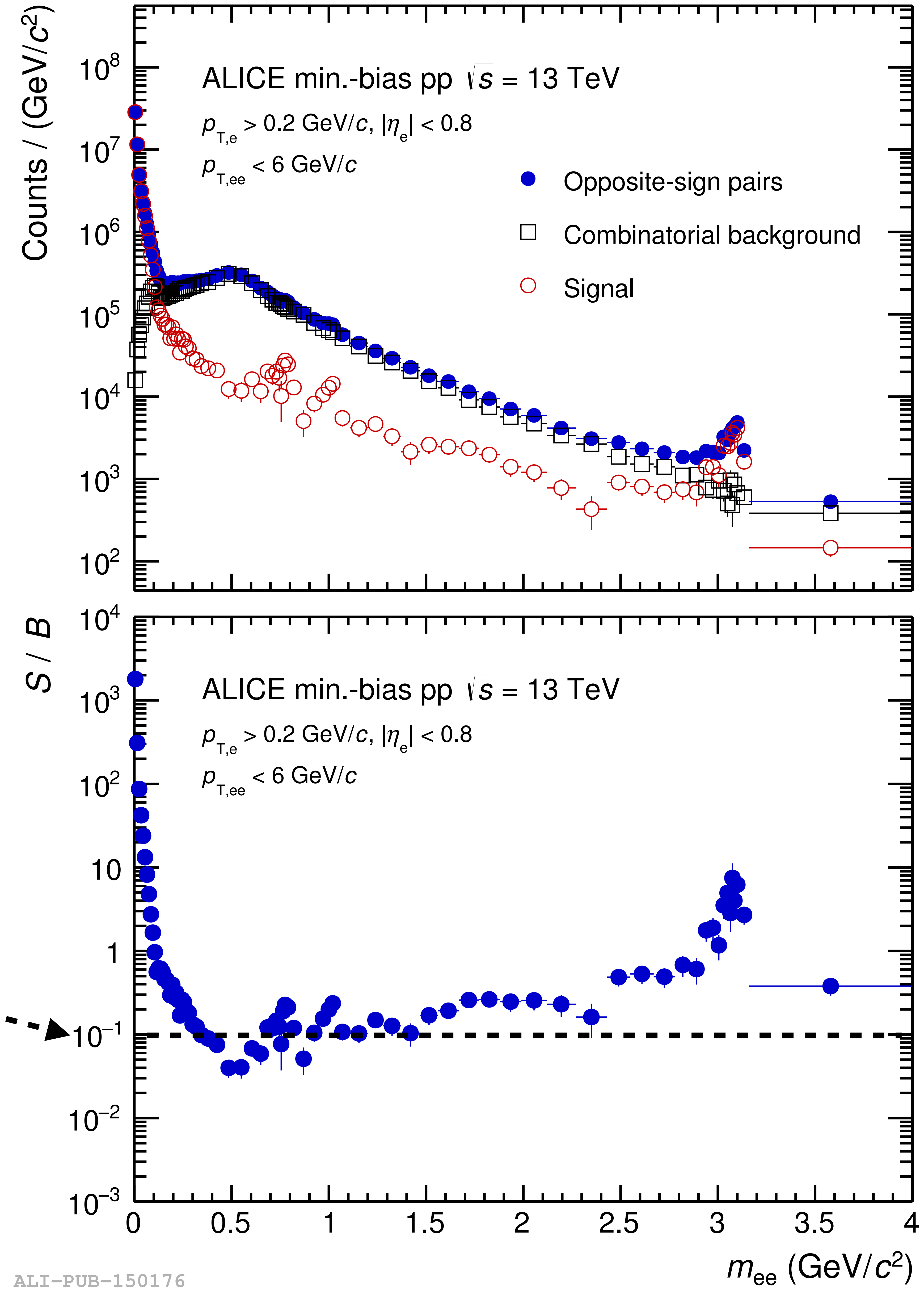


Dielectron Signal Extraction in ALICE

- Physics signal: $S = N_{+-} - B$
- Combinatorial background: $B = R \cdot 2\sqrt{N_{++} \cdot N_{--}}$
  geometric mean of same-sign pairs
- Pair acceptance correction factor
  (from mixed events)

$$R = \frac{M_{+-}}{2\sqrt{M_{++} \cdot M_{--}}}$$





Results in Pb-Pb Collisions

ALICE, arXiv:1807.00923 (accepted by PRC)

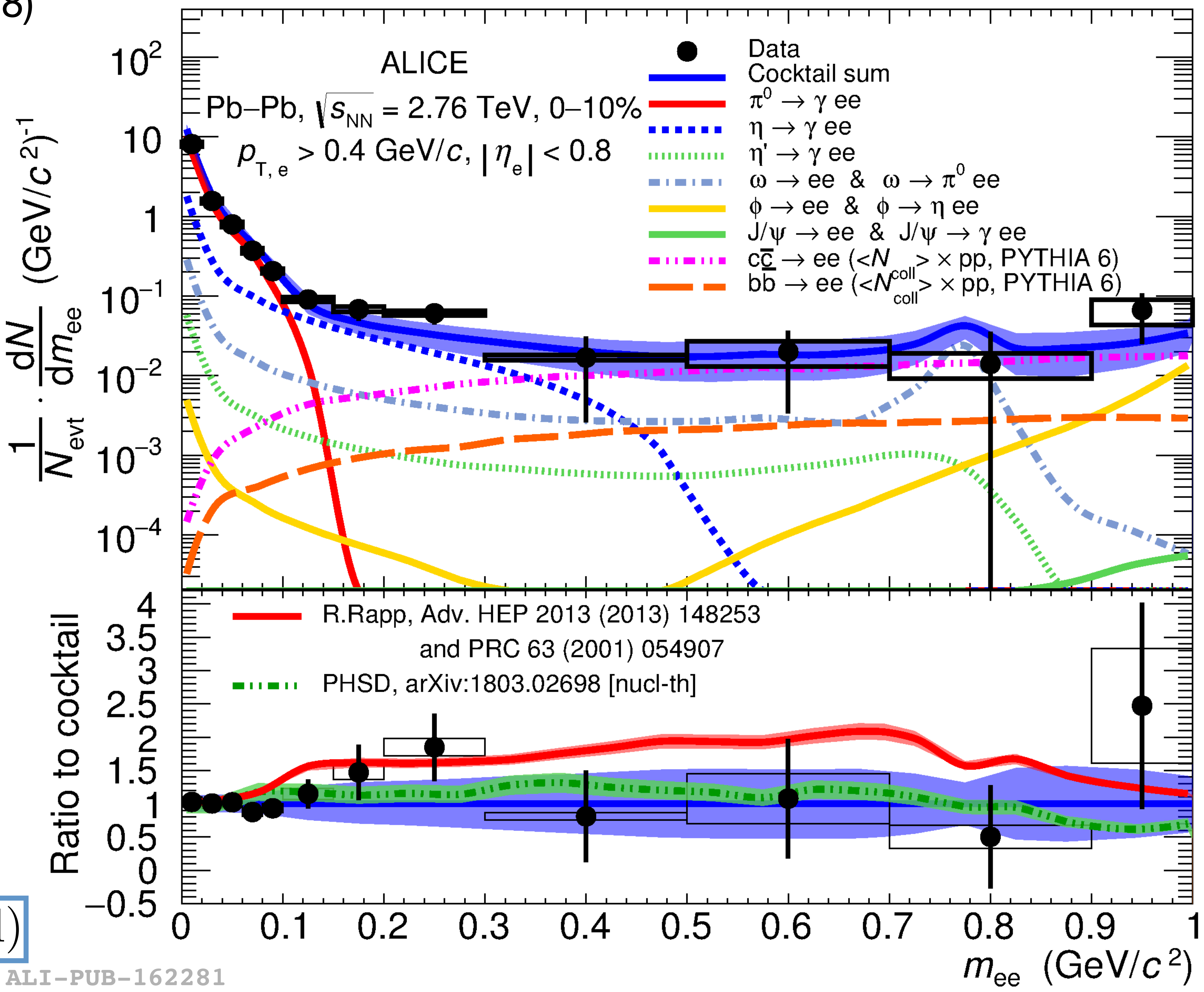
Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV

- Data compared to hadronic cocktail + models
  - apply detector acceptance ($p_{T,e}$ > 0.4 GeV/c, $|\eta_e|$ < 0.8) and resolution effects to cocktail
- Light-flavour sources:
  - Measured π^0, η/π and K/π
  - m_T scaling for other hadrons
- Heavy-flavour:
  - PYTHIA for pp at 2.76 TeV × N_{coll} from Glauber MC
  - No sensitivity to medium / shadowing effects
- Thermal radiation and modified ρ:
  - **Expanding fireball model**
  - **PHSD: transport approach**
- Data/cocktail (excluding vacuum ρ) in $0.15 < m_{ee} < 0.7$ GeV/c^2:

$$R = 1.38 \pm 0.28\,(\text{stat.}) \pm 0.08\,(\text{syst.}) \pm 0.27\,(\text{cocktail})$$

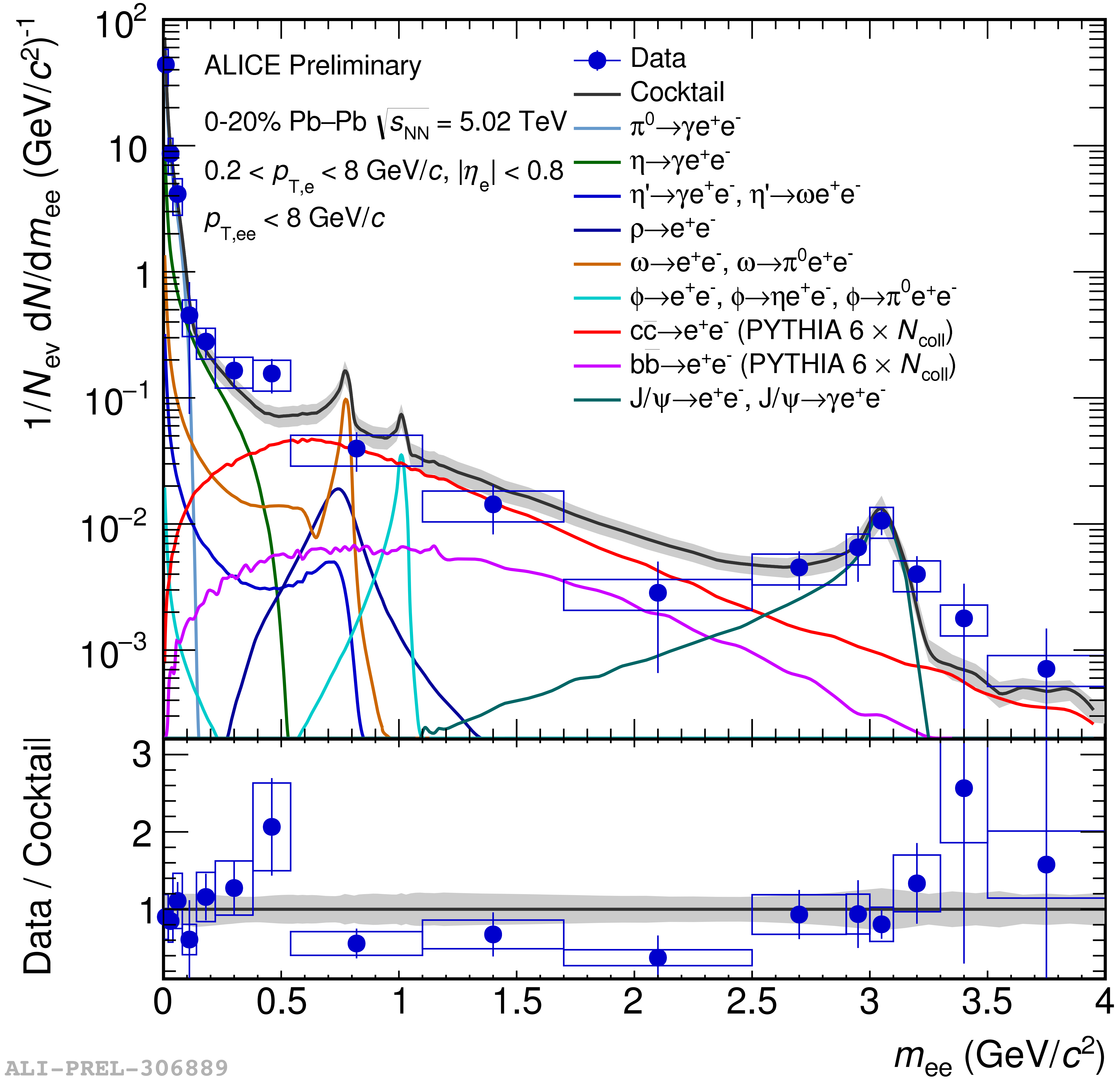
  - Consistent with models of enhancement
  - More data needed

ALICE, arXiv:1807.00923 (accepted by PRC)



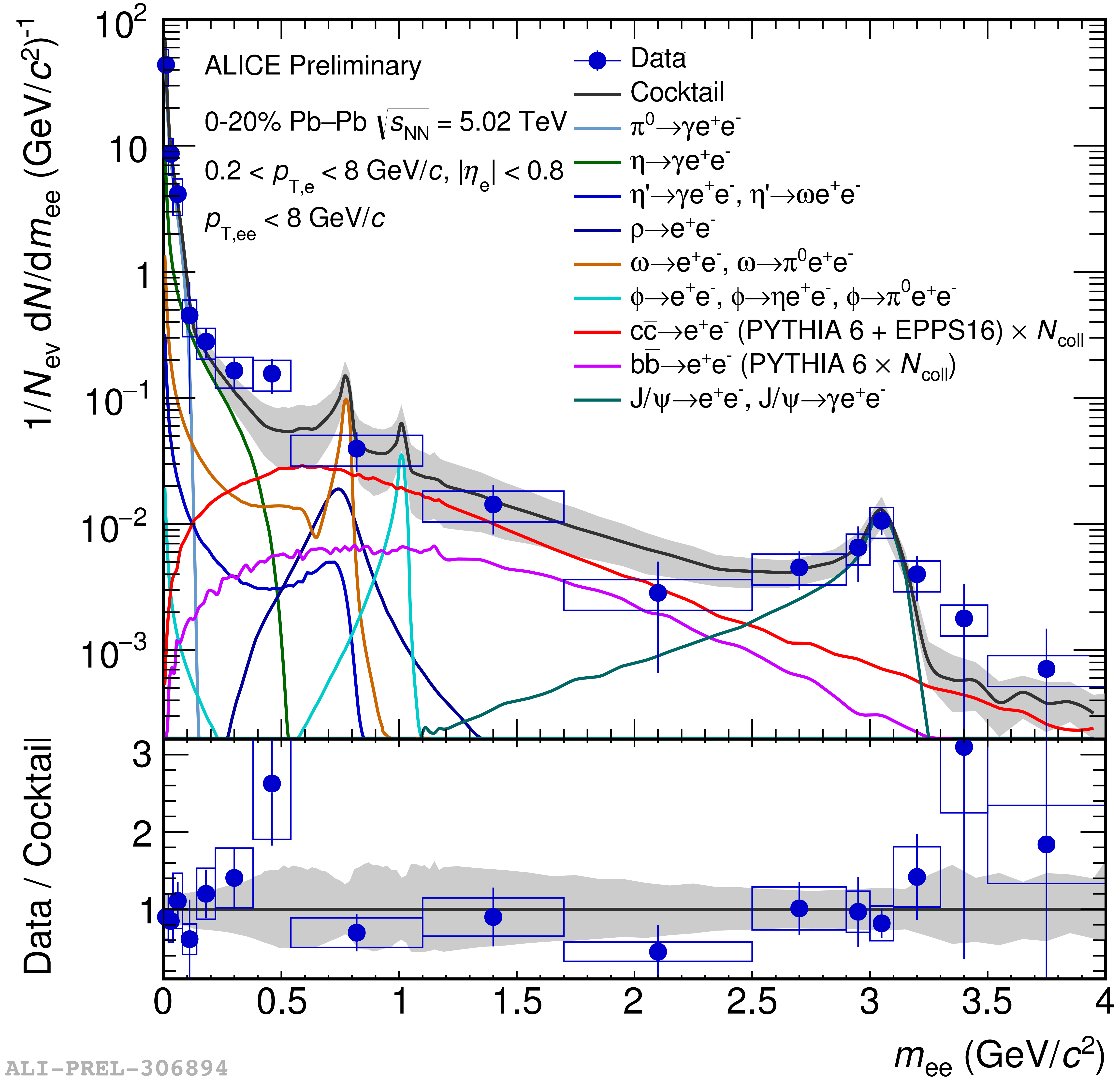
Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

- Data compared to hadronic cocktail + models
  - apply detector acceptance ($p_{T,e}$ > 0.2 GeV/c, $|\eta_e|$ < 0.8) and resolution effects to cocktail
- Light-flavour sources:
  - Measured π^0, η/π and K/π
  - m_T scaling for other hadrons
- Heavy flavours:
  - PYTHIA for pp at 5.02 TeV × N_{coll} from Glauber MC
  - Overestimates yield in intermediate mass region



Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

- Data compared to hadronic cocktail + models
  - apply detector acceptance ($p_{T,e}$ > 0.2 GeV/c, $|\eta_e|$ < 0.8) and resolution effects to cocktail
- Light-flavour sources:
  - Measured π^0, η/π and K/π
  - m_T scaling for other hadrons
- Heavy flavours:
  - PYTHIA for pp at 5.02 TeV × N_{coll} from Glauber MC
  - Overestimates yield in intermediate mass region
  - improved description when adding shadowing (EPPS16)



Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

- Data compared to hadronic cocktail + models
  - apply detector acceptance ($p_{T,e}$ > 0.2 GeV/c, $|\eta_e|$ < 0.8) and resolution effects to cocktail
- Light-flavour sources:
  - Measured π^0, η/π and K/π
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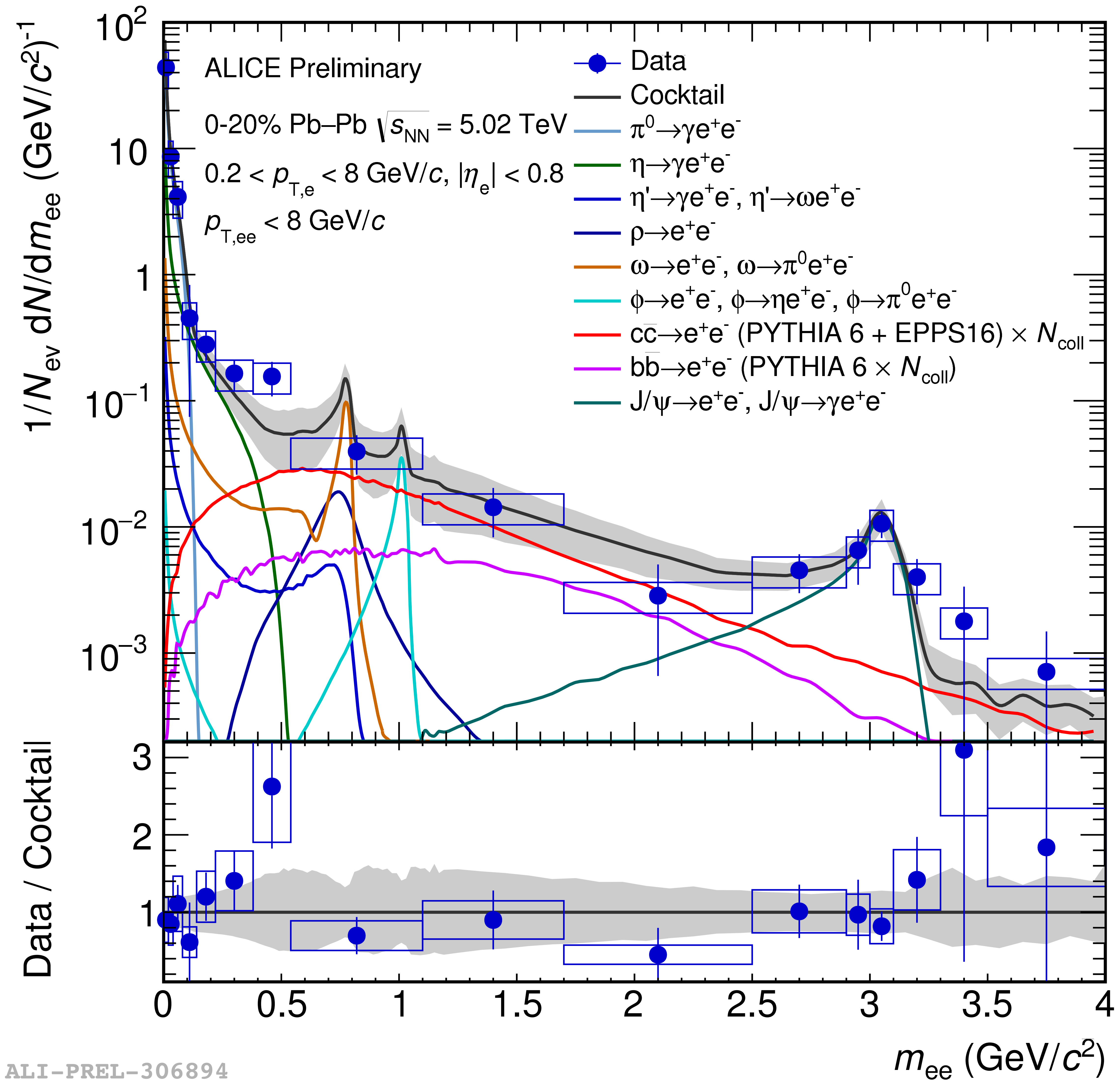
- Heavy flavours:
  - PYTHIA for pp at 5.02 TeV × N_{coll} from Glauber MC
  - Overestimates yield in intermediate mass region
  - improved description when adding shadowing (EPPS16)
- Data consistent with low mass enhancement
  - More data needed



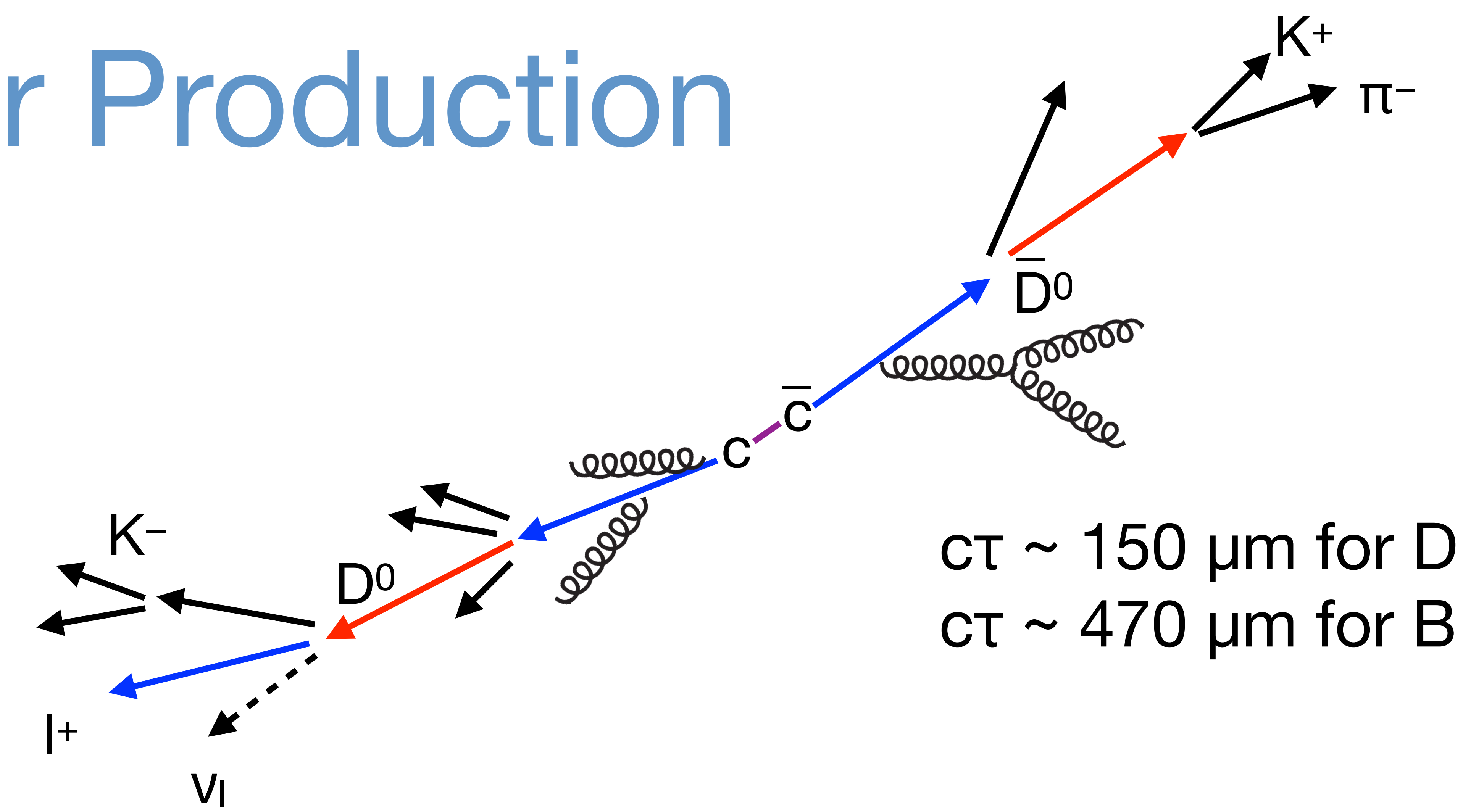
Results in pp collisions

$\sqrt{s}$ = 7 TeV: ALICE, JHEP 09 (2018) 064
$\sqrt{s}$ = 13 TeV: ALICE, PLB 788 (2019) 505

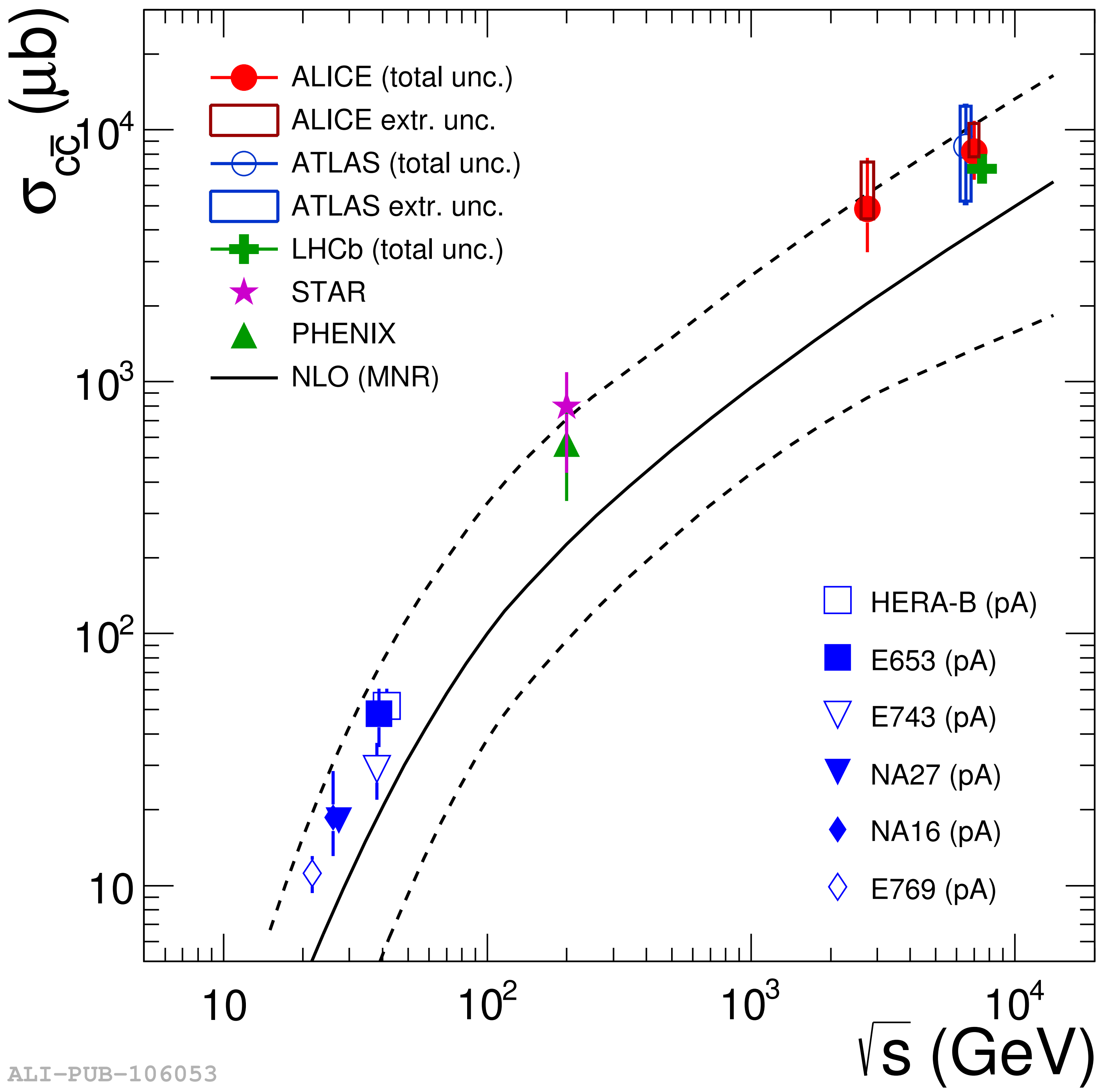
Heavy Flavour Production

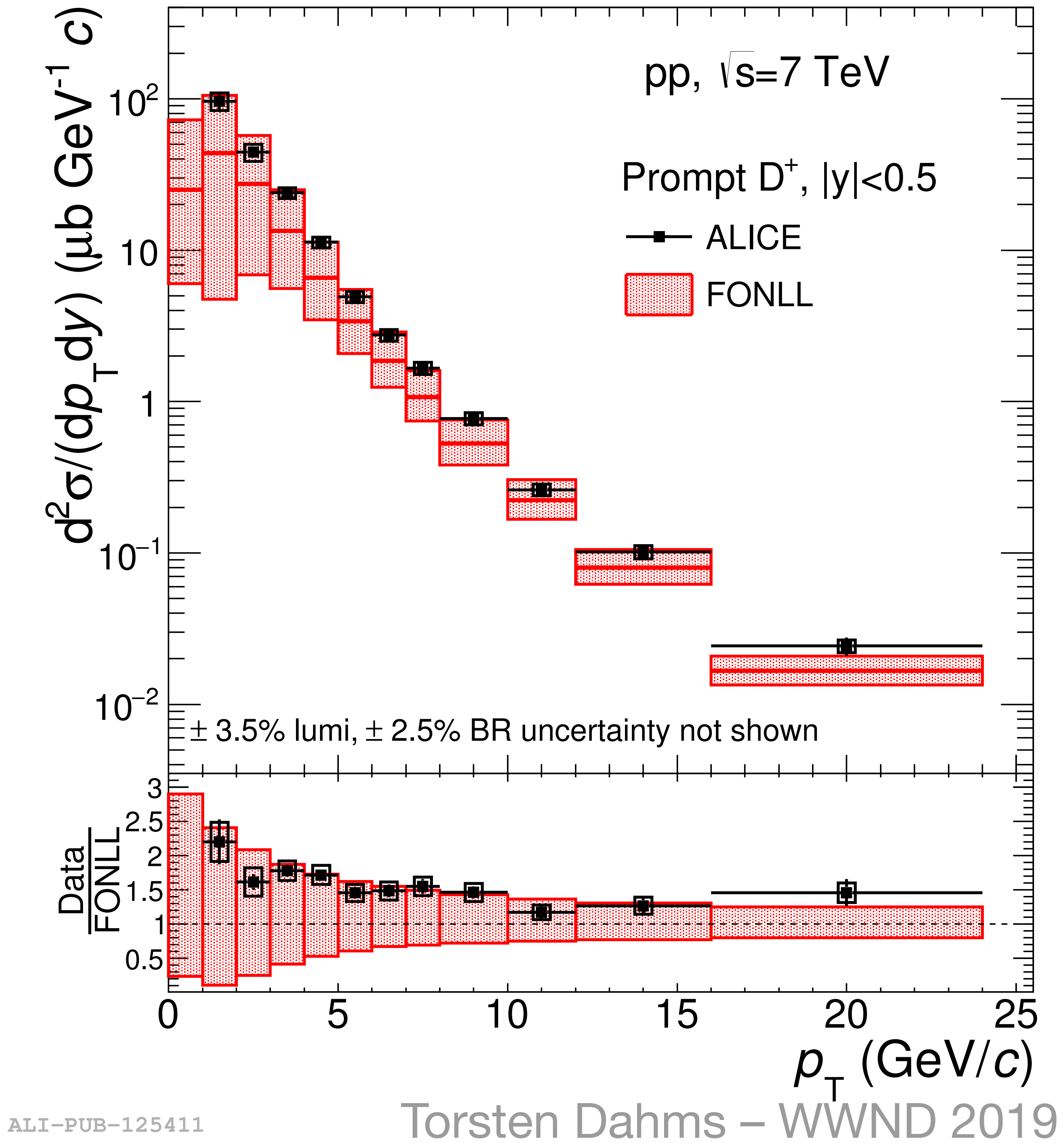
ALICE

- Large quark masses, produced only in initial hard processes
  - Production cross-sections calculable with pQCD
- Single hadron measurements in agreement with NLO
  - data on the upper edge of (large) theoretical uncertainties



