

CERN Masterclasses 23.2.2024

Z-Path

***Částicová fyzika
s experimentem
ATLAS***

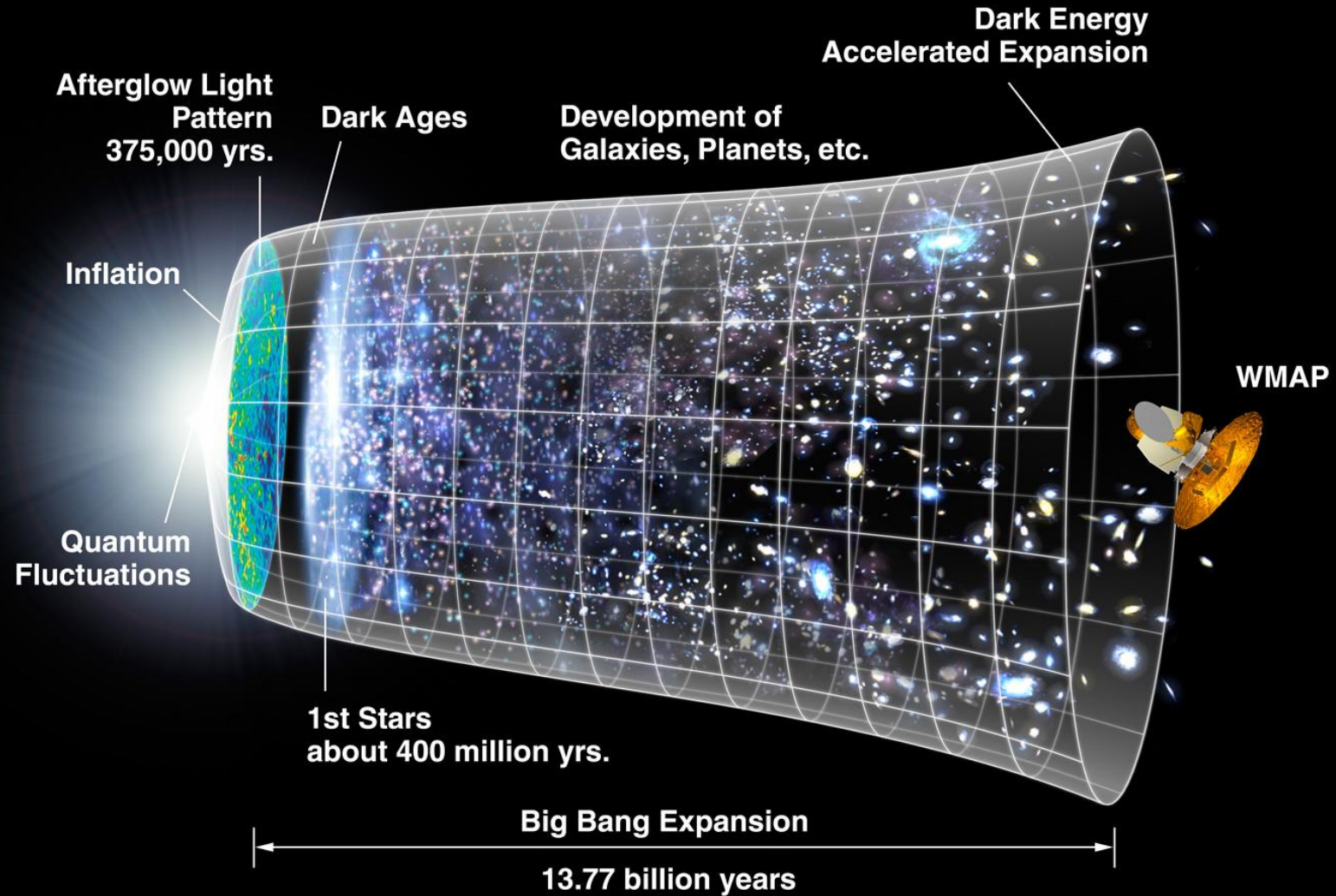
Jiří Kvita

Společná laboratoř optiky UP a FZÚ AVČR

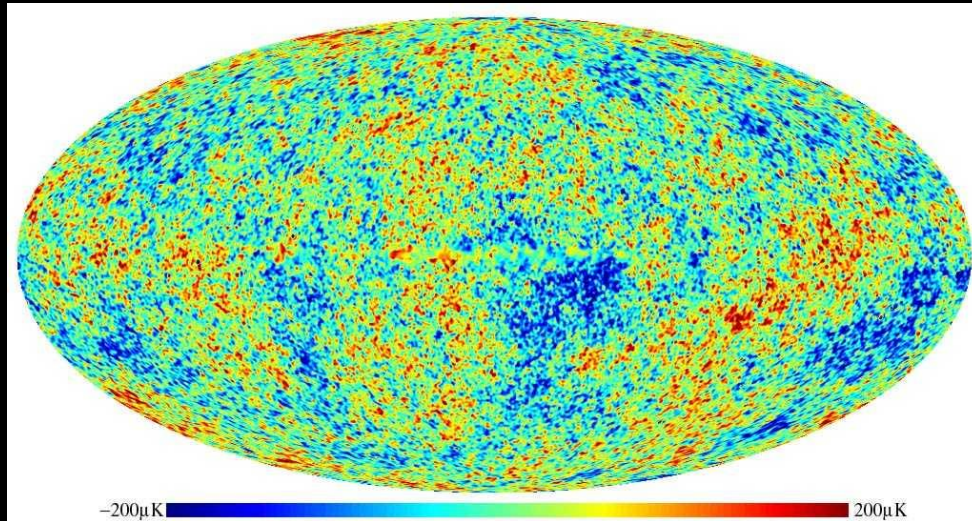
PřF UP Olomouc



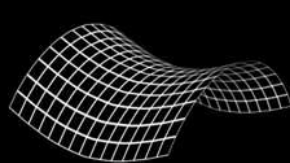
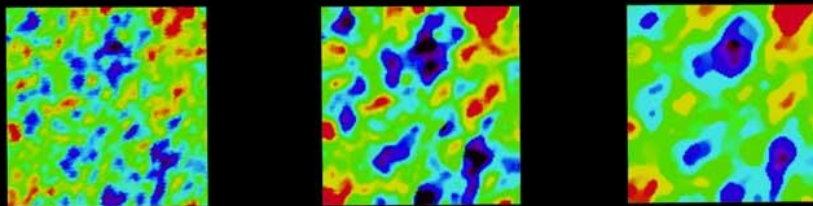
Od Velkého třesku po současnost



Fluktuace záření kosmického pozadí

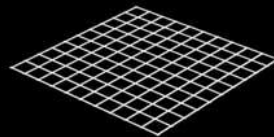


GEOMETRY OF THE UNIVERSE



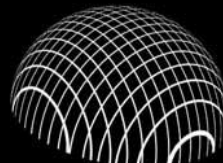
OPEN

Fluctuations largest on half-degree scale



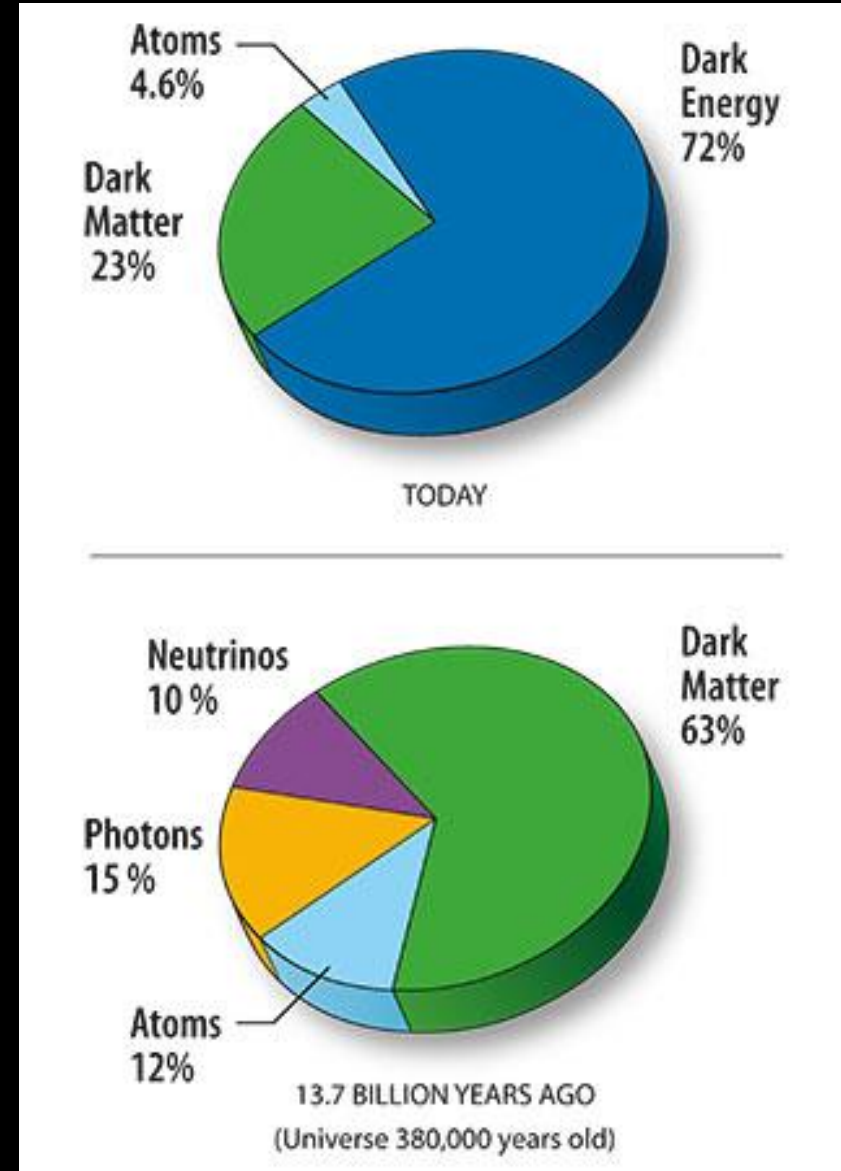
FLAT

Fluctuations largest on 1-degree scale

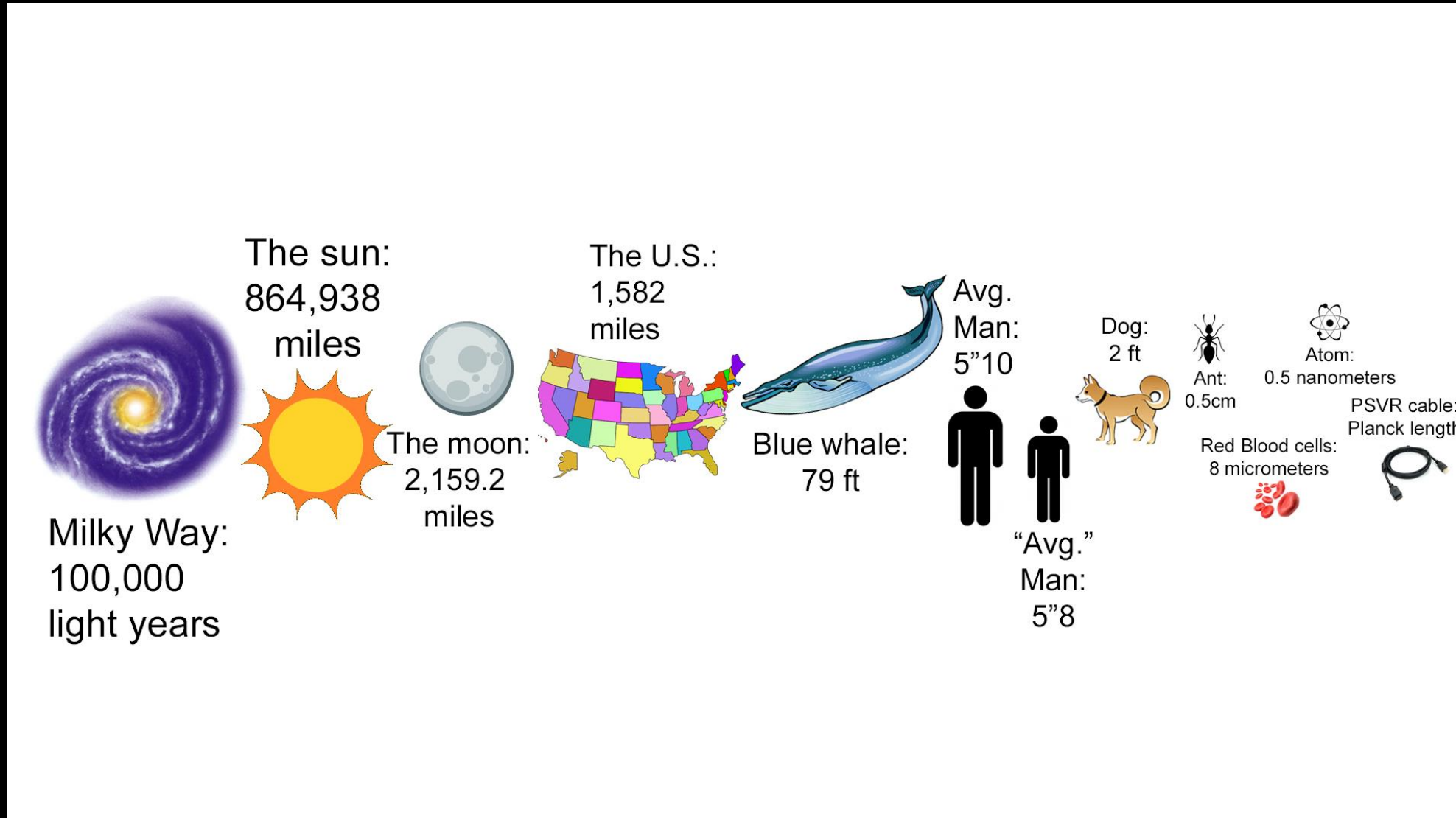


CLOSED

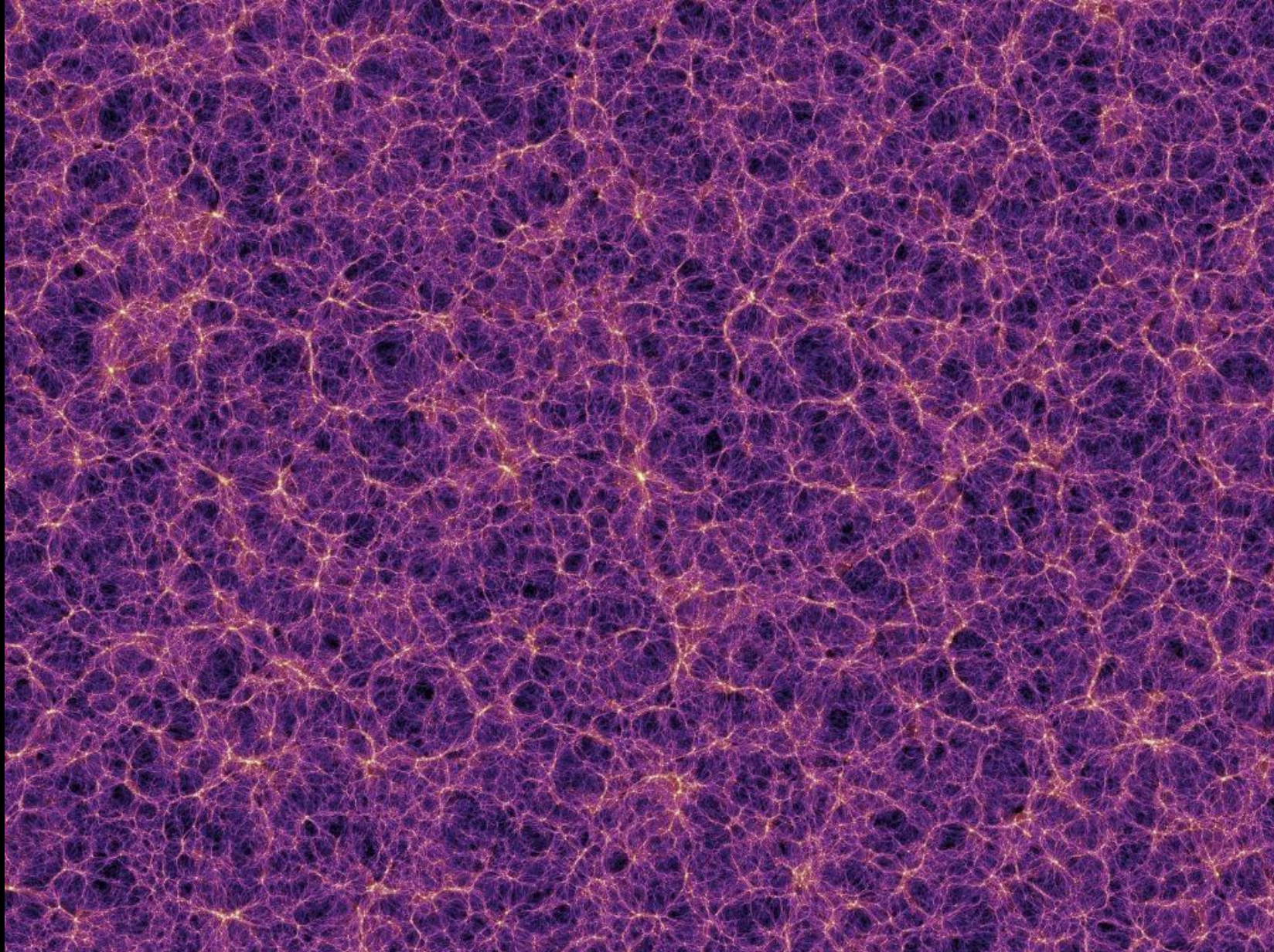
Fluctuations largest on greater than 1-degree scale



