Recent results on heavy-flavour production at RHIC and at the LHC

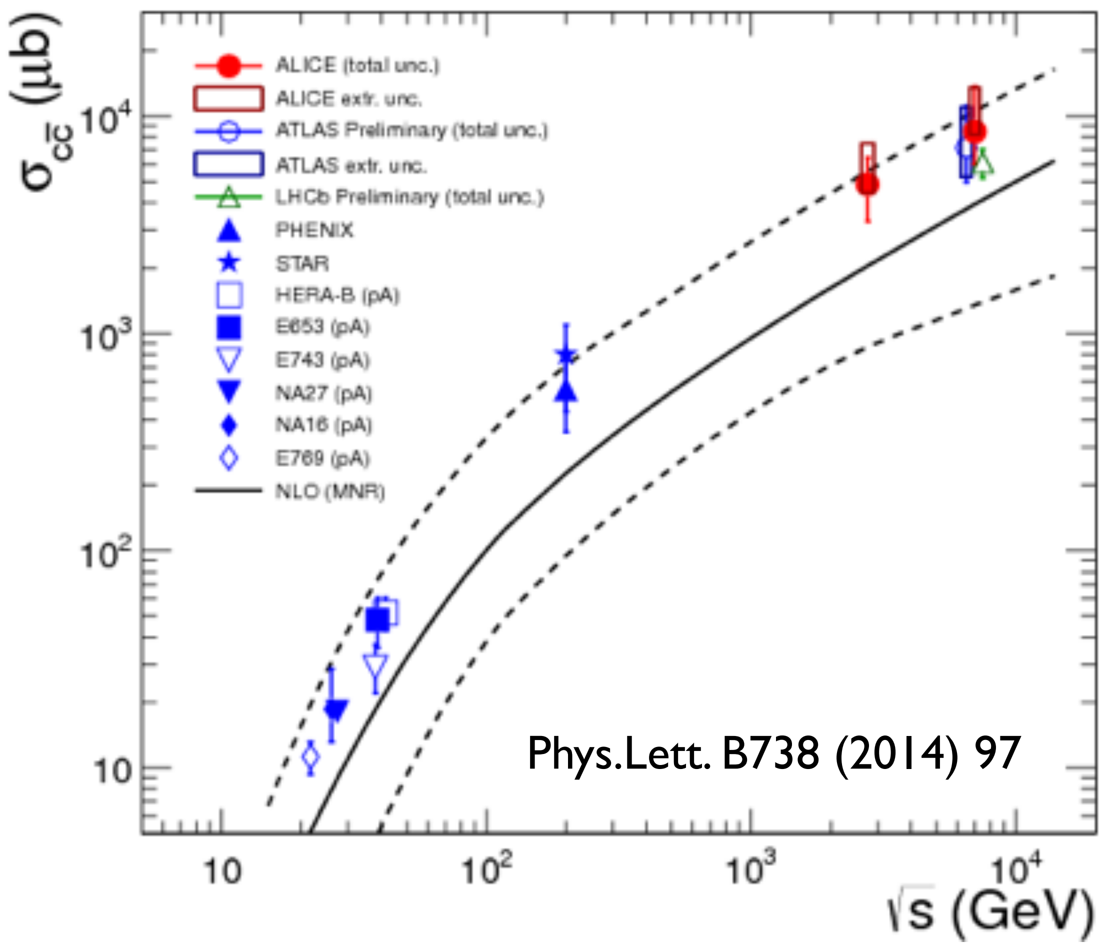
Gian Michele Innocenti
Massachusetts Institute of Technology (MIT)

"Recent RHIC and LHC results and their implications for heavy ion physics in the 2020's"

28-29 October 2016
MIT, Cambridge

Heavy flavours in heavy-ion collisions

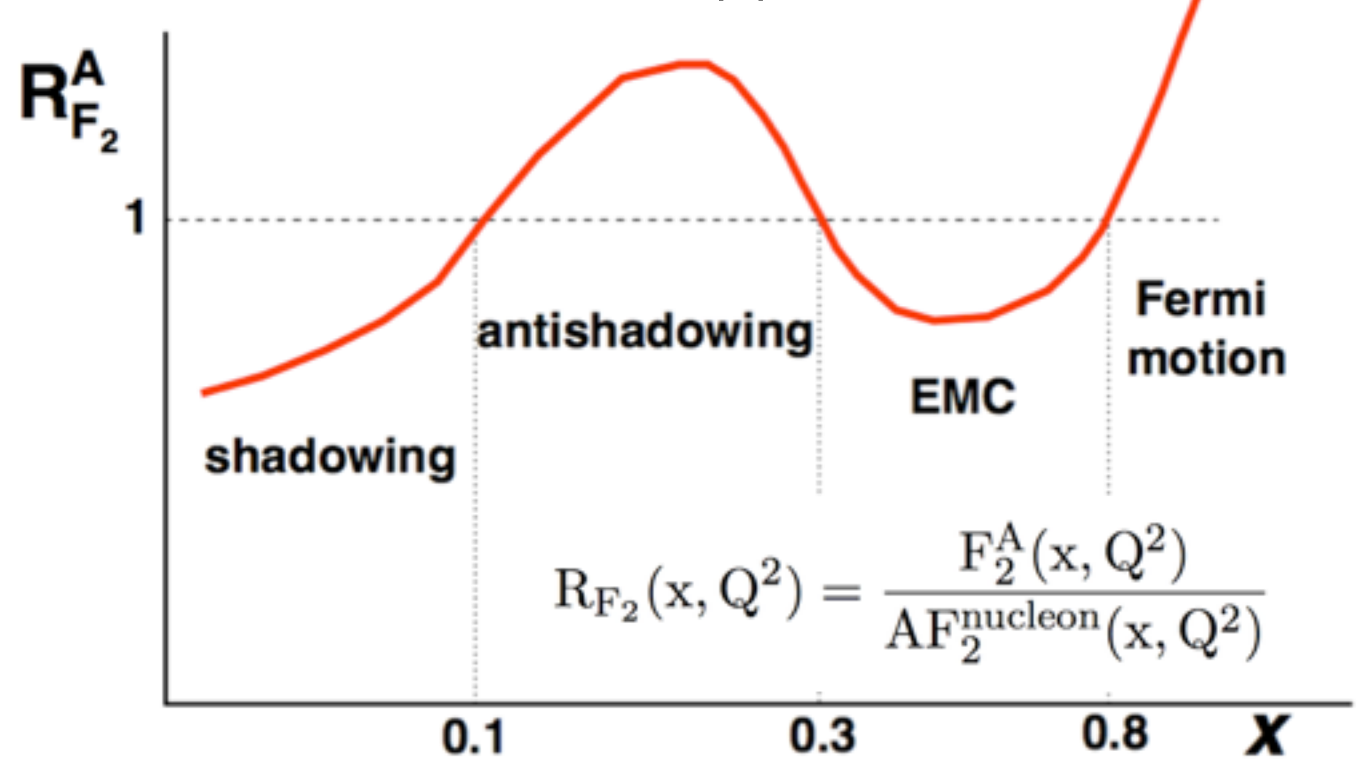
Heavy quarks produced in high-Q^2 processes at early stages of the collisions



pp:
- test of pQCD calculations
- reference for pA and AA measurements
- role of MPI interactions

pPb:
- test of cold nuclear matter effects
  - PDF modifications
  - saturation
  - final state effects
- collective evolution (hydro?)

N. Armesto, arXiv:hep-ph/0604108v2.



Heavy flavours in heavy-ion collisions

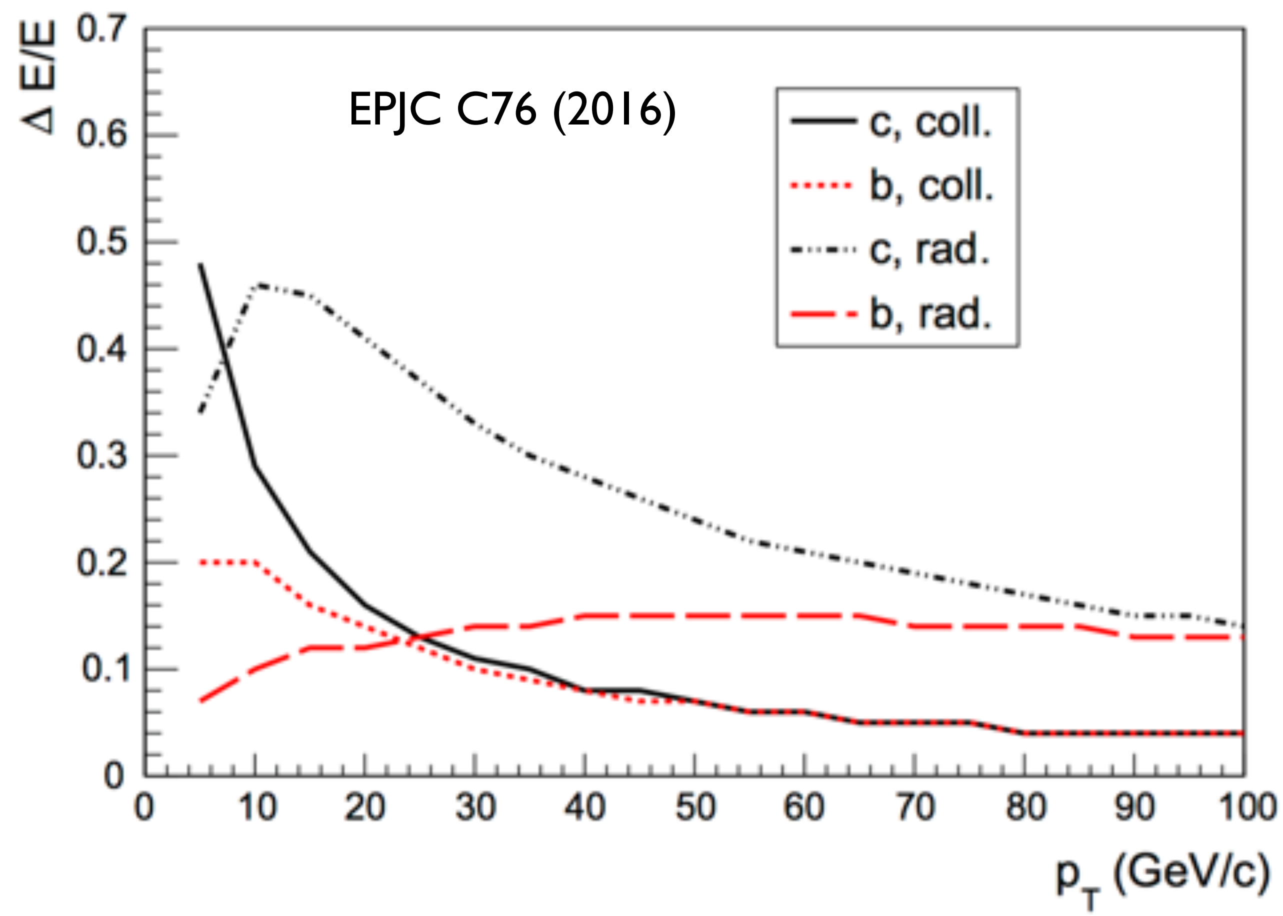
Heavy quark energy loss in PbPb:

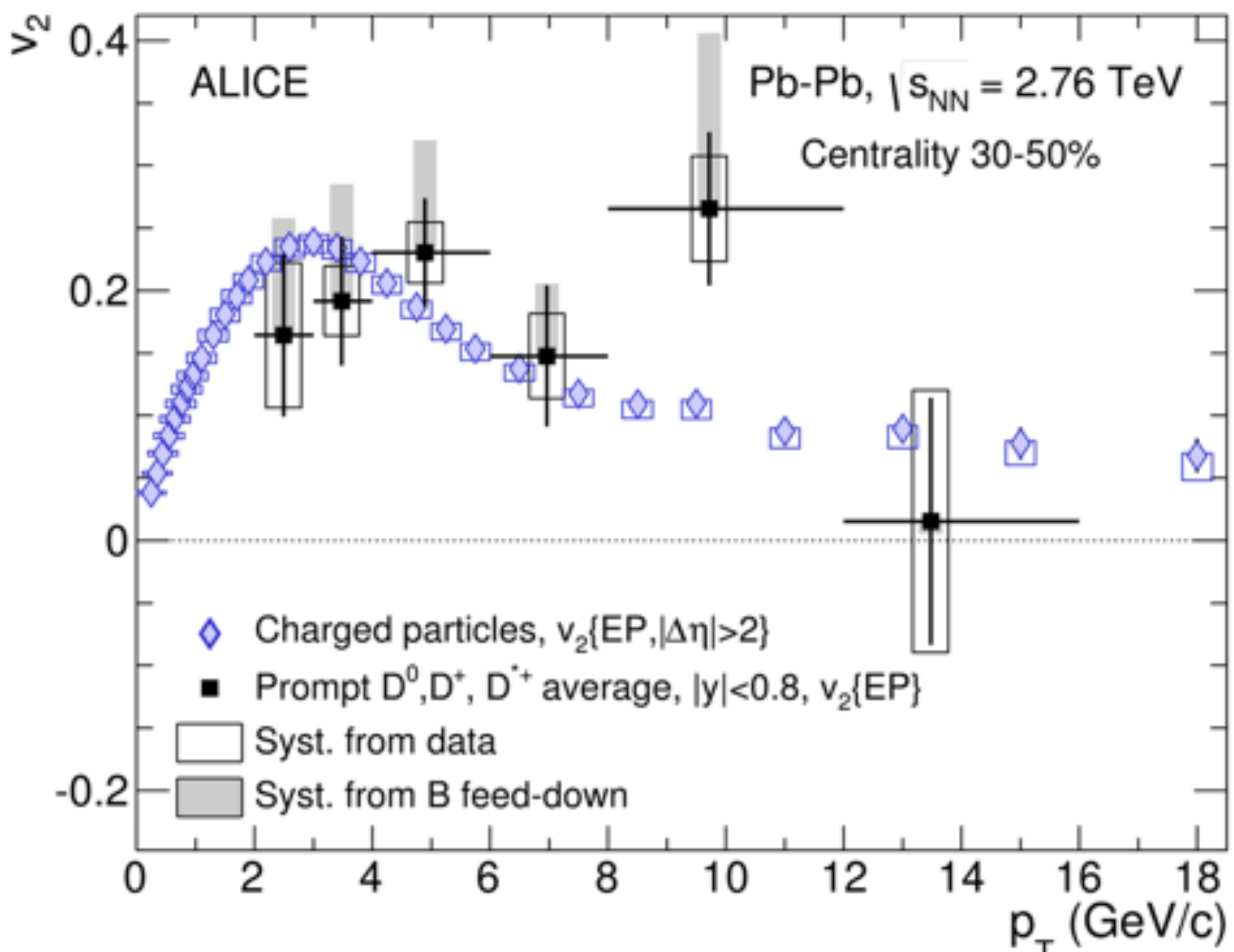
- **collisional** vs **radiative** component

Flavour dependence energy loss:

- $<\Delta E> \propto \alpha_s C_R q L^2$
- Dead cone effect: gluon radiation suppressed at small angles for massive quarks

→R_{AA}(charged)<R_{AA}(charm)<R_{AA}(beauty)?





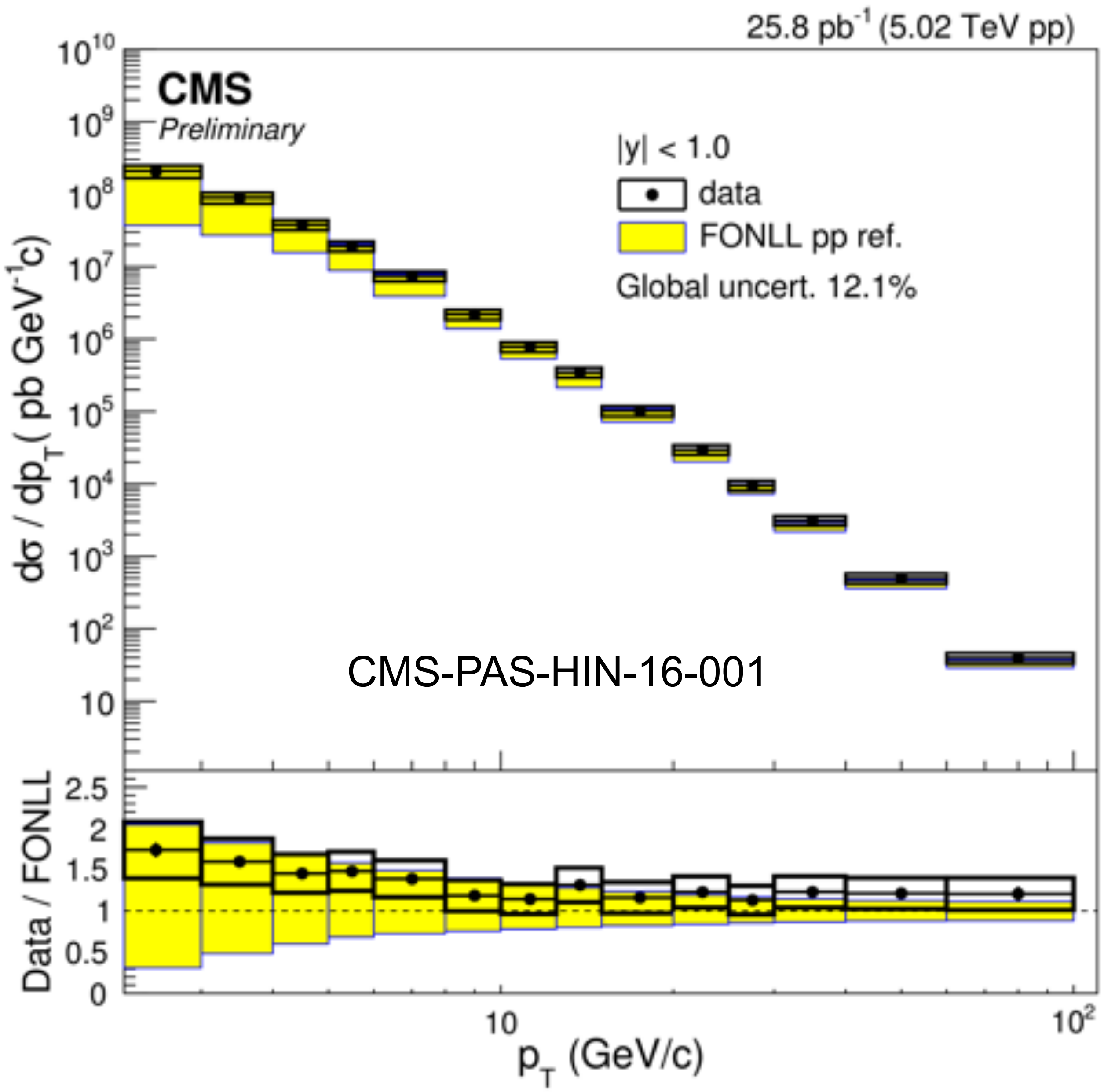
Collective behaviour:

- v_n measurements to study collective behaviour of heavy quarks
- charm recombination in medium?

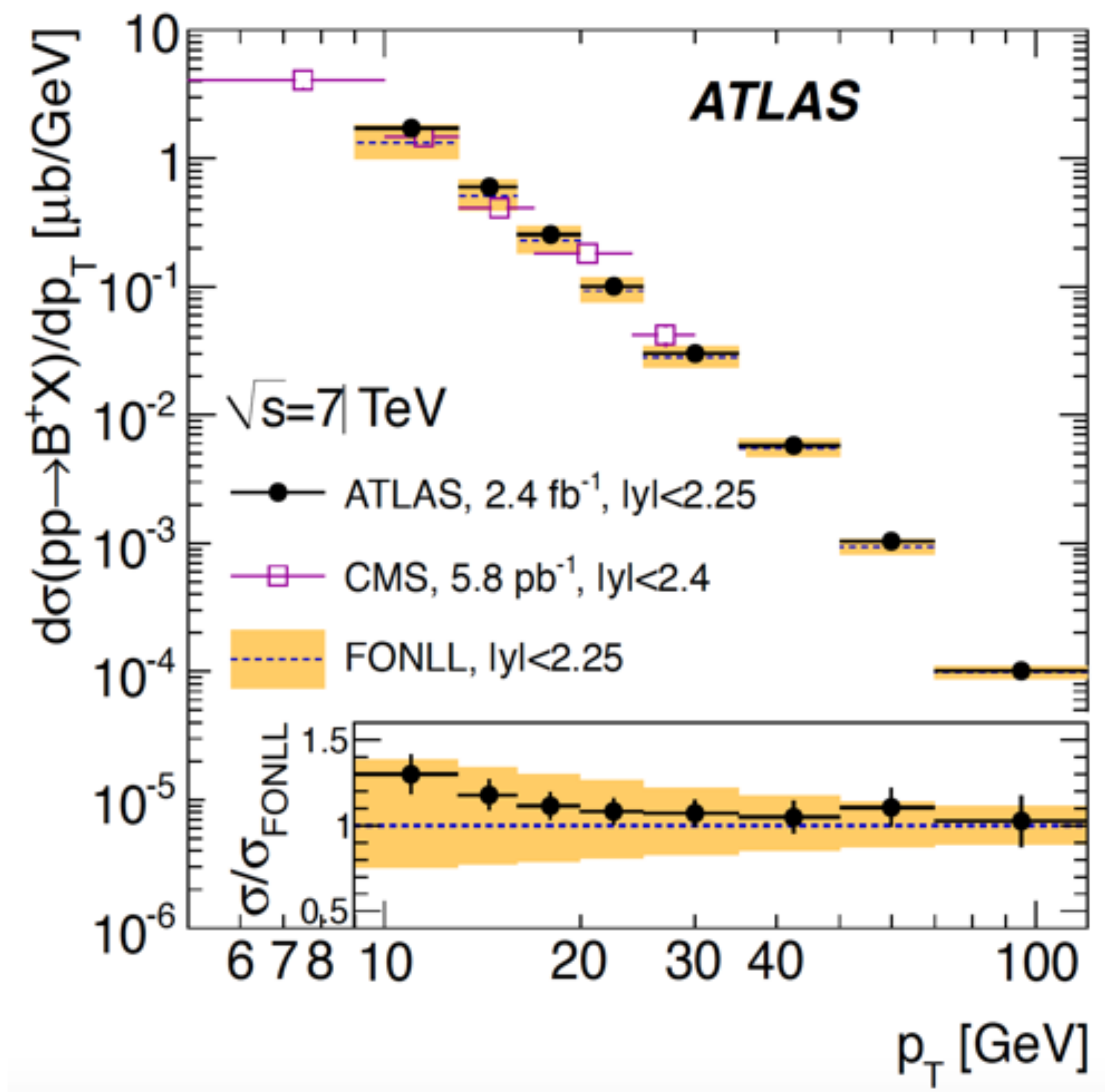
Open heavy flavour in pp collisions

D and B cross sections at LHC in pp collisions

CMS D^0 at 5.02 TeV, |y|<1.0



ATLAS B^+ measurement at 7 TeV, |y|<2.25

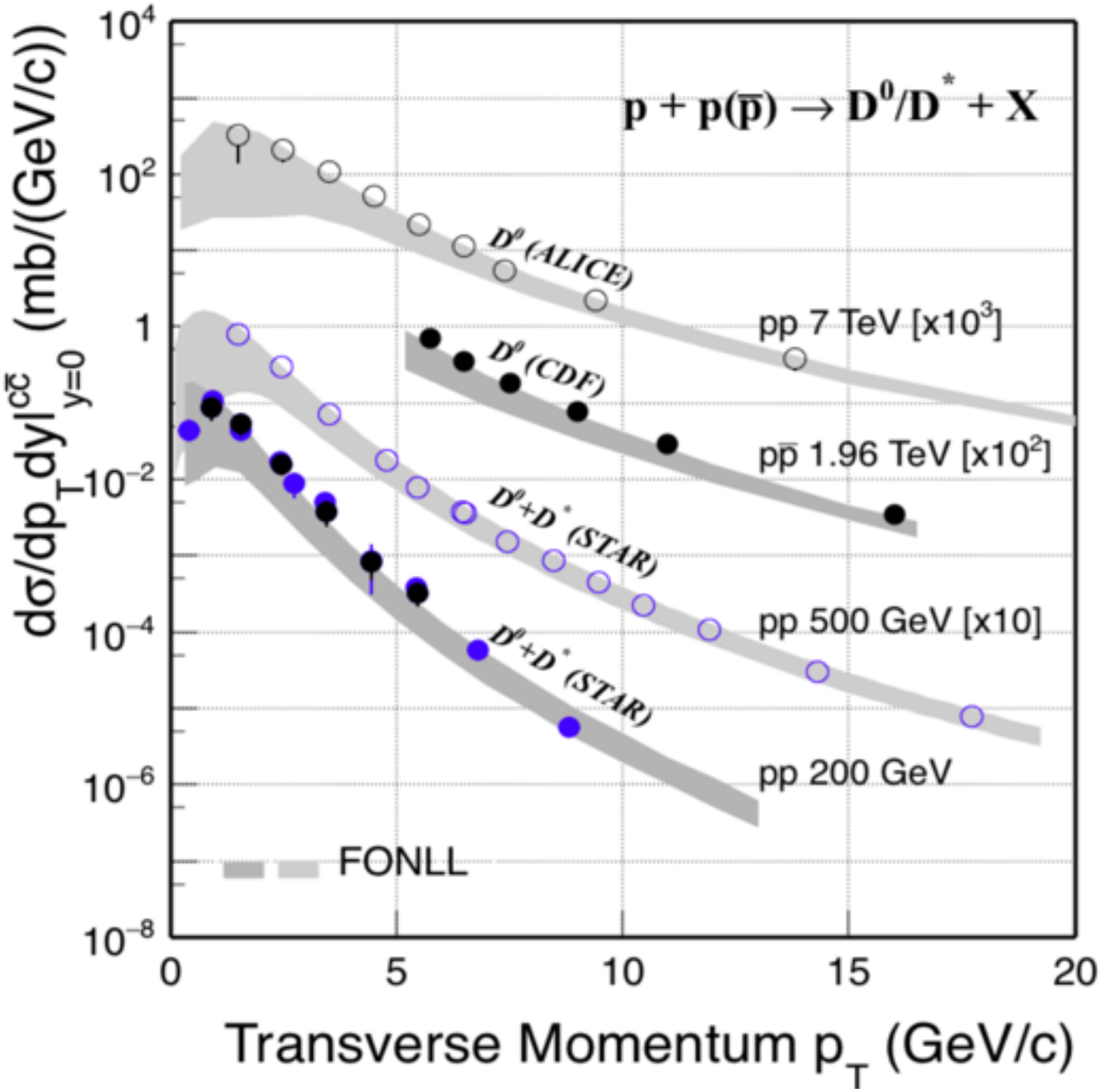


HF production cross sections well described by NLO calculations:

→*D meson upper edge of FONLL calculations*

→*B meson consistent with central values of FONLL*

Charm production at RHIC

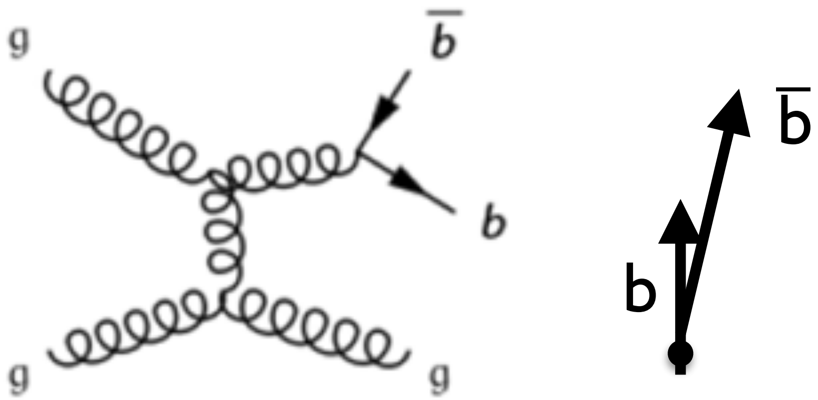


FONLL well describes charm production also at RHIC energies!

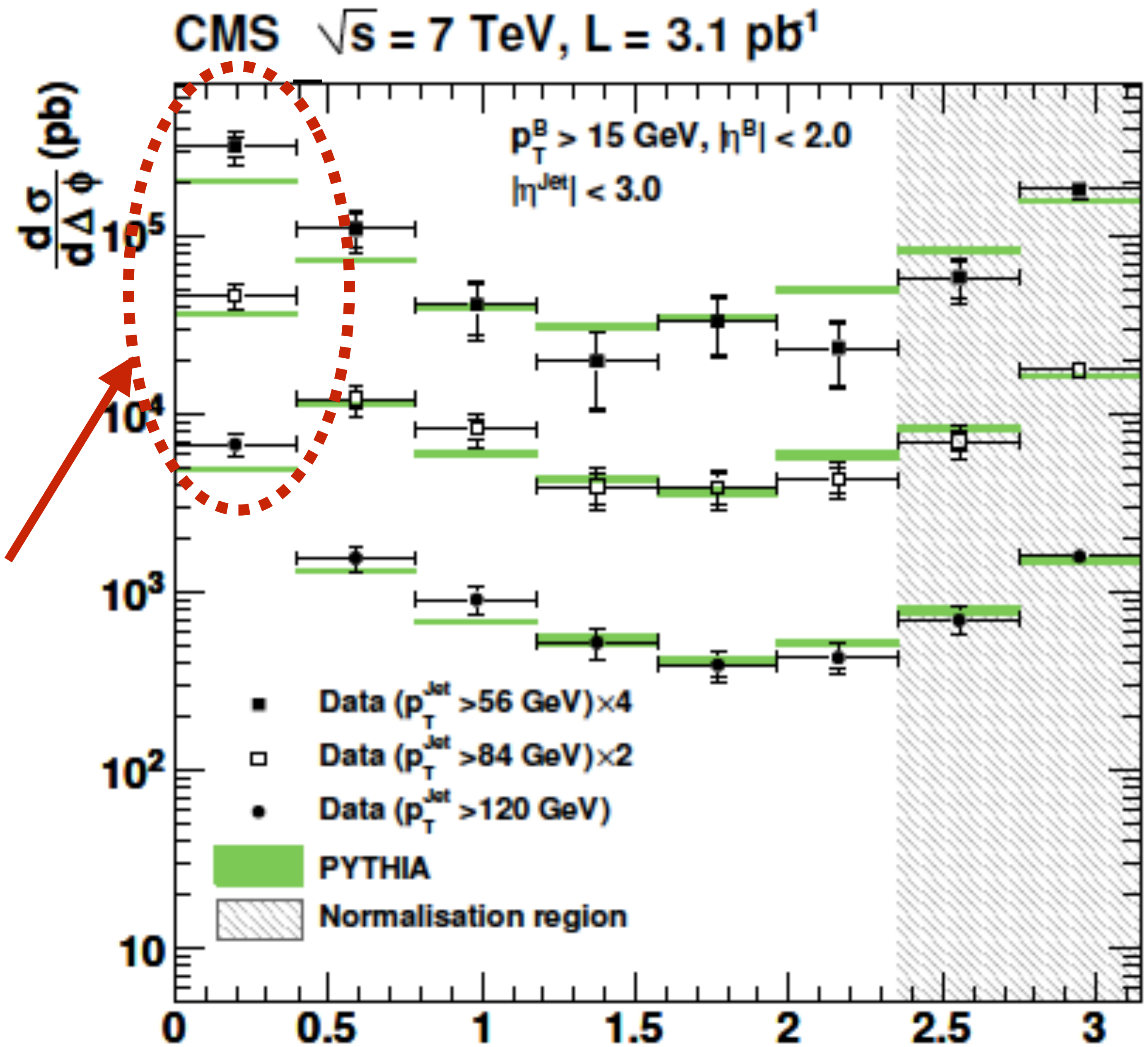
$B\bar{B}$ $\Delta\phi$ correlations

NLO process: Gluon splitting (GSP)

→ produced with small opening angles and asymmetric in p_T



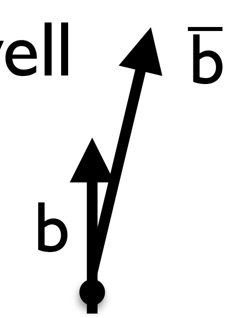
$B\bar{B}$ correlations strongly affected by gluon splitting processes at low $\Delta\phi$



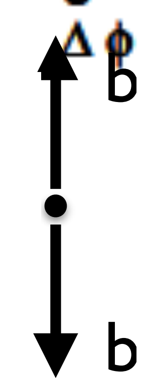
JHEP 1103:136,2011

Gluon splitting (GS) contribution not well modelled by most of the calculations

→GS contribution underestimated by models



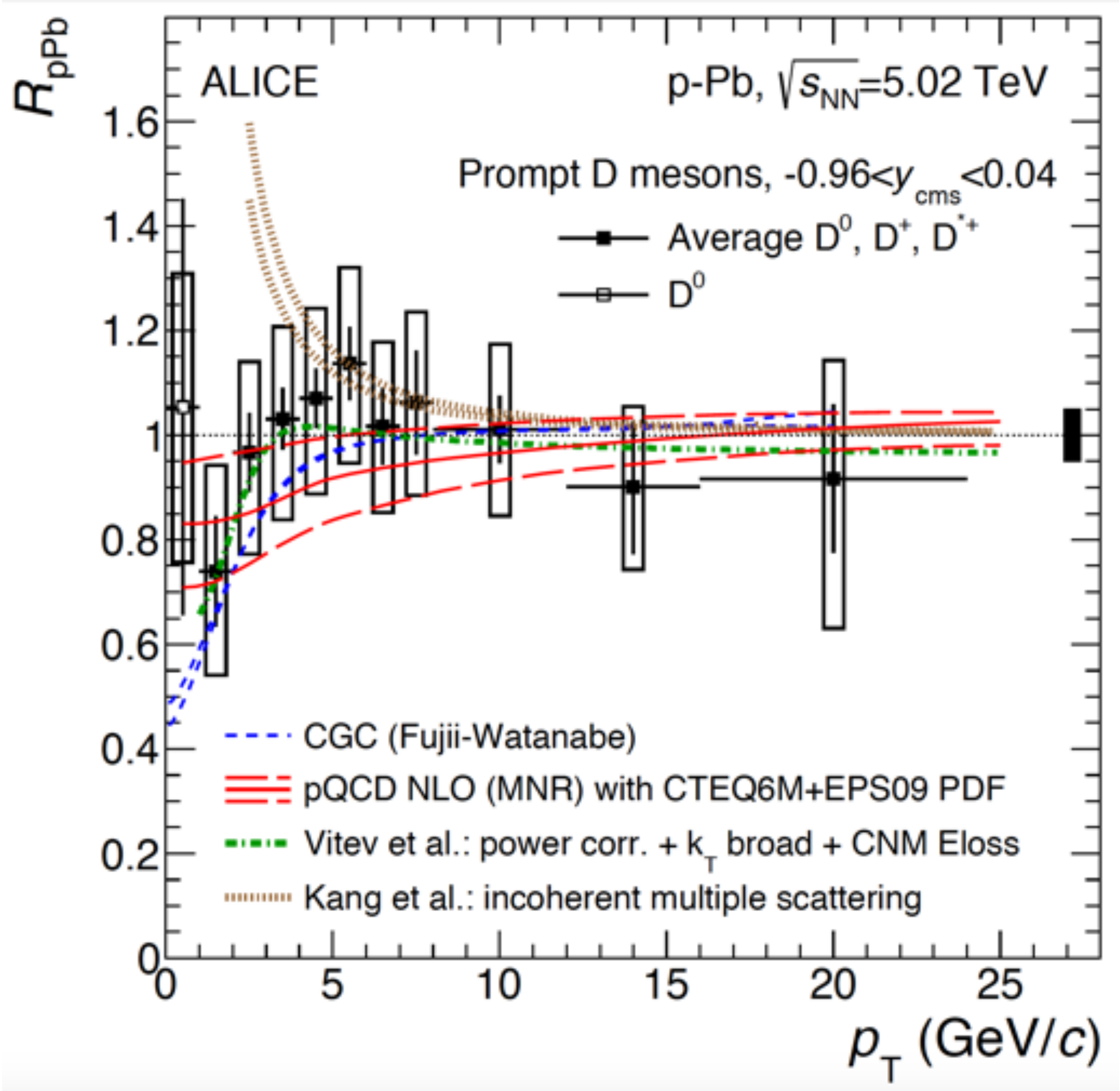
$\Delta\phi(B-\bar{B})$



Open heavy flavour in pPb collisions

D^0 production in pPb collisions in |y|<0.5

ALICE D measurements at 5.02 TeV, |y|<0.5



PRL 113 (2014) 232301

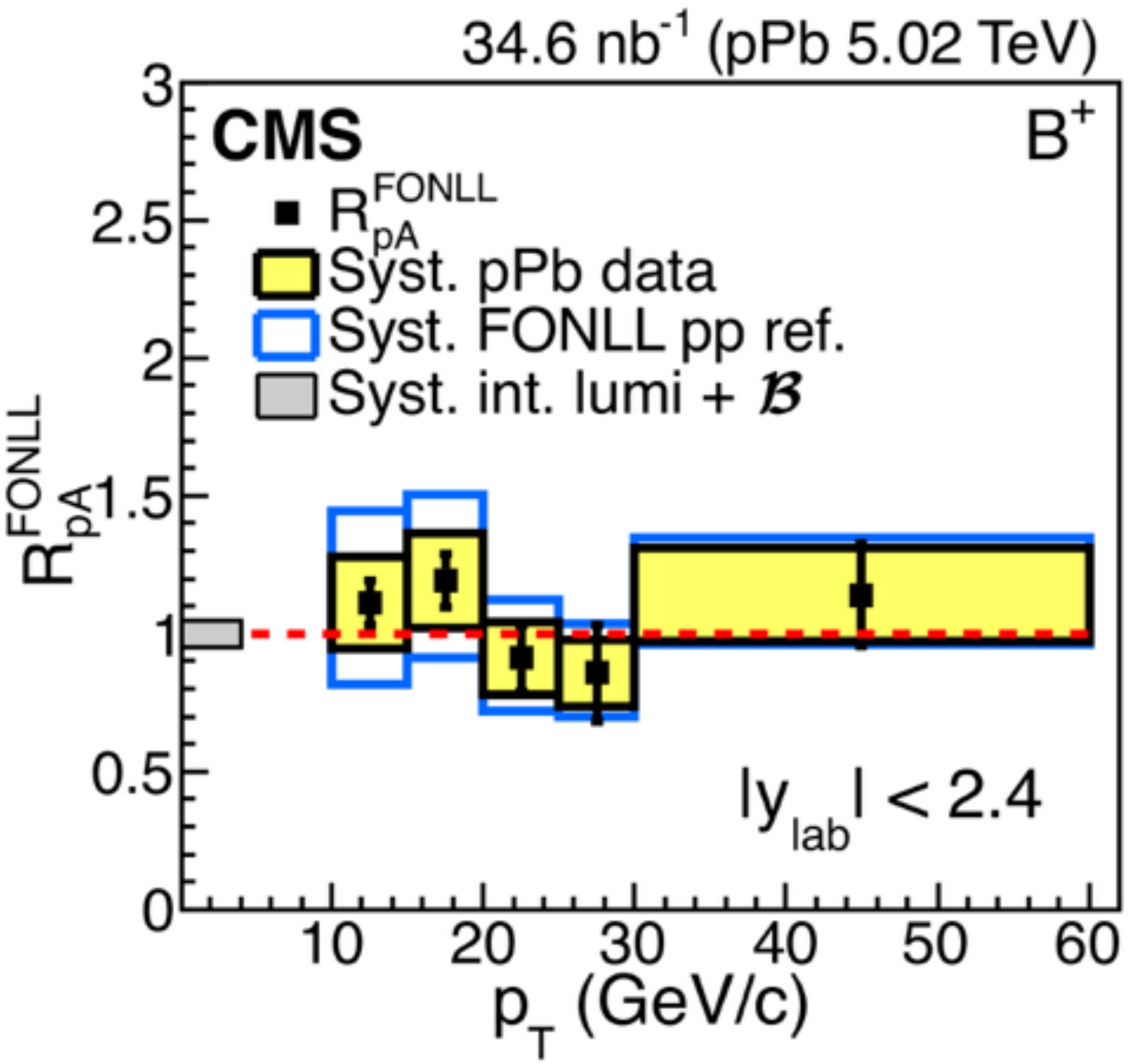
R_{pA}<1 at low p_T consistent with shadowing

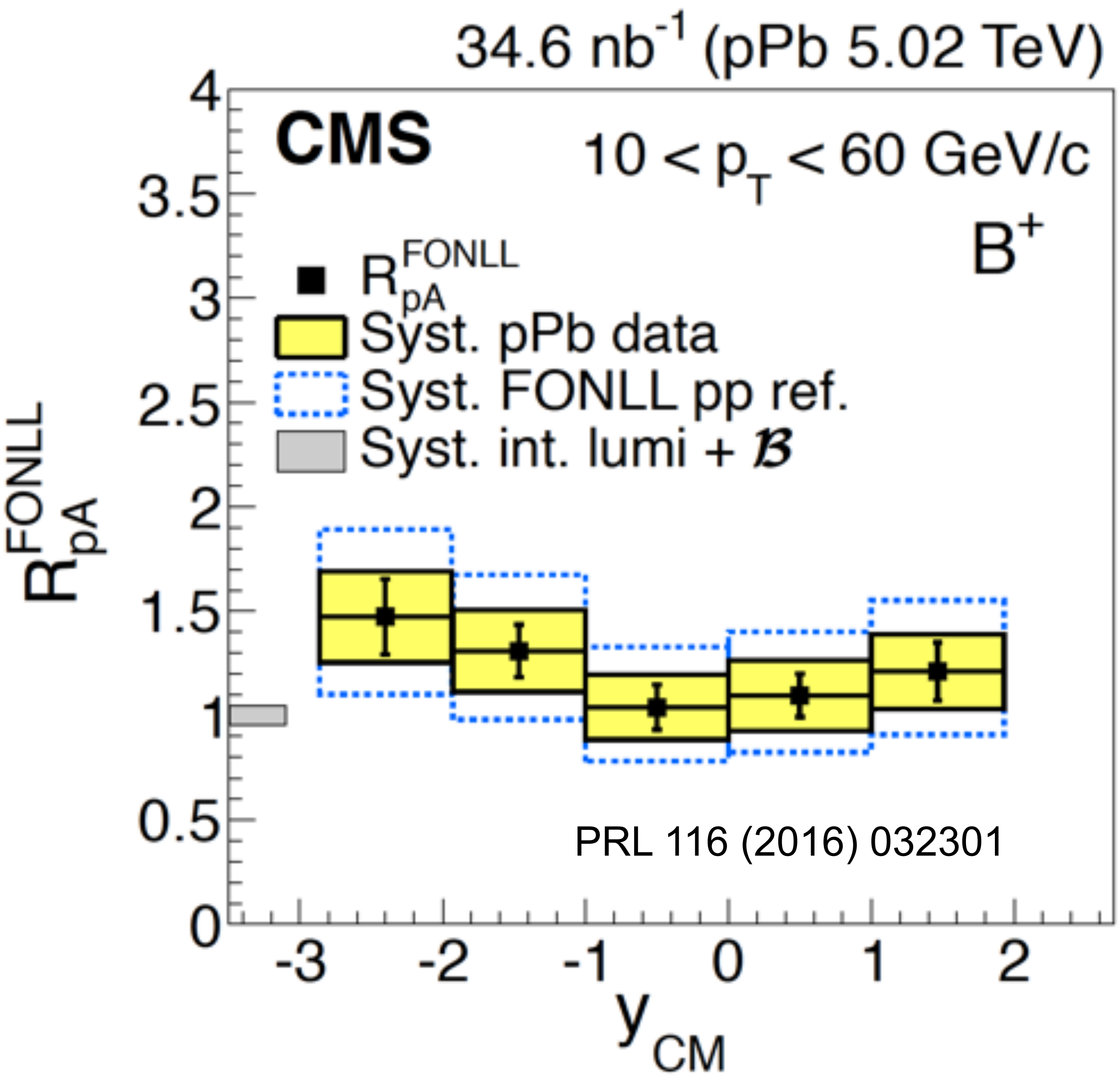
R_{pA}~1 at high p_T

R_{pA} well described by Cold Nuclear Matter (CNR) models and consistent with unity at high p_T!

Not possible to discriminate between various models with current uncertainties

B meson production in pPb collisions

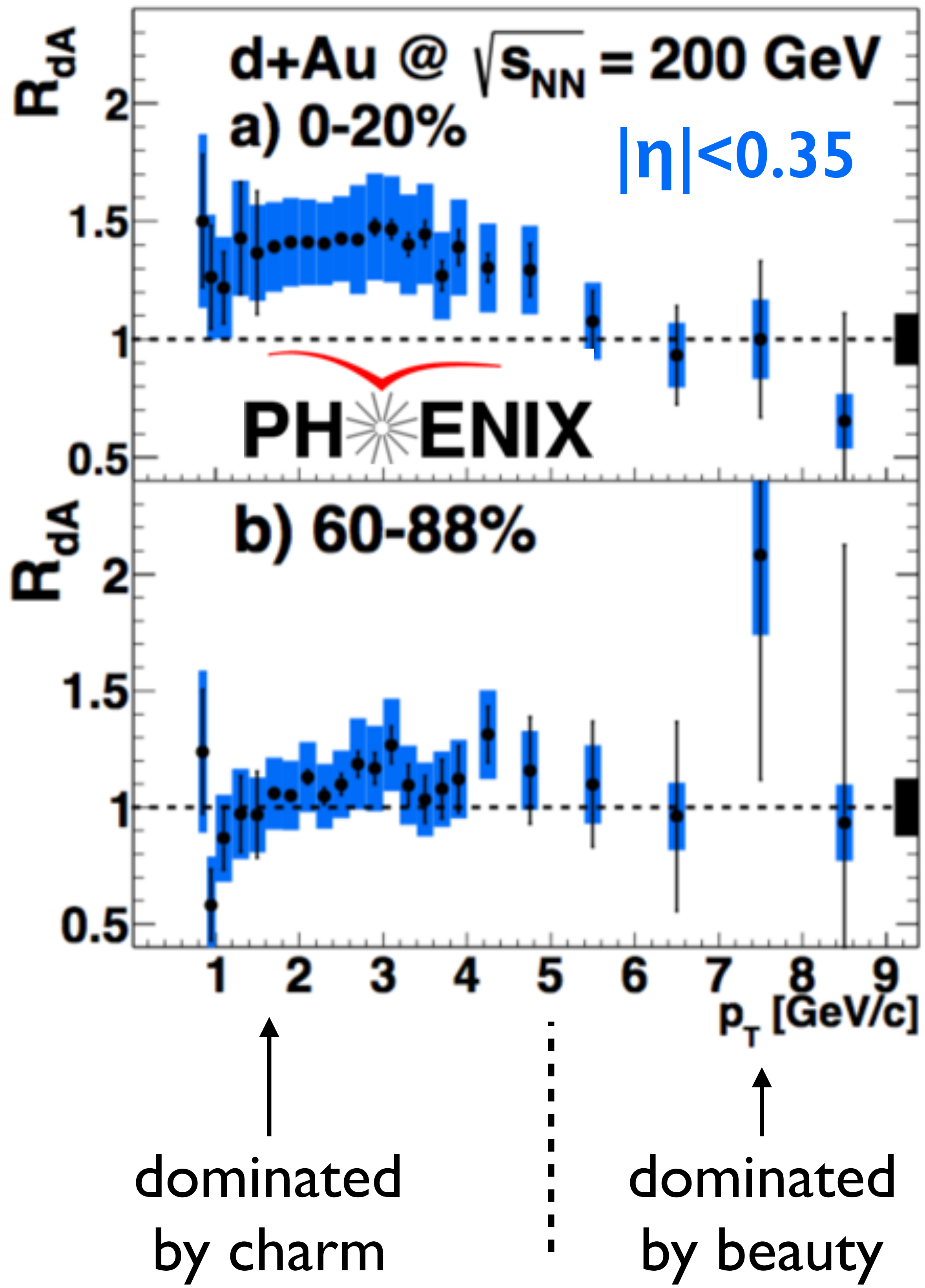




FONLL R_{pA} fully compatible with unity

No sizeable modification as a function of rapidity

R_{pA} of HF electrons at mid-rapidity at RHIC

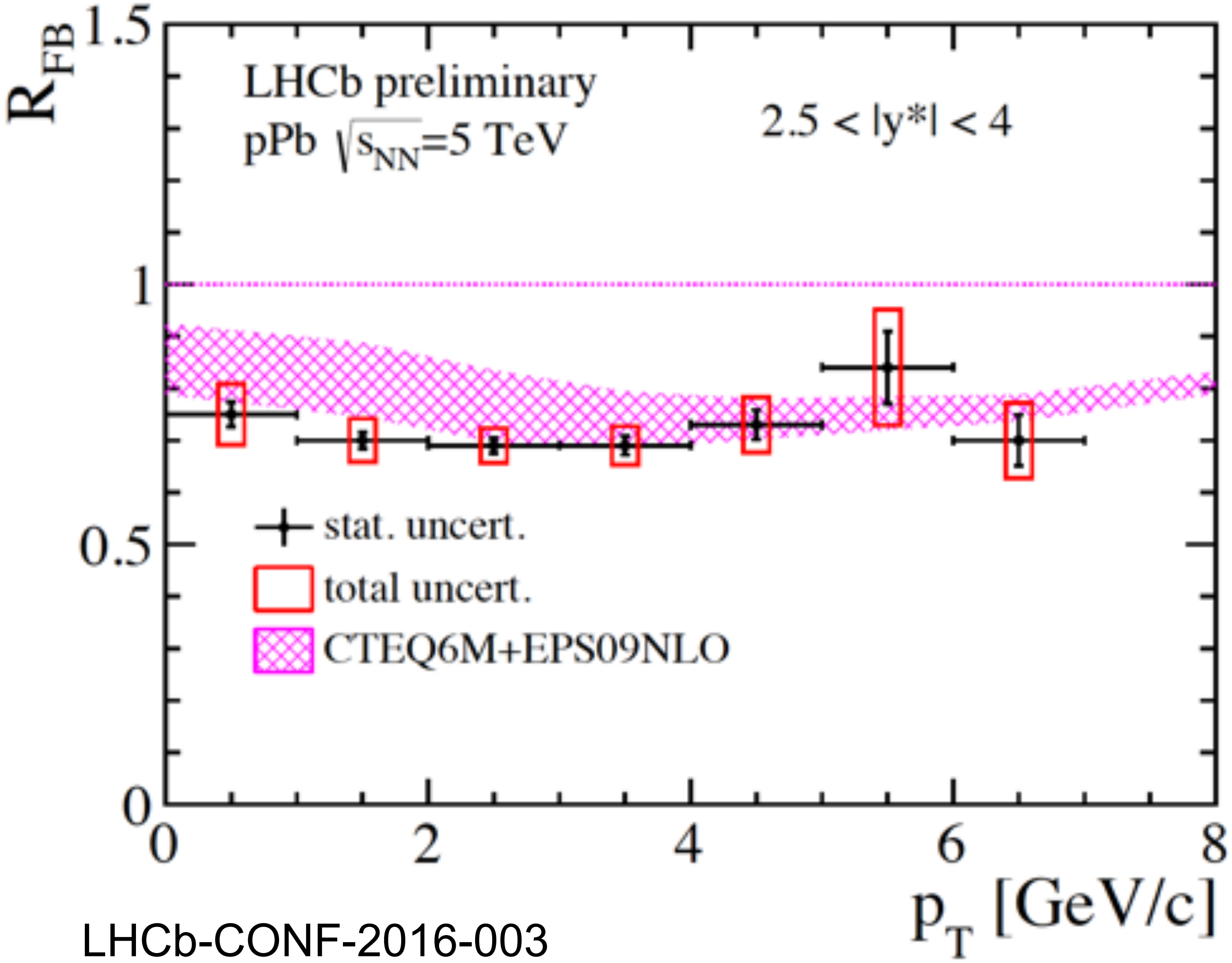


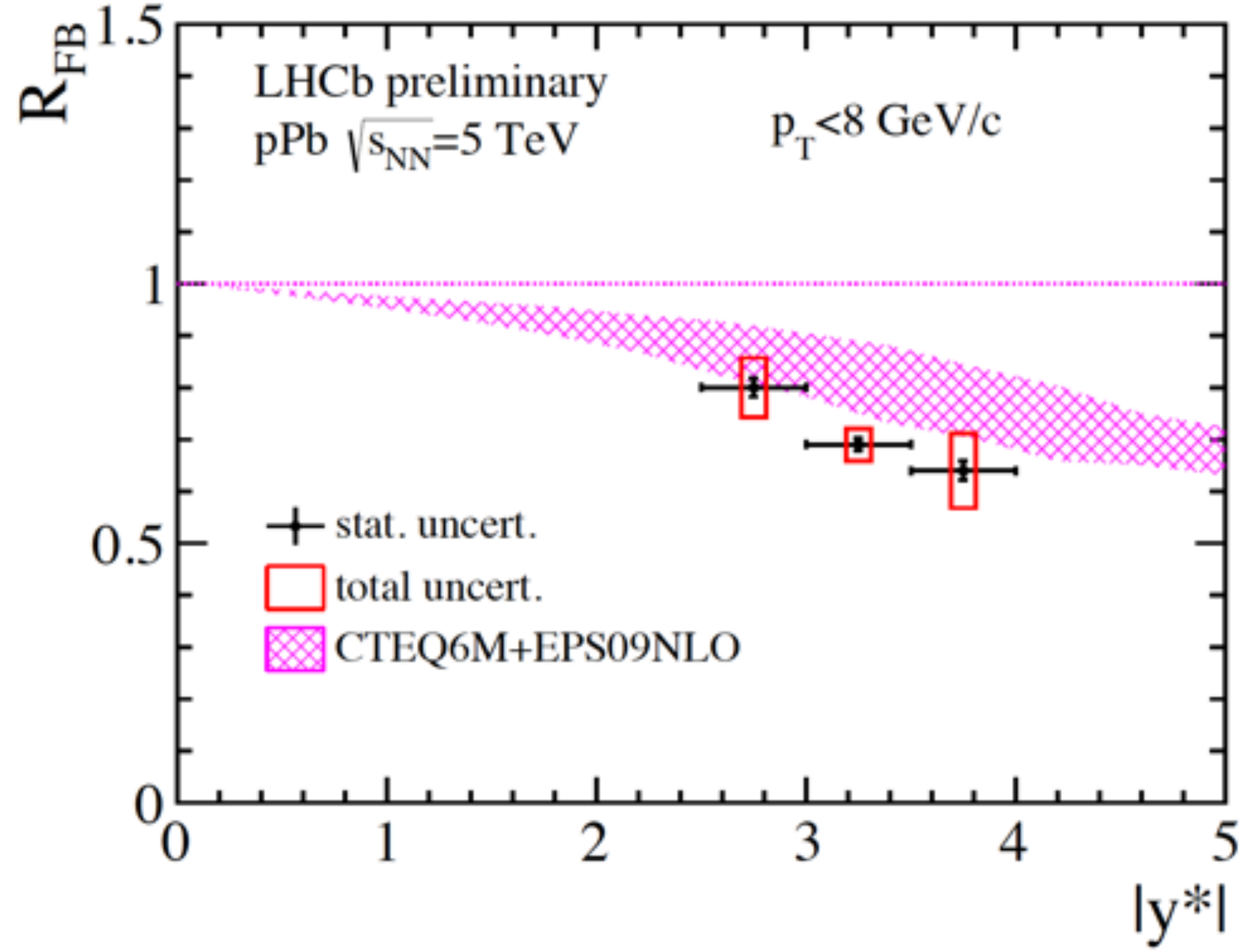
Enhancement in central pPb events
- radial flow?

