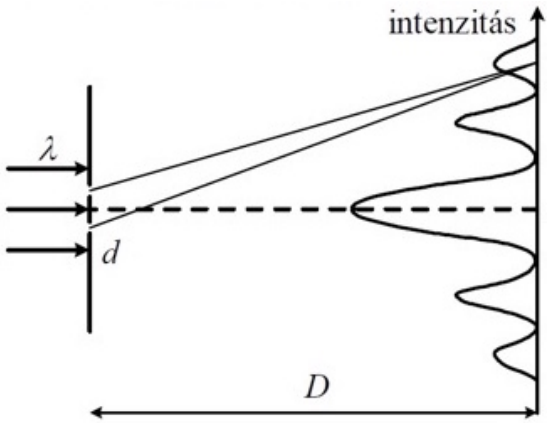
Miként láthatjuk a kis dolgokat? — avagy a felbontás kérdése



Első kioltás iránya

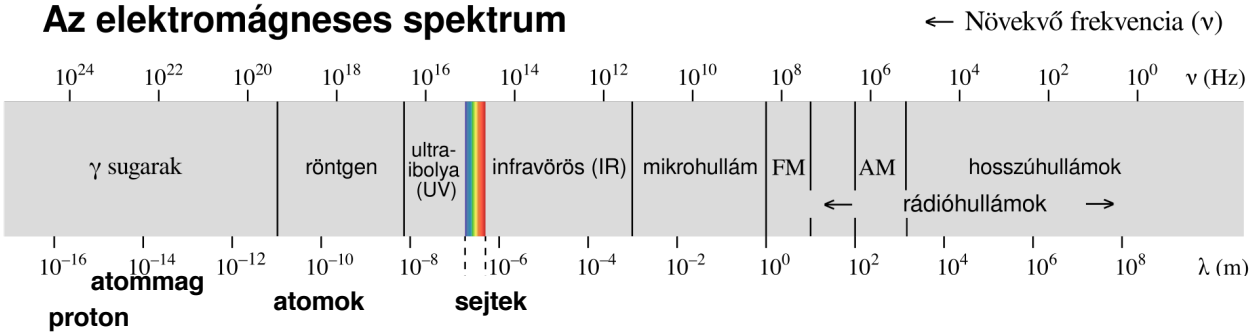
$$d \sin\theta = \lambda/2$$

legyen még látható az ernyőn:

$$\theta < 90°$$

$$\lambda \leq 2d$$

Az elektromágneses spektrum



A részecskék hullámtermészete

Louis de Broglie
(1892-1987)
Nobel-díj: 1929

$$\lambda = \frac{h}{p}$$

1924

Ha "látni" akarjuk az atommagot:

$$\lambda = 10^{-12}\ \mathrm{cm} \Rightarrow p \approx 6.6 \cdot 10^{-19}\ \mathrm{kgm/s}$$

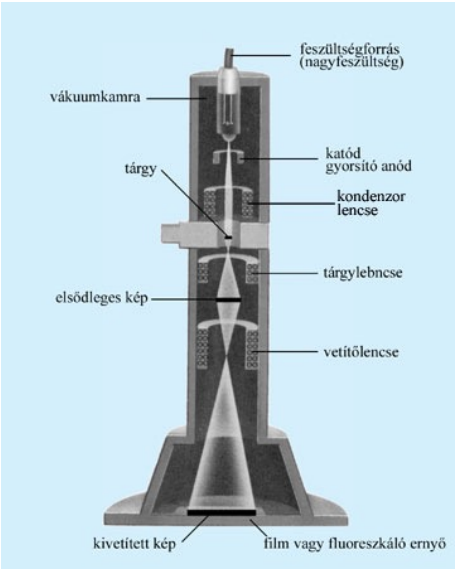
Az elektron tömege

$$m_e \approx 9.1 \cdot 10^{-31}\mathrm{kg}$$

akkor a sebessége

$$v = p/m_e = 7.3 \cdot 10^{11}\ \mathrm{m/s}$$

???

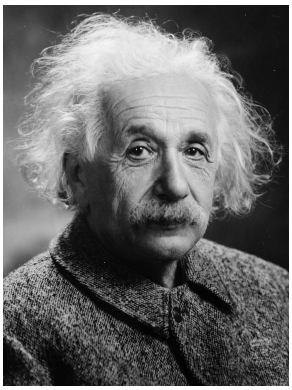


Elektronmikroszkóp

Ernst Ruska, 1933
Nobel-díj 1986

(Szilárd Leó, 1928)

Relativitáselmélet



Albert Einstein
(1879-1955)
Nobel-díj: 1921

$$p = \frac{mv}{\sqrt{1-\frac{v^2}{c^2}}} \qquad E = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$\text{Ha } v \ll c: \quad p \approx mv \quad E \approx mc^2 + \frac{1}{2}mv^2$$

Az elektronunk így is nagyon gyors kell legyen:

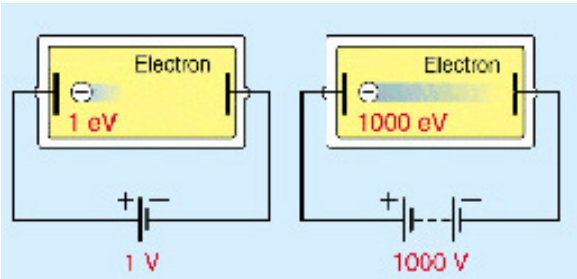
$$p \approx 6.6 \cdot 10^{-19}\ \text{kgm/s}$$
$$m_e \approx 9.1 \cdot 10^{-31}\ \text{kg}$$

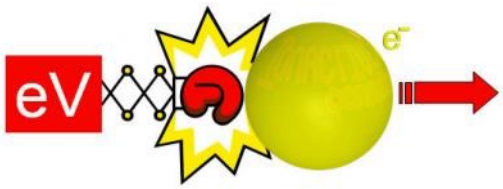
$$\Rightarrow \quad v \approx 0.999999915c$$

Energia, energia…

$$E = \sqrt{p^2c^2 + m^2c^4} \approx \begin{cases} mc^2 + \frac{p^2}{2m} & v \ll c \\ pc & v \approx c \end{cases}$$

Miben mérjük az energiát? Elektronvoltban!





$$1\ \text{eV} = 1.6 \cdot 10^{-19}\text{J}$$

Az elektronunk energiája akkor

$$E \approx 1.24 \cdot 10^9\ \text{eV} = 1.24\ \text{GeV}$$!!!

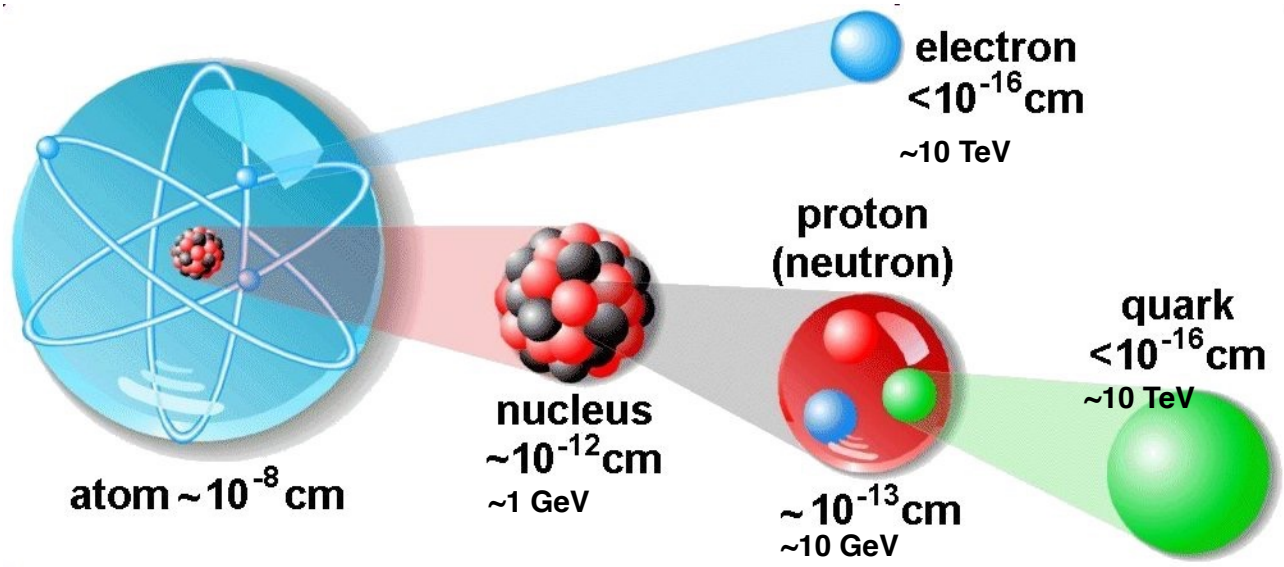
Energia… no de mennyi kell?

Nyugalmi energia: $E = mc^2$

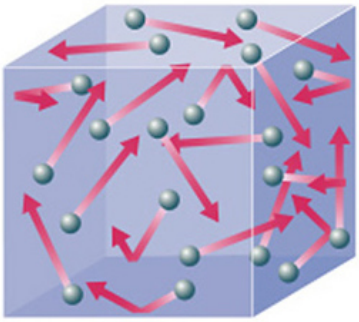
Elektron: $m_e c^2 \approx 0.511 \text{ MeV}$

Proton: $m_p c^2 \approx 938.3 \text{ MeV}$

Ultrarelativisztikus részecske: $E \approx pc \Rightarrow \lambda = \frac{h}{p} = \frac{hc}{E}$



Mekkora energia is ez?



