The role of correlations in disentangling between heavy-flavor energy-loss Models

~~Winter~~ Summer Workshop on Nuclear Dynamics

La Guadeloupe (Fr)

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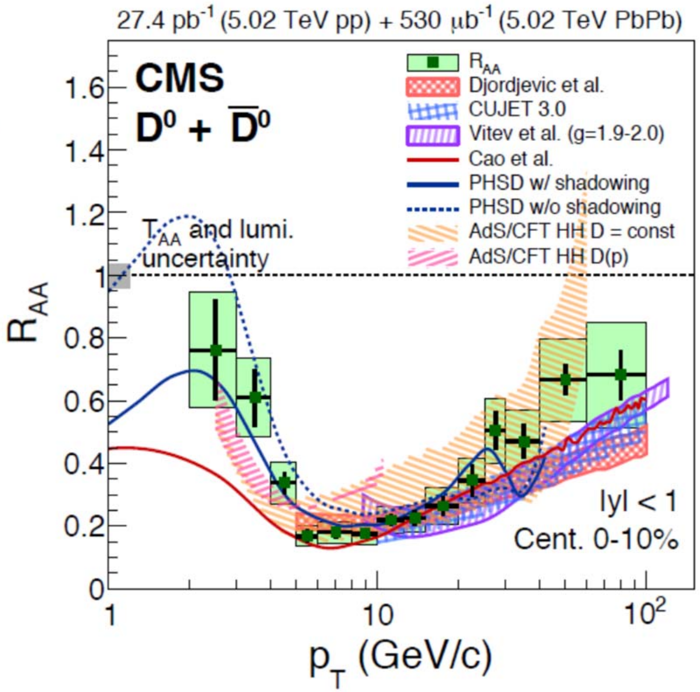
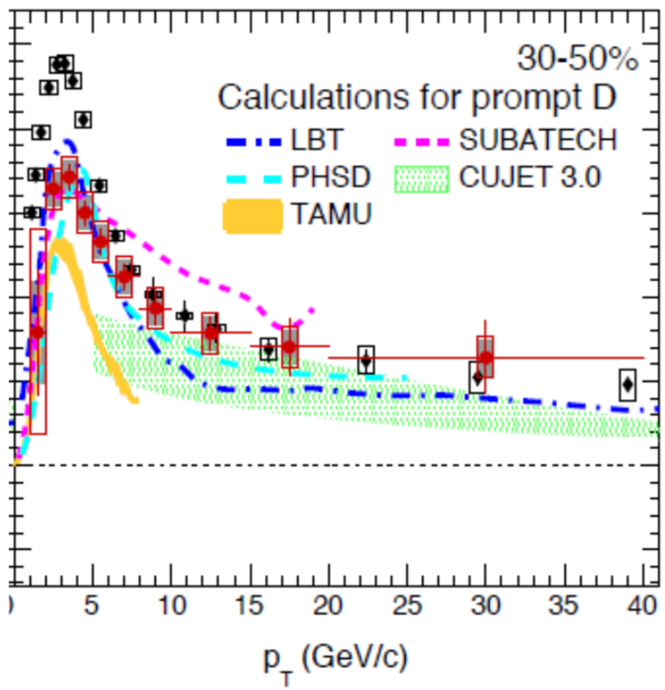
(Short) Motivation

- Nowadays, a large variety of models (most of them presented as “effective approaches”) are confronted with the data for the R_{AA} & v_2 single particle observables





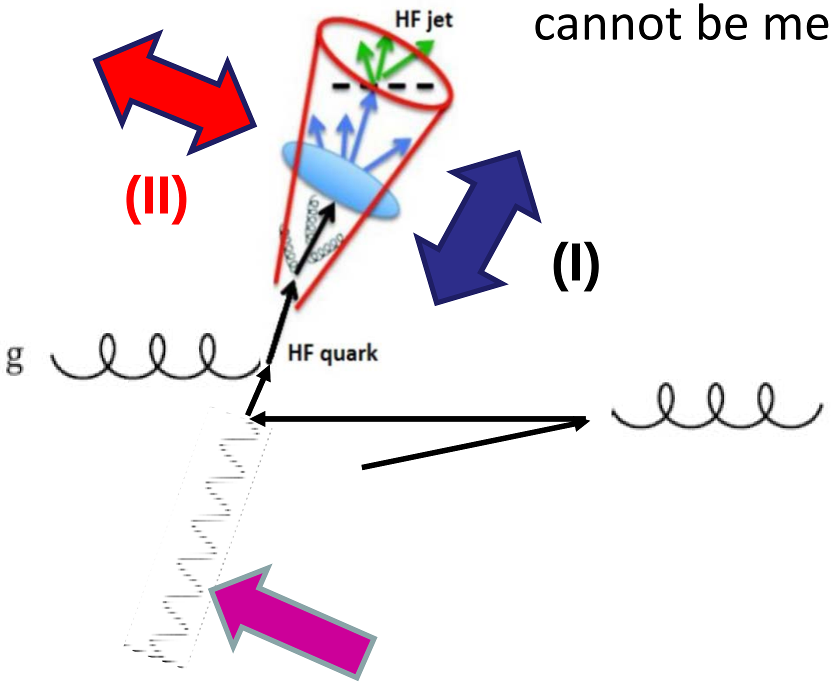
- For the purpose of making the contact with the fundamental theory, it is desirable to “constrain / pre-sort / rule out” some of the approaches

- Very often, correlations are advocated to be useful in this respect (warning: main viewpoint adopted in this presentation)

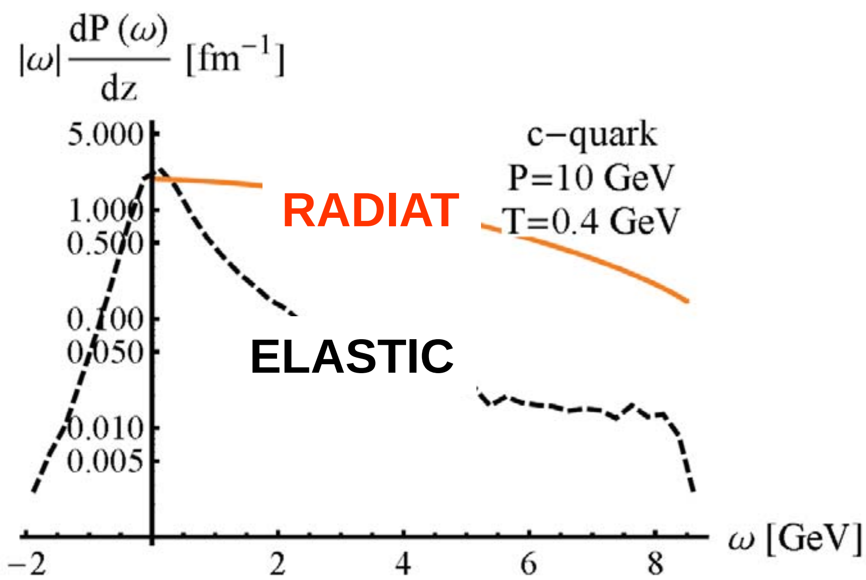
How does it help ? Best HF Correlation ever ?

- γ – D/B/c jet /b jet:

In QGP: **Longitudinal and transverse (qhat) fluctuations** of the HQ, which crucially depend on the Eloss mechanism and cannot be measured in usual observables like R_{AA} or v_2



No E loss => perfect probe of initial $\vec{P}_{HQ}$

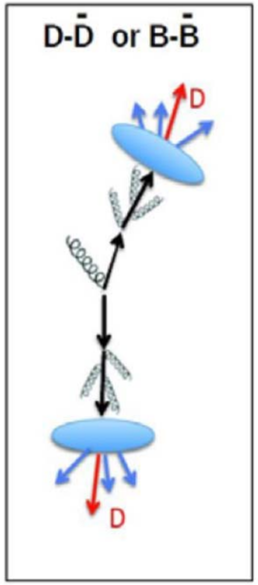


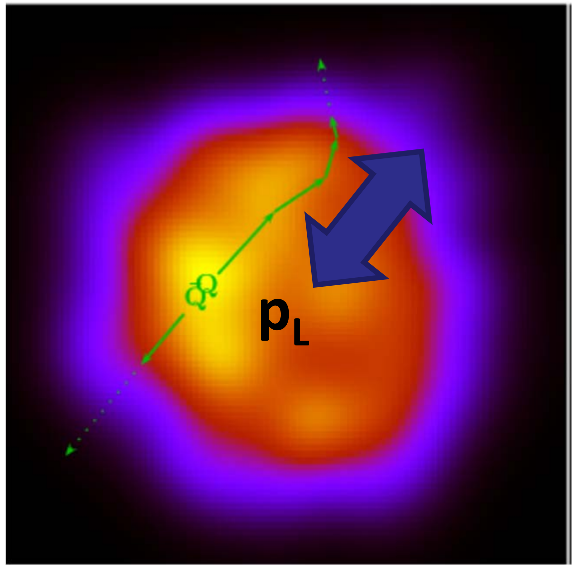
differential probability to loose energy ω per unit time

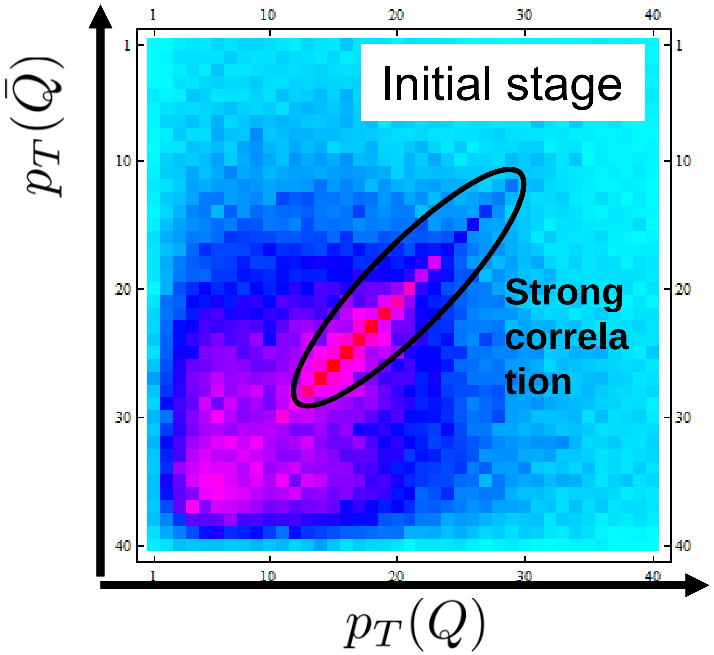
- Of course: NLO effect in the production mechanisms makes it not so trivial (not to speak about exp. Issues… RUN3 ? RUN4 ?)

Next best thing: HF-HF correlations

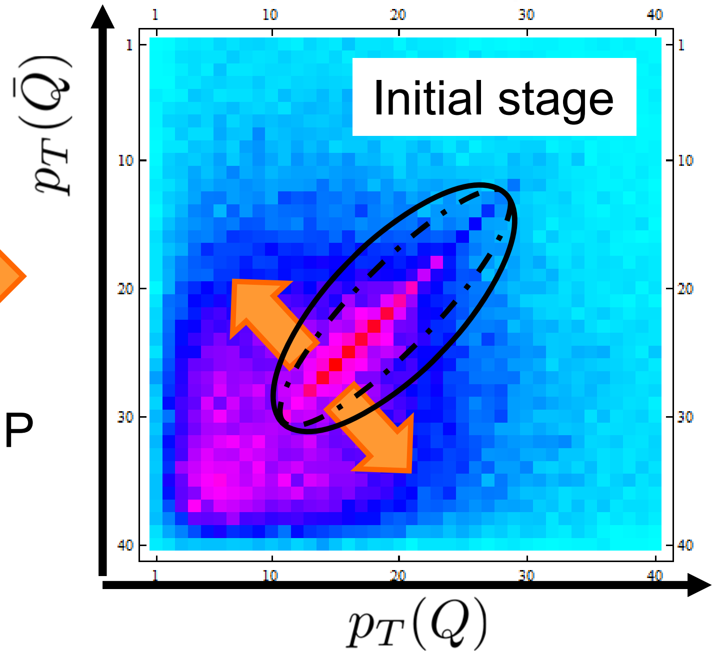
- Back to back D/Dbar or B/Bbar: As compared to γ-D/B: "triggering" itself is affected but symmetry between both particles could limitate the various effects:
- Large number of c-cbar from various NN collisions => large uncorrelated background
- Competing effects due to energy loss: …







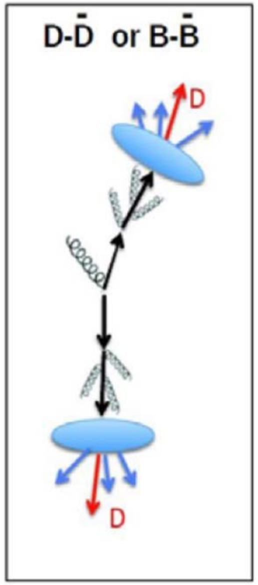
Evolution in hot QGP medium

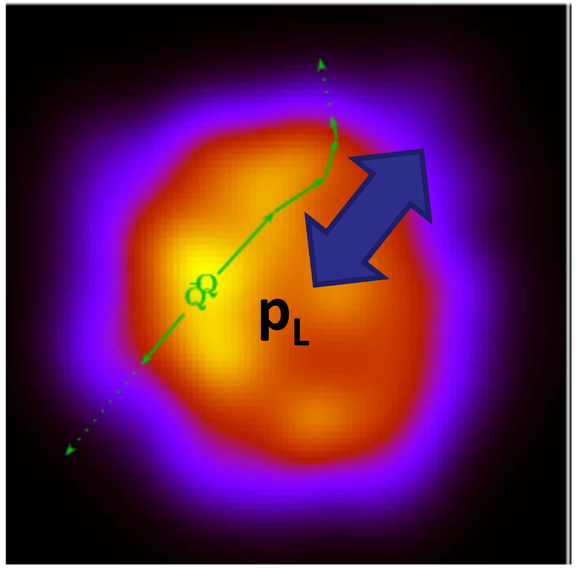


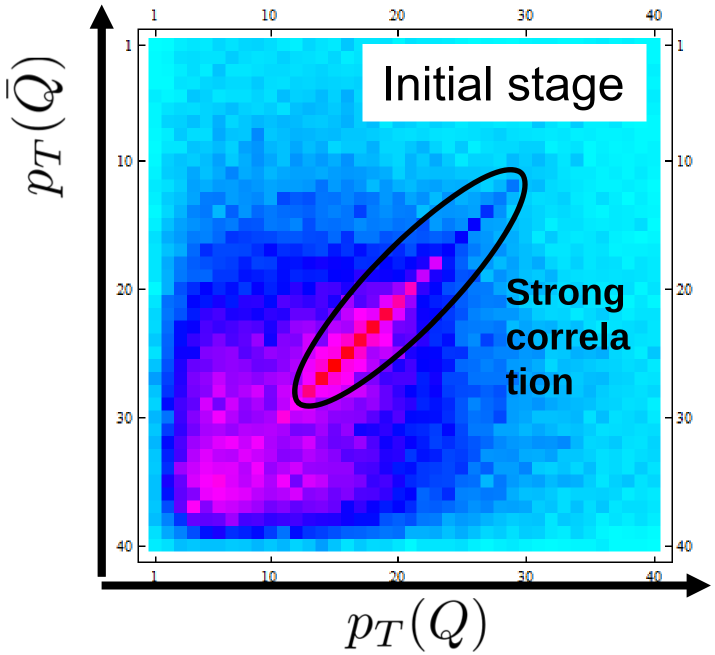
- decorrelation due to various path lengths + fluctuations: reduction

Next best thing: HF-HF correlations

- Back to back D/Dbar or B/Bbar: As compared to γ-D/B: "triggering" itself is affected but symmetry between both particles could limitate the various effects:
- Large number of c-cbar from various NN collisions => large uncorrelated background
- Competing effects due to energy loss: …







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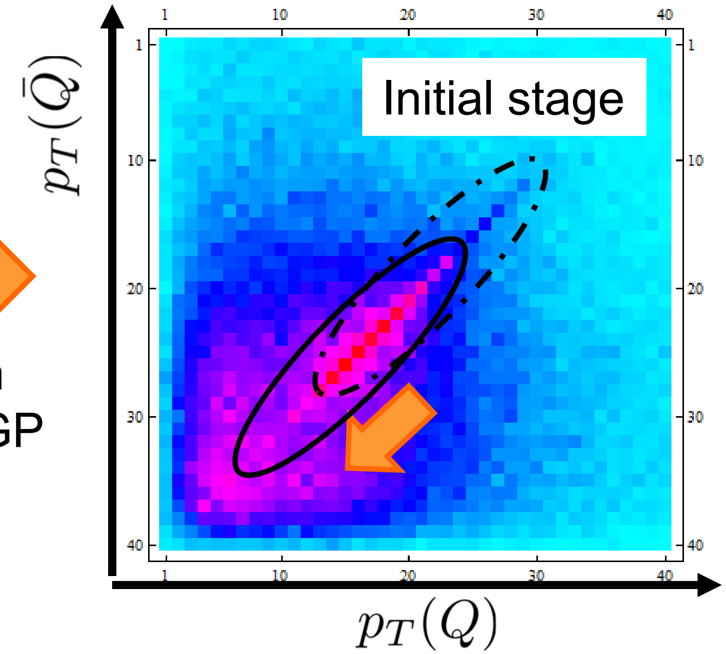
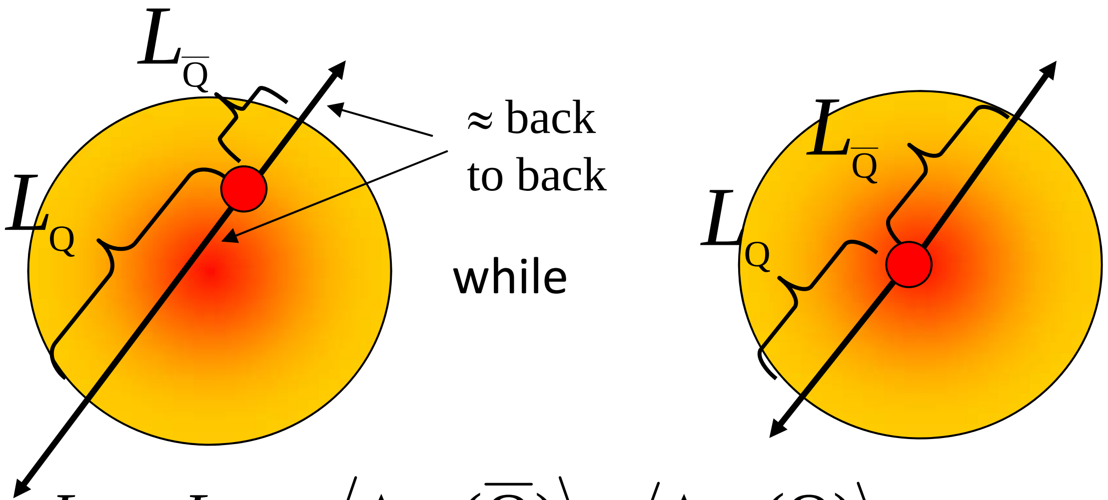


- feeding from higher p_T (stronger) correlations: increase

Once upon a time: momentum imbalance for hot core

- Challenge: tagging on the “central” Q, i.e. getting closer to the ideal “penetrating probe” concept:

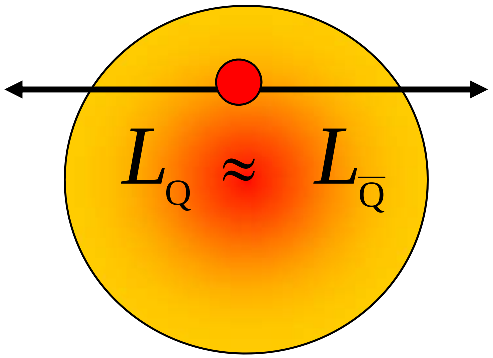


$$L_{\overline{Q}} \approx L_Q \Rightarrow \langle \Delta p_T(\overline{Q}) \rangle \approx \langle \Delta p_T(Q) \rangle$$

$$L_{\overline{Q}} < L_Q \Rightarrow \langle \Delta p_T(\overline{Q}) \rangle < \langle \Delta p_T(Q) \rangle$$

- Reversing the argument: selecting $\langle \Delta p_T(\overline{Q}) \rangle \approx \langle \Delta p_T(Q) \rangle$ might bias the data in favor of “central” pairs

Possible caveat:

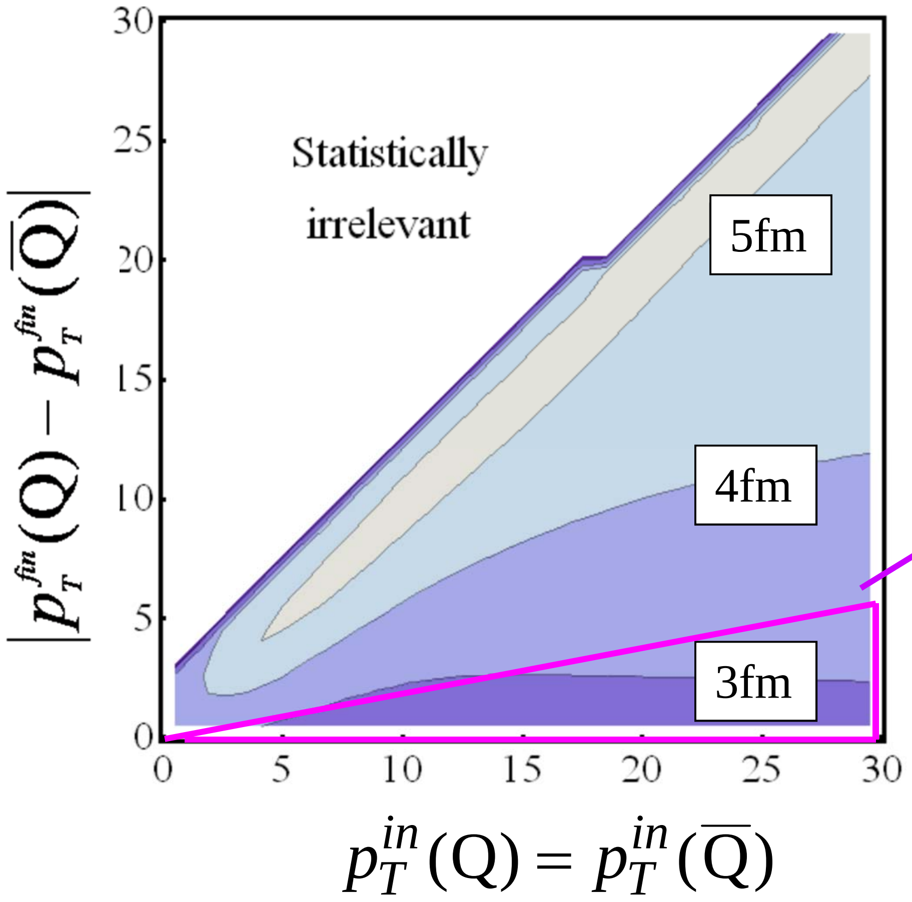


$\Rightarrow$ Need for a detailed study

Gossiaux et al, PHYSICAL REVIEW C 79, 044906 (2009)

Once upon a time: momentum imbalance for hot core

Average transv.-dist. to center as a function of Δp_T^{fin} *for various* p_T^{in}



Indeed some (favorable) bias for init p_T^{in} > 5GeV/c and "small" Δp_T^{fin}

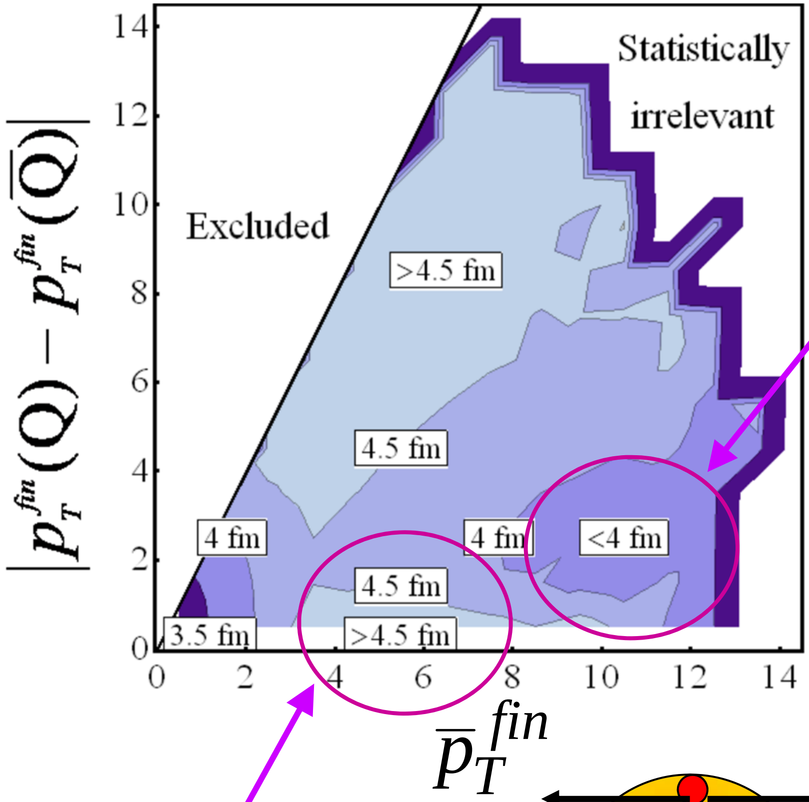
Hope to probe hotter regions of the QGP

However: No access to p_T^{in} !!!

