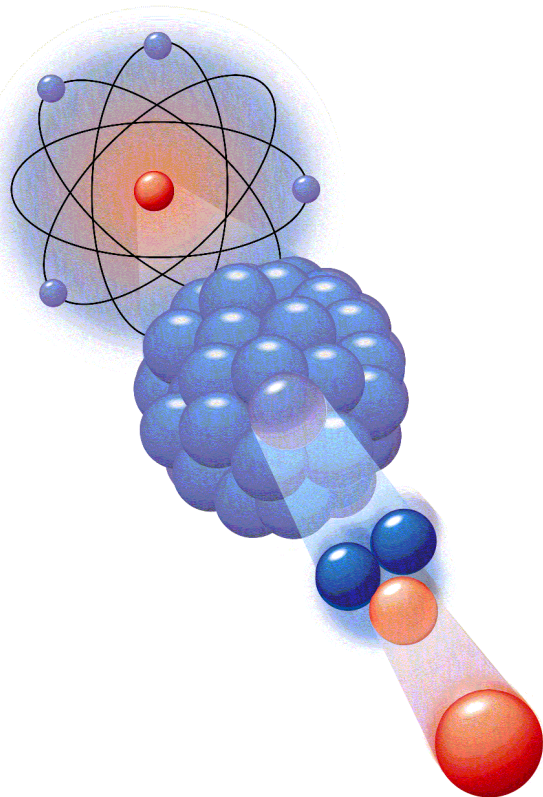
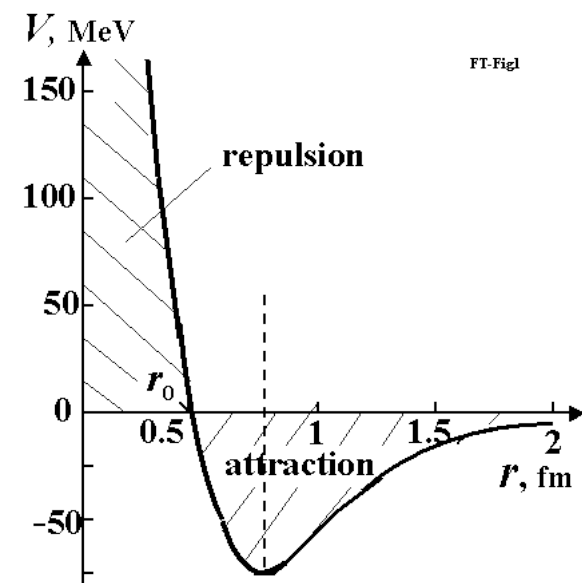


Exotic nuclei

(with a brief introduction to Nuclear Physics)



Alejandro Algora
IFIC (CSIC-Univ. Valencia)



The Dawn of the XX Century

The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their even being supplanted in consequence of new discoveries is exceedingly remote

.....Our future discoveries must be looked for in the 6th place of decimals

-A. A. Michelson, *Light Waves and Their Uses*, 1903 [Holton 1988, p. 88]



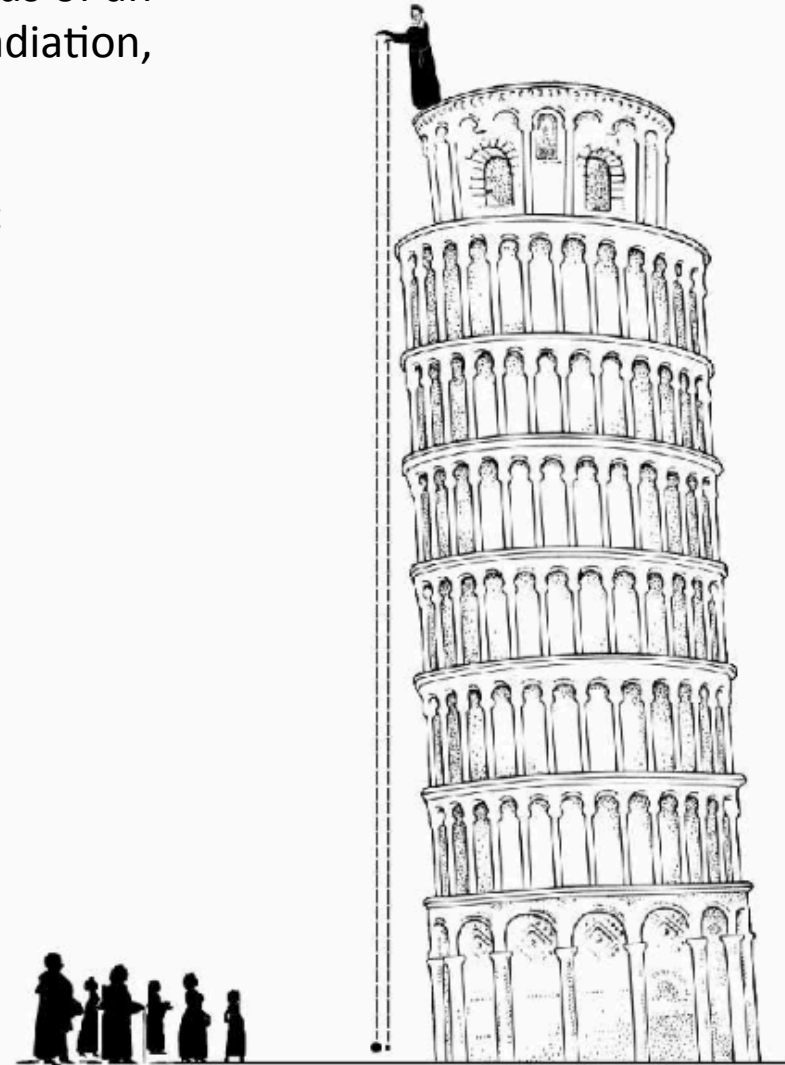
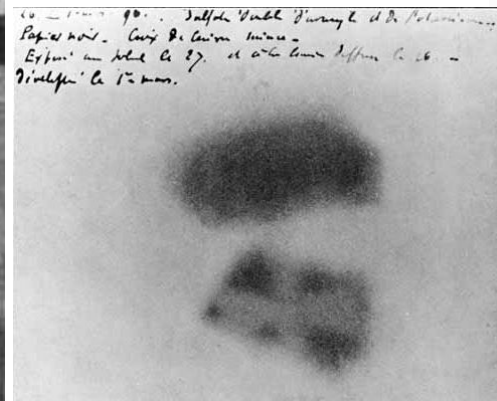
What is radioactivity ? ...

What is radioactivity? . It is the process by which a nucleus of an unstable element (or atom) loses energy by emitting radiation, including alpha, beta, gamma and conversion electrons.

The radiation can ionize gases, produce fluorescence, etc



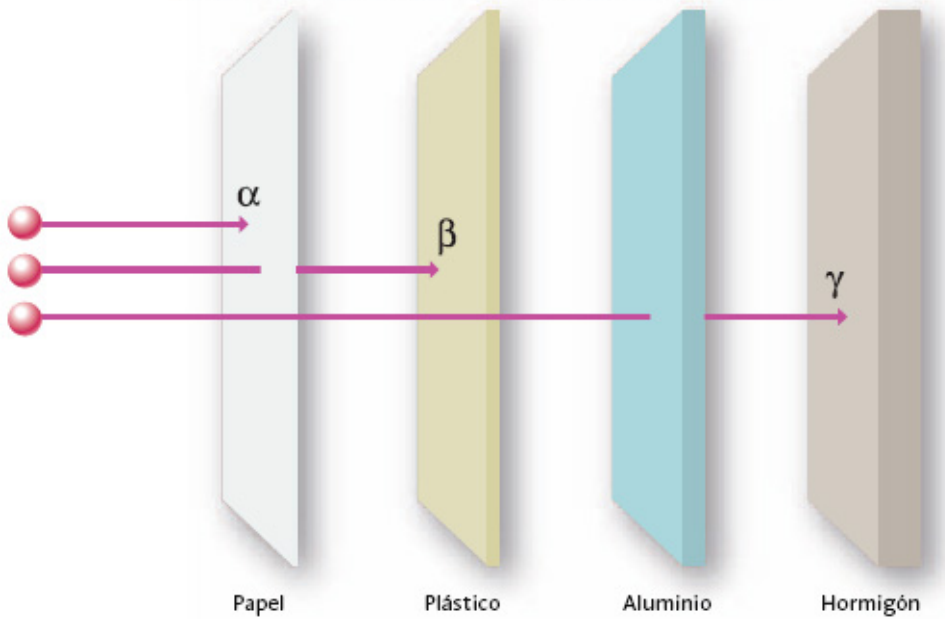
Henri Becquerel, 1896



Galileo's experiment

Radioactivity types

Capacidad de penetración de las radiaciones ionizantes

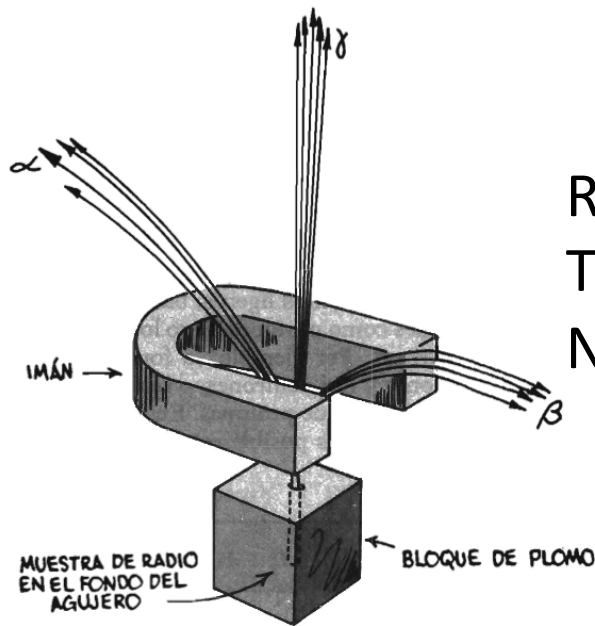


Alfa (α) ${}^4_2\text{He}$

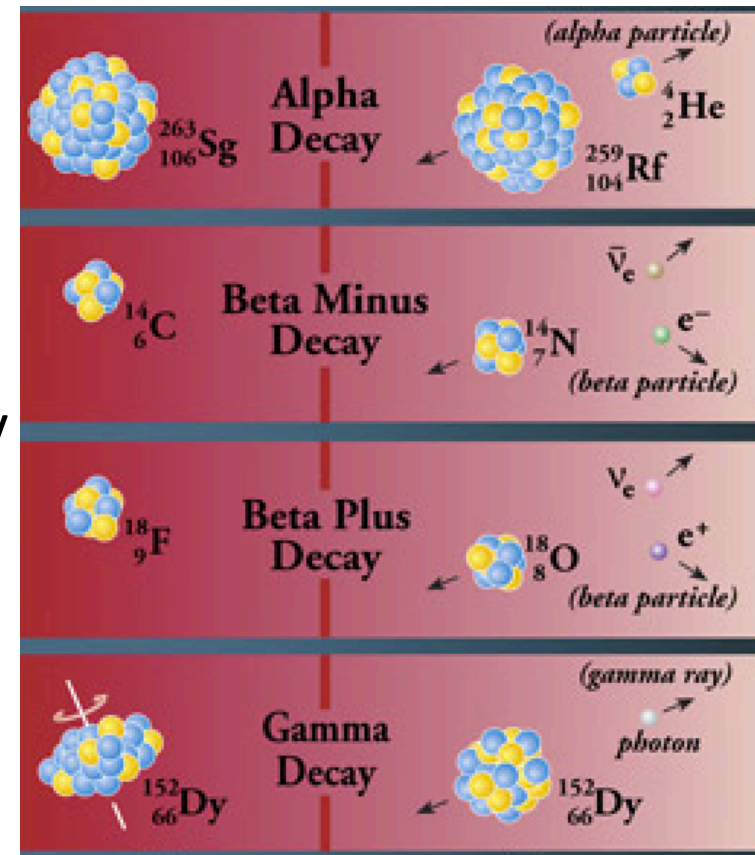
Beta ($-\beta, +\beta$) electrons, positrons

Gamma (γ) electromagnetic radiation

more exotic ones: p, fission, heavy ions

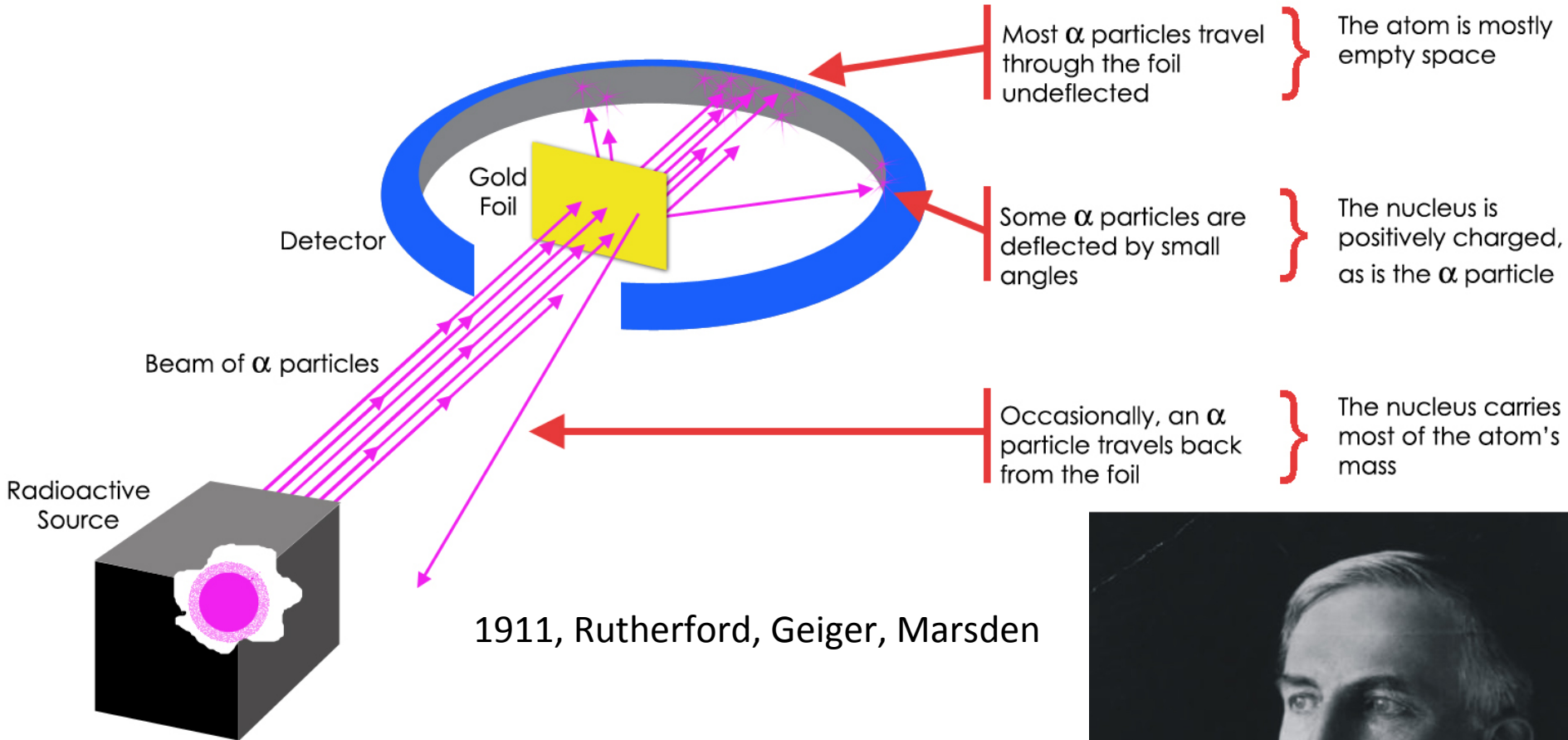


Rutherford and Soddy
Transmutation
Nobel in 1908

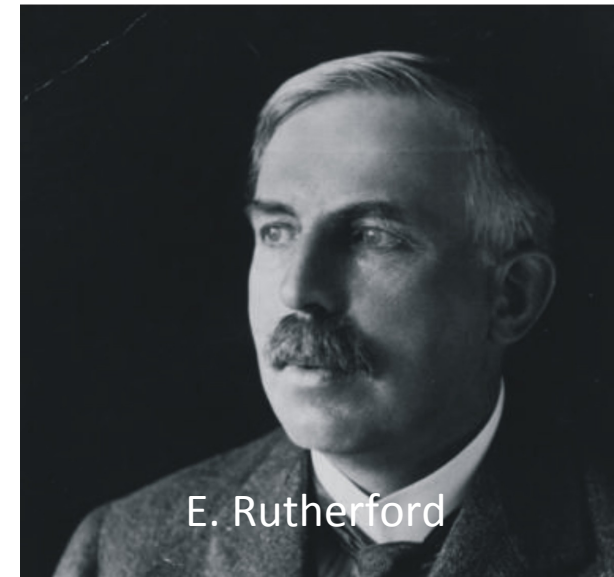


A little history ...

Rutherford's Gold Foil Experiment



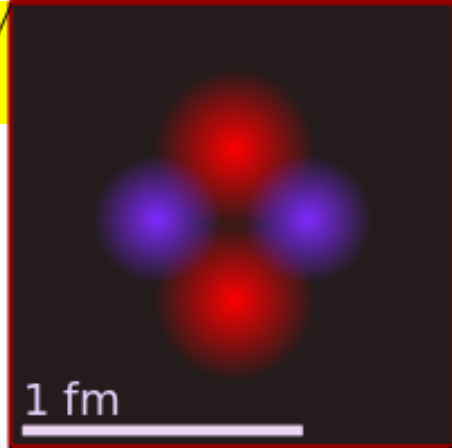
Just recently nuclear physics celebrated its 100th birthday. You might think that nuclear physics is already an old science and all questions have been answered but ...



E. Rutherford

The nuclear scale ...

1 fm (femtometer o Fermi)= 10^{-15} m
1 pm (picometer) = 10^{-12} m
1 Å = 10^{-10} m



${}^{197}\text{Au}$ example

Radius of Au nucleus aprox. 8.5 fm
 8.5×10^{-15} m

Radius of Au atom approx 174 pm
 174×10^{-12} m
 1.7×10^{-10} m = 1.7 Å

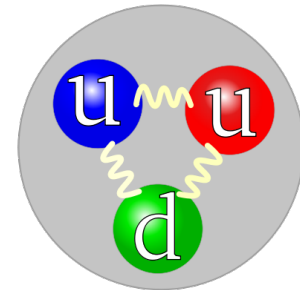
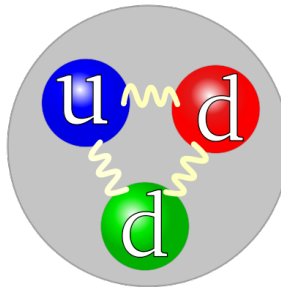
1 Å = 100,000 fm

1 Å = 10^{-10} m

The ingredients, two baryons ...

Baryon: particle composed
by three quarks

No fundamental particles
(composite ones)



	Neutron (n)	Proton (p)
Statistics	Fermion	Fermion
Interactions	Gravity, strong, weak, electromagnetic	Gravity, strong, weak, electromagnetic
Discovery	Chadwick, 1932 Theorized by Rutherford (1930)	Rutherford (1917-1919) Theorized by William Prout (1817)
$T_{1/2}$	881.5 (15) s (~ 14.7 min)	$> 2.1 \times 10^{29}$ years
Mass	939.5654133(58) MeV/c ² $1.674927471(21) \times 10^{-27}$ kg	938.2720813 (58) MeV/c ² $1.672621898(21) \times 10^{-27}$ kg
Spin, isospin Charge	1/2, 1/2 0	1/2, 1/2 +1 e

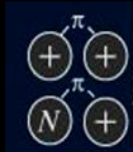
What keeps the nucleus together ?

	Relative strenght	Range
Gravity	1	Infinite
Electromagnetic	10^{36}	Infinite
Strong	10^{38}	10^{-15} m
Weak	10^{26}	10^{-18} m



Fuerzas Fundamentales

Fuerte



Fuerza que mantiene al nucleo unido

Intensidad Relativa

10^{38}

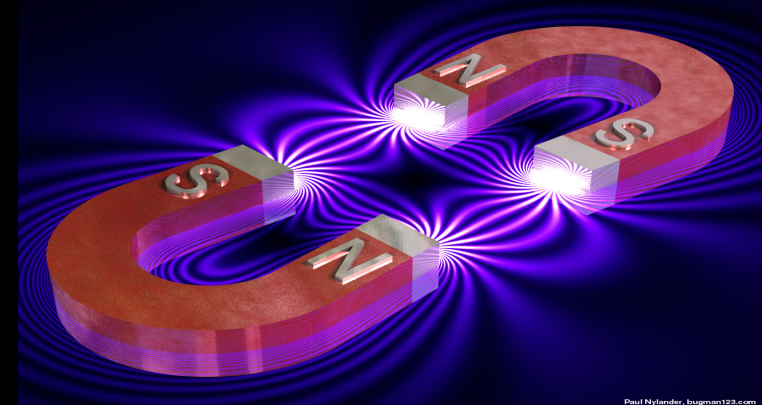
Alcance (m)

10^{-15}

Diametro de un nucleo de tamaño mediano

Particula

Gluones



Paul Nylander, bogmen123.com

Electro-magnética



10^{36}

∞
Infinito

Fotones

Débil



La interacción de los neutrinos induce el decaimiento beta

10^{25}

10^{-18}
0.1% del diametro de un proton

Bosones W y Z

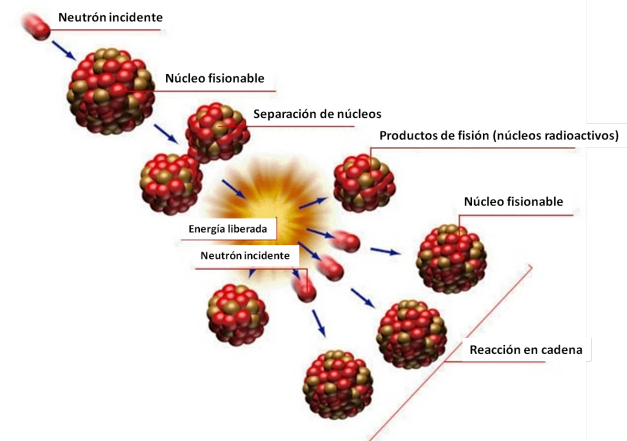
Gravitatoria



1

∞
Infinito

Gravitones
(Hipotético)



Lets put some order ...

