

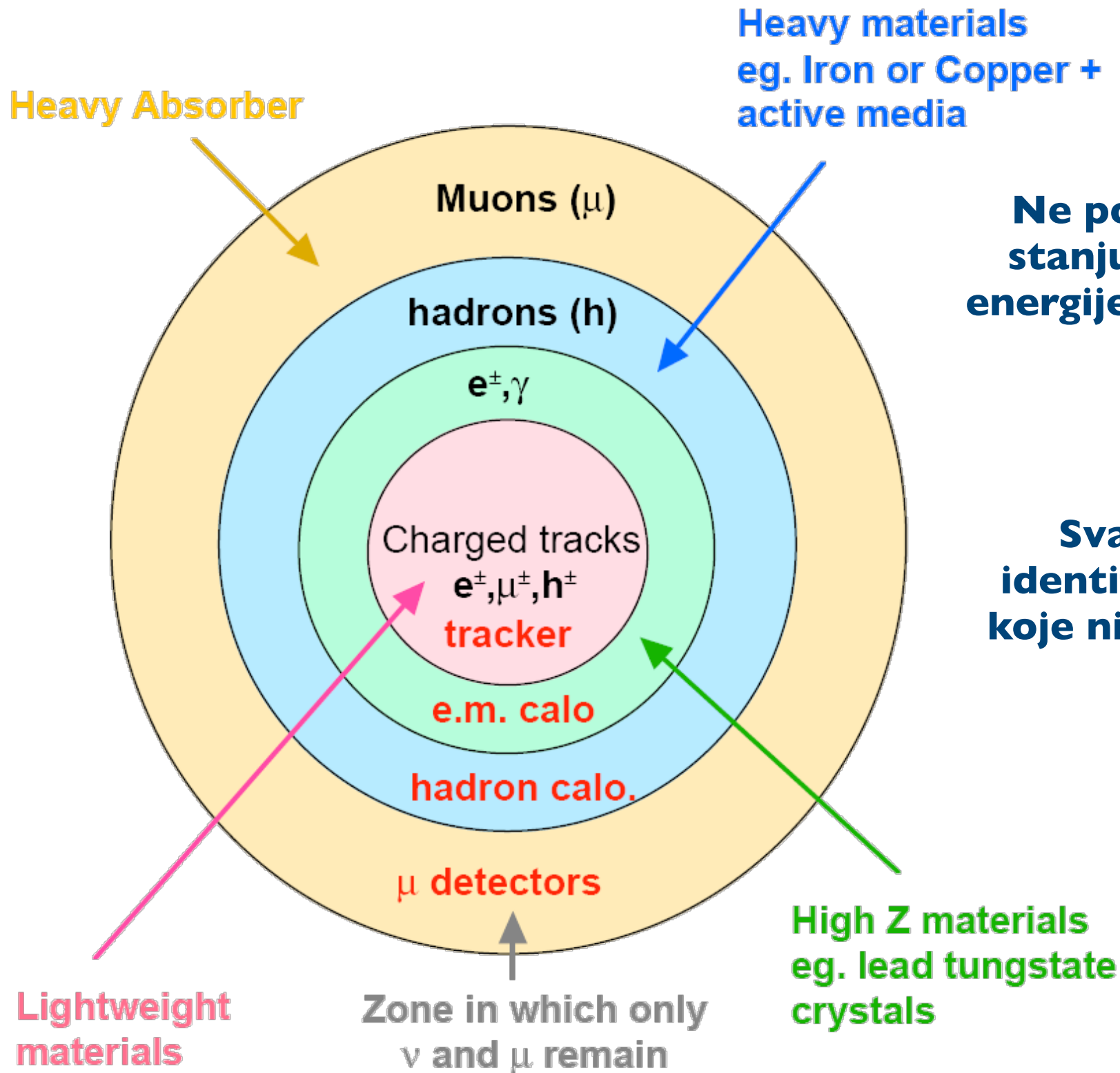
Detekcija elementarnih čestica i analiza događaja

Physics Masterclasses program u Srbiji

J. Jovičević (Institut za fiziku u Beogradu)

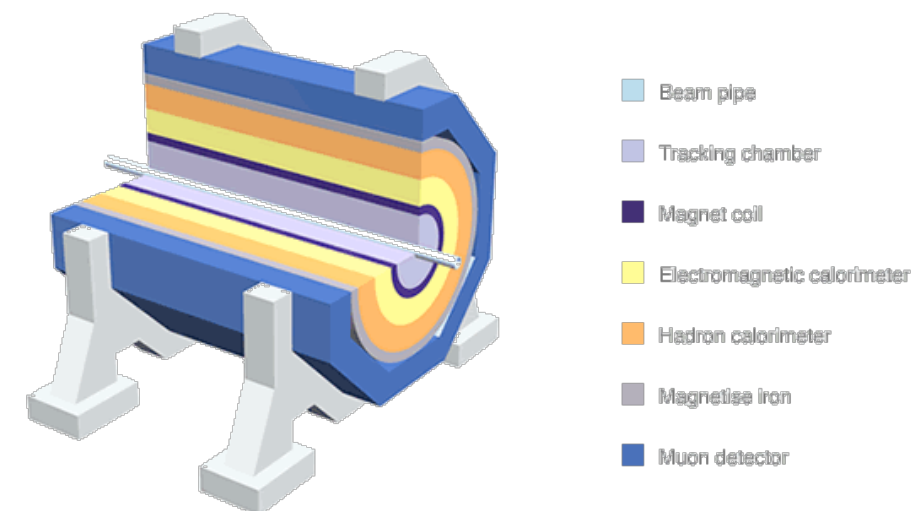


Struktura detektora u HEP



Ne postoji sloj-detektor koji je u stanju da efikasno odredi i izmeri energije/impulse svih čestica nastalih u nekom događaju

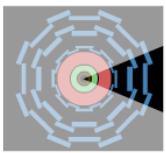
Svaki naredni sloj detektora identifikuje i meri energiju čestica koje nisu detektovane i izmerene u prethodnim slojevima



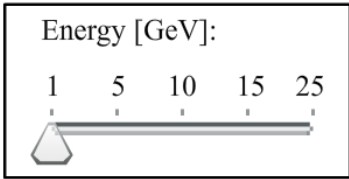
Detekcija elektrona

ATLAS

animation

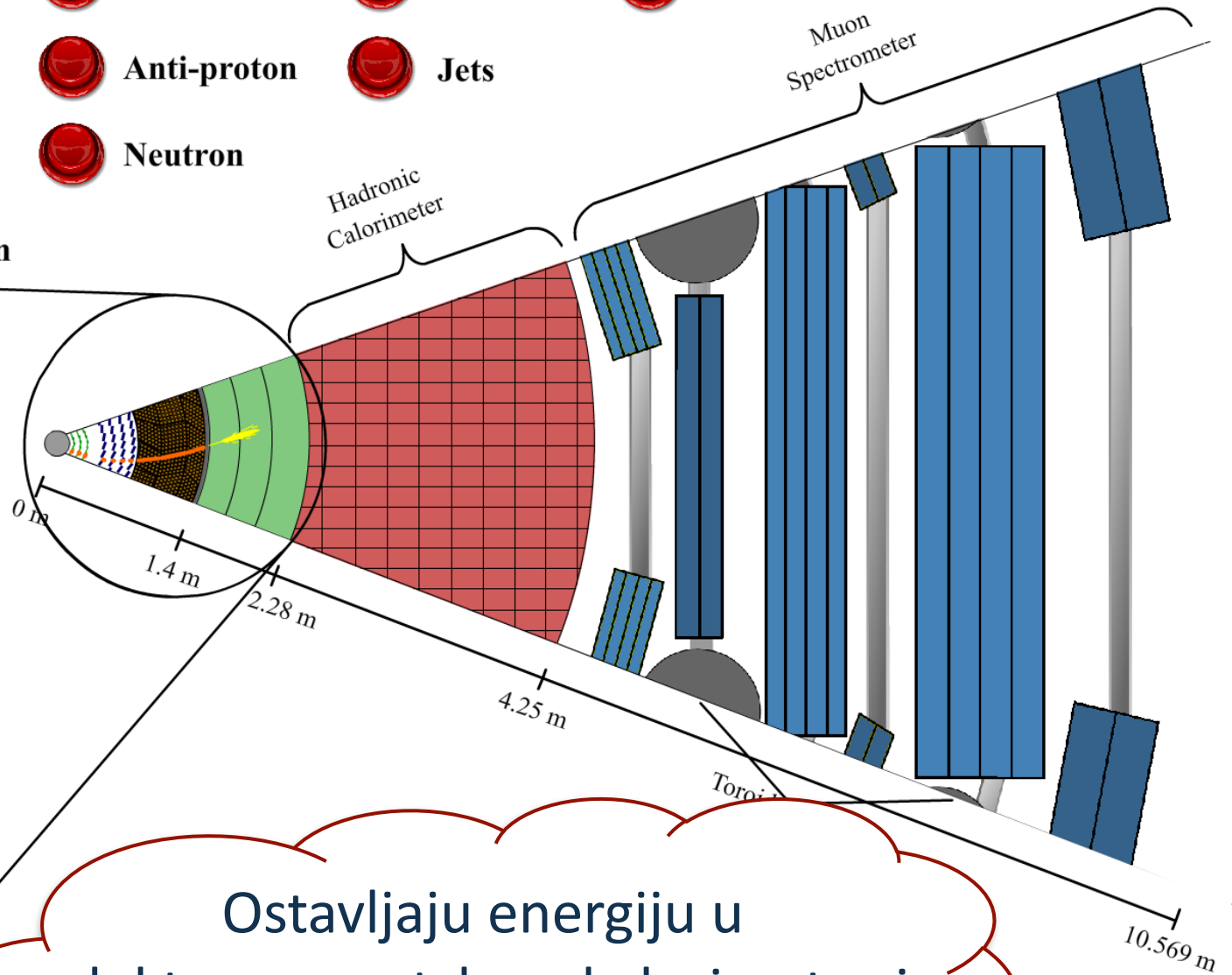
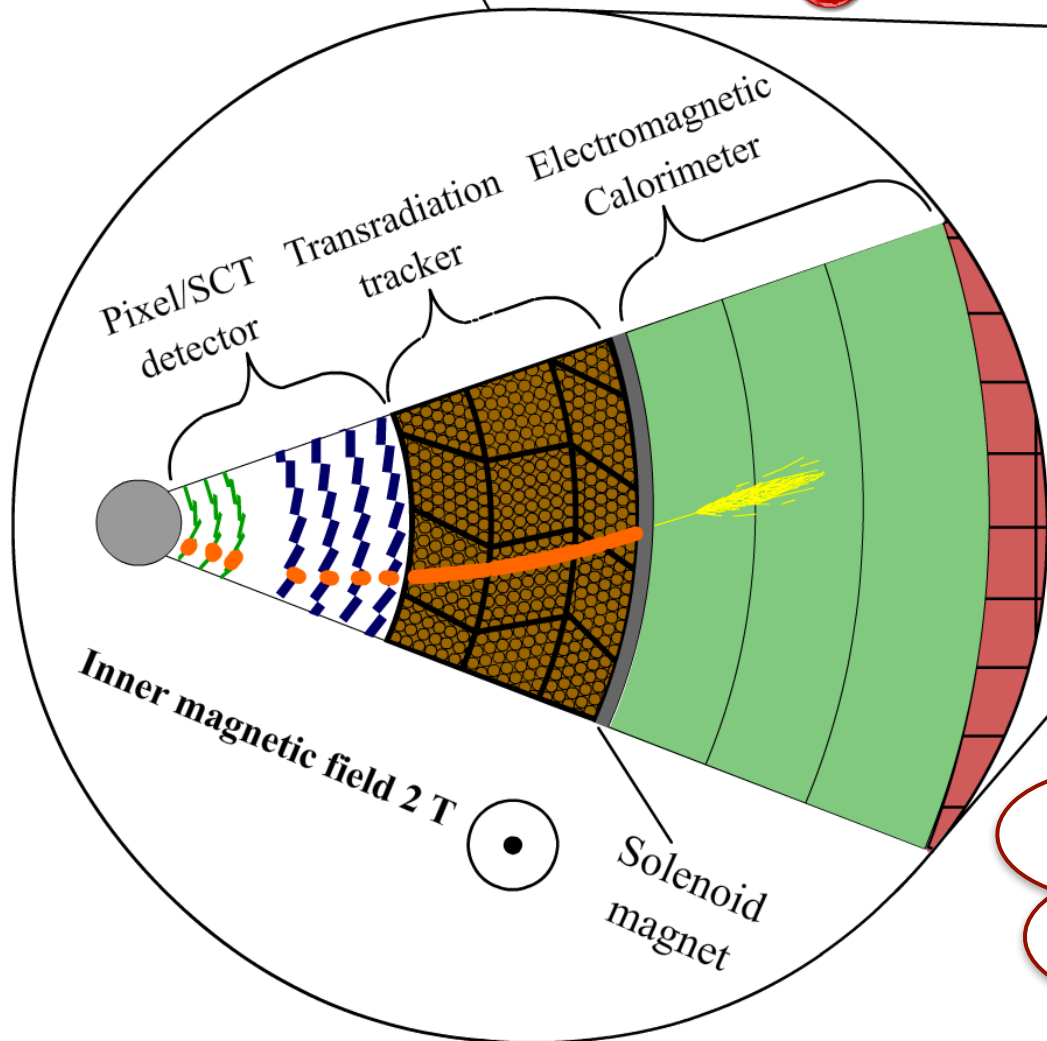


display instantly



- Electron
- Proton
- Neutrino
- Photon
- Positron
- Anti-proton
- Jets
- Muon
- Neutron
- Anti-muon

Magnification 3x



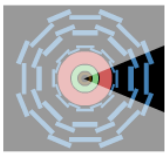
Ostavljaju energiju u elektromagnetskom kalorimetru i tragove u tracker-u

