Correlations and heavy-flavour jets

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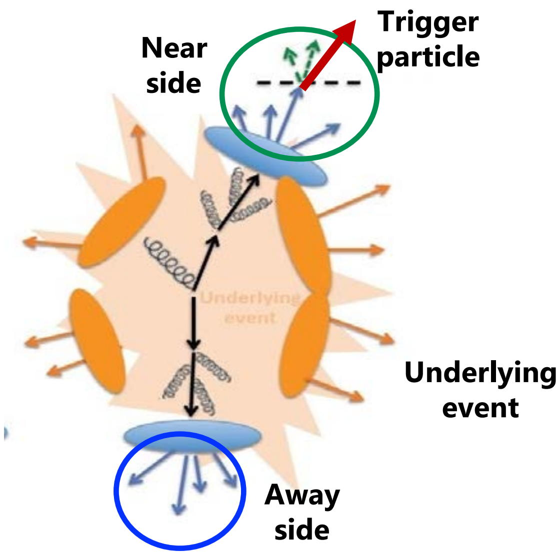
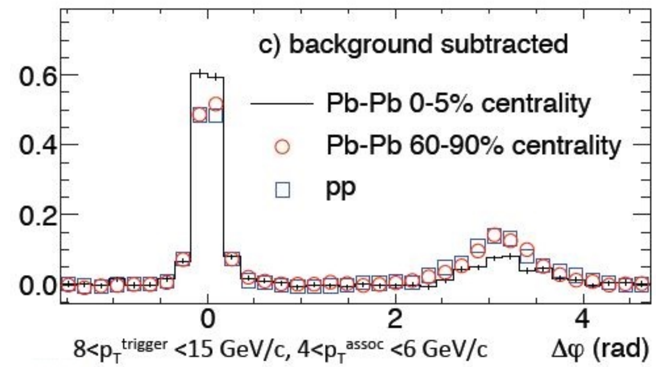
II incontro fisica ioni pesanti ad LHC – Torino – 10/10/2017

PHYSICS MOTIVATIONS – CORRELATIONS

Study of hard probes correlations in PbPb provide additional information w.r.t. single particle observables

- Probe QGP effects on hard partons via modifications of correlation pattern w.r.t. vacuum
  - ✓ Peak yields modifications (I_{AA}) to address jet quenching
  - ✓ Jet structure modification (particle multiplicity, opening angle, intra-jet p_T distribution)
- Investigate redistribution of parton energy loss (spatially and in momentum)
- Put constrain on models describing energy loss, in combination with single particle R_{AA}
- Study of collective effects – also in small systems! (not discussed here)



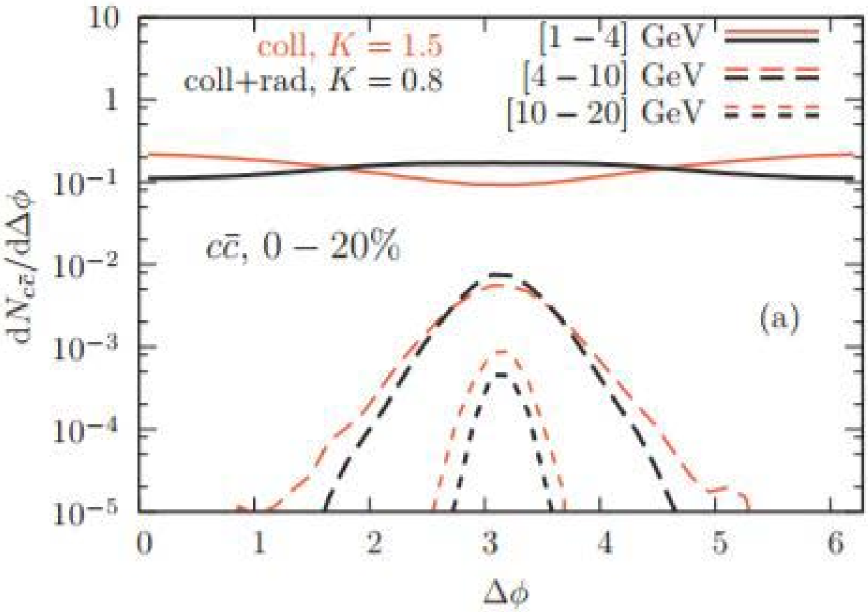


ALICE, PRL 108, 092301 (2012)

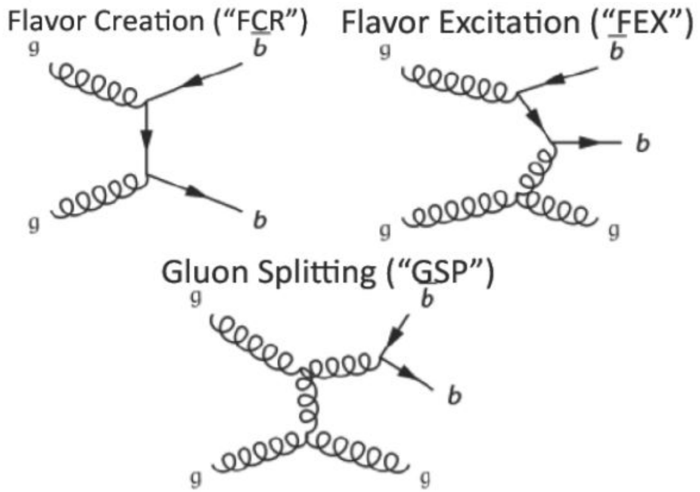
PHYSICS MOTIVATIONS – CORRELATIONS

In particular, for heavy-flavour correlations

- Disentangle radiative and collisional in-medium energy loss



M. Nahrgang et al., Phys. Rev. C 90 (2014) 024907

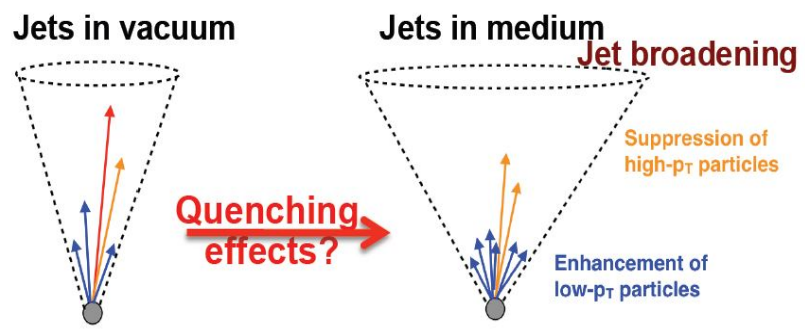


- Studies in small systems crucial not only as a reference for Pb-Pb:
  - ✓ HF quark production mechanisms
  - ✓ HF quark fragmentation into jets
  - ✓ Charm/beauty separation
  - ✓ Collective effects in high-multiplicity environment

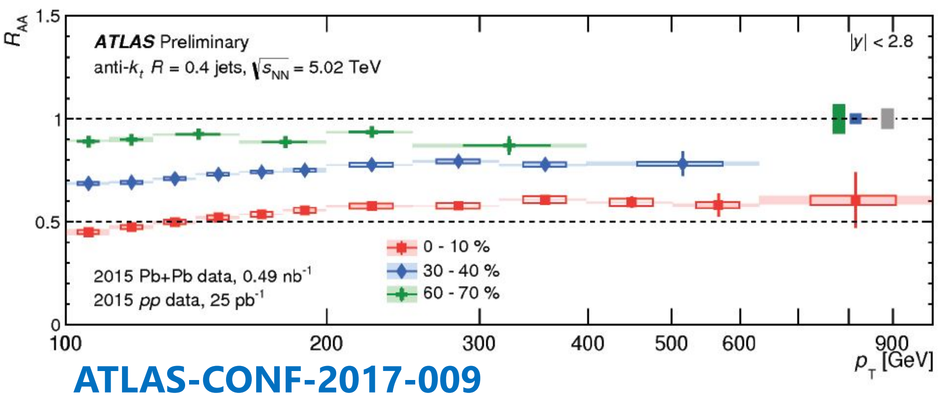
PHYSICS MOTIVATIONS – HF JETS

Inclusive jets already discussed in Leticia's talk
Let's deal with heavy-flavour jets (with b, c content)

- Tight connection with HF correlations (some shared goals, alternate approach):
  - ✓ Spatial distribution of energy lost in the medium by heavy quarks
  - ✓ Modification of heavy-quark fragmentation (via D-,B-tagged jets)



- Study of di-jet imbalance useful also in the HF sector
  - ✓ Further motivation: address NLO contribution to heavy-quark production



ATLAS-CONF-2017-009

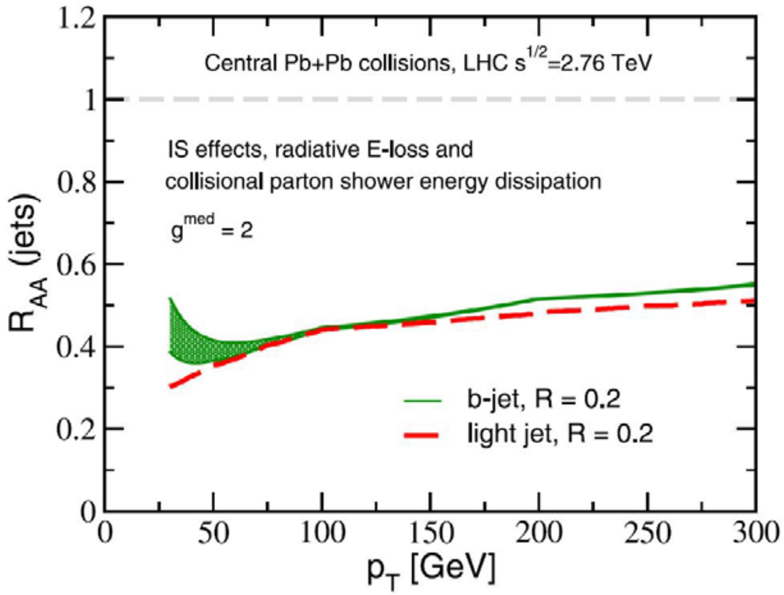
- Comparison of b-jet R_{AA} with inclusive jet to investigate mass effect on medium-induced energy loss

PHYSICS MOTIVATIONS – HF JETS

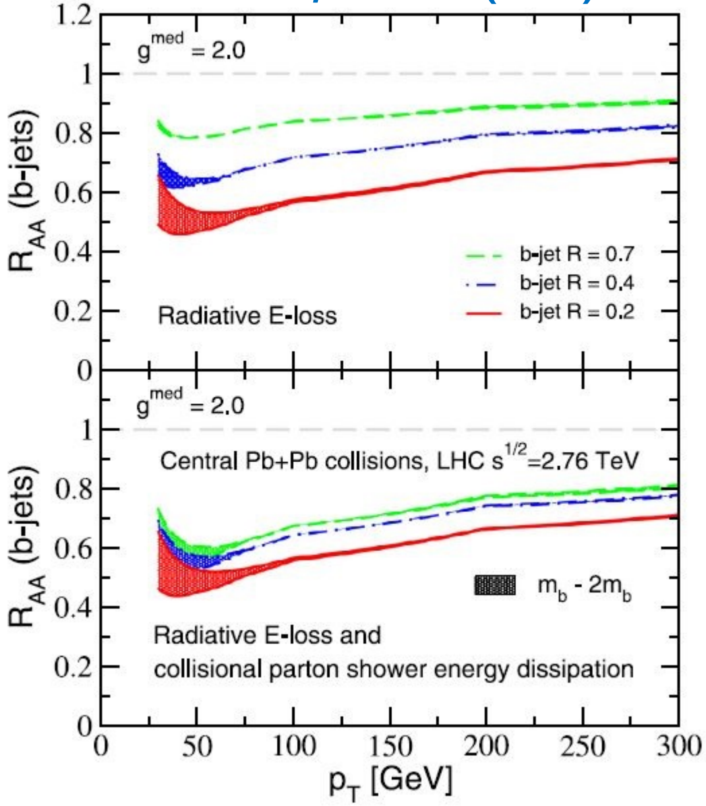
Model by Vitev et al., radiative energy loss + collisional parton shower energy dissipation

- ✓ Mass effects relevant for p_T<75 GeV/c, dead-cone effect enters in play
- ✓ Measurements vs opening radius R to characterize energy dissipation and possibly separate collisional and radiative energy loss
- ✓ Energy loss in gluon splitting cases: b-pair seen by medium as massive gluon?

What about c-jets? Some studies by Cao et al. (**Phys. Rev. C 93 (2016) 024912**) but no quantitative predictions for charm jets



Vitev et al., PLB 726 (2013) 251

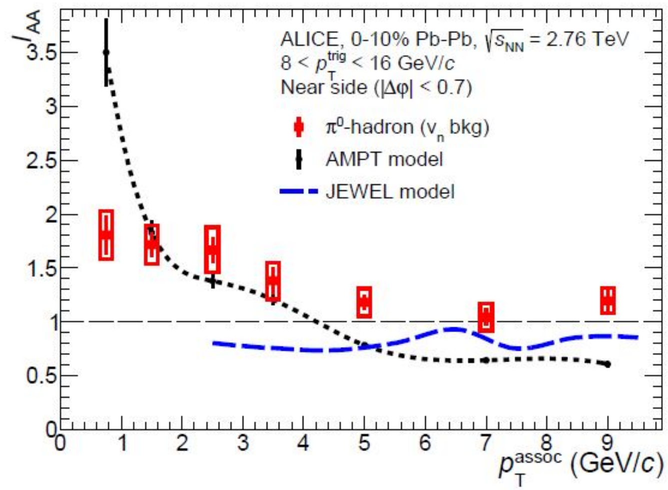


High-p_T, jet, HF correlations

HIGH p_T CORRELATIONS

Parton energy loss and jet quenching via high p_T hadron-hadron correlations in Pb-Pb

ALICE, Phys. Lett. B 763 (2016) 238

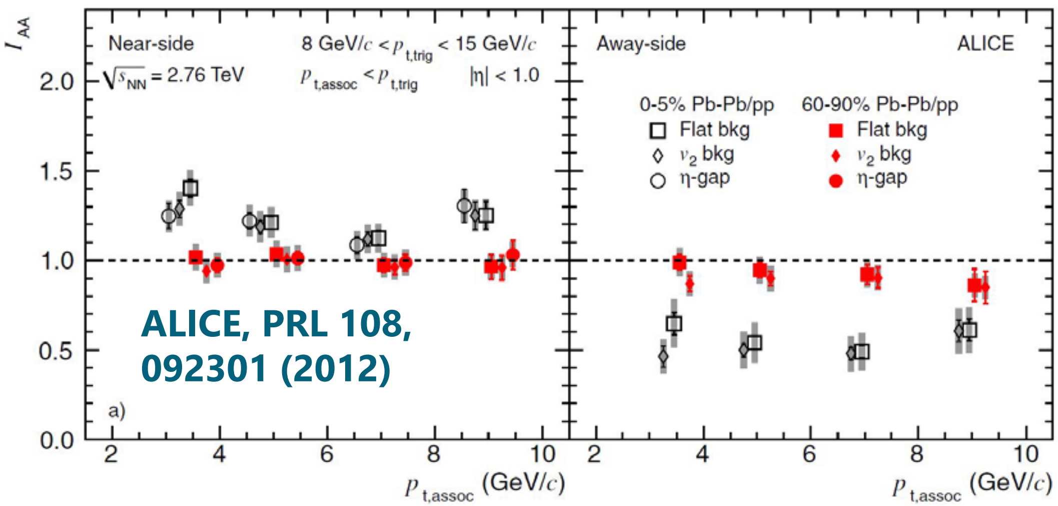


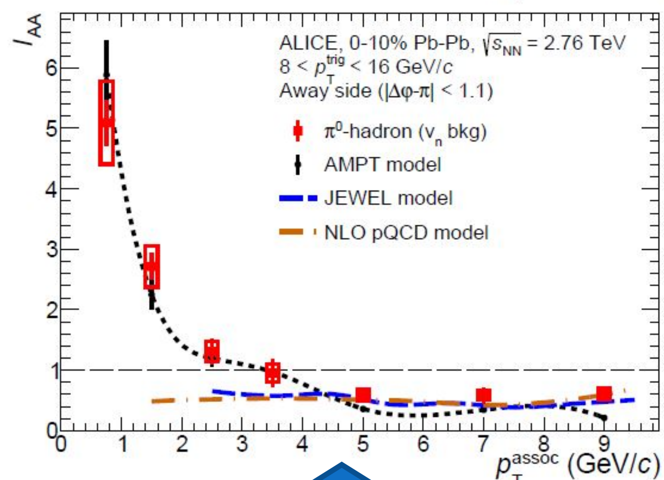
<u>**Away-side suppression at high p_T**</u>

- Large in-medium energy loss due to *surface bias*

<u>**Near-side peak enhancement**</u>, potential interplay of:

- Modification to quark/gluon ratio
- Bias in parton p_T spectrum due to energy loss
- Modified parton fragmentation