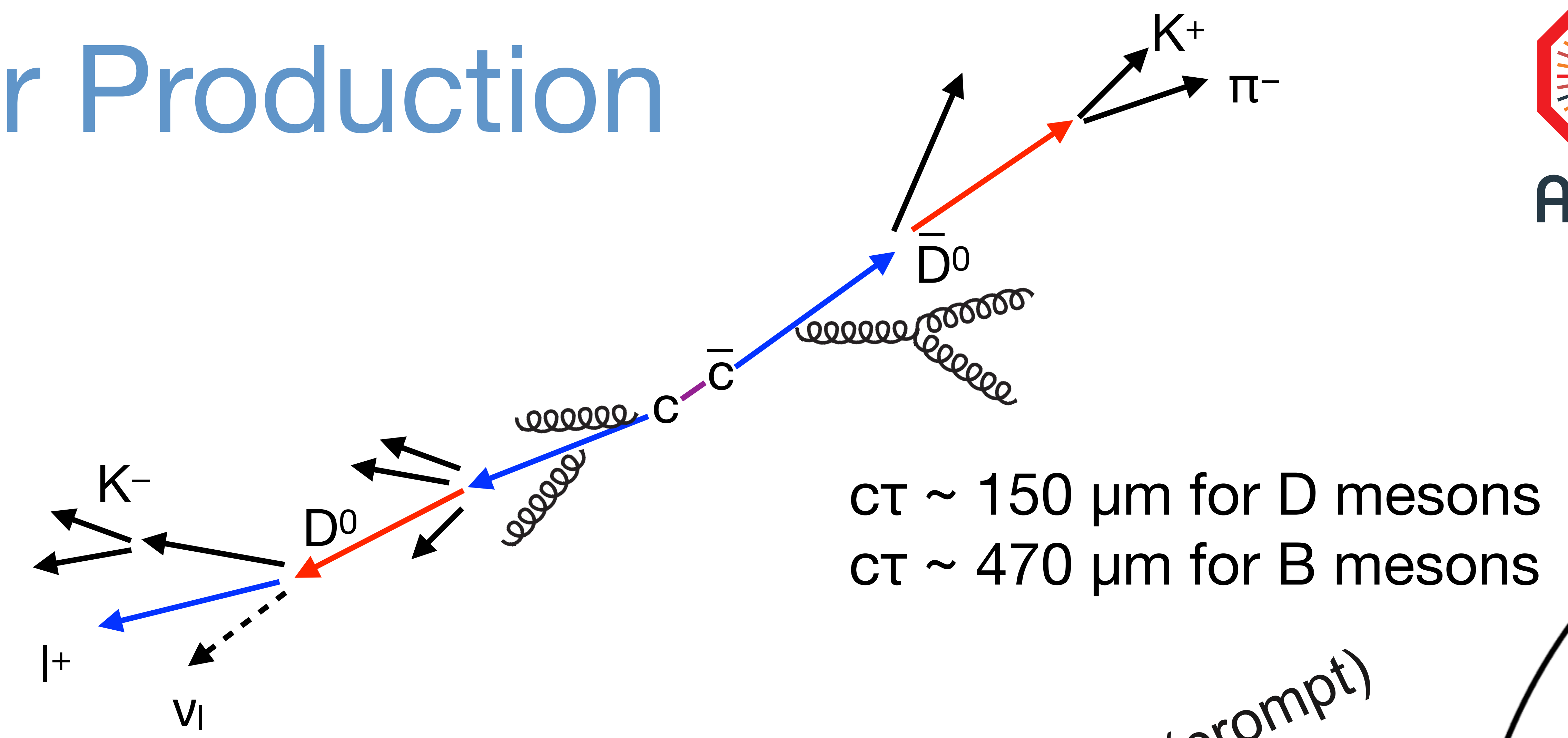
cτ ~ 150 μm for D mesons
cτ ~ 470 μm for B mesons





ALICE, PRC 94 (2016) 054908
ALICE, EPJ C 77 (2017) 550

Heavy Flavour Production



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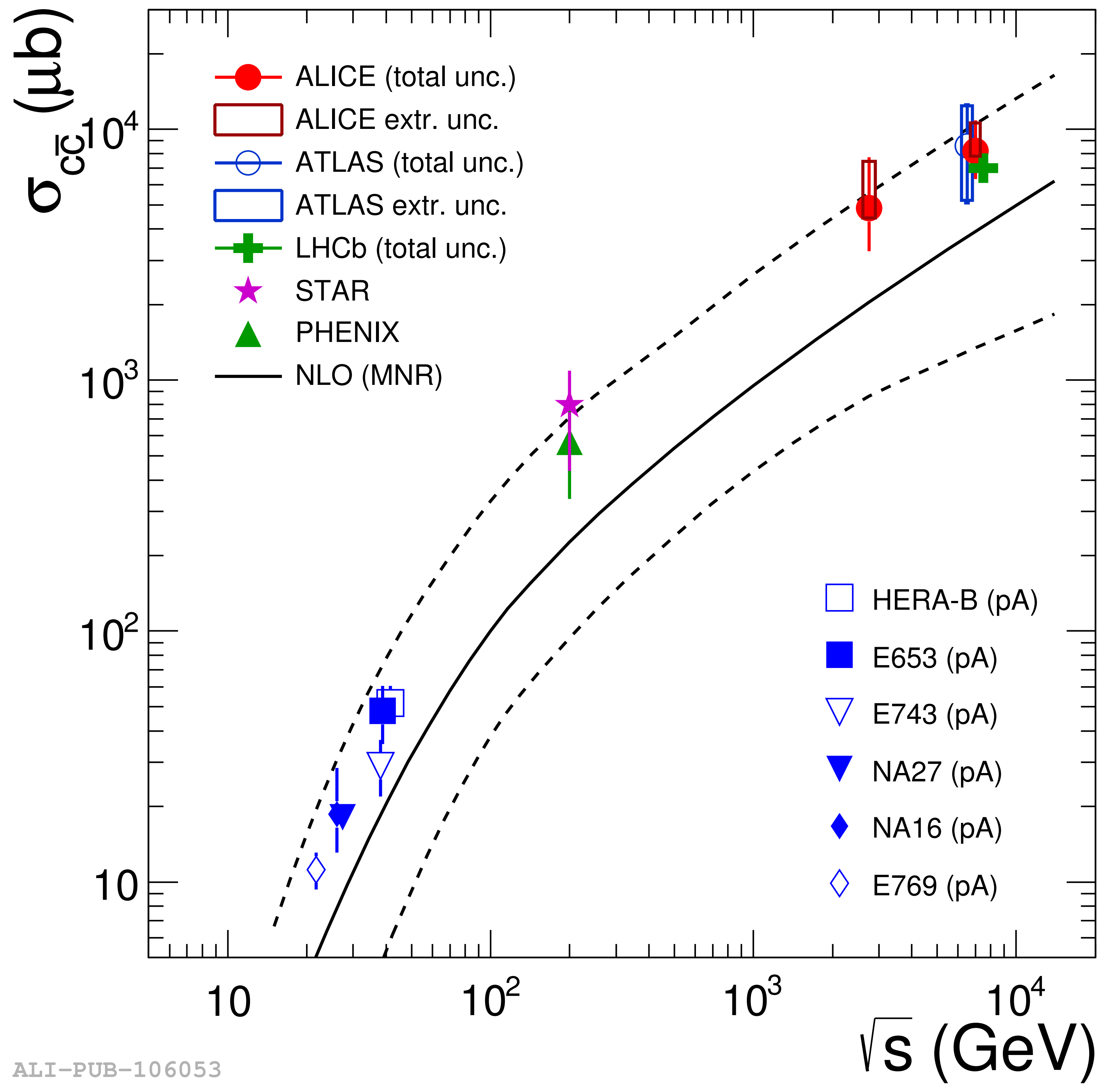
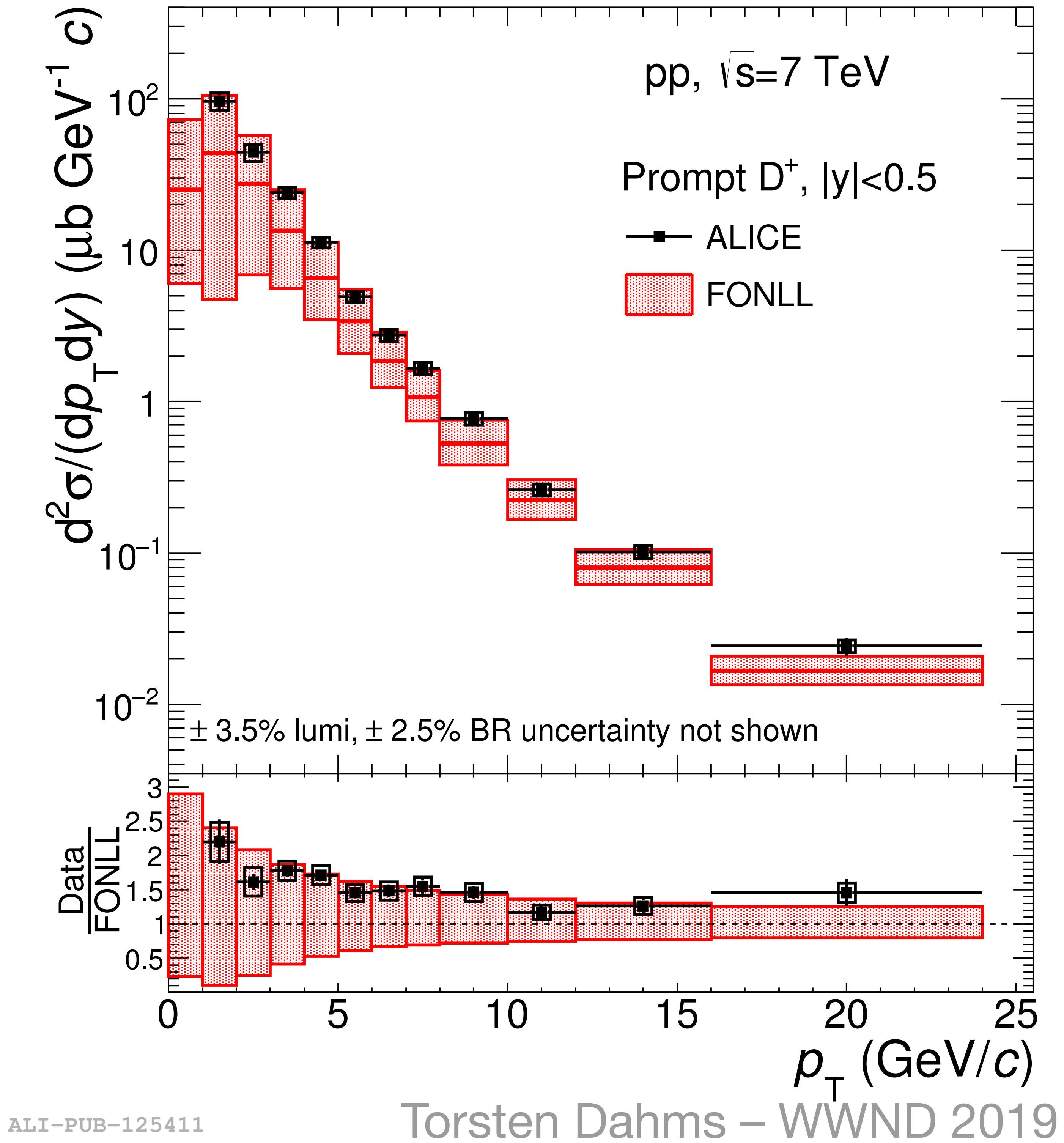
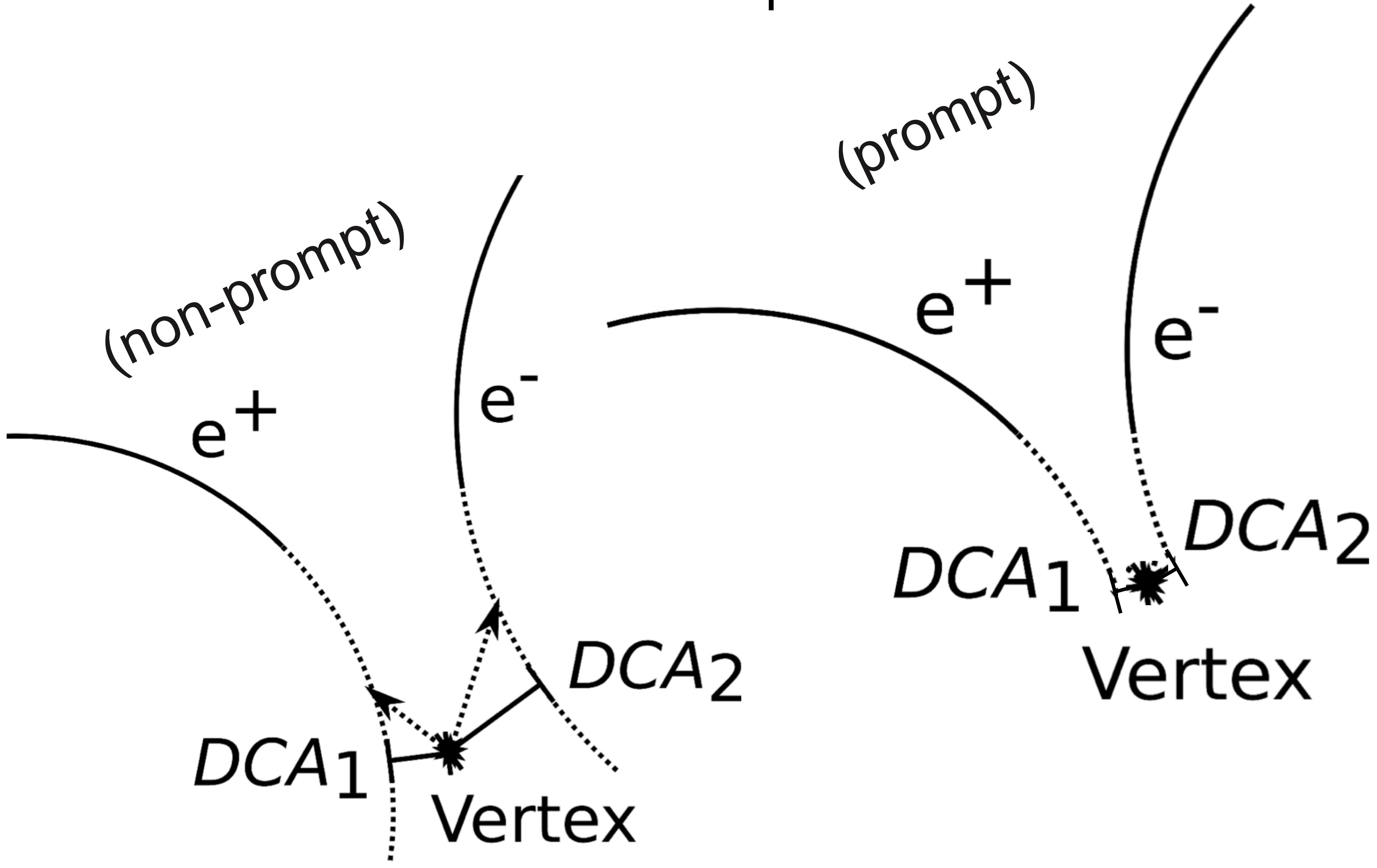






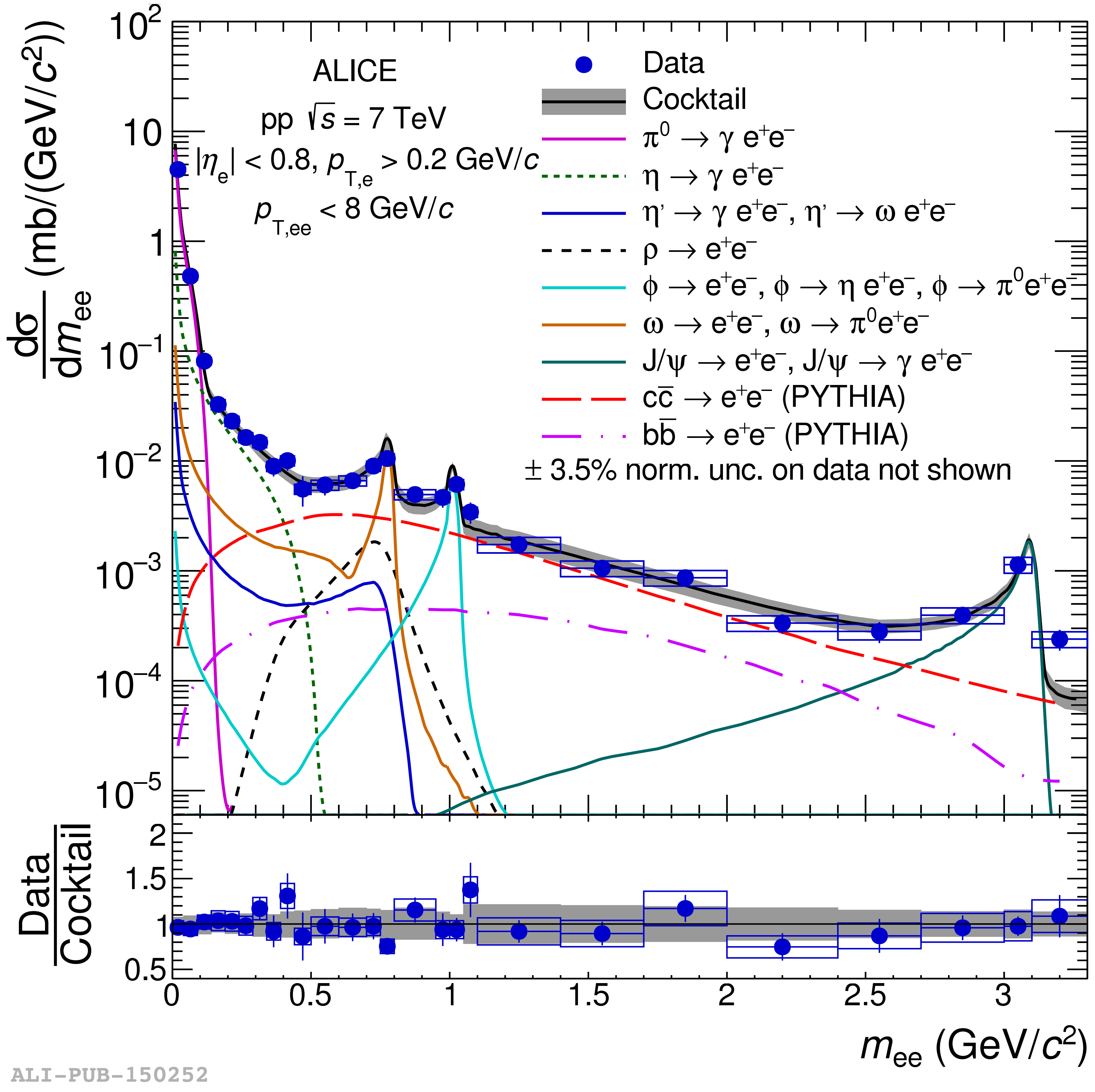
$$\mathrm{DCA_{ee}} = \sqrt{0.5\left(\left(\frac{\mathrm{DCA}_1}{\sigma_1}\right)^2 + \left(\frac{\mathrm{DCA}_2}{\sigma_2}\right)^2\right)}$$

ALICE, PRC 94 (2016) 054908
ALICE, EPJ C 77 (2017) 550

Invariant Mass Spectrum in pp at $\sqrt{s}$ = 7 TeV

- Cocktail of known hadronic sources:
  - Resonance / Dalitz decays of light-flavour hadrons, correlated heavy-flavour semi-leptonic decays
  - Apply detector acceptance ($p_{T,e}$ > 0.2 GeV/c, $|\eta_e|$ < 0.8) and resolution effects

m_{ee} spectrum



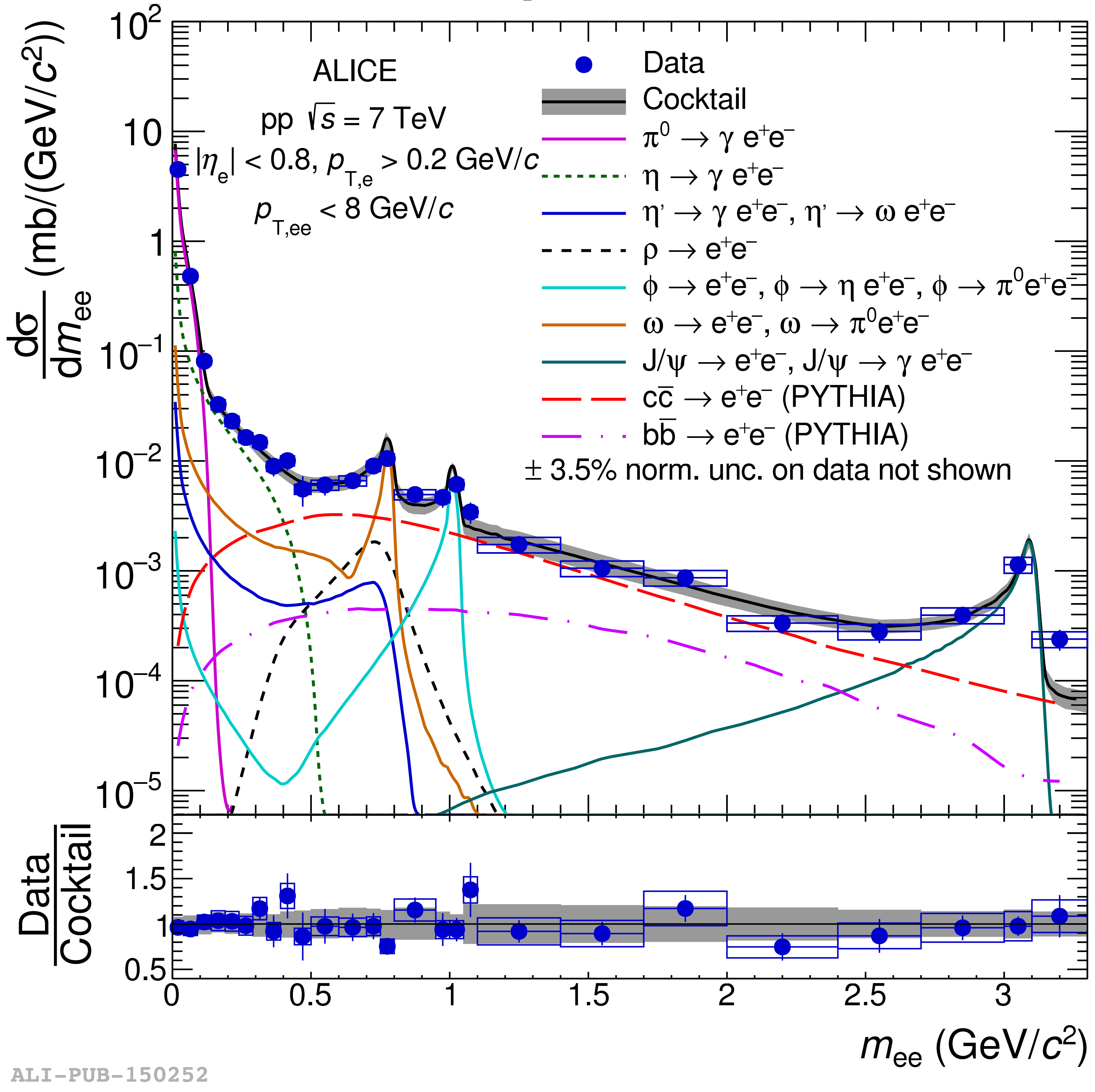
ALICE, JHEP 09 (2018) 064

Data in agreement with cocktail calculations within uncertainties

Invariant Mass, $p_{T,ee}$ and DCA_{ee} at low mass

- Mixture of prompt and non-prompt sources

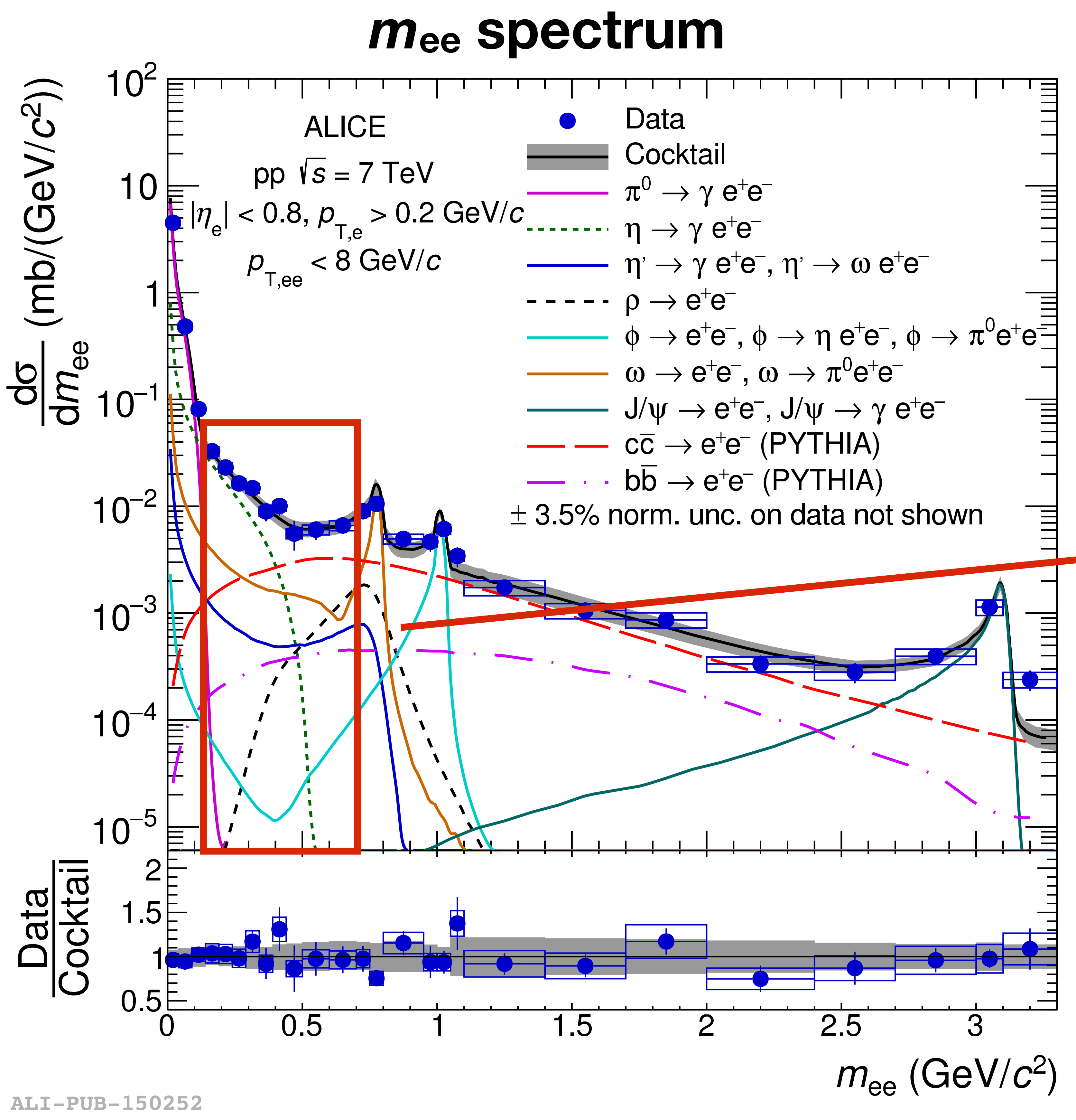
m_{ee} spectrum

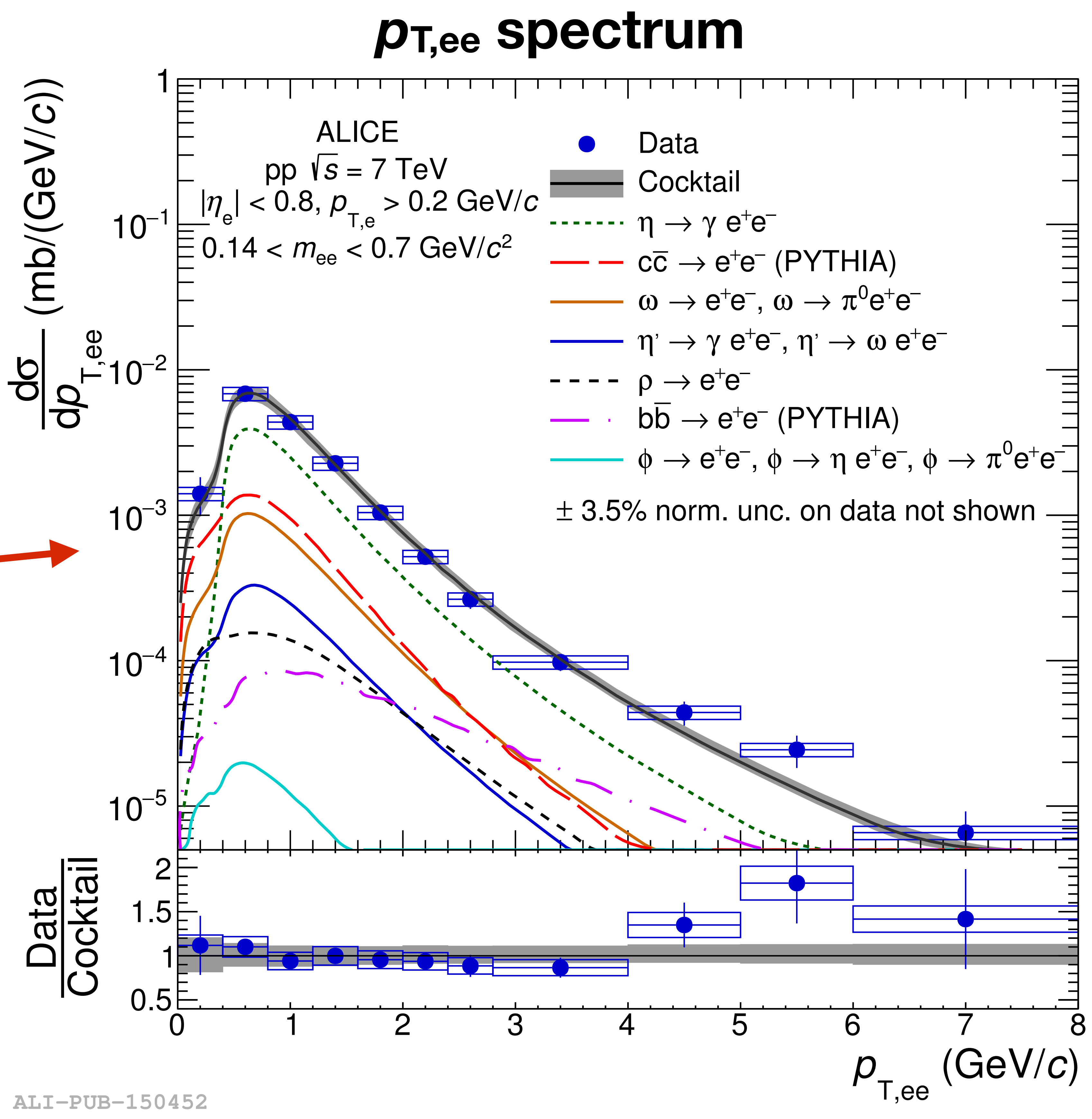


ALICE, JHEP 09 (2018) 064

Invariant Mass, $p_{T,ee}$ and DCA_{ee} at low mass

- Mixture of prompt and non-prompt sources
- m_{ee} and $p_{T,ee}$ cannot distinguish between prompt and non-prompt sources





