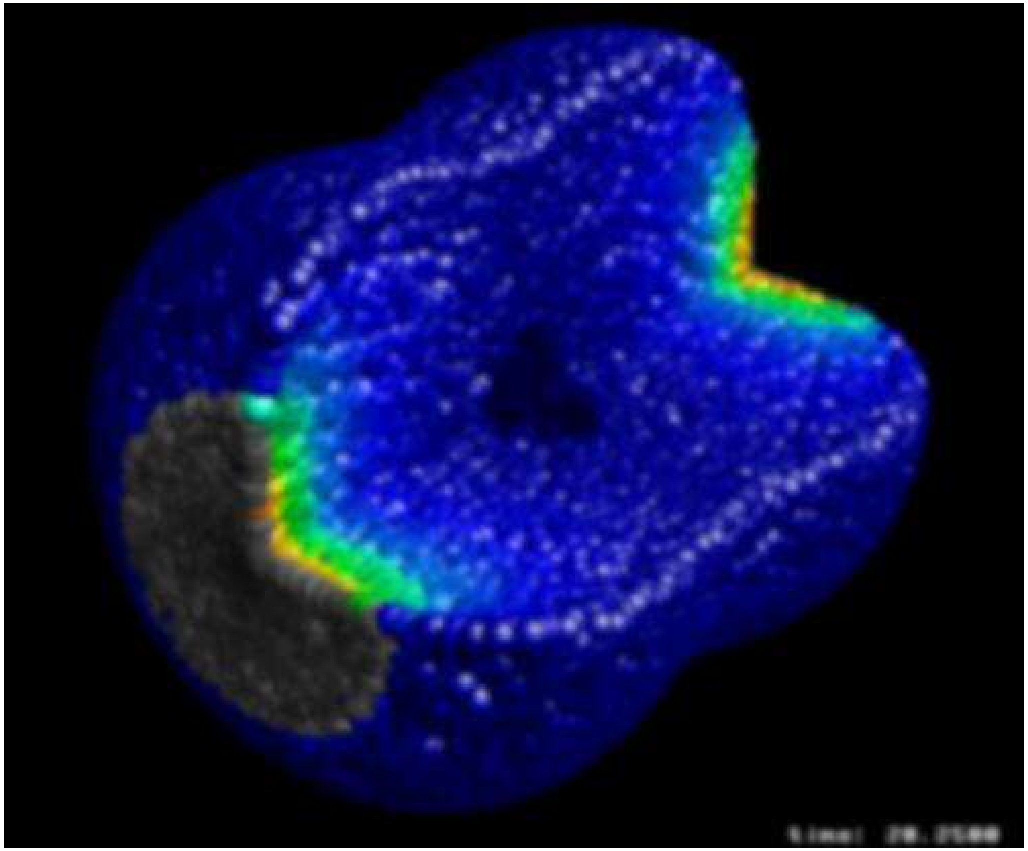
Elliptic flow from pQCD + saturation + hydro model

arXiv:0705.2114 [hep-ph]



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EKRT final state saturation

Eskola, Kajantie, Ruuskanen, Tuominen, Nucl. Phys. B **570** (2000) 379 [hep-ph/9909456]

- Idea: Low-p_T parton production is controlled by saturation among the produced gluons.

- Geometric estimate: Saturation sets in when produced gluons with $p_T > p_0$ fill the whole transverse overlap area of the colliding nuclei

