Il misterioso mondo dei nuclei: la loro struttura e le loro interazioni

T. Marchi

PID-LNL Programma per docenti

Lunedì 10 Febbraio 2020

Istituto Nazionale di Fisica Nucleare

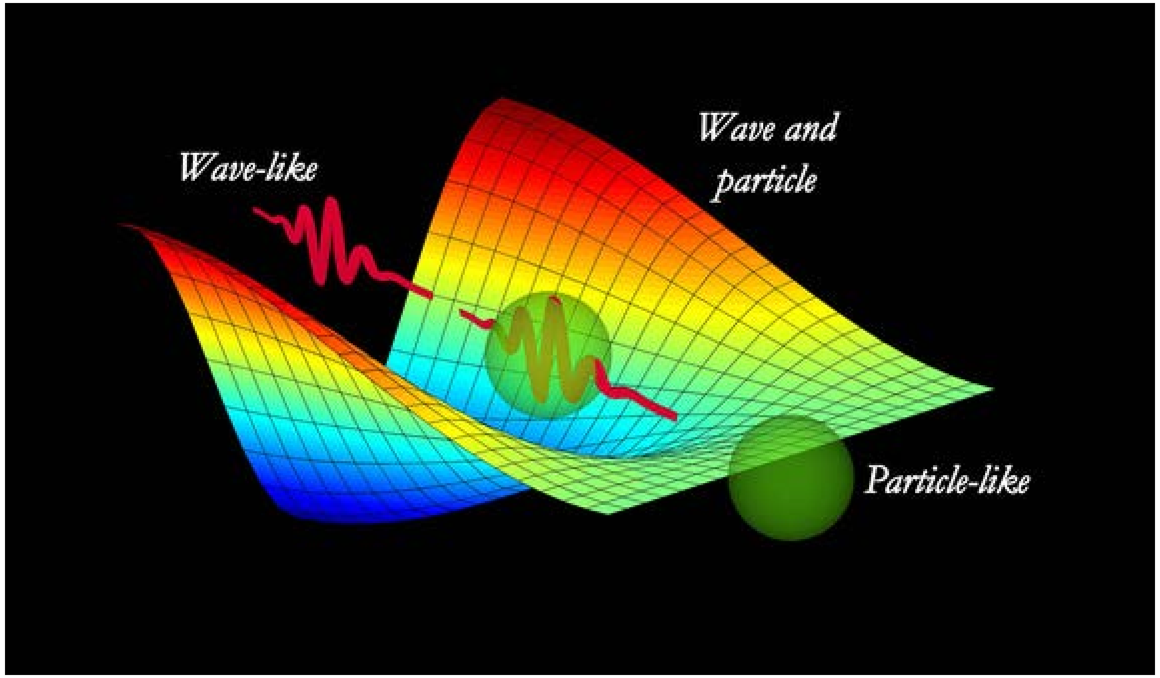
Indice

Parte 1: Il nucleo atomico e le reazioni nucleari

Un Sistema Quantistico, a molti corpi,
sorgente del campo di forze a cui è sottoposto

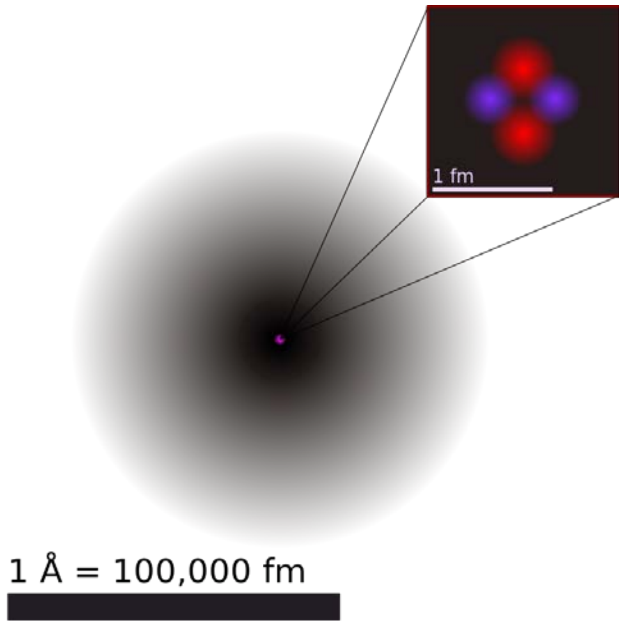
Disclaimer

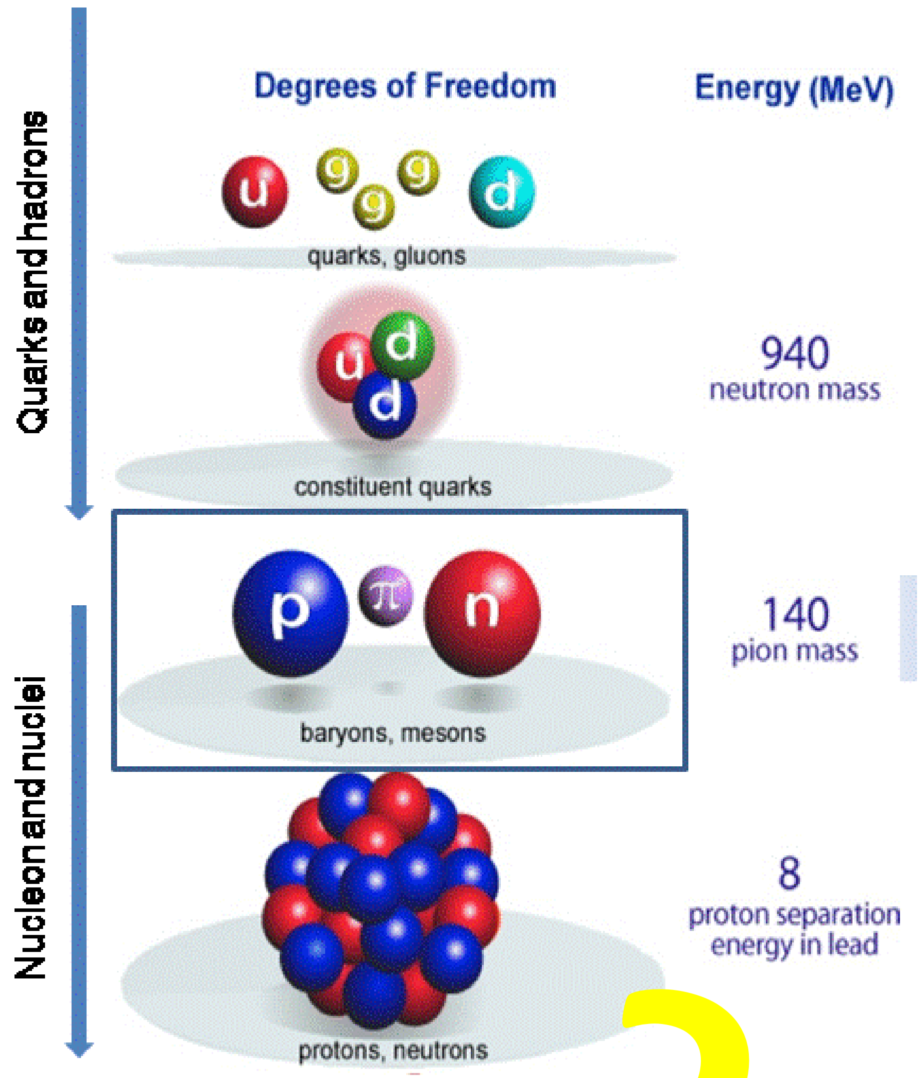
Louis de Broglie *1924*



$$\lambda = \frac{h}{P} = \frac{h}{mv}$$

Il Nucleo atomico: dimensioni

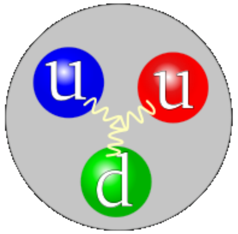




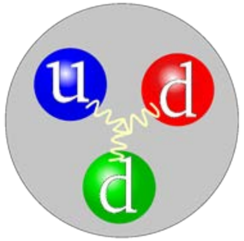
Ordine di grandezza: 1 fm (femtometro, Fermi) ~ $10^{-?}$ m

Il nucleo atomico: i nucleoni

Nucleone	Carica (Q_e)	Massa (MeV/c^2)	Spin	Vita media
Protone	+1	938,27	1/2	$>1{,}6 \times 10^{33}$ anni
Neutrone	0	939,57	1/2	880,2 s