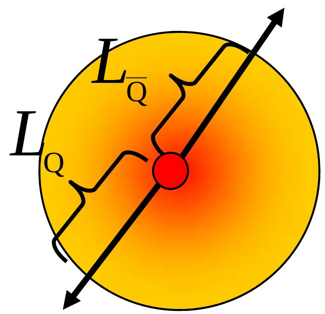
Once upon a time: momentum imbalance for hot core

Best ansatz: $p_T^{in}(Q) \rightarrow \bar{p}_T^{fin} := \dfrac{p_T^{fin}(Q) + p_T^{fin}(\bar{Q})}{2}$

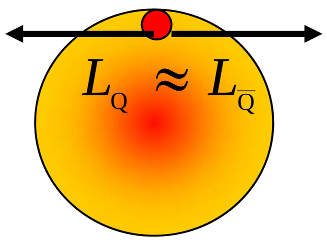
Average transv.-dist. to center as a function of $\Delta p_T^{\rm fin}$ *for various* $\bar{p}_T^{fin}$



Central production:

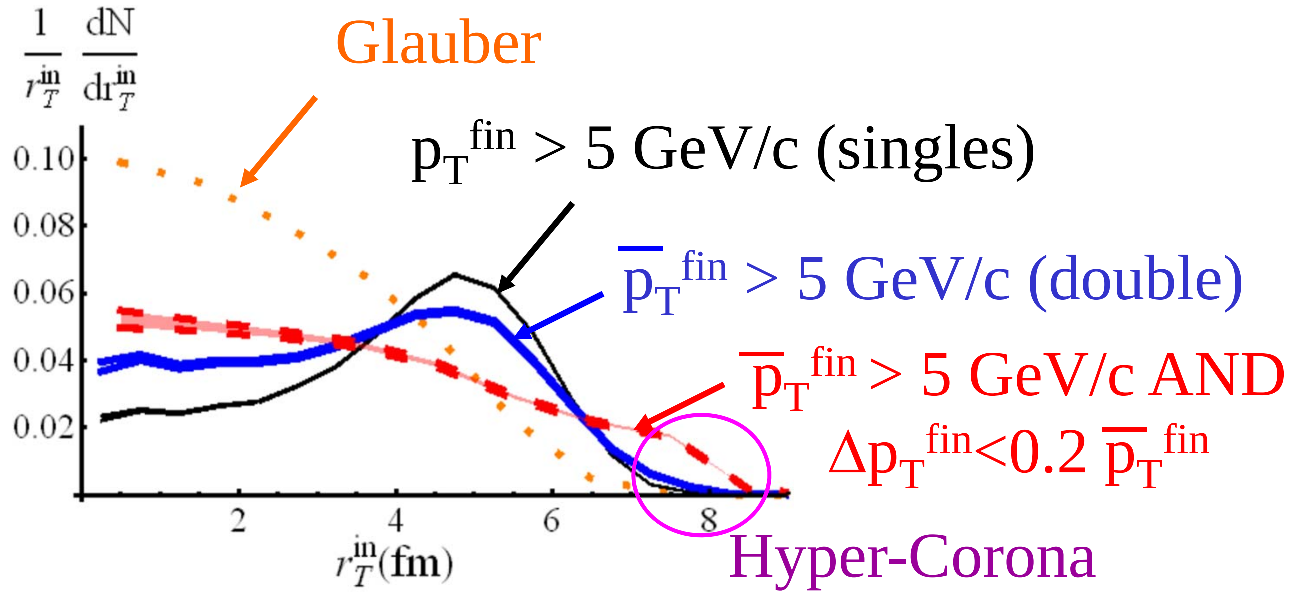


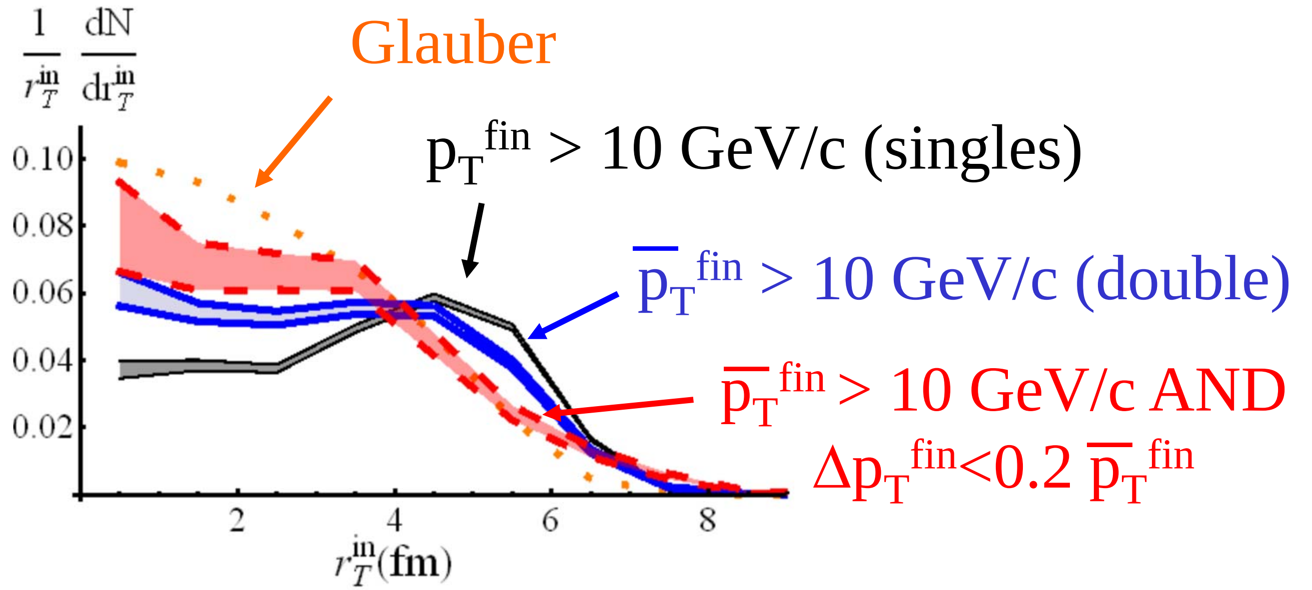
Tangential production



Conclusion: Favorable bias for av. $p_T^{\mathbf{fin}}$ > 8 GeV/c and "small" $\Delta p_T^{\mathbf{fin}}$

momentum imbalance for hot core: back to r_T distributions

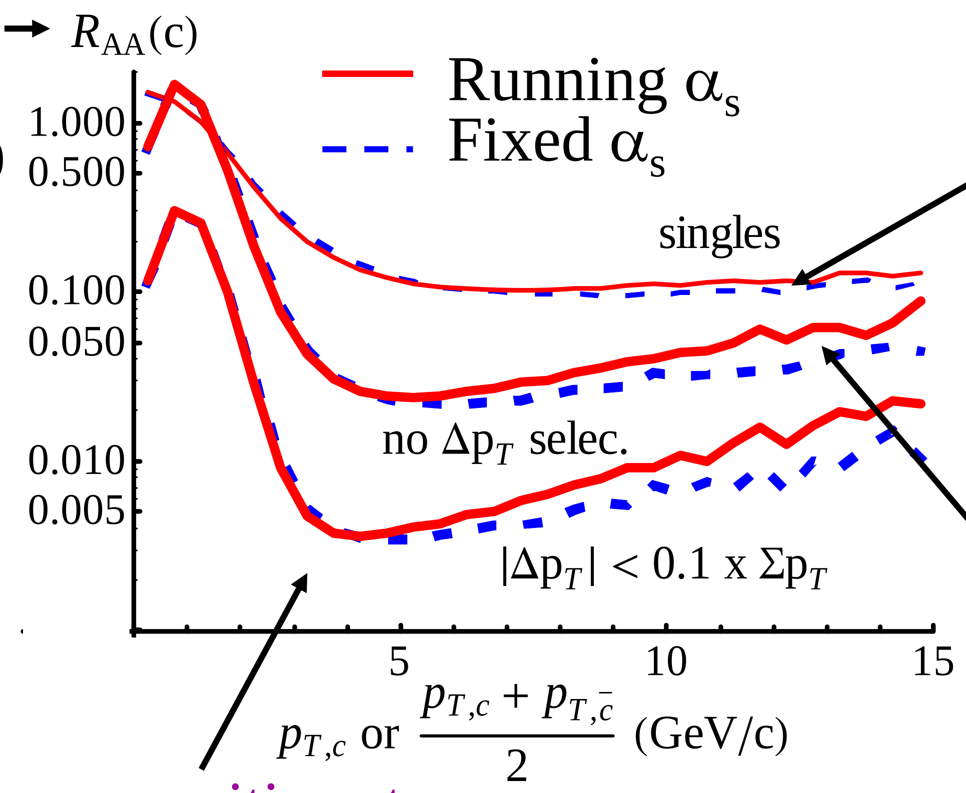




- Final cuts lead to various distributions of initial position
- One nearly recovers the Glauber profile for most severe cut

momentum imbalance: increase R_{AA} sensitivity

Usual ratio: Nb(Au+Au)/ Nb_{coll}*Nb(pp)



Usual flat

2 part

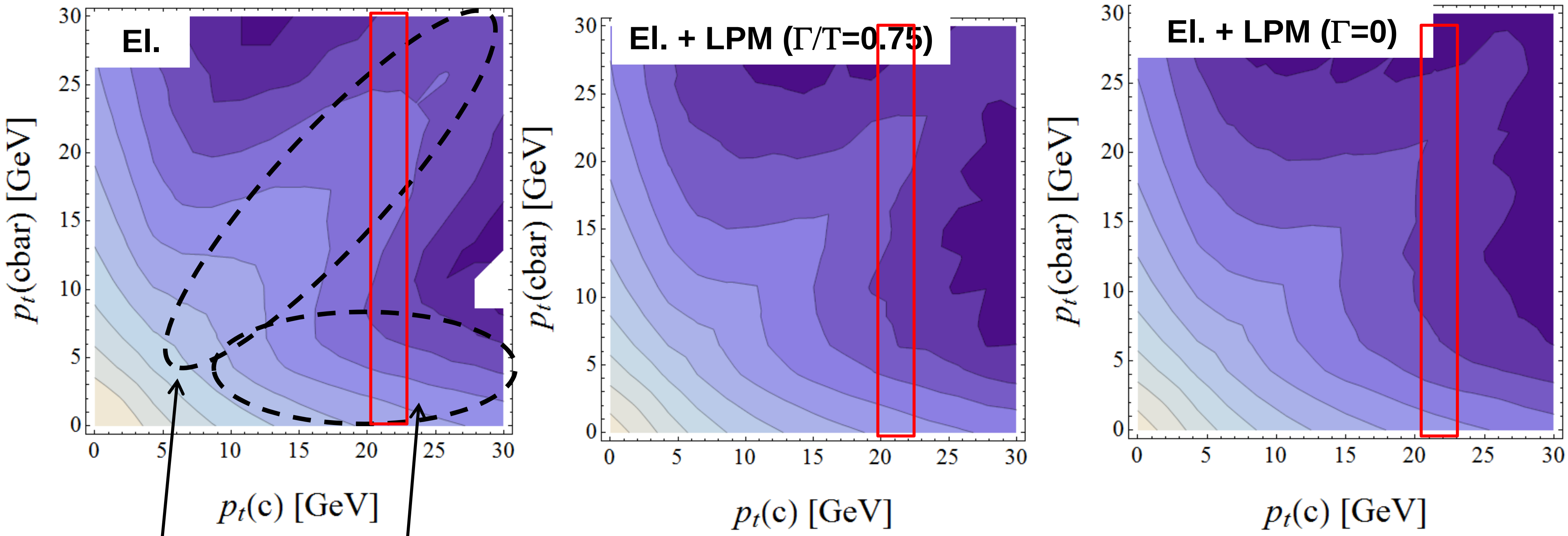
Rise with p_T although no selection ! Different behaviors are due to fluctuations

More and more sensitive at large p_T for HQ from center

Close to experimental prediction but not yet (Hadronization, NLO at the time of production, background substraction,…)

Consequences on the observables: $p_t(c)$-$p_t(cbar)$ correlations

Pb-Pb @ 2.76 TeV; 40-60%. **Toy study: back to back c-cbar** **(no NLO corrections)**



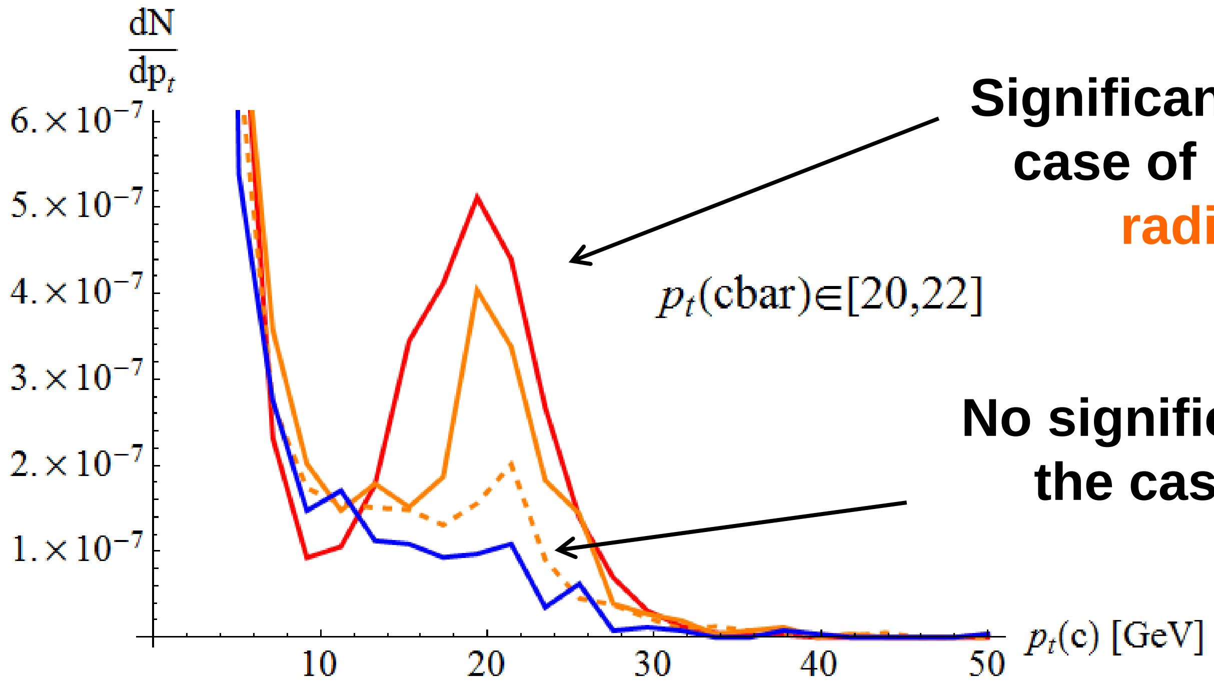
Background at small p_t

Tagging on 1 high p_T Qbar:

Residual correlation after evolution through QGP
(similar path length for most of HQ produced in the core of the reaction)

Consequences on the observables: p_T-$p_T$bar correlations

Pb-Pb @ 2.76 TeV; 40-60%. Toy study (proof of principle): back to back c-cbar



Significant residual correlation for the case of Elastic energy loss or LPM radiative + gluon damping

In the B2B region:

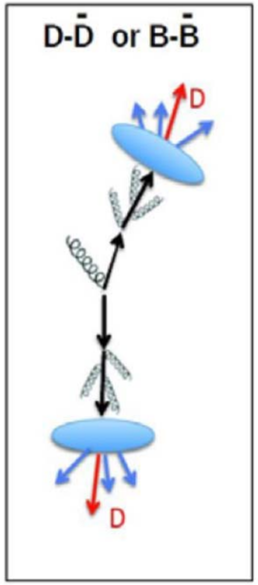
No significant residual correlation for the case of radiative GB or LPM radiative

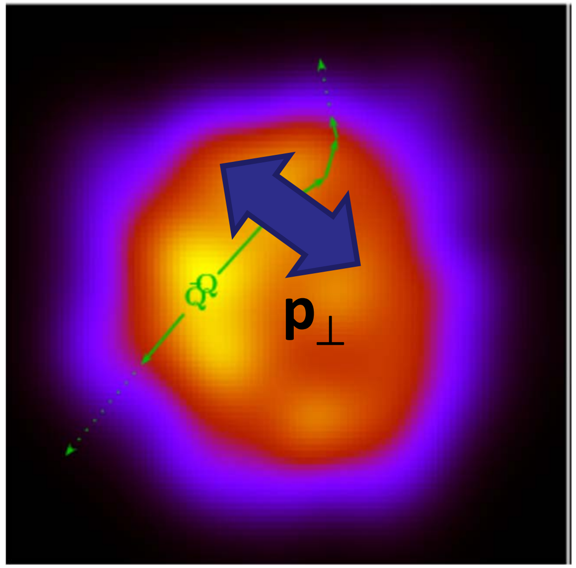
Background at small p_t

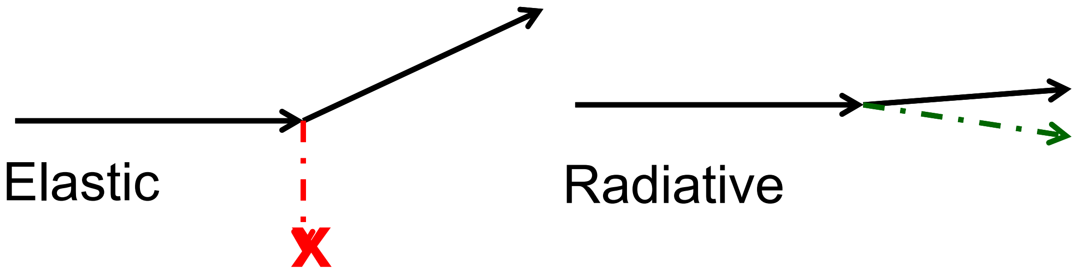
How does DGLAP evolution blur momentum imbalance ?

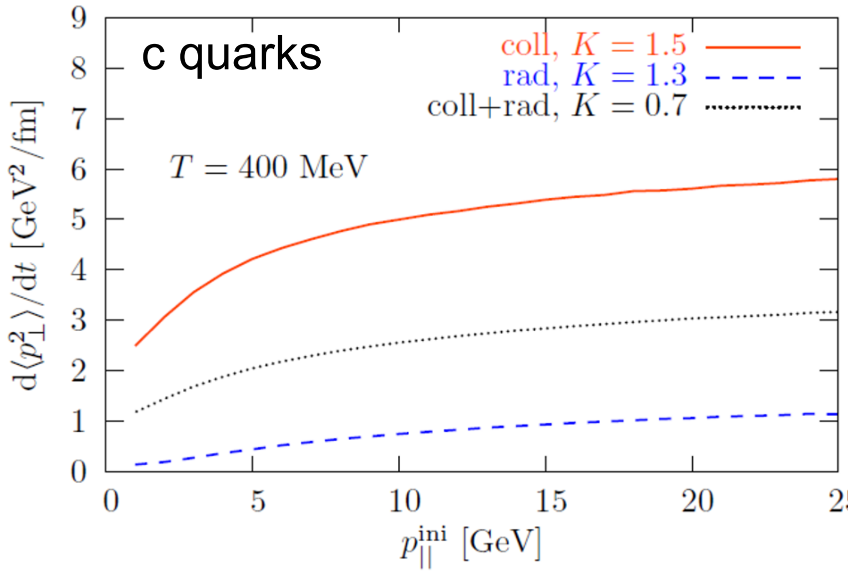
Next best thing: HF-HF correlations

- Back to back D/Dbar or B/Bbar: As compared to γ-D/B: "trigger" itself is affected but symmetry between both particles limitates the various effects.
- Elastic Eloss vs radiative Eloss: **The purely collisional scatterings lead to a larger average $\langle p_\perp^2 \rangle$ then the radiative "corrections"** (need for large scattering to be efficient)… although both types can give correct agreement with the data at intermediate p_T.