ALICE, JHEP 09 (2018) 064

Invariant Mass, $p_{T,ee}$ and DCA_{ee} at low mass

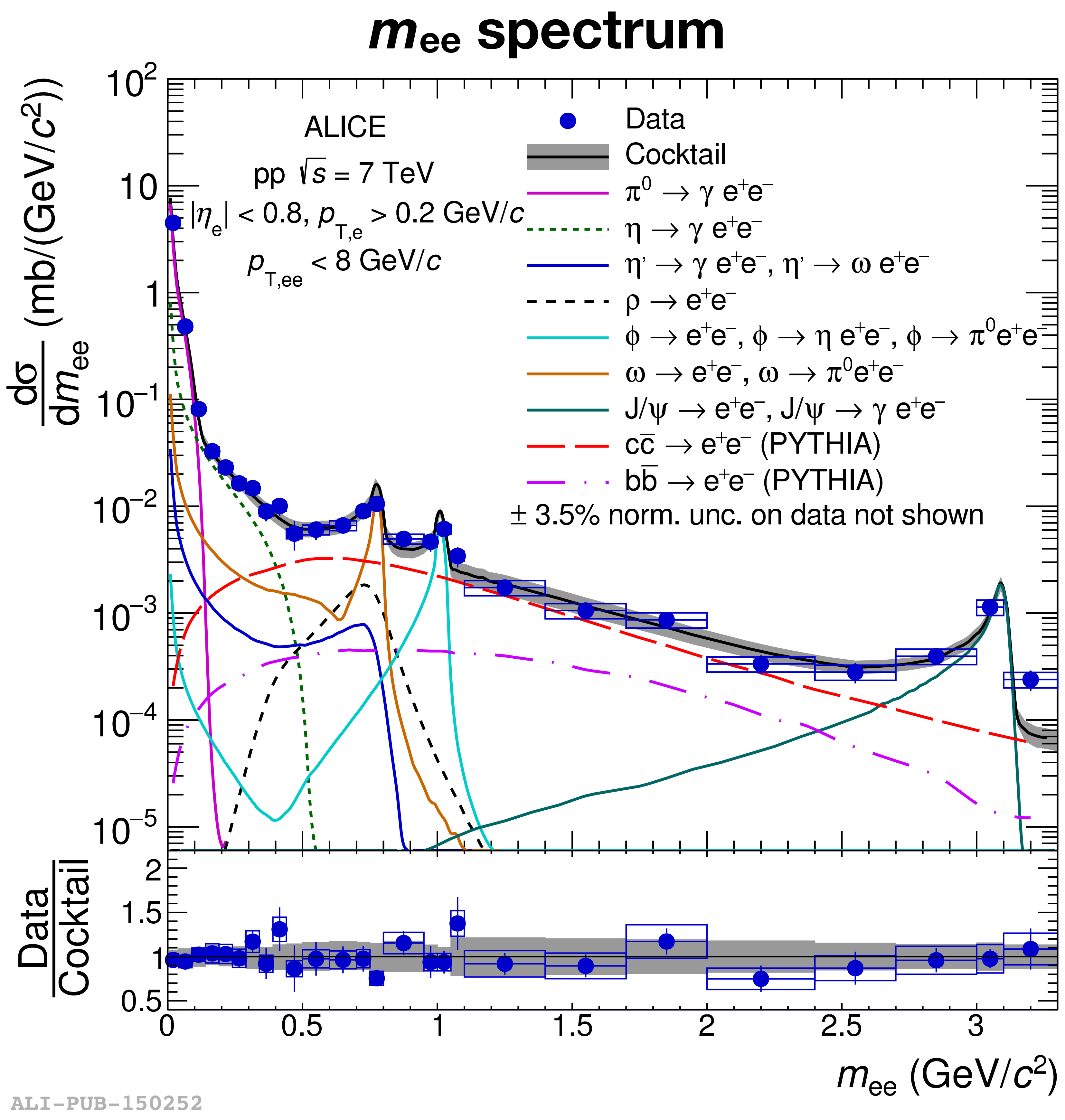
- Mixture of prompt and non-prompt sources
- m_{ee} and $p_{T,ee}$ cannot distinguish between prompt and non-prompt sources
- **But DCA_{ee} can!** Important for precise studies of ρ meson and thermal dileptons

m_{ee} spectrum **$p_{T,ee}$ spectrum** **DCA_{ee} spectrum**

ALICE, JHEP 09 (2018) 064

Invariant Mass, $p_{T,ee}$ and DCA_{ee} at intermediate mass

- Dominated by heavy-flavour decays

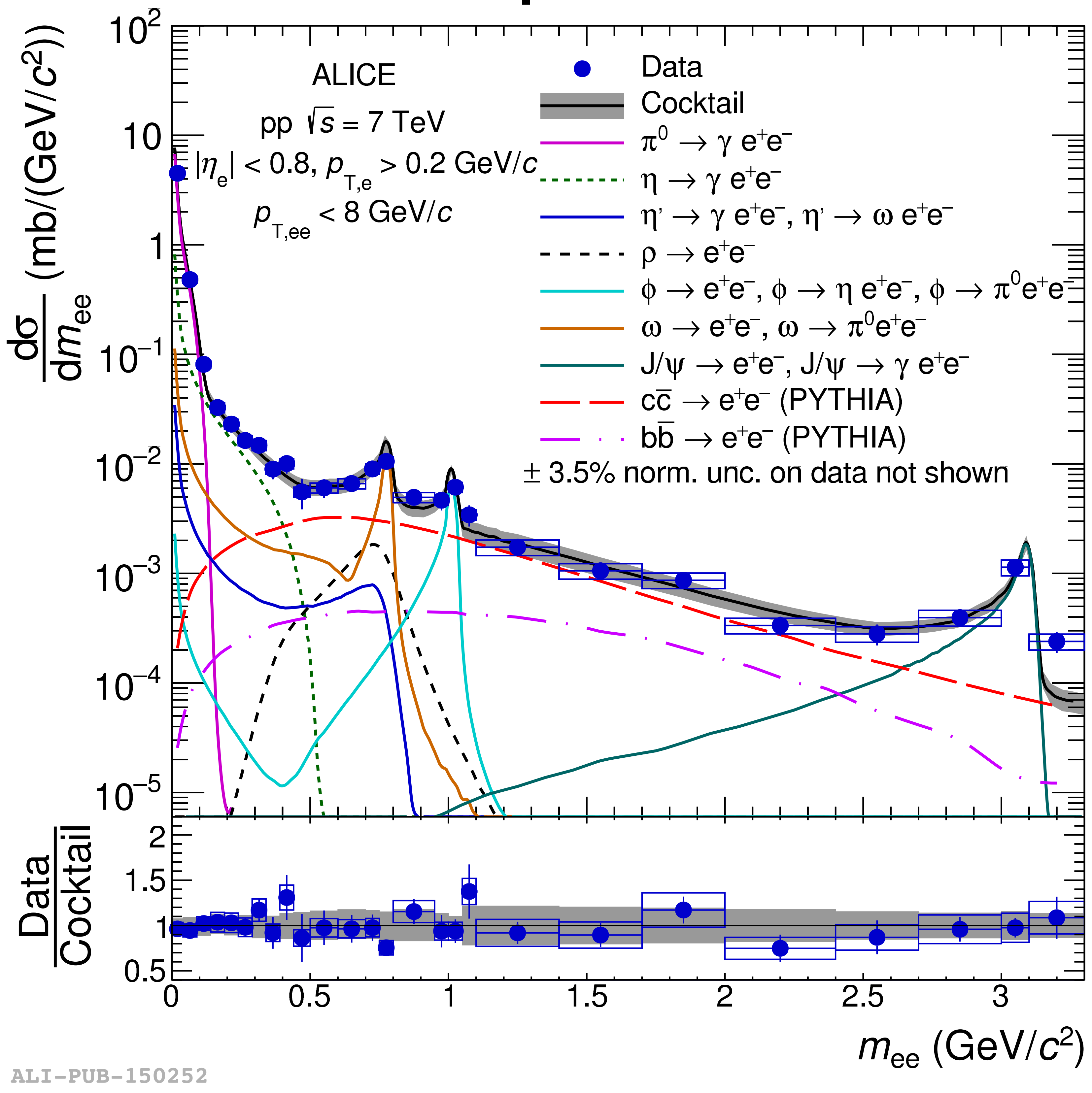


ALICE, JHEP 09 (2018) 064

Invariant Mass, $p_{T,ee}$ and DCA_{ee} at intermediate mass

- Dominated by heavy-flavour decays
- Leave the normalisation free for $c\bar{c}$ and $b\bar{b}$ contributions
- Fit dielectron spectra in 2D (m_{ee} vs $p_{T,ee}$) or in 1D (DCA_{ee}) with MC templates (PYTHIA, POWHEG) to extract σ_{cc} and σ_{bb}

m_{ee} spectrum



ALICE, JHEP 09 (2018) 064

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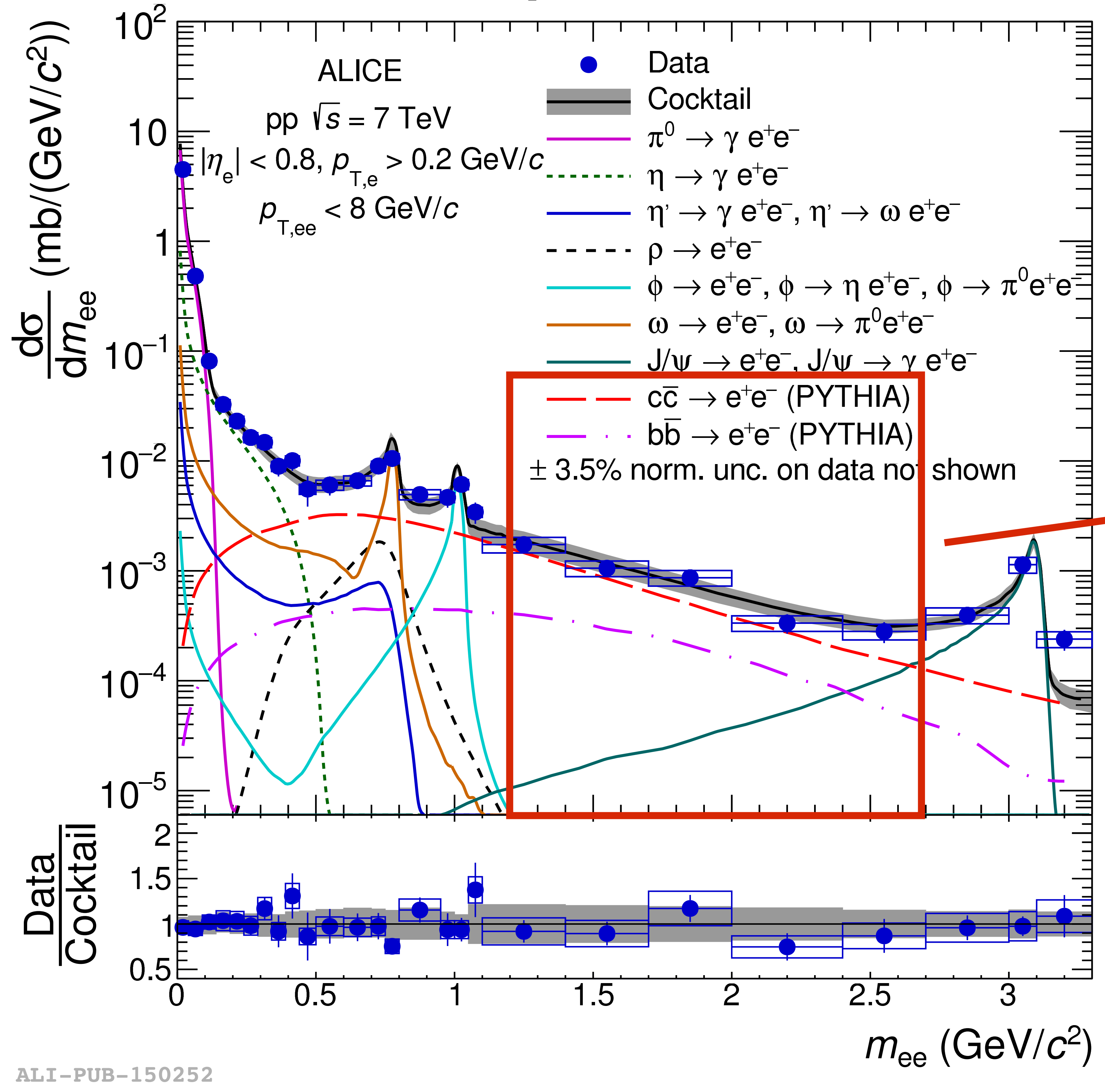
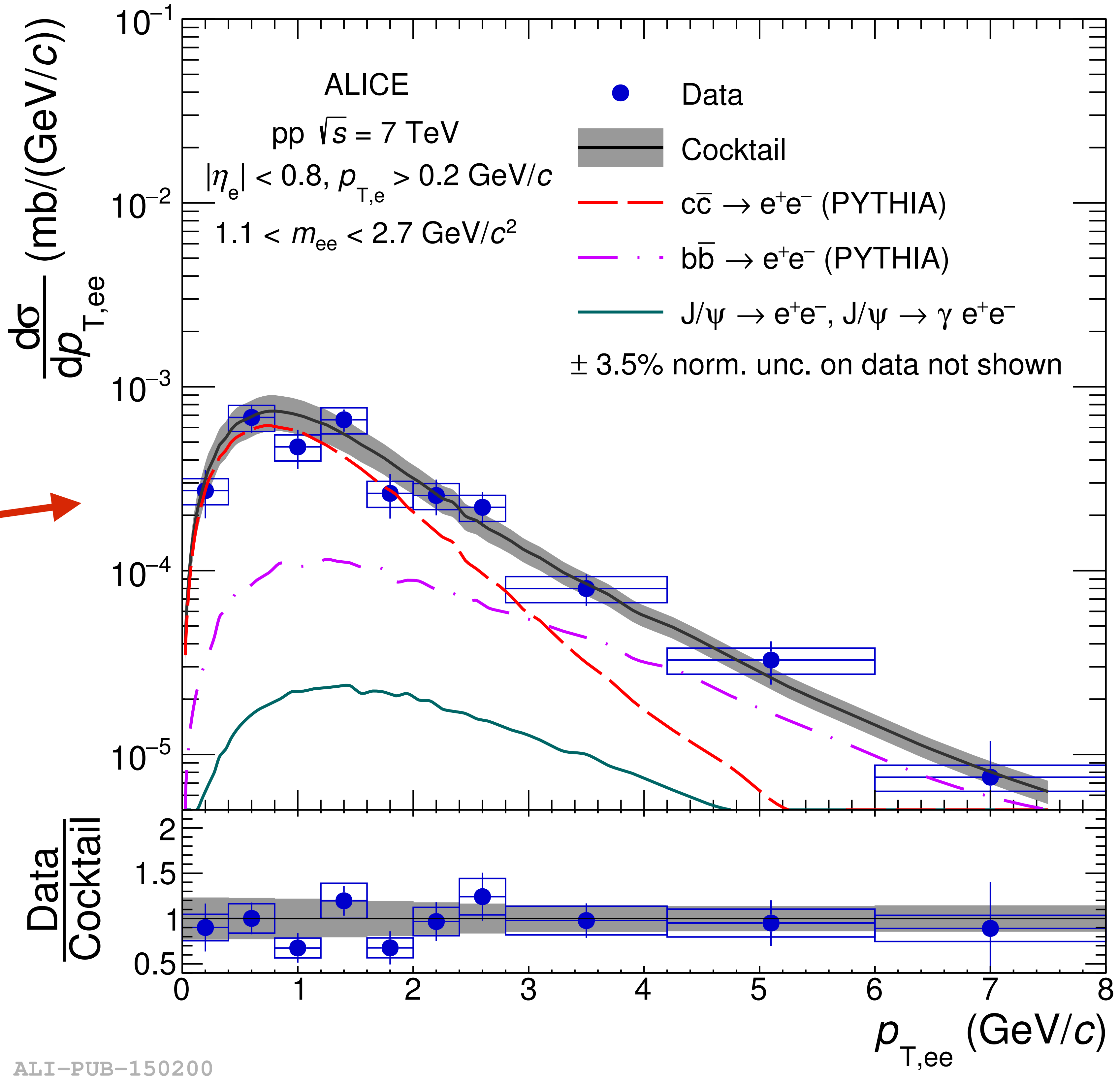


$p_{T,ee}$ spectrum



ALICE, JHEP 09 (2018) 064

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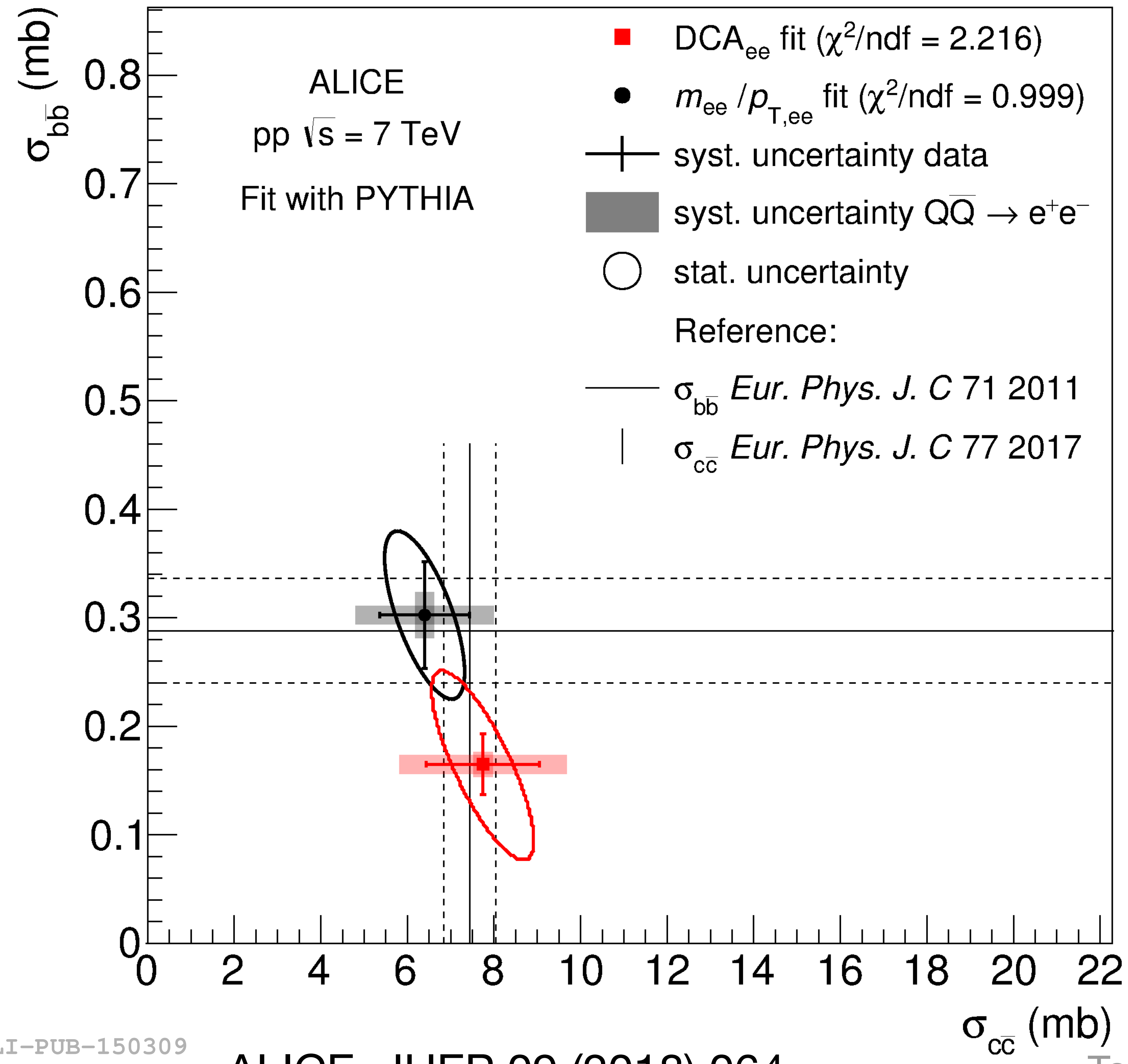
ALICE, JHEP 09 (2018) 064

Heavy Flavour Cross Section in pp at $\sqrt{s}$ = 7 TeV

- Results agree between two methods
- Sensitive to predicted acceptance and $m_{ee}/p_{T,ee}$ spectra
- In good agreement with previous independent measurements of single HF hadrons



ALI-PUB-150309

ALICE, JHEP 09 (2018) 064

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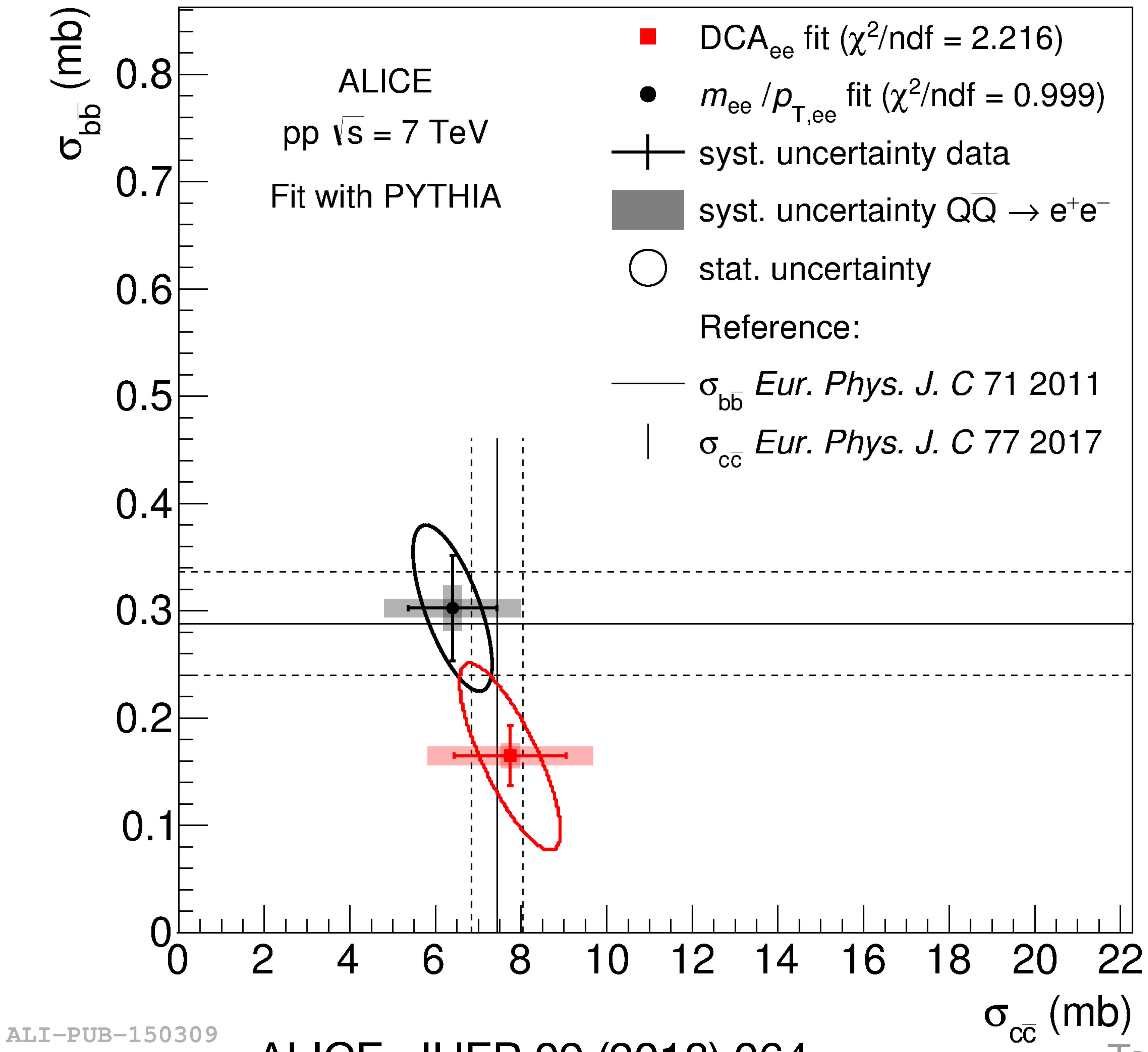
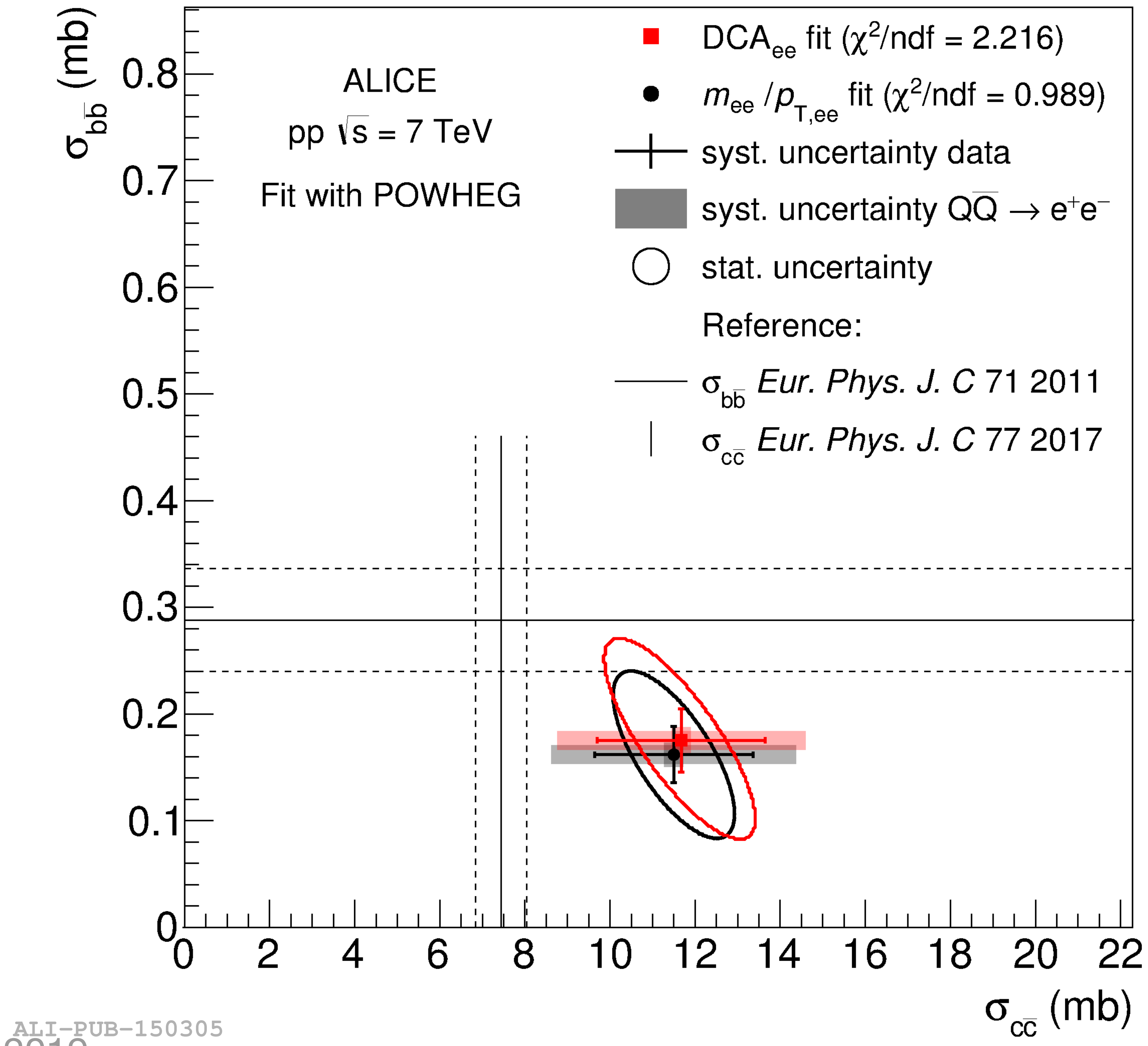
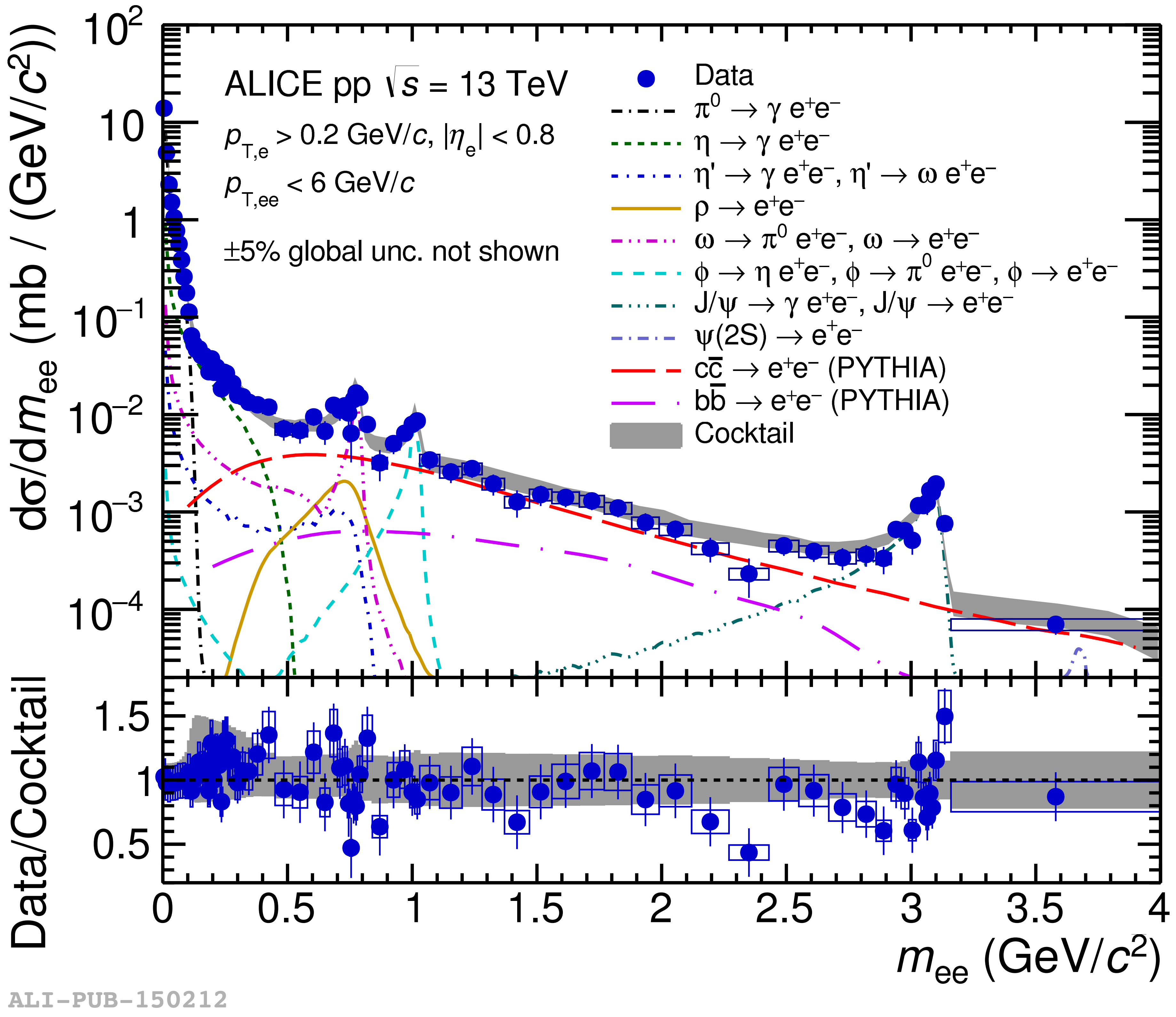
- Sizeable difference between PYTHIA and POWHEG! → sensitive to rapidity correlations