In peripheral events
- compatible with binary scaling

D^0 meson R_{pA} at 5.02 TeV at forward/backward

LHCb D^0 measurement at 5.02 TeV in forward(F) and backward (B) region as a function of transverse momentum and rapidity



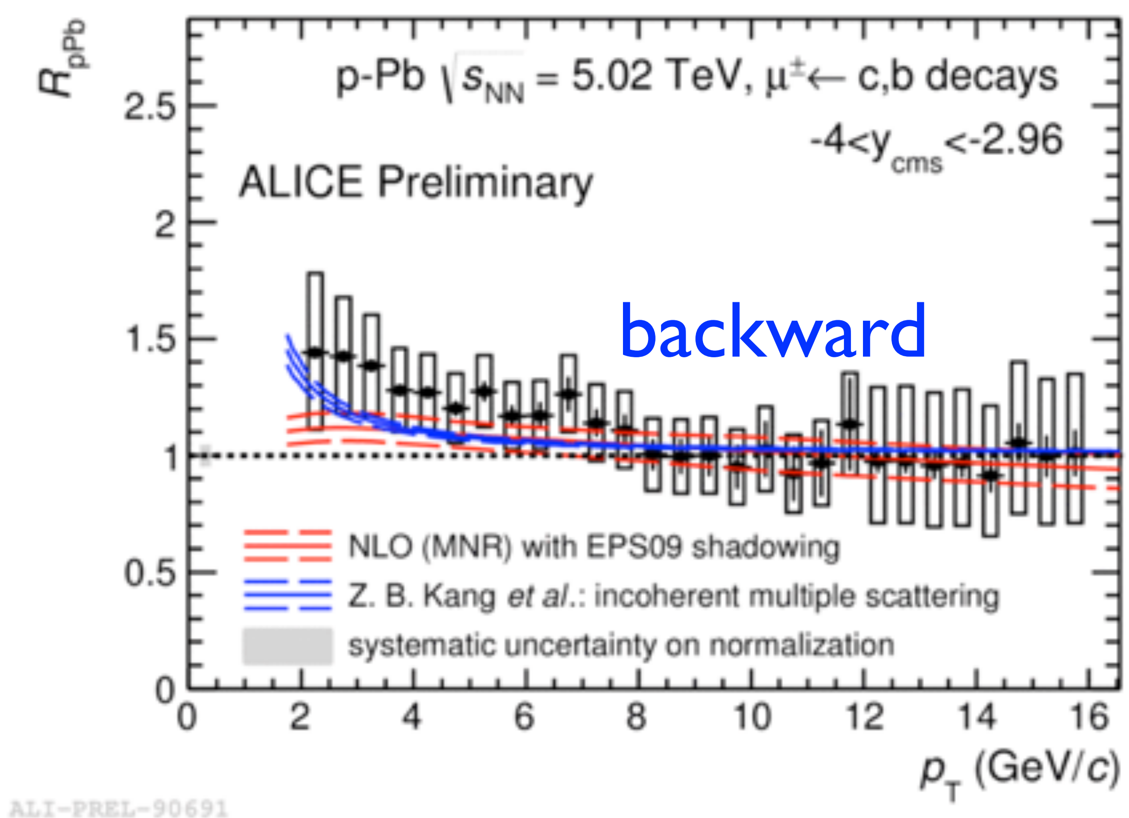


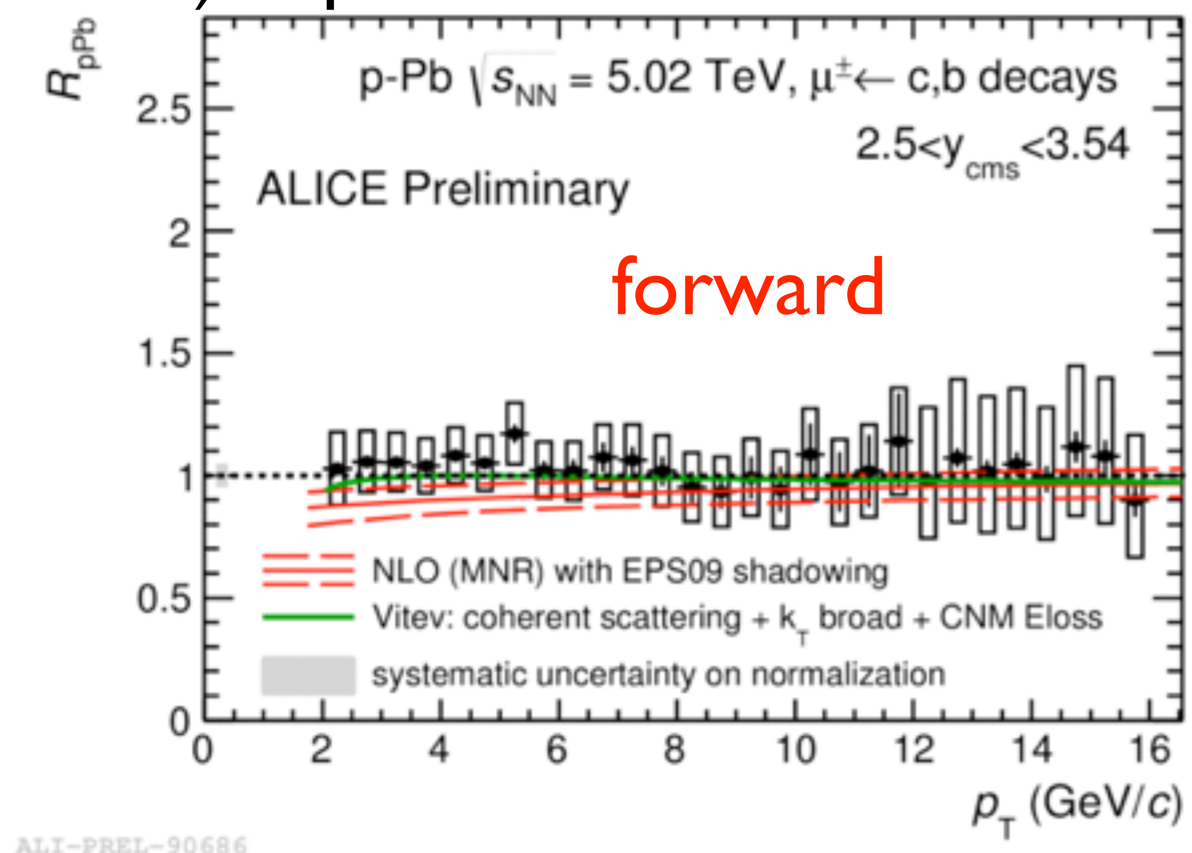
LHCb-CONF-2016-003

R_{pA} and R_{FB} described by to NLO prediction that include EPS09 parametrisation of the nuclear PDFs

Heavy flavour leptons: LHC vs. RHIC

ALICE heavy flavour electrons (c,b→muons) in pPb collisions at 5.02 TeV





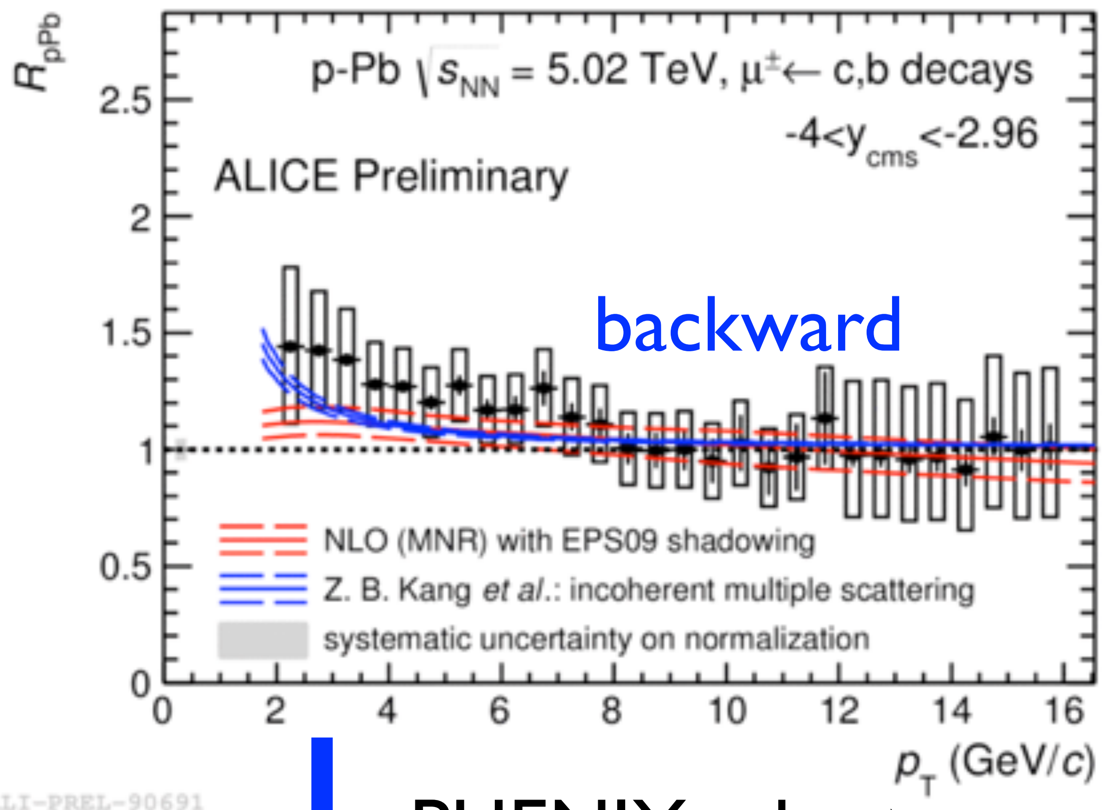
forward (shadowing)
backward (anti-shadowing)

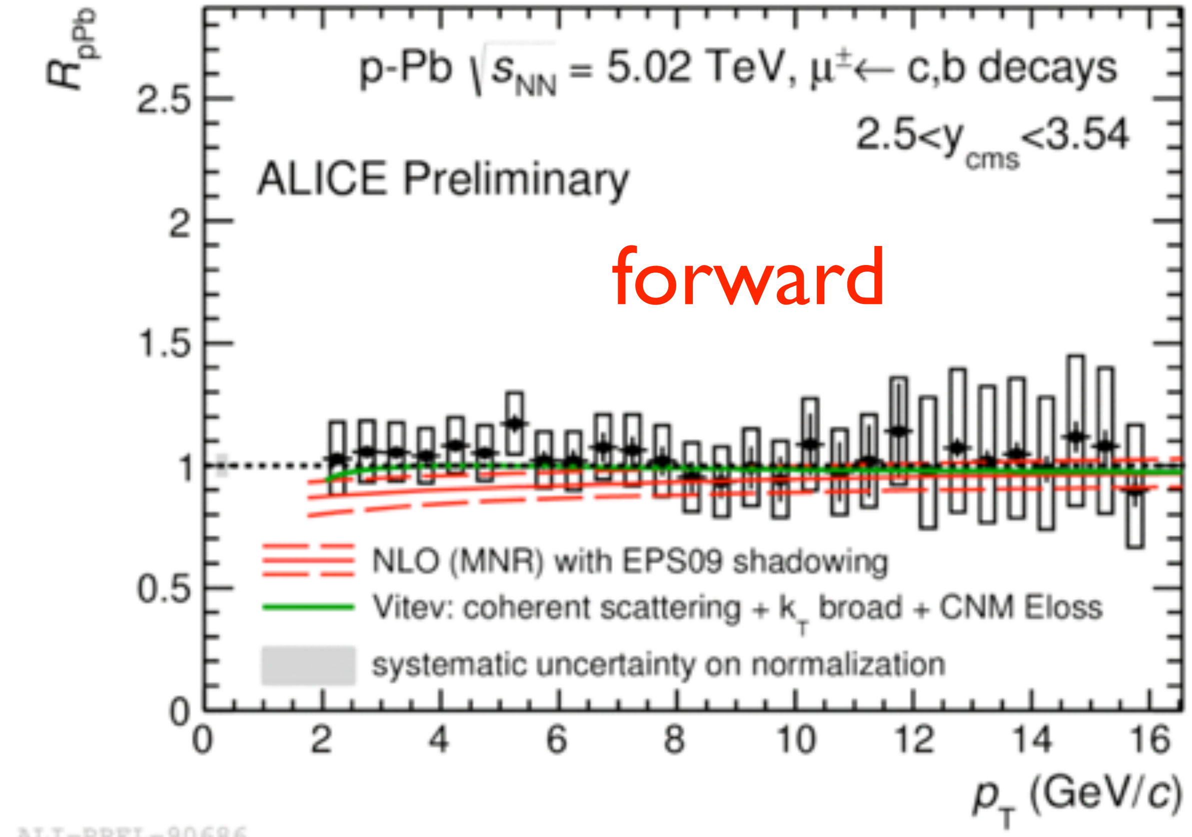
Models with CNM describe forward/backward rapidity at LHC

PRL112 (2014) 252301

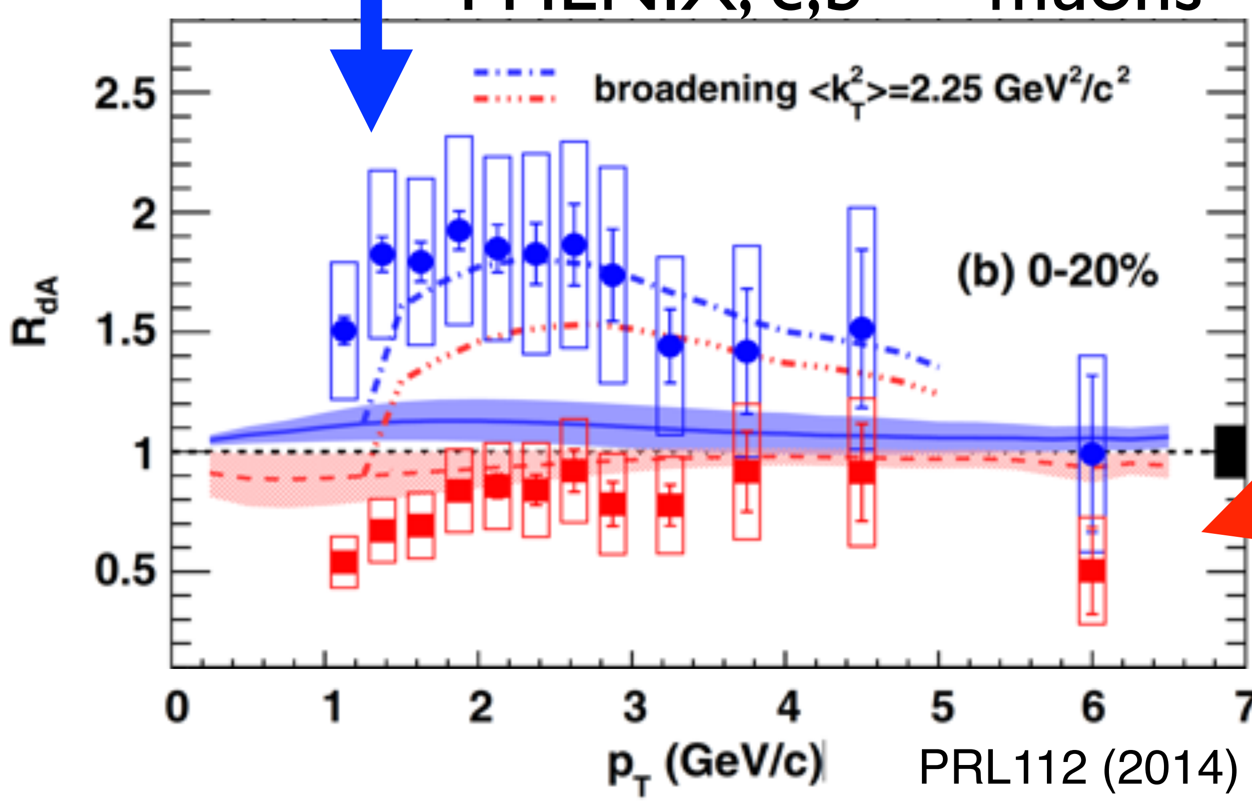
Heavy flavour leptons: LHC vs. RHIC

ALICE heavy flavour muons (c,b→muons) in pPb collisions at 5.02 TeV





PHENIX, c,b → muons



PRL112 (2014) 252301

forward (shadowing)

backward (anti-shadowing)

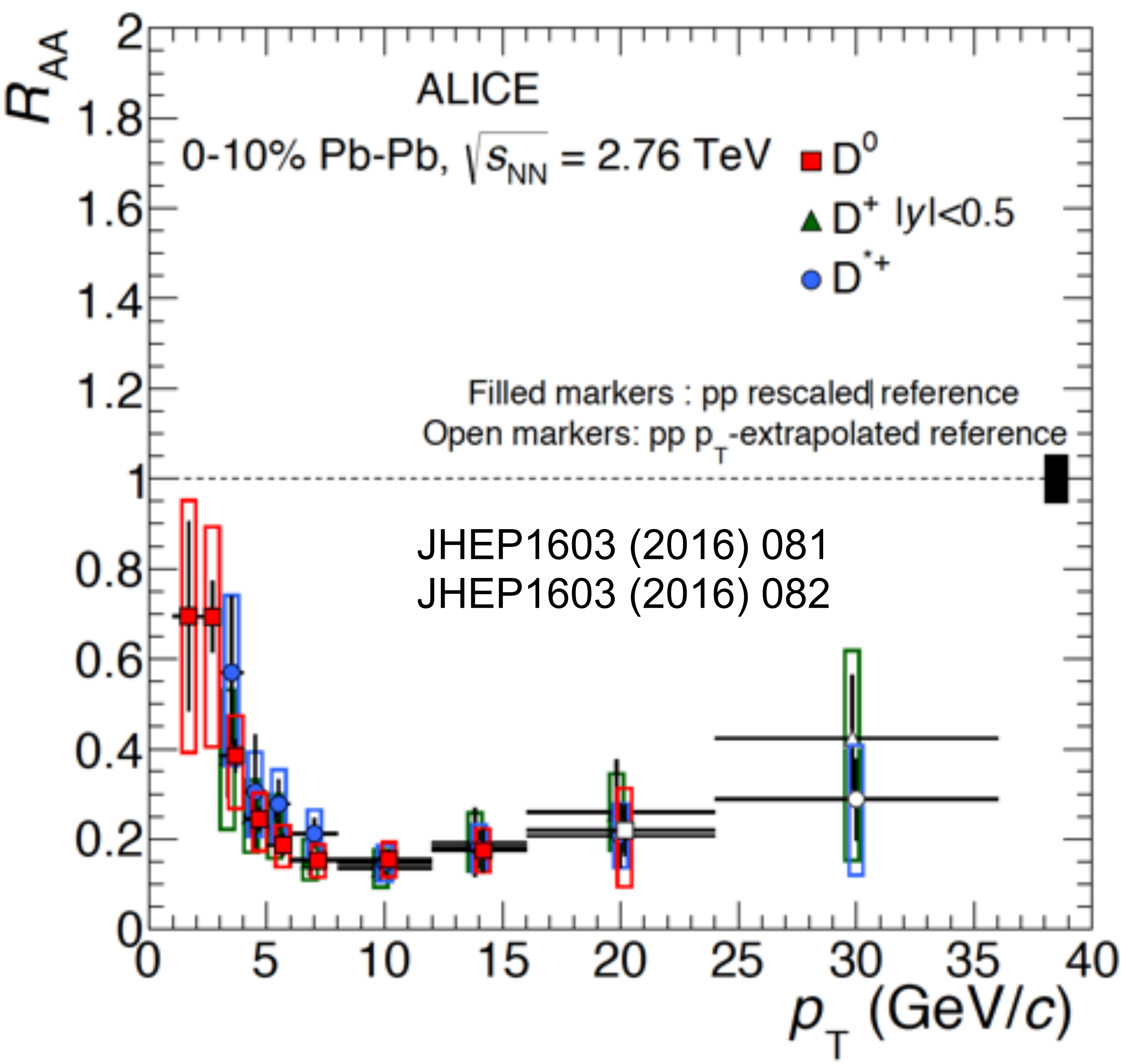
Models with CNM describe forward/backward rapidity at LHC

→ **Not possible at RHIC!**

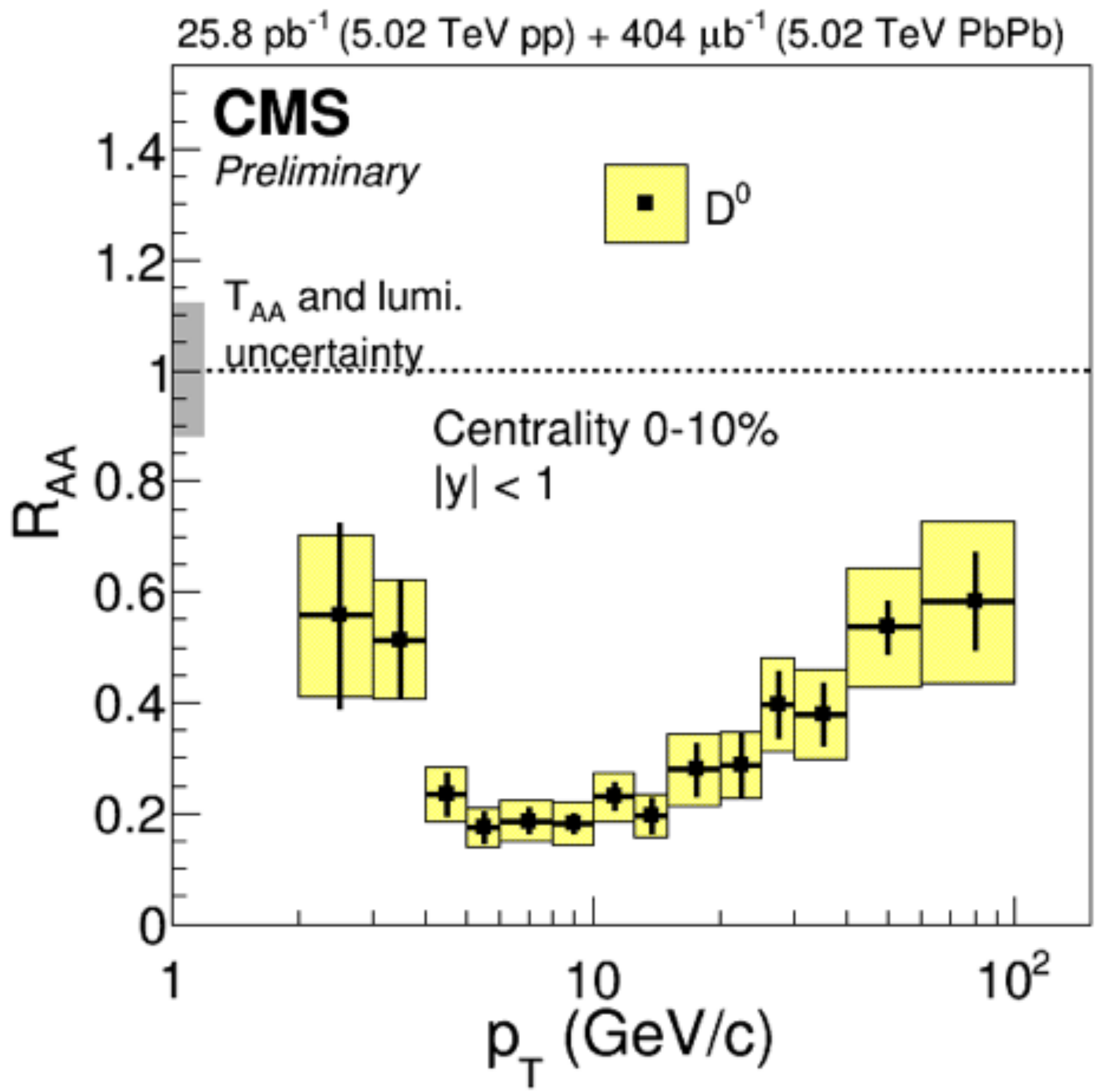
Open heavy flavour in PbPb collisions

D meson R_{AA} in 0-10%

ALICE D^0 R_{AA} **|y|<0.5** at **2.76 TeV**



CMS D^0 R_{AA} **|y|<1.0** at **5.02** TeV



CMS-PAS-HIN-16-001

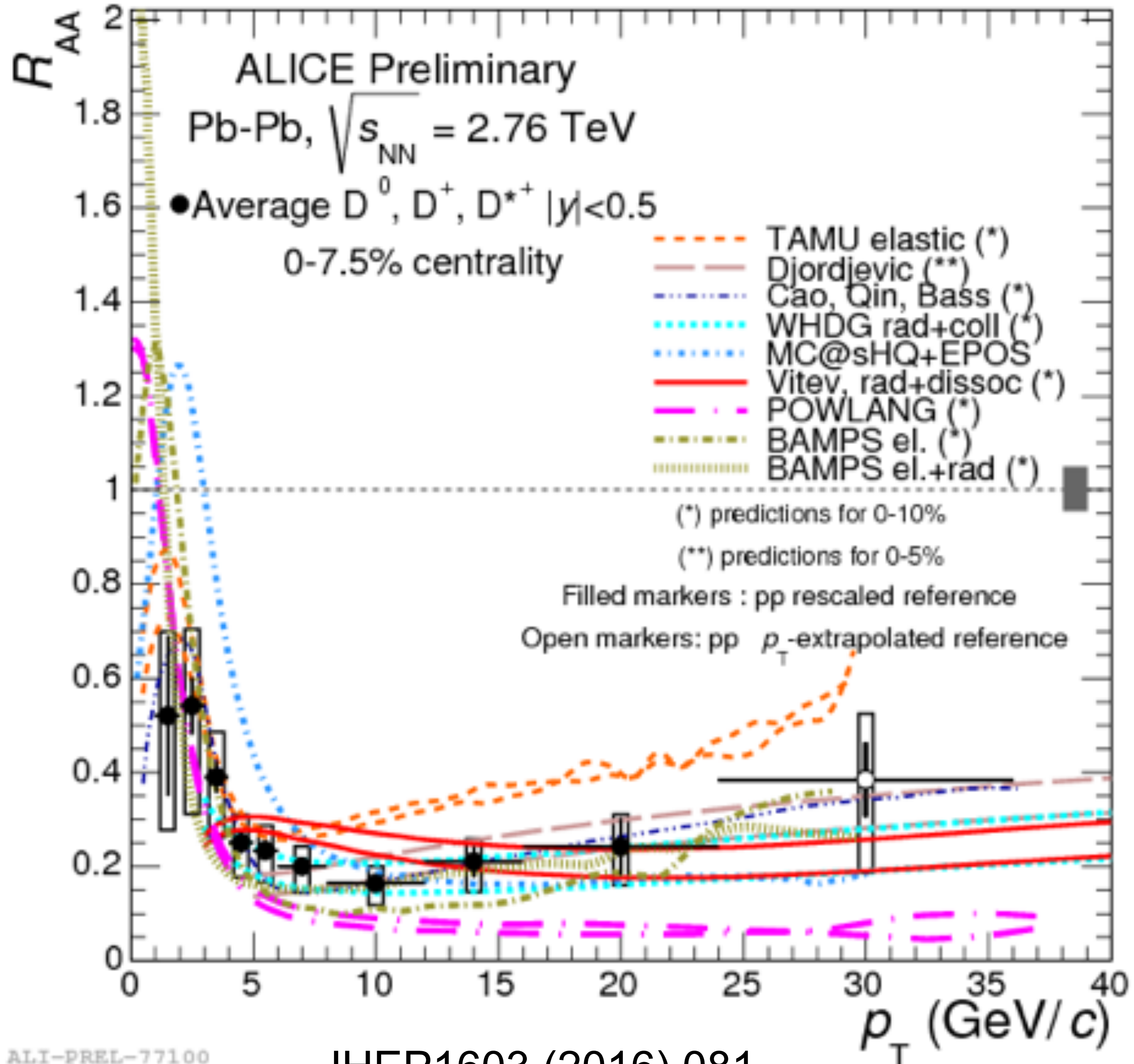
Strong suppression at 2.76 TeV:

same suppression for D^0,D^+,D^{*+}

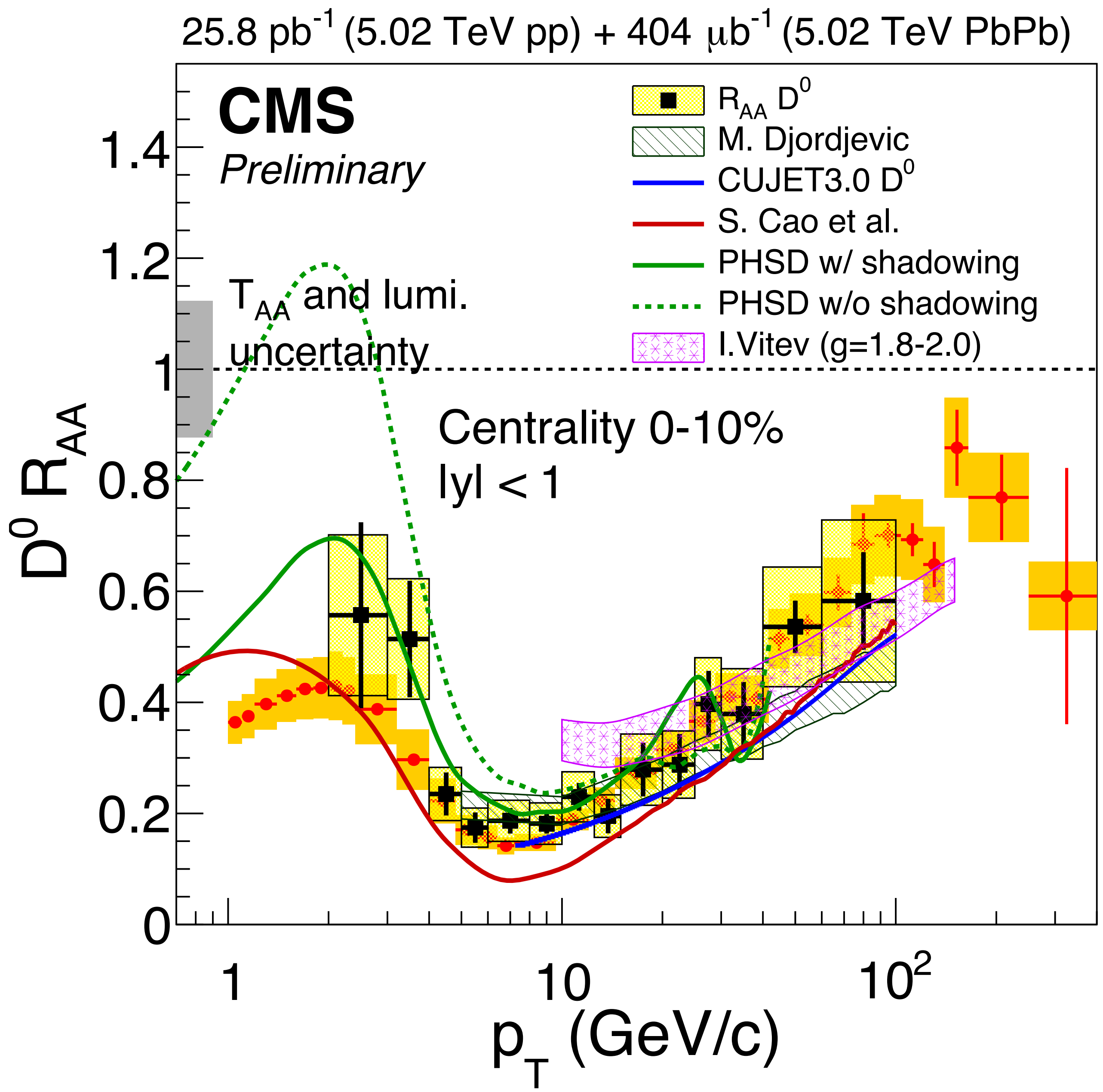
Similar suppression at 5.02 TeV:

Rising trend observed when going to high p_T

Comparison to theoretical calculations



JHEP1603 (2016) 081
JHEP1603 (2016) 082



CMS-PAS-HIN-16-001

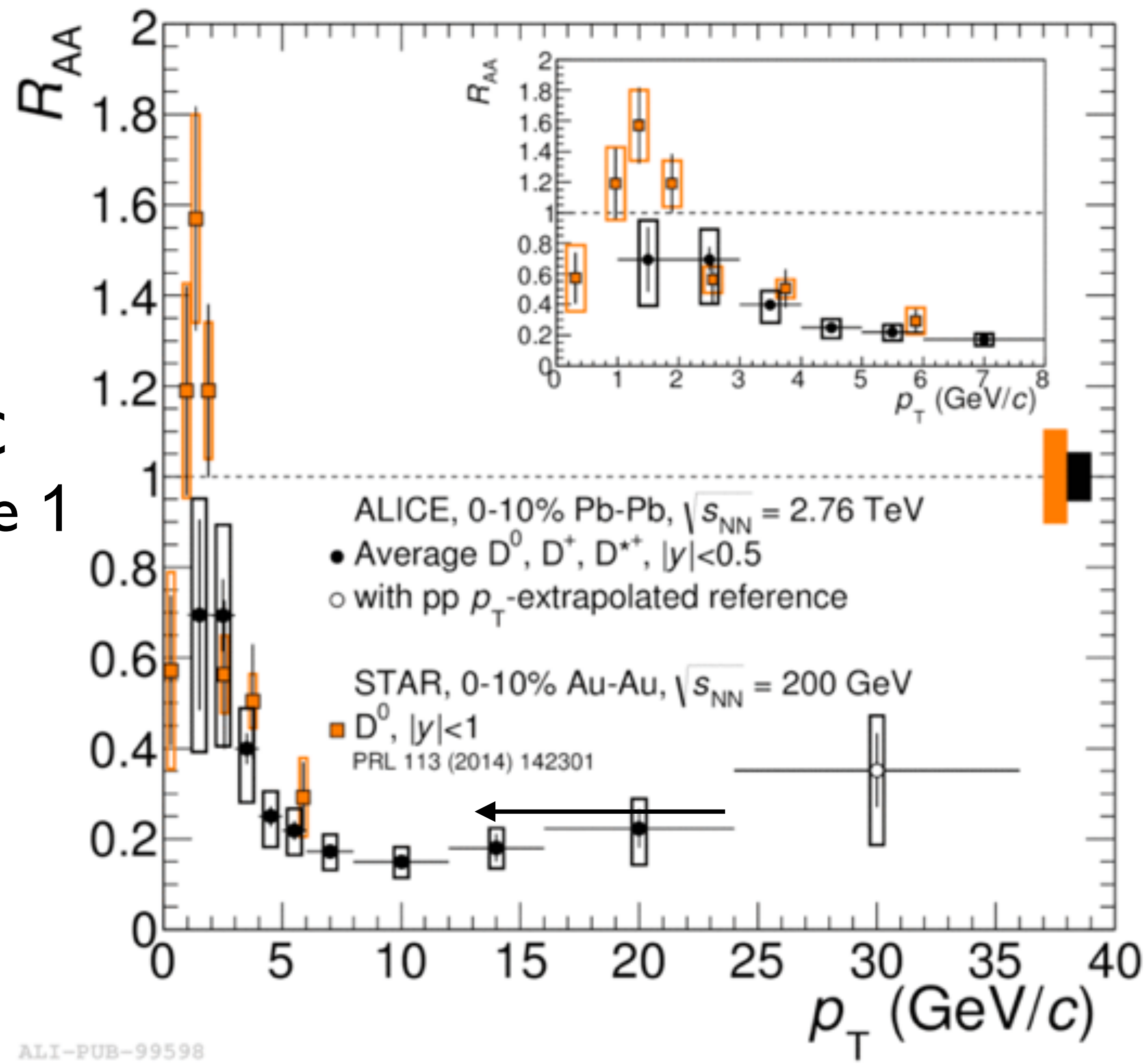
Several models describe the data within uncertainties:

- *hints at low p_T that collisional energy loss is non negligible*
- *pure collisional models can describe the R_{AA} up to high p_T (??)*
- *shadowing improve description of the data at low p_T*

Comparison with RHIC

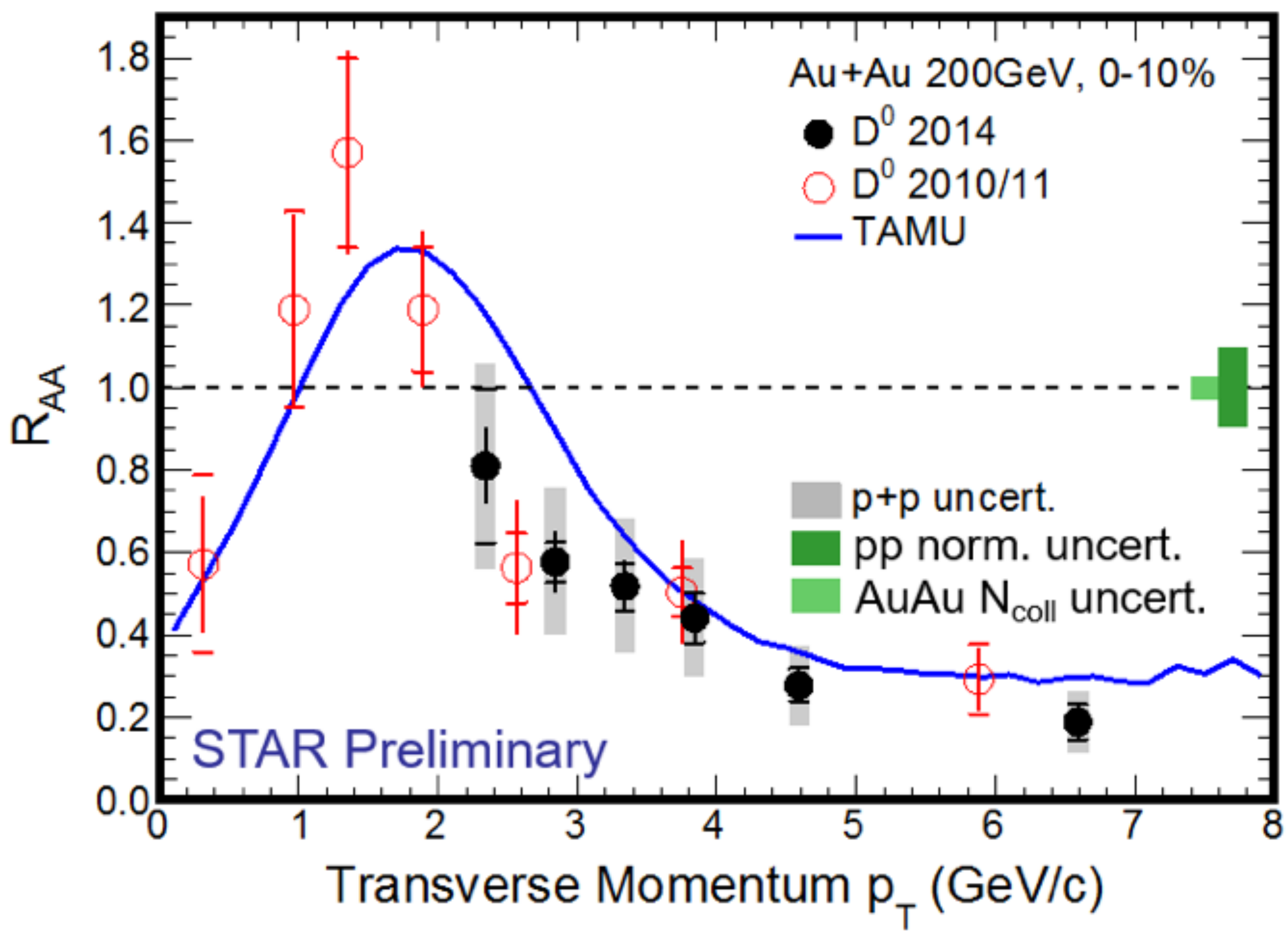
At lower $p_{T,}$ RHIC D^0 R_{AA} goes above 1

PRL113 (2014) 142301
JHEP1603 (2016) 081



Smaller suppression at RHIC can be a consequence of different magnitude of the shadowing at RHIC vs. LHC energies, different radial flow and different relevance of coalescence

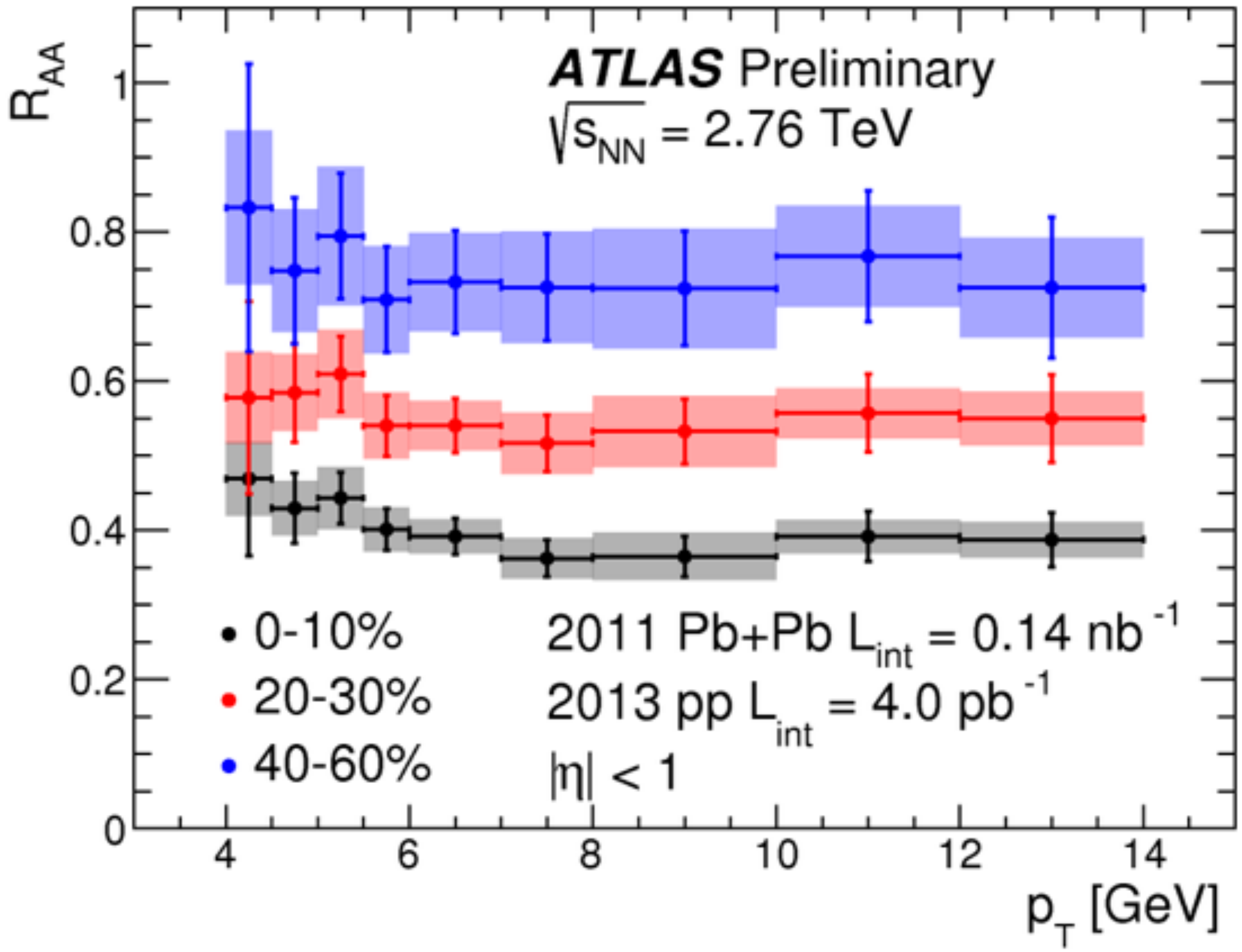
New D^0 R_{AA} from STAR



Extended the high p_T reach of the analysis up to 8 GeV!
Well described by theoretical calculations!

R_{AA} of heavy flavour muons

R_{AA} of heavy-flavour muons at 2.76 TeV from ATLAS



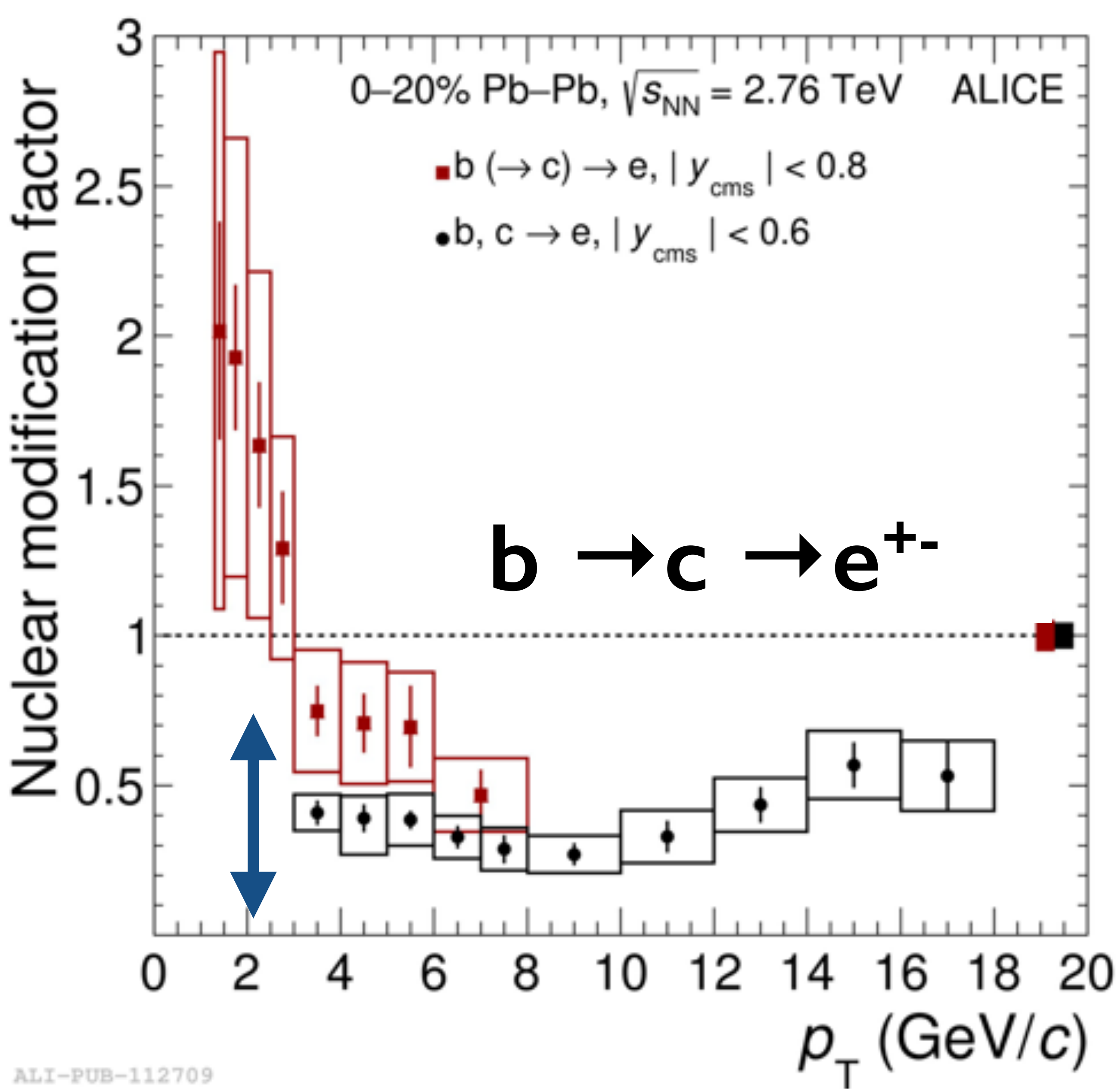
ATLAS-CONF-2015-053

Strong suppression observed for for HF muons!

