

Metode v eksperimentalni fiziki osnovnih delcev

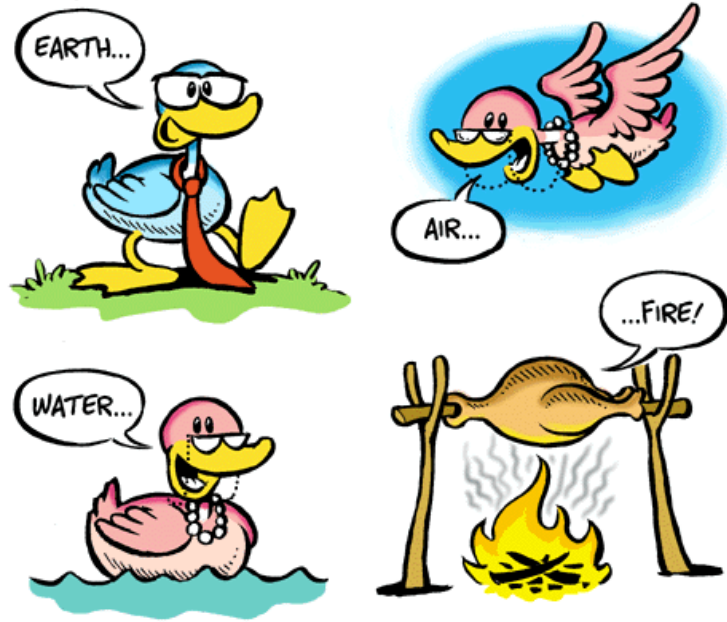
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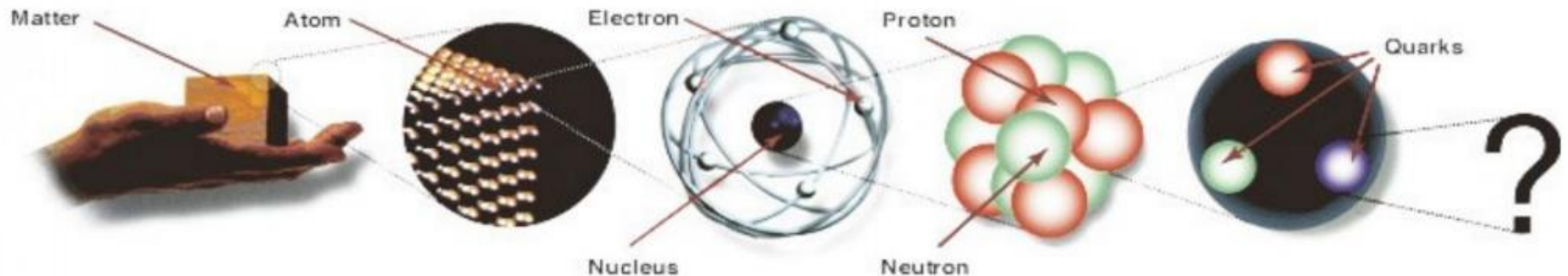
INTERNATIONAL
MASTERCLASSES

hands on particle physics

Gradniki Narave



- Kaj je najmanjši gradnik v naravi?
- Do katerega nivoja lahko snov še razbijemo?



Osnovni delci – Standardni model

- atomsko jedro sestavljajo protoni in nevtroni, ki so zgrajeni iz t.i. kvarkov
- danes vsi poznani osnovni delci skupaj tvorijo t.i. živalski vrt delcev
- Standardni model

The Particle Zoo website features a navigation bar with links: HOME, SHOP, NEWS, CONTACT, ABOUT, GALLERY, PRESS, and an App Store icon. The main title is 'The PARTICLE ZOO' with 'PARTICLE' in black and 'ZOO' in large, colorful letters. Below the title is the tagline 'Handmade Subatomic Particle Plushies FROM THE STANDARD MODEL OF PHYSICS & beyond! {age 13 and up}'.

The website is organized into several categories, each with a vertical label on the left:

- QUARKS:** Includes UP QUARK (teeny little point), DOWN QUARK (tiny little point), CHARM QUARK (charming second generation), STRANGE QUARK (strange about this second generation), TOP QUARK (heavyweight champion), and BOTTOM QUARK (third generation).
- LEPTONS:** Includes ELECTRON-NEUTRINO (minuscule), ELECTRON (familiar friend), MUON-NEUTRINO (like other 2 neutrinos), MUON (heavy electron), and TAU-NEUTRINO (tau now).
- THEORETICALS:** Includes TACHYON (devious and clever), DARK MATTER (mysterious), GRAVITON (unobserved), and HIGGS BOSON (one everyone wants to meet).
- FORCE CARRIERS:** Includes PHOTON (massless wobble) and GLUON (glue of the strong nuclear force).

Other featured items include:

- NUCLEONS:** NEUTRON (would not be here) and PROTON (insists on remaining neutral).
- UNIVERSE-IN-A-BOX:** A complete set of 22 or 36 mini particles + booklet.
- BIG PROTON:** With MINI QUARKS and GLUON.
- THE HISTORY of the UNIVERSE SERIES:** A 5-piece set.
- MINI POSTER:** A poster showing various particles.
- ZIPPER POUCHES:** Colorful pouches.
- PARTICLE PLAYING CARDS:** Cards for particle games.
- FORCE CARRIERS:** Includes PHOTON and GLUON.
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Velikosti v vesloju



Kako preizkušujemo osnovne delce?

- Z veliko hitrostjo (energijo, gibalno količino) zaletavamo delce v delce
- Podobno kot – trk dveh avtomobilov:

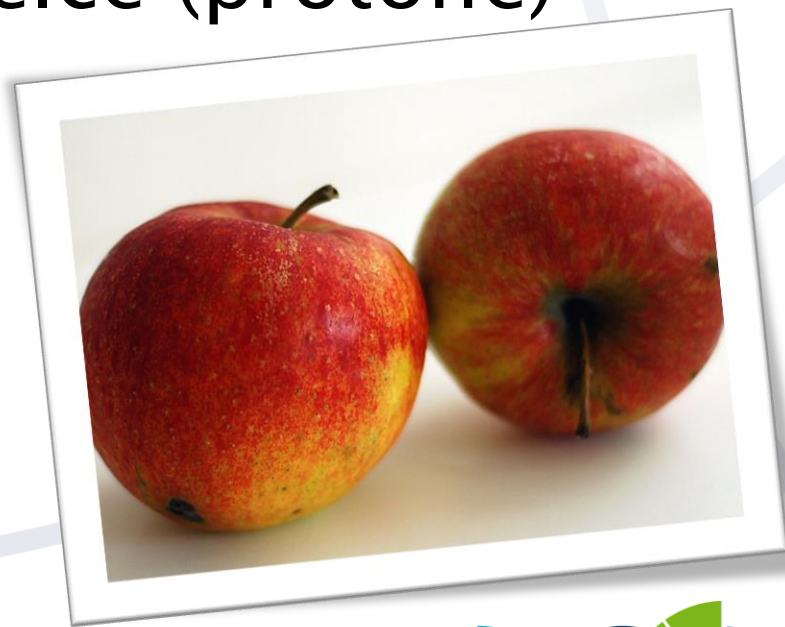


- Trk dveh delcev:



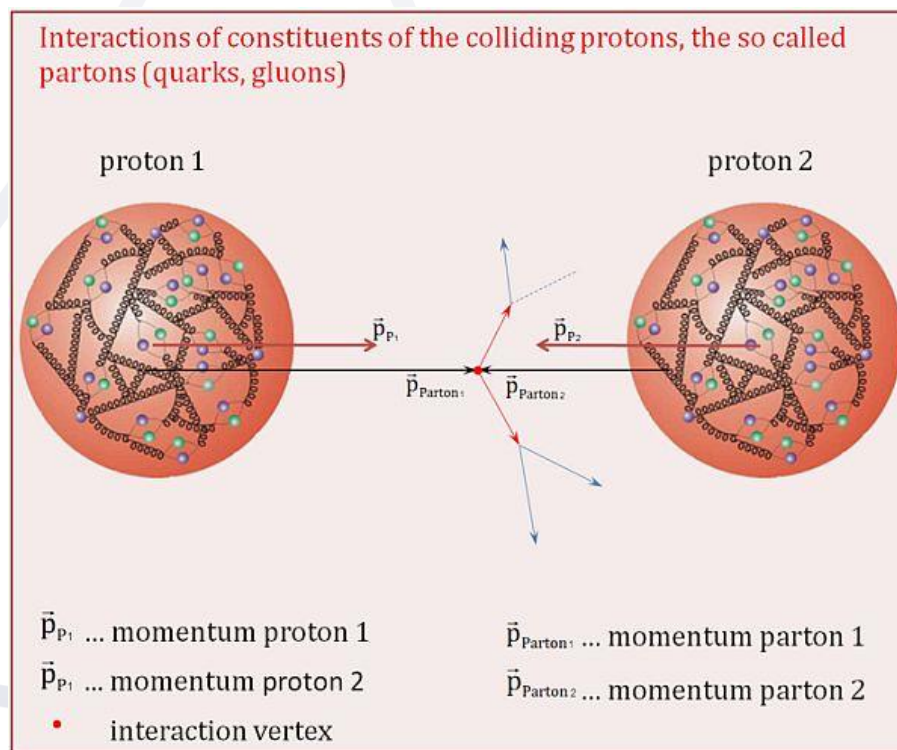
Trkalnik

- Veliki hadronski trkalnik – Large Hadron Collider (LHC) – največji trkalnik delcev na svetu
- Pospešimo in trkamo delce (protone)
- $E=mc^2$
Energija protonov se lahko spremeni tudi v maso novonastalih delcev

