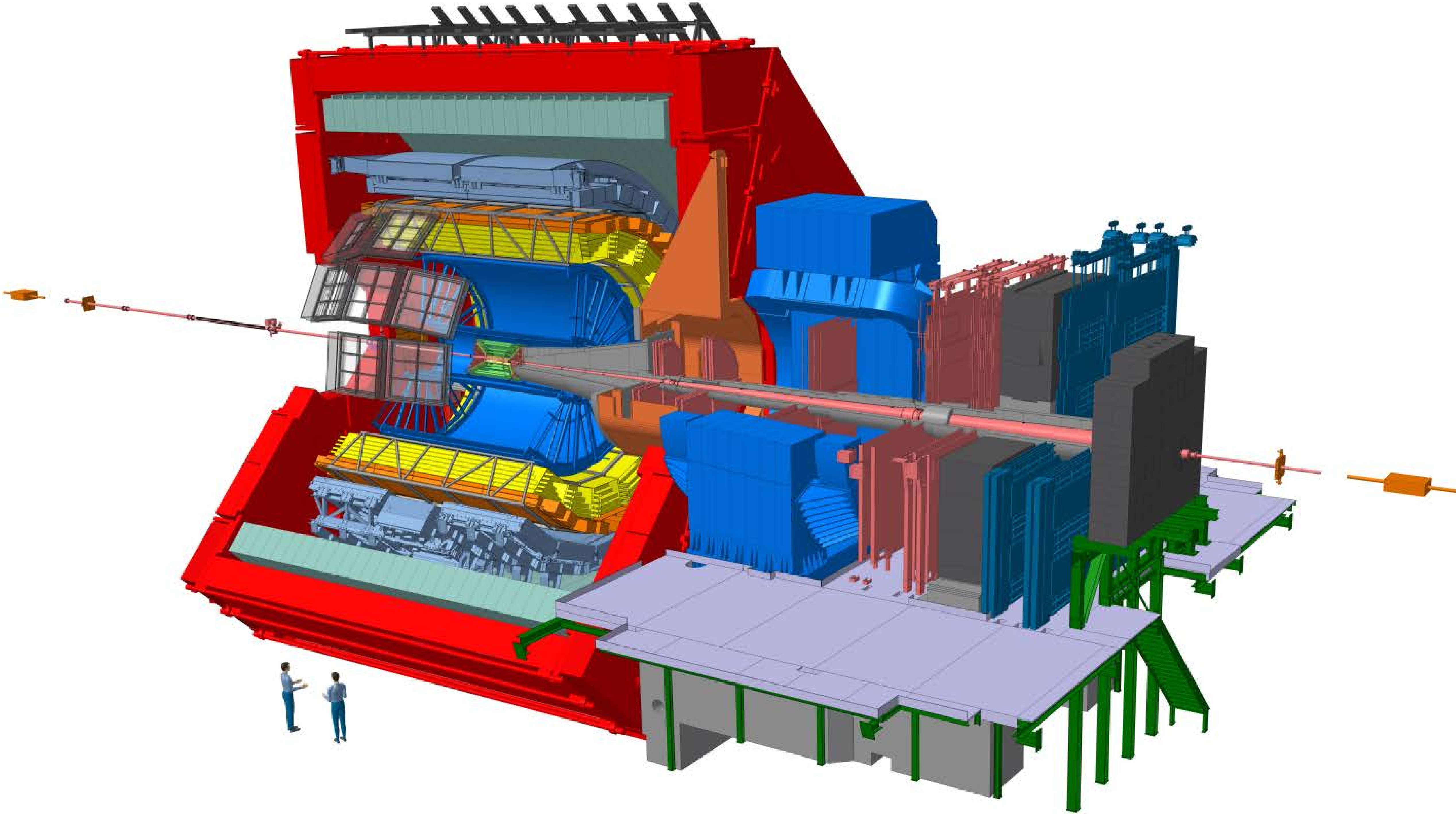
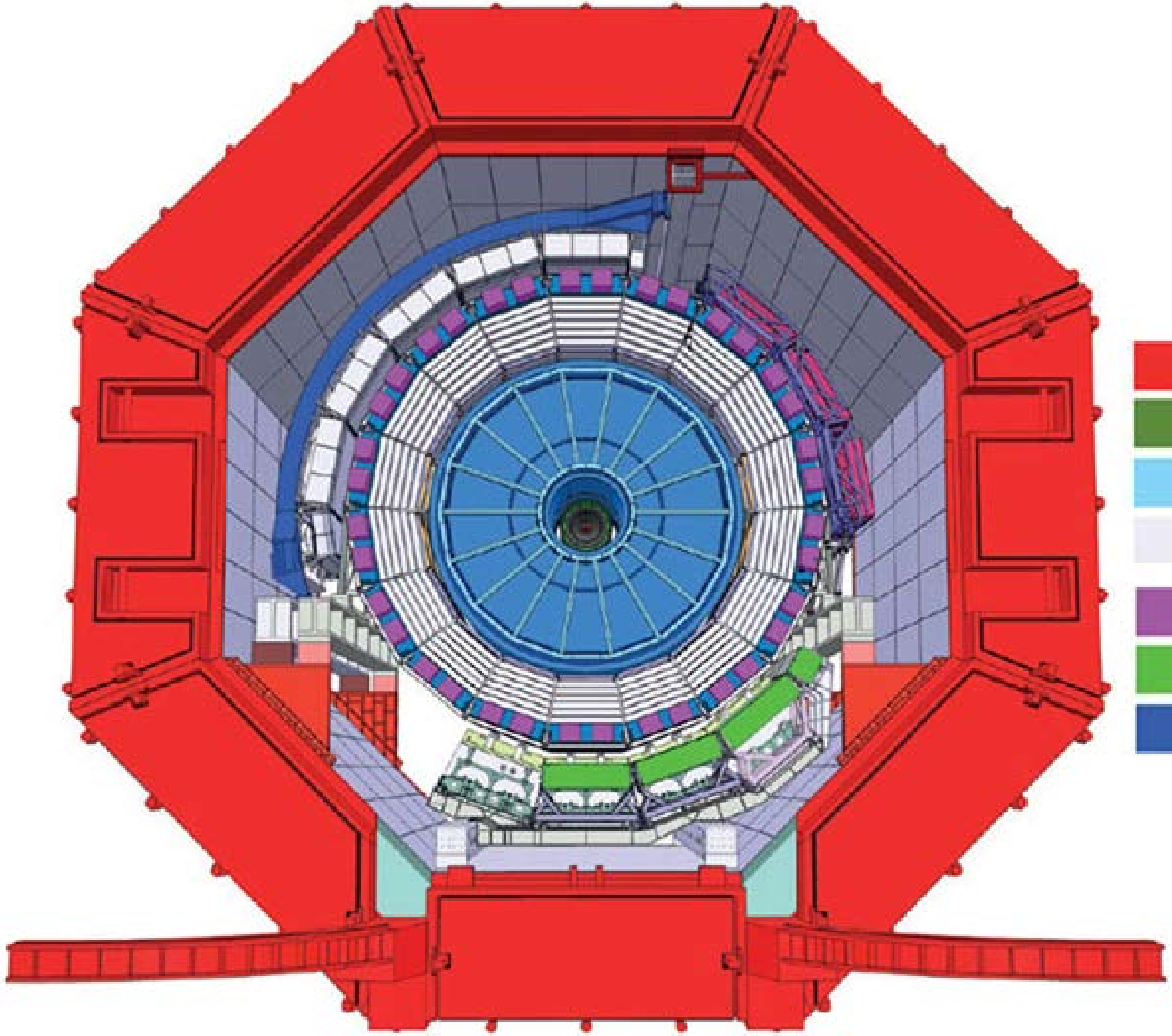
Overview of ALICE results on hard probes of the quark-gluon plasma

Miguel Arratia

7Th International Conference on HEP in the LHC era, Valparaiso, Chile.





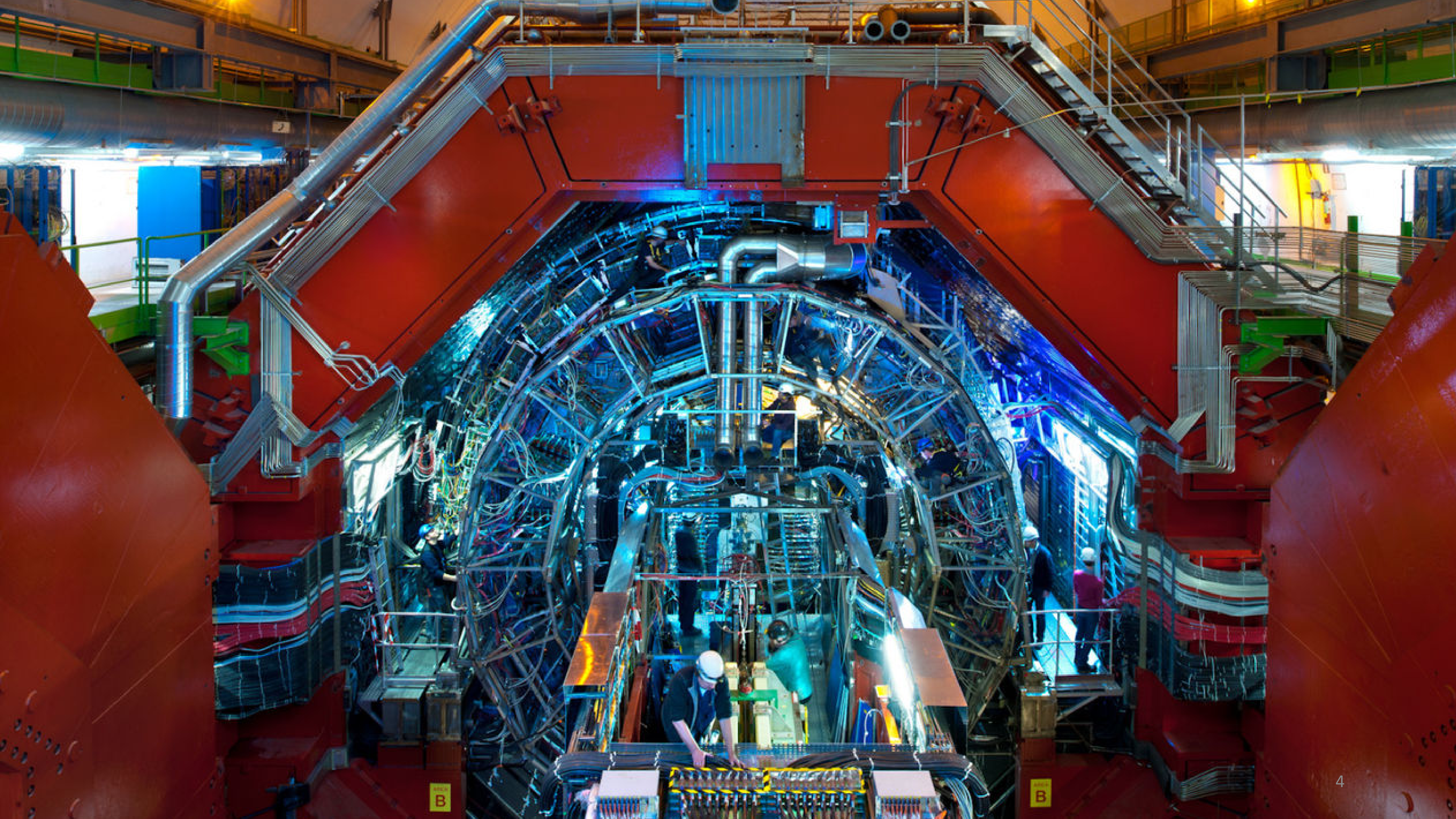
$$B = 0.5\ T$$

solenoid magnet (surrounds)
ITS (small ring, centre)
TPC ("spoked wheel")
TRD ("stripes")
TOF
DCAL
EMCAL

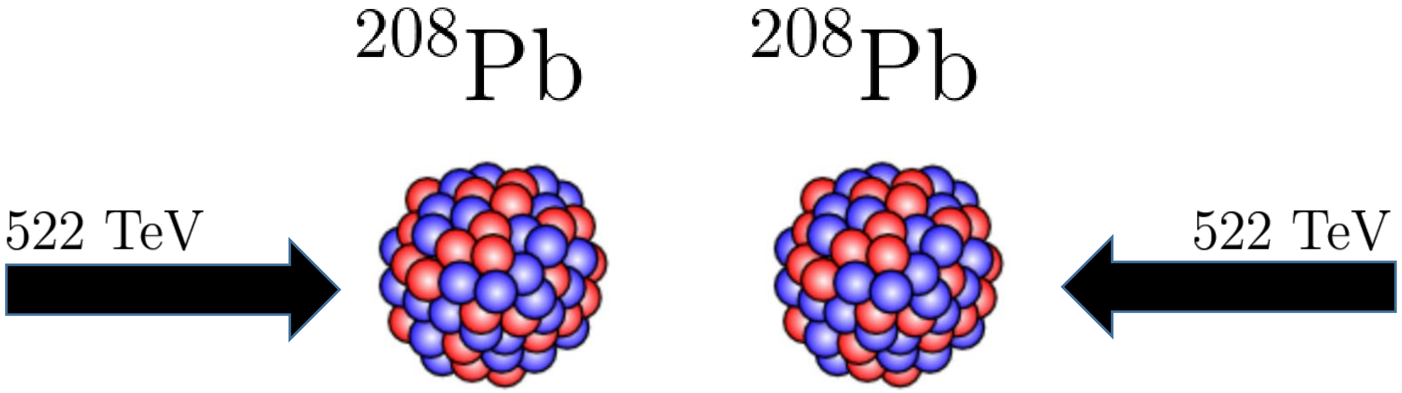
tracking

Particle ID

calorimetry


B
B

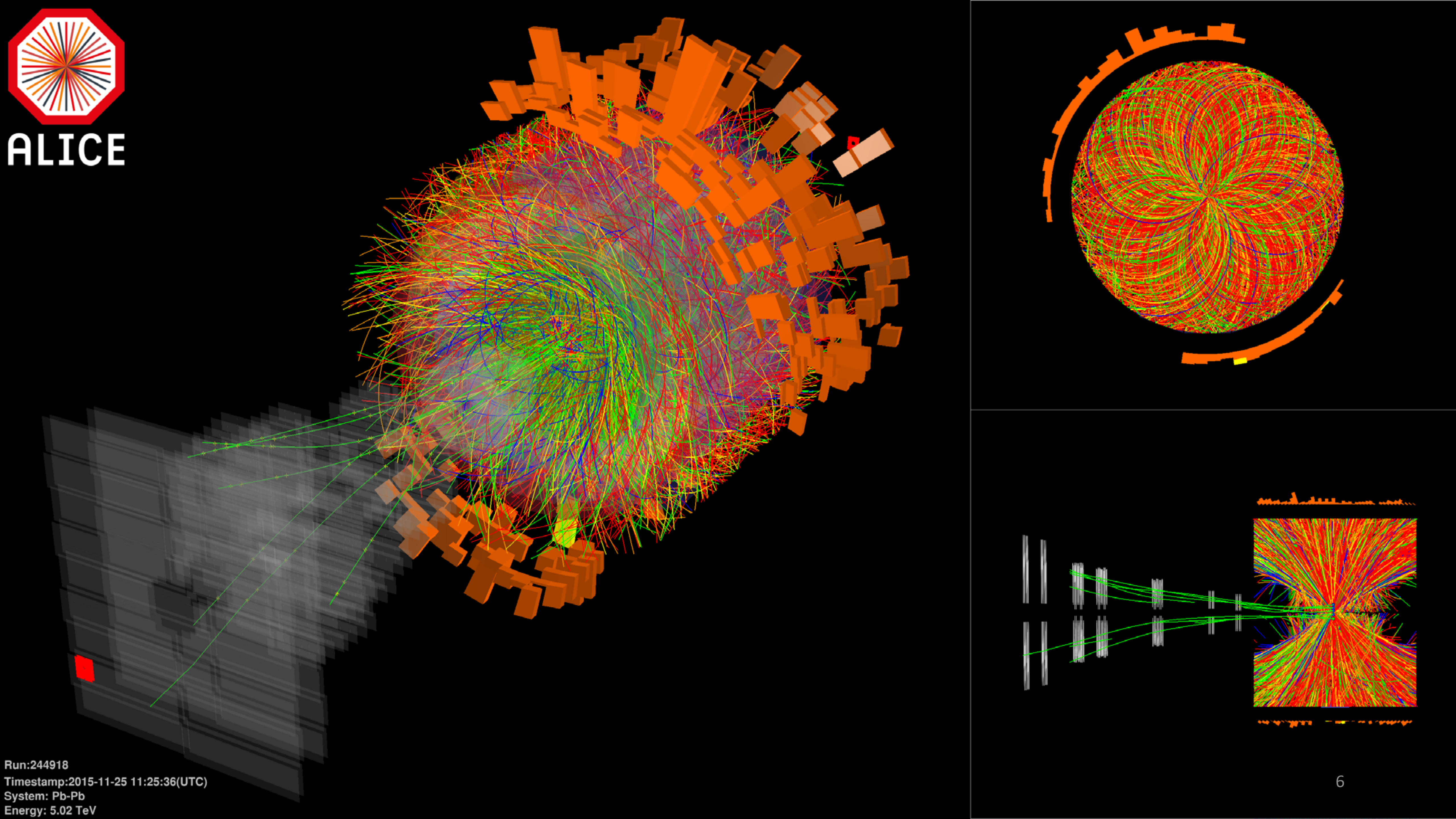
Nuclear collisions at the LHC



Average CM energy of pairs of colliding nucleons $\sqrt{s_{NN}} = 5\ \mathrm{TeV}$

We study collisions with many colliding nuclei that form matter with

$$T = O(100)\ \mathrm{MeV} = O(10^{12})K$$


ALICE
Run:244918
Timestamp:2015-11-25 11:25:36(UTC)
System: Pb-Pb
Energy: 5.02 TeV

Exploration of hot nuclear matter

- The quark-gluon plasma is a strongly-interacting system. We want to explore emergent phenomena
- We use high-Q^2 processes as natural probes

$$\frac{1}{Q} << \mathrm{QGP\ formation\ time} \sim O(1)\mathrm{fm}$$

Heavy quarks

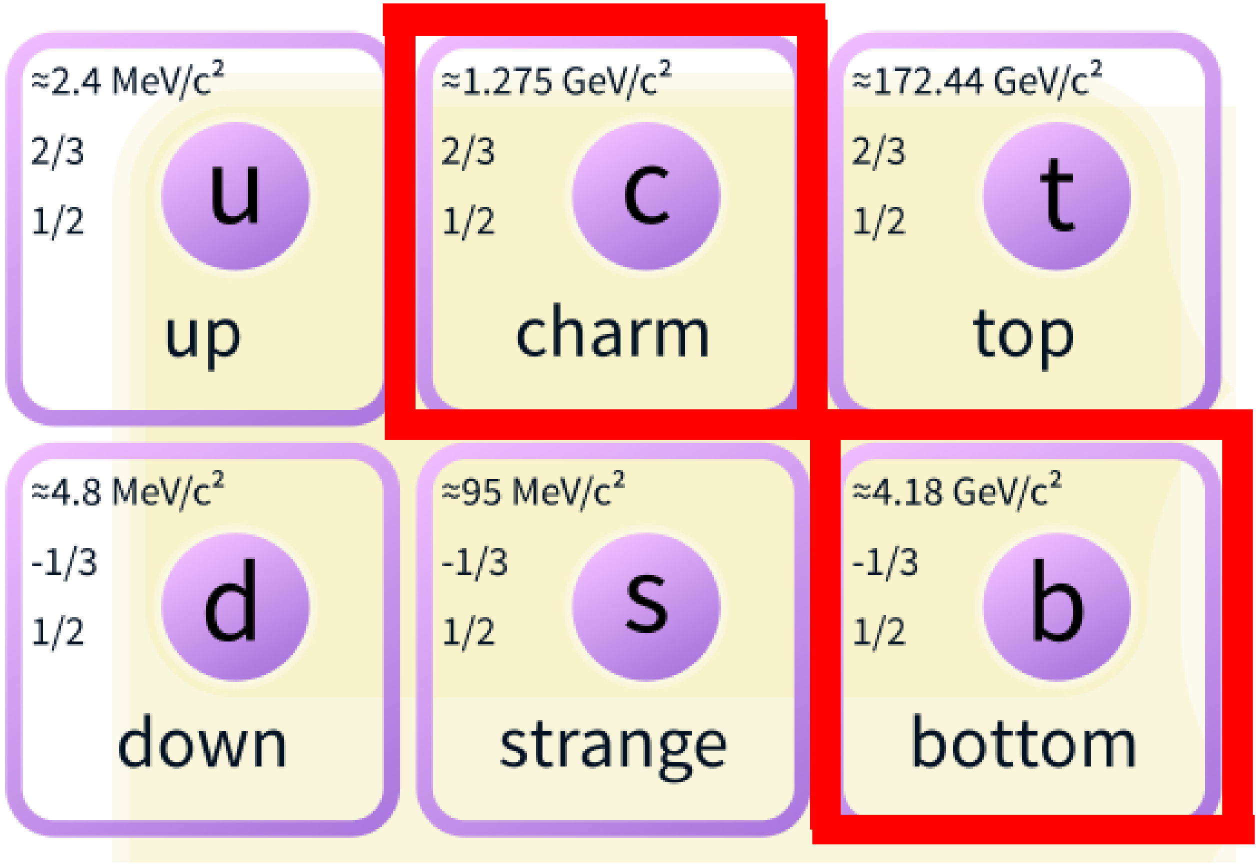
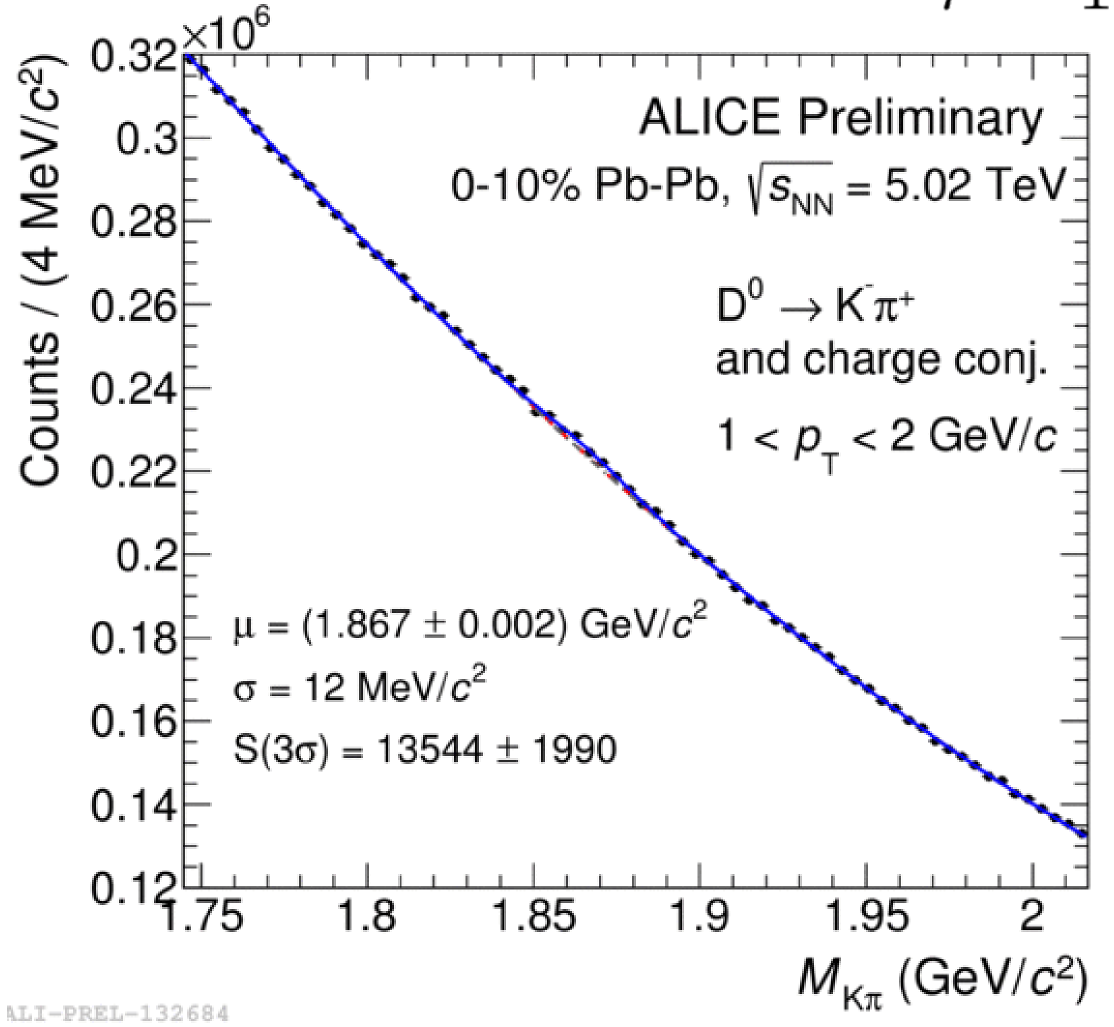


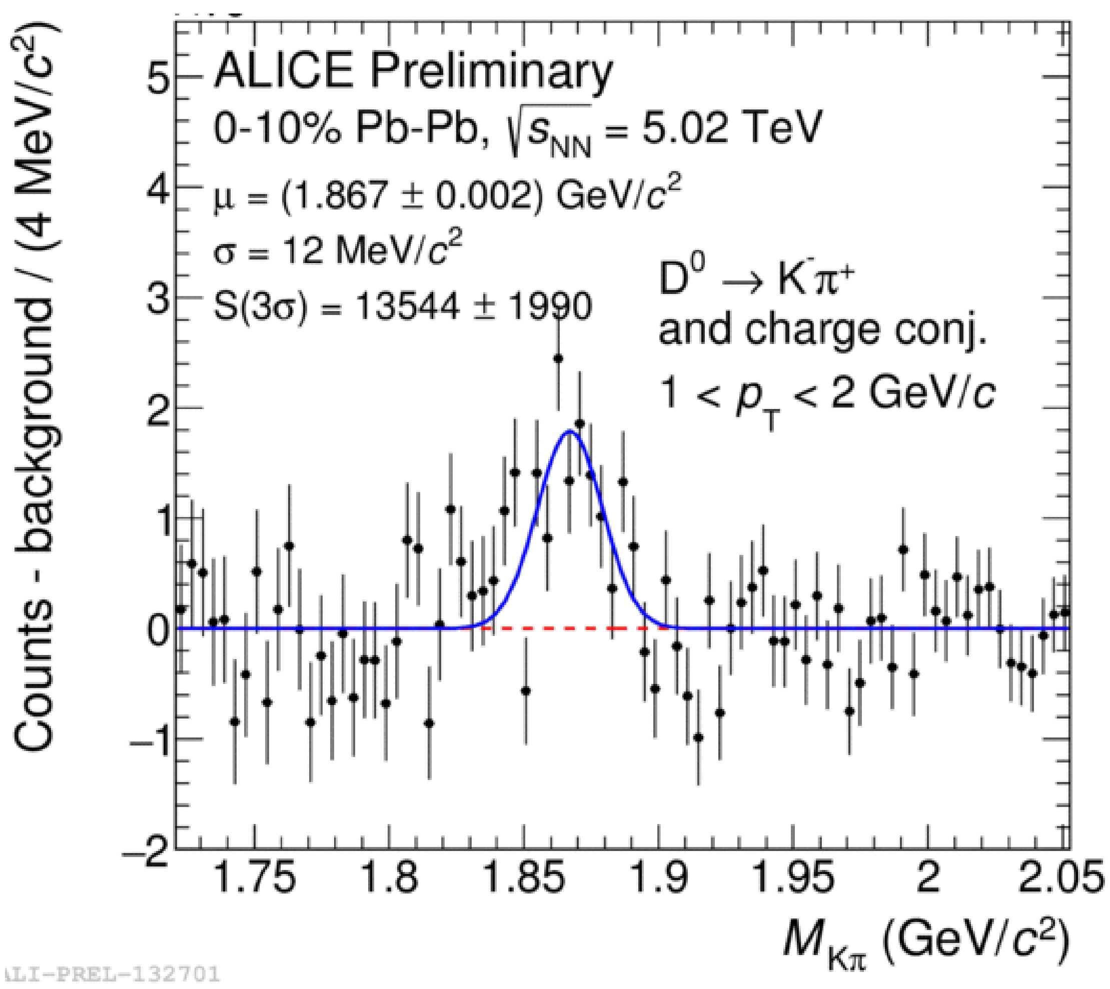
Figure from [1]

