Initial stage and jet quenching in High-Energy Nuclear Collisions

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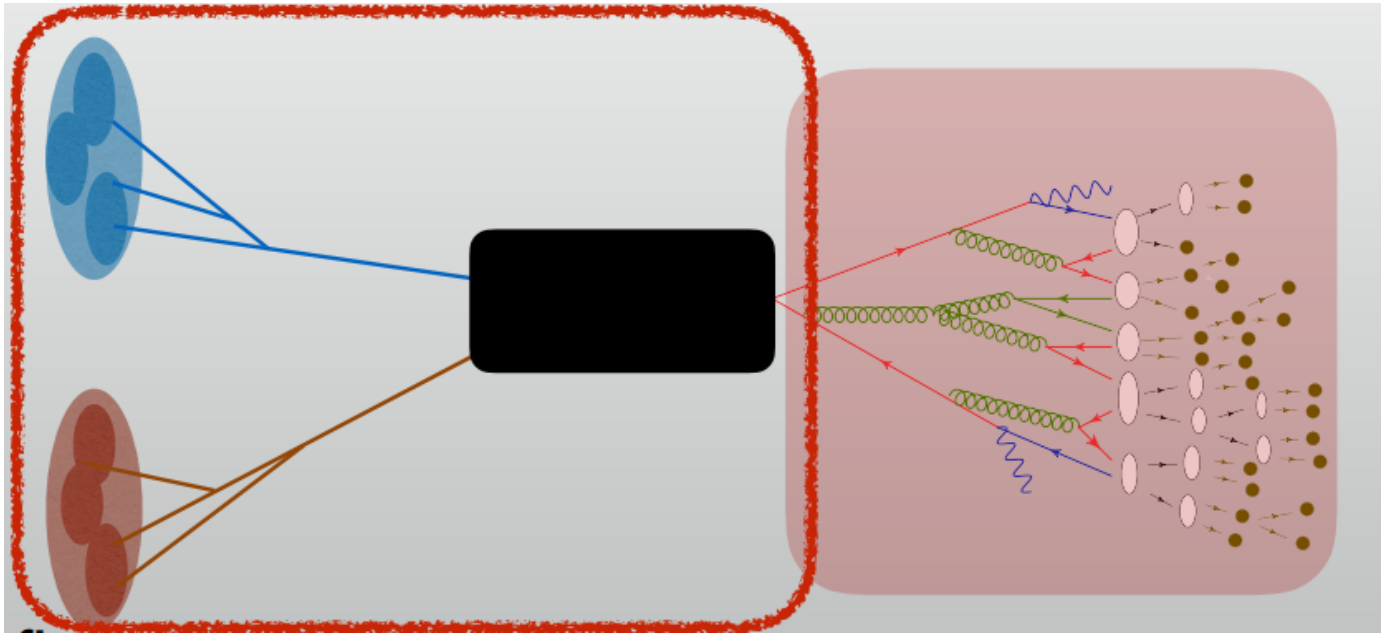
Outlilne

A little bit of myself...

- **October 2007-July 2012:** Studies in Physics at the Universidade de Santiago de Compostela (Spain).
- **October 2012-July 2013:** Masters course, Universidade de Santiago de Compostela (Spain).
- **December 2013-September 2017** PhD student at the Universidade de Santiago de Compostela.
  - Supervisors: Carlos A. Salgado and Carlos Pajares
  - Collaborators: Nestor Armesto, Pia Zurita, Matthew Luzum...
  - August 17th 2014-September 17th 2014: **CERN**, Theory Division.
  - April 27th 2015-July 28th 2015: **Oxford University**, UK. Supervisor: Juan Rojo.
  - October 5th 2016-December 5th 2016: **McGill University**, Montréal.
    Supervisors: Charles Gale and Jeon Sangyong.

Heavy-ion collision

Initial stage: nPDFs and CGC evolution.



Jet quenching: single-inclusive production..., heavy-flavour, EM probes...