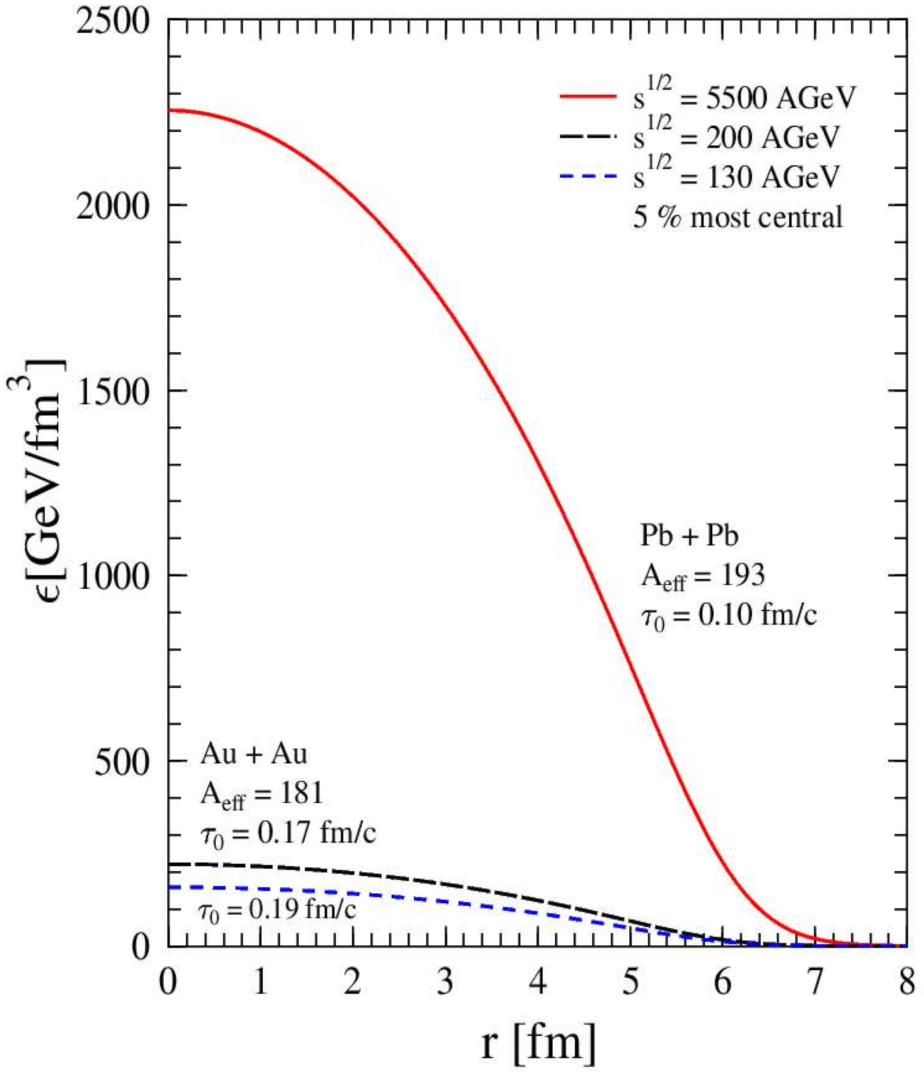
$$\underbrace{N_{AA}(p_0, \Delta y=1, \sqrt{s})}_{\text{Number of gluons with } p_T > p_0} \cdot \pi / p_0^2 = \pi R_A^2 \longrightarrow \text{Nuclear radius}$$

- Gives saturation scale p_{sat} for any ~ central AA collision
- If $p_{sat} \gg \Lambda_{QCD}$ pQCD particles with $p_T > p_{sat}$ can give a good estimate of the number of partons and energy produced to midrapidity
- $\tau_{prod} = 1/p_{sat}$

→ **transverse energy E_T & net baryon number N_B**

Initial state for hydrodynamics

central collisions:



RHIC $\sqrt{s_{NN}}$ = 200 GeV Au+Au
τ_0 ~ 0.17 fm/c
ε_{max} ~ 200 GeV/fm^3
dN_B/dy = 14.0

LHC $\sqrt{s_{NN}}$ = 5500 GeV Pb+Pb
τ_0 ~ 0.10 fm/c
ε_{max} ~ 2200 GeV/fm^3
dN_B/dy = 3.11

Hydrodynamics for low-p_T hadrons

If equilibration time τ_{therm} < production time $\tau_{\text{prod}} = 1/p_{\text{sat}}$ we can start hydrodynamics immediately after production of the initial state.

$$\partial_\mu T^{\mu\nu}(x) = 0 \qquad \text{and} \qquad \partial_\mu j^\mu_B(x) = 0,$$

