



FAKULTA MATEMATIKY,
FYZIKY A INFORMATIKY
Univerzita Komenského
v Bratislave

Budúcnosť časticových urýchľovačov

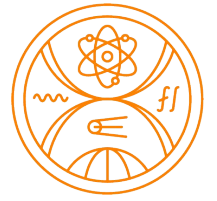
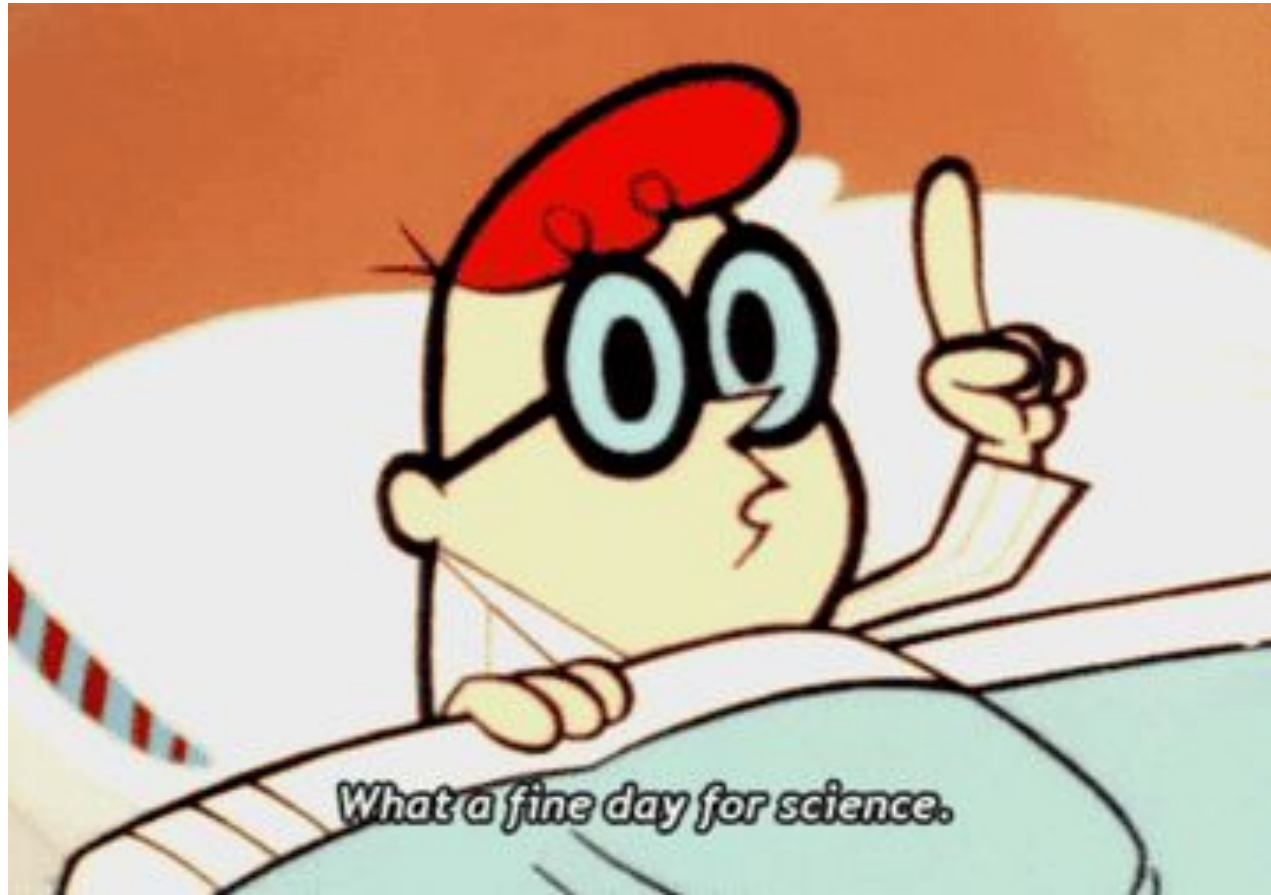
Juraj Tekel

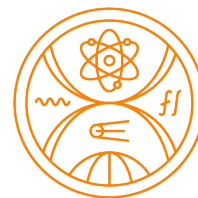
Katedra teoretickej fyziky

10. - 11. 6. 2024, 70 rokov CERNu, V Klub, Bratislava



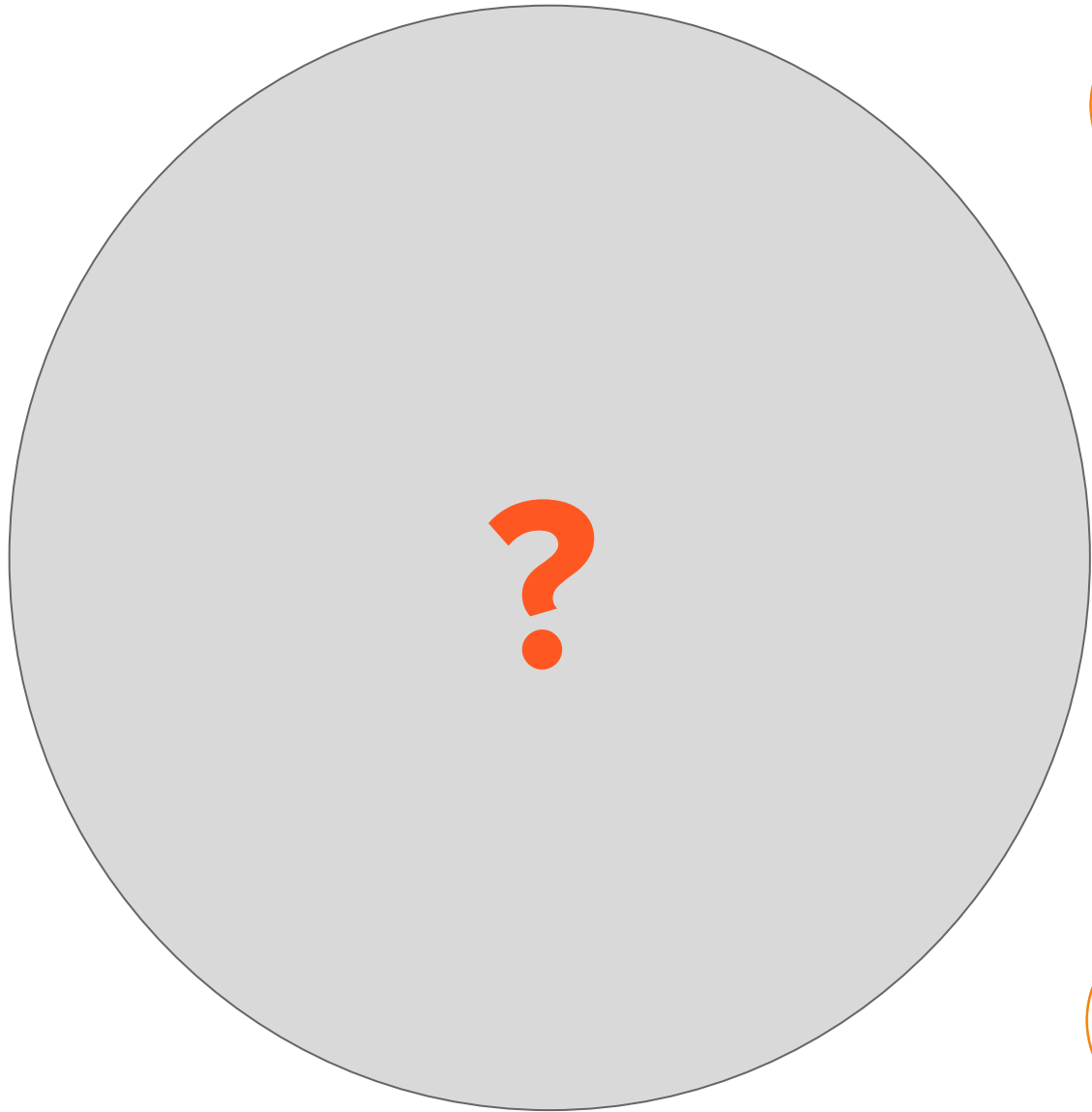


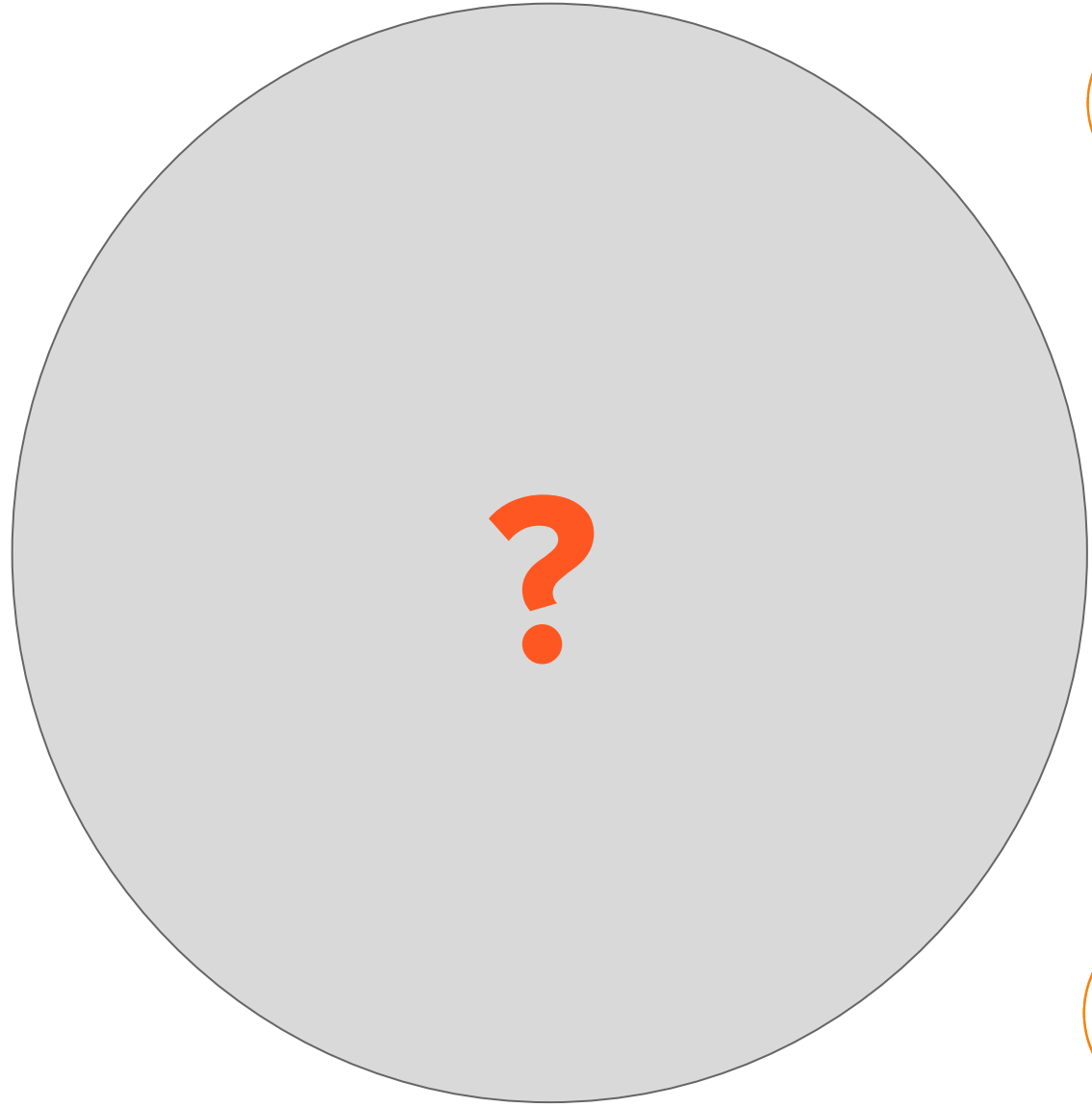
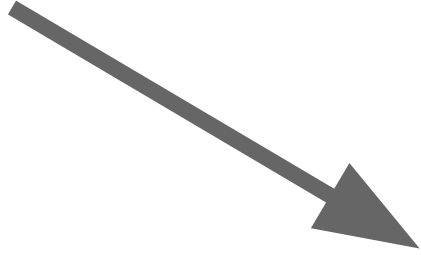


