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Reduced Coupling At The LHC?

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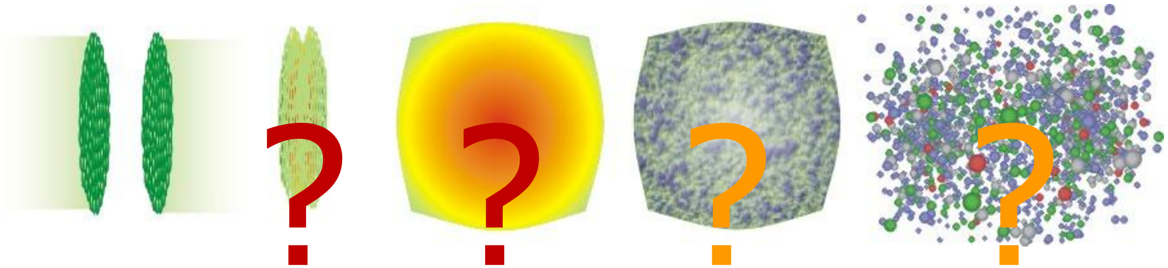
Miklos Gyulassy

High p_T Physics at LHC
Hanau, March 26/27, 2012

PRC **84**, 024913 (2011); arXiv:1201.0281

Motivation



S. Bass, Talk Quark Matter 2001

Two basic questions:

- What are the initial conditions (Glauber vs. CGC)?
- Is the medium weakly-or strongly-coupled (pQCD vs. AdS/CFT)?

Two medium observables:

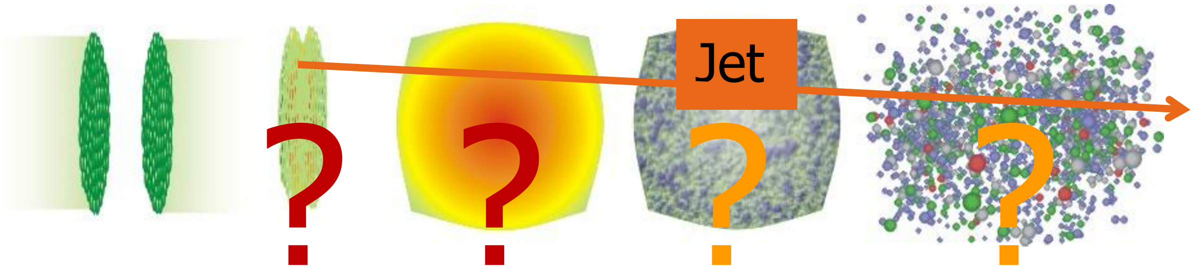
- jet quenching: opaque matter (QGP) formed

$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{1/\sigma_{\mathrm{A+A}}\, d\sigma^{\mathrm{A+A}}/dp_{\mathrm{T}}}{\langle N_{\mathrm{coll}}\rangle/\sigma_{\mathrm{p+p}}\, d\sigma^{p+p}/dp_{\mathrm{T}}}$$

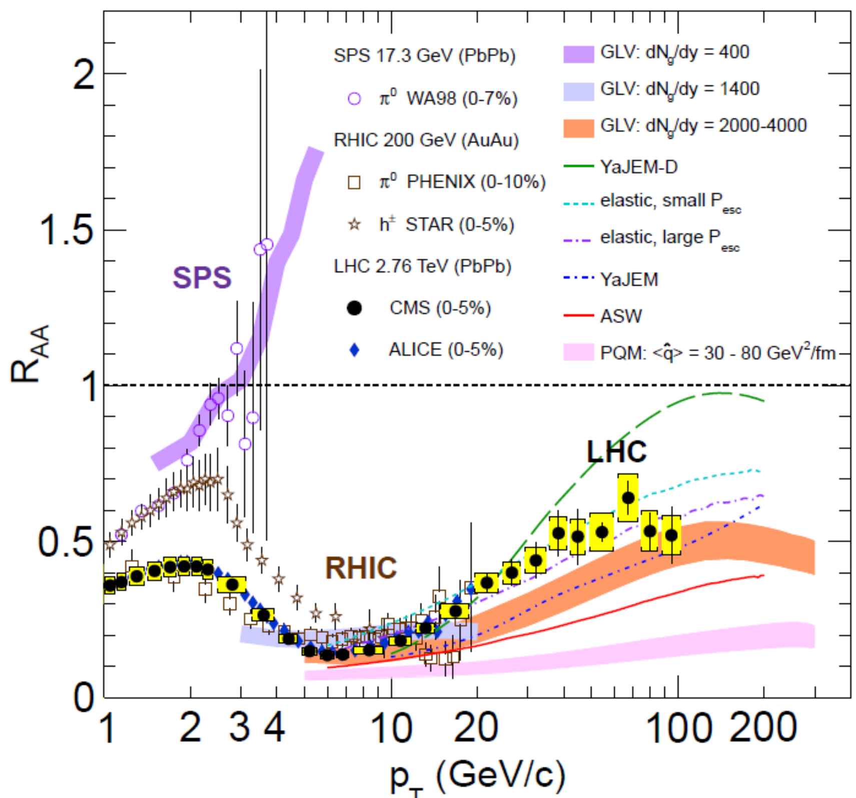
- elliptic flow: (nearly) perfect fluid created

$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left[1 + 2\sum_{n=1}^{\infty} v_n \cos(n\phi)\right]$$

Jet Tomography

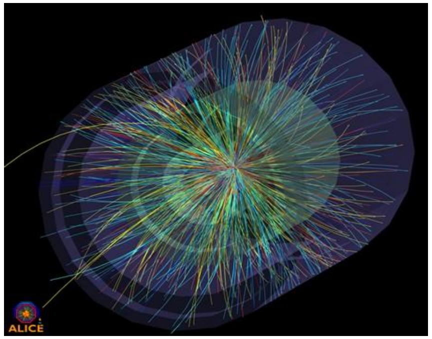


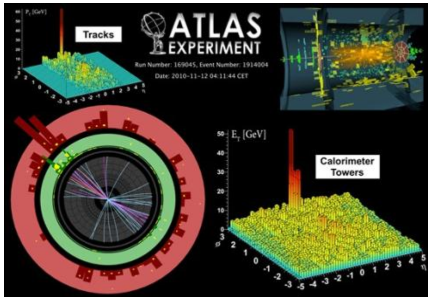
S. Bass, Talk Quark Matter 2001

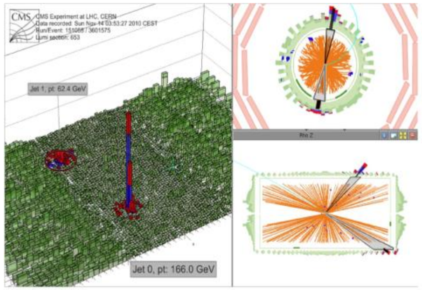


CMS Collaboration, arXiv: 1202.2554[nucl-ex]

determine the R_{AA} and v_2 of of high- p_T particles

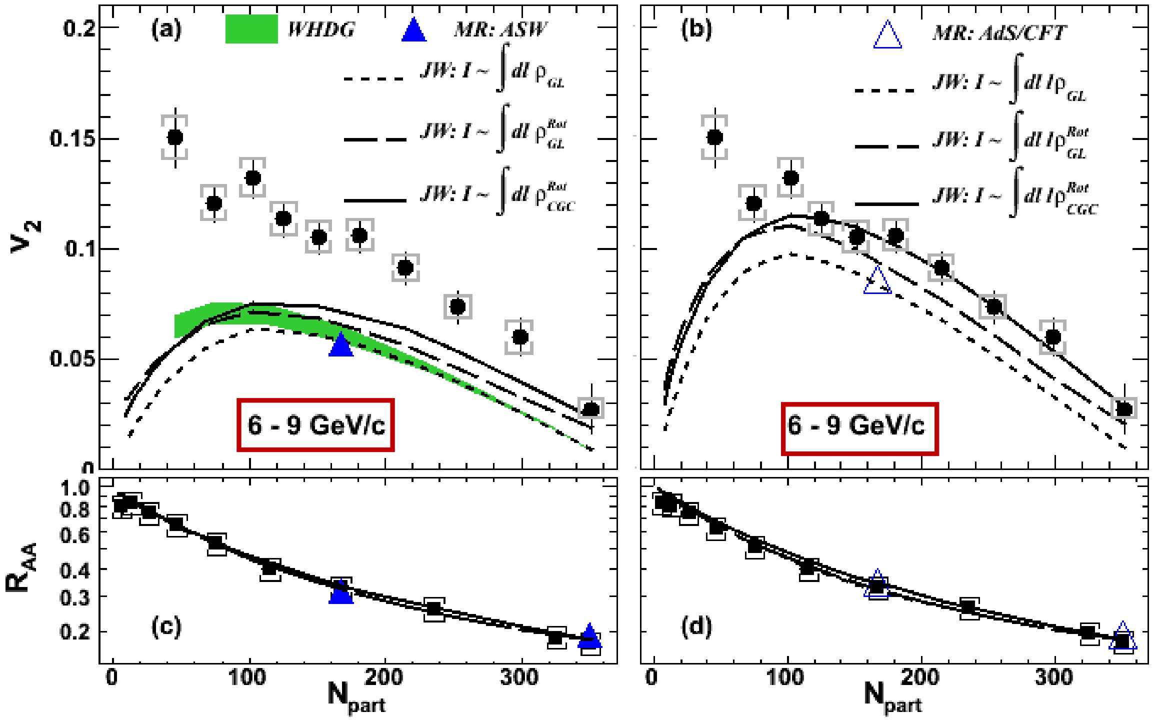






Energy-Loss Mechanisms

pQCD-like AdS/CFT-like



A. Adare et al, Phys. Rev. Lett. **105**, 142301 (2010)

Jia's jet-absorption model for high-p_T R_{AA} AND v_2 :

$$R_{AA}(N_{part}) = \langle e^{-\kappa I_m} \rangle$$

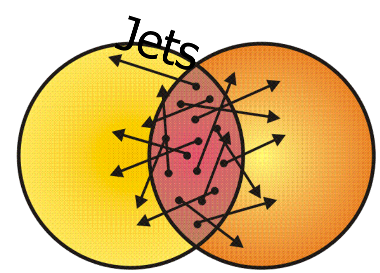
$$v_2 = \langle e^{-\kappa I_m} \cos 2\left(\phi - \Psi_{\rm part}\right) \rangle$$

$$I_m = \int_0^\infty dl\; l^{m-1}\, \rho(\vec{\mathbf{r}} + l\hat{\mathbf{v}})$$

$$m = 1, 2, \ldots$$

J. Jia et. al., PRC **82** (2010), 024902

most central R_{AA} is fitted

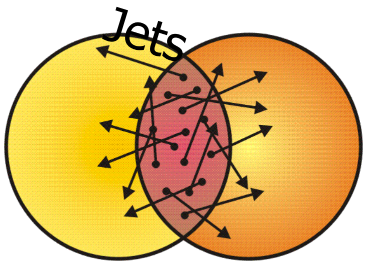


pQCD-like e-loss fails to describe data

AdS/CFT-like e-loss works for CGC in. cond.

