Constraints on longitudinal-dependent initial conditions from $dN_{ch}/d\eta$ and two-particle $\eta$-correlation @ LHC

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September 27, 2016
Motivation: a simple 3d-initial condition model

Boost-invariant hydrodynamic-based modelling is successful at mid-rapidity. But,

- model asymmetric collisions like pA;
- EbE longitudinal fluctuations in AA collisions;
- impact on medium evolution, probes propagation and observables.
Extend existing 2d-IC model (TRENTo) to 3d

- A parametric IC model at $\eta \sim 0$: $T_A(x_\perp), T_B(x_\perp) \rightarrow s_0(x_\perp)|_{\tau=\tau_0}$.

Add longitudinal dependence,

$$s(x_\perp, \eta_s) = s_0(x_\perp)g(x_\perp, y)\frac{dy}{d\eta}.$$ 

- Difference in $T_A(x_\perp), T_B(x_\perp)$ induces asymmetry in longitudinal profile function $g(x_\perp, y)$.
- Normalize $g(x_\perp, 0) = 1$ to preserve 2d-model calculation.
- $g(x_\perp, y)$ characterized by its first 3 $y$-cumulants:

<table>
<thead>
<tr>
<th>Cumulants</th>
<th>mean</th>
<th>width</th>
<th>skewness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Param-1 (relative)</td>
<td>$\mu_0 + \frac{1}{2} \ln \frac{T_A}{T_B}$</td>
<td>$\sigma_0$</td>
<td>$\gamma_0(\frac{T_A - T_B}{T_A + T_B})$</td>
</tr>
<tr>
<td>Param-2 (absolute)</td>
<td>$\frac{1}{2} \ln \frac{T_A}{T_B}$</td>
<td>$\gamma_0(T_A - T_B)$</td>
<td></td>
</tr>
</tbody>
</table>

$g(x_\perp, y)$ reconstructed from cumulant-generating function.
### Example events

<table>
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</thead>
<tbody>
<tr>
<td>Param-1 (relative)</td>
<td>$\mu_0 = 1$ $\frac{1}{2} \ln \frac{T_A}{T_B}$</td>
<td>$\sigma_0$</td>
<td>$\gamma_0 (T_A - T_B)/(T_A + T_B)$</td>
</tr>
</tbody>
</table>

- $T_A/T_B = 1.0$: $\mu_0 = 1$, $\gamma_0 = 0$
- $T_A/T_B = 2.0$: $\mu_0 = 0$, $\gamma_0 = 10$
- $T_A/T_B = 3.0$: $\mu_0 = 0$, $\gamma_0 = 10$

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**Graphical Representation**

- **ds(x, η)/dη** distribution for different values of $T_A/T_B$.
- **y [fm]** vs. **x [fm]** and **y [fm]** vs. **η_s** plots for Pb+Pb and p+Pb collisions.
Model Calibration and Selection

- Using Bayesian methodology, globally fit IC to $dN_{ch}/d\eta$ → data constrained IC parameters distribution.
- Optimal parameters → 3+1D hydro (Iurii Karpenko) + UrQMD. Calculate $C_N(\eta_1, \eta_2)$ observable $\langle a_1^2 \rangle$.
- Relative-skew model is better. $\mu_0 \sim 0$, $\gamma_0 \sim 7.2$. 

![Graphs showing dNch/d\eta for ALICE and ATLAS in Pb+Pb and p+Pb collisions, with comparisons of IC + Hybrid and IC models]

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Predictions

- IC model tuned on multiplicity observables ($\perp$-integrated).
- Predict $\eta$-diff flows and event-plane decorrelations ($\eta$ evolution of $\perp$ structure).
Conclusion

This work:

- A 3d extension of TRENTo initial condition model.
- Model tuned on $dN_{ch}/d\eta$ with Bayesian technique.
- Achieve a reasonable $\eta$-dependence of transverse structure.

Things to do and limitations:

- Use full model calculation to compare with $dN_{ch}/d\eta$.
- Study more longitudinal observables.
- Inclusion of proton geometry fluctuation in pA (3 quarks?).
- Lack of early stage dynamical fluctuations.