

Forward neutrons from ^{12}C - ^{12}C and ^{40}Ca - ^{40}Ca collisions in the SPD experiment as a probe of nucleon-nucleon correlations.

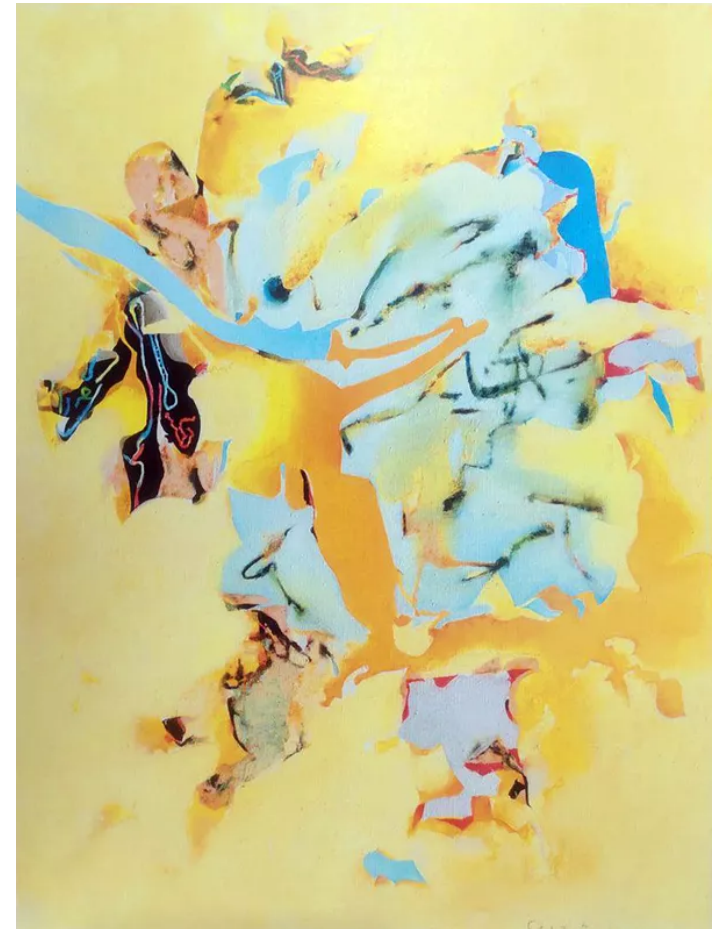
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P.Bevza, The temptation of the unconscious, 2020

Motivation

- Studies of collisions of non-polarized light nuclei, ^{12}C and ^{40}Ca , are also considered as a possible extension of the SPD research program¹⁾
- Zero-degree calorimeters (ZDC) to detect forward neutrons are considered for the first stage of the SPD experiment²⁾.
- The short range correlations between pair of neutrons can be related to the nuclear symmetry energy³⁾
- The production of spectator neutrons is affected by the initial cluster structure of ^{16}O ⁴⁾. Alpha-clustering is also predicted for ^{12}C ⁵⁾
- Can we probe the neutron correlations in ^{12}C and ^{40}Ca via forward neutrons detected by ZDCs?

1) V. V. Abramov et al. Phys. Part. Nucl. 52 (2021) 1044

2) "NICA Bulletin" №14

3) S.Gandolfi et al., Phys. Rev. C 85 (2012), 032801

4) S. A. et al. Physics 5 (2023), 381

5) Y.Kanada-En'yo. Progress of Theoretical Physics 121 (2009), 895

Outline

- Our model Abrasion-Ablation Monte Carlo for Colliders (AAMCC)
- The nucleon correlations in ^{12}C and ^{40}Ca nuclei
- Neutron production in relativistic ^{12}C – ^{12}C and ^{40}Ca – ^{40}Ca collisions, to be considered:
 - The cross-section of the production of a given number of neutrons
 - The dependence of the average neutron multiplicity on the event centrality

Abrasion-Ablation Monte Carlo for Colliders

- Nucleus-nucleus collisions are simulated by means of the Glauber Monte Carlo model ¹⁾. Non-participated nucleons form spectator matter (prefragment)
- Excitation energy of prefragment is calculated by parabolic ALADIN approximation ²⁾ tuned to describe the data for light nuclei.
- Decays of prefragments are simulated as follows:
 - pre-equilibrium decays modelled with MST-clustering algorithm ³⁾
 - Statistical Multifragmentation Model (SMM) from Geant4 v10.4 ⁴⁾
 - Fermi break-up model from Geant4 v9.2 ⁴⁾ $\varepsilon^* = \varepsilon_0 \sqrt{1 - c_0 \frac{A_{pf.}}{A}}$
 - Weisskopf-Ewing evaporation model from Geant4 v10.4 ⁴⁾

1) C. Loizides, J.Kamin, D.d'Enterria Phys. Rev. C **97** (2018) 054910

2) A. Botvina et al. NPA **584**

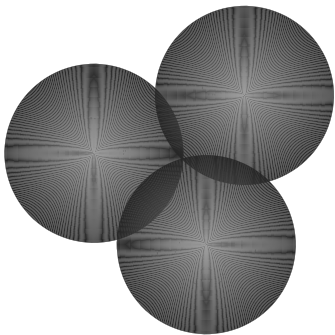
3) R. Nepeivoda, et al., Particles **5** (2022) 40

