Backward nucleon production by heavy baryonic resonances in proton-nucleus collisions

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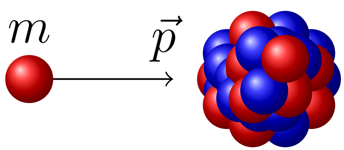
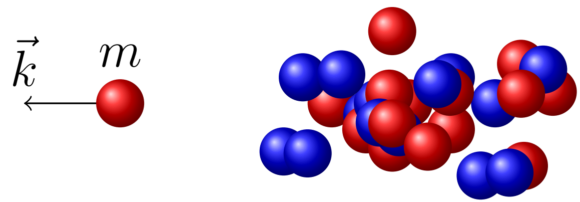
Cumulative effect

- It is a creation of particle in p+A collision with energy outside the kinematical boundary of p+p interactions.
- Discovered in 1971 in Dubna (Baldin, Leksin).



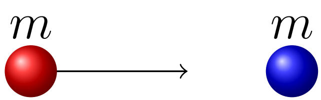
(a) Initial state.



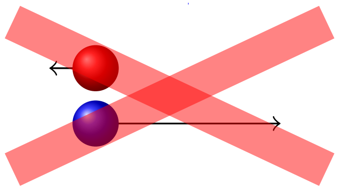
(b) Final state.

Cumulative nucleon = backward nucleon = $N(180^{\circ})$

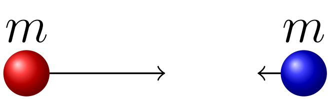
Ways of production or cumulative nucleons

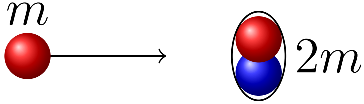


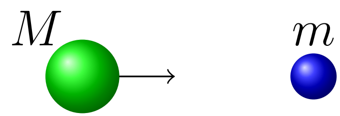
Initial state.



Final state.







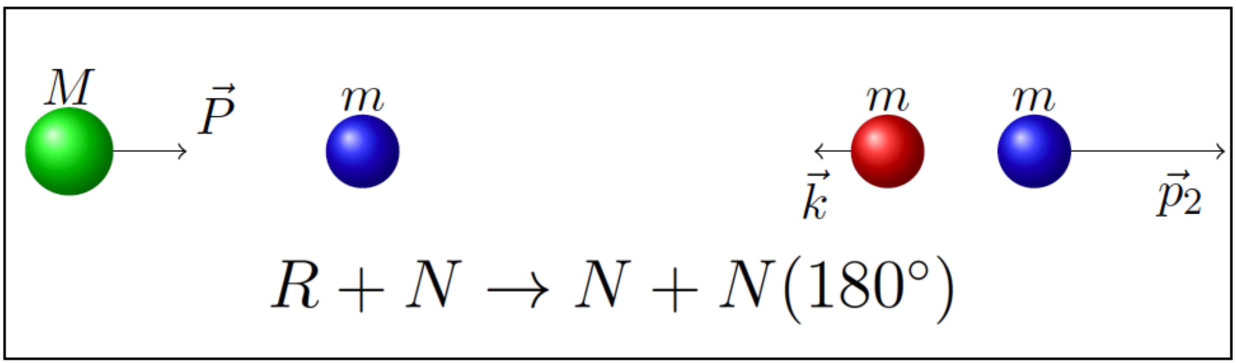
Frankfurt, Strikman, Phys. Lett. B, (1977).

Burov *et al.*, Phys. Lett. B, (1977).

Gorenstein, Zinovjev, Phys. Lett. B, (1977).

Cumulative nucleon production due to successive collisions with nuclear nucleons

(a) Initial state. (b) Intermediate state.



(c) Intermediate state. (d) Final state.

Maximal energy of cumulative nucleon and resonance mass in $R + N \to N + N(180^\circ)$

$$\sqrt{p^2+m^2}+n\,m=\sqrt{k_n^2+m^2}+\sum_{i=1}^{n}\sqrt{p_i^2+m^2}\ , \quad p=\sum_{i=1}^{n}p_i-k_n\ , \tag{1}$$