Factorisation

$$\frac{d\sigma^{AA\to h+X}}{dp_T dy} = \int \frac{dx_2}{x_2}\frac{dz}{z}\sum_{i,j} x_1 f_{i/A}(x_1, Q^2) x_2 f_{j/A}(x_2, Q^2) \times \frac{d\hat{\sigma}^{ij\to k}}{d\hat{t}} D_{k\to h}(z, \mu_F^2)$$

- nPDFs, linearly evolved using DGLAP evolution equations.
- Partonic cross-section: pQCD.
- Medium modifications of FFs: energy loss, hadronisation, recombination for quarkonia...

Current status

SET		EPS09 JHEP 0904 (2009) 065	DSSZ PRD85 (2012) 074028	nCTEQ PRD93 (2016) no.8, 085037	KA15 PRD93 (2016) no.1, 014026
data type	e-DIS	✔	✔	✔	✔
	D-Y	✔	✔	✔	✔
	hadrons	✔	✔	✔	✘
	ν-DIS	✘	✔	✘	✘
# data points		929	1579	740	1479
accuracy		NLO	NLO	NLO	NNLO
proton PDF		CTEQ6.1	MSTW2008	~ CTEQ6.1	JR09
scheme		ZM-VFNS	GM-VFNS	GM-VFNS	ZM-VFNS
comments		huge gluon shadowing/ anti-shadowing found	medium modified FFs	flavour separation considered, not enough sensitivity	deuteron data included

EPPS: NLO (with di-jet data)
A-Z: NNLO GM-VFNS

coming soon!

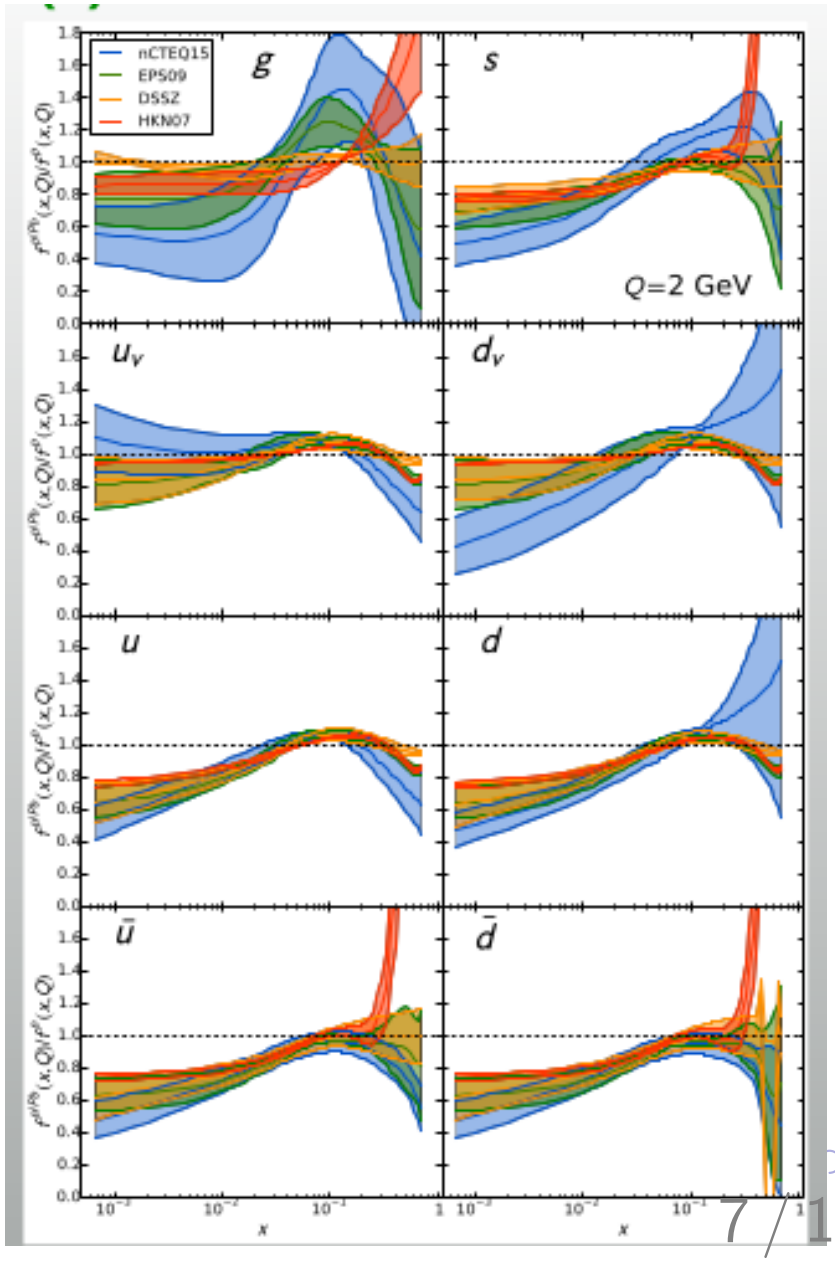
EPPS16: W's,Z's and di-jet. 1811 data points.