Clear suppression pattern observed as a function of centrality

R_{AA} of beauty electrons

ALICE R_{AA} of beauty electrons (b → c → e^{+-}) at 2.76 TeV

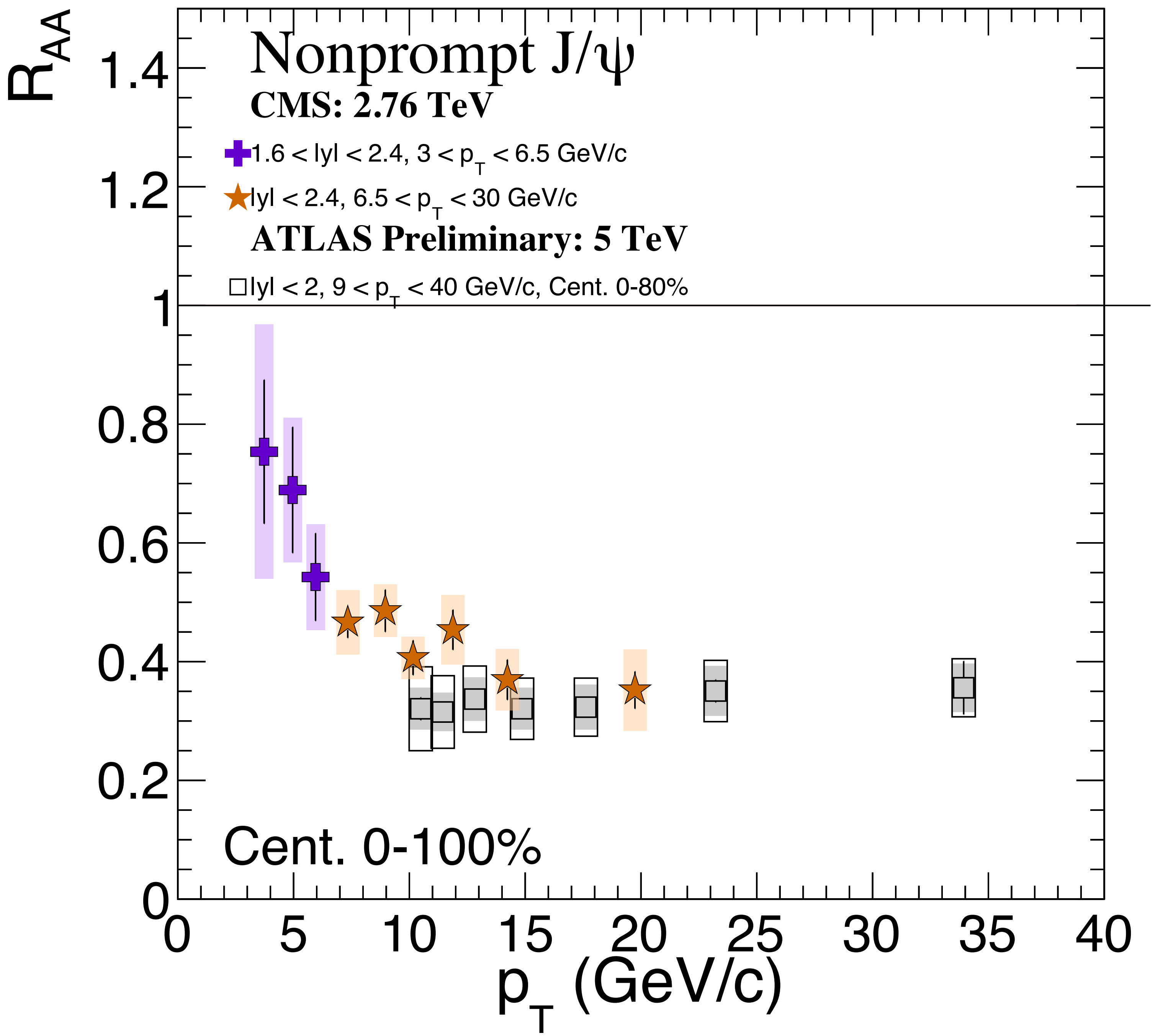


arXiv:1609.03898

Strong suppression observed for heavy-flavour (c,b) electrons and beauty electrons

Indication of difference suppression for charm and beauty electron vs. beauty electrons

R_{AA} of non prompt J/φ at 2.76 TeV and 5 TeV



CMS non prompt 1.6<|y|<2.4

CMS non prompt |y|<2.4

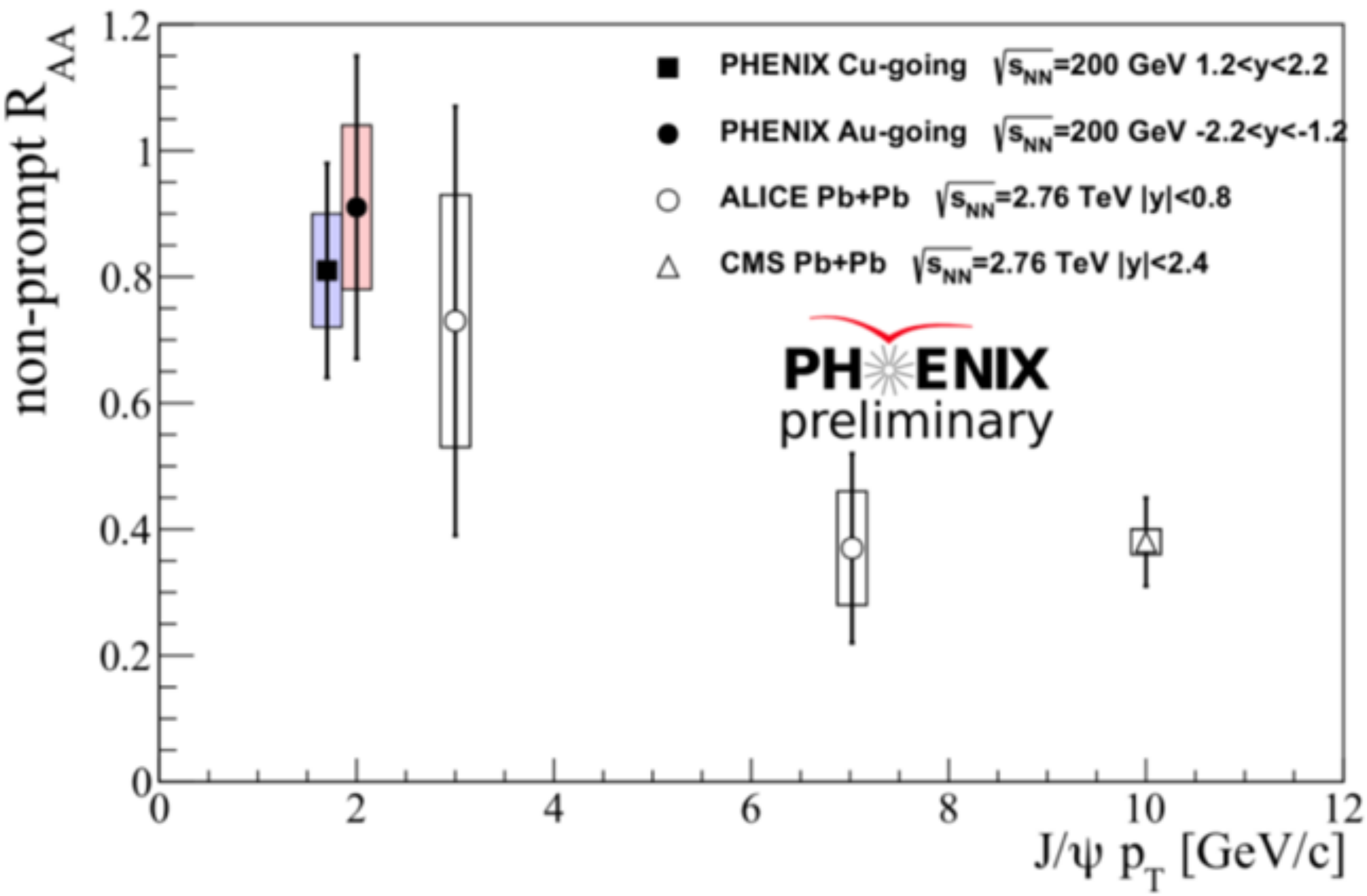
ATLAS non prompt |y|<2.9

Strong suppression observed for non prompt J/φ in PbPb collisions

Clear suppression as a function of p_T

2.76 TeV and 5.02 TeV results well consistent within uncertainties

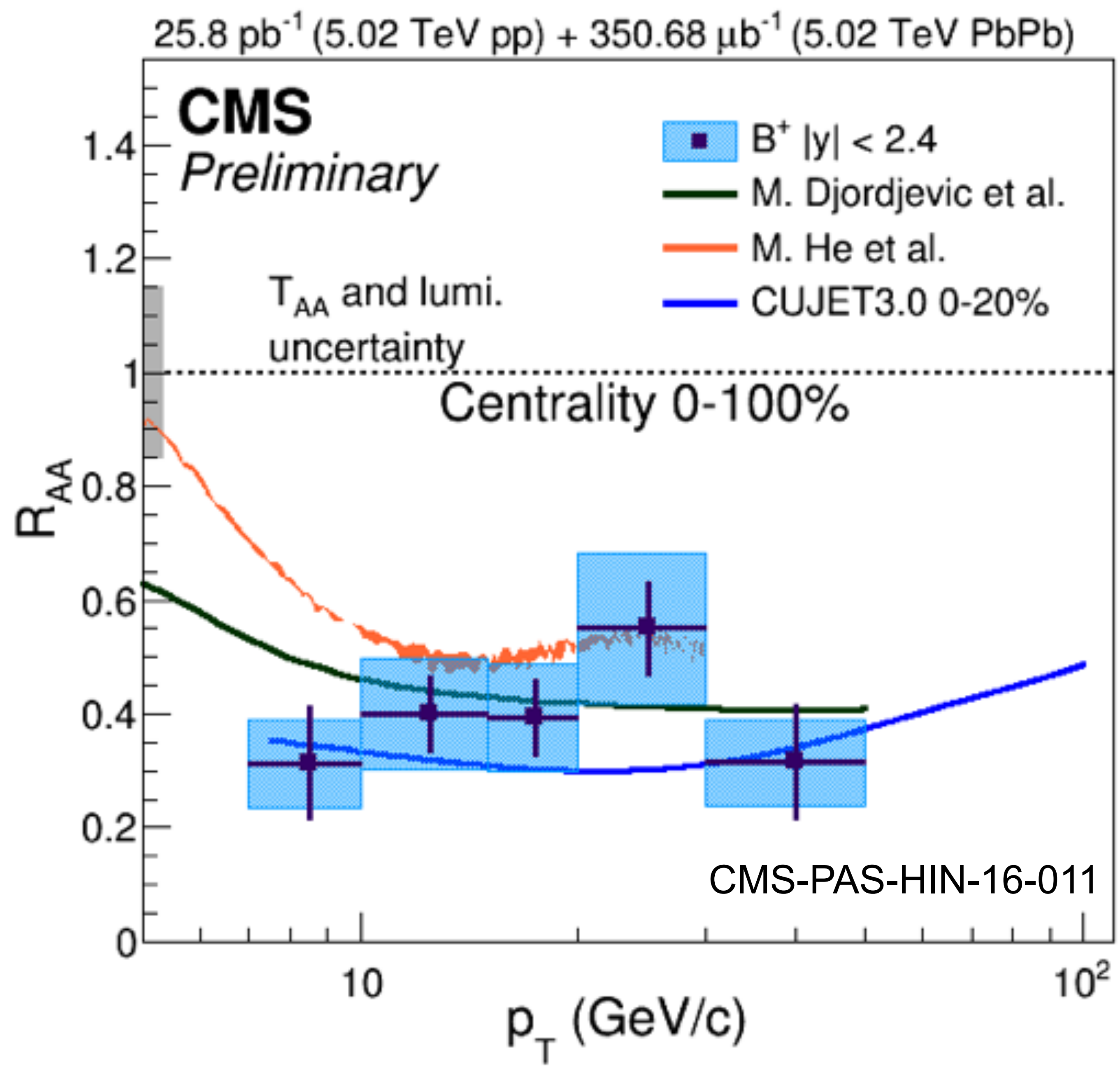
R_{AA} of non prompt J/ψ at 200 GeV



Very similar suppression also observed at 200 GeV!

Exclusive B^+ meson measurement in PbPb

CMS B^+ production in PbPb at central rapidity |y|<2.4

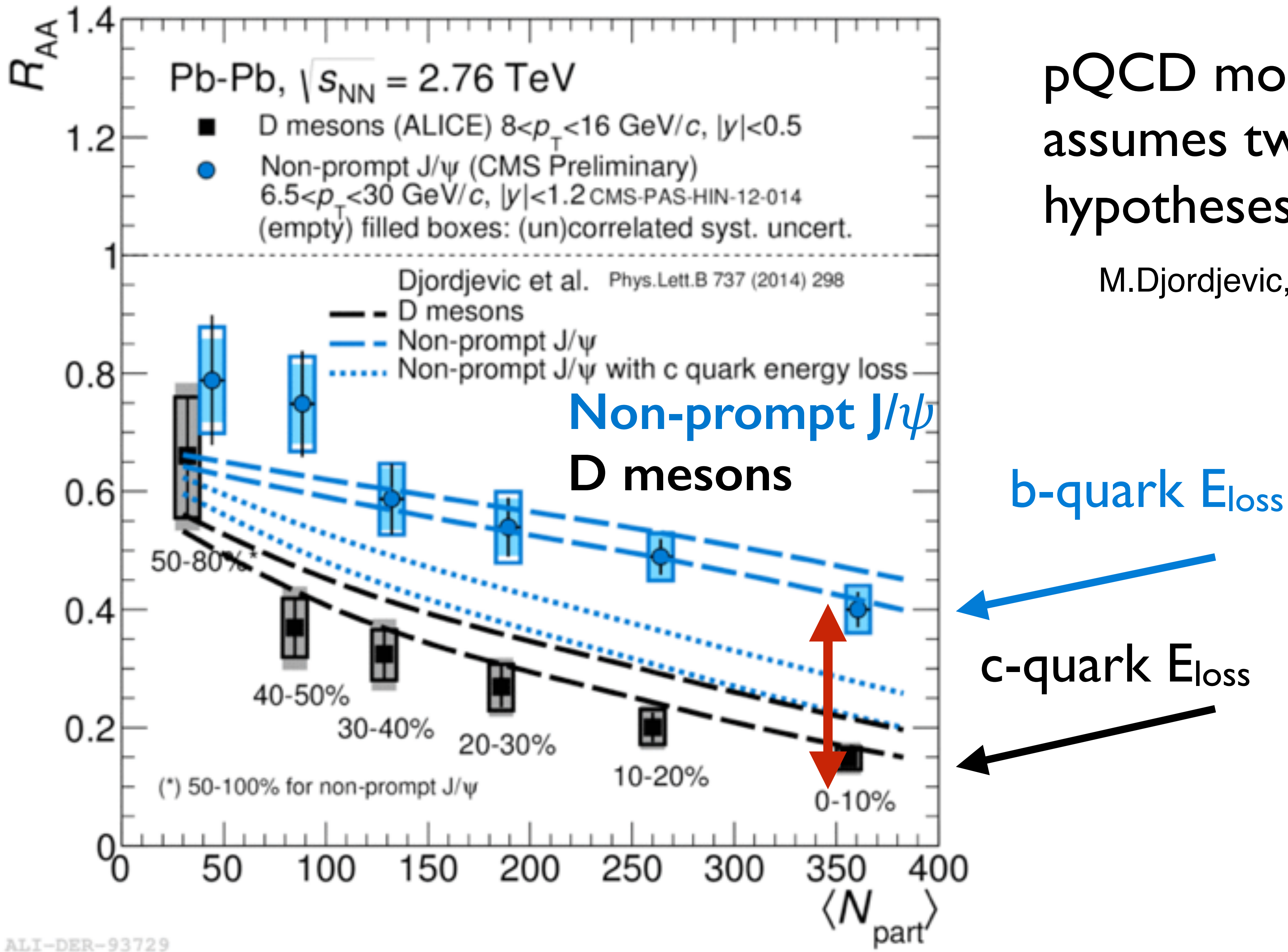


Strong suppression (R_{AA}~0.4) observed in 0-100% PbPb collision for p_T>7 GeV/c

Well described by theoretical calculations that include radiative energy loss

Flavour dependence of E_{loss} at 2.76 TeV

ALICE, JHEP 1511 (2015) 205



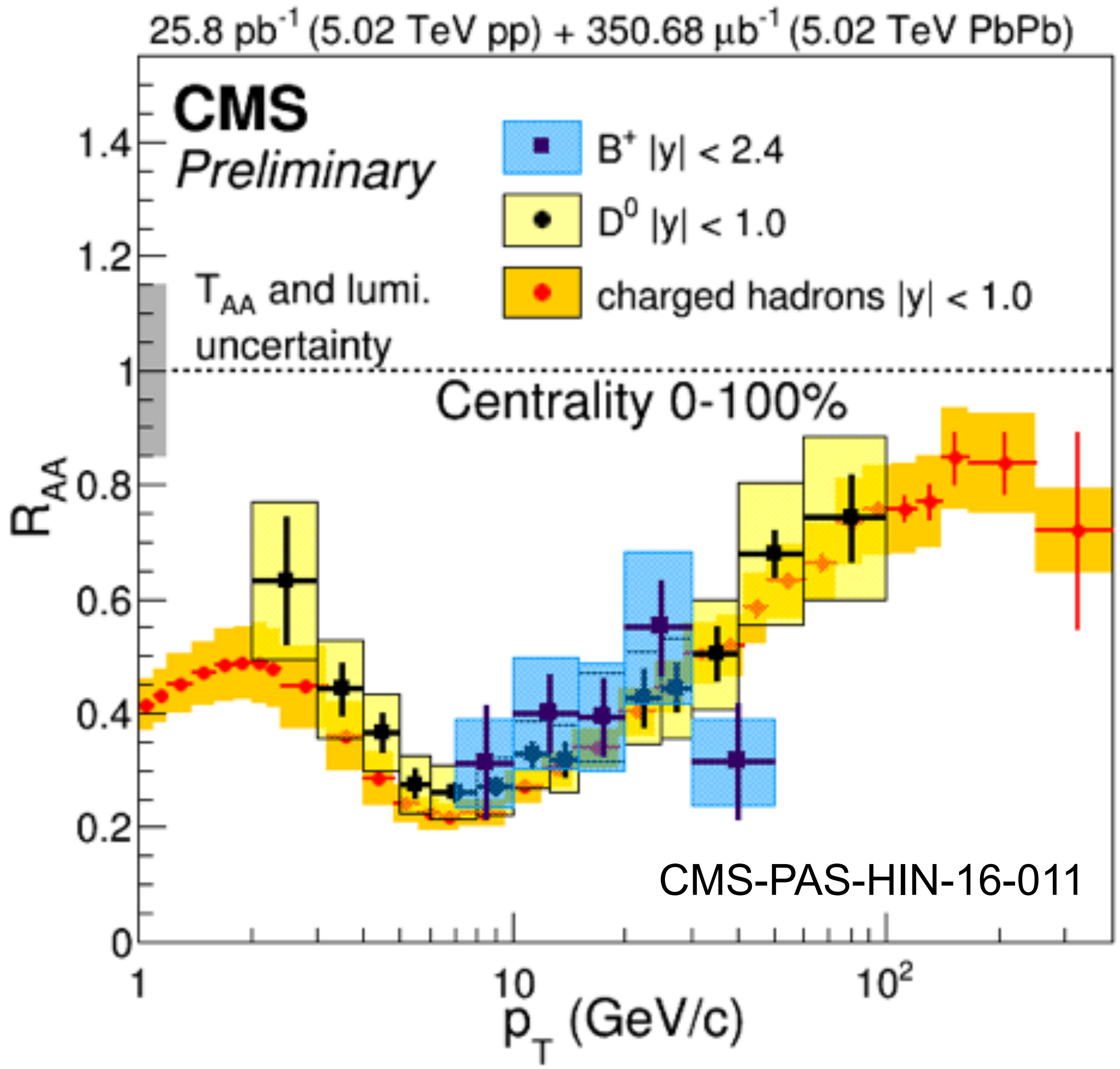
pQCD model (M.Djordjevic) that assumes two different mass hypotheses for non prompt J/ψ

M.Djordjevic, PRL 112, 042302 (2014)

***According to this model,** the difference R_{AA} for non prompt J/ψ and B can be attributed to a difference in the E_{loss} of charm and beauty quarks*

Flavour dependence of E_{loss} at 5.02 TeV

R_{AA} of B, D and charged particle compatible within uncertainties in the available p_T range

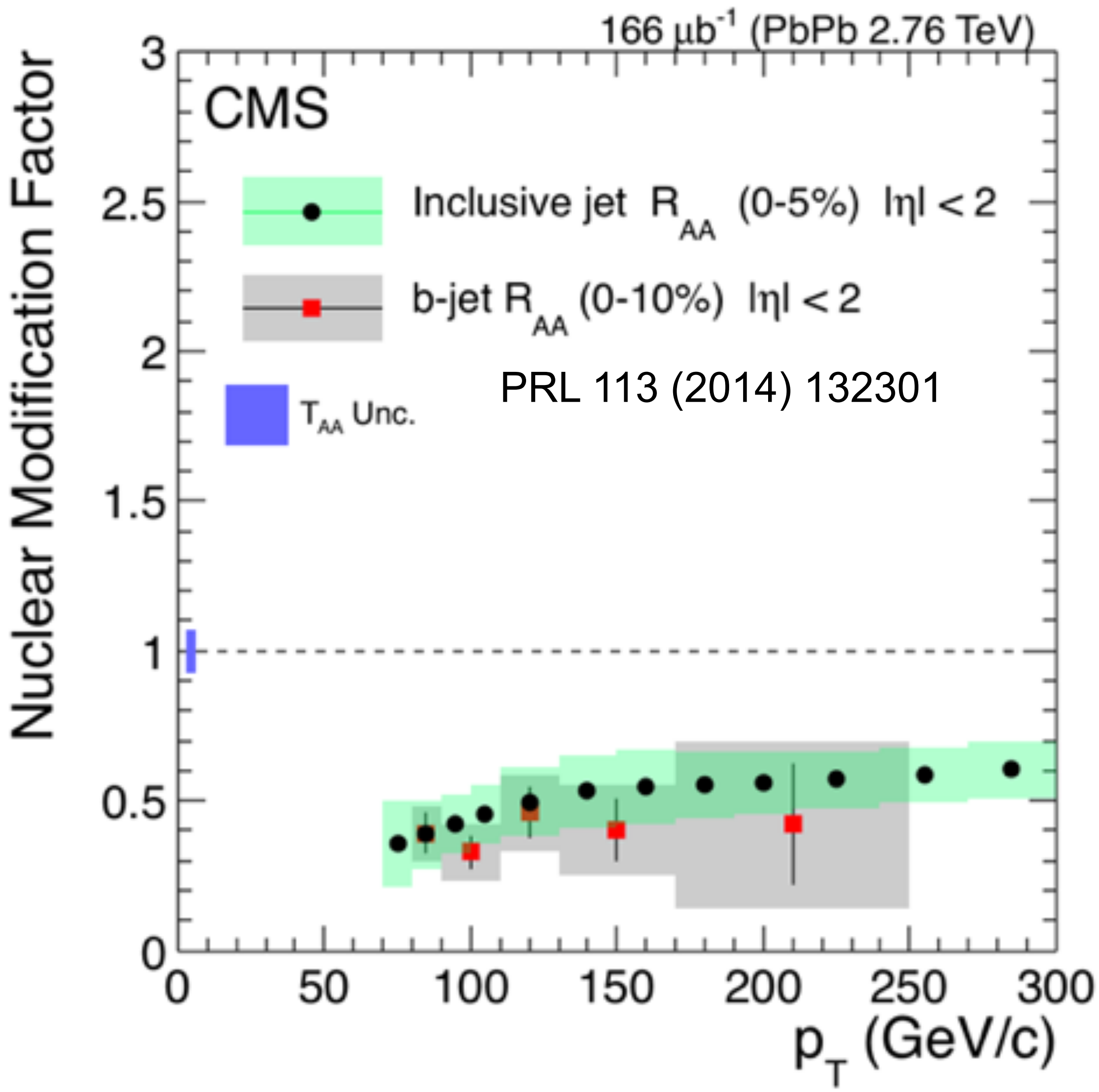


B meson
D meson
charged particle

Does it mean that there is no flavour dependence?

Not necessarily!

Flavour dependence at higher p_T



b-jet R_{AA}

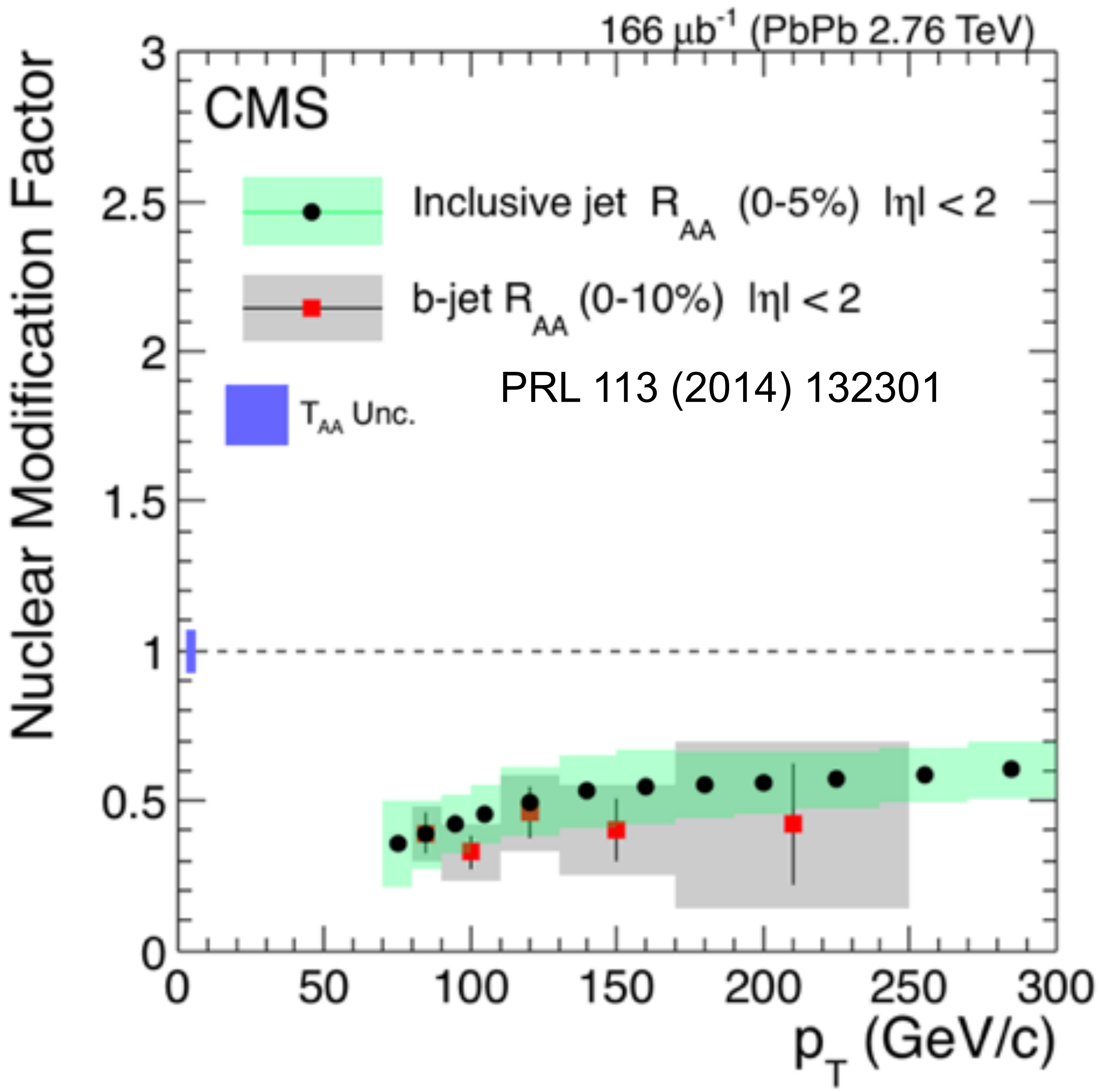
inclusive jet R_{AA}

Same suppression for b-jets and inclusive jets at high p_T

Mass difference negligible at high p_T

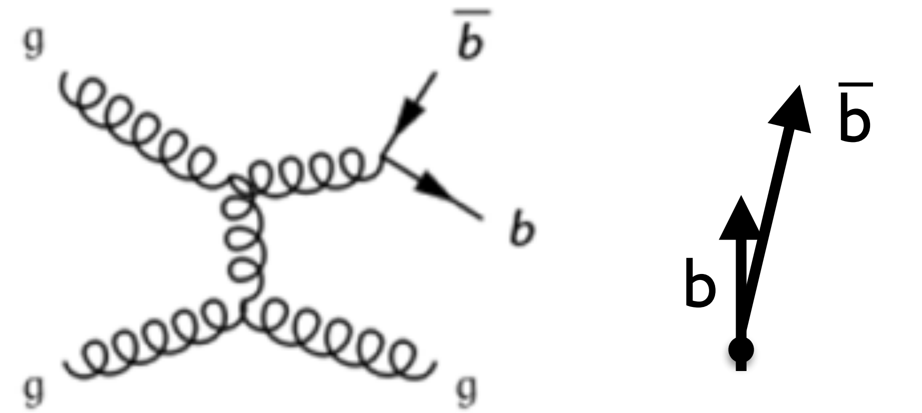
→***Large contribution of gluon splitting processes?*** *In GSP case, we are not measuring the b-quark E_{loss} but to some "fat" gluon E_{loss}*

Flavour dependence at higher p_T



b-jet R_{AA}

inclusive jet R_{AA}



NLO process: Gluon splitting ~20%

→ dominant at low opening angles

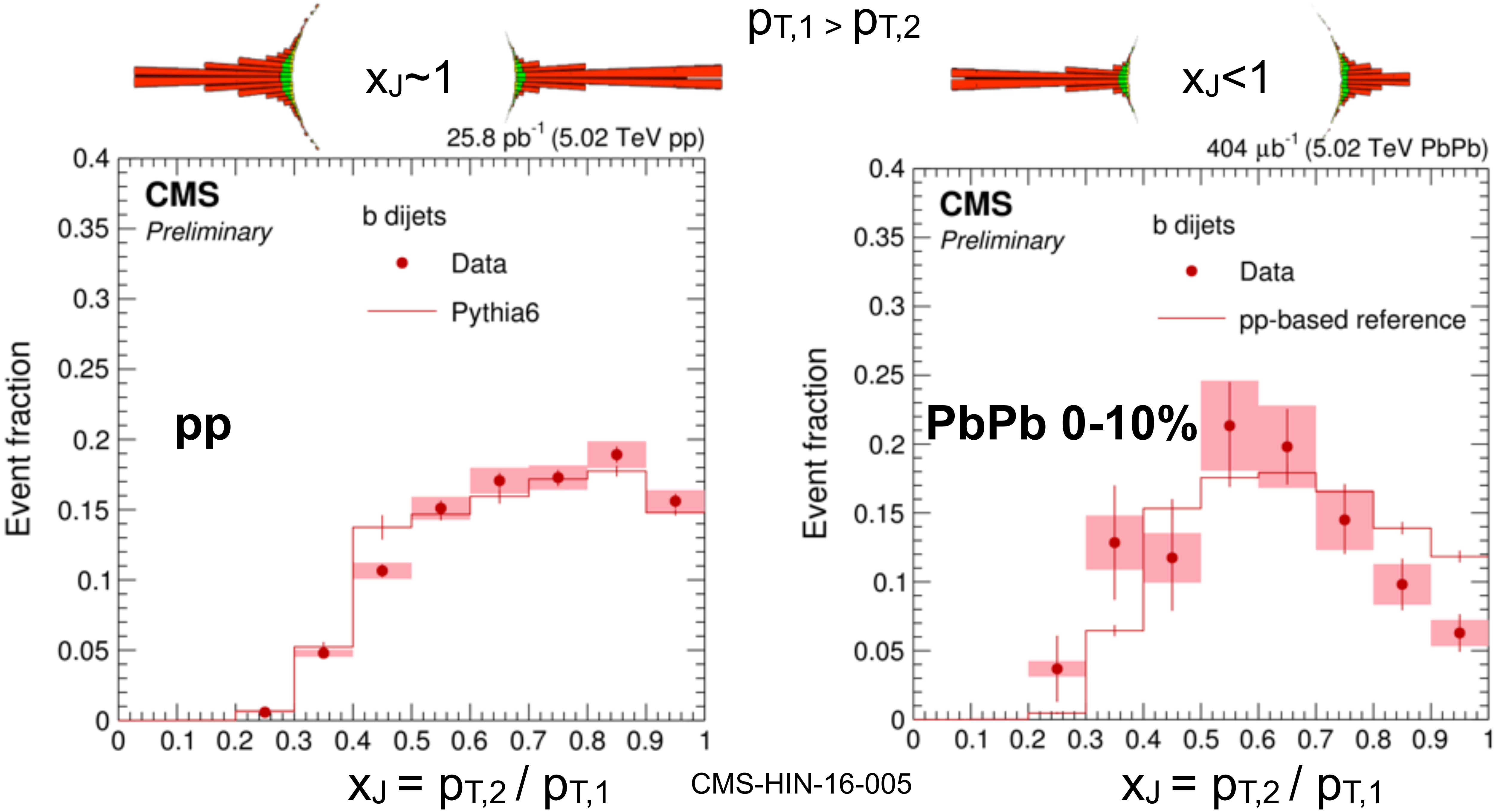
Same suppression for b-jets and inclusive jets at high p_T

Mass difference negligible at high p_T

→Large contribution of gluon splitting processes? In GSP case, we are not measuring the b-quark E_{loss} but to some "fat" gluon E_{loss}

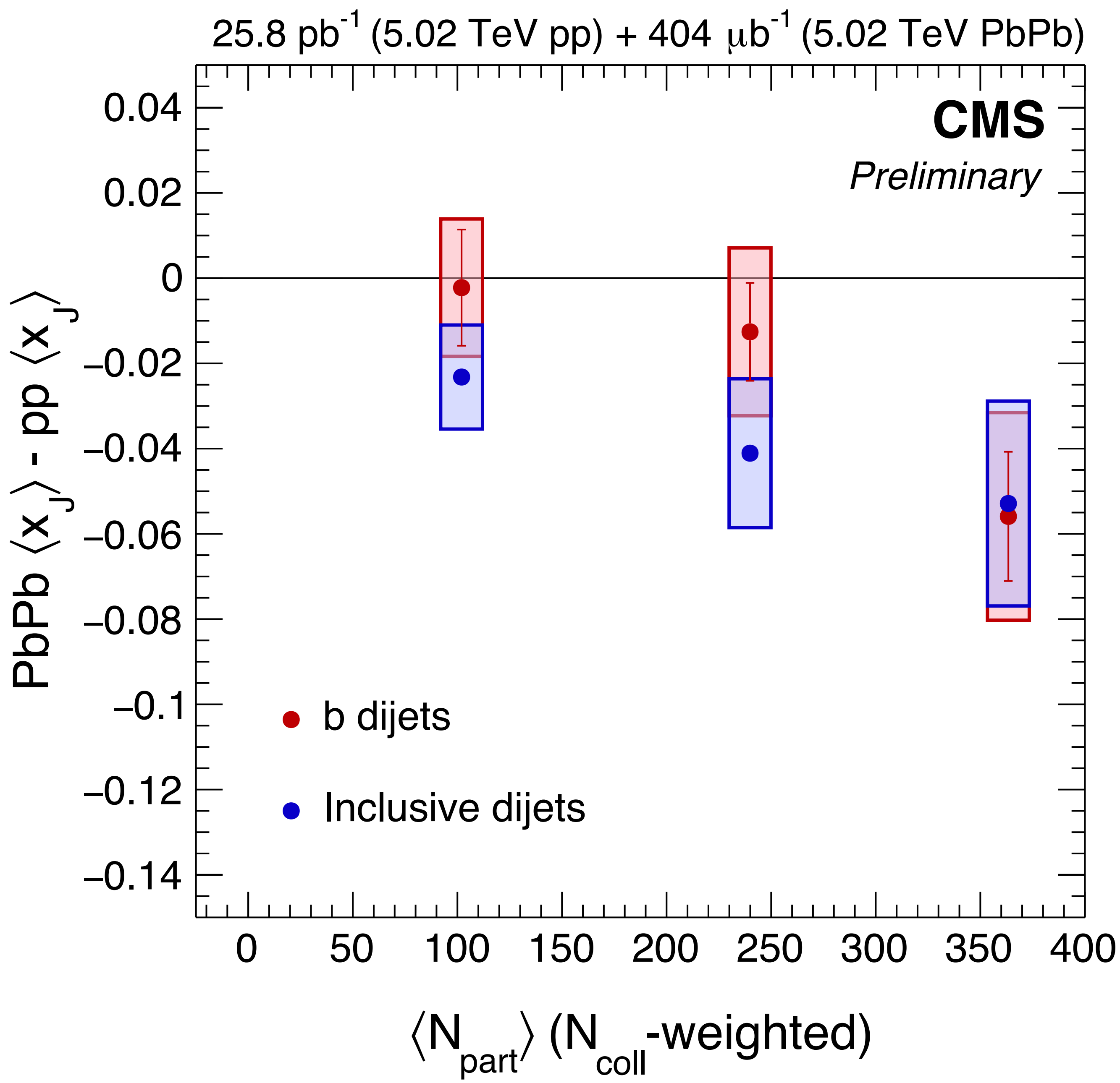
Di-b-jet measurement in PbPb at 5.02 TeV

→ In back-to-back events $b\bar{b}$ production via gluon splitting processes is negligible



x_J distributions of di-b-jets significantly modified in central PbPb collisions!

Di-b-jet measurement in PbPb at 5.02 TeV



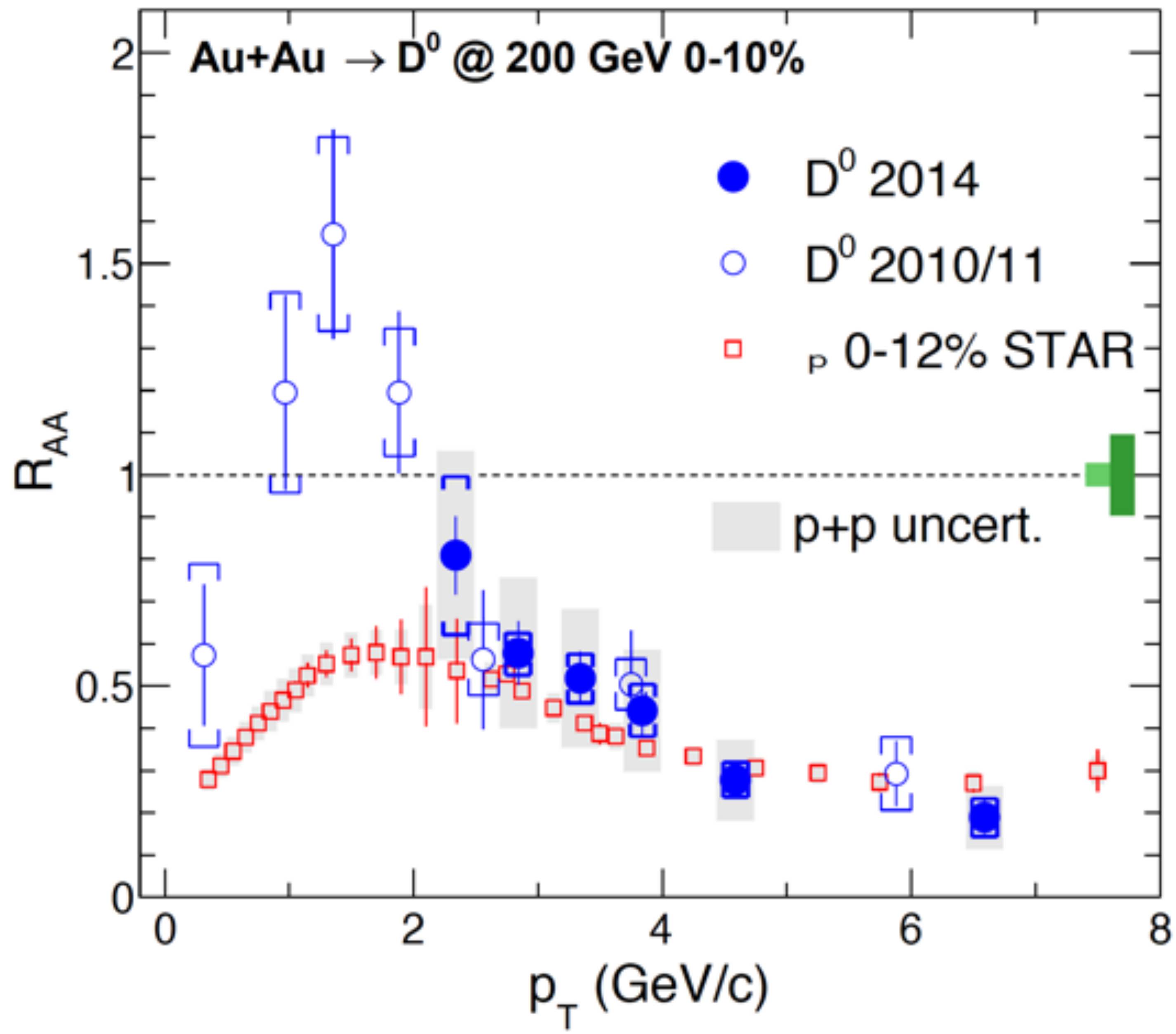
$$x_J = p_{T,2} / p_{T,1}$$

Same average asymmetry observed for inclusive jets!

CMS-HIN-16-005

There is no significant difference in the suppression of inclusive and b-jets even after excluding the contribution of gluon splitting processes

Flavour dependence at RHIC

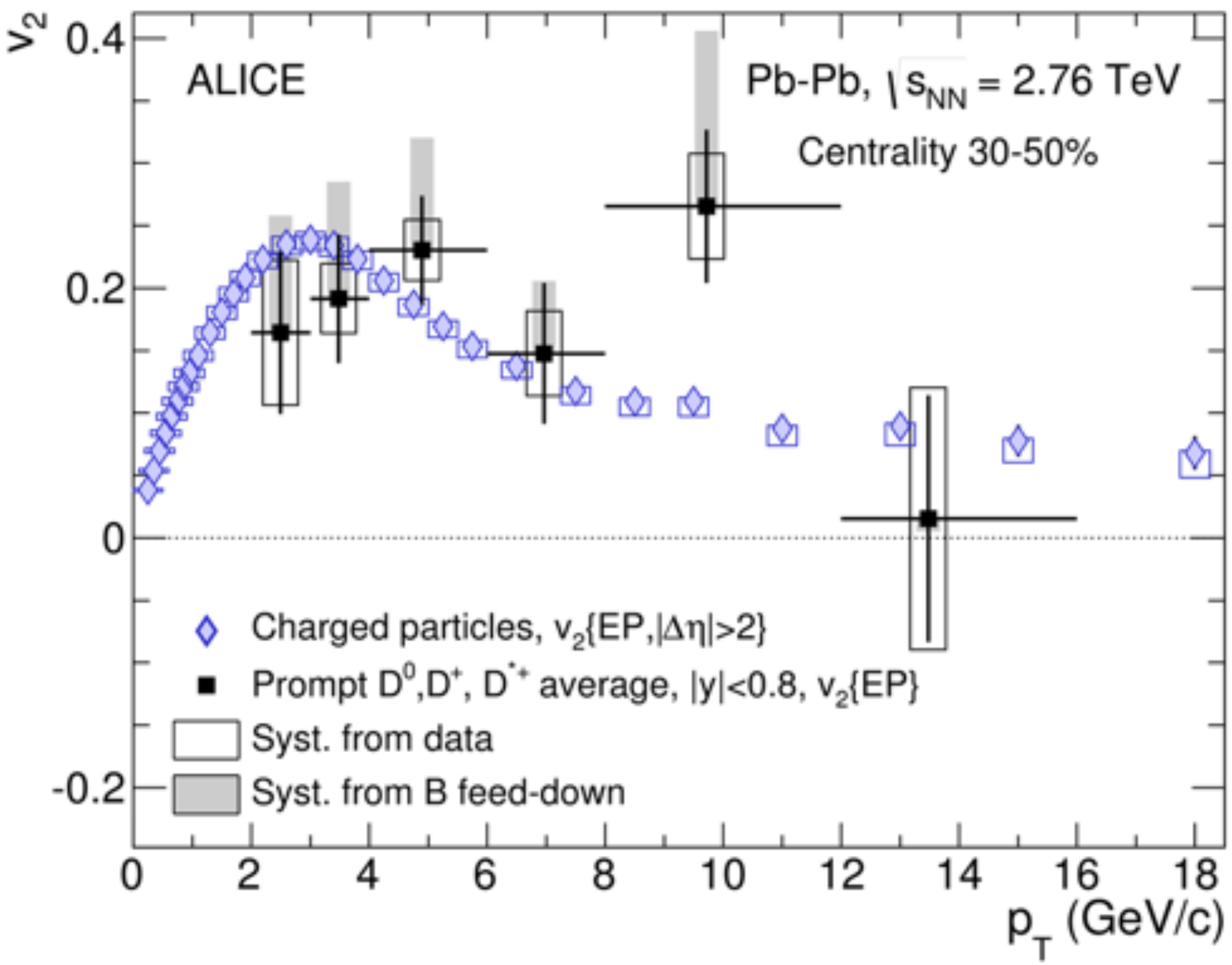


- RAA (D^0)~RAA(charged particles) for p_T>2 GeV/c as observed at LHC!

heavy flavours and collectivity

Does charm flow?

ALICE v_2 measurement in 30-50% at 2.76 TeV



PRL 111 (2013) 102301

→ D^0 meson $v_2>0$
→ compatible with v_2 of charged particles

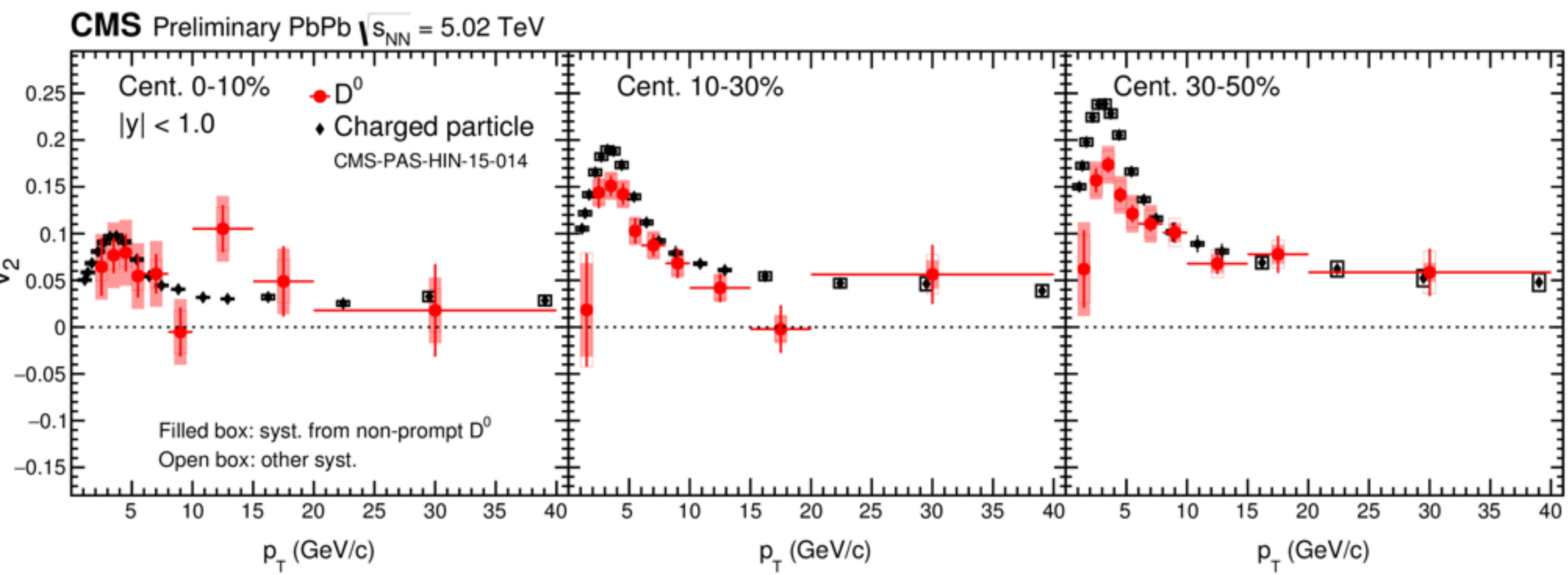
BUT non zero v_2 doesn't necessarily imply that charm flows!

A ~small v_2 can be generated in the recombination of "static" charm with "flowing" light quarks!