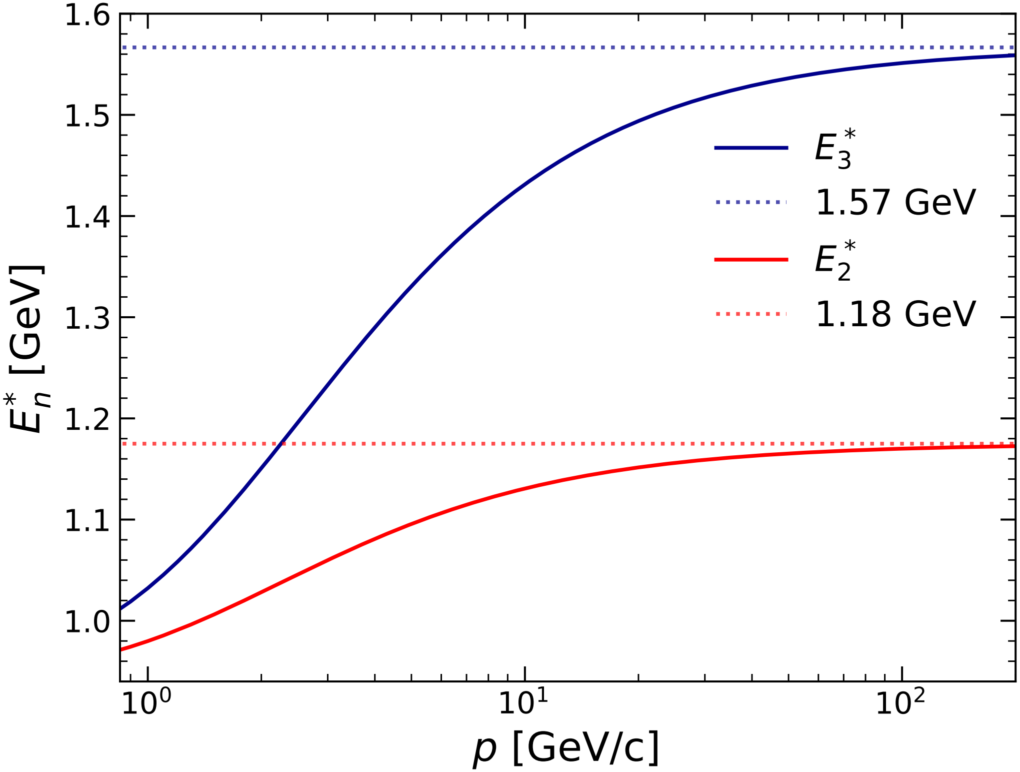
$$p_1=\ldots=p_n=\frac{p+k_n}{n}\ , \tag{2}$$

$$E_n^*=n\ m+\sqrt{p^2+m^2}-\sqrt{n^2\ m^2+(p+k_n^*)^2}\ , \tag{3}$$

$$M_n^2=\left[\sqrt{p^2+m^2}-(n-1)\left(\sqrt{\left(\frac{p+k_n^*}{n}\right)^2+m^2}-m\right)\right]^2-$$

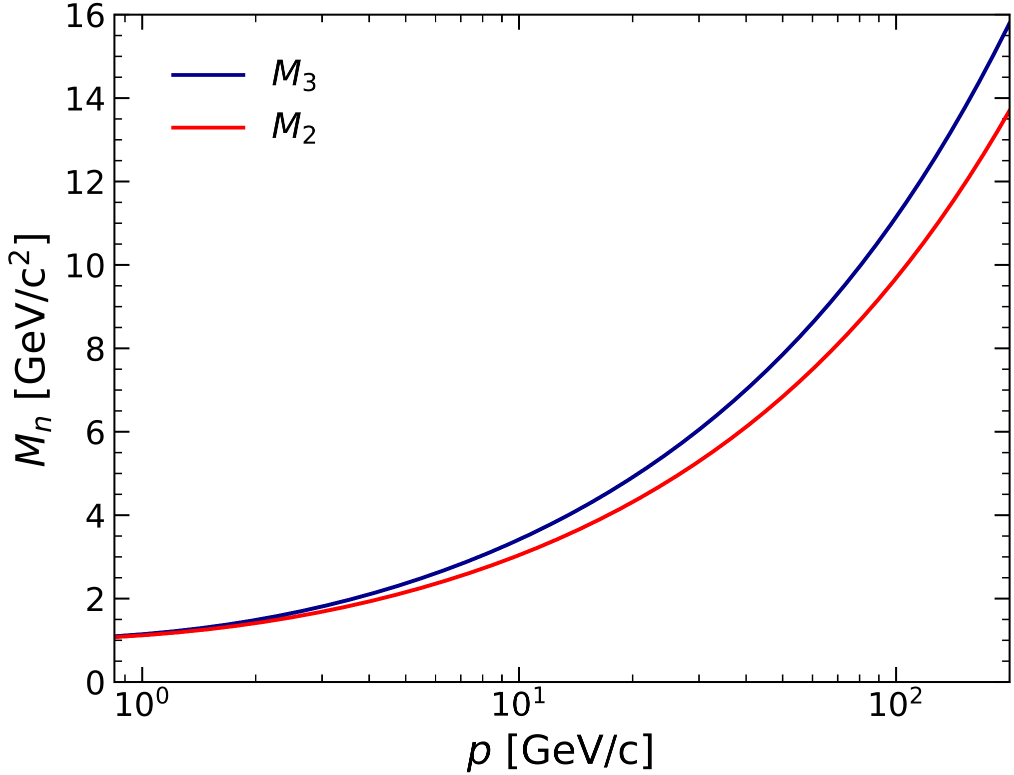
$$-\left[p-(n-1)\left(\frac{p+k_n^*}{n}\right)\right]^2\ , \tag{4}$$

