Bourses postdoctorales Banting Postdoctoral Fellowships

McGill

Collision energy dependence of anisotropic flow and the temperature dependence of eta/s

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with:

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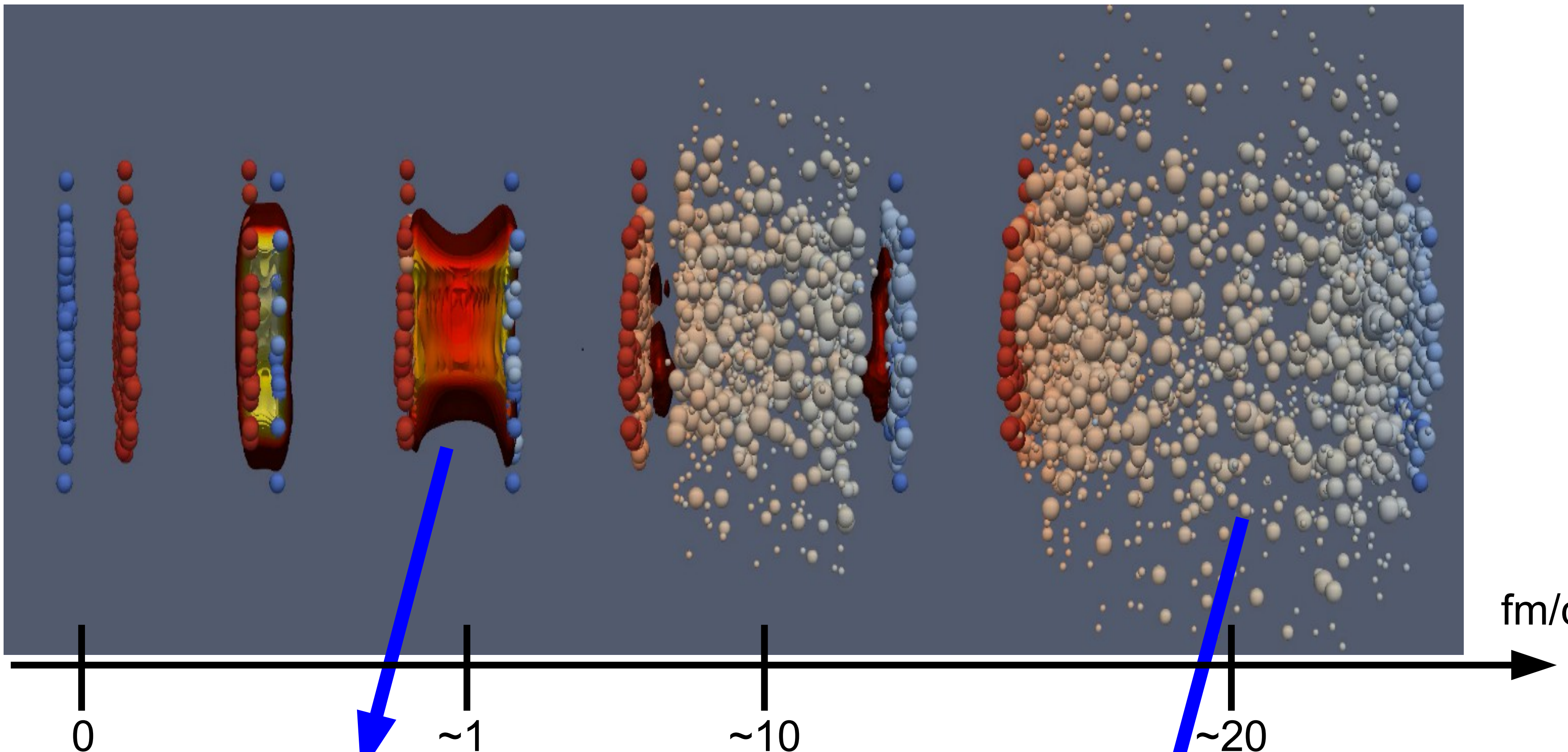
Ions at the FCC, Sep. 22-23, CERN

Theoretical Challenge

Properties of the bulk nuclear matter created have to be reverse-engineered!

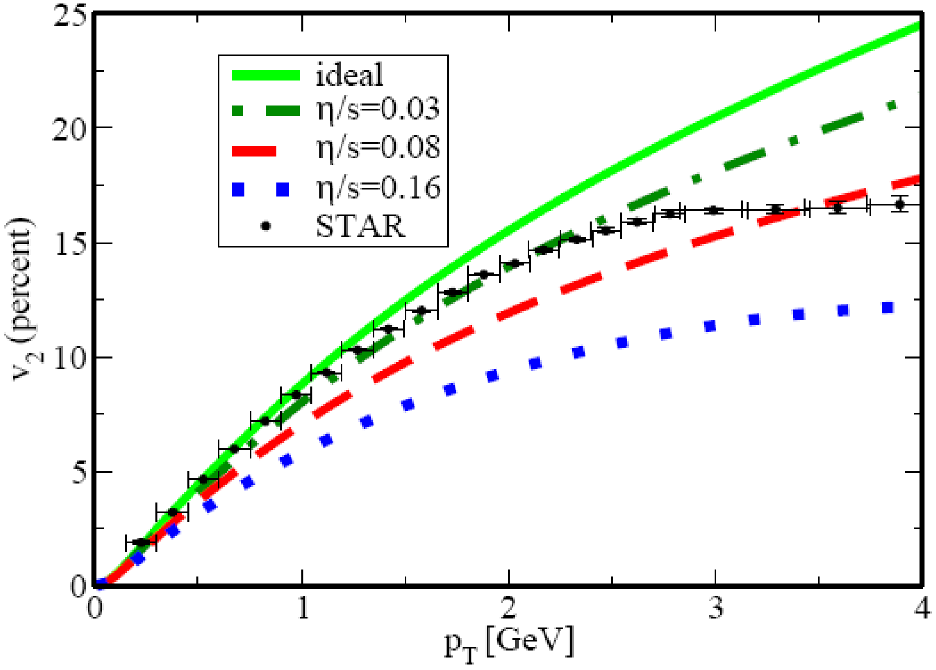


Quark-Gluon plasma is only created transiently!

What is measured are hadrons, leptons, and photons produced during the reaction

Main Motivation

Elliptic flow coefficient is sensitive to the transport properties of the QGP

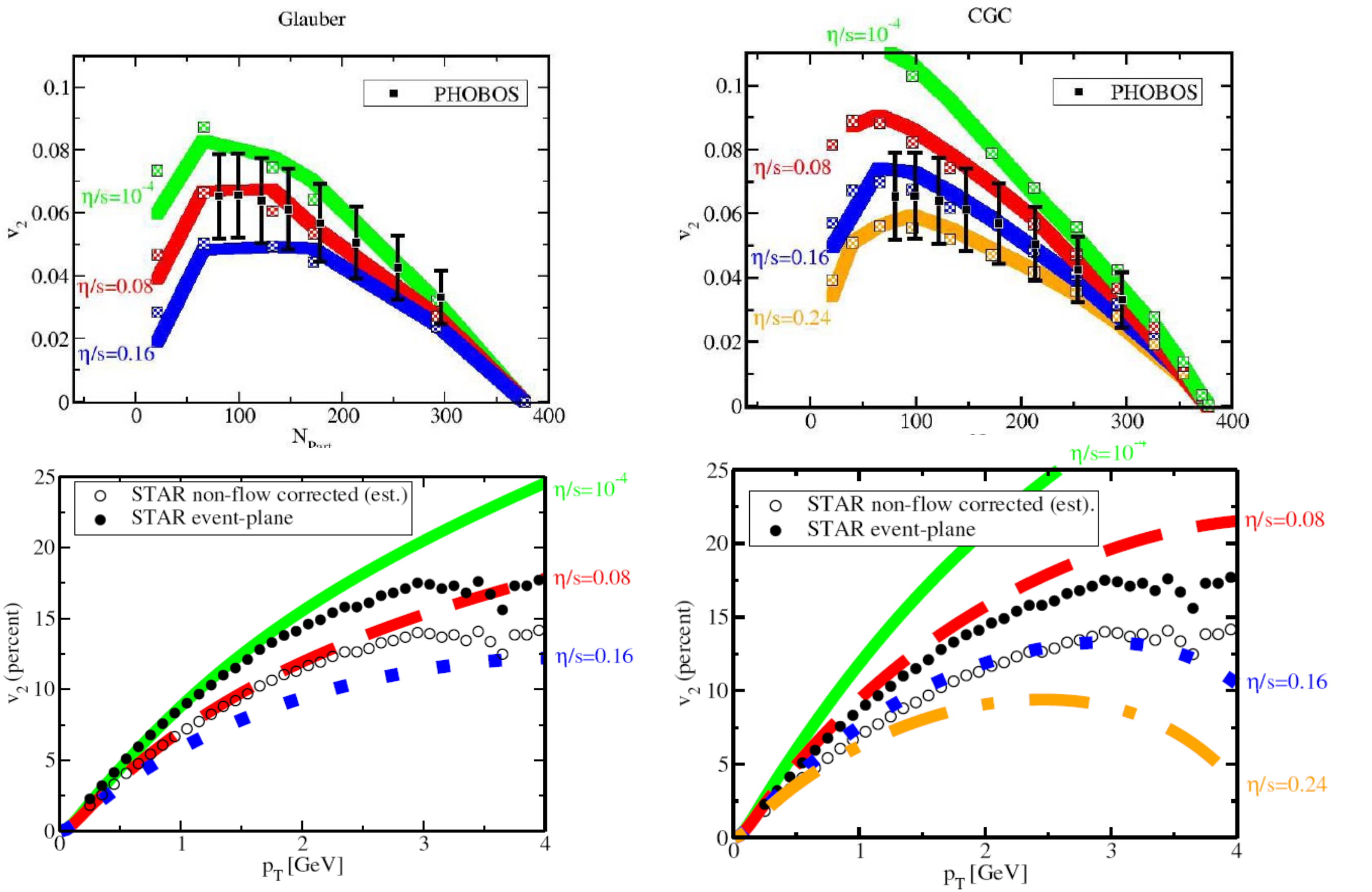


Romatschke&Romatschke PRL 99, 172301 (2007)

Viscosity can be estimated using data

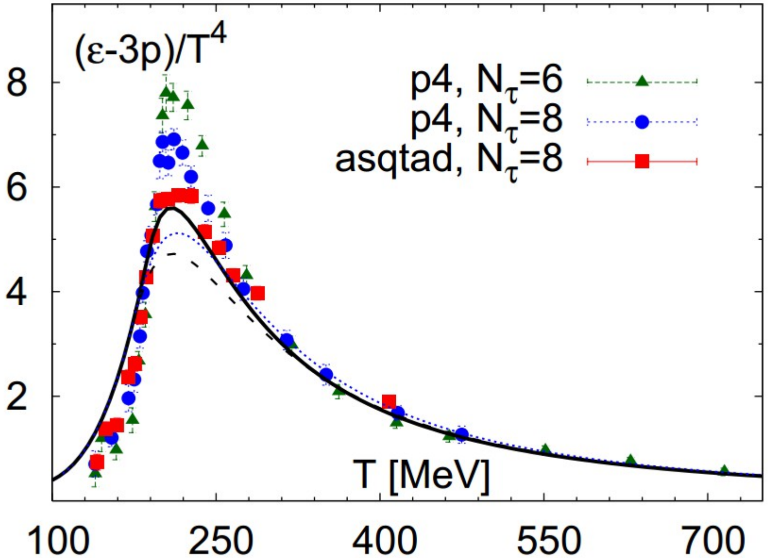
Constraining shear viscosity using the data

Luzum&Romatschke PRC 78, 034915 (2008)



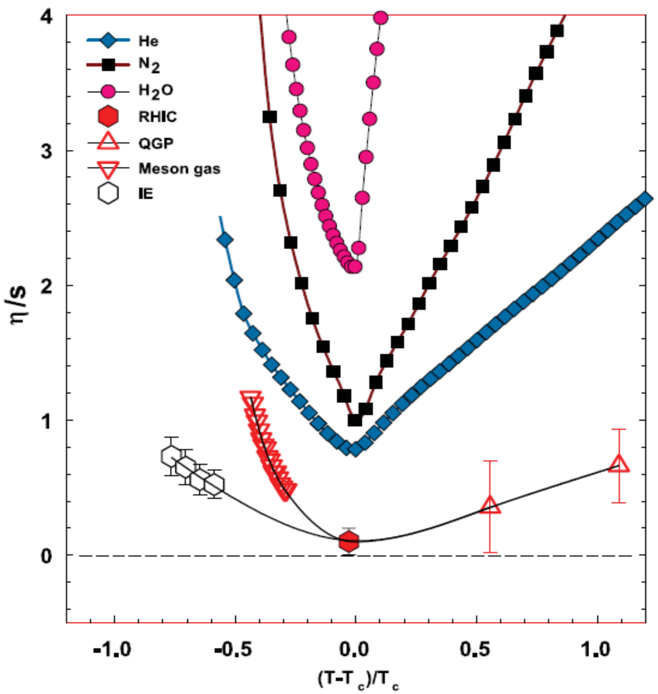
Anisotropic flow indicates that the "QGP" has a small shear viscosity: ~10 times smaller than predictions from pQCD

QCD is not conformal

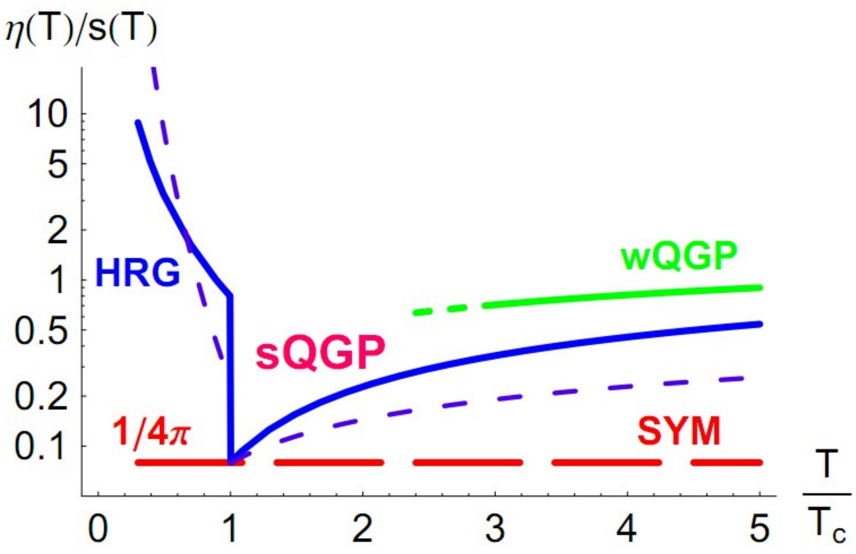


Lattice QCD calculations demonstrate that the EoS of QCD matter deviates from that of a conformal fluid