A chemical element or element is a species of atoms having the same number of protons in their atomic nuclei (118 in total, 94 in nature, 24 artificial created in nucl. labs and reactors)

11A1A

18VIIIA8A

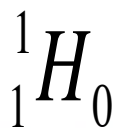
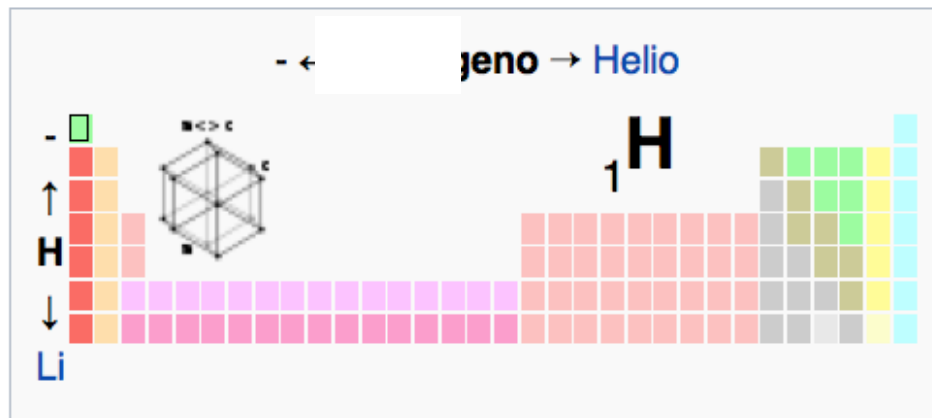
Periodic Table of the Elements

1 H Hydrogen 1.0079	2 He Helium 4.00260																	13 B Boron 10.811	14 C Carbon 12.011	15 N Nitrogen 14.00674	16 O Oxygen 15.9994	17 F Fluorine 18.998403	18 Ne Neon 20.1797
3 Li Lithium 6.941	4 Be Beryllium 9.01218																	5 Al Aluminum 26.981539	6 Si Silicon 28.0855	7 P Phosphorus 30.973762	8 S Sulfur 32.066	9 Cl Chlorine 35.4527	10 Ar Argon 39.948
11 Na Sodium 22.989768	12 Mg Magnesium 24.305	3 IIIB3B	4 IVB4B	5 VB5B	6 VIB6B	7 VIIB7B	8 VIII8	9 VIII8	10 VIII8	11 IB1B	12 IIB2B	13 Al Aluminum 26.981539	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948						
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.95591	22 Ti Titanium 47.88	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938	26 Fe Iron 55.847	27 Co Cobalt 58.9332	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92159	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80						
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium 98.9072	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.90447	54 Xe Xenon 131.29						
55 Cs Cesium 132.90543	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.9665	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98037	84 Po Polonium [208.9824]	85 At Astatine 209.9871	86 Rn Radon 222.0176						
87 Fr Francium 223.0197	88 Ra Radium 226.0254	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Uuq Ununquadium [289]	115 Uup Ununpentium unknown	116 Uuh Ununhexium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown						
Lanthanide Series		57 La Lanthanum 138.9055	58 Ce Cerium 140.115	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium 144.9127	62 Sm Samarium 150.36	63 Eu Europium 151.9655	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967							
Actinide Series		89 Ac Actinium 227.0278	90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium 237.0482	94 Pu Plutonium 244.0642	95 Am Americium 243.0614	96 Cm Curium 247.0703	97 Bk Berkelium 247.0703	98 Cf Californium 251.0796	99 Es Einsteinium [254]	100 Fm Fermium 257.0951	101 Md Mendelevium 268.1	102 No Nobelium 259.1009	103 Lr Lawrencium [262]							
		Alkali Metal	Alkaline Earth	Transition Metal	Basic Metal	Semimetals	Nonmetals	Halogens	Noble Gas	Lanthanides	Actinides												

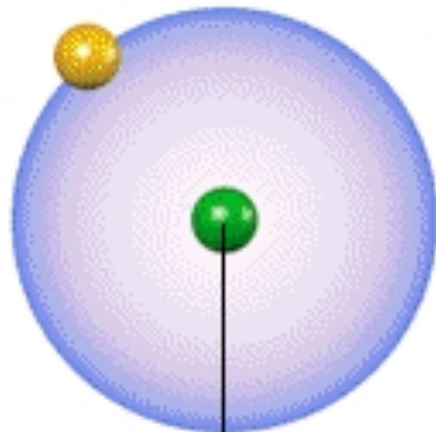
Some basic concepts: isotopes

Atomic masses not integers

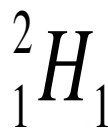
Frederick Soddy, 1913
Studies between Pb, and U
40 nucl. species vs. 11 elements



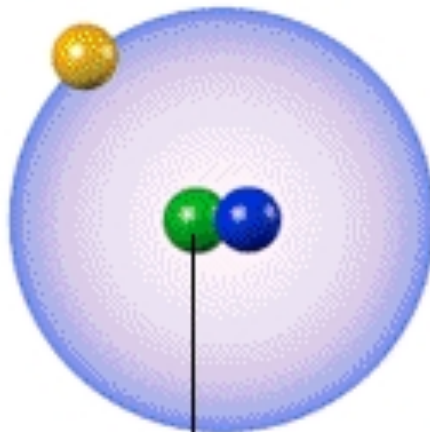
HIDRÓGENO
COMÚN



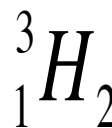
Un **protón**



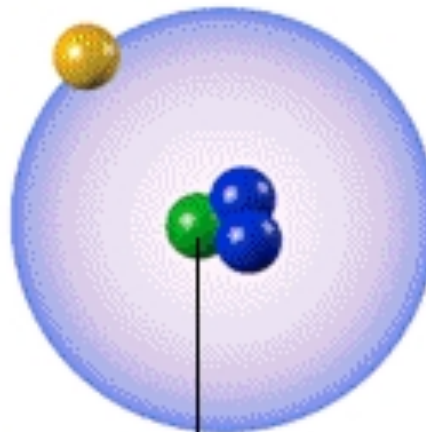
DEUTERIO



Un protón
y un neutrón



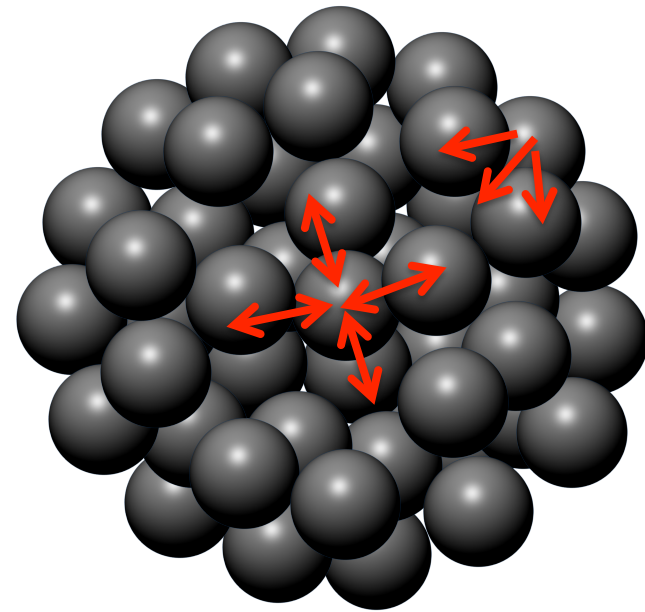
TRITIO



Un protón
y dos neutrones

Formas
isotópicas
*Un átomo
contiene protones
y neutrones. Los
isótopos difieren
por el número
de neutrones.*

The simplest nuclear model: the liquid drop

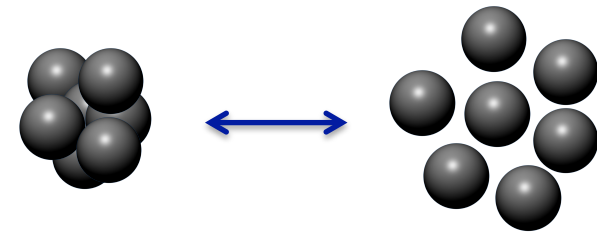


Gamow, Bohr, Wheeler: the nucleus is a fluid composed of n-s and p-s keep together by the strong interaction

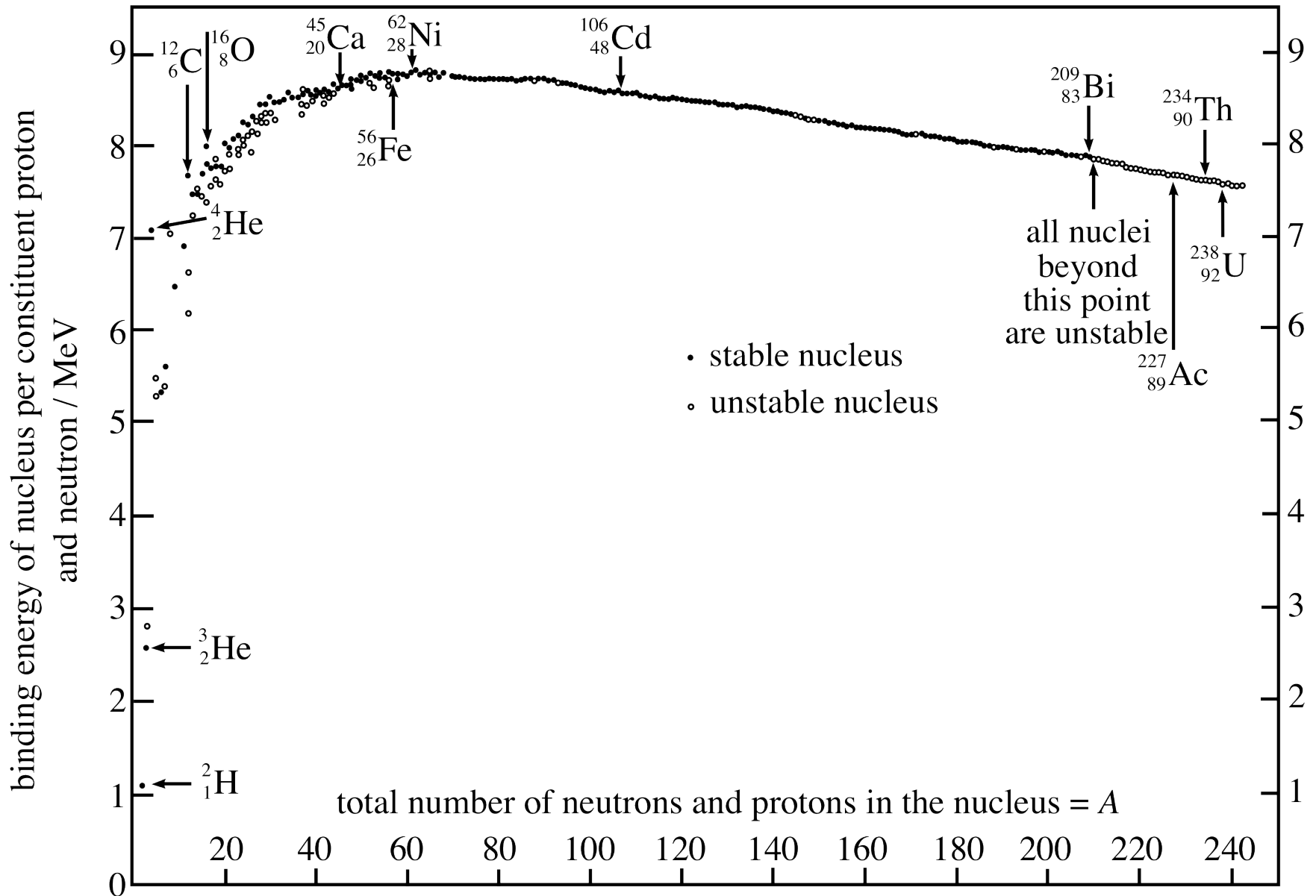
$$E = mc^2$$

$$Mc^2 \leq Zm_p c^2 + Nm_n c^2$$

$$B = (Zm_p c^2 + Nm_n c^2) - Mc^2$$



The simplest nuclear model: B/A



The simplest nuclear model

$$R = R_o A^{1/3} \quad R_o = 1.2 fm \quad \text{Nuclear Radius}$$

$$B = a_v A - a_s A^{2/3} - a_c Z(Z-1)A^{-1/3}$$

$$-a_{sym} \frac{(A-2Z)^2}{A} + \delta$$

$$a_v \approx 16 MeV$$

$$a_s \approx 20 MeV$$

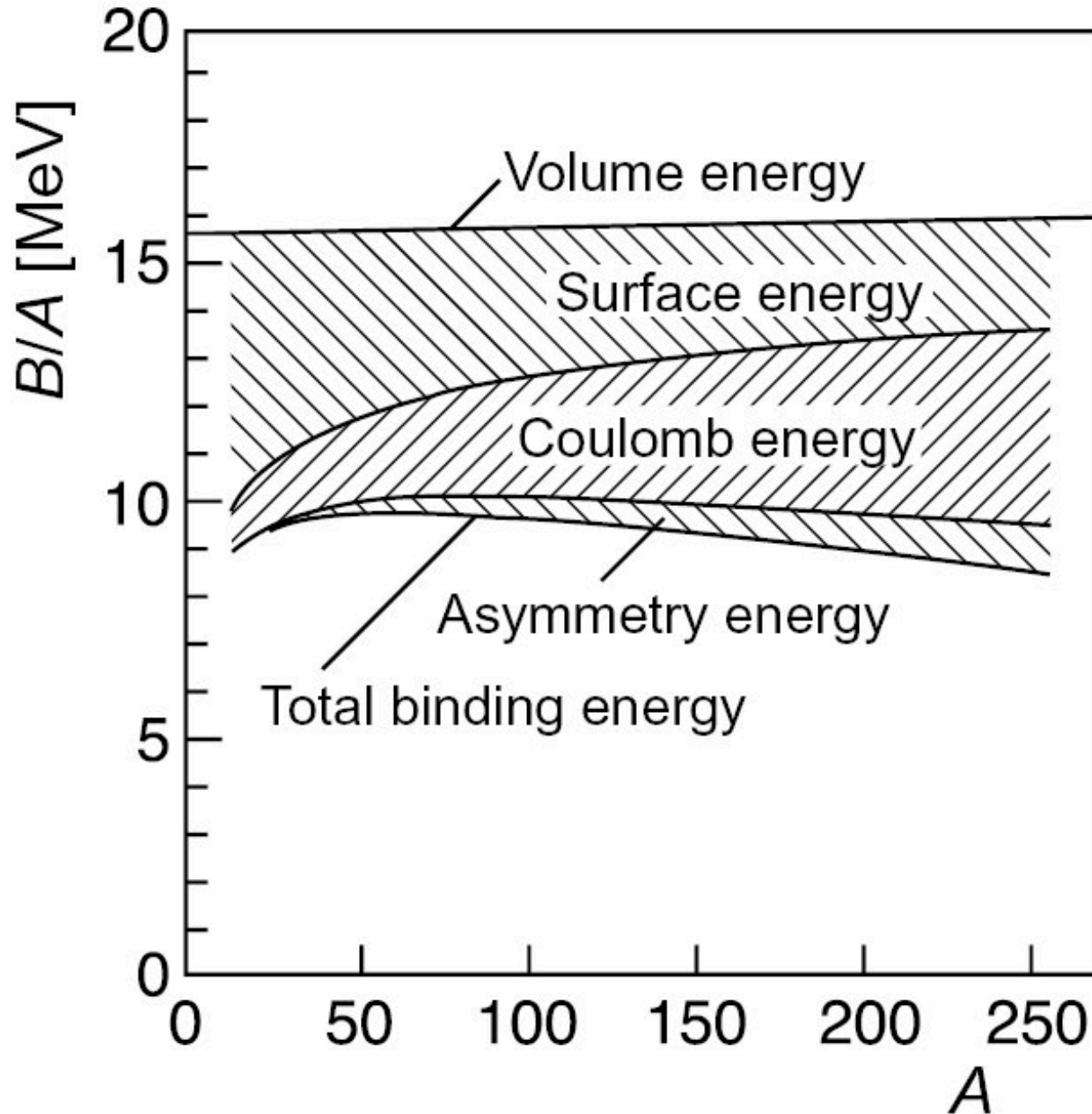
$$a_c \approx 0.75 MeV$$

$$a_{sym} \approx 21 MeV$$

$$\delta = \begin{cases} +a_p A^{-3/4} & \text{for Z, N even} \\ -a_p A^{-3/4} & \text{for Z and N odd} \\ 0 & \text{for A odd} \end{cases}$$

Carl Friedrich von Weizsäcker in 1935

The simplest nuclear model



$$a_v \approx 16 \text{ MeV}$$

$$a_s \approx 20 \text{ MeV}$$

$$a_c \approx 0.75 \text{ MeV}$$

$$a_{\text{Sym}} \approx 21 \text{ MeV}$$

The nuclear force: the real nightmare



The nuclear force: the real nightmare



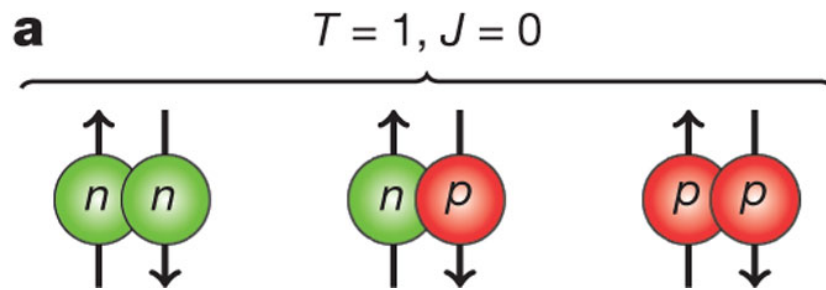
Properties:

- Short range force (strong at the order of 1 fm)
- Charge independent (np, pp, nn is the same)
- Shows a saturation feature (only interact with its neighbours)
- Do not obey $1/r^2$ law, non central, non conservative forces (orbital momentum is not conserved because of the tensor part of the potential)

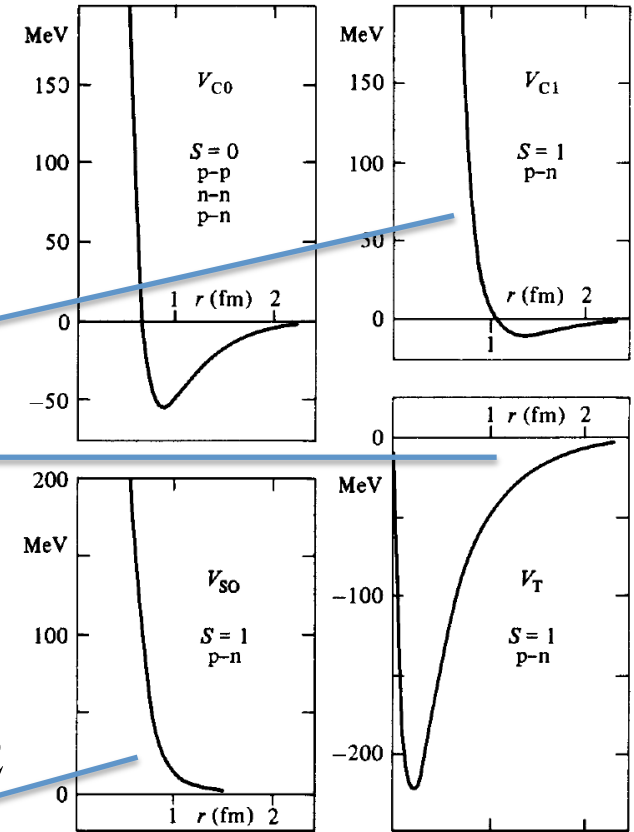
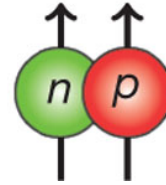
The force depends on the orientation of the spins, and on the velocities of the nucleons. etc.

It is possible to measure pp, np, components of the potential energy

The nuclear force: the real nightmare



b $T = 0, J > 0$



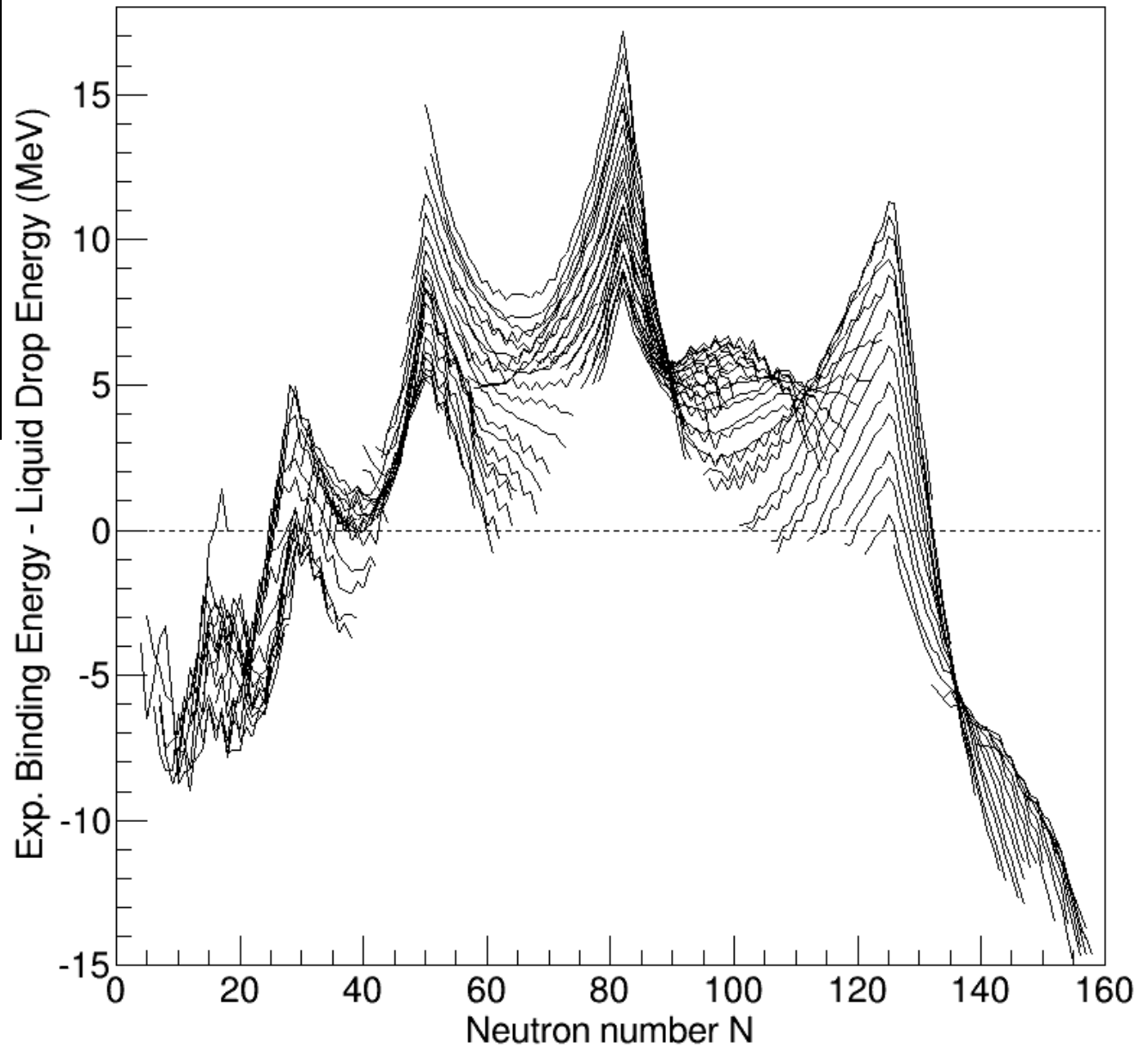
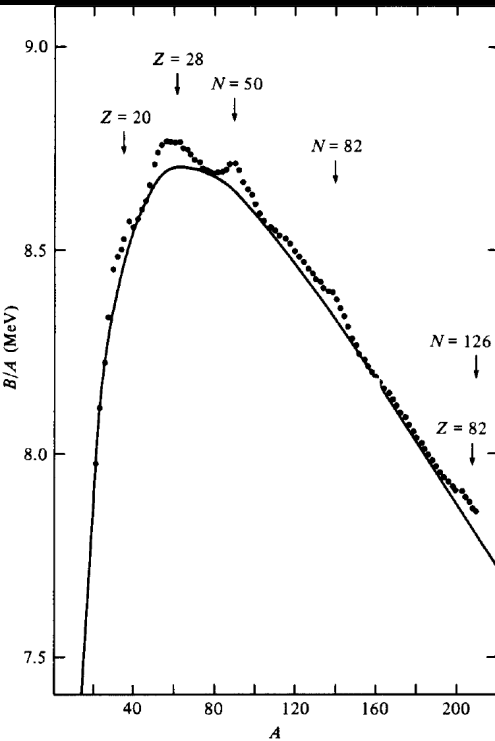
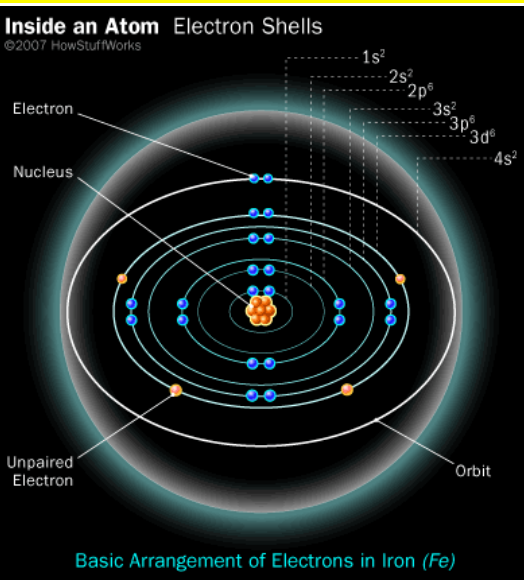
$$V(r) = V_{Cl}(r) + V_T(r)\Omega_T + V_{SO}(r)\Omega_{SO} + V_{SO2}(r)\Omega_{SO2}$$

$$\Omega_T = 3 \frac{(\sigma_1 \cdot r)(\sigma_2 \cdot r)}{r^2} - \sigma_1 \cdot \sigma_2$$

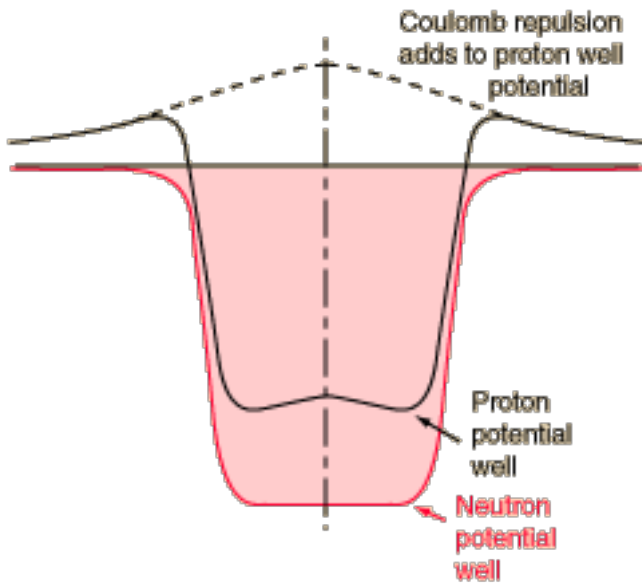
$$\hbar\Omega_{SO} = (\sigma_1 + \sigma_2) \cdot L$$

$$\hbar^2\Omega_{SO2} = (\sigma_1 \cdot L)(\sigma_2 \cdot L) + (\sigma_2 \cdot L)(\sigma_1 \cdot L)$$