- We want to study their transport through the quark-gluon plasma

$$D^0 \to K\pi$$

$$\tau = 123\ \mu m$$

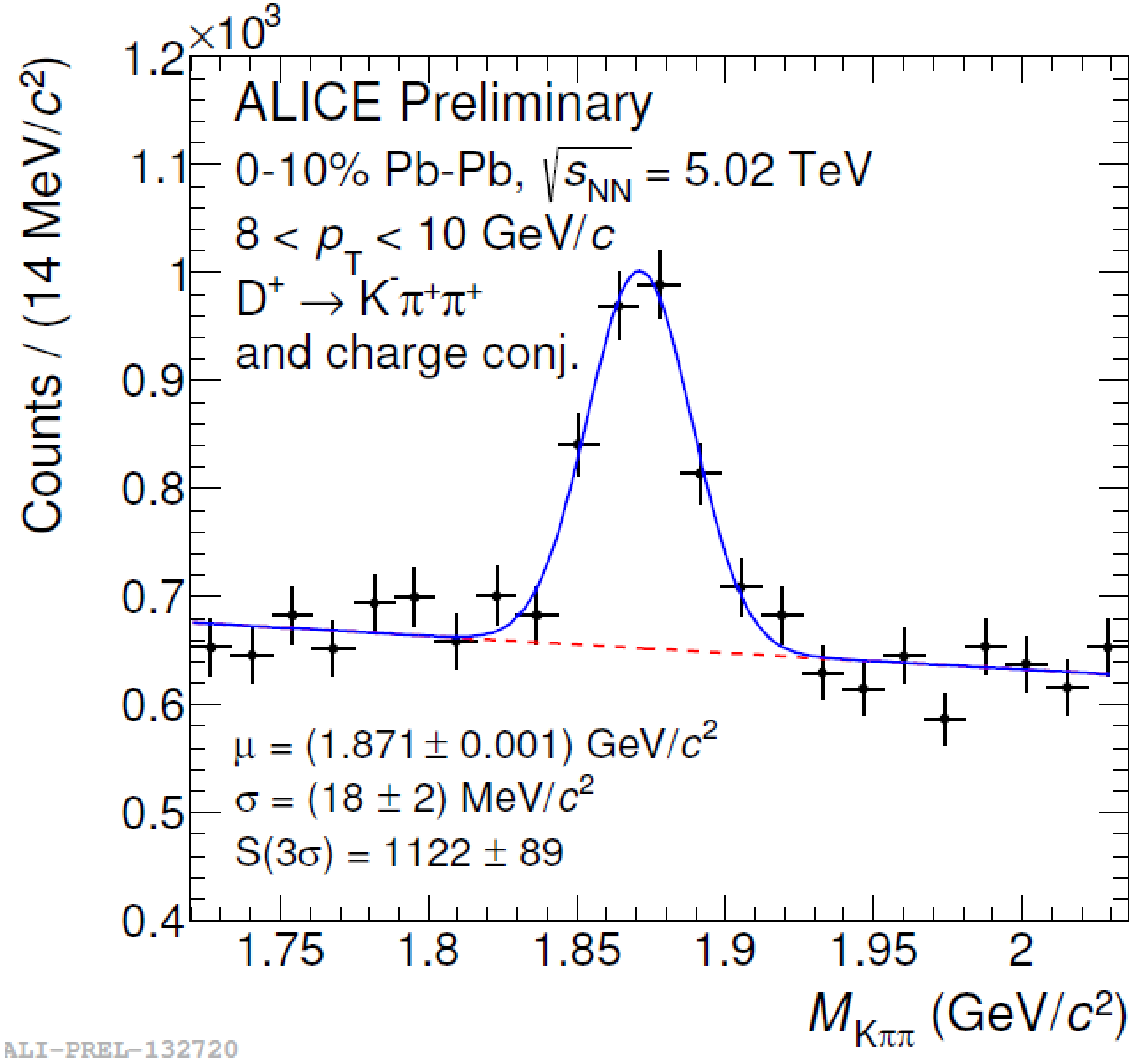




Low p_T D-mesons are our best proxies for stationary c-quarks

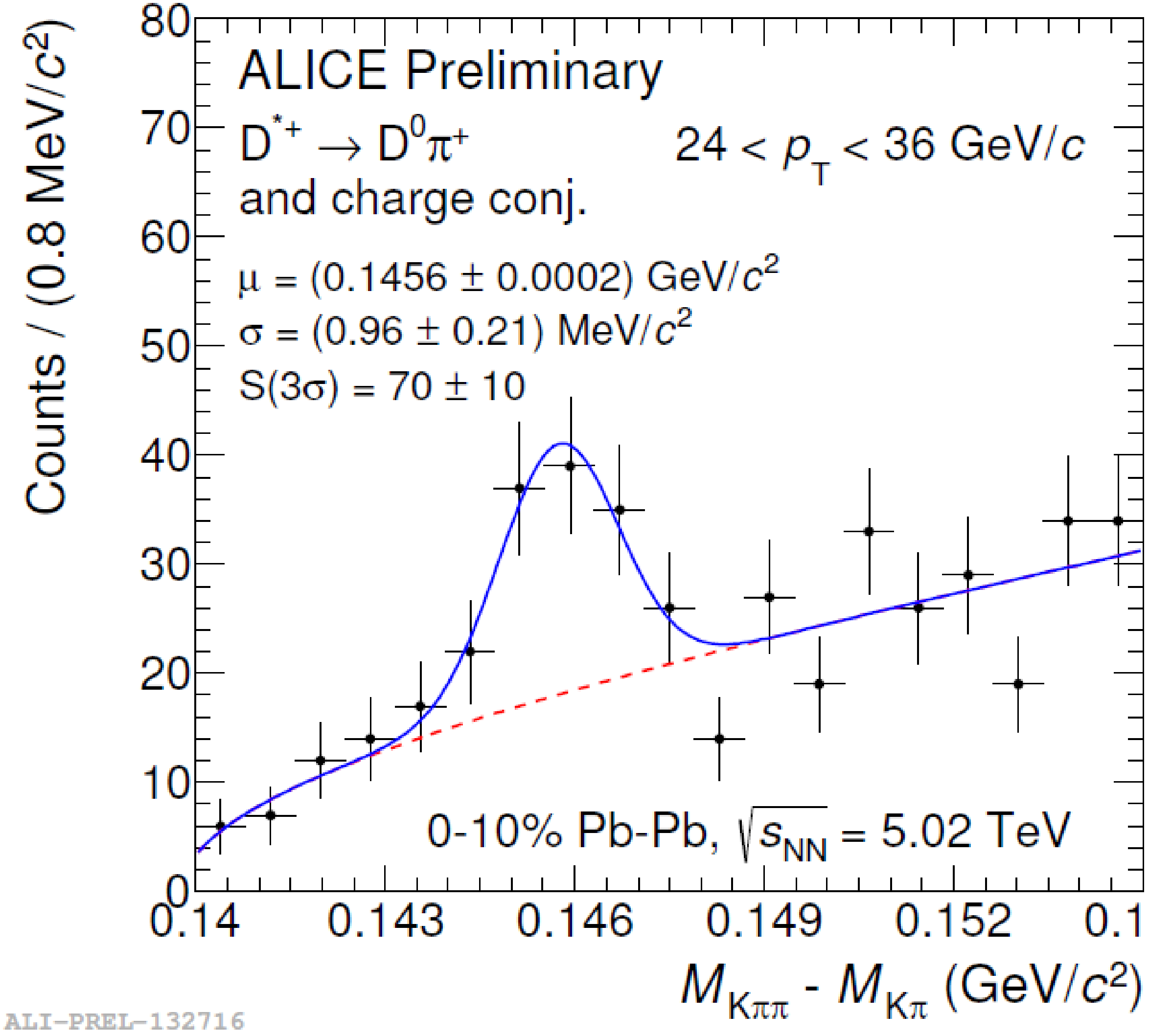
$\tau = 312\ \mu m$

$$D^+ \to K^-\pi^+\pi^+$$



$\tau = 123\ \mu m$

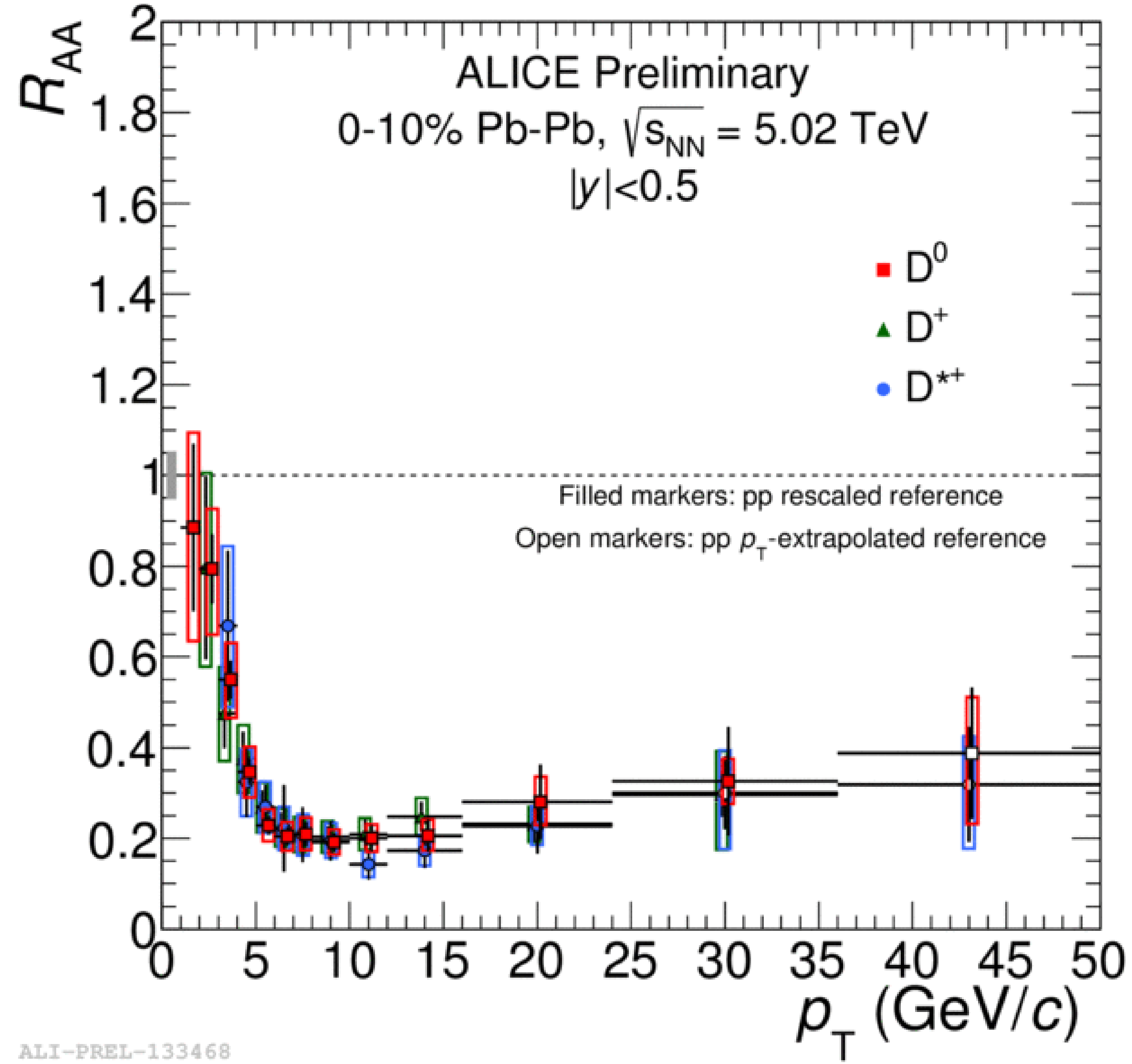
$$D^{*+} \to D^0\pi^+$$



Nuclear modification factor

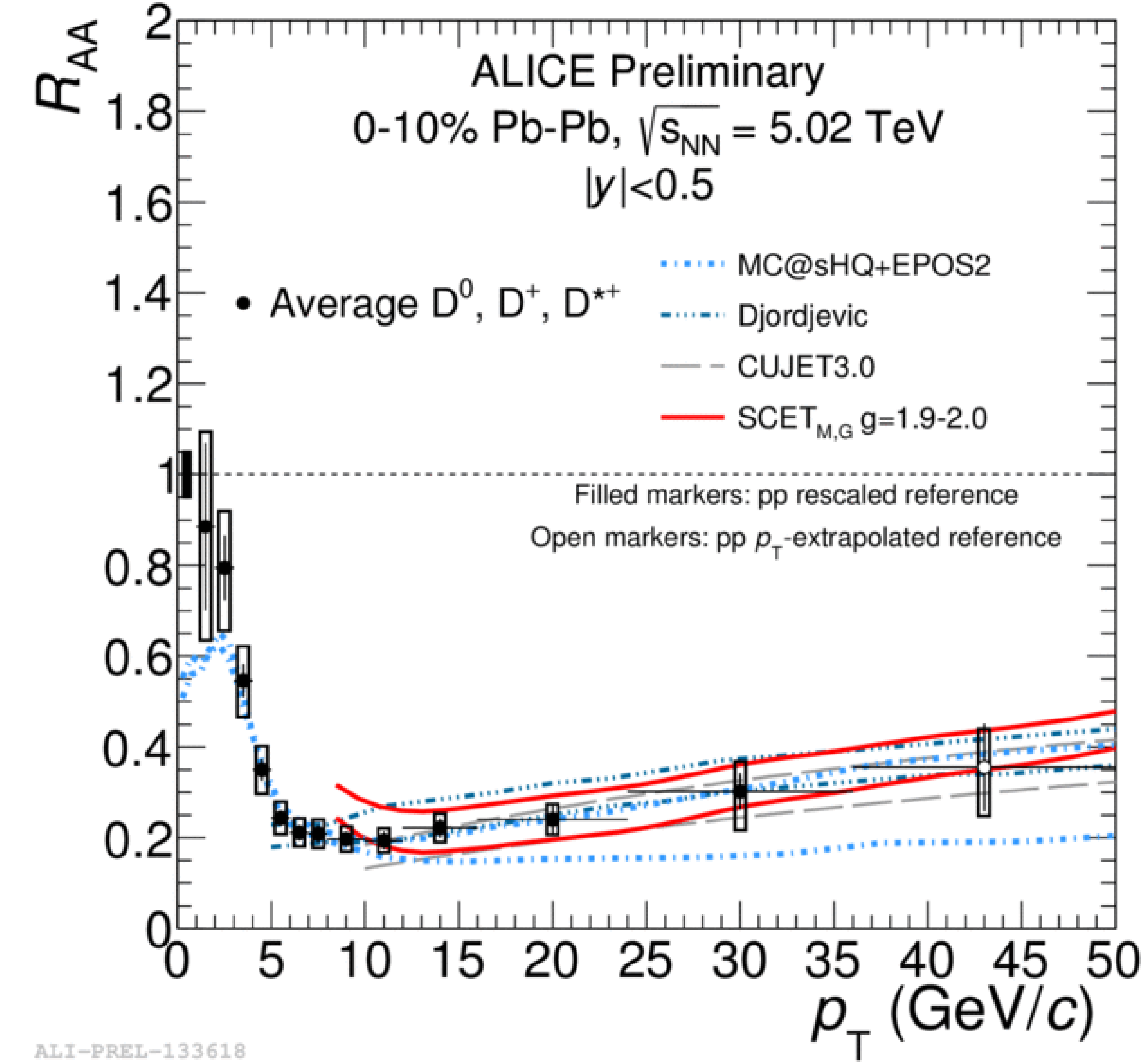
$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{< T_{\mathrm{AA}} > \mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

- $R = 1$ means that nuclear collisions are a trivial superposition of pp collisions

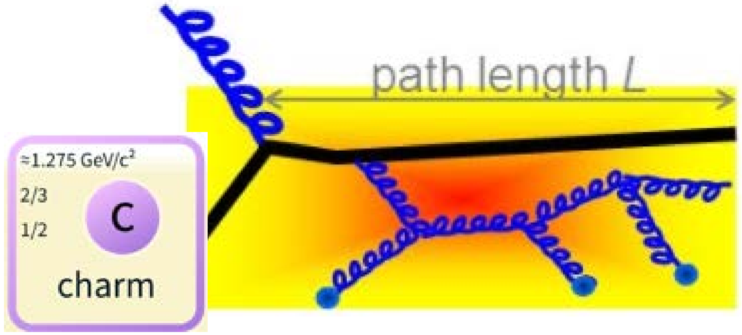


Same suppression pattern for all species

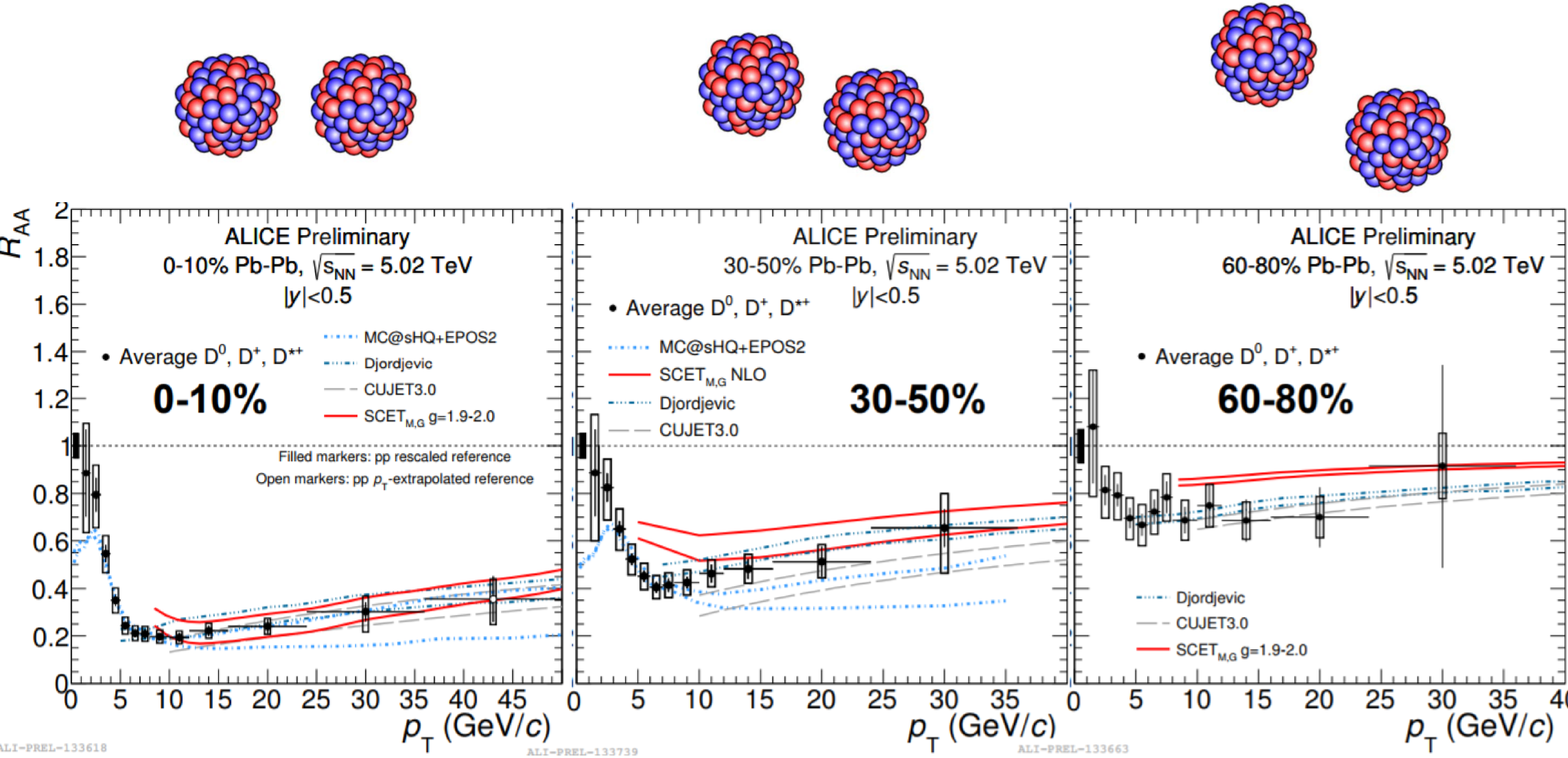
Strong p_T trend at low p_T
Mild increase at high p_T



Models with radiative energy loss match data at high p_T



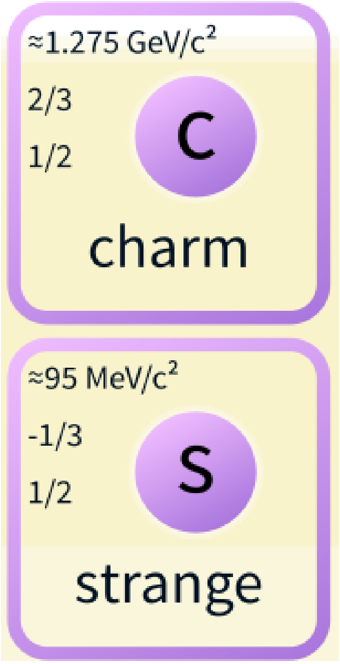
Nahrgang et al. [2], Djordjevic et al.[3], Xu et al. [4], Kang et al.[5]

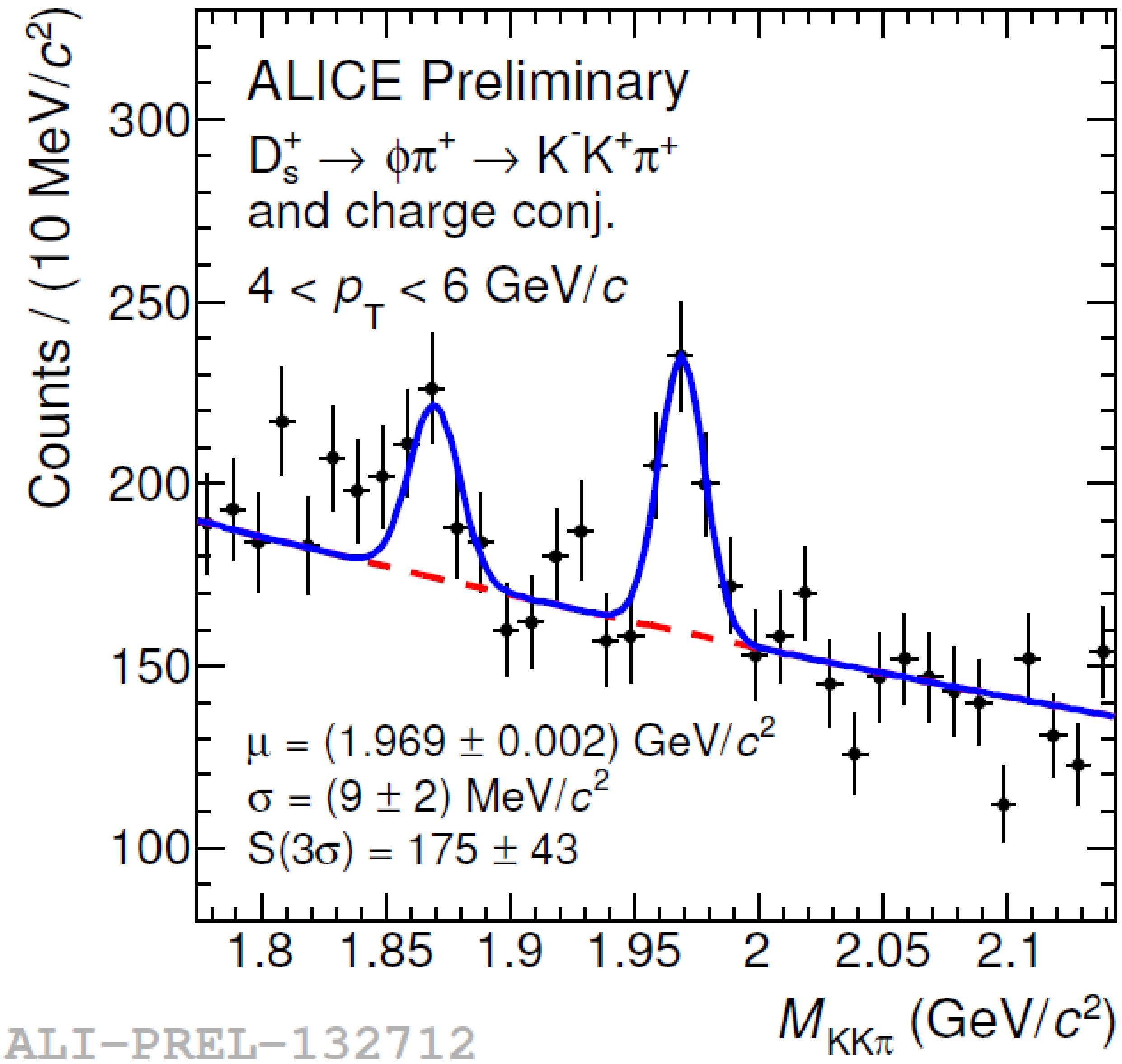


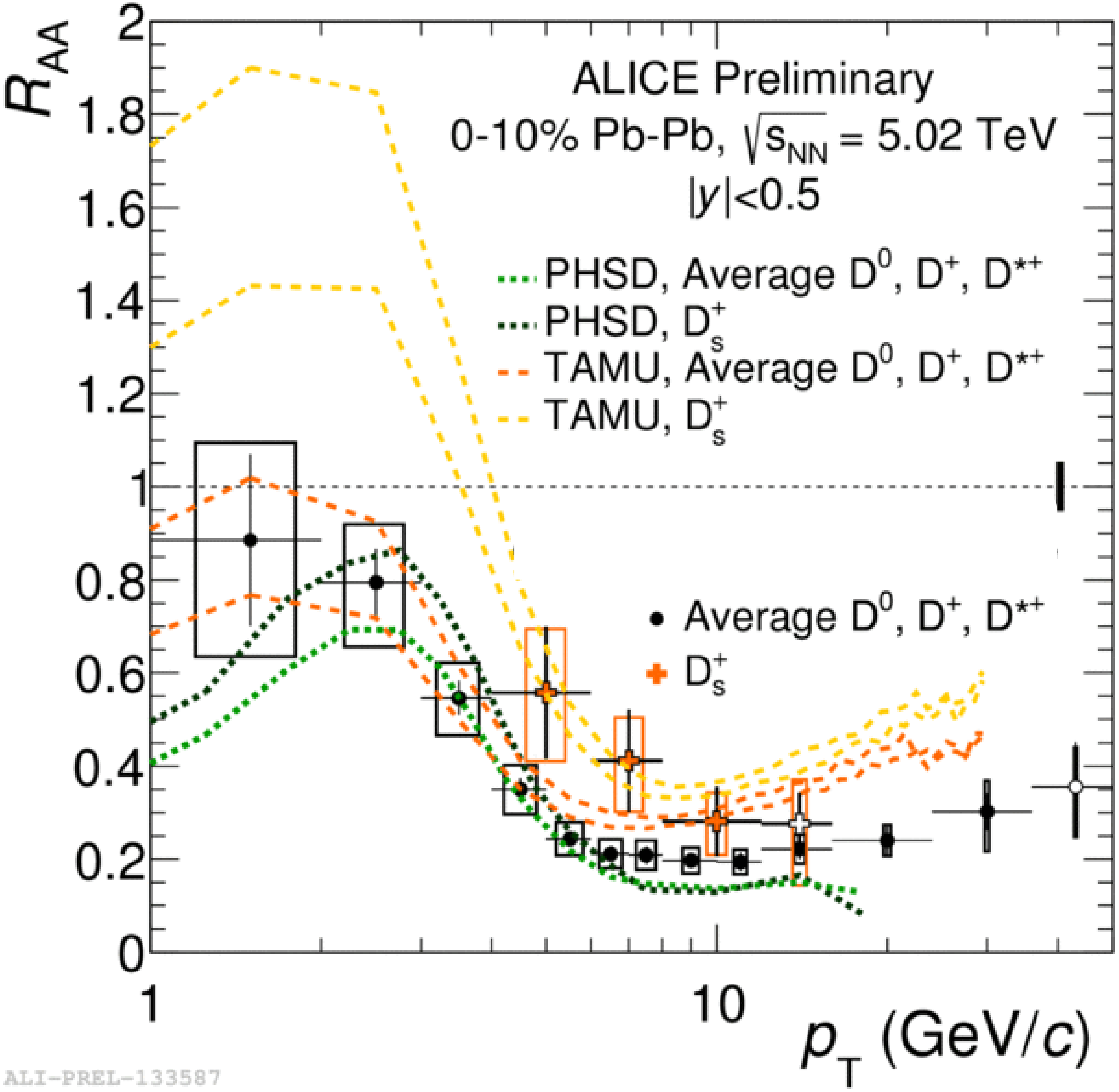
Models with radiative energy loss describe data

Nahrgang et al. [2], Djordjevic et al.[3], Xu et al. [4], Kang et al.[5]

$$D_s^* \xrightarrow{\tau\,=\,150\ \mu m} KK\pi$$



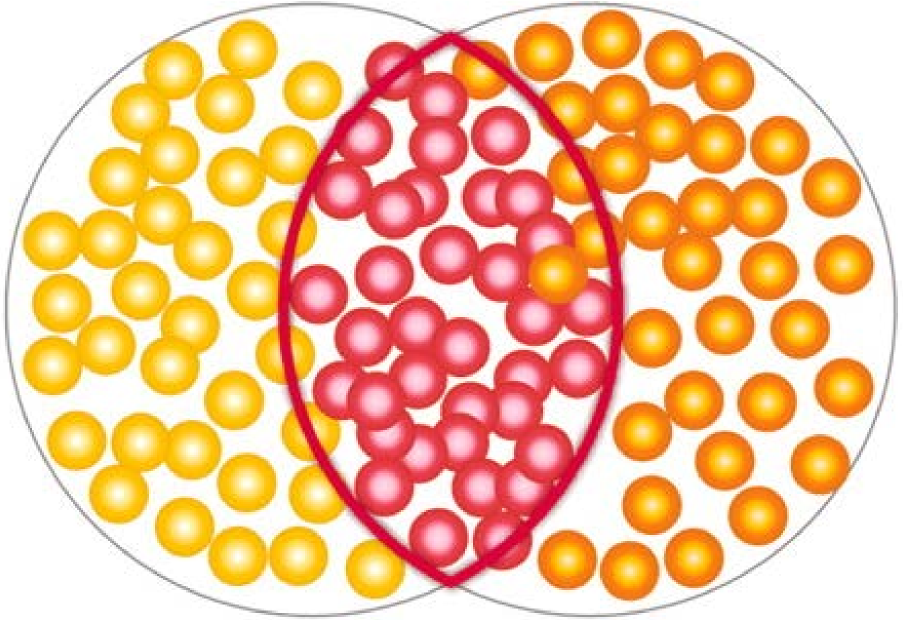




- Hint of less suppression for D_s^+
- Models that include **coalescence** of charm and strange quark predict just that

Song et al.[6], Xe et al.[7]

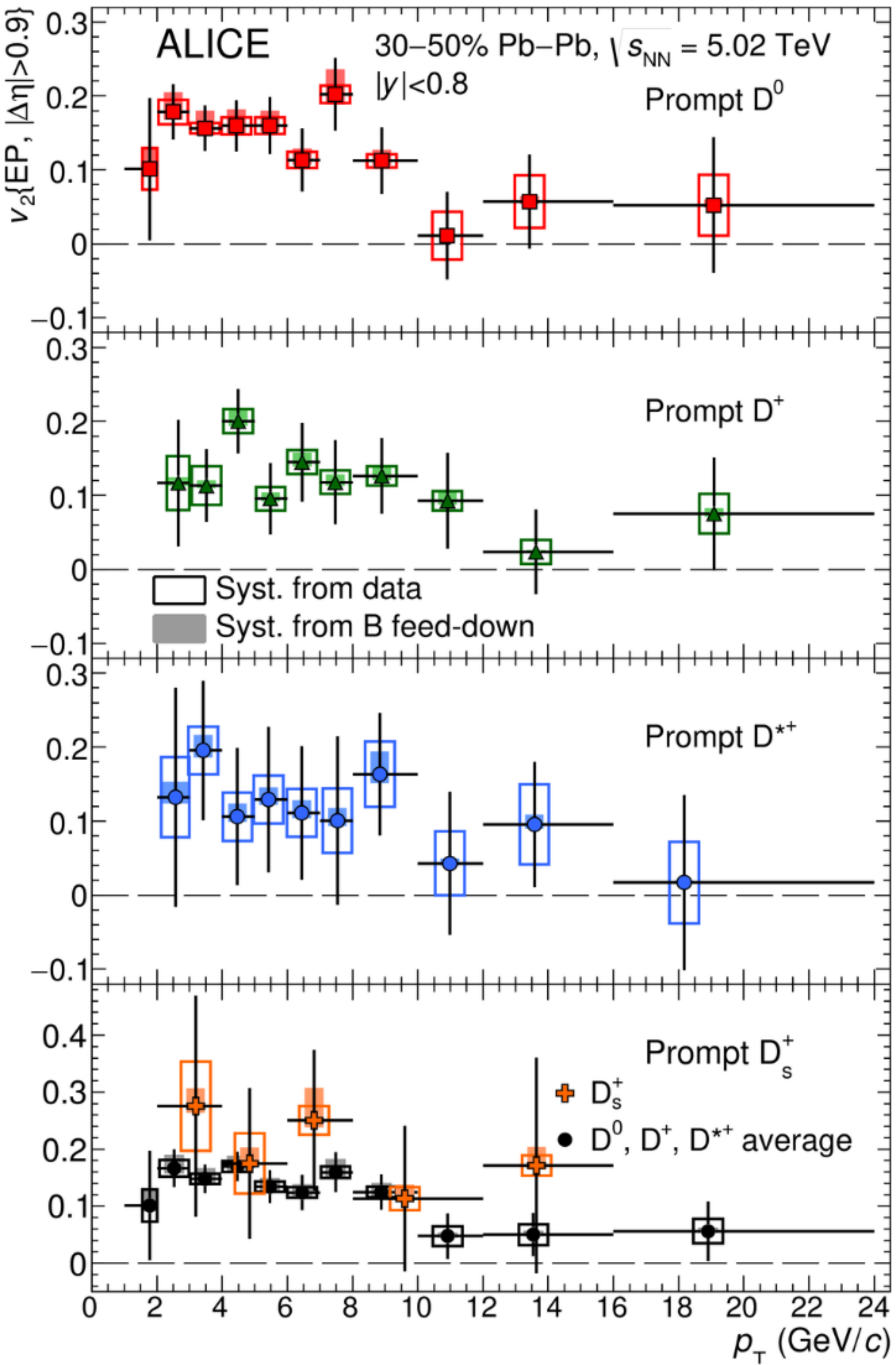
Elliptic flow in Pb-Pb collisions



- Initial anisotropy gets imprinted in particle momentum distribution after hydrodynamic expansion

