

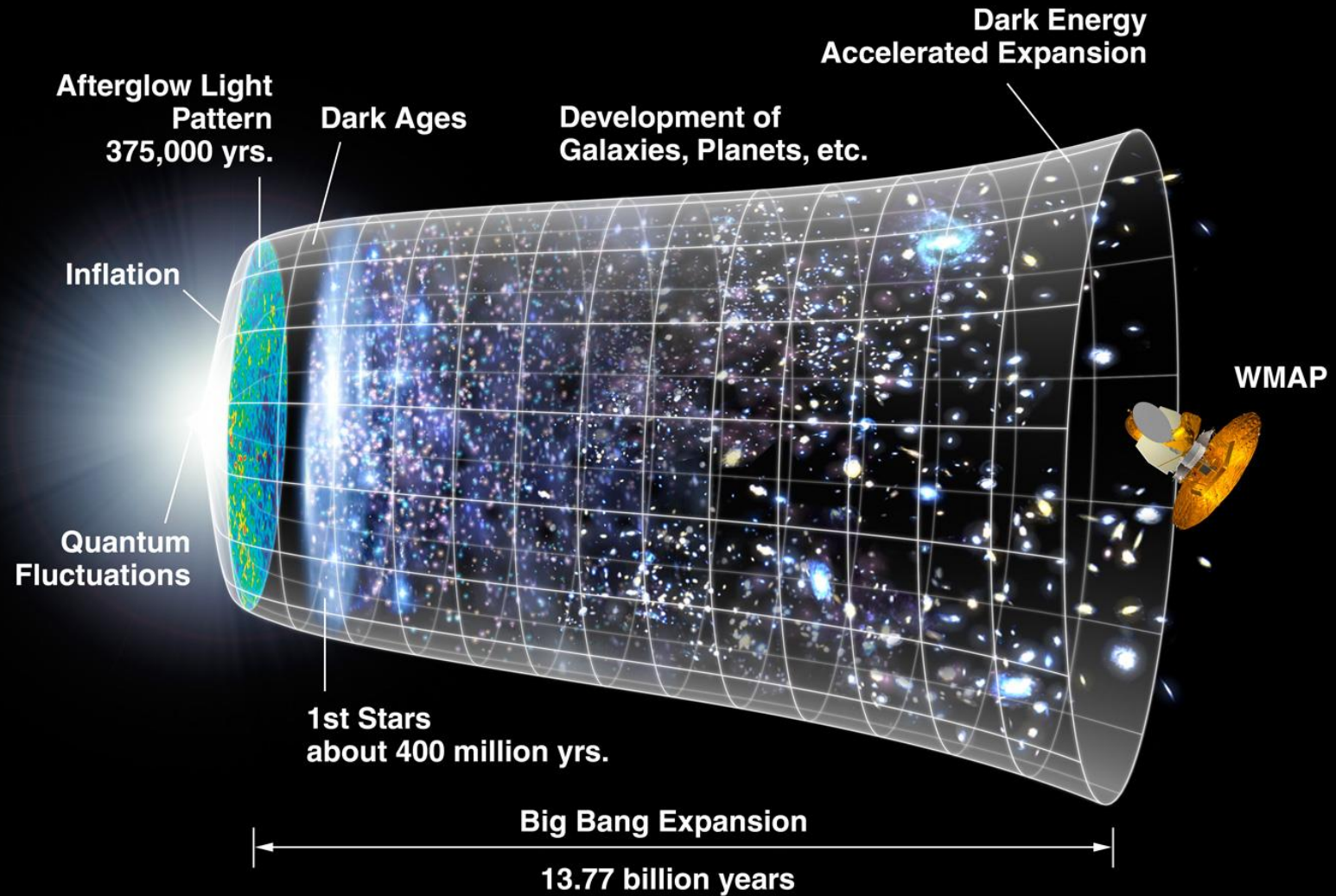
*Částicová fyzika  
s experimentem  
ATLAS*

Jiří Kvita

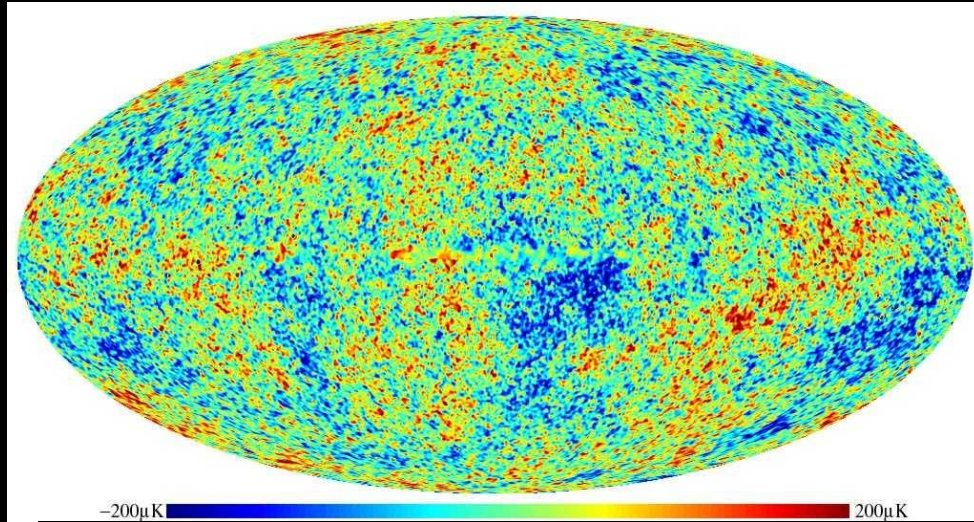
PřF UP, RCPTM, Olomouc



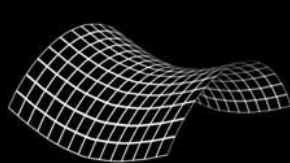
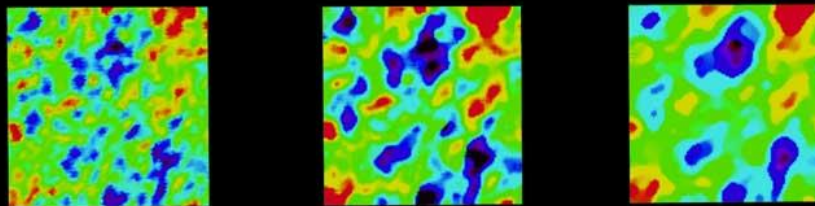
# Od Velkého třesku po současnost



# Fluktuace záření kosmického pozadí

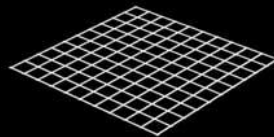


## GEOMETRY OF THE UNIVERSE



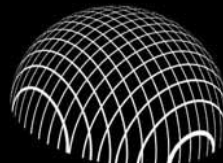
**OPEN**

Fluctuations largest on half-degree scale



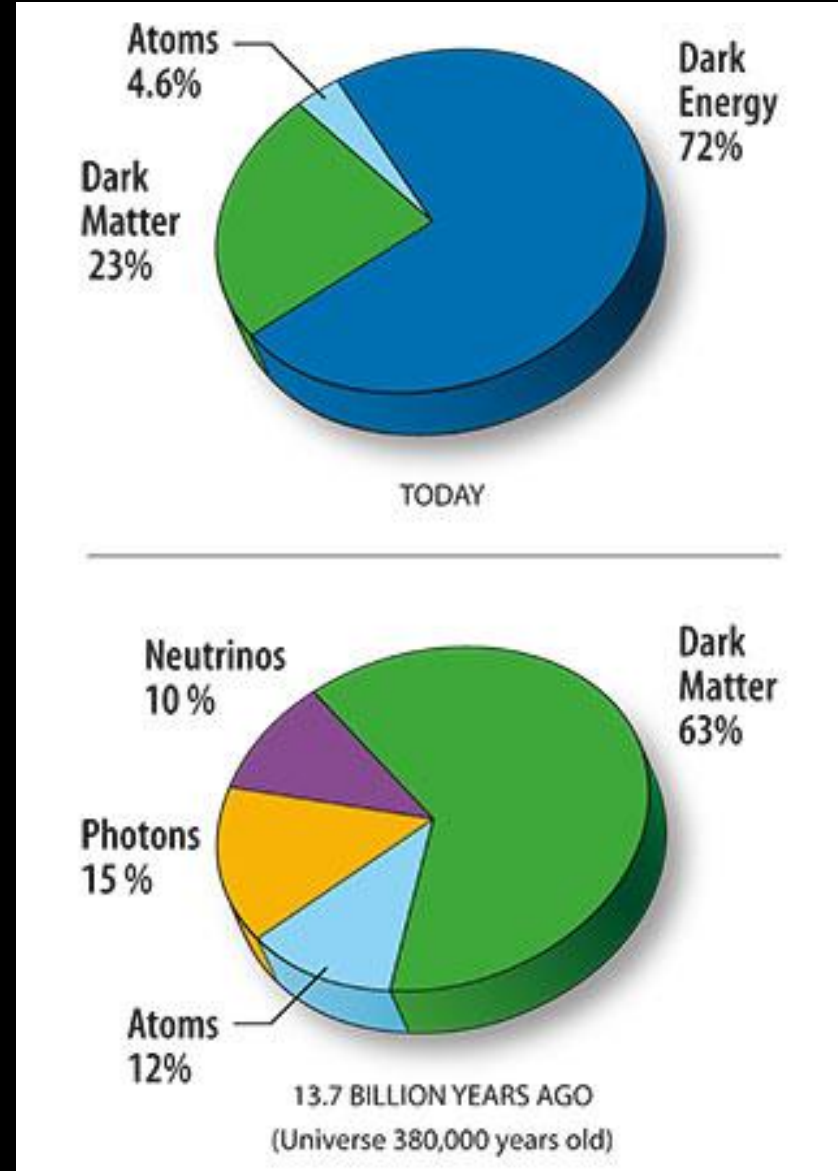
**FLAT**

Fluctuations largest on 1-degree scale

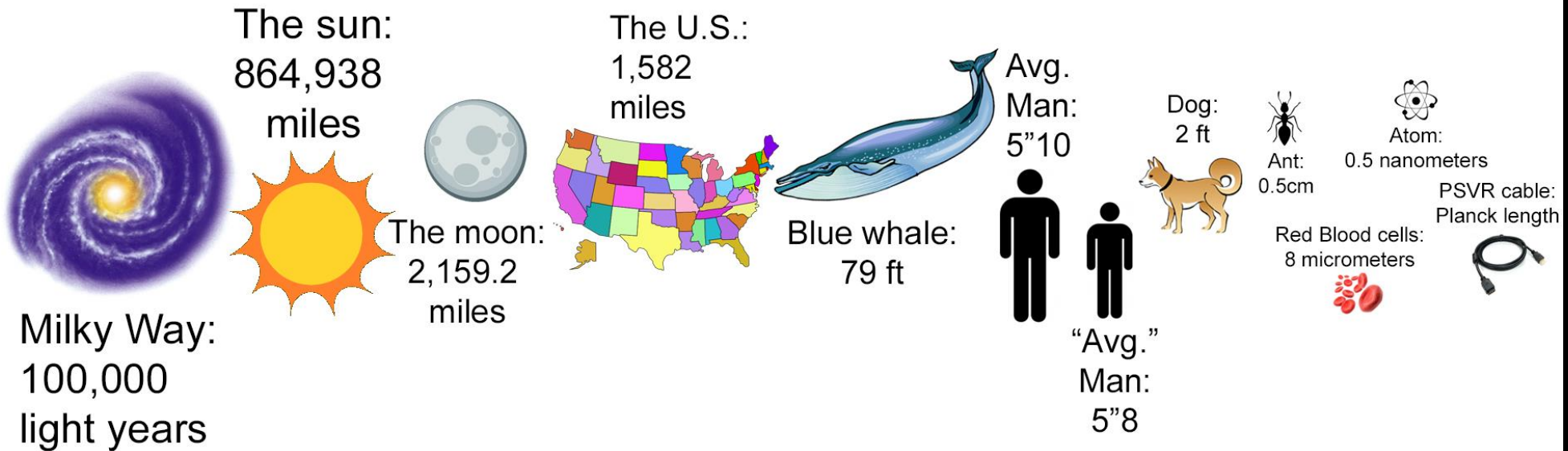


**CLOSED**

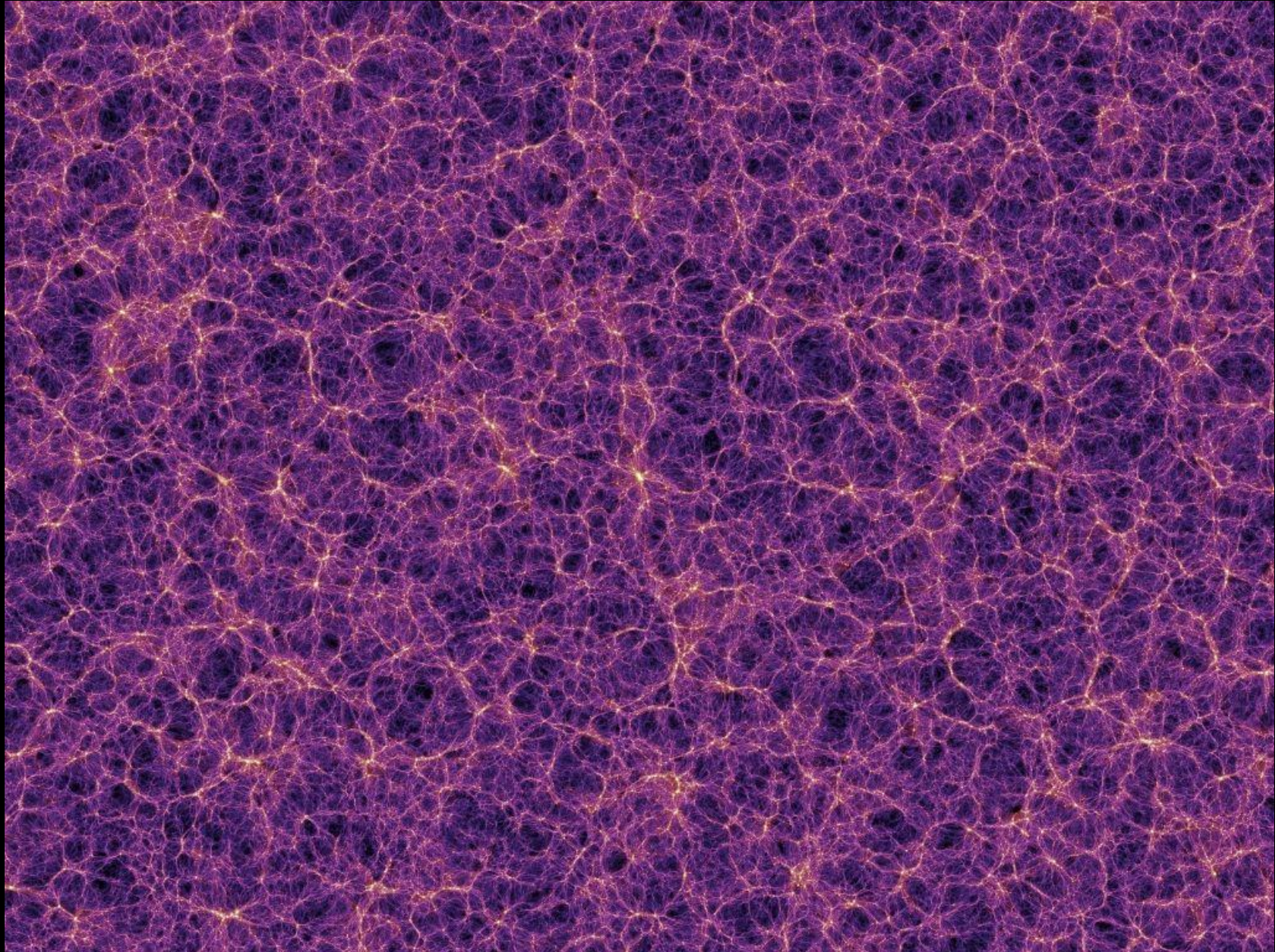
Fluctuations largest on greater than 1-degree scale



