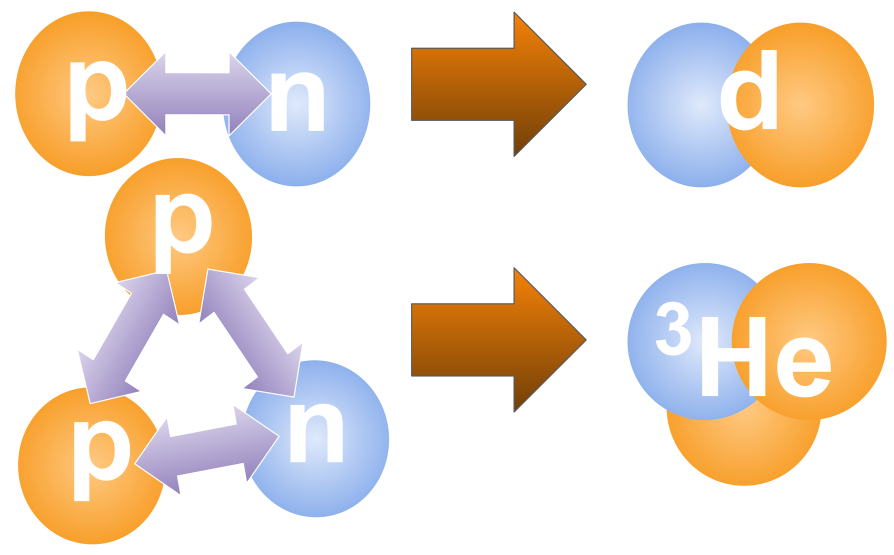
Modelling the formation of light (anti)nuclei via coalescence using Monte Carlo generators

Maximilian Horst[1], Laura Fabbietti[1], Luca Barioglio[1], Chiara Pinto[1], Francesca Bellini[2], Bhawani Singh[1], Sushanta Tripathy[2]

[1]Technical University of Munich, [2]INFN and University of Bologna

(Anti)nuclei 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*
  - Assigns a coalescence probability on an event-by-event basis
  - No free parameters



Wigner function formalism

- Based on the Wigner function of the deuteron

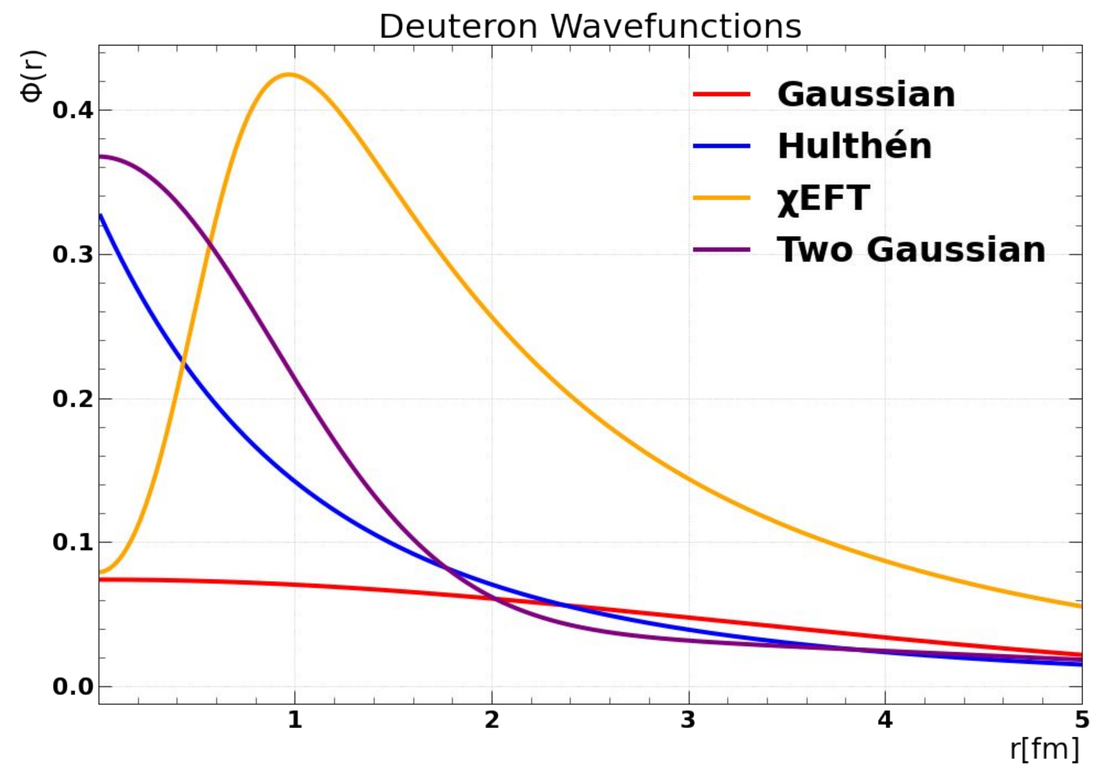
$$W(x,p) = \frac{1}{\pi\hbar}\int_{-\infty}^{\infty} \psi^*(x+y)\psi(x-y)e^{2ipy/\hbar}\,dy$$