Maximal energy of cumulative nucleon



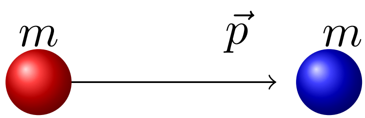
E_n^* in $R + N \to N + N(180^\circ)$ reaction.

Resonance mass

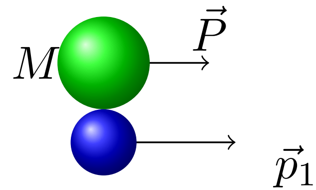


M_n in $R + N \to N + N(180^\circ)$ reaction.

Cumulative nucleon production due to successive collisions with nuclear nucleons and resonance decay

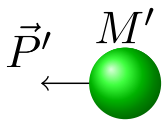


(a) Initial state.

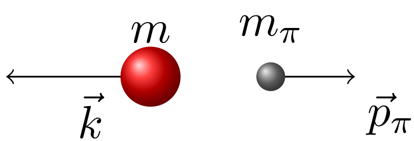


(b) Intermediate state.

$\cdots$



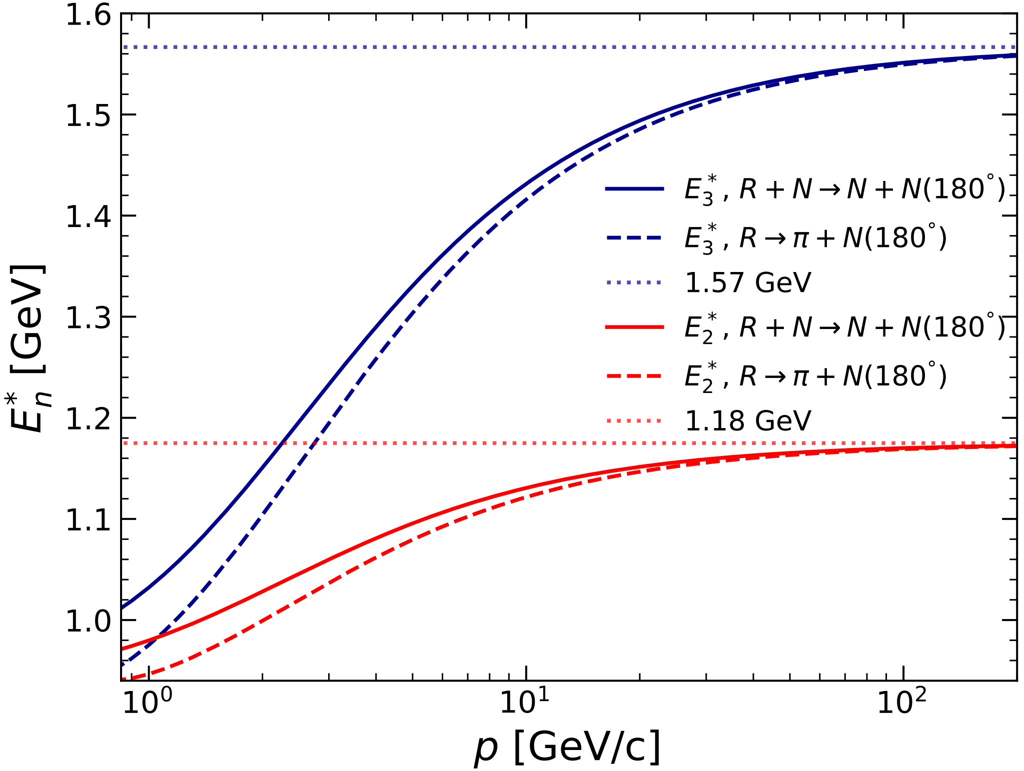
(c) Intermediate state.