Created by T. Herrmann, O. Jeřábek, K. Jende, M. Kobel

Detekcija pozitrona

ATLAS

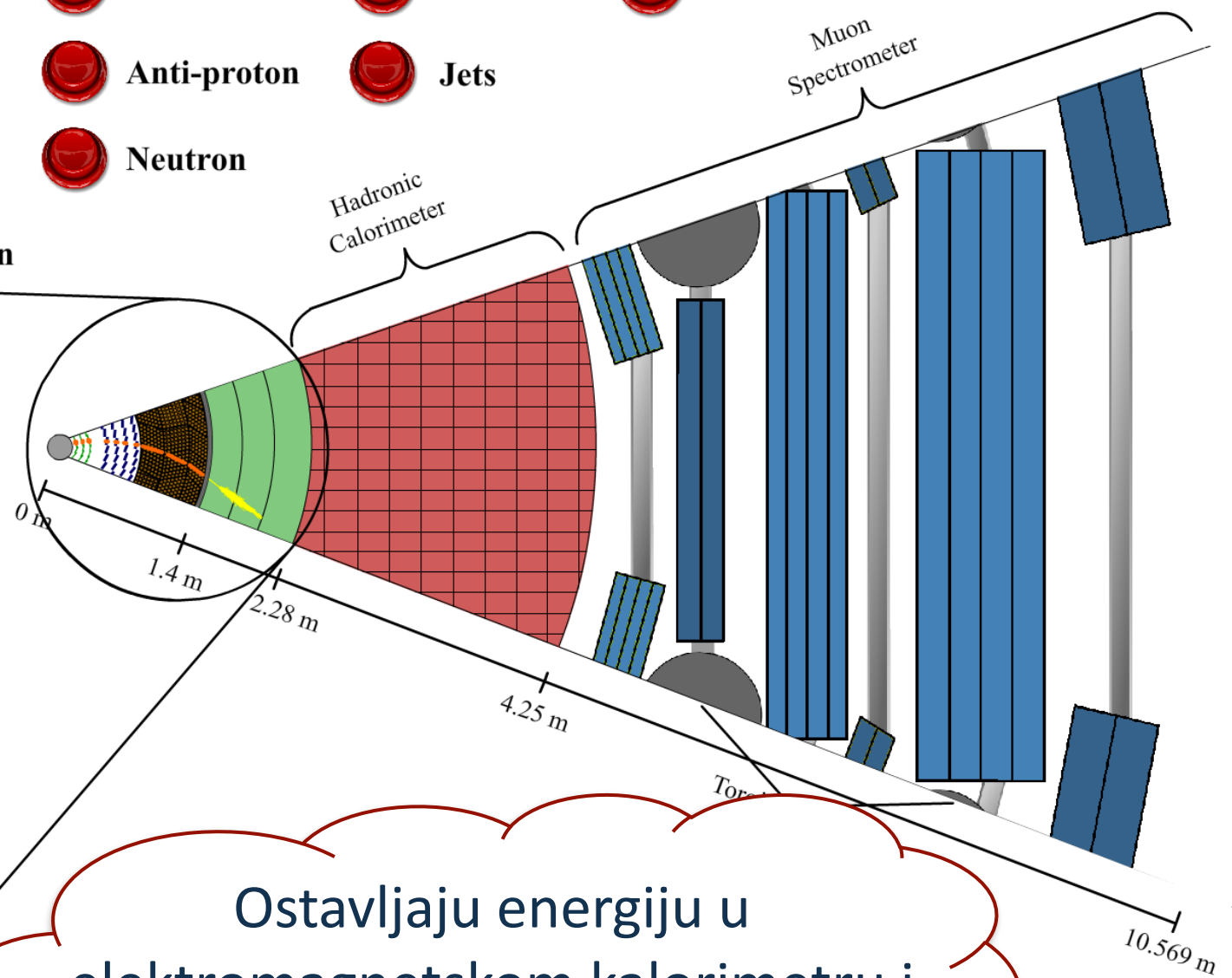
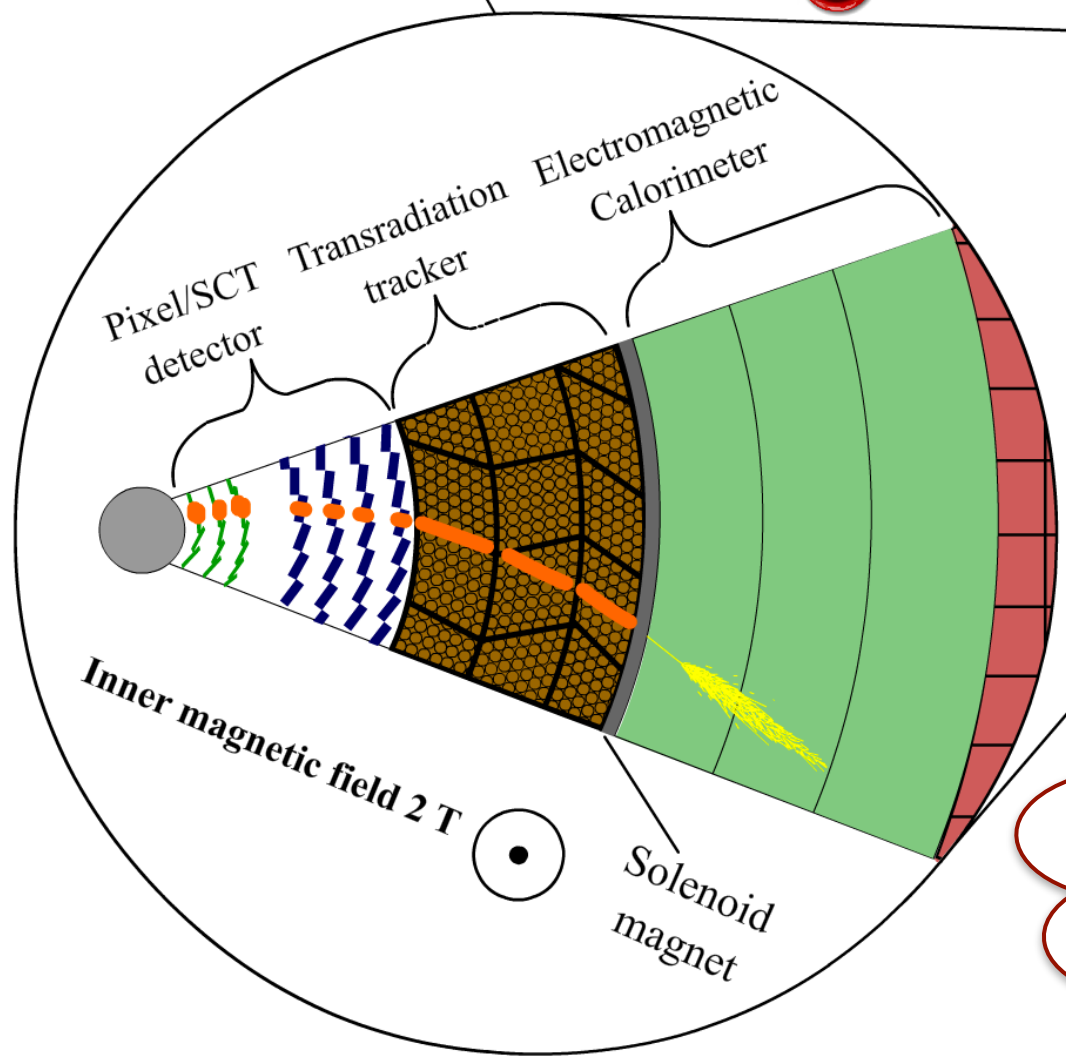
animation



display instantly

- Electron
- Proton
- Neutrino
- Photon
- Positron
- Anti-proton
- Jets
- Muon
- Neutron
- Anti-muon

Magnification 3x



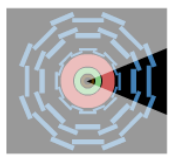
Ostavljaju energiju u elektromagnetskom kalorimetru i tragove u tracker-u

Created by T. Herrmann, O. Jeřábek, K. Jende, M. Kobel

Detekcija fotona

ATLAS

animation



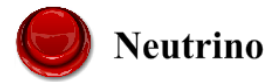
display instantly



Electron



Proton



Neutrino



Photon



Positron



Anti-proton



Jets



Muon

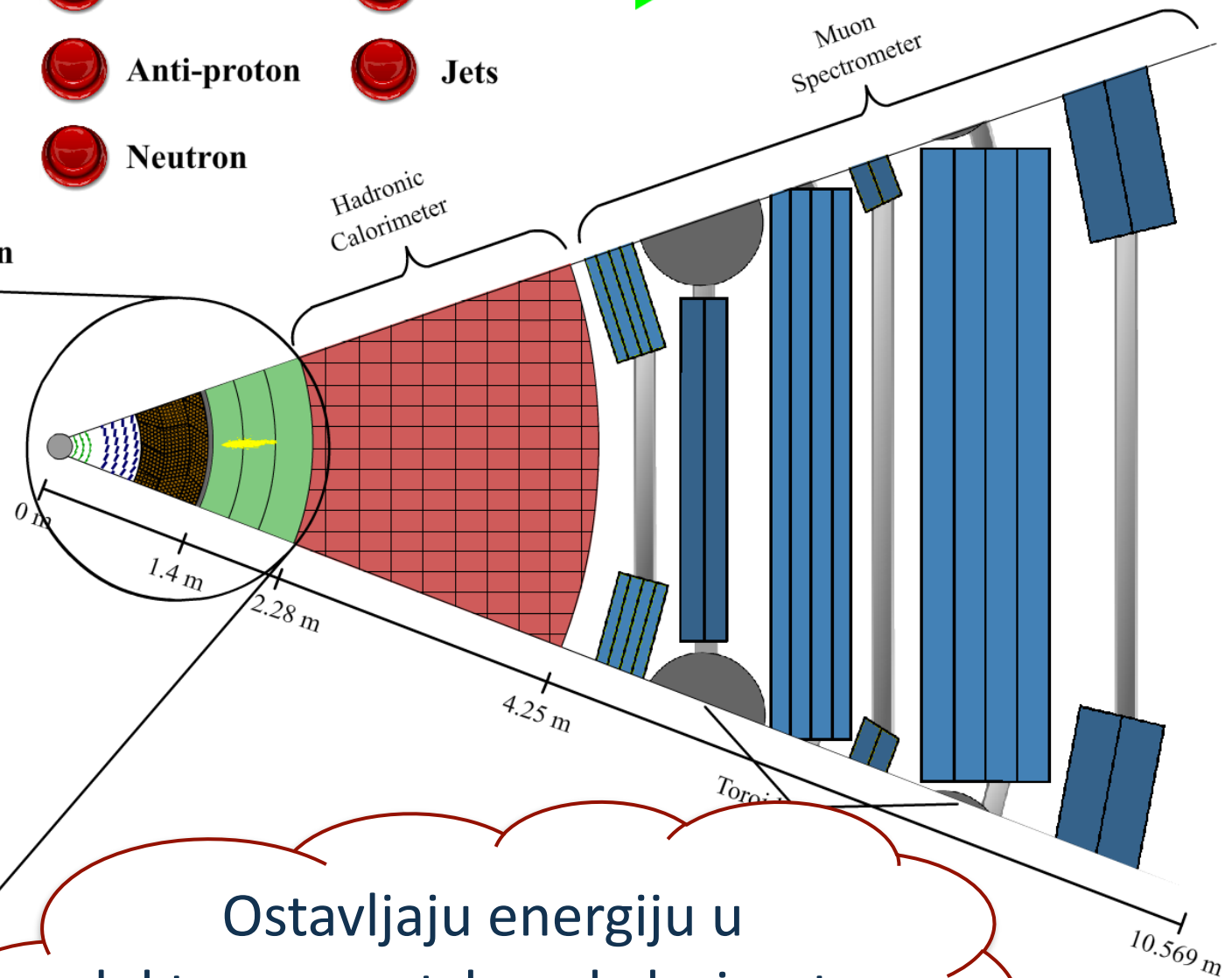
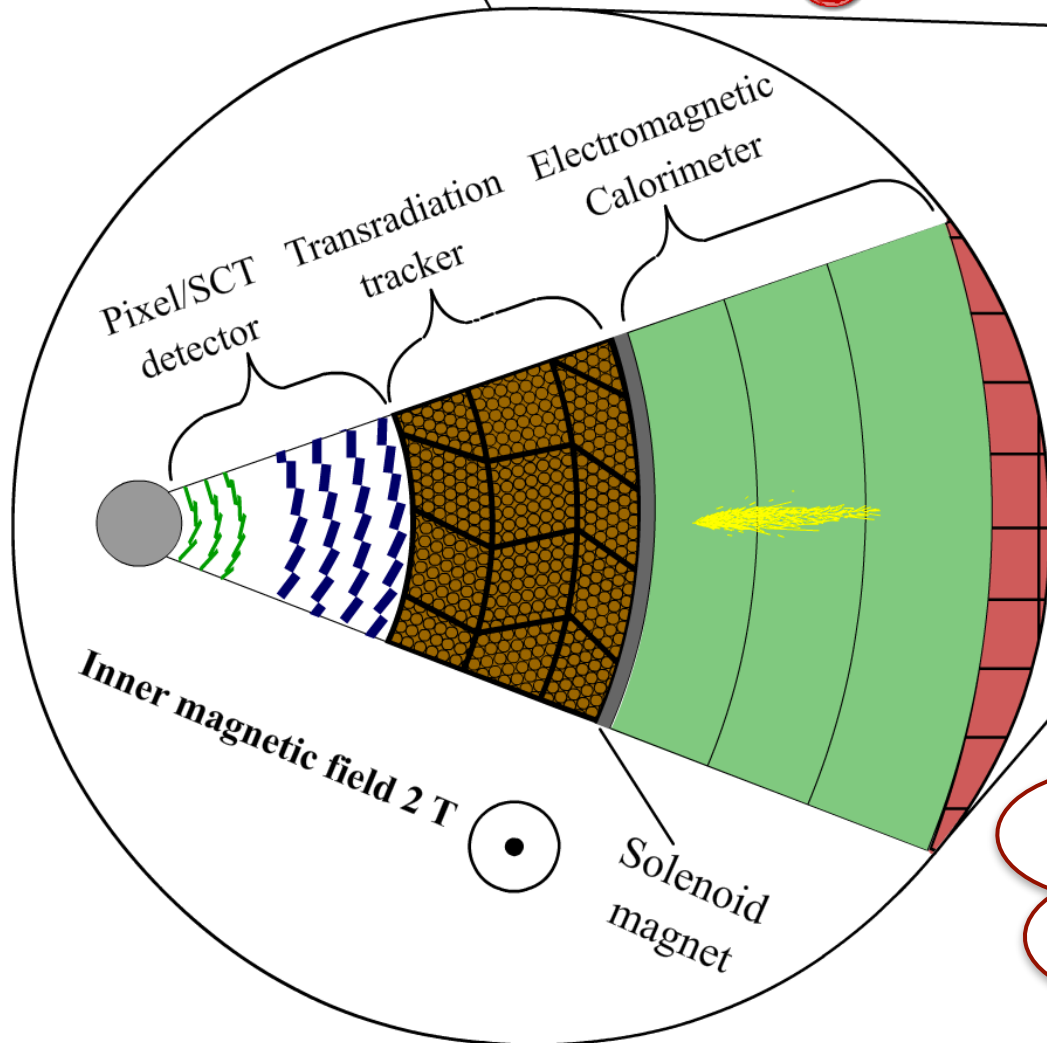


Neutron



Anti-muon

Magnification 3x



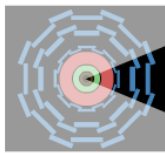
Ostavljaju energiju u elektromagnetskom kalorimetru, bez tragova u tracker-u

Created by T. Herrmann, O. Jeřábek, K. Jende, M. Kobel

Detekcija naelektrisanih hadrona

ATLAS

animation



display instantly



Electron



Proton



Neutrino



Photon



Positron



Anti-proton



Jets



Muon

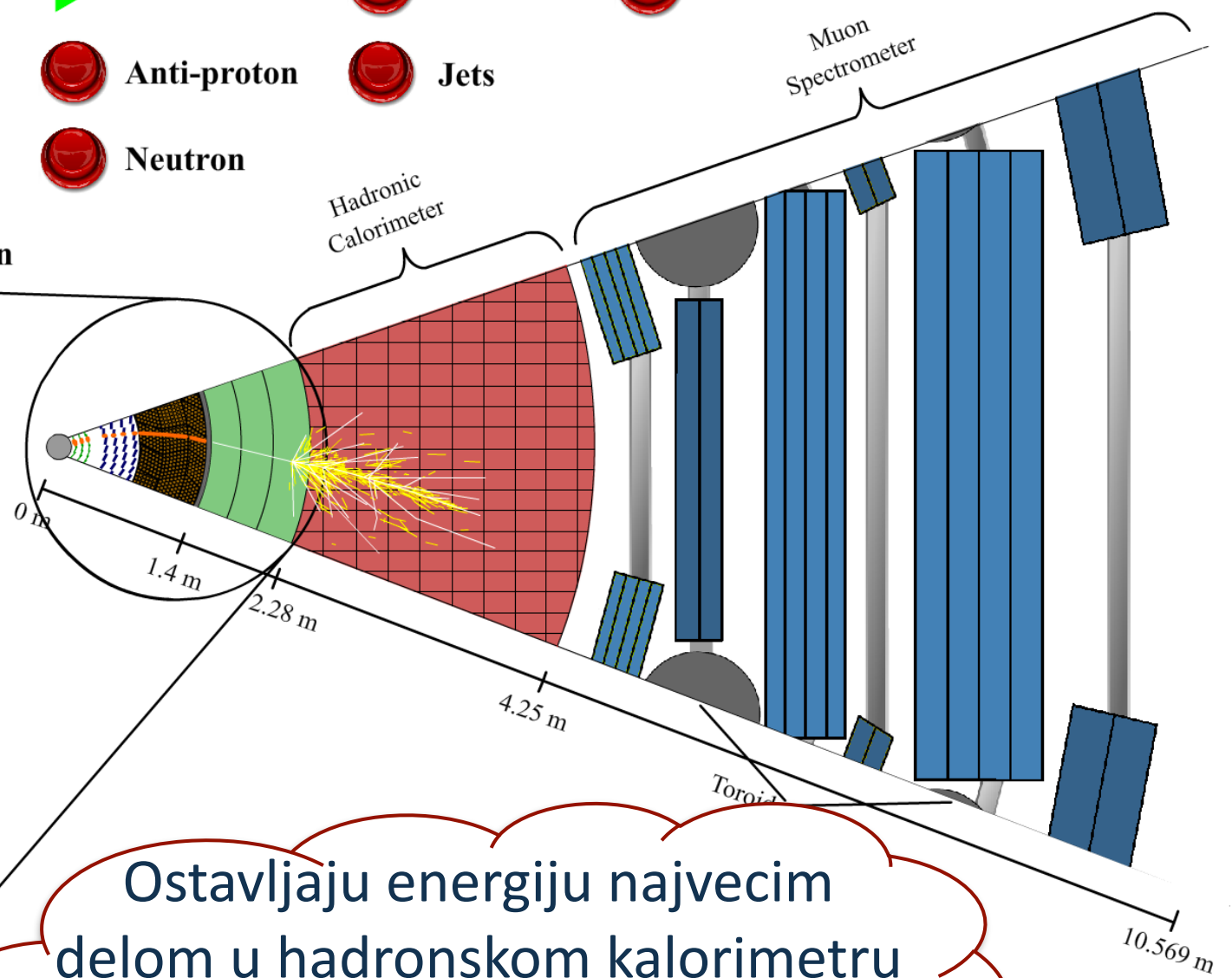
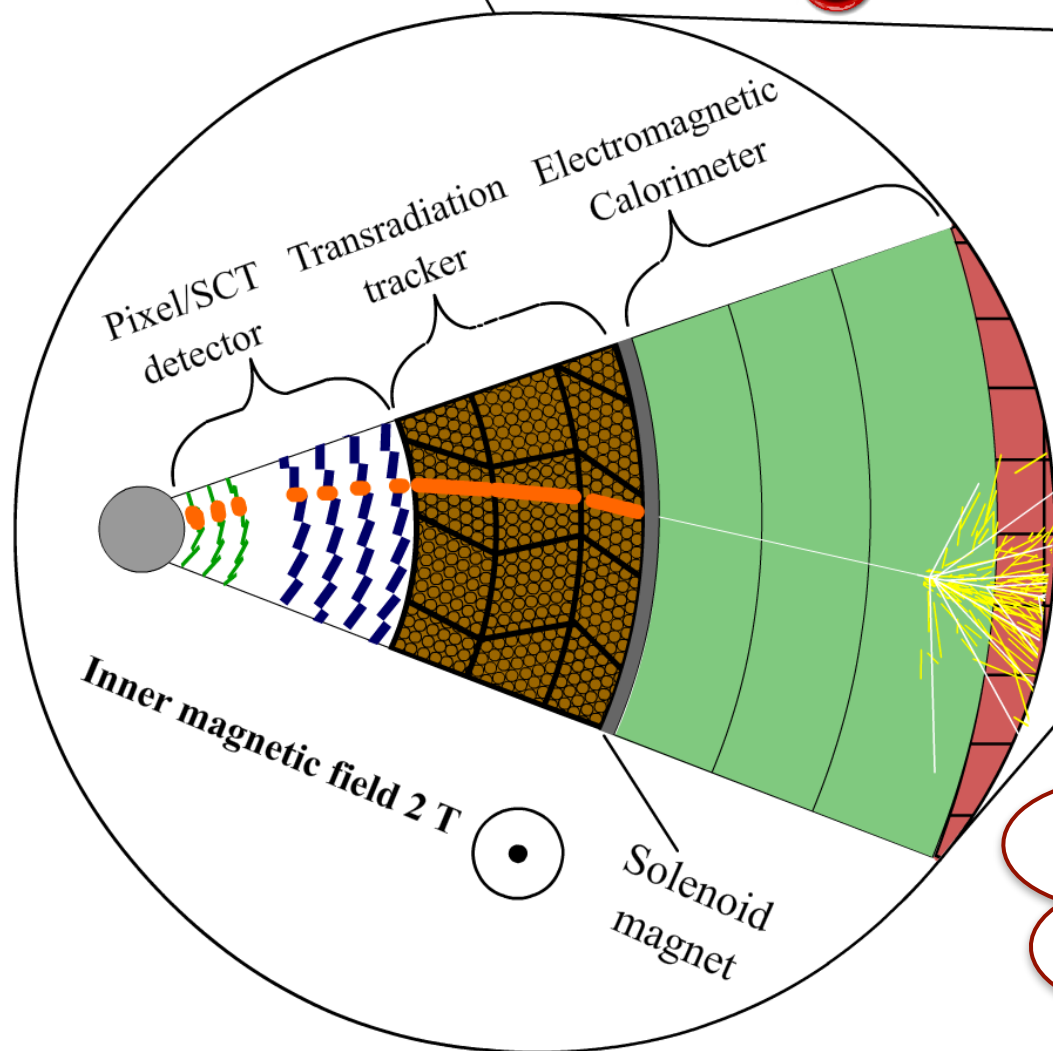


