ALMA MATER STUDIORUM – UNIVERSITÀ DI BOLOGNA

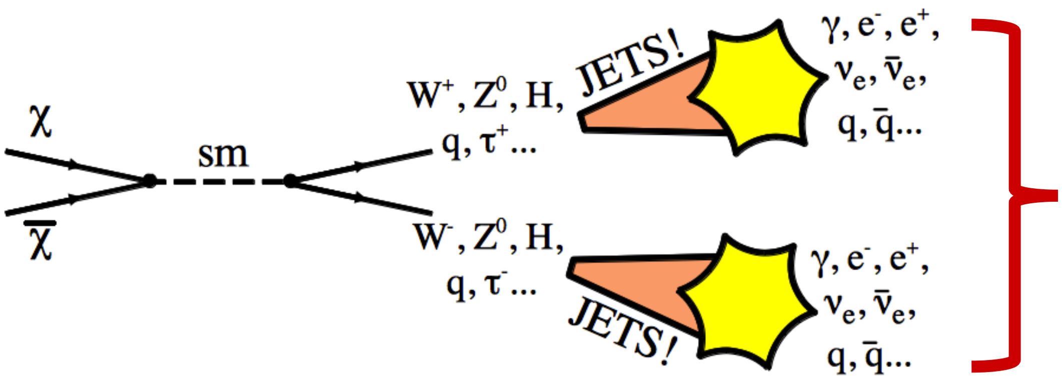
Scuola di Scienze
Dipartimento di Fisica e Astronomia

Coalescence parameter study and source characterization in the production of (anti)nuclei in high-energy collisions

CosmicAntiNuclei ERC project - Dott. Lorenzo Valla

WIMPs and cosmic (anti)nuclei

WIMPs: Dark matter candidates ($m_\chi \approx 1\ \mathrm{GeV} \div 1\ \mathrm{TeV}$)



SM particles, detectable in the cosmic rays

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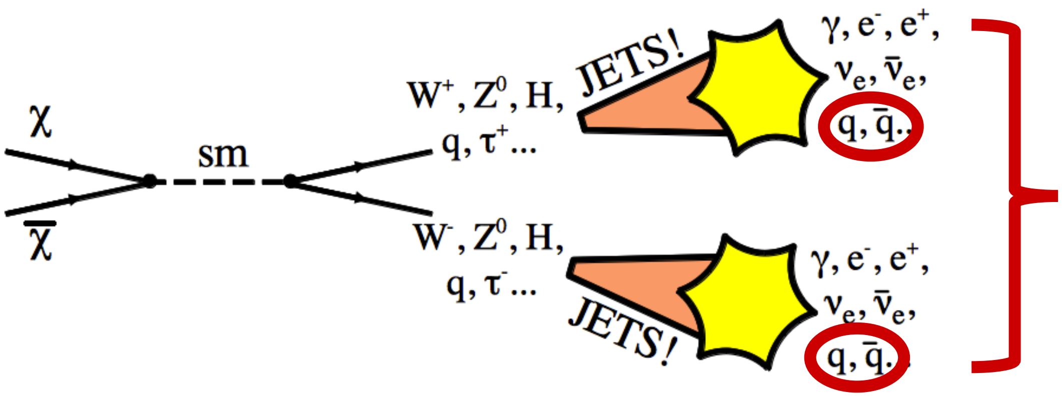

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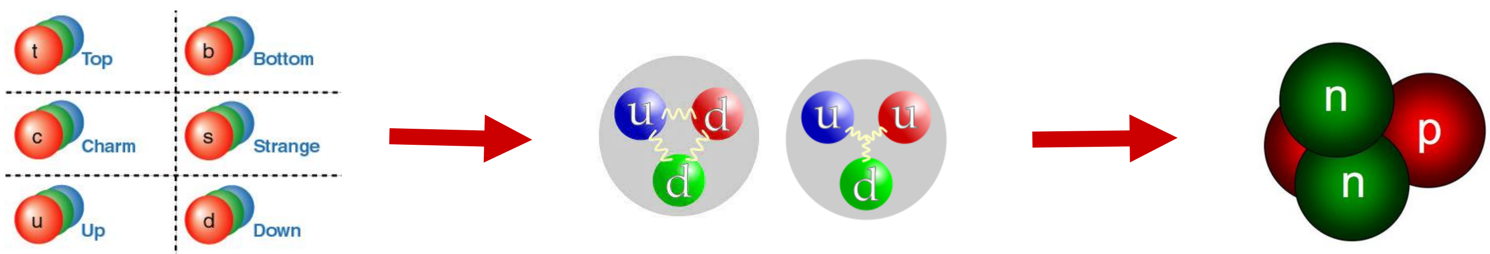