Škály délek



Vesmír

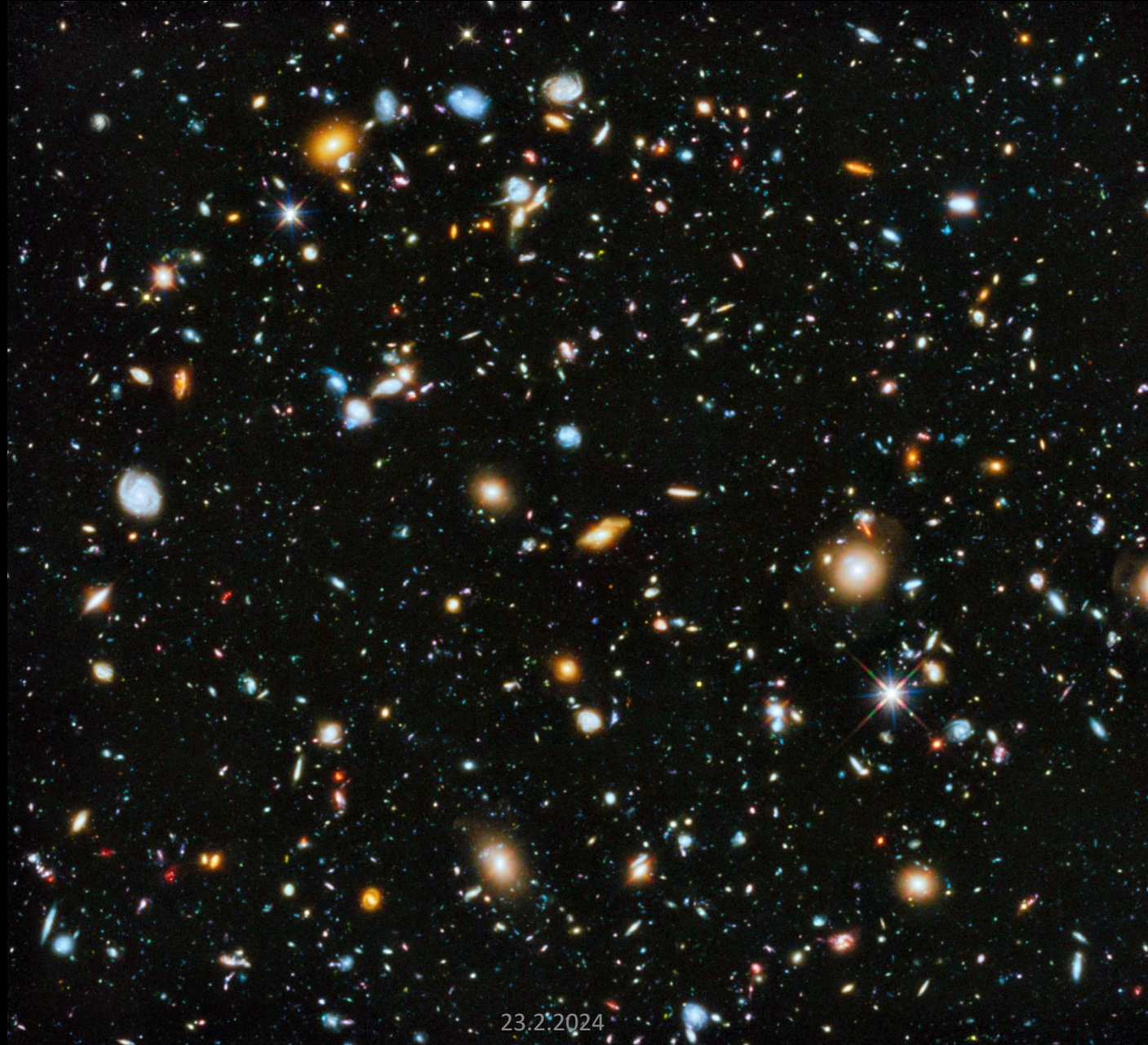


10^{26} m, 10 Gly

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Millennium Simulation⁵

Kupy galaxií

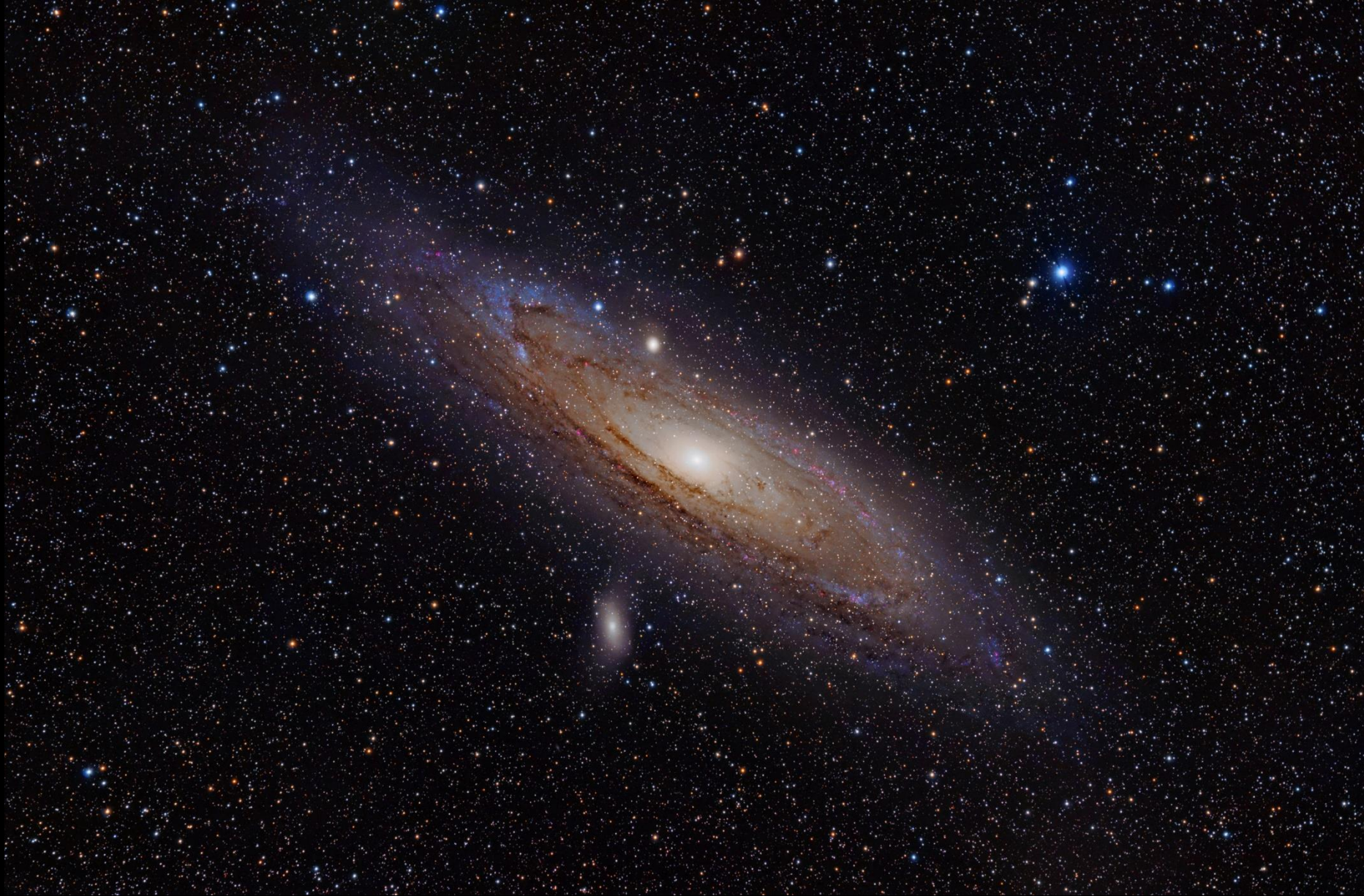


10^{23} m, 10 Mly

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Hubble Space Telescope

Galaxie

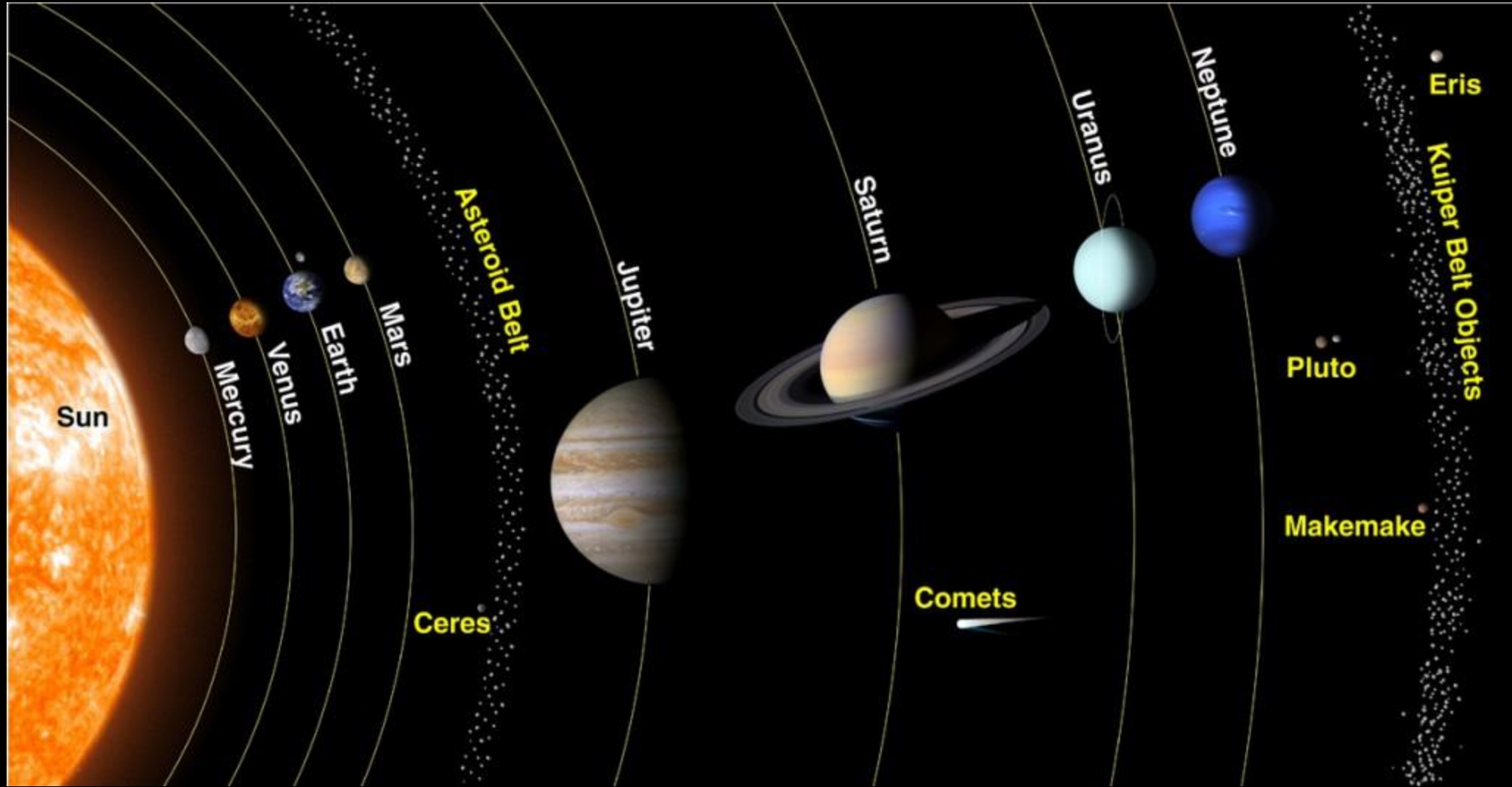


10^{21} m, 100 kly

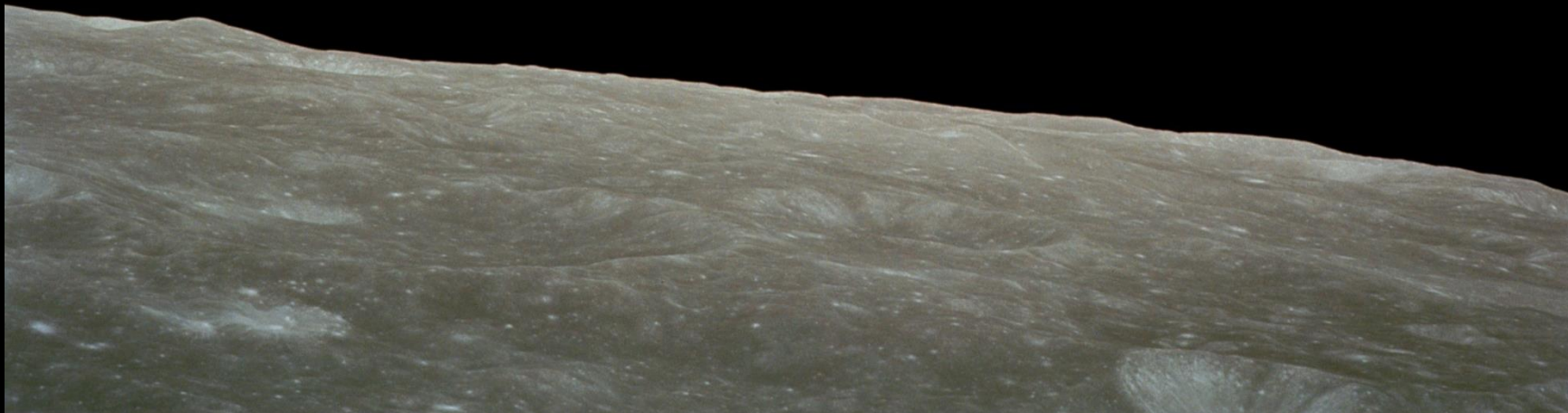
23.2.2024

Adam Evans

Sluneční soustava



Ze Země na Měsíc



Země



10⁷ m 29. 3. 2019

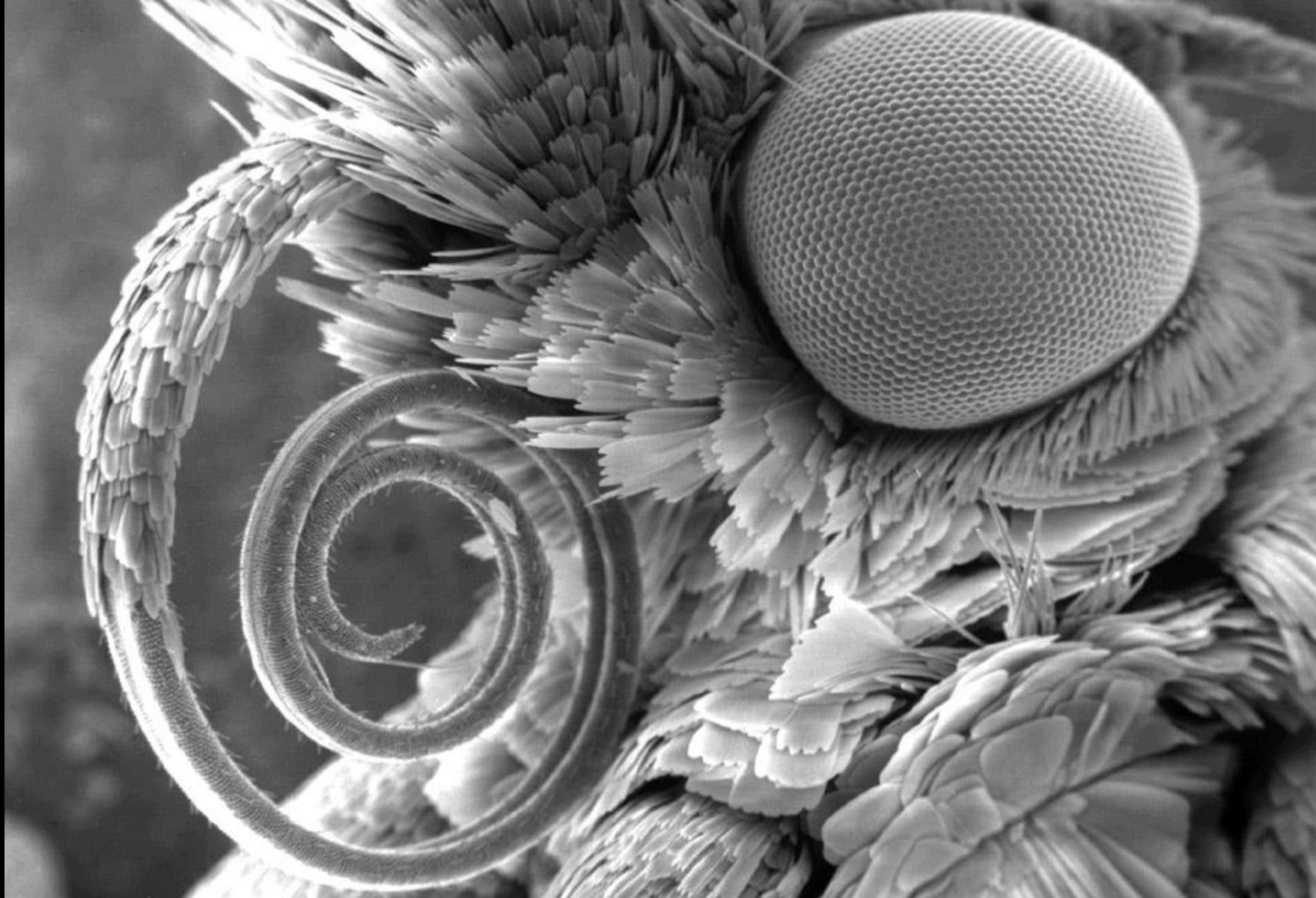
23.2.2024

by Apollo 17

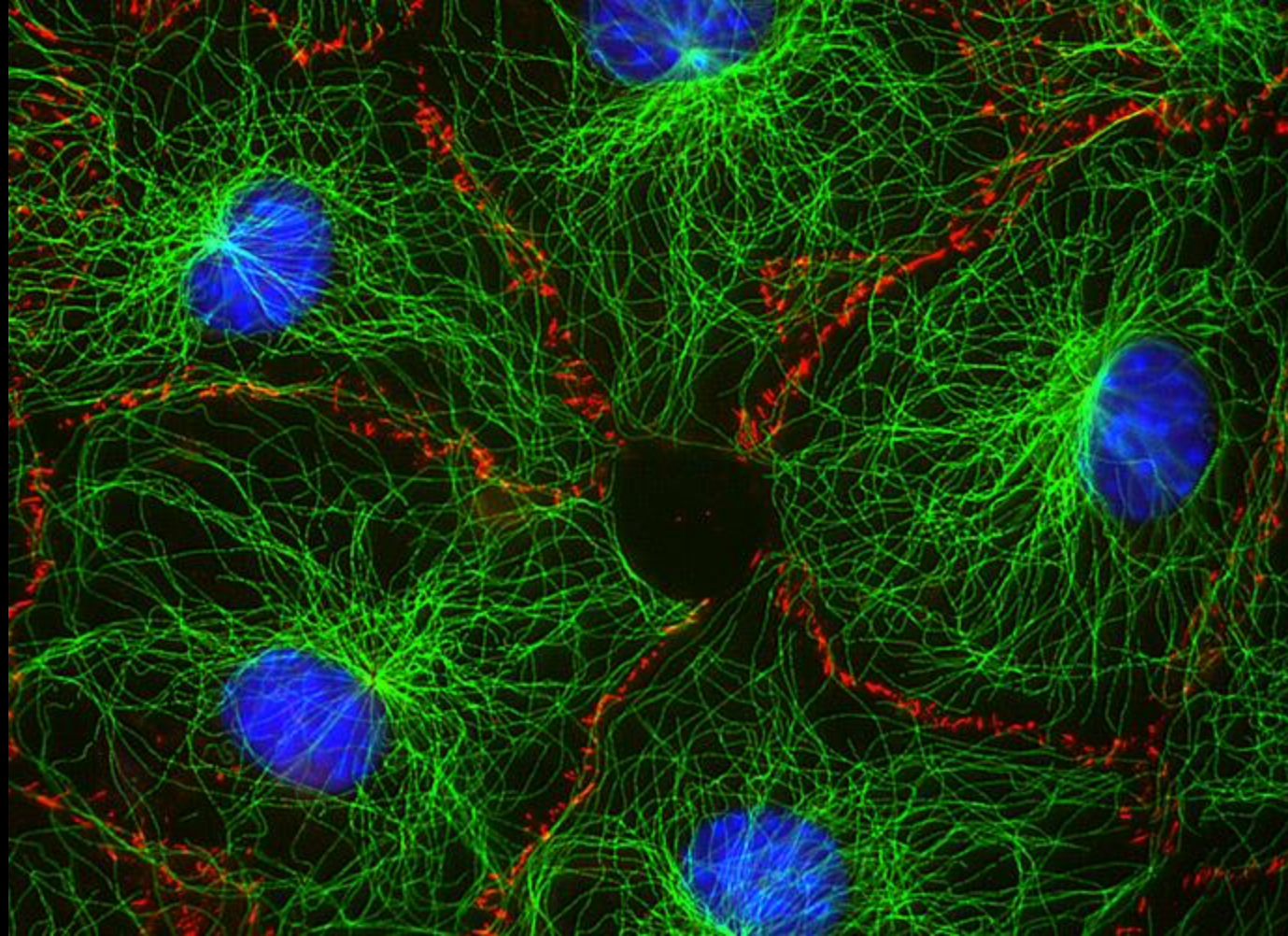
Tvor



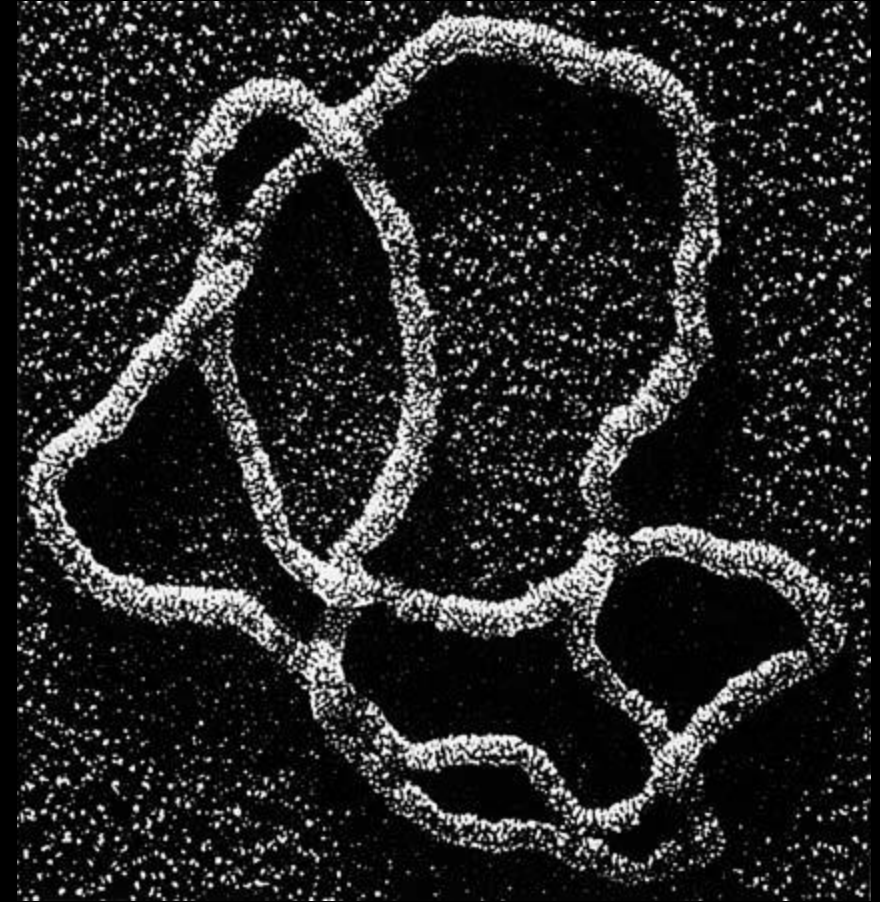
Tvor II



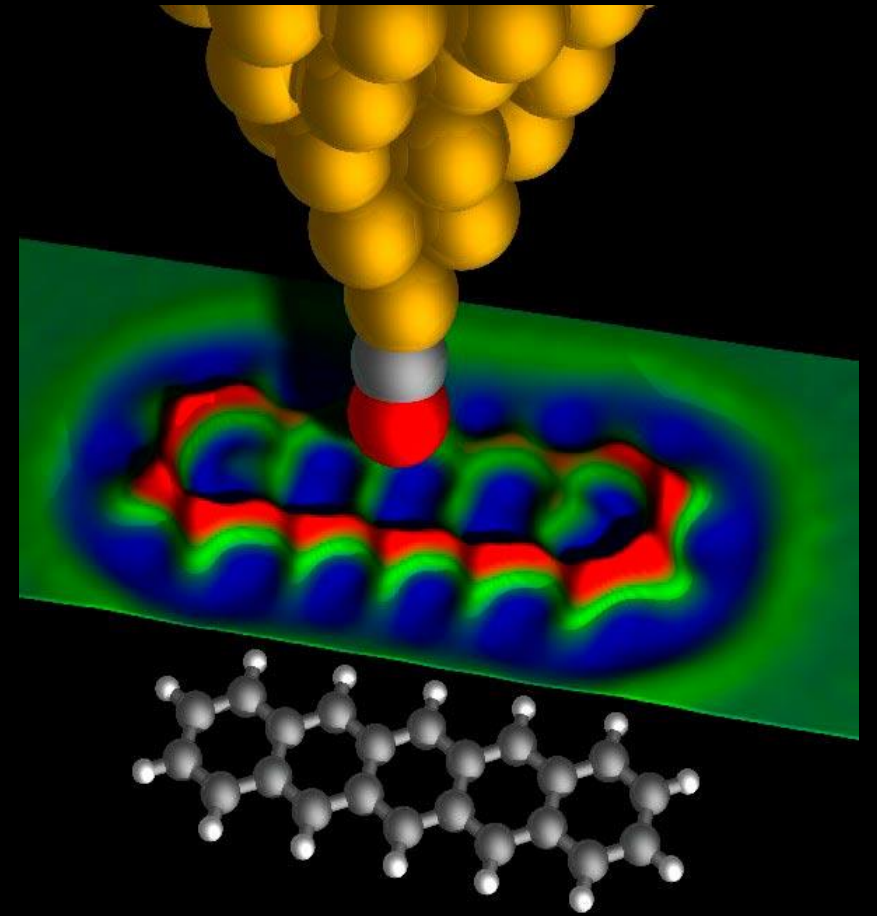
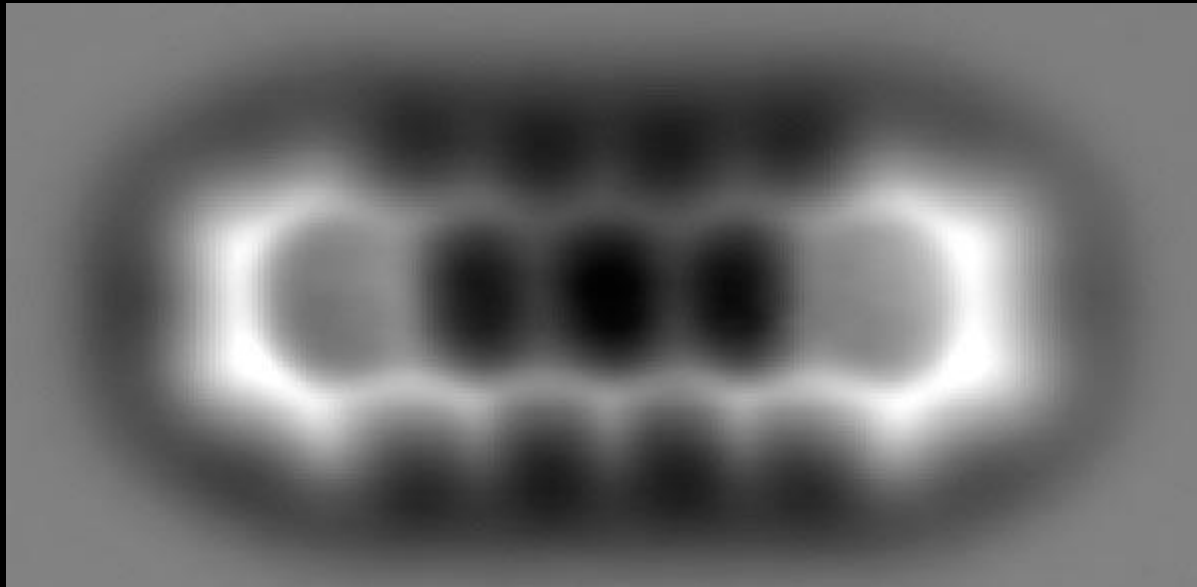
Buňka



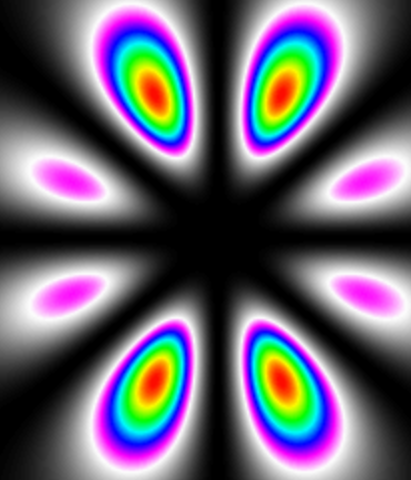
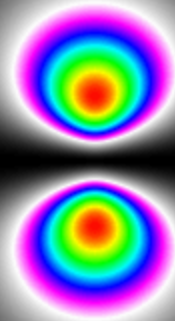
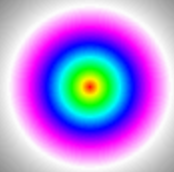
Molekula DNA – model vs. fotografie



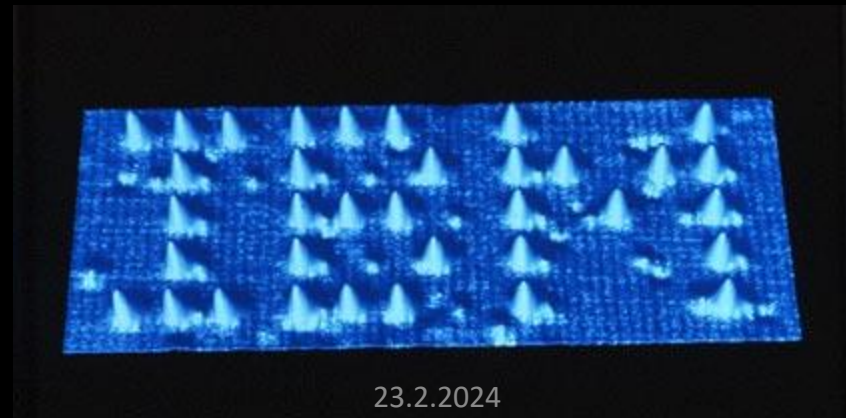
Molekula pentacenu – obláčky elektronů



Atom – stojaté vlny elektronů kolem jádra

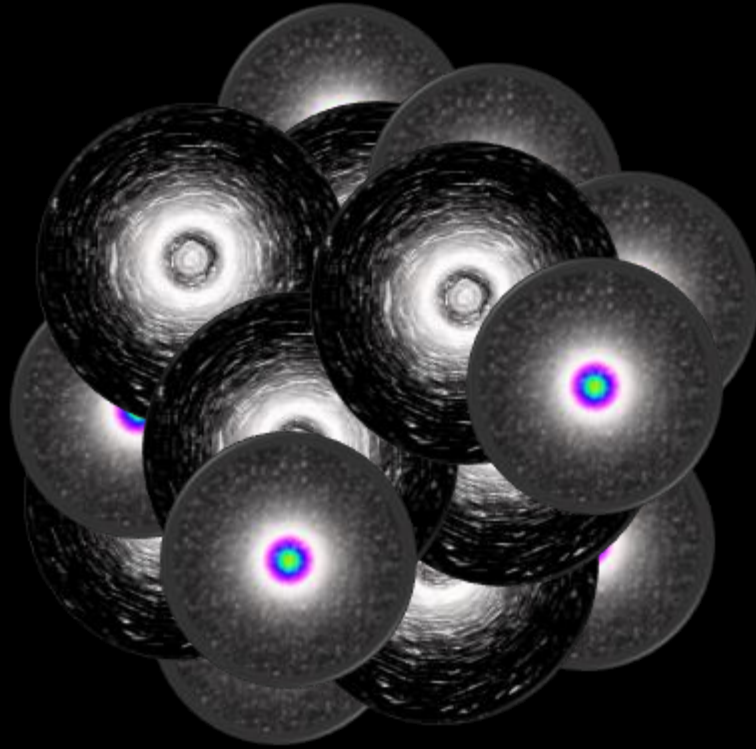


10^{-10} m, eV, keV



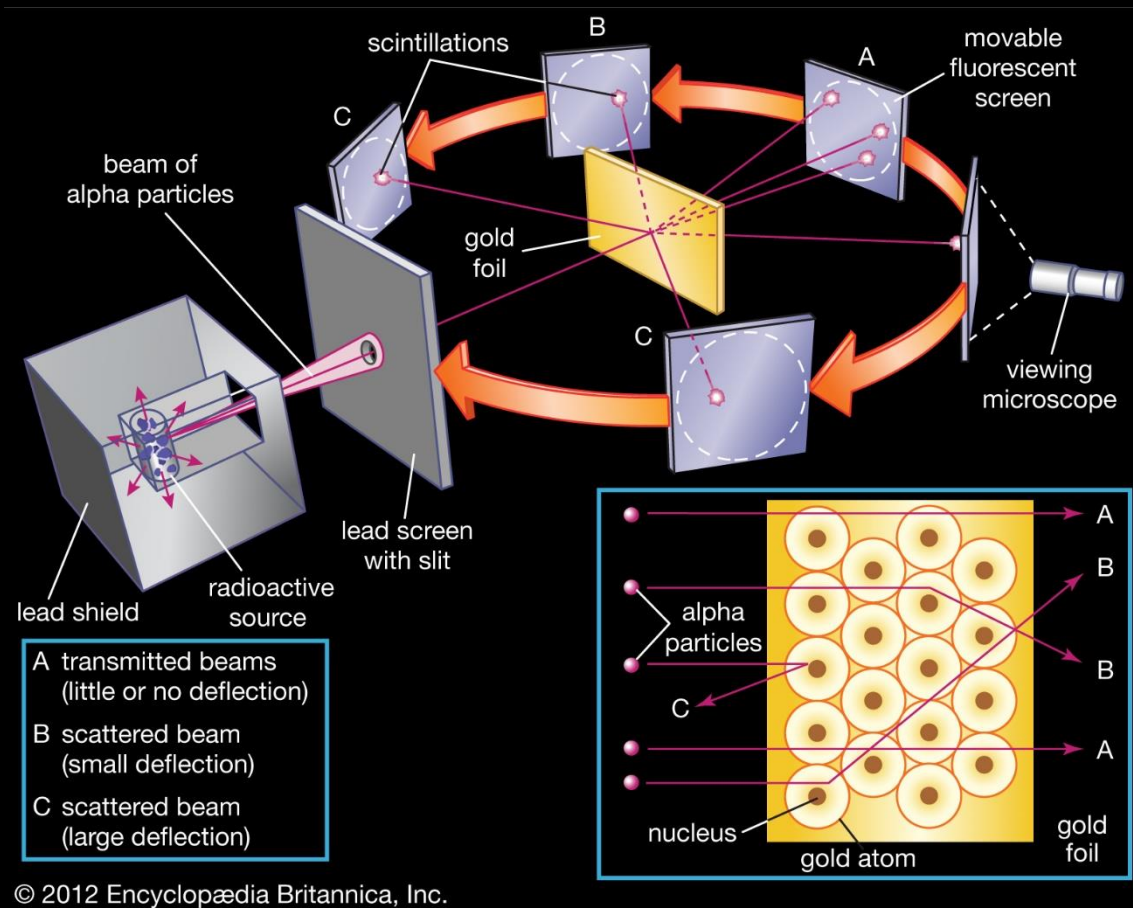
23.2.2024

Jádro – protony a neutrony

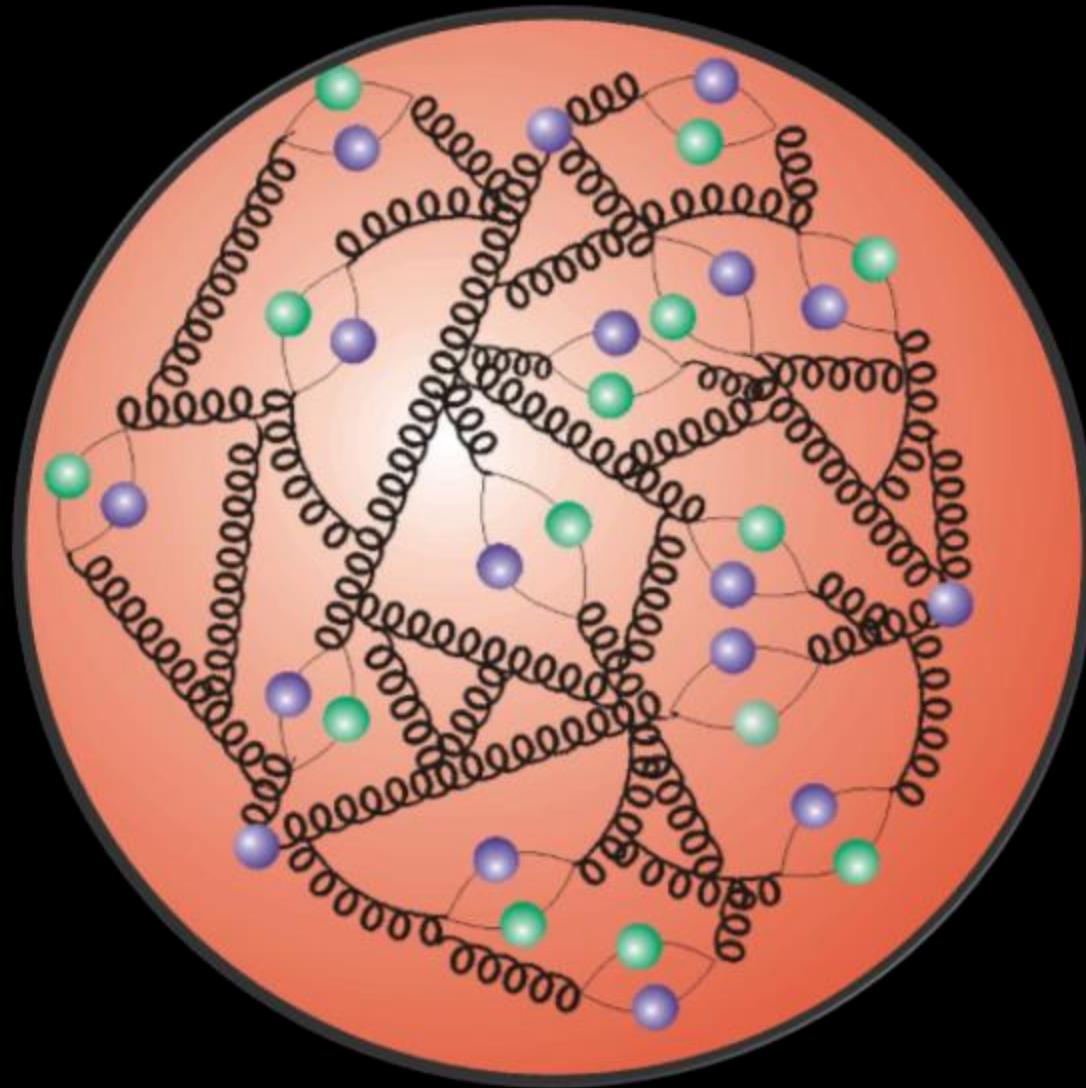


Jádro – objev

- Ernest Rutherford (1871-1937)
- Geiger-Marsdenův experiment
 - Hans Geiger (1882-1945)
 - Ernest Marsden (1889-1970)
- „Bombardování“ zlaté fólie jádry helia (alfa částice)
- **Rozptylová experiment**
- Zpětný odraz alfa částic možný jen když je hmota koncentrována do malé oblasti, atomového jádra!
- 1910