- This can be studied with Fourier analysis

$$v_n = < \cos n(\varphi - \Psi_{\mathrm{RP}}) >$$

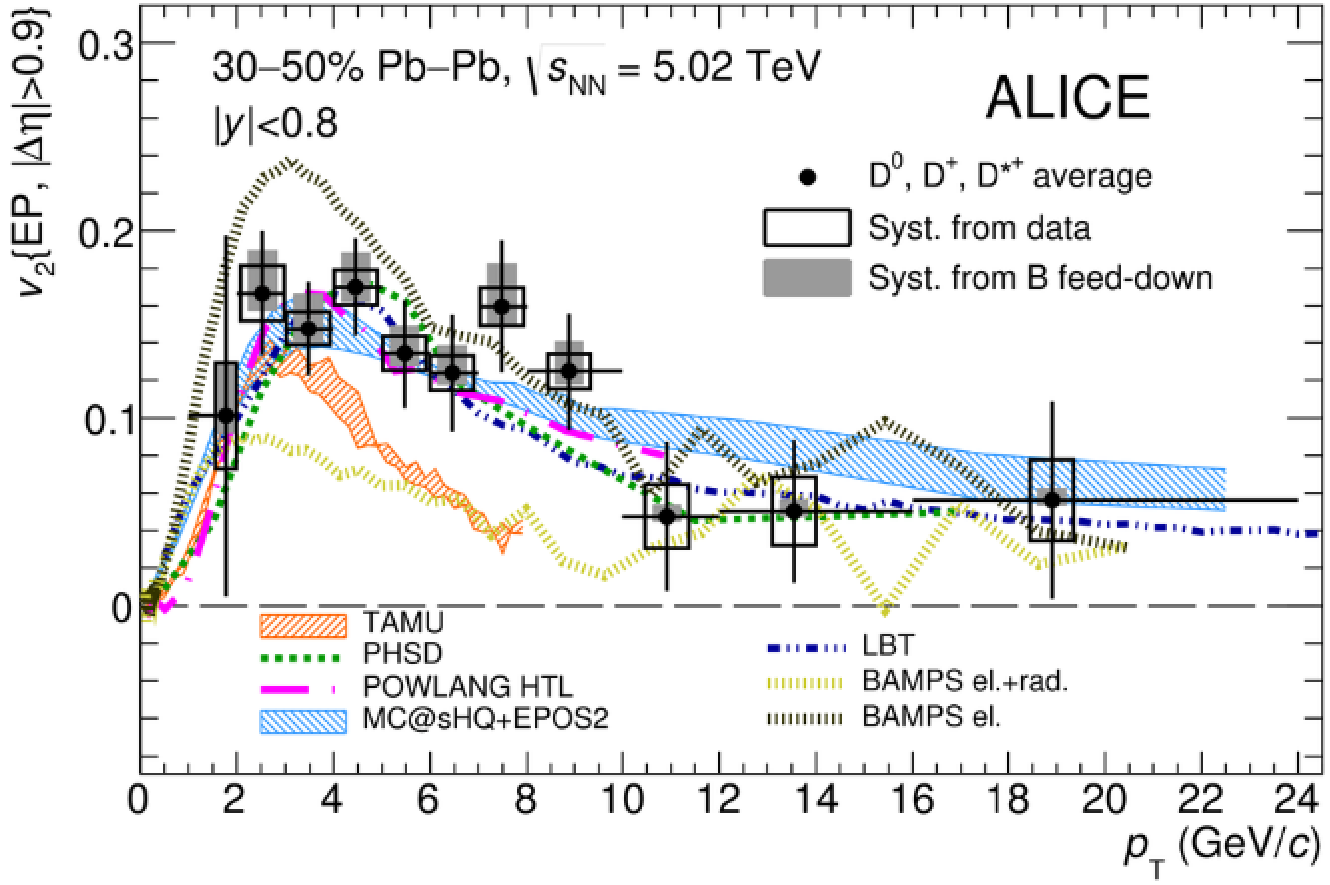


D-meson elliptic flow

arXiv:1707.01005 Submitted to: **PRL**

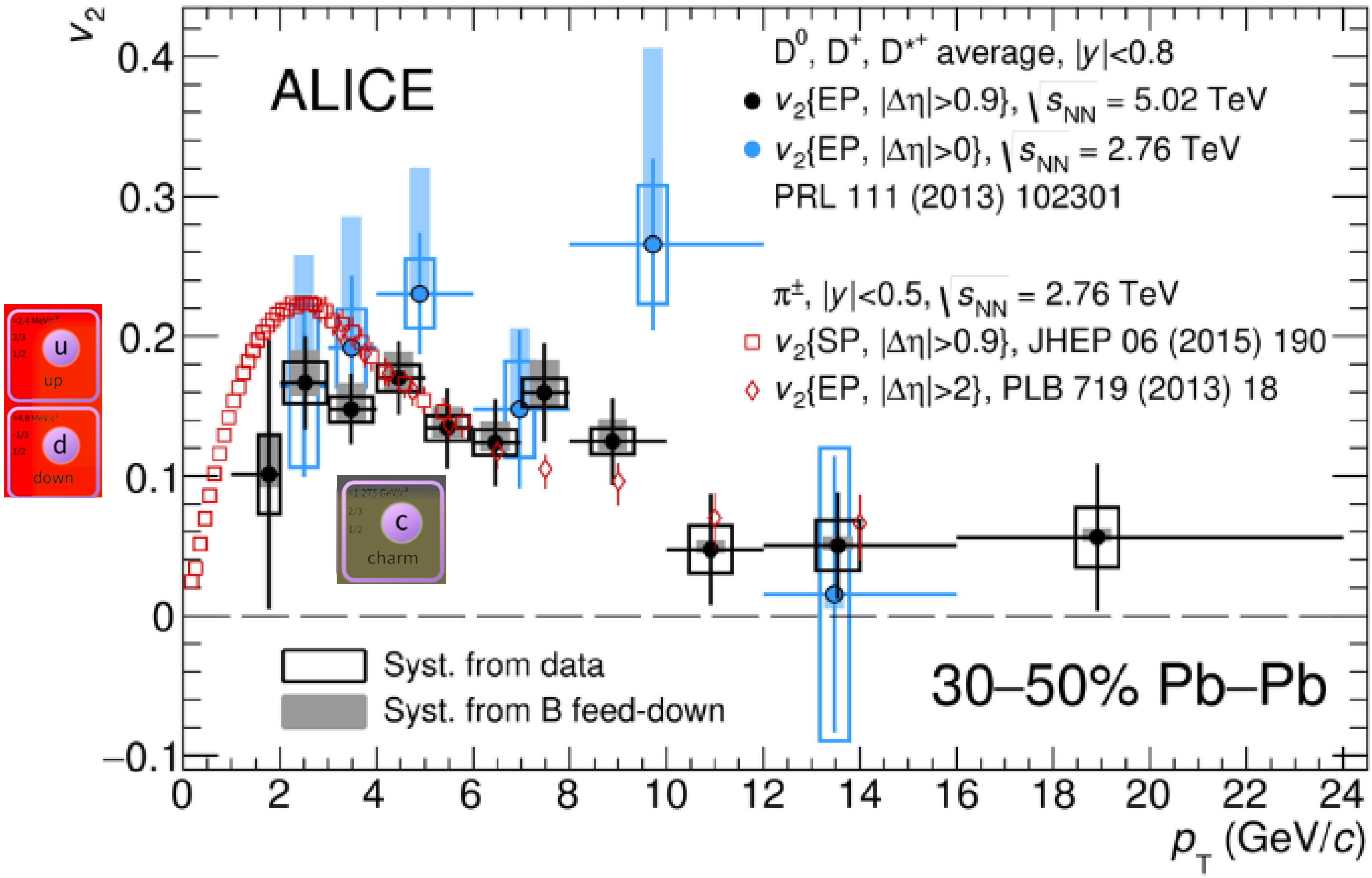
Charm-quarks take part in the hydrodynamic expansion of the quark-gluon plasma

Constraining charm-quark diffusion coefficient



$$2\pi T\, D_s(T) \approx 1.5\text{–}7 \text{ at the critical temperature } T_c$$

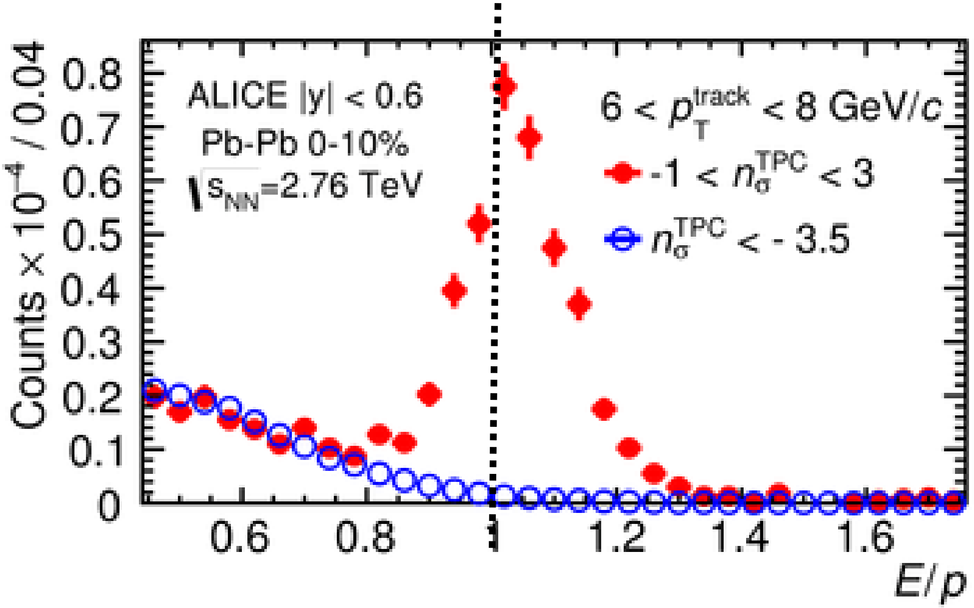
Comparison with light quarks (pions)

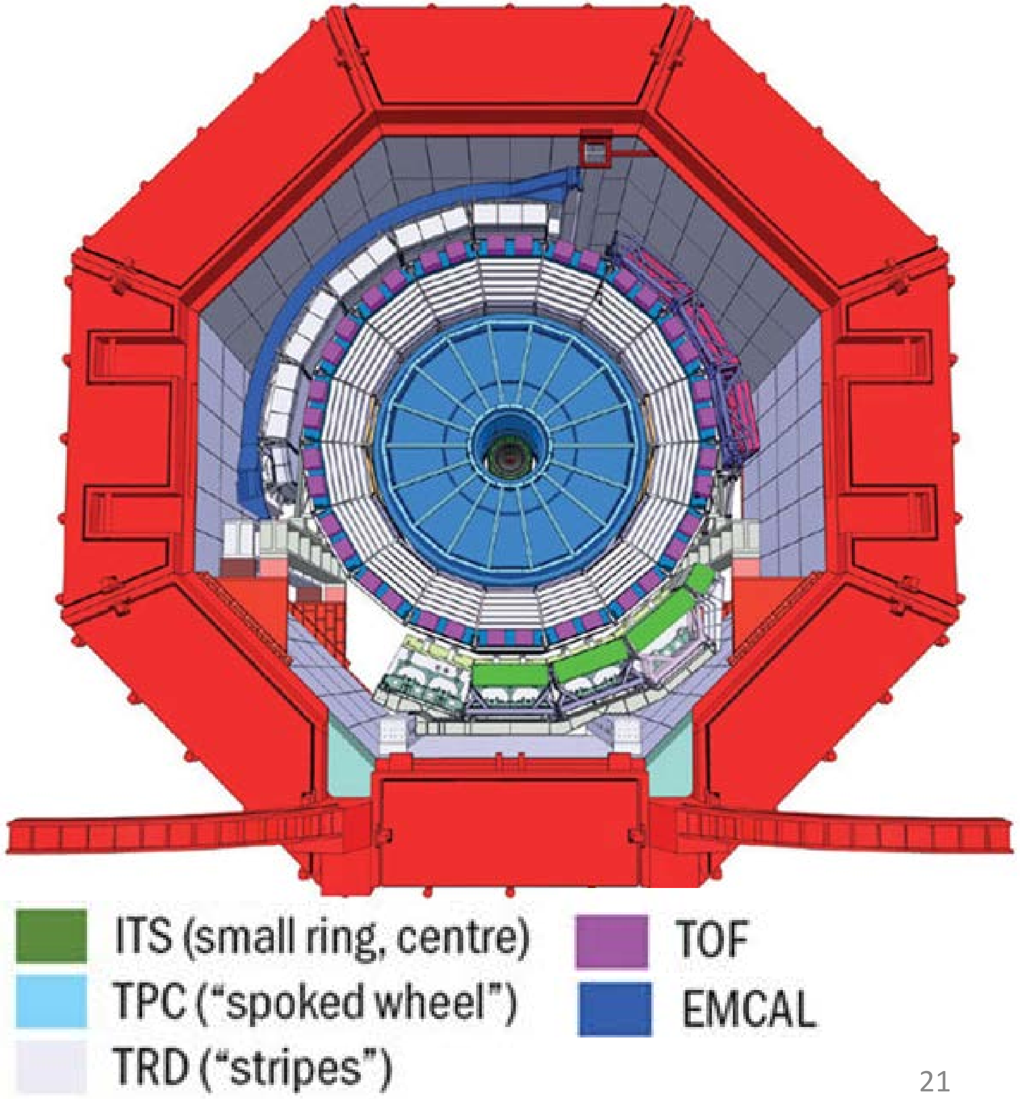


Mass ordering at low p_T, as expected from hydrodynamic calculations.

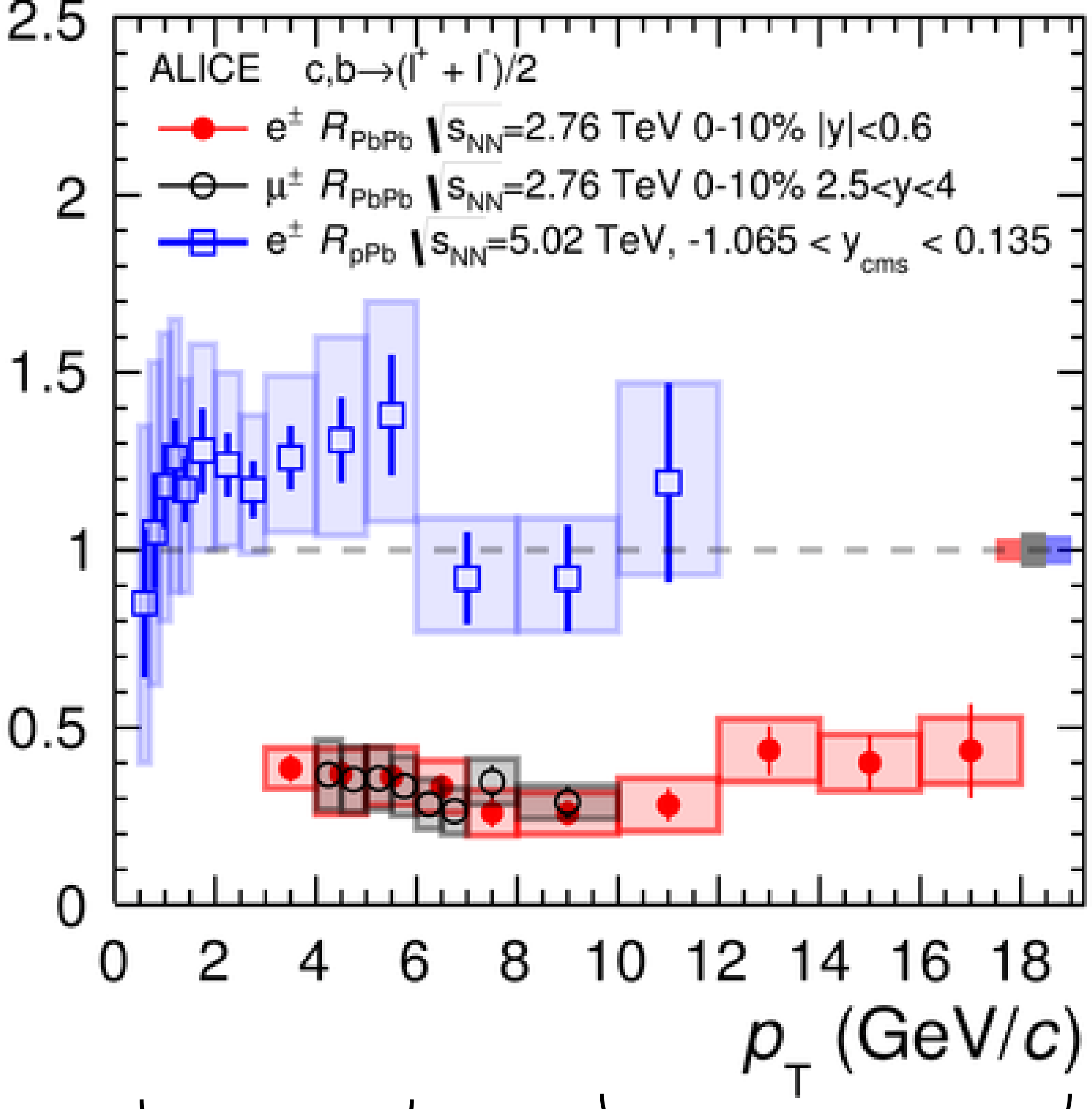
Measurement of the production of high-p_T electrons in Pb-Pb collisions at 2.76 TeV

Phys. Lett. B 771 (2017) 467-481

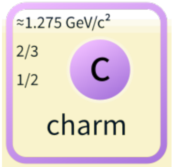




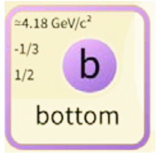
R



Mostly

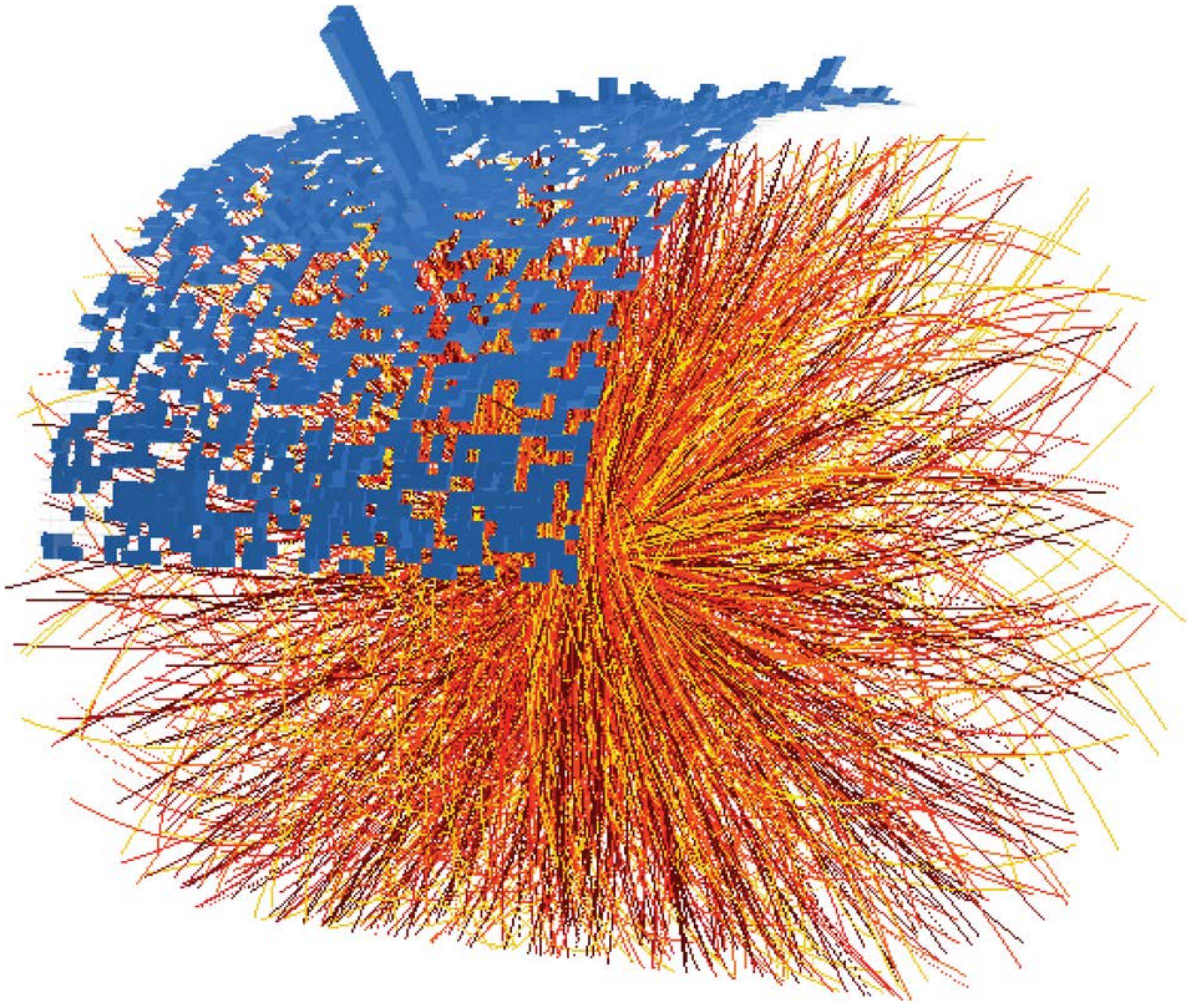


Mostly

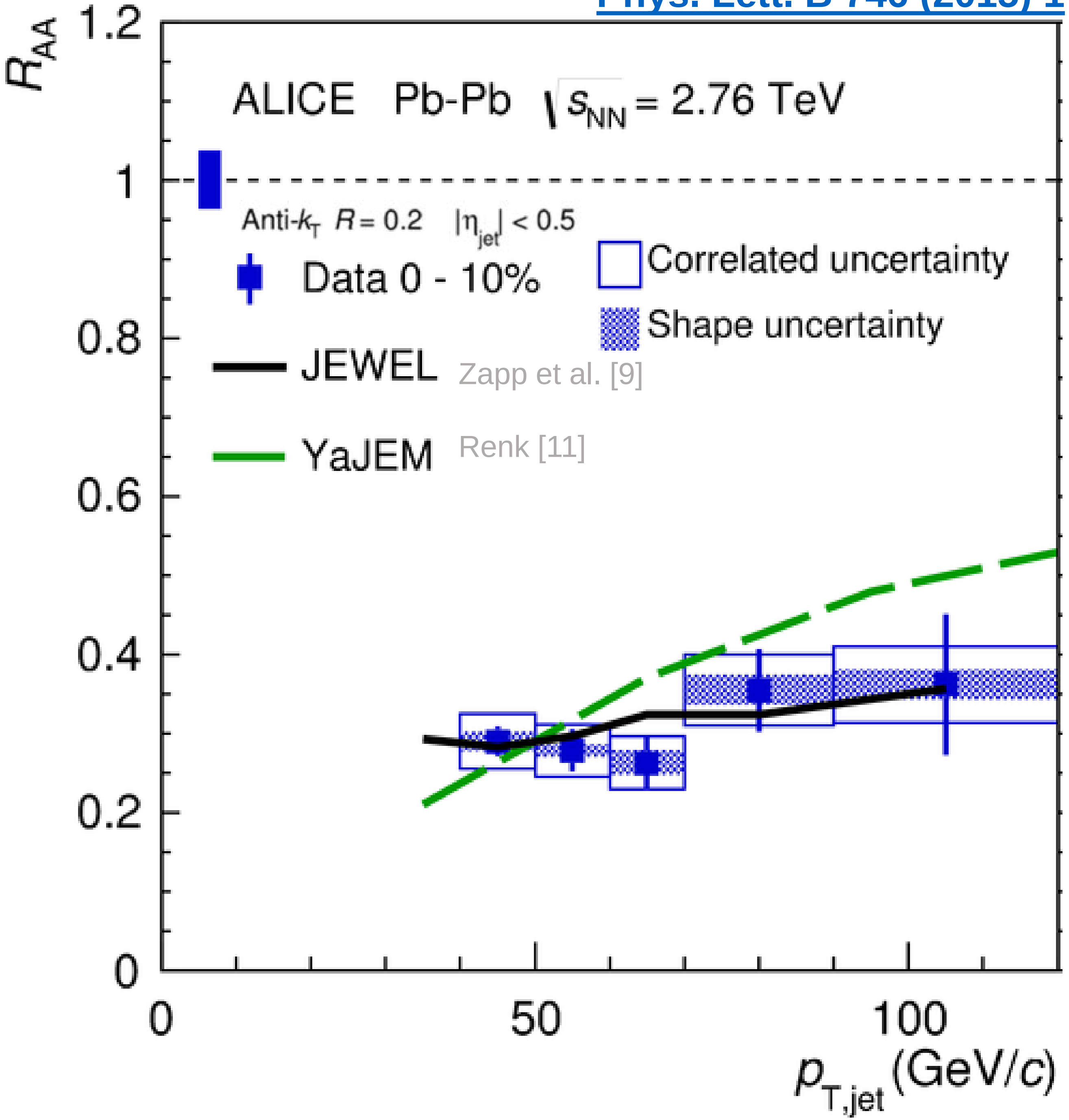


Electrons (and muons) from c and b quarks are suppressed in Pb-Pb, but not in p-Pb

A jet in ALICE



Phys. Lett. B 746 (2015) 1

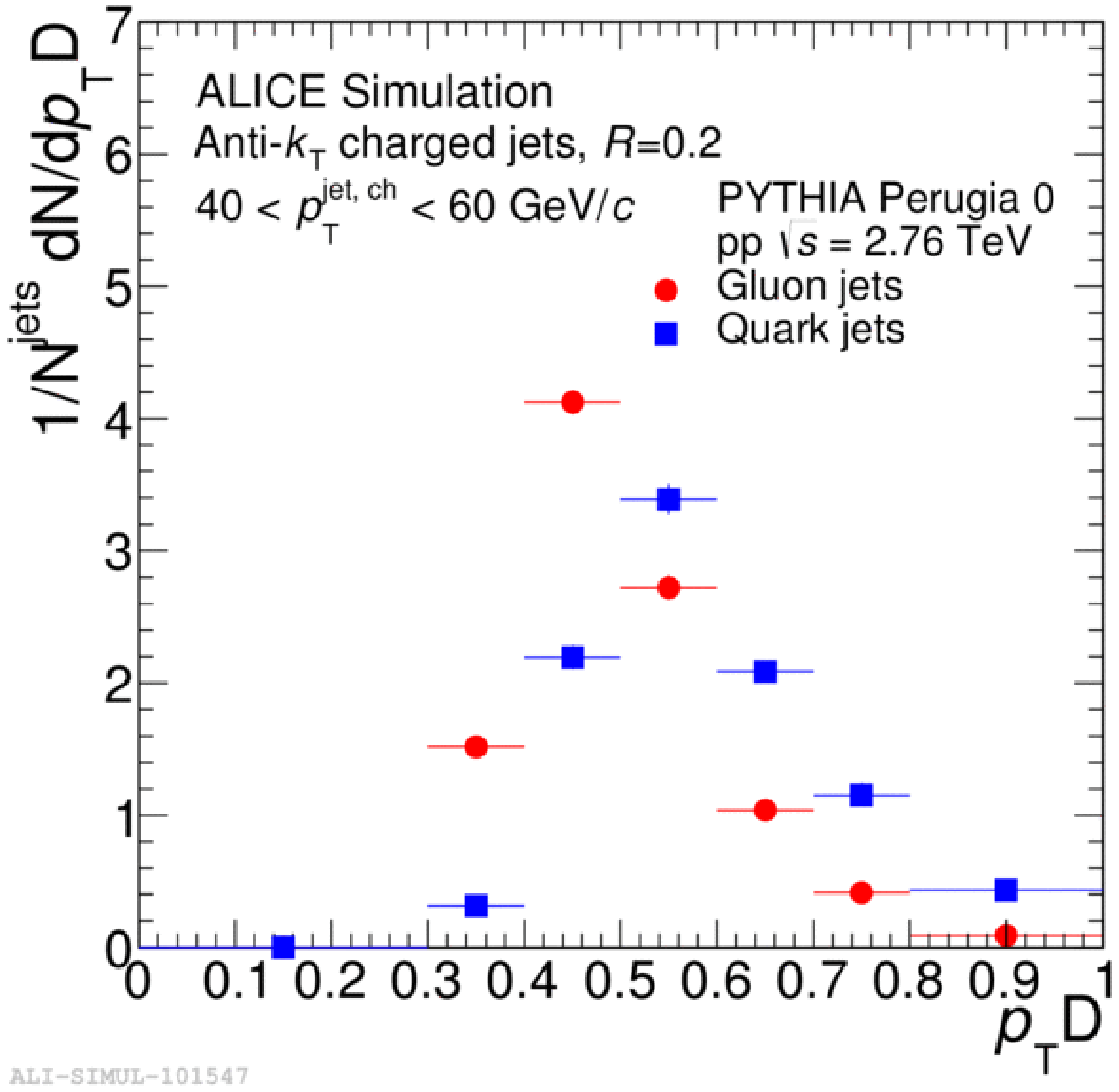


Jet suppression in central Pb-Pb collisions

- Jets are our best proxy for partons.
- Fair agreement with models with parton energy loss

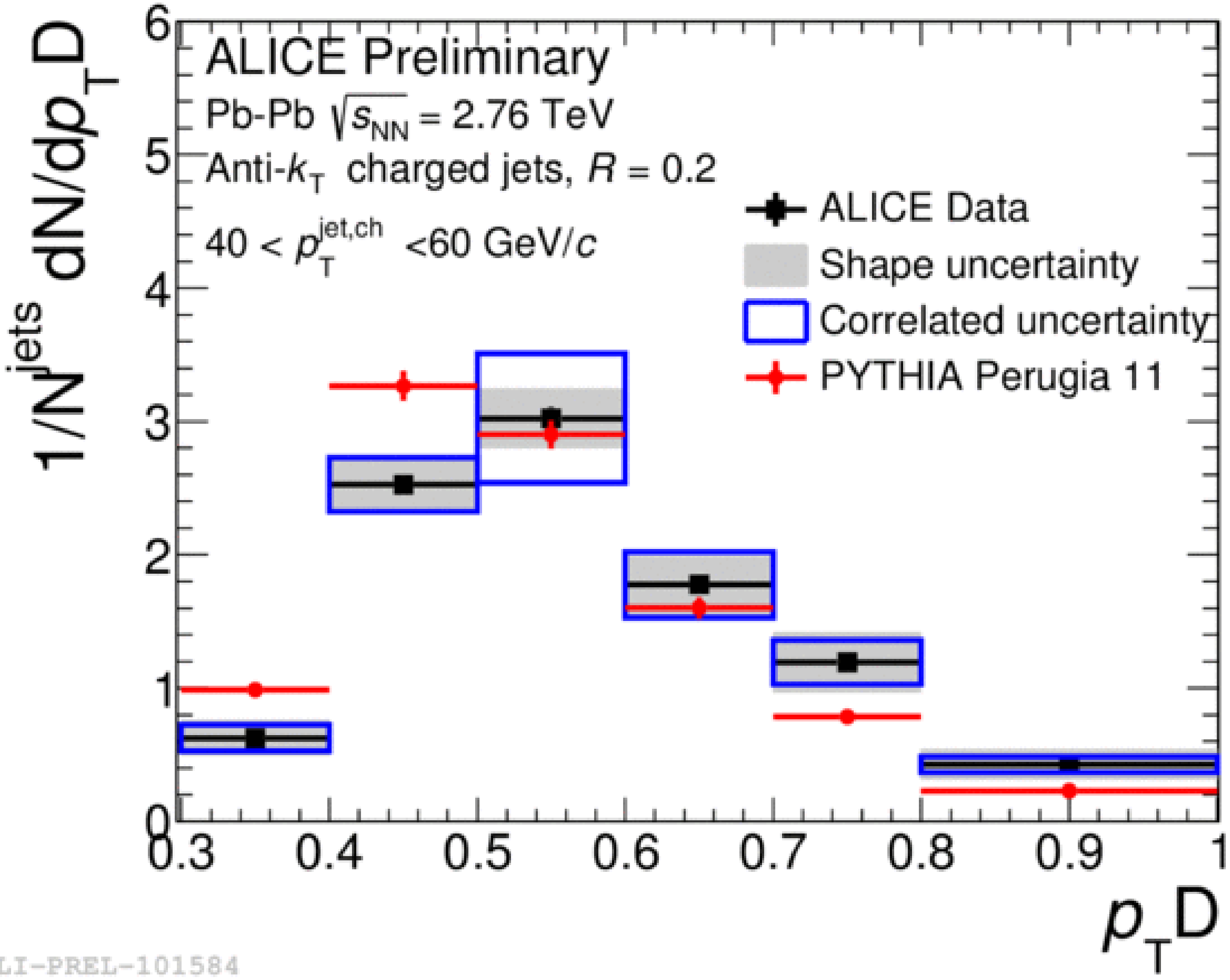
Jet dispersion

Gallicchio et al. PRL 107 (2011) 172001



$$p_T D = \frac{\sqrt{\sum_i p_{T,i}^2}}{\sum_i p_{T,i}}$$

Quark jets, having fewer constituents, have higher dispersion



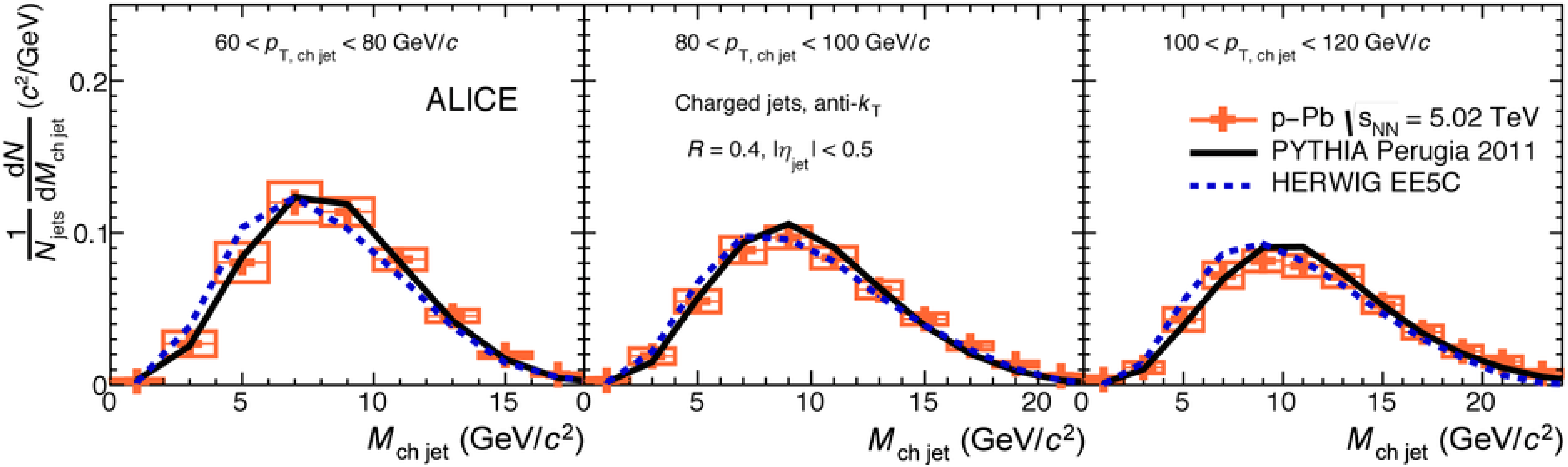
Jet dispersion in Pb-Pb

$$p_T D = \frac{\sqrt{\sum_i p_{T,i}^2}}{\sum_i p_{T,i}}$$

Hint of data being more "quark-like" in Pb-Pb compared to Pythia, as expected.