Generic Energy-Loss Model

Ansatz for the jet-energy loss:



$$\frac{dP}{d\tau}(\vec{x}_0,\phi,\tau) = -\kappa P^a(\tau)\tau^z T^{z-a+2}[\vec{x}_\perp(\tau),\tau]$$

considering Bjorken expansion, including fragmentation, and assuming that τ_0 = 1fm leads to high-p_T R_{AA} AND v_2 for either Glauber or CGC-like initial conditions (fKLN)

fKLN:

$$x_j \to x_j \sqrt{\frac{< x^2 >_{\mathrm{KLN}}}{< x^2 >_{\mathrm{Glauber}}}}$$

$$e(i,j) \to e(i,j) \Big/ \frac{\sqrt{< x^2 >< y^2 >_{\mathrm{KLN}}}}{\sqrt{< x^2 >< y^2 >_{\mathrm{Glauber}}}}$$

B.Betz et.al., arXiv:1201.0281

In the following, I will only show an "averaged scenario" since we found that there is only a small difference to the event-by-event results

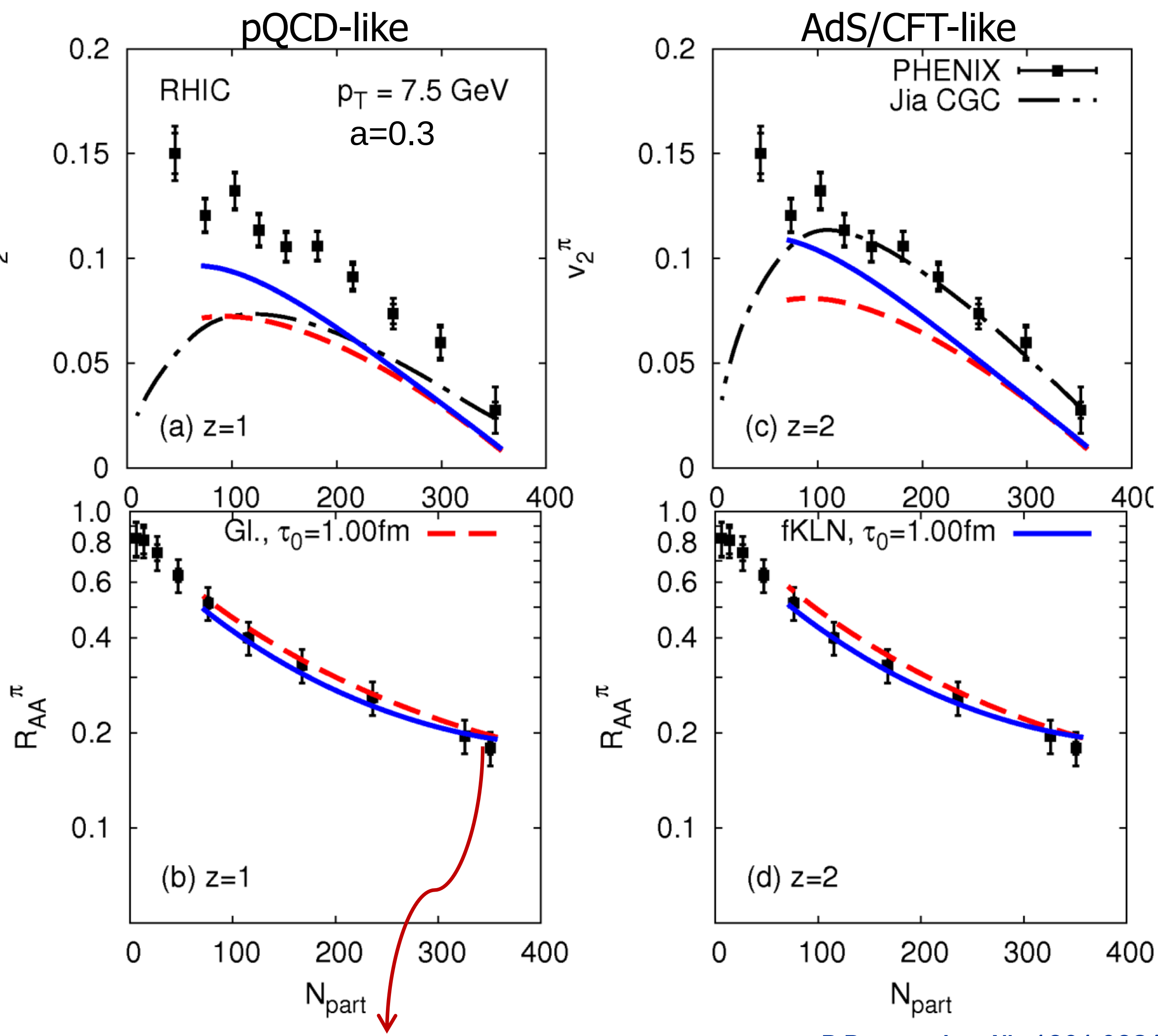
B.Betz et.al., PRC **84**, 024913 (2011)

R_{AA} and v_2 at RHIC

- R_{AA}(Centr.) can be reproduced for both in. cond. and path-length dependencies

- Glauber fails to describe the v_2(Centr.)

⇒ SMALL difference between pQCD- and AdS/CFT-like energy loss



Fitting point for κ

B.Betz et.al., arXiv:1201.0281

R_{AA} and v_2 at RHIC

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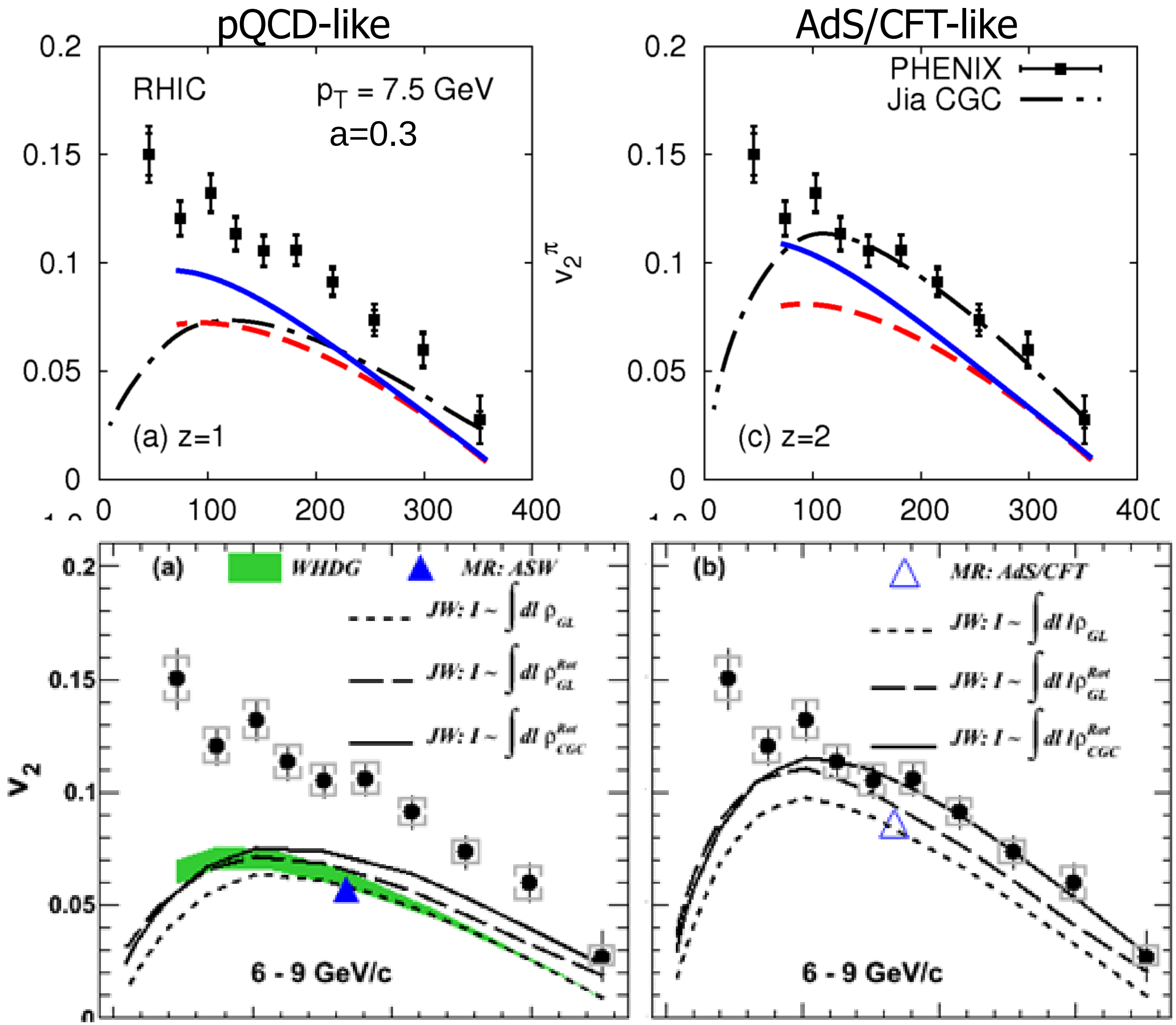


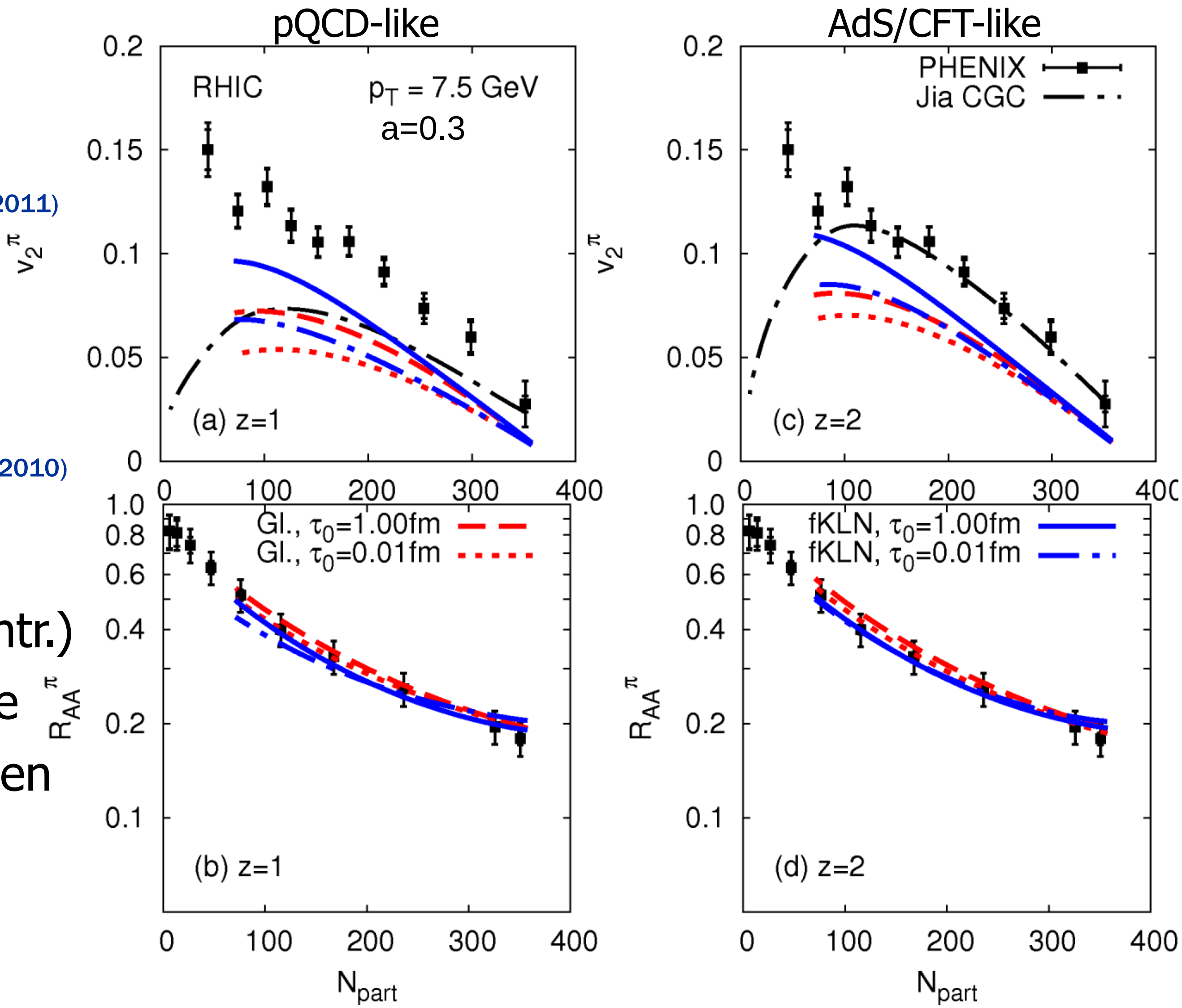
Adare et al, Phys. Rev. Lett. **105**, 142301 (2010)

Initial time

We set τ_0 = 1fm
H. Song et.al., PRL **106**, 192391 (2011)

Jia's model has
τ_0 = 0fm
A. Adare et al., PRL **105**, 142301 (2010)

⟹ A smaller τ_0 reduces the v_2(Centr.) and increases the difference between the pQCD and AdS/CFT results.



