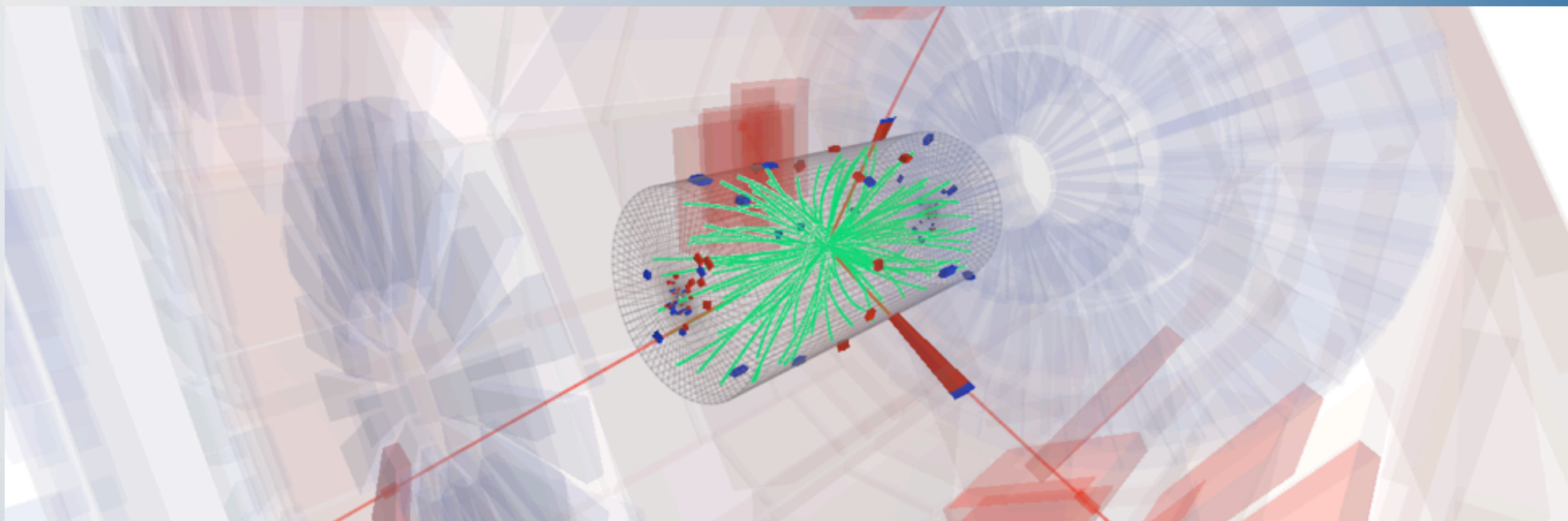


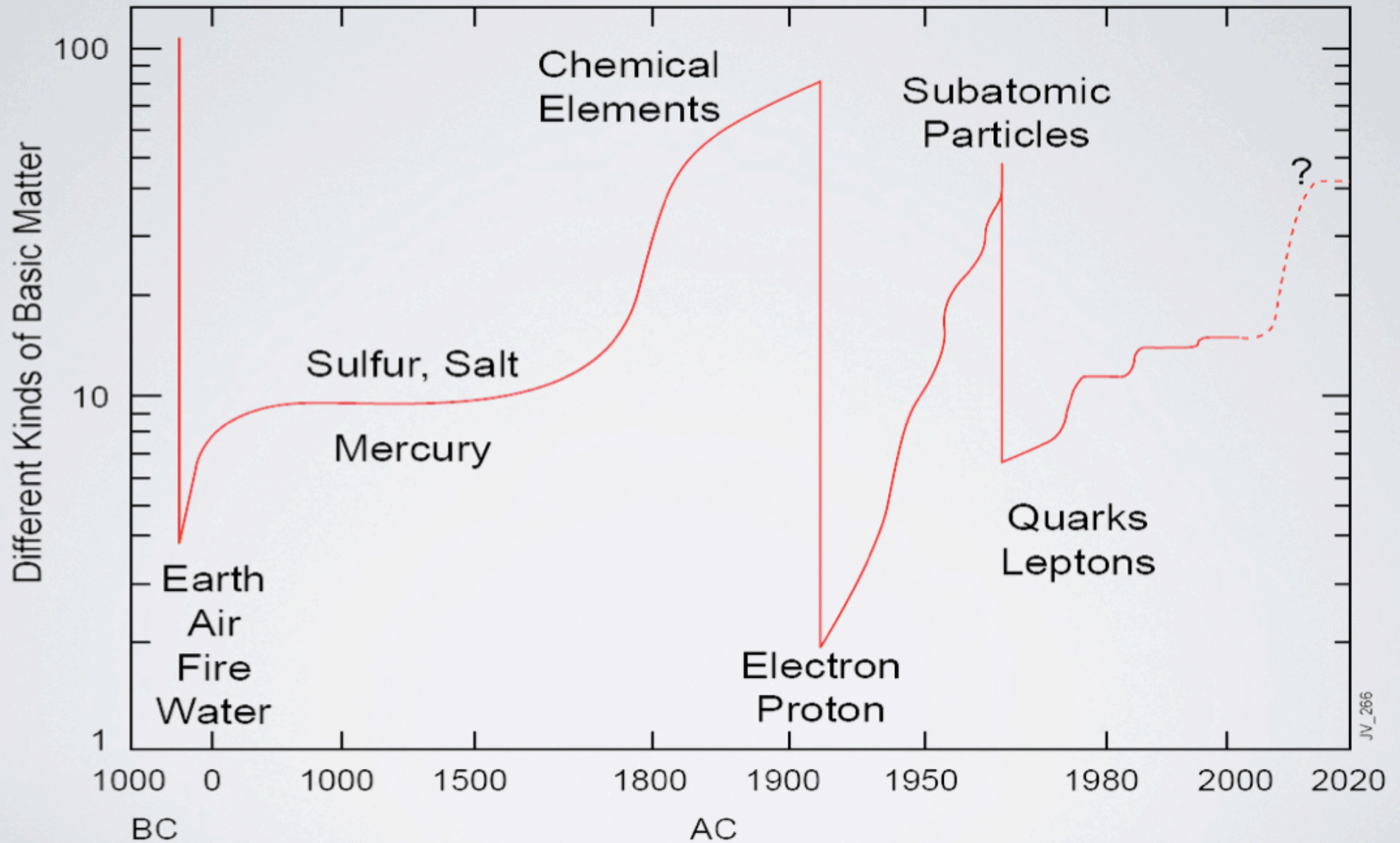
# OTKRIĆE HIGGS BOZONA (?) - II DEO

Dr Predrag Milenović

**“CERN u Srbiji”, Beograd, Oktobar 2012**



# Osnovni gradivni blokovi materije



# Standardni Model i Veliki Hadronski Sudarač

- Fizika elementarnih čestica danas

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}^a F^{a\mu\nu} + i\bar{\psi}D\psi \quad \text{The gauge sector (1)}$$