4) J. Alison et al. Nucl. Inst. A **835** (2016) 186



Nucleon correlations in ^{12}C and ^{40}Ca

- Correlations between nucleons is driven by the internuclear potential that involves two, three and higher number of nucleons¹⁾
- Binary nucleon-nucleon correlations and alpha-clustering can be used as a probe of nucleons interaction potential¹⁾
- A study suggests that the ^{12}C nucleus has three alpha-clusters arranged into a triangle²⁾
- In contrast, there is no evidence of the alpha-clustering in ^{40}Ca

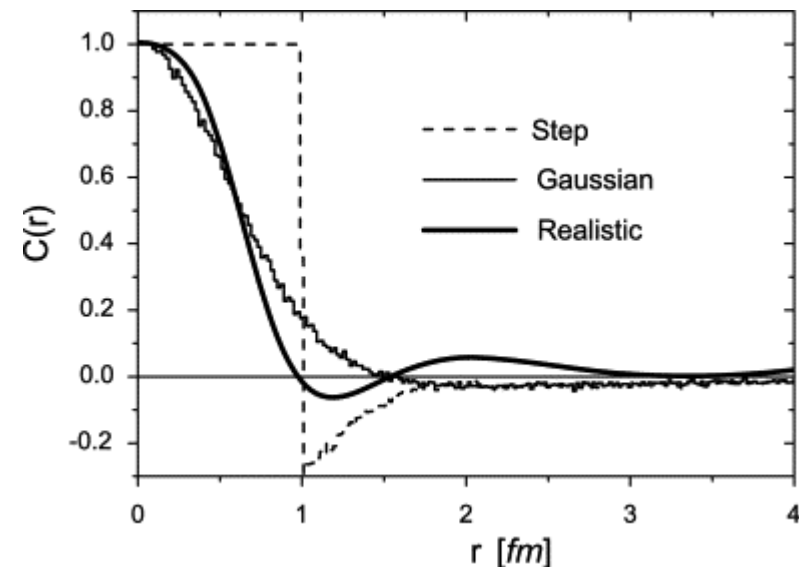


1) L.Frankfurt et al. Int. J. Mod. Phys. A 23, 2991 (2008)

2) T.Furuta et al, Phys. Rev. C 82, 034307 (2010)

Short range nucleon-nucleon correlations (SRC)

- Following the papers ^{1,2)}, SRC include the nucleon-nucleon repulsion caused, in particular, by Pauli principle.
- To account for SRC a method based on Monte Carlo Markov Chain²⁾ was implemented. Two nucleon-nucleon correlation functions can be used: Gaussian or step-like.
- The number of participants is slightly increased with accounting for SRC ¹⁾. The deuterium production is enhanced in Pb-Pb collisions ³⁾. One can expect a similar effect in C-C and Ca-Ca collisions.



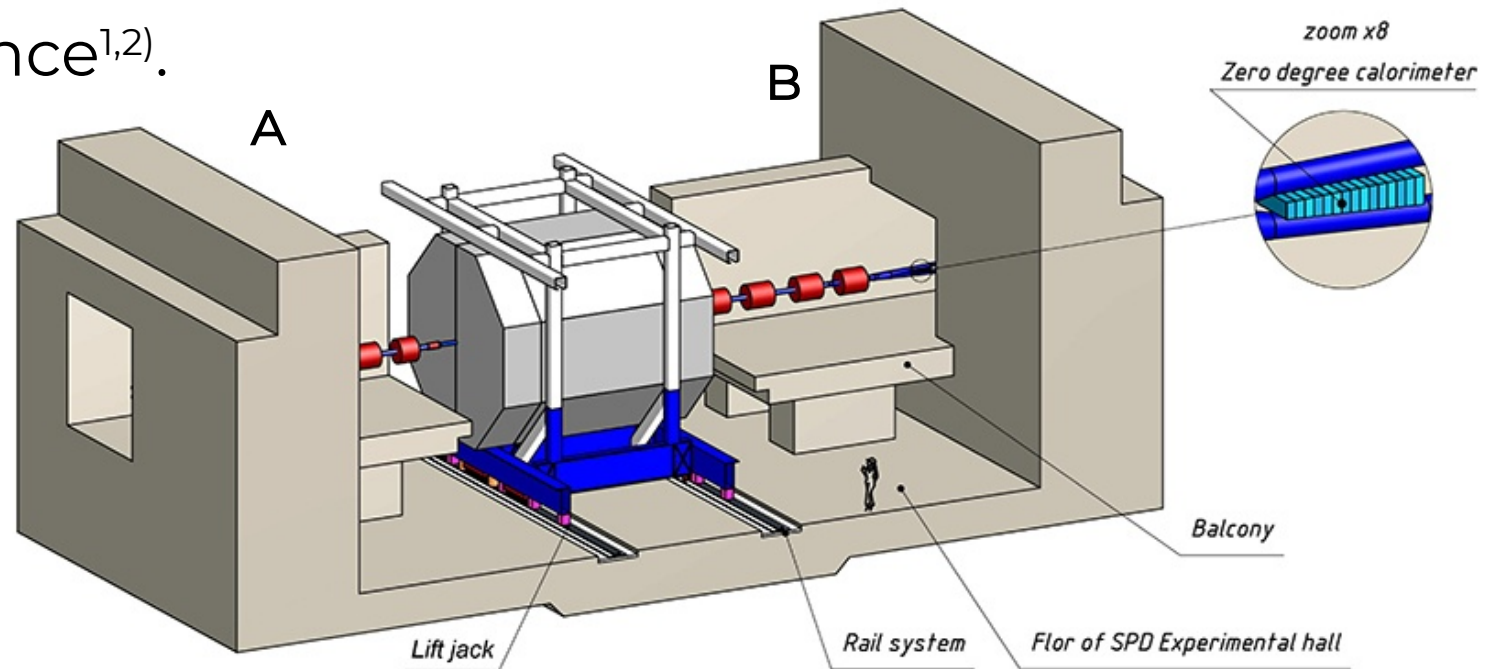
1) M.Alvioli et al, PRC 85 (2012) 034902

