Uma viagem ao coração da Matéria

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Nuclear and Hadron Physics

Investigates the “core” of visible,
ordinary matter (hadrons, nuclei) :
the mechanism of its mass formation and
the reactions in stars that determine to the evolution of the universe.

- Give the basis of the cosmic creation and distribution of elements in the Universe. (Cosmic Chemistry) .
- Shows that we are a cosmic nuclear accident.

→ Would the effective nuclear force be slightly weaker, we would not exist.
The deuteron, the first step in formation of all elements, would not have been formed.
E_B =(2.22461 ± 7x 10^{-5}) MeV; $V_{nuclear}$= 40 MeV

Como é feito um núcleo?

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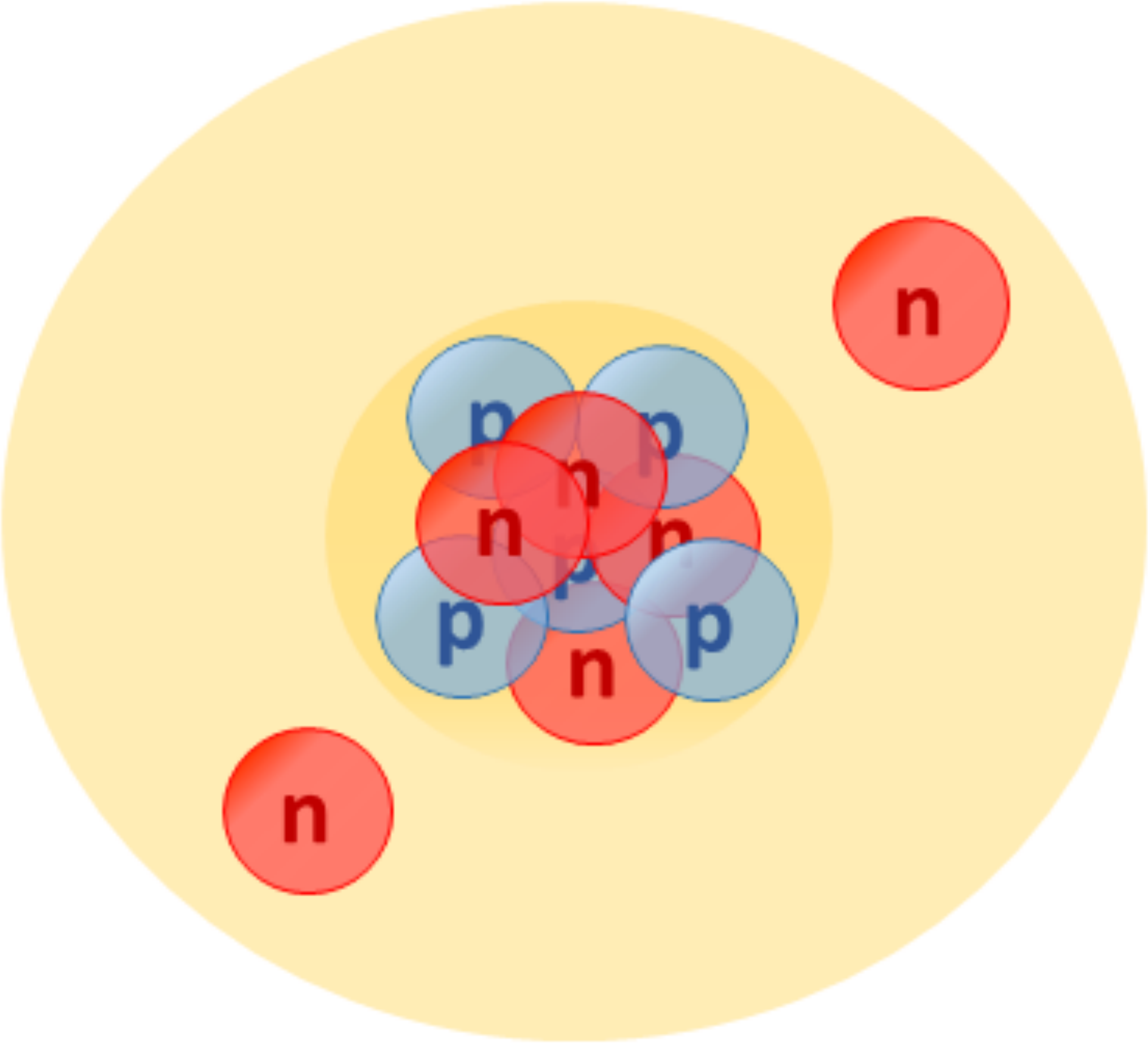