Hőmozgás: 0.03 eV (25 °C)

Kémiai kötés: 1-10 eV

Magreakciók: ~200 MeV

Részecskék táblázata

(illetve annak egy kis része...)

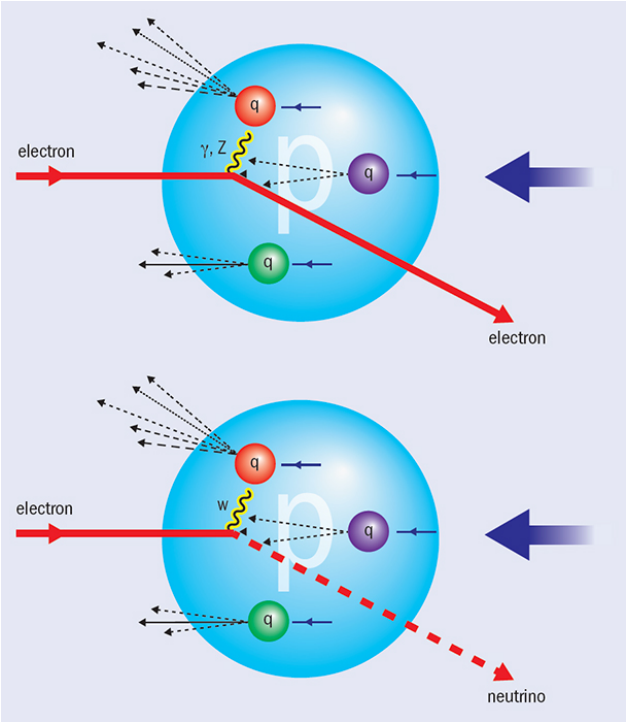
Some Particles and Their Properties

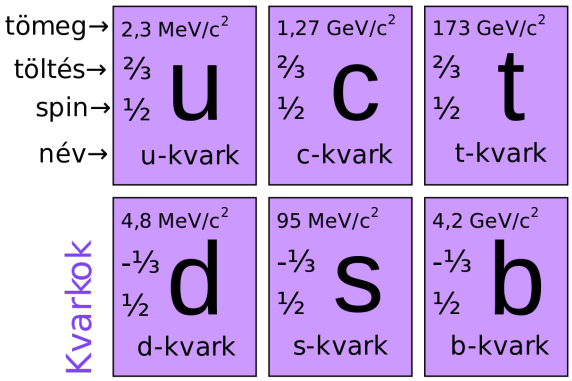
Category	Particle Name	Symbol	Anti-particle	Mass (MeV/c^2)	B	L_e	L_μ	L_τ	S	Lifetime(s)	Principal Decay Modes[a]
Leptons	Electron	e^-	e^+	0.511	0	+1	0	0	0	Stable	
	Electron–neutrino	ν_e	$\overline{\nu}_e$	$< 7\text{eV}/c^2$	0	+1	0	0	0	Stable	
	Muon	μ^-	μ^+	105.7	0	0	+1	0	0	2.20×10^{-6}	$e^-\overline{\nu}_e\nu_\mu$
	Muon–neutrino	ν_μ	$\overline{\nu}_\mu$	< 0.3	0	0	+1	0	0	Stable	
	Tau	τ^-	τ^+	1 784	0	0	0	+1	0	$< 4 \times 10^{-13}$	$\mu^-\overline{\nu}_\mu\nu_\tau$, $e^-\overline{\nu}_e\nu_\tau$
	Tau–neutrino	ν_τ	$\overline{\nu}_\tau$	< 30	0	0	0	+1	0	Stable	
Hadrons											
Mesons	Pion	π^+	π^-	139.6	0	0	0	0	0	2.60×10^{-8}	$\mu^+\nu_\mu$
		π^0	Self	135.0	0	0	0	0	0	0.83×10^{-16}	2γ
	Kaon	K^+	K^-	493.7	0	0	0	0	+1	1.24×10^{-8}	$\mu^+\nu_\mu$, $\pi^+\pi^0$
		K^0_S	K^0_S	497.7	0	0	0	0	+1	0.89×10^{-10}	$\pi^+\pi^-$, $2\pi^0$
		K^0_L	K^0_L	497.7	0	0	0	0	+1	5.2×10^{-8}	$\pi^\pm e^\mp\overline{\nu}_e$, $3\pi^0$ $\pi^\pm\mu^\mp\overline{\nu}_\mu$
	Eta	η	Self	548.8	0	0	0	0	0	$< 10^{-18}$	2γ, 3π
		η'	Self	958	0	0	0	0	0	2.2×10^{-21}	$\eta\pi^+\pi^-$
Baryons	Proton	p	$\overline{p}$	938.3	+1	0	0	0	0	Stable	
	Neutron	n	$\overline{n}$	939.6	+1	0	0	0	0	920	$pe^-\overline{\nu}_e$
	Lambda	Λ^0	$\overline{\Lambda}^0$	1 115.6	+1	0	0	0	−1	2.6×10^{-10}	$p\pi^-$, $n\pi^0$
	Sigma	Σ^+	$\overline{\Sigma}^-$	1 189.4	+1	0	0	0	−1	0.80×10^{-10}	$p\pi^0$, $n\pi^+$
		Σ^0	$\overline{\Sigma}^0$	1 192.5	+1	0	0	0	−1	6×10^{-20}	$\Lambda^0\gamma$
		Σ^-	$\overline{\Sigma}^+$	1 197.3	+1	0	0	0	−1	1.5×10^{-10}	$n\pi^-$
	Xi	Ξ^0	$\overline{\Xi}^0$	1 315	+1	0	0	0	−2	2.9×10^{-10}	$\Lambda^0\pi^0$
		Ξ^-	$\overline{\Xi}^+$	1 321	+1	0	0	0	−2	1.64×10^{-10}	$\Lambda^0\pi^-$
	Omega	Ω^-	$\overline{\Omega}^+$	1 672	+1	0	0	0	−3	0.82×10^{-10}	$\Xi^0\pi^0$, Λ^0K^-

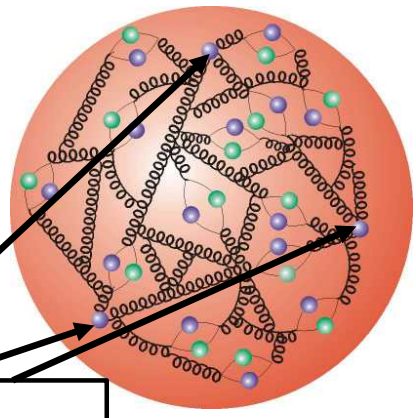
[a]Notations in this column, such as $p\pi^-$, $n\pi^0$, mean two possible decay modes. In this case the two possible decays are $\Lambda^0 \to p + \pi^-$ and $\Lambda^0 \to n + \pi^0$.

Mi van egy hadronban? Kvarkok és glüonok

A proton-"Rutherford" kísérlet (SLAC, 1969)