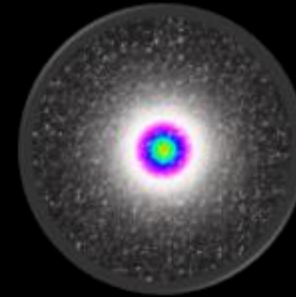
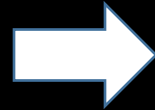
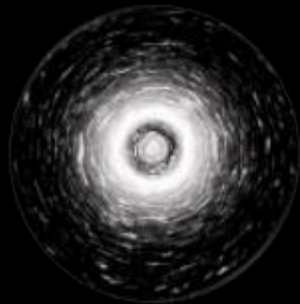


Proton – polévka kvarků a gluonů



Rozpad volného neutronu

Neutron



Proton

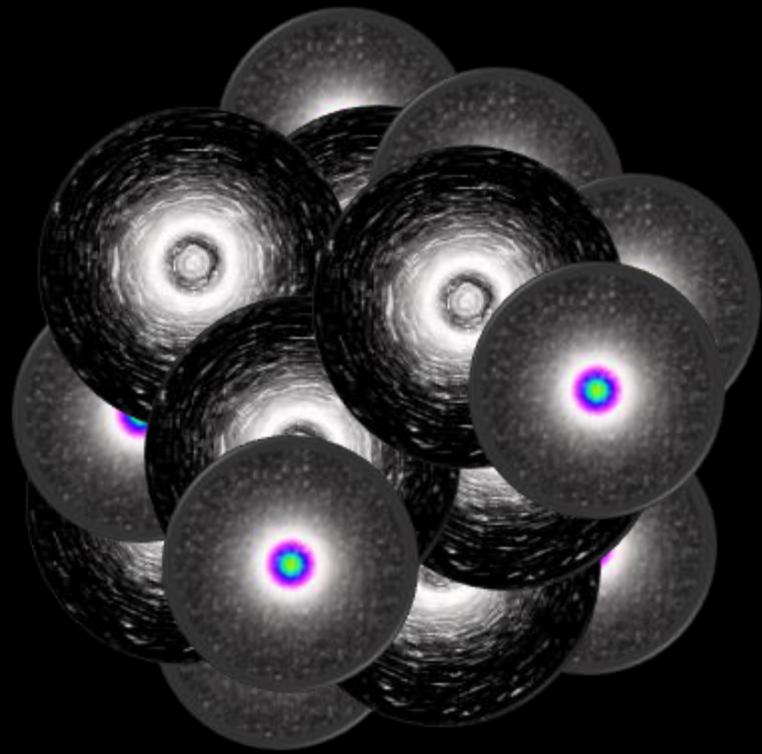


Elektron



**Elektronové
antineutrino**

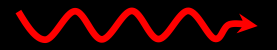
Rozpad atomu



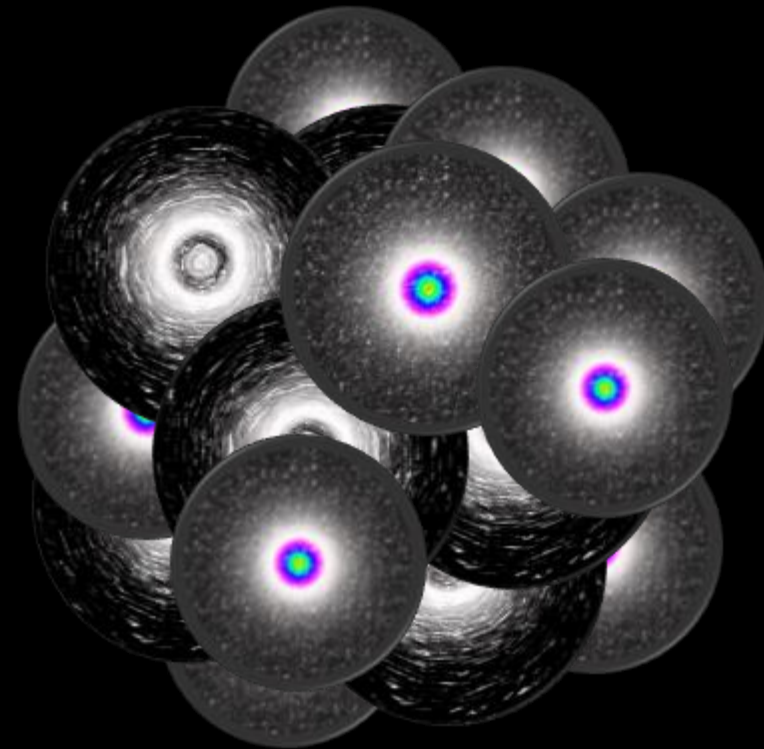
Elektron



Gama



Foton



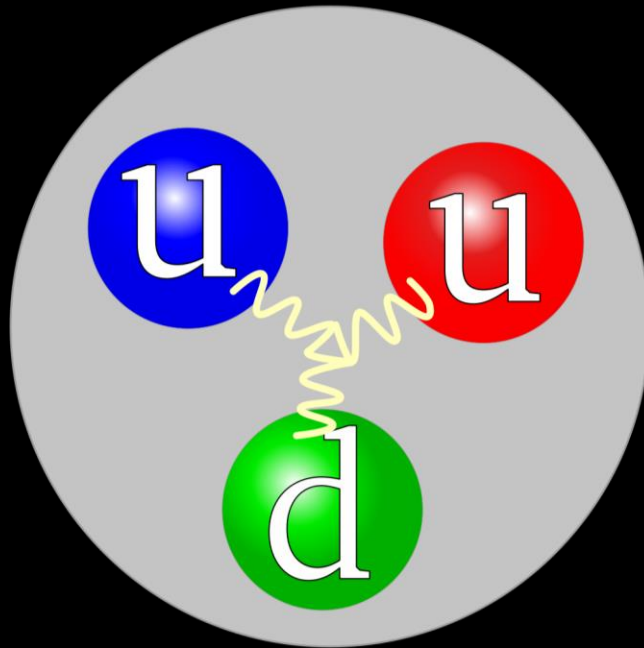
Elektronové
antineutrino



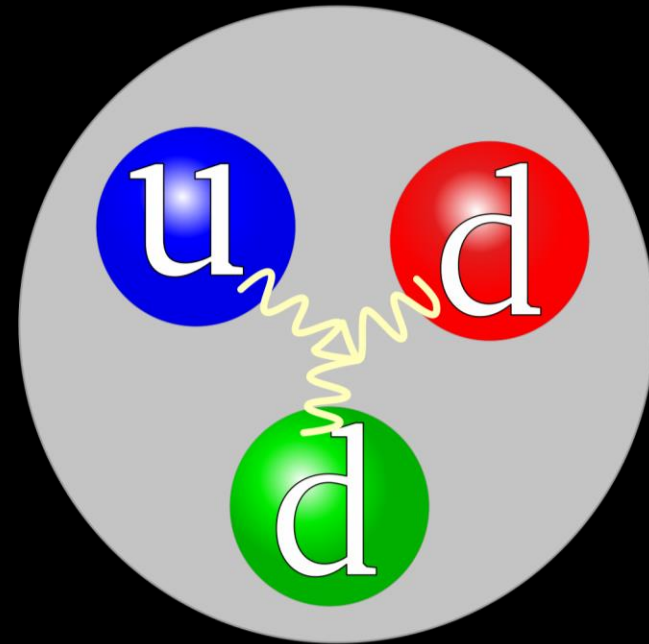
Elektron v jádře předtím nebyl. Prostě vznikl. Částice vznikají a zanikají.

Proton a neutron

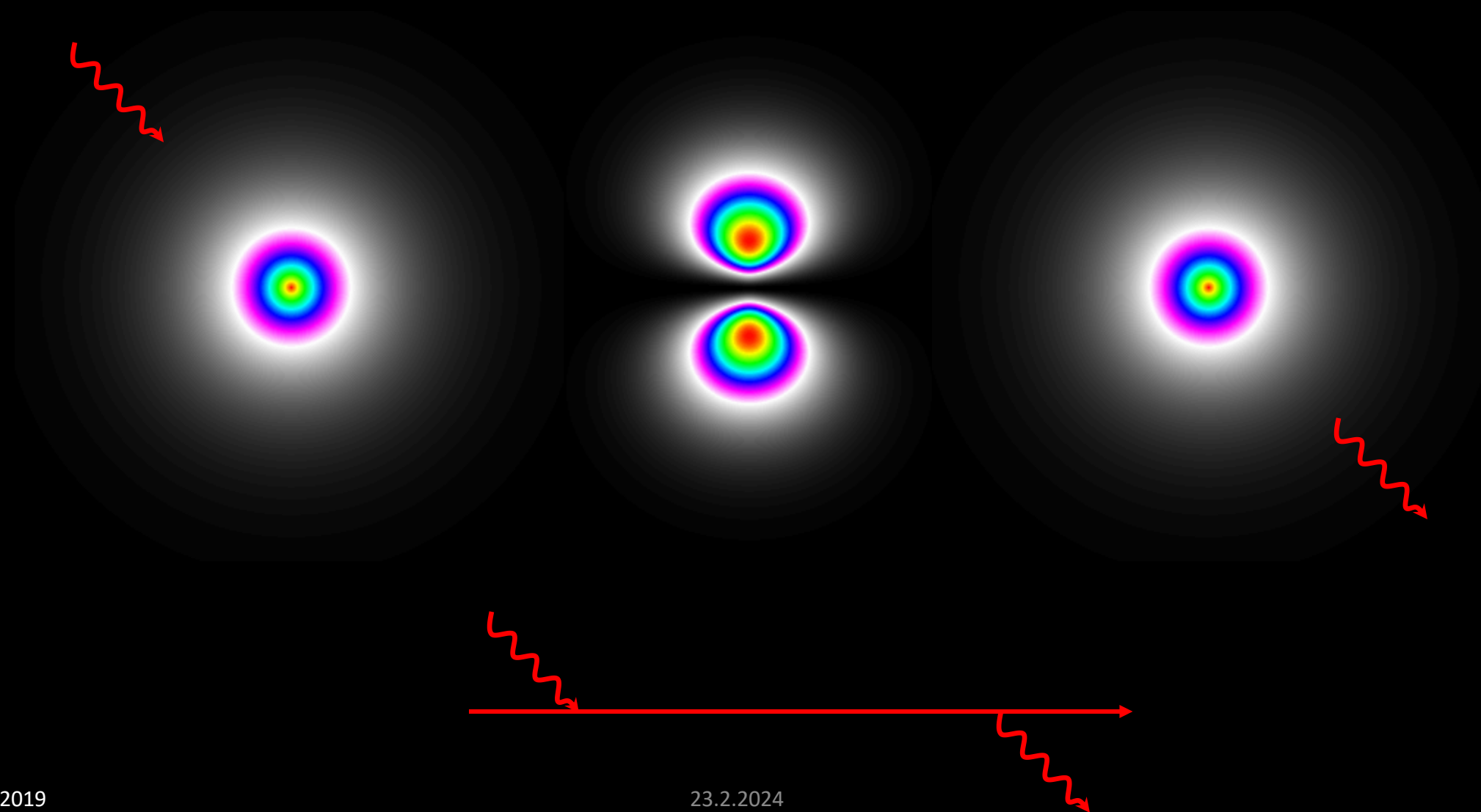
Proton



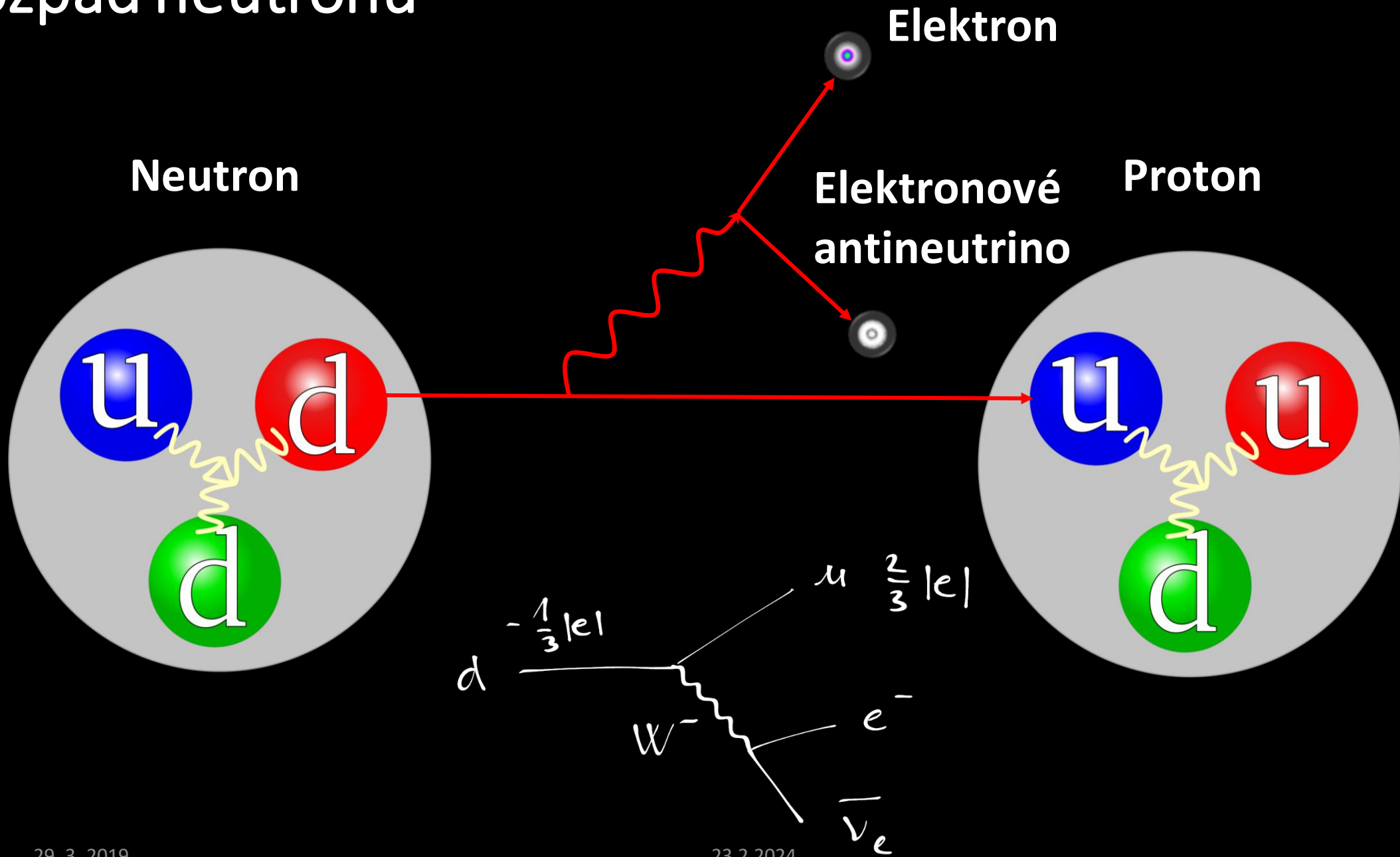
Neutron



Posvitíme si na atom!

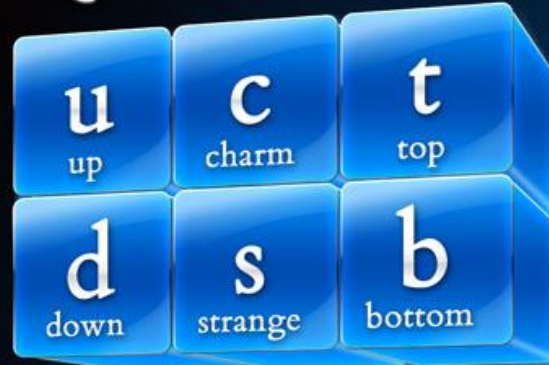


Rozpad neutronu



Elementární částice

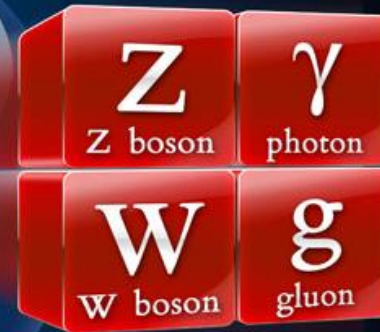
Quarks



Leptons



Force Carriers



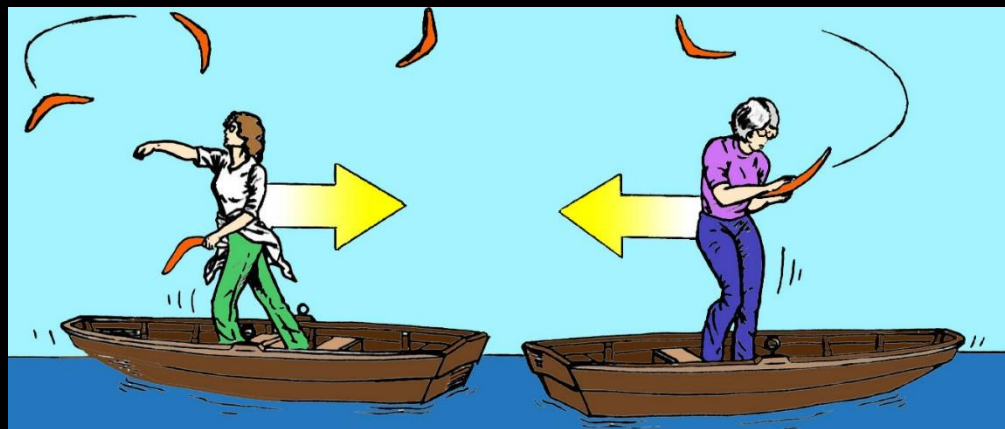
H
Higgs boson

Interakce jako výměna částic

- Odpuzování



- Přitahování

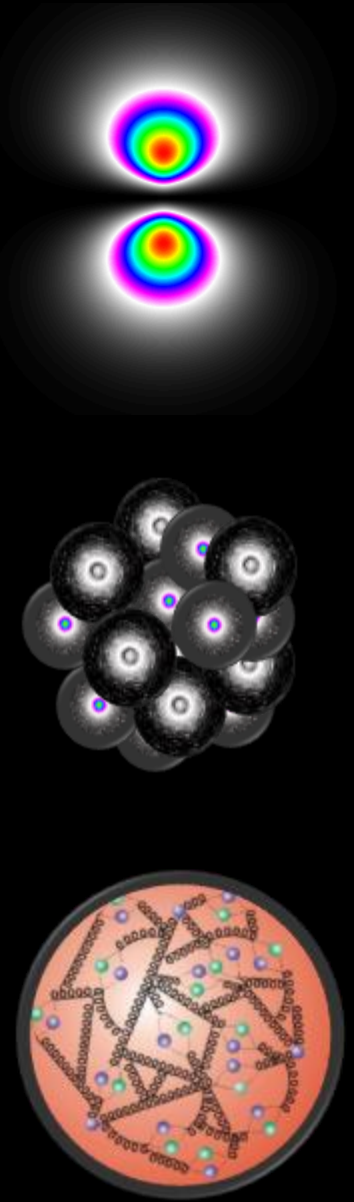


Škály energií

- 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

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

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

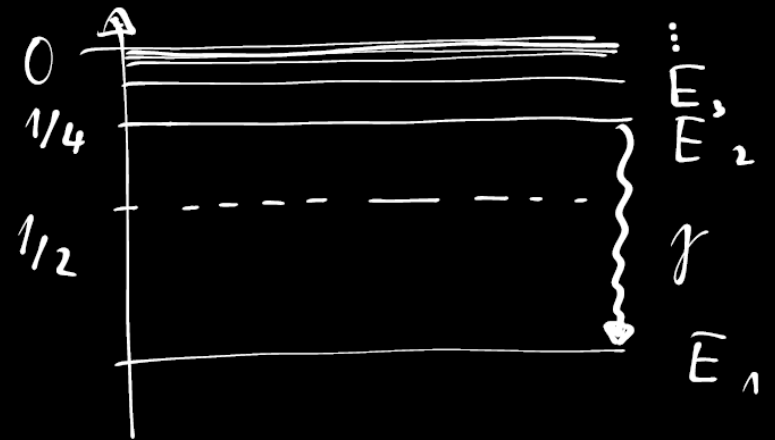
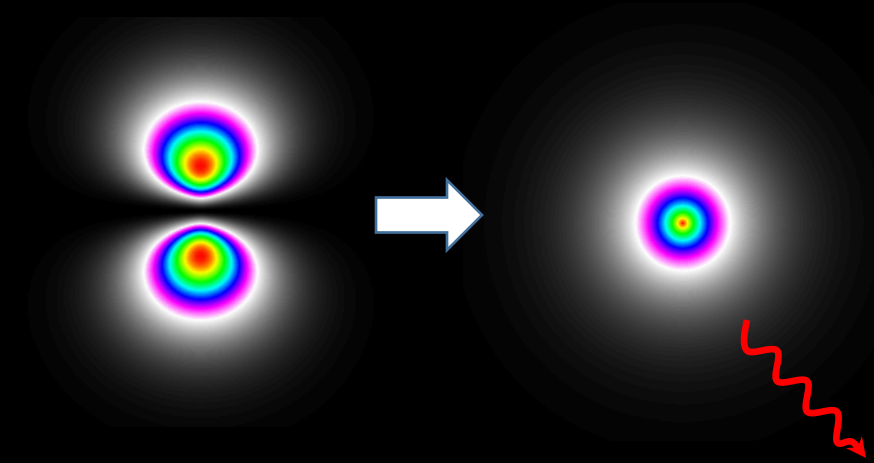
$$= 13.6 \cdot \frac{3}{4} = 10.2 \text{ eV}$$

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

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

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

$$\lambda_{12} = 120 \text{ nm}$$



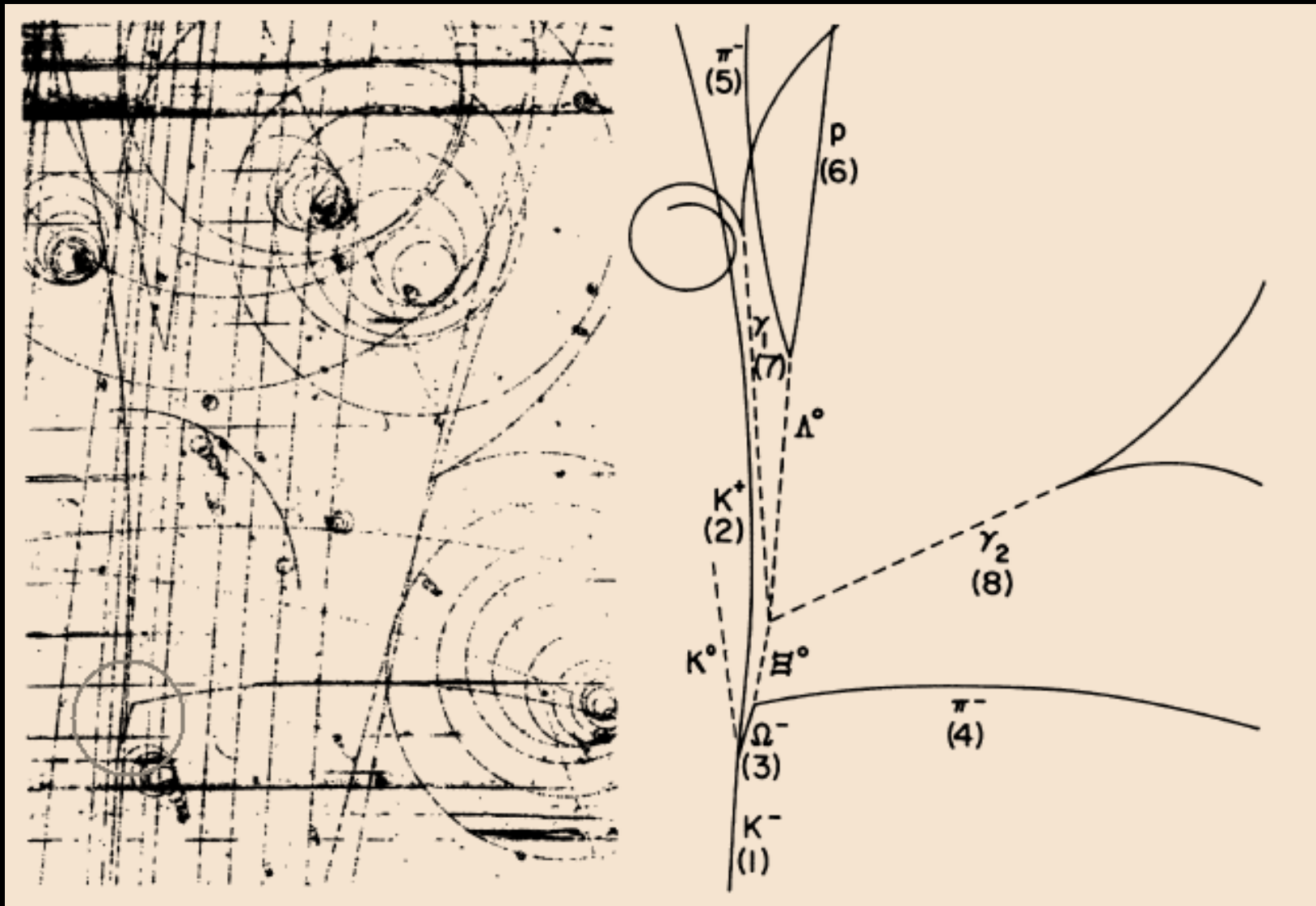
$$E_n = - \frac{13.6 \text{ eV}}{n^2}$$

Jak vidíme částice?