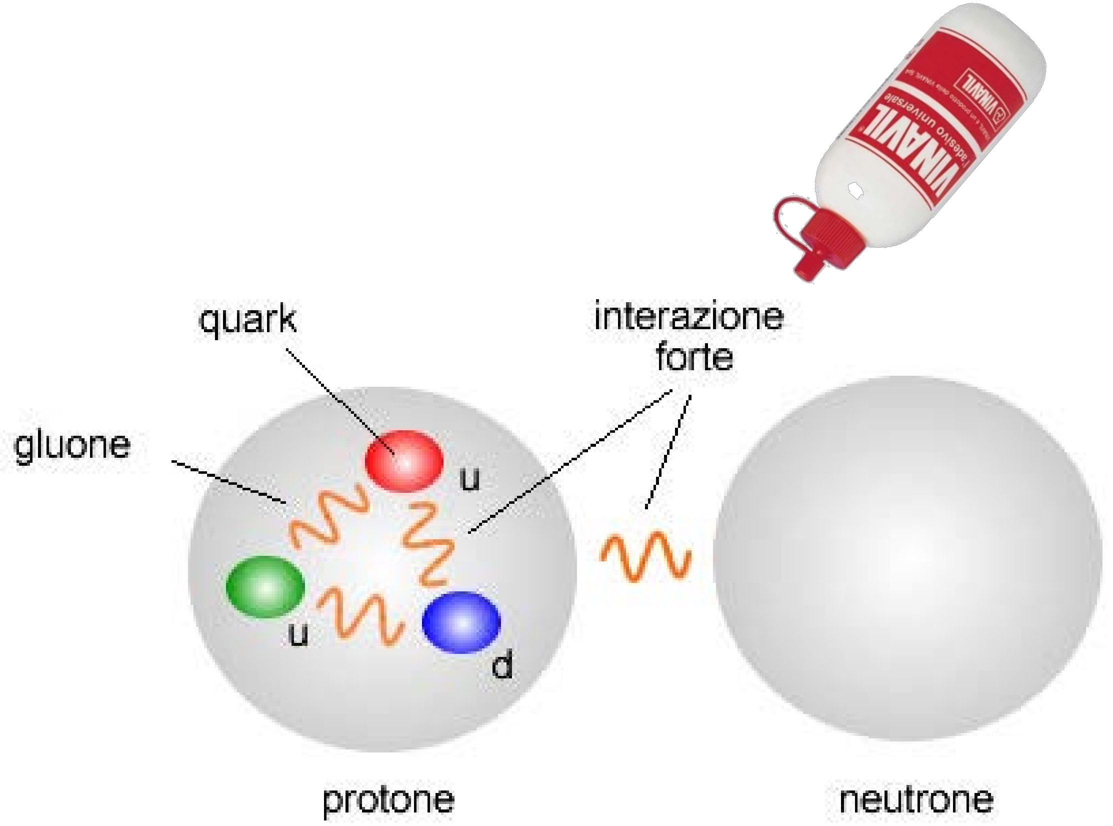


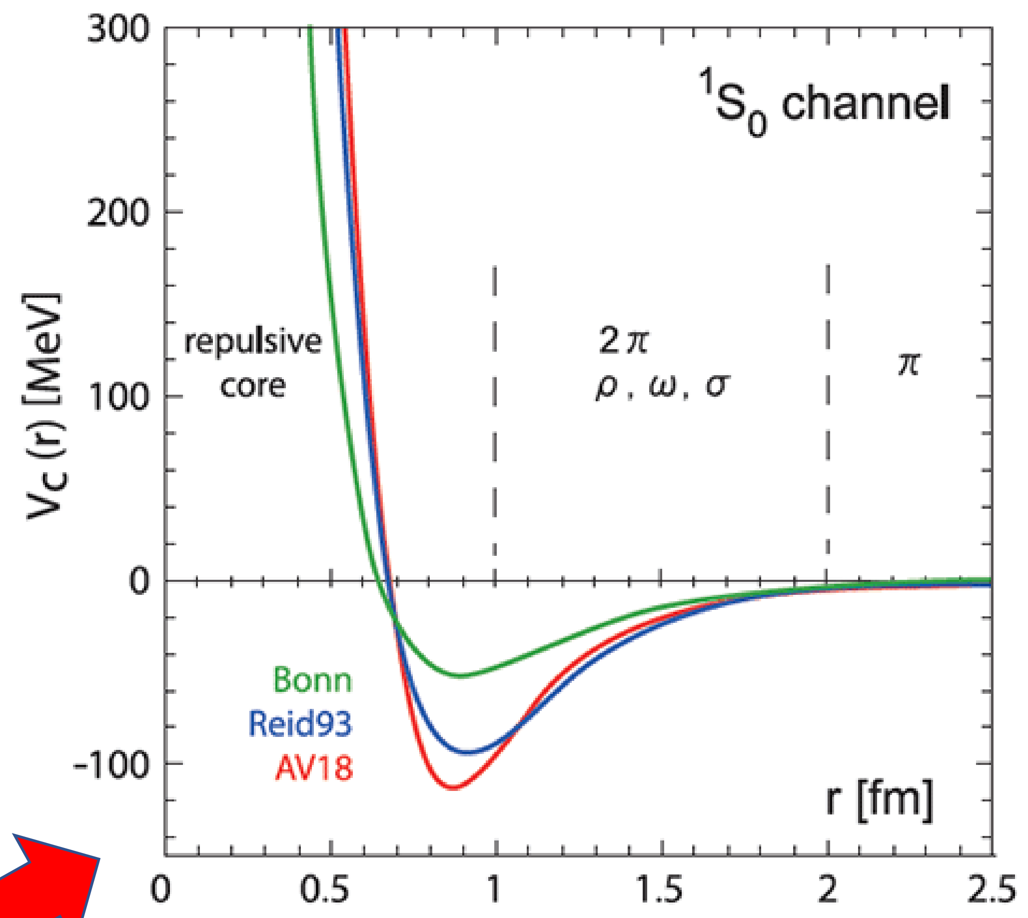
Protone



Neutrone

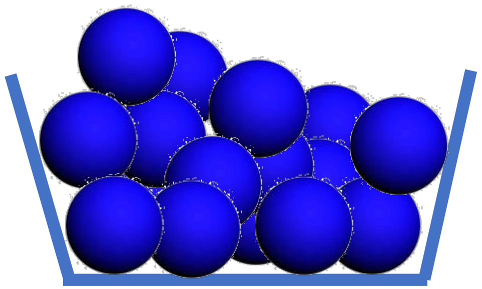
Il nucleo atomico: la forza forte

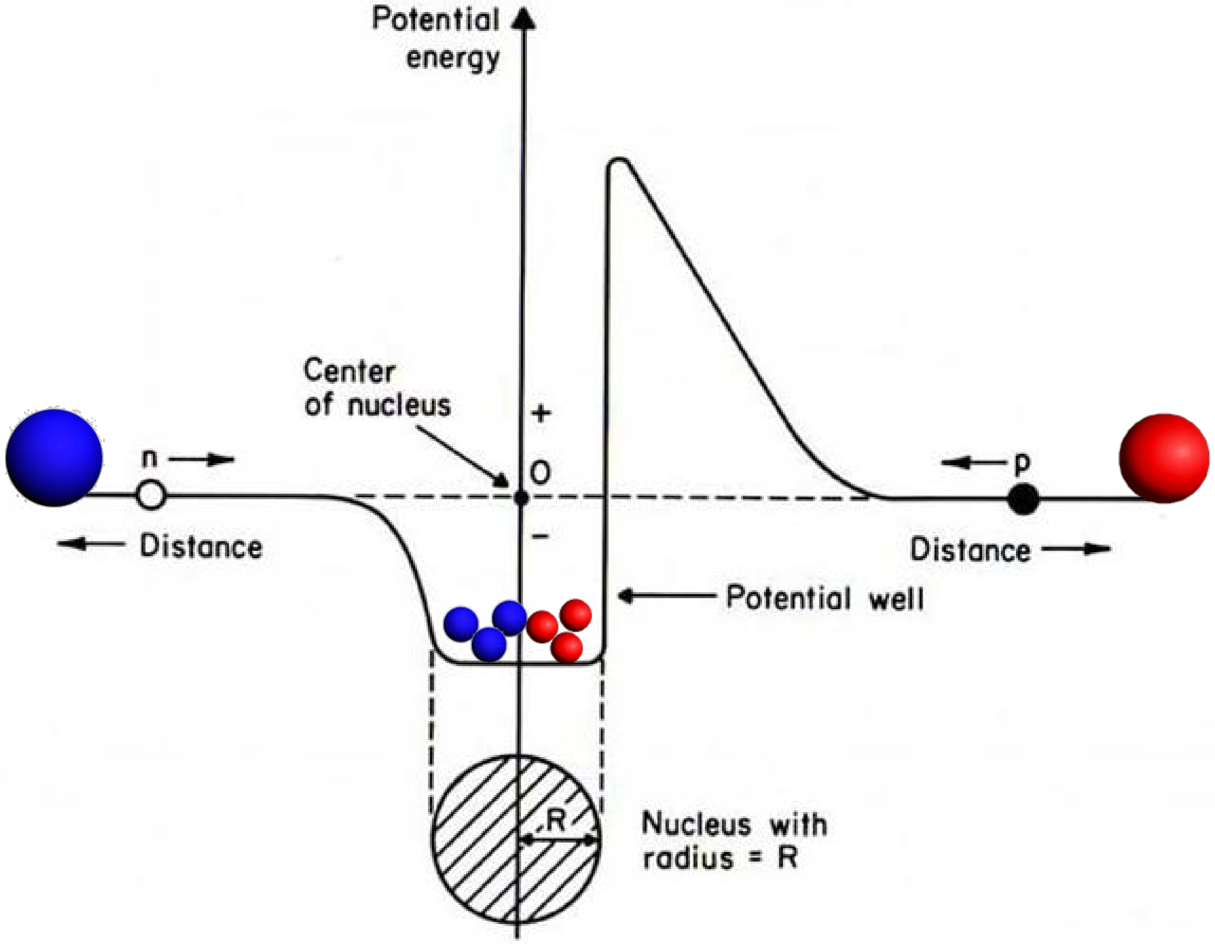


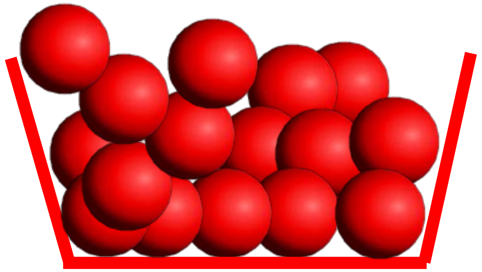


IL PROBLEMA è tutto qui…

Costruiamo un nucleo

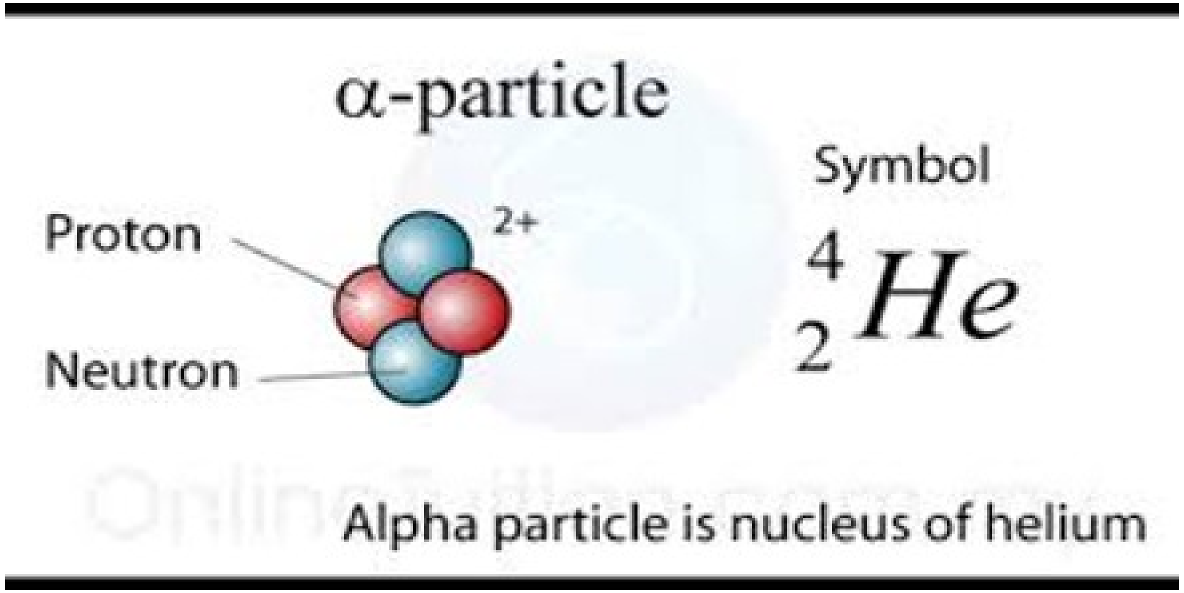




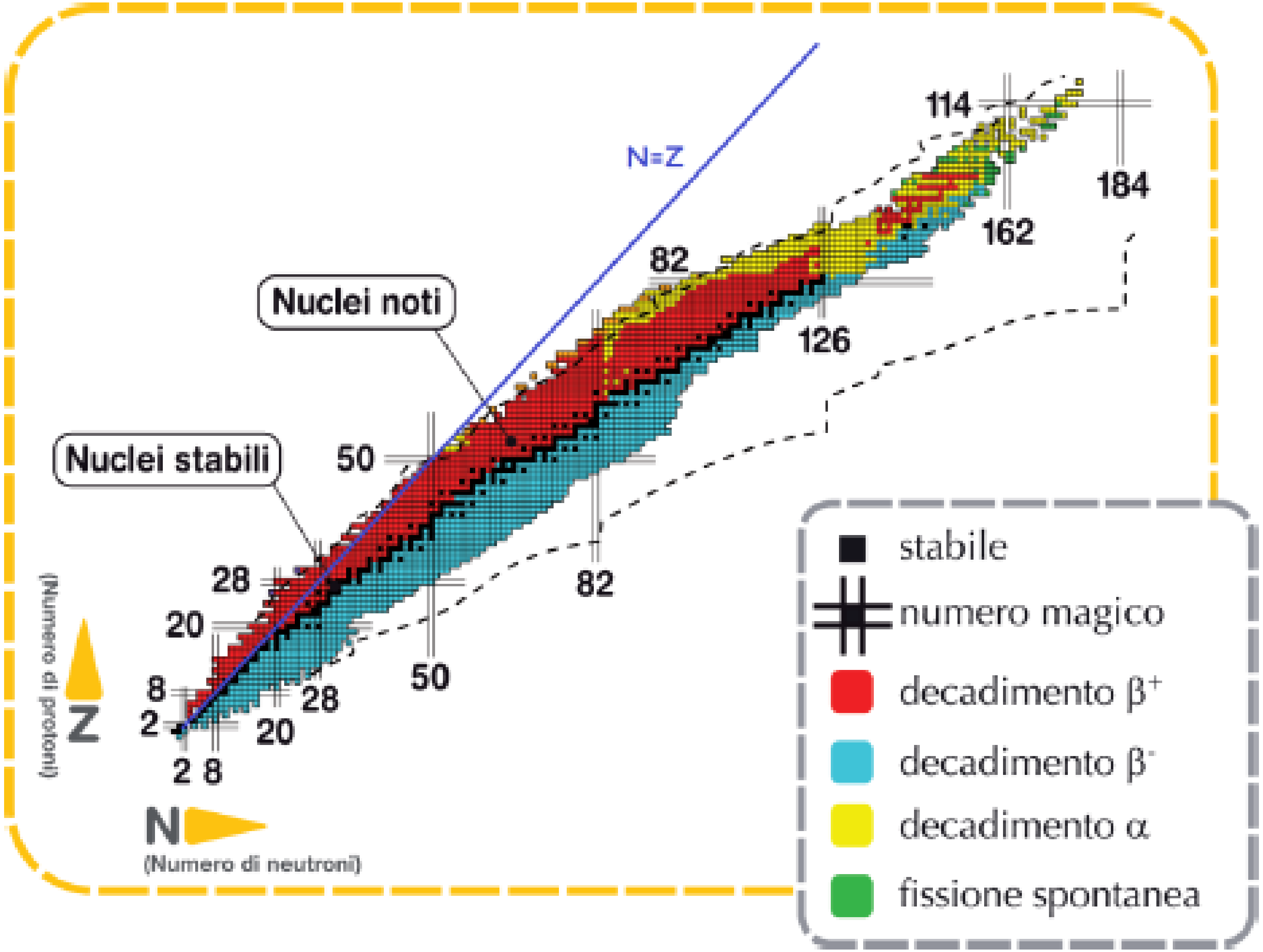


Prendete Z protoni e N neutroni, mescolate con abbondante colla vinilica

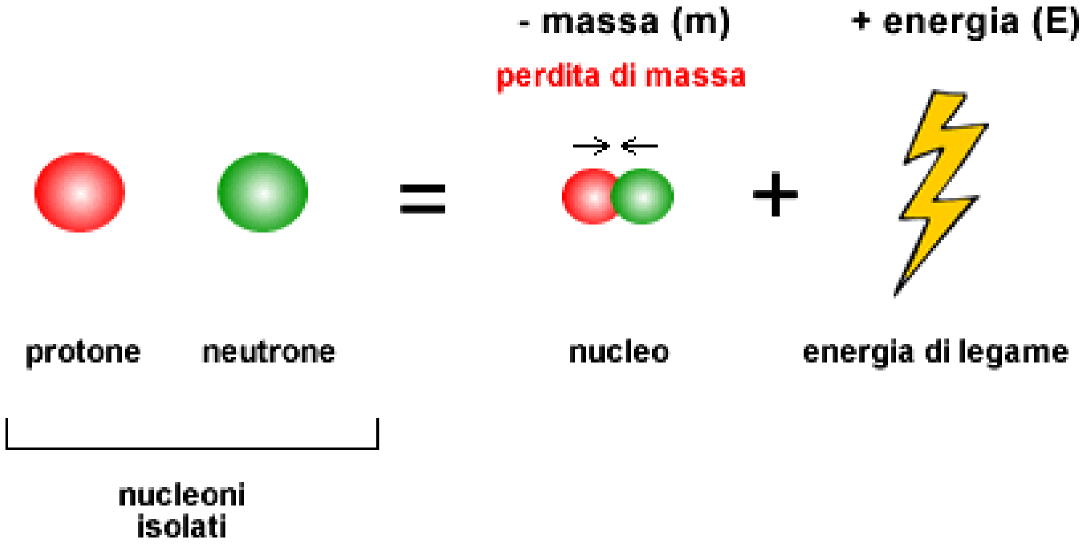
Costruiamo un nucleo

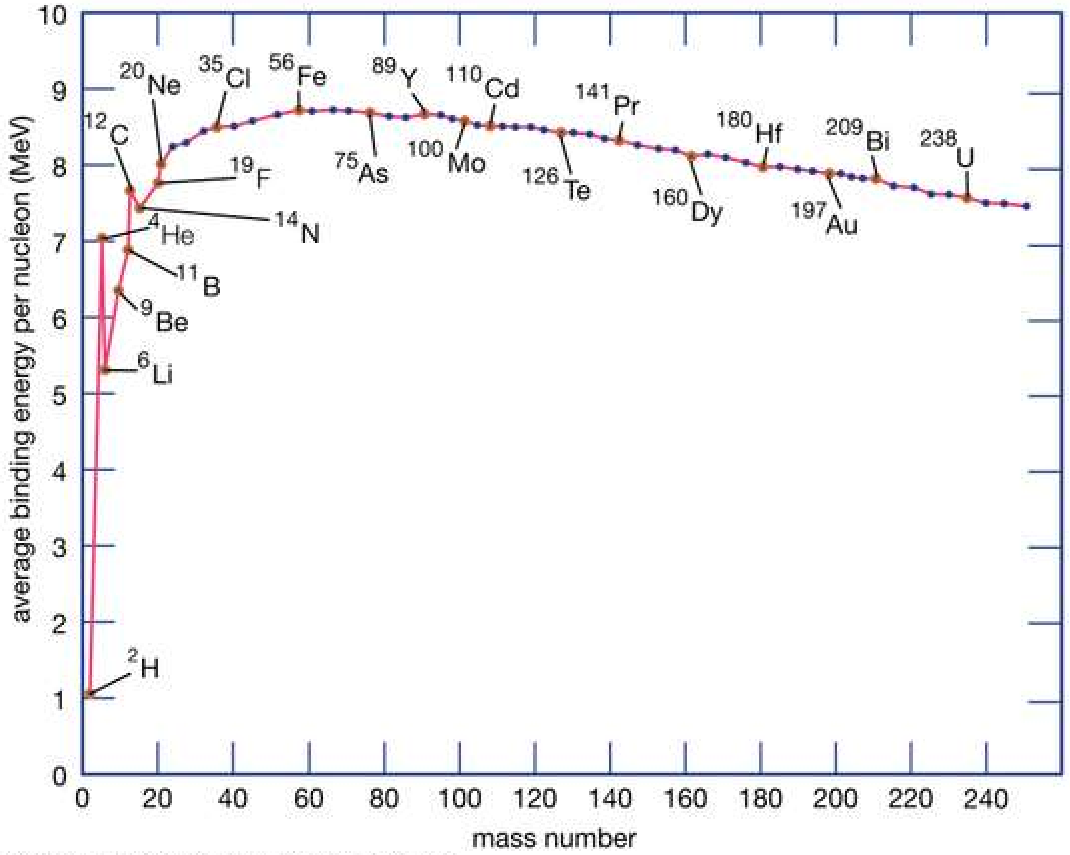


La carta dei Nuclidi

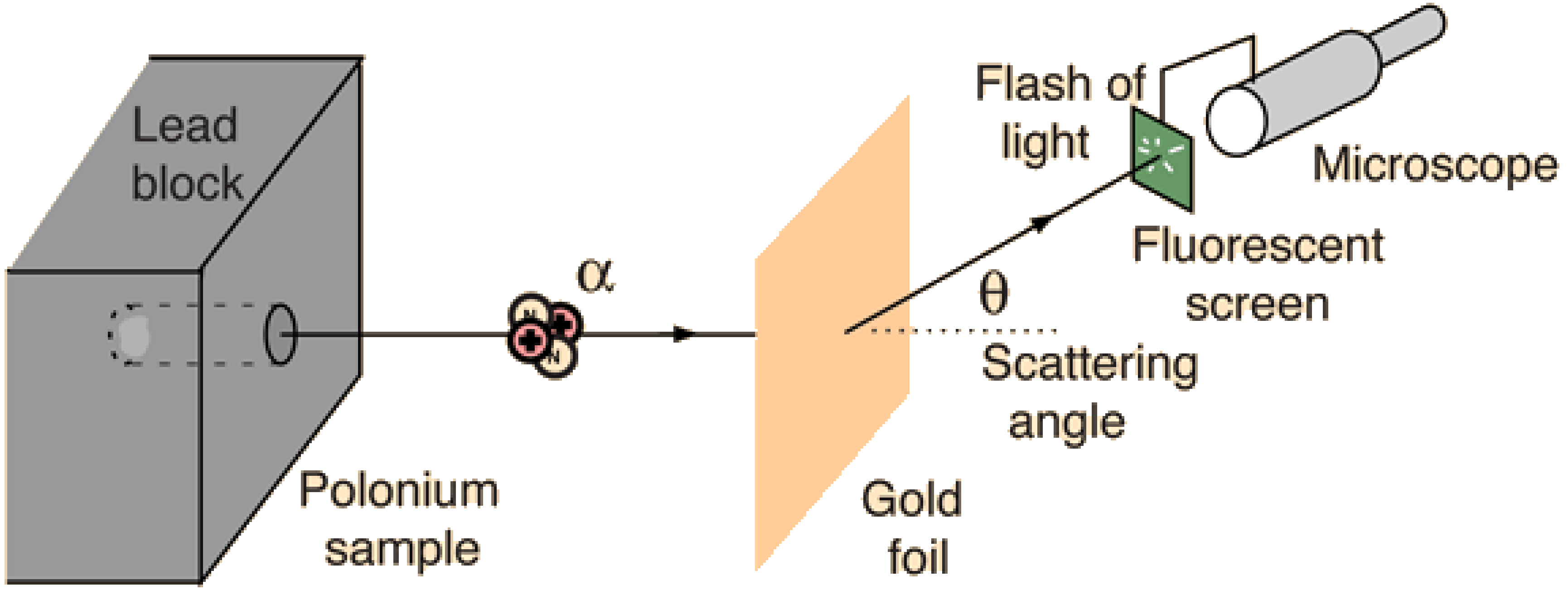


