The Tetraneutron

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18/09/2007

Tetraneutron ^{4}n

A **tetraneutron** is a hypothesised stable cluster of four neutrons.

This cluster of particles is not supported by current models of nuclear forces.

However, there is some empirical evidence which suggests this particle does exist

The first claim of experimental observation of $^{4}\mathbf{n}$:

V. A. Ageev, I. N. Vishnevskii, V. I. Gavrilyuk, et.al., Preprint KIYaI-85-4, Inst. For Nuclear Research Academy of Sciences of Ukraine, Kiev, 1985;

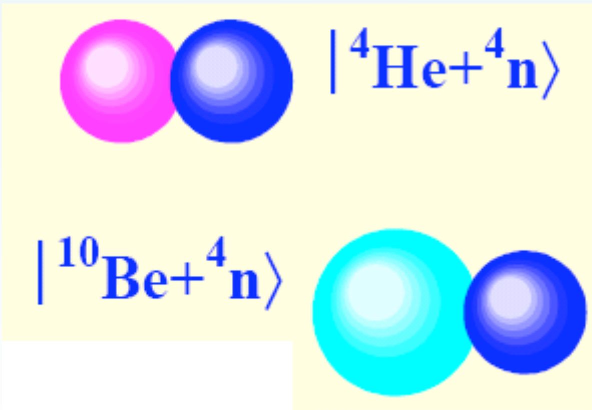
V. A. Ageev et.al. Ukr. Phys. J **31**, 1771 (1986)

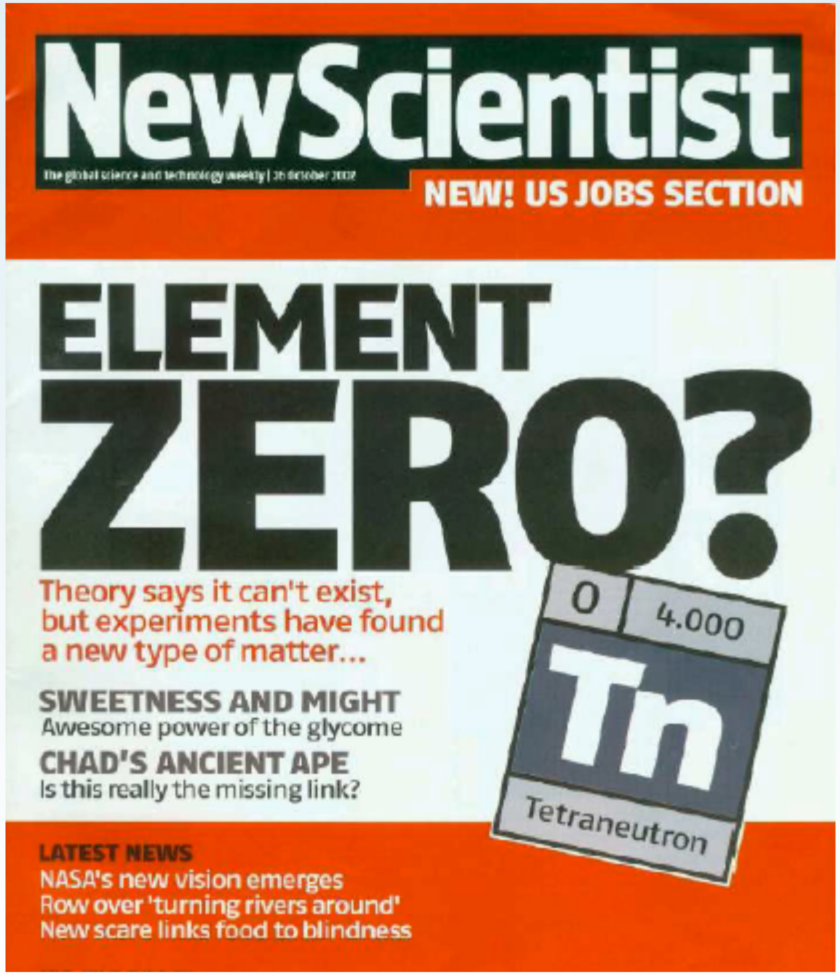
Recent reports:

F. M. Marqués et al., Detection of neutron clusters, Phys. Rev. C **65**, 044006 (2002) *using a novel detection method in observations of the disintegration of* $^{14}\mathbf{Be}$ *nuclei (6 events)*

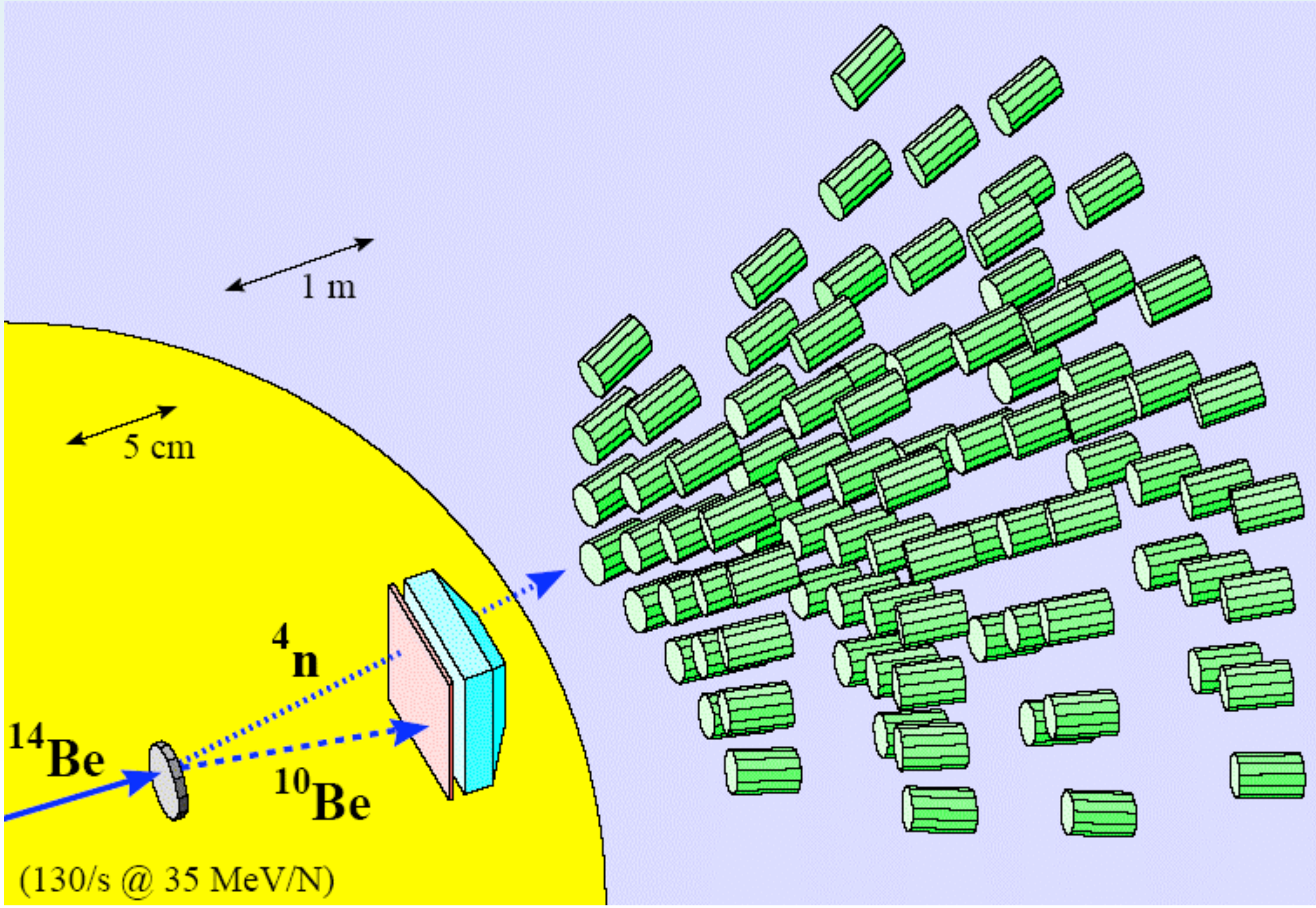
V. Bouchat, F.M.Marqués, F. Hanappe, et al., in Proceedings of International Symposium on Exotic Nuclei (EXON-2004), Peterhoff, Lake Ladoga, Russia, 2004: *12 events associated with a bound* $^{4}\mathbf{n}$ *cluster in the α+4n channel in the experiment with a* $^{8}\mathbf{He}$ *beam*.