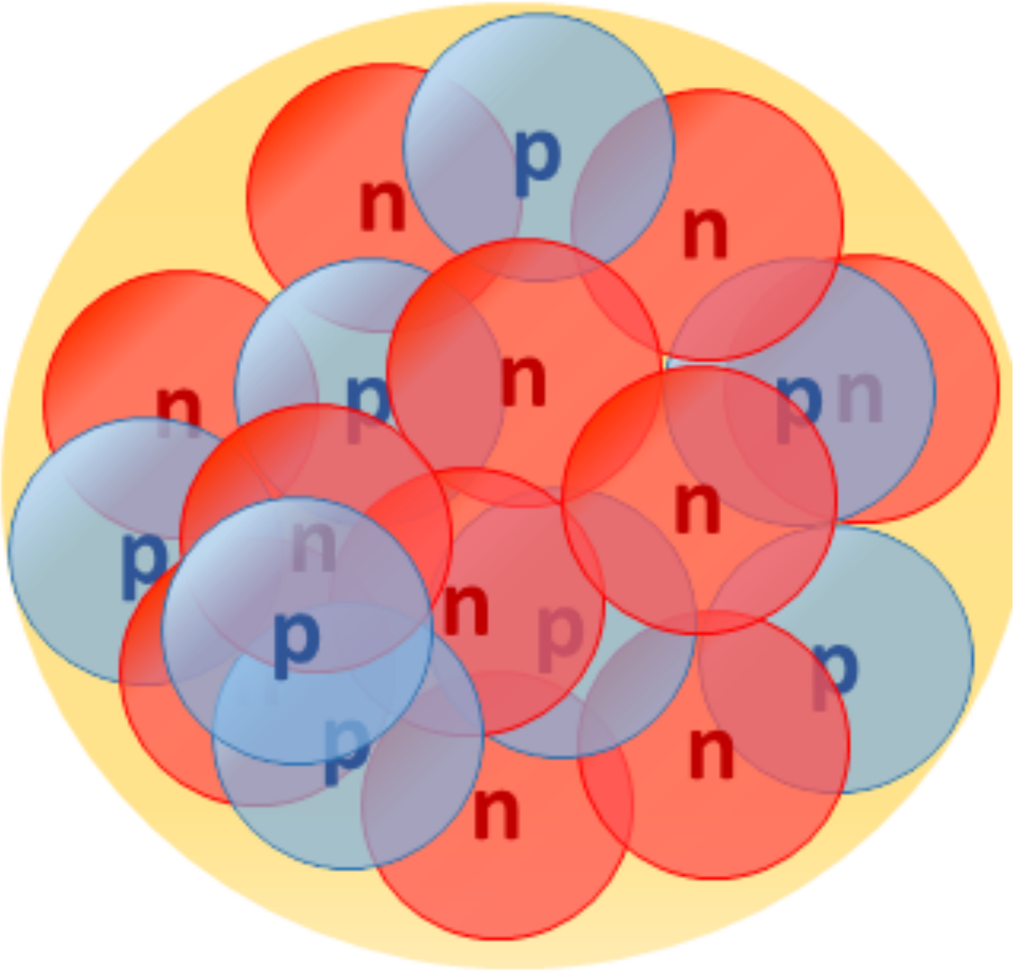

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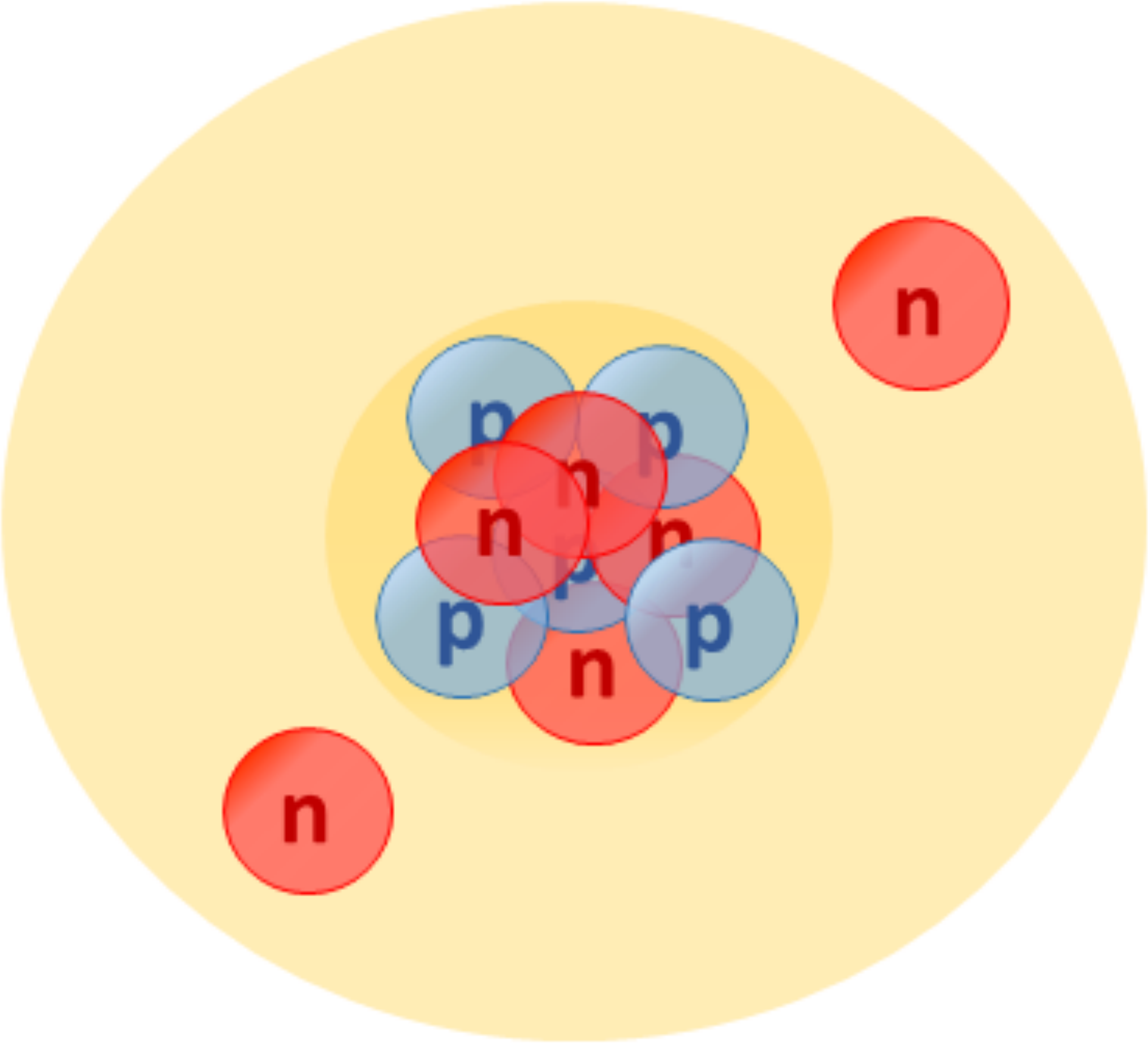
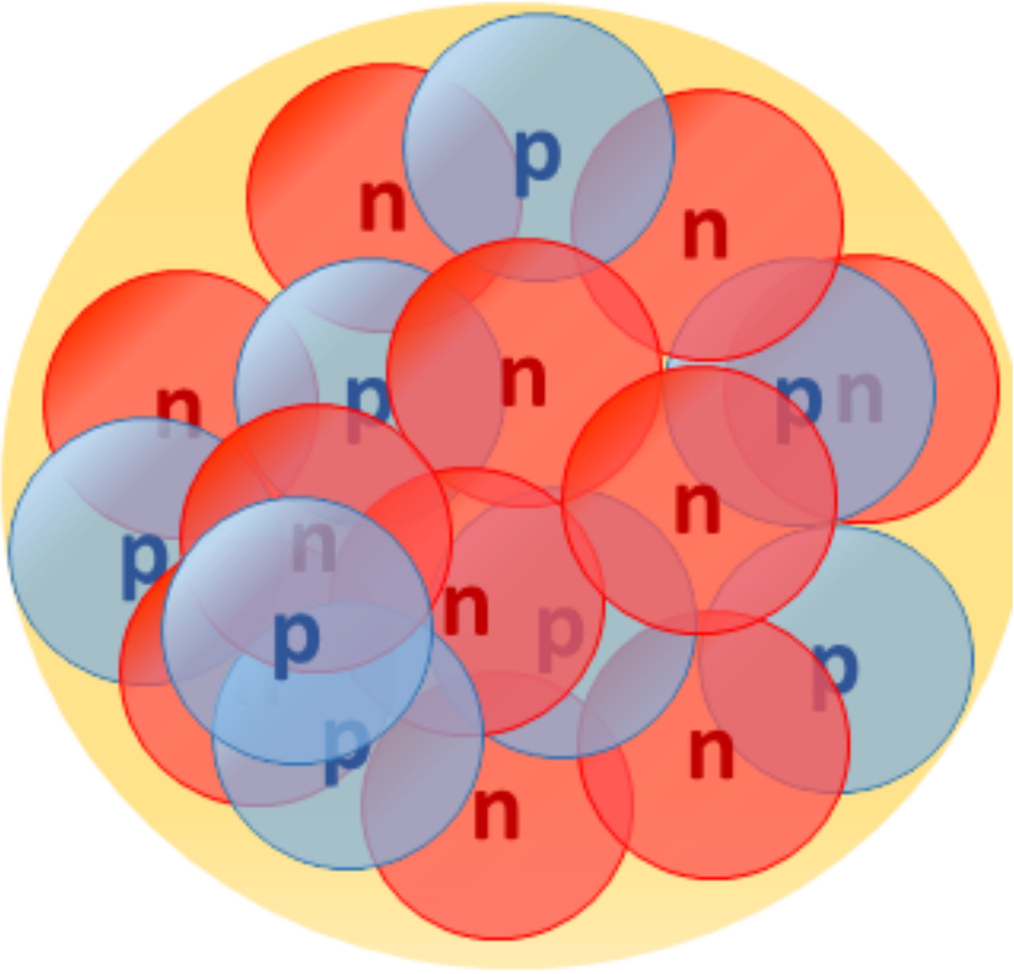




Ambas as configurações, planetárias e de empacotamento existem!

E há núcleos macroscópicos

Estrelas de neutrões

Tamanho de uma estrela de neutrões versus o tamanho de Manhattan NY

20-30 km de raio.