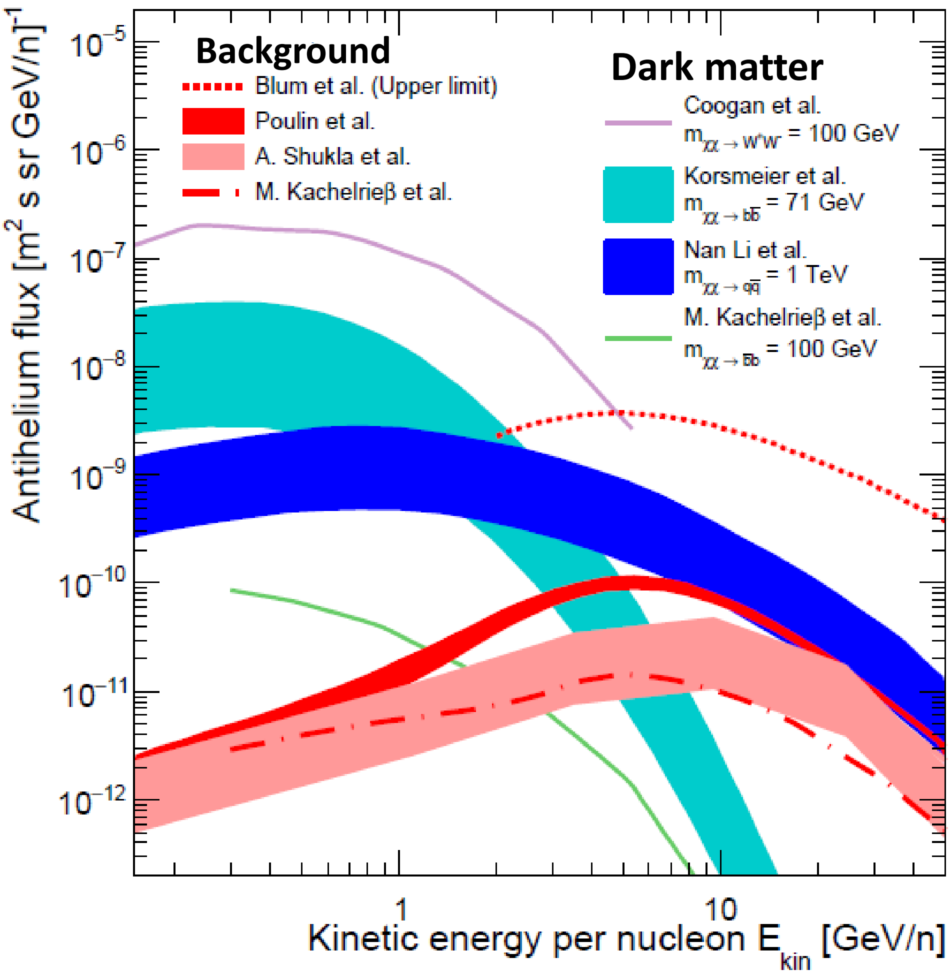
(Anti)quark (Anti)nucleons (Anti)nuclei

Antinuclei have **low astrophysics «background»** from collisions between cosmic rays and the ISM

→ **smoking guns**

Cosmic antinuclei flux

P. von Doetinchem et al., JCAP 08 (2020), 035



Predictions
(production + propagation)

VS

Experimental measurements
(esperimenti PAMELA, BESS, AMS-02…)

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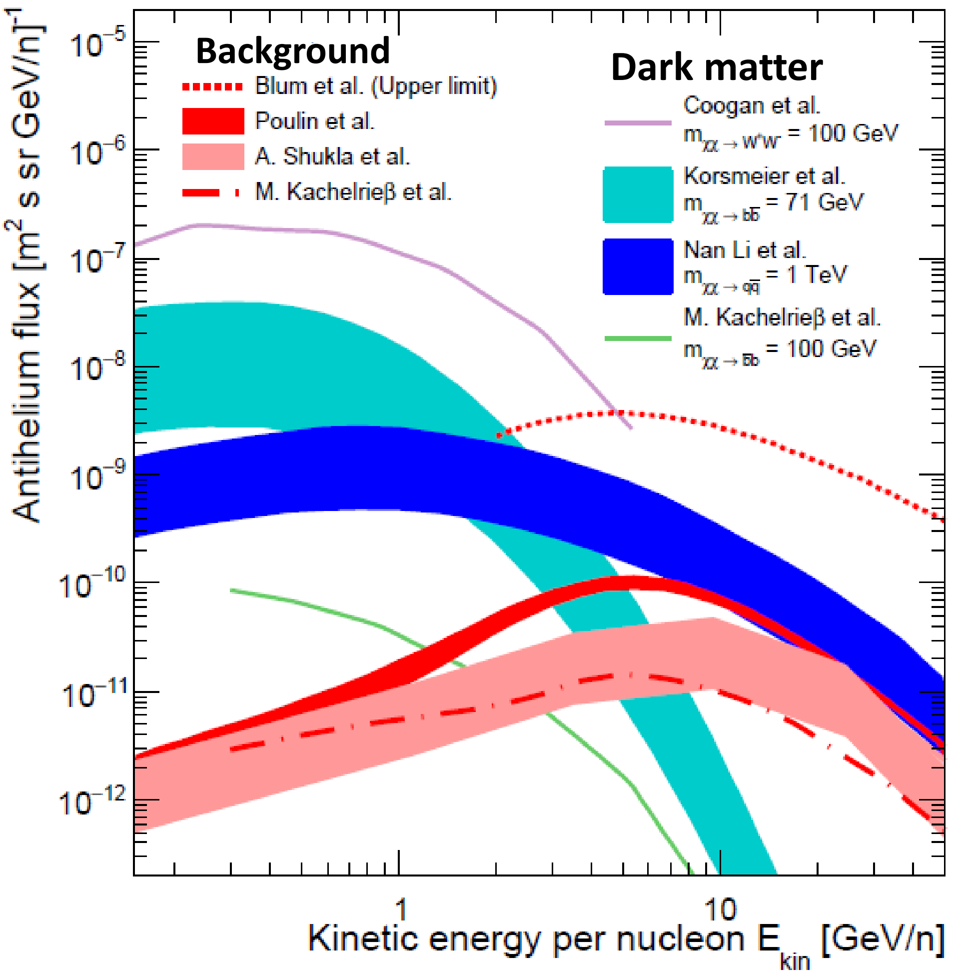


Predictions
(production + propagation)