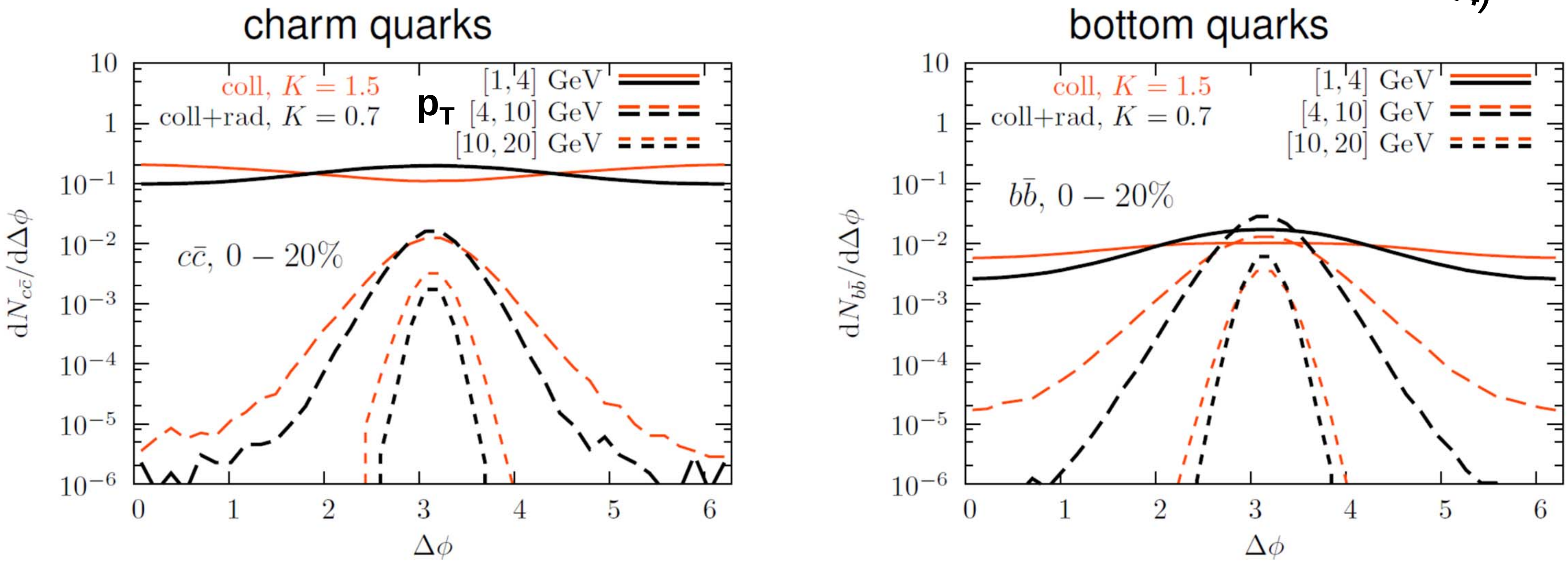
Tuned to reproduce the R_{AA}

- Expected consequences for azimuthal correlations (probe of B_T: good: **complimentary** to usual RAA and v2)

Next best thing: azimuthal correlations

- Assumption of back 2 back emission of initial QQbar (naïve LO…)

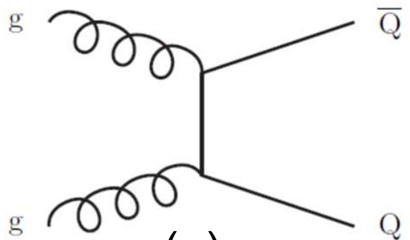
Nahrgang et al. Phys. Rev. C 90, 024907 (2014)



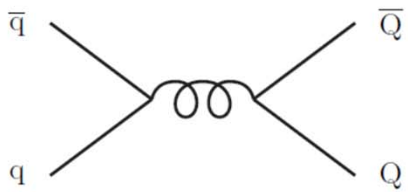
- Indeed, rather large differences found for both b and c, and all kind of p_T cuts (… but good to see there is an effect though,…)
- For the smallest p_T bin and elastic energy loss, we even find an inversion of the correlation ("hot partonic wind" push; v_0 bulk => v_1 correl; underlying event)

Next best thing: azimuthal correlations

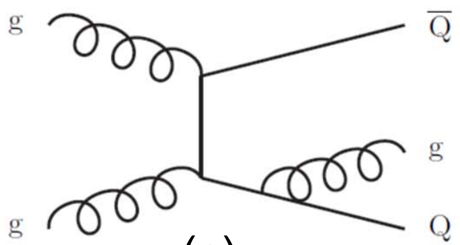
- …but higher orders can have a significant impact:



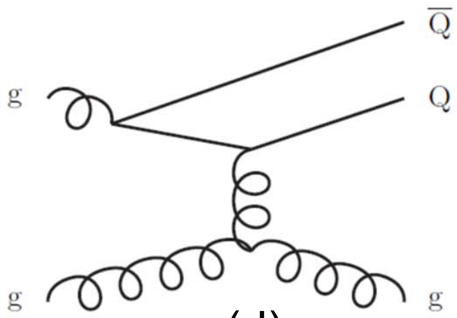
(a)



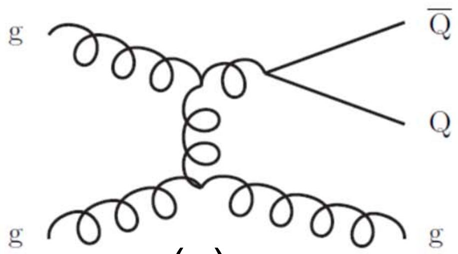
(b)



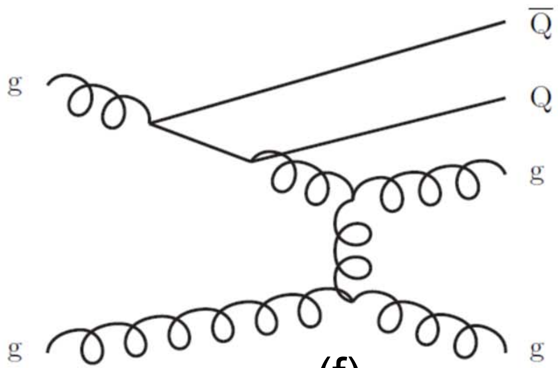
(c)



(d)



(e)



(f)

- LO; (a): back to back peak

- NLO;

(c): "blurring" of B2B peak

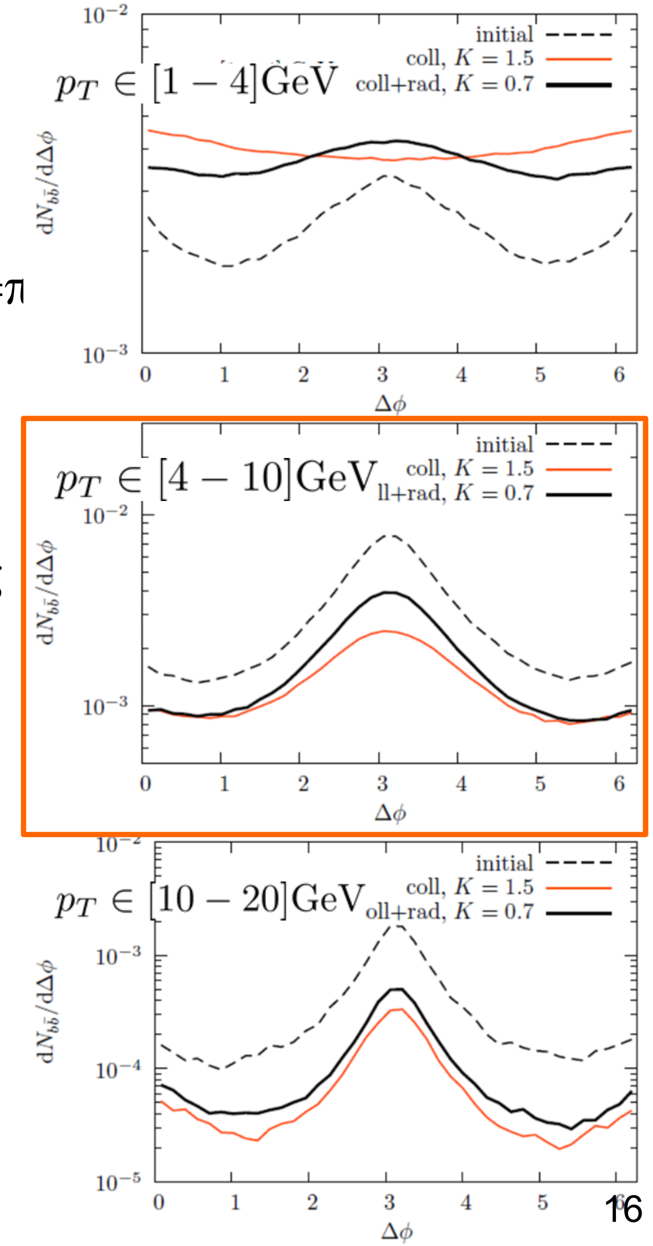
(d): "flavor excitation": no strong azimuthal correlation expected

(e): gluon splitting: strong peak around $\Delta\phi$=0

(f): higher order FE; both Q and Qbar in the "remnant" region

Next best thing: azimuthal correlations

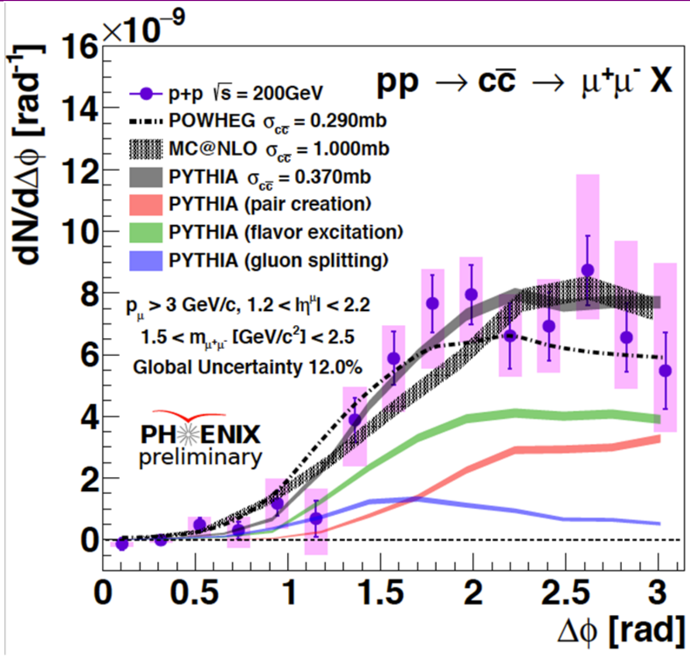
- NLO effect simulated with MC@NLO + HERWIG (parton shower)
- Gluon splitting processes lead to an initial enhancement of the correlations around $\Delta\phi=0$; Strong broadening of the $\Delta\phi=\pi$ peak ("vacuum" radiation is dominant)
- For intermediate p_T : increase of the variances due to Eloss from 0.43 (initial NLO) to 0.51 (+20%) for the purely elastic mechanisms and to 0.47 (+10%) for the interaction including **radiative** corrections.
- Correlations at large p_T seem to be dominated by the initial correlations. **Nothing will be learned on the Eloss mechanisms in this region**
- Different NLO+parton shower approaches agree on bottom quark production, differences remain for charm quark production
- Study by other groups (Duke, CCNU-LBL,PHSD,...)



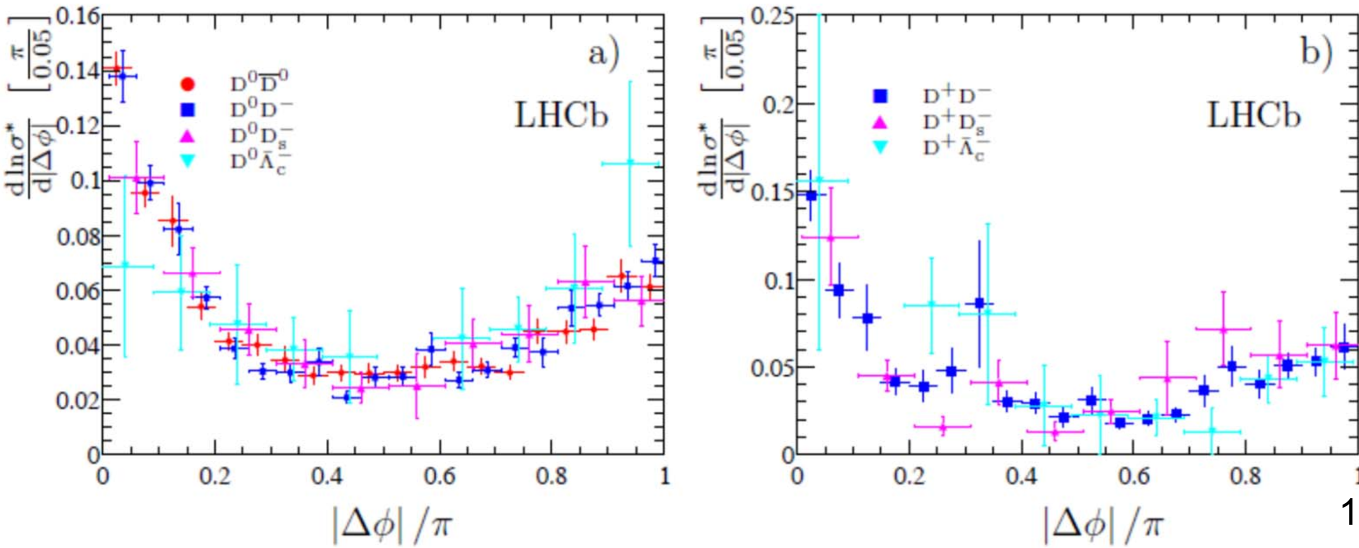
Azimuthal correlations from experimental viewpoint

- Measured in pp both at RHIC and LHC (rising gluon splitting peak)
- Not even sure one could resolve a 10% difference in the width for the pp !!!
- A+A: expected after upgrades ?

PHENIX



LHCb



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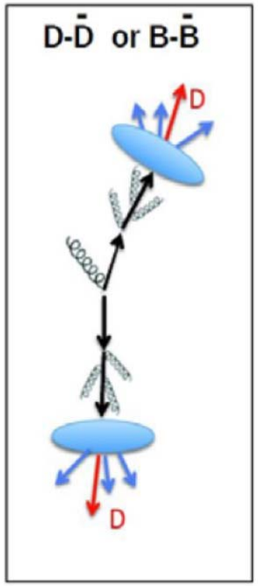
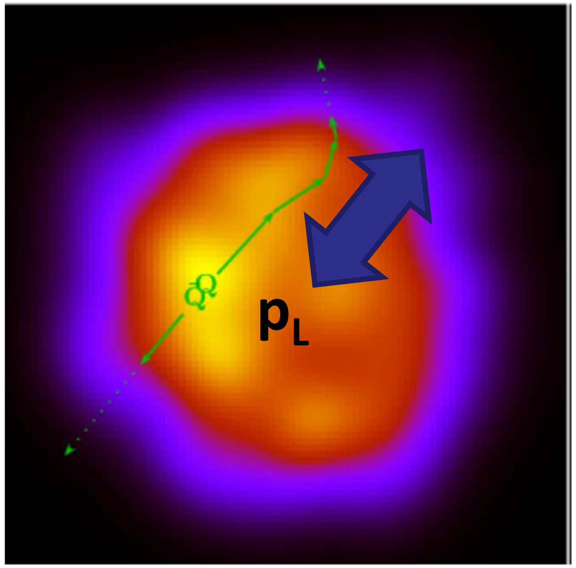




- Of course: NLO effect in the production mechanisms makes it not so trivial (not to speak about exp. Issues… RUN 3 ? RUN 4 ?)

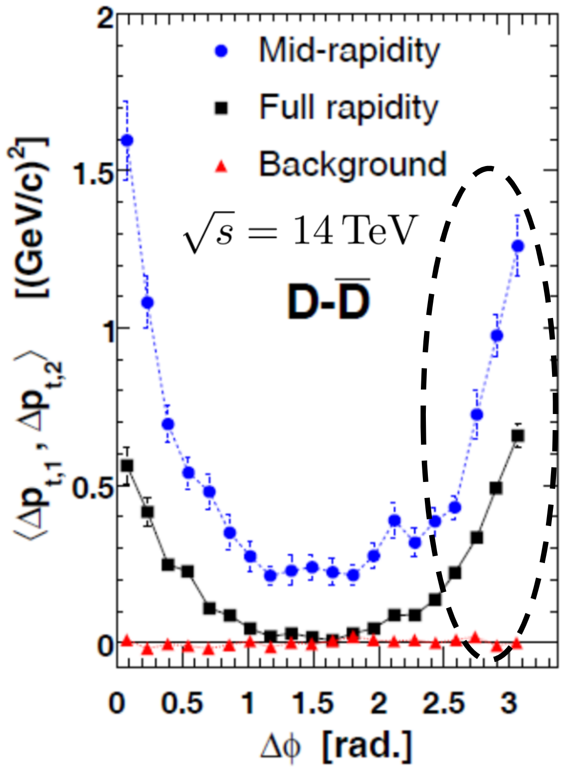
Not so naïve approach: Momentum imbalance in **pp**

- … including "realistic" initial stage in pp (PYTHIA 6)

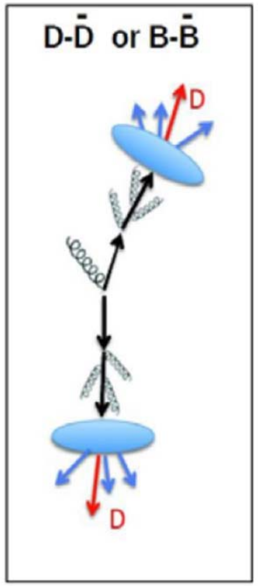
G. Tsiledakis et al., Nucl. Phys. A 858 (2011) 86.

- Average auto-correlation:

$$\langle \Delta p_{t,1}, \Delta p_{t,2} \rangle^{(D\overline{D})} = \frac{1}{\sum_{k=1}^{n_{ev}} N_k^D N_k^{\overline{D}}} \cdot \sum_{k=1}^{n_{ev}} \sum_{i=1}^{N_k^D} \sum_{j=1}^{N_k^{\overline{D}}} (p_{ti} - \overline{p_t}^{(D)})(p_{tj} - \overline{p_t}^{(\overline{D})})$$



In the back-to back region, NLO corrections (FSR) still preserve some degree of correlation



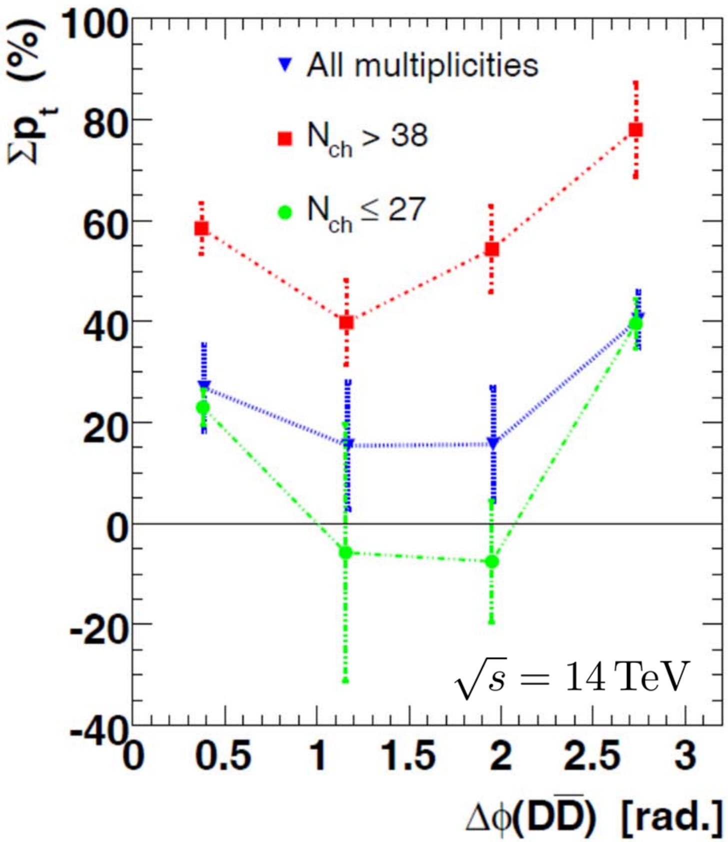
Not so naïve approach: Momentum imbalance in **pp**

- … including "realistic" initial stage in pp (PYTHIA 6)

G. Tsiledakis et al., Nucl. Phys. A 858 (2011) 86.

- Average *relative* auto-correlation:

$$\Sigma_{pt} = \mathrm{sgn}(\langle \Delta p_{t,1}, \Delta p_{t,2} \rangle) \frac{\sqrt{|\langle \Delta p_{t,1}, \Delta p_{t,2} \rangle|}}{\overline{p_t}}$$



- Encouraging signs of significant finite (transverse) momentum correlation in pp, i.e. in the initial stage of A-A collisions
- Going beyond average ?
- Lessons from CMS: Pythia has problems to reproduce Q-Qbar azimuthal correlations

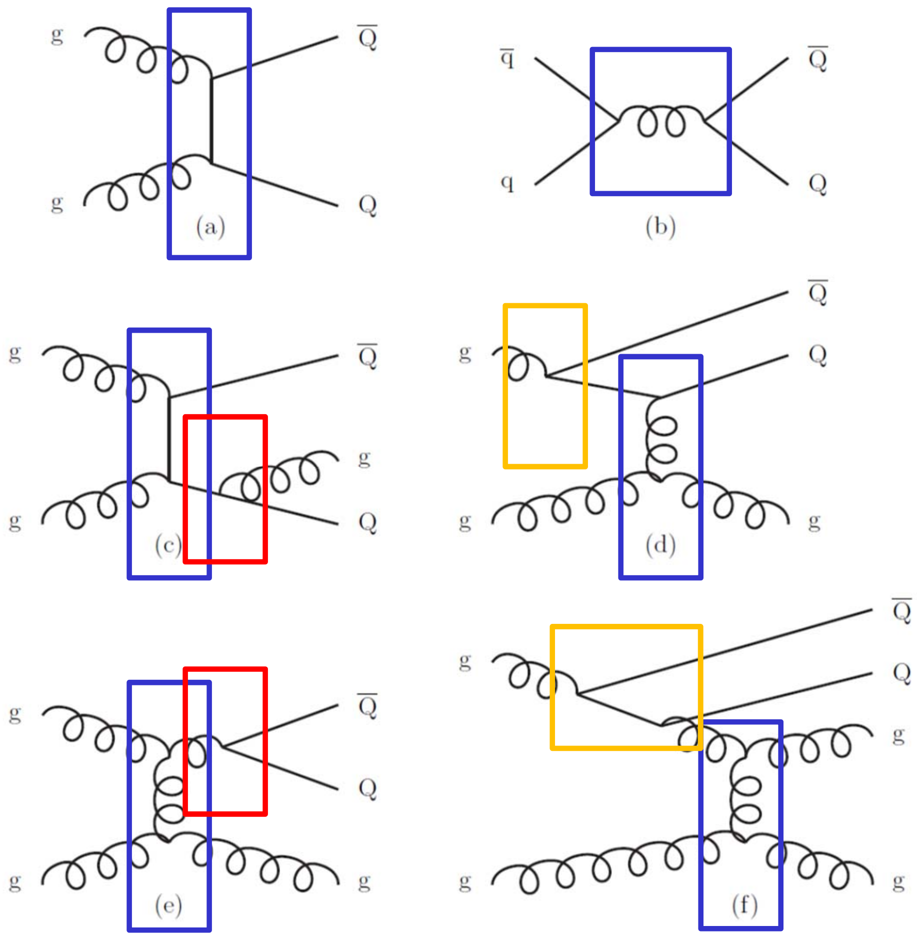
CMS-PASHIN-16-005.