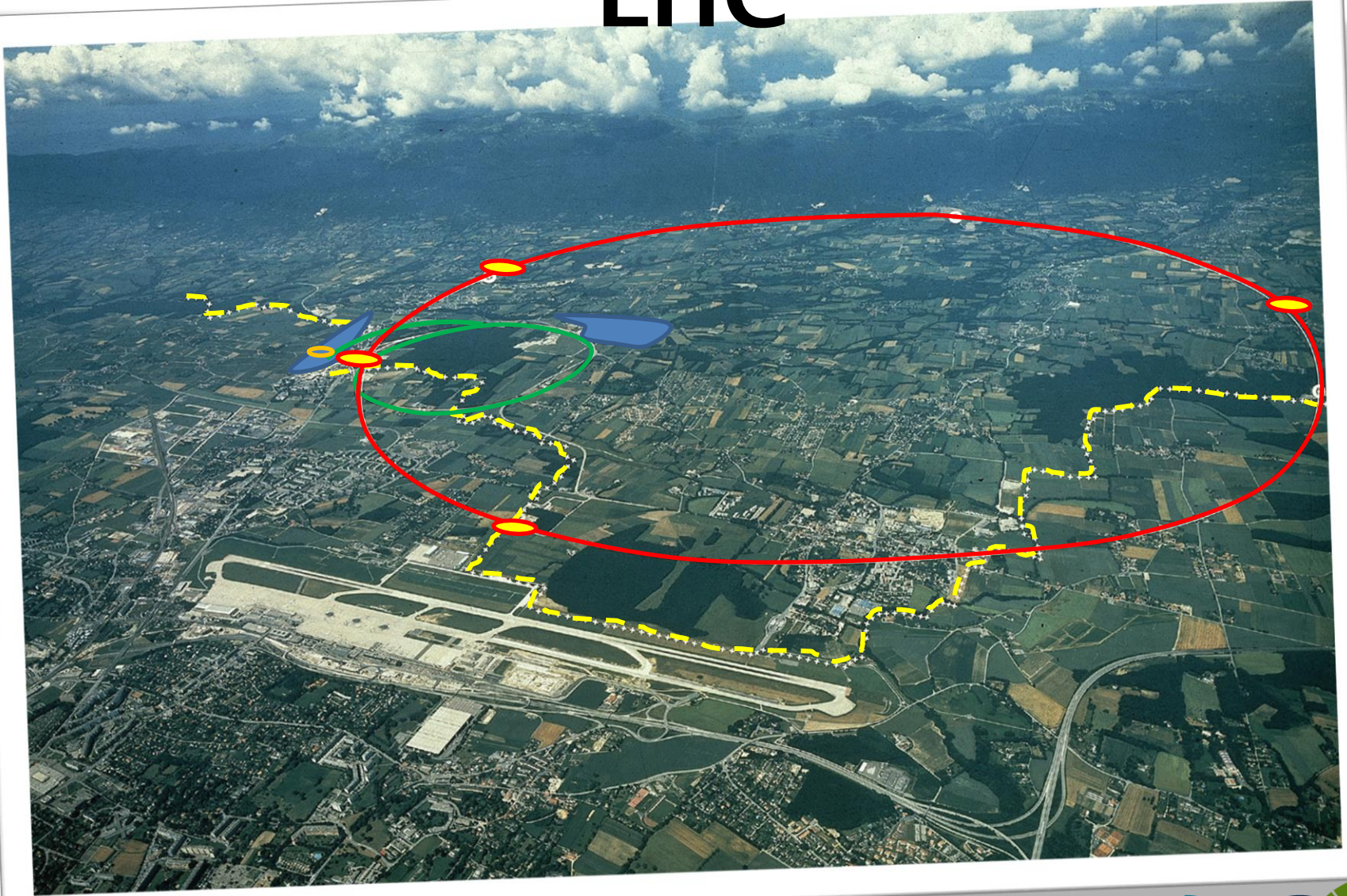


Trk dveh protonov

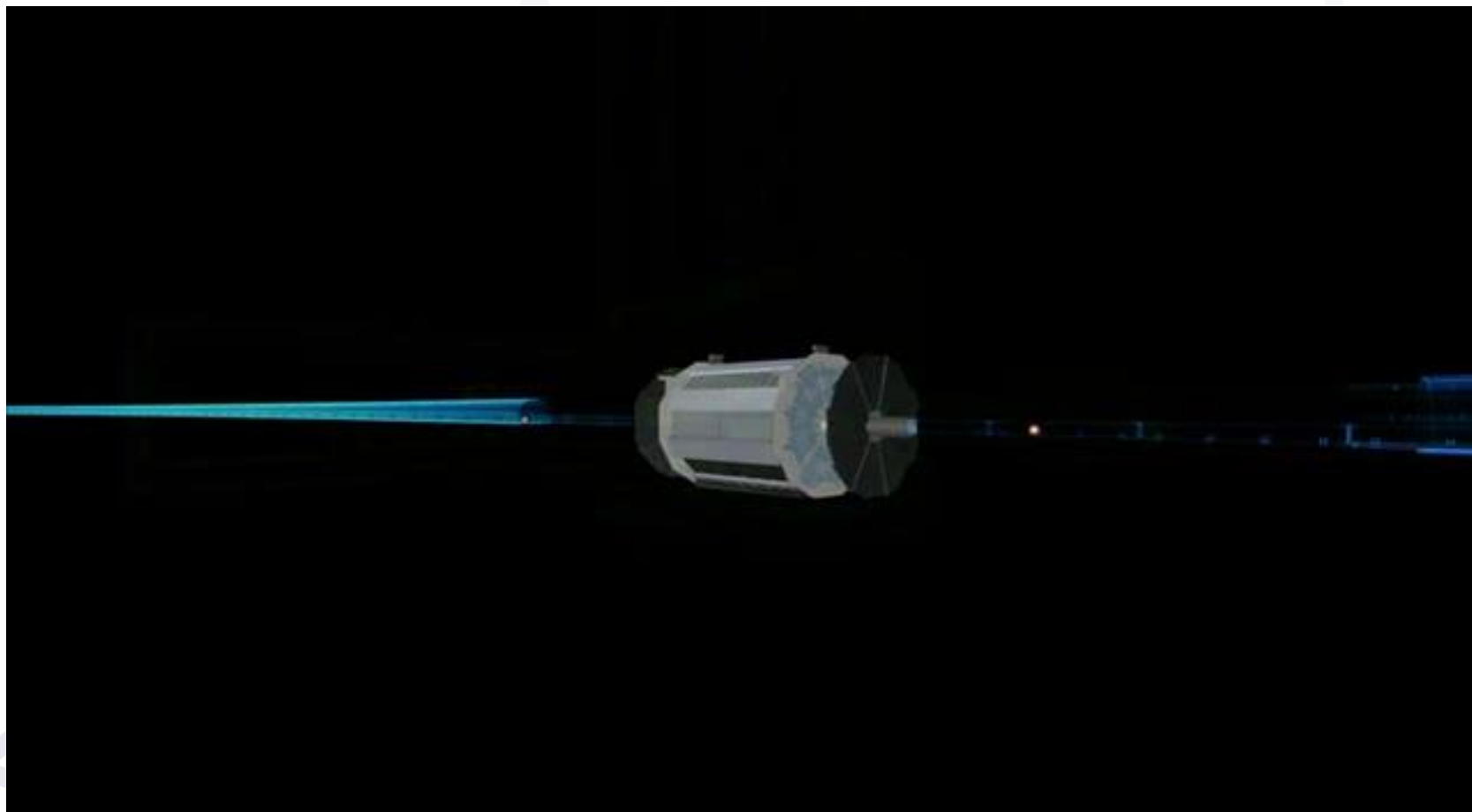
- protoni so sestavljeni iz kvarkov in gluonov
- valenčni in “morski” kvarki (sea quarks)



