Department of Physics
Inha university, Incheon

Beauty production in pp and Pb−Pb collisions with ALICE

Jonghan Park
for the ALICE Collaboration

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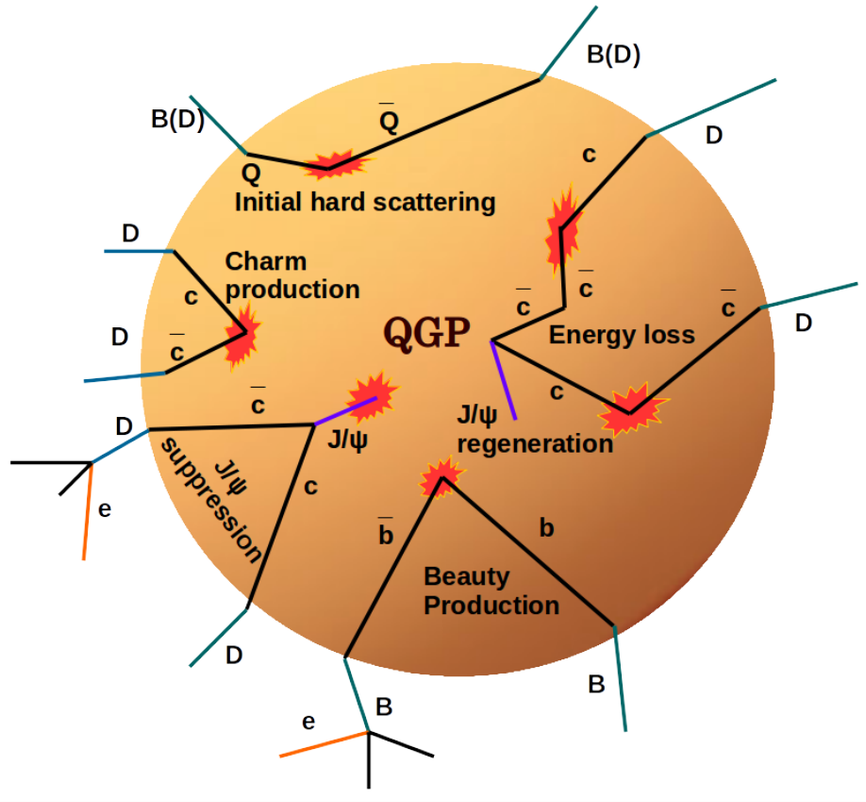
Physics Motivation

- **Heavy quarks (charm and beauty)** produced in hard scattering processes in the initial stage of the collisions, before QGP formation
  - $\tau_{\mathrm{b}} \approx 0.02 < \tau_{\mathrm{c}} \approx 0.07 < \tau_{\mathrm{QGP}} \approx 0.1 - 1\mathrm{fm}/c$
- **Experience full evolution of the medium**
  - Not created nor destroyed in the medium → **flavor is preserved**
- **In-medium parton energy loss** via both collisional and radiative processes
  - Expect to be mass and color charge dependences
  - Color-charge effect : $\Delta E_{\mathrm{gluons}} > \Delta E_{\mathrm{quarks}}$ due to coupling
  - Mass effect : $m_{\mathrm{u,d,s}} < m_{\mathrm{c}} < m_{\mathrm{b}} \longleftrightarrow \Delta E_{\mathrm{u,d,s}} > \Delta E_{\mathrm{c}} > \Delta E_{\mathrm{b}}$
- **Provide a hint of mass dependence of the in-medium parton energy loss by comparing beauty with charm**
- **In pp collisions**
  - Test pQCD calculations at LHC energies
  - Baseline for p-Pb and Pb-Pb collisions
- **In p–Pb collisions**
  - Cold Nuclear Matter (CNM) effects



Beauty measurements with ALICE

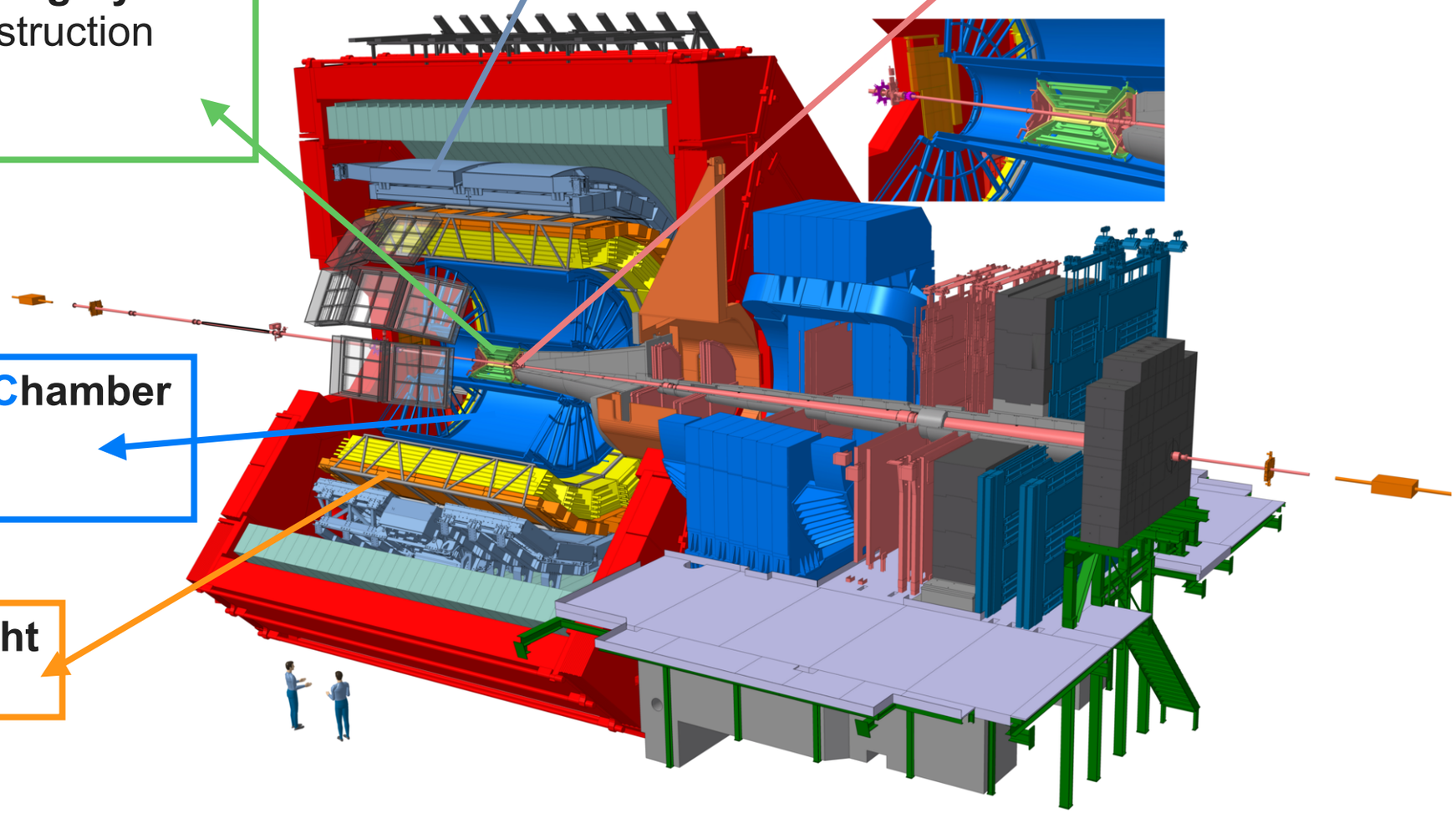
Central barrel coverage : $|\eta| < 0.9$

Beauty measurements:
- **Electrons from beauty-hadrons (b→e)**
- **Non-prompt D mesons (b→D^0→$K^- + \pi^+$)**
- **Non-prompt J/ψ (b→J/ψ→e^+e^-)**
- **b-tagged jets**

ElectroMagnetic Calorimeter
- Trigger
- PID

VZERO
- Trigger
- Event topology

Inner Tracking System
- PV reconstruction
- Tracking
- PID



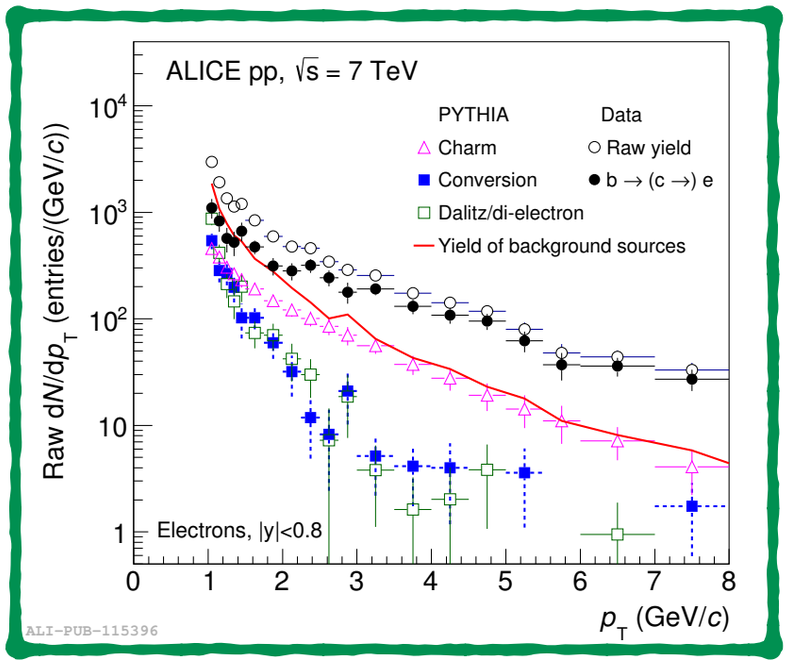
Time Projection Chamber
- Tracking
- PID

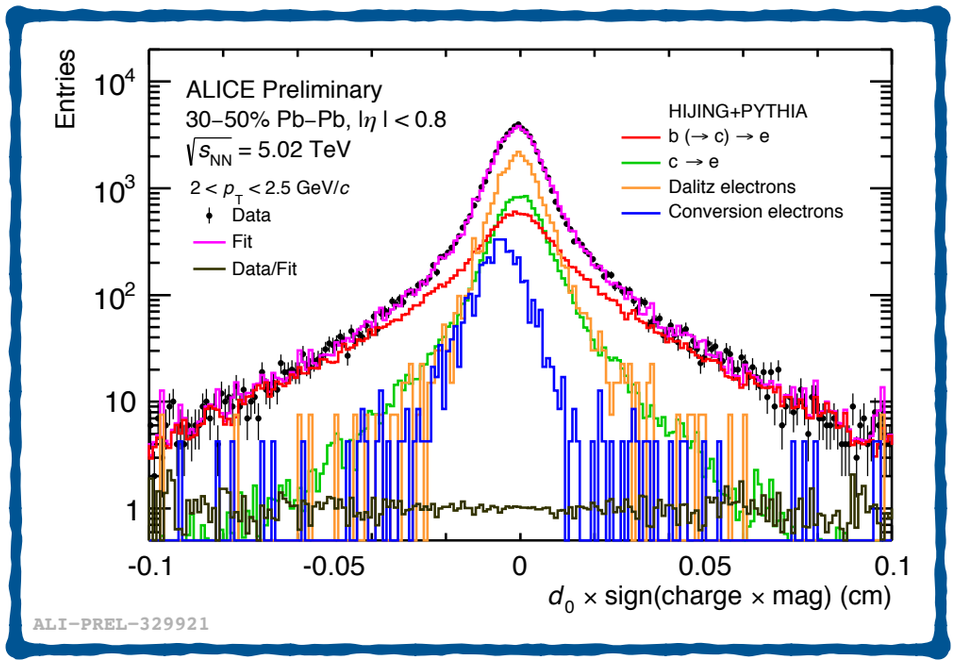
Time Of Flight
- PID

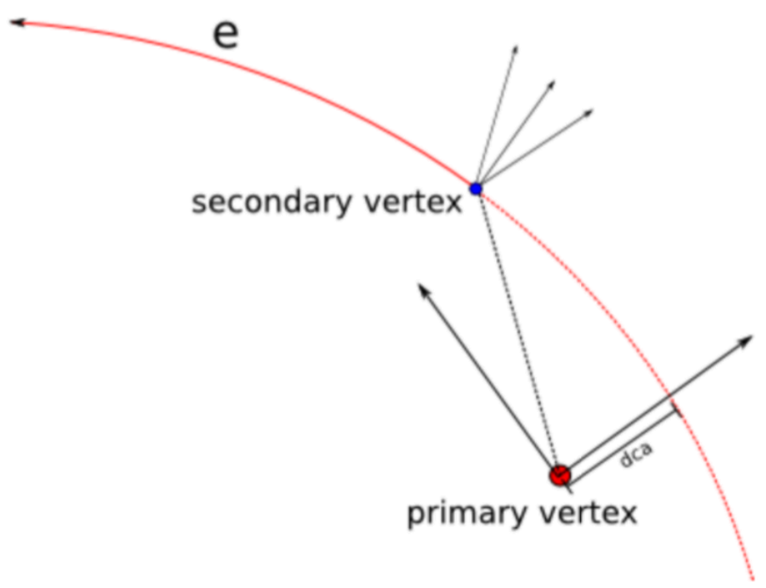
- Analysis Methods -

Electrons from beauty hadrons

- Study via electrons from semi-leptonic decays of beauty hadrons
  - Substantial branching ratio : b → e + X (~10%), b → c → e + X
- Long lifetime of beauty hadrons ($c\tau \approx 500\,\mu\mathrm{m}$) → larger impact parameter (IP)
  IP : DCA (Distance of Closest Approach) of the reconstructed track to the primary vertex in a plane perpendicular to the beam
- **Two different methods**
  - **IP cut method** : Apply minimum IP cut and subtract background via cocktail simulation
  - **IP fit method** : fit the IP distribution of the inclusive electrons in data using templates obtained from Monte Carlo simulation (based on Maximum likelihood approach)
  - **The templates are corrected to have realistic p_T shape based on the measurements**



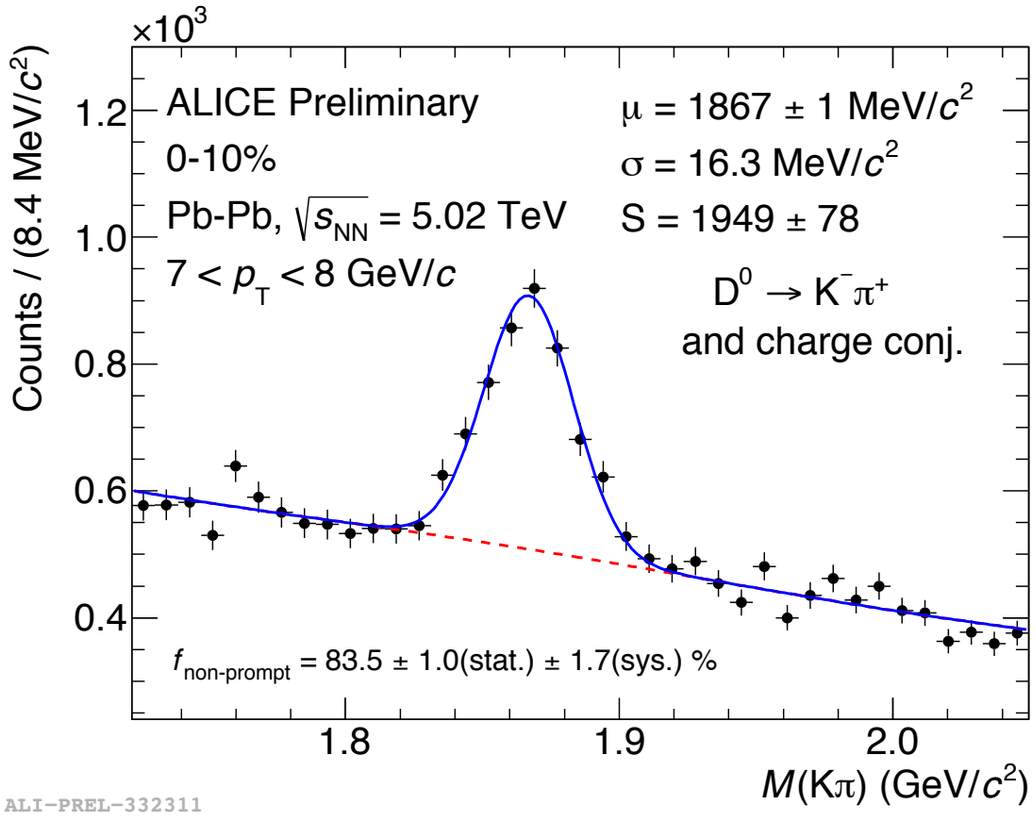


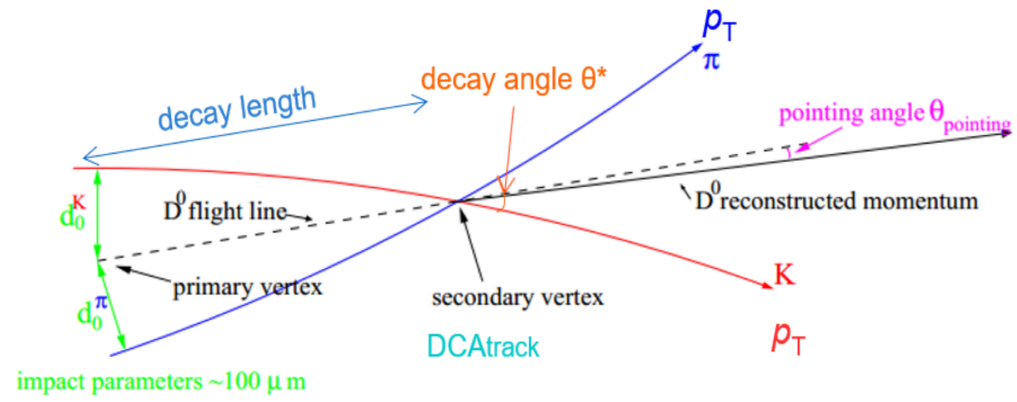


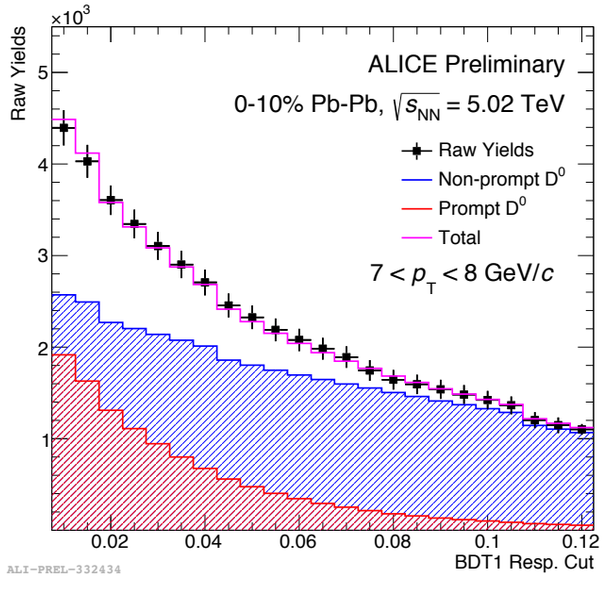
Physics Letters B, Volume 763, 10 Dec 2016, Pages 507-509