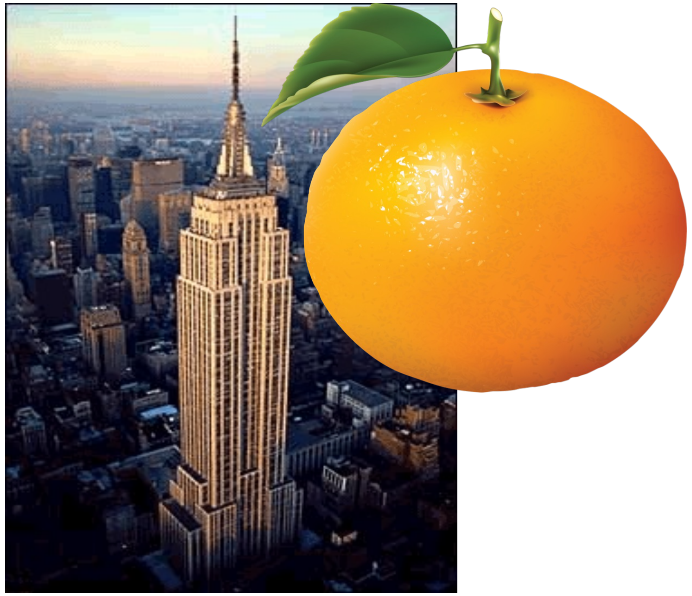
O núcleo atómico é matéria em condições extremas

A densidade nuclear é praticamente a mesma para todos os núcleos.
E é extremamente grande

10^{39} nucleões/cm^3

Densidade nuclear $\rho = 3.8 \times 10^{11}$ tonelada /dm^3

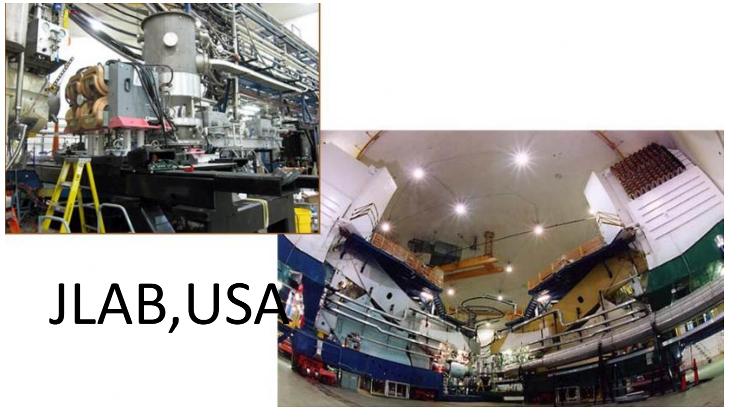
Densidade média na Terra 5.5 kg/dm^3



Como um líquido classico, a matéria de um núcleo é **incompressível.**

A densidade e a energia de ligação por nucleão são independentes do número de nucleões.

Os núcleos são como trufas de **chocolate**



JLAB,USA

Nuclear dermatology clinic. The vessel containing the lead sample in the PREX experiment (*left*) and the massive spectrometers used to detect the electrons scattered from the lead nuclei and measure the nuclei's skin.

Photos Courtesy of Robert Michaels

Physicists Measure the Skin of a Nucleus

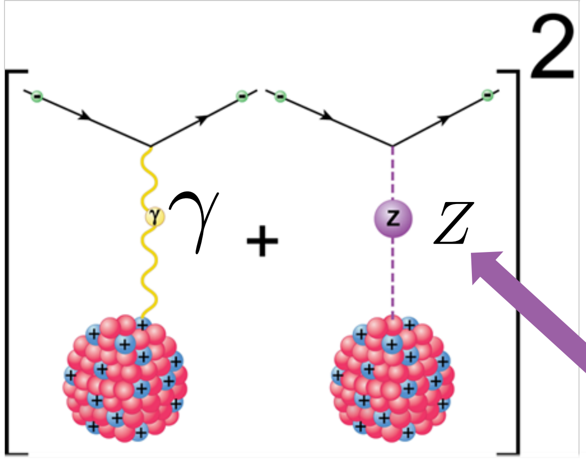
By **Adrian Cho** | Mar. 2, 2012 , 4:16 PM

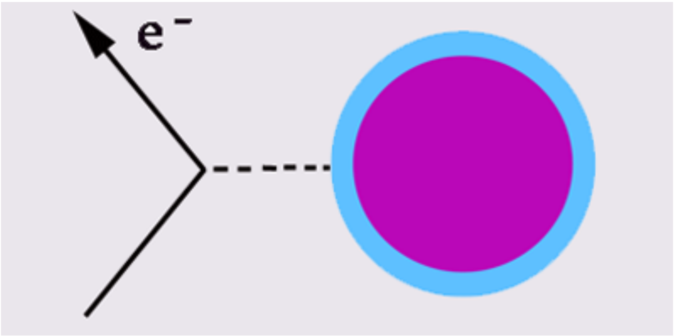
PREX Collaboration, Phys. Rev. Lett. 108, 112502 (2012)

Repulsão de muito curto alcance entre 2 neutrões "sela" o núcleo:
impede o seu colapso sob a atração da força no interior entre neutrões e protões.

Nuclei are like chocolate truffles

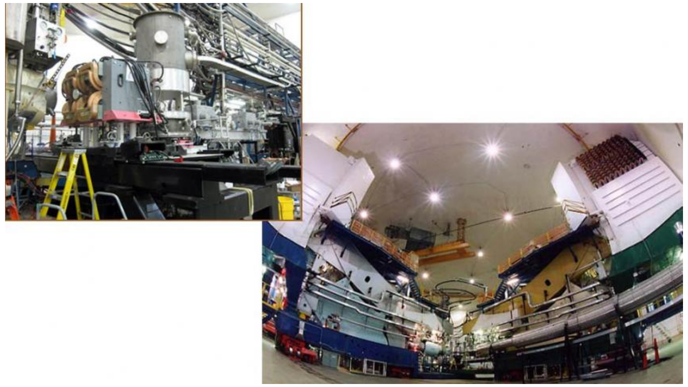
Interacting electrons with nuclei gives information on a non homogeneous nuclear structure: a *skin* of neutrons at the surface of heavy nuclei is measured.





APS

The weak neutral current creates a very small parity violation effect in the results



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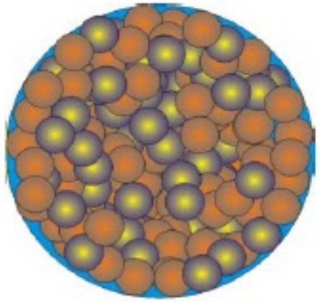
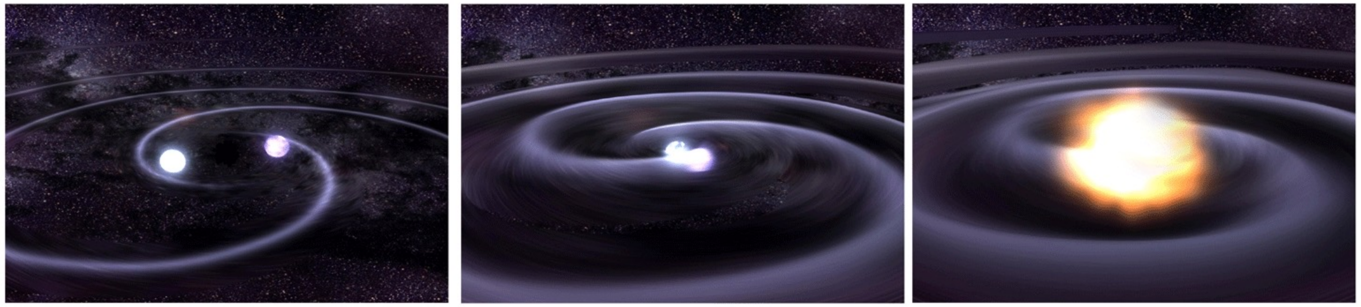


