Advanced coalescence model based on the Wigner function formalism

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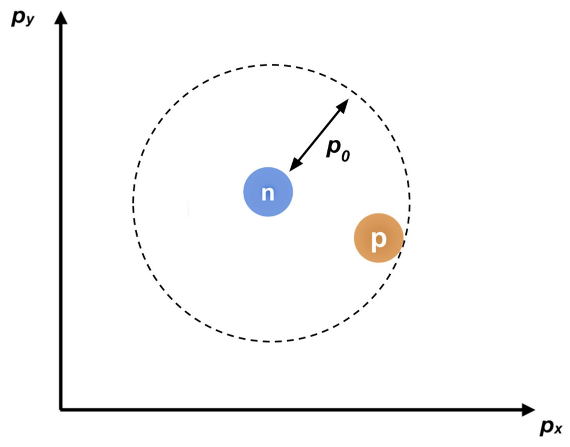
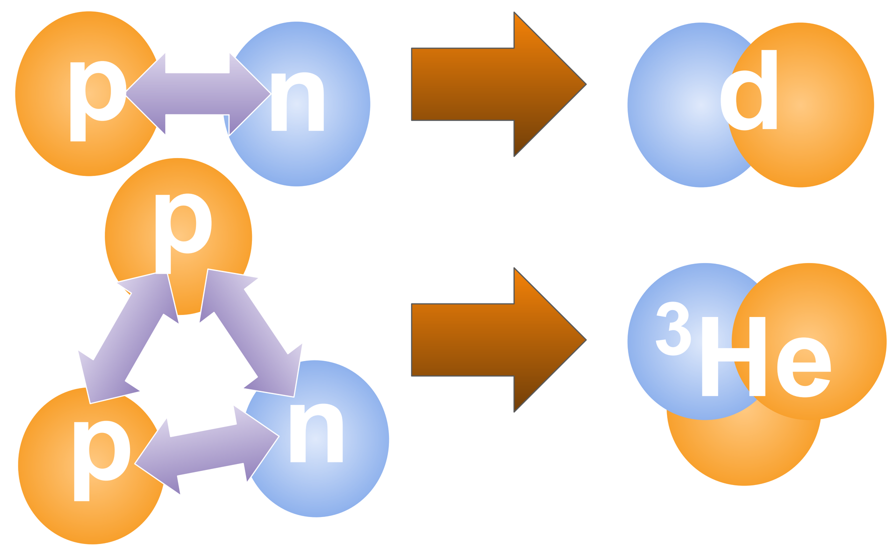
(Anti)nuclear formation using coalescence

- (Anti)protons and (anti)neutrons close in phase-space can coalesce and form a nucleus
- Simplistic implementation: spherical approximation
  - (Anti)nucleons with a relative momentum $k^* < p_0$ coalesce
  - p_0 obtained by fitting measurements
- Improved coalescence model: *Wigner function formalism* [1]
  - Assigns a coalescence probability on an event-by-event basis
  - Depending on the nucleus wavefunction





Wigner function formalism

- Projecting the (anti)nucleon density matrix on the deuteron density matrix [1] we have

$$d^3N/dP^3 = S\int d^3q \int d^3r_p \int d^3r_n\, W(q,r)\; W_{np}(p_n,p_p,r_n,r_p)/(2\pi)^6$$

From event generators — Deuteron Wigner function — Wigner function of the p-n state

being $W_{np}(\vec{P}/2+\vec{q}, \vec{P}/2-\vec{q}, r_n, r_p) = H_{np}(\vec{r}_n, \vec{r}_p)\, G_{np}(\vec{P}/2+\vec{q}, \vec{P}/2-\vec{q})$