2) M. Alvioli et al, Phys. Lett. B 680 (2009) 225

3) N.Kozyrev et al., Eur. Phys J. A 58 (2022) 184

SRC at SPD

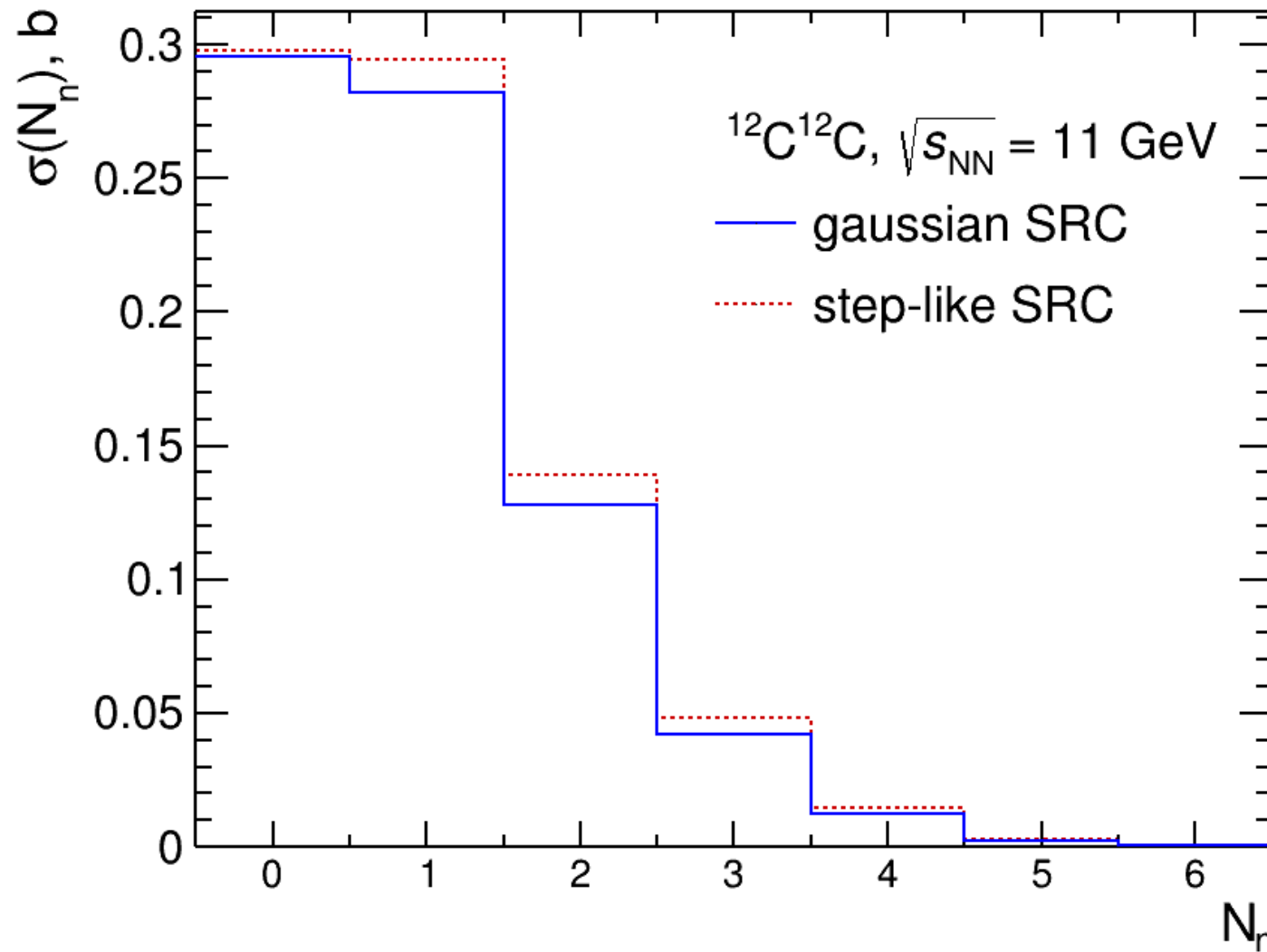
- A minimal configuration of the SPD includes a pair of neutron ZDC
- Along with it, other detector system can be used for the centrality determination
- There is a well-established technique to measure the multinucleon events with ZDC with the limited acceptance^{1,2)}.