Neutron



Anti-muon

Magnification 3x



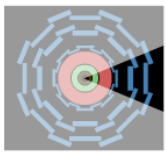
Ostavljaju energiju najvećim delom u hadronskom kalorimetru i tragove u tracker-u

Created by T. Herrmann, O. Jeřábek, K. Jende, M. Kobel

Detekcija neutralnih hadrona

ATLAS

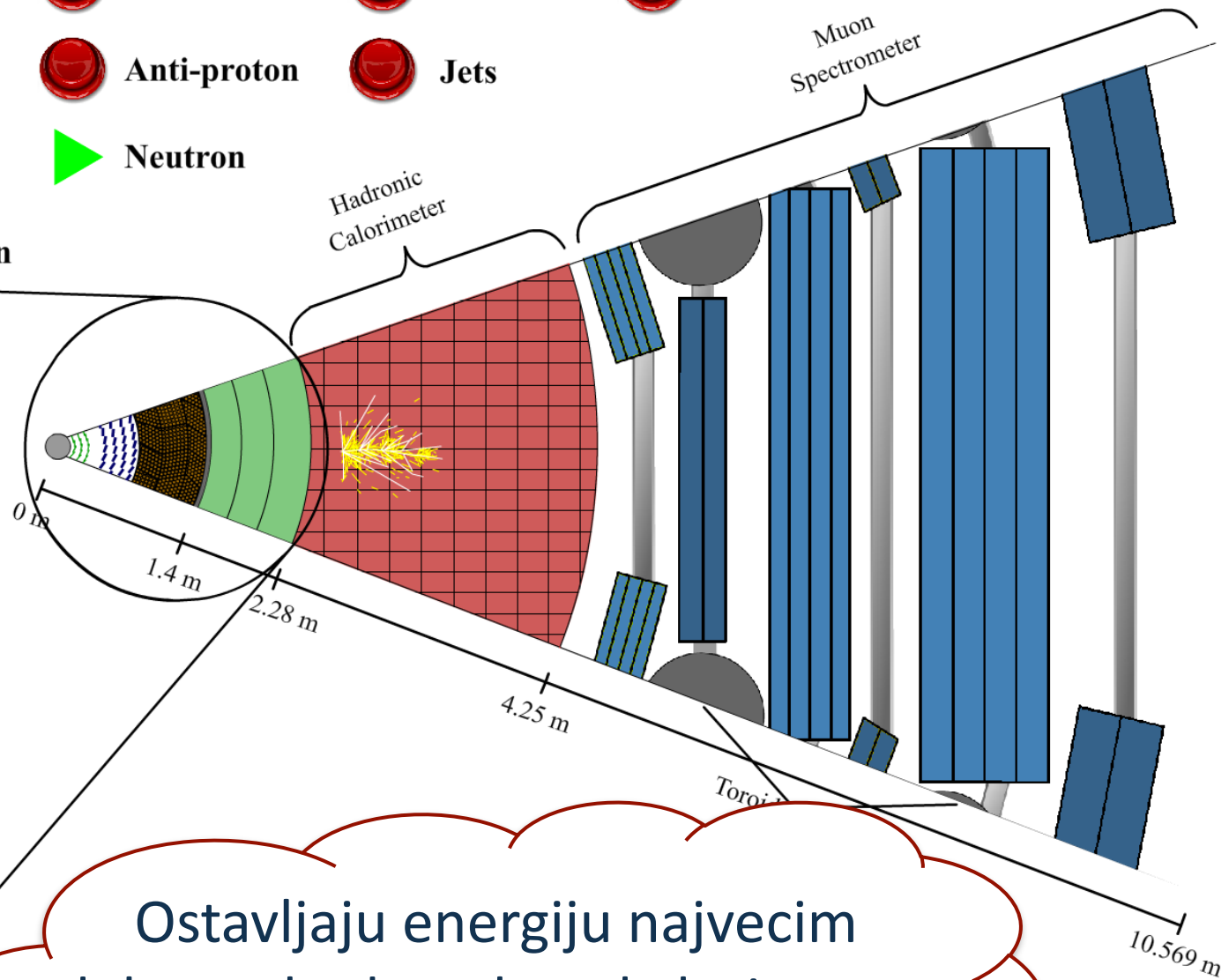
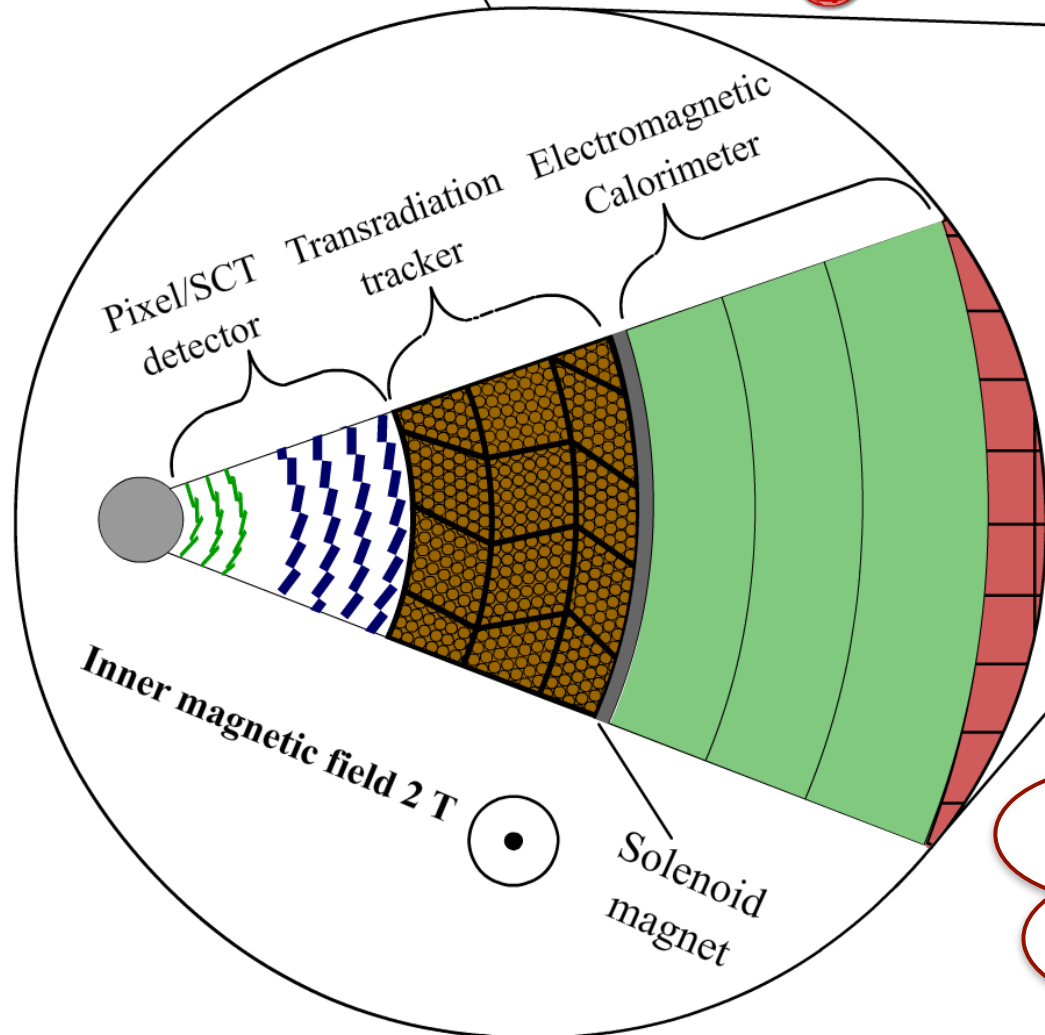
animation



display instantly

- Electron
- Proton
- Neutrino
- Photon
- Positron
- Anti-proton
- Jets
- Muon
- Neutron
- Anti-muon

Magnification 3x



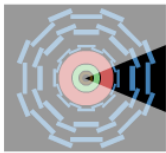
Ostavljaju energiju najvećim delom u hadronskom kalorimetru, bez tragova u tracker-u

Created by T. Herrmann, O. Jeřábek, K. Jende, M. Kobel

Detekcija miona

ATLAS

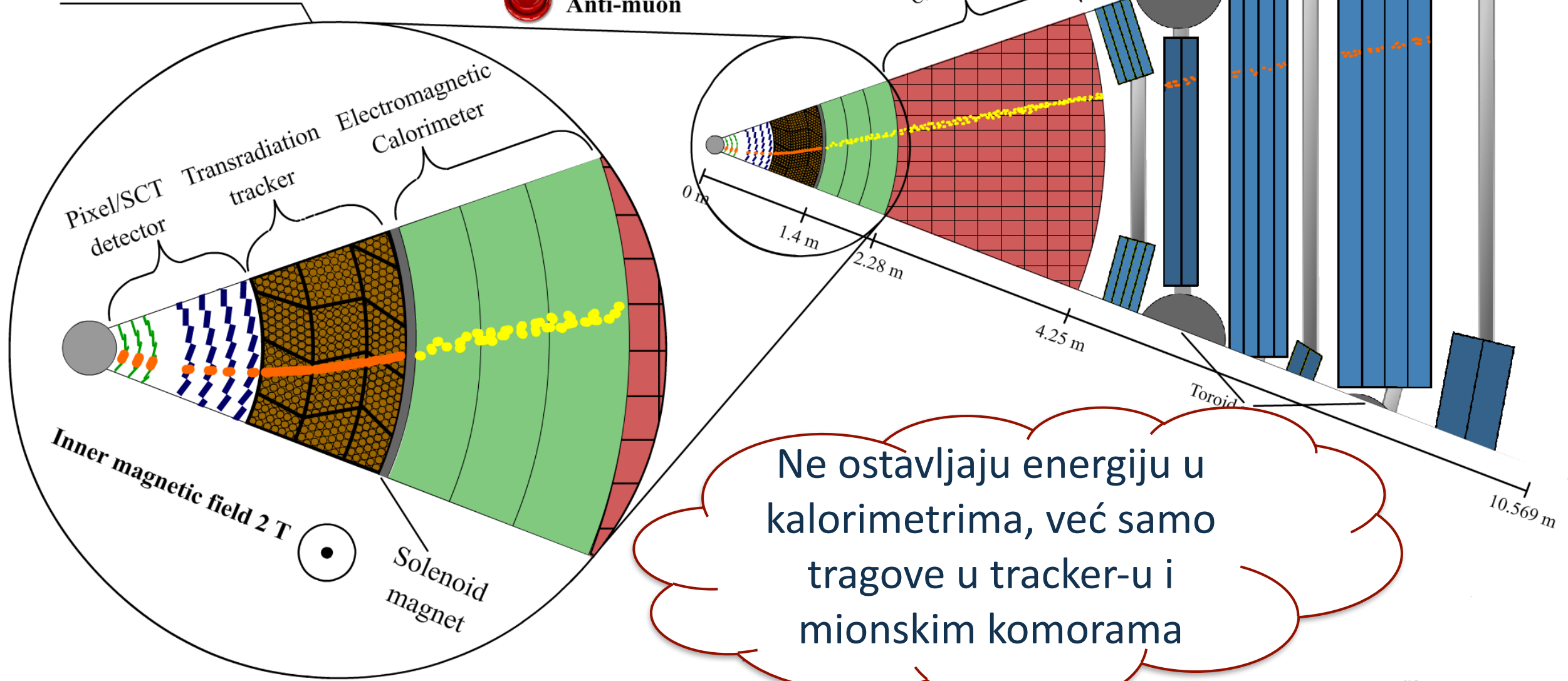
animation



display instantly

- Electron
- Proton
- Neutrino
- Photon
- Positron
- Anti-proton
- Jets
- Muon
- Neutron
- Anti-muon

Magnification 3x



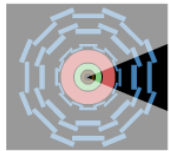
Ne ostavljaju energiju u kalorimetrima, već samo tragove u tracker-u i mionskim komorama