Jet mass in p-Pb collisions $M = \sqrt{E^2 - p_T^2 - p_z^2}$

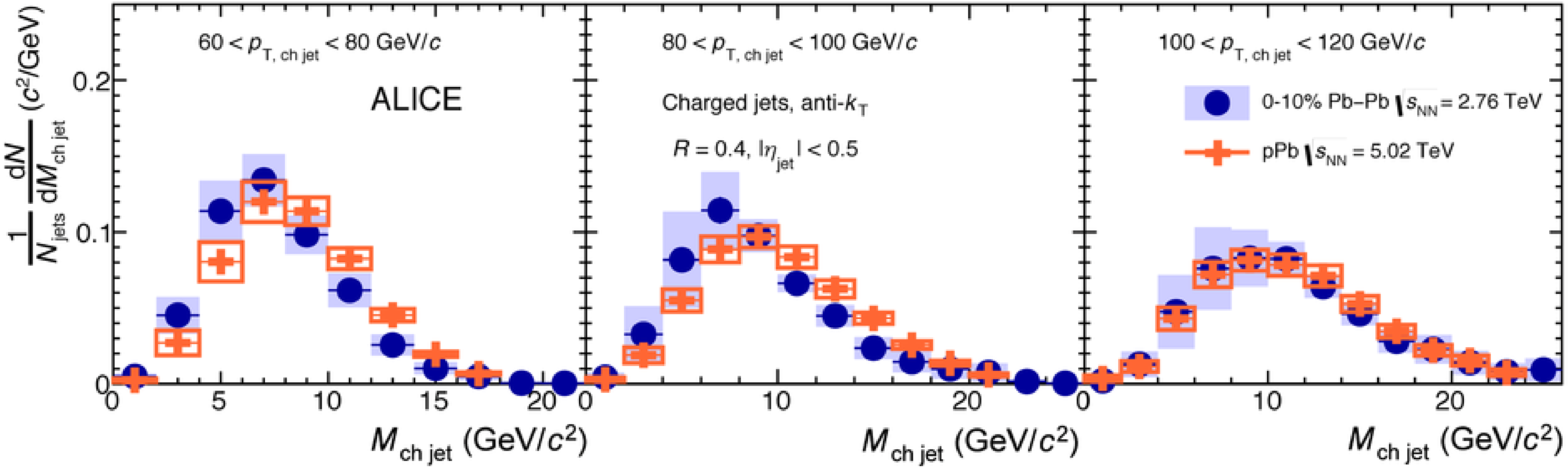
Phys. Lett. B 776 (2018) 249 **(first measurement)**



Data well described by pp event generators

Jet mass in Pb-Pb and p-Pb collisions

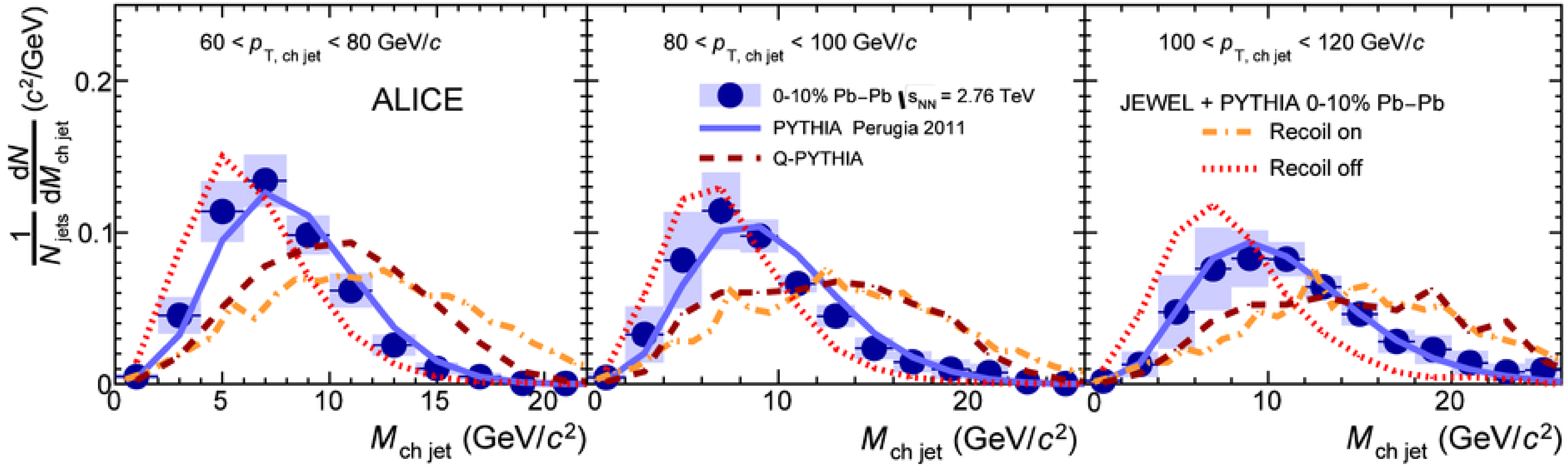
Phys. Lett. B 776 (2018) 249 **(first measurement)**



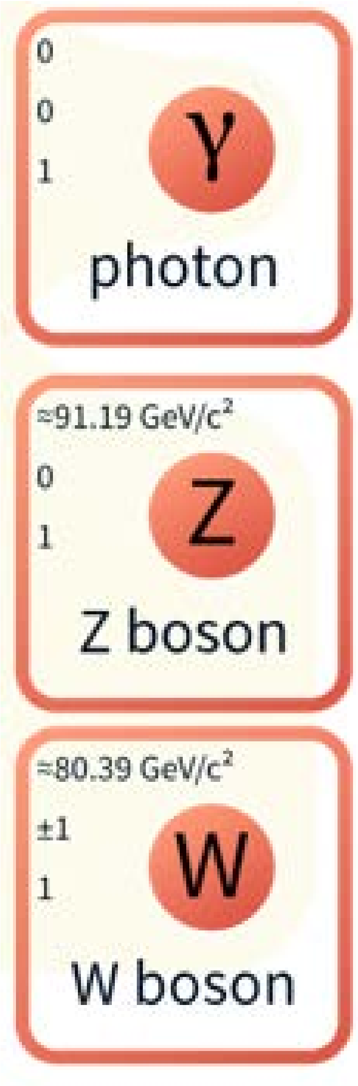
Little or no difference between Pb-Pb and p-Pb data

Jet mass in Pb-Pb

Phys. Lett. B 776 (2018) 249 **(first measurement)**



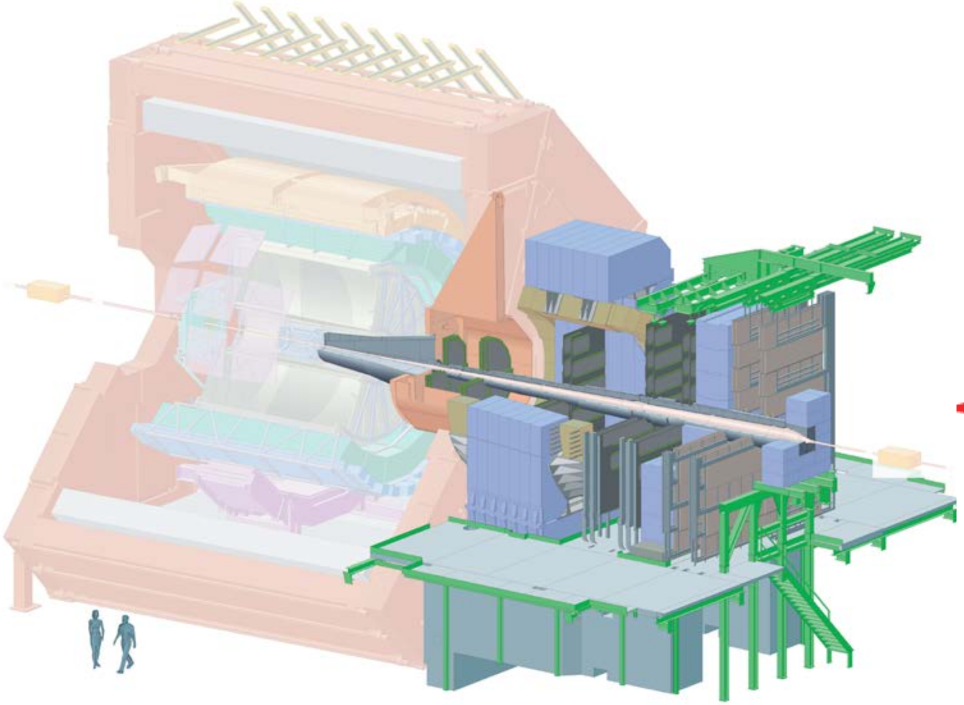
Models with energy loss miss data,
Pythia (pp) describes it fairly well

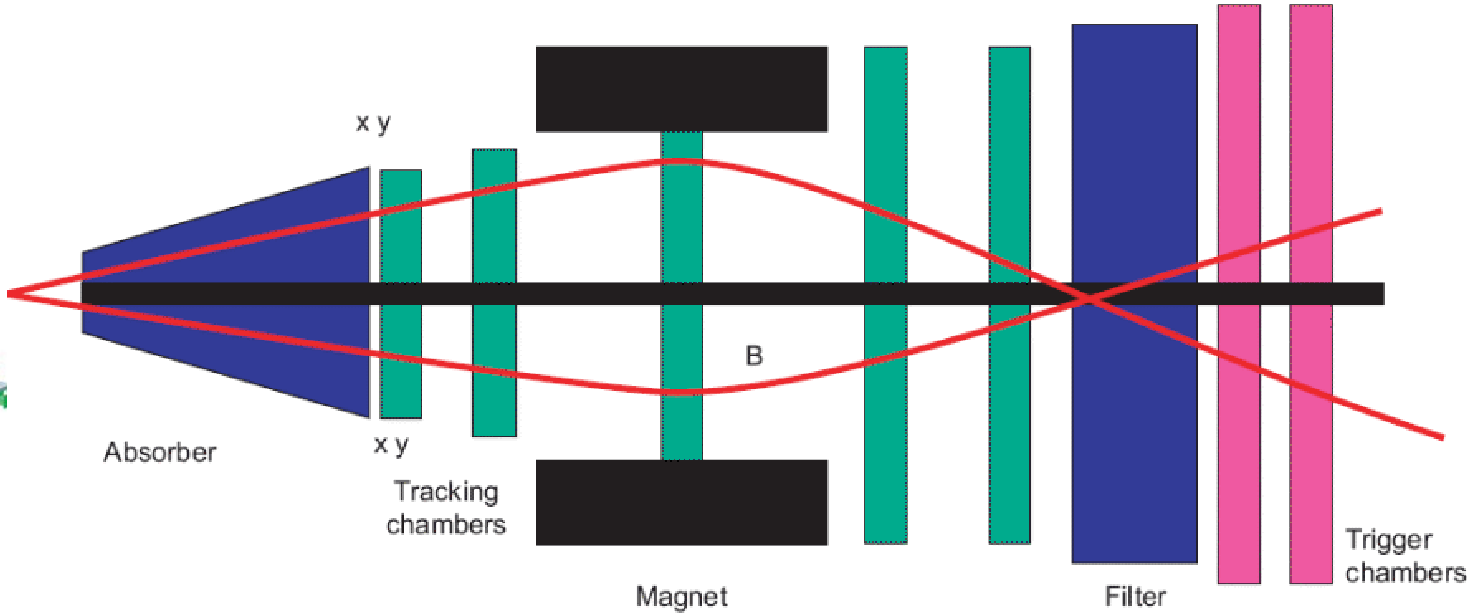


Electroweak bosons

- No color charge, thus very large mean-free path in the quark-gluon plasma
- "Standard candles" in Pb-Pb probe nuclear PDFs in p-Pb

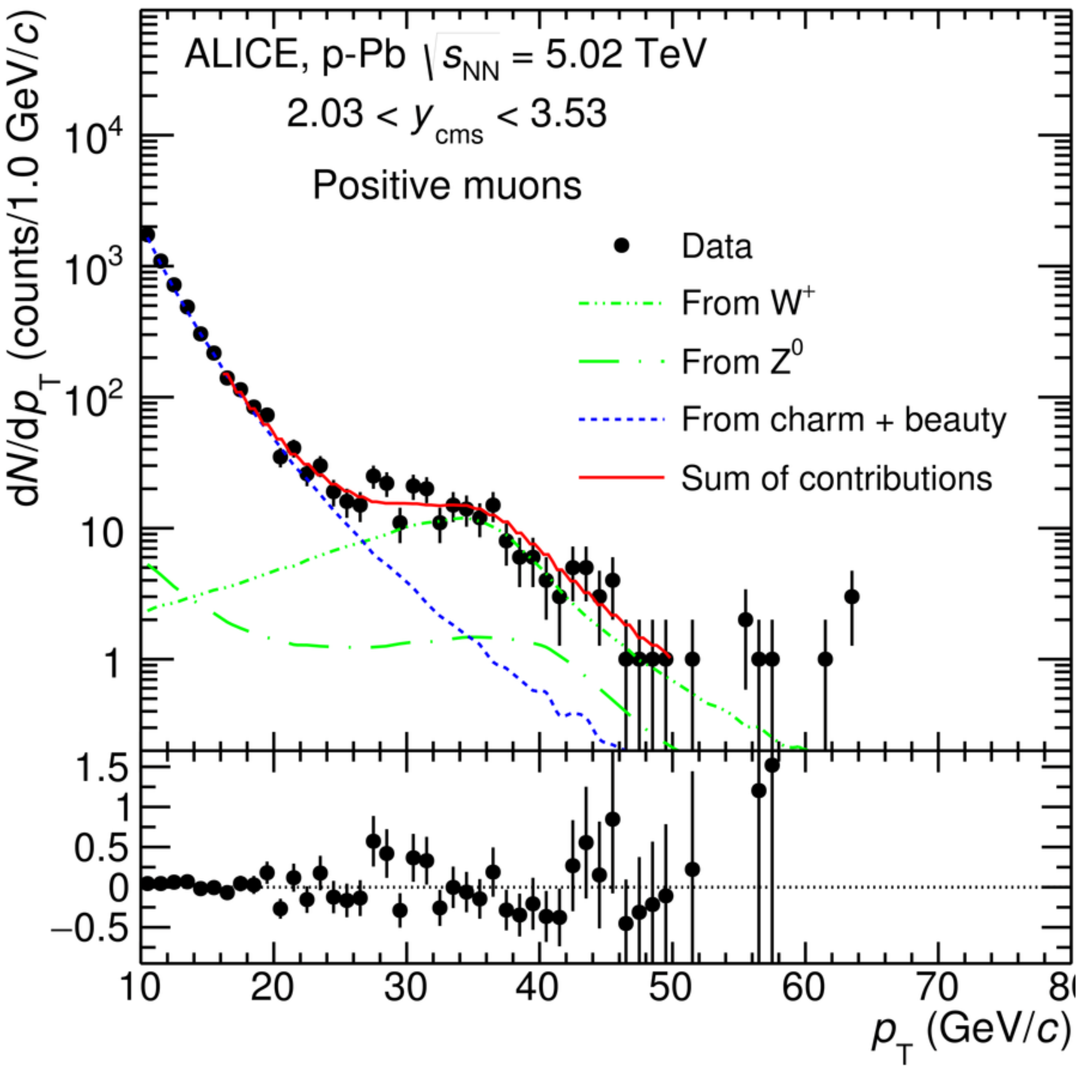
Muon measurements for $$Z \to \mu\mu$$ $$W \to \nu\mu$$

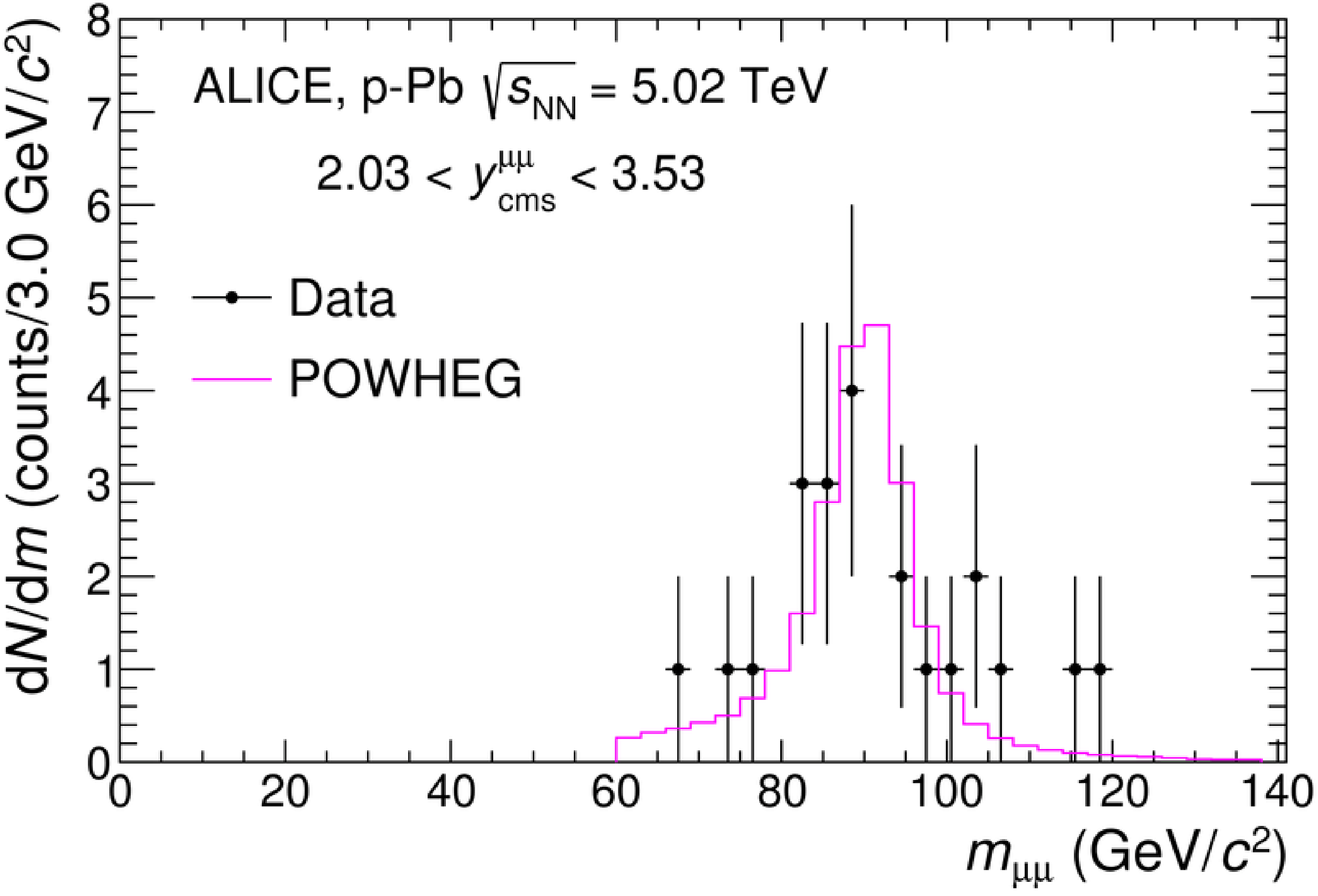


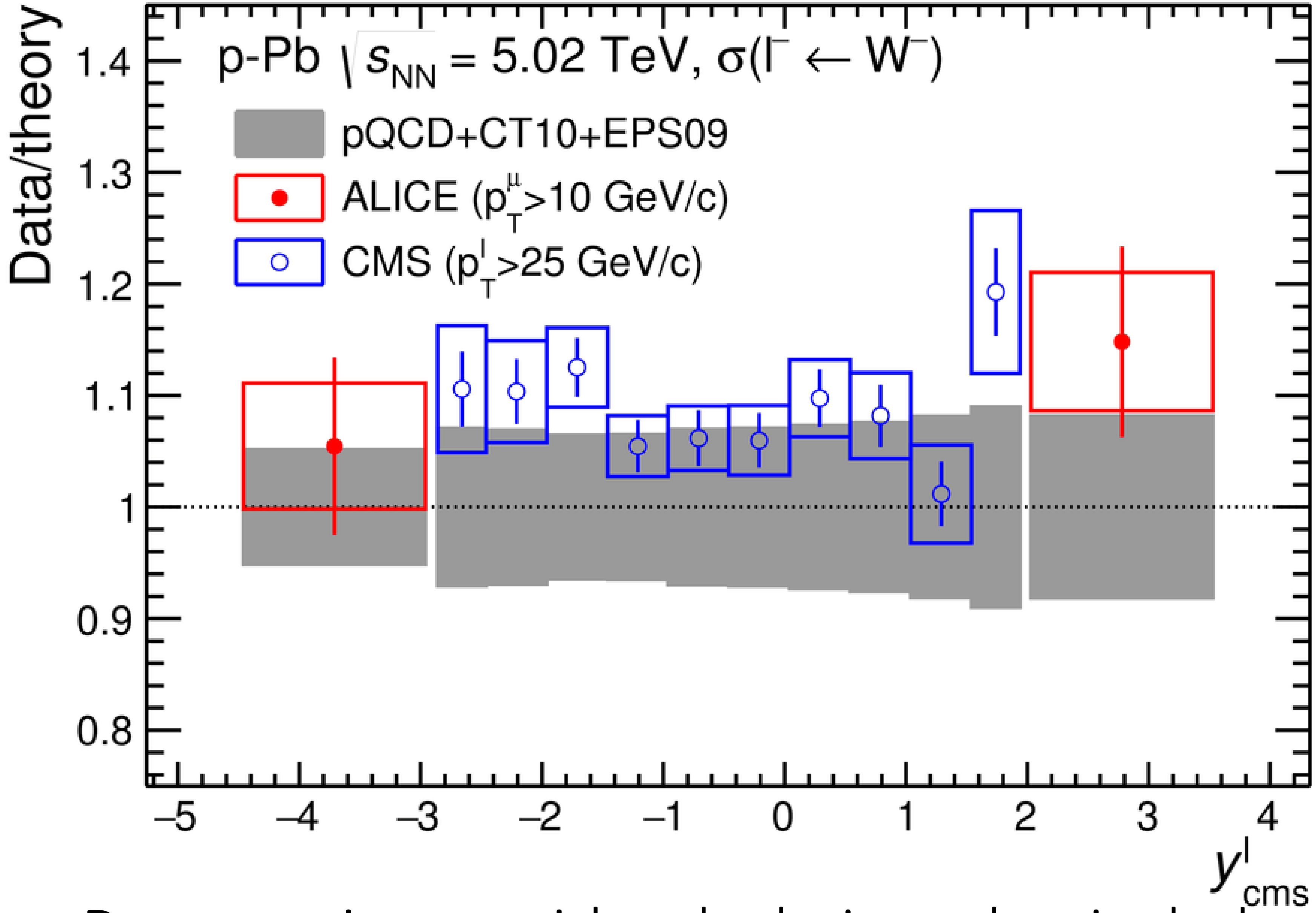


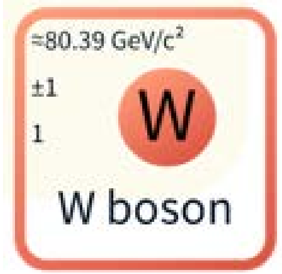
W and Z bosons in p-Pb collisions

JHEP 02 (2017) 077

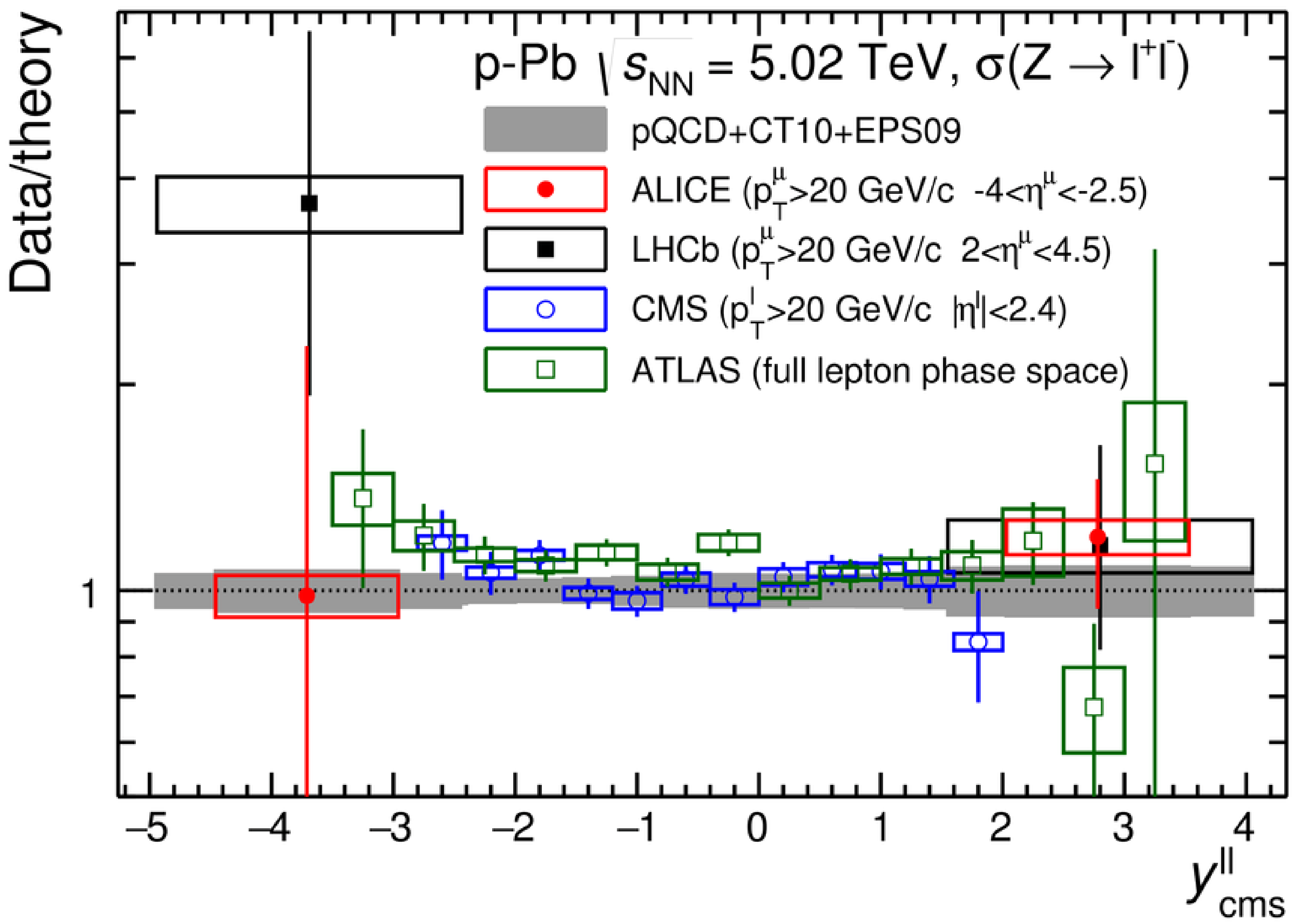








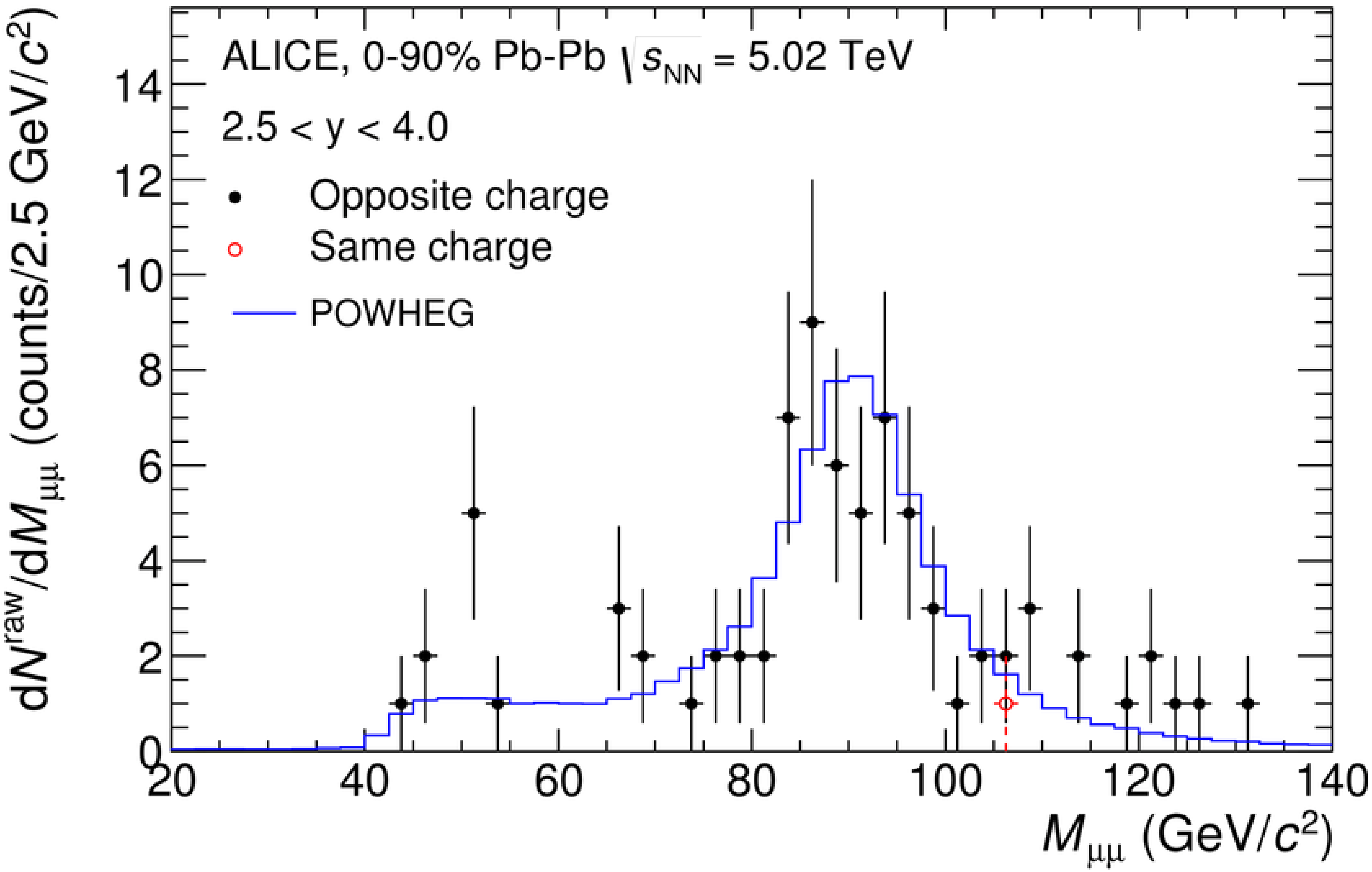
Data consistent with calculations that include nuclear effects, extending measurements to larger rapidity Paukkunen et al[15]