Breakup of very neutron-rich nuclei

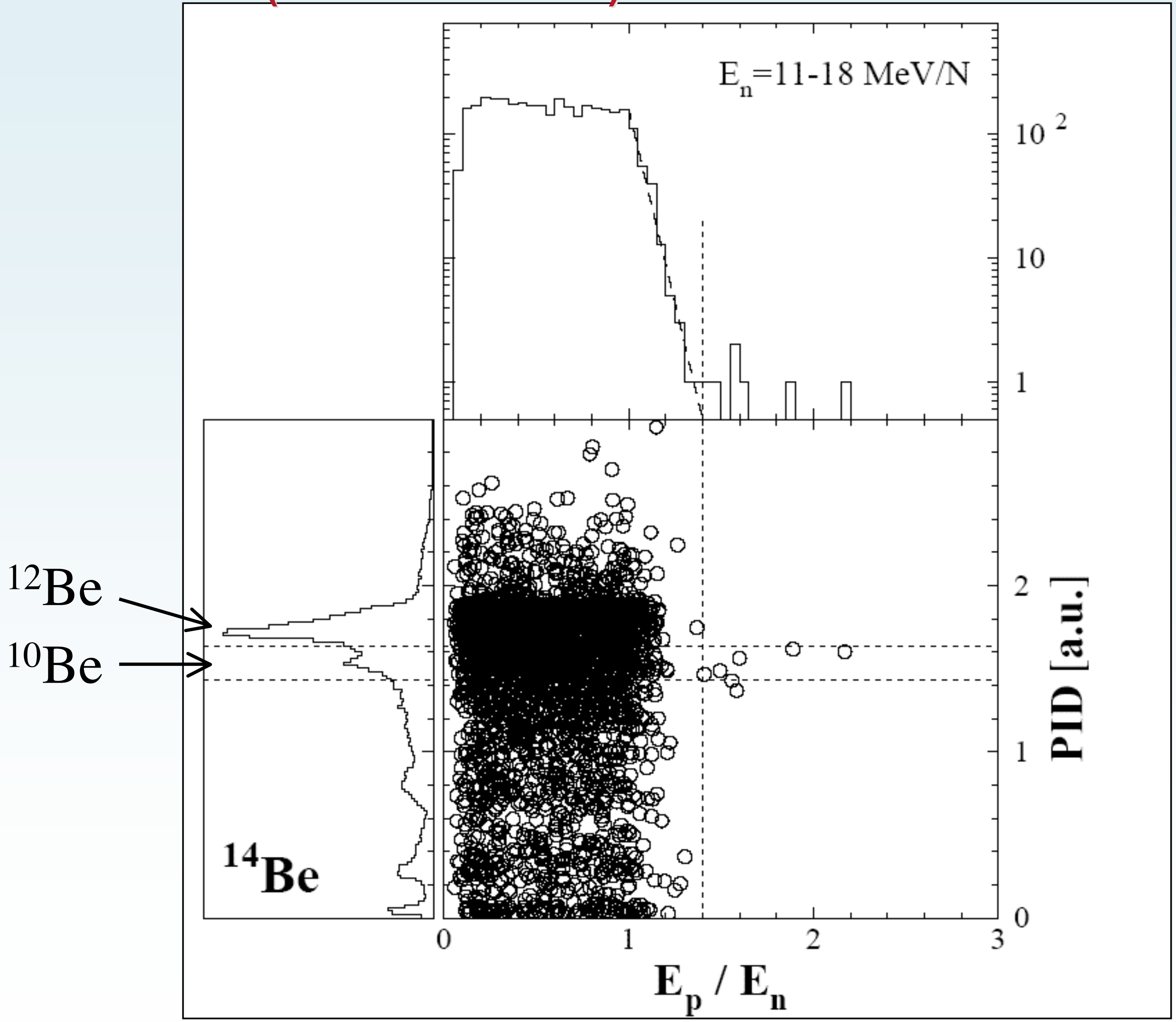




Production: ^{14}Be (35 MeV/u) + C → ^{10}Be + ^{4}n

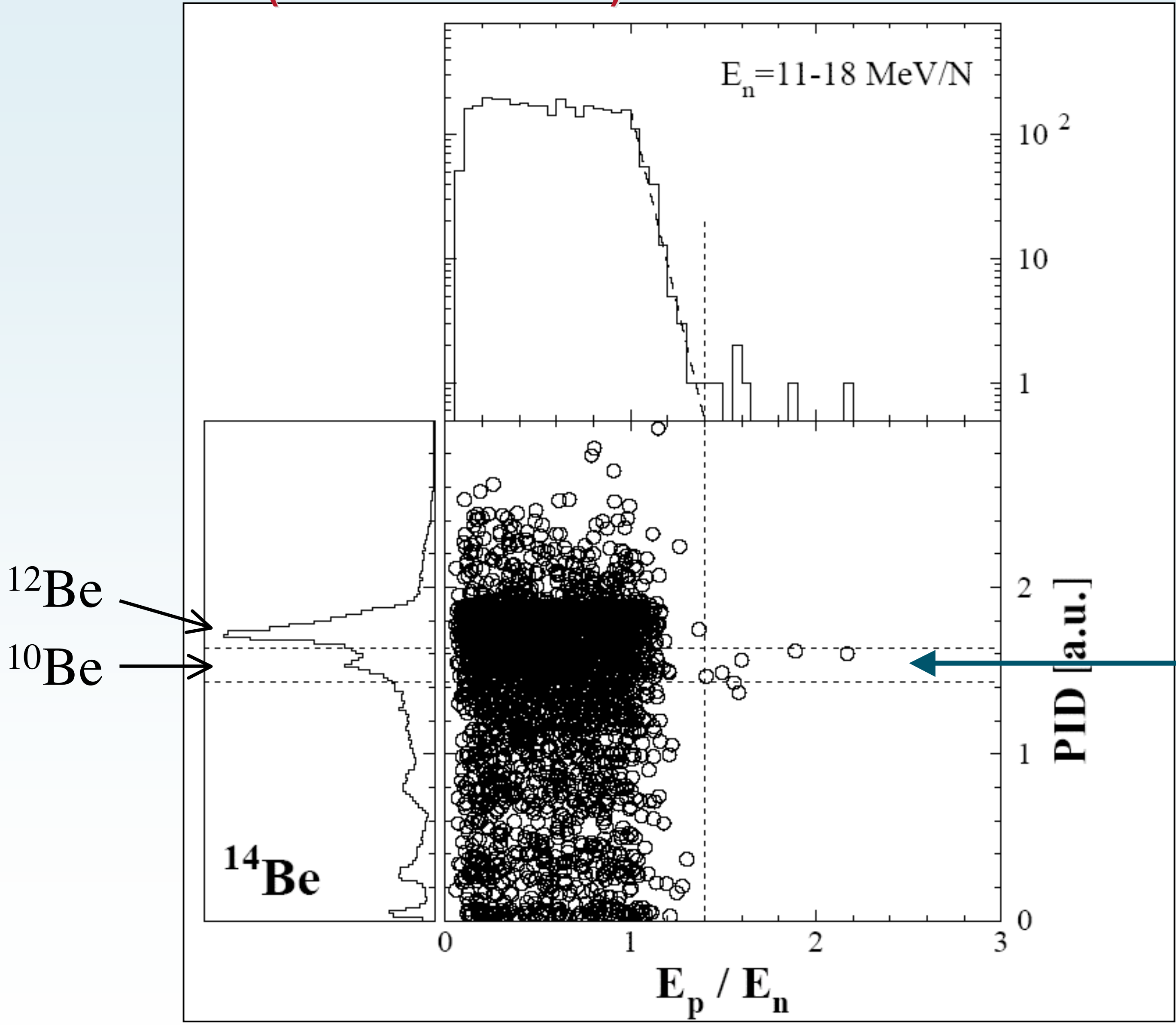


Results: ^{14}Be (35 MeV/nucleon) + C → ^{A}Be + ^{x}n



FM Marqués et al., PRC (2002)