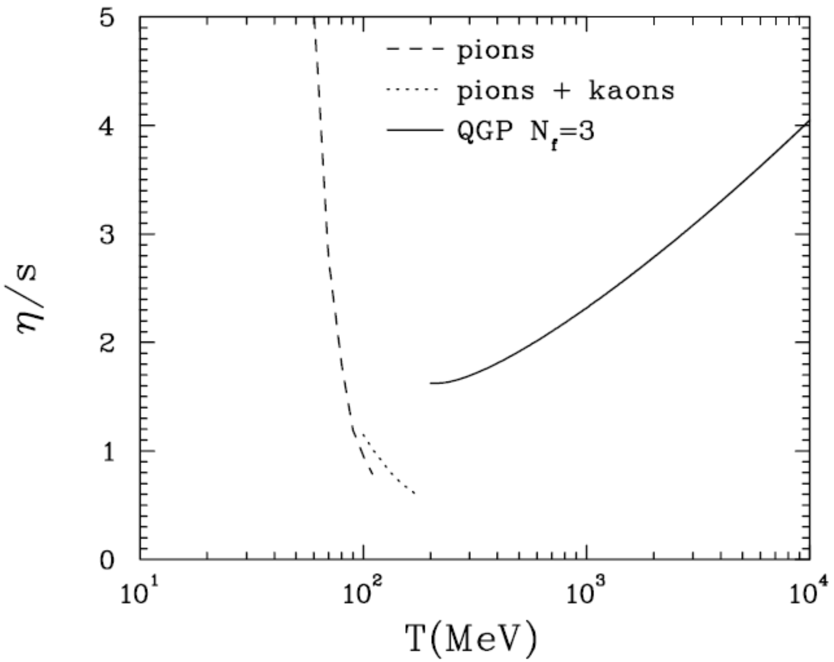
shear viscosity should display some T-dependence



Old news ...



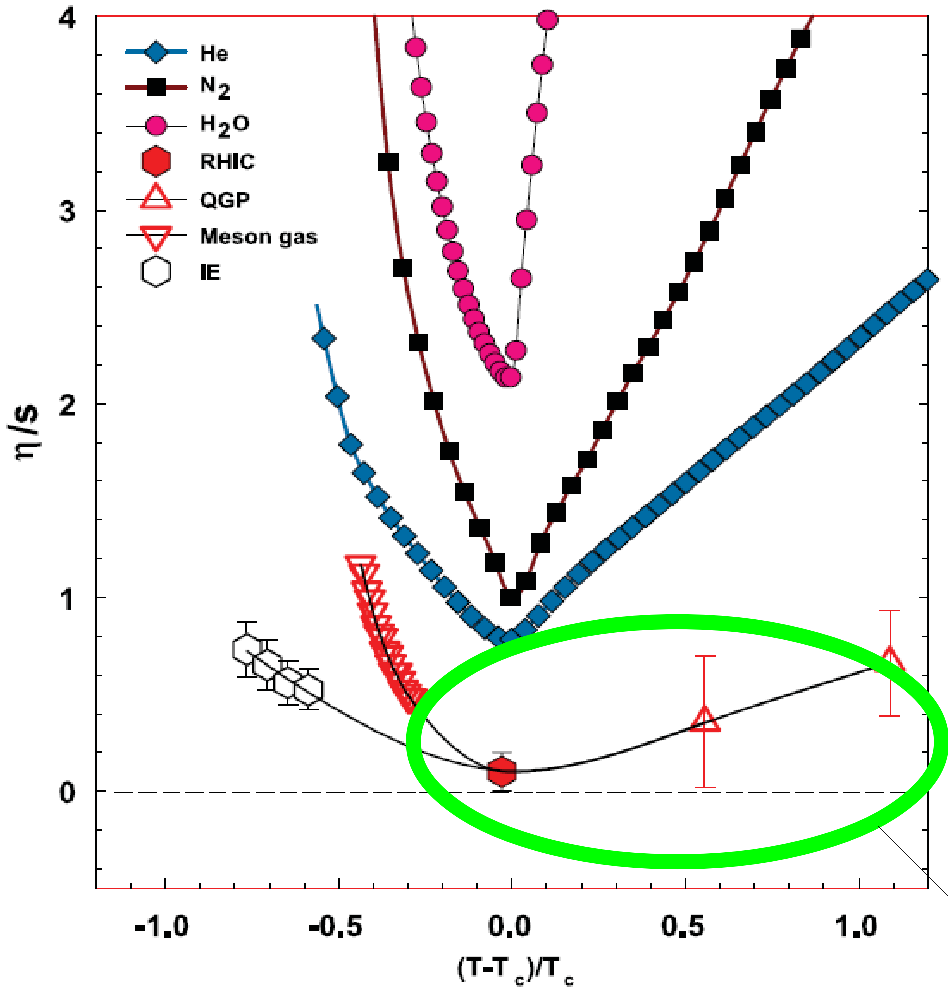
Hirano&Gyulassy(2006)



Csernai&Kapusta&McLerran(2007)

QCD is not conformal

→ η/s is not constant!



Lacey *et al*(2007)

In principle, T-dependence can be strong

η/s only expected to be small around the transition region

η/s=cte is only an effective viscosity. Not simply related to the real viscosity

Unknown!!

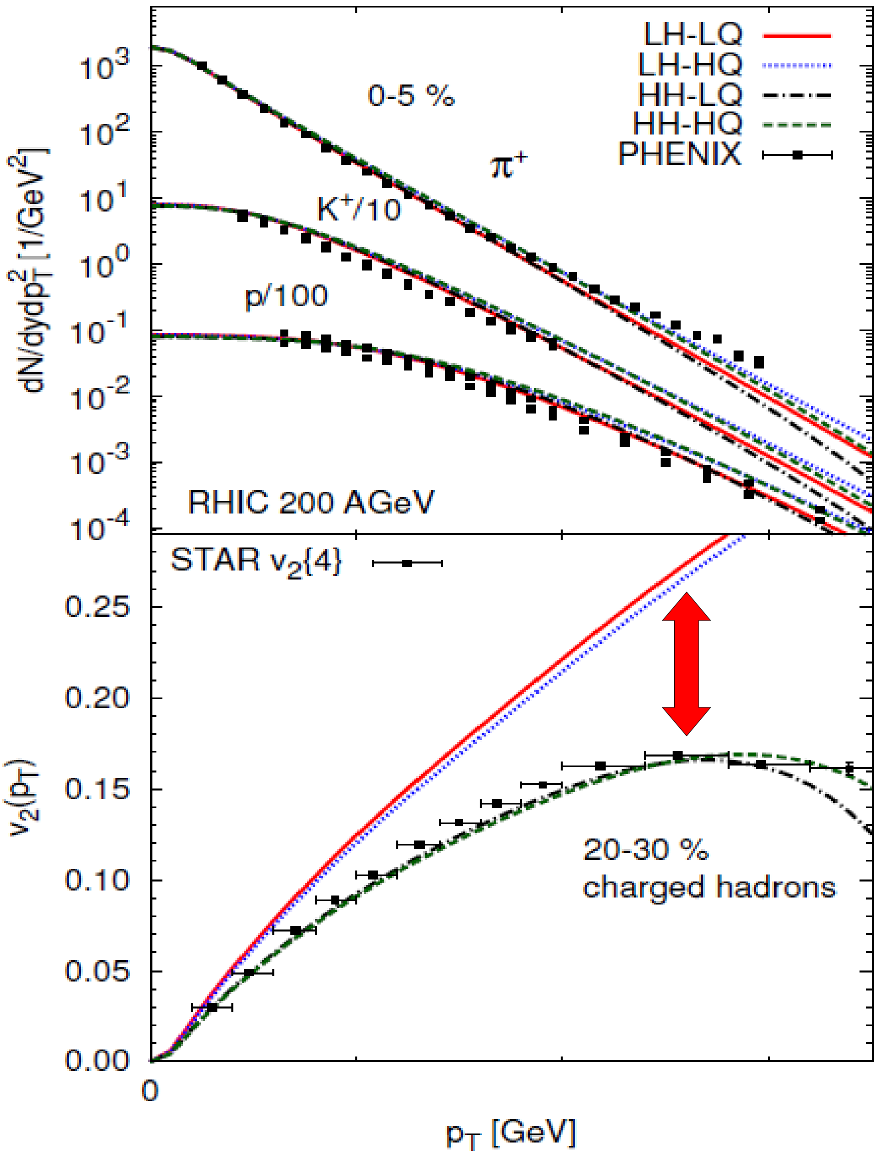
Relevant Questions

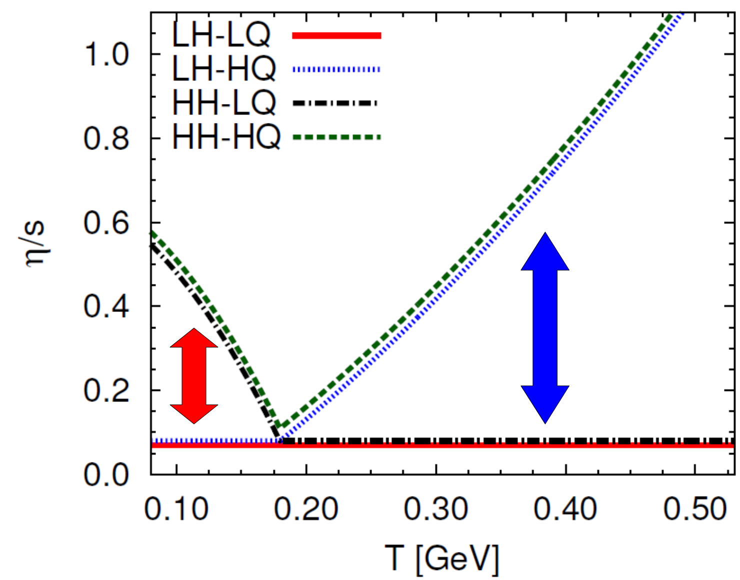
- ✓ What does a constant η/s mean ?
- ✓ Can we measure the temperature dependence?

Can we extract η/s(T) ?

RHIC 200 GeV

Niemi *et al*, PRL 106, 212302 (2011)



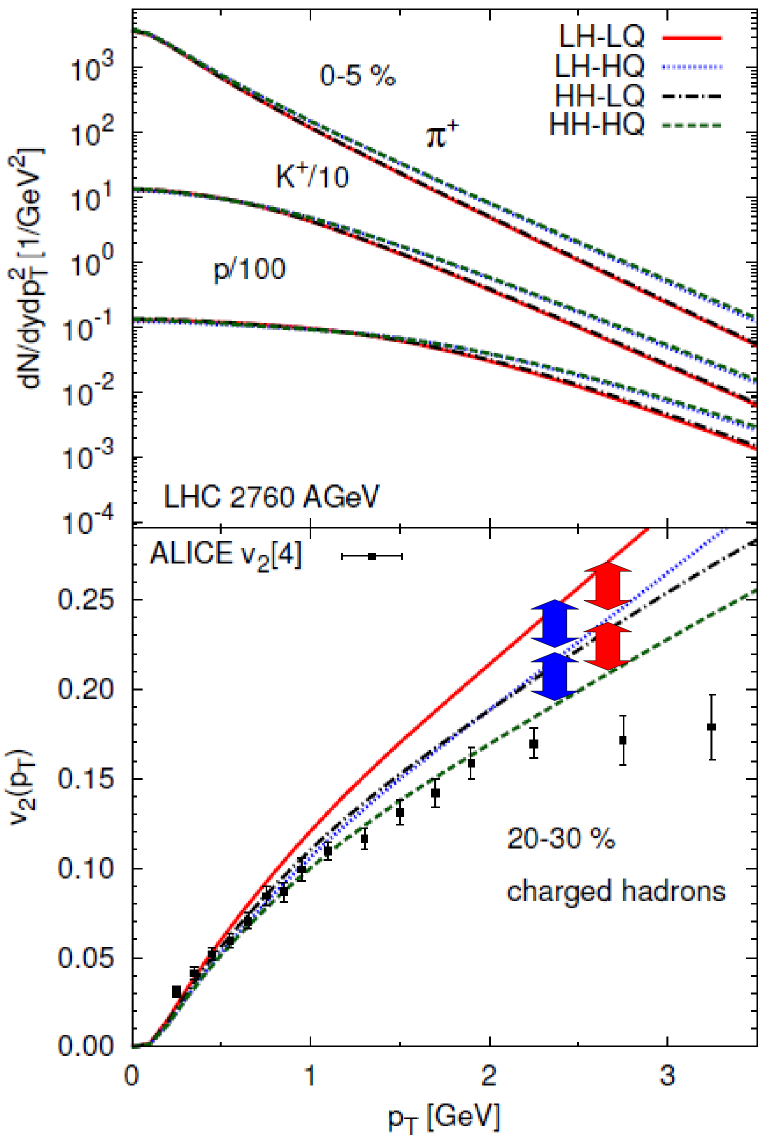


not at RHIC!

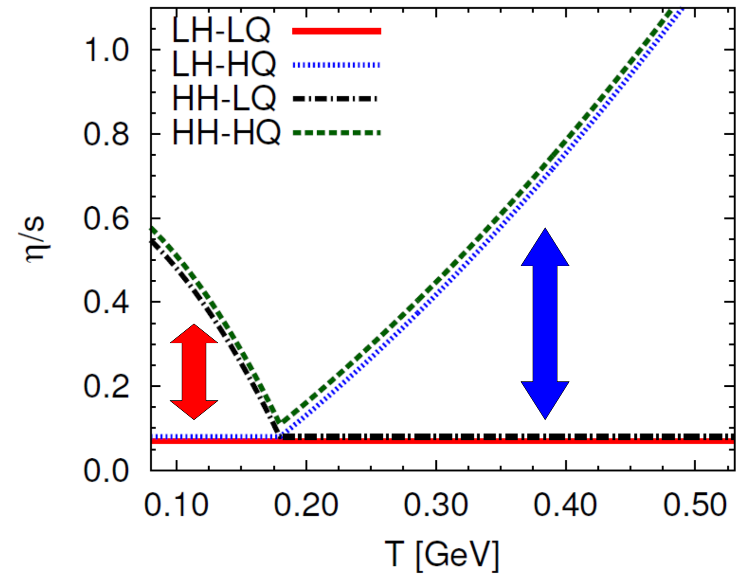
Flow coefficients are insensitive to QGP viscosity!