(d) Final state.

$$R' \to N(180^\circ) + \pi$$

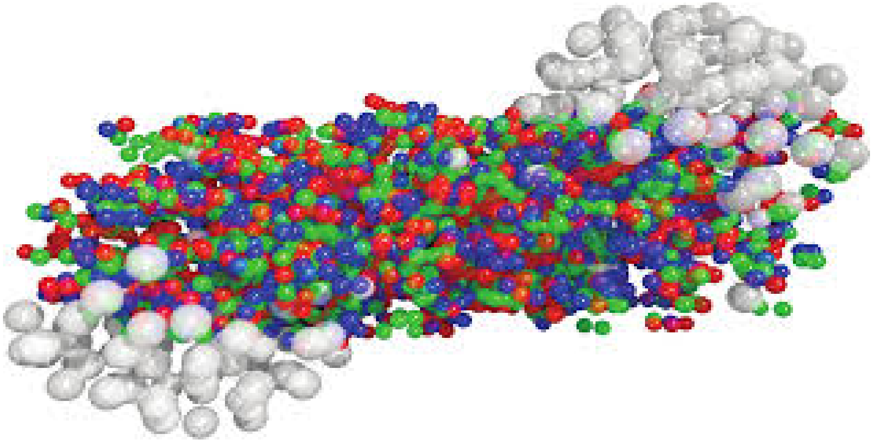
Maximal energy of cumulative nucleon



E_n^* in $R + N \to N + N(180°)$ and $R \to N(180°) + \pi$ reactions.

UrQMD

UrQMD is a microscopic transport model used to simulate (ultra)relativistic heavy ion collisons in the wide range of energies developed in Frankfurt.



S. A. Bass *et al.*, Prog. Part. Nucl. Phys. 41 (1998) 225-370,
M. Bleicher *et al.*, J. Phys. G: Nucl. Part. Phys. 25 (1999) 1859-1896.

UrQMD

- Represents a Monte Carlo method for the time evolution of the various phase space densities of particle species.
- Based on the covariant propagation of all hadrons on classical trajectories in combination with stochastic binary scatterings, resonance and string formation with their subsequent decay.
- Gives information about full history of every collision and sources of particles.
- The collision criterion:

$$d < d_0 = \sqrt{\frac{\sigma_{tot}(\sqrt{s}, \text{type})}{\pi}}.$$

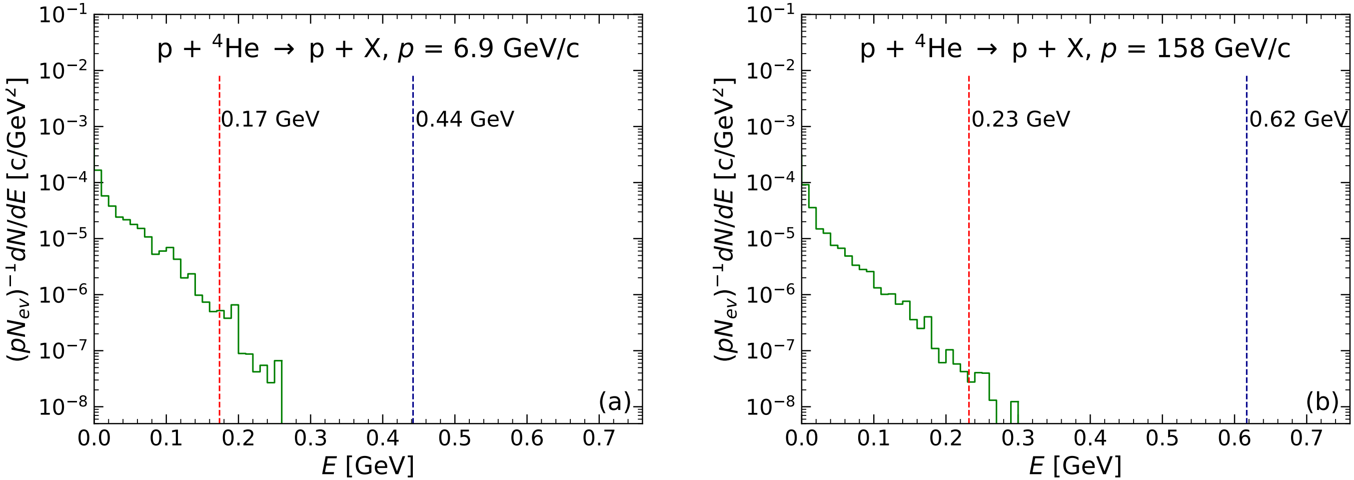
UrQMD. List of included particles

nucleon	Δ	Λ	Σ	Ξ	Ω
N_{938}	Δ_{1232}	Λ_{1116}	Σ_{1192}	Ξ_{1317}	Ω_{1672}
N_{1440}	Δ_{1600}	Λ_{1405}	Σ_{1385}	Ξ_{1530}	
N_{1520}	Δ_{1620}	Λ_{1520}	Σ_{1660}	Ξ_{1690}	
N_{1535}	Δ_{1700}	Λ_{1600}	Σ_{1670}	Ξ_{1820}	
N_{1650}	Δ_{1900}	Λ_{1670}	Σ_{1775}	Ξ_{1950}	
N_{1675}	Δ_{1905}	Λ_{1690}	Σ_{1790}	Ξ_{2025}	
N_{1680}	Δ_{1910}	Λ_{1800}	Σ_{1915}		
N_{1700}	Δ_{1920}	Λ_{1810}	Σ_{1940}		
N_{1710}	Δ_{1930}	Λ_{1820}	Σ_{2030}		
N_{1720}	Δ_{1950}	Λ_{1830}			
N_{1900}		Λ_{1890}			
N_{1990}		Λ_{2100}			
N_{2080}		Λ_{2110}			
N_{2190}					
N_{2200}					
N_{2250}					

0^{-+}	1^{--}	0^{++}	1^{++}
π	ρ	a_0	a_1
K	K^*	K_0^*	K_1^*
η	ω	f_0	f_1
η'	ϕ	f_0^*	f_1'
1^{+-}	2^{++}	$(1^{--})^*$	$(1^{--})^{**}$
b_1	a_2	ρ_{1450}	ρ_{1700}
K_1	K_2^*	K_{1410}^*	K_{1680}^*
h_1	f_2	ω_{1420}	ω_{1662}
h_1'	f_2'	ϕ_{1680}	ϕ_{1900}

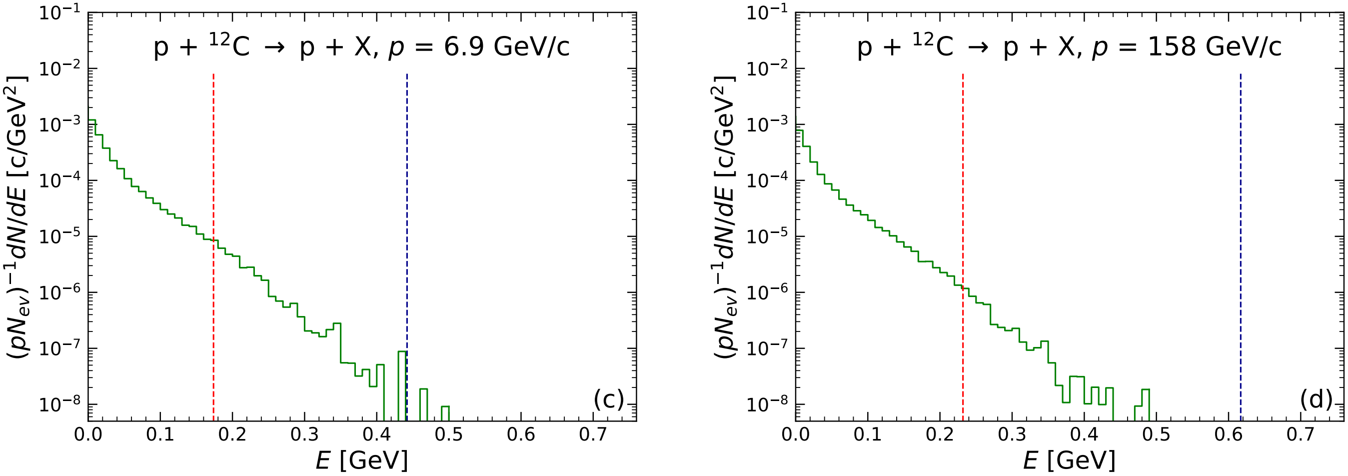
- All antiparticles and isospin-projected states are implemented.
- Cross sections are taken from PDG.
- Resonances are implemented in Breit–Wigner form.
- Strings are included (can't participate in reactions as real objects, they can only decay).