^{208}Pb ~ 10^{-15} m

Neutron star ~ 10^{4} m

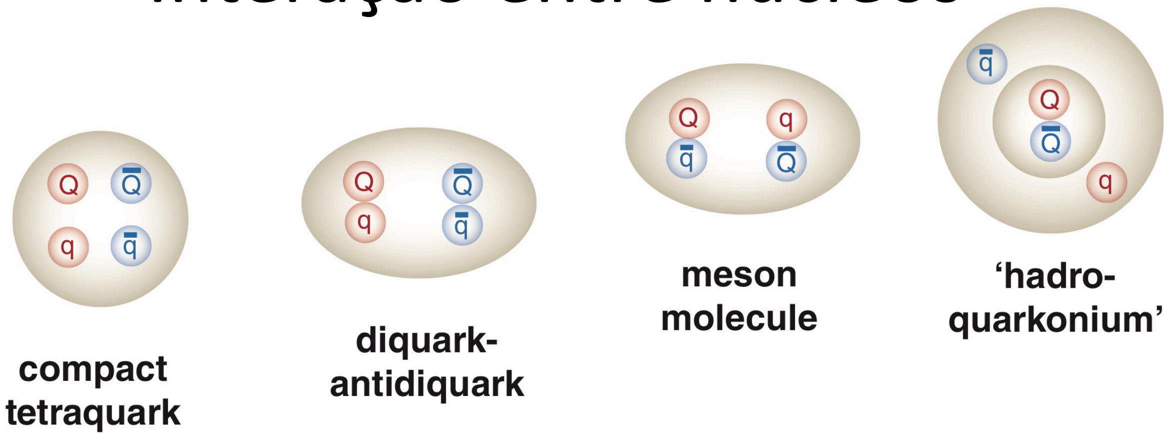


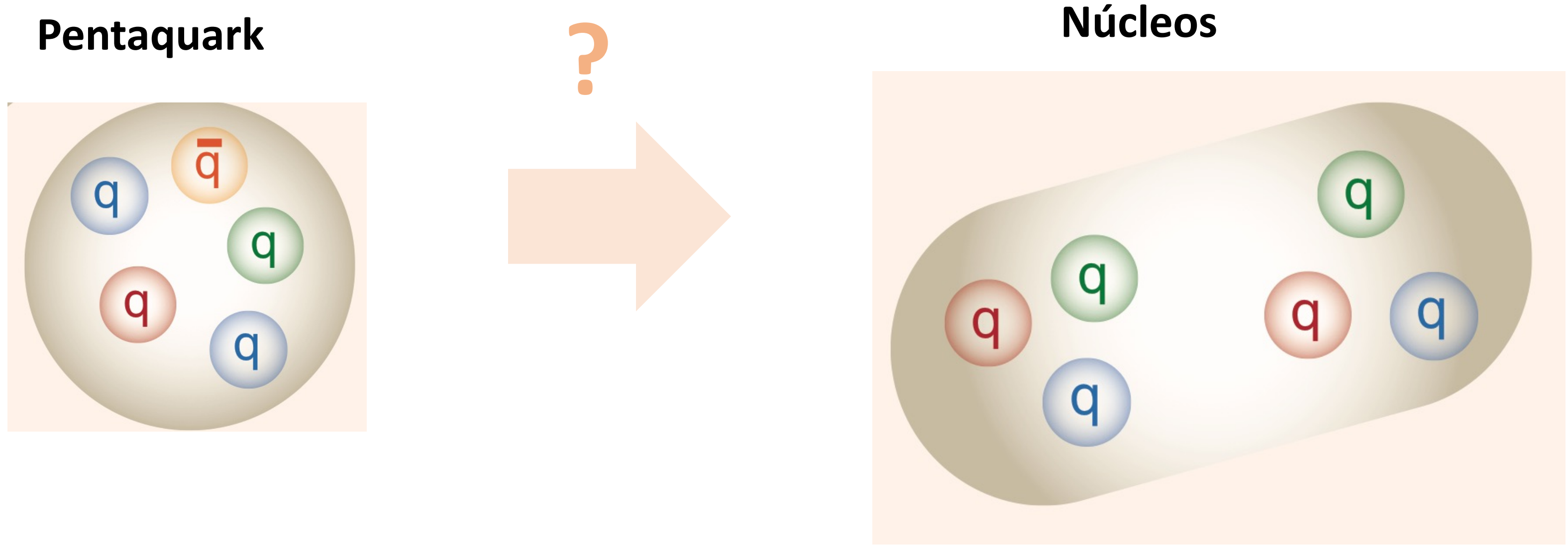
A repulsão de curto alcance entre neutrões

- contraria o colapso de estrelas de neutrões em buracos negros;
- explica os resultados recentes sobre ondas gravitacionais (GW) resultantes da colisão de estrelas de neutrões:

Mmax ≥ $2M_S$ em vez de Mmax ≥ $1{,}5M_S$ inferidos anteriormente de dados sobre os pulsars PSR J1903+0327 e PSR J0348+0432.

Problema em aberto
Interação entre núcleos





Problema em aberto
Massa dos quarks dentro dos nucleões

u	d	s	c	b	t
0.003	0.005	0.1	1	4	175
0.35	0.35	0.5	1.5	4.5	175

Bare quark

Dressed quark

Take-home message

Física Nuclear/Hadrónica

Investiga

- o “coração ” da matéria visível no universo,

(**núcleos**, hadrões, que têm estruturas diversas e são matéria em condições extremas)

- o mecanismo da formação de massa,

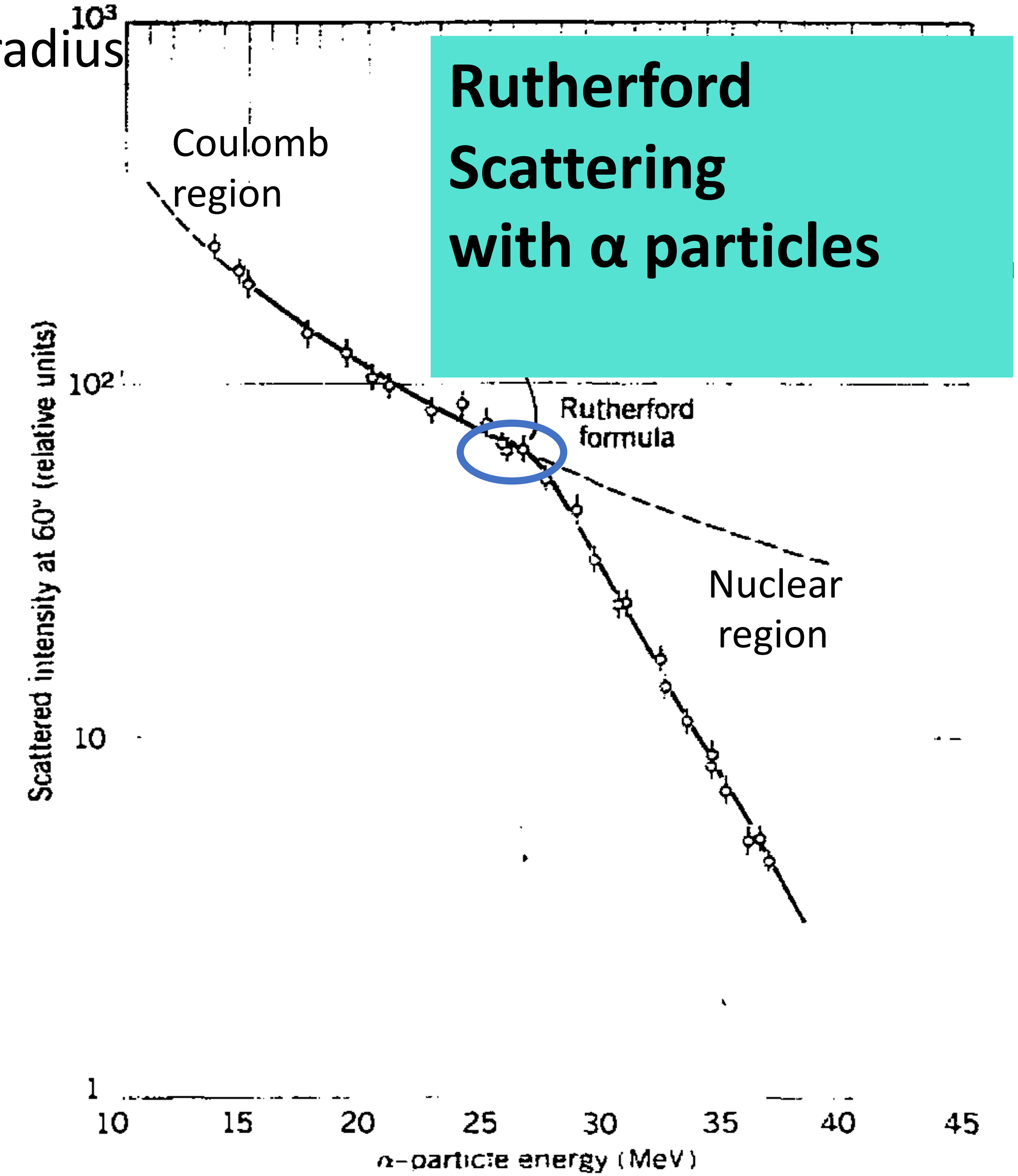
- as reacções nas estrelas que determinam a evolução do universo.