Can we extract η/s(T) ?

LHC
2.76 TeV



Niemi *et al*, PRL 106, 212302 (2011)

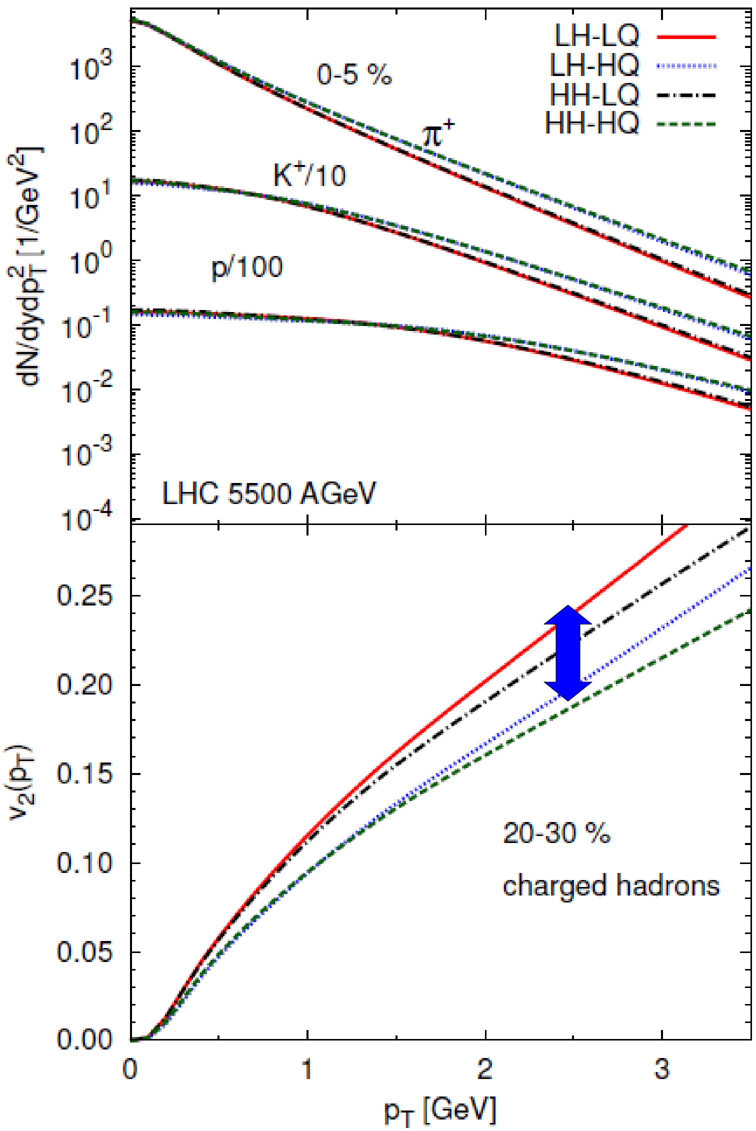


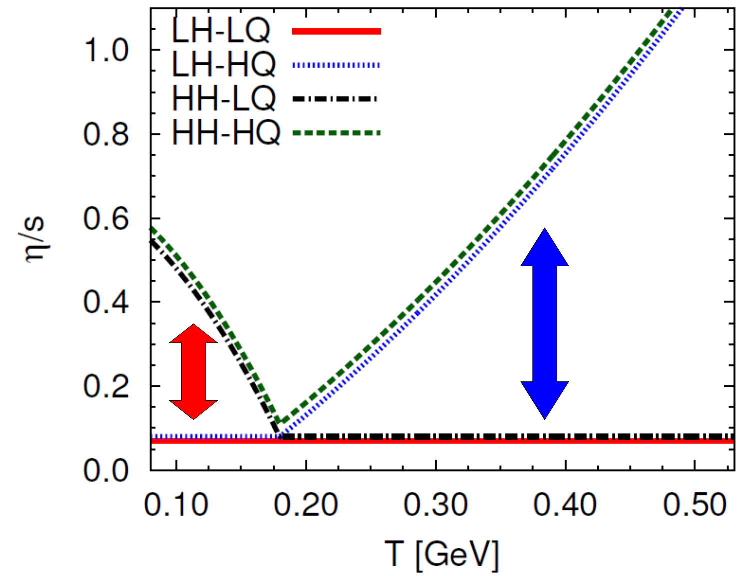
Only at the LHC some sensitivity appears

Can we extract η/s(T) ?

LHC
5.5 TeV

Niemi *et al*, PRL 106, 212302 (2011)

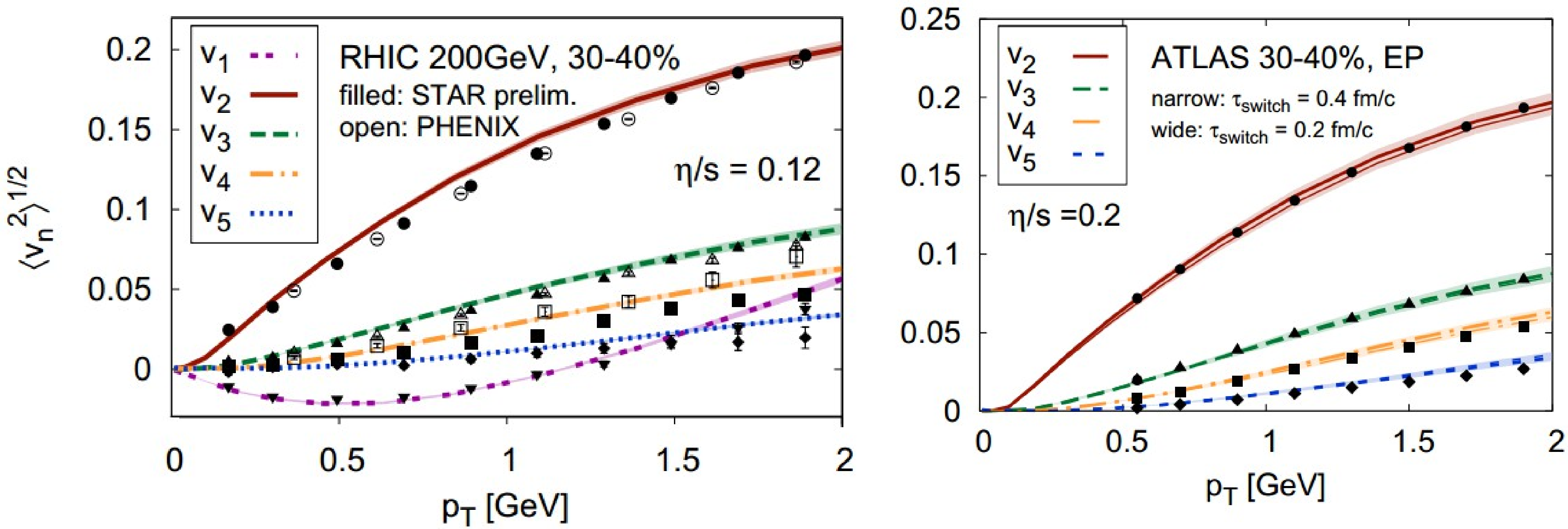




At the highest LHC energy η/s(T) should start to become accessible

Can we extract η/s(T) ?

Gale *et al*, PRL 110, 012302 (2013)

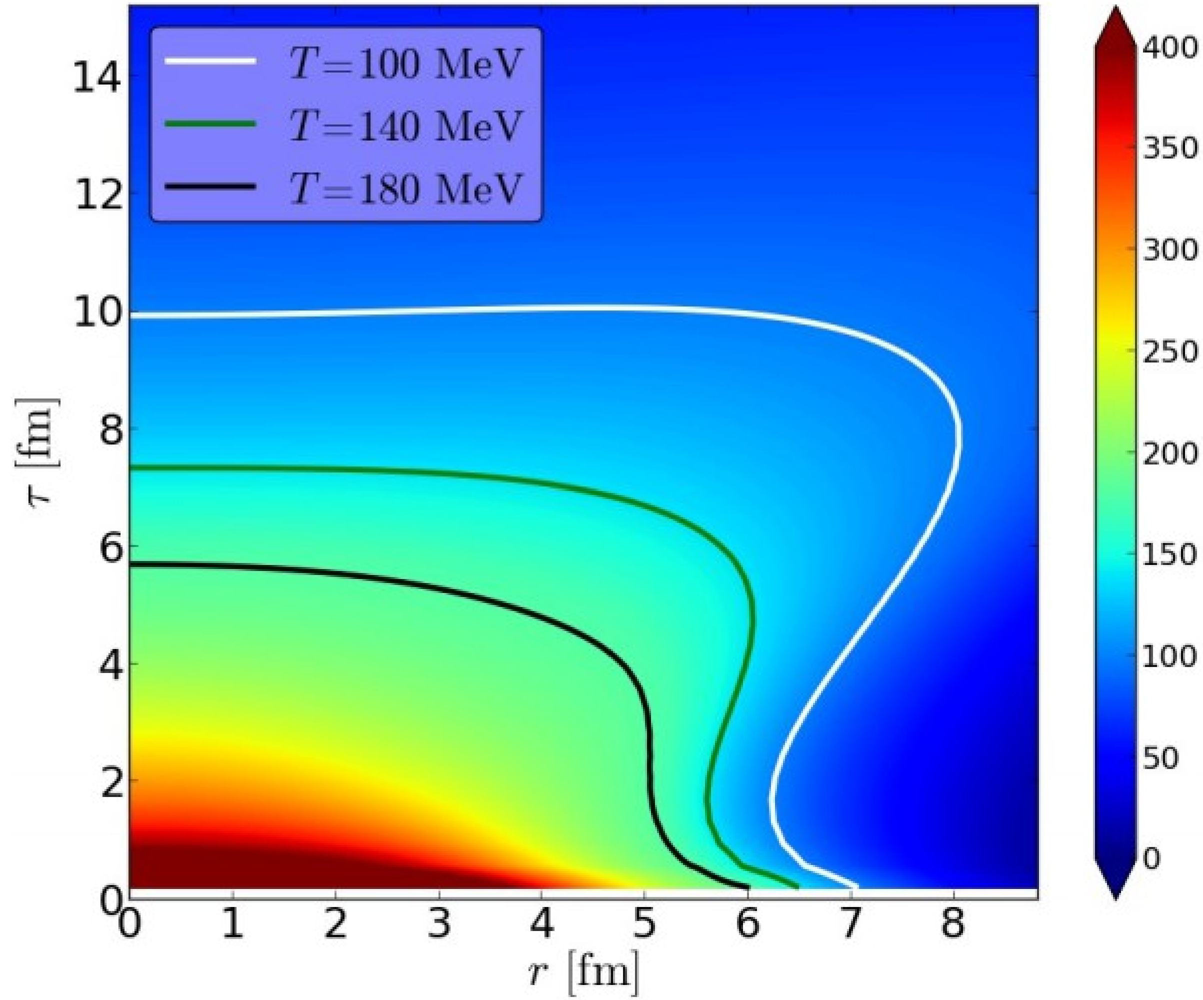


$\eta/s=0.12$ → $\eta/s=0.2$

For IP-Glasma initial conditions, a constant η/s is unable to simultaneously describe RHIC and LHC data

Niemi&GSD, arXiv:1404.7327

Temperature profile of the collision



noncentral collision (x=y), Optical Glauber, LHC, τ_0=0.2 fm, η/s=0.08

Higher collision energies are important to study $\eta/s(T)$

At RHIC – 200 GeV

- elliptic flow is independent of high temperature η/s
- but sensitive to hadronic η/s (and at minimum)

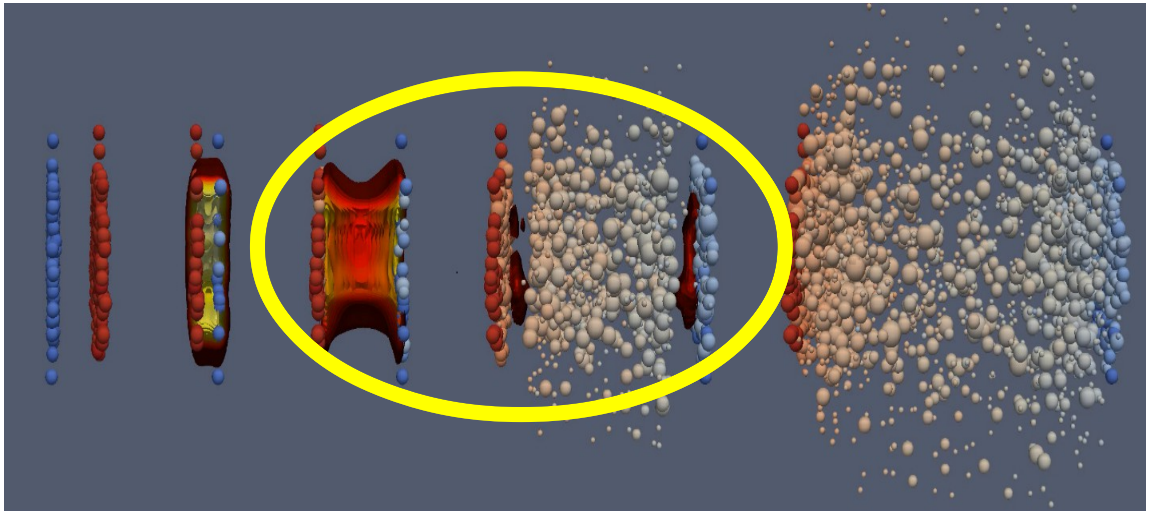
At LHC – 5.5 TeV

- elliptic flow is independent of hadronic $\eta/s(T)$
- and starts to become sensitive to QGP's $\eta/s(T)$

What about higher energies?