# Škály délek



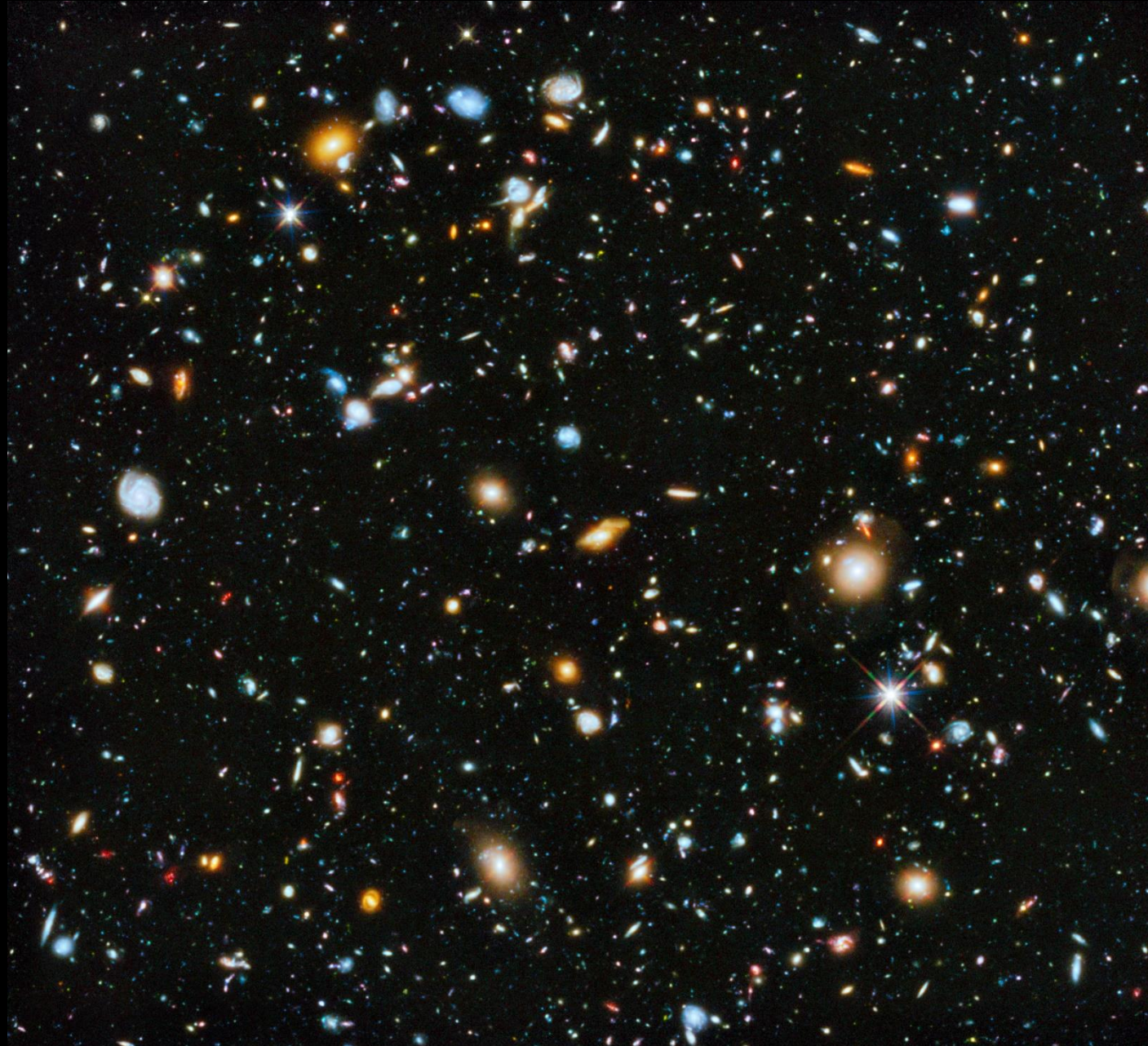
# Vesmír



$10^{26}$  m, 10 Gly

Millennium Simulation

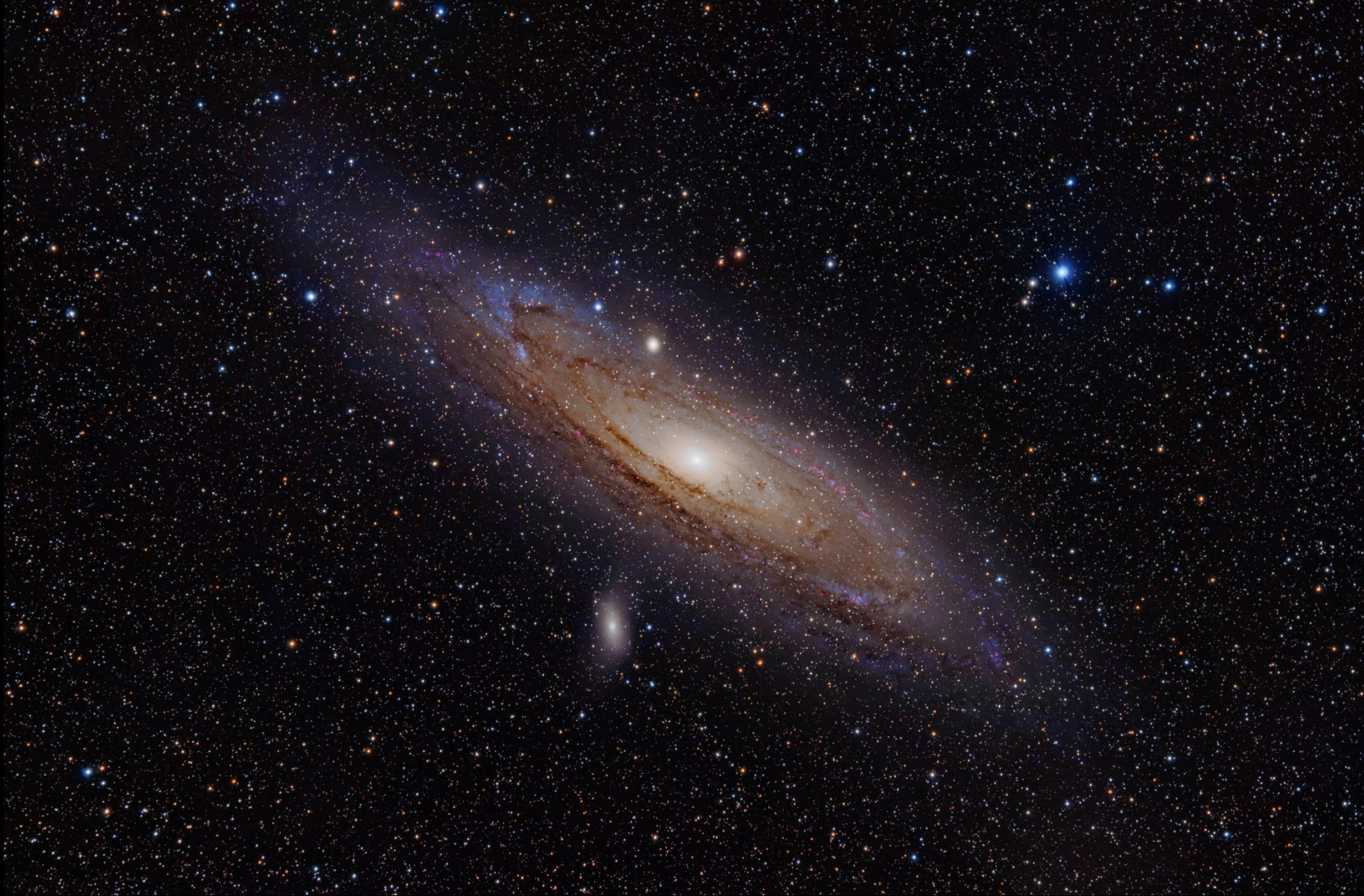
# Kupy galaxií



$10^{23}$  m, 10 Mly

Hubble Space Telescope

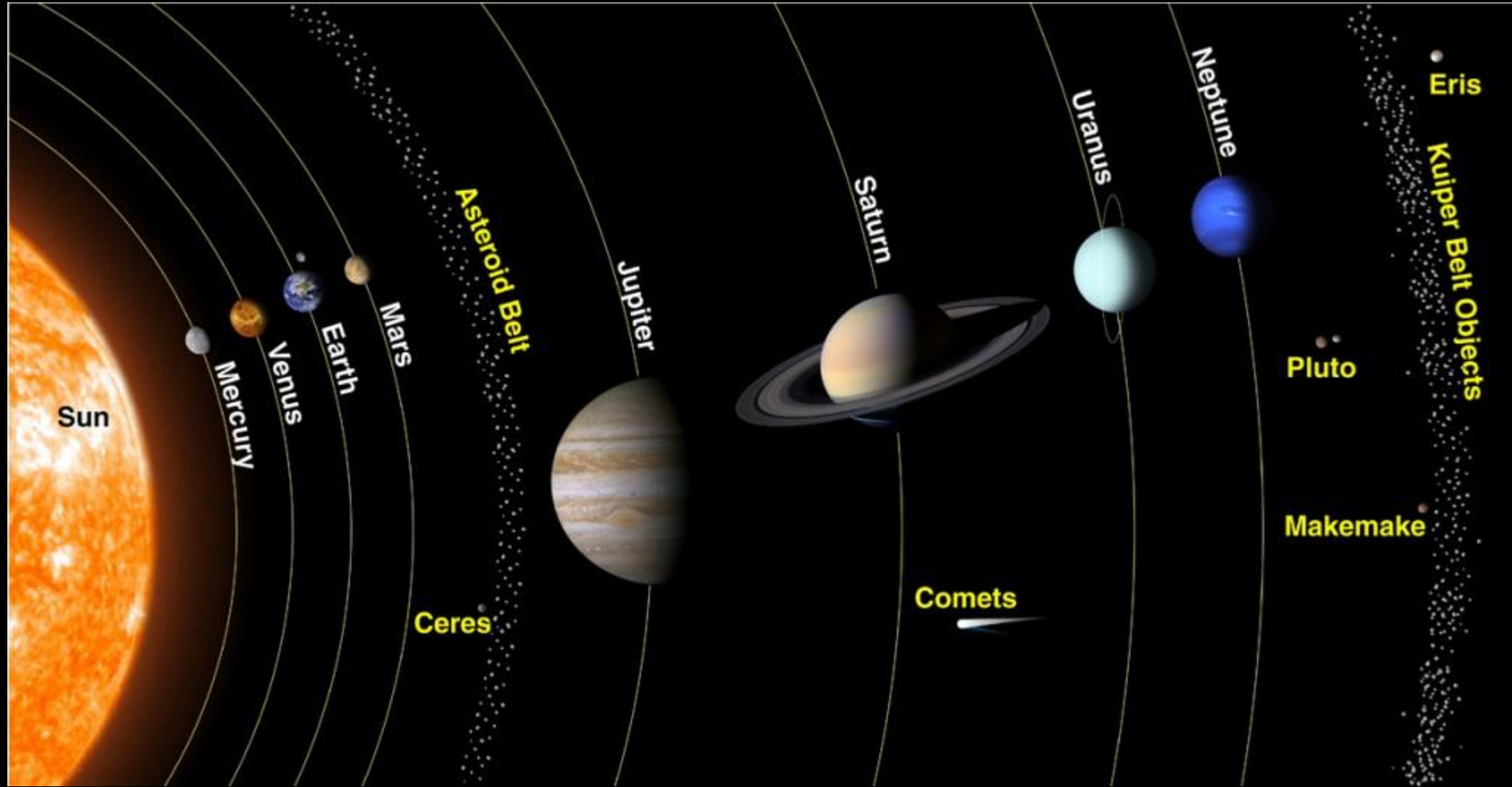
# Galaxie



$10^{21}$  m, 100 kly

Adam Evans

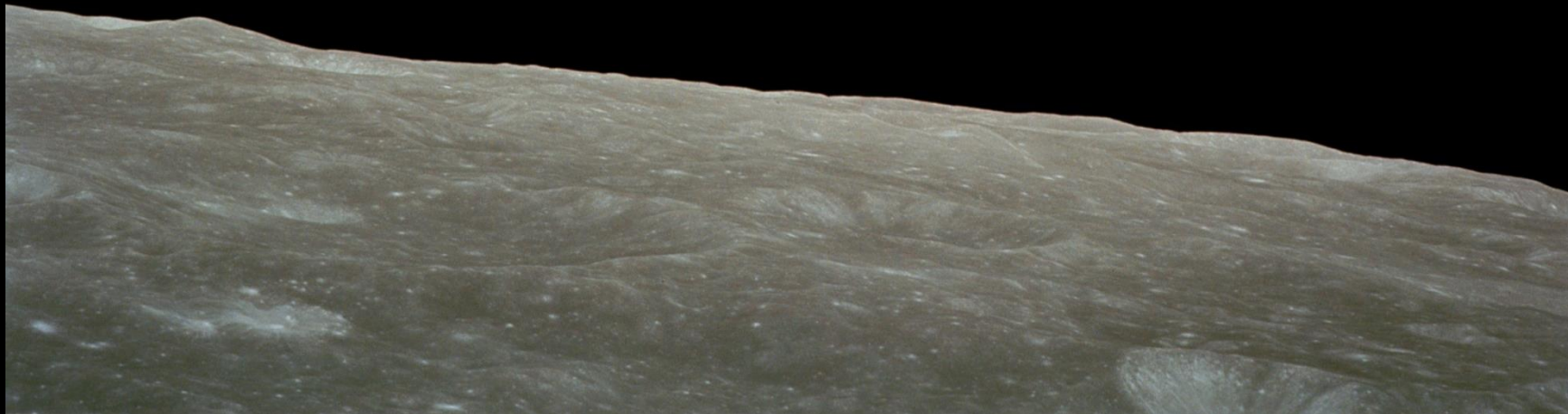
# Sluneční soustava



$10^{11}$  m, 10 lh



# Ze Země na Měsíc



$10^8$  m, 1 ls

# Země



$10^7$  m

by Apollo 17

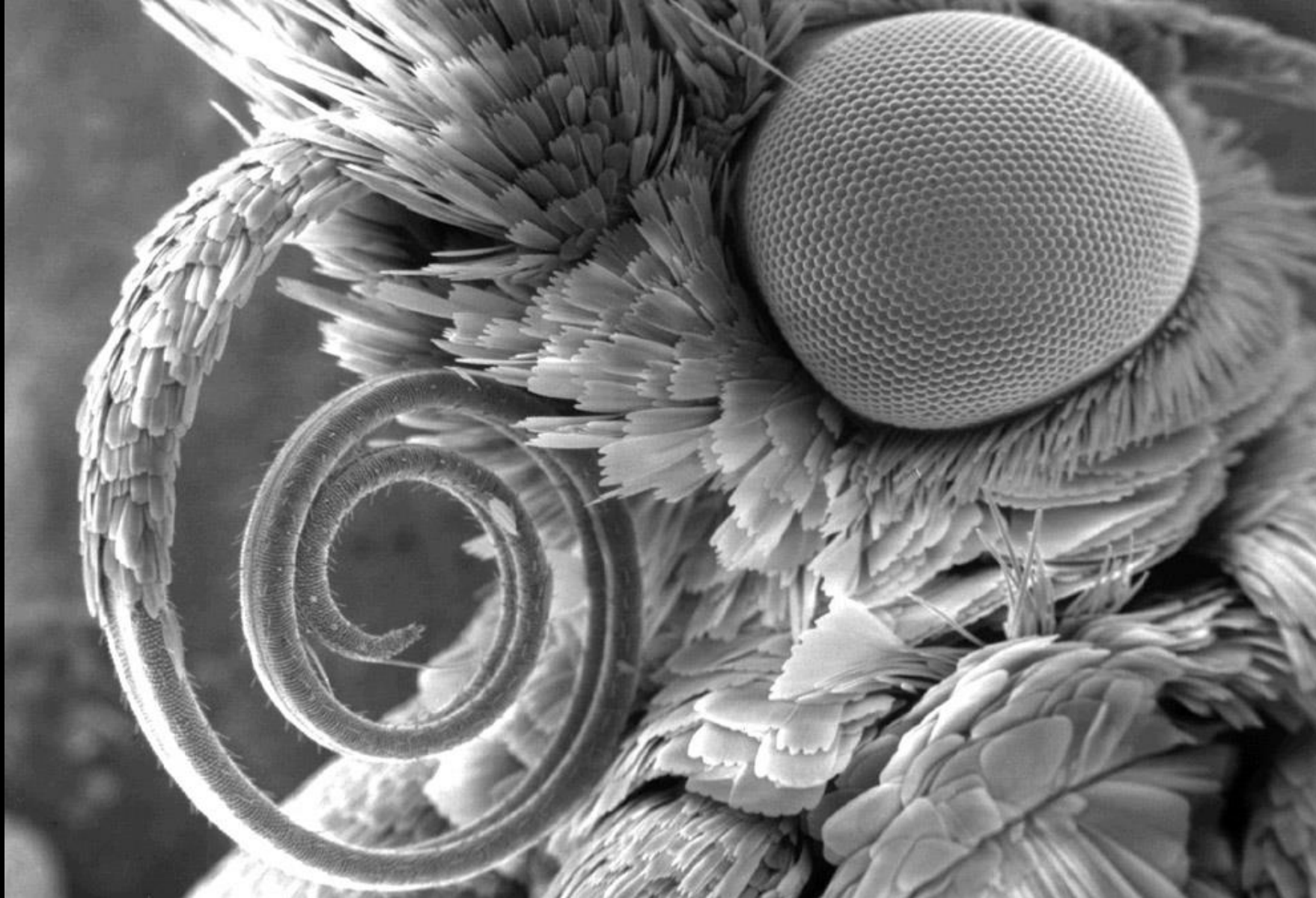
# Tvor



$10^{-2}$  m

Optická fotografie listovnice nádherné, ifauna.cz

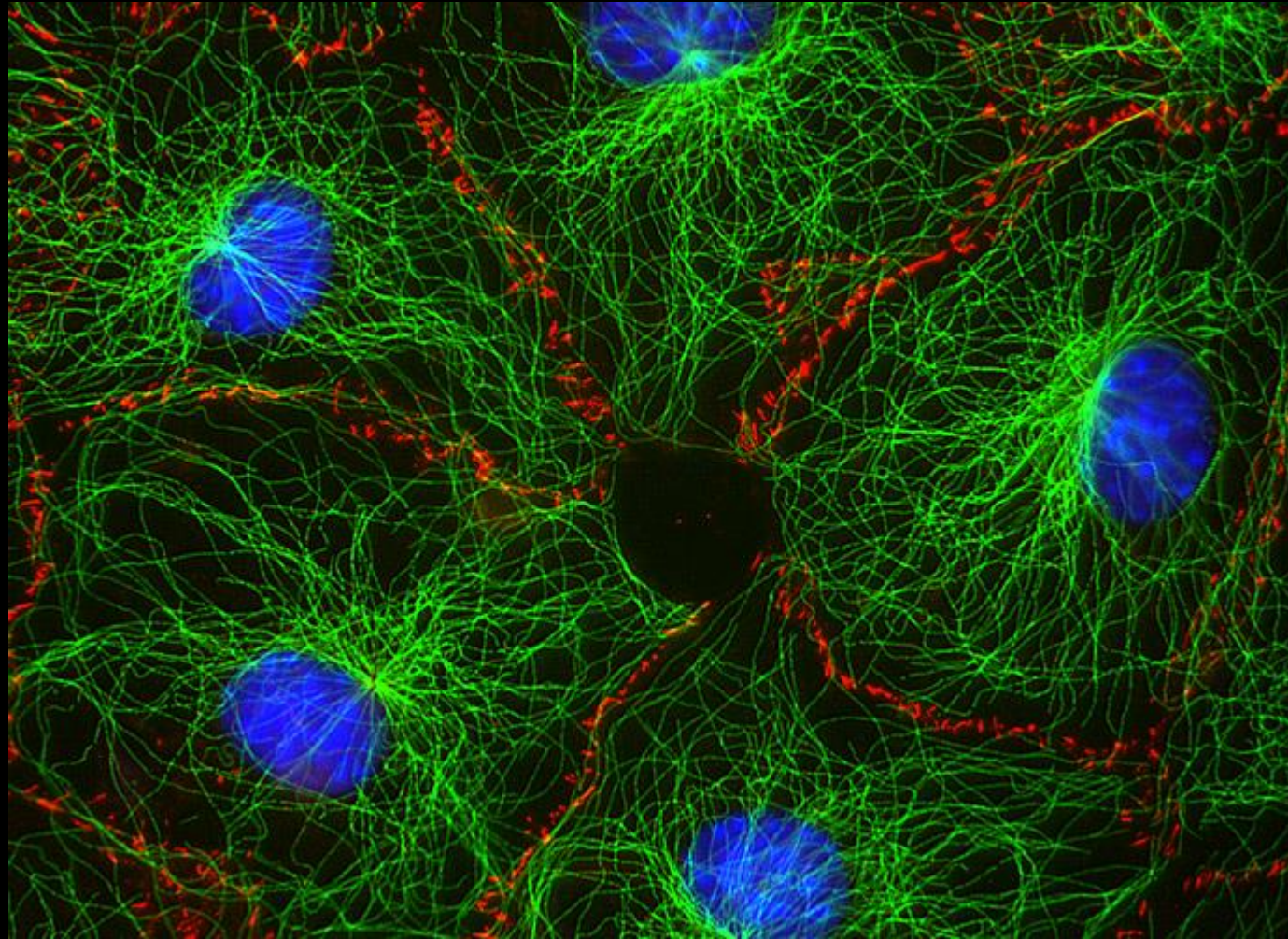
# Tvor II



$10^{-3}$  m

Motýl elektronovým mikroskopem na Dartmouth College

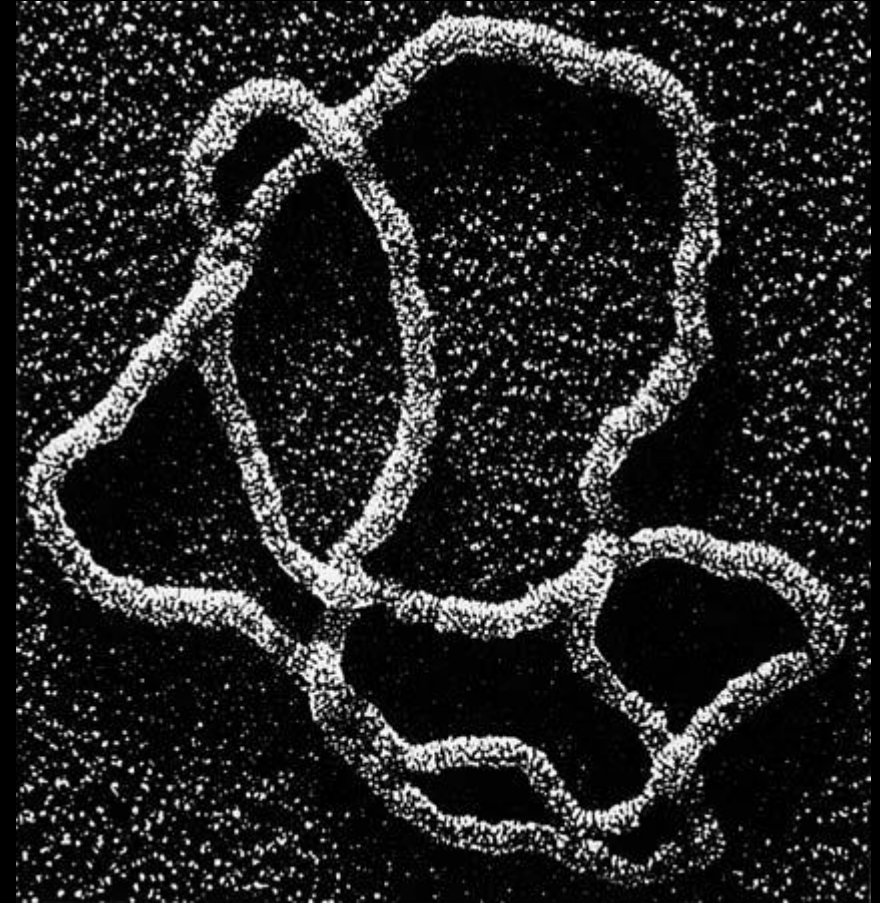
# Buňka



$10^{-5}$  m

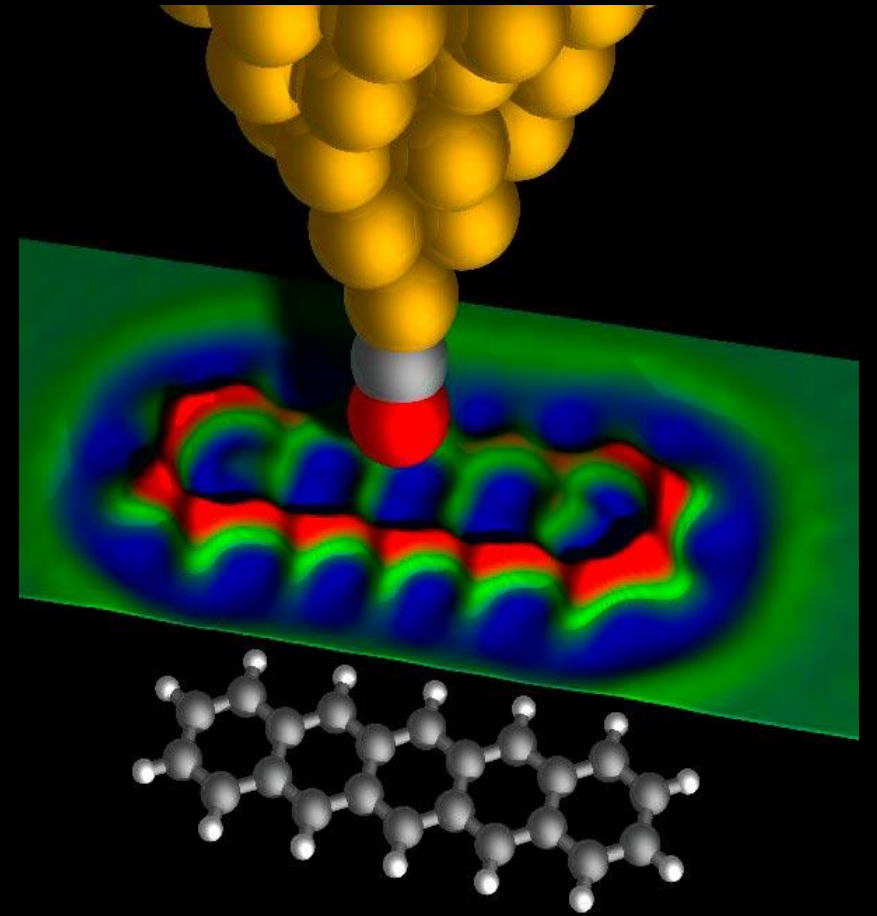
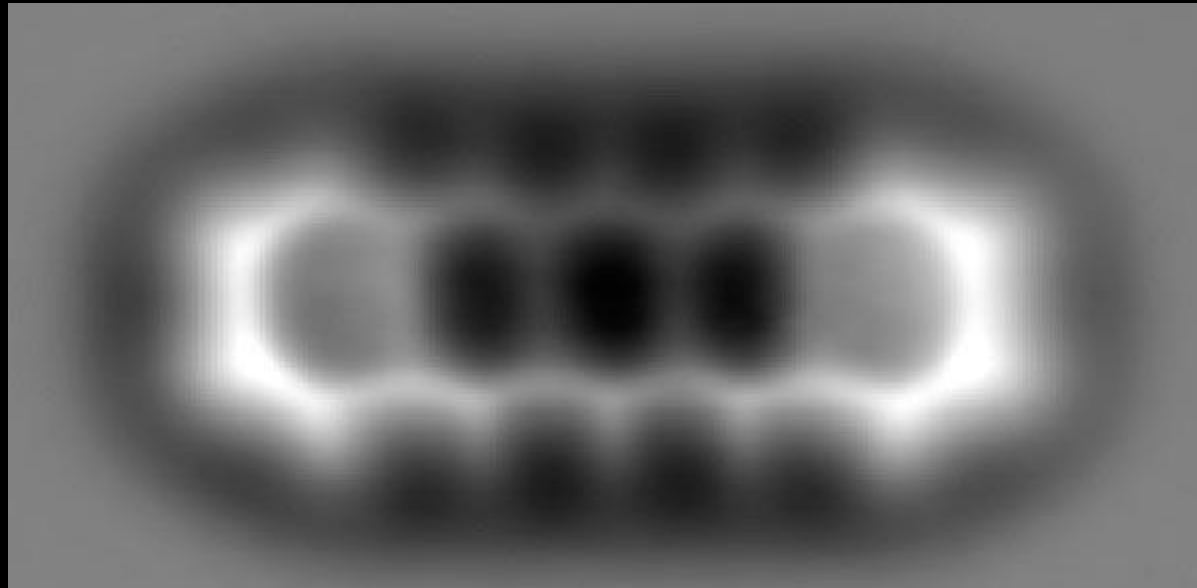
myší vazivová buňka, Jan Schmoranzner

# Molekula DNA – model vs. fotografie

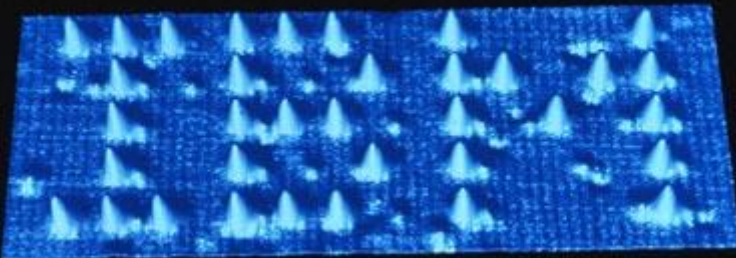
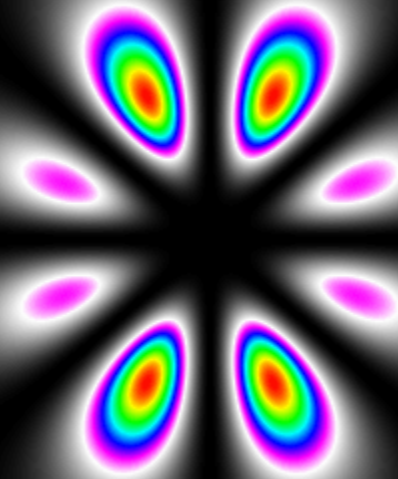
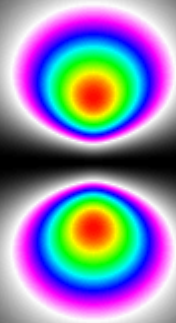
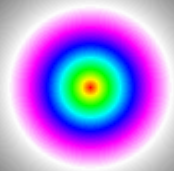


$10^{-8}$  m

# Molekula pentacenu – obláčky elektronů



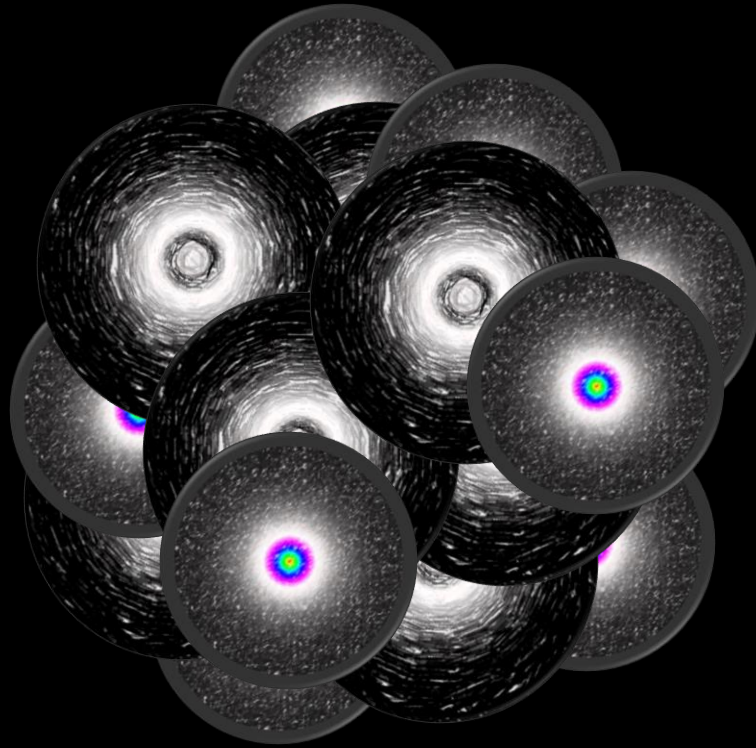
# Atom – stojaté vlny elektronů kolem jádra



$10^{-10}$  m, eV – keV

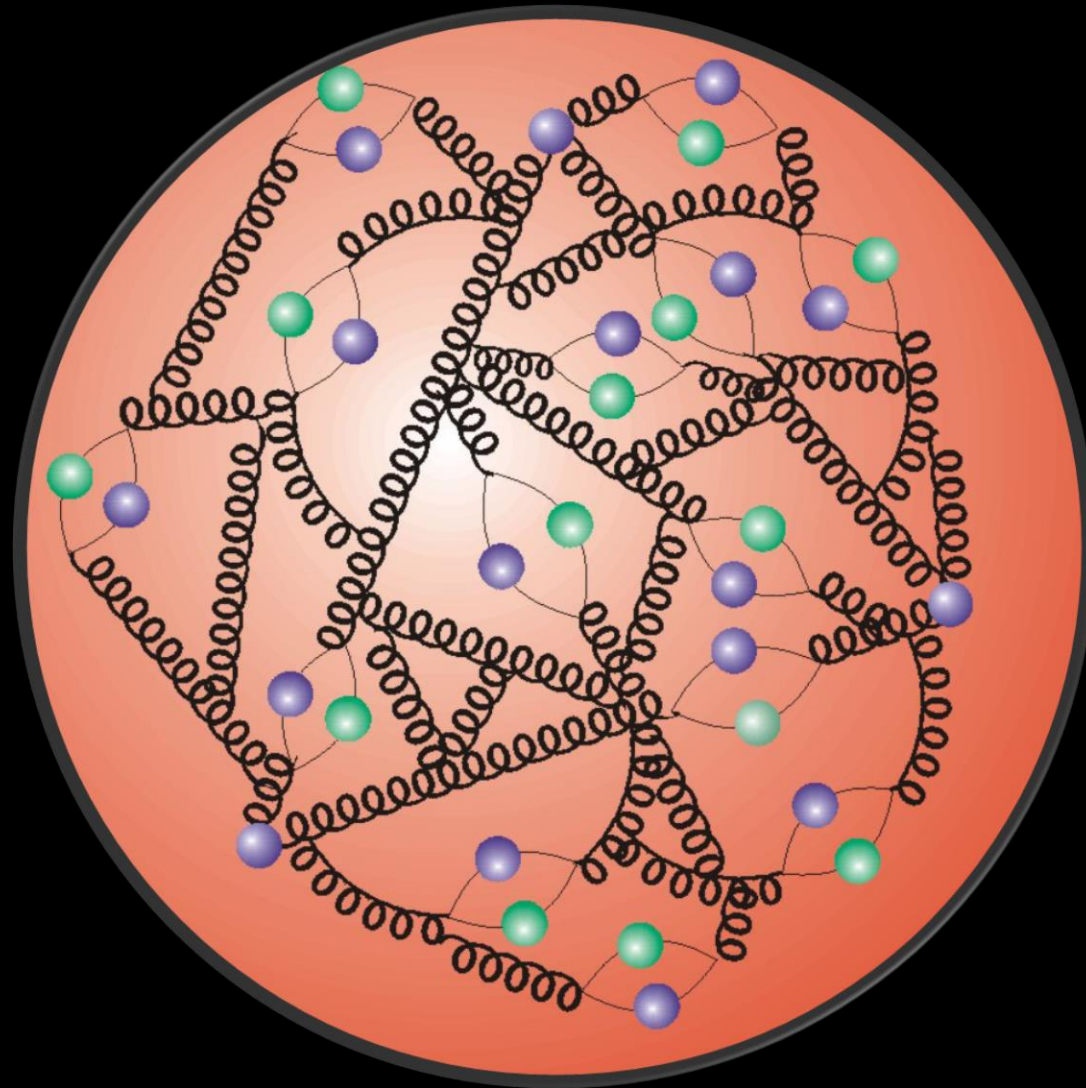


# Jádro – protony a neutrony



$10^{-14}$  m, MeV

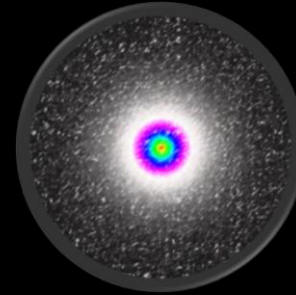
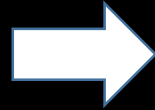
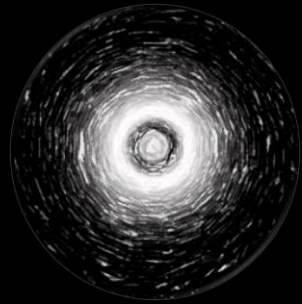
# Proton – polévka kvarků a gluonů



$10^{-15}$  m, GeV

# Rozpad volného neutronu

Neutron



Proton

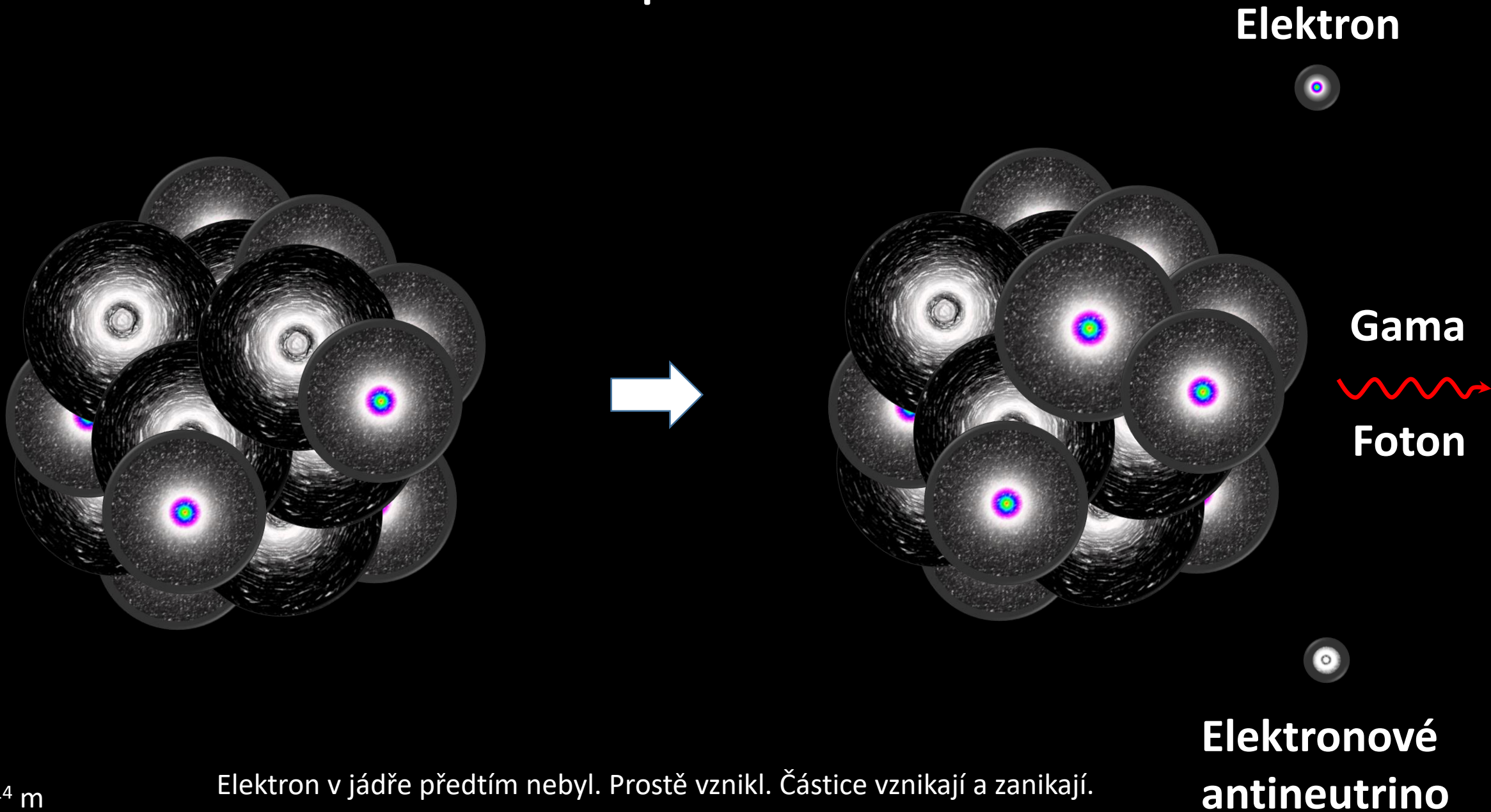


Elektron



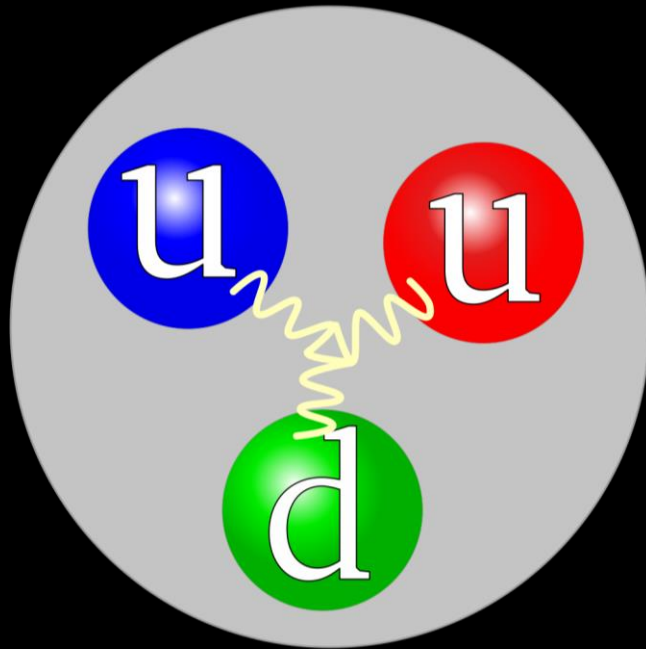
Elektronové  
antineutrino

# Rozpad atomu

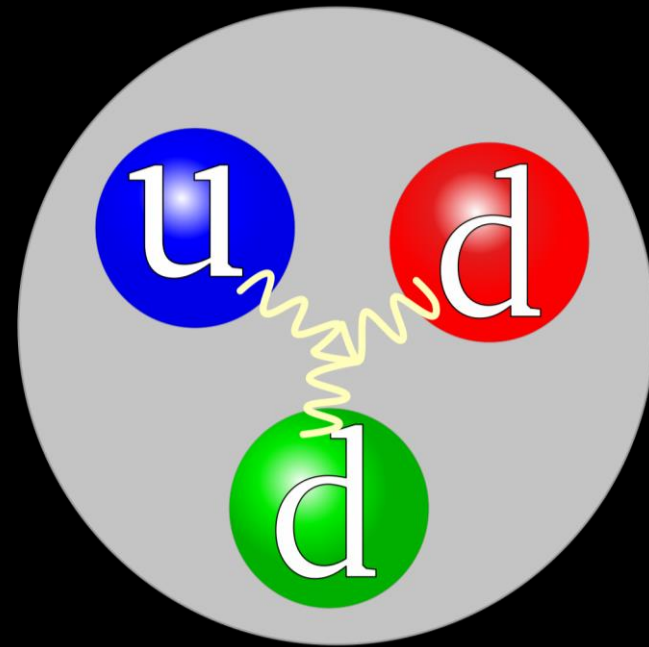


# Proton a neutron

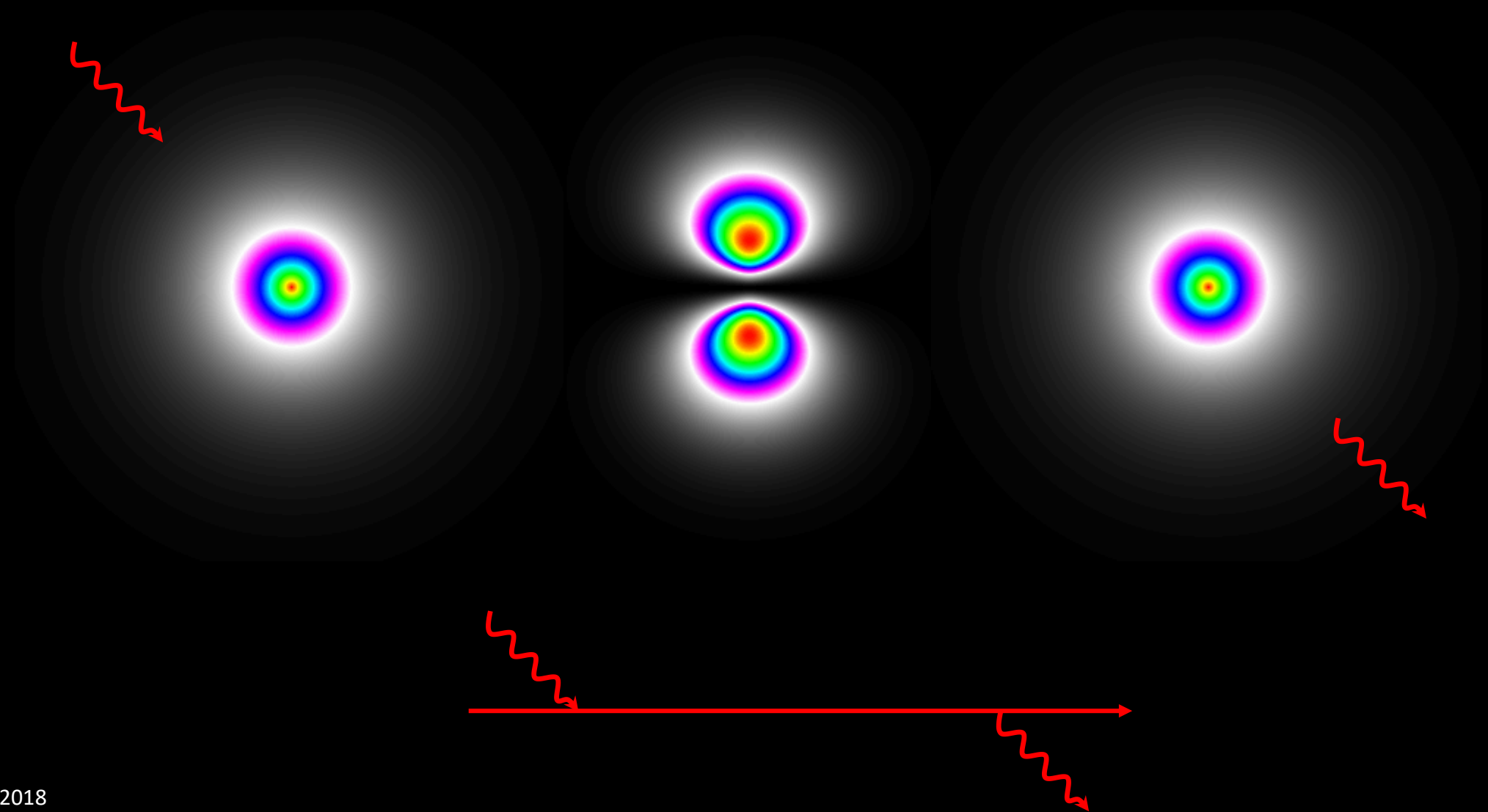
Proton



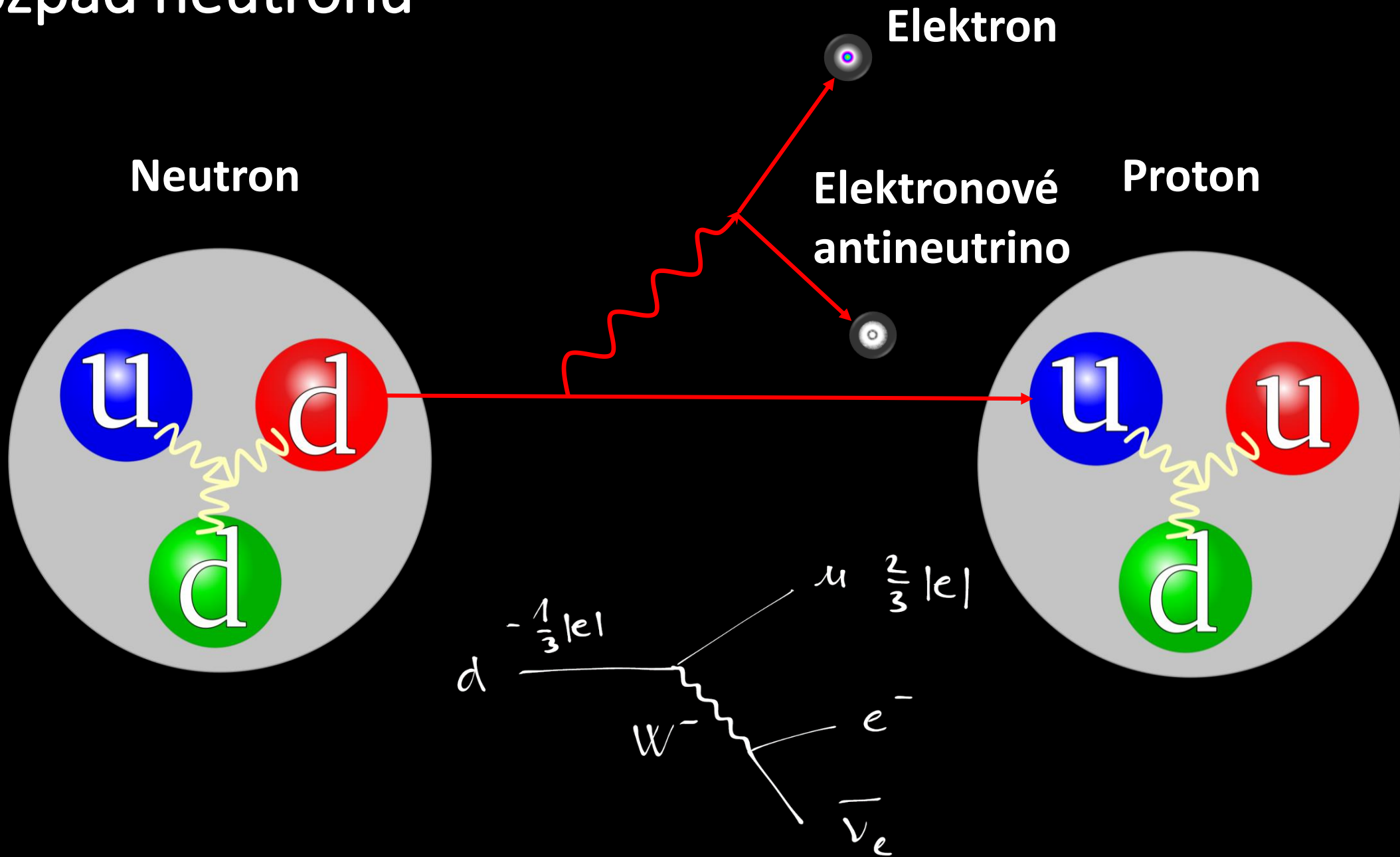
Neutron



# Posviťme si na atom!

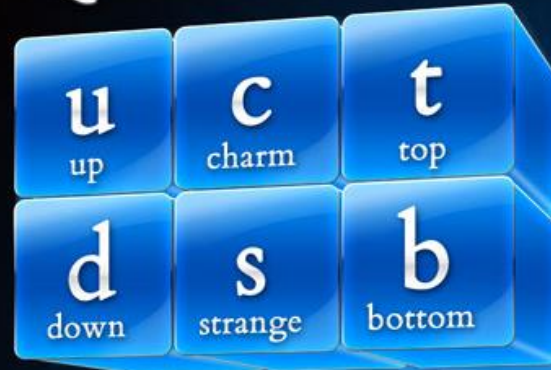


# Rozpad neutronu



# Elementární částice

## Quarks



## Leptons



## Force Carriers



H  
Higgs boson

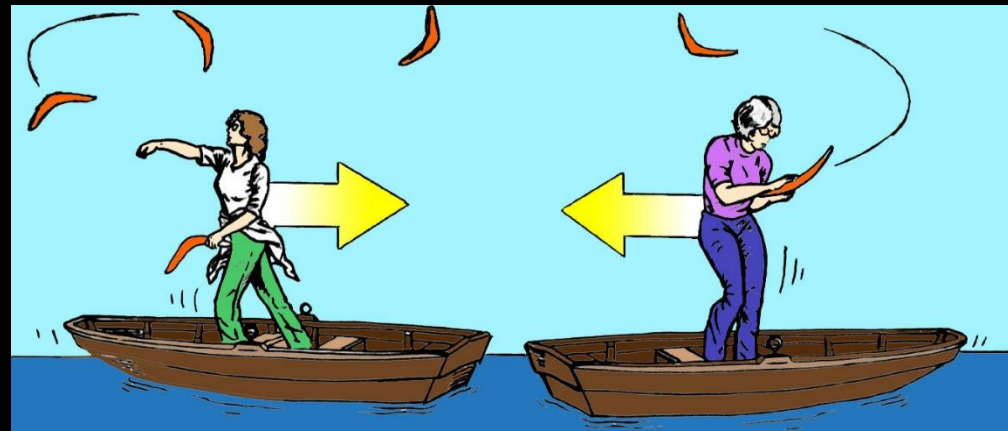


# Interakce jako výměna částic

- Odpuzování



- Přitahování

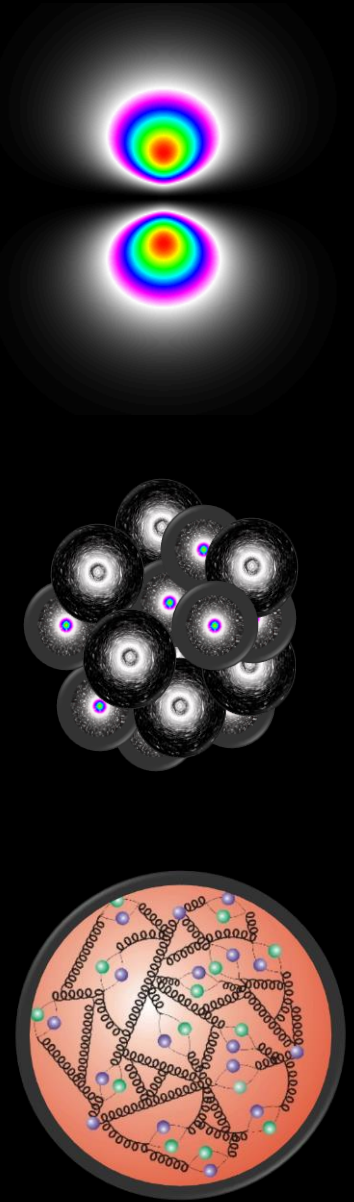


# Škály energií

- Atomový obal
  - 10 nm, 10 eV – keV
- Atomové jádro
  - 100 fm, MeV – 10 MeV
- Struktura protonu
  - 1 fm, GeV

1 elektronvolt: kinetické energie, kterou získá částice náboje velikosti náboje elektrony po urychlení napětím jednoho voltu.