Nucleon momentum phase-space

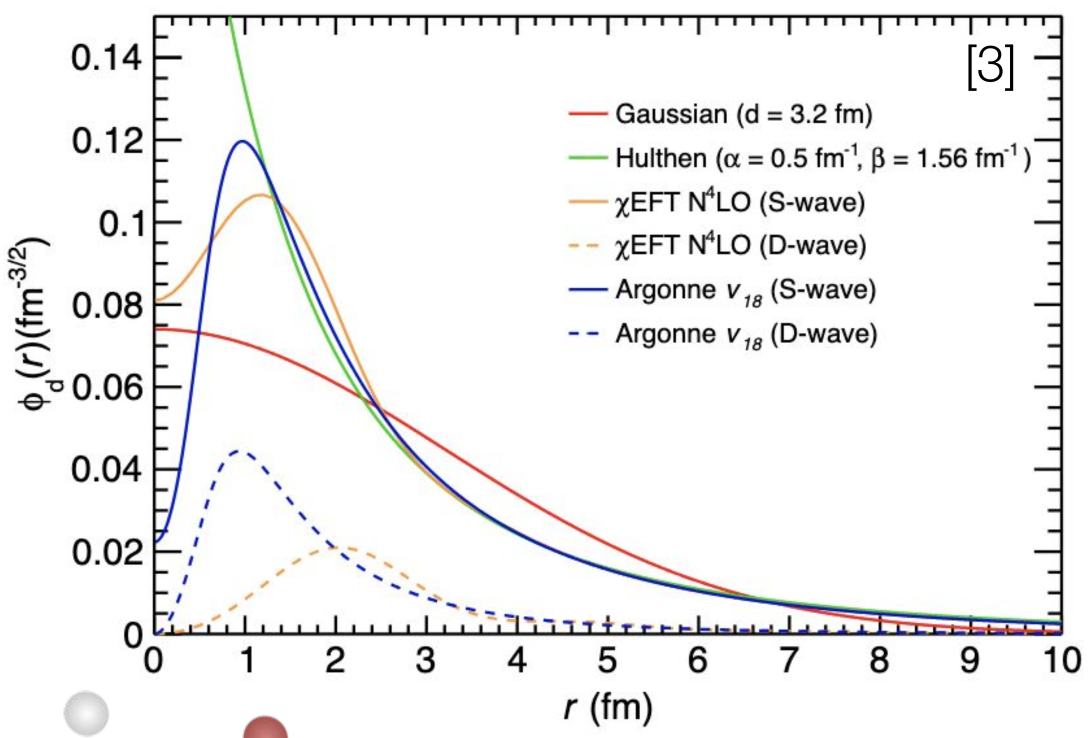
- H_{np} is the spatial distribution of nucleons. Assuming a Gaussian source [2] the coalescence probability p(q,σ) as a function of the relative momentum q and size of the emission source σ can be derived