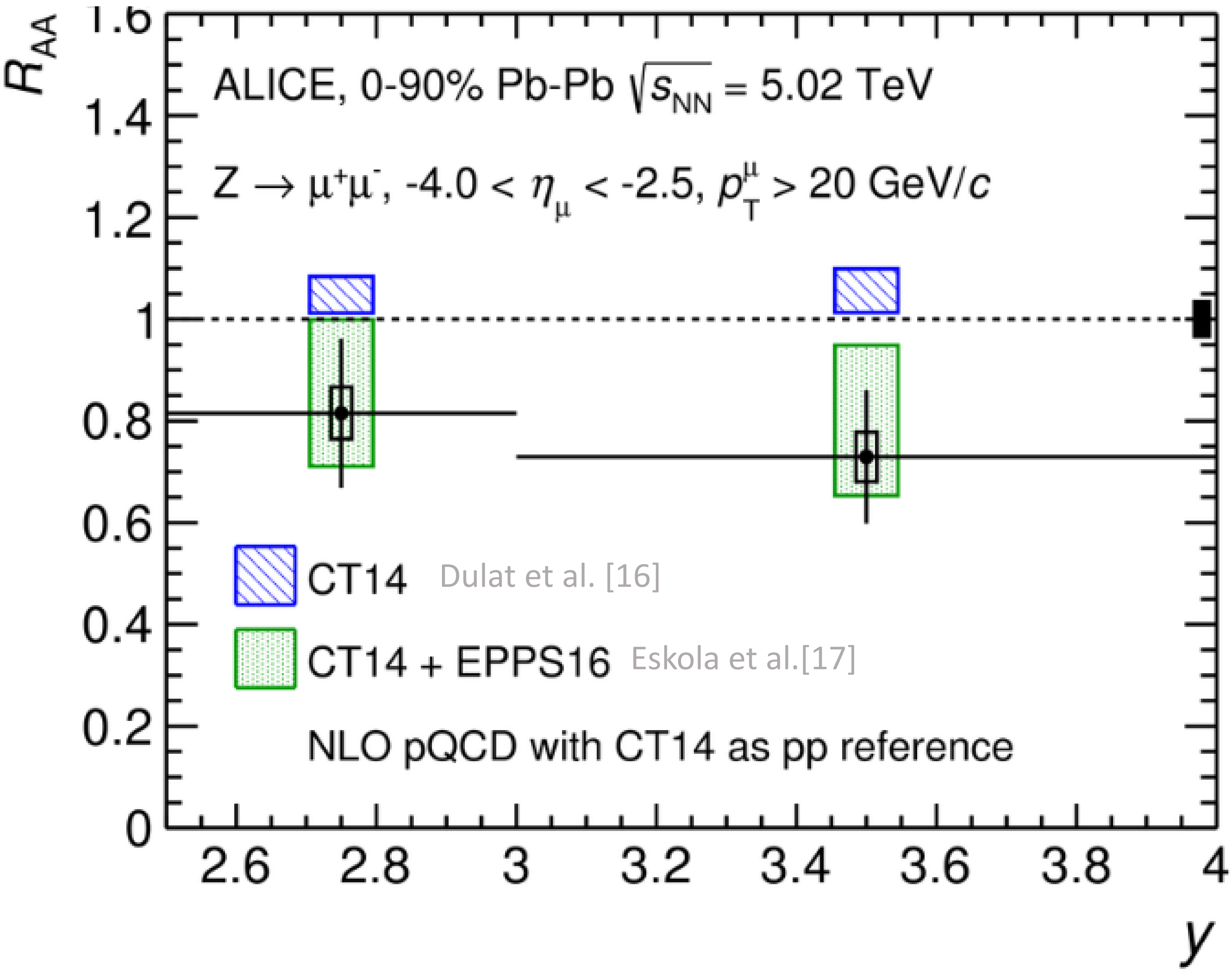


Data consistent with calculations that include nuclear effects, extending measurements to larger rapidity Paukkunen et al[15]

Z boson in Pb-Pb collisions

arXiv:1711.10753 , submitted to PLB



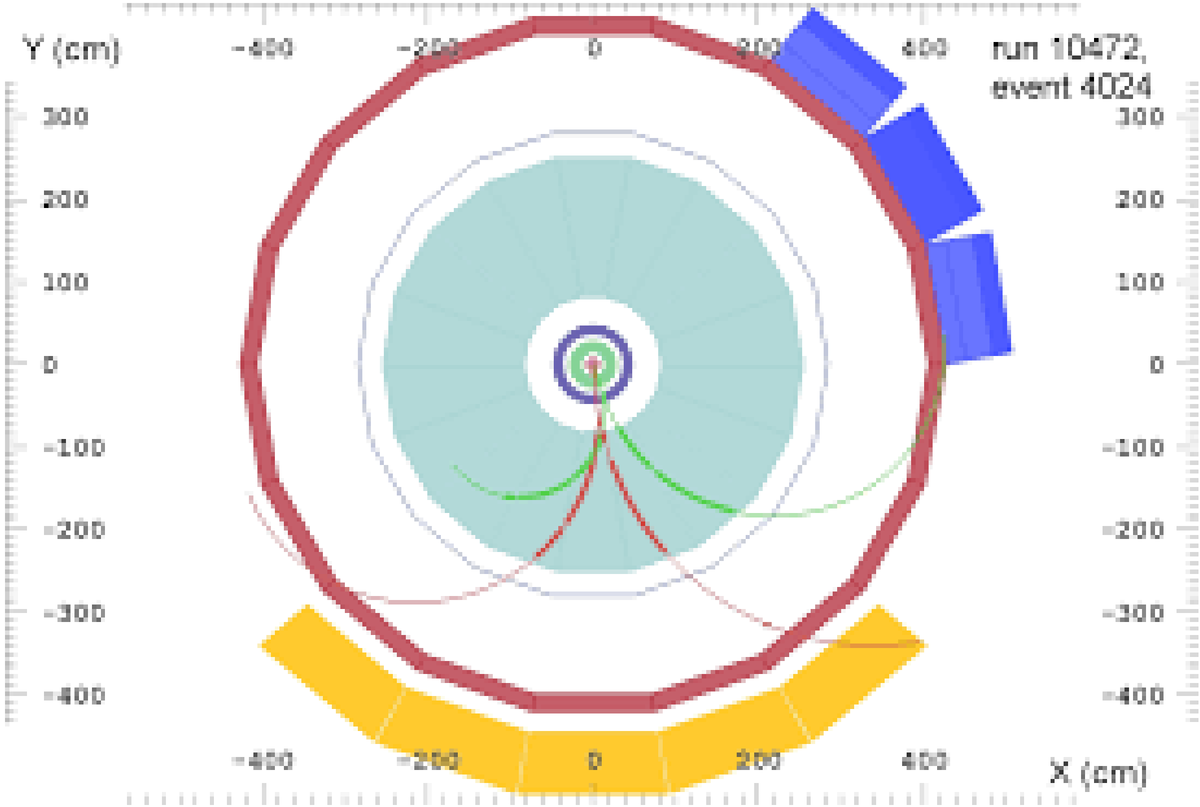


Data well described by calculations with nuclear effects.

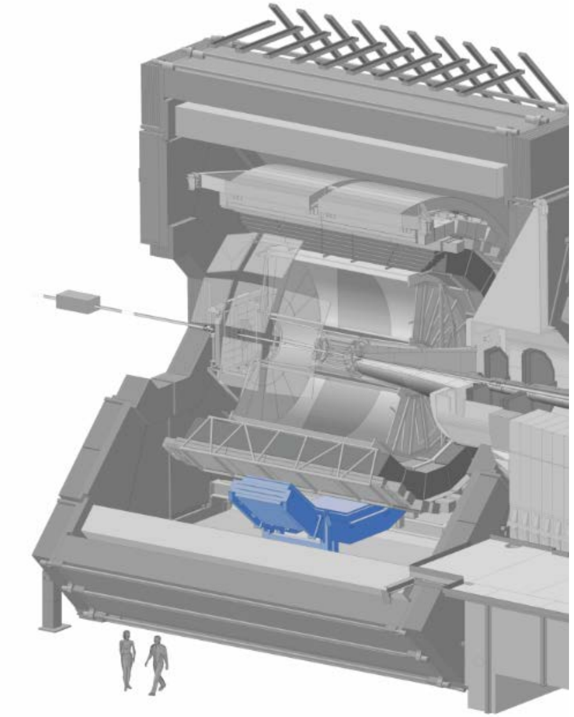
Direct photon production in Pb–Pb collisions

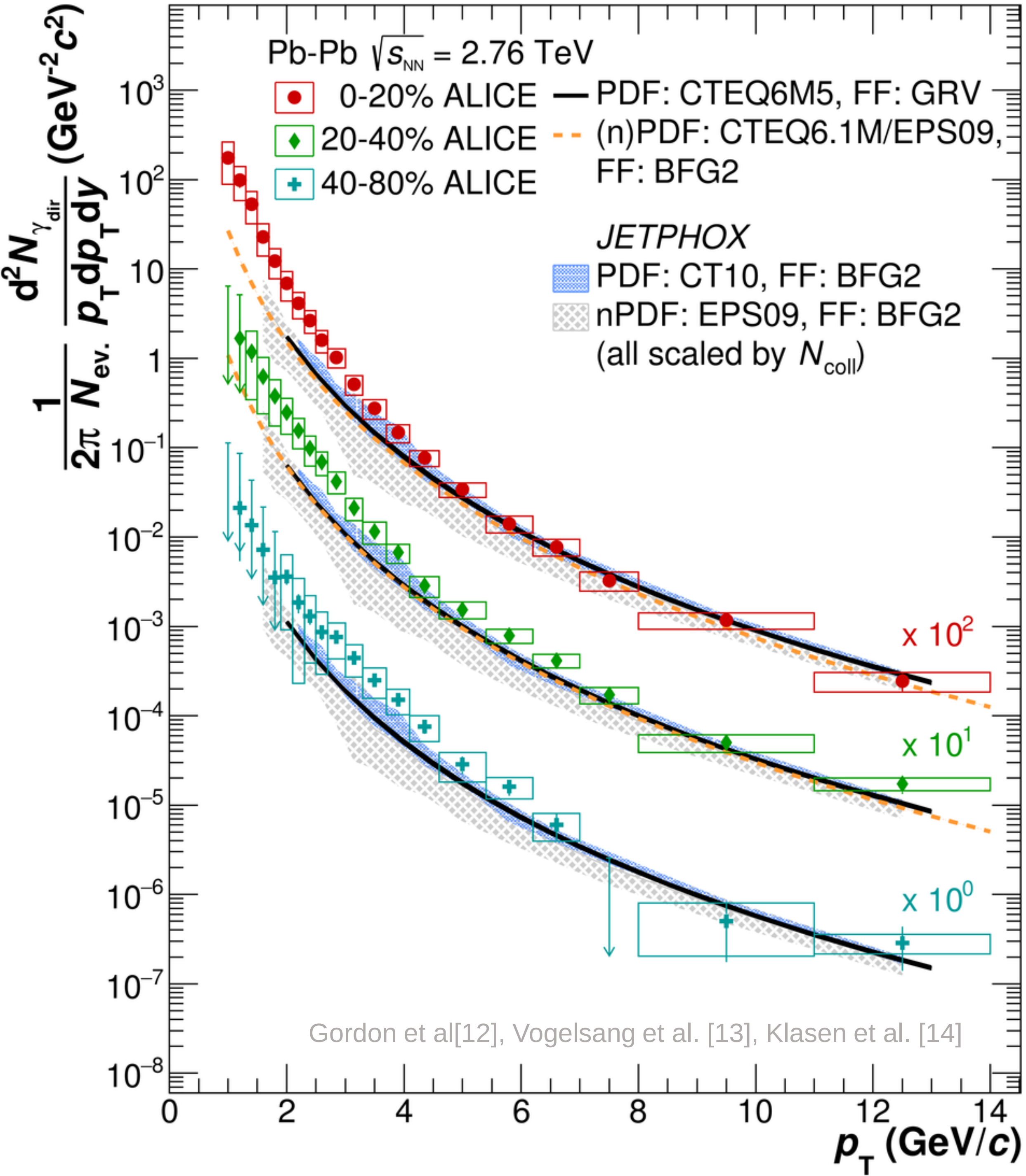
[Phys. Lett. B 754 (2016) 235-248]

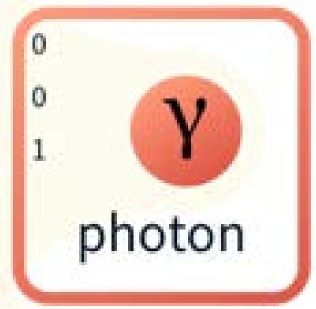
Pair conversion method



PHOS calorimeter

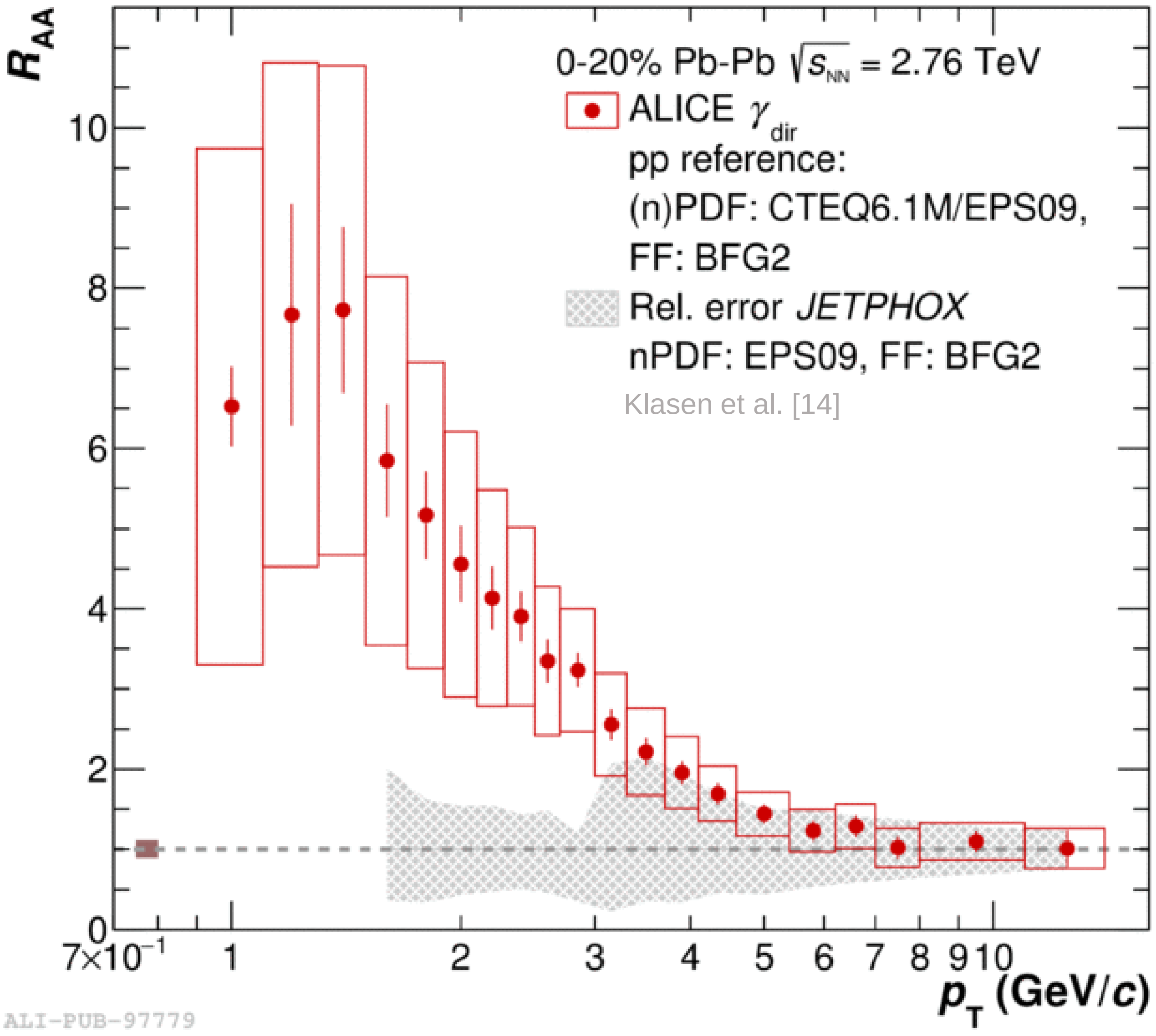


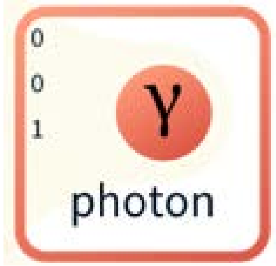




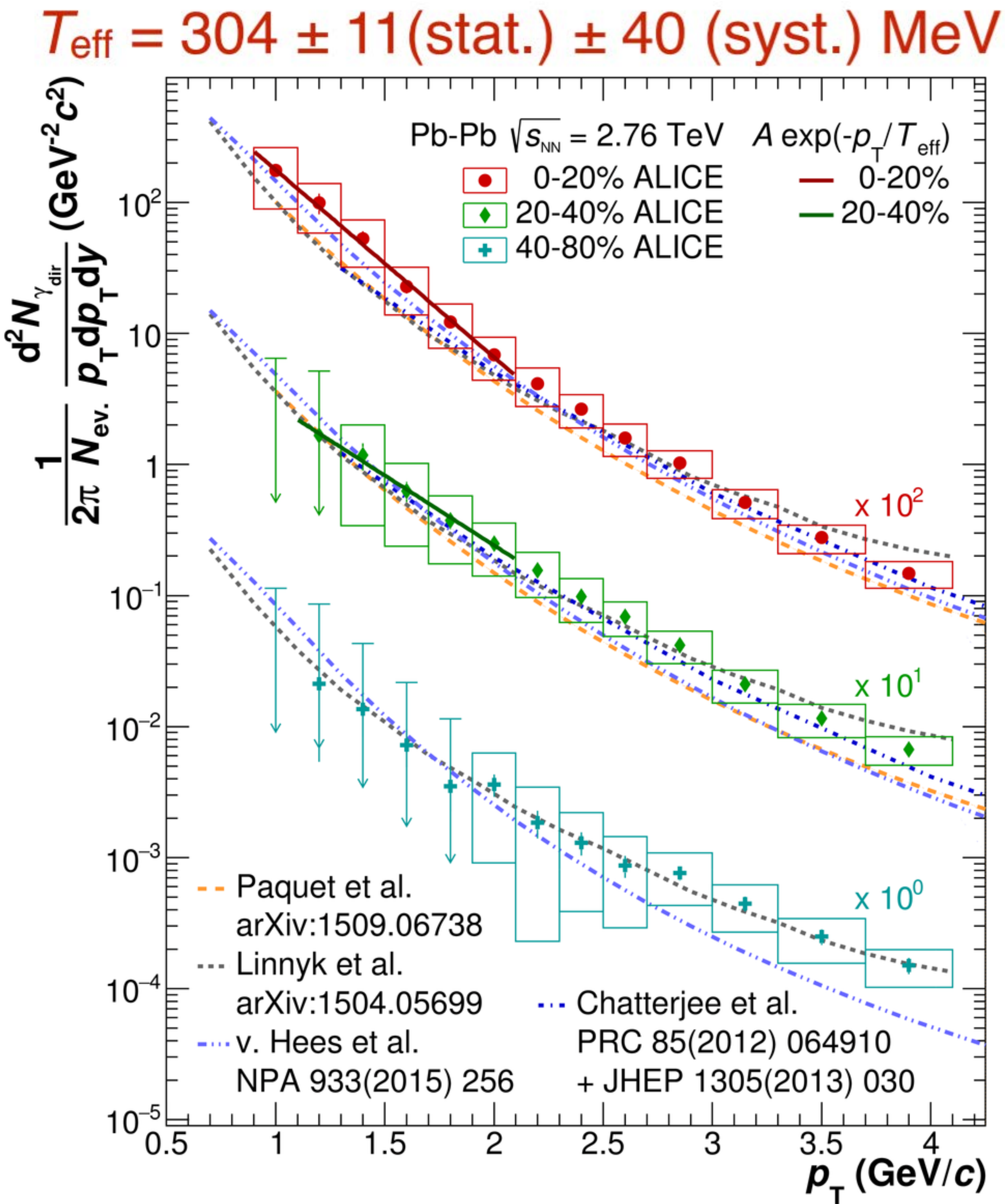
- Data well described by pQCD at high momentum
- Data at low momentum shows enhancement

Thermal radiation from Quark-Gluon Plasma





Confirms the expected scaling



- T_{eff}, which is average T, blue-shifted due to radial expansion
- Models suggest an initial T ~ 400—750 MeV for more central collisions

In summary:

- Heavy quark measurements constrain energy loss models at high p_T, and charm-quark transport at low p_T $2\pi T D_s(T) \approx 1.5$–$7$
- Jet data constrain opacity to energetic quarks and gluons. “Jet substructure” shows, so far, only small modifications.
- Electroweak bosons constrain nuclear effects on parton density functions, and geometric modelling.
- Photons reveal temperature: ~400—750 MeV

What will the near future of the hard-probes program bring?

- Novel jet substructure observables
- More precise D and B mesons results, (with new silicon tracker)
- New photon, and photon-jet results
- And much more!

Studying the bulk properties of matter under extreme conditions with ALICE

12 Jan 2018, 04:05
35m

Speaker

David Dobrigkeit Chinellato

The ALICE detector upgrade program

12 Jan 2018, 10:20
20m
Building A, Modular room ()

Speaker

Stefano Panebianco (Université Paris-Sacl...)

References

- [1] Particle data group
- [2] M. Nahrgang et al. Phys.Rev. C89 no. 1, (2014) 014905.
- [3] M. Djordjevic and M. Djordjevic, Phys. Rev. C92 no. 2, (2015) 024918.
- [4] J. Xu et al. JHEP 02 (2016) 169.
- [5] Z.-B. Kang, et al. JHEP 03 (2017) 146.
- [6] T. Song et al. Phys. Rev. C93 no. 3, (2016) 034906.
- [7] M. Xe et al. Phys.Lett. B735 (2014) 445–450.
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- [10] Z. Liu et al. Eur. Phys. J. C76 no. 1, (2016) 20
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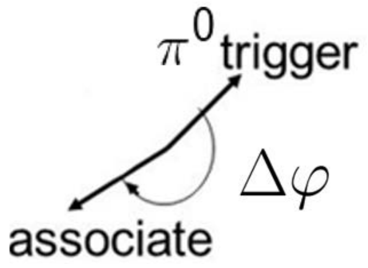
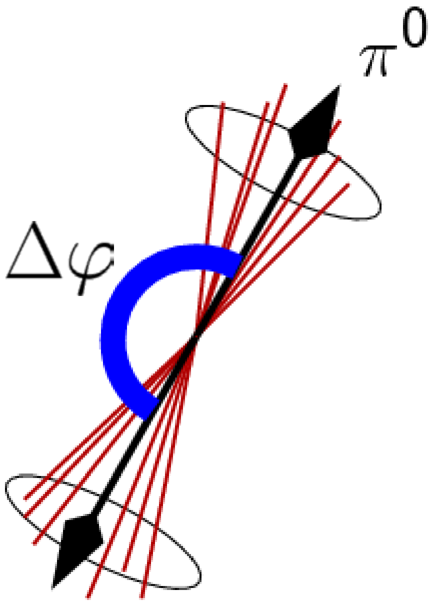
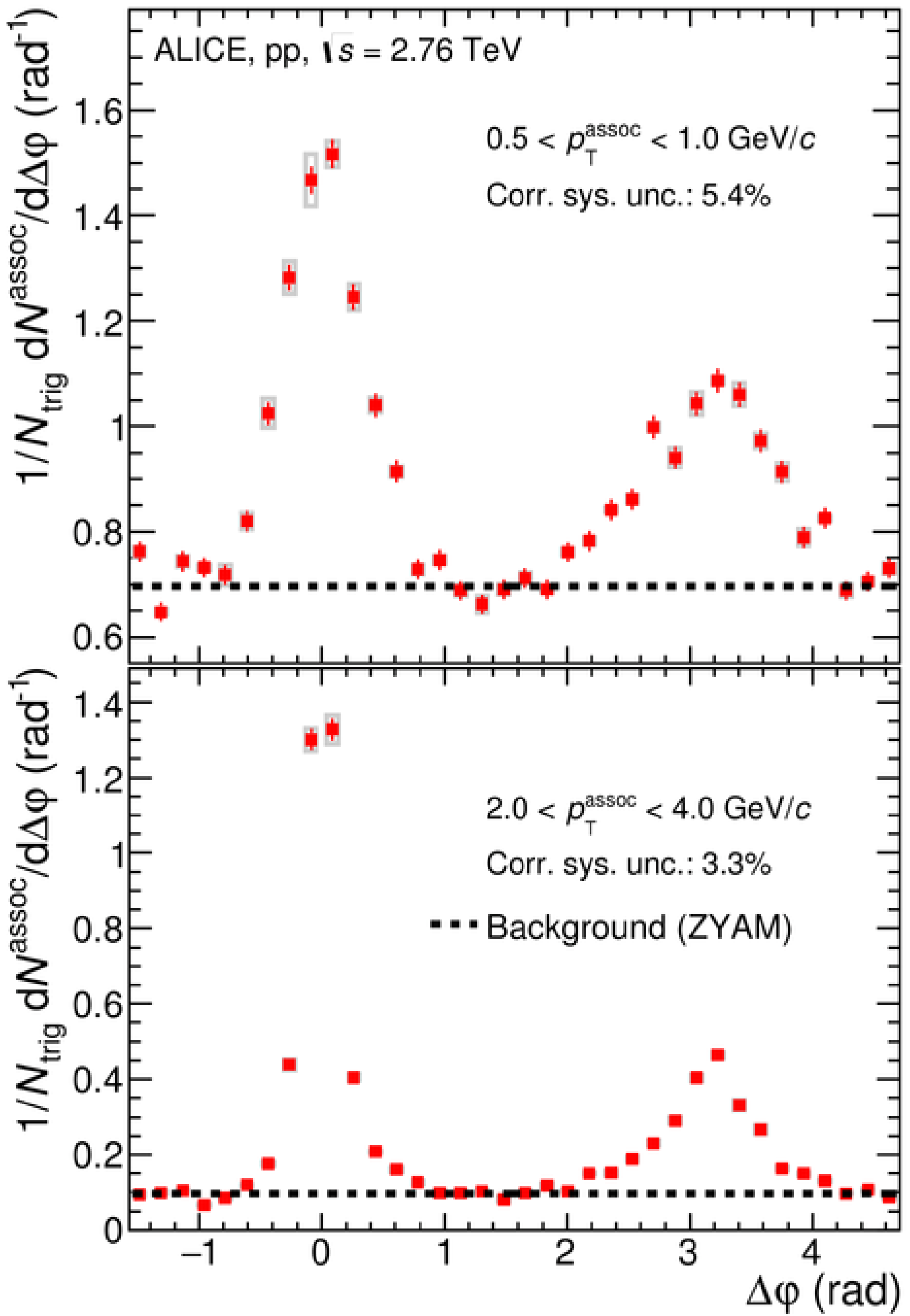
- [12] Gordon et al. Phys. Rev. D 48 (1993) 3136–3159.
- [13] Vogelsang et al. J. Phys. G 23 (1997)
- [14] Klasen et al. High Energy Phys. 1310 (2013)
- [15] Paukkunen et al. JHEP 1103 (2011)
- [16] Dulat et. Al JHEP 04 (2009) 065
- [17] Eskola et al. Eur. Phys. J. C77 no. 3, (2017)

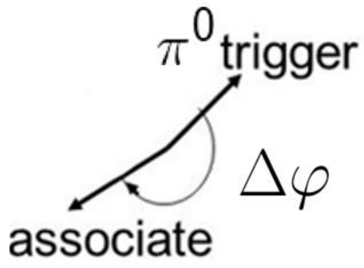
Jet-like correlations with neutral pion triggers [PLB 763 (2016) 238-250]

