Measurements of heavy-flavour decay leptons in Pb-Pb and Xe-Xe collisions with ALICE at the LHC

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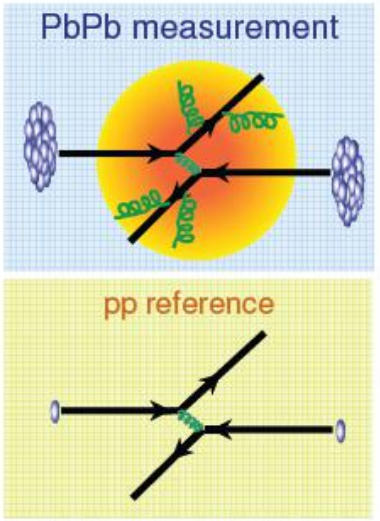
Outline

- ❑ Physics motivations
- ❑ Open heavy-flavour reconstruction in ALICE
- ❑ Open heavy-flavour nuclear modification factor
- ❑ Model comparisons
- ❑ Conclusion and outlook

CLHCP2018,
19-22 Dec. 2018, Wuhan, China

Physics motivations

Charm and beauty quarks: sensitive probes of the medium properties



Open heavy flavours in nucleus-nucleus (AA) collisions

- In-medium parton energy loss: gluon radiation and elastic collisions

  - path length and medium density
  - color charge (Casimir factor)
  - quark mass (dead cone effect)

$$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$$

Is this reflected in: $R_{\mathrm{AA}}(\pi) < R_{\mathrm{AA}}(\mathrm{D}) < R_{\mathrm{AA}}(\mathrm{B})$?

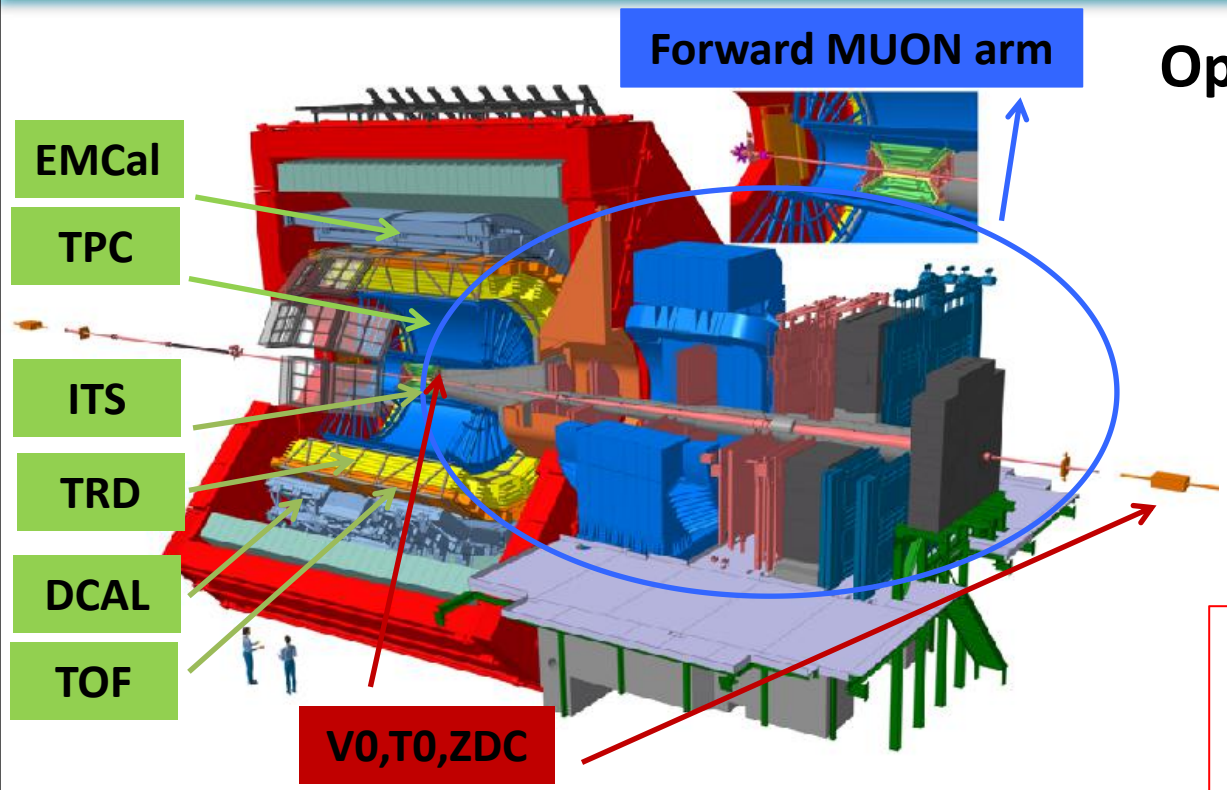
Observables sensitive to the medium effects

✓ The nuclear modification factor, R_{AA}

$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{1}{\langle T_{\mathrm{AA}} \rangle} \times \frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}} = \frac{QCD\ \mathrm{Medium}}{QCD\ \mathrm{Vacuum}}$$

- ✓ If no nuclear effects: $R_{\mathrm{AA}} = 1$
- ✓ Effects of the hot and dense medium produced in the collision breakup binary scaling: $R_{\mathrm{AA}} \neq 1$

Open heavy-flavour reconstruction in ALICE



Open heavy flavours

Charmed hadrons (|y| < 0.5)

- $D^0 \rightarrow K^-\pi^+$
- $D^* \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$
- $D^+ \rightarrow K^-\pi^+\pi^+$

} non-strange D mesons

- $D_s^+ \rightarrow \phi\pi^+ \rightarrow K^-K^+\pi^+$
- $\Lambda_c^+ \rightarrow pK_s^0 \rightarrow p\pi^+\pi^-$

"Focus of this talk"

leptons

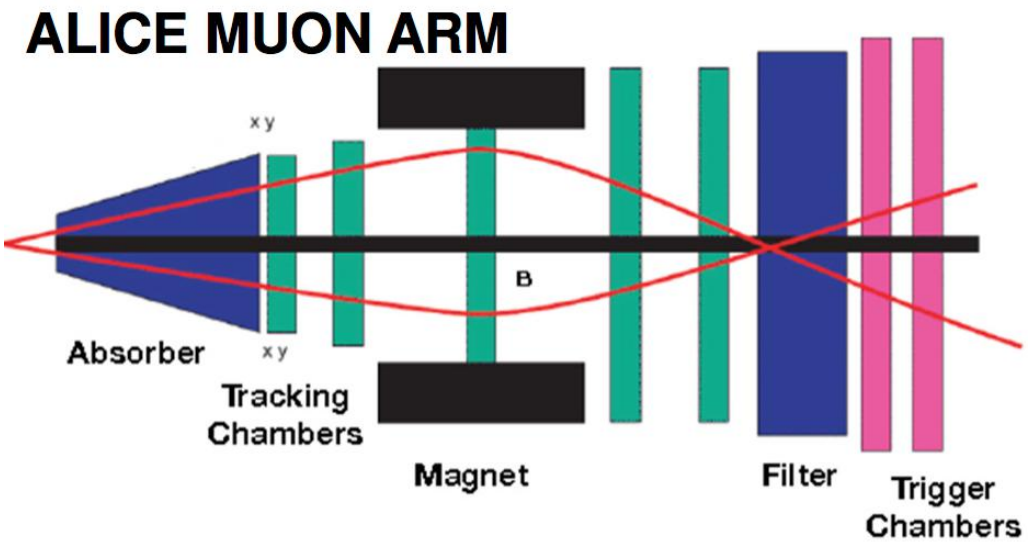
- **c,b → μX (2.5 < *y* < 4)**
- **c,b → eX (|*y*| < 0.8)**

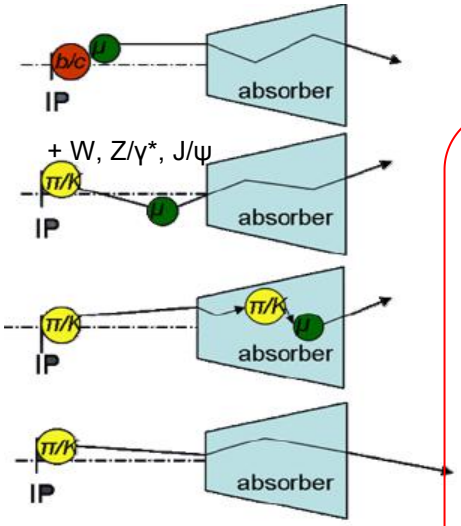
Forward MUON arm (-4 < η < -2.5)
- Muon trigger, tracking

Mid-rapidity (|η|<0.9)
- ITS, TPC, TOF, TRD: vertexing, tracking, PID
- EMCal, DCAL: high-p_T electron trigger, PID

Forward detectors: V0, T0, ZDC
- Event trigger, centrality and event plane determination