Fluid-dynamical model:

Improving the fluid-dynamical modeling of HIC



Basics of fluid dynamics

Energy-momentum conservation

$$\partial_\mu T^{\mu\nu} = 0$$

$$T^{\mu\nu} = \varepsilon u^\mu u^\nu - \Delta^{\mu\nu}\left(P_0 + \Pi\right) + \pi^{\mu\nu}$$

Bulk viscous pressure (Π)

Shear stress tensor ($\pi^{\mu\nu}$)

Usual: no Bulk

Shear-Only: $\tau_\pi \dot{\pi}^{\langle\mu\nu\rangle} + \pi^{\mu\nu} = 2\eta\sigma^{\mu\nu} - \frac{4}{3}\tau_\pi \pi^{\mu\nu}\theta$

Simulation

- ✔ We solve the fluid-dynamical equations using a relativistic version of the KT algorithm – **MUSIC**

  Schenke&Jeon&Gale

  Phys.Rev. C82 (2010) 014903

- ✔ Freeze-out via Cooper-Frye, T=120 MeV

- ✔ δf from Monnai&Hirano, Phys. Rev. C80 (2009) 054906

- ✔ lQCD + HRG EoS by Huovinen&Petrescky

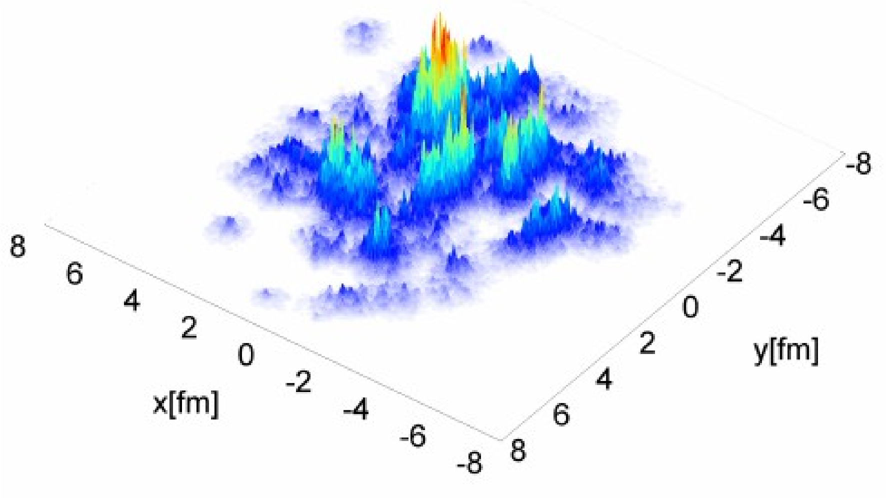
  T_{chem}=160 MeV Nucl.Phys. A837 (2010) 26-53

- ✔ Rescaled IP-Glasma initial conditions **30-40%**

Initial condition

✔ Rescaled IP-Glasma initial conditions, τ=0.4 fm

30-40%

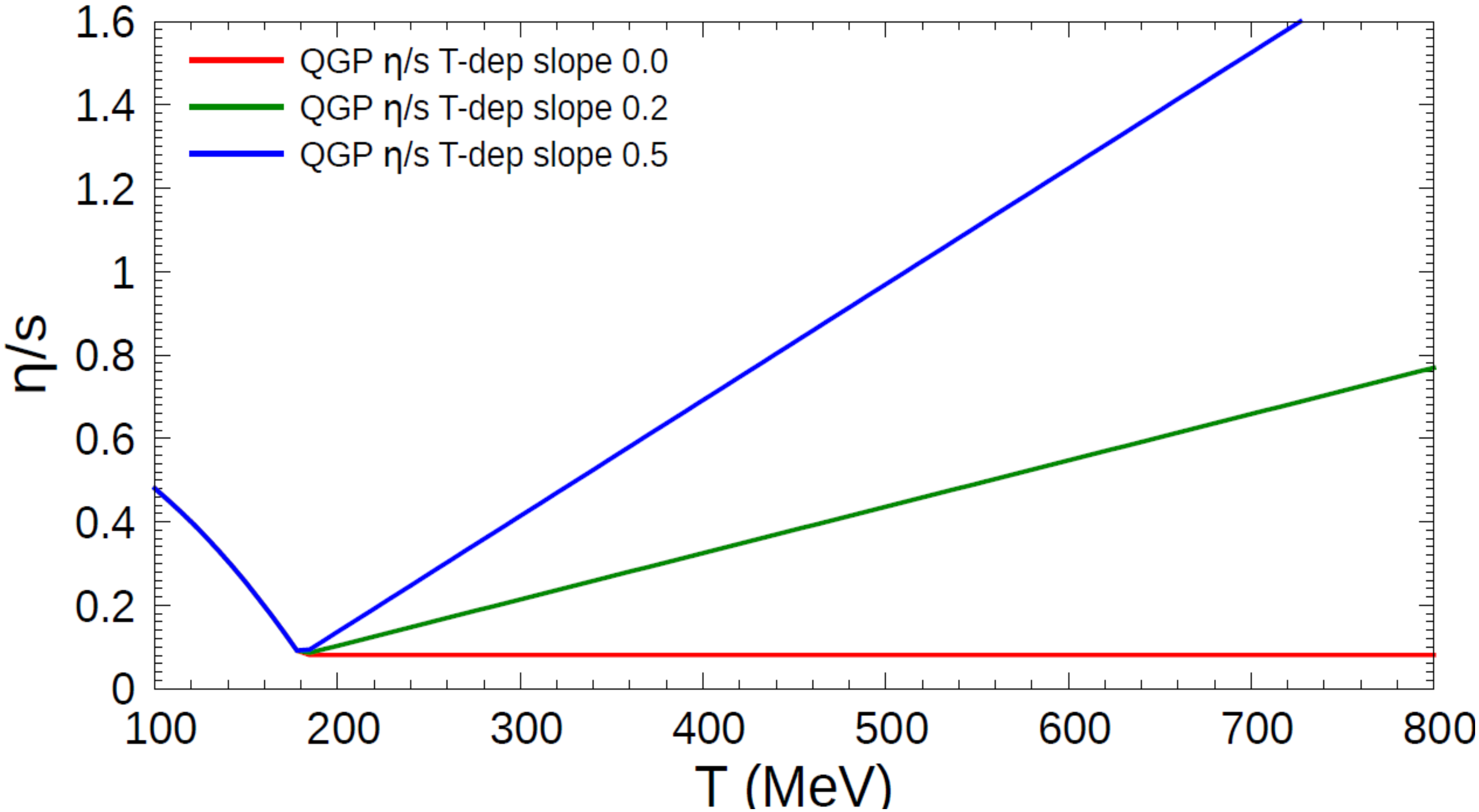


Works very well for RHIC and LHC energies

IP-Glasma initial condition is not known for higher collision energies

We simple rescale the initial energy density by a global factor – increasing the initial entropy of the system.

Shear Viscosity:



Hadronic phase : Noronha-Hostler *et al*, PRL 103 (2009) 172302

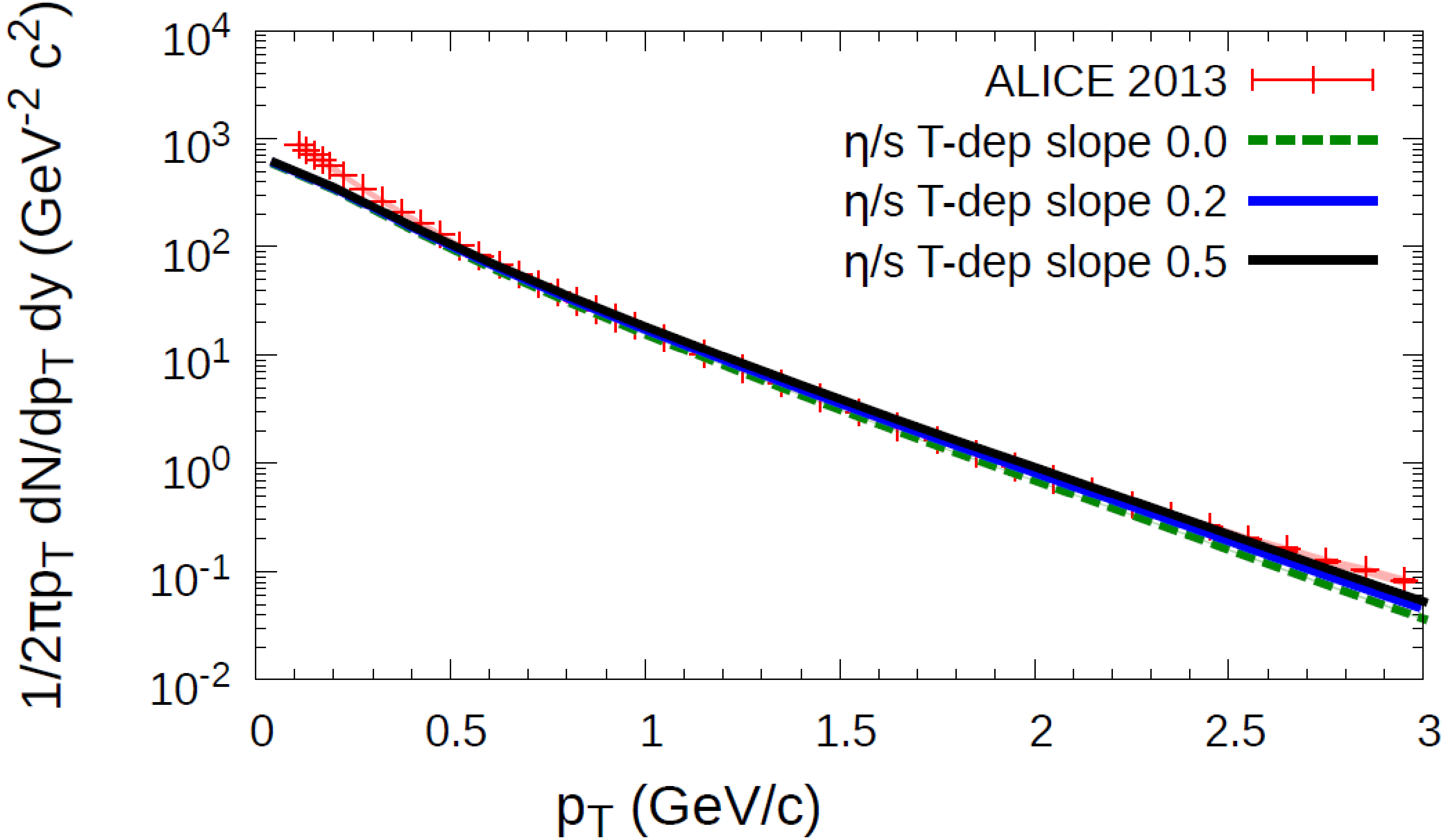
QGP phase : parametrizations

Relaxation time:

$$\tau_\pi = 5\frac{\eta}{\varepsilon + P}$$

Results

Current LHC energy **30-40%**



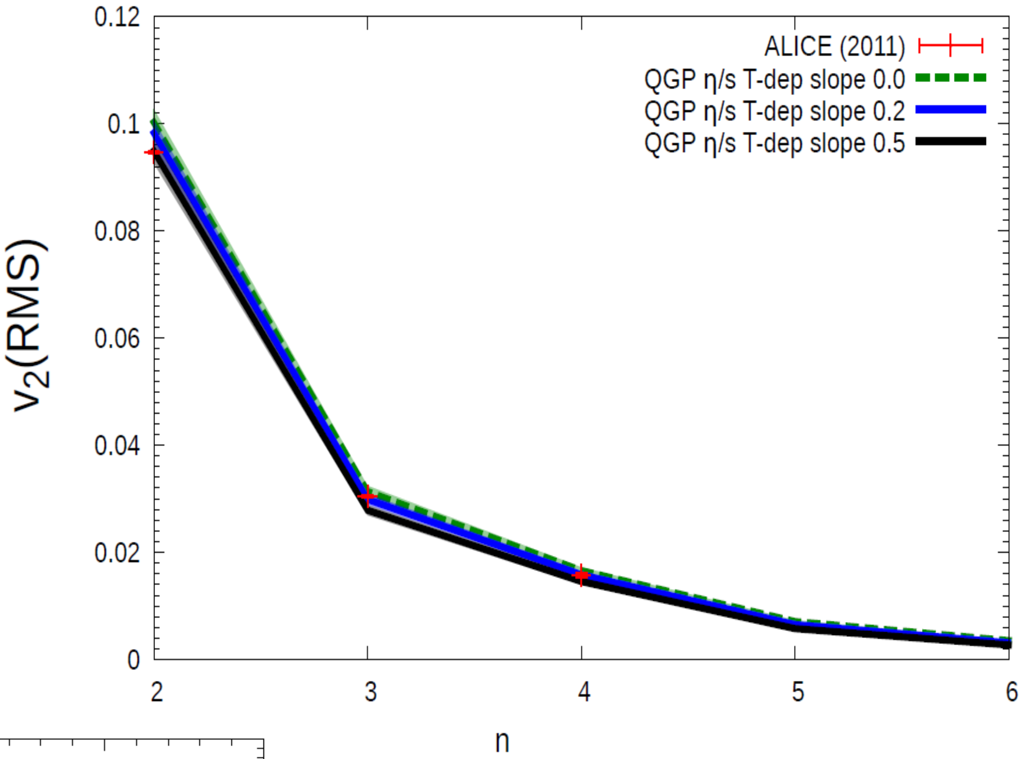
We did not readjust the parameters to fit the spectra

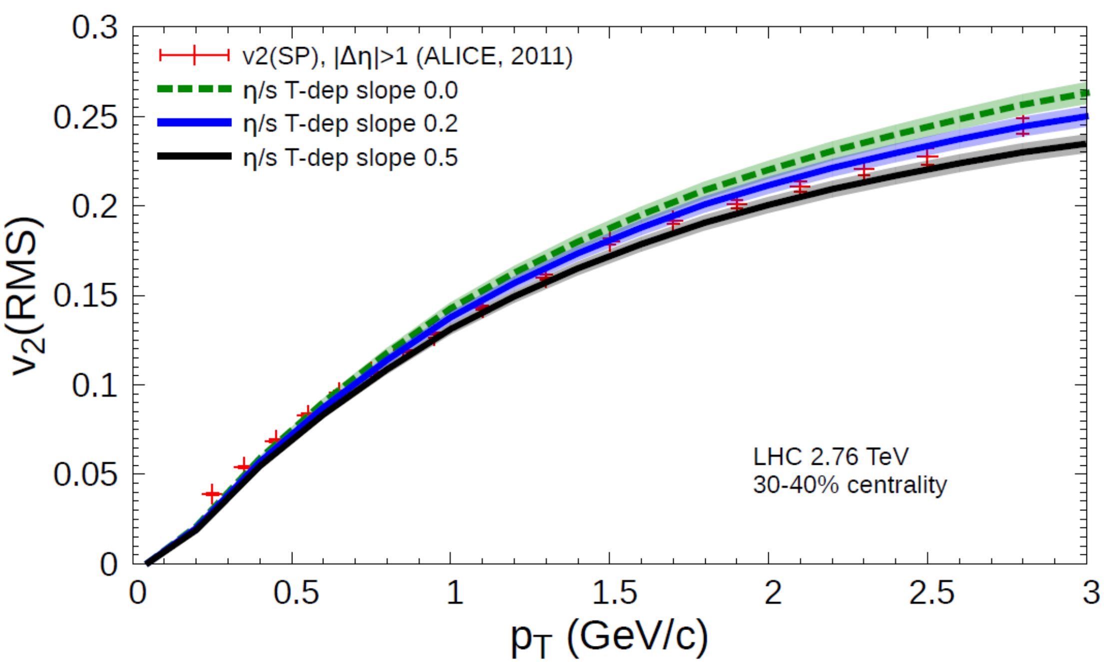
Effect on spectra can still go away ...