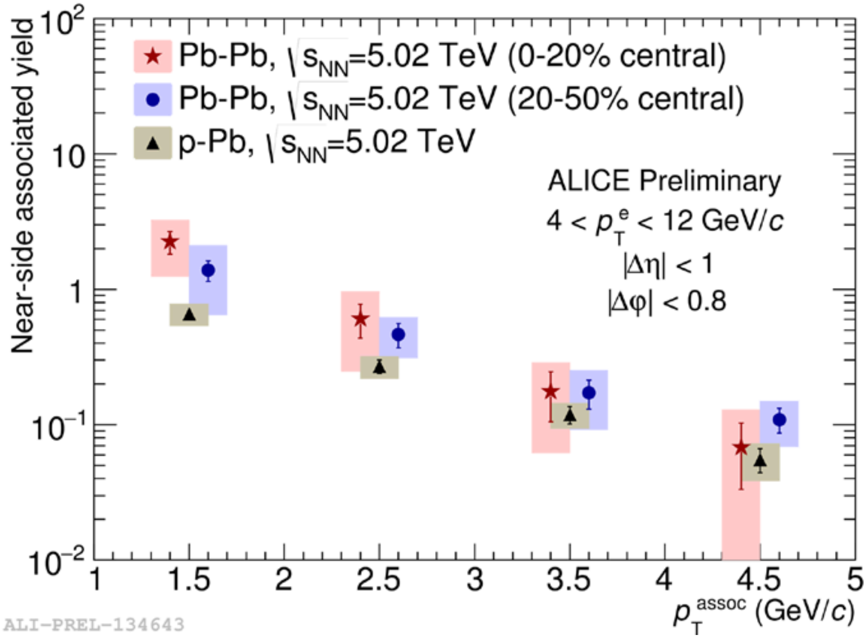
Similar results from in extended p_T range via π^0-hadron correlations

- Enhancement of low-p_T track in away-side peak → Redistribution of lost energy

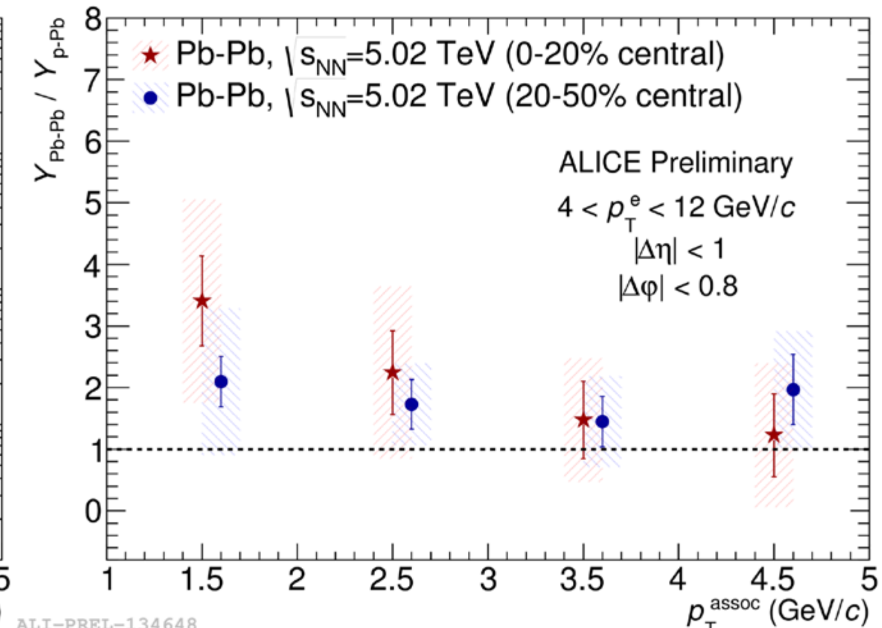
HF CORRELATIONS

Do same features hold also in the heavy-flavour sector?

- HF electron-hadron correlations from ALICE, currently sensitivity only for near-side
- At high p_T^{assoc}, yields are consistent within uncertianty
- Going lower with p_T^{assoc}, **hints of a hierarchy in NS yields**, despite large uncertainties
- Direct comparison with h-h not fair (different fragmentation, energy loss, …), interesting to have predictions from models



Near-side yields comparison

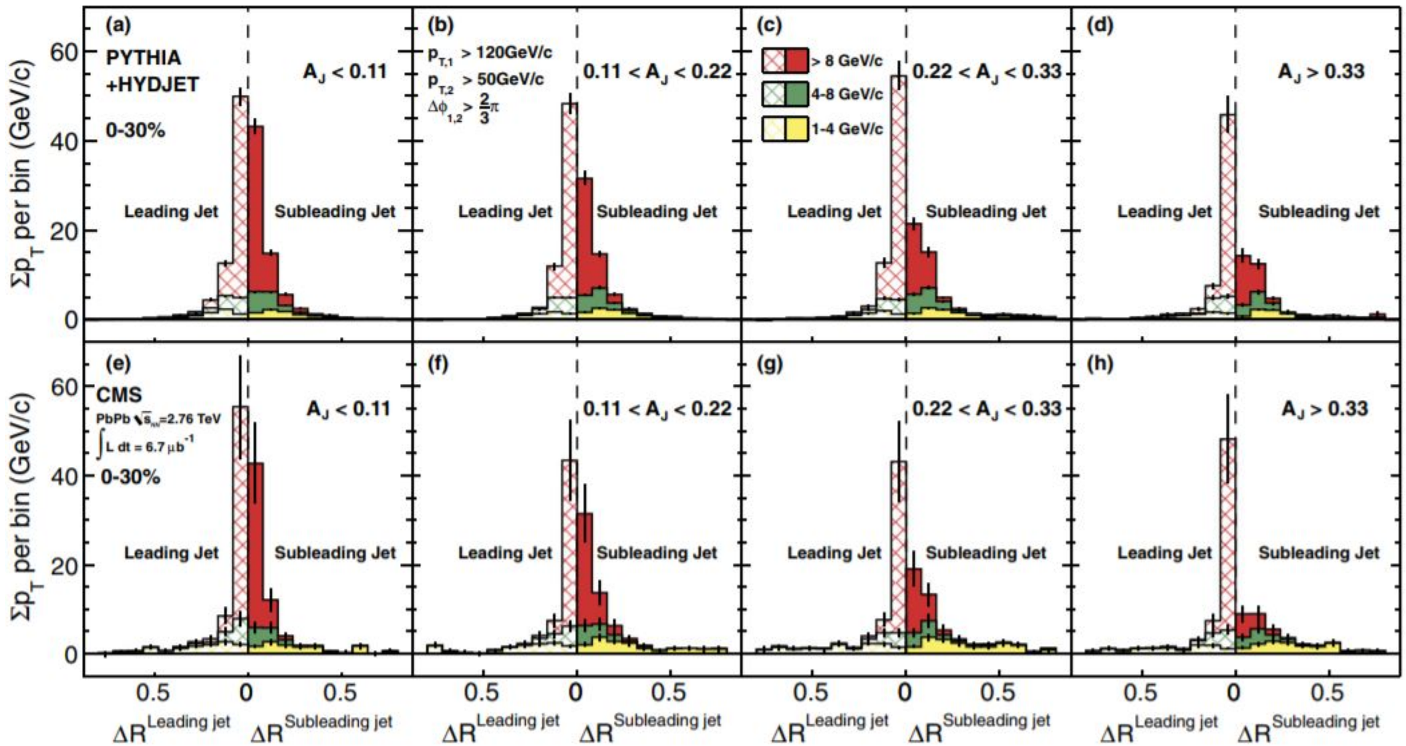


Ratio of near-side yields to p-Pb

JET-TRACK CORRELATIONS

Jet tomography and quenching via jet-track and jet-jet correlations

- Large imbalance in di-jet p_T in central Pb-Pb collisions, consistent with jet quenching
- **Softened and broadened sub-leading jet fragmentation**, due to energy redistribution from parton-medium interaction
- Full momentum balance recovered integrating over a wide away-side area



$$A_J = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}$$

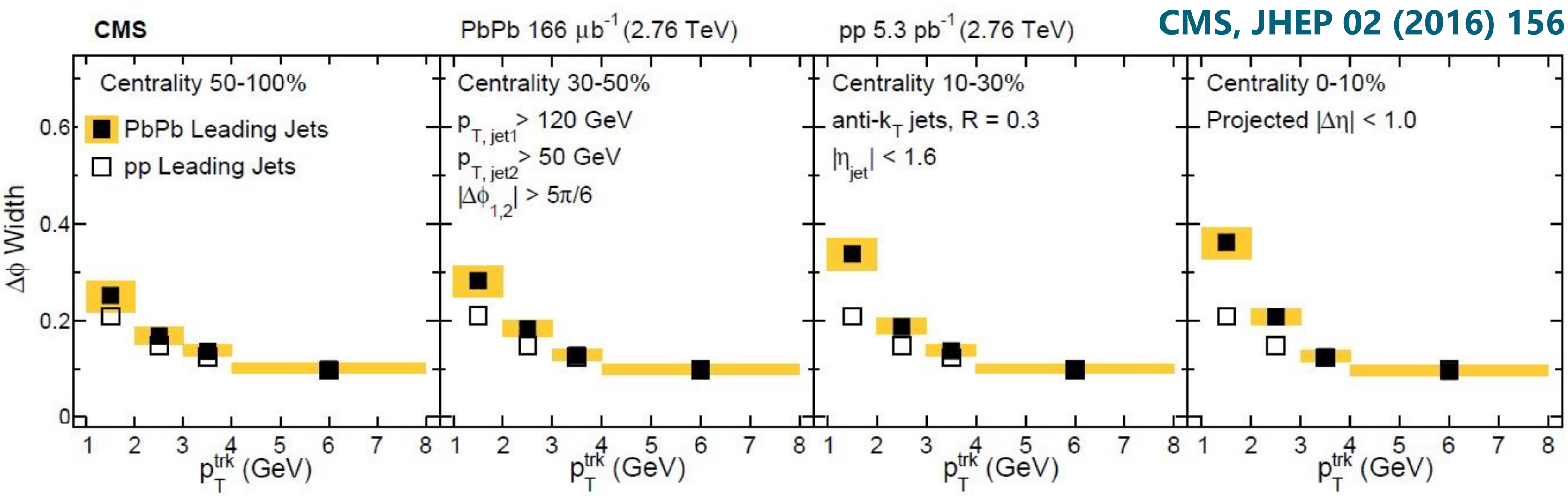
CMS, Phys. Rev. C 84 (2011) 024906, see also **ATLAS, PRL 105, (2010) 252303**

JET-TRACK CORRELATIONS

Modification of jet shape and yields vs track p_T via via jet-track correlations

- Excess of low-p_T tracks ($1 < p_T < 2$ GeV/c) in PbPb w.r.t. pp both for leading and sub-leading jets, spatially extended over a $|\Delta\varphi| < 1$, $|\Delta\eta| < 1$ region
  - Up to 30-40% larger width of jets in $\Delta\varphi$, $\Delta\eta$, for low p_T tracks
- Enhancement of yield for both leading and subleading jets for tracks up to 4 GeV/c, decreasing with track p_T, stronger in more central collisions
- Results consistent with **quenching of leading jet** as well, despite shorter path lenght

CMS, JHEP 02 (2016) 156



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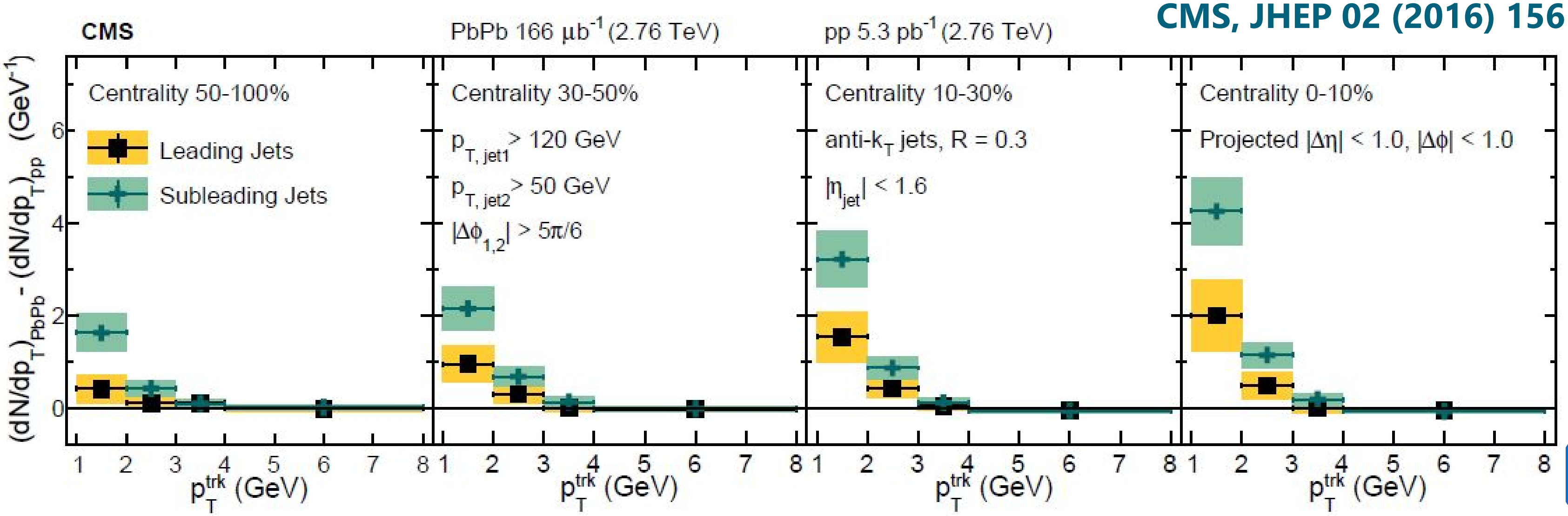
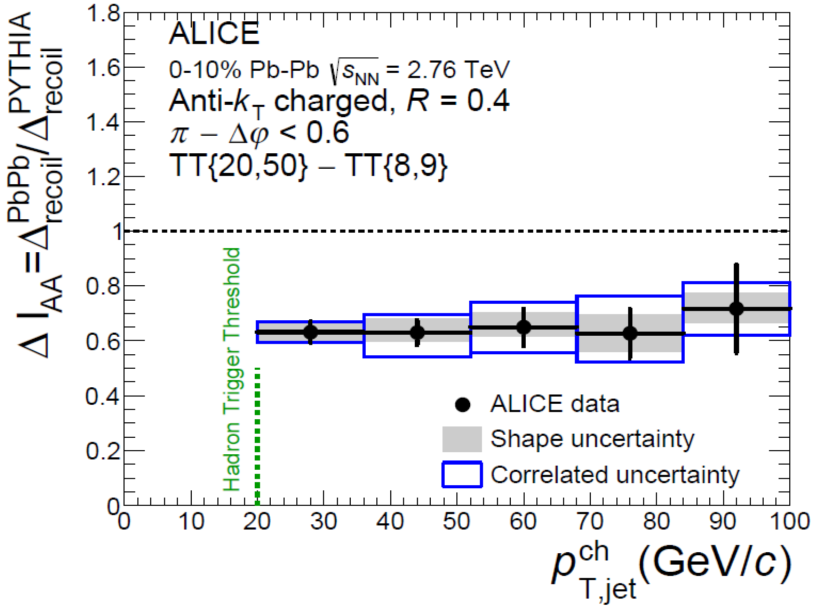
CMS, JHEP 02 (2016) 156

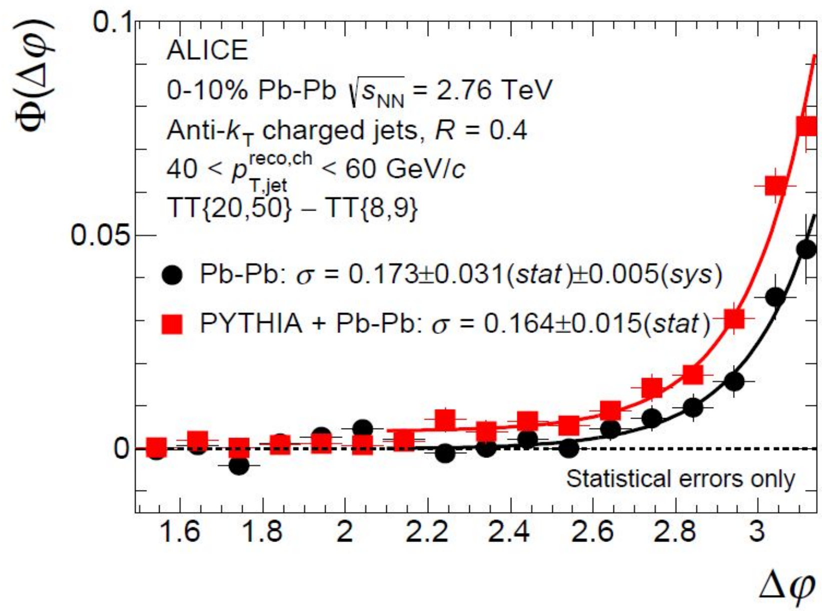


HADRON-JET CORRELATIONS

Quenching of recoiling jets via high p_T hadron-jet correlations

- Recoil jet yield **suppressed by up to a factor two** in 0-10% Pb–Pb collisions w.r.t. pp
- From measurements at different *R*, no evidence for intra-jet broadening
  - Comparison with CMS results not straightforward (different observables, different fragmentation bias), need predictions for the two observables to interpret the results
- Δφ distribution of recoil jets in pp/Pb-Pb shows no significant medium-induced acoplanarity