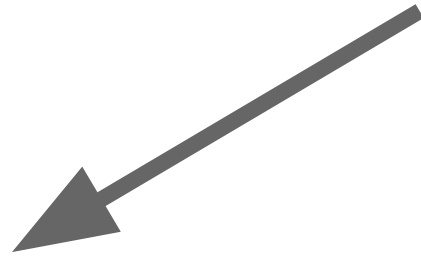
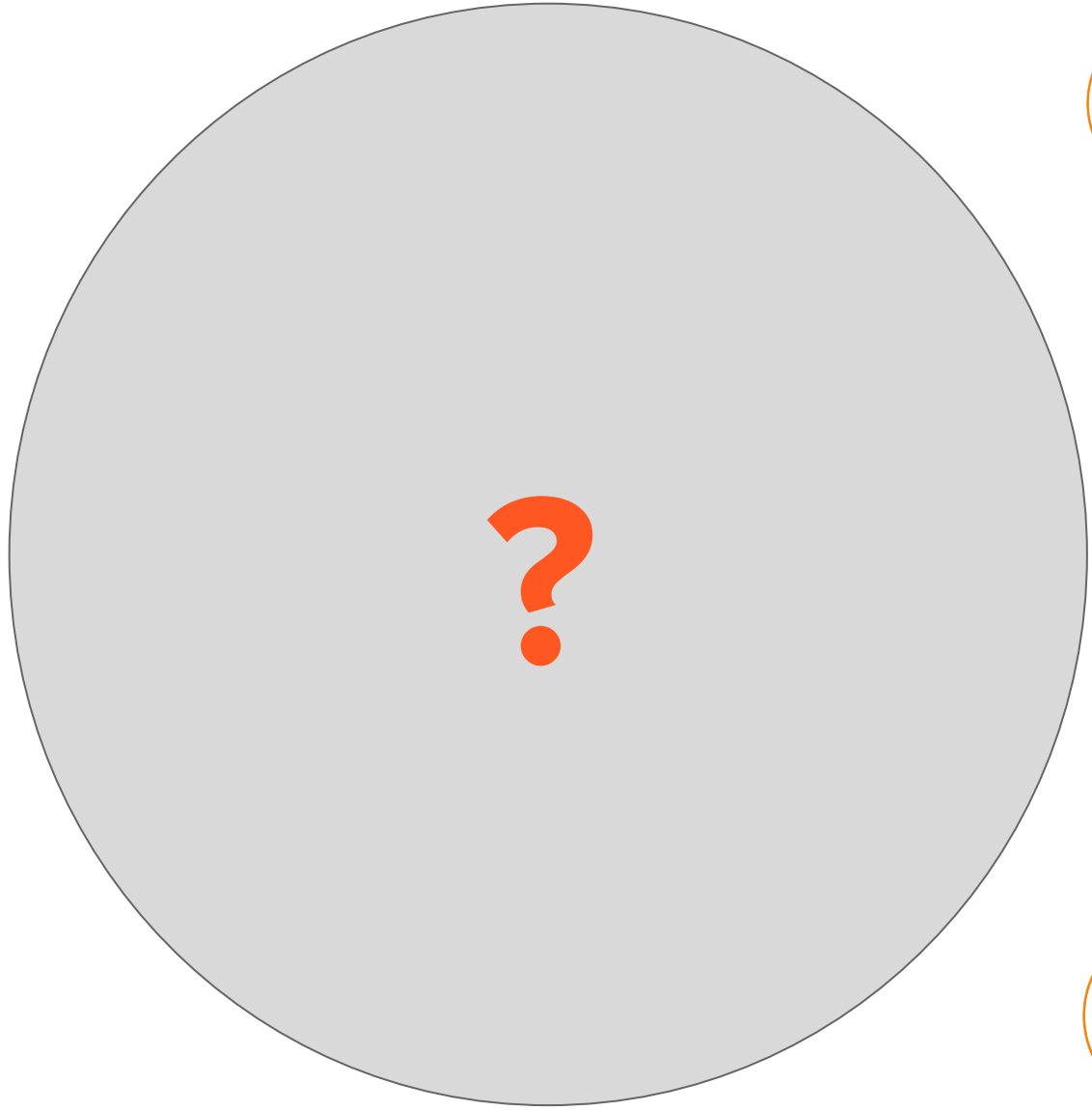
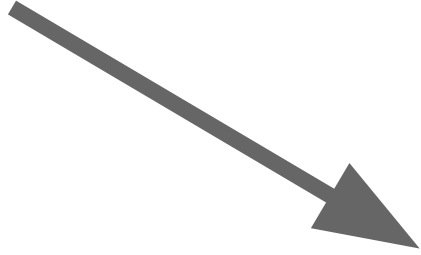


Časticové urýchľovače

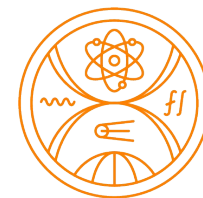
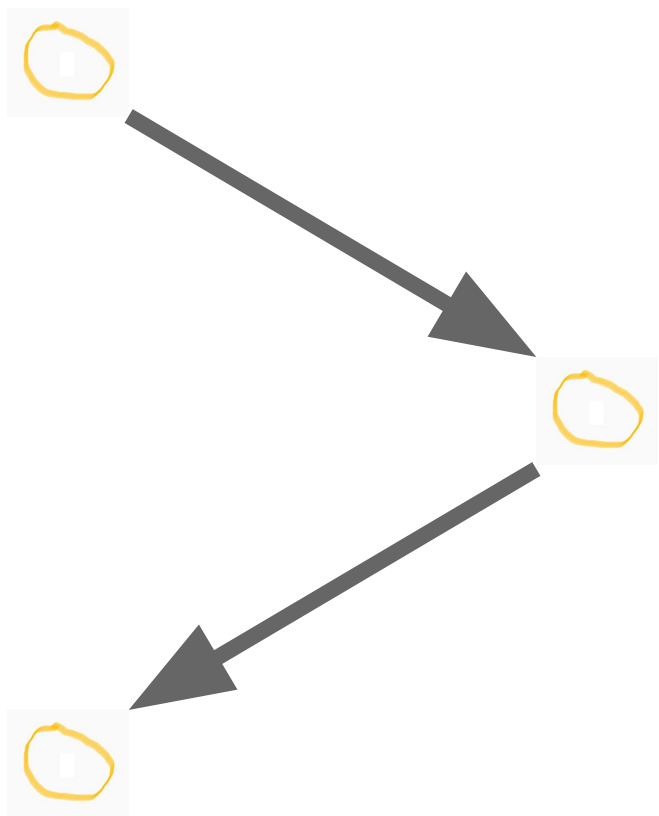








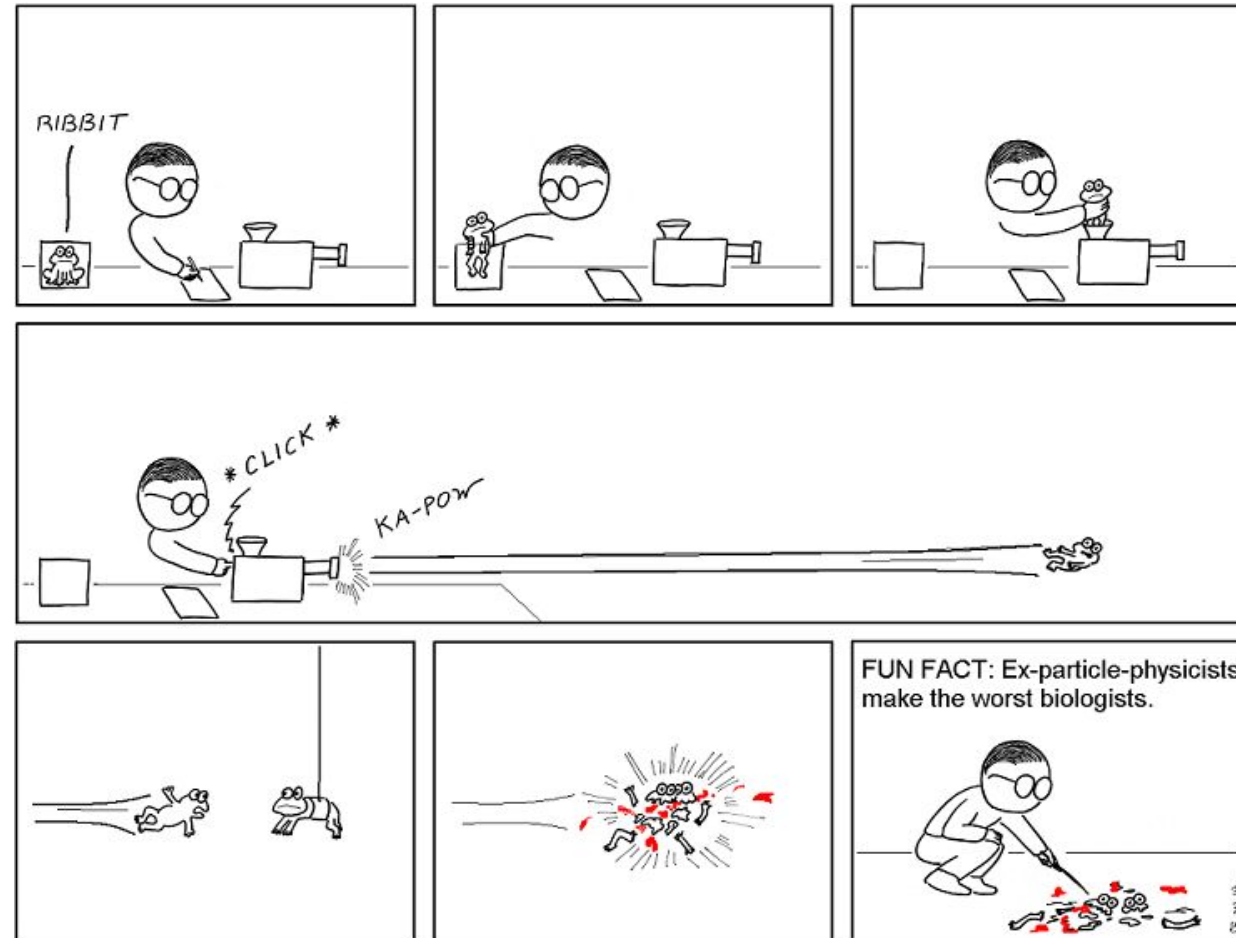




Zrážaním ľahších častíc vieme dostať ťažšie
častice



Zrážaním ľahších častíc vieme dostať ťažšie častice





Zrážaním ľahších častíc vieme dostať ťažšie častice



- Zrážaním častíc sa vieme čosi dozvedieť o ich **vnútornej štruktúre**.



Zrážaním ľahších častíc vieme dostať ťažšie častice



- Zrážaním častíc sa vieme čosi dozvedieť o ich **vnútornej štruktúre**.
- Pri dostatočnej energii vieme **vytvoriť nové častice**, ktoré sú ťažšie ako tie pôvodné.



Zrážaním ľahších častíc vieme dostať ťažšie častice



- Zrážaním častíc sa vieme čosi dozvedieť o ich **vnútornej štruktúre**.
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$$E = m c^2$$



Zrážaním ľahších častíc vieme dostať ťažšie častice



- V polovici dvadsiateho storočia bolo takto objavených **niekoľko stoviek** “elementárnych” častíc.
- Všetky nové sa veľmi rýchlo rozpadajú.
- Dávali im rôzne mená ako K , π , Λ , Σ , Ξ a podobne.
- Veríme, že to na elementárnej úrovni musí byť jednoduchšie.
- **Riešenie**: častice ako protón, neutrón a stovky bratrancov a sesterníc sa z niečoho skladú. **Až toto niečo je skutočne elementárne.**

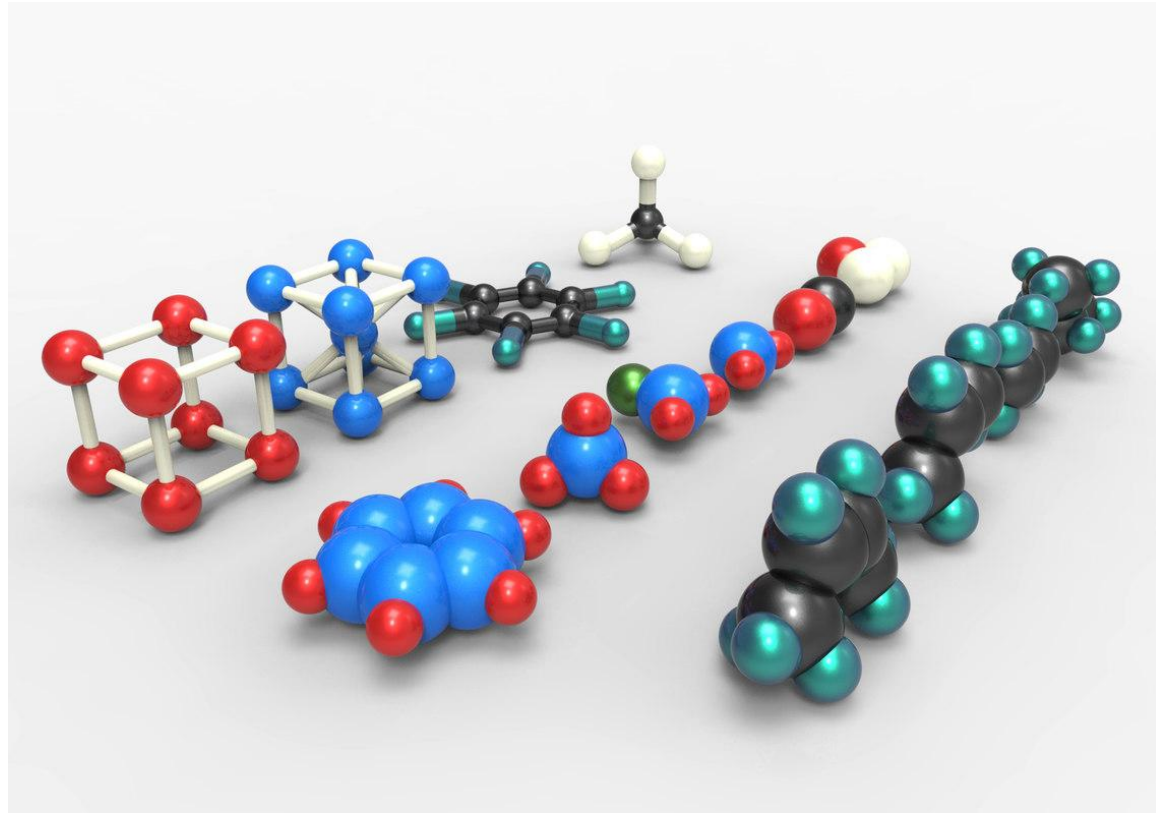
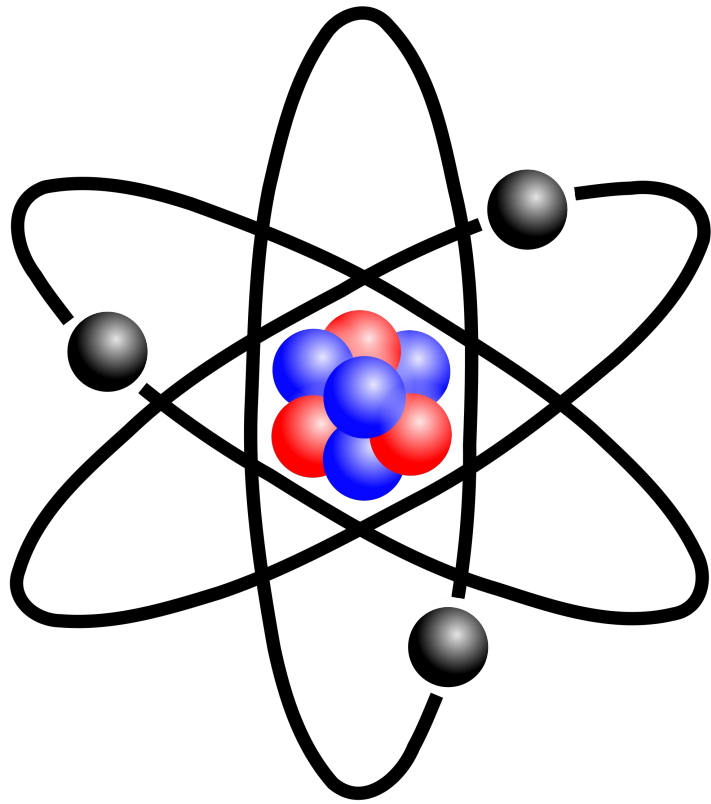