B.Betz et.al., arXiv:1201.0281

⟹ We will ONLY consider z=1 (pQCD) in the following.
Checked for LHC B.Betz et.al., arXiv:1201.0281

Initial time

τ_0 = 1fm ⟶ Assumption: NO energy loss within 1fm

- pQCD does not give excuse for this ansatz,
  τ_0 = 0fm most natural assumption

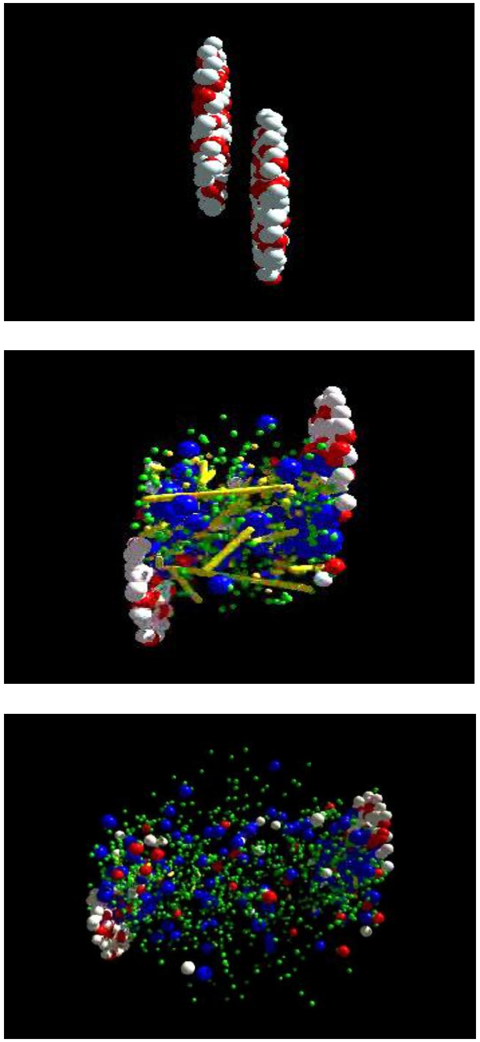
Adare et al, Phys. Rev. Lett. **105**, 142301 (2010)

- describes formation time of hydrodynamics
  → no pressure at early times, everything is free flow

τ_0 = 1fm ⟶ essentially equivalent to AdS/CFT
energy loss suppression of early times

⇒ v_2(high- p_T) not sensitive to long distance $dE/dx \sim l^1$ vs. $dE/dx \sim l^2$, but to short distance properties < 1fm!

⇒ We cannot access the center of the collision!



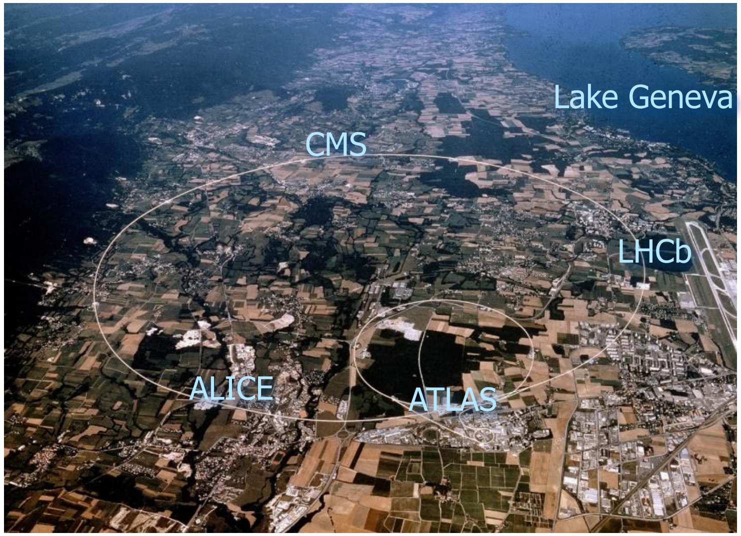
UrQMD Simulartion, H. Weber

RHIC


RHIC
BOOSTER
LINAC
AGS
HTB
TANDEMS
HITL

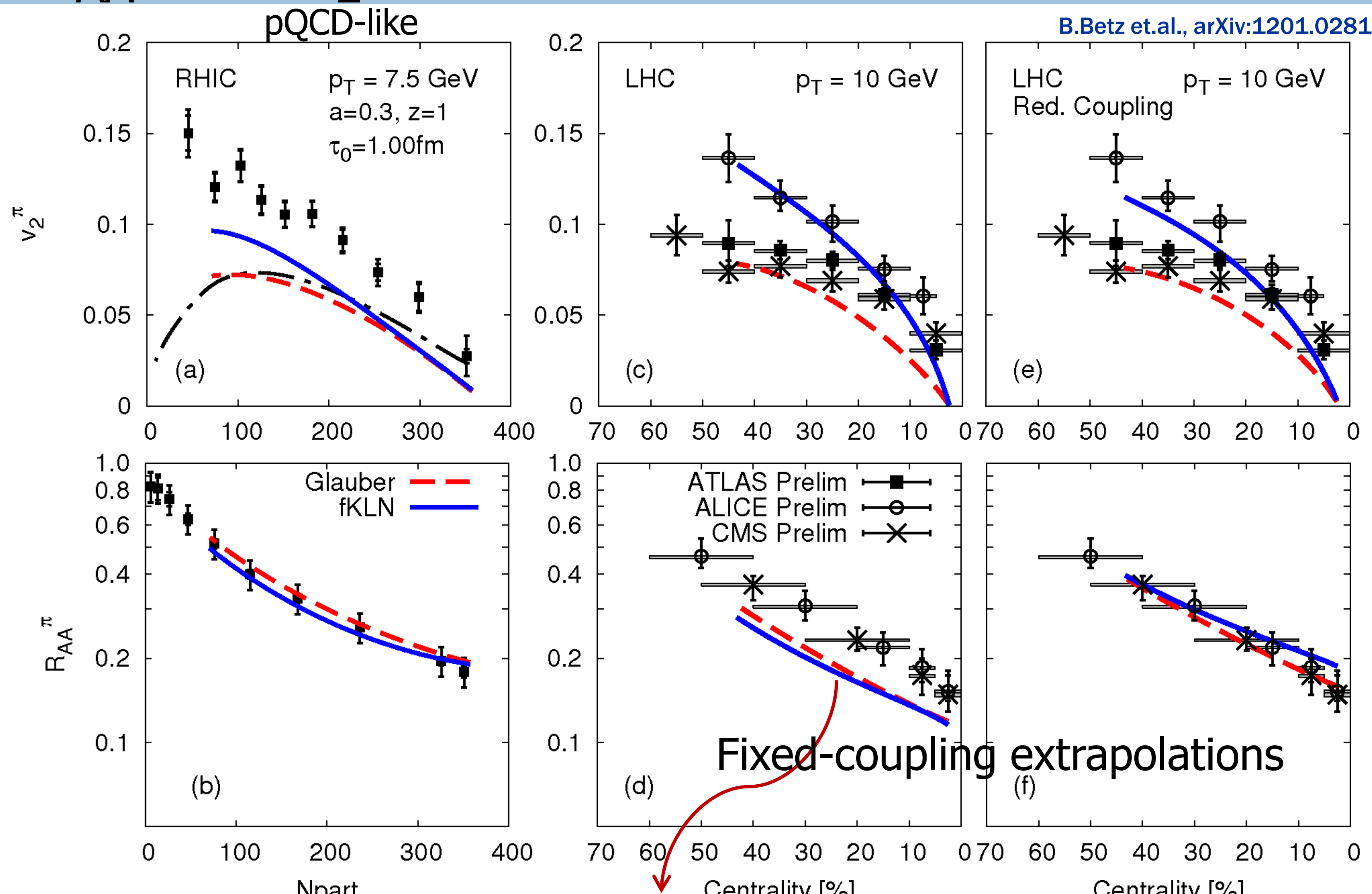
vs.

LHC


Lake Geneva
CMS
LHCb
ALICE
ATLAS

R_{AA} and v_2 at RHIC vs. LHC

B.Betz et.al., arXiv:1201.0281

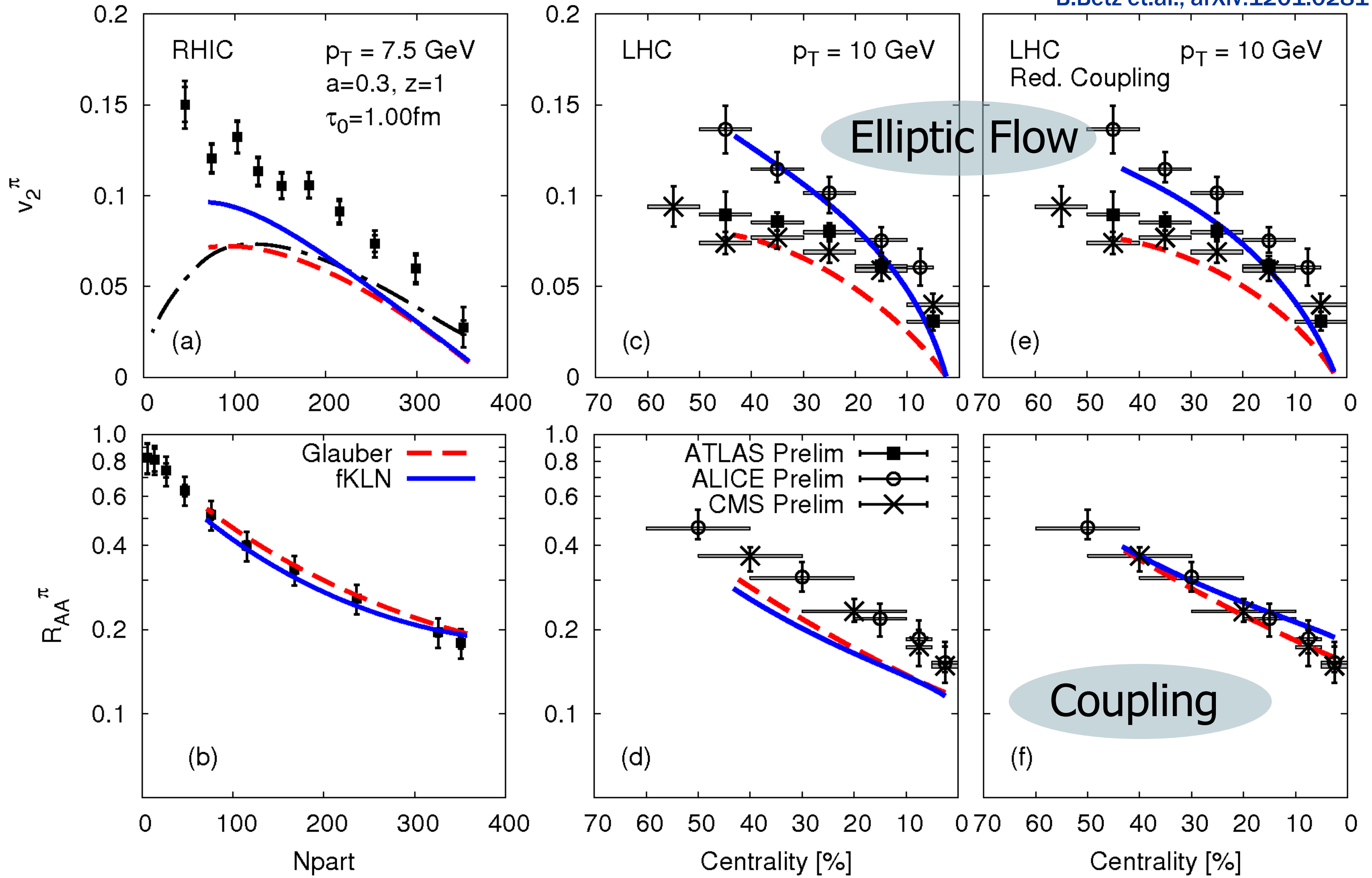


Puzzling similarity of jet quenching at RHIC and LHC,
hard to understand with any density-dependent jet-absorption model