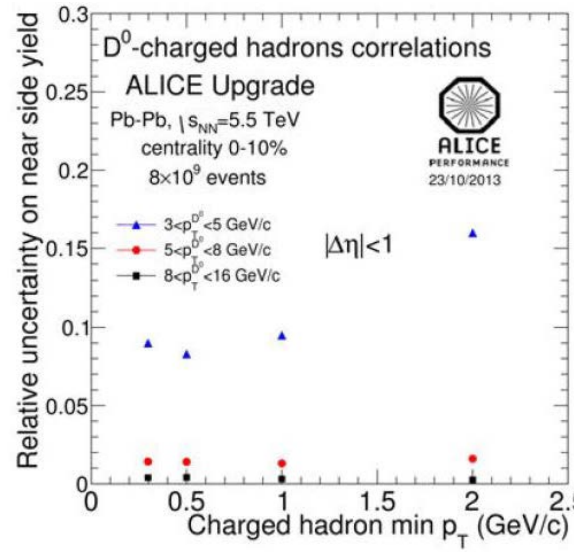
$$\Delta_{recoil} = \frac{1}{N_{trig}^{AA}} \frac{d^2 N_{jet}^{AA}}{dp_{T,jet}^{ch} d\eta_{jet}}\bigg|_{p_{T,trig}\in TT_{Sig}} - c_{Ref} \cdot \frac{1}{N_{trig}^{AA}} \frac{d^2 N_{jet}^{AA}}{dp_{T,jet}^{ch} d\eta_{jet}}\bigg|_{p_{T,trig}\in TT_{Ref}}$$

ALICE, JHEP 09 (2015) 170

FUTURE PERSPECTIVES

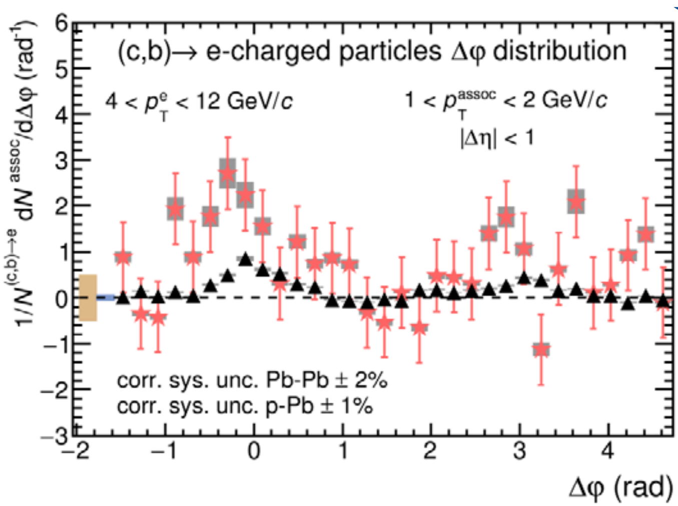
Large benefit from detector upgrades during LHC long shutdown 2 (2019-20)

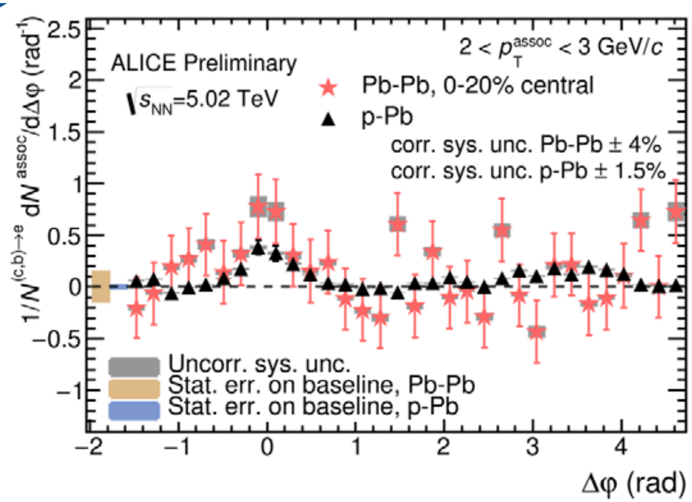
- e.g. ALICE: x100 statistics + improved spatial, d_0 resolutions



Let's focus given on HF Correlations

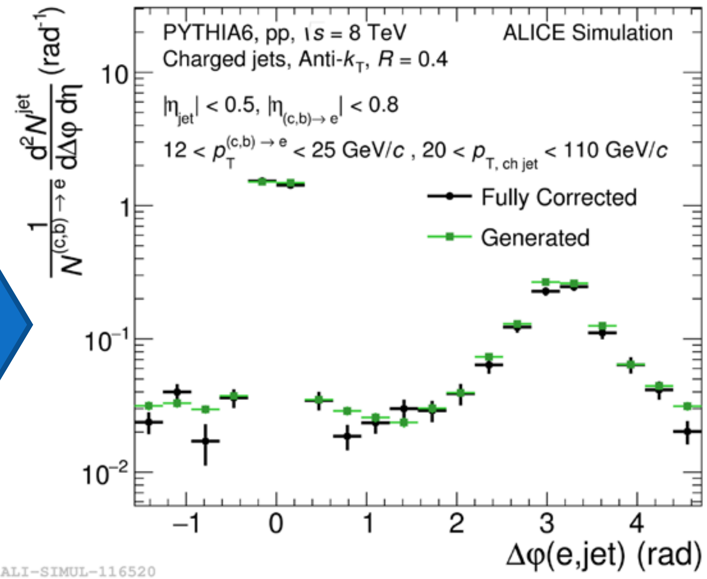
- HF jet tomography and fragmentation studies via «indirect» observables, including intra-jet effects
  - D-track, HFe/HFμ-track, HF jet-track, …
- Increase precision on already measured observables
  - e.g. e-h ALICE → access also to away side! How jet quenching differs from light flavour sector?

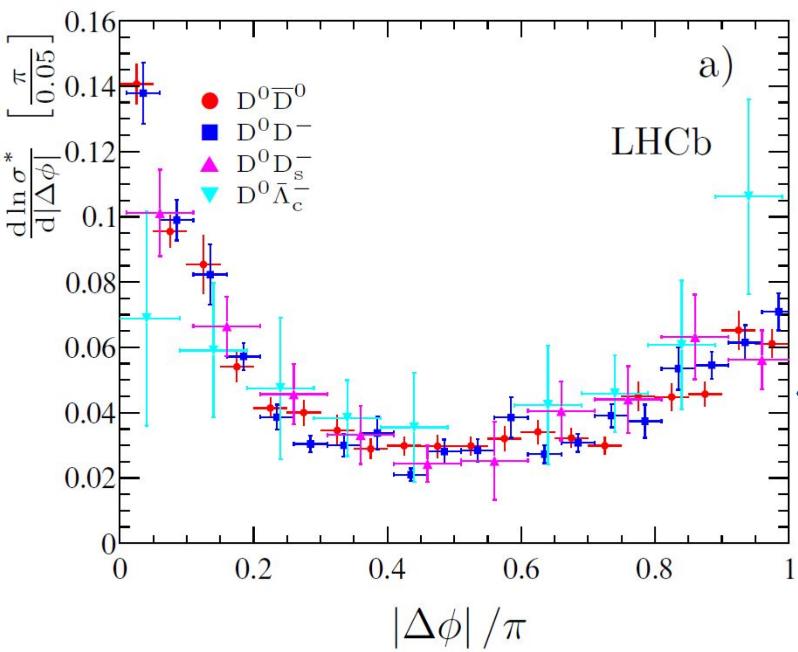




FUTURE PERSPECTIVES

- Gain closer access to hard scattering via more «direct» measurements
  - D-Đ, B-Ƀ, D-HFe/HFμ, HFjet-HFjet, …
- Probing HF recoil jets, possible also in Pb-Pb?
  - Do the same conclusions from hadron-jet correlations hold for HF jets?





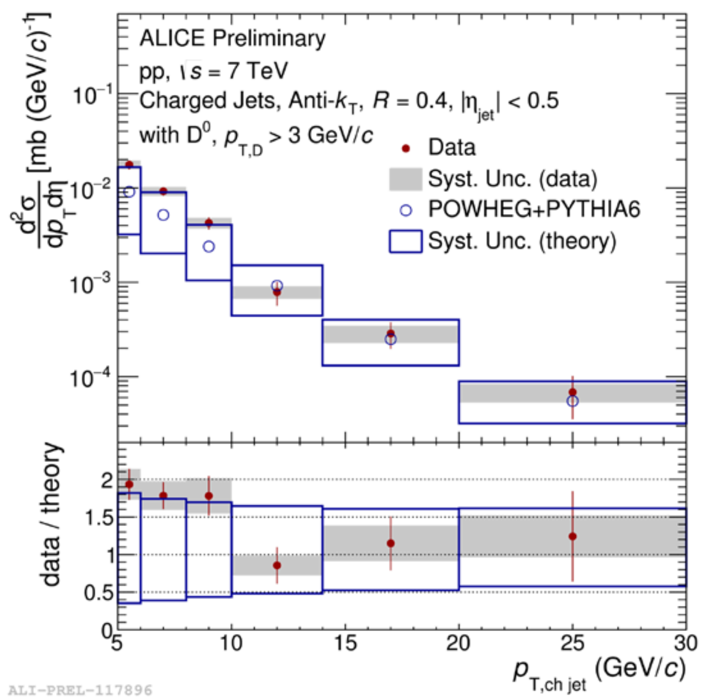
- Possibilty of disentangling production mechanisms
  - Some measurements already available for pp
  - Much more challenging in Pb-Pb (larger underlying event, uncorrelated pairs, …)

Heavy-flavour jets

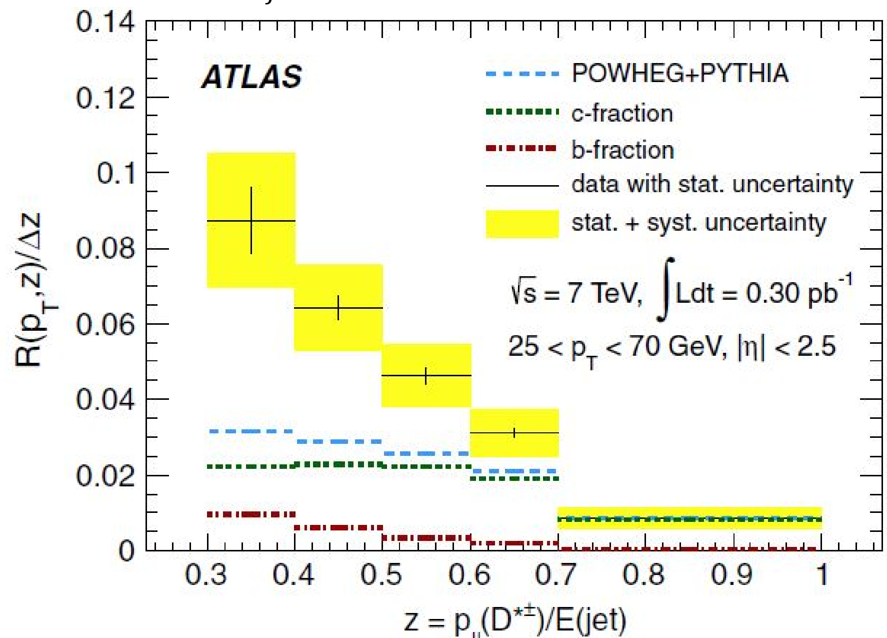
D-TAGGED JETS – pp

First measurements of D-tagged jets production and fragmentation at LHC

- Help to better constrain HF production models introducing fragmentation effects
- D^0-jet production cross section (ALICE) within POWHEG+PYTHIA uncertainty bands
- D^{*+}-jet production vs *z* (ATLAS) **underestimated by models** at low *z*
  - ➢ Larger discrepancy at lower p_T, predicted (p_T,z)-integrated rate lower by a factor 2
- Production of HF jets and/or fragmentation in D-meson to be refined in MC generators?

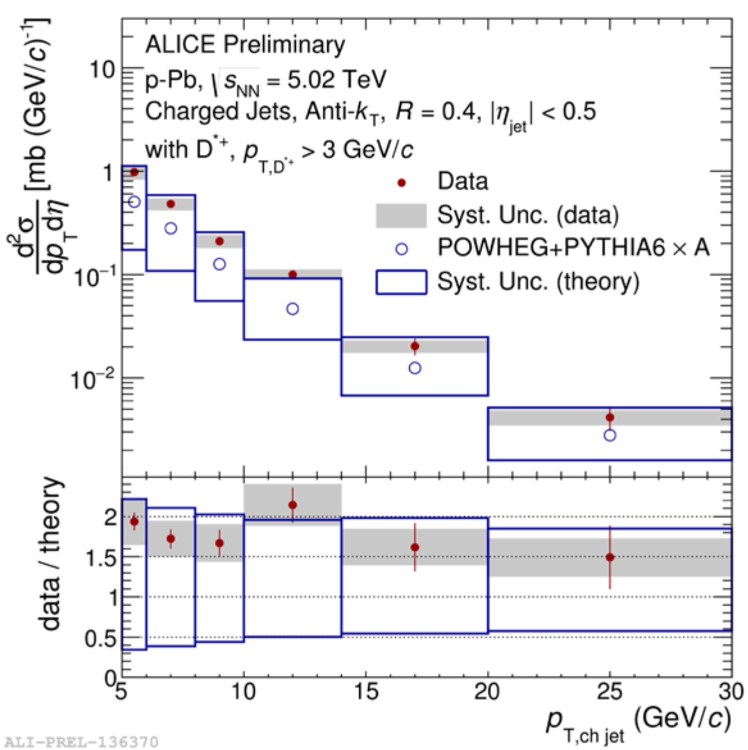


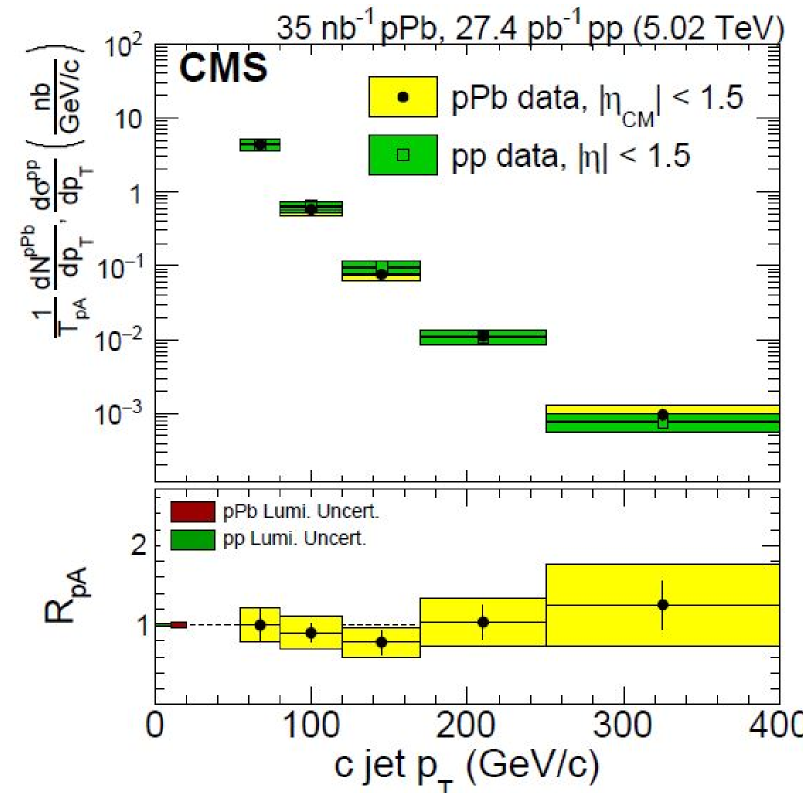
$$R(p_T, z) = \frac{N_{D^{*+}}N(p_T,z)}{N_{jet}(p_T)} = 0.025 \pm 0.001(\text{stat.}) \pm 0.004(\text{syst.})$$



D- AND c-TAGGED JETS – p-Pb

- D^{*+}-jet production cross section (ALICE) on upper band of POWHEG+PYTHIA predictions
- Alternate tagging approach from CMS (via displaced vertices)
  - ➢ c-jet R_{pPb} consistent with unity and flat in p_T, with large uncertainties
- **What about R_{pPb} in the low p_T region**? No available results, but work is ongoing