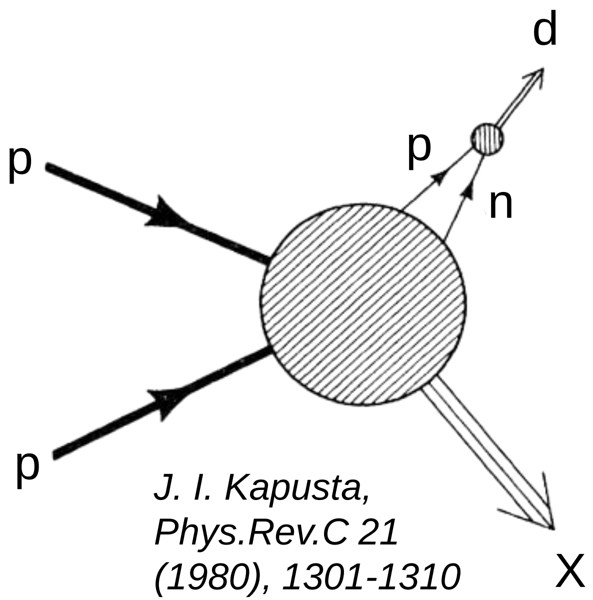
VS

Experimental measurements
(esperimenti PAMELA, BESS, AMS-02…)

➡ Study of the formation model through LHC pp collisions data, where $\bar{\mathbf{A}}/\mathbf{A} \approx \mathbf{1}$

Coalescence model

Coalescence parameter B_A



J. I. Kapusta, Phys.Rev.C 21 (1980), 1301-1310

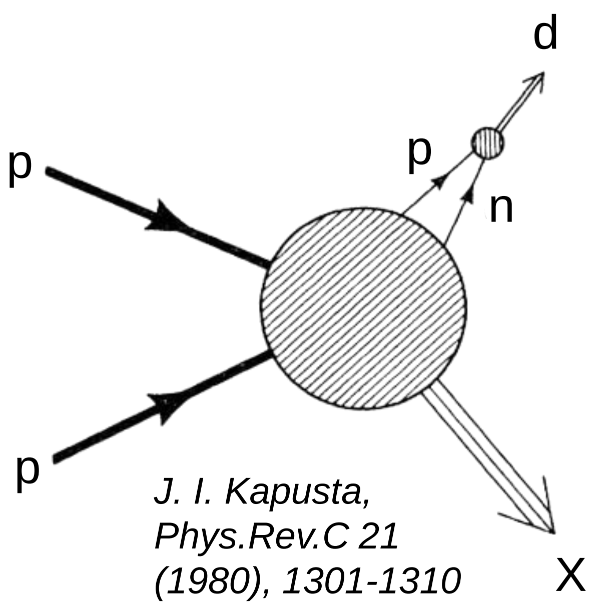
Operational definition:

$$E_A \frac{d^3 N}{dp_A^3} = B_A \left(E_{p,n} \frac{d^3 N_{p,n}}{dp_{p,n}^3} \right)^A_{\vec{p}_p = \vec{p}_n = \frac{\vec{p}_A}{A}}$$

Obtained by Bellini, Kalweit *(Phys.Rev.C 99 (2019) 5, 054905)*:

$$B_A = \frac{2J_A + 1}{2^A} \frac{1}{\sqrt{A}} \frac{1}{\boldsymbol{m_T^{A-1}}} \left[\frac{2\pi}{\boldsymbol{R}^2 + \left(\frac{\boldsymbol{r_A}}{2}\right)^2} \right]^{\frac{3}{2}(A-1)}, \quad m_T = \sqrt{p_T^2 + m_0^2}$$

Coalescence model



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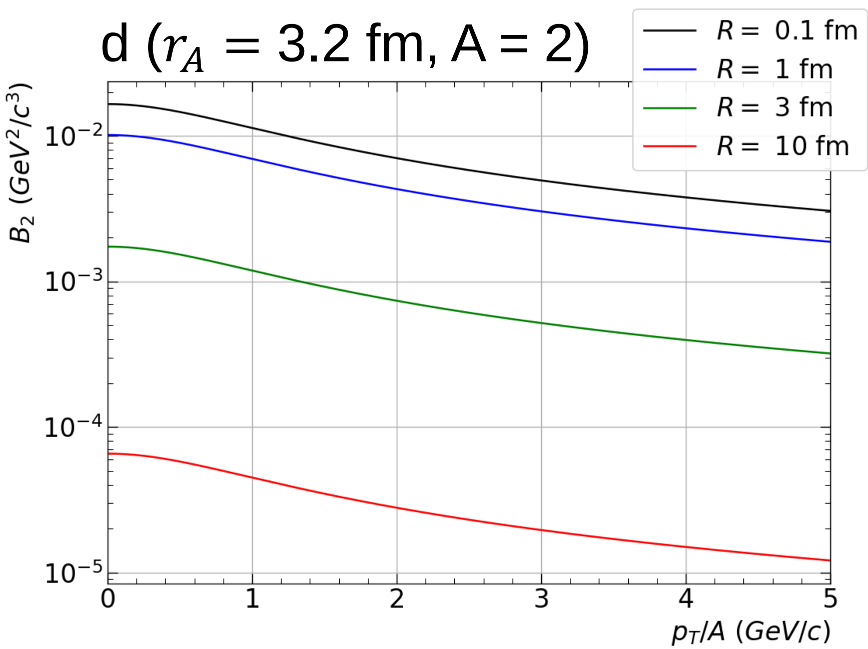
What is the dependence $R(p_T)$?