Results: ^{14}Be (35 MeV/nucleon) + C → ^{A}Be + ^{x}n



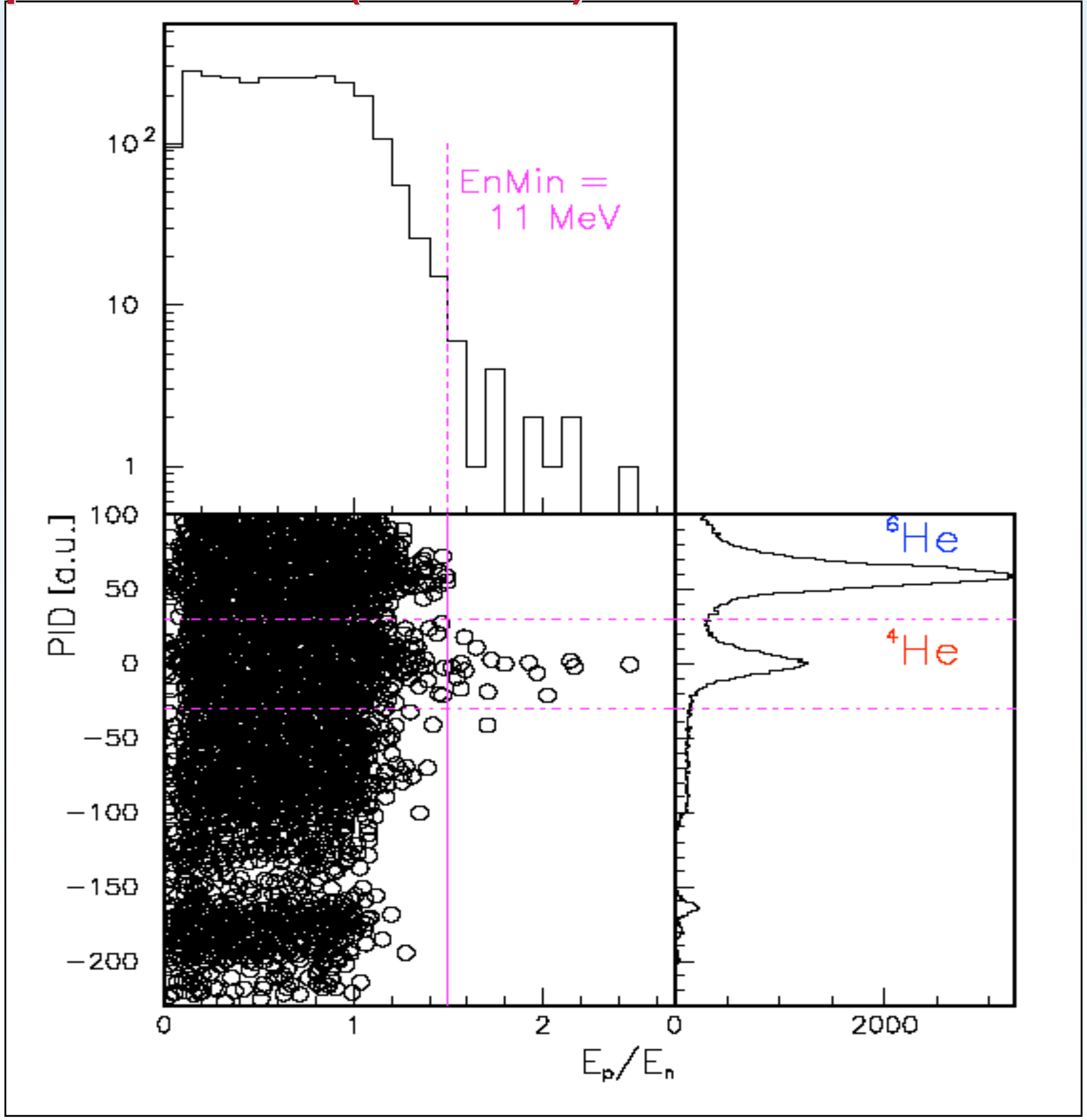
6 events

pileup < 0.8

"2σ signal"

FM Marqués et al., PRC (2002)

New Experiment: ^{8}He (16 MeV/u) + C → ^{A}He + ^{x}n



Group Exotiques-ULB: V. Bouchat, FM Marqués et al., 2004

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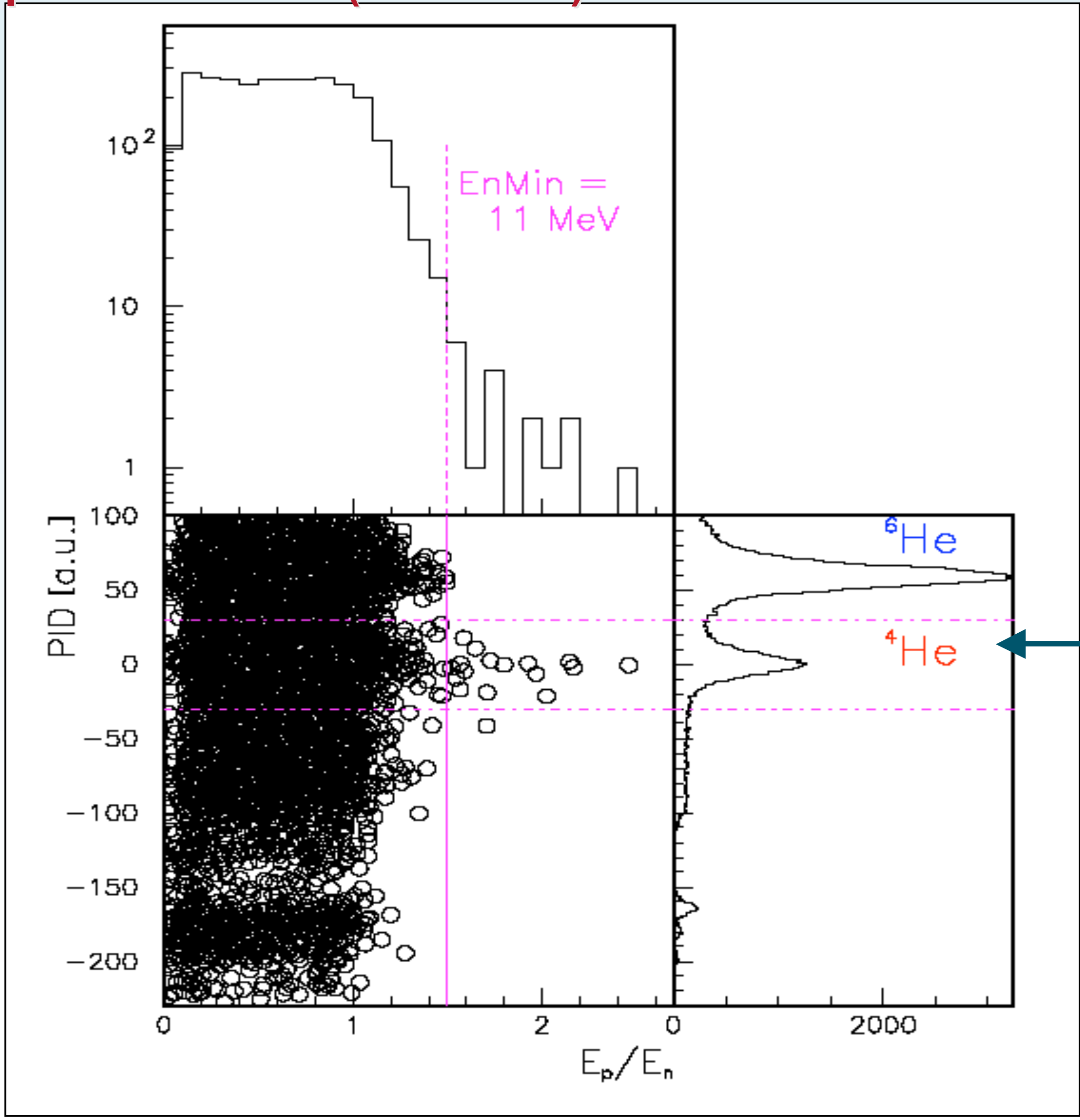