$$+ \psi_i \lambda_{ij} \psi_j h + h.c. \quad \text{The flavor sector (2)}$$

$$+ |D_\mu h|^2 - V(h) \quad \text{The EWSB sector (3)}$$

provereno, izvanredna preciznost

značajan razvoj poslednjih godina

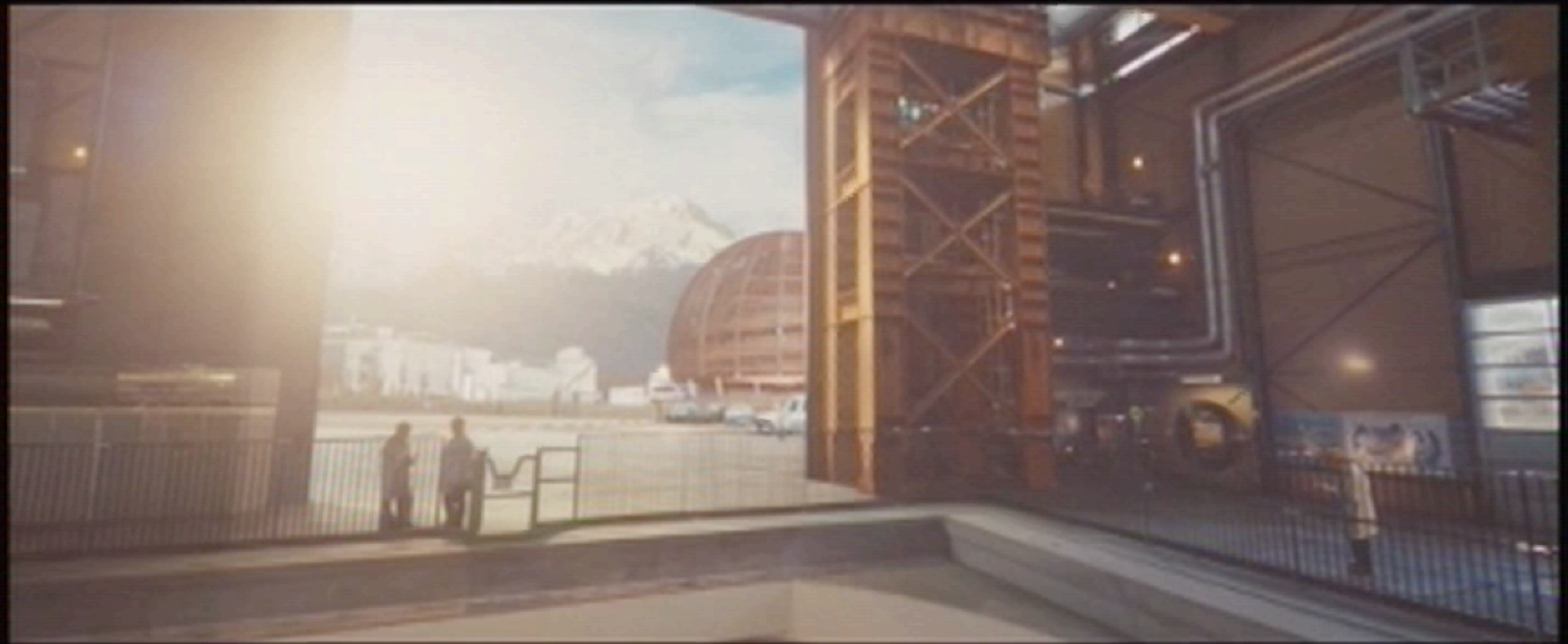
obavijeno misterijom... do sada...

- Testiranje Standardnog modela i otvorena fundamentalna pitanja  
**Prioritet:** Narušenje elektroslabe simetrije i Higgs-ov mehanizam