Coalescence parameter

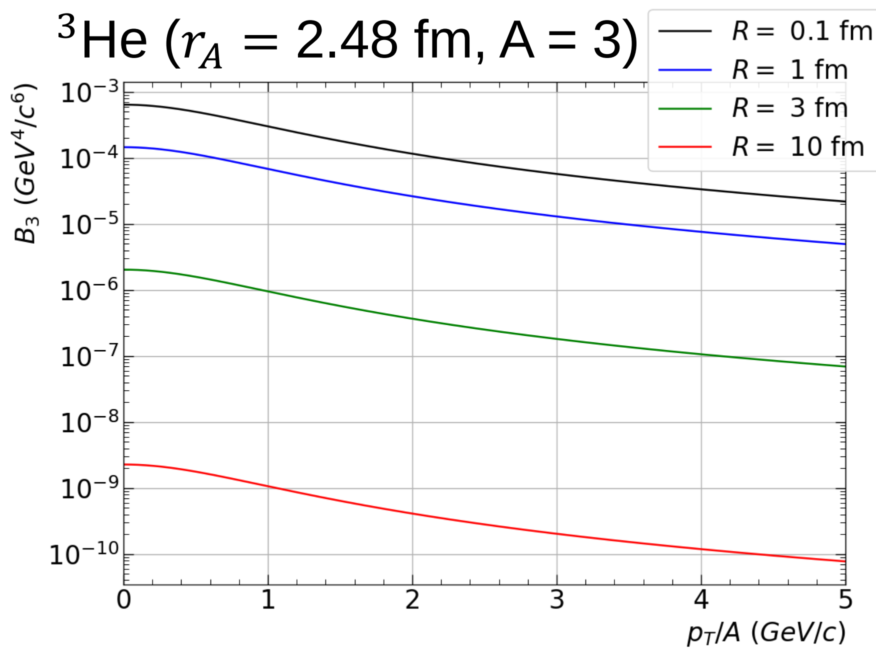
Study of the dependence of $\boldsymbol{B_A}$ on $\boldsymbol{p_T}$, with constant R

$$B_A = \frac{2J_A + 1}{2^A} \frac{1}{\sqrt{A}} \frac{1}{m_T^{A-1}} \left[\frac{2\pi}{R^2 + \left(\frac{r_A}{2}\right)^2} \right]^{\frac{3}{2}(A-1)}$$

d (r_A = 3.2 fm, A = 2)



^{3}He (r_A = 2.48 fm, A = 3)



→ $\boldsymbol{B_A}$ **decreases** as either $\boldsymbol{R}$ or $\boldsymbol{p_T}$ increase

Coalescence parameter

Study of the dependence of $\boldsymbol{B_A}$ on $\boldsymbol{R}$ (independent from p_T), at p_T fixed

$$B_A = \frac{2J_A+1}{2^A}\frac{1}{\sqrt{A}}\frac{1}{m_T^{A-1}}\left[\frac{2\pi}{\boldsymbol{R^2}+\left(\frac{r_A}{2}\right)^2}\right]^{\frac{3}{2}(A-1)}$$

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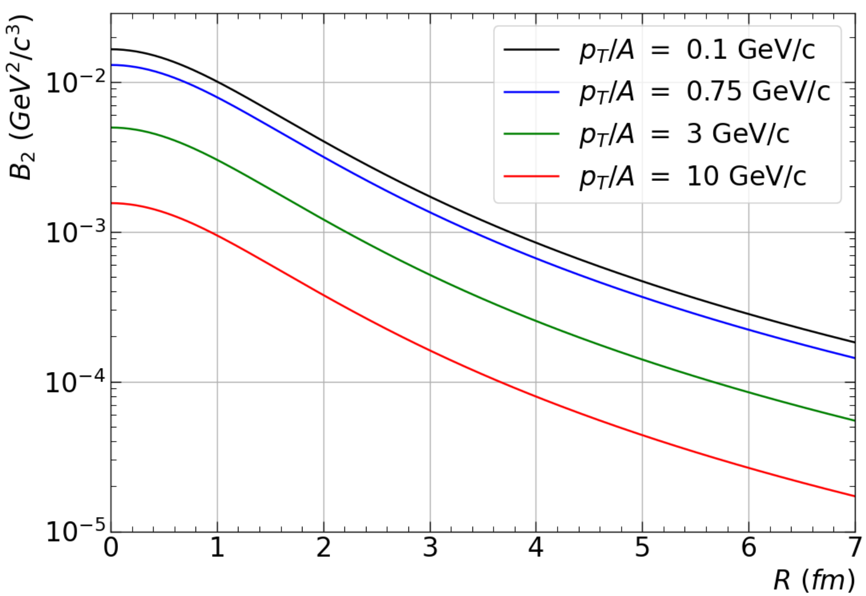