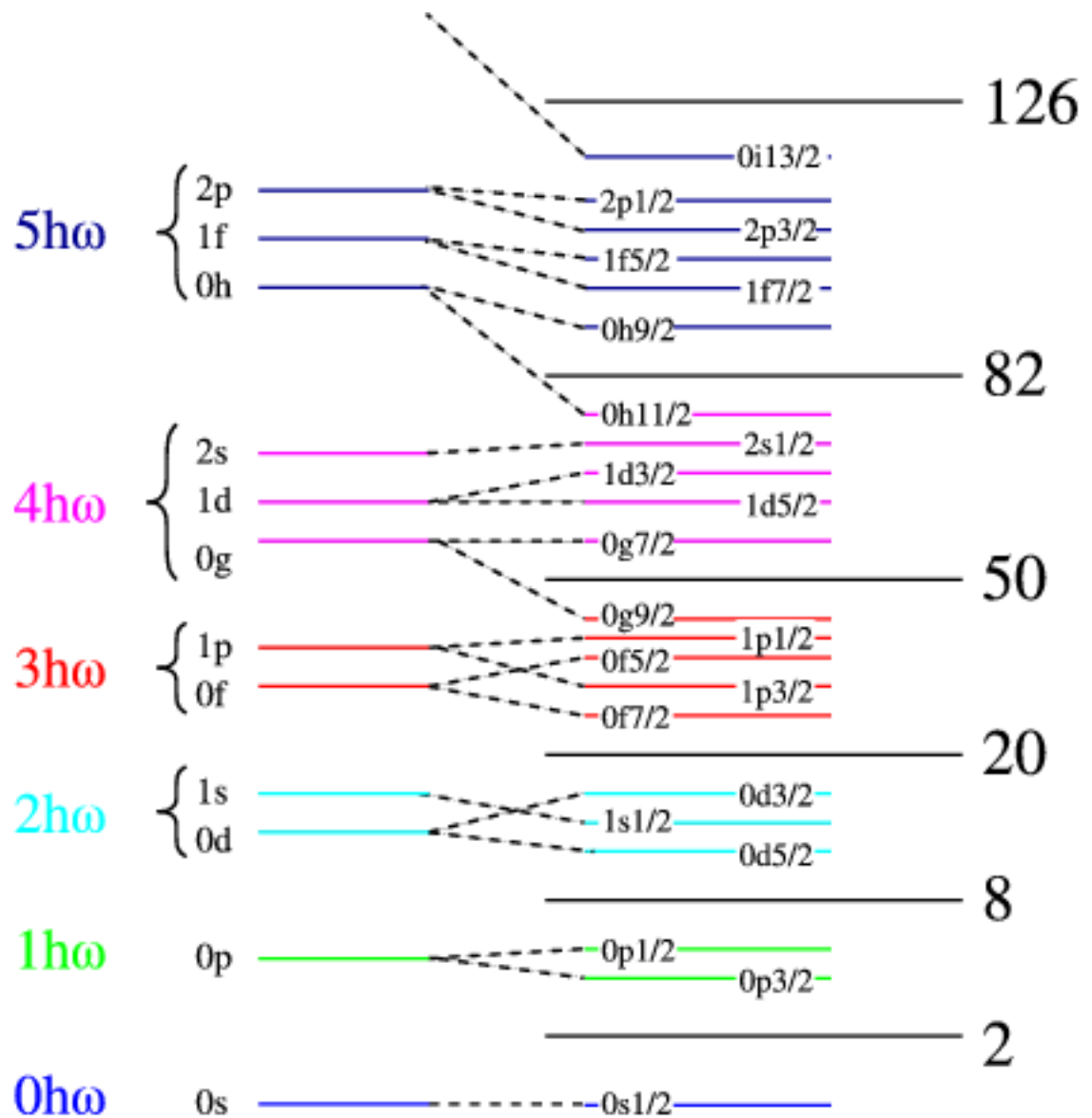
Shells in the nucleus?



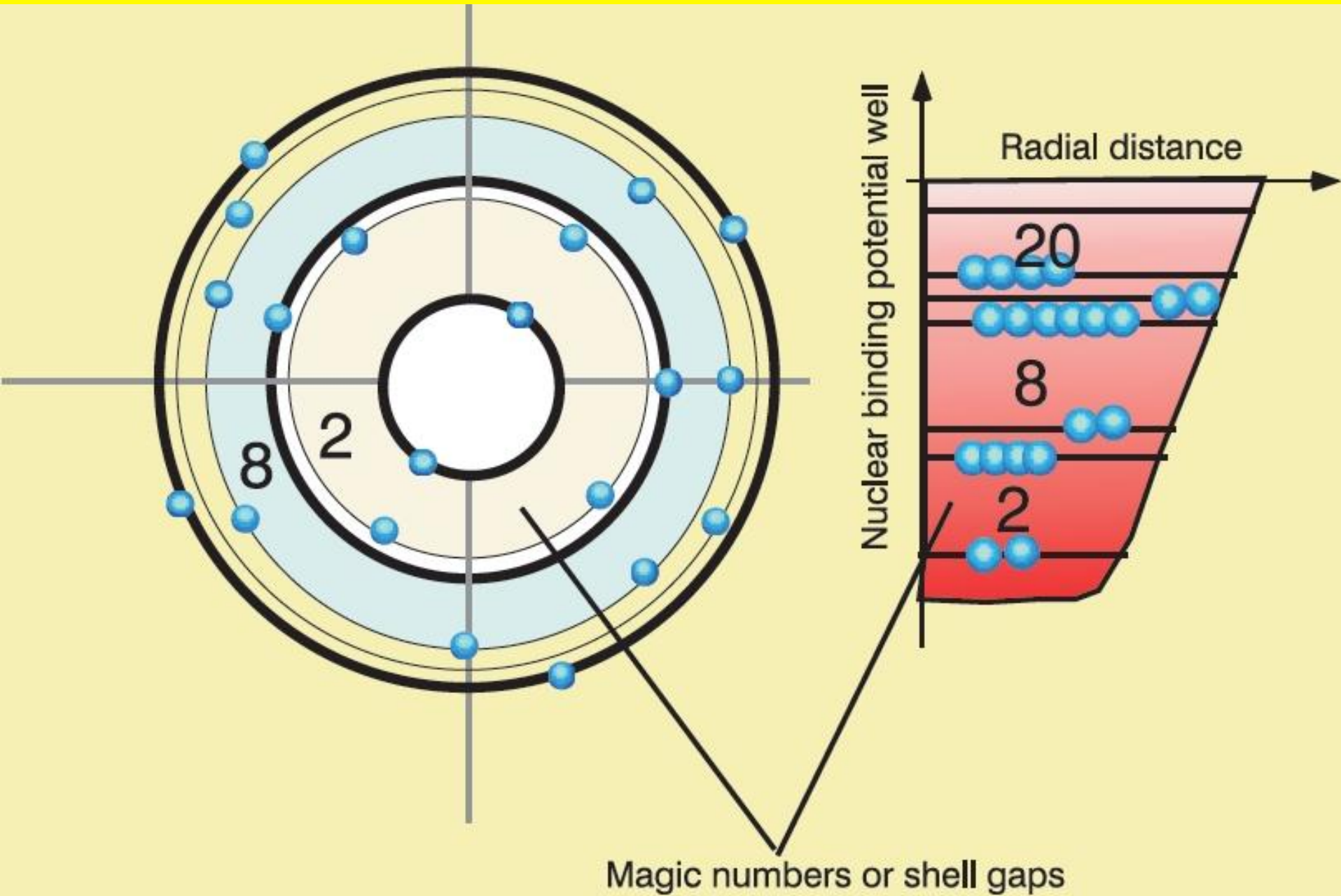
Shells in the nucleus?



Goeppert-Meyer and Jensen
Nobel prize 1963
(shared with E. Wigner)

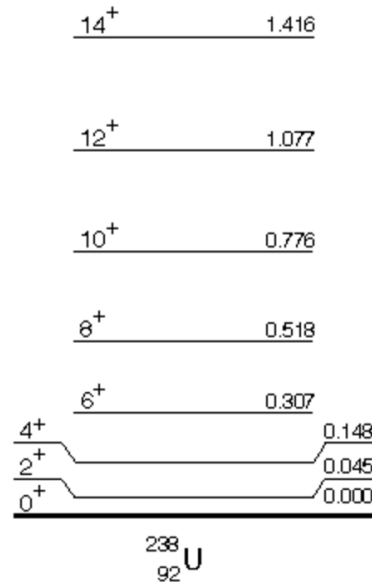
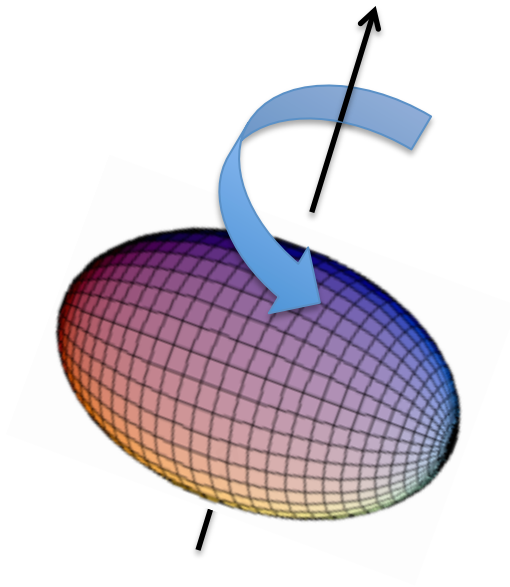


Shells in the nucleus?



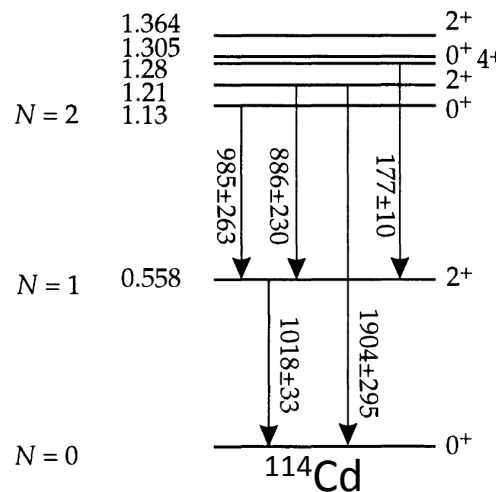
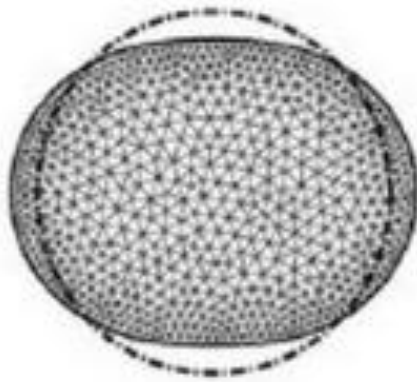
Nucleus as a rotating or vibrating object?

The collective model



$$E = \frac{J(J+1)}{2\Theta}$$

Bohr, Mottelson, Rainwater
Nobel prize 1975



Phonon number

Experiment

$$E = \hbar\omega\left(N + \frac{5}{2}\right)$$

Summary: what is the nucleus then?

Nuclei show also excited states that can be populated in beta, alpha decay and in nuclear reactions. These states have to be interpreted using nuclear models. This is one of the major challenges in nuclear physics.

We will see that to understand those states we will use different models, apparently contradictory among themselves, but highly successful and that show the complexity of the nuclear world.

The nucleus behaves as:

Collective system like the liquid drop: it rotates, vibrates, splits (fission)

COLLECTIVE MODELL

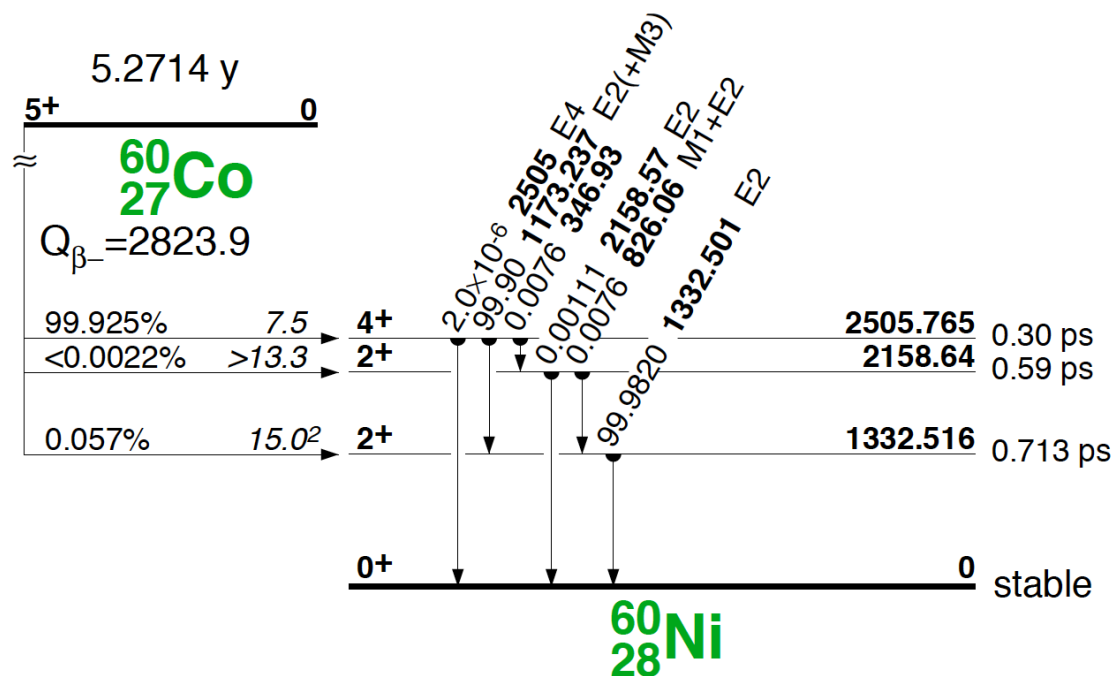
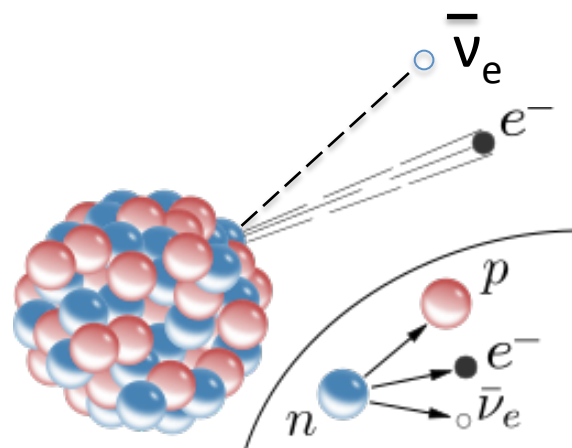
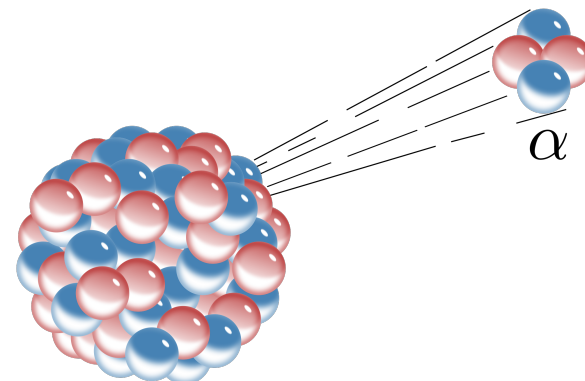
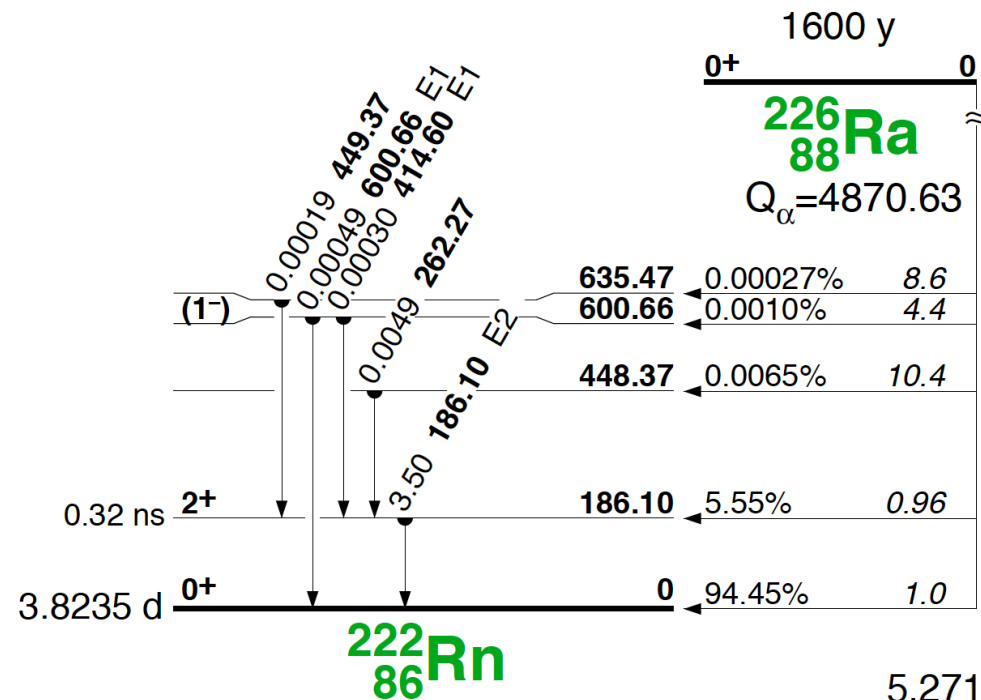
“Planetary system” like the atom: it shows that many times the properties of the states in a nucleus are determined by single nucleons in discrete states

SHELL MODELL

Cluster system: it emits cluster (groups) of nucleons, that might exist in the nucleus

CLUSTER MODELL

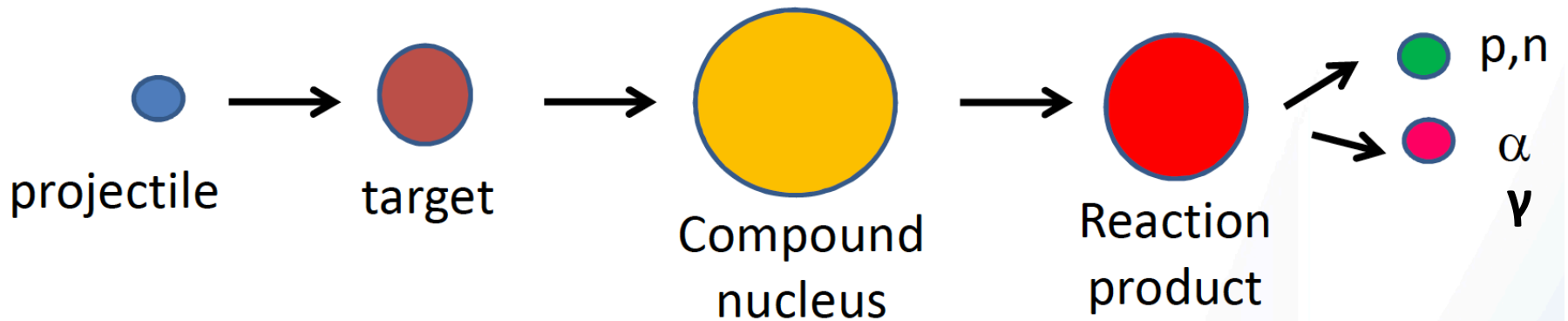
How excited states can be studied ?



Nuclear reactions basics



First artificial nuclear reaction
(Rutherford, 1919)



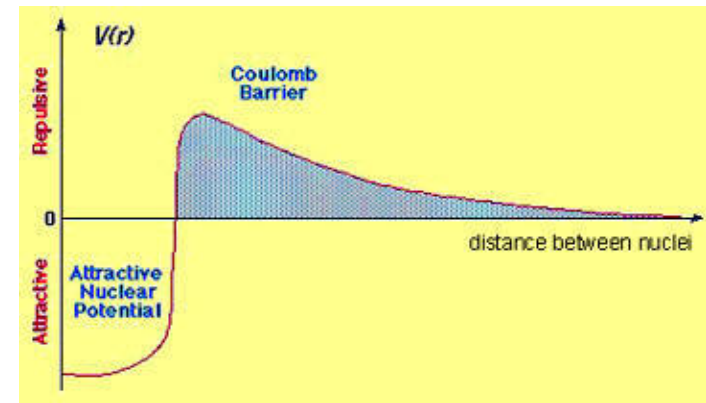
To make it happen, you need to overcome the Coulomb force

$$V = \frac{kQq}{r}$$

Diagram showing two nuclei, ${}^{A_p}_{Z_p}X$ and ${}^{A_t}_{Z_t}Y$, separated by a distance r .

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

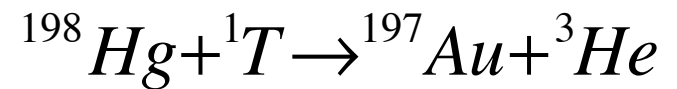
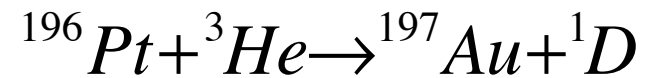
$$V = \frac{1.24 * Z_p * Z_t}{A_p + A_t}$$



This is why you need accelerators to study nuclei, and why they were born in 1932

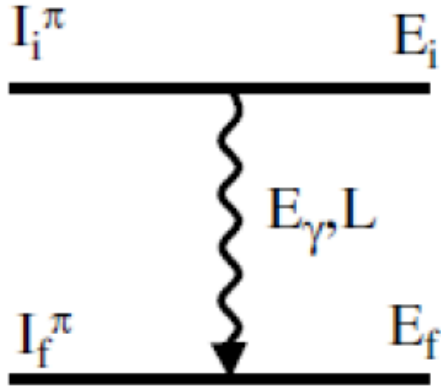
Alchemy

Alchemy is a philosophical and protoscientific tradition practiced throughout Europe, Egypt and Asia. It aimed to purify, mature, and perfect certain objects. Common aims were chrysopoeia, the transmutation of "base metals" (e.g., lead) into "noble" ones (particularly gold); the creation of an elixir of immortality; the creation of panaceas able to cure any disease, etc.



What we detect from a nuclear reaction or decay?