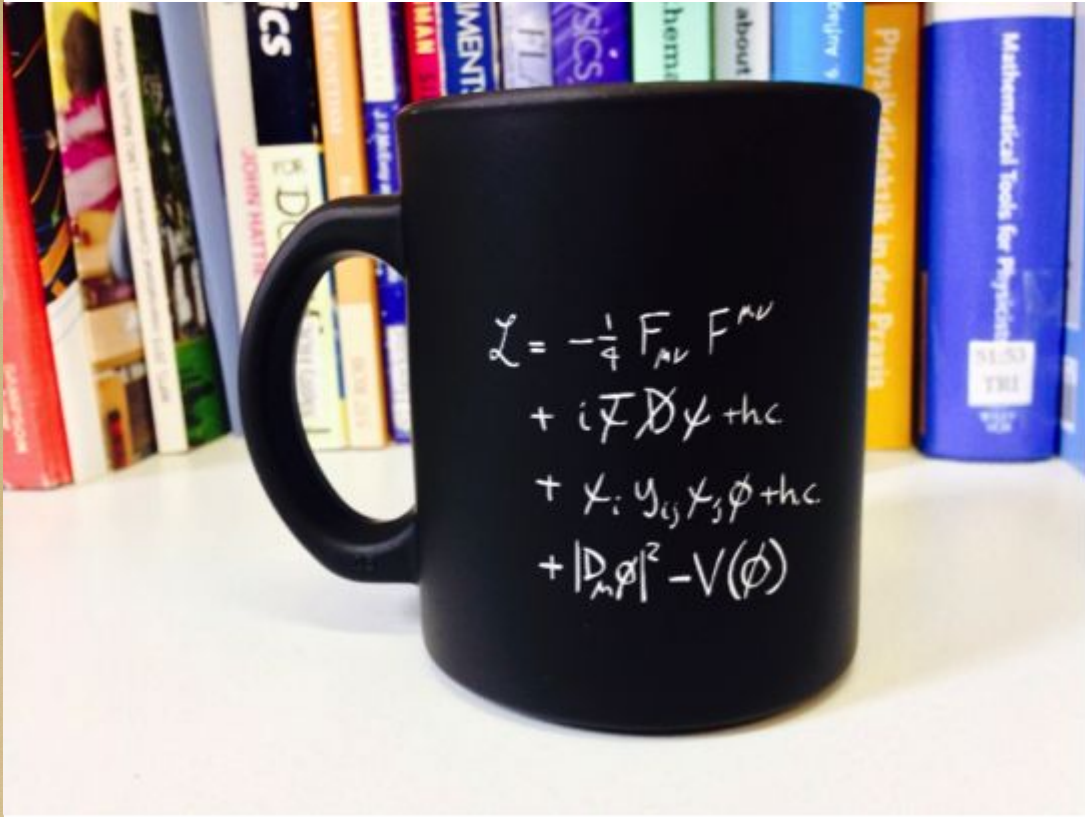
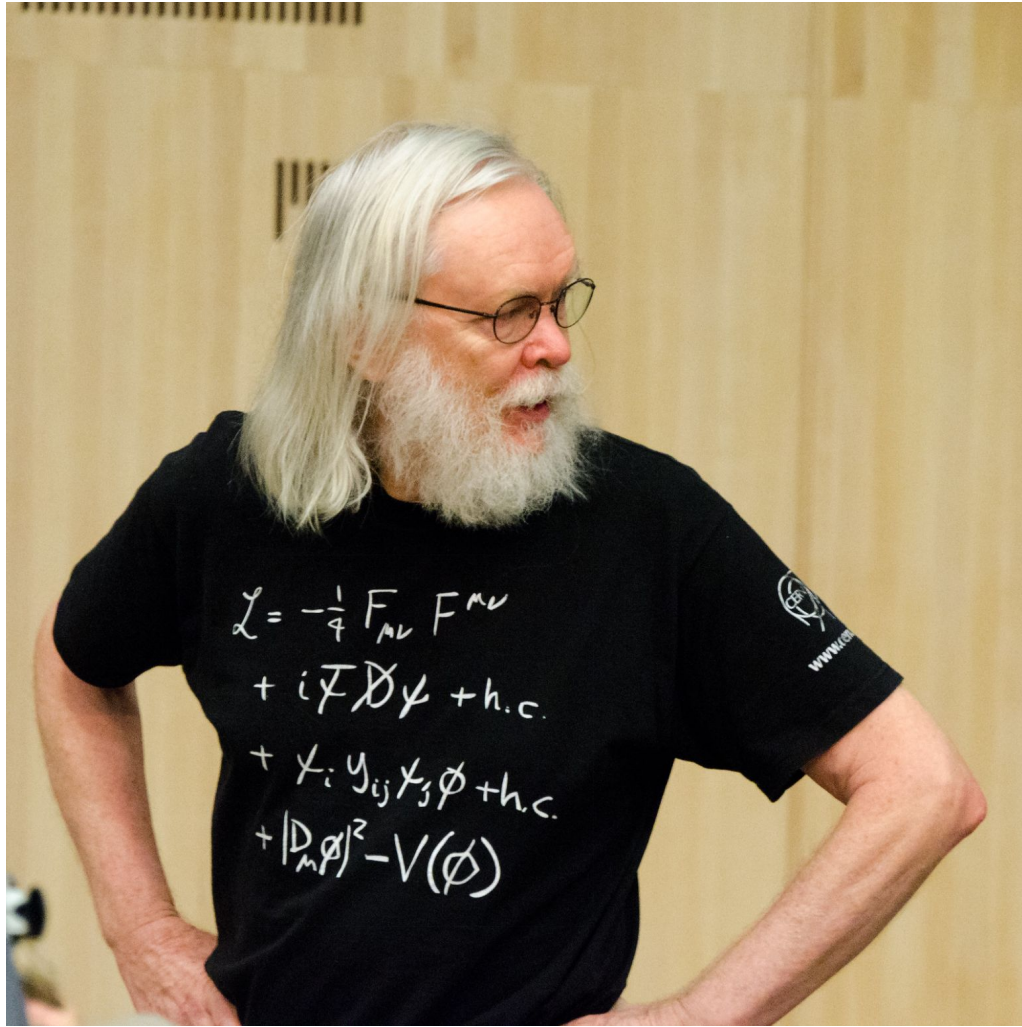


Štandardný model elementárnych častíc



Štandardný model elementárnych častíc







$$\begin{aligned}
\mathcal{L}_{\text{SM}} = & -\frac{1}{2}\partial^\nu g^{a\mu}\partial_\nu g_{a\mu} - g_s f^{abc}\partial^\mu g^{a\nu}g_\mu^b g_\nu^c - \frac{1}{4}g_s^2 f^{abc}f^{ade}g^{b\mu}g^{c\nu}g_\mu^d g_\nu^e \\
& -\partial^\nu W^{+\mu}\partial_\nu W_\mu^- + m_W^2 W^{+\mu}W_\mu^- - \frac{1}{2}\partial^\nu Z^{0\mu}\partial_\nu Z_\mu^0 + \frac{m_W^2}{2c_w^2}Z^{0\mu}Z_\mu^0 - \frac{1}{2}\partial^\nu A^\mu\partial_\nu A_\mu + \frac{1}{2}\partial^\mu H\partial_\mu H - \frac{1}{2}m_H^2 H^2 \\
& +\partial^\nu\phi^+\partial_\nu\phi^- - m_W^2\phi^+\phi^- + \frac{1}{2}\partial^\nu\phi^0\partial_\nu\phi^0 - \frac{m_W^2}{2c_w^2}(\phi^0)^2 - \beta_H\left[\frac{2m_W^2}{g^2} + \frac{2m_W}{g}H + \frac{1}{2}(H^2 + (\phi^0)^2 + 2\phi^+\phi^-)\right] + \frac{2m_W^4}{g^2}\alpha_H \\
& -igc_w\left[\partial^\nu Z^{0\mu}(W_\mu^+W_\nu^- - W_\nu^+W_\mu^-) - Z^{0\nu}(W^{+\mu}\partial_\nu W_\mu^- - W^{-\mu}\partial_\nu W_\mu^+) + Z^{0\mu}(W^{+\nu}\partial_\nu W_\mu^- - W^{-\nu}\partial_\nu W_\mu^+)\right] \\
& -ig s_w\left[\partial^\nu A^\mu(W_\mu^+W_\nu^- - W_\nu^+W_\mu^-) - A^\nu(W^{+\mu}\partial_\nu W_\mu^- - W^{-\mu}\partial_\nu W_\mu^+) + A^\mu(W^{+\nu}\partial_\nu W_\mu^- - W^{-\nu}\partial_\nu W_\mu^+)\right] \\
& -\frac{1}{2}g^2 W^{+\mu}W_\mu^- W^{+\nu}W_\nu^- + \frac{1}{2}g^2 W^{+\mu}W^{-\nu}W_\mu^+W_\nu^- + g^2 c_w^2(Z^{0\mu}W_\mu^+Z^{0\nu}W_\nu^- - Z^{0\mu}Z_\mu^0 W^{+\nu}W_\nu^-) \\
& +g^2 s_w^2(A^\mu W_\mu^+ A^\nu W_\nu^- - A^\mu A_\mu W^{+\nu}W_\nu^-) + g^2 s_w c_w[A^\mu Z^{0\nu}(W_\mu^+W_\nu^- + W_\nu^+W_\mu^-) - 2A^\mu Z_\mu^0 W^{+\nu}W_\nu^-] \\
& -g\alpha_H m_W[H^3 + H(\phi^0)^2 + 2H\phi^+\phi^-] - \frac{1}{8}g^2\alpha_H[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 2H^2(\phi^0)^2 + 4H^2\phi^+\phi^-] \\
& +g m_W W^{+\mu}W_\mu^- H + \frac{1}{2}g\frac{m_W}{c_w^2}Z^{0\mu}Z_\mu^0 H + \frac{1}{2}ig[W^{+\mu}(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^{-\mu}(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] \\
& -\frac{1}{2}g[W^{+\mu}(H\partial_\mu\phi^- - \phi^-\partial_\mu H) + W^{-\mu}(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)] - \frac{1}{2}\frac{g}{c_w}Z^{0\mu}(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) \\
& +ig\frac{s_w^2}{c_w}m_W Z^{0\mu}(W_\mu^+\phi^- - W_\mu^-\phi^+) - ig s_w m_W A^\mu(W_\mu^+\phi^- - W_\mu^-\phi^+)
\end{aligned}$$



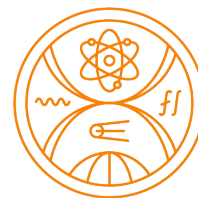


$$\begin{aligned}
& + i g \frac{s_w^2 - c_w^2}{2c_w} Z^{0\mu} (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - i g s_w A^\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) \\
& + \frac{1}{4} g^2 W^{+\mu} W_\mu^- [H^2 + (\phi^0)^2 + 2\phi^+ \phi^-] + \frac{1}{8} \frac{g^2}{c_w^2} Z^{0\mu} Z_\mu^0 [H^2 + (\phi^0)^2 + 2(s_w^2 - c_w^2) \phi^+ \phi^-] \\
& + \frac{1}{2} g^2 \frac{s_w^2}{c_w} Z^{0\mu} \phi^0 [W_\mu^+ \phi^- + W_\mu^- \phi^+] + \frac{1}{2} i g^2 \frac{s_w^2}{c_w} Z^{0\mu} H [W_\mu^+ \phi^- - W_\mu^- \phi^+] - \frac{1}{2} g^2 s_w A^\mu \phi^0 [W_\mu^+ \phi^- + W_\mu^- \phi^+] \\
& - \frac{1}{2} i g^2 s_w A^\mu H [W_\mu^+ \phi^- - W_\mu^- \phi^+] + g^2 \frac{s_w}{c_w} (c_w^2 - s_w^2) A^\mu Z_\mu^0 \phi^+ \phi^- + g^2 s_w^2 A^\mu A_\mu \phi^+ \phi^- \\
& + \bar{e}^\sigma (i\gamma^\mu \partial_\mu - m_e^\sigma) e^\sigma + \bar{\nu}^\sigma i\gamma^\mu \partial_\mu \nu^\sigma + \bar{d}_j^\sigma (i\gamma^\mu \partial_\mu - m_d^\sigma) d_j^\sigma + \bar{u}_j^\sigma (i\gamma^\mu \partial_\mu - m_u^\sigma) u_j^\sigma \\
& + g s_w A^\mu \left[-(\bar{e}^\sigma \gamma_\mu e^\sigma) - \frac{1}{3} (\bar{d}_j^\sigma \gamma_\mu d^{j\sigma}) + \frac{2}{3} (\bar{u}_j^\sigma \gamma_\mu u_j^\sigma) \right] + \frac{g}{4c_w} Z^{0\mu} \left[(\bar{\nu}^\sigma \gamma_\mu (1 - \gamma^5) \nu^\sigma) + (\bar{e}^\sigma \gamma_\mu (4s_w^2 - (1 - \gamma^5)) e^\sigma) \right. \\
& \left. + (\bar{d}_j^\sigma \gamma_\mu (\frac{4}{3}s_w^2 - (1 - \gamma^5)) d_j^\sigma) + (\bar{u}_j^\sigma \gamma_\mu (-\frac{8}{3}s_w^2 + (1 - \gamma^5)) u_j^\sigma) \right] \\
& + \frac{g}{2\sqrt{2}} W^{+\mu} \left[(\bar{\nu}^\sigma \gamma_\mu (1 - \gamma^5) P^{\sigma\tau} e^\tau) + (\bar{u}_j^\sigma \gamma_\mu (1 - \gamma^5) C^{\sigma\tau} d_j^\tau) \right] \\
& + \frac{g}{2\sqrt{2}} W^{-\mu} \left[(\bar{e}^\sigma \gamma_\mu (1 - \gamma^5) P^{\dagger\sigma\tau} \nu^\tau) + (\bar{d}_j^\sigma \gamma_\mu (1 - \gamma^5) C^{\dagger\sigma\tau} u_j^\tau) \right]
\end{aligned}$$



