

Higgs Story aneb Jak se dělají částice

Jiří Kvita, PŘF UP

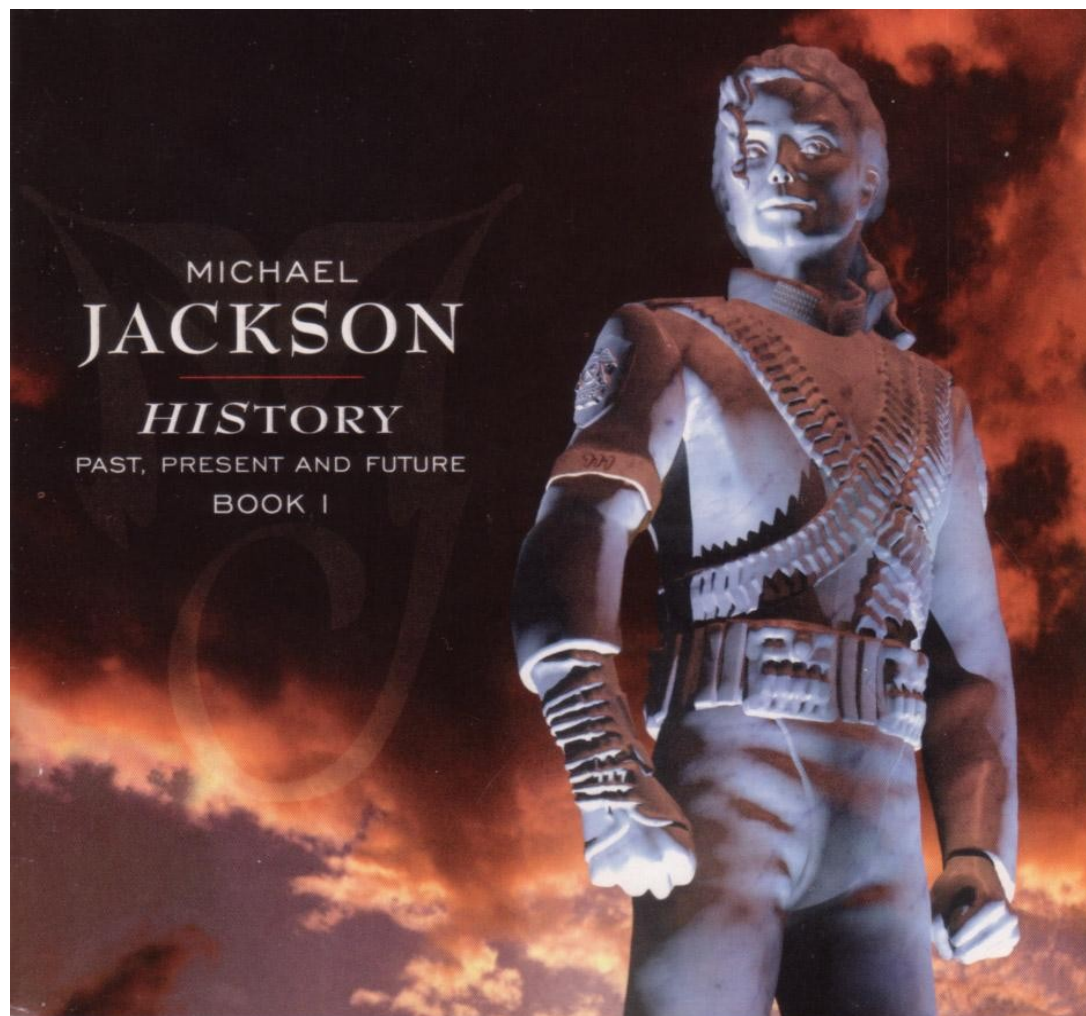


INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

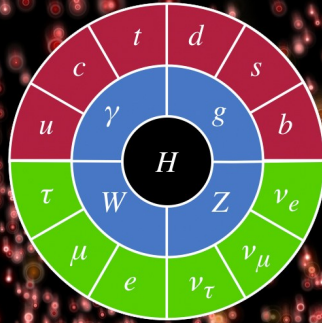


YEARS / ANS CERN

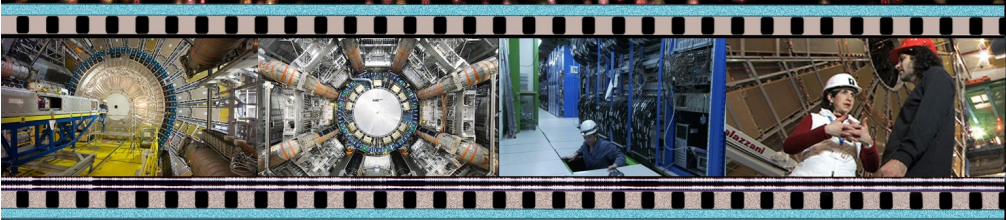
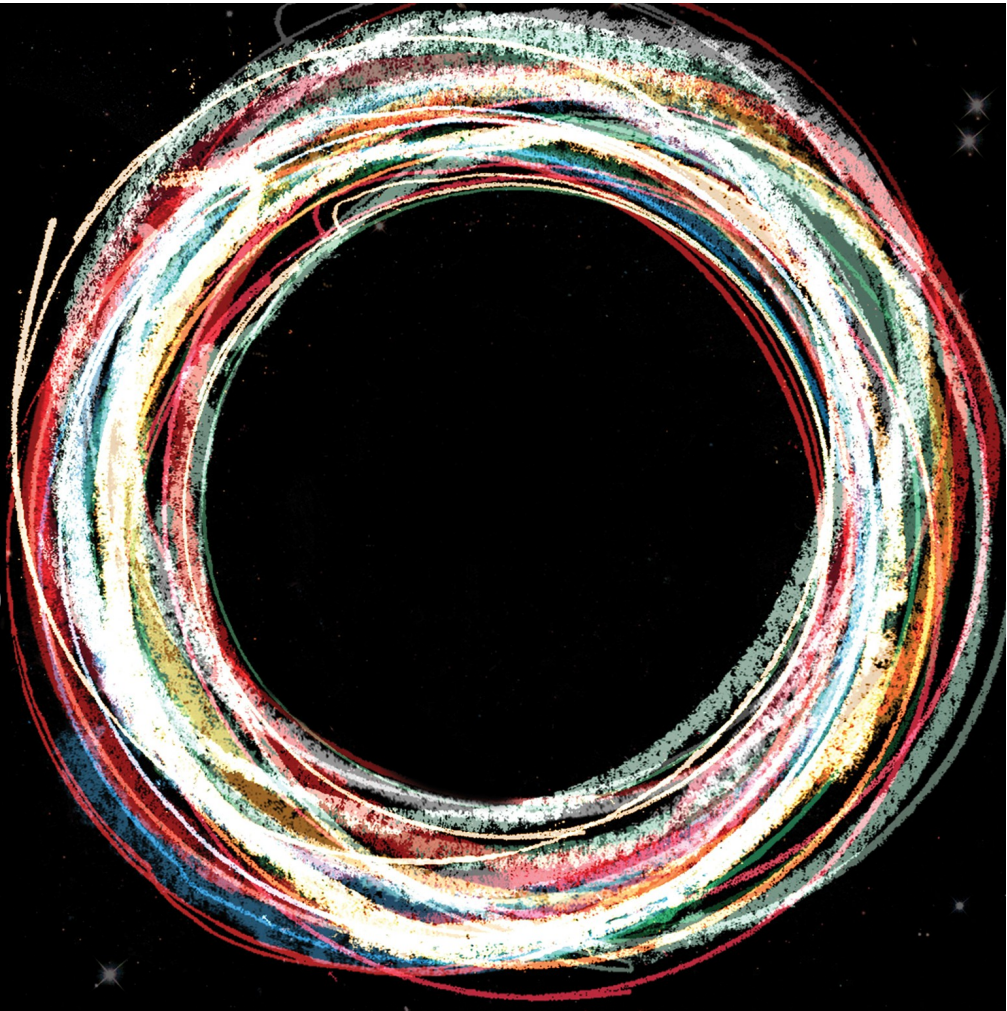
Higgs Story aneb Jak se dělají částice



Physicists are on the cusp of the greatest scientific discovery of all time -- or perhaps their greatest failure.



PARTICLE FEVER



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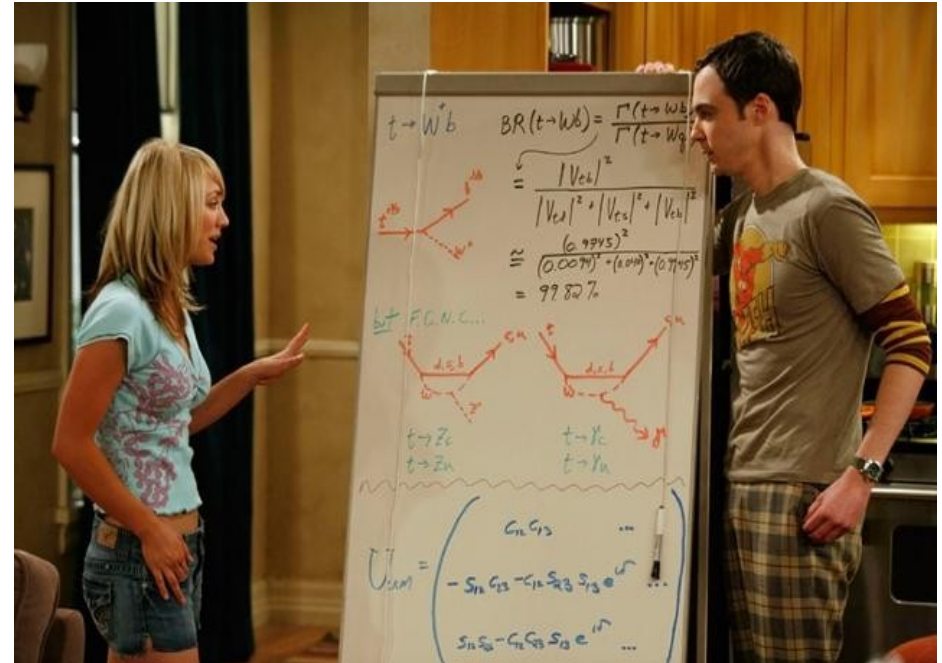
PARTICLE FEVER

WITH ONE SWITCH, EVERYTHING CHANGES





9.1.2015



Stavební kameny chemie

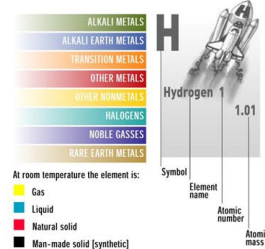
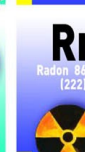
PRODUCED BY THE FOUNDATION FOR EDUCATION, SCIENCE AND TECHNOLOGY FOR NATIONAL SET WEEK 2003

PERIODIC TABLE of the ELEMENTS



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VIII A 18

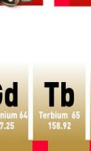
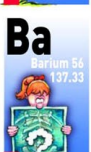
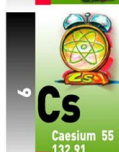
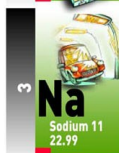
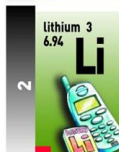
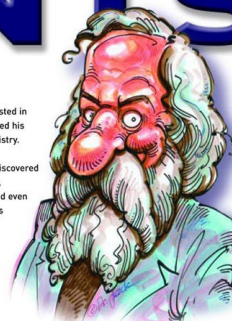


DMITRI MENDELEYEV (1834 - 1907)

The Russian chemist, Dmitri Mendeleev, was the first to observe that if elements were listed in order of atomic mass, they showed regular (periodical) repeating properties. He formulated his discovery in a periodic table of elements, now regarded as the backbone of modern chemistry.

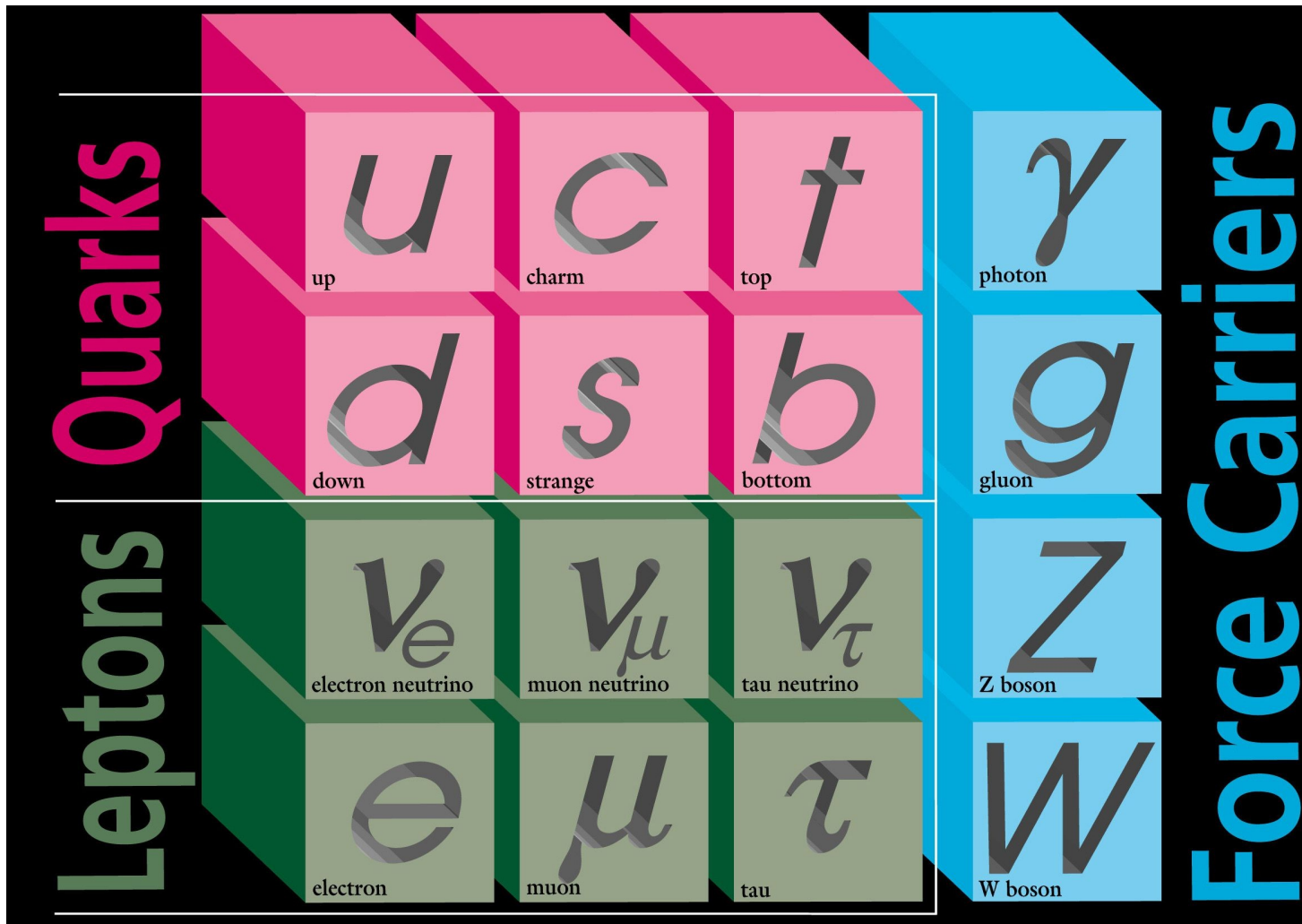
The crowning achievement of Mendeleev's periodic table lay in his prophecy of then, undiscovered elements. In 1869, the year he published his periodic classification, the elements gallium, germanium and scandium were unknown. Mendeleev left spaces for them in his table and even predicted their atomic masses and other chemical properties. Six years later, gallium was discovered and his predictions were found to be accurate. Other discoveries followed and their chemical behaviour matched that predicted by Mendeleev.

This remarkable man, the youngest in a family of 17 children, has left the scientific community with a classification system so powerful that it became the cornerstone in chemistry teaching and the prediction of new elements ever since. In 1955, element 101 was named after him: Md, Mendeleevium.

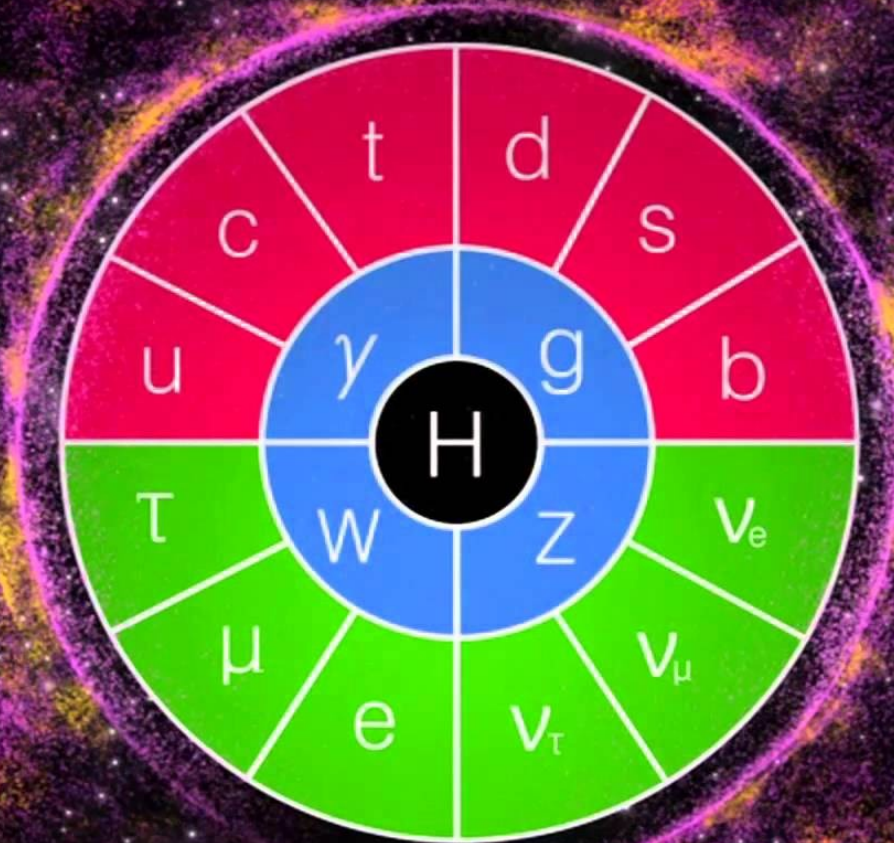


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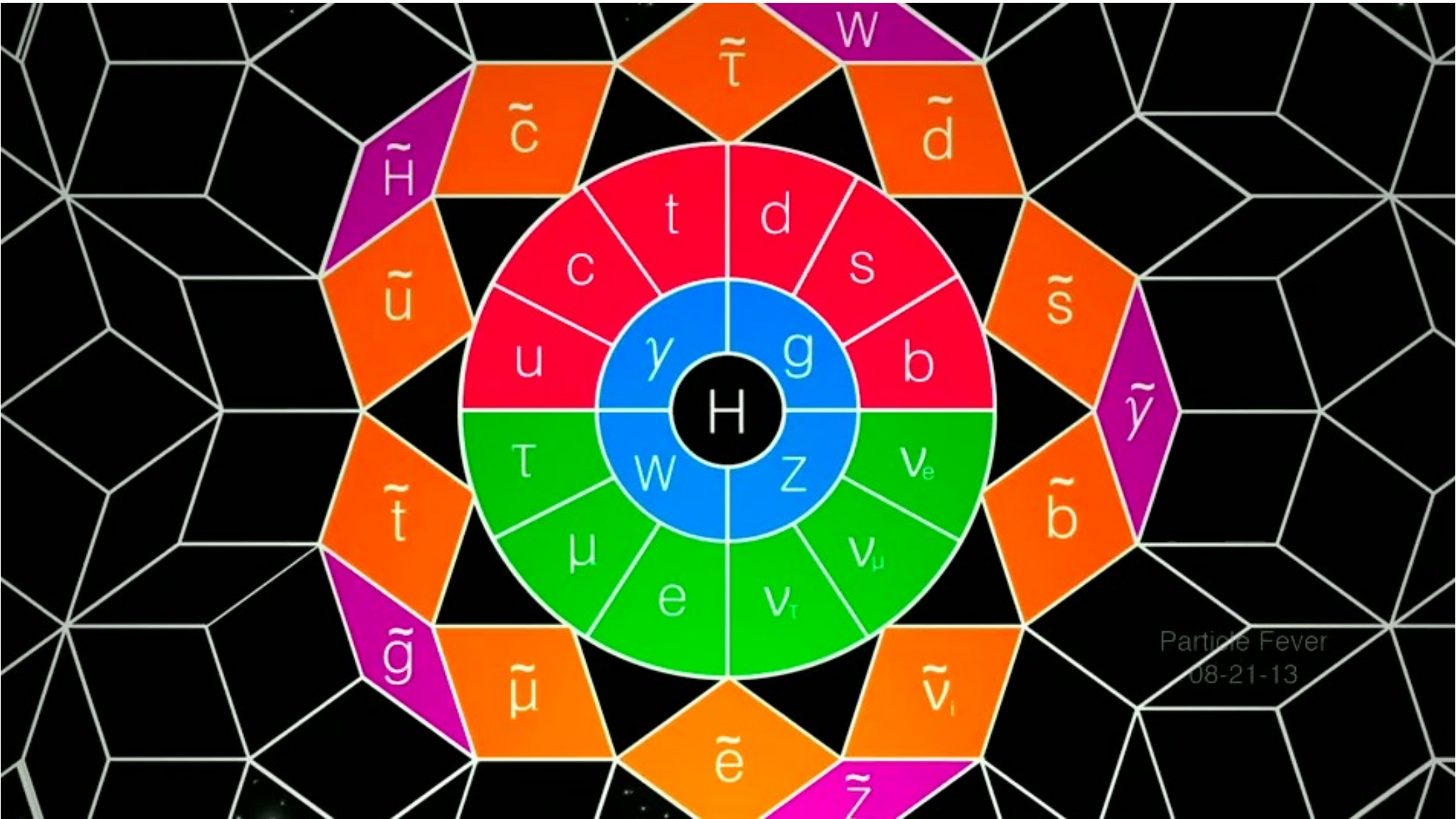
Stavební kameny fyziky



Stavební kameny fyziky



Stavební kameny fyziky

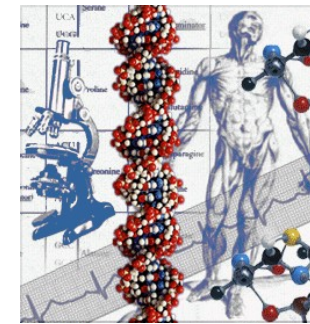


Síly (interakce) v přírodě

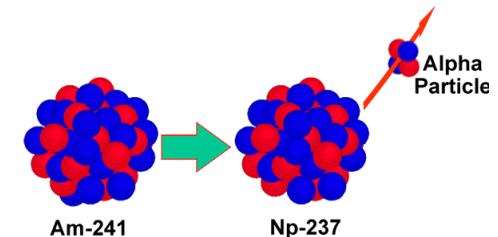
- **Gravitační** – makroskopická tělesa, Vesmír.