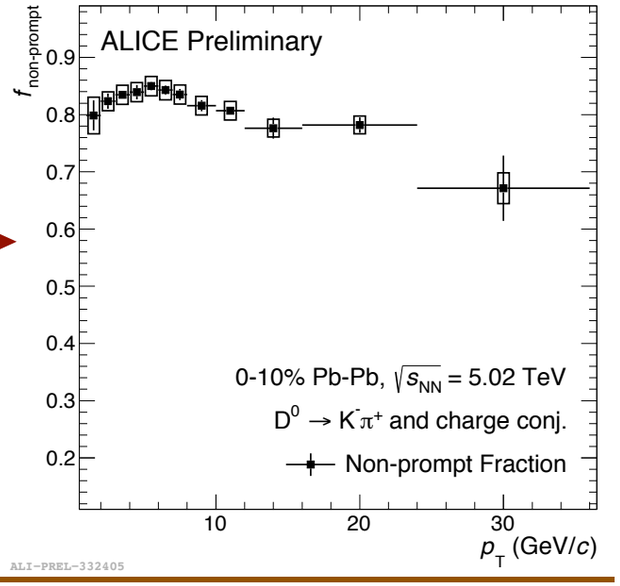
Non-prompt D^0

- Reconstruct $D^0 \rightarrow K^- + \pi^+$ using invariant mass and secondary vertex (SV) displaced from primary vertex
- **BDT (Boosted Decision Trees)** utilizes geometrical variables from decay topology associated to the primary vertex and secondary vertex
  - Suppress combinatorial background
  - Disentangle non-prompt D^0 from inclusive signals
  - Subtract prompt D^0 by exploiting a min-χ^2 approach with BDT cut variation on the raw yield







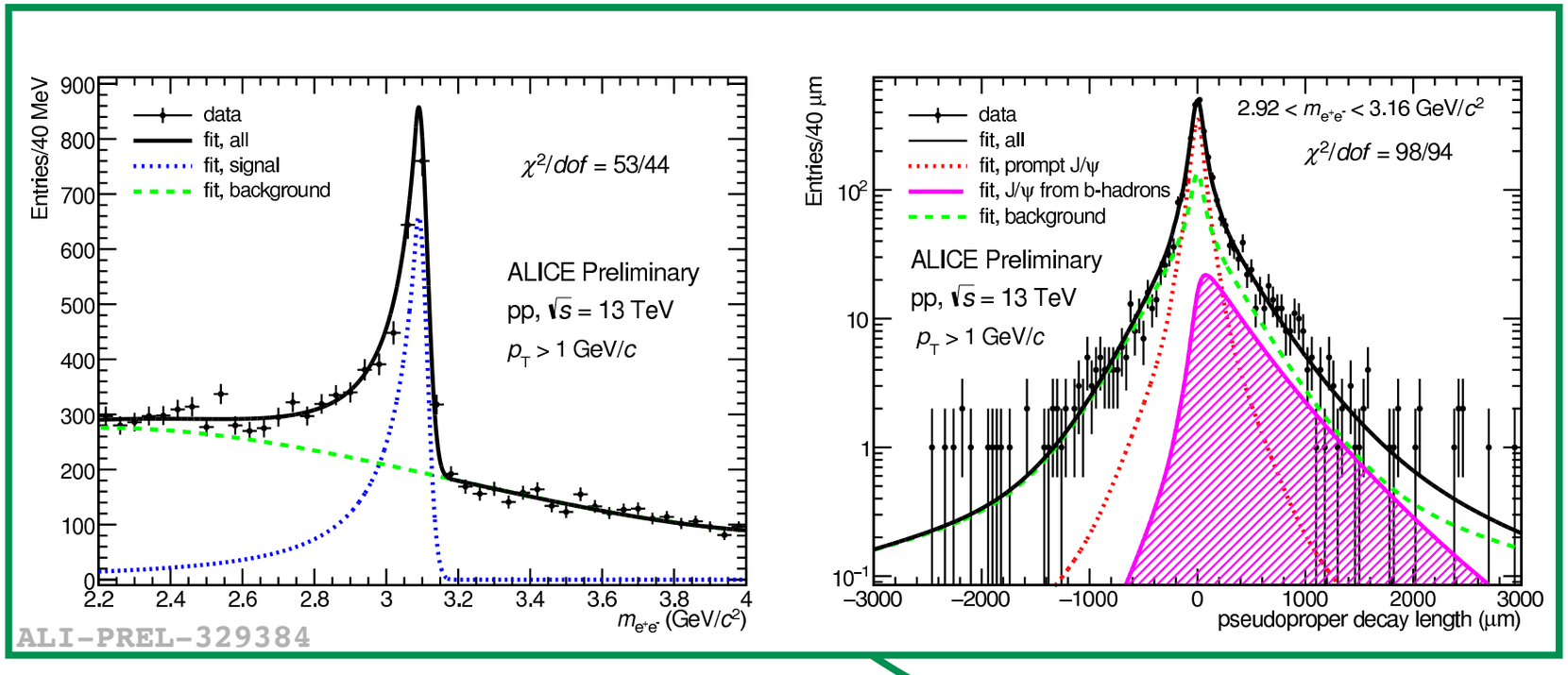


Non-prompt J/ψ

- Reconstruct J/ψ → $e^+ + e^-$ using invariant mass technique
- Fraction of non-prompt J/ψ relies on the statistical discrimination of J/ψ produced far from the primary vertex by **pseudo-proper decay length, *x***

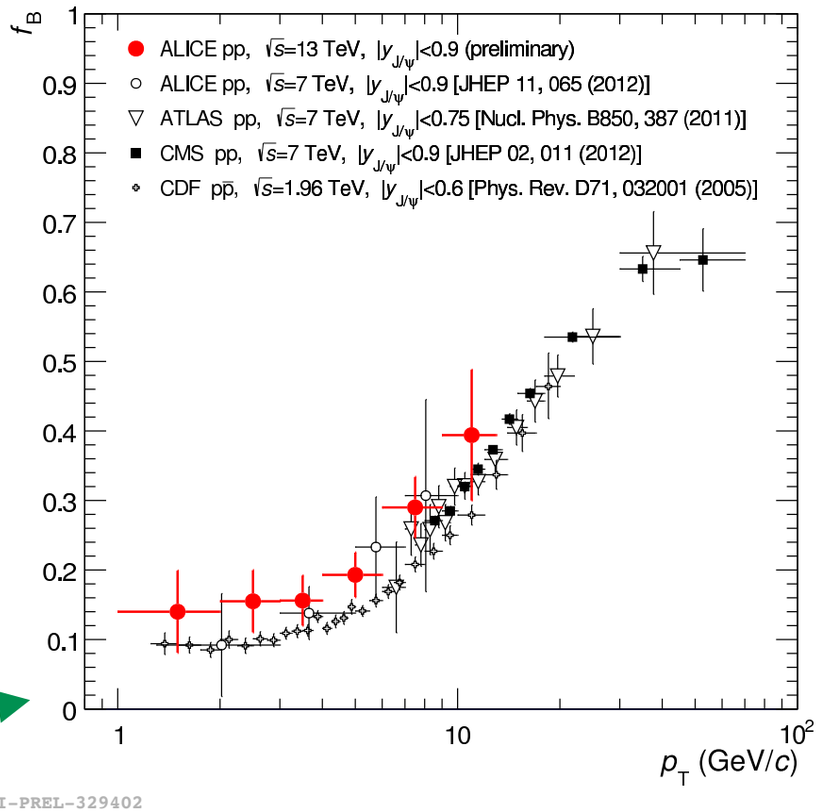
$$x = \frac{\vec{L} \cdot \vec{p_{\mathrm{T}}}}{p_{\mathrm{T}}} \cdot \frac{c \cdot m_{\mathrm{J}/\psi}}{p_{\mathrm{T}}}$$

- Perform an un-binned likelihood fit of two-dimensional distributions of invariant mass, m_{e+e-}, and *x* of both signal and background



$$f_B = \frac{N_{h_B \to \mathrm{J}/\psi}}{N_{h_B \to \mathrm{J}/\psi} + N_{\text{prompt J}/\psi}}$$

Fraction of b→ J/ψ



b-tagged jets

Most displaced secondary vertex (SV)

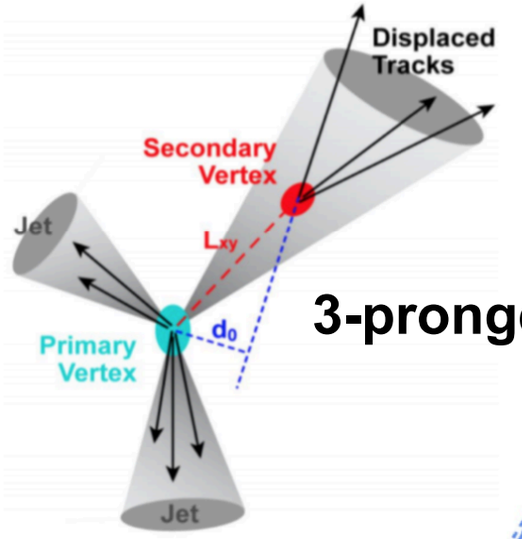
- Select jets with a 3-prong secondary vertex
- Reconstruction of displaced SV with a significance :

$$SL_{xy} = \frac{L_{xy}}{\sigma_{L_{xy}}} > \alpha$$

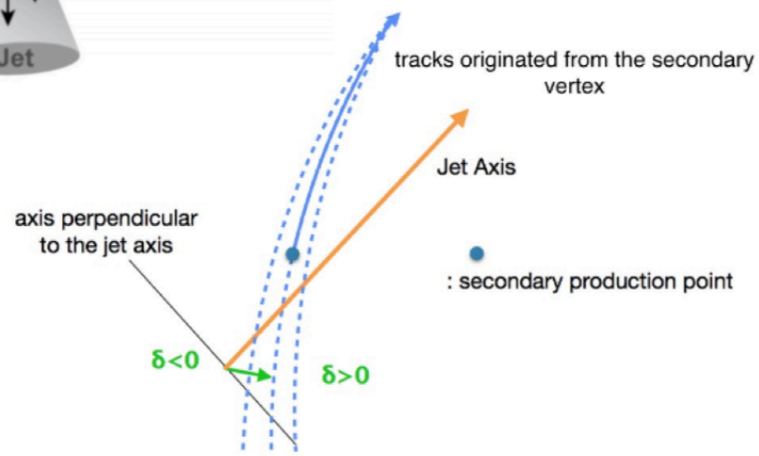
- SV tagging efficiency correction (PYTHIA+EPOS)
- Purity correction (POWHEG+PYTHIA)

Track counting algorithm (IP)

- Use a large impact parameter of B hadrons
- Evaluate a discriminator : $sd_{xy} = sign(\overrightarrow{d_{xy}} \cdot \overrightarrow{p_{jet}})d_{xy}$
- Most displaced track in a jet with $d_{xy} > d_{xy}^{threshold}$
- Data-driven methods for both efficiency and purity

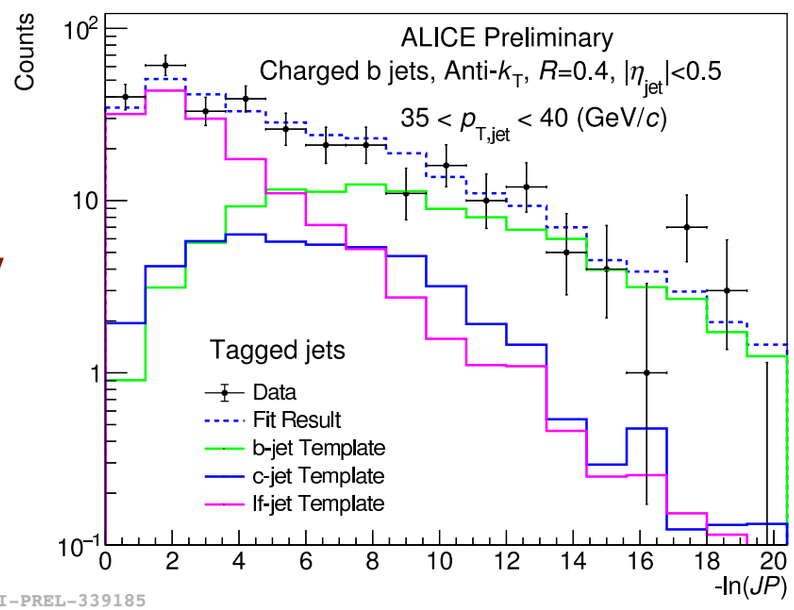


3-pronged



tracks originated from the secondary vertex are more likely to have positive SIP

SV



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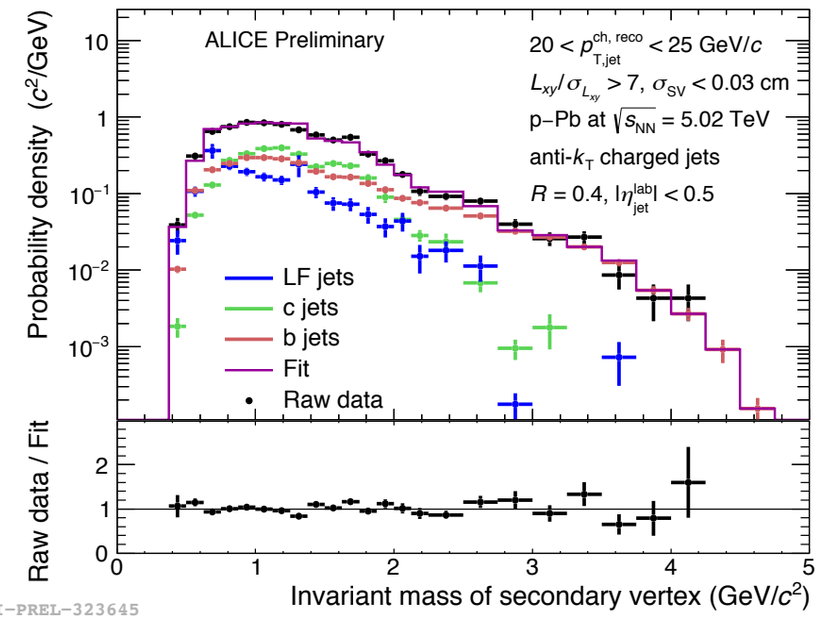
IP