$$\begin{aligned}
& +i \frac{g}{2\sqrt{2}} \frac{m_e^\sigma}{m_W} [-\phi^+ (\bar{\nu}^\sigma (1 + \gamma^5) e^\sigma) + \phi^- (\bar{e}^\sigma (1 - \gamma^5) \nu^\sigma)] - \frac{g}{2} \frac{m_e^\sigma}{m_W} [H \bar{e}^\sigma e^\sigma - i \phi^0 \bar{e}^\sigma \gamma^5 e^\sigma] \\
& +i \frac{g}{2\sqrt{2}} \frac{m_u^\sigma}{m_W} \phi^+ [-m_d^\tau (\bar{u}_j^\sigma C^{\sigma\tau} (1 + \gamma^5) d_j^\tau) + m_u^\tau (\bar{u}_j^\sigma C^{\sigma\tau} (1 - \gamma^5) d_j^\tau)] \\
& +i \frac{g}{2\sqrt{2}} \frac{m_d^\sigma}{m_W} \phi^- [m_d^\tau (\bar{d}_j^\sigma C^{\dagger\sigma\tau} (1 - \gamma^5) u_j^\tau) - m_u^\tau (\bar{d}_j^\sigma C^{\dagger\sigma\tau} (1 + \gamma^5) u_j^\tau)] \\
& - \frac{g}{2} \frac{m_u^\sigma}{m_W} H \bar{u}_j^\sigma u_j^\sigma - \frac{g}{2} \frac{m_d^\sigma}{m_W} H \bar{d}_j^\sigma d_j^\sigma - i \frac{g}{2} \frac{m_u^\sigma}{m_W} \phi^0 \bar{u}_j^\sigma \gamma^5 u_j^\sigma + i \frac{g}{2} \frac{m_d^\sigma}{m_W} \phi^0 \bar{d}_j^\sigma \gamma^5 d_j^\sigma \\
& - \frac{1}{2} i g_s \bar{d}_i^\sigma \gamma^\mu \lambda_{ij}^a d_j^\sigma g_\mu^a - \frac{1}{2} i g_s \bar{u}_i^\sigma \gamma^\mu \lambda_{ij}^a u_j^\sigma g_\mu^a \\
& - \bar{X}^+ (\partial^\mu \partial_\mu + m_W^2) X^+ - \bar{X}^- (\partial^\mu \partial_\mu + m_W^2) X^- - \bar{X}^0 \left(\partial^\mu \partial_\mu + \frac{m_W^2}{c_w^2} \right) X^0 - \bar{Y} \partial^\mu \partial_\mu Y \\
& - i g c_w W^{+\mu} (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) - i g s_w W^{+\mu} (\partial_\mu \bar{Y} X^- - \partial_\mu \bar{X}^+ Y) \\
& - i g c_w W^{-\mu} (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) - i g s_w W^{-\mu} (\partial_\mu \bar{X}^- Y - \partial_\mu \bar{Y} X^+) \\
& - i g c_w Z^{0\mu} (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) - i g s_w A^\mu (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) \\
& - \frac{1}{2} g m_W \left[\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w^2} \bar{X}^0 X^0 H \right] \\
& + \frac{s_w^2 - c_w^2}{2c_w} i g m_W [\bar{X}^+ X^0 \phi^+ - \bar{X}^- X^0 \phi^-] + \frac{1}{2c_w} i g m_W [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] \\
& + i g m_W s_w [\bar{X}^- Y \phi^- - \bar{X}^+ Y \phi^+] + i \frac{1}{2} g m_W [\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0] \\
& - \bar{G}^a \partial^\mu \partial_\mu G^a - g_s f^{abc} \partial^\mu \bar{G}^a G^b g_\mu^c
\end{aligned}$$

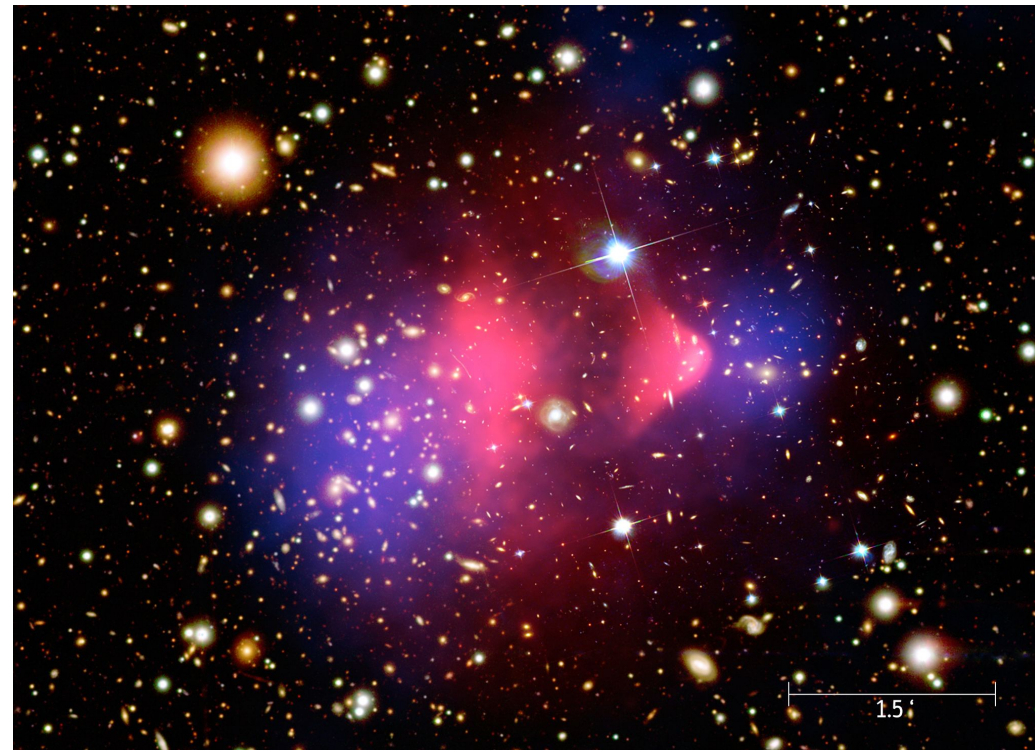
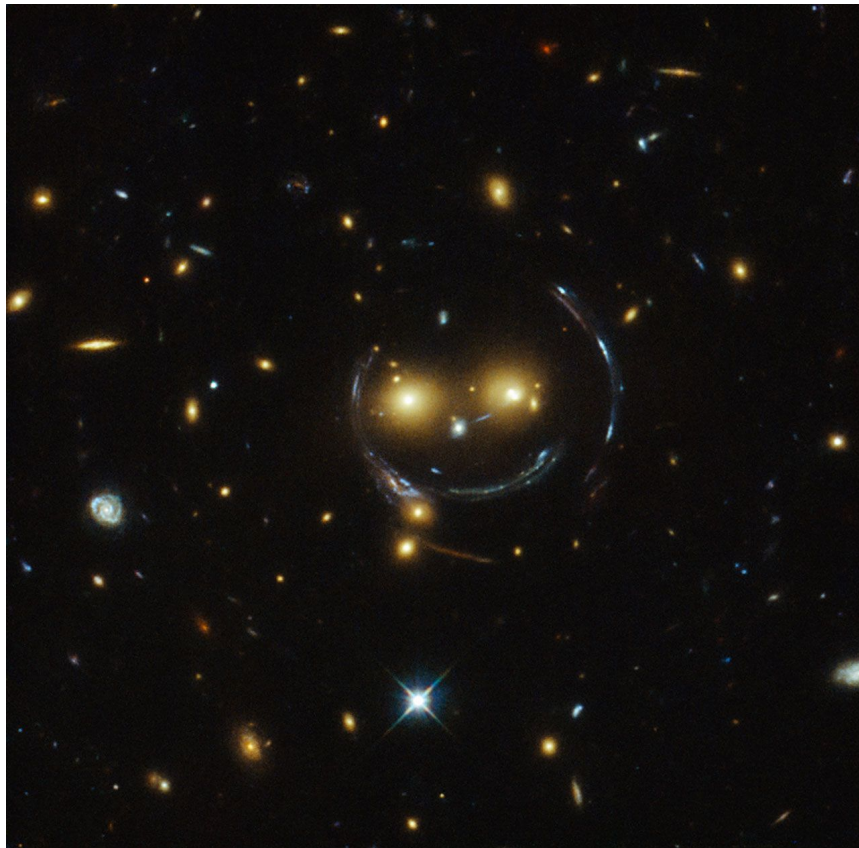