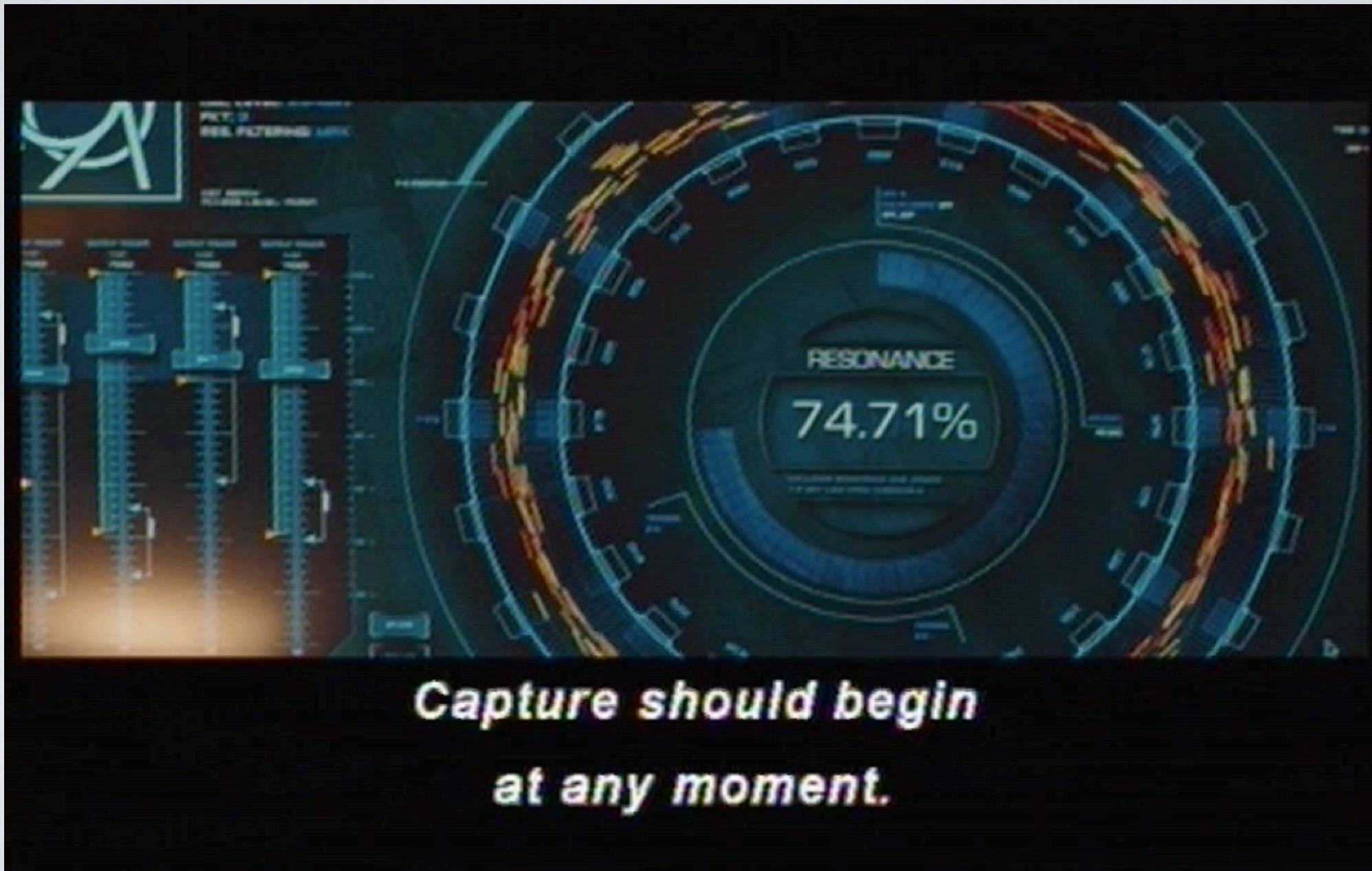


Large Hadron Collider, proton-proton sudari na energijama od 7/8 TeV