W. Horowitz et. al, Nucl. Phys. A872 (2011) 265

R_{AA} and v_2 at RHIC vs. LHC

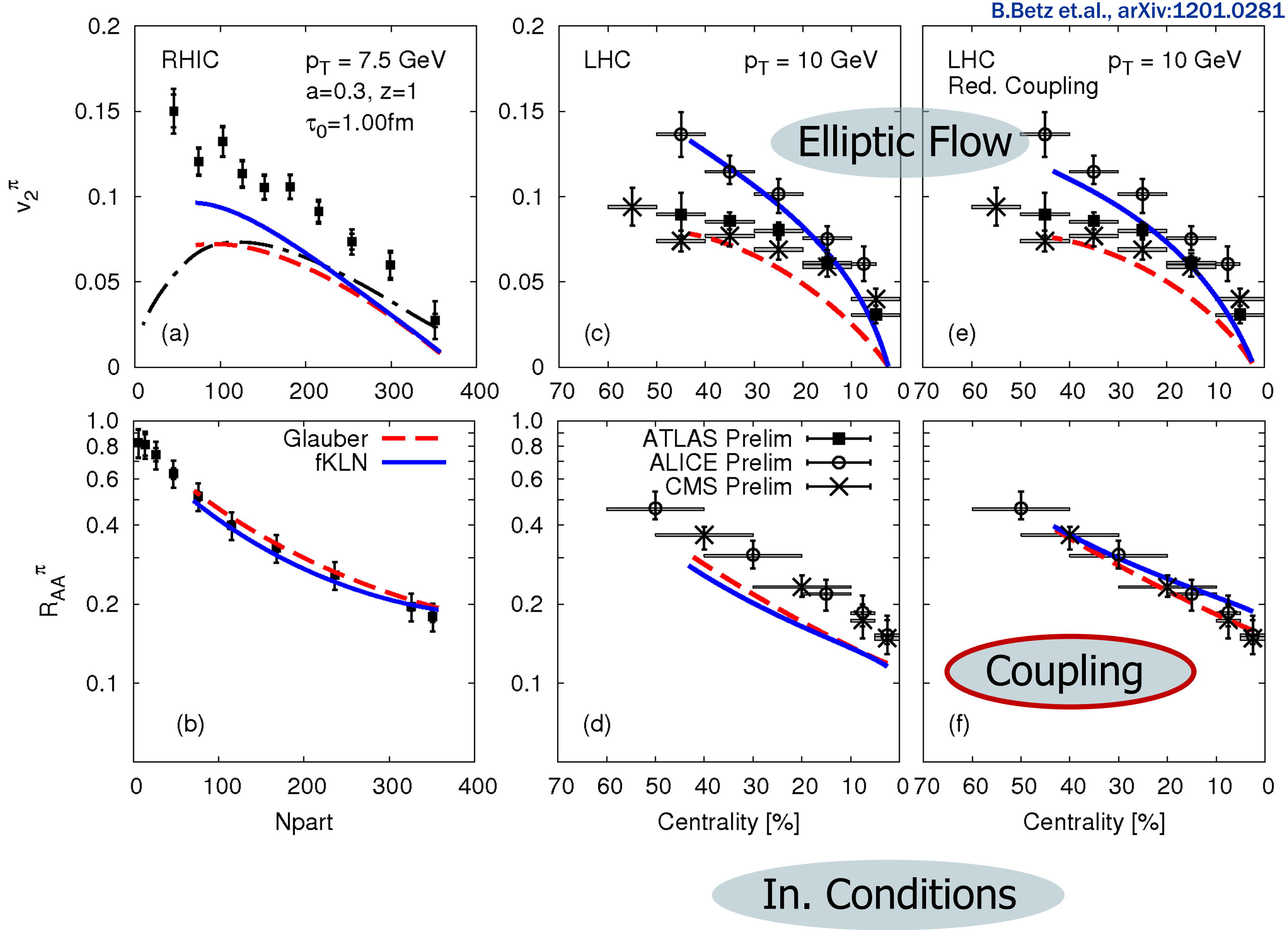
B.Betz et.al., arXiv:1201.0281



In. Conditions

R_{AA} and v_2 at RHIC vs. LHC

B.Betz et.al., arXiv:1201.0281



Reduced Jet-Medium Coupling

What is the physical meaning of adjusting κ ?

pQCD: $\kappa \propto \alpha^3$

$$\alpha_{\mathrm{LHC}} = (\kappa_{\mathrm{LHC}}/\kappa_{\mathrm{RHIC}})^{1/3}\alpha_{\mathrm{RHIC}} \qquad \alpha_{\mathrm{RHIC}} \sim 0.3$$

inserting the values used: $\alpha_{\mathrm{LHC}} \sim 0.23 - 0.27$

(independent of initial time)

B.Betz et.al., arXiv:1201.0281

⇒ Reasonable moderate reduction of the running coupling

AdS/CFT: $\kappa \propto \sqrt{\lambda}$ ← t'Hooft coupling

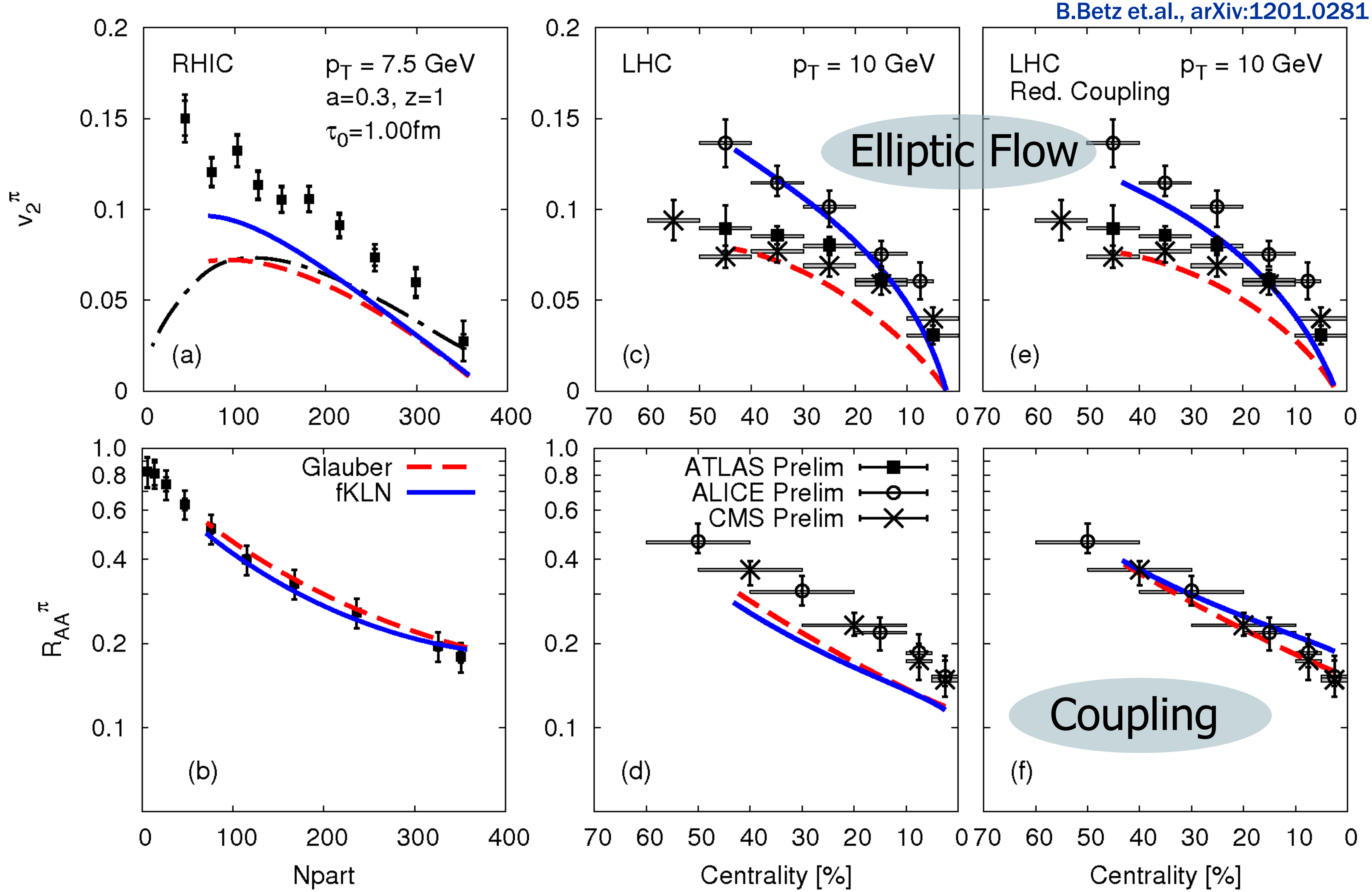
$$\lambda_{\mathrm{LHC}} = (\kappa_{\mathrm{LHC}}/\kappa_{\mathrm{RHIC}})^2\, \lambda_{\mathrm{RHIC}} \qquad \lambda_{\mathrm{RHIC}} \sim 20 \text{ (heavy quarks)}$$