Gamma Emission



$$E_\gamma = E_i - E_f$$

$$|I_i - I_f| \leq L \leq I_i + I_f$$

$$\Delta\pi(EL) = (-1)^L$$

$$\Delta\pi(ML) = (-1)^{L+1}$$

Excited nuclei main decay modes

- p, n, alpha emission
- gamma emission /electron conversion
- beta decay
- alpha decay
- fission

From the gamma decay (very common)

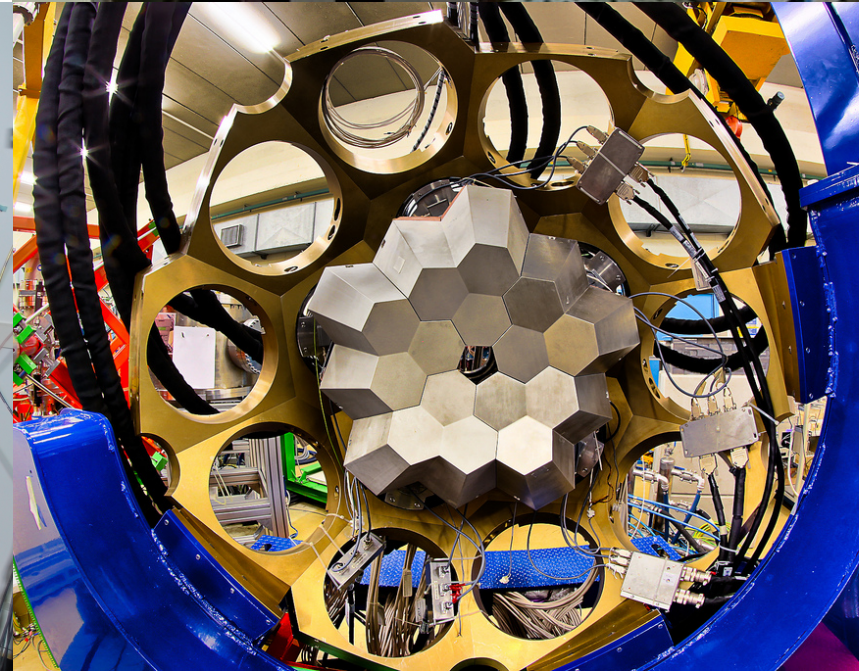
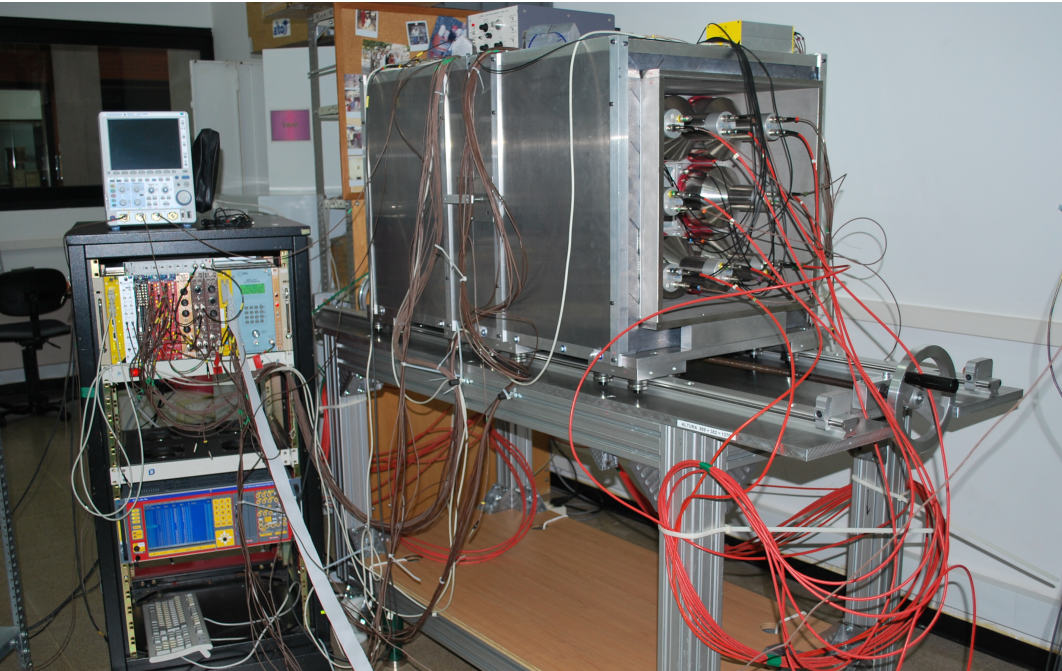
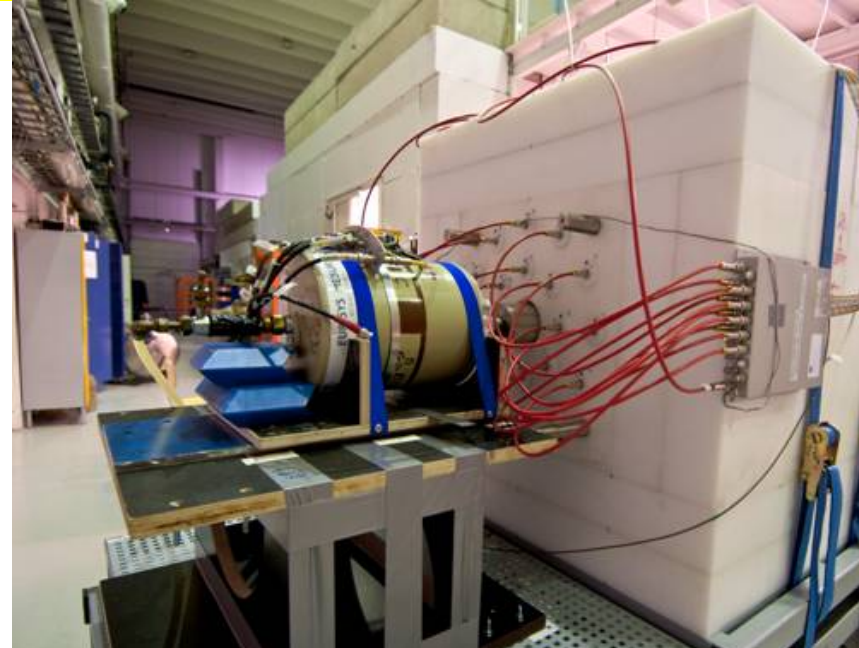
- energies of states
- spin-parities of state
- life-time of states
- etc.



What we detect from a nuclear reaction or decay?

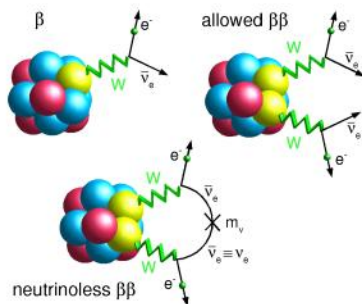
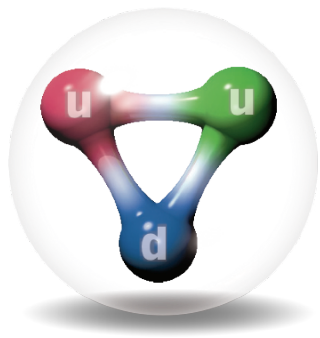
Excited nuclei main decay modes

- p, n, alpha emission
- gamma emission /electron conversion
- beta decay
- alpha decay
- fission



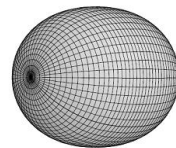
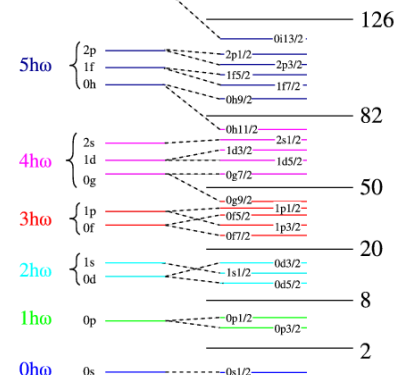
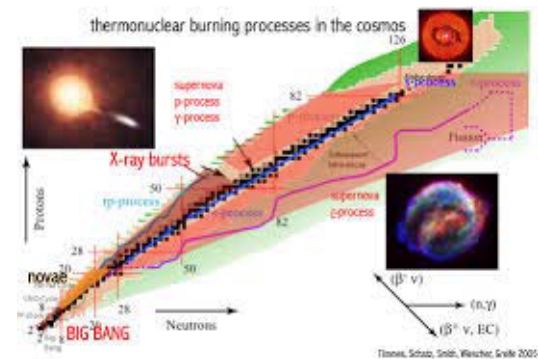
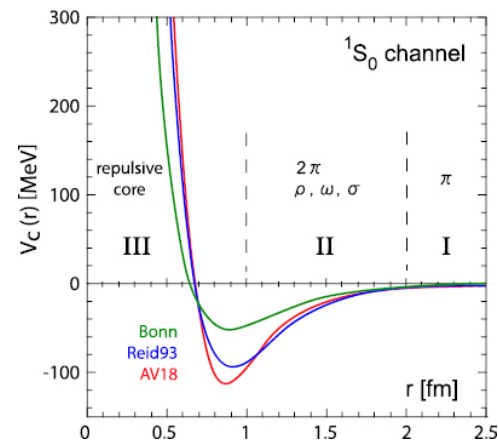
Why Nuclear Physics is still special?

- Quantum system of variable number of particles ($1 \leq A \leq 300$)
- Playground of the strong, electromagnetic and weak interaction
- The states of these quantum systems can be excited more or less flexibly (by means reactions and beta decay, constrained by nature laws)
- Test ground of many-body approaches
- Explain many things related also to the macroscopic World (nuclear astrophysics, the internal heat of our planet, etc.)
- Multiple applications in our lives (nuclear energy, medical diagnostics, cancer therapy, non-proliferation control, monitor climate change, material analysis, etc.).



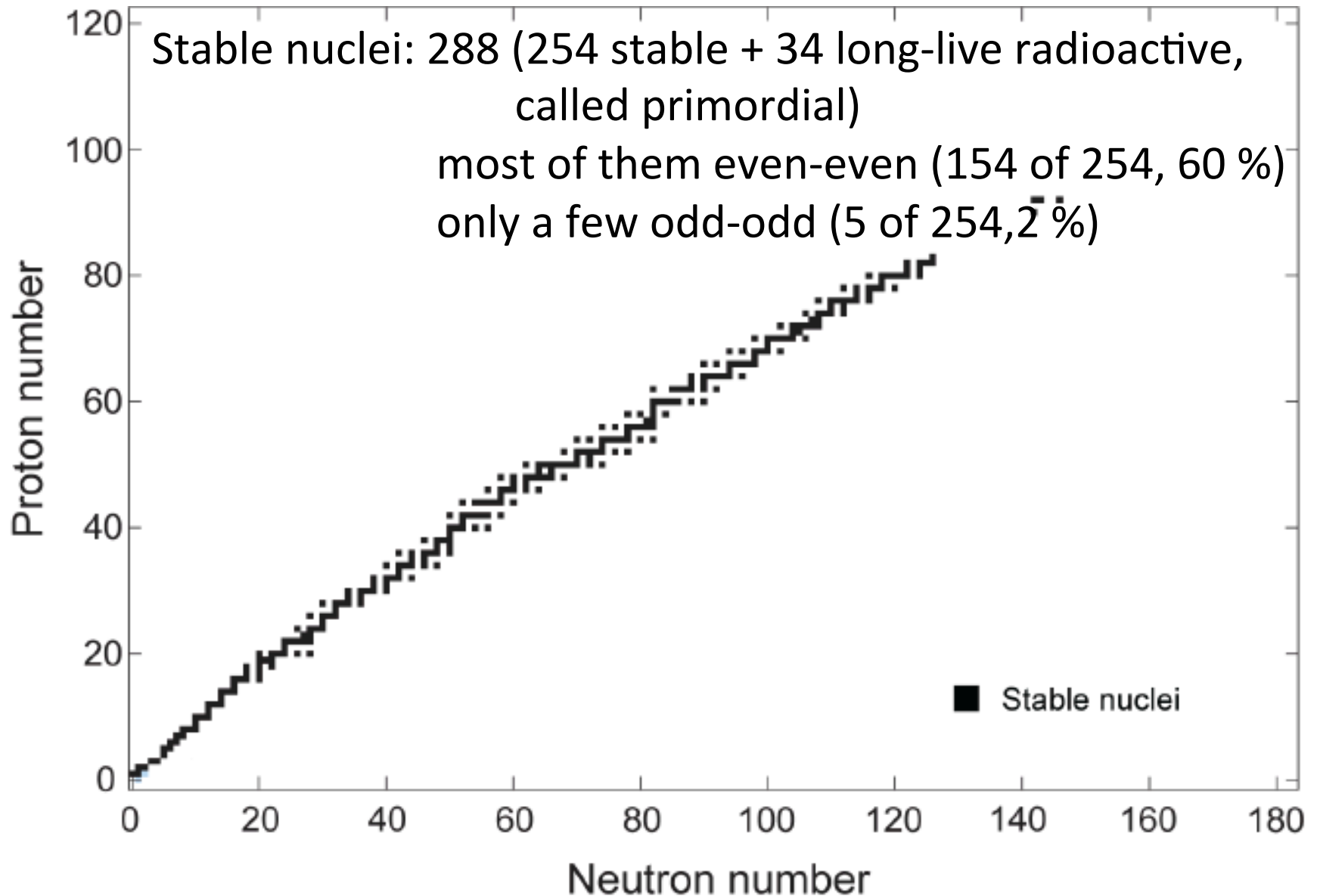
Main questions in current Nuclear Structure Research

- What is the nature of the nuclear force that binds nucleons in stable nuclei and rare isotopes ? How it evolves going to exotic regimes ?
- What are the limits of nuclear existence? What is the heaviest element we can make and where does the neutron-dripline lie?
- What is the origin of the elements of the cosmos ?
- What is the origin of simple patterns in the spectrum of complex nuclei ?

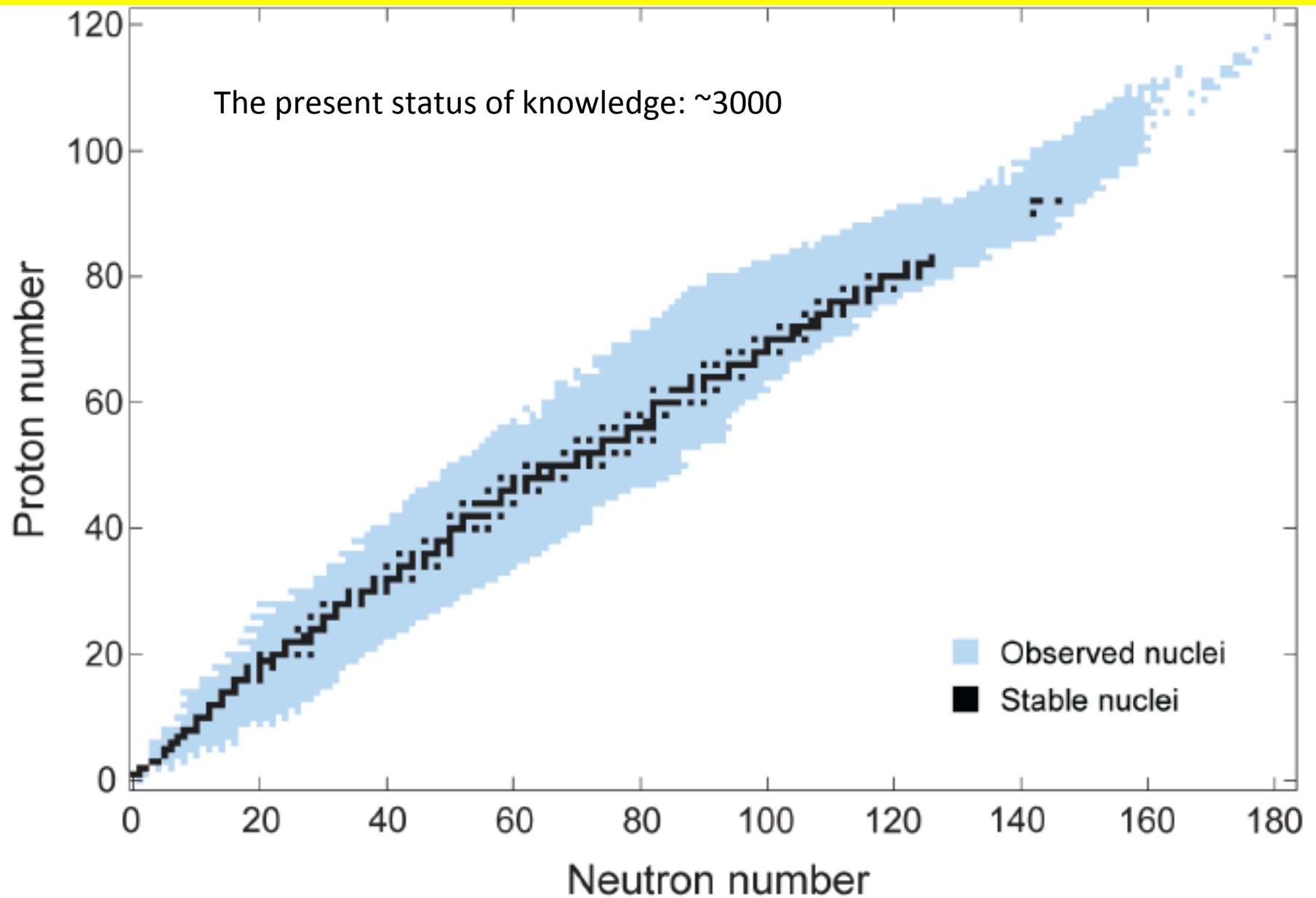


Taken from NUPECC long range plans

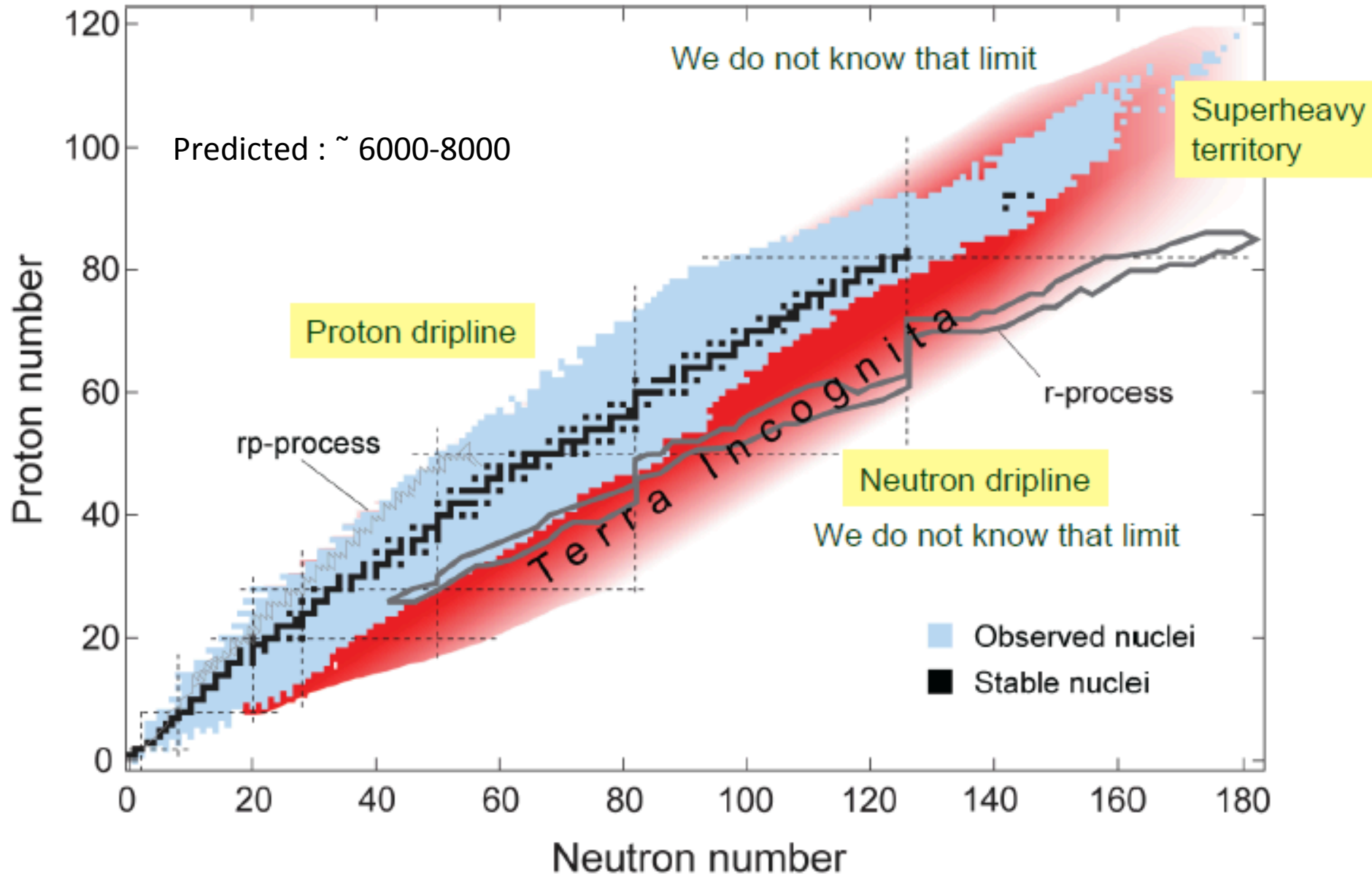
The nuclear landscape



The nuclear landscape

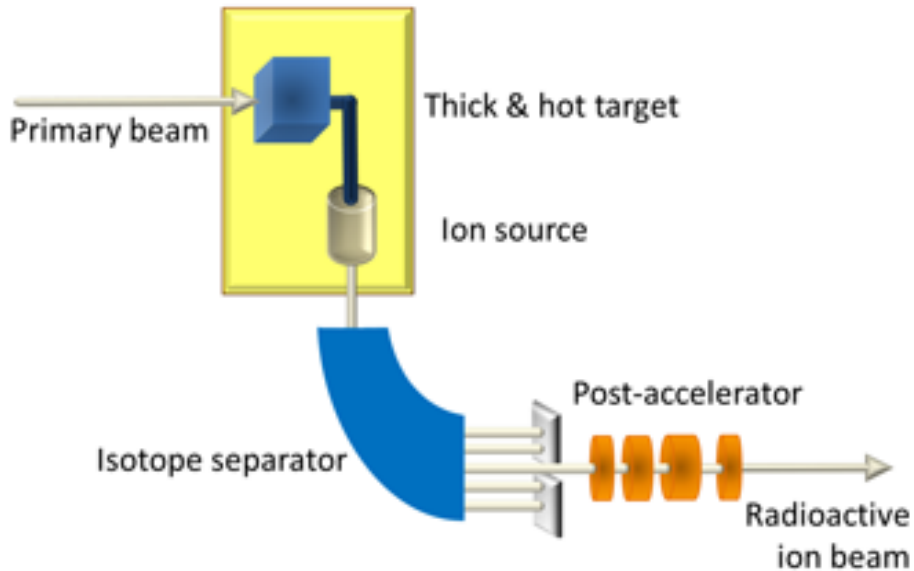


The nuclear landscape

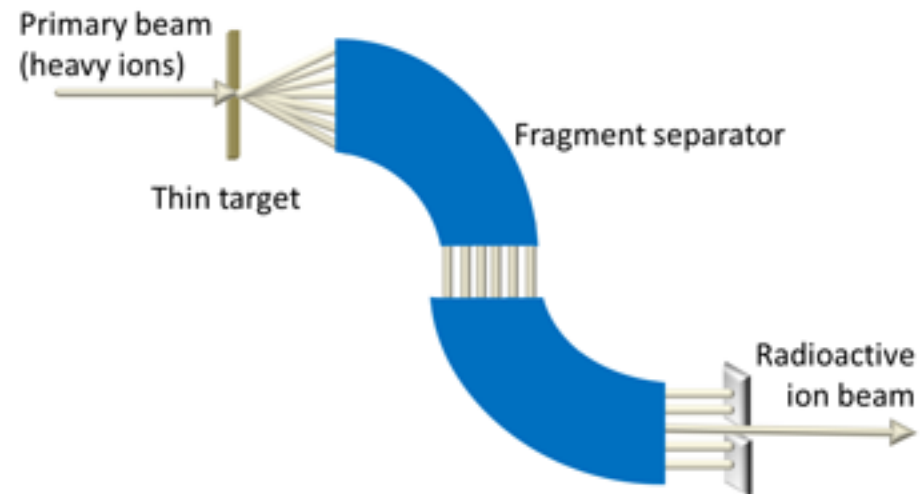


How we produce “exotic” nuclei for study ?