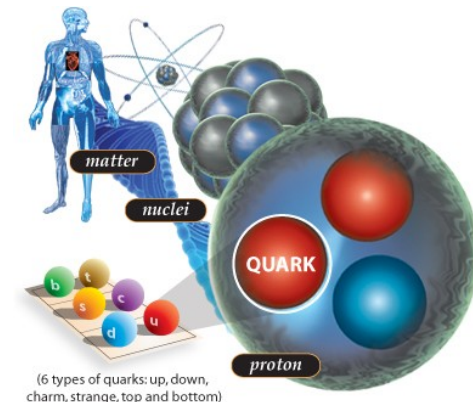
- **Elektromagnetická** – stavba atomu, chemie, život.



- **Slabá** – radioaktivita, procesy hoření ve Slunci.

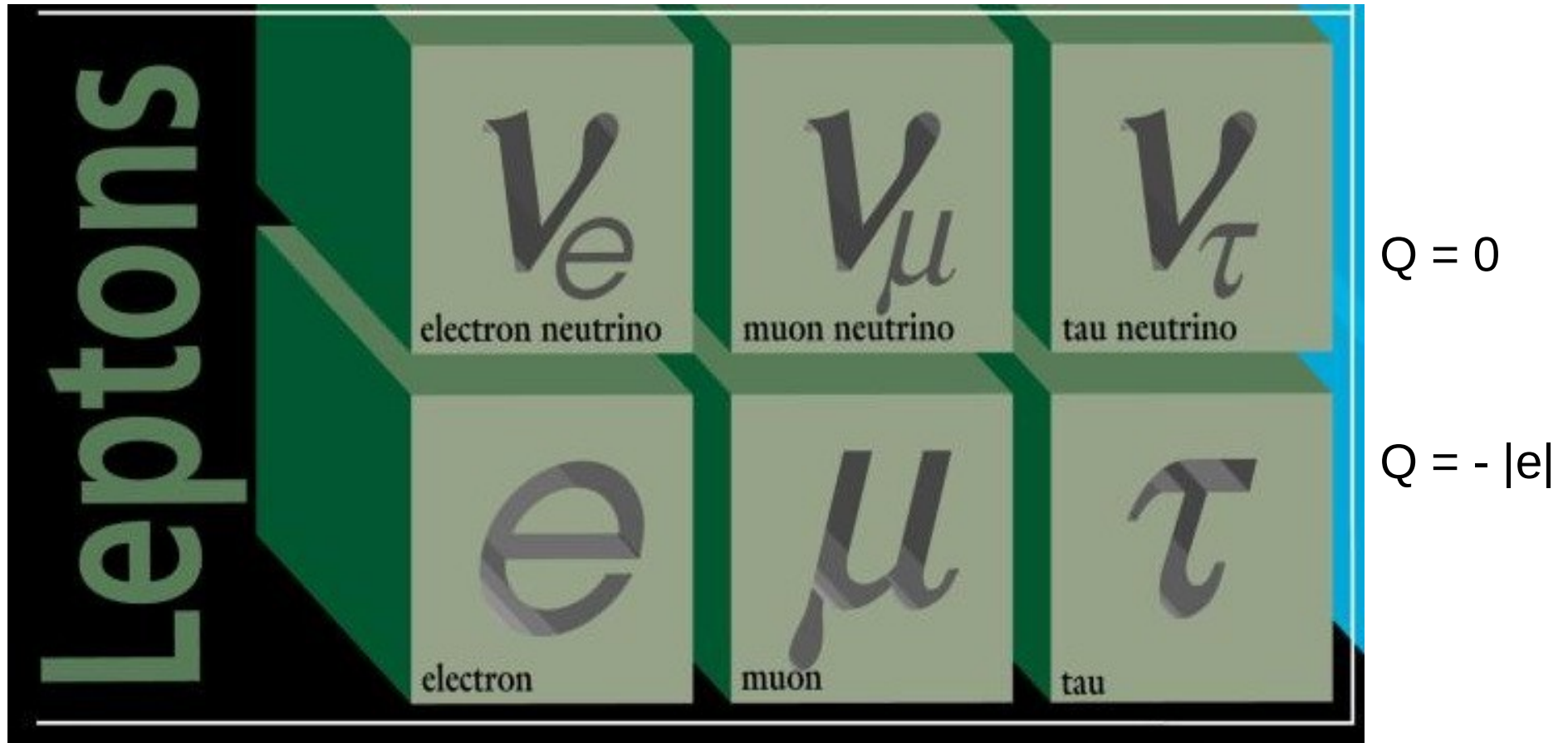


- **Silná** – stavba atomového jádra, interakce mezi nukleony, hlouběji mezi kvarky.



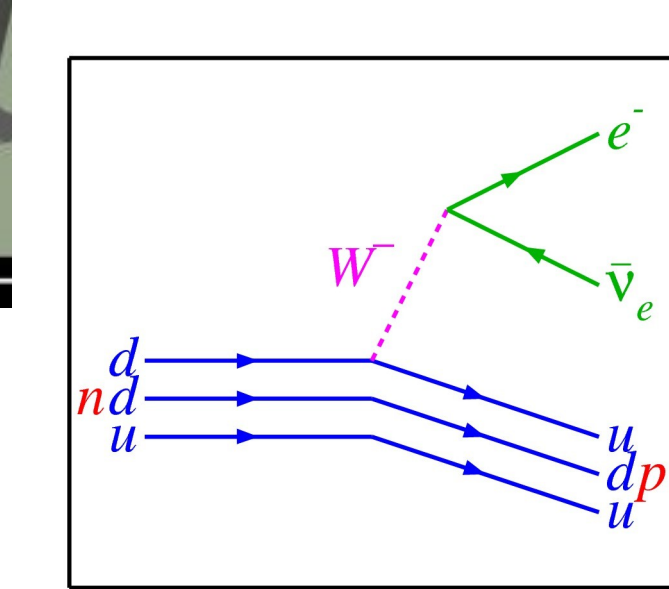
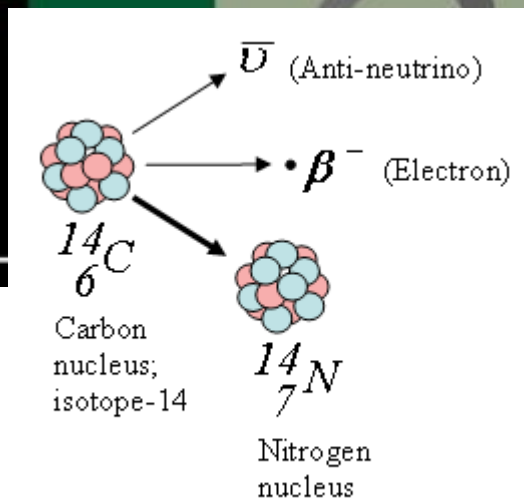
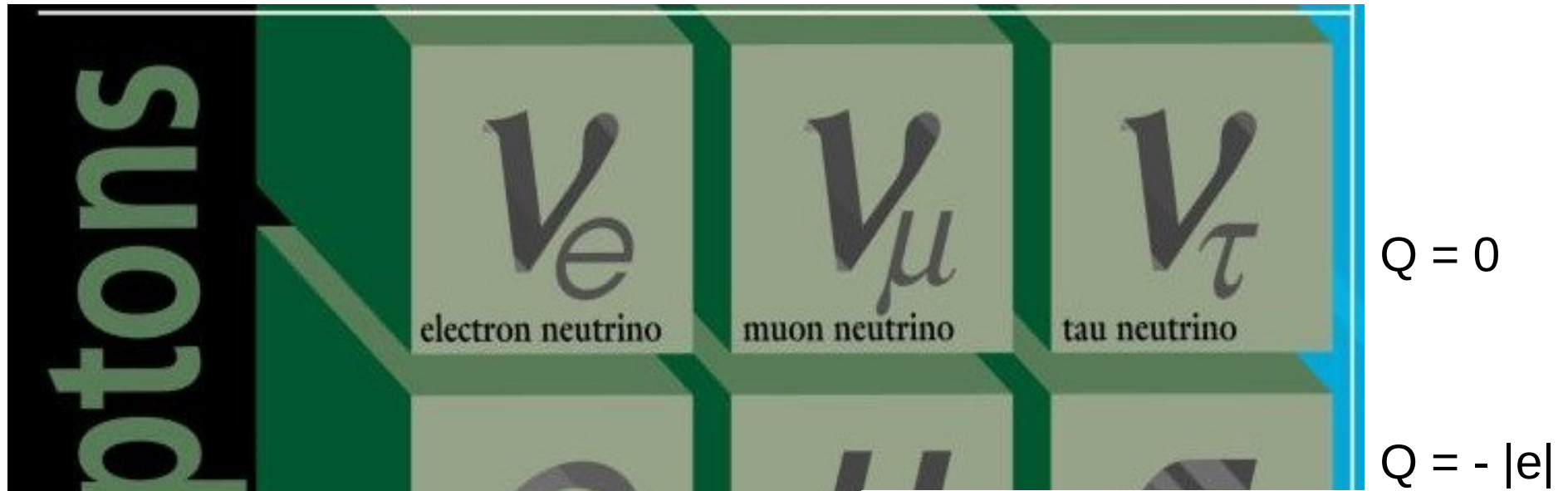
Lepton

- řecky *λεπτός* - drobný

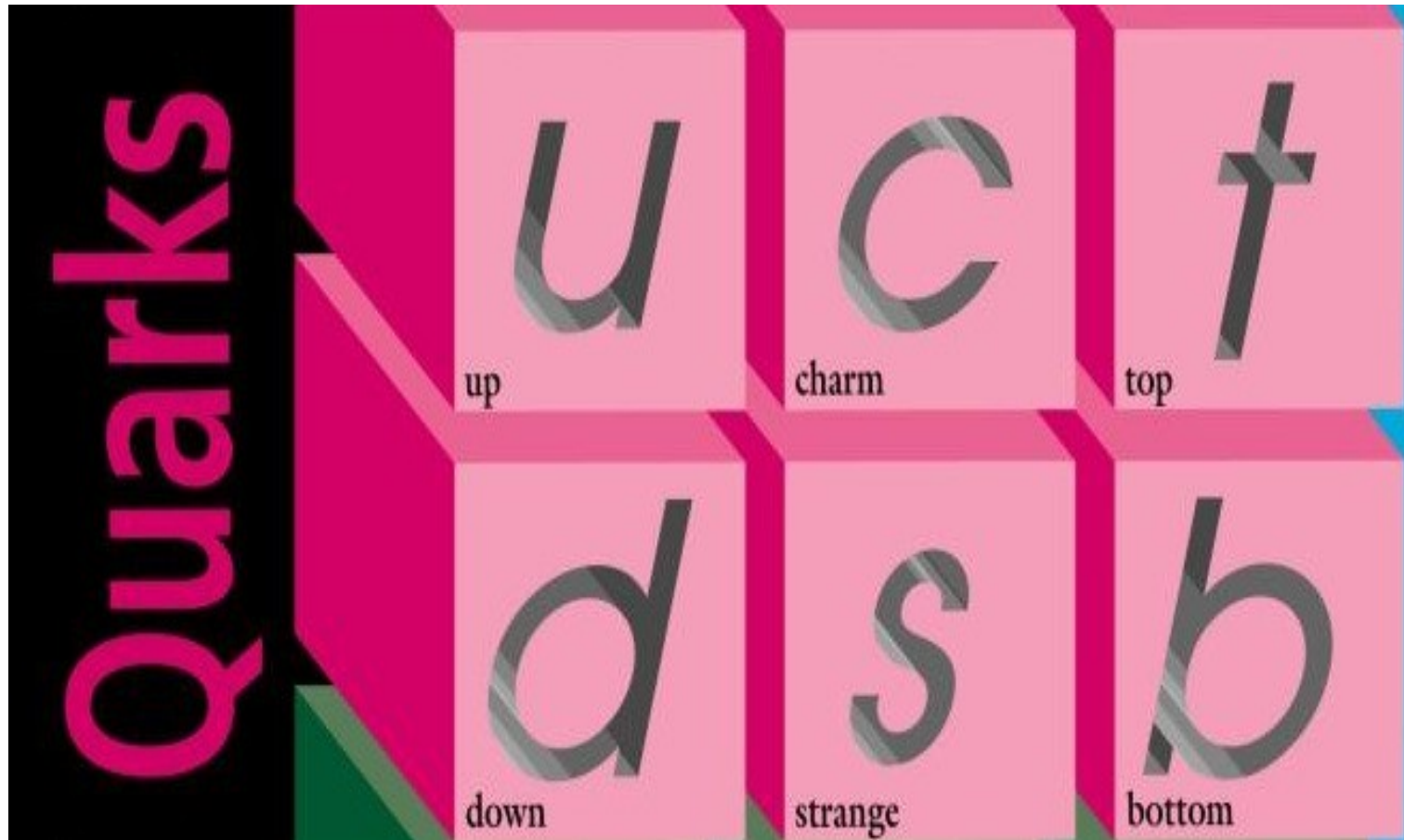


Lepton

- řecky *λεπτός* - drobný



Hadrony: částice z kvarků

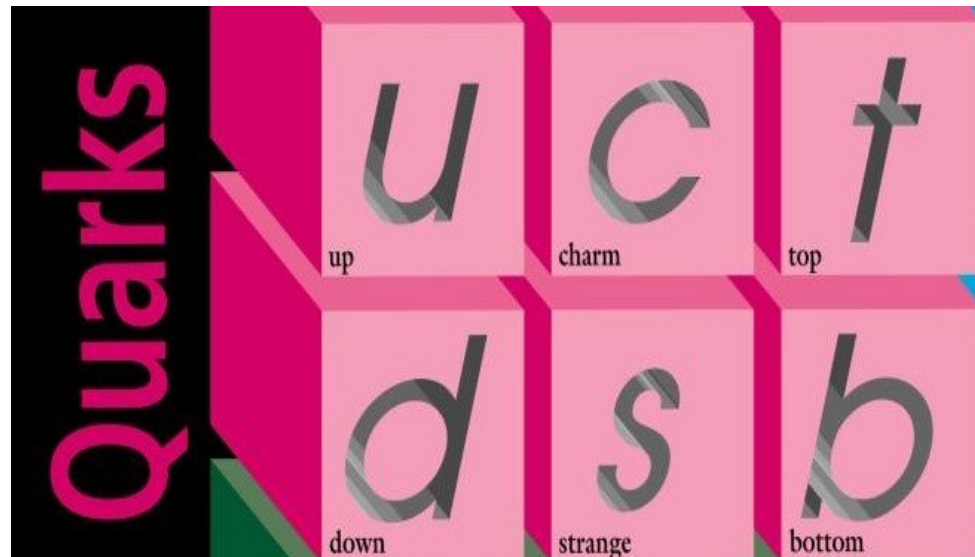


$$Q = +2/3 |e|$$

$$Q = -1/3 |e|$$

Hadrony: částice z kvarků

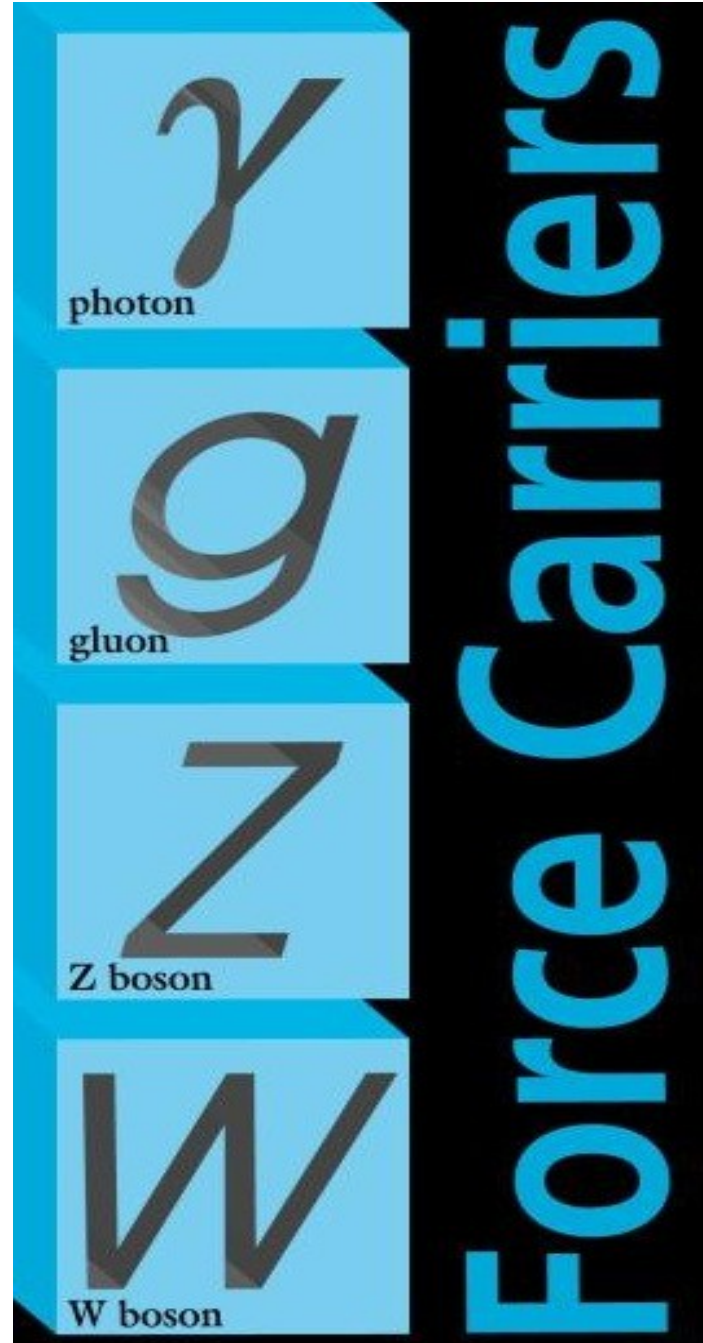
- Hadrony -- částice složené z kvarků.
- Účastní se silné interakce – drží pohromadě atomové jádro.
- Proton či neutron jsou příkladem **baryonů** (řecky βαρύς - těžký), částic složených ze tří kvarků, které mají polocelý spin (fermiony).
- Piony patří mezi **mezony** (řecky μέσος - střední), skládající se z páru kvark-antikvark, které mají celočíselný spin (bosony).



$$Q = +2/3 |e|$$

$$Q = -1/3 |e|$$

Výměnné částice sil



Higgsův boson

HIGGS BOSON



The **HIGGS BOSON** is the particle of the Higgs mechanism, believed by physicists to reveal how all matter in the universe gets its mass. On July 4, 2012, the CMS and Atlas collaborations at CERN announced a 5-sigma level of certainty that the Higgs boson had been detected with a mass of around 125 GeV.

\$10.49 PLUS SHIPPING

LIGHT ●●●●●●●●●●●●●●●● **HEAVY**

Wool felt, fleece with gravel fill for maximum mass.