One can determine the nuclear radius from nuclear scattering

This is possible because of the relation between impact parameter, scattering angle and beam energy

$$b = C\frac{cotg(\theta/2)}{E}$$

A first estimate of the nuclear radius is obtained from *b* at the scattering angle and energy where there the breakdown of the Coulomb results is seen.



Are there other measurements of size?

Wavelength of light that is needed must be small.

Are there measureents of size?

Wavelength of a proton with kinetic energy of 5 MeV that collides to a nucleus.

This proton is non-relativistic.

$$\lambda = \frac{h}{p} \quad p = \sqrt{2mE} \quad \lambda = 5.76\ fm \qquad d \approx 1 fm \quad \lambda \approx d$$

The condition $\lambda << d$ does not hold.

Geometric optics is not valid.

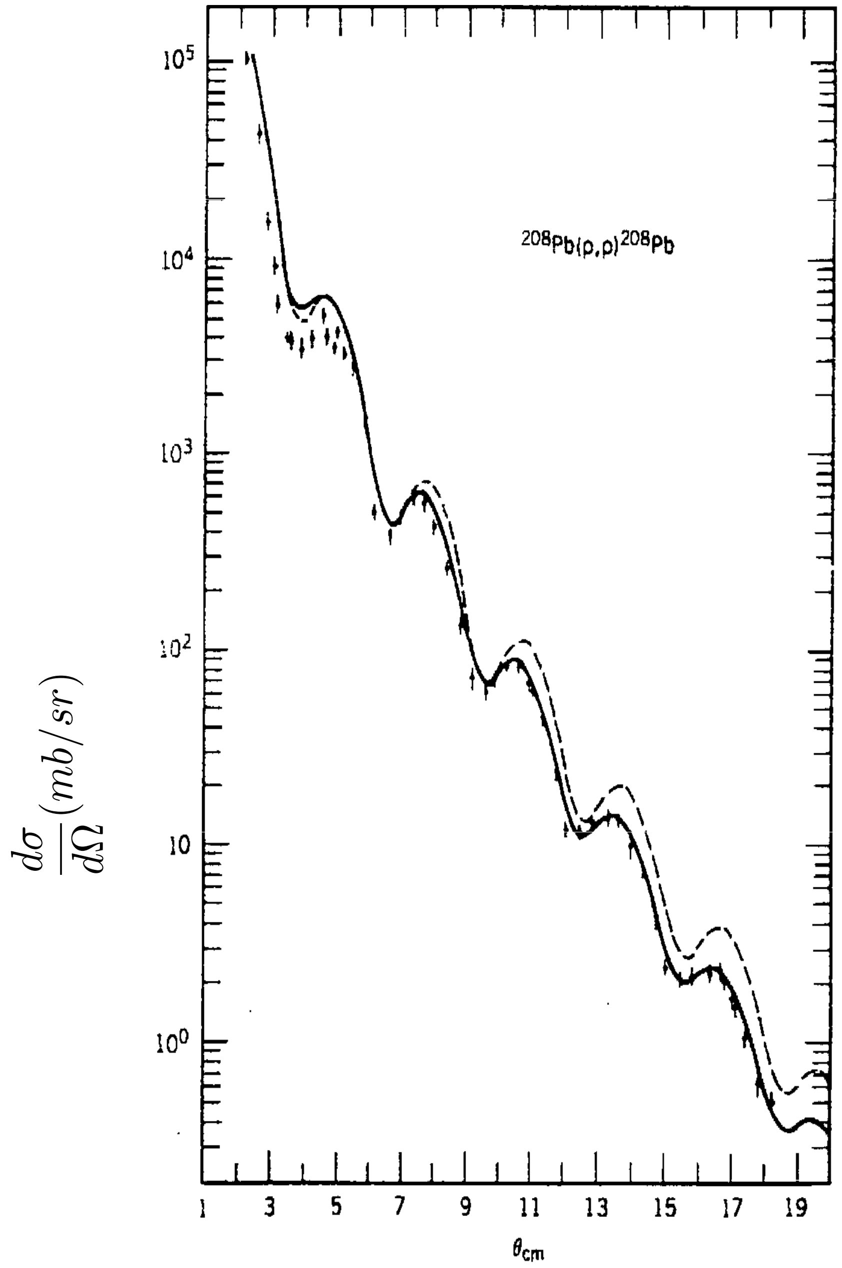
Diffraction occurs when a proton scatters from another nucleus.

This does not happen in the scattering of two classical particles.

Nucleons have a quantum mechanical behavior.

Proton beam
of 1.050 GeV
on a Pb target

Diffraction patterns are obtained and the position of minima give information on the proton size

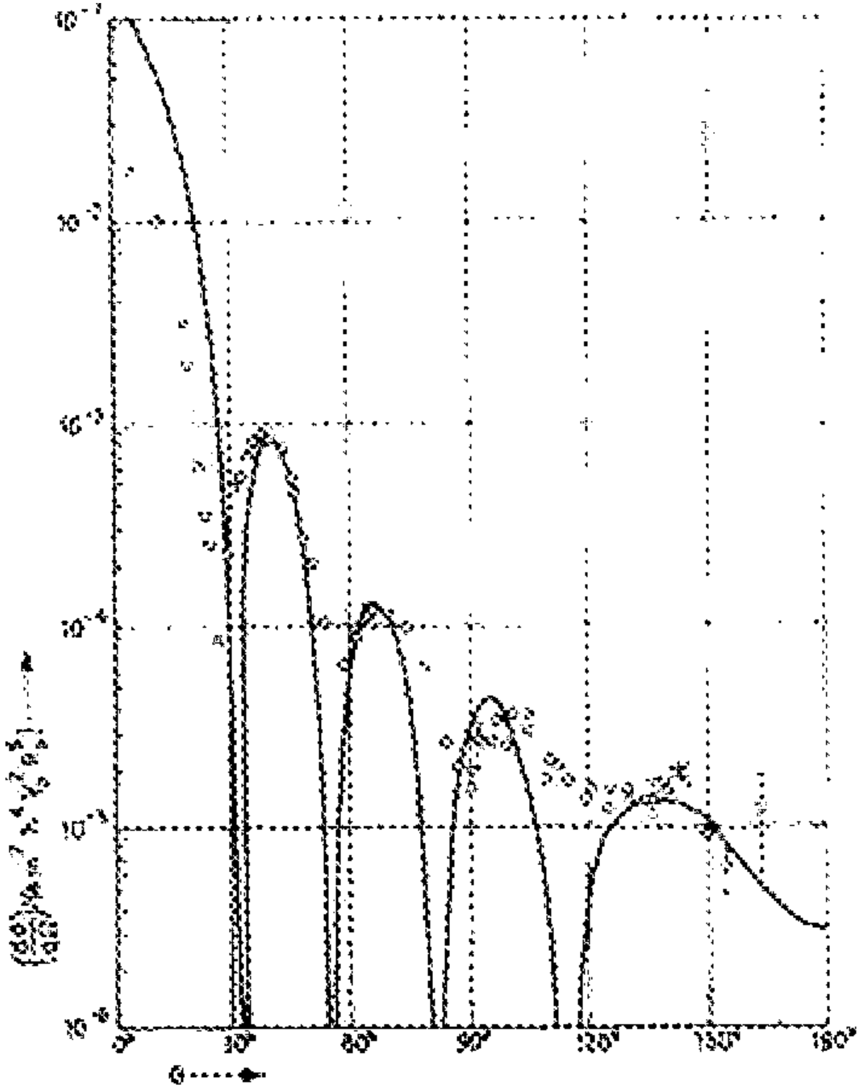


Minima are not sharp: "Difuseness" of radius

Determination of radius with nucleon-nucleus scattering is not precise.