- bublinová komora, 1960s-1970s

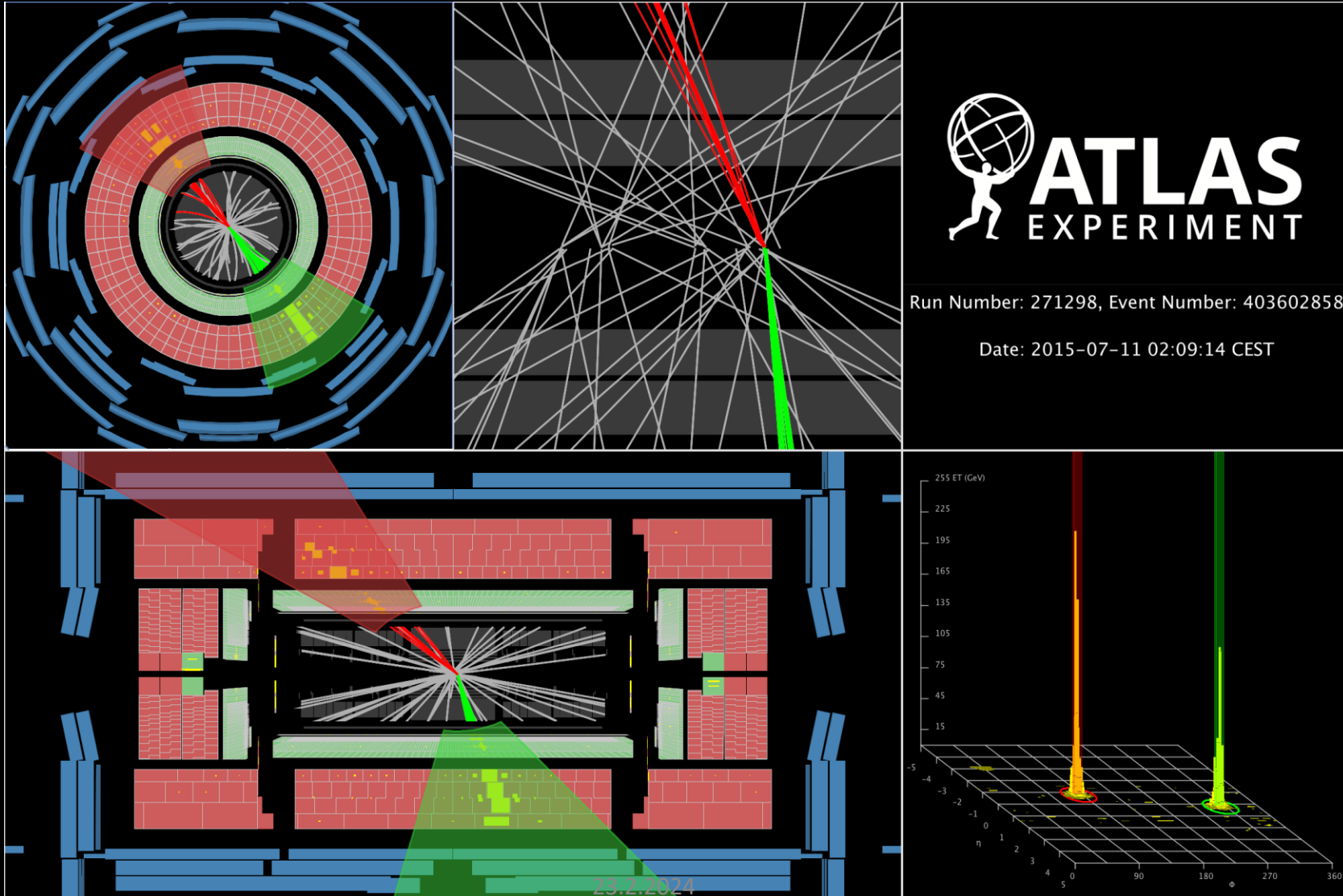


Objev částice Ω^- , 1964



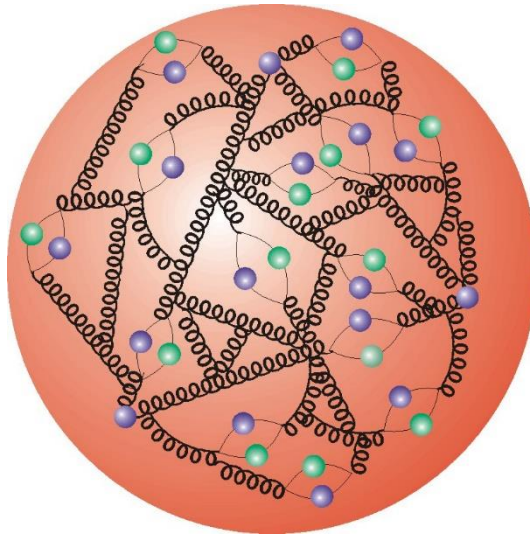
Jak vidíme částice?

- současnost



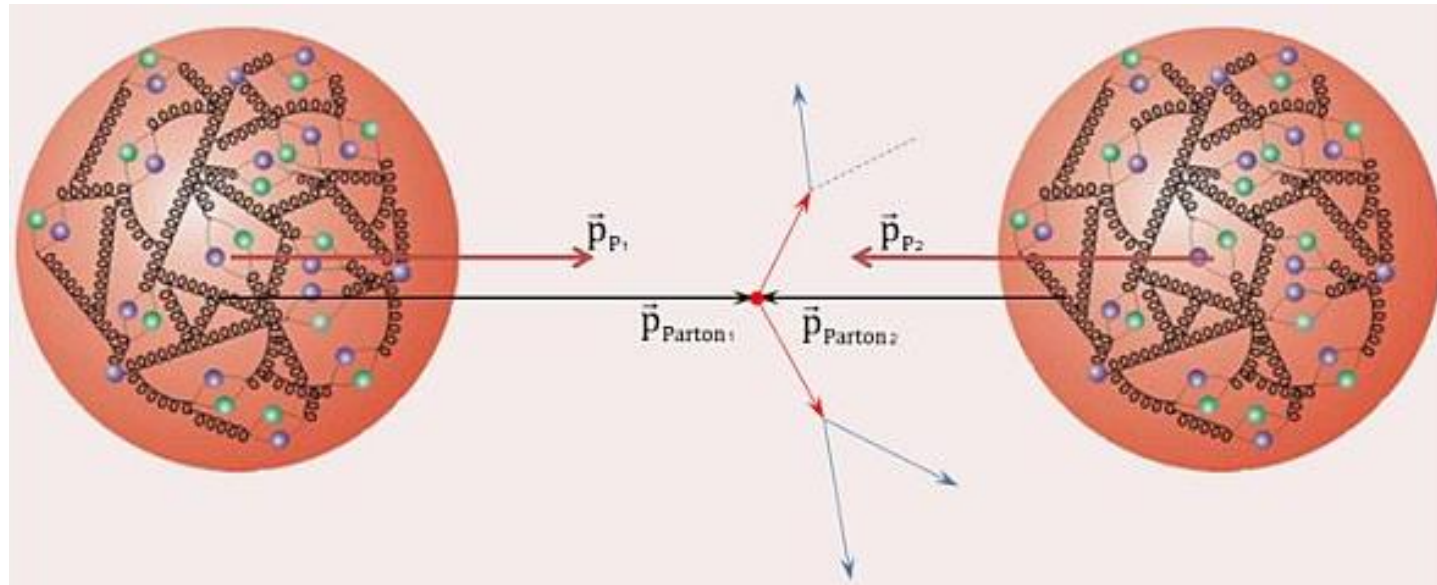
Srážky částic

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



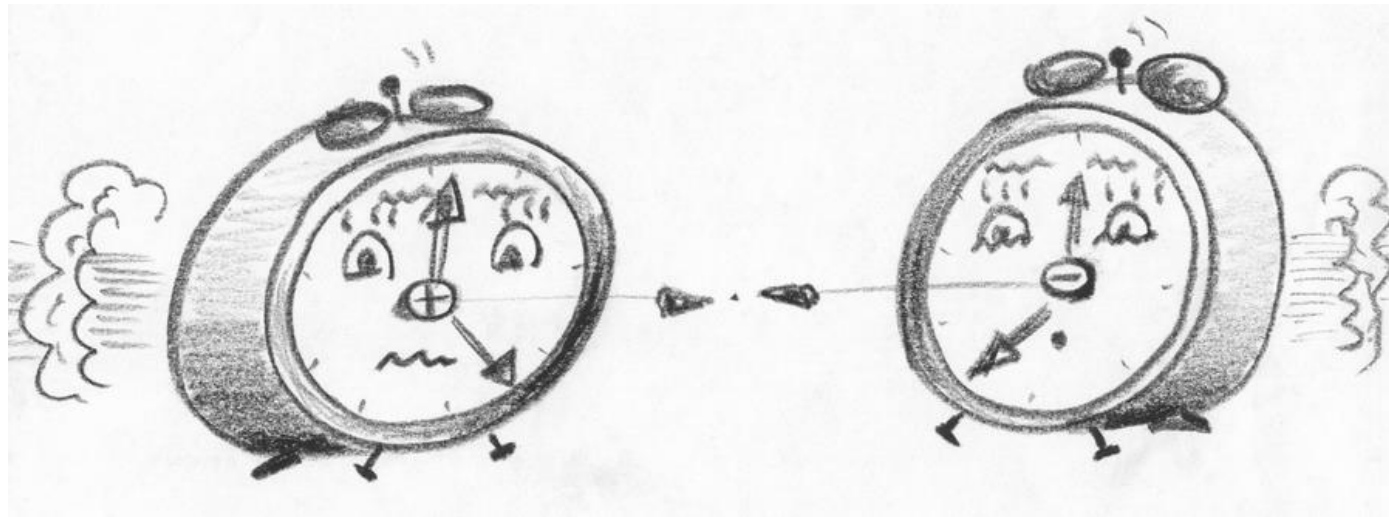
Srážky částic

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



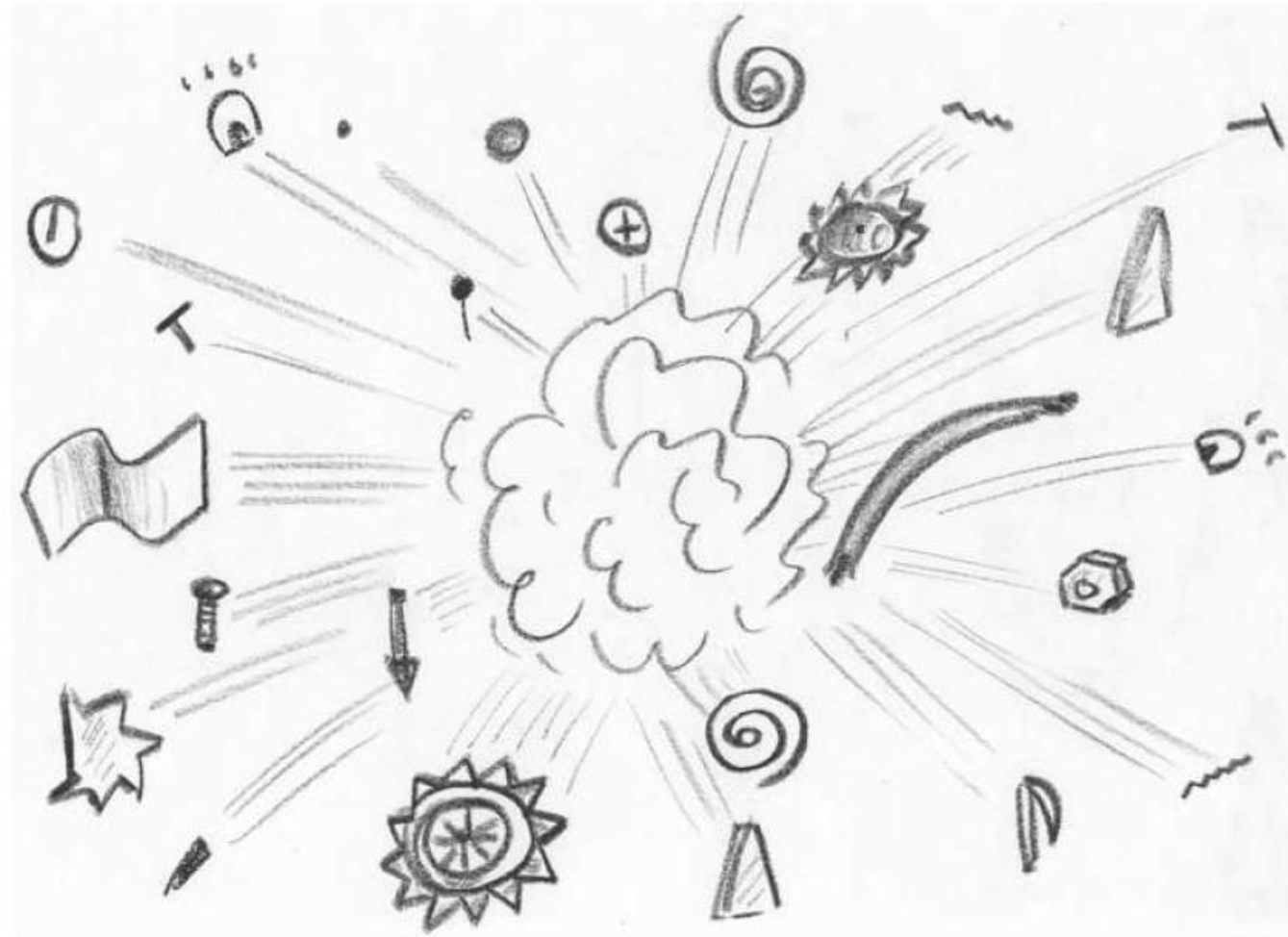
Srážky částic

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



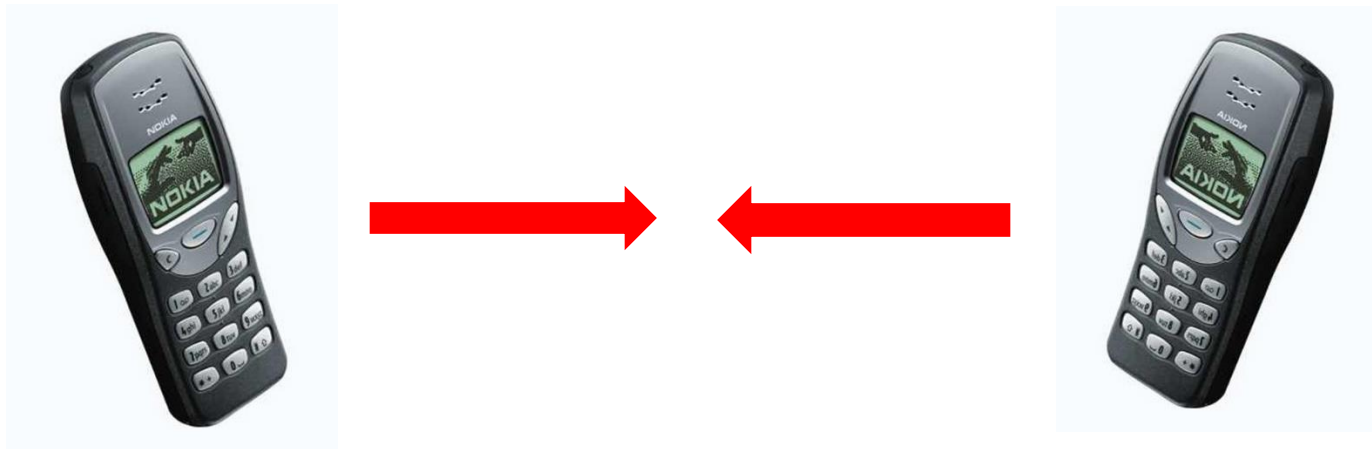
Srážky částic

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



Srážky částic

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



Srážky částic

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



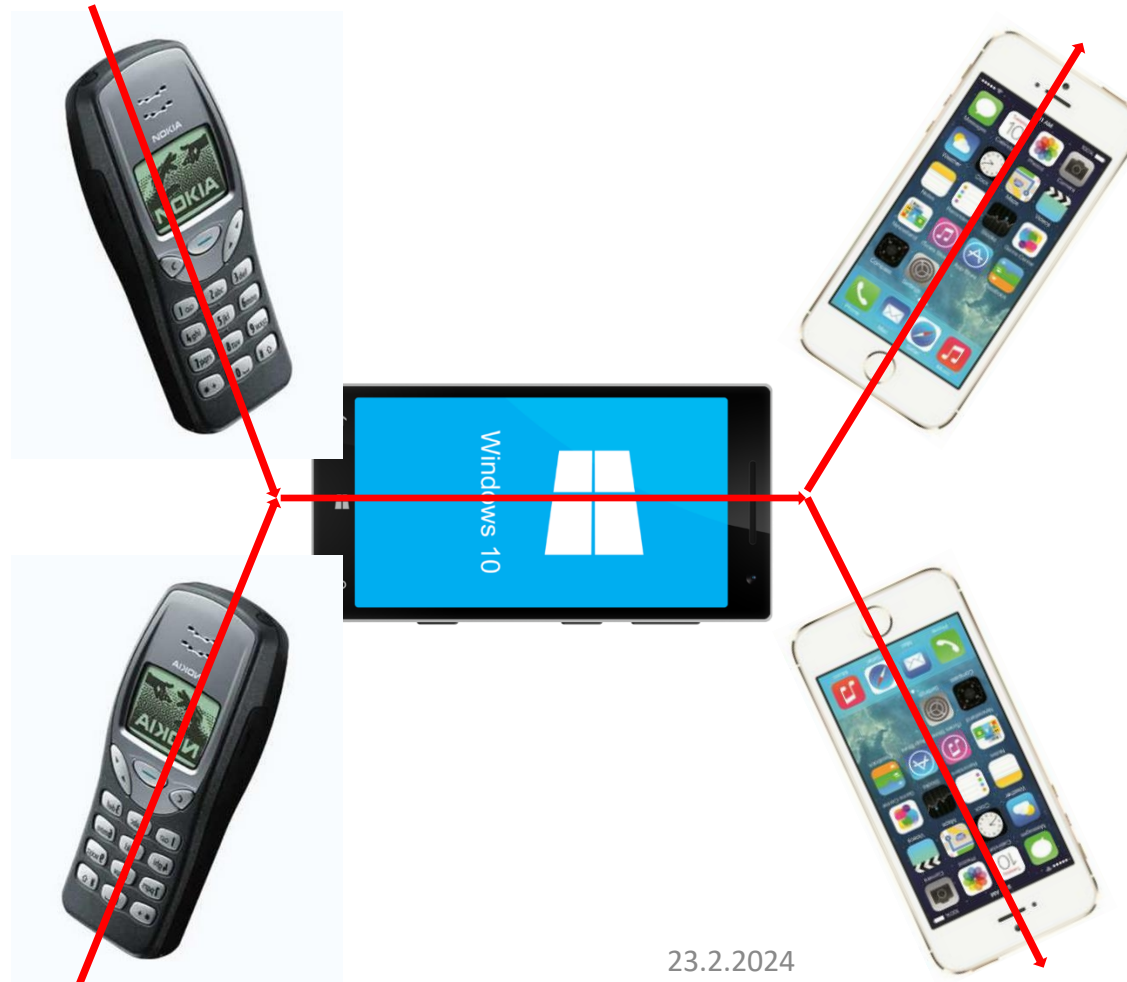
Srážky částic

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



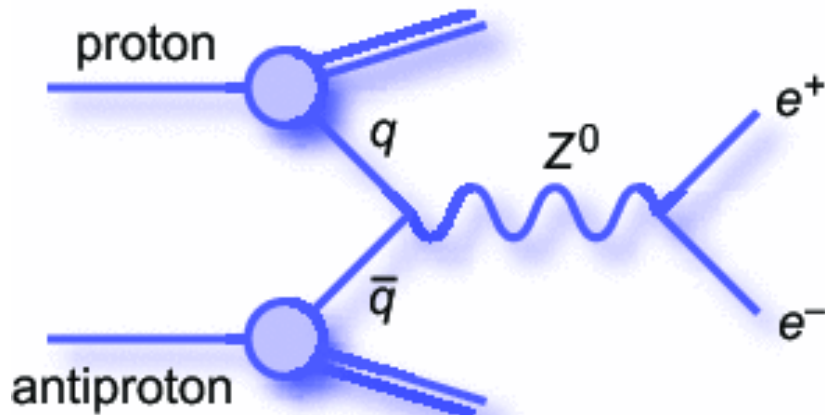
Srážky částic

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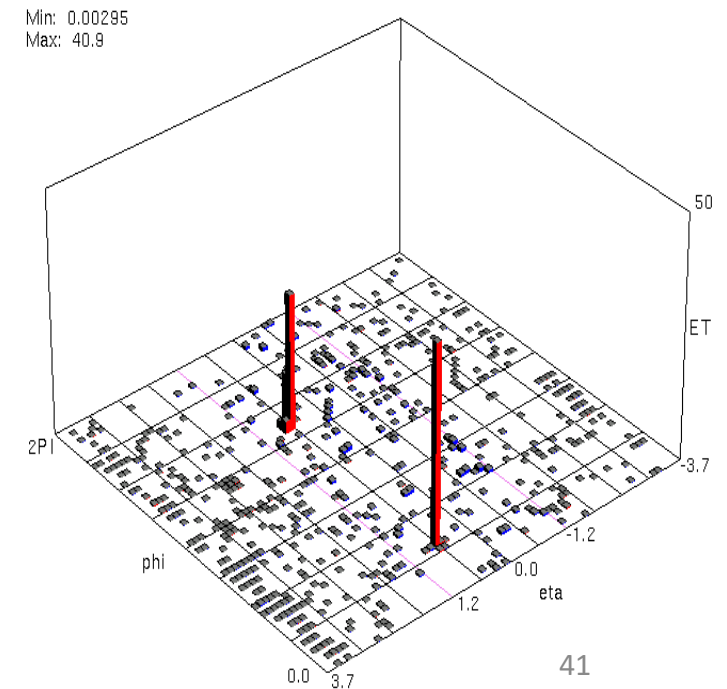
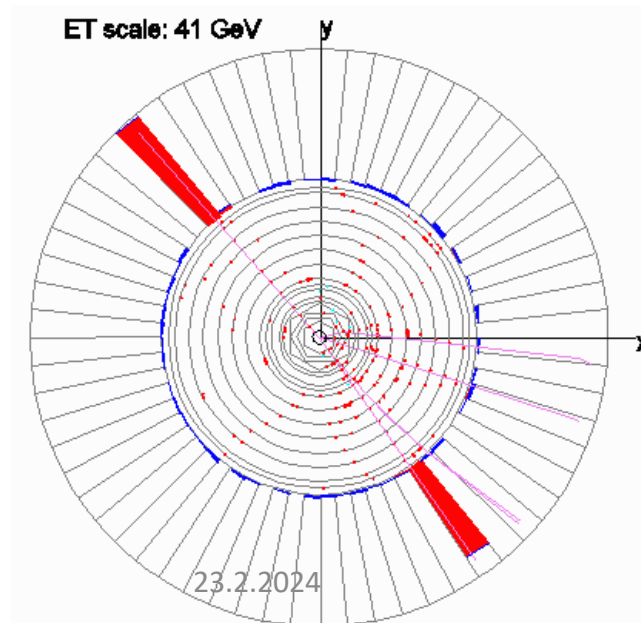


Interakce

- 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?



