Decrease $\sqrt{s}$: Saturation turns off ($Q_s(x) \sim \Lambda_{QCD}$), hydro phase shorter ($T_{initial}$ decreases, τ_0 increases), maybe jumps with ($c_s, \eta/s$ at deconfinement), Knudsen number $\sim$ $(TR)^{-1}$ higher, chemical composition different ($\tau, Kn \sim \mu_B$?)

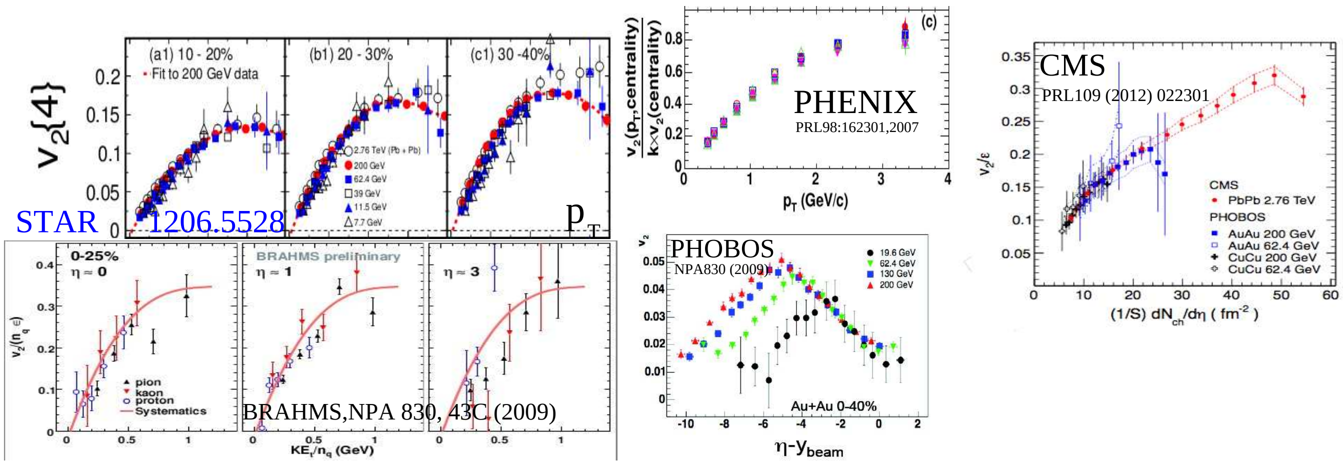
Increase rapidity: Saturation effects larger, hydro phase shorter (as above)

Decrease system size Slightly less saturation,$T_0(\sim N_{part}^{1/3})$, bigger R_0^{-1} Knudsen number
(pA : Higher y and smaller size!)

Increase p_T first role of flow is increased, then tomographic regime

Abundance of experimental data makes "toy models" useful

Low p_T harmonics the experimental situation



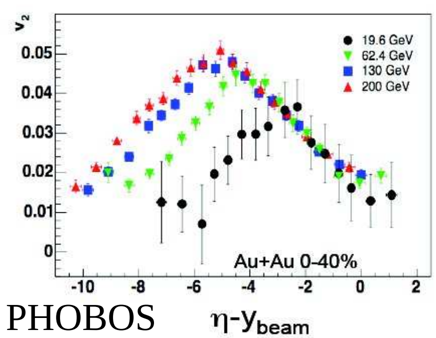
Here is what we know experimentally

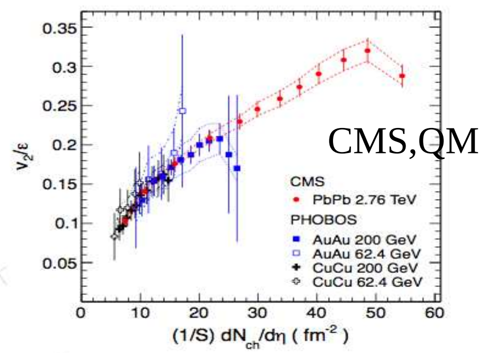
$$v_2 \simeq \epsilon(b, A) F(p_T) \quad , \quad \langle v2 \rangle \simeq \int dp_T F(p_T) f\left(p_T, \langle p_T \rangle_{y,A,b,\sqrt{s}}\right)$$