$$1\text{eV} = 1,602 \cdot 10^{-19} \text{ J}$$



# Klidové energie částic

$$E = mc^2$$

$$m_e c^2 \doteq 0.511 \text{ MeV}$$

$$m_\mu c^2 \doteq 105.7 \text{ MeV}$$

$$m_p c^2 \doteq 938 \text{ MeV}$$

$$m_n c^2 \doteq 939 \text{ MeV}$$

$$m_W c^2 \doteq 80.4 \text{ GeV}$$

$$m_Z c^2 \doteq 91.2 \text{ GeV}$$

$$m_H c^2 \doteq 125 \text{ GeV}$$

# Přechody mezi hladinami

$$h\nu_{n,m} = h\omega_{n,m} = E_m - E_n$$

$$h\nu_{2,1} = 13.6 \left[ \frac{1}{1^2} - \frac{1}{2^2} \right]$$

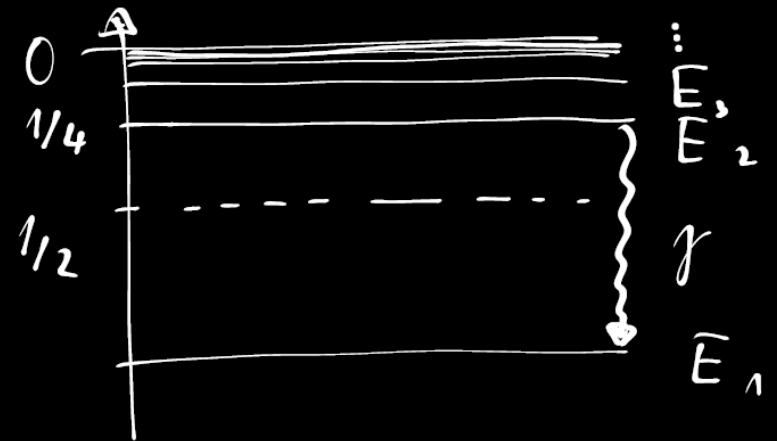
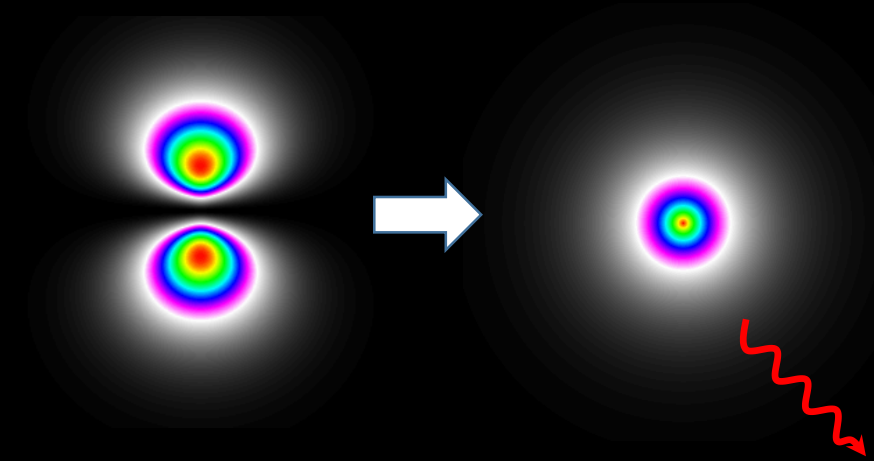
$$= 13.6 \cdot \frac{3}{4} = 10.2 \text{ eV}$$

$$\lambda = cT = c/\nu$$

$$\lambda_{nm} = \frac{hc}{E_1 \left( \frac{1}{n^2} - \frac{1}{m^2} \right)}$$

$$E_1 = 13.6 \text{ eV}$$

$$\lambda_{12} = 121.6 \text{ nm}$$



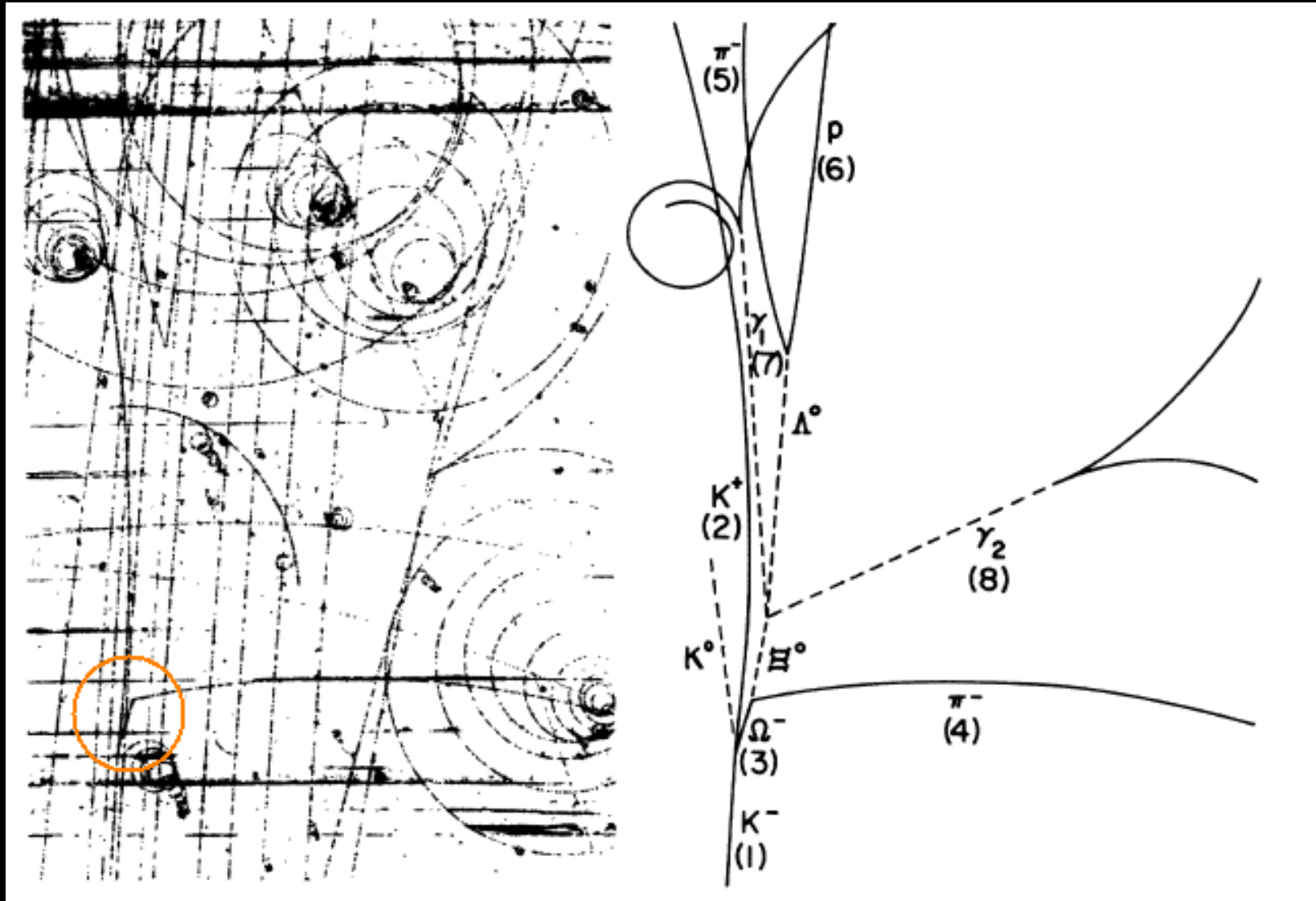
$$E_n = -\frac{13.6 \text{ eV}}{n^2}$$

# Jak vidíme částice?

- bublinová komora, 1960s-1970s

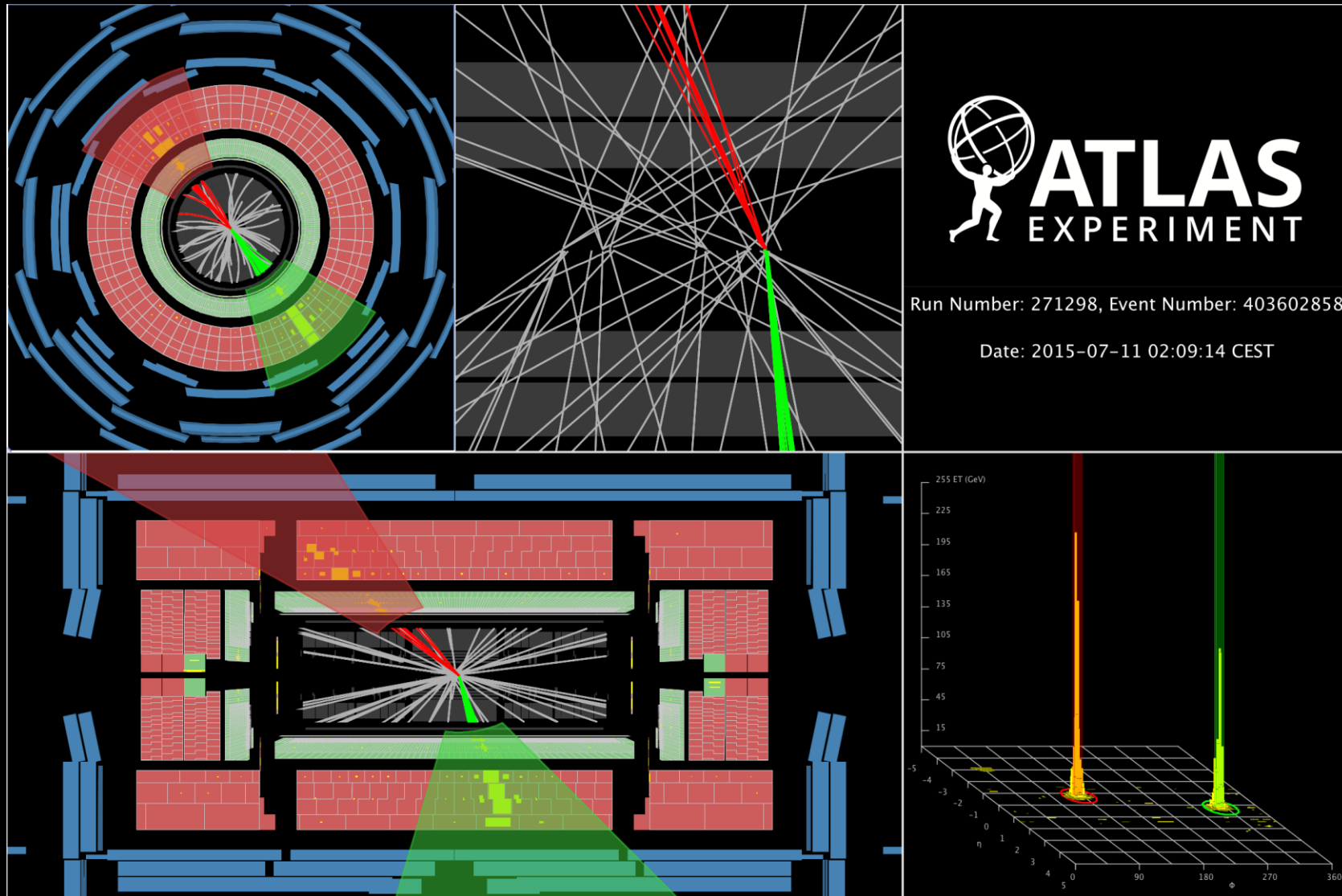


# Objev částice $\Omega^-$ , 1964



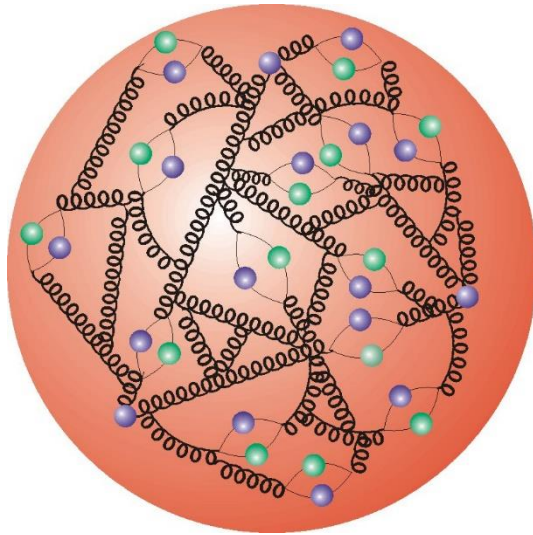
# Jak vidíme částice?

- současnost



# Srážky částic

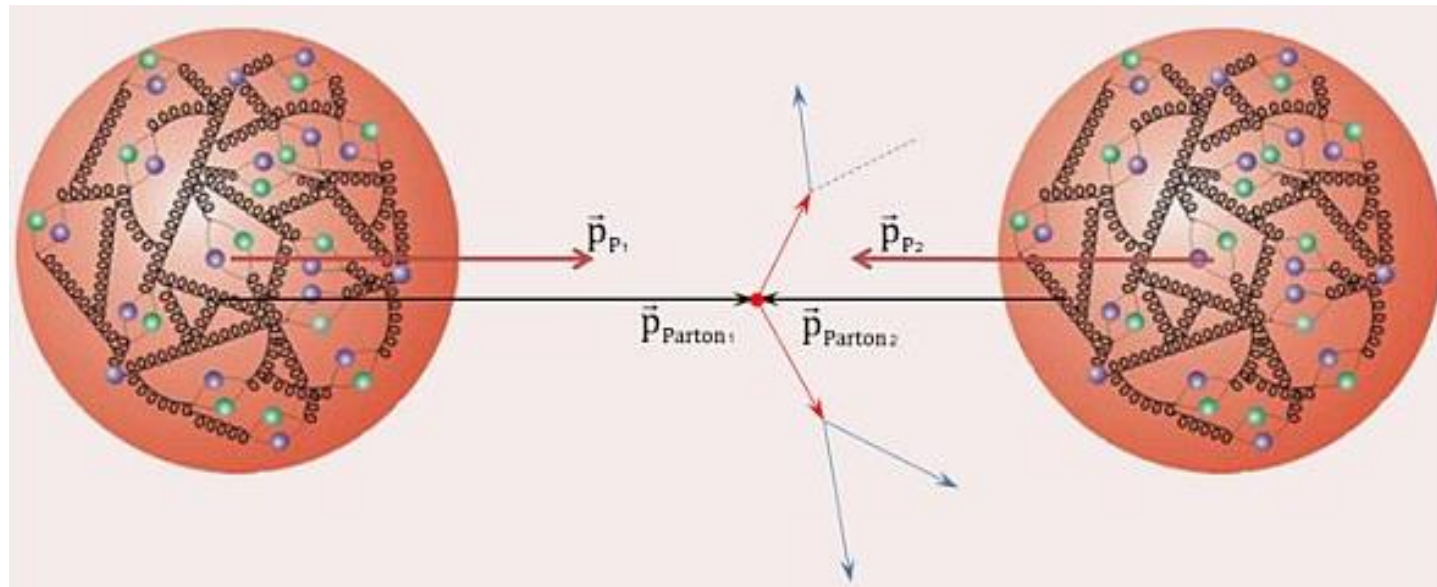
- Chceme-li něco nového vytvořit, musíme nejprve něco rozbít 😊
- Proton:





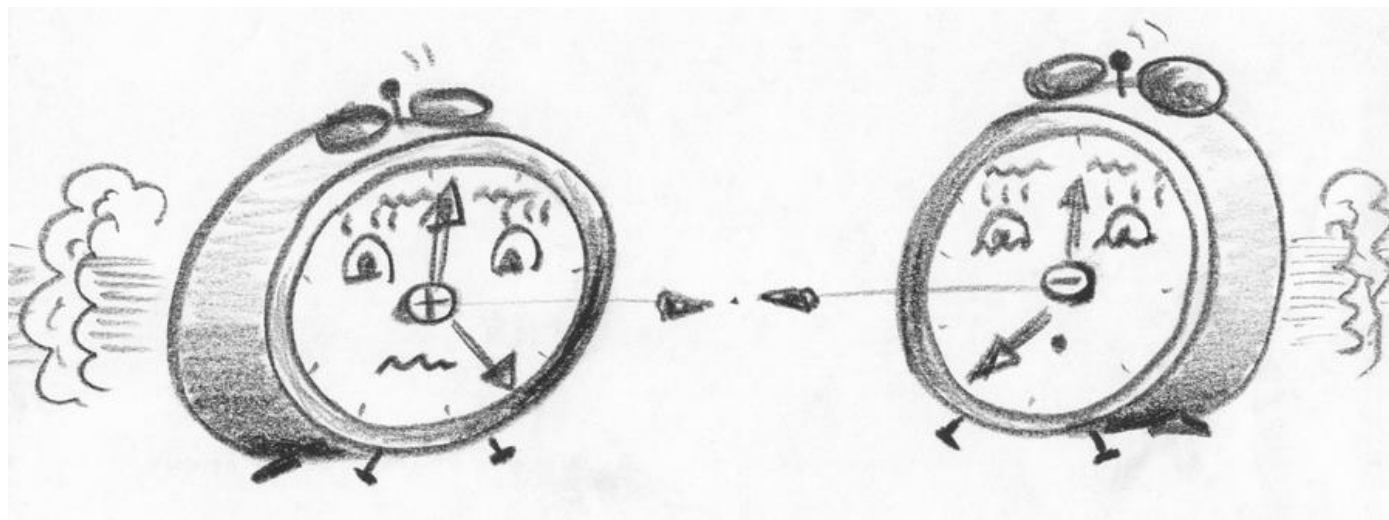
# Srážky částic

- Chceme-li něco nového vytvořit, musíme nejprve něco rozbít ☺
- Srážka dvou protonů:



# Srážky částic

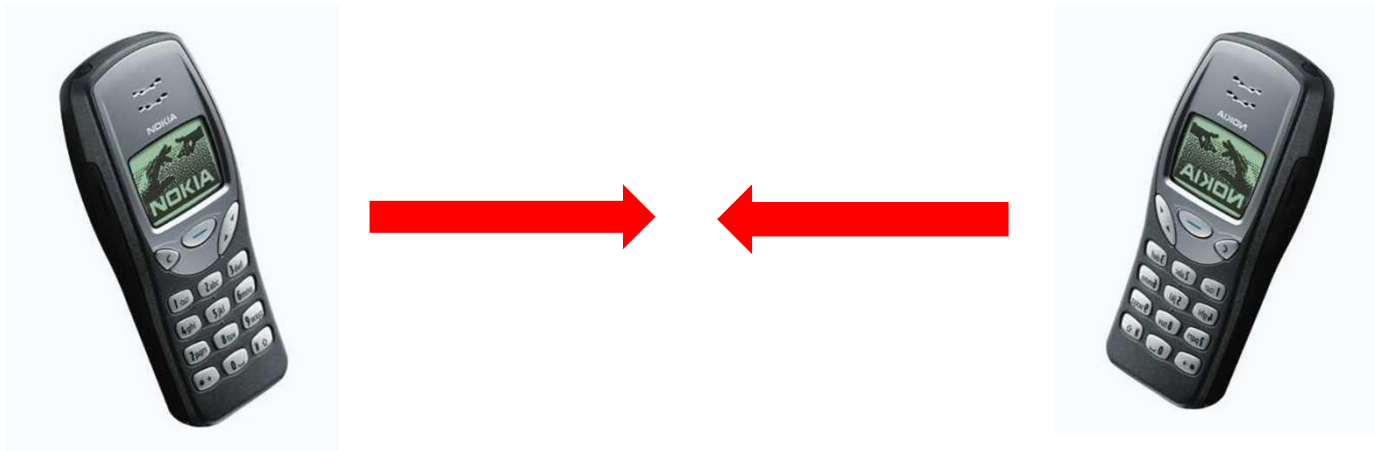
- Chceme-li něco nového vytvořit, musíme nejprve něco rozbít 😊





# Srážky částic

- Chceme-li něco nového vytvořit, musíme nejprve něco rozbít 😊



# Srážky částic

- Chceme-li něco nového vytvořit, musíme nejprve něco rozbít.
- Často se ale nestane skoro nic...



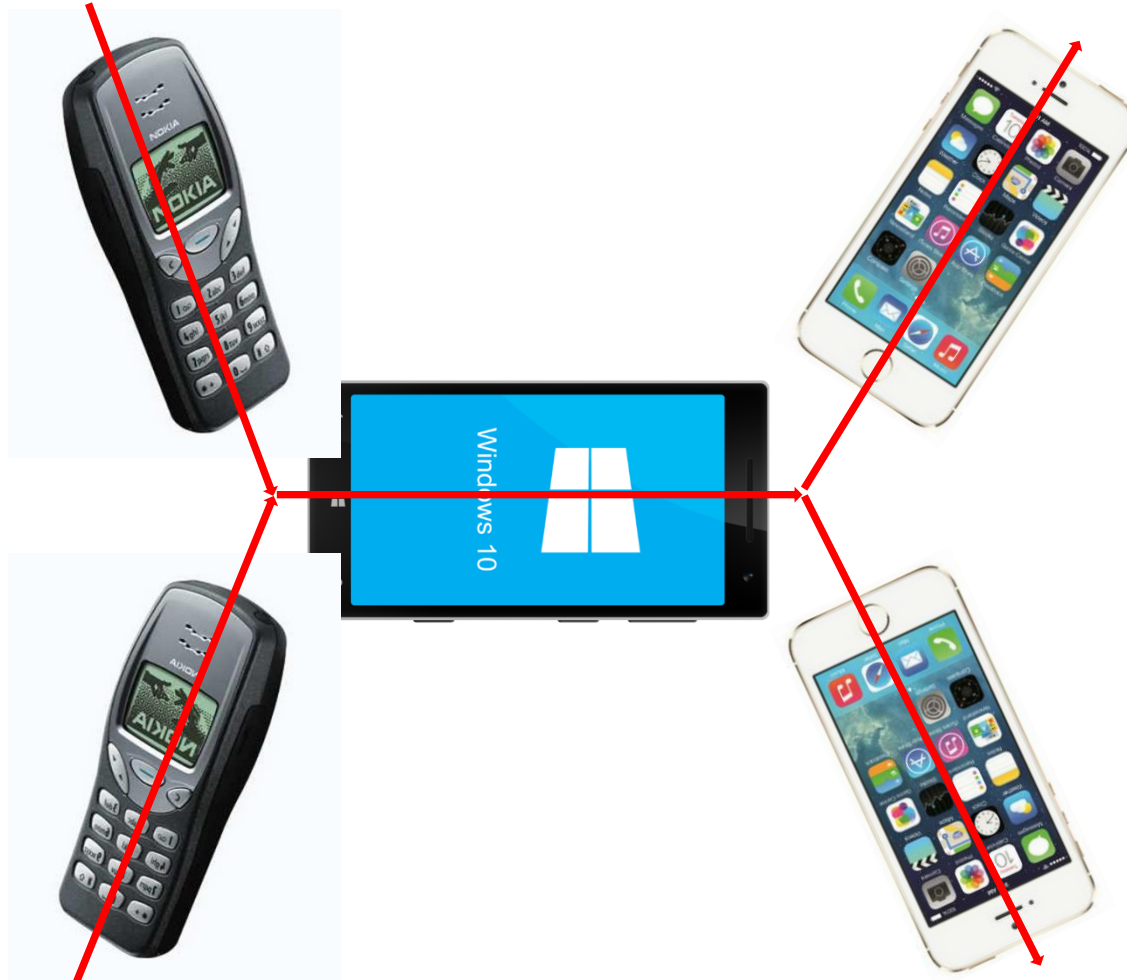
# Srážky částic

- Chceme-li něco nového vytvořit, musíme nejprve něco rozbít.
- Ve srážkách ale mohou vznikat částice nové!
- $E = mc^2$



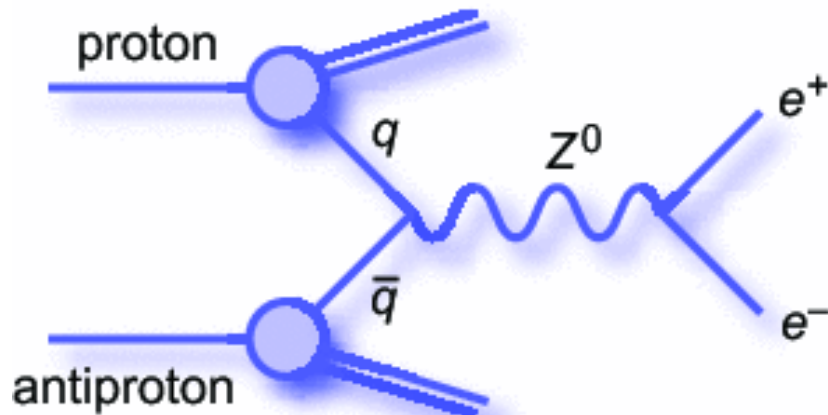
# Srážky částic

- Chceme-li něco nového vytvořit, musíme nejprve něco rozbít.
- Ve srážkách ale mohou vznikat částice nové!

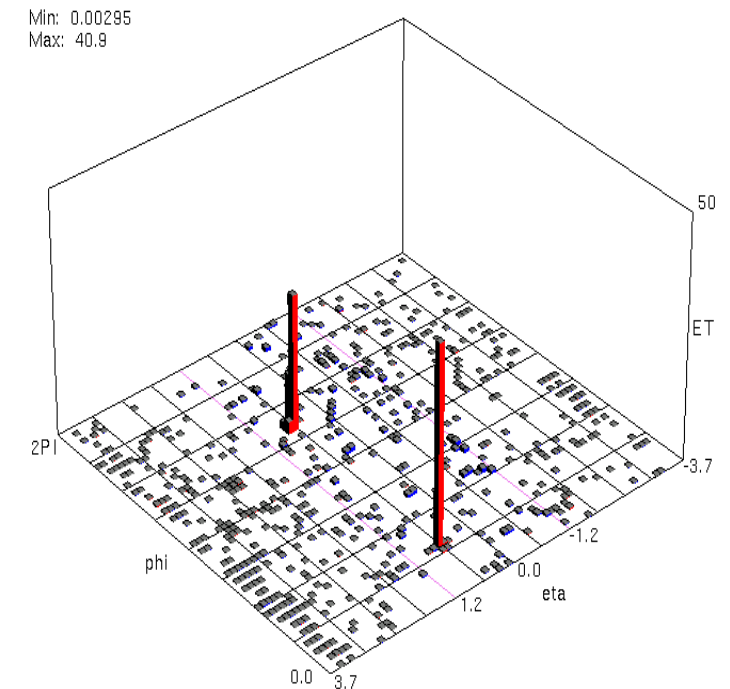
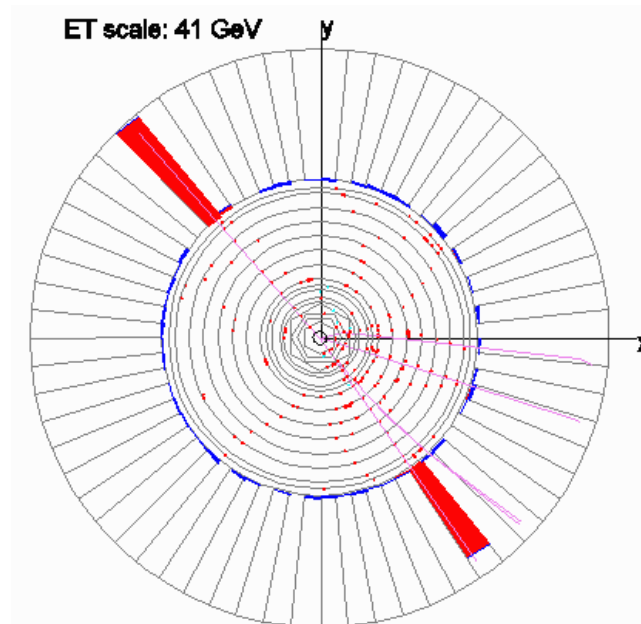


# Interakce

- Energie se může přeměnit v hmotu nové těžké částice.
- Zde Z boson  $\sim$  těžký foton, nestabilní a rychle se rozpadá.
- Jak změřit hmotnost Z bosonu?



16. 3. 2018





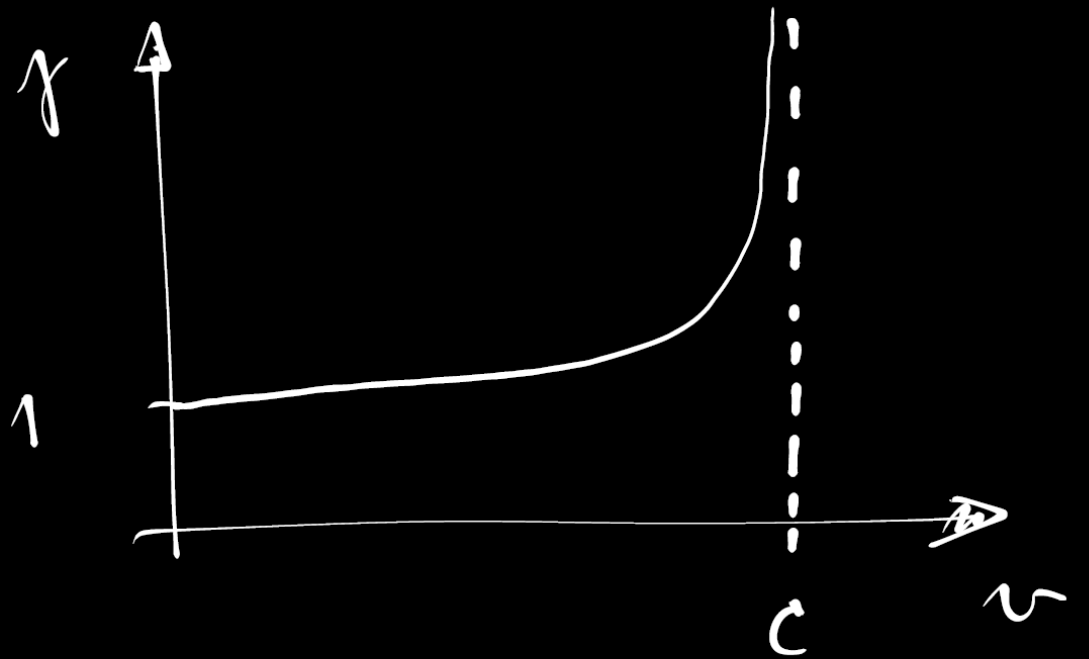
# Invariantní hmota

$$E = mc^2$$

$$E = \gamma mc^2$$

$$\gamma = \frac{1}{\sqrt{1 - \beta^2}}$$

$$\beta = \frac{v}{c}$$



# Invariantní hmota

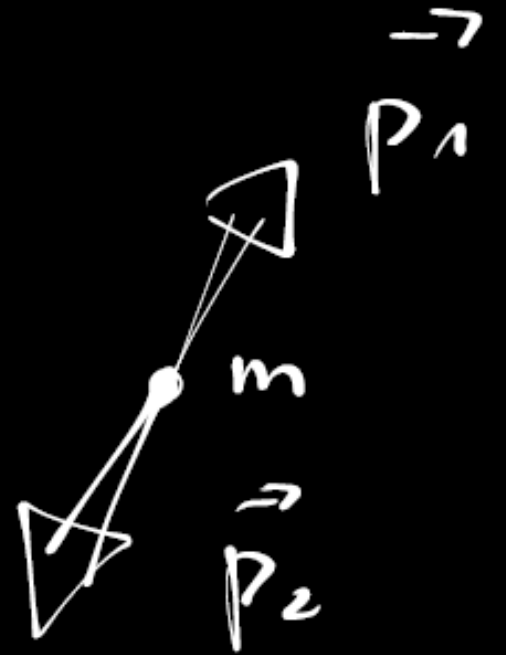
$$E = \sqrt{p^2 c^2 + m^2 c^4}$$

$$E^2 = p^2 c^2 + m^2 c^4$$

v jednotkách

$$m^2 = E^2 - p^2 \quad c=1$$

$$m^2 = \left( \sum_i E_i \right)^2 - \left( \sum_i \vec{p}_i \right)^2$$

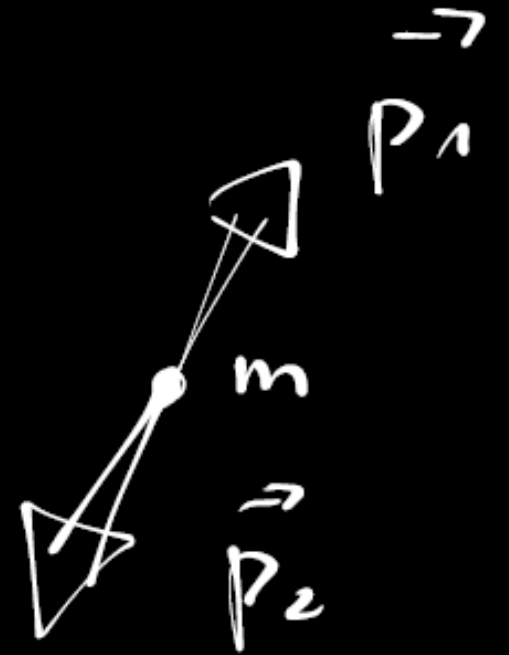


# Invariantní hmota

$$m^2 = \left( \sum_i E_i \right)^2 - \left( \sum \vec{p}_i \right)^2$$

$$E = E_1 + E_2$$

$$\vec{p} = \vec{p}_1 + \vec{p}_2$$



# Invariantní hmota

$$m^2 = \left( \sum_i E_i \right)^2 - \left( \sum_i \vec{p}_i \right)^2$$

$$E = E_1 + E_2$$

$$\vec{p} = \vec{p}_1 + \vec{p}_2$$

$$\vec{p}^2 \equiv \vec{p} \cdot \vec{p} = \vec{p}_1^2 + 2\vec{p}_1 \cdot \vec{p}_2 + \vec{p}_2^2$$

$$m_1 \approx m_2 \approx 0 \Rightarrow$$

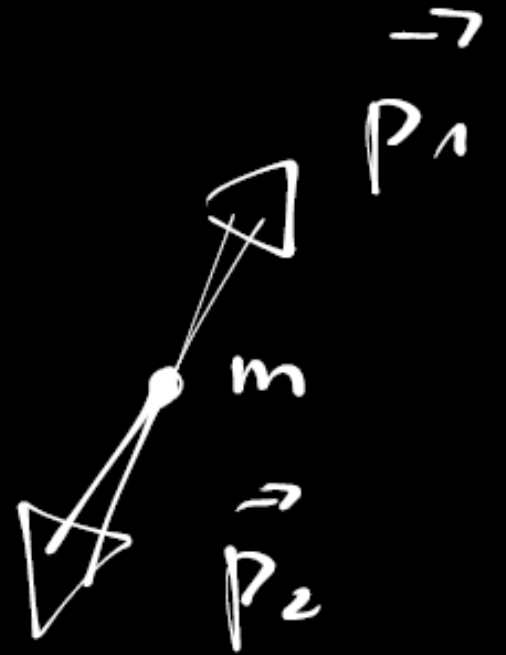
$$= E_1^2 + 2\vec{p}_1 \cdot \vec{p}_2 + E_2^2$$

$$= E_1^2 + E_2^2 + 2E_1E_2 \cos \beta_{12}$$

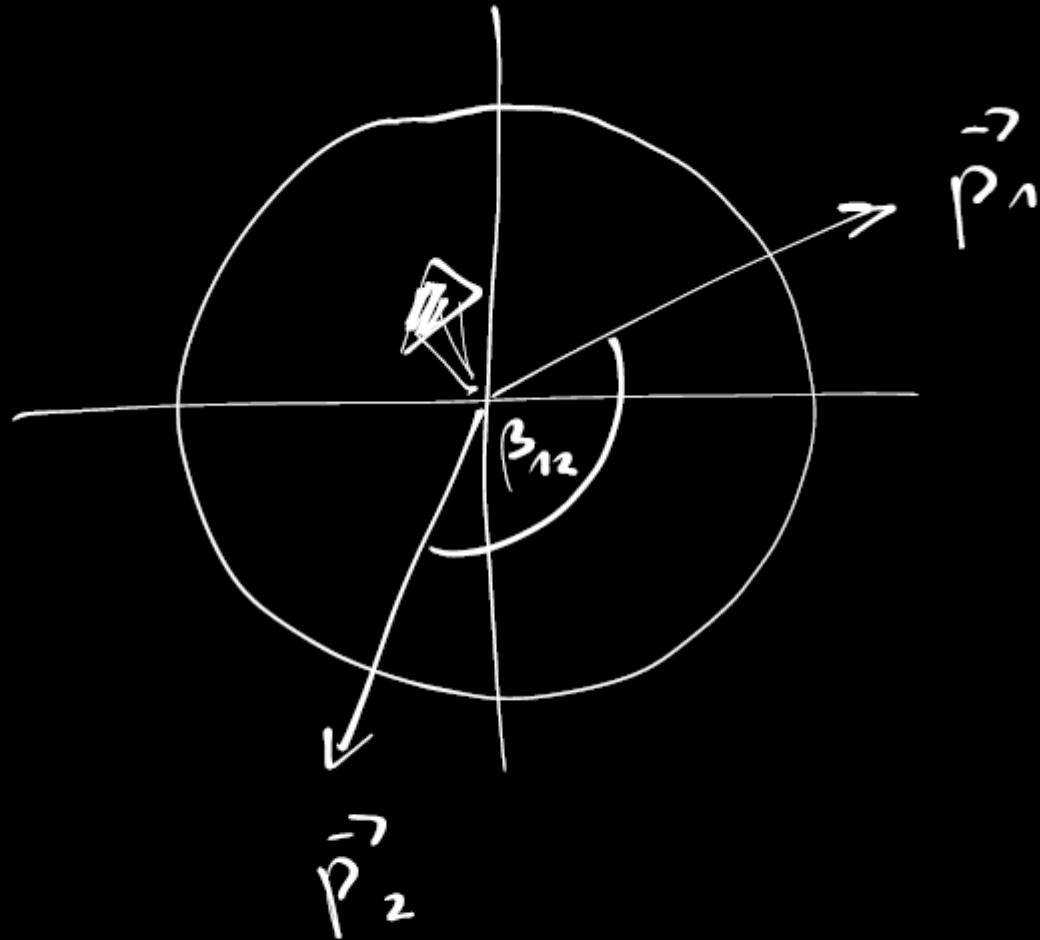
$$m^2 = (E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2$$