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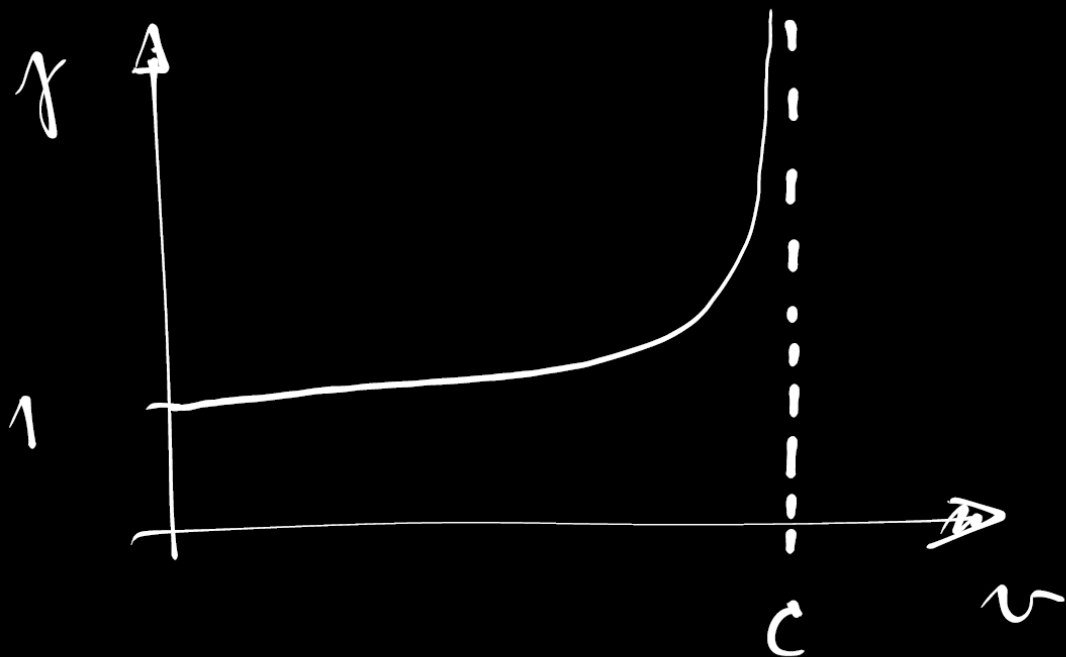
Invariantní hmota

$$E = mc^2$$

$$E = \gamma mc^2$$

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

$$\beta \equiv v/c$$



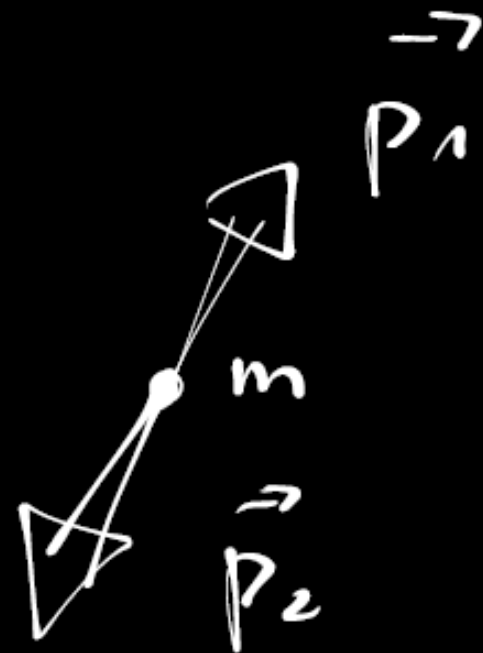
Invariantní hmota

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

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

$$m^2 = E^2 - p^2 \quad \begin{array}{l} \text{v jednotkách} \\ c=1 \end{array}$$

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

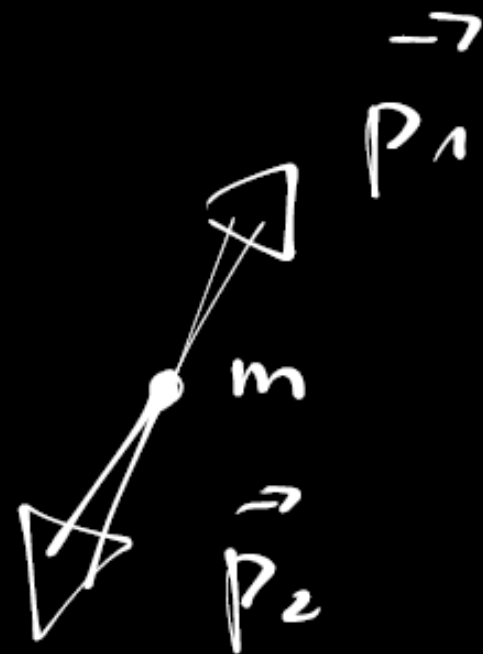


Invariantní hmota

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

$$E = E_1 + E_2$$

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



Invariantní hmota

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

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

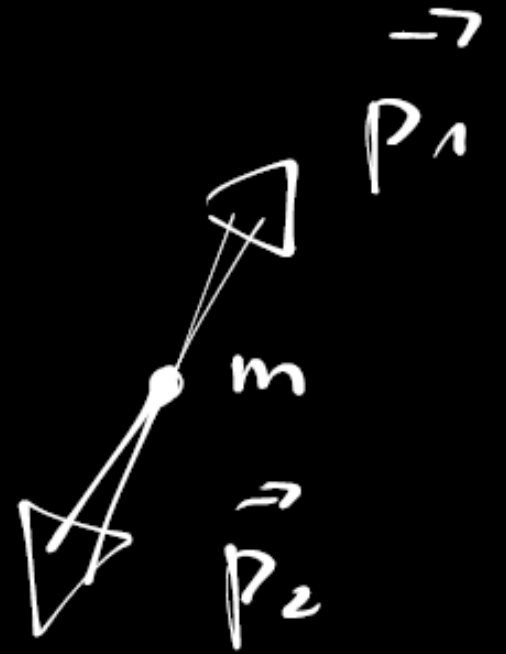
$$E = E_1 + E_2$$

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

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

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

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

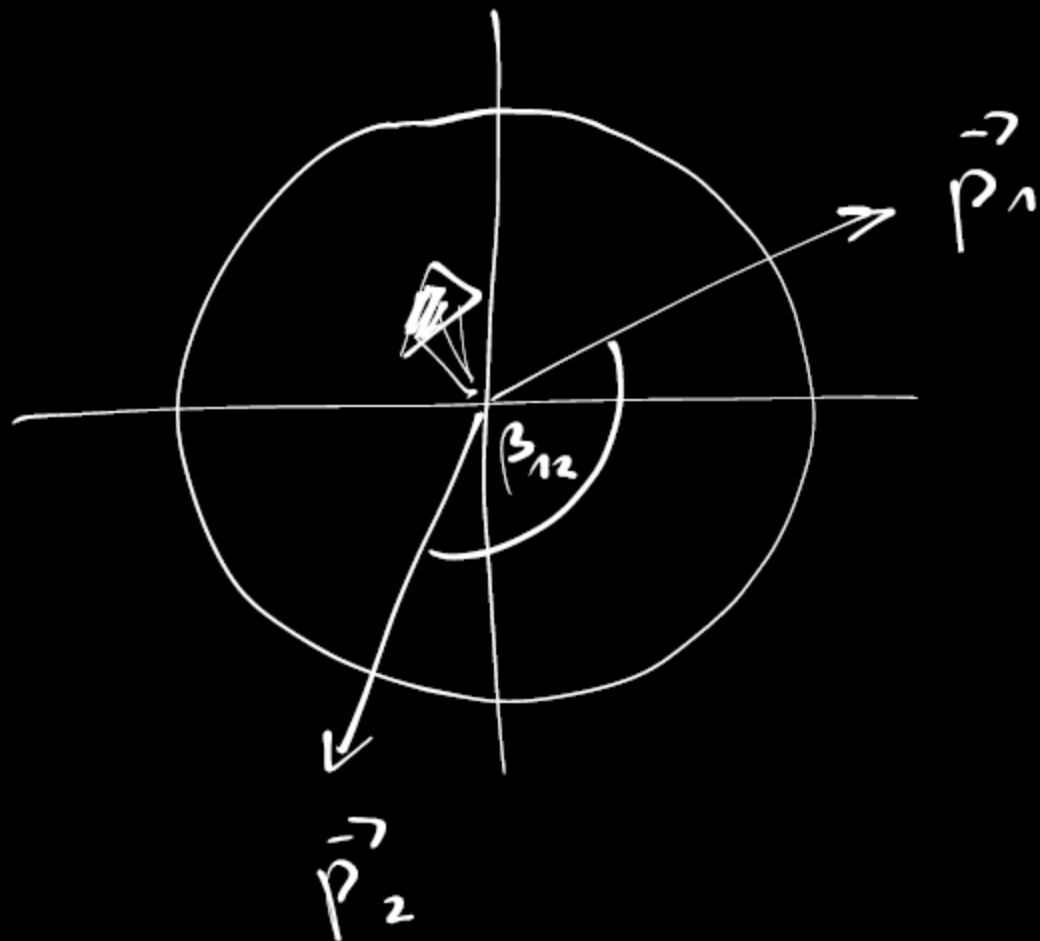


$$m^2 = (E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2$$

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

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

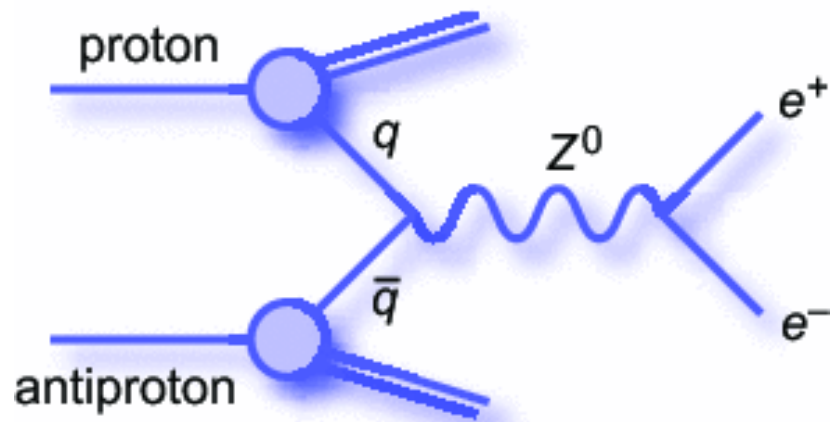
Invariantní hmota



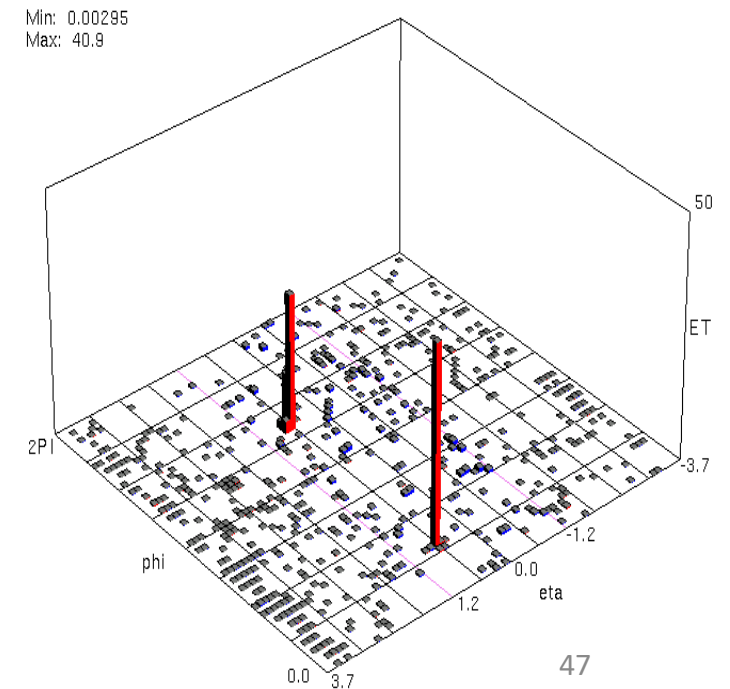
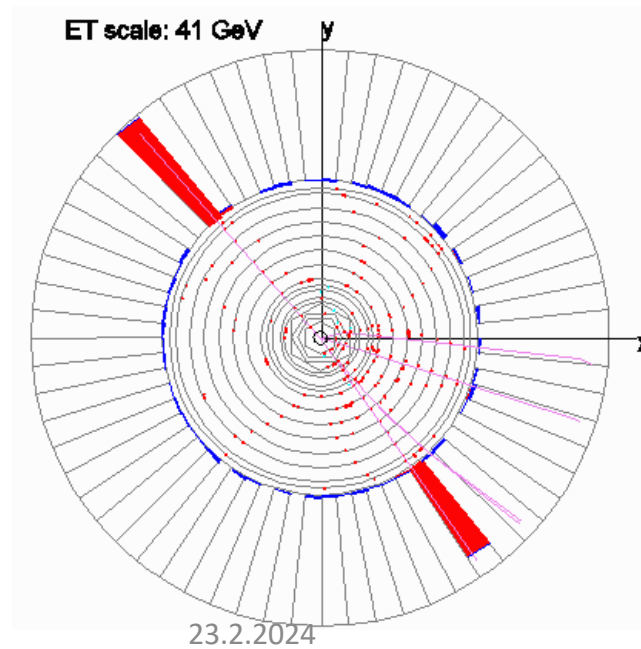
$$m^2 \simeq 2E_1E_2 (1 - \cos \beta_{12})$$

Interakce

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



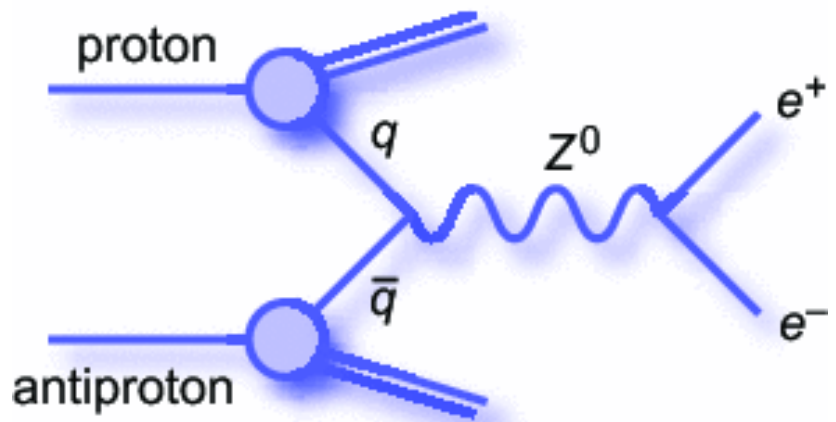
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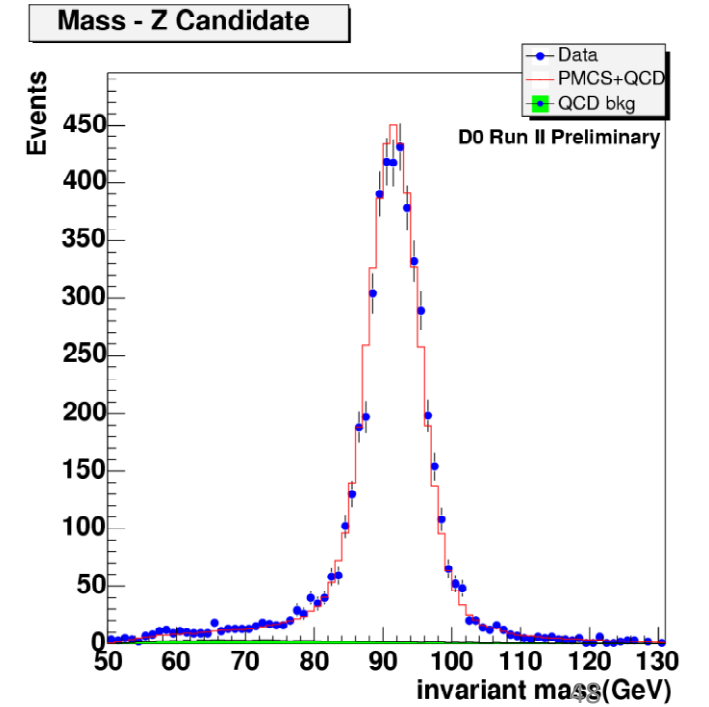
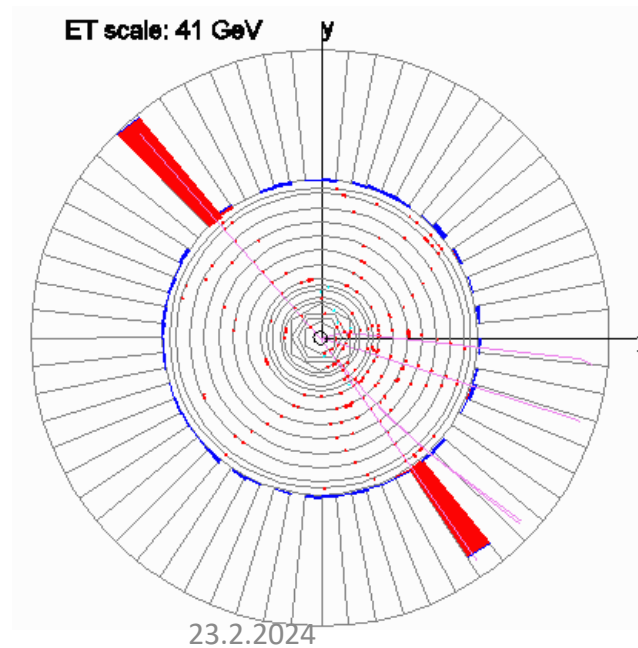
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Interakce

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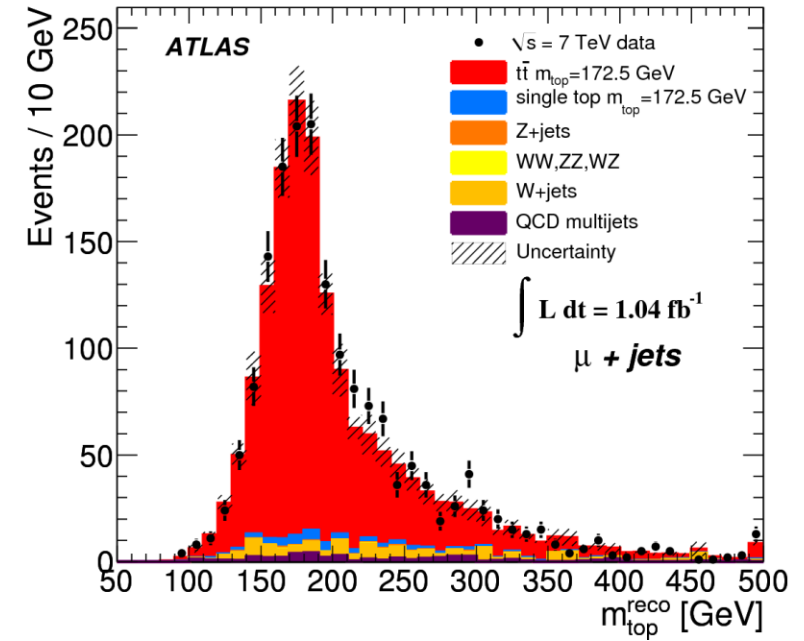
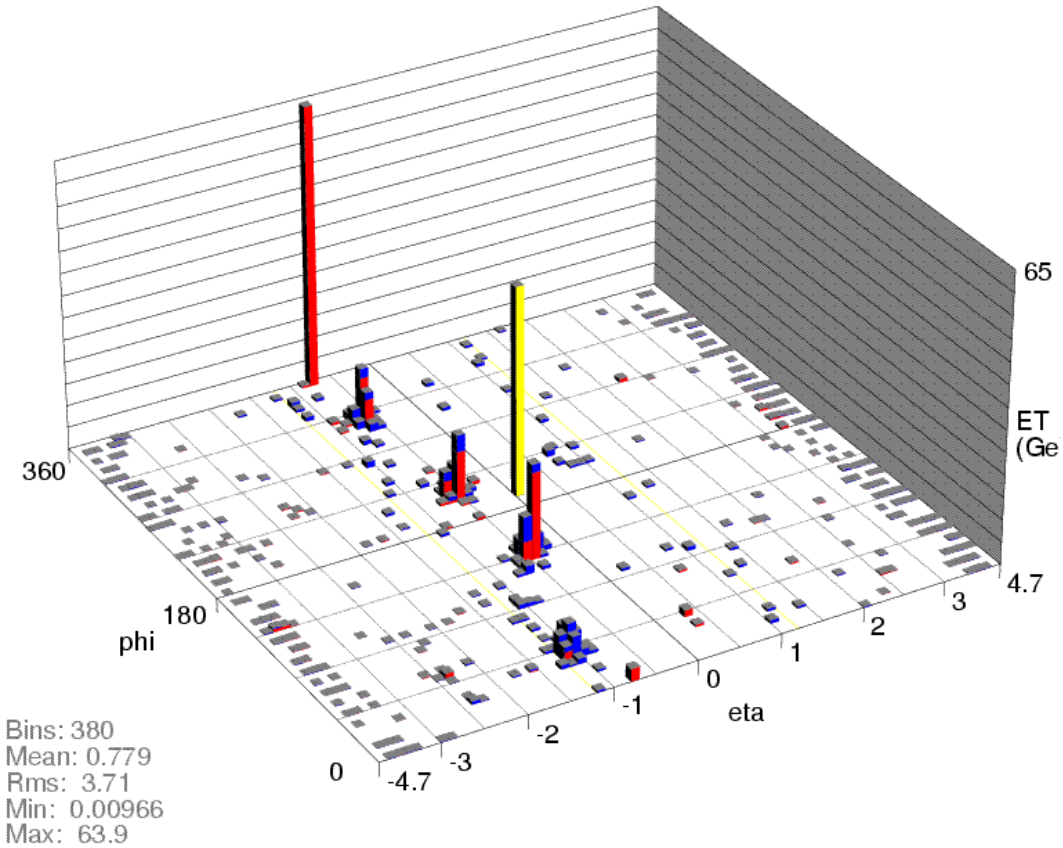
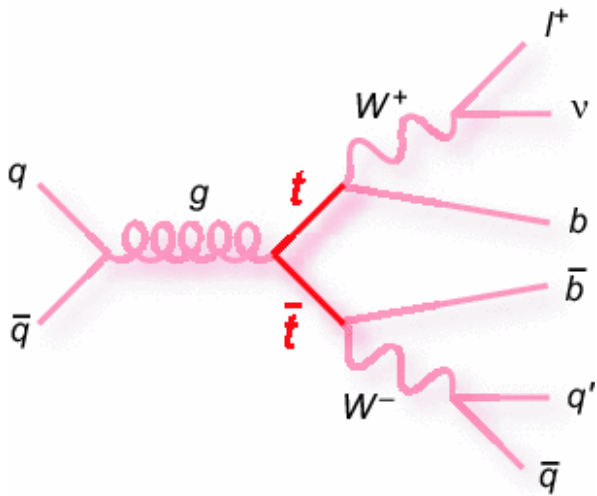


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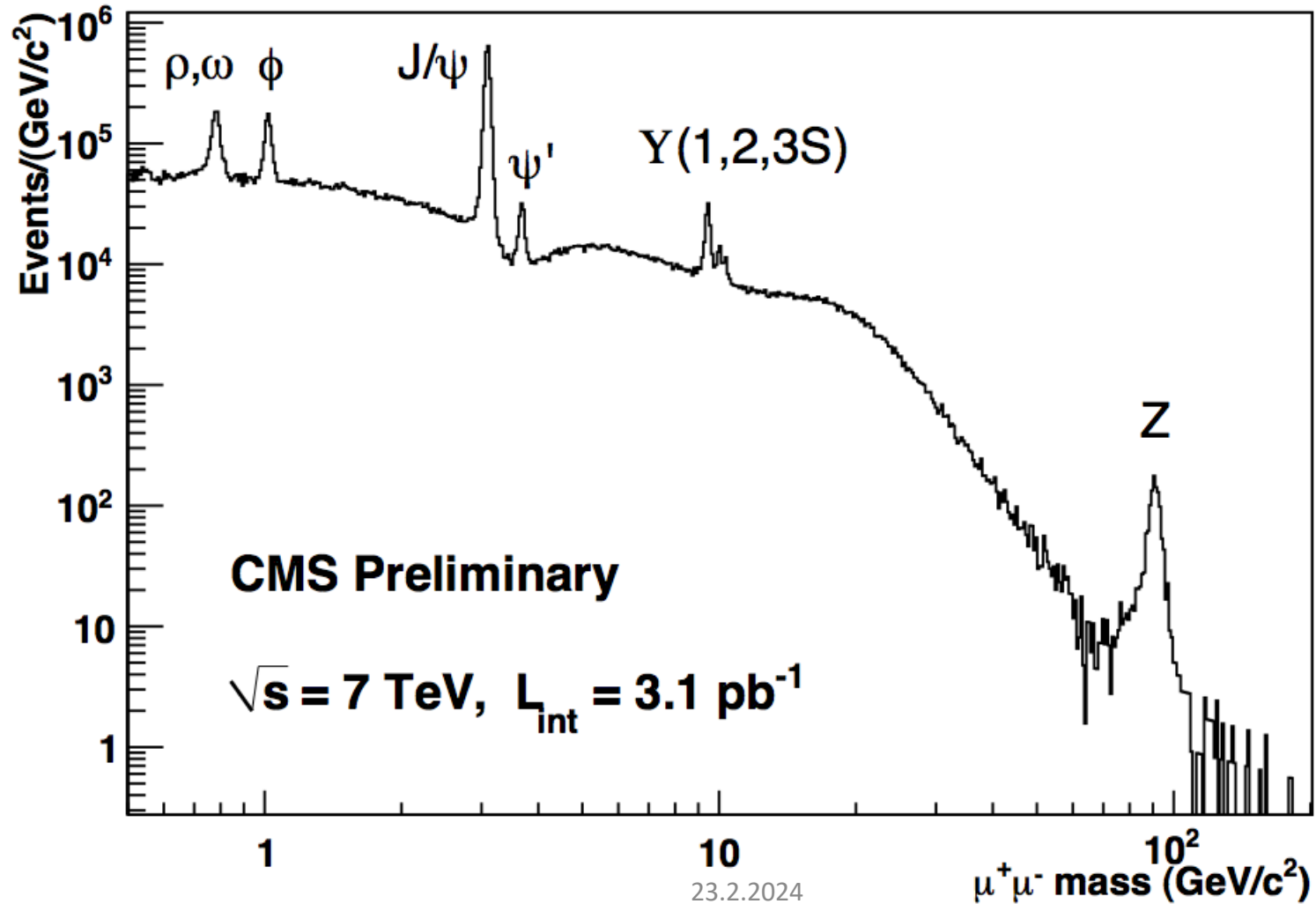
Interakce

- Složitější případ...



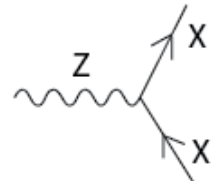
„Částice je kopeček!“

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

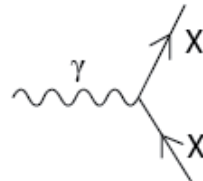


Všecky interakce světa [zatím...]

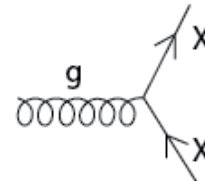
Standard Model Interactions (Forces Mediated by Gauge Bosons)



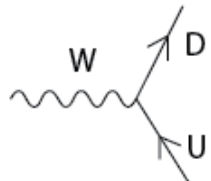
X is any fermion in the Standard Model.



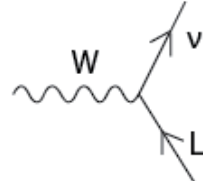
X is electrically charged.



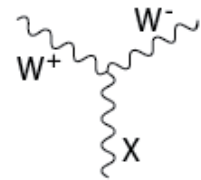
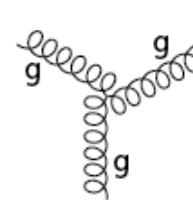
X is any quark.



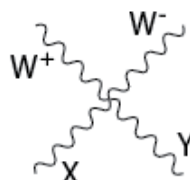
U is a up-type quark;
D is a down-type quark.



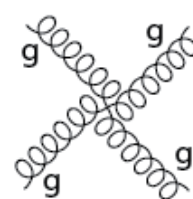
L is a lepton and ν is the corresponding neutrino.