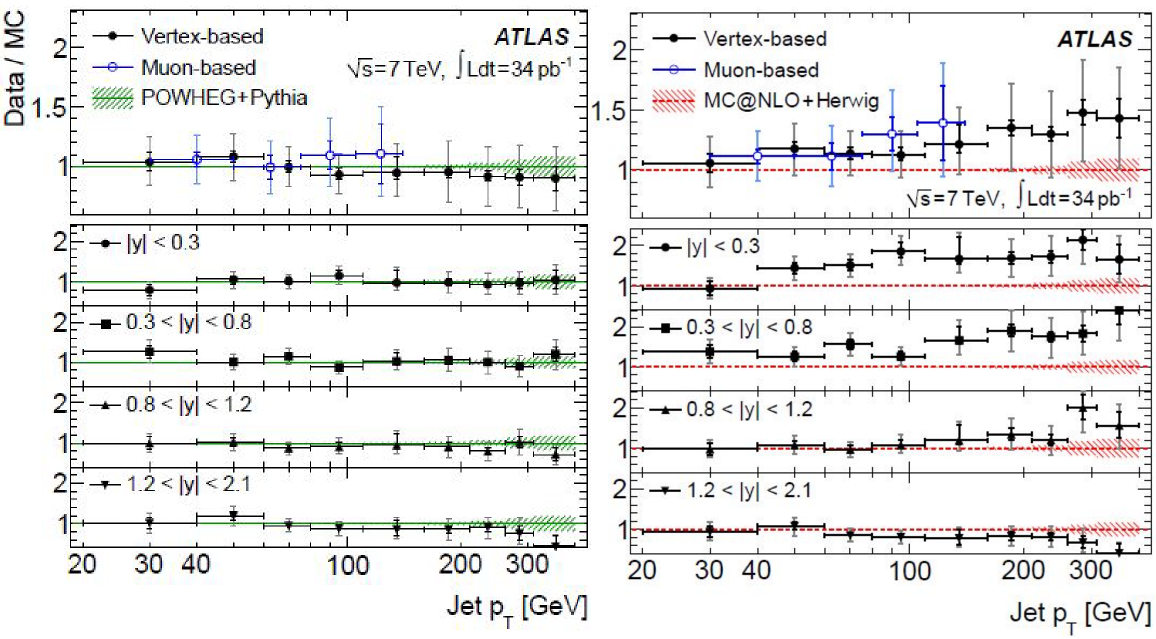
arXiv:1612.08972v1

BEAUTY JETS – pp

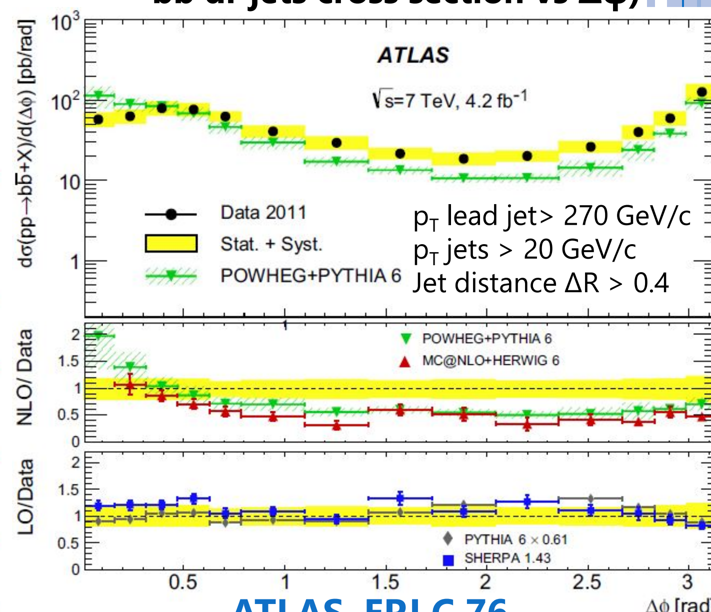
Measurements of b-tagged jet and b-tagged di-jet differential cross sections

- b-jet cross section described by POWHEG+PYTHIA predictions, some tension with MC@NLO
- di-jet production cross section vs azimuthal separation
  - Kinematic selection favours 3 b-jets topologies
  - NLO models overpredict small Δφ contribution, underpredict production for Δφ > 0.5
- Current MC generators struggle in describing regions **not dominated by two hard b-jets**

b-jets cross section vs p_T (ratio data/MC)



bb di-jets cross section vs Δφ)



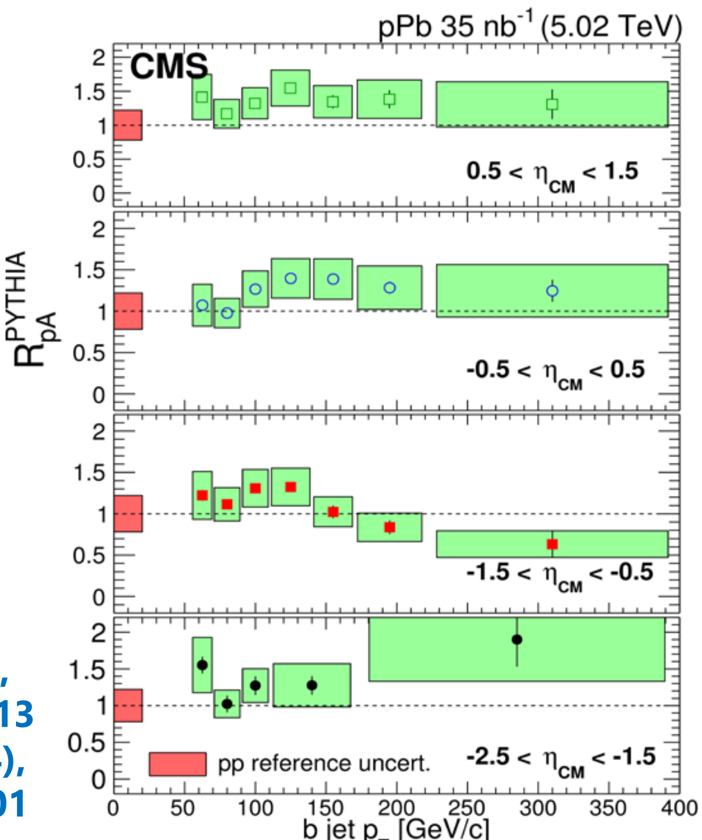
ATLAS, EPJ C 76 (2016) 670

ATLAS, EPJ C 71 (2011) 1846, see also **CMS, JHEP 04 (2012) 084**

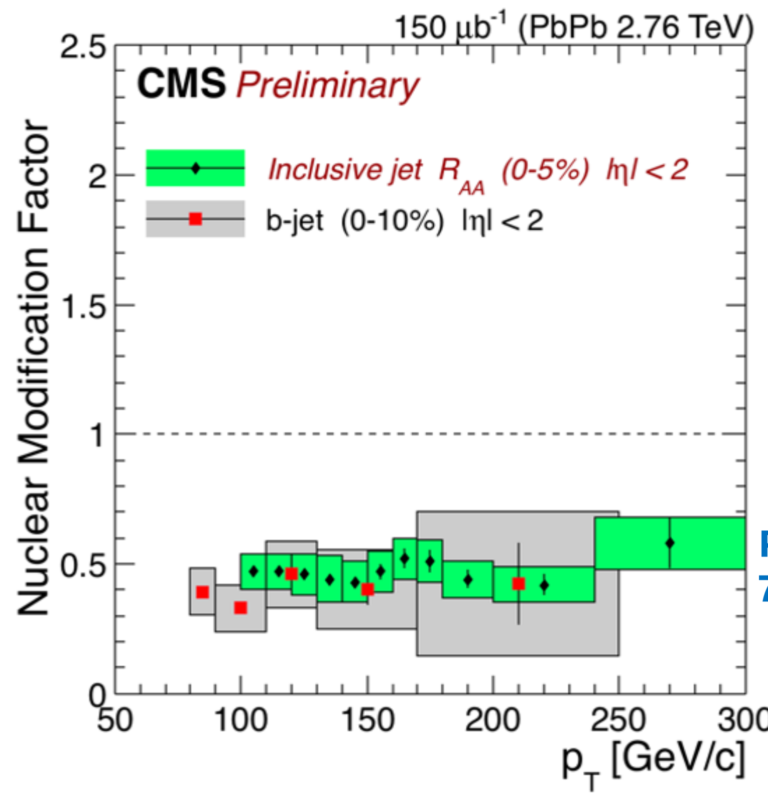
BEAUTY JETS – Pb-Pb (AND p-Pb)

Nuclear modification factor of b-tagged jets in p-Pb and Pb-Pb

- R_{pPb} measurements compatible with absence of cold nuclear matter effects in all η ranges
- **Similar R_{PbPb} for b-jet and inclusive jets**, though with large uncertainties
  - ➢ Region where mass effects could enter in play still not covered by the measurements



CMS, PRL 113 (2014), 132301

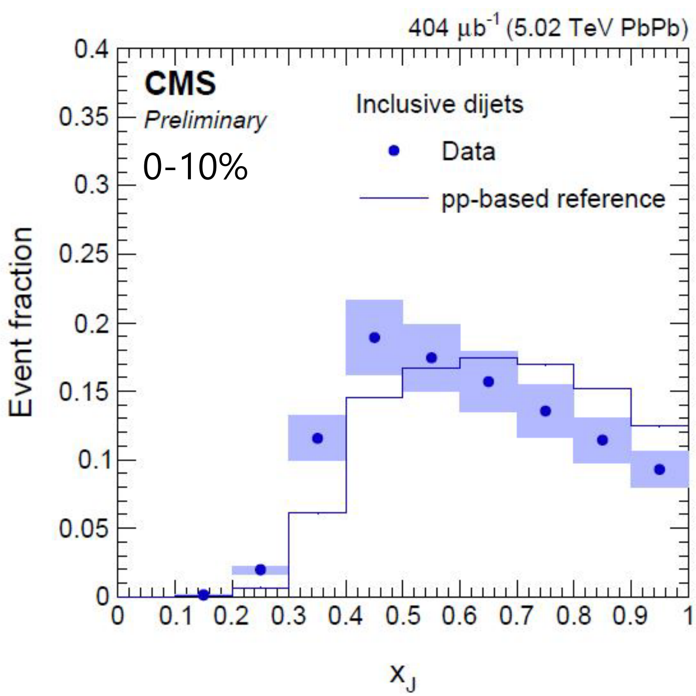


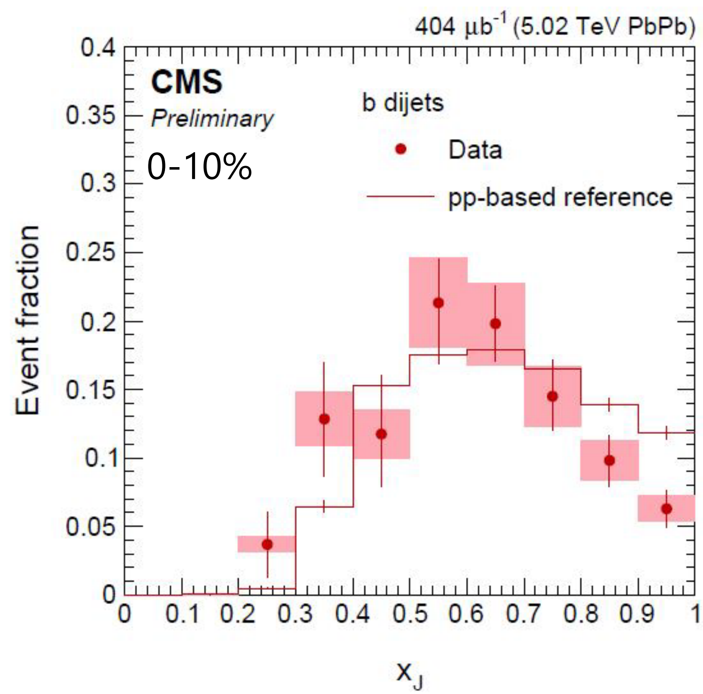
CMS, Phys.Lett.B 754 (2017), 59

BEAUTY DI-JET CORRELATIONS – Pb-Pb

Momentum imbalance of b-tagged jet pairs in Pb-Pb

- First measurement of b-bbar correlations in heavy ions
- Selection of back-to-back pairs tend to favour LO pair-production production process
- As for R_{PbPb}, also **b-jet imbalance looks like inclusive jet** (but min p_T is very high)
  - ➢ pp-based reference predicts much smaller imbalance: effect of **jet quenching**



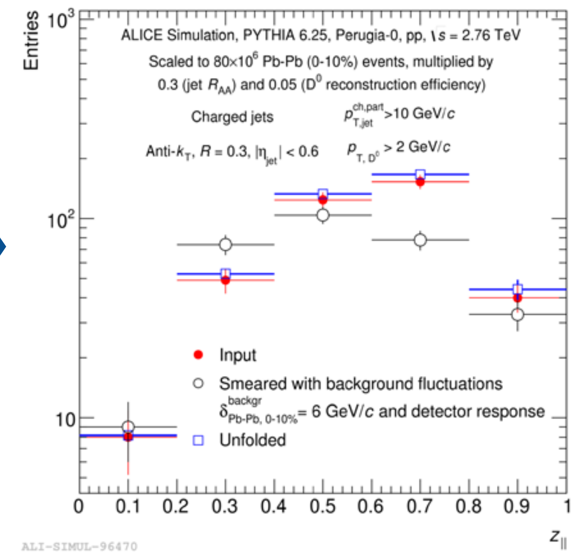


$p_{T,1} > 100$ GeV
$p_{T,2} > 40$ GeV
$\Delta\varphi > 2\pi/3$!
$|\eta| < 1.5$

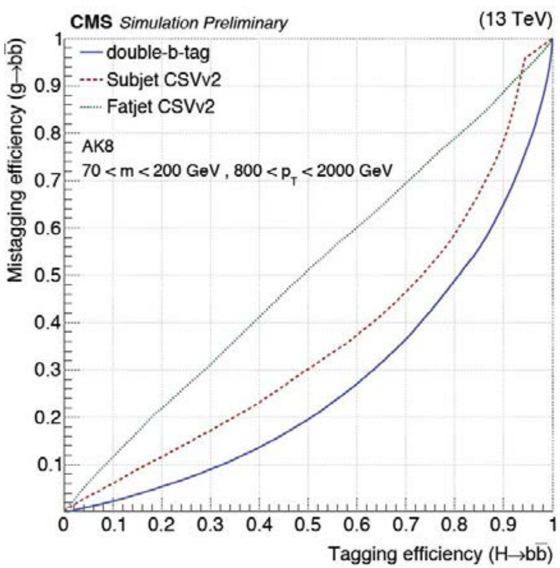
$$x_J = \frac{p_T^{subleading}}{p_T^{leading}}$$

FUTURE PERSPECTIVES

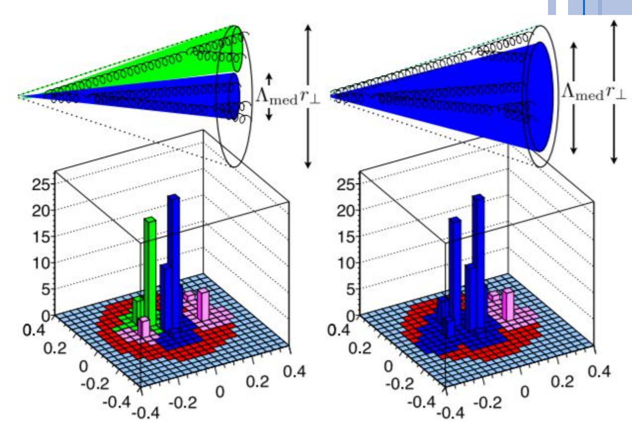
- Extend D-jet measurements to Pb-Pb systems
  - Compare fragmentation function with pp
  - Study charm jet-shape modifications
  - Study cross-section ratio for different *R*
- Access to low p_T region for b-tagged jets
  - Probe energy loss mass dependence,
- Study color coherence for beauty quarks



CMS-PAS-BTV-15-002



- Studies for double b-jet tagging algorithms
  - Can we identify b-jets from gluon splitting and study their features?
  - How HQ pair and single HQ energy losses differ in presence of color coherence effects?



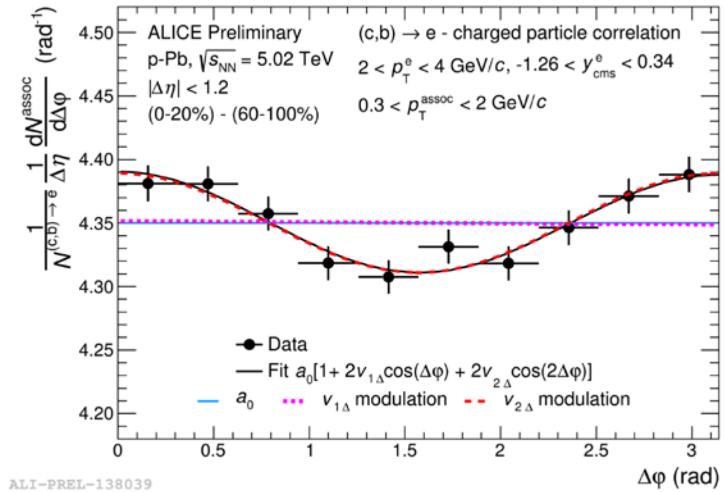
CONCLUSIONS

- Lots of measurements already available for hard probes and heavy flavour correlations and jets from the LHC (this was only a selection!)
- Shed light of some fundamental question about the hard-parton – medium interaction, like:
  - How does lost energy redistribute in the event?
  - How is jet structure modified?
  - How mass effects influence parton energy loss?
  - Color coherence: how does the medium sees two collinear partons?
- …but lots of open points remain!
- More precise and more differential measurements expected already from Run2, but especially in Run 3 after the upgrades
- Constant interaction with theorists is crucial!
  - New models and predictions for available/ongoing measurements
  - Which furhter observables to explore?