where ψ is the wavefunction of the deuteron (several options)
- Projecting the (anti)nucleon density matrix on the deuteron density matrix we have [1]:

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

From event generator! (EPOS 3)

Deuteron Wigner function — Nucleon phase-space

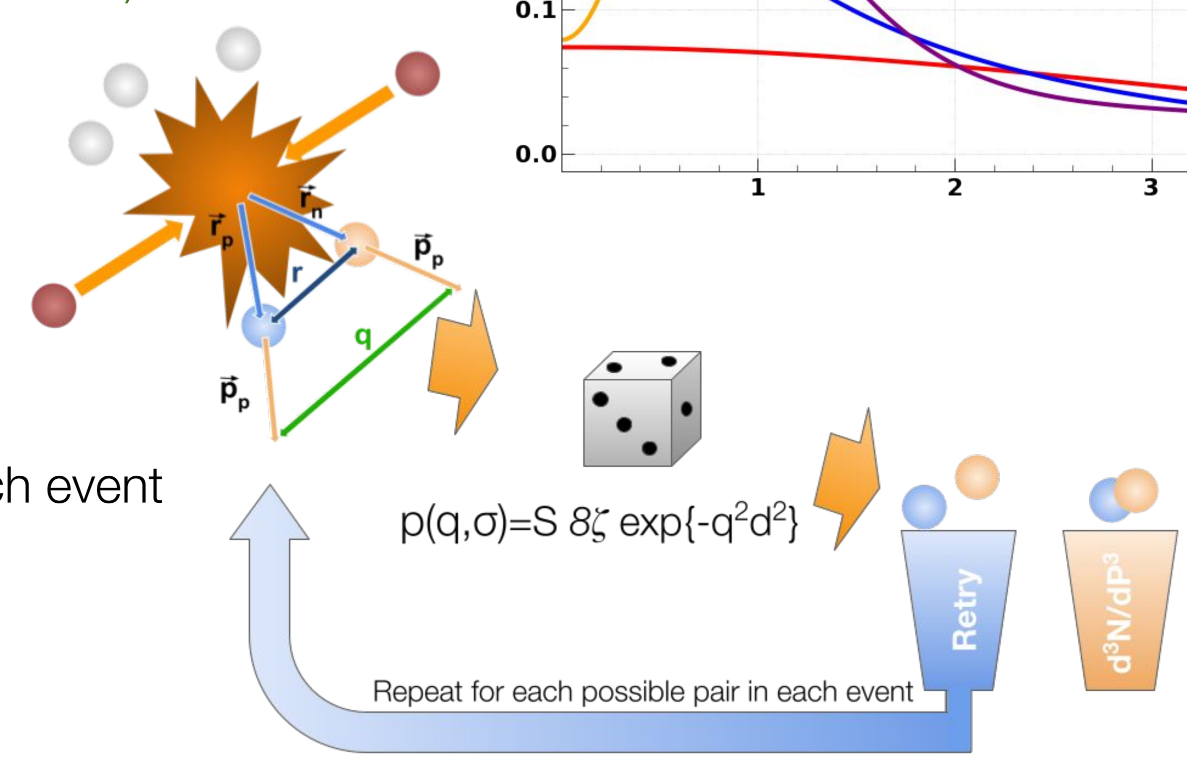


- When assuming a Gaussian source [2] an expression for the coalescence probability p(q,σ) as a function of the relative momentum and size of the emission source can be derived
- This probability can be applied on each (anti)proton-(anti)neutron pair (triplet) in each event
- Probability for Gaussian wave functions (the only known ones)
  - Single Gaussian:

$$p(q,r) = 3\zeta\exp(-q^2d^2) \qquad \zeta = \left(\frac{d^2}{d^2+\sigma^2}\right)^{3/2}$$