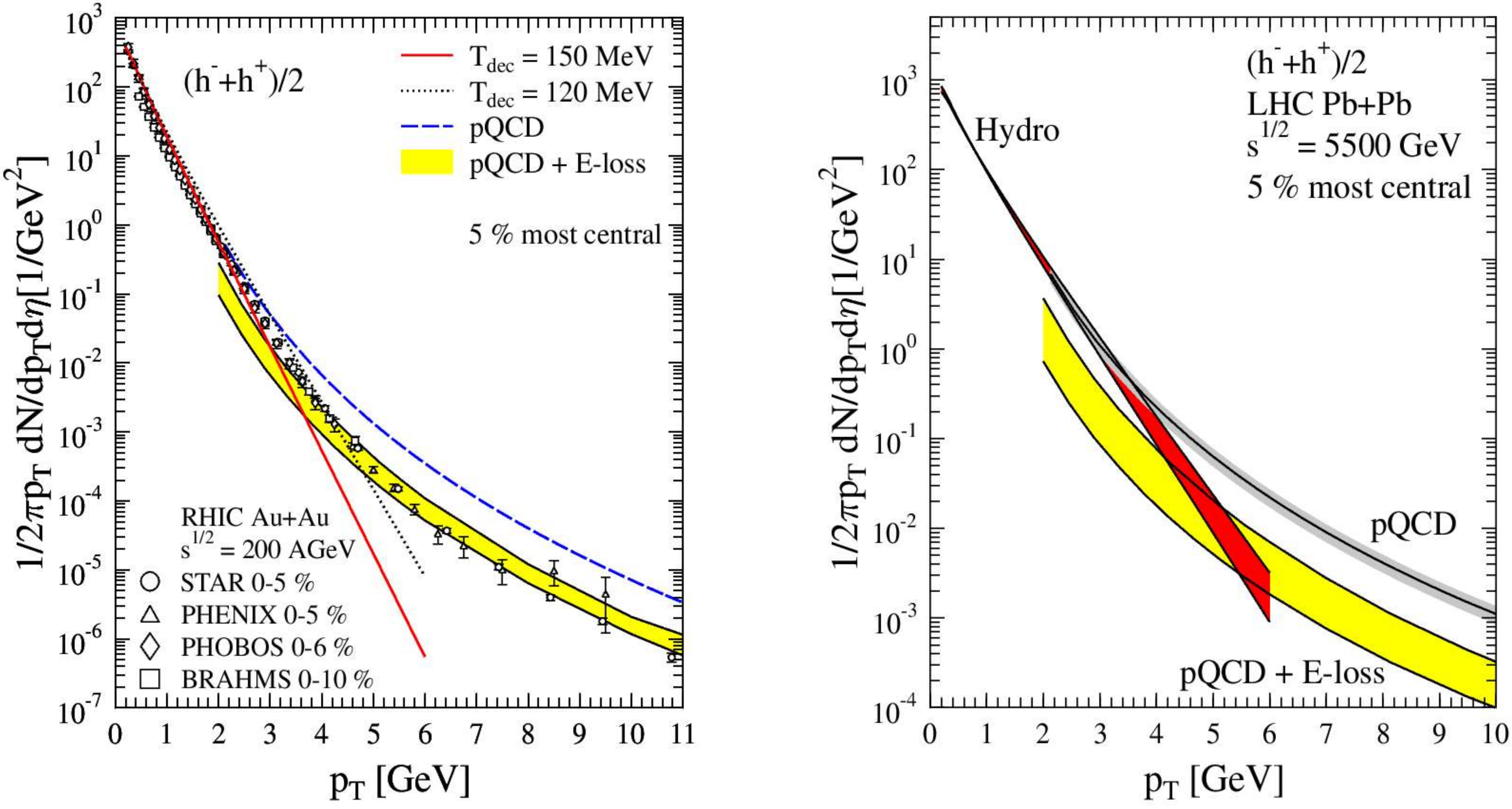
$$T^{\mu\nu} = (\epsilon + P)u^\mu u^\nu - P g^{\mu\nu} \qquad \text{and} \qquad j^\mu_B = n_B u^\mu$$

- Boost invariant perfect fluid hydrodynamics with transverse expansion
- Full kinetic and chemical equilibrium
- Equation of State: Bag model EoS connecting Hadron gas with all hadronic states with m < 2 GeV and QGP with $N_f = 3$ ($T_c = 165$ MeV)
- Cooper-Frye decoupling
- All 2- and 3-body decays of unstable hadronic states