Muons from heavy-flavour hadron decays





μ from heavy flavours

μ from primary π, K, W,Z/γ*, J/ψ

μ from secondary π, K

punch through hadrons

background ⇔

Muon track selection

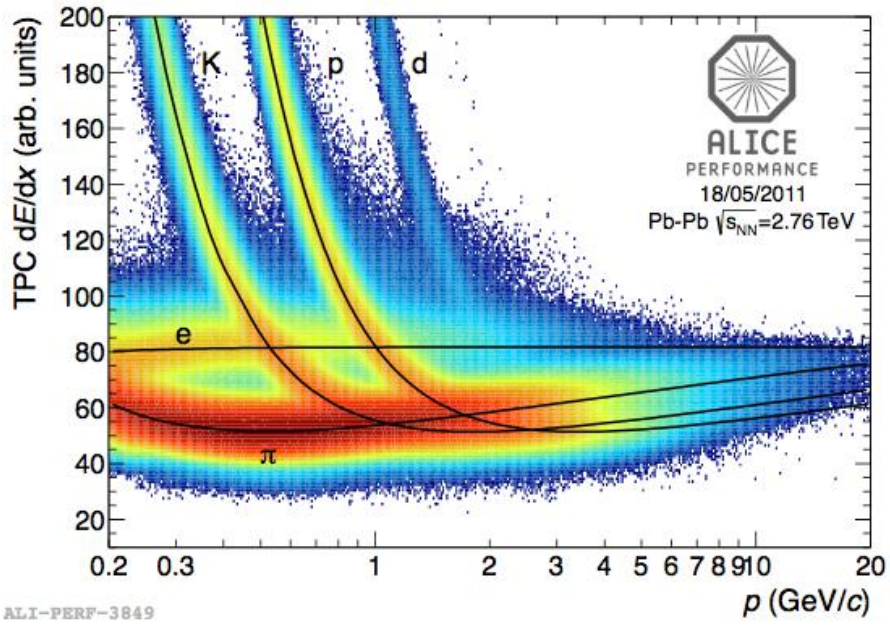
- **Acceptance & geometrical cuts**
  select tracks in the spectrometer acceptance
- **p_T cut at 3 GeV/*c***
  reject μ from secondary π, K
- **Muon tracking-trigger matching**
  reject hadrons crossing the front absorber
- **p × DCA (Dist. of Closest Approach) in 6σ**
  reject beam-gas interactions & particles produced in the absorber

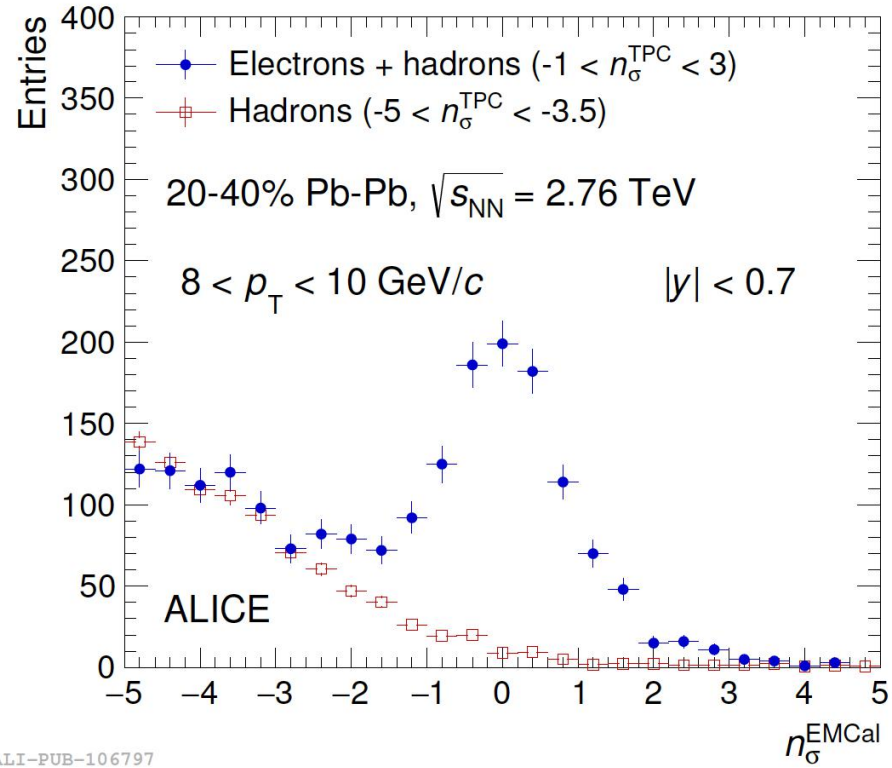
$\mu^{\pm} \leftarrow$ b, c studies

- **Background subtraction**
  μ ← primary π, K (main contribution at low p_T) **, J/ψ decays** (dominates at 5 GeV/*c*):
  data-tuned background cocktail
  μ ← W, Z/γ* decays (main contribution at high p_T):
  POWHEG simulation

Electrons from heavy-flavour hadron decays

-Low-p_T electrons: PID via TPC dE/dx complemented with TOF and ITS
-High-p_T electrons: PID using TPC, EMCal





Main background sources:

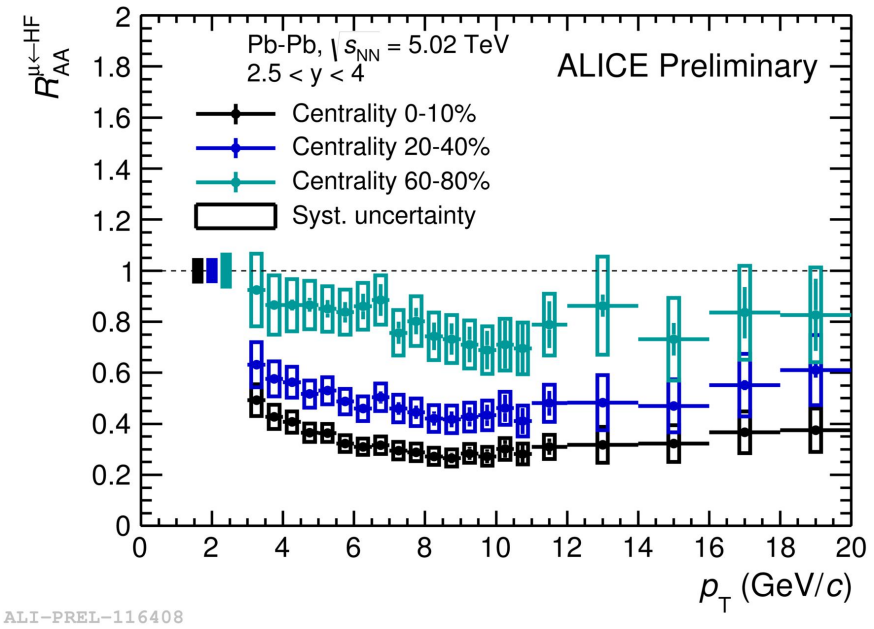
-γ conversions
-π^0 and η Dalitz decays

Background subtraction:

-Measured: photonic-electron tagging method (e^+e^- pairs)
-Calculated: data-tuned background cocktail

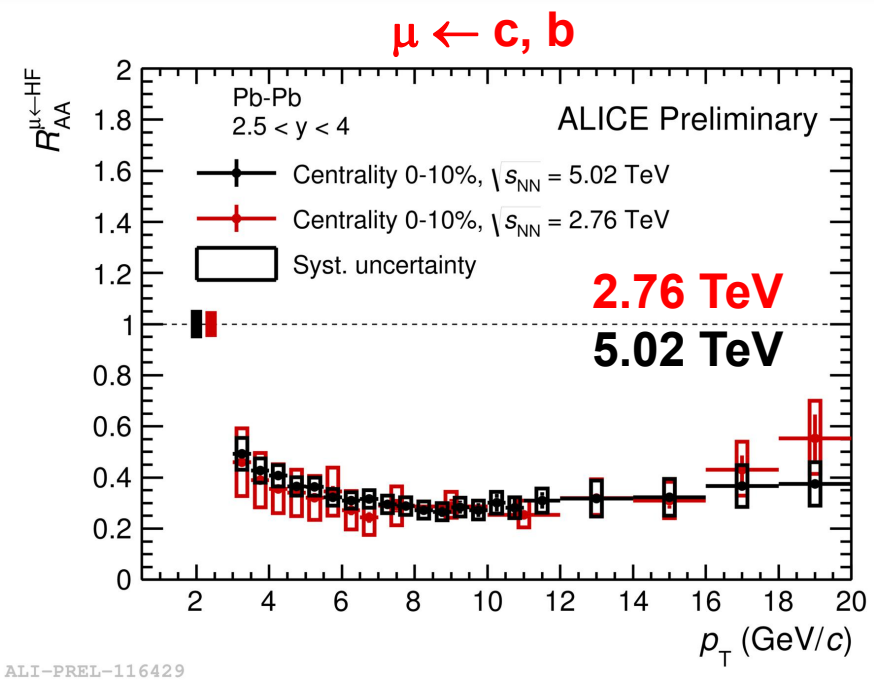
p_T-differential R_{AA} of muons ← c, b in Pb-Pb collisions