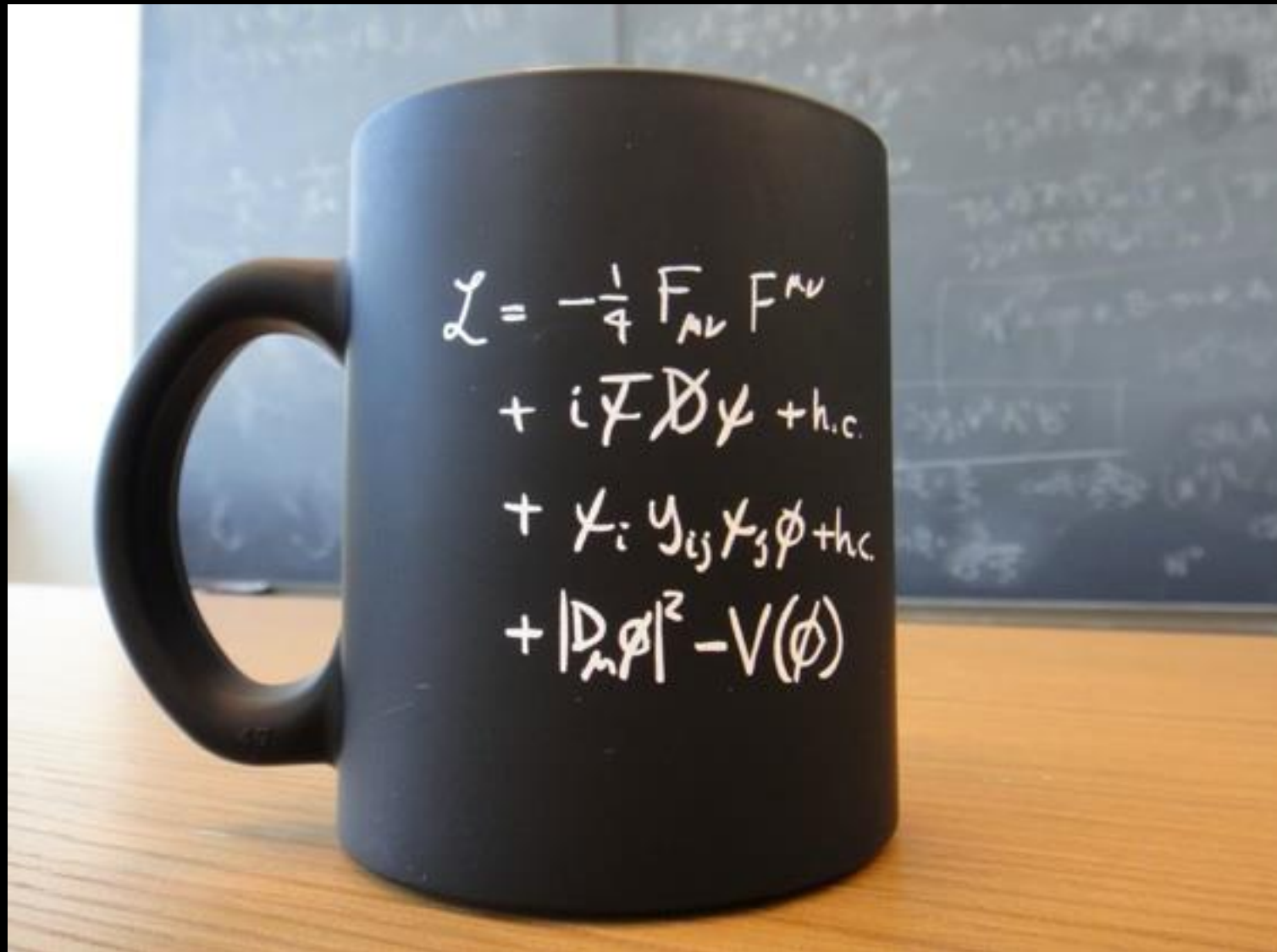
X is a photon or Z-boson.



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



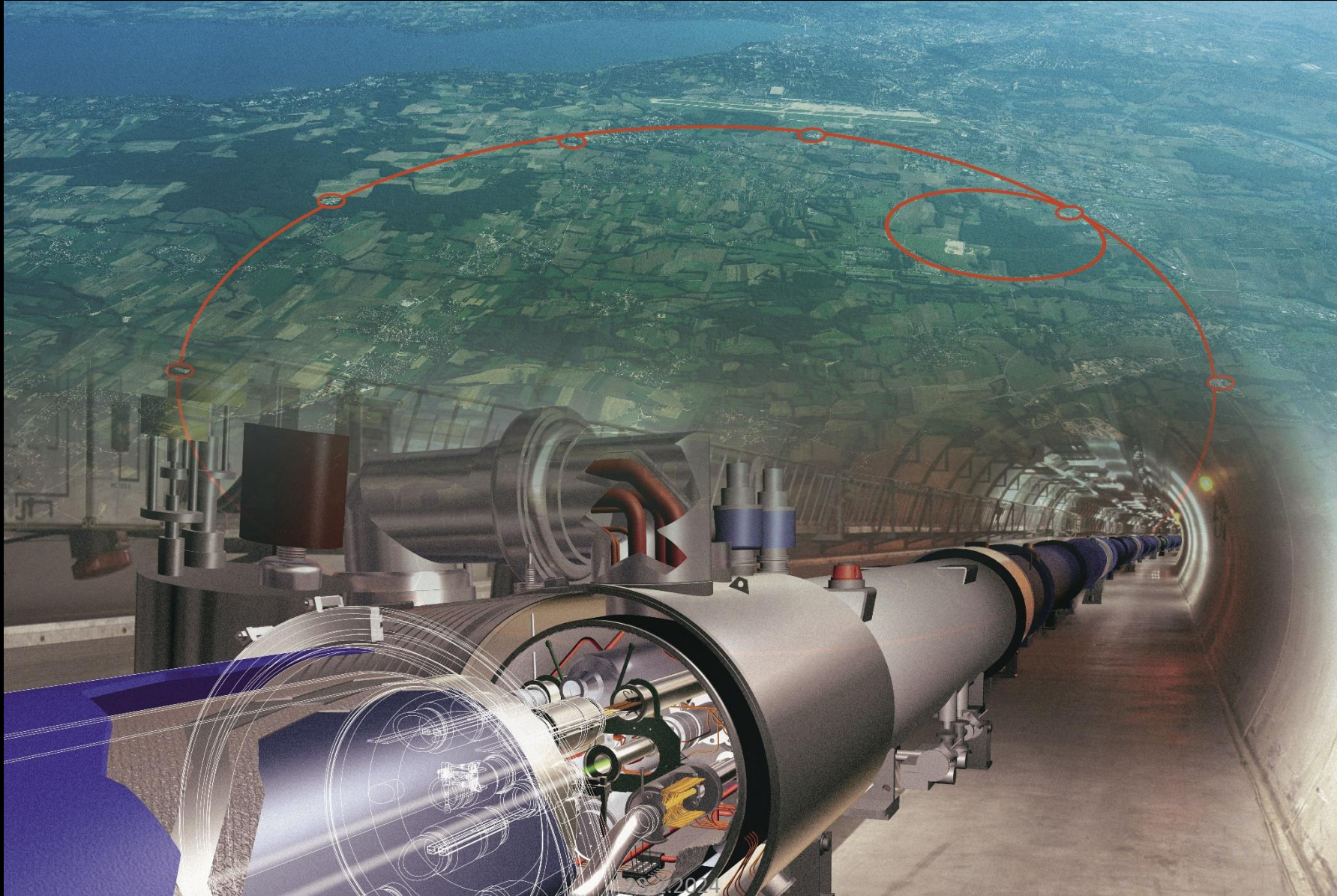
Všecky interakce světa [zatím...]



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_\mu^+ 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_\mu^- - W_\nu^+ W_\nu^-) - 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_\mu^- W_\nu^+ 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_\mu \phi^+ \phi^- + \frac{1}{2}ig_s \lambda_{ij}^a (\bar{q}_i^\alpha \gamma^\mu q_j^\alpha) 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\dagger}_{\kappa\lambda} \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^\kappa (\bar{\nu}^\lambda U^{lep}_{\lambda\kappa} (1 + \gamma^5) e^\kappa) + \\
 & \frac{ig}{2M\sqrt{2}} \phi^- (m_e^\kappa (\bar{e}^\lambda U^{lep\dagger}_{\lambda\kappa} (1 + \gamma^5) \nu^\kappa) - m_\nu^\kappa (\bar{e}^\lambda U^{lep\dagger}_{\lambda\kappa} (1 - \gamma^5) \nu^\kappa)) - \frac{g}{2} \frac{m_e^\lambda}{M} H (\bar{\nu}^\lambda \nu^\lambda) - \\
 & \frac{g}{2} \frac{m_e^\lambda}{M} H (\bar{e}^\lambda e^\lambda) + \frac{ig}{2} \frac{m_e^\lambda}{M} \phi^0 (\bar{\nu}^\lambda \gamma^5 \nu^\lambda) - \frac{ig}{2} \frac{m_e^\lambda}{M} \phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda) - \frac{1}{4} \bar{\nu}_\lambda M_{\lambda\kappa}^R (1 - \gamma_5) \hat{\nu}_\kappa - \\
 & \frac{1}{4} \bar{u}_\lambda M_{\lambda\kappa}^R (1 - \gamma_5) \hat{u}_\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^\kappa (\bar{u}_j^\lambda C_{\lambda\kappa} (1 + \gamma^5) d_j^\kappa) + \\
 & \frac{ig}{2M\sqrt{2}} \phi^- (m_d^\kappa (\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_u^\lambda}{M} H (\bar{u}_j^\lambda u_j^\lambda) - \\
 & \frac{g}{2} \frac{m_d^\lambda}{M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2} \frac{m_u^\lambda}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \frac{ig}{2} \frac{m_d^\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^-) + \frac{1}{2}igM (\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0) .
 \end{aligned}$$

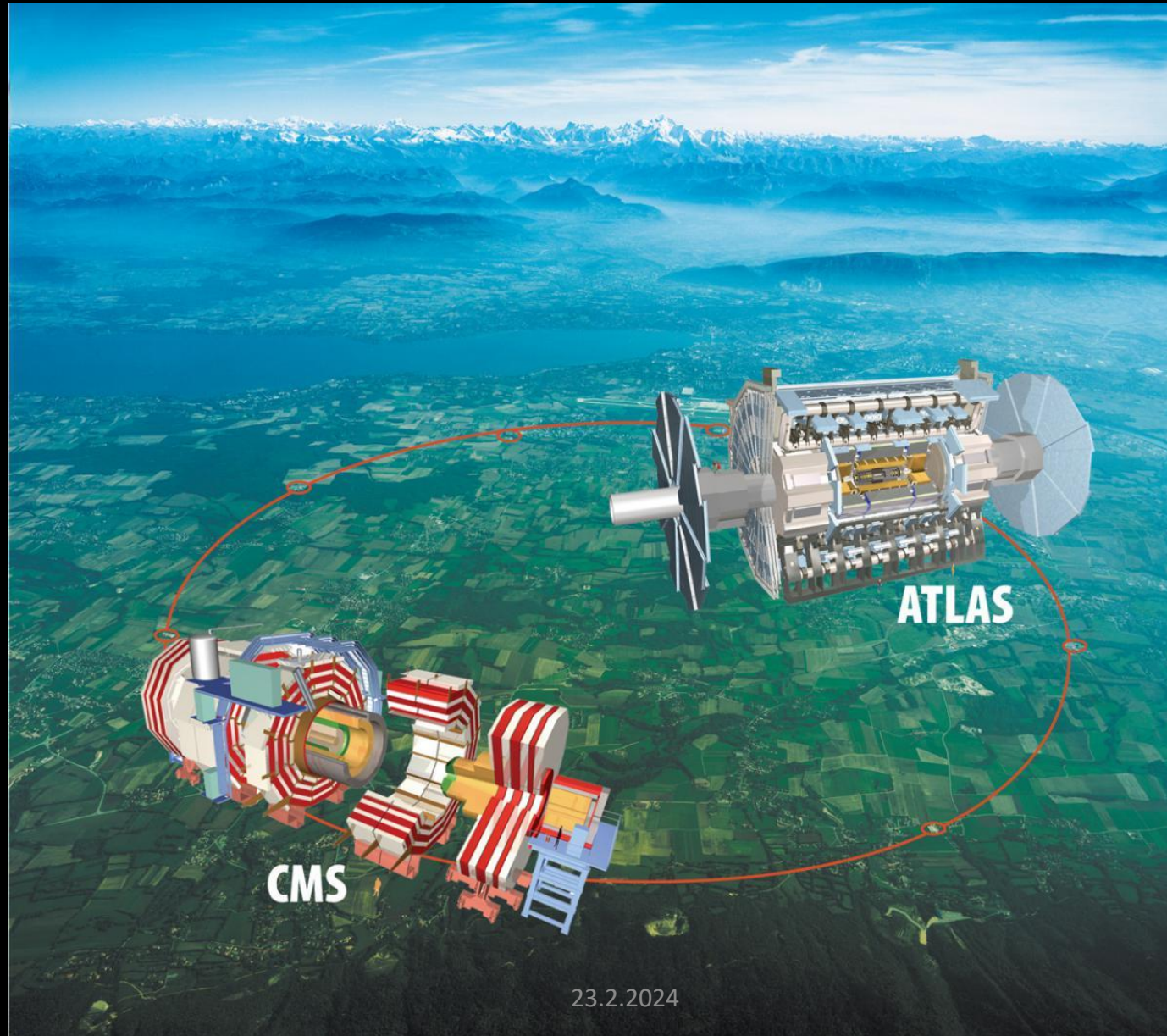
CERN: laboratoř „ $E = mc^2$ “



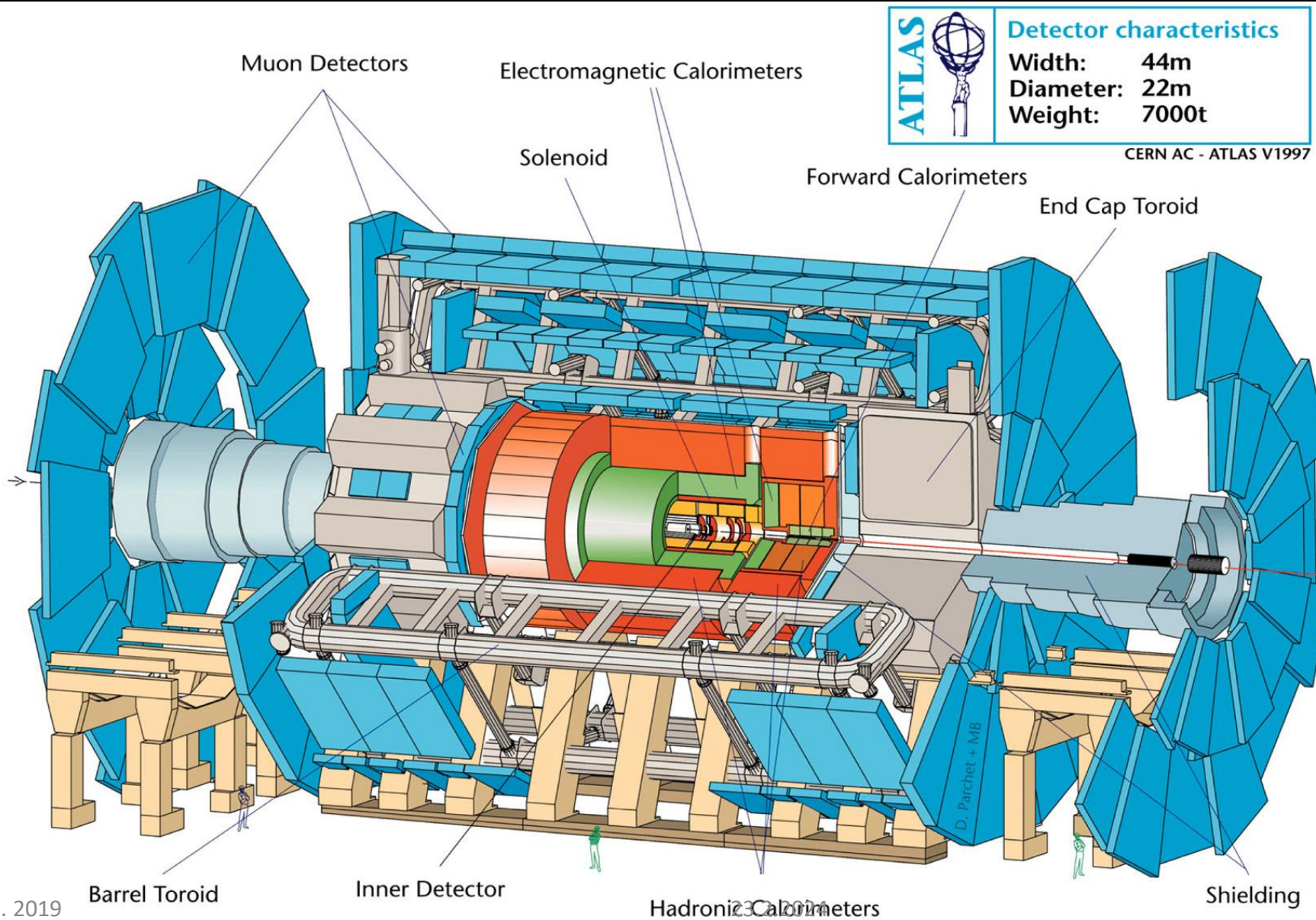
CERN: laboratoř „ $E = mc^2$ “

- 27 km obvod.
- Supravodivé dipólové magnety chlazeny 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 μ s.
- Protony jsou ve shlucích po 10^{10} částic.
- Shluků je ≈ 2000 .
- Frekvence srážek je 40 MHz, tj. každých 25 ns.
- Spotřeba energie jako kanton Ženeva.

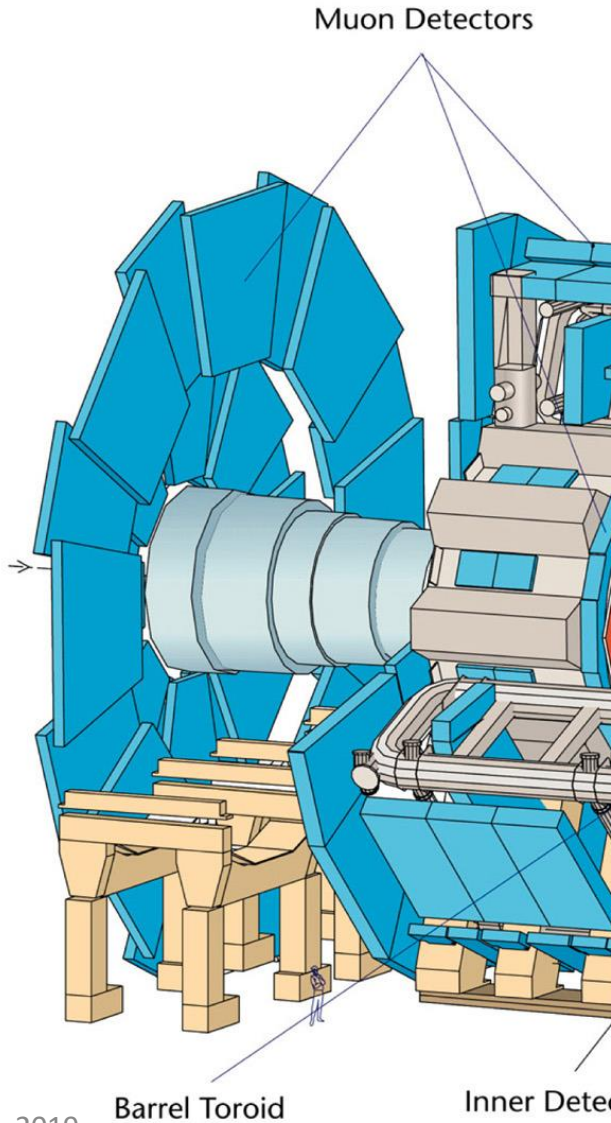
CERN – Evropské centrum (sub)jaderného výzkumu



Experiment ATLAS



Experiment ATLAS



Electromagnetic Calorimeters

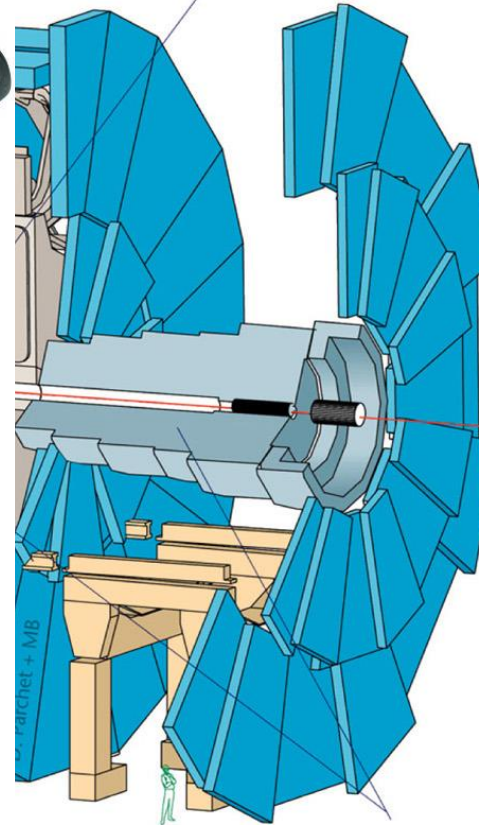
Solenoid

Forward Calorimeters

End Cap Toroid



Hadronic Calorimeters




Shielding

ATLAS		Detector characteristics	
		Width:	44m
		Diameter:	22m
		Weight:	7000t

CERN AC - ATLAS V1997

Experiment ATLAS

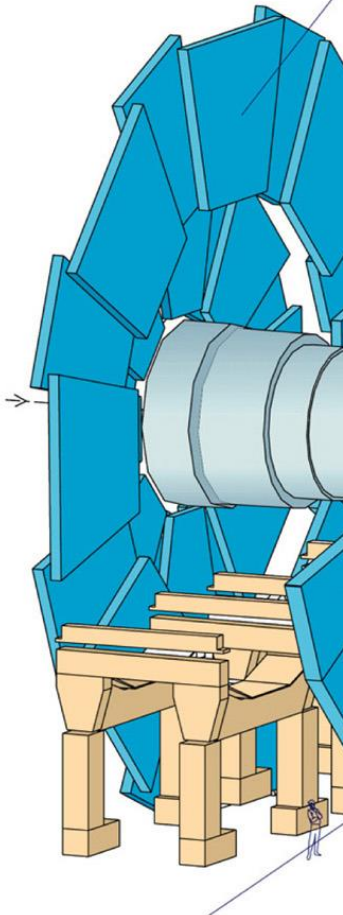
ATLAS 	Detector characteristics	
	Width:	44m
	Diameter:	22m
	Weight:	7000t