Momentum imbalance: not so naïve approach

- Goal of the study: investigate whether p_T-p'_T correlations survive NLO effects

L. Vermunt et al.
arXiv:1710.09639

- Method for "systematics": use 2 event generators: PYTHIA (6.4) & EPOS3



- In pythia, those topologies are generated by coupling LO processes (implying 0,1 or 2 HQ) and ISR + FSR … This will be referred to as « LO + NLO ccbar » (strictly speaking, no NLO !)

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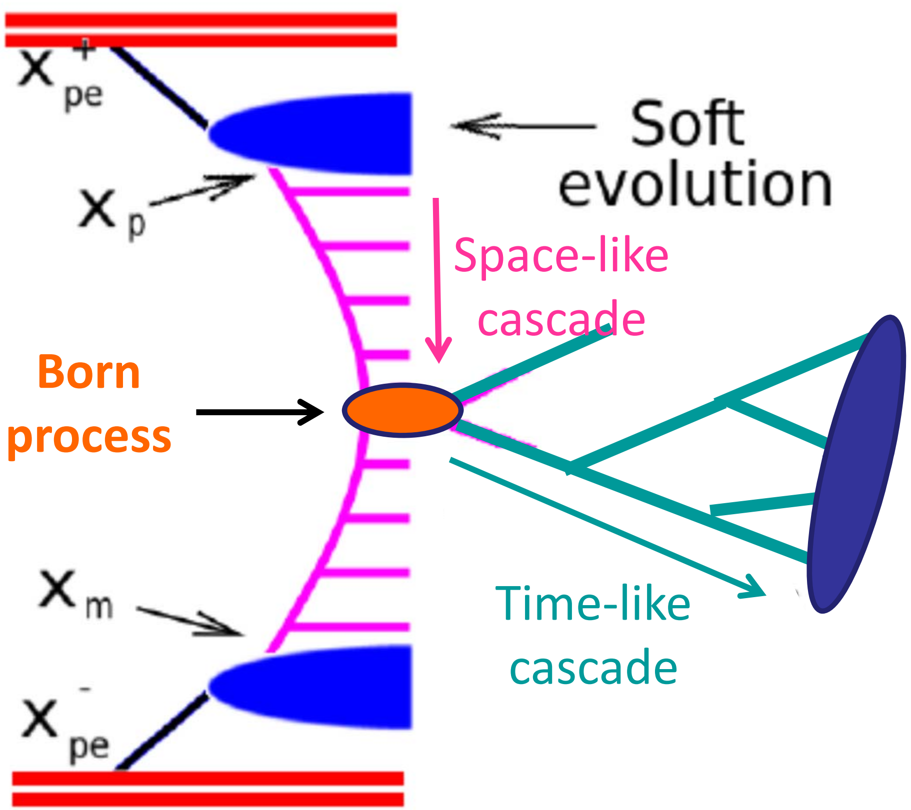

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- Same « strategy » in EPOS3, with « semi-hard pomeron » approach (with some soft evolution included), with various LO Born processes.

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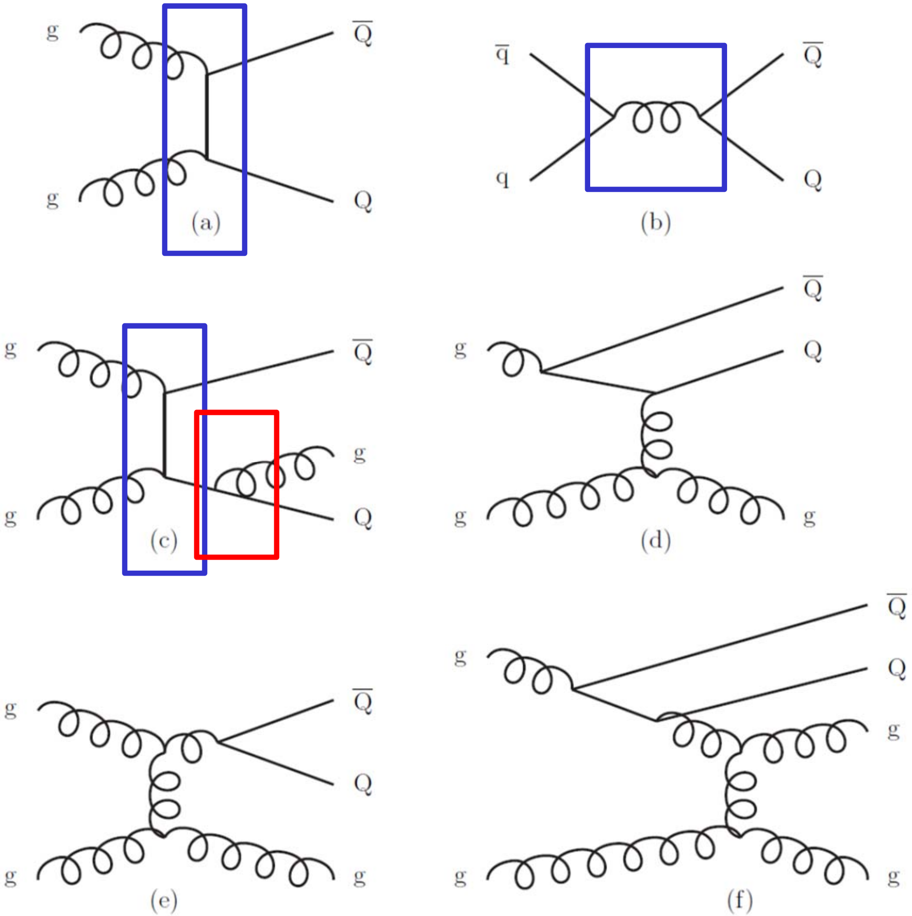

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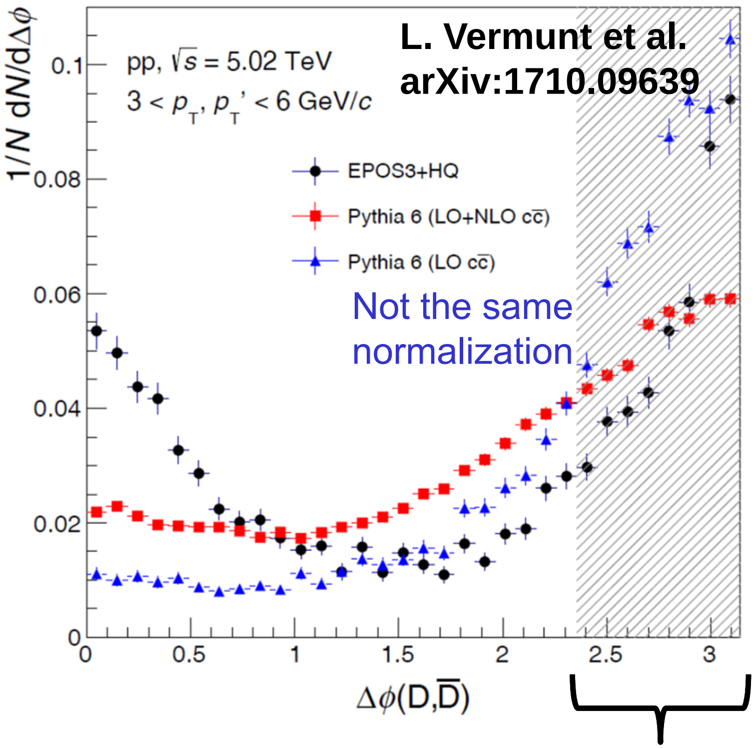
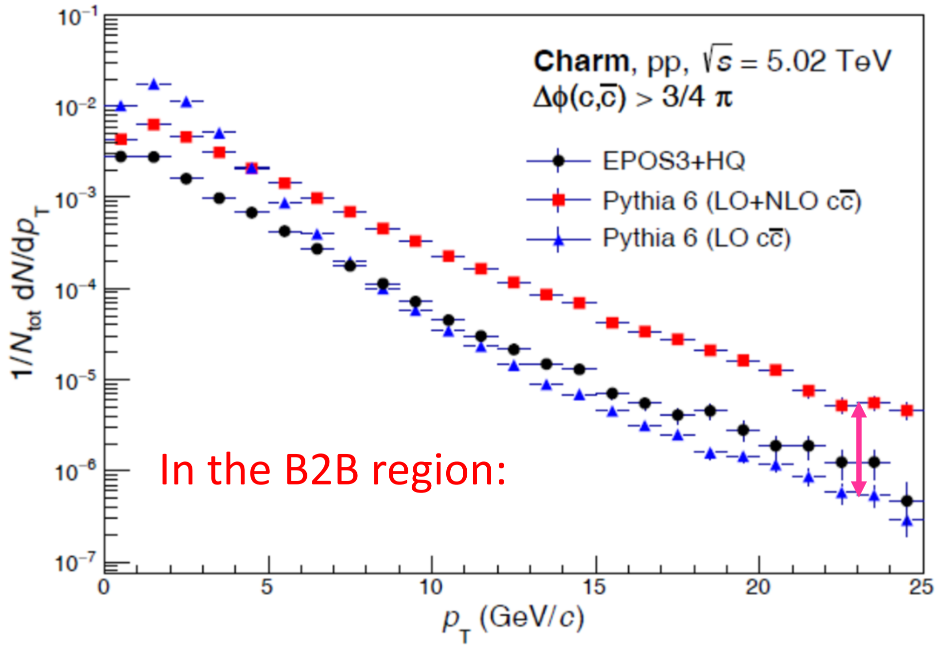
- Same « strategy » in EPOS3, with « semi-hard pomeron » approach (with some soft evolution included), with various LO Born processes.
- In pythia, possibility to restrict to LO ccbar production processes with massive elements (MSEL=1 -> MSEL=4 flag), still switching on the … ISR + FSR … This will be referred to as « LO ccbar »

Momentum imbalance: not so naïve approach

➢ Including NLO effects in the charm production (N.B. :beauty would be better for our purpose, but very low statistics)



B2B selection

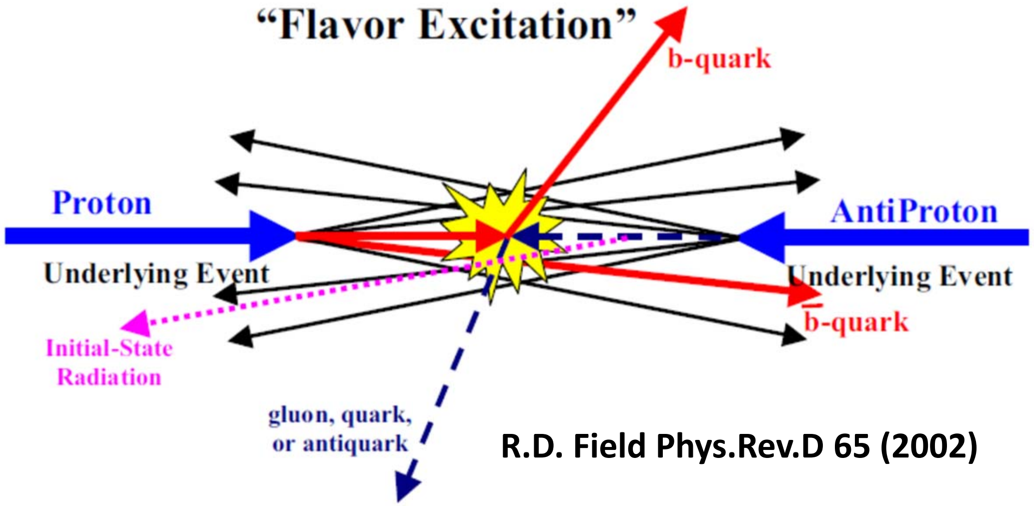


- Good agreement in the normalization for EPOS3 vs PYTHIA « LO » (MSEL=4)
- Large excess PYHTIA « NLO »; shown to be due to flavor excitation like process

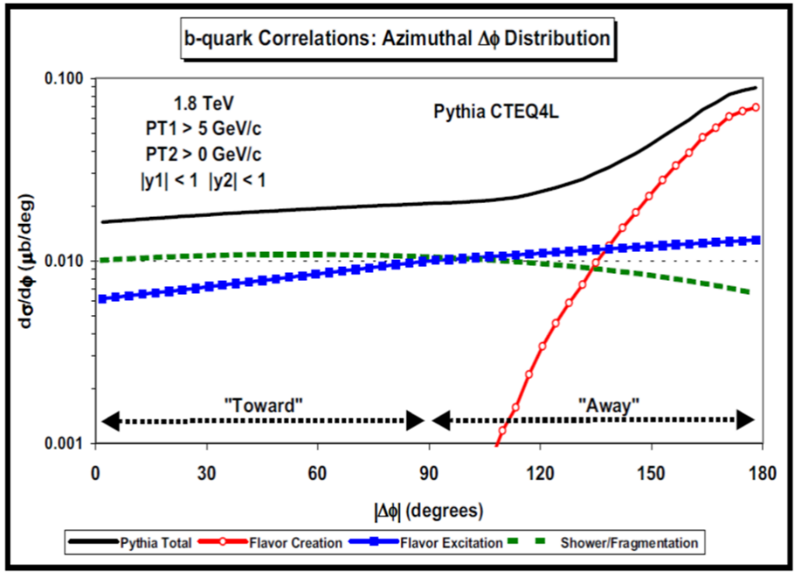
<u>N.B.</u>: Pythia MSEL=4: at least 1 ccbar pair un each event => Normalized according to high-p_T LO charm creation in Pythia MSEL=1

Momentum imbalance: not so naïve approach

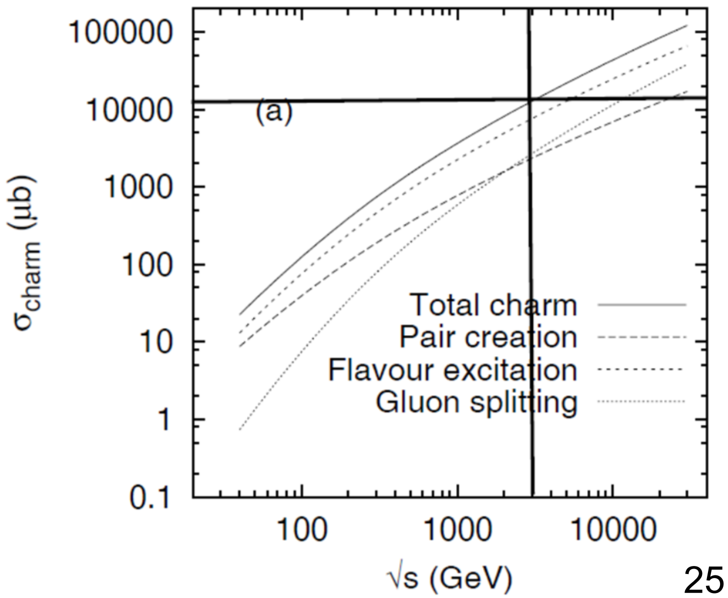
➢ Including NLO effects in the charm production:



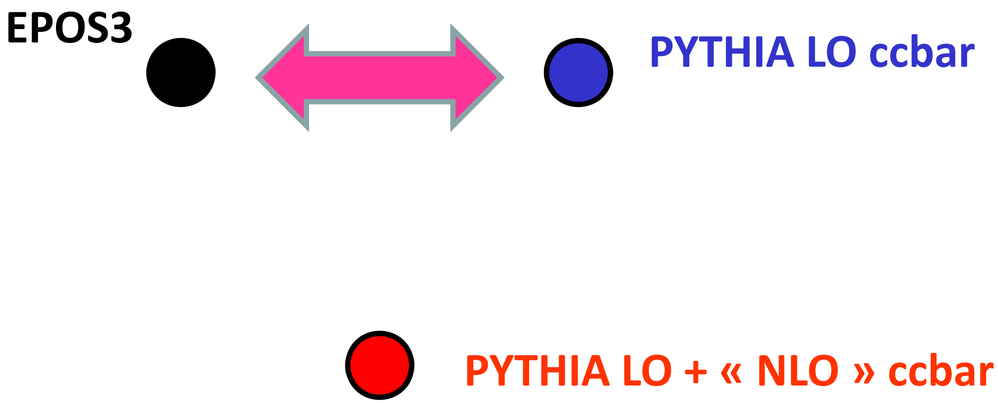
R.D. Field Phys.Rev.D 65 (2002)

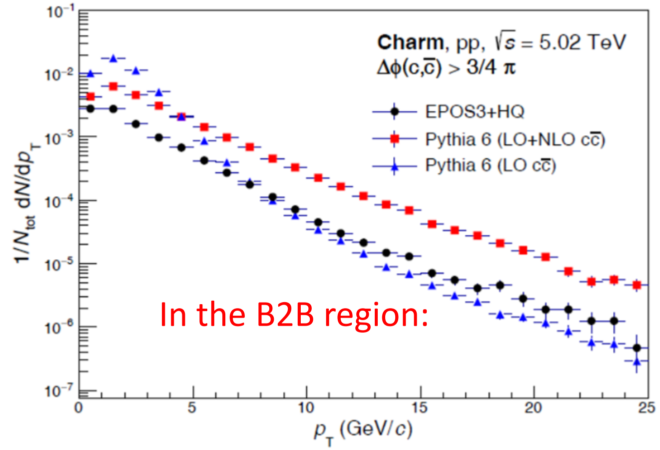


- Flavor excitation: very sensitive to the ccbar in the proton sea, i.e. to the gluon evolution -> large Q^2
- σ_{charm} (Pythia 6,) exceeds measured ALICE value by a factor 3-5. Mostly due to large FEX contribution.
- Similar conclusion of sur-abundant FEX found by CMS (CMS-PAS-HIN-16-005) for beauty quarks



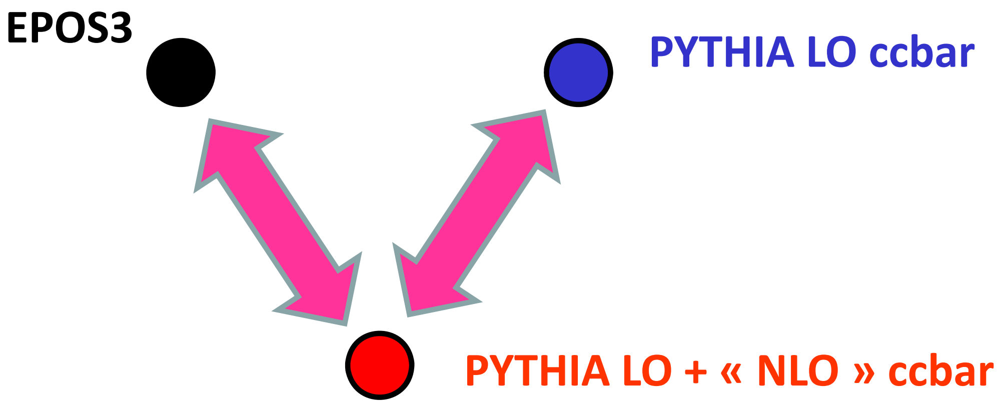
Momentum imbalance: not so naïve approach

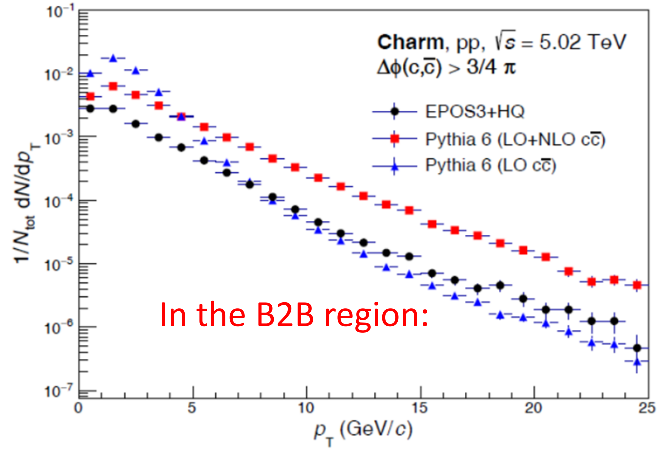




- Same process in the B2B => use the p_T correlations to investigate FSR

Momentum imbalance: not so naïve approach

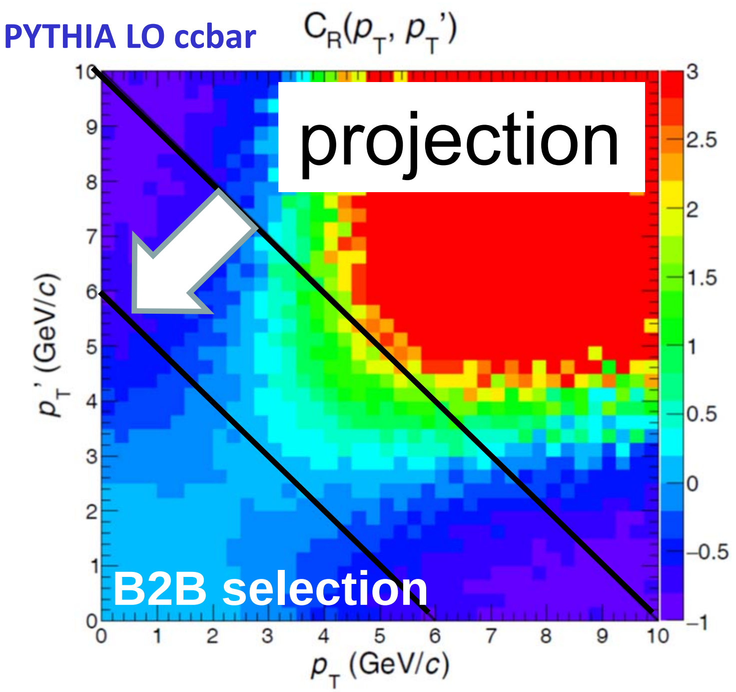




- Same process in the B2B => use the p_T correlations to investigate FSR

- Use p_T correlations to resolve FEX contribution in the B2B region

Momentum imbalance: not so naïve approach



Abolute correlation:

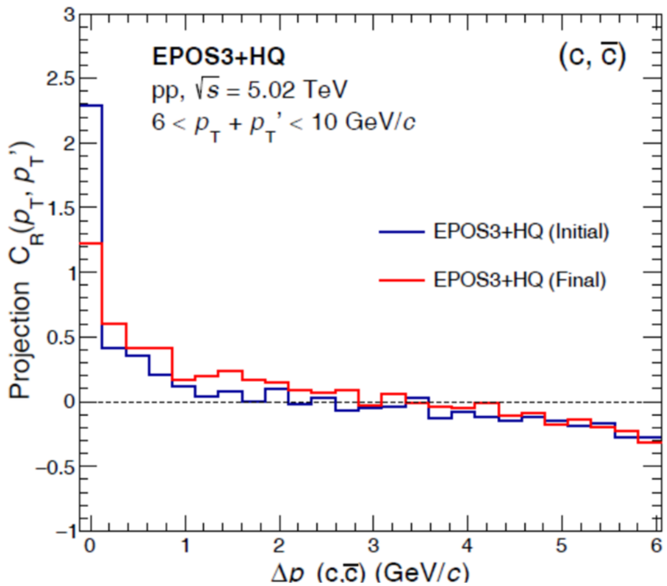
$$C(p_T, p'_T) := \frac{1}{N}\frac{d^2N(p_T, p'_T)}{dp_T dp'_T} - \frac{1}{N}\frac{dN(p_T)}{dp_T} \times \frac{1}{N}\frac{dN(p'_T)}{dp'_T}$$