D meson v_2 at 5.02 TeV in PbPb collisions

New CMS measurement of v_2 and v_3 in PbPb collisions at 5.02 TeV in different collision centralities

CMS-PAS-HIN-16-007



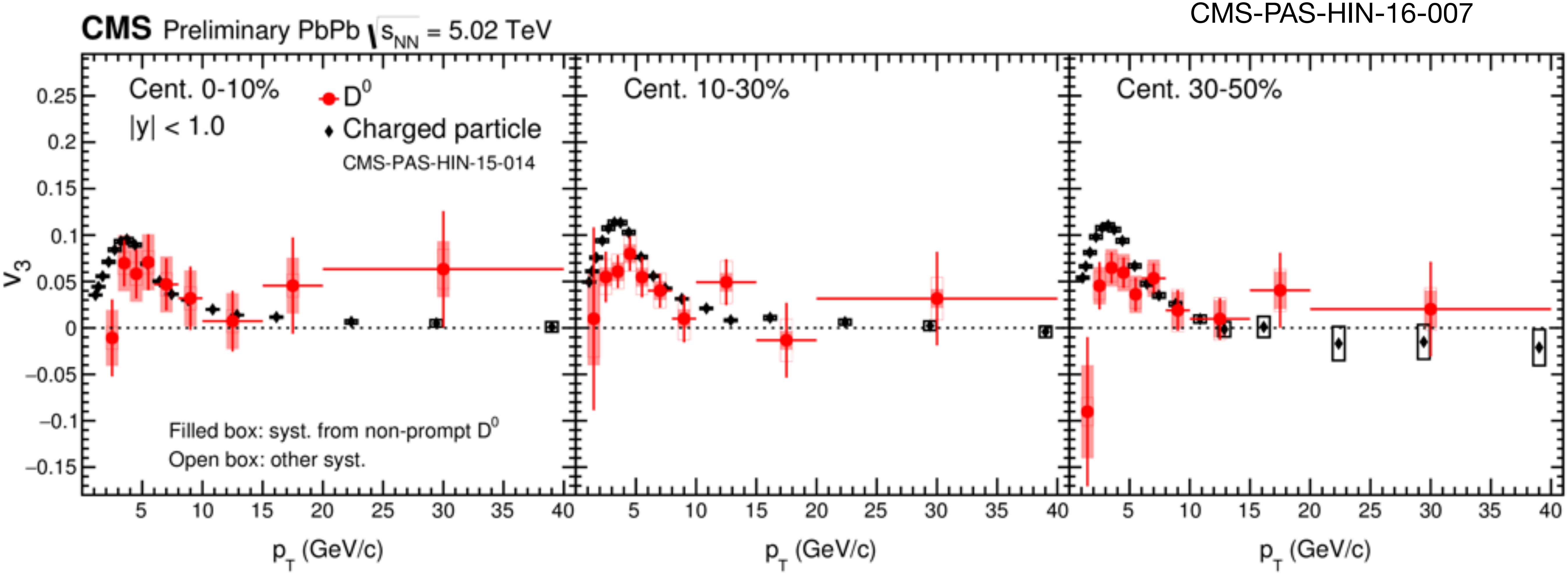
Significant confirmation of $v_2>0$ for D^0 at 5.02 TeV:

v_2 of D mesons larger than v_2 of charged particles

v_2(0-10%)< v_2(10-30%) ~ v_2(30-50%)

D meson v_3 at 5.02 TeV in PbPb collisions

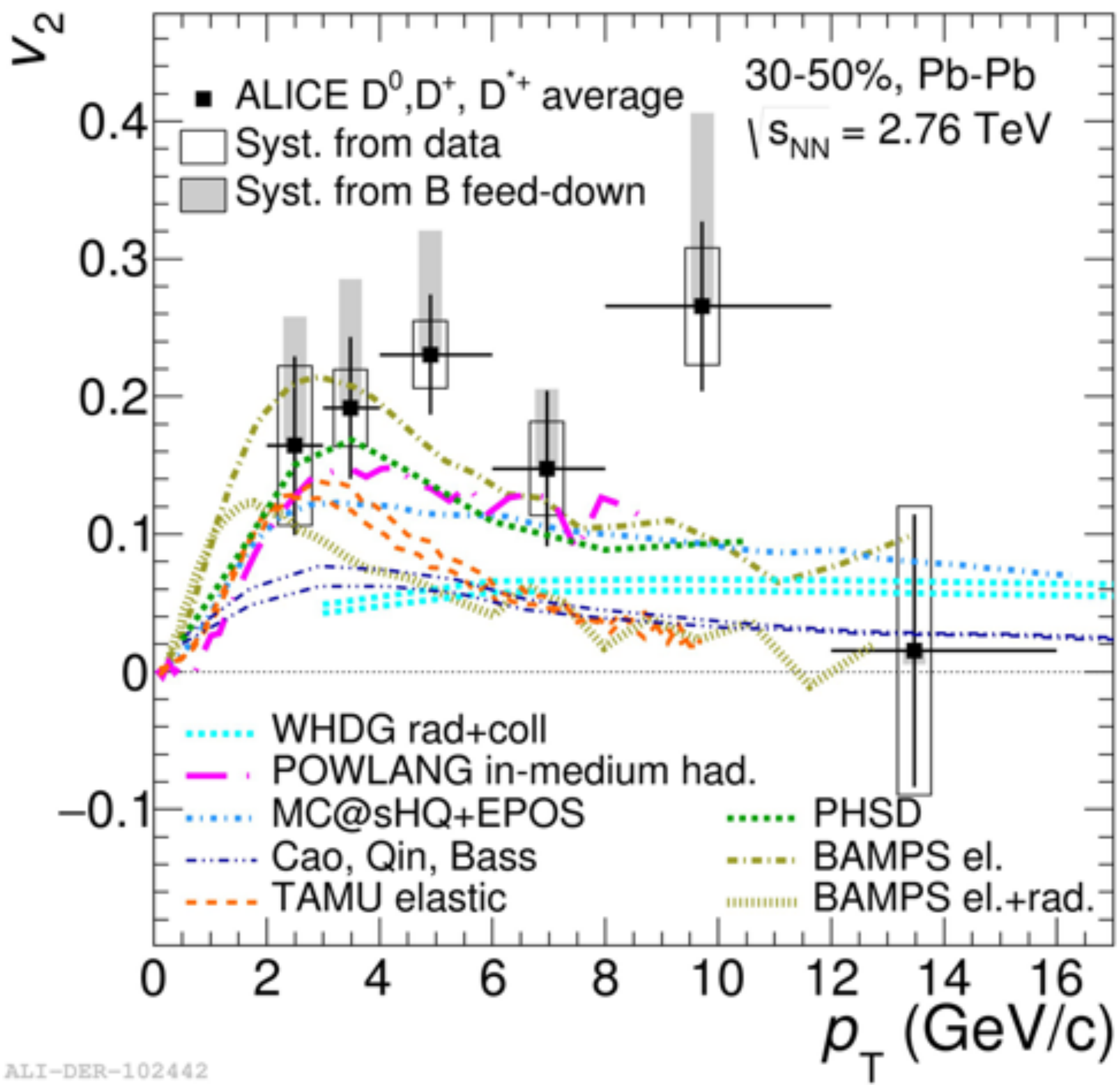
CMS-PAS-HIN-16-007

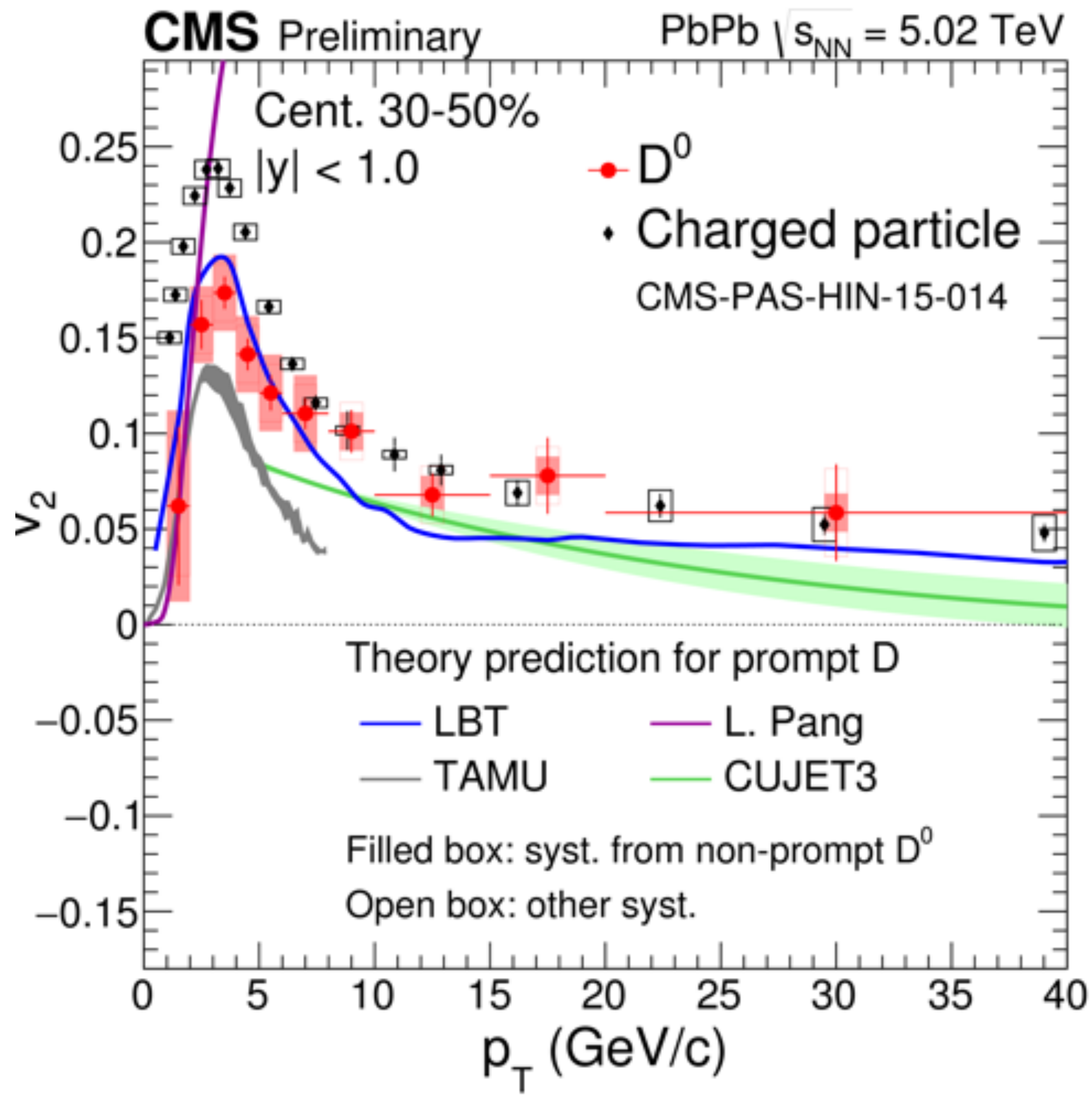


First observation of v_3>0 for charm!

v_3 for charged particle larger that D^0 v_3 although not fully significative given current uncertainties

Comparison with models

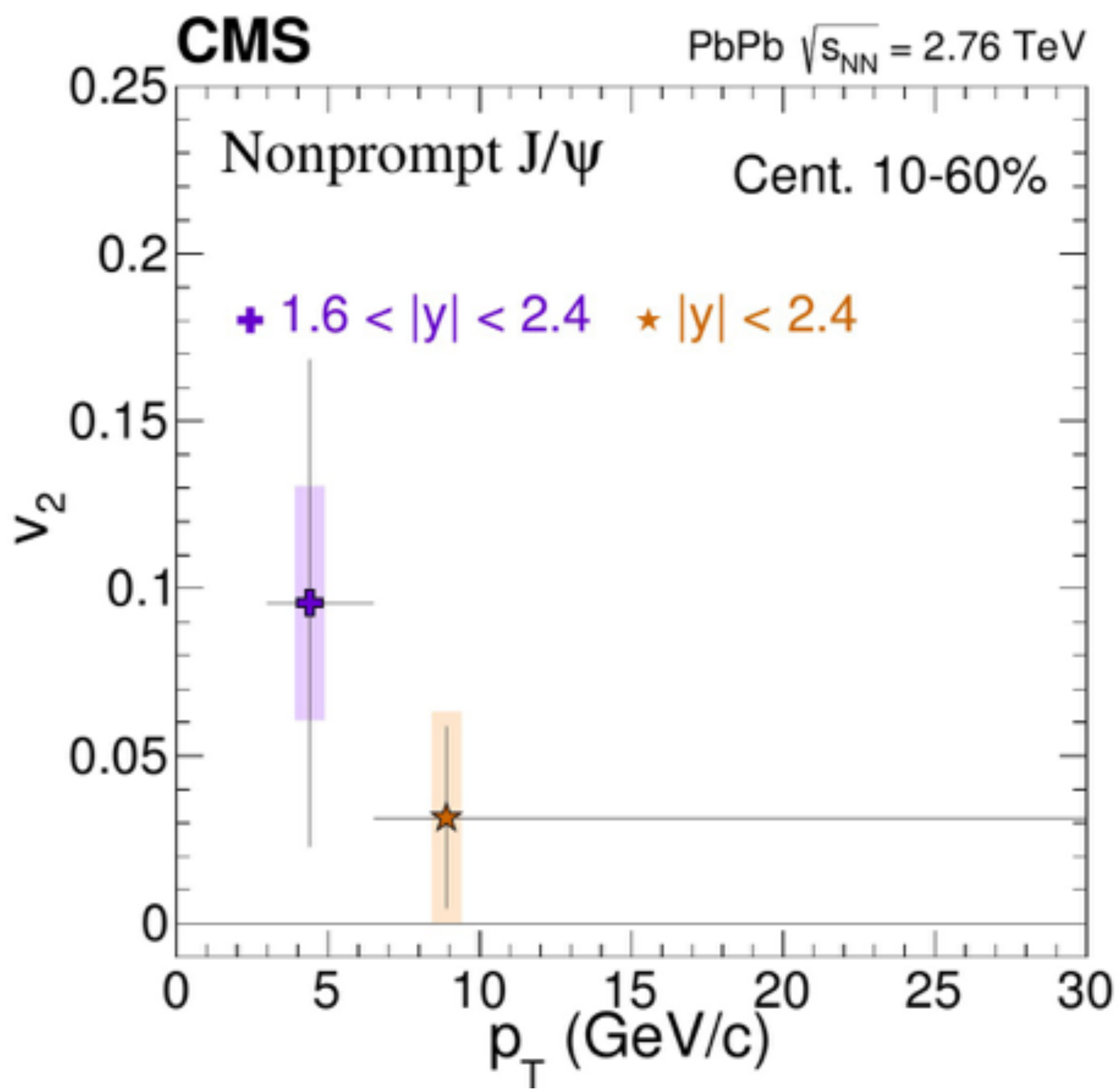




we need **charm quark diffusion** to describe the magnitude of the D meson v_2!

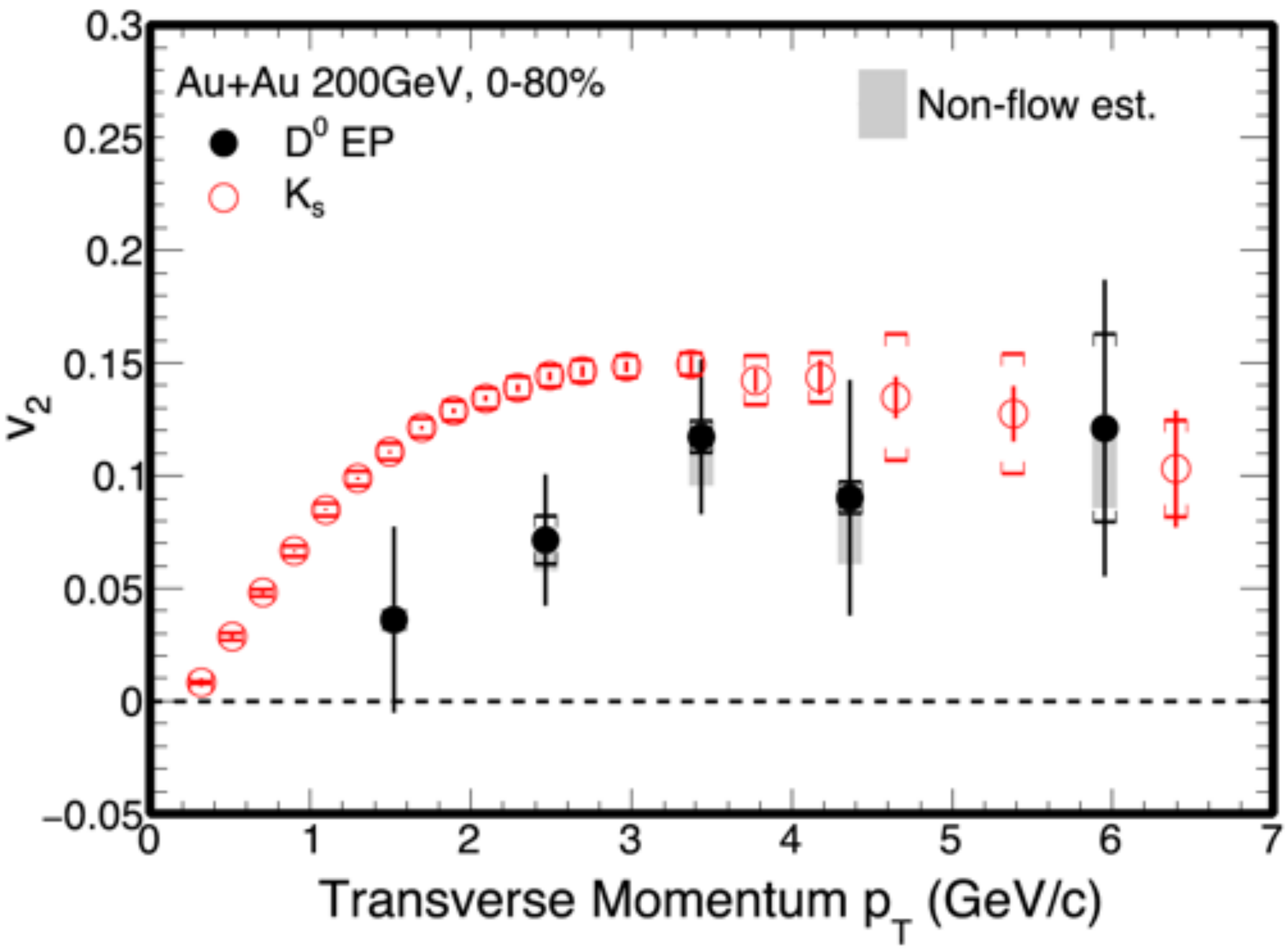
v_2 of non prompt J/ψ

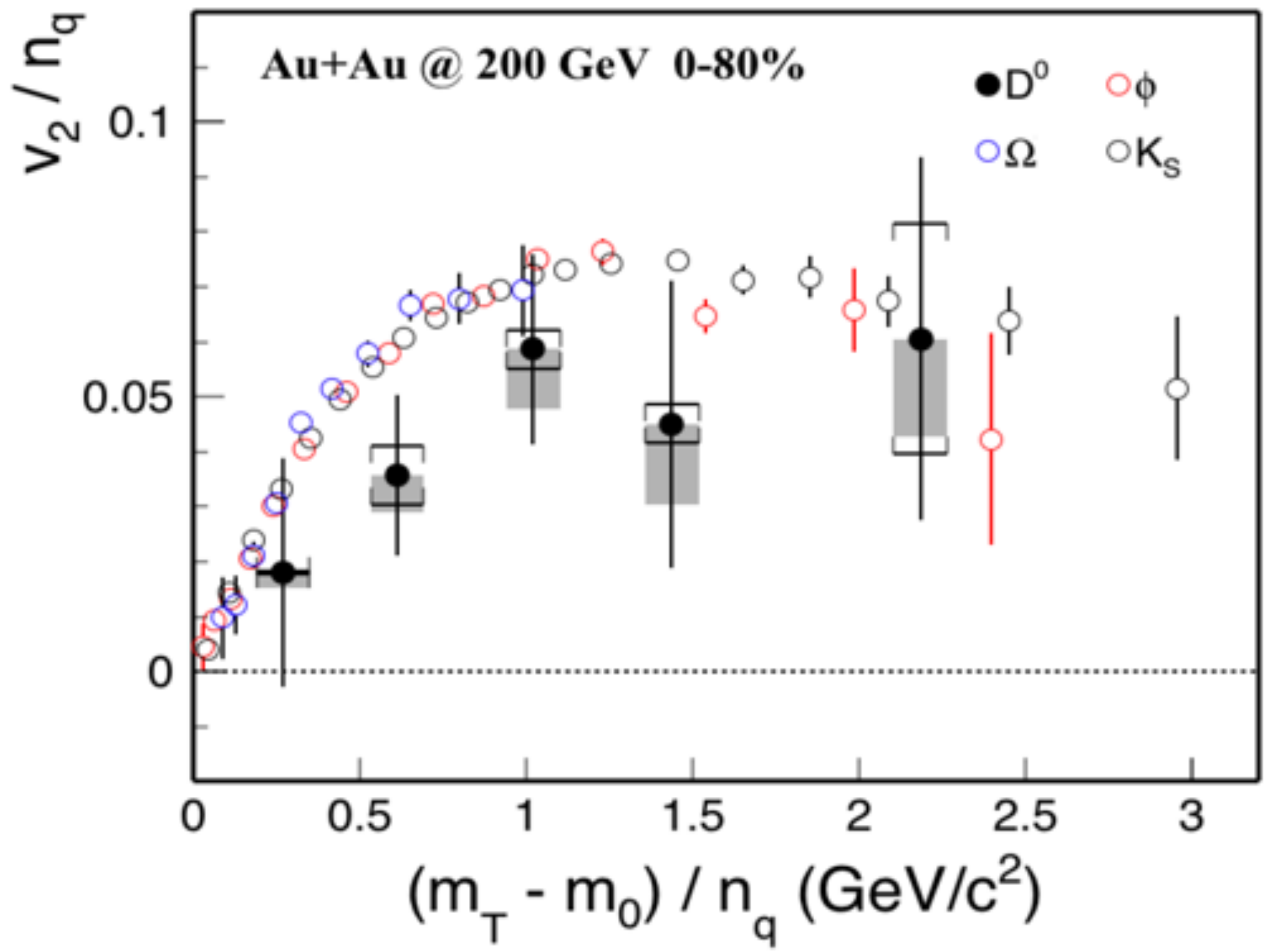
New measurement of v_2 of non prompt J/ψ in PbPb collisions at 2.76 TeV



→Central value of v_2 of non prompt J/ψ but still compatible in 2σ with 0
Looking to see the new measurement with Run2 data with higher statistics!

D^0 meson v_2 at 200 GeV with STAR



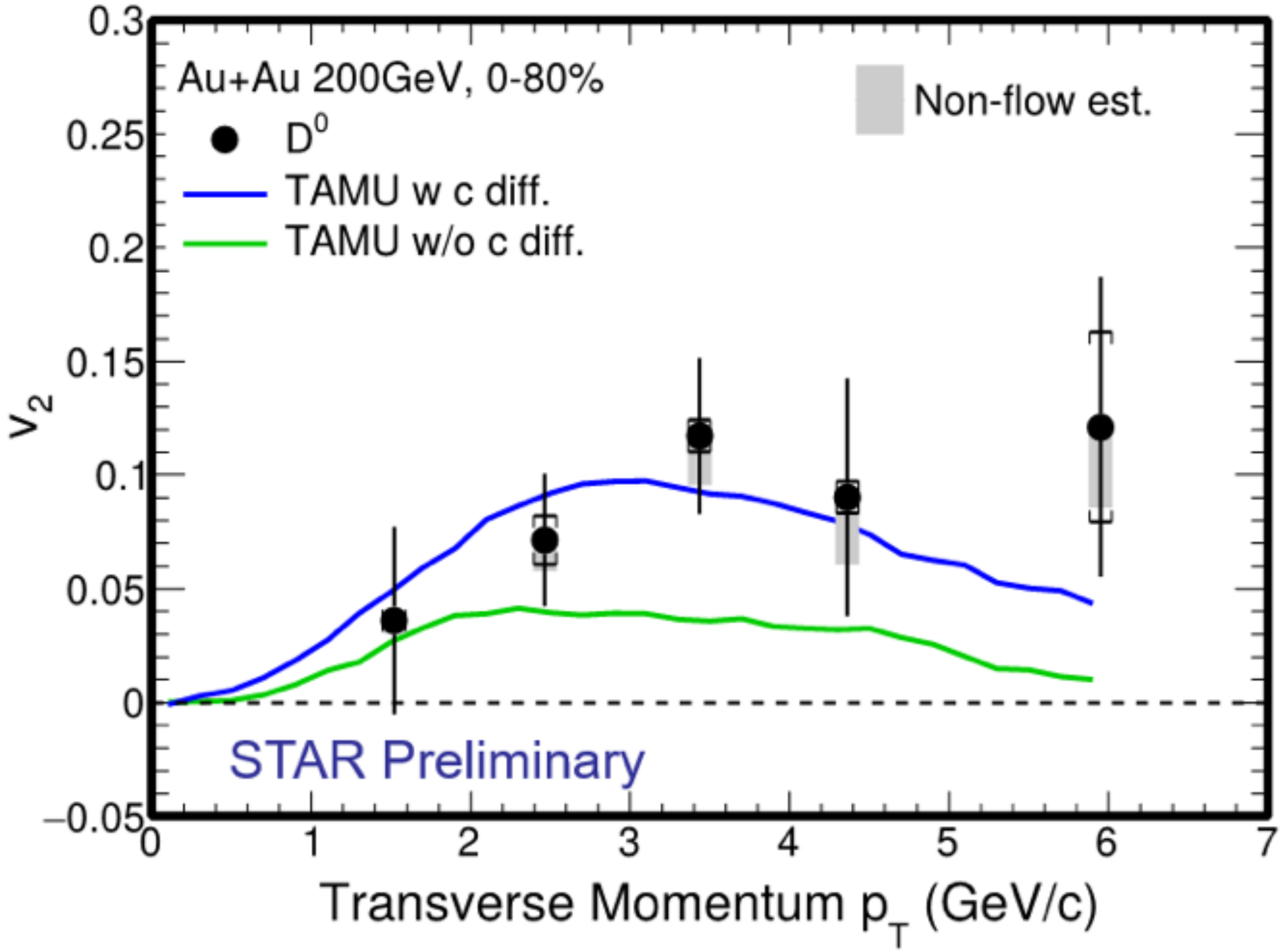


→Hints of $v_2(D) < v_2(hadron)$ and $v_2(D)/n_q < v_2(hadron)/n_q$ as observed at LHC!
CAVEAT: very wide centrality bin (0-80%) might bias the comparison!

Need for more measurements in finer bins of centrality…

PRC 77 (2008) 54901
PRL 116 (2016) 62301

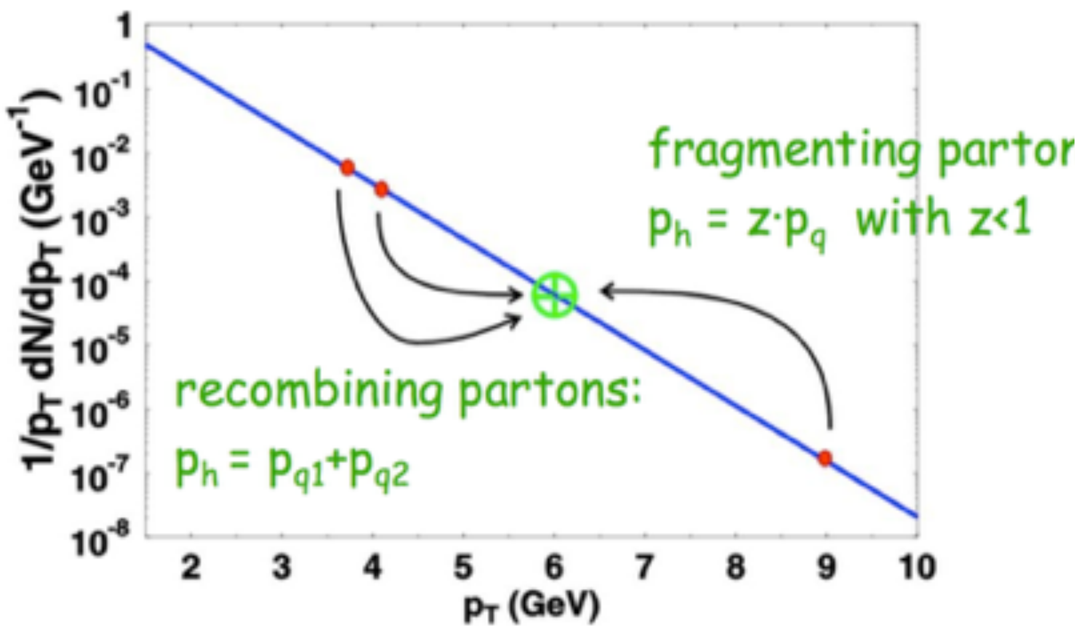
Comparison to theoretical calculations

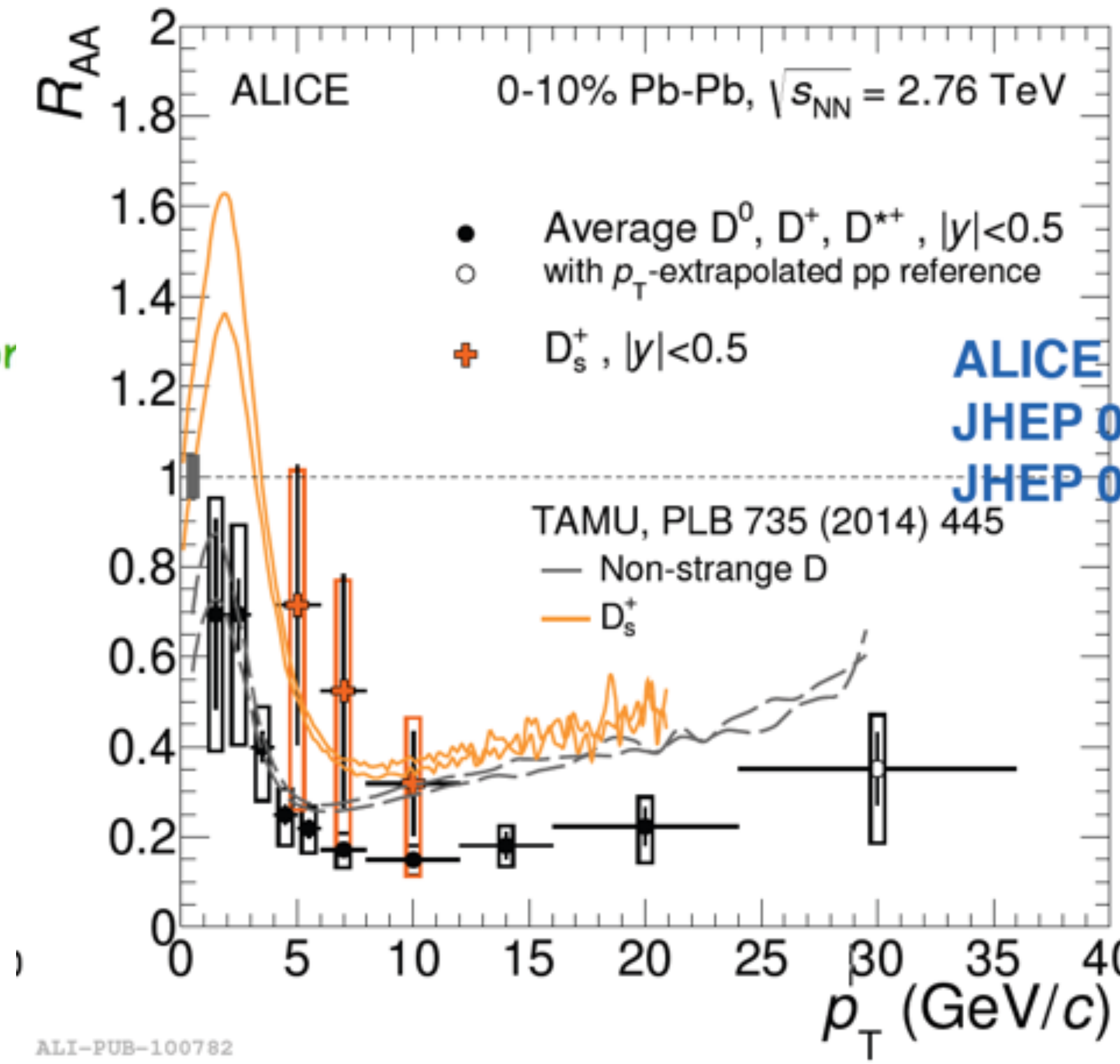


Well described by theoretical calculations that include charm diffusion!

D_s as a probe for charm recombination

R_{AA} of D_s > R_{AA} D^0 if coalescence is a relevant production mechanisms for charm as a consequence of the strangeness enhancement in PbPb collisions





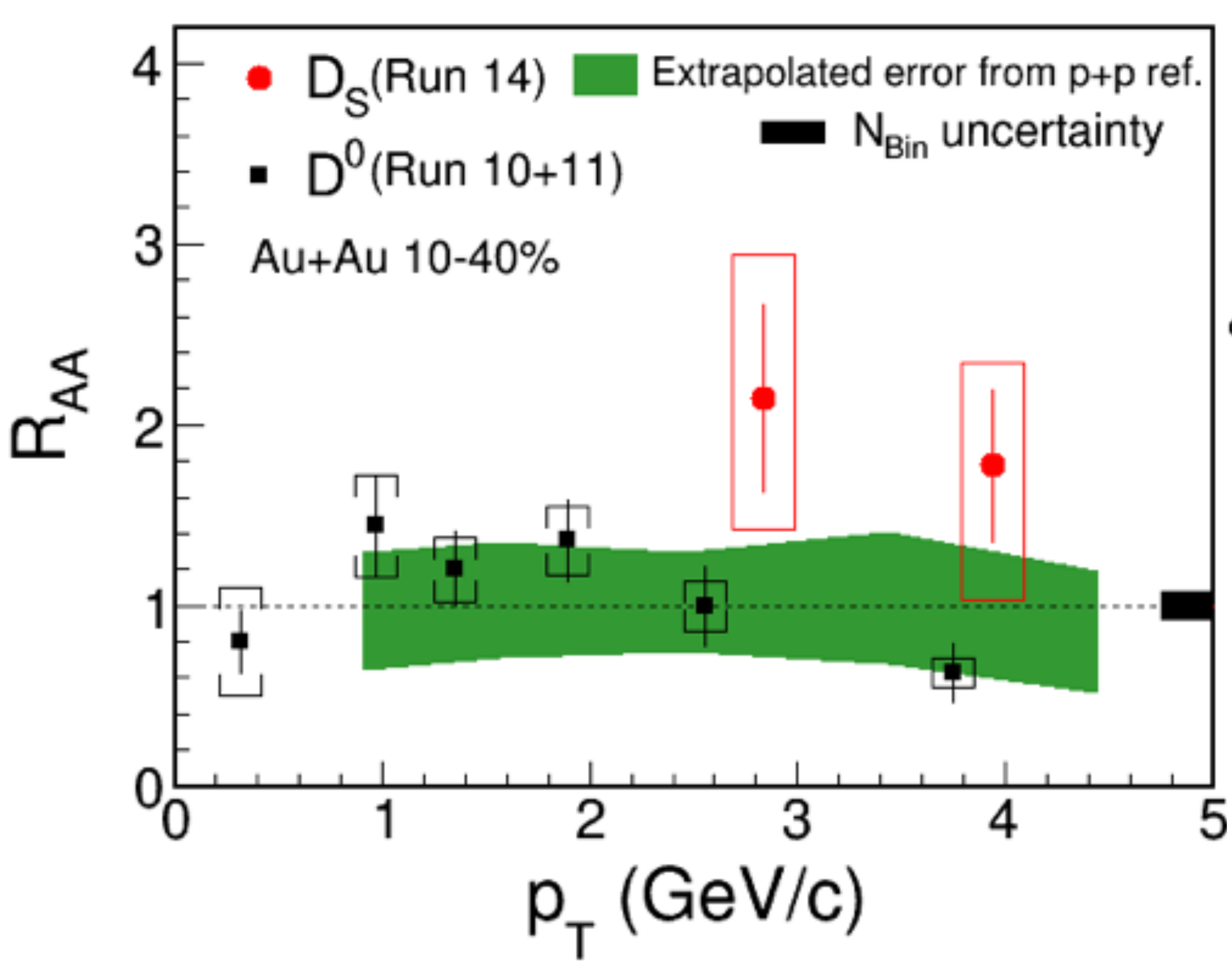
ALICE
JHEP 03 (2016) 081
JHEP 03 (2016) 082

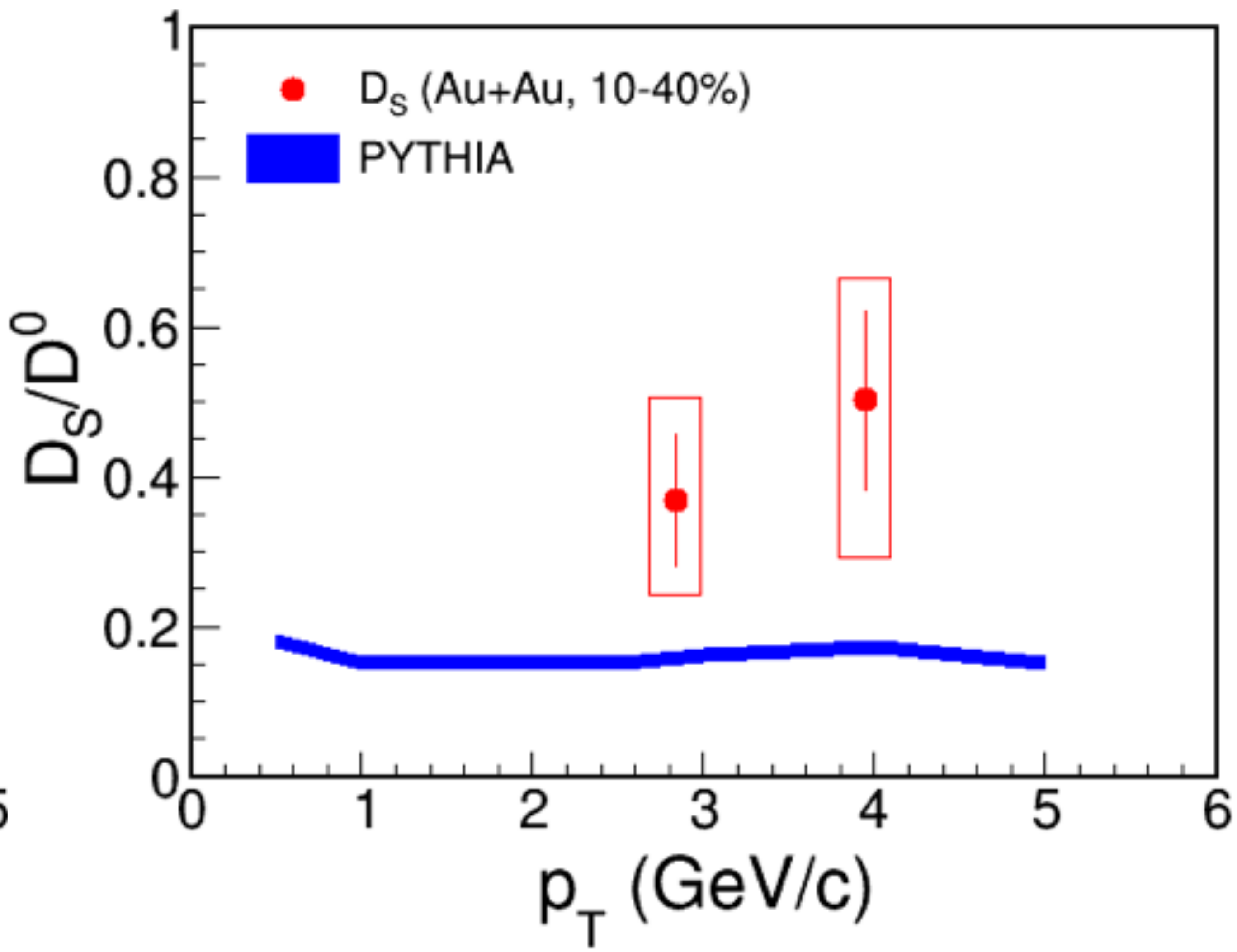
Central values of D_s R_{AA} > D^0 R_{AA}

not yet significant given current uncertainties

→ *Waiting to see new D_s results with higher statistics from Run2 data!*

First D_s measurement in AuAu at STAR





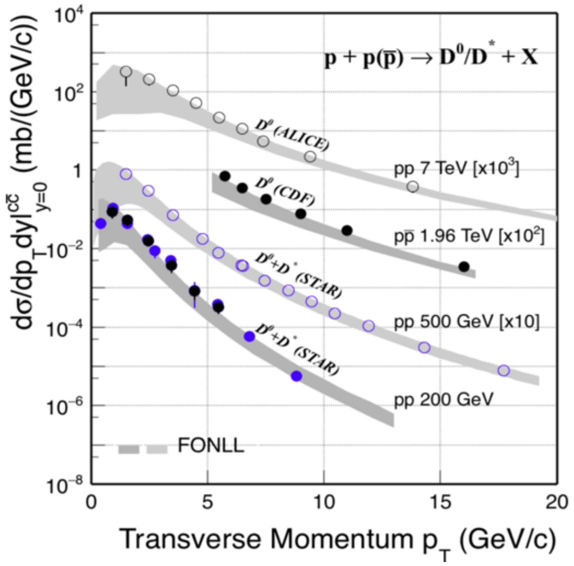
Also at RHIC central values of D_s R_{AA}> D^0 R_{AA}

→ *More statistics is needed for conclusions!*

Conclusions (I)

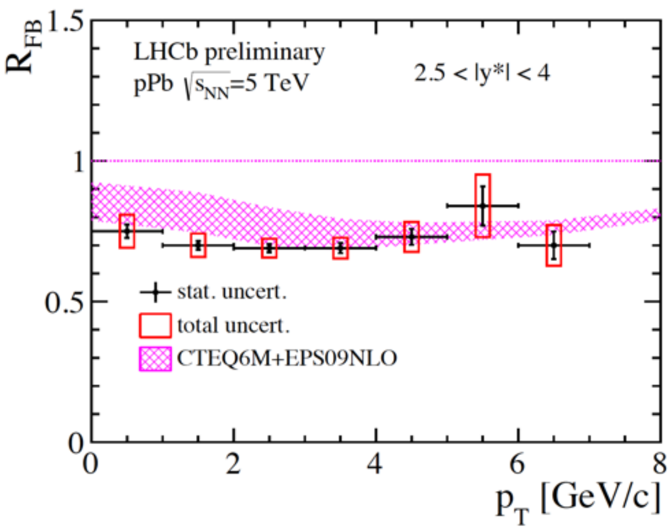
Do we understand the production mechanism?

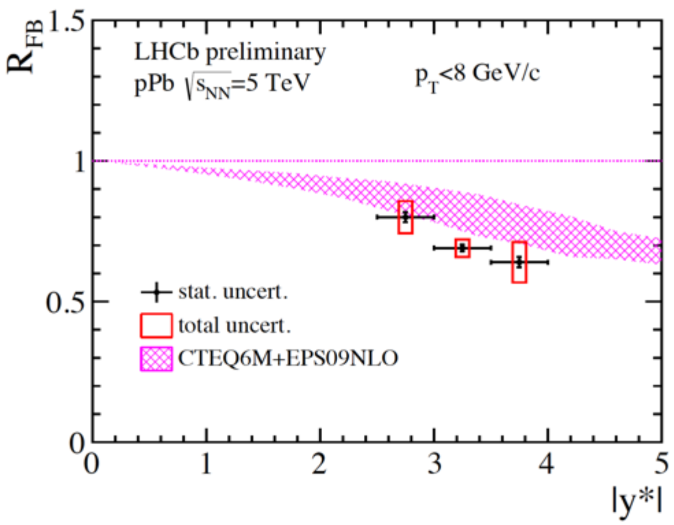
- charm and beauty production are well described by pQCD calculations at both RHIC and LHC energies



Is the initial state modified?

- the HF production cross sections are consistent with the prediction of CNM models at LHC energies.
- Still in apparent contraction with RHIC results in which CNM based models do not describe forward/backward asymmetry

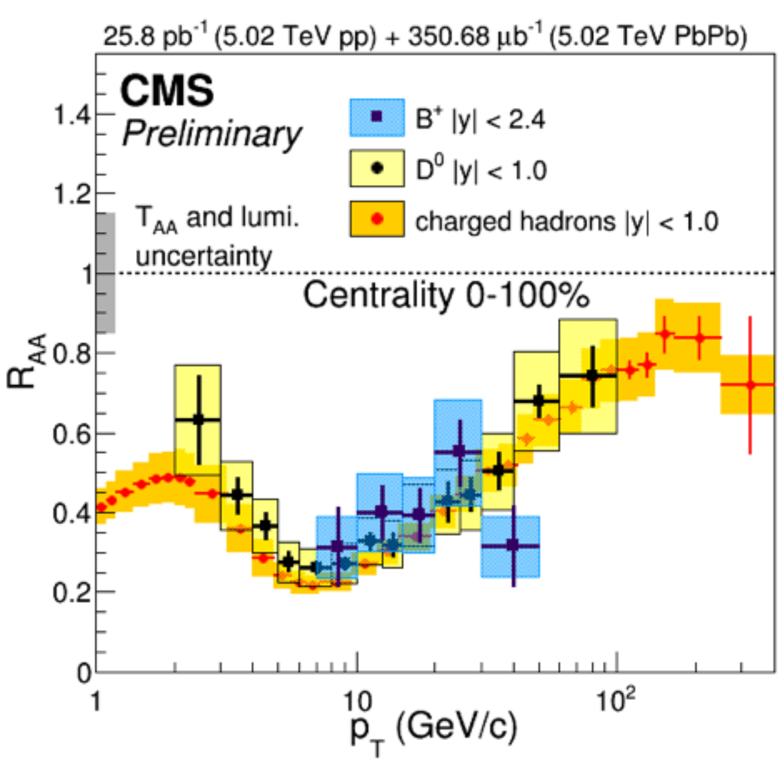


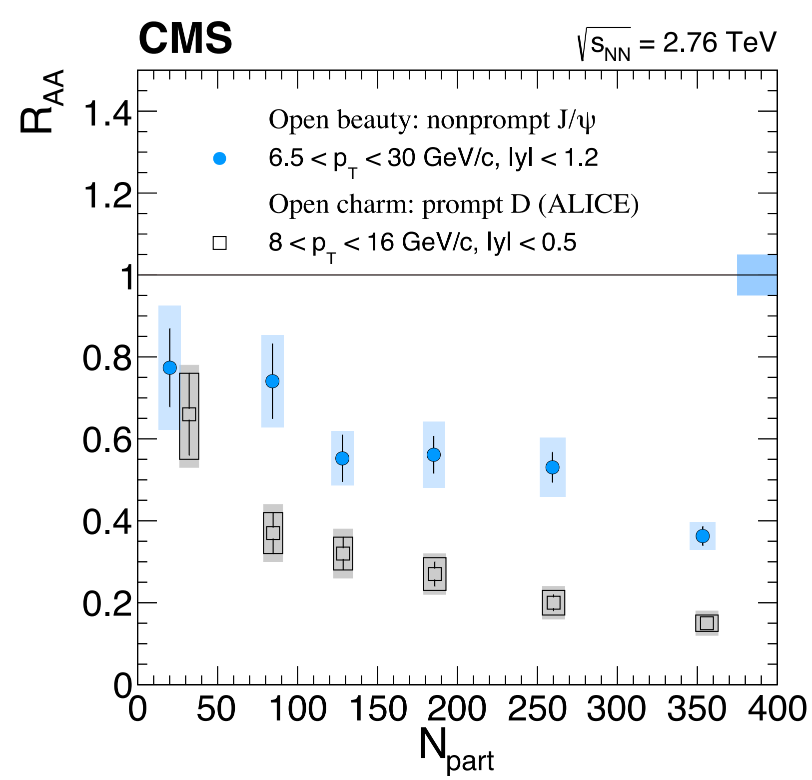


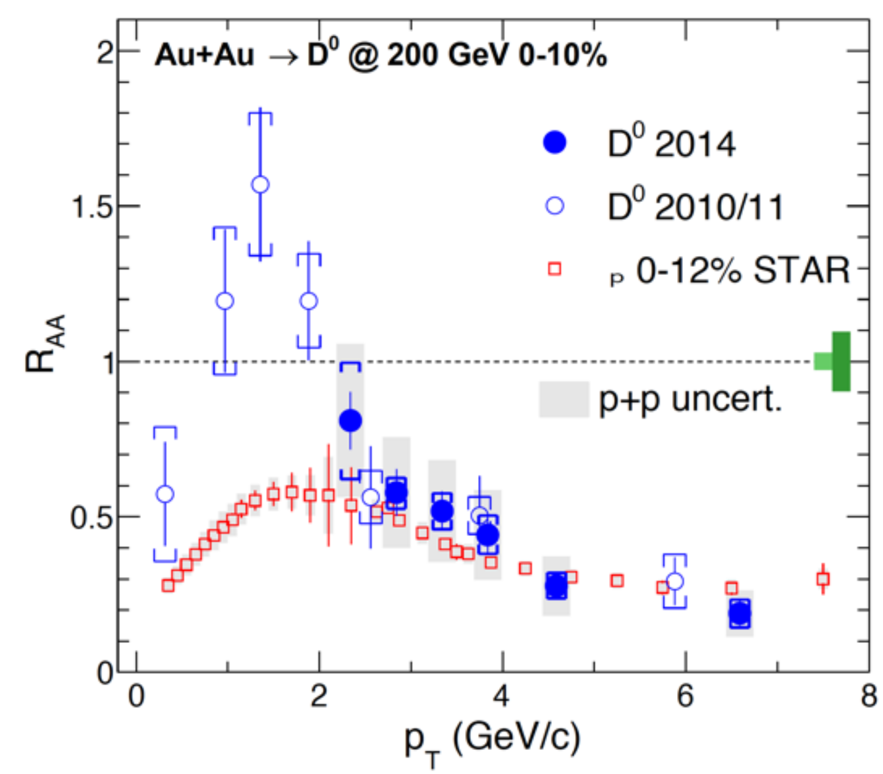
Conclusions (II)

How do HF lose energies?