Neutron beam of
14,5 MeV
on a Pb target

Diffraction patterns
again

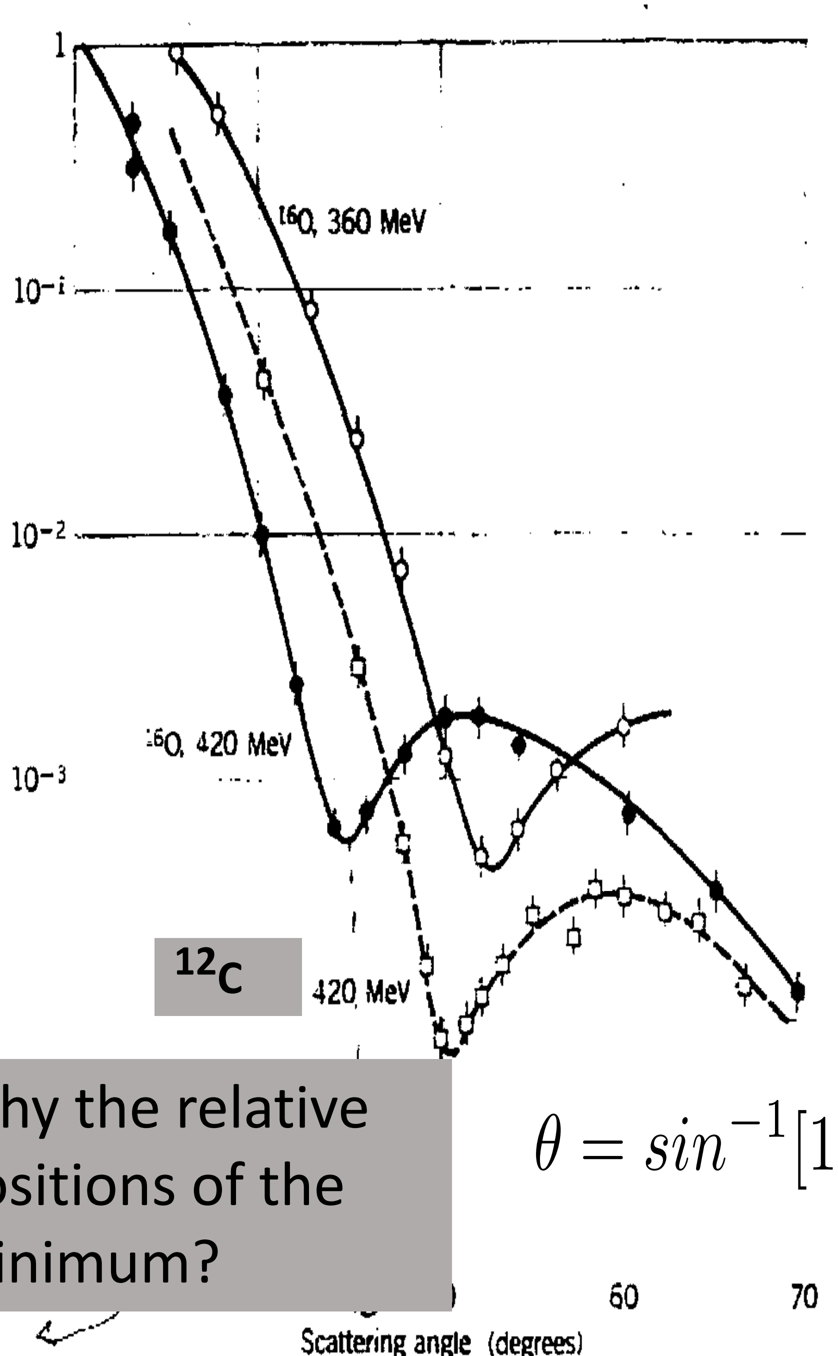


Neutron- nucleus scattering probe nuclear mass distribution and not charge distributions

Figure 1b.3. Angular distribution for elastic scattering on the square-well potential, as discussed in the text, obtained using the Born approximation with plane waves (see equation I.b.20) and with $kR_0 = 8.35$. The data correspond to 14.5 MeV neutron scattering on Pb. (Taken from Mayer-Kuckuk 1979.)

The Diffraction patters from Electron scattering experiments give more precise results for the nuclear radius.

One can check that the positions of the first minima are consistent with
the beam energies,
and the larger radius of oxygen 16



^{12}C

Why the relative positions of the minimum?