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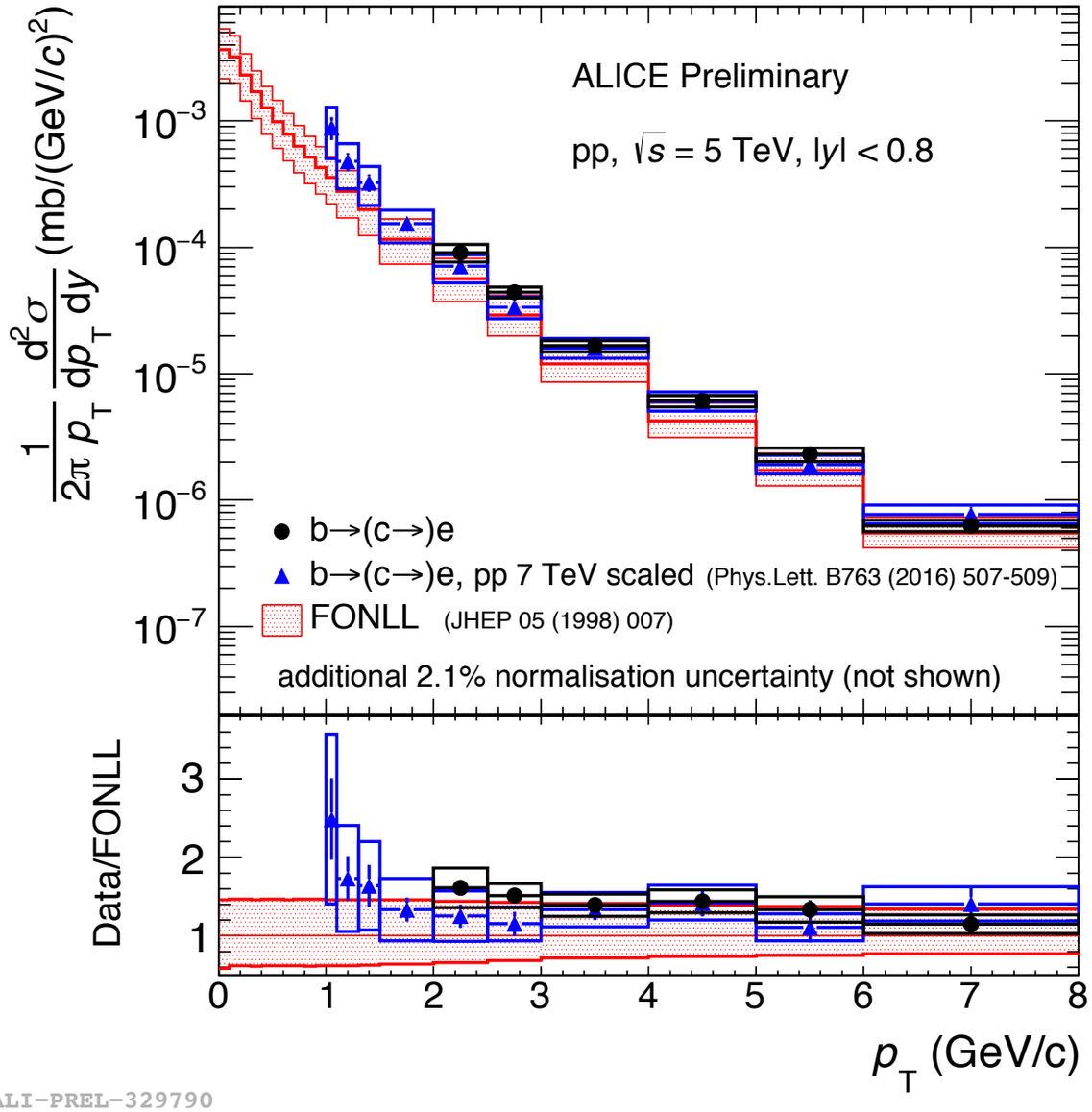
- Results -

Electrons from beauty hadrons

Fraction and cross section of b→e measured in pp collisions at $\sqrt{s} = 5.02\,\mathrm{TeV}$

- Measurements agree with FONLL predictions within uncertainties
  - Cross section lies on the upper edge of the FONLL predictions
- b→e cross section in pp 5.02 TeV is compatible with the scaled 7 TeV measurement within uncertainties

Phys. Lett. B 721 (2013) 13-23, Phys. Lett. B 763 (2016) 507-509 (erratum) - 7 TeV



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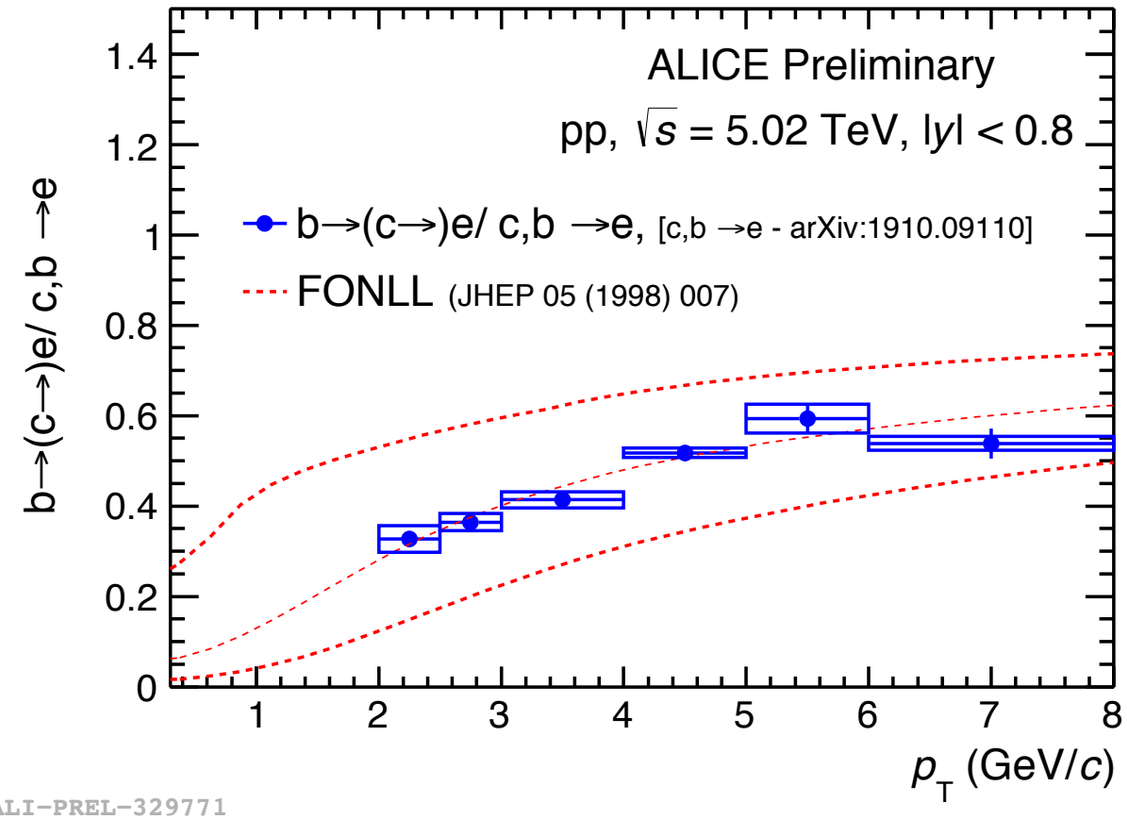

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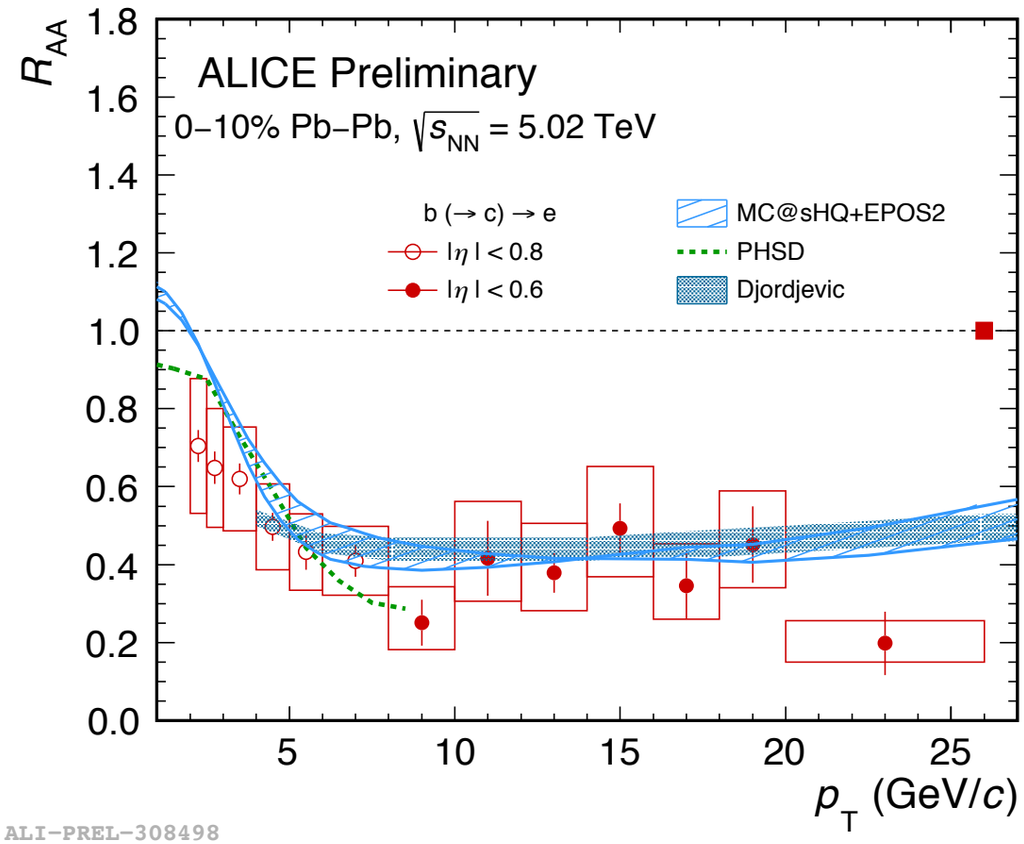
Electrons from beauty hadrons

R_{AA} of b→e measured in 0−10% and 30-50% Pb−Pb collisions at $\sqrt{s_{NN}} = 5.02\,\mathrm{TeV}$

- Observed a suppression of beauty-decay electrons for $p_T > 2\,\mathrm{GeV}/c$
- Good agreement with models in 0−10%
  - **PHSD** : collisional energy loss, fragmentation and coalescence
  - **Djordjevich** : collisional+radiative energy loss and fragmentation
  - **MC@sHQ+EPOS2** : collisional+radiative energy loss, fragmentation and coalescence
- R_{AA} in 30-50% is systematically higher than 0-10% and to be confirmed by higher precision measurements



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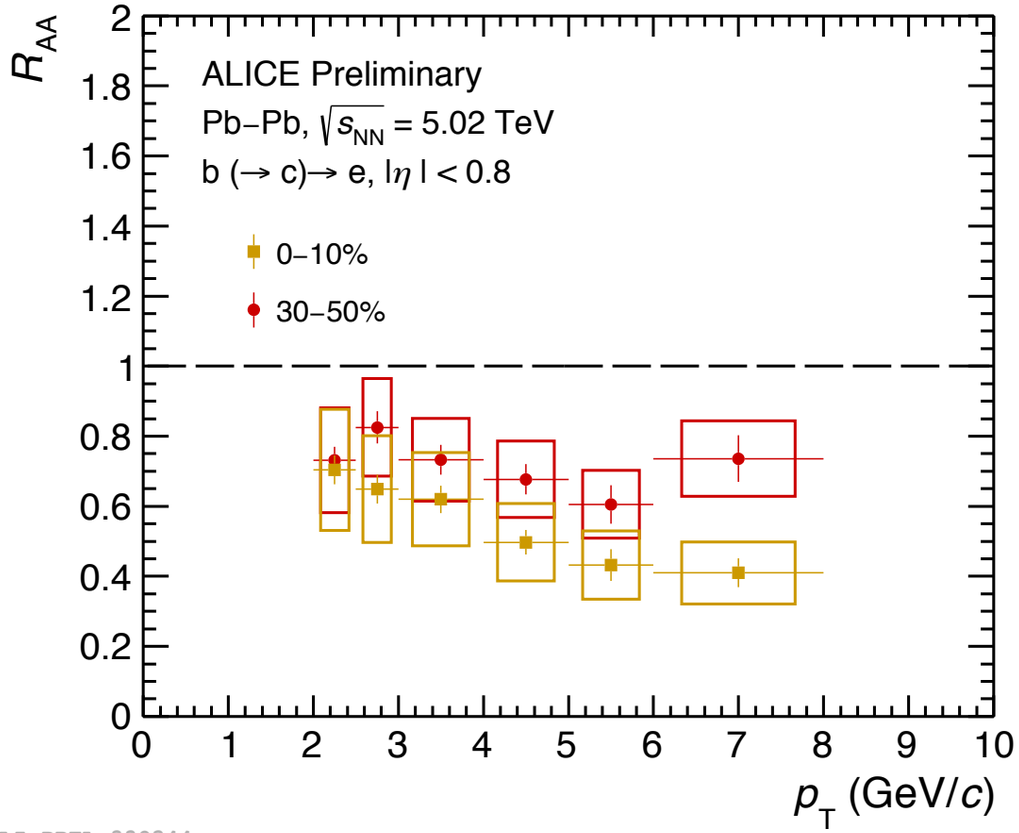
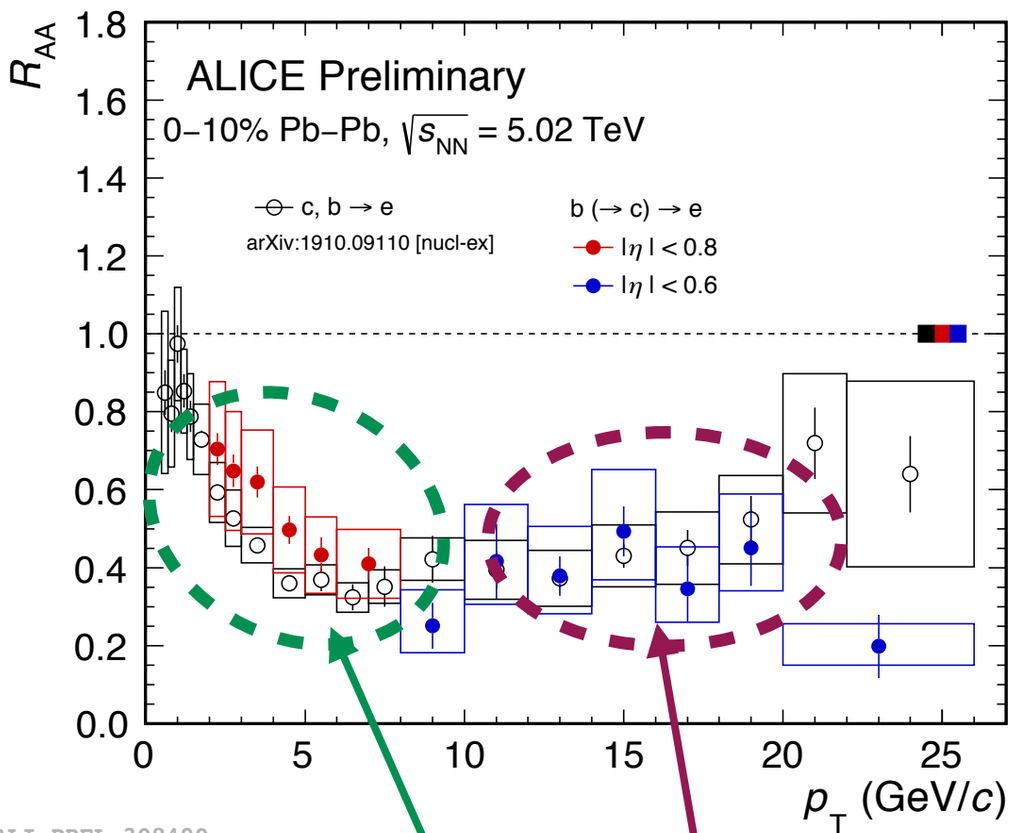


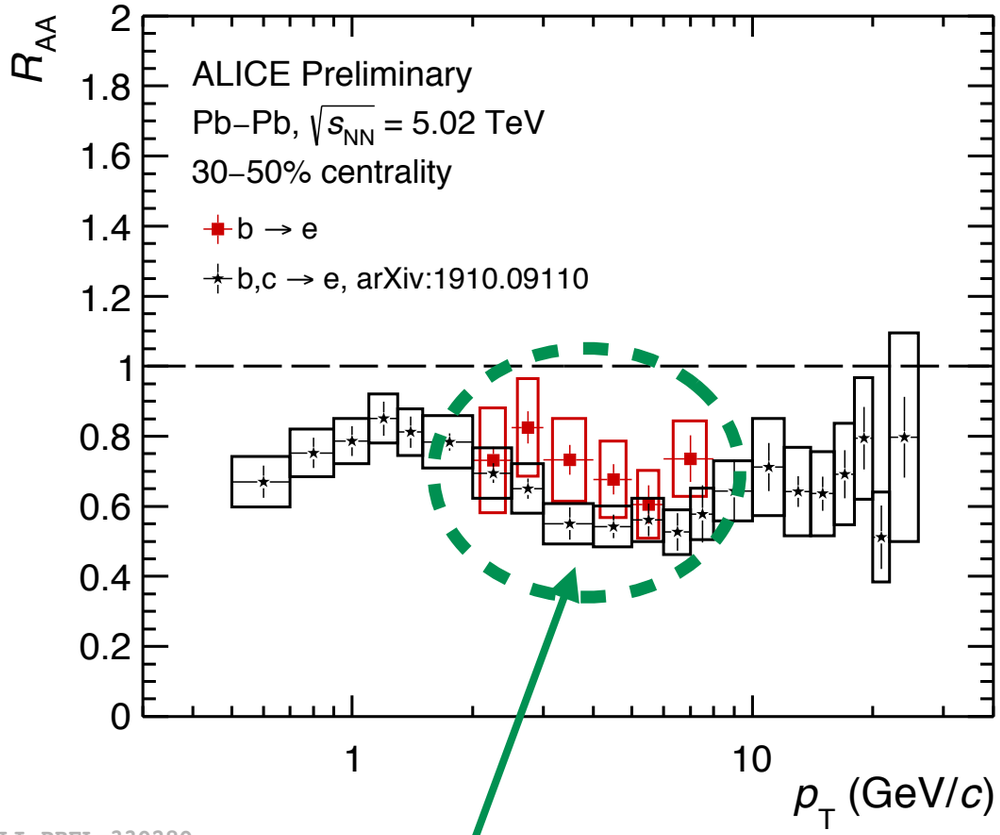
ALI-PREL-330244

Electrons from beauty hadrons

R_{AA} of b→e measured in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

- Comparison with R_{AA} of electrons from heavy flavors (HFe)
  - Less suppression of beauty-decay electrons than HFe at low p_T, even though they are compatible within uncertainties
  - In 0−10%, R_{AA} of b→e is extended up to 26 GeV/c and both R_{AA}'s are merged at high p_T as beauty contribution dominates at high p_T