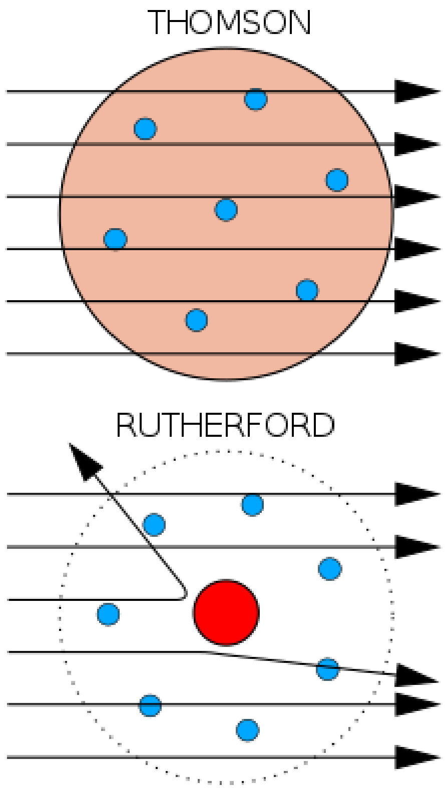
L'energia di legame



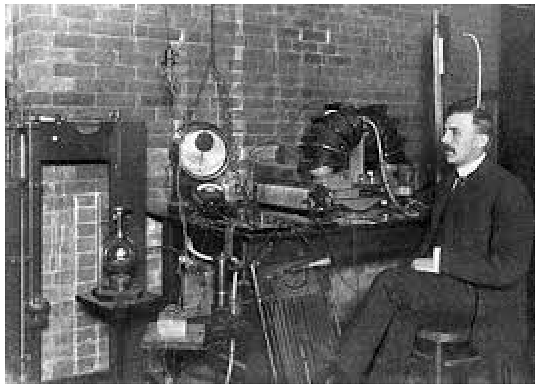


L'Esperimento di Rutherford - osservazione

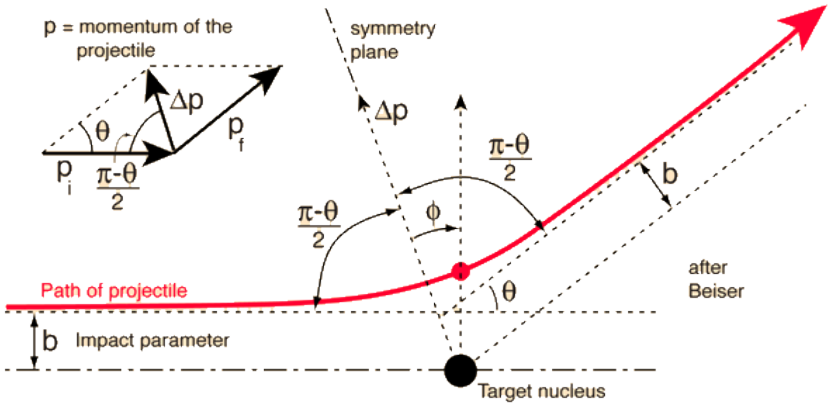




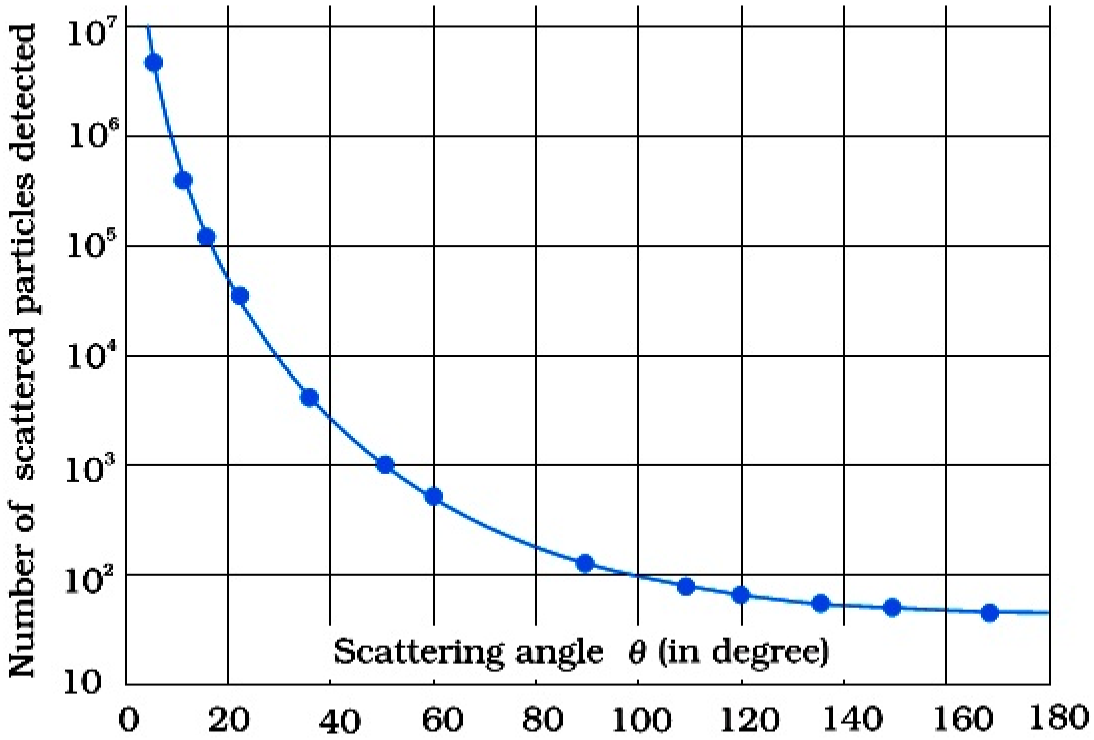
Simulazione esperimento di Rutherford:
https://phet.colorado.edu/en/



L’Esperimento di Rutherford - modello



$$N(\theta) = \frac{nt}{4r^2}\left(\frac{zZ}{2K}\right)^2\left(\frac{e^2}{4\pi\epsilon_0}\right)^2\frac{1}{\sin^4(\frac{1}{2}\theta)}$$



L'Esperimento di Rutherford - pubblicazione

LXXIX. *The Scattering of α and β Particles by Matter and the Structure of the Atom.* *By* Professor E. RUTHERFORD, *F.R.S., University of Manchester* *.