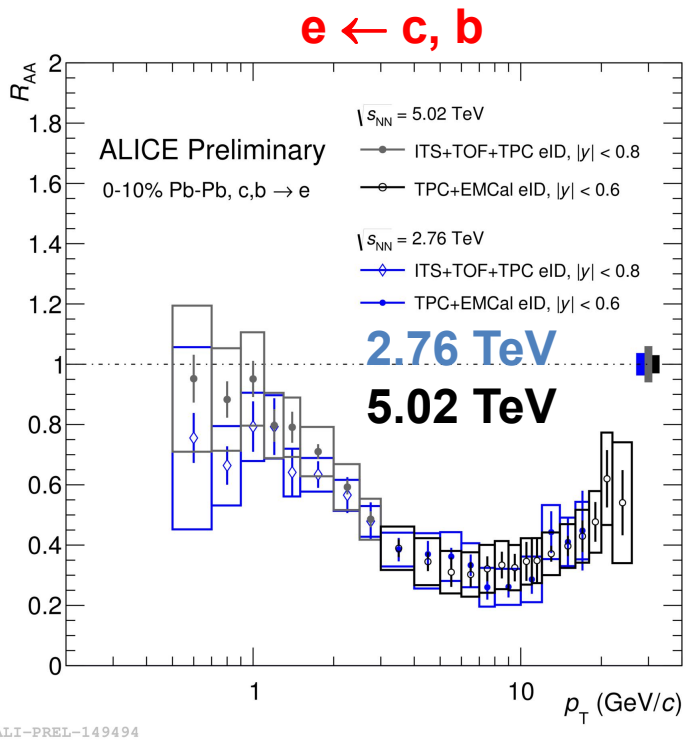
μ ← c, b



- Clear increase of the suppression for more central events: about a factor 3 at p_T~8 GeV/c in 0-10% Pb-Pb collisions
- High p_T, beauty component dominant, indication of beauty energy loss

p_T-differential R_{AA} of leptons ← c, b in Pb-Pb collisions: energy dependence

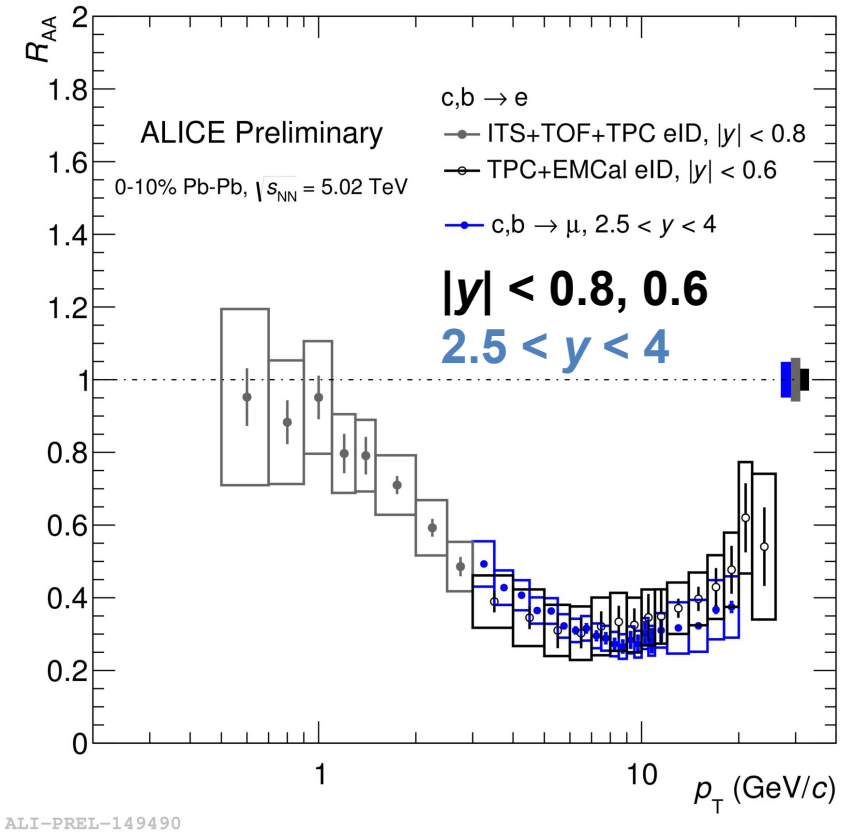




- Similar suppression at 5.02 TeV and at 2.76 TeV: described by model [1] at two energies → harder spectra and denser medium counterbalance
- e ← c, b R_{AA} measurements down to p_T = 0.5 GeV/c: low-p_T measurements crucial in all systems to test binary scaling of total cc-bar cross section and possible effect of initial-state effects like nuclear PDF (shadowing)
- Improved precision at 5.02 TeV

[1] Djordjevic: Phys. Rev. C92 (2015) 024918

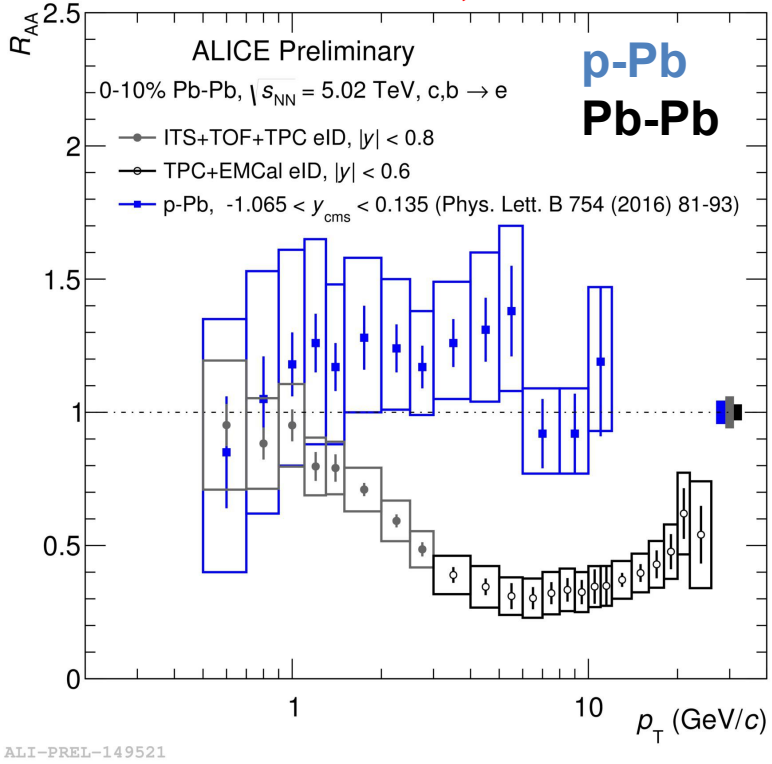
p_T-differential R_{AA} of leptons ← c, b in Pb-Pb collisions: rapidity dependence



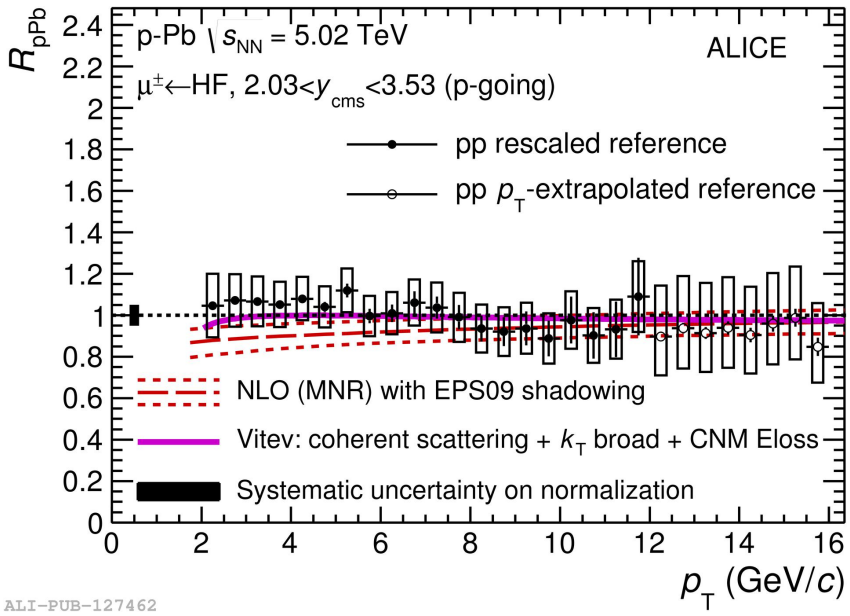
- Compatible results within uncertainties for heavy-flavour decay electrons ($|y| < 0.8, 0.6$) and heavy-flavour decay muons ($2.5 < y < 4$) R_{AA}. Indication that heavy quarks suffer a strong in-medium energy loss in a wide rapidity interval