The **PARTICLE ZOO**

GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU NEUTRINO MUON UP QUARK
NEUTRON DOWN QUARK TAU GLUON **HIGGS BOSON** NEUTRINO TACHYON ELECTRON UP QUARK DOWN
NEUTRINO MUON UP QUARK PROTON NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON
UP QUARK DOWN QUARK TAU NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU GLUON
NEUTRON DOWN QUARK TAU NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU GLUON
DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU NEU

Leptony, Kvarky, Kvanta polí

ELEMENTARY PARTICLES

Quarks	u up	c charm	t top	Force Carriers
	d down	s strange	b bottom	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	
	e electron	μ muon	τ tau	
	γ photon	g gluon	Z Z boson	
	W W boson			

I II III
Three Generations of Matter

HIGGS BOSON



The **HIGGS BOSON** is the particle of the Higgs mechanism, believed by physicists to reveal how all matter in the universe gets its mass. On July 4, 2012, the CMS and Atlas collaborations at CERN announced a 5-sigma level of certainty that the Higgs boson had been detected with a mass of around 125 GeV.

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Wool felt, fleece with gravel fill for maximum mass.

LIGHT ●●●●●●●● HEAVY ●●●●●●●●

THE PARTICLE ZOO

Leptony, Kvarky, Kvanta polí

Částice:

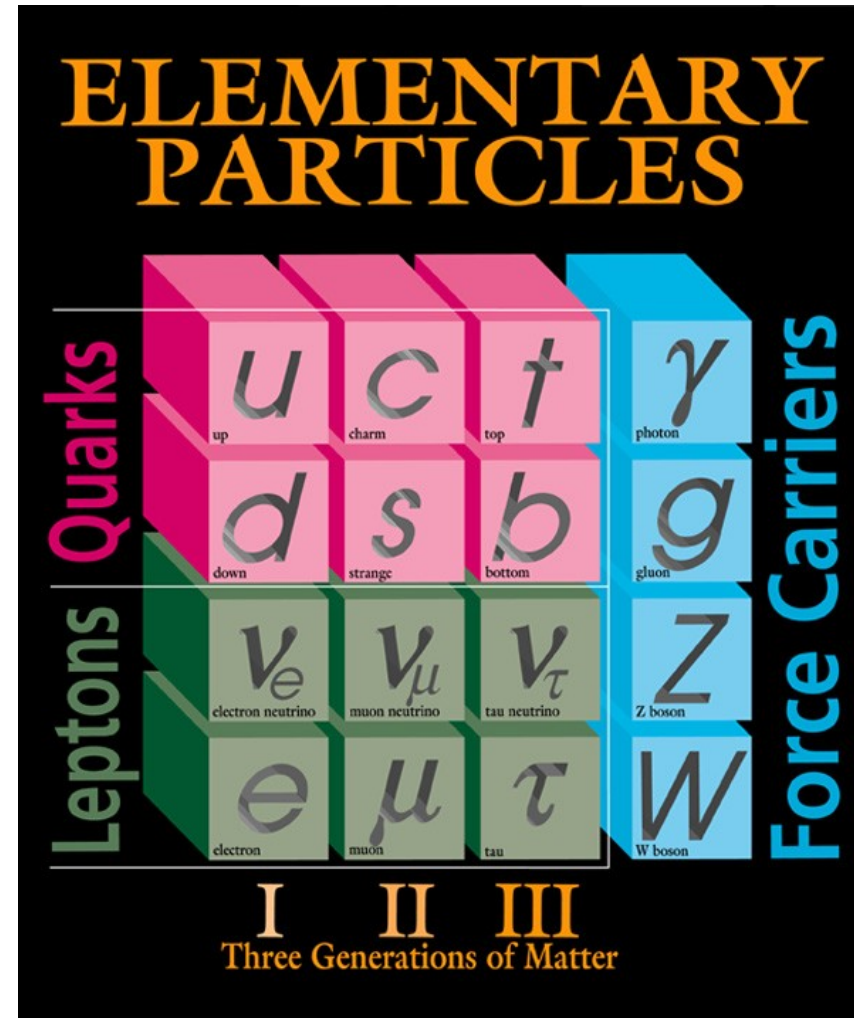
- **Leptony:** elektron a neutrino + dvě další rodiny
- **Kvarky:** tvoří hadrony
 - mezony: kvark+antikvark (piony)
 - baryony: 3 kvarky (proton, neutron)
- **Intermediální bosony** – W^\pm , Z , γ , 8 gluonů.

Higgsův boson: zodpovědný za hmotnosti částic.

Síly (interakce):

- Gravitační
- Slabá + Elektromagnetická = Elektroslabá
- Silná
- Interakce s Higgsovým bosonem.

9.1.2015



Fermilab 95-759

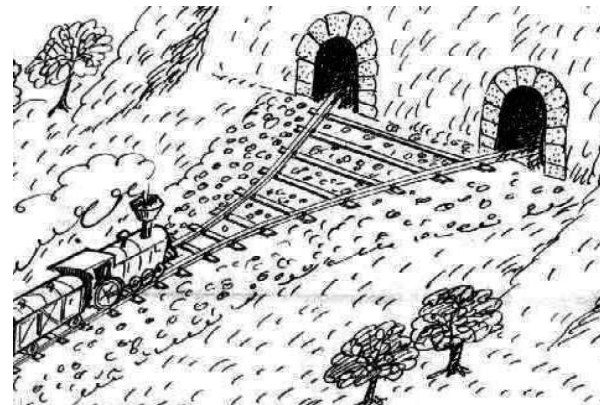
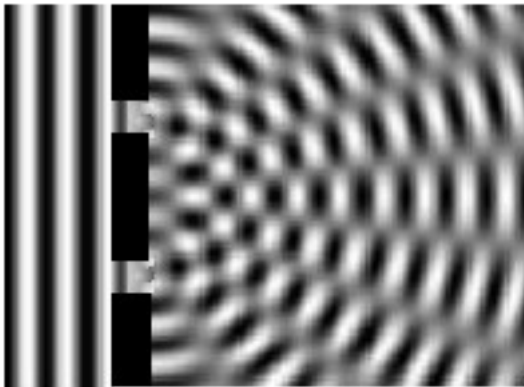
Částice

- **Elementární částice**: bez vnitřní struktury, bodové: elektron, foton, neutrino...
- **Částicové ZOO je plné částic složených**: proton a neutron tvořeny kvarky.

Kuličky, ale i vlny: umějí interferovat, ale také třeba z obalu atomu vyrazit elektron či způsobit zčernání zrna na fotopapíře.

Mikrosvět je popsán **kvantovou mechanikou**.

Běžnému životu podivuhodné věci: elektron v atomu může mít jen určité hodnoty energie, nelze přesně současně říci, kde elektron je a jakou má rychlost (relace neurčitosti).

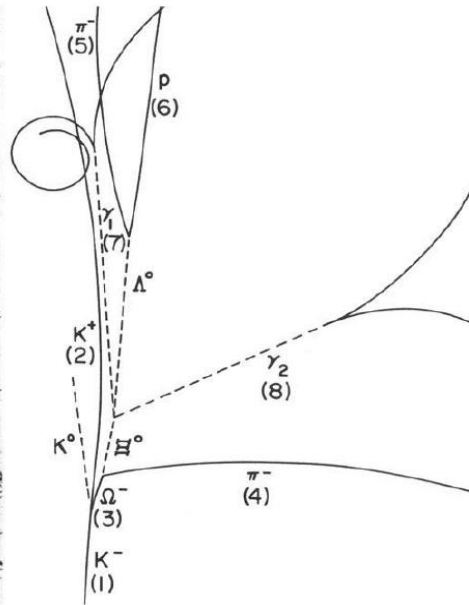
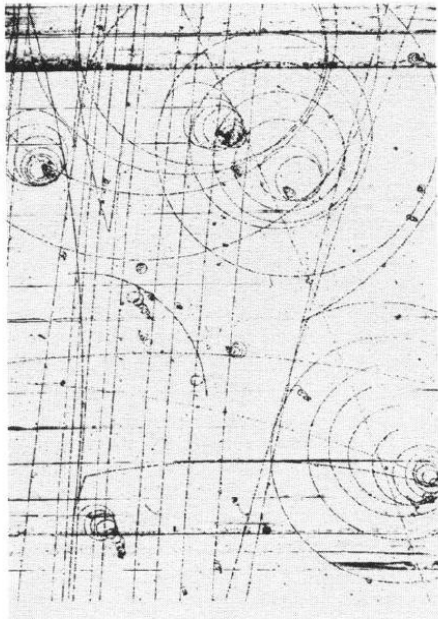
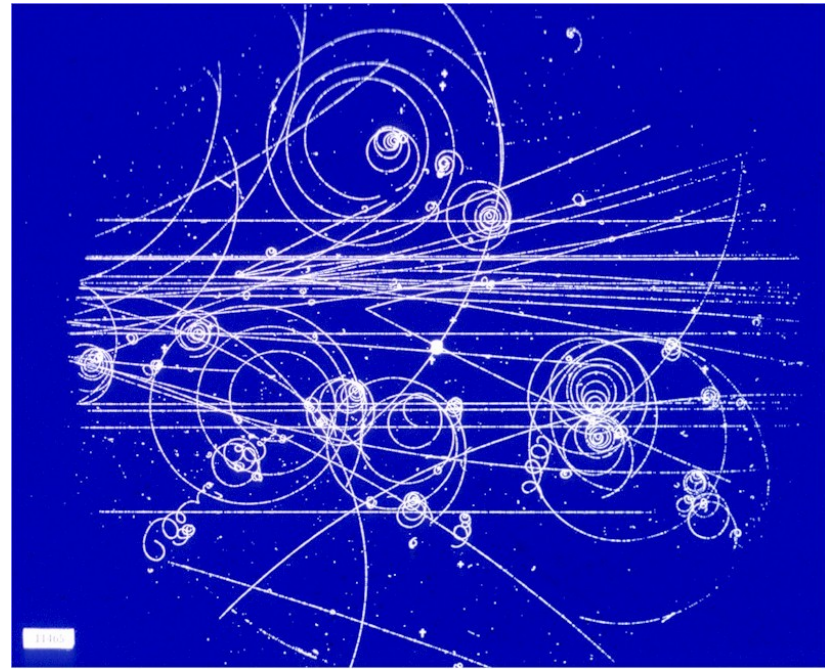
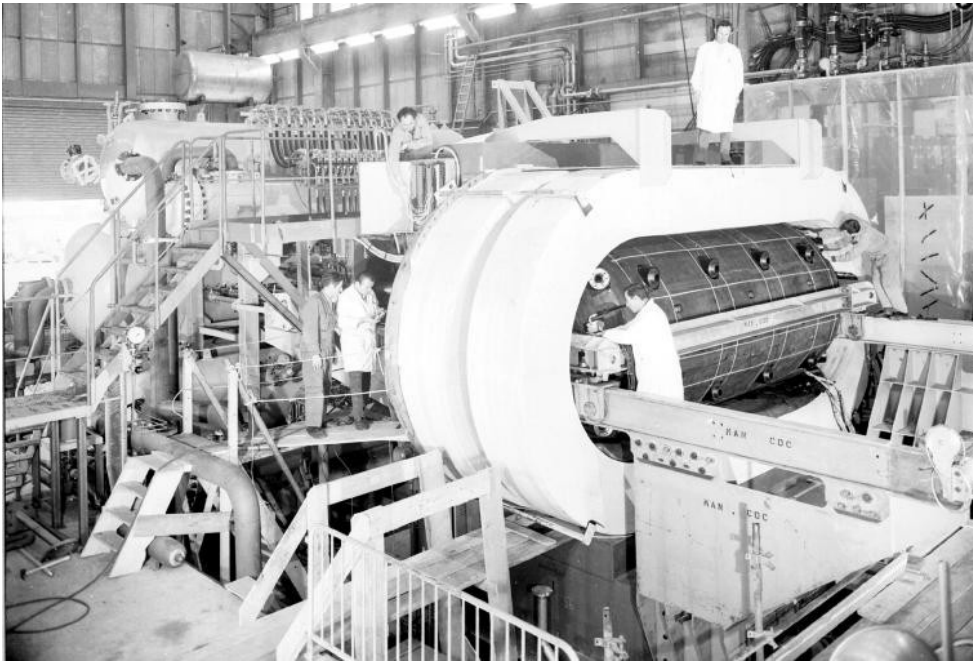


Jak částice vypadají?



Bublinová komora

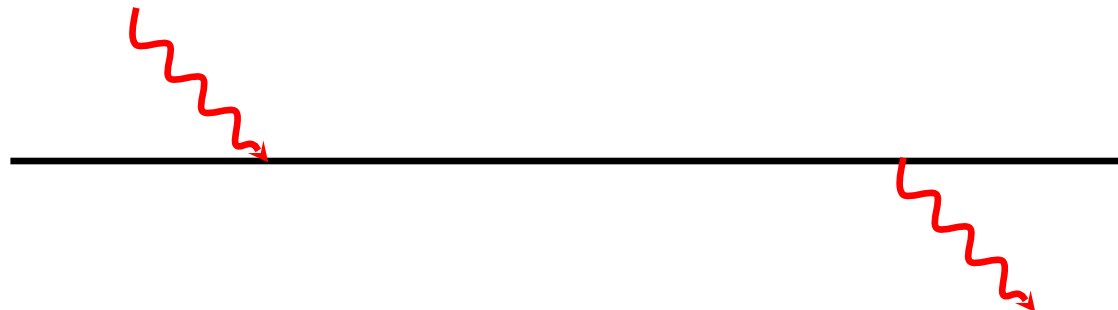
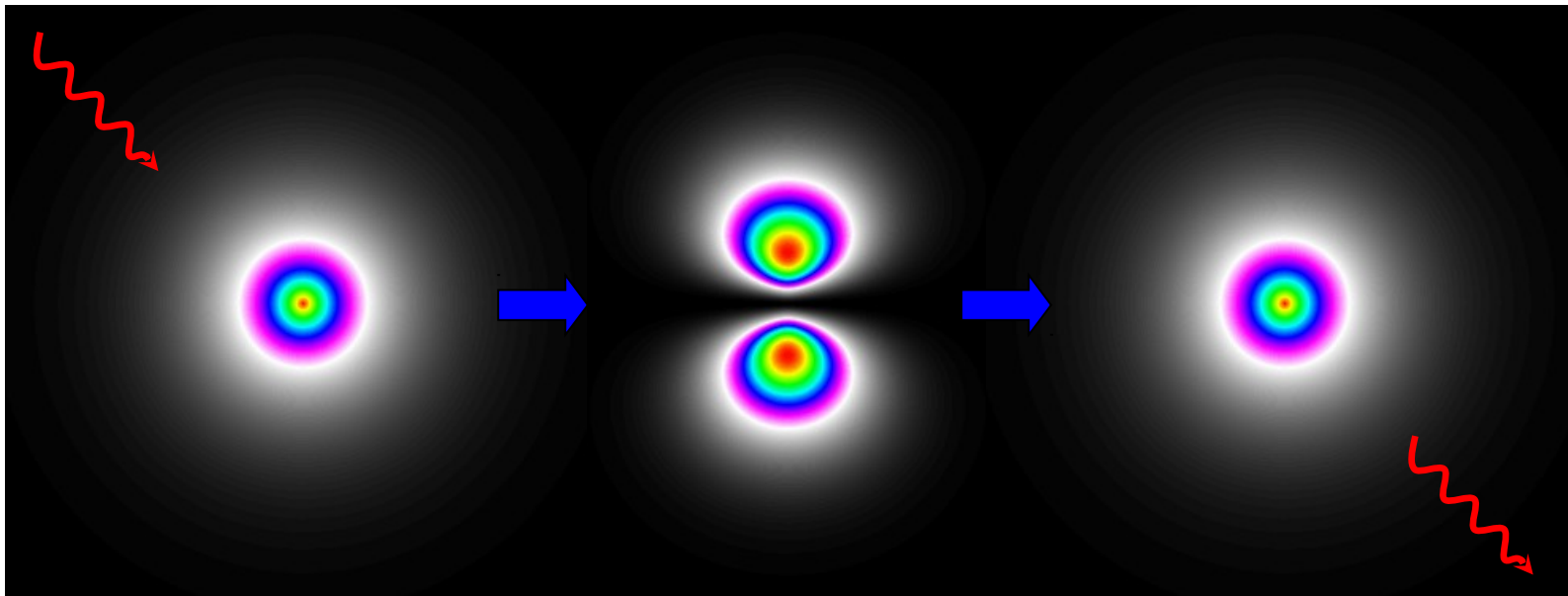
Bublinová komora



Takto by to ale dále dlouho nešlo...
(ruční prohlížení fotografií)

Interakce I

- Excitace atomu fotonem a opětovná emise.
- Částice vznikají a zase zanikají – na rozdíl od objektů v běžném světě!



Interakce II

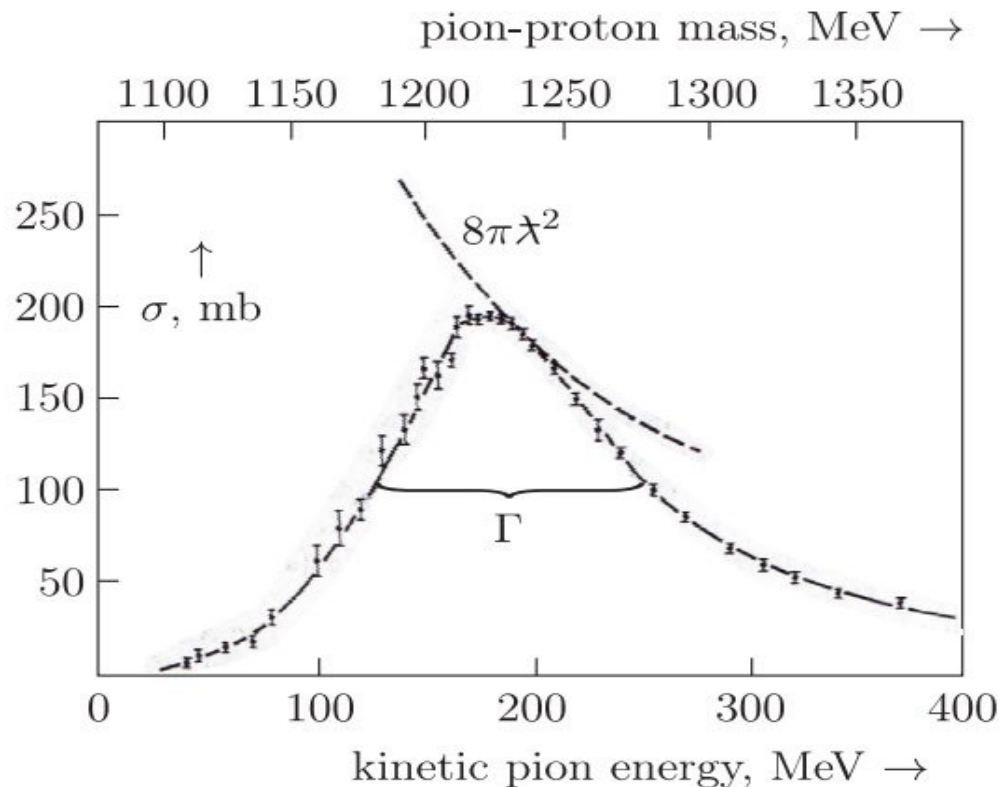
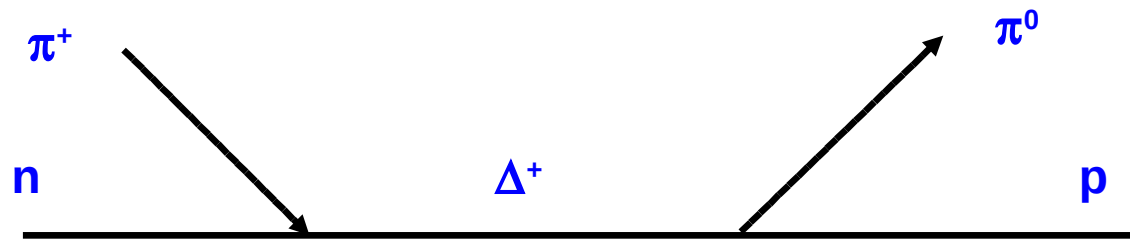
- Částice zvané **piony** lze připravit jednoduše ostřelováním terče:



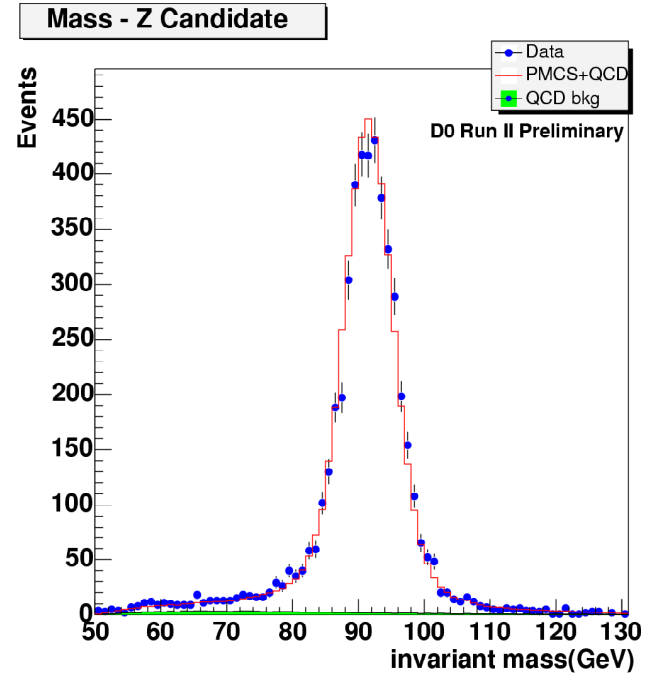
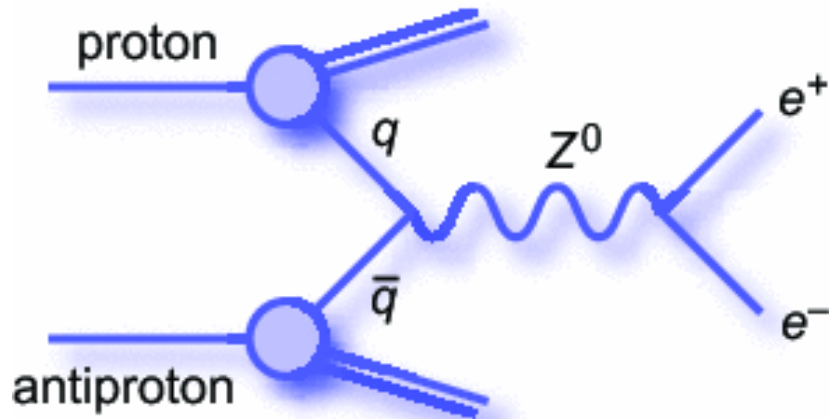
- Svazkem pionů pak můžeme zase střílet na další terč, může vzniknout krátce žijící částice (rezonance) zvaná **Delta**:



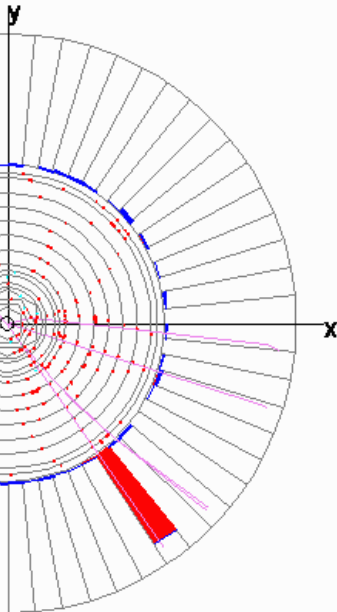
Delta se může rozpadnout i na něco jiného:



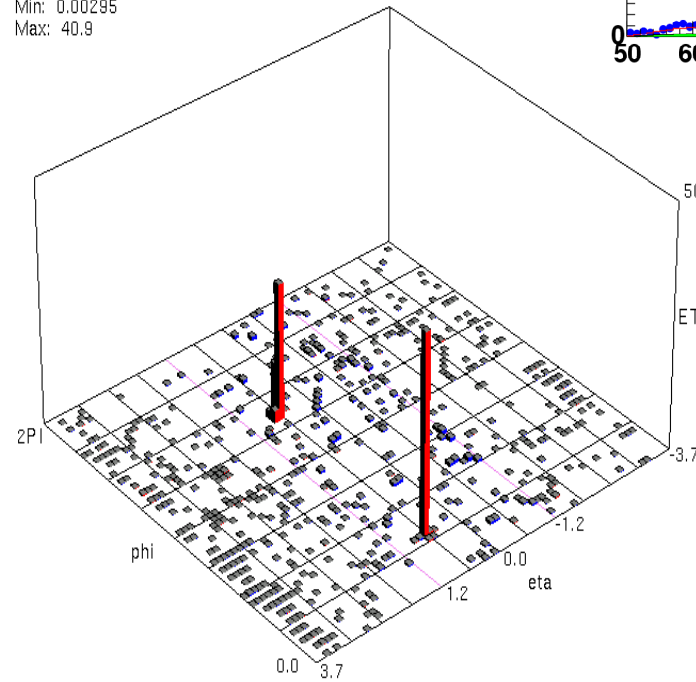
Interakce I: $qq \rightarrow Z \rightarrow e^+e^-$



ET scale: 41 GeV



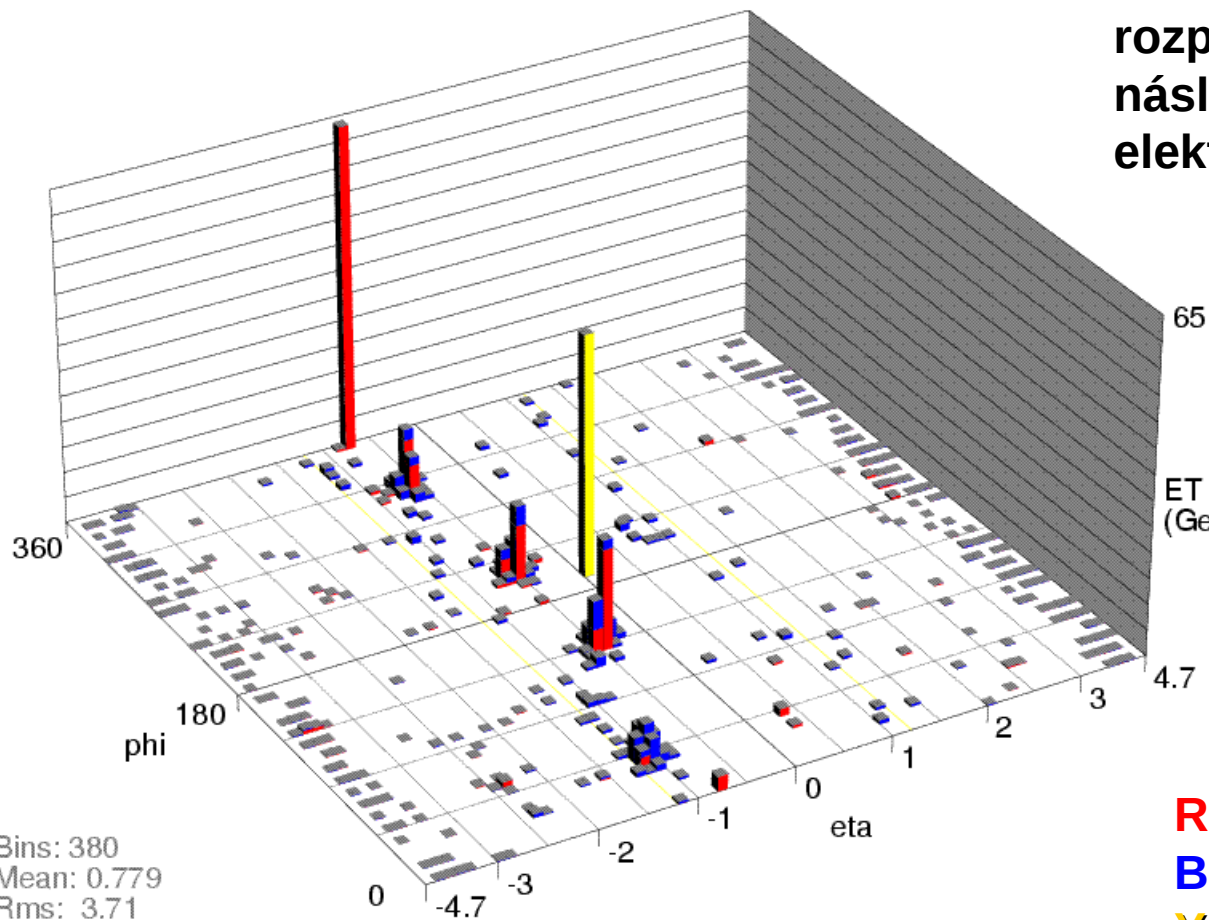
Min: 0.00295
Max: 40.9



Interakce II

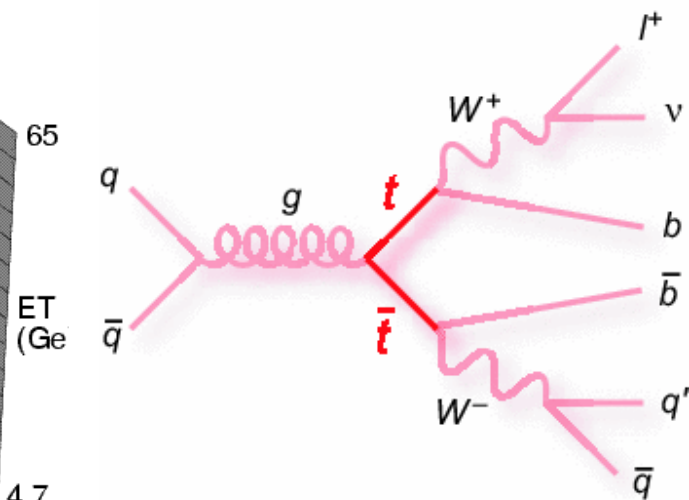
Top-antitop pár, jak viděno DØ Detektorem

Pár top-anti top
rozpadající se na $WbWb$ a
následně na 4 jety,
elektron a neutrino.



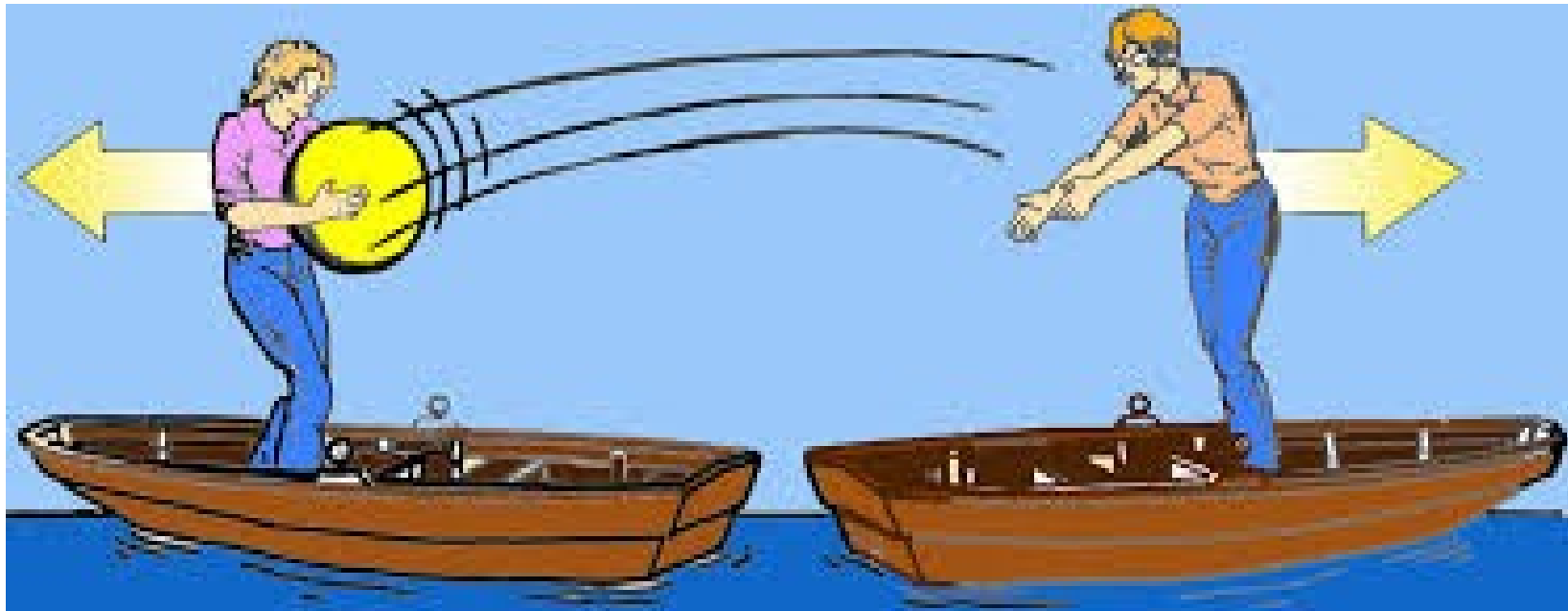
Bins: 380
Mean: 0.779
Rms: 3.71
Min: 0.00966
Max: 63.9

mE_t: 47.2
phi_t: 195 deg

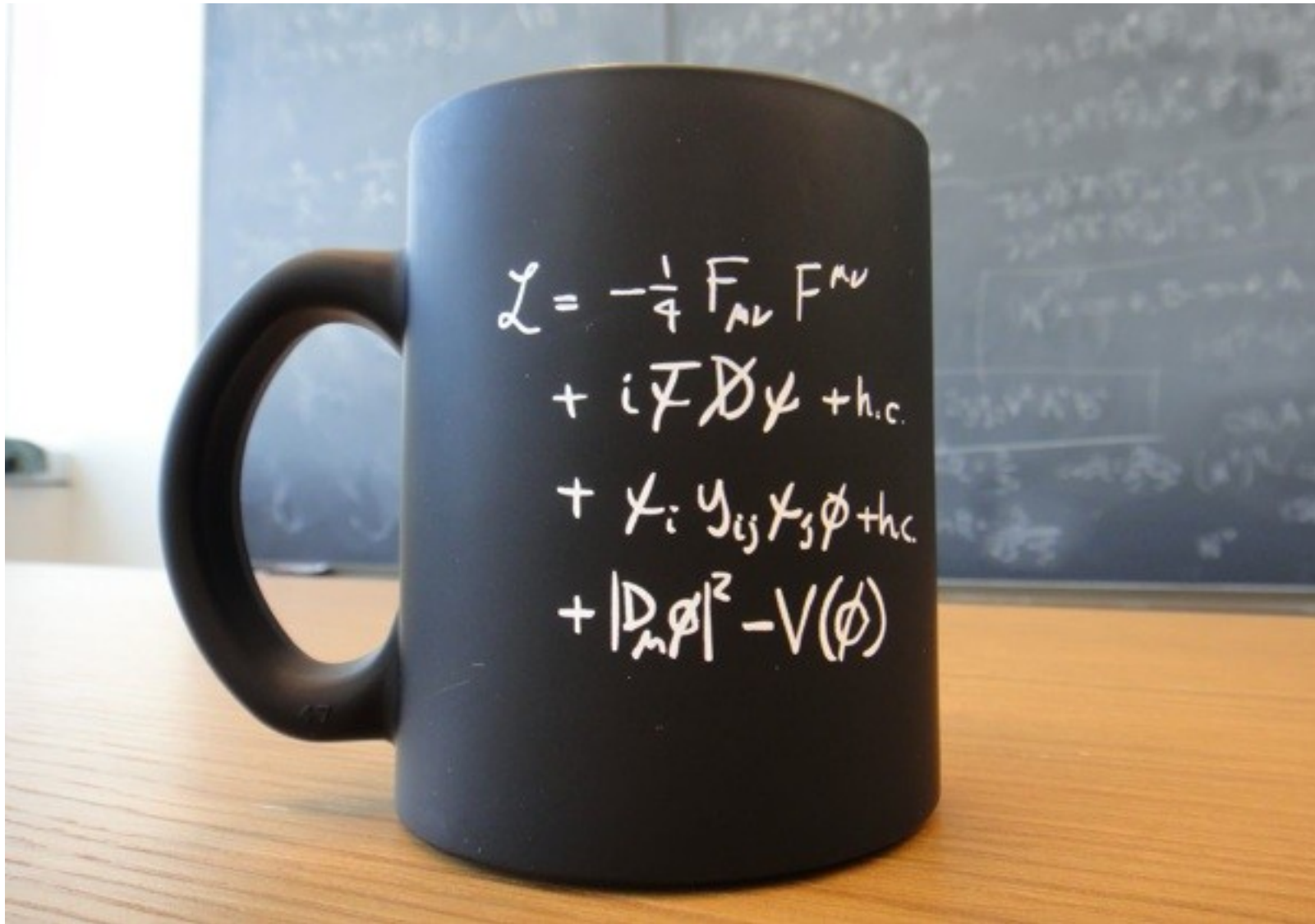


Red: EM Calorimeter
Blue: Hadronic Calorimeter
Yellow: Missing Energy
(neutrino signature)