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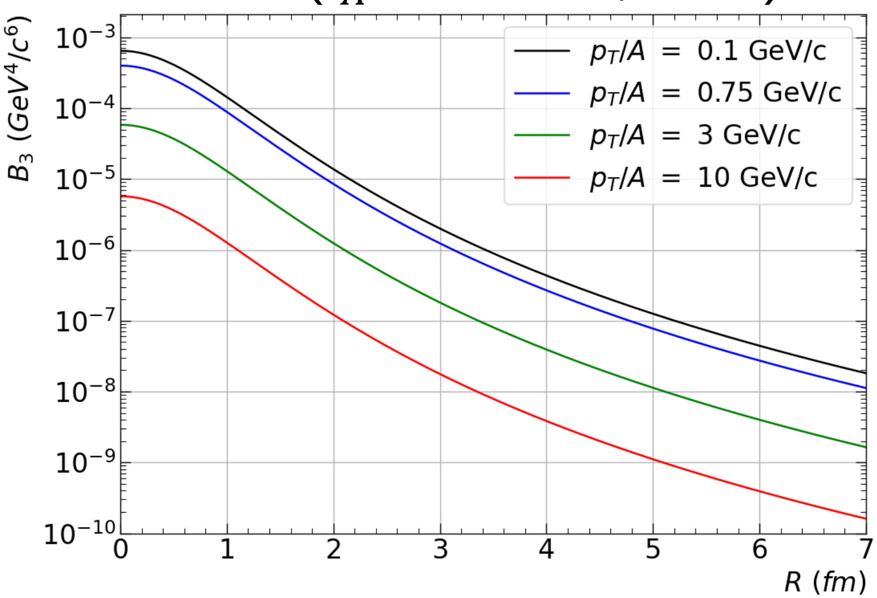
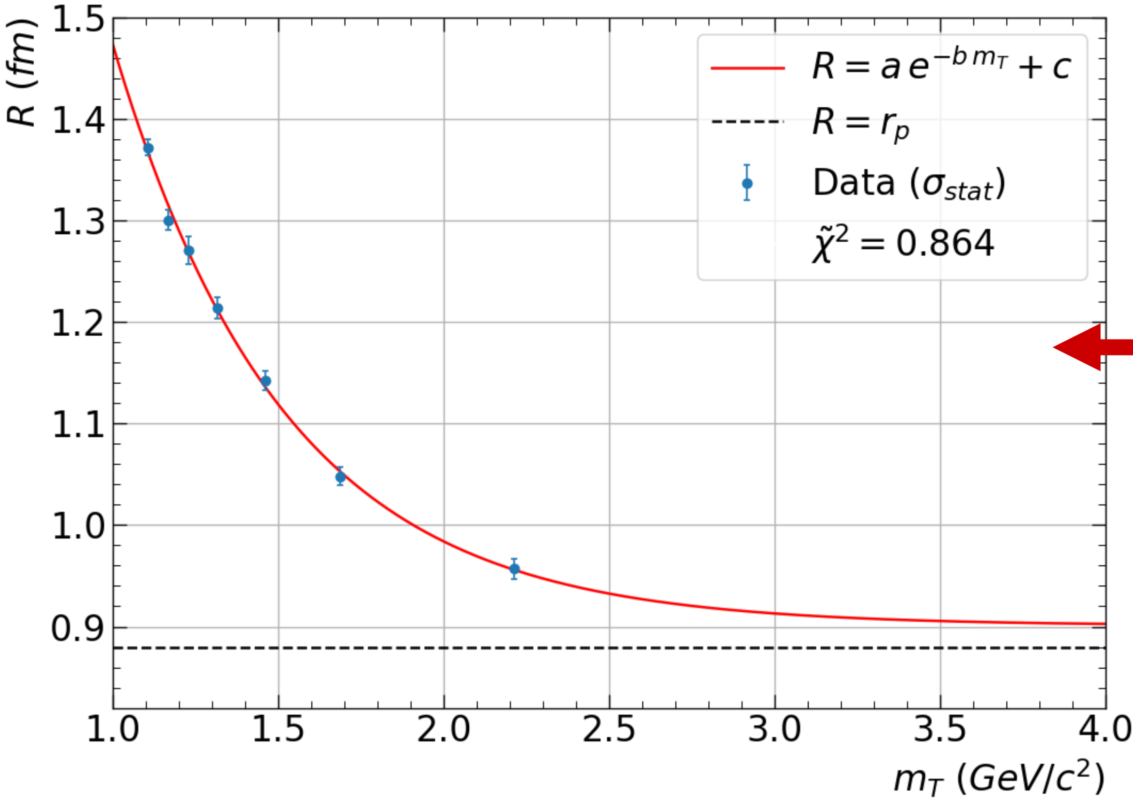


$\boldsymbol{B_A}$ **decreases** as either $\boldsymbol{R}$ or $\boldsymbol{p_T}$ increase

Dependence of *R* on p_T

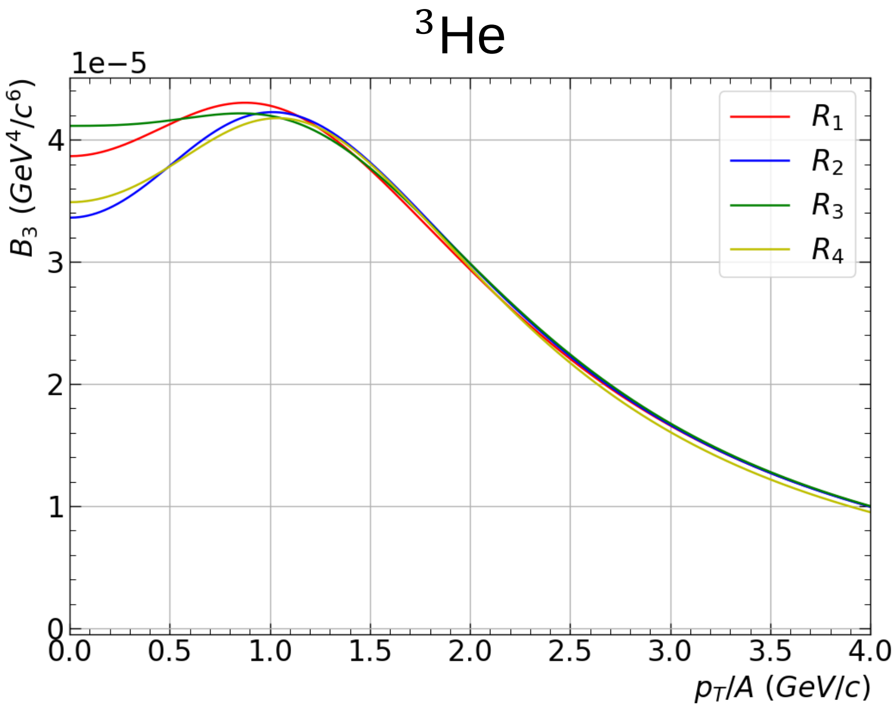
Fit to ALICE pp collisions high multiplicity data, at $\sqrt{s} = 13$ TeV *(Phys.Lett.B 811 (2020), 135849)*