Results for the most central collisions

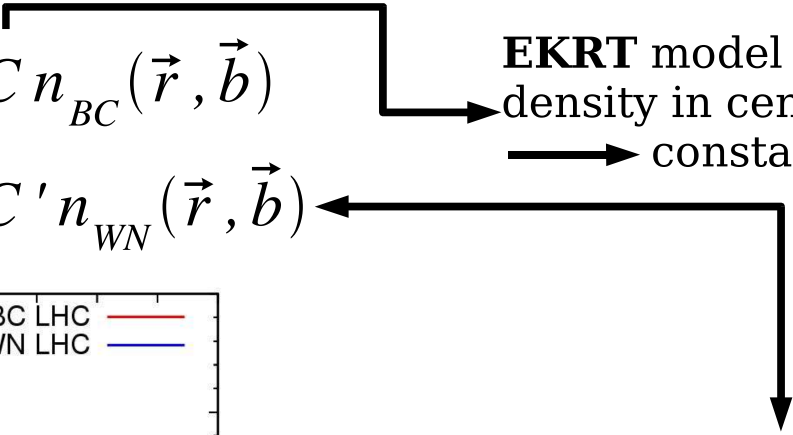
(see talk by K. Eskola)

K.J. Eskola, H. Honkanen, H. Niemi, P.V. Ruuskanen and S.S. Räsänen, Phys. Rev. C **72** (2005) 044904 [arXiv:hep-ph/0506049].



Extension to non-central collisions

- We consider two limits for centrality dependence of initial energy density: **eBC** & **eWN** from Kolb et. al. Nucl.Phys.A**696**:197-215,2001
- In **eBC**(**eWN**) energy density is proportional to density of *binary collisions* (*wounded nucleons*) calculated from optical Glauber model