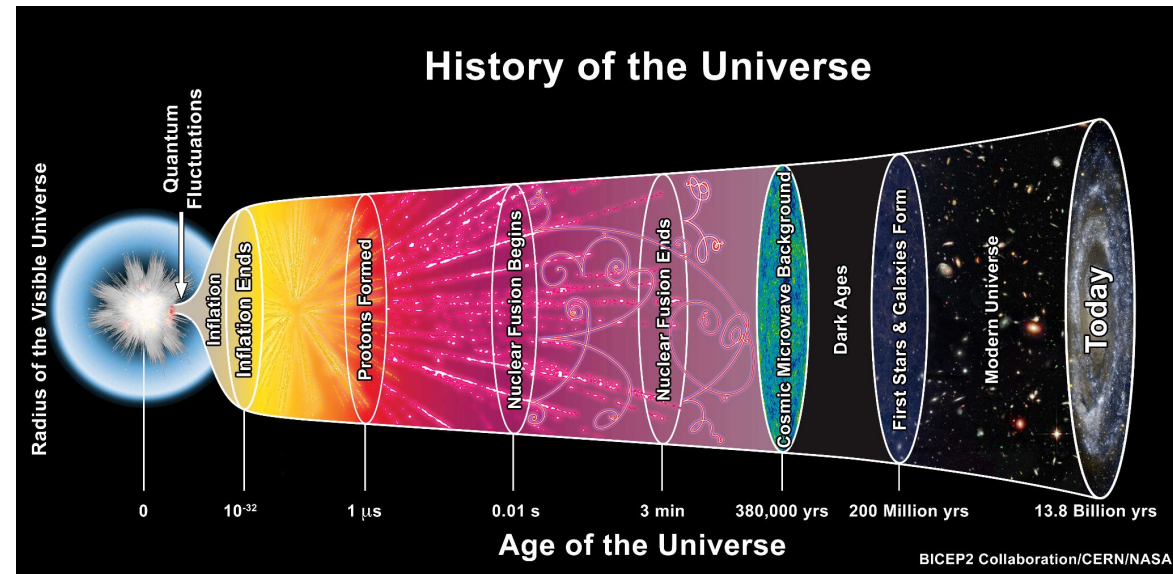
Fyzika za Štandardným modelom

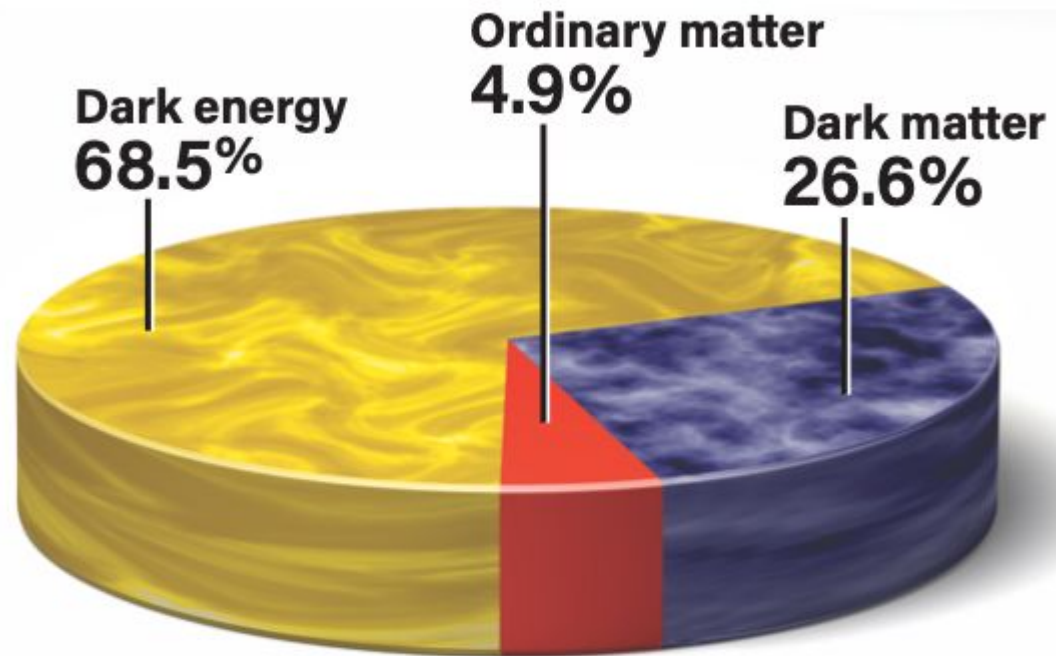


Tmavá hmota



Tmavá energia





Neutrína



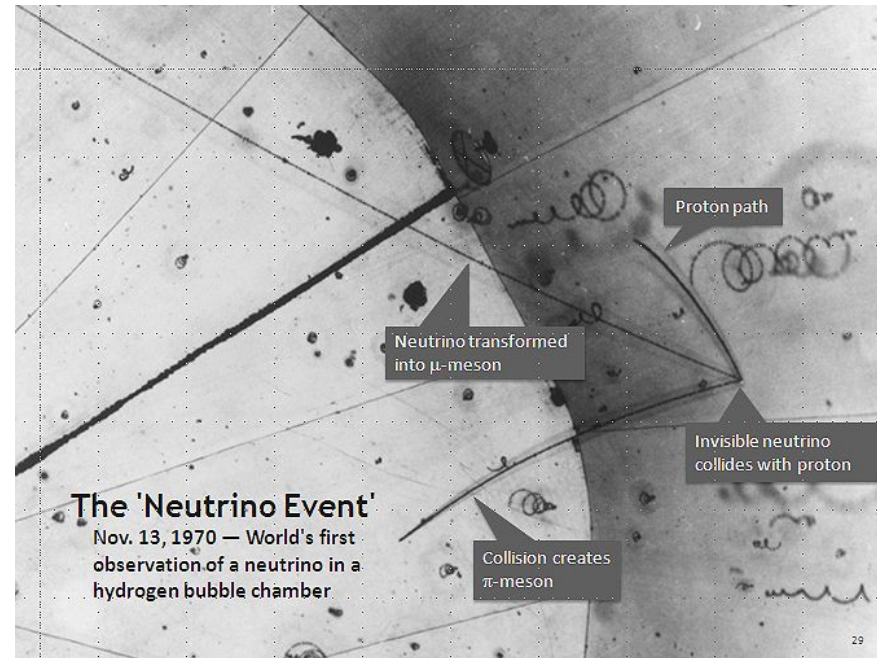
KVARKY hmotnosť náboj spin	$\approx 2.2 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	$\approx 1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$\approx 173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	0 0 1 g gluón	$\approx 124.97 \text{ GeV}/c^2$ 0 0 H higgs	
	$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$\approx 96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$\approx 4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 γ fotón		
	$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e elektrón	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muón	$\approx 1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau	$\approx 91.19 \text{ GeV}/c^2$ 0 -1 1 Z Z bozón		
	$< 2.2 \text{ eV}/c^2$ 0 $\frac{1}{2}$ ν_e elektrónové neutríno	$< 0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_μ muónové neutríno	$< 18.2 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_τ tau neutríno	$\approx 80.39 \text{ GeV}/c^2$ ± 1 1 W W bozón		
LEPTÓNY				BOZÓNY		



Neutrína



KVARKY	hmotnost $\approx 2.2 \text{ MeV}/c^2$ náboj $\frac{2}{3}$ spin $\frac{1}{2}$ u up	hmotnost $\approx 1.28 \text{ GeV}/c^2$ náboj $\frac{2}{3}$ spin $\frac{1}{2}$ c charm	hmotnost $\approx 173.1 \text{ GeV}/c^2$ náboj $\frac{2}{3}$ spin $\frac{1}{2}$ t top	0 0 1 g gluón	hmotnost $\approx 124.97 \text{ GeV}/c^2$ 0 0 0 H higgs
	hmotnost $\approx 4.7 \text{ MeV}/c^2$ náboj $-\frac{1}{3}$ spin $\frac{1}{2}$ d down	hmotnost $\approx 96 \text{ MeV}/c^2$ náboj $-\frac{1}{3}$ spin $\frac{1}{2}$ s strange	hmotnost $\approx 4.18 \text{ GeV}/c^2$ náboj $-\frac{1}{3}$ spin $\frac{1}{2}$ b bottom	0 0 1 γ fotón	
	hmotnost $\approx 0.511 \text{ MeV}/c^2$ náboj -1 spin $\frac{1}{2}$ e elektrón	hmotnost $\approx 105.66 \text{ MeV}/c^2$ náboj -1 spin $\frac{1}{2}$ μ muón	hmotnost $\approx 1.7768 \text{ GeV}/c^2$ náboj -1 spin $\frac{1}{2}$ τ tau	hmotnost $\approx 91.19 \text{ GeV}/c^2$ 0 0 1 Z Z bozón	
LEPTÓNY	hmotnost $< 2.2 \text{ eV}/c^2$ 0 náboj $\frac{1}{2}$ ν_e elektrónové neutrino	hmotnost $< 0.17 \text{ MeV}/c^2$ 0 náboj $\frac{1}{2}$ ν_μ muónové neutrino	hmotnost $< 18.2 \text{ MeV}/c^2$ 0 náboj $\frac{1}{2}$ ν_τ tau neutrino	hmotnost $\approx 80.39 \text{ GeV}/c^2$ ± 1 1 W W bozón	BOZÓNY



Asymetria medzi hmotou a antihmotou



KVARKY hmotnosť náboj spin	$\approx 2.2 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	$\approx 1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$\approx 173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	0 0 1 g gluón	$\approx 124.97 \text{ GeV}/c^2$ 0 0 H higgs	
	$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$\approx 96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$\approx 4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 γ fotón		
	$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e elektrón	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muón	$\approx 1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau	$\approx 91.19 \text{ GeV}/c^2$ 0 -1 1 Z Z bozón		
	$< 2.2 \text{ eV}/c^2$ 0 $\frac{1}{2}$ ν_e elektrónové neutríno	$< 0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_μ muónové neutríno	$< 18.2 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_τ tau neutríno	$\approx 80.39 \text{ GeV}/c^2$ ± 1 1 W W bozón		
LEPTÓNY				BOZÓNY		



Asymetria medzi hmotou a antihmotou



hmotnosť náboj spin	$\approx 2.2 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	$\approx 1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$\approx 173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	0 0 1 g gluón	$\approx 124.97 \text{ GeV}/c^2$ 0 0 H higgs
	KVARKY	$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$\approx 96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$\approx 4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 γ fotón
LEPTÓNY	$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e elektrón	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muón	$\approx 1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau	$\approx 91.19 \text{ GeV}/c^2$ 0 1 Z Z bozón	BOZÓNY
	$< 2.2 \text{ eV}/c^2$ 0 $\frac{1}{2}$ ν_e elektrónové neutrino	$< 0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_μ muónové neutrino	$< 18.2 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_τ tau neutrino	$\approx 80.39 \text{ GeV}/c^2$ ± 1 1 W W bozón	

$\approx 124.97 \text{ GeV}/c^2$ 0 0 H higgs	0 1 p gluón	$\approx 173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	$\approx 1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$\approx 2.2 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	KVARKY
0 0 1 γ fotón	0 1 $\frac{1}{2}$ d down	$\approx 4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$\approx 96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ e elektrón	KVARKY
$\approx 91.19 \text{ GeV}/c^2$ 0 1 Z Z bozón	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ Σ muónové neutrino	$\approx 1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau	$\approx 1.28 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ μ muón	$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e elektrón	LEPTÓNY
$\approx 80.39 \text{ GeV}/c^2$ ± 1 1 W W bozón	$\approx 18.2 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_τ tau neutrino	$\approx 1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ ν_μ muónové neutrino	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ ν_e elektrónové neutrino	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muón	LEPTÓNY



Supersymetria



hmotnosť náboj spin	$\approx 2.2 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	$\approx 1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$\approx 173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	0 1 1 g gluón	$\approx 124.97 \text{ GeV}/c^2$ 0 0 H higgs
KVARKY	$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$\approx 96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$\approx 4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 γ fotón	
LEPTÓNY	$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e elektrón	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muón	$\approx 1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau	$\approx 91.19 \text{ GeV}/c^2$ 0 1 Z Z bozón	
	$< 2.2 \text{ eV}/c^2$ 0 $\frac{1}{2}$ ν_e elektrónové neutríno	$< 0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_μ muónové neutríno	$< 18.2 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_τ tau neutríno	$\approx 80.39 \text{ GeV}/c^2$ ± 1 1 W W bozón	BOZÓNY

$\approx 124.97 \text{ GeV}/c^2$ 0 0 H higgs	$\approx 1.28 \text{ GeV}/c^2$ 0 1 g gluón	$\approx 173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	$\approx 124.97 \text{ GeV}/c^2$ 0 0 H higgs	$\approx 124.97 \text{ GeV}/c^2$ 0 0 H higgs	$\approx 124.97 \text{ GeV}/c^2$ 0 0 H higgs
$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$\approx 96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$\approx 4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$\approx 96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$\approx 4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom
$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e elektrón	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muón	$\approx 1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau	$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e elektrón	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muón	$\approx 1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau
$< 2.2 \text{ eV}/c^2$ 0 $\frac{1}{2}$ ν_e elektrónové neutríno	$< 0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_μ muónové neutríno	$< 18.2 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_τ tau neutríno	$< 2.2 \text{ eV}/c^2$ 0 $\frac{1}{2}$ ν_e elektrónové neutríno	$< 0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_μ muónové neutríno	$< 18.2 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_τ tau neutríno



Supersymetria



hmotnosť náboj spin	$=2.2 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	$=1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$=173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	0 0 1 g gluón	$=124.97 \text{ GeV}/c^2$ 0 0 0 H higgs
	$=4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$=96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$=4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 γ fotón	
LEPTÓNY	$=0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e elektrón	$=105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muón	$=1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau	$=91.19 \text{ GeV}/c^2$ 0 0 1 Z Z bozón	
	$<2.2 \text{ eV}/c^2$ 0 0 ν_e elektrónové neutrino	$<0.17 \text{ MeV}/c^2$ 0 0 ν_μ muónové neutrino	$<18.2 \text{ MeV}/c^2$ 0 0 ± 1 ν_τ tau neutrino	$=80.39 \text{ GeV}/c^2$ 0 1 1 W W bozón	BOZÓNY

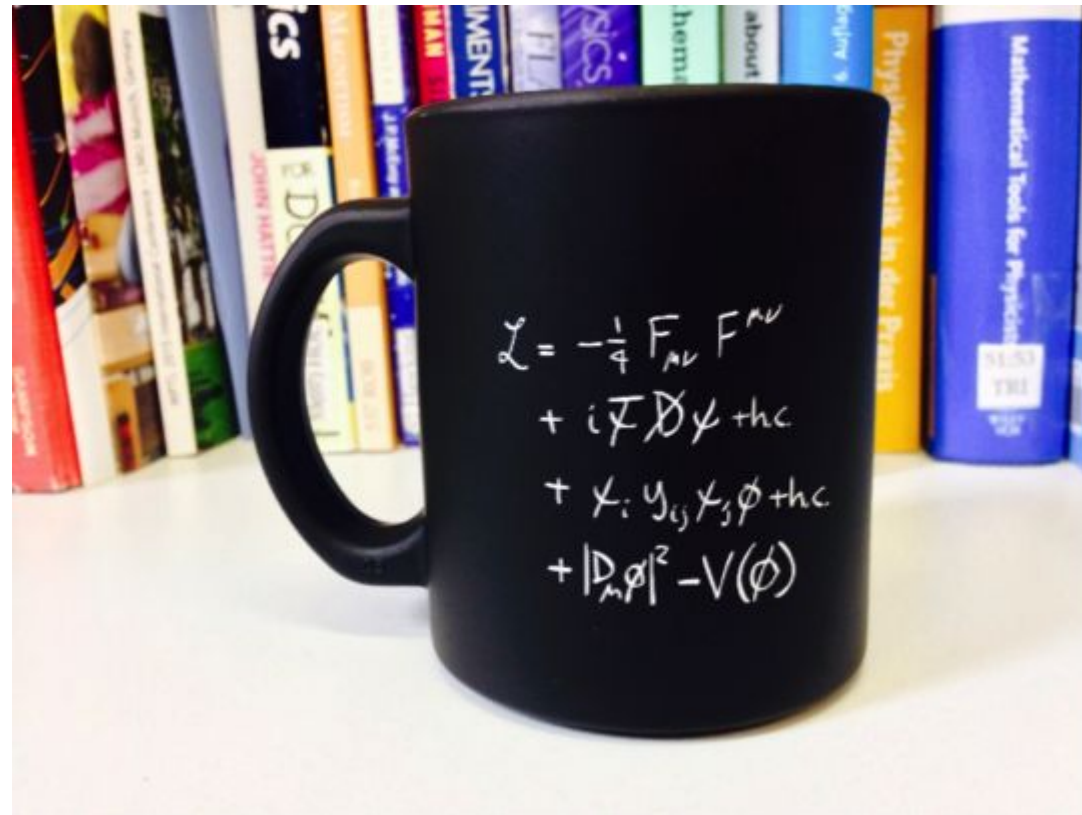
LEPTÓNY	$<2.2 \text{ eV}/c^2$ 0 0 $\bar{\nu}_e$ elektrónové neutrino	$<0.17 \text{ MeV}/c^2$ 0 0 $\bar{\nu}_\mu$ muónové neutrino	$<18.2 \text{ MeV}/c^2$ 0 0 ± 1 $\bar{\nu}_\tau$ tau neutrino	$=80.39 \text{ GeV}/c^2$ 0 1 1 \bar{W} W bozón	BOZÓNY
	$=0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ \bar{e} elektrón	$=105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ $\bar{\mu}$ muón	$=1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ $\bar{\tau}$ tau	$=91.19 \text{ GeV}/c^2$ 0 0 1 \bar{Z} Z bozón	
KVARKY	$=2.2 \text{ MeV}/c^2$ $-\frac{2}{3}$ $\frac{1}{2}$ \bar{u} up	$=1.28 \text{ GeV}/c^2$ $-\frac{2}{3}$ $\frac{1}{2}$ \bar{c} charm	$=173.1 \text{ GeV}/c^2$ $-\frac{2}{3}$ $\frac{1}{2}$ \bar{t} top	0 0 1 \bar{d} down	$=124.97 \text{ GeV}/c^2$ 0 0 0 H higgs
	$=4.7 \text{ MeV}/c^2$ $\frac{1}{3}$ $\frac{1}{2}$ \bar{d} down	$=96 \text{ MeV}/c^2$ $\frac{1}{3}$ $\frac{1}{2}$ \bar{s} strange	$=4.18 \text{ GeV}/c^2$ $\frac{1}{3}$ $\frac{1}{2}$ \bar{b} bottom	0 0 1 \bar{u} up	