UrQMD simulations p+He collisions

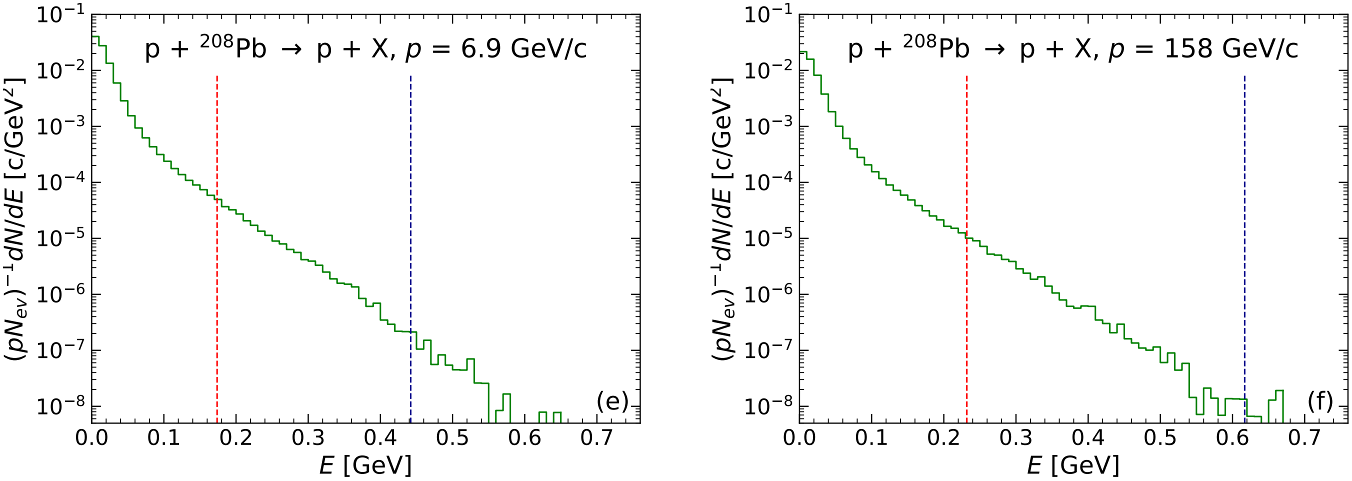


The backward proton spectra in p + He collisions at $p = 6.9$ GeV/c and 158 GeV/c.

UrQMD simulations p+C collisions

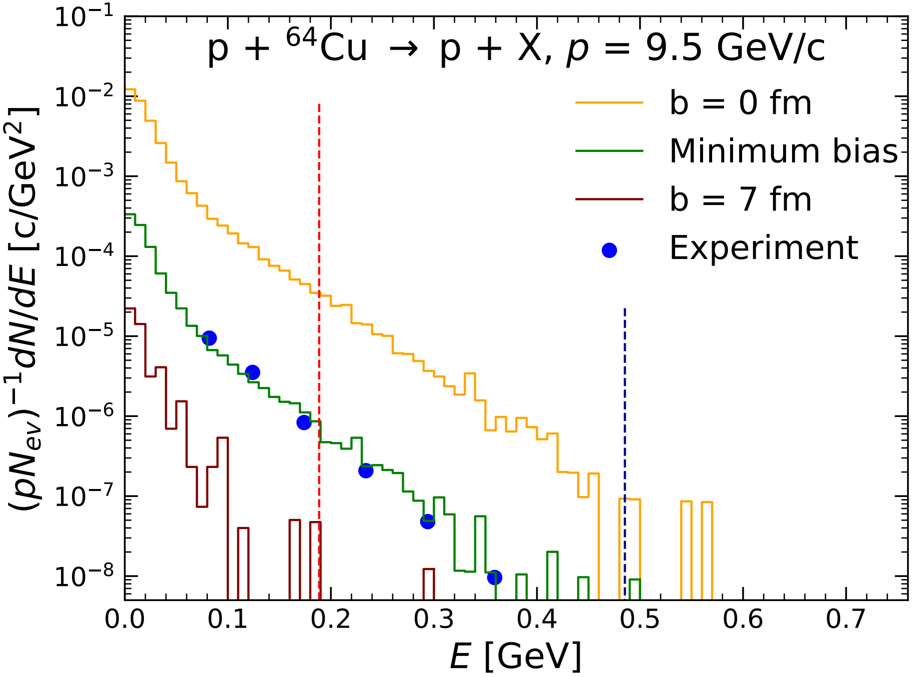


The backward proton spectra in p + C collisions at $p = 6.9$ GeV/c and 158 GeV/c.



The backward proton spectra in p + Pb collisions at $p = 6.9$ GeV/c and 158 GeV/c.