$F(p_T)$ universal for all energies , $f(p_T)$ tracks mean momentum, $\sim \frac{1}{S}\frac{dN}{dy}$
This is an experimental statement, as good as the error bars

$$\frac{v_n}{\epsilon_n} \sim c_s f \underbrace{\left(\frac{1}{T_f^3\tau_0 R^2}\frac{dN}{dy}\right)}_{\sim\tanh(\ldots)} \left(1-\mathcal{O}(1)\frac{\eta}{s}\underbrace{\frac{1}{TR}}_{no\ \ scaling}\right)$$

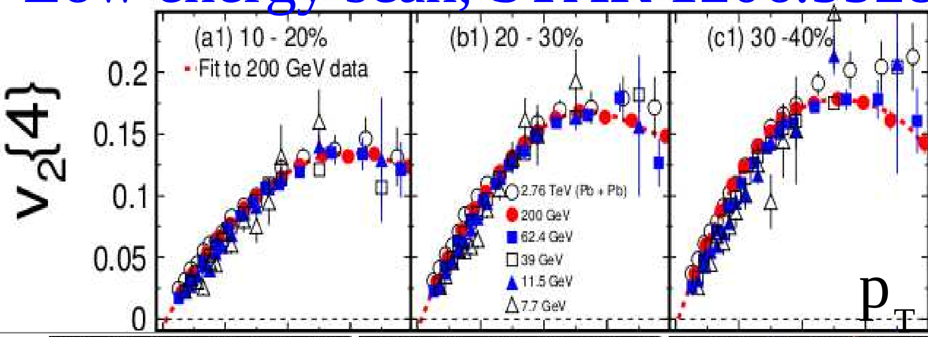
No change in any of these termsobserved, from SPS to RHIC!

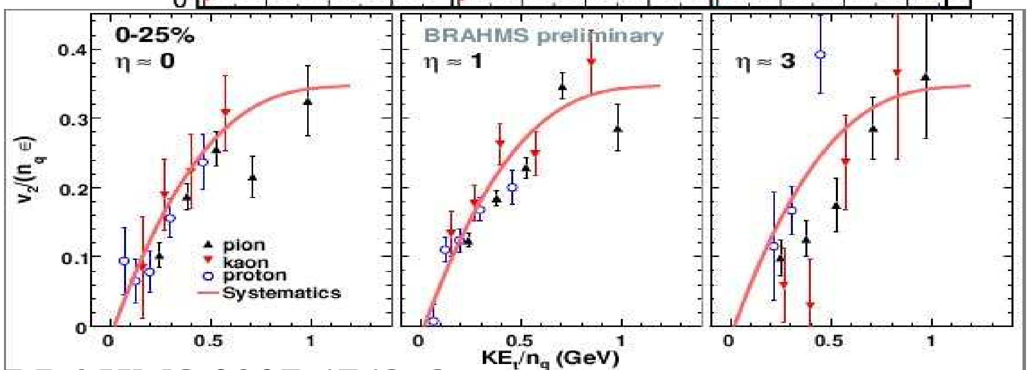




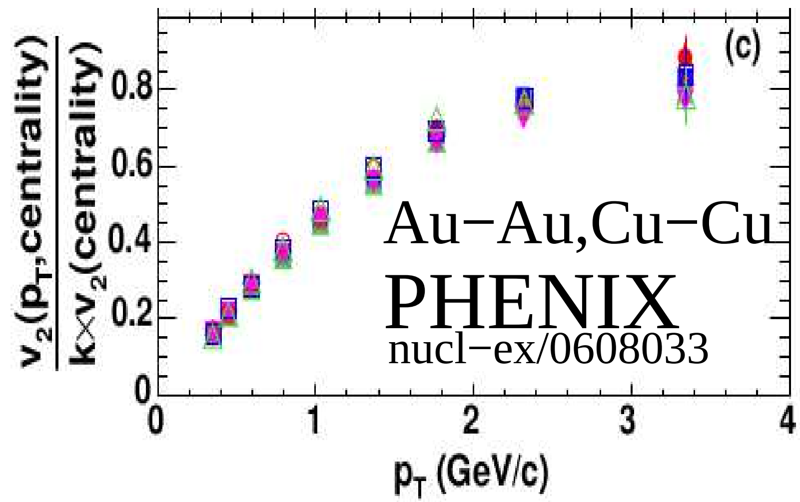
No sign of Knudsen number. v_3 of pA,AA amazing , as $\epsilon_3^{pA} \simeq \epsilon_3^{AA}$, but Kn $\mathcal{O}(10)$ bigger. Also no $\tau_0(\sqrt{s})$ seen.