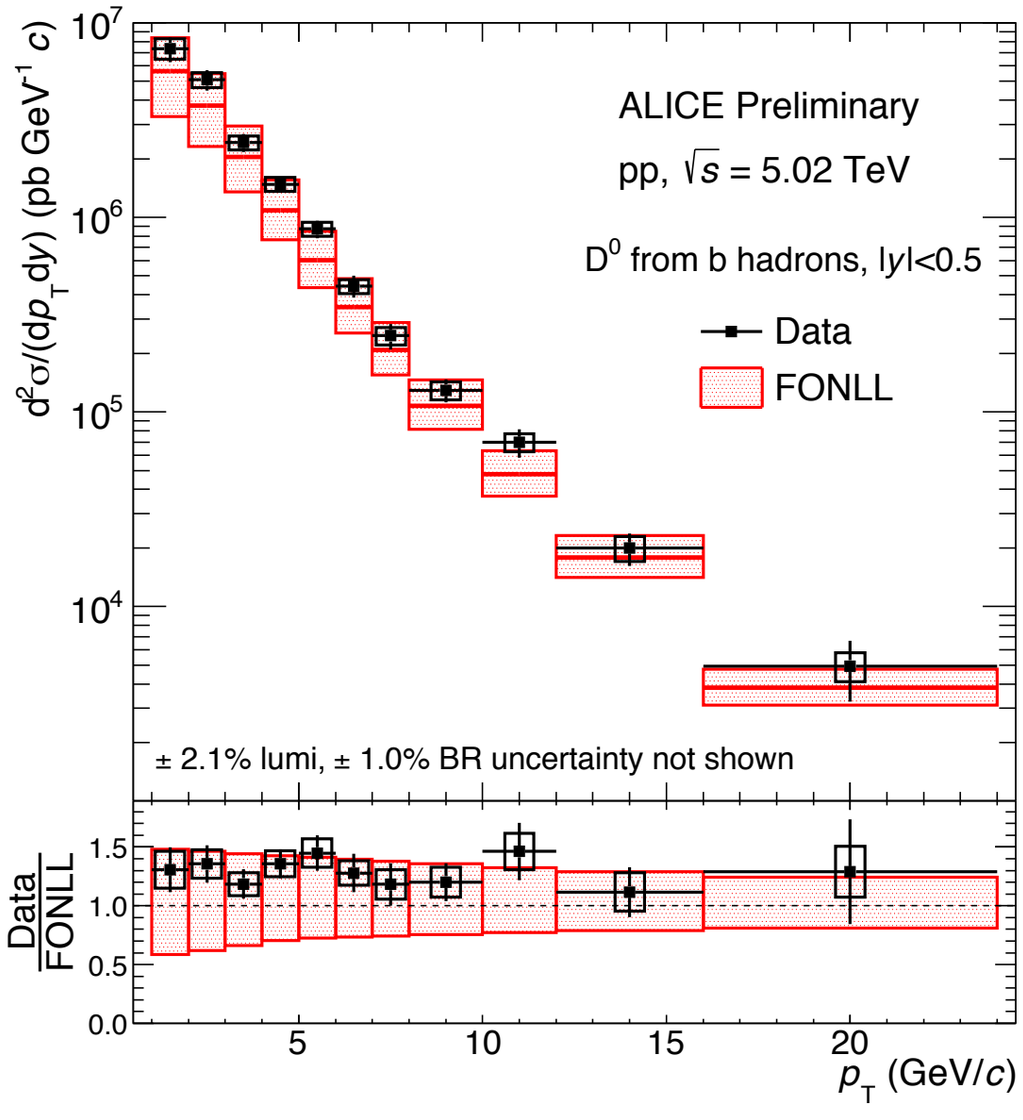
Merged R_{AA} of b→e and HFe

Less suppression of b→e than HFe at low p_T

Non-prompt D^0

Cross section of non-prompt D^0 measured in pp collisions at $\sqrt{s} = 5.02\,\mathrm{TeV}$
& p_T spectra measured in 0−10% and 30−50% Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02\,\mathrm{TeV}$

- Measurements down to 1 GeV/*c*
- Cross section in pp collisions described by FONLL predictions → agreement within uncertainties



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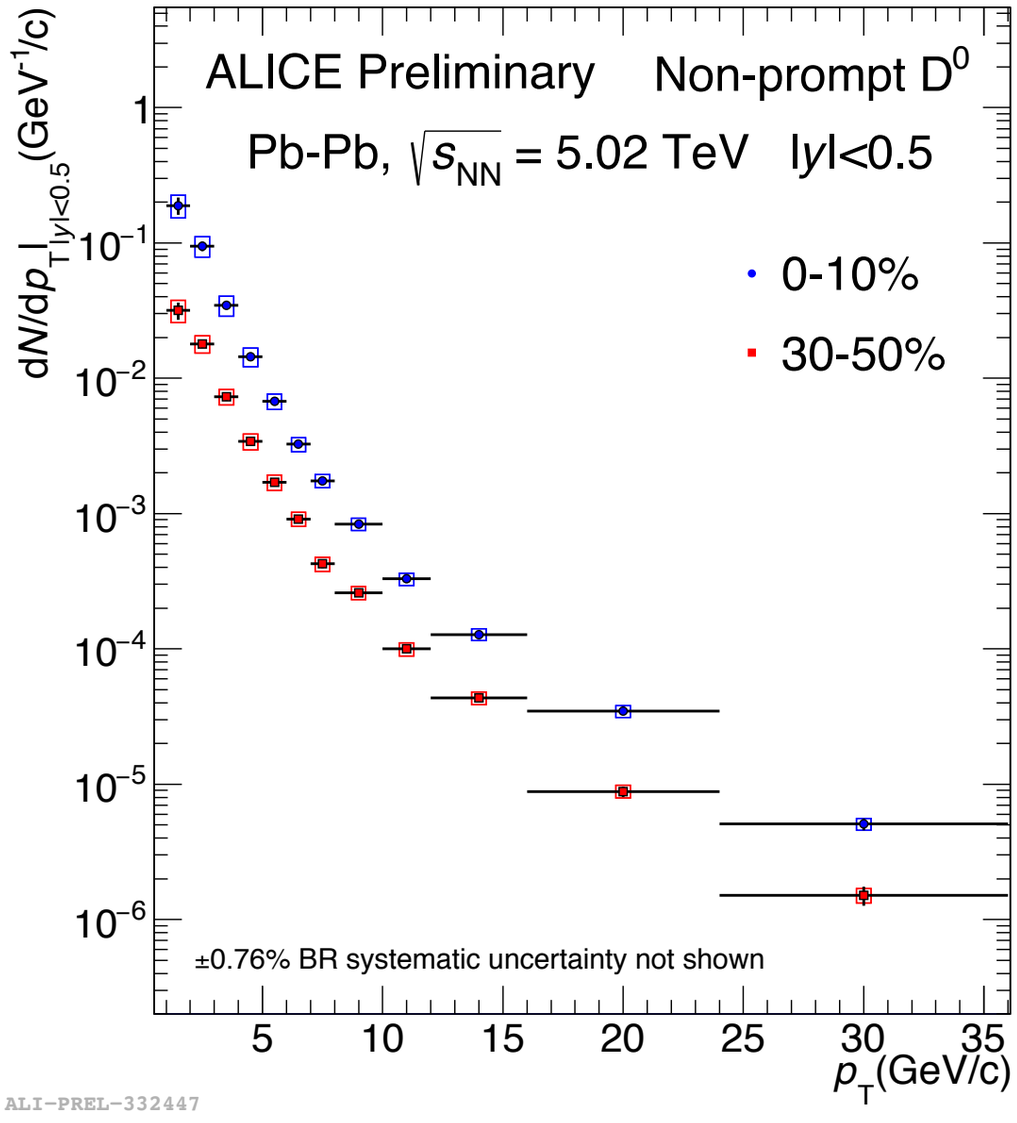

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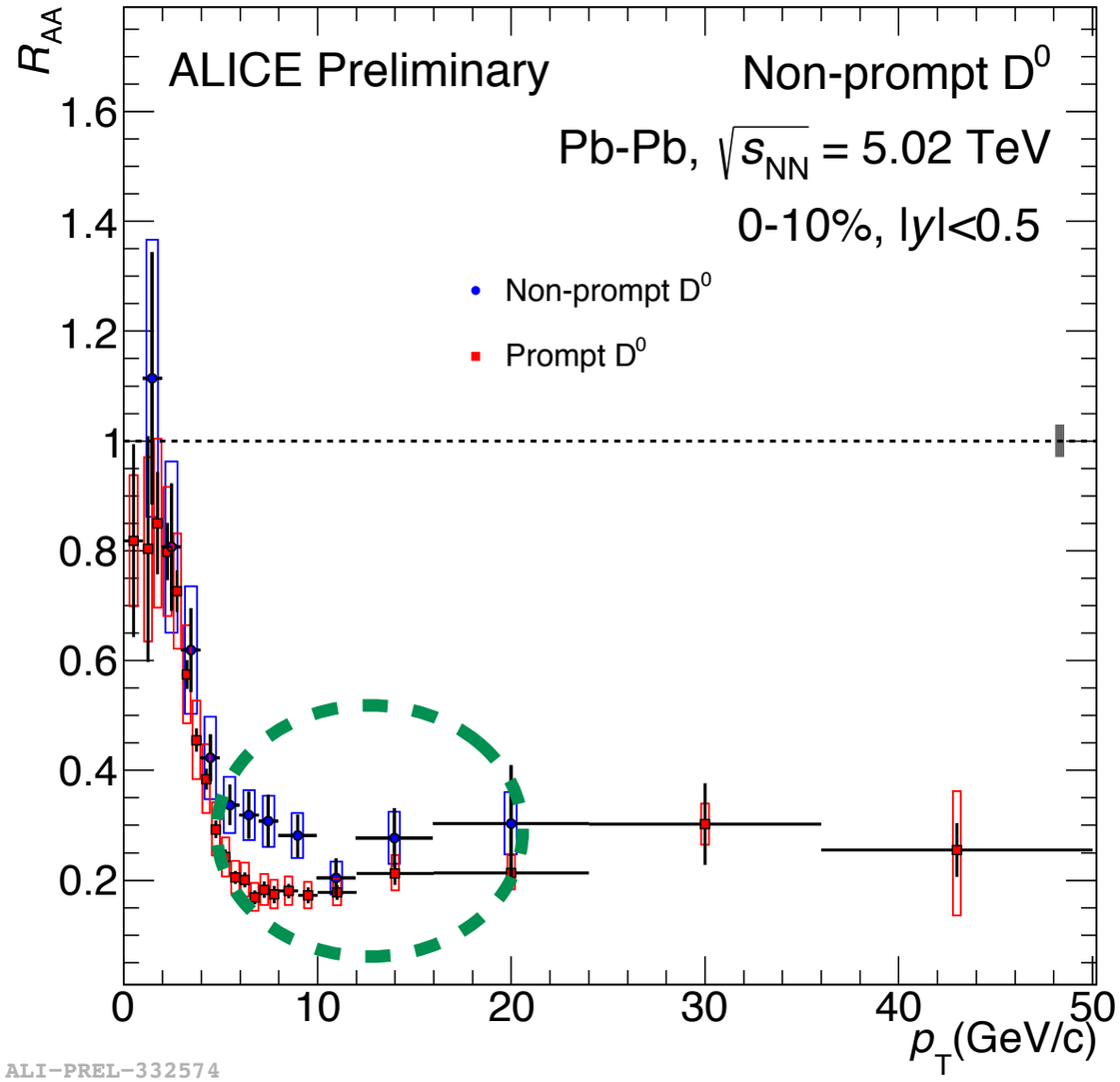
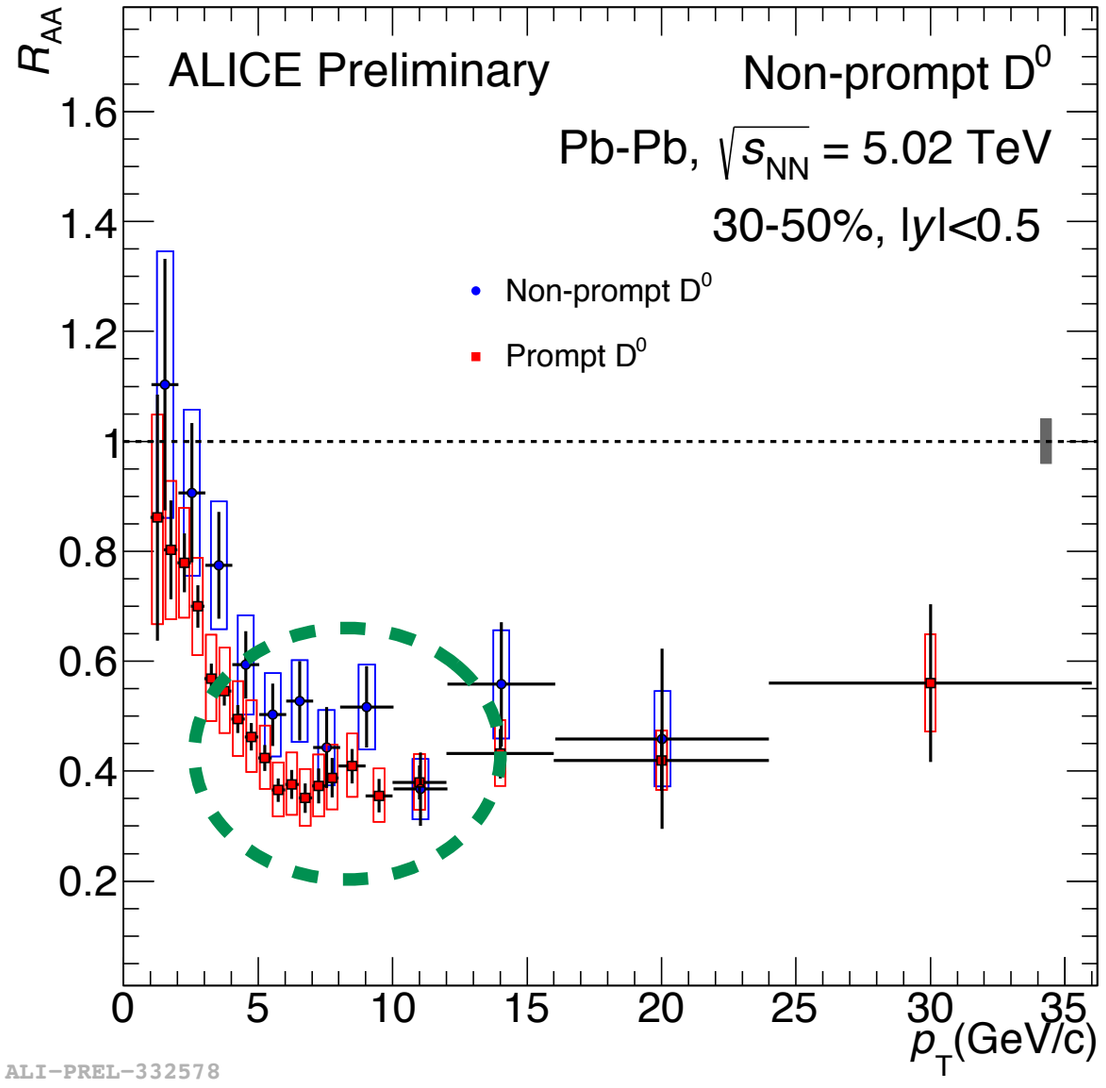
Non-prompt D^0

R_{AA} measured in 0−10% and 30−50% Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02\,\mathrm{TeV}$

- Suppression observed for $p_T > 2\,\mathrm{GeV}/c$
- Less suppression of non-prompt D^0 → lower energy loss for beauty than charm
- Less suppression in semi-central than that in most-central in intermediate p_T range