with the values used: $\lambda_{\mathrm{LHC}} \sim 5 - 10$

⇒ Rather strong conformal symmetry breaking over a narrow temperature interval

R_{AA} and v_2 at RHIC vs. LHC

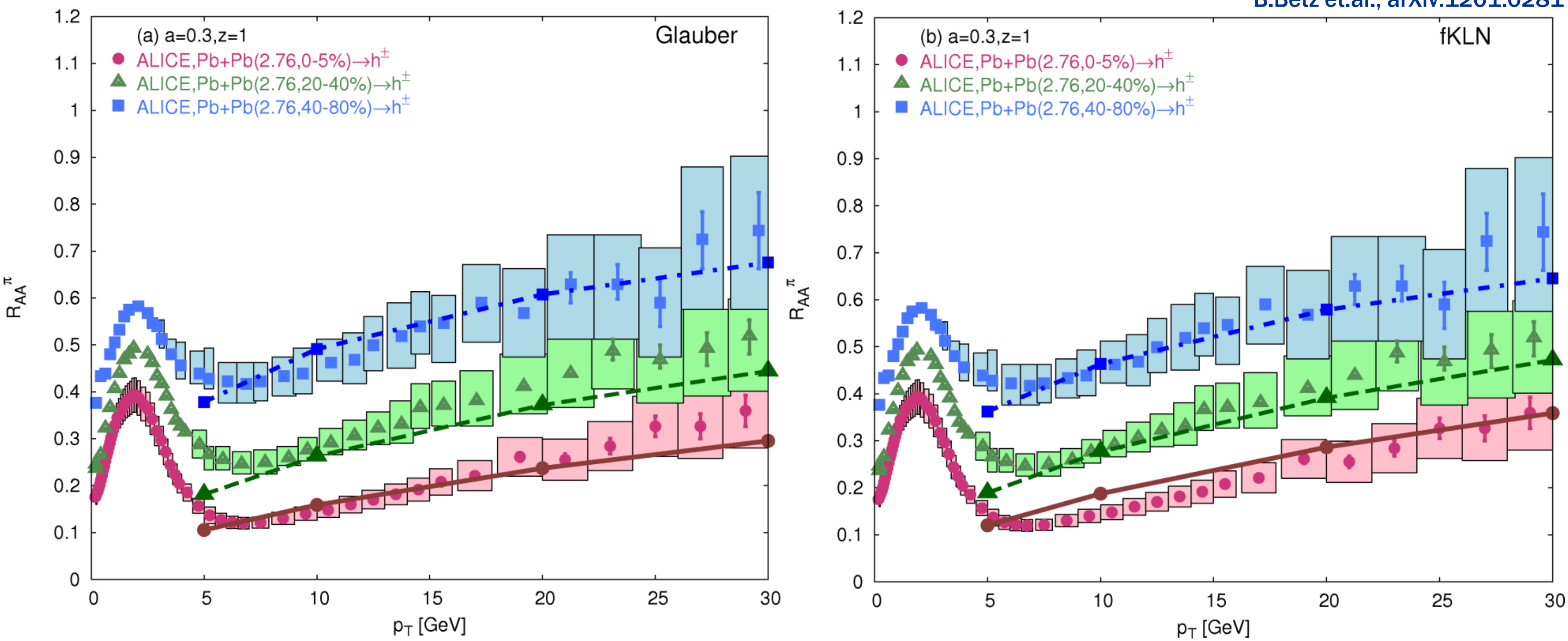
B.Betz et.al., arXiv:1201.0281



In. Conditions

$R_{AA}(p_T$, Centrality) at LHC

B.Betz et.al., arXiv:1201.0281

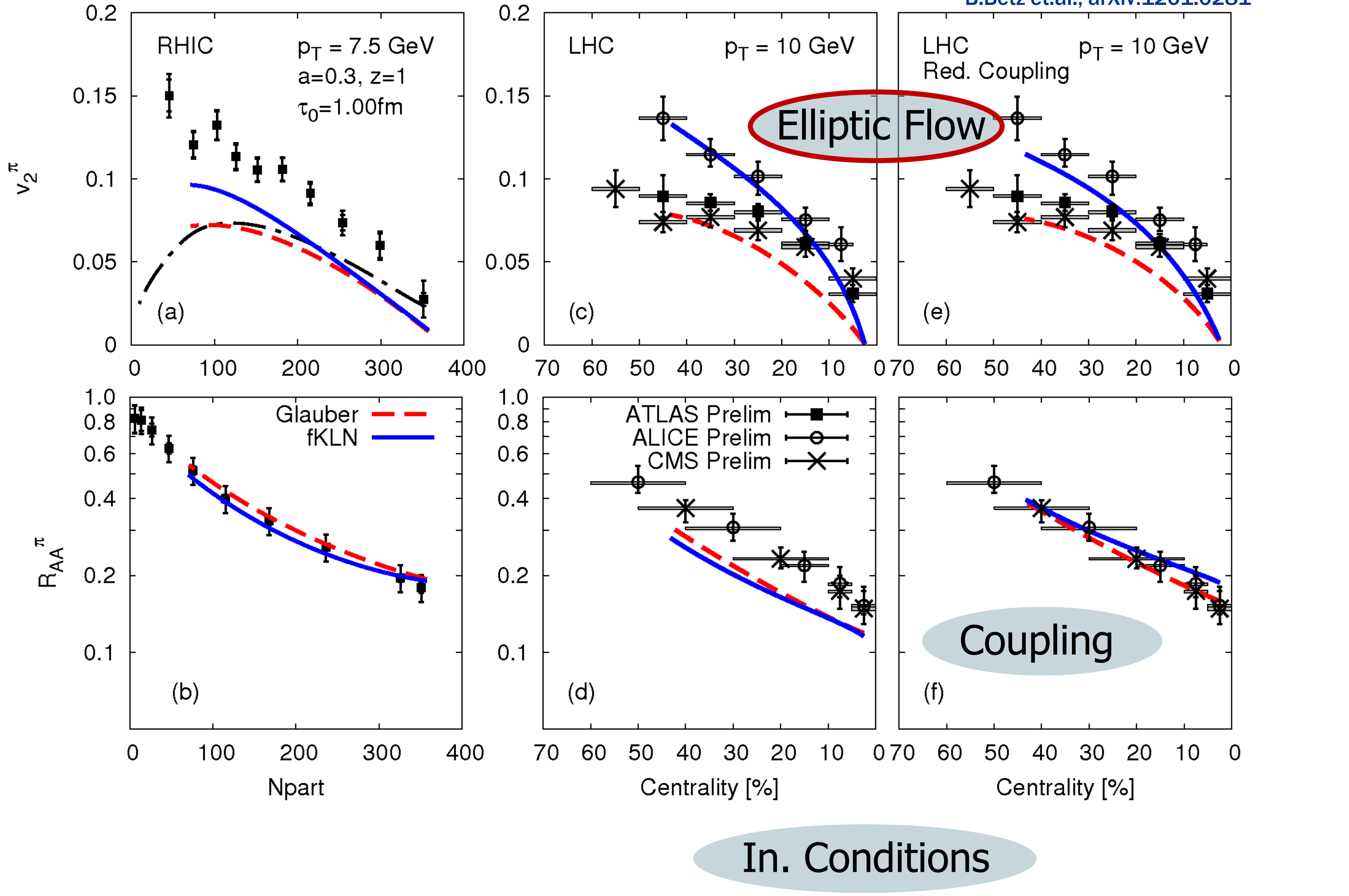


Remarkably insensitive to the initial conditions

⟹ It's NOT sufficient to just study ONE variable!

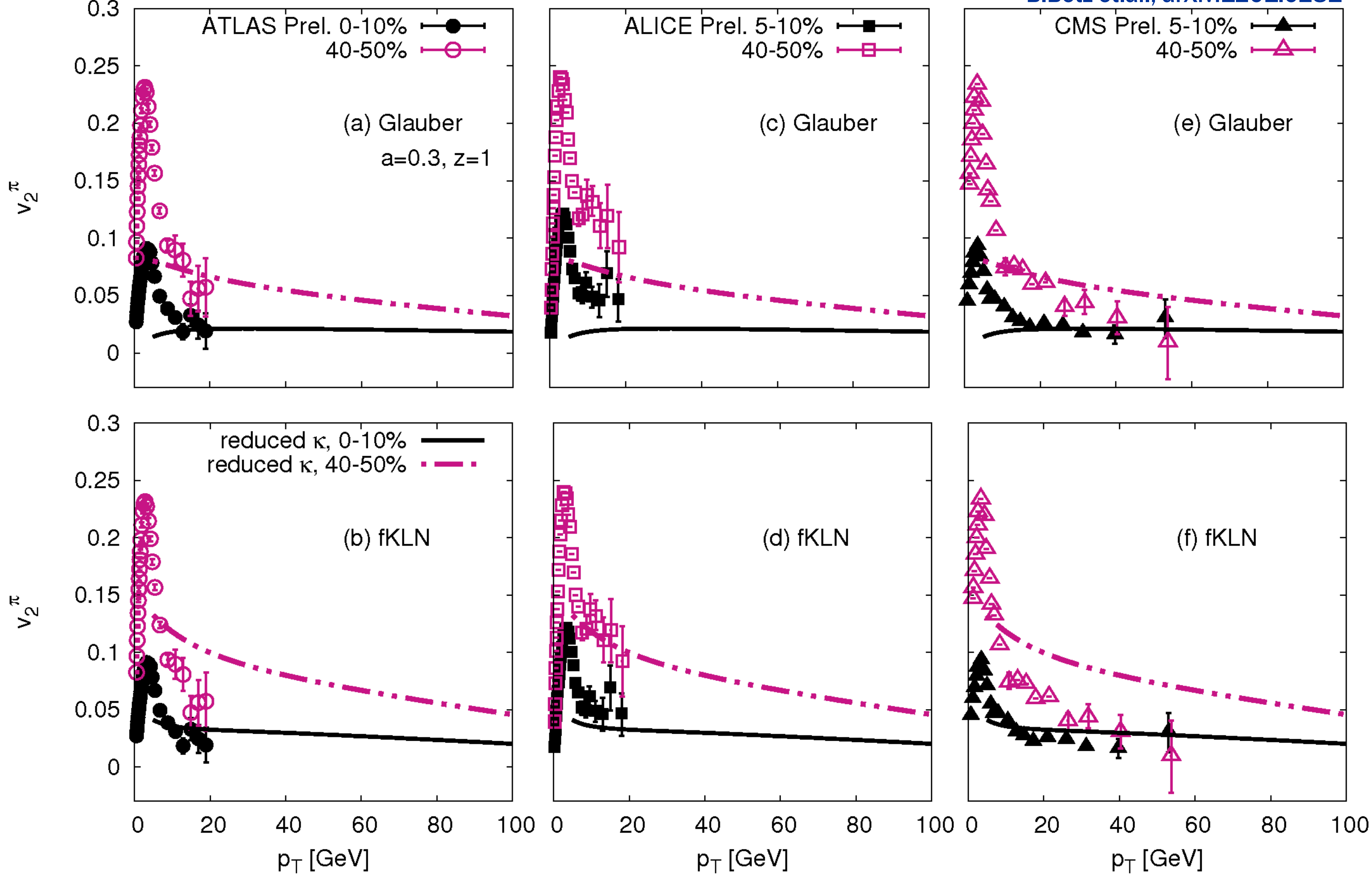
R_{AA} and v_2 at RHIC vs. LHC

B.Betz et.al., arXiv:1201.0281



$v_2(p_T$, Centrality) at LHC

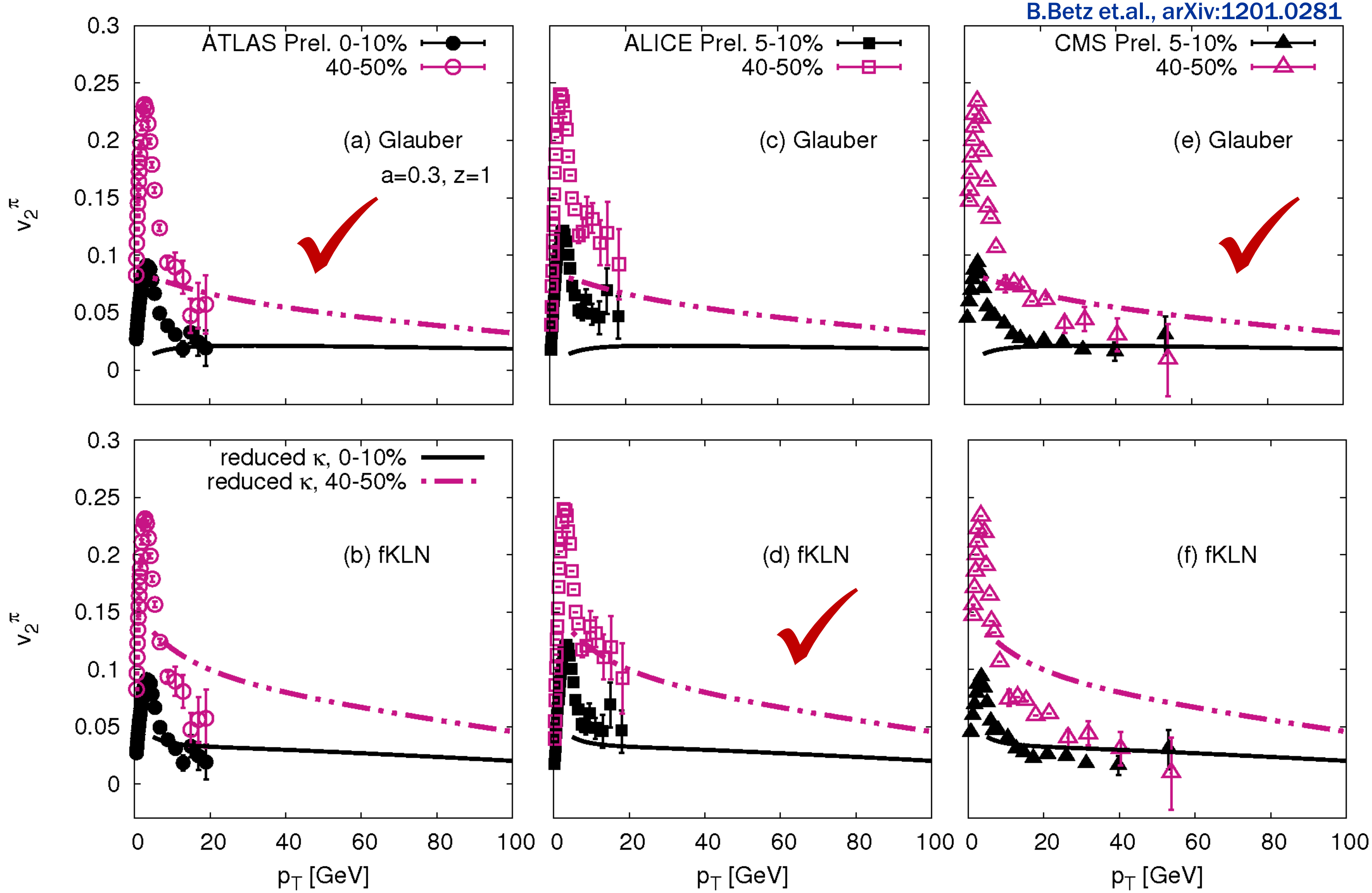
B.Betz et.al., arXiv:1201.0281



- ⇒ Puzzle: fKLN "wins" at RHIC, Glauber at LHC
- ⇒ Firmer conclusions need reduced discrepancies between data