p_T-differential R_{AA} of leptons ← c, b in Pb-Pb and p-Pb collisions

e ← c, b



μ ← c, b

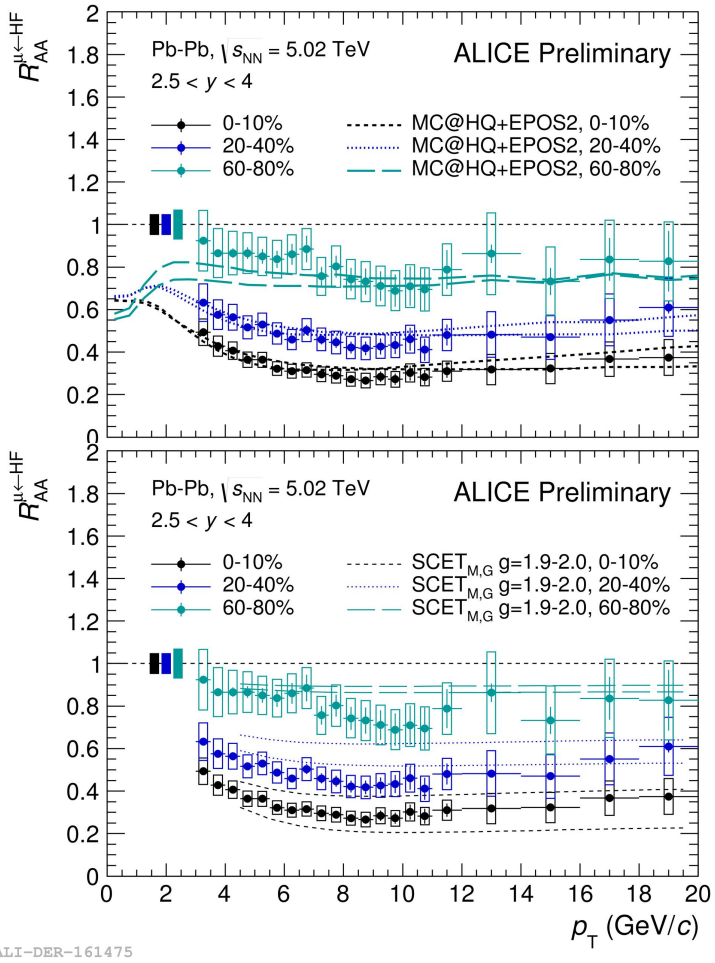


p-Pb: Phys. Lett. B 770 (2017) 459-472

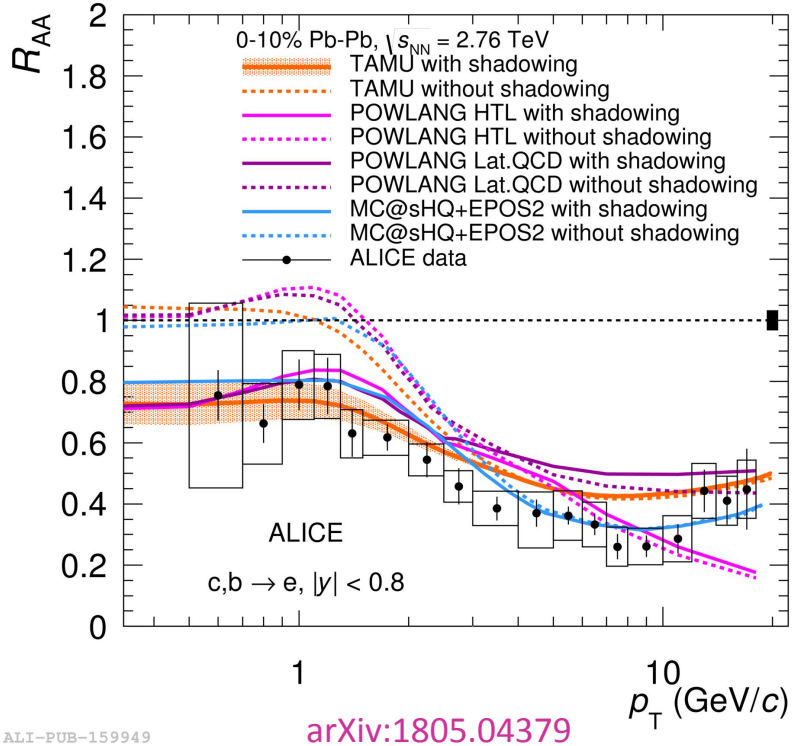
- R_{pPb} at mid- and forward rapidity: consistent with unity within uncertainties over the whole measured p_T interval
- The suppression observed at high p_T in central Pb-Pb collisions results from final-state effects related to parton energy loss

Model comparison: R_{AA} in Pb-Pb collisions (1/2)

μ ← c, b



e ← c, b



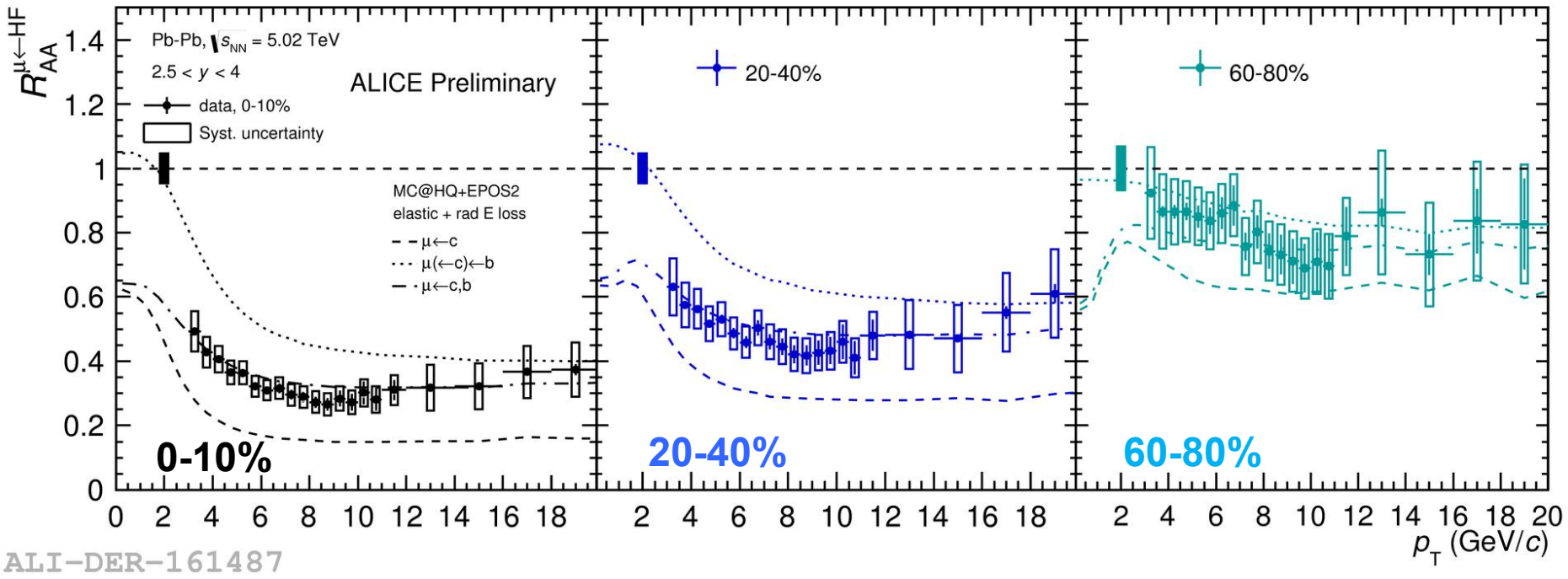
arXiv:1805.04379

MC@sHQ: Phys.Rev. C89, (2014) 014905;
SCET: Phys. Rev. C 80 (2009) 054902
POWLANG: EPJ C73 (2013) 2481;
TAMU: PLB735 (2014) 445–450;

- R_{AA} measurements at $\sqrt{s_{NN}}$ = 5.02 TeV provide new constraints on energy loss models
- Data are better described by models when nuclear PDF (EPS09) are used

Model comparison: R_{AA} in Pb-Pb collisions (2/2)

μ ← b and μ ← c predictions, separately !

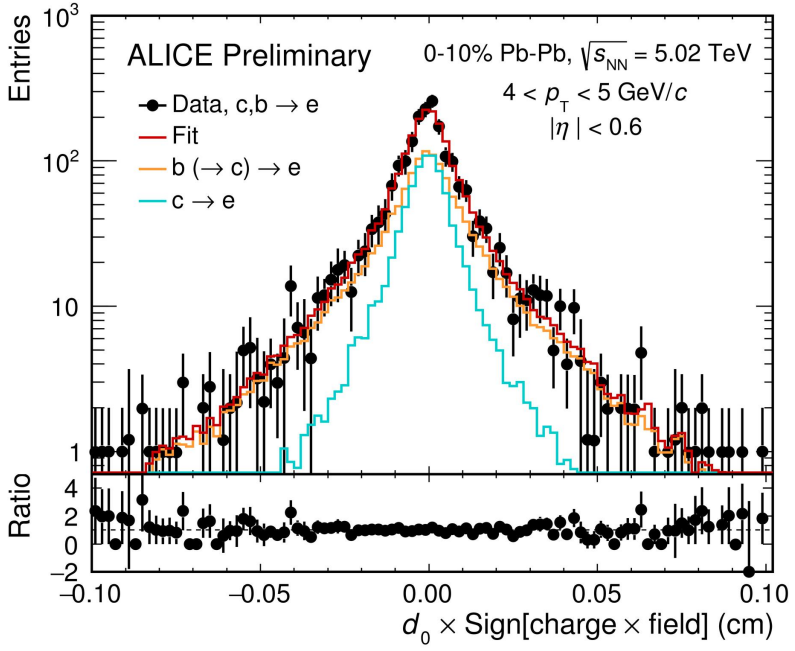


- Data at high p_T very close to μ ← b MC@sHQ+EPOS2 predictions in different centrality classes
- MC@sHQ+EPOS2, which reproduces well μ←c,b R_{AA}, expects μ←b R_{AA} > ~ 2 x μ←c R_{AA}