CERN AC - ATLAS V1997

Muon Detectors

Electromagnetic Calorimeters

Solenoid

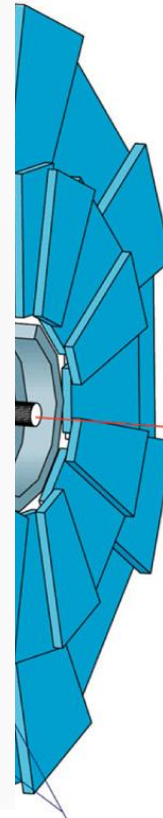


Barrel Toroid



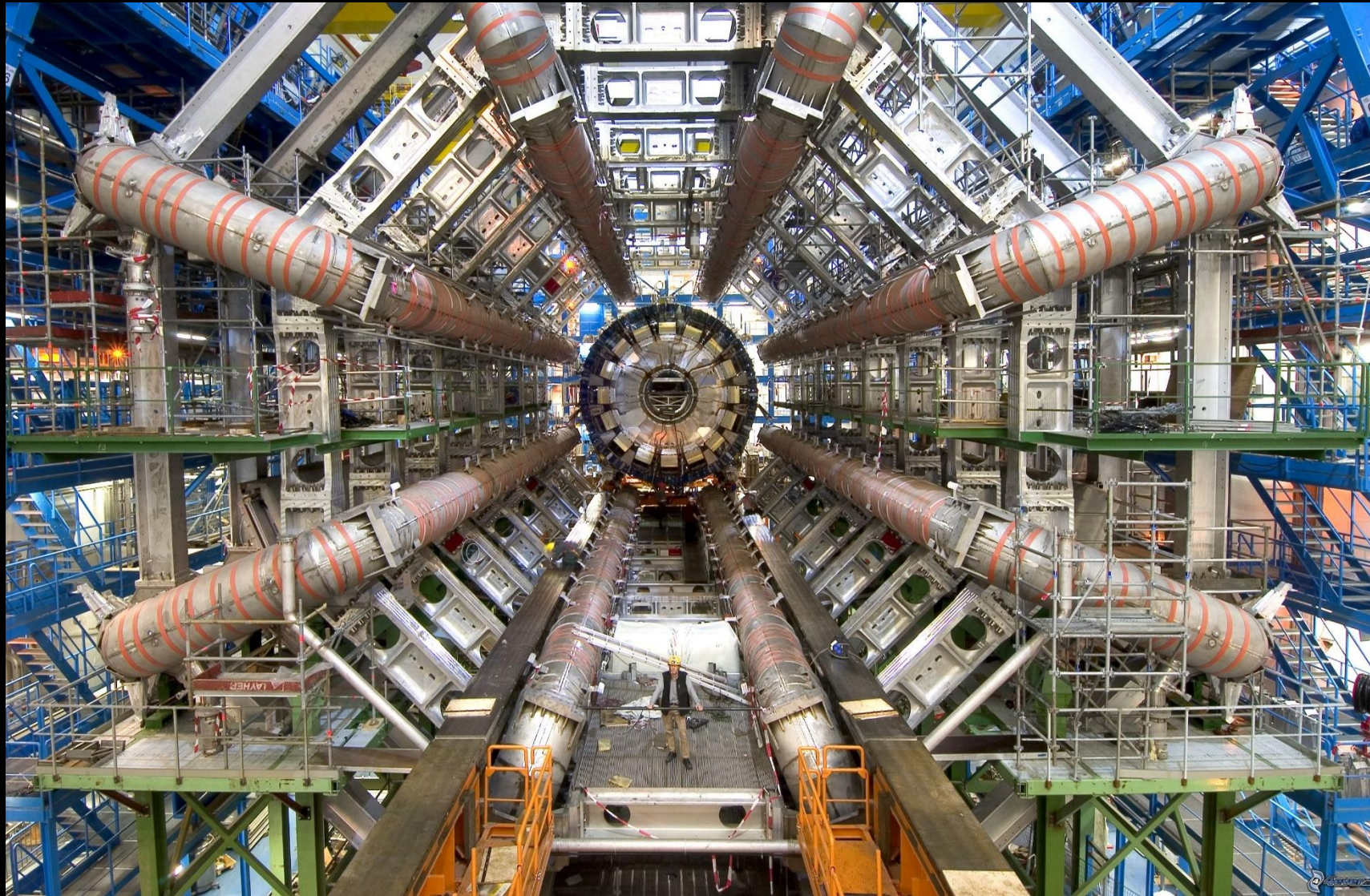
Inner Detector

Hadronic Calorimeters



Shielding

Experiment ATLAS



Experiment ATLAS



Experiment ATLAS



Experiment ATLAS



Experiment ATLAS



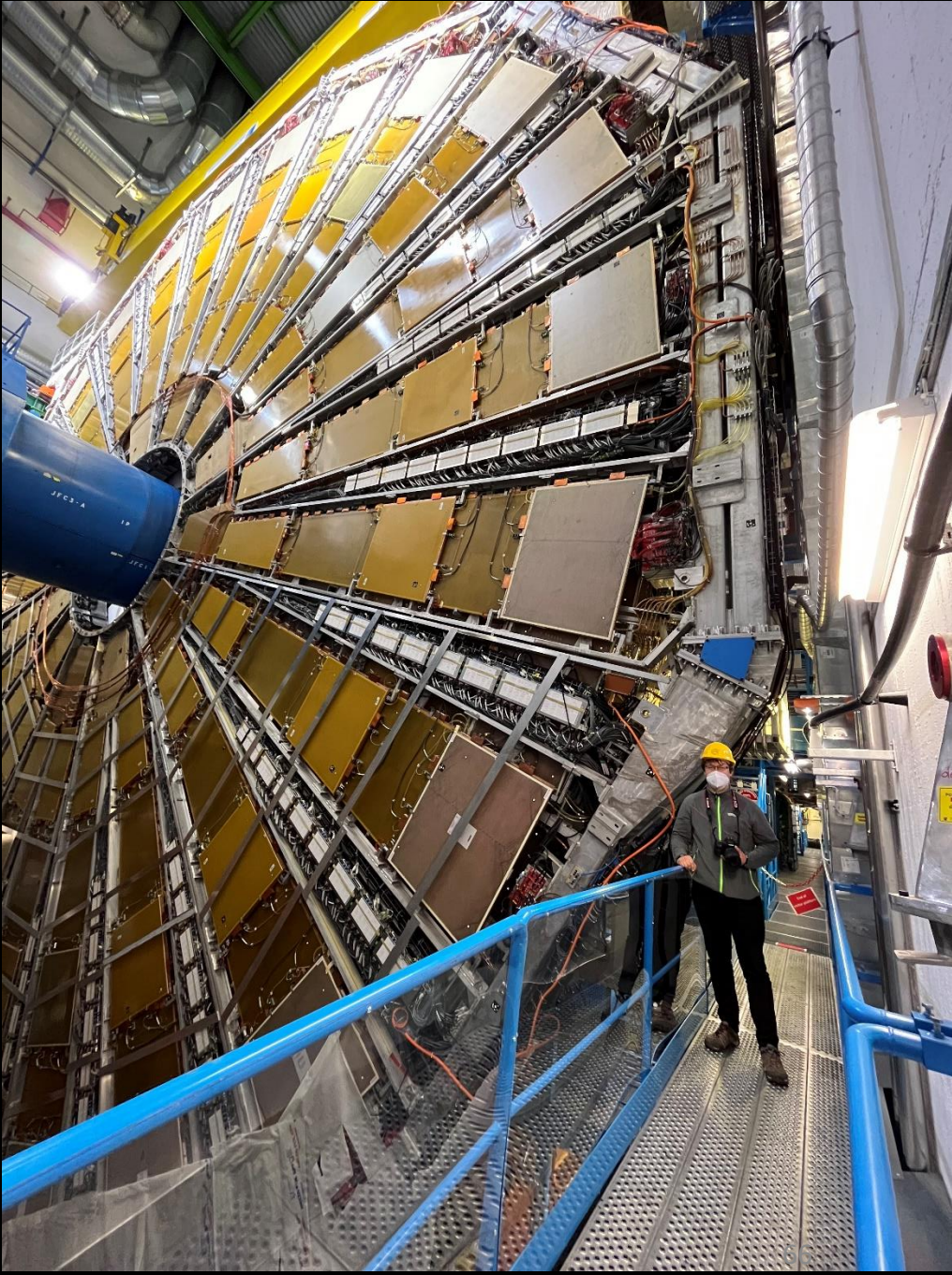
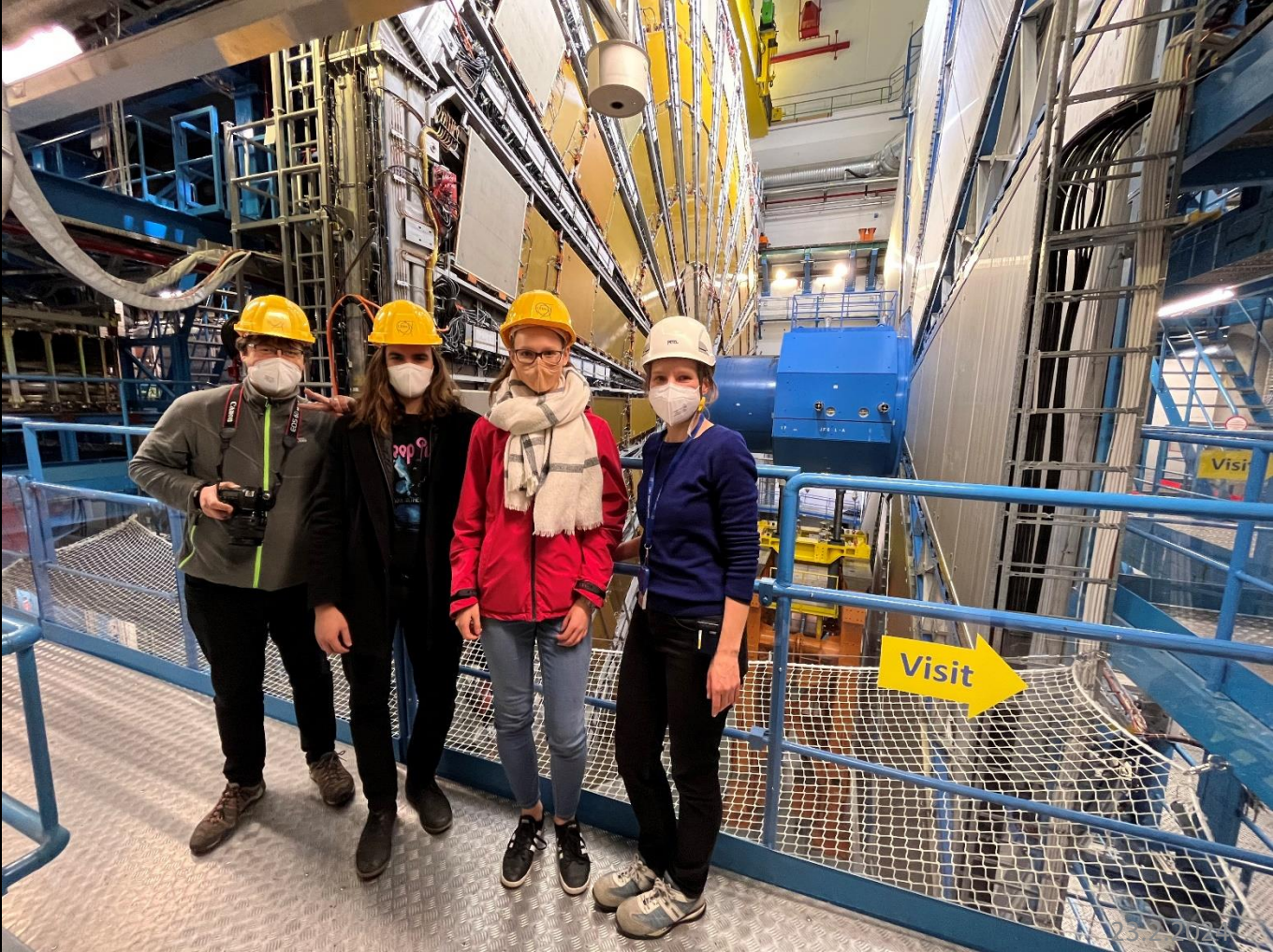
Experiment



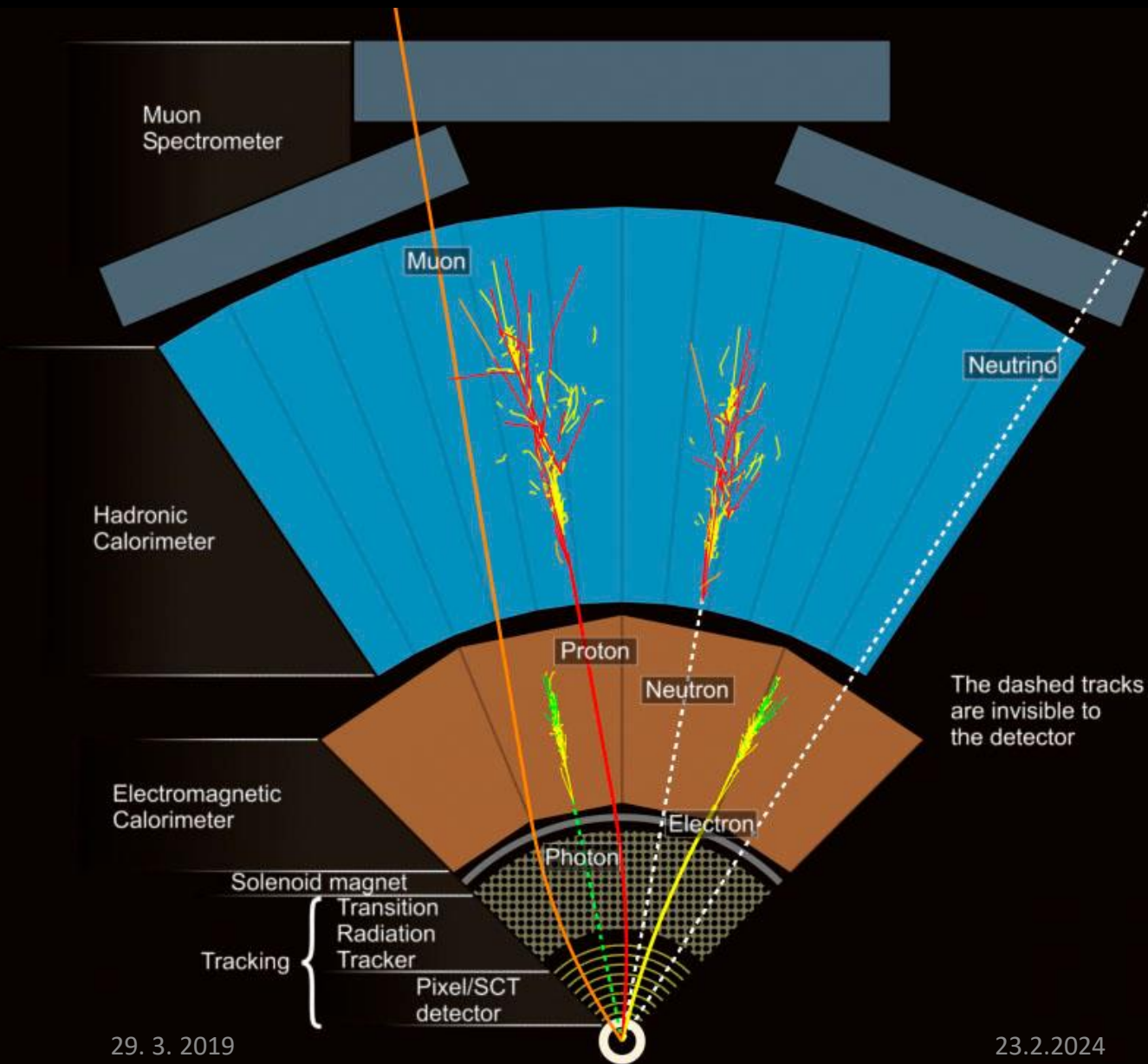
29. 3. 2019

23.2.2024

Experiment ATLAS

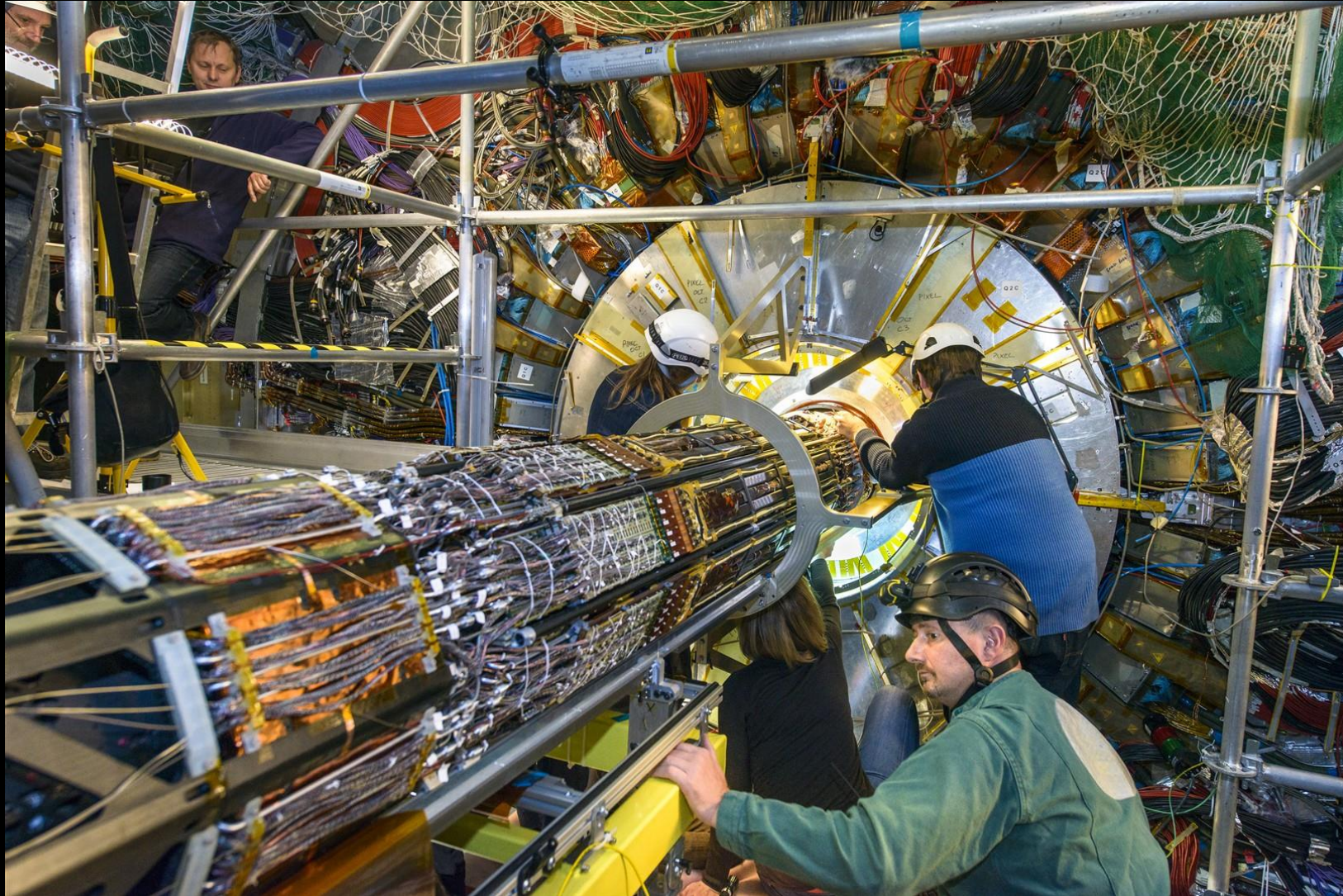


Jak ATLAS vidí částice



- 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.

ATLAS Inner Detector



ATLAS Tile Calorimeter



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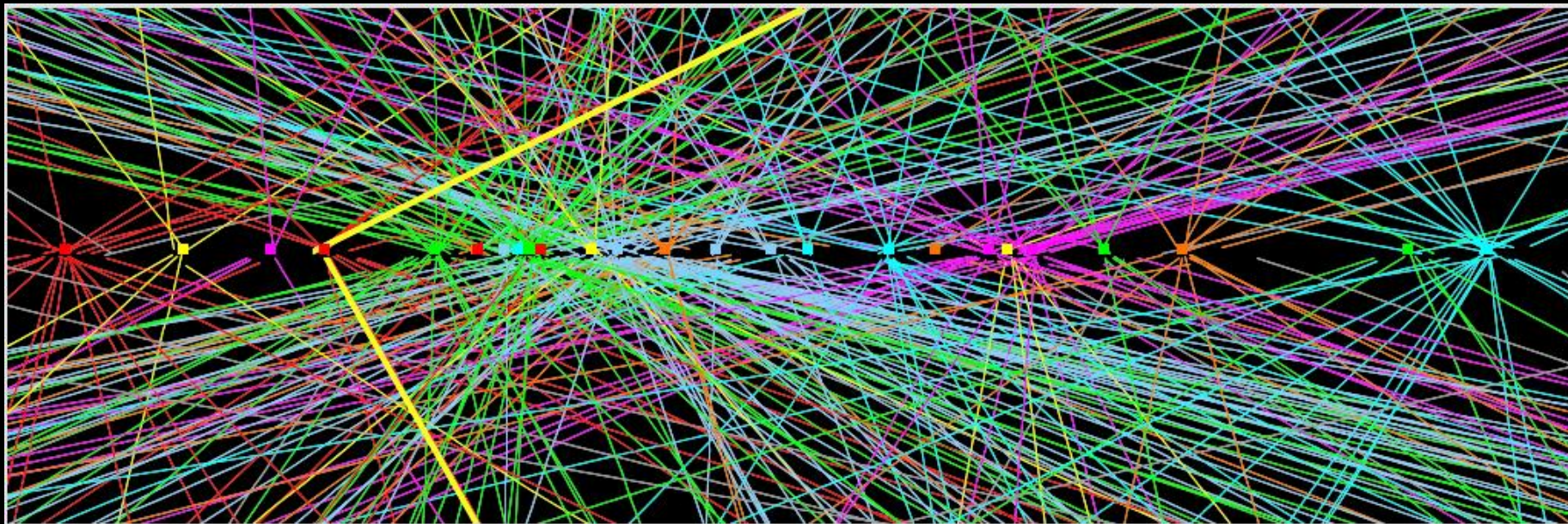


23.2.2024

69

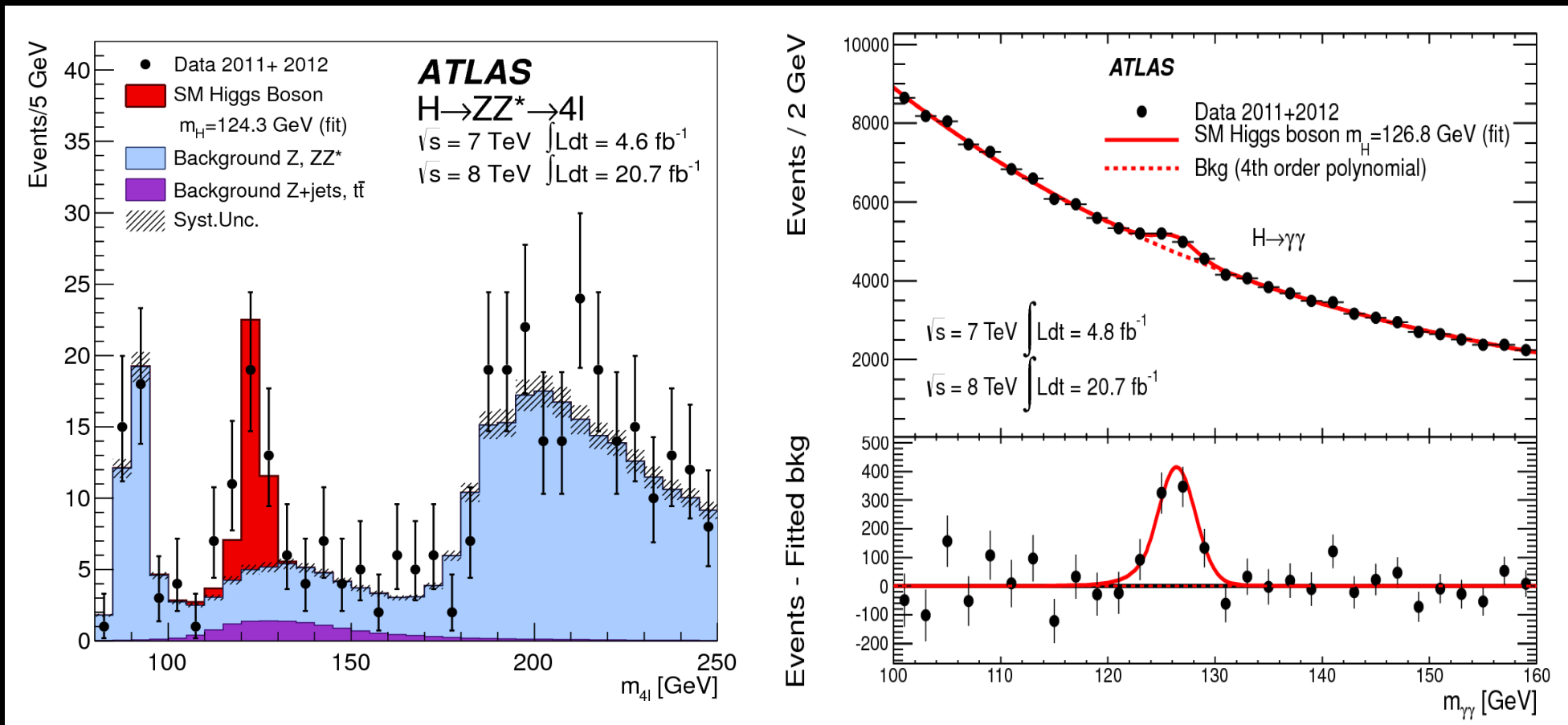
Jak ATLAS vidí částice

- 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:)



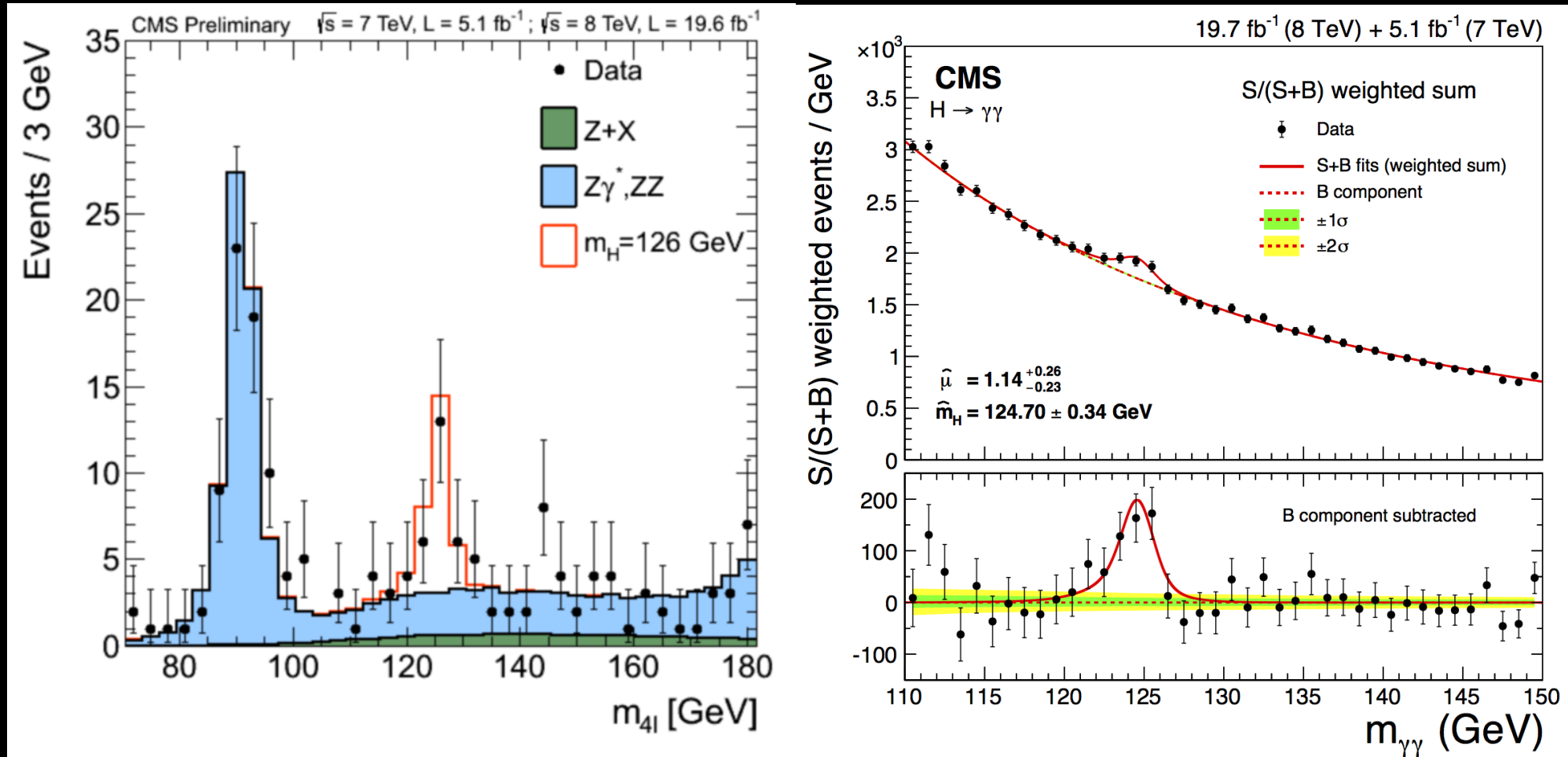
Higgsův boson

- Viděno experimentem ATLAS:



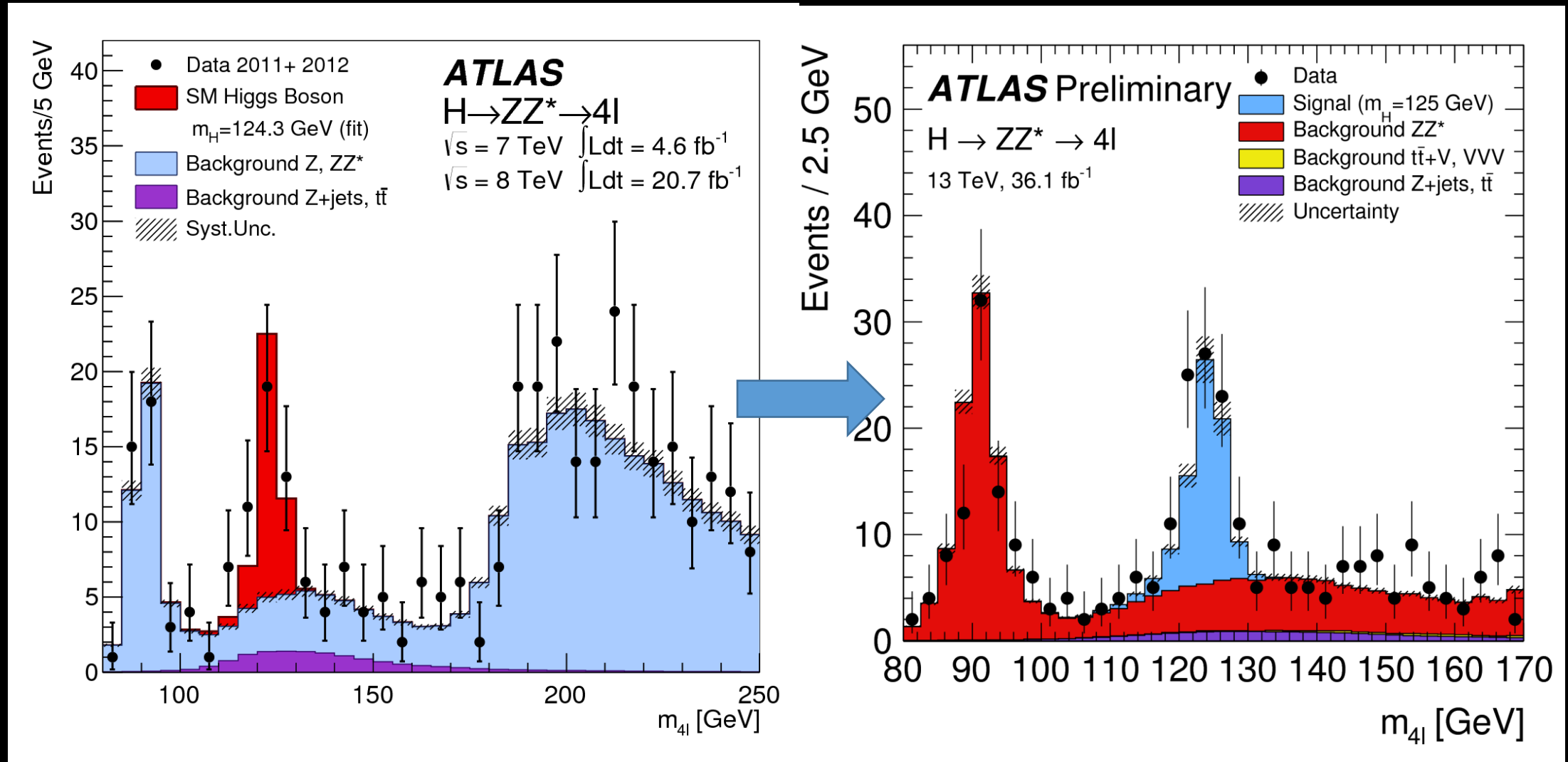
Higgsův boson

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



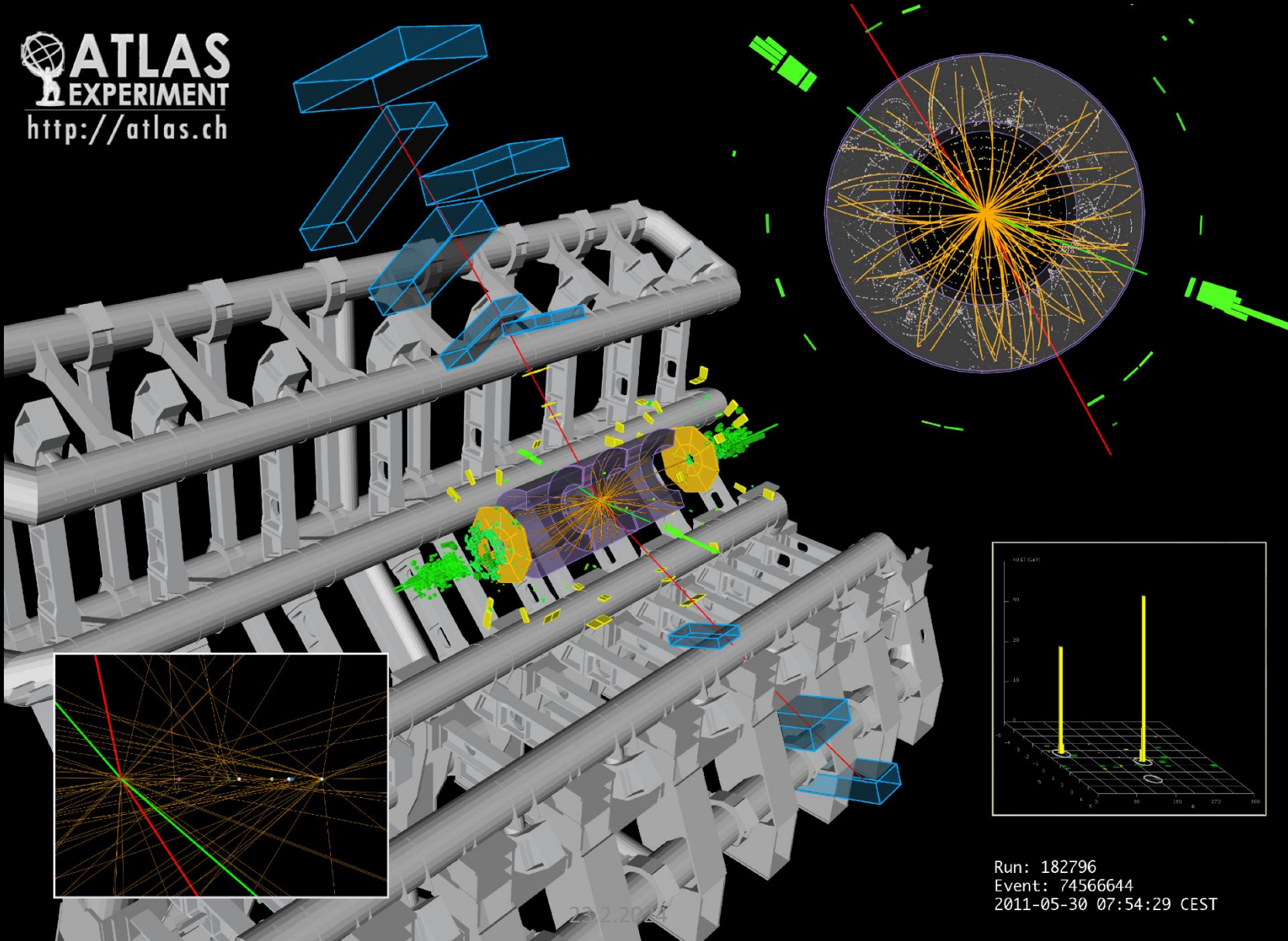
Higgsův boson

- ...a se zahrnutím dat z let 2015—2016:

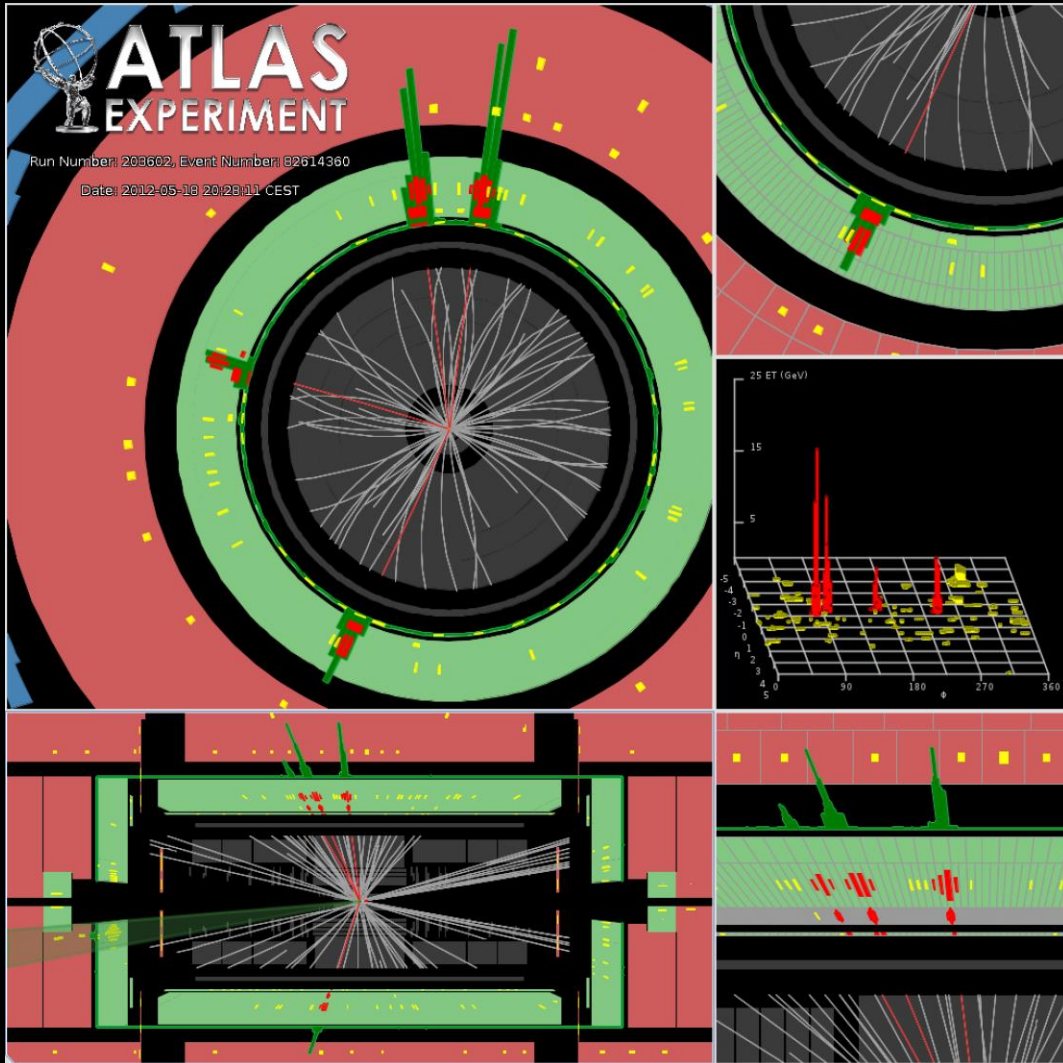


$$H \rightarrow ZZ^* \rightarrow ee \mu \mu$$

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

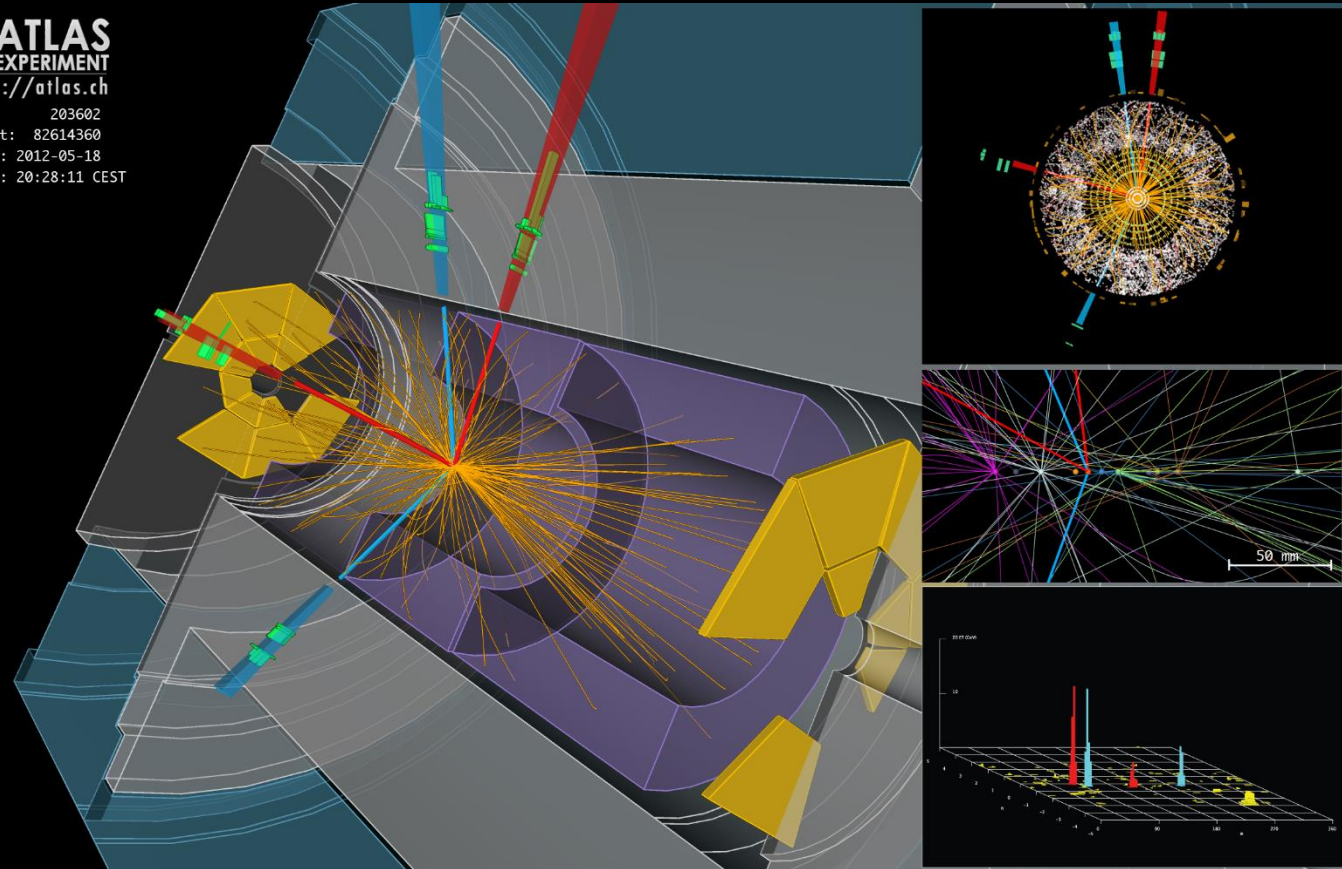


$$H \rightarrow ZZ^* \rightarrow 4e$$



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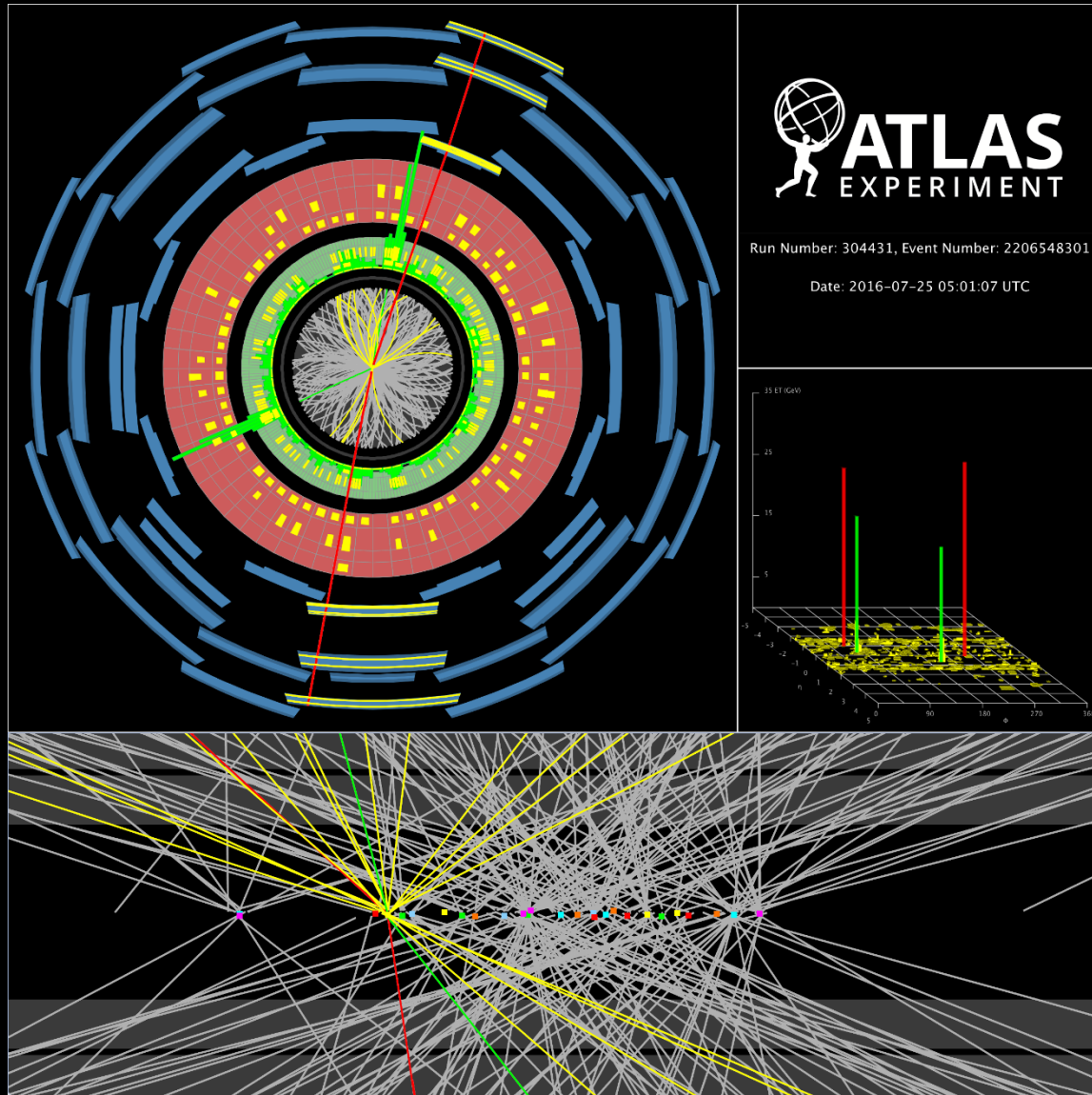
ATLAS EXPERIMENT
<http://atlas.ch>
Run: 203602
Event: 82614360
Date: 2012-05-18
Time: 20:28:11 CEST



23.2.2024

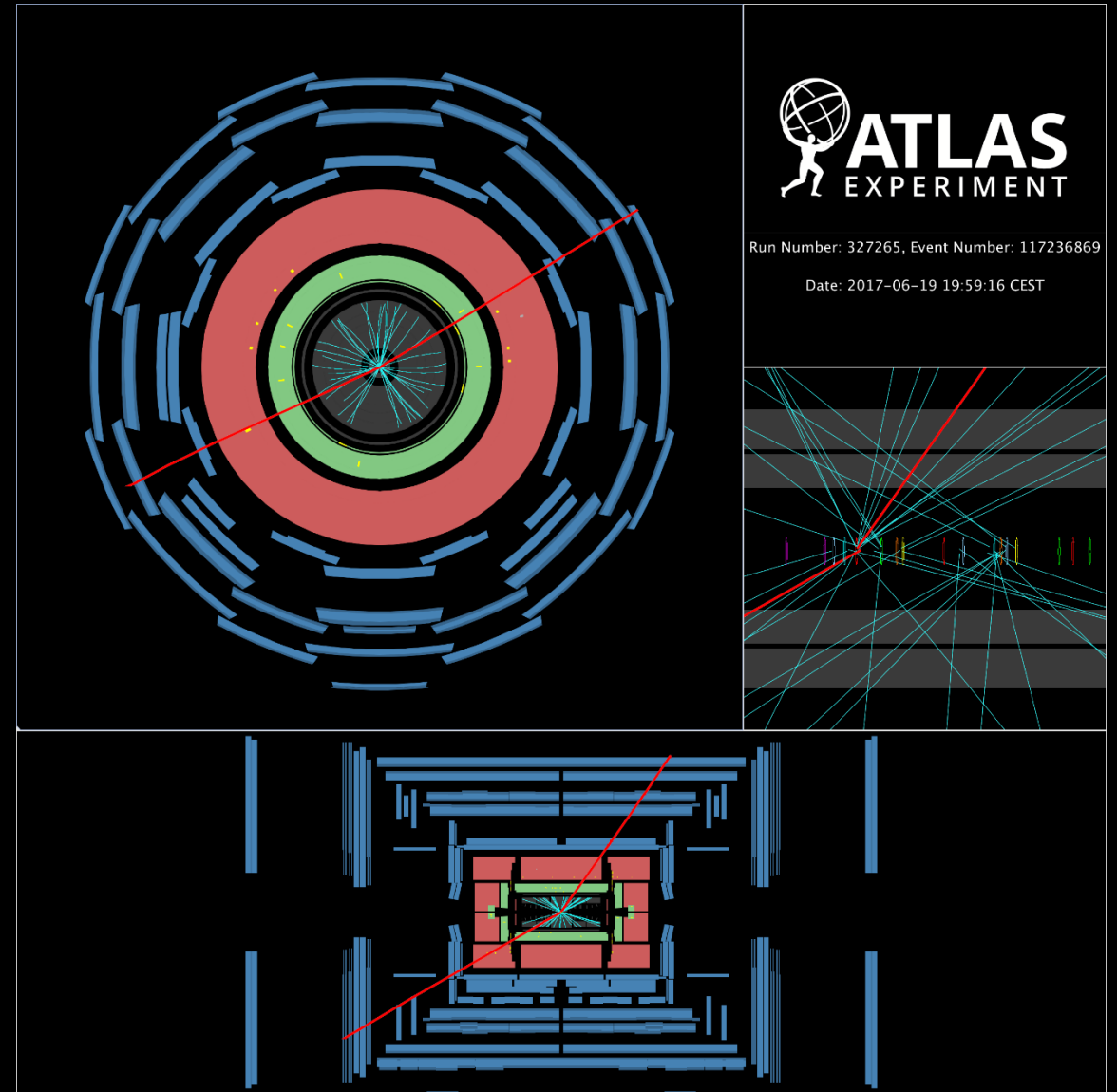
75

$pp \rightarrow H \rightarrow e e \mu \mu$



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$pp \rightarrow Z \rightarrow \mu \mu$

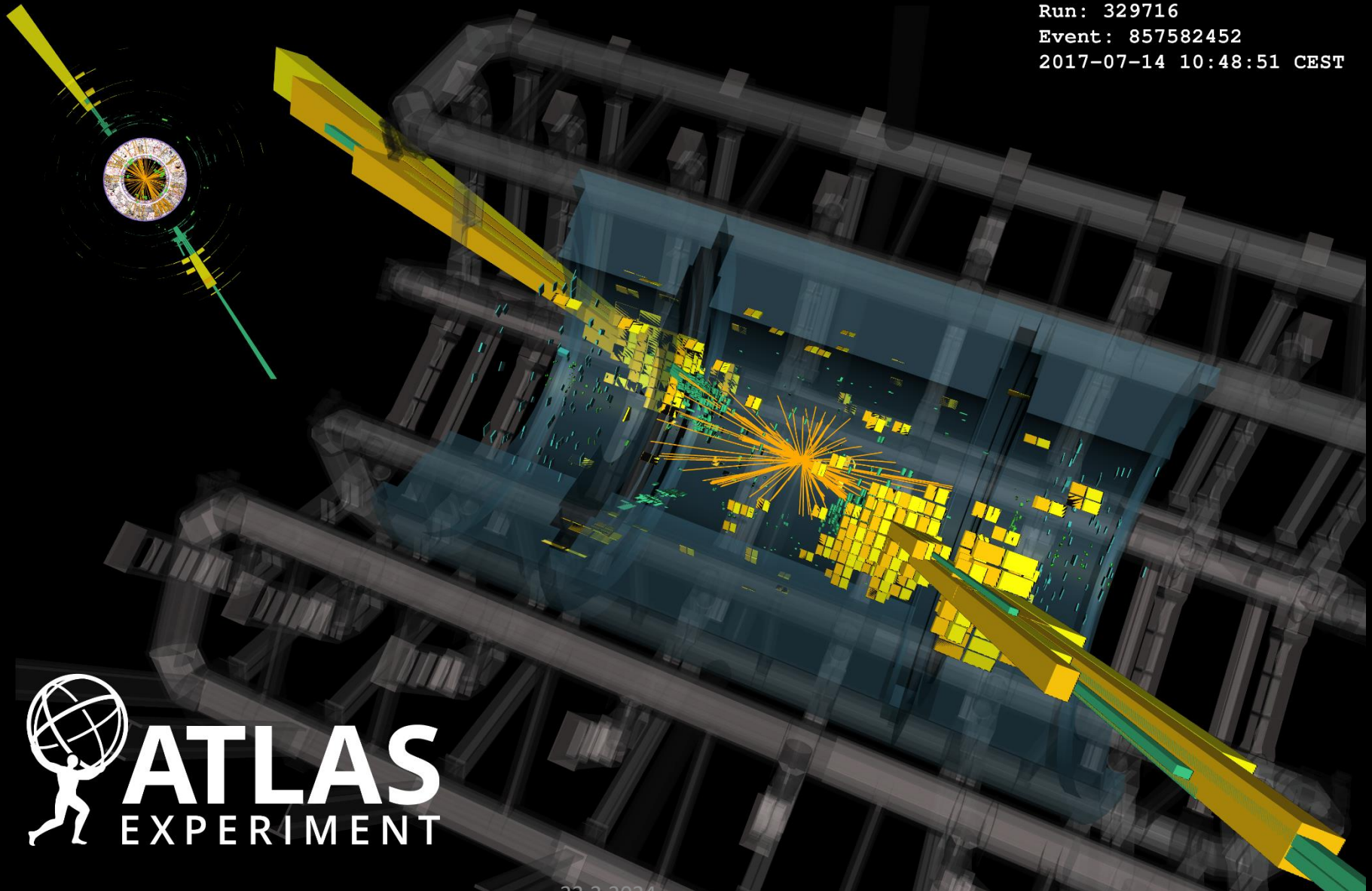


23.2.2024

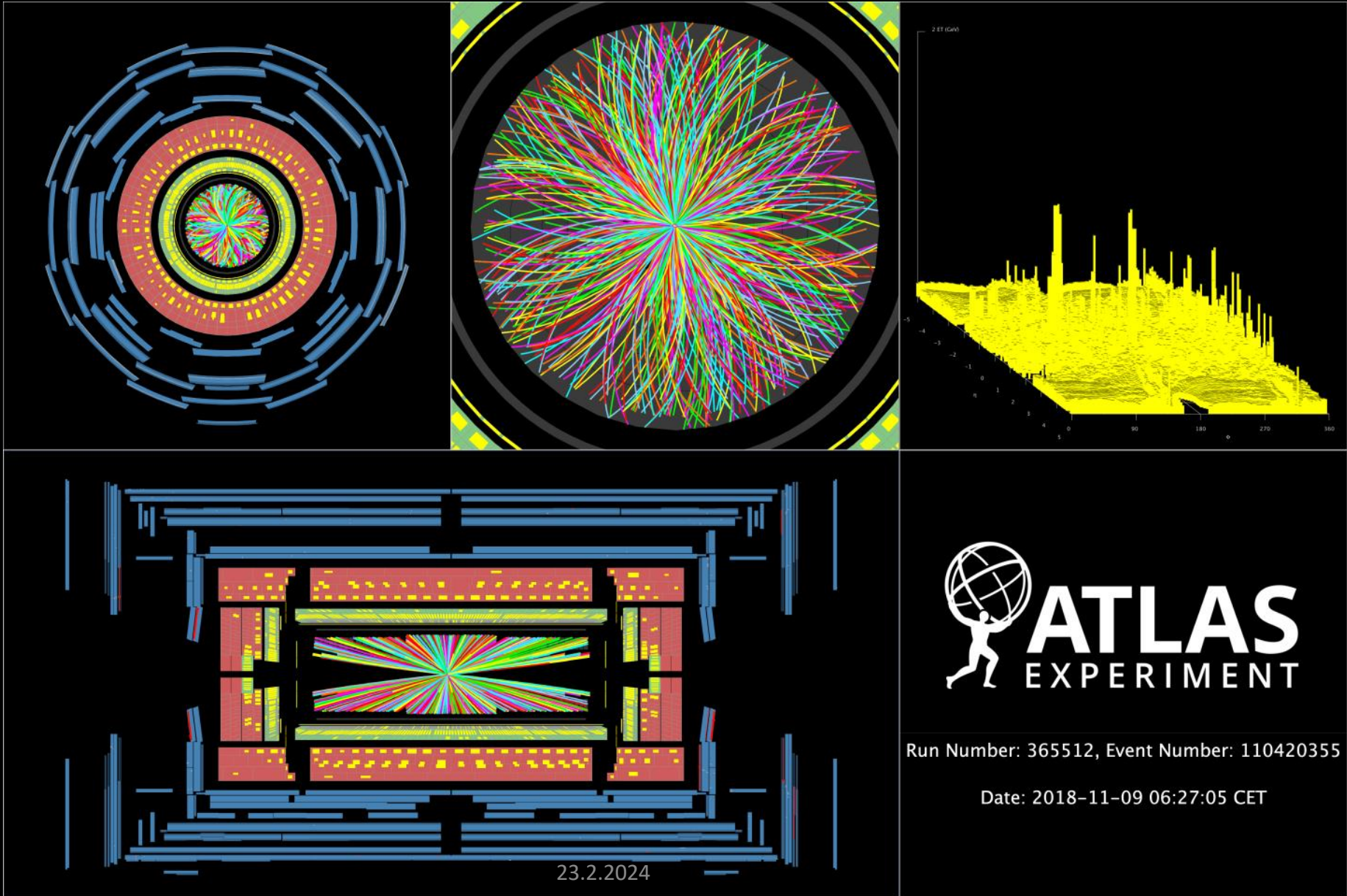
76

pp → jety

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



Srážky jader olova 😊



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