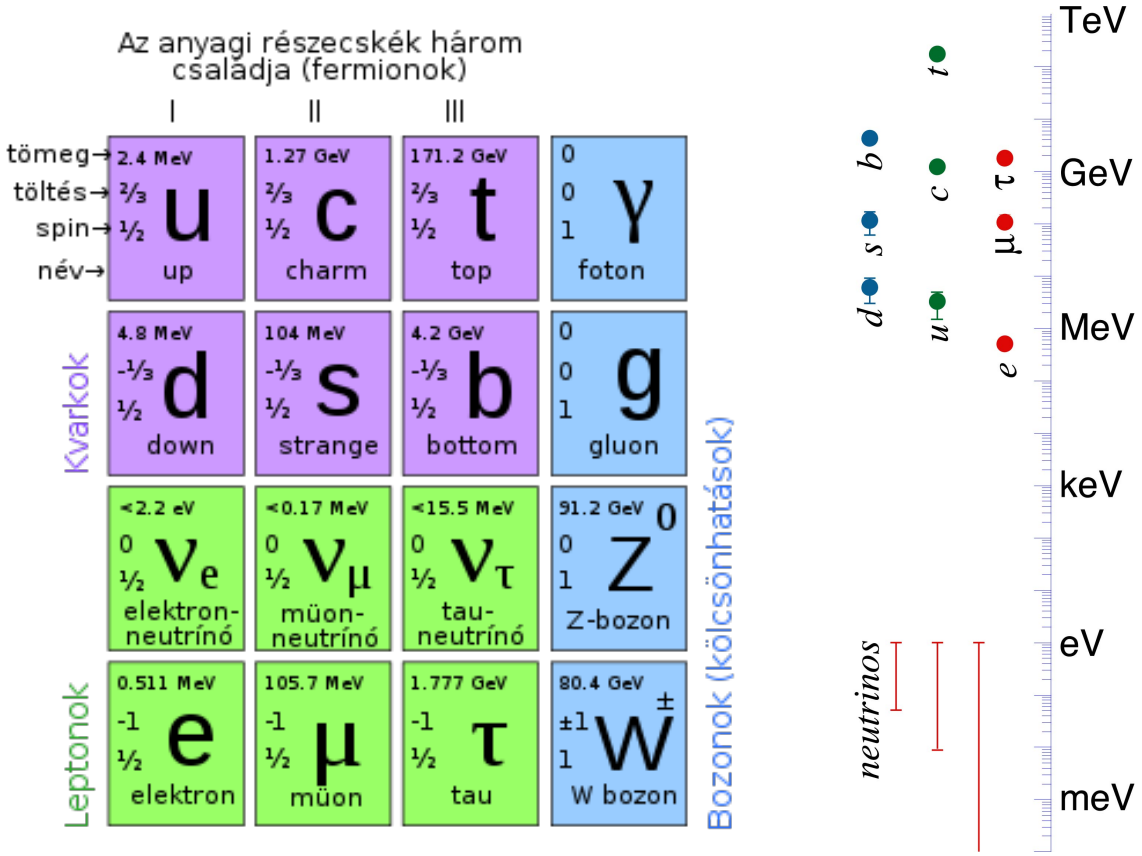






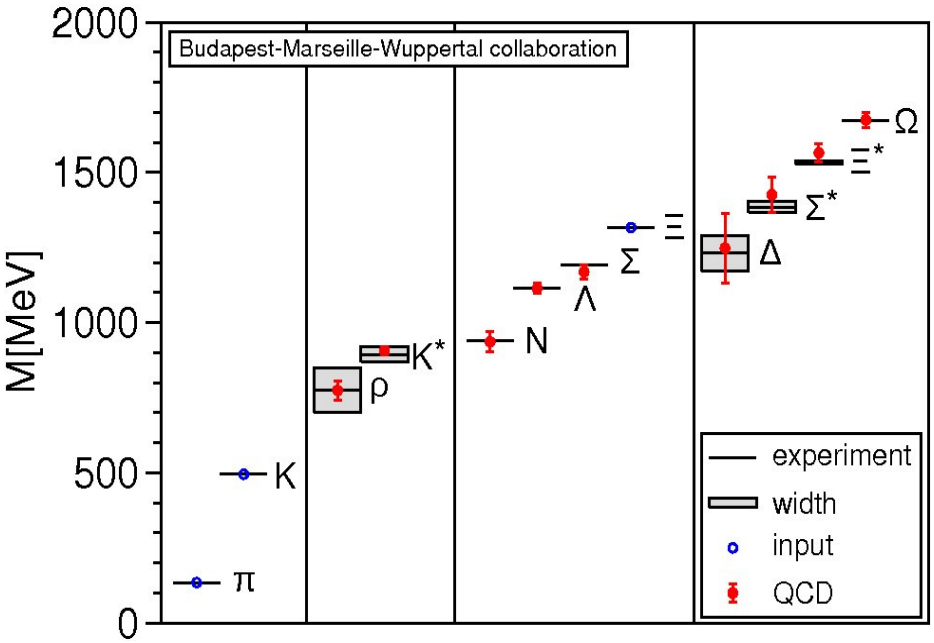
Valencia kvarkok
Proton: uud Neutron: udd

A ma ismert “elemi” részecskék

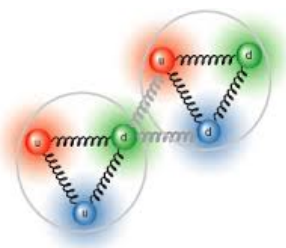


Erős kölcsönhatás:

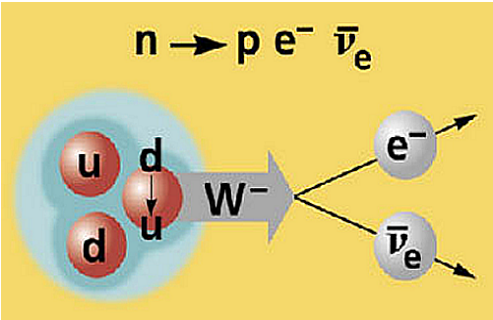
hadron spektrum és magerők



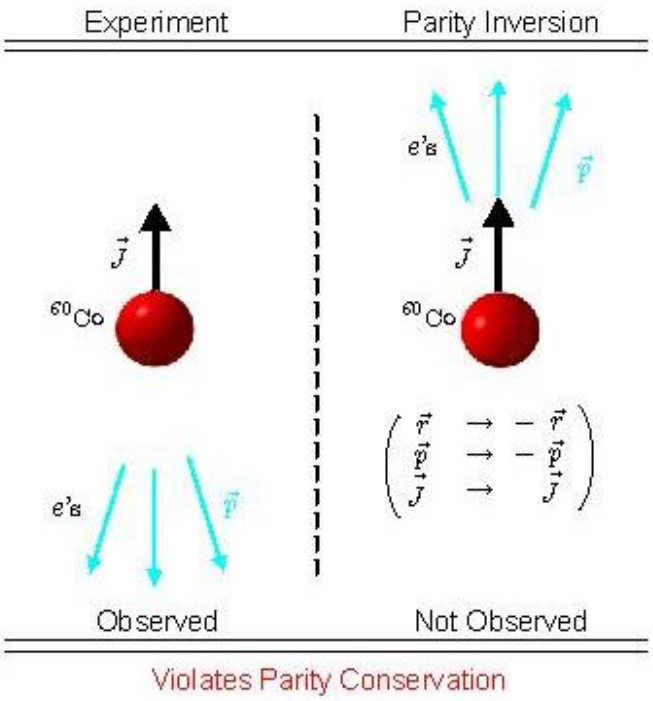
Magerők: erős “van der Waals”

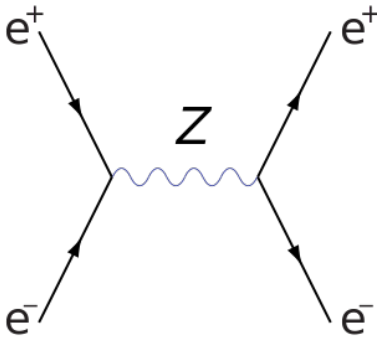


Gyenge kölcsönhatás

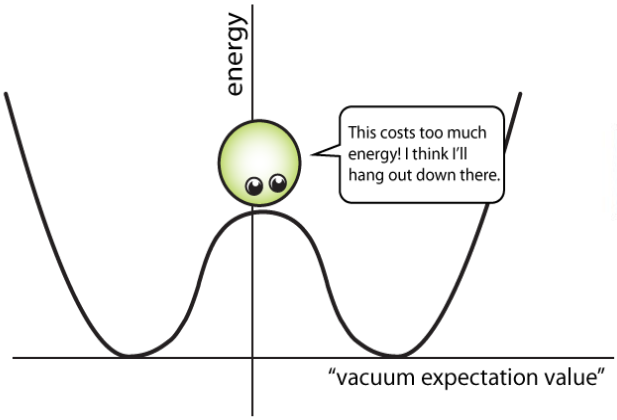


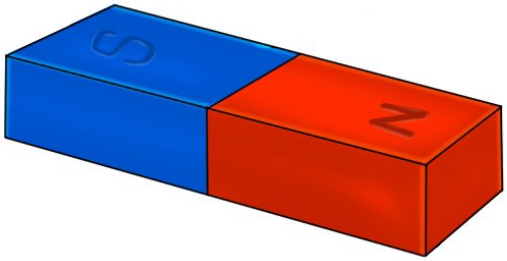
Sérti a jobb/bal tükrözési szimmetriát!



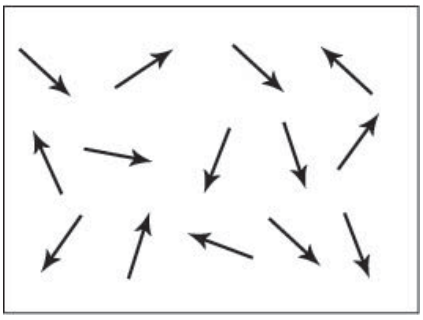


Spontán szimmetriasértés



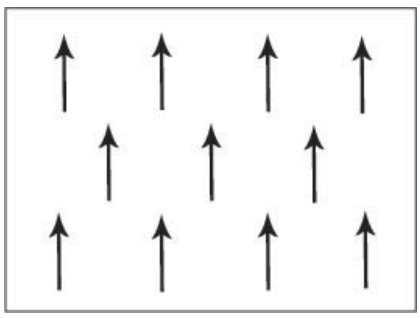


$T > T_{Curie}$



Paramágneses fázis

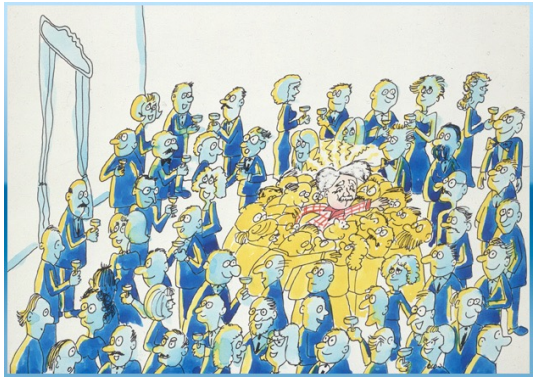
$T < T_{Curie}$

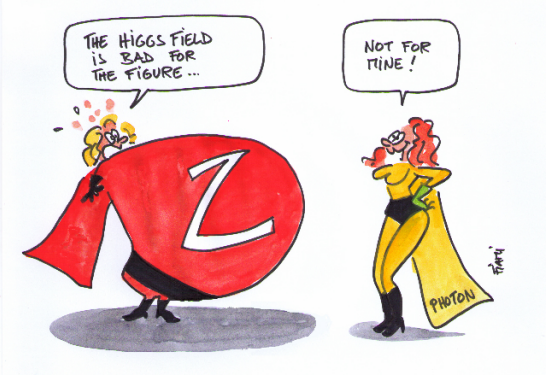


Ferromágneses fázis

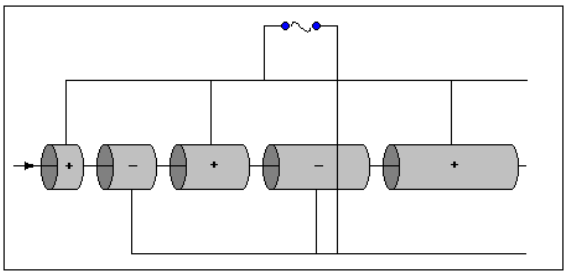
A részecskék tömegének eredete: a Higgs mező