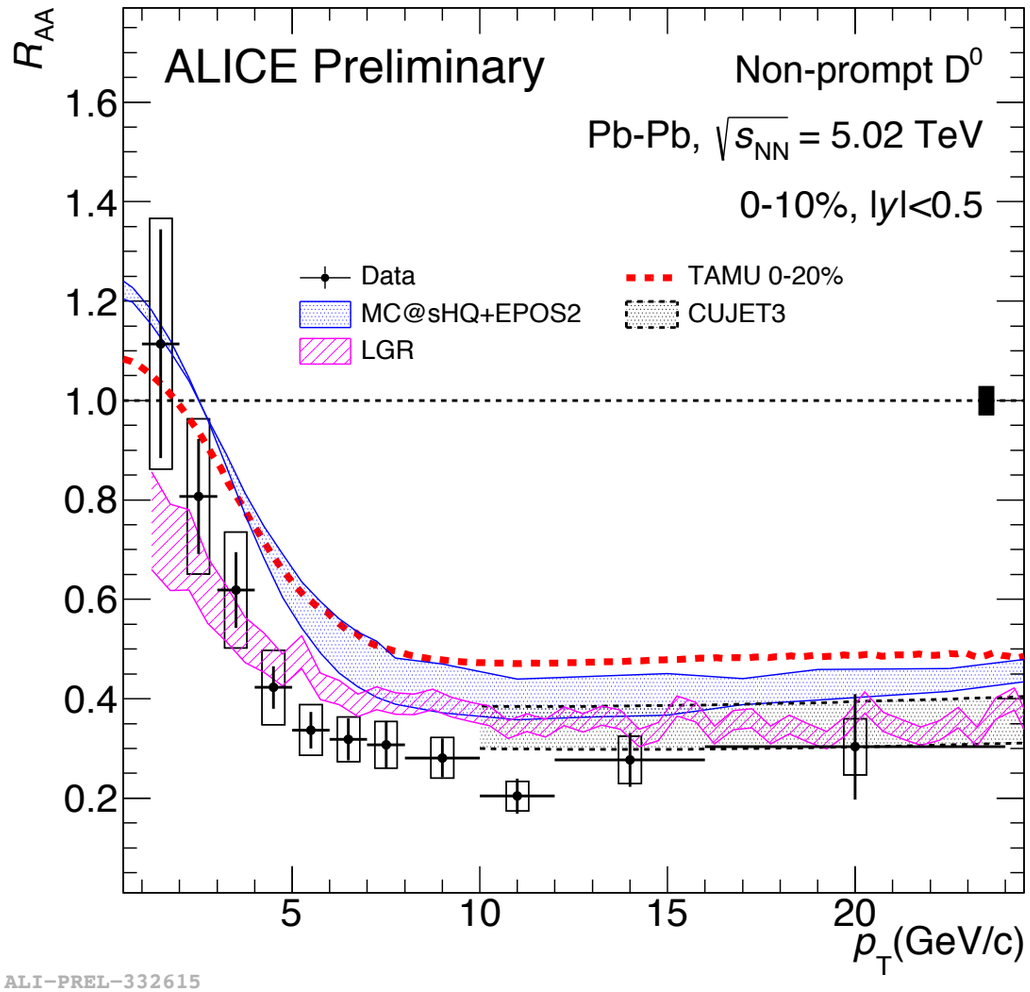




Non-prompt D^0

R_{AA} measured in 0−10% and 30−50% Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02\,\mathrm{TeV}$

- Transport models with collisional energy loss describe the data within uncertainties
  - TAMU : PLB 735 (2014) 455
  - MC@sHQ+EPOS2 : PRC 89 (2014) 014905
  - LGR : arXiv:1901.06400; 1805.05807
- Models based on pQCD provide good estimation for $p_{\mathrm{T}} > 10\,\mathrm{GeV}/c$
  - CUJET3 : arXiv:1411.3673; 1508.00552; 1804.01915; 1808.05461



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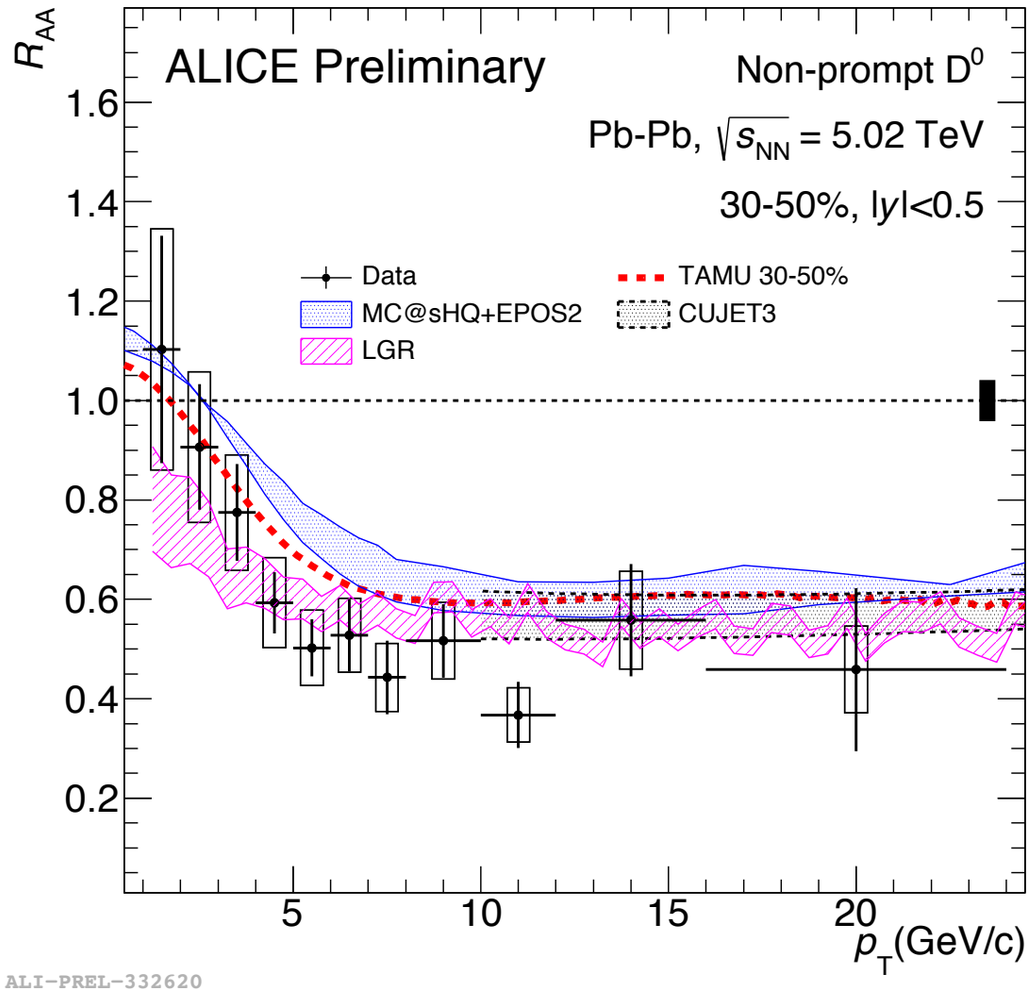

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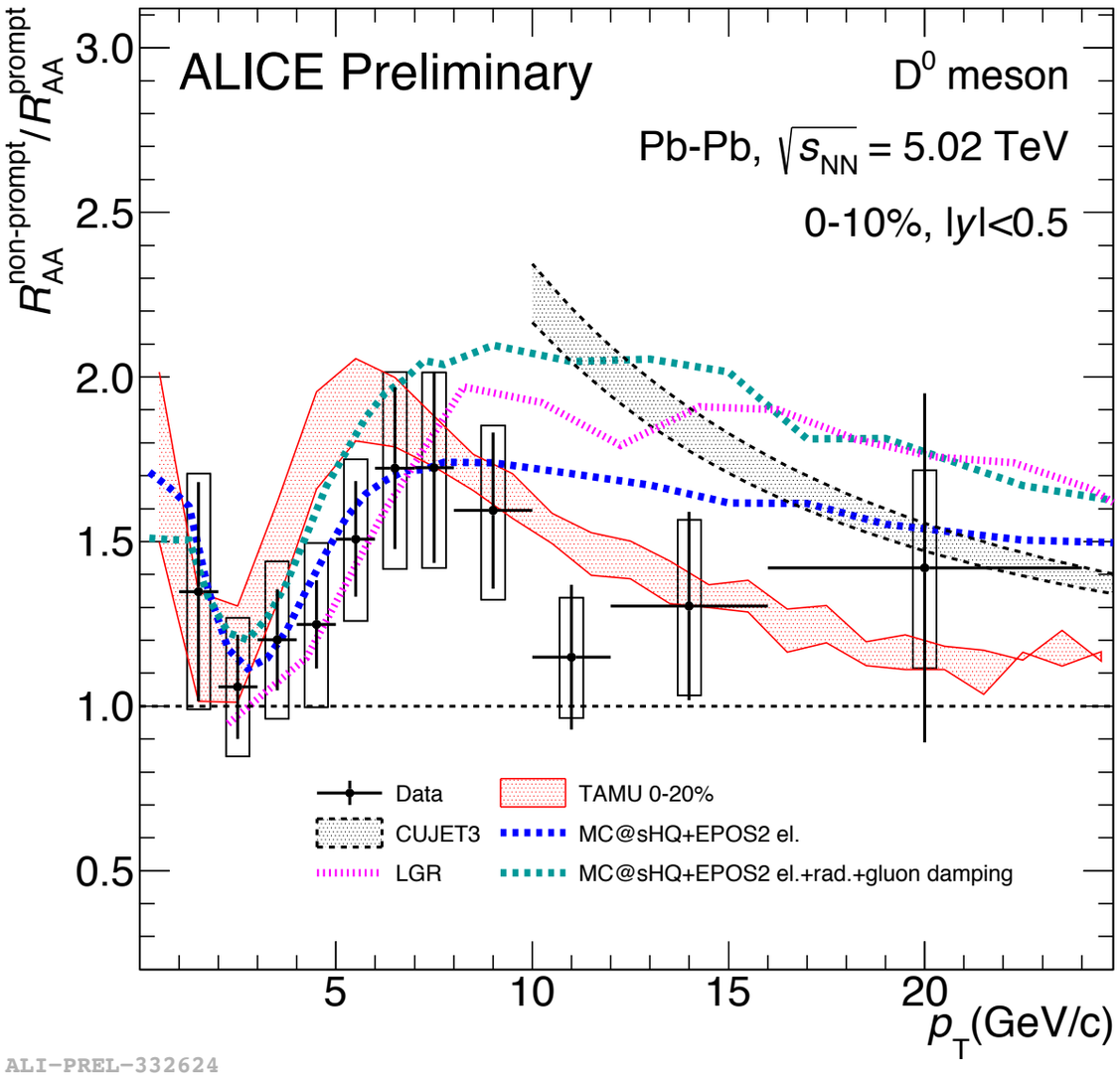
Non-prompt D^0

R_{AA} ratio measured in 0−10% and 30−50% Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$

- Model predictions match data within uncertainties for both centrality classes
- In 0–10%, bumpy structure
  - Different kinematics / different energy loss due to the mass dependence
- In 30–50%, no evidence for the same bump over the measured p_T range

$$\frac{R_{AA}^{\text{non-prompt}}}{R_{AA}^{\text{prompt}}}$$



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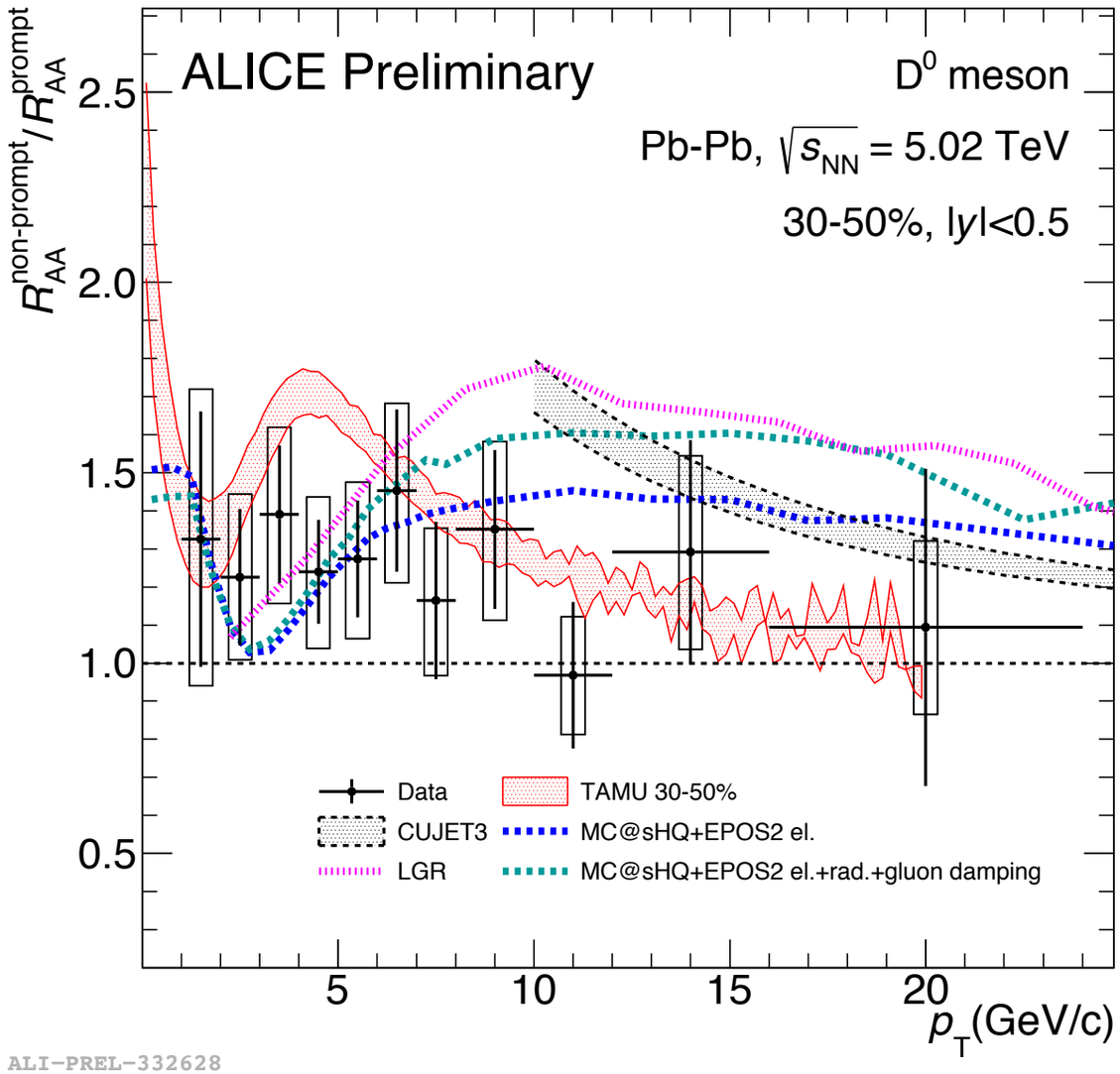