LHC



Pri neverjetnih energijah



Pri neverjetnih energijah

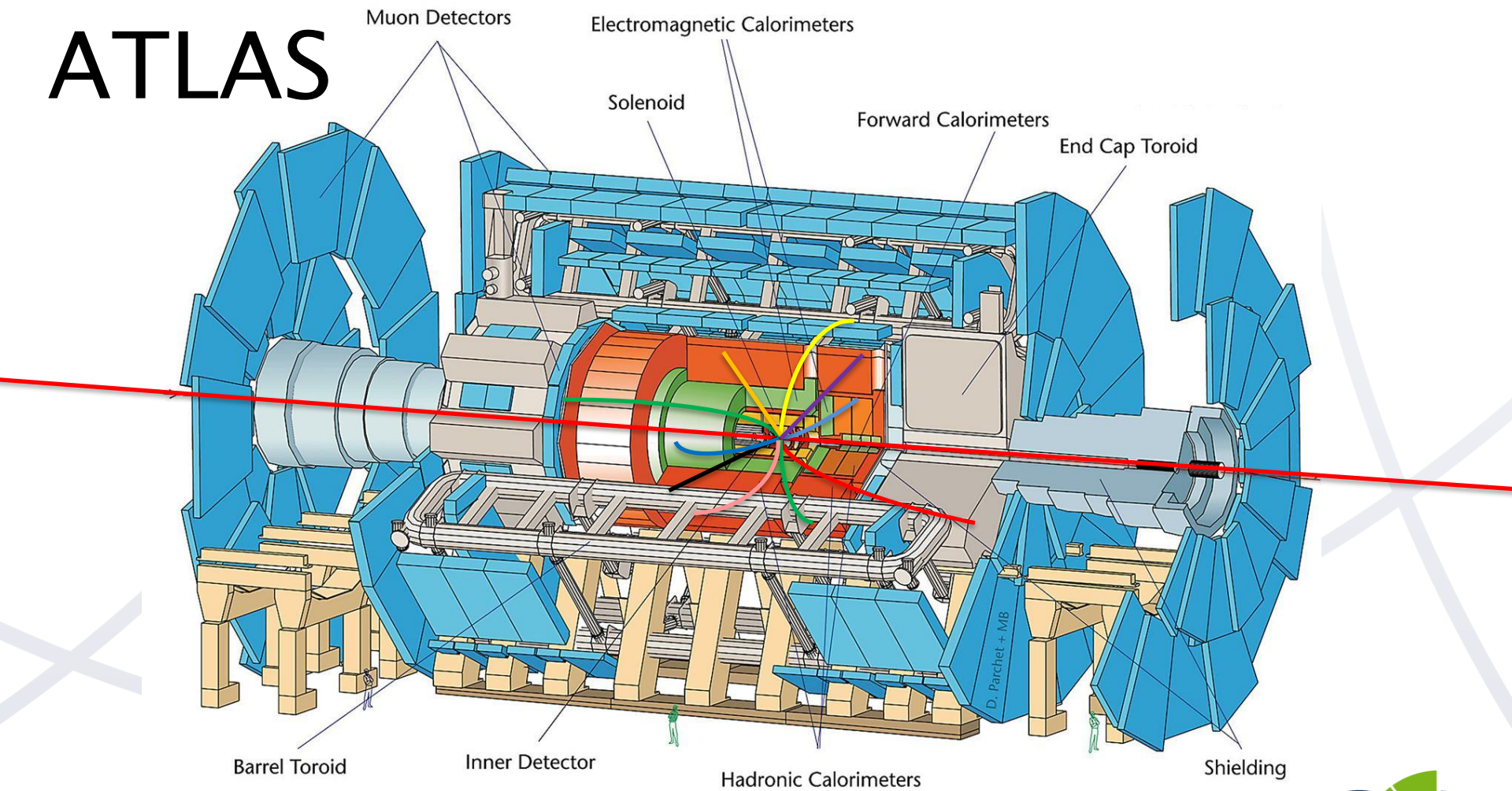
7 TeV+7 TeV



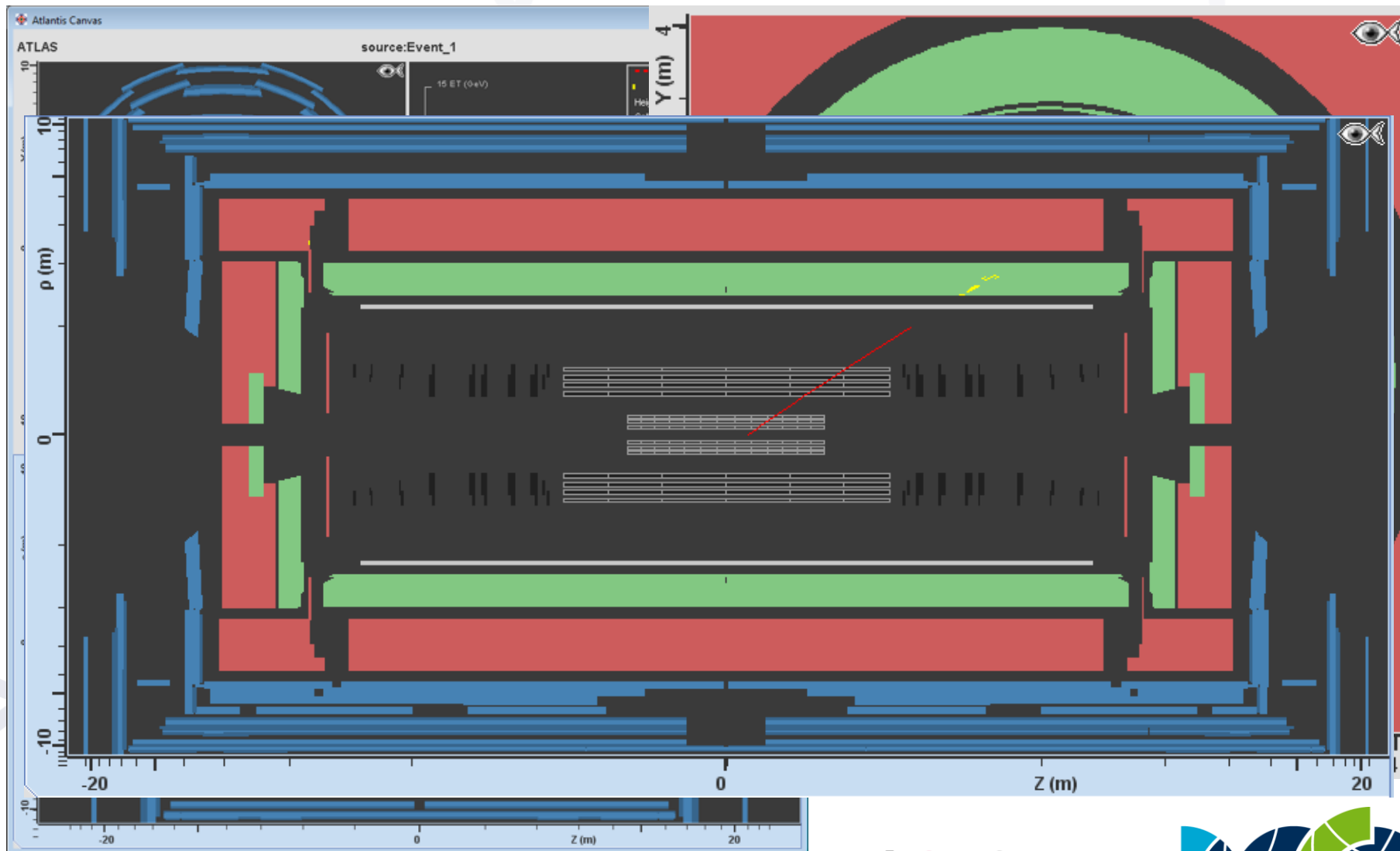
- Odrasla komarčica z maso ~ 2 miligrama
- $7 \text{ TeV} = 11.2 \times 10^{-7} \text{ J}$
- $\frac{1}{2} m v^2 = 11.2 \times 10^{-7} \text{ J}$
- $v = 3.8 \text{ km/h}$

Kako vidimo delce?