§ 1. IT is well known that the α and β particles suffer deflexions from their rectilinear paths by encounters with atoms of matter. This scattering is far more marked for the β than for the α particle on account of the much smaller momentum and energy of the former particle. There seems to be no doubt that such swiftly moving particles pass through the atoms in their path, and that the deflexions observed are due to the strong electric field traversed within the atomic system. It has generally been supposed that the scattering of a pencil of α or β rays in passing through a thin plate of matter is the result of a multitude of small scatterings by the atoms of matter traversed. The observations, however, of Geiger and Marsden † on the scattering of α rays indicate that some of

the α particles must suffer a deflexion of more than a right angle at a single encounter. They found, for example, that a small fraction of the incident α particles, about 1 in 20,000, were turned through an average angle of 90° in passing through a layer of gold-foil about ·00004 cm. thick, which was equivalent in stopping-power of the α particle to 1·6 millimetres of air. Geiger ‡ showed later that the most probable angle of deflexion for a pencil of α particles traversing a gold-foil of this thickness was about 0°·87. A simple calculation based on the theory of probability shows that the chance of an α particle being deflected through 90° is vanishingly small. In addition, it will be seen later that the distribution of the α particles for various angles of large deflexion does not follow the probability law to be expected if such large deflexions are made up of a large number of small deviations. It seems reasonable to suppose that the deflexion through a large angle is due to a single atomic encounter, for the chance of a second encounter of a kind to produce a large deflexion must in most cases be exceedingly small. A simple calculation shows that the atom must be a seat of an intense electric field in order to produce such a large deflexion at a single encounter.

Recently Sir J. J. Thomson § has put forward a theory to

* Communicated by the Author. A brief account of this paper was communicated to the Manchester Literary and Philosophical Society in February, 1911.

† Proc. Roy. Soc. lxxxii. p. 495 (1909).

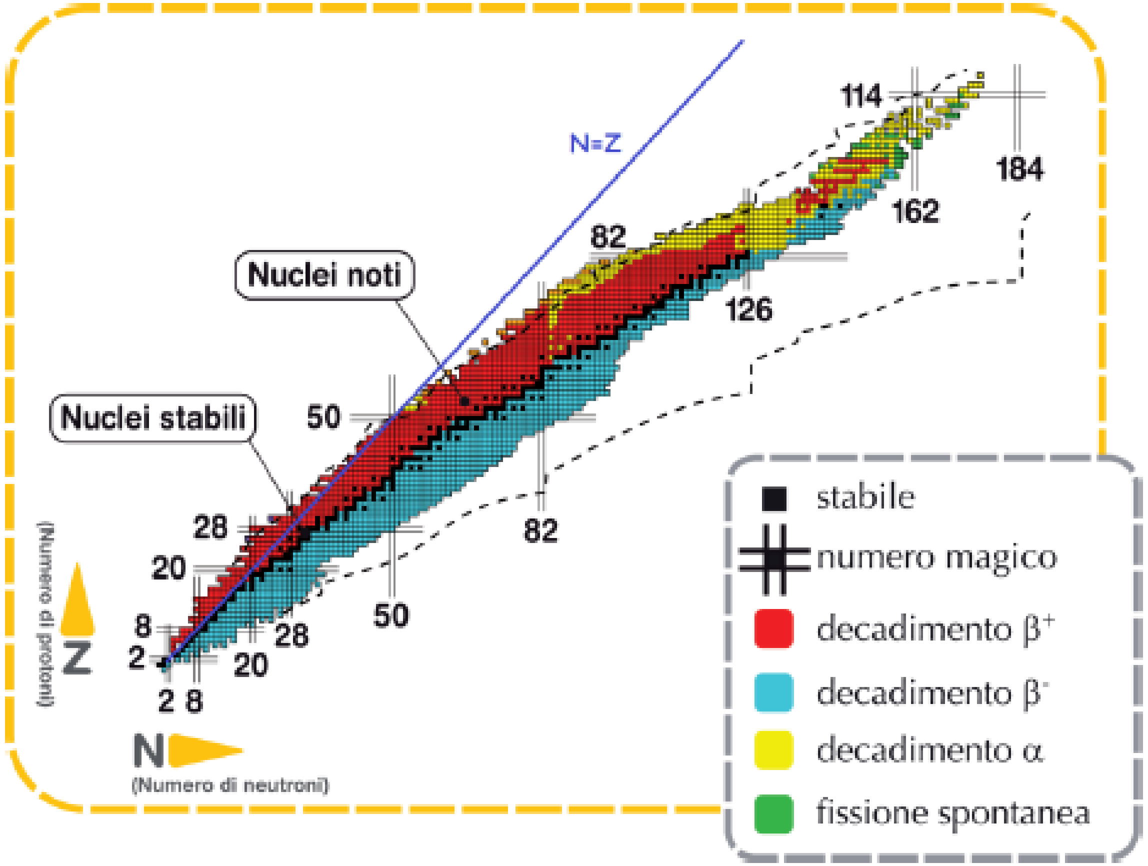
‡ Proc. Roy. Soc. lxxxiii. p. 492 (1910).

§ Camb. Lit. & Phil. Soc. xv. pt. 5 (1910).

Philosophical Magazine, 21 (1911) 669

L'Esperimento di Rutherford
è il prototipo di qualsiasi esperimento moderno

E quindi? E' tutto chiaro. O no?



(Alcuni) problemi aperti, da affrontare nei prossimi anni:

- **Eslporare** la carta dei nuclidi e trovare sperimentalmente limiti di esistenza nucleare
- **Osservare** proprietà esotiche dei nuclei (forme, strutture, etc.)
- **Spiegare** il ruolo della simmetria di isospin (nEOS, E_{sym})

Studiare la fisica della **forza nucleare forte** all'interno del Sistema nucleare, **per conoscere le interazioni fondamentali e definire le leggi di simmetria della natura.**

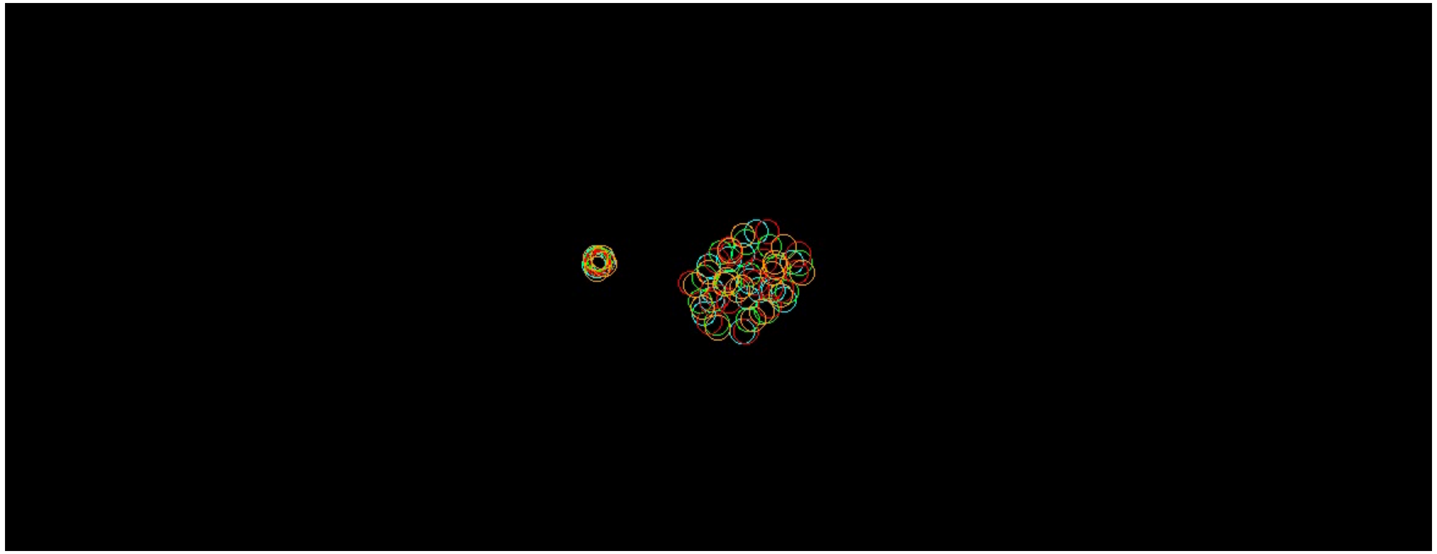
Reazioni Nucleari oggi

Reazioni Nucleari

- Caratterizzare i **meccanismi** tipici delle reazioni Nucleari e descriverne la **dinamica**
- Studiare gli **effetti della struttura nucleare sui meccanismi di reazione**
- Fornire **dati di precisione** per le applicazioni

Parametri di reazione

- A, Z, J^{π} proiettile e bersaglio (struttura)
- Asimmetria di massa
- Energia del proiettile
- Parametro di impatto