  - Double Gaussian:

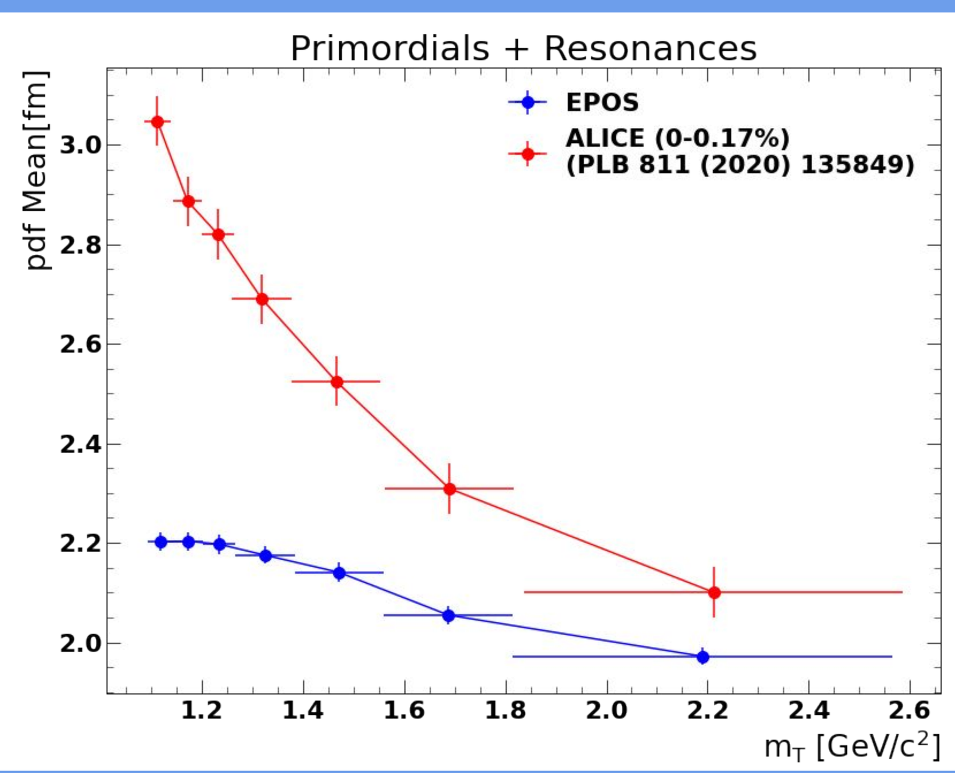
$$p(q,r) = 3(\zeta_1\Delta\exp(-q^2d_1^2) + \zeta_2(1-\Delta)\exp(-q^2d_2^2))$$