(CERN)

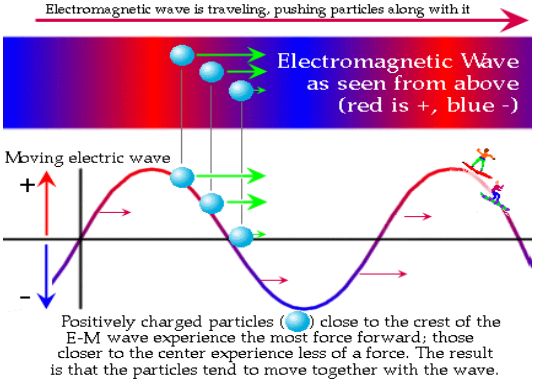




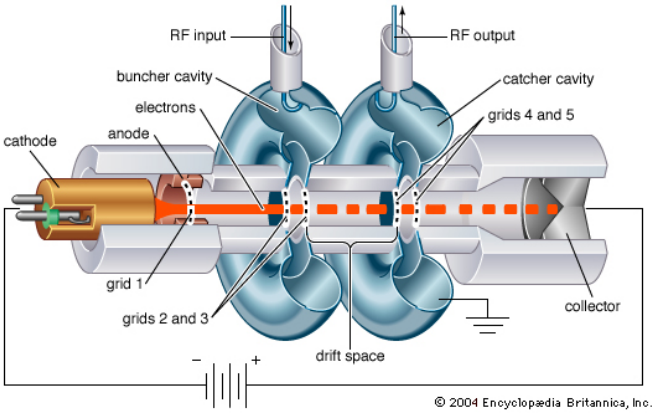
Lineáris gyorsító



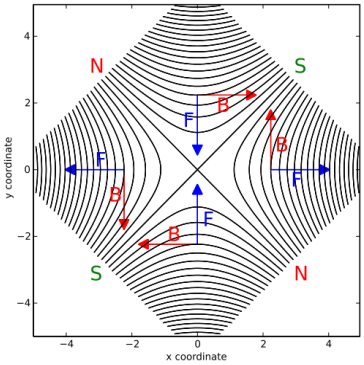
Simplified version of the Luis Alvarez linear accelerator.