Thanks to Pia Zurita.

Current status

- High x: no constrain (g)
- Low x: no constrain, (g, sea, valence). Extrapolations.
- No sensitivity to flavor separation ($R_u = R_d$).
- No LHC data included **YET**.

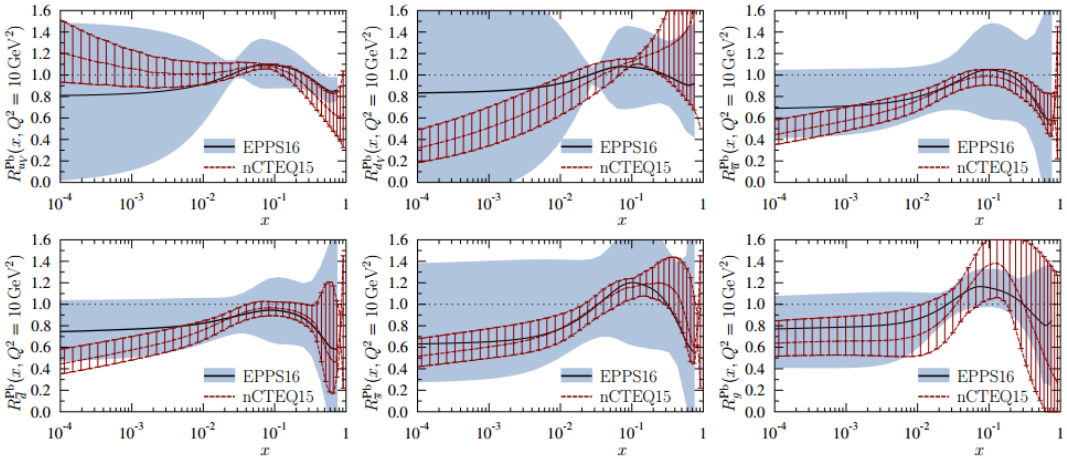
nCTEQ16: Phys. Rev. D 93, 085037 (2016).

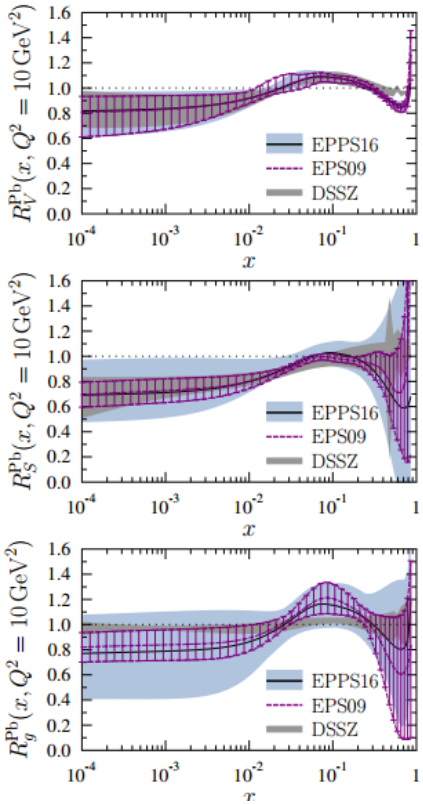


Current status

EPPS16

Neutrinos, W's, Z's and di-jets included.