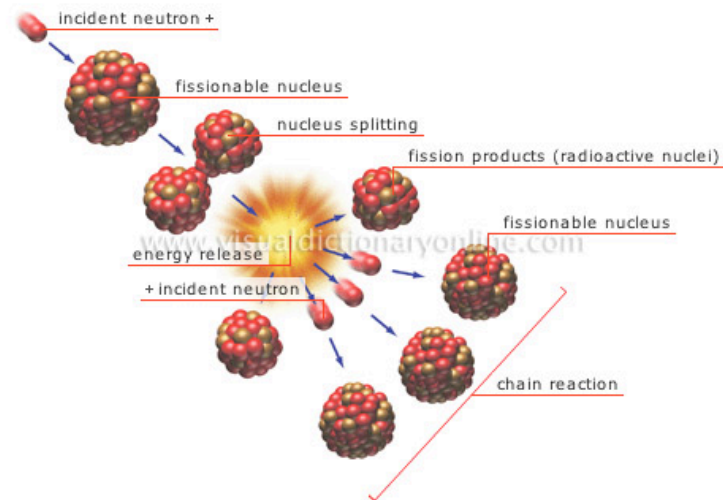
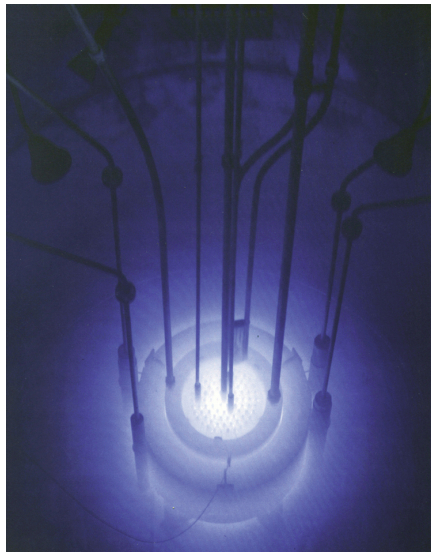
ISOL Method



In-flight separation



**Also from fission
(in nuclear reactors or using fission)**



Some examples of recent work (GANIL)

PRL **112**, 222501 (2014)

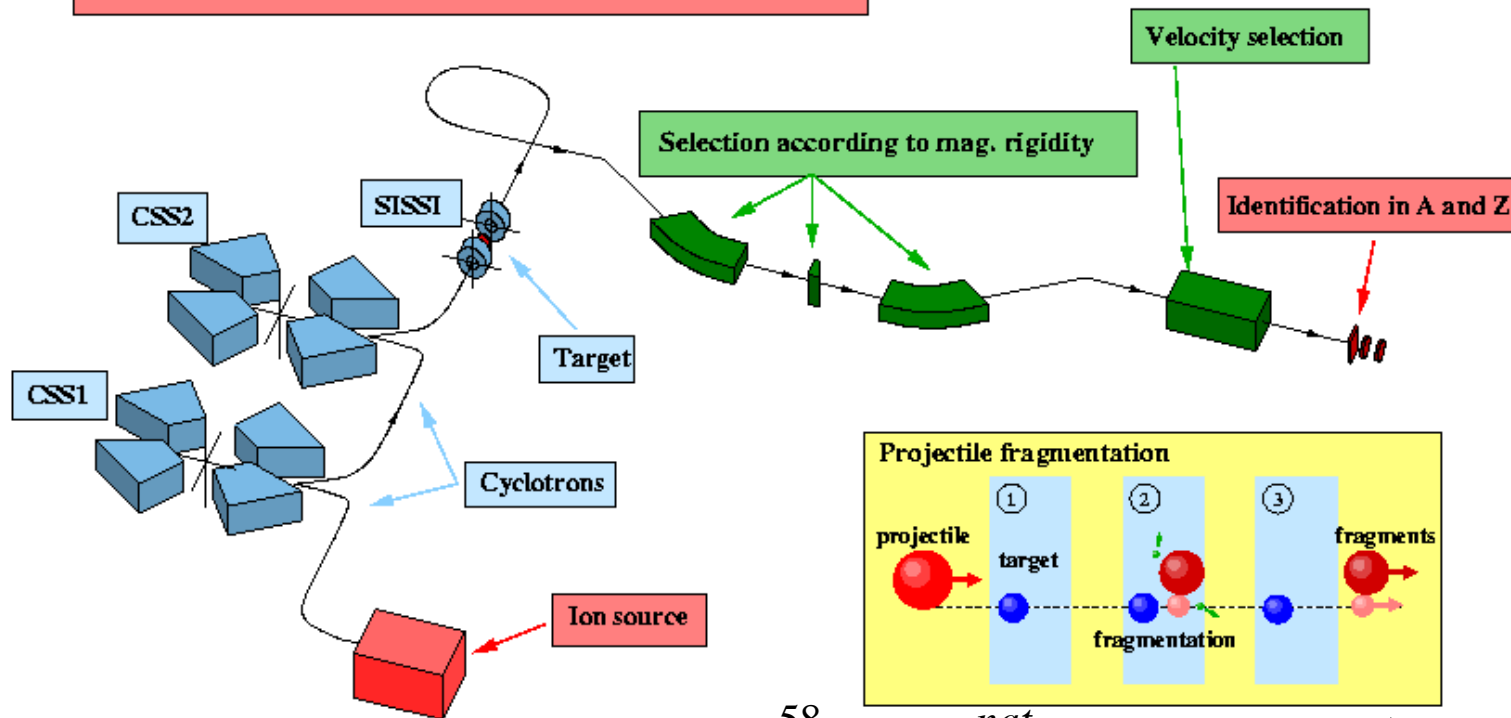
PHYSICAL REVIEW LETTERS

week ending
6 JUNE 2014

Observation of the β -Delayed γ -Proton Decay of ^{56}Zn and its Impact on the Gamow-Teller Strength Evaluation

S. E. A. Orrigo,^{1,*} B. Rubio,¹ Y. Fujita,^{2,3} B. Blank,⁴ W. Gelletly,⁵ J. Agramunt,¹ A. Algora,^{1,6} P. Ascher,⁴ B. Bilgier,⁷ L. Cáceres,⁸ R. B. Cakirli,⁷ H. Fujita,³ E. Ganioglu,⁷ M. Gerbaux,⁴ J. Giovinnazzo,⁴ S. Grévy,⁴ O. Kamalou,⁸ H. C. Kozar,⁷ L. Kucuk,⁷ T. Kurtukian-Nieto,⁴ F. Molina,^{1,9} L. Popescu,¹⁰ A. M. Rogers,¹¹ G. Susoy,⁷ C. Stodel,⁸ T. Suzuki,³ A. Tamii,³ and J. C. Thomas⁸

LISE 3 separator at GANIL



$^{58}\text{Ni} + {}^{nat}\text{Ni}$ at 74.5 MeV / A

Some examples of recent work (GANIL)

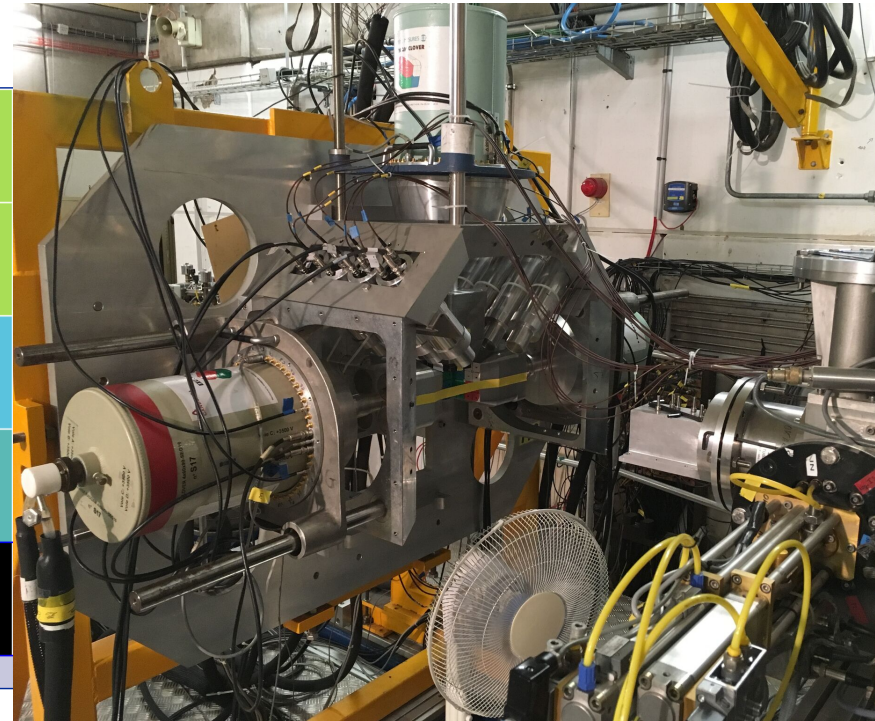
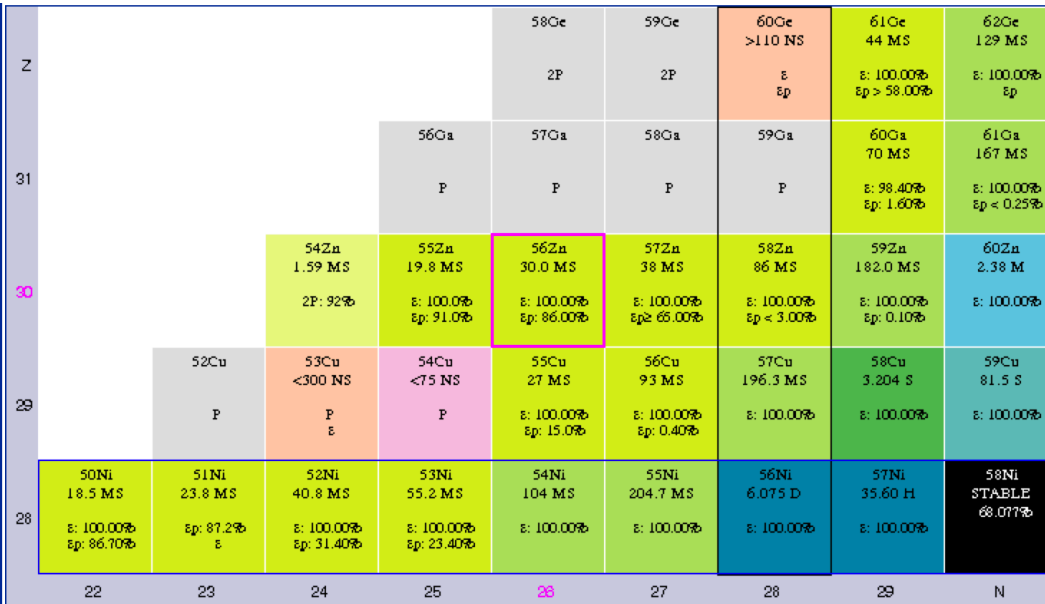
PRL **112**, 222501 (2014)

PHYSICAL REVIEW LETTERS

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Some examples of recent work

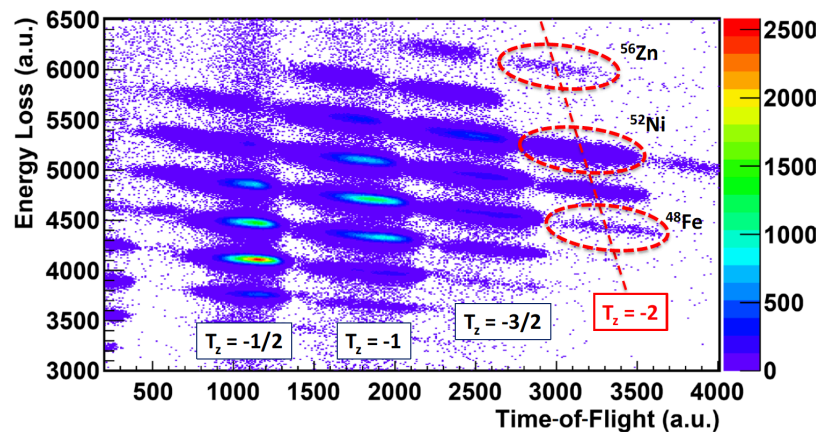
PRL **112**, 222501 (2014)

PHYSICAL REVIEW LETTERS

week ending
6 JUNE 2014

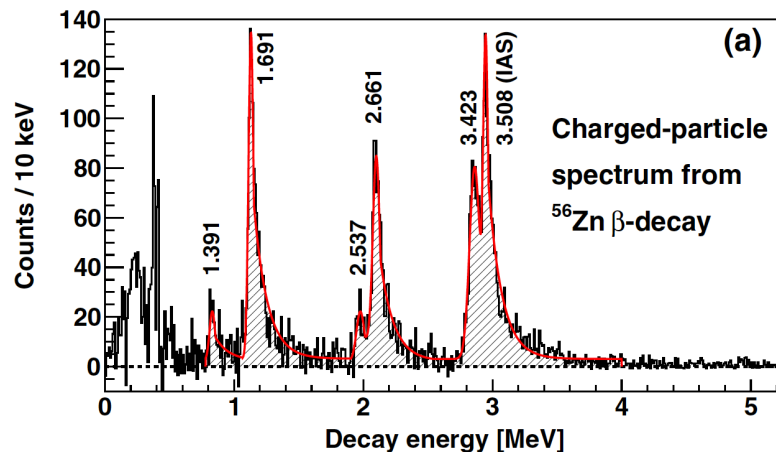
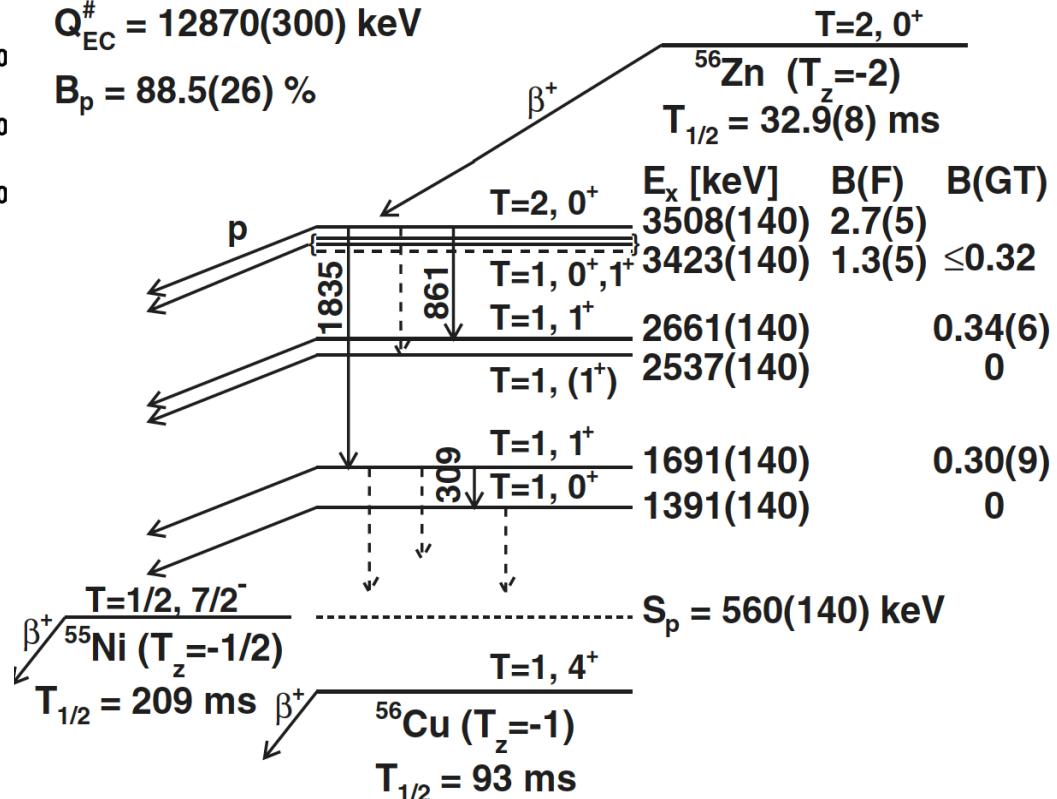
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$$Q_{\text{EC}}^{\#} = 12870(300) \text{ keV}$$

$$B_p = 88.5(26) \%$$



Some examples of recent work (Jyväskylä)

 Selected for a **Viewpoint** in *Physics*

PRL **105**, 202501 (2010)

PHYSICAL REVIEW LETTERS

week ending
12 NOVEMBER 2010



Reactor Decay Heat in ^{239}Pu : Solving the γ Discrepancy in the 4–3000-s Cooling Period

A. Algora,^{1,2,*} D. Jordan,¹ J. L. Taín,¹ B. Rubio,¹ J. Agramunt,¹ A. B. Perez-Cerdan,¹ F. Molina,¹ L. Caballero,¹ E. Nácher,¹ A. Krasznahorkay,² M. D. Hunyadi,² J. Gulyás,² A. Vitéz,² M. Csatlós,² L. Csige,² J. Äystö,³ H. Penttilä,³ I. D. Moore,³ T. Eronen,³ A. Jokinen,³ A. Nieminen,³ J. Hakala,³ P. Karvonen,³ A. Kankainen,³ A. Saastamoinen,³ J. Rissanen,³ T. Kessler,³ C. Weber,³ J. Ronkainen,³ S. Rahaman,³ V. Elomaa,³ S. Rinta-Antila,³ U. Hager,³ T. Sonoda,³ K. Burkard,⁴ W. Hüller,⁴ L. Batist,⁵ W. Gelletly,⁶ A. L. Nichols,⁶ T. Yoshida,⁷ A. A. Sonzogni,⁸ and K. Peräjärvi⁹

PRL **115**, 102503 (2015)

PHYSICAL REVIEW LETTERS

week ending
4 SEPTEMBER 2015

Total Absorption Spectroscopy Study of ^{92}Rb Decay: A Major Contributor to Reactor Antineutrino Spectrum Shape

A.-A. Zakari-Issoufou,¹ M. Fallot,¹ A. Porta,^{1,*} A. Algora,^{2,3} J. L. Tain,² E. Valencia,² S. Rice,⁴ V. M. Bui,¹ S. Cormon,¹

PRL **115**, 062502 (2015)

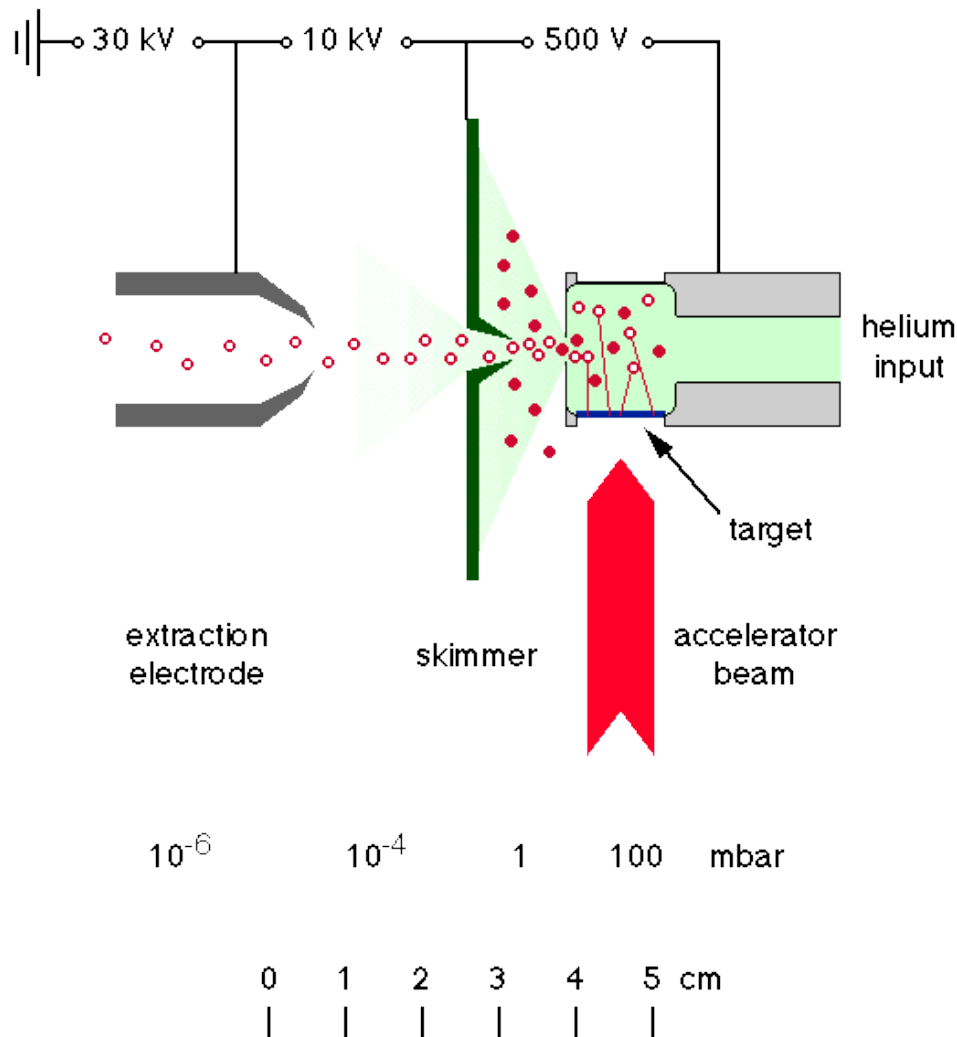
PHYSICAL REVIEW LETTERS

week ending
7 AUGUST 2015

Enhanced γ -Ray Emission from Neutron Unbound States Populated in β Decay

J. L. Tain,^{1,*} E. Valencia,¹ A. Algora,¹ J. Agramunt,¹ B. Rubio,¹ S. Rice,² W. Gelletly,² P. Regan,² A.-A. Zakari-Issoufou,³ M. Fallot,³ A. Porta,³ J. Rissanen,⁴ T. Eronen,⁴ J. Äystö,⁵ L. Batist,⁶ M. Bowry,² V. M. Bui,³ R. Caballero-Folch,⁷ D. Cano-Ott,⁸ V.-V. Elomaa,⁴ E. Estevez,¹ G. F. Farrelly,² A. R. Garcia,⁸ B. Gomez-Hornillos,⁷ V. Gorlychev,⁷ J. Hakala,⁴ M. D. Jordan,¹ A. Jokinen,⁴ V. S. Kolhinen,⁴ F. G. Kondev,⁹ T. Martínez,⁸ E. Mendoza,⁸ I. Moore,⁴ H. Penttilä,⁴

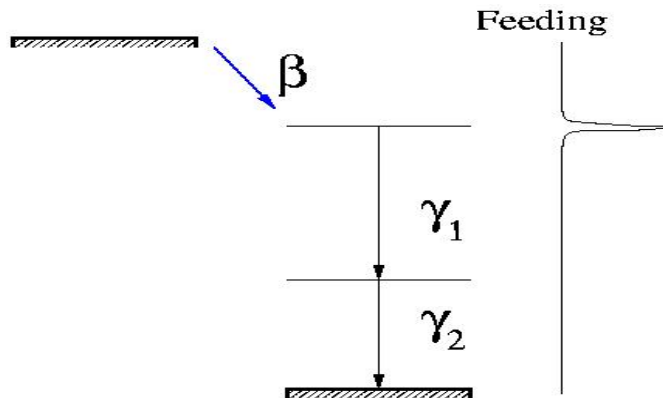
The ion guide technique (ISOL, Jyväskylä)



Generic ion guide: the nuclear reaction products are stopped in a gas and are transported through a differential pumping system into the accelerator stage of the mass separator.

The process is fast enough for the ions to survive as single charged ions. The system is chemically insensitive and very fast (sub-ms).

TAGS measurements



Since the gamma detection is the only reasonable way to solve the problem, we need a highly efficient device:

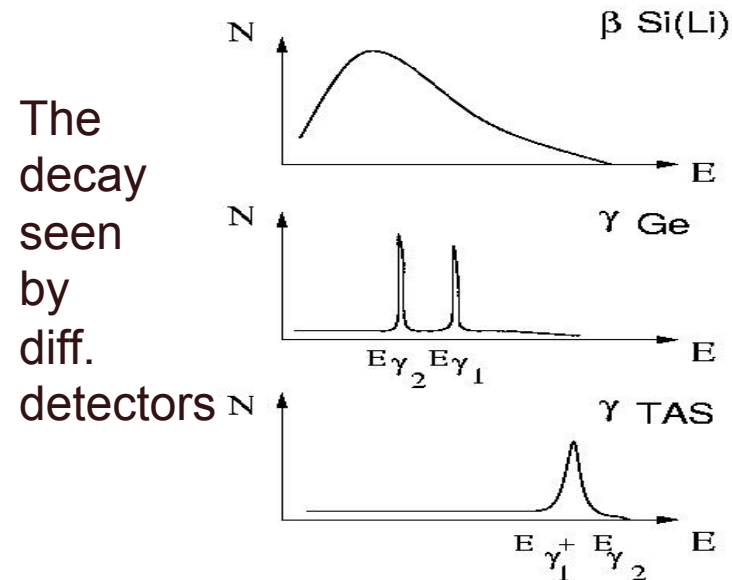
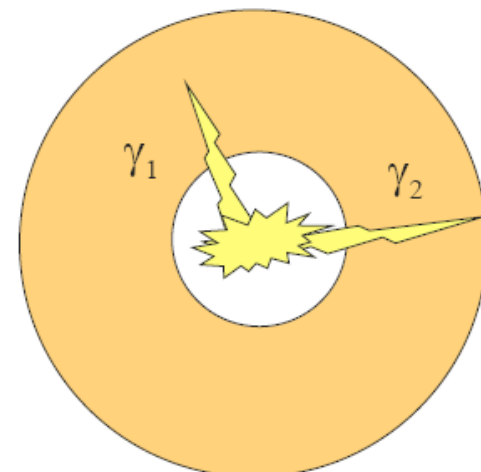
A TOTAL ABSORPTION SPECTROMETER

But we need a change in philosophy. Instead of detecting the individual gamma rays we sum the energy deposited by the gamma cascades in the detector.