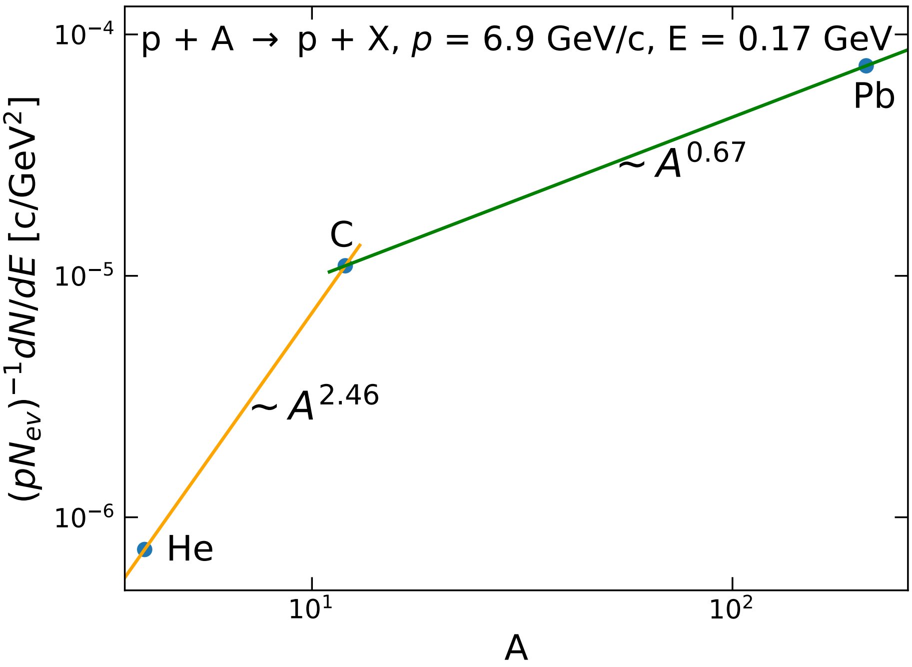
Comparison of UrQMD results with experimental data



Comparison of the UrQMD results for proton spectra at 180° with experimental data for p + Cu reactions at $p = 9.5$ GeV/c [1].

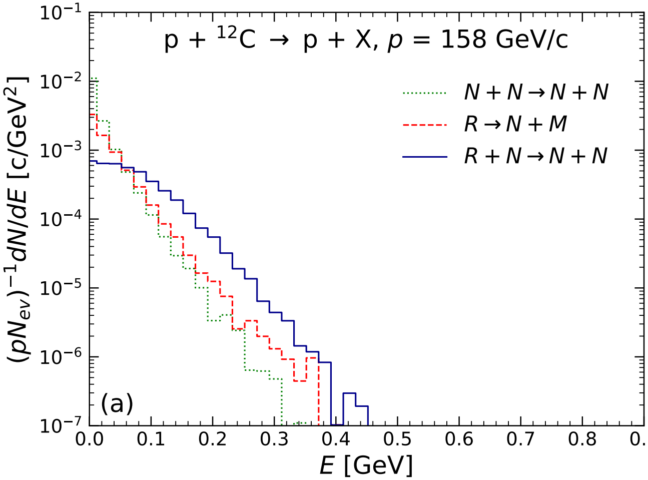
[1] S. Frankel, Phys. Rev. Lett.38, 1338 (1977).

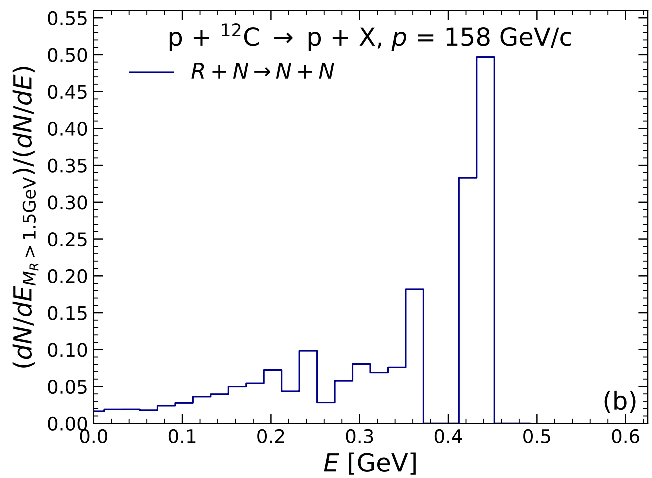
Spectra analysis



The backward proton spectra at $E = E_2^* = 0.17$ GeV in p + He, p + C and p + Pb collisions at $p = 6.9$ GeV$/c$.