EPPS16: arXiv:1612.05741 [heph.ph]

A-Z NNLO nPDFs

- NNLO precision mandatory for future facilities: EIC and LHeC.
- First NNLO nPDF set in GM-VFNS.
- Evolution at NNLO in Mellin space.
- Neutral and neutrino DIS data already included (around 2000 data points).
- LHC, Drell-Yan in progress.
- Nuclear efects in deuteron.
- Flavour separation?

In preparation with Pia Zurita.

Future improvements

- nPDFs **uncertainties significant**.

A better knowledge of the nPDFs will be **essential** to future facilities as the **EIC**.

- More data required: LHC run 2, EIC and LHeC DIS.
- Inclusion of photon distributions.
- QCD-QED evolution.
- More sophisticated treatment of heavy quarks.
- Proton PDFs and nPDFs in a single fit

Pb NNPDFs

Neural network determination of nuclear PDFs in Lead

- nPDFs contain a **few lead data**.
- *Transform* neutral DIS data for different nuclei into lead data. Fit the new data with the **NNPDF** methodology.

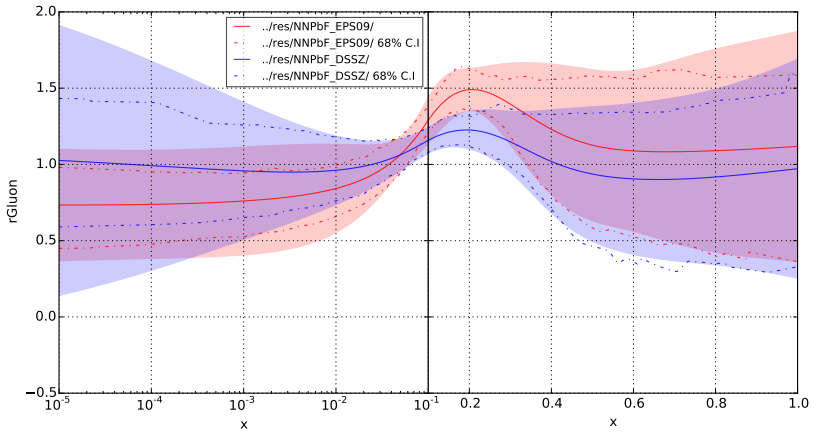
$$\frac{F_2^{Pb}(x,Q^2)}{F_2^{d}(x,Q^2)}_{exp+th} = \frac{F_2^{A_1}(x,Q^2)}{F_2^{A_2}(x,Q^2)}_{exp} \cdot \mathcal{C}_{th}(x,Q^2,A_1,A_2)$$

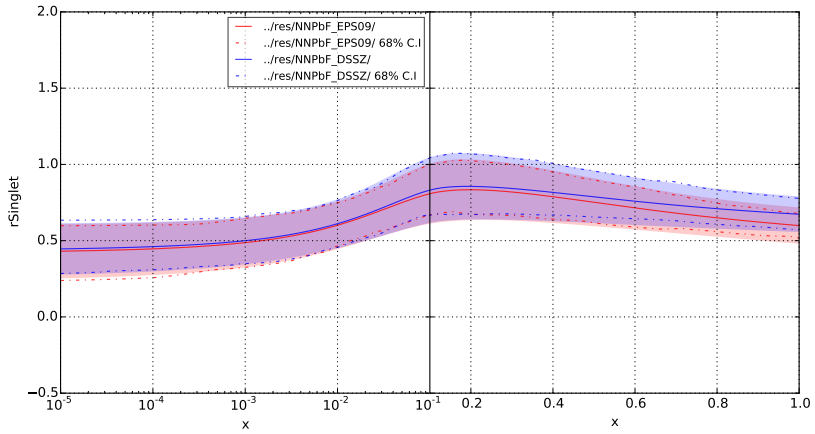
$$\mathcal{C}_{th}(x,Q^2,A_1,A_2) \equiv \frac{F_2^{A_2}(x,Q^2)}{F_2^{A_1}(x,Q^2)}_{th} \cdot \frac{F_2^{Pb}(x,Q^2)}{F_2^{d}(x,Q^2)}_{th}$$

th: EPS09 or DSSZ.