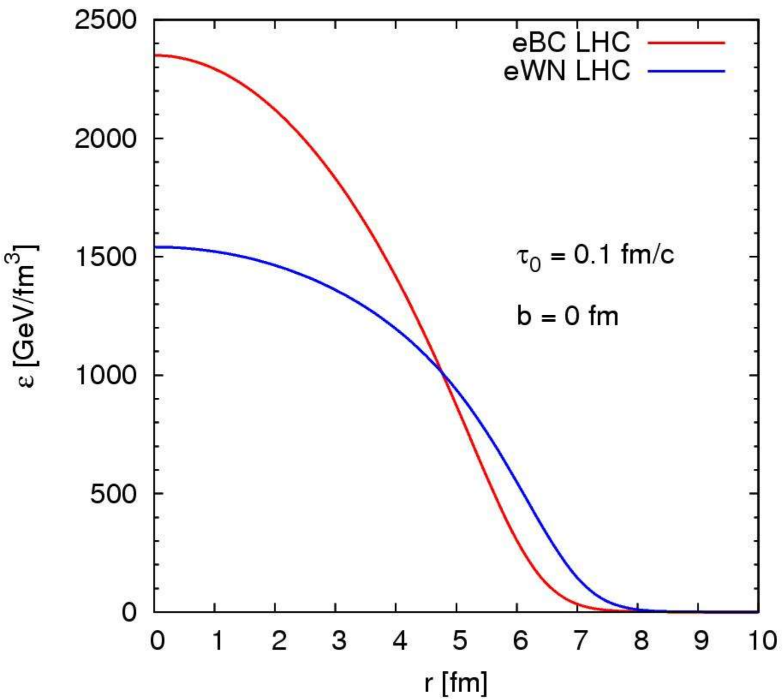


eBC: $\varepsilon(\vec{r},\vec{b}) = C\, n_{BC}(\vec{r},\vec{b})$

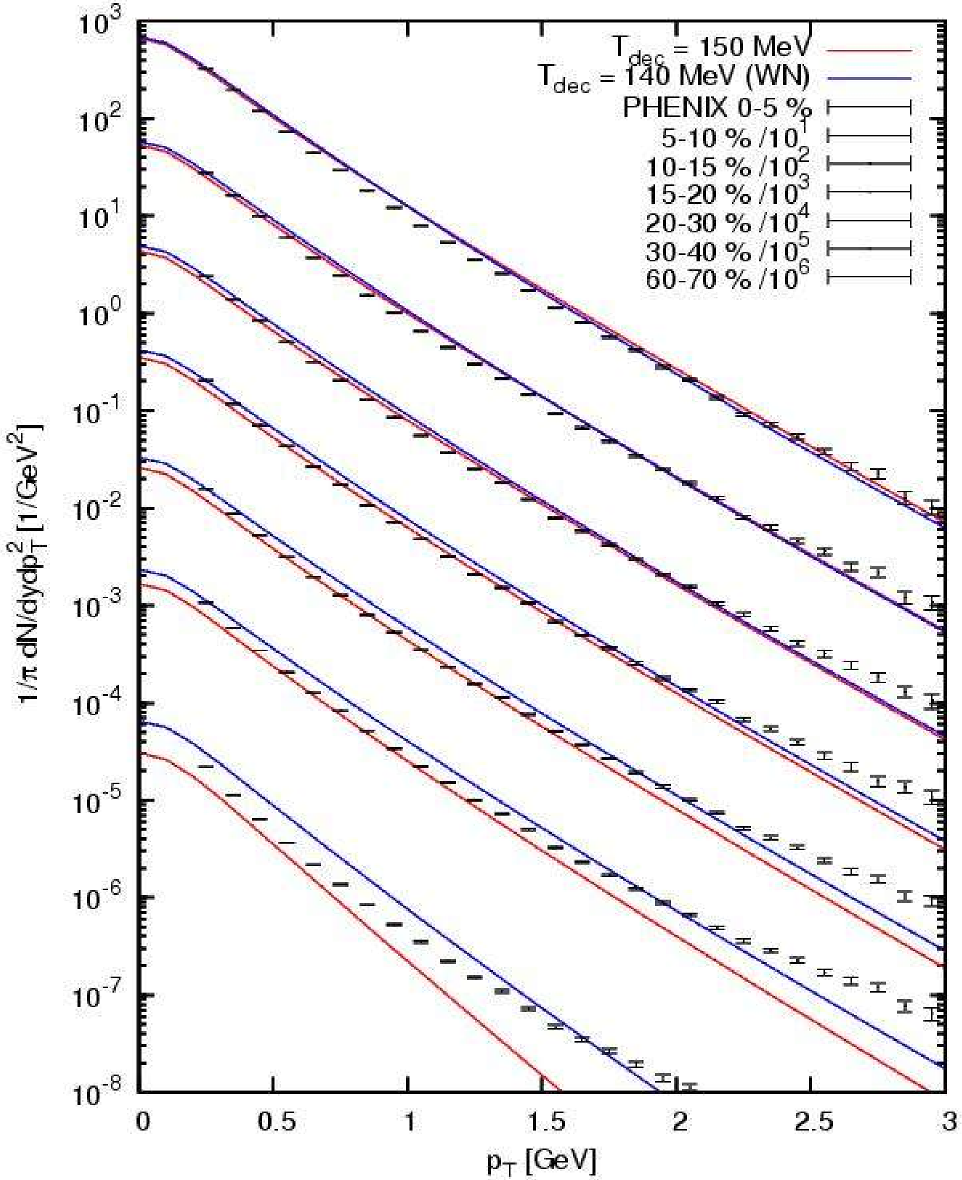
eWN: $\varepsilon(\vec{r},\vec{b}) = C'\, n_{WN}(\vec{r},\vec{b})$

EKRT model gives energy density in central collisions ⟶ constant C

Constant C' determined from **eBC** by requiring the same dS/dη for **eWN** as in **eBC** for b = 0 collision



Pion spectra for different centralities at RHIC



- Both models are in good agreement with low-p_T pion spectra for central and mid-peripheral collisions