$$\theta = sin^{-1}[1.22\frac{\lambda}{d}]$$

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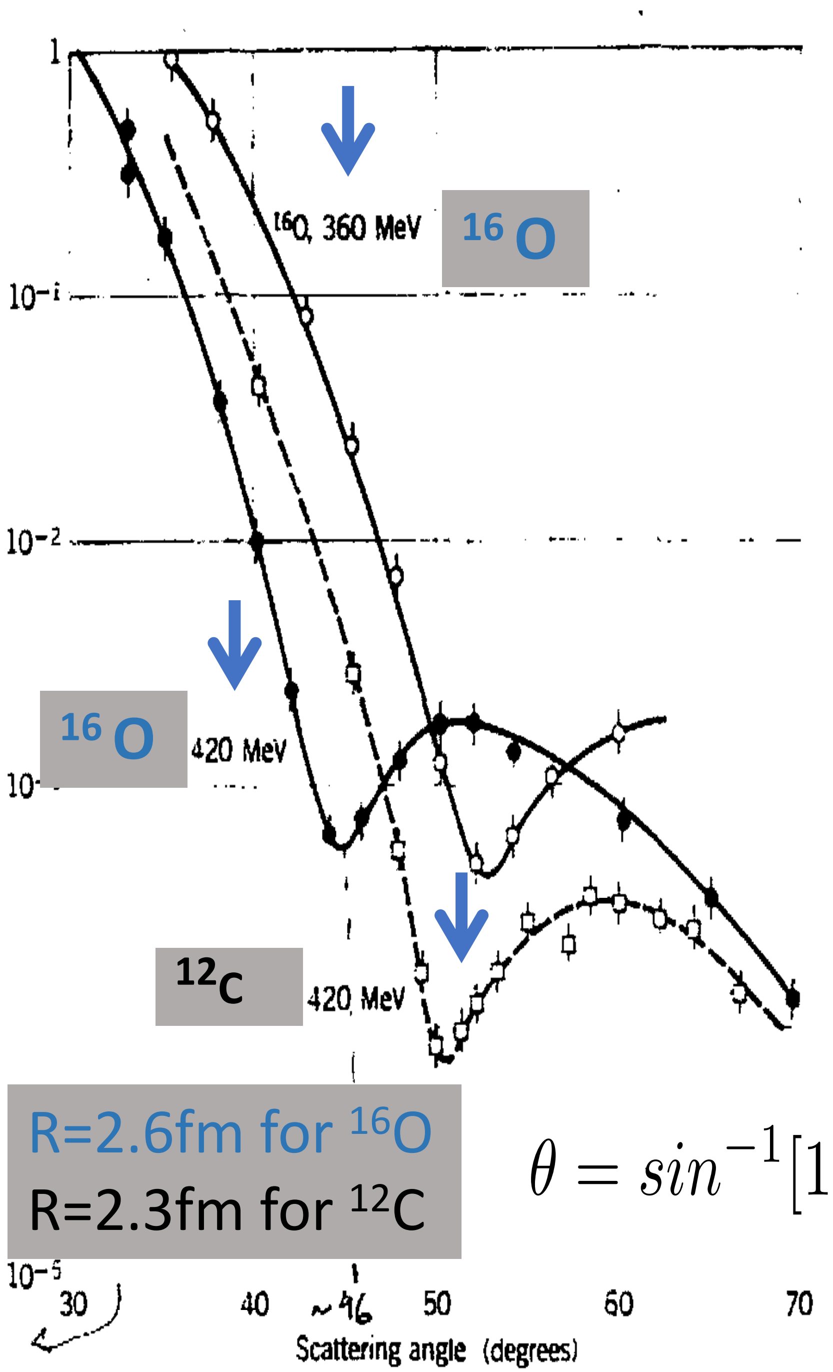
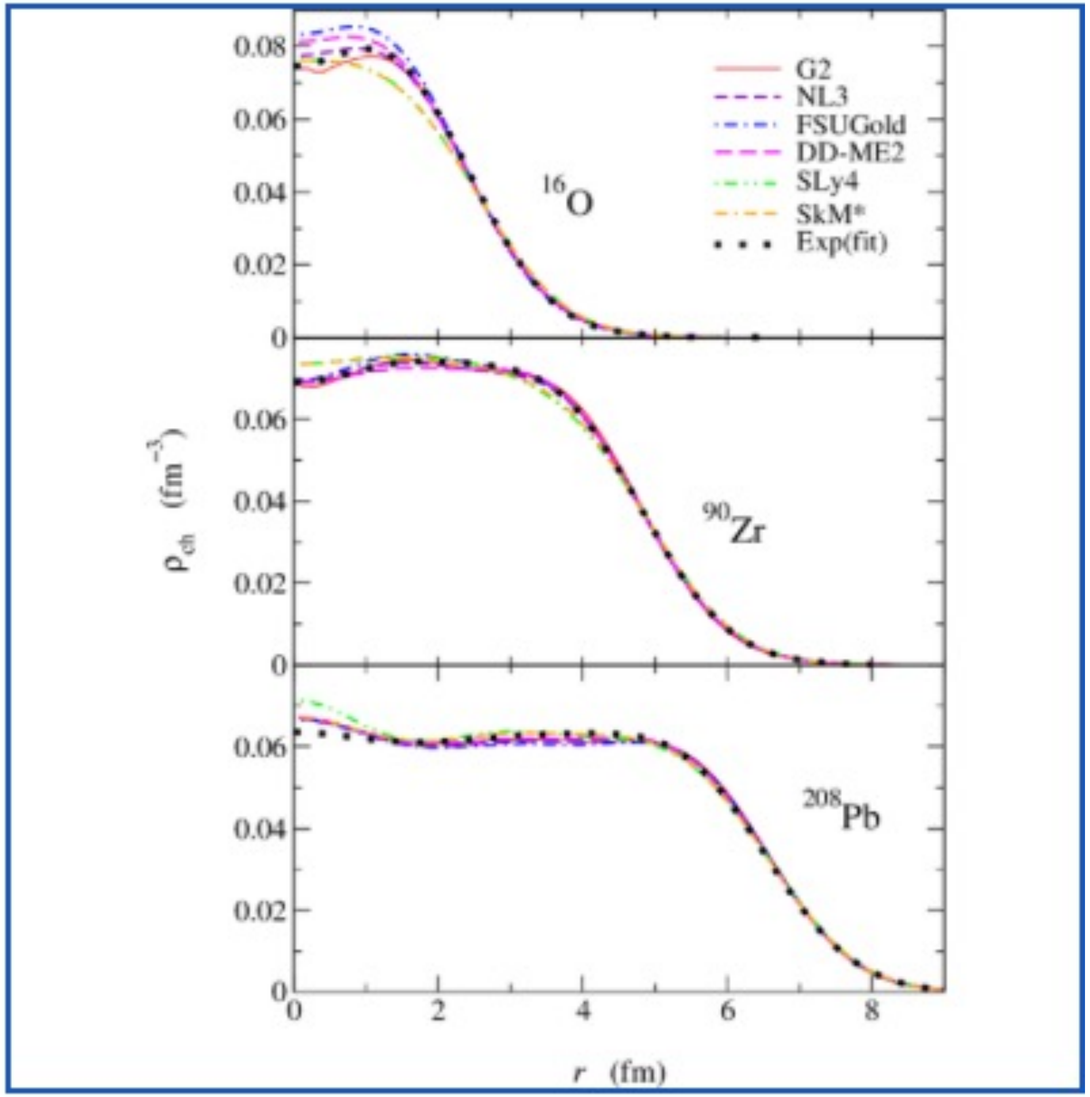


$$\theta = sin^{-1}[1.22\frac{\lambda}{d}]$$

Electron scattering cross section factorizes
into the cross section for a point nucleus scattering and
the Fourier Transform of the charge distribution

Recent results for charge distributions in some nuclei



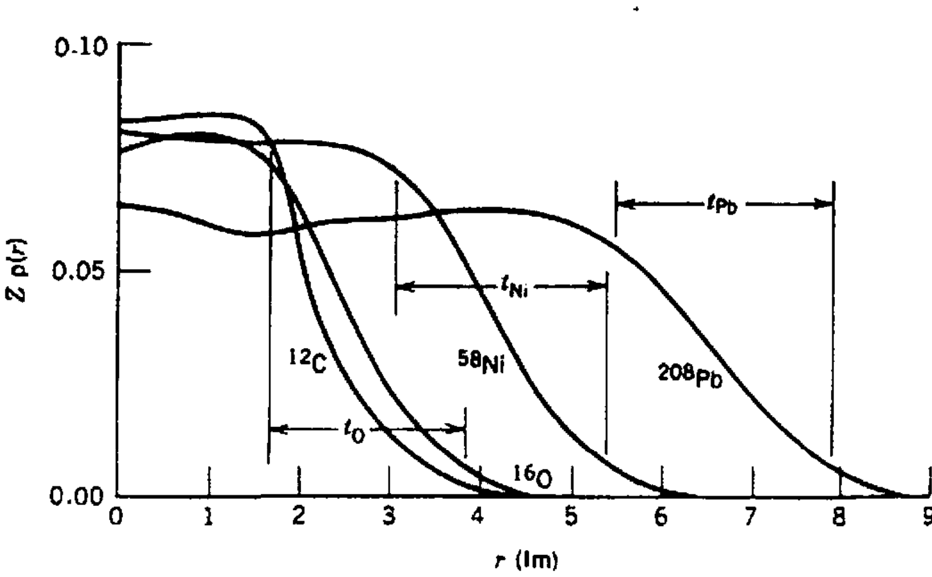
DOI:10.1103/PhysRevC.78.044332

Nucleon charge distribution

1. The shape of the nuclear density is almost the same for all nuclei with large nucleon number

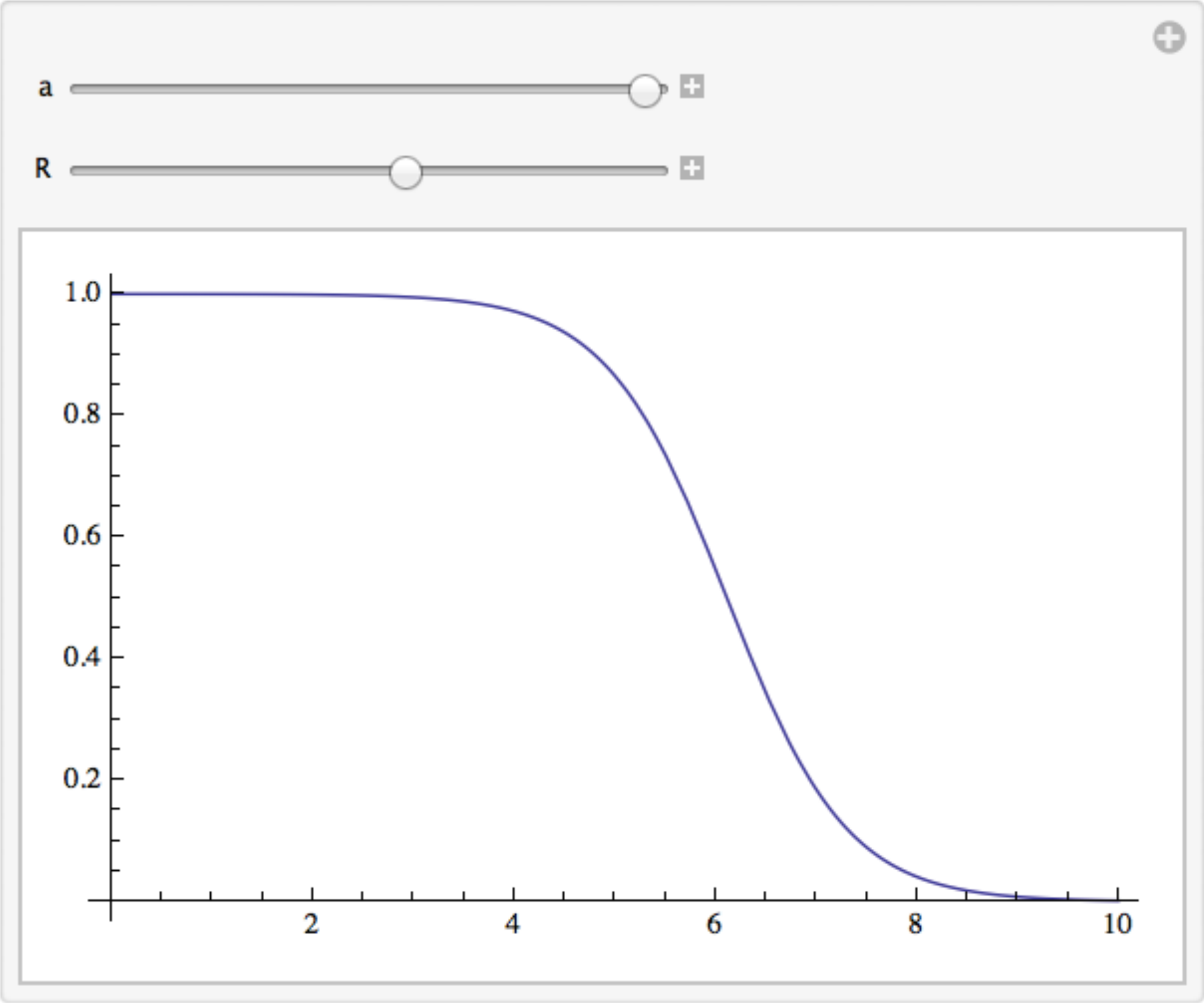
2. It is practically constant at the core until it starts to decrease near the surface.