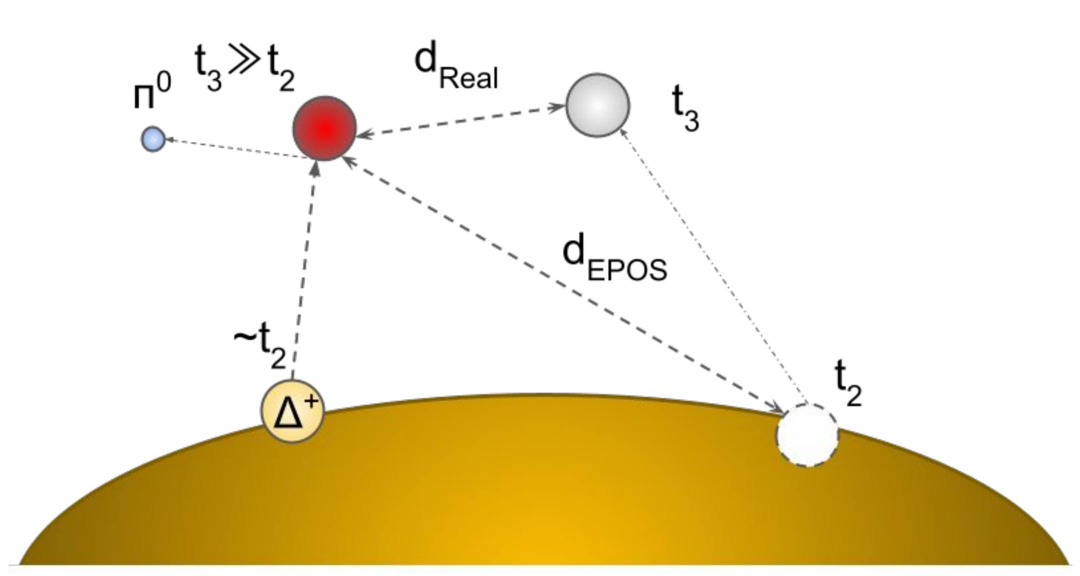


[1] EPJA 56 (2020) 1, 4
[2] PLB 811 (2020) 135849

The emission source

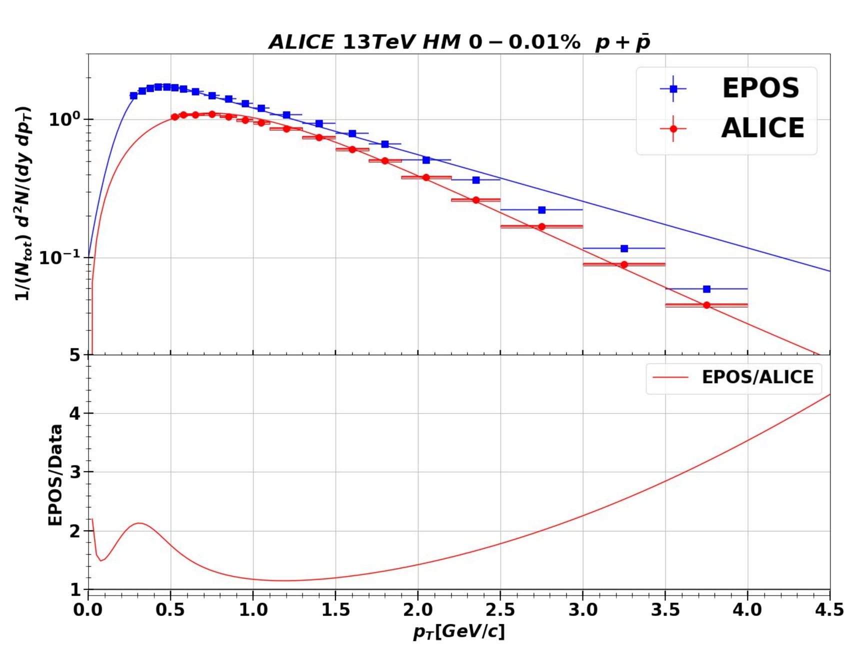
- The size of the particle emission source is an important input for the coalescence model
- There are two options to obtain the source:
  - Use the measured source size
  - Use semi-classical traces in event generators (propagated to equal time)