Current LHC energy

30-40%

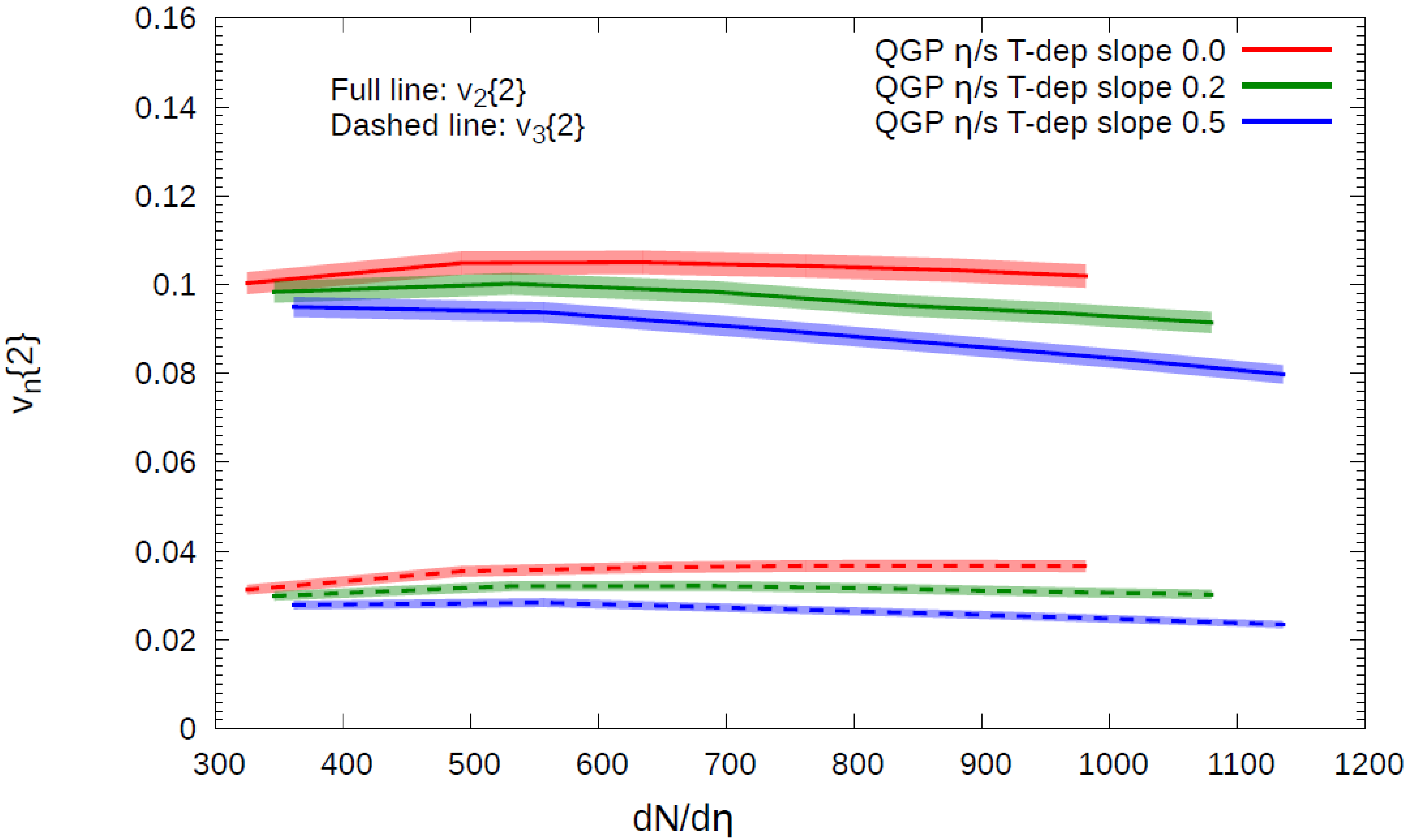
Small effect on integrated Vn





Slightly visible on differential Vn

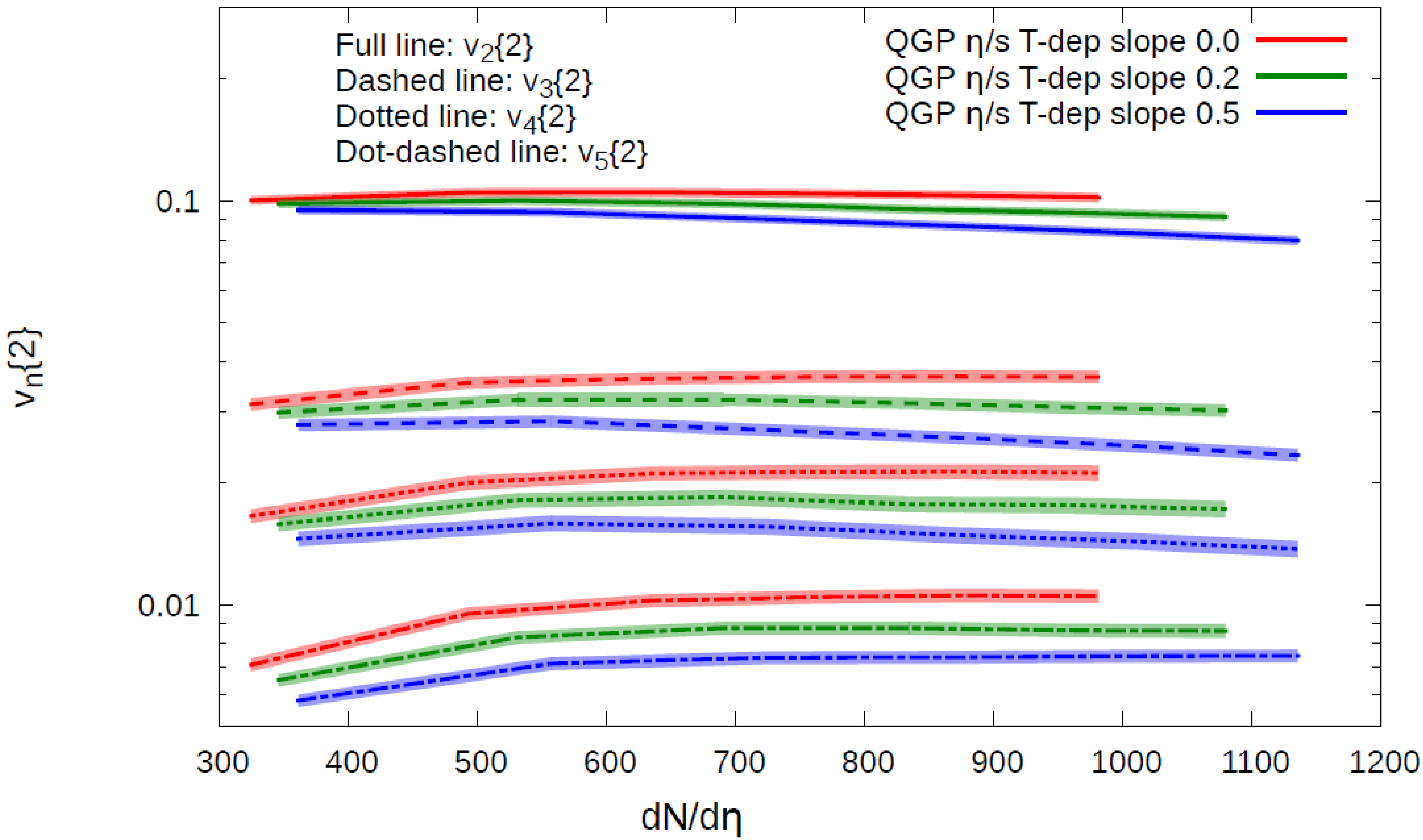
Energy Scan **30-40%**



Large effect!

Depending on η/s(T), Vn can start to decrease at larger energies

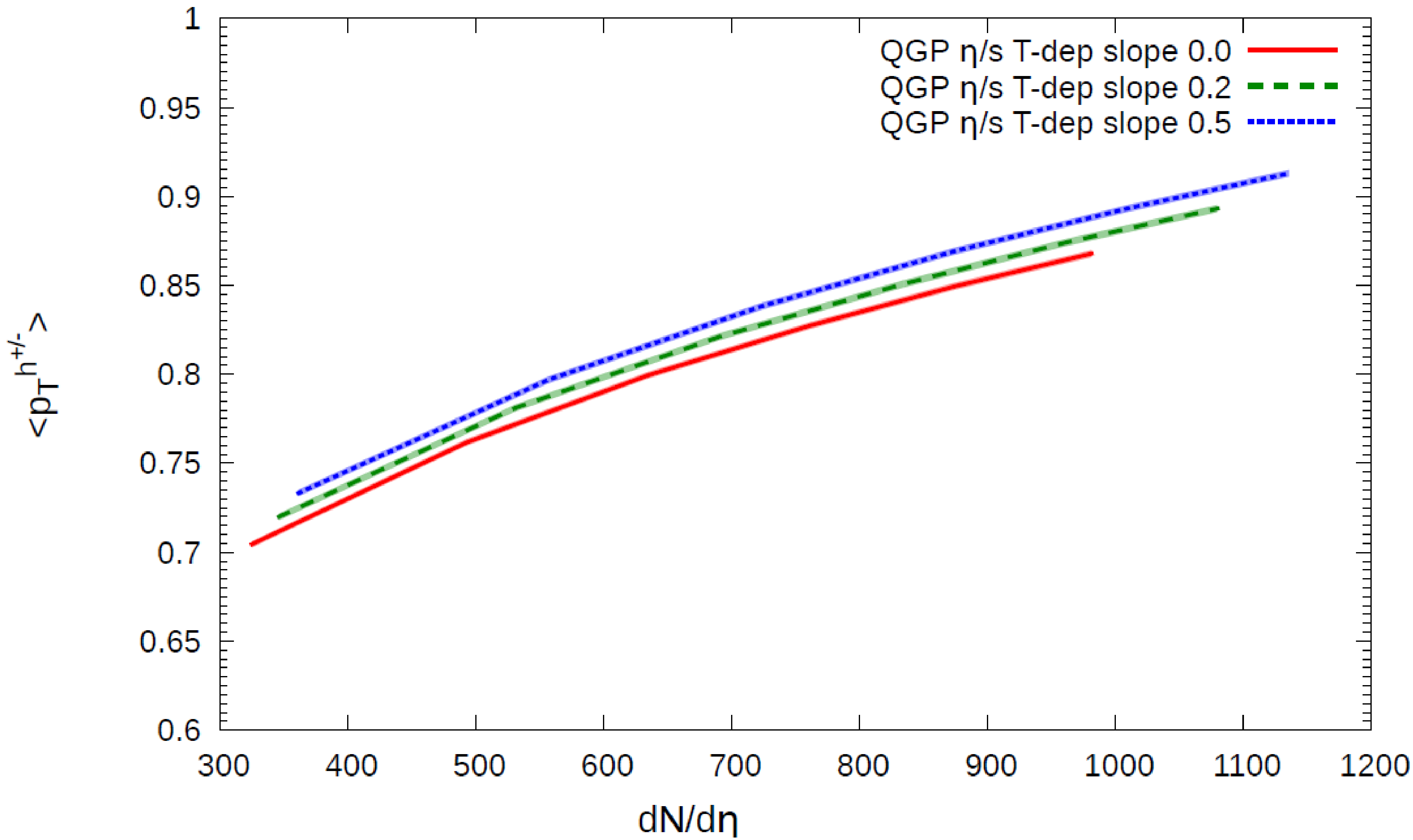
Energy Scan (log scale) **30-40%**



Large effect!