Created by T. Herrmann, O. Jeřábek, K. Jende, M. Kobel

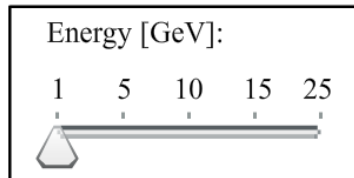
Detekcija anti-miona

ATLAS

animation

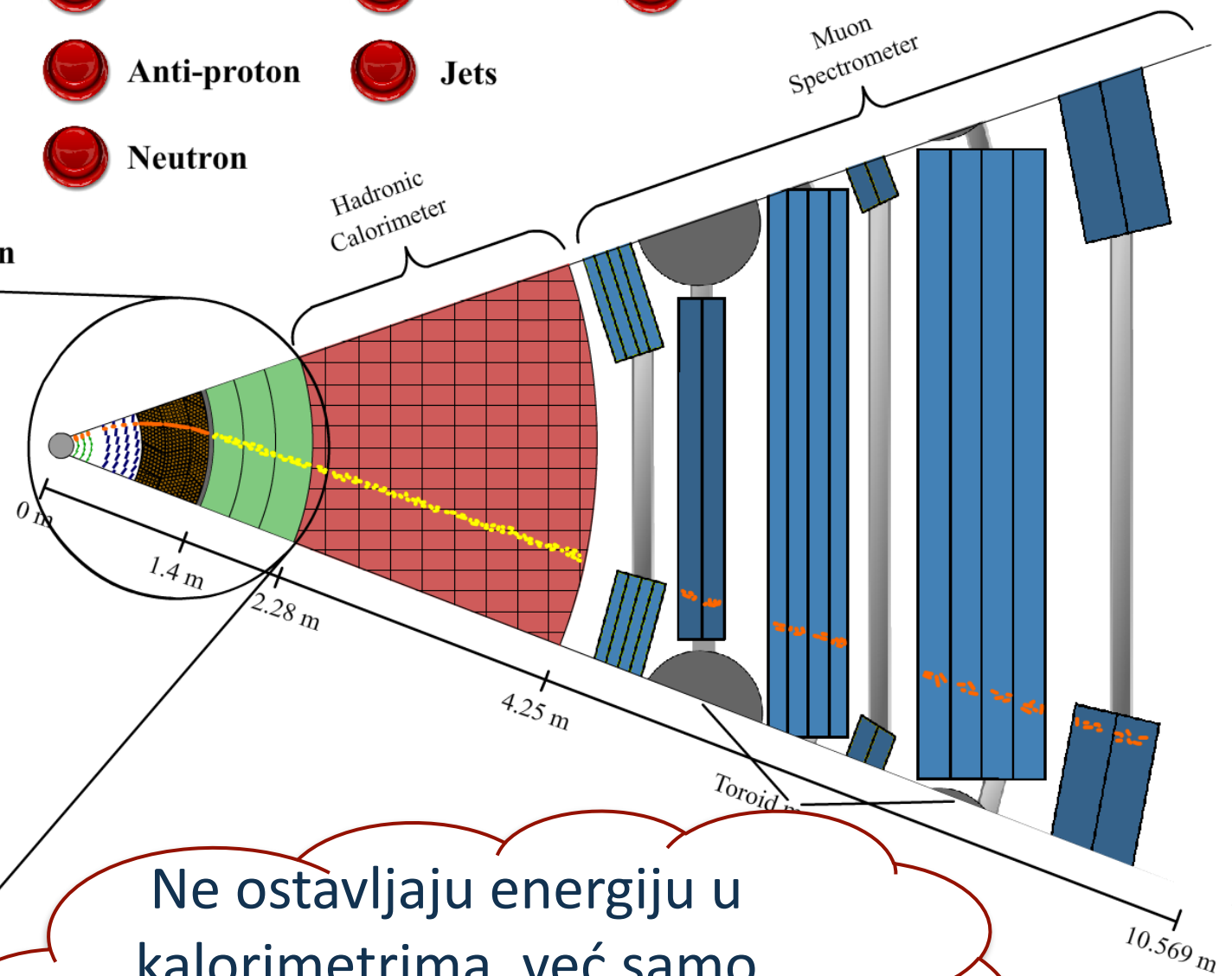
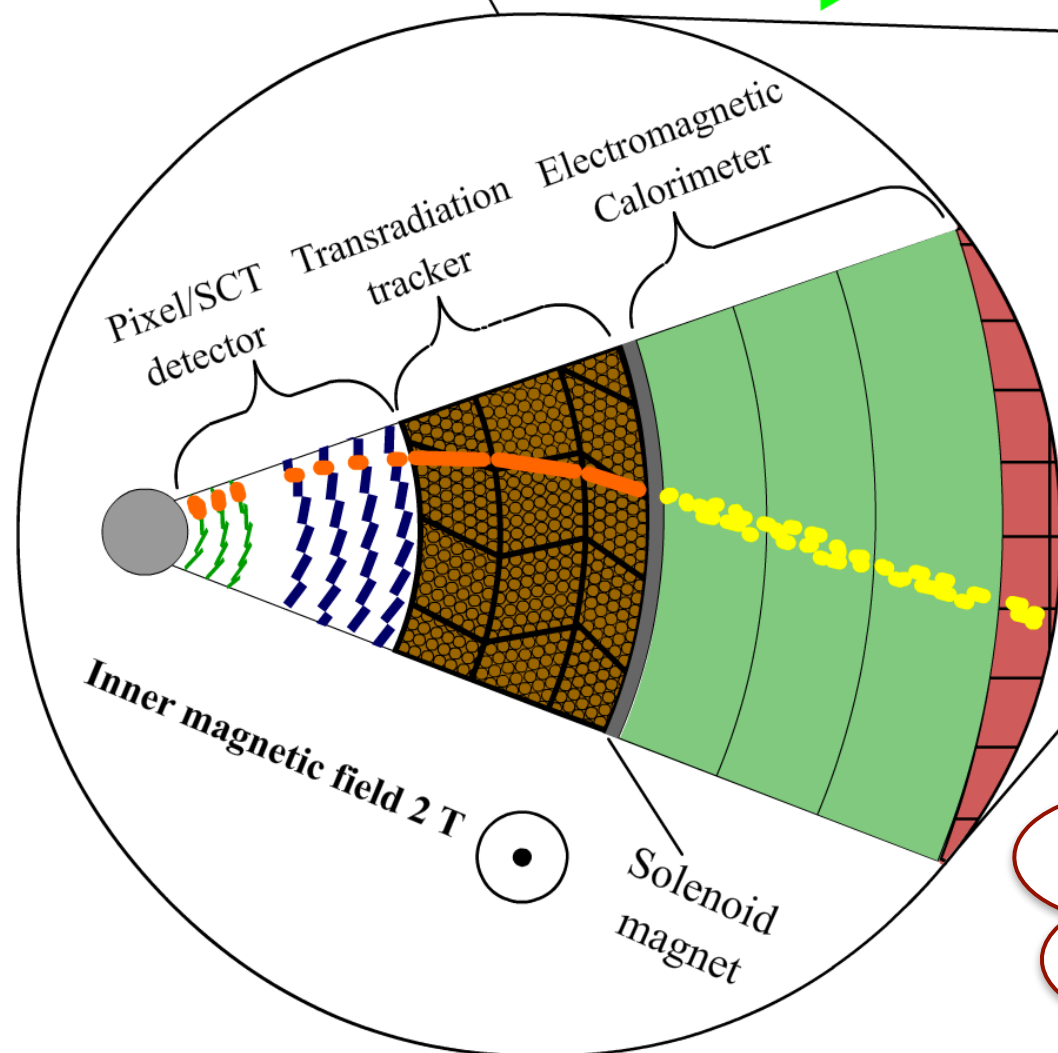


display instantly



- Electron
 - Proton
 - Neutrino
 - Photon
 - Positron
 - Anti-proton
 - Jets
 - Muon
 - Neutron
- Anti-muon

Magnification 3x



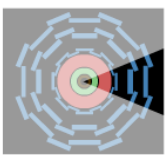
Ne ostavljaju energiju u kalorimetrima, već samo tragove u tracker-u i mionskim komorama

Created by T. Herrmann, O. Jeřábek, K. Jende, M. Kobel

Detekcija jet-ova hadrona

ATLAS

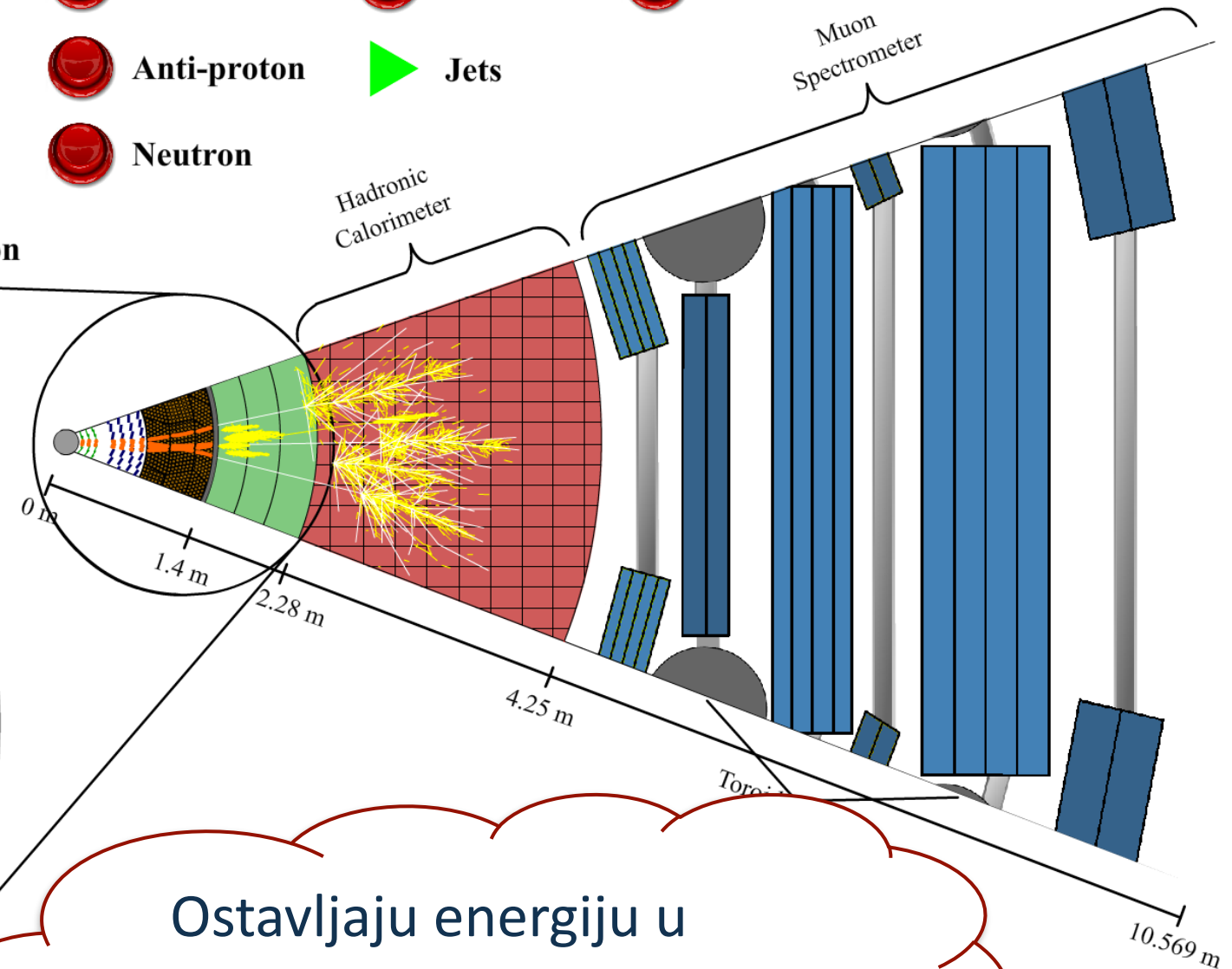
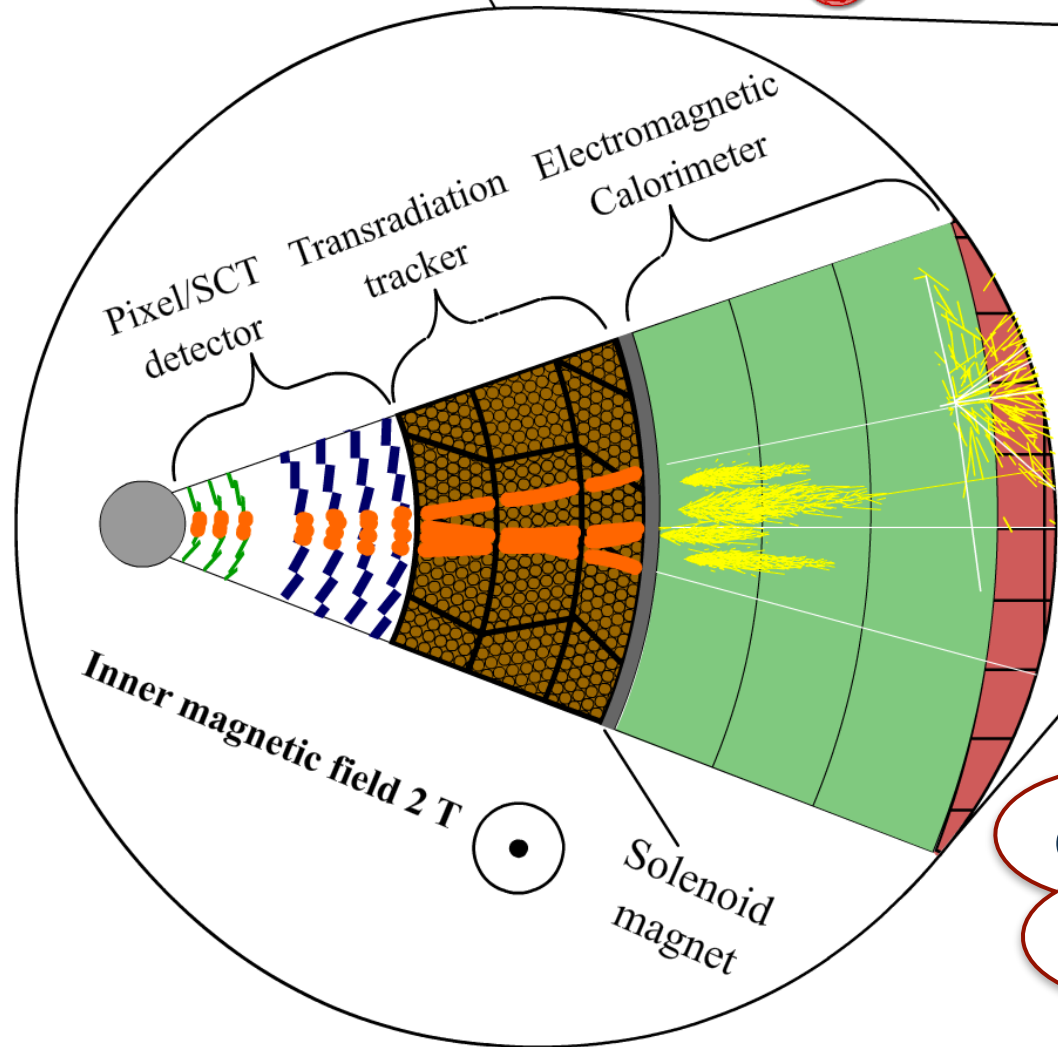
animation



display instantly

- Electron
- Proton
- Neutrino
- Photon
- Positron
- Anti-proton
- Jets
- Muon
- Neutron
- Anti-muon

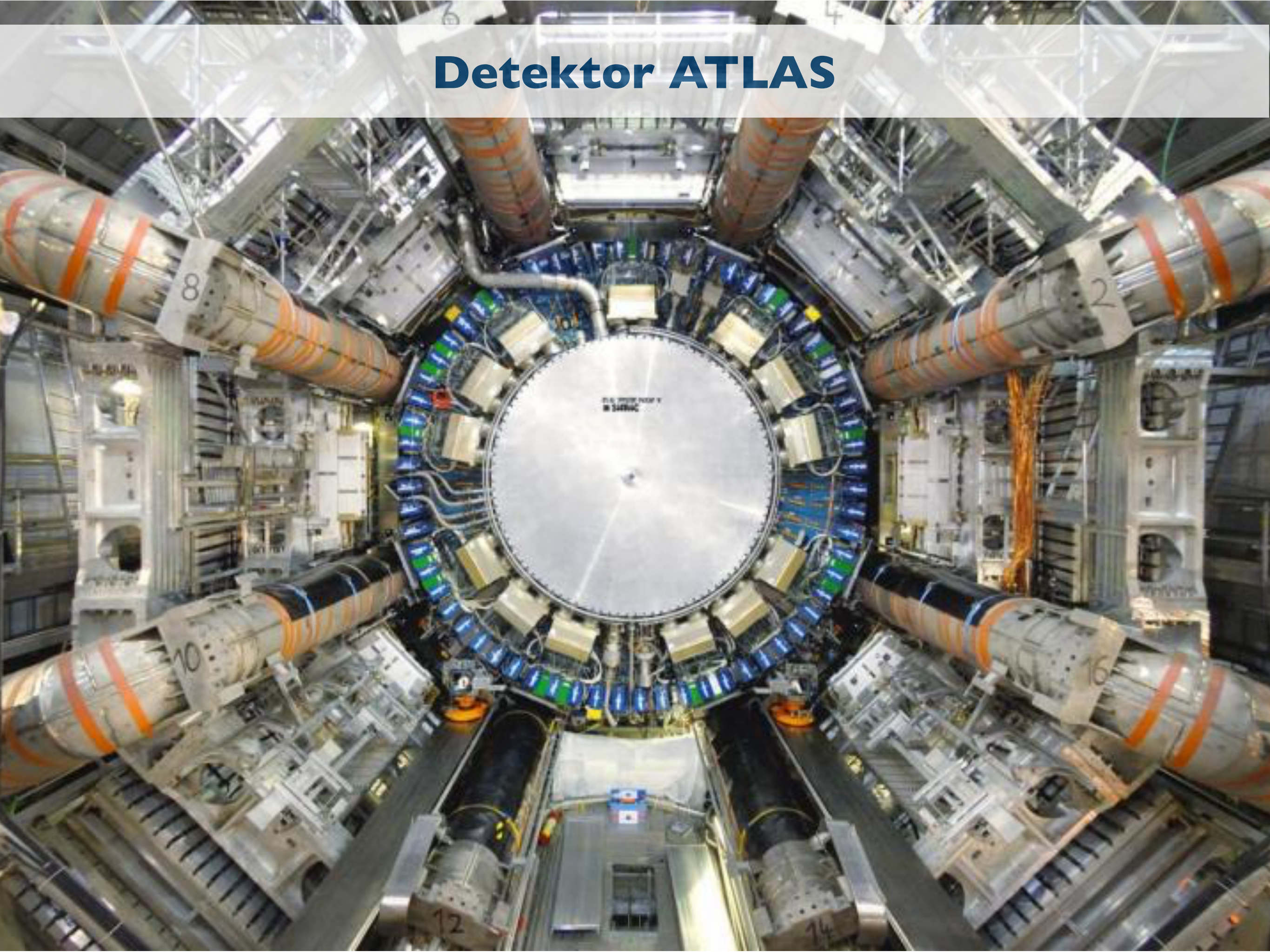
Magnification 3x



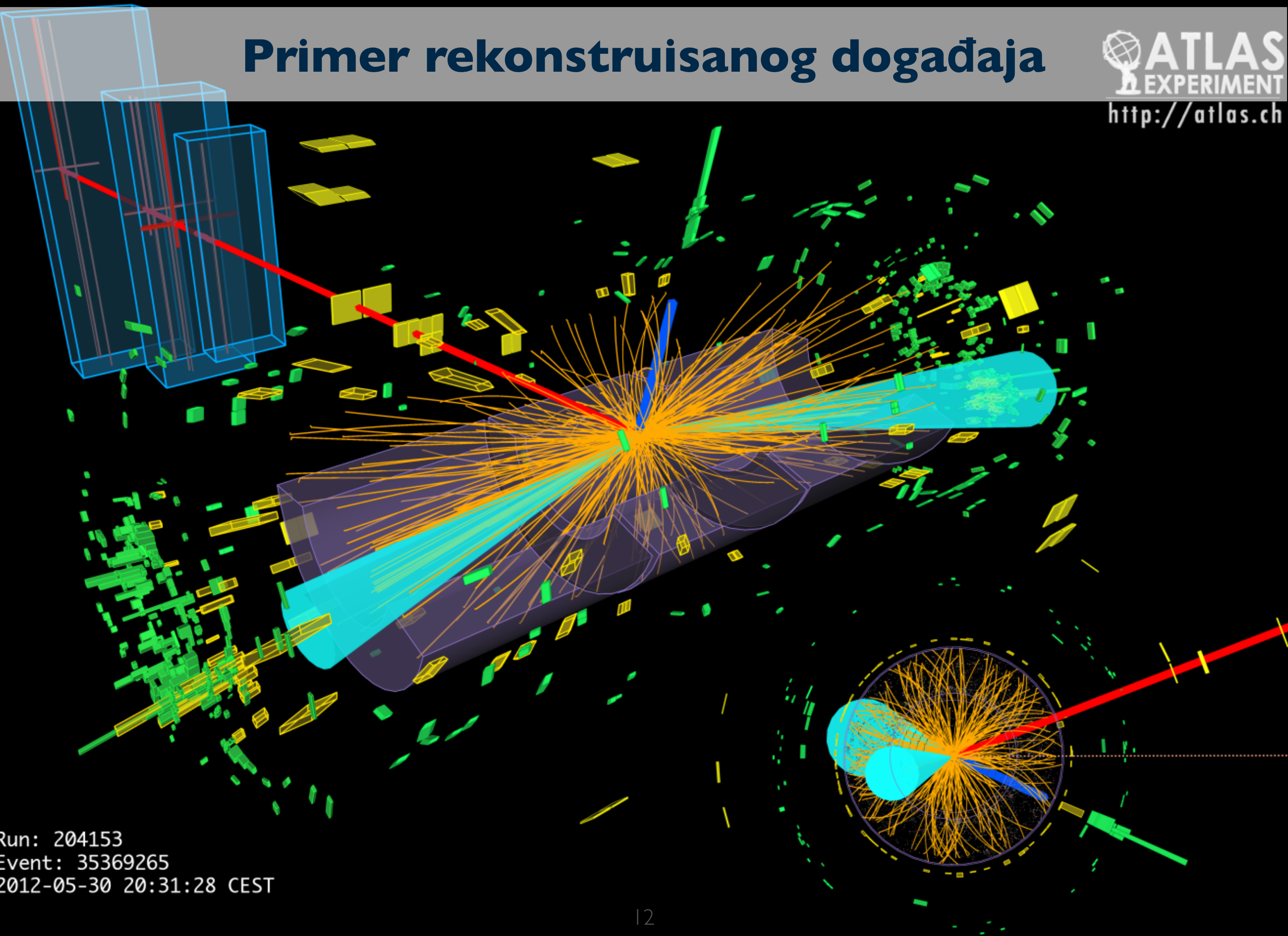
Ostavljaju energiju u elektromagnetskom i hadronskom kalorimetru i tragove u tracker-u