- LHC: hints of flavour dependence D vs B at low p_T (caveats as usual…)
- LHC: indications of mild/no flavour dependence at higher p_T
- both at LHC and RHIC no indication of different suppression of charged particle and D for p_T>2 GeV/c







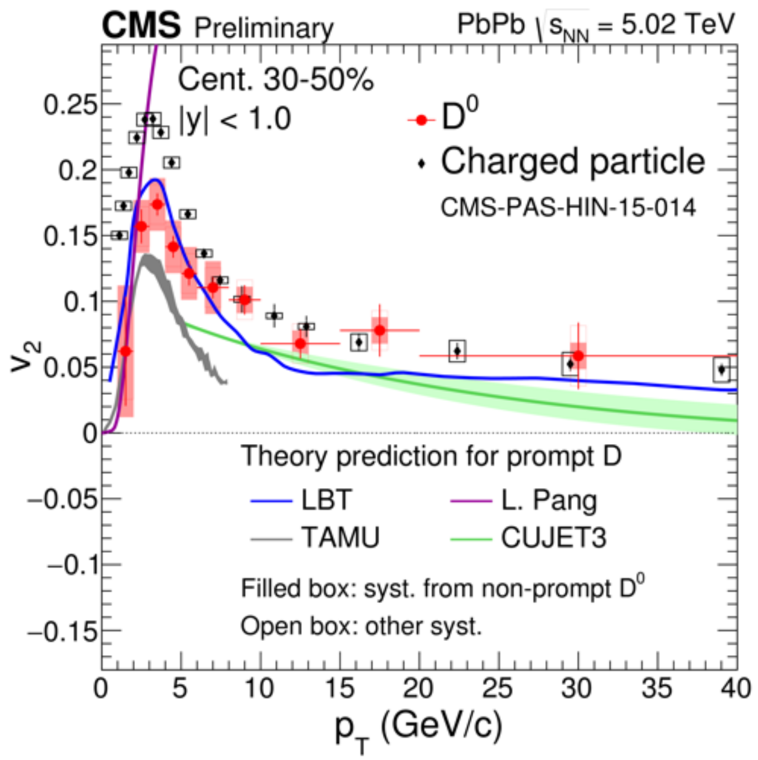
Conclusions (III)

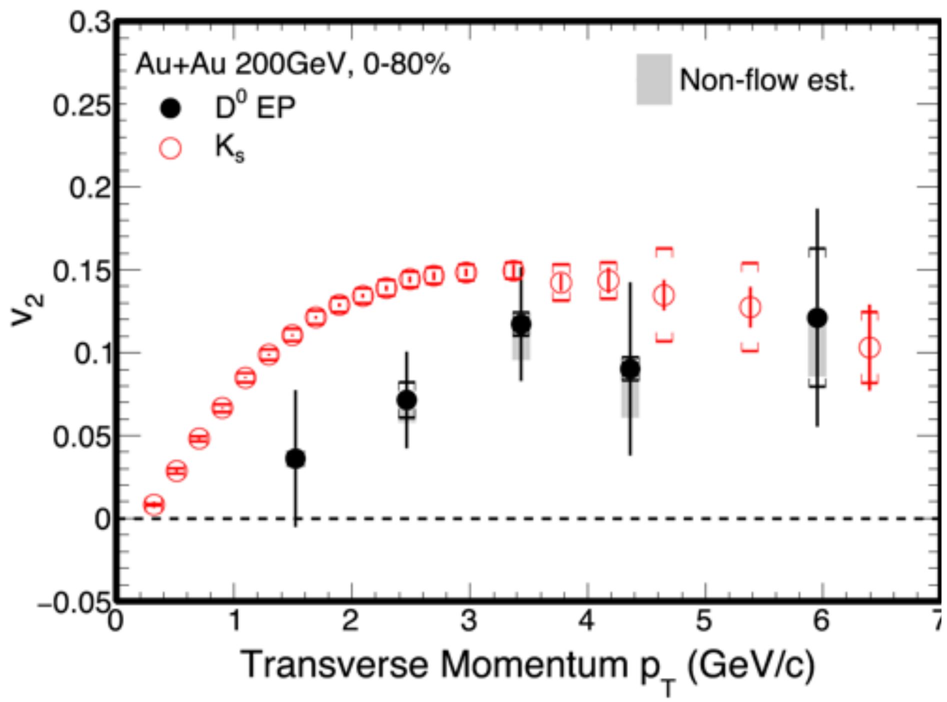
Do heavy quarks participate in the collective expansion of the medium?

- At LHC and RHIC: v_2 significantly > 0 for D^0
- Similar observation of $v_2(D) < v_2(\text{charged})$ at both LHC and RHIC

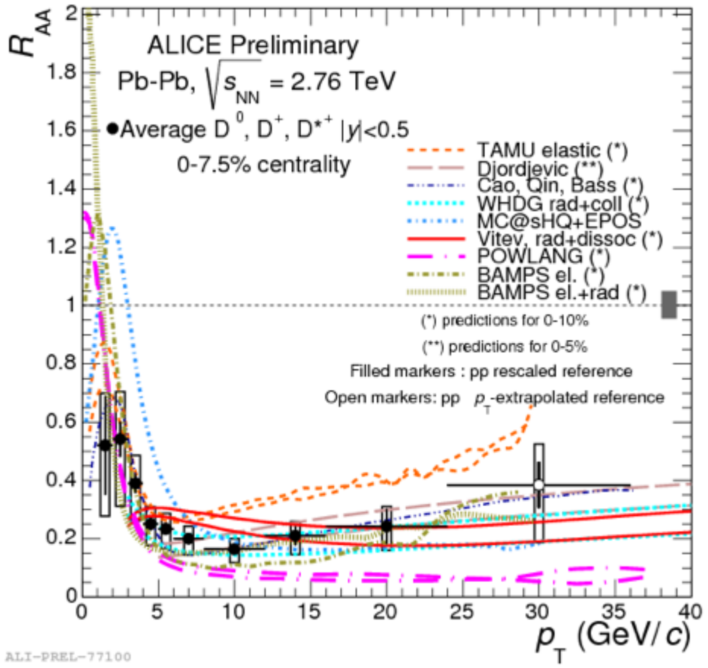
→ Comparison with theoretical calculations:

- we need charm diffusion to describe the v_n measurement!
- **charm participates in the collective motion of the fireball**

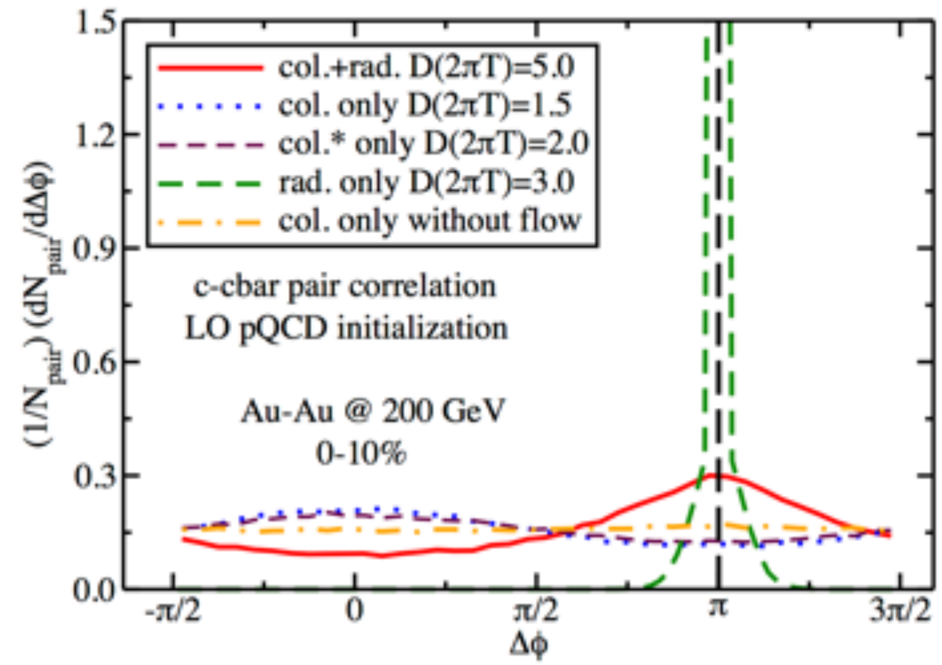




Some ideas for the future..



- Reducing current uncertainties and access the very low p_T for charm and beauty

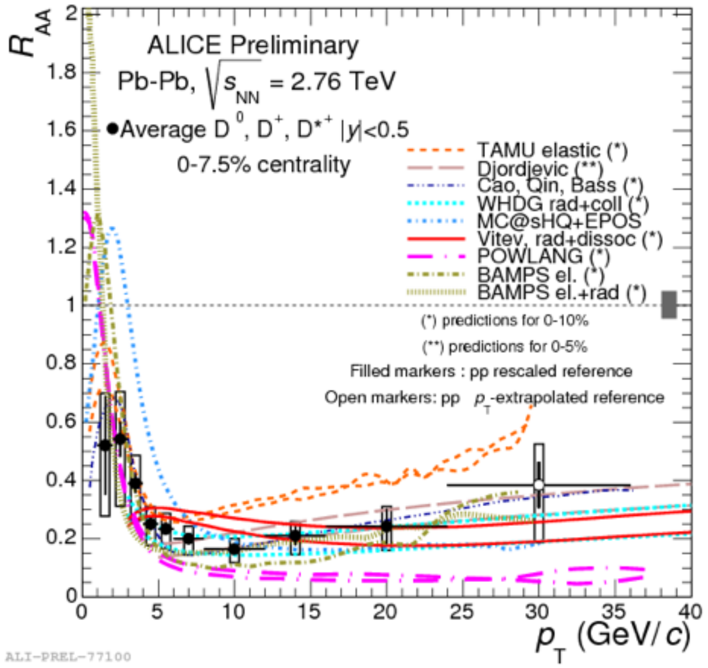


- More differential measurements (e.g. DD correlations) to disentangle collisional and radiative processes

- charm and beauty measurements of flow in pPb collisions!

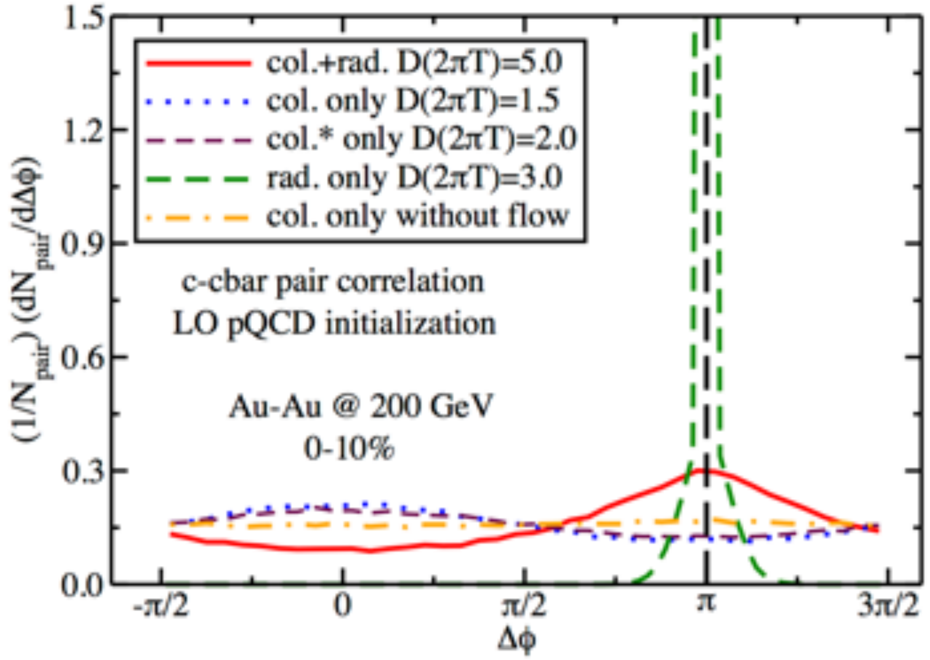
RHIC vs LHC: only with precise measurements from both LHC and RHIC we can really put constraints on theoretical calculations!

Some ideas for the future..



- Reducing current uncertainties and access the very low p_T for charm and beauty

- More differential measurements (e.g. DD correlations) to disentangle collisional and radiative processes

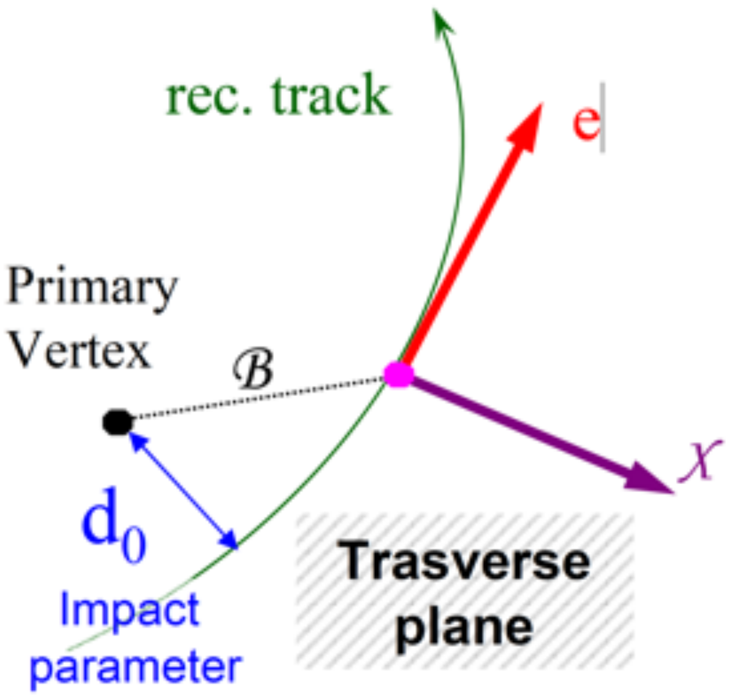


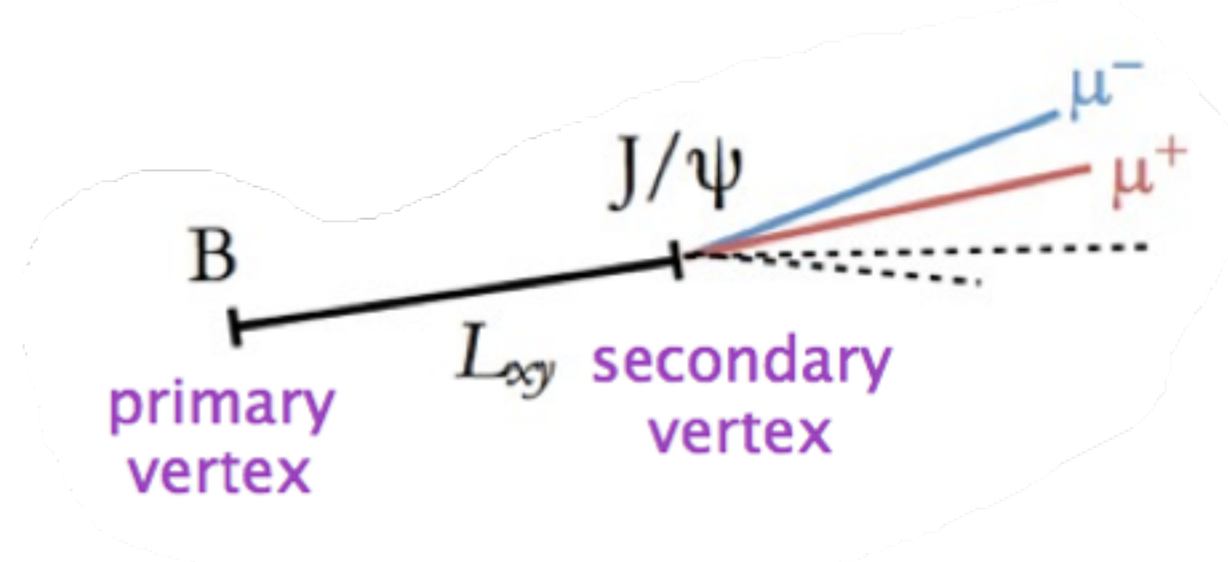
- charm and beauty measurements of flow in pPb collisions!

Thank you for your attention!

BACKUP

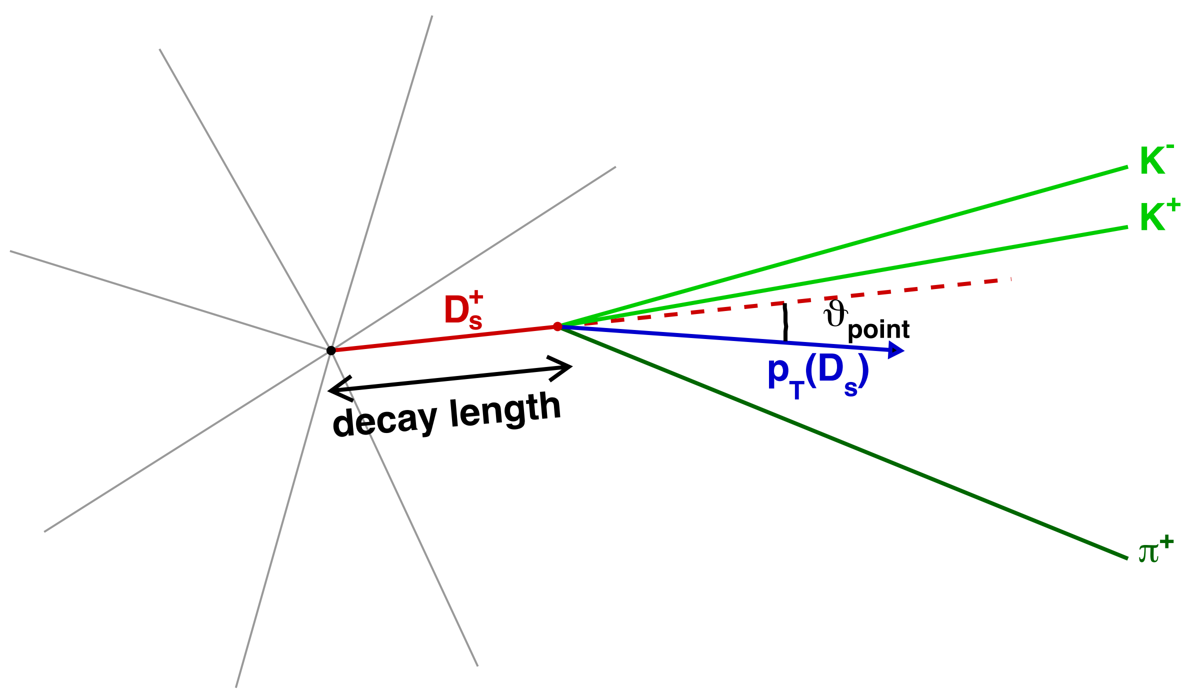
Our experimental tools





Displayed J/ψ from B decays

Semi-leptonic electrons and muons from c and b quarks



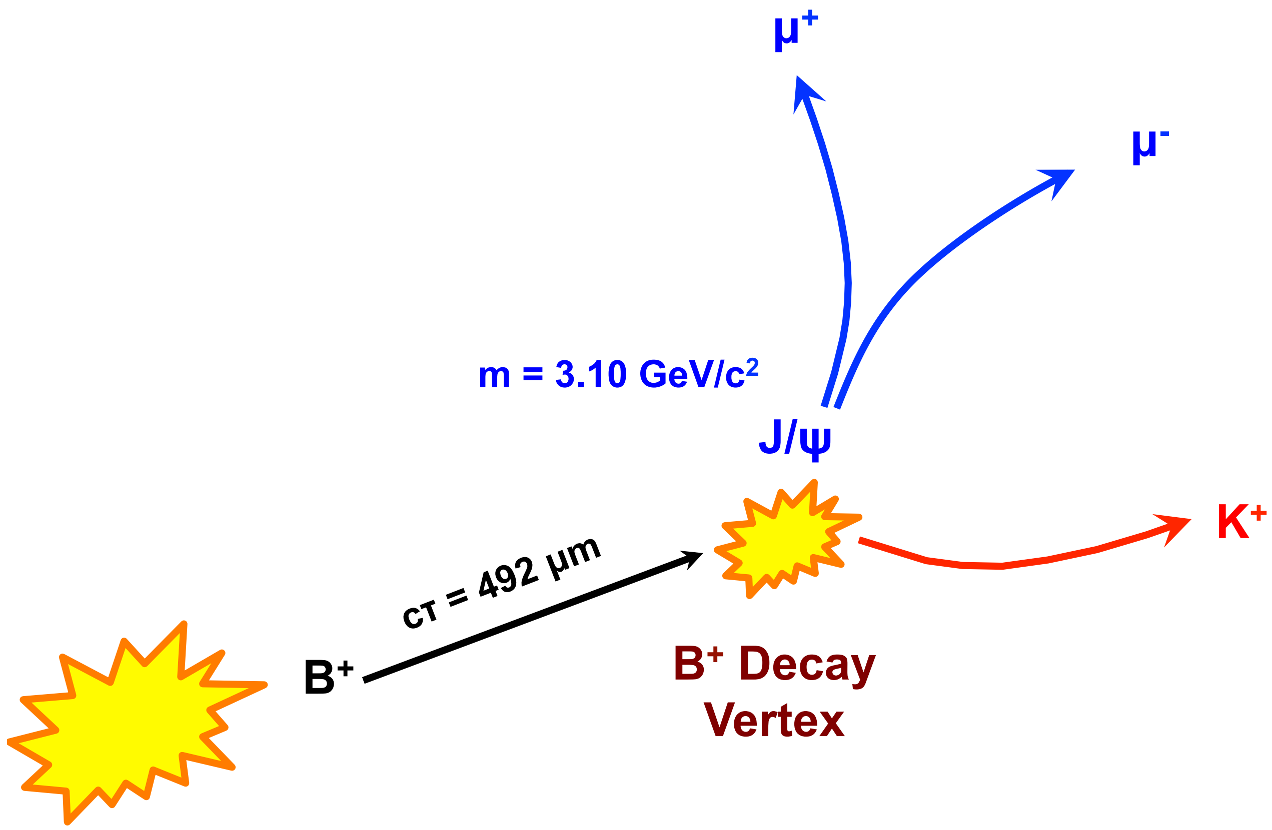
Fully reconstructed D meson decays:

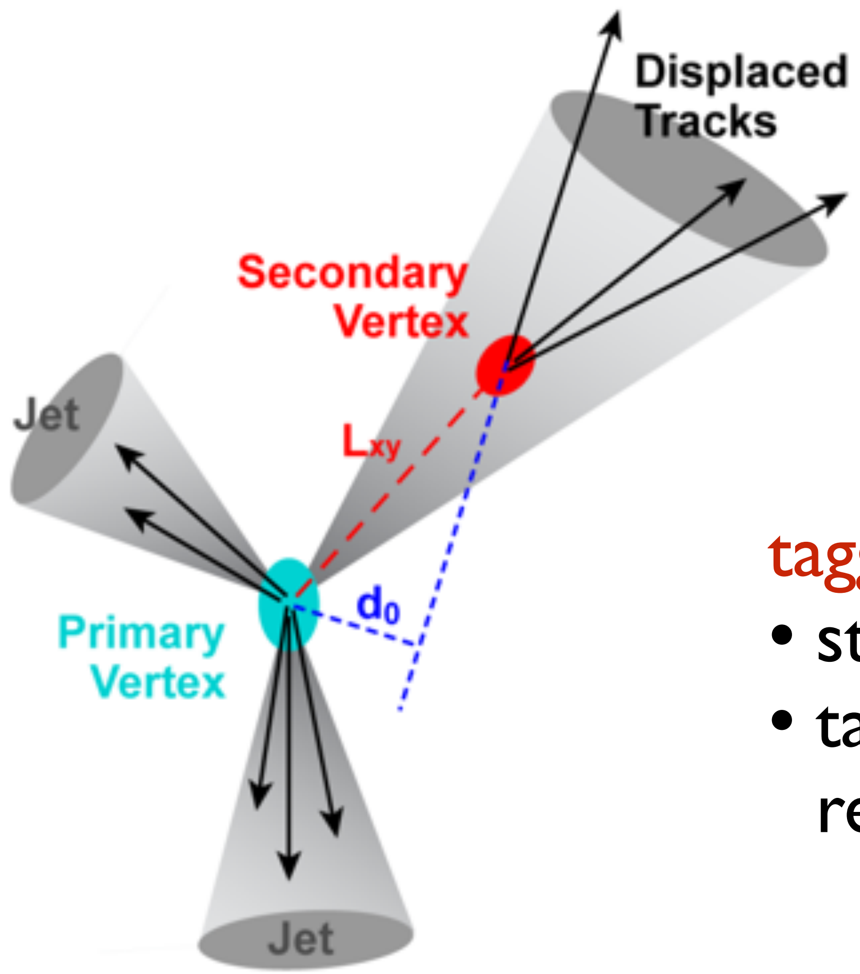
- $D^0 \rightarrow K^- + \pi^+$
- $D^+ \rightarrow K^- + \pi^+ + \pi^+$
- $D^{*+} \rightarrow D^0 + \pi^+$
- $D^+_s \rightarrow \phi + \pi^+$

Our experimental tools

Fully reconstructed B meson decays:

- $B^+ \rightarrow J/\psi\ K^+ \rightarrow \mu^+\mu^-\ K^+$
- $B^0 \rightarrow J/\psi\ K^{0*} \rightarrow \mu^+\mu^-\ K^+\pi^-$
- $B_s \rightarrow J/\psi\ \phi \rightarrow \mu^+\mu^-\ K^+K^-$

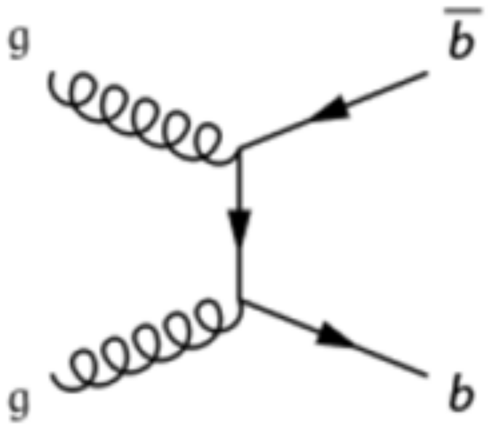




tagged c- and b-jets

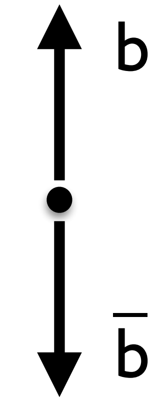
- standard jet reconstruction
- tagging based on the displacement with respect to the primary vertex

heavy quark production mechanism



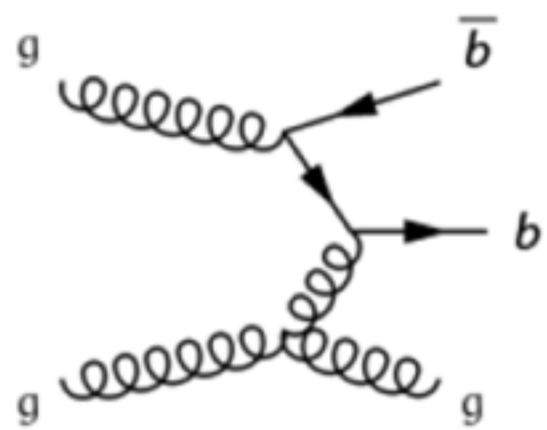
LO process: Flavour Creation (FCR)

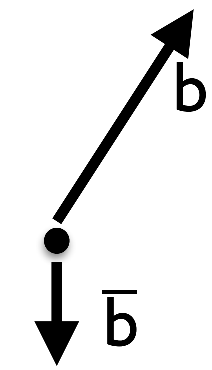
→ $b\bar{b}$ produced back-to-back in azimuthal plane and symmetric in p_T

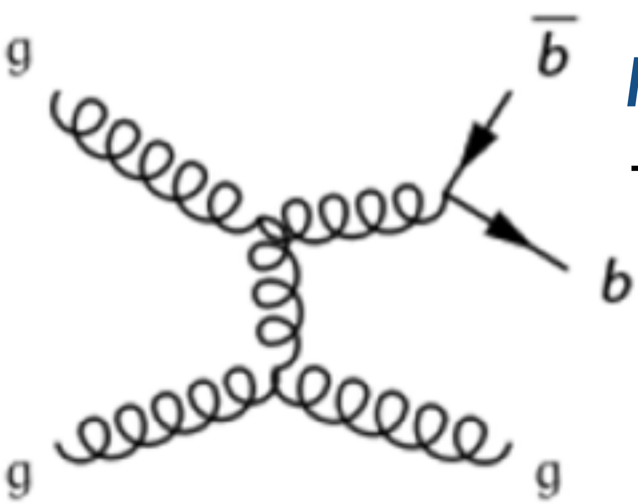


NLO process: Flavour Excitation (FEX)

→ $b\bar{b}$ pairs produced asymmetric in p_T and with a broad opening angle



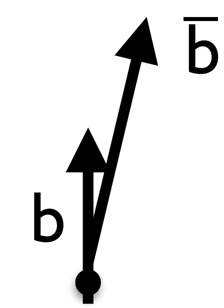




NLO process: Gluon splitting (GSP)

→ produced with small opening angles and asymmetric in p_T

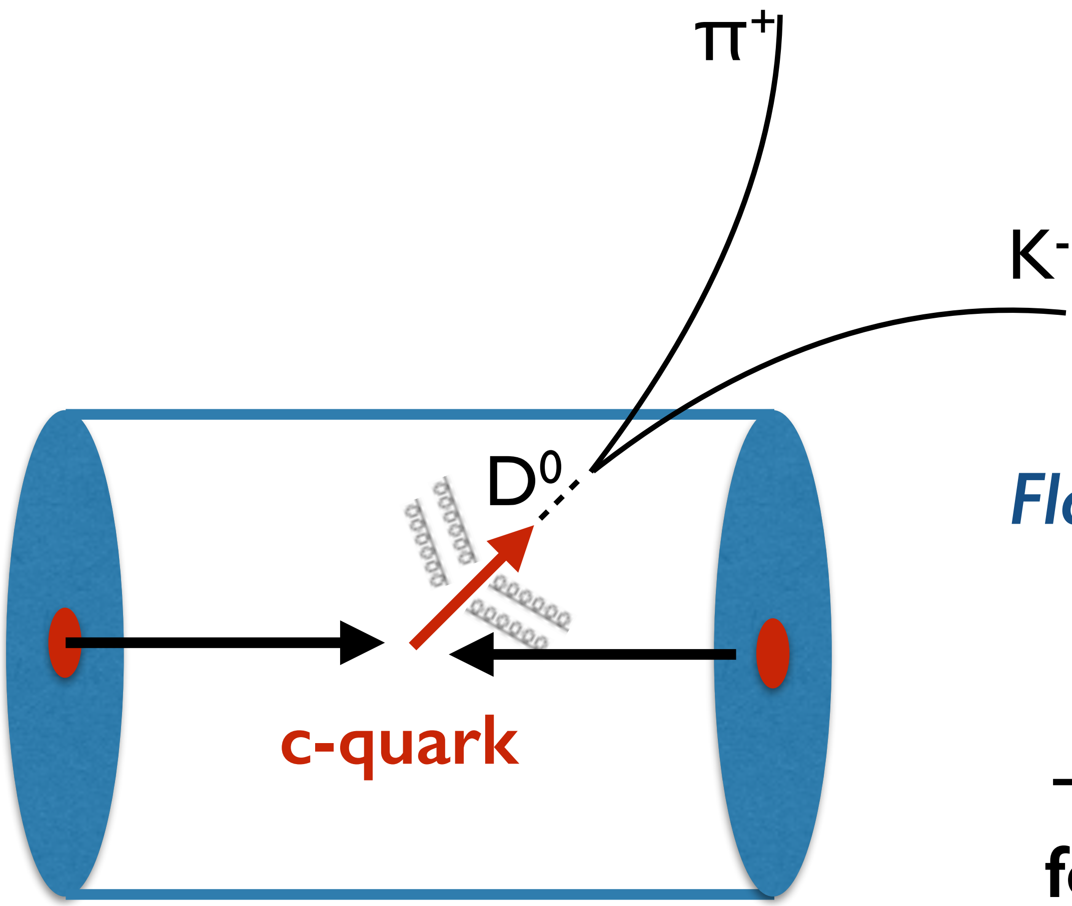
→ $b\bar{b}$ are not involved in the hard scattering but produced later

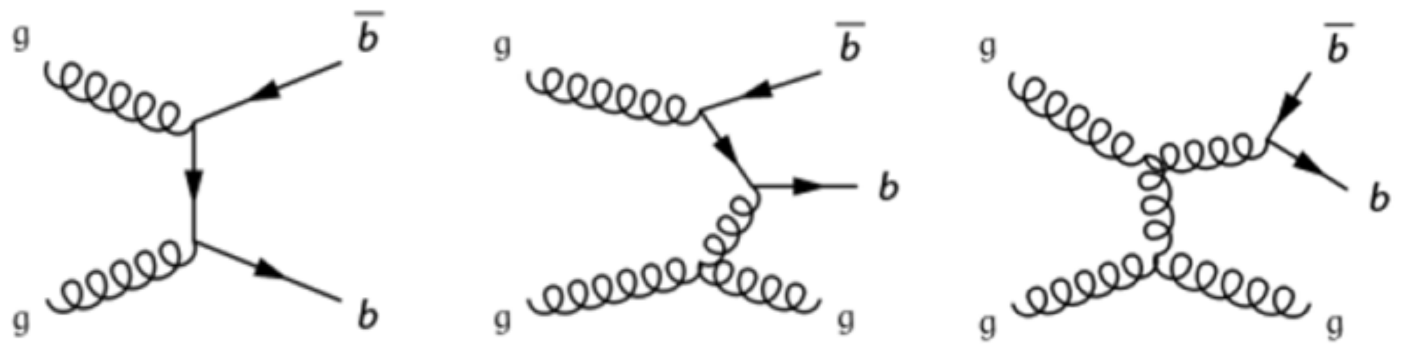


HQ production mechanisms

Do we understand the production mechanism?

- high Q^2 processes + large mass:
  → calculated in pQCD down to low p_T
- Very short formation time ~0.1 fm/c
  → much smaller than QGP formation time
  → production is not affected by the medium



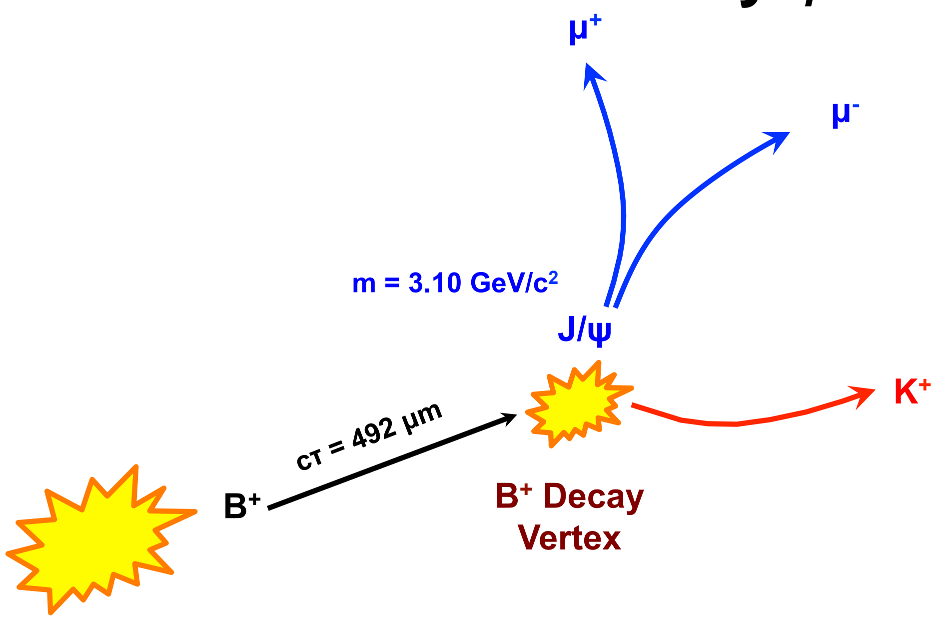


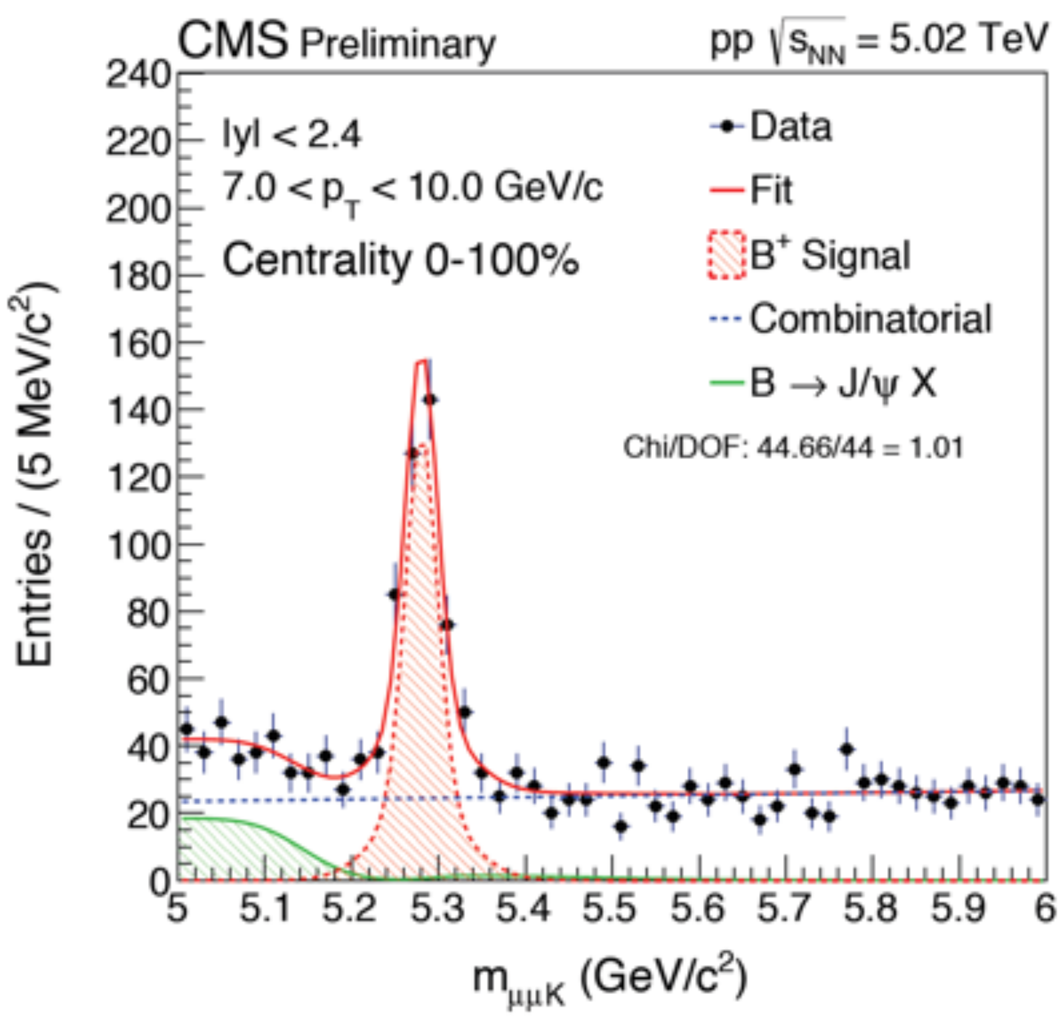
Flavour Creation *Flavour Excitation* *Gluon splitting*

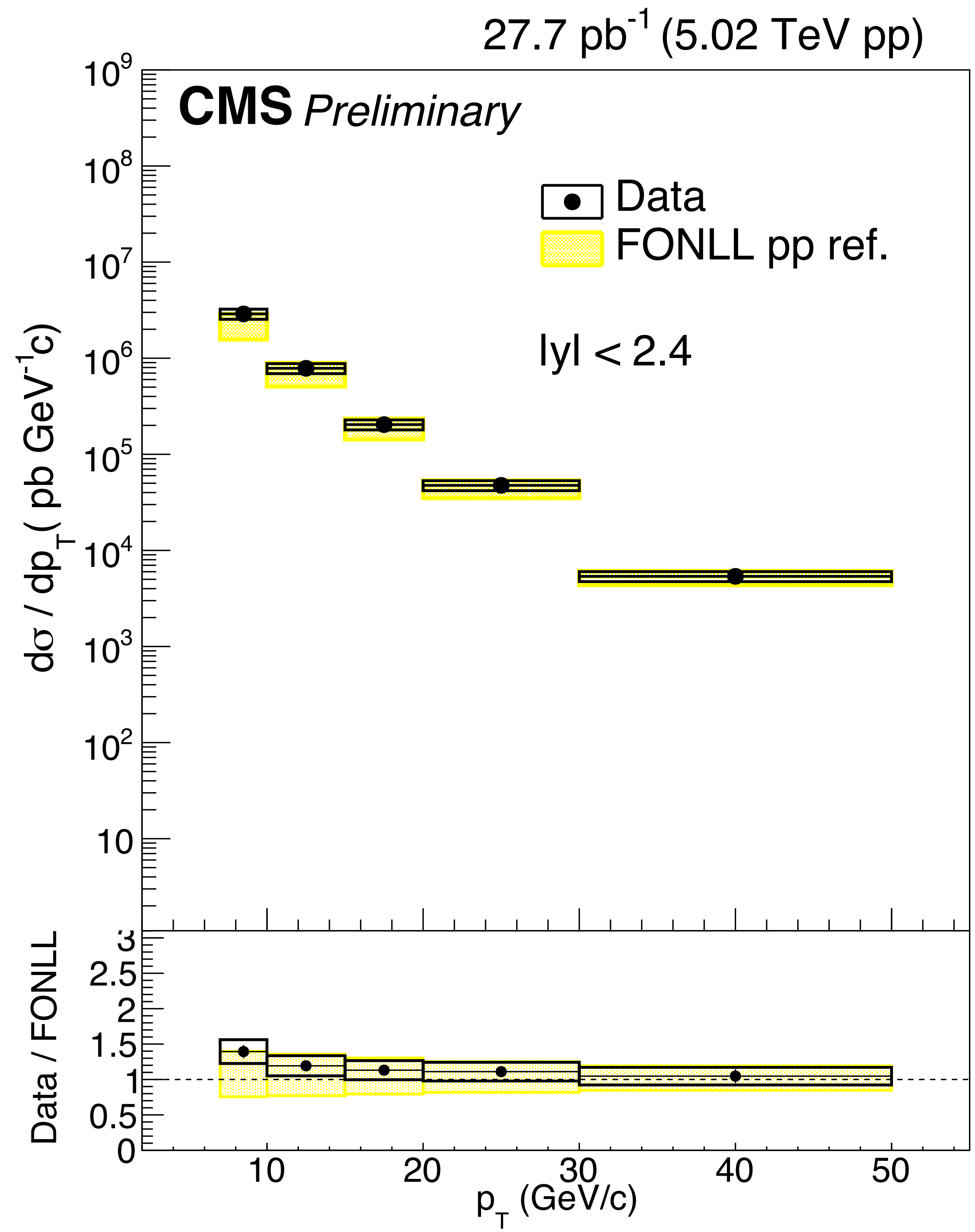
→ main difficult on theory side is to account for the logarithmic divergent terms that arise from gluon splitting processes

B production at LHC in pp collisions

New measurement of $B^+ \to J/\psi\, K^+$ production by CMS at 5.02 TeV:

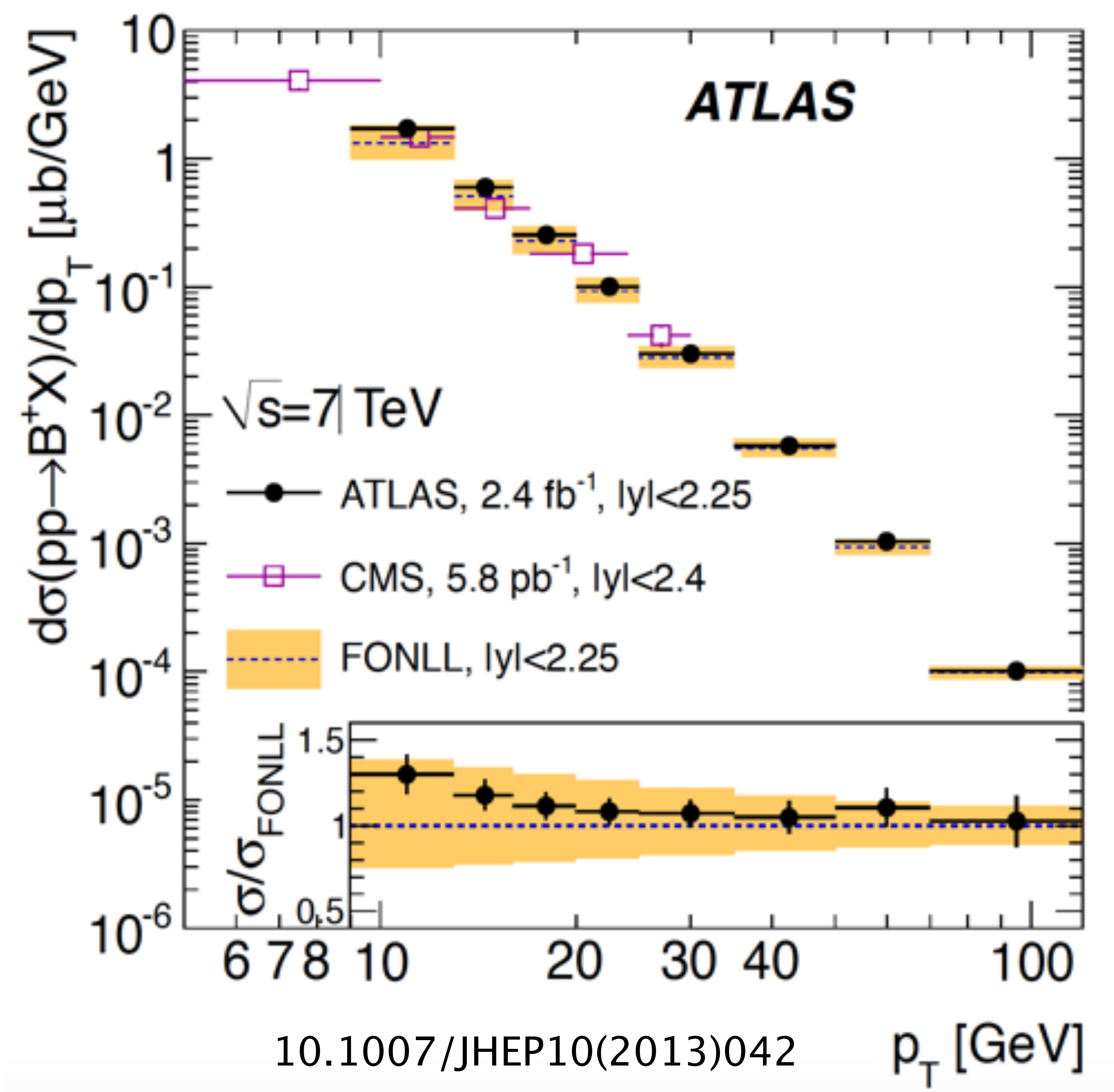




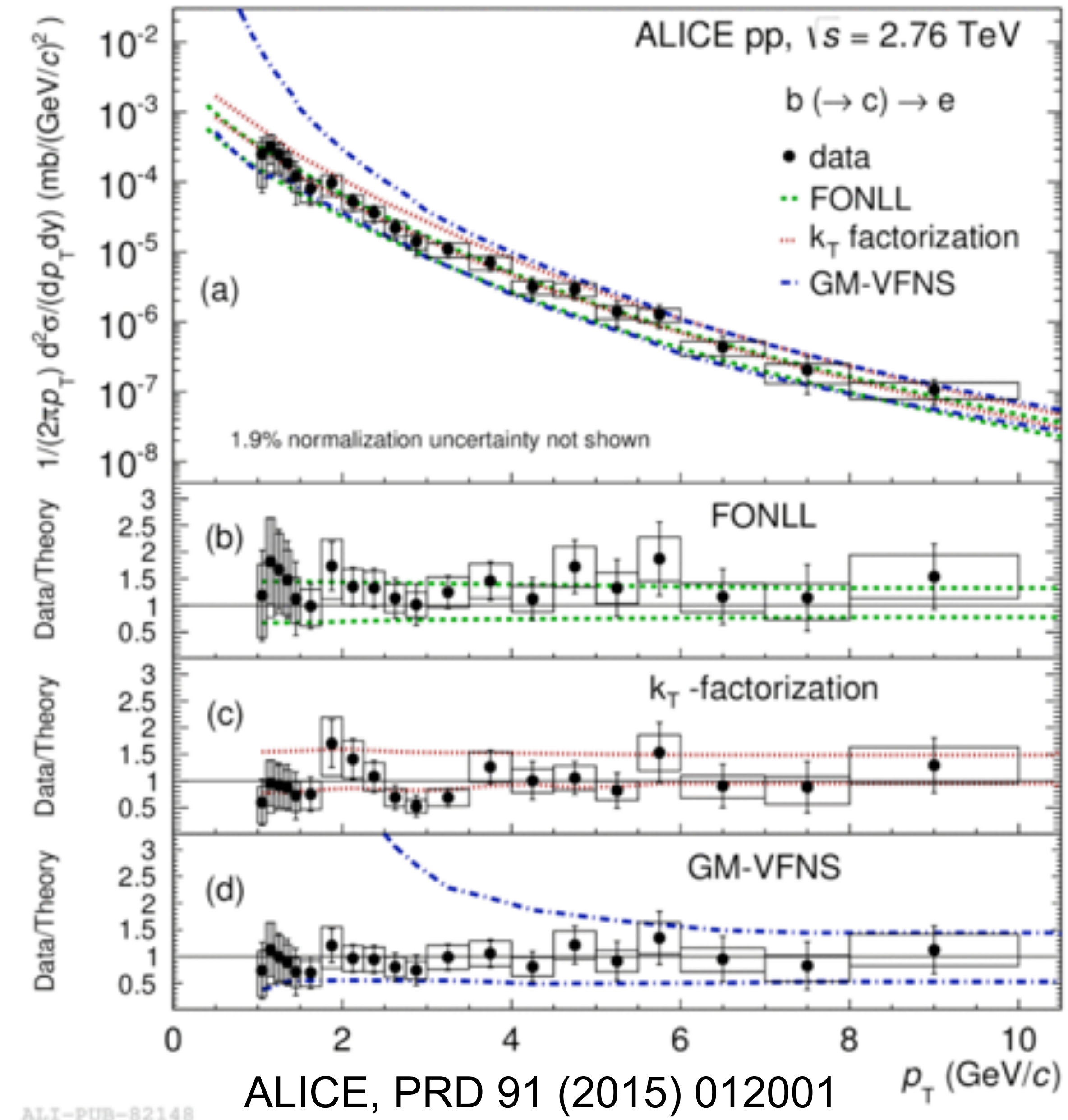


B production at LHC in pp collisions

ATLAS B^+ measurement at 7 TeV, |y|<2.25



ALICE b->e^{+-}, |y|<0.8



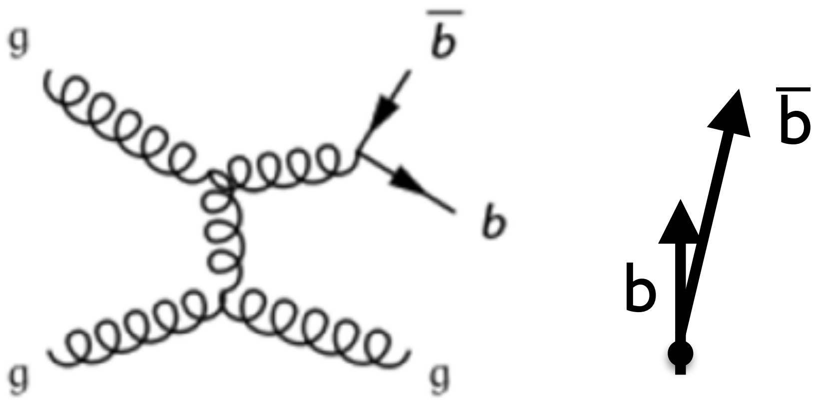
B meson production cross sections well described by NLO calculations:

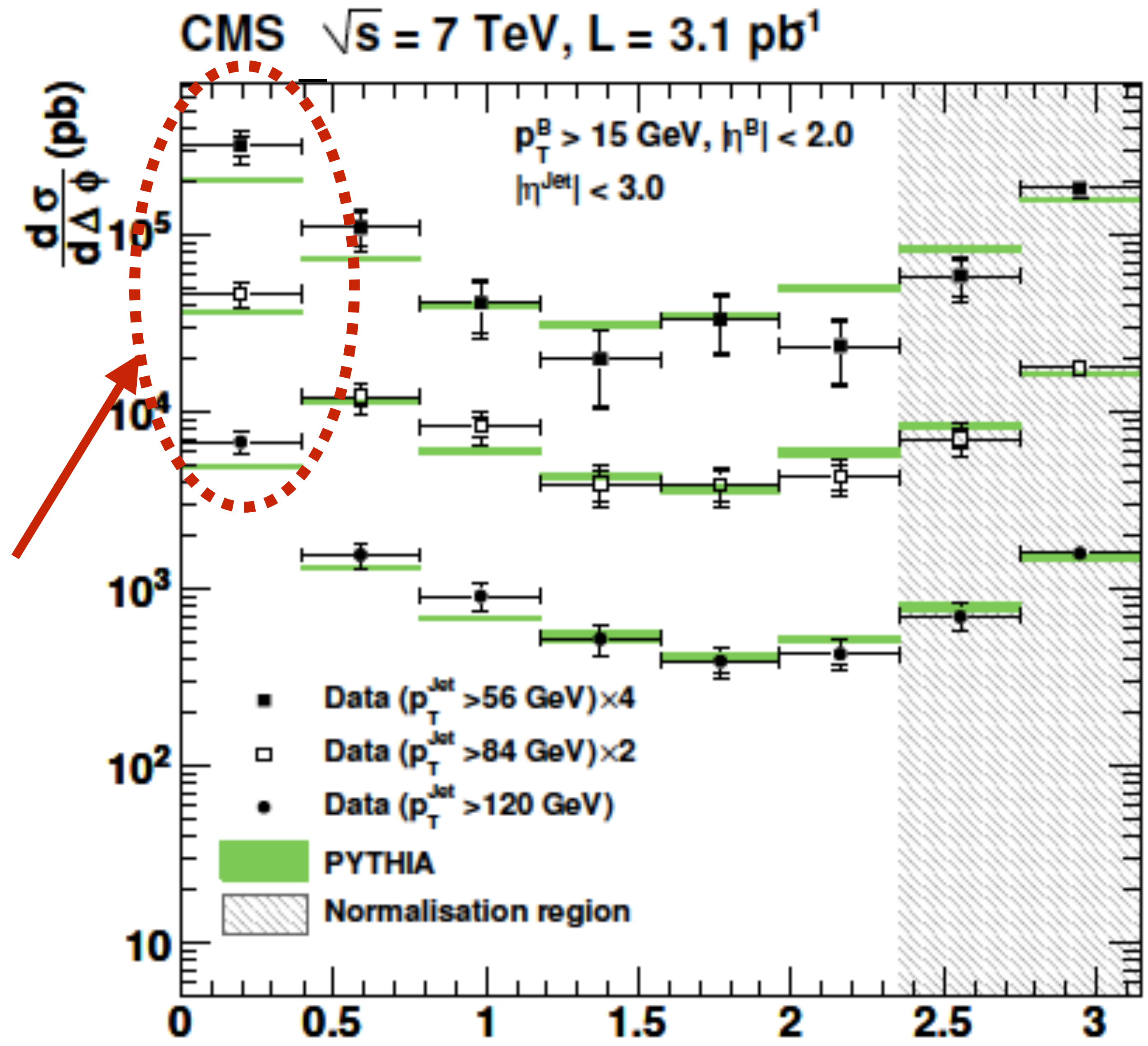
→*compatible with central values of FONLL, GM-VFNS and k_T-factorisation*

$B\bar{B}$ $\Delta\phi$ correlations

NLO process: Gluon splitting (GSP)

→ produced with small opening angles and asymmetric in p_T

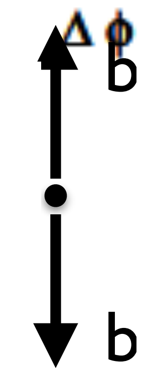




JHEP 1103:136,2011

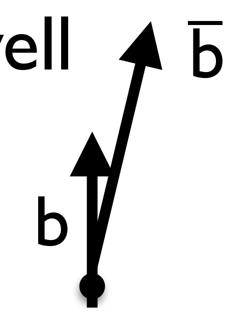
$B\bar{B}$ correlations strongly affected by gluon splitting processes at low $\Delta\phi$

$\Delta\phi(B-\bar{B})$



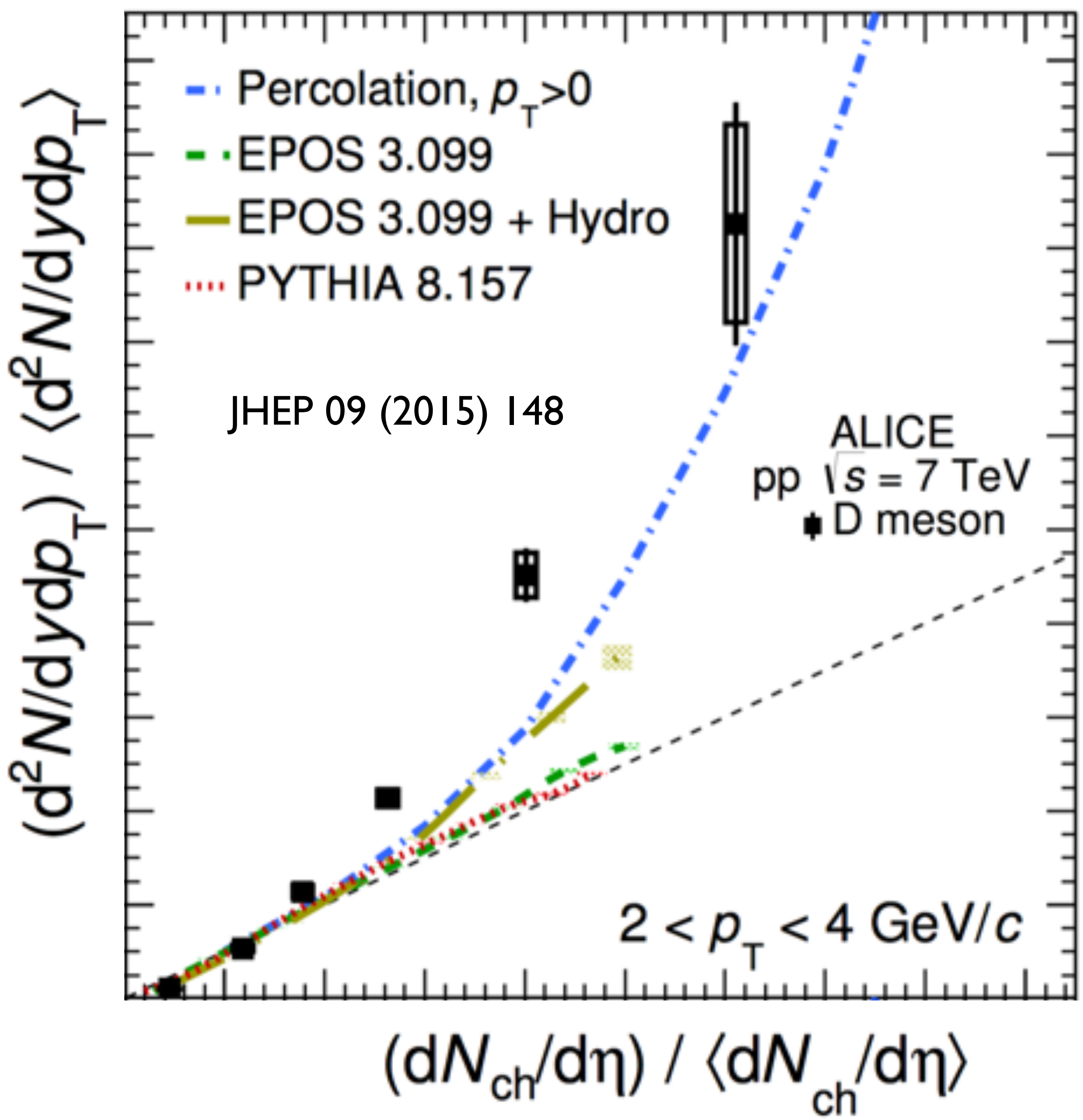
Gluon splitting (GS) contribution not well modelled by most of the calculations

→*GS contribution underestimated by PYTHIA*



D meson in pp as a function of multiplicity

Sensitive to interplay between hard and soft processes in particle production and to Multi-Particle-Interactions



Percolation (Ferreiro, Pajares, PRC 86 (2012) 034903

Particle production via exchange of colour sources between projectile and target (close to MPI scenario)

EPOS 3.099 (Werner et al., PRC 89 (2014) 064903)

Gribov-Regge multiple-scattering formalism.
Saturation scale to model non-linear effects
Number of MPI directly related to multiplicity

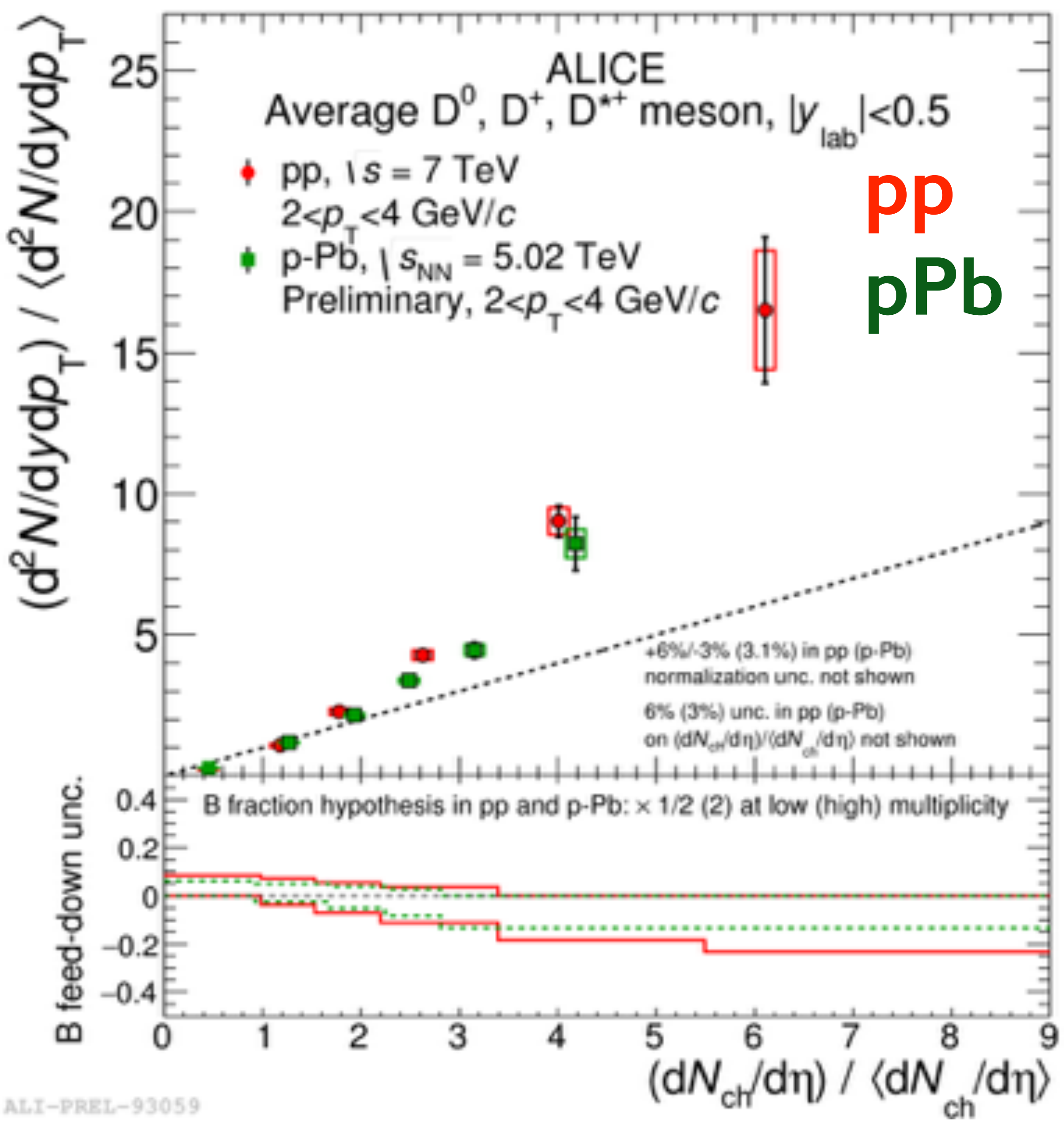
PYTHIA 8 (Sjostrand et al., Comput. Phys. Commun. 178 (2008) 852)

Soft-QCD tune, Colour reconnection, MPI

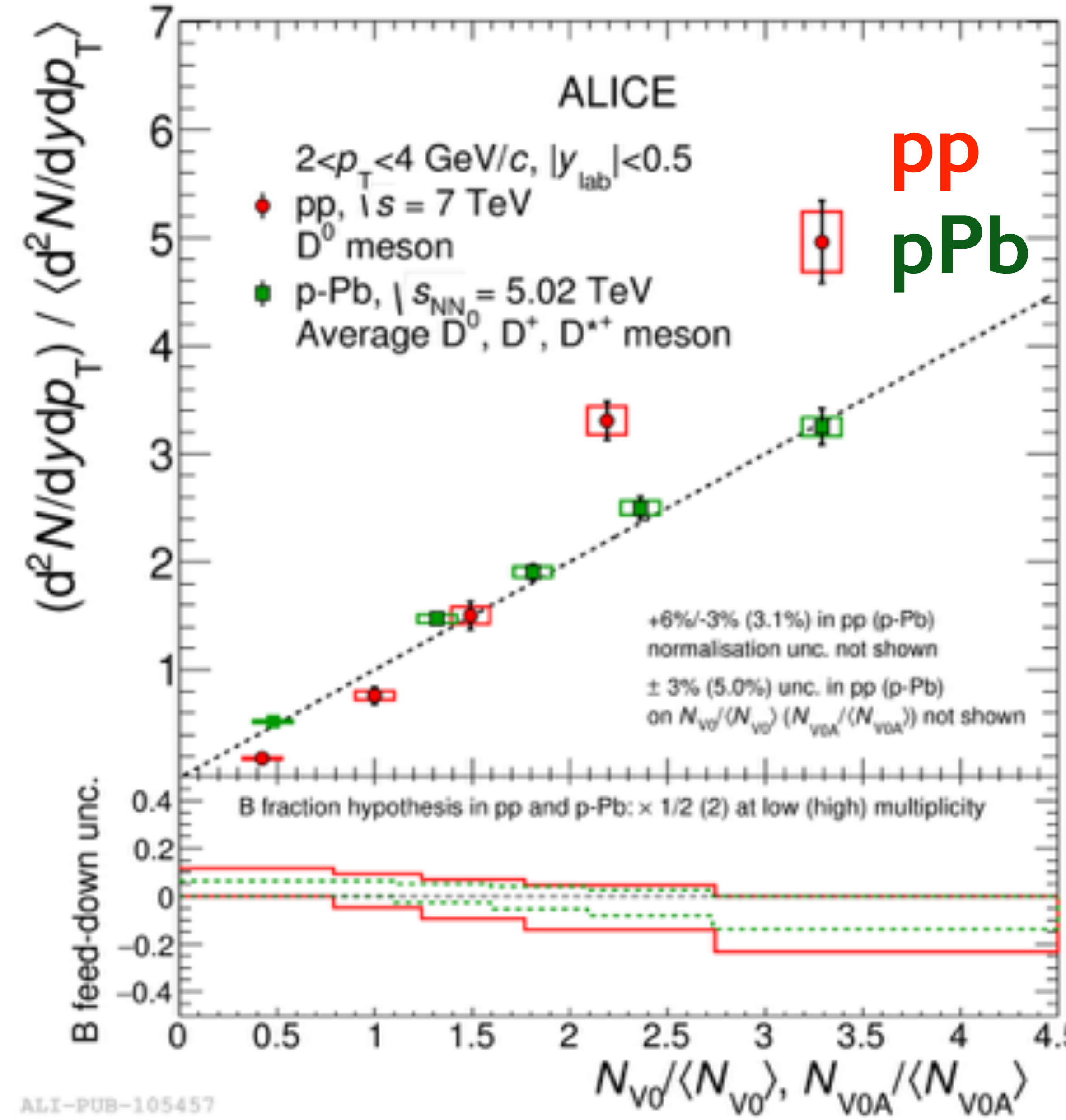
Very sharp increase of yields as function of multiplicity:
data favour models that includes MPI, hints of hydro?

D meson in pPb as a function of multiplicity

mid rapidity



backward rapidity

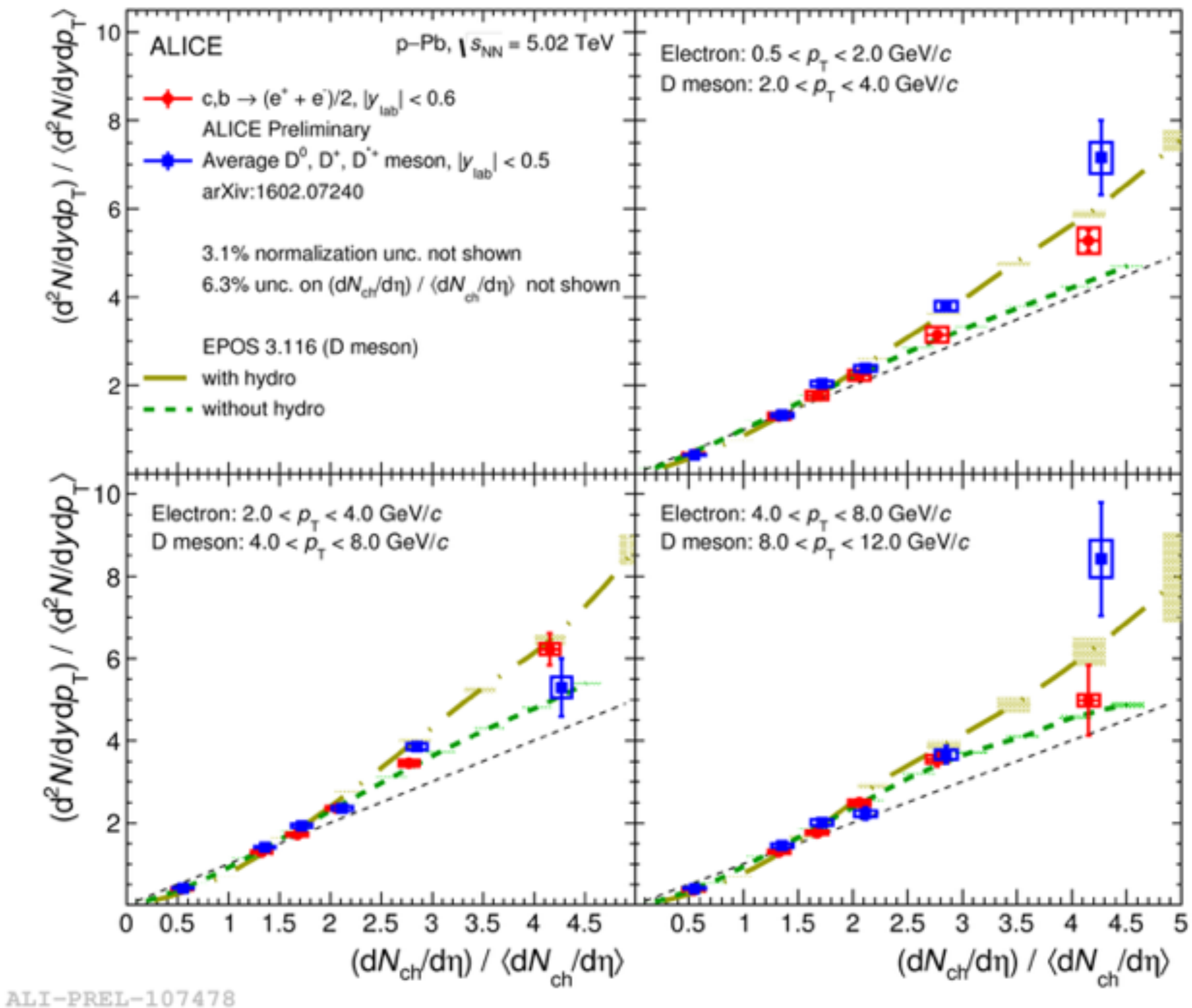


In pPb interplay of MPI and collision geometry (N_{coll}>1):

- ***at central rapidity**: pp and pPb show similar trend wrt multiplicity*
- ***at backward rapidity**: pp increases faster that pPb (??)*

JHEP 09 (2015) 148
JHEP 08 (2016) 1

D meson and HF electrons vs multiplicity in pPb



c,b → e^{+-}

D mesons

D meson and HF electrons normalised yields compatible within uncertainties

comparison to models seems to favour calculations that include hydro-evolution of the medium (still not conclusive thus)

D-hadron correlations in pp and pPb

Sensitive to charm quark fragmentation properties and to both initial and final-state effects

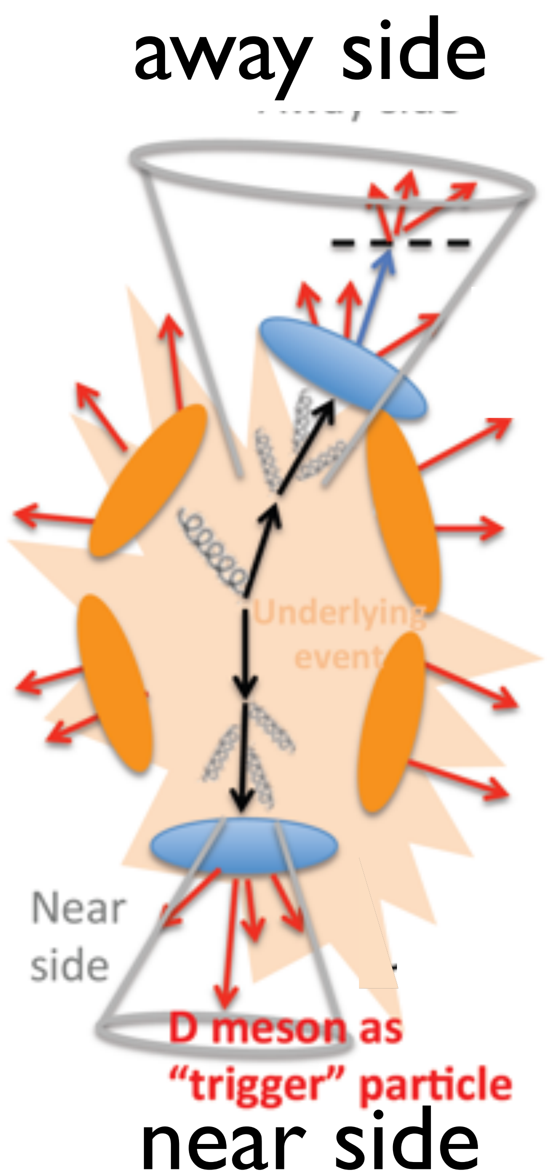
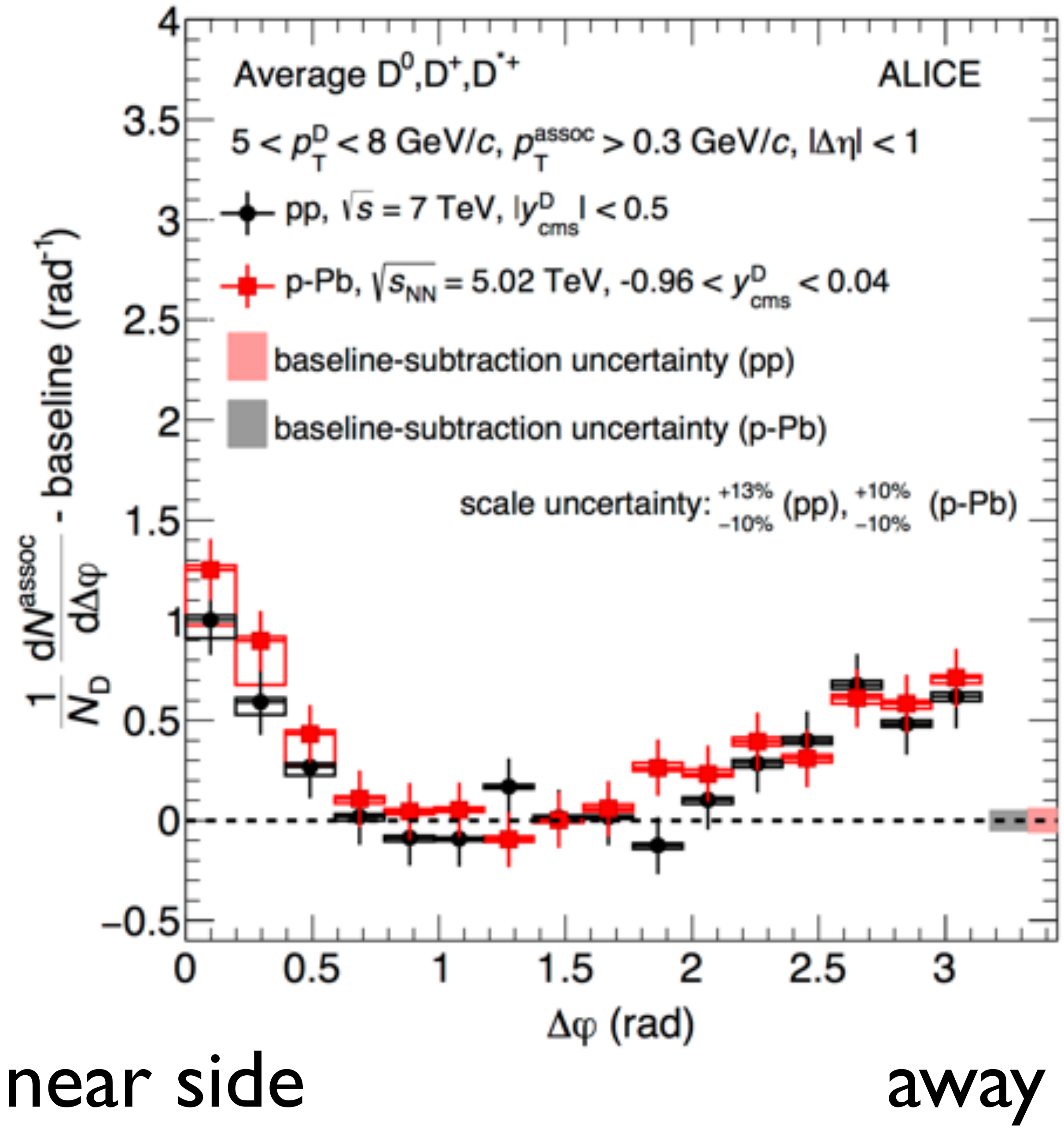


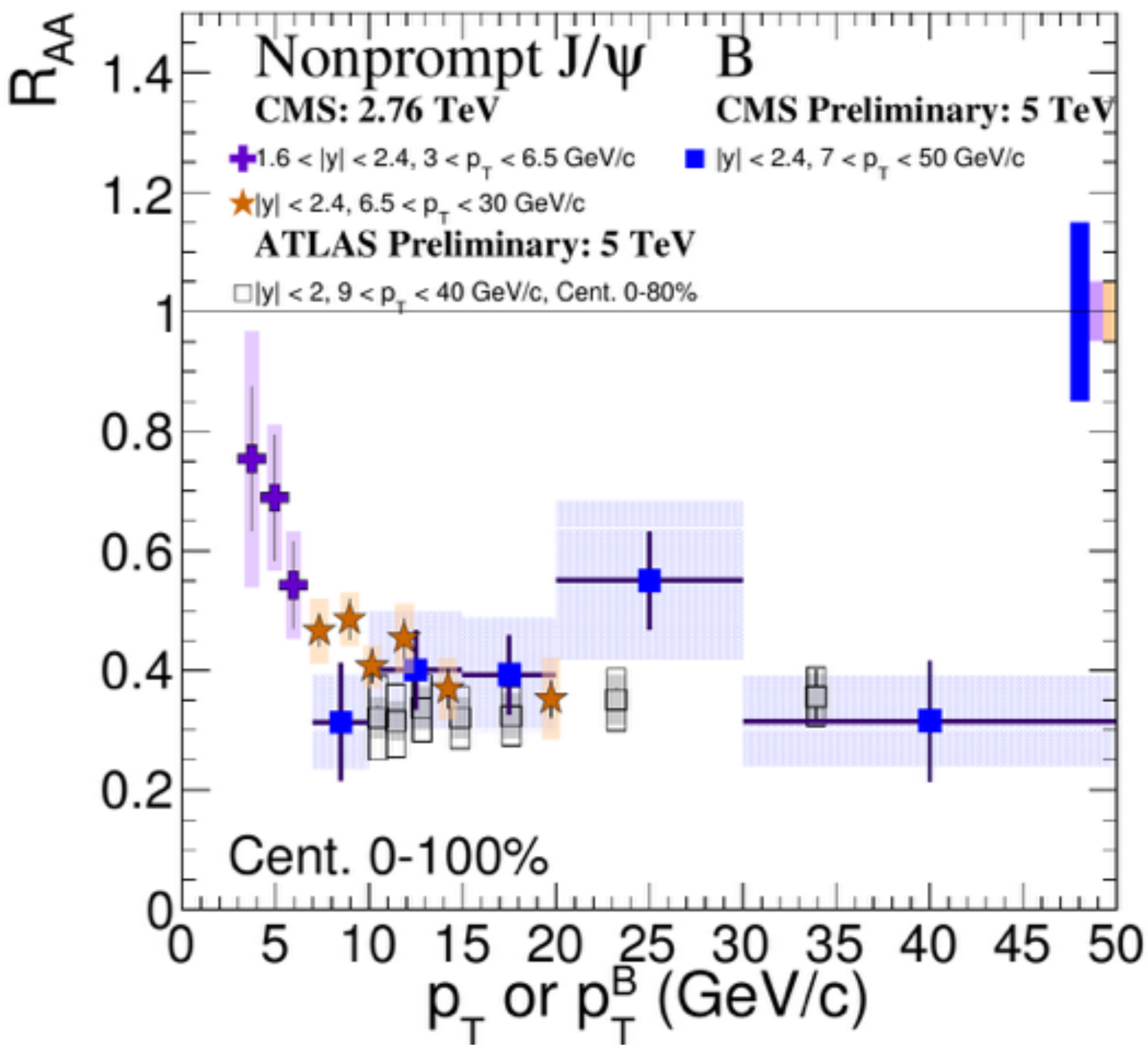
Figure from A.Rossi's LHCC talk



ALICE, arXiv:1605.06963

pp and pPb azimuthal correlations compatible after baseline subtraction!

Non-prompt J/φ at 2.76 TeV vs B$^+$ at 5.02 TeV

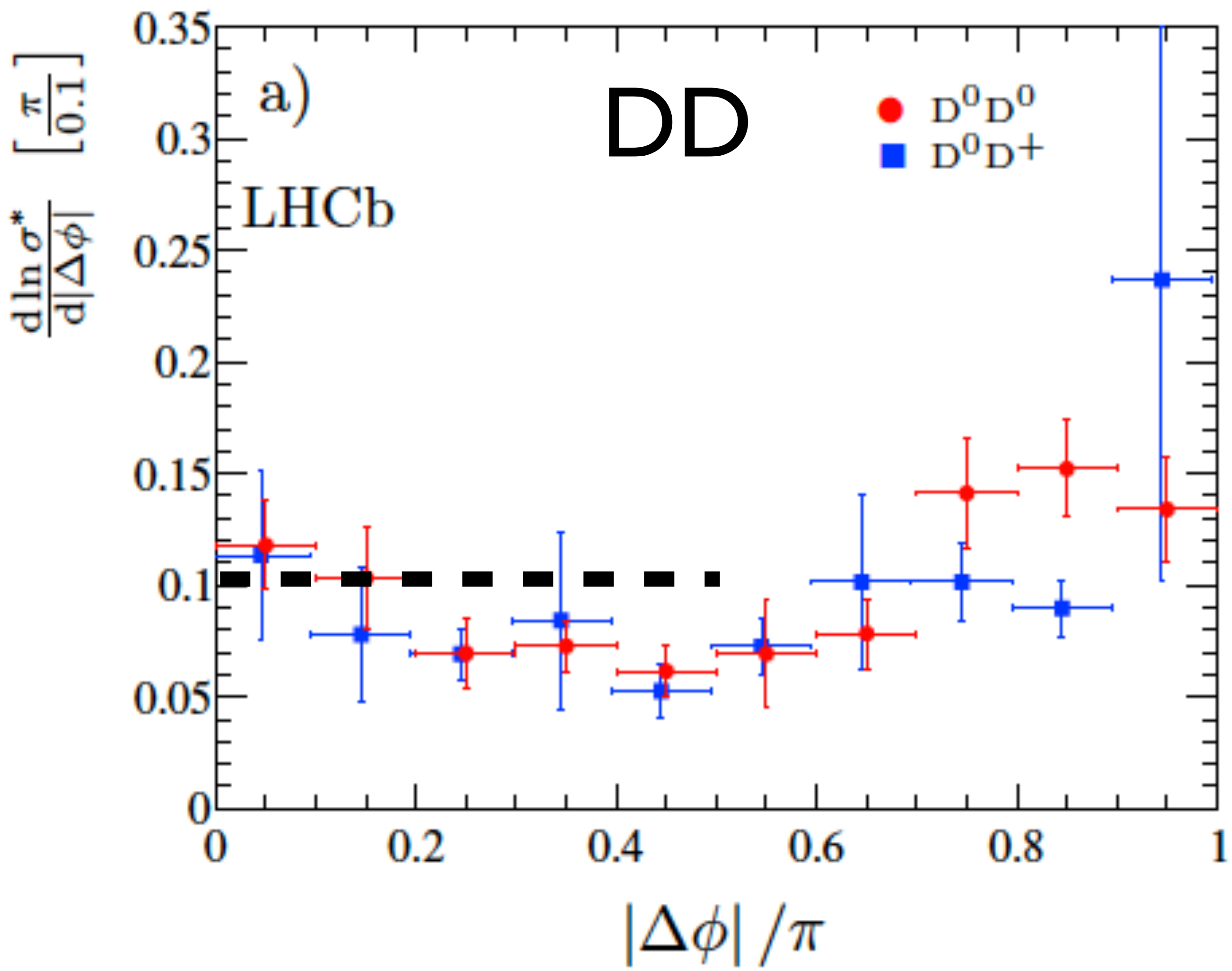


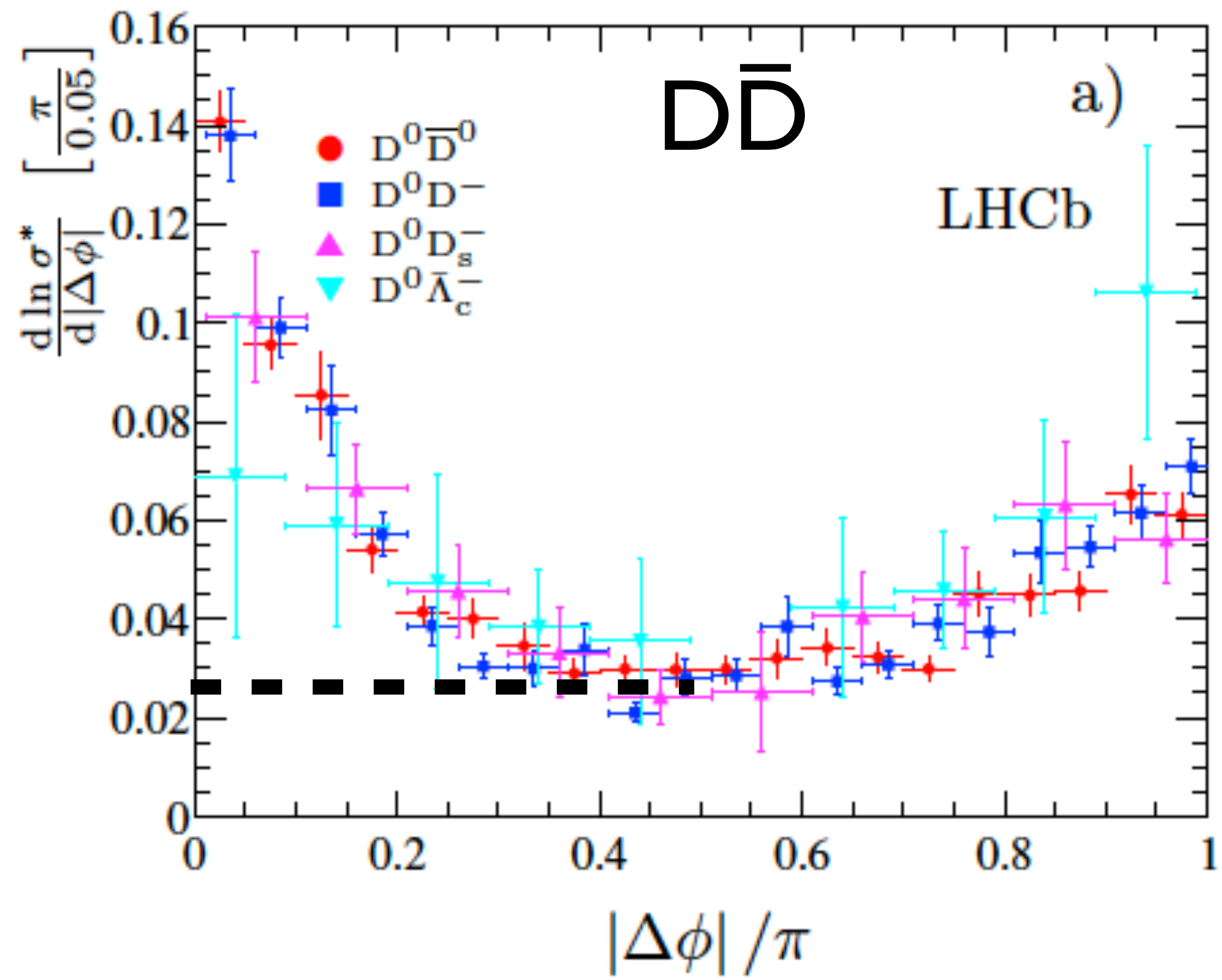
The B$^+$ R_{AA} at 5.02 TeV and non-prompt J/φ at 2.76 fully compatible within uncertainties!

BIG CAVEAT: different energies!

DD and D$\bar{D}$ correlations

DD and D$\bar{D}$ correlations measured by LHCb at 5.02 TeV

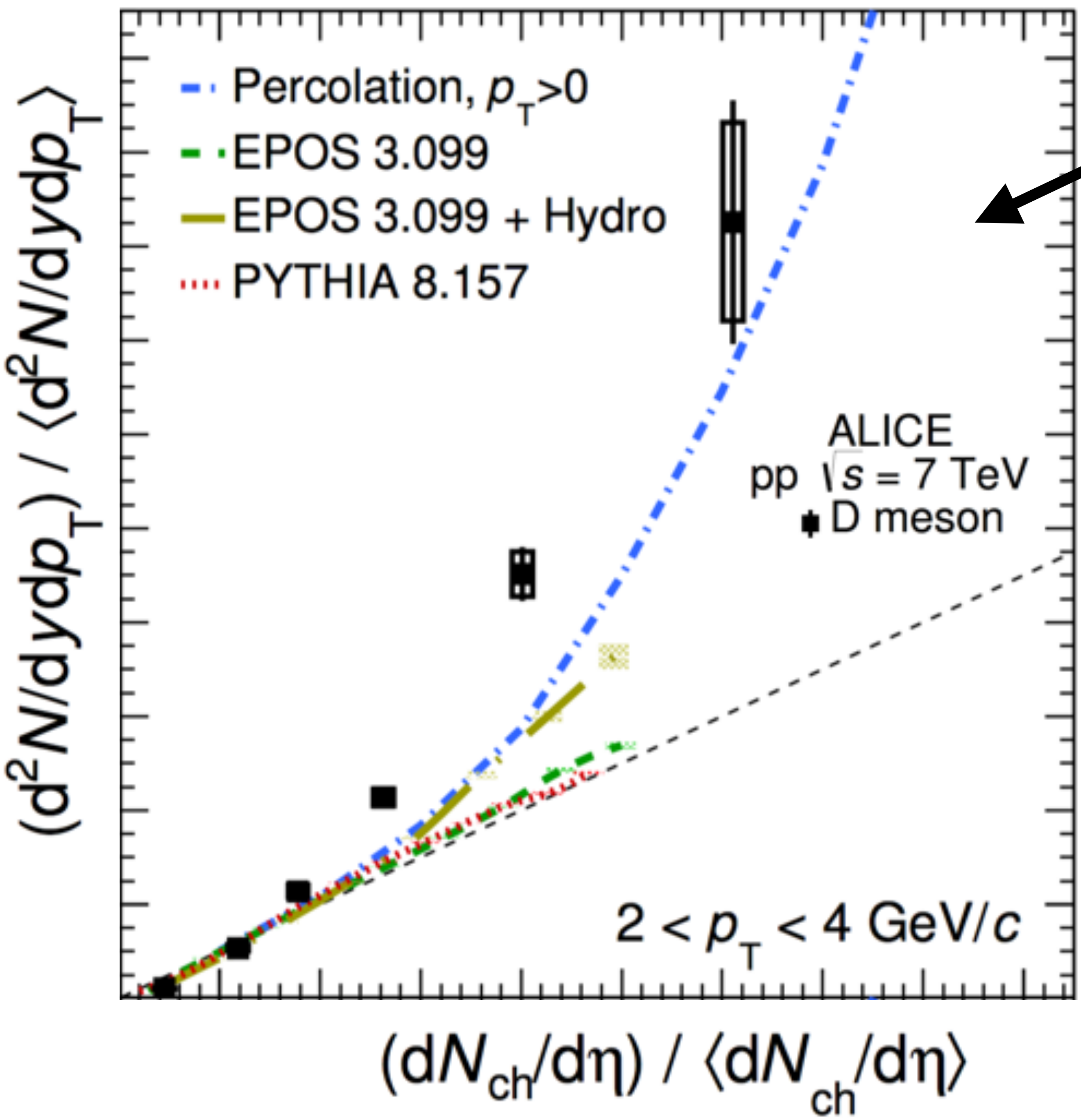




D$\bar{D}$ correlation show an enhancement with respect to DD correlation at low $\Delta\phi$ consistent with consistent contribution from gluon splitting

c$\bar{c}$ pairs produce by gluon splitting processes

HQ production as a function of multiplicity

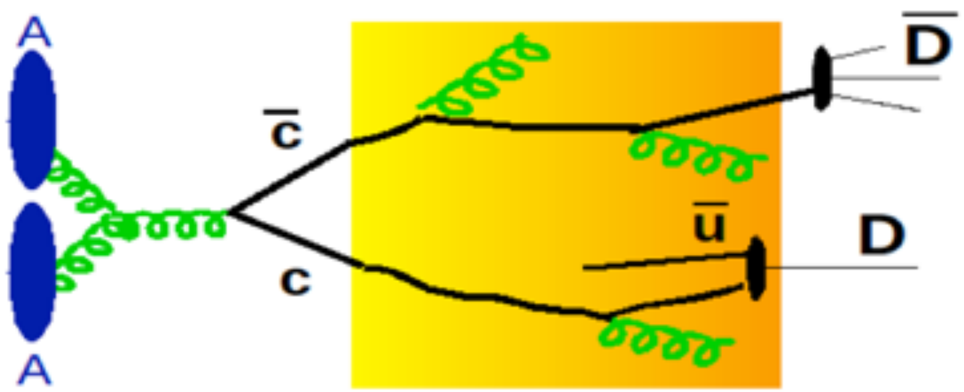


Strong dependence of D meson yield vs multiplicity

Need to include Multi-Particle-Interaction (MPI) to describe experimental data

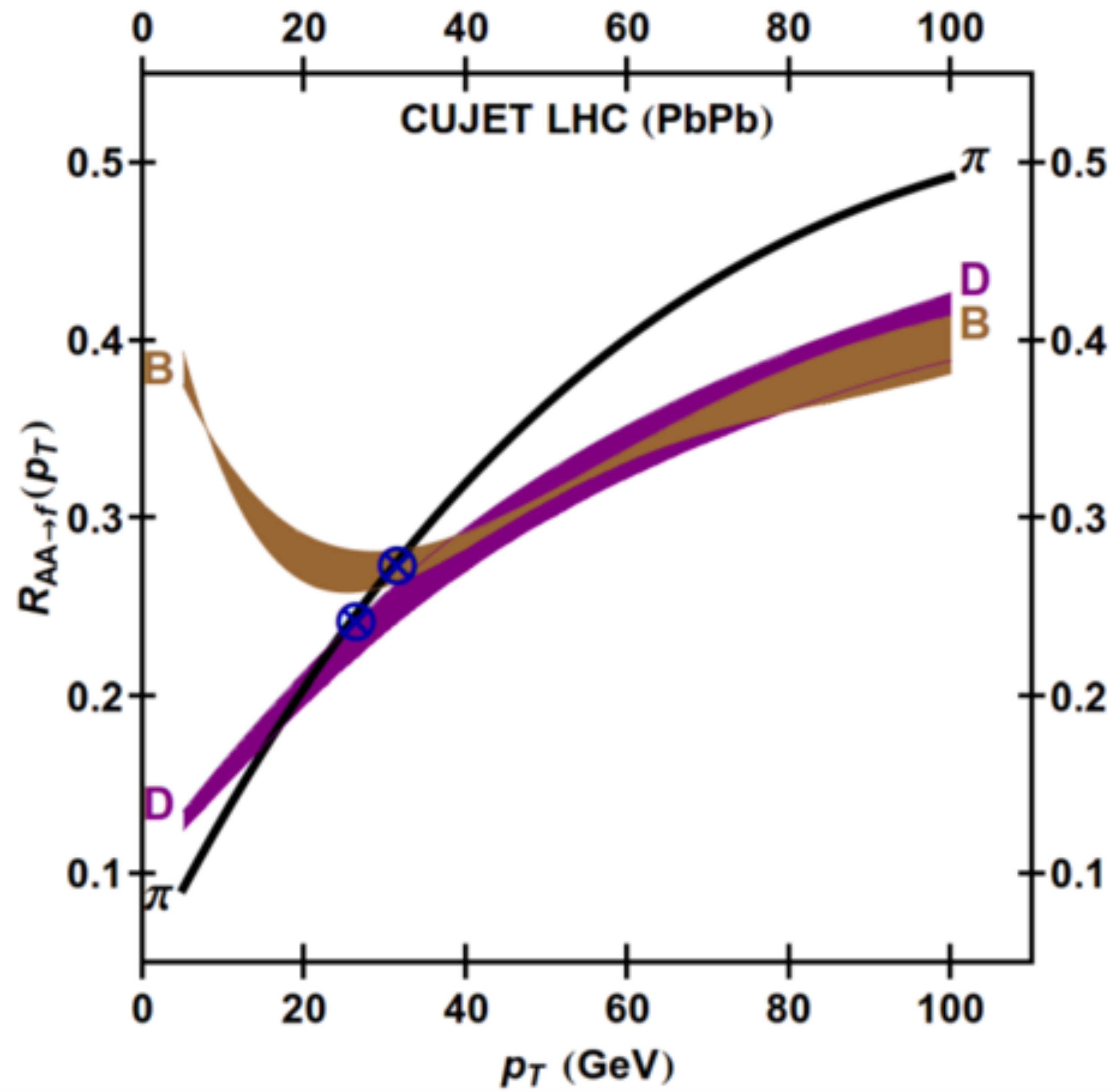
ALICE data favours MPI models that includes a non linear dependence vs multiplicity (hydro?)

Reminder on HF energy loss



- produced early in the collision, they strongly interact with the deconfined medium

→ In-medium energy loss as a consequence of radiative and collisional processes.