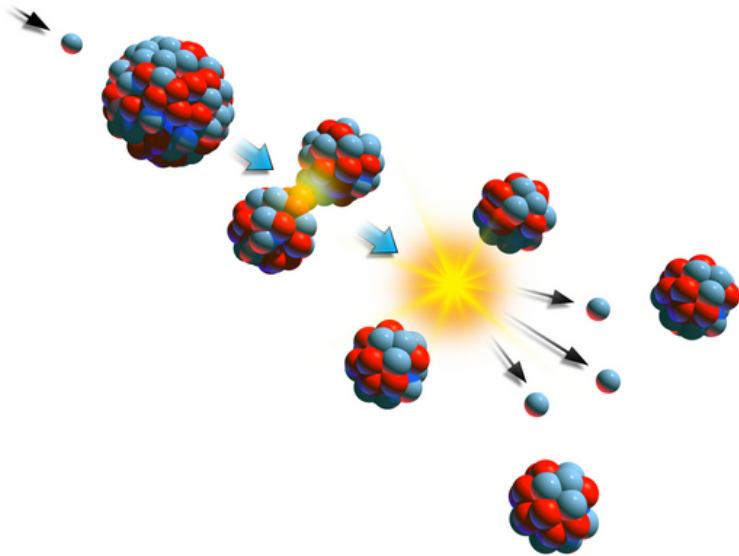
A TAS is like a calorimeter!

Big crystal, 4π

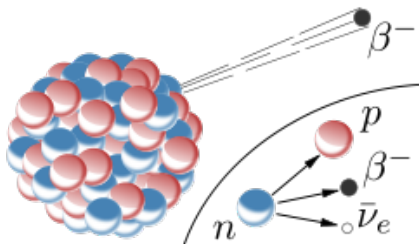
$$d = R(B) \cdot f$$



Decay data needs for reactor applications



Each fission is approximately followed by 6 beta decays (sizable amount of energy released by the fission products)



Energy released in the fission of ^{235}U

Energy distribution	MeV
Kinetic energy light fission fragment	100.0
Kinetic energy heavy fission fragment	66.2
Prompt neutrons	4.8
Prompt gamma rays	8.0
Beta energy of fission fragments	7.0
Gamma energy of fission fragments	7.2
Subtotal	192.9
Energy taken by the neutrinos	9.6
Total	202.7

James, J. Nucl. Energy 23 (1969) 517

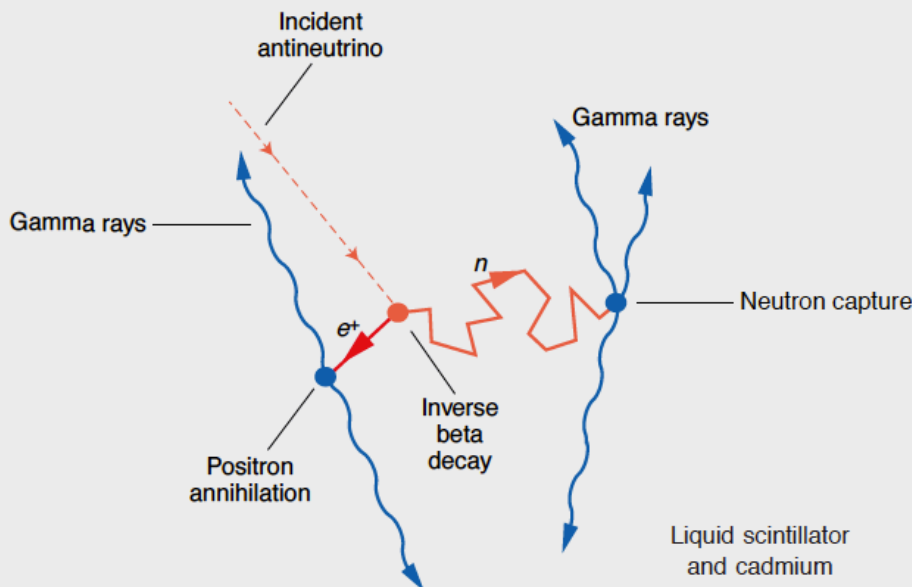


Nuclear reactors and neutrino physics I

Neutrino postulated by Pauli, 1930
Nuclear reactors are the strongest
(peaceful) human source of
antineutrinos .

Reines, Cowan, 1956

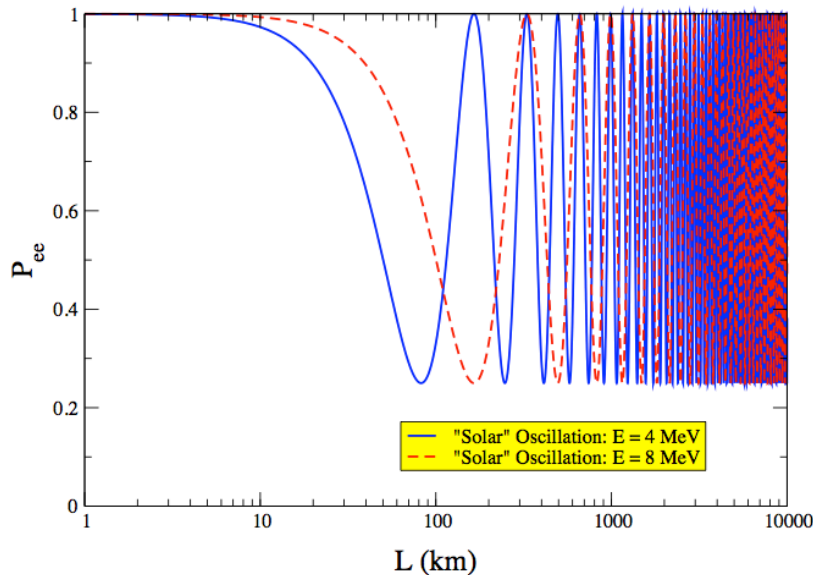
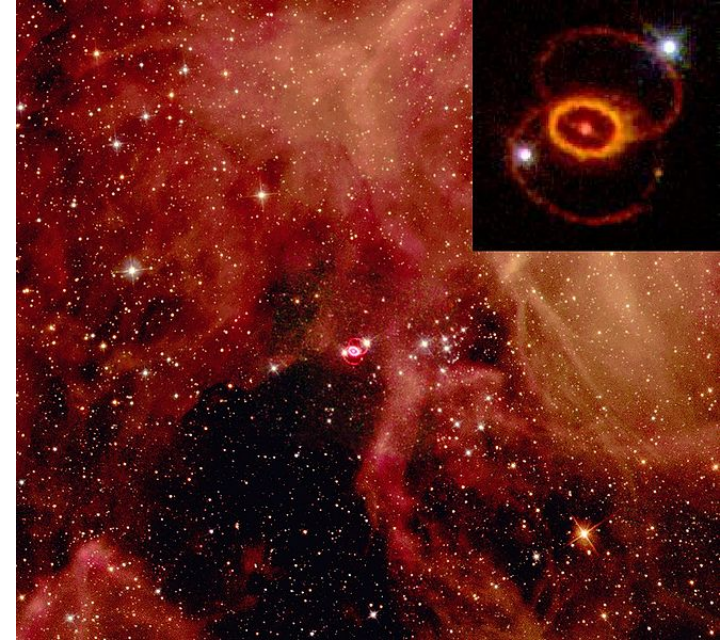
$$\bar{\nu} + p \rightarrow e^{+} + n$$



Neutrino flux at the *Savannah River*
reactor: 5×10^{13} neutrino/s.cm²
They detected 3 neutrinos/h
Science 20, vol 124 no. 3212 pp. 103-104

Why worth studying: neutrinos as messengers

- We hear about many types of neutrinos: solar neutrinos, geo-neutrinos, atmospheric neutrinos, supernova neutrinos, Big Bang neutrinos, reactor neutrinos, etc., etc.
- They can provide information about the processes that happen inside those objects, because they can travel very long distances without interaction.
- Quantum effects at macroscopic scales



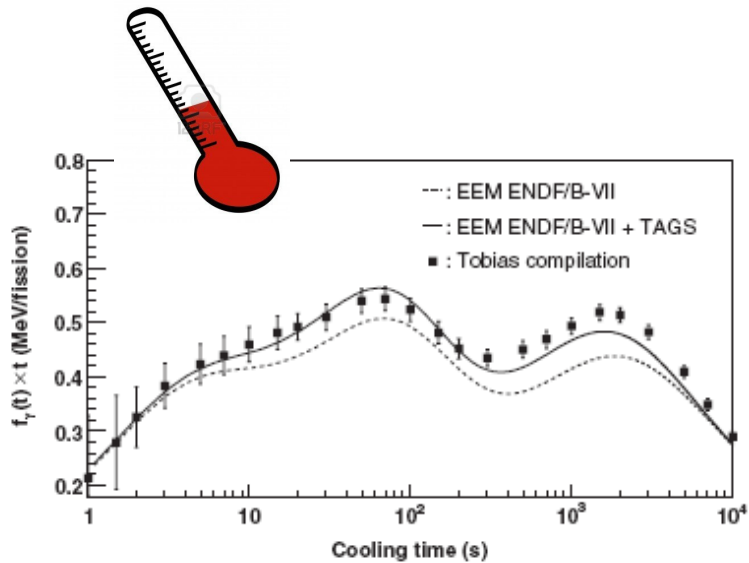
Oscillations !!!

(solar neutrino deficit, atm. neutrino deficit, ^{238}U , ^{232}Th , ^{40}K content, etc.)

Example of reactor neutrino oscillation experiment: Double Chooz, Θ_{13}



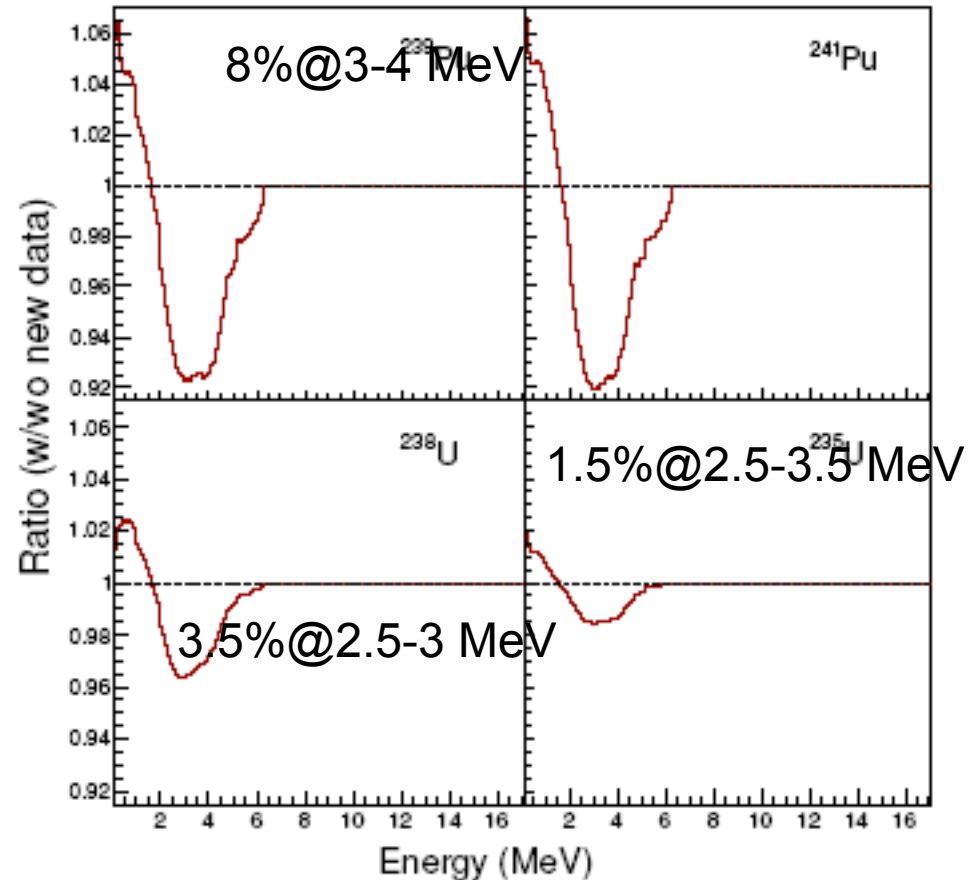
Impact of our data (published up to now)



Dolores Jordan, PhD thesis
 Algora et al., PRL 105, 202501, 2010



M. Fallot et al., PRL 109.202504



Ratio between 2 antineutrino spectra built with and without the $^{102,104,105,106,107}\text{Tc}$, ^{105}Mo , ^{101}Nb TAS data

New questions: reactor anomaly ?

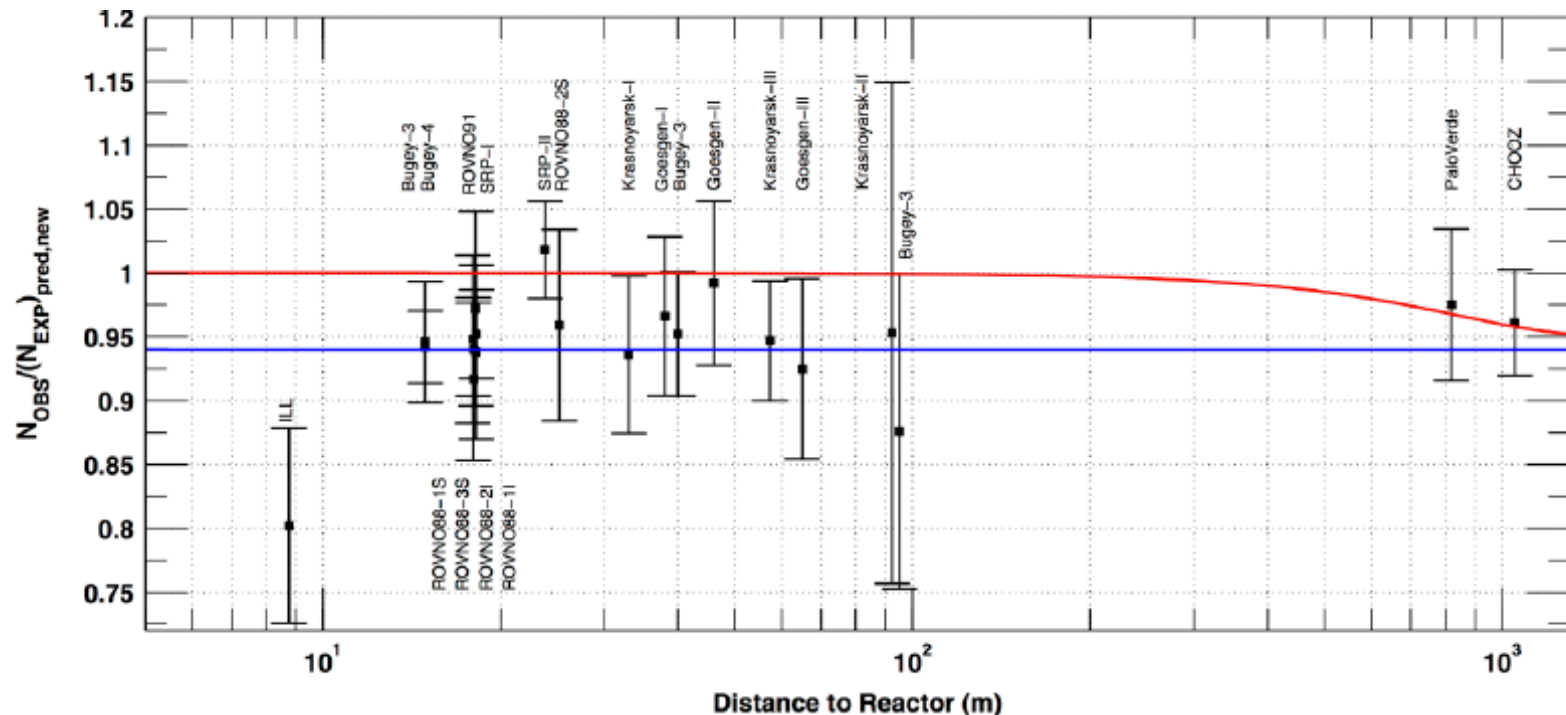


Illustration of the reactor anomaly. Rates in various experiments are compared with the expectations based on the Mueller et al. (2011) spectrum. The mean is 0.943 ± 0.023 .

Possible explanation:

1) Wrong reactor flux or its error

2) Bias in all experiments

3) New physics at short baseline involving a sterile 4th neutrino

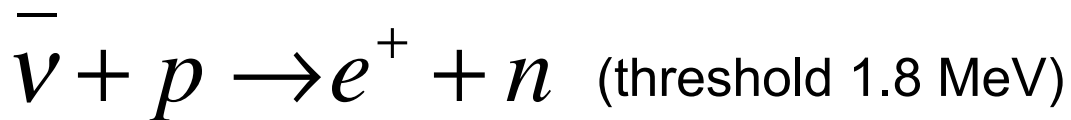
ν_{new} with $\Delta m^2 \sim 1 \text{ eV}^2$ and mixing with ν_e with $\theta_{\text{new}} \sim 10^\circ$

The explanation 3) could be supported by several other, so far unconfirmed anomalies. It would involve unexpected but significant "New Physics"

From P. Vogel

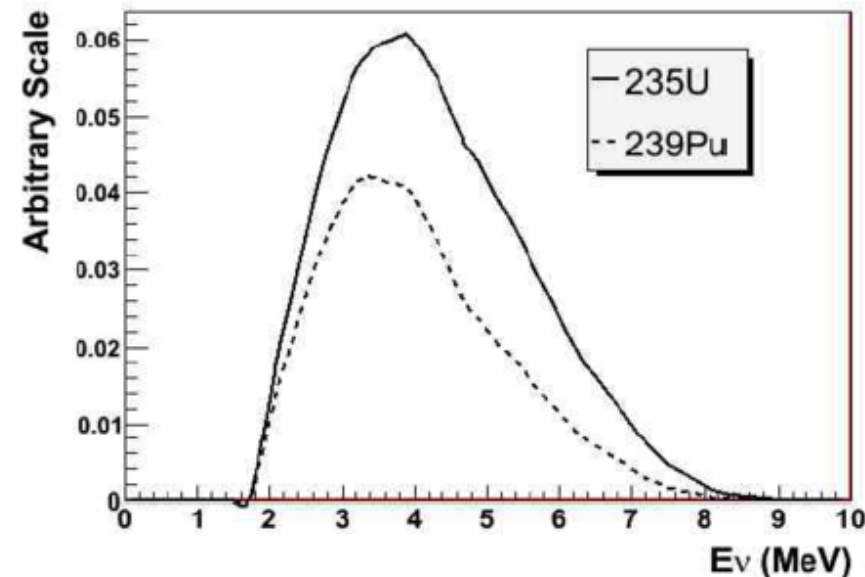
Another application: prediction of the neutrino spectrum from reactors for non-proliferation

	²³⁵U	²³⁹Pu
Released E per fission	201.7 MeV	210.0 MeV
Mean neutrino E	2.94 MeV	2.84 MeV
Neutrinos/fission >1.8 MeV	1.92	1.45
Aver. Int. cross section	$3.2 \times 10^{-43} \text{cm}^2$	$2.8 \times 10^{-43} \text{cm}^2$

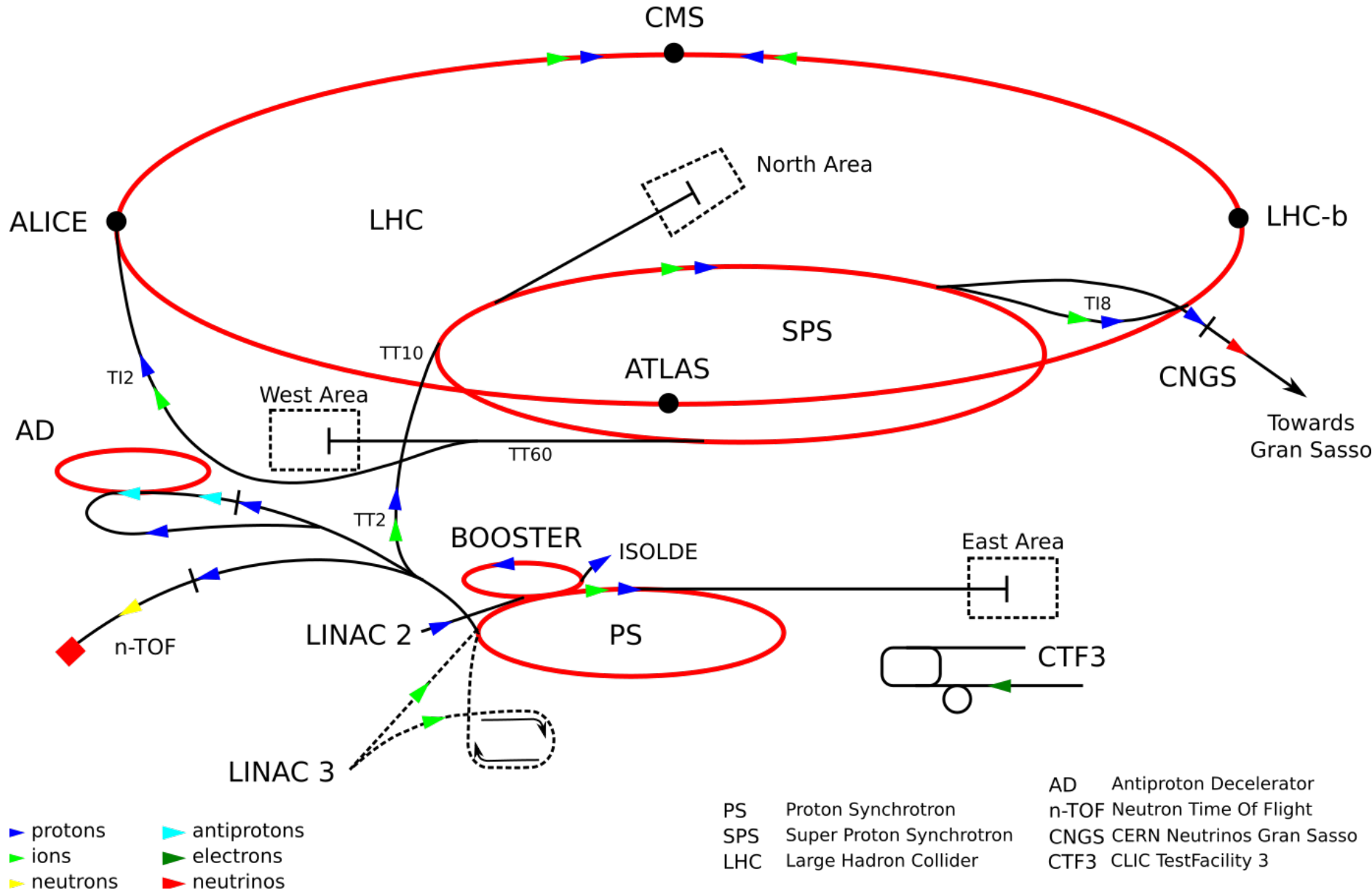


- Relevance for non-proliferation studies (working group of the IAEA). Neutrino flux can not be shielded. Study to determine fuel composition and power monitoring. Non-intrusive and remote method.