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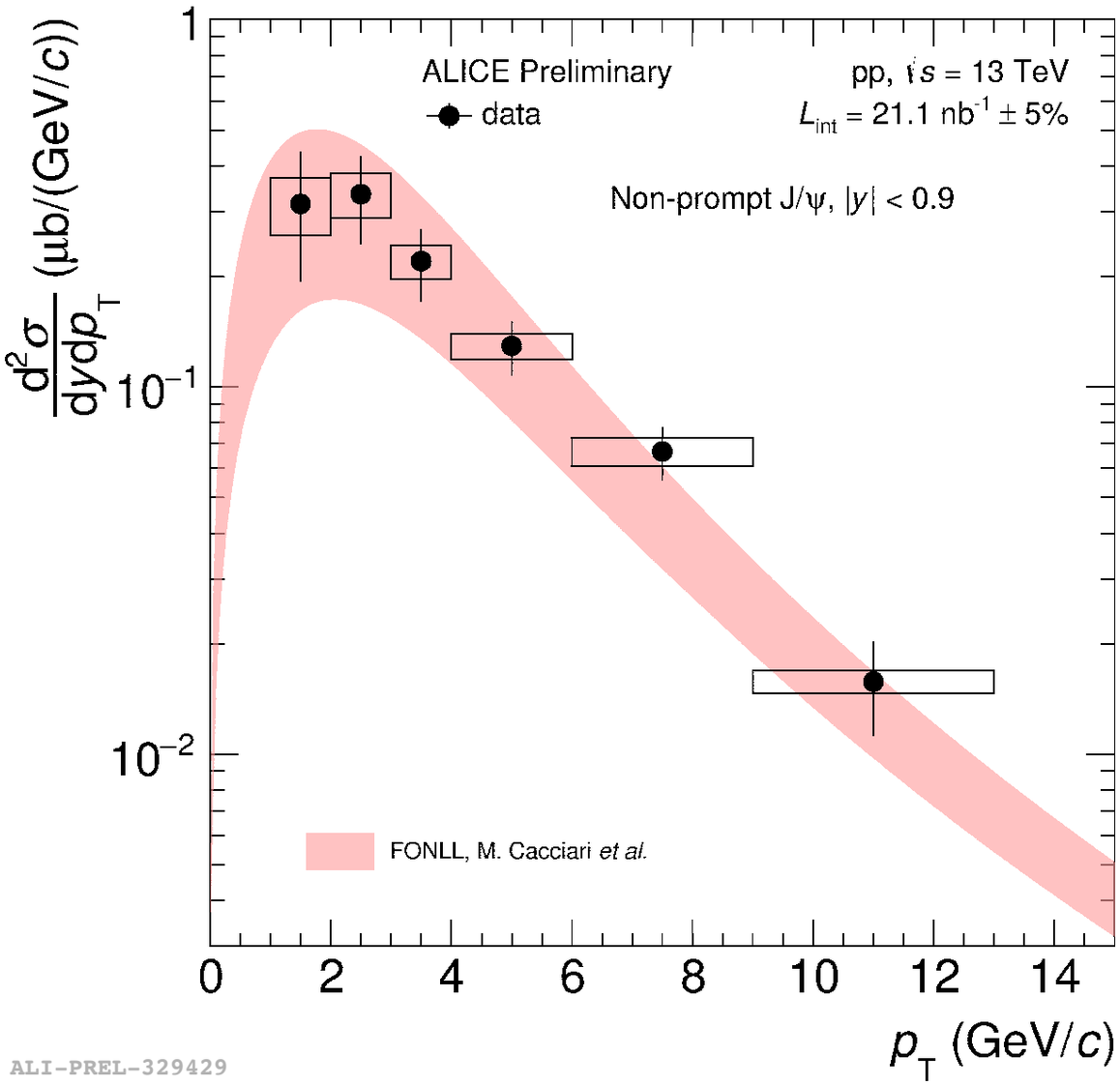
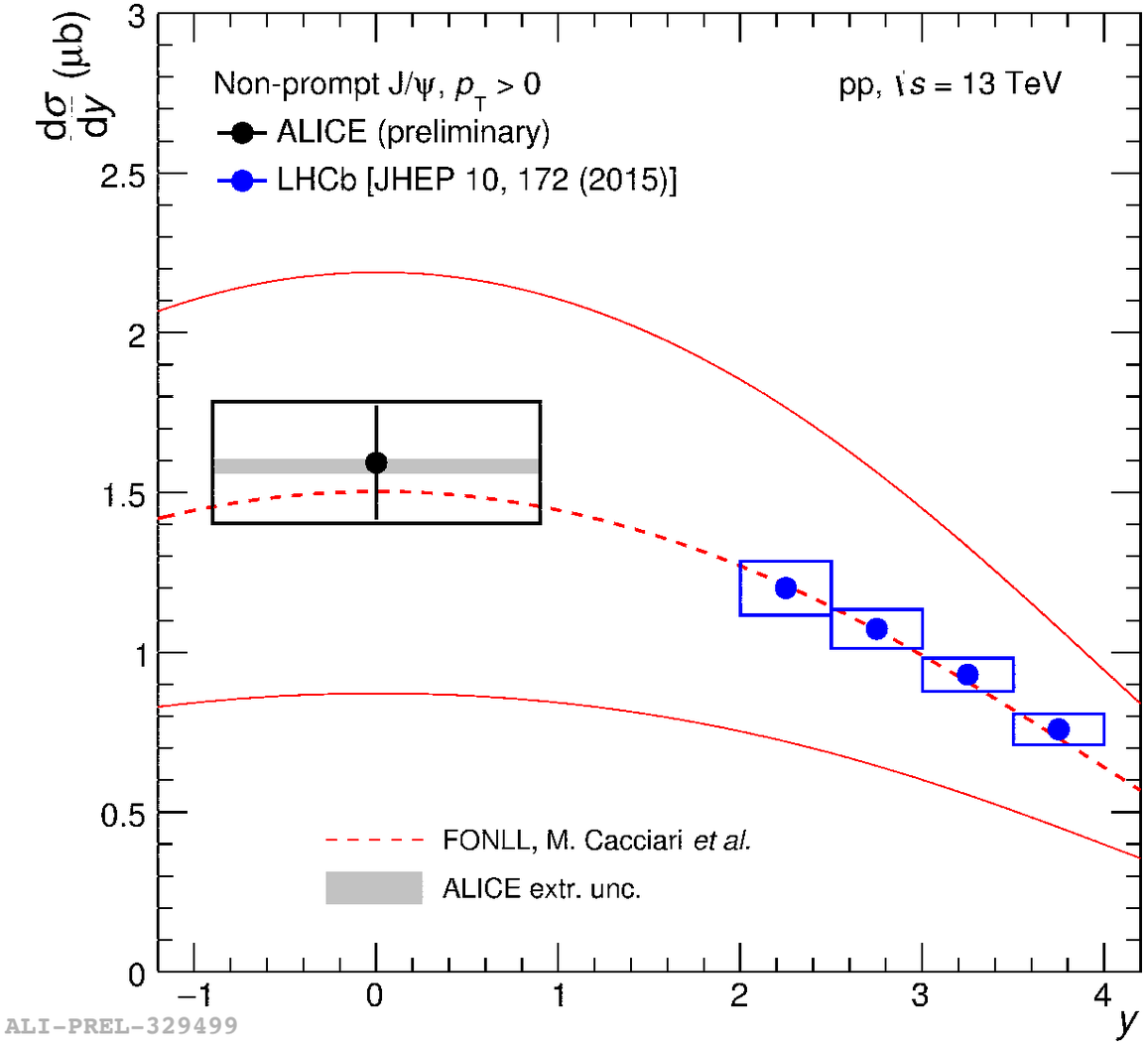
Non-prompt J/ψ

Cross section of non-prompt J/ψ measured in pp collisions at $\sqrt{s} = 13\ \mathrm{TeV}$

- Measurement as a function of p_T and as a function of rapidity → well described by FONLL

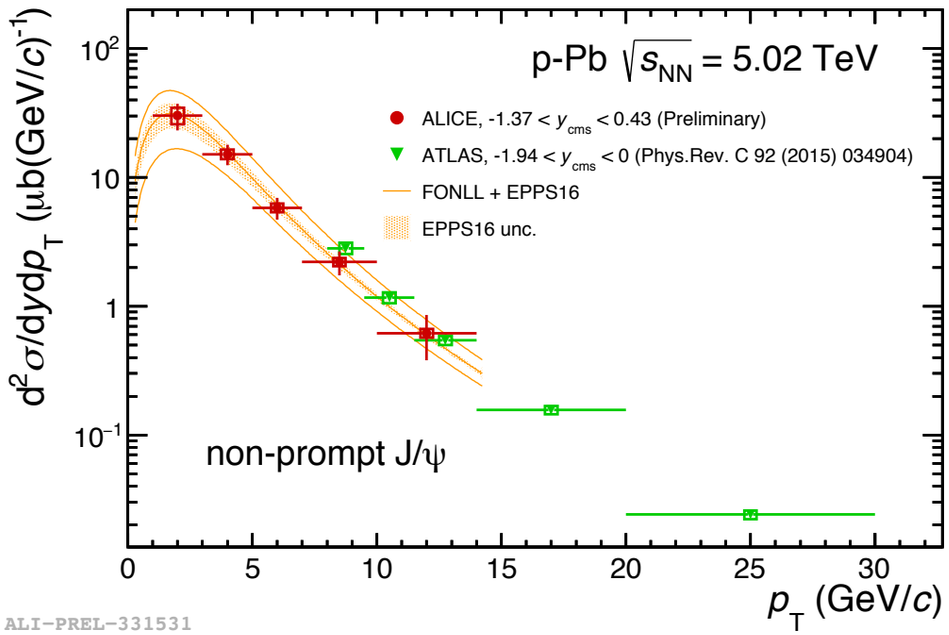


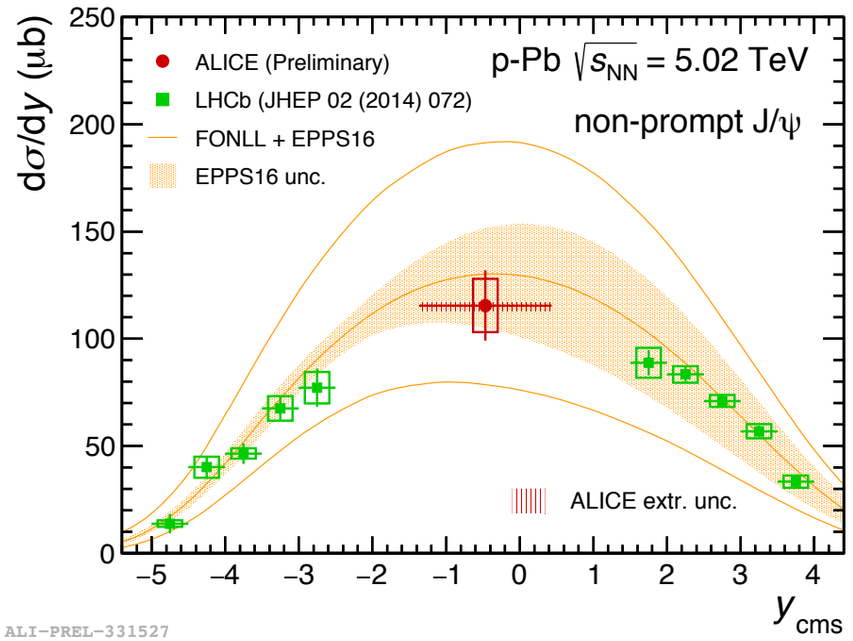


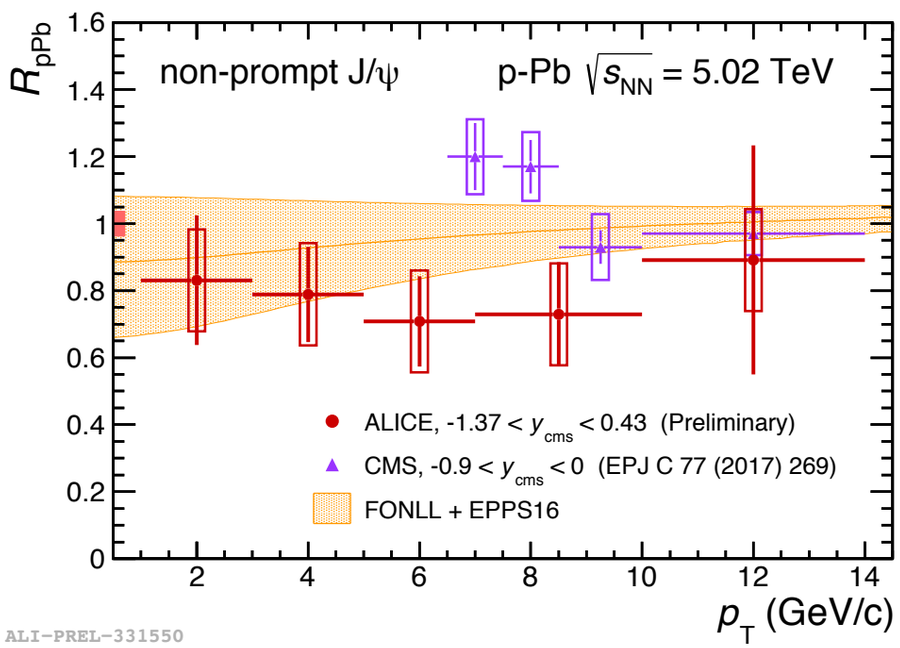
Non-prompt J/ψ

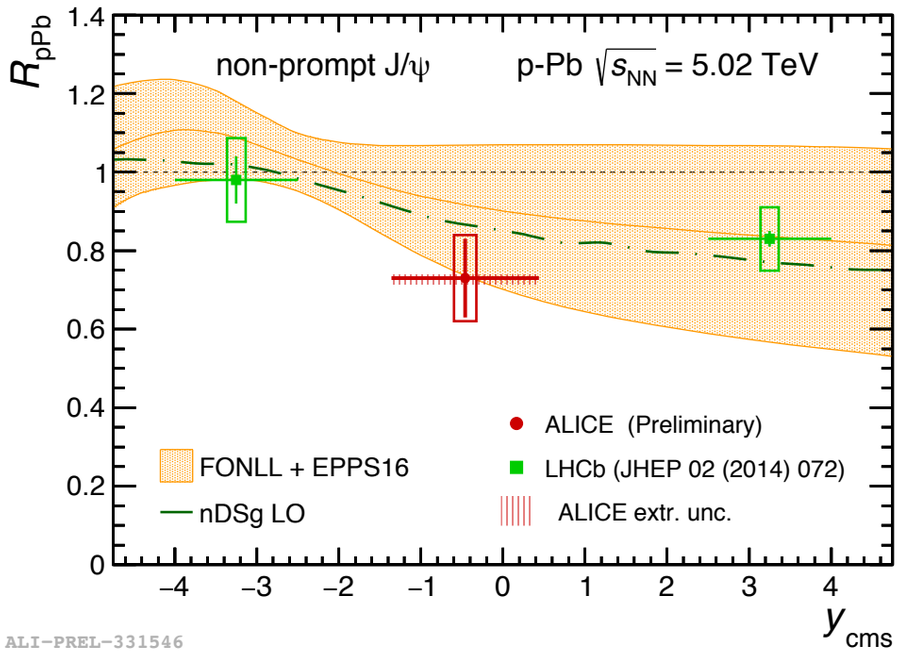
Cross section and R_{pPb} of non-prompt J/ψ measured in p−Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$

- Measurement as a function of p_{T} and as a function of rapidity
- Compatible with model implementing CNM effects within uncertainties





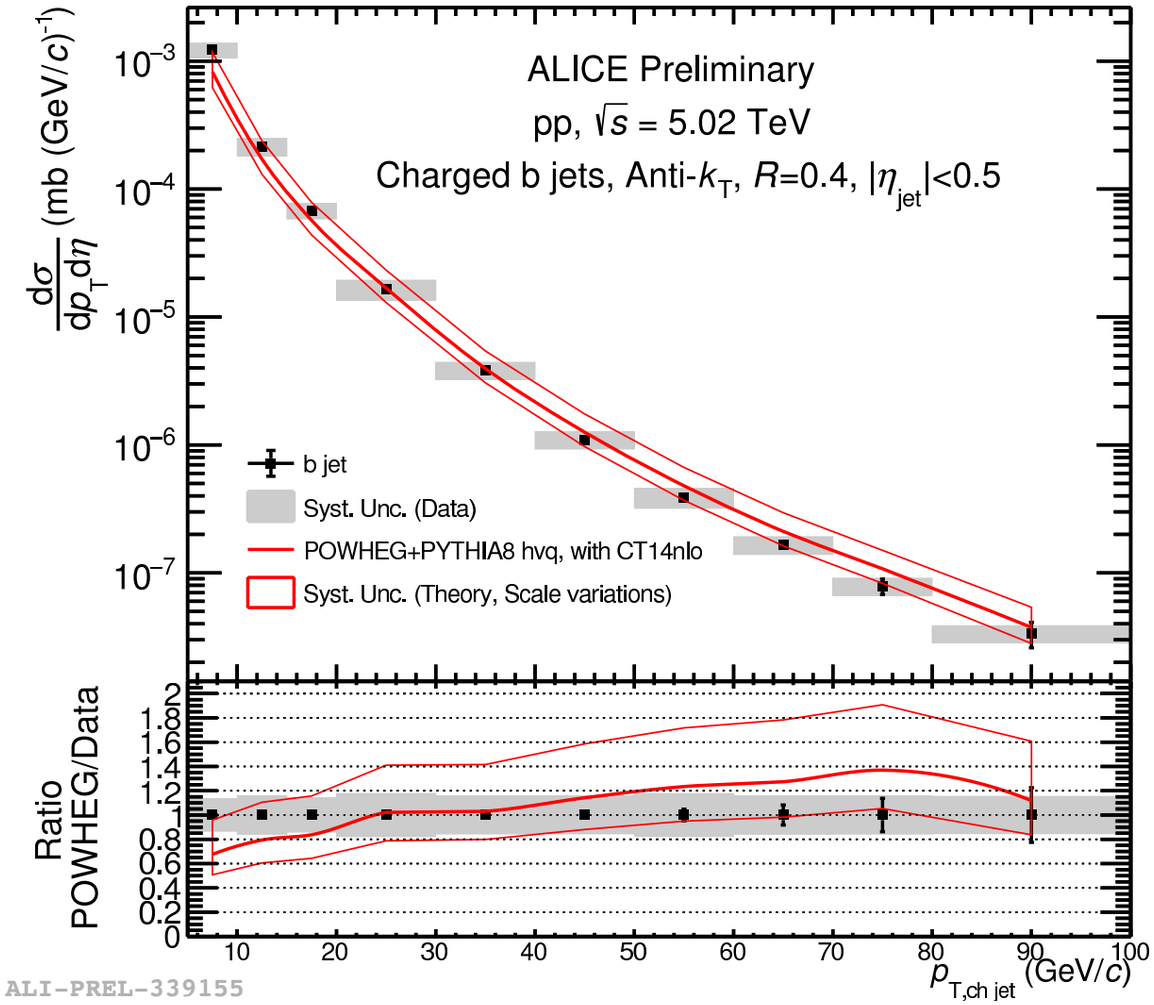




b-tagged jets

b-jets measured in pp collisions at $\sqrt{s} = 5.02\,\mathrm{TeV}$

- **Consistent with model calculations**
  - POWHEG HVQ EPS09NLO + PYTHIA6 (SV)
  - POWHEG HVQ CT14NLO + PYTHIA8 (IP)
  - POWHEG Dijet EPPS16 + PYTHIA8 (SV)
  - POWHEG Dijet CT14NLO + PYTHIA8 (IP)