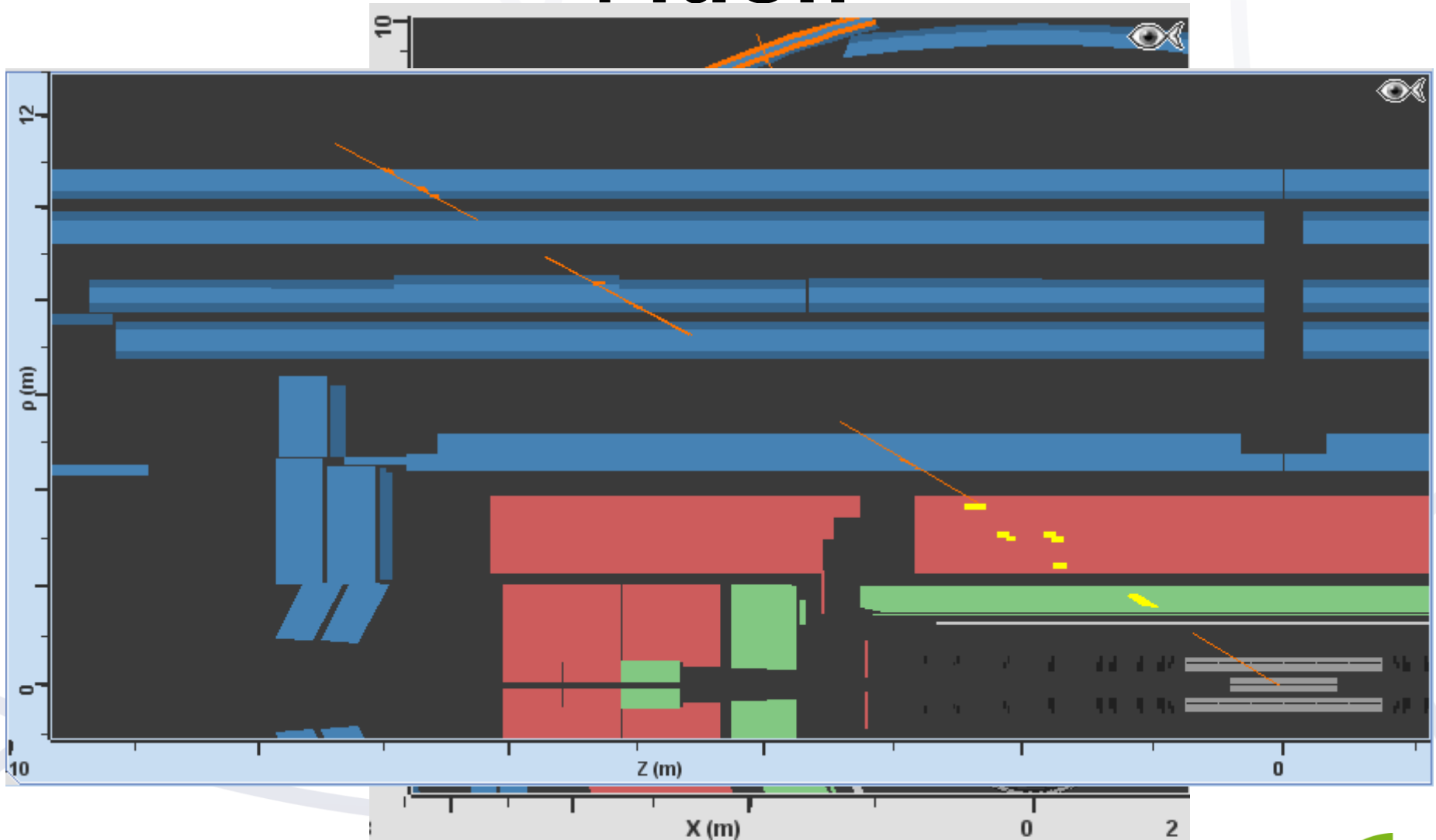
ATLAS



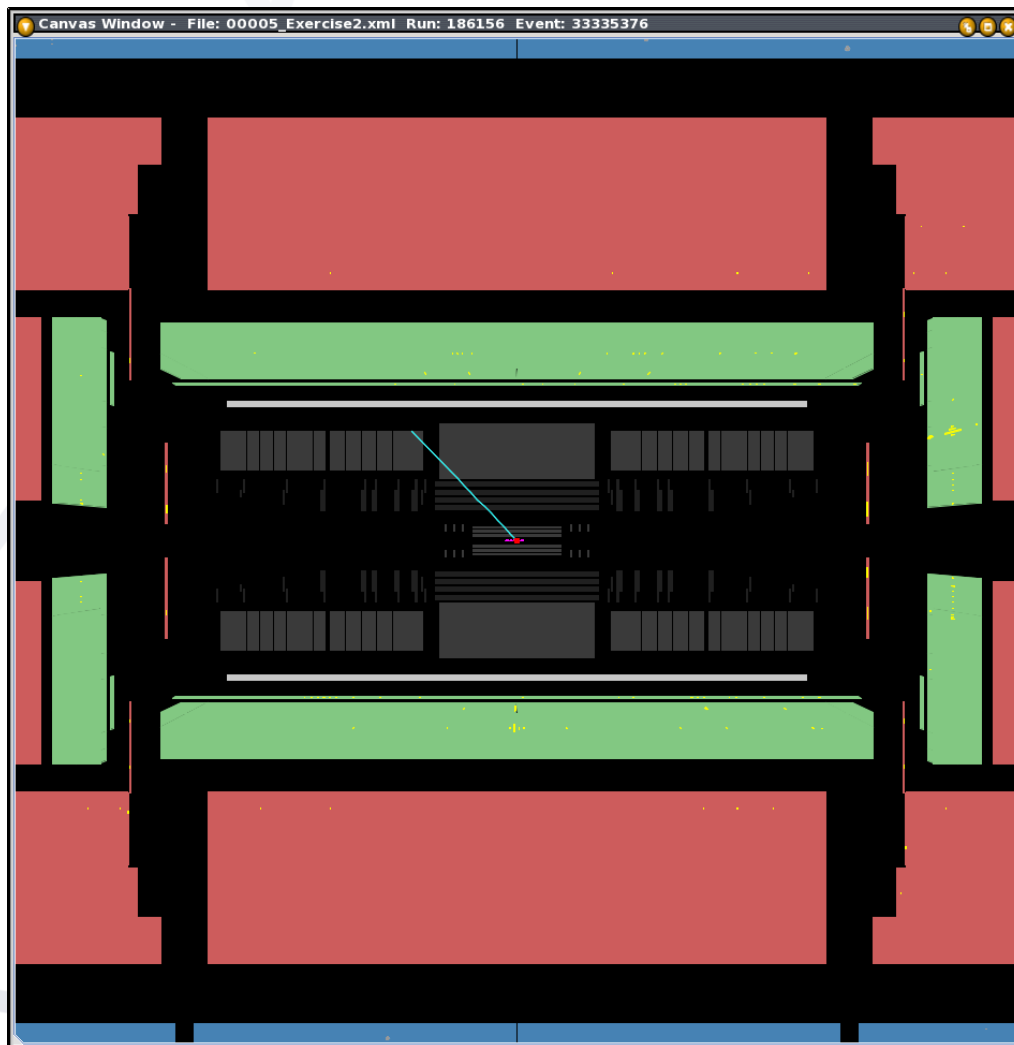
Elektron



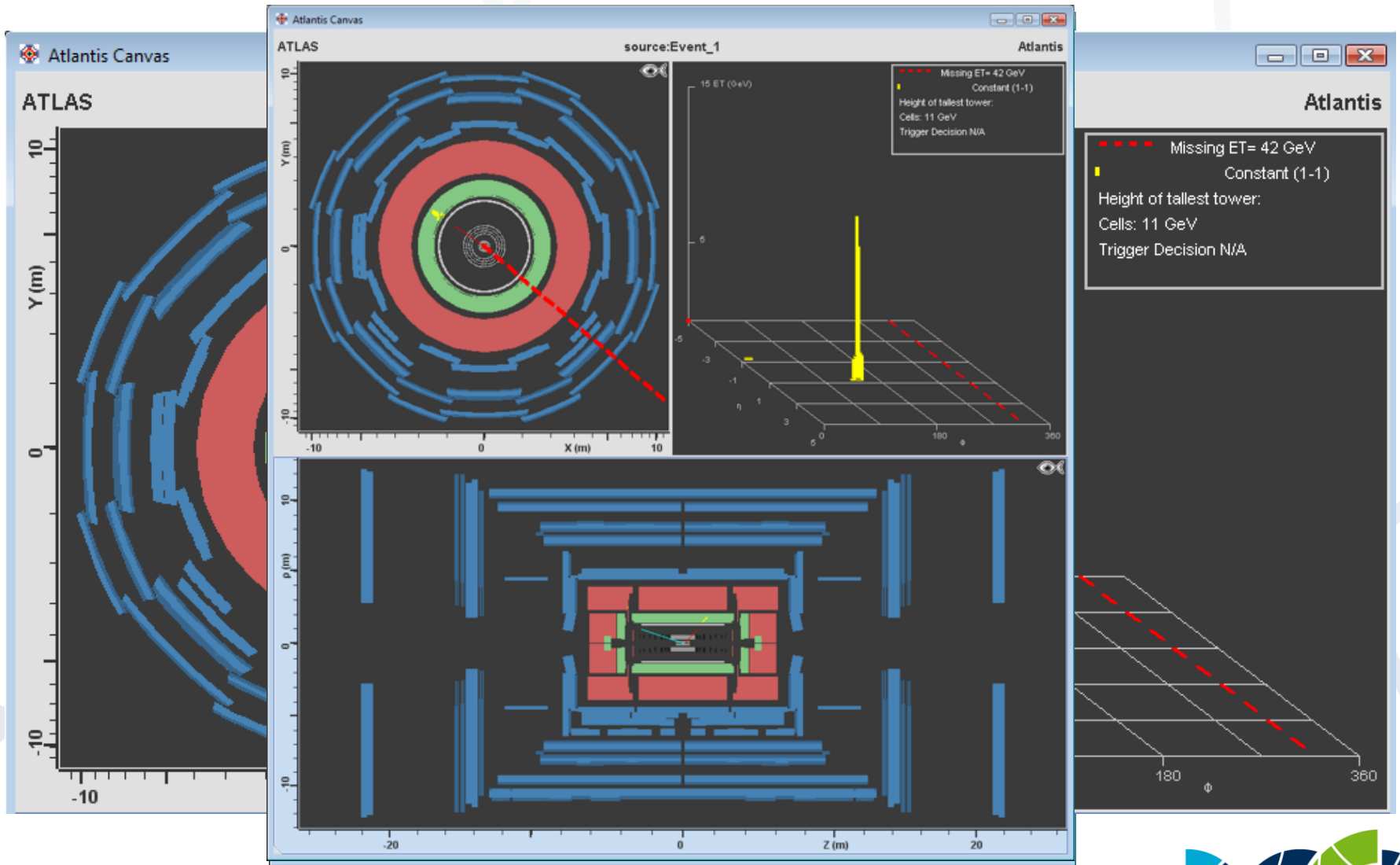
Muon



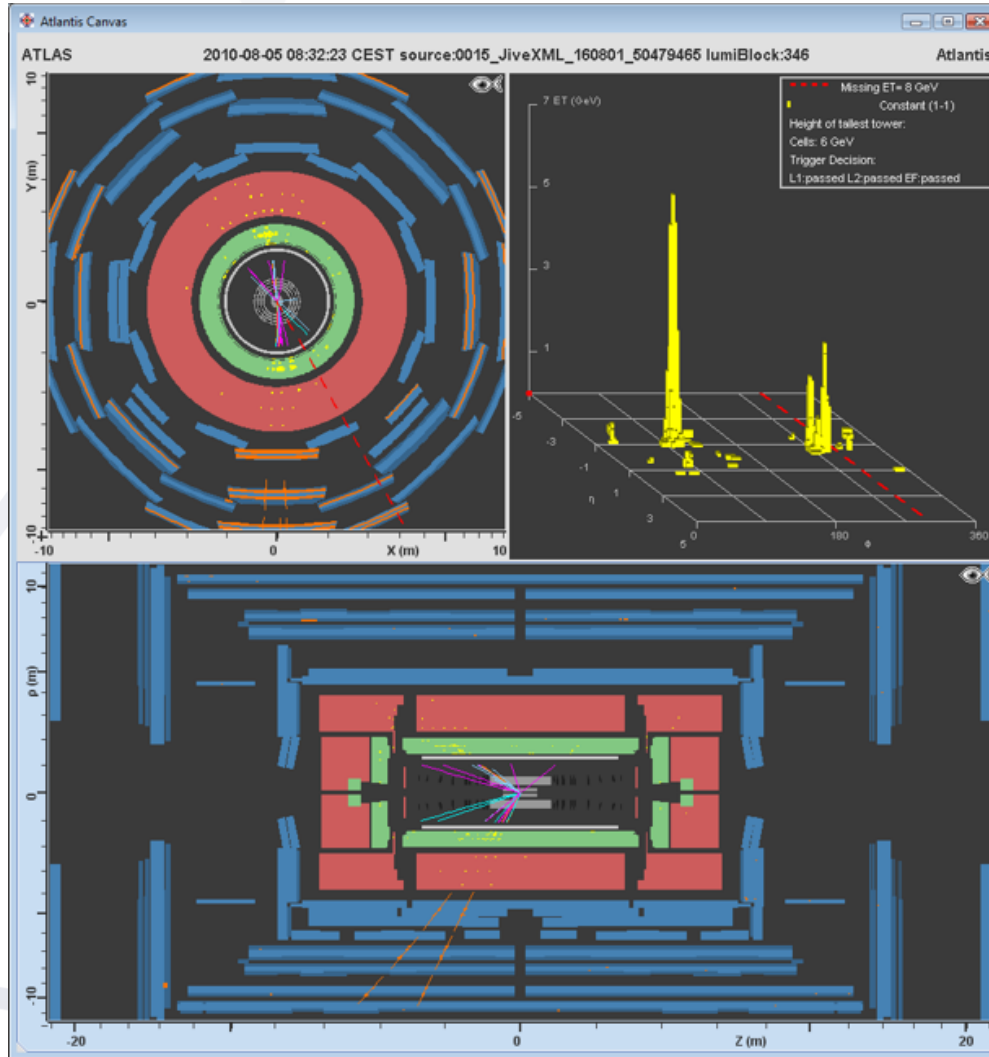
Foton



Neutrino



Pljuski (jets)



Merjenje energije

- elektron-volt eV
- $1\text{ eV} = 1.6 \cdot 10^{-19}\text{ J}$
- $1\text{ MeV} = 1000000\text{ eV} = 10^6\text{ eV}$
- $1\text{ GeV} = 1000000000\text{ eV} = 10^9\text{ eV}$
- $1\text{ TeV} = 1000000000000\text{ eV} = 10^{12}\text{ eV}$

$$14\text{ TeV} = 14 \cdot 10^{12}\text{ eV} = 14 \cdot 10^{12} \cdot 1,602 \cdot 10^{-19}\text{ J}$$

$$14\text{ TeV} = \underbrace{14 \cdot 1,602}_{=22,428} \cdot \underbrace{10^{12} \cdot 10^{-19}}_{=10^{12+(-19)}=10^{-7}}\text{ J}$$

$$14\text{ TeV} = 2,243 \cdot 10^{-6}\text{ J}$$

$$1\text{ J} = \frac{1\text{ eV}}{1,602 \cdot 10^{-19}} = 6,242 \cdot 10^{18}\text{ eV} = 6,242 \cdot 10^3\text{ PeV}$$

Gibalna količina

- klasično:
 $\mathbf{p} = m \mathbf{v}$
- v LHC trkih nastanejo delci z zelo velikimi hitrostmi (blizu svetlobne c)
- 7TeV protoni imajo $v=0,9999999991c$
- moramo uporabiti relativistične enačbe