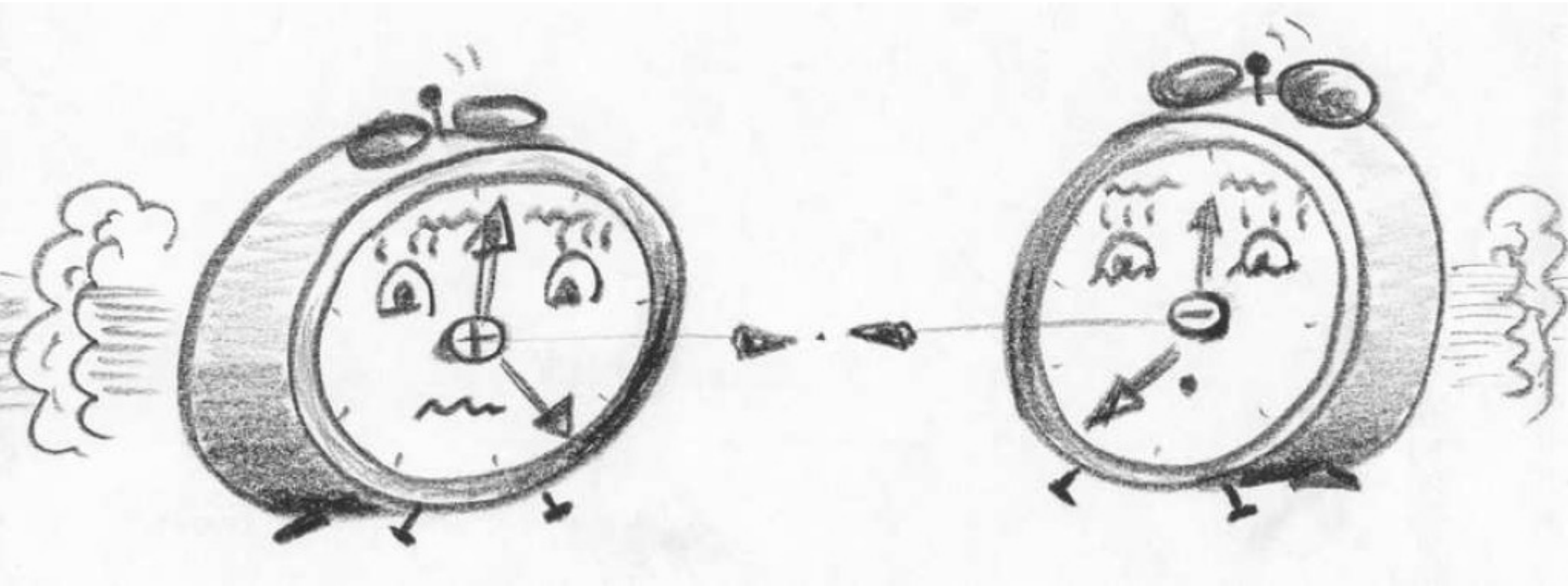
Interakce částic

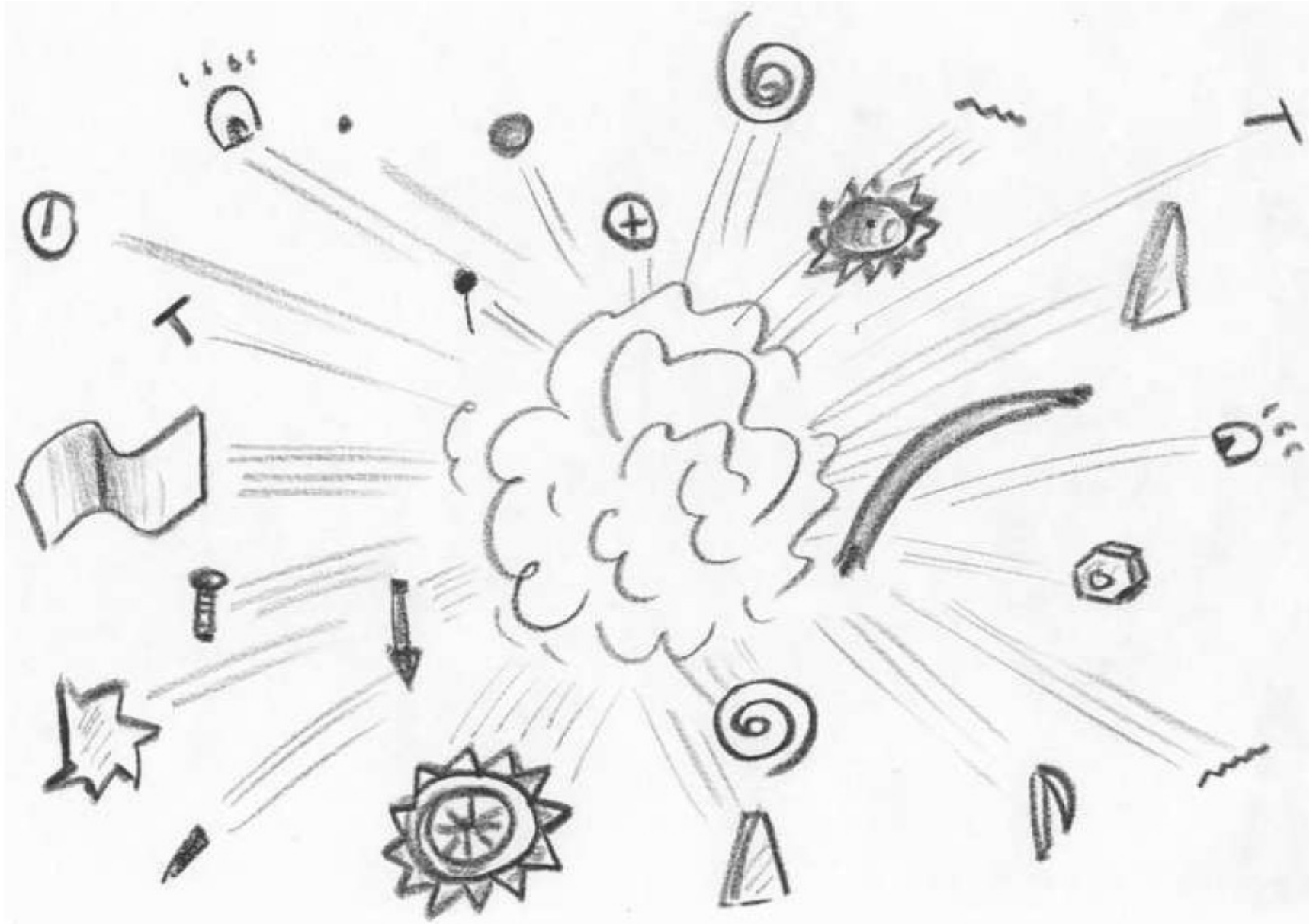


Interakce částic



$$\begin{aligned}
& -\frac{1}{2}\partial_\nu g_\mu^a \partial_\nu g_\mu^a - g_s f^{abc} \partial_\mu g_\nu^a g_\mu^b g_\nu^c - \frac{1}{4}g_s^2 f^{abc} f^{ade} g_\mu^b g_\nu^c g_\mu^d g_\nu^e + \\
& \frac{1}{2}ig_s^2(\bar{q}_i^\sigma \gamma^\mu q_j^\sigma)g_\mu^a + \bar{G}^a \partial^2 G^a + g_s f^{abc} \partial_\mu \bar{G}^a G^b g_\mu^c - \partial_\nu W_\mu^+ \partial_\nu W_\mu^- - \\
& M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{2c_w^2}M^2 Z_\mu^0 Z_\mu^0 - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H - \\
& \frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2}M\phi^0 \phi^0 - \beta_h[\frac{2M^2}{g^2} + \\
& \frac{2M}{g}H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-)] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z_\mu^0(W_\mu^+ W_\nu^- - \\
& W_\nu^+ W_\mu^-) - Z_\nu^0(W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + Z_\mu^0(W_\nu^+ \partial_\nu W_\mu^- - \\
& W_\nu^- \partial_\nu W_\mu^+)] - ig s_w[\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^+)] - \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_\mu^0 W_\mu^+ Z_\nu^0 W_\nu^- - Z_\mu^0 Z_\nu^0 W_\mu^+ W_\nu^-) + \\
& g^2 s_w^2(A_\mu W_\mu^+ A_\nu W_\nu^- - A_\mu A_\nu W_\mu^+ W_\nu^-) + g^2 s_w c_w[A_\mu Z_\nu^0(W_\mu^+ W_\nu^- - \\
& W_\nu^+ W_\mu^-) - 2A_\mu Z_\mu^0 W_\nu^+ W_\nu^-] - g\alpha[H^3 + H\phi^0 \phi^0 + 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^- + 4H^2 \phi^+ \phi^- + 2(\phi^0)^2 H^2] - \\
& gMW_\mu^+ W_\mu^- H - \frac{1}{2}g\frac{M}{c_w^2}Z_\mu^0 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}g\frac{1}{c_w}(Z_\mu^0(H\partial_\mu \phi^0 - \phi^0 \partial_\mu H) - ig\frac{s_w^2}{c_w}MZ_\mu^0(W_\mu^+ \phi^- - W_\mu^- \phi^+) + \\
& ig s_w MA_\mu(W_\mu^+ \phi^- - W_\mu^- \phi^+) - ig\frac{1-2c_w^2}{2c_w}Z_\mu^0(\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + \\
& ig 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}{4}g^2 \frac{1}{c_w^2}Z_\mu^0 Z_\mu^0 [H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2 \phi^+ \phi^-] - \frac{1}{2}g^2 \frac{s_w^2}{c_w}Z_\mu^0 \phi^0 (W_\mu^+ \phi^- + \\
& W_\mu^- \phi^+) - \frac{1}{2}ig^2 \frac{s_w^2}{c_w}Z_\mu^0 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}ig^2 s_w A_\mu H(W_\mu^+ \phi^- - W_\mu^- \phi^+) - g^2 \frac{s_w}{c_w}(2c_w^2 - 1)Z_\mu^0 A_\mu \phi^+ \phi^- - \\
& g^1 s_w^2 A_\mu A_\mu \phi^+ \phi^- - \bar{e}^\lambda (\gamma \partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma \partial \nu^\lambda - \bar{u}_j^\lambda (\gamma \partial + m_u^\lambda) u_j^\lambda - \\
& \bar{d}_j^\lambda (\gamma \partial + m_d^\lambda) d_j^\lambda + ig s_w A_\mu [-(\bar{e}^\lambda \gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}_j^\lambda \gamma^\mu u_j^\lambda) - \frac{1}{3}(\bar{d}_j^\lambda \gamma^\mu d_j^\lambda)] + \\
& \frac{ig}{4c_w}Z_\mu^0 [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (\frac{4}{3}s_w^2 - \\
& 1 - \gamma^5) u_j^\lambda) + (\bar{d}_j^\lambda \gamma^\mu (1 - \frac{8}{3}s_w^2 - \gamma^5) d_j^\lambda)] + \frac{ig}{2\sqrt{2}}W_\mu^+ [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + \\
& (\bar{u}_j^\lambda \gamma^\mu (1 + \gamma^5) C_{\lambda\kappa} d_j^\kappa)] + \frac{ig}{2\sqrt{2}}W_\mu^- [(\bar{e}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{d}_j^\kappa C_{\lambda\kappa}^\dagger \gamma^\mu (1 + \\
& \gamma^5) u_j^\lambda)] + \frac{ig}{2\sqrt{2}}\frac{m_\kappa^\lambda}{M}[-\phi^+(\bar{\nu}^\lambda (1 - \gamma^5) e^\lambda) + \phi^-(\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda)] - \\
& \frac{g}{2}\frac{m_\lambda^\lambda}{M}[H(\bar{e}^\lambda e^\lambda) + i\phi^0(\bar{e}^\lambda \gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}}\phi^+[-m_d^\kappa(\bar{u}_j^\lambda C_{\lambda\kappa}(1 - \gamma^5) d_j^\kappa) + \\
& m_u^\lambda(\bar{u}_j^\lambda C_{\lambda\kappa}(1 + \gamma^5) d_j^\kappa) + \frac{ig}{2M\sqrt{2}}\phi^-[m_d^\lambda(\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger(1 + \gamma^5) u_j^\kappa) - m_u^\kappa(\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger(1 - \\
& \gamma^5) u_j^\kappa) - \frac{g}{2}\frac{m_\lambda^\lambda}{M}H(\bar{u}_j^\lambda u_j^\lambda) - \frac{g}{2}\frac{m_\lambda^\lambda}{M}H(\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2}\frac{m_\lambda^\lambda}{M}\phi^0(\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \\
& \frac{ig}{2}\frac{m_\lambda^\lambda}{M}\phi^0(\bar{d}_j^\lambda \gamma^5 d_j^\lambda) + \bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \\
& \frac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2 Y + igc_w W_\mu^+(\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) + ig s_w W_\mu^+(\partial_\mu \bar{Y} X^- - \\
& \partial_\mu \bar{X}^+ Y) + igc_w W_\mu^-(\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) + ig s_w W_\mu^-(\partial_\mu \bar{X}^- Y - \\
& \partial_\mu \bar{Y} X^+) + igc_w Z_\mu^0(\partial_\mu \bar{X}^+ X^- - \partial_\mu \bar{X}^- X^+) + ig s_w A_\mu(\partial_\mu \bar{X}^+ X^- - \\
& \partial_\mu \bar{X}^- X^+) - \frac{1}{2}gM[\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w^2}\bar{X}^0 X^0 H] + \\
& \frac{1-2c_w^2}{2c_w}igM[\bar{X}^+ X^0 \phi^+ - \bar{X}^- X^0 \phi^-] + \frac{1}{2c_w}igM[\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \\
& igM s_w[\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \frac{1}{2}igM[\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0]
\end{aligned}$$

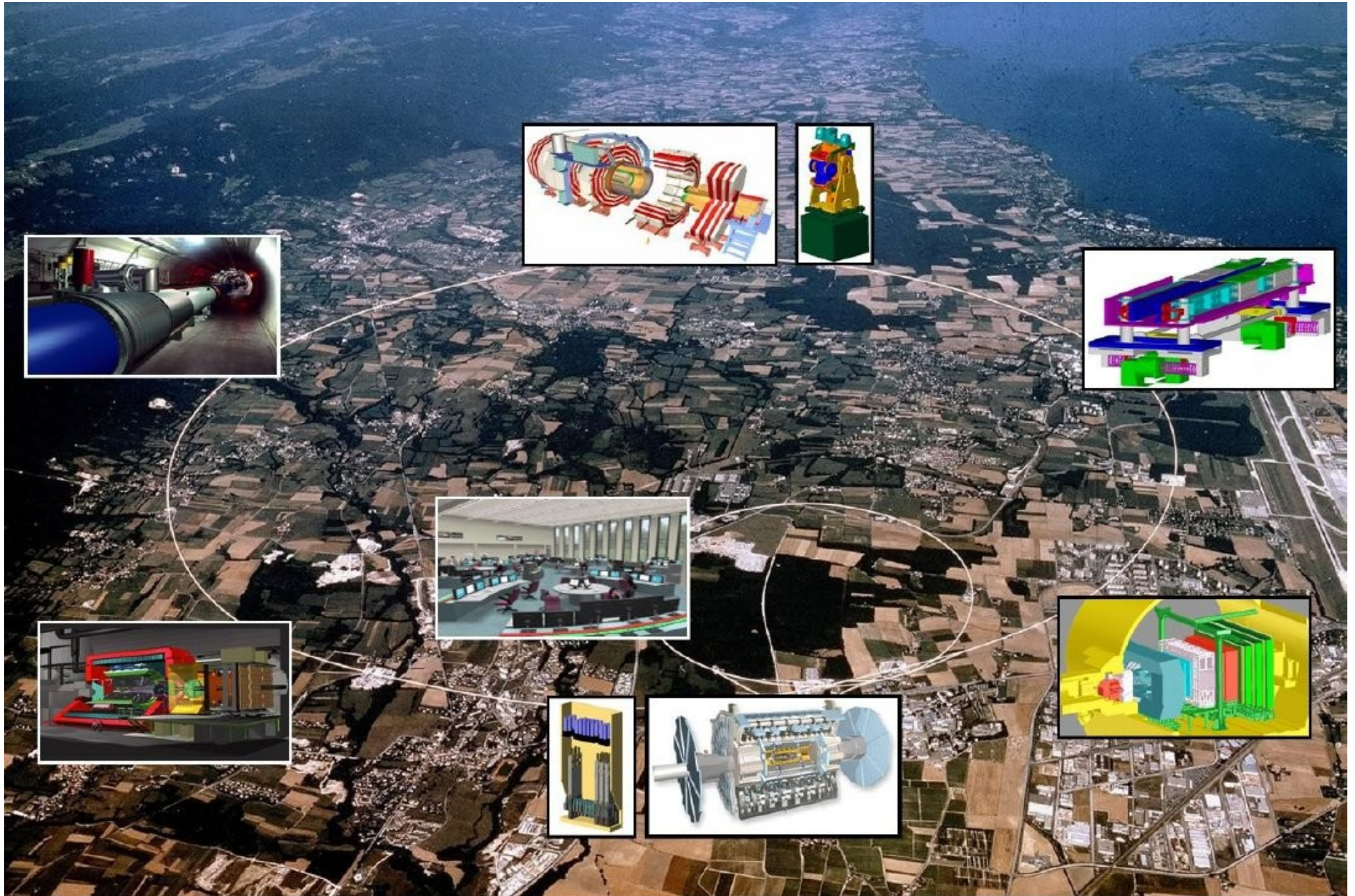




CERN, Fermilab, Brookhaven, DESY



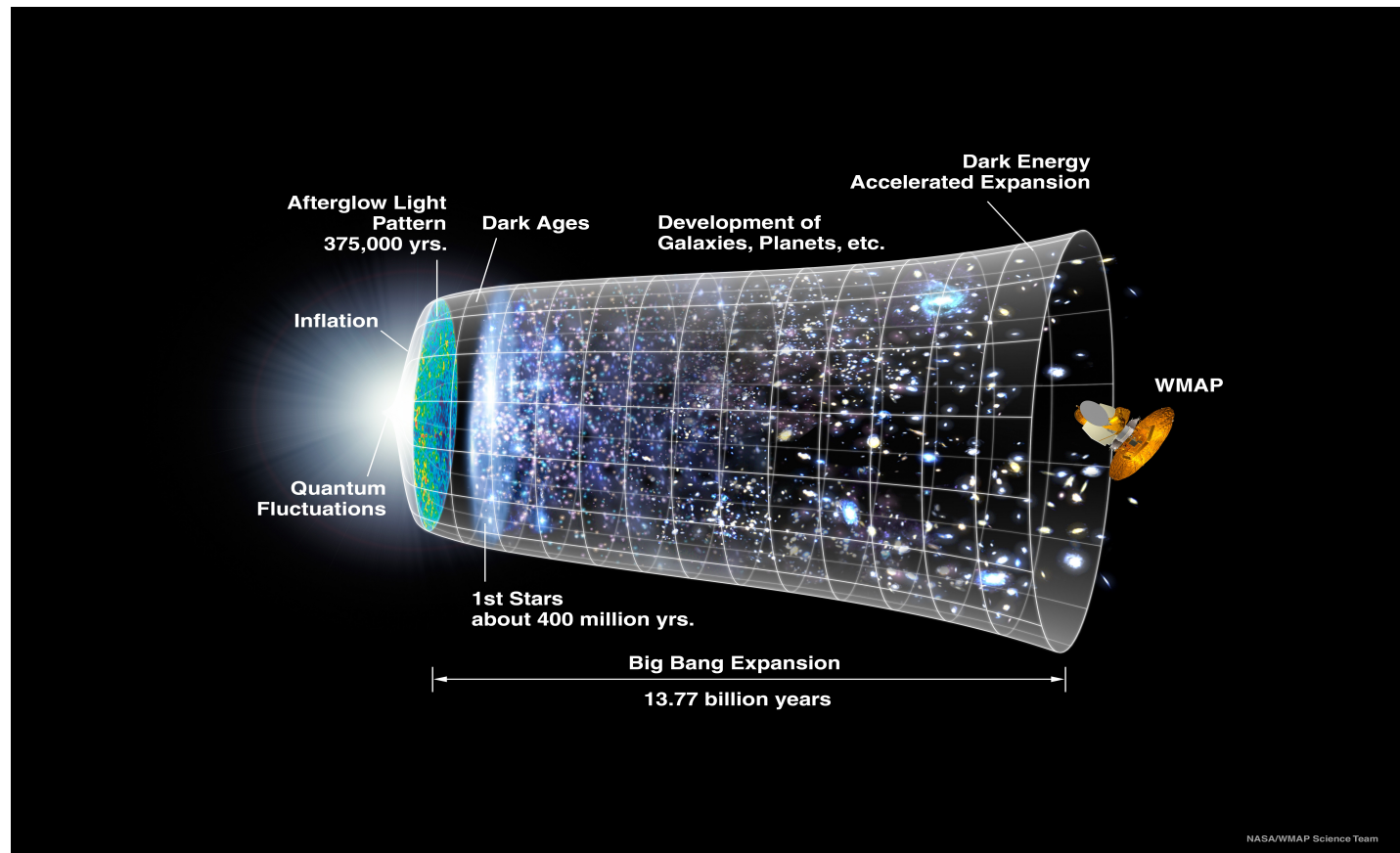
CERN



Co se v CERNu studuje?

- Jaké jsou síly v přírodě?
- Kolik máme rodin částic?
- Proč tady jsme?

- Proč je Vesmír z hmoty a ne z antihmoty?
- Co je to temná hmota a temná energie?
- Jsou další síly či částice v přírodě?



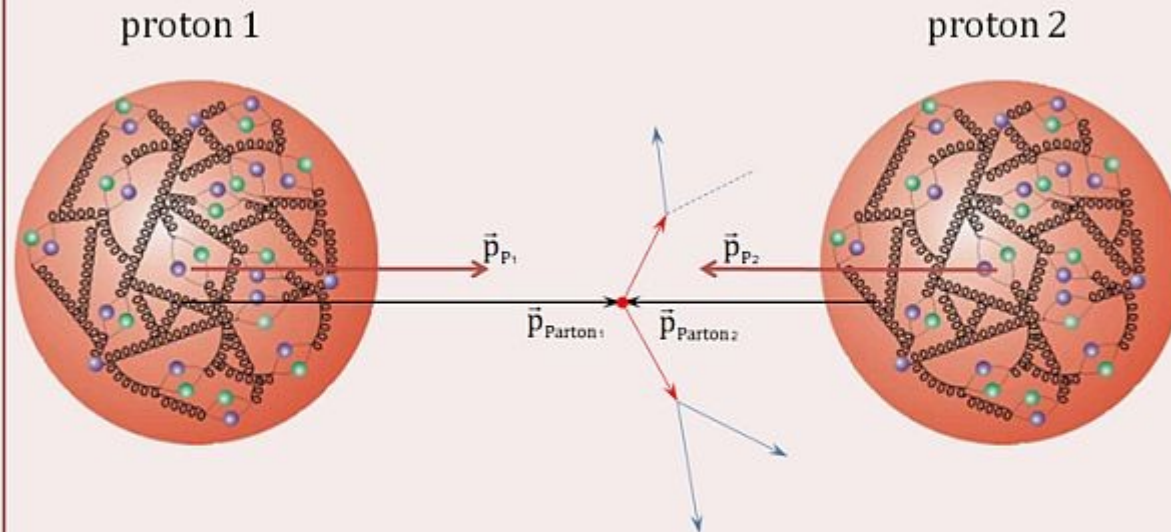
LHC

- Sráží protony při velkých energiích s frekvencí 40MHz pro hledání vzácných procesů, zatím neznámých částic, a vytváří podmínky jako těsně po Velkém třesku.