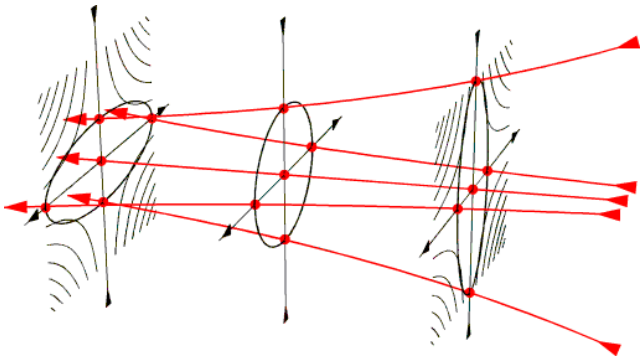


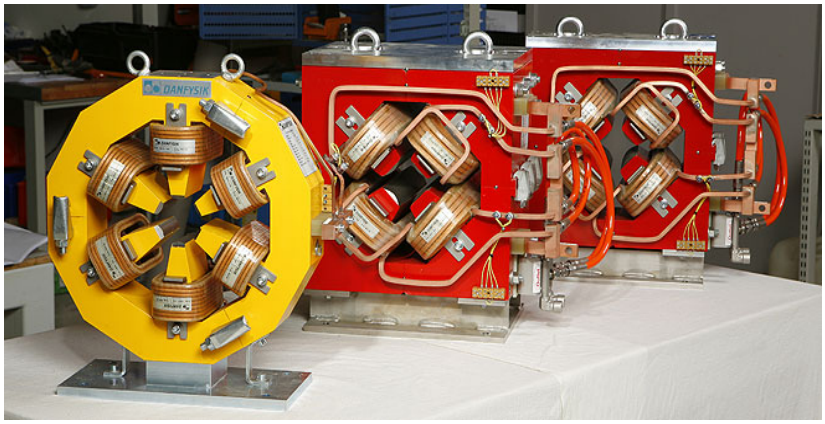
Nagy teljesítményű RF tér: klystron



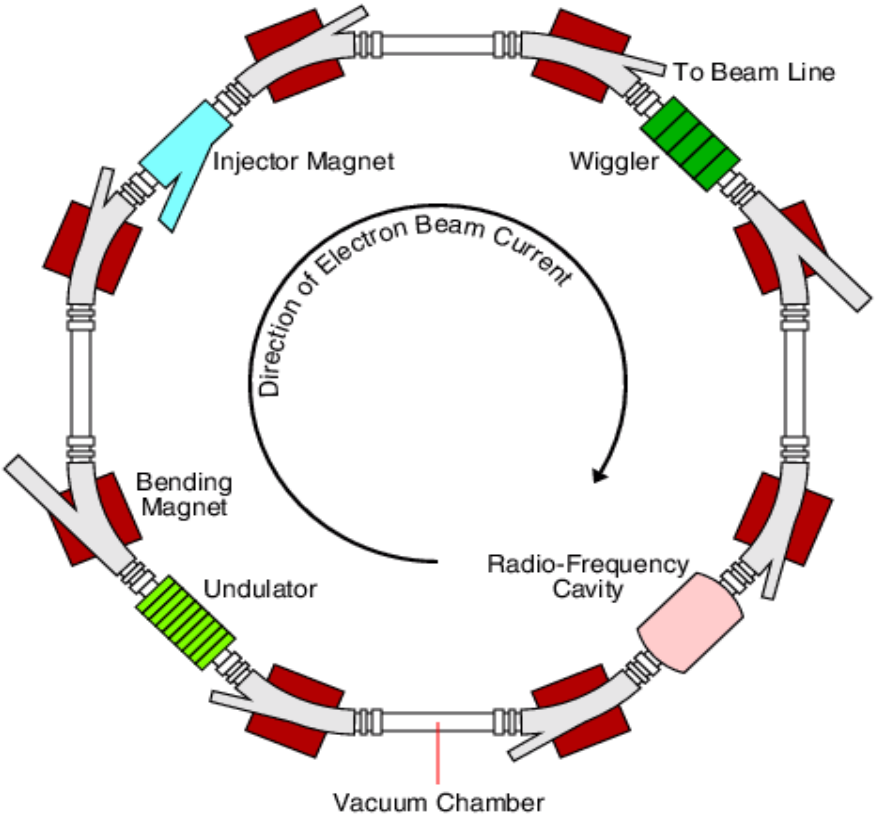
Fókuszálás: kvadrupól mágnesek



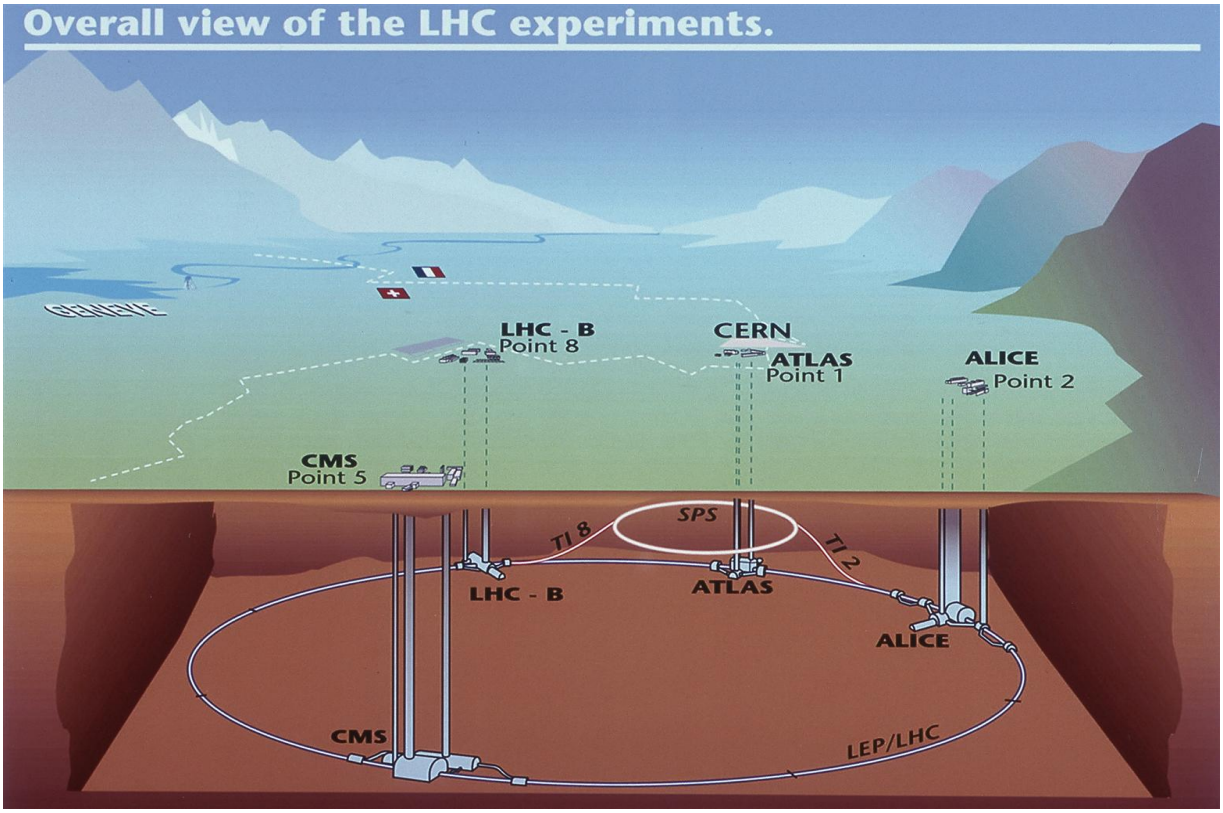




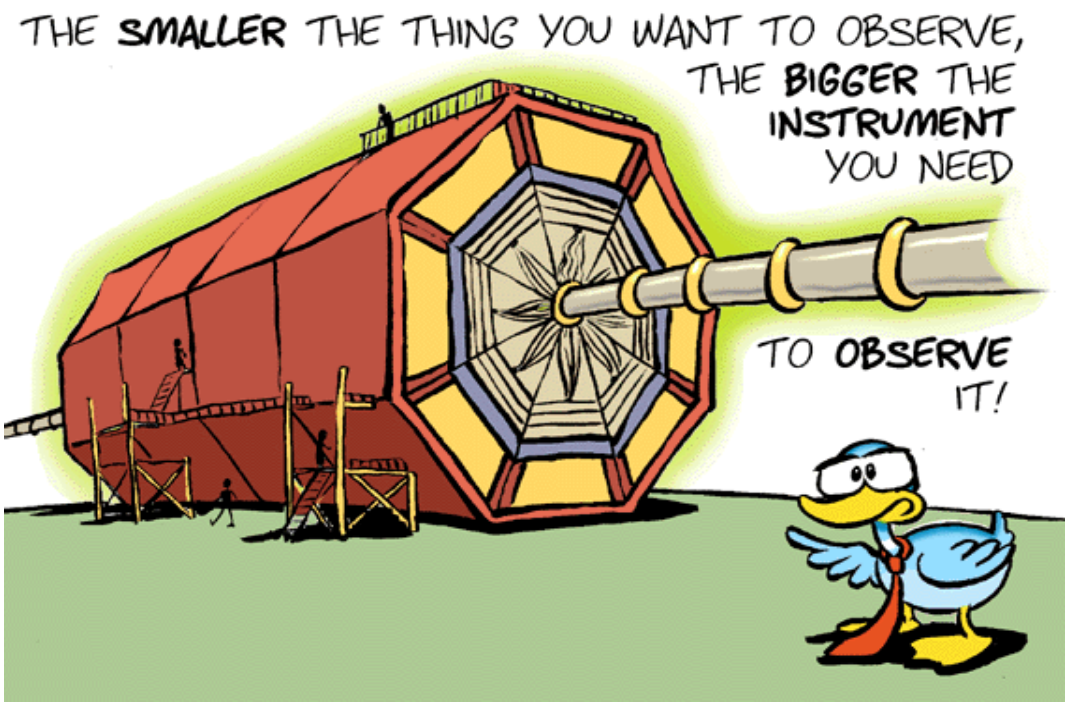
Szinkrotron



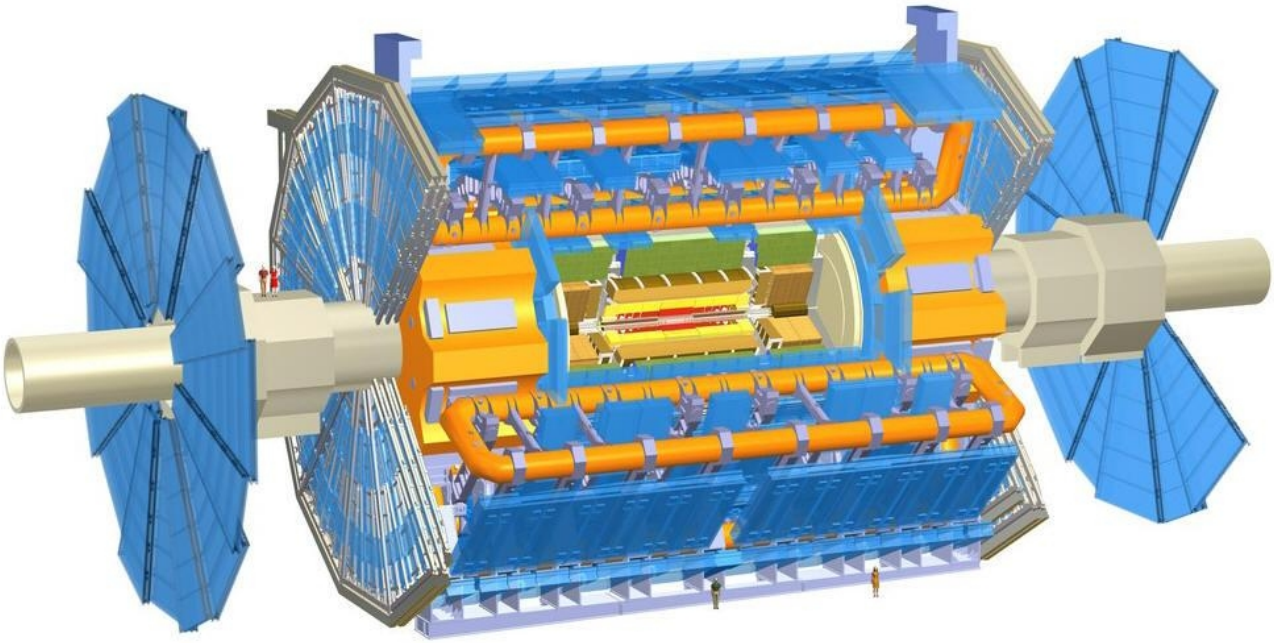
Large Hadron Collider



Egy igazi detektor: LHC ATLAS

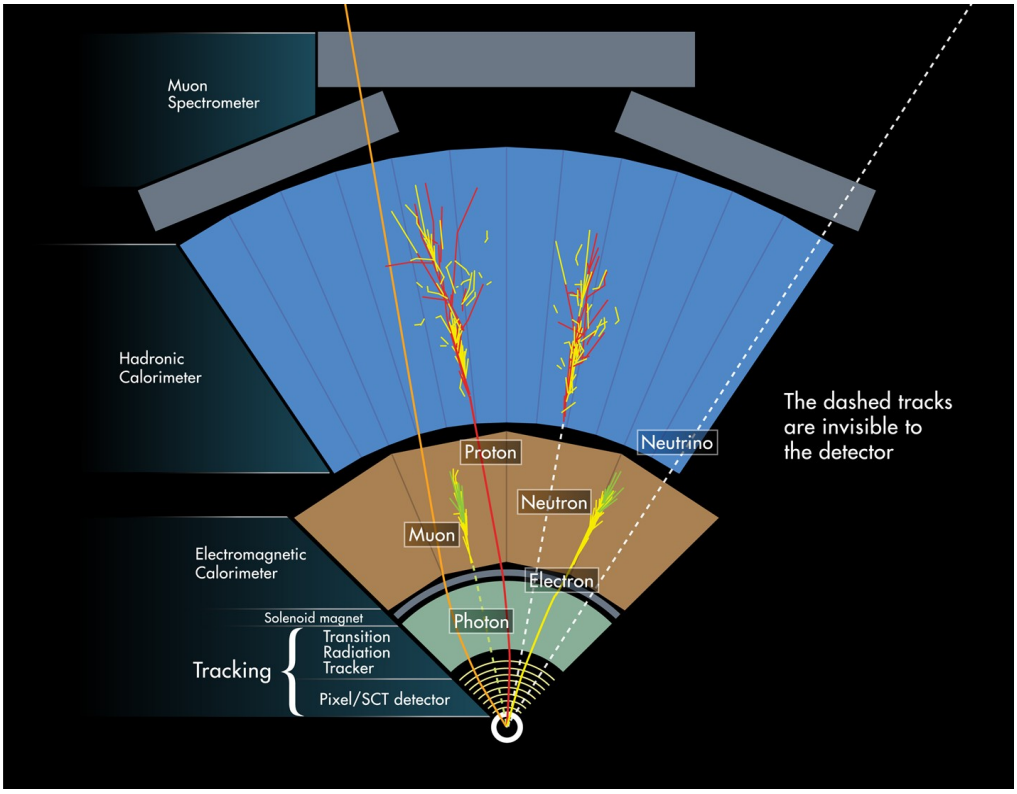


CERN ATLAS



A Toroidal LHC Apparatus (ATLAS): 45 méter hosszú, 25 méter átmérőjű, 7000 tonna.
Kollaboráció: mintegy 3,000 fizikus, 175 intézet, 38 ország.
Higgs-keresés, CP-sértés, W tömeg mérés, top kvark mérése, szuperszimmetria keresés.