14 events

pileup < 2

"3.5σ signal"

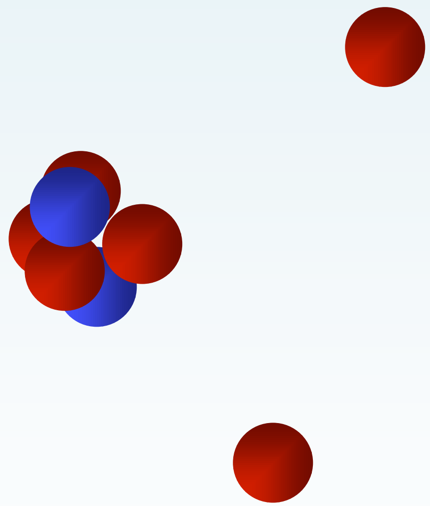
Group Exotiques-ULB: V. Bouchat, FM Marqués et al., 2004

Nevertheless,

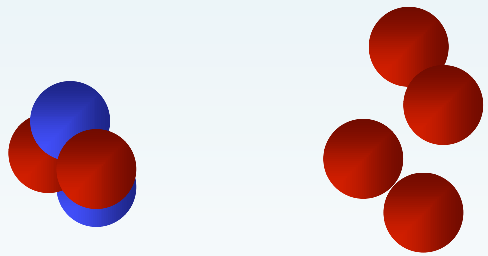
An overall conclusion of a number of theoretical papers is that the tetraneutron cannot exist:

it does not seem possible to change modern nuclear Hamiltonians to bind a tetraneutron without destroying many other successful predictions of those Hamiltonians

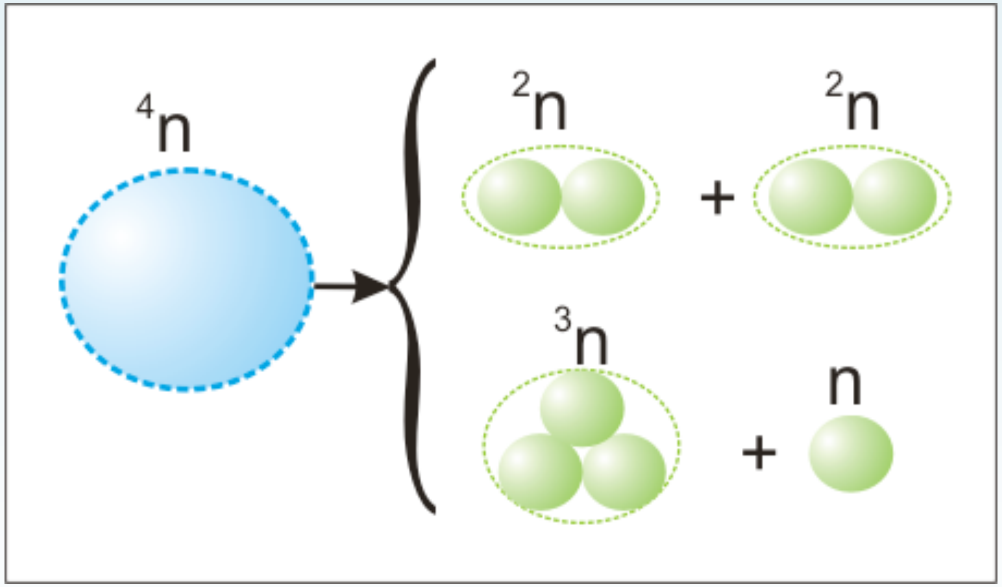
-S. C. Pieper, Phys. Rev. Lett., 90, 252501 (2003)
- N. K. Timofeyuk, J. Phys. G 29, L9 (2003)
-R. Lazauskas, J. Carbonell, Phys. Rev. C 72, 034003 (2005)



^{6}He



^{8}He



^4n
^2n
^2n
+
^3n
n
+

Here is a radical proposal:

- Use magnetic fields to model nucleon-nucleon interactions
- Use a composite model of nucleons
- Use a composite model of elementary particles

Using a colour-preon model of composite fundamental particles

- V. N. Yershov, Few-Body Syst., **37**, 79-106 (2005)
- V. N. Yershov, Physica D **226**, 136-143 (2007)

The basic element of this model is a primitive particle (preon) with:

- A unit electric charge
- A unit colour charge
- SU(3) x U(1) symmetry

and having no other properties !

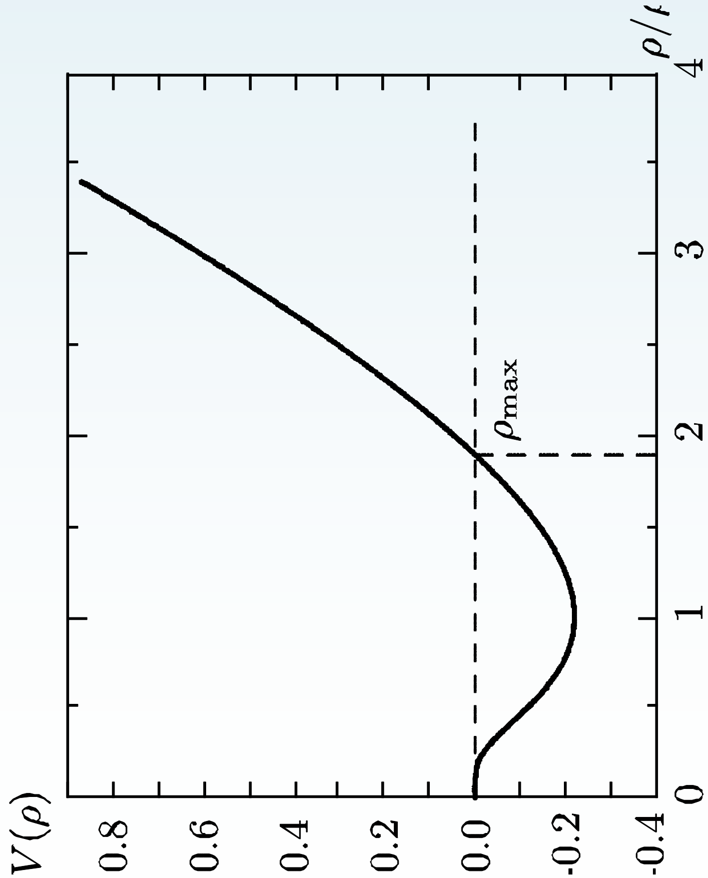
The simplest functional form for the basic field of the colour-preon is taken to be:

- $F = F_1 + F_2$
- $F_1(\rho) = \aleph \exp(-k\rho^{-1})$
- $F_2(\rho) = - F_1'(\rho) = - \aleph\, k\, \rho^{-2} \exp(-k\rho^{-1})$