ALICE, JHEP 09 (2018) 064

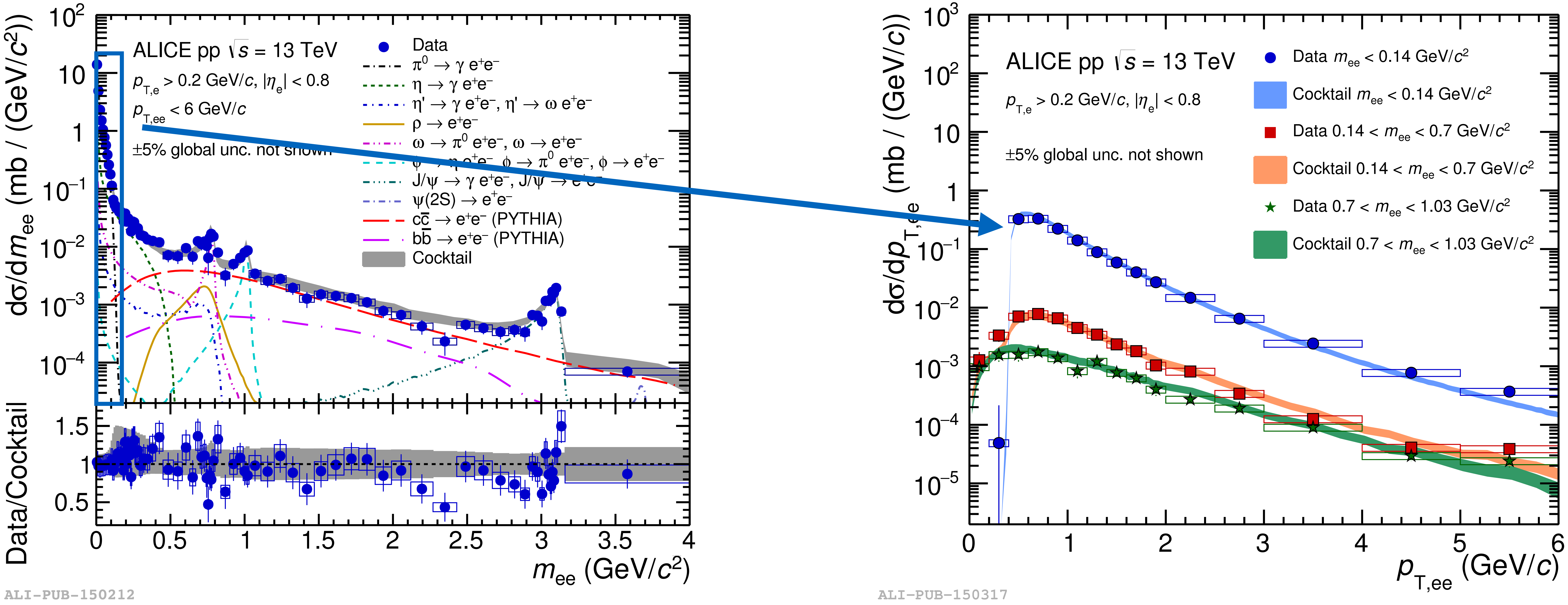
Dielectron Spectra in pp at $\sqrt{s}$ = 13 TeV



- Data well described with cocktail of known hadron decays in mass and $p_{T,ee}$
  - also measured in pp at $\sqrt{s}$ = 7 TeV: JHEP 09 (2018) 064
- Intermediate mass region dominated by charm and beauty: fit data to extract cross sections

ALICE, PLB 788 (2019) 505

Dielectron Spectra in pp at √s = 13 TeV



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ALICE, PLB 788 (2019) 505

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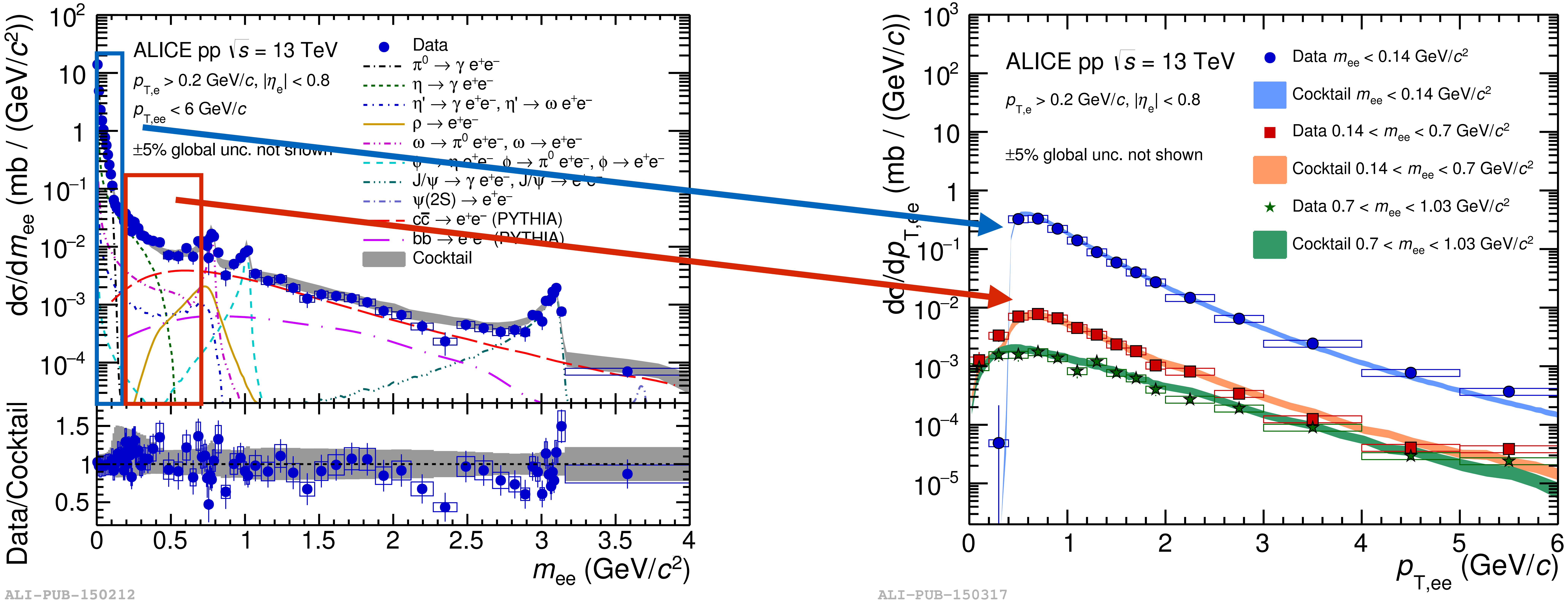

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ALICE, PLB 788 (2019) 505

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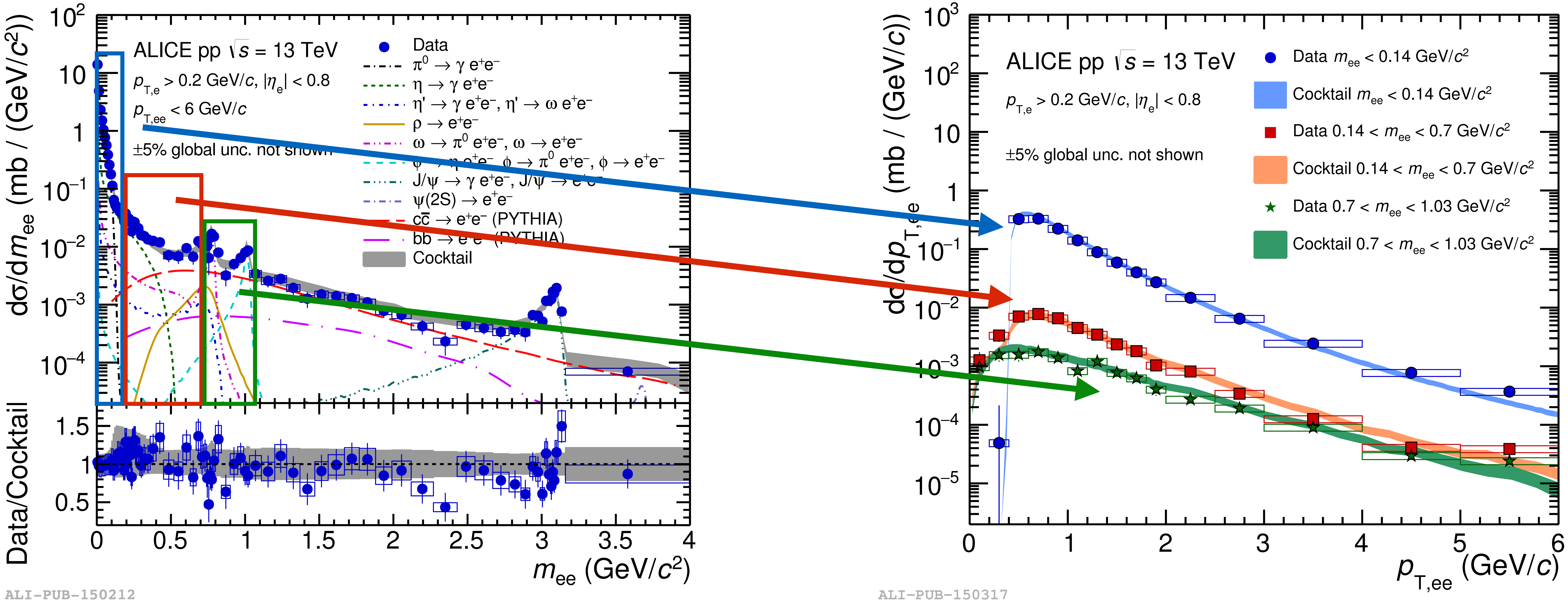

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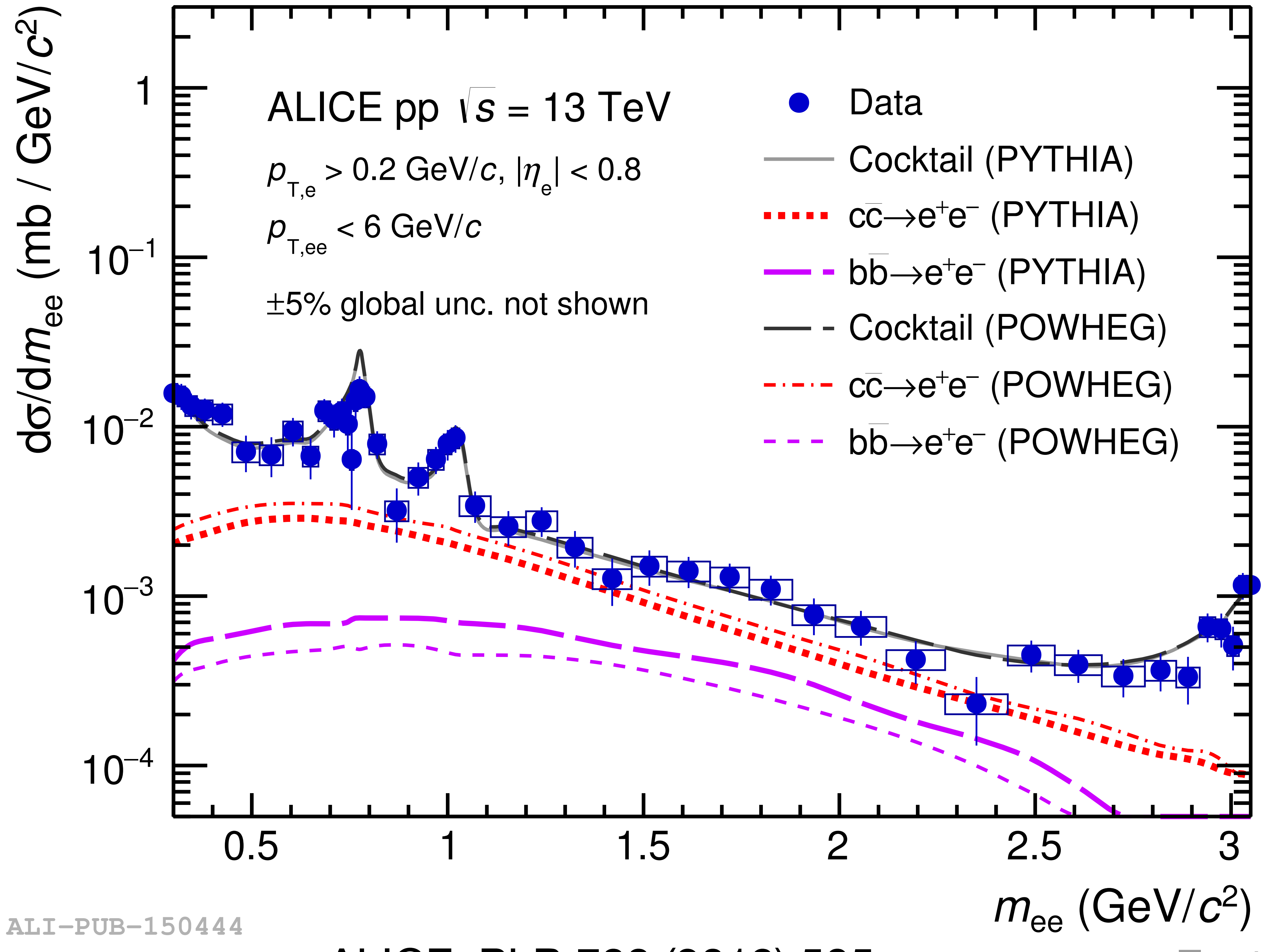
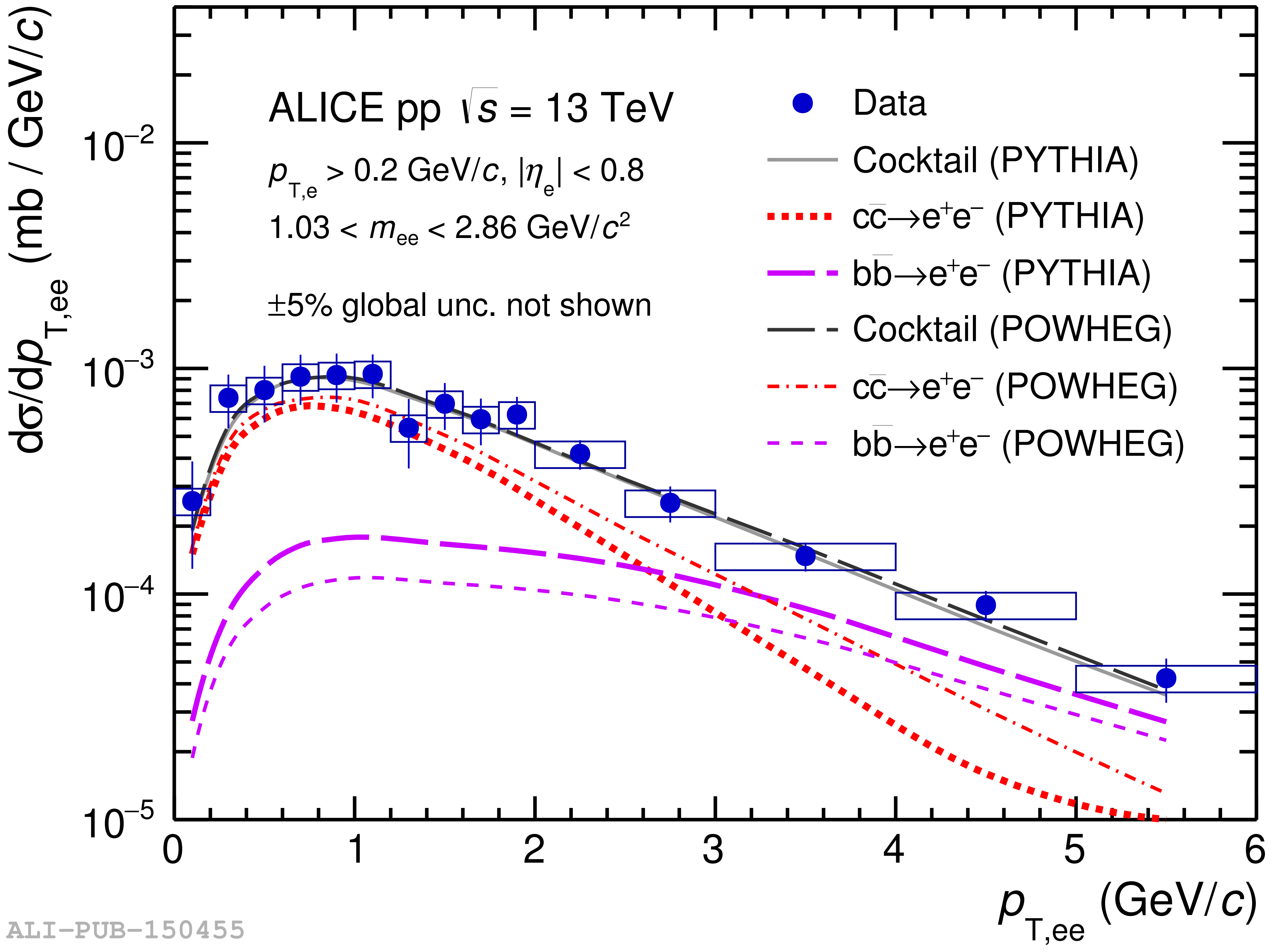
ALICE, PLB 788 (2019) 505

Heavy Flavour Cross Section in pp at $\sqrt{s}$ = 13 TeV

- Fit dielectron spectra in 2D (m_{ee} vs $p_{T,ee}$) at intermediate mass



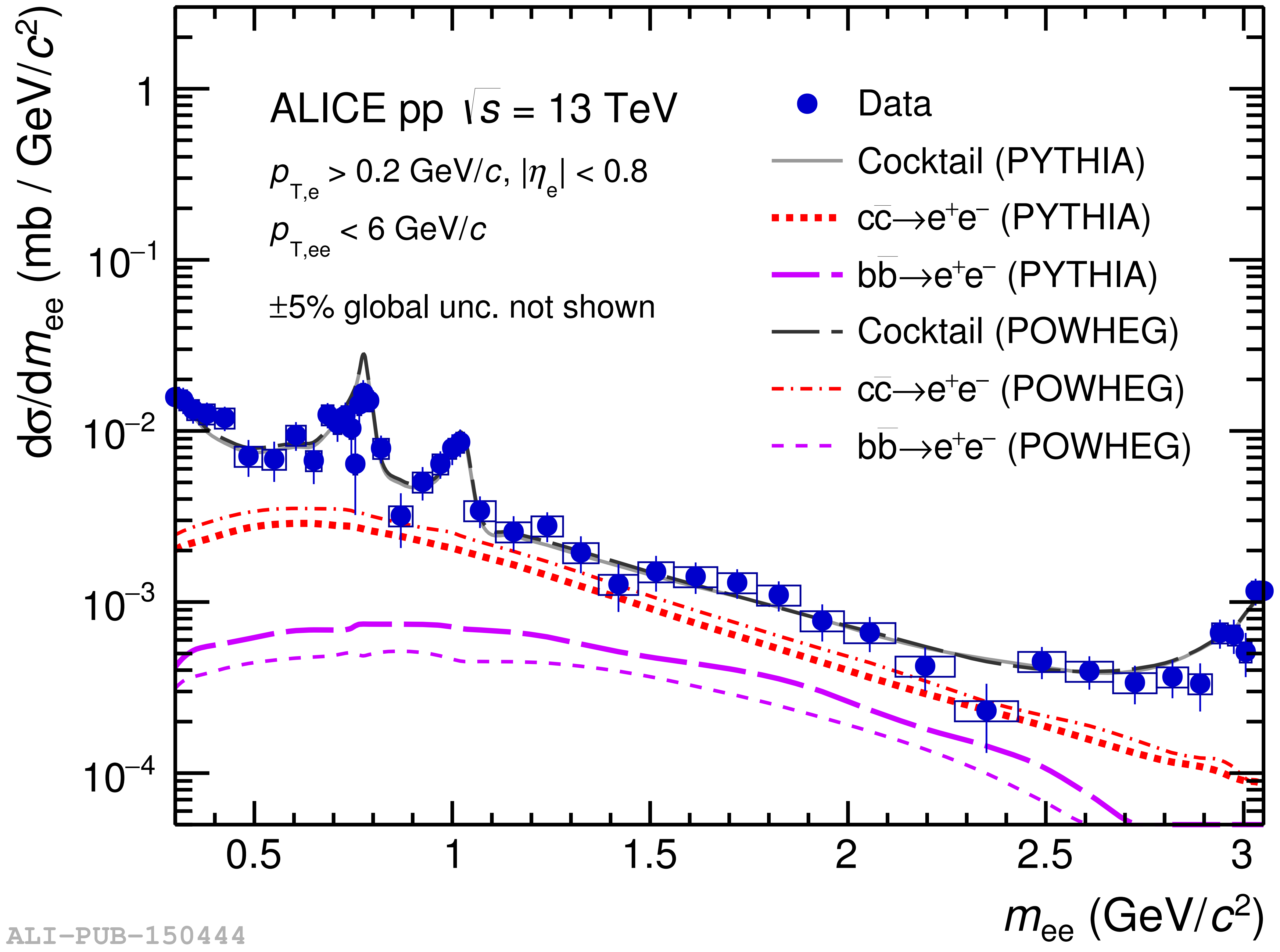


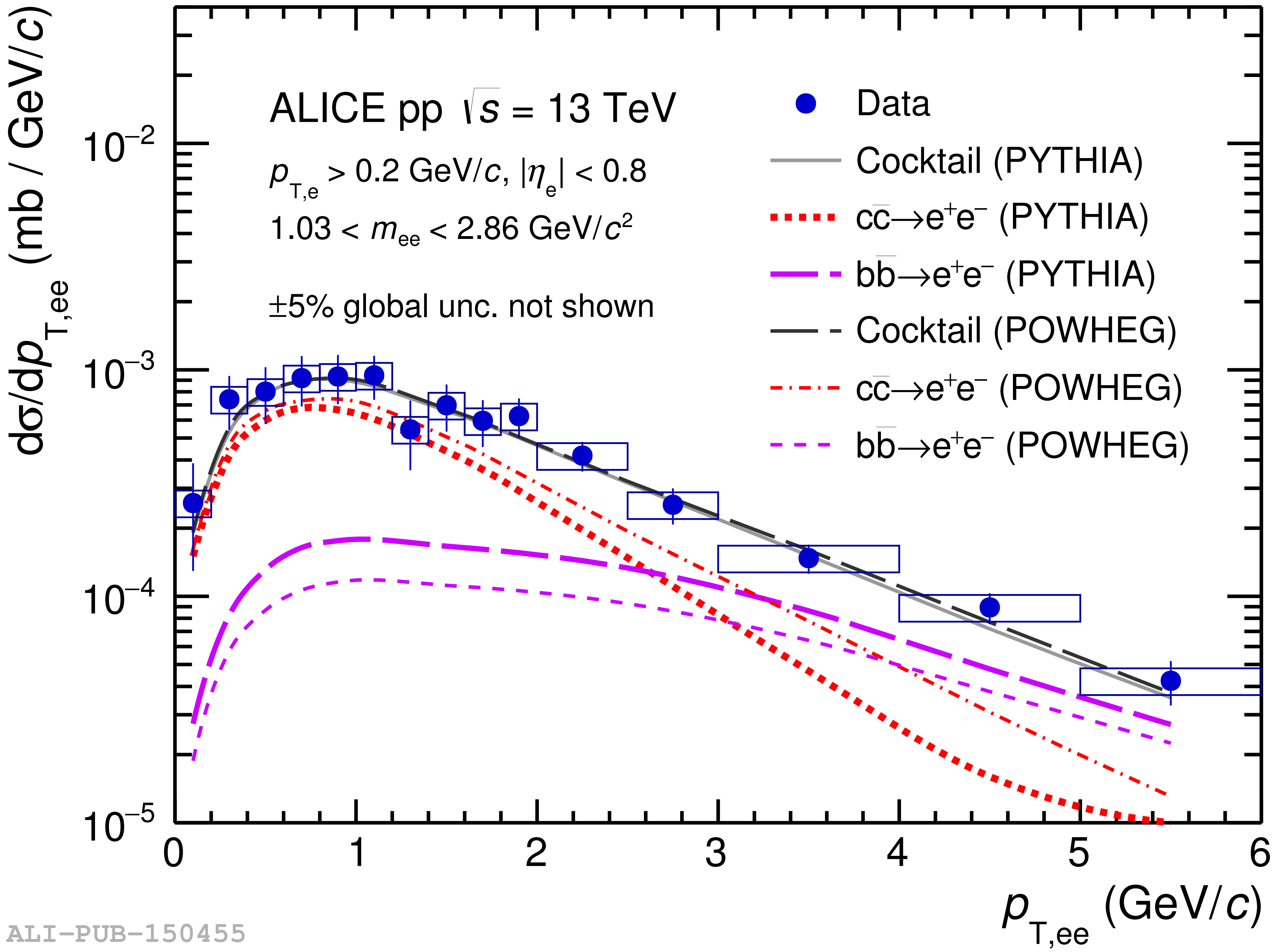
ALICE, PLB 788 (2019) 505

Heavy Flavour Cross Section in pp at $\sqrt{s}$ = 13 TeV

- Fit dielectron spectra in 2D (m_{ee} vs $p_{T,ee}$) at intermediate mass
- **First charm and beauty cross sections at midrapidity at 13 TeV**