Low energy scan, STAR 1206.5528





BRAHMS,0907.4742v2



Puzzle2: Why is $v_2(p_T)$ constant (at least at high p_T)?

NB: this means $v_2(p_T)/\langle v_2 \rangle$ independent of $N_{part}, y, \sqrt{s}$

Cooper-Frye

$$v_2(p_T) = \int d\phi \cos(2\phi) \left(E - p_T \left(\frac{dt}{dr} + \Delta \frac{dt}{dr}(\phi) \right) \right) e^{\left(-\frac{\gamma (E - p_T (u_T + \delta u_T(\phi)))}{T} \right)}$$

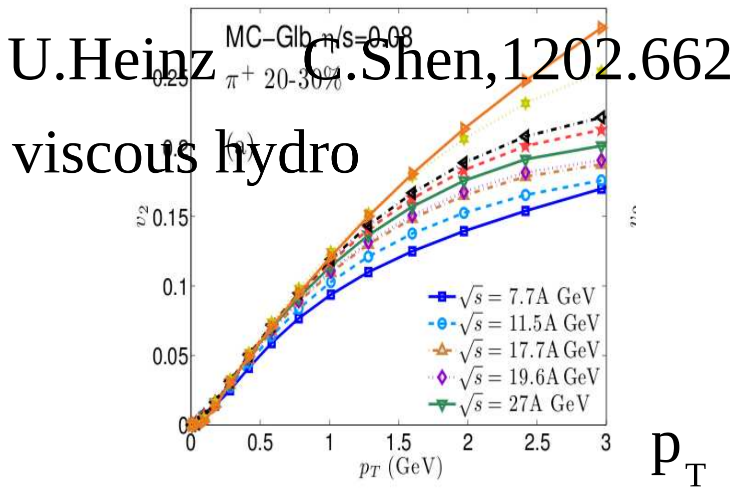
$$\simeq \int d\phi \cos^2(2\phi) \left[\underbrace{e^{-\frac{\gamma(E - p_T u_T)}{T}}}_{=0} - \underbrace{p_T \Delta \frac{dt}{dr}}_{\epsilon p_T} + \underbrace{\frac{\gamma \delta u_T(\phi) p_T}{T}}_{\sim \frac{\delta v_T}{T} p_T \sim \epsilon p_T / T} + \mathcal{O}\left(\epsilon^2\right) + \mathcal{O}\left(Kn\right) \right]$$

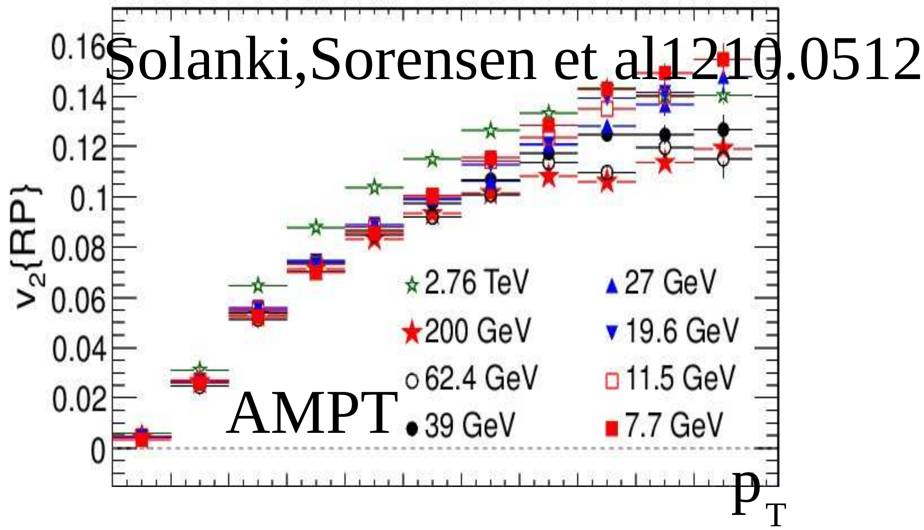
As long as $\frac{\delta v_T}{T} \sim \epsilon s^0$ (close to saturation of ϵ_p), $v_2(p_T)$ independent of $\sqrt{s}$

.