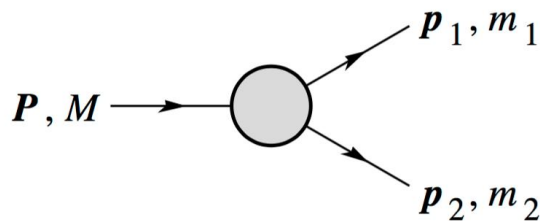
$$E = \sqrt{(\vec{p} \cdot c)^2 + (m_0 \cdot c^2)^2}$$

$$p = \sqrt{\left(\frac{E}{c}\right)^2 - (m_0 \cdot c)^2}$$

- četverec gibalne količine:
 $p^\mu = (E/c, \mathbf{p})$

Masa

- Invariantna masa:
 $m_0 = ((E/c^2)^2 - (p/c)^2)^{1/2}$
- Razpad v dva delca



- Gibelna količina se ohranja

- npr. $Z \rightarrow e^+e^-$

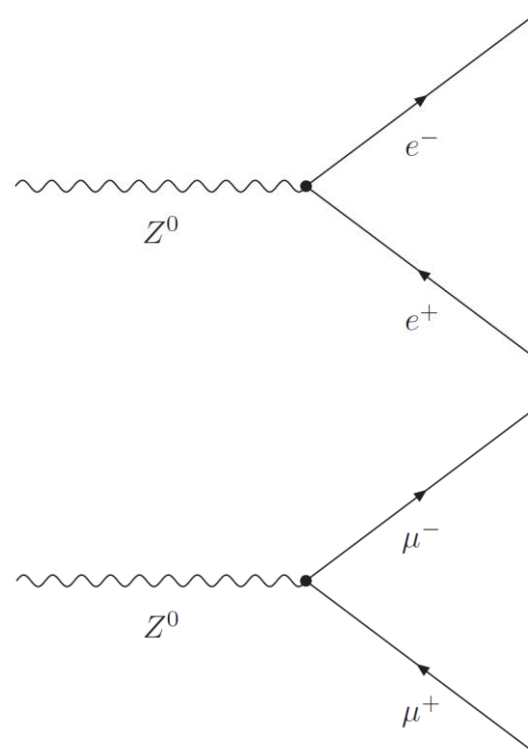
$$m_0^{(Z)} = \sqrt{\left(\frac{(E_{e^-} + E_{e^+})}{c^2}\right)^2 - \left(\frac{\vec{p}_{e^-} + \vec{p}_{e^+}}{c}\right)^2}$$

- Z merjenjem gibalnih količin razpadnih produktov lahko določimo invariantno maso razpadlega delca

Razpadi bozonov Z

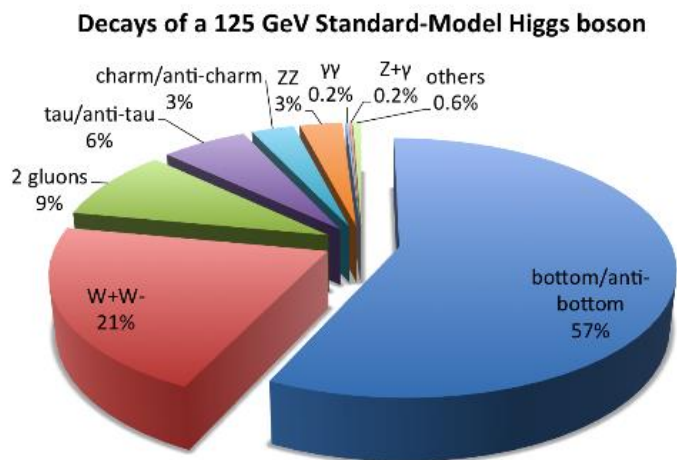
- Z živi samo $3 \cdot 10^{-25} \text{s}$
 $0.00000000000000000000000003 \text{s}$
- Nemogoče ga je direktno izmeriti
- Merimo njegov razpad (smrt)
- Z lahko razpade v 2 leptona ali 2 kvarka (24 različnih načinov)

- Mi bomo gledali razpade v elektrone in mione



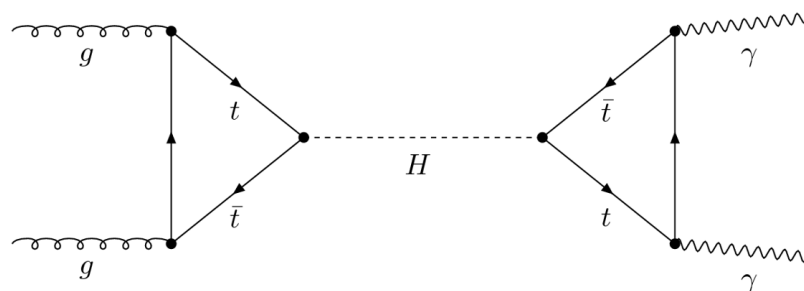
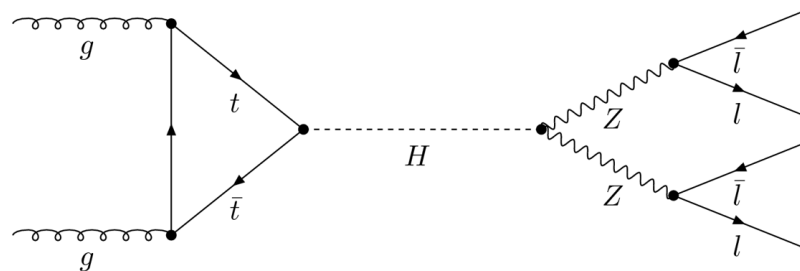
Razpadi Higgsovih bozonov

- 4. julij 2012
- Mnogo razpadnih načinov
- Samo nekateri “dobri” za meritve, ker se jih da izluščiti iz ozadja
- V ATLAS in CMS proučujemo razpade v
 - pare bozonov Z, ki razpadeta na 2 para leptonov
 - pare fotonov
 - pare bozonov W, ki razpadeta v 2 nabita leptona in 2 navtrina
 - 2 tauona



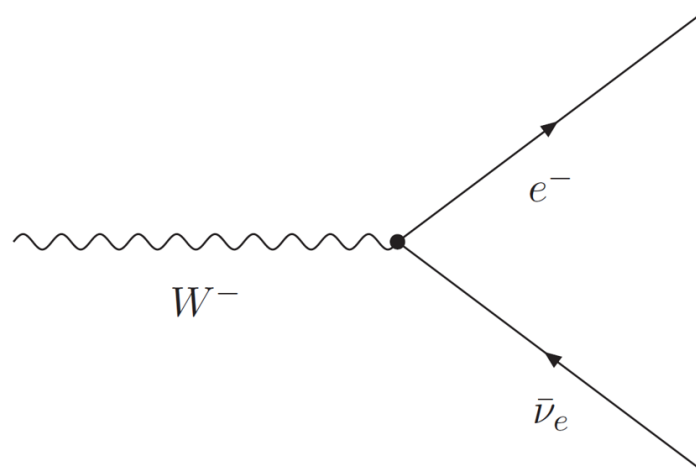
Razpadi Higgsovih bozonov

- V vajah popoldne bomo obravnavali samo “najlažje” razpade v:
 - ZZ
 - $\gamma\gamma$