$R_i(m_T)$
$R_1 = a\,e^{-b\,m_T} + r_p$
$R_2 = a\,e^{-b\,m_T} + c$
$R_3 = a\,m_T\,e^{-b\,m_T} + r_p$
$R_4 = a\,m_T\,e^{-b\,m_T} + c$

Dependence of *R* on p_T

It is possible to express $B_A(p_T)$ through the fit functions and to estimate the uncertainty due to the choice of the function.



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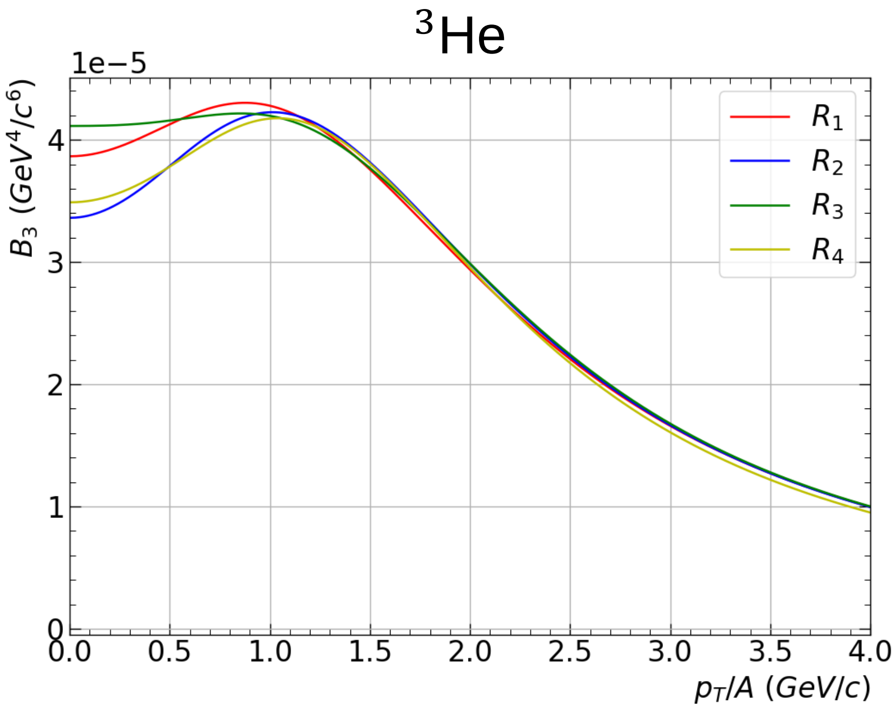
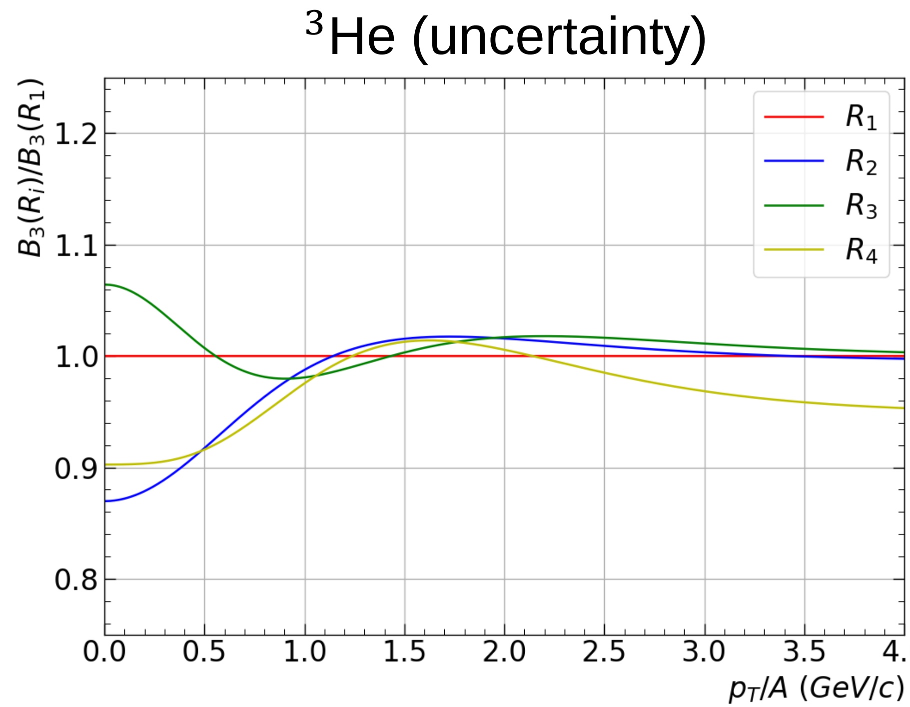
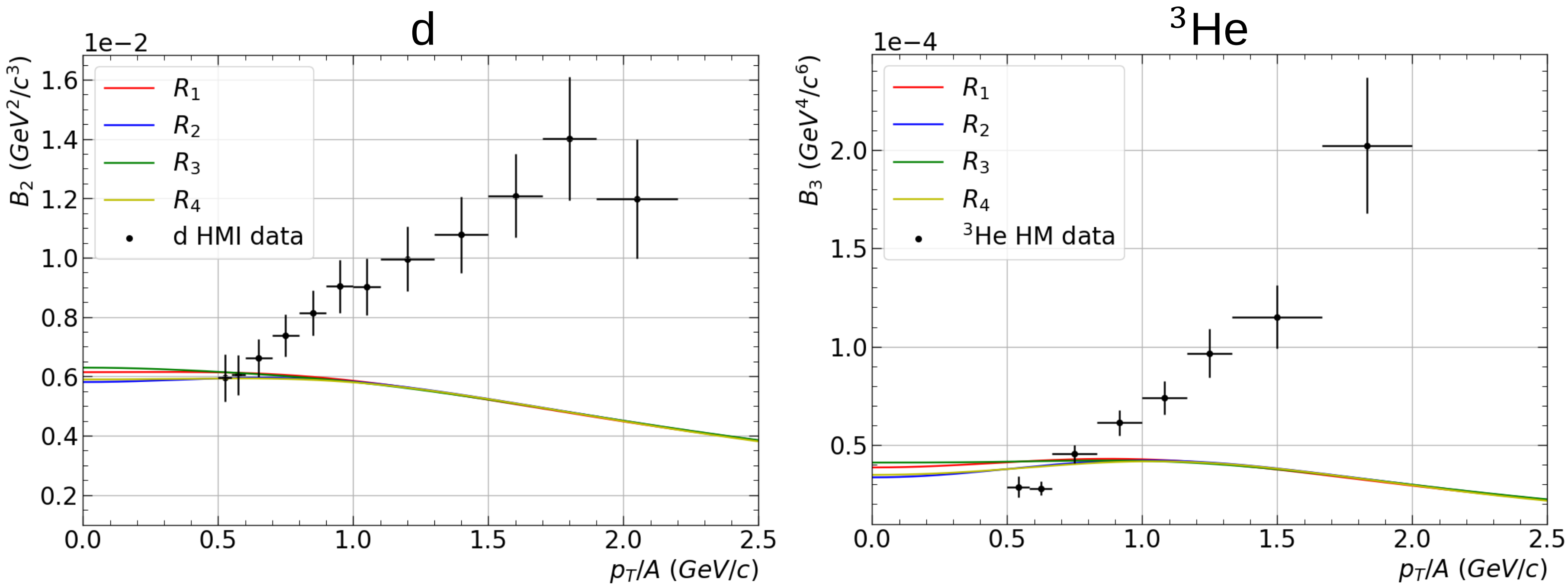