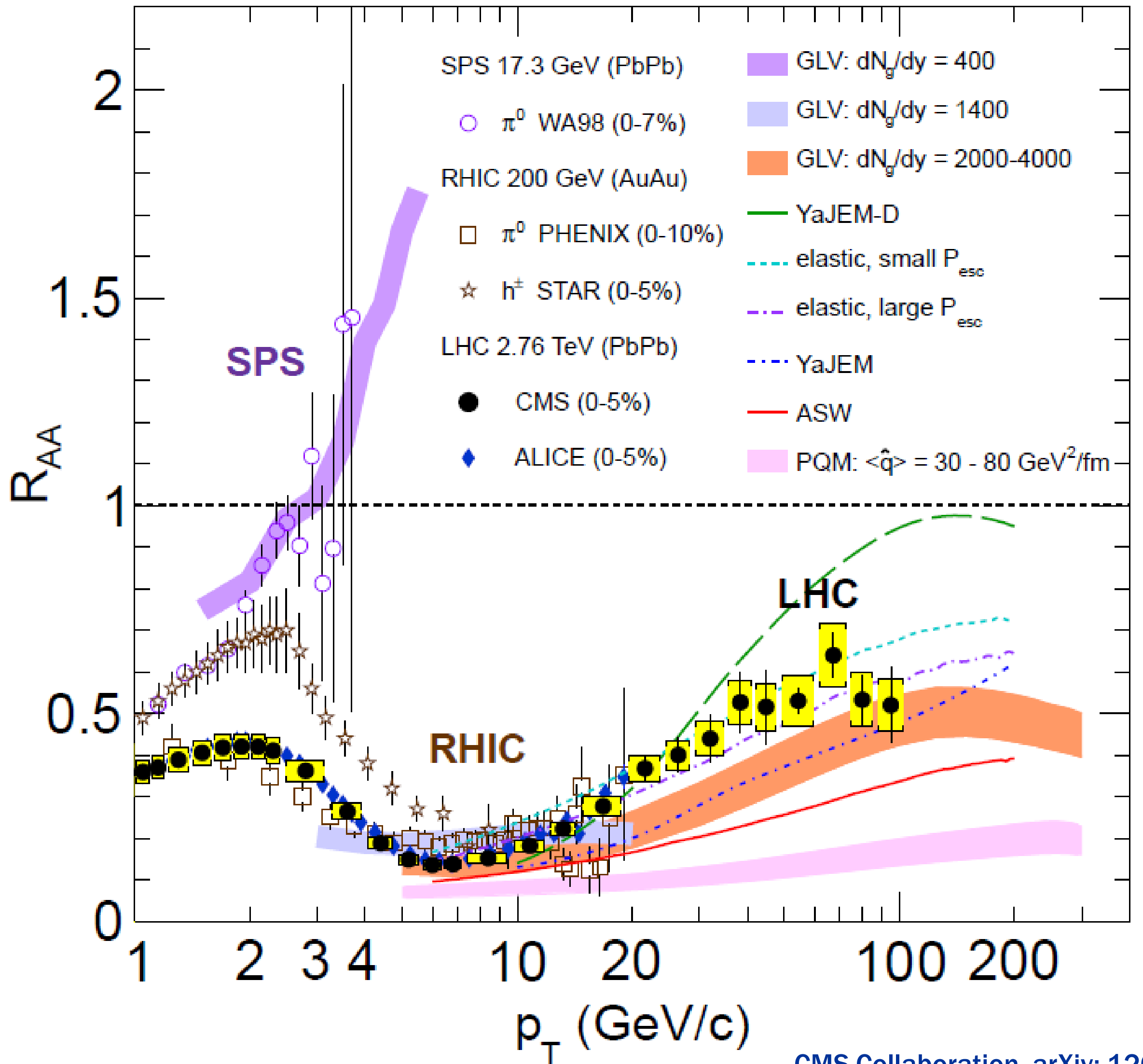
$v_2(p_T$, Centrality) at LHC

B.Betz et.al., arXiv:1201.0281



- ⇒ Puzzle: fKLN "wins" at RHIC, Glauber at LHC
- ⇒ Firmer conclusions need reduced descrepancies between data

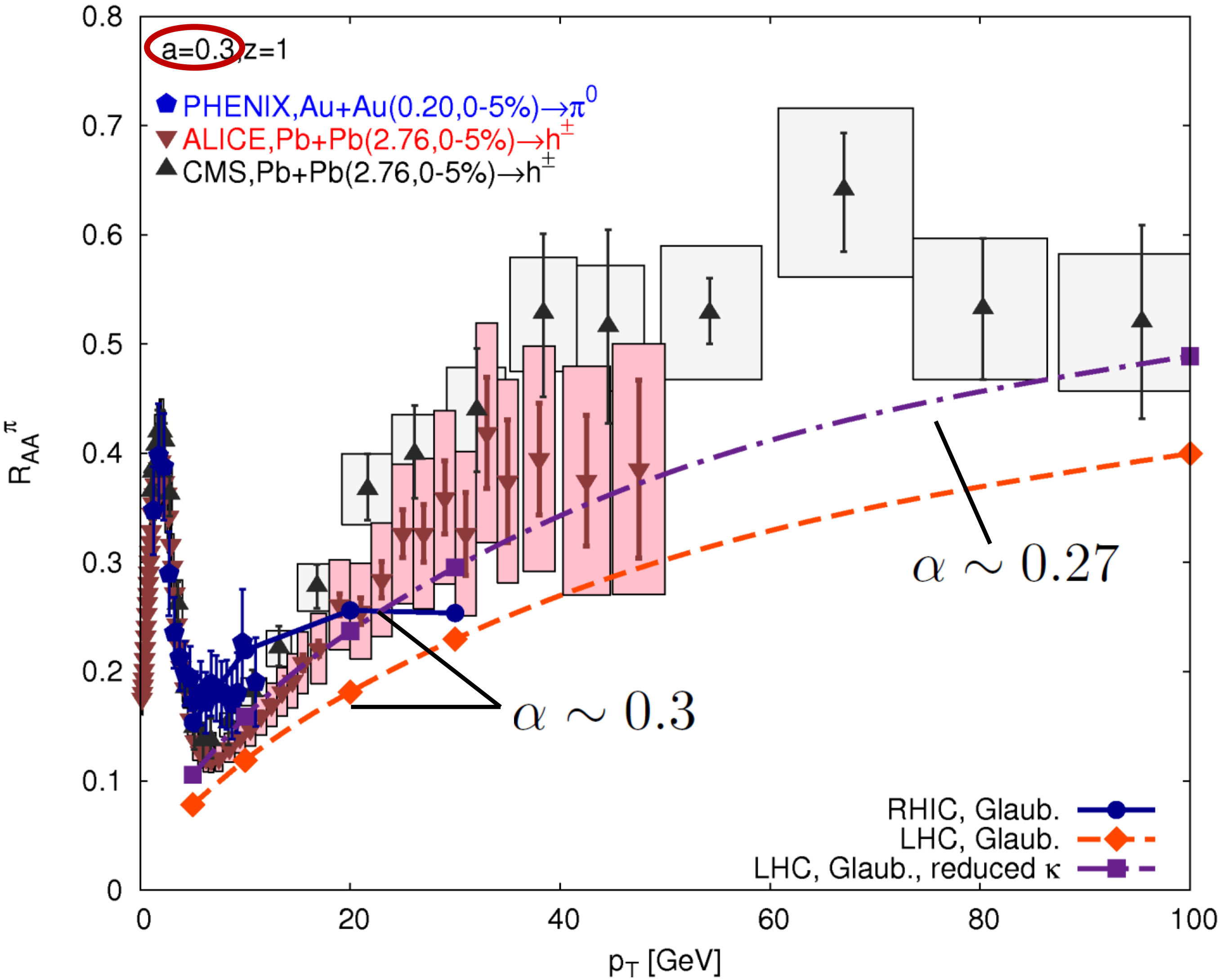
The Big Picture



CMS Collaboration, arXiv: 1202.2554[nucl-ex]

$R_{AA}(p_T)$ at RHIC vs. LHC

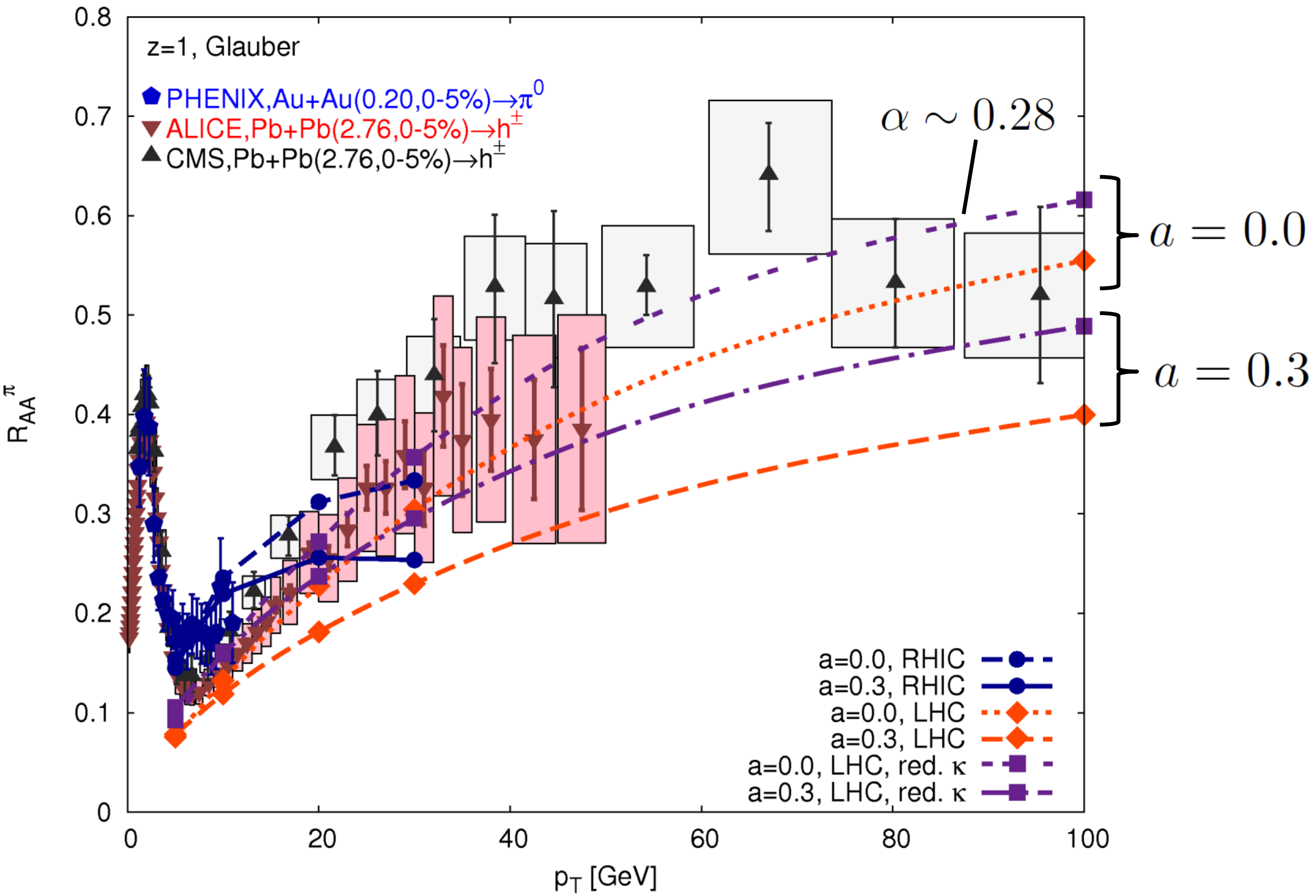
B.Betz et.al., arXiv:1201.0281



AdS/CFT: a=0.3, z=2 $\Rightarrow$ a=0.3 is a weak lower bound for falling strings

Energy Dependence of Energy Loss

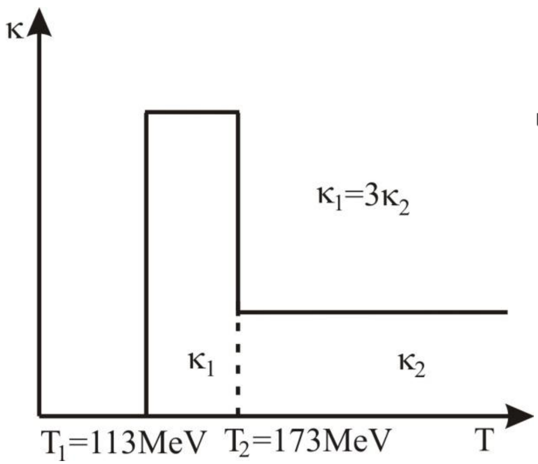
B.Betz et.al., in preparation



a=0.0 & reduced coupling seems to work better at LHC but NOT at RHIC!