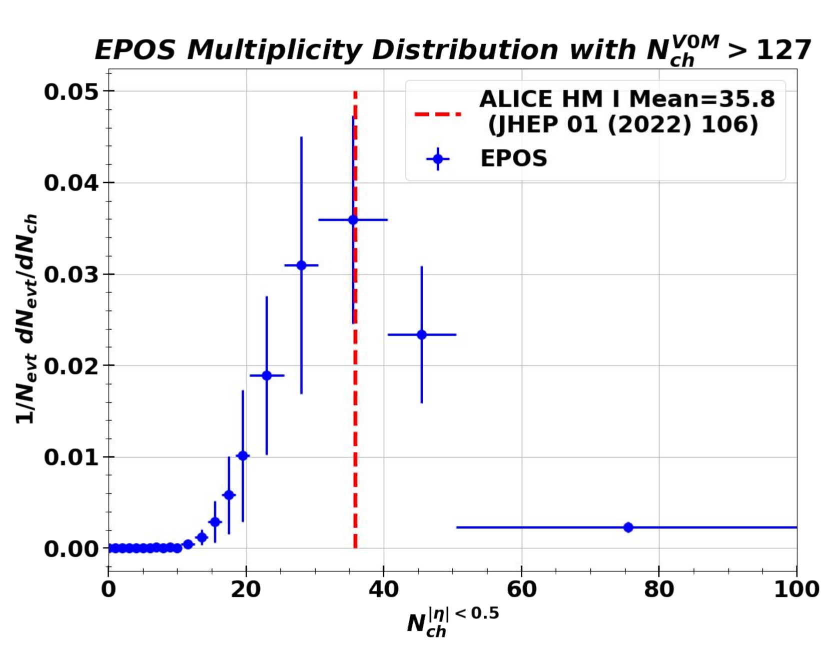




Correcting the event generator

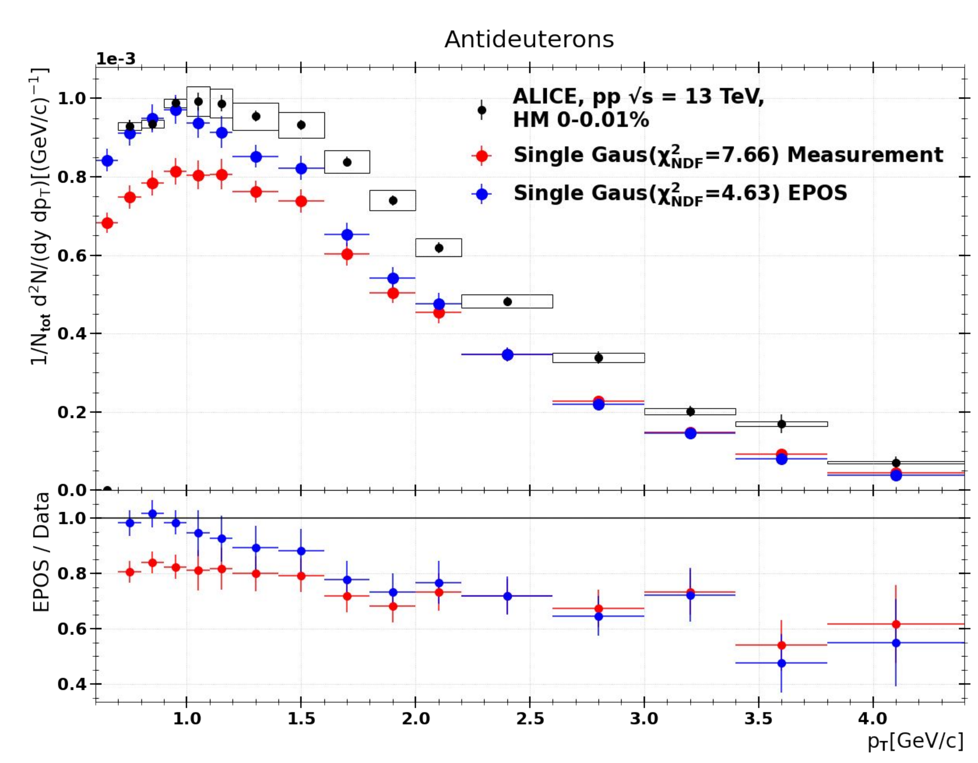
- Event generators are known to not perfectly describe nature
  ⇨ Correct them using measurements
- Important parameters: source size, momentum distribution, multiplicity
- Source size was only measured in pp collisions at 13 TeV with a HM trigger (0-0.01%) by ALICE
- Momentum: Use p_T spectra from [3] to reweight each nucleon
- Multiplicity: implement a HM trigger into the event generator which mimics the trigger used by ALICE
- Trigger for forward multiplicity for which average midrapidity mult. is reproduced





(Anti)deuteron spectra

- Predictions using ALICE source measurement are ~20% lower than the measured antideuteron spectra [3] but reproduce the shape of the spectrum
- Predictions using the EPOS model describe the yields at low p_T but don't reproduce the shape of the spectrum
- Coalescence model is sensitive to the source model
  ⇨ Develop improved source models in the future



[3] JHEP 01 (2022) 106