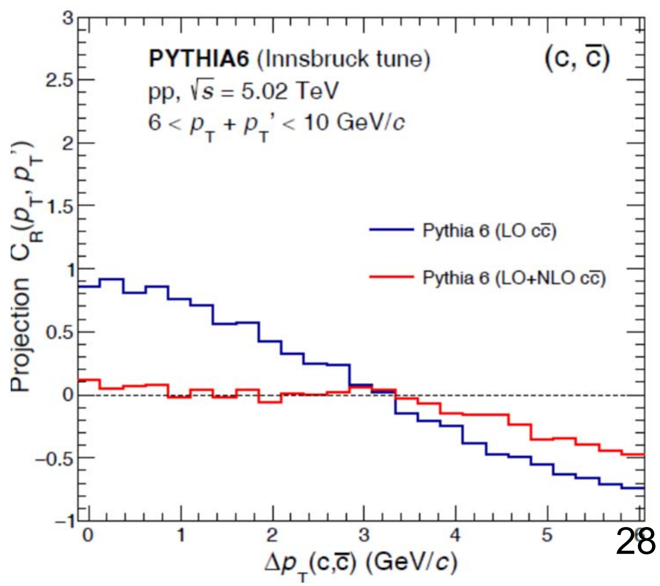
- Vanishes if d^2N factorizes ($d^2N(p,p') = dN(p) \times dN(p')$)
- Satisfies $\int C(p_T, p'_T) dp_T d'_T = 0$

Relative correlation: $C_R(p_T, p'_T) := \frac{C(p_T, p'_T)}{\frac{1}{N}\frac{dN(p_T)}{dp_T} \times \frac{1}{N}\frac{dN(p'_T)}{dp'_T}}$

- Reveals correlation at finite p_T

- Different p_T imbalance for 3 production models in pp
- 2 of them show that NLO effects does not completely destroy the perfect correlation found in LO production
- Similar results for DDbar

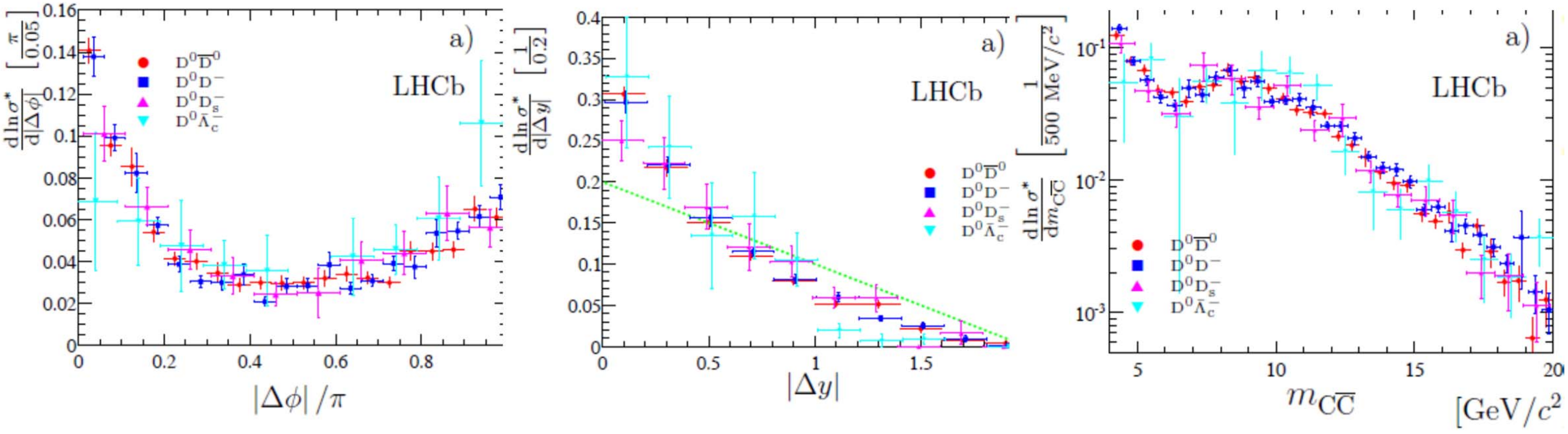




From the experimental viewpoint

- No momentum imbalance so far in pp @ LHC (to my knowledge)…
- But valuable data from LHCb on DD:

LHCb, J. High Energy Phys. 06, 141 (2012)



- Under present investigation

Momentum imbalance in A-A

- Some recent works:
  - J. Uphoff et al. (BAMPS): Phys. Rev. C 89 (2014), 064906

All including realistic c-cbar « initial » production

Momentum imbalance in A-A

J. Uphoff et al. (BAMPS): Phys. Rev. C 89 (2014), 064906:

- Collisional Energy loss model calibrated on v_2(D) meson; lead to acceptable results for R_{AA} as well.
- Chosen observable:

$$A_D = \frac{p^D_{T;1} - p^D_{T;2}}{p^D_{T;1} + p^D_{T;2}}$$

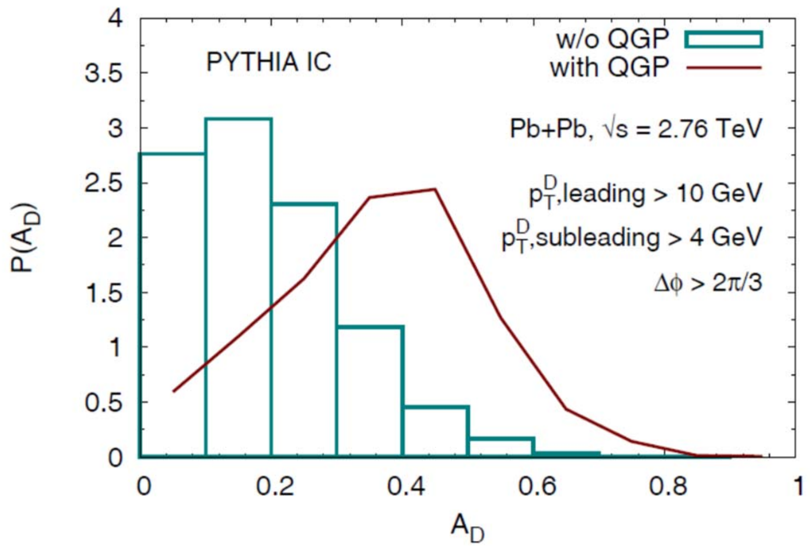
Leading D/Dbar

Sub- Leading D/Dbar

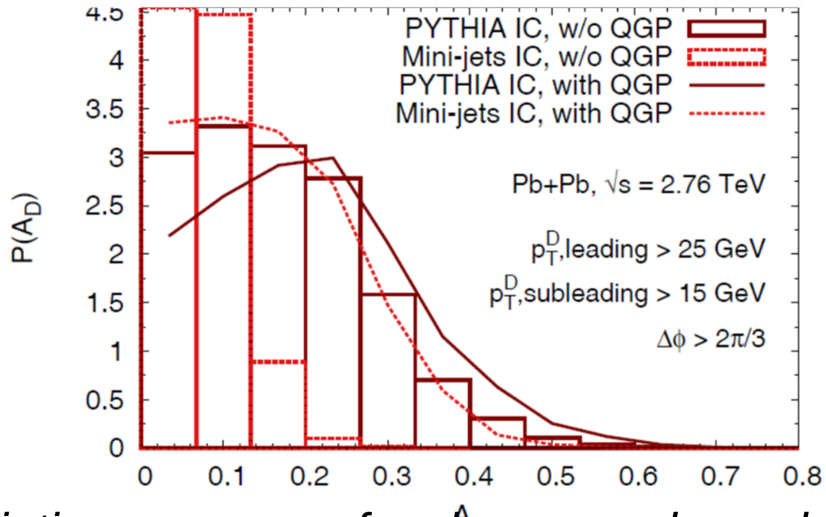
- Back to back selection
- Two selections for most central Pb-Pb collisions:
  - "Intermediate": $p^D_{T;1} > 10\,\mathrm{GeV} \quad \text{and} \quad p^D_{T;2} > 4\,\mathrm{GeV}$
  - "High": $p^D_{T;1} > 25\,\mathrm{GeV} \quad \text{and} \quad p^D_{T;2} > 15\,\mathrm{GeV}$

Momentum imbalance in A-A (BAMPS)

- Intermediate p_T selection:
  - Strong momentum imbalance resulting from c-quark interaction with QGP
  - Large fraction of c-cbar pairs stemming from disconnected NN interactions



- High p_T selection (focusing on PYTHIA IC):
  - Large fraction of c-cbar pairs stemming from single NN interactions Strong
  - Moderate momentum imbalance resulting from c-quark interaction with QGP (MI dominated by IC, as for azimuthal correlations)



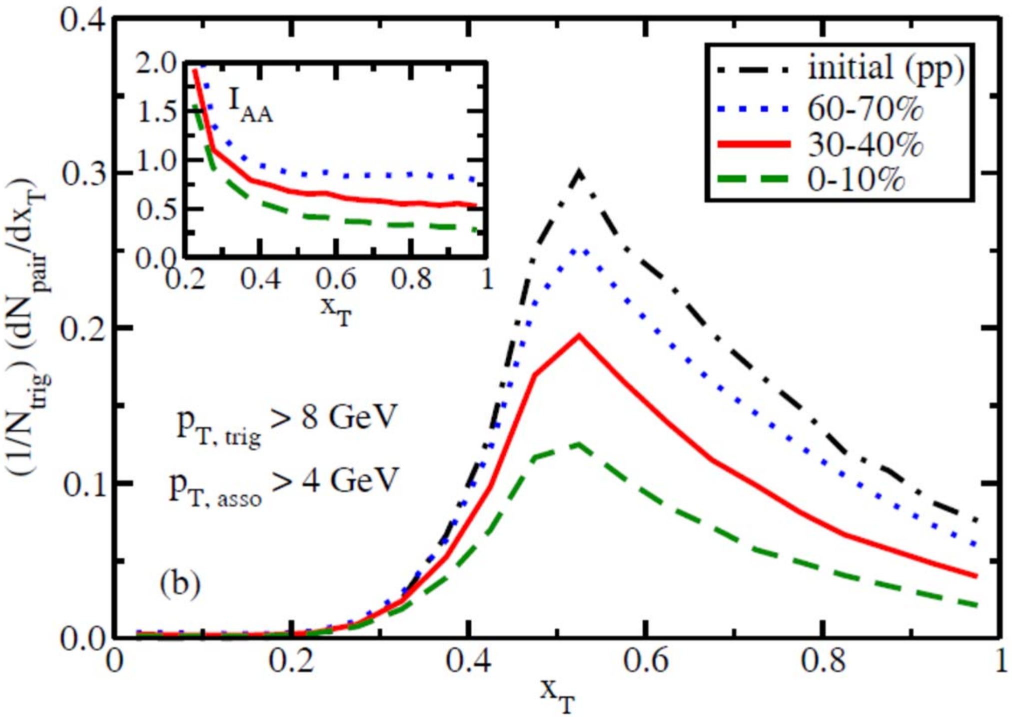
“ Furthermore, it would be intriguing to include also radiative processes for charm quarks and investigate their effects on A_D »

Momentum imbalance in A-A

- Some recent works:

All including realistic c-cbar « initial » production

  - S. Cao et al.: Phys. Rev. C 92 (2015), 054909 (focused on RHIC energies)



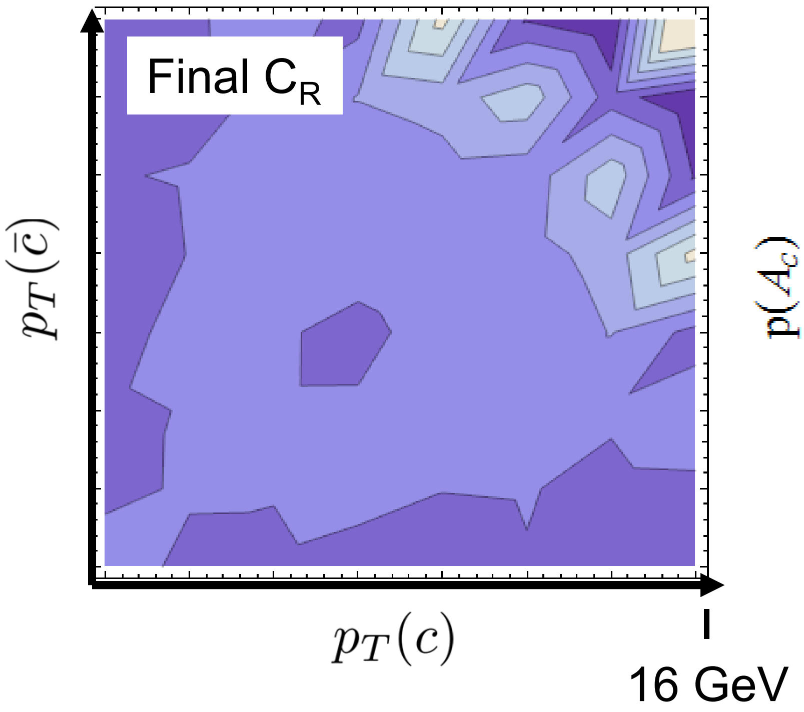
- Observable: $x_T := \frac{p_T^{D(\bar{D}),\mathrm{sublead}}}{p_T^{\bar{D}(D),\mathrm{lead}}}$
- Moderate increase of momentum imbalance from pp $\rightarrow$ peripheral Au-Au $\rightarrow$ central Au-Au collisions
- *"…momentum imbalances … value does not strongly depend on the detailed energy loss mechanism as long as the transport coefficient is properly adjusted to describe the D meson RAA. »*

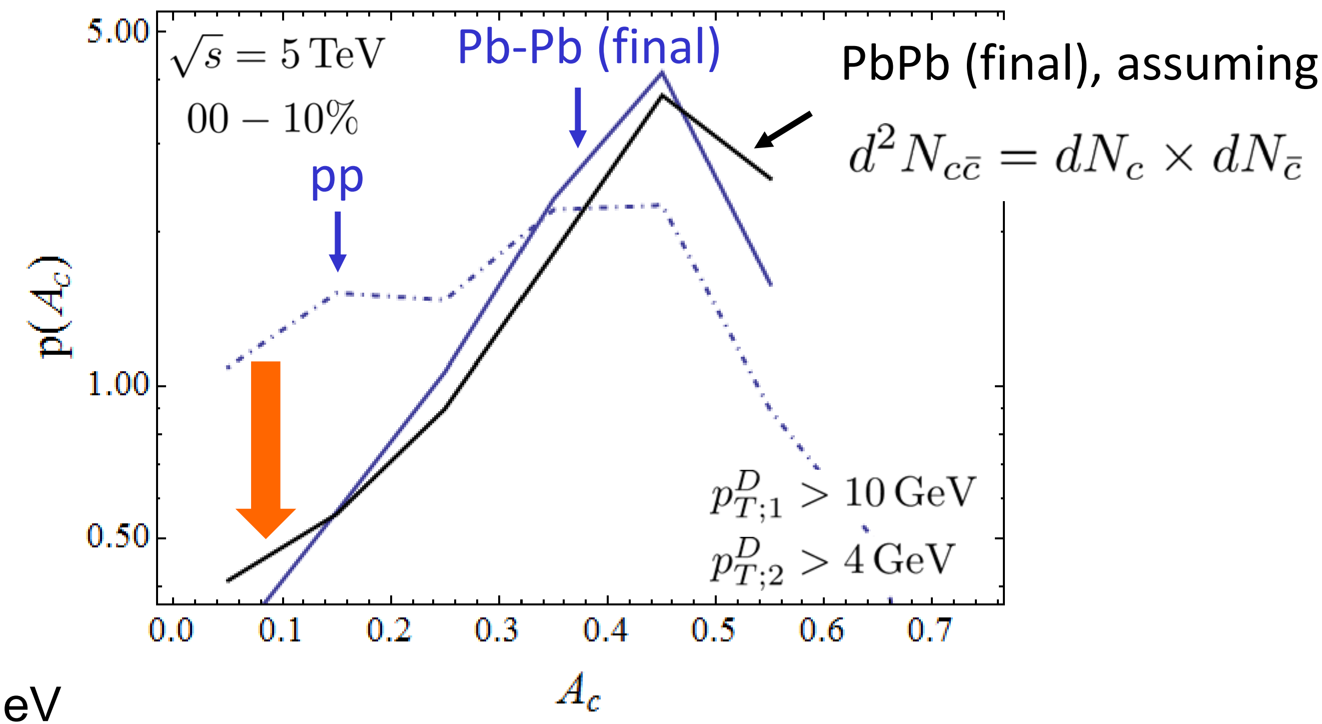
  - T. Song et al. (PHSD): Phys. Rev. C 96 (2017), 014905 (azimuthal correlations)

Momentum imbalance in central Pb-Pb (EPOSHQ)

- All HQ produced according to EPOSHQ (V3210)
- Final c-cbar:

Collisional Energy loss (K=1.5)



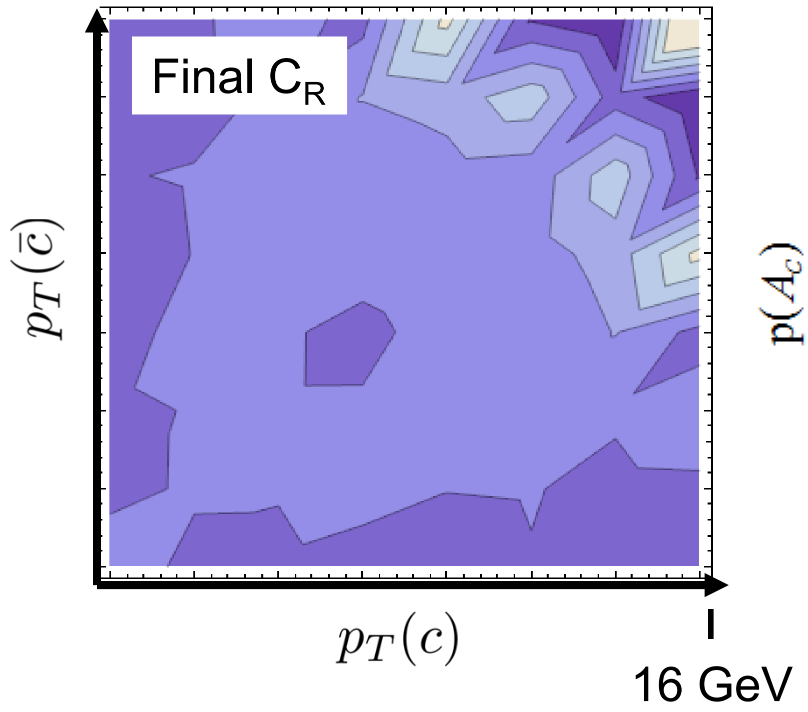


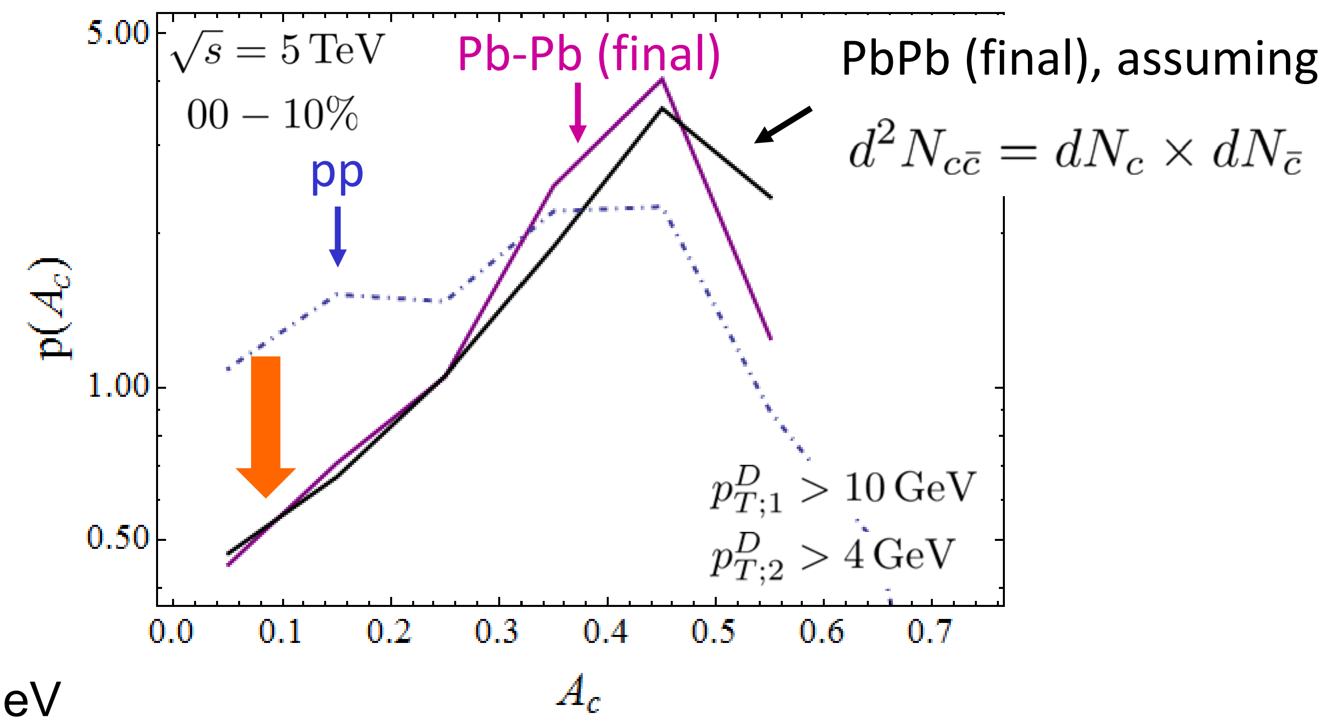
- Very few remaining corre-lations in the final stage of the collision
- ≈ 100% memory loss of initial correlations

Momentum imbalance in central Pb-Pb (EPOSHQ)

- All HQ produced according to EPOSHQ (V3210)
- Final c-cbar:

Col + Rad Energy loss (K=0.8)