Pb NNPDFs

- Using neutral DIS data: sensivity only to the gluon and to the singlet.
- Structure functions computed in the FONLL GM-VFNS.
- NNLO evolution given by APFEL.



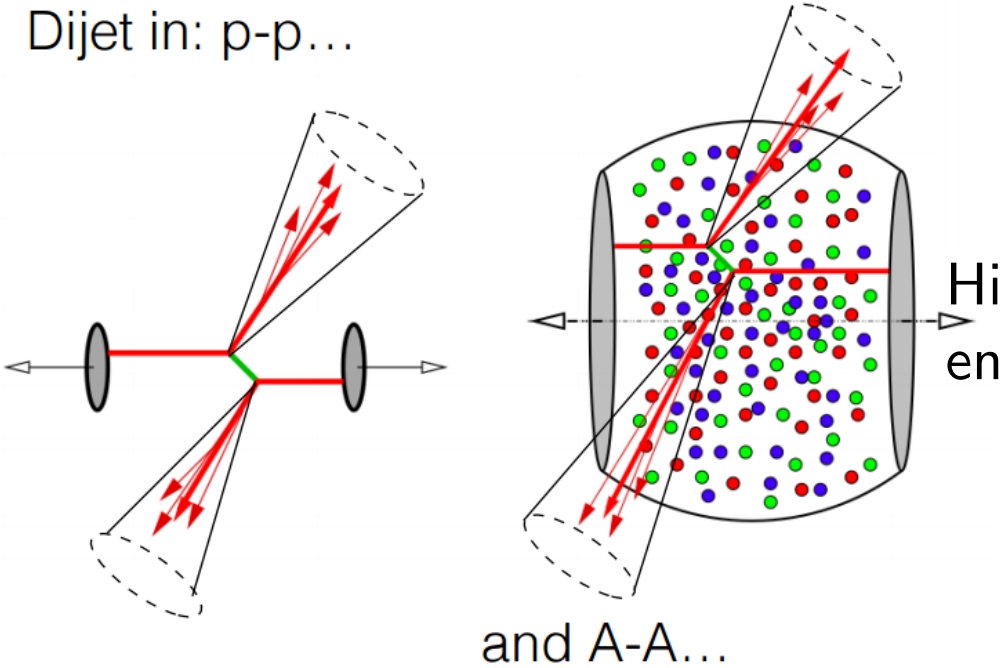


- Future improvements: include Drell-Yan data.

Carlota Andres, Nathan P. Hartland and Juan Rojo, in preparation

Heavy Ion Collisions

- **QGP** created in HIC.
- Probe the properties of the QGP using bulk osbervables or hard probes, such as: quarkonia, high p_t hadrons, **jets**...



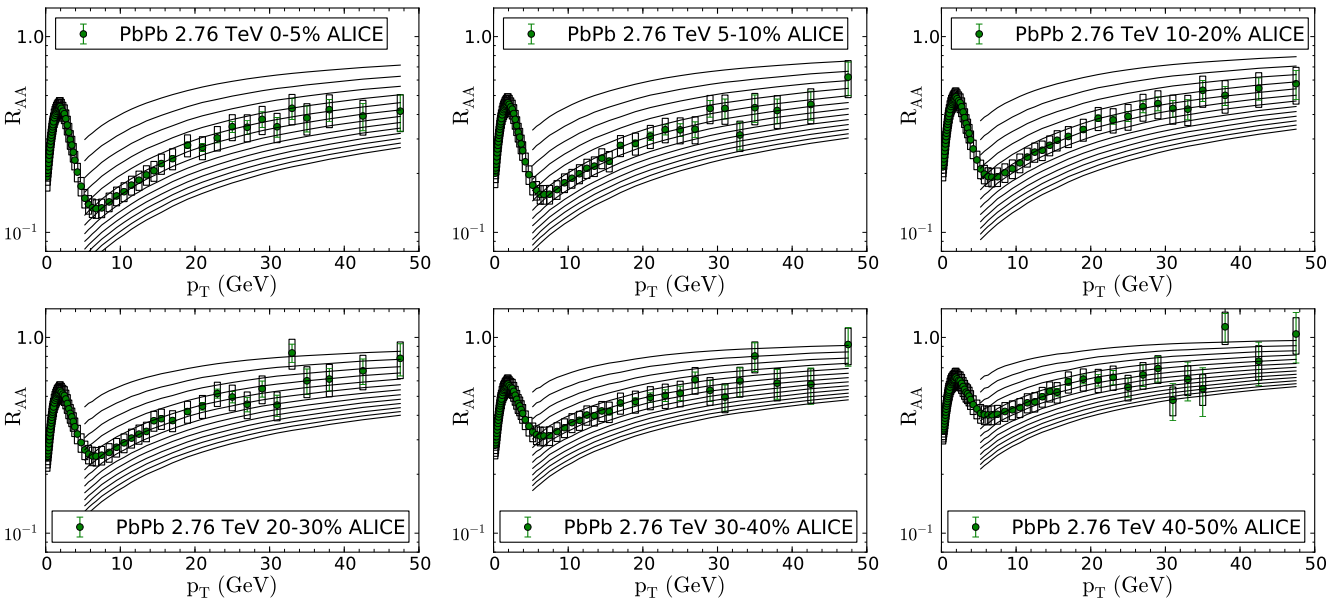
High energy jets lose energy to the medium