$$p(\sigma,q) = \int d^3r_p d^3r_n h(r_n) h(r_p) W(q,r)$$

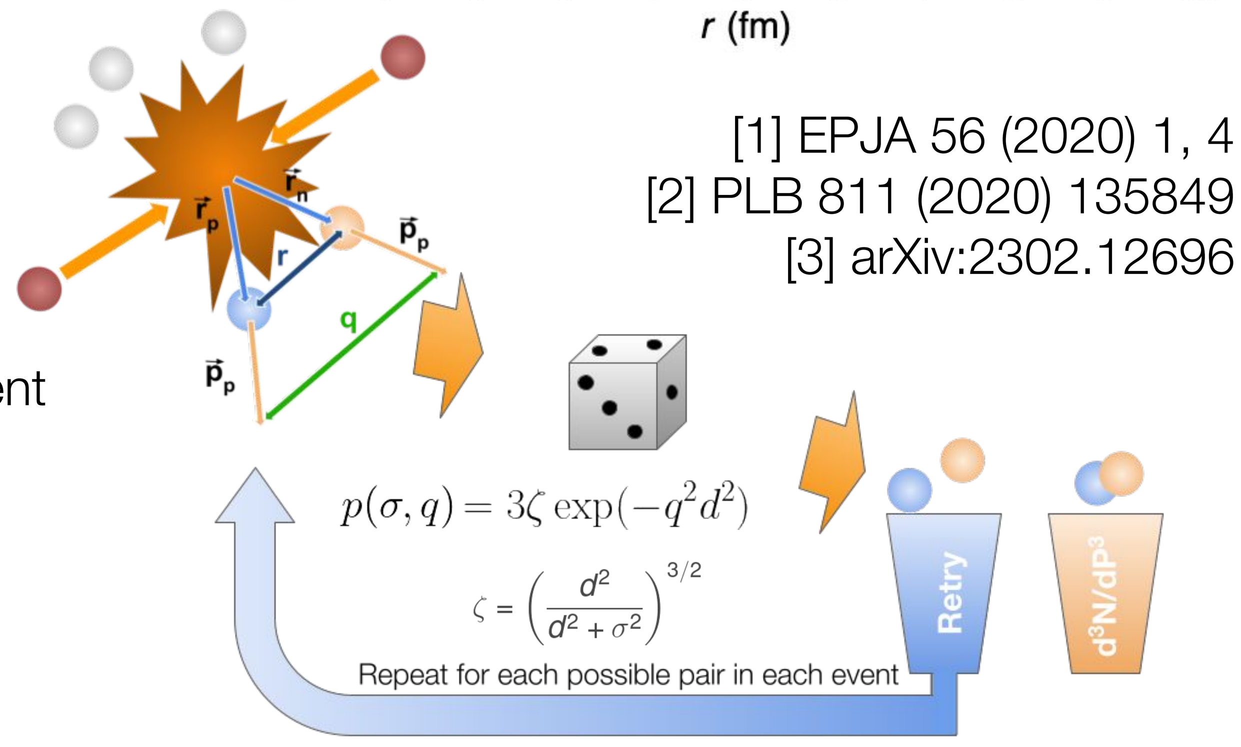
- This allows us to calculate the coalescence probability for any Wigner function and to probe different wavefunctions ψ for the final state (several options)

$$W(\vec{q},\vec{r}) = \int d^3\zeta\; \Psi(\vec{r}+\vec{\zeta}/2)\Psi^*(\vec{r}-\vec{\zeta}/2)e^{i\vec{q}\vec{\zeta}}$$

- This probability can be applied on each (anti)proton-(anti)neutron pair (triplet) in each event



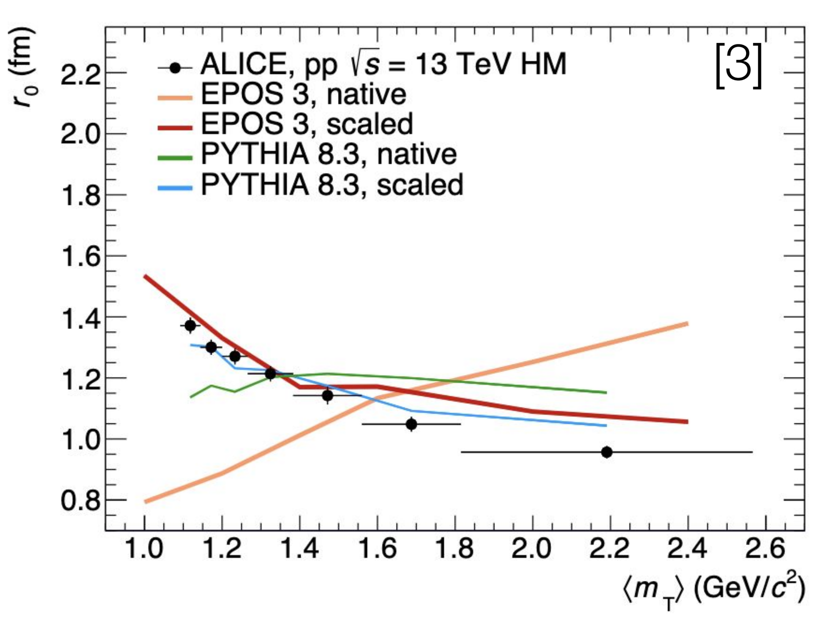
[1] EPJA 56 (2020) 1, 4
[2] PLB 811 (2020) 135849
[3] arXiv:2302.12696