MC@sHQ: Phys.Rev. C89, (2014) 014905

R_{AA} of $e^{\pm} \leftarrow b$ in Pb-Pb collisions (1/2)

New



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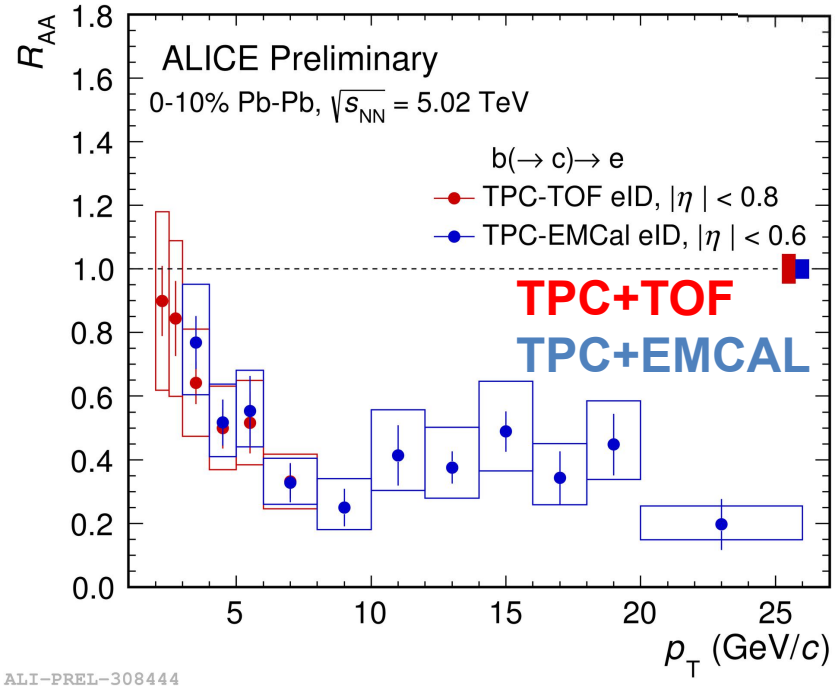
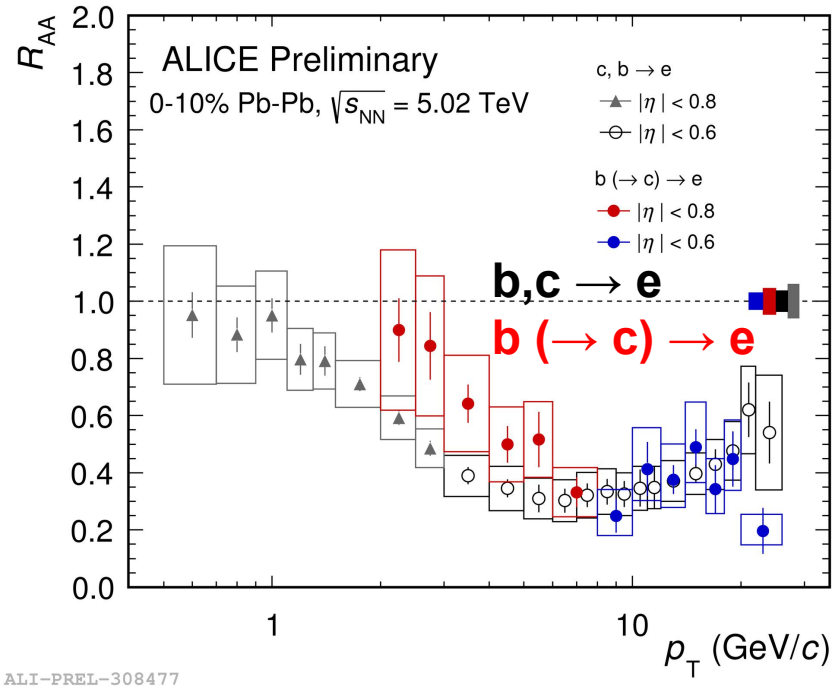


ALI-PREL-308444

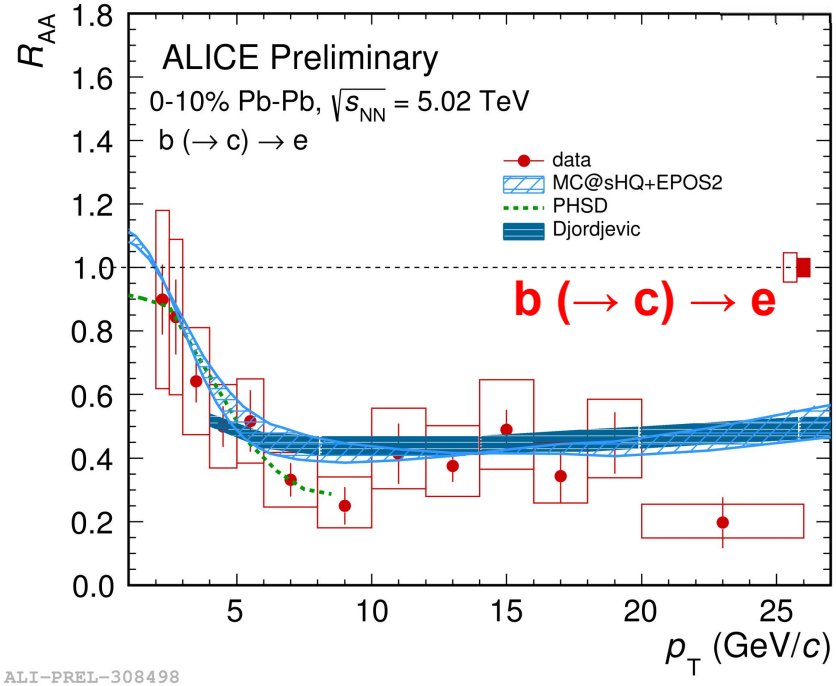
- Analysis of $e^{\pm} \leftarrow b$ based on the electron impact parameter distribution. Beauty-decay electron yield measured up to 26 GeV/c using EMCAL-triggered data
- Consistent result with TPC-TOF based analysis and EMCAL-TPC based analyis in overlapping p_T interval

R_{AA} of $e^{\pm} \leftarrow$ b in Pb-Pb collisions (2/2)

New



ALI-PREL-308477



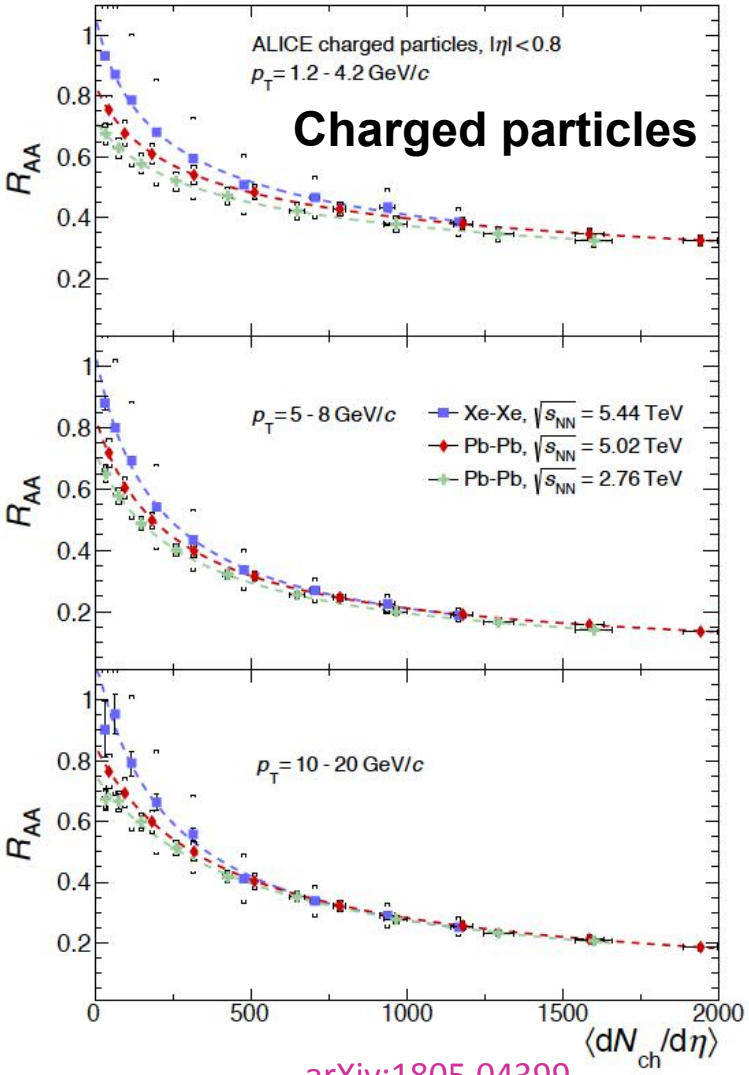
ALI-PREL-308498

- Hint of a smaller suppression for beauty-decay electron for p_T < 6 GeV/c
- Data are reproduced by models within uncertainties, implementing mass-dependent energy loss