- **Jet quenching** as a tool to extract medium properties.

Nuclear modification factor

$$R_{AA} = \frac{dN_{AA}/d^2p_T dy}{\langle N_{coll}\rangle dN_{pp}/dp_T^2 dy}$$

- Smooth hydro + ASW Quenching Weights



$$\hat{q}(\xi) = K\hat{q}_{QGP}(\xi) \simeq K \cdot 2\epsilon^{3/4}(\xi)$$

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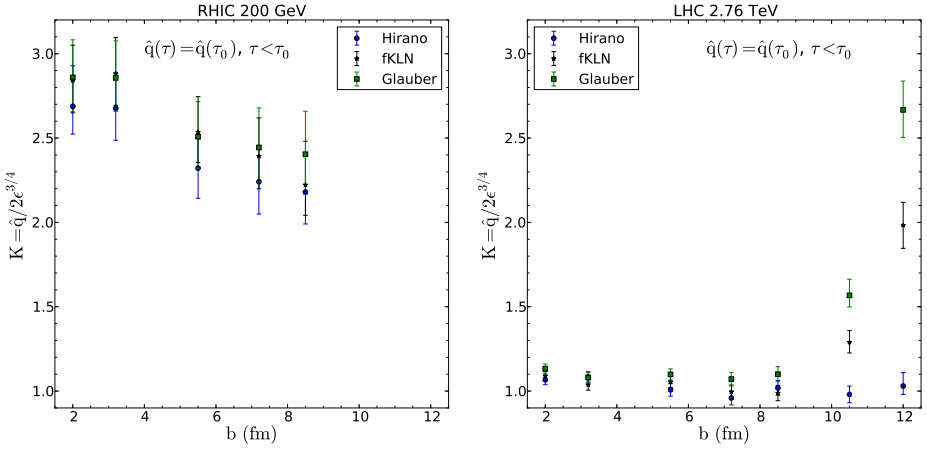
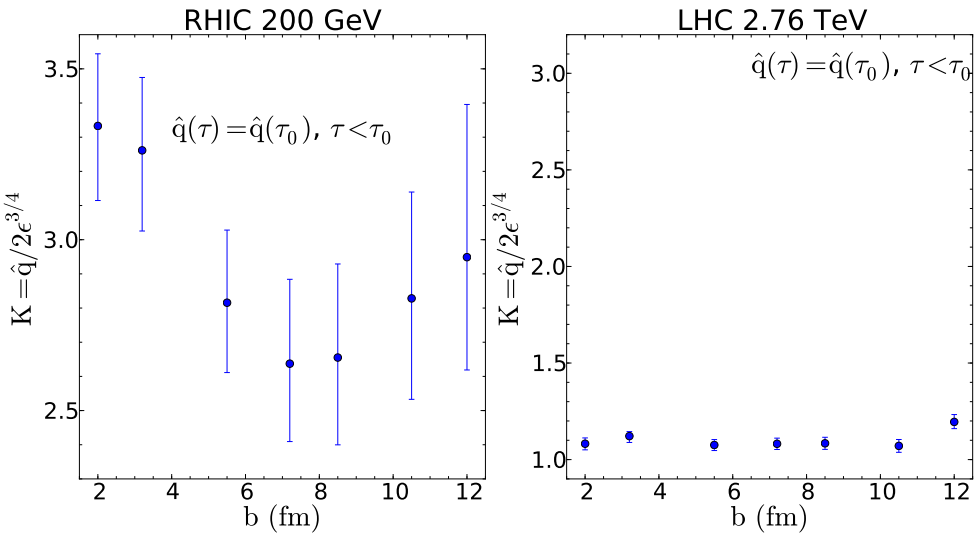
K-factor vs. centrality