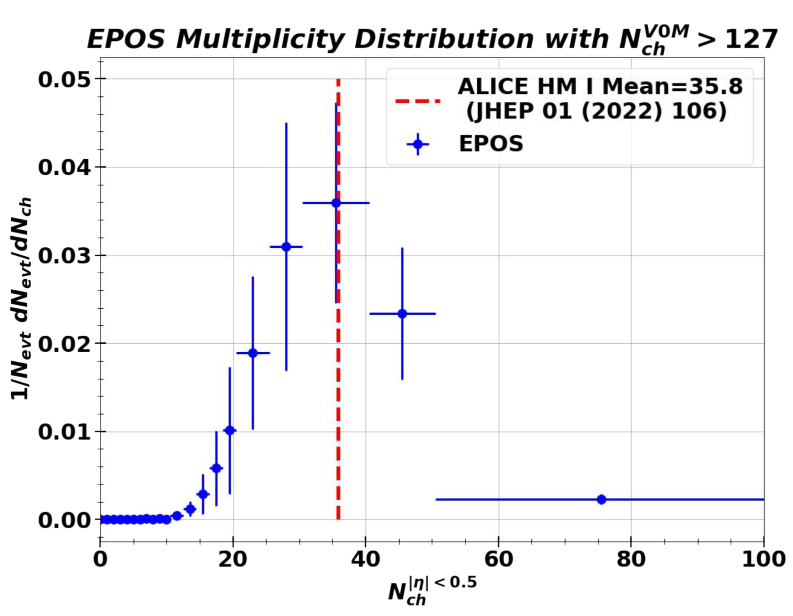


Tuning the event generators

Event generators (EPOS 3, Pythia 8.3) are corrected using measurements:

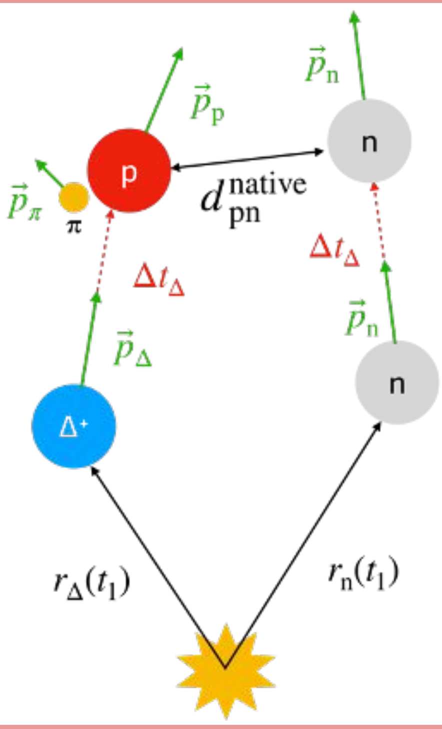
- Multiplicity: a HM trigger into the event generator which mimics the trigger used by ALICE is implemented, reproducing the average midrapidity multiplicity (35.8 ± 0.5) [4]
- Momentum: proton p_T spectra from [4] used to calibrate each (anti)nucleon p_T distribution
- Resonance cocktail: tuned to reproduce Statistical Hadronisation Model yields
- Source size: tuned to the r_0 measured in pp collisions at 13 TeV with a HM trigger (0-0.01%) by ALICE (primordials + resonances)
- Wavefunction: several wavefunctions are tested