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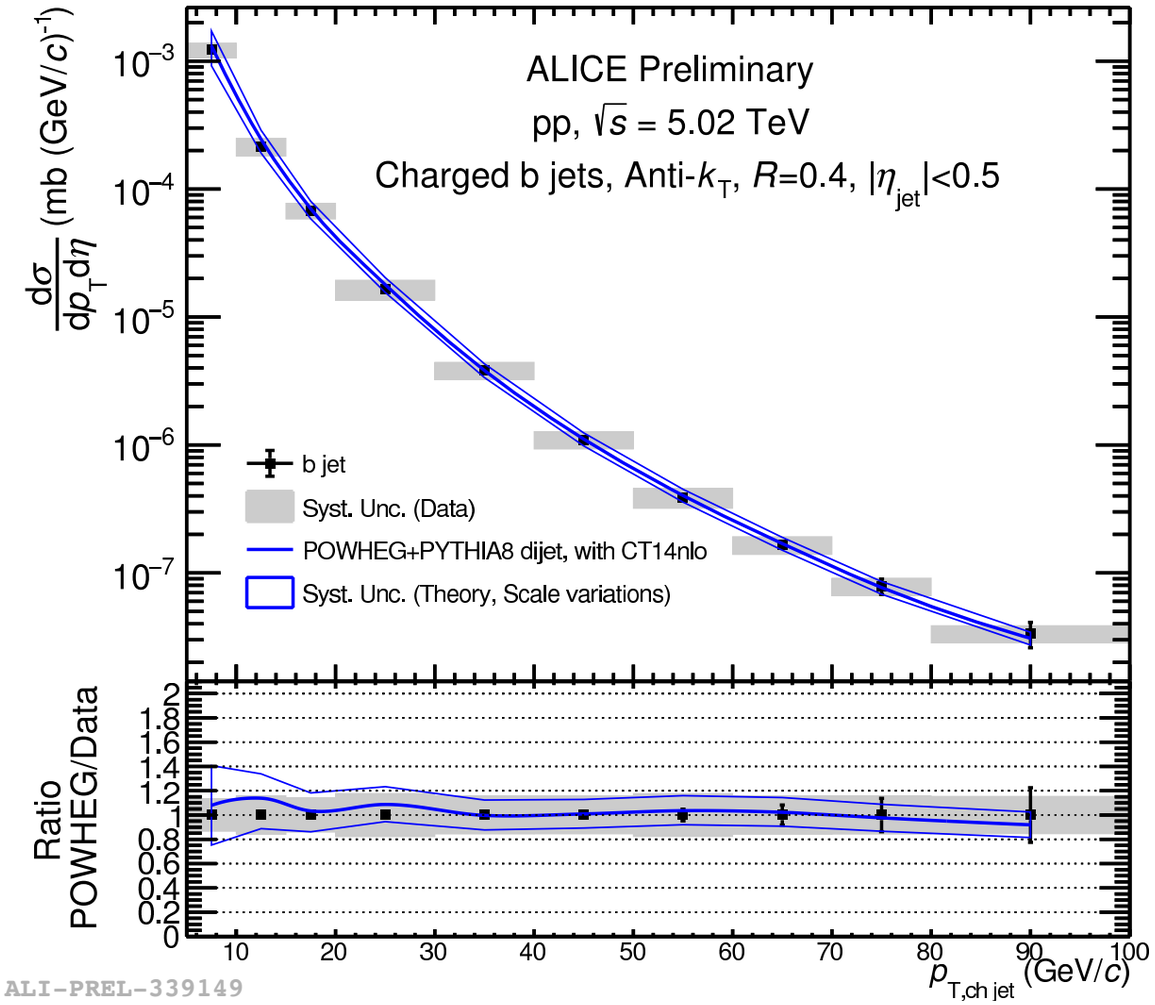

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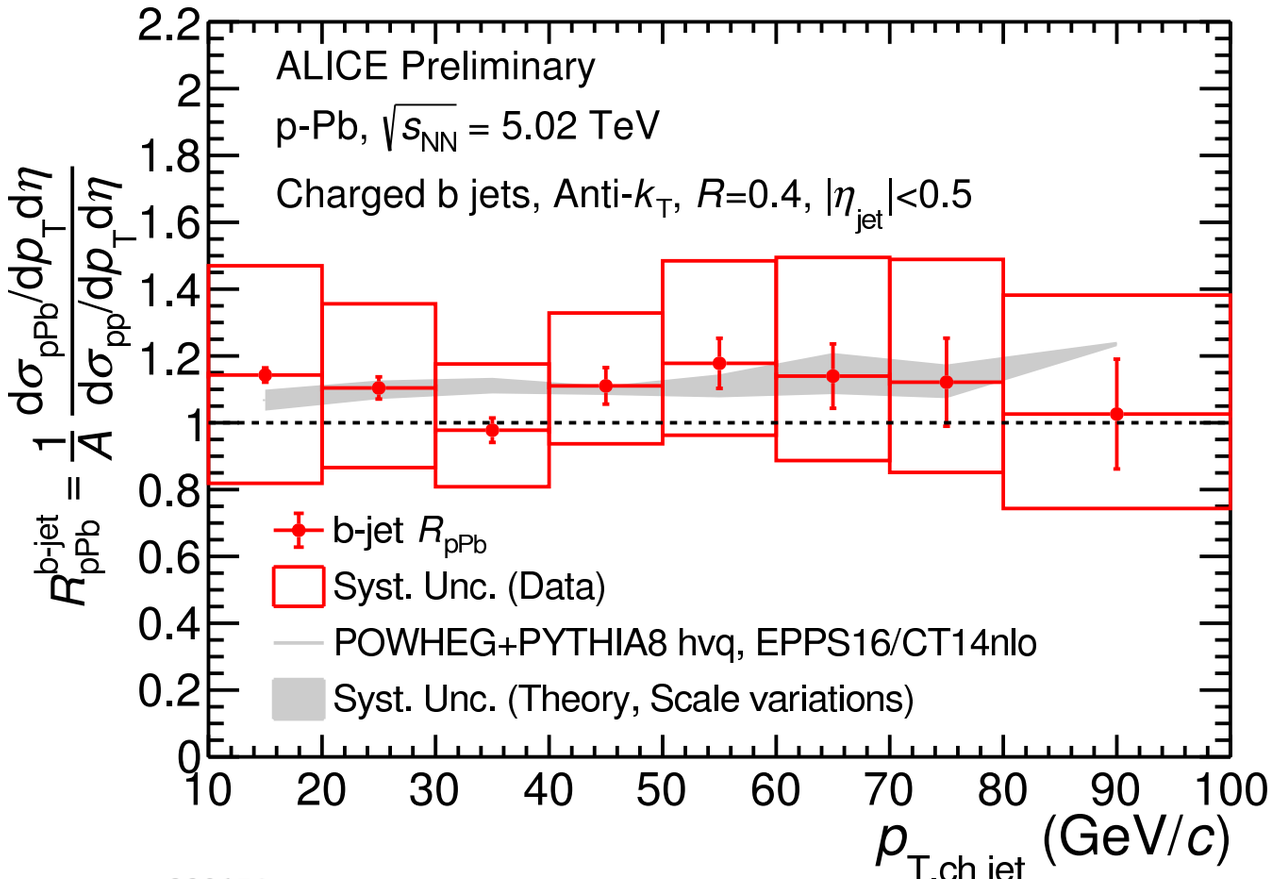
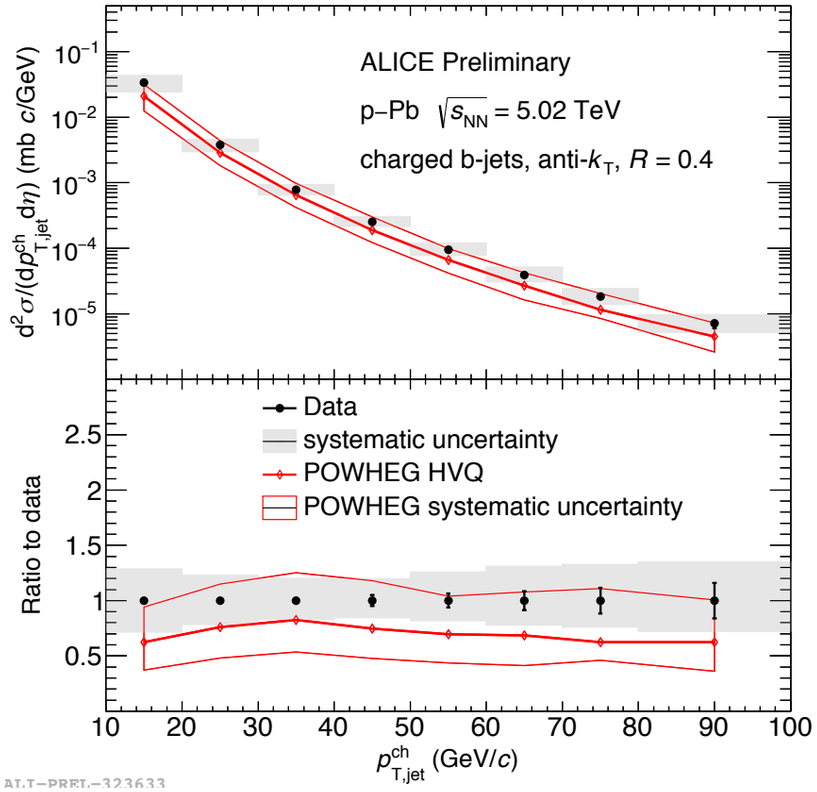
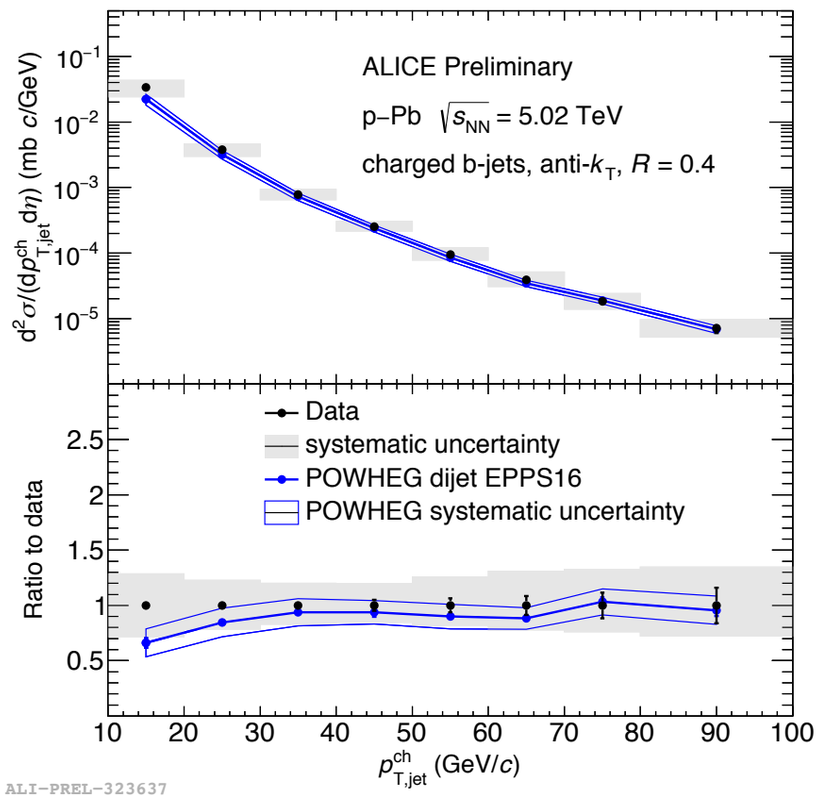
b-tagged jets

b-jets measured in p−Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$

- **Consistent with model calculations**
  - POWHEG HVQ EPS09NLO (SV) + PYTHIA6 (CT14NLO for IP)
  - POWHEG Dijet EPPS16 (SV) + PYTHIA8 (CP14NLO for IP)
- **R_{pPb} of b-jet is consistent with unity within uncertainties → b-jet production is insensitive to CNM effects within uncertainties**







Summary & Outlook

Beauty production studied in pp, p−Pb, and Pb−Pb collisions with ALICE detector

- **In pp collisions :**
  - Cross section of b→e, non-prompt D^0, non-prompt J/ψ and b-tagged jets well described by pQCD calculations
- **In p−Pb collisions :**
  - R_{pPb} of b-tagged jets consistent with unity → small influence of CNM effects
  - Cross section and R_{pPb} of non-prompt J/ψ and b-tagged jets described by model predictions implementing CNM effects
- **In Pb−Pb collisions :**
  - R_{AA} of b→e and non-prompt D^0 less than unity → undergo energy loss in the medium
  - Measurements described by models that include collisional and radiative energy loss

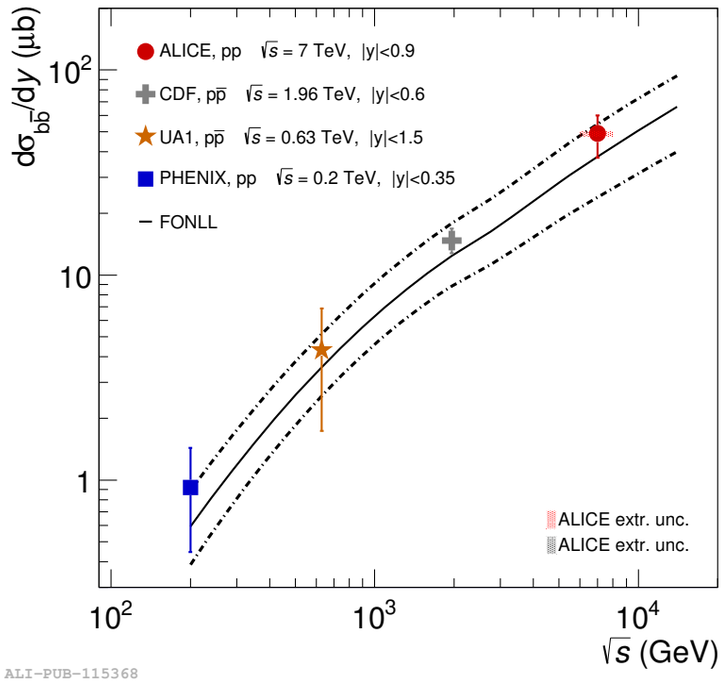
In the future, beauty production will be studied via full reconstruction in pp, p−Pb and Pb−Pb collisions with ALICE detector upgrade at the LHC energies

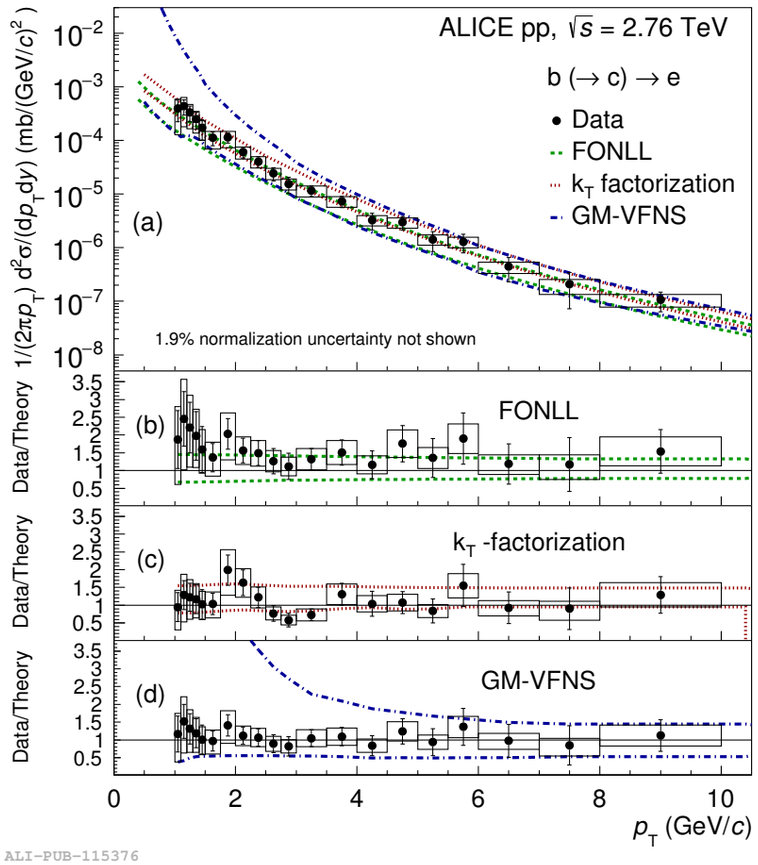
BACKUP

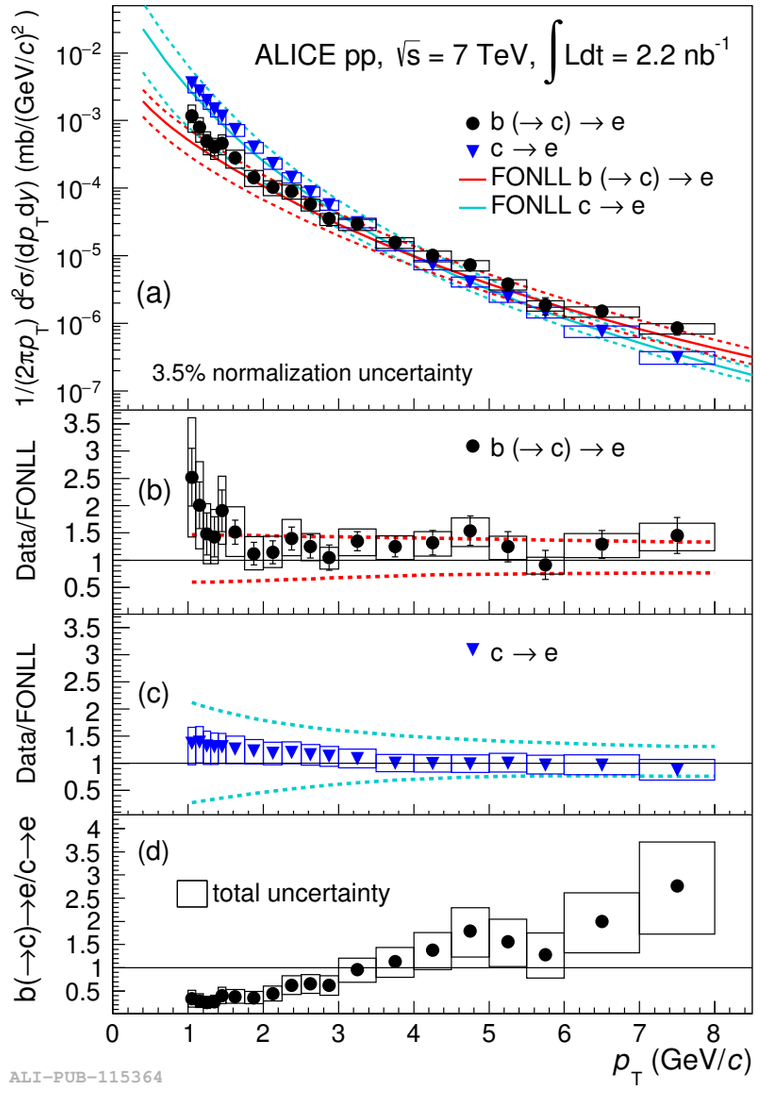
Results : electrons from beauty hadrons

Cross section of electrons from beauty-hadron decays measured in pp collisions at $\sqrt{s} = 2.76\,\mathrm{TeV}$ and $7\,\mathrm{TeV}$