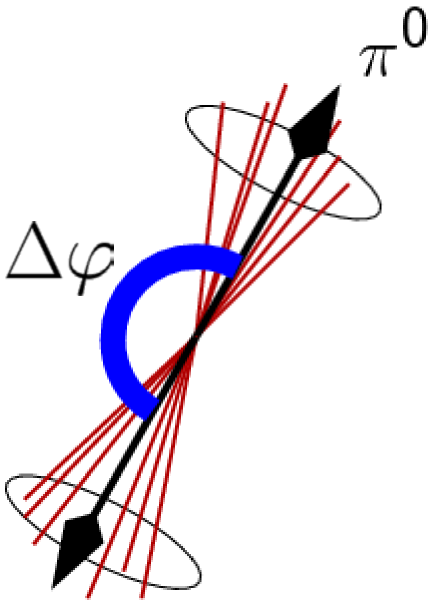


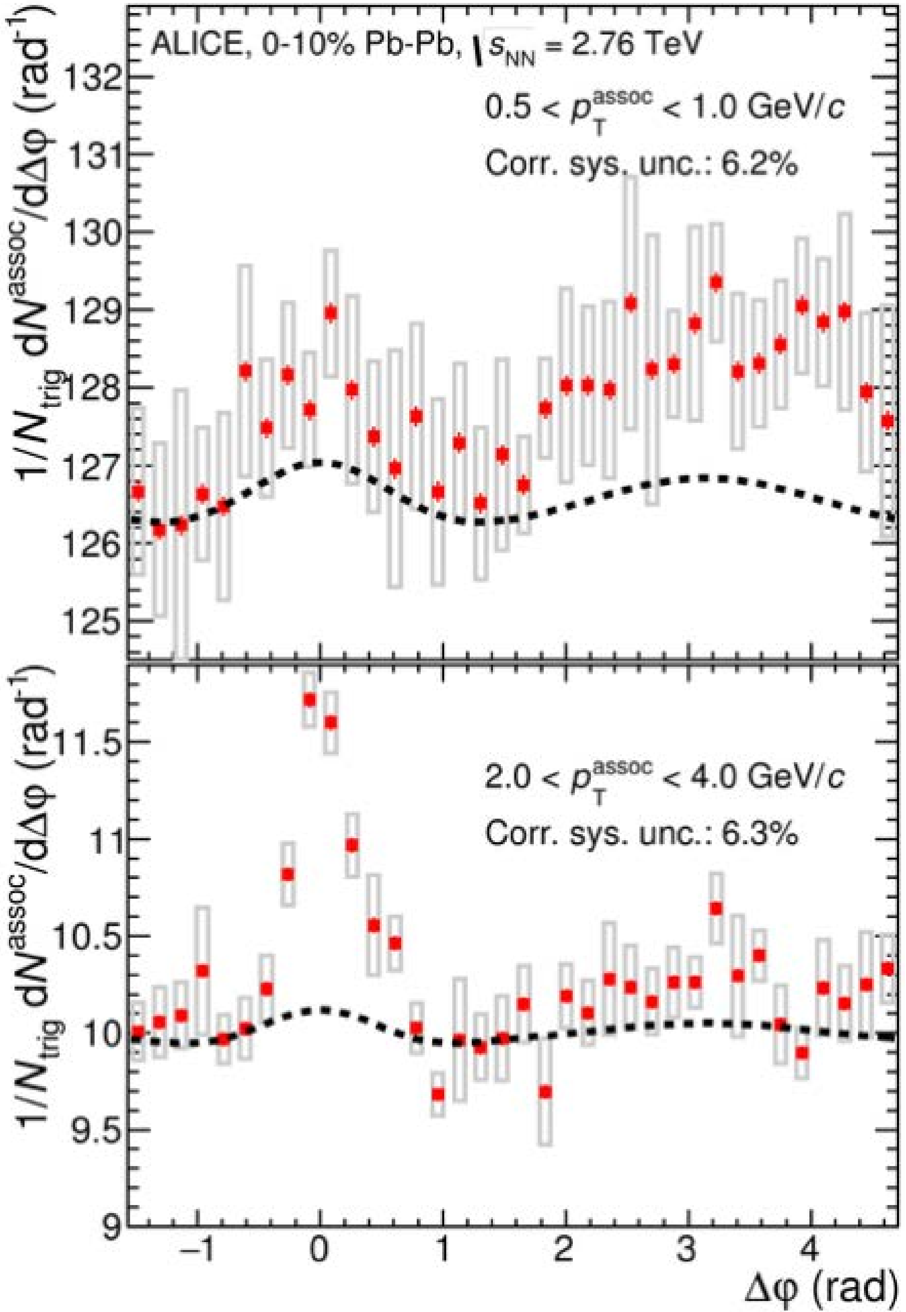




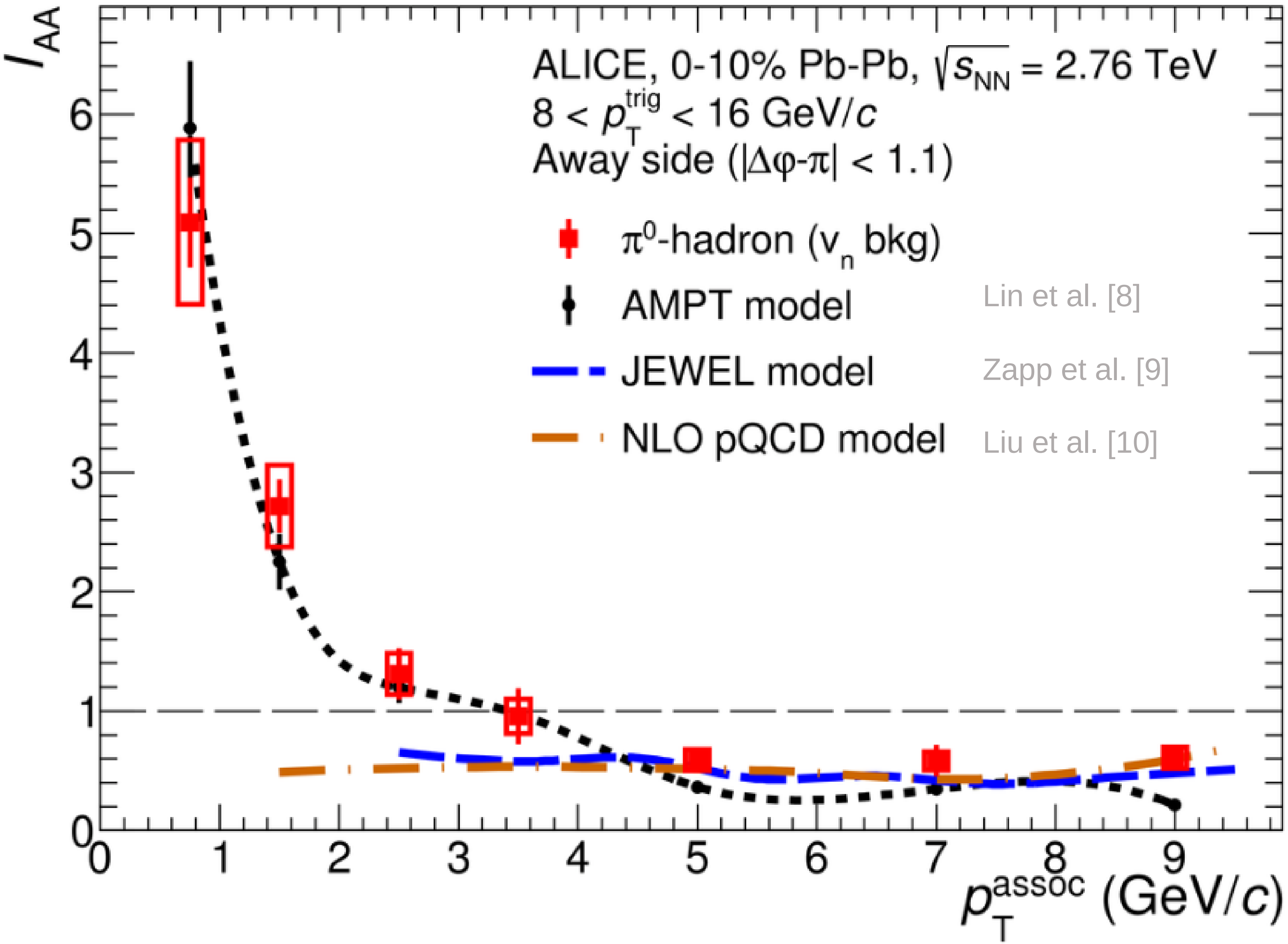
Jet-like correlations with neutral pion triggers [PLB 763 (2016) 238-250]

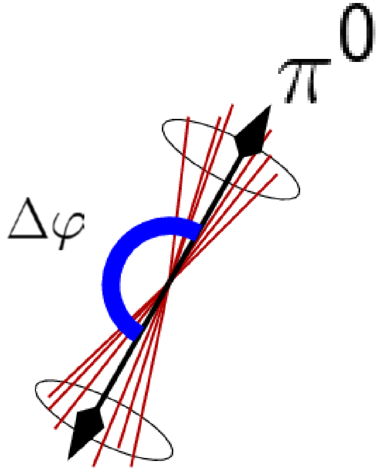






Modification of integral at $\Delta\varphi = \pi$

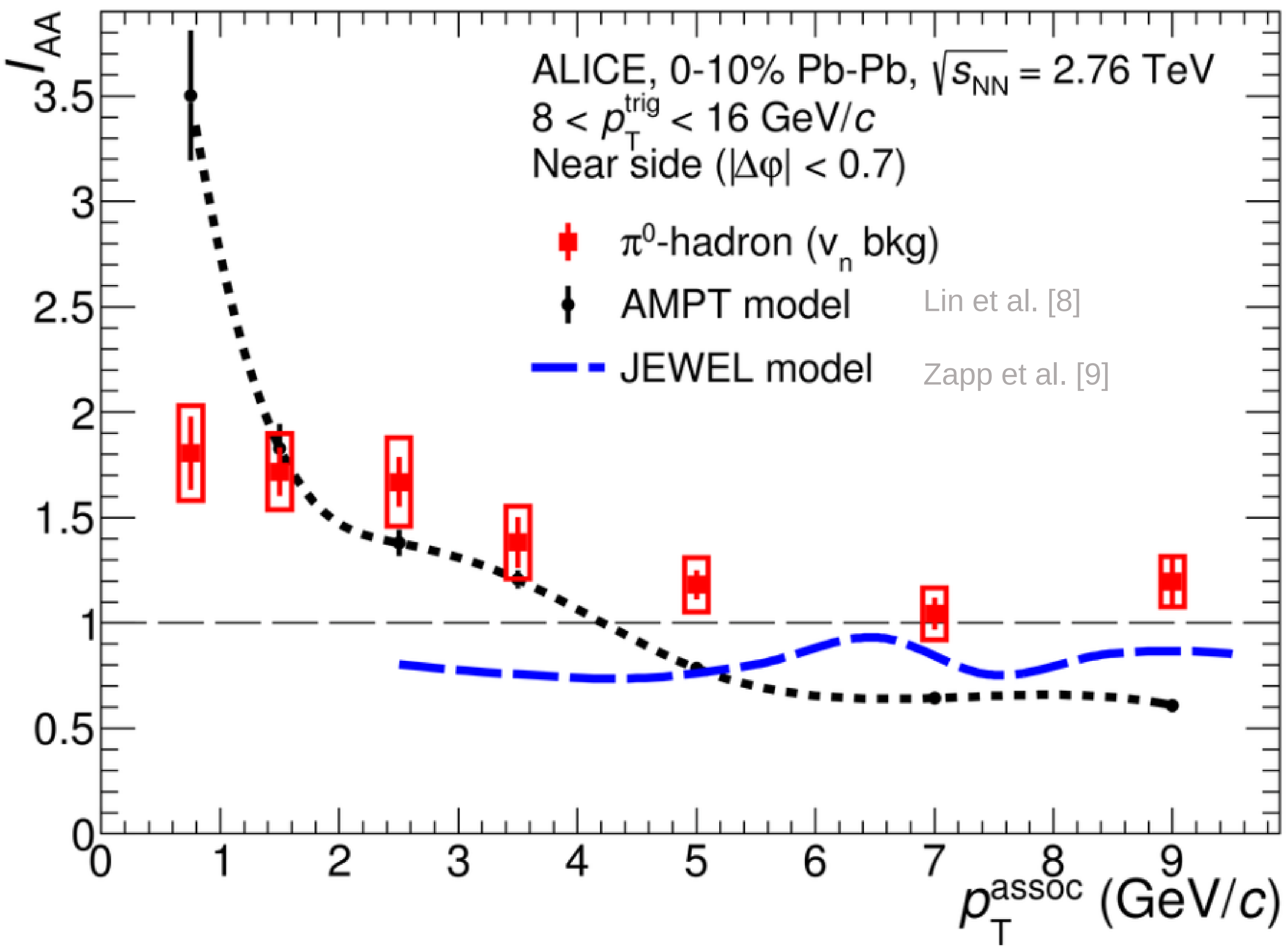


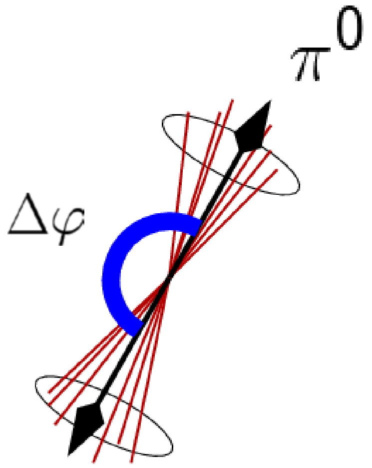


Models that include parton energy loss describe suppression at high p_T

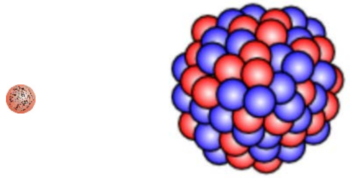
Enhancement at low p_T described by model that includes jet-medium interaction

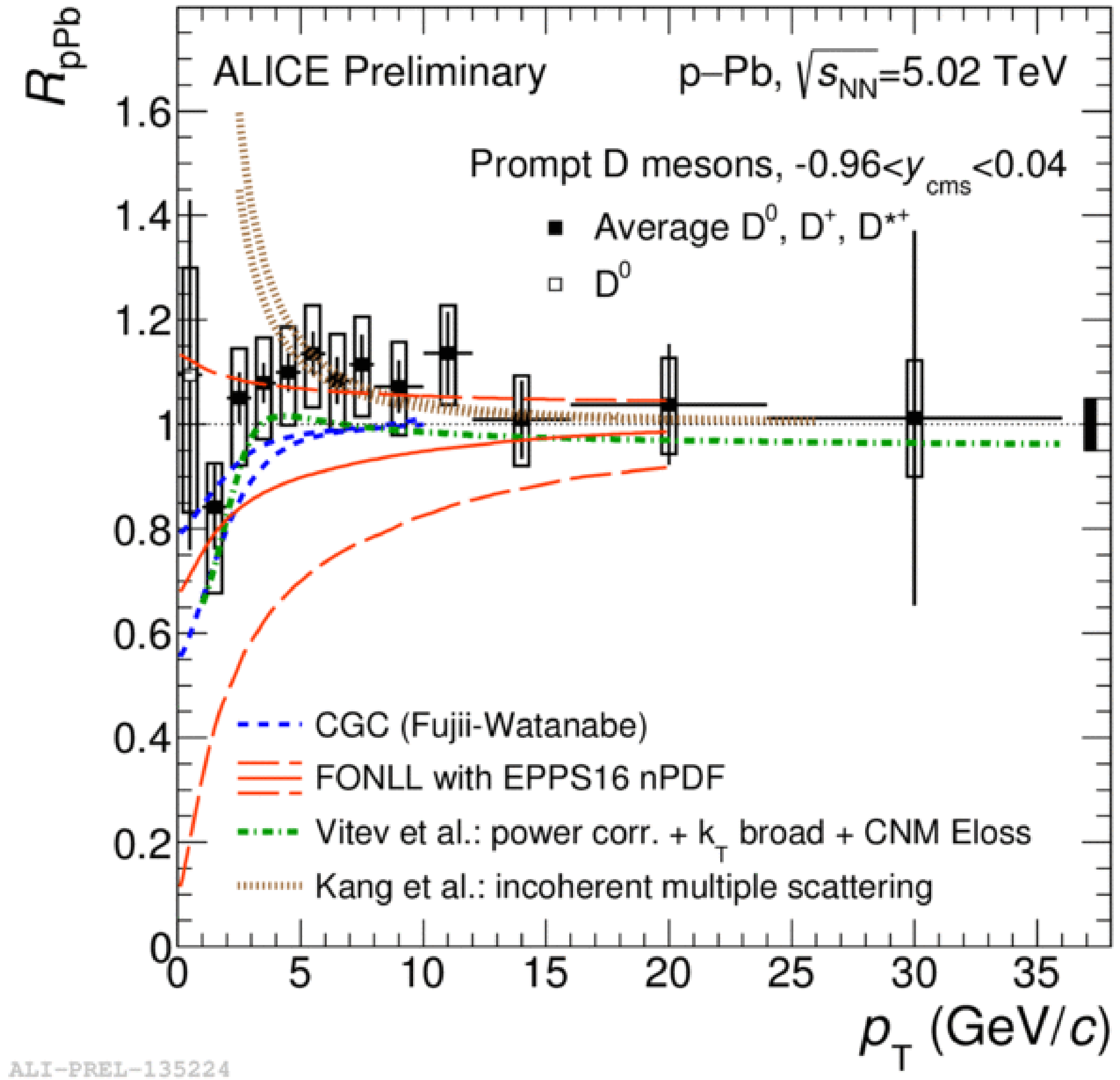
Modification of integral at $\Delta\varphi = 0$



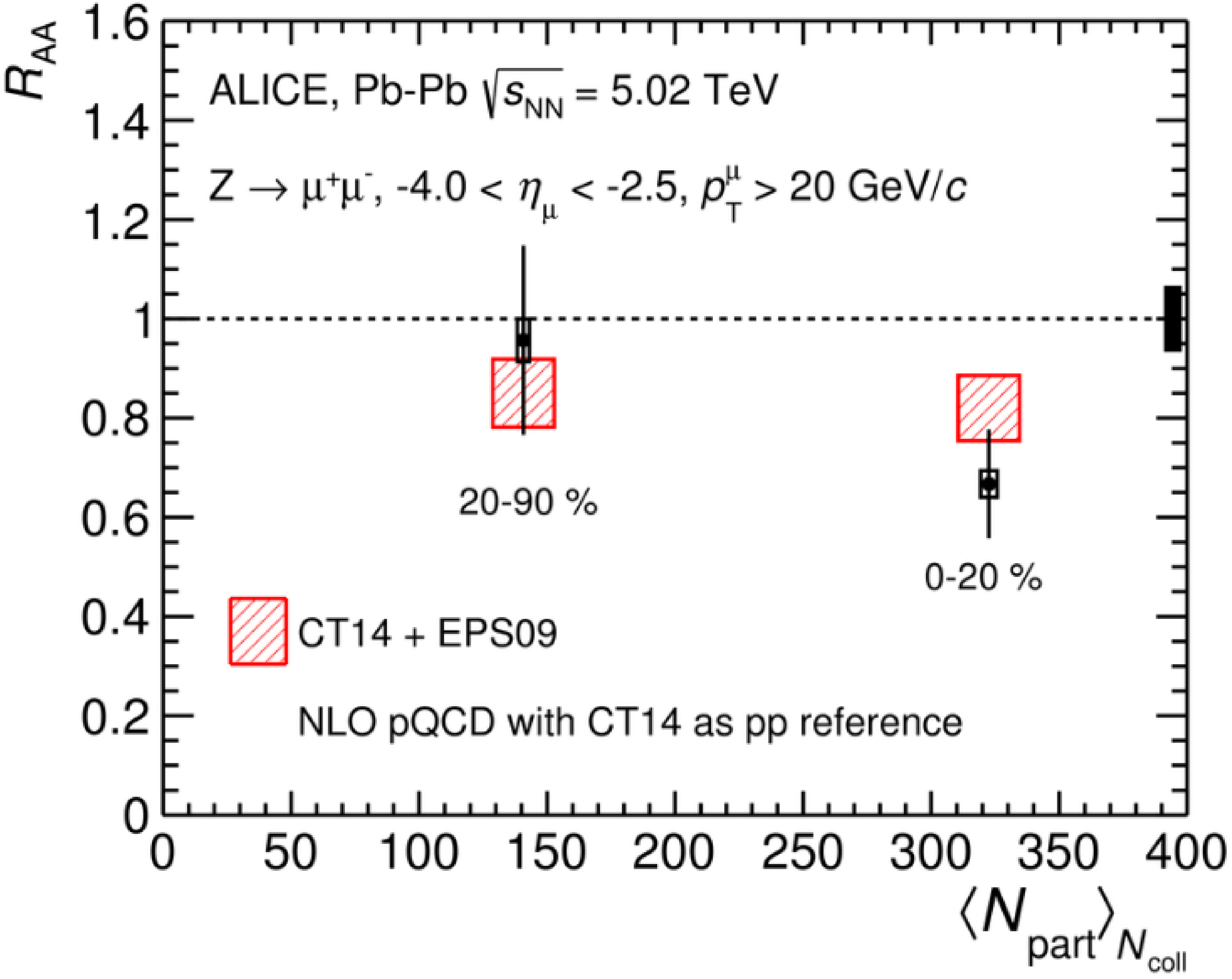


Modifications to the “near side” not described well

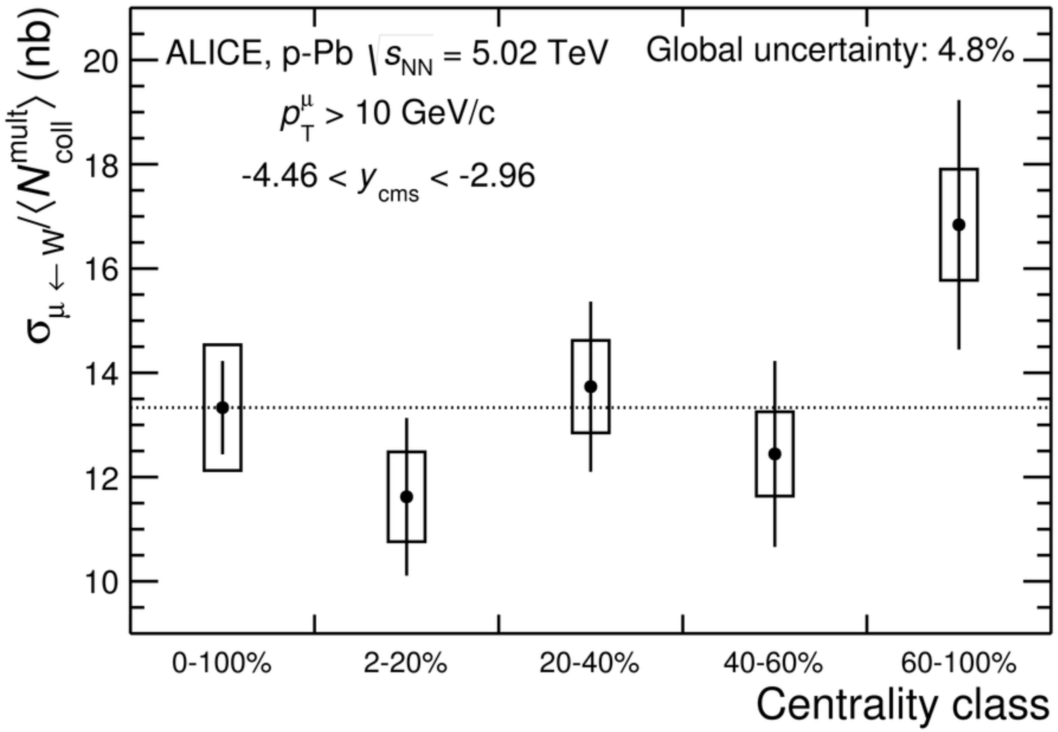


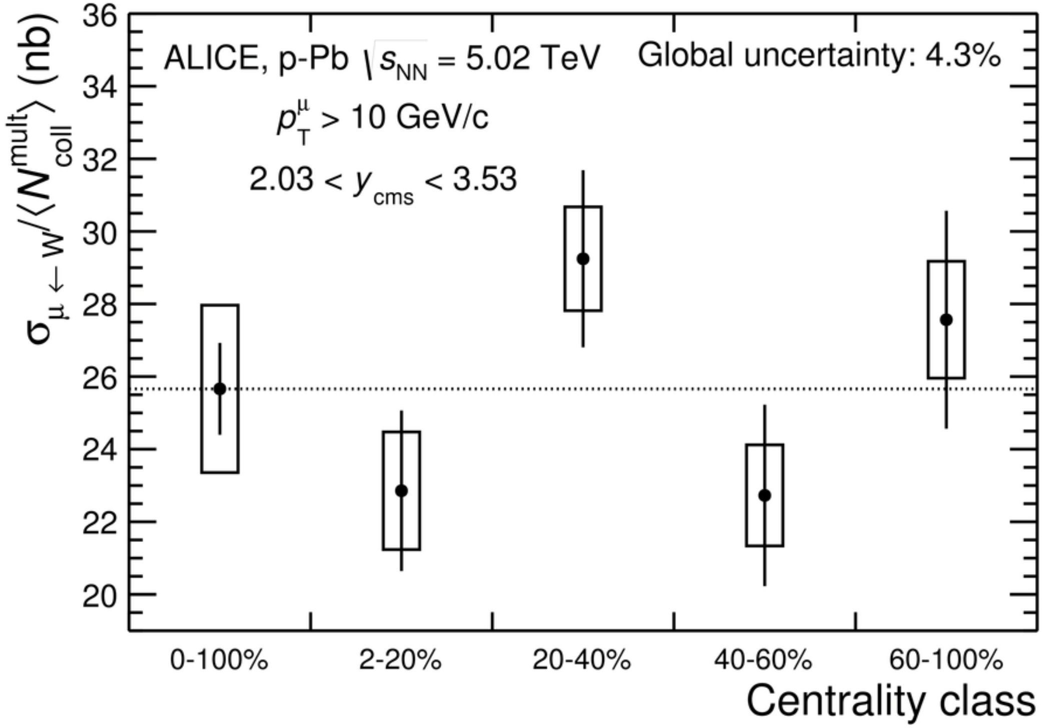


No suppression in p-Pb
Thus, suppression in Pb-Pb
due to quark-gluon plasma

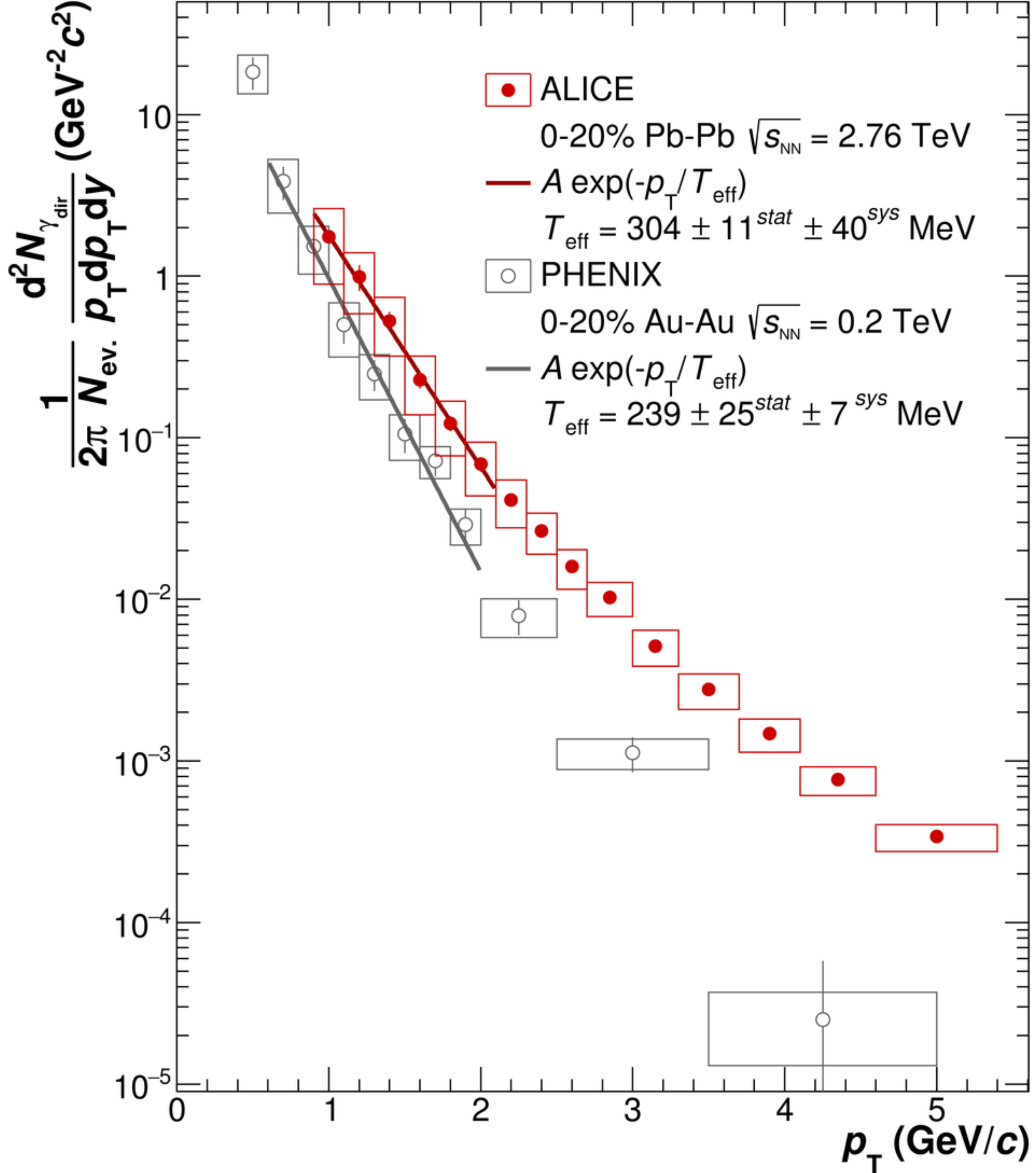

R_{AA}
ALICE, Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
$Z \rightarrow \mu^+\mu^-$, $-4.0 < \eta_\mu < -2.5$, $p_T^\mu > 20$ GeV/c
20-90 %
0-20 %
CT14 + EPS09
NLO pQCD with CT14 as pp reference
$\langle N_{part} \rangle_{N_{coll}}$
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
50
100
150
200
250
300
350
400