$$= \cancel{E_1^2} + 2E_1E_2 + \cancel{E_2^2}$$

$$- \cancel{E_1^2} - \cancel{E_2^2} - 2E_1E_2 \cos \beta_{12}$$



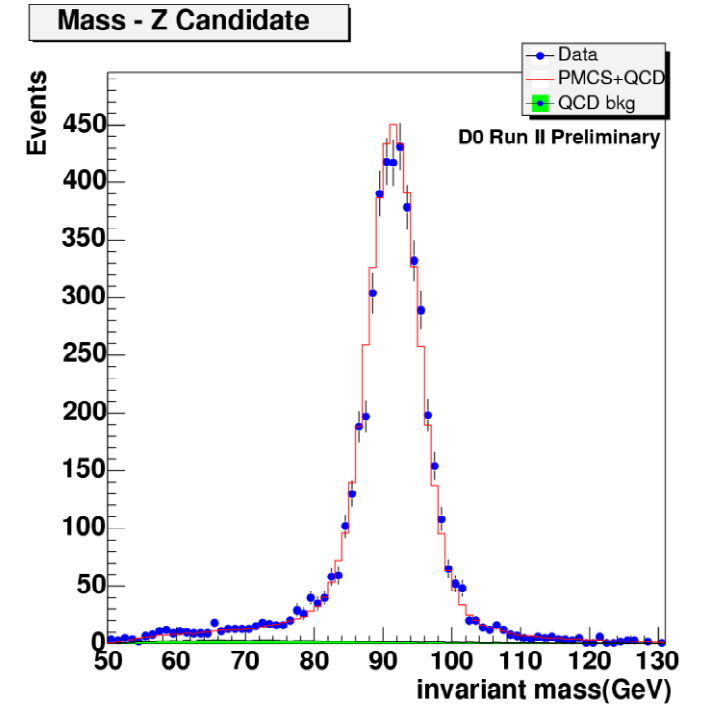
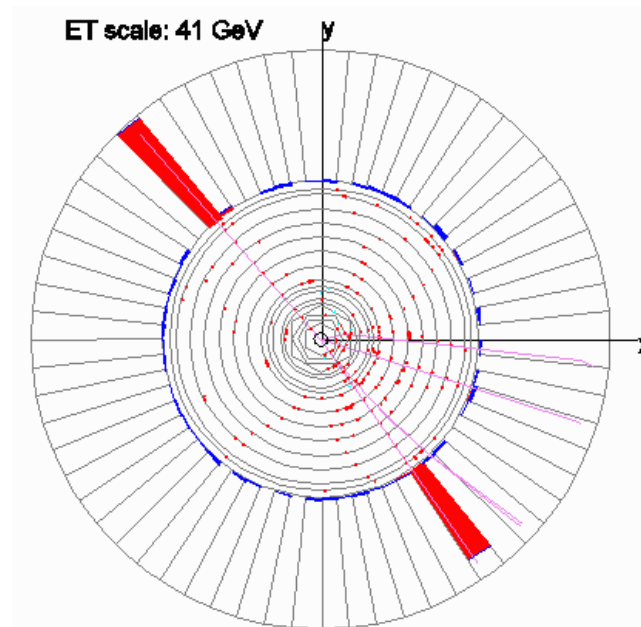
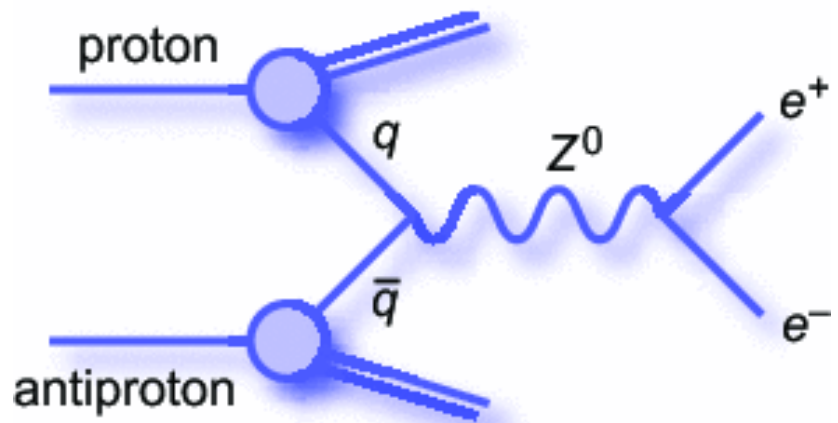
# Invariantní hmota



$$m^2 \simeq 2E_1E_2 (1 - \cos \beta_{12})$$

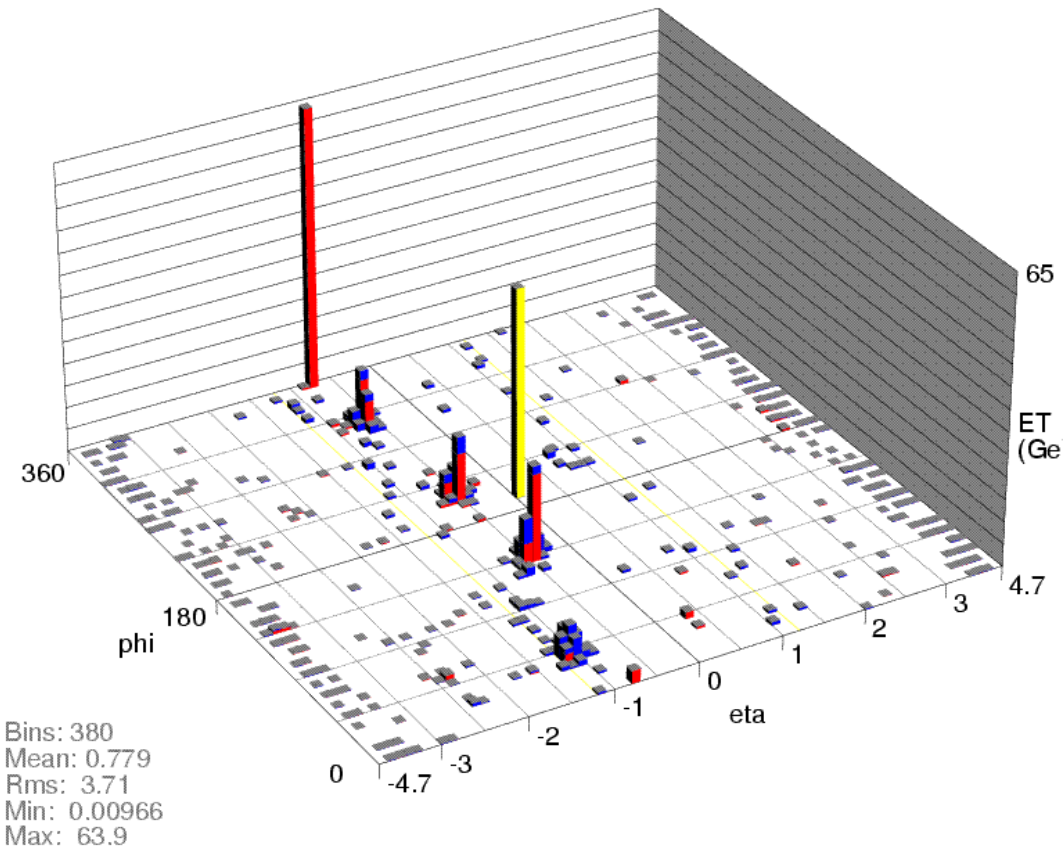
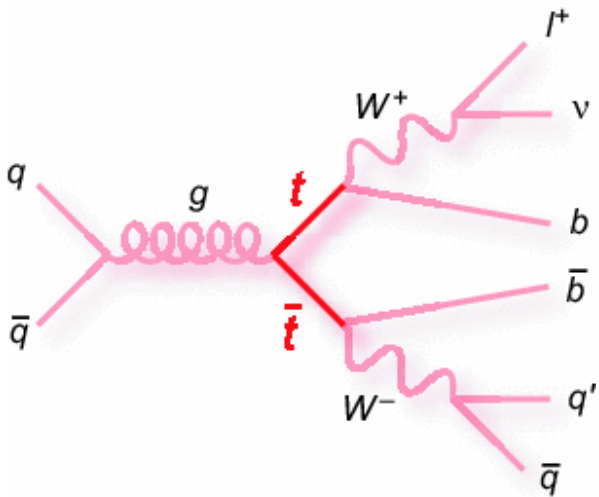
# Interakce

- Energie se může přeměnit v hmotu nové těžké částice.
- Zde Z boson  $\sim$  těžký foton.

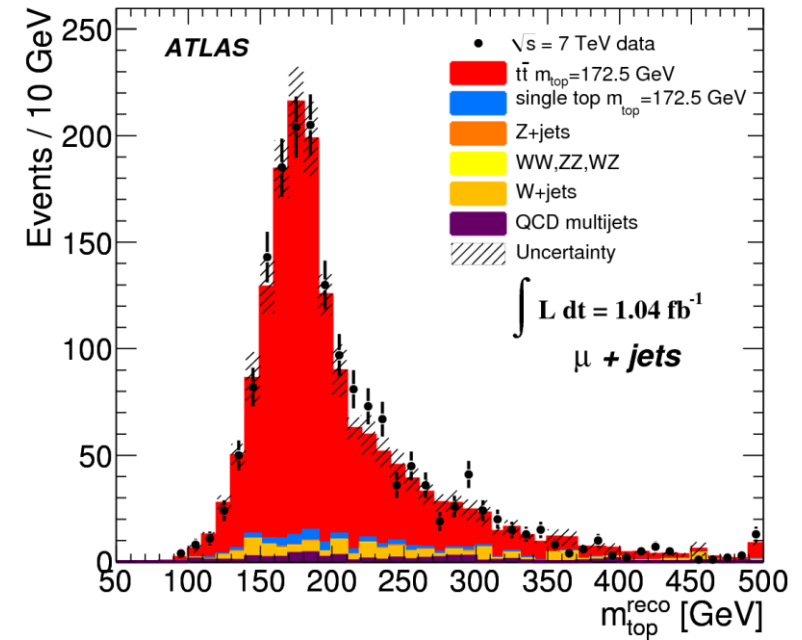


# Interakce

- Složitější případ...

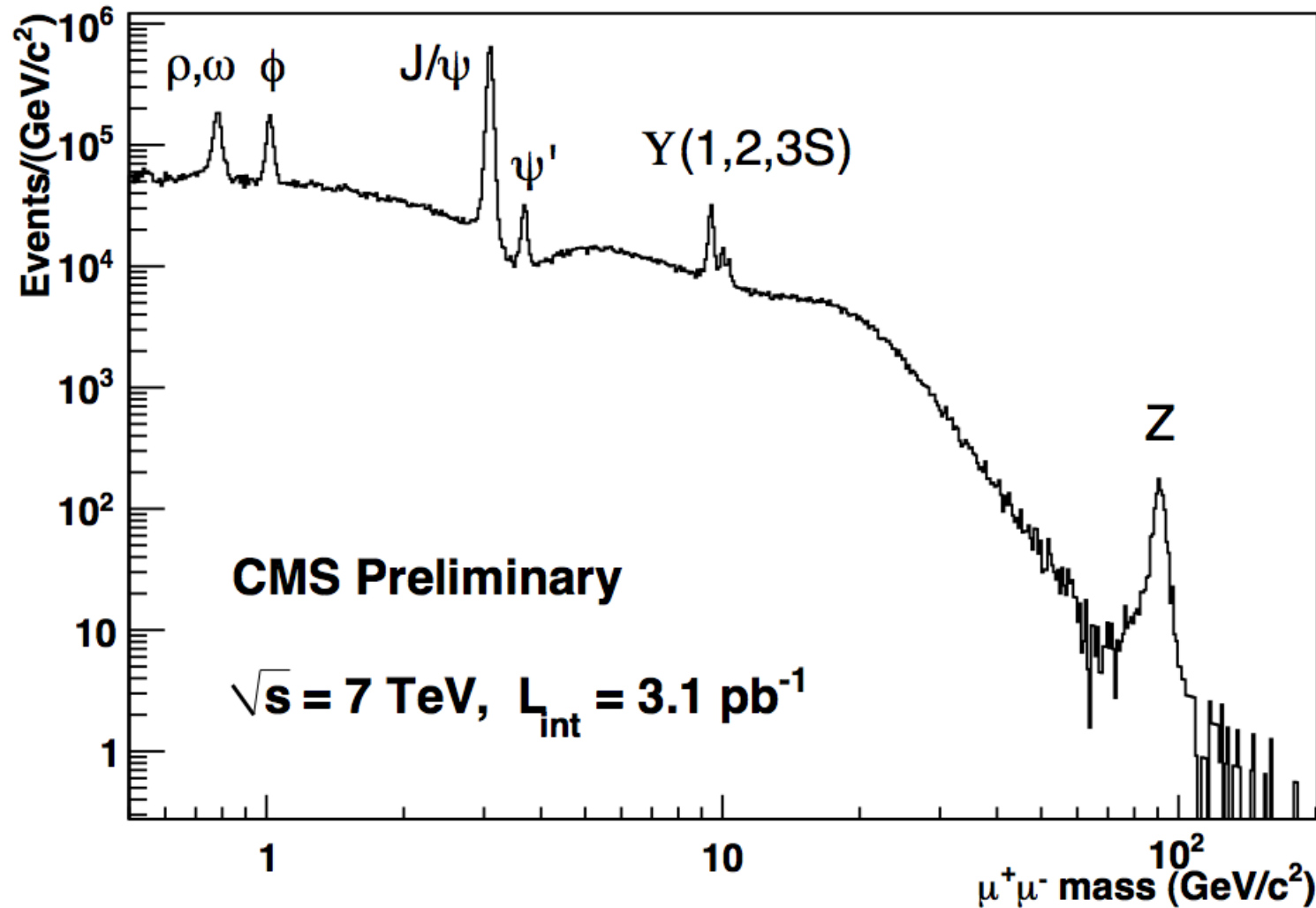


mE\_t: 47.2  
 phi\_t: 195 deg



# „Částice je kopeček!“

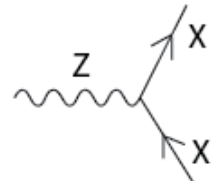
- ...když zkoumám, jak často se něco děje při různé energii.



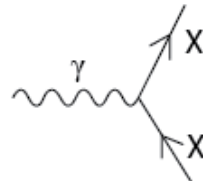


# Všecky interakce světa [zatím...]

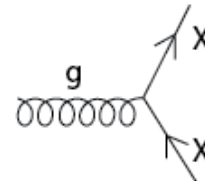
## Standard Model Interactions (Forces Mediated by Gauge Bosons)



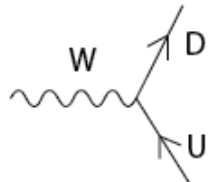
X is any fermion in the Standard Model.



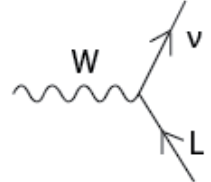
X is electrically charged.



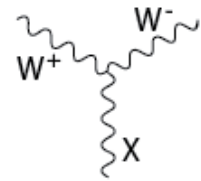
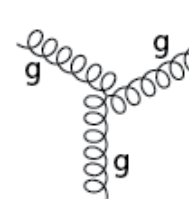
X is any quark.



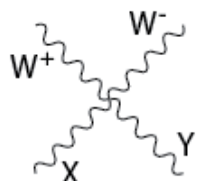
U is a up-type quark;  
D is a down-type quark.



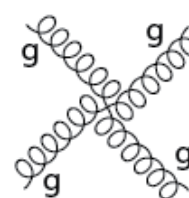
L is a lepton and  $\nu$  is the corresponding neutrino.



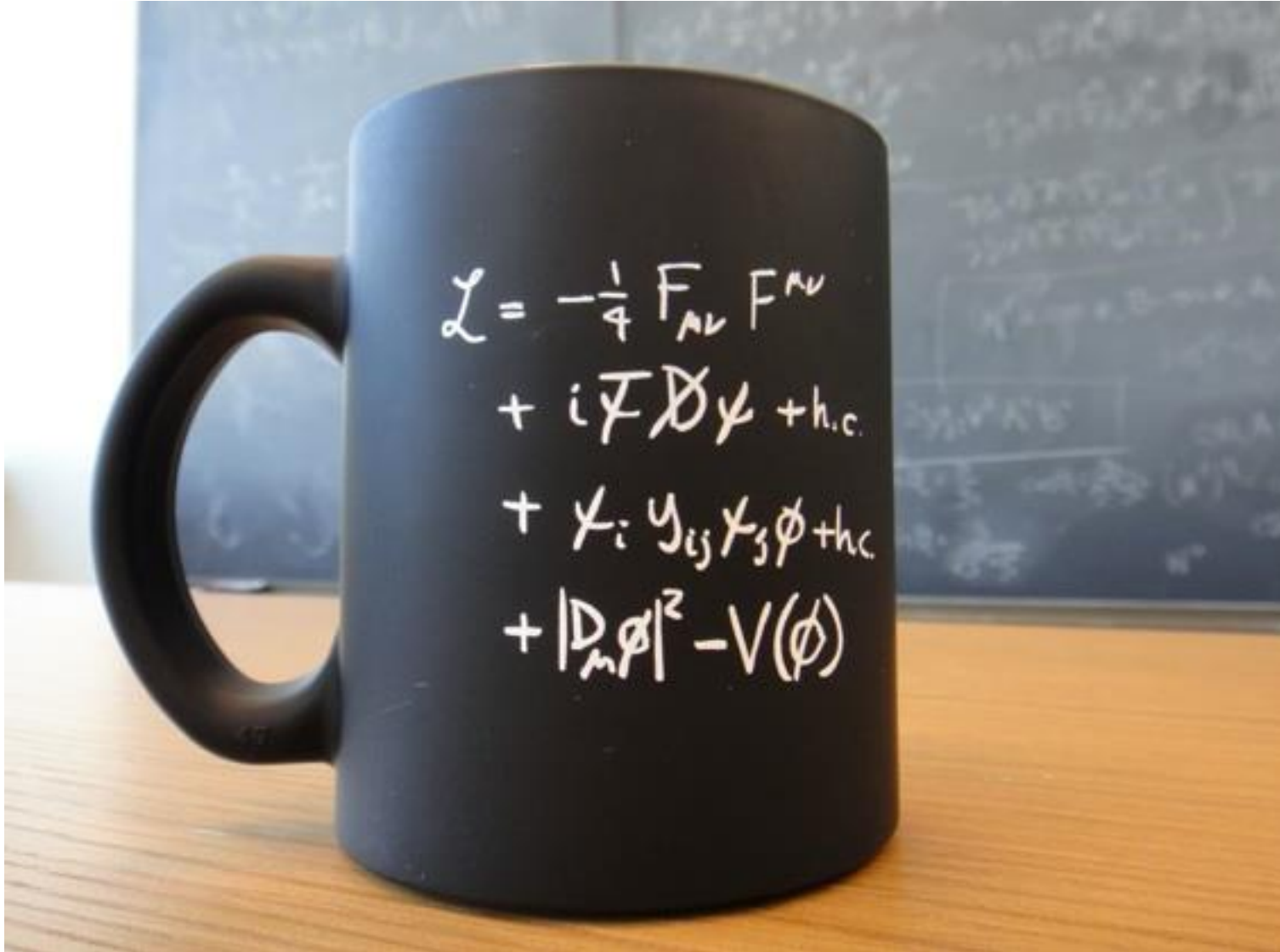
X is a photon or Z-boson.



X and Y are any two electroweak bosons such that charge is conserved.



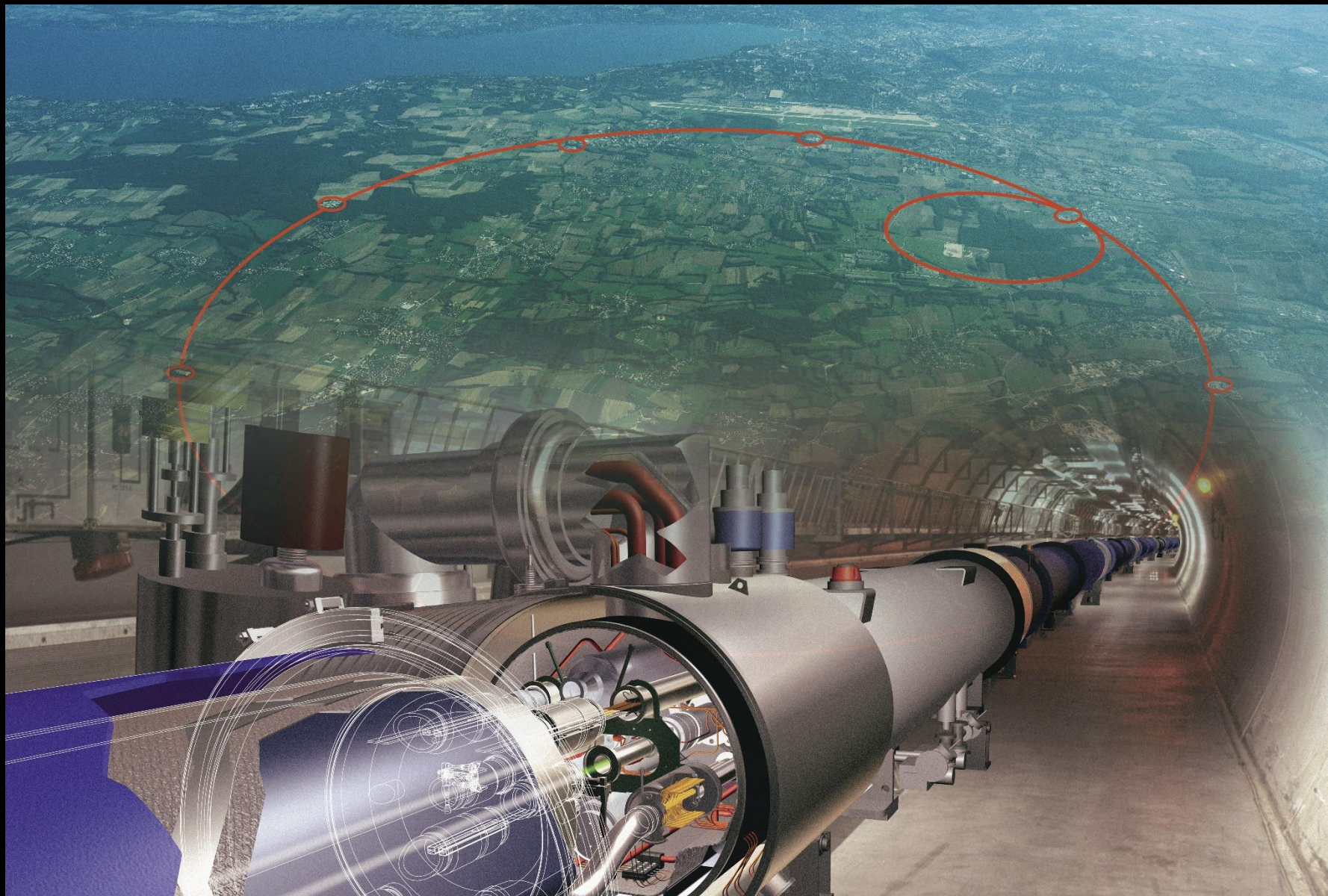
# Všecky interakce světa [zatím...]



# Všecky interakce světa [zatím ve skutečnosti...]

$$\begin{aligned}
 \mathcal{L}_{SM} = & -\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 - \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 - ig_{c_w} (\partial_\nu Z_\mu^0 (W_\mu^+ W_\mu^- - \\
 & W_\nu^+ W_\nu^-) - 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_\nu^- W_\nu^+ W_\mu^- + \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^-) - \frac{1}{2}\partial_\mu H \partial_\mu H - 2M^2 \alpha_h H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \\
 & \beta_h \left( \frac{2M^2}{g^2} + \frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-) \right) + \frac{2M^4}{g^2} \alpha_h - \\
 & g\alpha_h M (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) - \\
 & gM W_\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) + \\
 & M (\frac{1}{c_w} Z_\mu^0 \partial_\mu \phi^0 + W_\mu^+ \partial_\mu \phi^- + W_\mu^- \partial_\mu \phi^+)) - ig \frac{s_w^2}{c_w} M Z_\mu^0 (W_\mu^+ \phi^- - W_\mu^- \phi^+) + ig_{s_w} M A_\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}{8}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^2 s_w^2 A_\mu A_\nu \phi^+ \phi^- + \frac{1}{2}ig_s \lambda_{ij}^a (\bar{q}_i^\mu \gamma^\mu q_j^\mu) g_\mu^a - \bar{e}^\lambda (\gamma \partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda (\gamma \partial + m_\nu^\lambda) \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{d}_j^\lambda \gamma^\mu (\frac{4}{3}s_w^2 - 1 - \gamma^5) d_j^\lambda) + \\
 & (\bar{u}_j^\lambda \gamma^\mu (1 - \frac{8}{3}s_w^2 + \gamma^5) u_j^\lambda) \} + \frac{ig}{2\sqrt{2}} W_\mu^+ ((\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) U^{lep}{}_{\lambda\kappa} e^\kappa) + (\bar{u}_j^\lambda \gamma^\mu (1 + \gamma^5) C_{\lambda\kappa} d_j^\kappa)) + \\
 & \frac{ig}{2\sqrt{2}} W_\mu^- ((\bar{e}^\kappa U^{lep}{}_{\kappa\lambda}^\dagger \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{d}_j^\kappa C_{\kappa\lambda}^\dagger \gamma^\mu (1 + \gamma^5) u_j^\lambda)) + \\
 & \frac{ig}{2M\sqrt{2}} \phi^+ (-m_e^\kappa (\bar{\nu}^\lambda U^{lep}{}_{\lambda\kappa} (1 - \gamma^5) e^\kappa) + m_\nu^\lambda (\bar{\nu}^\lambda U^{lep}{}_{\lambda\kappa} (1 + \gamma^5) e^\kappa) + \\
 & \frac{ig}{2M\sqrt{2}} \phi^- (m_e^\lambda (\bar{e}^\lambda U^{lep}{}_{\lambda\kappa}^\dagger (1 + \gamma^5) \nu^\kappa) - m_\nu^\kappa (\bar{e}^\lambda U^{lep}{}_{\lambda\kappa}^\dagger (1 - \gamma^5) \nu^\kappa) - \frac{g}{2} \frac{m_e^\lambda}{M} H (\bar{\nu}^\lambda \nu^\lambda) - \\
 & \frac{g}{2} \frac{m_c^\lambda}{M} H (\bar{e}^\lambda e^\lambda) + \frac{ig}{2} \frac{m_c^\lambda}{M} \phi^0 (\bar{\nu}^\lambda \gamma^5 \nu^\lambda) - \frac{ig}{2} \frac{m_c^\lambda}{M} \phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda) - \frac{1}{4} \bar{\nu}_\lambda M_{\lambda\kappa}^R (1 - \gamma_5) \bar{\nu}_\kappa - \\
 & \frac{1}{4} \bar{\nu}_\lambda M_{\lambda\kappa}^R (1 - \gamma_5) \bar{\nu}_\kappa + \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{G}^a \partial^2 G^a + g_s f^{abc} \partial_\mu \bar{G}^a G^b g_\mu^c + \\
 & \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 + ig_{c_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) + ig_{c_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^+) + ig_{c_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} \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}$$

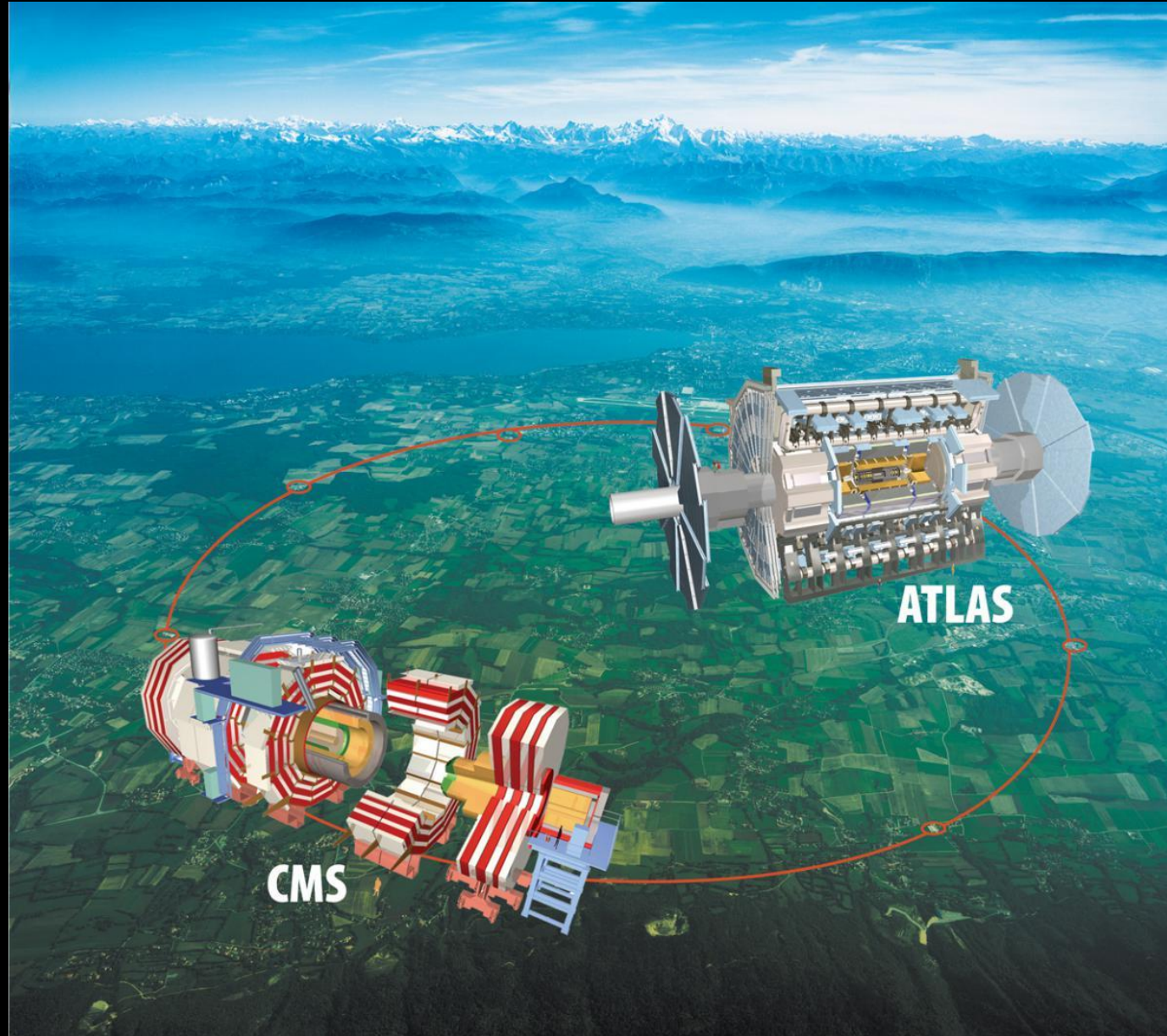
# CERN: laboratoř „ $E = mc^2$ “



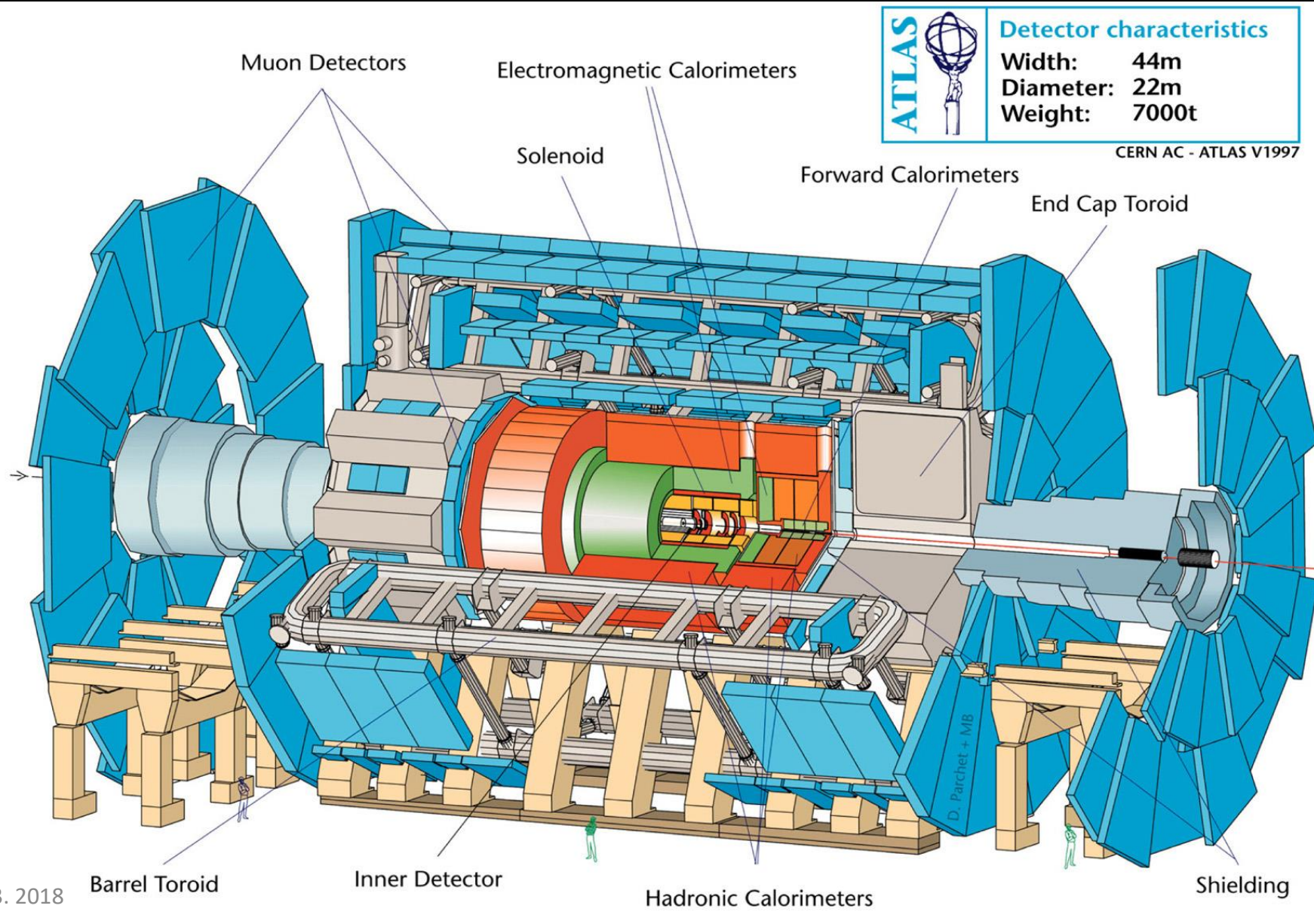
# CERN: laboratoř „ $E = mc^2$ “

- 27 km obvod.
- Supravodivé dipólové magnety chlazené na 1,9 K.
  - Studenější než Vesmír.
- Mikroskop s rozlišením 0,01 fm.
- Srážky protonů: lokální teplota  $10^{16}$  Kelvinů.
  - Místo s nejvyšší teplotou ve Sluneční soustavě.
- Protony o energii 6,5 TeV oběhnou za 90  $\mu$ s.
- Protony jsou ve shlucích po  $10^{10}$  částic.
- Shluků je  $\approx 2000$ .
- Frekvence srážek je 40 MHz, tj. každých 25 ns.
- Spotřeba energie jako kanton Ženeva.