LHC

Interactions of constituents of the colliding protons, the so called partons (quarks, gluons)



\vec{p}_{P_1} ... momentum proton 1

\vec{p}_{P_2} ... momentum proton 2

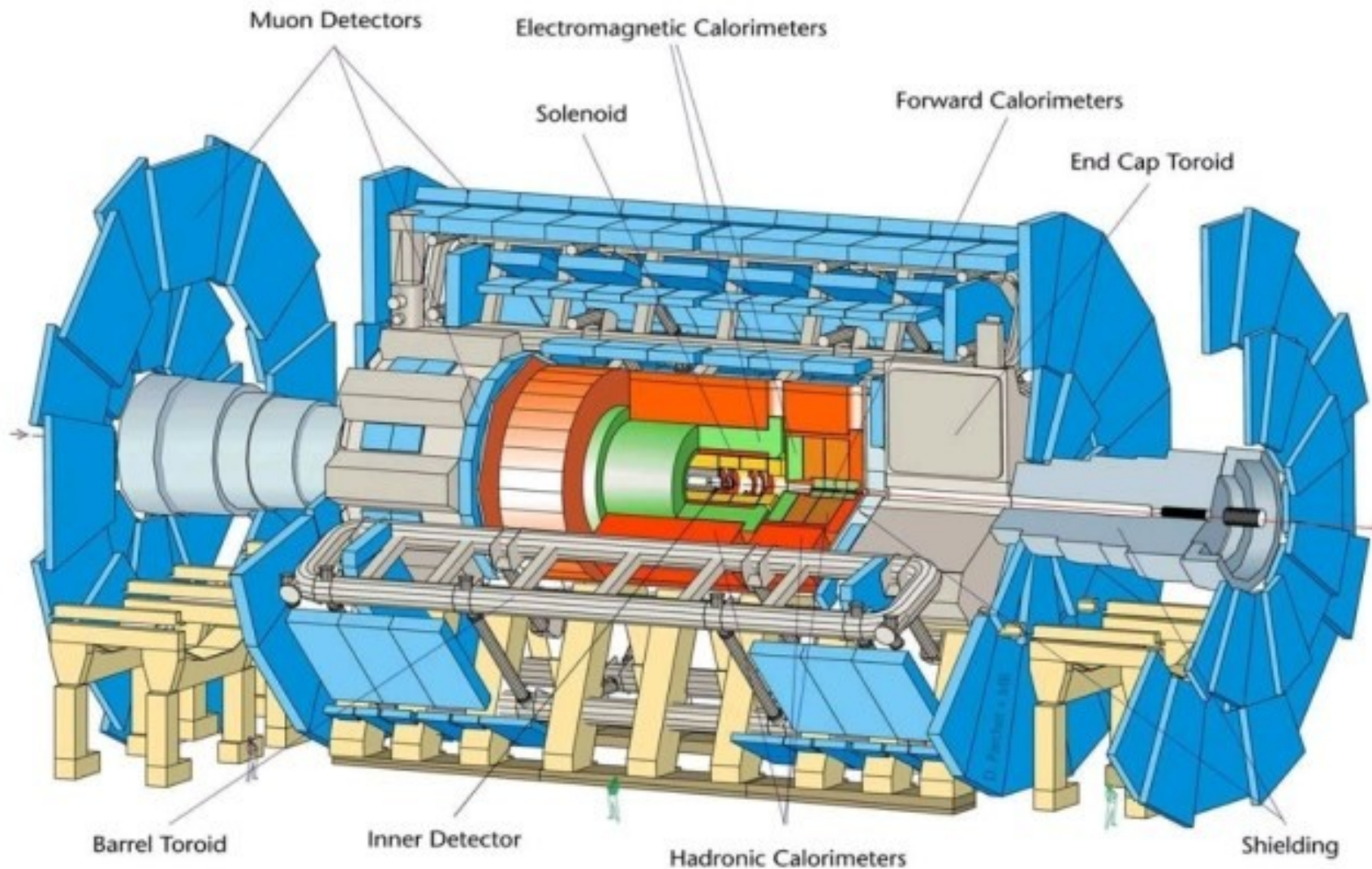
• interaction vertex

$\vec{p}_{\text{Parton}_1}$... momentum parton 1

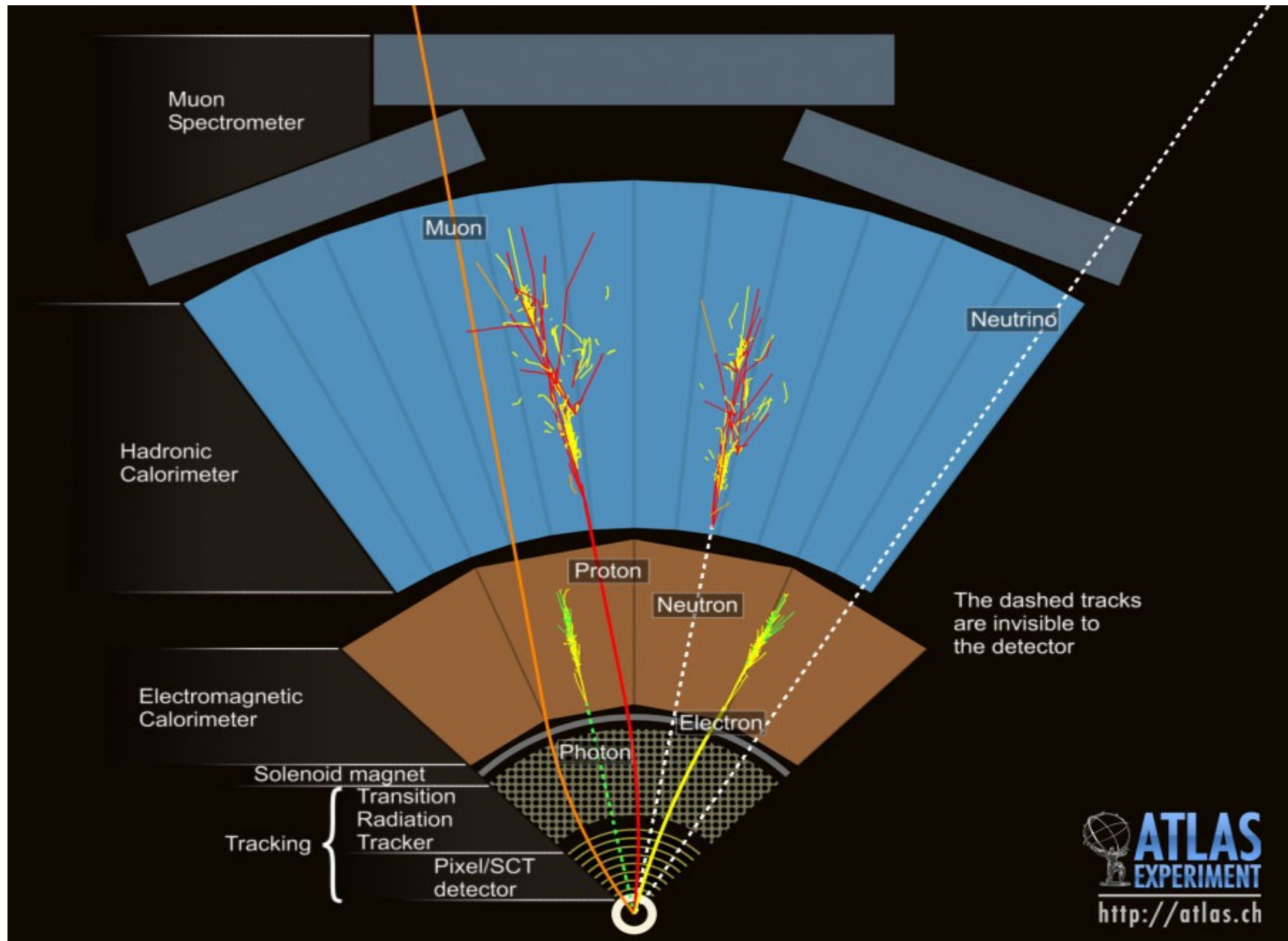
$\vec{p}_{\text{Parton}_2}$... momentum parton 2

ATLAS Experiment

- Jeden ze dvou víceúčelových experimentů na urychlovači LHC



Průchod částic detektorem ATLAS



Každodenní realita

The image shows a desktop environment with three main windows:

- Left Window (C++ Code):** A code editor showing C++ code for event selection and calculation. Key lines include:

```
MMLepton rc_lepton;
rc_lepton.pt = ed->leptons.pT.at(0) / GeV;
rc_lepton.eta = ( rc_channel == FakesWeights::EJETS ) ? ed->electrons.property["el_cl_eta"].at(0) : ed->nuon...
rc_lepton.eta = fabs( rc_lepton.eta );

double hthad = 0.;
double dR_lj_min = 1e10; // distance between the electron and the closest jet
double pTDR_lj_min = 0.; //pT/dR (lepton-closest jet)
for( size_t j = 0; j < ed->jets.n; ++j ) {
    const double jet_pT = ed->jets.pT.at(j) / GeV;

    hthad += jet_pT;

    double dR_lj = PhysicsHelperFunctions::DeltaR( ed->leptons, 0, ed->jets, j );

    //cout << "Nj = " << ed->jets.n << " j_ind = " << j << " dR_lj = " << dR_lj << endl;

    if( dR_lj < dR_lj_min ) {
        dR_lj_min = dR_lj;

        pTDR_lj_min = jet_pT / dR_lj;
    }
}
rc_event.hthad = hthad;
rc_lepton.dR = dR_lj_min;
rc_lepton.dRpt = pTDR_lj_min;

const double lep_phi = ed->leptons.phi.at(0);
const double met_phi = ed->MET.phi;
double dPhi = PhysicsHelperFunctions::Phi_mphi_phi( lep_phi - met_phi );
rc_lepton.dPhi = fabs( dPhi );

int trigger = ed->leptons.property["trigMatch"].at(0); // which trigger the lepton is matched to
// (use lep_trigMatch in MiniSL)
rc_lepton.trigger = trigger; // 1,2 or 3, or even adding the info on the prescale

bool tight = ( rc_channel == FakesWeights::EJETS ) ? ed->electrons.property["tight"].at(0);

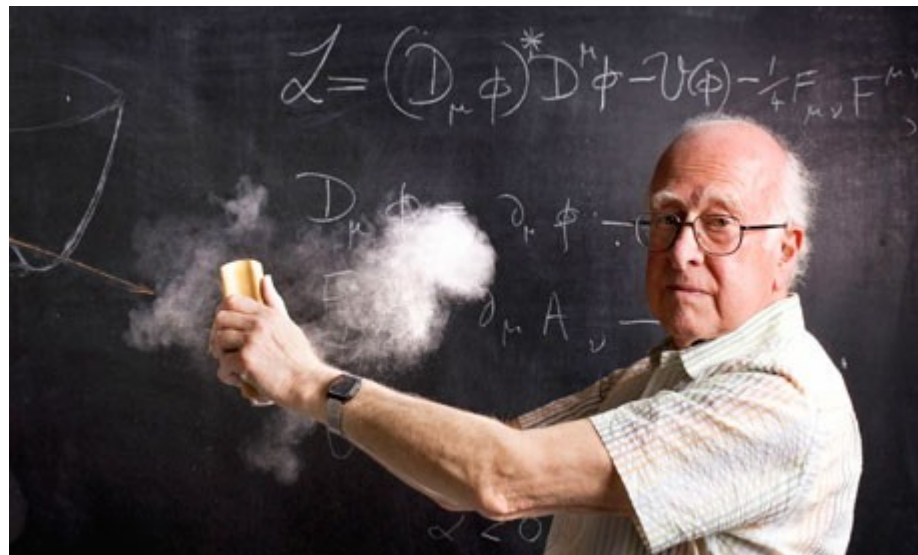
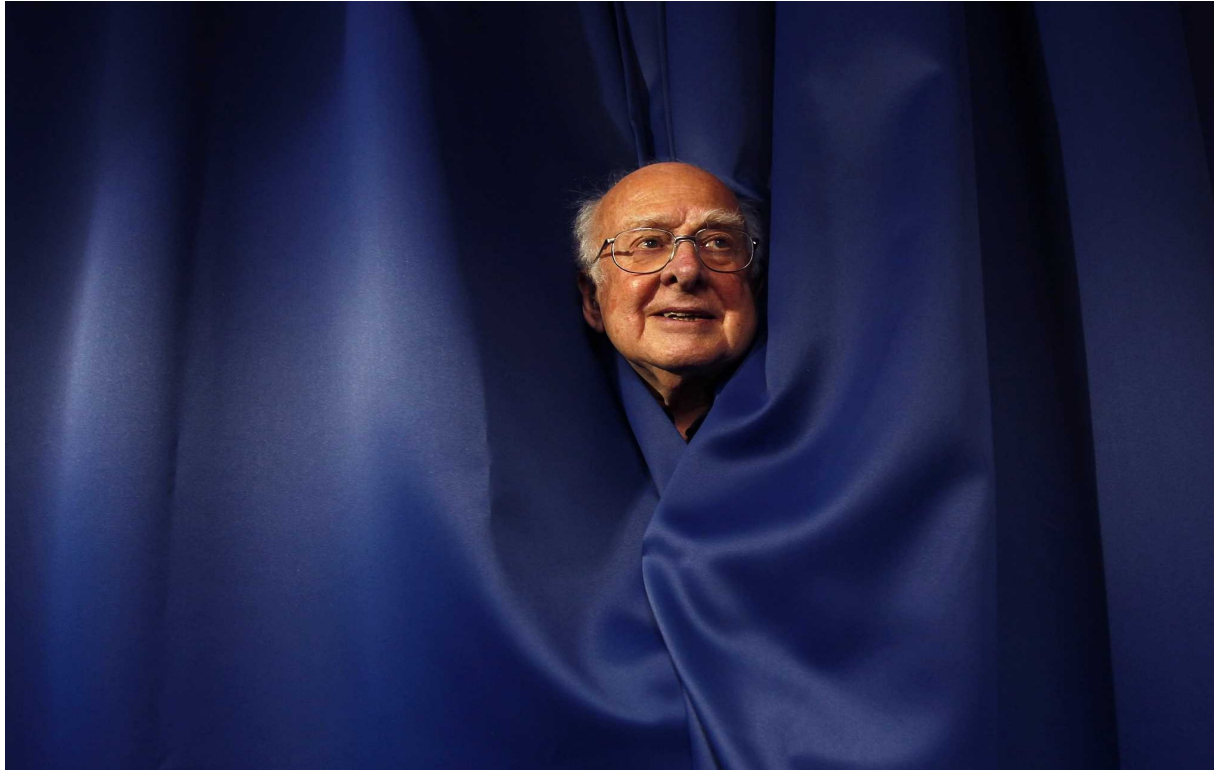
// Finally..
qcd_weight = m_moma->GetFakesWeight( rc_channel, rc_event, rc_lepton, tight );
// qcd_weight = m_moma->GetFakesWeight( rc_channel, tight, rc_lepton.pt, rc_lepton.eta, rc_lepton.dRpt, rc_event.jetpt, rc_event.njets, rc_event.ntag, rc_lepton.trigger );

// cout << "ch: " << rc_channel << " tight = " << tight << " pT = " << rc_lepton.pt << " dR_lj_min = " << rc_lepton.dR << " dPhi_MET = " << rc_lepton.dPhi << " trigger = " << trigger << endl;
// CutFlowTtbarResolved.cxx 51% L613 (C++/L Abbrev)
```
- Top-Right Window (Python Script):** A Python script using ROOT and MAMBoPlottingToolkit:

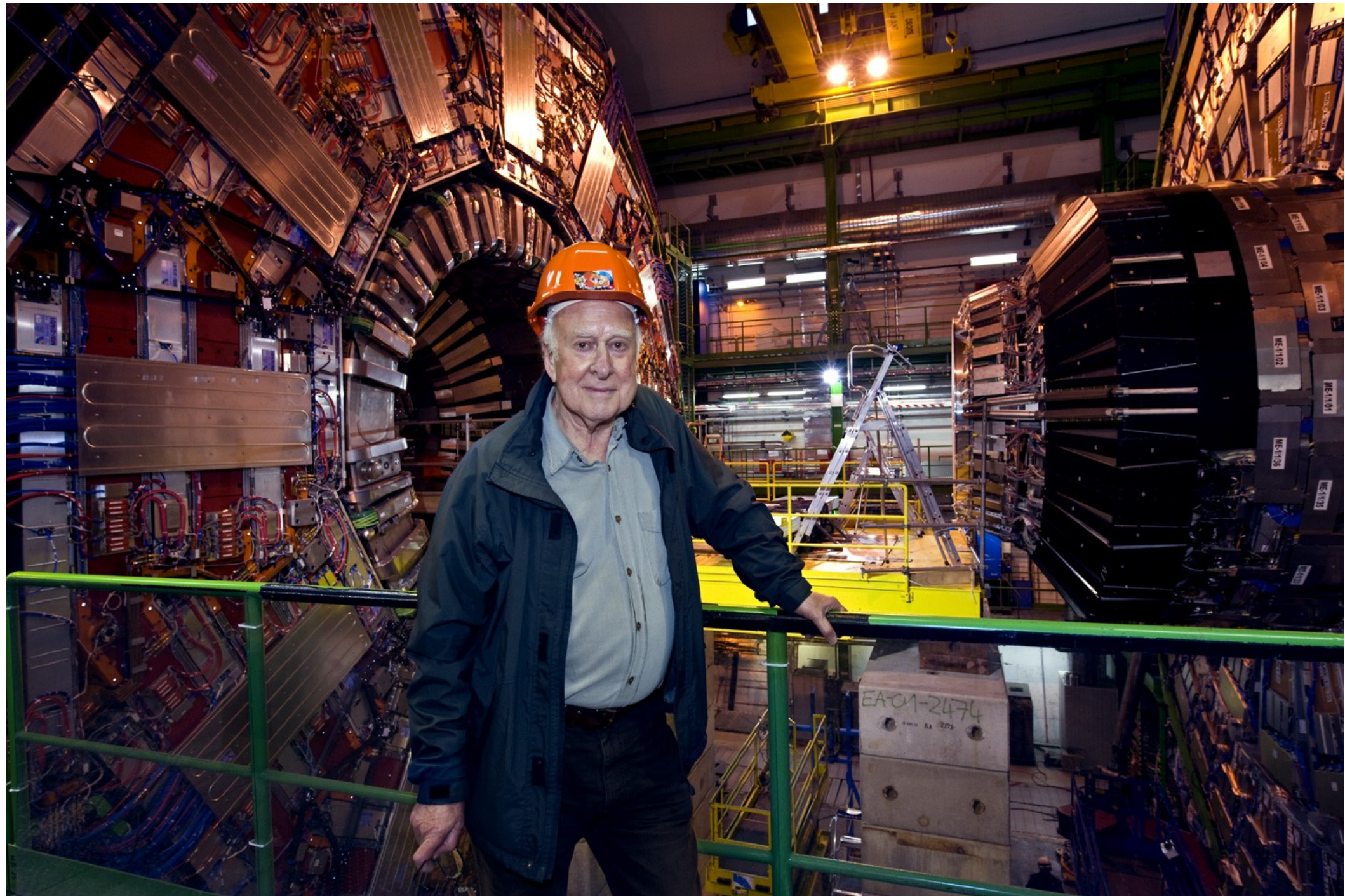
```
#!/usr/bin/python
import os, sys
from ROOT import *
from array import array

from MAMBoPlottingToolkit import *
_cans = []
_files = []
_corr = []
```
- Bottom-Right Window (ROOT Plot):** A plot titled "ATLAS" showing "Events / GeV" vs " m_T^W [GeV]". The plot includes:
 - Text: $\sqrt{s}=7$ TeV $\int L dt = 4.6 \text{ fb}^{-1}$
 - Legend for "e+jets": Data (black dots), $t\bar{t}$ (l+jets) (white), $t\bar{t}$ (dilepton) (green), Single top (blue), W+jets (orange), Multijet (purple), Other (yellow).
 - Y-axis: 0 to 400 Events / GeV.
 - X-axis: 0 to 300 m_T^W [GeV].
 - Bottom Panel: "Data/Prediction" ratio vs m_T^W [GeV], with a horizontal line at 1.0 and a shaded region for uncertainty.