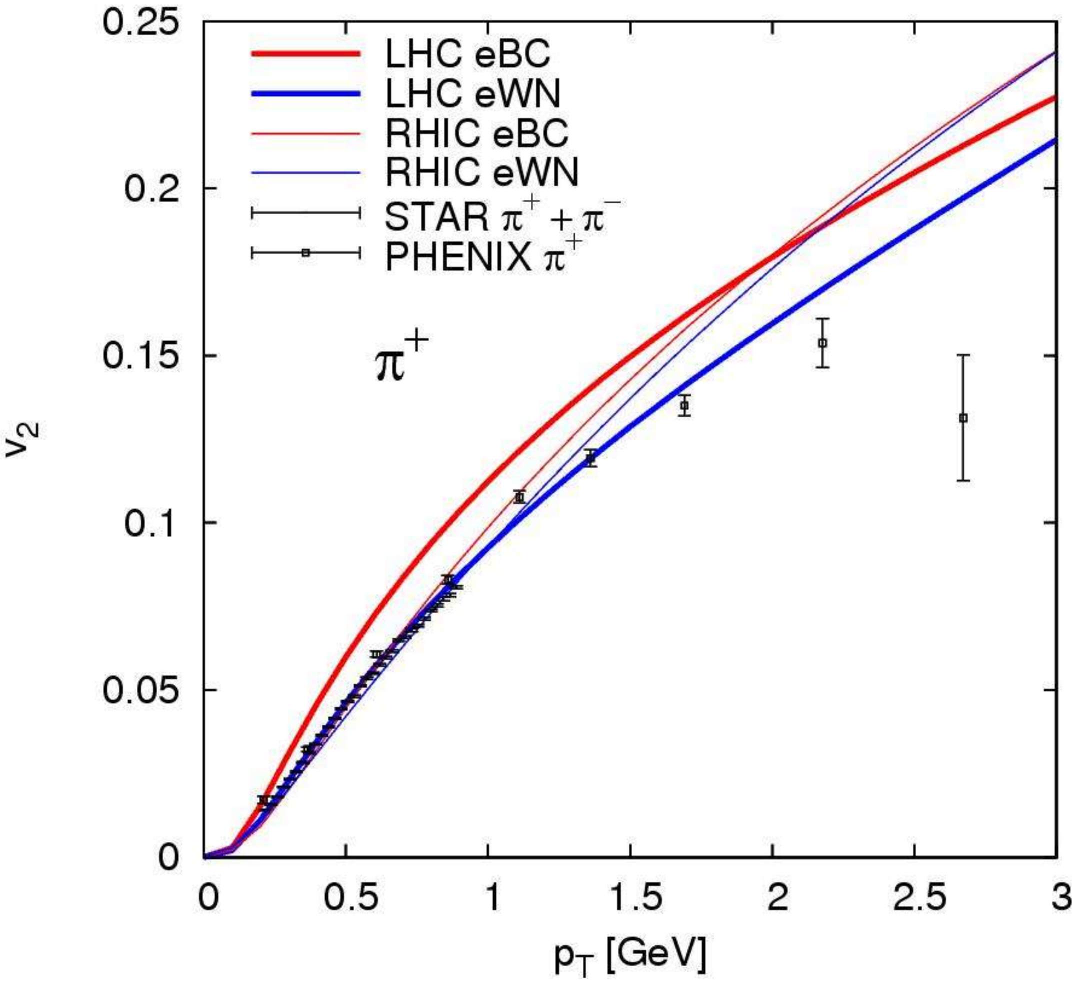
- **eBC**: T_{DEC}=150 MeV
  eWN: T_{DEC}=140 MeV