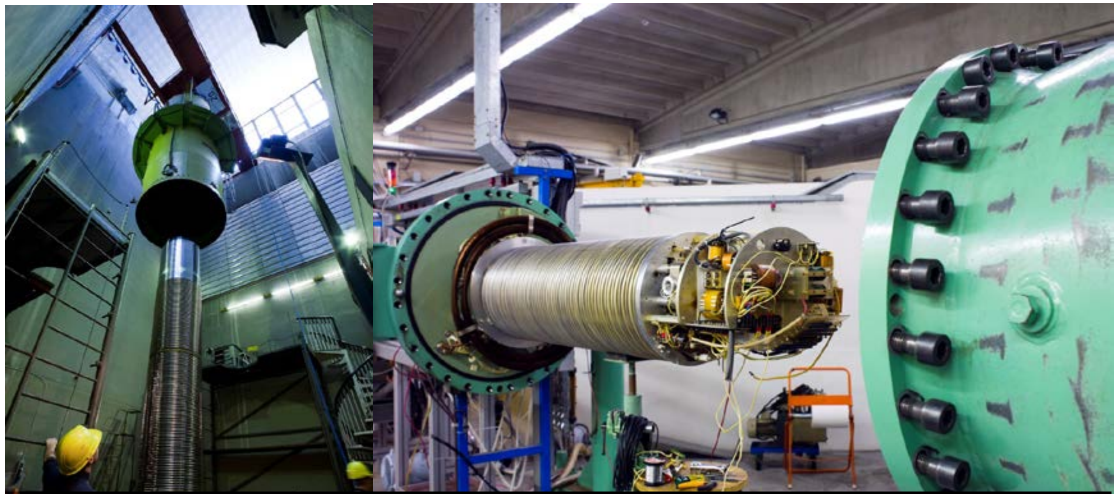


Le macchine dei Laboratori Nazionali di Legnaro

TANDEM 15MV

CICLOTRONE BEST p70

ALPI



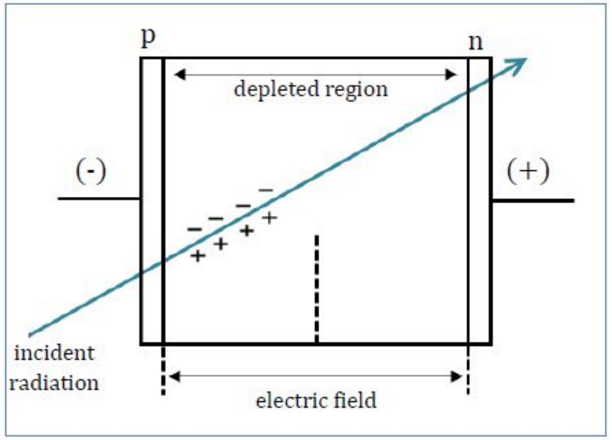
CN ed AN2000

Rivelatori di Radiazione, in generale

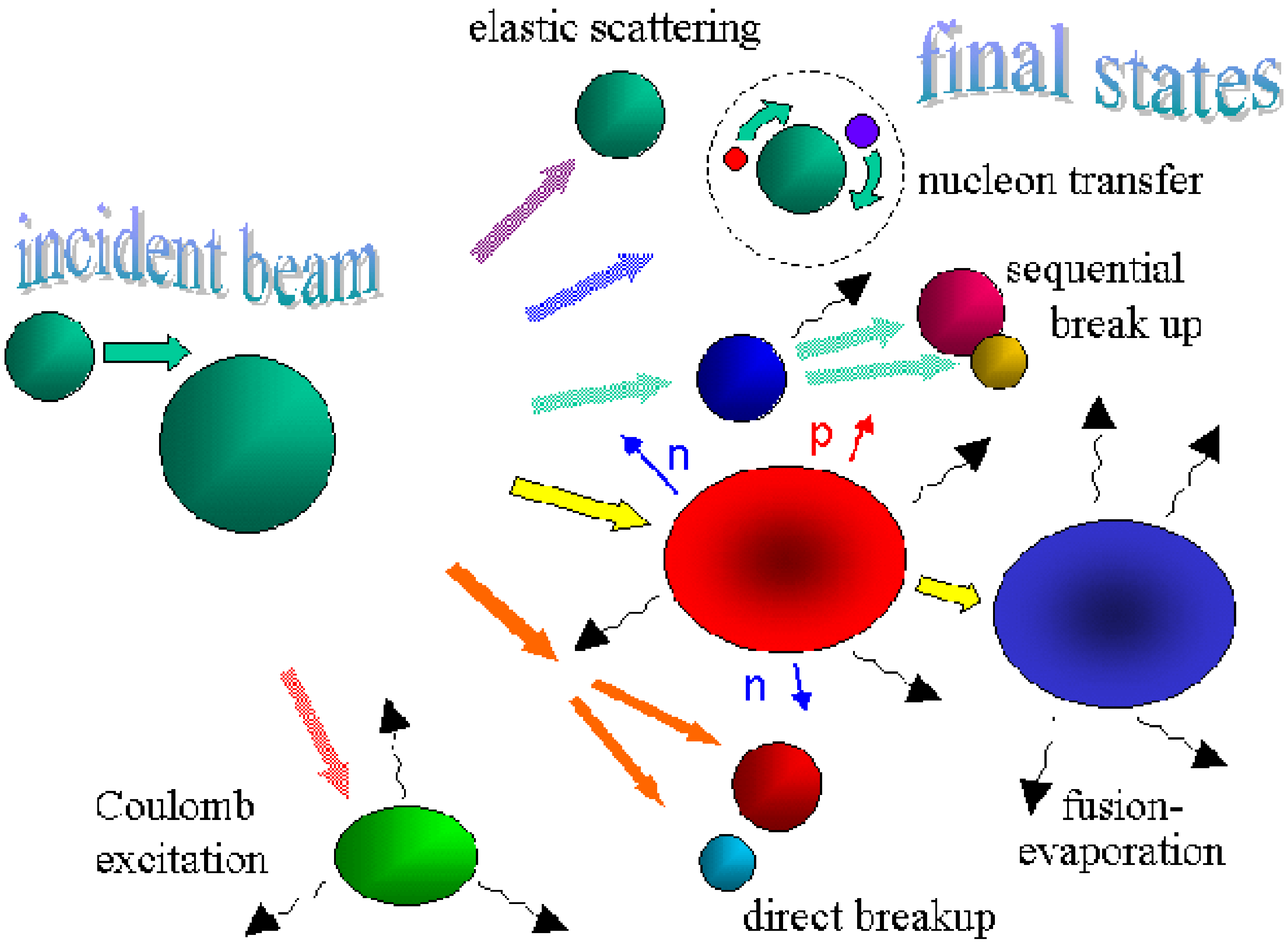
Assorbitore
- Energia persa per ionizzazione diretta o indiretta e/o eccitazione del mezzo

Conversione
- Raccolta di un segnale elettrico
- Conversione in un segnale elettrico

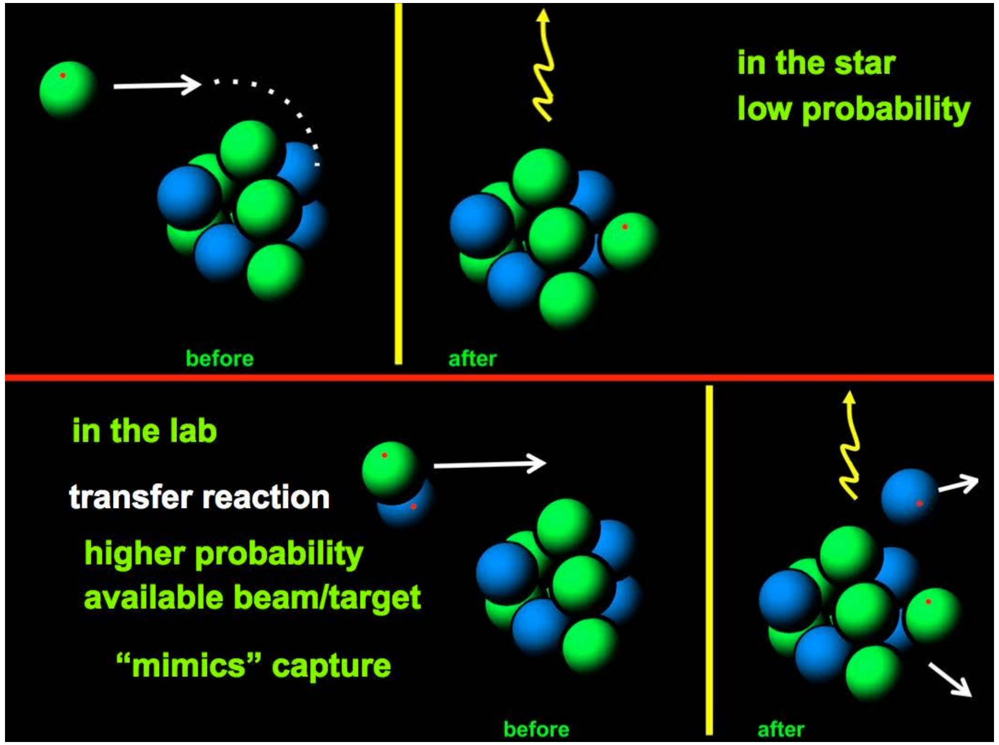
Elettronica
- Processamento
- Digitalizzazione

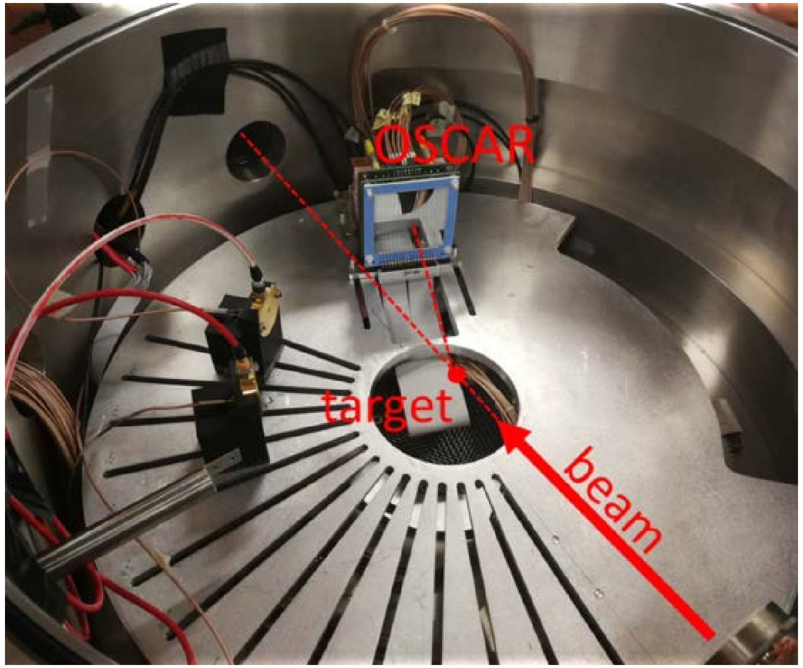


Meccanismi di Reazione



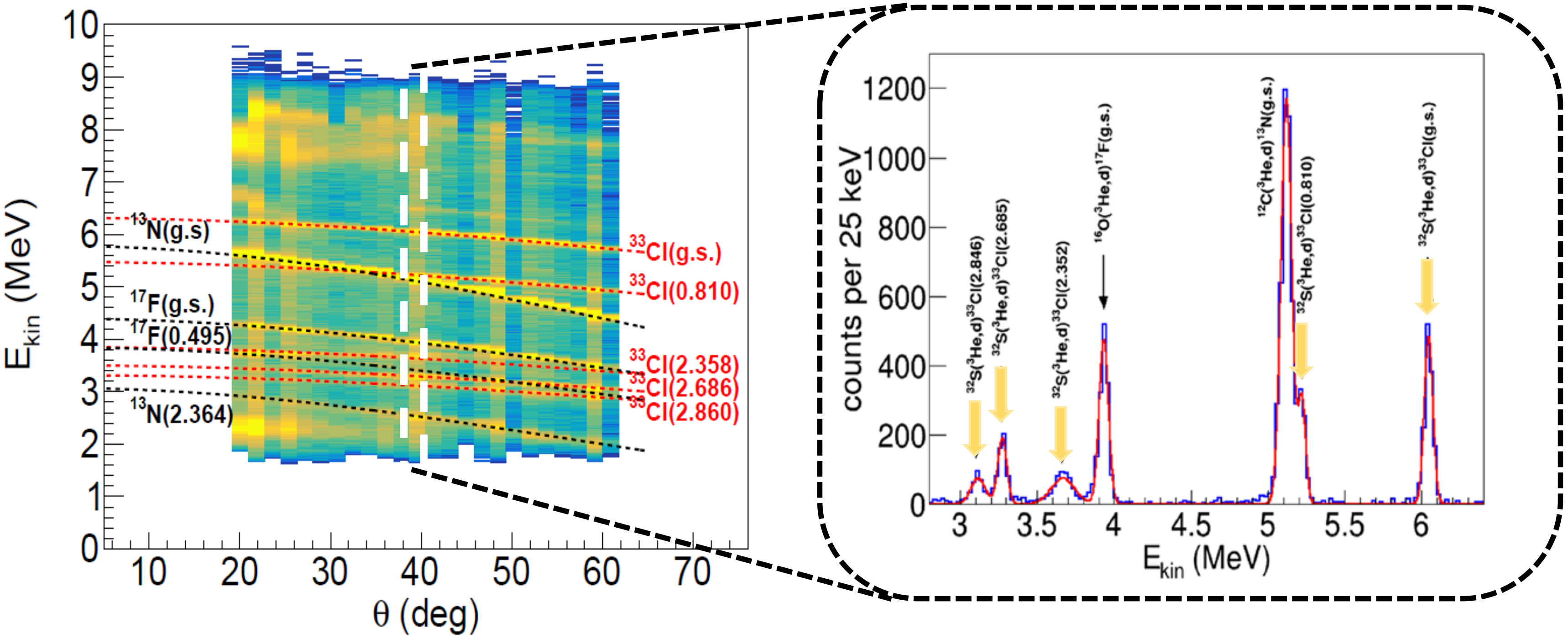
Un esempio tipico: OSCAR e le reazioni dirette