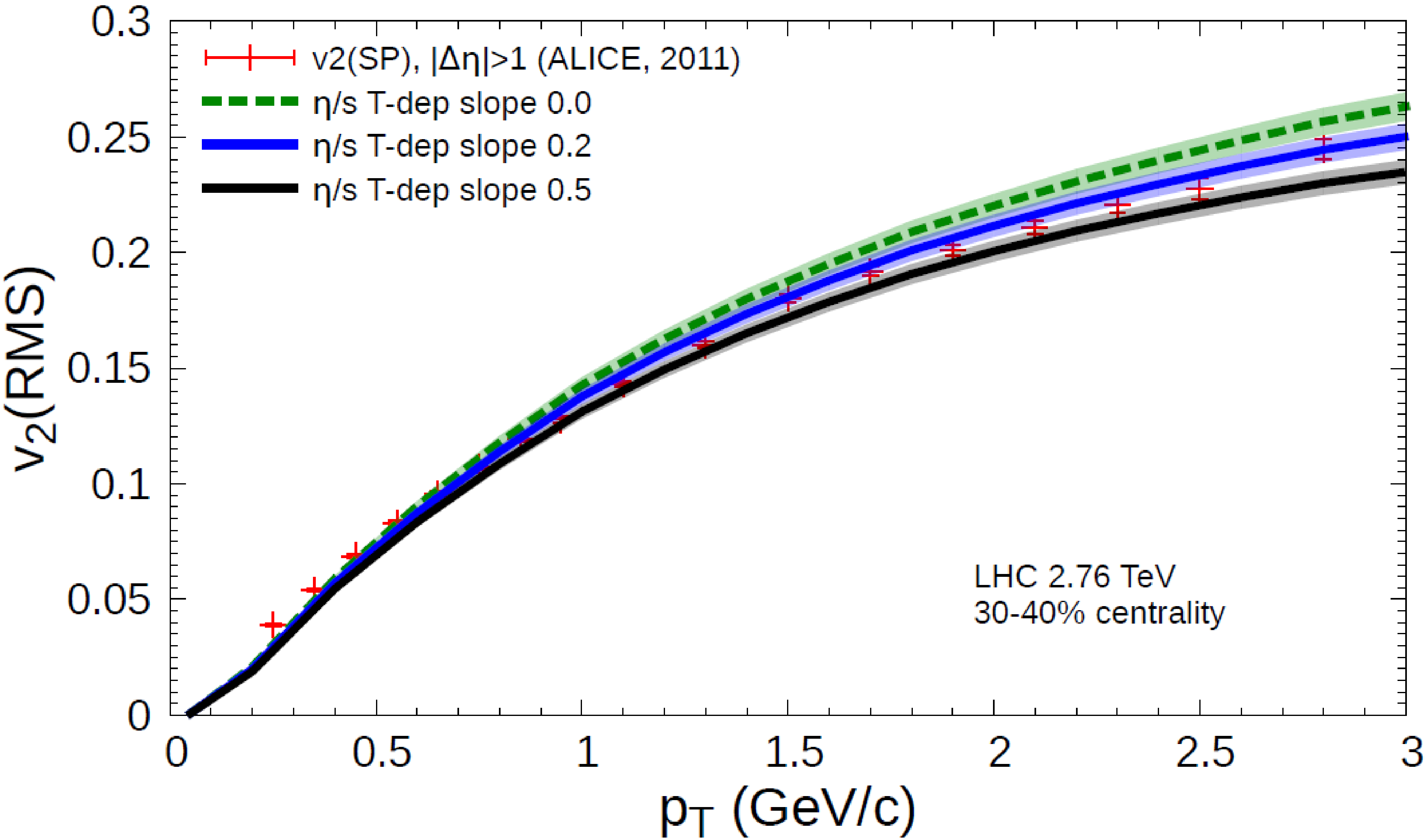
Depending on η/s(T), Vn can start to decrease at larger energies