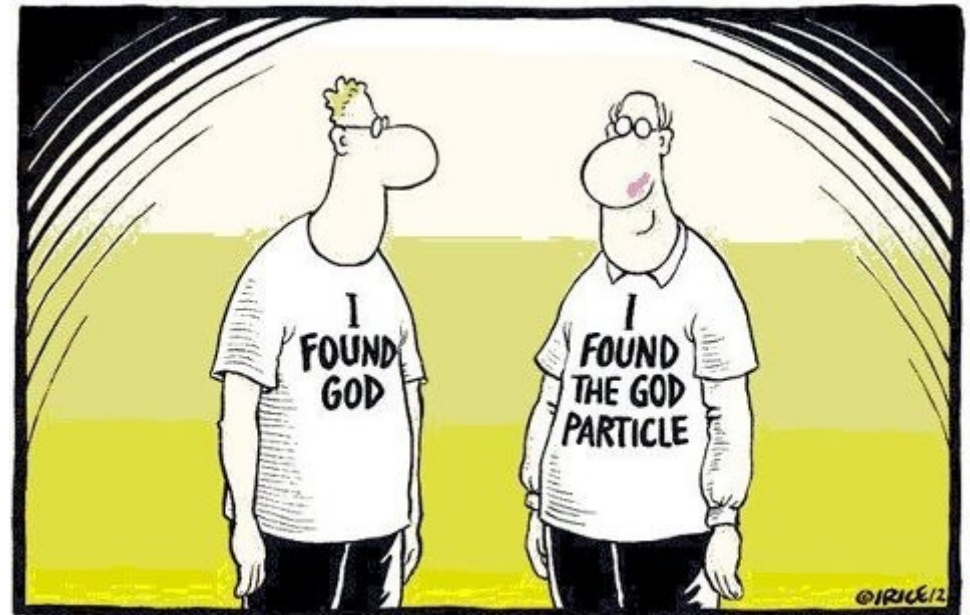
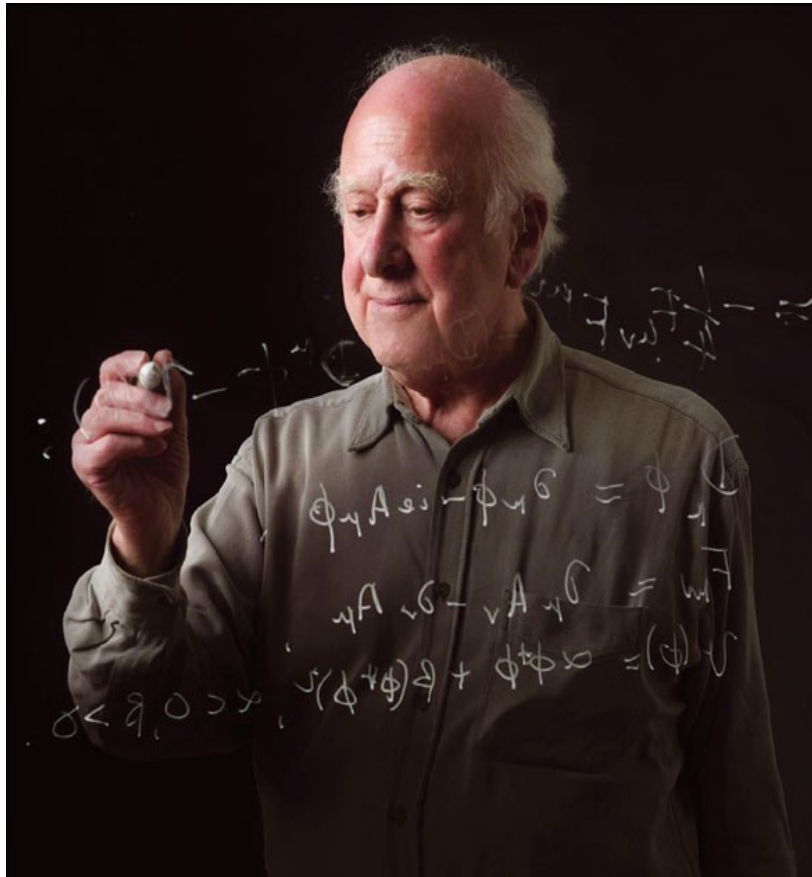
Higgs



Higgs



Higgs



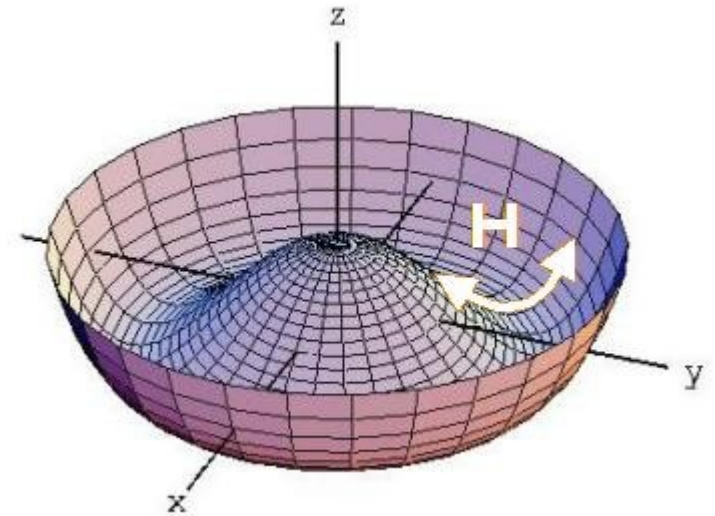
THEOLOGY VS. PHYSICS

Higgs – Jak?

$$\mathcal{L}_{Higgs} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + (\partial_\mu - igA_\mu)\varphi(\partial^\mu + igA^\mu)\varphi^* - \lambda\left(\varphi\varphi^* - \frac{v^2}{2}\right)^2$$

$$\varphi(x) = \rho(x) \exp\left(i\frac{\pi(x)}{v}\right)$$

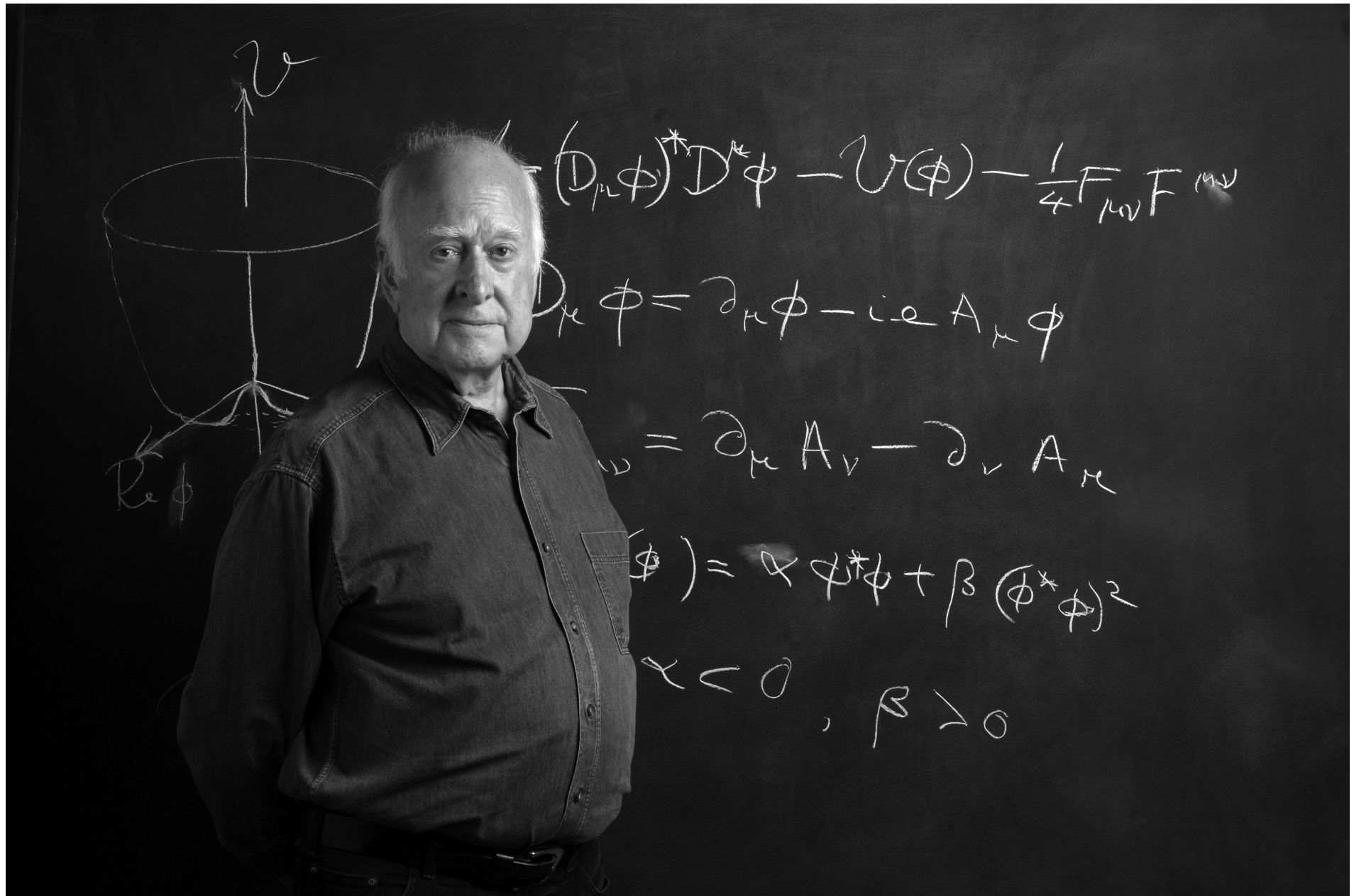
$$\rho = \frac{1}{\sqrt{2}}(\sigma + v)$$



$$\mathcal{L}_{Higgs}^{(U)} = \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma - \lambda v^2\sigma^2 - \frac{1}{4}G_{\mu\nu}G^{\mu\nu} + \frac{1}{2}g^2v^2B_\mu B^\mu + g^2v\sigma B_\mu B^\mu + \frac{1}{2}g^2\sigma^2B_\mu B^\mu - \lambda v\sigma^3 - \frac{1}{4}\lambda\sigma^4$$

Hmotový člen pro pole B

Higgs – Jak?



Higgs – Co?

ONE OF THE THINGS PEOPLE PREDICT WILL COME OUT IS

THE HIGGS BOSON



THE HIGGS IS THE PARTICLE RESPONSIBLE FOR GIVING MASS TO OTHER PARTICLES.



WHAT IS MASS?

WHEN YOU THINK OF THINGS HAVING MASS, IT MEANS IT HAS "STUFF" TO IT, RIGHT?



IT'S NOT ACTUALLY "STUFF"

PARTICLES HAVE MASS BUT NO VOLUME.



(THEY'RE POINT PARTICLES)

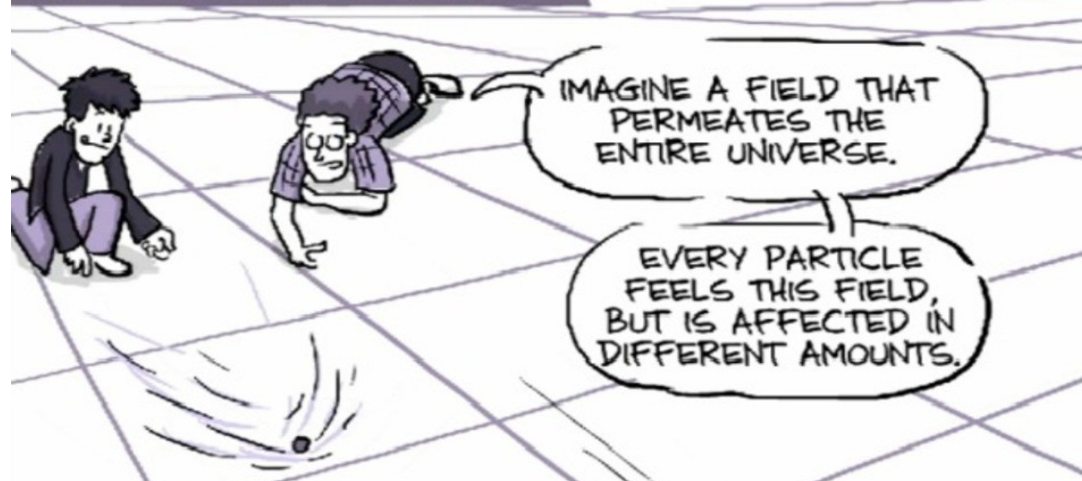
MASS IS A CHARACTERISTIC OF A PARTICLE, LIKE CHARGE.

SOME HAVE IT, SOME DON'T



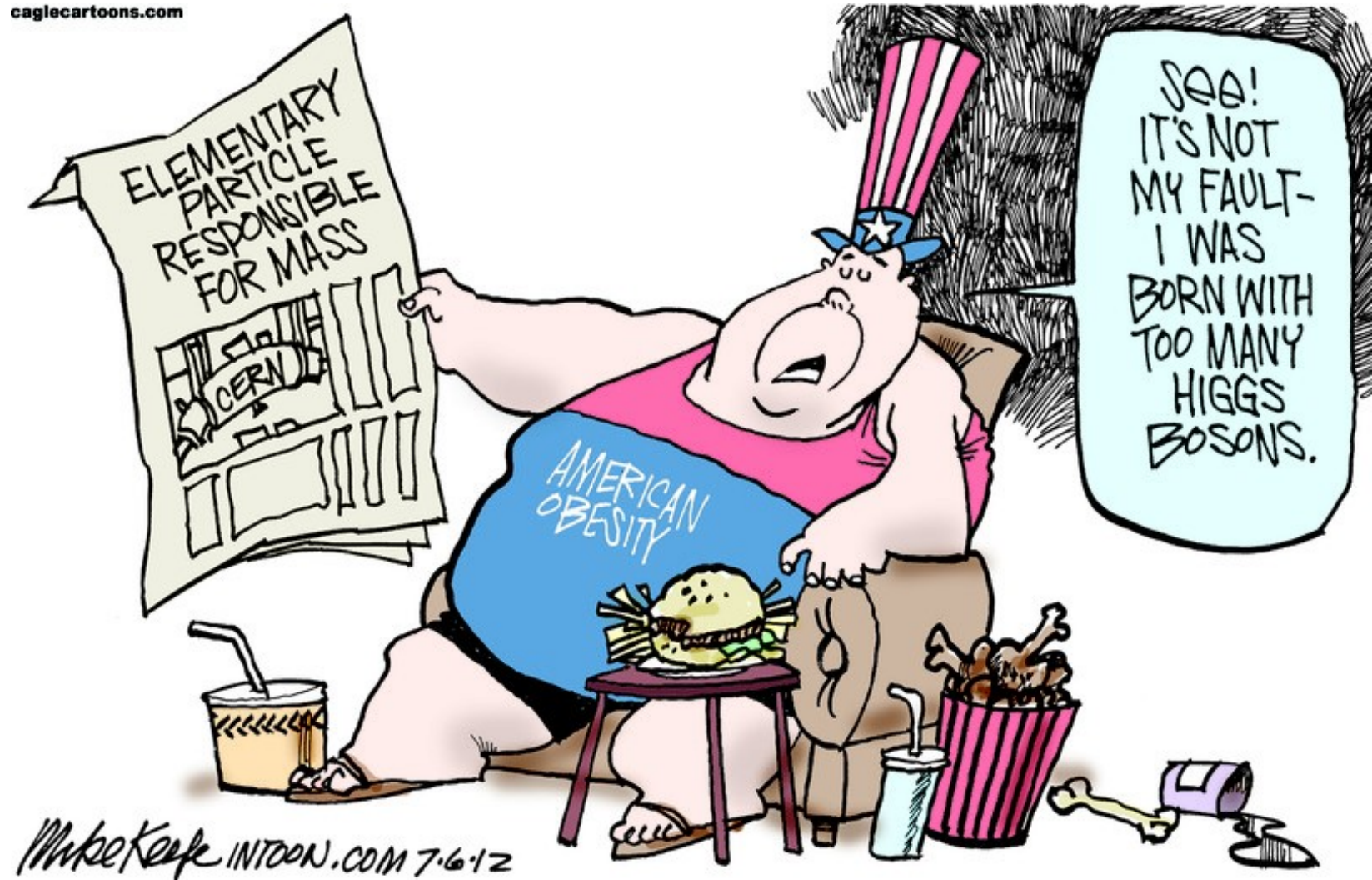
IT'S JUST A DIFFERENT KIND OF CHARGE...

HIGGS THEORY STARTS WITH THIS:



Higgs

caglecartoons.com



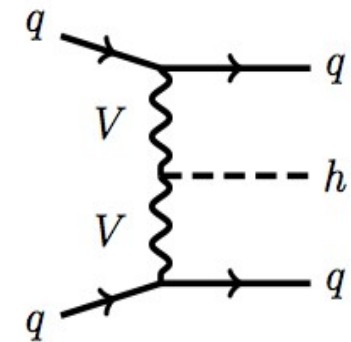
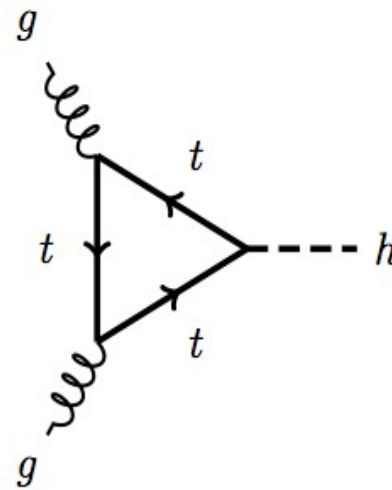
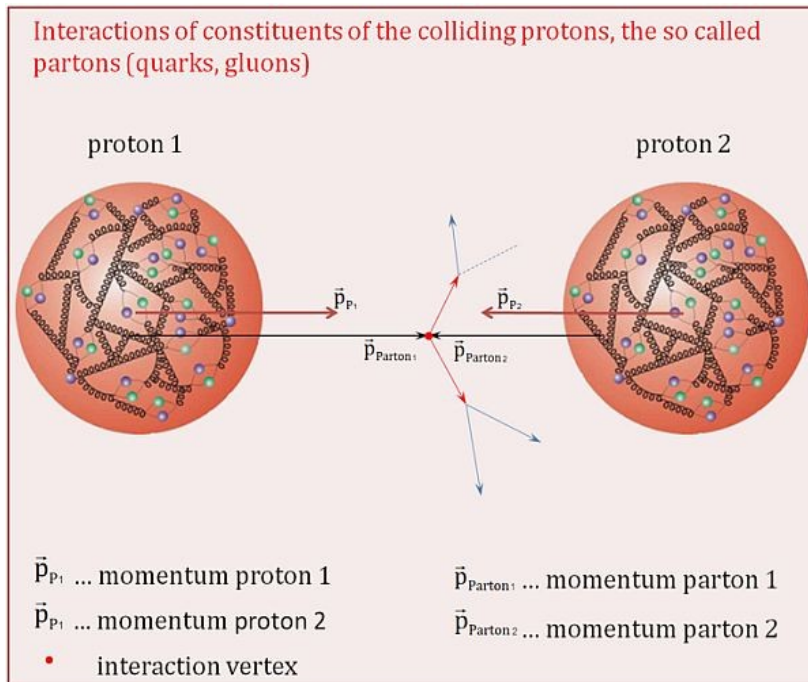
Higgs – Jak?

- Coctail party analogy:
- Hosté: Higgsovo pole.
- Osobnost: částice, obalením obdivovateli se pohybuje pomaleji: získala hmotnost.



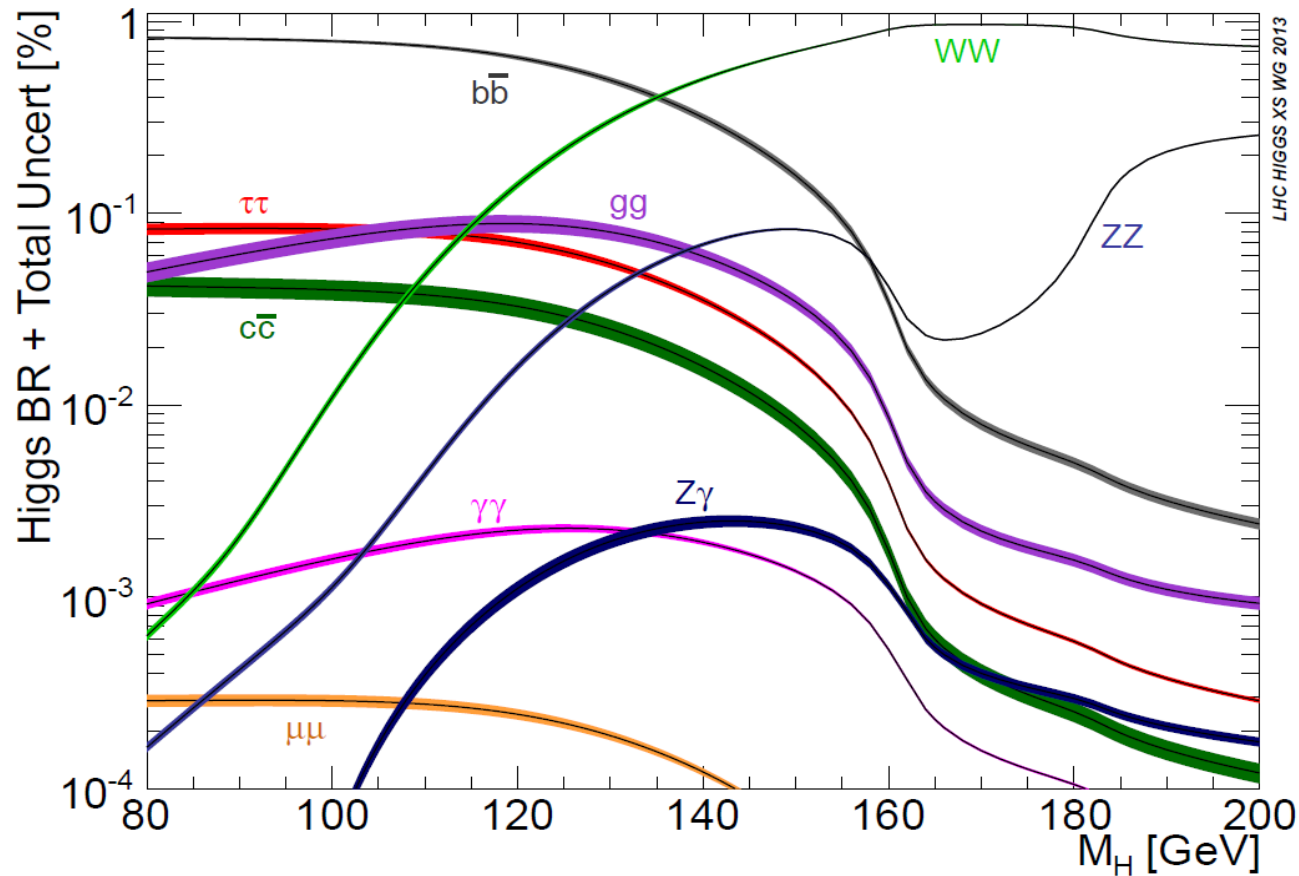
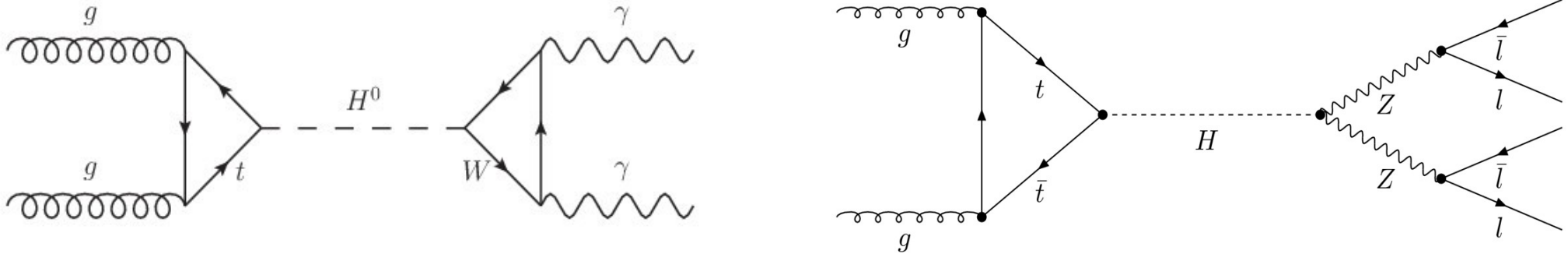
Higgs – Jak objevit?