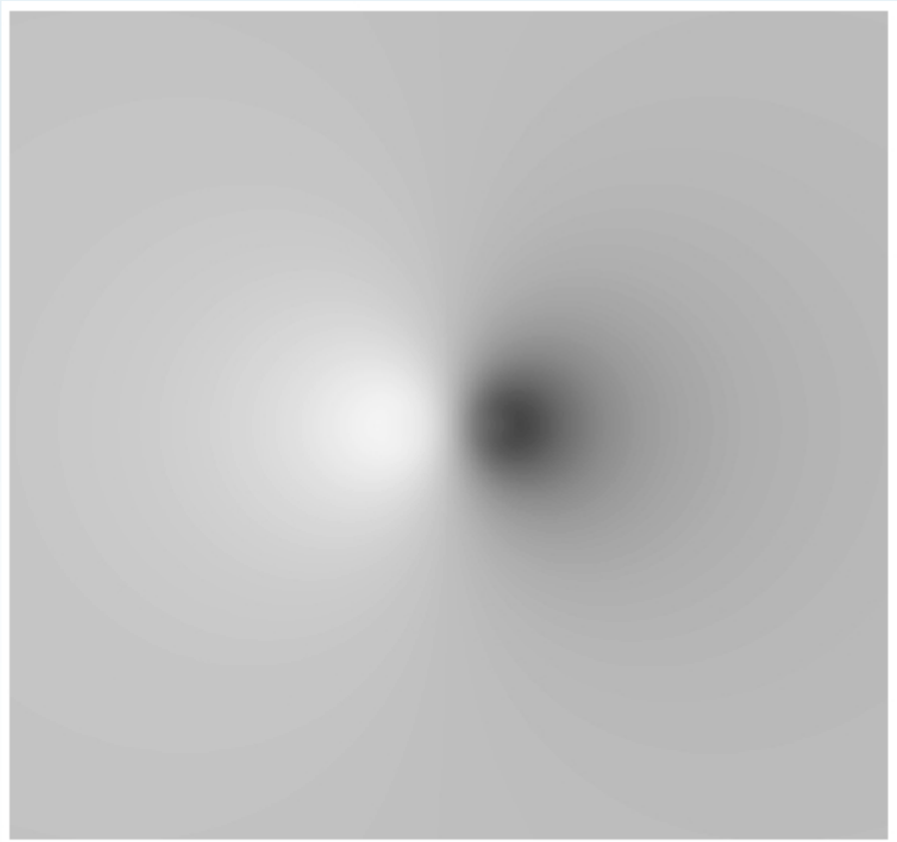
SU(3) $\longrightarrow$ F_1, U(1) $\longrightarrow$ F_2

Leading to the potential:

$V(\rho) = \exp(-k\rho^{-1})[\rho + \mathrm{Ei}(-k\rho^{-1})-1]$



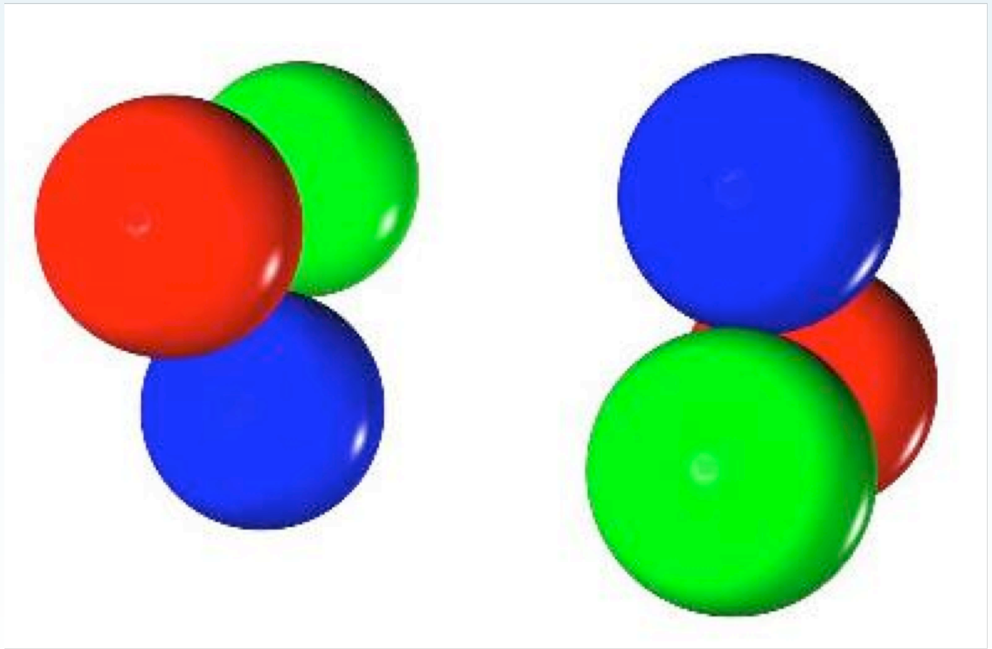
Electric dipole



Chromoelectric tripole

Chromoelectric tripole

Tripoles can combine and form stable equilibrium configurations due to the polarisation of their chromofields



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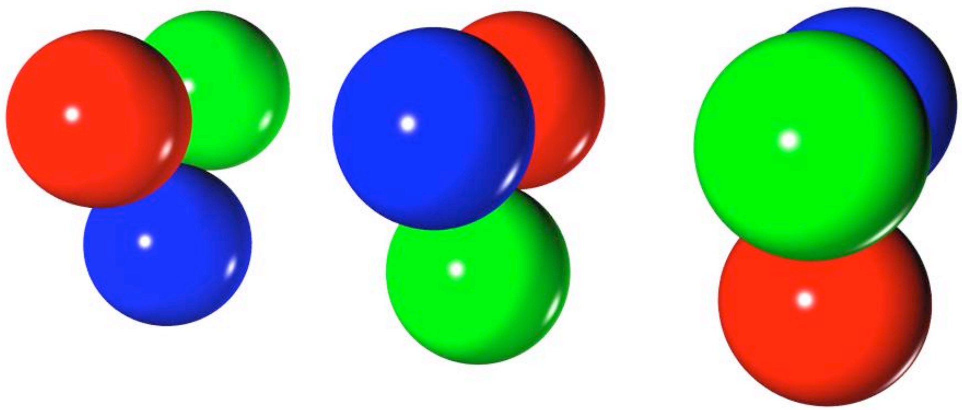
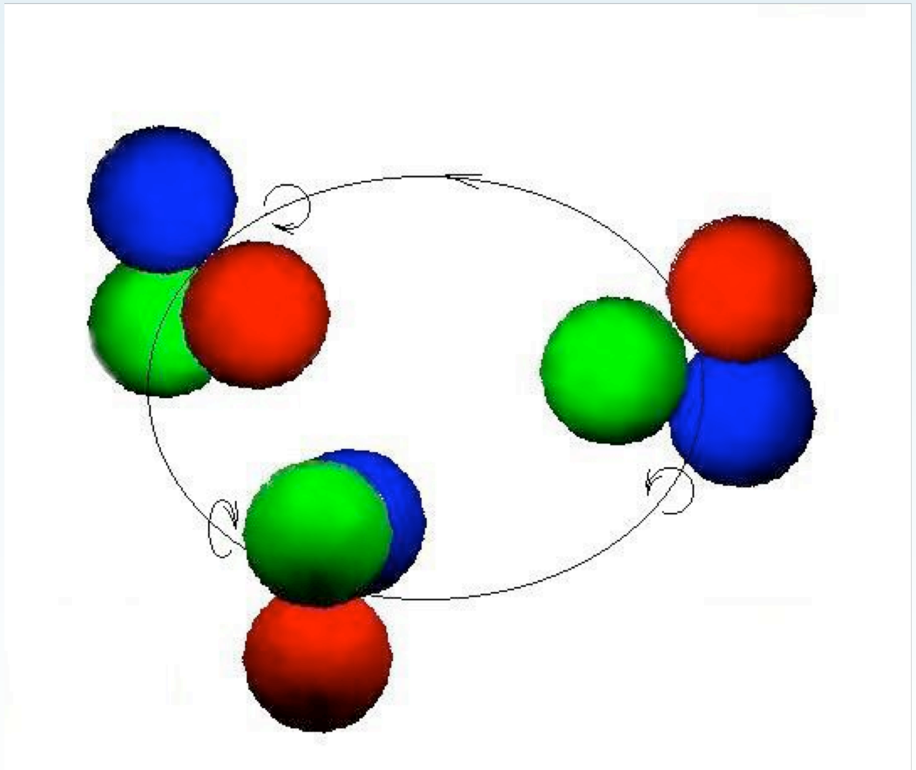
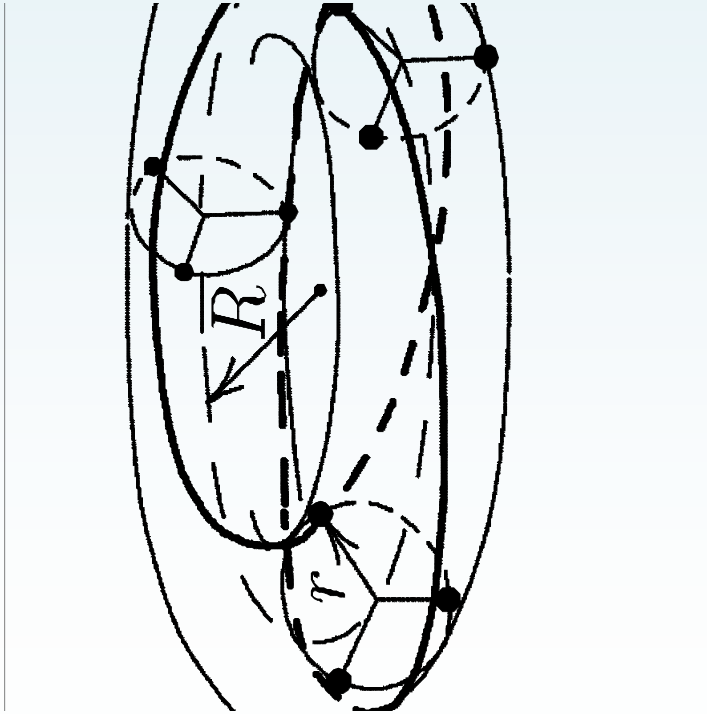