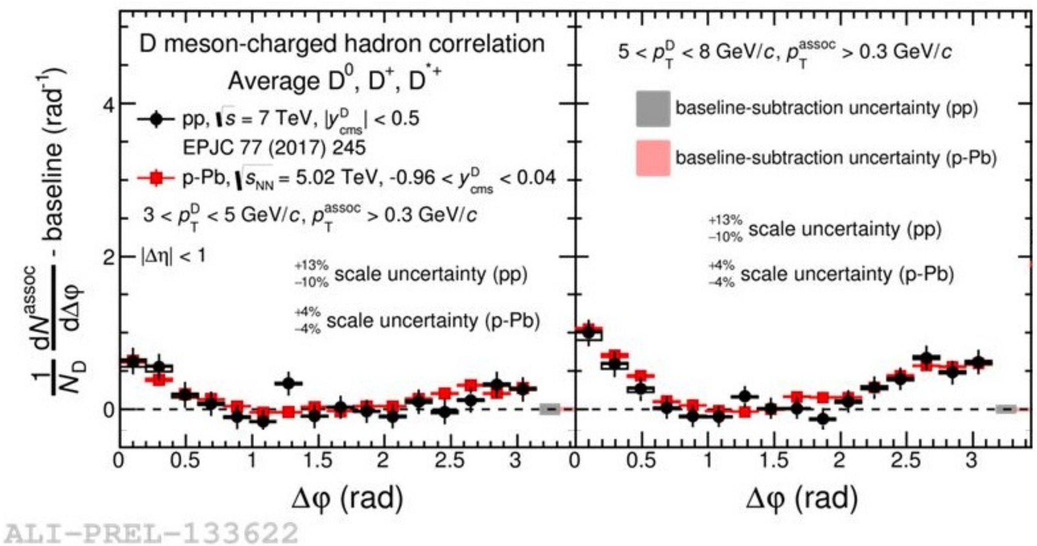
Backup Slides

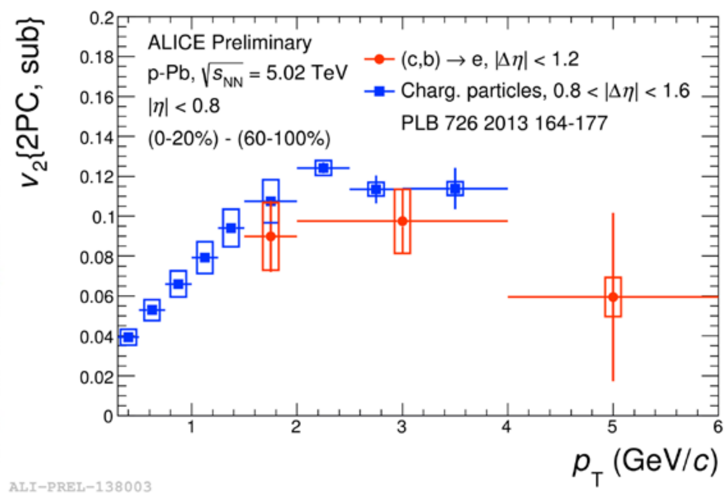
HF CORRELATIONS – SMALL SYSTEMS

- D-h azimuthal correlations: compatible correlation pattern (after baseline subtraction) in pp and p-Pb collisions in all kinematic ranges
  - ➢ No CNM effects can be claimed, with this uncertainties level
  - ➢ Similar yield and width of near-side associated peak



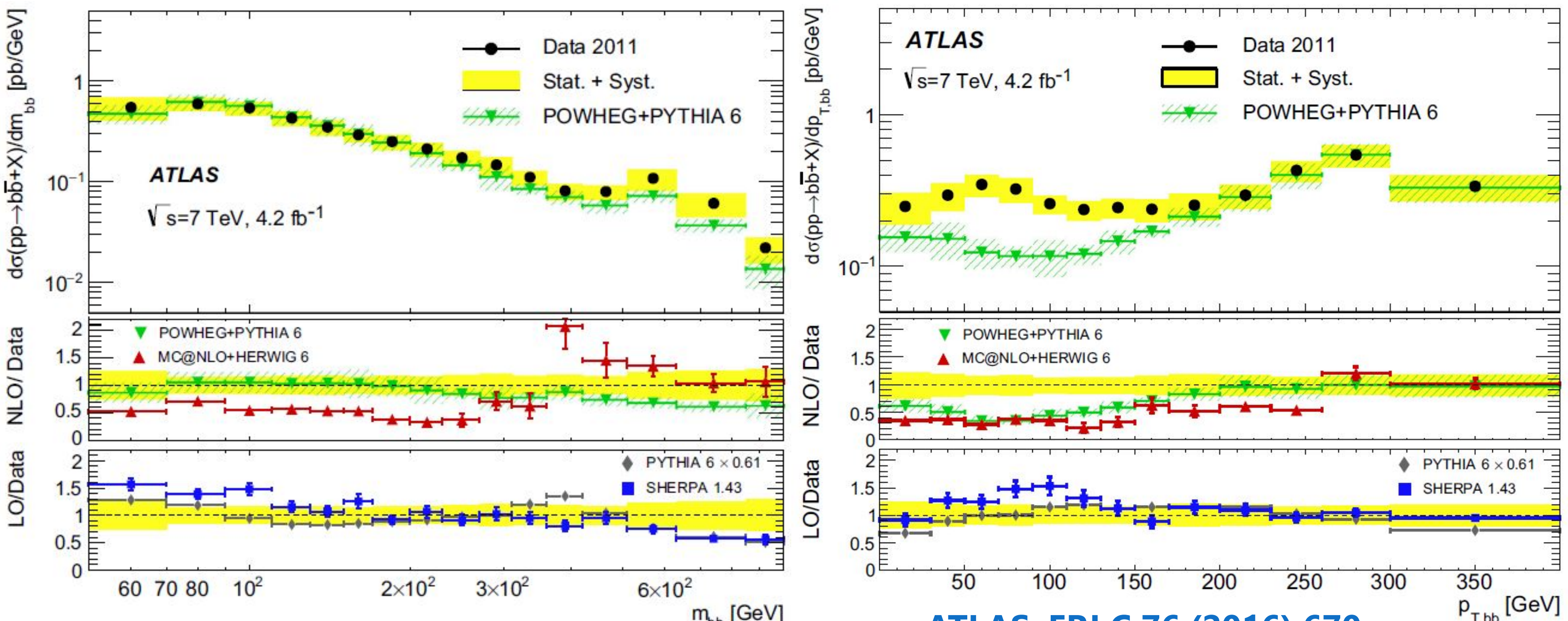
- HFe-h correlations in p-Pb: evidence for a non-zero v_2 of heavy-flavour decay electrons





BEAUTY DI-JET CORRELATIONS – pp

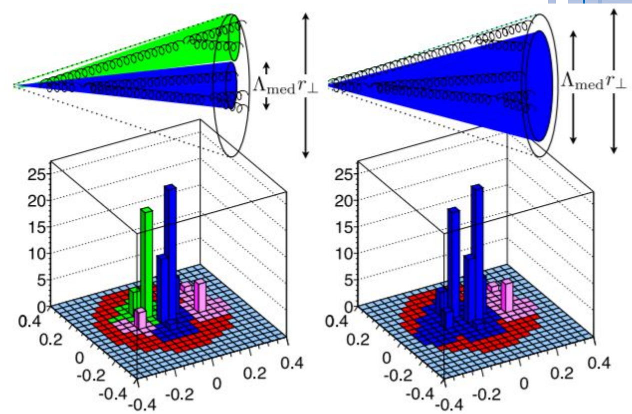
- di-jet production cross section, additional dependencies
  - Mass of di-jet system very good described by PYTHIA, with the exception of the
  - MC@NLO is consistently below data up to m_{bb} < 350 GeV, then becomes higher (the point where flavour-creation process begins to contribute).
  - NLO models give bad description of lower p_T region of di-jet system
- Current MC generators struggle in describing regions **not dominated by two hard b-jets**

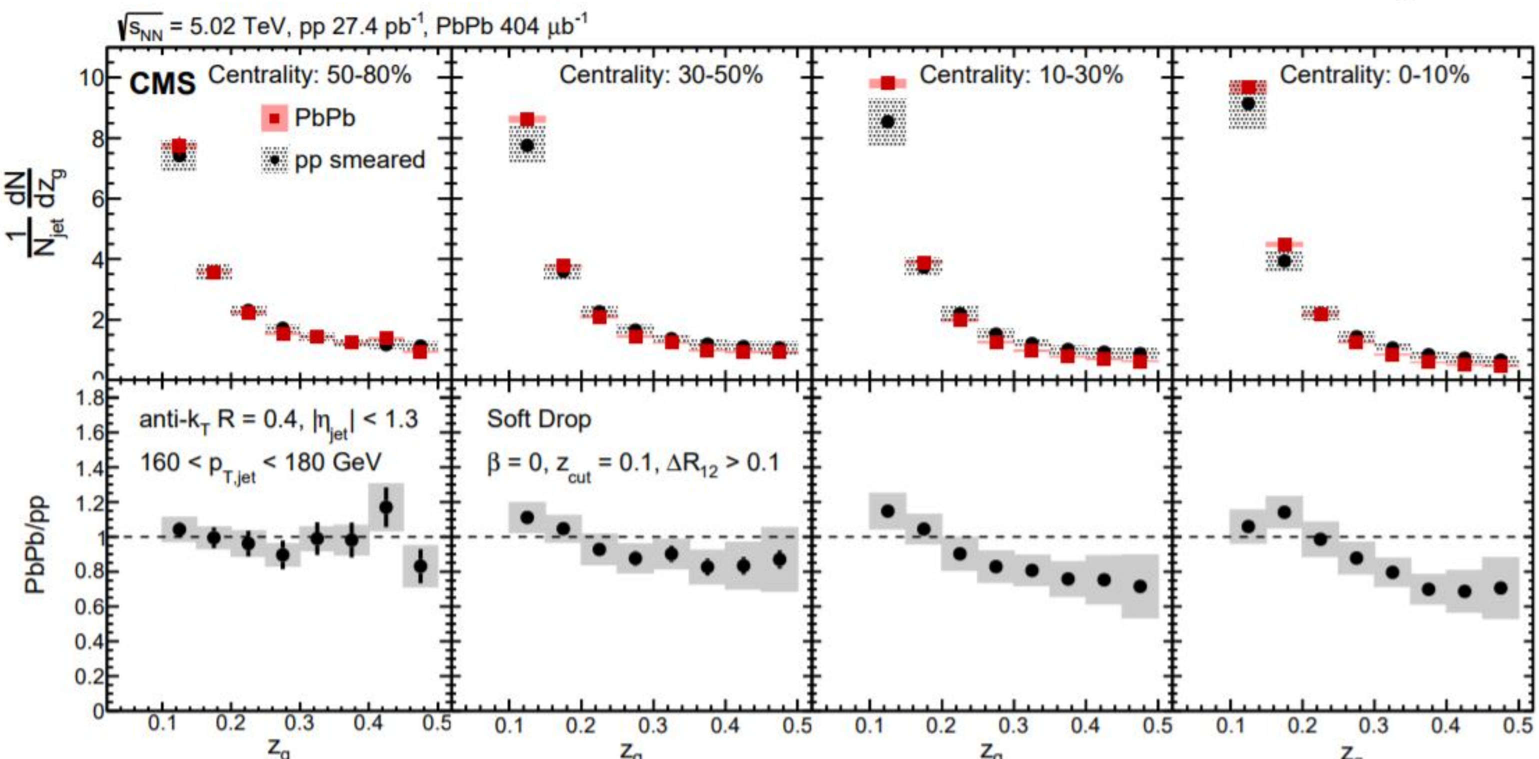


ATLAS, EPJ C 76 (2016) 670

FUTURE PERSPECTIVES

- How well can medium can resolve nearby partons? Studies ongoing with inclusive jets, what about HF?
  - $g \rightarrow b\bar{b}/c\bar{c}$ is the dominant process at large jet p_T
  - How energy loss from a HQ pair and of single HQ differ in presence of color coherence effects?



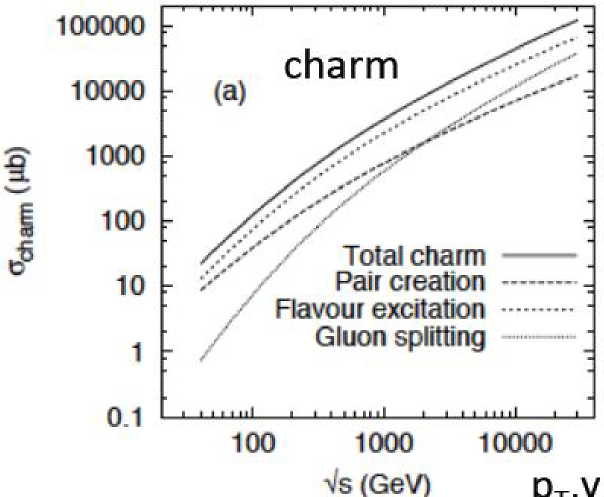


$$z_g = \frac{p_{T,2}}{p_{T,1} + p_{T,2}}$$

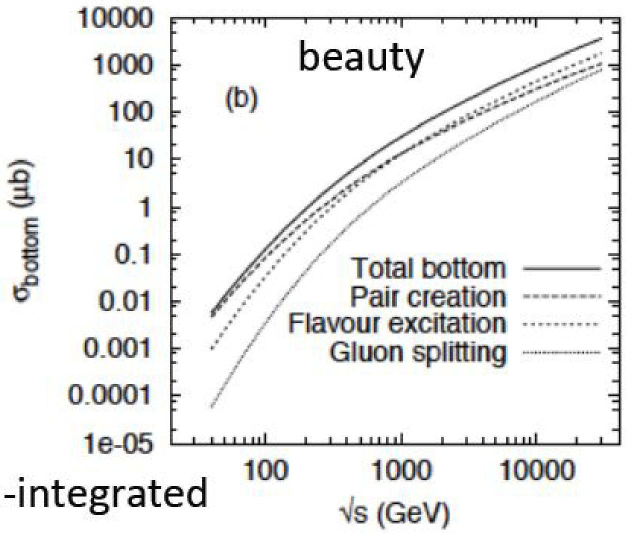
CMS, PLB 725 (2013) 357

HEAVY QUARK PRODUCTION

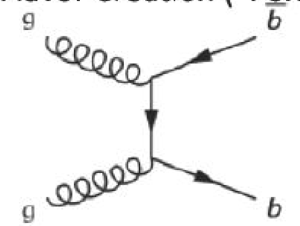
PYTHIA (E. Norrbin, T. Sjostrand, Eur.Phys.J.C17:137-161,2000)



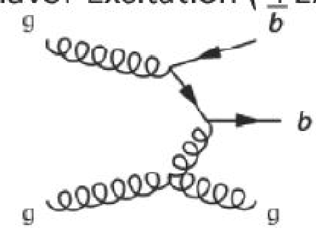
p_T,y -integrated



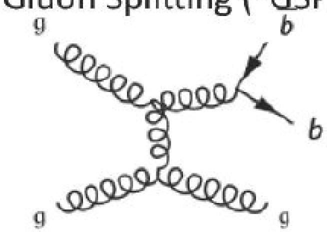
Flavor Creation (“FCR”)



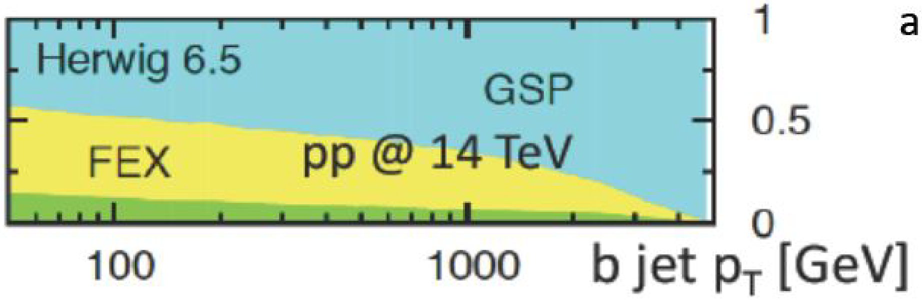
Flavor Excitation (“FEX”)



Gluon Splitting (“GSP”)