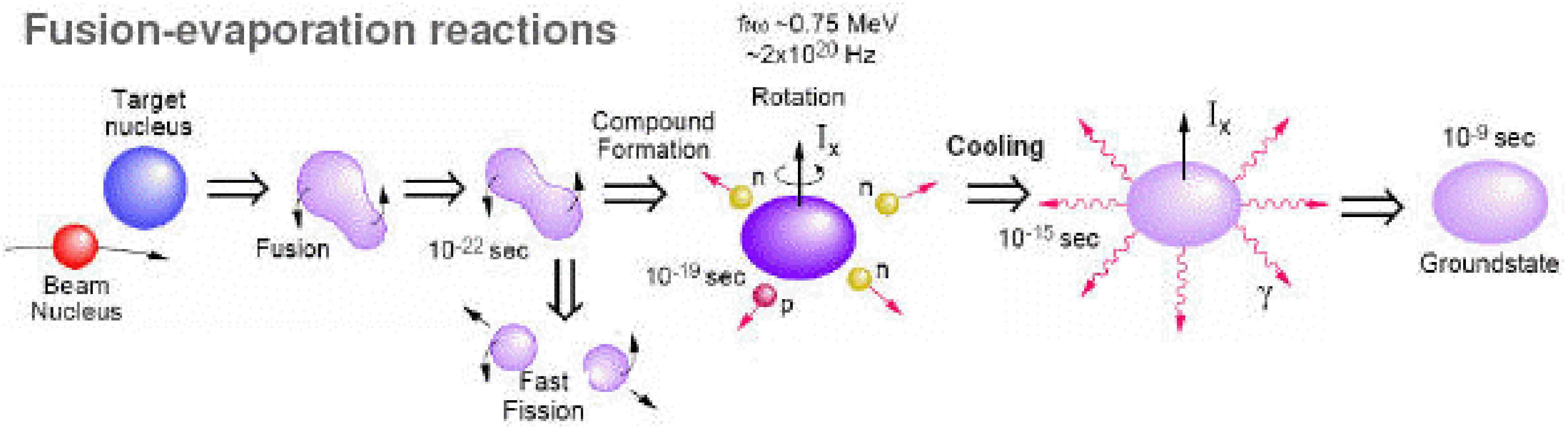


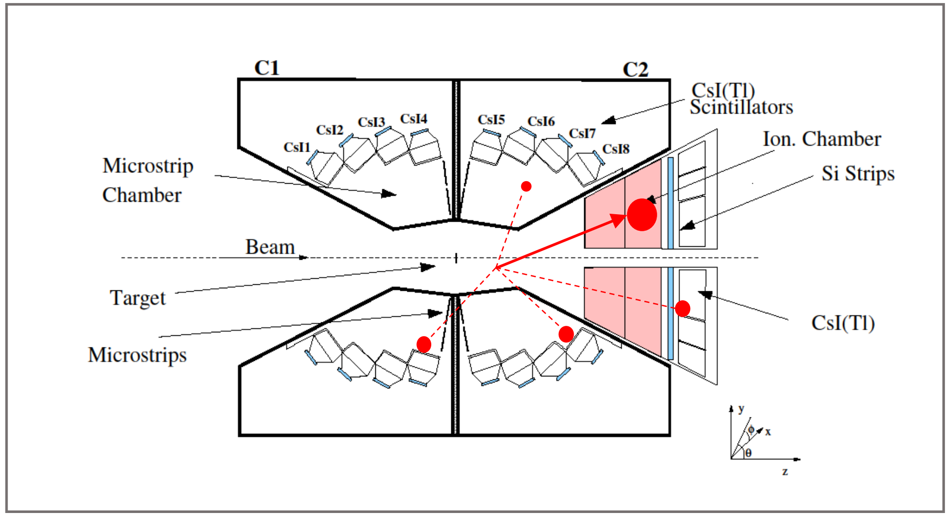
$^{32}S(^{3}He,d)^{33}Cl$

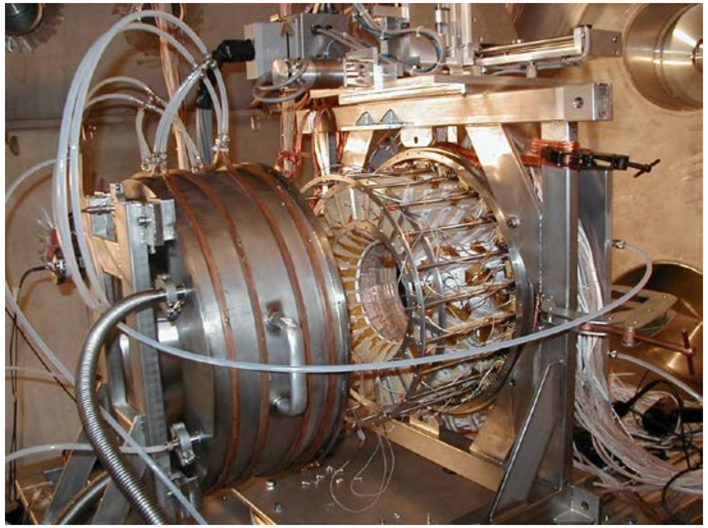
Un esempio tipico: OSCAR e le reazioni dirette



GARFIELD e le reazioni di fusione-evaporazione







GARFIELD e le reazioni di fusione-evaporazione

PHYSICAL REVIEW C
covering nuclear physics

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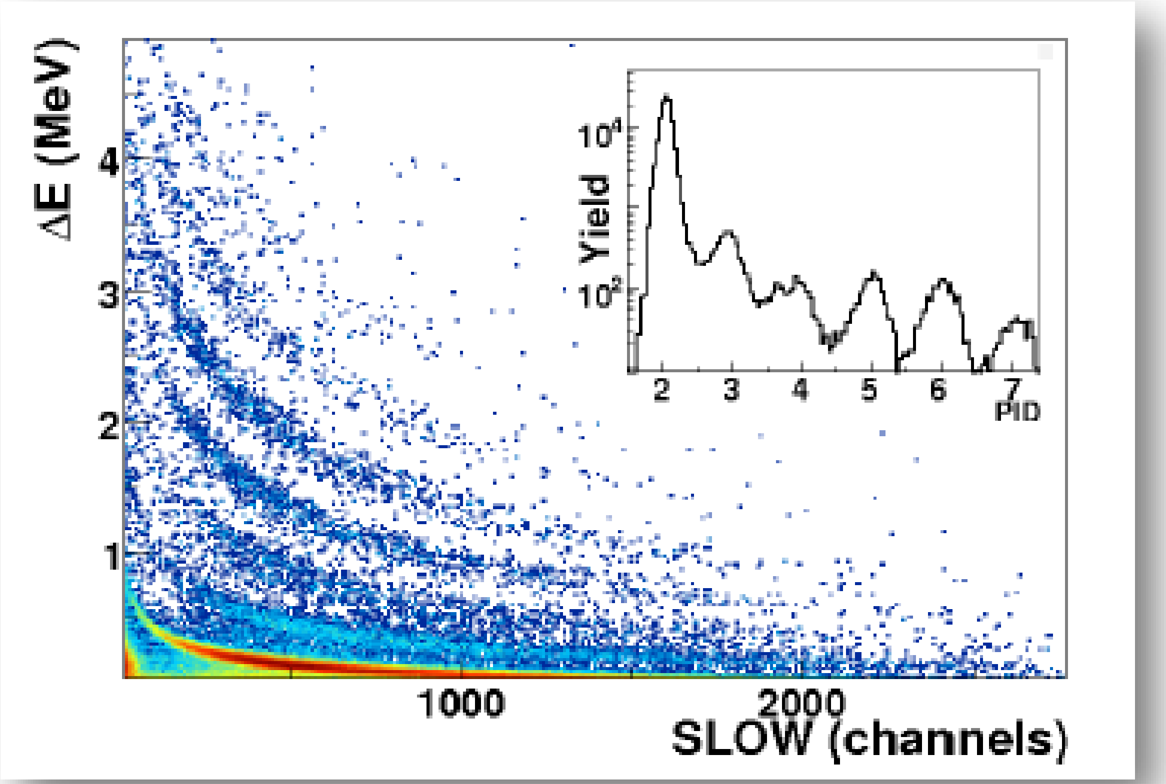
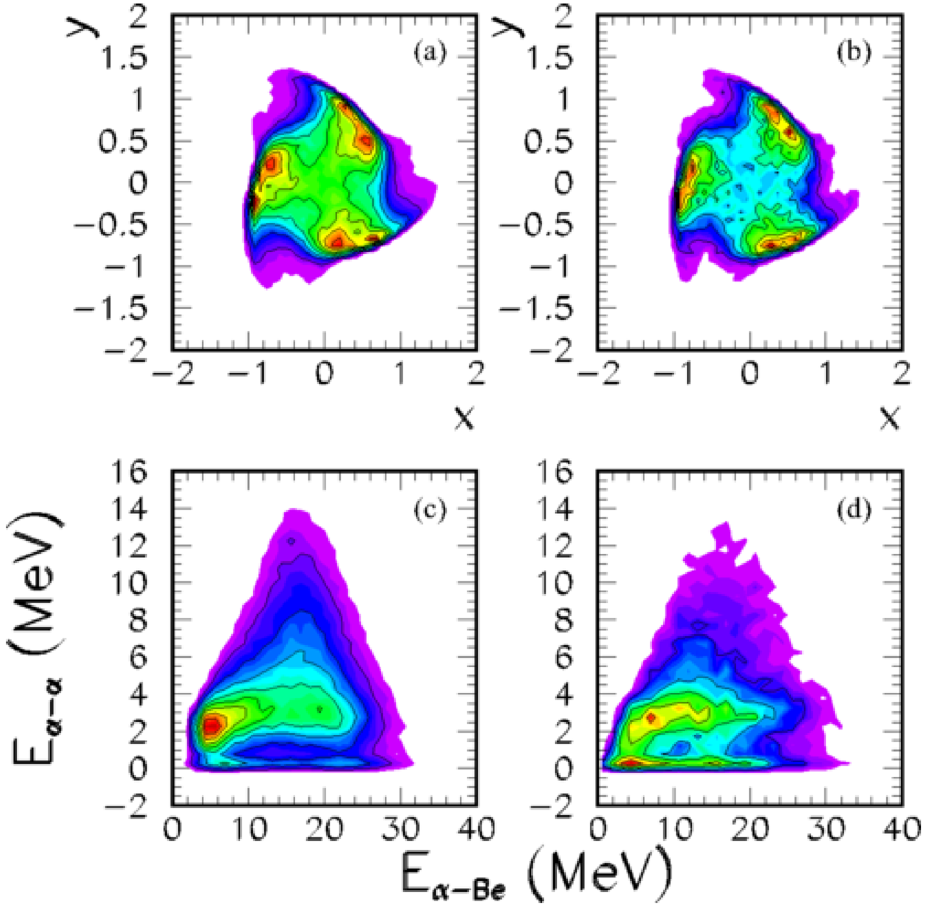
Full disassembly of excited ^{24}Mg into six α particles

L. Morelli, M. Bruno, M. D'Agostino, G. Baiocco, F. Gulminelli, S. Barlini, A. Buccola, A. Camaiani, G. Casini, C. Ciampi, C. Frosin, N. Gelli, A. Olmi, P. Ottanelli, G. Pasquali, S. Piantelli, S. Valdré, M. Cicerchia, M. Cinausero, F. Gramegna, G. Mantovani, T. Marchi, M. Degerlier, D. Fabris, and V. L. Kravchuk
Phys. Rev. C **99**, 054610 – Published 9 May 2019





