

Longitudinal structure of light ion collisions

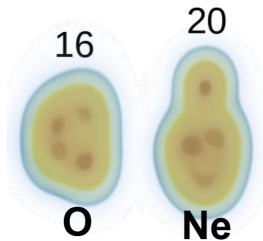
Andreas Kirchner



Light ion collisions at the LHC, CERN, December 2025

Introduction

Light ion runs



Very successful light ion run
in this summer

→ Multiplicity distribution
already shows signs of
interesting new physics

Longitudinal structure of small collision systems important

→ 3D description needed

Model

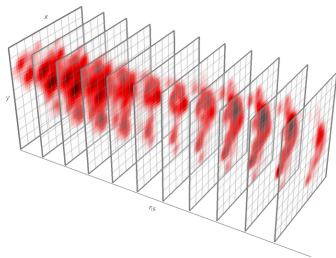
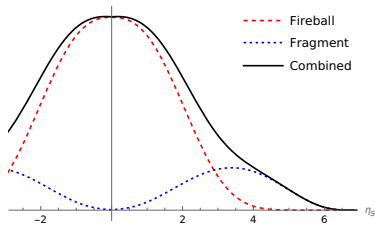
Trento 3D

- Extend 2D description by decomposing thickness into **fireball** & **fragmentation** profiles

$$\epsilon = \epsilon_{fb} + \epsilon_{frag,A} + \epsilon_{frag,B}$$

- Central fireball given by $\epsilon_{fb} = N_{fb} \sqrt{T_A T_B} f_{fb}(\eta)$
- **Fireball profile function** defines size of central plateau
- **Fragmentation profile function** scales with target/projectile **thickness functions** $\epsilon_{frag,X} \propto F_X$
→ Asymmetric collisions accounted for

Trento 3D



- Energy & momentum conservation for **fireball** and **fragmentation** enforced
- Energy distribution between **fireball** and **fragmentation** fluctuates

Setup

Fluid evolution

First analysis using simplified toy model:

- 1+1D fluid evolution constrained to longitudinal direction:

$$\rightarrow \text{EoM } \nabla_{\mu} T^{\mu\nu} = 0 \text{ with } T^{\mu\nu} = \begin{pmatrix} \epsilon_{LH} & \frac{1}{\tau} p_z \\ \frac{1}{\tau} p_z & \frac{c_s^2}{\tau^2} \epsilon_{LH} \end{pmatrix}$$

$$\rightarrow \text{EoS } P = c_s^2 \epsilon_{LH} \text{ and } c_s^2 = \frac{1}{3}$$

- Full dynamics given by **transverse Gaussianization**

$$\epsilon(\tau, r, \phi, \eta_s) = \epsilon_{LH}(\tau, \eta_s) \frac{1}{2\pi\sigma_G^2} e^{-r^2/2\sigma_G^2}$$

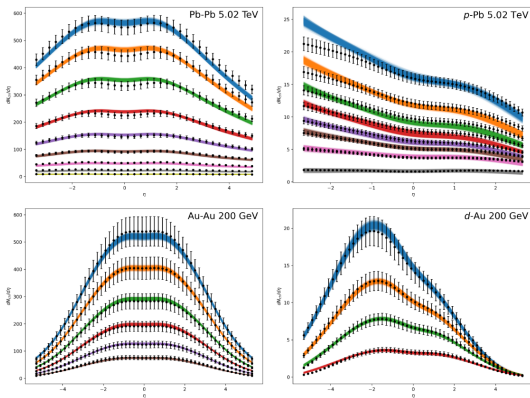
- Initial profiles given by centrality-averaged Trento 3D events

Freeze-out

Particlization through Cooper-Frye prescription:

- Freeze-out hypersurface defined via $\epsilon(\tau, r, \phi, \eta_s) = \epsilon_{FO}$
→ Freeze-out radius $r_{FO} = \sqrt{2\sigma_G^2 \ln \frac{\epsilon_{LH}(\tau, \eta_s)}{2\pi\sigma_G^2 \epsilon_{FO}}}$
- Pseudorapidity number density given by Cooper-Frye integral $\frac{dN}{d\eta}(\eta) \propto \int dp_T \int d\phi_p \sqrt{1 + \frac{m^2}{p_T^2 \cosh^2 \eta}} \int d^3\Sigma_\mu p^\mu f$
- Transverse fluid velocity given by cylindrically symmetric case

Parameter calibration

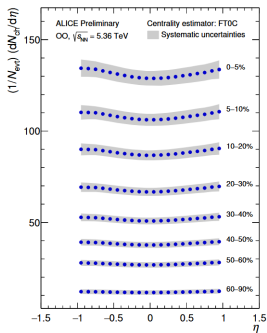
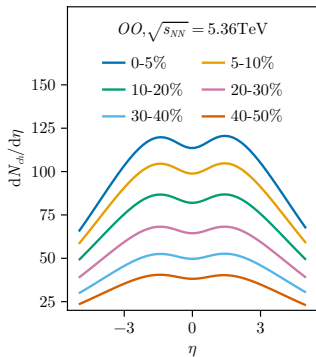


Parameters constrained through calibration to Pb-Pb, p-Pb, Au-Au, d-Au at different energies

⇒ Use for prediction of light ion collisions

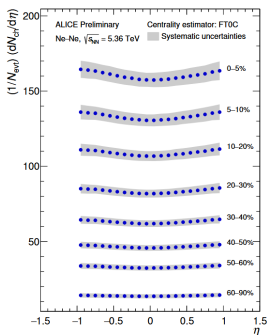
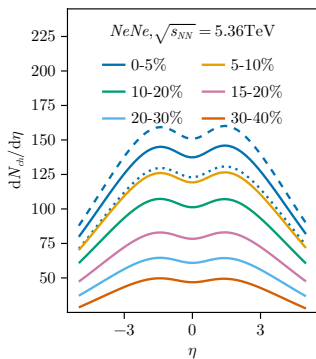
Predictions

Predictions 00



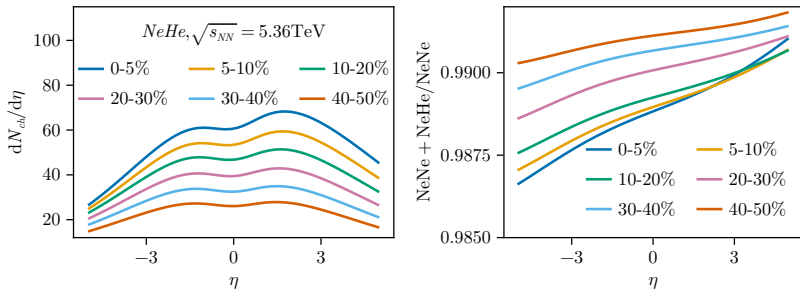
- Prediction based on large ions has similar magnitude and features at mid-rapidity
- Discrepancy due to unconstrained initial time τ_0

Predictions NeNe



- Multiplicity can be matched by changing τ_0
→ Different pre-eq. dynamics than large ion collisions
- Different centralities seem to need different τ_0
→ More precise study needed

Predictions NeHe



Contamination of asymmetric events due to $Ne \rightarrow He$ transmutation can be accounted for

Conclusion & outlook

Conclusion & outlook

- Reasonable agreement with data despite simple model & Pb-Pb centrality definition
→ Discrepancy hint for new physics?
- Next steps: Integration into fully 3D simulation
→ Exact reproduction of experimental analysis possible, including centrality definition
- Plethora of physics ahead: Light ion structure, body-body vs tip-tip, ...