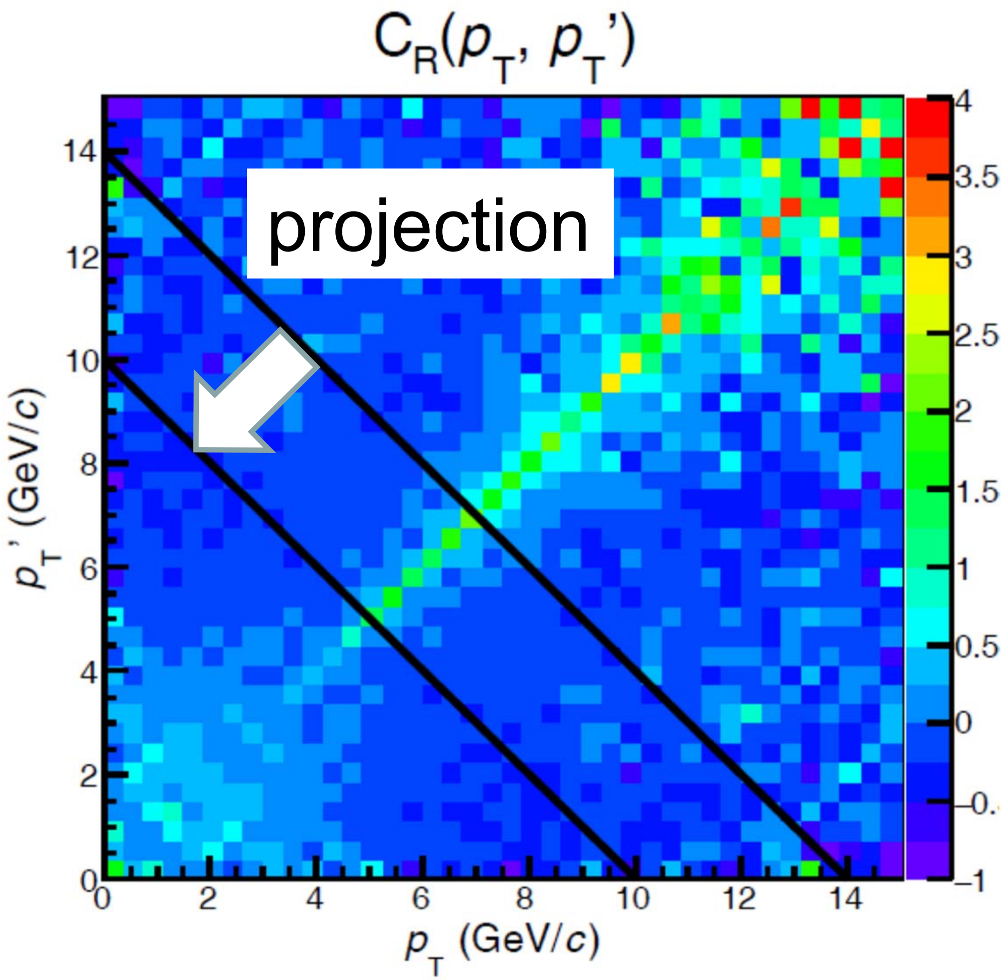


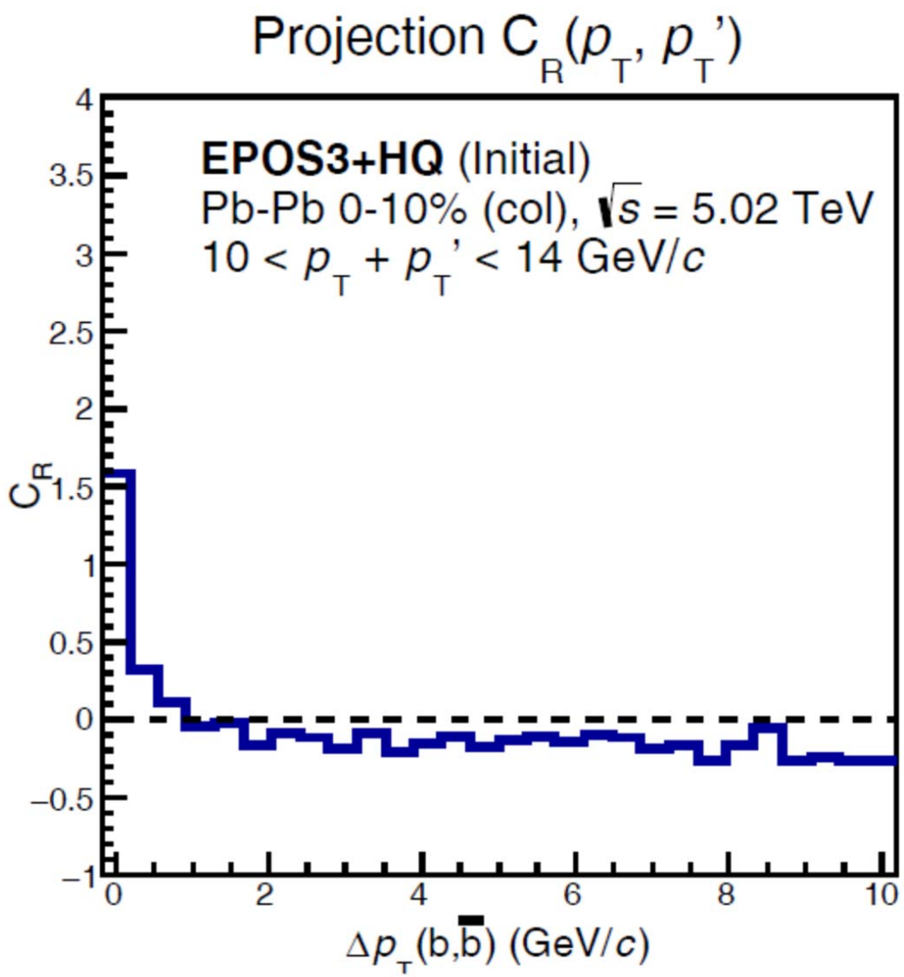


- Very few remaining correlations in the final stage of the collision
- ≈ 100% memory loss of initial correlations, irrespective of E loss mechanism => no good discrimination (also for beauty)
- Problem with A_D: no clear decorrelation limit

Momentum imbalance: b-bar in Pb-Pb

- "Initial" stage (before evolution with the medium)

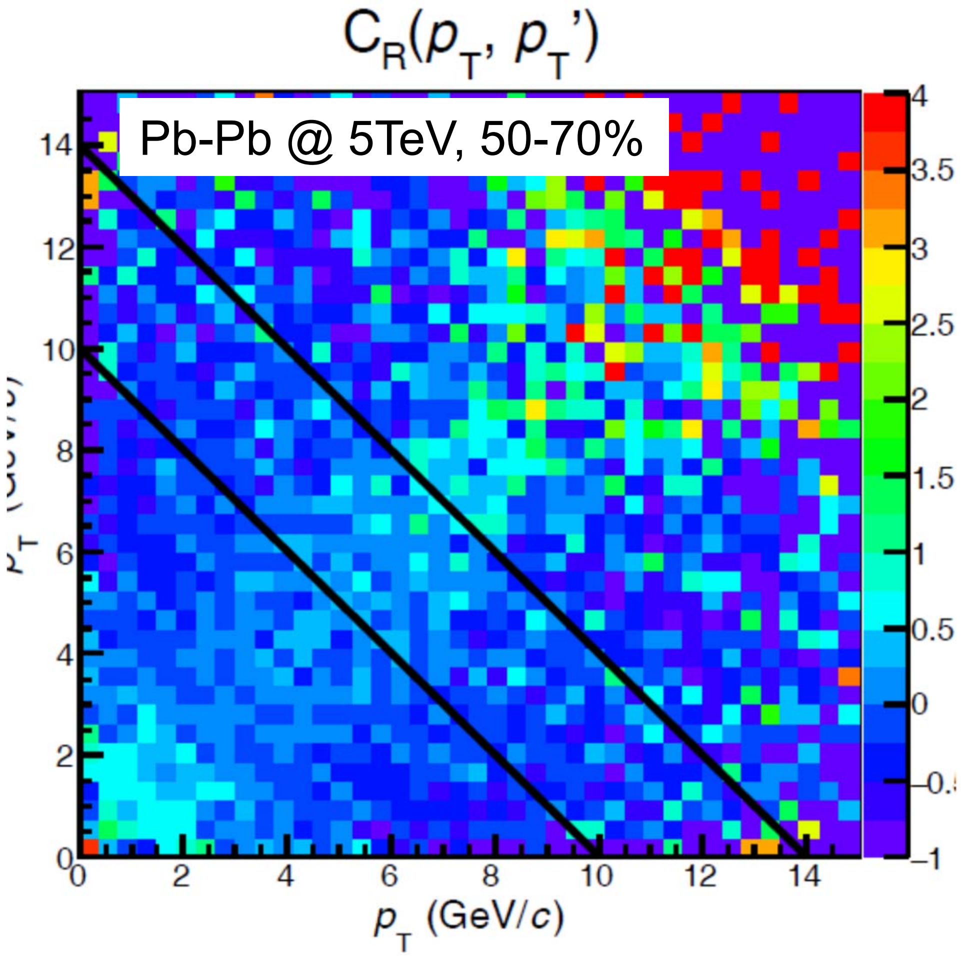




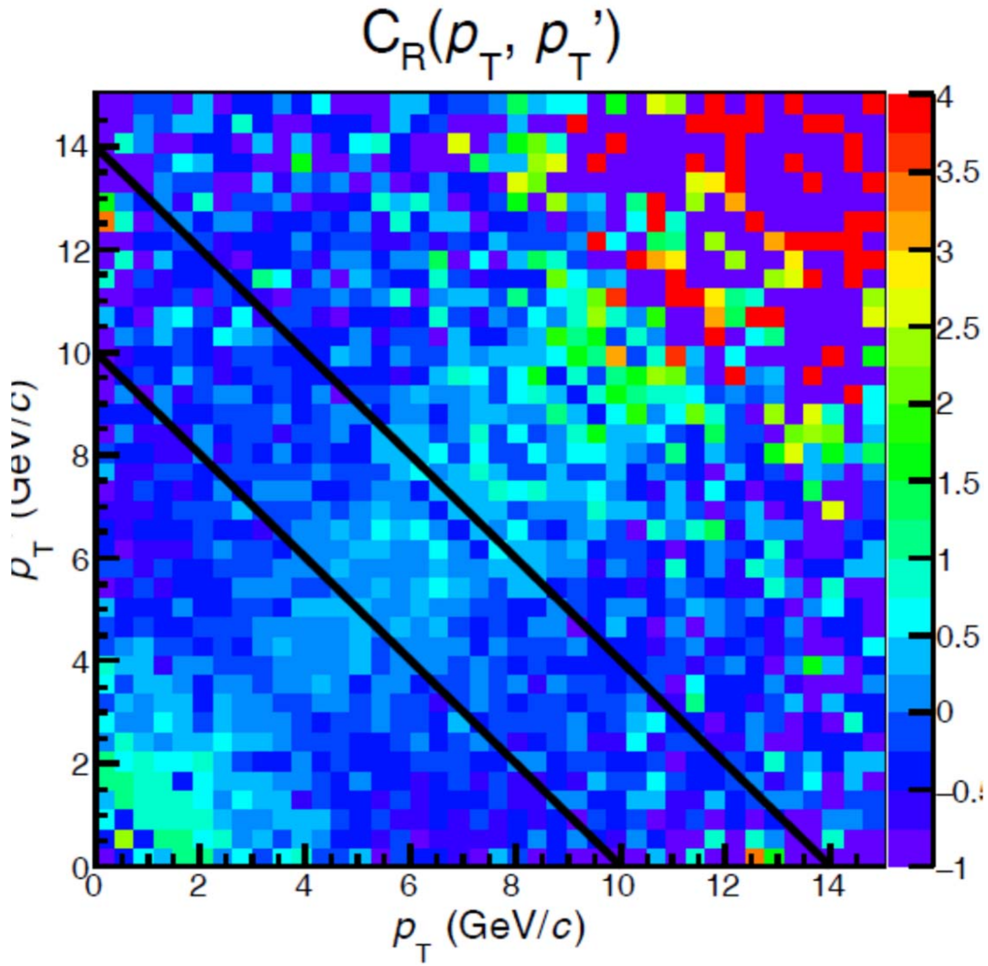
- Very good correlation for intermediate p_T
- Much less uncorrelated background than for c-cbar.

Momentum imbalance: b-bar in Pb-Pb

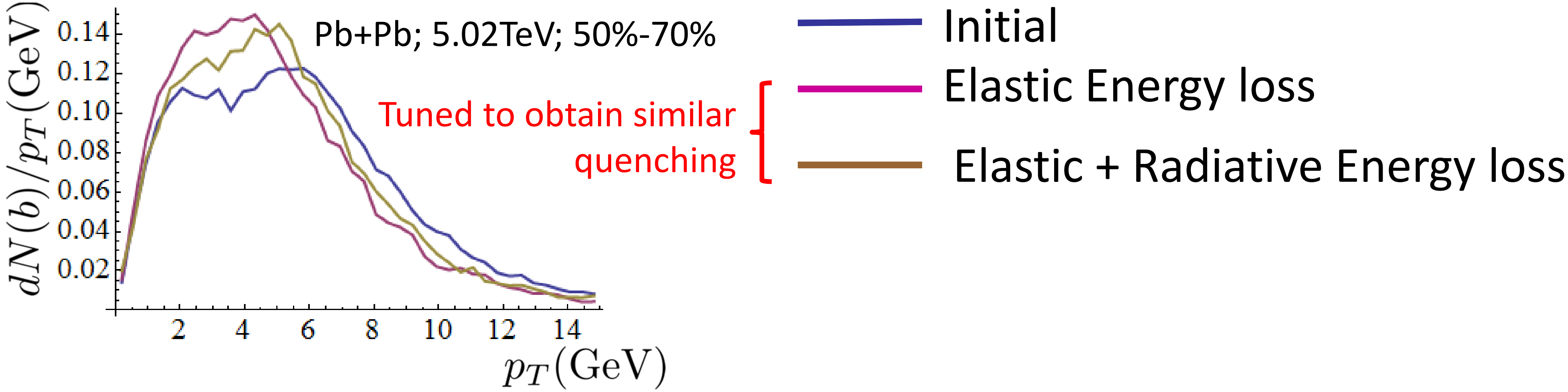
Elastic Energy loss

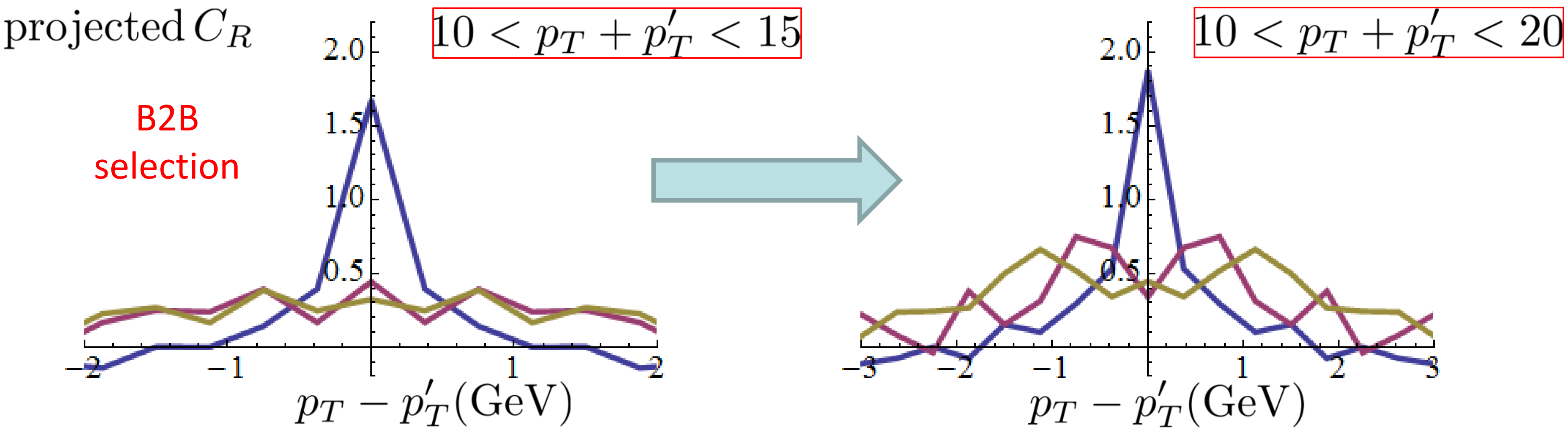


Elastic + Radiative Energy loss



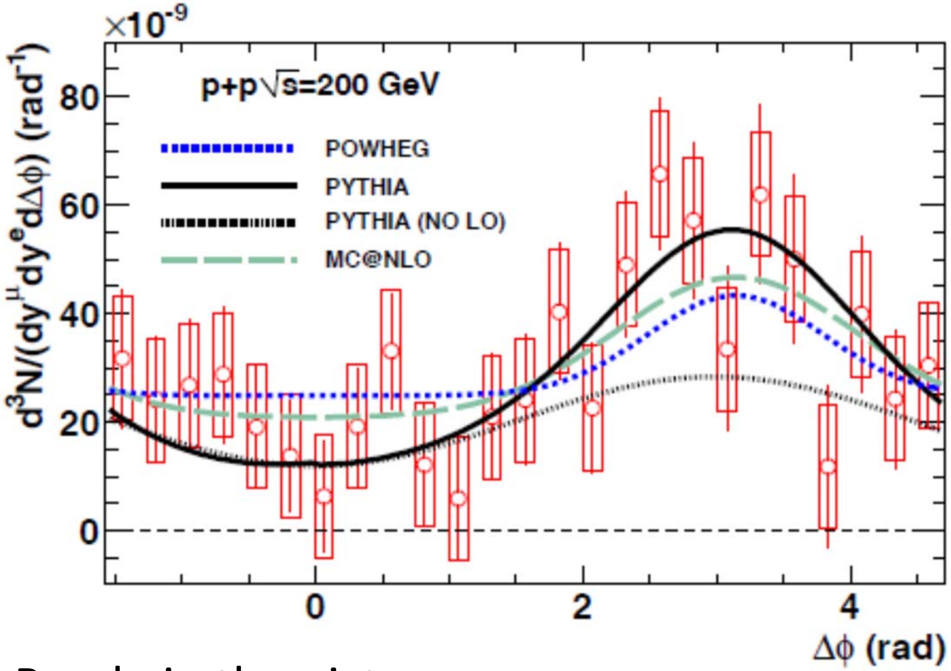
Momentum imbalance: b-bar in Pb-Pb





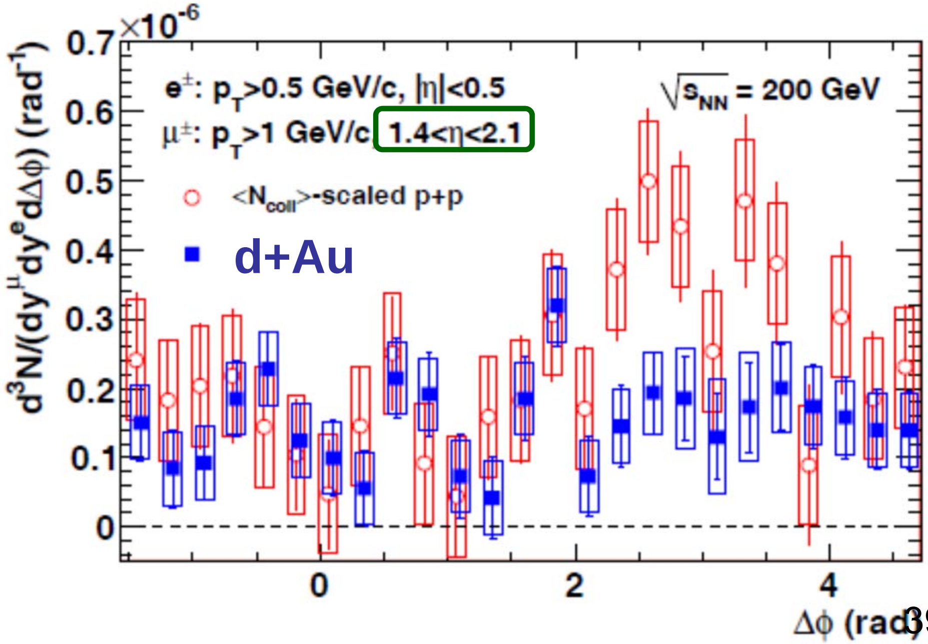
- QGP partly washes away the correlation peak... Possible window to estimate the relative weights of elastic and radiative energy loss for bottom quarks

Next best thing: HF-HF -> e-μ correlations



PHENIX: Phys. Rev. C. 89, 034915 (2014)

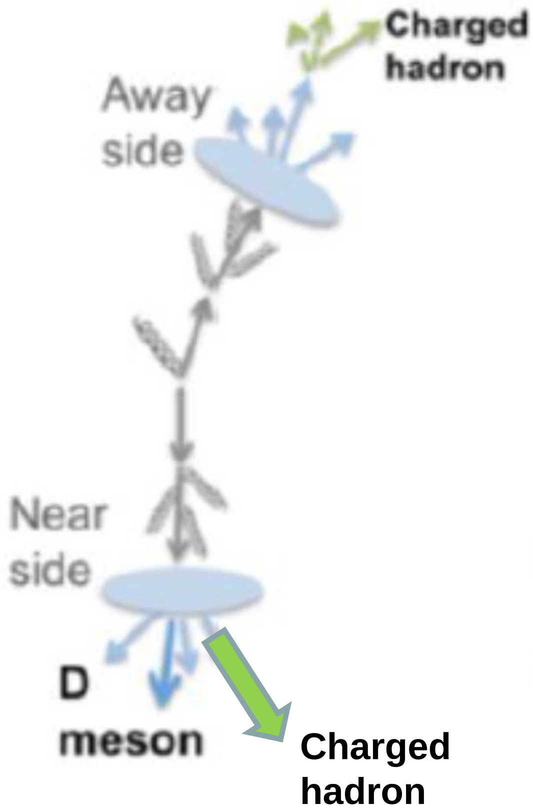
- Puzzle in the picture:
- "Such a suppression could arise due to nuclear PDF shadowing, saturation of the gluon wavefunction in the Au nucleus, or initial/final state energy loss and multiple scattering. »
- Did not seem to have received enough attention from the community

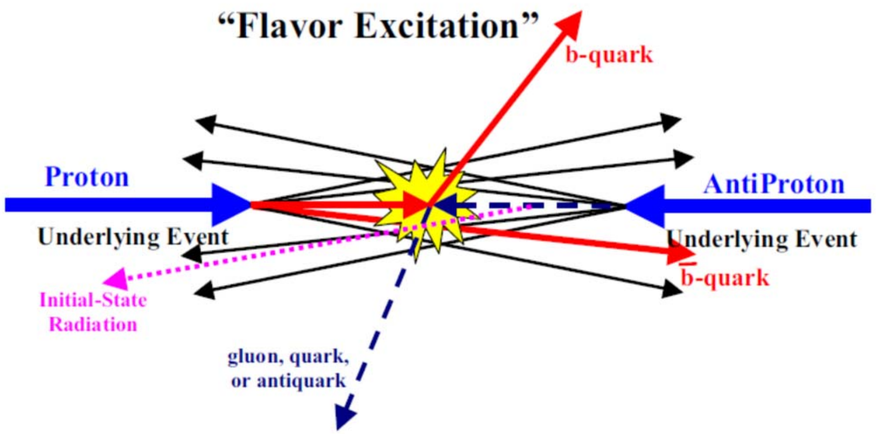


Some words on D/B-h / e-h / … correlations

- + : less demanding in terms of statistics (already some experimental results at RHIC and at LHC after run 2 @ LHC)
- + : the near side can provide us new information about the "in medium" fragmentation.