- Srážet a čekat:)
- A hledat všude – teorie nepředpovídá jeho hmotnost.
- Higgs interaguje s částicemi “silou” úměrnou jejich hmotnosti.
- Neváže se tedy přímo na foton ani gluon.
- “Rád” se rozpadá na těžké částice.

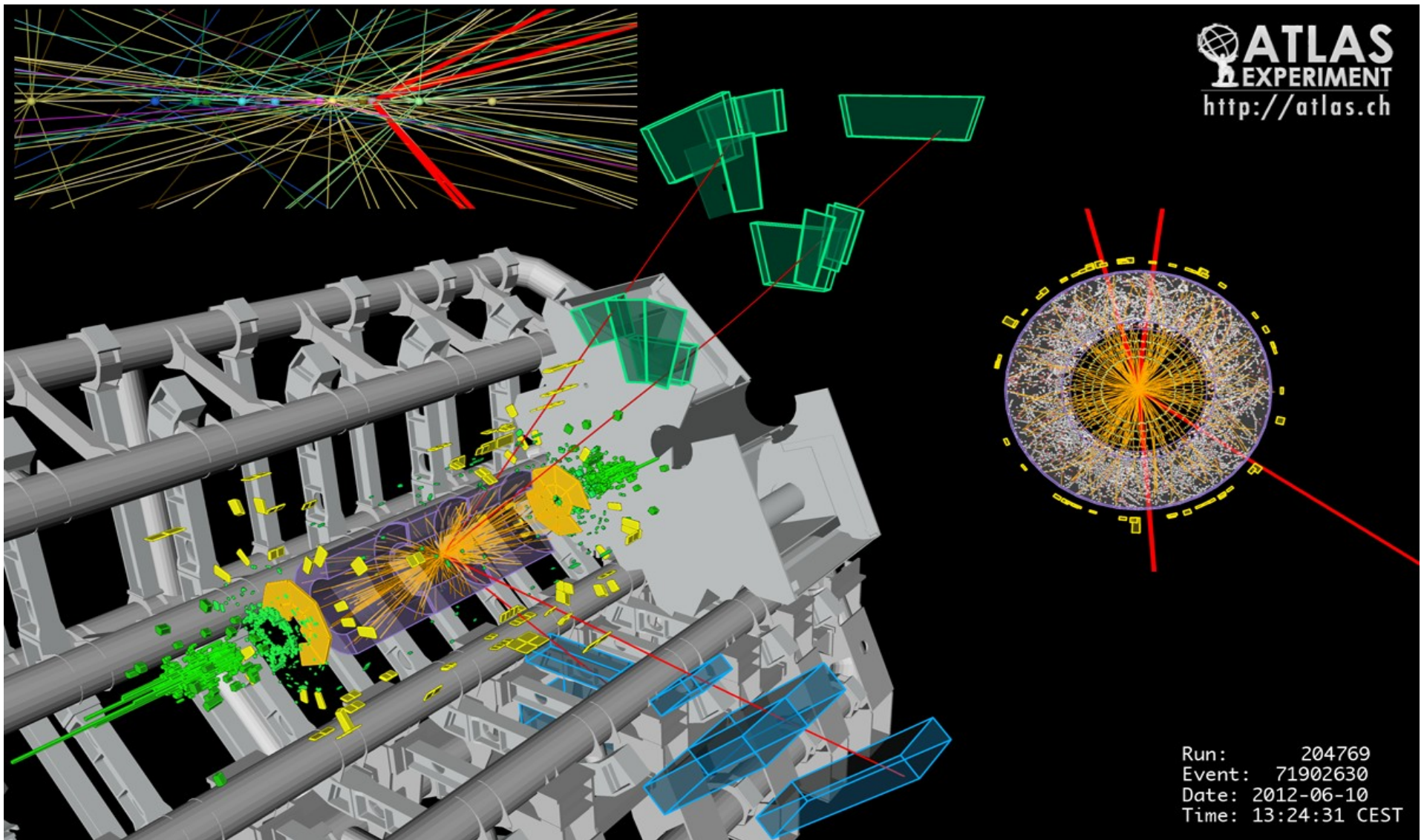


Higgs – Jak uvidět?

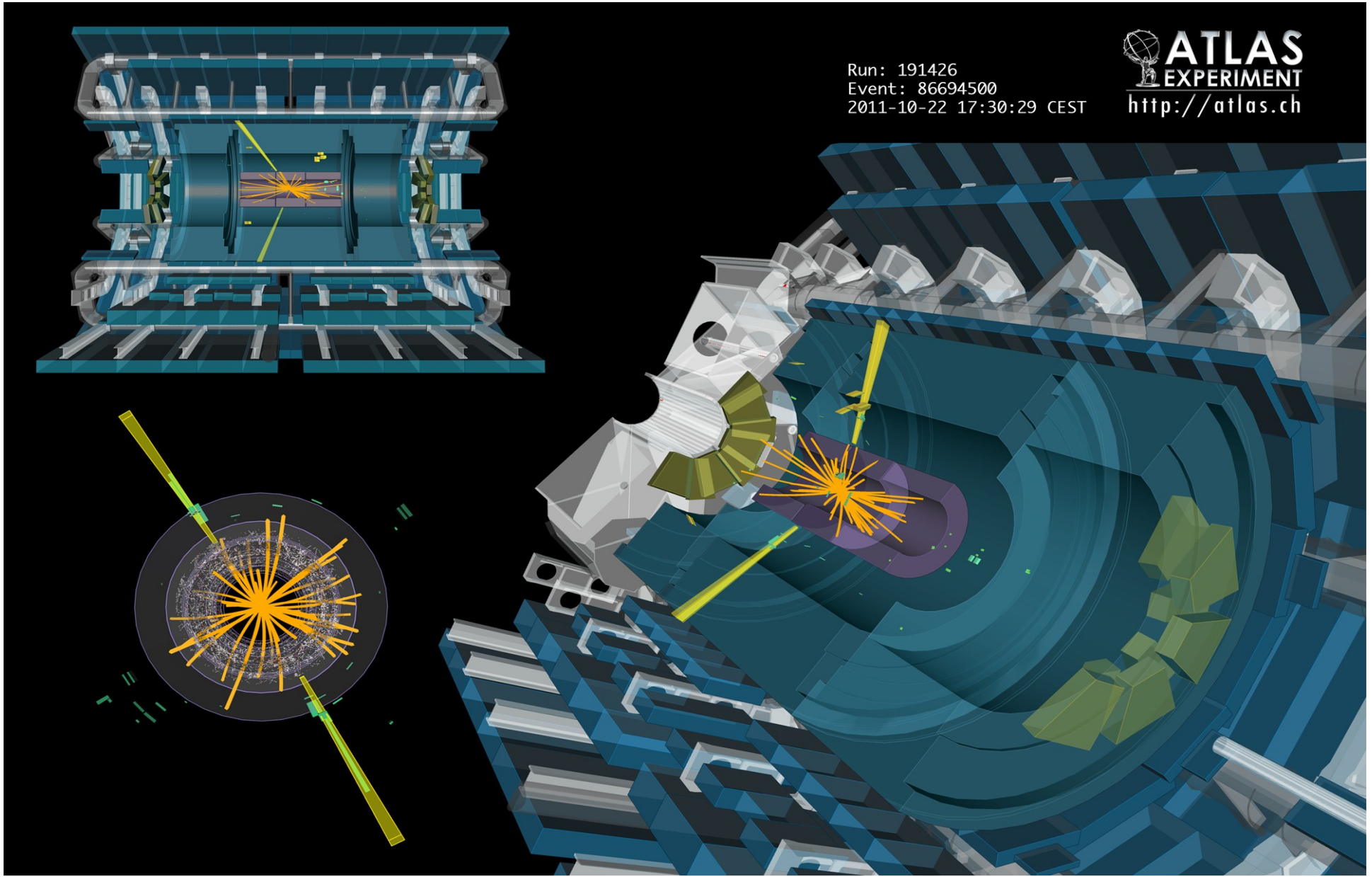
- Dle toho, na co se rozpadá: a to už teorie předpovídá!



Higgs – Jak vypadá?

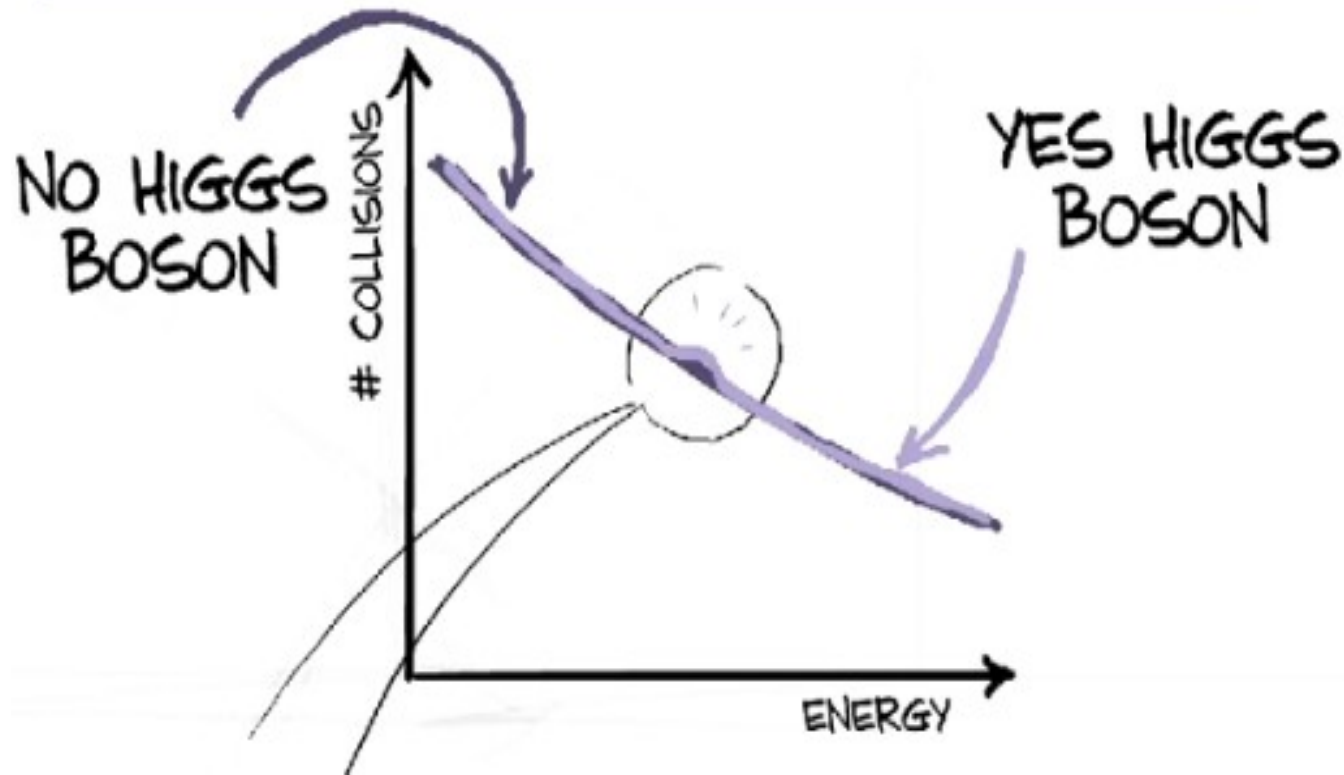


Higgs – Jak vypadá?



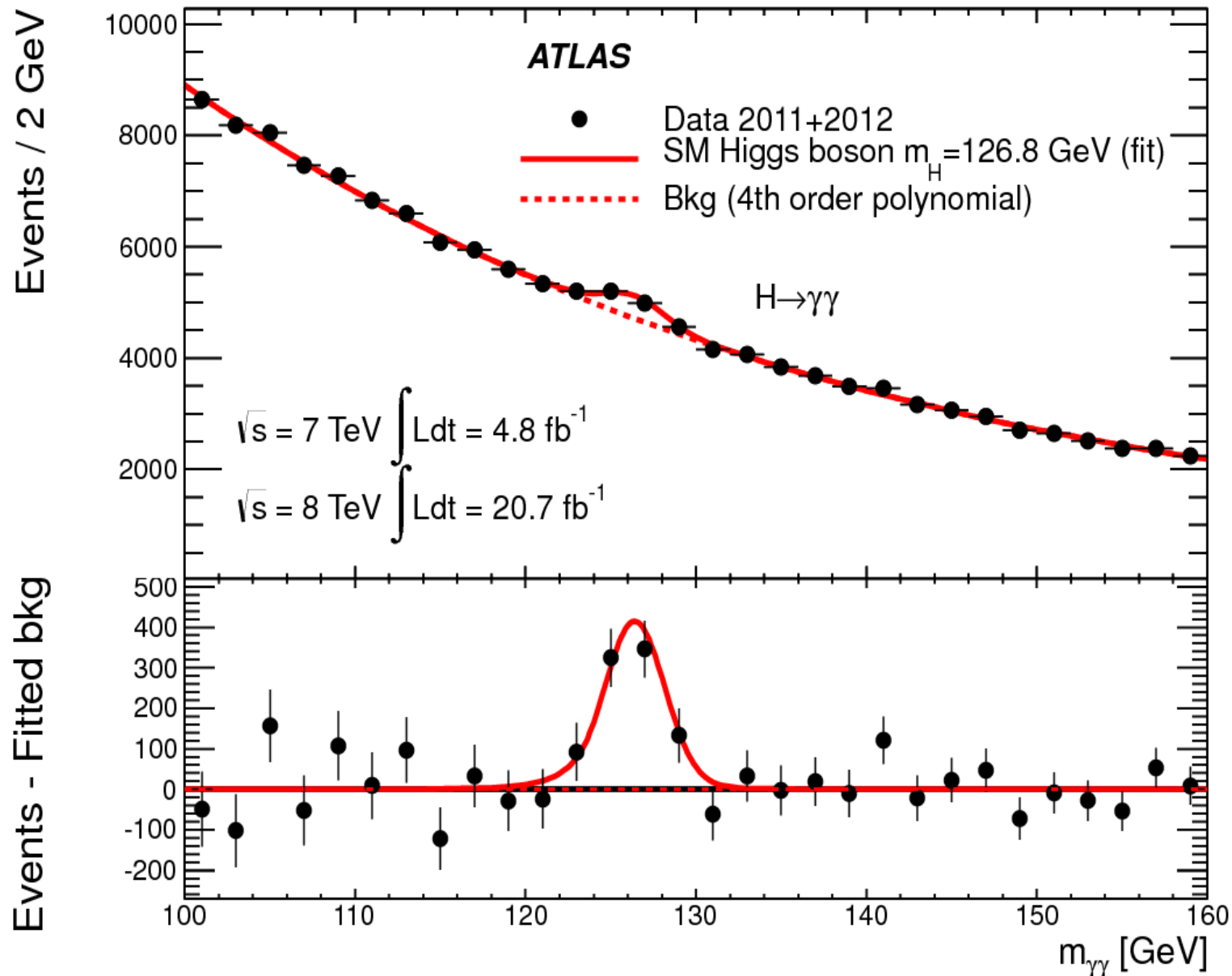
Higgs – Jak byl objeven?

THEN YOU HAVE 2 THEORIES THAT PREDICT THE DATA:



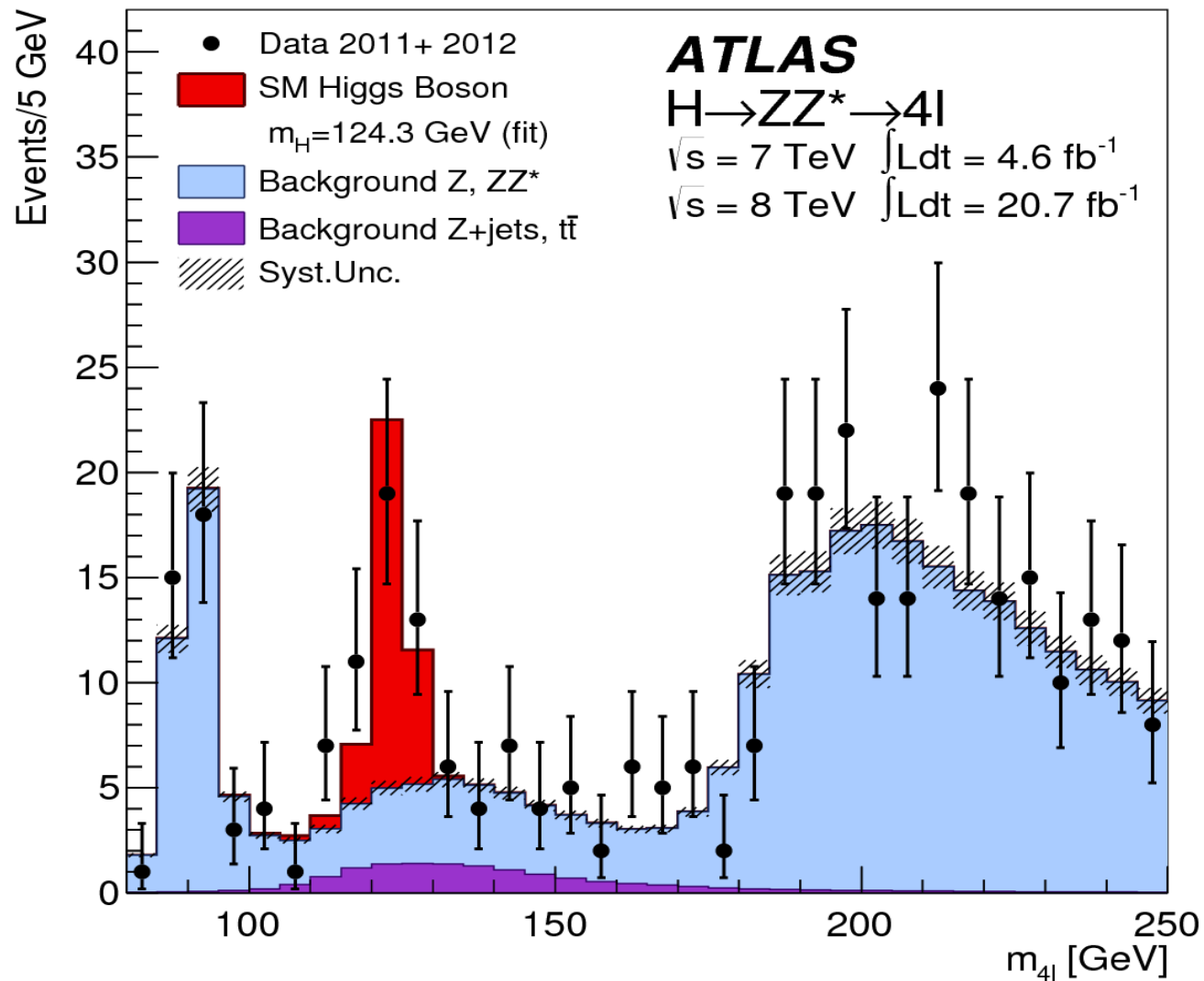
Higgs – Jak byl objeven?

- Data z roku 2011 (energie srážek 7TeV) a 2012 (8TeV).



Higgs – Jak byl objeven?

- Data z roku 2011 (energie srážek 7TeV) a 2012 (8TeV).



Higgs – objev

- Oznámen 4.7.2012 (ale náznaky již prosinec 2011).
- Poslední chybějící kousek Standardního modelu.
- Triumf teorie staré 50 let.
- <http://www.atlas.ch/HiggsResources/>

The Nobel Prize in Physics 2013

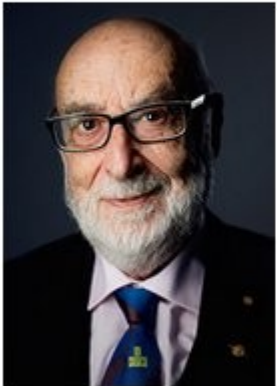


Photo: A. Mahmoud
François Englert
Prize share: 1/2



Photo: A. Mahmoud
Peter W. Higgs
Prize share: 1/2

9.1.2015



Higgs – objev



Higgs – objev



Higgs – objev



<https://www.facebook.com/ParticleOlomouc>
<http://www.phdcomics.com/comics.php?f=1489>
<http://www.atlas.ch/HiggsResources/>

www.cern.ch
www.atlas.ch
<http://particlefever.com/>