- Model fails at high-p_T and for peripheral collisions

- Protons would require more detailed treatment of the hadron gas dynamics

PHENIX data:
S.S. Adler, et al, Phys.Rev. C**69** (2004) 034909

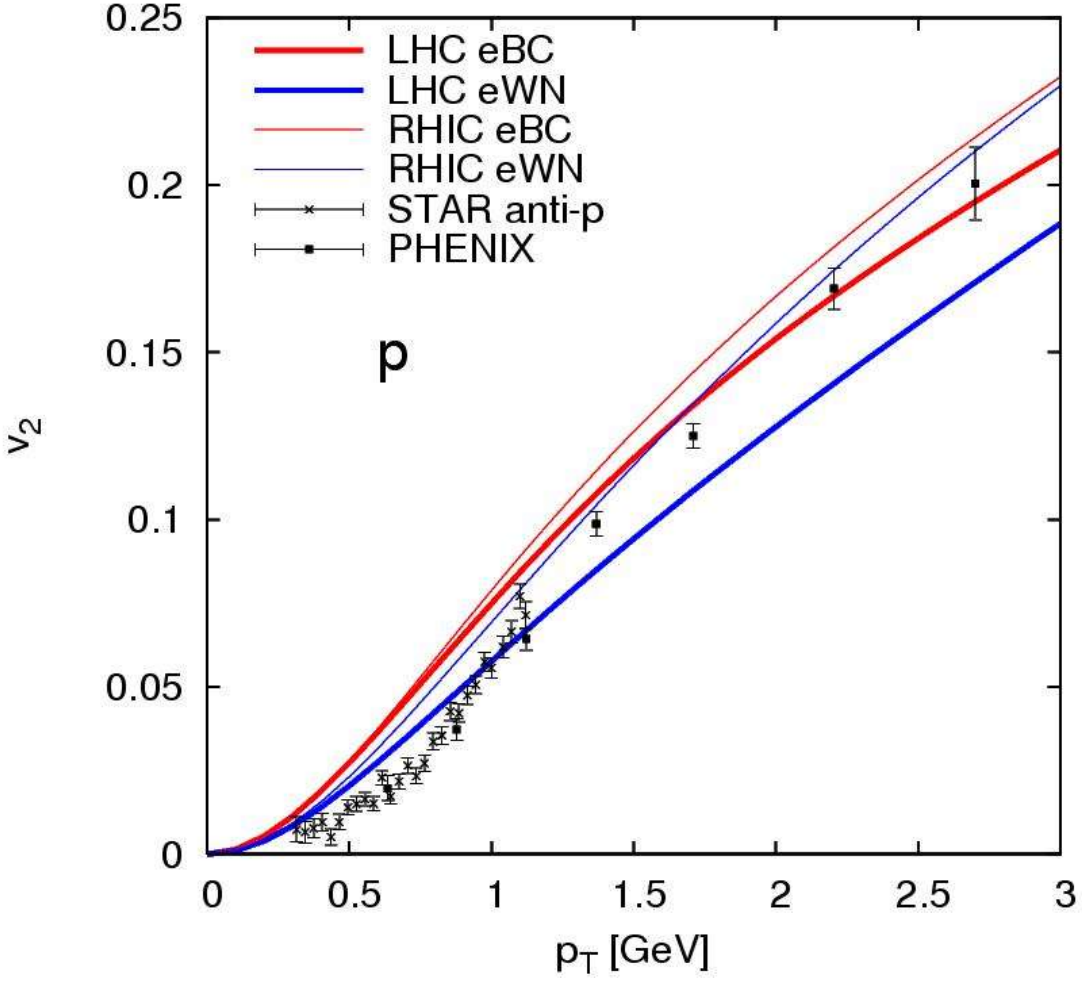
Minimum bias v_2 for pions at RHIC & LHC



- Both **eBC** and **eWN** models give a good description of low-p_T RHIC data
- We use same freeze-out temperatures as at RHIC
  eBC: T_{DEC}=150 MeV
  eWN: T_{DEC}=140 MeV
- For **eWN** v_2 at the LHC is very close to RHIC data
- Model **eBC** gives clearly larger v_2 in the whole p_T range

- **LHC $v_2(p_T) \geq$ RHIC $v_2(p_T)$ for pions**
- **Hydrodynamic region is larger at LHC: $v_2(p_T)$ reaches 0.2 at $p_T \approx 2.5$ GeV**

Minimum bias v_2 for protons at RHIC & LHC



- The model overpredicts the RHIC data at low p_T (Need more detailed description of hadron gas dynamics e.g. hadron cascade)
- There is still clear distinction in behaviour of v_2 between pions and protons from RHIC to LHC
- At fixed p_T proton v_2 is less at the LHC than at RHIC, when comparing between model calculations.

- **LHC $v_2(p_T) \leq$ RHIC $v_2(p_T)$ for protons**

Conclusions

- We have predicted minimum bias elliptic flow at the LHC for pions, using EKRT model initial state for central collisions as a starting point

- Centrality dependence is modeled using two Glauber model limits (**eBC and eWN**)

- The model is tested against RHIC data

- **LHC $v_2(p_T) \geq$ RHIC $v_2(p_T)$ for pions**
- **Hydrodynamic region is larger at LHC: $v_2(p_T)$ reaches 0.2 at $p_T \approx 2.5$ GeV**

- **LHC $v_2(p_T) \leq$ RHIC $v_2(p_T)$ for protons**