ATLAS részecske azonosítás



Belső szolenoid 2 Tesla: 400 MeV alatti részecskék át se jutnak!
Külső szupravezetőtoroid: 2-8 Tesla (hadron kalori + muon kamrák, 1.6 GJ energia)

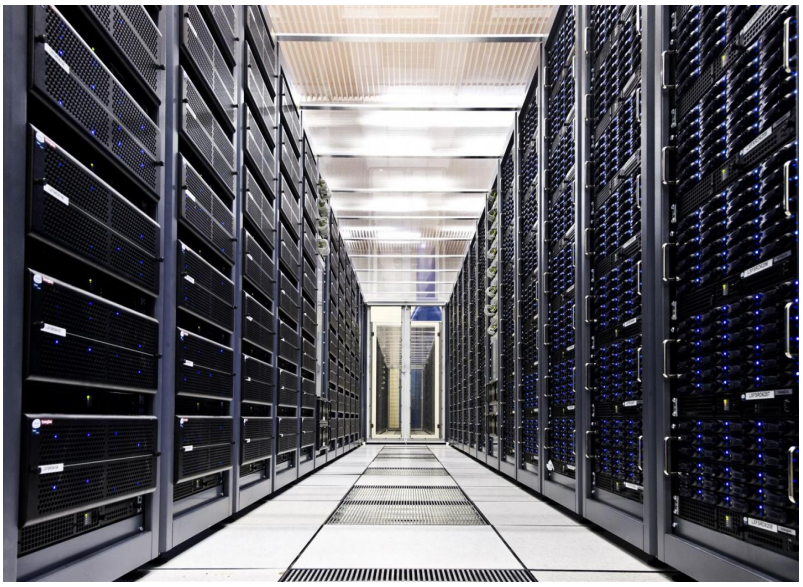
Adatfeldolgozás

25 MB/esemény, 40 millió esemény/sec → 1 petabyte/sec !!!!

Triggerek: eseményválogatás

Első szint: detektoron belüli elektronika → 100000/sec
Második/harmadik szint: detektor melletti klaszter

Marad: pár száz/sec

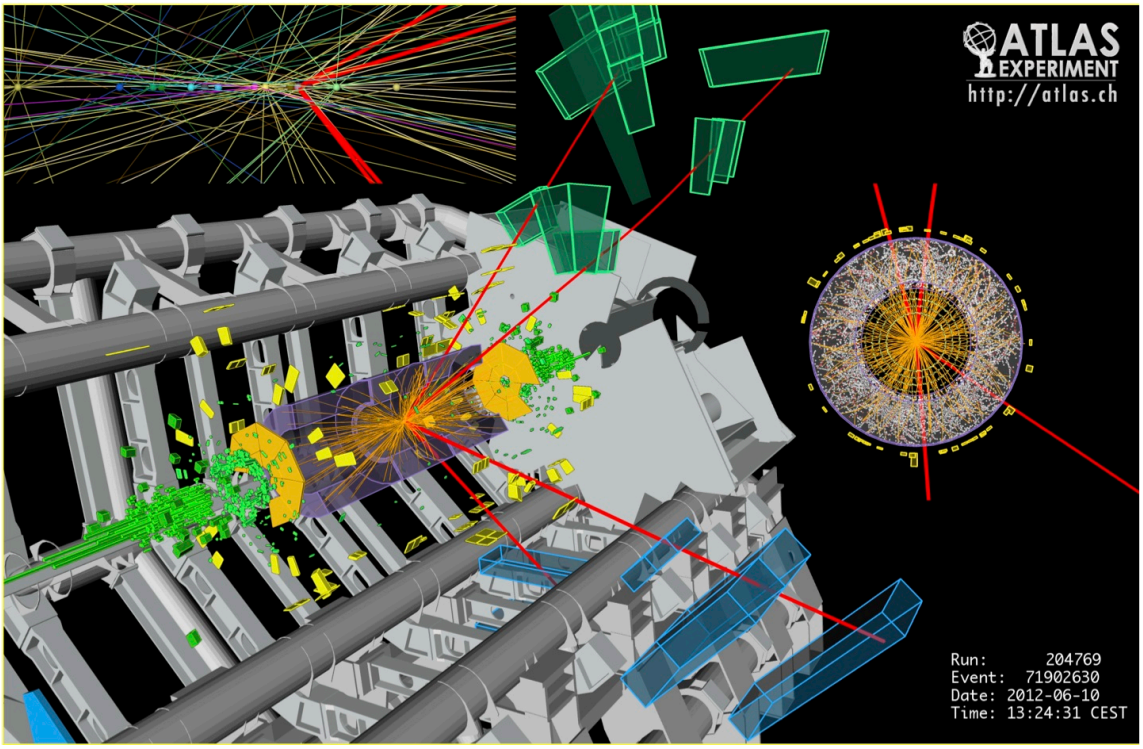


Tömörítés után: kb 100 MB/sec

Esemény rekonstrukció: offline

Grid számítóközpontok

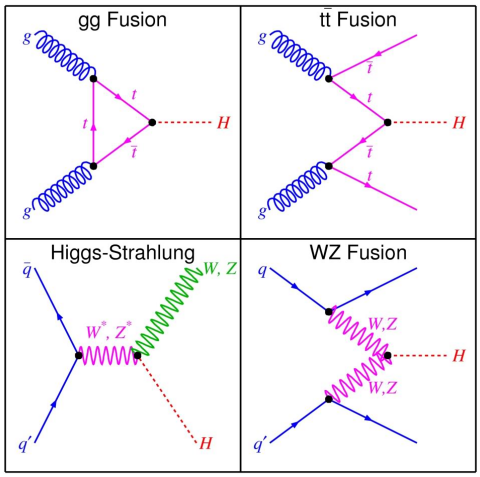
4-müon Higgs jelölt

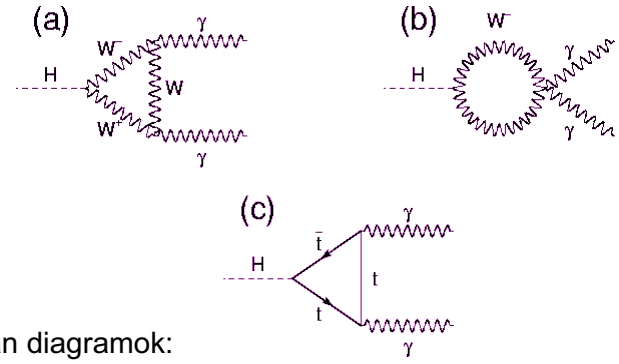


$H \rightarrow 2\,Z \rightarrow 2\,\mu^{+} + 2\,\mu^{-}$

Higgs bozon:
a Higgs mező kvantuma

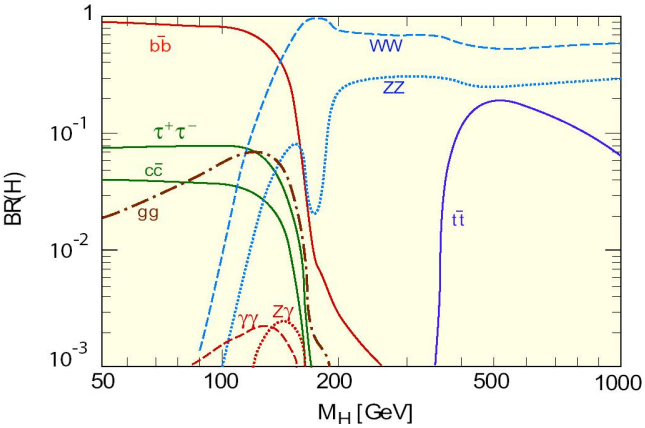
Higgs-bozon keltés és bomlás



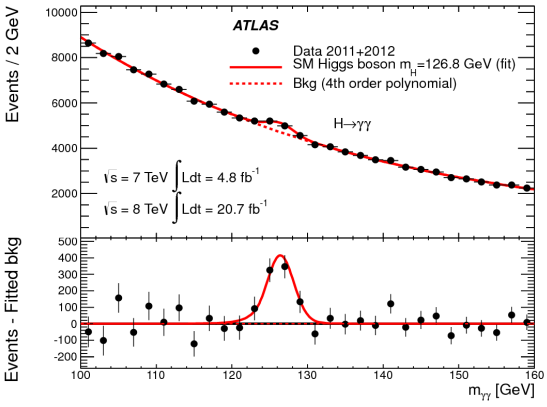


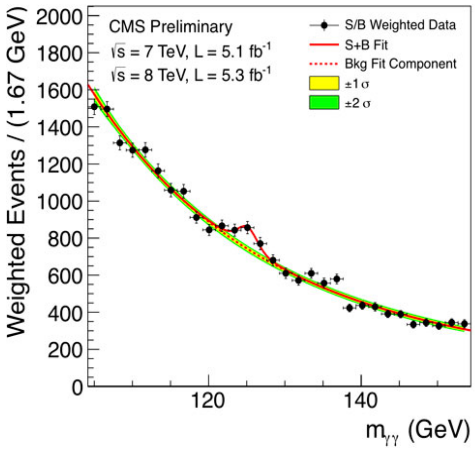
Feynman diagramok:
grafikusan ábrázolt integrálok,
a folyamatok valószínűségeit adják.