Created by T. Herrmann, O. Jeřábek, K. Jende, M. Kobel

Detektor ATLAS



Primer rekonstruisanog događaja



Run: 204153
Event: 35369265
2012-05-30 20:31:28 CEST

Analiza događaja

- **Akcelerator LHC:** proton–proton sudari energije **8 TeV**
- Edukativni program za vizuelizaciju događaja : **HYPATIA**
- **Zadatak 1:** Rekonstrukcija događaja i potraga za:
 - Raspadima neutralnih čestica na par elektrona ili miona (J/ψ , Υ , Z^0 ...)
Primer: $Z^0 \rightarrow \mu^- \mu^+$ & $Z^0 \rightarrow e^- e^+$
 - Raspadima Higgs bozona na par fotona ili par Z^0 bozona
Primer: $H^0 \rightarrow \gamma \gamma$
 $H^0 \rightarrow e^- e^+ e^- e^+$ & $H^0 \rightarrow \mu^- \mu^+ \mu^- \mu^+$ & $H^0 \rightarrow \mu^- \mu^+ e^- e^+$
- **Zadatak 2:** Snimanje masenog spektra za događaje sa **parom leptona**, ili **parom fotona**, ili **parom $Z^0 Z^0$** bozona.
Upoređivanje rezultata sa merenjima na eksperimentima ATLAS i CMS.
- **Zadatak 3:** Upoređivanje i kombinovanje rezultata sa rezultatima studenata ostalih instituta koji učestvuju u ovom programu (V.C.)

Analiza događaja programom HEPATIA

The screenshot displays the HYPATIA software interface, which is used for analyzing particle collision events. The main window is titled "HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window". It features a menu bar (File, View, Histograms, Preferences, Help) and a data table at the top. The table lists event parameters such as File Name, ETMis [GeV], Track, P [GeV], +/-, Pt [GeV], φ , η , M(2) [GeV], M(eeee) [GeV], M(eemm) [GeV], M(mmmm) [GeV], and e/m/g.

The interface is divided into several panels:

- Transverzalni prikaz (Transverse view):** A circular plot showing the detector's cross-section with tracks and energy deposits. A callout bubble points to this view.
- Longitudinalni prikaz (Longitudinal view):** A 3D plot showing the detector's longitudinal structure. A callout bubble points to this view.
- Prozor za biranje događaja i selekciju objekata (Event selection and object selection window):** A window titled "HYPATIA - Track Momenta Window" with a table of track parameters. A callout bubble points to this window.
- Prozor za kontrolu prikaza detektora i objekata (Detector and object display control window):** A window titled "HYPATIA - Parameter Control" with a table of detector and object parameters. A callout bubble points to this window.

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	φ	η	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]	M(mmmm) [GeV]	e/m/g
JiveXML_106051_1950731.xml	13.877	Tracks 1	126.1	+	39.4	-2.413	1.830	91.054				e
		Tracks 3	167.9	-	53.0	0.906	1.820					e

Track	+/-	P [GeV]	Pt [GeV]	φ	θ
Tracks 2	-	108.74			0.562
Tracks 4	+				473
Tracks 10	-				
Tracks 21	+				
Tracks 410	-				
Tracks 579	-				
Tracks 626	+				
Tracks 627	+				
Tracks 629	+	44			2.900
Tracks 631	-	81.25			0.754
Tracks 632	+	97.55	33.18	-2.863	0.347
Tracks 634	-	29.37	27.66	2.324	1.914
Tracks 635	-	36.12	27.85	-2.173	0.881
Tracks 636	+	96.97	47.21	2.286	2.633
Tracks 643	-	58.49	32.36	-0.636	2.555
Tracks 655	-	12.49	8.29		
Tracks 657	-	13.39			
Tracks 664	+	10.52			
Tracks 667	-	7.87			
Tracks 669	+	22.48			
Tracks 673	+	9.86			
Tracks 675	-	9.28			

Projection	Name	Value
InDet		
Calo		
MuonDet	<input checked="" type="checkbox"/> Pt	> 5.0 GeV
Objects	<input type="checkbox"/> Pt2	< 700.0 MeV
ATLAS	<input checked="" type="checkbox"/> d0	< 2.5 mm
	<input checked="" type="checkbox"/> z0	< 20.0 cm
	<input type="checkbox"/> d0 Loose	< 2.0 cm
	<input type="checkbox"/> z0-zVtx	< 2.5 mm

Kontrola prikaza detektora i objekata

The image displays two screenshots of the HYPATIA Control Window interface. The top screenshot shows the 'Interaction and Window Control' tab with a toolbar containing icons for Zoom, Pick, and other functions. The bottom screenshot shows the 'Parameter Control' tab with a table of parameters for various detector components.

Zoom

Pick

Interakcija sa prikazom detektora i objekata

Kontrola parametara prikaza

Granična vrednost transverzalnog momenta za prikaz objekta

Component	Name	Value
Calo	<input checked="" type="checkbox"/> Pt	> 1.5 GeV
	<input type="checkbox"/> d0 Loose	< 2.0 cm
MuonDet	<input checked="" type="checkbox"/> d0	< 2.5 mm
	<input type="checkbox"/> z0-zVtx	< 2.5 mm
Objects	<input checked="" type="checkbox"/> z0	< 20.0 cm
	<input type="checkbox"/> Layer	> 0
	<input type="checkbox"/> Number Pixel Hits	>= 2
	<input type="checkbox"/> Number SCT Hits	>= 7

Analiza događaja programom HEPATIA

The screenshot displays the HYPATIA software interface, which is used for event analysis in ATLAS. The main window is titled "HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window". It features a menu bar (File, View, Histograms, Preferences, Help) and a data table at the top. The table lists event parameters such as File Name, ETMis [GeV], Track, P [GeV], +/-, Pt [GeV], φ , η , M(2) [GeV], M(eeee) [GeV], M(eemm) [GeV], M(mmmm) [GeV], and e/m/g.

On the left side, there are two detector views: a top view labeled "Transverzalni prikaz" (Transverse view) and a bottom view labeled "Longitudinalni prikaz" (Longitudinal view). Both views show the detector geometry with particle tracks overlaid. A 3D histogram is also visible in the center, representing the invariant mass distribution.

On the right side, there is a "HYPATIA - Track Momenta Window" which contains a table of track parameters and a "Parameter Control" panel. The track table lists parameters for various tracks, including Track ID, +/-, P [GeV], Pt [GeV], φ , and θ . The "Parameter Control" panel allows users to set various cuts and filters for the analysis, such as $|Pt| > 5.0$ GeV and $|d0| < 2.5$ mm.

Three callout boxes provide additional information:

- "Transverzalni prikaz" points to the top detector view.
- "Longitudinalni prikaz" points to the bottom detector view.
- "Prozor za biranje događaja i selekciju objekata" (Window for event selection and object selection) points to the track table.
- "Prozor za kontrolu prikaza detektora i objekata" (Window for detector and object display control) points to the parameter control panel.

Biranje prethodnog/sledećeg događaja

Biranje prethodnog ili sledećeg događaja

Track	Charge	P [GeV]	Pt [GeV]	φ	θ
Tracks 0			3.78	3.017	0.219
Tracks 7			4.82	3.088	0.736
Tracks 8		1.34	1.01	0.972	2.967
Tracks 9		1.30	1.29	2.753	1.442
Tracks 10	+	6.28	1.34	-0.133	2.927
Tracks 11	-	5.93	1.04	-0.829	2.966
Tracks 12	+	4.59	1.35	1.769	0.298
Tracks 13	+	6.48	2.11	0.257	0.332
Tracks 15	+	6.50	1.16	2.404	0.179
Tracks 17	+	6.19	2.52	0.122	2.722
Tracks 18	-	4.68	1.07	2.430	2.912
Tracks 19	+	3.53	1.26	1.626	2.777
Tracks 20	+	6.55	1.43	-1.504	0.219
Tracks 22	-	7.52	1.54	2.978	0.206
Tracks 24	+	2.28	2.28	-2.111	1.657
Tracks 26	+	12.72	2.55	-1.088	2.940
Tracks 27	-	6.60	1.50	1.665	2.912
Tracks 29	+	2.35	2.16	-2.994	1.163
Tracks 30	+	3.95	1.09	-0.813	2.863
Tracks 32	+	28.89	16.72	-3.081	0.617
Tracks 34	-	3.73	1.86	1.054	2.620
Tracks 35	+	4.01	1.30	2.397	2.813

Selekcija rekonstruisanih objekata

ETMis: 33.441 GeV φ : 0.518 rad Collection: MET_RefFinal

/Users/predragm/Downloads/groupA/event021.xml

Track	+	Energy (GeV)	Momentum (GeV/c)	φ	θ
Tracks 0	-			3.017	0.219
Tracks 7	-			3.088	0.736
Tracks 8	+	5.8		0.972	2.967
Tracks 9	+	1.30		2.753	1.442
Tracks 10	+	6.28	1.34	-0.133	2.927
Tracks 11	-	5.93	1.04	-0.829	2.966
Tracks 12	+	4.59	1.35	1.769	0.298
Tracks 13	+	6.48	2.11	0.257	0.332
Tracks 15	+	6.50	1.16	2.404	0.179
Tracks 17	+	6.19	2.52	0.122	2.722
Tracks 18	-	4.68	1.07	2.430	2.912
Tracks 19	+	3.53	1.26	1.626	2.777
Tracks 20	+	6.55	1.43	-1.504	0.219
Tracks 22	-	7.52	1.54	2.978	0.206
Tracks 24	+	2.28	2.28	-2.111	1.657
Tracks 26	+	12.72	2.55	-1.088	2.940
Tracks 27	-	6.60	1.50	1.665	2.912
Tracks 29	+	2.35	2.16	-2.994	1.163
Tracks 30	+	3.95	1.09	-0.813	2.863
Tracks 32	+	28.89	16.72	-3.081	0.617
Tracks 34	-	3.73	1.86	1.054	2.620
Tracks 35	+	4.01	1.30	2.397	2.813

Brisanje selektovanih objekata

ETMis: 33.441 GeV ϕ : 0.518 rad Collection: MET_Reffinal

/Users/predragm/Downloads/groupA/event021.xml

Tracks Physics Objects

Track	+/-	P [GeV]	Pt [GeV]	θ
Tracks 0	-	17.40	3.78	1.9
Tracks 7	-	7.18	4.82	7.36
Tracks 8	+	5.84	1.01	2.967
Tracks 9	+	1.30	1.29	2.753
Tracks 10	+	6.28	1.34	-0.133
Tracks 11	-	5.93	1.04	-0.829
Tracks 12	+	4.59	1.35	1.769
Tracks 13	+	6.48	2.11	0.257
Tracks 15	+	6.50	1.16	2.404
Tracks 17	+	6.19	2.52	0.122
Tracks 18	-	4.68	1.07	2.430
Tracks 19	+	3.53	1.26	1.626
Tracks 20	+	6.55	1.43	-1.504
Tracks 22	-	7.52	1.54	2.978
Tracks 24	+	2.28	2.28	-2.111
Tracks 26	+	12.72	2.55	-1.088
Tracks 27	-	6.60	1.50	1.665
Tracks 29	+	2.35	2.16	-2.994
Tracks 30	+	3.95	1.09	-0.813
Tracks 32	+	28.89	16.72	-3.081
Tracks 34	-	3.73	1.86	1.054
Tracks 35	+	4.01	1.30	2.397

Brisanje selektovanih objekata iz liste

Selekcija rekonstruisanih fotona

File ← → e μ γ X ↔

Previous Event Next Event Electron Muon Photon Delete Track Reset Canvas

ETMis: 33.441 GeV φ: 0.518 rad Collection: MET_RefFinal

/Users/predragm/Downloads/groupA/event021.xml

Tracks Physics Objects

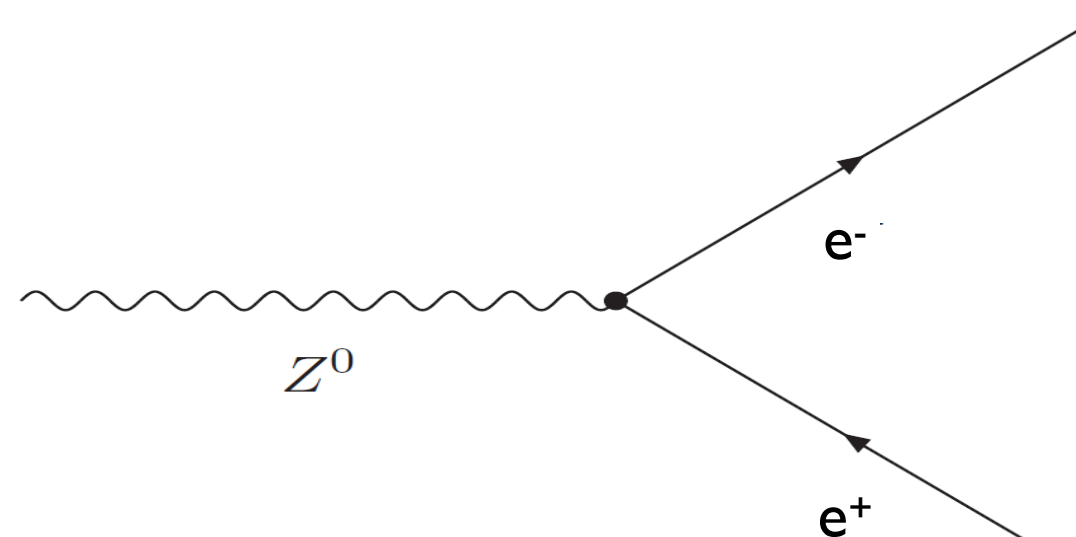
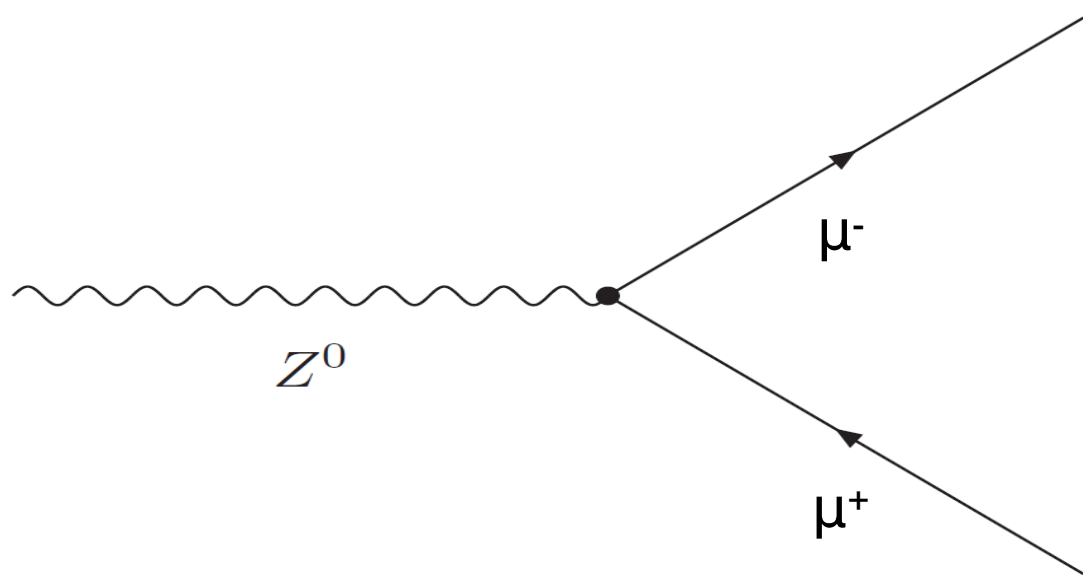
Track	P [GeV]	Pt [GeV]	φ	θ
Object 0	191.71	57.84	0.372	0.268
Object 1	32.13	31.11	-1.763	1.745