	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





ALICE, PLB 788 (2019) 505

Heavy Flavour Cross Section in pp at $\sqrt{s}$ = 13 TeV

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- Sizeable difference between PYTHIA and POWHEG!
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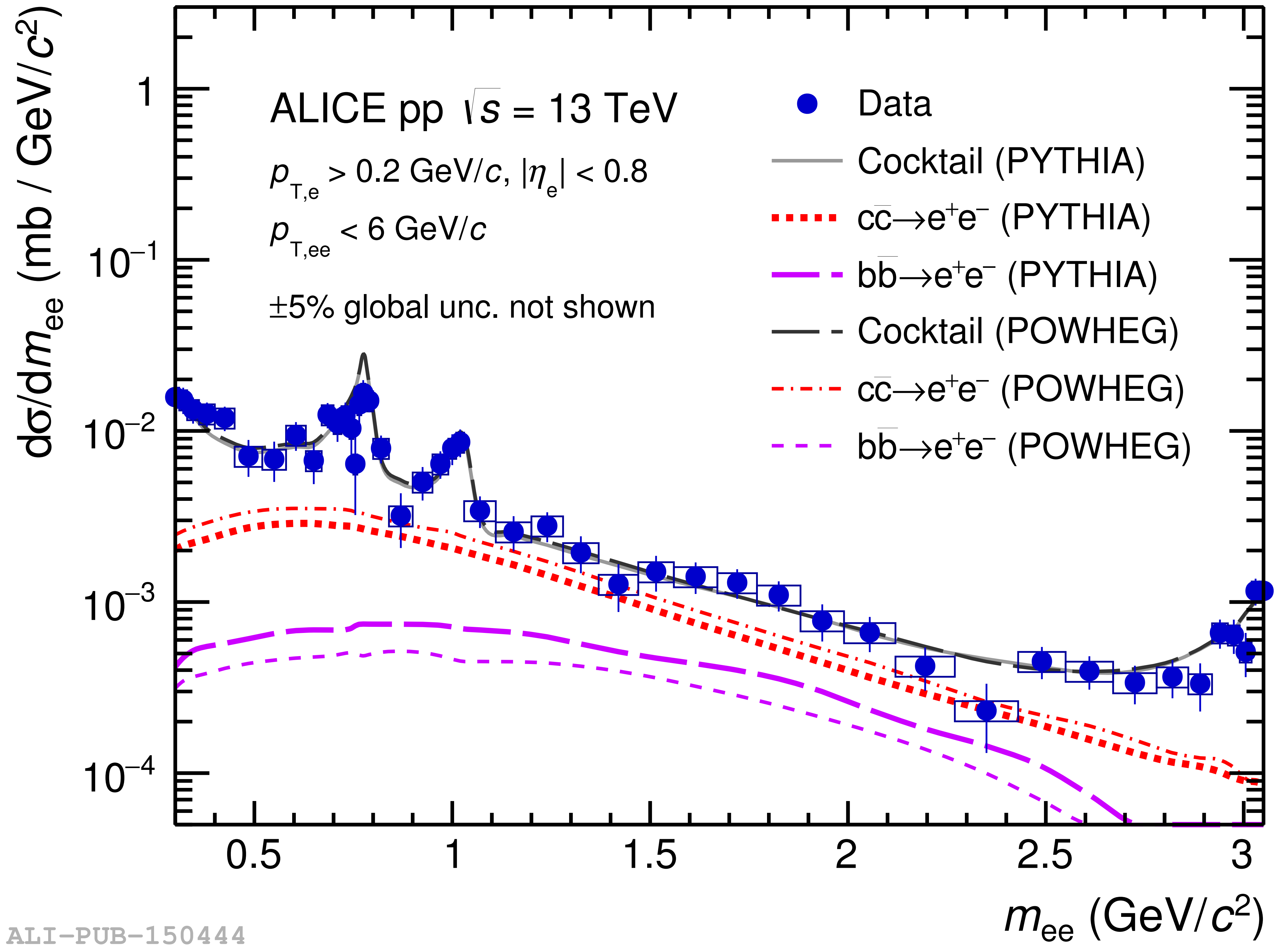
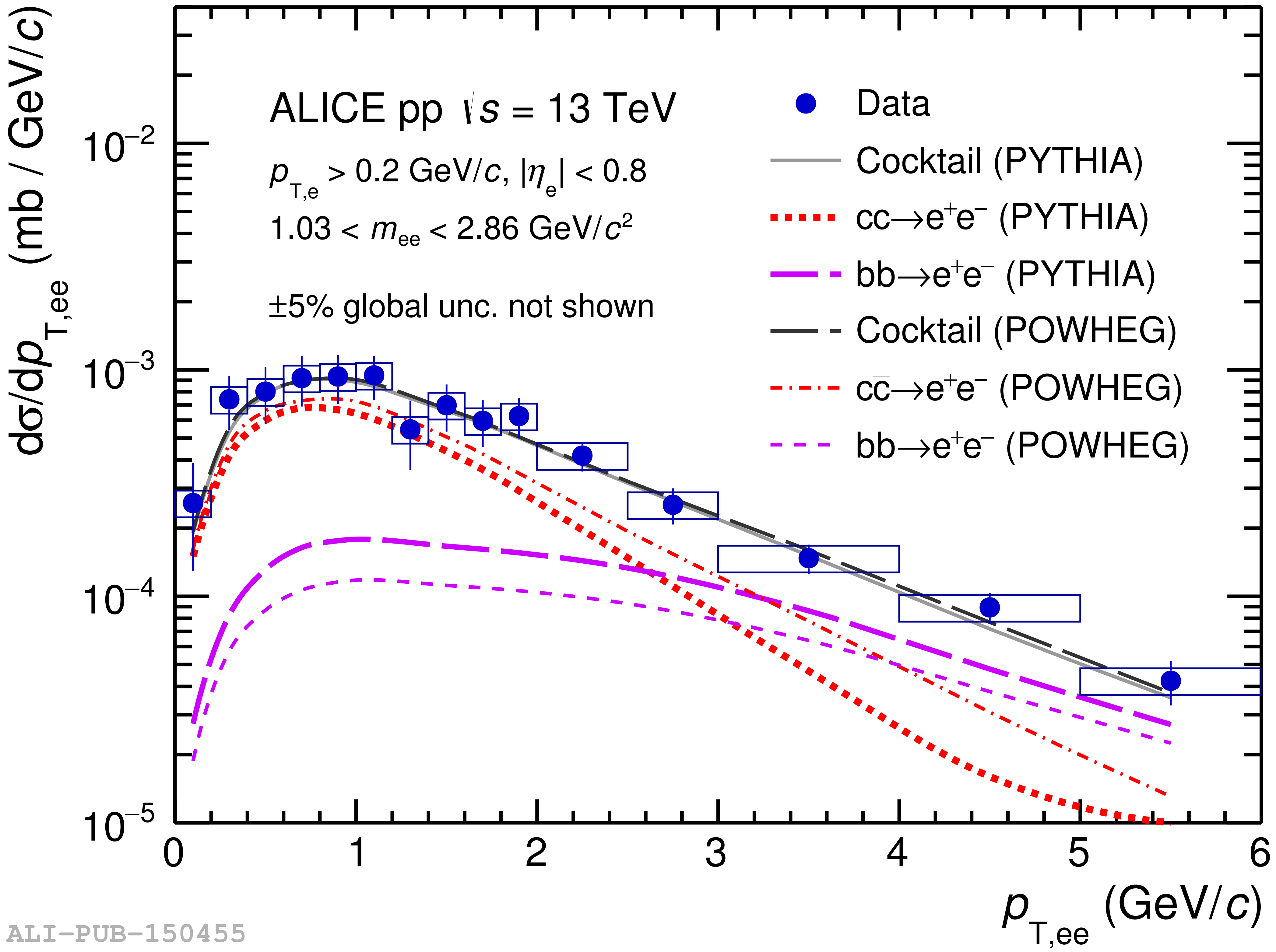
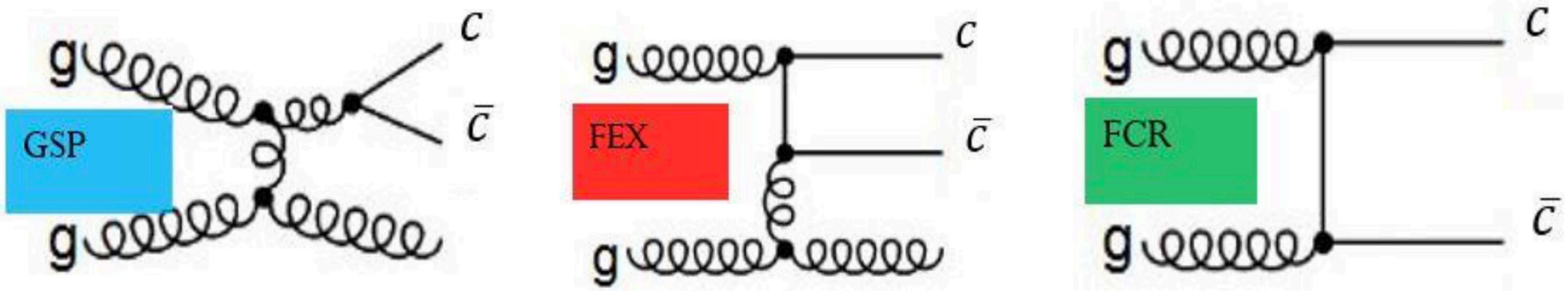




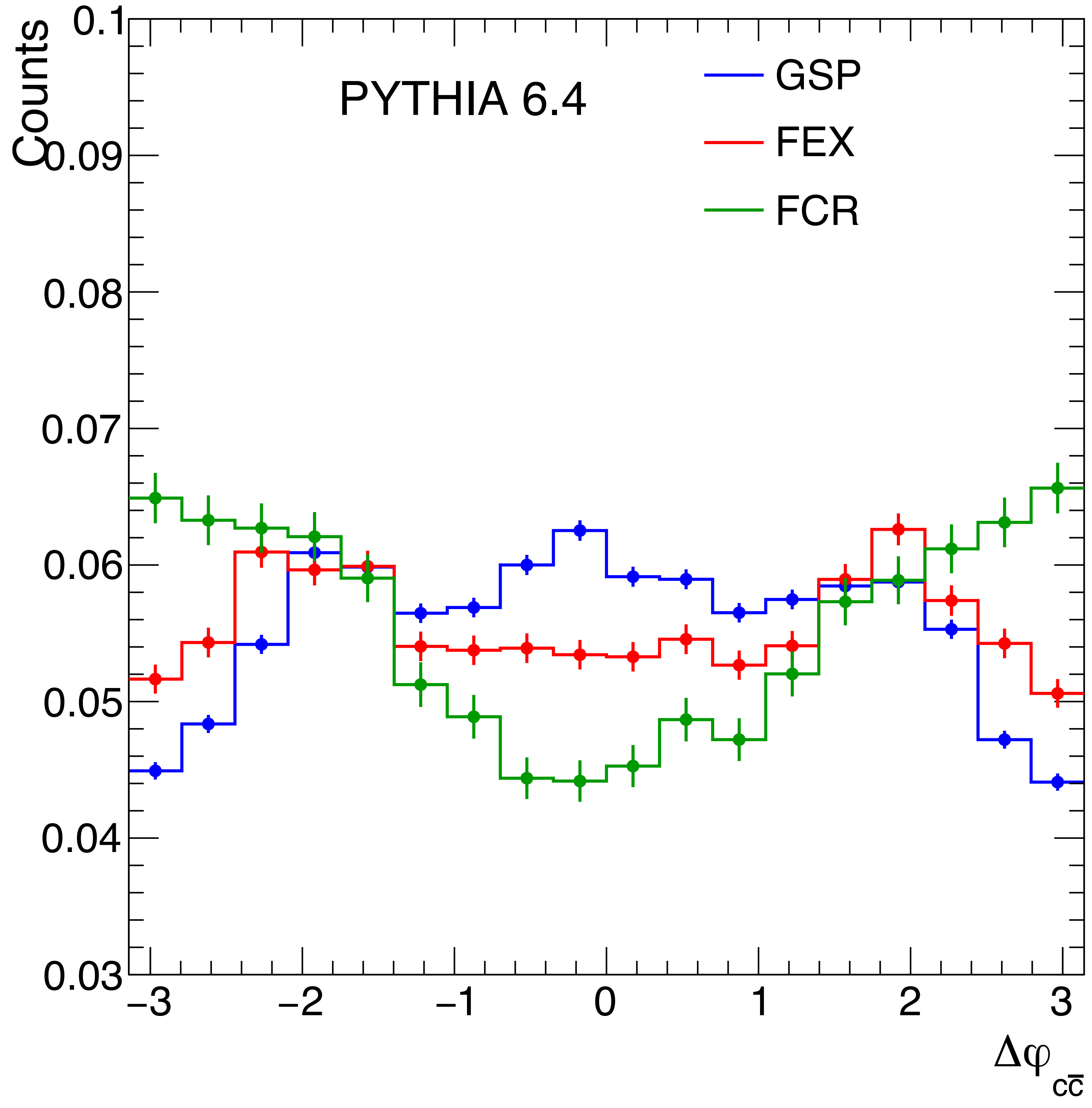
ALICE, PLB 788 (2019) 505

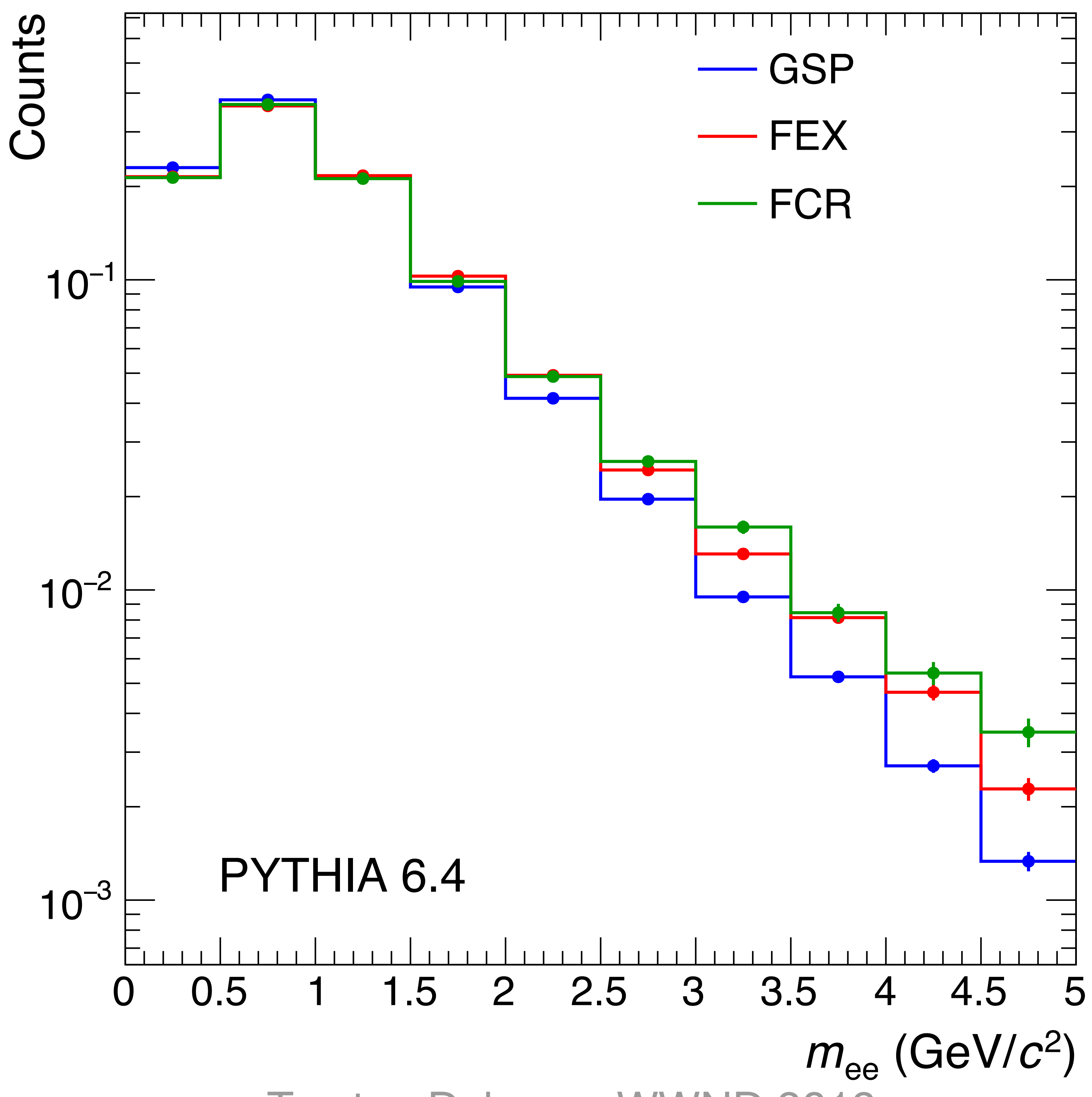
Heavy Flavour Production Mechanisms

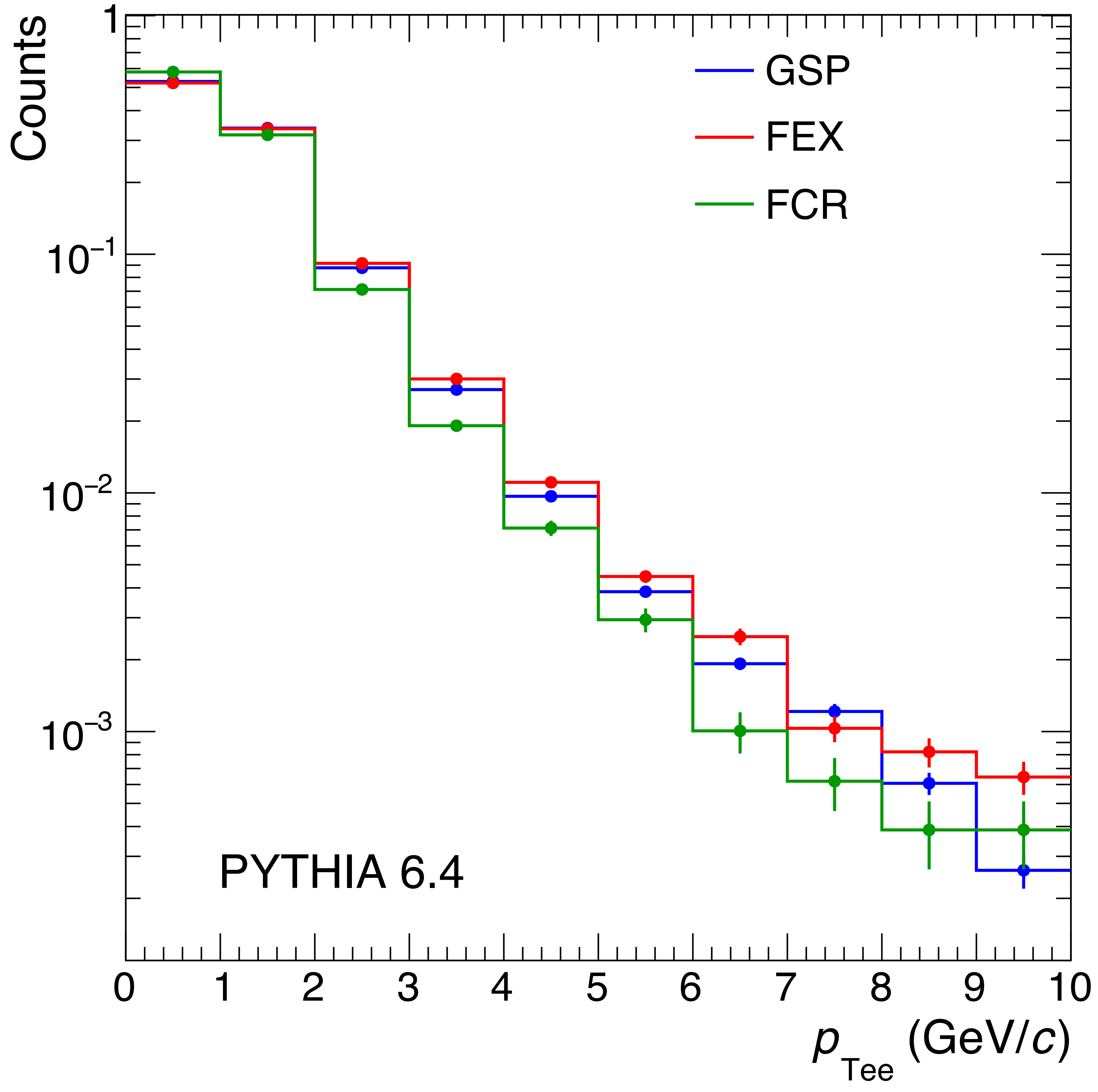
- Idea: study different charm production processes using PYTHIA 6 simulations
  - Gluon splitting (GSP) (default fraction 55%)
  - Flavour excitation (FEX) (20%)
  - Flavour creation (FCR) (10%)
  - e+e− from b$\bar{b}$ (15%)



$$m_{\mathrm{ee}}^2 \approx 2 p_{\mathrm{T},1}\, p_{\mathrm{T},2} (1 - \cos \Delta\varphi_{\mathrm{ee}})$$







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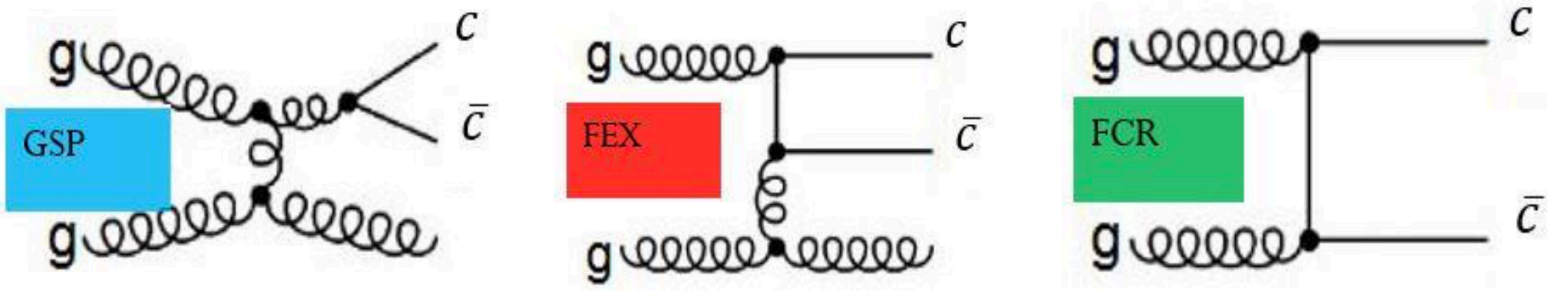
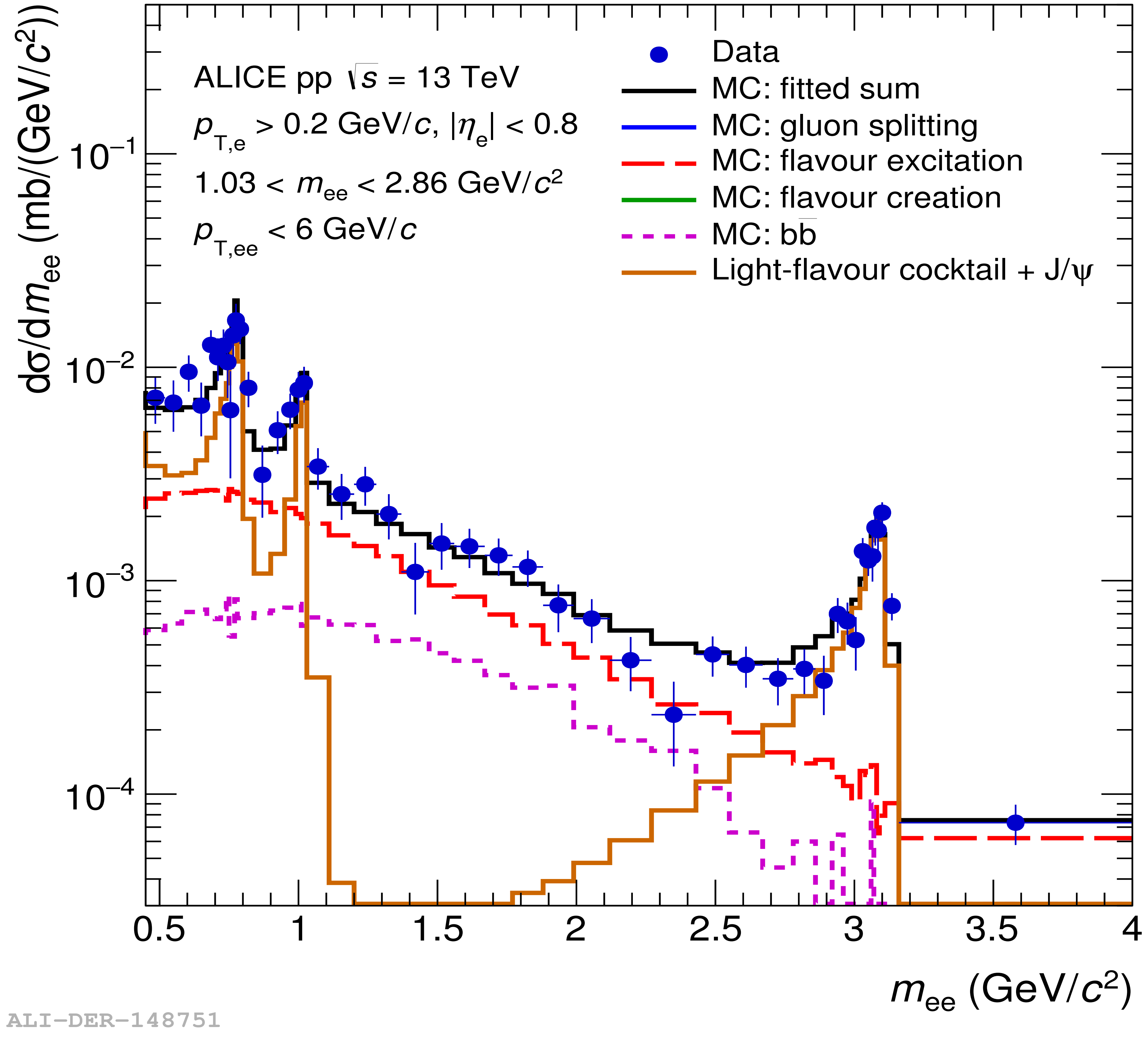


- Fit the data in 2D (m_{ee} vs $p_{T,ee}$) allowing each fractional contribution to be between 0 and 1
- Fit results:
  - GSP: (0.00 ± 0.67)
  - FEX: (0.68 ± 0.06)
  - FCR: (0.00 ± 0.99)
  - e^+e^- from bb: (0.32 ± 0.06)
- Poor constraint on FCR and GSP contributions
  - More data or better S/B needed
  - Run-3: analysis in 3D (m_{ee} vs $p_{T,ee}$ vs DCA_{ee})
  - Angular correlations, …

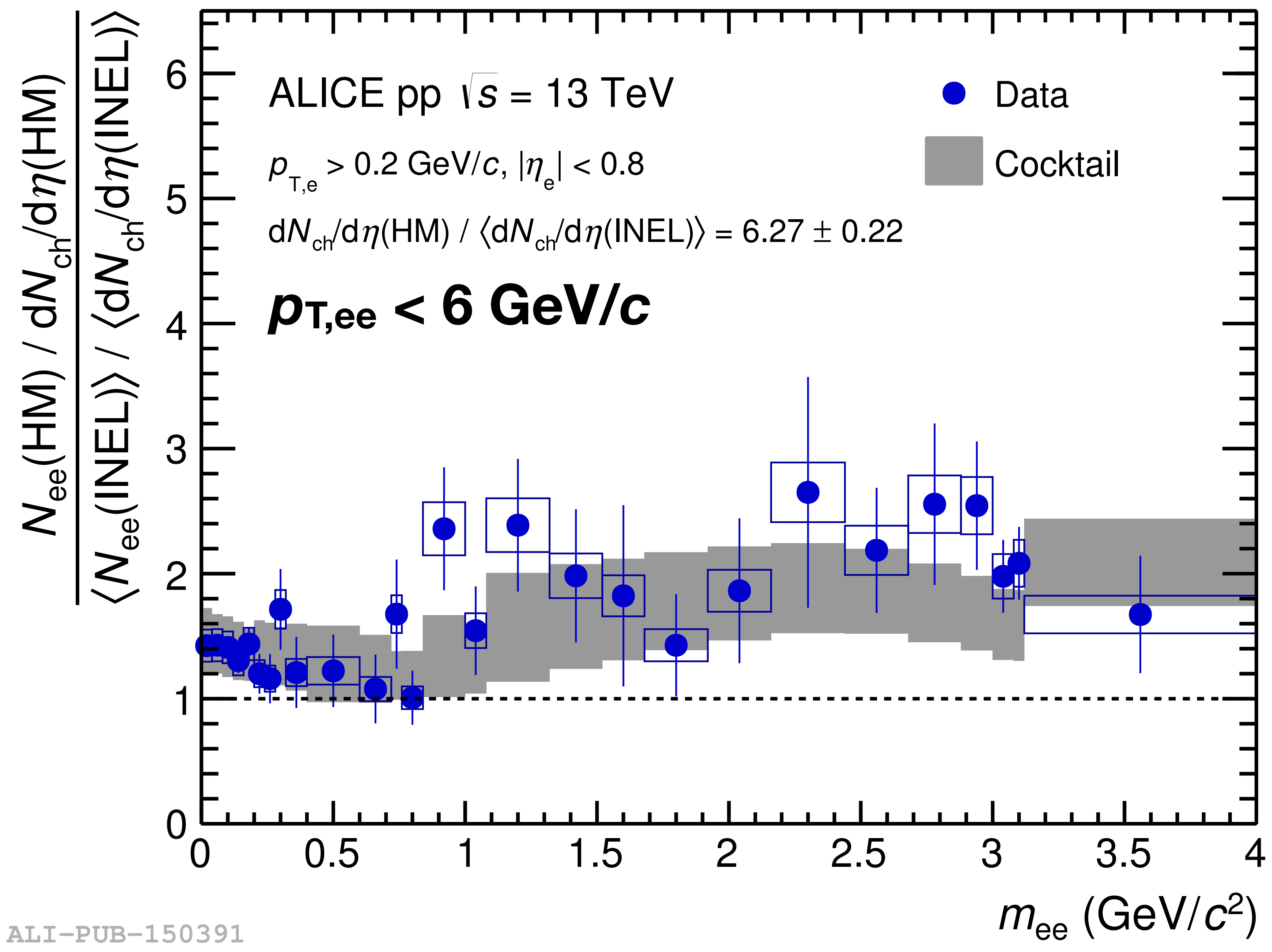


First Look at High-Multiplicity pp Collisions

- Production of ρ? Thermal radiation? Role of Multiple Parton Interactions?
- Idea: produce a ratio of dielectron spectra scaled by multiplicity

$$\frac{N_{\mathrm{ee}}(\mathrm{HM})}{\langle N_{\mathrm{ee}}\rangle} \times \frac{\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle}{\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta(\mathrm{HM})}$$