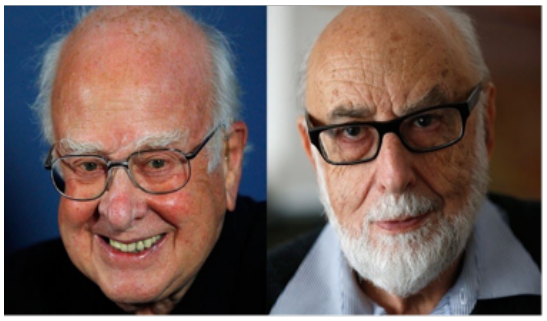
Richard Feynman
(1918-1988)
Nobel-díj: 1965



Higgs-bozon felfedezése



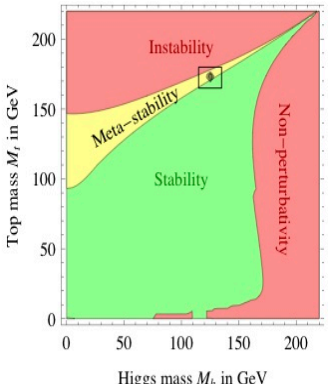


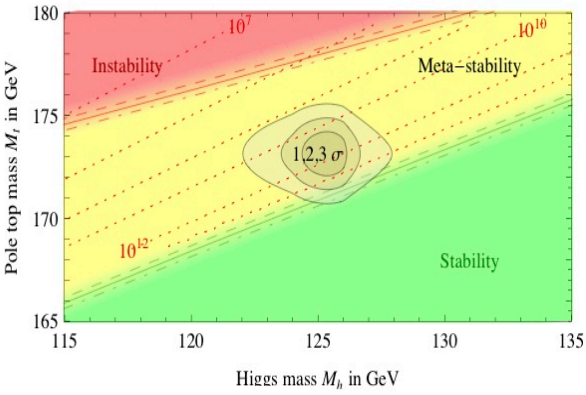


Peter Higgs Francois Englert
Nobel-díj: 2013

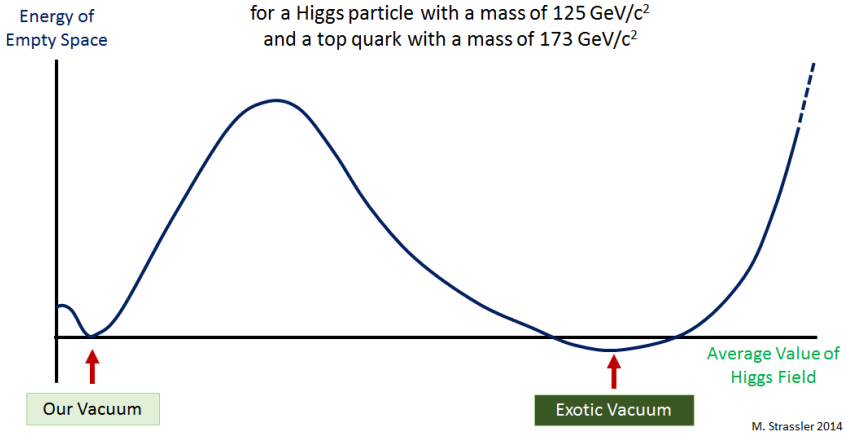
CERN
2012. július 4.

Metastabil univerzum?





Sketch of What the Standard Model Predicts
for a Higgs particle with a mass of 125 GeV/c²
and a top quark with a mass of 173 GeV/c²

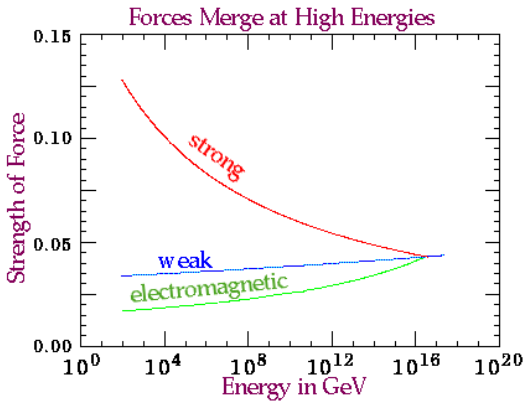


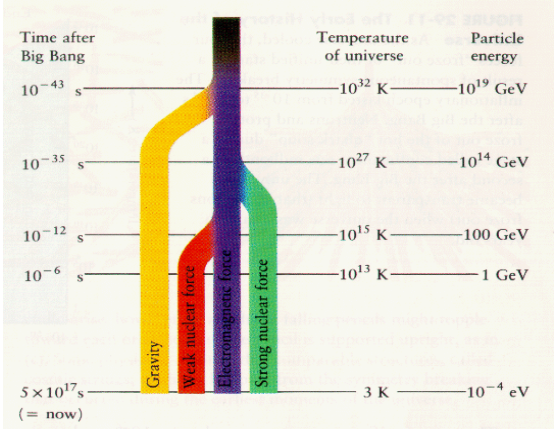
Azért nyugi:

$T_D > 10^{100}$ év

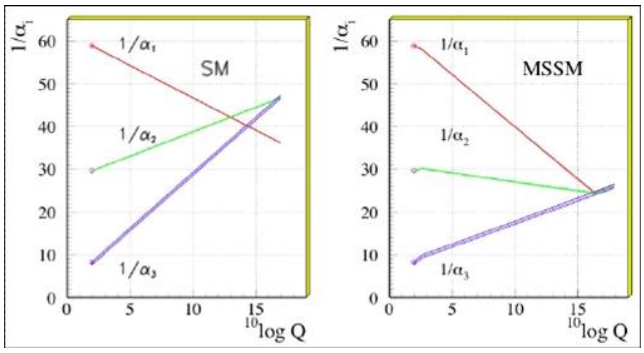
$T_U = 13.7 \times 10^9$ év

Nagy egyesítés?

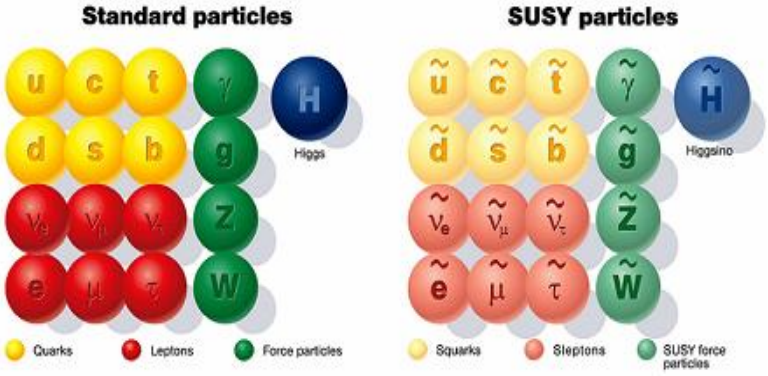




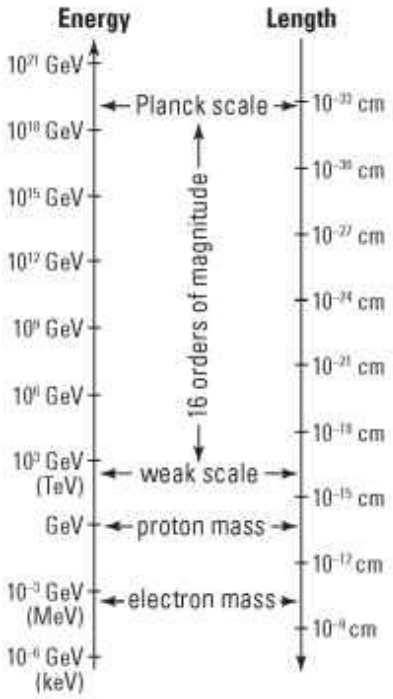
Ehhez lehet, hogy szuperszimmetria kell… ???