Energy Scan **30-40%**

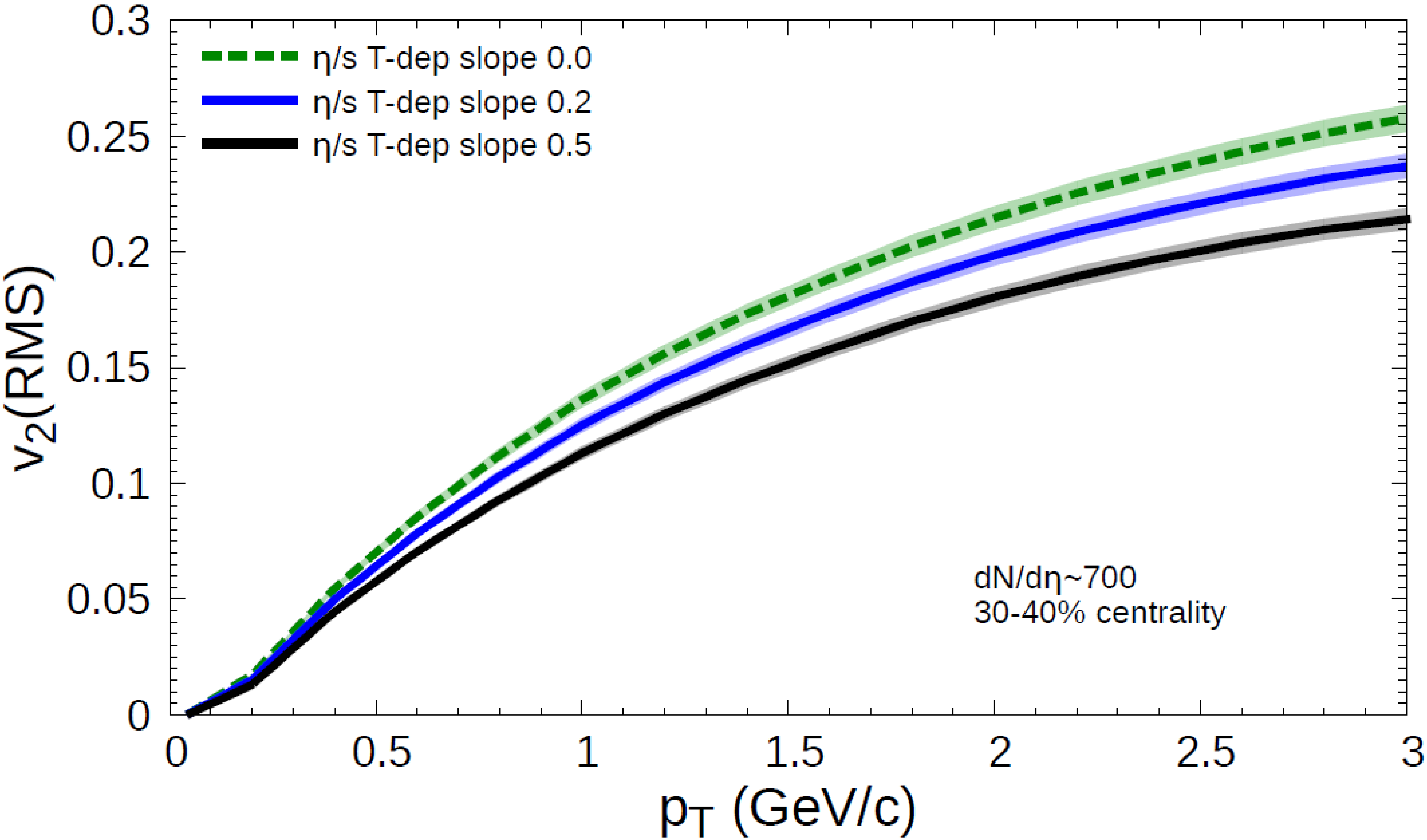


The average pT still increases with collision energy

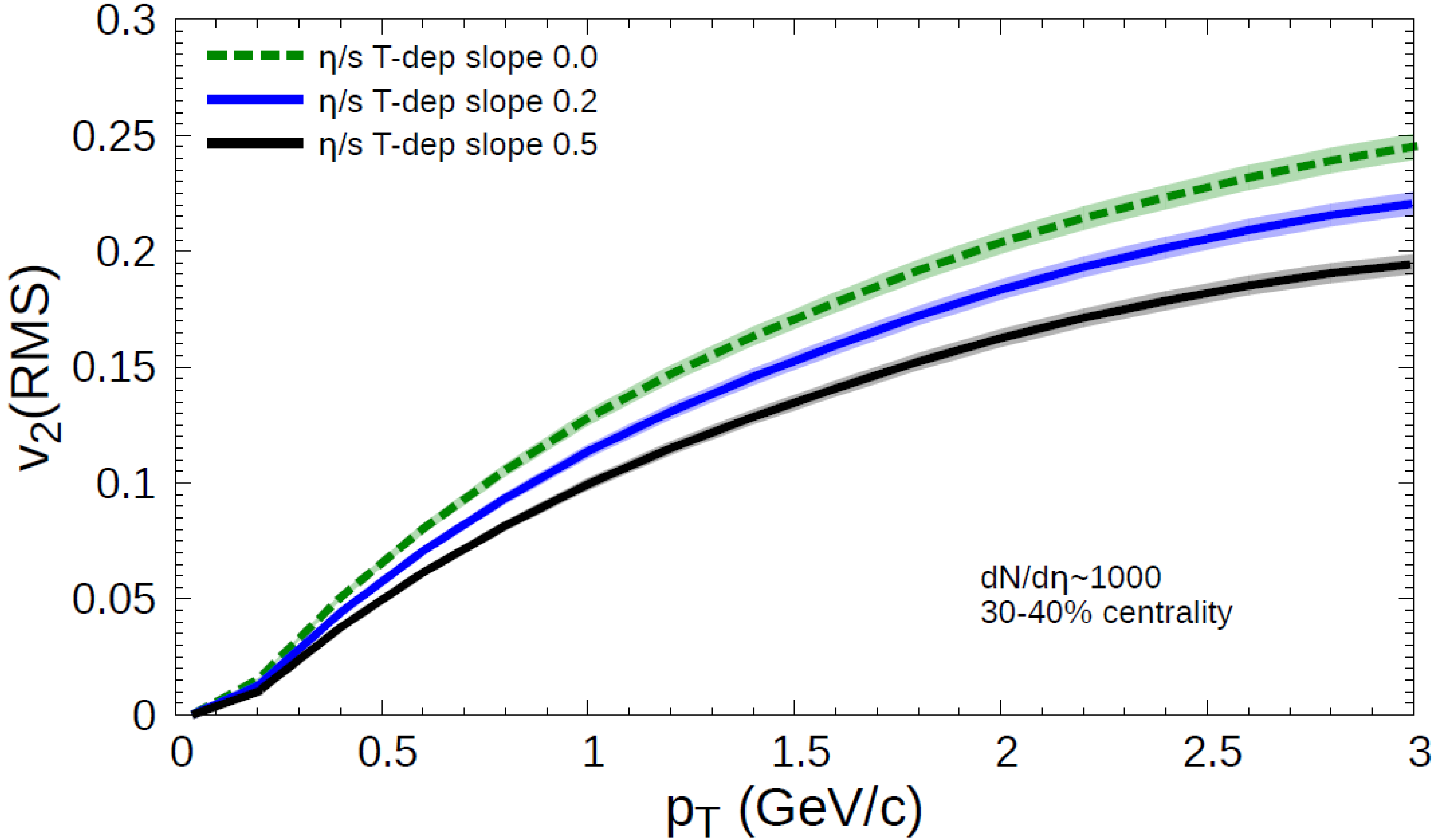
Differential V2: lowest LHC **30-40%**



Differential V2: entropy x 2.5 **30-40%**

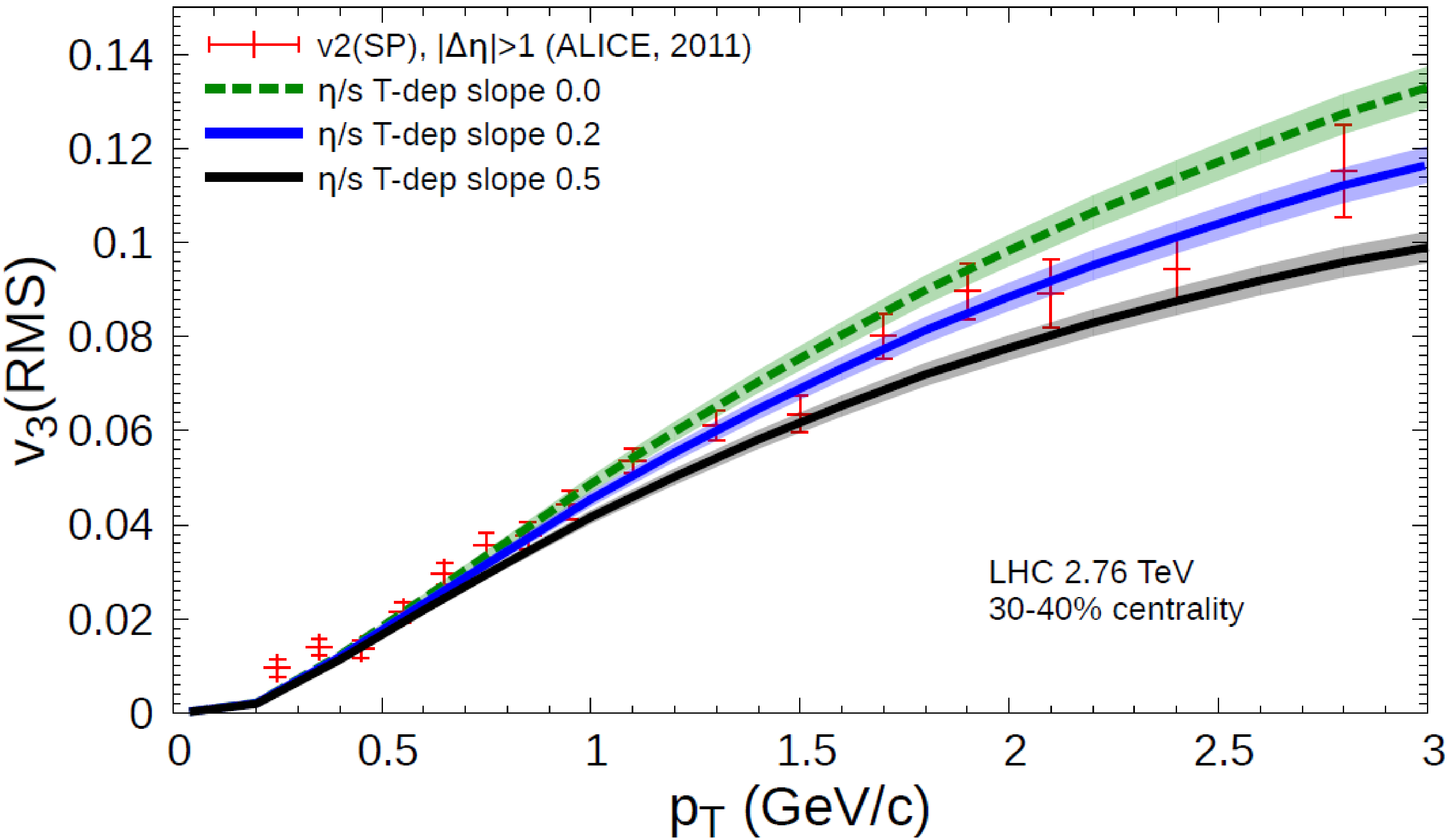


Differential V2: entropy x 4 **30-40%**

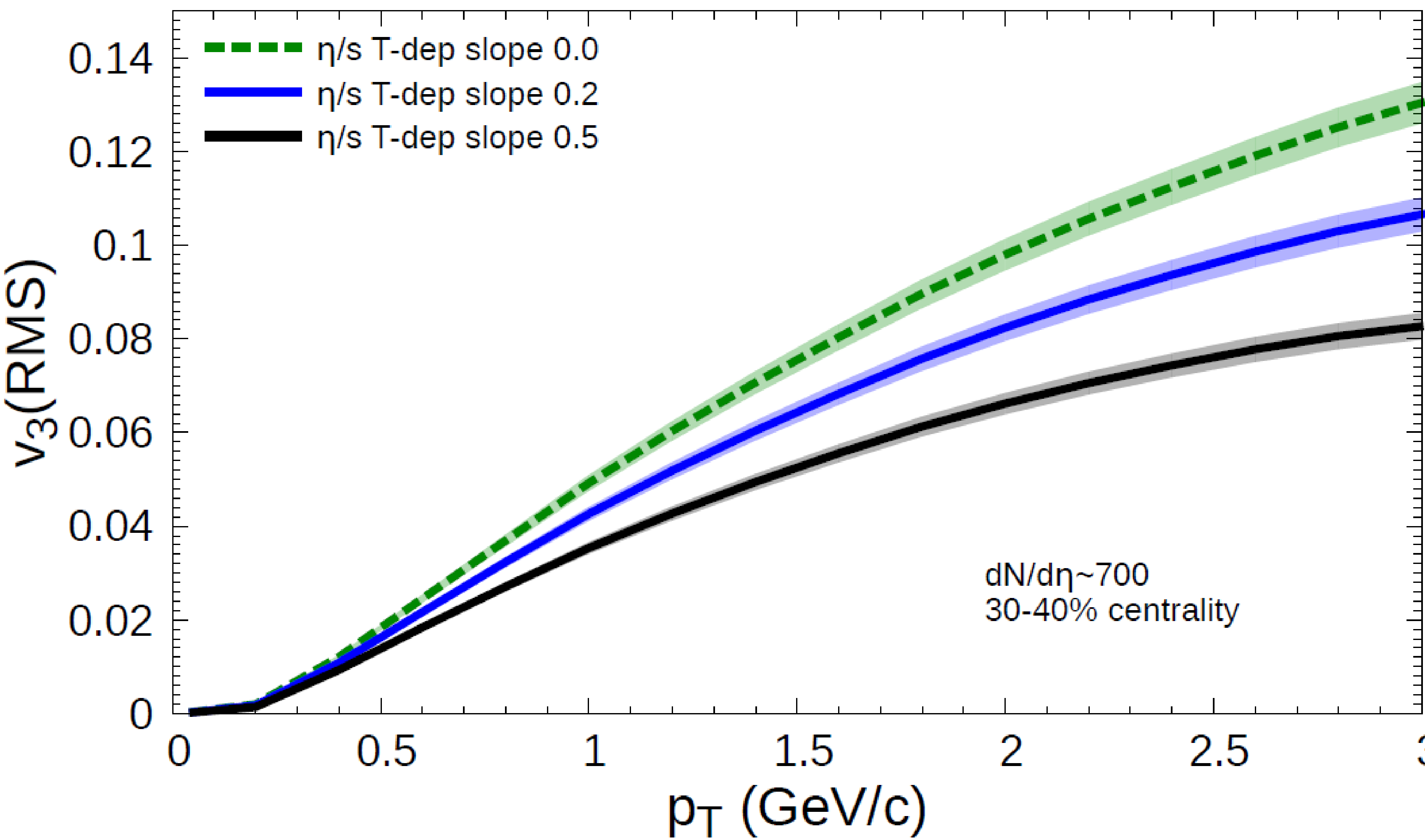


The effect of η/s increases with the collision energy

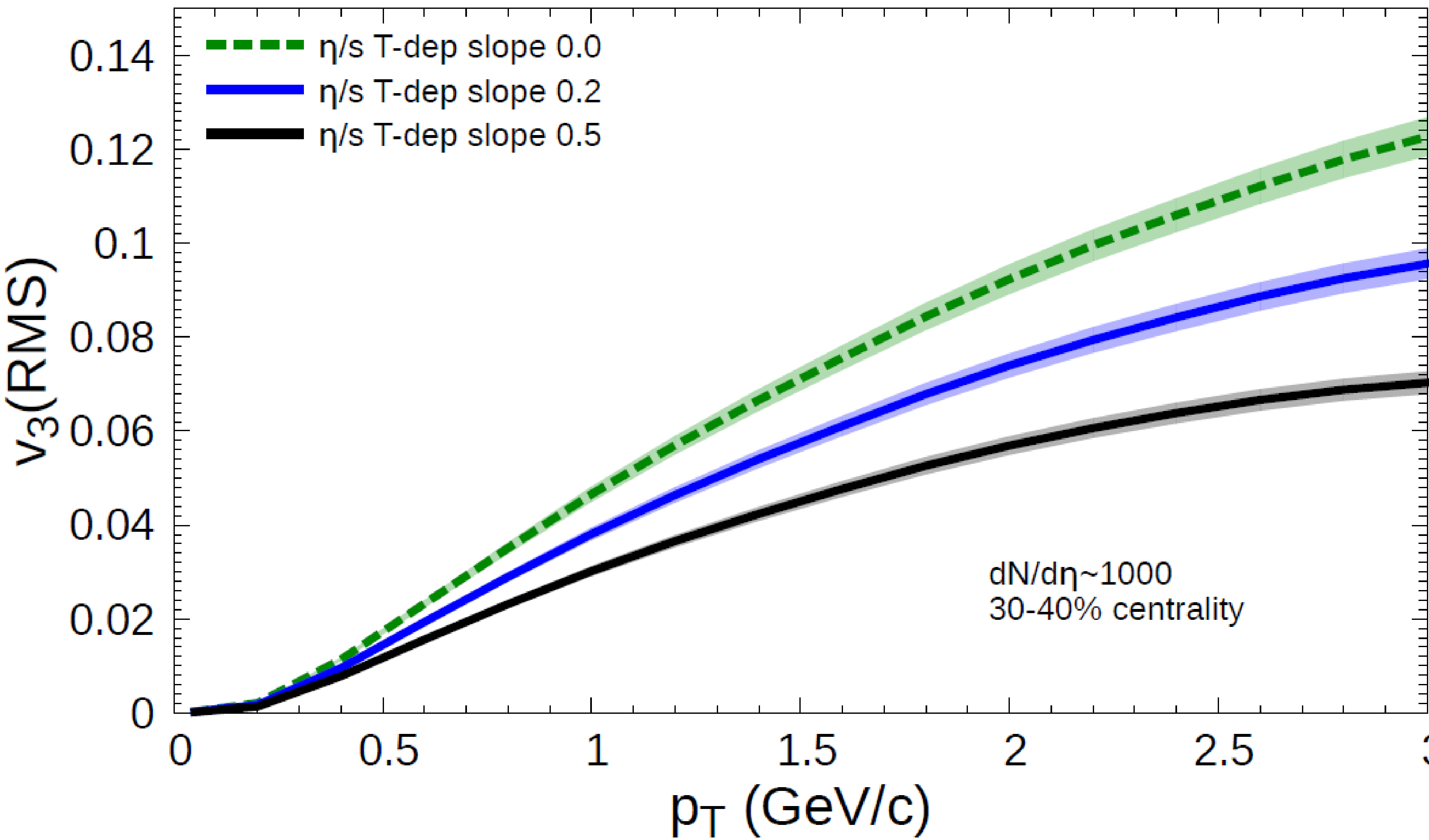
Differential V3: lowest LHC **30-40%**



Differential V3: entropy x 2.5 **30-40%**



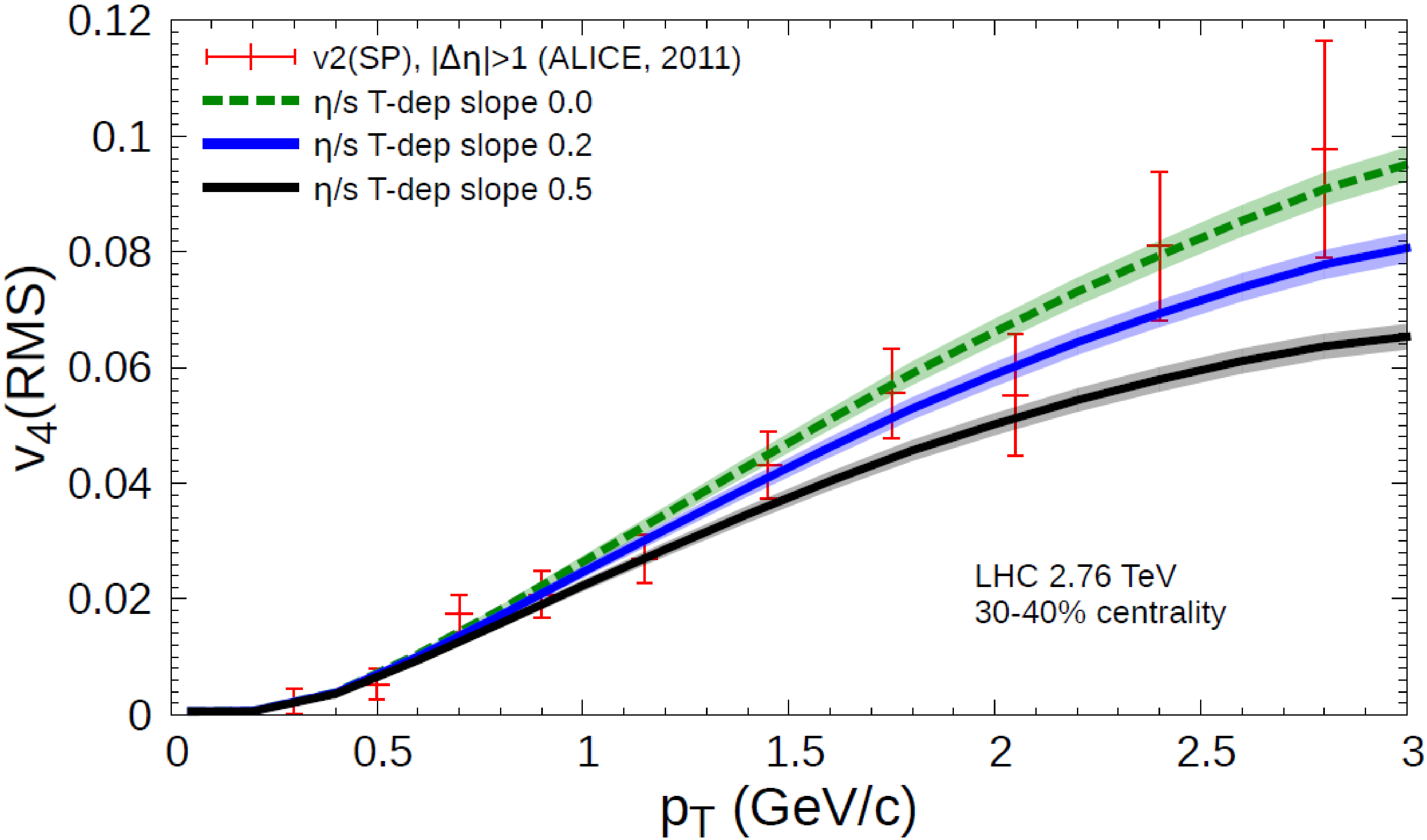
Differential V3: entropy x 4 **30-40%**



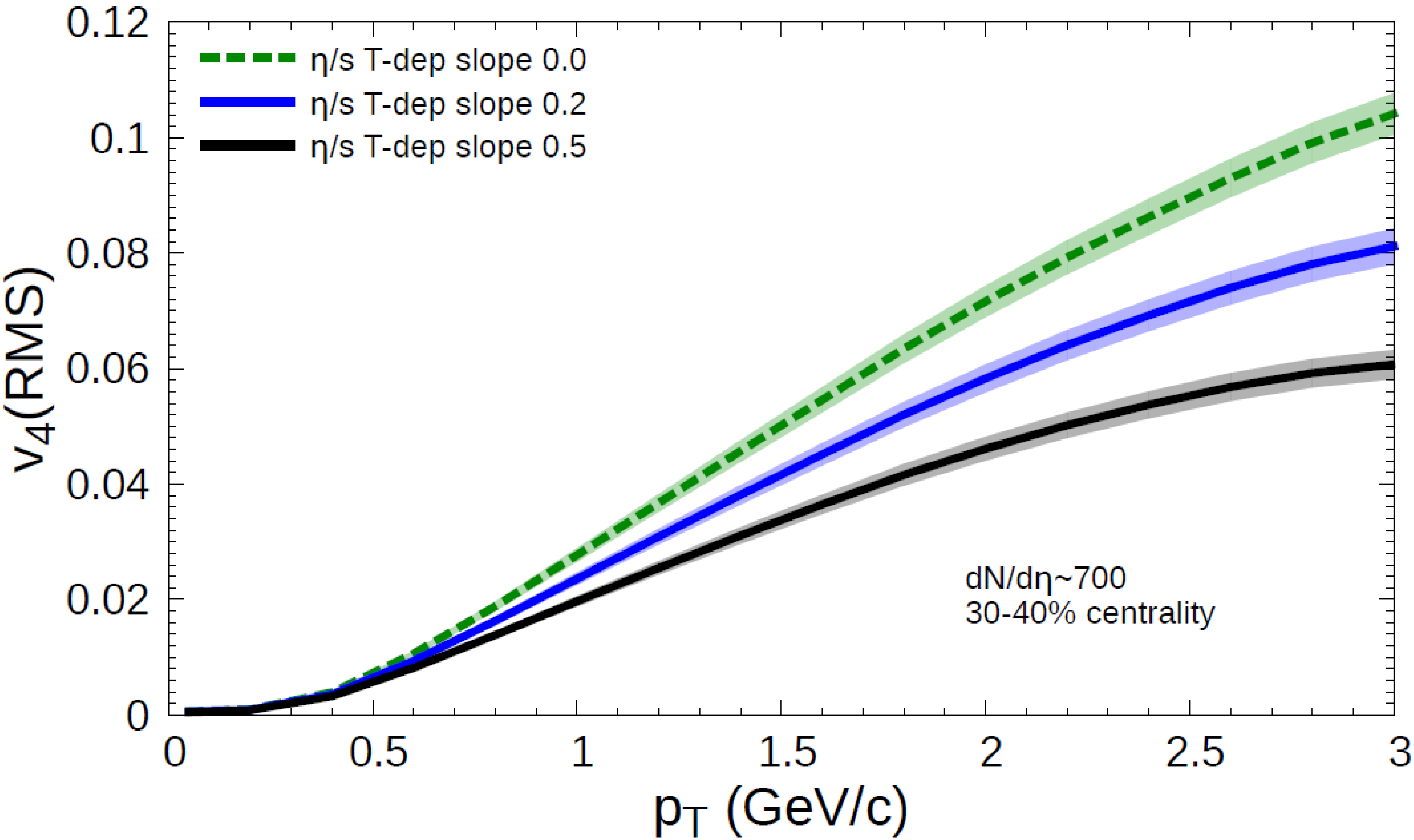
The effect of η/s increases with the collision energy