- B_A **decreases** as p_T increases
- At low momenta, due to the scarcity of data, uncertainties up to **+6%** and **-13%** for ^{3}He (increasing with A).

Results

Comparison with ALICE data from **d** and **^{3}He** high multiplicity pp collisions, at $\sqrt{s} =$ 13 TeV*(ALICE Collaboration, JHEP 01 (2022), 106)*



The curve found **is not able to reproduce** the data, in which $\boldsymbol{B_A}$ **increases as** $\boldsymbol{p_T}$ **increases**.

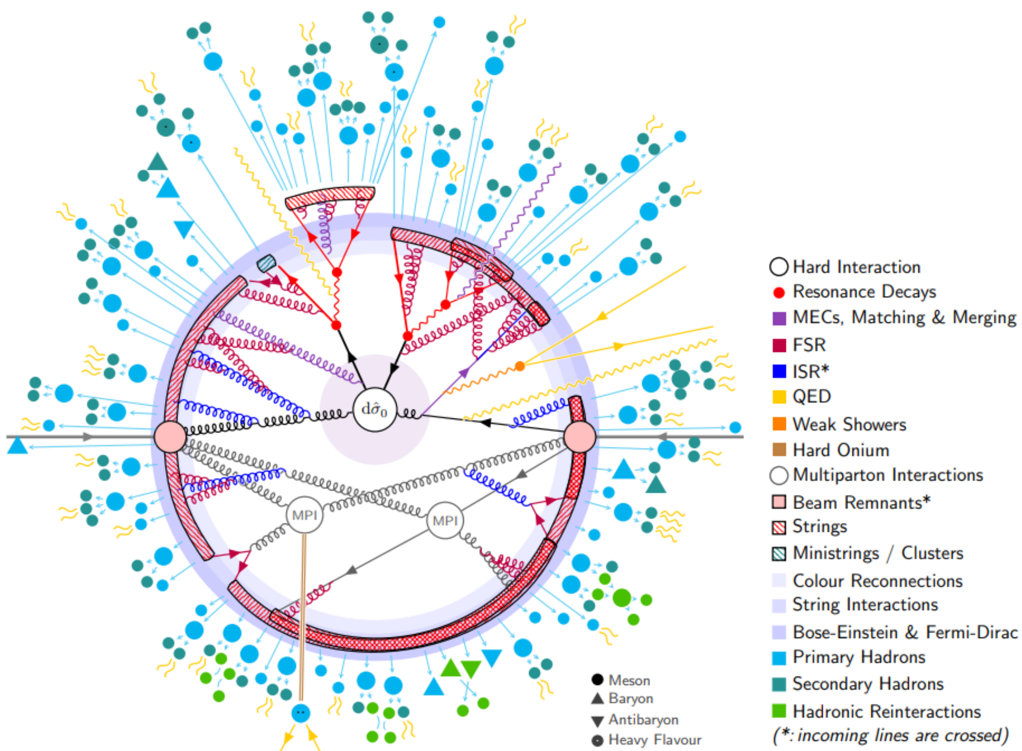
The possible explanation: The model used to obtain the B_A formula was derived for **Pb-Pb collisions**, and thus has to be adapted to **pp collisions**.

PYTHIA 8.3

A different approach: **event by event simulation** of nuclei formation via coalescence.