1) U.Dmitrieva, I.Pshenichnov, NIM A, 906, 114 (2018)

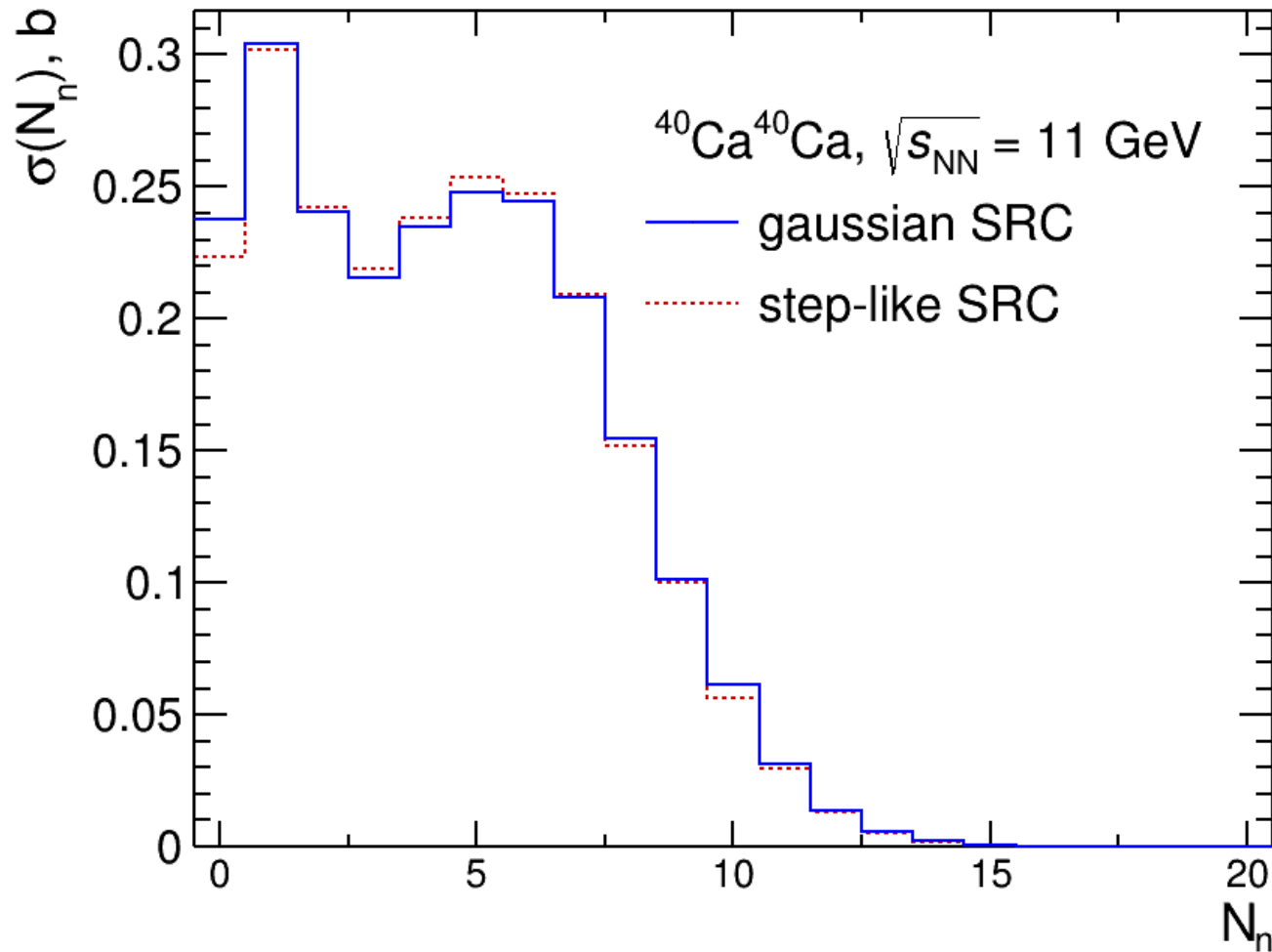
2) S.Acharaya et al., Phys. Rev. C, 111, 054906 (2025)

