Jet R_{AA} and v_n for PbPb 5.02 TeV with JEWEL+v-USPhydro

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April 26, 2022

Model and Methodology

JEWEL: BDMPS-Z Monte-carlo generator for parton showers with **medium interaction**.

PYTHIA: hard scattering + hadronization.

Apply a **state-of-the-art description** of the medium:

Default Medium

- Simplistic Glauber
- Bjorken expansion
- No event-by-event fluctuations

2+1 Hydrodynamics

- TRENTo
- v-USPhydro
- Shear viscosity
- Local flow dependence

- **Recoils on** (4MomSub).
- Free parameters tuning: ATLAS PbPb 5.02 TeV 0-10%.
- Rivet+FastJet analyses.
- Statistical uncertainties only.

Event Generators

PYTHIA: initial hard scattering $\rightarrow$ start of **parton shower**.
JEWEL: MC event generator that solves parton showers ($t = Q^2$) with **medium interaction**.
QGP $\rightarrow$ temperature-dependent **scattering centers**.

$$\frac{d\hat{\sigma}}{d\hat{t}}(\hat{s},\hat{t}) = \frac{C_R \pi \alpha_s(|\hat{t}| + \mu_D^2)}{\hat{s}^2} \frac{\hat{s}^2 + (\hat{s} - |\hat{t}|)^2}{(|\hat{t}| + \mu_D^2)^2}$$

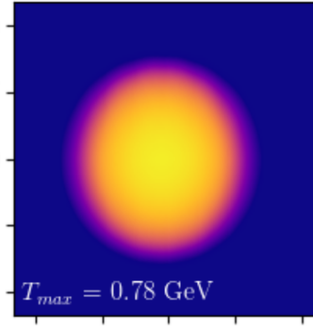
Gluon emissions are treated in a coherent manner (LPM effect)

$$\tau_f \sim \frac{E}{t} = \frac{2\omega}{k_T^2}, \quad \begin{cases} \Delta L > \tau_f \Rightarrow \text{incoherence: gluon is formed.} \\ \Delta L < \tau_f \Rightarrow \text{coherence: } k_T \rightarrow k_T + s_T, \text{ repeat.} \end{cases}$$

End of parton shower $\rightarrow$ hadronization is handled by **PYTHIA** (Lund Model).

Glauber

Main hypothesis: entropy deposition via overlap of participants' **thickness functions** $T_{A/B}(x, y)$.



- Woods-Saxon distribution of nucleons.
- Density of participants:

$$n_{AB}(b; x, y) = T_A(\vec{s}) \left[1 - \exp(-\sigma_{NN} T_B(|\vec{b} - \vec{s}|))\right] + T_B(|\vec{b} - \vec{s}|) \left[1 - \exp(-\sigma_{NN} T_A(\vec{s}))\right]$$

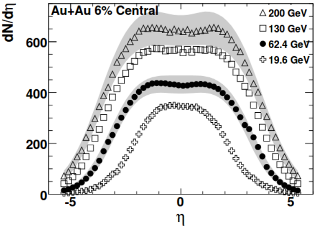
- (JEWEL) Relation between energy and participant densities defines temperature:

$$\frac{\epsilon_{AA}(b; x, y)}{\epsilon_i} = \frac{n_{AA}(b; x, y)}{\langle n_{AA}(b = 0)\rangle} \Rightarrow T(b; x, y) \approx T_i \left(n_{AA}(b; x, y) \frac{\pi R_A^2}{2A}\right)^{\frac{1}{4}}.$$

Bjorken Longitudinal Expansion

- Assume a fluid velocity without azimuthal and radial components $u^\mu \doteq (u_t, 0, 0, u_z)$.
- *Central plateau* in particle production $\Rightarrow$ system **scales with rapidity** $\Rightarrow$ $u^\mu = (\cosh y, 0, 0, \sinh y)$.
- Entropy current conservation:

$$\partial_\mu (u^\mu s) = 0 \Rightarrow T(\tau) = T(\tau_0) \left(\frac{\tau}{\tau_0}\right)^{-c_s^2}$$

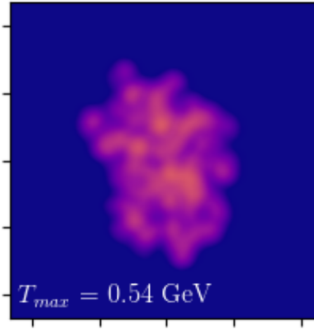


TRENTo

Main hypothesis: entropy deposition via a generalized **reduced thickness function** $T_R(p; T_A, T_B)$.

- Woods-Saxon distribution of nucleons (one or multiple gaussians).
- Monte-Carlo sampling of participants ⇒ **Fluctuations**.
- Parametrization of entropy (p as free parameter)

$$\frac{dS}{dy} \propto T_R(p; T_A, T_B) = \left(\frac{T_A^p + T_B^p}{2}\right)^{\frac{1}{p}}$$



v-USPhydro

State-of-the-art (2+1) hydrodynamic expansion with shear and bulk viscosity.