Fixed vs. Temperature-Dependent Coupling

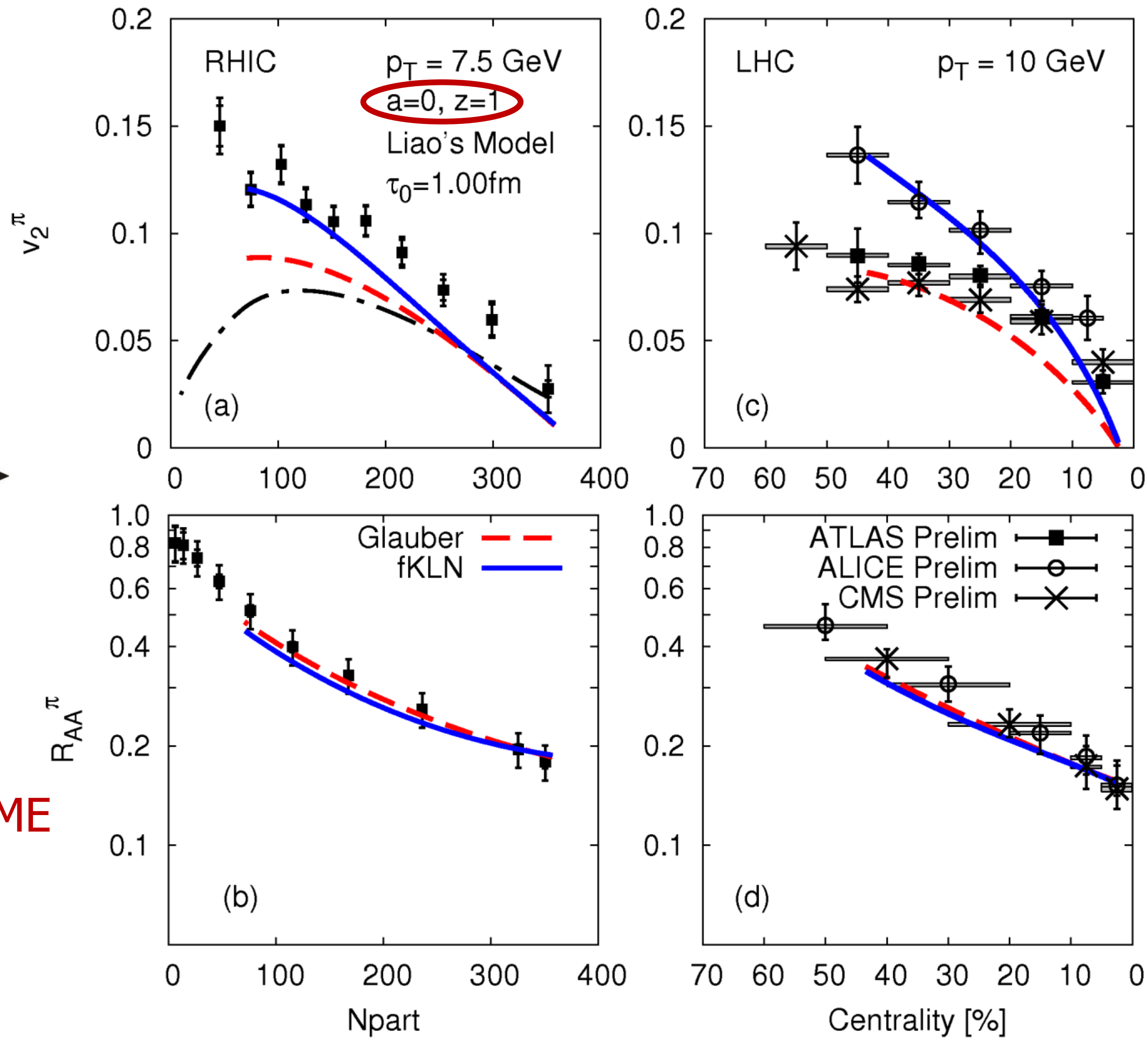
Temperature-dependent Coupling



J.Liao et al,. PRL **102** (2009) 202302

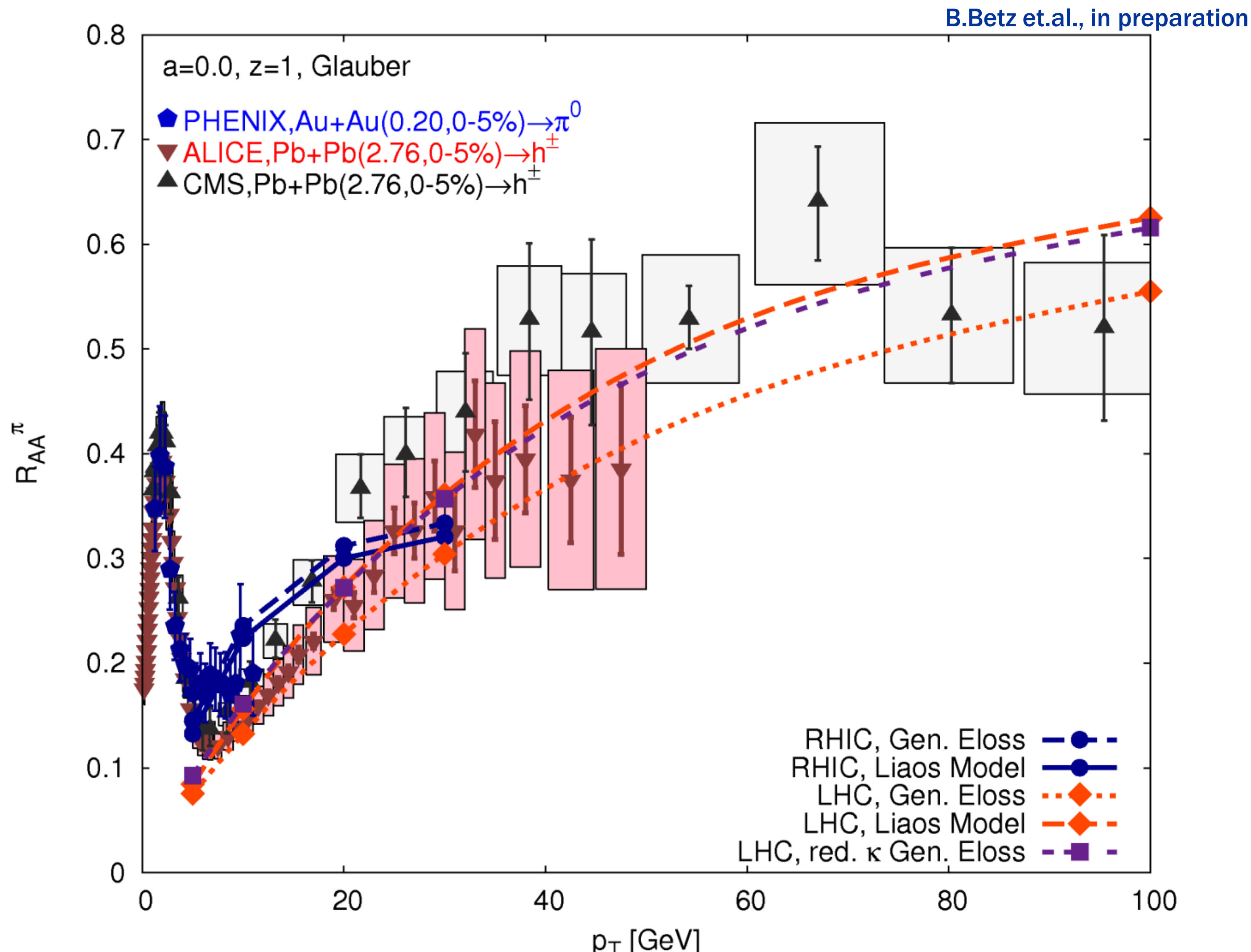
⟹ Coupling is the SAME for RHIC and LHC

B.Betz et.al., in preparation



$R_{AA}(p_T)$ at RHIC vs. LHC

B.Betz et.al., in preparation



⇒ Temperature-dependent and reduced couplings lead to similar $R_{AA}(p_T)$

⇒ How should one distringuish the two scenarios?

Summary & Open Problems

- Puzzle of overquenching using density-dependent jet-energy loss models can be solved:
  - reduced jet-medium coupling at LHC ($\alpha \sim 0.27$)
  - temperature-dependent jet-medium coupling
  - or a combination
- For τ_0=1fm, the path-length differences are small

  $\Longrightarrow$ Not suitable to distinguish between pQCD-like and AdS/CFT-like energy loss

- Puzzles:
  1. Why do fKLN initial conditions work well for RHIC while Glauber initial conditions describe LHC data?
  2. Is the energy loss at LHC different from the one at RHIC?

$\Longrightarrow$ It is important to always look at all combinations of available data to fully test the consistency of the model

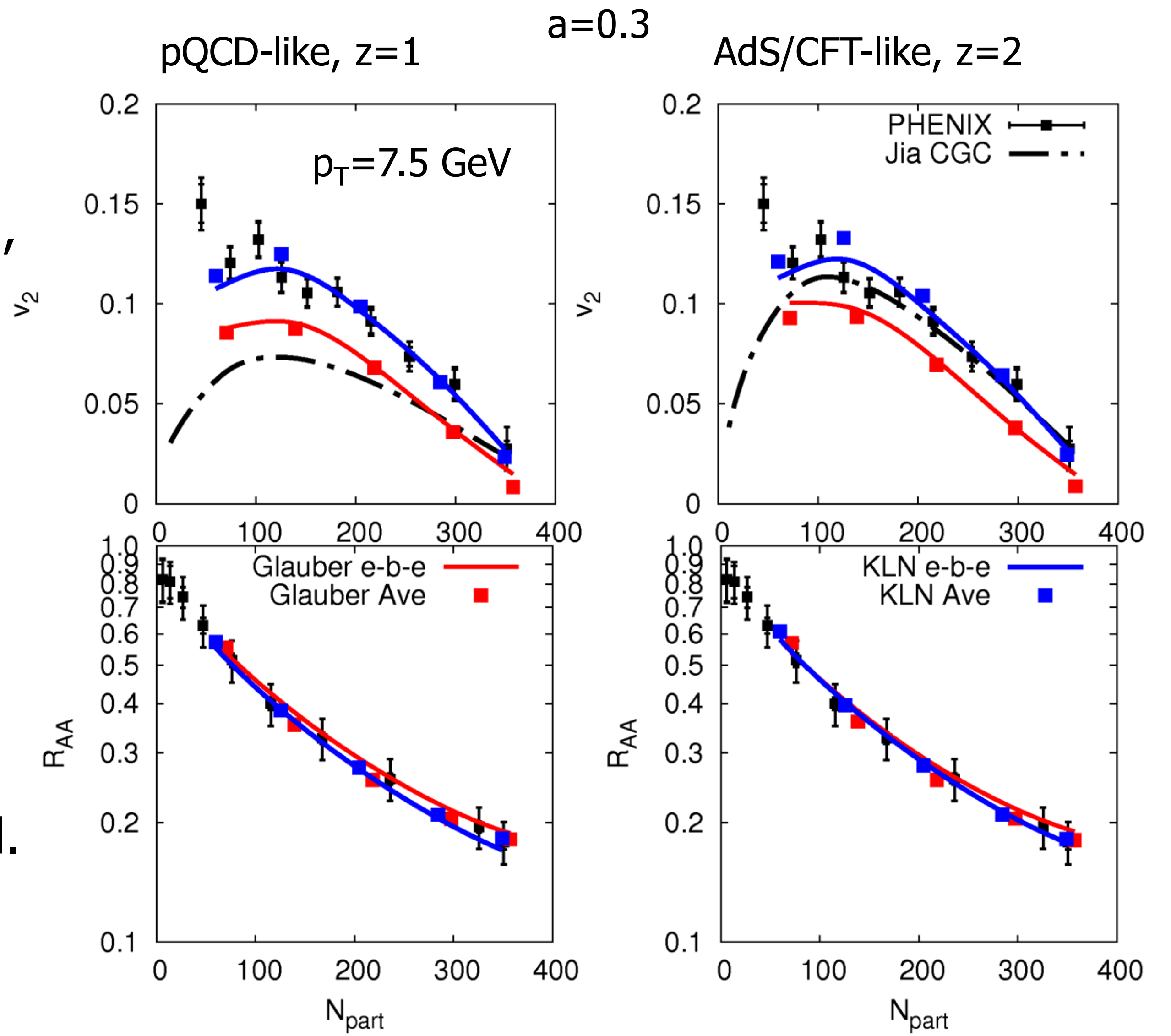
Backup

R_{AA} and v_2

→ Having fixed κ for $R_{AA}(N_{part}=350) \sim 0.18$, $R_{AA}(N_{part})$ can be reproduced