# CERN – Evropské centrum (sub)jaderného výzkumu



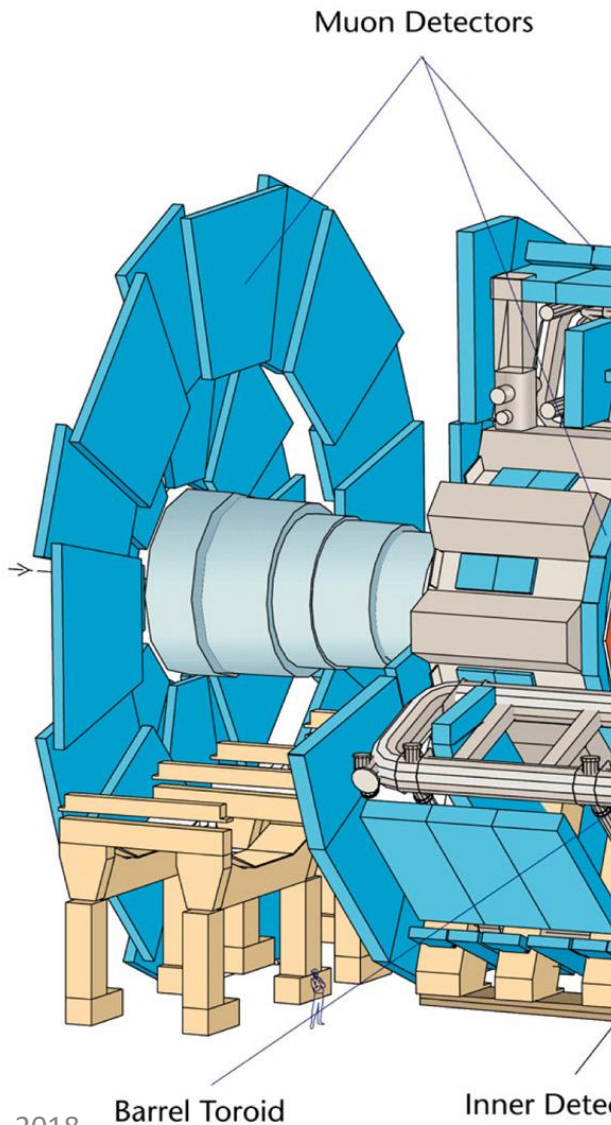
# Experiment ATLAS



# Experiment ATLAS

|   |                                 |              |
|---|---------------------------------|--------------|
| <b>ATLAS</b><br> | <b>Detector characteristics</b> |              |
|   | <b>Width:</b>                   | <b>44m</b>   |
|   | <b>Diameter:</b>                | <b>22m</b>   |
|   | <b>Weight:</b>                  | <b>7000t</b> |

CERN AC - ATLAS V1997

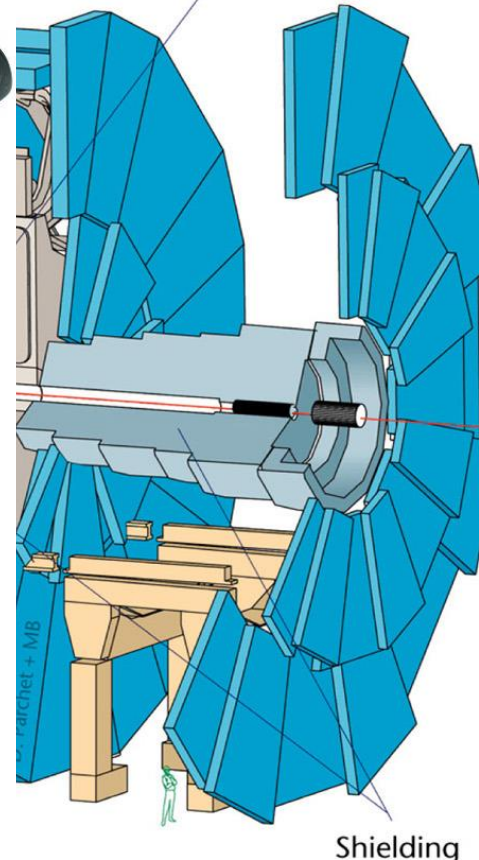


Electromagnetic Calorimeters

Solenoid

Forward Calorimeters

End Cap Toroid





# Experiment ATLAS



## Detector characteristics

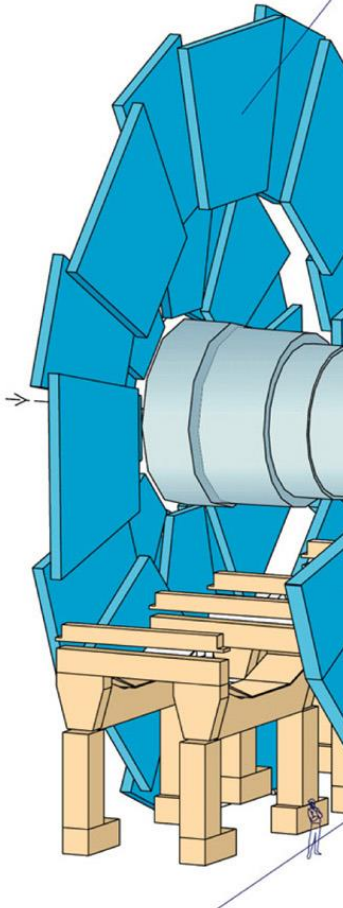
Width: 44m  
Diameter: 22m  
Weight: 7000t

CERN AC - ATLAS V1997

Muon Detectors

Electromagnetic Calorimeters

Solenoid

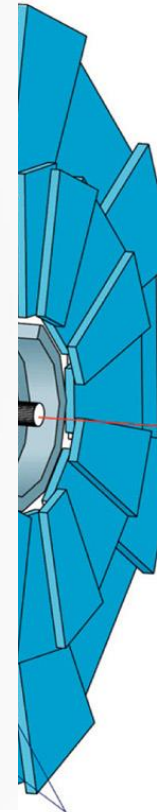


Barrel Toroid



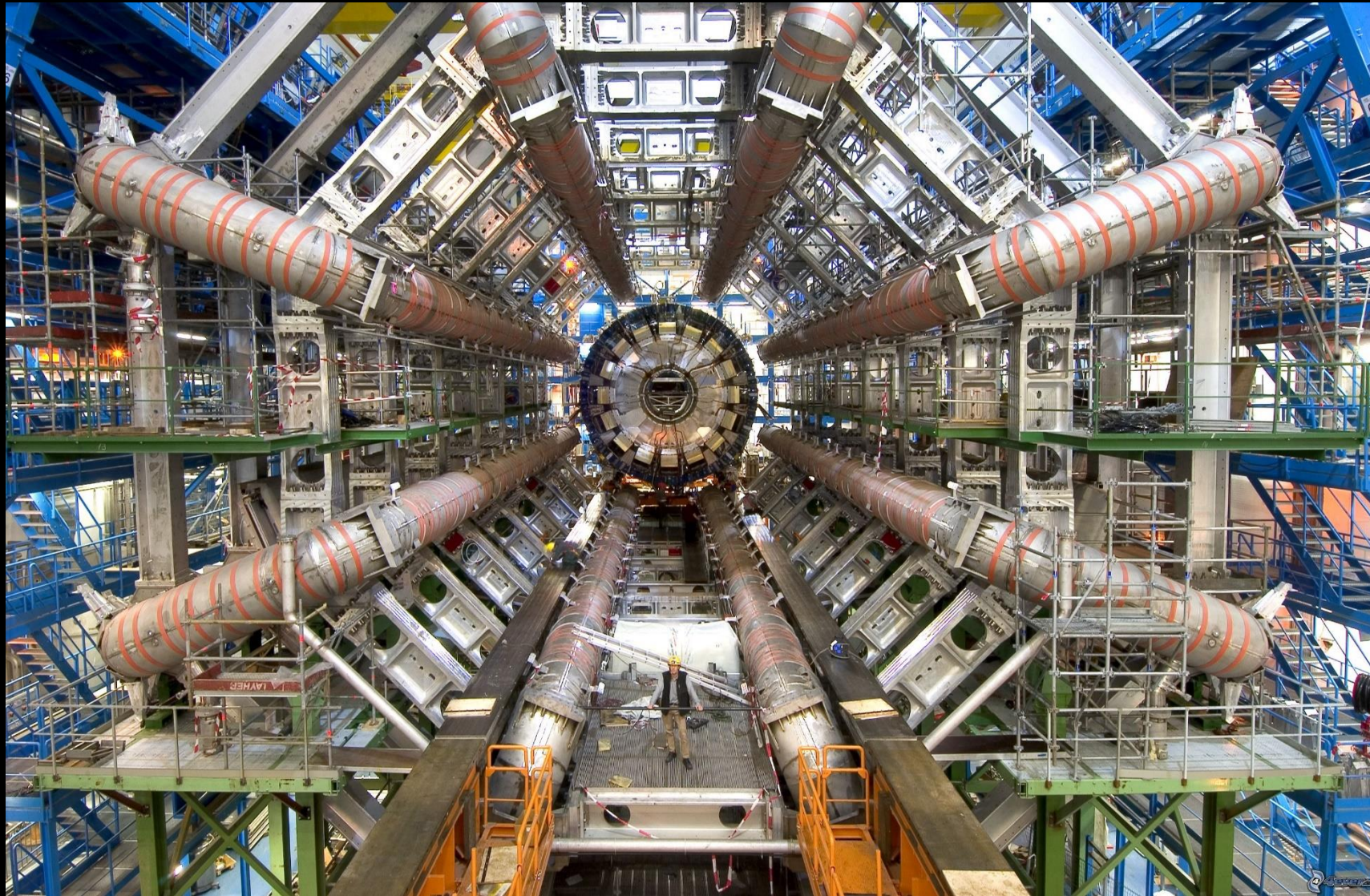
Inner Detector

Hadronic Calorimeters



Shielding

# Experiment ATLAS



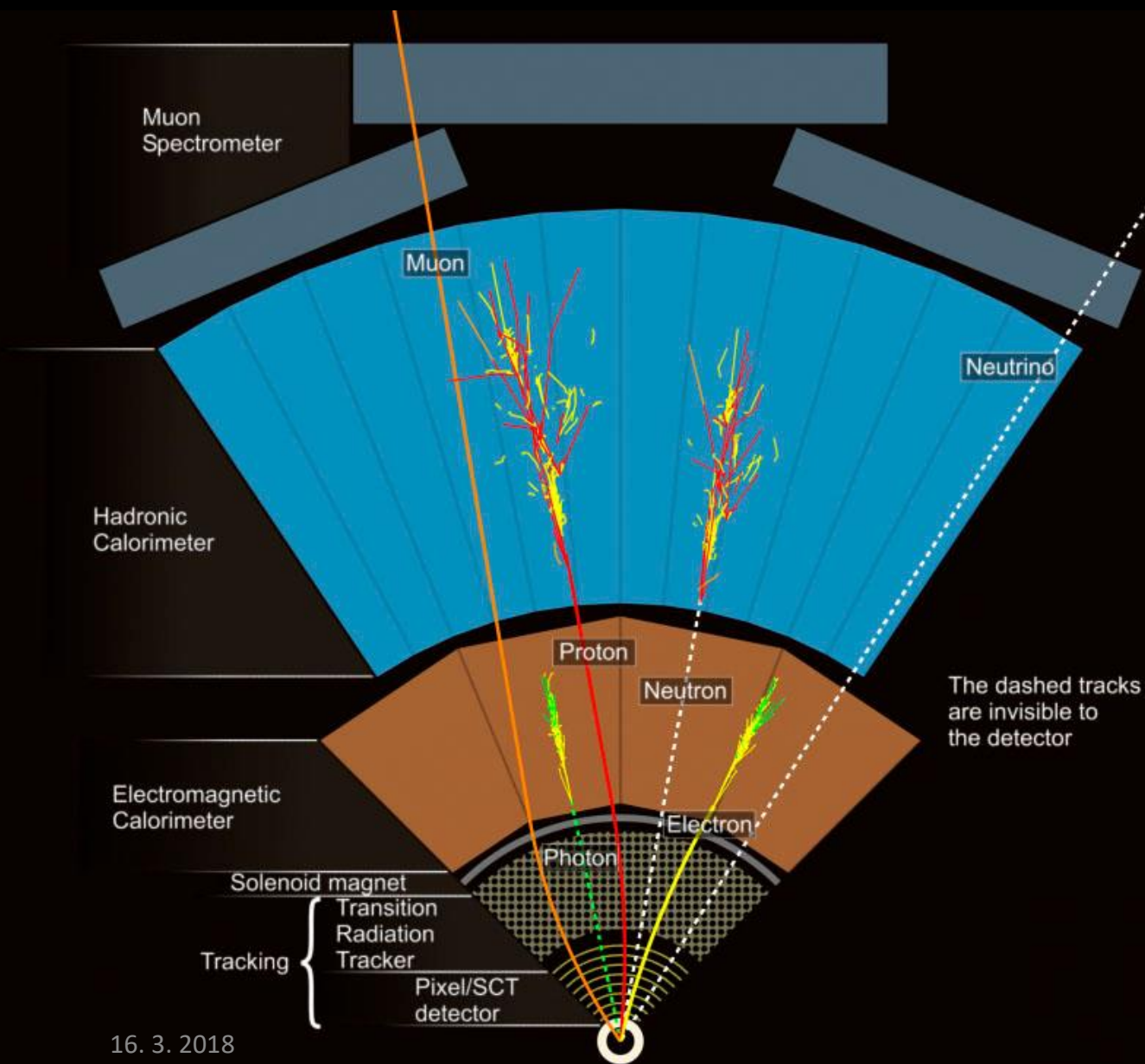
# Experiment ATLAS



# Experiment ATLAS



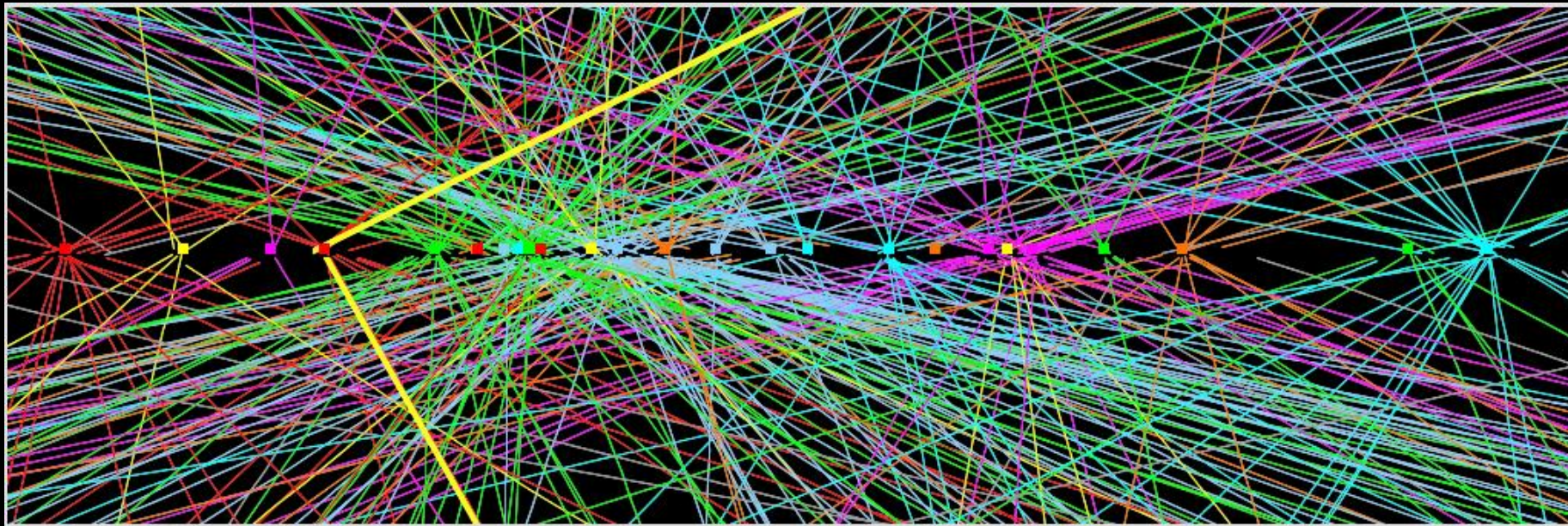
# Jak ATLAS vidí částice



- Částice většinou nejsou takto ideálně izolované.
- V praxi se definuje jejich „ID“ či kvalita např. na základě toho, jak moc dalších drah či energie je okolo mionu či elektronu.

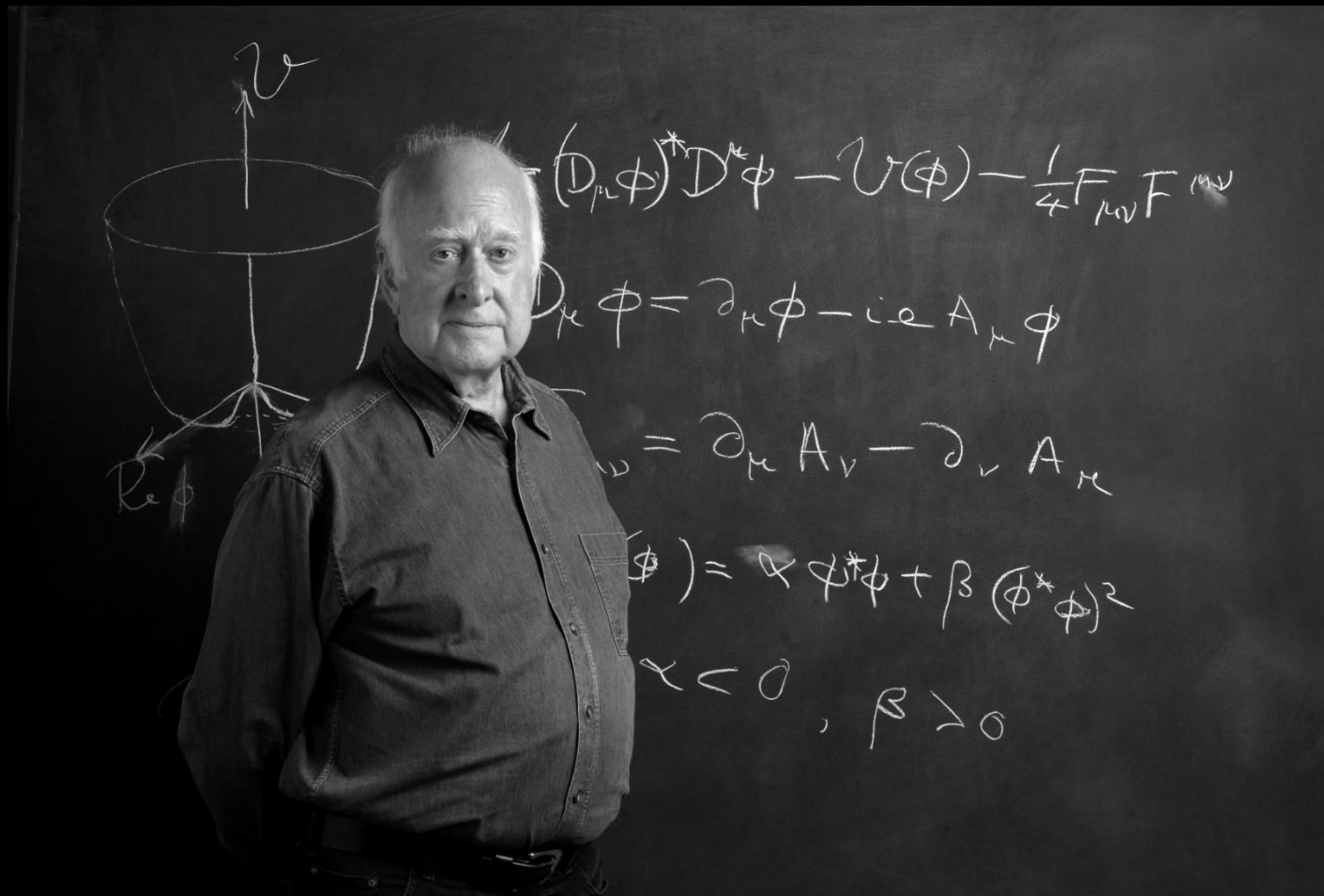
# Jak ATLAS vidí částice

- Až 100 interakcí na jednom snímku z detektoru při jednom průchodu shluků částic (tzv. pile-up).
- Higgsův boson produkován cca v jedné srážce z 10 miliard, tj cca každých 5 min.
  - (někde v atmosféře každých 8s:)



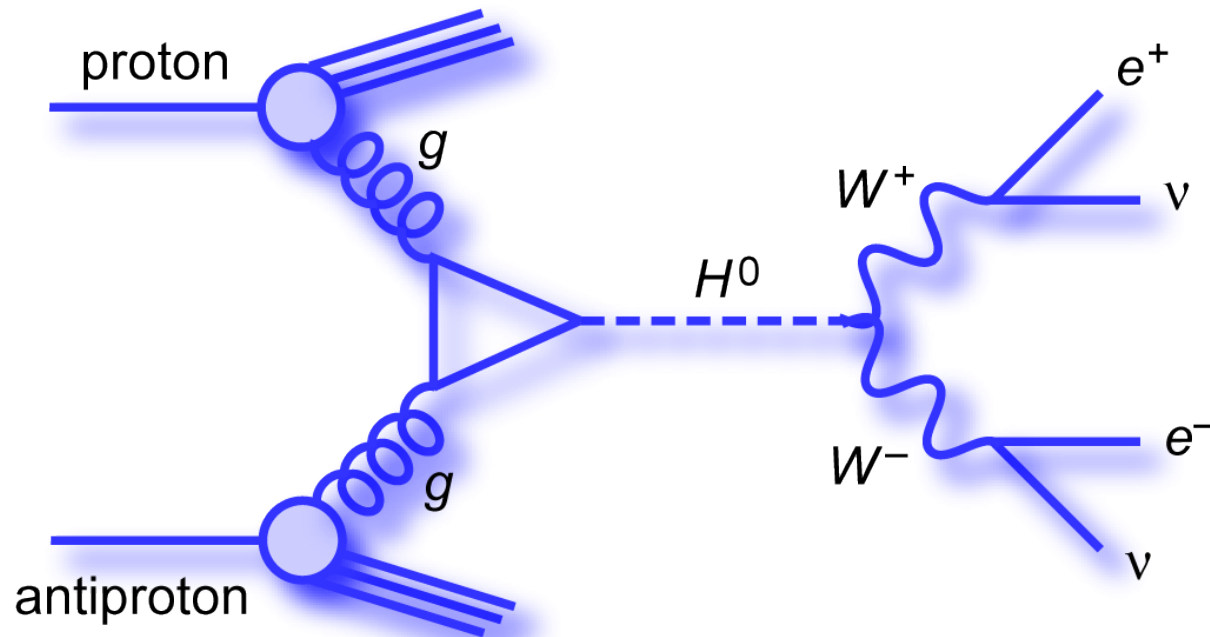
# Higgs :: Peter Higgs

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \text{h.c.}$$



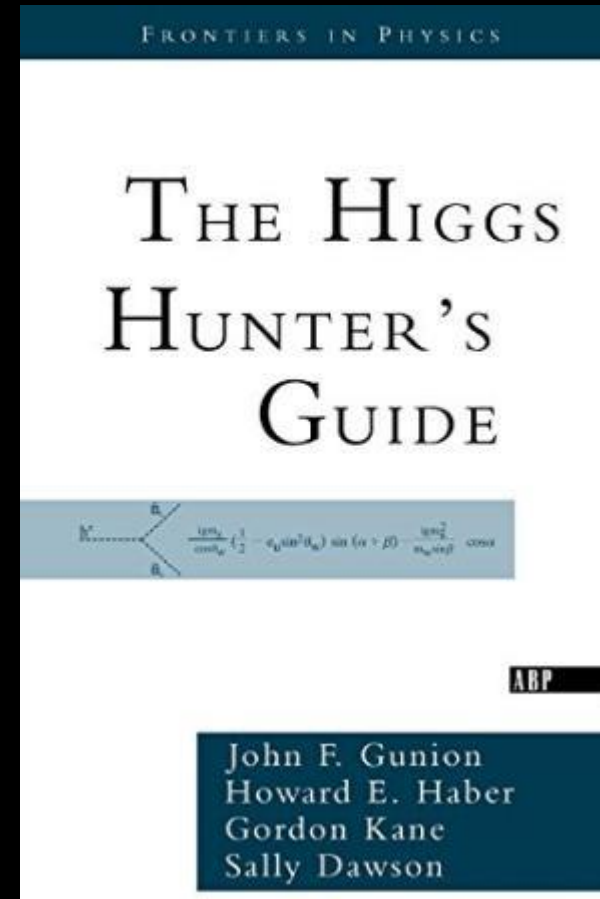
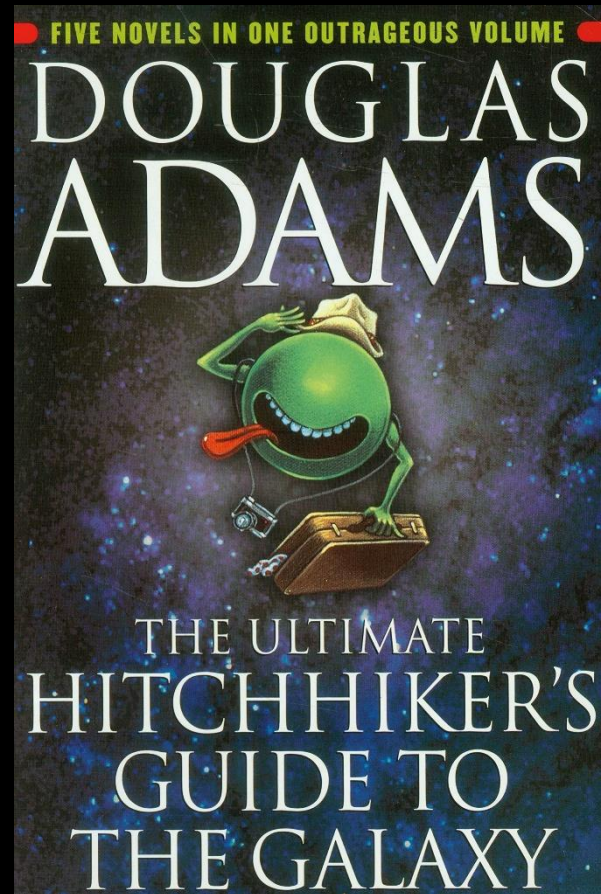
# Higgův boson

- Interakcí s Higgsovým polem získávají částice hmotnost (r. 1964).
- Bonus: Teorie předpovídá novou částici (Higgs), ale neříká, jak těžkou.
- Čekajme tedy někde kopeček, ale hledějme, jestli vůbec, a kde.



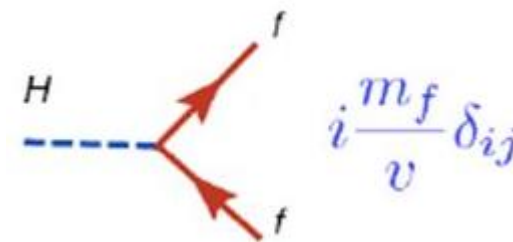
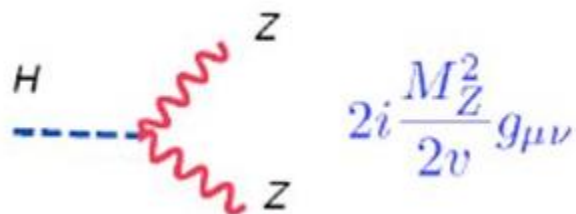
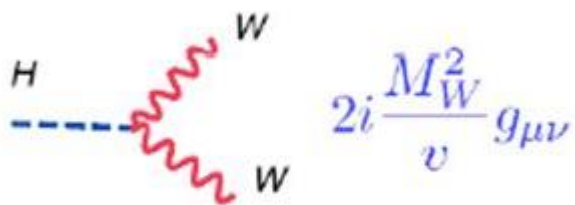


# Hon na Higgsův boson



# Higgsův boson

- BEH boson (Brout, Englert, Higgs).
- Do r. 2012: Neutrální a zřejmě těžká (dosud nepozorovaná) částice.
- Interakce BEH bosonu s danou částicí je tím větší, čím je částice těžší.
- A zkoumejme zároveň více možností, na co se Higgs může rozpadat:



# Higgsův boson

- BEH boson (Brout, Englert, Higgs).  
(a také Gerald Guralnik, C. R. Hagen, a Tom Kibble )



The Nobel Prize in Physics 2013  
François Englert, Peter Higgs

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## The Nobel Prize in Physics 2013



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

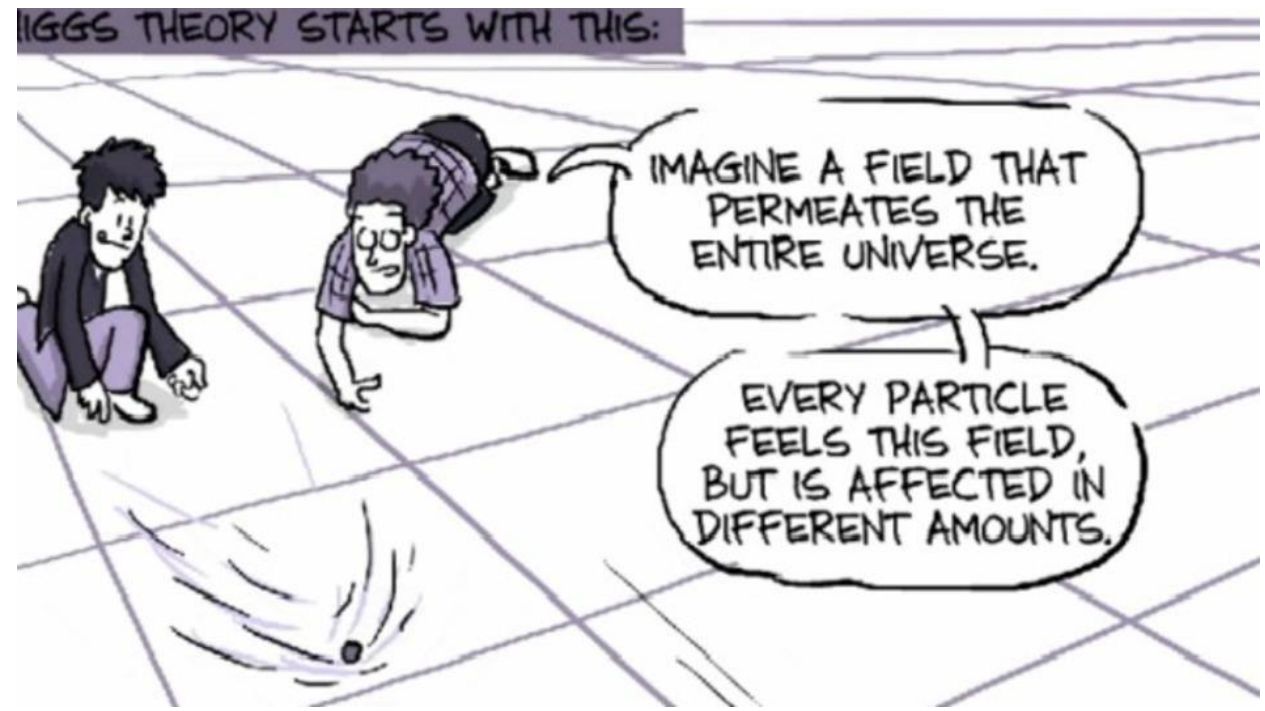


Photo: A. Mahmoud  
**Peter W. Higgs**  
Prize share: 1/2



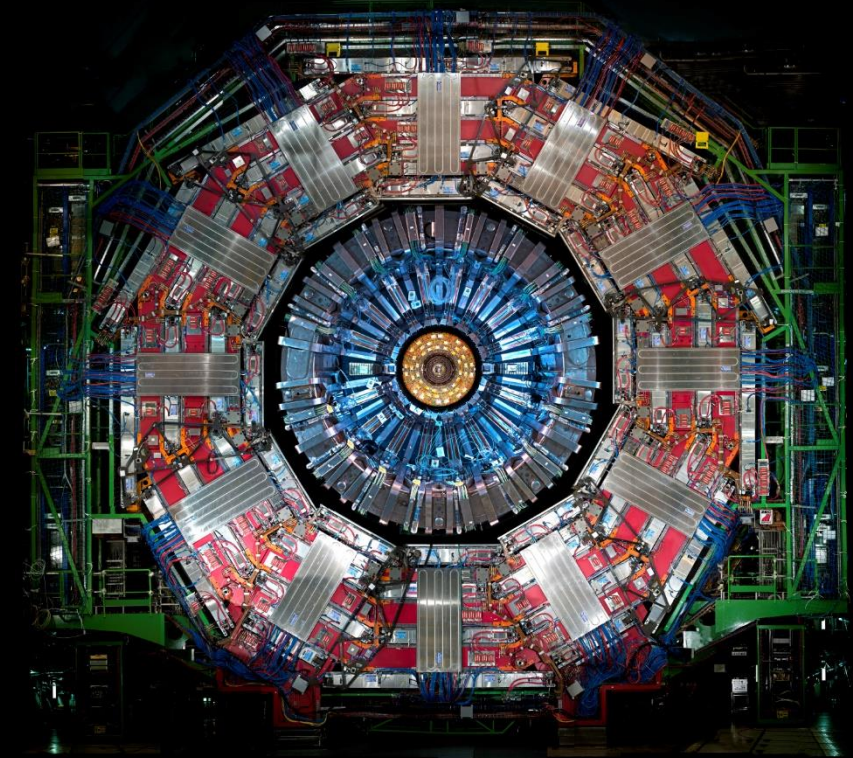
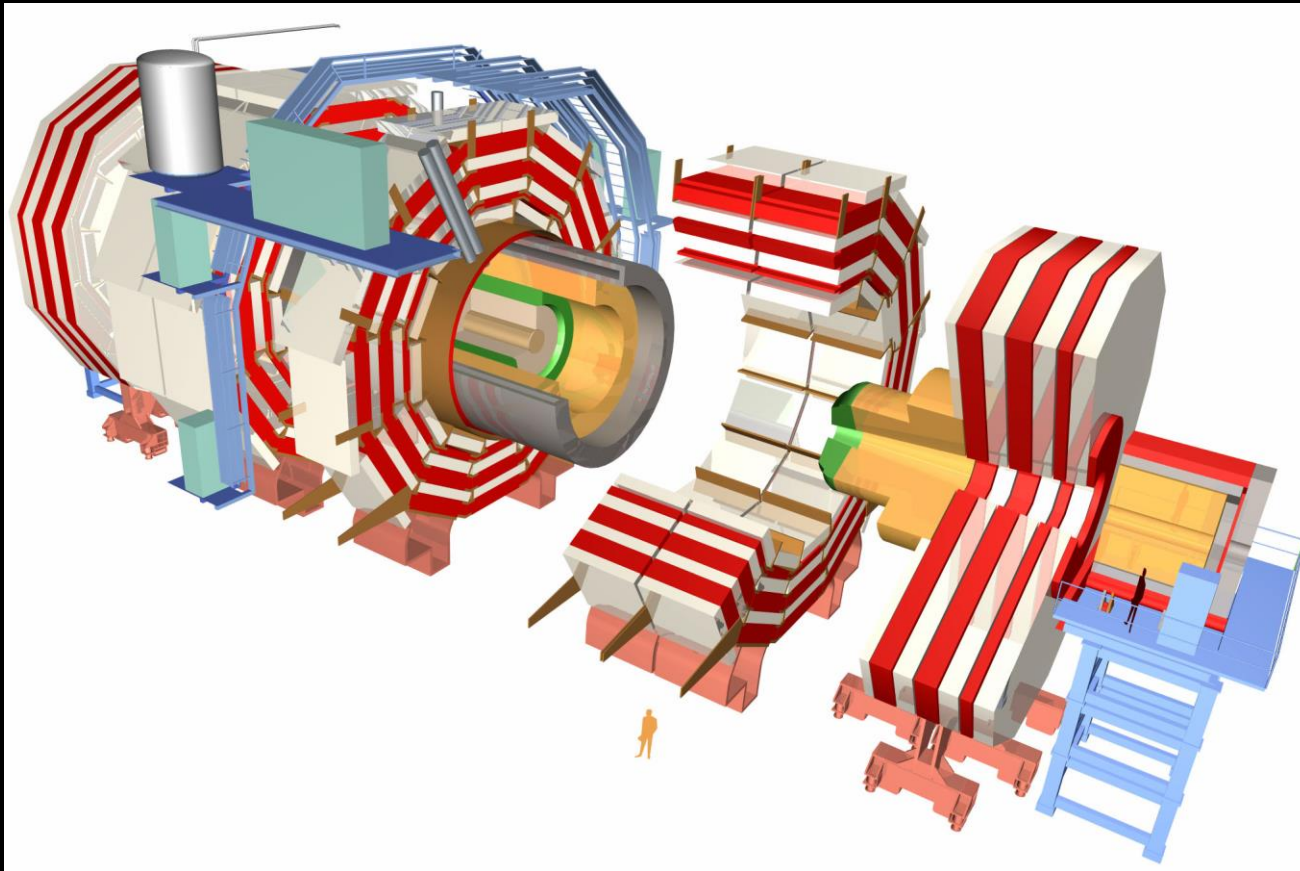
Robert Brout (1928 -- 2011)

# Higgs



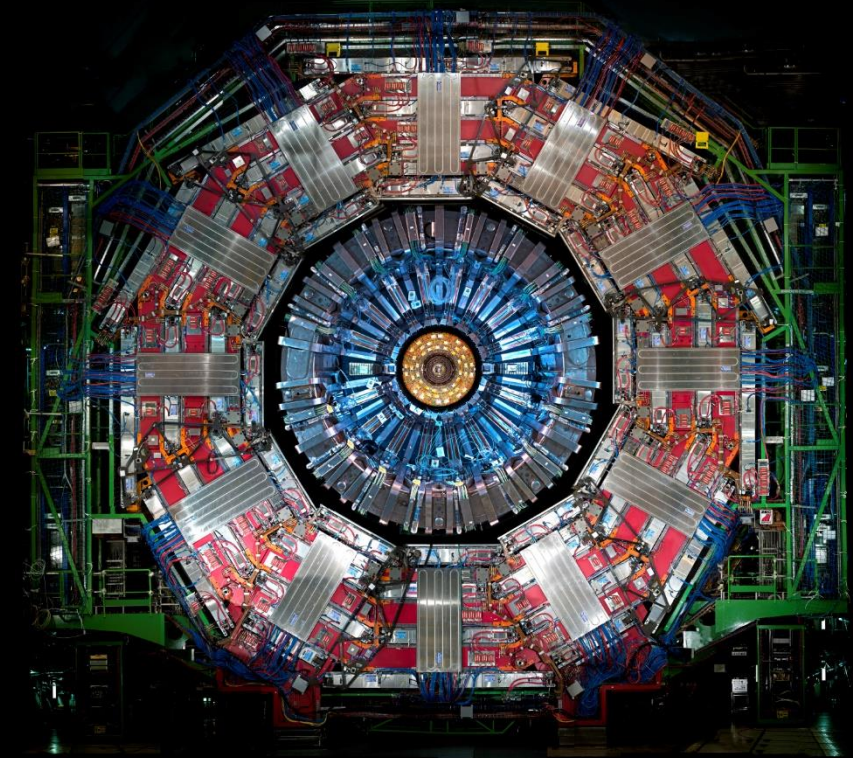
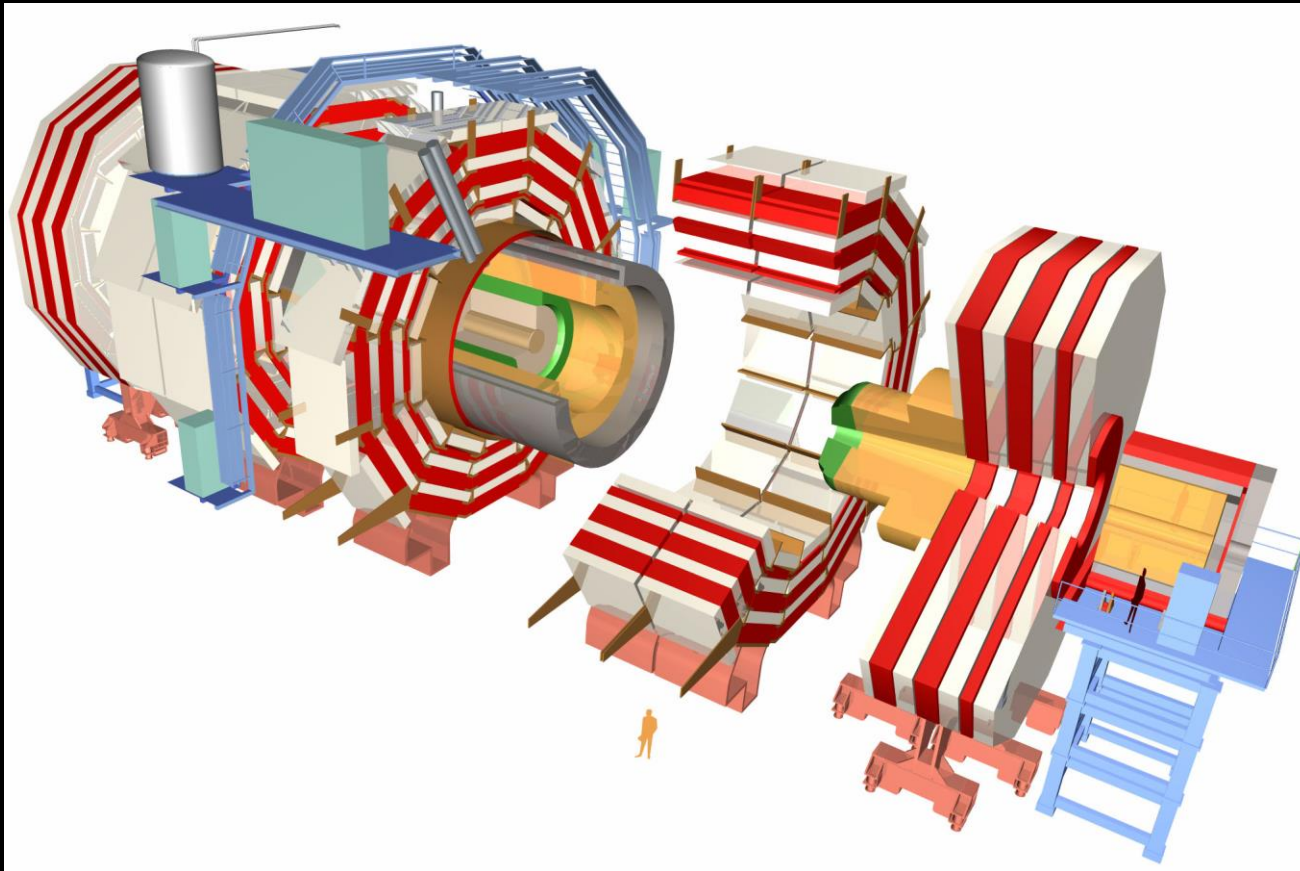
# Mezitím u konkurence ... Experiment CMS...