Cross section of the production of a given number of neutrons from ^{12}C



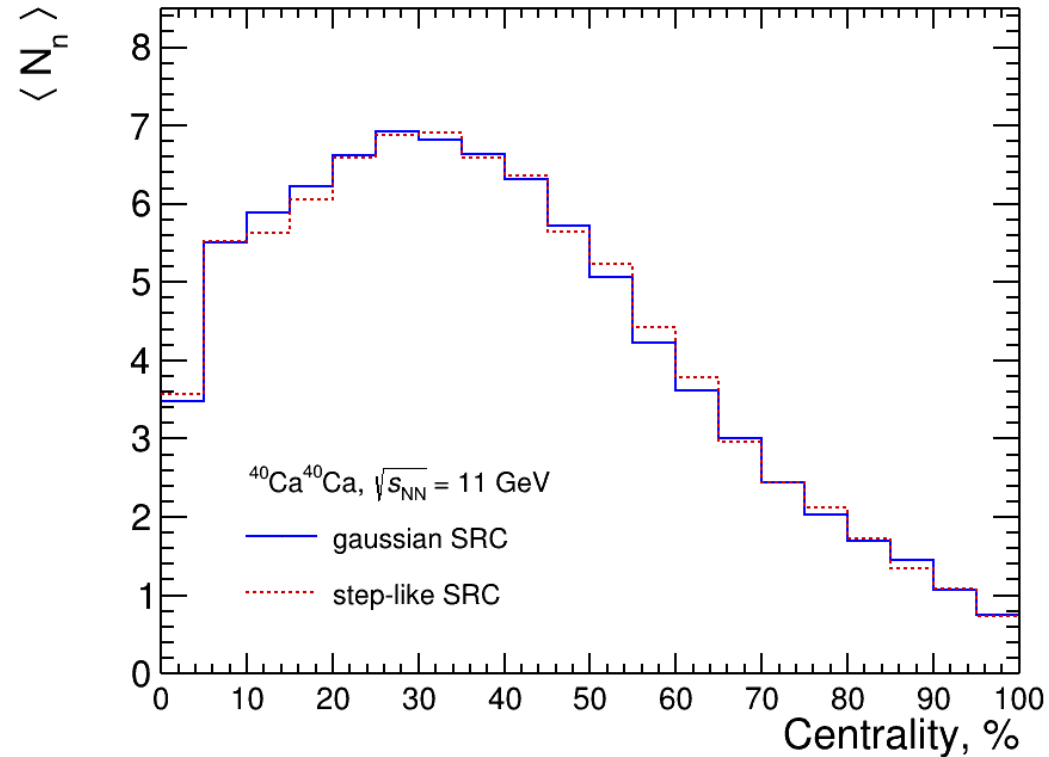
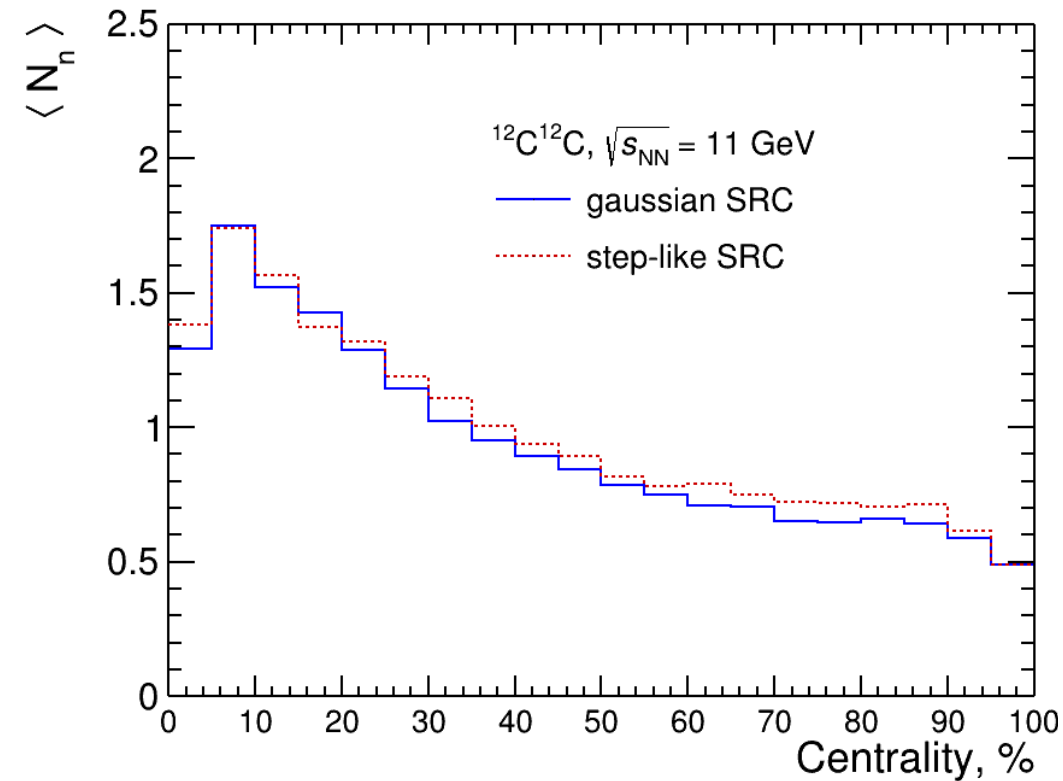
No significant difference between the cross-sections obtained with two parametrisations of SRC