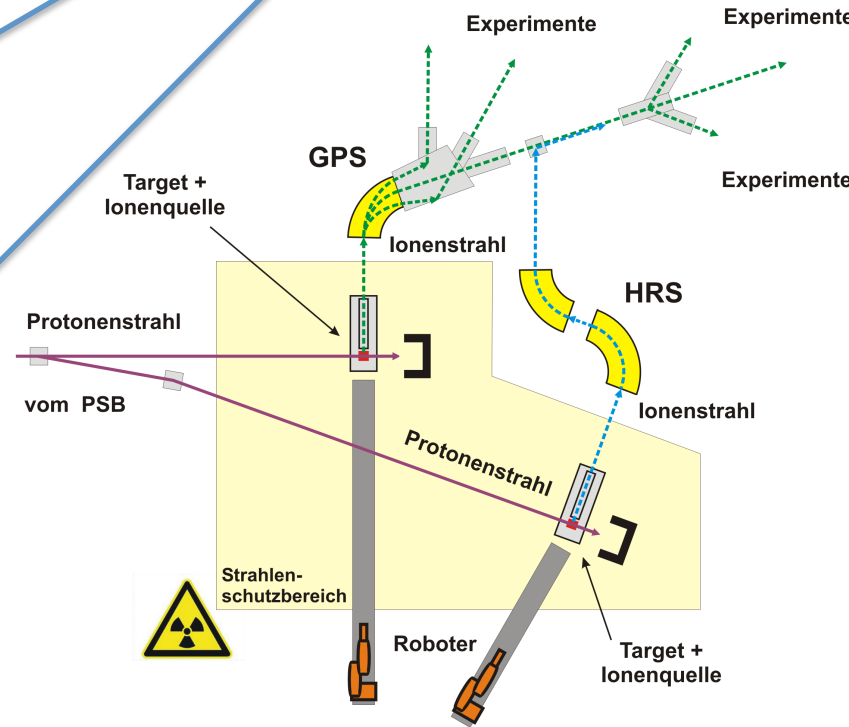
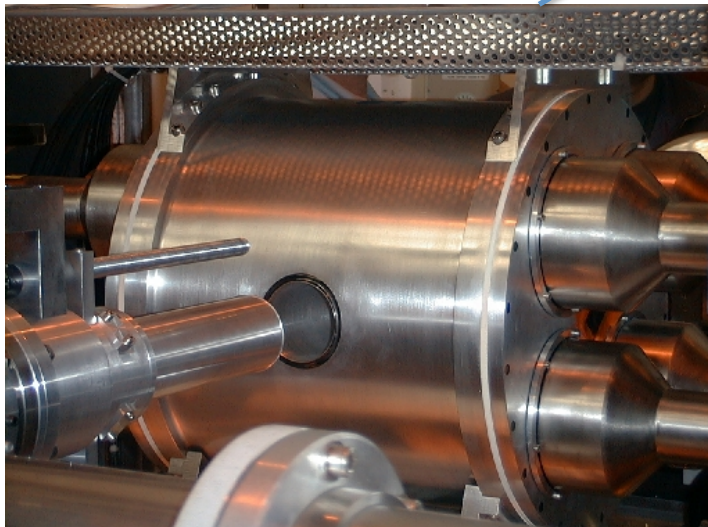
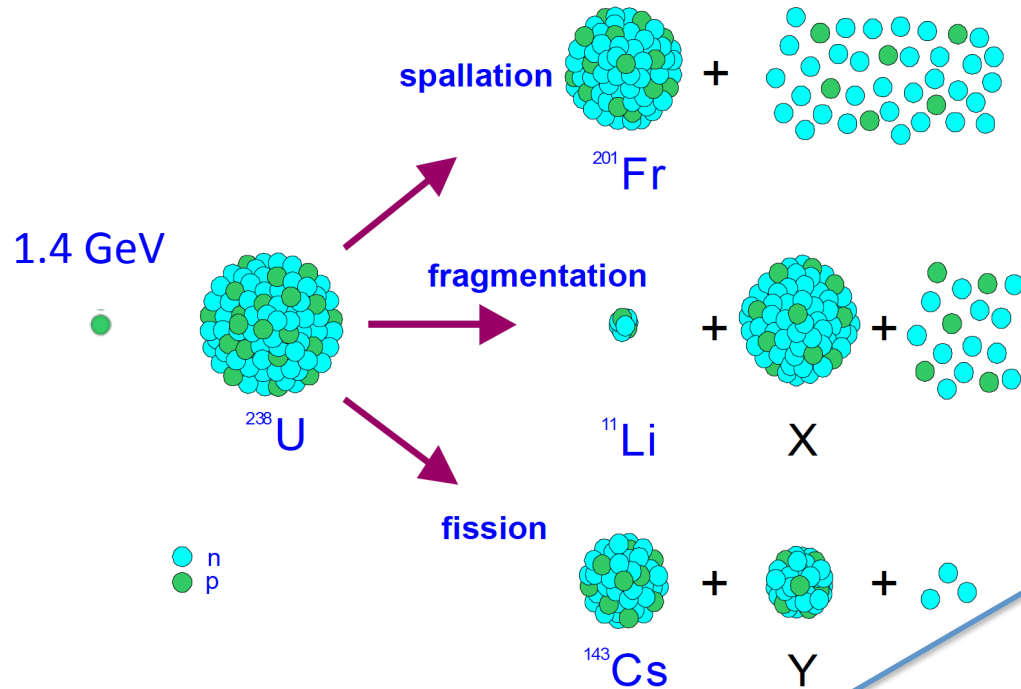
- Recently performed experiment to study some Rb, Sr, Y, Nb, I and Cs (IGISOL, trap assisted TAS) (Fallot, Tain, Algora)



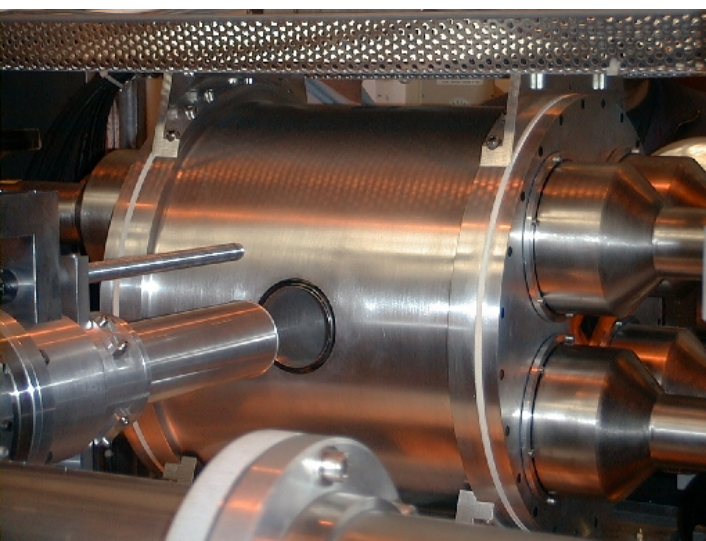
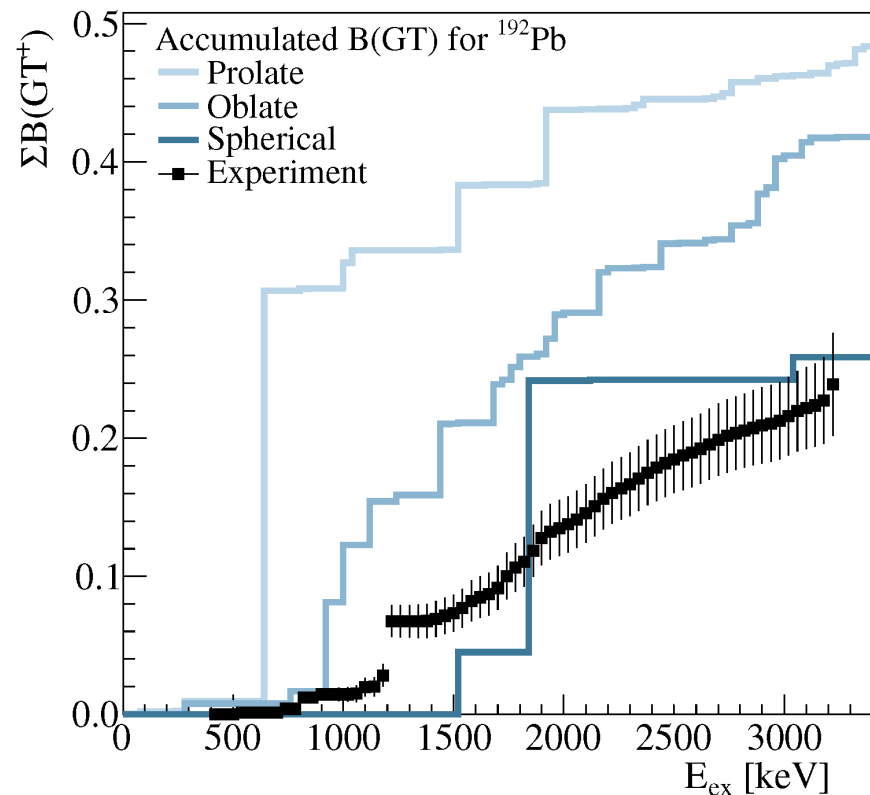
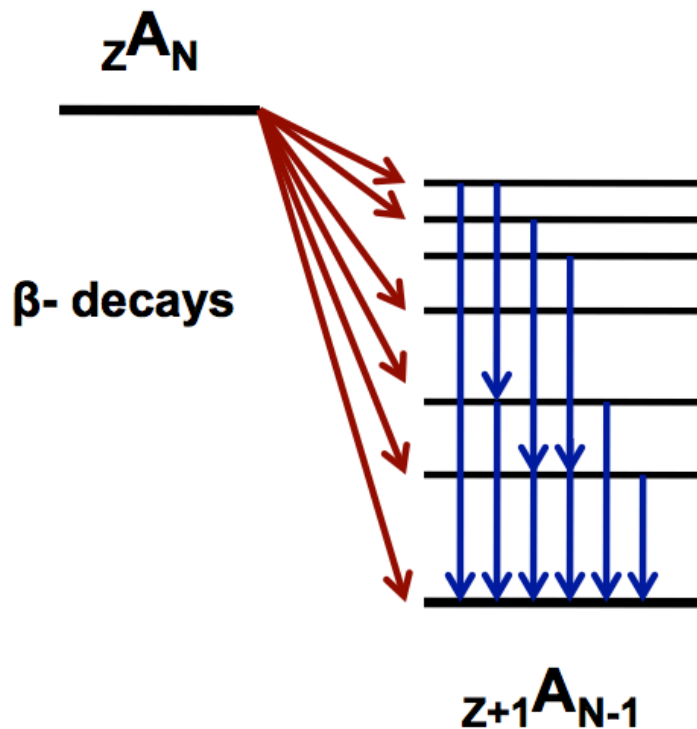
Some examples of recent work (ISOLDE, CERN)



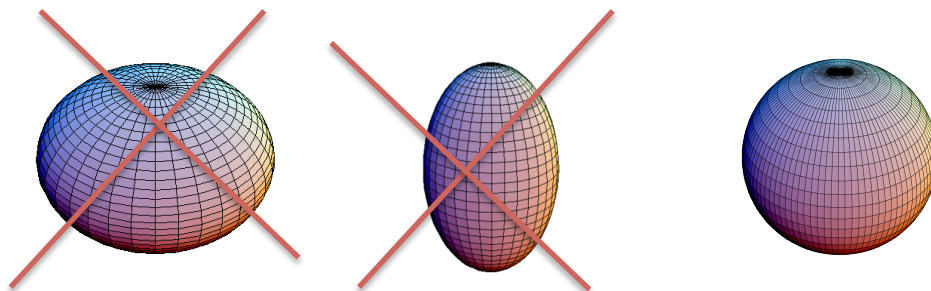
Some examples of recent work (ISOLDE, CERN)



Some examples of recent work (ISOLDE, CERN)



^{192}Pb (gs)

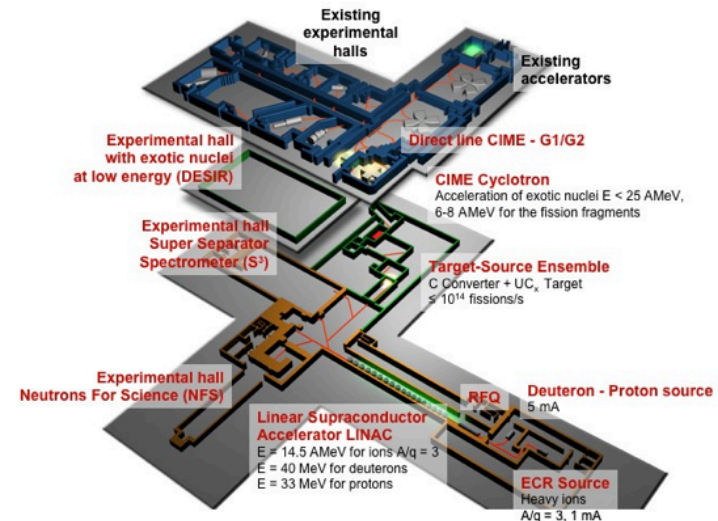
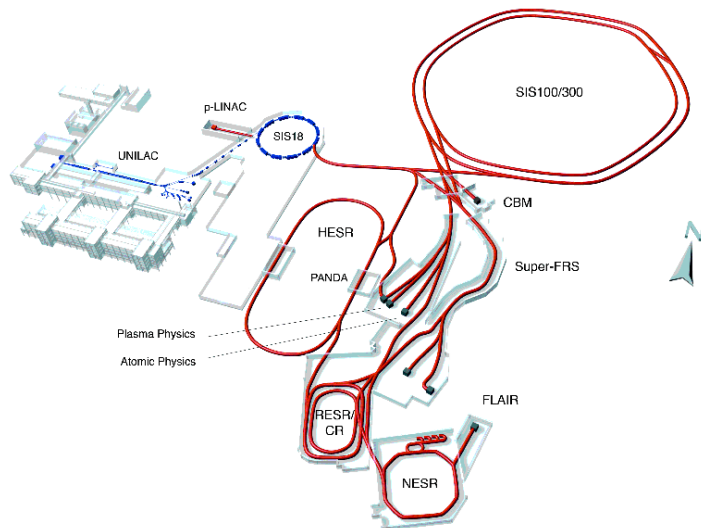
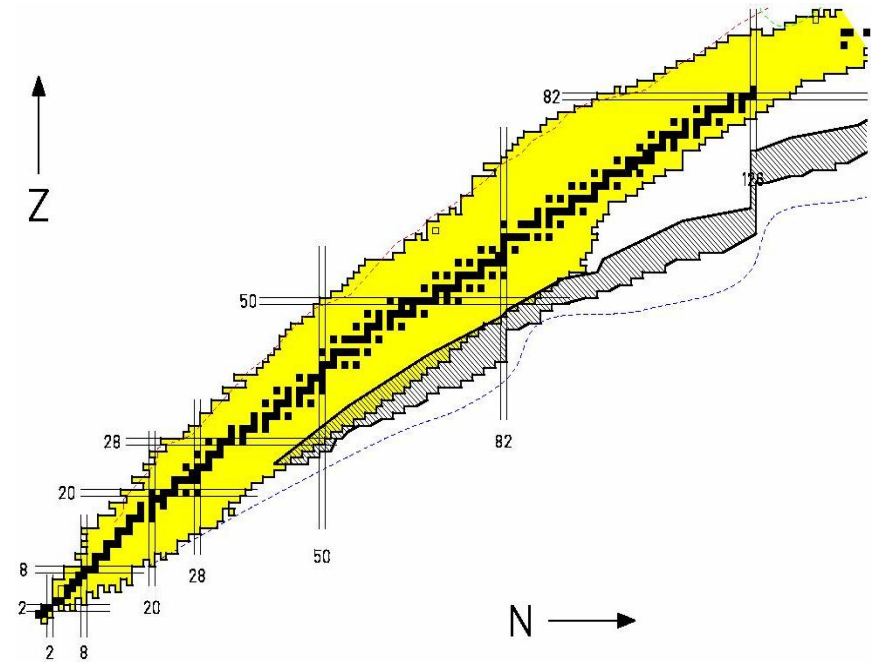


Instrumentation developments

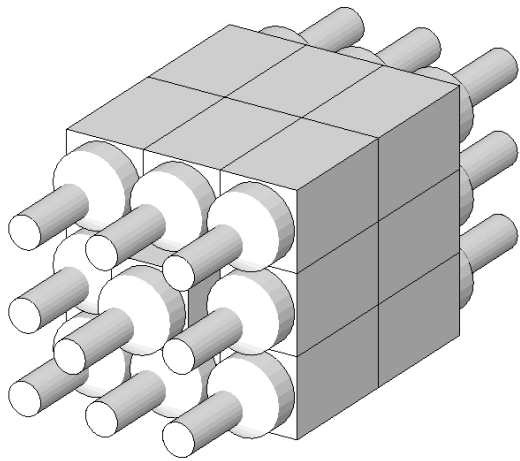
The advent of the first generation of RIBF facilities has already opened up a new era in probing nuclei beyond the limits of stability.

But there is still a large amount of work to be done. Presently we only know approximately 3000 nuclei from the 8000 that are assumed to exist.

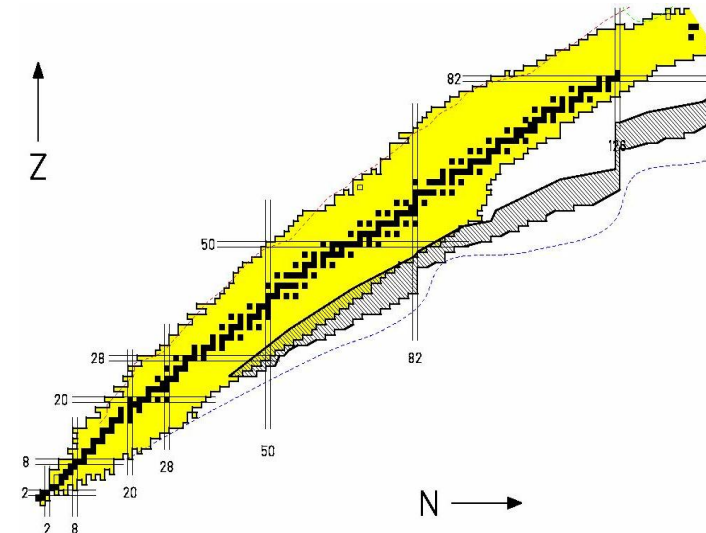
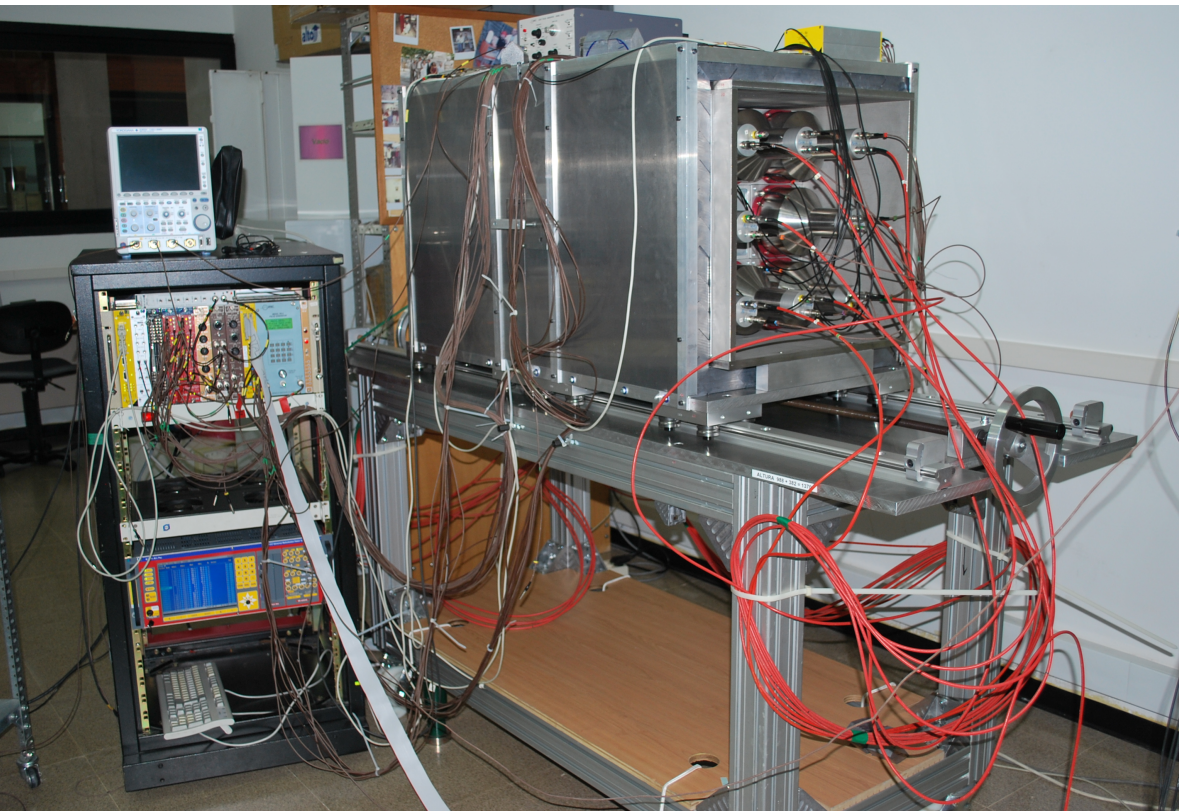
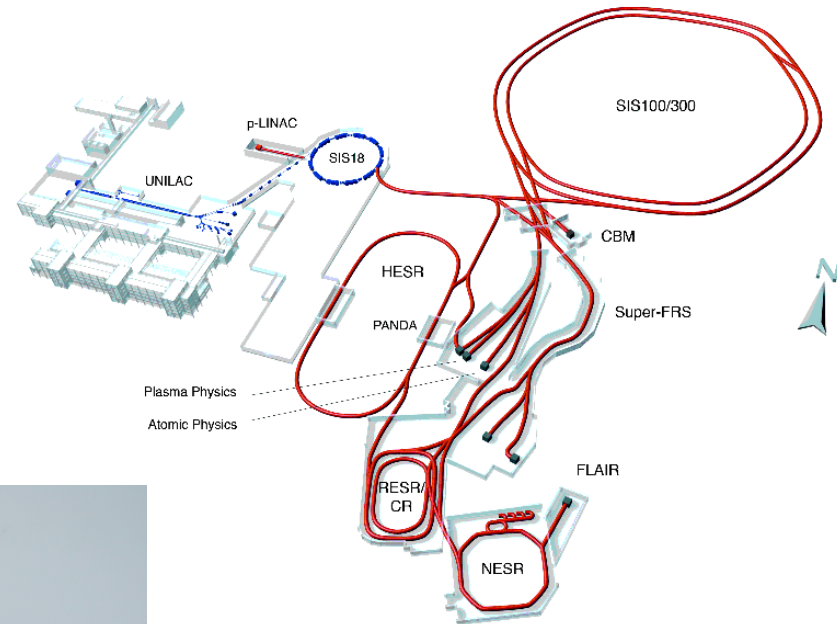
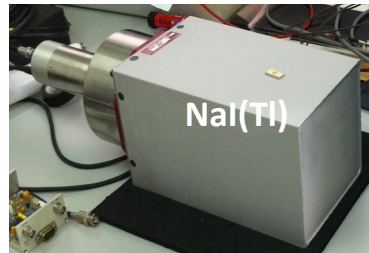
Their study will open new frontiers in our knowledge.