- Cocktail calculations take into account expected modifications:
  - Measured hardening of h± p_{T} spectrum (jets) → assume same multiplicity scaling for LF hadrons at the same m_{T}
  - Measured D and J/ψ production vs multiplicity → assume same enhancement for beauty as for open charm
- Increase of dielectron production in good agreement with cocktail (light + heavy flavour)



ALICE, arXiv:1805.04407 (PLB, in press)

First Look at High-Multiplicity pp Collisions

- Production of ρ? Thermal radiation? Role of Multiple Parton Interactions?
- Idea: produce a ratio of dielectron spectra scaled by multiplicity
- Cocktail calculations take into account expected modifications:
  - Measured hardening of $h^{\pm}$ p_T spectrum (jets) → assume same multiplicity scaling for LF hadrons at the same m_T
  - Measured D and J/ψ production vs multiplicity → assume same enhancement for beauty as for open charm
- Increase of dielectron production in good agreement with cocktail (light + heavy flavour)

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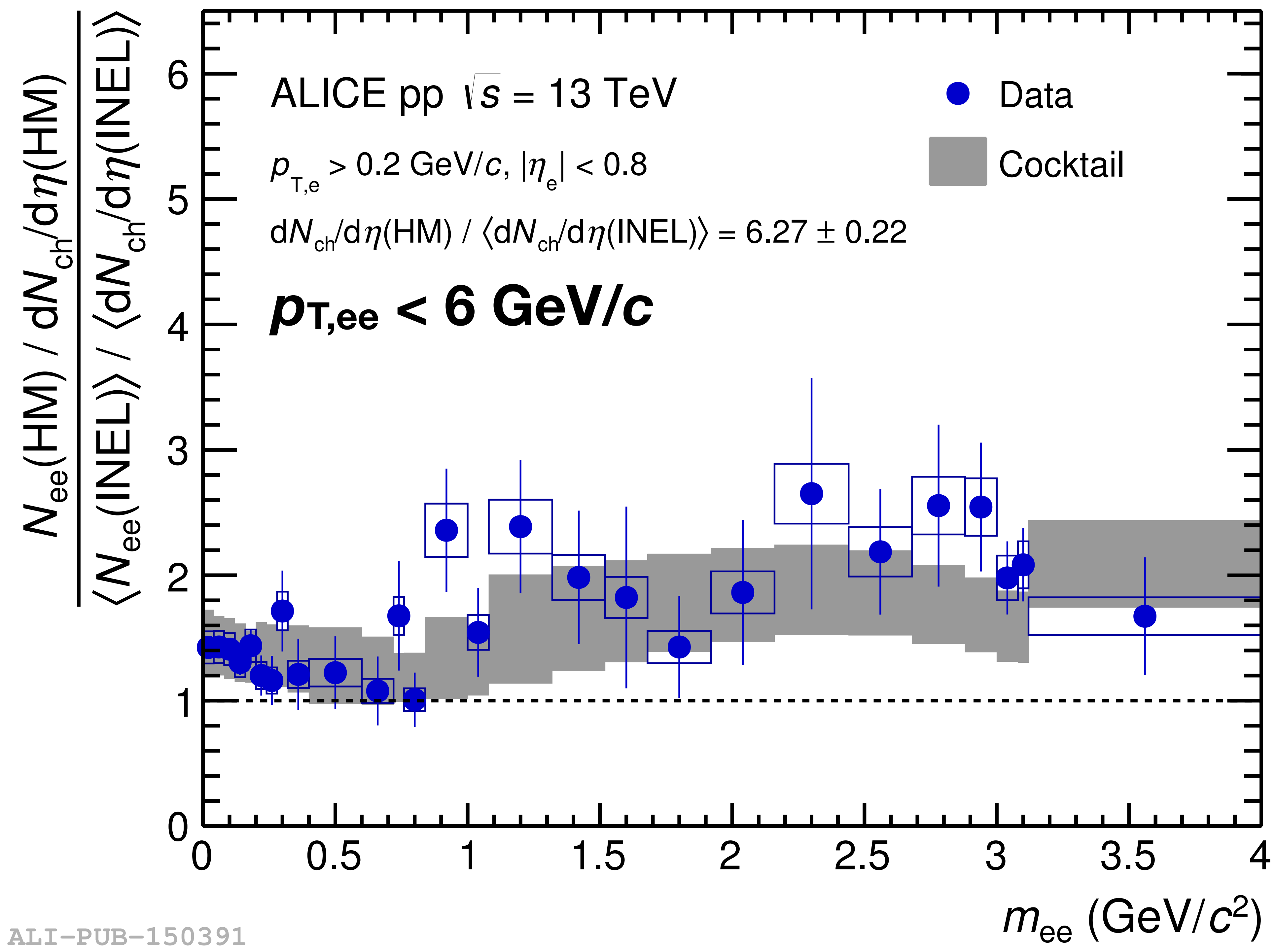

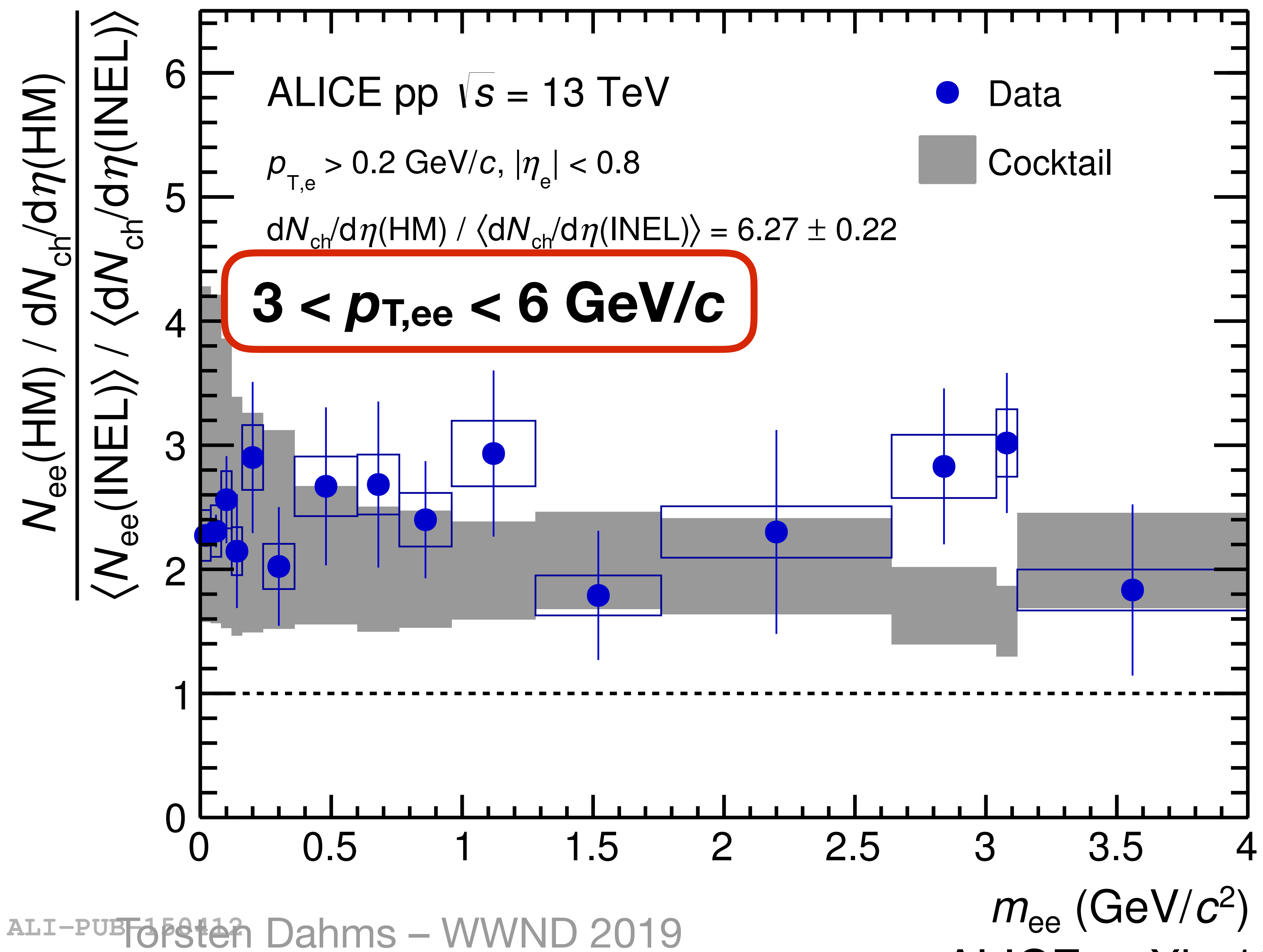

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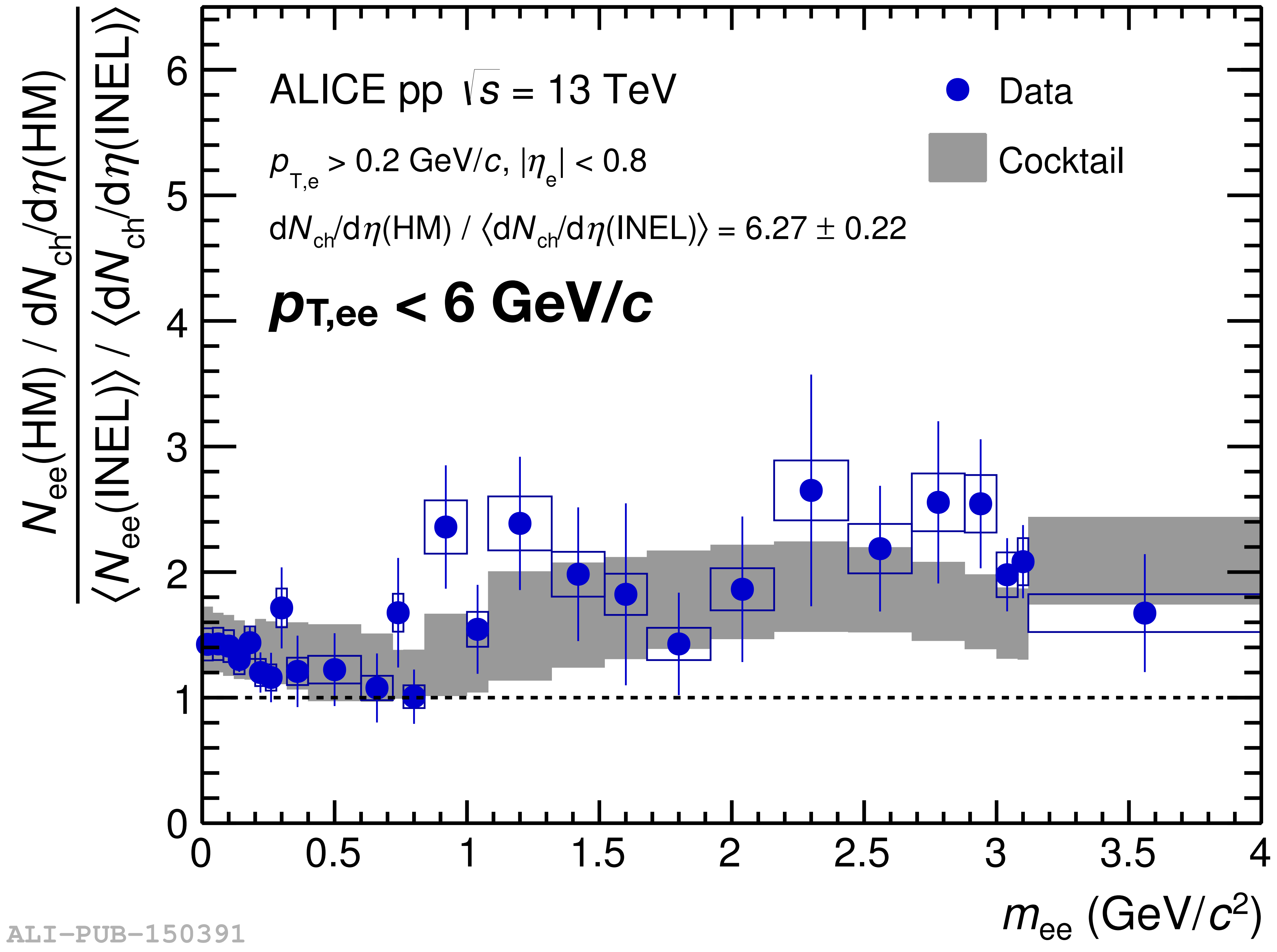
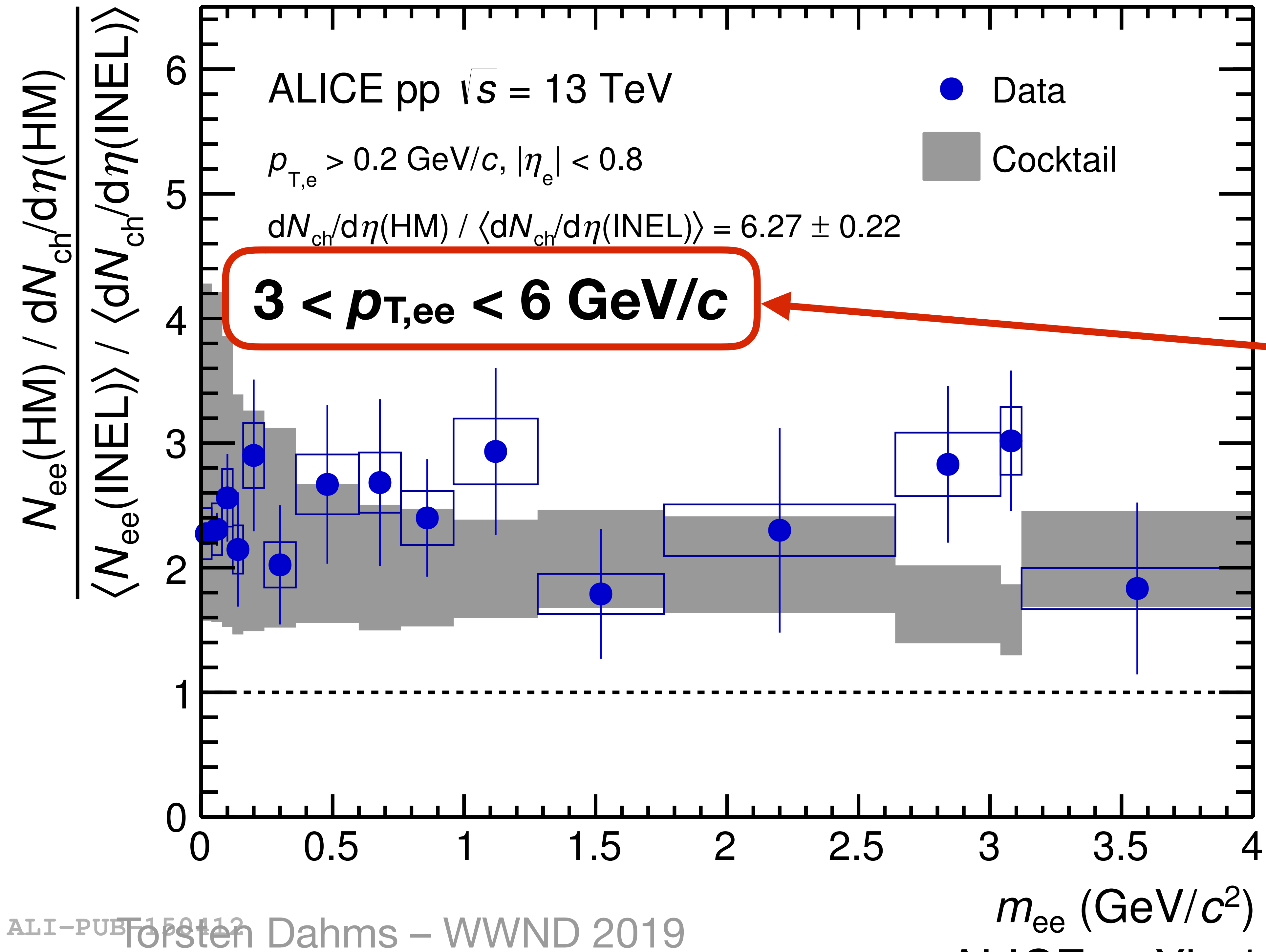
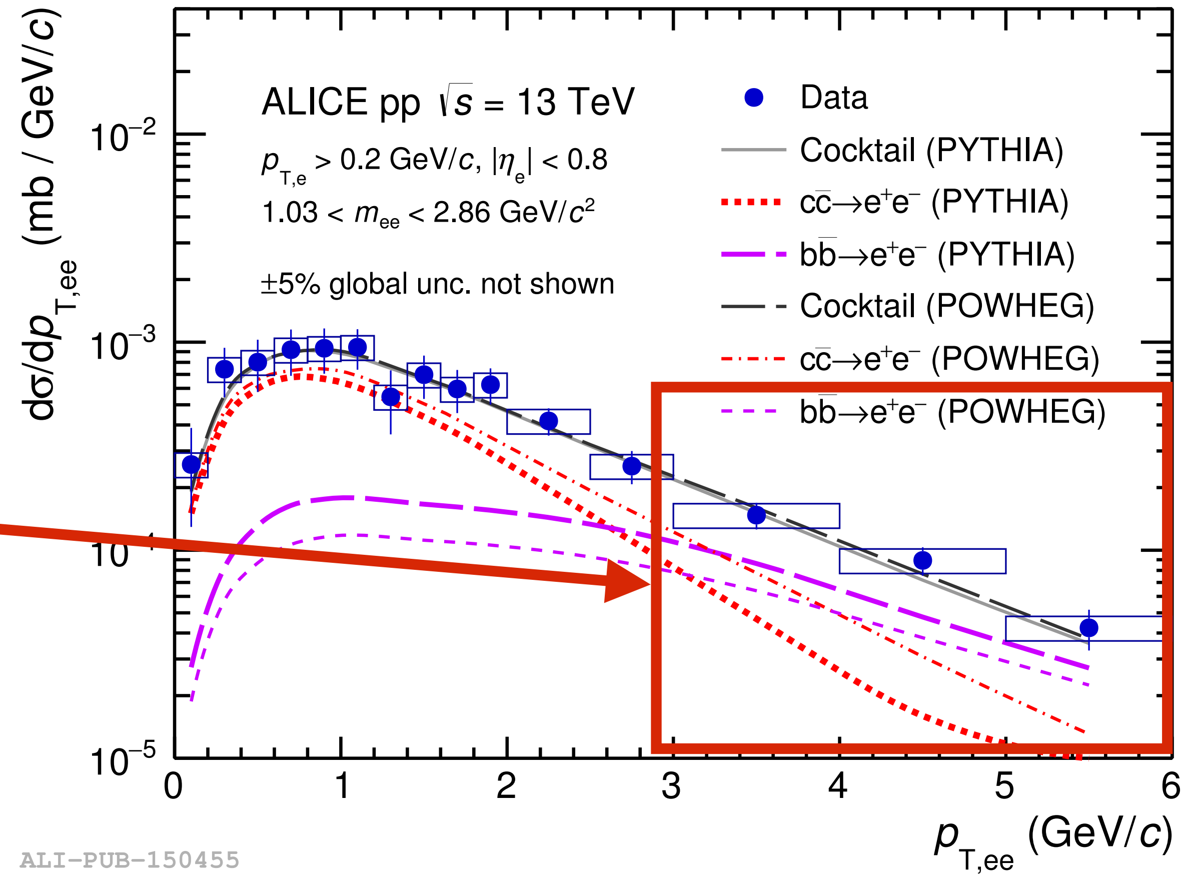






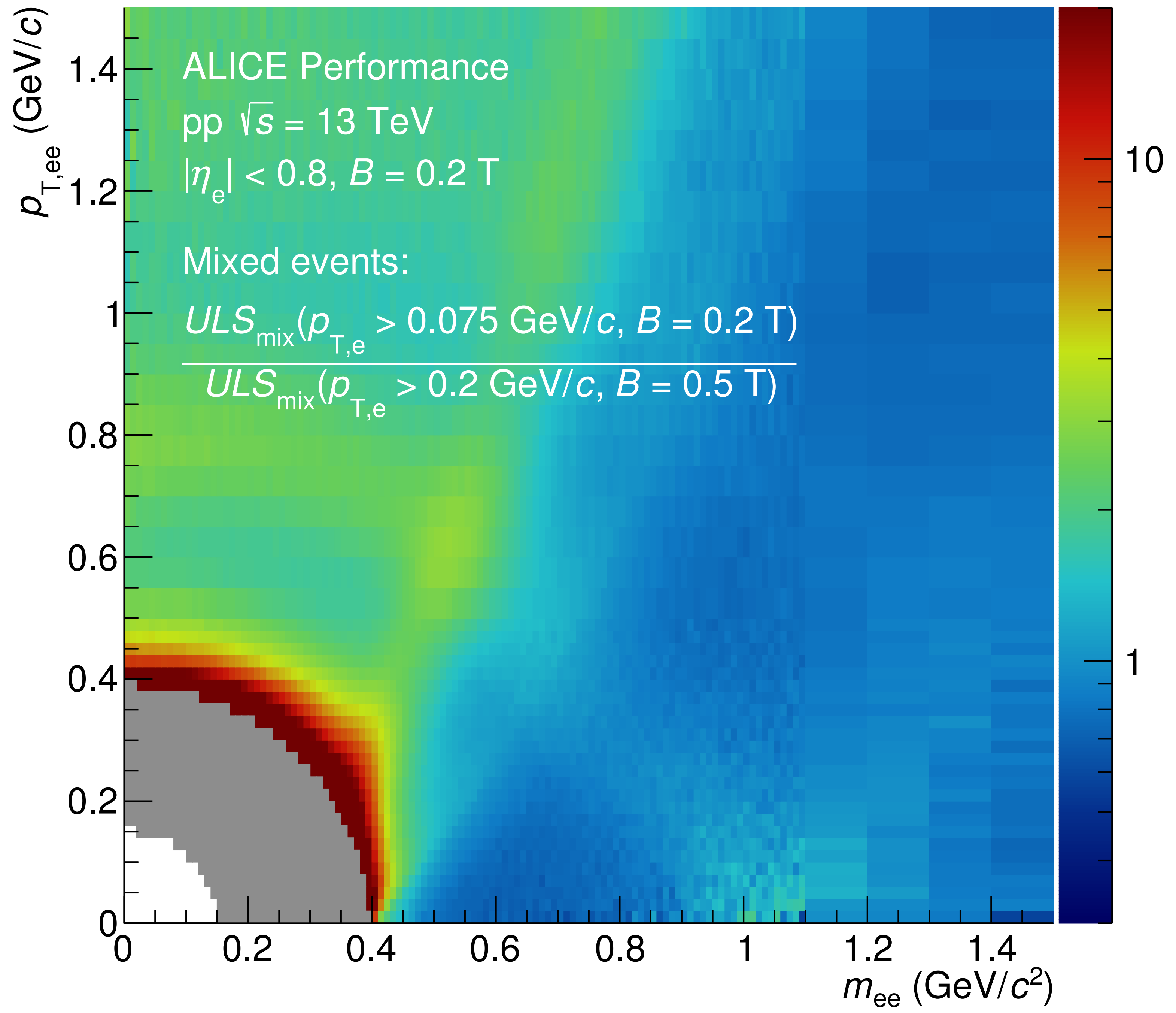
beauty has same multiplicity dependence as charm

ALICE, arXiv:1805.04407 (PLB, in press)

Perspectives for LHC Run-3

Low B-field studies in pp $\sqrt{s}$ = 13 TeV

- Reduced magnetic field in central barrel (0.5 T → 0.2 T)
- Increased charged-particle acceptance (p_T > 0.2 GeV/c → p_T > 0.075 GeV/c)
  → access to very low-p_T / low-m_{ee} pairs



ALI-PREL-148880

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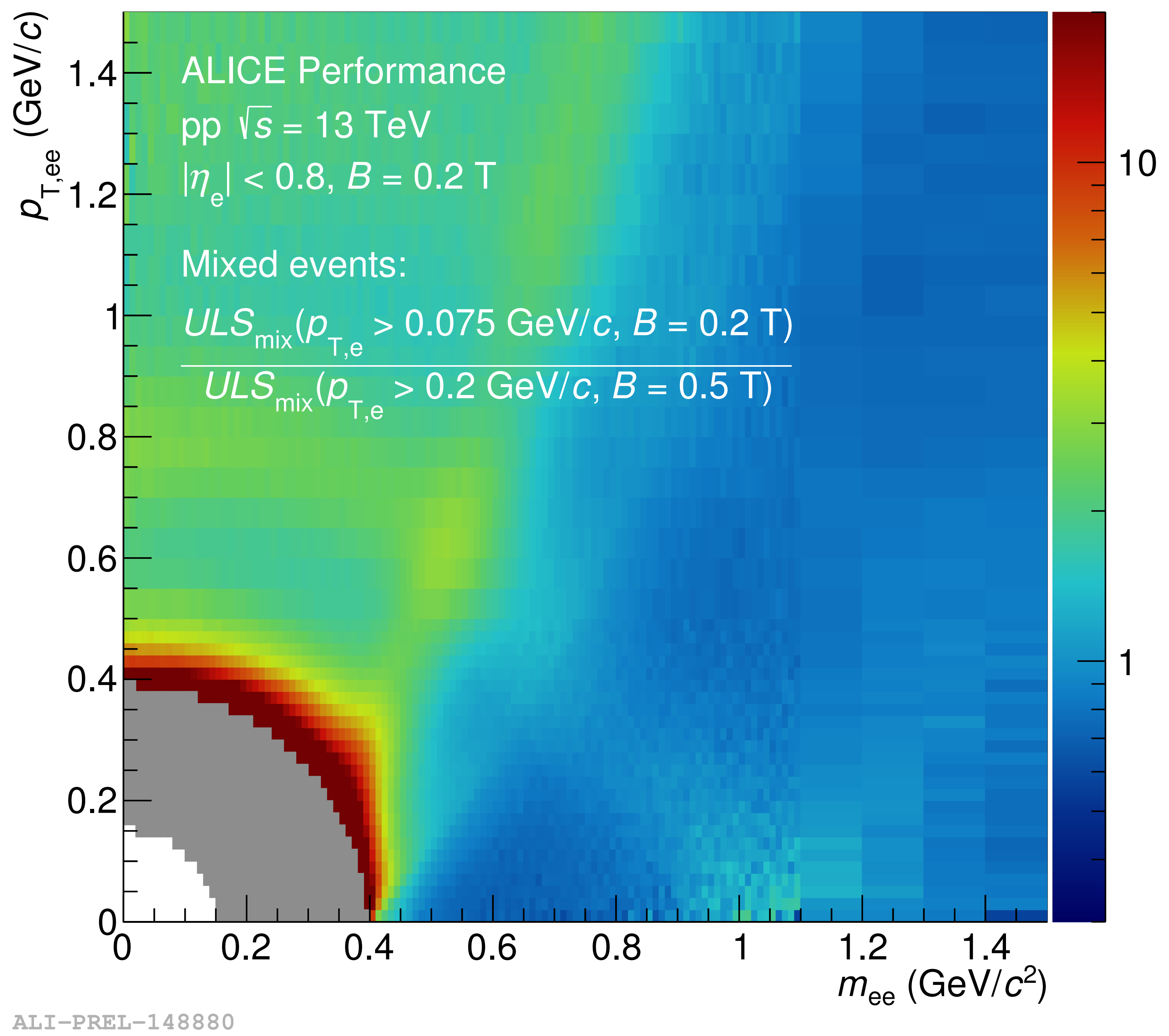
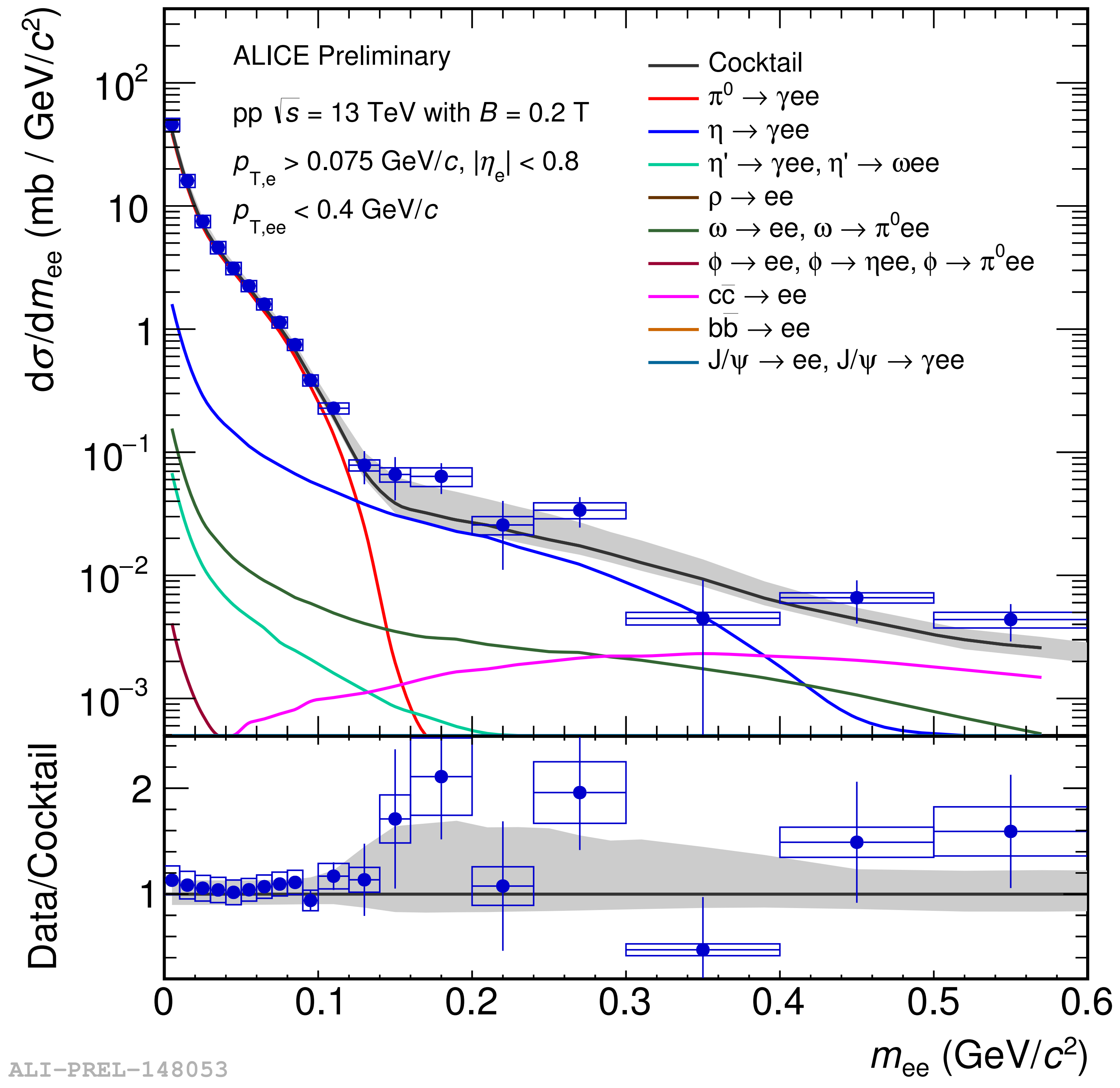
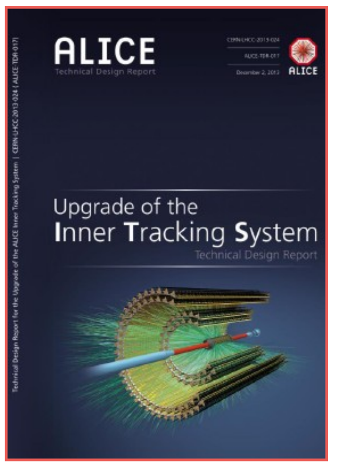