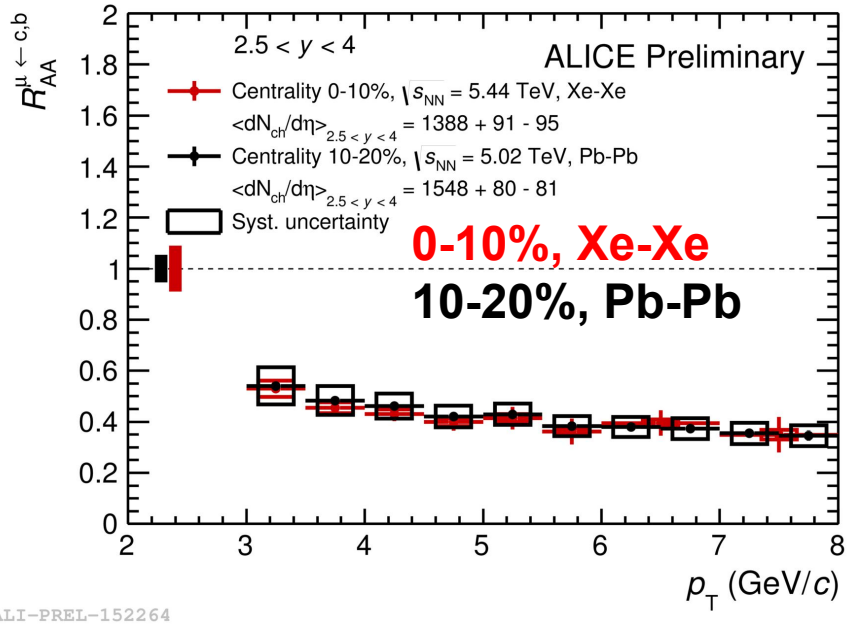
MC@sHQ: Phys.Rev. C89 no. 1, (2014) 014905
PHSD: Phys. Rev. C93 no. 3, (2016) 034906
Djordjevic: Phys. Rev. C92 (2015) 024918

p_T-differential R_{AA} of leptons ← c, b in Xe-Xe collisions: geometry and path-length dependence

Charged particles: similar R_{AA} is observed in Xe-Xe and Pb-Pb at similar <dN/dη>



arXiv:1805.04399

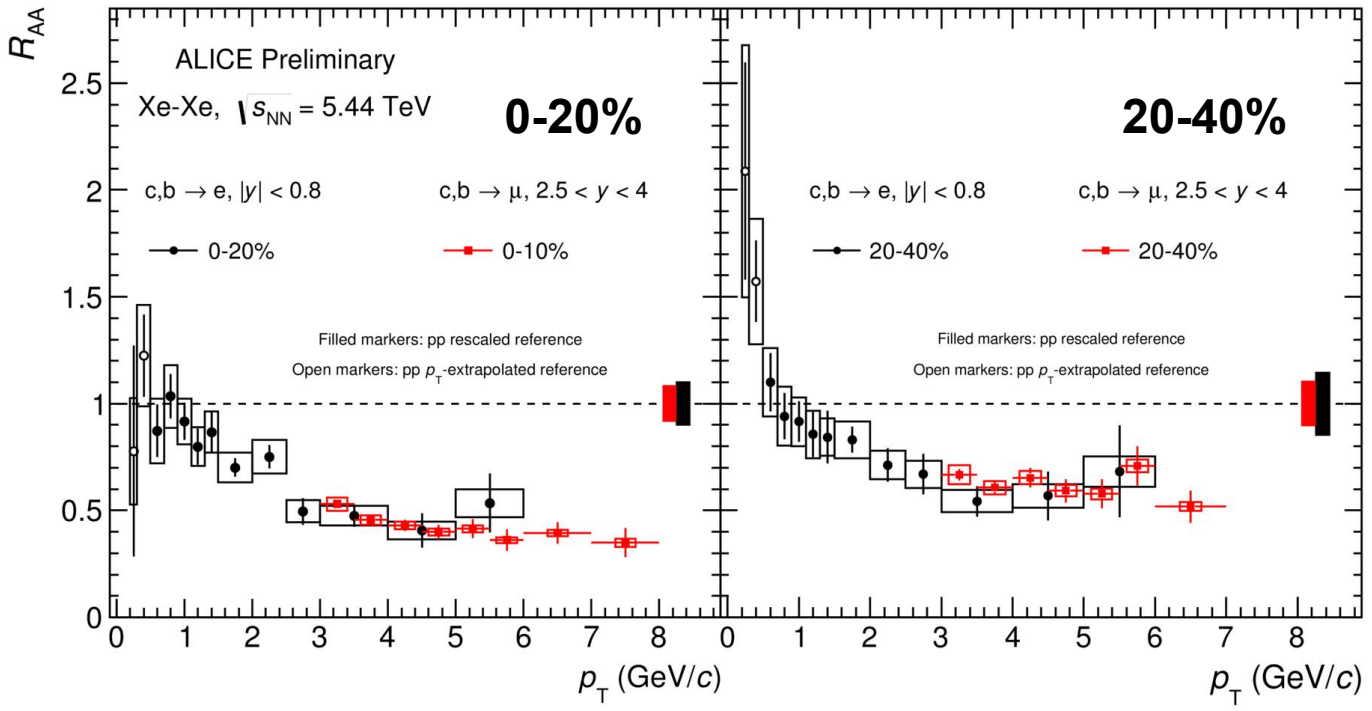


- Similar heavy-flavour hadron decay muon R_{AA} observed in 0-10% Xe-Xe and 10-20% Pb-Pb collisions at similar <dN/dη>
  - ✓ Possible interplay of geometry and path-length dependence

M. Djordjevic et al, arXiv: 1805.04030

p_T-differential R_{AA} of leptons ← c, b in Xe-Xe collisions: rapidity dependence

Heavy-flavour decay electron R_{AA} measured down to p_T = 0.2 GeV/c thanks to the low B field used during the Xe-Xe data taking!



- Compatible results within uncertainties for heavy-flavour decay electrons ($|y| < 0.8$) and heavy-flavour decay muons ($2.5 < y < 4$) R_{AA} in central and semi-central collisions

Conclusion

- R_{AA} of open heavy-flavour decay leptons in heavy-ion collisions
  - ✓ Strong suppression in 0-10% centrality class. The measured suppression is due to final-state effects (R_{pPb} ~ 1)
  - ✓ Similar R_{AA} at mid and forward rapidity
  - ✓ Similar heavy-flavour hadron decay muon R_{AA} observed in 0-10% Xe-Xe and 10-20% Pb-Pb collisions

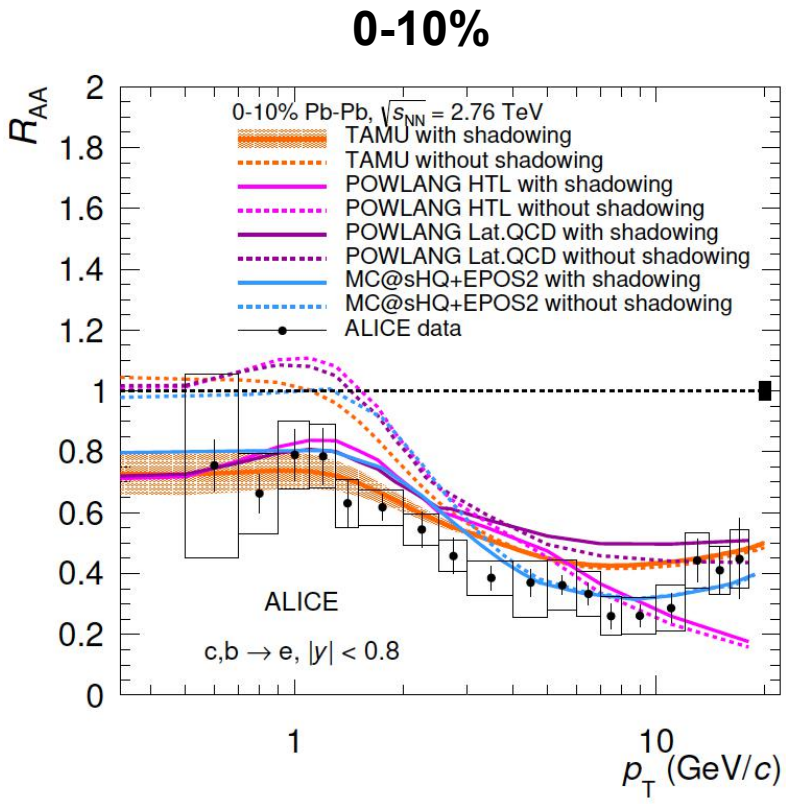
More differential measurements will come soon with new data from the Pb-Pb run in end of 2018