W boson scaling



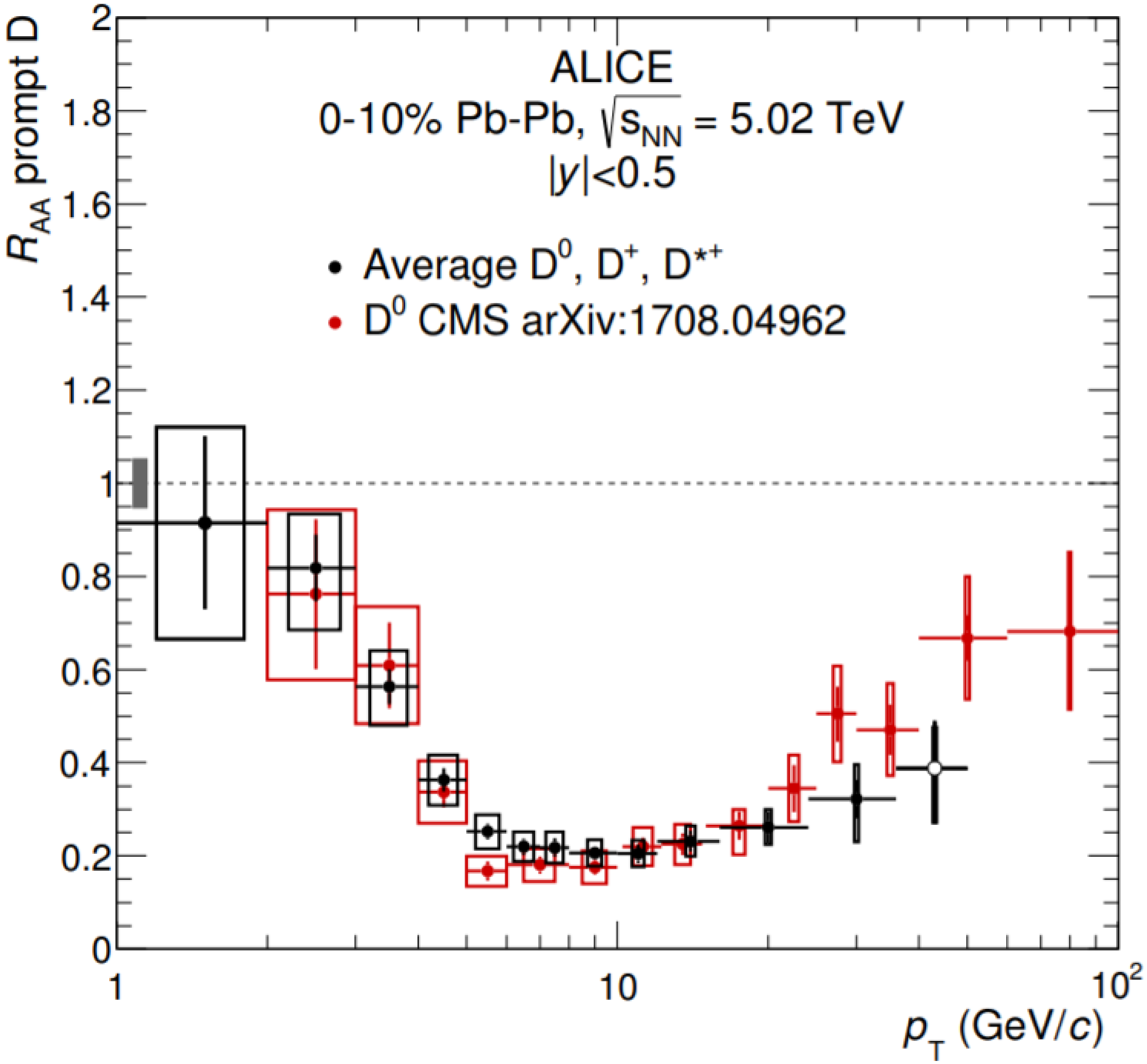


W scales with number of collisions estimated with Glaubel model

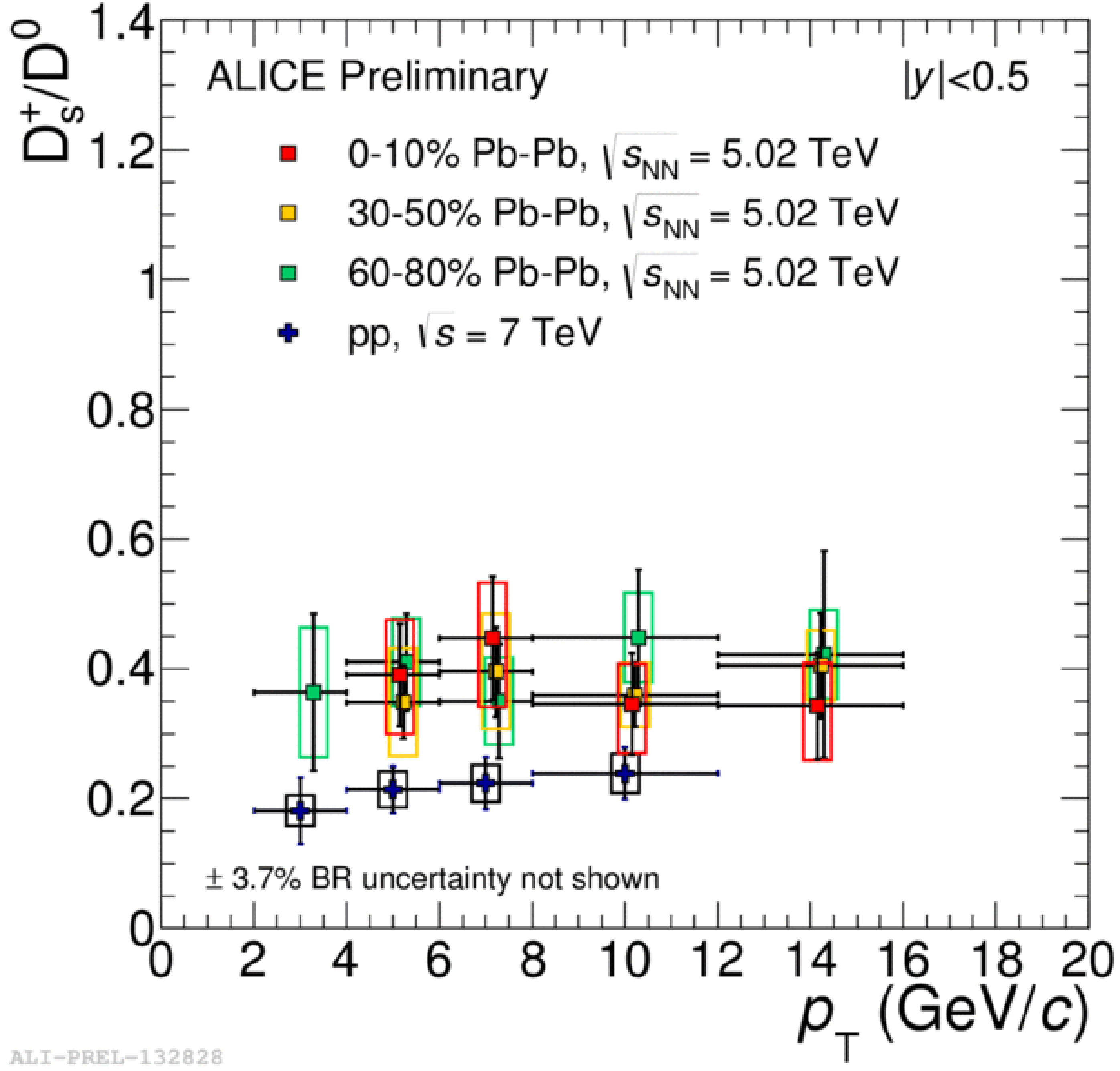


$$T_{\text{eff}} = \sqrt{\frac{1+\beta_{\text{flow}}}{1-\beta_{\text{flow}}}} \times T$$

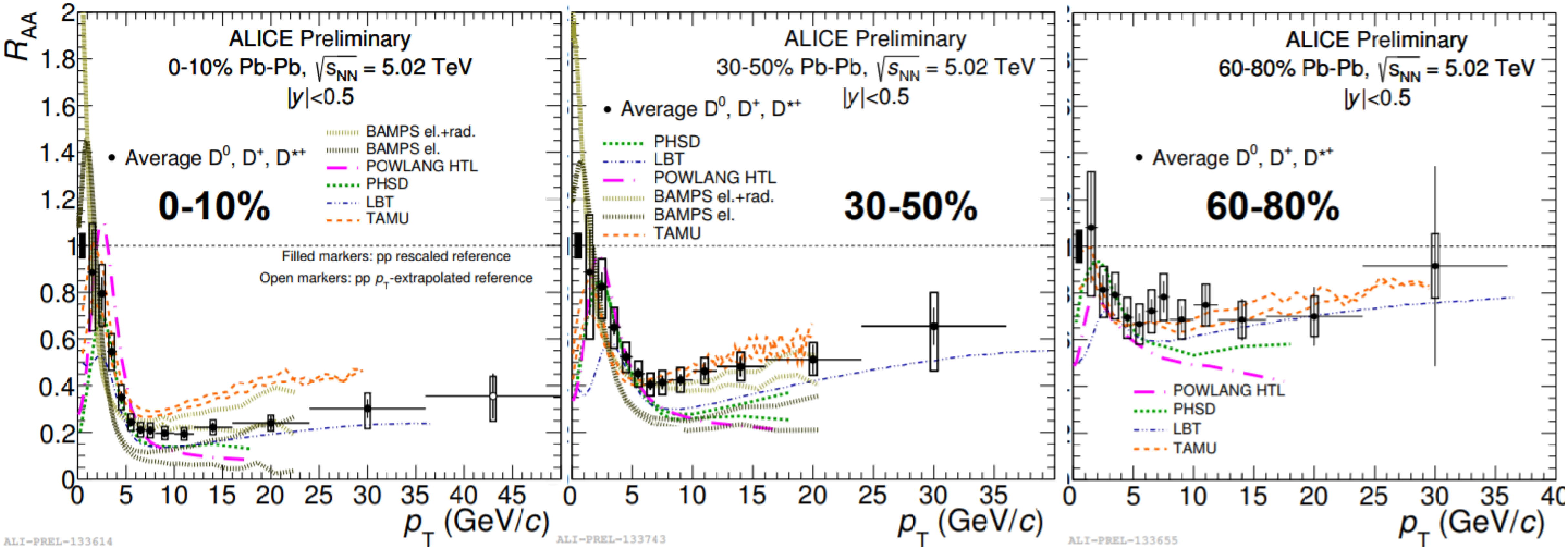
- Blue shift due to radial expansion and integration over space-time complicate extraction of initial temperature



Good agreement with CMS result.
D-meson results well stablished at LHC

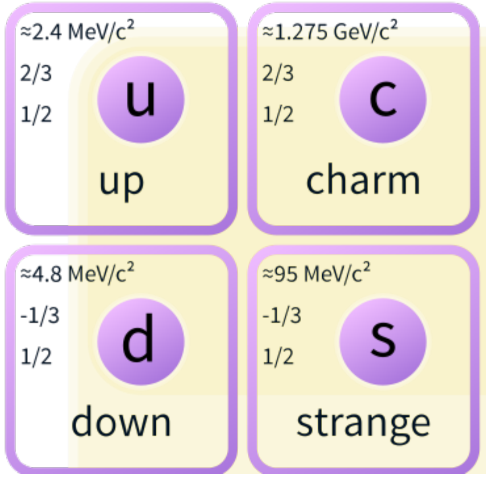


Ratio slightly larger than in pp, charm-strange coalescence

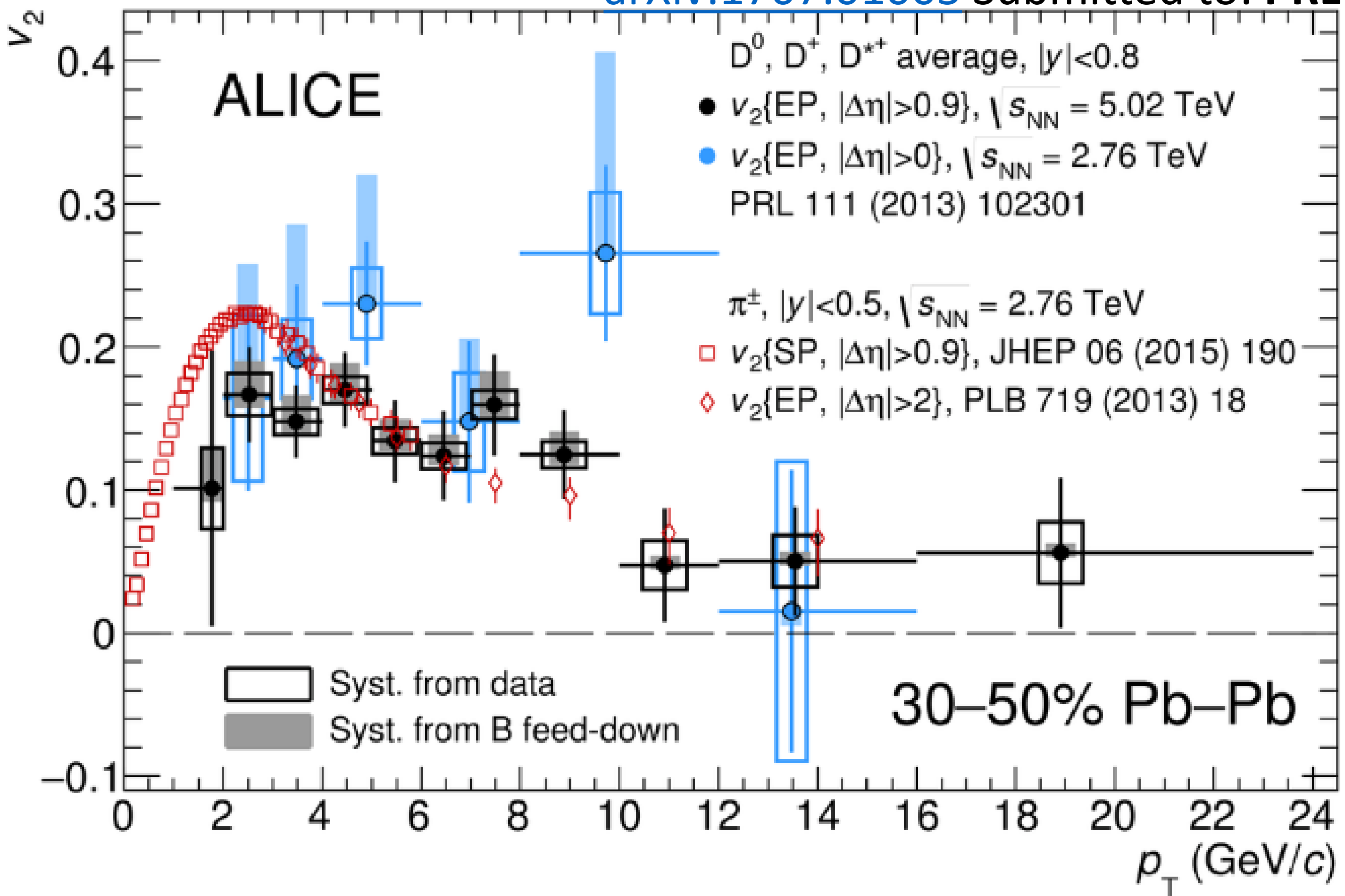


R_{AA}
ALICE Preliminary
0-10% Pb-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
$|y|$<0.5
Average D^0, D^+, D^{*+}
0-10%
BAMPS el.+rad.
BAMPS el.
POWLANG HTL
PHSD
LBT
TAMU
Filled markers: pp rescaled reference
Open markers: pp p_T-extrapolated reference
p_T (GeV/c)
ALI-PREL-133614
ALICE Preliminary
30-50% Pb-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
$|y|$<0.5
Average D^0, D^+, D^{*+}
PHSD
LBT
POWLANG HTL
BAMPS el.+rad.
BAMPS el.
TAMU
30-50%
p_T (GeV/c)
ALI-PREL-133743
ALICE Preliminary
60-80% Pb-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
$|y|$<0.5
Average D^0, D^+, D^{*+}
60-80%
POWLANG HTL
PHSD
LBT
TAMU
p_T (GeV/c)
ALI-PREL-133655

Comparison with light quarks (pions)



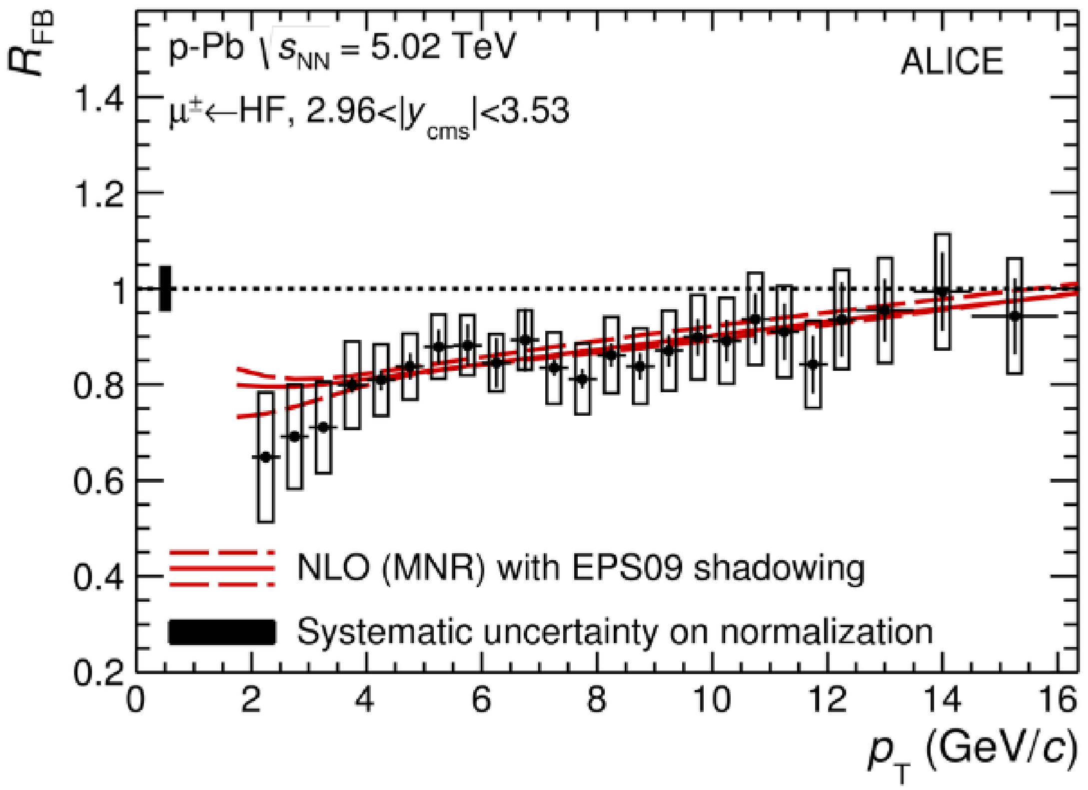
arXiv:1707.01005 Submitted to: **PRL**



- Mass ordering at low-pT, as expected from hydrodynamic calculations.

Forward/backward rapidity ratio, in pPb

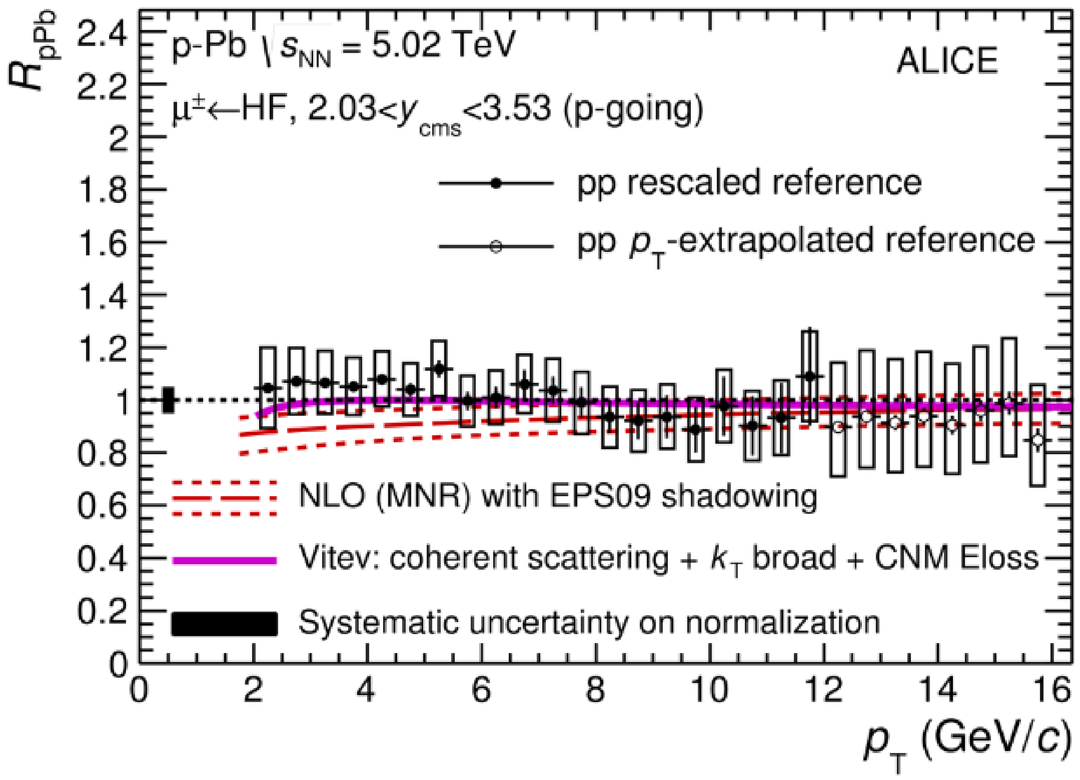
[Phys. Lett. B 770 (2017) 459-472]

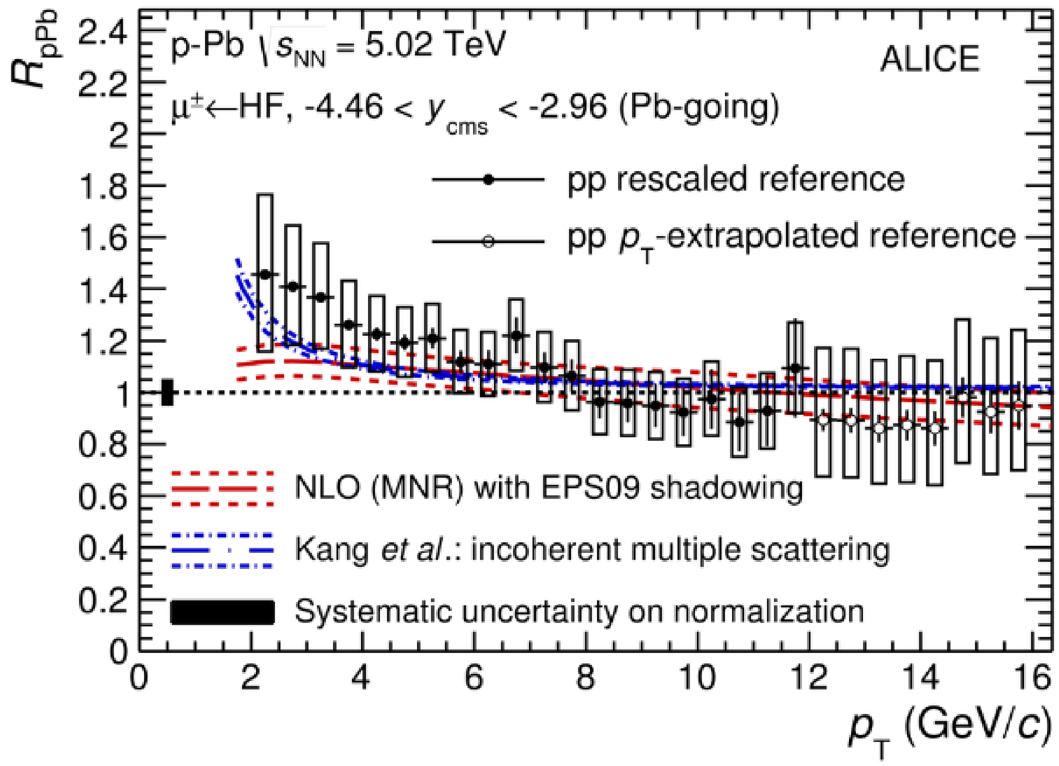


- Data well described by models with gluon shadowing

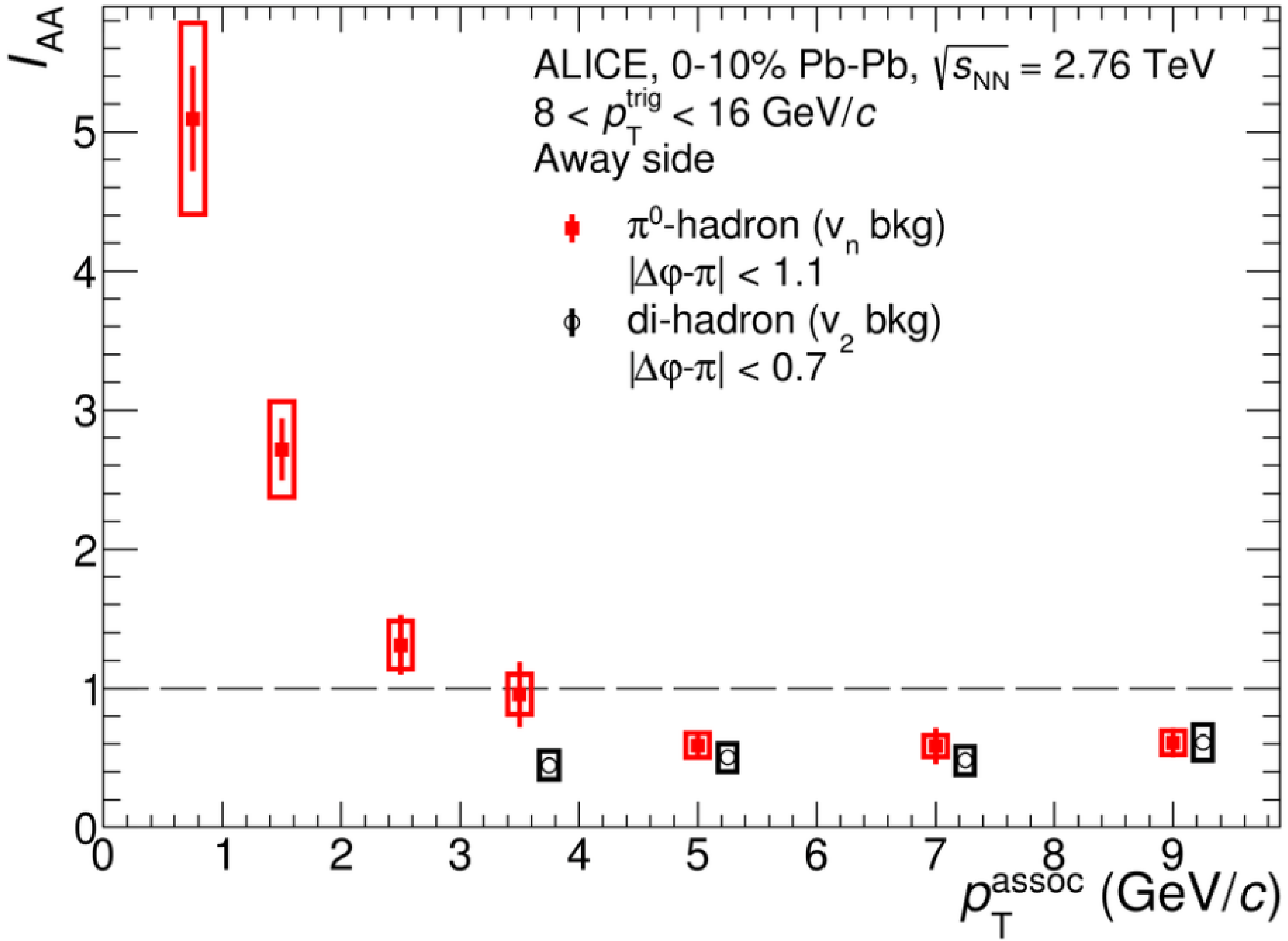
Muons from bottom and charm decays, in pPb

[Phys. Lett. B 770 (2017) 459-472]



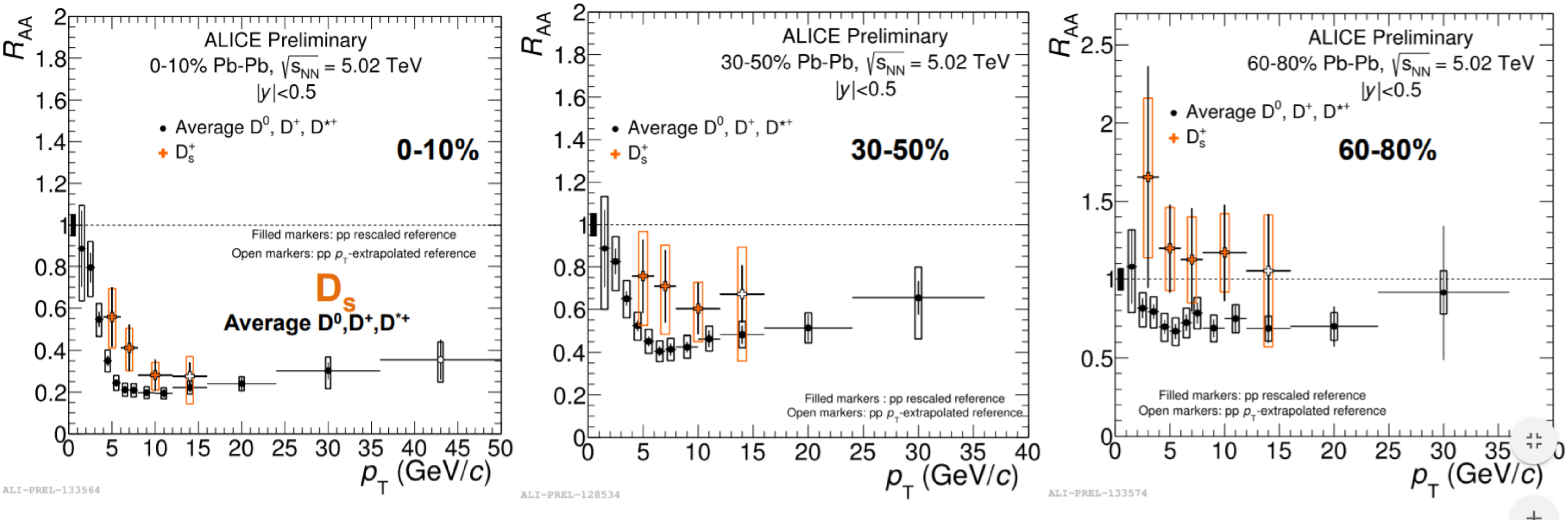


- Data well described by models with gluon shadowing



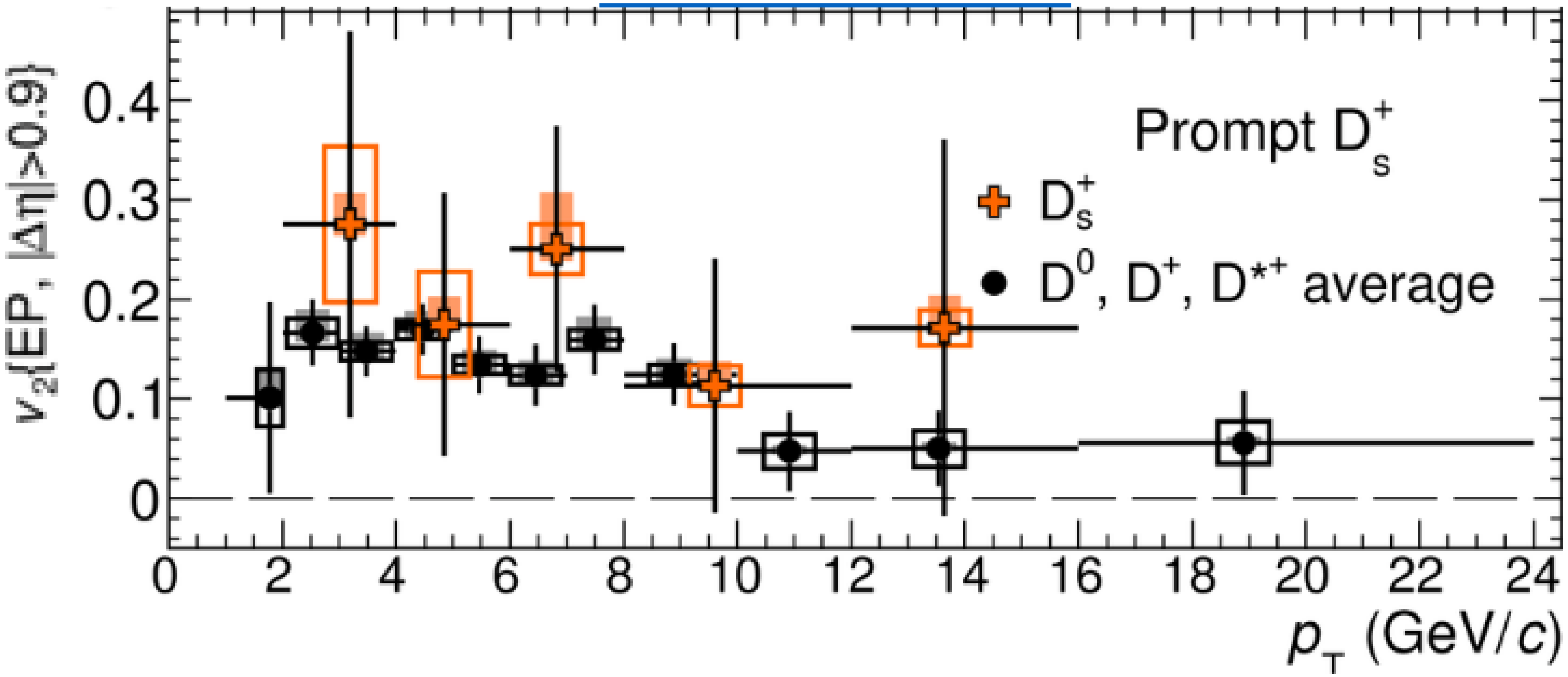
I_{AA}
ALICE, 0-10% Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
8 < p_T^{trig} < 16 GeV/c
Away side
π^0-hadron (v_n bkg)
$|\Delta\varphi-\pi|$ < 1.1
di-hadron (v_2 bkg)
$|\Delta\varphi-\pi|$ < 0.7
0
1
2
3
4
5
6
7
8
9
p_T^{assoc} (GeV/c)