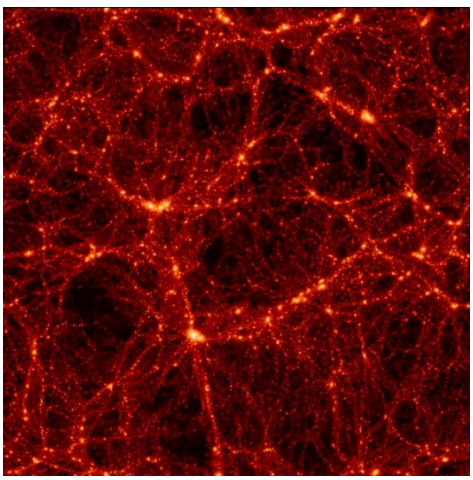


Szuperszimmetria



Hierarchia probléma

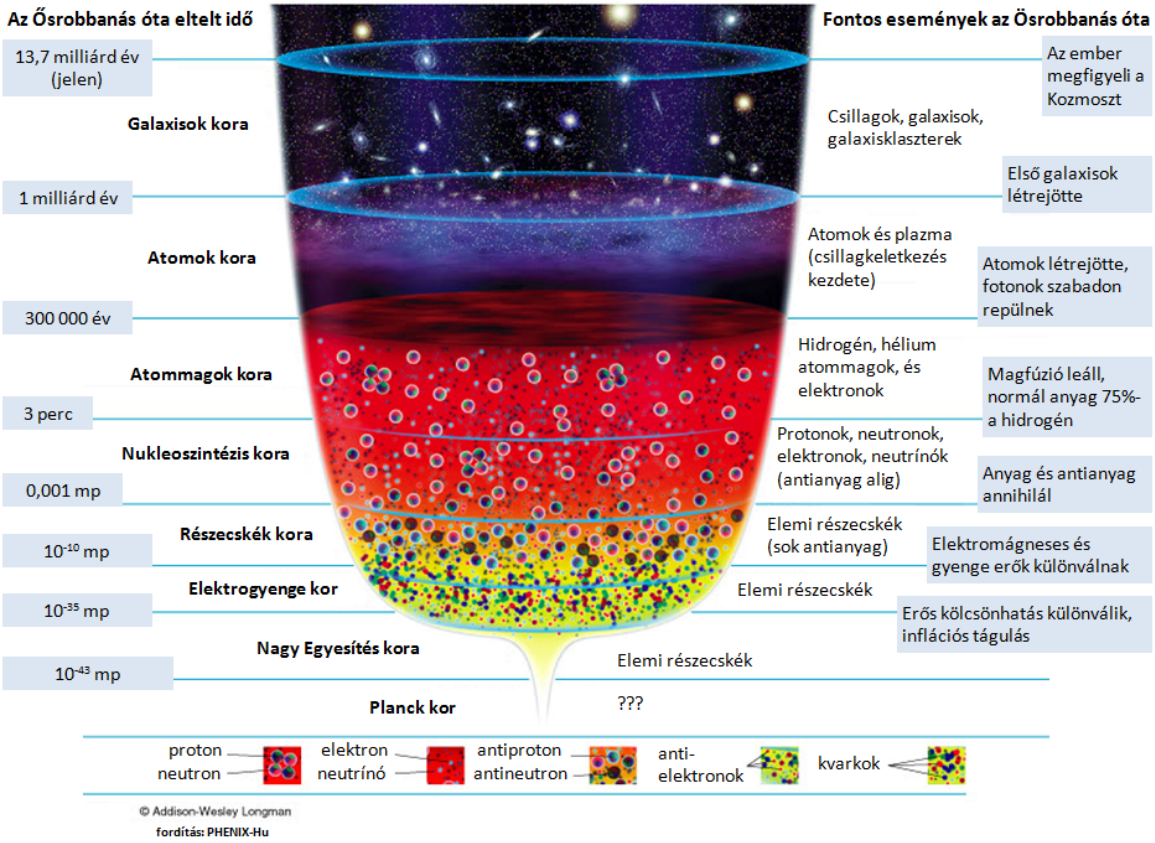




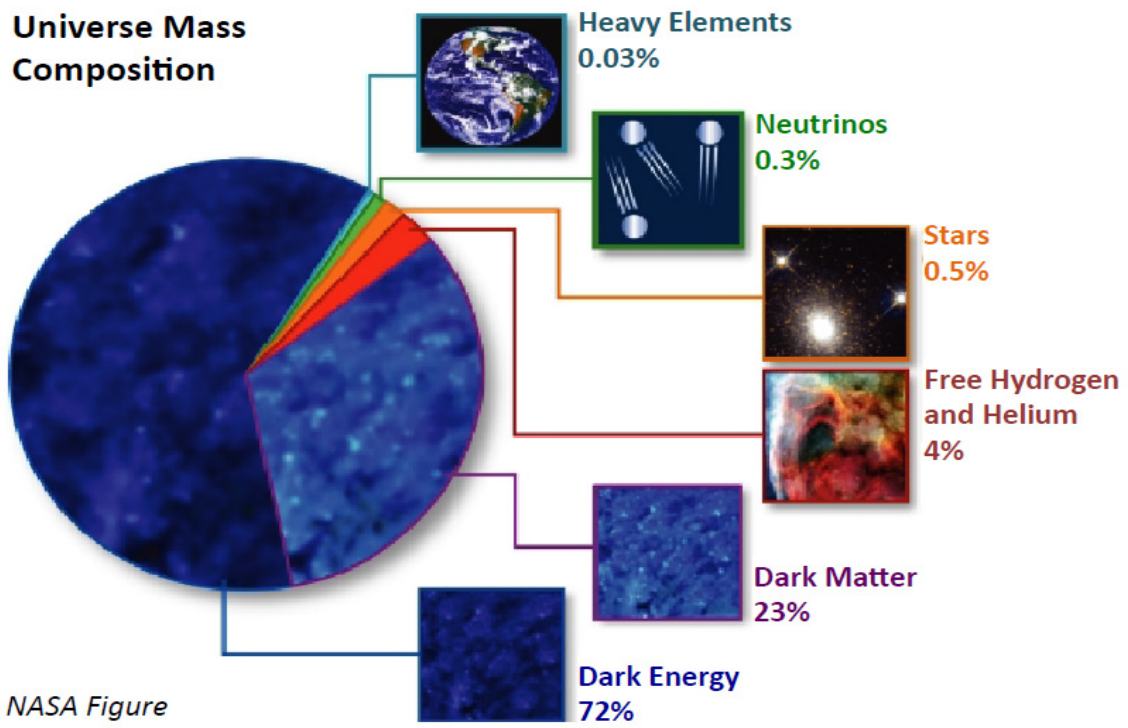
Legkönnyebb szuperpartner:

természetes jelölt az Univerzum sötét anyagára

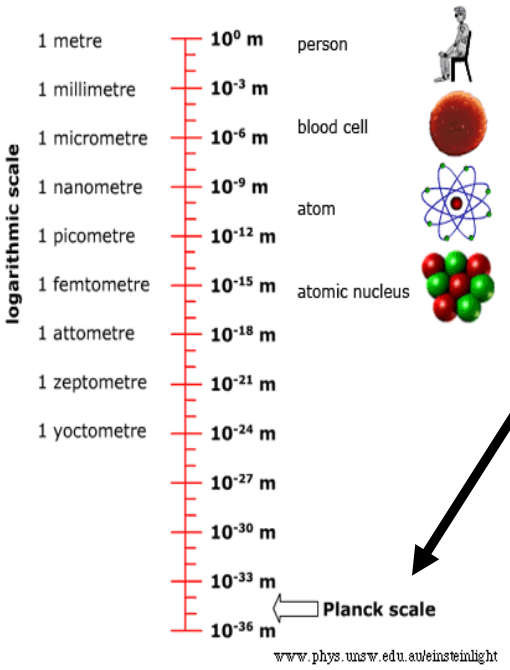
Az Univerzum eredete

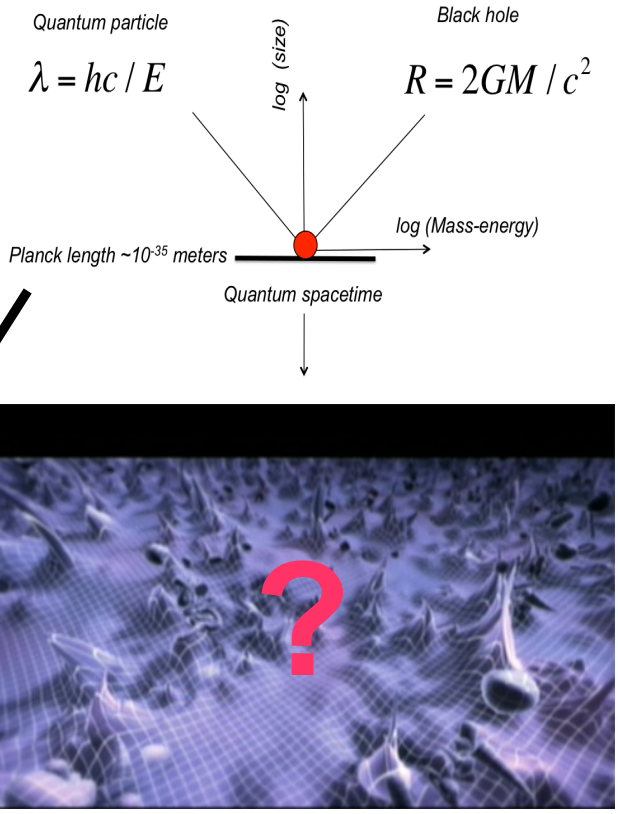
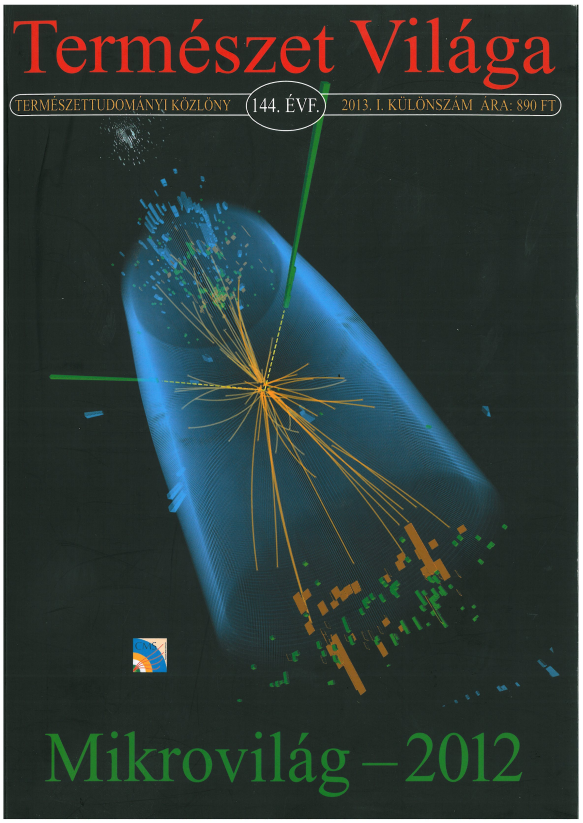


Sötét anyag és energia?



Kvantumgravitáció?





További olvasnivaló