- ...byl navržen tak, aby nejlépe viděl rozpad Higgsova bosonu na dva fotony.



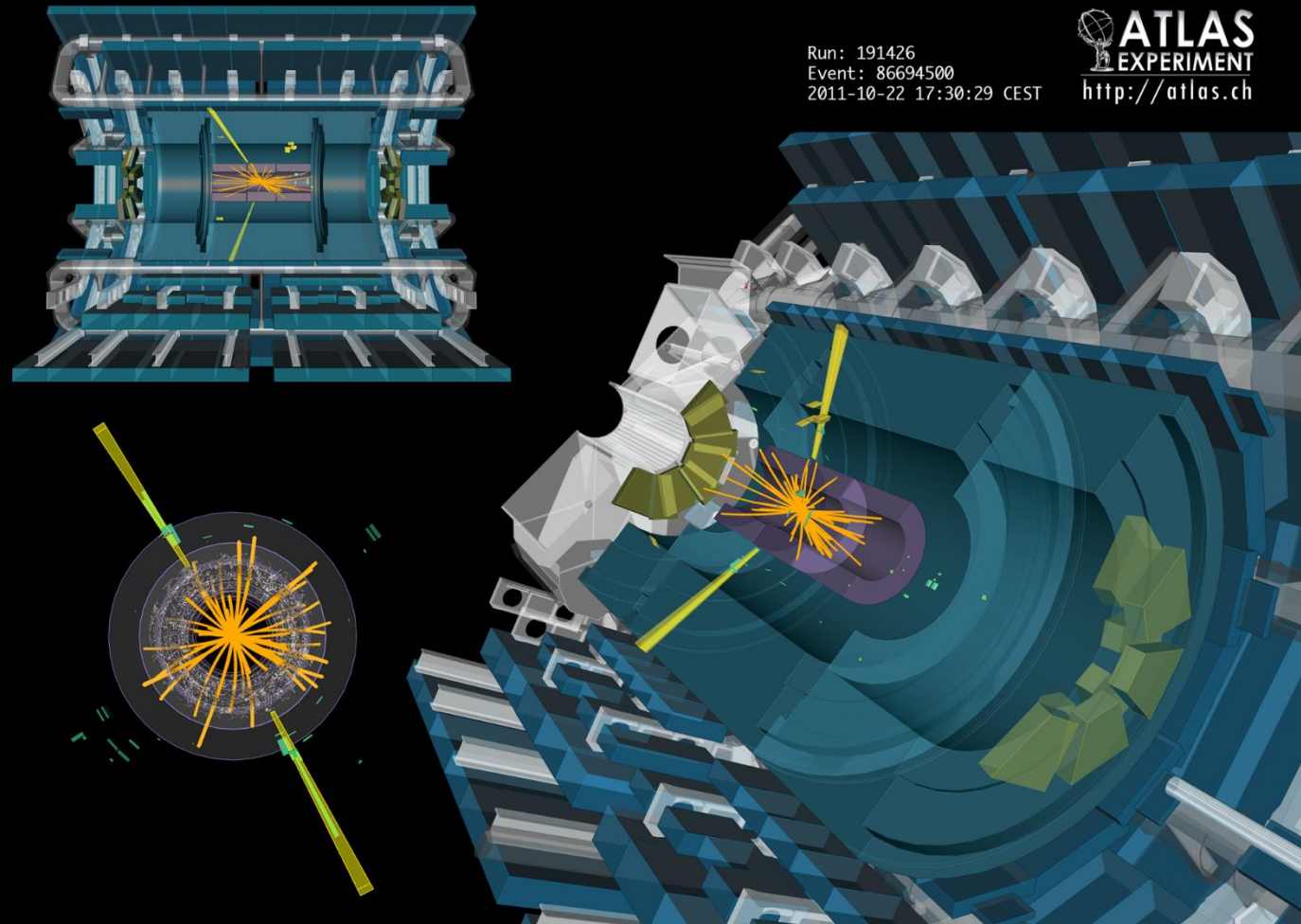
# Mezitím u konkurence ... Experiment CMS...

- ...byl navržen tak, aby nejlépe viděl rozpad Higgsova bosonu na dva fotony.
- Rozpad Higgsova bosonu na dva fotony??



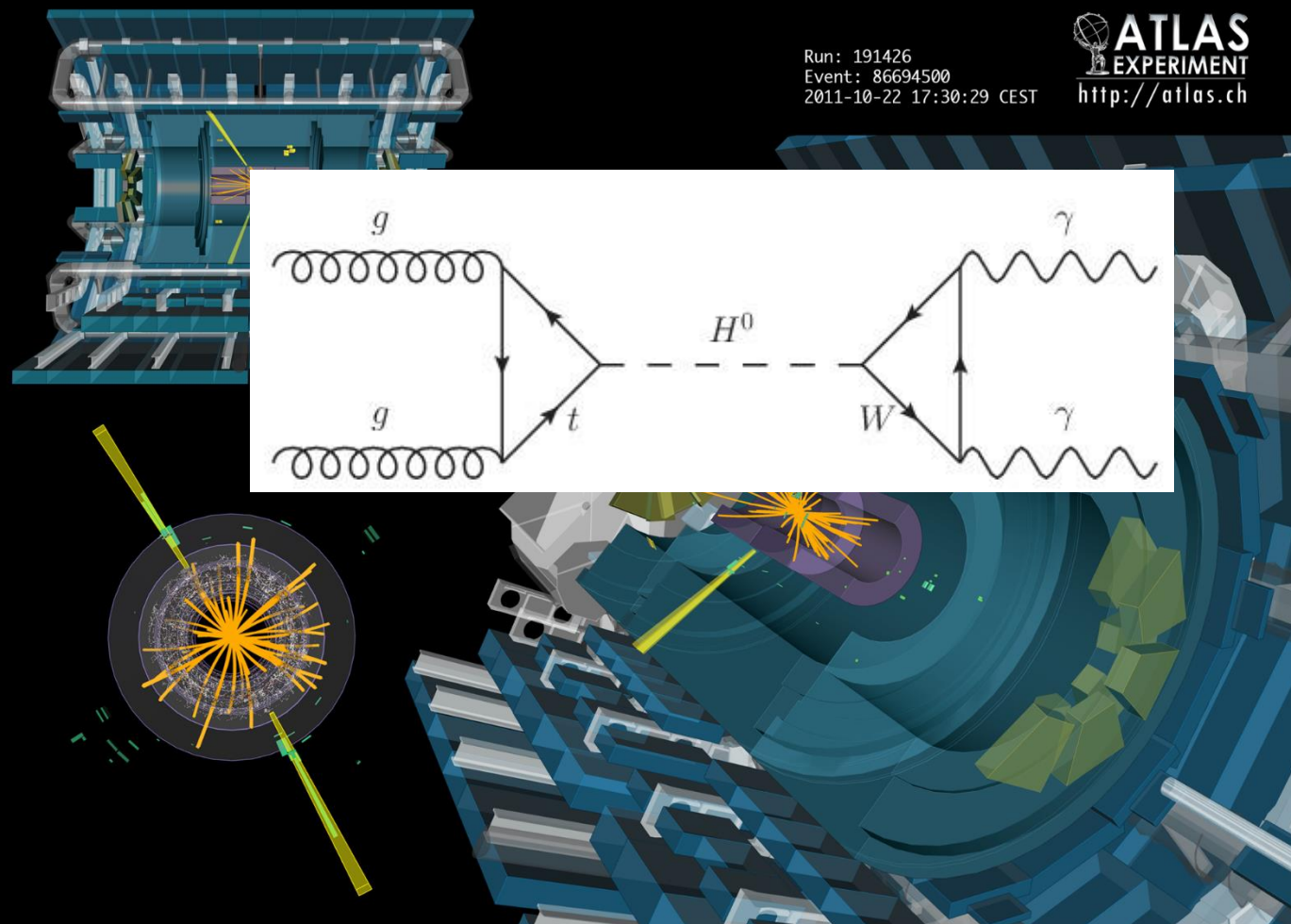
# Higgsův boson

- Rozpad Higgsova bosonu na dva fotony??



# Higgsův boson

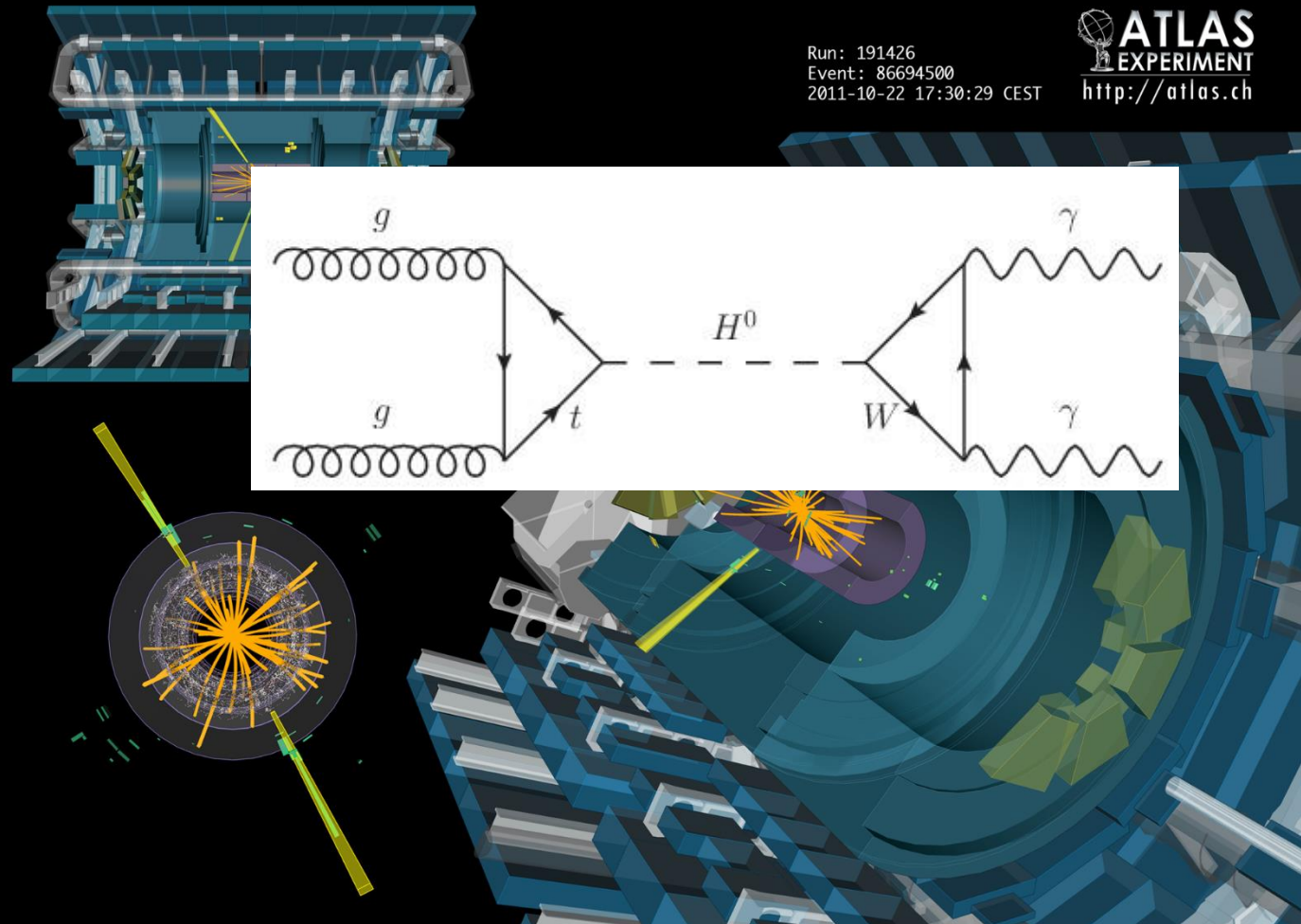
- Rozpad Higgsova bosonu na dva fotony?? – Ano!!





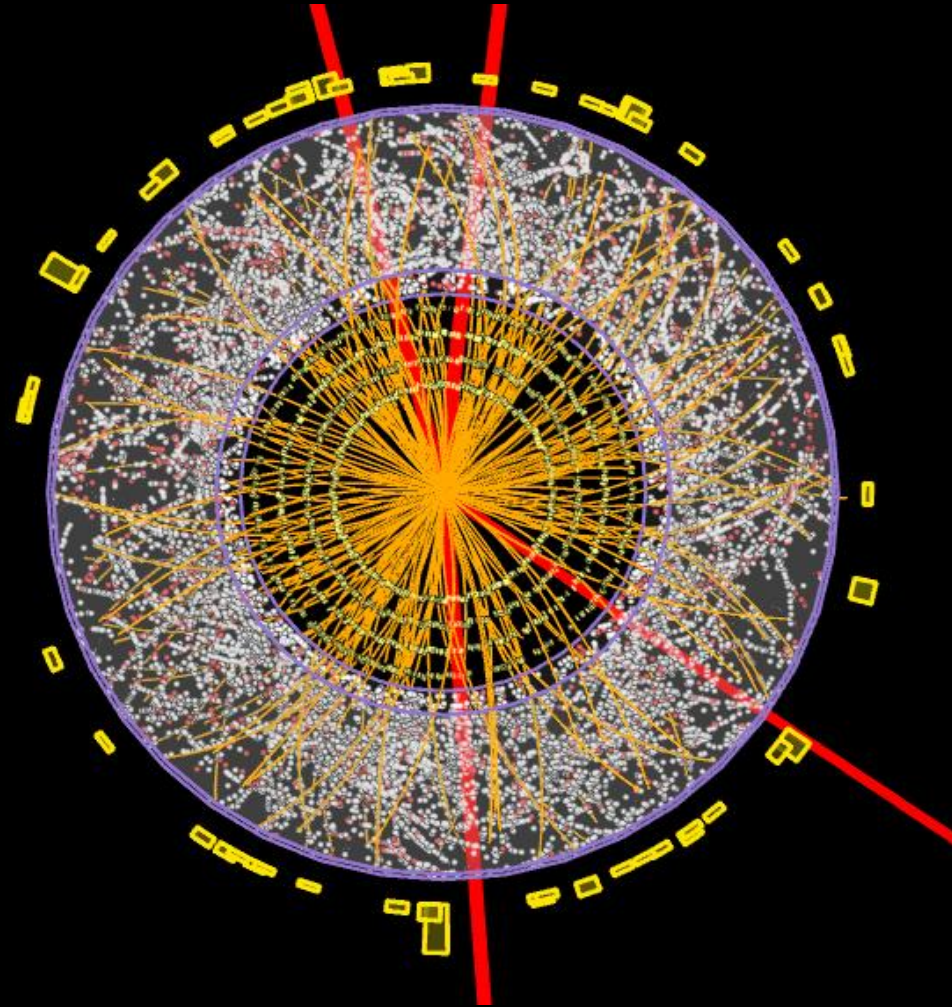
# Higgsův boson

- Rozpad Higgsova bosonu na dva fotony?? – Ano!!
- Higgs si vlastně posvítí na nás 😊



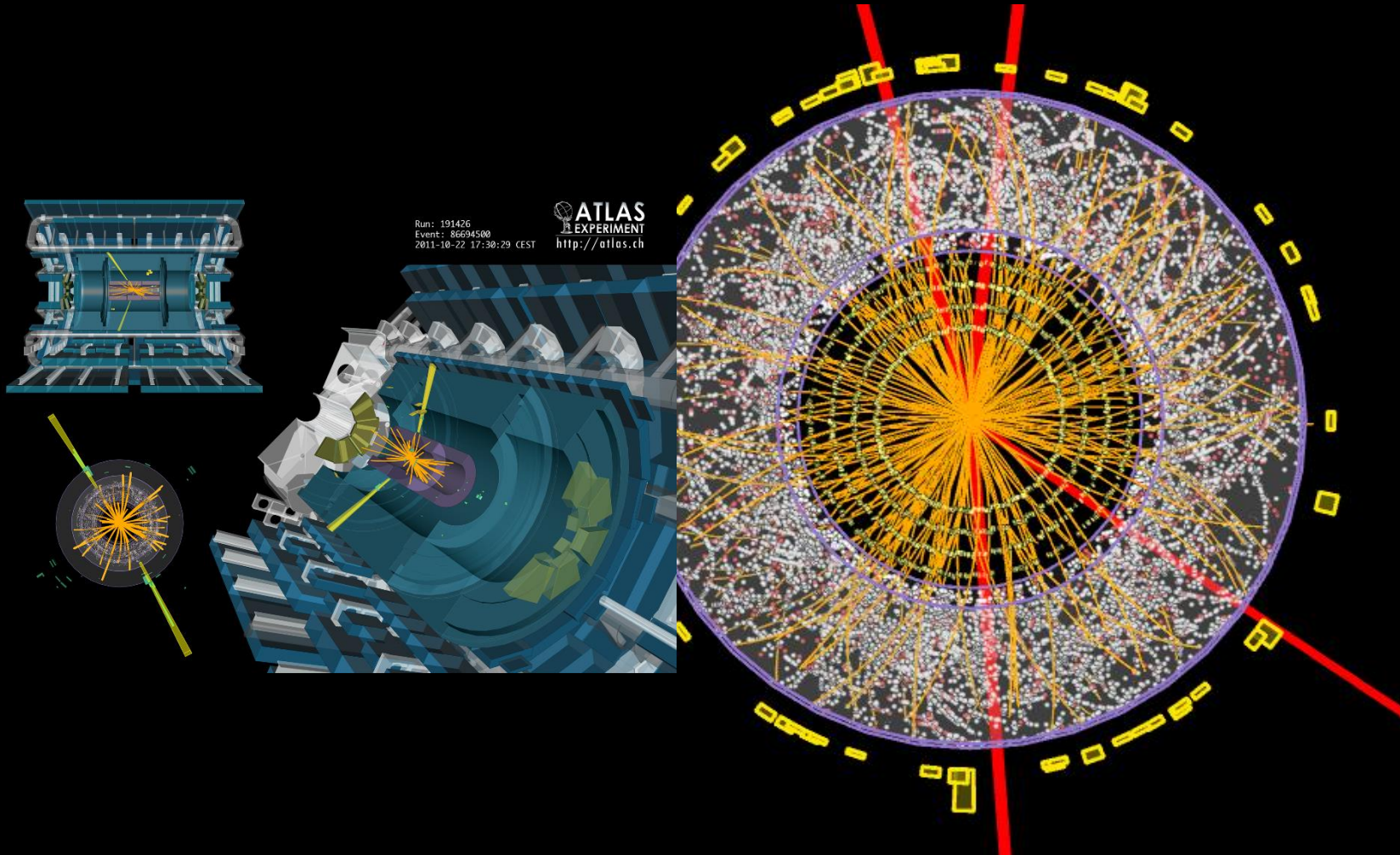
# Higgsův boson

- Jak vypadá? Aneb: jedna vlašťovka jaro nedělá...



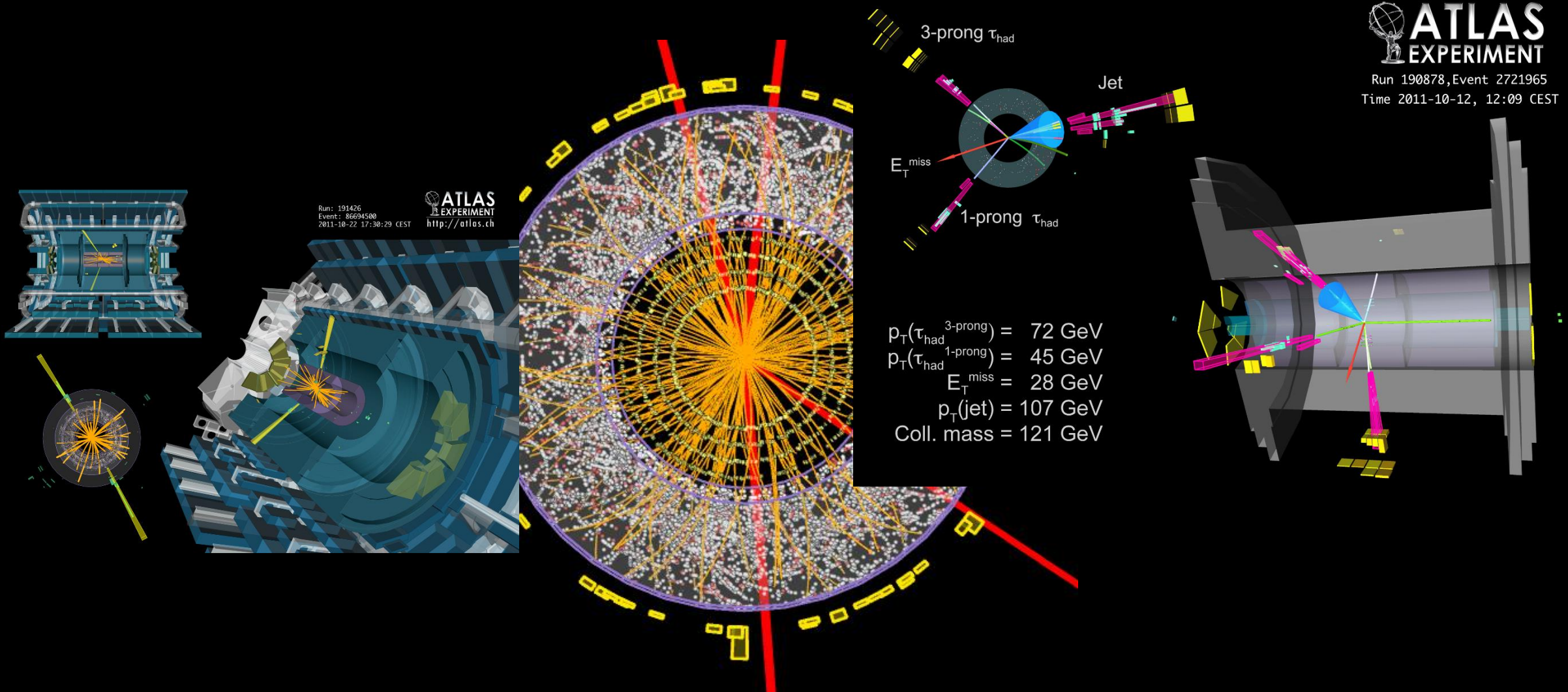
# Higgsův boson

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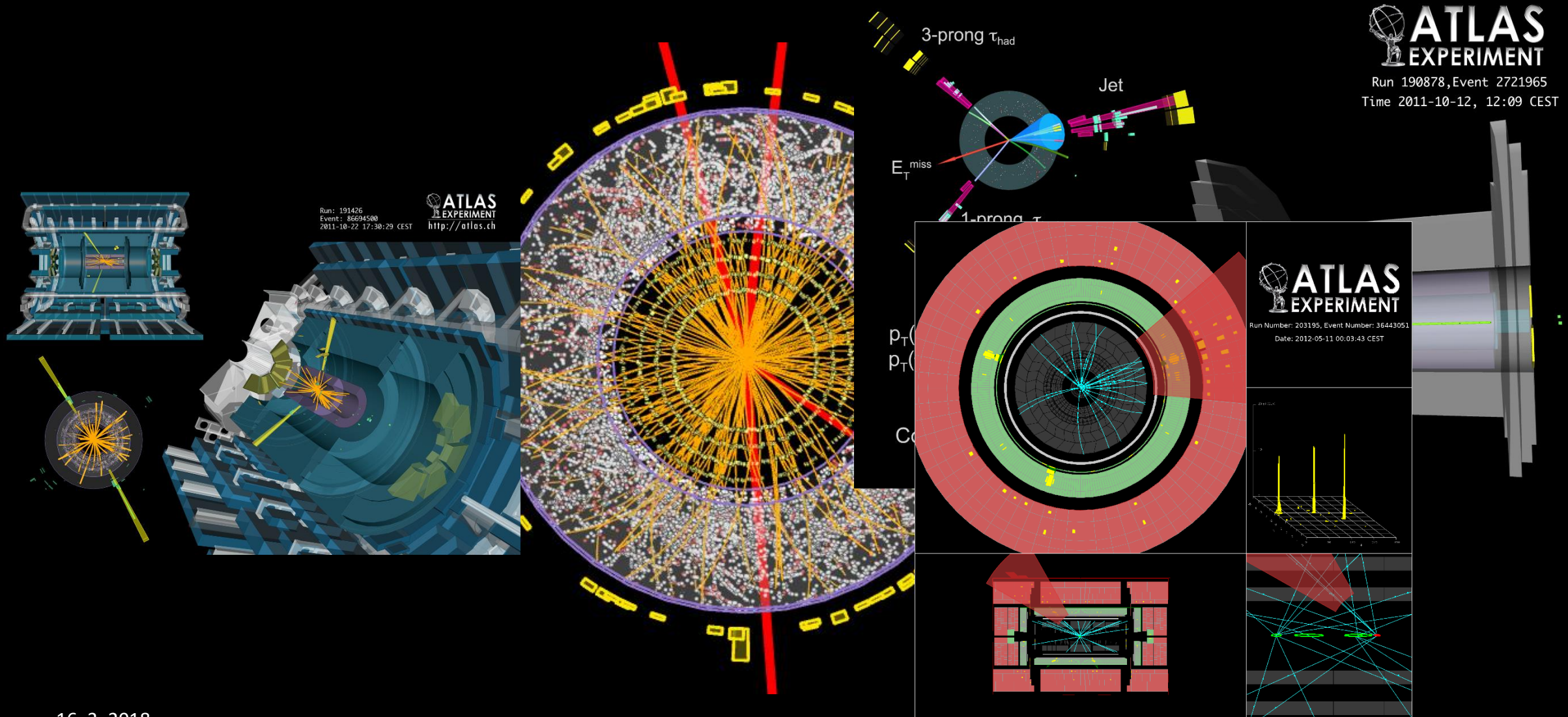
# Higgsův boson

- Jak vypadá? Aneb: jedna vlašťovka jaro nedělá...



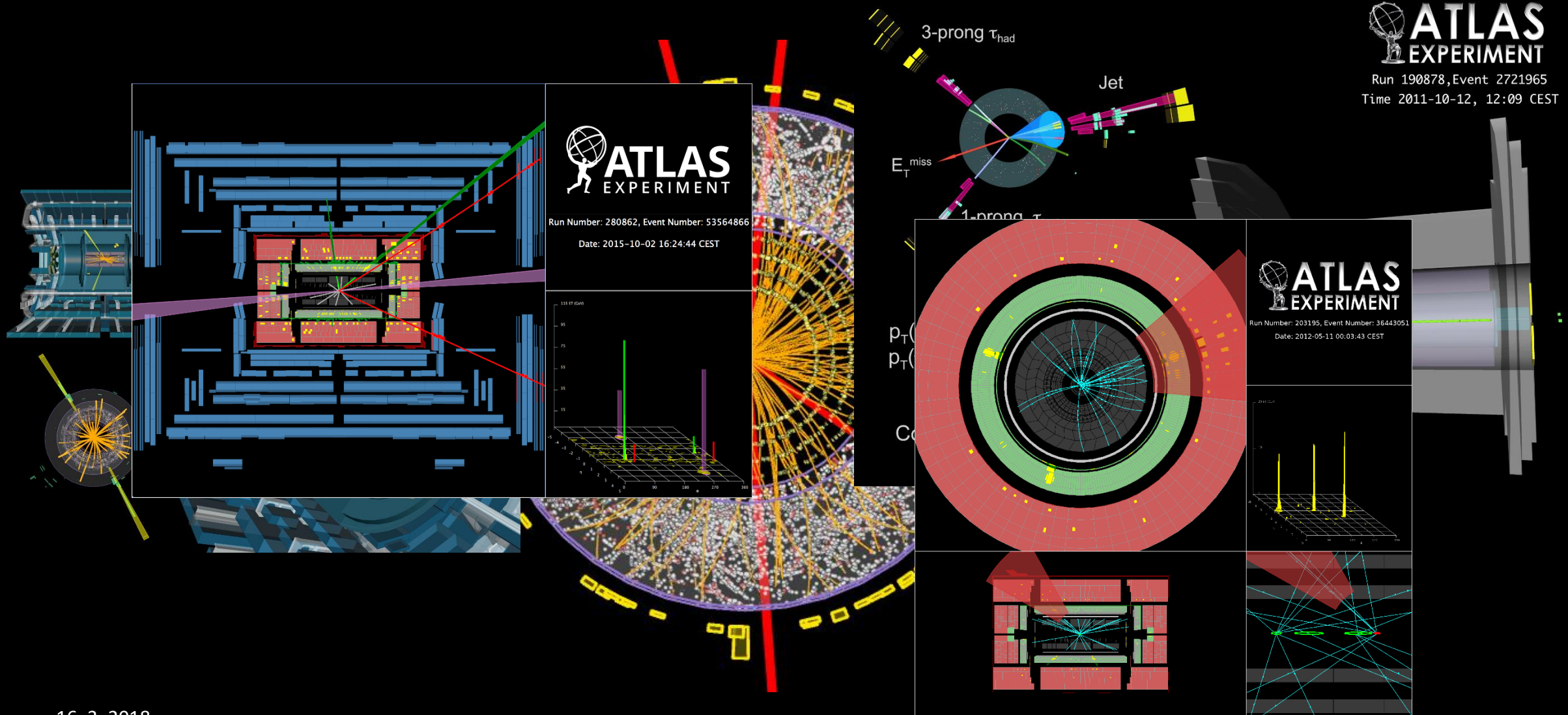
# Higgsův boson

- Jak vypadá? Aneb: jedna vlašťovka jaro nedělá...



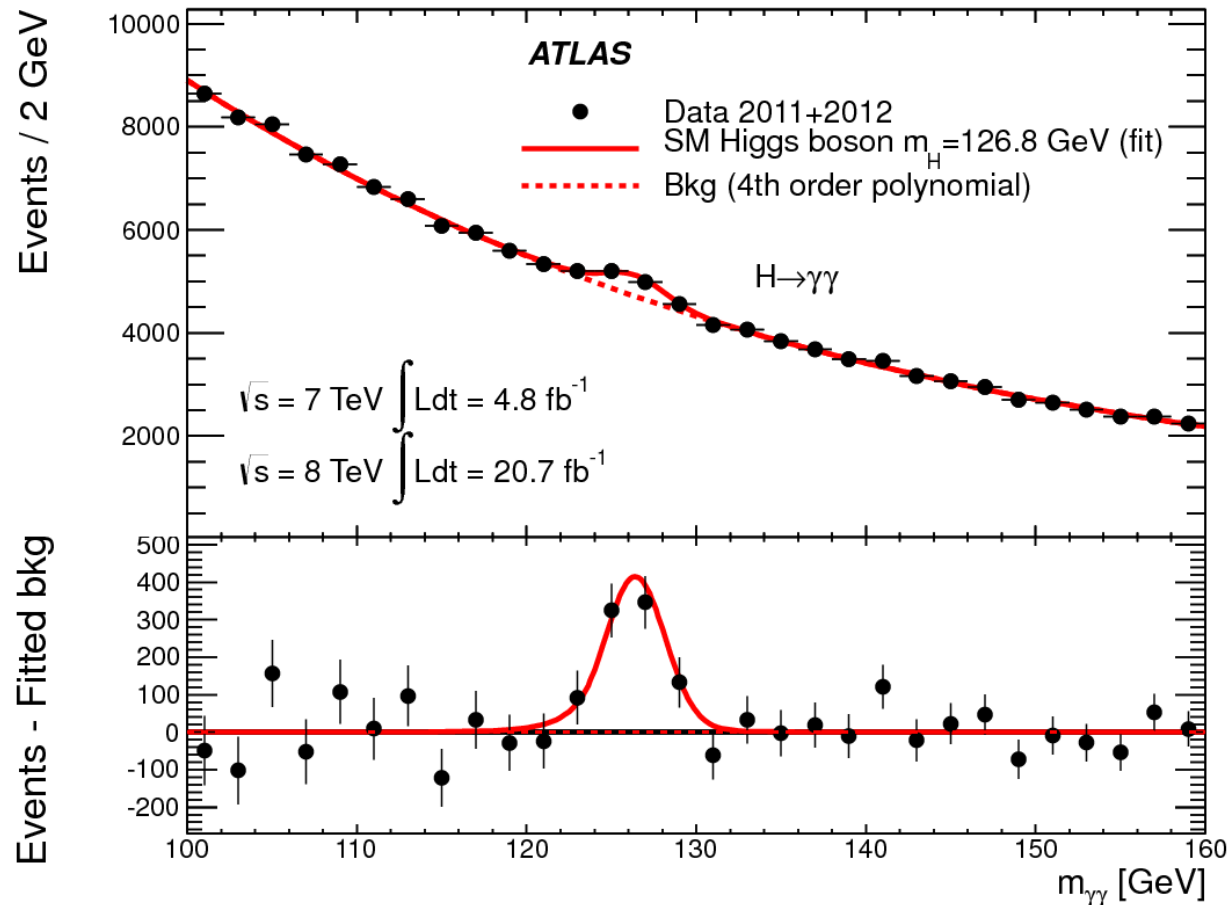
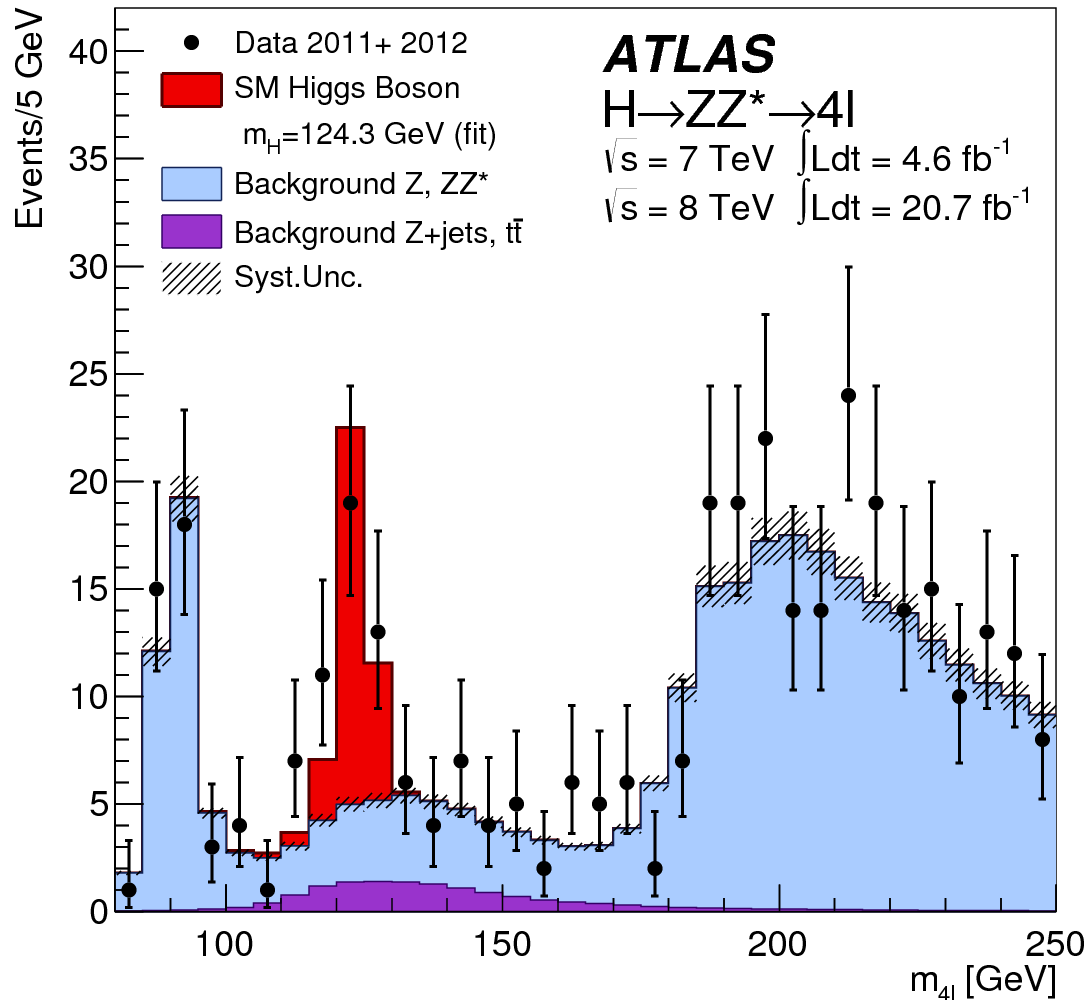
# Higgsův boson

- Jak vypadá? Aneb: jedna vlaštovka jaro nedělá...