Hint of less suppression for strange-D

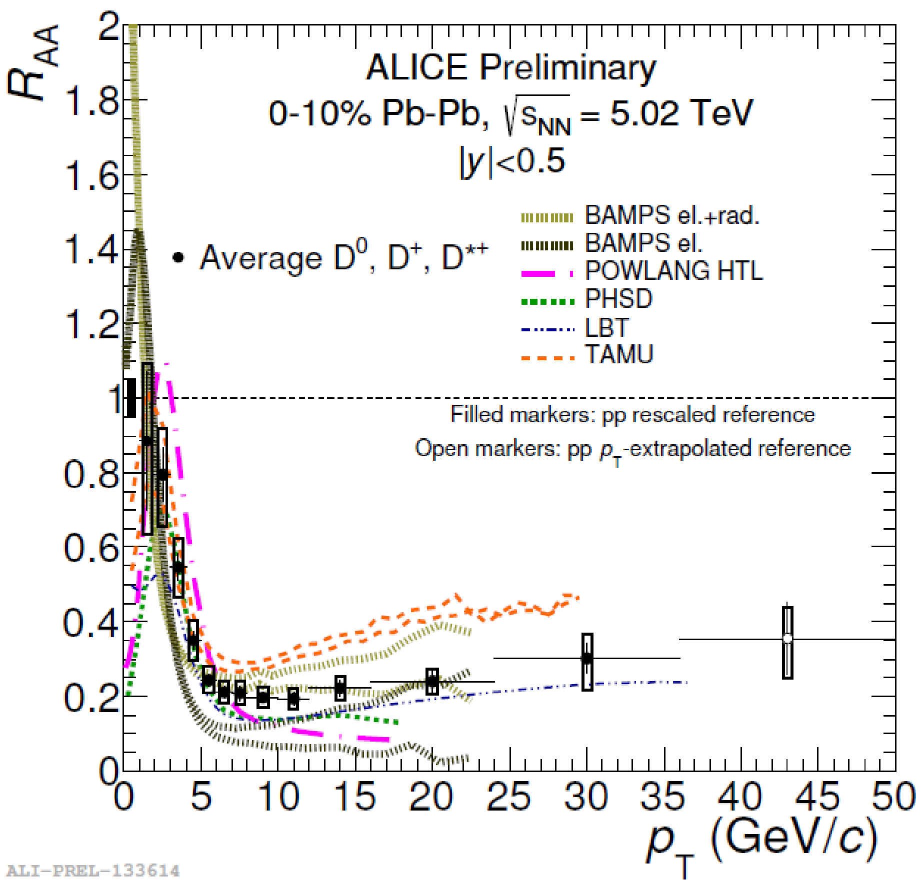


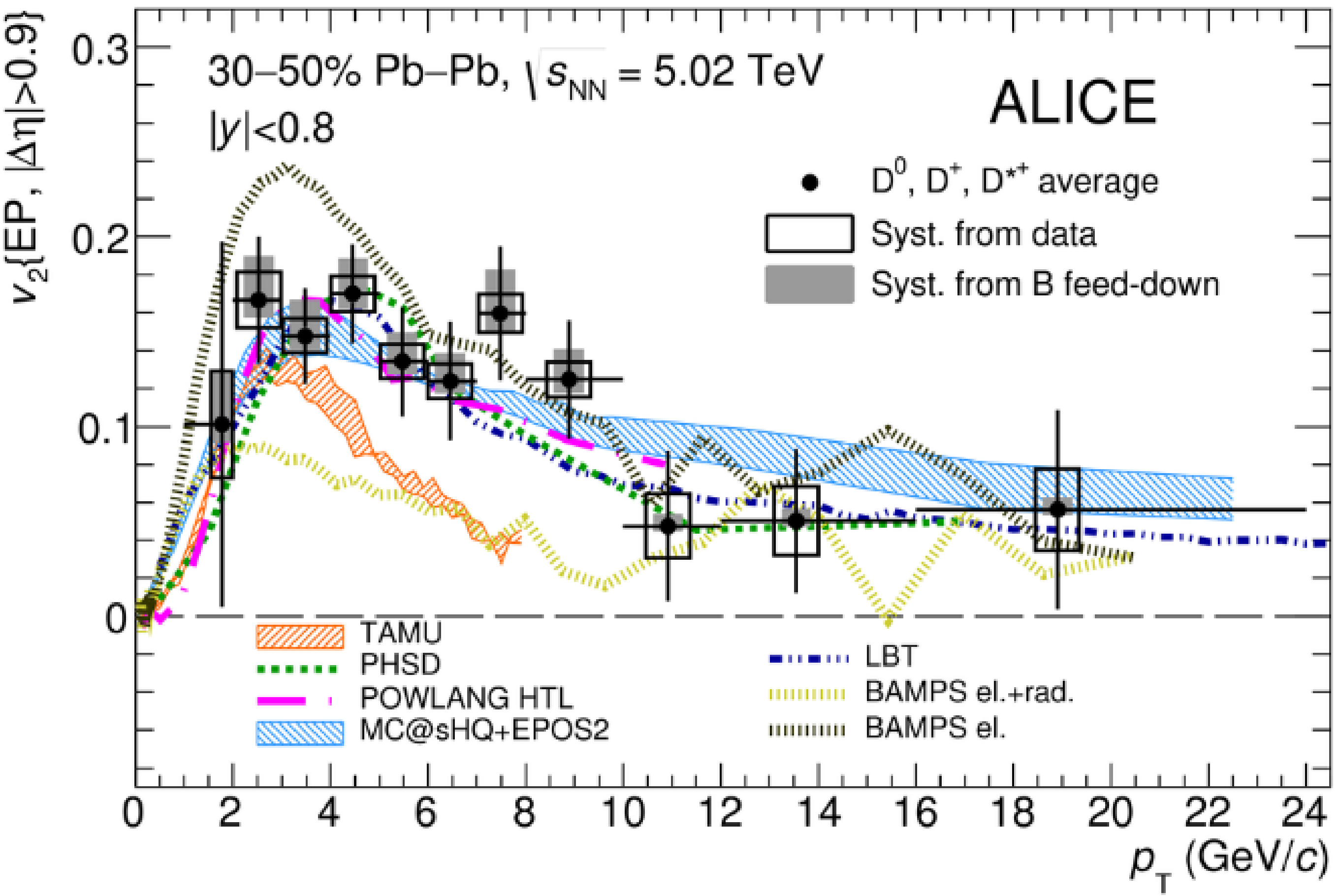
Strange D-meson, Ds*

arXiv:1707.01005 Submitted to: **PRL**



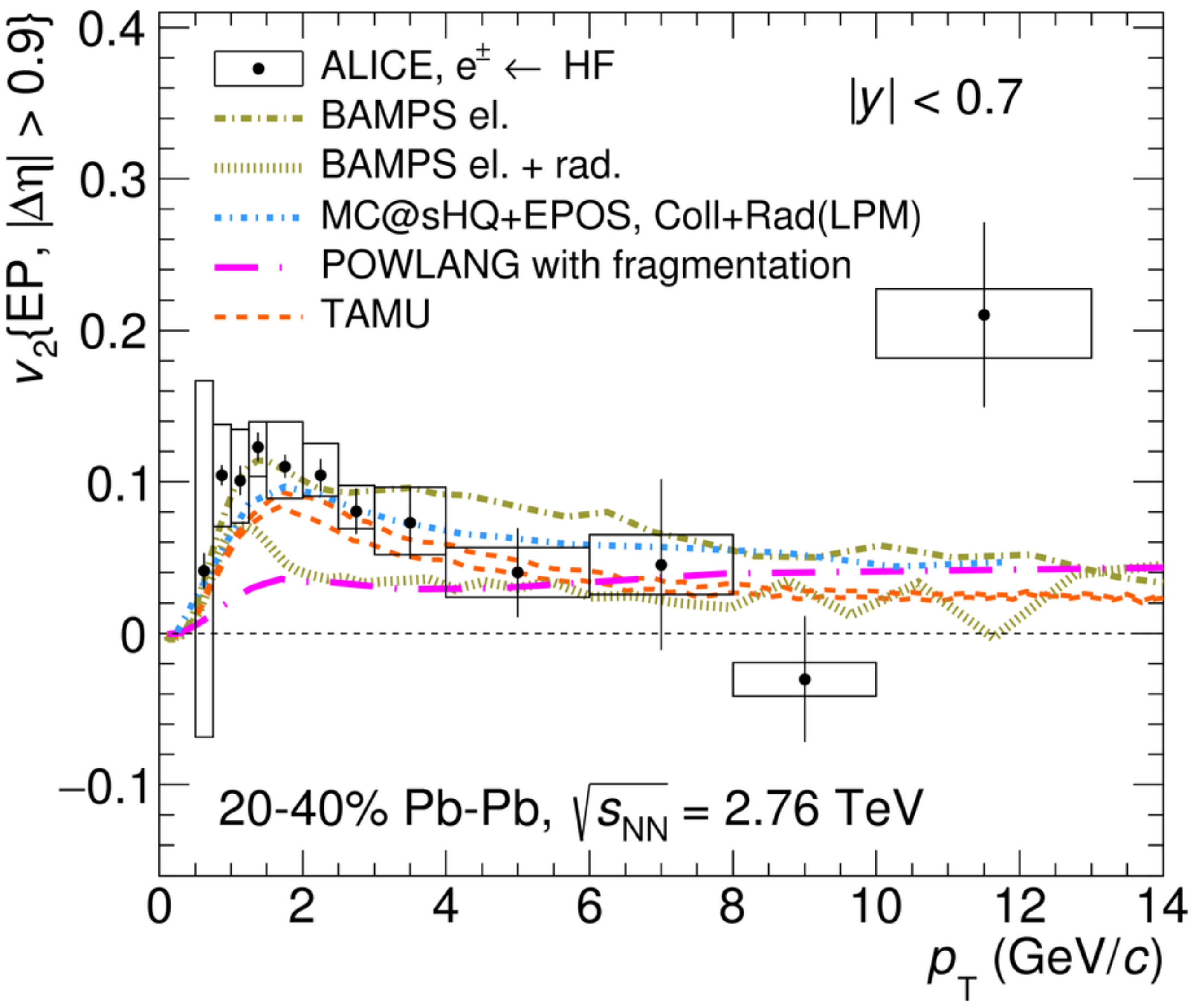
First LHC measurement, compatible with that of non-strange D-mesons





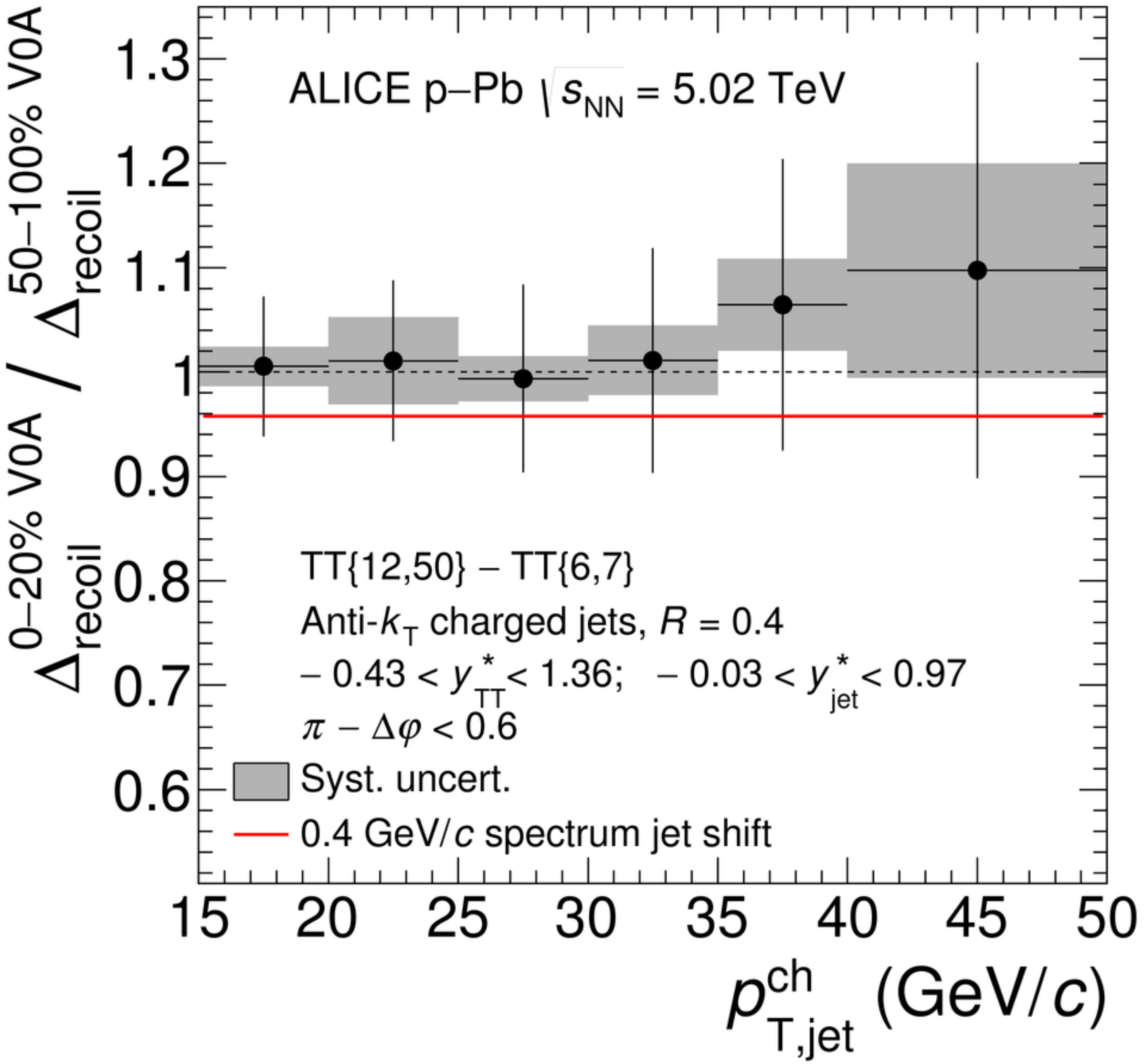
$$2\pi T D_s(T) \approx 1.5\text{–}7 \text{ at the critical temperature } T_c$$

Elliptic flow of electrons from heavy quarks



Constraints on jet quenching in p-Pb collisions

arXiv:1712.05603 submitted to: JHEP

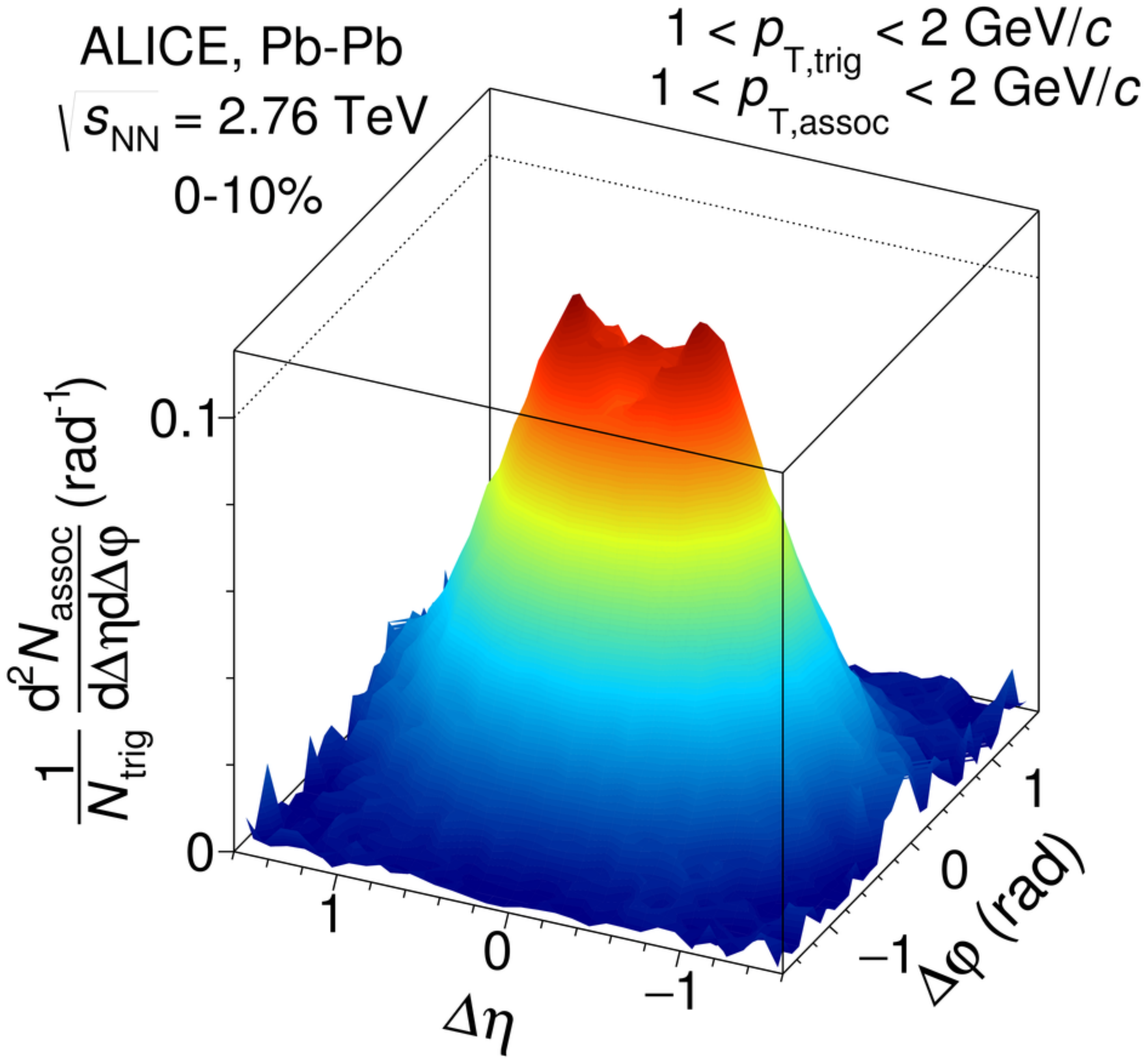


- Coincidence hadron—jet measurements in p+Pb collisions are used to constrain possible energy loss in p-Pb collisions.

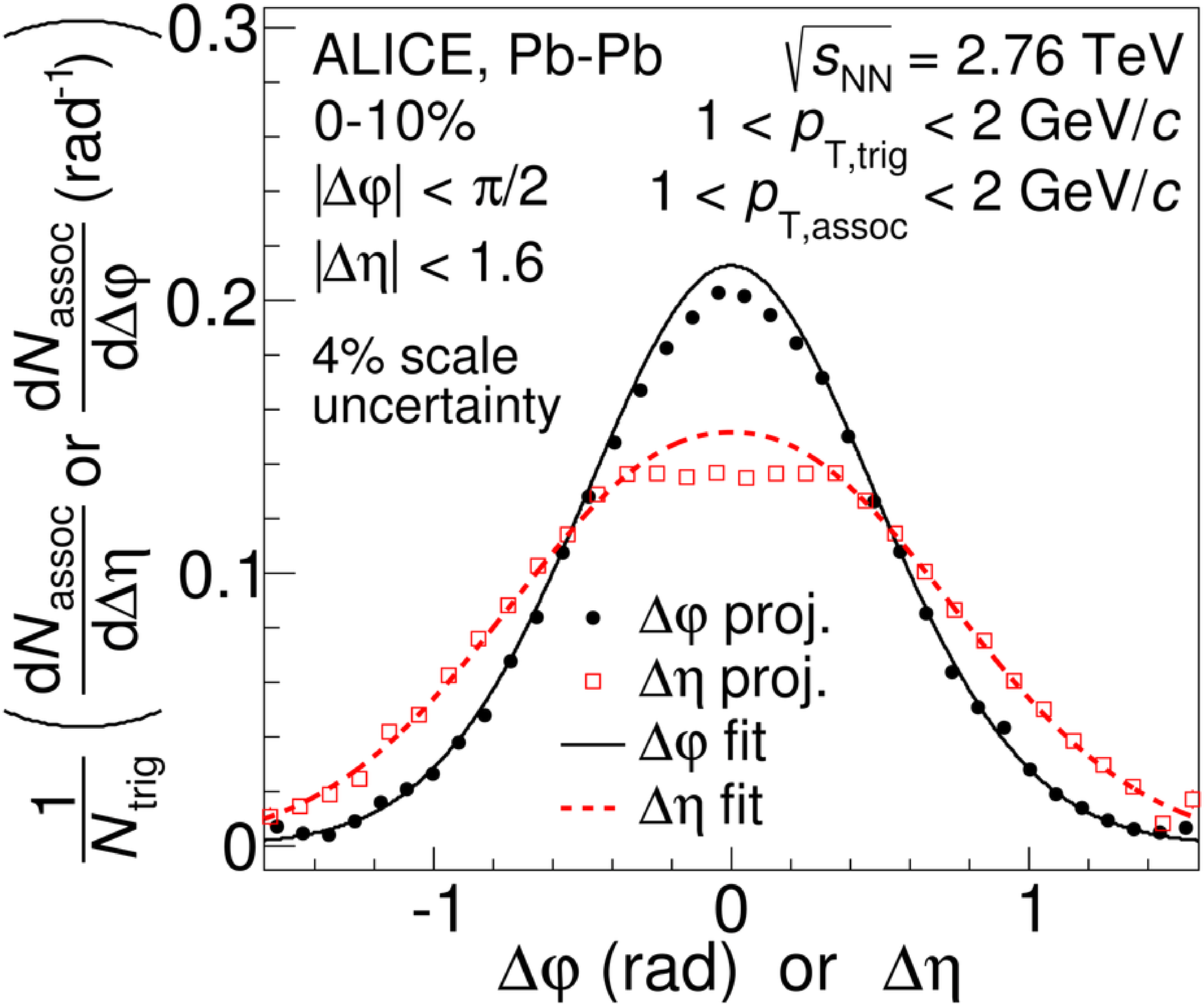
- ΔE < 400 MeV at 90 CL

Anomalous Evolution of the Near-Side Jet Peak Shape

[Phys.Rev.Lett. 119 (2017) 102301]

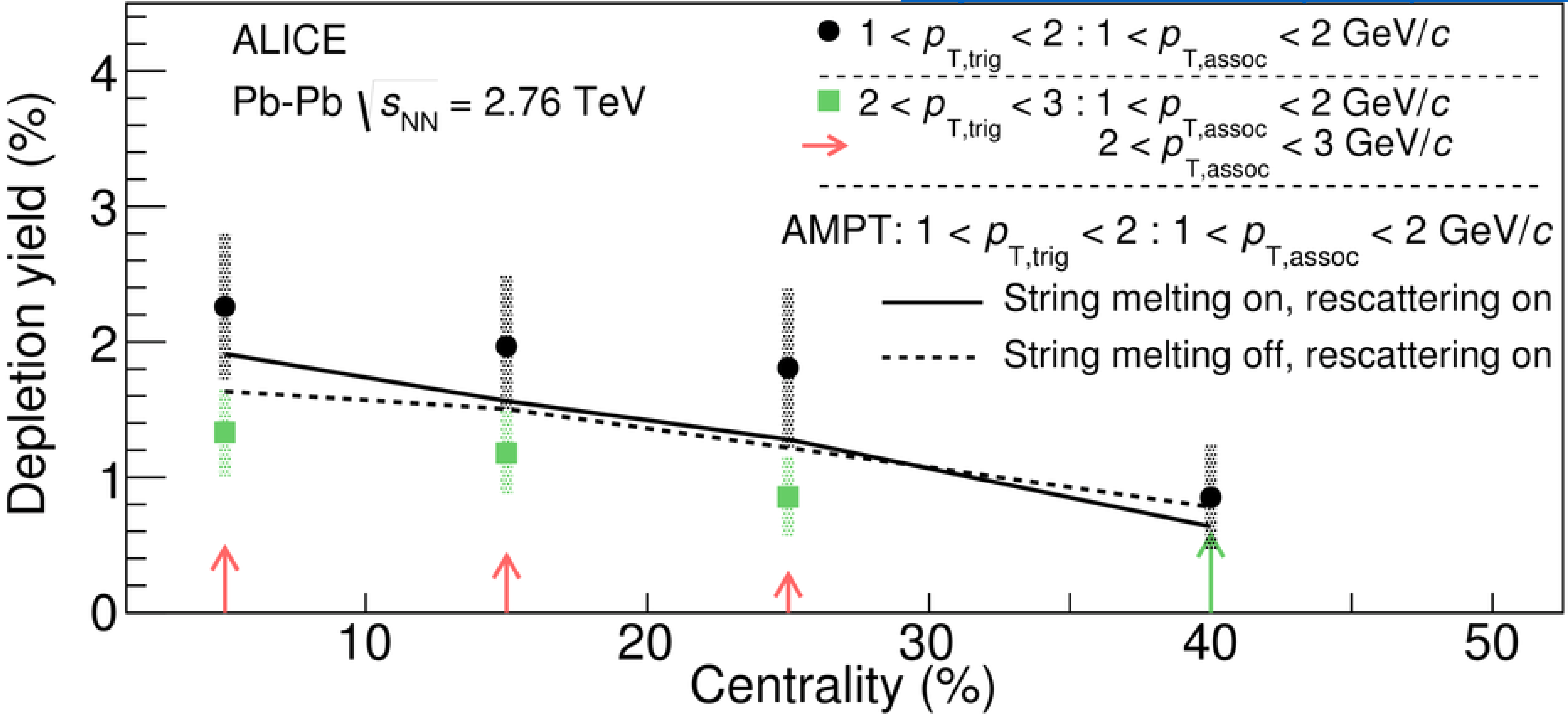


Phys.Rev.Lett. 119 (2017) 102301

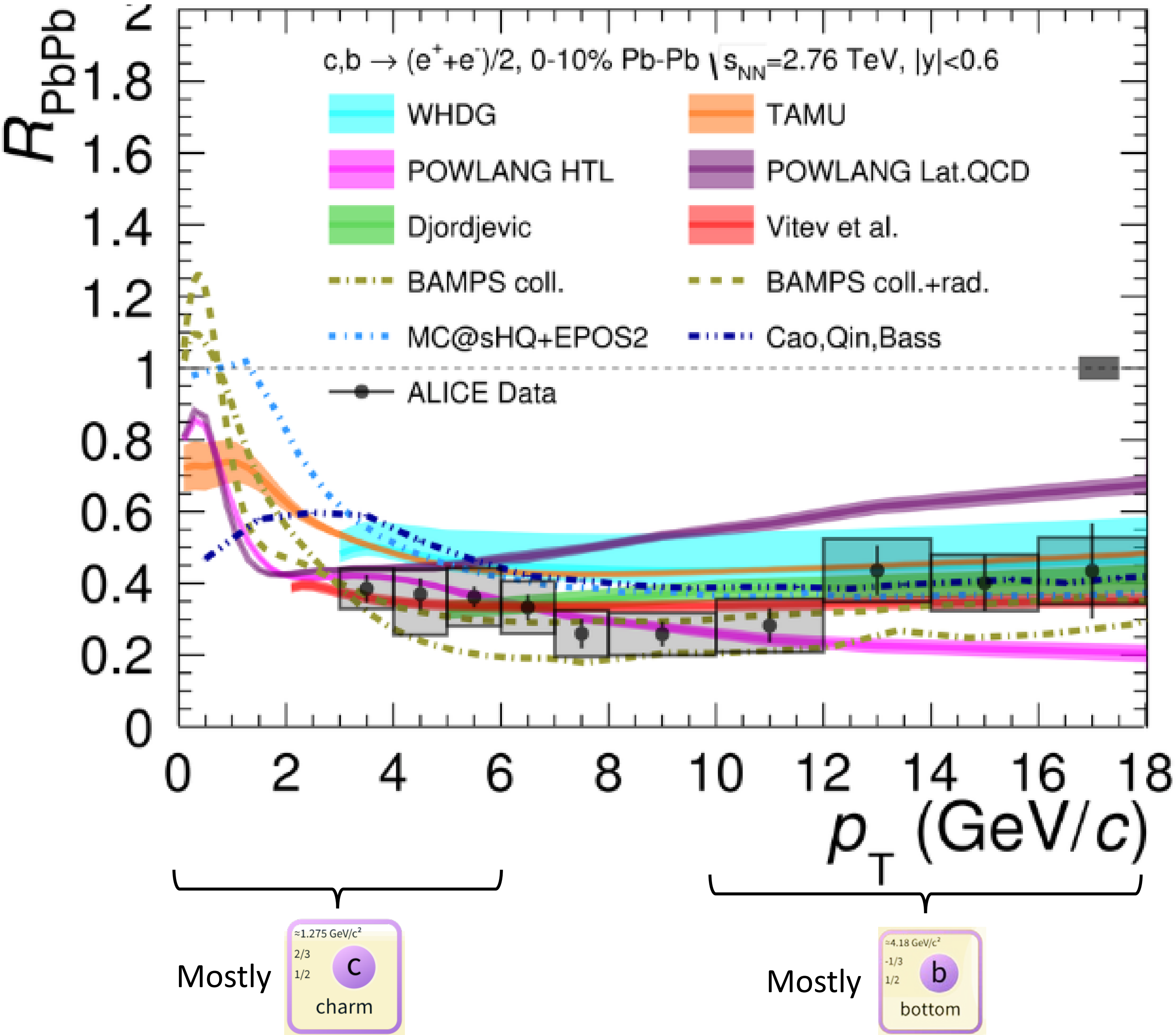


Flattening in $\Delta\eta$ is a previously unobserved effect

Phys.Rev.Lett. 119 (2017) 102301



Broadening depletion connected to flow



Both c and b quarks lose substantial part of their energy in quark-gluon plasma