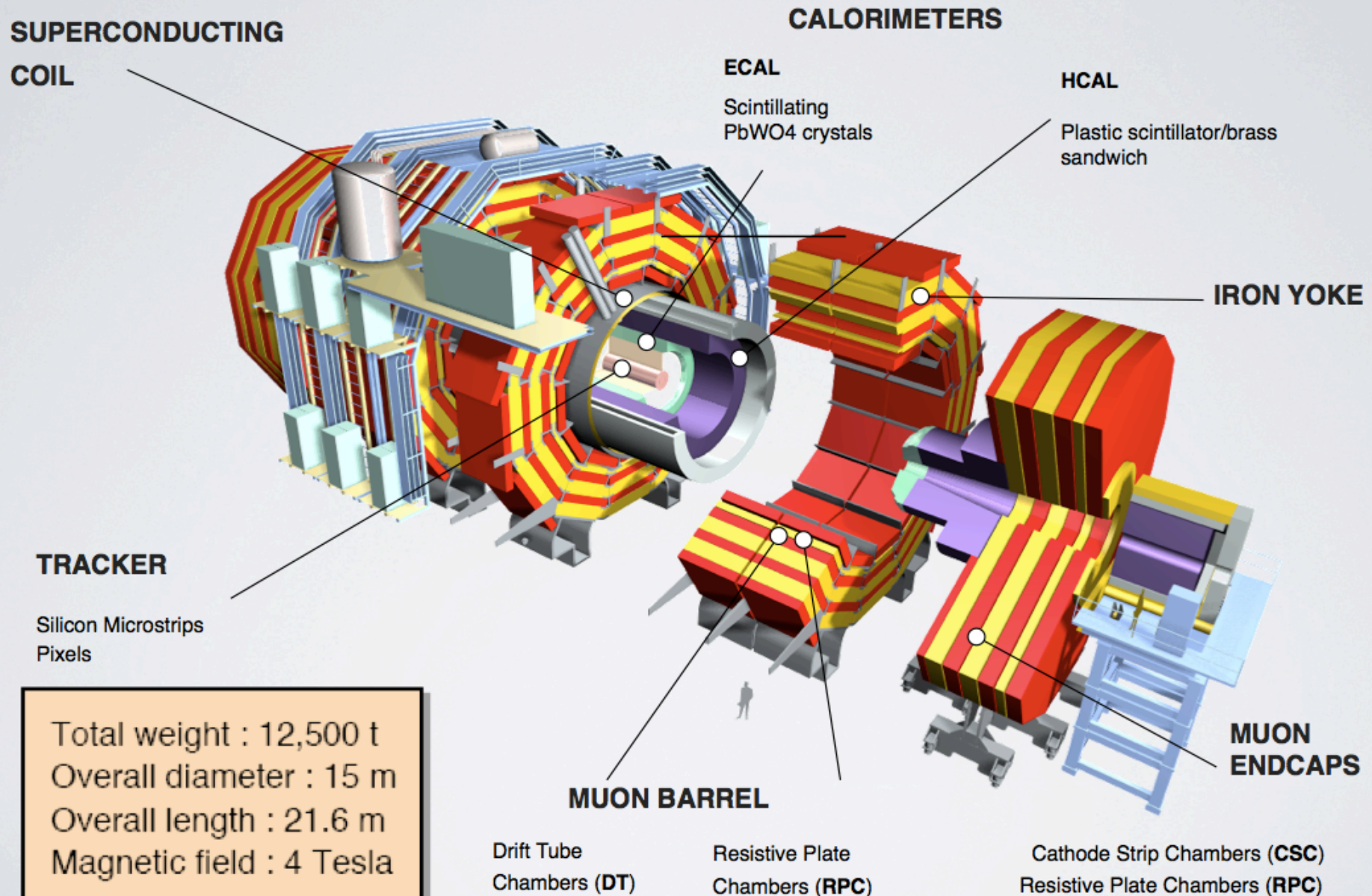
# U Hollywood nisu nikada sagradili detektor..