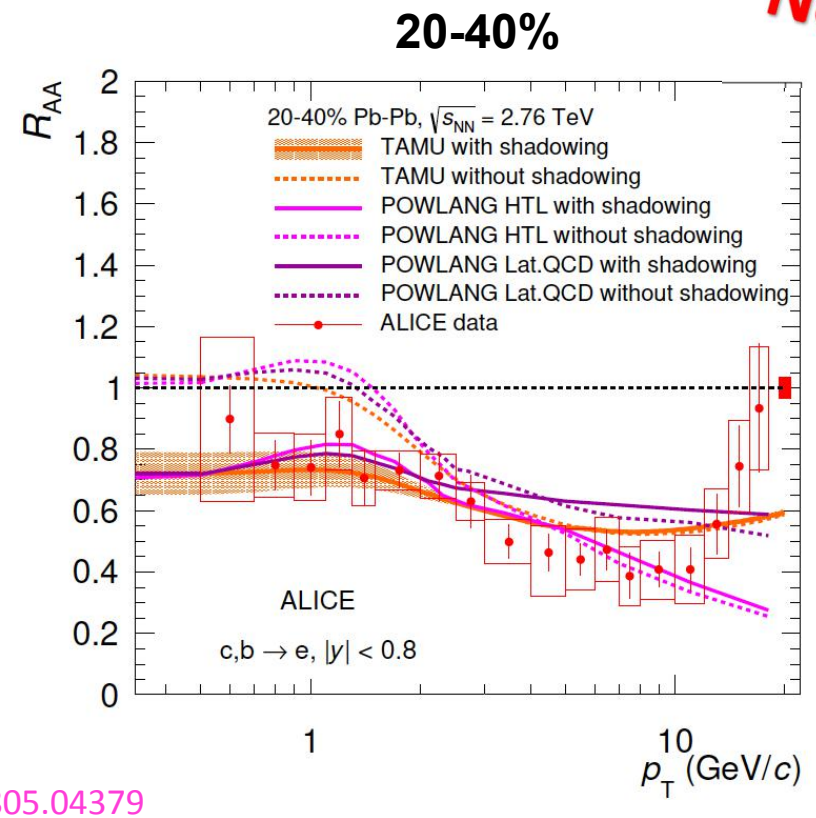
Thank you for your attention

Backup

Model comparison: R_{AA} in Pb-Pb collisons (2/2)

New





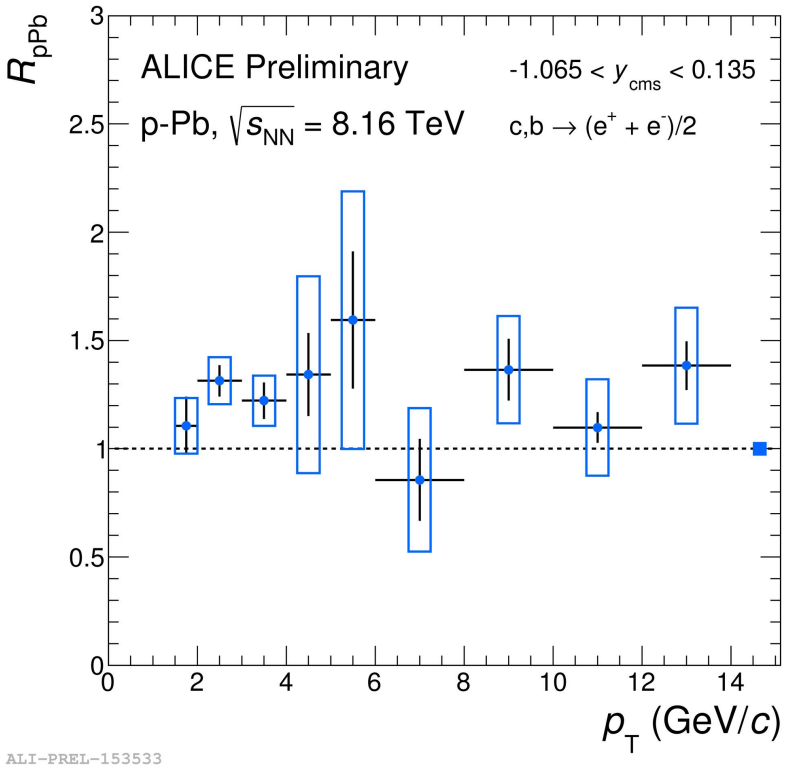
arXiv:1805.04379

- Data are better described when the nuclear PDFs (EPS09) are included in the model calculation (TAMU, POWLANG and MC@sHQ+EPOS2) in both centrality intervals
- Suppression at intermediate/high p_T is better described by models that include both radiative and collisional energy loss processes

MC@sHQ: Phys.Rev. C89 no. 1, (2014) 014905
TAMU: Phys. Lett. B 735 (2014) 445
POWLANG: Eur. Phys. J. C75 no. 3, (2015) 121

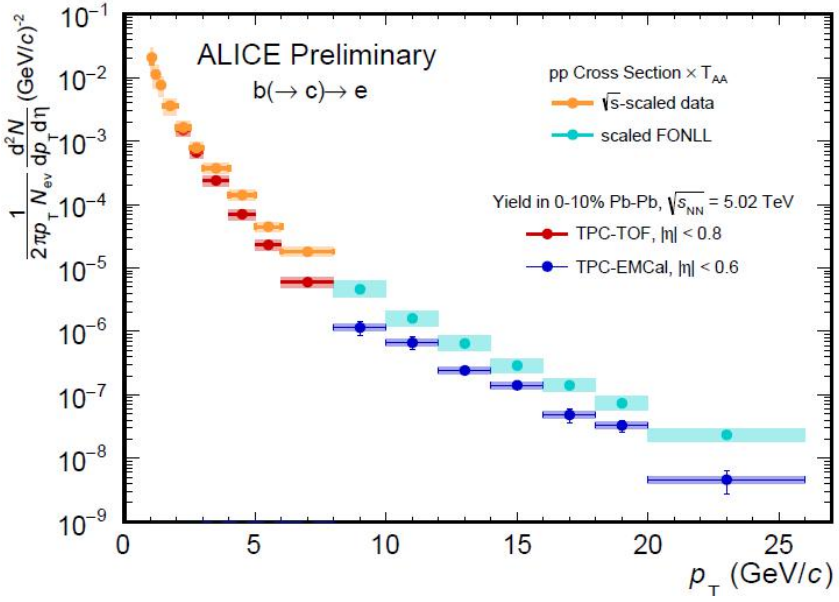
p_T-differential R_{AA} of leptons ← c, b in p-Pb collisions

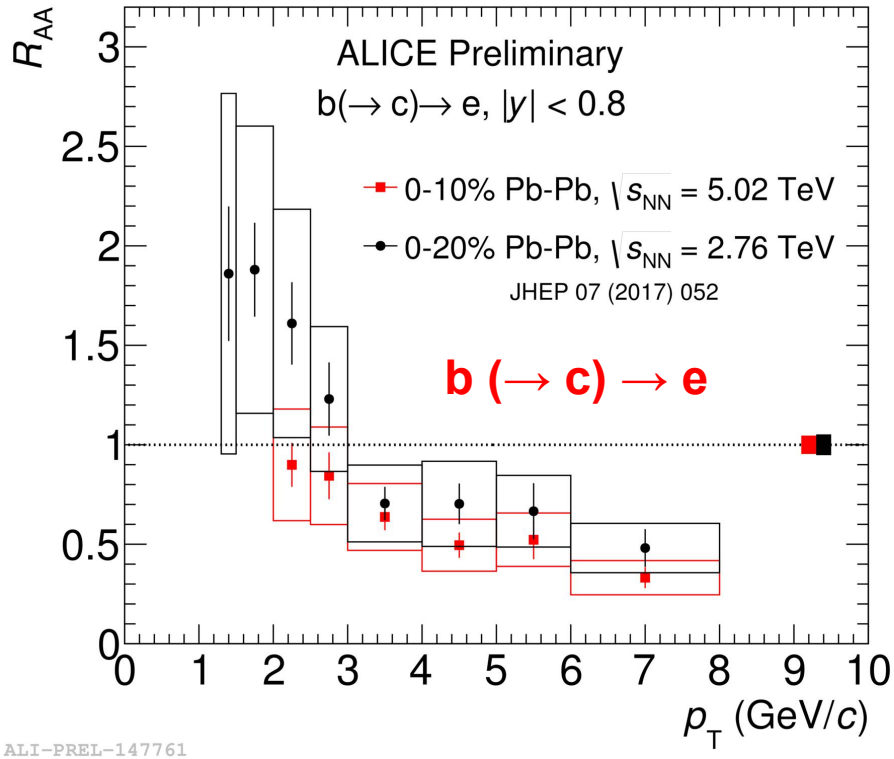
e ← c, b



- R_{pPb} at mid- and forward rapidity: consistent with unity within uncertainties over the whole p_T range