GALILEO e la spettroscopia GAMMA

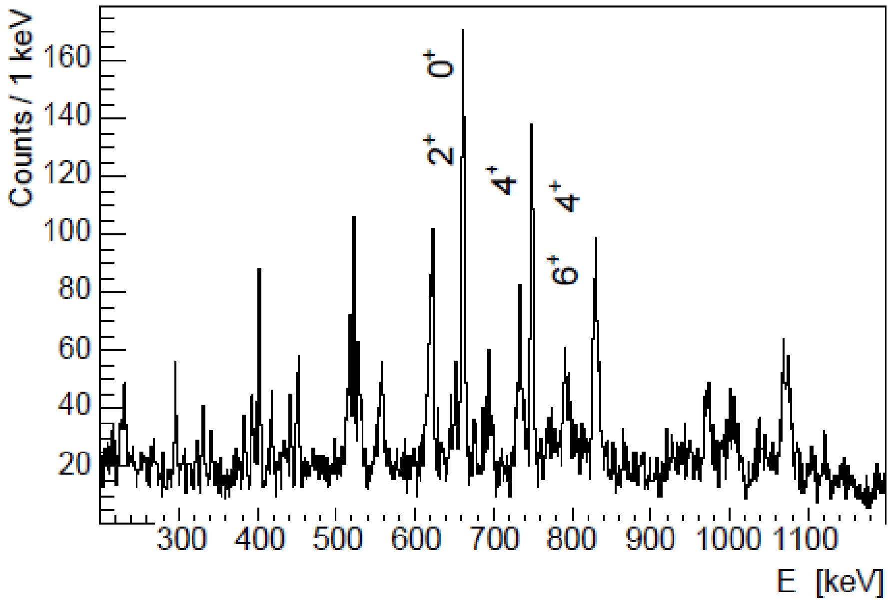
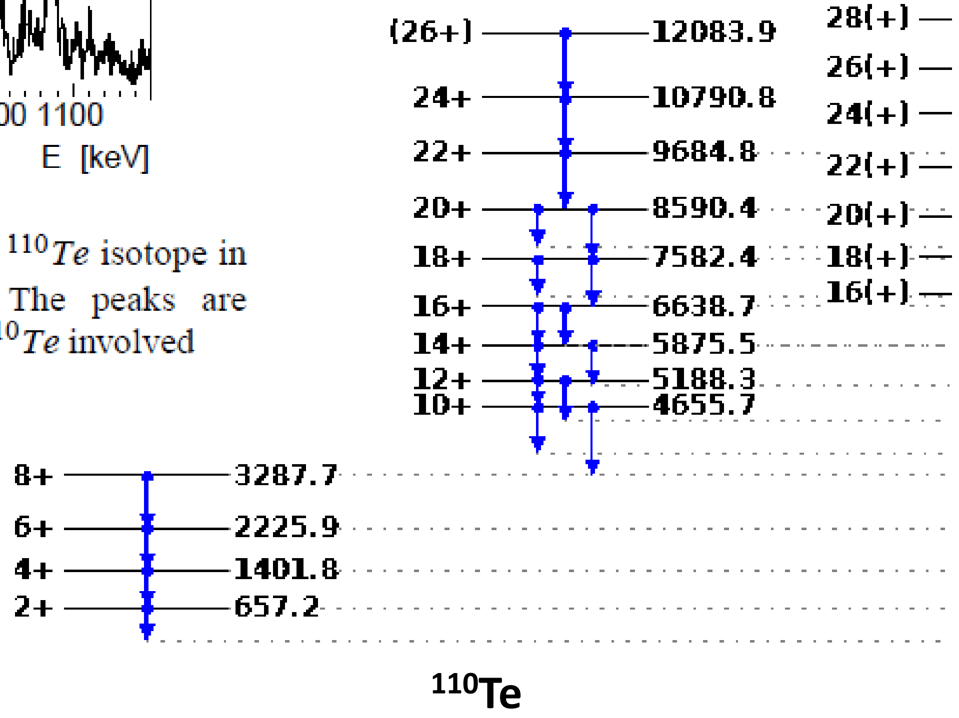
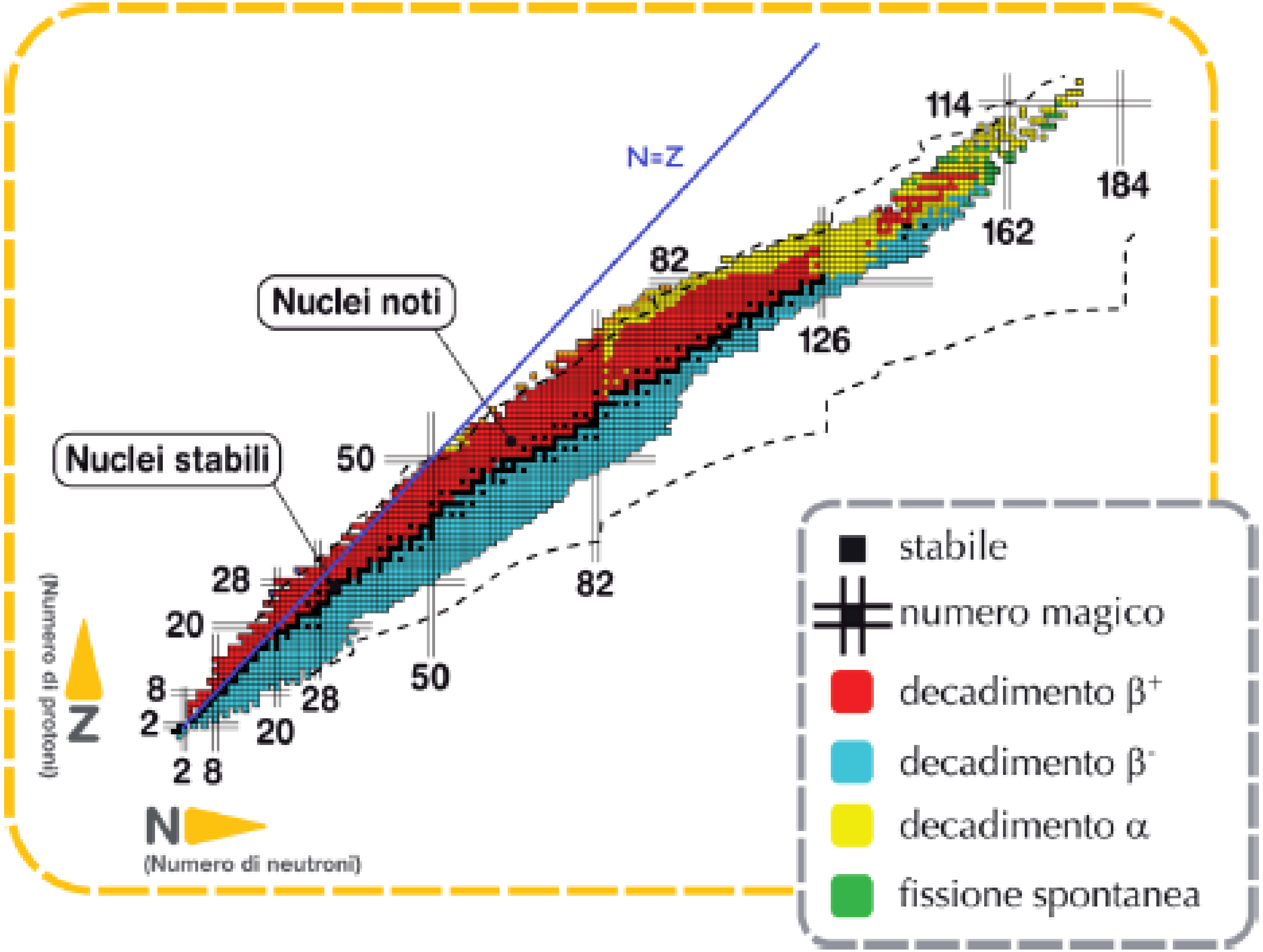


Fig. 3. Doppler corrected γ-ray spectrum for the ^{110}Te isotope in coincidence with an evaporated α particle. The peaks are labelled with the spin and parity of the levels of ^{110}Te involved



La carta dei Nuclidi



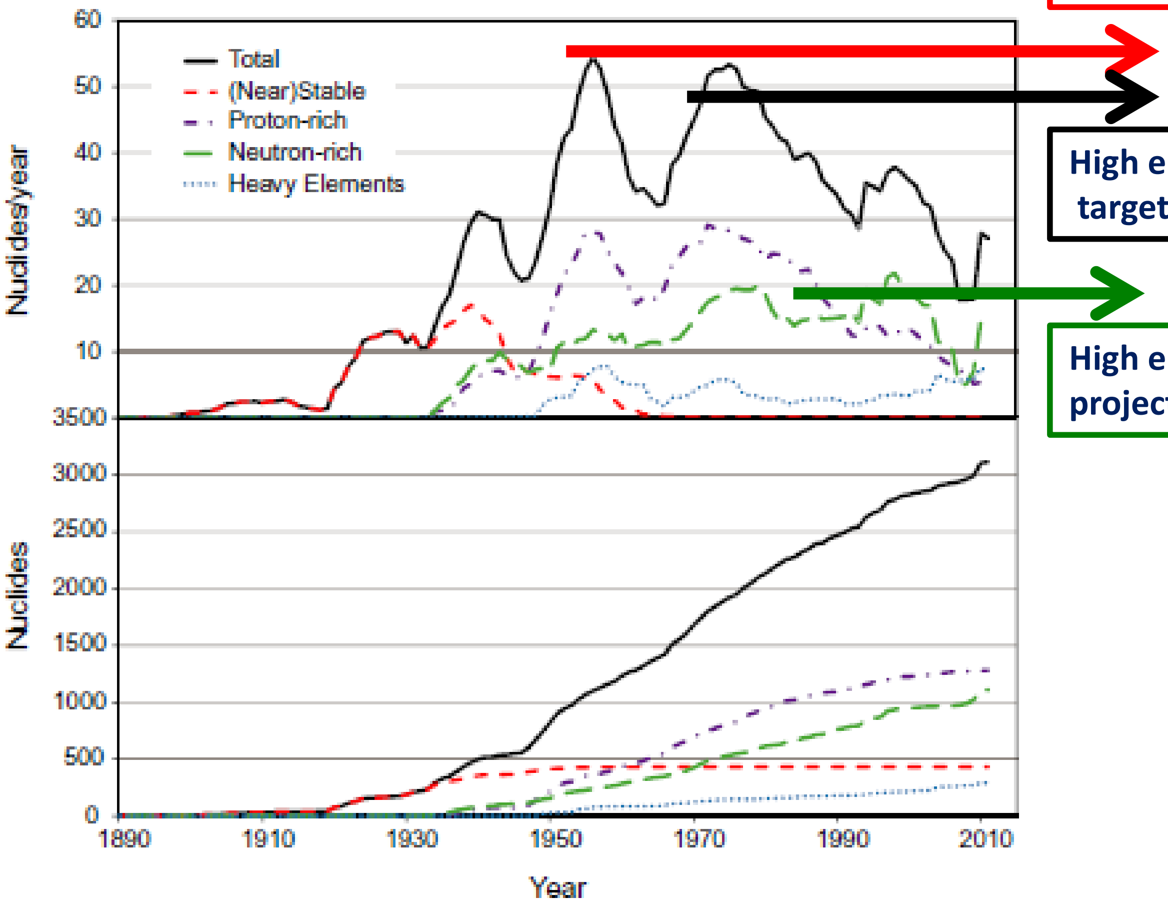
Alchimia contemporanea

IOP Publishing — Reports on Progress in Physics
Rep. Prog. Phys. 76 (2013) 056301 (14pp) doi:10.1088/0034-4885/76/5/056301

Current status and future potential of nuclide discoveries

M Thoennessen

Rep. Prog. Phys. **76** (2013) 056301

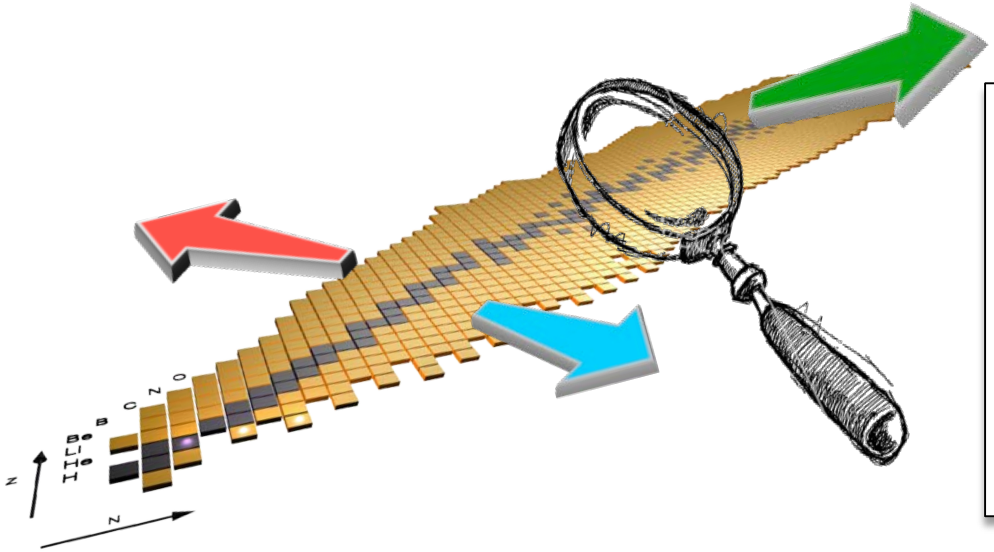


Fusion-Evaporation reactions with Heavy Ions.
Increasing energy and intensities

High energy light beams:
target fragmentation/fission. (ISOL)

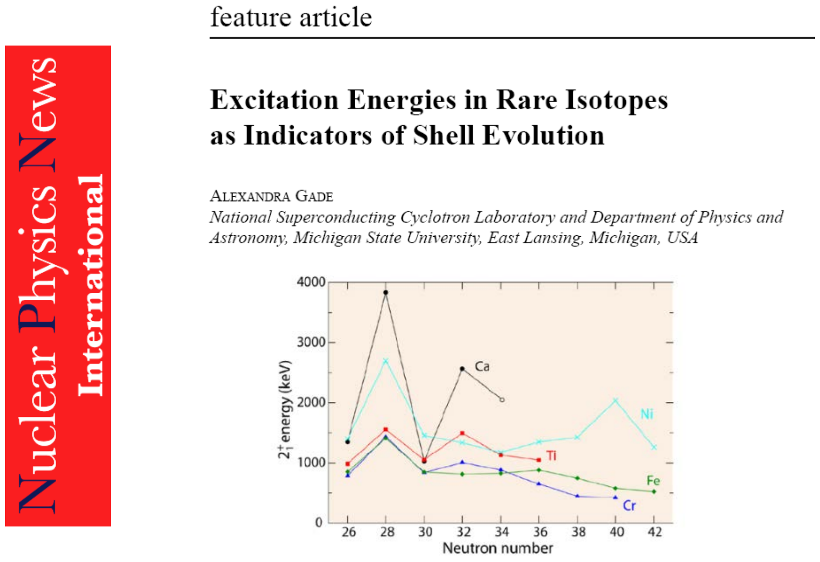
High energy heavy beams:
projectile fragmentation/fission. (In-flight)

Oltre alla scoperta di nuovi isotopi



In the next decades, Nuclear Physics will focus on Radioactive ion beams to:

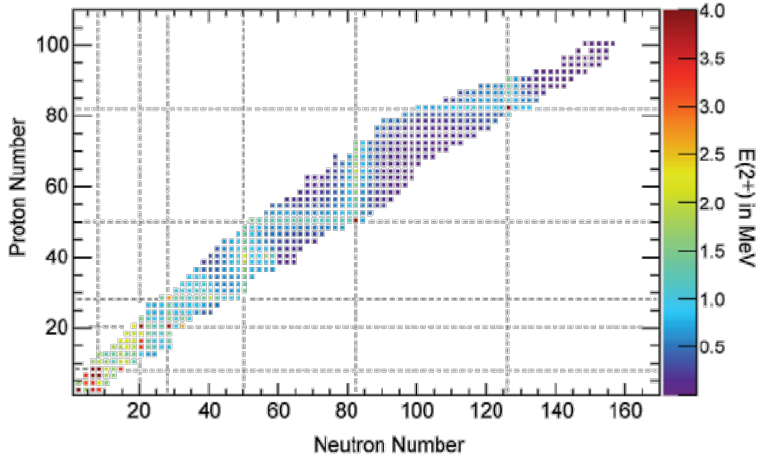
- **Explore** and locate the extremes of nuclear existence
- **Discover** exotic properties of nuclei (shapes, structure evolution)
- **Explain** the role of isospin in complex systems (nEOS, E_{sym})


Nuclear Physics News International

feature article

Excitation Energies in Rare Isotopes as Indicators of Shell Evolution

ALEXANDRA GADE
National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA



[A. Gade, Nucl Phys News 23-4 (2013) 10]

Beyond Isotopes discovery – challenges

Nuclear Structure

G.s. & E.s. properties, Decay properties, Shell evolution and Collectivity.
State-of-the-art theoretical models: **ab-initio.**

Reaction Dynamics

Characterize the mechanisms that drive nuclear reactions and describe reaction dynamics. Study the interplay between structure and reactions (e.g. clusters).