The emission source

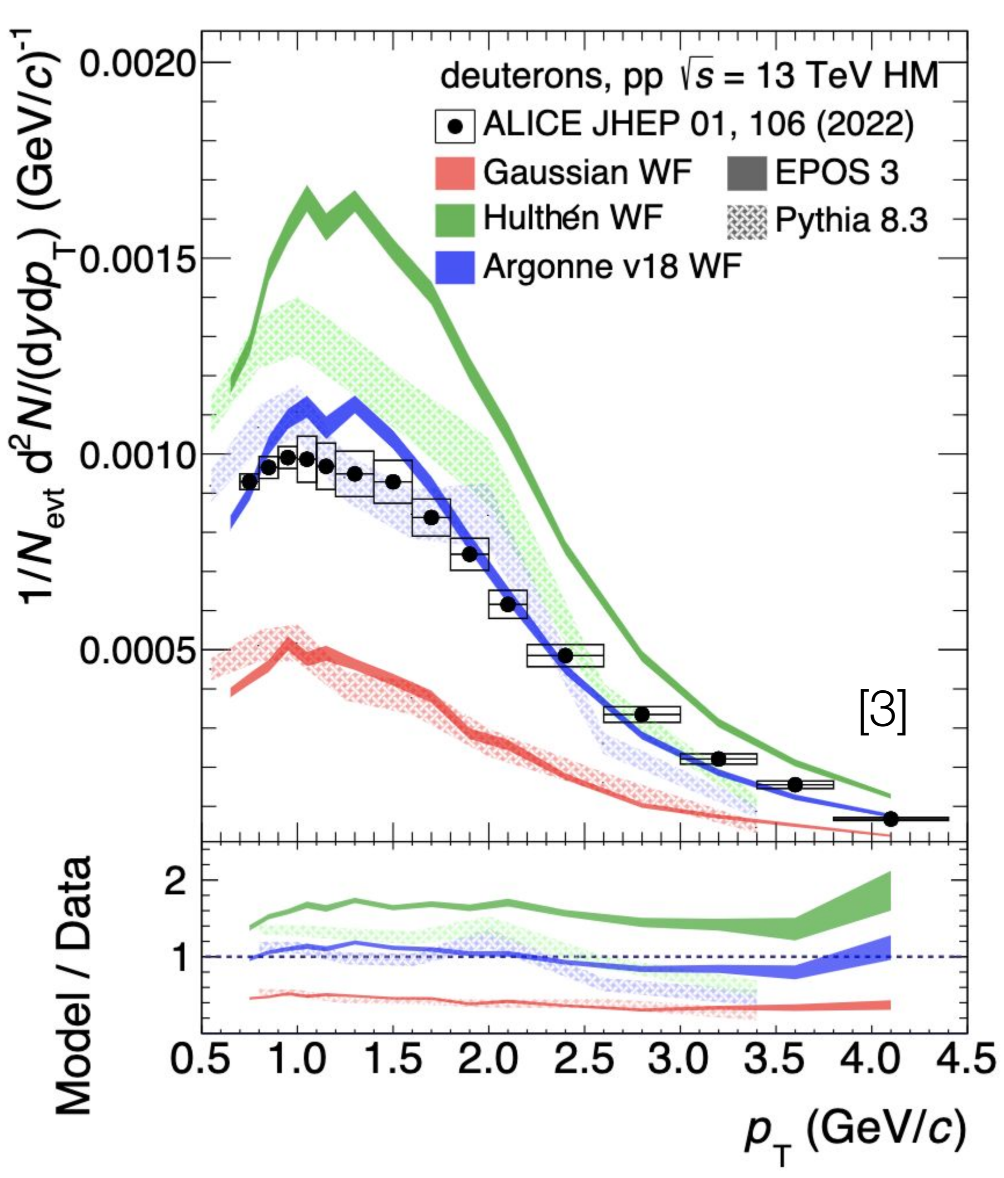
- The size of the particle emission source is an important input for the coalescence model
- The source size measured by ALICE [2] is used
- After the resonance abundancies are tuned to SHM, particles are propagated on an event-by-event basis
- The native source size d_{pn}^{native} is obtained
- m_T–dependent scaling is finally tuned to data



(Anti)deuteron spectra

- Once the event generators are tuned to the measurements, this model provides (anti)deuteron transverse momentum spectrum predictions
- Excellent agreement with the measured distribution [4] is found when using a realistic wavefunction (Argonne v_{18})
- Coalescence model is sensitive to the source size and nucleus wavefunction
- No free parameters!

→This model can be extended to any collision energy, if nucleon p_T spectra and emitting source size measurements are provided



[4] JHEP 01 (2022) 106