BOZÓNY	$=124.97 \text{ GeV}/c^2$ 0 0 0 H higgs	$=1.28 \text{ GeV}/c^2$ 0 0 1 g gluón	$=173.1 \text{ GeV}/c^2$ 0 0 1 t top	$=1.28 \text{ GeV}/c^2$ 0 0 1 c charm	$=2 \text{ MeV}/c^2$ 0 0 1 u up
	$=91.19 \text{ GeV}/c^2$ 0 0 1 Z Z bozón	$=80.39 \text{ GeV}/c^2$ 0 1 1 W W bozón	$=4.18 \text{ GeV}/c^2$ 0 0 1 b bottom	$=4.7 \text{ MeV}/c^2$ 0 0 1 d down	$=96 \text{ MeV}/c^2$ 0 0 1 s strange
KVARKY	$=4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$=96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$=4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	$=4.7 \text{ MeV}/c^2$ $\frac{1}{3}$ $\frac{1}{2}$ u up	$=1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm
	$=2.2 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	$=1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$=173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	$=124.97 \text{ GeV}/c^2$ 0 0 0 H higgs	

BOZÓNY	$=124.97 \text{ GeV}/c^2$ 0 0 0 H higgs	$=1.28 \text{ GeV}/c^2$ 0 0 1 g gluón	$=173.1 \text{ GeV}/c^2$ 0 0 1 t top	$=1.28 \text{ GeV}/c^2$ 0 0 1 c charm	$=2 \text{ MeV}/c^2$ 0 0 1 u up
	$=91.19 \text{ GeV}/c^2$ 0 0 1 Z Z bozón	$=80.39 \text{ GeV}/c^2$ 0 1 1 W W bozón	$=4.18 \text{ GeV}/c^2$ 0 0 1 b bottom	$=4.7 \text{ MeV}/c^2$ 0 0 1 d down	$=96 \text{ MeV}/c^2$ 0 0 1 s strange
KVARKY	$=4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$=96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$=4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	$=4.7 \text{ MeV}/c^2$ $\frac{1}{3}$ $\frac{1}{2}$ u up	$=1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm
	$=2.2 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	$=1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$=173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	$=124.97 \text{ GeV}/c^2$ 0 0 0 H higgs	