Ozadje

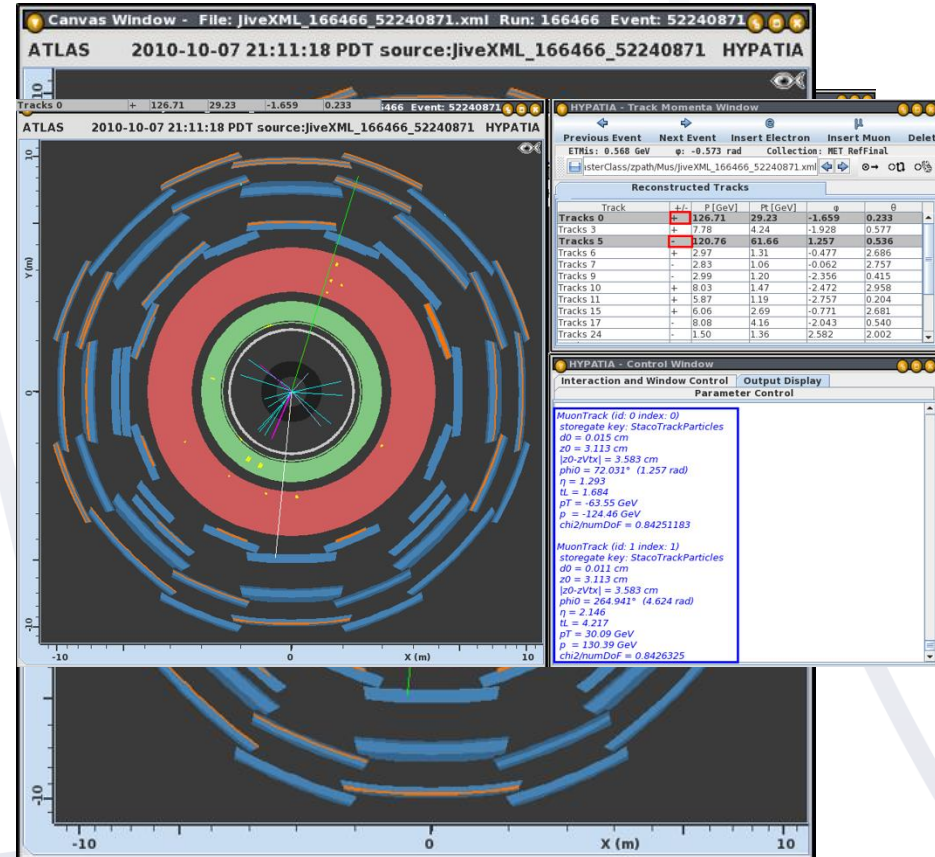
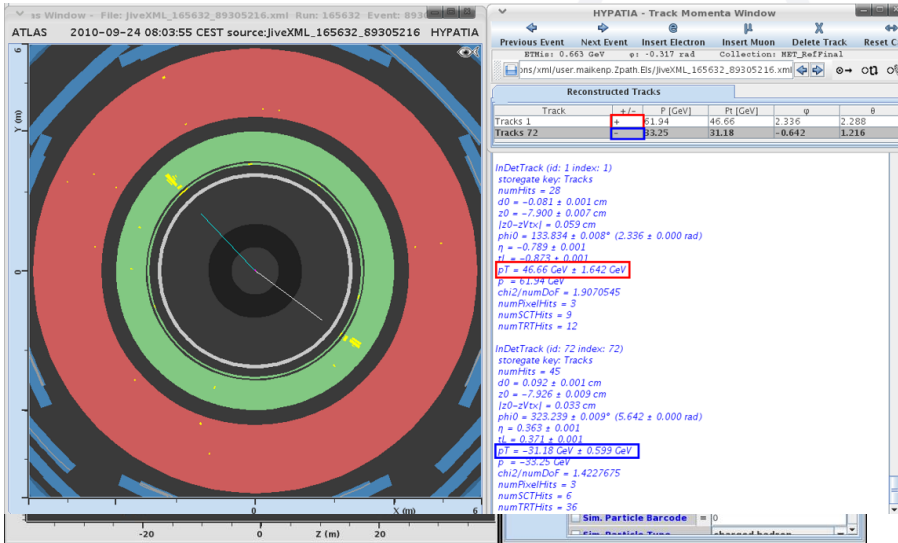
- V trkih protonov nastane ogromno različnih delcev
- Dogodke, ki lahko izgledajo podobno kot signal, imenujemo ozadje
- Pri razpadu W tudi nastane elektron ali pozitron z veliko gibalo količino



Vizualizacija

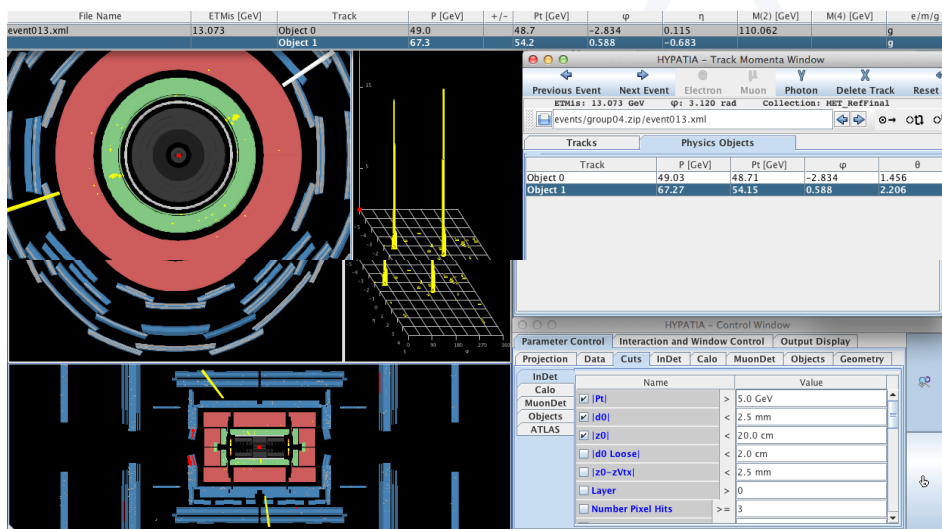
- $Z \rightarrow e^- + e^+$

- $Z \rightarrow \mu^- + \mu^+$

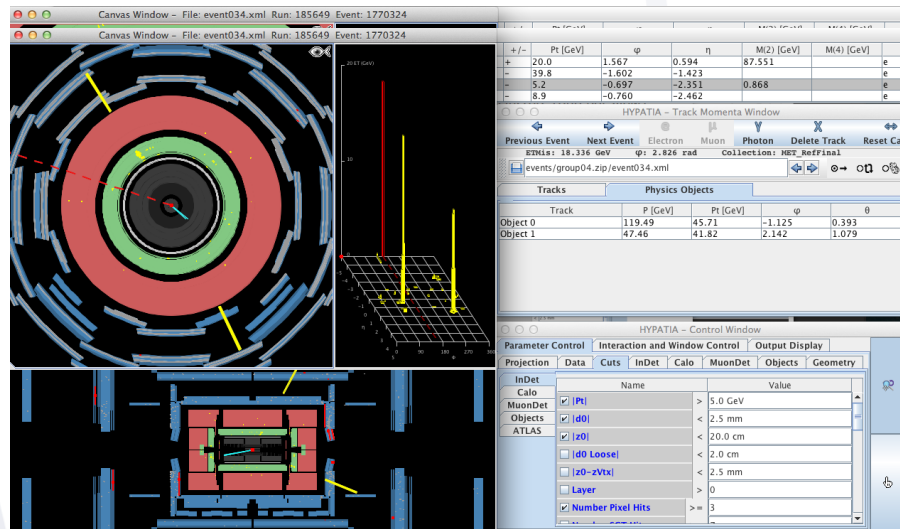


Vizualizacija

• $\Upsilon\Upsilon$



• $\Upsilon\Upsilon$



Vizualizacija

- $ZZ \rightarrow \mu\mu ee$

- $ZZ \rightarrow eeee$