Selekcija rekonstruisanih fotona

Detekcija Z^0 bozona

$$Z^0 \rightarrow \mu^+ \mu^-, Z^0 \rightarrow e^+ e^-$$

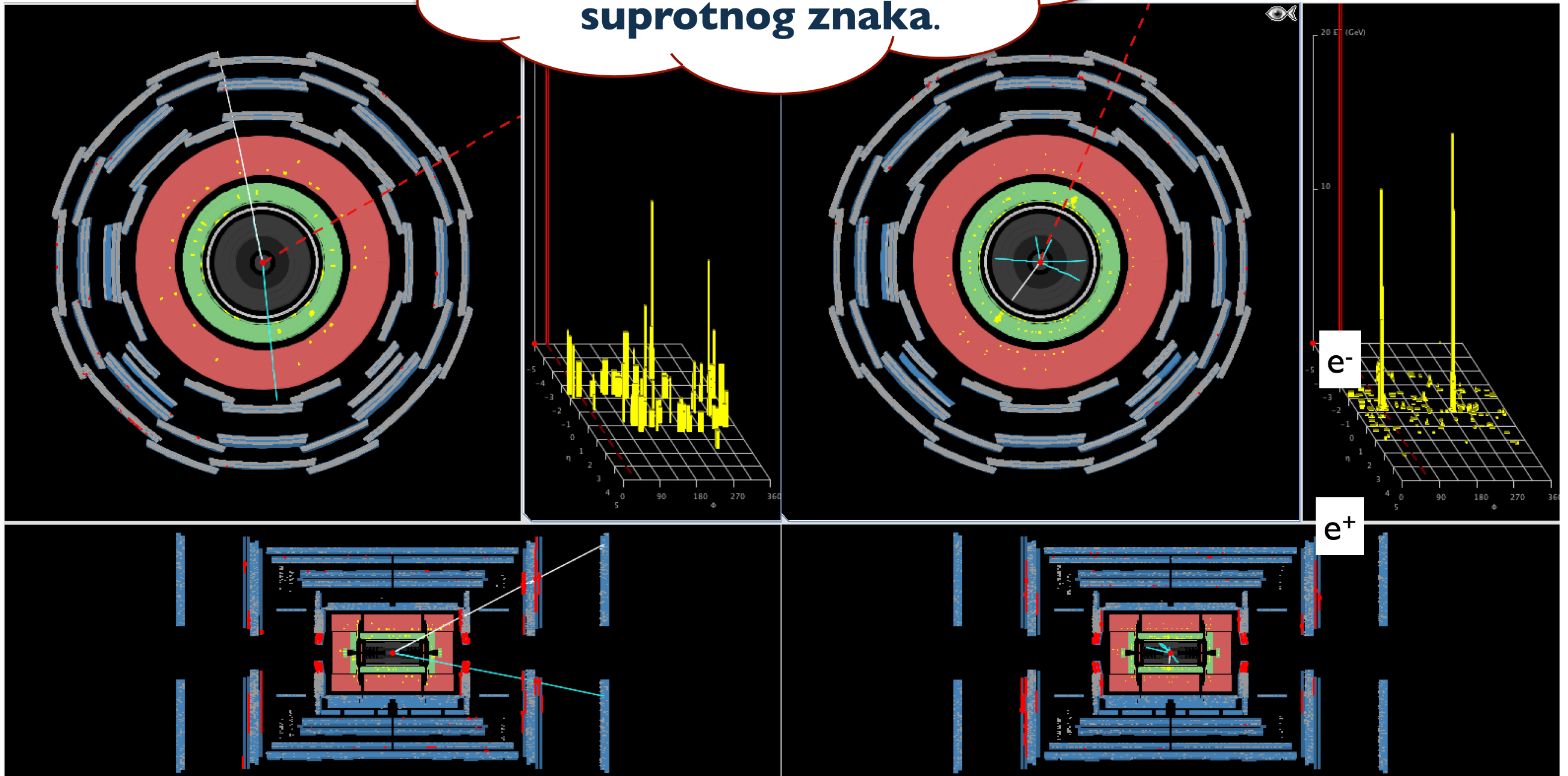
Zapis u detektoru sadrži jedan **par miona ili elektrona suprotnog znaka.**



Detekcija Z^0 bozona

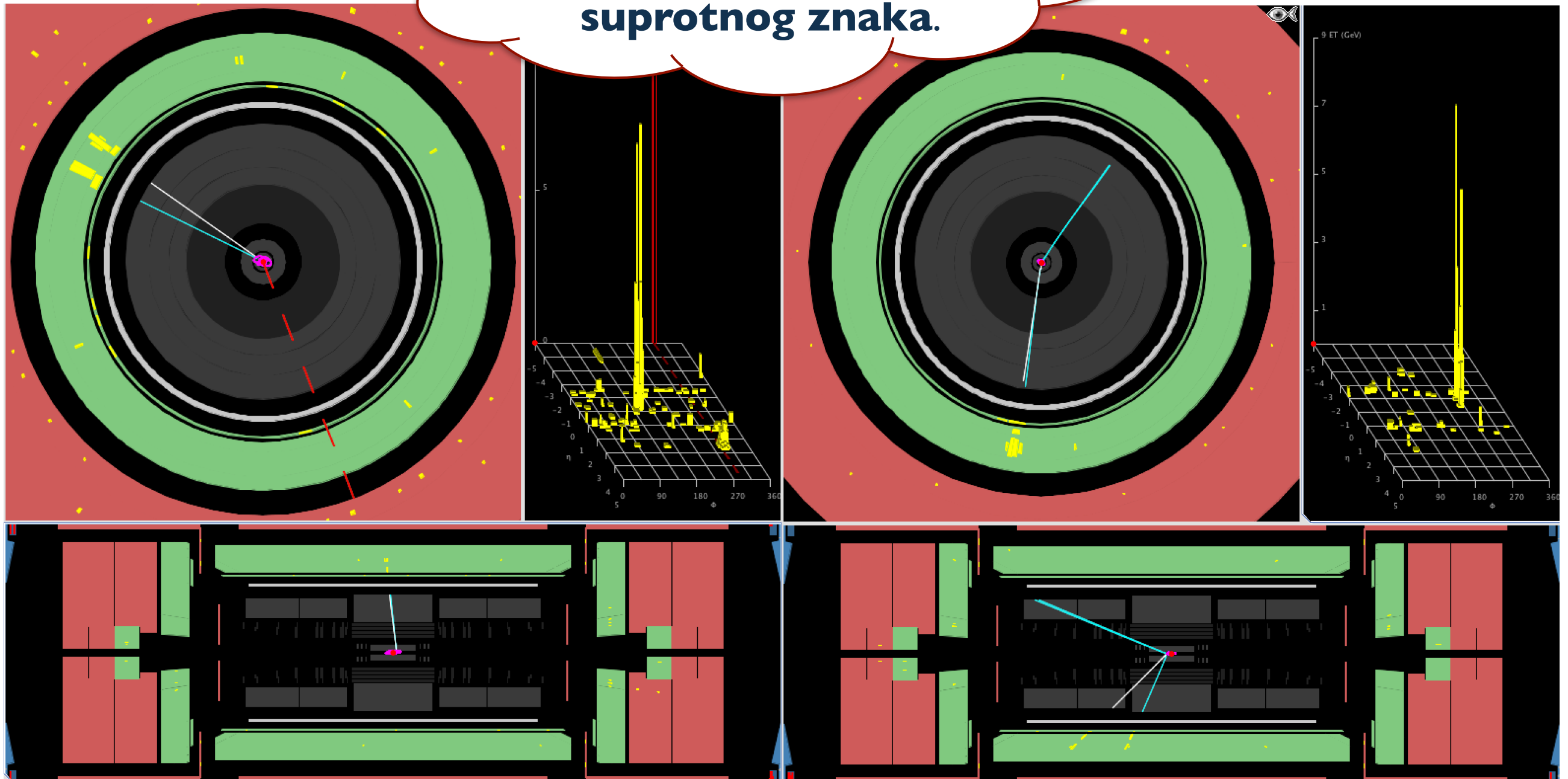
$$Z^0 \rightarrow \mu^+ \mu^-, Z^0 \rightarrow e^+ e^-$$

Zapis u detektoru sadrži jedan par miona ili elektrona suprotnog znaka.



Detekcija J/ψ and Υ mezona

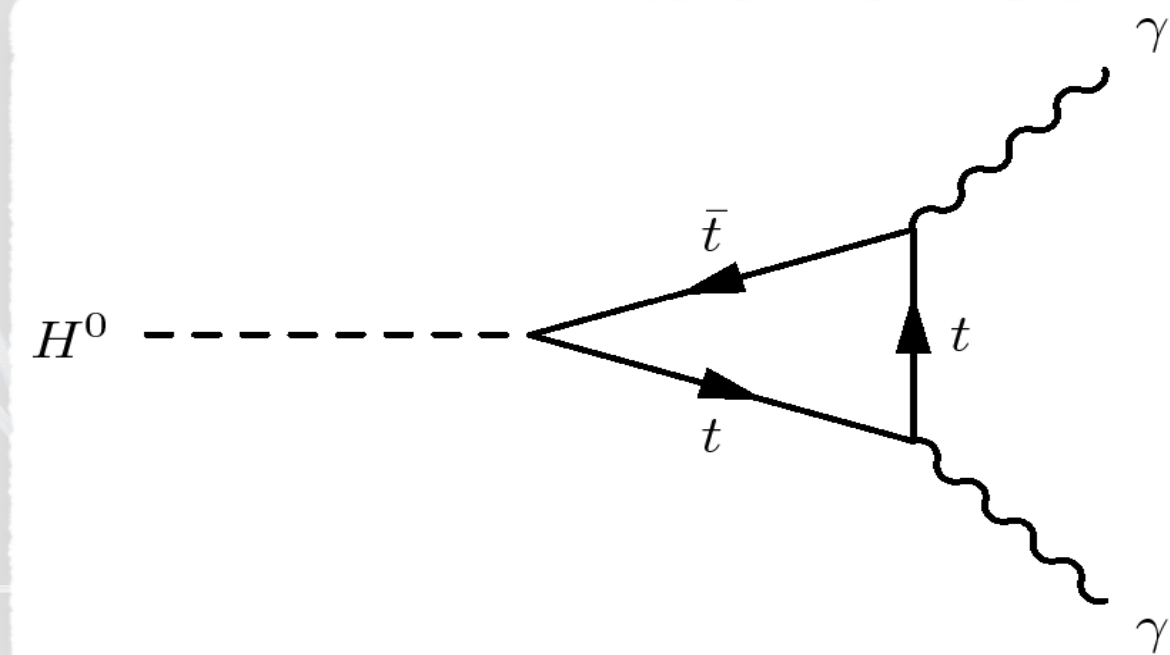
$J/\psi^0 \rightarrow \mu^+ \mu^-$, $\Upsilon^0 \rightarrow e^+ e^-$
Zapis u detektoru sadrži jedan
par miona ili elektrona
suprotnog znaka.



Detekcija H^0 bozona

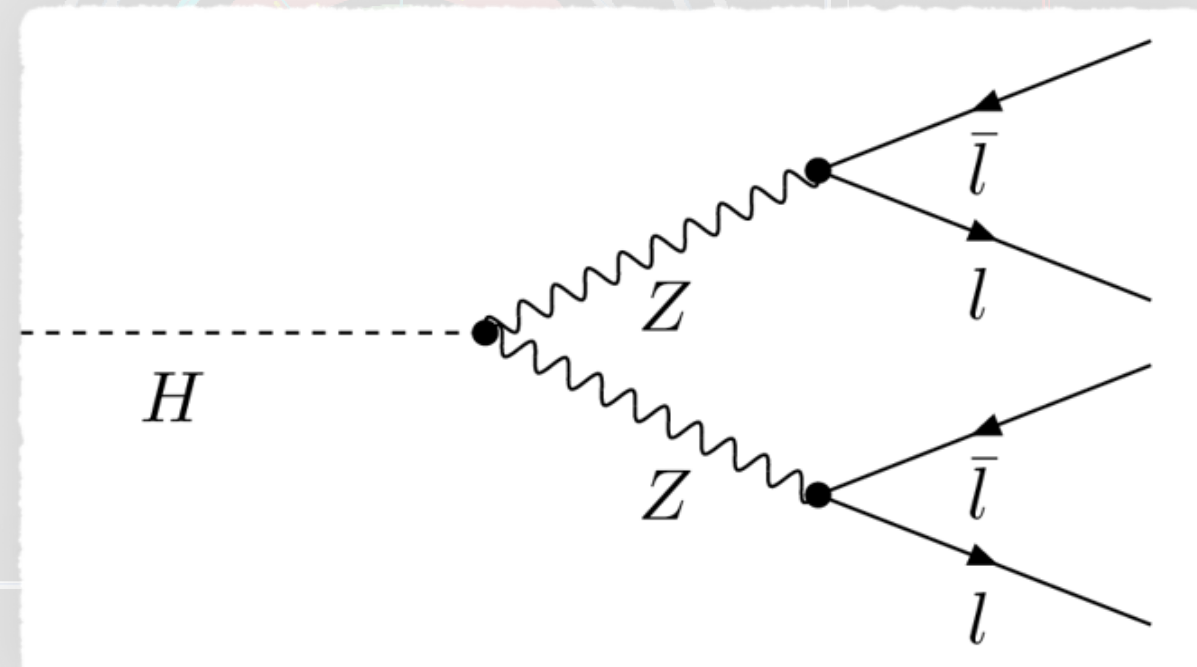
$$H^0 \rightarrow \gamma\gamma$$

Zapis u detektoru sadrži
jedan para fotona.



$$H^0 \rightarrow Z^0 Z^0 \rightarrow 4 \text{ leptona}$$

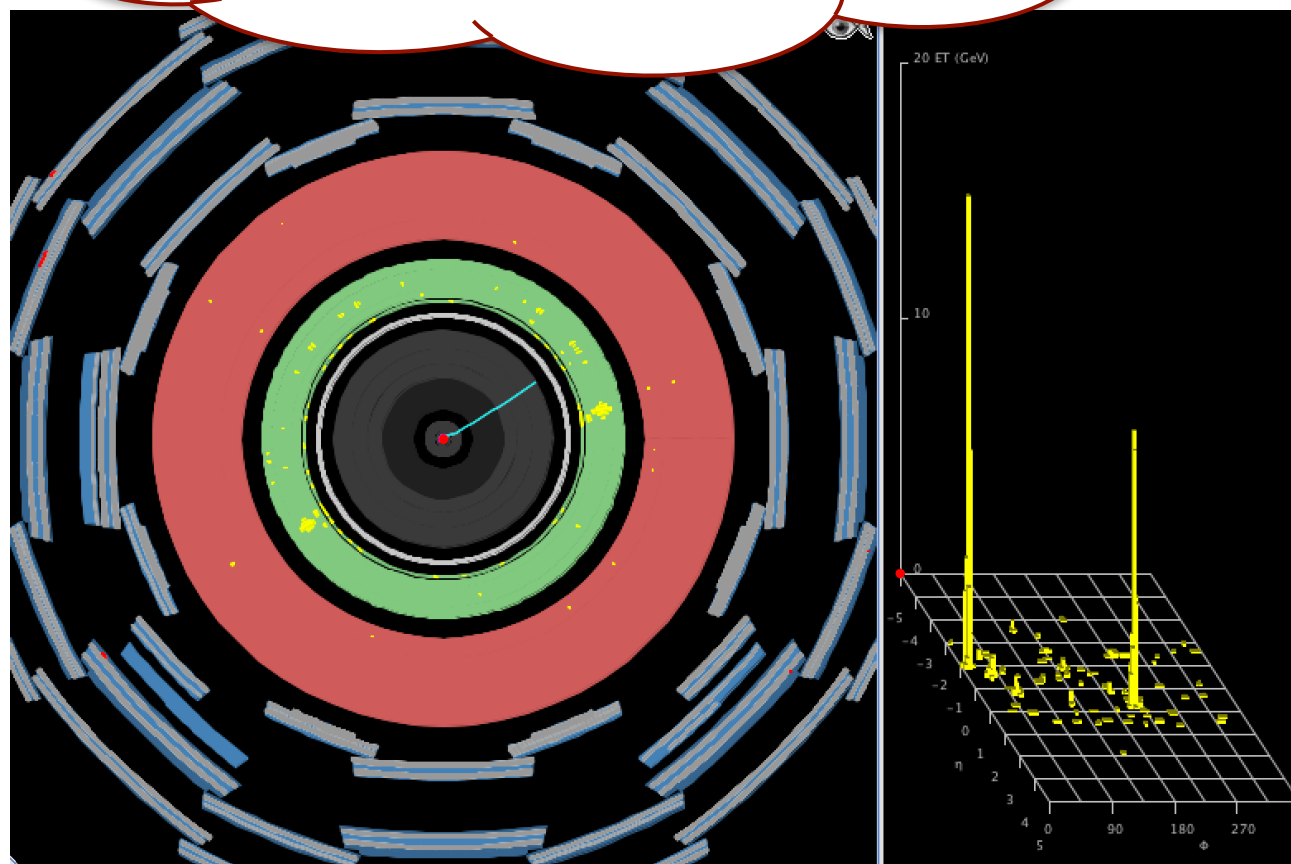
Zapis u detektoru sadrži **dva**
para miona ili elektrona.