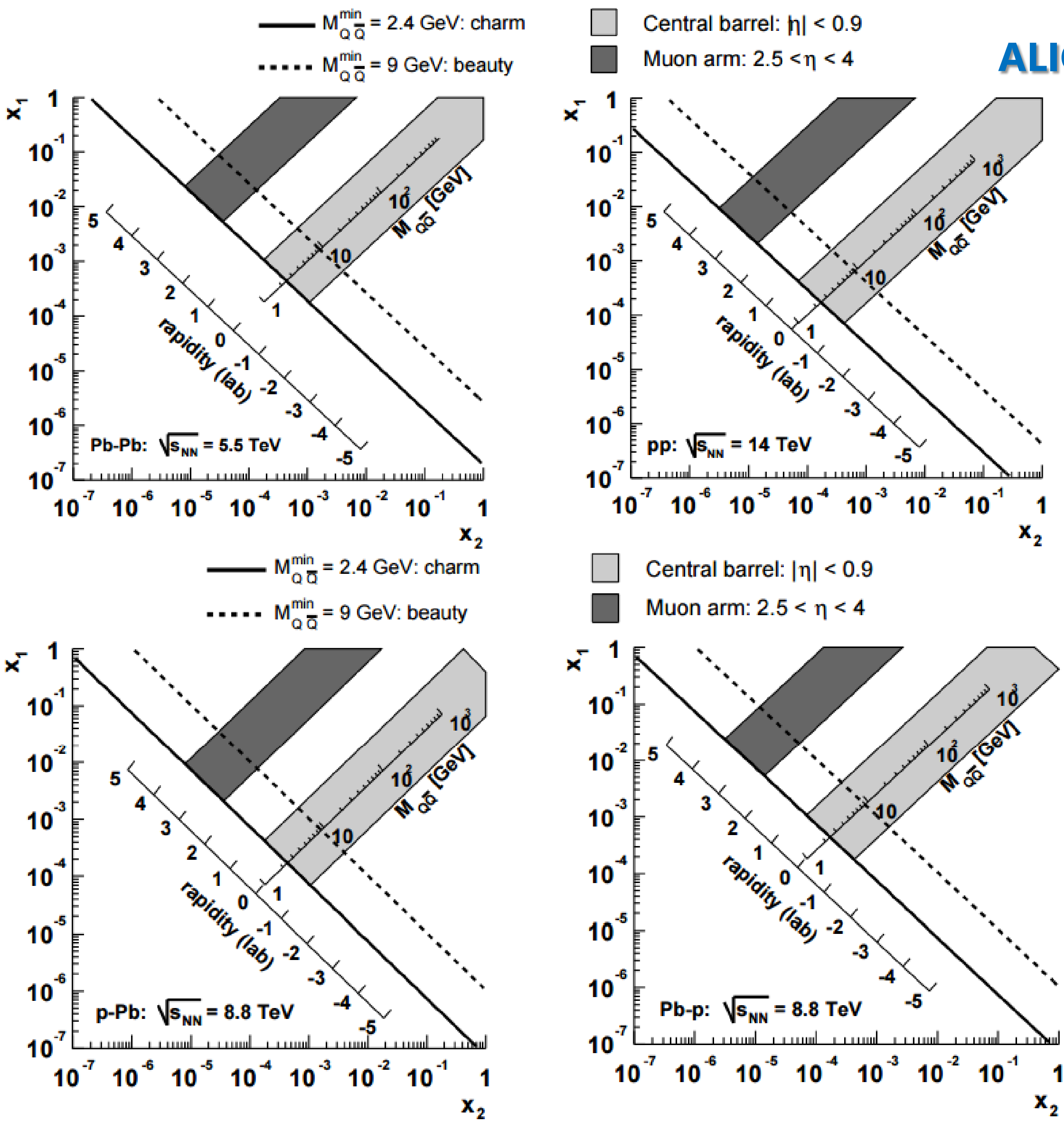


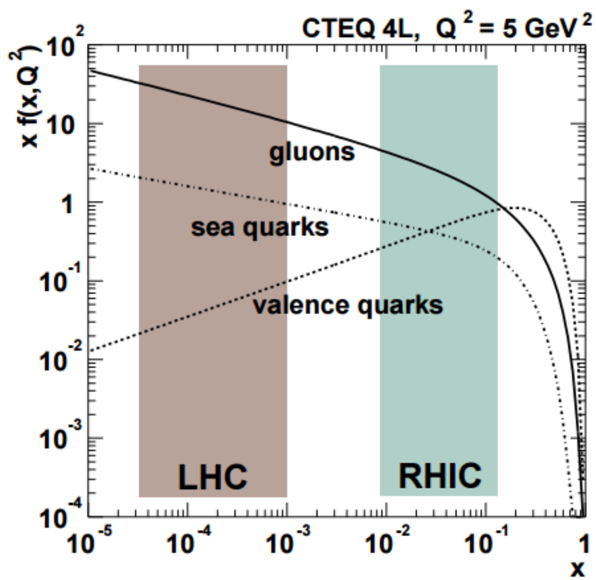
HERWIG 6.5 (A. Banfi, G. Salam, G. Zanderighi, JHEP 0707:026,2007, arXiv:0704.2999)



Bjorken x regions at the LHC and PDF

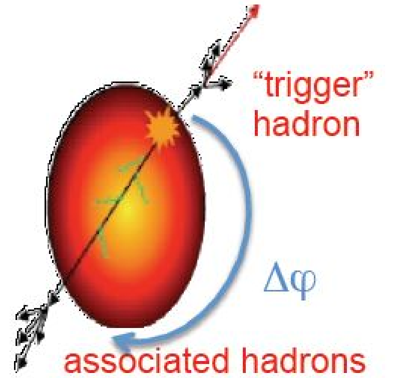
ALICE, J. Phys. G, 32 (2010) 1295





Parton Distribution Functions in CTEQ 4L parametrization, for Q^2 = 5 GeV^2

Angular correlations with heavy-flavour signals



I_{AA}= ratio of associated yield (Au-Au)/pp

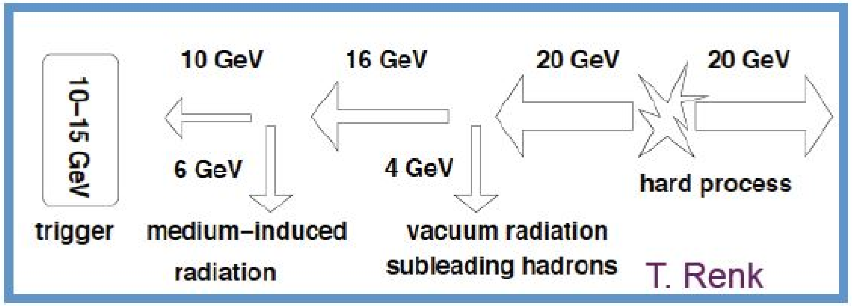
Correlations of heavy-flavour signals vs. light particles

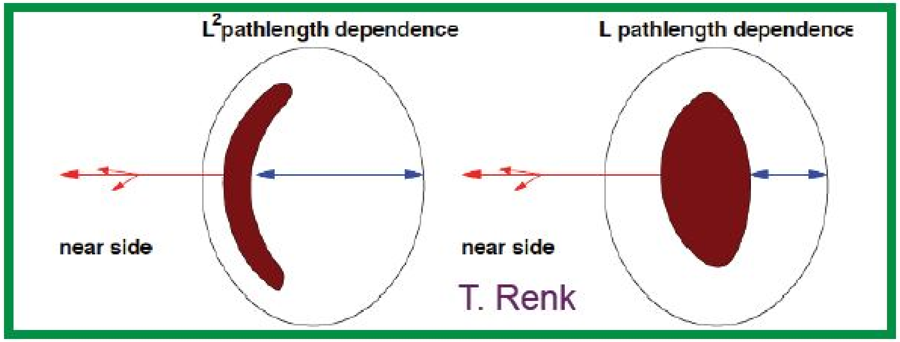
- Trigger particle defined by identity, not by momentum range as in e.g. hadron-hadron correlations → **(heavy)quark tagging**
- **Different fragmentation** than light quarks and gluons
- **Different energy loss** for heavy quarks than light quarks and gluon
  - C_R , "dead-cone" effect
  - Possible different contributions of radiative and collisional energy loss, which have a different **path length dependence**

→ Different "kinematic bias", different "geometrical bias"

→ Different biases might translate into different I_{AA} for light and heavy quarks.

→ Complementary information than v_2 and R_{AA} → further constrain energy loss models



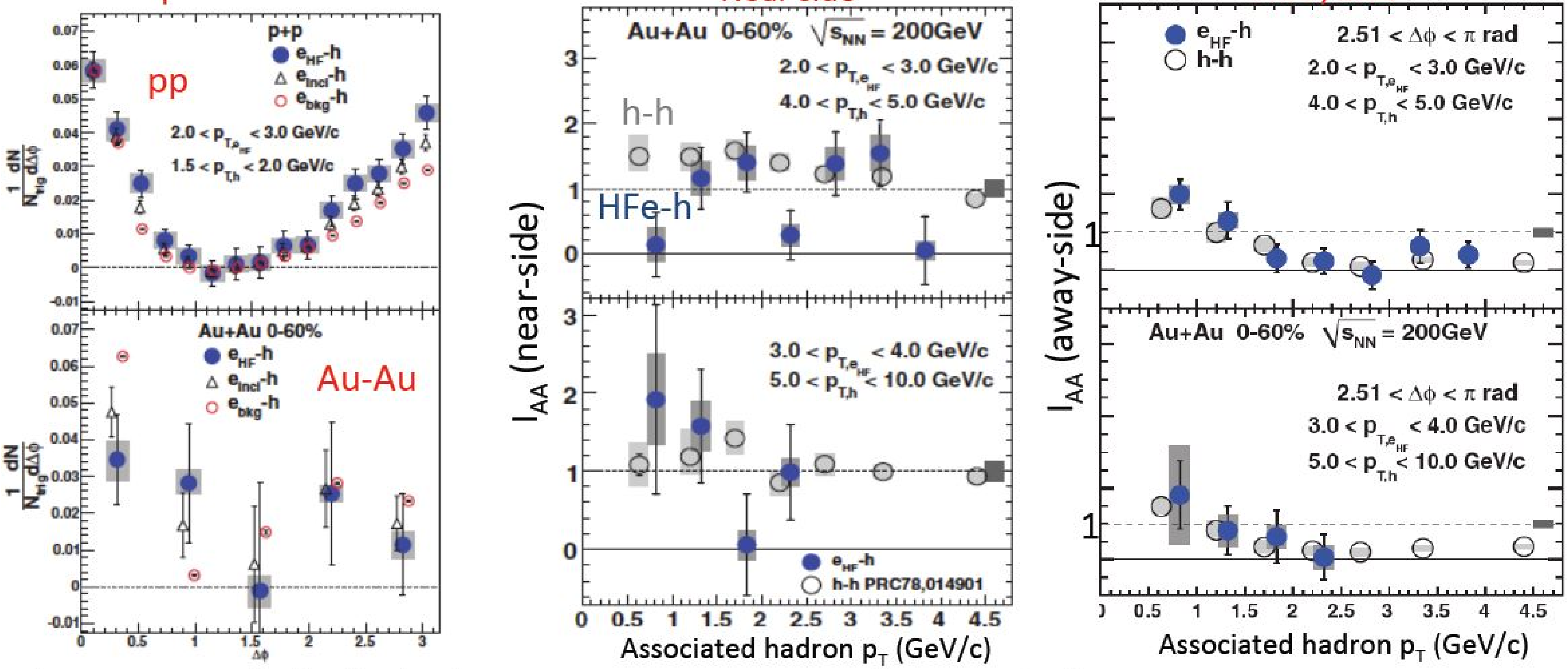


A. Rossi

Heavy-flavour electron – charged particle correlations at RHIC, PHENIX

PHENIX Coll.: PRC 83, 044912 (2011)

I_{AA}= ratio of associated yield (Au-Au)/pp

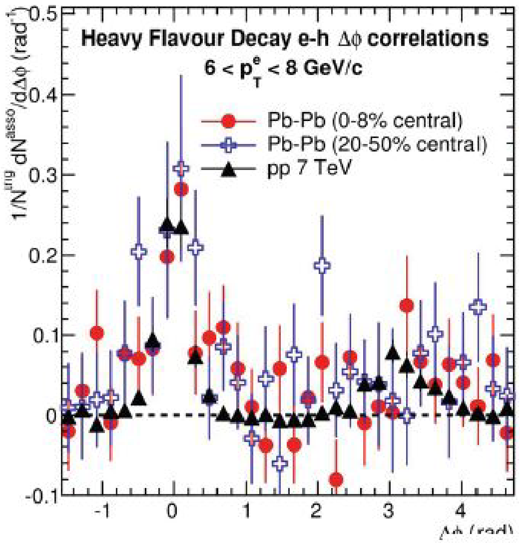


- Large uncertainties in Au-Au measurement prevent firm conclusions
- Suggest a decreasing I_{AA} trend with hadron p_T in the away side
- Similar results than hadron-hadron correlations (a coincidence?)

→ **Higher precision with new data**

A. Rossi

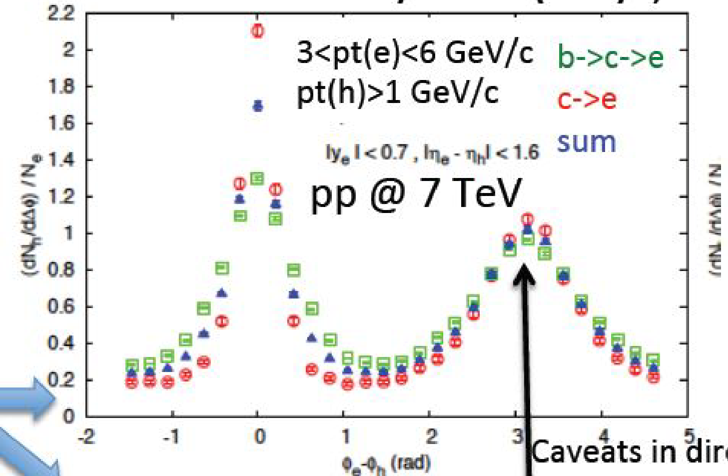
HF electron- hadron correlations



ALICE measurements in pp and Pb-Pb

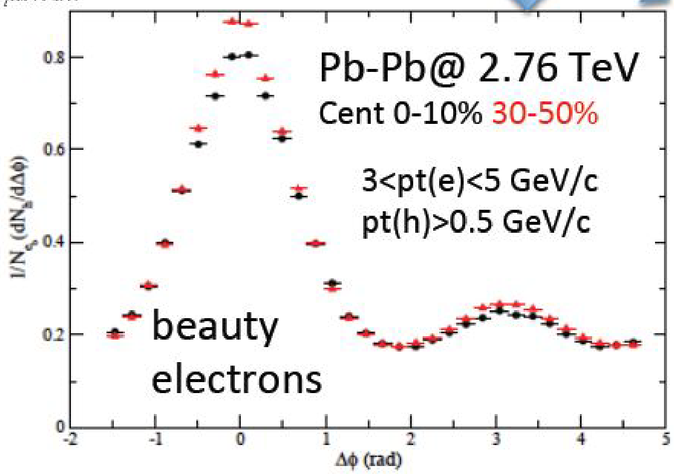
6<pt(e)<8 GeV/c
4<pt(h)<6 GeV/c

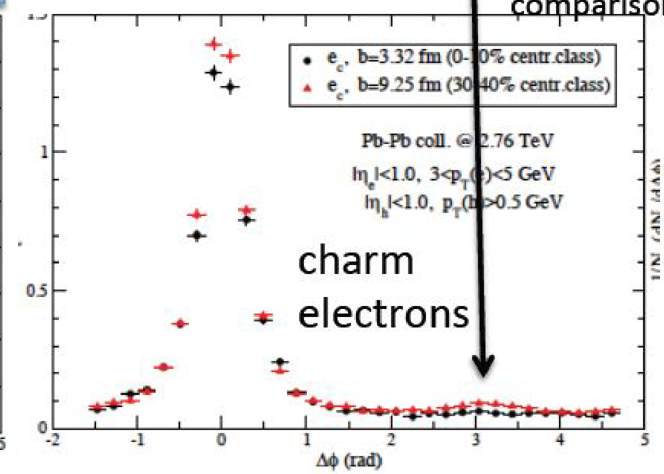
A. Beraudo et al. Eur. Phys. J. C75 (2015) 3, 121