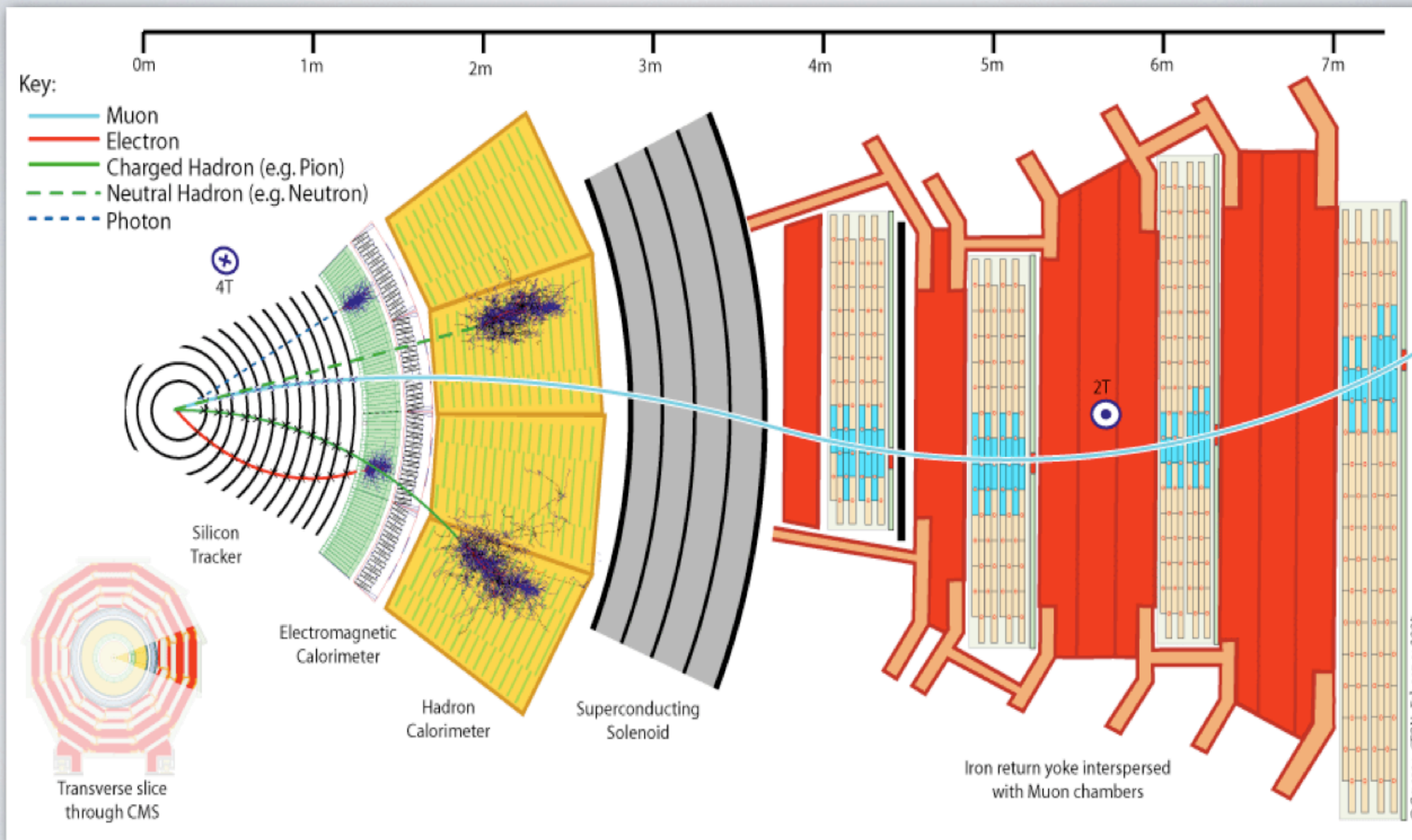
**...ali misle da znaju kako on radi!**