Cross section of the production of a given number of neutrons from ^{40}Ca



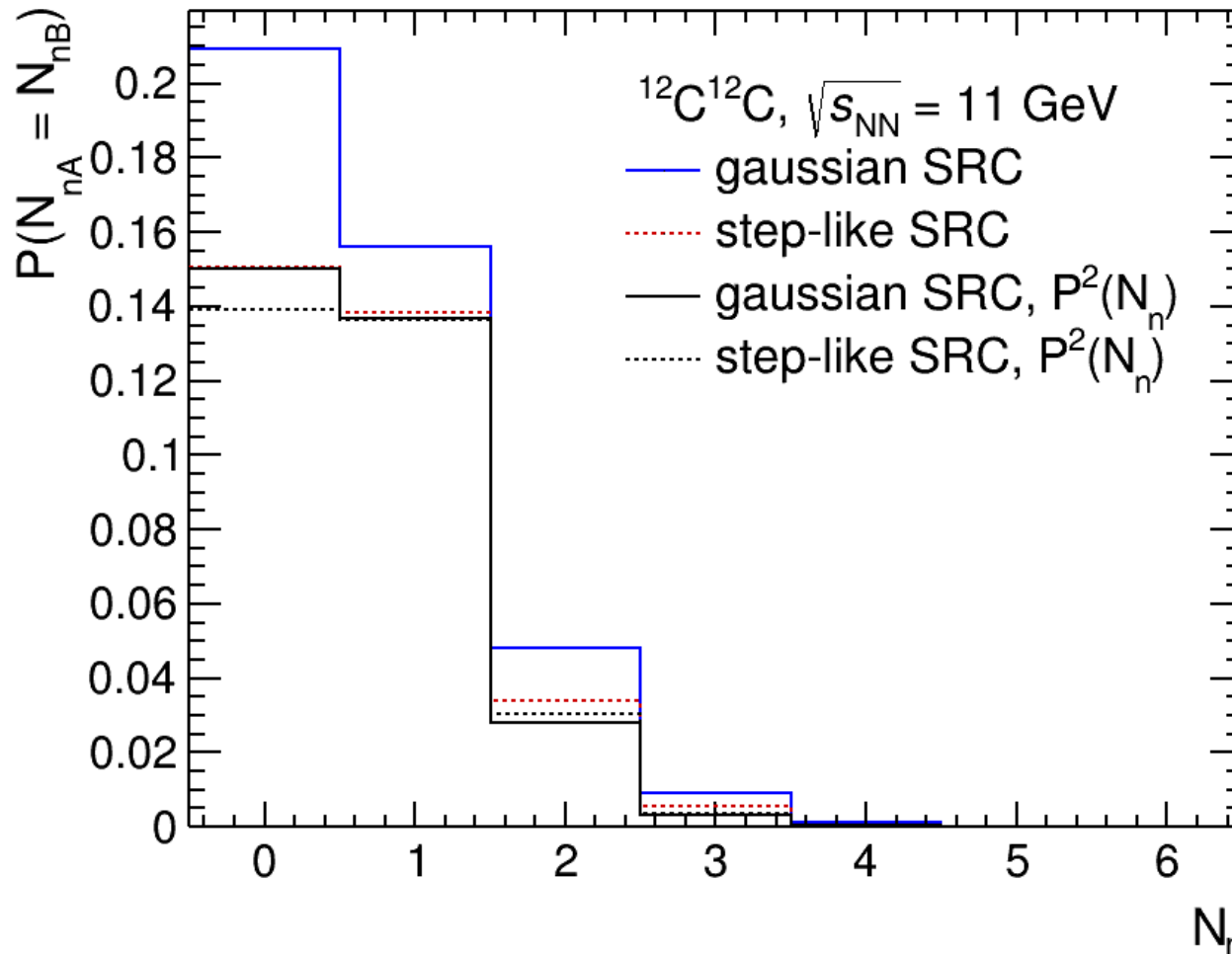
No significant difference between the cross-sections obtained with two parametrisations of SRC

Average neutron multiplicity



A slight increase in the multiplicity for the more peripheral events is observed for both ^{12}C and ^{40}Ca

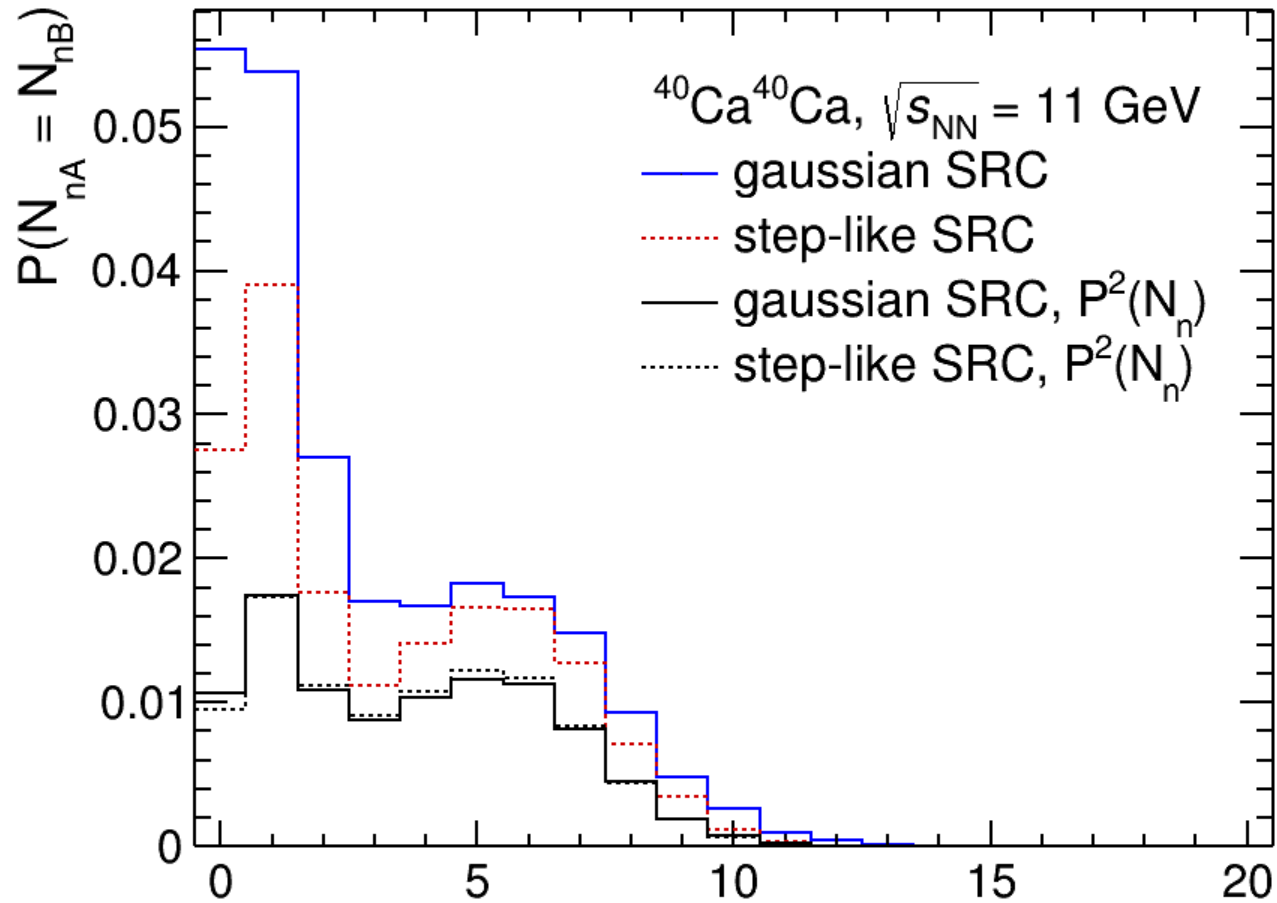
Probabilities to have same number of neutrons on both sides