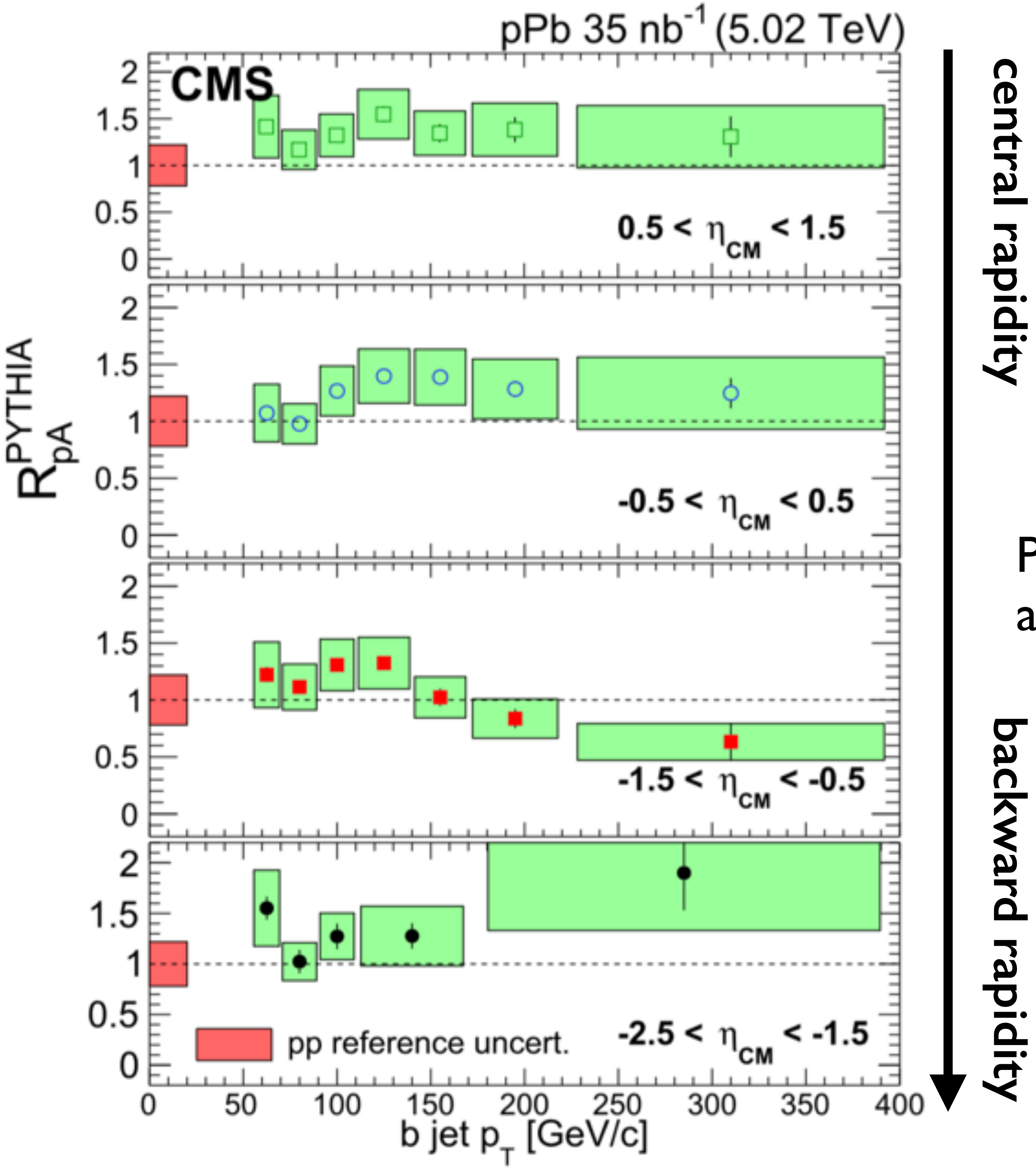


Flavour-dependence of radiative energy loss:

- Larger for gluons than for quarks
  E.g. in BDMPS model [1] $\langle\Delta E\rangle \propto \alpha_s C_R \hat{q} L^2$
- Dead cone effect: gluon radiation suppressed at small angles for massive quarks

$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$ → $R_{AA}^{B} > R_{AA}^{D} > R_{AA}^{light}$ (??)

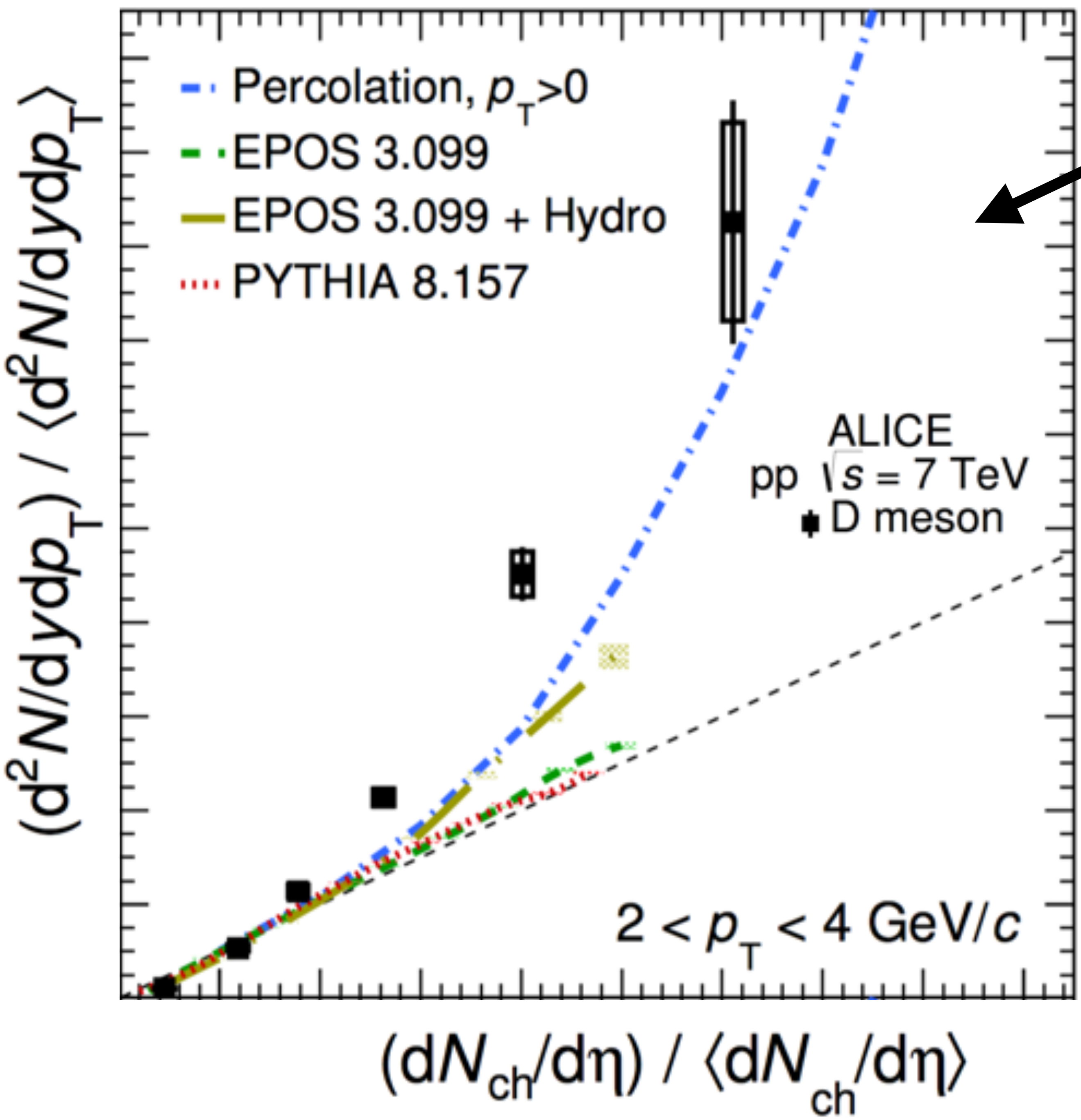
b-jet nuclear modification factor in pPb



CMS b-jet R_{pA} in bins of transverse momentum and pseudo-rapidity

PYTHIA R_{pA} consistent with unity as a function of p_T and pseudo-rapidity

HQ production as a function of multiplicity

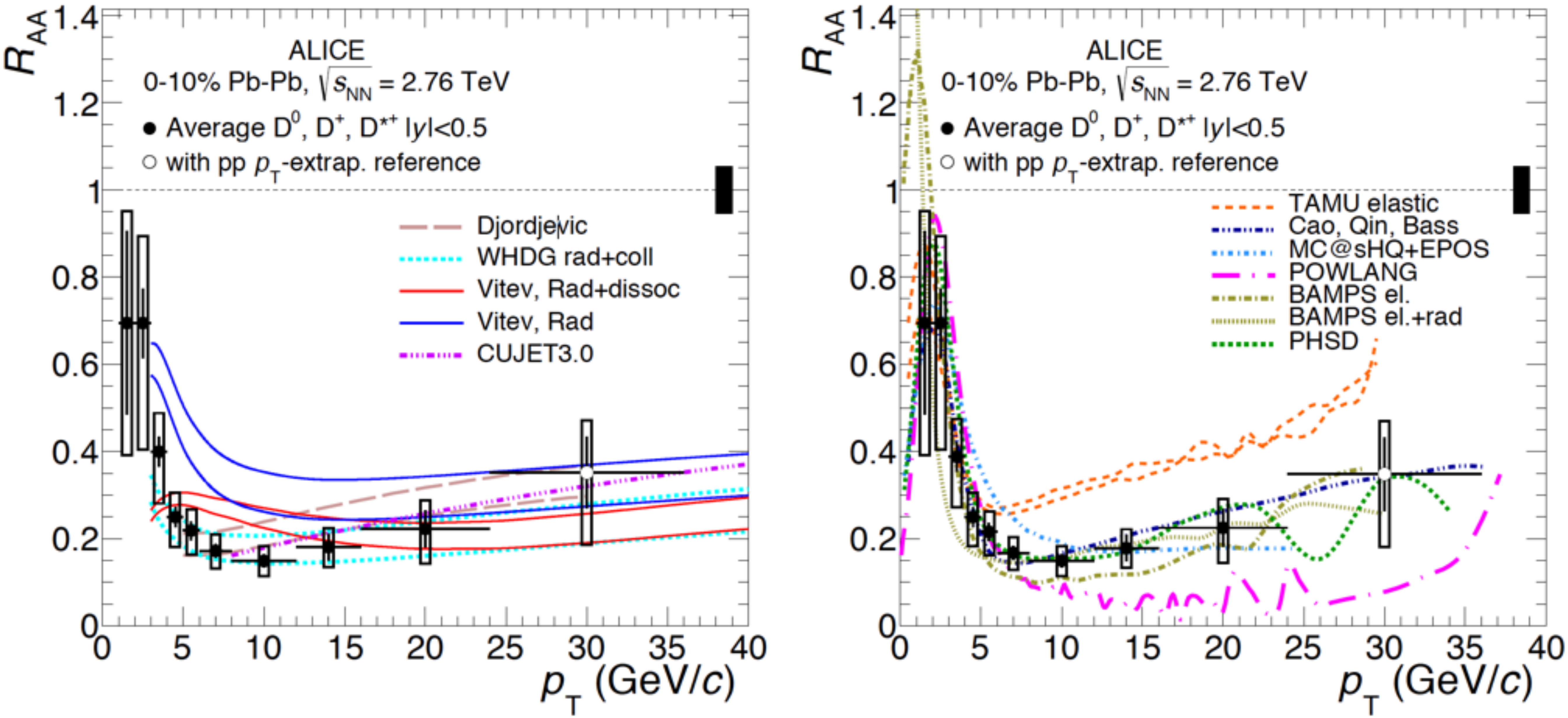


Strong dependence of D meson yield vs multiplicity

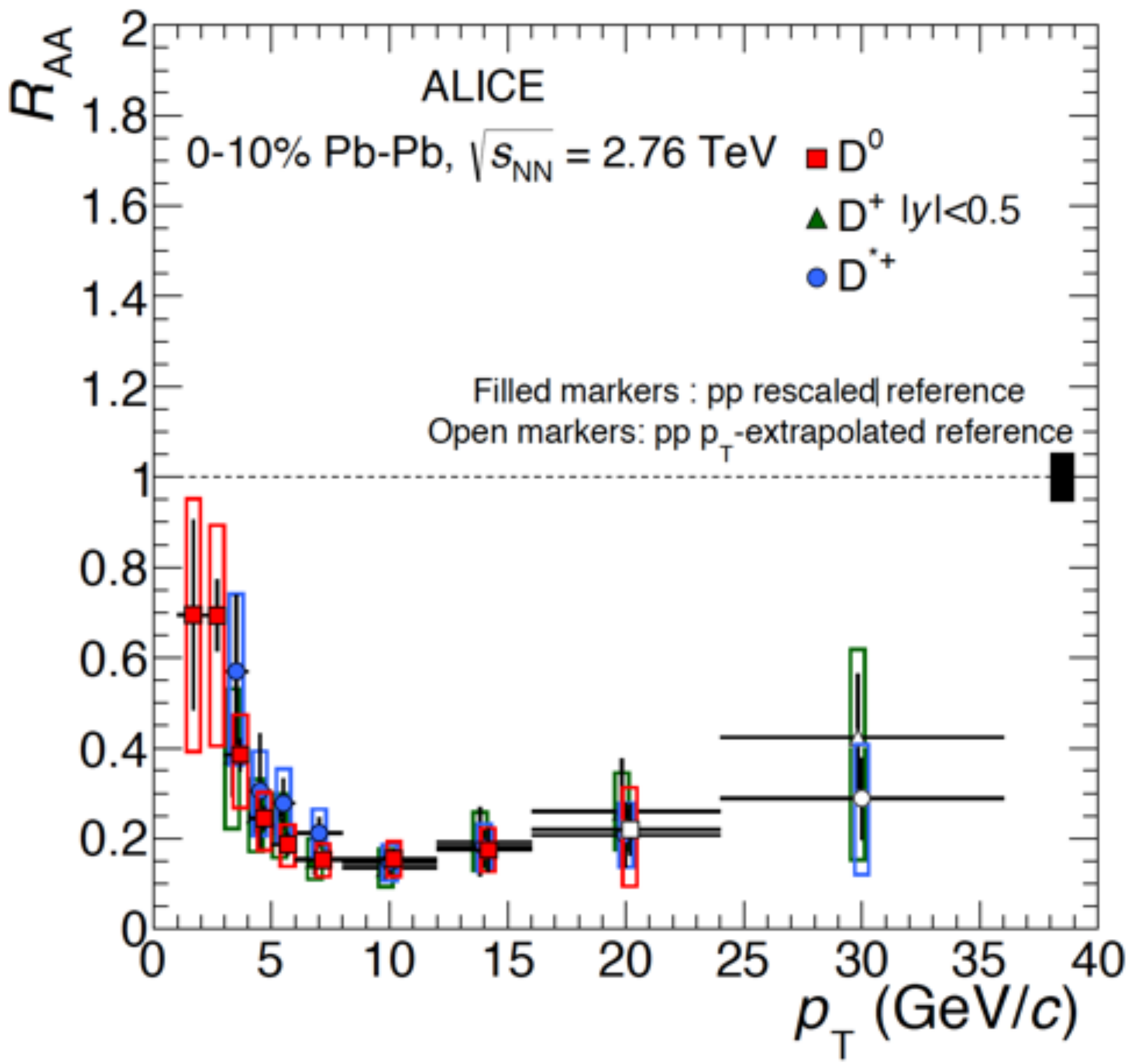
Need to include Multi-Particle-Interaction (MPI) to describe experimental data

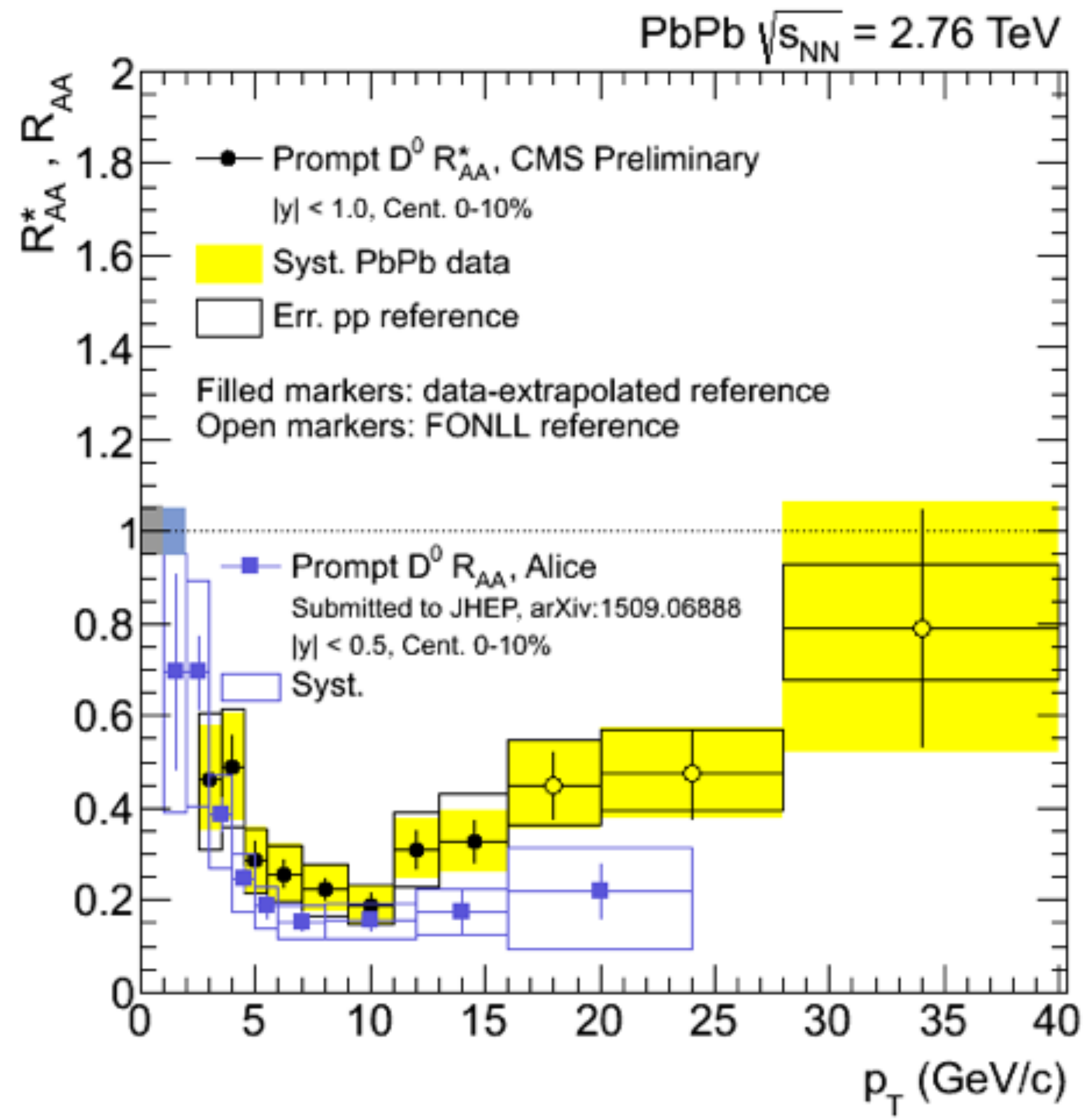
ALICE data favours MPI models that includes a non linear dependence vs multiplicity (hydro?)

D meson RAA at 2.76 TeV



D meson R_{AA} at 2.76 TeV





Strong suppression in central PbPb events:

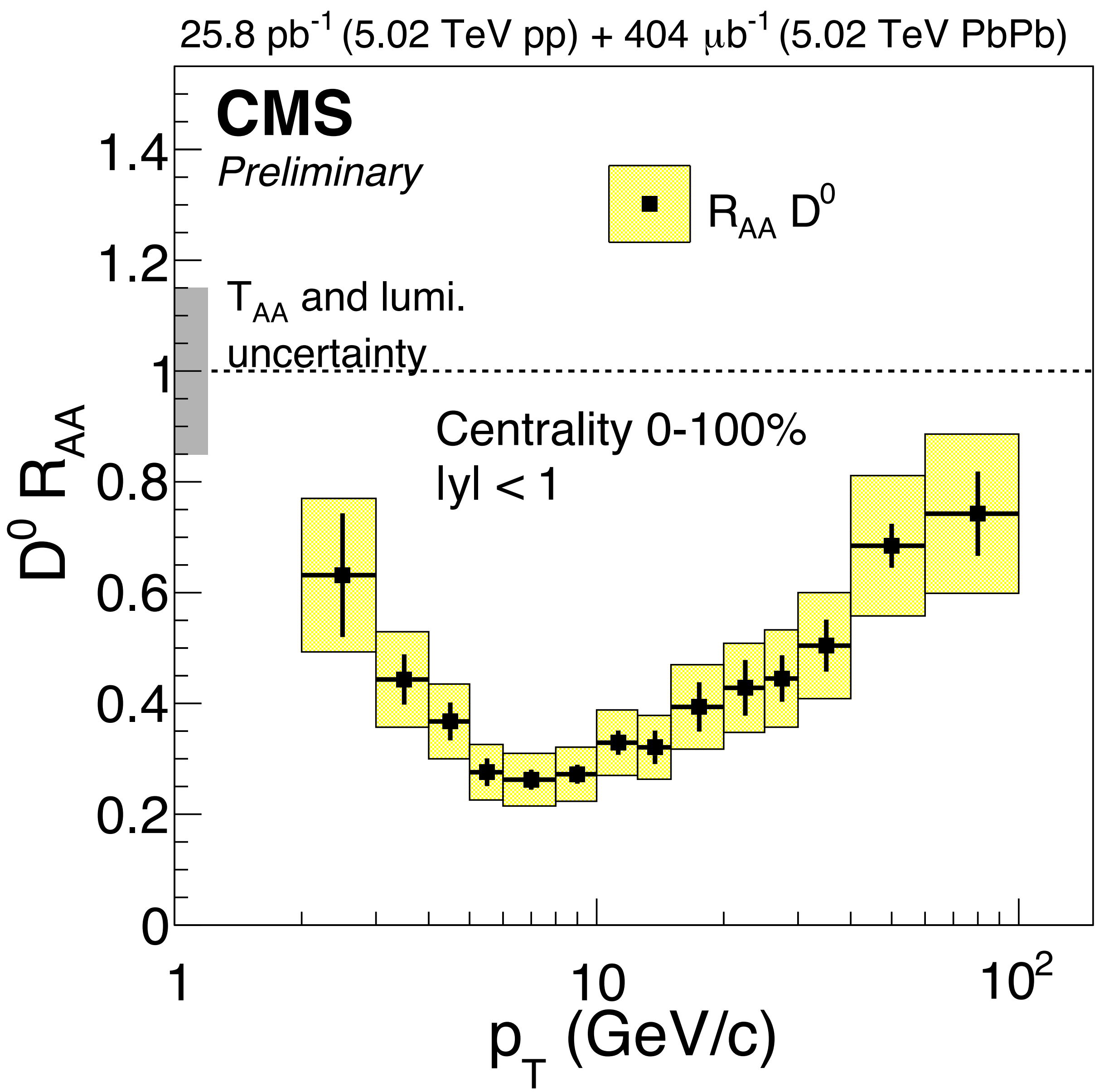
same suppression for D^0,D^+,D^{*+} indicate independence from fragmentation

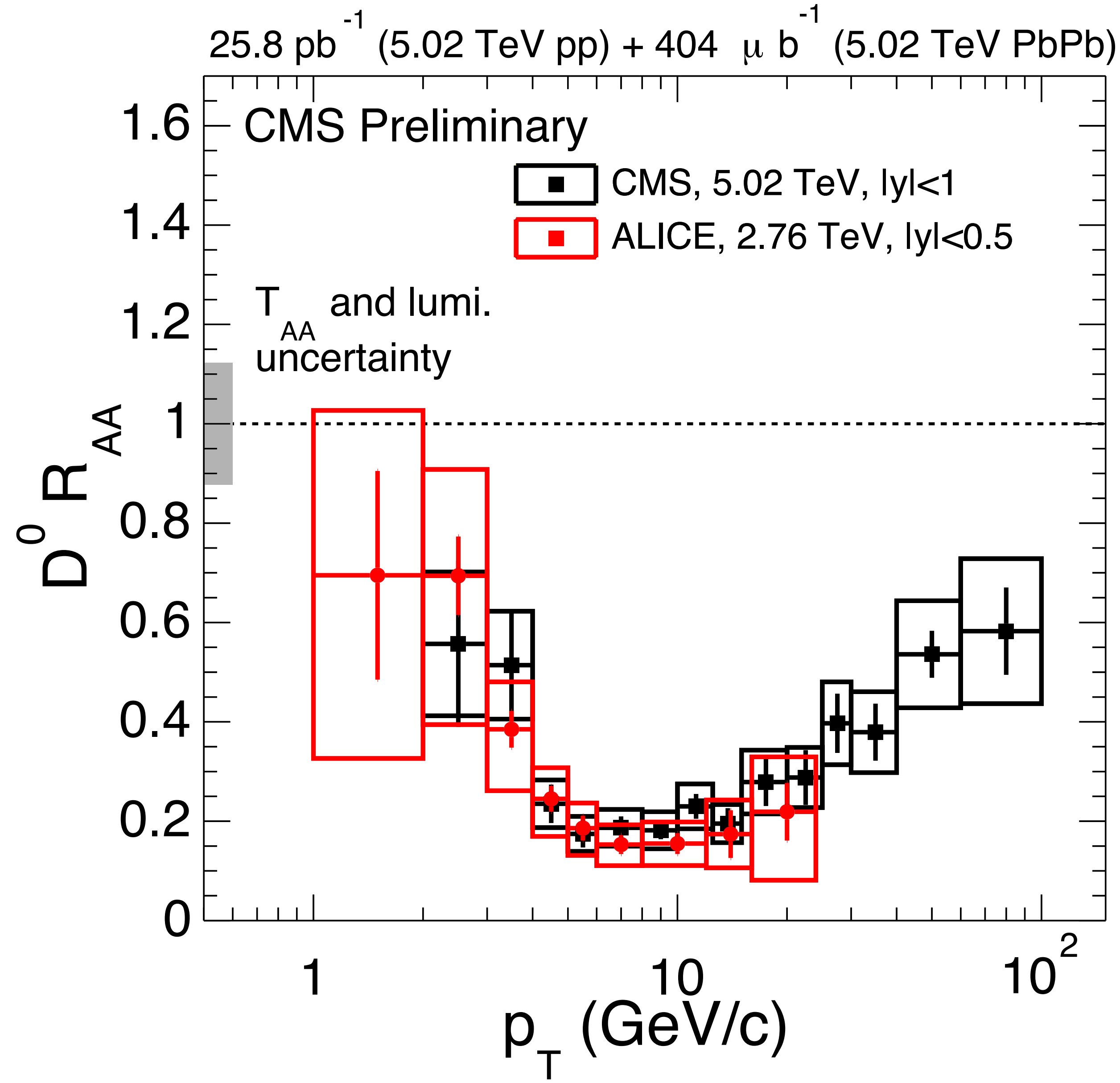
ALICE and CMS in good agreement

Differences at higher p_T due to different pp references

D^0 meson R_{AA} at 5.02 TeV

CMS D^0 R_{AA} |y|<1.0 at 5.02 TeV





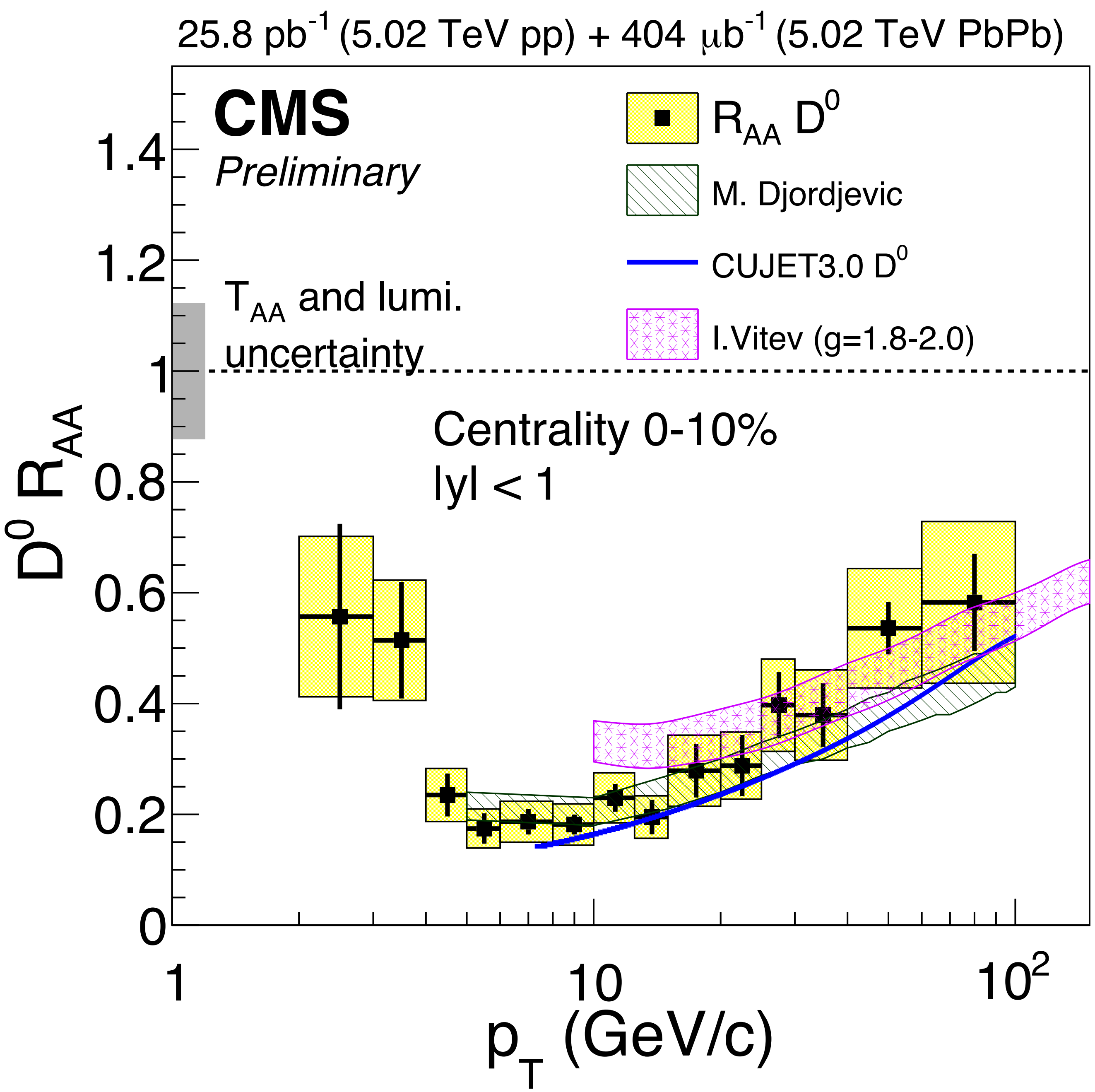
Strong suppression observed at 5.02 TeV

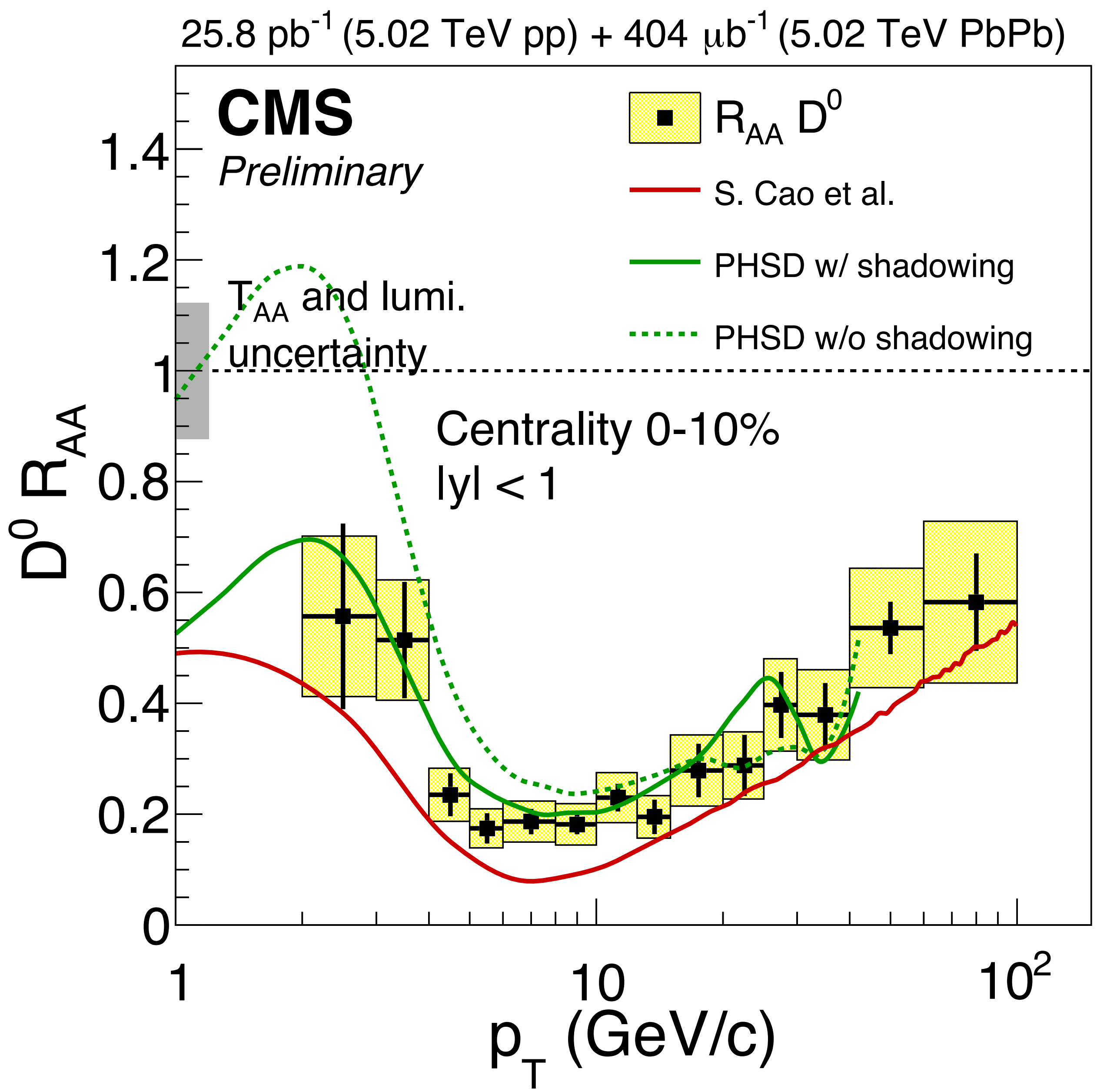
Rising trend observed when going to high p_T

Similar suppression observed at 2.76 and 5.02 TeV by CMS and ALICE

Caveat: different rapidities

Comparison with theoretical calculations





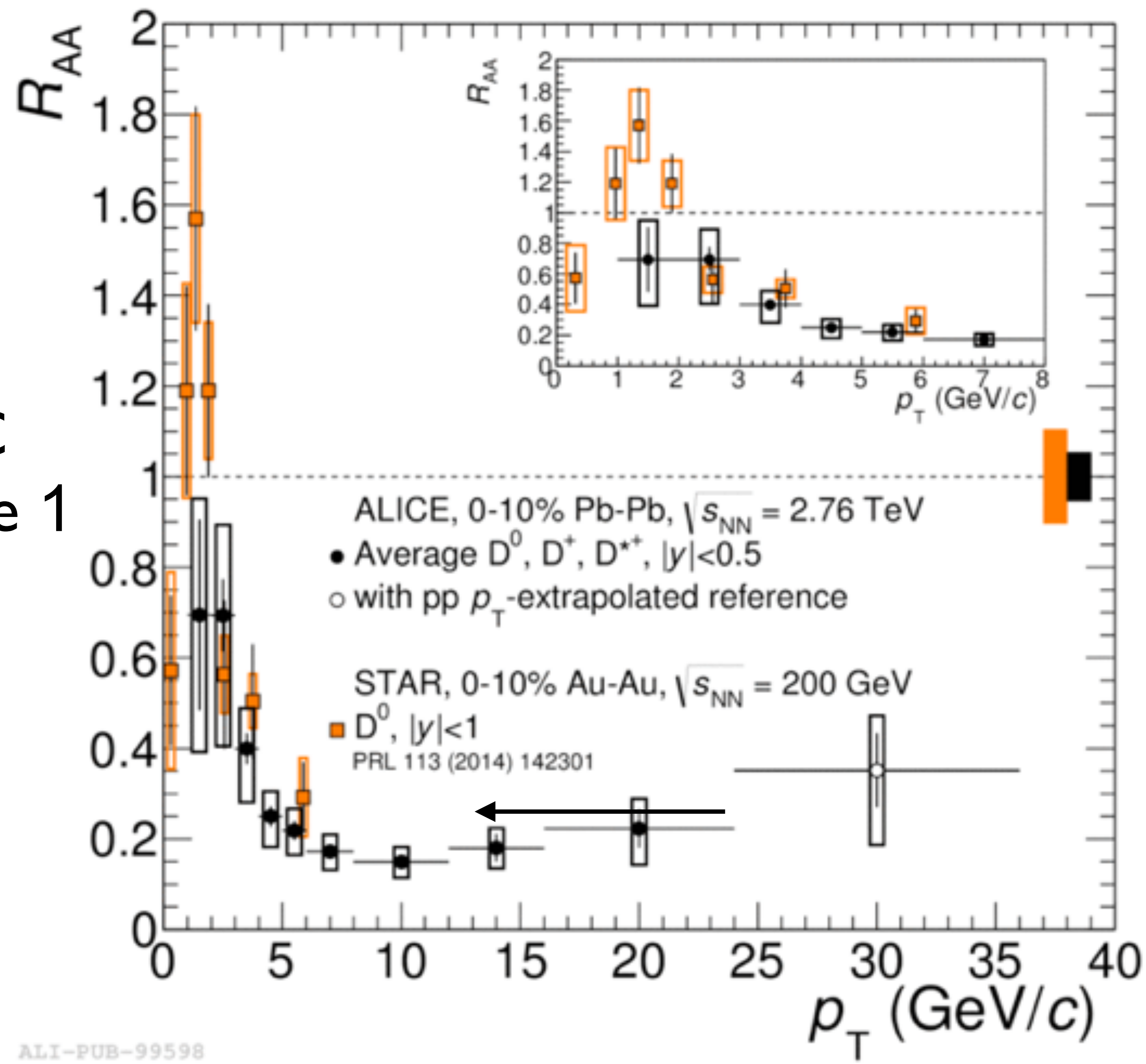
To describe D^0 R_{AA} in the full p_T range, models have to include:

- both collisional and radiative energy loss
- shadowing

Comparison with RHIC

At lower $p_{T,}$ RHIC D^0 R_{AA} goes above 1

PRL113 (2014) 142301
JHEP1603 (2016) 081

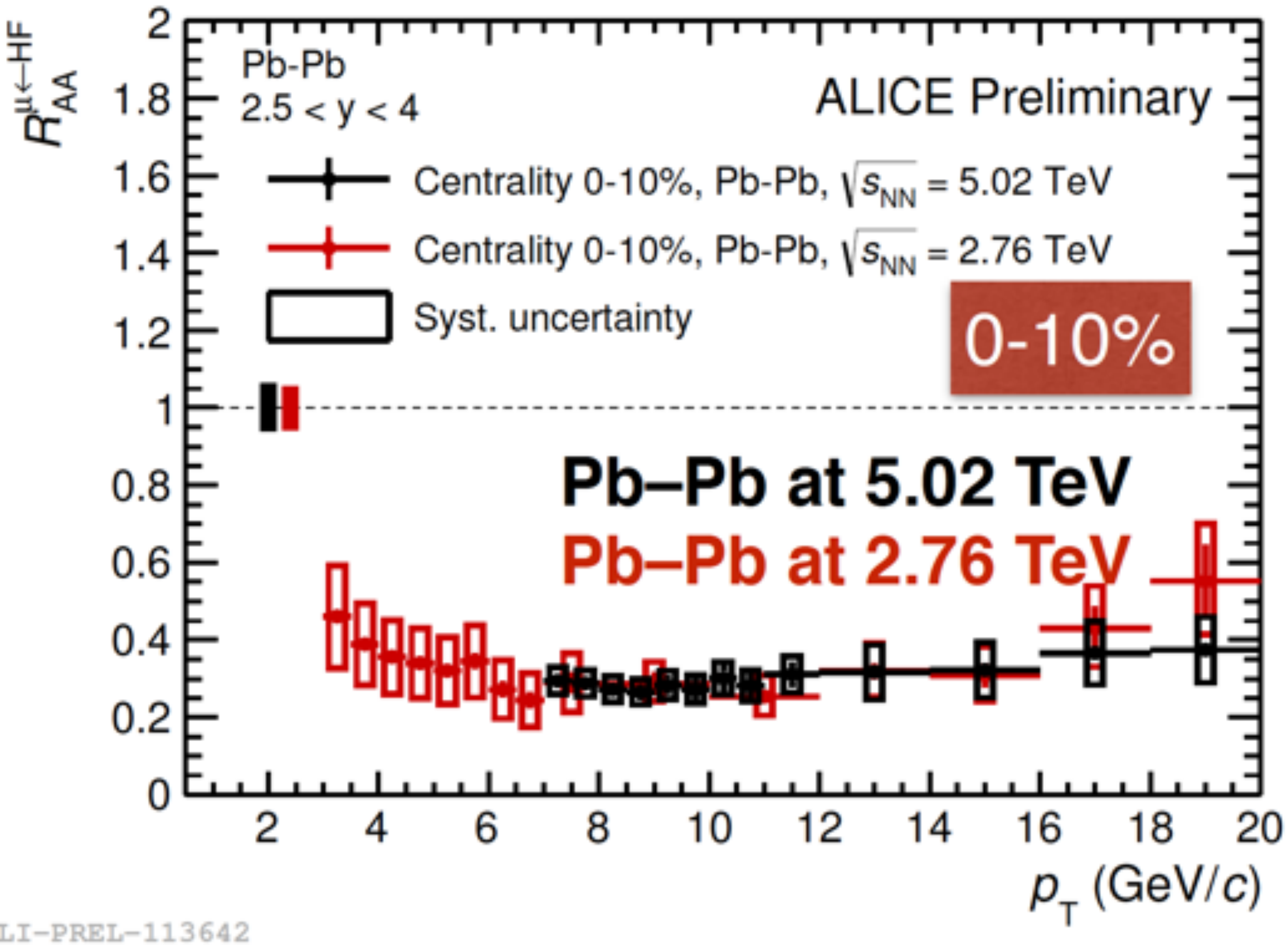


Smaller suppression at RHIC can be a consequence of different magnitude of the shadowing at RHIC vs. LHC energies

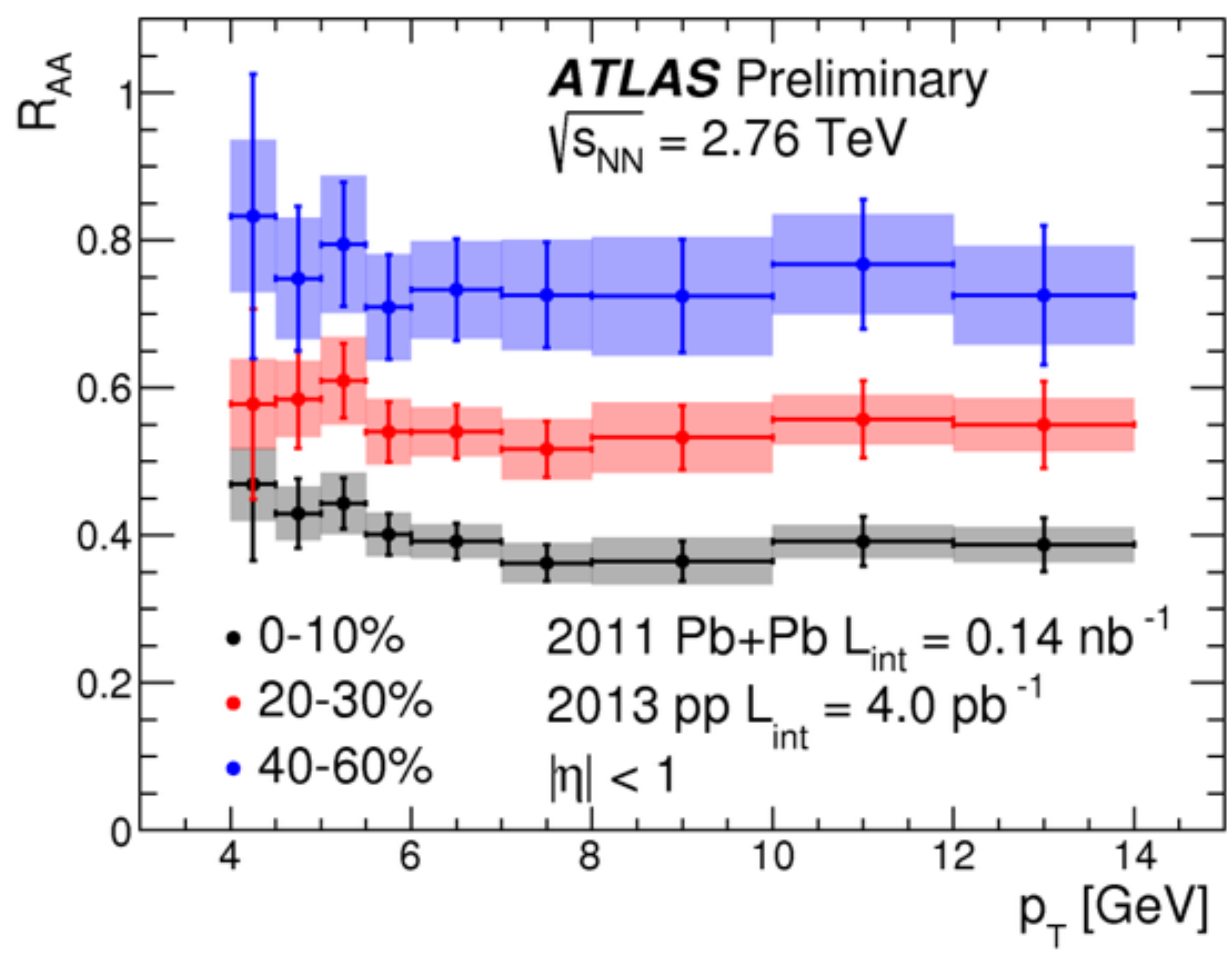
x_{BJ} (200 GeV) ~ 10^{-2} , x_{BJ} (2.76 TeV) ~ $8 \cdot 10^{-4}$

R_{AA} of heavy flavour muons

ALICE R_{AA} of heavy-flavour muons at 2.76 TeV and 5.02 TeV



R_{AA} of heavy-flavour muons at 2.76 TeV from ATLAS



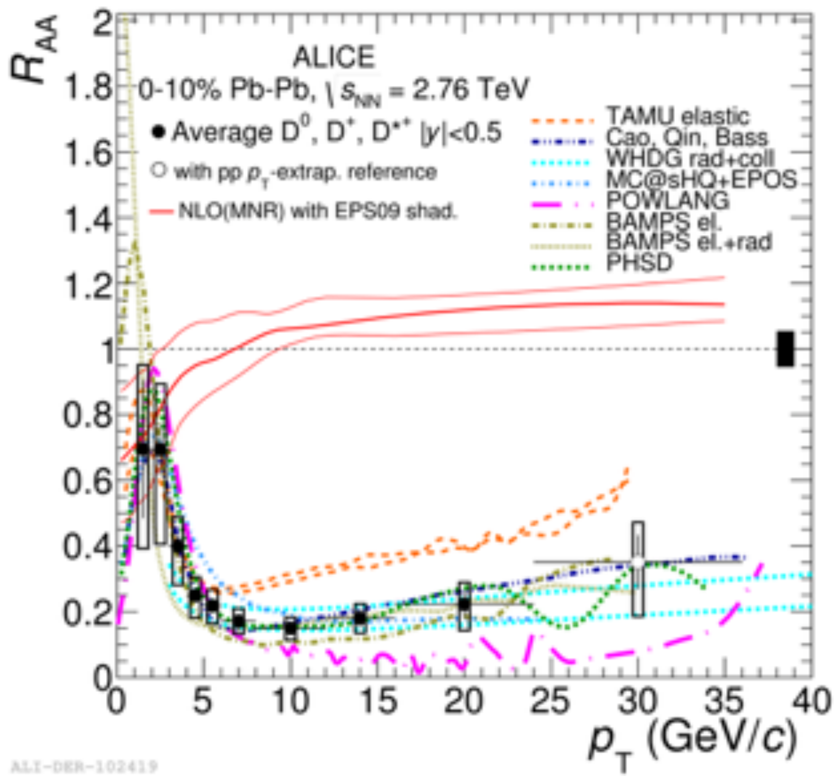
ATLAS-CONF-2015-053

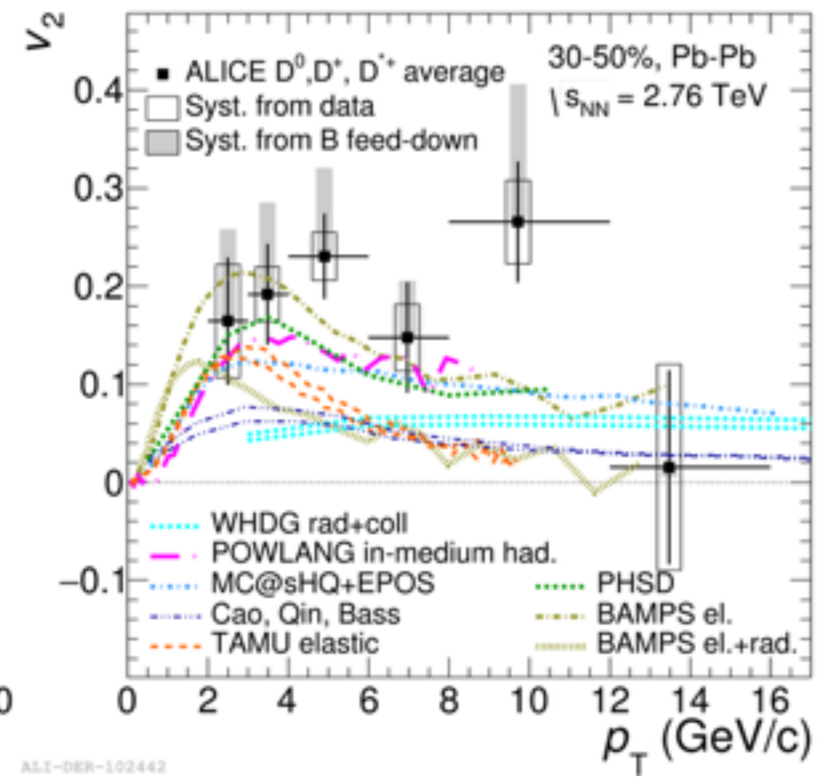
Precise measurement of HF muons at low p_T

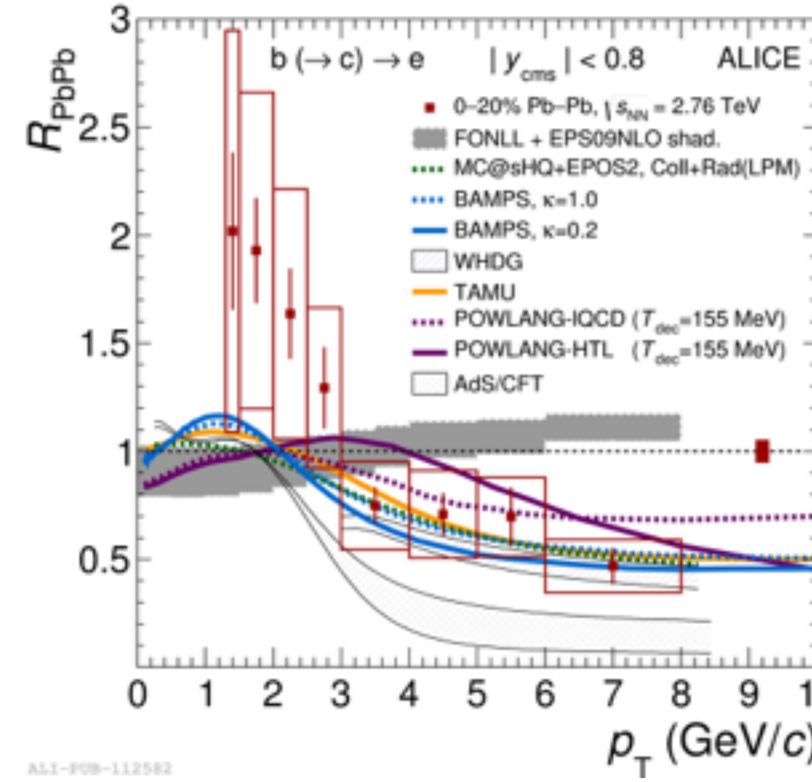
Same suppression observed at the two energies