→ z=1: CGC in. cond. close to data

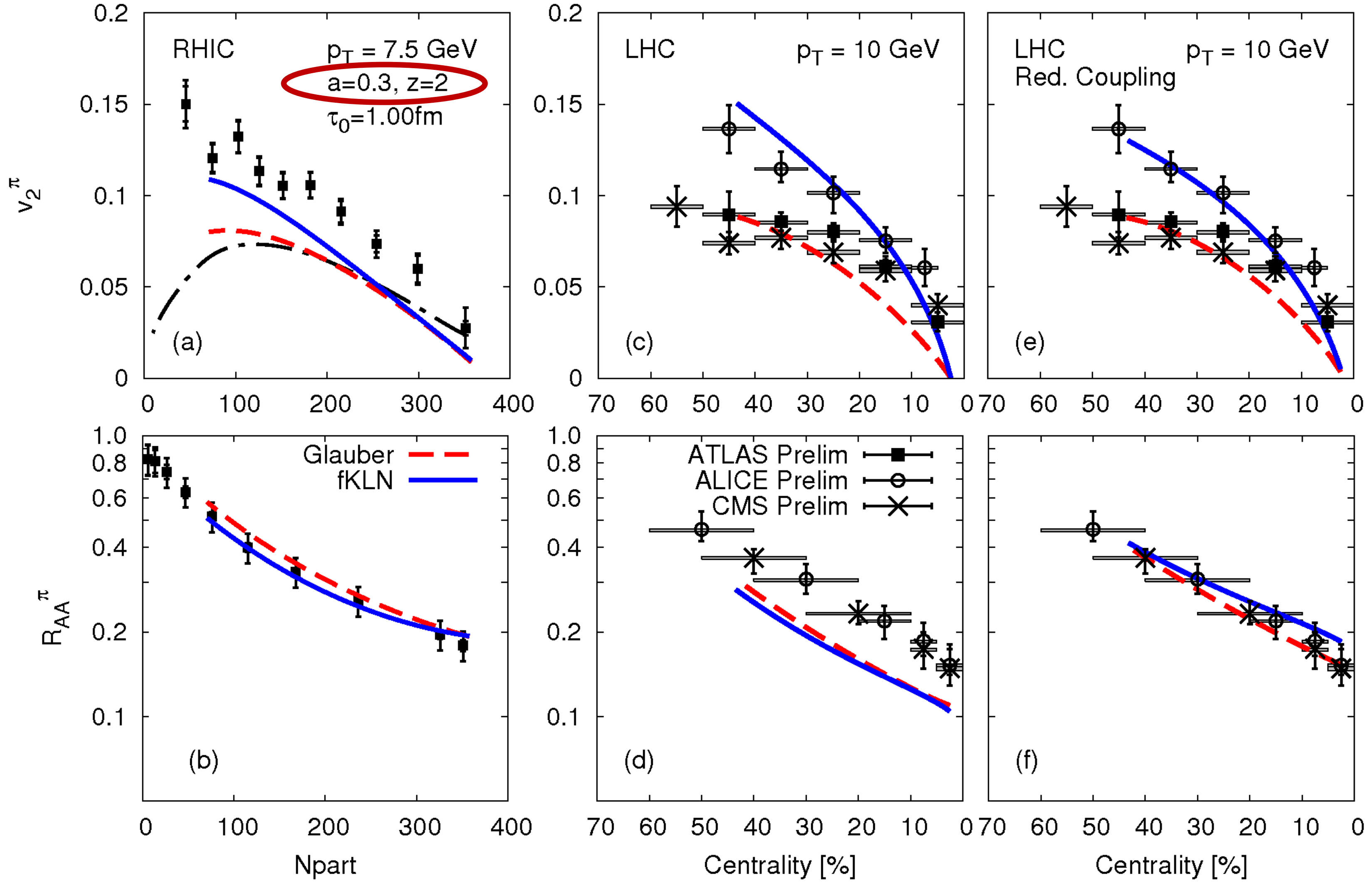
z=2: CGC in. cond. describe data, Glauber in. cond. getting closer



⇒ Similar results for event-by-event and averaged scenarios!

B.Betz et.al., PRC **84**, 024913 (2011)

R_{AA} and v_2 at RHIC vs. LHC



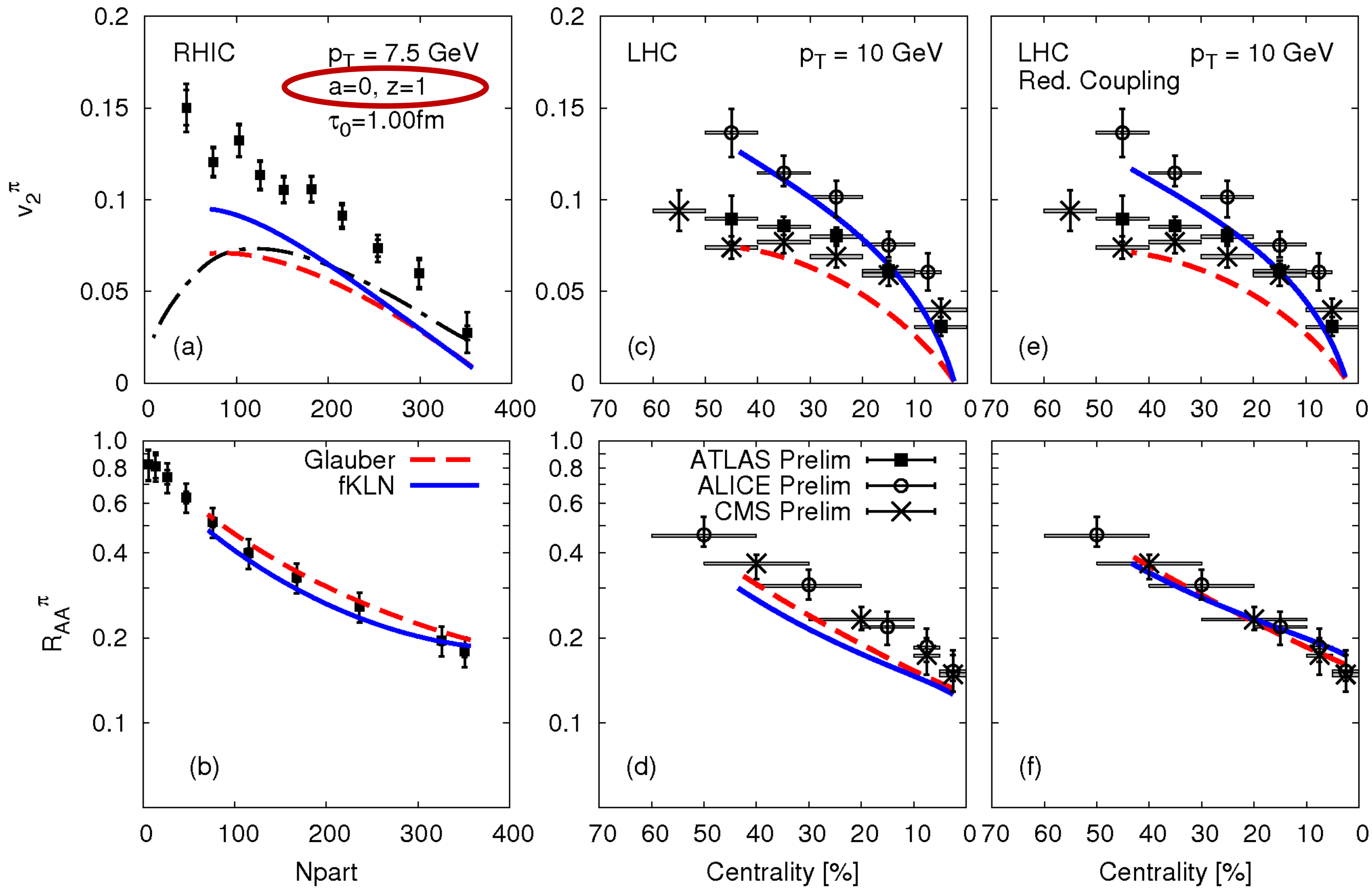
Reduced Jet-Medium Coupling

B.Betz et.al., arXiv:1201.0281

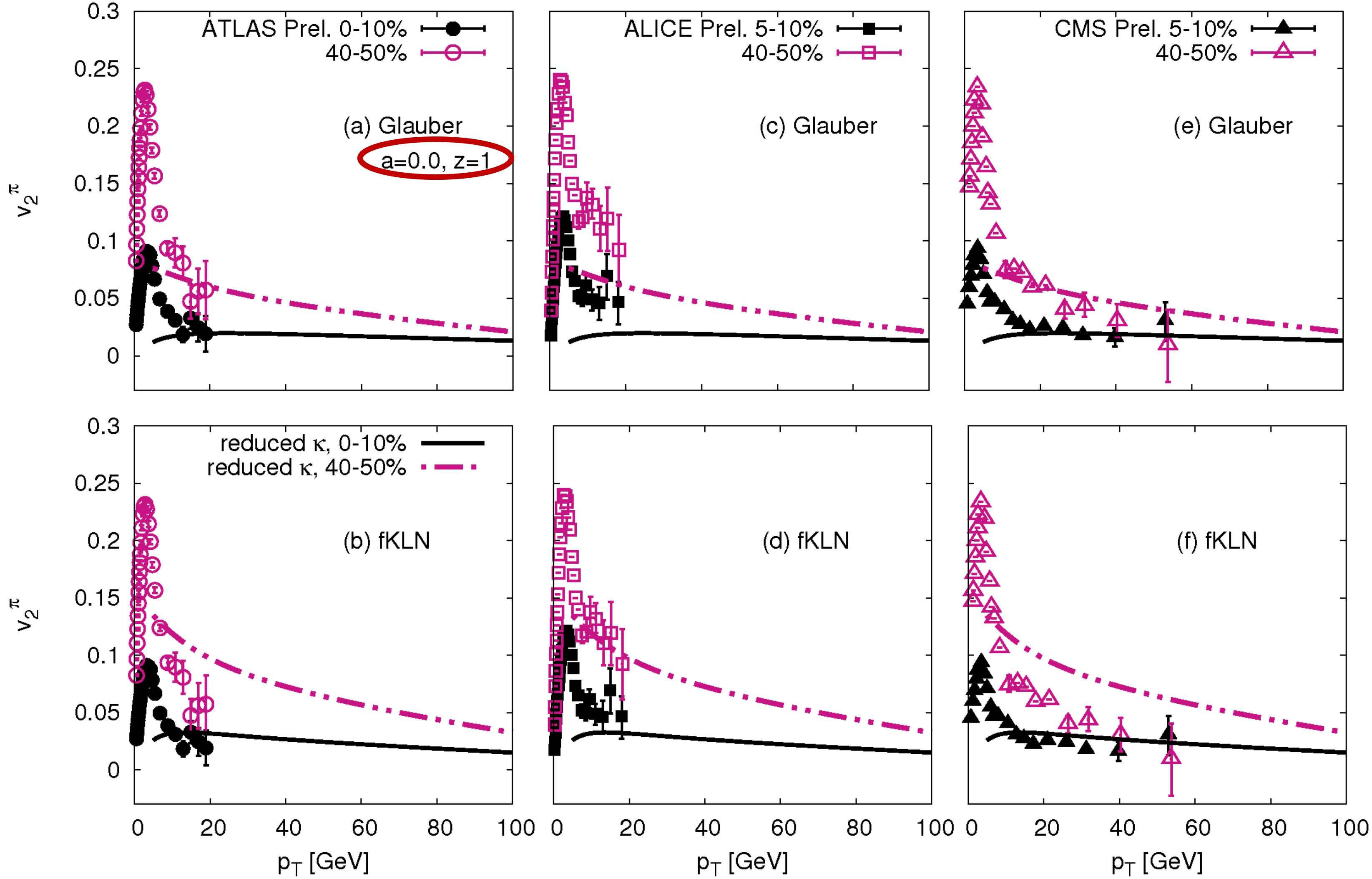
Effective Coupling κ assuming $\tau_0 = 1.0$ fm/c				
$\sqrt{s}$	GL, z=1	fKLN, z=1	GL, z=2	fKLN, z=2
0.20	0.93	1.05	0.55	0.63
2.76	0.66	0.64	0.33	0.29
LHC/RHIC	0.71	0.61	0.60	0.46

Effective Coupling κ assuming $\tau_0 = 0.01$ fm/c				
$\sqrt{s}$	GL, z=1	fKLN, z=1	GL, z=2	fKLN, z=2
0.20	0.60	0.62	0.44	0.45
2.76	0.45	0.43	0.26	0.24
LHC/RHIC	0.75	0.69	0.59	0.53

R_{AA} and v_2 at RHIC vs. LHC



$v_2(p_T, \text{Centrality})$ at LHC



$v_2(p_T$, Centrality) at LHC