Black lines represent squares of one-side distributions

A clear contribution of the correlations for the gaussian SRC is seen

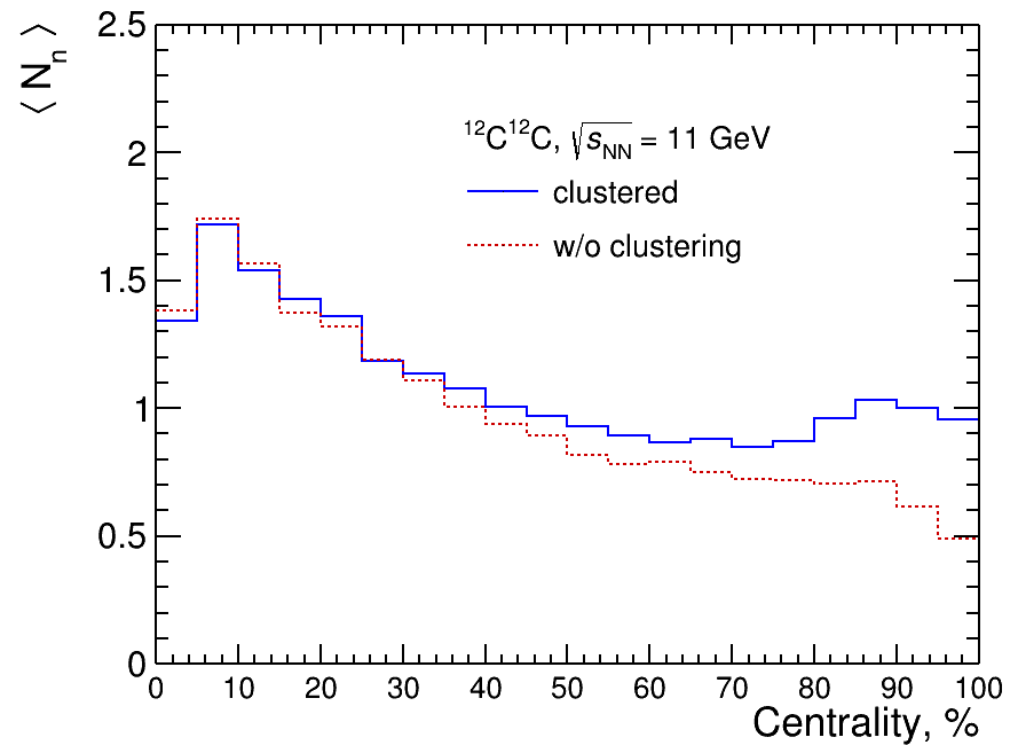
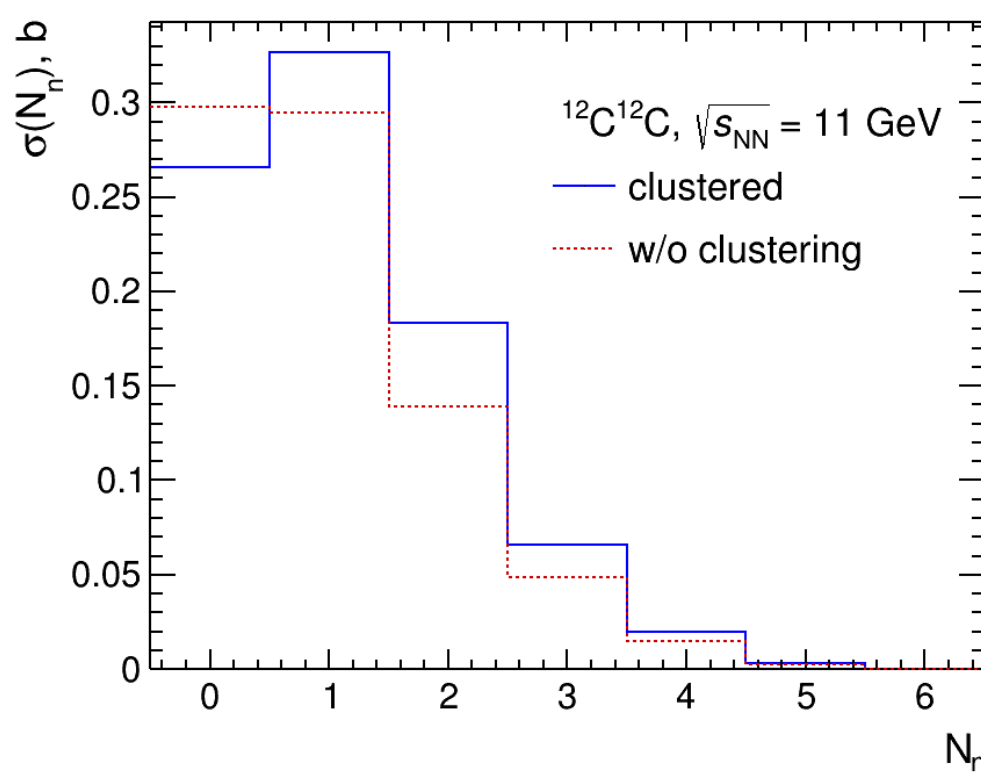
Probabilities to have same number of neutrons on both sides