Spectra analysis

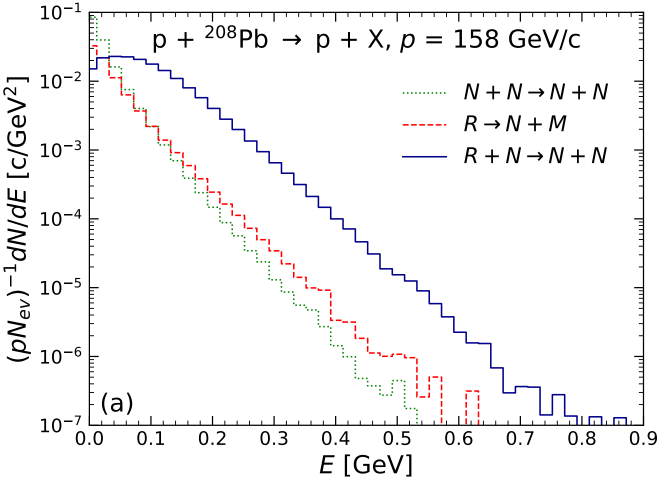


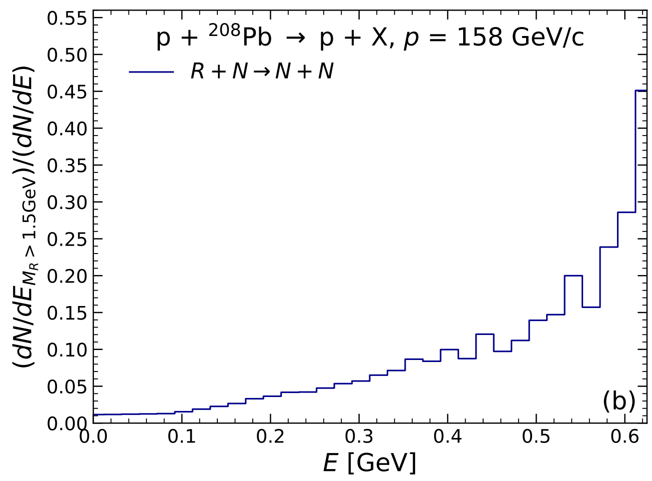


Sources of cumulative nucleons in p+C collisions at $E = 158$ GeV.

Fraction of cumulative nucleons from $R + N \to N + N(180°)$ with $m_R > 1.5$ GeV.

Spectra analysis





Sources of cumulative nucleons in p+Pb collisions at $E = 158$ GeV.

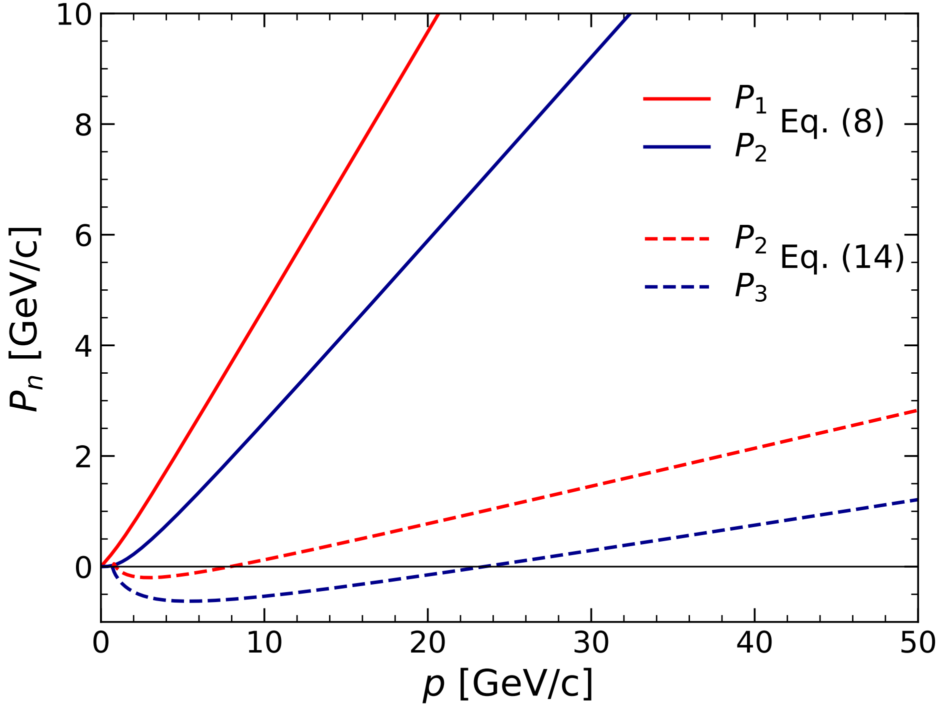
Fraction of cumulative nucleons from $R + N \to N + N(180°)$ with $m_R > 1.5$ GeV.

Summary

- Production of backward nucleons is possible only after 2 or more successive collisions.
- Creation of cumulative nucleon that moves backwards with maximal momentum requires existence of heavy resonances.
- Production of cumulative nucleon that moves backwards with maximal momentum is possible in $R + N \to N + N(180^\circ)$ reaction.
- Baryonic resonances with masses more than masses of well known baryonic resonances can exist and may be discovered soon.

  Experimental studies of cumulative effect is one of the best ways to find them.

Resonance momenta



P_n for $n = 2$ (upper solid red line) and $n = 3$ (lower solid blue line) in $R + N \to N + N(180°)$ reaction and for $n = 2$ (upper dashed red line) and $n = 3$ (lower dashed blue line) in $R \to N(180°) + \pi$ reaction.