In ideal <u>and long-lived limit</u> $\frac{\eta}{sT} \ll R$ in $v_2(p_T) \sim \epsilon \tanh\left(\epsilon \frac{p_T}{T_f} \right) \underbrace{\rightarrow}_{p_T \gg T} p_T^0$

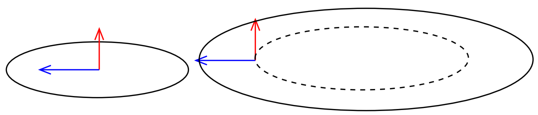
NB: deviations $\sim p_T$, more prominent at @high p_T





This is why all hydro and transport models generally give a systematic shift of $v_2(p_T)$ going up with p_T , as long as $p_T \sim \mathcal{O}(1) \langle p_T \rangle$. Thus this data-model disagreement not likely to go away!

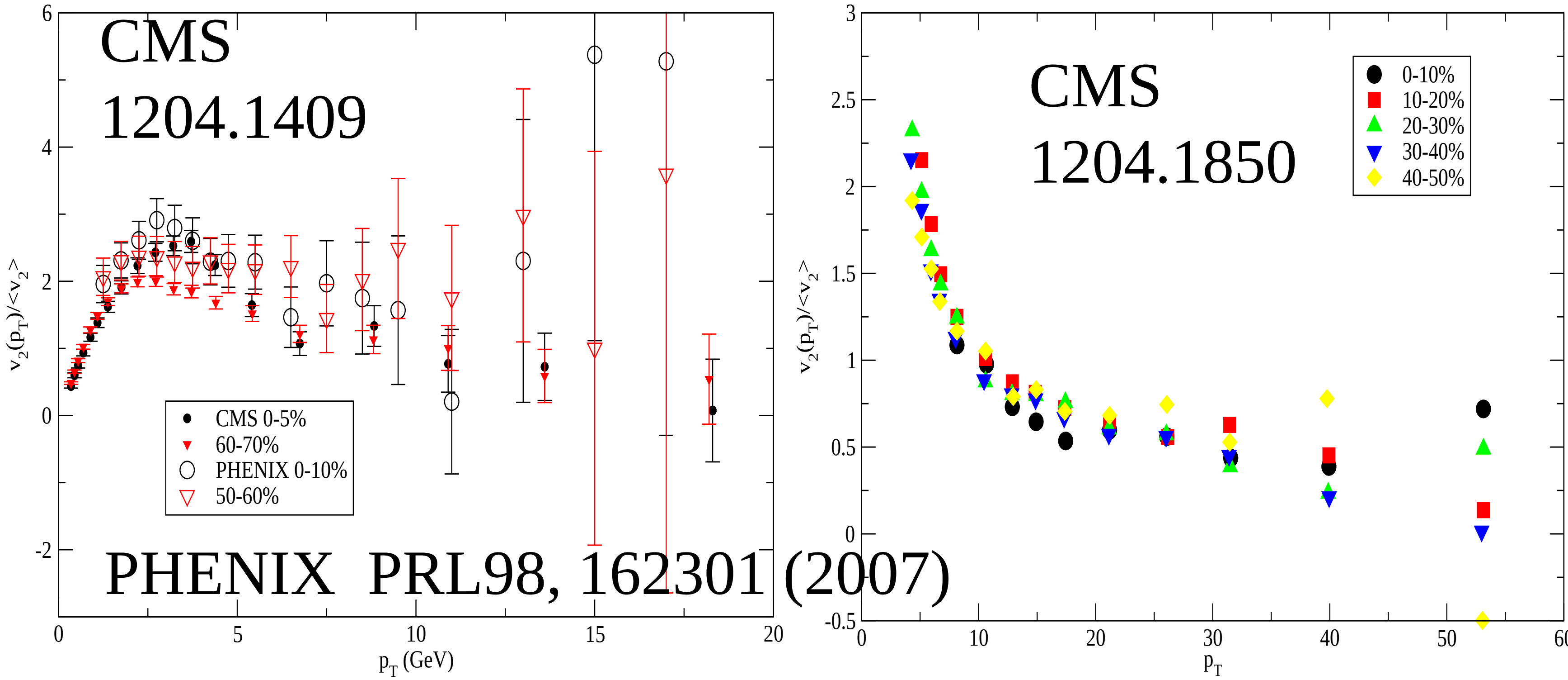
Go to high p_T: At $Kn(pT-T)\geq 1$ tomographic regime
Tomographic v_n,unlike hydrodynamic v_n, depends on size as well as density