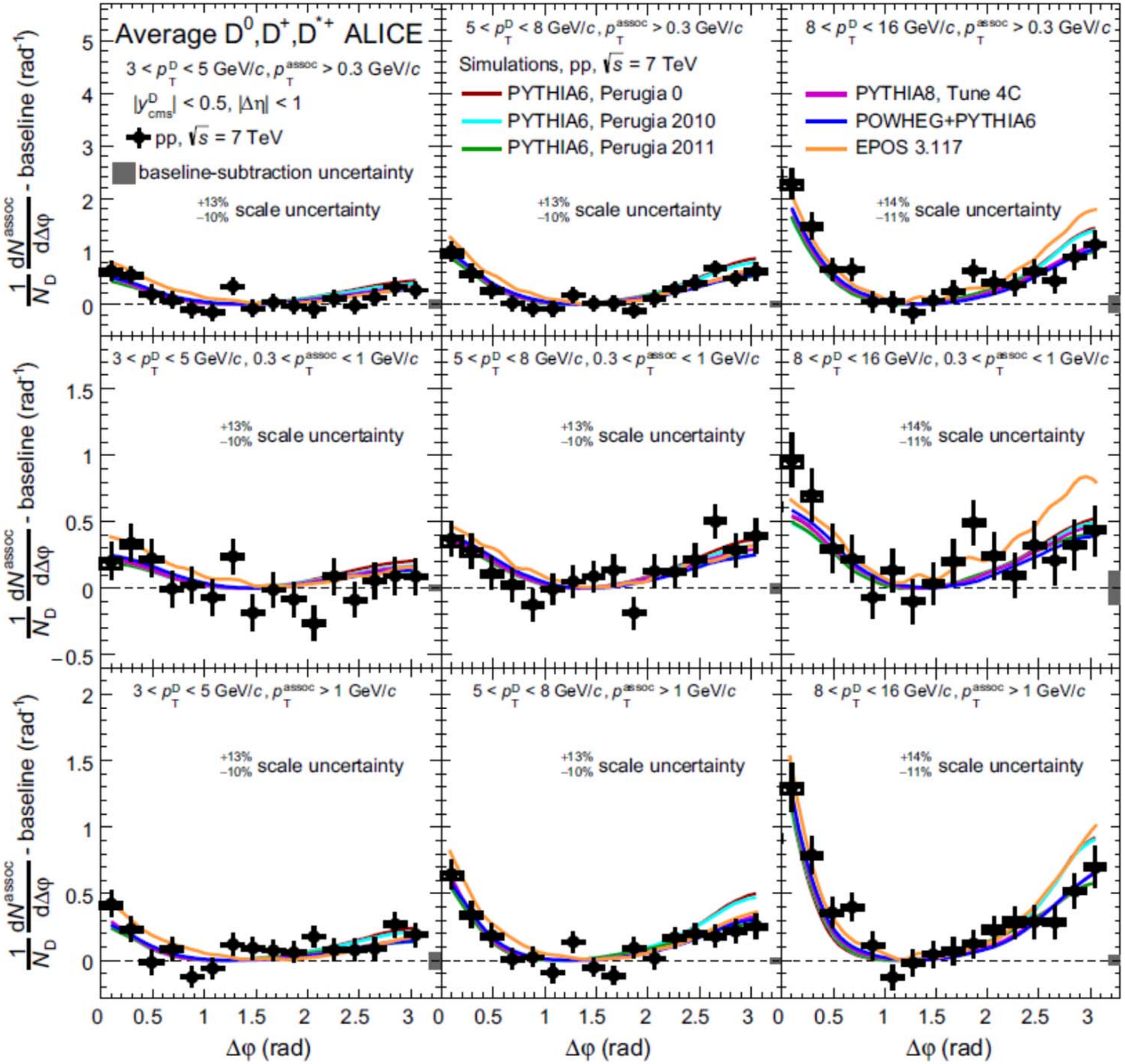
- - : Access to QQbar angular correlations is more indirect and "washed out"
- - : More influenced by the "underlying event" than HF-HF correlations : maybe, HF also feel the influence of the bulk
- - : New processes implied in the away side region:





More involved from a theory / modelling view point; requires multi-component models

Some words on D-h … in pp



ALICE, Eur. Phys. J. C (2017) 77:245

- Qualitative agreement between data and models, within the (large) uncertainties
- EPOS3 predicts larger and wider peaks than the PYTHIA/POWHEG for Δϕ correlations

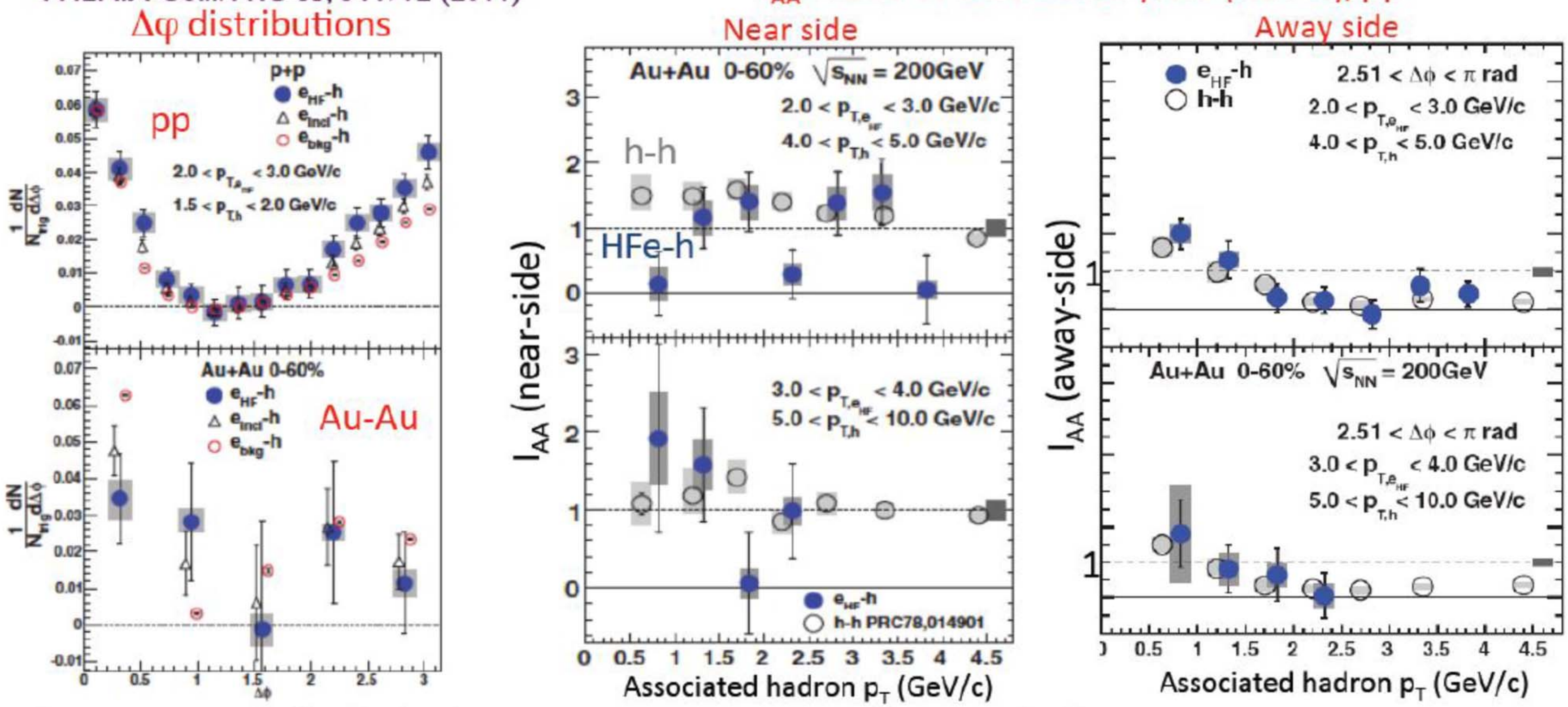
Calibration ≈ ok

Some words on e-h / … in AA (at RHIC)

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

PHENIX Coll.: PRC 83, 044912 (2011)

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



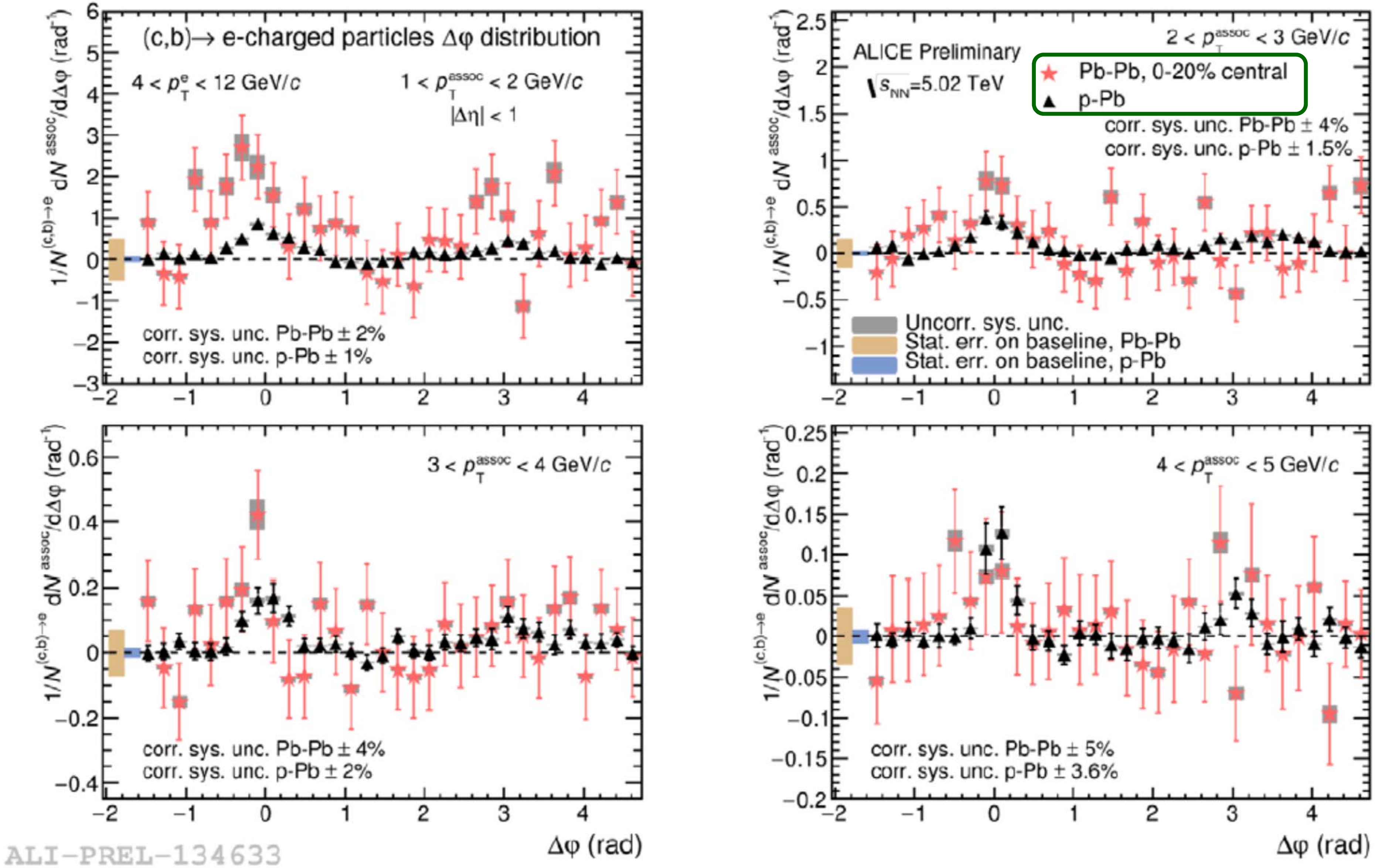
Large uncertainties in Au-Au measurement prevent firm conclusions
Suggest a decreasing I_{AA} trend with hadron p_T in the away side
Similar results than hadron-hadron correlations (a coincidence?)

→ Higher precision with new data

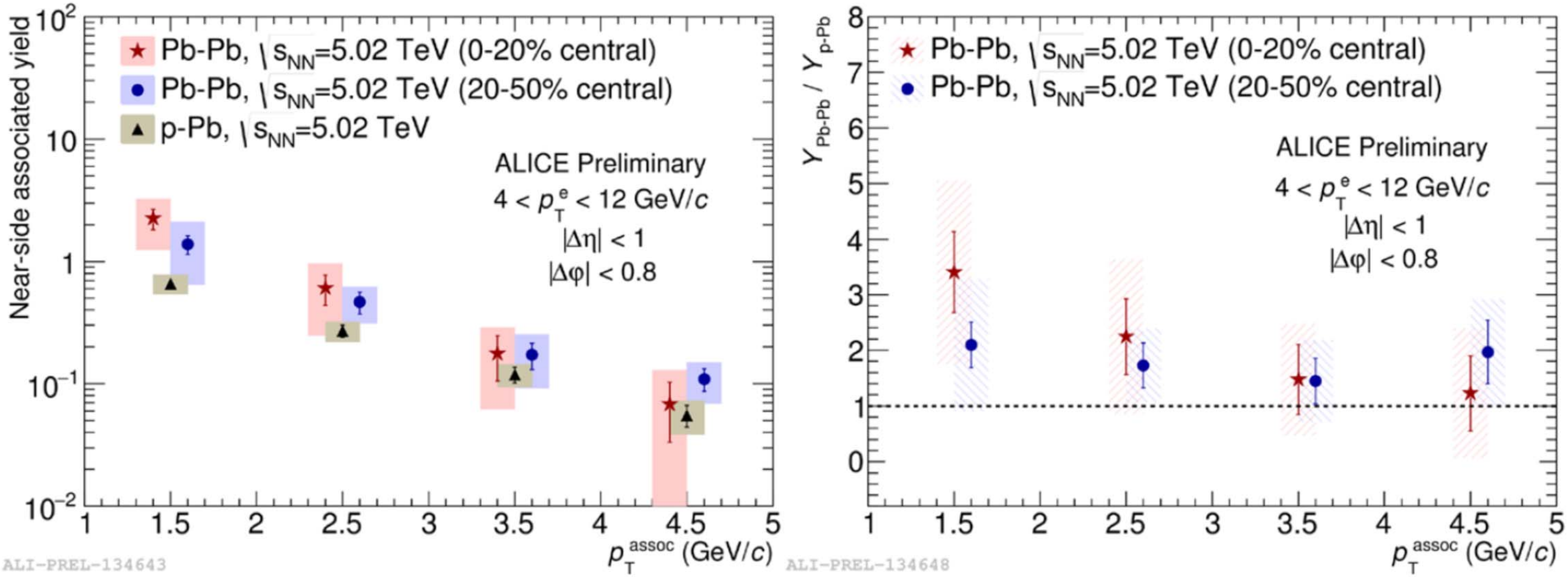
A. Rossi

55

Some words on e-h / … in AA (at LHC)



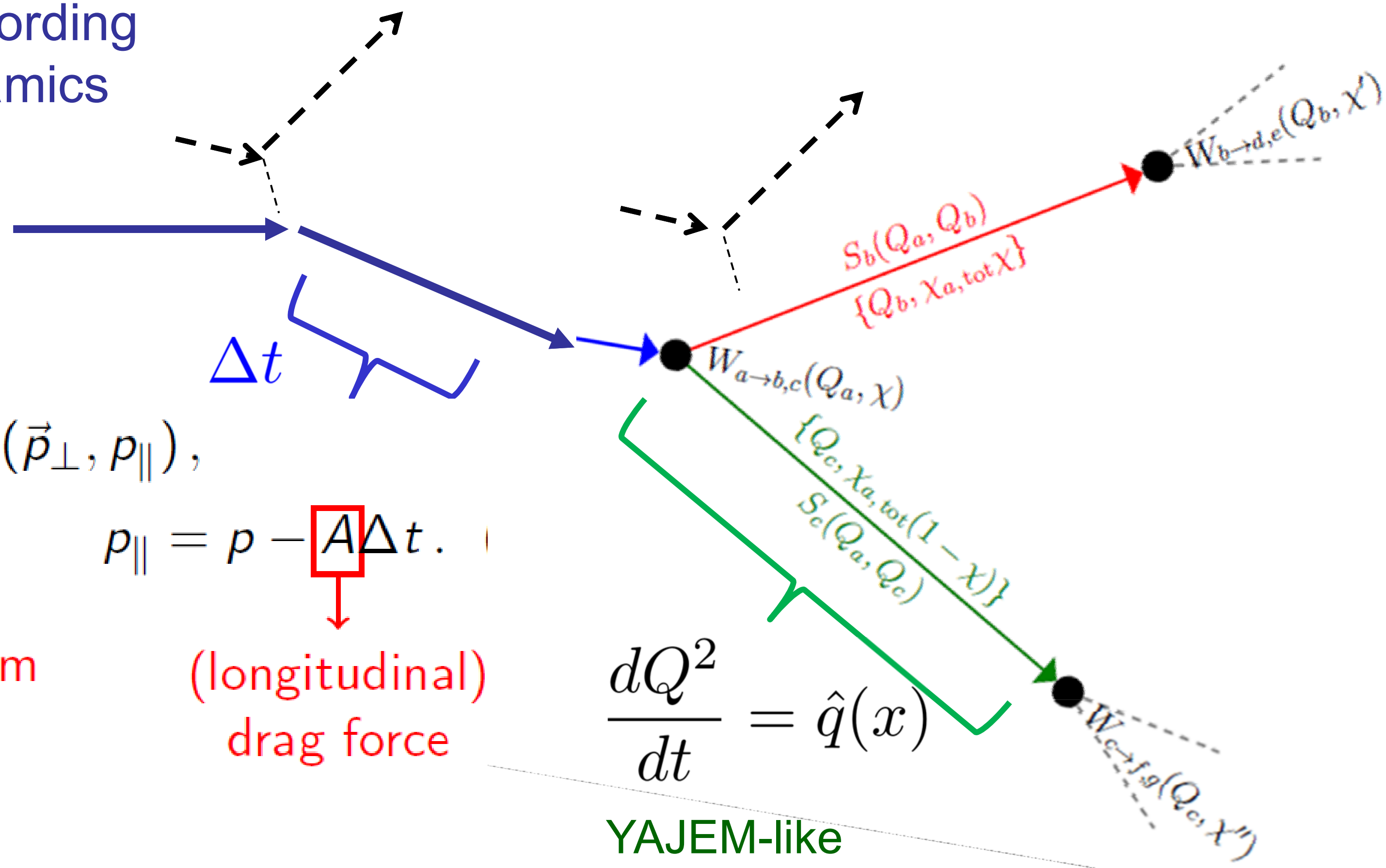
Some words on e-h / … in AA (at LHC)



- ALICE concludes: "Going lower with p_T^{assoc}, hints of a hierarchy in NS yields: Pb-Pb 0-20% shows an enhancement w.r.t. p-Pb, despite very large total uncertainties" : priority 1
- No conclusion for the away side peak after run 2. priority >1

Modified DGLAP (Elastic + induced radiation)

Rescattering according to Langevin dynamics



$$\vec{p} = (\vec{0}, p) \mapsto \vec{p}' = (\vec{p}_\perp, p_\parallel),$$

$$p_\perp = \sqrt{\hat{q}\Delta t}, \qquad p_\parallel = p - A\Delta t.$$

$\hat{q}$ → transverse momentum transfer

A → (longitudinal) drag force

$$A = \frac{\hat{q}}{\kappa T}$$

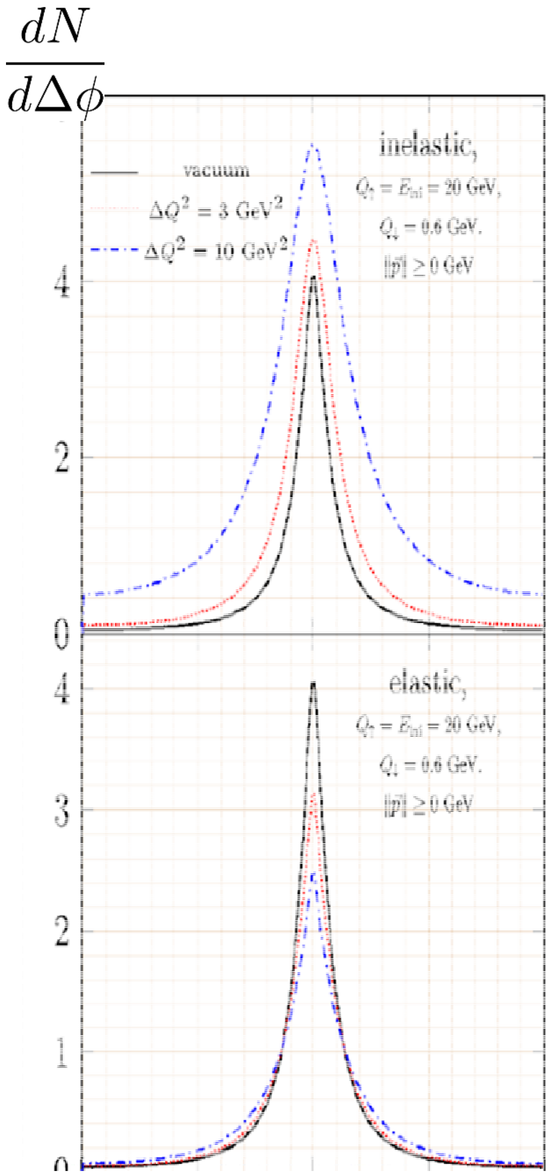
[H. Berrehrah et al. PRC 90, 064906 (2014)]

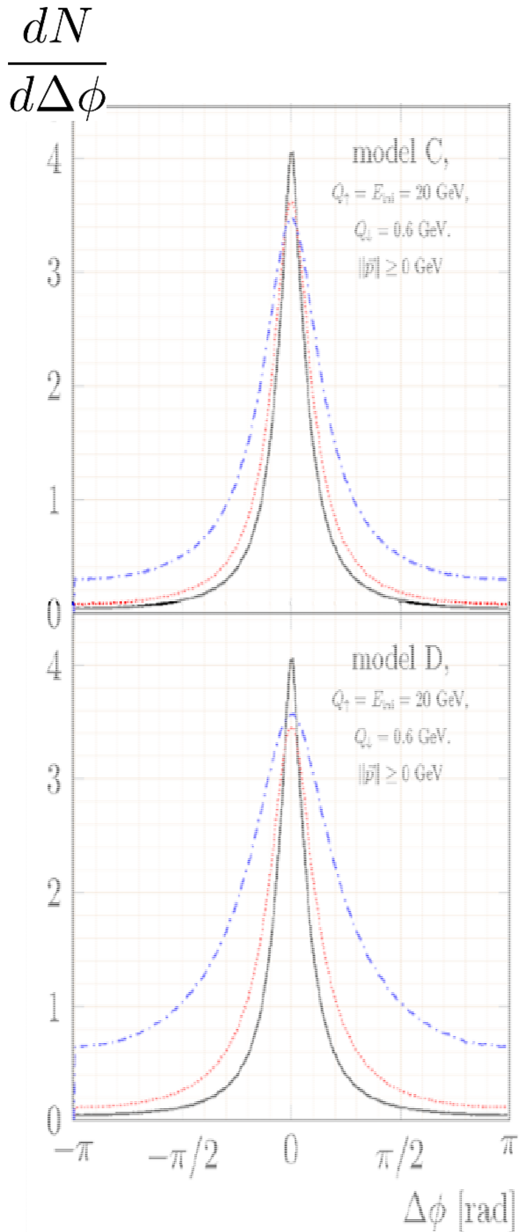
$$\frac{dQ^2}{dt} = \hat{q}(x)$$

YAJEM-like

increase of the virtuality => extra induced radiation.