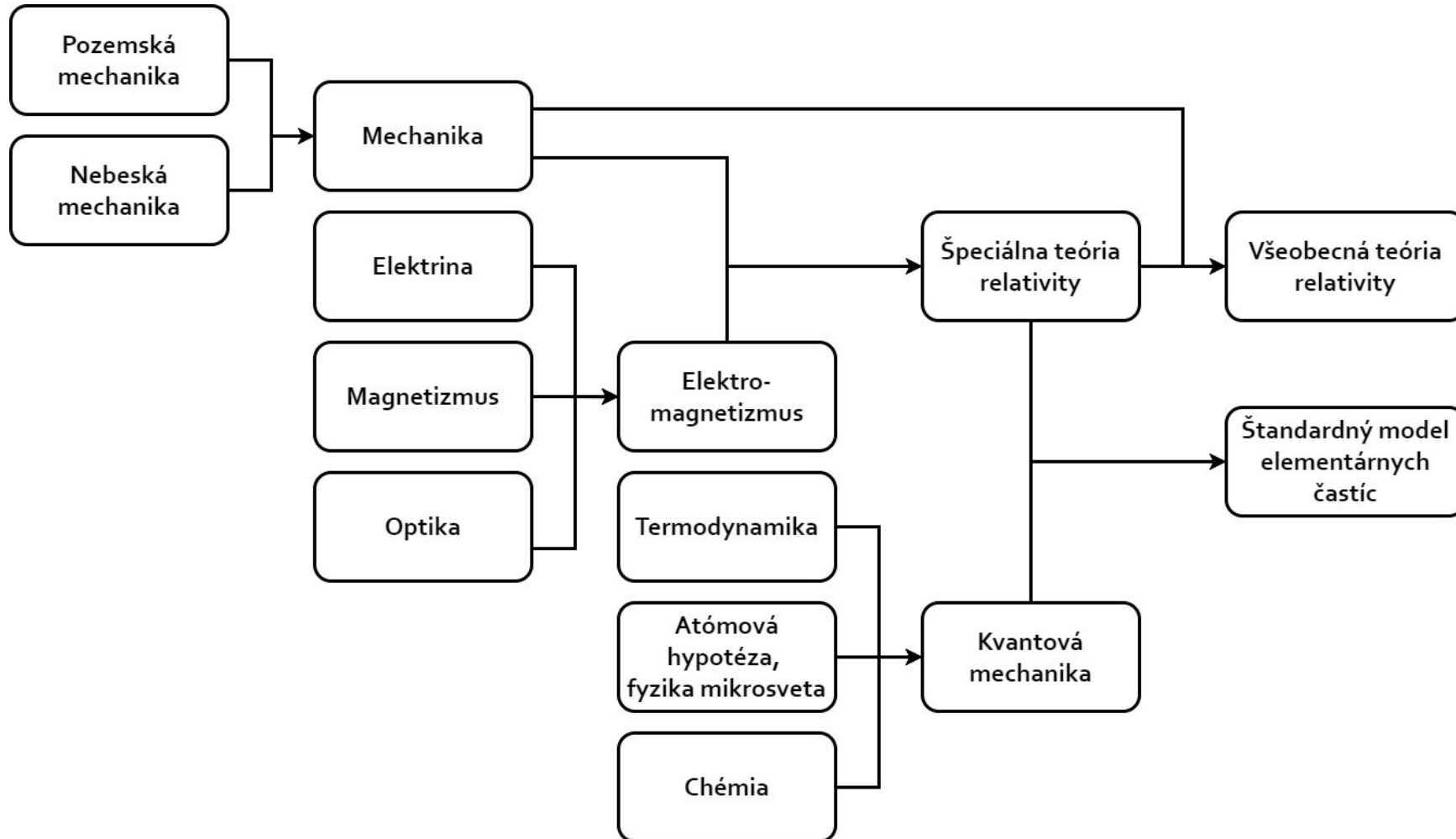
Supersymmetria



Gravitácia



Gravitácia







Plány pro urýchlivače v CERNu

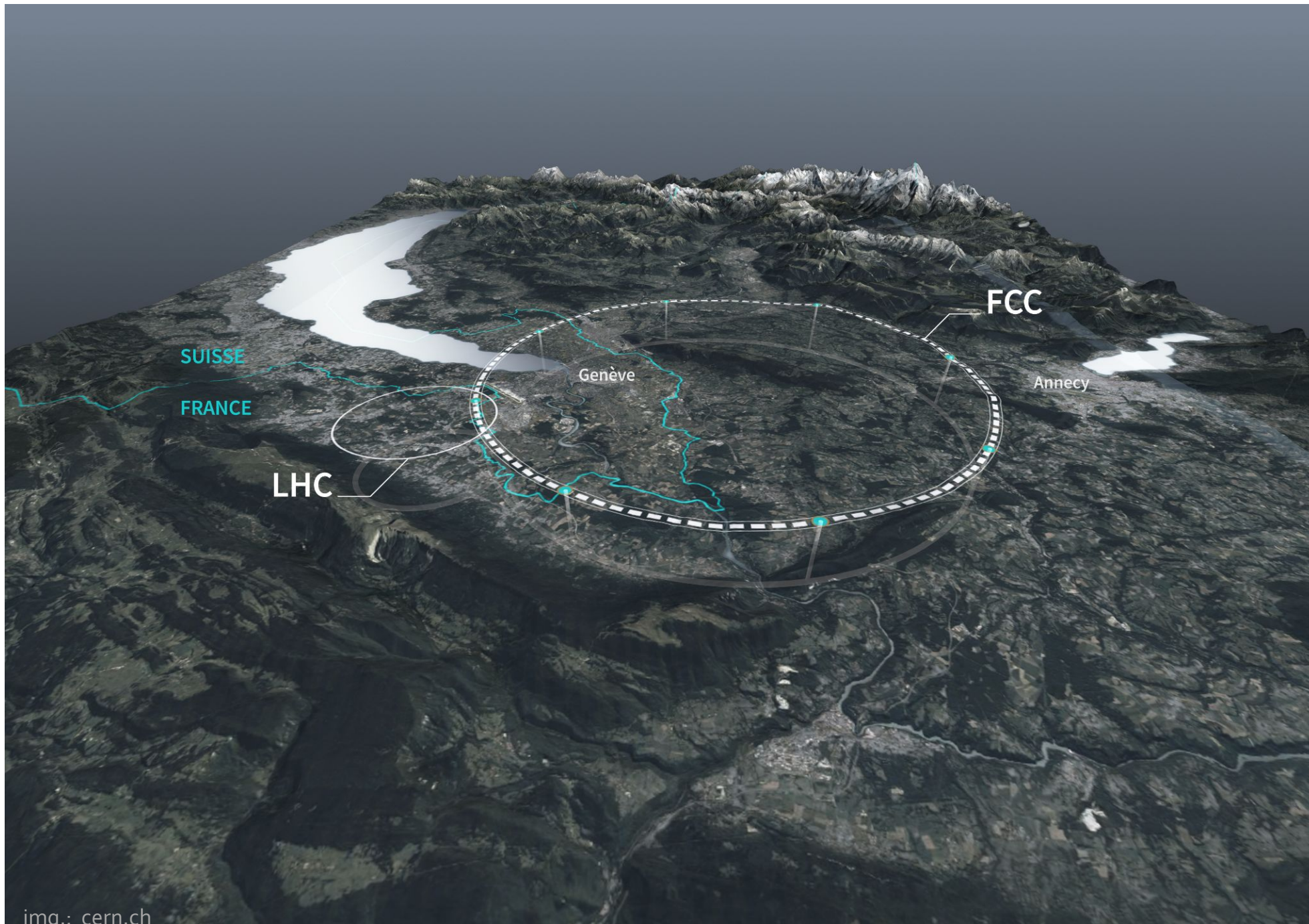




FUTURE CIRCULAR COLLIDER

Expanding our Horizons

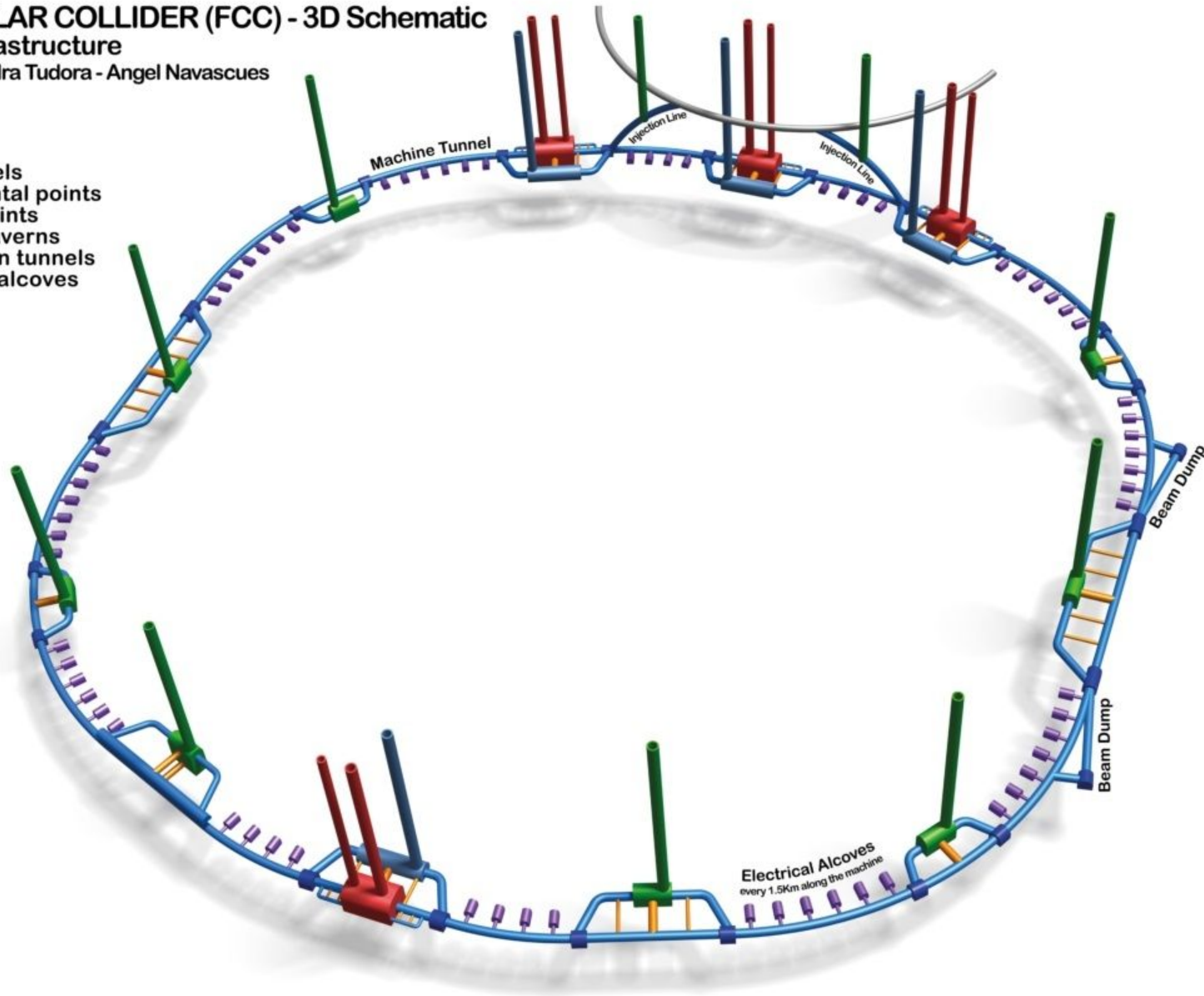




FUTURE CIRCULAR COLLIDER (FCC) - 3D Schematic Underground Infrastructure

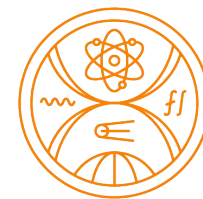
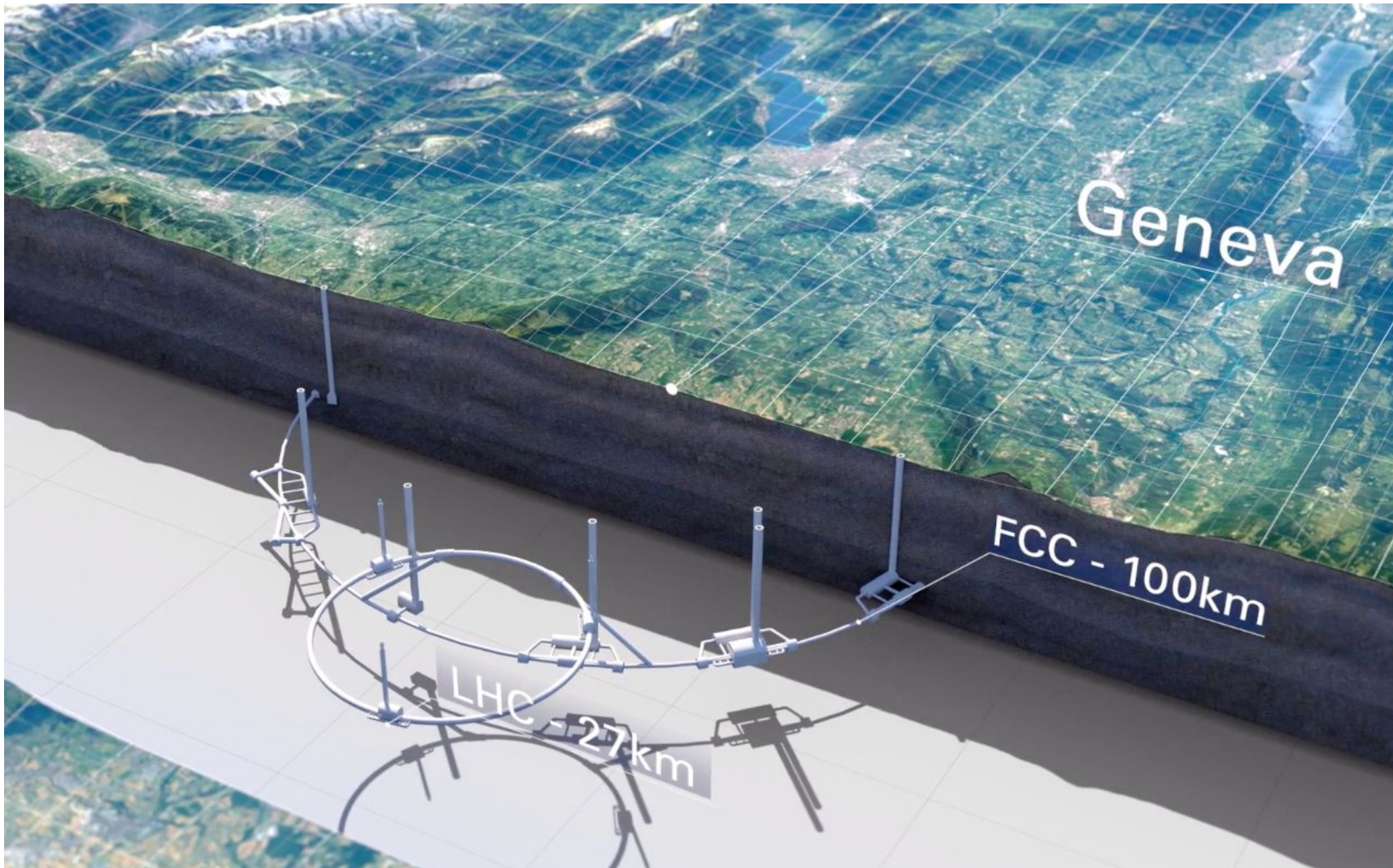
John Osborne - Alexandra Tudora - Angel Navascues

- FCC Tunnels
- Experimental points
- Access points
- Service caverns
- Connection tunnels
- Electrical alcoves
- LHC

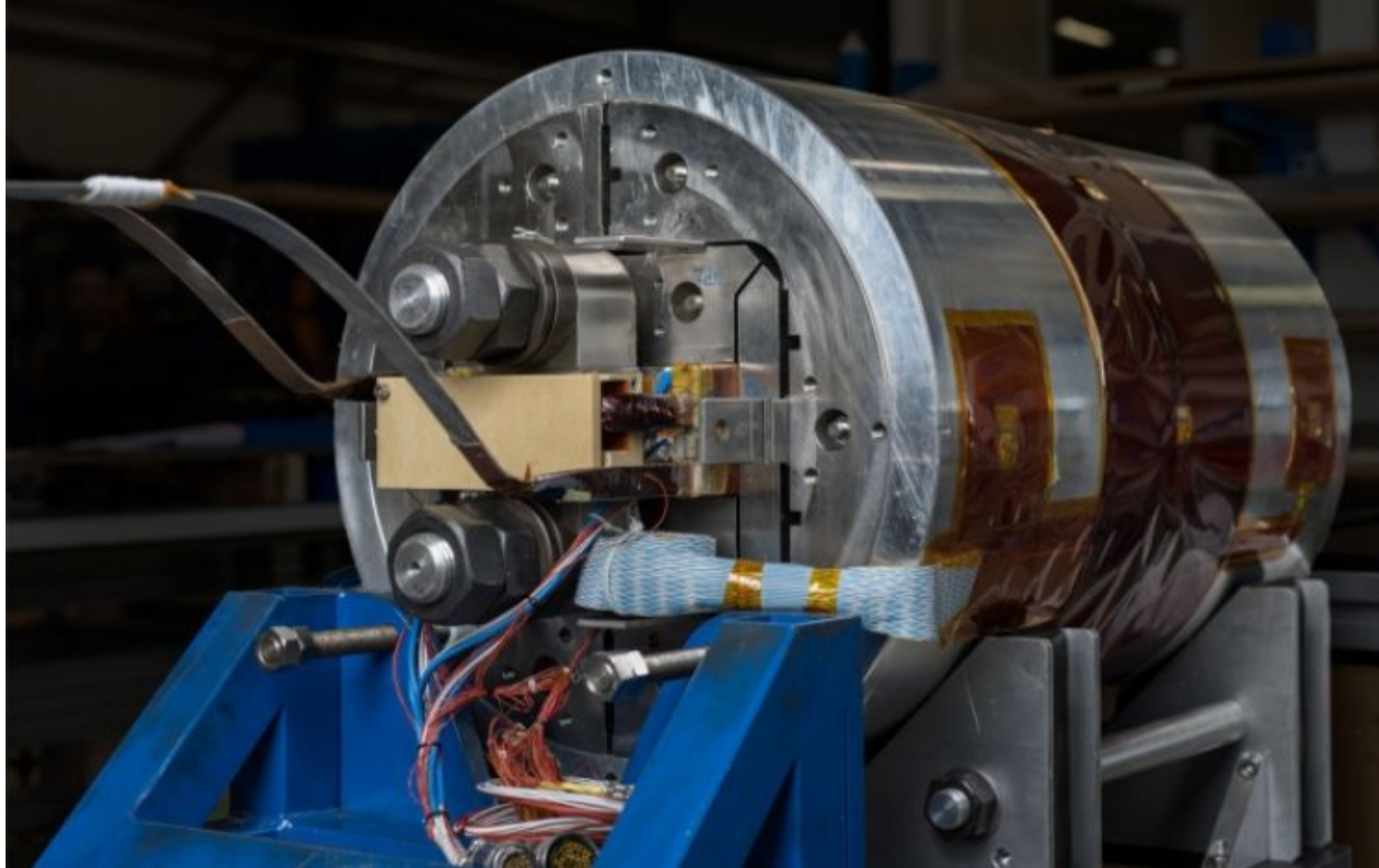


Not to scale
Frequency of connection tunnels for illustration only











Future circular collider

- Najskôr FCCee – zrážky elektrónov
- Neskôr FCChh – zrážku ťažších častíc, napríklad protóny alebo ióny

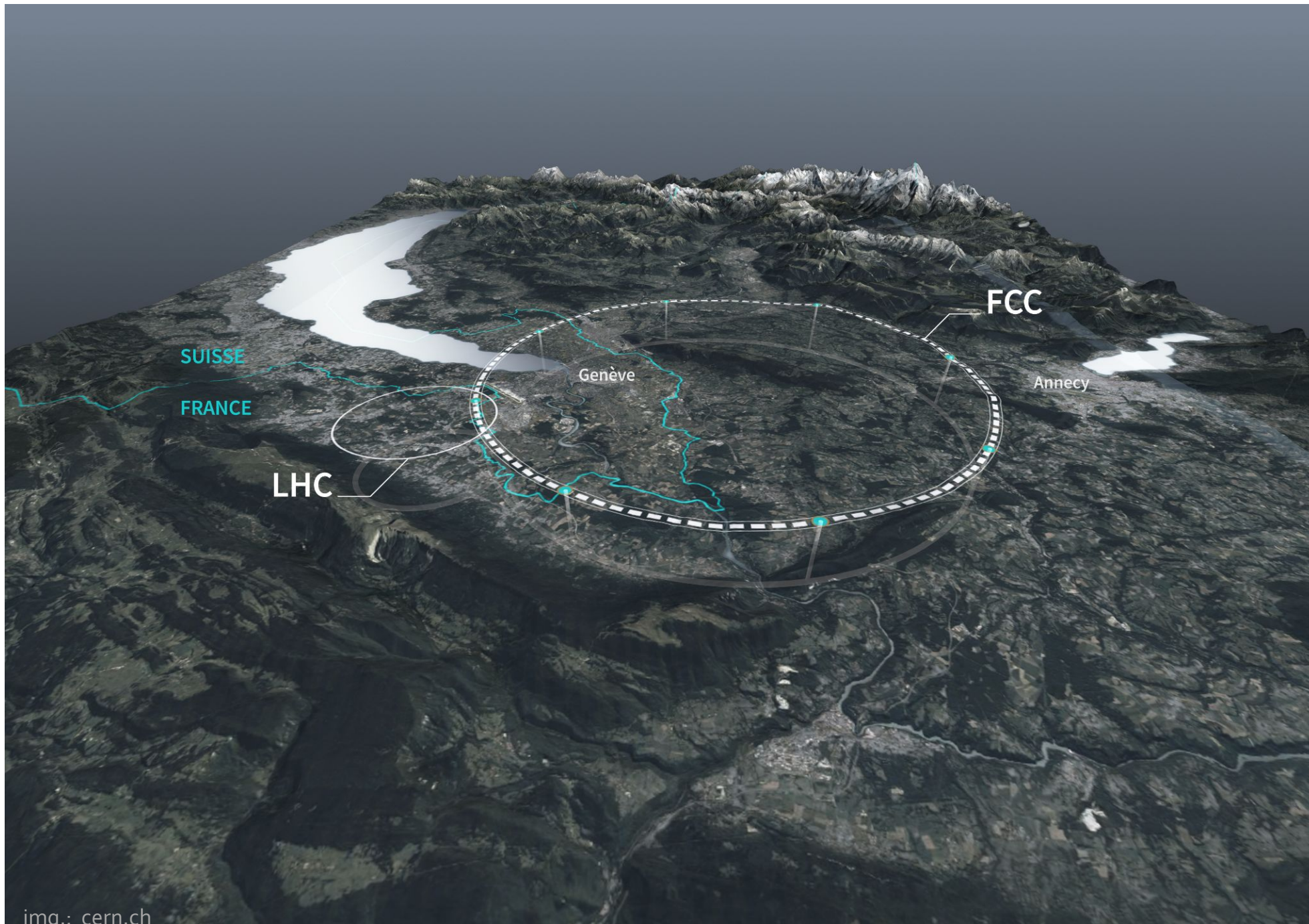


Future circular collider



- Nový tunel dlhý 91km, hĺbka okolo 200m.
- Plánovaná cena 17 miliárd eur.
- Schválenie 2028.
- Začiatok budovania FCCee 2035, prvé behy 2045.
- Začiatok budovania FChh cca 2060, prvé behy cca 2070, očakávané trvanie 25 rokov.