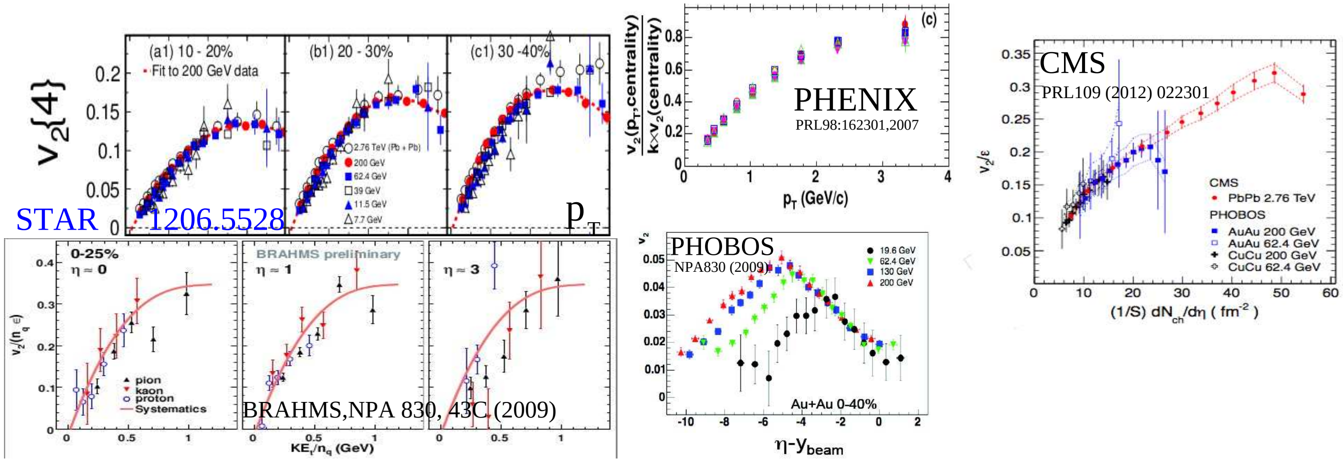
Take, as an initial condition, an elliptical distribution of matter at a given ϵ_n , run jets through it and calculate v_n . Now increase R with constant ϵ_n
.

$$\left.\frac{v_n}{\epsilon_n}\right|_{tomo} \rightarrow \frac{Surface}{Volume} \rightarrow 0 \quad , \quad \left.\frac{v_n}{\epsilon_n}\right|_{hydro} \rightarrow \mathrm{constant}$$

Role of "size" different in tomo vs hydro regime (M.Gyulassy,B.Betz,GT).
$\frac{dE}{d\tau}\sim \kappa E^a T^b \tau^c \Rightarrow \Delta E \sim \left\langle E^x \right\rangle \left\langle T^y \right\rangle \left\langle R \right\rangle^z \neq f\left(\frac{1}{S}\frac{dN}{dy}\right)$
Volcanoes and waterfalls can only make this worse, as $\epsilon_n(T\sim T_c)\neq \epsilon_n^{total}$



But , it seems no scaling break up to $p_T \sim 3.5$ GeV, maybe til 20 GeV. Split@intermediate p_T , reunification (?) higher (but big errors!). If no scaling violation for all momenta, puzzle for tomography



Anti-conclusion: Scalings puzzling for all popular models

Unless scalings break (Experimentalists?) model constrains on scalings more useful than "my model with 10 parameters fits this data at this $\sqrt{s}$".

Remember Bjorken scaling/partons. QCD a descendant of a scaling non-trivial with bootstrap/Smatrix/...

More info: arXiv:1208.5996, arXiv:0911.4775 (PRC), nucl-th/0702013 (PRC) , extensive calculation with ABC model using TITAN supercomputer in progress!