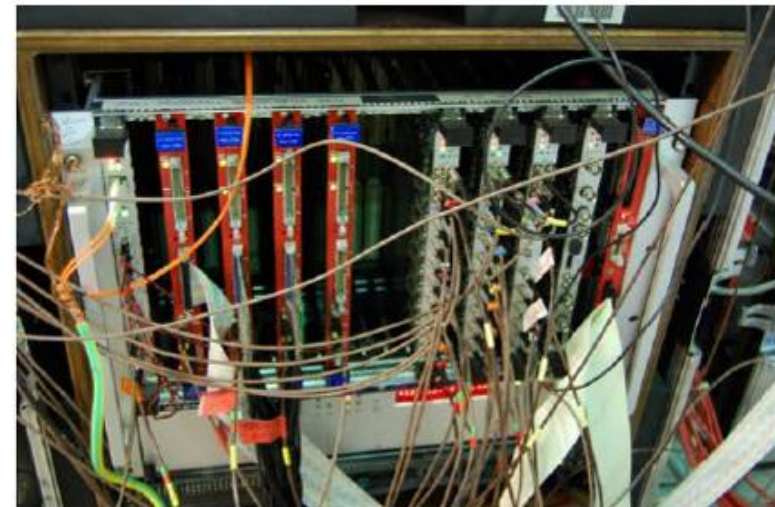
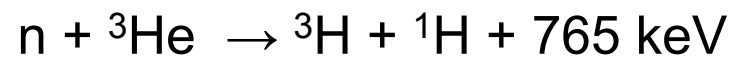
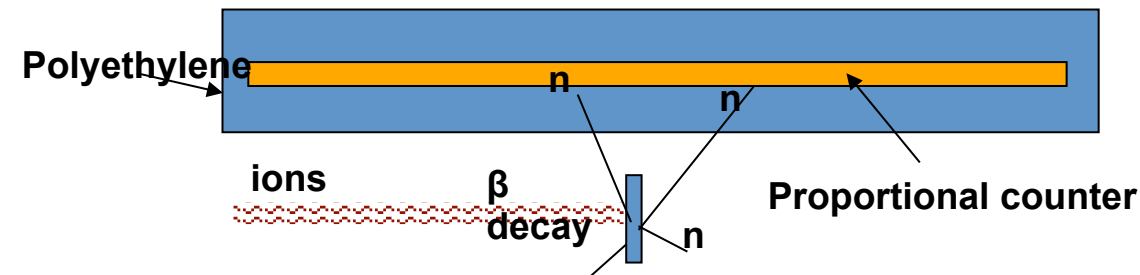
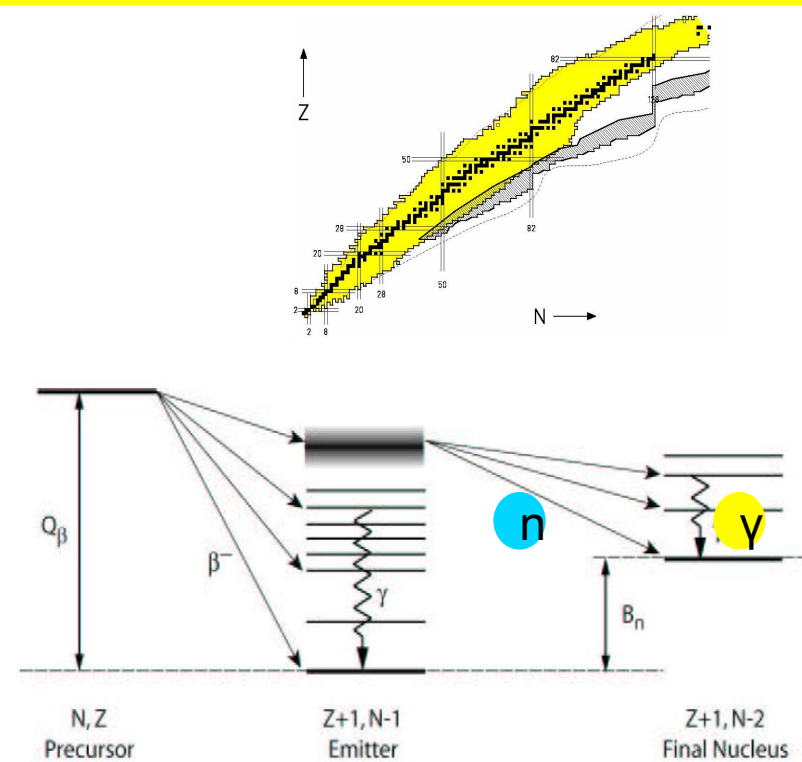
Development of instrumentation



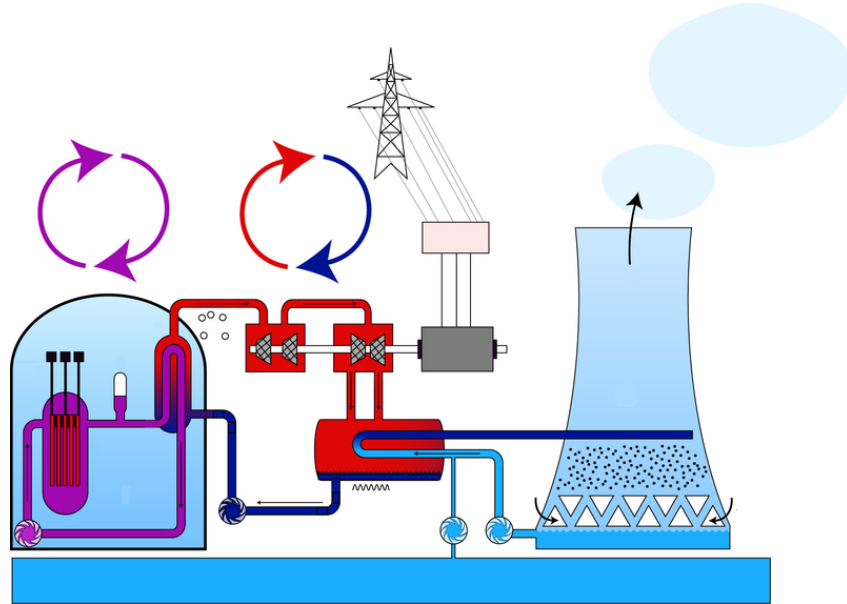
DTAS detector



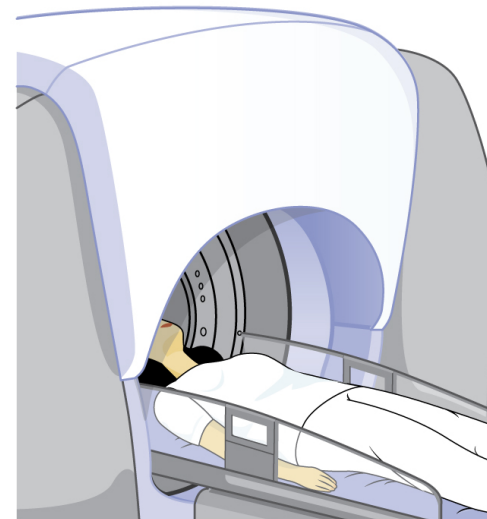
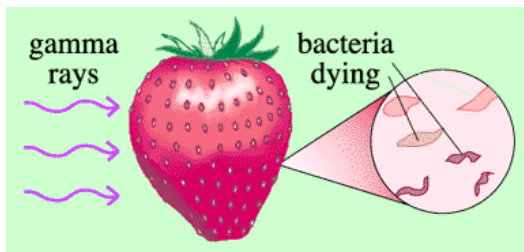
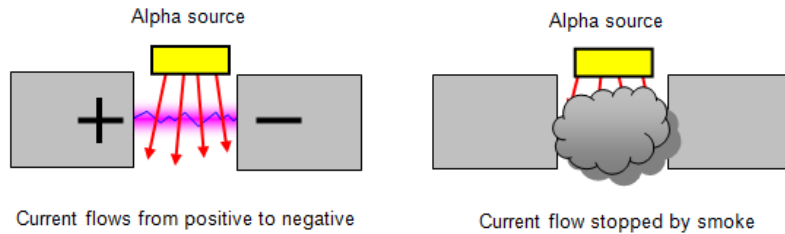
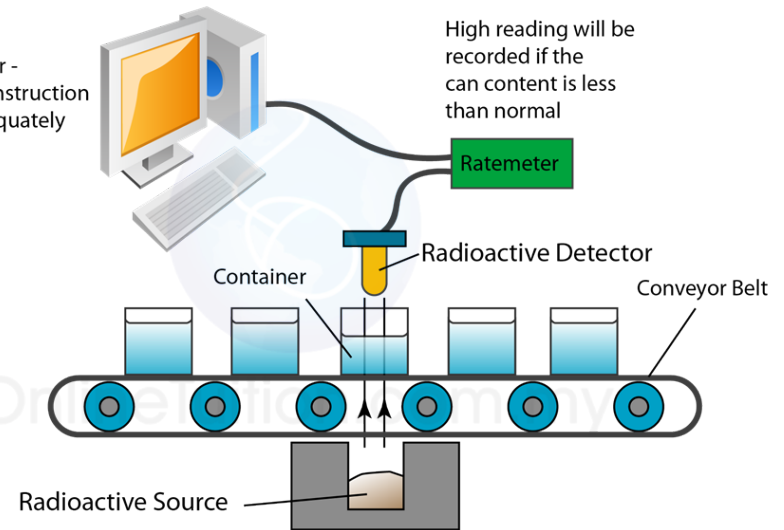
Development of instrumentation (BELEN)



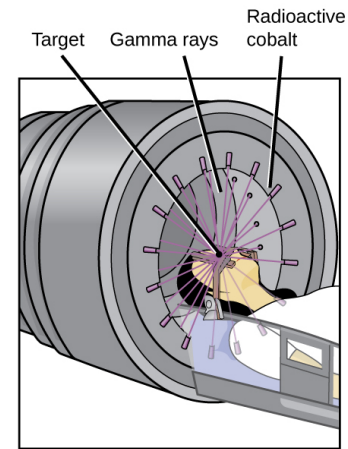
Applications



Monitor by computer -
Computer will give instruction
to remove the inadequately
filled can

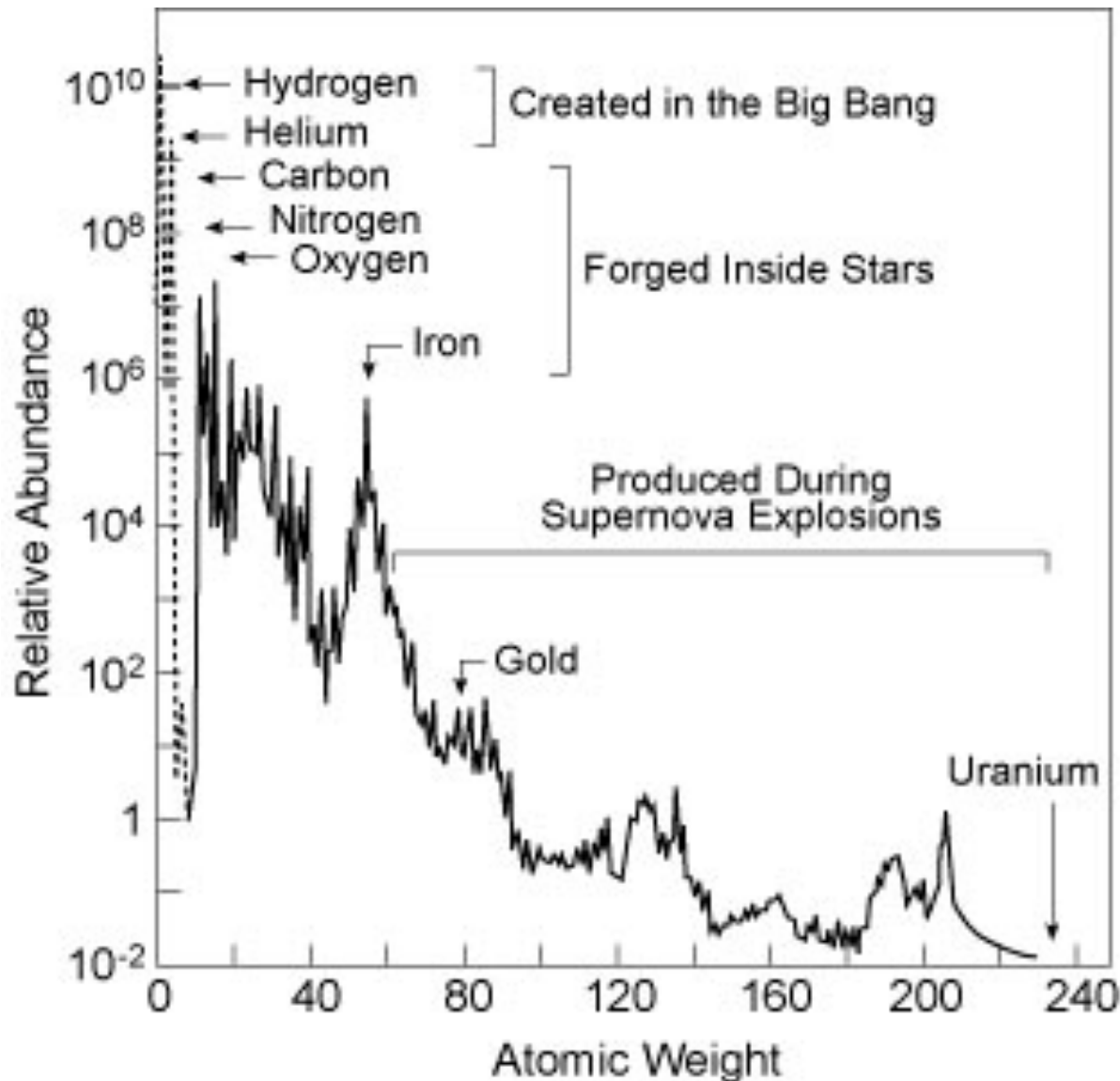


(a)



(b)

The abundance of the elements in the solar system



Light nuclei: 4He , 2H , from fusion of 1H in the early universe

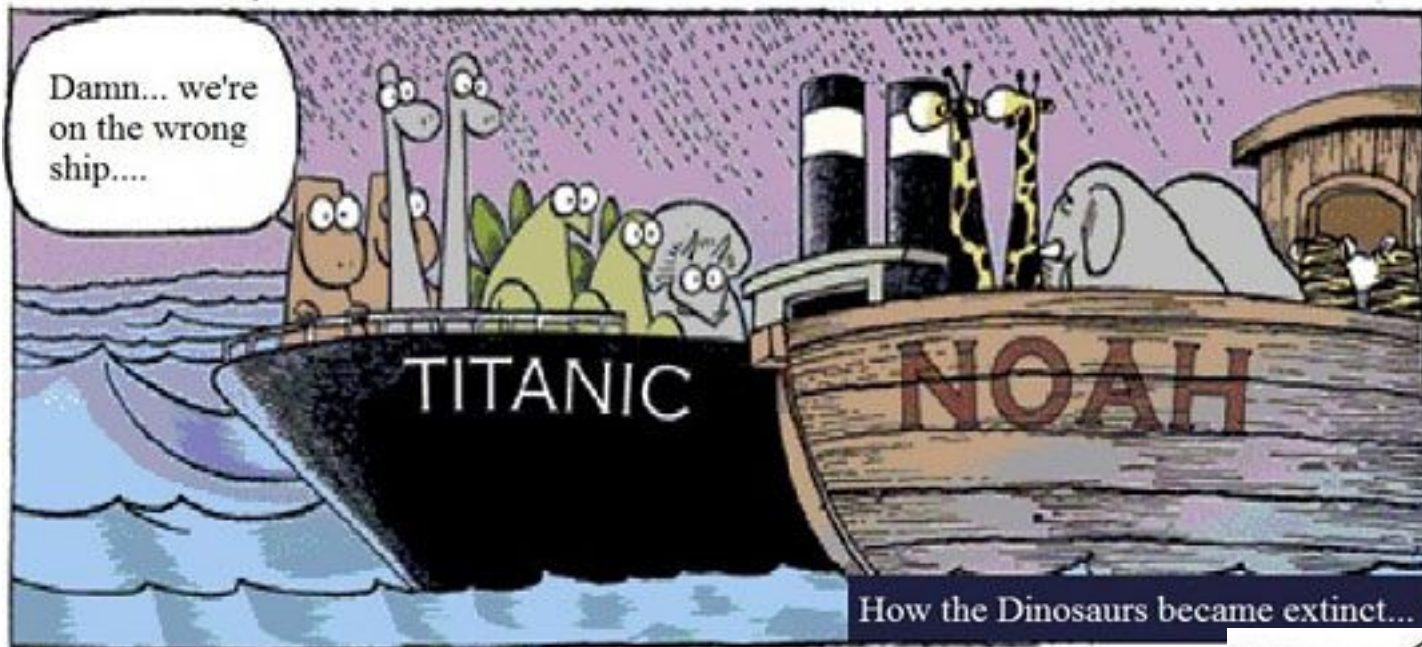
Nuclei up to 56Fe : nuclear fusion in stars

Heavier nuclei: explosive nuclear environments

(figure from NASA)



What killed the dinosaurs ?



How to test a theory ?



Extraterrestrial Cause for the Cretaceous-Tertiary Extinction

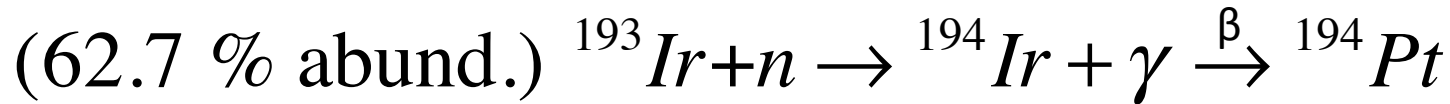
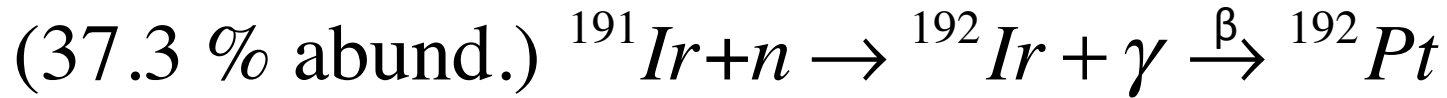
Luis W. Alvarez¹, Walter Alvarez², Frank Asaro³, Helen V. Michel⁴

+ Author Affiliations

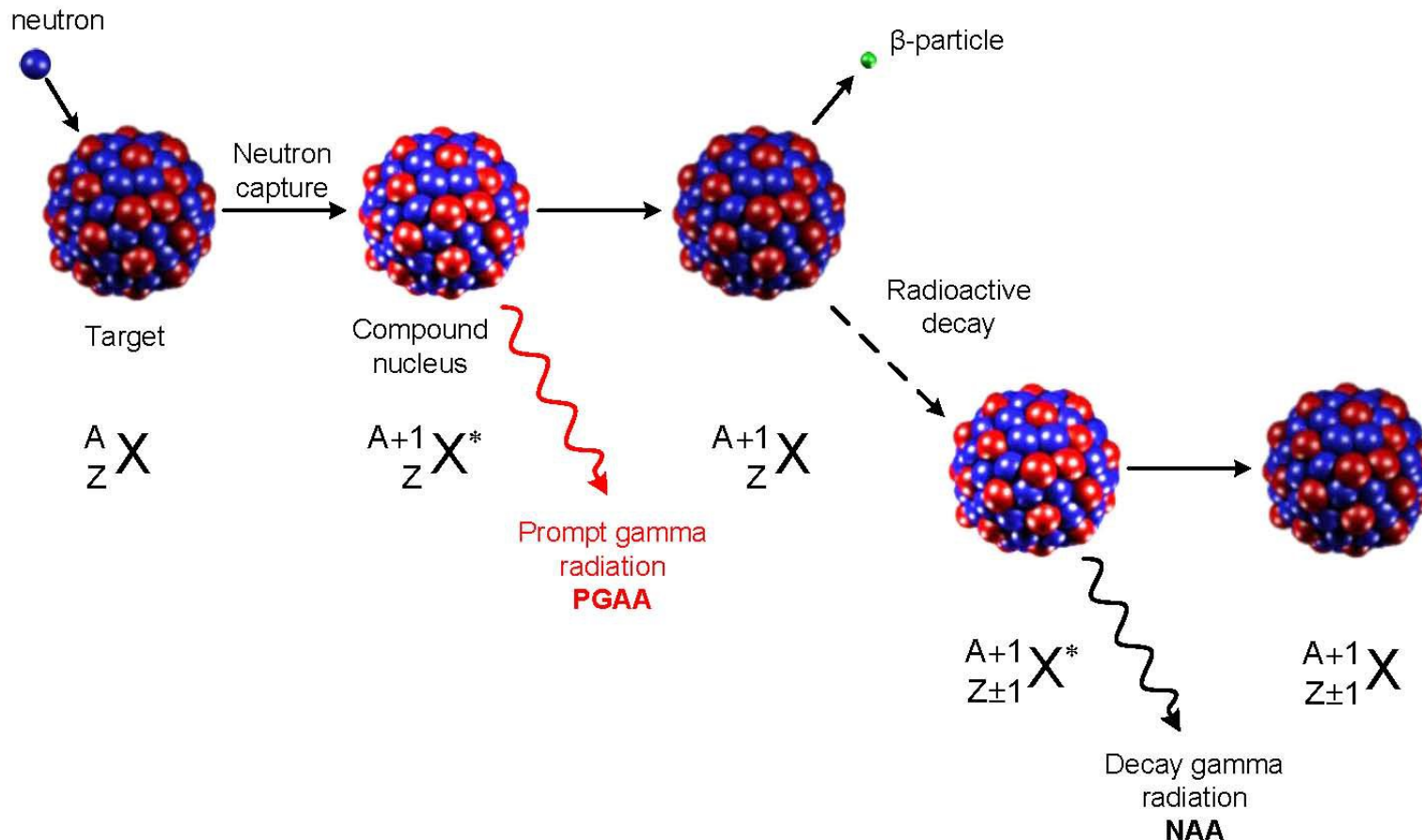
Science 06 Jun 1980:
Vol. 208, Issue 4448, pp. 1095-1108
DOI: 10.1126/science.208.4448.1095

Luis W. Alvarez
Nobel in 1968
Liquid H bubble chamber

How to test a theory



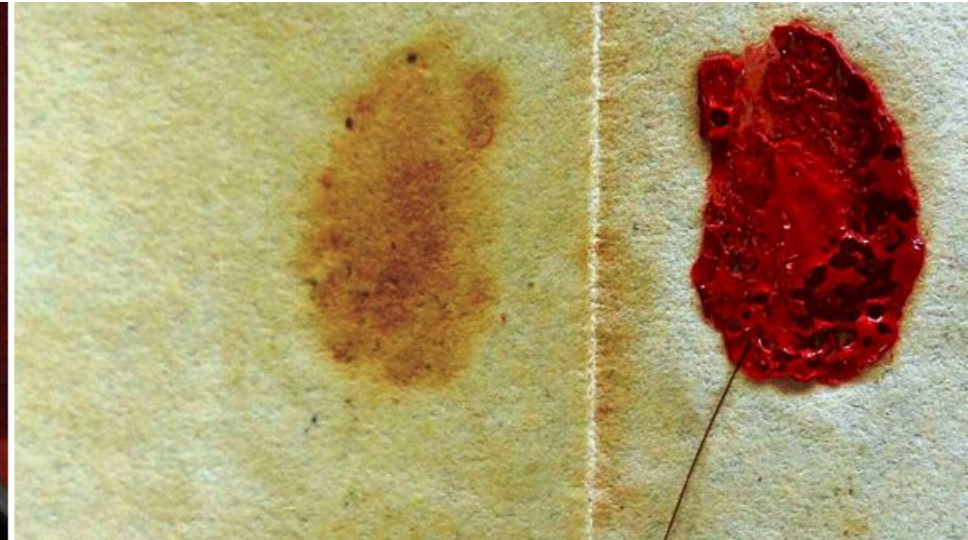
Ir is more abundant in chondritic meteorites than in the earth crust



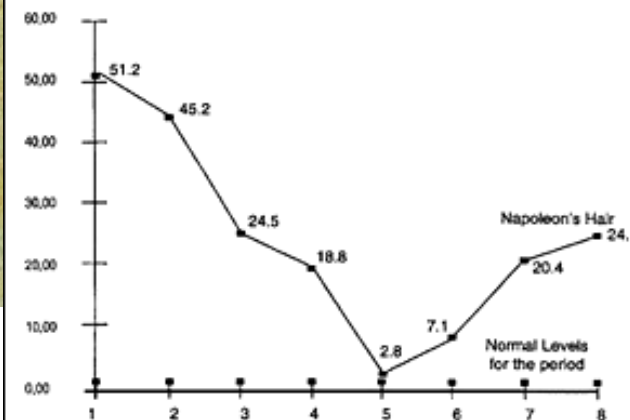
Forensic science example

What killed the emperor ?

Was he killed by poisoning (arsenic) or just cancer ?



Sectional Analysis of Napoleon's Hair
Graph showing Arsenic (parts/million)



Talking moonshine

THE TIMES

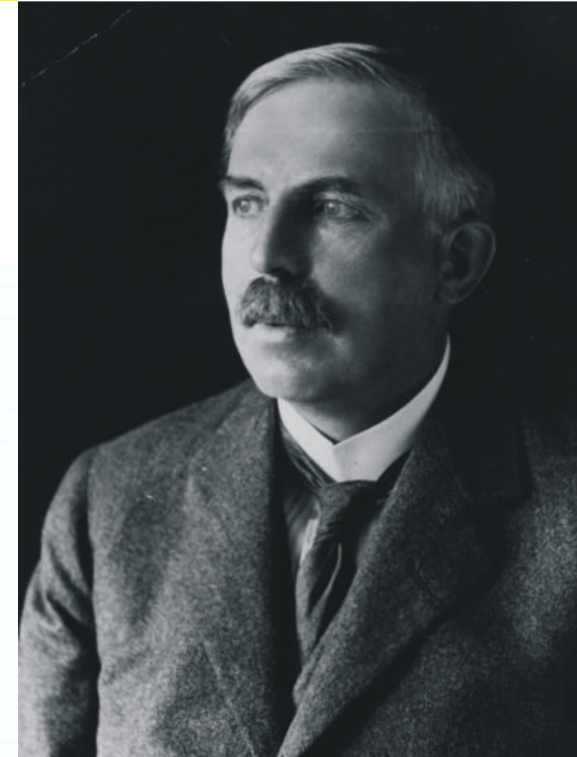
September 12, 1932

HOPE OF TRANSFORMING ANY ATOM

What, Lord Rutherford asked in conclusion, were the prospects 20 or 30 years ahead?

High voltages of the order of millions of volts would probably be unnecessary as a means of accelerating the bombarding particles. Transformations might be effected with 30,000 or 70,000 volts. . . . He believed that we should be able to transform all the elements ultimately.

We might in these processes obtain very much more energy than the proton supplied, but on the average we could not expect to obtain energy in this way. It was a very poor and inefficient way of producing energy, and anyone who looked for a source of power in the transformation of the atoms was talking moonshine.



Thesaurus

Talking moonshine: foolish or visionary talk

Talking moonshine

THE TIMES

Times edition, September 12 1932

After reading the article in a depressing morning in London, Szilard Leo, an immigrant Hungarian physicist, thinks that Rutherford is wrong. The neutron was discovered in 1932, and he thinks that the only thing necessary to produce energy is to find a reaction that produces more particles and liberates energy. As in chemistry was already shown: chain reaction (see Polanyi)

Leo was a key member of the Manhattan project and after the completion of the atomic bomb, he wrote a letter with Einstein to not use it. His ideas were fundamental in the construction of the first nuclear reactor by Fermi.



"Pronouncement of experts to the effect that something cannot be done has always irritated me."

Leo Szilard

Thank you for your attention

NGC 6960: The Witch's Broom Nebula