Near side study with a generic jet – medium model





M. Rohrmoser's PhD thesis (2017)

Preliminary results in J.Phys. Conf. Ser. 779 (2017), 012032

...To be implemented in EPOSHQ with bulk back-reaction

Conclusions

- HF Correlations are for sure interesting per se and offers a bright future… but:
- One should not expect huge effects ! Up to now, the best effects I am aware of in realistic calculations are of the order of 10 %
- They often imply a much deeper understanding of the production mechanisms (one additional ingredient in the game !)
- Brand new study on momentum imbalance : avoid central (and even semi-central) collisions in order to discriminate between Eloss mechanisms.
- Too early to conclude; as a theorist, one has to get ready to deal with the improved precision data in the HF-HF or γ-HF sector
- HF – hadrons correlations requires fully fledged models and simulators
- By then, the most efficient "constrain" can be obtained by performing systematic multi-domain comparison of the traditional single particle observables…

Pentaquark state discovered at “La Guadeloupe”

Back up

Our basic ingredients for HQ energy loss

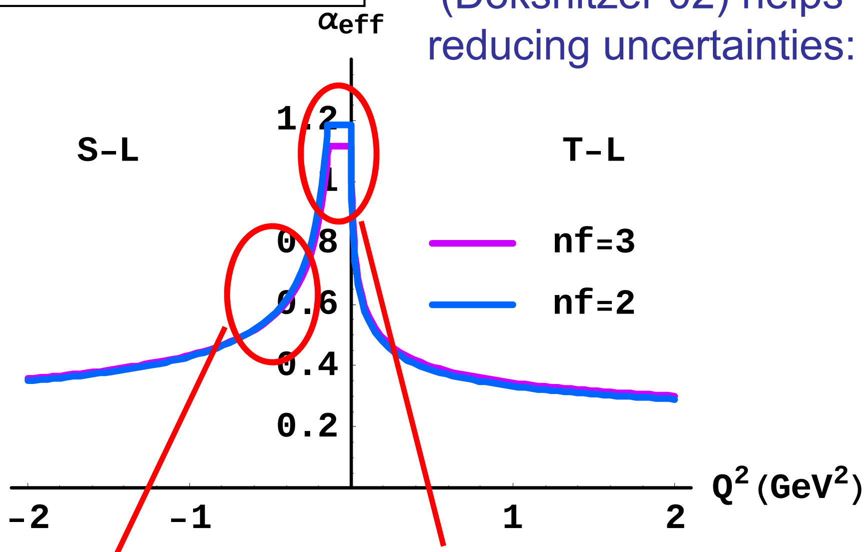
Elastic

Motivation: Even a fast parton with the largest momentum P will undergo collisions with moderate q exchange and large $\alpha_s(Q^2)$. The running aspect of the coupling constant is often “forgotten/neglected” in some approaches

Effective $\alpha_s(Q^2)$ (Dokshitzer 95, Brodsky 02)

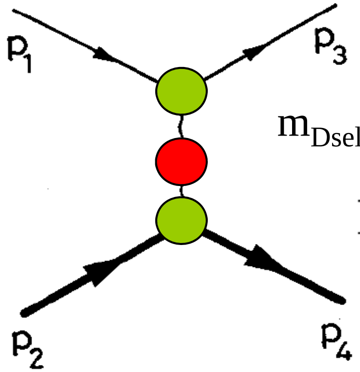
$$\frac{1}{Q_u}\int_{|Q^2|\leq Q_u^2} dQ\,\alpha_s(Q^2) \approx 0.5$$

“Universality constrain” (Dokshitzer 02) helps reducing uncertainties:



IR safe. Q^2 close to 0 does not contribute to Eloss

Large values for intermediate momentum-transfer => larger cross section

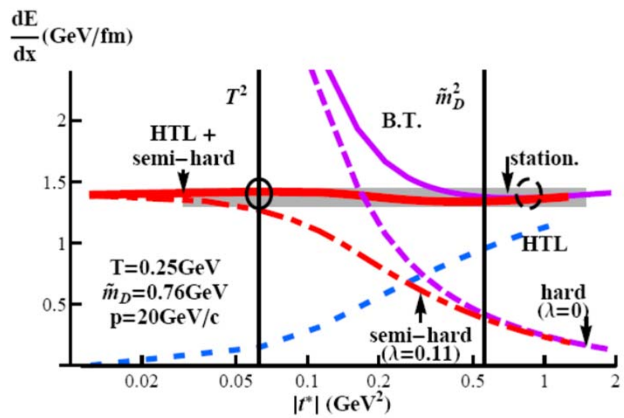


$$m_{Dself}^2(T) = (1+n_f/6)\, 4\pi\alpha_{eff}(m_{Dself}^2)\, T^2$$

$$\text{prop} \propto \frac{1}{q^2 - \kappa m^2_{\mathrm{Dself}}(T)}$$

+ u and s channels

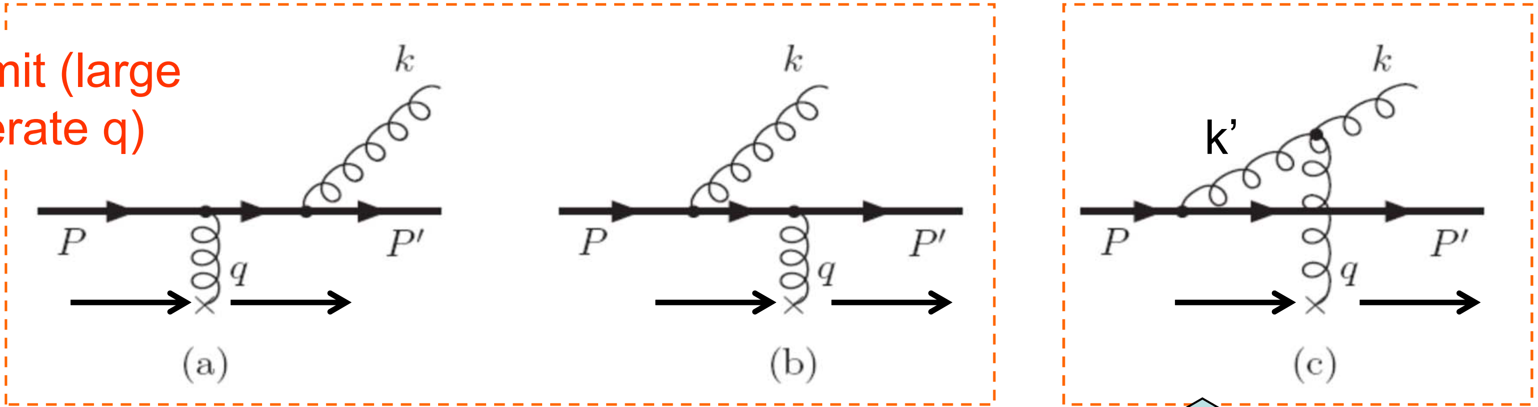
One gluon exchange effective propagator, designed in order to guarantee maximal insensitivity of dE/dx in Braaten-Thomas scheme



Induced Energy Loss

Generalized Gunion-Bertsch (NO COHERENCE) for finite HQ mass, dynamical light partons

Eikonal limit (large E, moderate q)



Dominates as small x as one "just" has to scatter off the virtual gluon k'

$$\omega \frac{d^3\sigma_{\rm rad}^{x\ll 1}}{d\omega d^2k_\perp dq_\perp^2} = \frac{N_c\alpha_s}{\pi^2}(1-x) \times \frac{J_{\rm QCD}^2}{\omega^2} \times \frac{d\sigma_{\rm el}^{Qq}}{dq_\perp^2}$$

with

$$\frac{J_{\rm QCD}^2}{\omega^2} = \left(\frac{\vec{k}_\perp}{k_\perp^2 + x^2M^2 + (1-x)m_g^2} - \frac{\vec{k}_\perp - \vec{q}_\perp}{\left(\vec{k}_\perp - \vec{q}_\perp\right)^2 + x^2M^2 + (1-x)m_g^2} \right)^2$$

Gluon thermal mass ~2T (phenomenological; not in BDMPS)

Quark mass

Both cures the collinear divergences and influence the radiation spectra (dead cone effect)

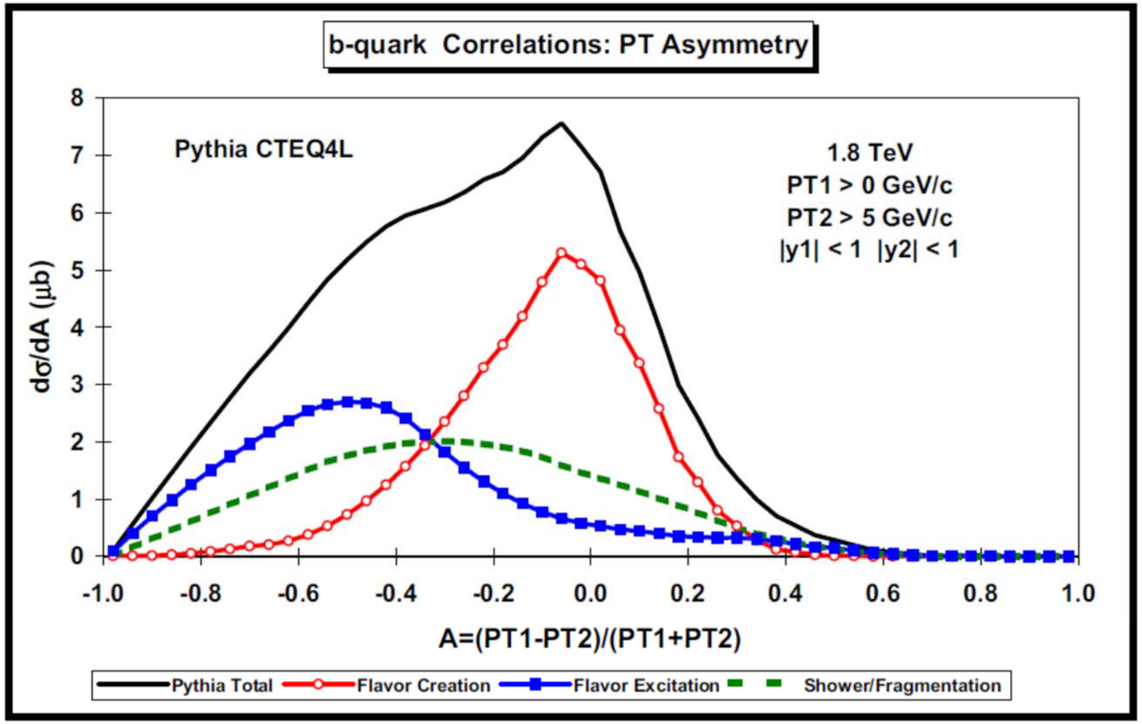
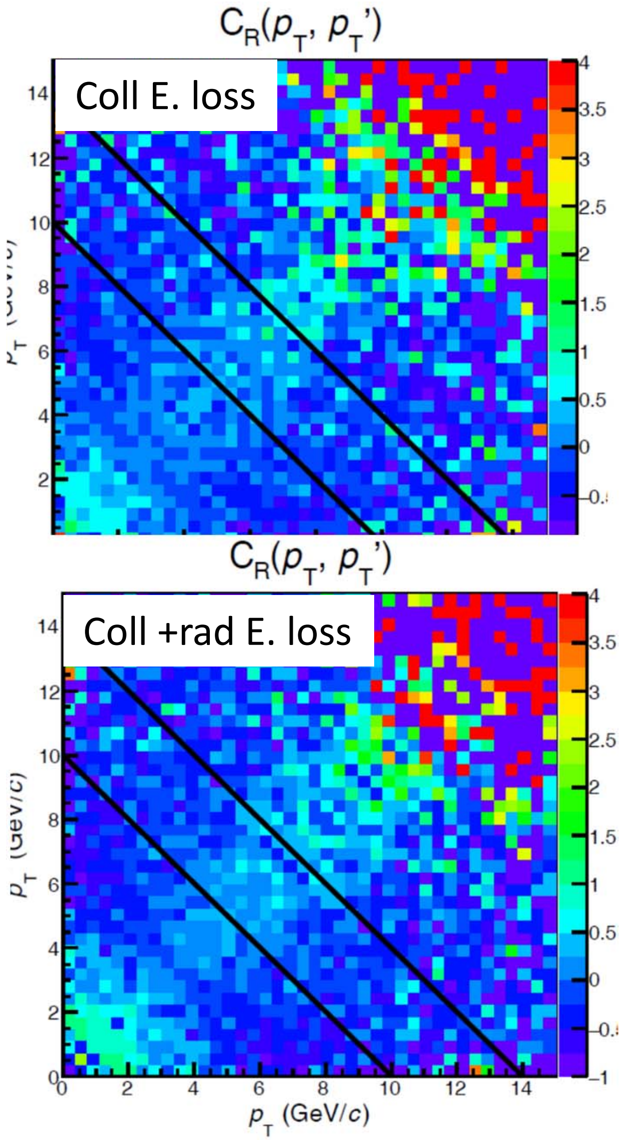


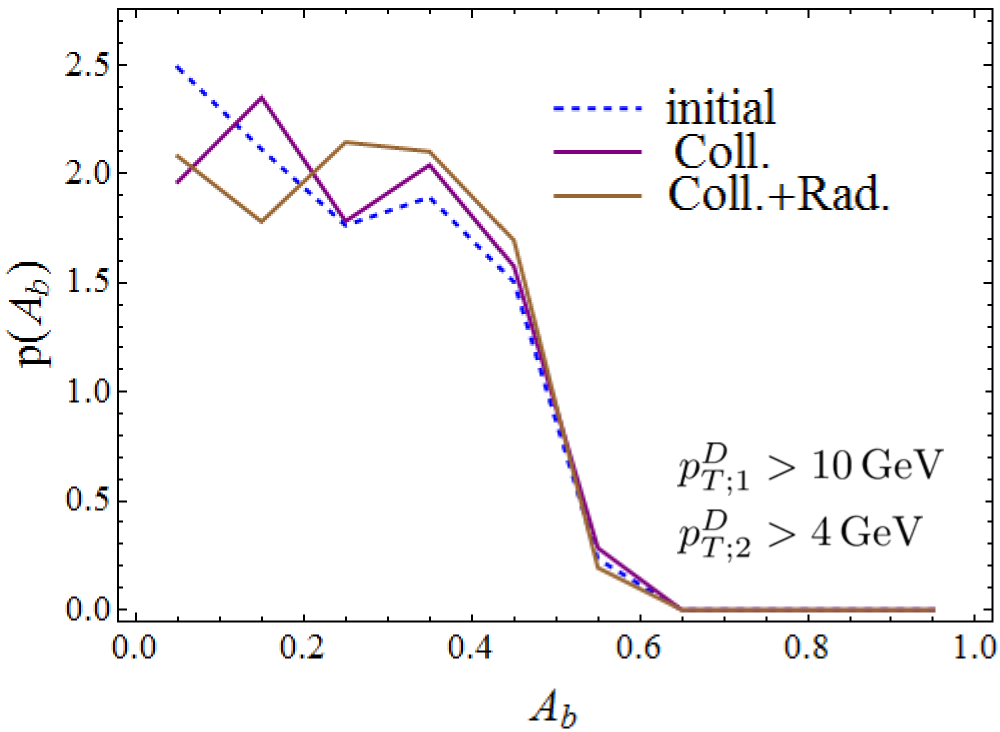
FIG. 18: Prediction of PYTHIA 6.158 (CTEQ4L, p_T(hard)> 0) for the p_T asymmetry, $A = (p_{T1} - p_{T2})/(p_{T1} + p_{T2})$, for events with a b-quark with $p_{T1} > 0$ and $|y_1| < 1.0$ and a $\bar{b}$-quark with $p_{T2} > 5$ GeV/c and $|y_2| < 1.0$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/dA$ (μb) for flavor creation (FIG. 1), flavor excitation (FIG. 3), shower/fragmentation (FIG. 4), and the resulting total.

$$\frac{d\sigma}{dA} = \int \Sigma \frac{d\Sigma}{2} \frac{d\sigma}{dp_T dp'_T}(p_T = \frac{\Sigma}{2}(1+A), p'_T = \frac{\Sigma}{2}(1-A))$$

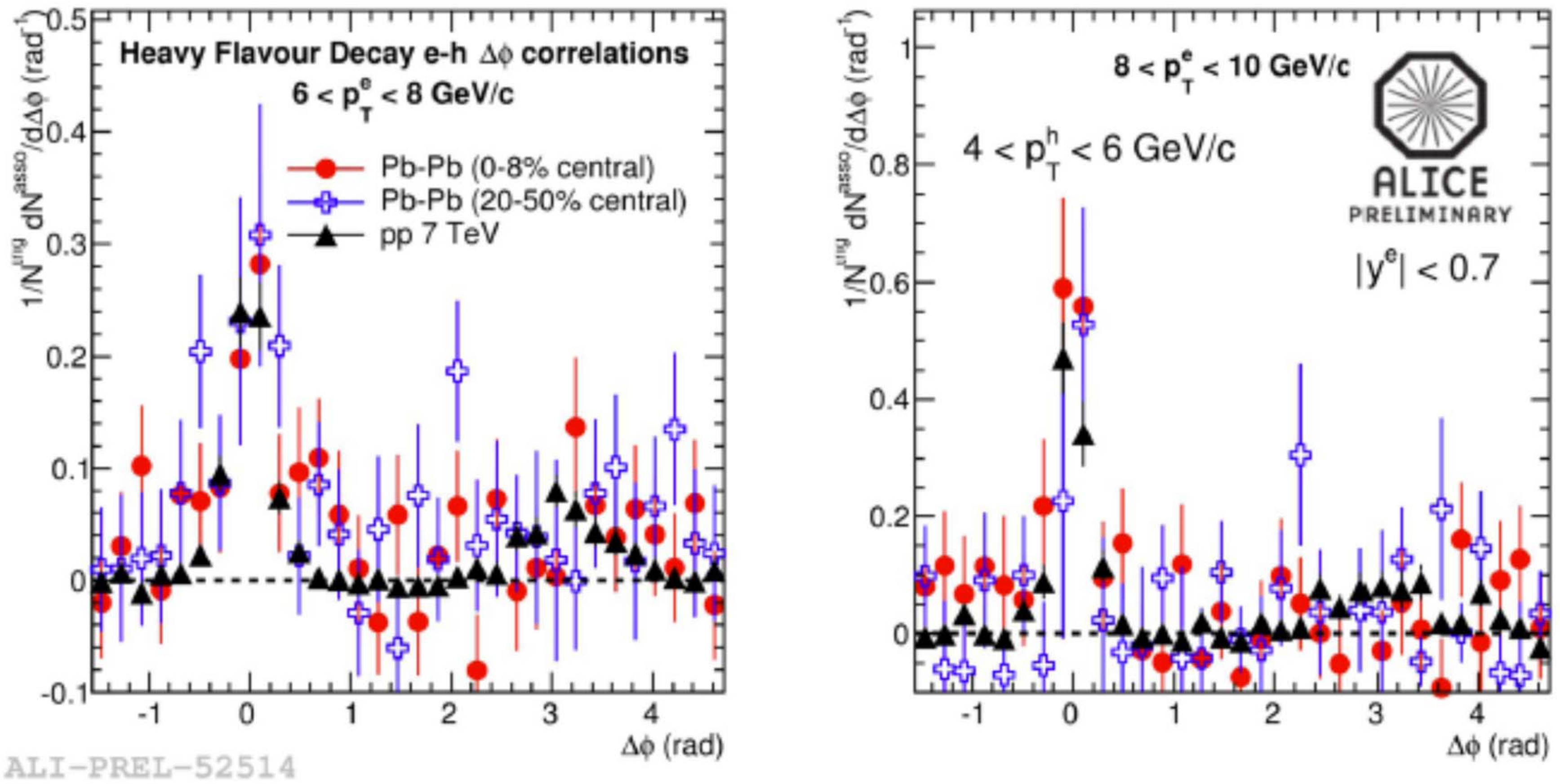
Momentum imbalance: b-bar in Pb-Pb

Pb-Pb @ 5TeV, 50-70%





ALICE: e-h correlations in Pb-Pb



Modified DGLAP ("full"; model D)

« Full » : we combine ingredients from model A and model B:

Both induced radiation, rescattering of partons in the jet and energy loss -> medium

model	Q	$\vec{p}_{\parallel}$	$\vec{p}_{\perp}$	E	
A (radiative/YaJEM-like)	$\uparrow$	=	=	$\uparrow$	
B (collisional)	=	$\downarrow$	$\uparrow$	$\downarrow\uparrow$	Most questionable
C (hybrid/no transverse force)	$\uparrow$	$\downarrow$	=	$\downarrow\uparrow$	
D (hybrid/transverse force)	$\uparrow$	$\downarrow$	$\uparrow$	$\downarrow\uparrow$	Most « realistic »

Motivation: Looking at various observables for these models may help us to better understand the role of induced energy loss

Medium evolution: For the time, we use a toy-model parametrization of the transport coefficient:

D & C vs A: role of the Energy transfer -> medium & medium response

Further model ingredients

1. Medium evolution: For the time, we use a toy-model parametrization of the transport coefficient:

$$\hat{q}(t) = \frac{a}{(t+b)^c}$$

With b=1.5 fm/c, c=2.2

(jet emanating from the center of the medium)

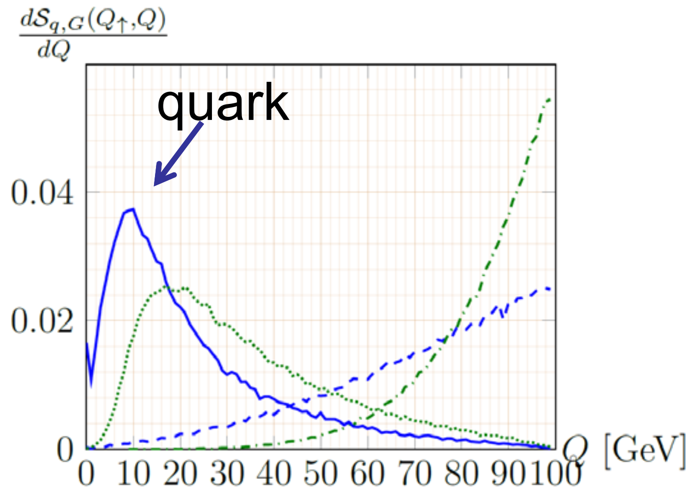
[Th. Renk: Phys.Rev.C 78, 034908 (2008)]

with $$\int_{t_0}^{t_f} \hat{q}(t)dt = \Delta Q^2$$

Parameter fixing the jet-medium coupling

2. Evolutions are initiated starting from a HQ with energy E_{ini} and a virtuality ranging from $Q_\uparrow = E_{ini}$ down do $Q_0 \approx 1$ GeV

3. For the following results: no further evolution in the QGP once partons are on-shell



Double differential angular correlations

Angle between jet and HQ