Detekcija H^0 bozona

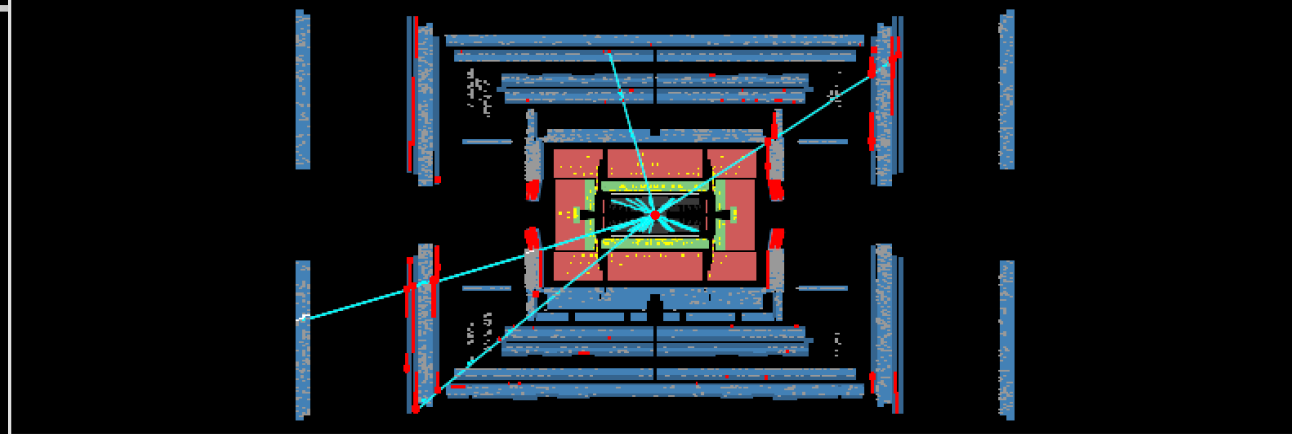
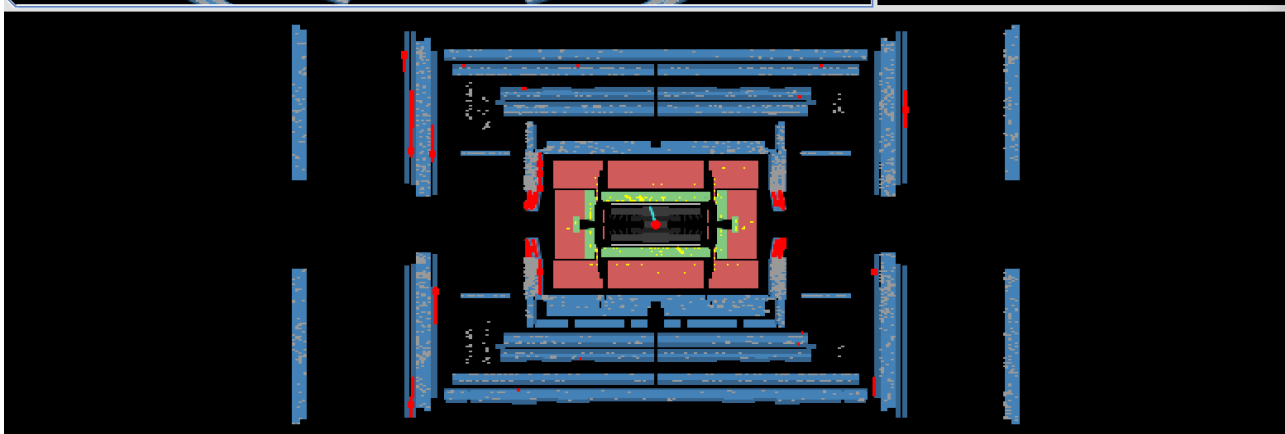
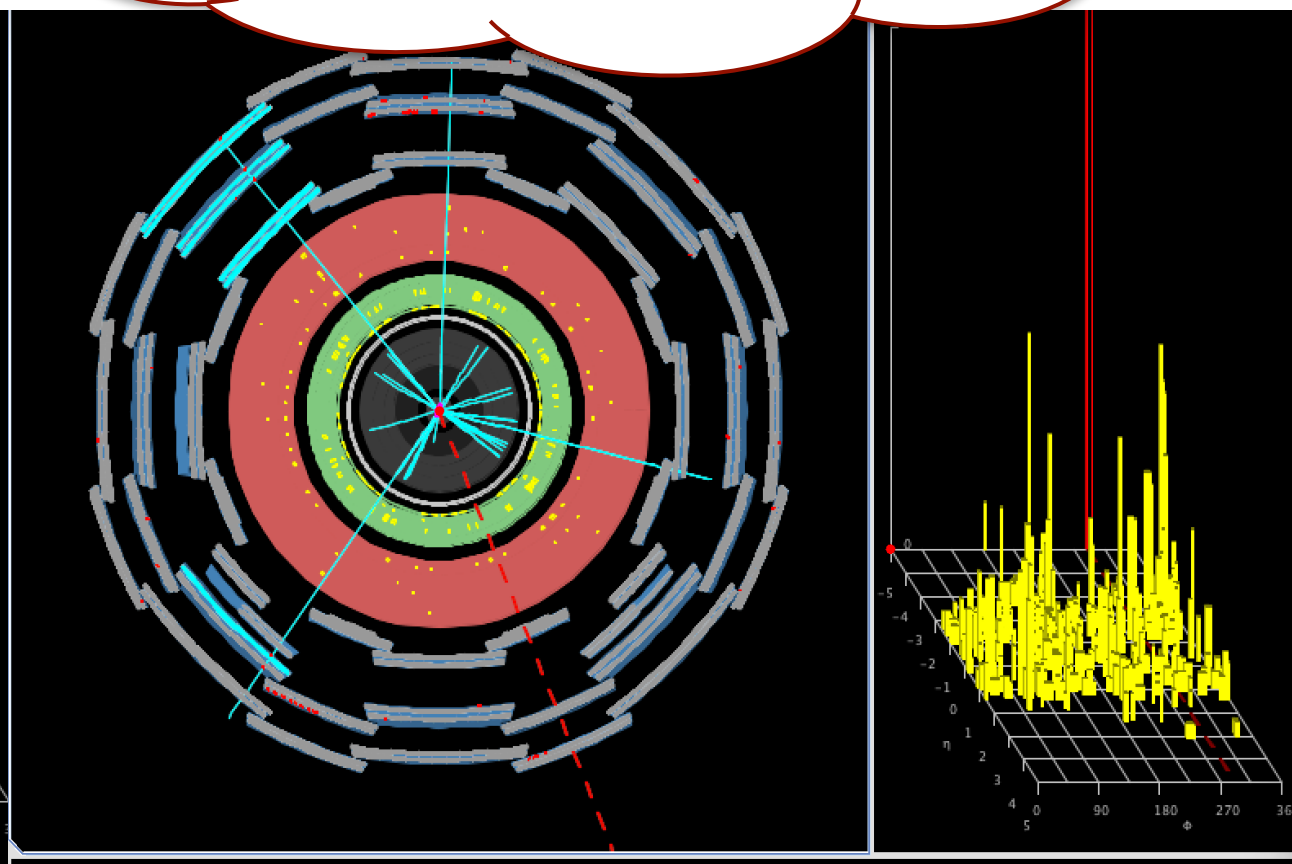
$$H^0 \rightarrow \gamma\gamma$$

Zapis u detektoru sadrži jedan para fotona.



$$H^0 \rightarrow Z^0 Z^0 \rightarrow 4 \text{ leptona}$$

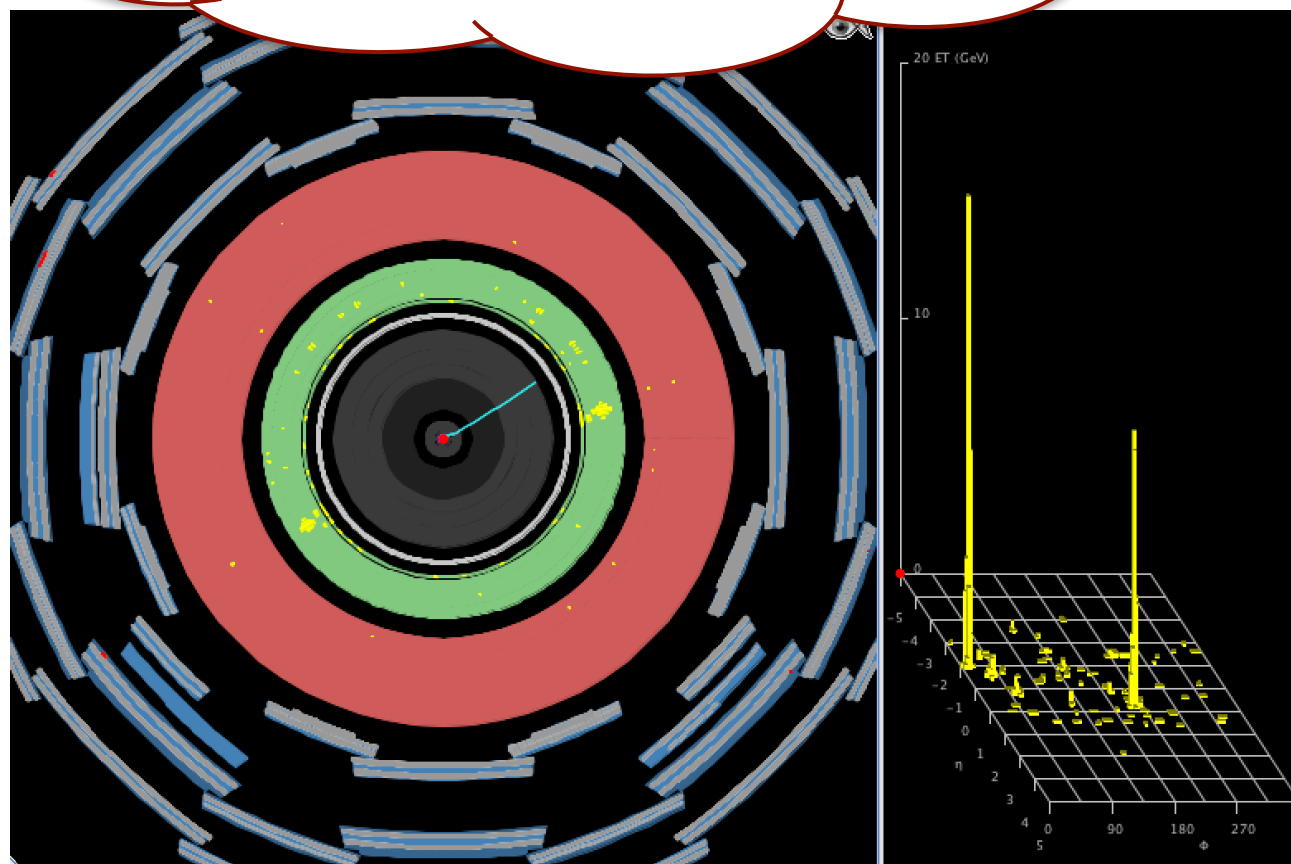
Zapis u detektoru sadrži dva para miona ili elektrona.



Detekcija H^0 bozona

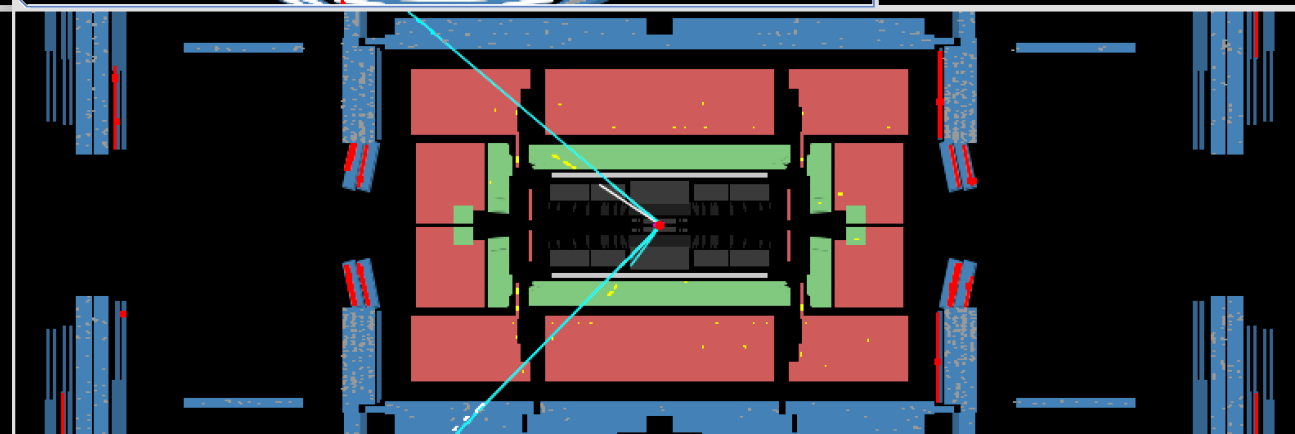
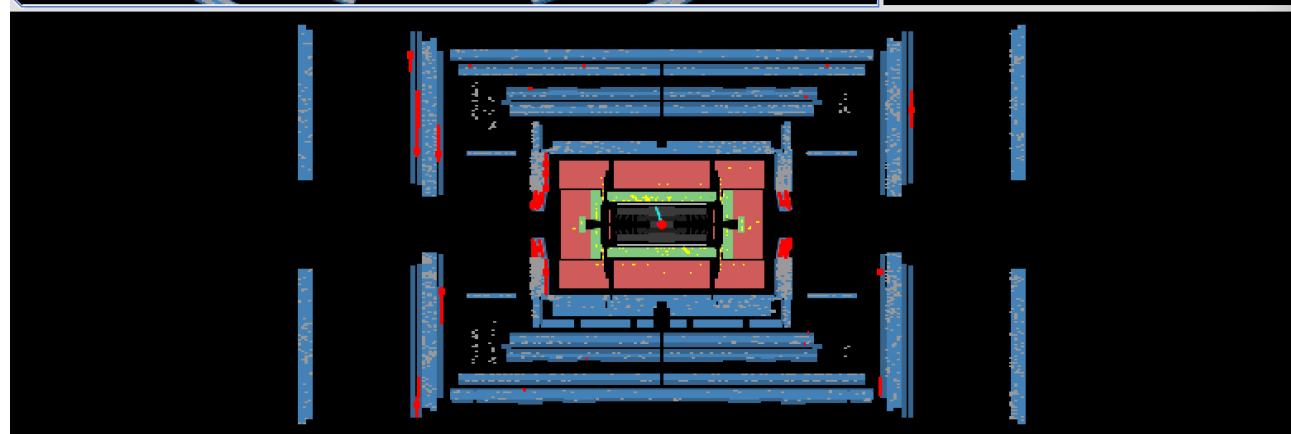
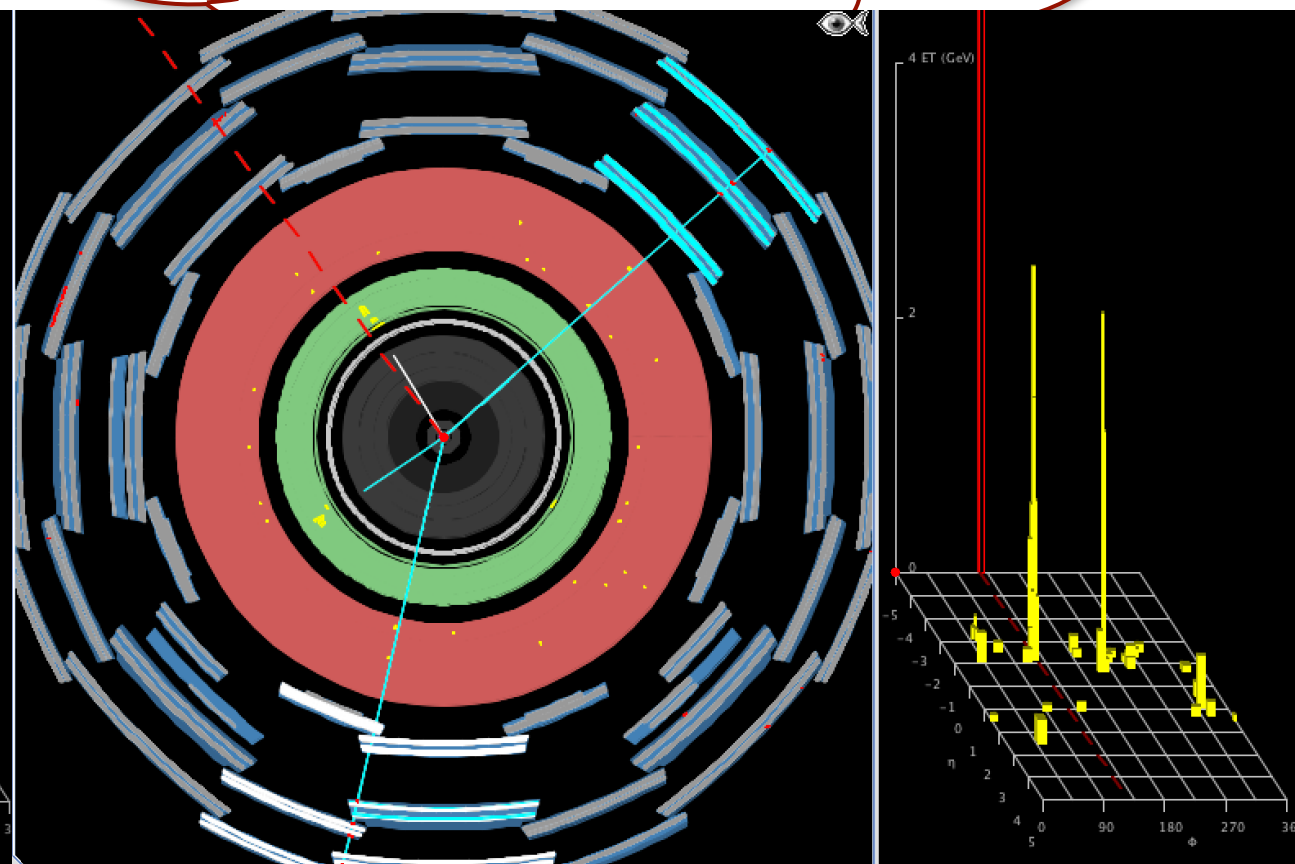
$$H^0 \rightarrow \gamma\gamma$$

Zapis u detektoru sadrži jedan para fotona.



$$H^0 \rightarrow Z^0 Z^0 \rightarrow 4 \text{ leptona}$$

Zapis u detektoru sadrži dva para miona ili elektrona.