Black lines represent squares of one-side distributions N_n

Clear contribution of the correlations for both step-like and gaussian SRC is seen in contrast to ^{12}C

Neutrons from clustered ^{12}C



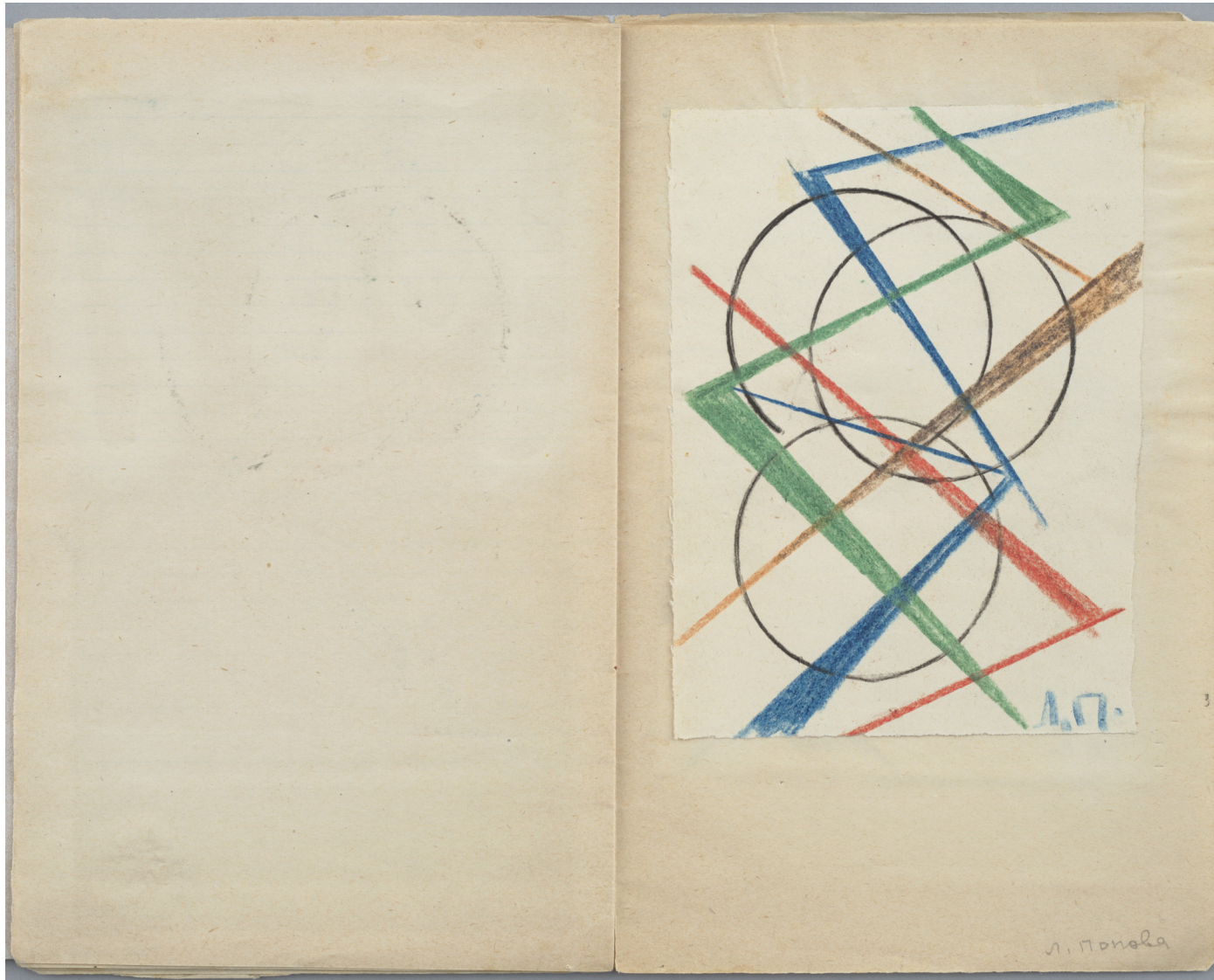
Following Ref. 1, the step-like parametrization of the SRC were considered

As for ^{16}O , accounting for the alpha-clusterisation increases the average neutron multiplicity, especially in the most peripheral events

Summary

- Projectile fragmentation has been studied in fixed target experiments with beams of light nuclei. SPD at NICA provides a unique possibility to study fragmentation of both colliding nuclei, in particular, spectator neutrons.
- As calculated, the yields of spectator neutrons are sensitive to the presence of alpha-clusters in ^{12}C , but not to the SRC in ^{12}C and ^{40}Ca
- In contrast, the correlation between the spectator nucleons from the both colliding nuclei provides information on neutron-neutron correlations in colliding nuclei.
- The yields of neutrons in the events with the same number of neutrons on both sides are sensitive to the specific parametrisation of the SRC for both ^{12}C and ^{40}Ca

To conclude, an artists view of the carbon nuclei fragmentation



Liubov Popova, Folio from 5 x 5 = 25: Vystavka zhivopisi, 1921