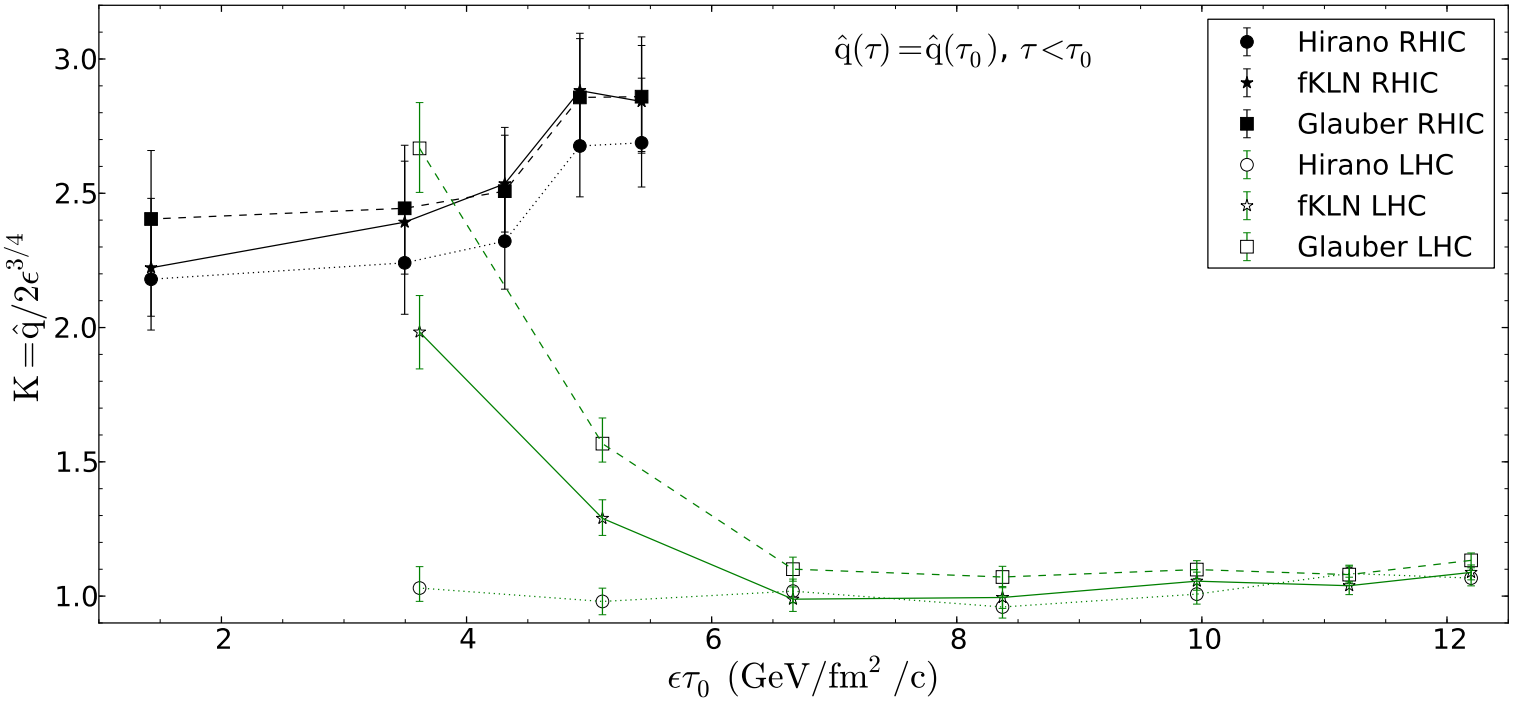
Smooth hydro



EKRT+minijet

K depends mainly on the energy and it is almost independent of the centrality of the collision