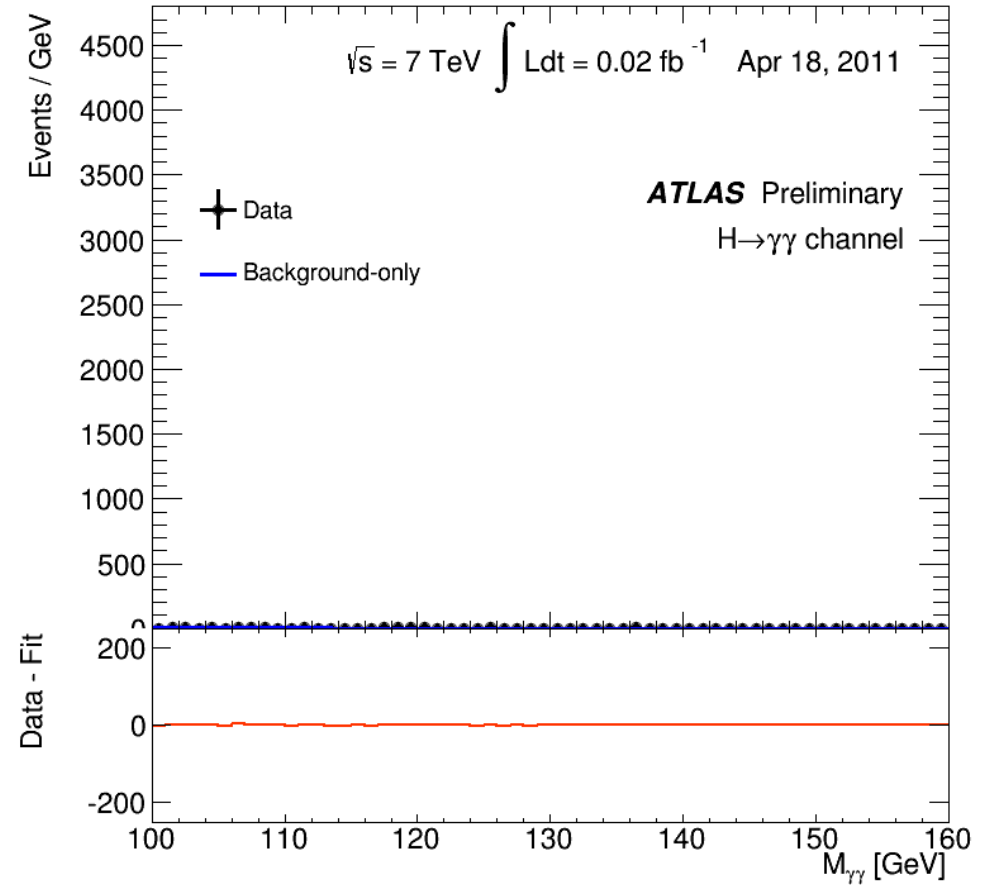
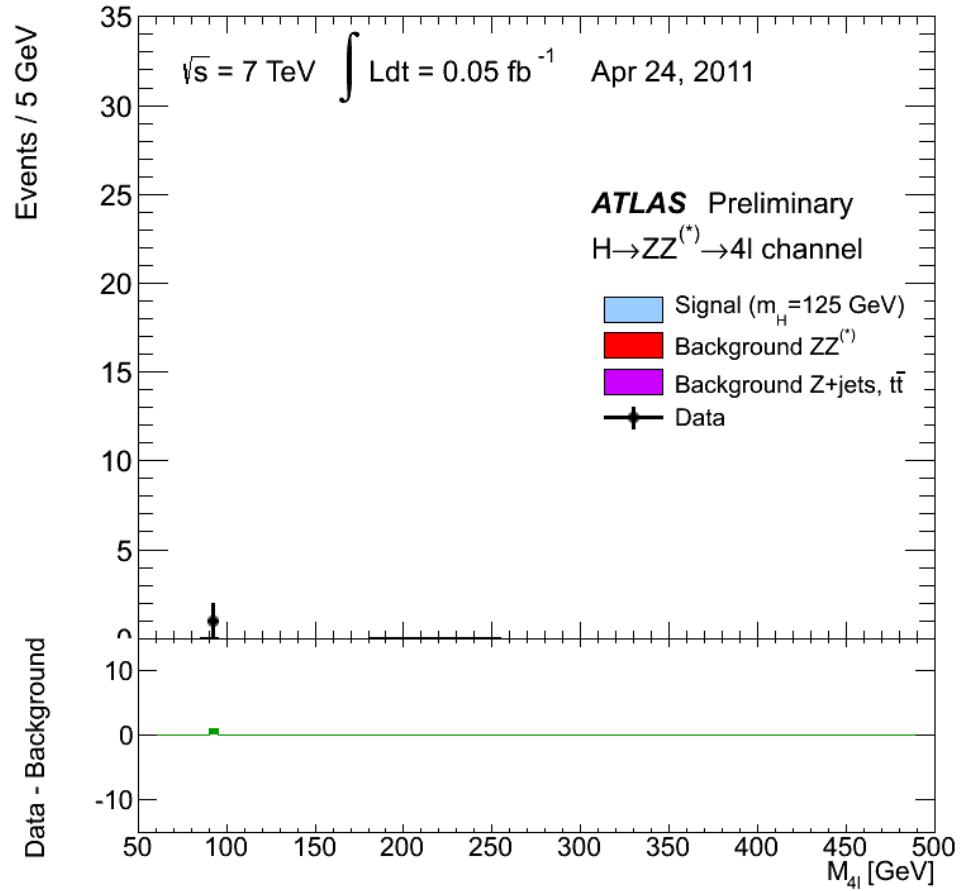
# Higgsův boson

- Mnoho událostí, měsíce běhu urychlovače a provozu detektoru:



# Higgsův boson

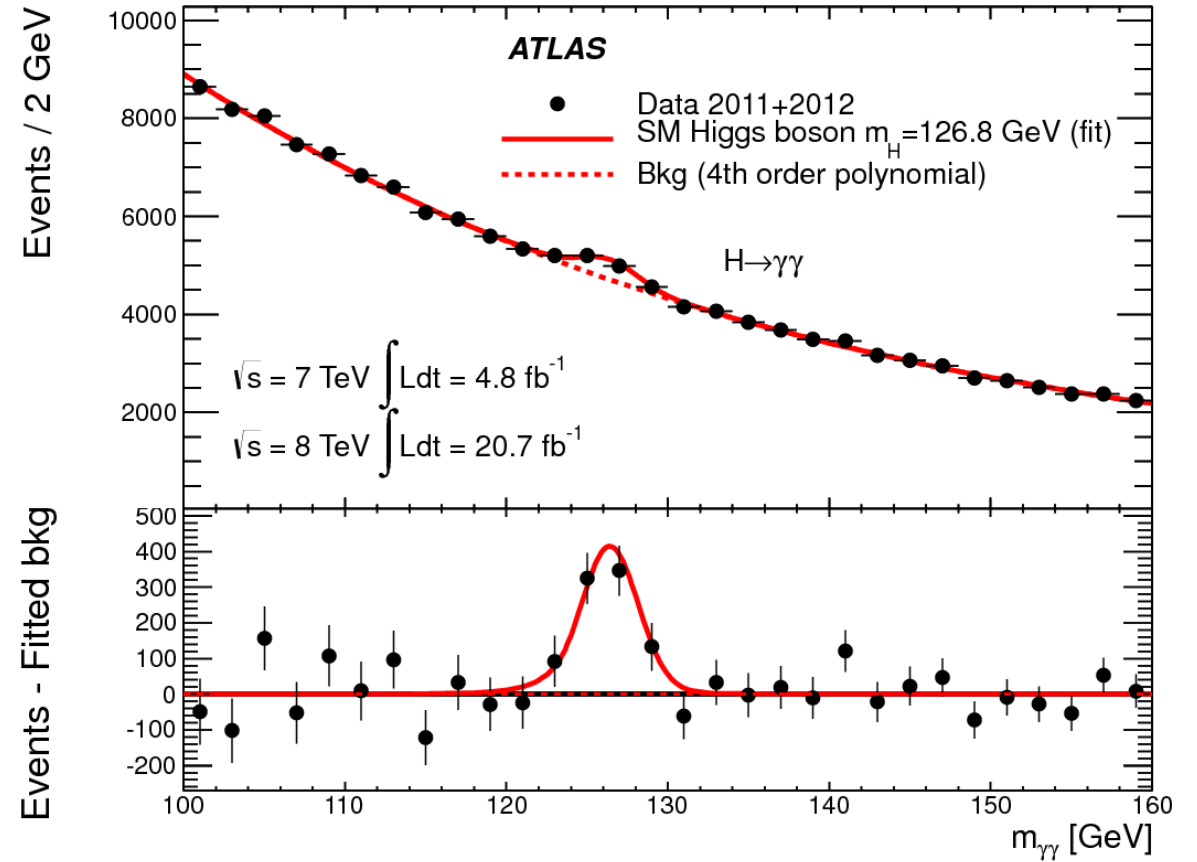
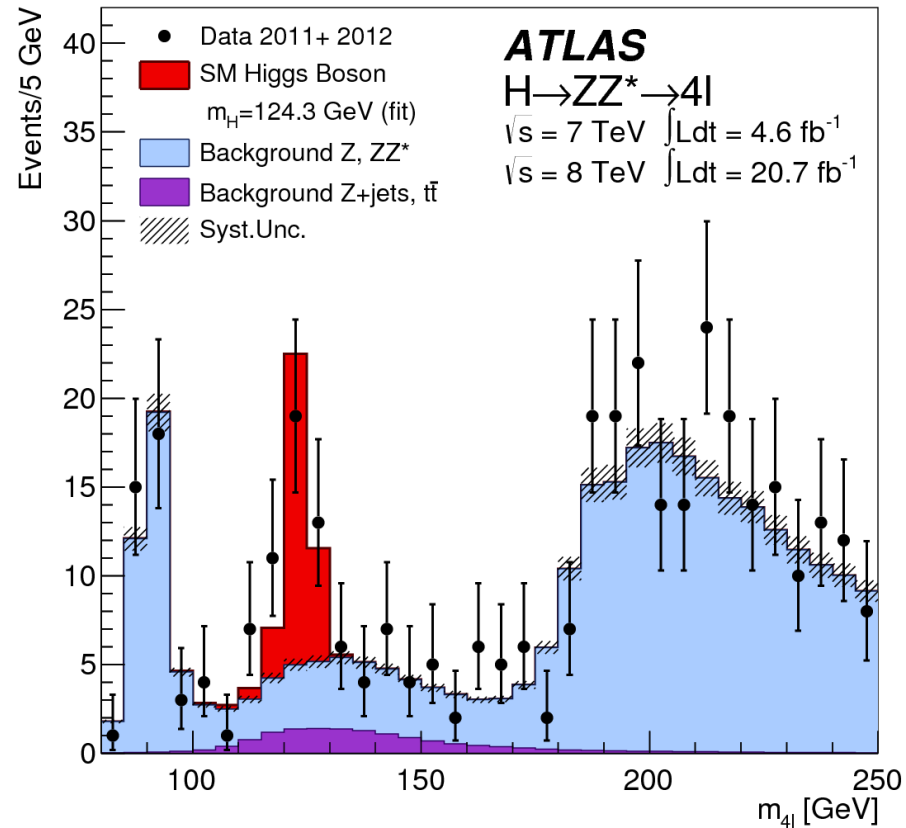
- Čekání na Higgse.





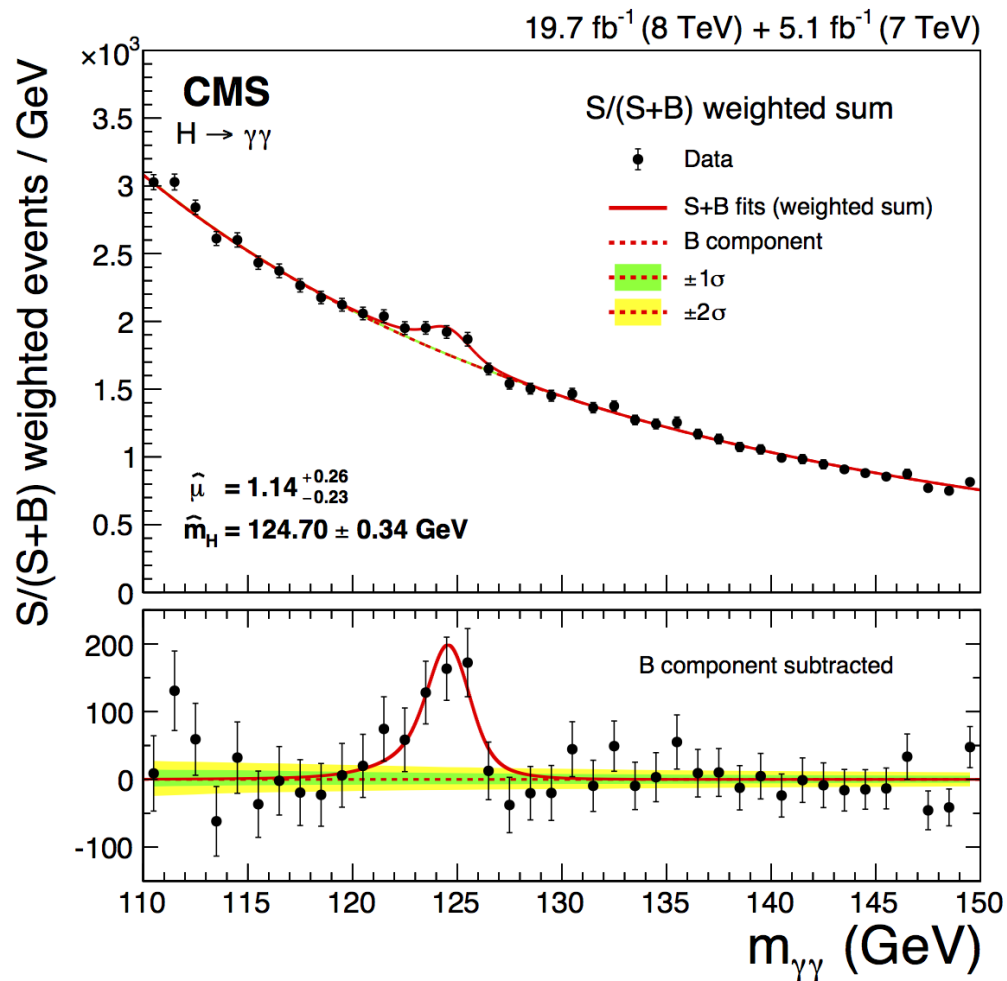
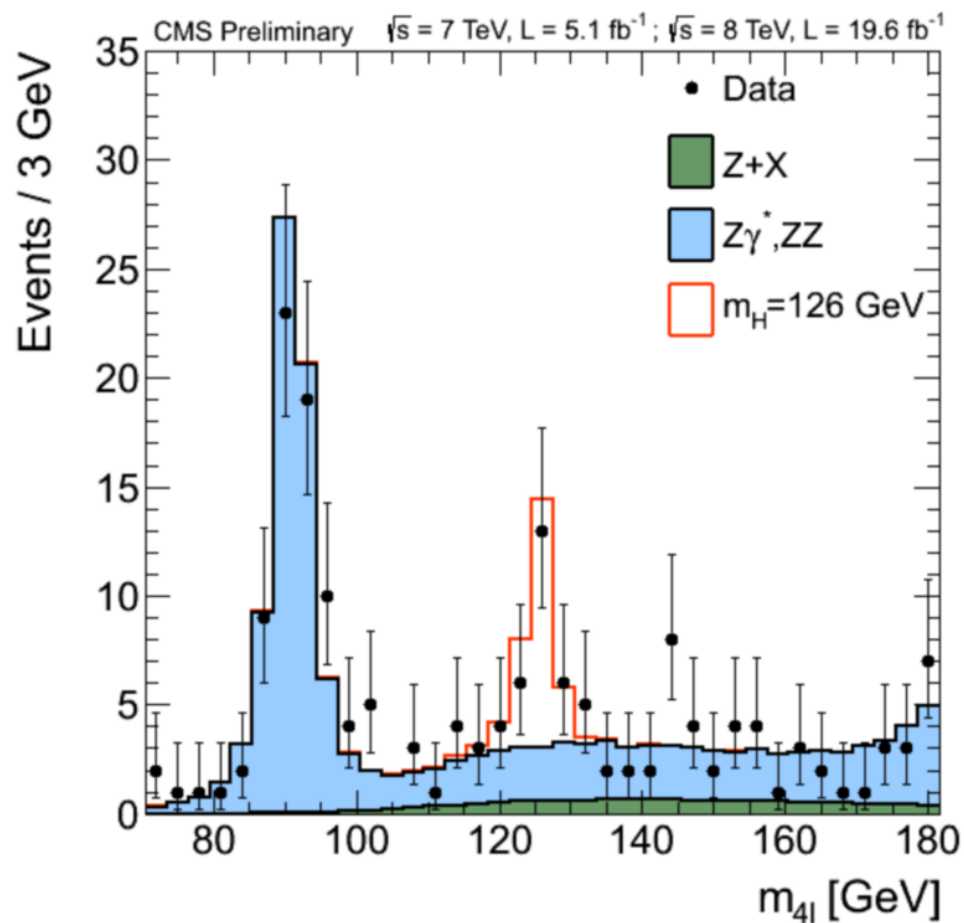
# Higgsův boson

- Viděno experimentem ATLAS:



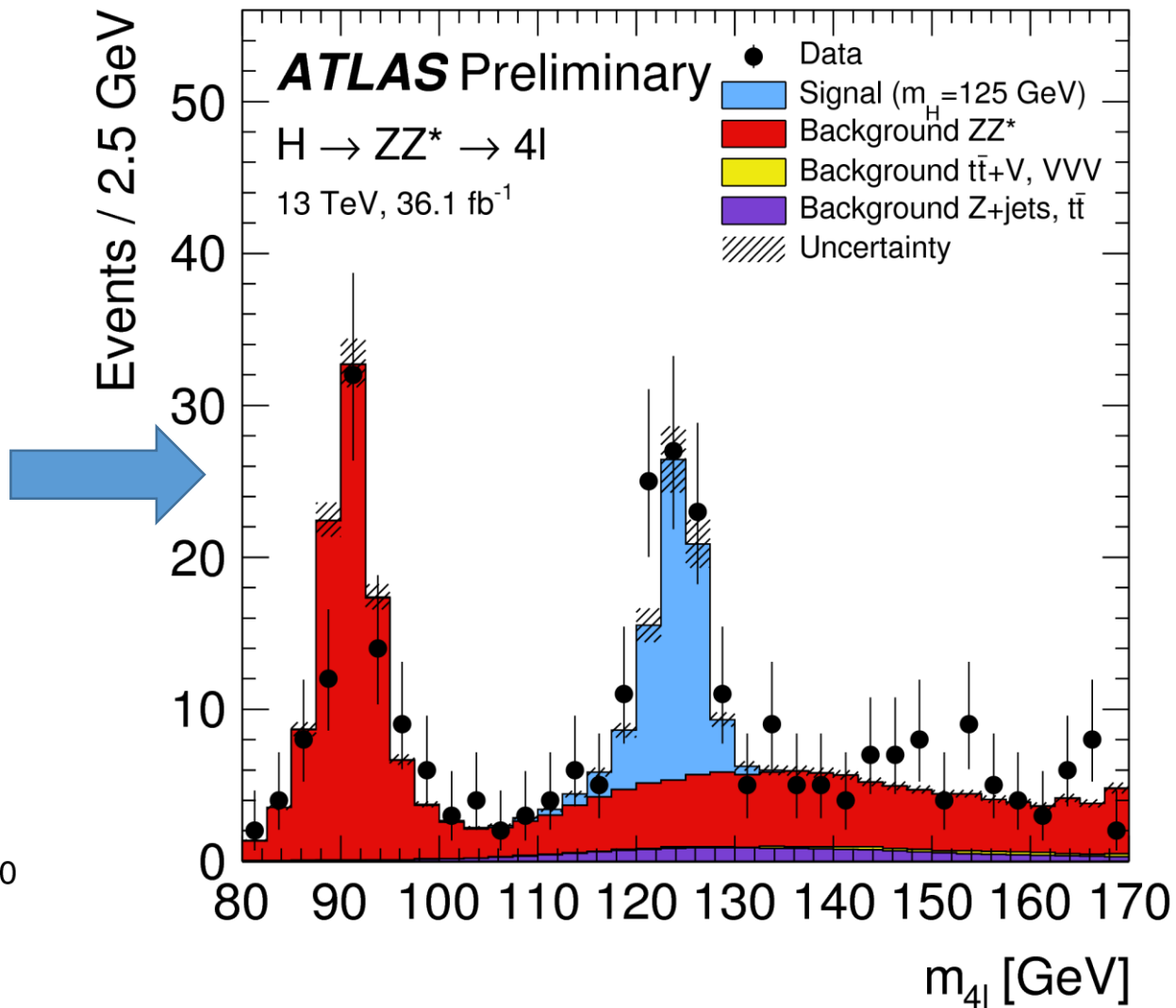
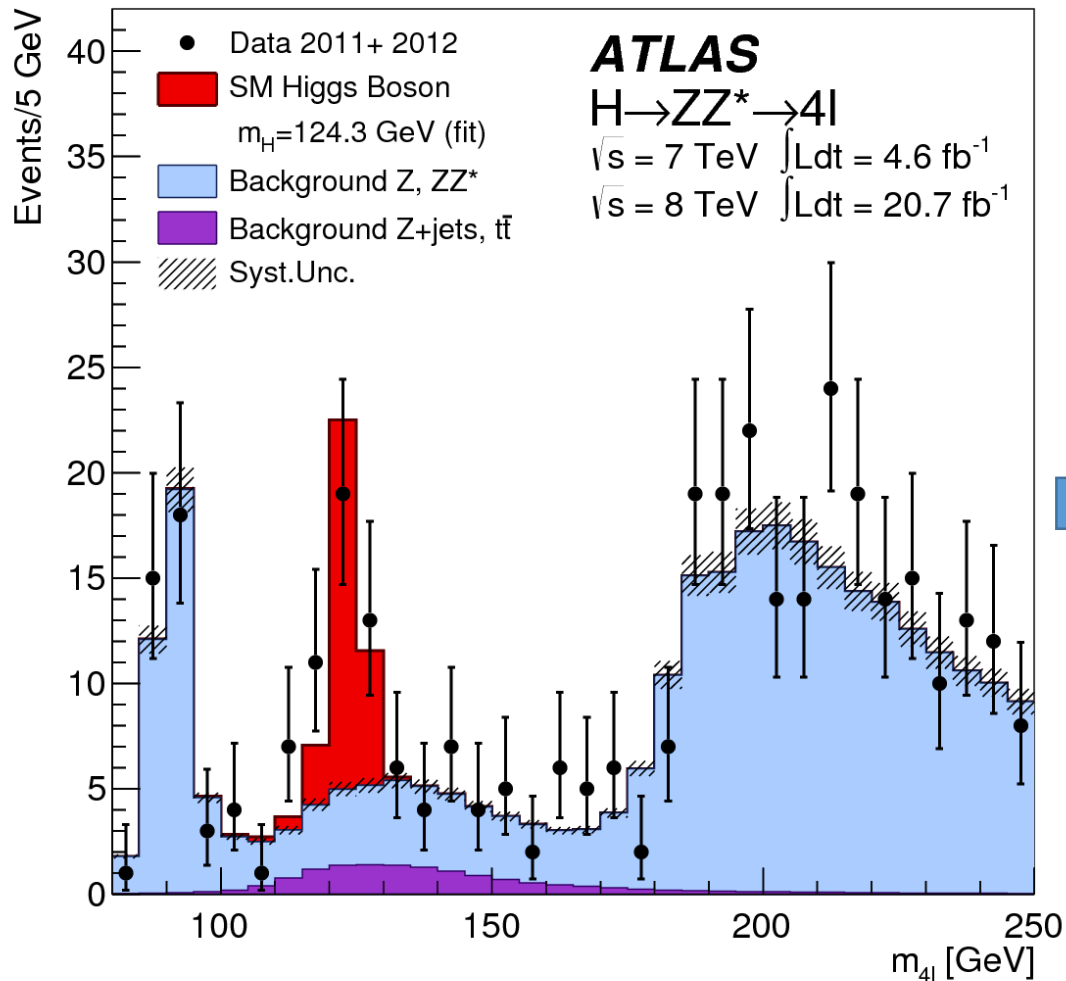
# Higgsův boson

- ...mezitím u konkurence (experiment CMS):



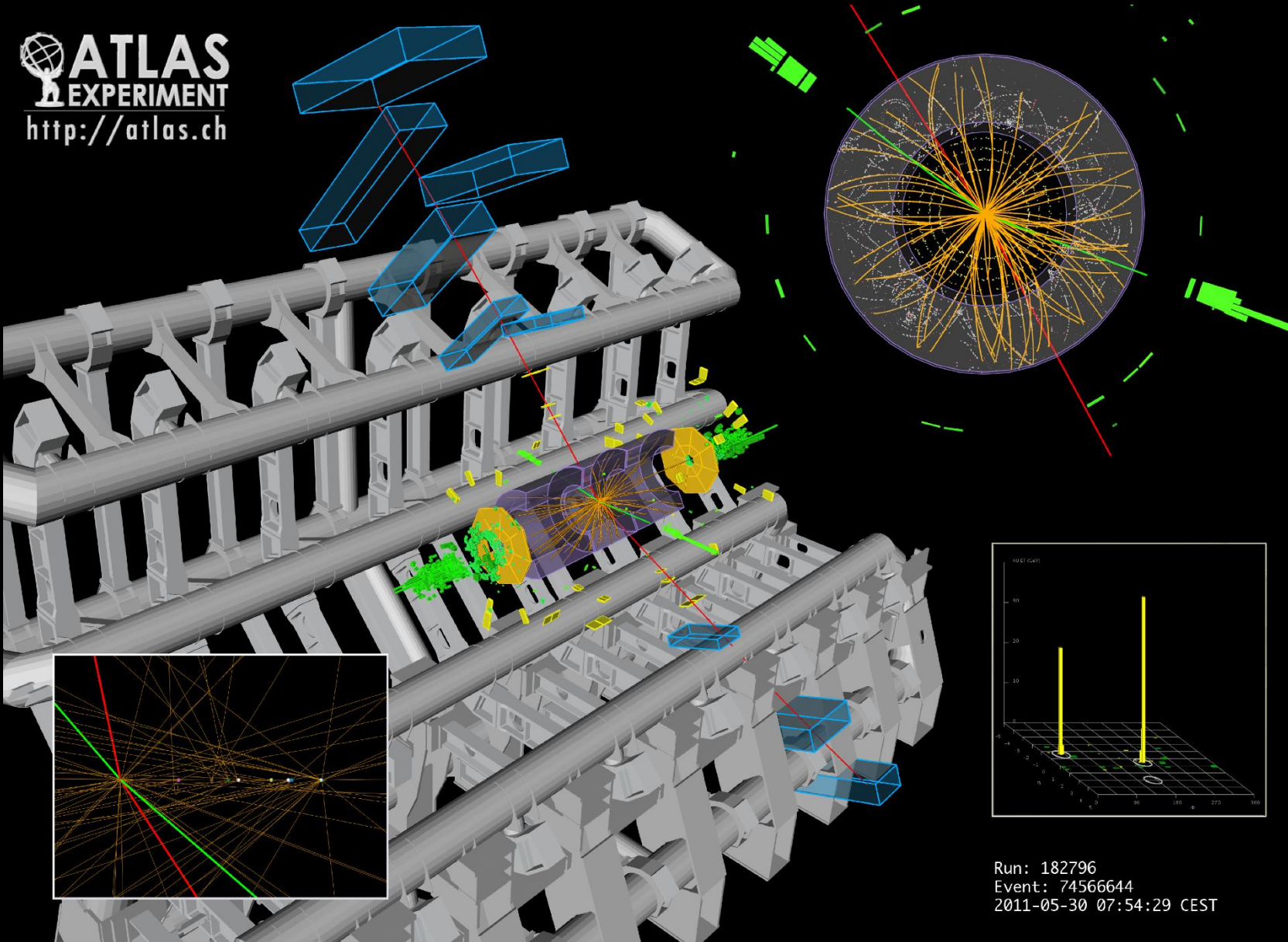
# Higgsův boson

- ...a zahrnutím dat z let 2015–2016:



$$H \rightarrow ZZ^* \rightarrow ee \mu \mu$$

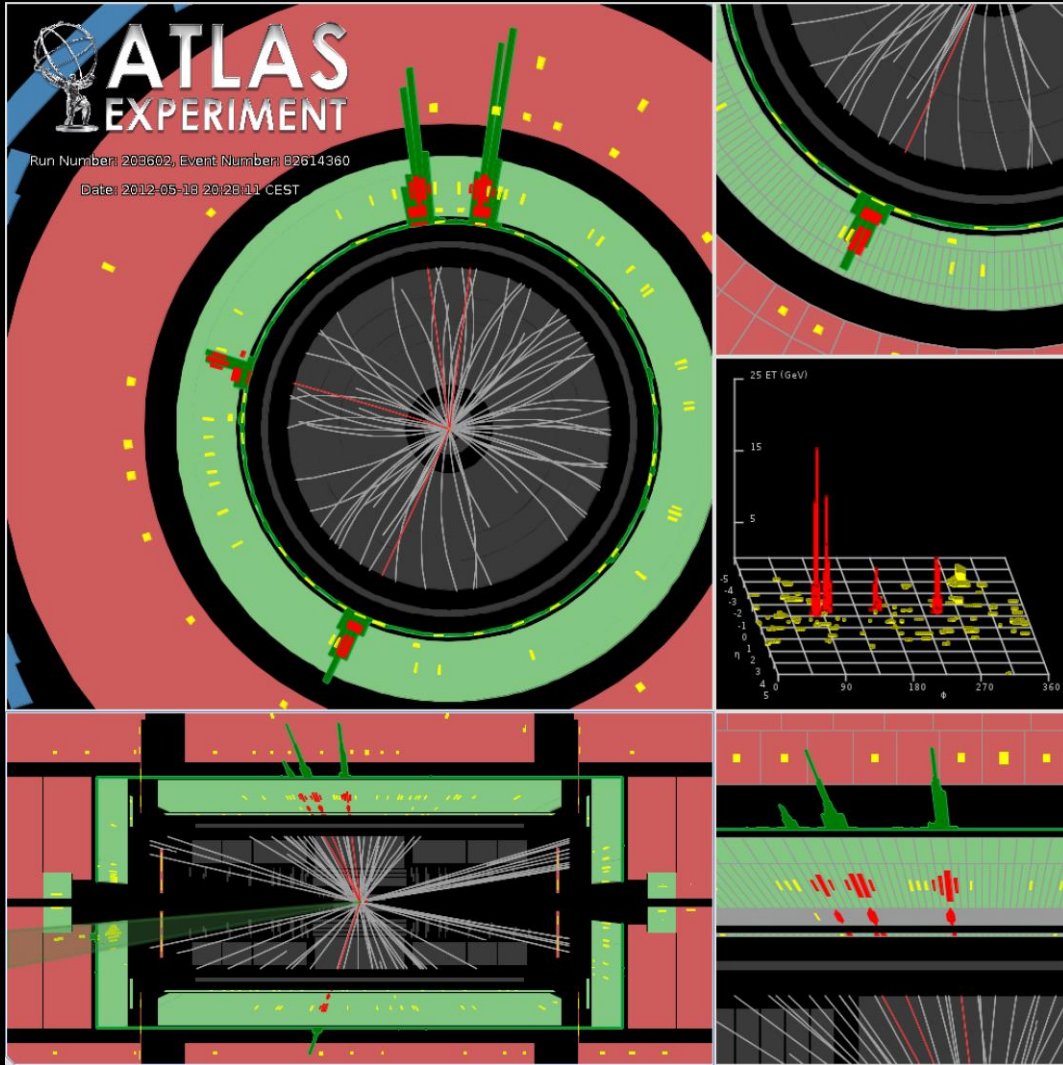
 **ATLAS**  
EXPERIMENT  
<http://atlas.ch>