Effect is larger for v3

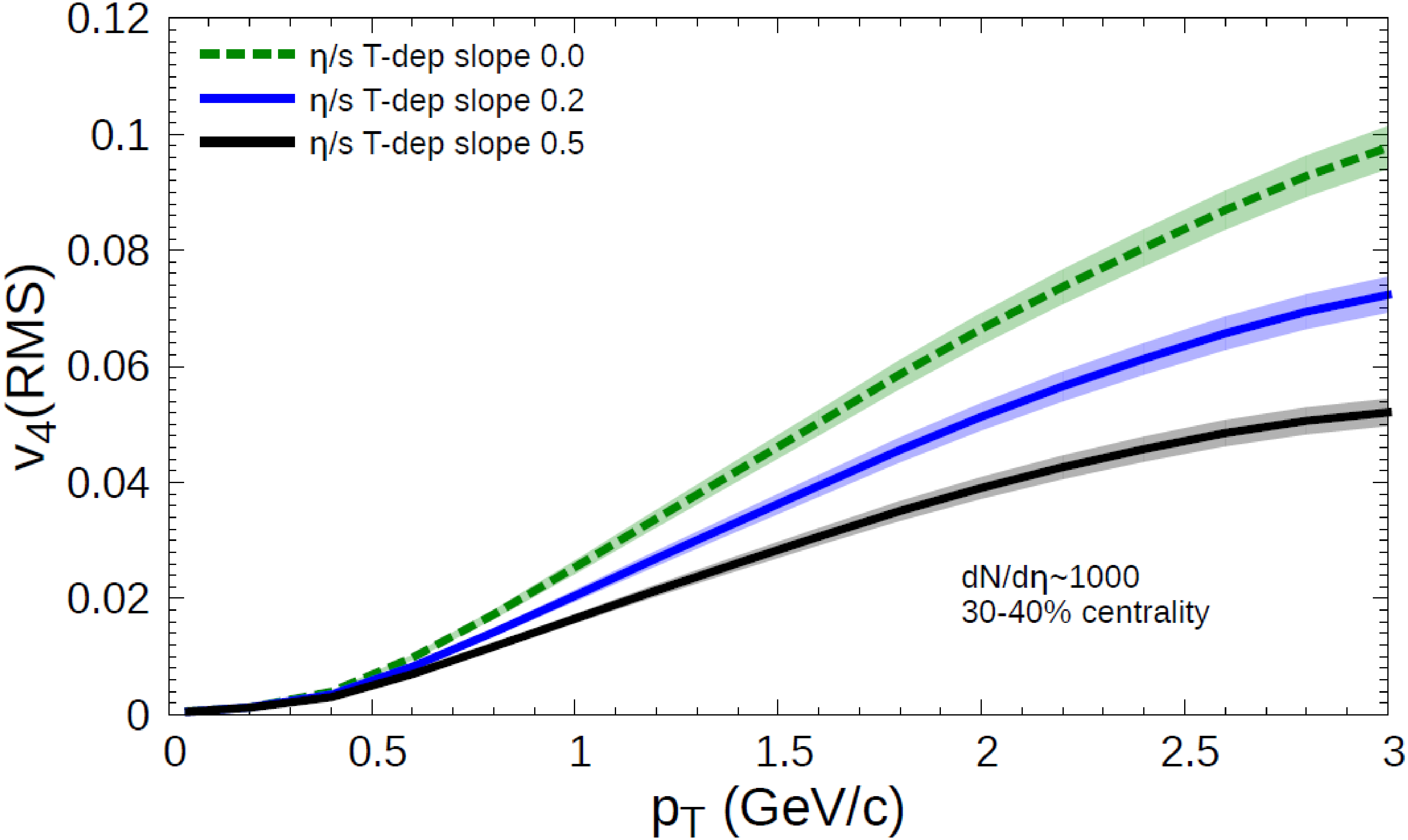
Differential V4: lowest LHC **30-40%**



Differential V4: entropy x 2.5 **30-40%**



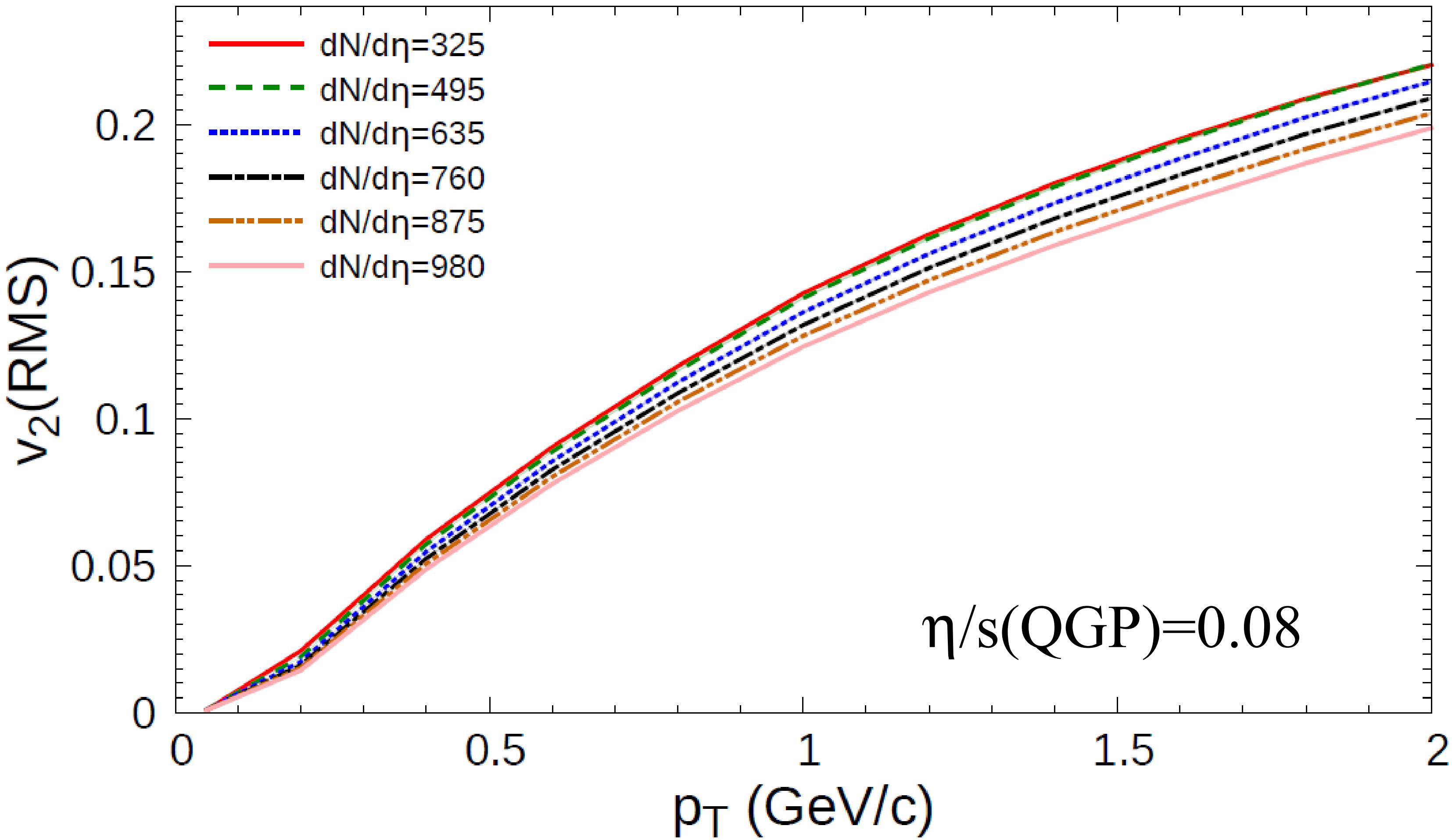
Differential V4: entropy x 4 **30-40%**



The effect of η/s + collision energy is different for v4

Differential V2 vs sqrt(s)

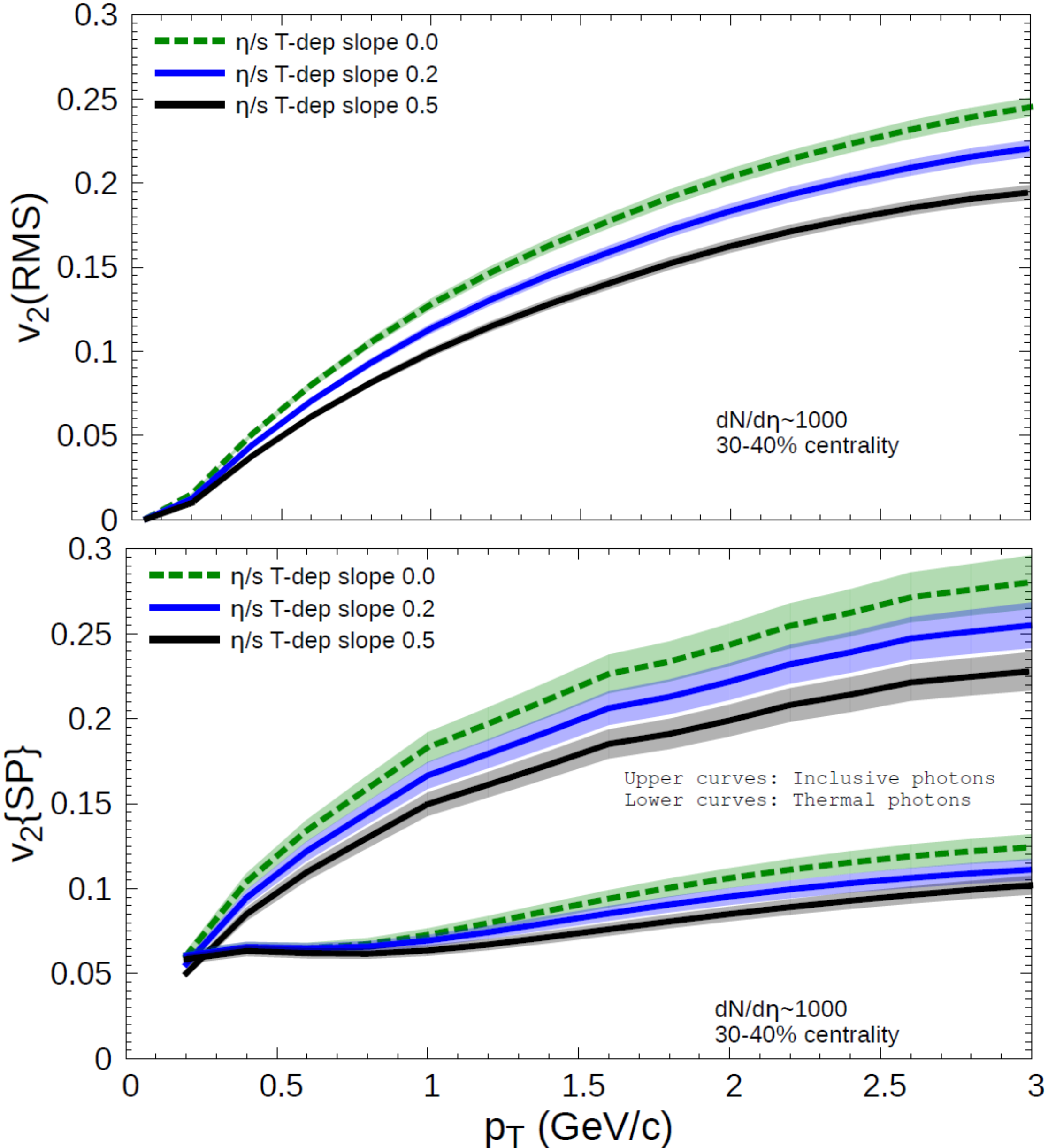
30-40%



First curve corresponds to the **LHC** energy

Prediction: differential v2,3 will not remain the same as the energy increases

Curiosity – differential V2: entropy x 4



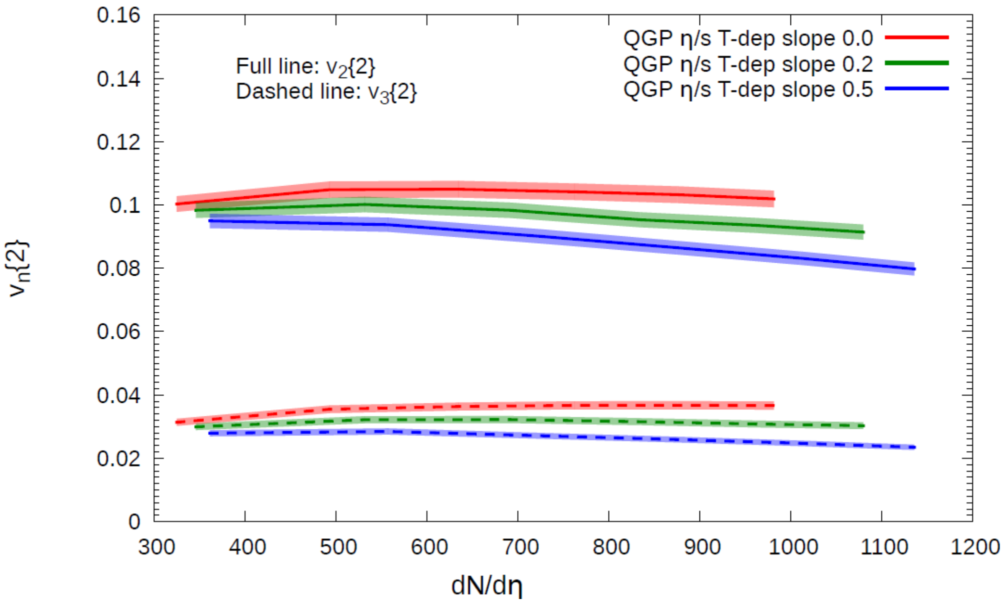
hadrons

photons

Conclusions

We studied how the effect of η/s(T) changes with collision energy

- We find that, as the initial entropy increases, the system becomes more dependent on the value of shear viscosity at higher T



- The effect is there for all flow harmonics. But v2 and v3 are more affected.