The puzzle



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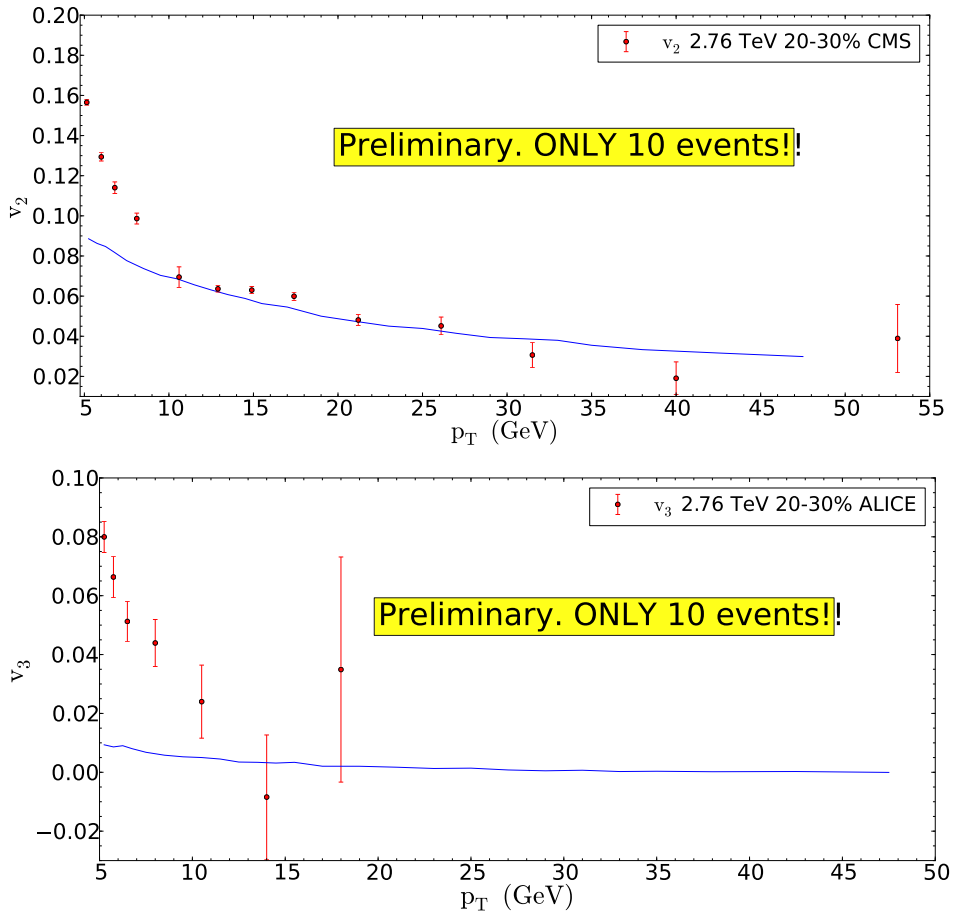
Difficult to reconcile the energy and centrality dependence!! A new puzzle??

Next steps: Check this result with an ebye hydro. Use this hydro to compute high-p_T harmonics.

v_2 and v_3 at high p_T

- Using the fitted value of K for R_{AA}



Carlota Andrés, Néstor Armesto, Harri Niemi, Risto Paatelainen, Carlos A. Salgado and Pia Zurita.

- Compute high p_T harmonics with EKRT hydro (work in progress).
- Compute other observables: di-jets, heavy-quark suppression... (work in progress).
- Implement the antenna radiation in the QW.
- Collisional energy loss?
- In the QW perturbative tails are neglected.

  These tails are inclued in AMY formalism.

  Compute the R_{AA} using AMY rate equation.

  Work in progress in collaboration with Charles Gale and Sangyong Jeon.