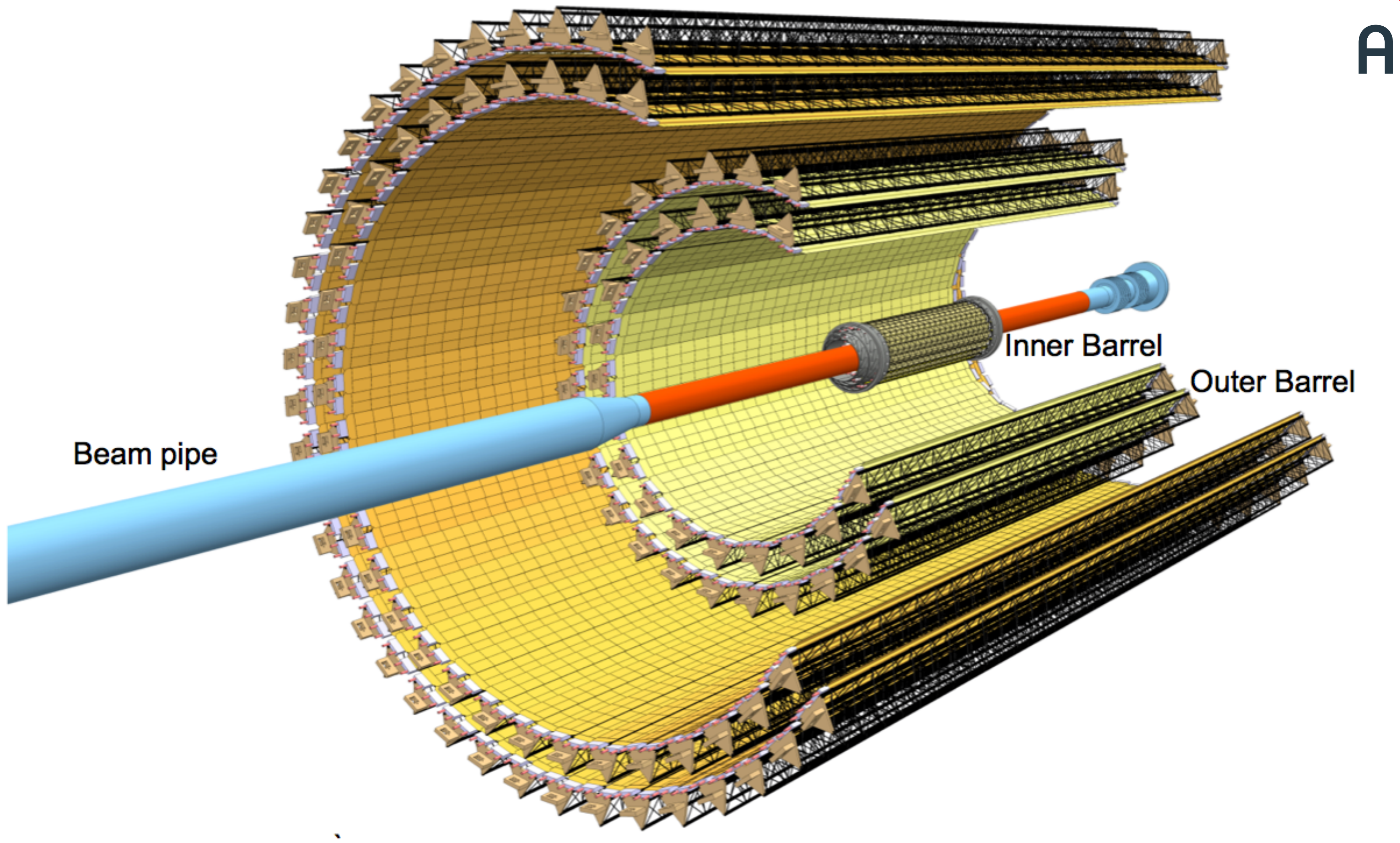
- Results from pilot runs in 2016 and 2017: data on the upper edge of the cocktail uncertainties
  - Need more data and η meson measurements at very low p_T
  - Will help to understand the excess of dielectrons observed by the AFS experiment at the ISR (V. Hedberg, PhD thesis, Lund (1987))

ALICE Upgrade for LHC Run-3

- **Major upgrades of main tracking systems**
- **Completely new 7-layer ITS detector**
  - Precise information about vertex and heavy-flavour production
  - Less radiation length: smaller conversion probability



ALICE-TPC Upgrade TDR, CERN-LHCC-2013-020



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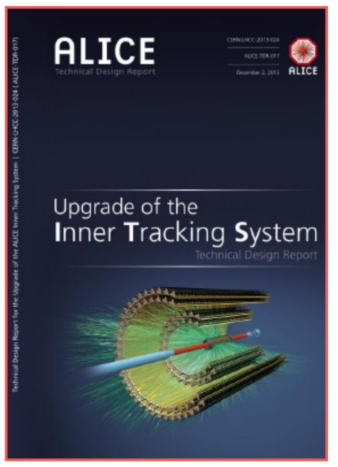

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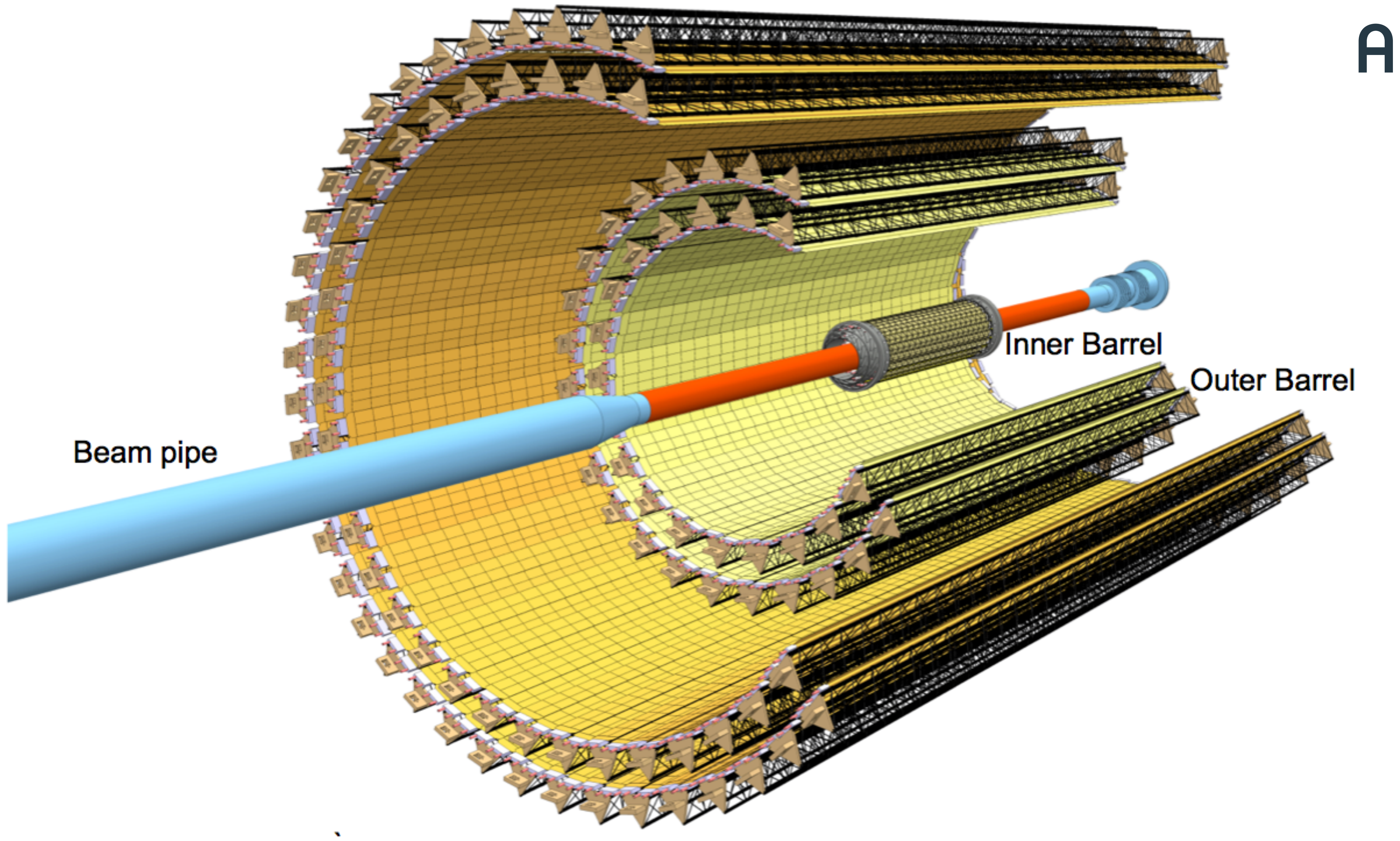
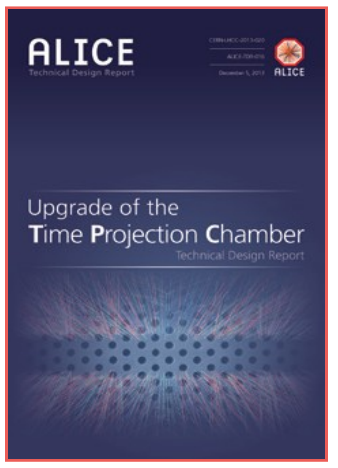
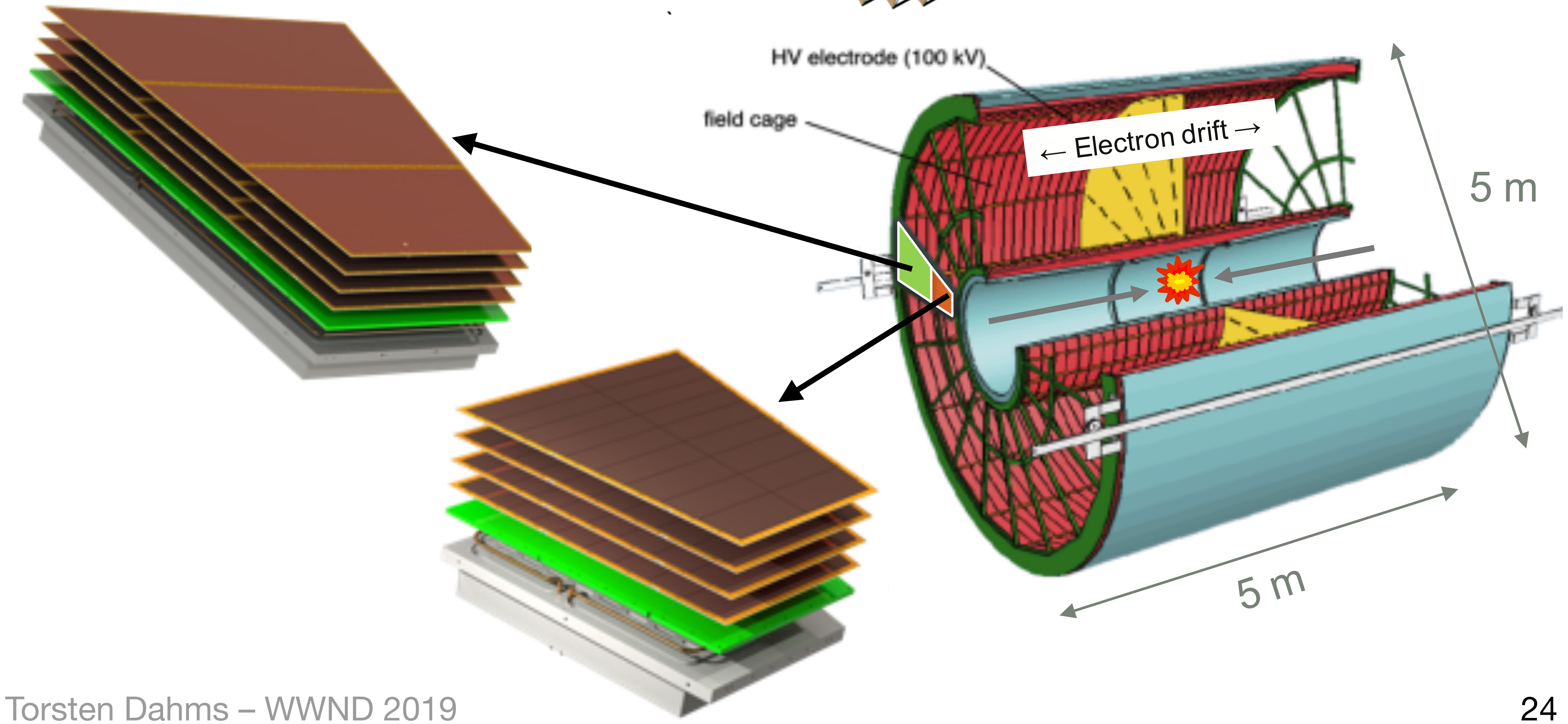


- **New TPC GEM-based readout chambers**
  - Continuous readout at IR in Pb–Pb up to 50 kHz (~50× compared to Run-2)



ALICE-ITS Upgrade TDR, CERN-LHCC-2013-024



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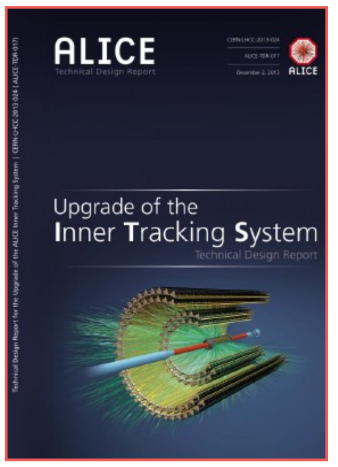
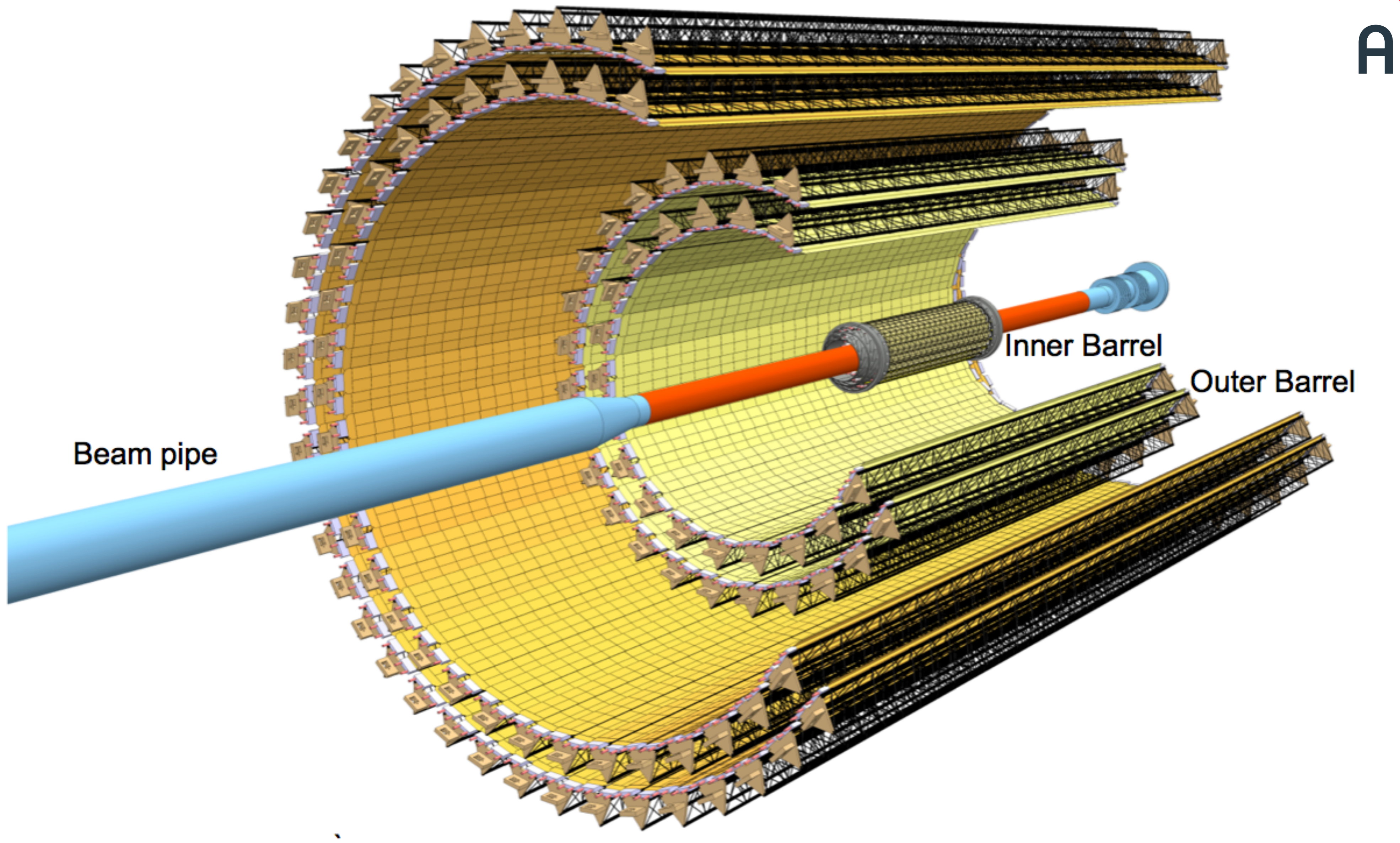


ALICE-TPC Upgrade TDR, CERN-LHCC-2013-020



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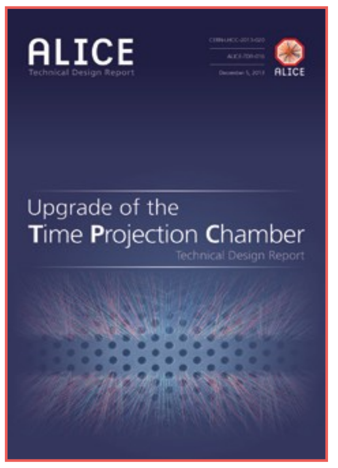

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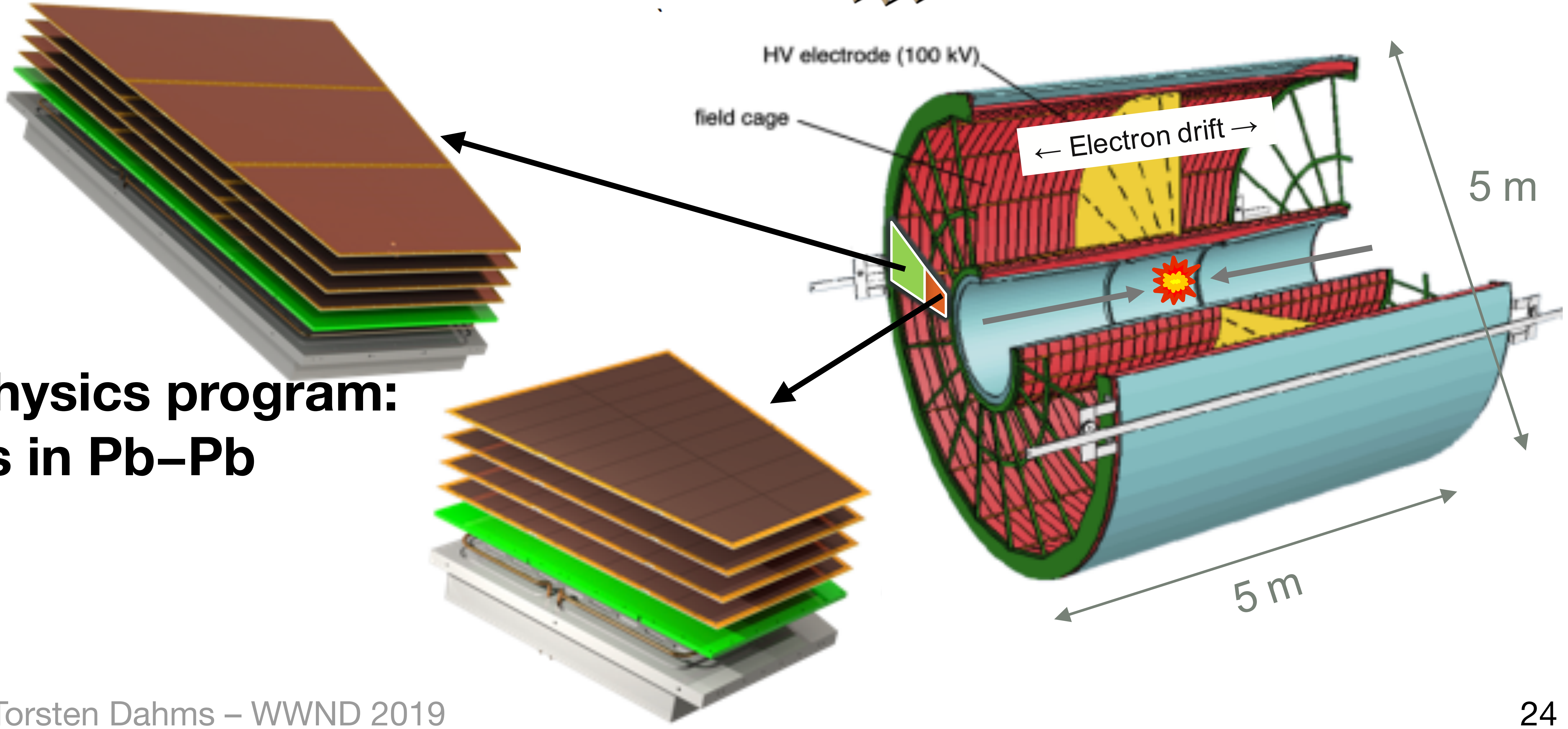


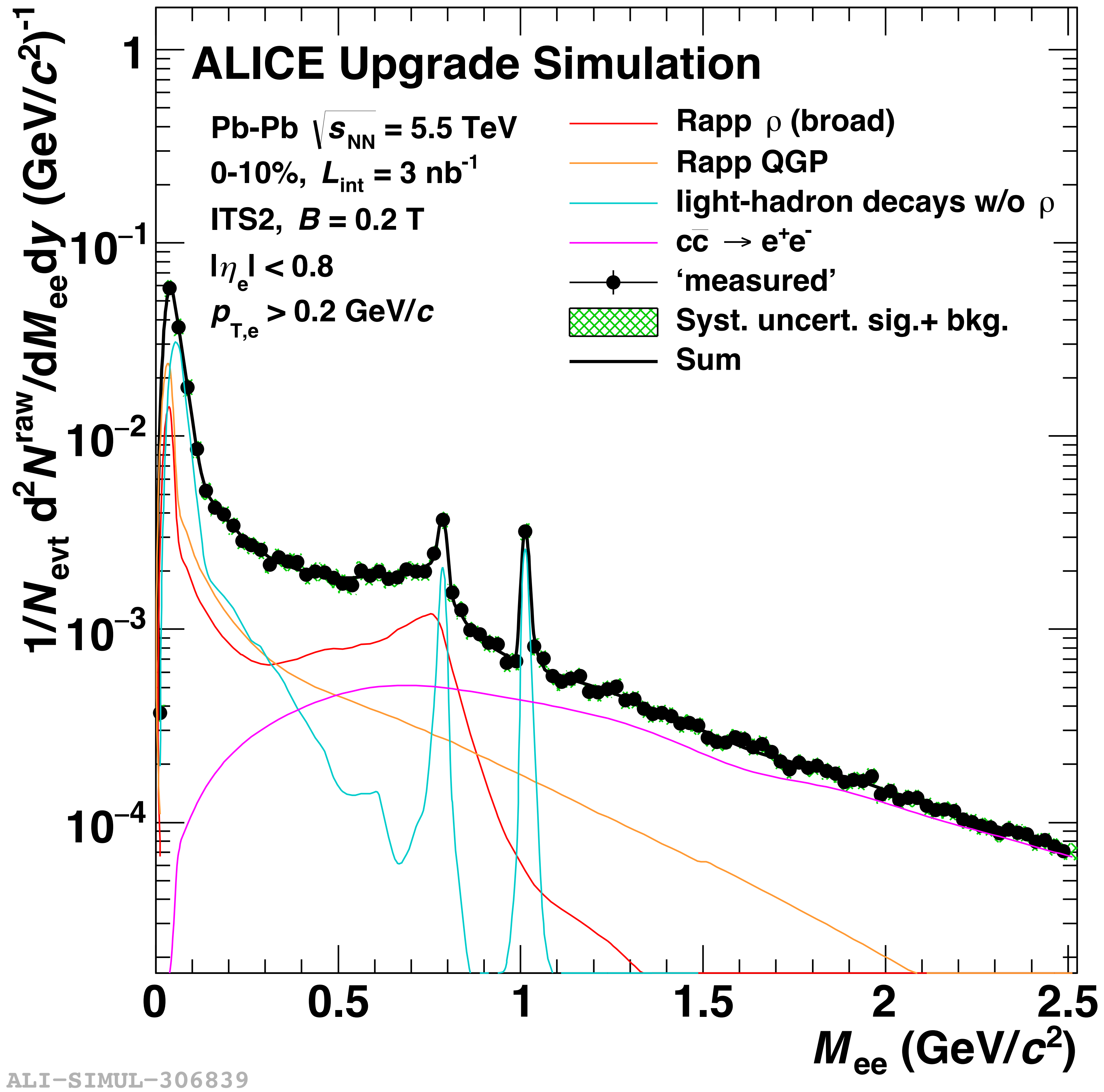
- **One of the main objectives of the physics program: low-mass dielectron measurements in Pb–Pb collisions**
  - Dedicated run with reduced magnetic field

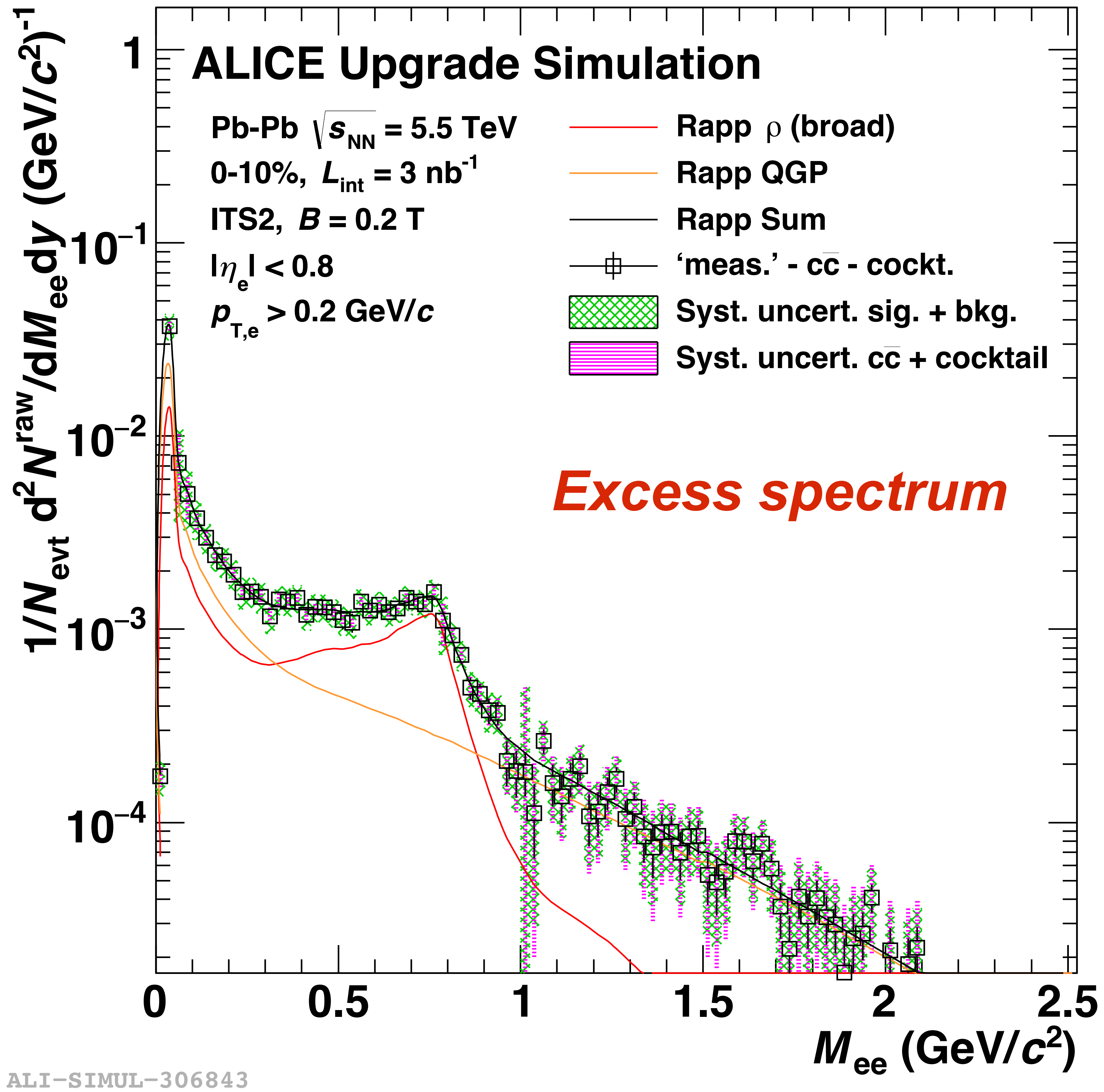
Low Mass Dileptons in ALICE: Future

- TPC and ITS upgrades:
  - allow high data rates
  - reduce charm background with impact parameter cut
- Dedicated low *B*-field run (*B* = 0.2 T)