3. The distance for it to drop to zero is almost the same for all nuclei. It drops from 90% to 10% of the central value in 2.3fm for almost all nuclei. (surface thickness). One can speak of a nucleus skin.



In[52]:=
```
Manipulate[Plot[(1 + Exp[(r - R) / a])^-1, {r, 0, 10}, PlotRange → All],
 {a, 0.1, 0.6}, {R, 1, 10}]
```

Out[52]=



$$\rho(r) = \frac{1}{1+exp\frac{r-R}{a}}$$

For nuclei of large mass number A the radius of the charge and neutron distributions is about the same

The radii of charge and nucleon distribution differ by only about 0.1fm and both vary with the nucleon number A in the same way.

$$R = R_0 A^{1/3}$$

This result is intriguing because there are more neutrons (n) than protons (p) in heavy nuclei.

The proton-neutron nuclear attraction is responsible for this effect.

- Neutrons attract protons counteracting the Coulomb force between them.
- The neutron-proton attraction is stronger than the proton-proton nuclear attraction.

(we see the signature of this in Nature: the deuteron is bound but there is no di-neutron or di-proton bound state).

- The neutron-proton attraction is so strong that protons and neutrons overlap and mix, making the radii of the charge and neutron distributions aboutequal.

What does the size and matter distributions of nuclei tell us on the nuclear interaction?

Nuclear Physics

Exploring the Heart of Matter

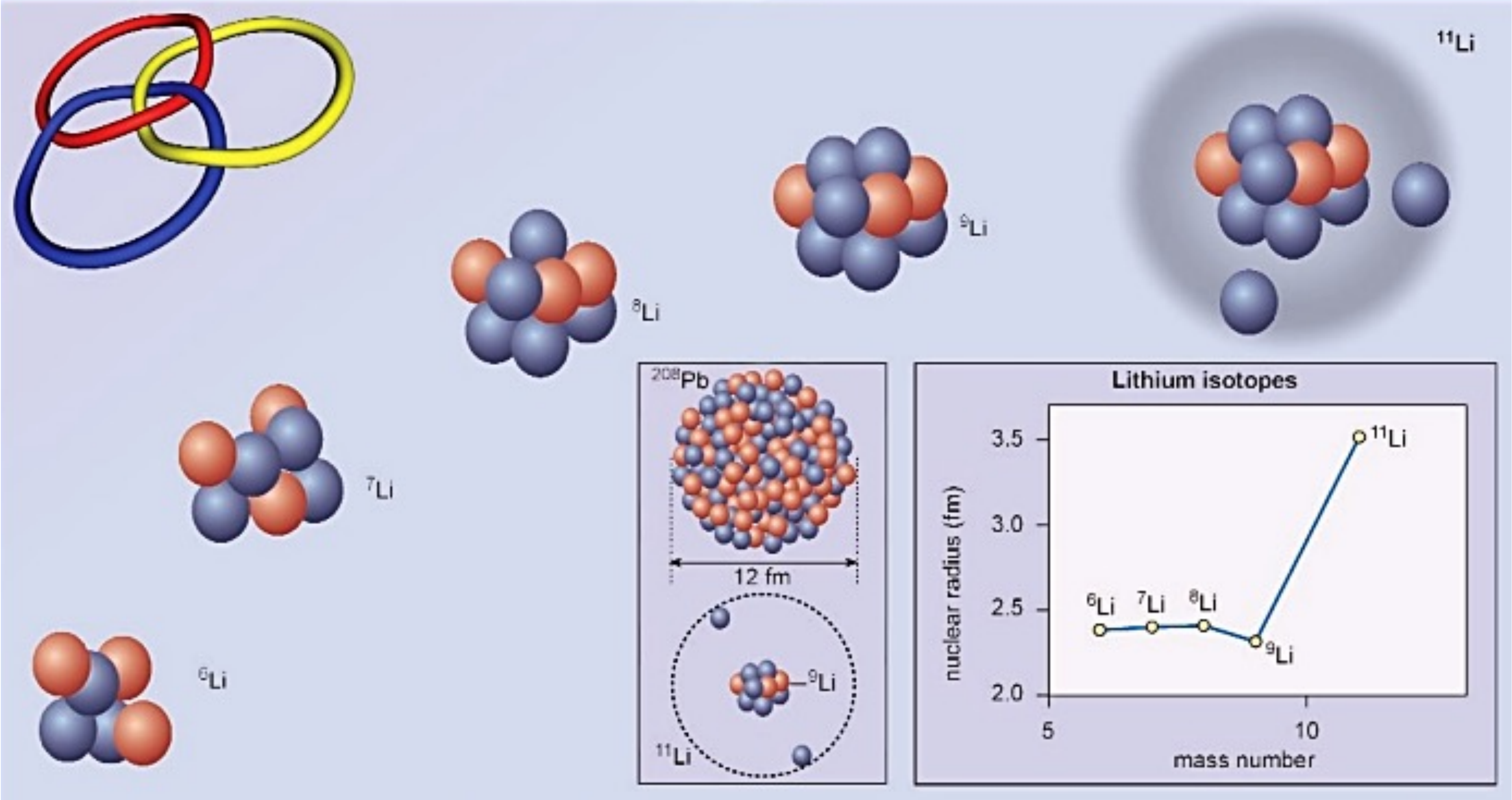
Committee on the Assessment of and Outlook for Nuclea
Physics
Board on Physics and Astronomy
Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL

Take-home message

Information on the NN interaction
can be inferred from the radius and the nucleon distributions

- **Short-range character:** *small impact parameter to obtain deviations from the Rutherford (Coulomb) cross section*
  - Another signature of the short-range is the observed **saturation** of binding energy per nucleon, i.e. *beyond a certain number of nucleons in the nucleus, the binding energy per nucleon does not vary.*
- **Repulsive short-range core :** *the nucleus charge distributions depict nuclei as being incompressible i.e. density is independently of the number of particles*
  - This repulsion can also be deduced from experimental results from several nuclei showing that nucleon pairs of have total momentum 0 and large relative momentum



11Li
9Li
8Li
7Li
6Li
208Pb
12 fm
9Li
11Li
Lithium isotopes
nuclear radius (fm)
3.5
3.0
2.5
2.0
5
10
mass number
6Li
7Li
8Li
9Li
11Li