A three-component string of like-charge tripoles will close in a loop (minimising its energy)

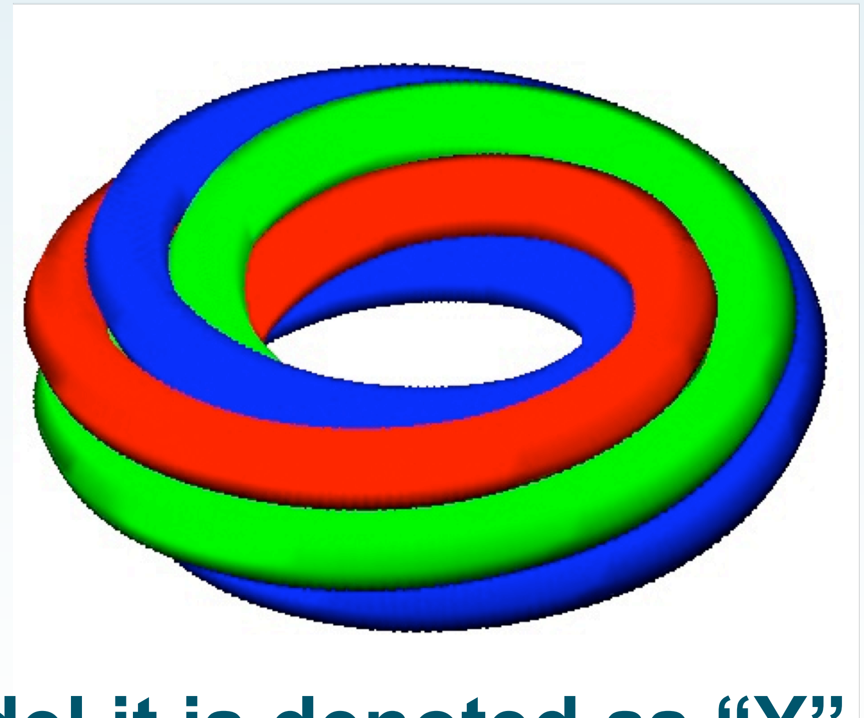


The tripoles in this structure spin, generating the poloidal and toroidal magnetic fields



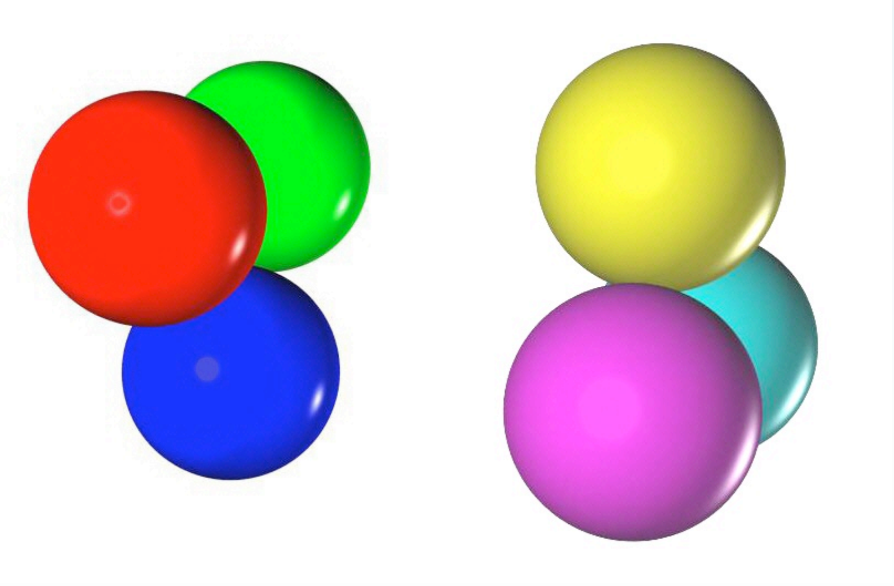
This is a system of looped (helical) electric currents

Y^-



In this model it is denoted as “Y” (either Y^+ or Y^- depending on the polarity of its electric charge)

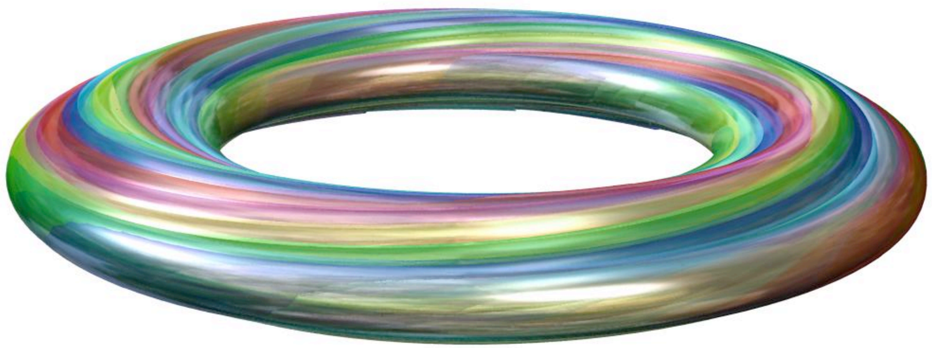
Tripole-antitripole pairs can also form loops



The minimal loop formed of the tripole-antitripole pairs contains six such pairs (12 tripoles)

This is a quite complicated system of looped electric currents

X



It is denoted as “X” in this model (it is a neutral particle)

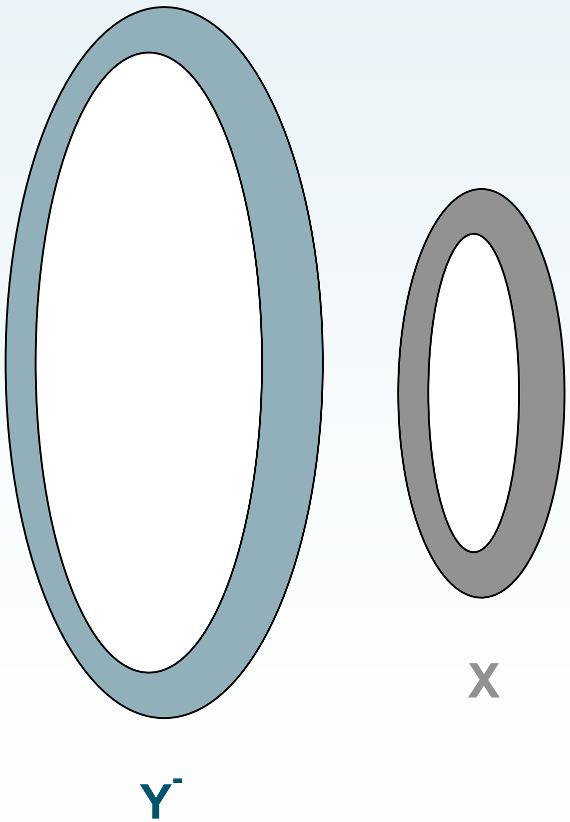
The X and Y particles can combine because of their residual chromaticism:

$$W^{(\pm)}=XY^{(\pm)}$$

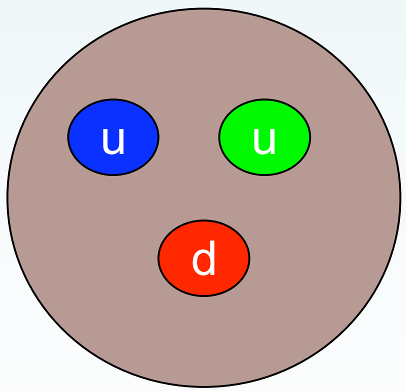
They oscillate with respect to each other (concentrically, passing through each other)