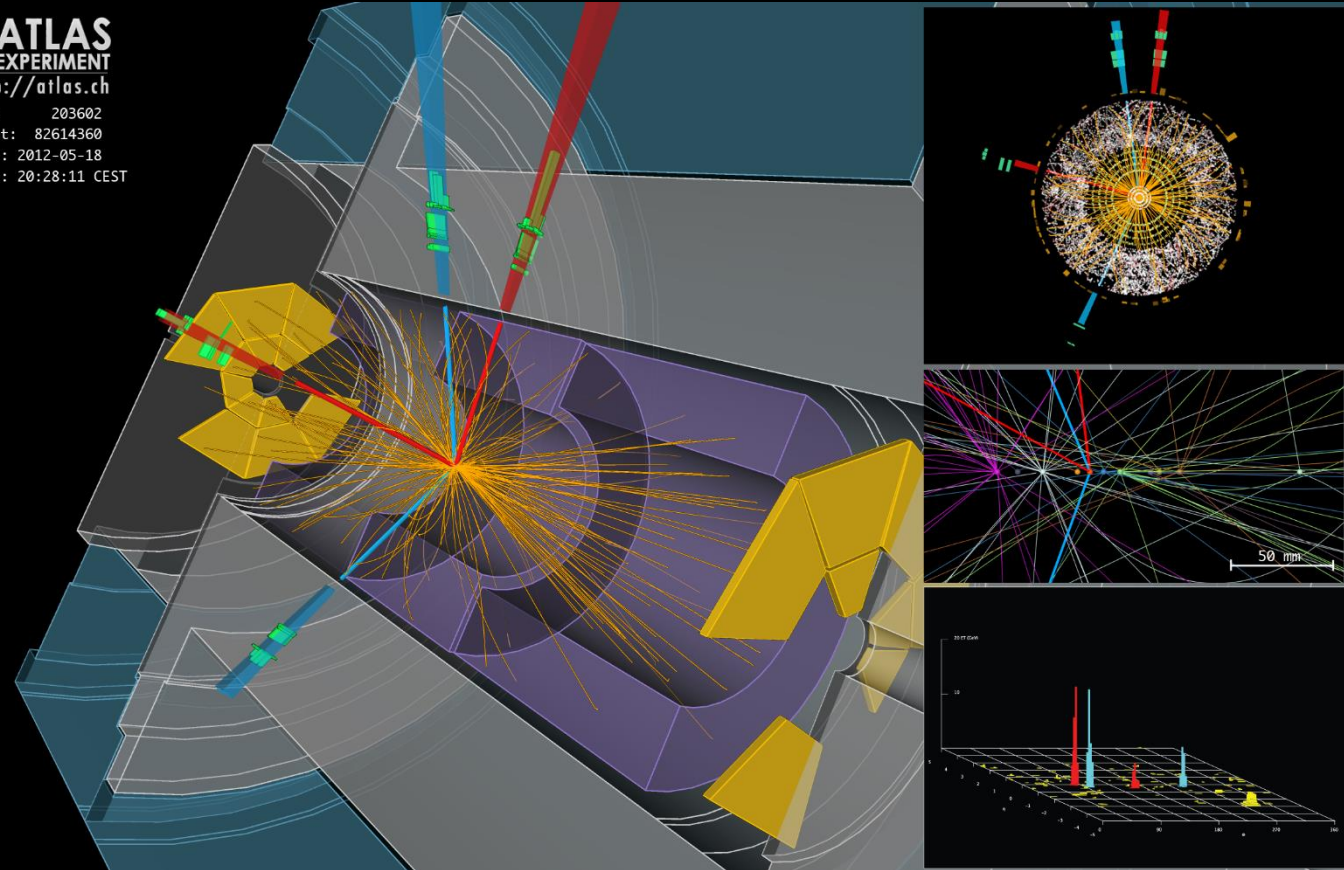
16. 3. 2018

Run: 182796  
Event: 74566644  
2011-05-30 07:54:29 CEST

$$H \rightarrow ZZ^* \rightarrow 4e$$



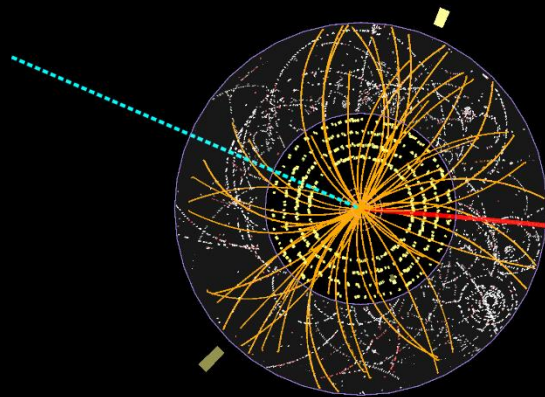
ATLAS EXPERIMENT  
<http://atlas.ch>  
Run: 203602  
Event: 82614360  
Date: 2012-05-18  
Time: 20:28:11 CEST



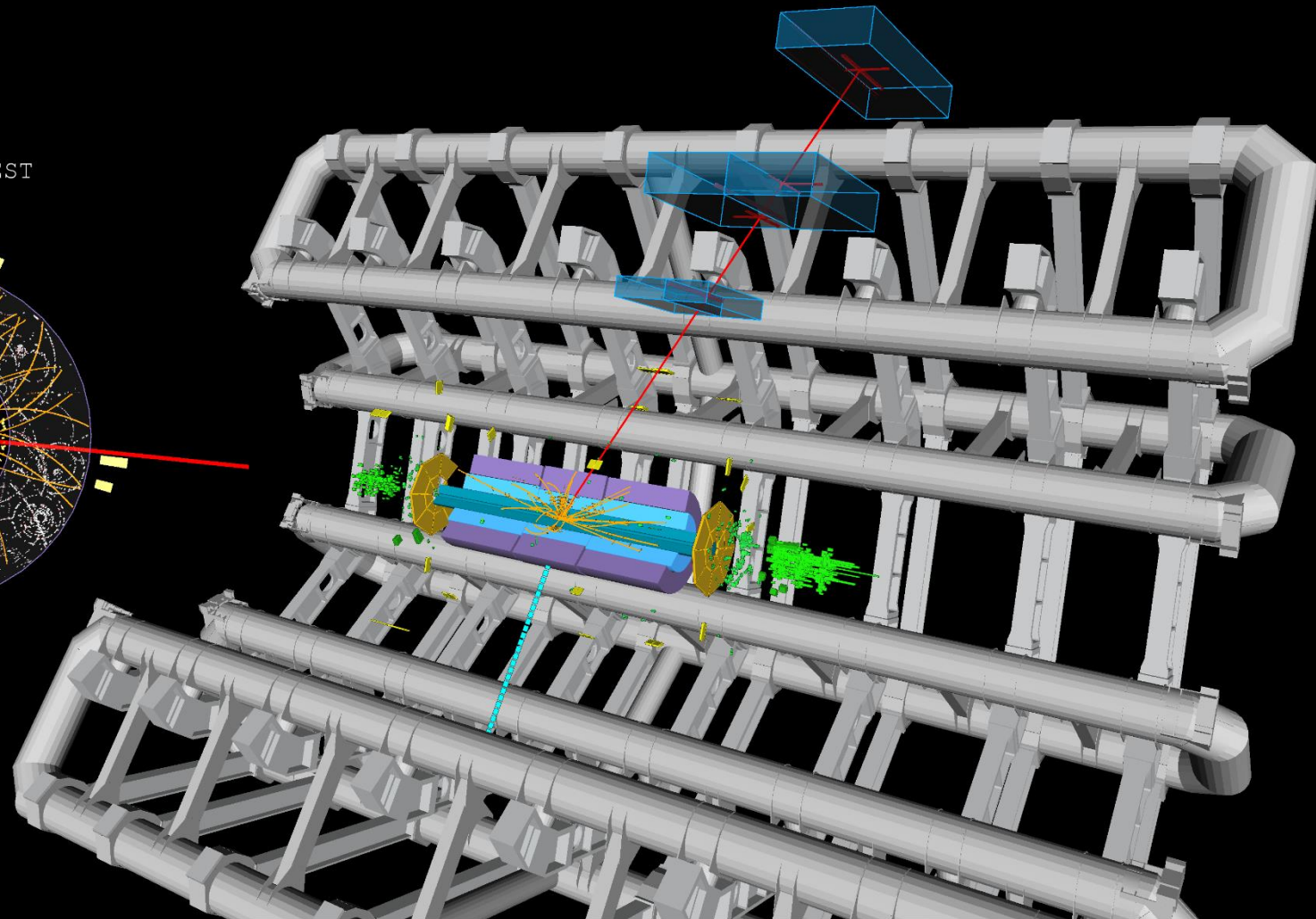
$$pp \rightarrow W + X \rightarrow \mu \nu + X$$



Run: 183081  
Event: 101291517  
2011-06-05 17:09:02 CEST

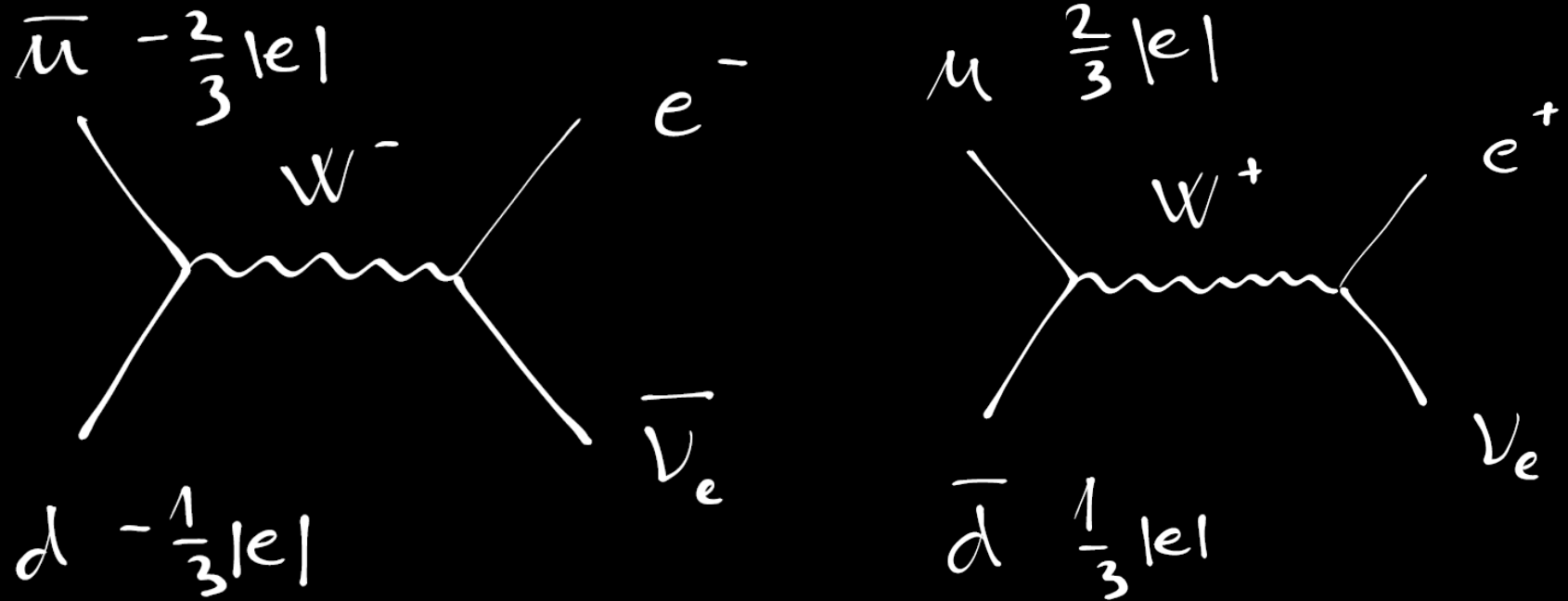
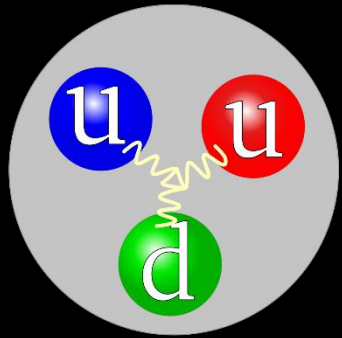


$M_T = 82.9 \text{ GeV}$   
 $p_T \text{ muon} = 32.8 \text{ GeV}$   
 $E_T^{\text{miss}} = 52.4 \text{ GeV}$



# $pp \rightarrow W + X \rightarrow \mu \nu + X$

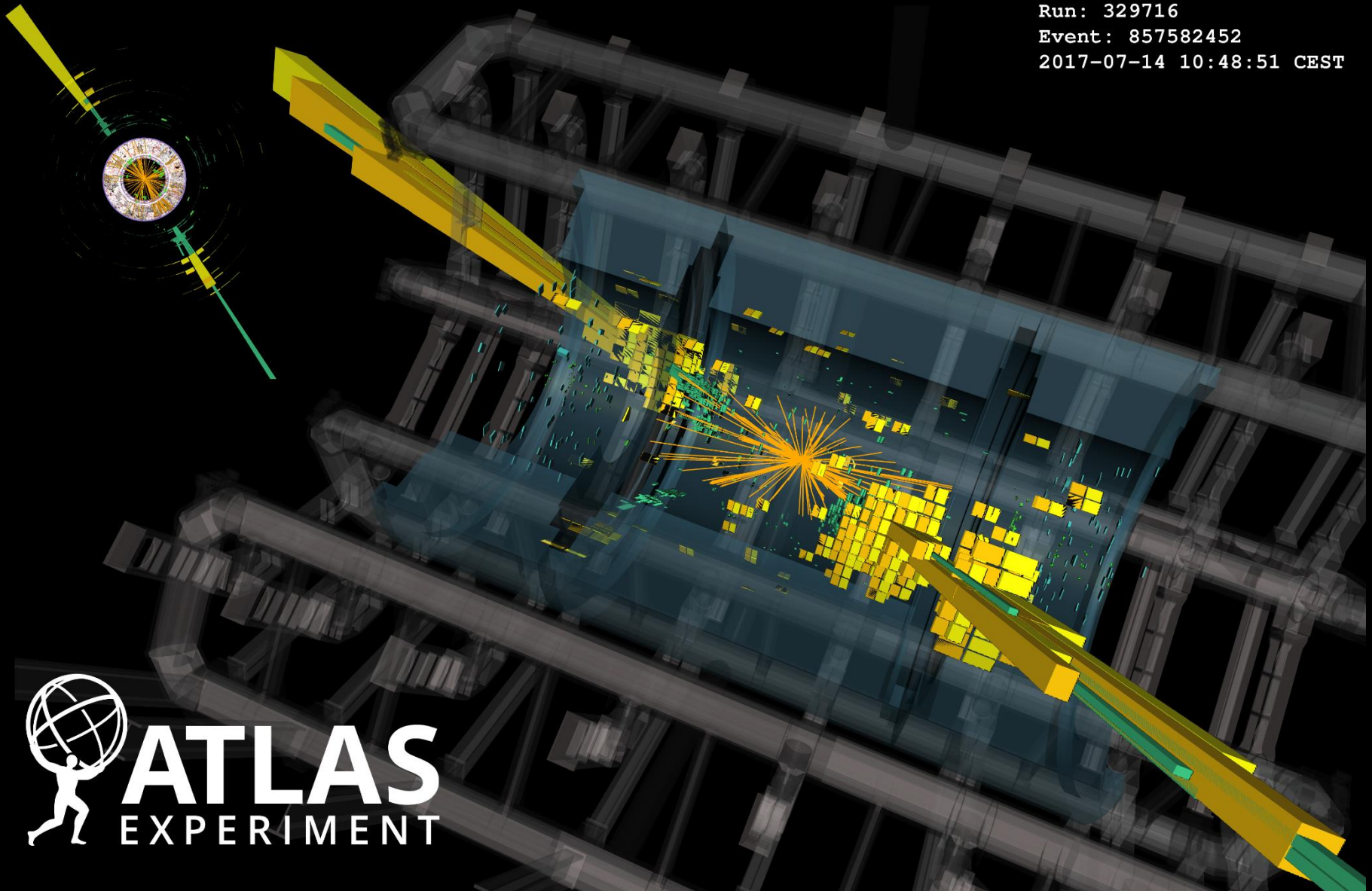
- V pp srážkách se mohou rodit  $W^+$  a  $W^-$  bosony. Rodí se stejně často?
- Proton = (uud)



$$R \equiv \frac{N_{W^+}}{N_{W^-}} \doteq 2$$

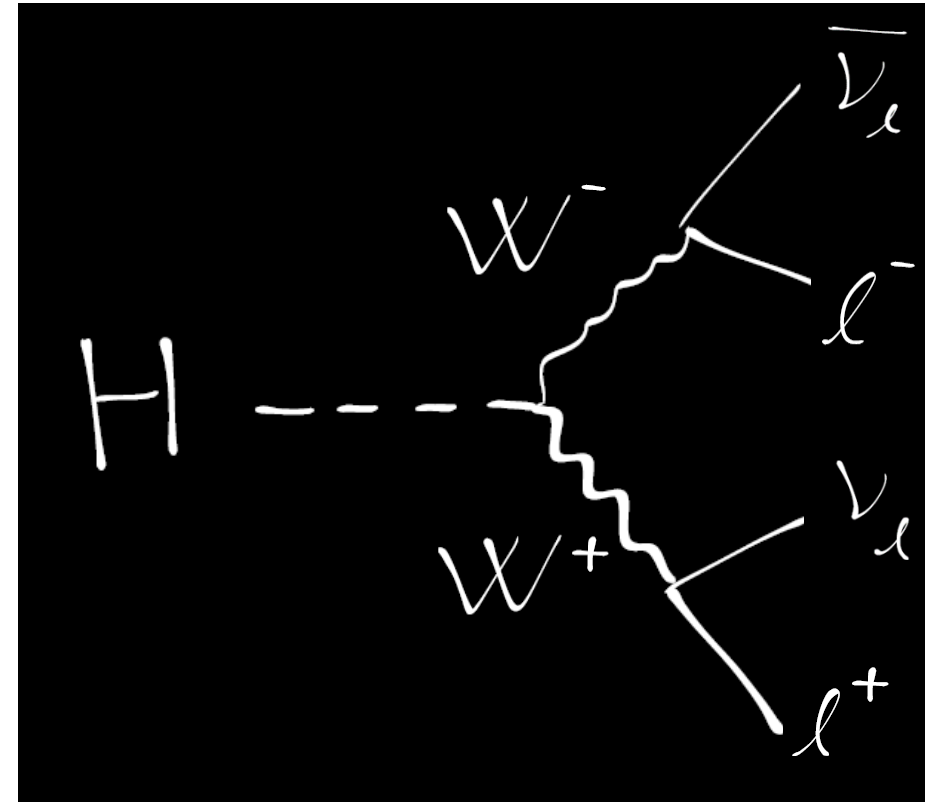
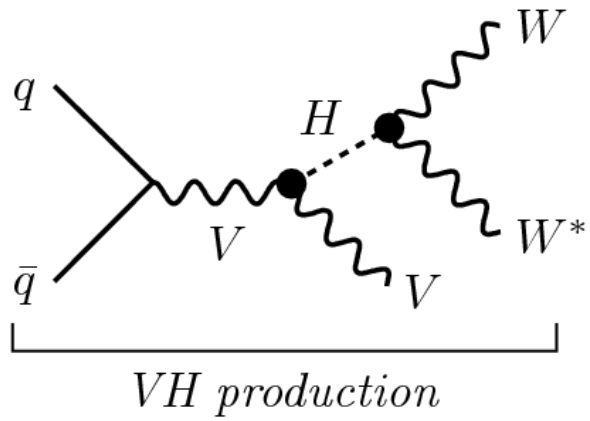
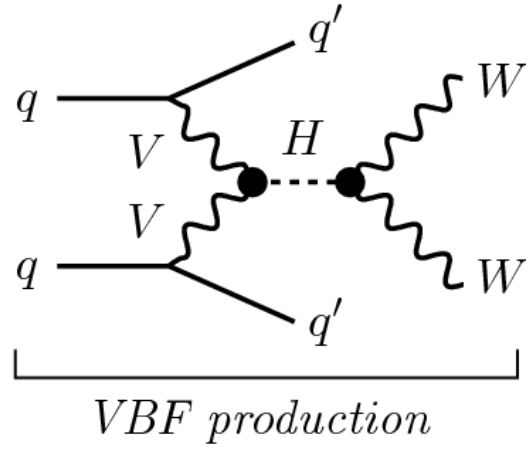
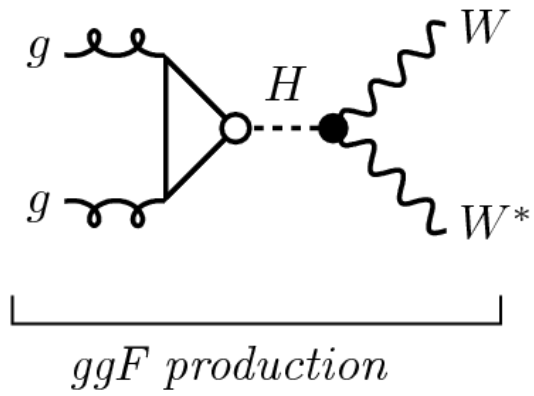
pp  $\rightarrow$  jety

Run: 329716  
Event: 857582452  
2017-07-14 10:48:51 CEST

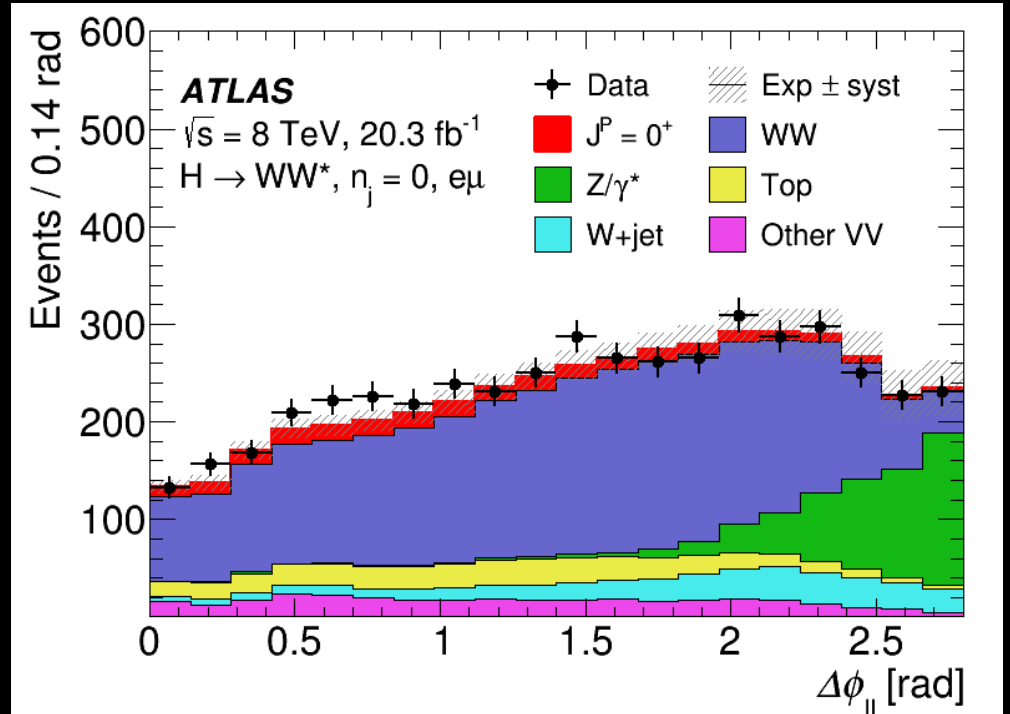
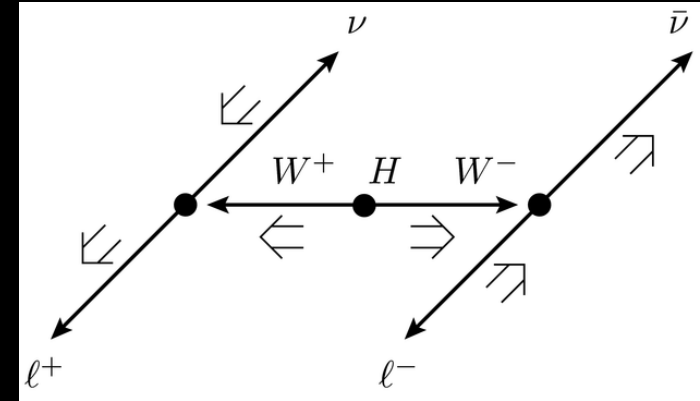
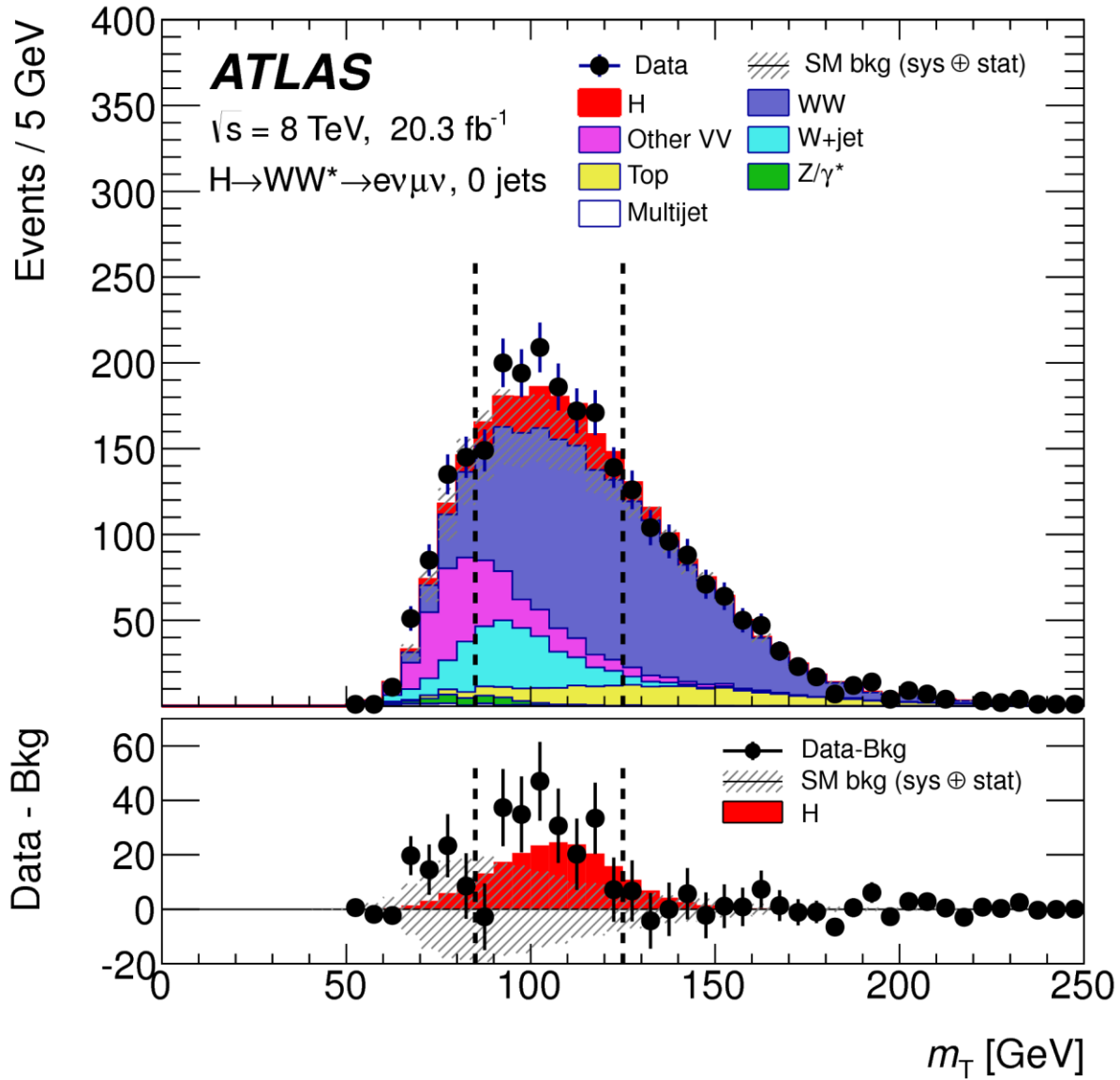




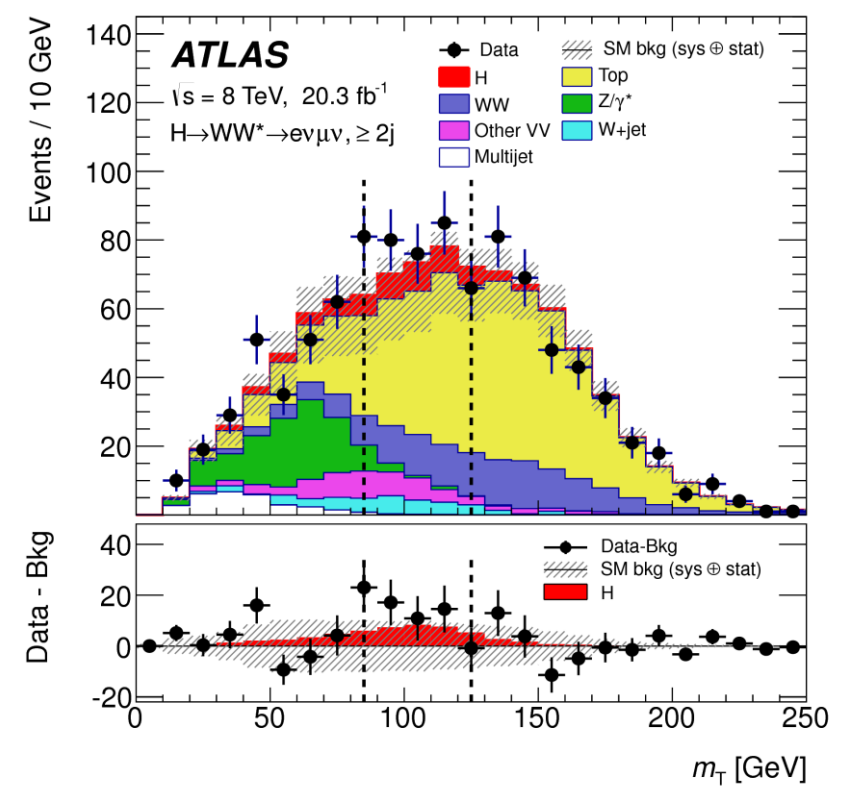
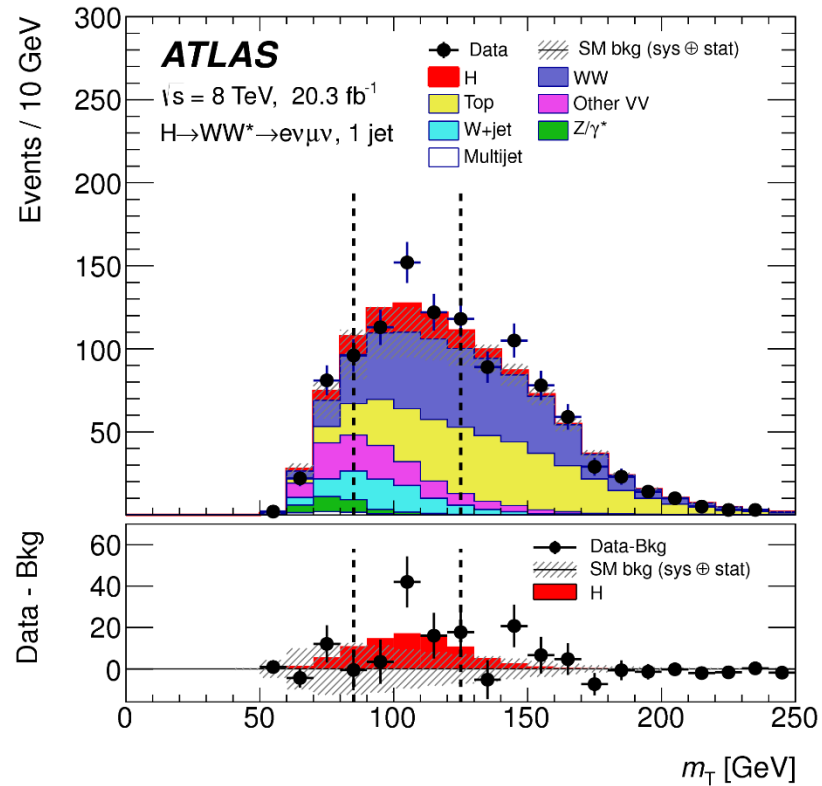
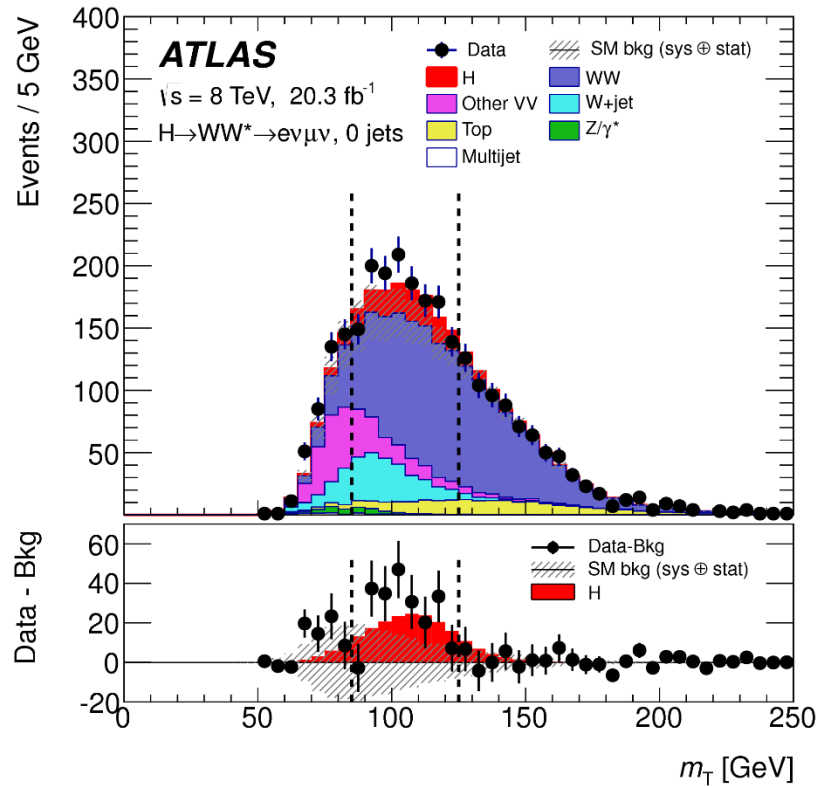
# $pp \rightarrow H \rightarrow WW^*$



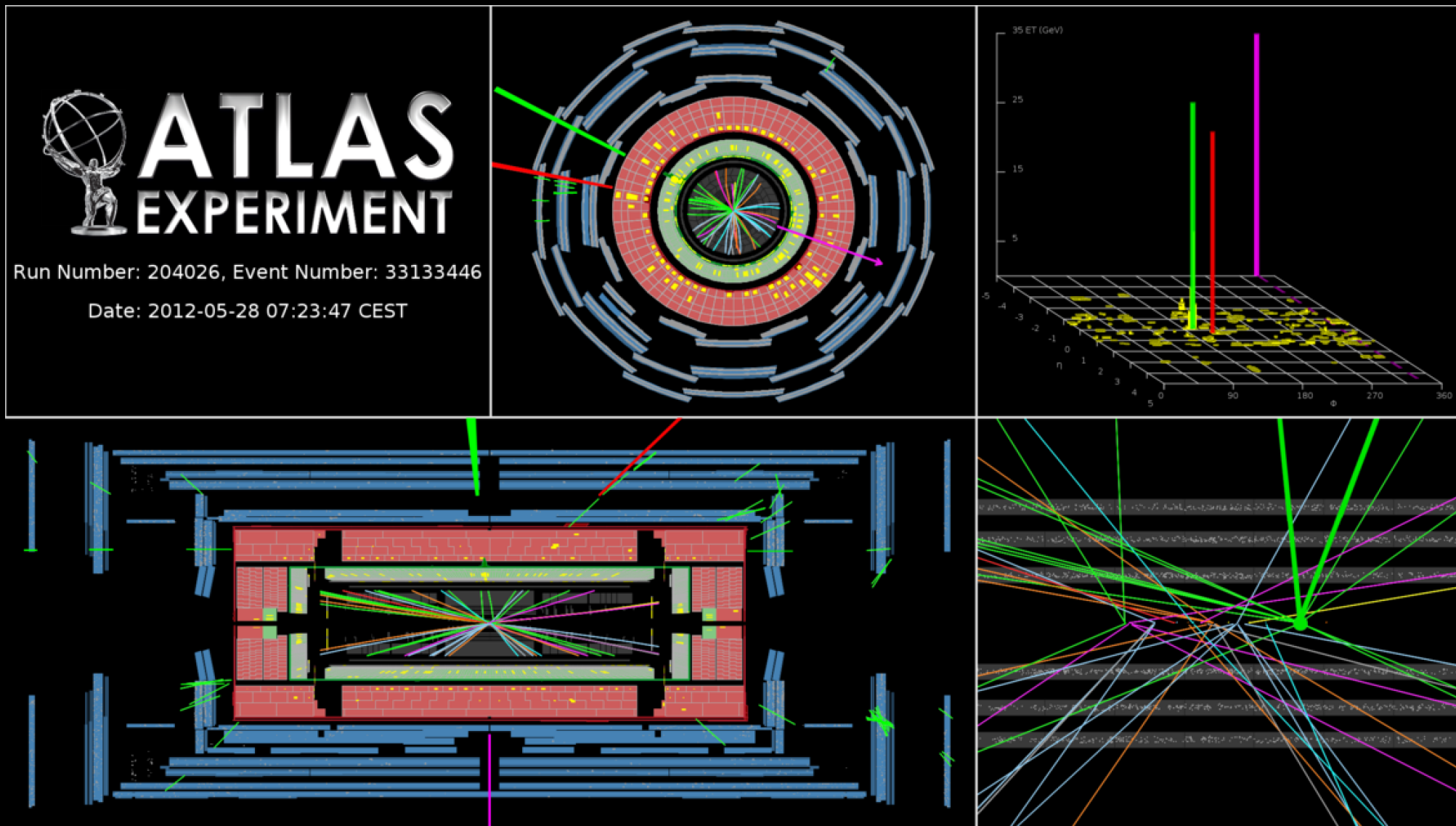
# pp $\rightarrow$ H $\rightarrow$ WW\*



# pp $\rightarrow$ H $\rightarrow$ WW\* + n jets



$$H \rightarrow WW^* \rightarrow e\nu\mu\nu$$



# Zdroje

- <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplaysFromHiggsSearches>
- <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults>
- [https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayRun2Physics#W candidate event decaying to on](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayRun2Physics#W_candidate_event_decaying_to_on)