Čuvanje rezultata - invarijantne mase

Hybrid pupils' analysis tool for interactions in ATLAS - version 7.2.1 - Invariant Mass Window

File View Histograms Preferences Help

Read Event Locally
 Read Event From URL (live)
 Clear Hypatia Project
 Load Hypatia Project
 Save Hypatia Project
Export Invariant Masses (MII)
 Loop over events
 Save Image of Canvas
 Animated Event
 Event Properties
 Read Geometry
 Read G4Steps
 Exit

ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	φ	η	M(2l) [GeV]	M(4l) [GeV]	e/ μ
9.980	Tracks 2	6.9	+	2.5	1.917	1.662	13.167		e
	Tracks 5	6.7	-	1.2	3.127	-2.391			e
	Tracks 4	5.8	+	1.0	-2.037	2.401	6.195		μ
	Tracks 8	1.9	-	1.1	-2.995	-1.136			μ
28.772	Tracks 6	3.9	+	3.8	-2.674	0.147	8.274		e
	Tracks 10	7.5	+	2.4	1.902	-1.796			e

Previous Event Next Event Insert Electron Insert Muon Delete Track Reset Canvas
 ETMis: 23.276 GeV φ : -2.006 rad Collection: MET_Reffinal
 /Users/nenadv/Downloads/groupA-1/event006.xml

Reconstructed Tracks

Track	+/-	P [GeV]	Pt [GeV]	φ	θ
s 1	+	117.38	42.10	1.169	2.775
s 2	+	12.75	2.50	-0.965	2.944
s 3	+	4.28	1.25	-2.531	2.846
s 4	-	17.94	6.68	1.240	2.760
s 5	+	3.35	1.19	1.057	2.777
s 6	+	3.87	3.83	-2.674	1.425
s 8	-	7.01	6.92	-2.596	1.414
s 9	+	8.62	3.61	-1.861	0.431
s 10	+	7.48	2.42	1.902	2.813
s 11	+	3.03	2.10	-0.237	0.763
s 13	-	1.69	1.23	-1.888	2.327
s 14	-	5.29	2.45	-1.734	0.482
s 15	-	3.90	1.80	-1.566	0.480
s 17	+	3.54	1.30	-1.211	2.766
s 18	-	9.05	2.99	2.147	2.805
s 20	-	6.17	1.06	-1.262	0.173
s 23	-	1.07	1.06	-2.187	1.419
s 24	-	11.34	11.20	-2.706	1.415
s 25	-	5.19	1.33	1.715	2.882
s 29	+	9.95	1.75	0.060	0.176
s 31	+	3.40	1.60	-0.837	0.489
s 34	+	1.34	1.32	2.876	1.416
s 36	+	8.72	3.71	0.804	0.439
s 39	-	24.27	8.30	1.160	2.793
s 41	+	2.17	2.17	-2.828	1.623
s 44	+	1.80	1.77	2.560	1.384
s 46	-	3.64	2.05	0.331	2.543

HYPATIA - Control Window
 meter Control Interaction and Window Control Output Display
 Event Data
 W S X LMR 123 U 3
 B 456 C 6
 789 D 9

Konačni rezultati

OPlOT – MasterClass – Student page

Start Student Moderator Tutor Administrator

Student Tasks

Please select items from the drop-down boxes to submit your results!

2022 April 04 Novi Sad 6

Group letter

- A
- B
- C
- D**
- E
- F
- G
- H
- I
- J
- K
- L
- M
- N
- O
- P
- Q
- R
- S
- T

Sačuvajte podatke pod imenom vaše grupe (A, B, C...), i submit-ujte ih na: <http://cernmasterclass.uio.no/OPlOT/>

Konačni rezultati

OPIoT – MasterClass – Student page

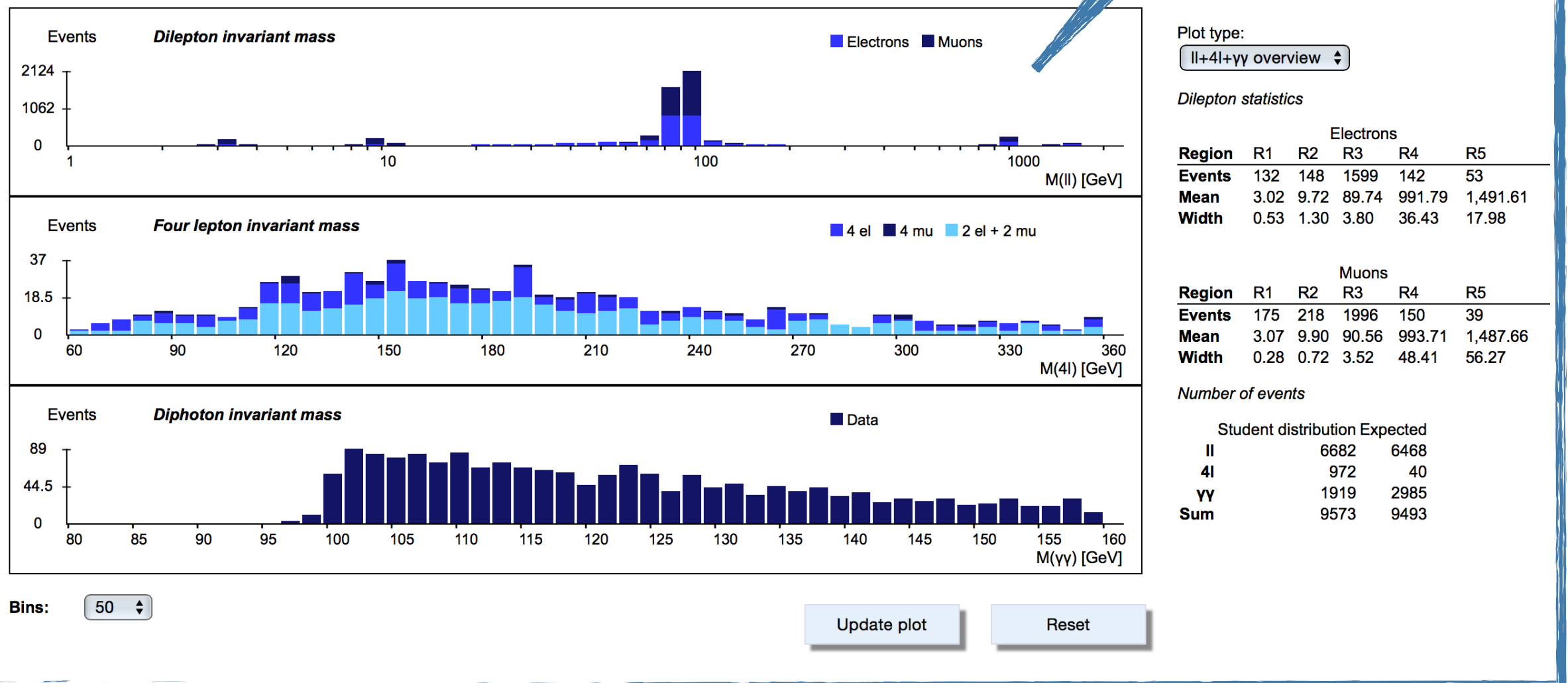
Start Student Moderator Tutor Administrator

Student Tasks

Please select items from the drop-down boxes to submit your results!

2022 April 04 Novi Sad 6 ✓ Group letter A

distribucije invariantnih masa svih analiziranih događaja



Konačni rezultati

OPIoT – MasterClass – Student page

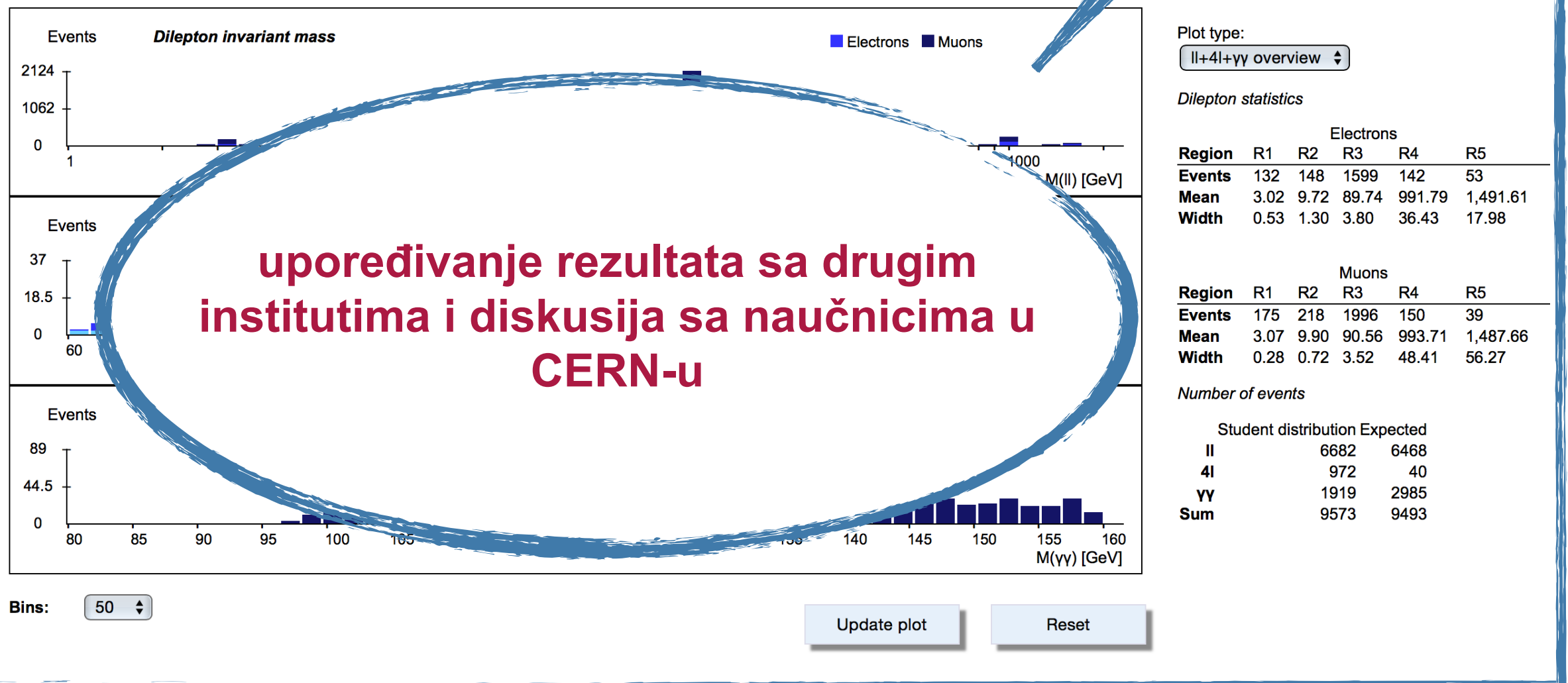
Start Student Moderator Tutor Administrator

Student Tasks

Please select items from the drop-down boxes to submit your results!

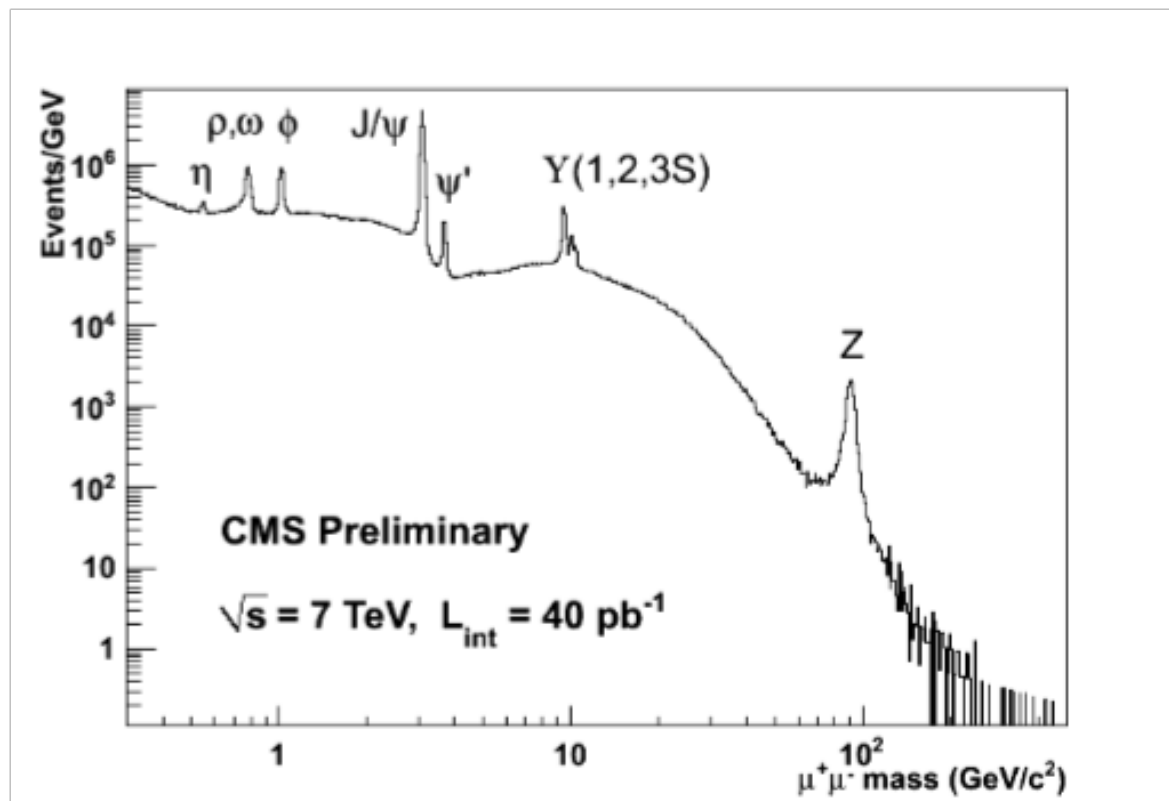
2022 April 04 Novi Sad 6 ✓ Group letter A

distribucije invariantnih masa svih analiziranih događaja

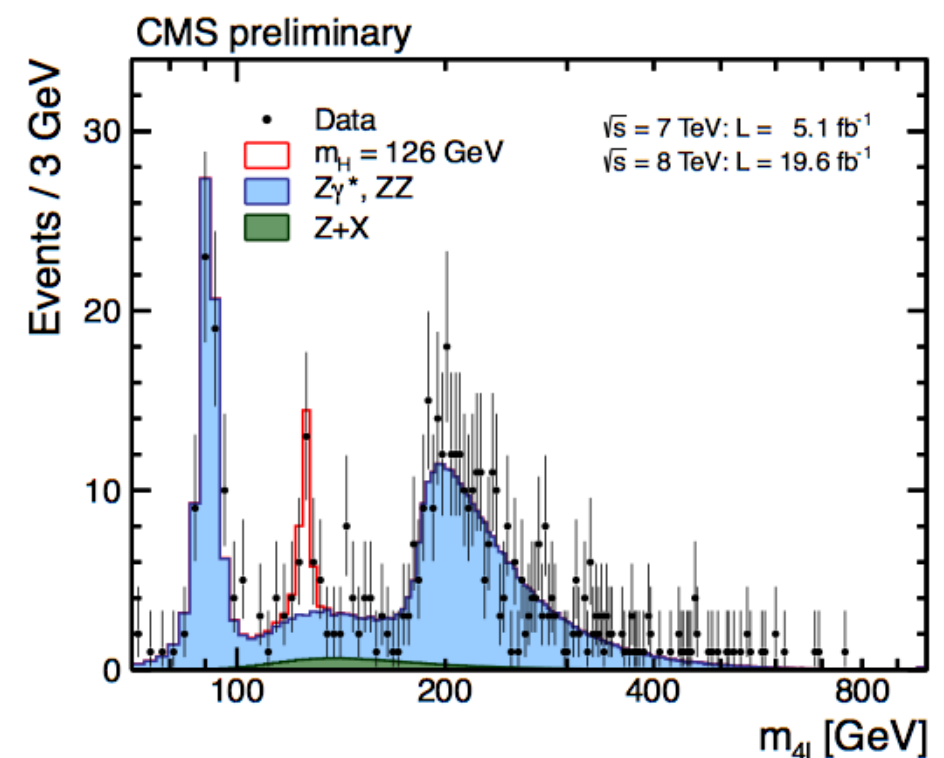


Maseni spektar za jedan ili dva Z^0 bozona

Masesni spektar J/Psi i Y mezona, Z^0 bozona i mnogih drugih čestica



Masesni spektar za par Z^0Z^0 bozona



Kreirajte i vi histogram invarijantne mase za vaše događaje!

Mozda ćete baš vi imati sreće da pronađete događaje koji su potencijalno raspadi Higgs bozona na par fotona ili par Z^0Z^0 bozona!



Nadamo se da čete uživati i da čete se dobro zabaviti!

Run: 204153
Event: 35369265
2012-05-30 20:31:28 CEST