Nuclear Astrophysics and Applications

Provide Nuclear Data (cross sections, J^{π}, C^2S …)

Understand the physics of the nuclear force
within the many-body nuclear system,
probing fundamental symmetries and interactions

Acceleratori di particelle

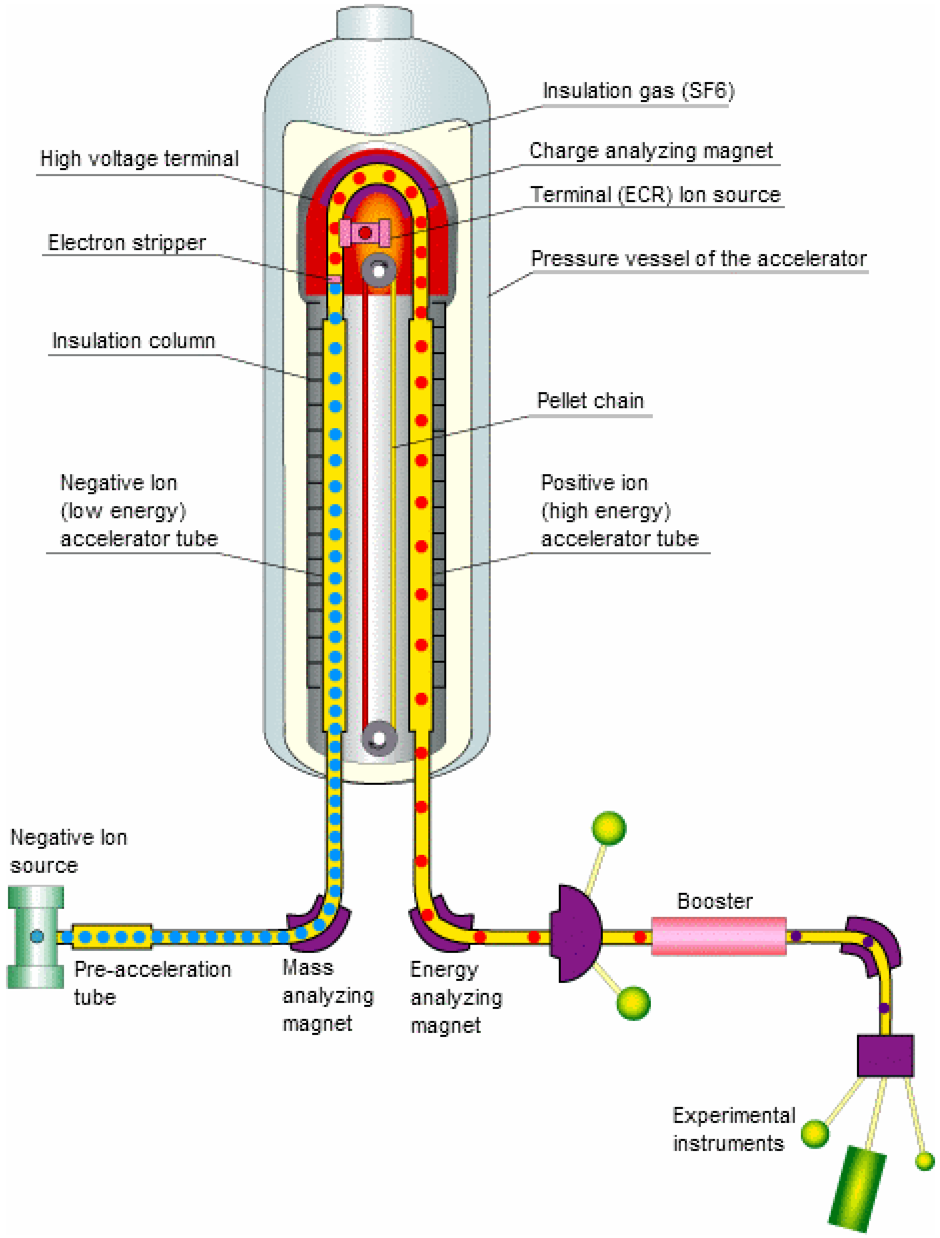
Due tipi di approccio:

- Colliders
- A bersaglio fisso

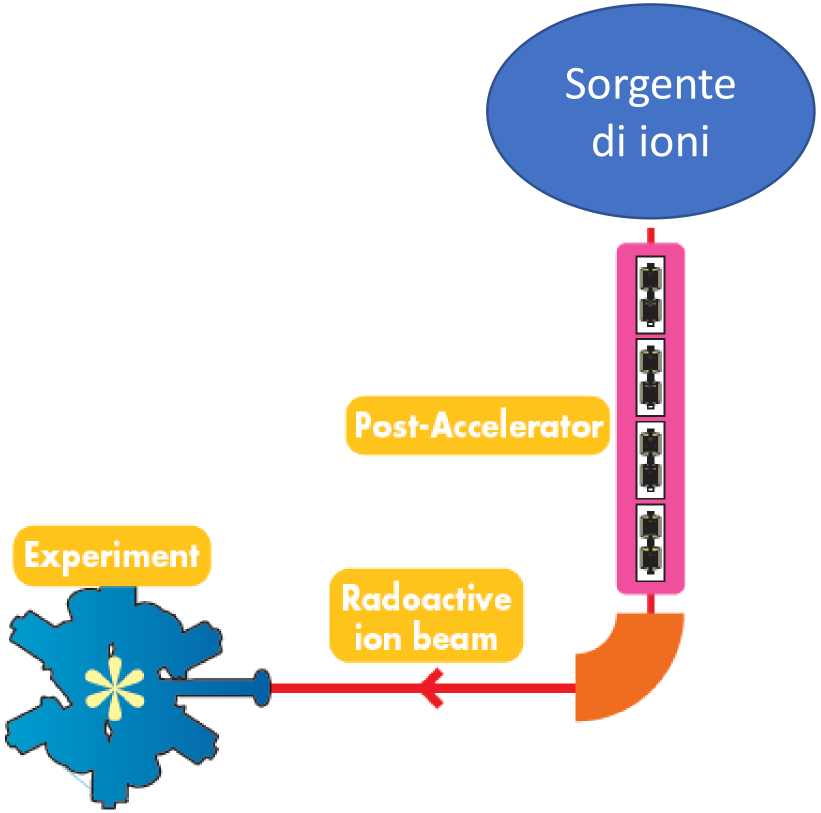
Diversi tipi di acceleratore:

- Elettrostatici
- A radiofrequenza.
  - Normal o super conduttivi
  - Lineari o Circolari

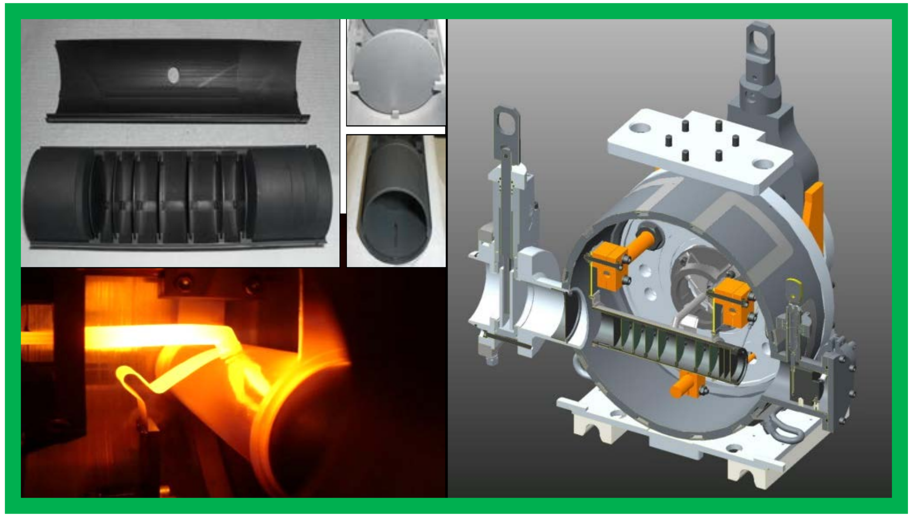
Sorgente di ioni → Acceleratore → Linea di trasporto



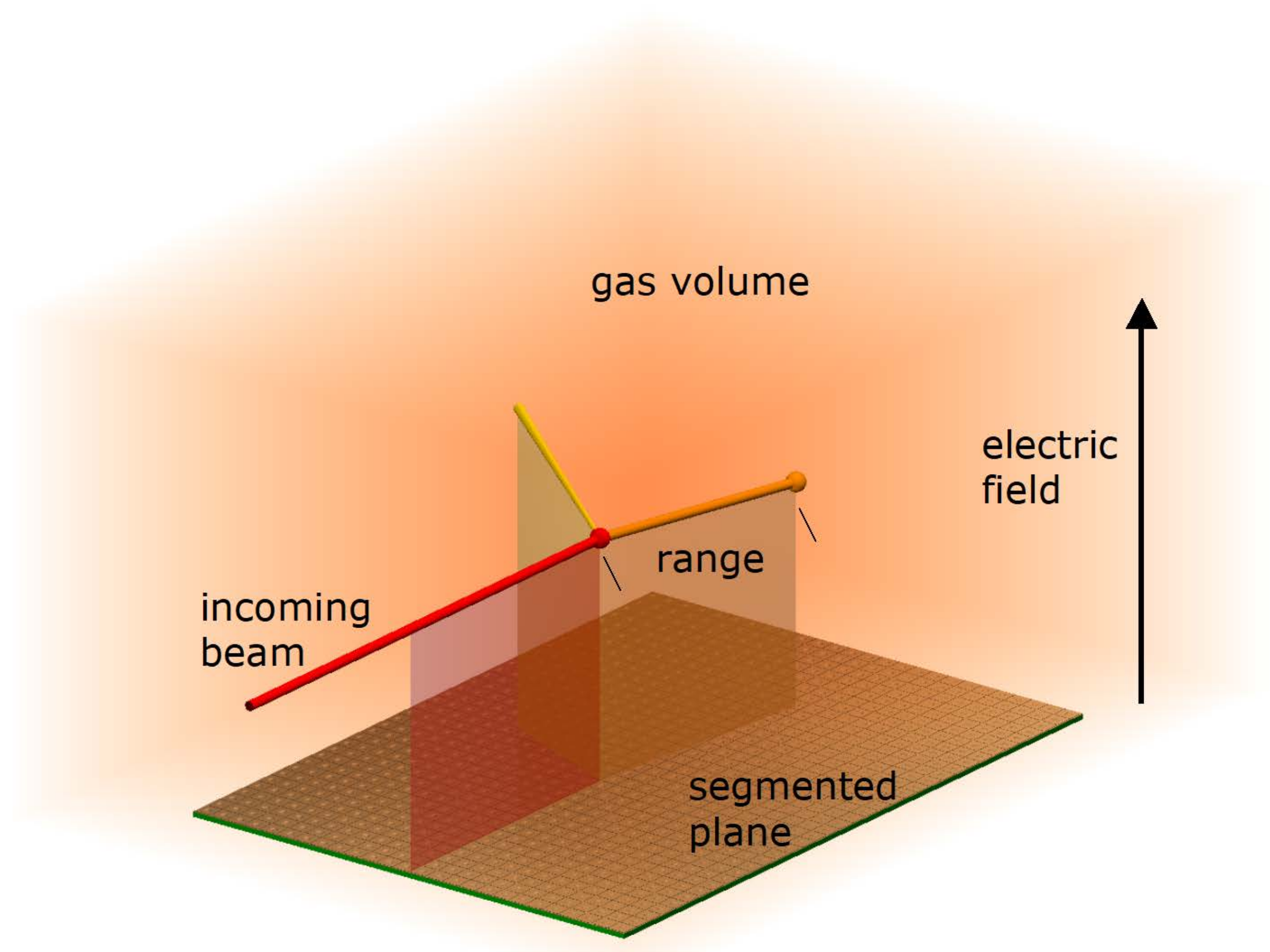
LNL e SPES



SPES ISOL Target:
UCx, SiC,...
10^{13} fiss./s
T ~ 2000°C
3 sources SIS, LIS, PIS
~ 8 kW power



Un rivelatore per il futuro: Active Target



Un rivelatore per il futuro: Active Target