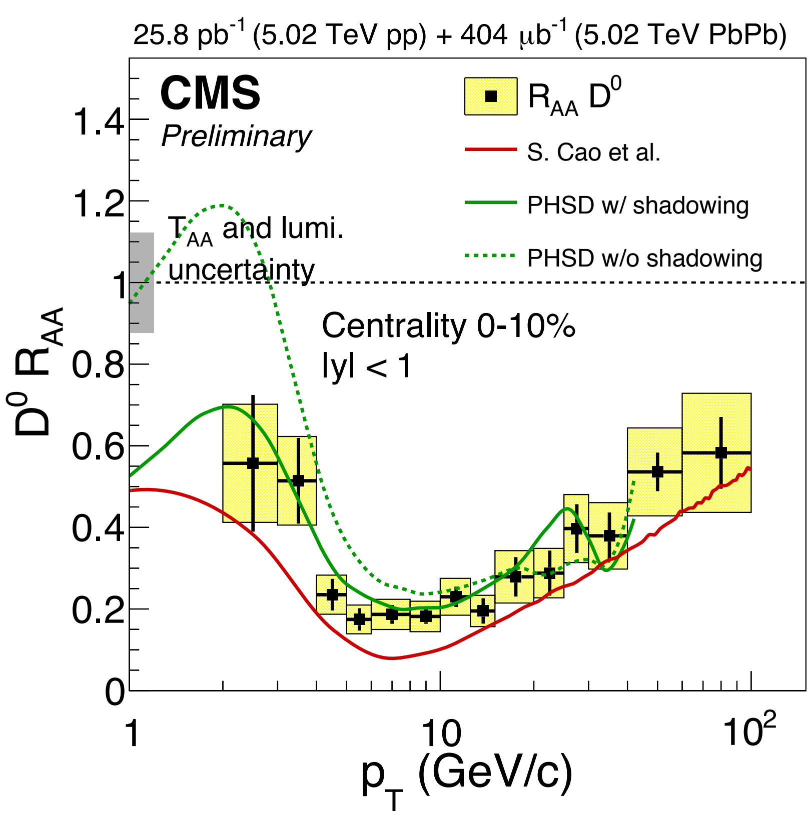
Clear suppression pattern observed as a function of centrality

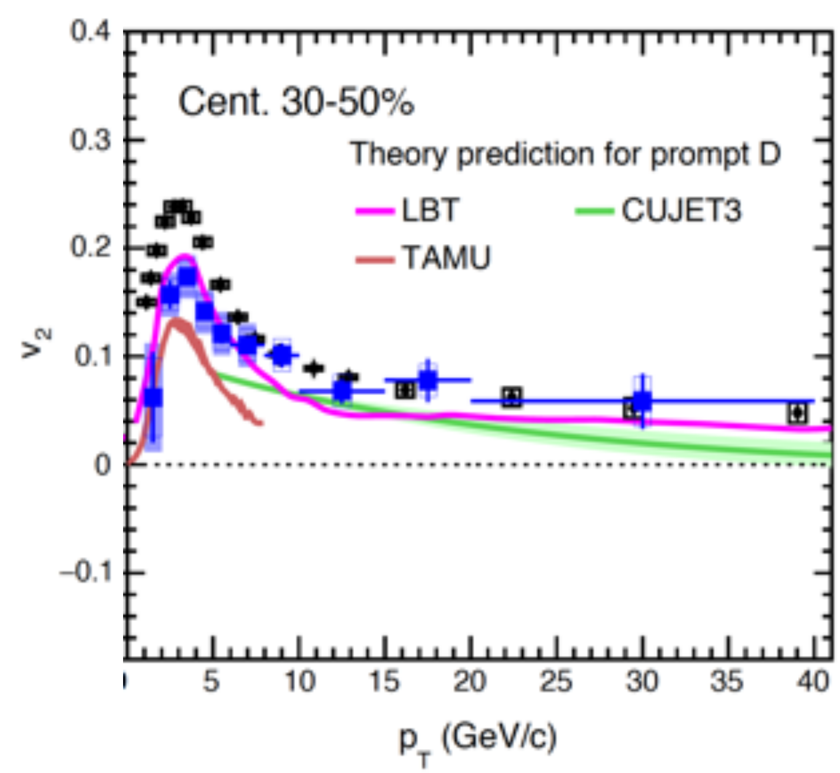
The final picture

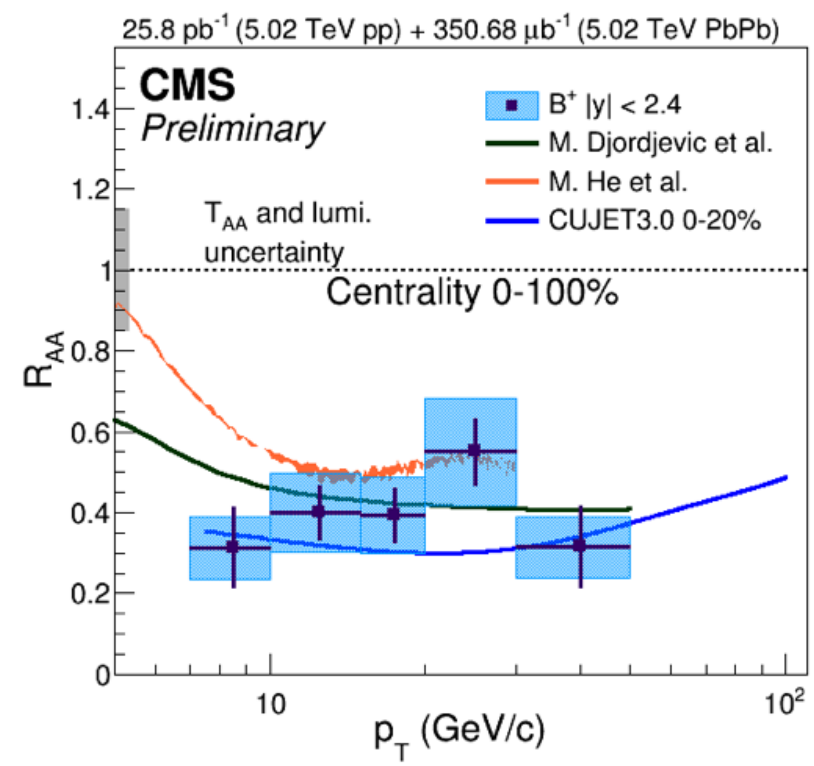




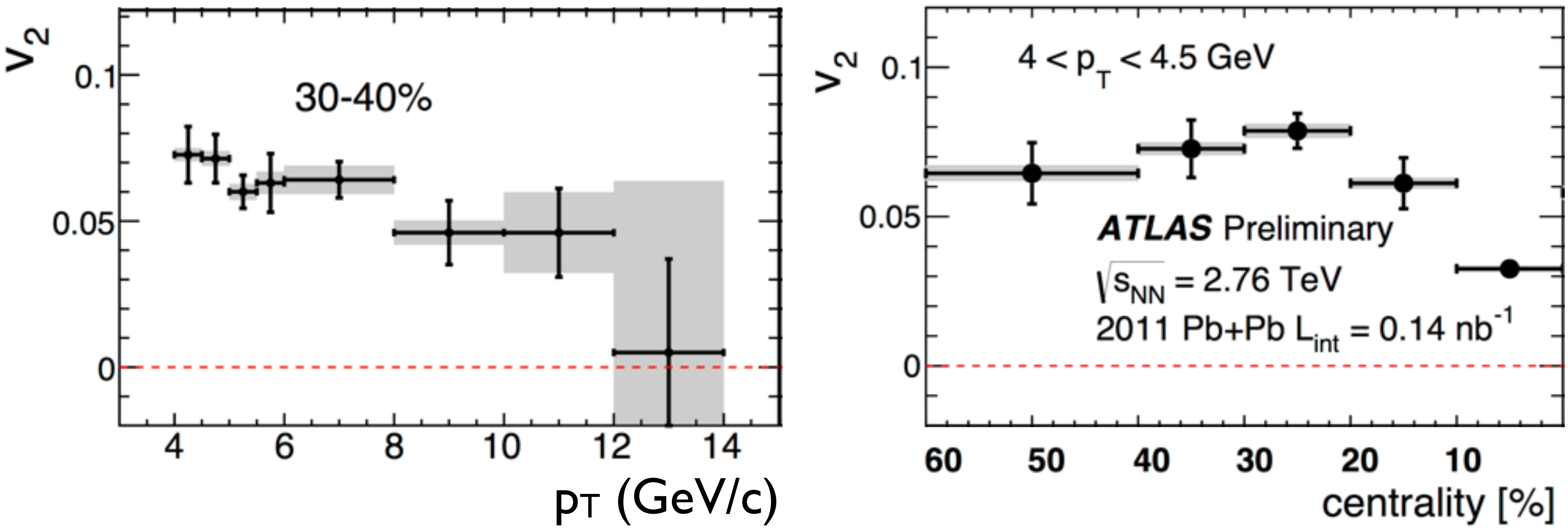








Heavy-flavour muons at 2.76 TeV



ATLAS-CONF-2015-053

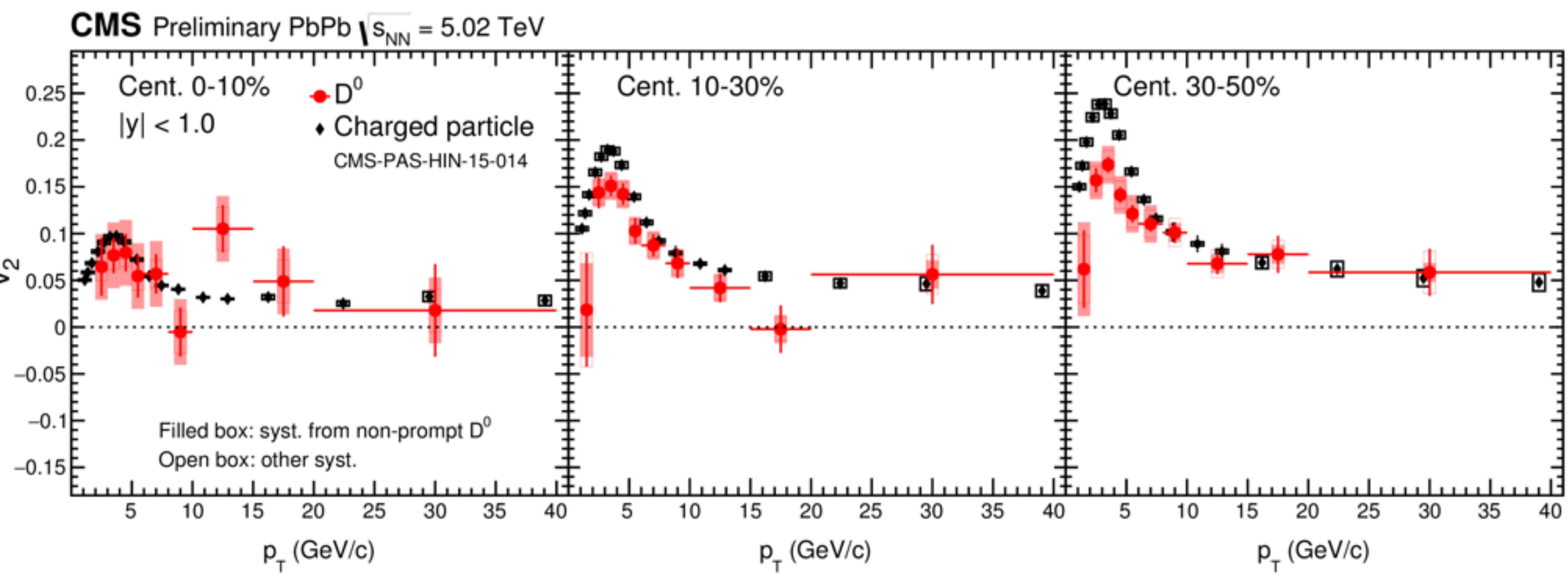
Positive v_2 for muons from heavy-flavour decays (b+c) at LHC:

- include the contributions of beauty to v_2 that is currently unknown
- **v_2 of heavy flavour muons < v_2 (D^0) from ALICE**

→ *indirect indication of $v_2(b)<v_2(c)$?*

D meson v_2 at 5.02 TeV in PbPb collisions

New CMS measurement of v_2 and v_3 in PbPb collisions at 5.02 TeV in different collision centralities

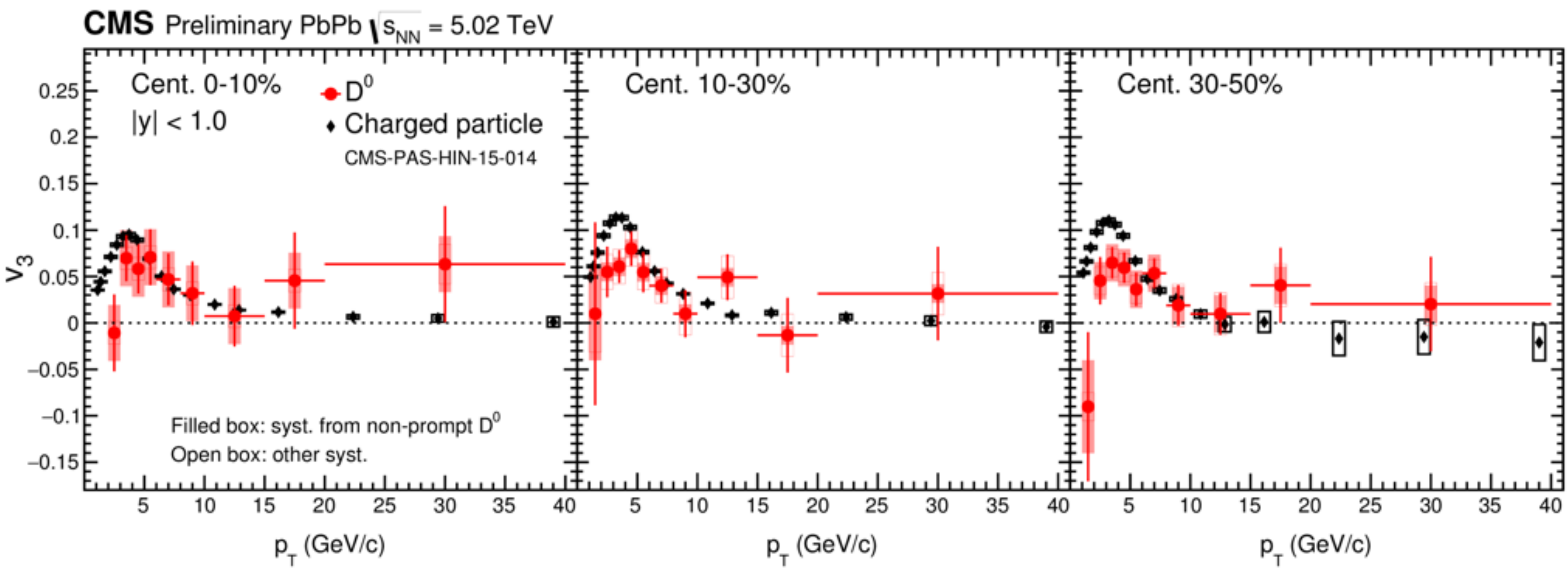


Significant confirmation of $v_2>0$ for D^0 at 5.02 TeV:

v_2 of D mesons larger than v_2 of charged particles

$v_2(0\text{-}10\%) < v_2(10\text{-}30\%) \sim v_2(30\text{-}50\%)$

D meson v_3 at 5.02 TeV in PbPb collisions

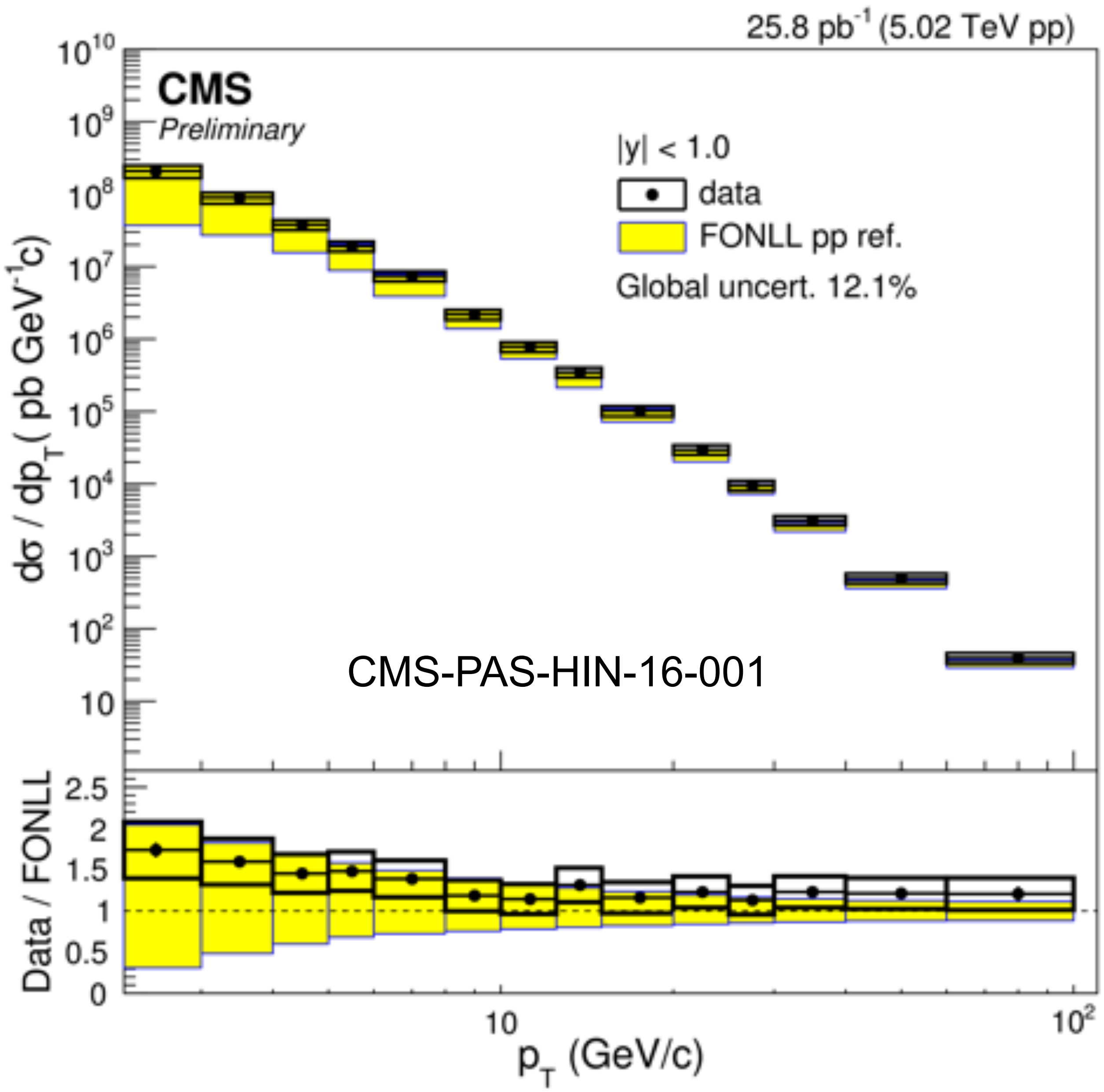


First observation of v_3>0 for charm!

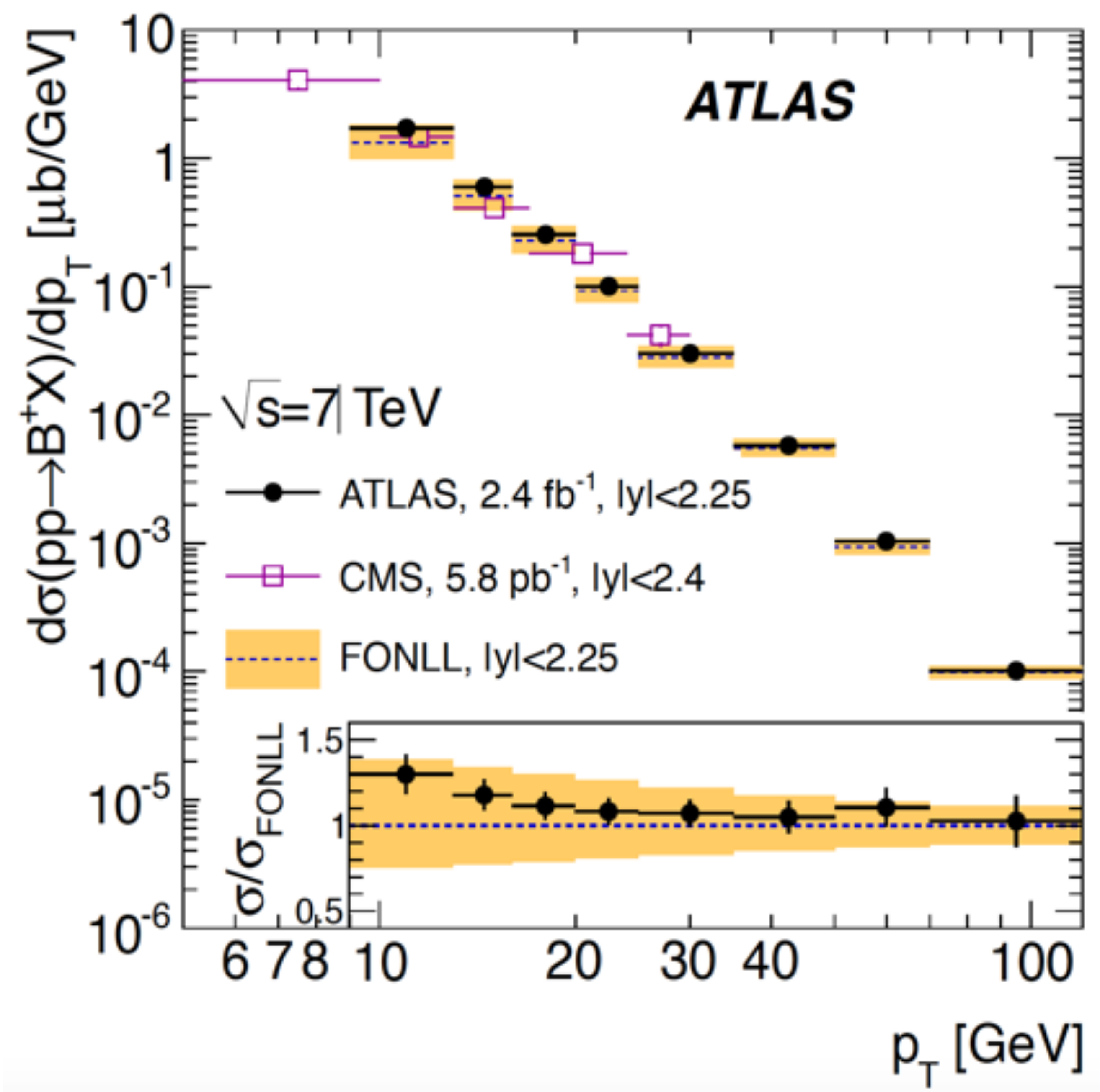
v_3 for charged particle larger that D^0 v_3 although not fully significative given current uncertainties

D and B cross sections at LHC in pp collisions

CMS D^0 at 5.02 TeV, |y|<1.0



ATLAS B^+ measurement at 7 TeV, |y|<2.25



D and B meson production cross sections well described by NLO calculations:

→*D meson upper edge of FONLL calculations*

→*B meson consistent with central values of FONLL*

J.Wang and T.W.Wang's talks, Saturday

HF models overview

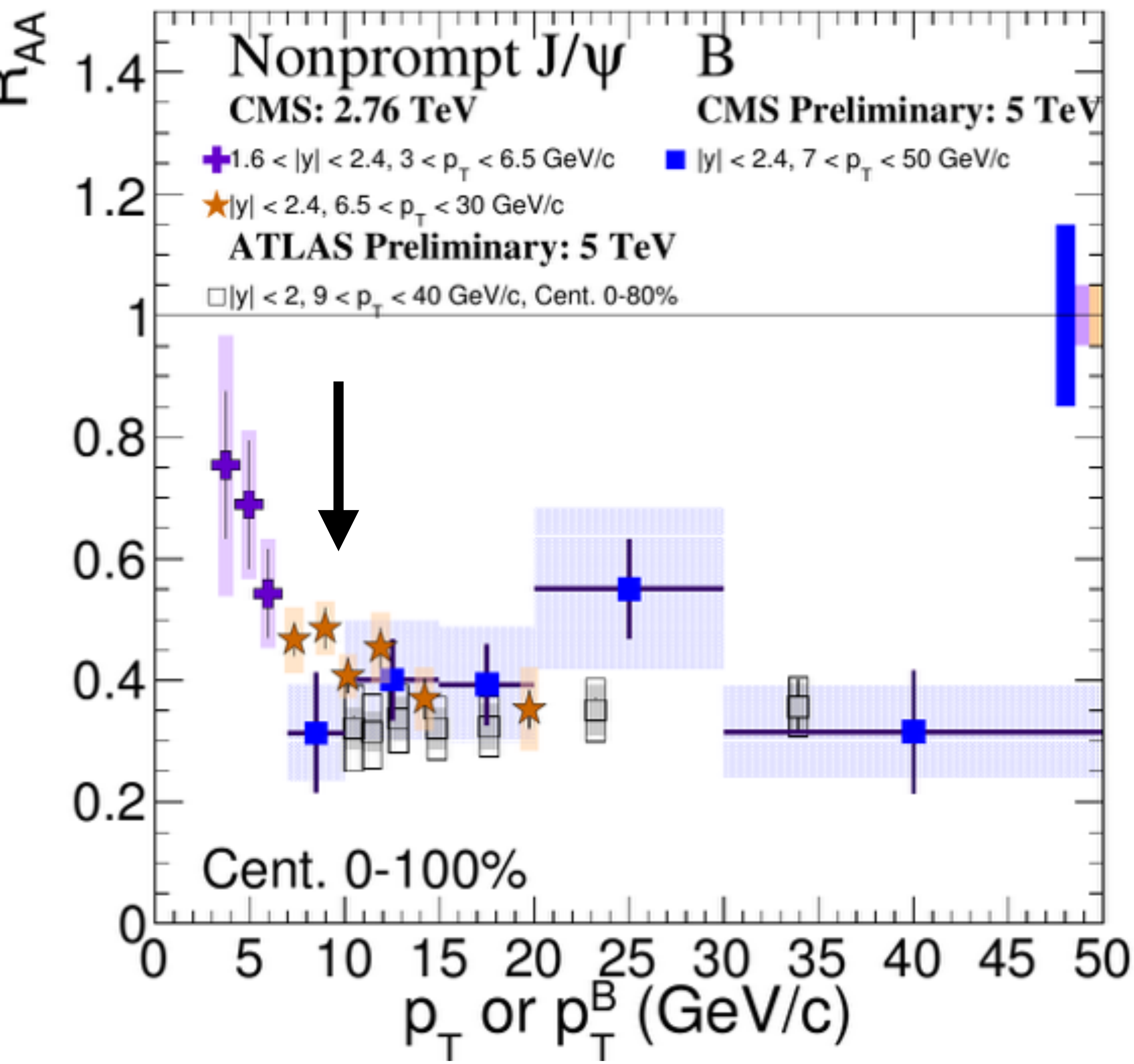
Table 11: Comparative overview of the models for heavy-quark energy loss or transport in the medium described in the previous sections.

Model	*Heavy-quark production*	*Medium modelling*	*Quark–medium interactions*	*Heavy-quark hadronisation*	*Tuning of medium-coupling (or density) parameter(s)*
Djordjevic *et al.* [511–515]	FONLL no PDF shadowing	Glauber model nuclear overlap no fl. dyn. evolution	rad. + coll. energy loss finite magnetic mass	fragmentation	Medium temperature fixed separately at RHIC and LHC
WHDG [459, 519]	FONLL no PDF shadowing	Glauber model nuclear overlap no fl. dyn. evolution	rad. + coll. energy loss	fragmentation	RHIC (then scaled with $dN_{ch}/d\eta$)
Vitev et al. [422, 460]	non-zero-mass VFNS no PDF shadowing	Glauber model nuclear overlap ideal fl. dyn. 1+1d Bjorken expansion	radiative energy loss in-medium meson dissociation	fragmentation	RHIC (then scaled with $dN_{ch}/d\eta$)
AdS/CFT (HG) [624, 625]	FONLL no PDF shadowing	Glauber model nuclear overlap no fl. dyn. evolution	AdS/CFT drag	fragmentation	RHIC (then scaled with $dN_{ch}/d\eta$)
POWLANG [507–509, 585, 586]	POWHEG (NLO) EPS09 (NLO) PDF shadowing	2+1d expansion with viscous fl. dyn. evolution	transport with Langevin eq. collisional energy loss	fragmentation recombination	assume pQCD (or l-QCD *U* potential)
MC@$_s$HQ+EPOS2 [528–530]	FONLL EPS09 (LO) PDF shadowing	3+1d expansion (EPOS model)	transport with Boltzmann eq. rad. + coll. energy loss	fragmentation recombination	QGP transport coefficient fixed at LHC, slightly adapted for RHIC
BAMPS [537–540]	MC@NLO no PDF shadowing	3+1d expansion parton cascade	transport with Boltzmann eq. rad. + coll. energy loss	fragmentation	RHIC (then scaled with $dN_{ch}/d\eta$)
TAMU [491, 565, 606]	FONLL EPS09 (NLO) PDF shadowing	2+1d expansion ideal fl. dyn.	transport with Langevin eq. collisional energy loss diffusion in hadronic phase	fragmentation recombination	assume l-QCD *U* potential
UrQMD [608–610]	PYTHIA no PDF shadowing	3+1d expansion ideal fl. dyn.	transport with Langevin eq. collisional energy loss	fragmentation recombination	assume l-QCD *U* potential
Duke [587, 628]	PYTHIA EPS09 (LO) PDF shadowing	2+1d expansion viscous fl. dyn.	transport with Langevin eq. rad. + coll. energy loss	fragmentation recombination	QGP transport coefficient fixed at RHIC and LHC (same value)

[1506.03981]

Non-prompt J/φ at 2.76 TeV vs B^+ at 5.02 TeV

No tension between the two measurements!



To be handled with care!!

- *B meson p_T and non prompt J/φ are different! Need to correct for different kinematic*

CMS non prompt 1.6<|y|<2.4

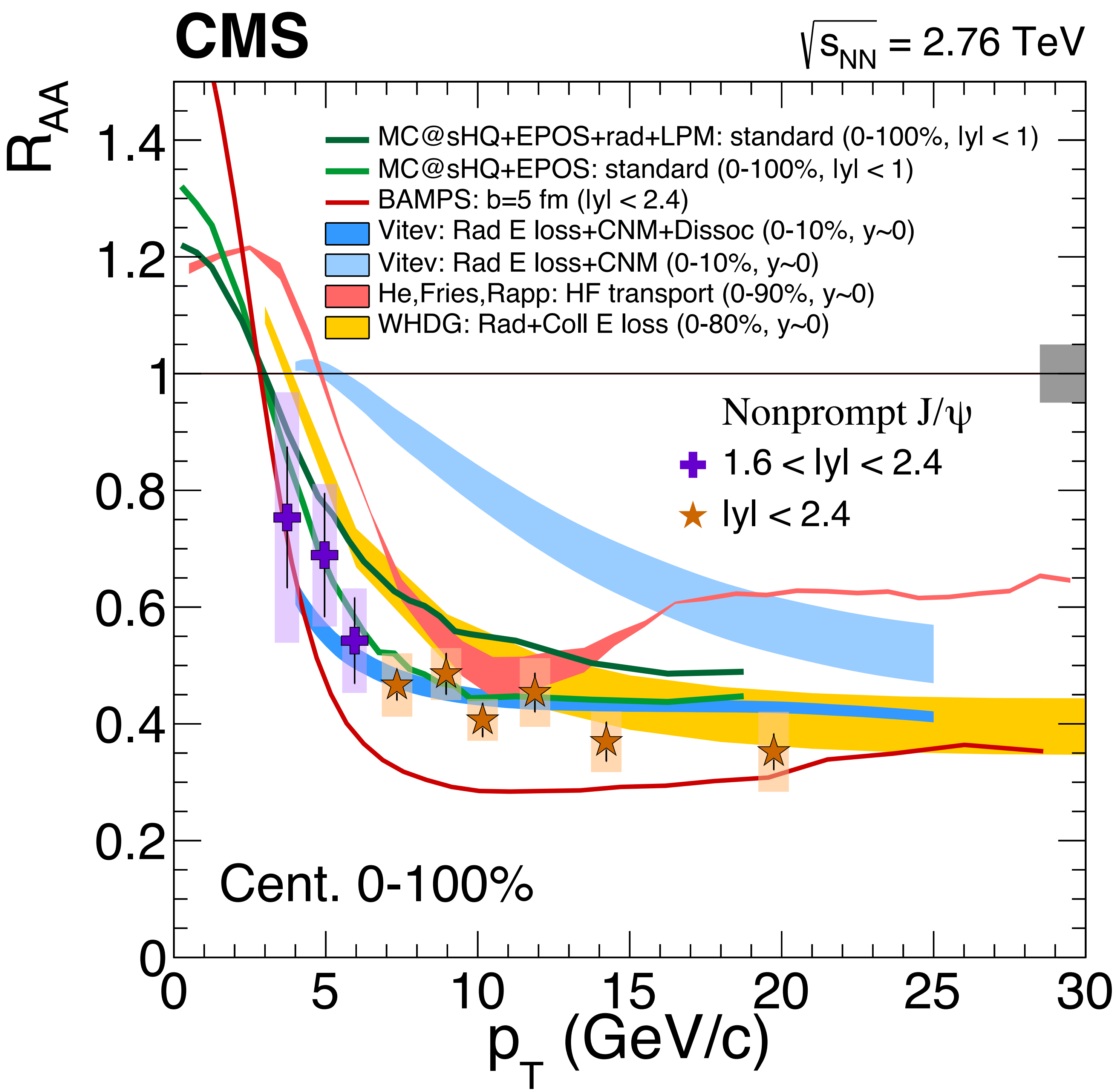
CMS non prompt |y|<2.4

ATLAS non prompt |y|<2.9

CMS B+ |y|<2.4

M. Ho's talk, Sunday

Comparison to theoretical calculations



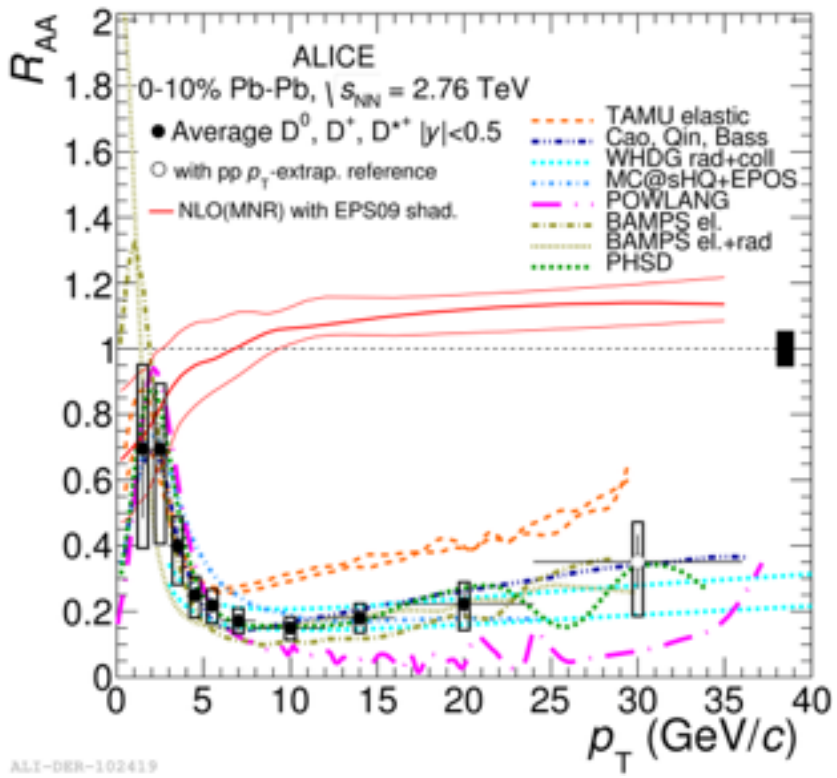
CMS non prompt 1.6<|y|<2.4

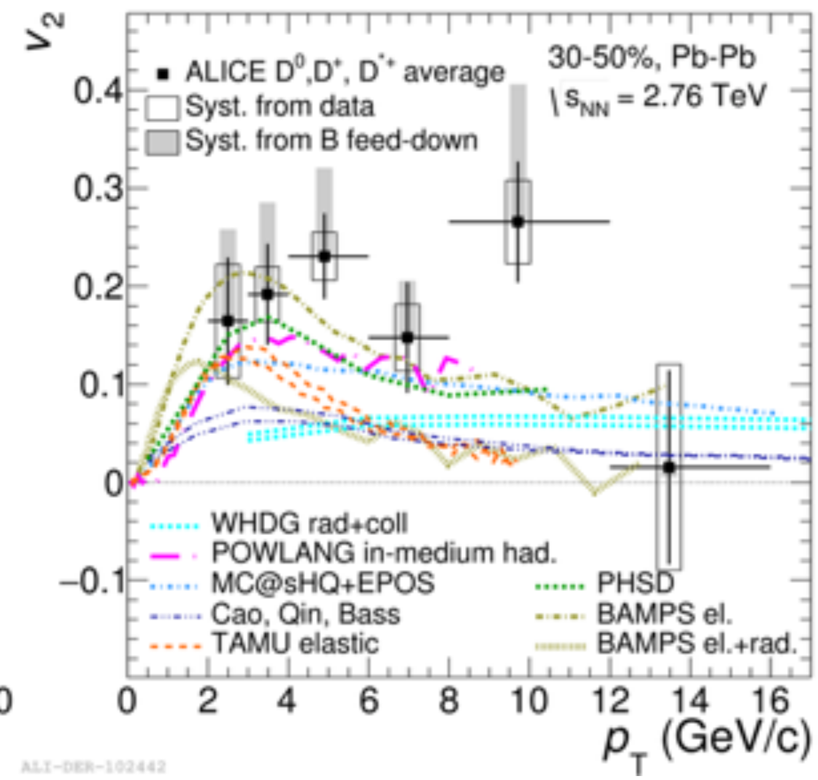
CMS non prompt |y|<2.4

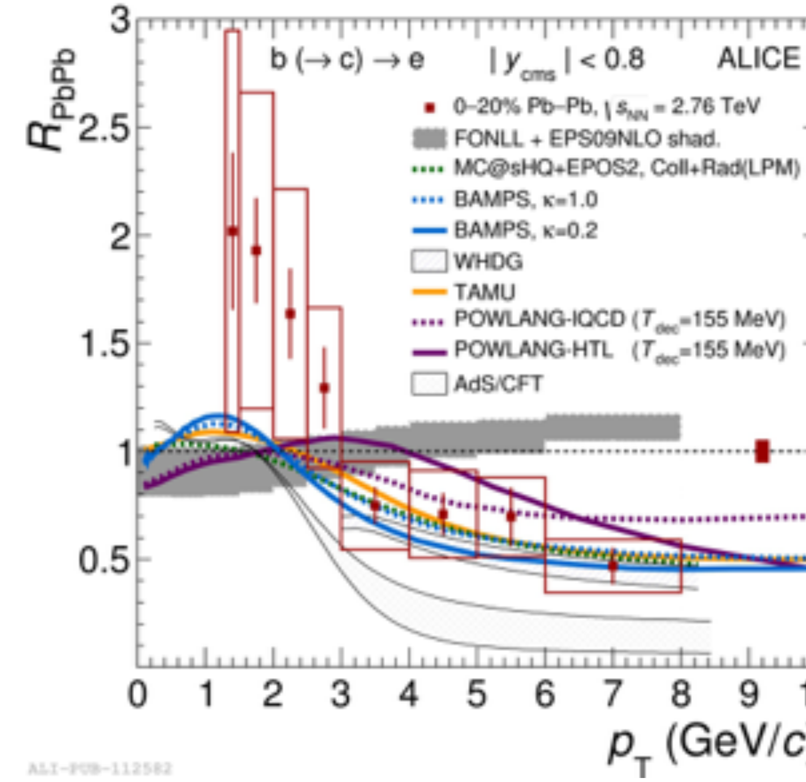
Strong suppression observed for non prompt J/φ in PbPb collisions

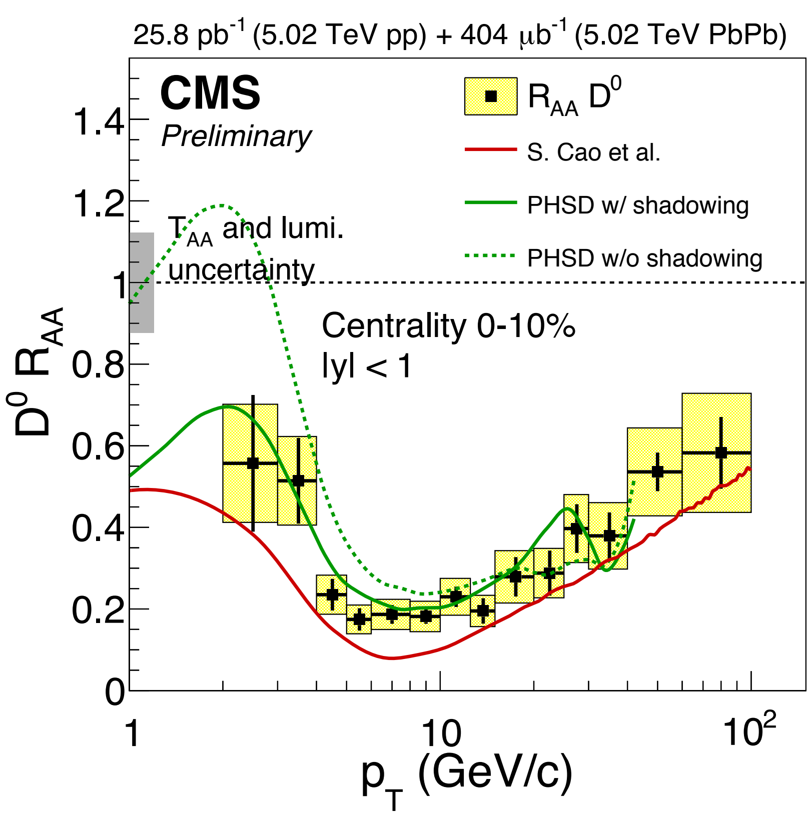
Clear suppression as a function of p_T

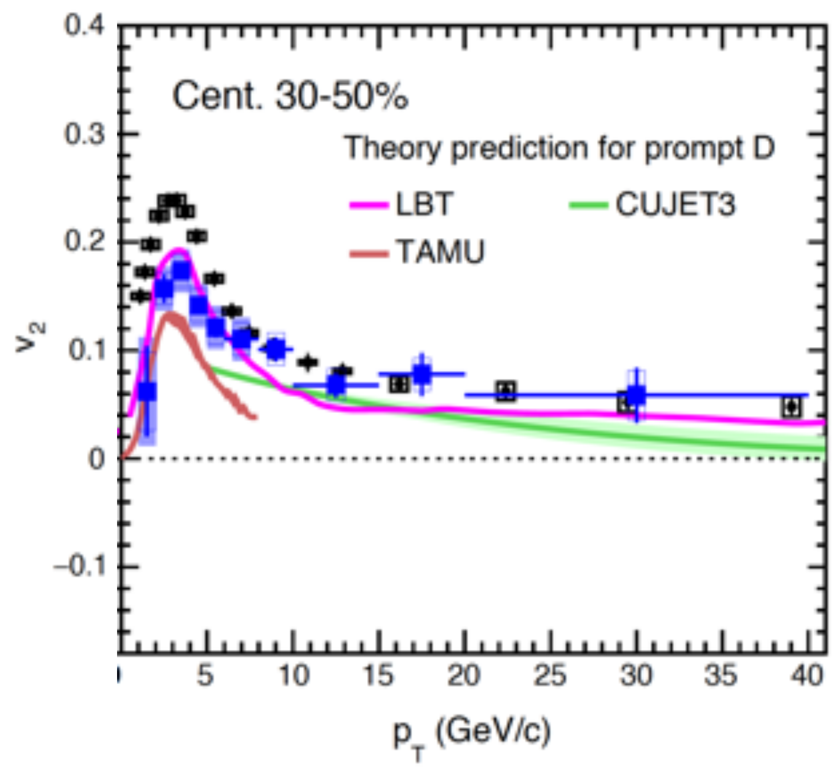
The final picture

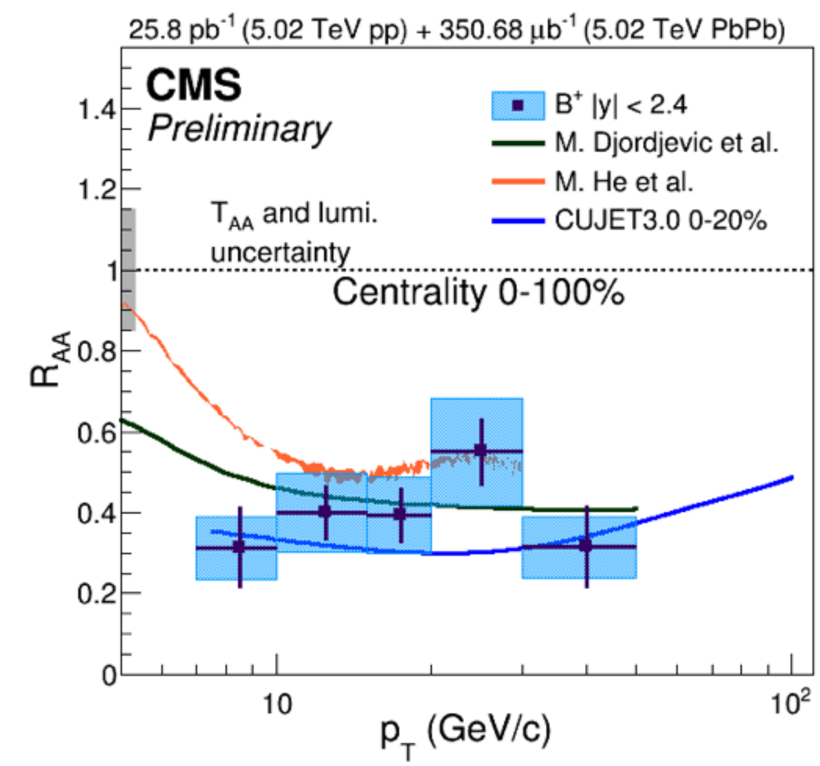






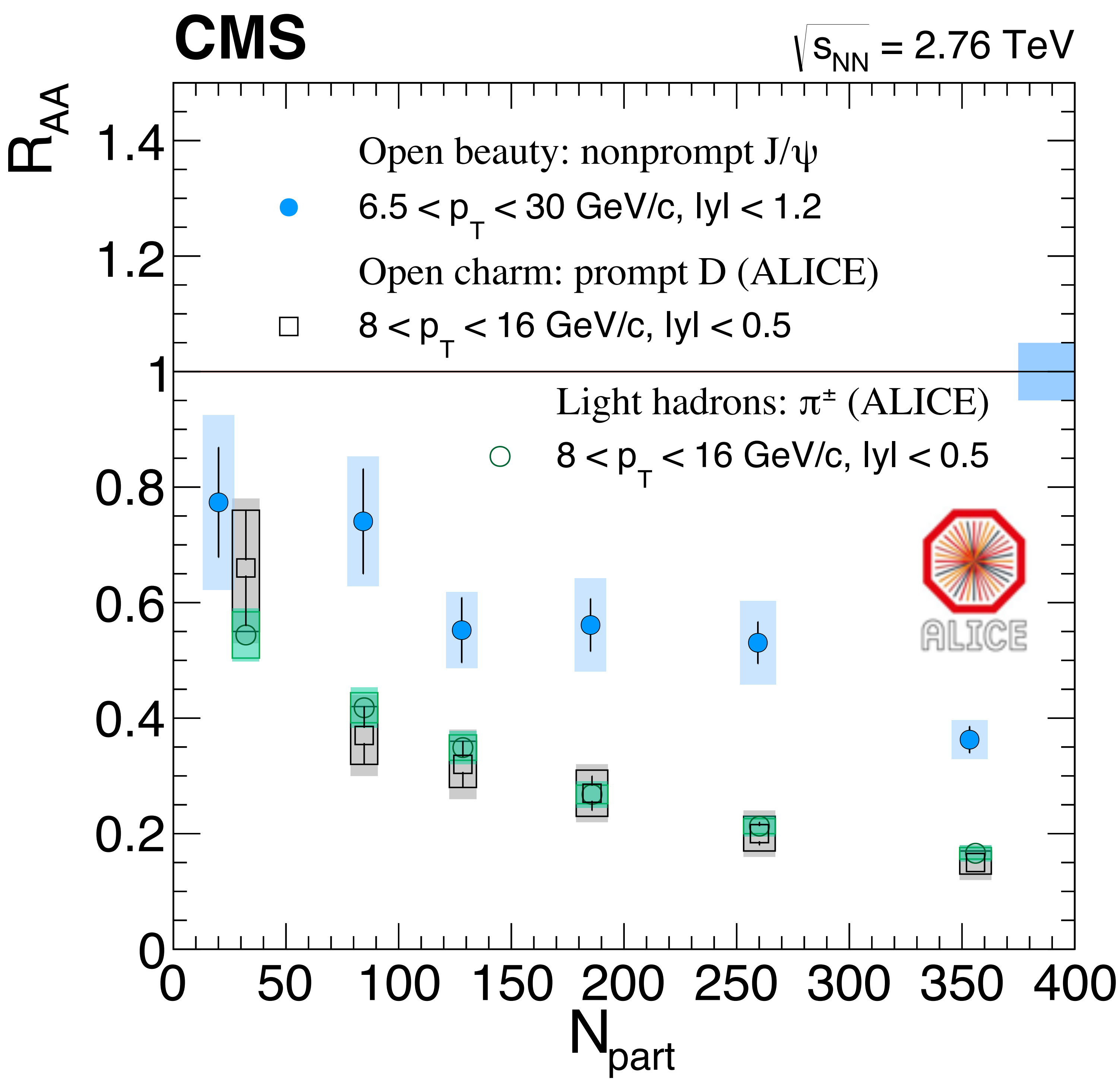






Flavour dependence of E_{loss} at 2.76 TeV

CMS-PAS-HIN-15-005



Non-prompt J/ψ

D mesons

π^{+-}

No change in the physics message when comparing to the final result of non prompt J/ψ R_{AA} from CMS

BB Δϕ correlations