Ďalšie plánované urýchľovače



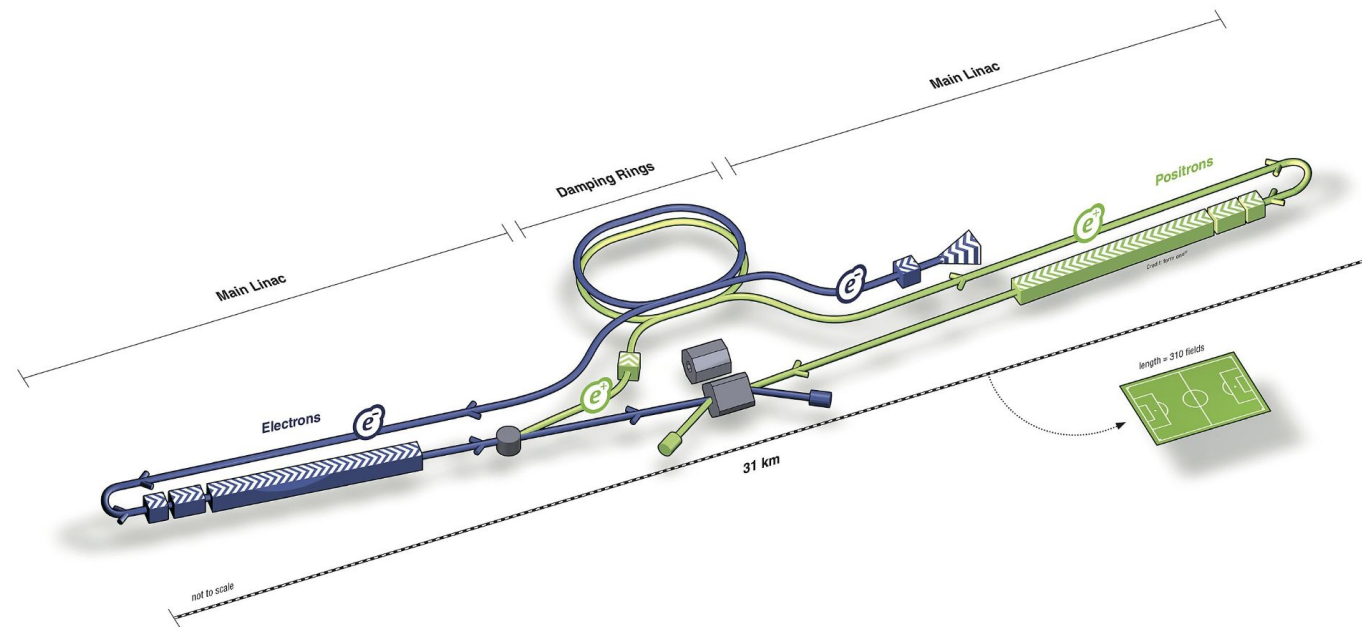
Ďalšie plánované urýchľovače

- High-Luminosity LHC, CERN



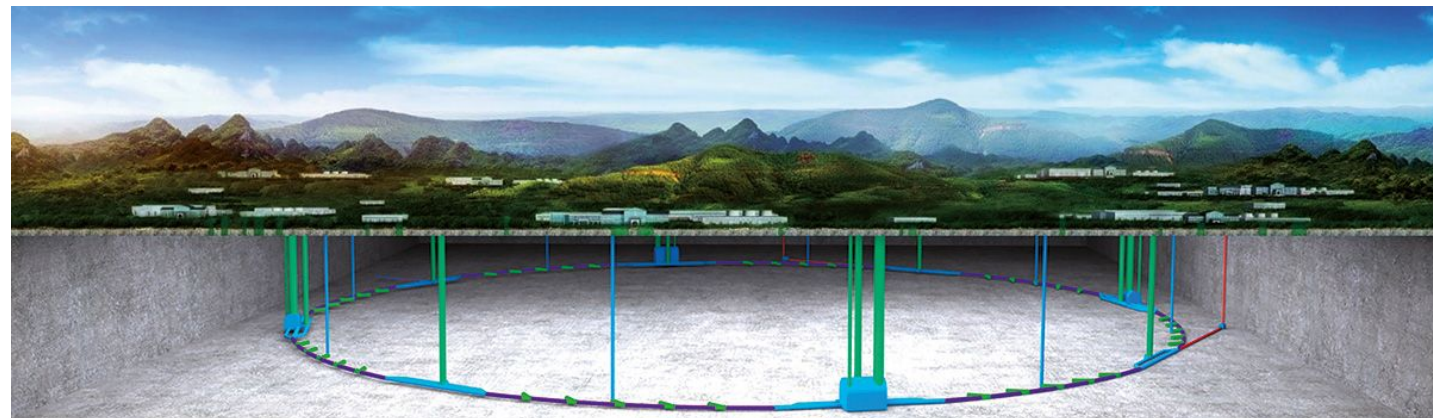
Ďalšie plánované urýchľovače

- High-Luminosity LHC, CERN
- International Linear Collider, Japonsko



Ďalšie plánované urýchľovače

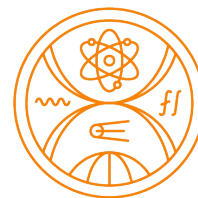
- High-Luminosity LHC, CERN
- International Linear Collider, Japonsko
- Circular Electron Positron Collider, Čína



Ďalšie plánované urýchľovače

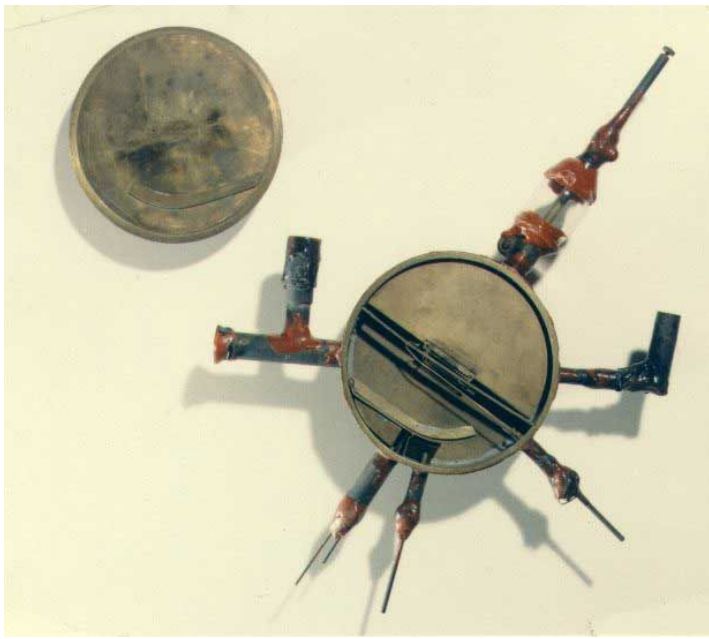
- High-Luminosity LHC, CERN
- International Linear Collider, Japonsko
- Circular Electron Positron Collider, Čína
- miónové urýchľovače, CERN, USA

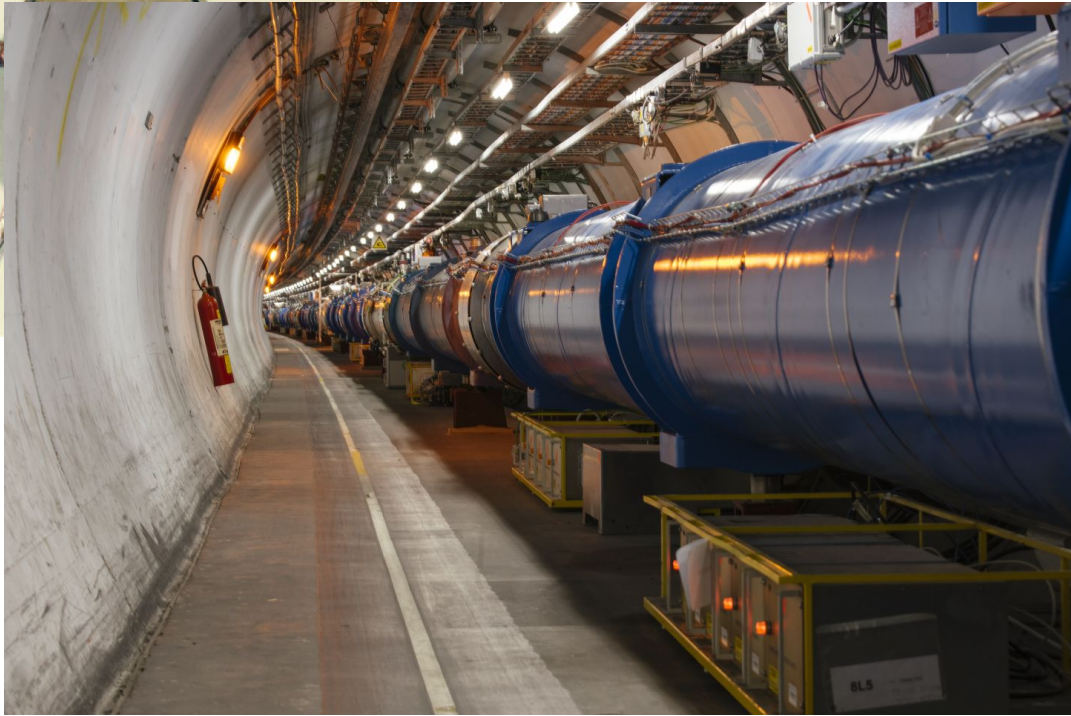


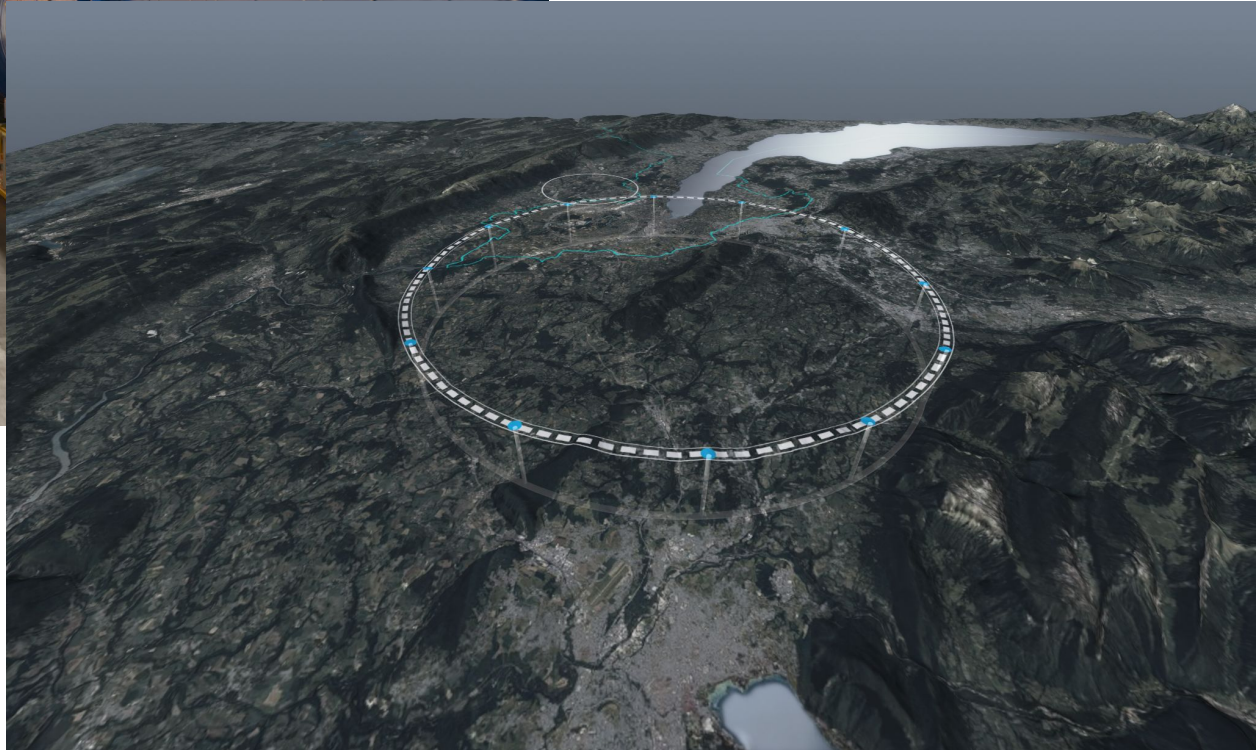
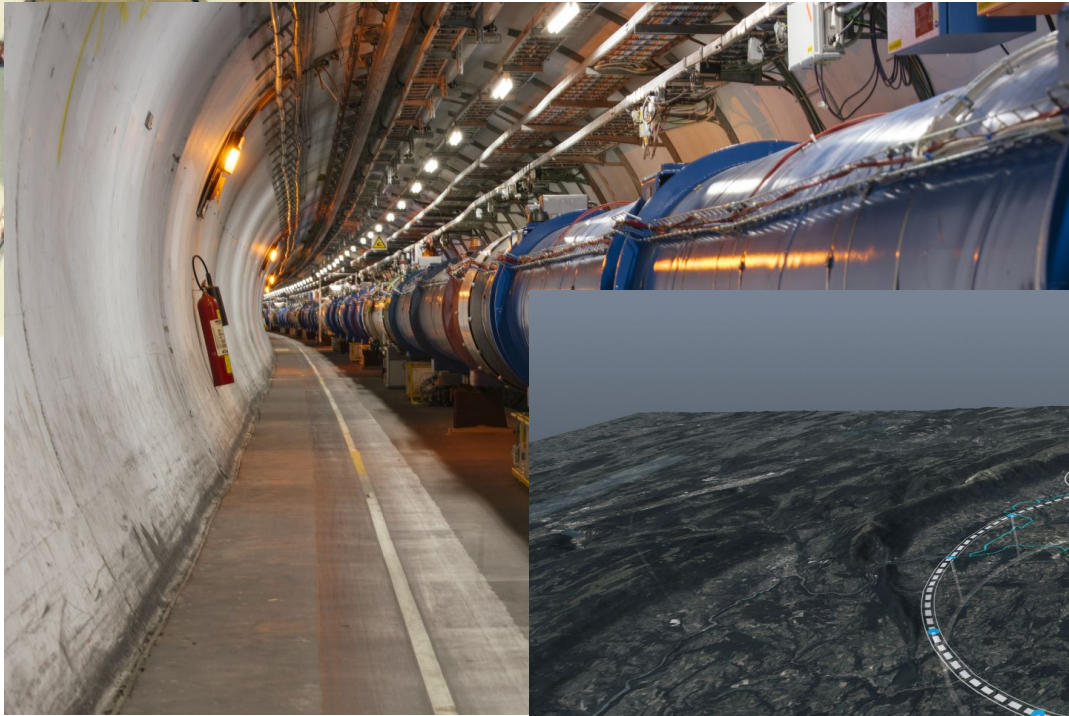


Budúcnosť časticových urýchľovačov











Ďakujem za
pozornosť!