- Solution of equations of motion of a fluid via **Smoothed Particle Hydrodynamics** (SPH).

$$\begin{aligned}\frac{1}{\sigma}\partial^{\mu}(p+\Pi) =&\gamma\frac{\partial}{\partial\tau}\left[\frac{\epsilon+p+\Pi}{\sigma}u^{\mu}\right]\\ 0 =&\gamma\frac{\partial}{\partial\tau}\left(\frac{s}{\sigma}\right)+\left(\frac{\Pi}{\sigma}\right)\frac{\theta}{T}\\ 0 =&\tau_{\Pi}\left(\frac{\Pi}{\sigma}\right)+\frac{\Pi}{\sigma}+\frac{\zeta}{\sigma}\theta\end{aligned}$$

- Transformation between SPH particles and space-fixed frames

$$\tau\gamma\sigma \to \sigma^{*}(\vec{r},\tau) = \sum_{i=1}^{N_{SPH}} \nu_i \cdot W[\vec{r}-\vec{r}_i(\tau);h]$$

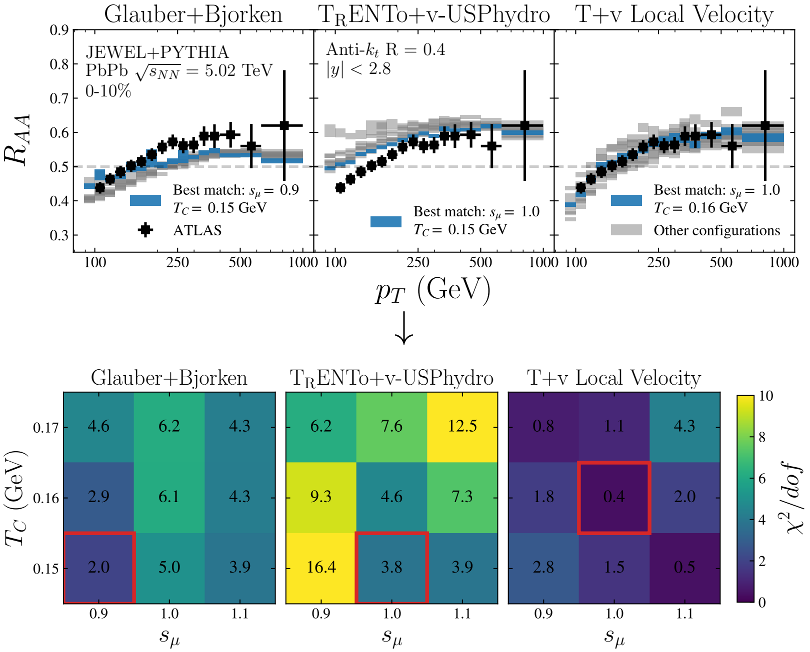
$$\Rightarrow a^{*}(\vec{r},\tau) = \sum_{i=1}^{N_{SPH}} \nu_i \left(\frac{a}{\sigma}\right)_i \cdot W[\vec{r}-\vec{r}_i(\tau);h]$$

- Bjorken scaling in longitudinal direction.

Free Parameter Tuning

ATLAS central R_{AA} data for tuning free parameters via **minimum χ^2 estimation**.

- Free parameters: temperature regulator s_μ ($\mu_D = 3s_\mu T$) and critical temperature T_C.
- Original JEWEL tuned to RHIC data w/o recoils, only s_μ considered and T_C fixed at 0.17 GeV.
- Lower freeze-out temperature in v-USPhydro $\Rightarrow$ T_C as free parameter.
- "Best" (s_μ, T_C) configuration vs. experimental R_{AA} $\Rightarrow$ choice for each model.
- Consistent relative behavior when varying free parameters.

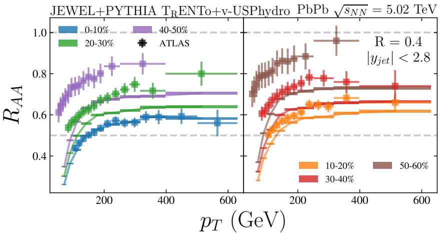


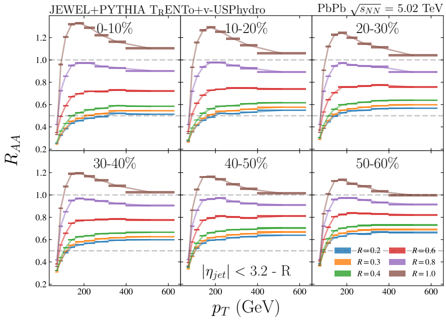
Glauber+Bjorken
TRENTo+v-USPhydro
T+v Local Velocity
JEWEL+PYTHIA
PbPb $\sqrt{s_{NN}} = 5.02$ TeV
0-10%
Anti-k_t R = 0.4
$|y| < 2.8$
Best match: $s_\mu = 0.9$
$T_C = 0.15$ GeV
ATLAS
Best match: $s_\mu = 1.0$
$T_C = 0.15$ GeV
Best match: $s_\mu = 1.0$
$T_C = 0.16$ GeV
Other configurations
R_{AA}
p_T (GeV)
Glauber+Bjorken
TRENTo+v-USPhydro
T+v Local Velocity
T_C (GeV)
s_μ
χ^2/dof
4.6 6.2 4.3
2.9 6.1 4.3
2.0 5.0 3.9
6.2 7.6 12.5
9.3 4.6 7.3
16.4 3.8 3.9
0.8 1.1 4.3
1.8 0.4 2.0
2.8 1.5 0.5