CERN-LPCC-2018-07
(arXiv:1812.06772)

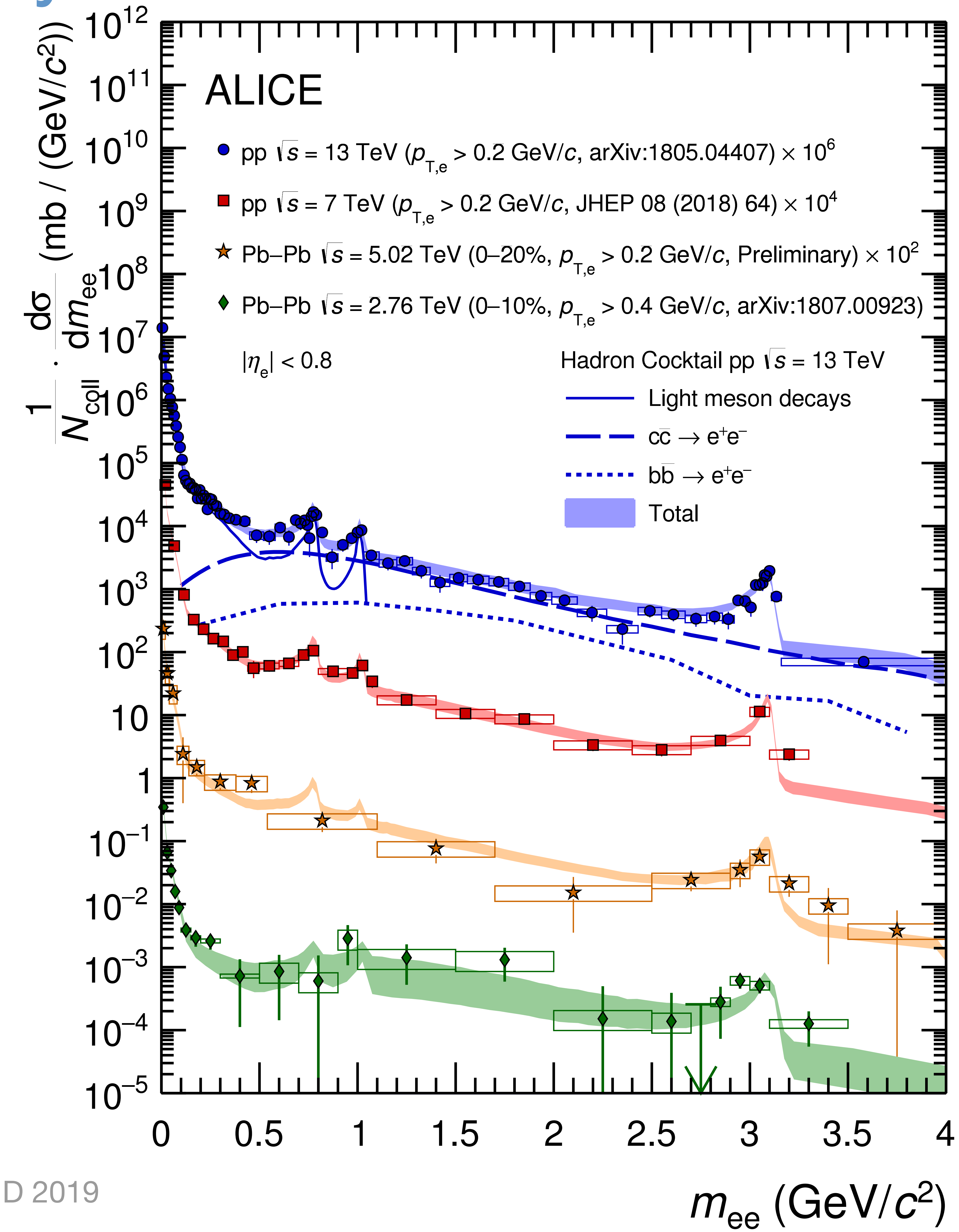
2.5×10⁹ events = “1 year” at 50 kHz





Summary

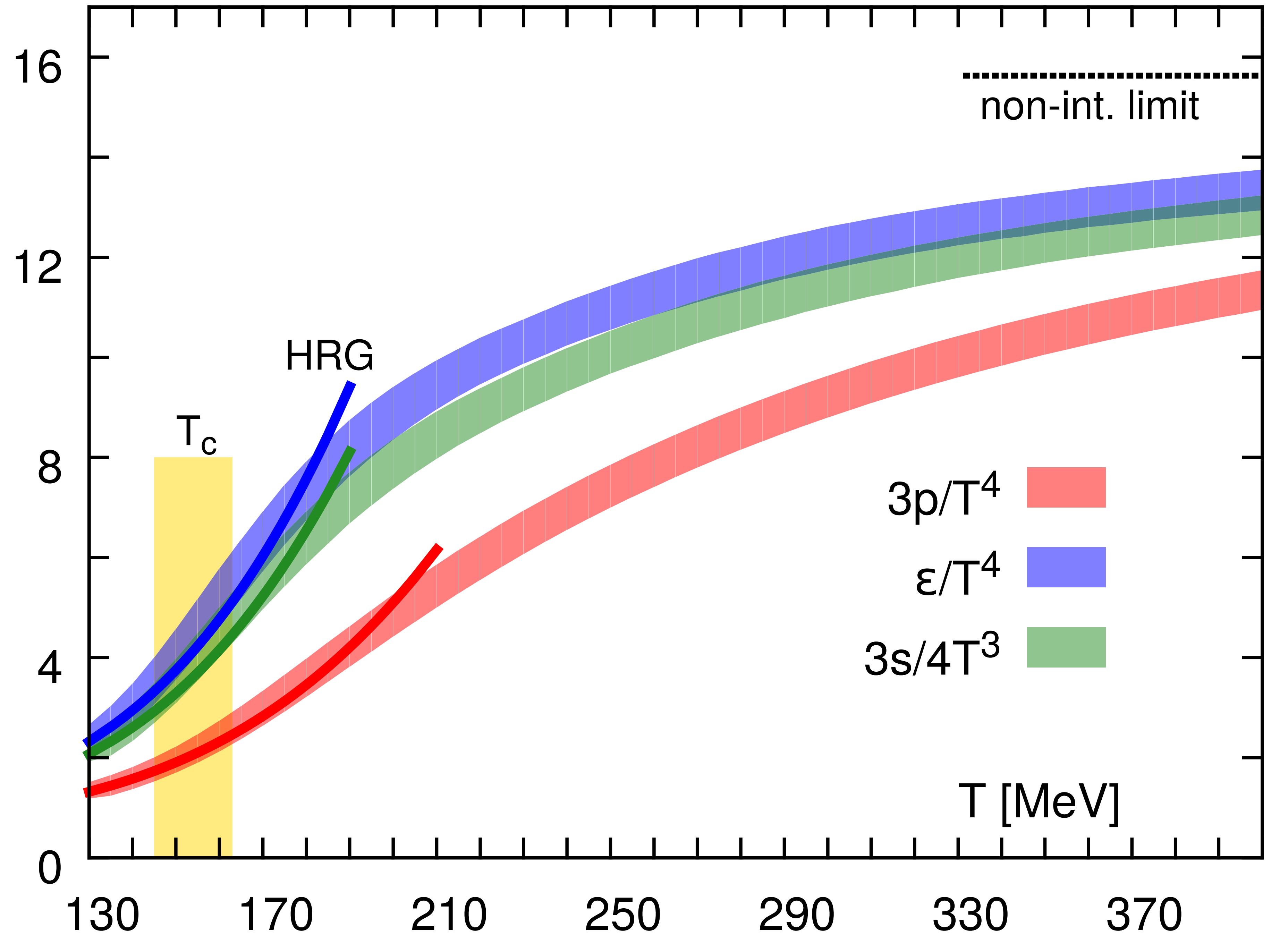
- Published results in pp at $\sqrt{s}$ = 7 and 13 TeV and Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV
- Preliminary results in Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
- **pp baseline consistent with cocktail expectation**
  - hadron decay background understood
  - complementary information on heavy-flavour production
  - first look at high-multiplicity pp collisions
- Pb–Pb data not yet sensitive to quantify the presence of any enhancement
  - challenging analysis, limited sensitivity for detailed studies
  - active studies of MVA methods to improve S/B
- **Ready for Run-3 when precise measurement will be possible thanks to ALICE Upgrade**
  - ~100× more central Pb–Pb events, access to T_{init}



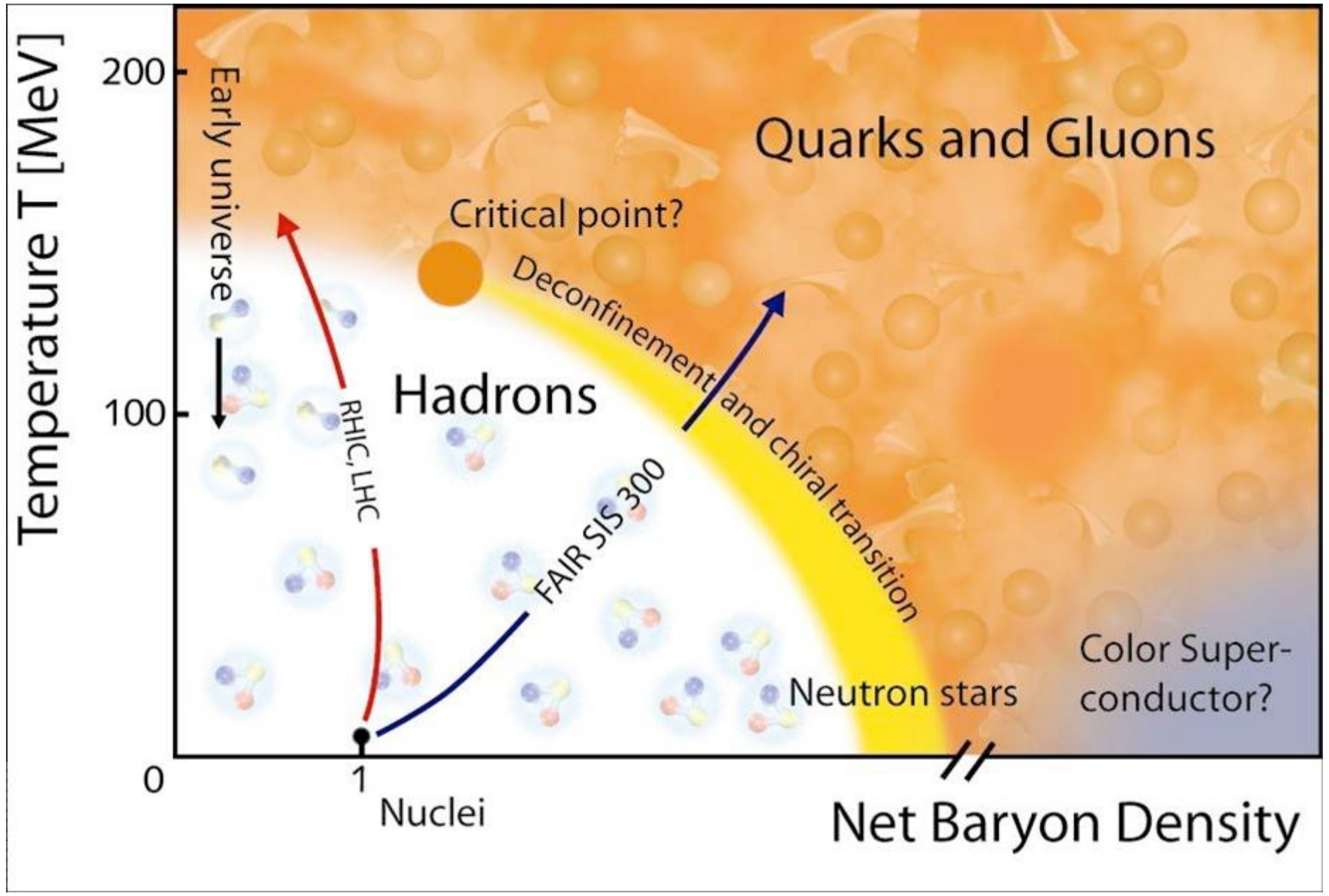
ALICE, JHEP 09 (2018) 64
ALICE, PLB 788 (2019) 505
ALICE, arXiv:1807.00923 (accepted by PRC)

Backup

Phases of QCD Matter



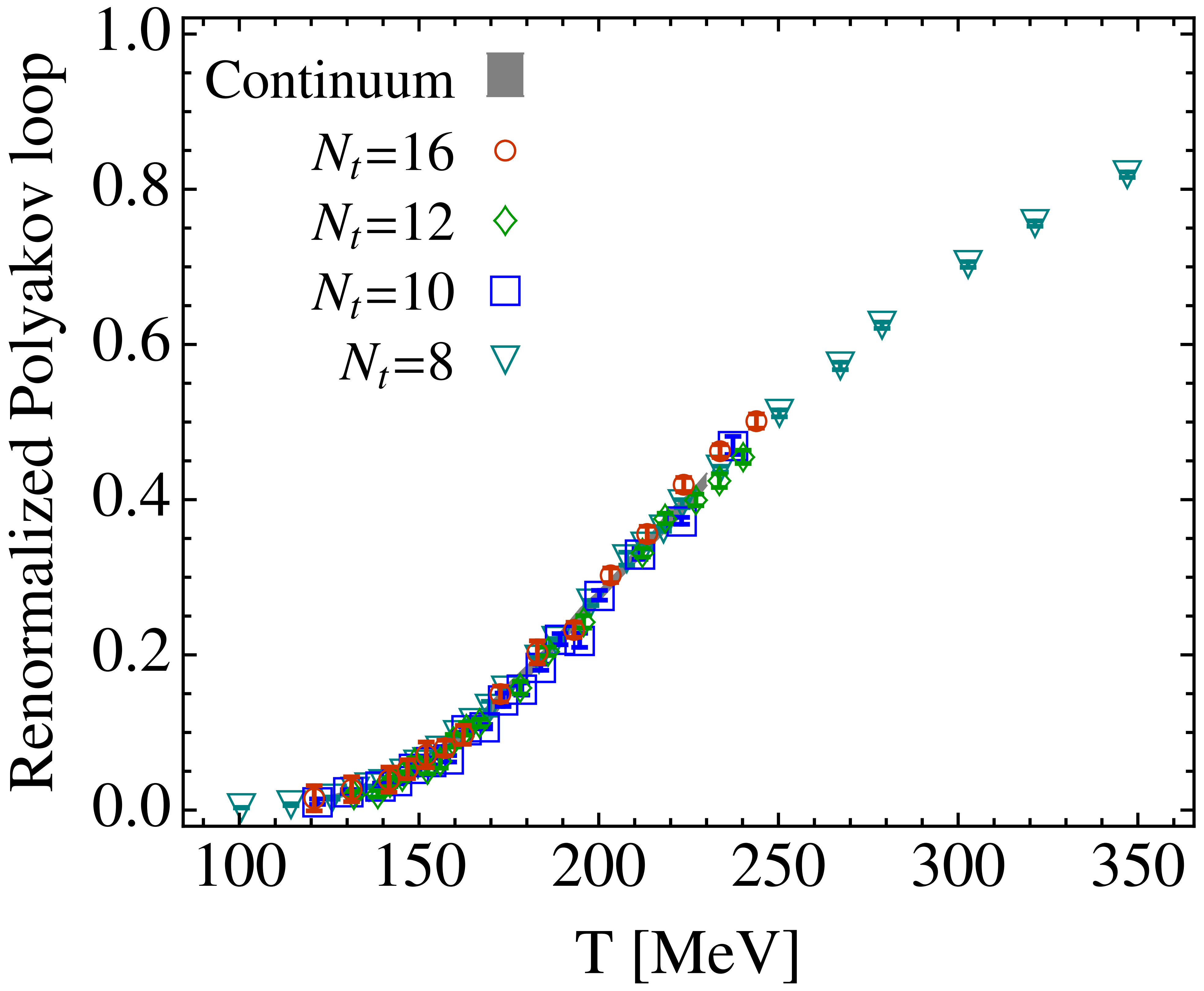
Wuppertal-Budapest, JHEP 09 (2010) 073
HotQCD, PRD 90 (2014) 094503



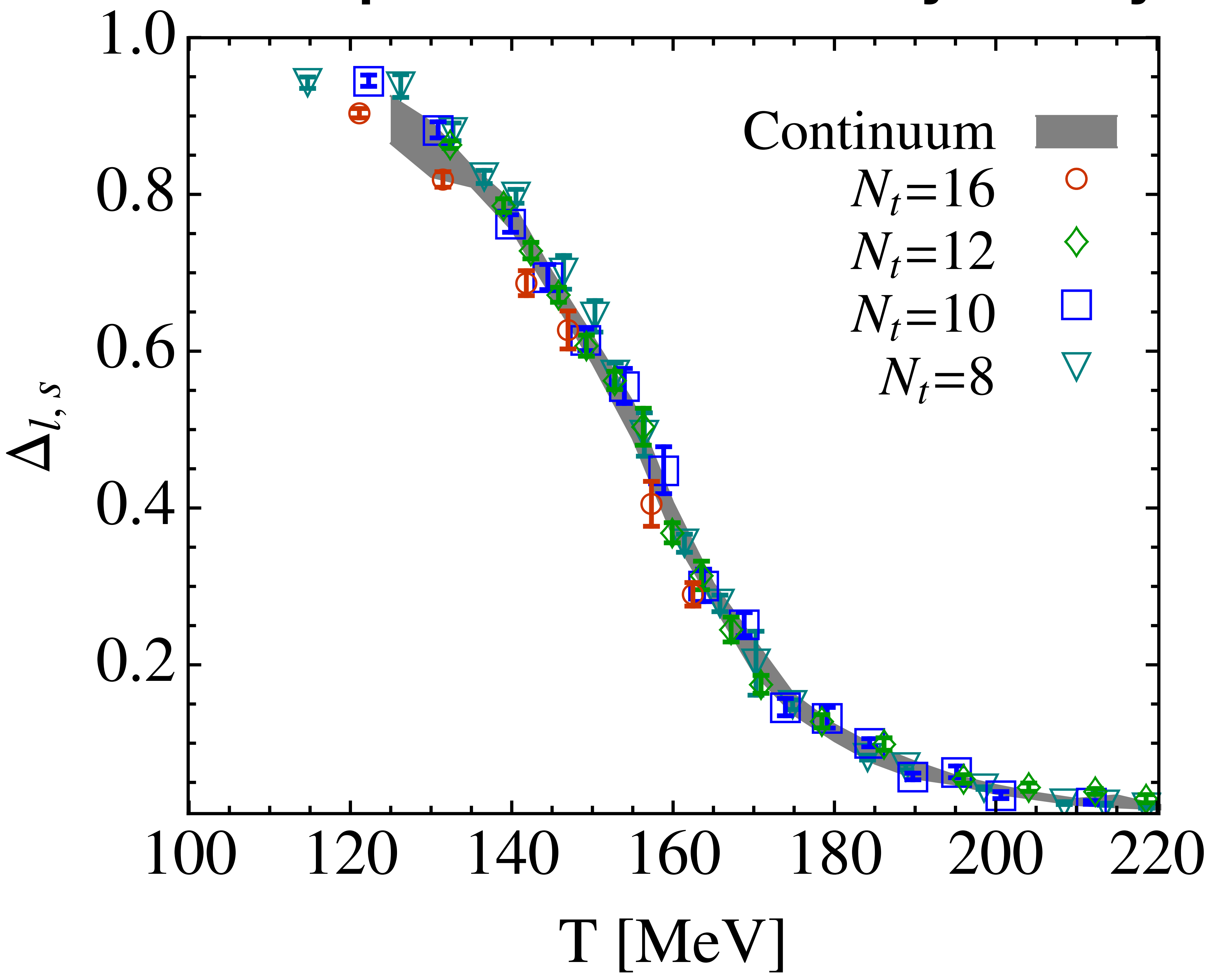
- Cross over from hadron gas to quark-gluon plasma at T_c = 154±9 MeV
  - 1 MeV ~ 10^{10} K → $T_c = 2\times10^{12}$ K
- Centre of the sun: $T = 2\times10^{7}$ K
- The QGP is more than 100 000 times hotter than the centre of the sun

QCD Phase Transitions

Order parameter of deconfinement



Order parameter of chiral symmetry



Wuppertal-Budapest Collaboration,
JHEP 09 (2010) 073

- Lattice QCD calculation
  - Predict (partial) chiral symmetry restoration already at *T* lower than deconfinement phase transition

Summary: Dilepton Production

- Emission rate of dileptons per volume:

$$f^B(q_0,T) = 1/(e^{q_0/T} - 1)$$

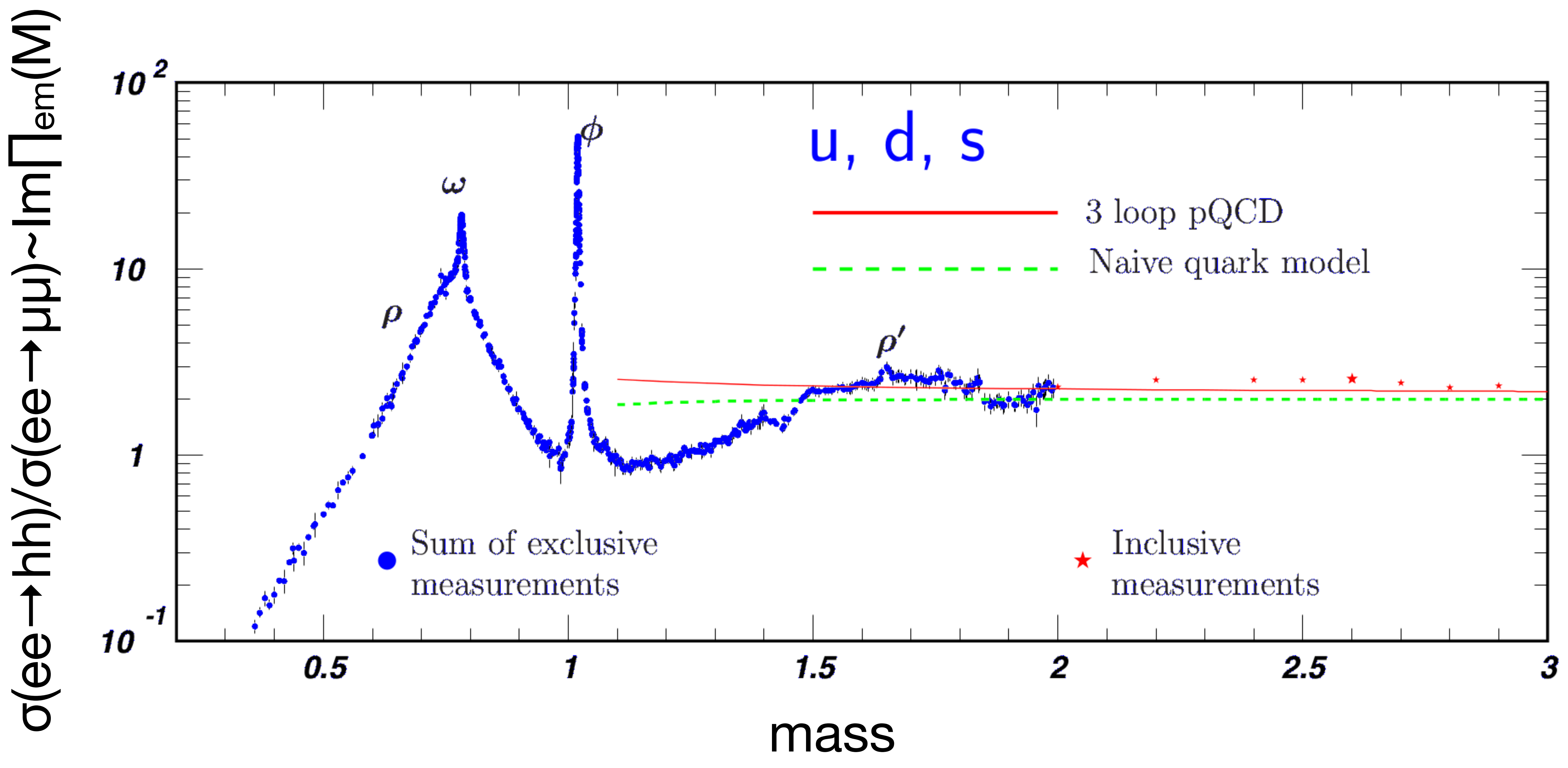
$$\frac{dR_{ll}}{d^4q} = -\frac{\alpha^2}{3\pi^3}\frac{L(M)}{M^2}\,\mathrm{Im}\Pi^{\mu}_{\mathrm{em},\mu}(M,q;T)\,f^B(q_0,T)$$

$$L(M) = \sqrt{1-\frac{m_l^2}{M^2}}\left(1+\frac{2m_l^2}{M^2}\right)$$

$\gamma^* \to e^+e^-$ decay

EM correlator medium property

Boltzmann factor temperature



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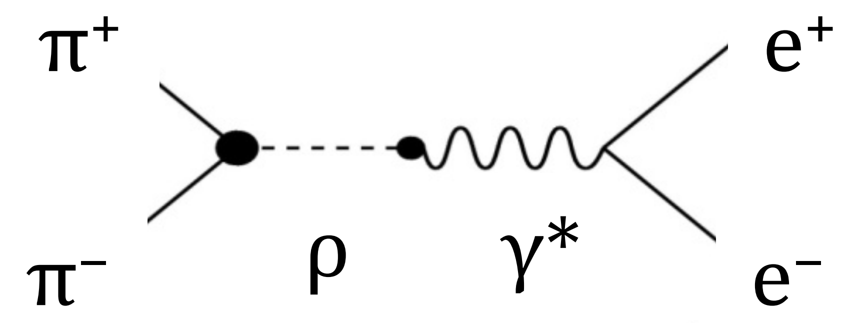
EM correlator medium property

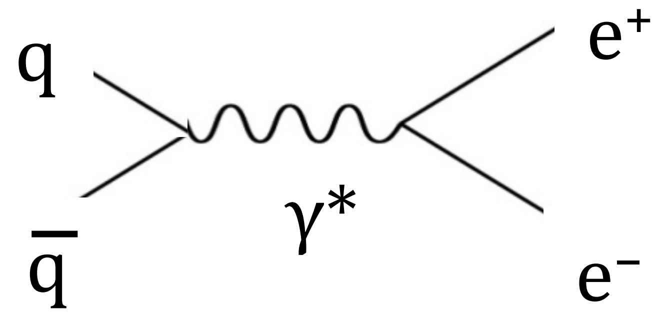
Boltzmann factor temperature

Hadronic contribution
Vector Meson Dominance → Medium modification of meson
Chiral restoration



$$\mathrm{Im}\,\Pi^{\mathrm{vac}}_{\mathrm{em}}(M) = \begin{cases} \sum_{V=\rho,\omega,\phi}\left(\frac{m_V^2}{g_V}\right)^2 \mathrm{Im}D_V(M) \\ -\frac{M^2}{12\pi}\left(1+\frac{\alpha_s(M)}{\pi}+\ldots\right)N_c\sum_{q=u,d,s}(e_q^2) \end{cases}$$

$q\bar{q}$ annihilation →



Thermal radiation from partonic phase (QGP)

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$$f^B(q_0,T) = 1/(\mathrm{e}^{q_0/T} - 1)$$

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$\gamma^* \rightarrow e^+e^-$ decay — EM correlator medium property — Boltzmann factor temperature

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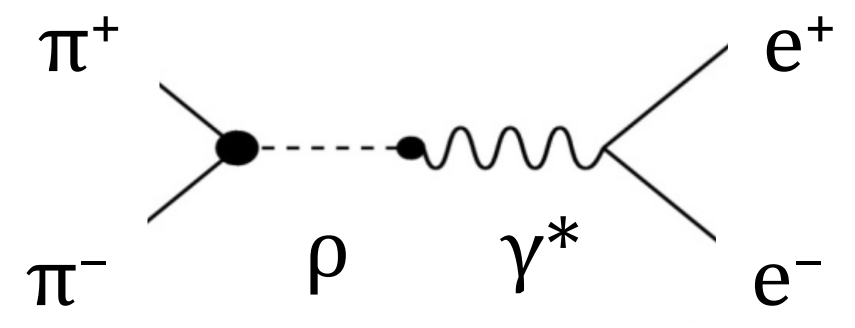

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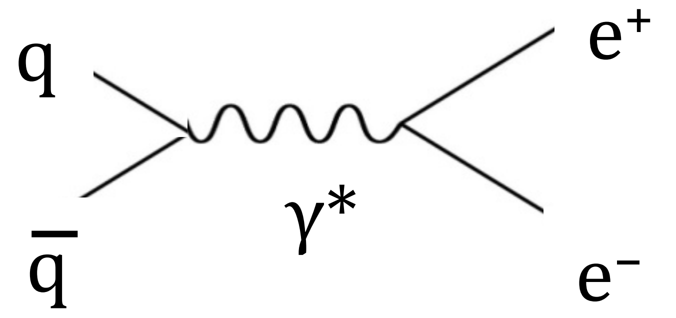

- From emission rate of dileptons one can decode:

$$M < 1.5\,\mathrm{GeV}/c^2: \quad \frac{dN_{ll}}{dM} = M^{3/2} \times \langle \exp(-M/T) \times \mathrm{Im}\,\Pi_{\mathrm{em}}(M)\rangle$$

in-medium EM correlator: chiral symmetry

$$M > 1.5\,\mathrm{GeV}/c^2: \quad \frac{dN_{ll}}{dM} = M^{3/2} \times \langle \exp(-M/T)\rangle$$

Planck-like: thermometer distinguishes hadrons from partons

State of the Art: NA60 at the SPS

- Measured excess of low mass dimuons in In-In collisions at $\sqrt{s_{NN}}$ = 17.3 GeV
- Subtracted hadronic cocktail w/o: access ρ spectral function
  - favours broadening scenario (Rapp-Wambach)
  - no mass shift needed (Brown-Rho)

NA60, EPJ C61 (2009) 711