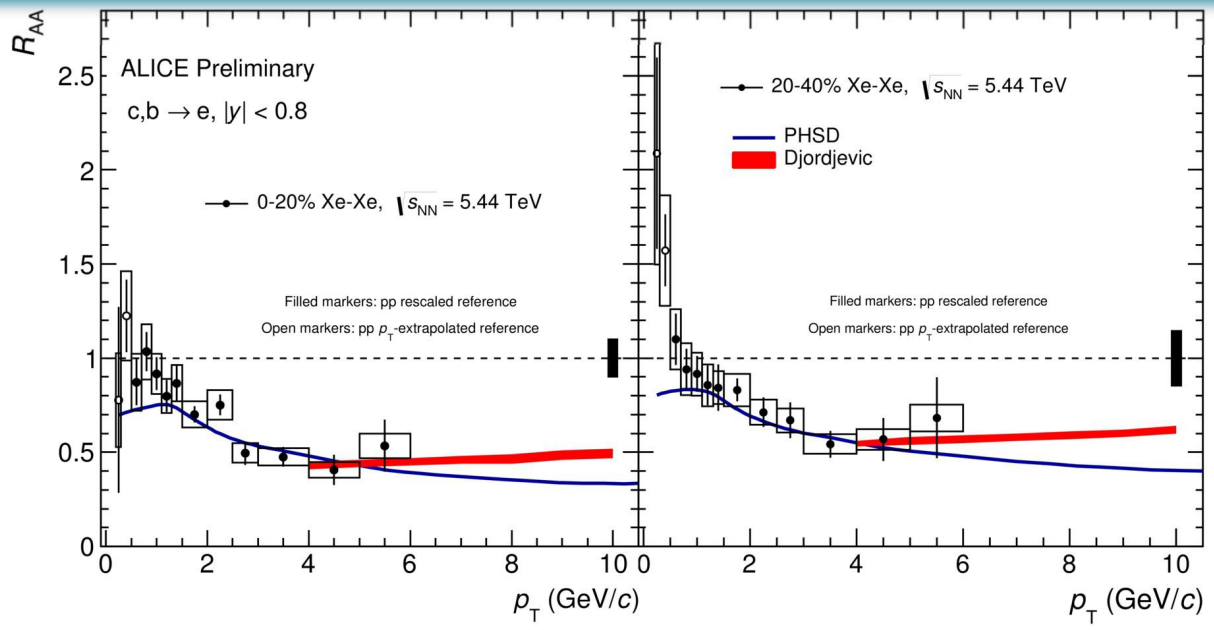
R_{AA} of $e^{\pm} \leftarrow b$ in Pb-Pb collisions





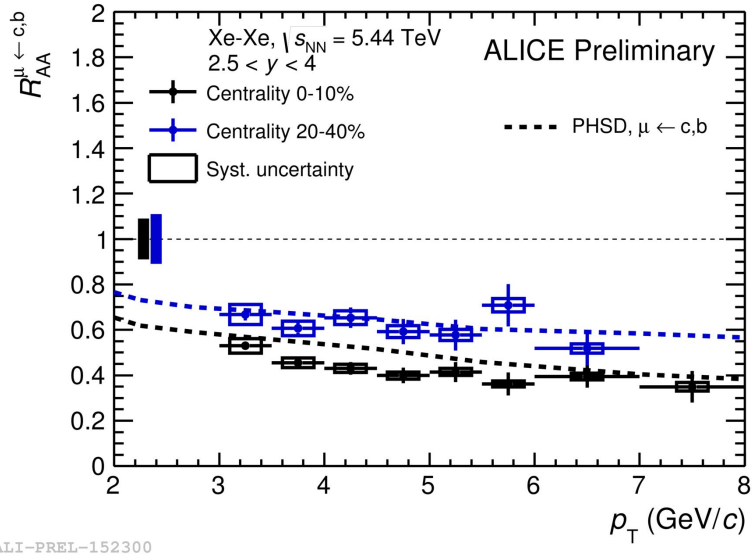
R_{AA} of leptons ← c, b in Xe-Xe collisions

New



ALI-PREL-146838

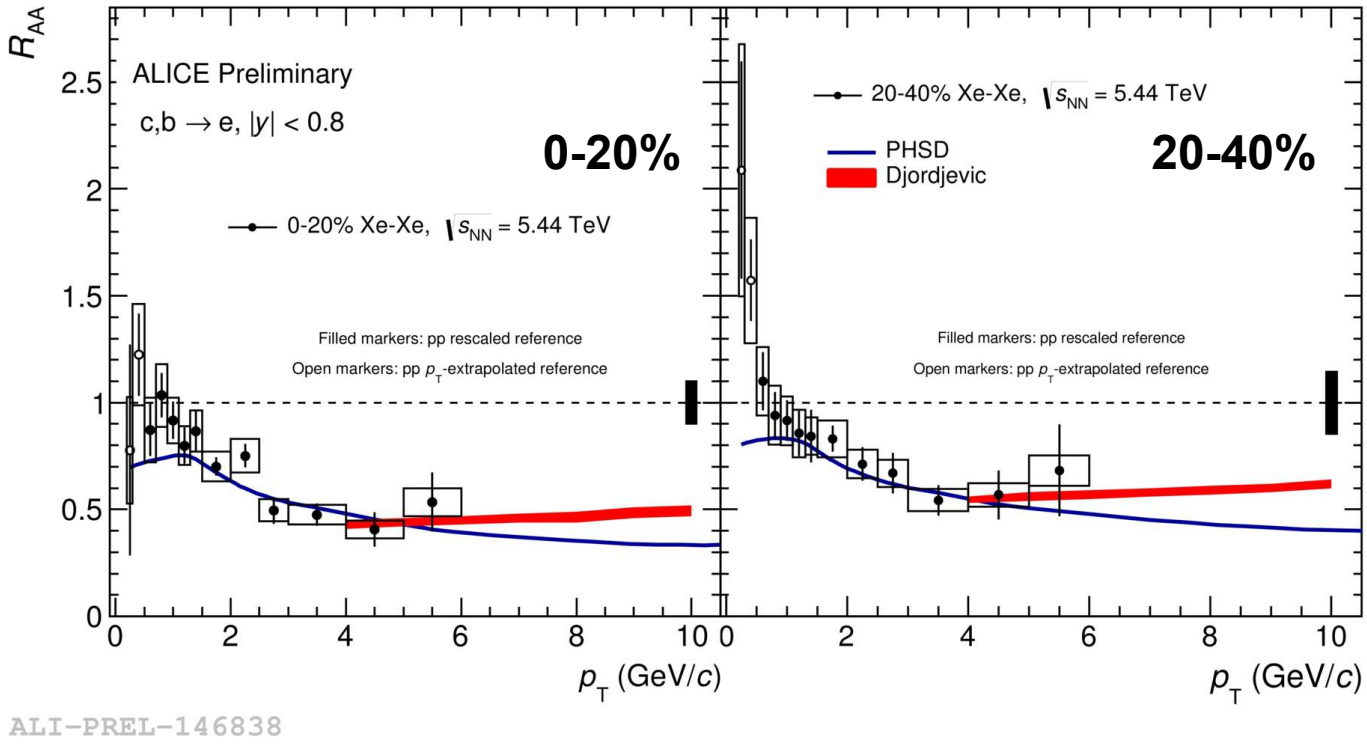
- Data are reproduced by models in Xe-Xe collisions within uncertainties



ALI-PREL-152300

PHSD: Phys. Rev. C93 no. 3, (2016) 034906
Djordjevic: Phys. Rev. C92 (2015) 024918

Model comparison: R_{AA} in Xe-Xe collisions



- Data are reproduced by models in Xe-Xe collisions within uncertainties

PHSD: Phys. Rev. C93 no. 3, (2016) 034906
Djordjevic: Phys. Rev. C92 (2015) 024918

T_{AA} values in Xe-Xe and Pb-Pb collisions

Xe-Xe

Cent (%)	Npart	RMS	Sys	Ncoll	RMS	Sys	TAA	RMS	Sys
0-10%	221.2	19	2.2	843.1	1.4e+02	70	12.33	2	1
10-20 %	164.8	18	2.8	510.6	86	51	7.465	1.3	0.74
20-30 %	118.4	14	3.8	302.8	58	40	4.426	0.85	0.59
30-40 %	82.21	11	3.9	171.3	38	27	2.505	0.56	0.4
40-50 %	54.56	8.8	3.6	91.81	24	16	1.342	0.35	0.24
50-60 %	34.06	6.5	3	46.04	14	8.8	0.6731	0.2	0.13
60-70 %	19.72	4.7	2.1	21.65	7.6	4.1	0.3166	0.11	0.061
70-80 %	10.5	3.1	1.1	9.515	3.9	1.6	0.1391	0.056	0.024
80-90 %	5.127	1.9	0.46	3.838	1.9	0.5	0.05611	0.028	0.0074
90-100 %	2.488	0.8	0.12	1.449	0.73	0.1	0.02118	0.011	0.0015

Pb-Pb

Cent	bmin [fm]	bmax [fm]	Npart	RMS	Sys	Ncoll	RMS	Sys	TAA	RMS	Sys
00 - 10 %	0.00	4.96	359	31.2	3.0	1636	246	170	23.4	3.51	0.78
10 - 20 %	4.96	7.01	263	27.1	3.6	1001	154	97	14.3	2.2	0.46
20 - 30 %	7.01	8.59	188	22.5	3.0	601	106	54	8.59	1.52	0.27
30 - 40 %	8.59	9.92	131	19.1	2.3	344	74.7	29	4.92	1.07	0.16
40 - 50 %	9.92	11.1	86.3	16.3	1.7	183	50.8	14	2.61	0.726	0.1
50 - 60 %	11.1	12.1	53.6	13.6	1.2	89.8	32.4	6	1.28	0.463	0.063
60 - 70 %	12.1	13.1	30.4	10.8	0.76	39.8	19.1	2.4	0.569	0.273	0.032
70 - 80 %	13.1	14.0	15.6	7.83	0.45	16.2	10.5	0.92	0.232	0.15	0.015
80 - 90 %	14.0	15.0	7.59	4.89	0.19	6.57	5.27	0.3	0.0923	0.0753	0.007
90 - 100 %	15.0	19.6	3.77	2.5	0.079	2.66	2.41	0.088	0.0378	0.0344	0.0033