Nuclear Modification Factor R_{AA} for Jets

$$R_{AA}(p_T) \doteq \frac{1}{\langle N_{coll}\rangle} \frac{\frac{1}{N_{evt}} \frac{dN}{dp_T}\Big|_{AA}}{\frac{1}{N_{evt}} \frac{dN}{dp_T}\Big|_{pp}}$$

- Comparison to ATLAS data (arxiv:1805.05635).





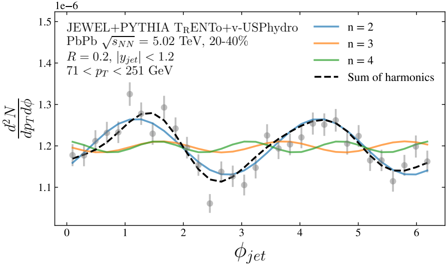
- Anti-k_T jets with $|\eta_{jet}| < 3.2 - R$, $p_T = 63$ GeV to 630 GeV for all R.
- Good description of central collisions only.
- Higher modification in peripheral systems.
- Large R enhancement.

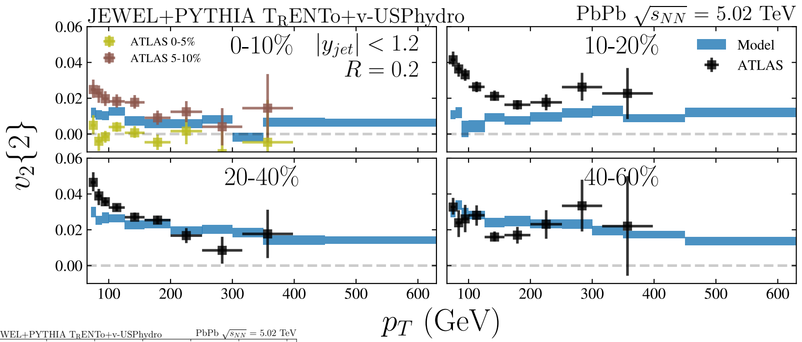
Anisotropic Flow Coefficients $v_{n=2,3}$ for Jets

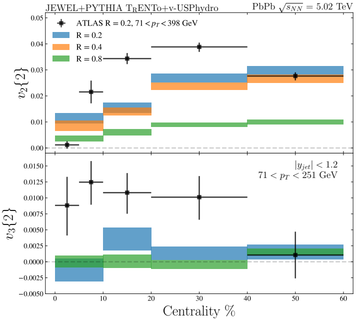
Calculated coefficients given by **Jet-Soft correlations**:

$$v_n\{2\}(p_T) = \frac{\langle v_n^{soft} v_n^{jet}(p_T) \cos(n(\Psi_n^{soft} - \Psi_n^{jet}(p_T)))\rangle}{\sqrt{\left\langle \left(v_n^{soft}\right)^2 \right\rangle}}$$

- **Event-by-event** study of anisotropies.
- Not possible in JEWEL Default (no soft sector).
- Media are not modified by the parton shower evolution.
- Comparison to ATLAS data (arxiv:2111.06606), $71 < p_T < 398$ GeV, $|y_{jet}| < 1.2$ and $R = 0.2$.

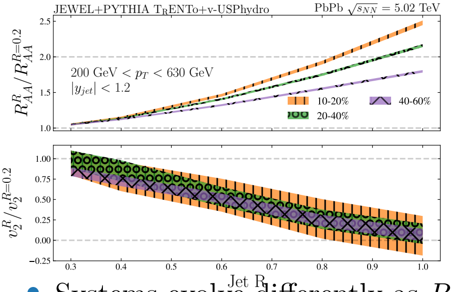






- Only most peripheral centrality class matches experimental $v_{n=2,3}$.
- Positive v_2 even for larger jets.
- $v_3 > 0$ for $R = 0.2$ except 0-10% (one order of magnitude smaller than v_2).

R-dependence Ratios



- Systems evolve differently as R increases. R_{AA} and v_2 anti-correlation is maintained.

Conclusions

- Implementation of a 2+1 hydrodynamic medium description in JEWEL.
- Wide p_T range analyses of jet R_{AA} and $v_{n=2,3}$.
- Event-by-event correlation study between jet and soft sectors.
- Jet radius dependence: insights into medium response.
- Next steps: jet substructure, smaller systems, HF effects.

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