Predictions (POWLANG)
Strong away side suppression

Caveats in direct comparison



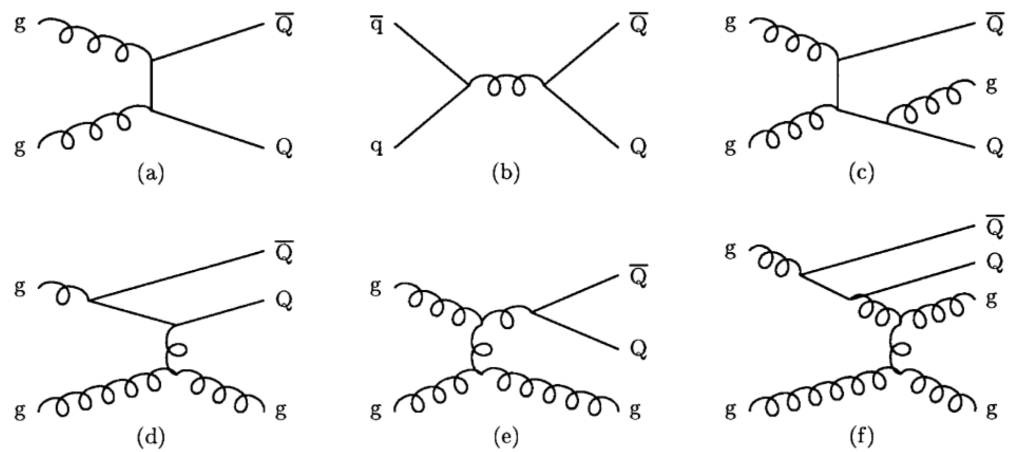


POWLANG (transport model, Langevin in a 2+1 hydro medium; hadronization from Q - medium q string decay)

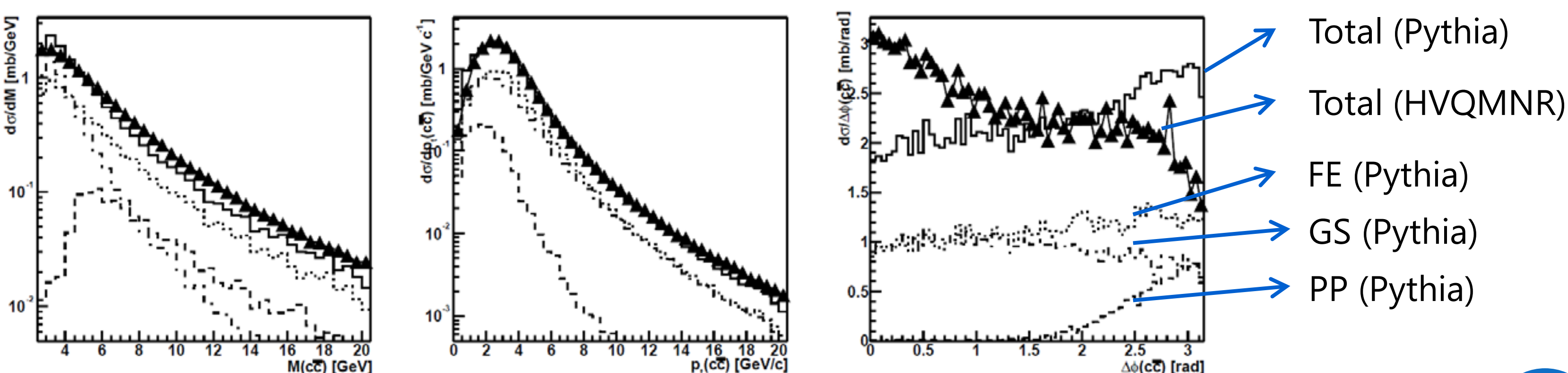
A. Rossi

CHARM AZIMUTHAL CORRELATIONS

- Can we disentangle the charm production mechanisms?
  - ➢ Pair production (a, b)
  - ➢ Flavour excitation (d)
  - ➢ Gluon splitting (e)

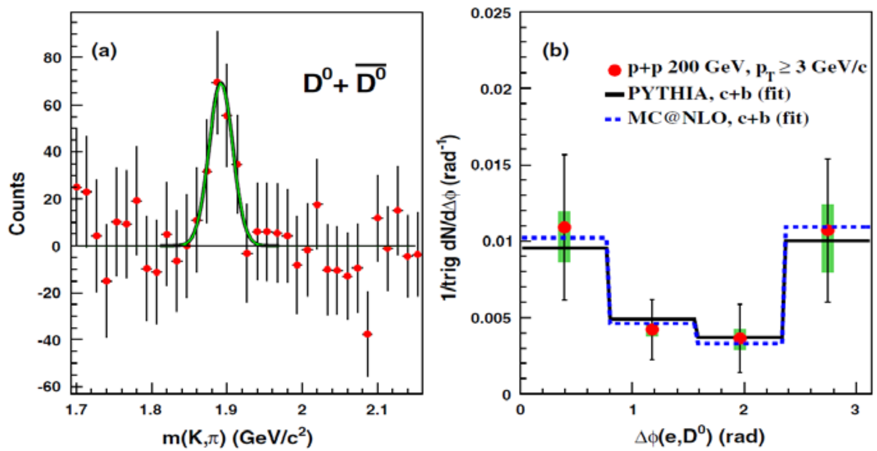


Sjostrand et al., Comput.Phys.Commun. 135 (2001) 238



PREVIOUS RESULTS ON HF CORRELATIONS

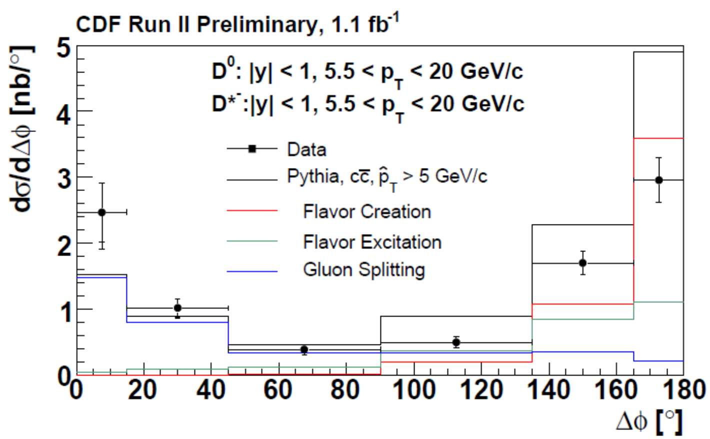
- STAR measurements for D^0-HFe correlations in pp collisions at 200 GeV, compared with PYTHIA simulation and MC@NLO theoretical predictions

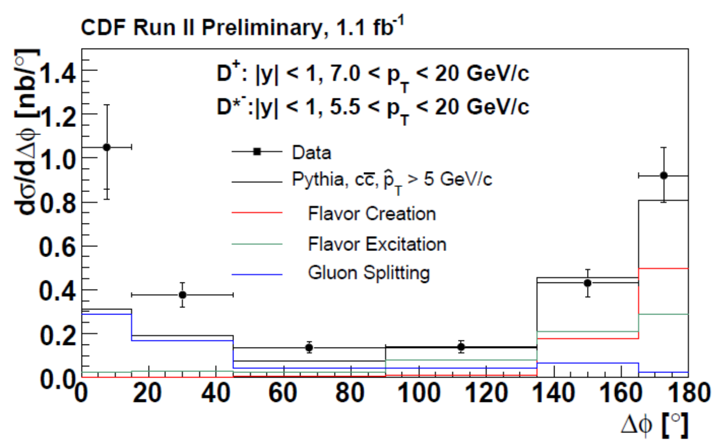


STAR, PRL 105 (2010) 202301

- CDF measurements for D^0-D^{*+} and D^+-D^{*+} correlations
  - Comparison to PYTHIA, with different production mechanism breakdown
  - PYTHIA overestimates LO (b2b) and underestimates NLO contribution (collinear production)

CDF, Nucl.Phys.Proc.Suppl. 170 (2007) 243–247

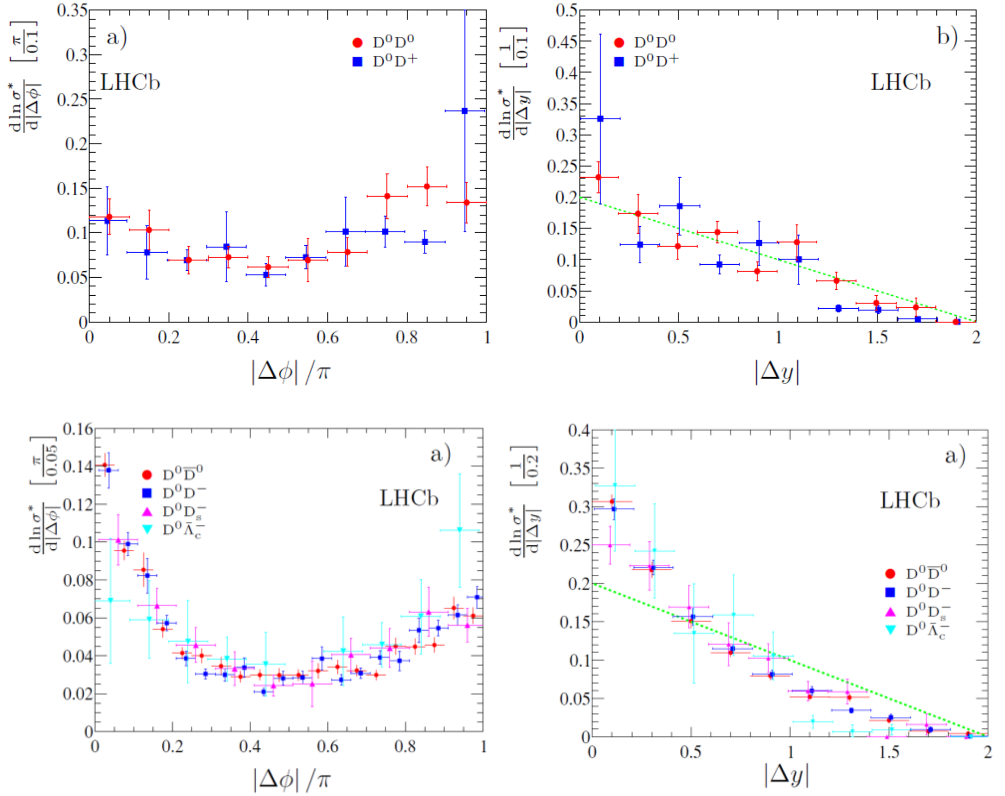




PREVIOUS RESULTS ON HF CORRELATIONS

Selection of LHCb measurements for DD (top row) and DDbar (bottom row) angular correlations in pp collisions at 7 TeV:

- DD are uncorrelated (independently produced)
- DDbar are mostly produced in the same hard scattering
  - ✓ NS and AS peaks are clearly visible

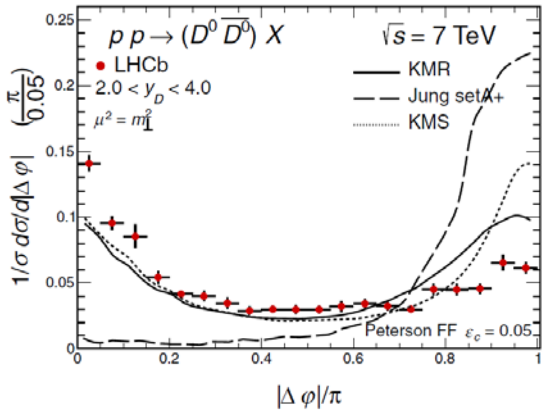


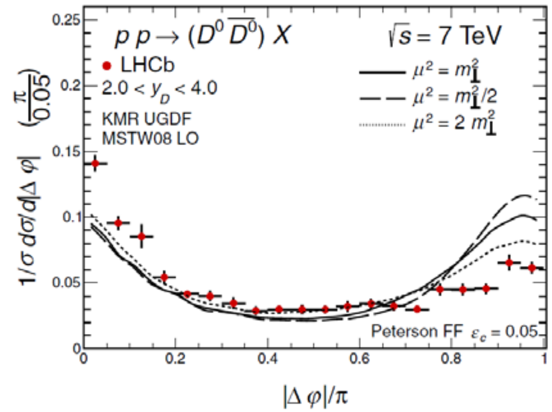
LHCb, JHEP 06 (2012) 141

PREVIOUS RESULTS ON HF CORRELATIONS

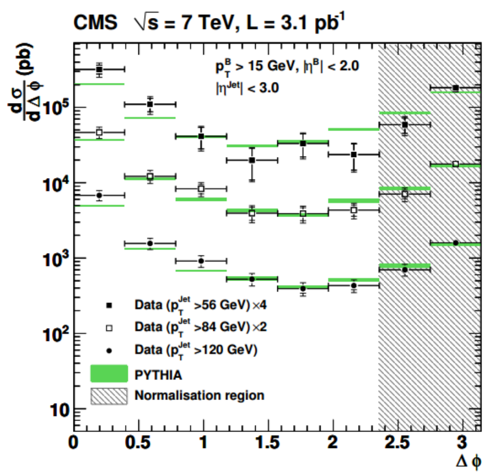
- LHCb measurements for D^0-D^0bar correlations compared with calculations from k_T-factorization approach, in pp collisions at 7 TeV

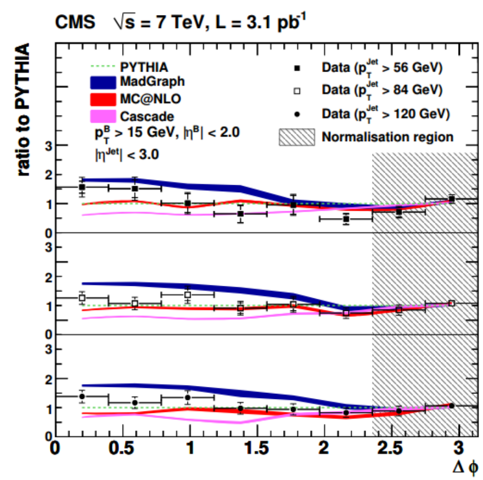
LHCb, JHEP 06 (2012) 141





- CMS measurements for B-Bbar production cross section as a function of $\Delta\varphi$, compared with predictions, in pp collisions at 7 TeV





CMS, JHEP 136 (2011) 1103

PREVIOUS RESULTS ON HF CORRELATIONS

Observables directly tracking QQbar azimuthal correlations:

D-D, B-B (or proxy)

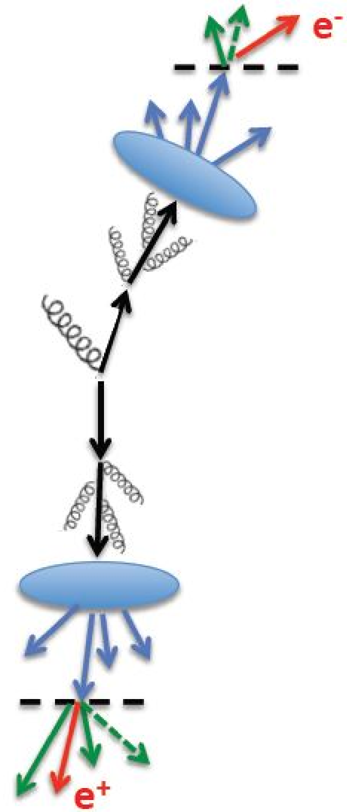
b jet – b jet

B or D - HF (e/μ)

HF (e/μ) – jets

HF (e/μ) – HF (e/μ)

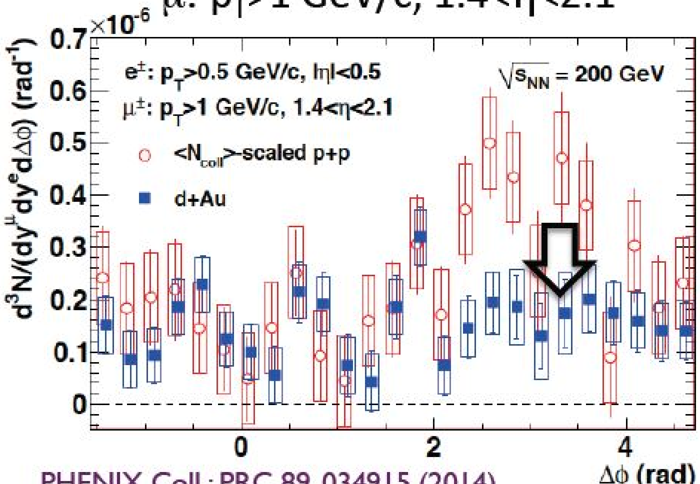
↓ Reduced angular and kinematic correlation w.r.t. parent quarks



PHENIX: $e^{\pm}$ - $\mu^{\mp}$ correlations in pp and d-Au

e: p_T>0.5 GeV/c, $|\eta|$<0.5

μ: p_T>1 GeV/c, 1.4<η<2.1



PHENIX Coll.: PRC 89, 034915 (2014)

pp

d-Au

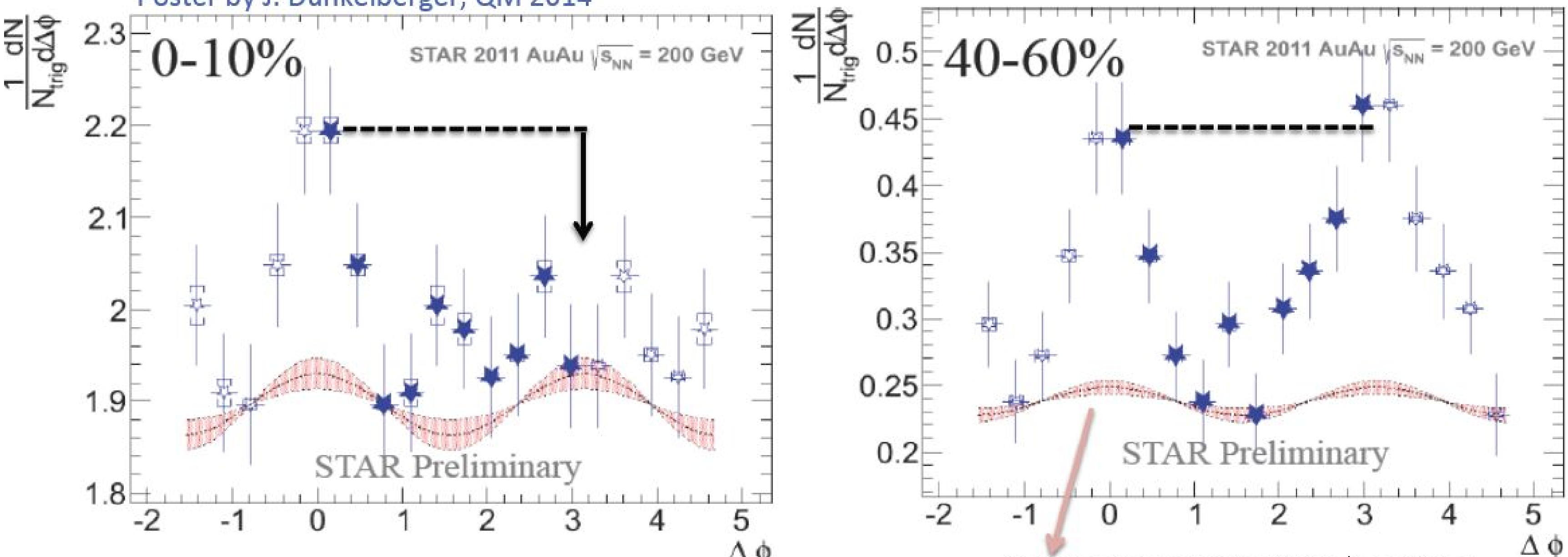
Hint of away-side peak suppression

Initial (e.g. CGC) or final state effect?