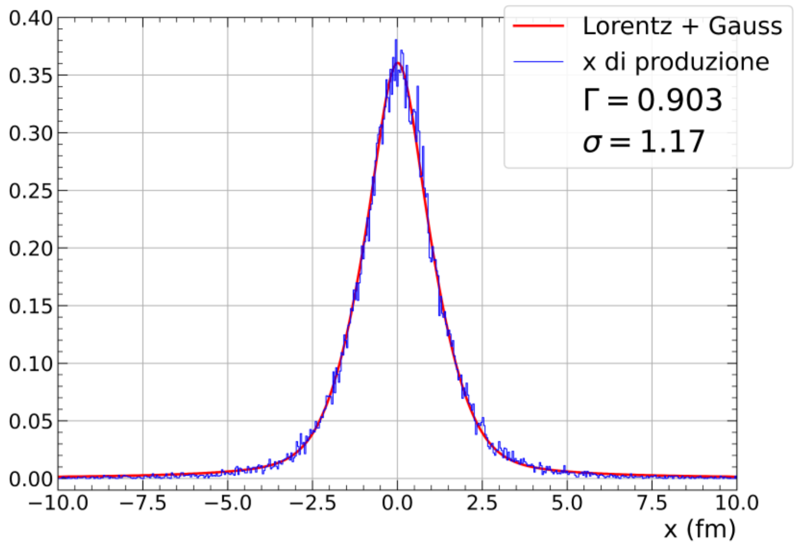
→ Characterization of the midrapidity ($|y| < 1$) proton source through the Monte Carlo generator **PYTHIA 8.3** with **Monash 2013** configuration.

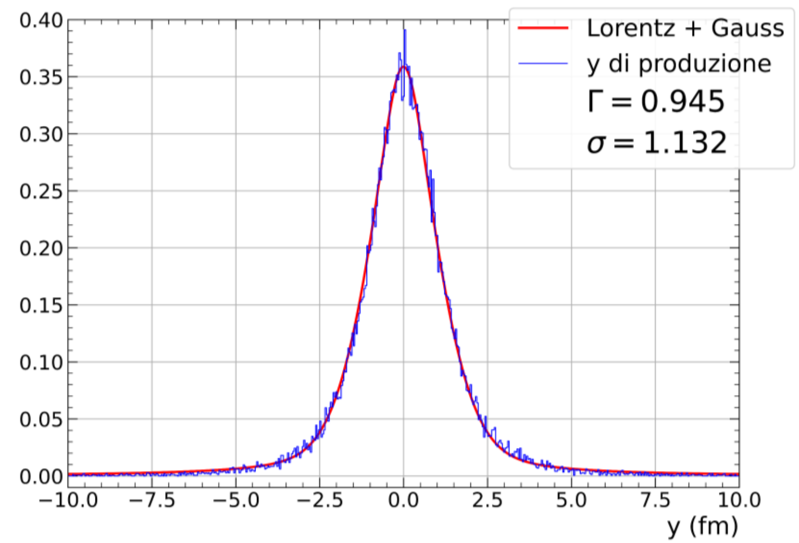
A general PYTHIA event scheme. Christian Bierlich et al., ArXiv:2203.11601

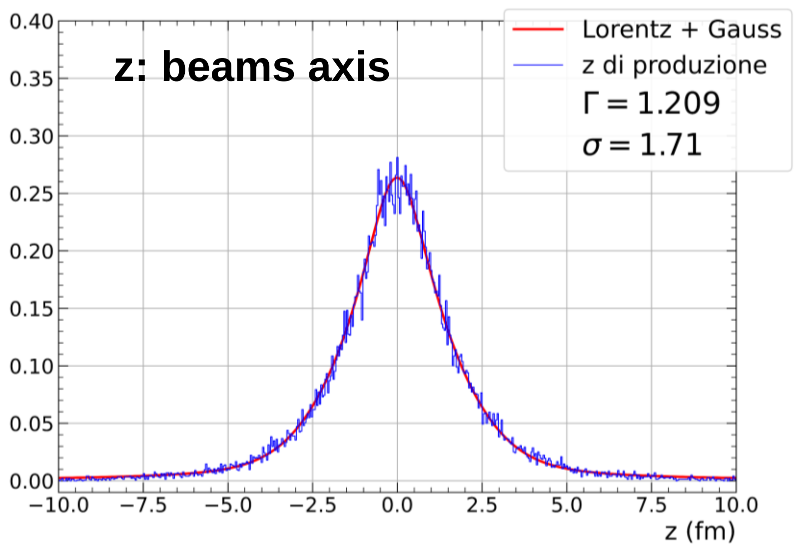


The source in PYTHIA

Production coordinates distributions (protons):







- **Gaussian + lorentzian**
- **Spheroidal** source
- $\boldsymbol{\sigma, \Gamma} \approx$ **1 fm**, in agreement with other data

Conclusions

Work

Inclusion of the $\boldsymbol{R(p_T)}$ dependence in the calculation for the coalescence parameter $\boldsymbol{B_A}$ via a fit to ALICE data, with applications in the study of cosmic **(anti)nuclei formation**.

Conclusions

The $B_A(p_T)$ dependence obtained **does not reproduce the experimental data**. The model at the origin of B_A must be revised and properly adapted to pp collisions.

Work

Study of the **proton source** as generated by PYTHIA 8.3 for future simulations of nuclei formation via coalescence in pp events.

Conclusions

PYTHIA generates a **spheroidal source**, which is isotropic in the *xy* plane. The characteristic dimension is of the order of **1 fm**, comparable with the experimental data.

THANK YOU FOR YOUR ATTENTION