- Consistent with pQCD calculations within uncertainties



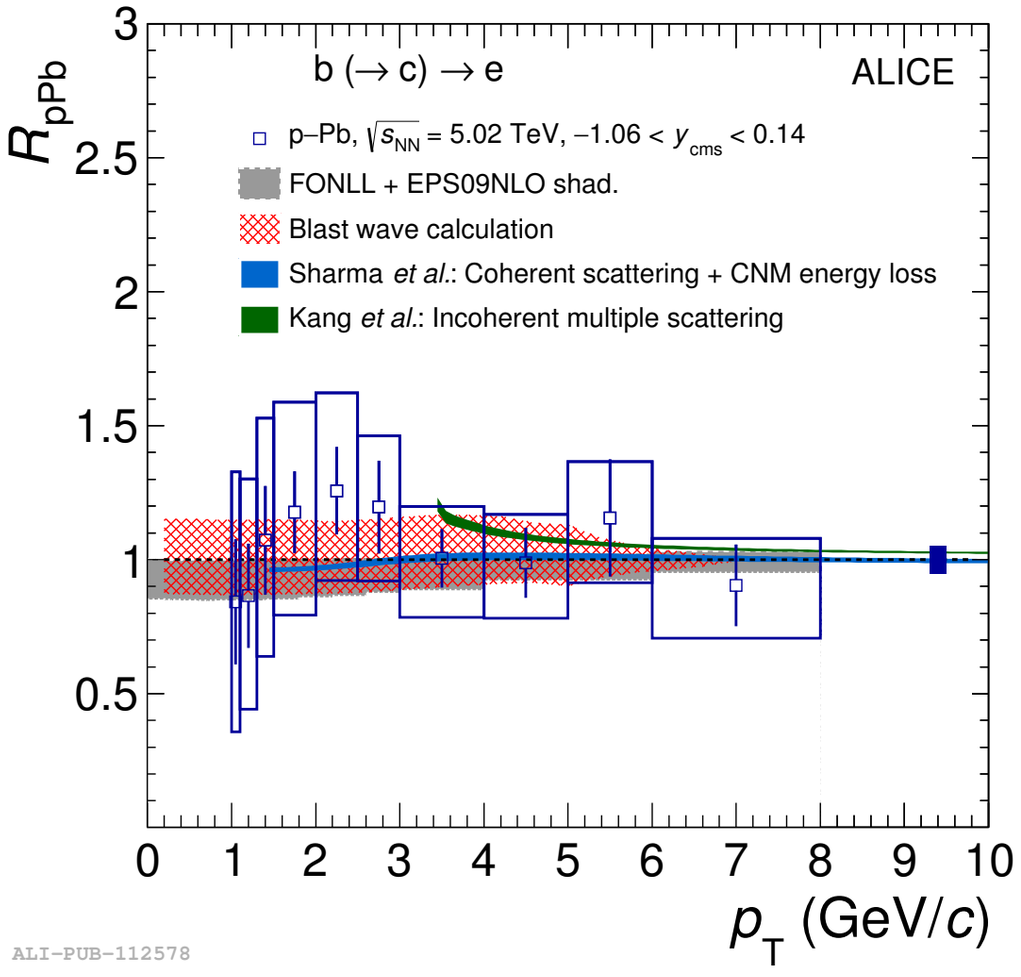


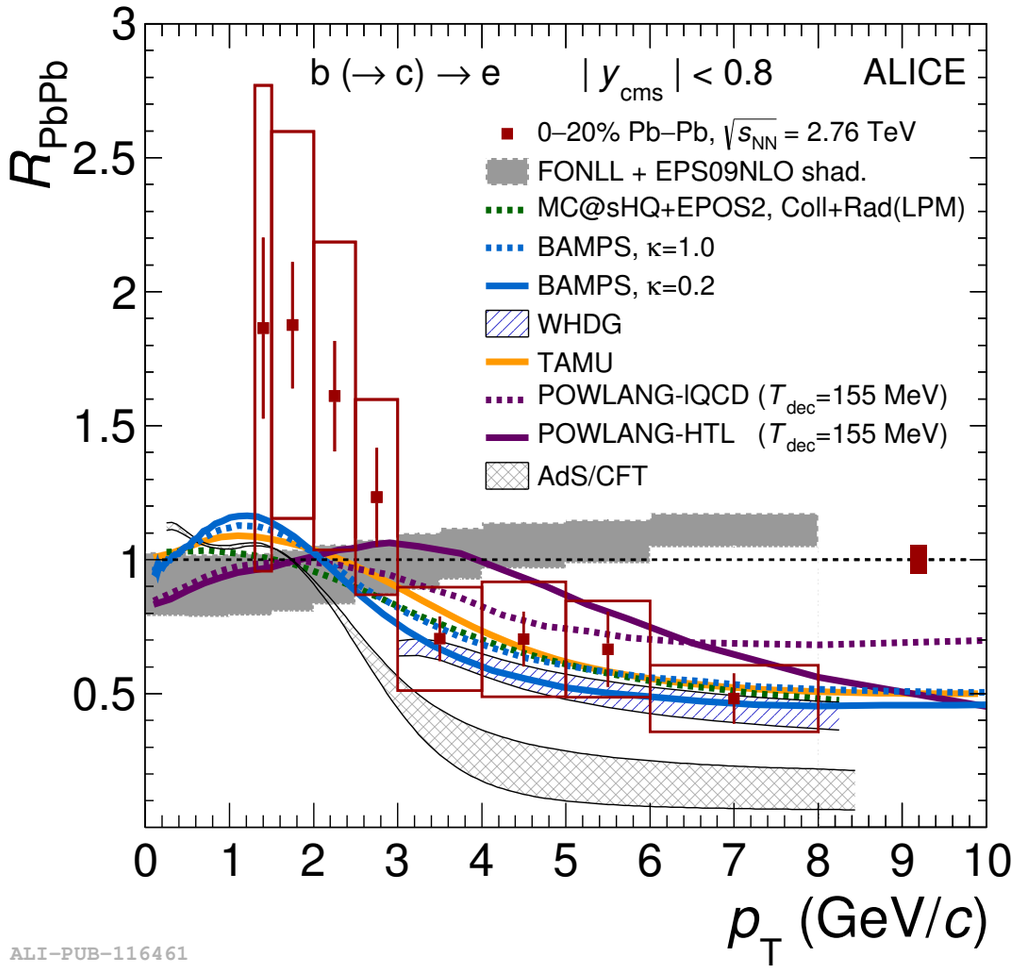


Results : electrons from beauty hadrons

Nuclear modification factors of electrons from beauty-hadron decays measured in pPb collisions at $\sqrt{s} = 5.02\,\mathrm{TeV}$ and Pb−Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76\,\mathrm{TeV}$

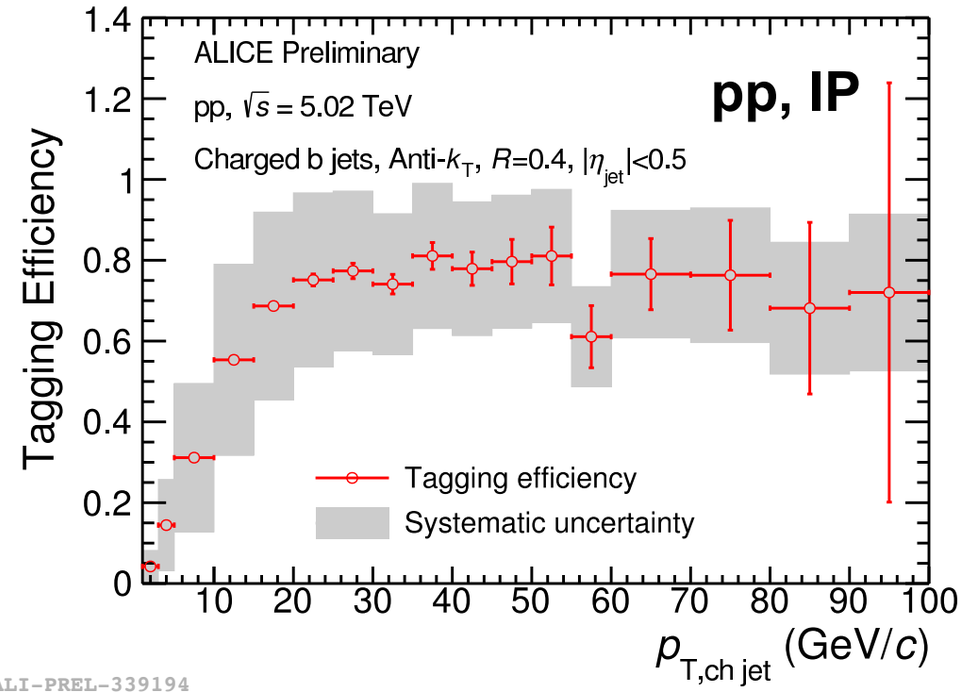
- CNM effects are negligible within uncertainties
- Medium-induced energy loss in Pb−Pb collisions above 3 GeV/*c*





b-tagged jets

Tagging efficiency



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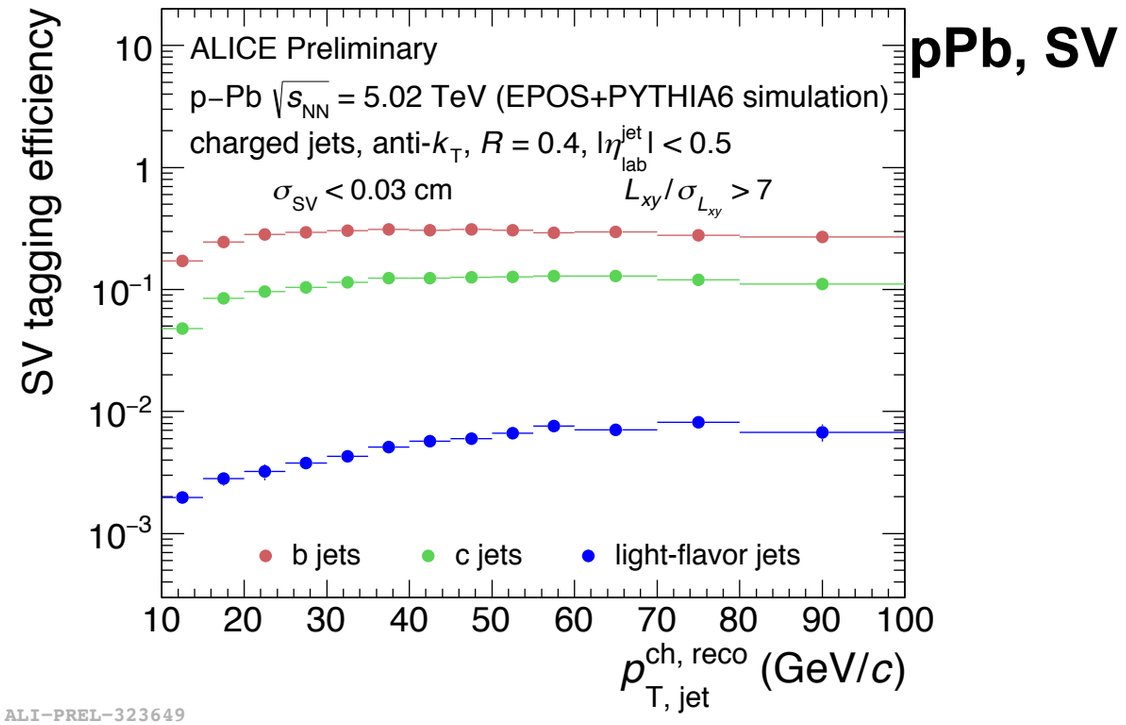

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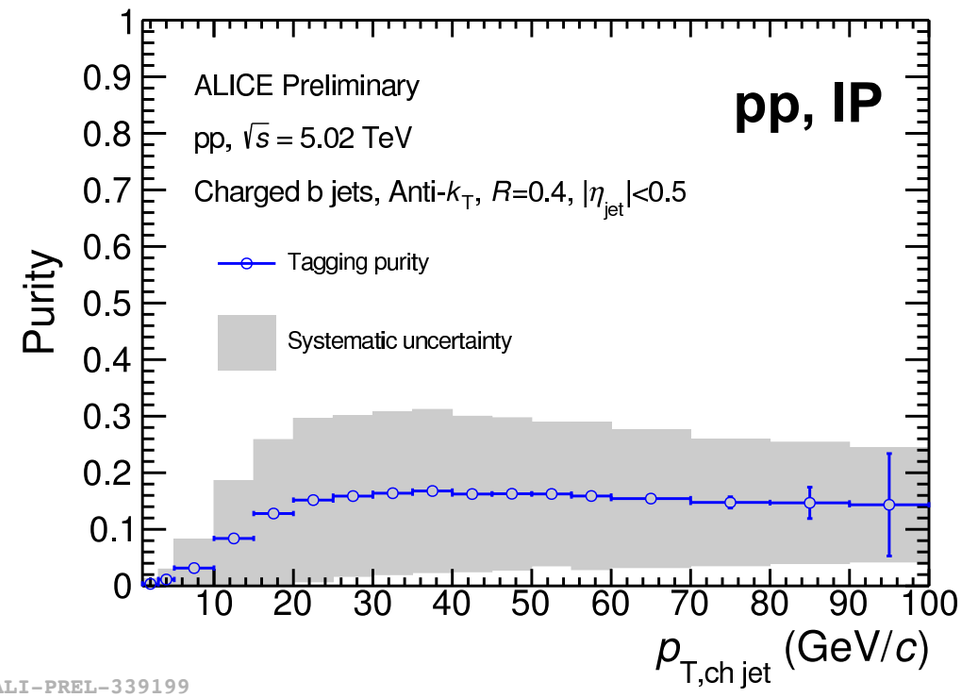
Purity



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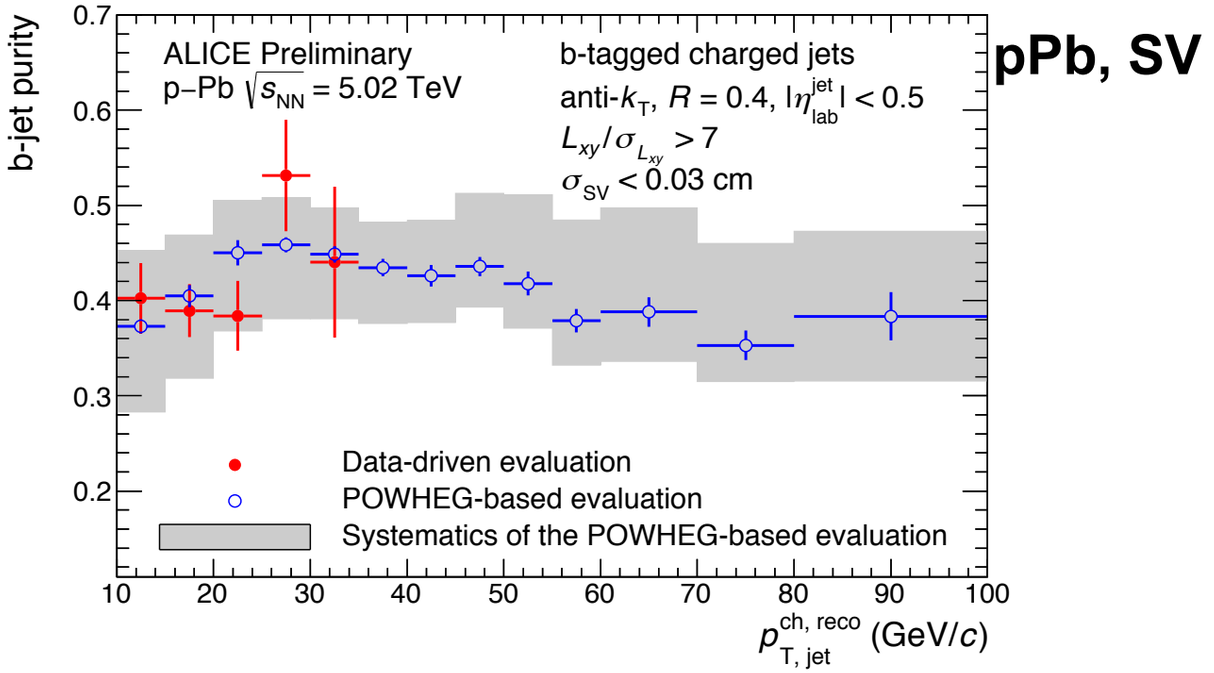

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