These oscillations are not symmetrical because the neutral (X) particle has a residual magnetic moment due to the dynamical polarisation of its unlike-charged constituents

Eventually, the X-components exits the system



It follows from this model that the proton structure is different from the conventional picture



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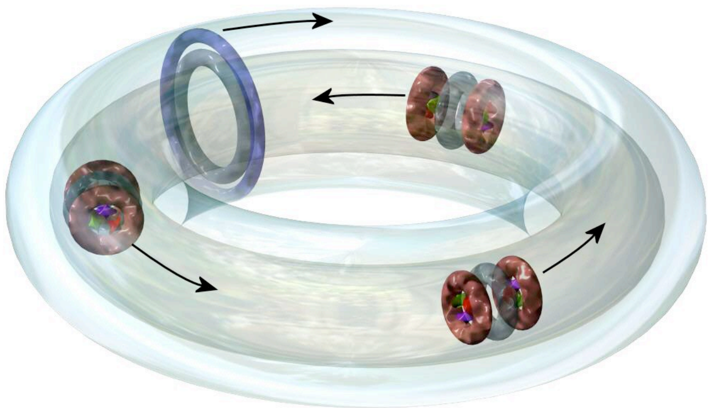
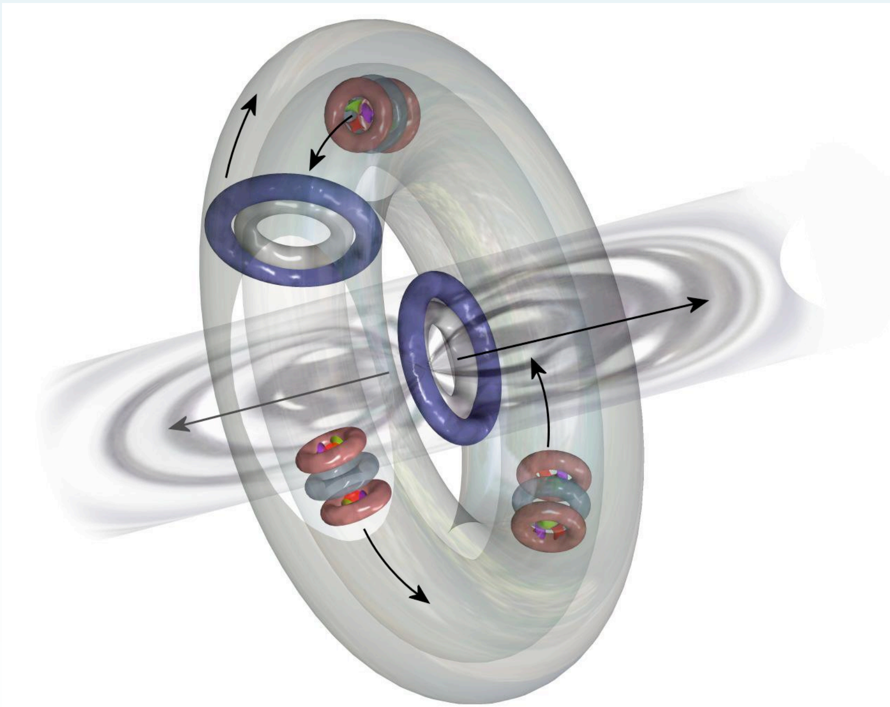
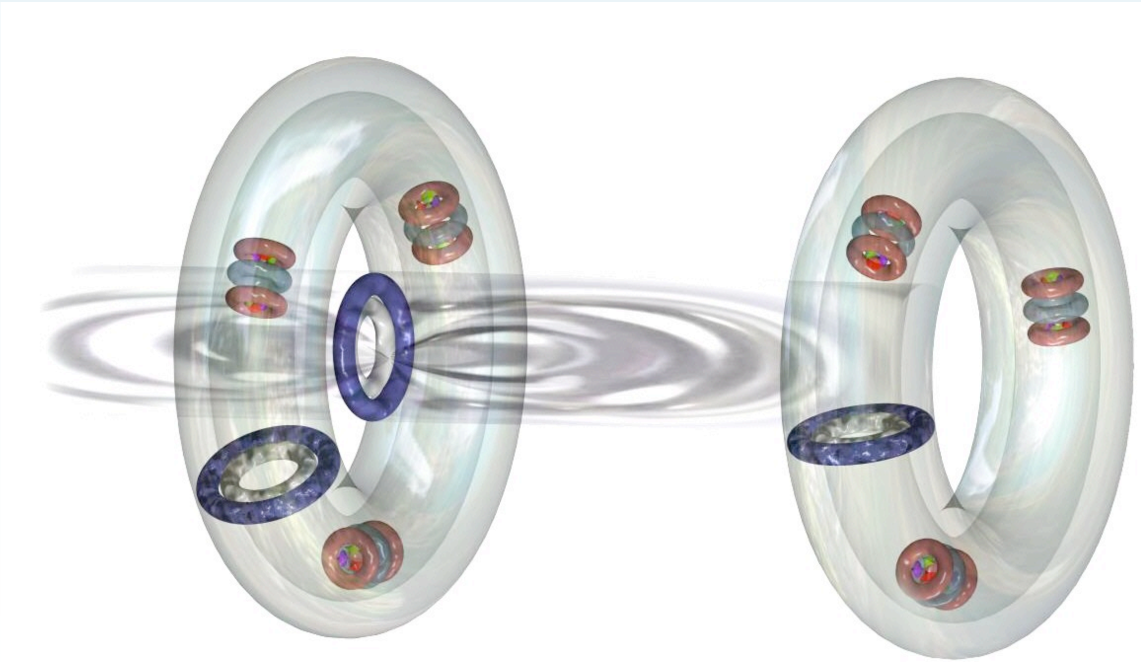


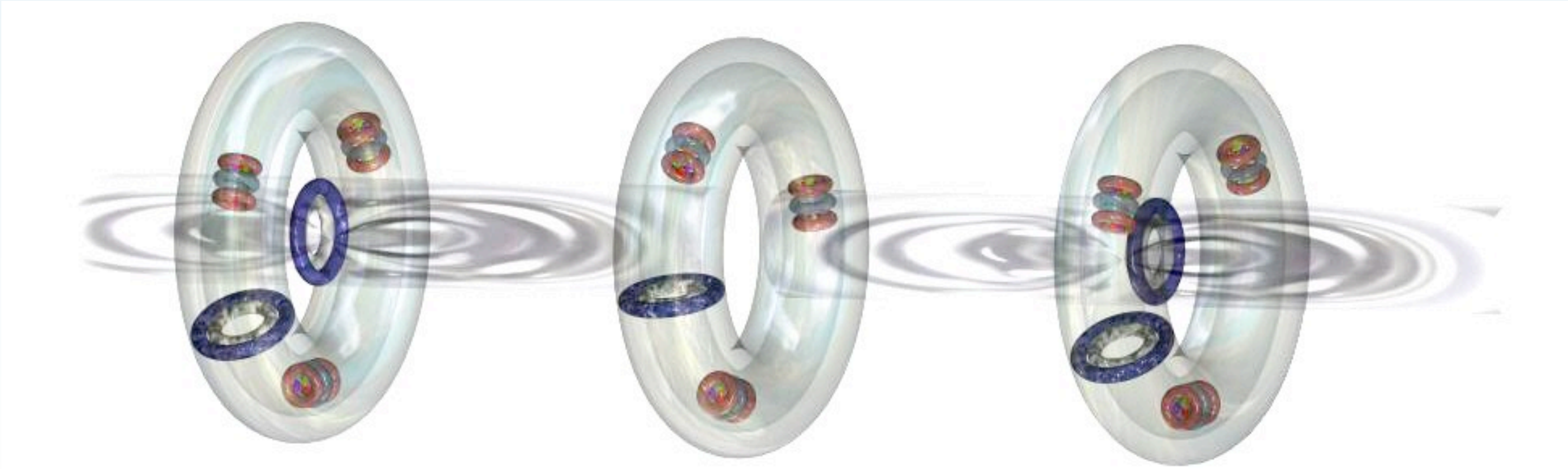
The neutron, then, is a combination of the proton with the W^- -particle oscillating concentrically along the torus axis