A. Rossi

PREVIOUS RESULTS ON HF CORRELATIONS

Poster by J. Dunkelberger, QM 2014



$3<p_T^e<6$ GeV/c
$p_T^h>2$ GeV/c

flow background: $1+2v_2^e v_2^h \cos(2\Delta\varphi)$
$0.05<v_2^e<0.15$

Maybe a too rigorous usage of the ZeroYieldAtMinimum prescription for estimating the baseline

Hint of away side peak suppression in central collisions

A. Rossi

PYTHIA 6/8 - DETAILS

- Large set of hard parton processes, including heavy quark generation
- Hard scattering only at leading order (2→2 processes)
  - Next-to-leading order processes mimicked in the parton shower
- p_T ordering for initial-state and final-state radiation
  - Change from virtuality ordering in previous versions
- Lung string model for hadronization
- Includes multi-parton-interactions (MPI)

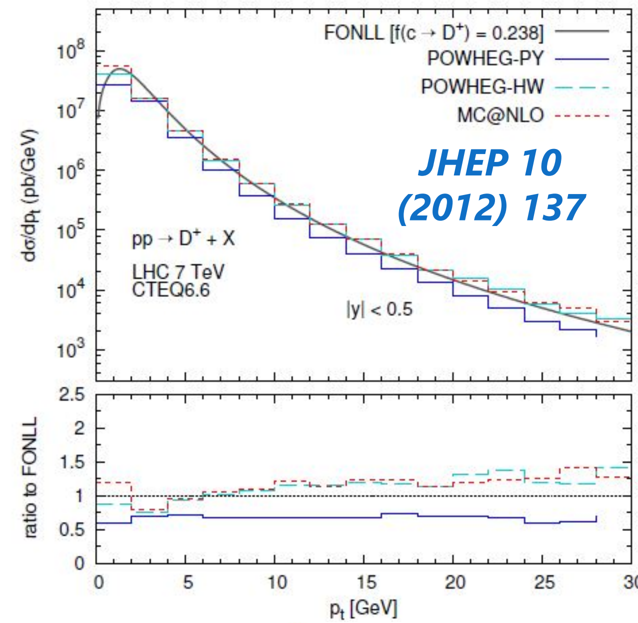
- **PYTHIA 6** Perugia tunes: differ from the previous ("S0") for improved initial- and final-state radiation models, underying event, color reconnection. CTEQ5L PDF set is used.
  - **Perugia 0**: first of the series
  - **Perugia 2010**: different amount of final-state radiation, modification of z fragmentation (hardening of spectra)
  - **Perugia 2011**: first tune to use LHC data

- **PYTHIA 8**: better treatment of MPI and color reconnection w.r.t. PYTHIA 6

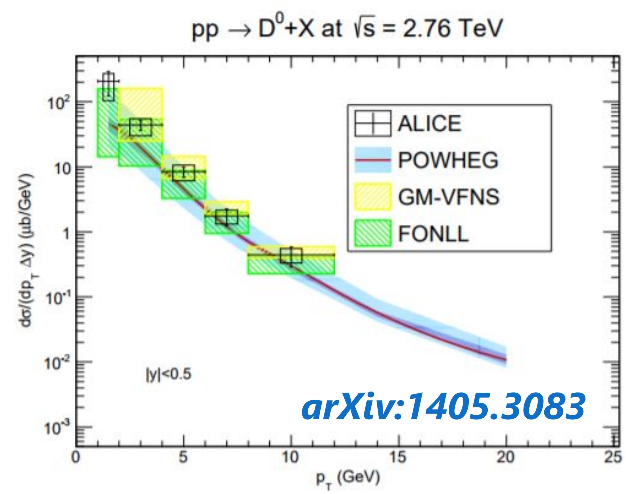
- Reference manuals: ***arXiv:hep-ph/0603175*** (v6.4), ***arXiv:1410.3012 [hep-ph]*** (v8.2)

POWHEG - DETAILS

- Hard processes provided at NLO level
- Replaces the harder part of parton shower (up to a certain Q^2 threshold) with its own, with NLO accuracy
- Softer part of the parton shower dealt by a subsequent shower Monte Carlo (i.e. PYTHIA or HERWIG)
  - ➢ Feeding done via Les Houches interface
  - ➢ Easy matching in case of pT-ordered parton showers (like PYTHIA), more tricky for angular-ordered ones (like HERWIG) – "double" showering must be avoided



- For open heavy flavour production, comparison with FONLL and GM-VFNS gives agreement within models uncertainties
- Non negligible dependence on the shower Monte Carlo (and even on its tune) is observed



arXiv:hep-ph/0709.2092

EPOS 3 - DETAILS

- Initial conditions based on Gribov–Regge theory
- pp (Pb-Pb) collision decomposed in simple interactions, called “parton ladders”, composed of an hard scattering è ISR/FSR.
- The parton ladders decay producing quark-antiquark pairs, creating in this way fragments, identified with hadrons
- Multi-parton interactions are also accounted for
- Non-linear effects are included via a saturation scale
- Hydrodynamic behaviour can be switched on for the core of the collision
  - ➢ Already for pp collisions, the energy density is enough to justify this treatment

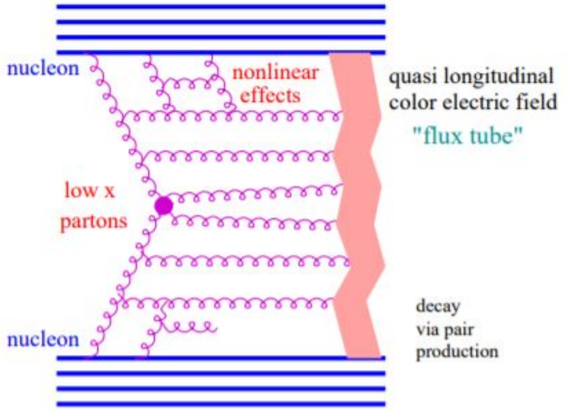
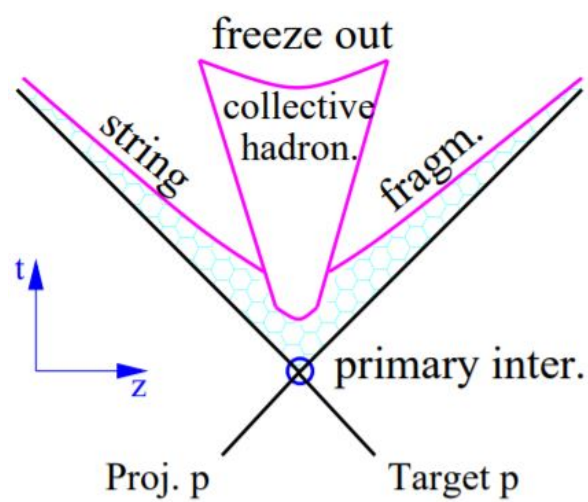


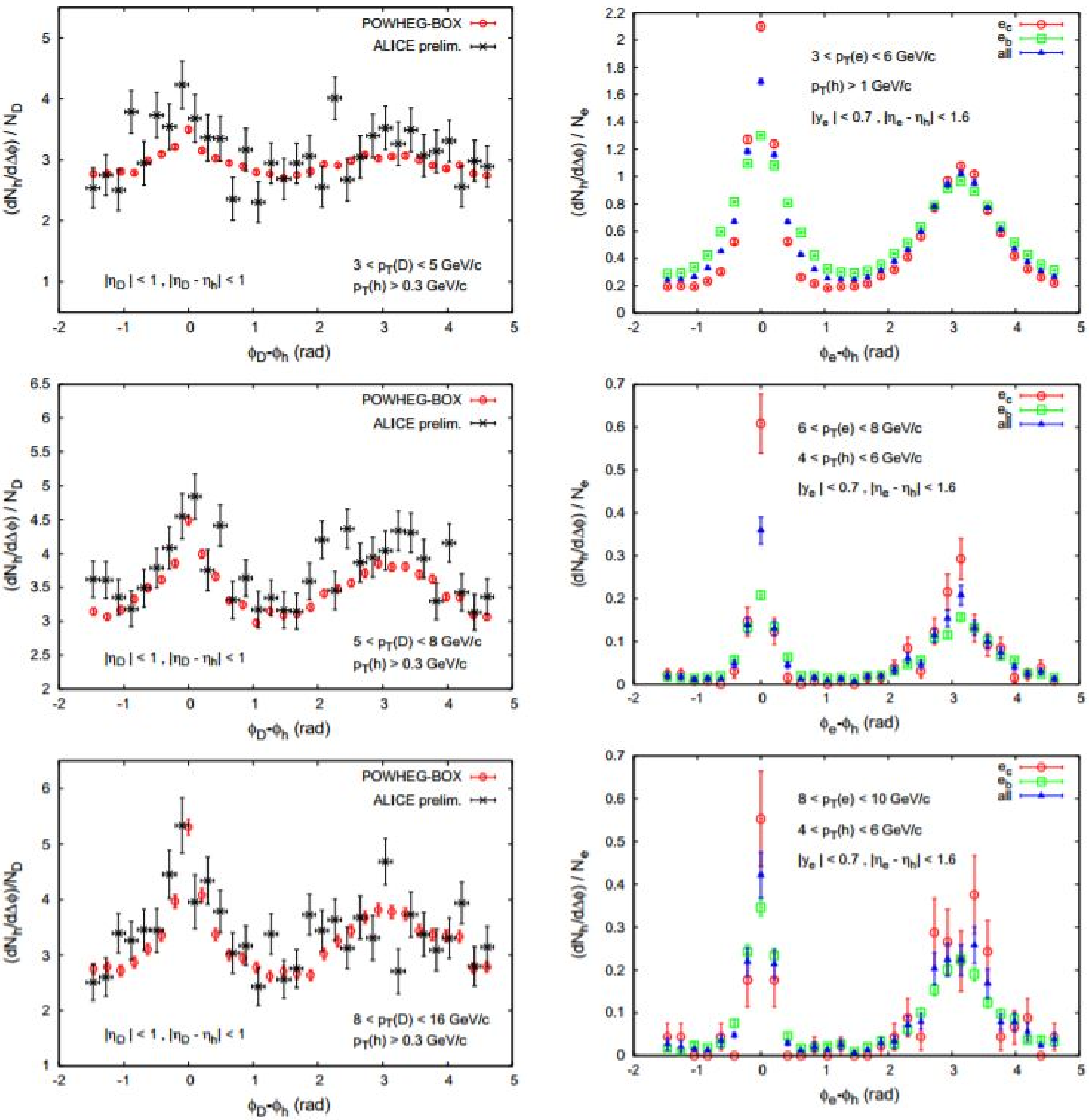
Figure 2. Elementary interaction in the EPOS model.



Phys. Rev. C 92, 034906 (2015)

arXiv:hep-ph/0709.2092

POWLANG PREDICTIONS (D-h, e-h)



POWLANG: initial hard production of the QQ pairs and parton-shower stage through the POWHEG-BOX package + successive evolution in the plasma through the relativistic Langevin equation

Left: Azimuthal D–h correlations in pp collisions at √s = 7 TeV for various cuts compared to preliminary ALICE data

Right: Azimuthal e–h correlations in p–p collisions at √s = 7 TeV for various kinematical cuts accessible by ALICE

AMPT MODEL

Phys.Rev.C72:064901,2005

The AMPT model consists of four main components: the initial conditions, partonic interactions, the conversion from the partonic to the hadronic matter, and hadronic interactions. The initial conditions, which include the spatial and momentum distributions of minijet partons and soft string excitations, are obtained from the HIJING model [51, 52, 53, 54]. Currently, the AMPT model uses the HIJING model version 1.383 [55], which does not include baryon junctions [56]. Scatterings among partons are modeled by Zhang's parton cascade (ZPC) [18], which at present includes only two-body scatterings with cross sections obtained from the pQCD with screening masses. In the default AMPT model [39, 40, 41, 42, 43, 44, 46, 47, 49], partons are recombined with their parent strings when they stop interacting, and the resulting strings are converted to hadrons using the Lund string fragmentation model [57, 58, 59]. In the AMPT model with string melting [45, 48, 50], a quark coalescence model is used instead to combine partons into hadrons. The dynamics of the subsequent hadronic matter is described by a hadronic cascade, which is based on the ART model [14, 25] and extended to include additional reaction channels that are important at high energies. These channels include the formation and decay of K^* resonance and antibaryon resonances, and baryon-antibaryon production from mesons and their inverse reactions of annihilation. Final results from the AMPT model are obtained after hadronic interactions are terminated at a cutoff time (t_{cut}) when observables under study are considered to be stable, i.e., when further hadronic interactions after t_{cut} will not significantly affect these observables. We note that two-body partonic scatterings at all possible times have been included because the algorithm of ZPC, which propagates partons directly to the time when the next collision occurs, is fundamentally different from the fixed time step method used in the ART model.

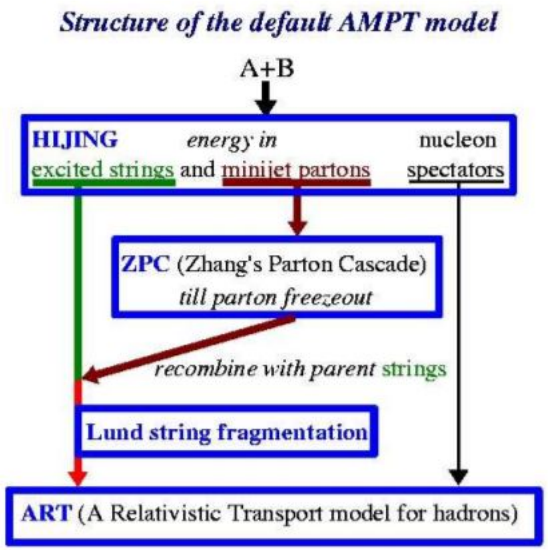


FIG. 1: (Color online) Illustration of the structure of the default AMPT model.

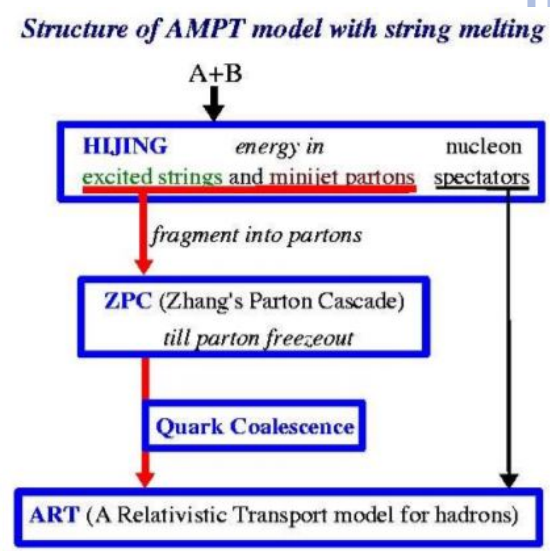


FIG. 2: (Color online) Illustration of the structure of the AMPT model with string melting.