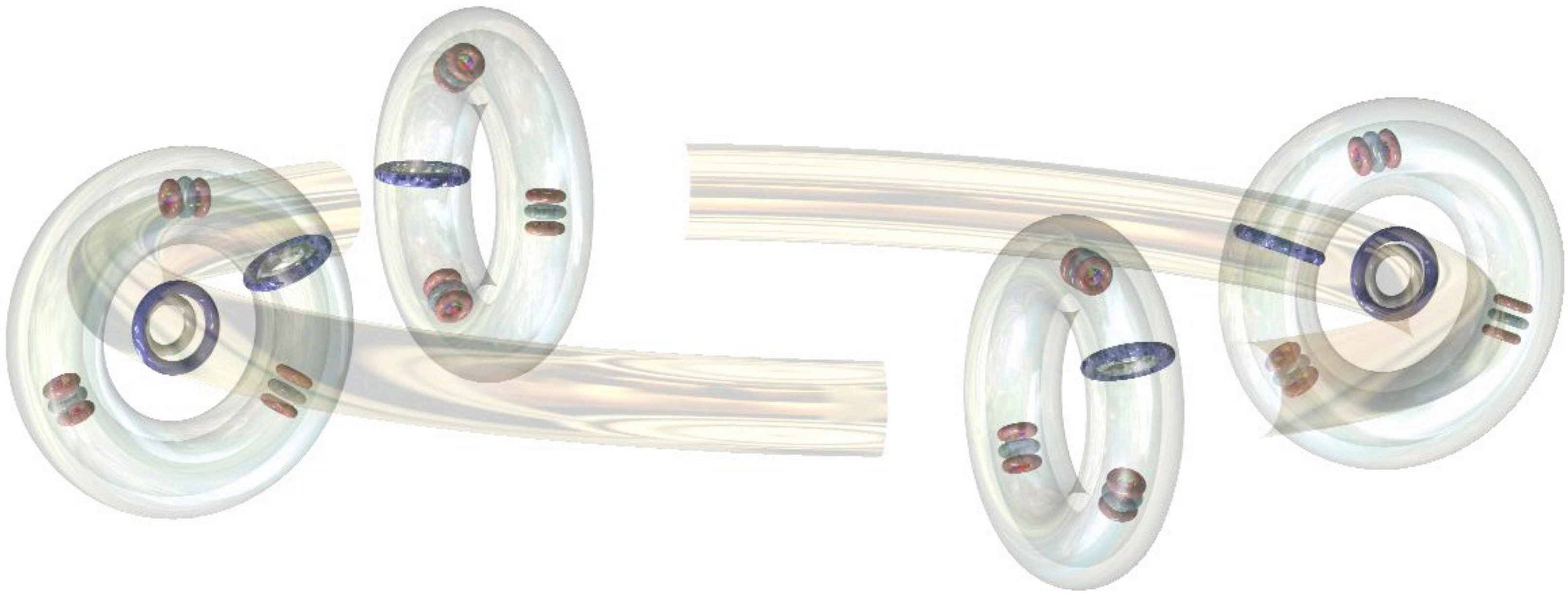
The oscillations of the W-particle could be stabilised by a second proton couple to the first one by the magnetic fields of both particles and their topological (helical) charges



A single proton can stabilise the oscillations of two W-particles that belong to two neigbouring neutrons



This leads to the following structure of the 2p+2n structure (the helium-4 nucleus):

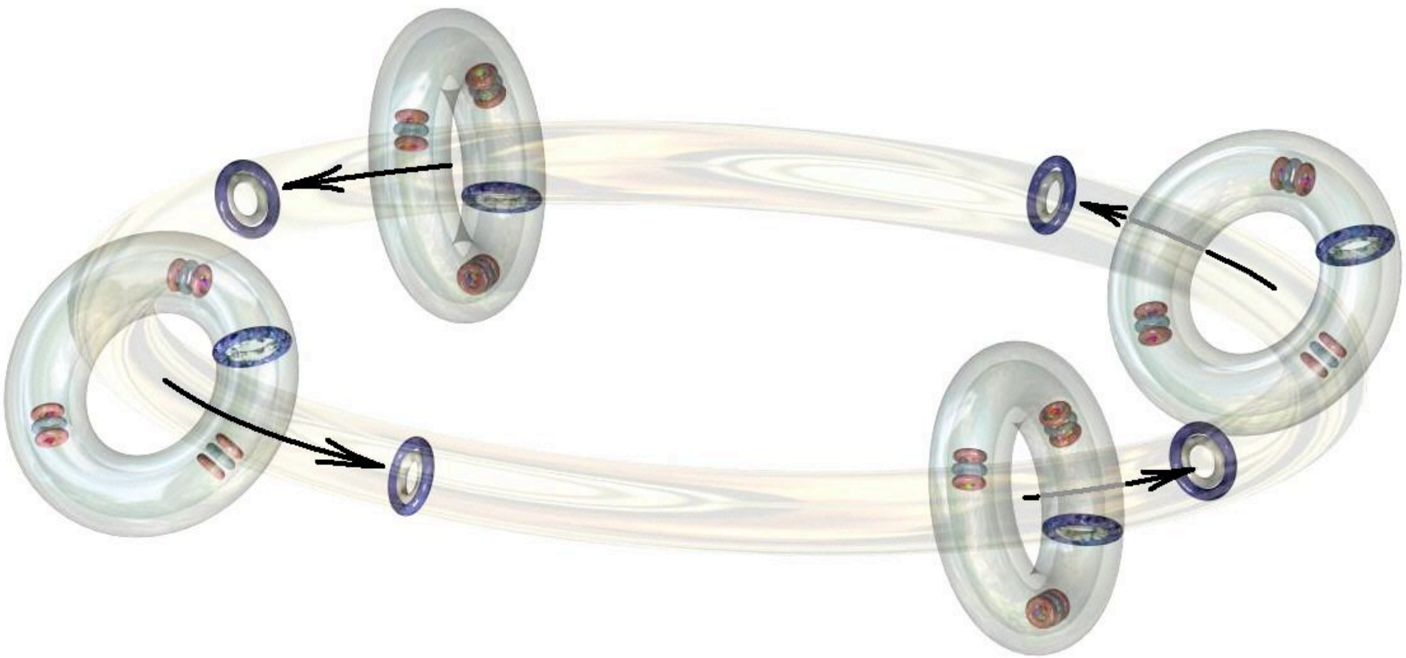


It is known that a system of two protons and two neutrons has an unusually high binding energy.

Its magnetic field is vanishing, which is explicable by the toroidal shape of this system.

Similarly, when the motions of the W-components of the neutrons is synchronised, two neutrons can form a bound system

That's is how four neutrons can combine in a ring-closed structure (the tetraneutron)



Predictions of the colour-preon model as to the properties of the tetraneutron:

- Its net magnetic moment is vanishing since the magnetic fields of its constituents (four neutrons are confined in a torus)
- The neutron matter composed of tetraneutrons should have a property of superfluidity (by analogy with helium-4, which is also a ring-closed structure in this model)

The existence of tetraneutrons has important implications for studying physical processes in the interiors of neutron stars:

- Neutron star crust structure
- Neutron stars EOS and neutron skin
- Pairing, phase transitions and cooling
- Superfluidity
- Superconductivity

Using a colour-preon model of composite fundamental particles

- V. N. Yershov, Few-Body Syst., **37**, 79-106 (2005) arxiv:physics/0609185

- V. N. Yershov, Physica D **226**, 136-143 (2007) arxiv:physics/0603054

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