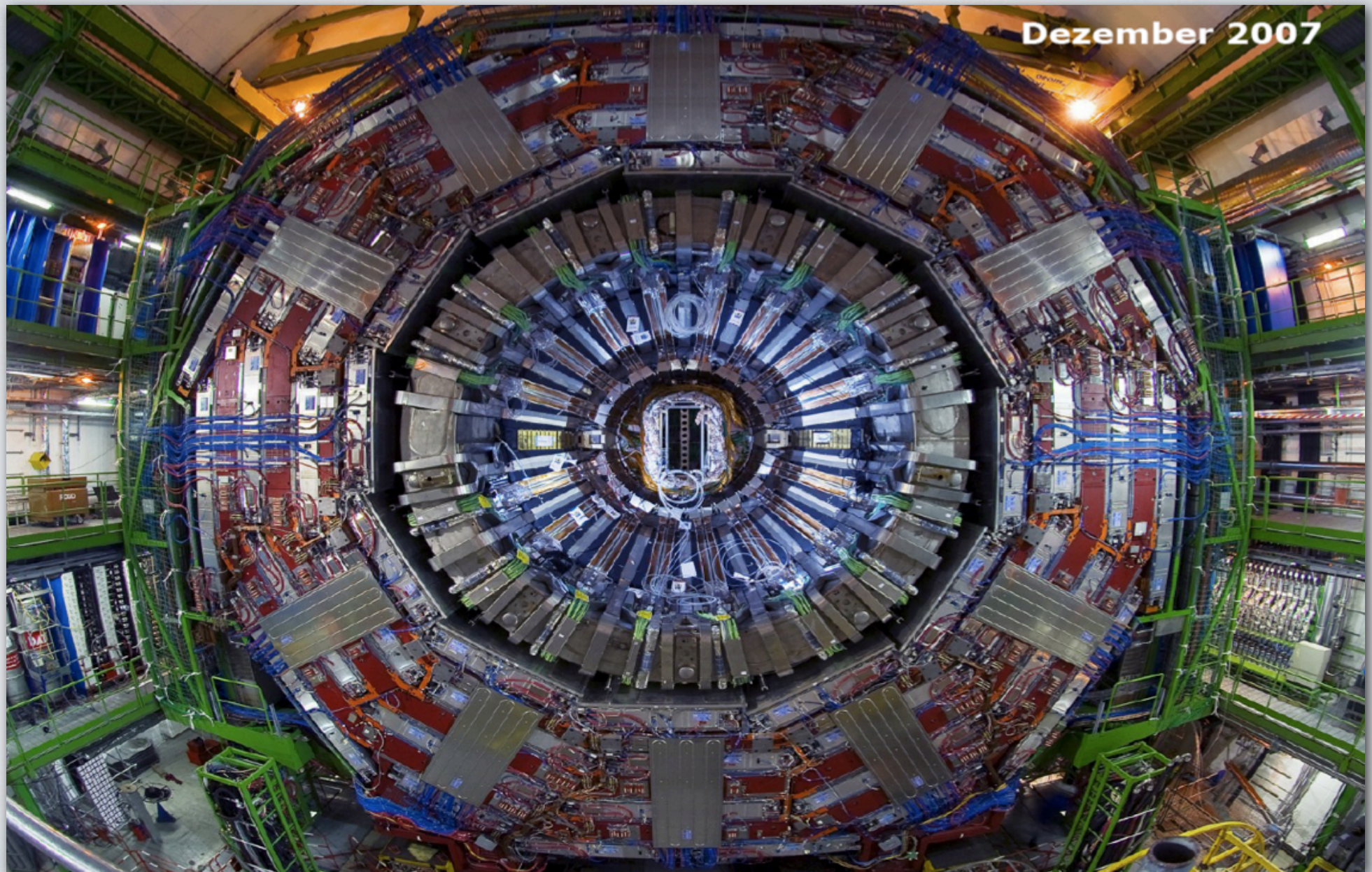
# Kompaktni Mionski Solenoid (CMS)



# Rekonstrukcija čestica

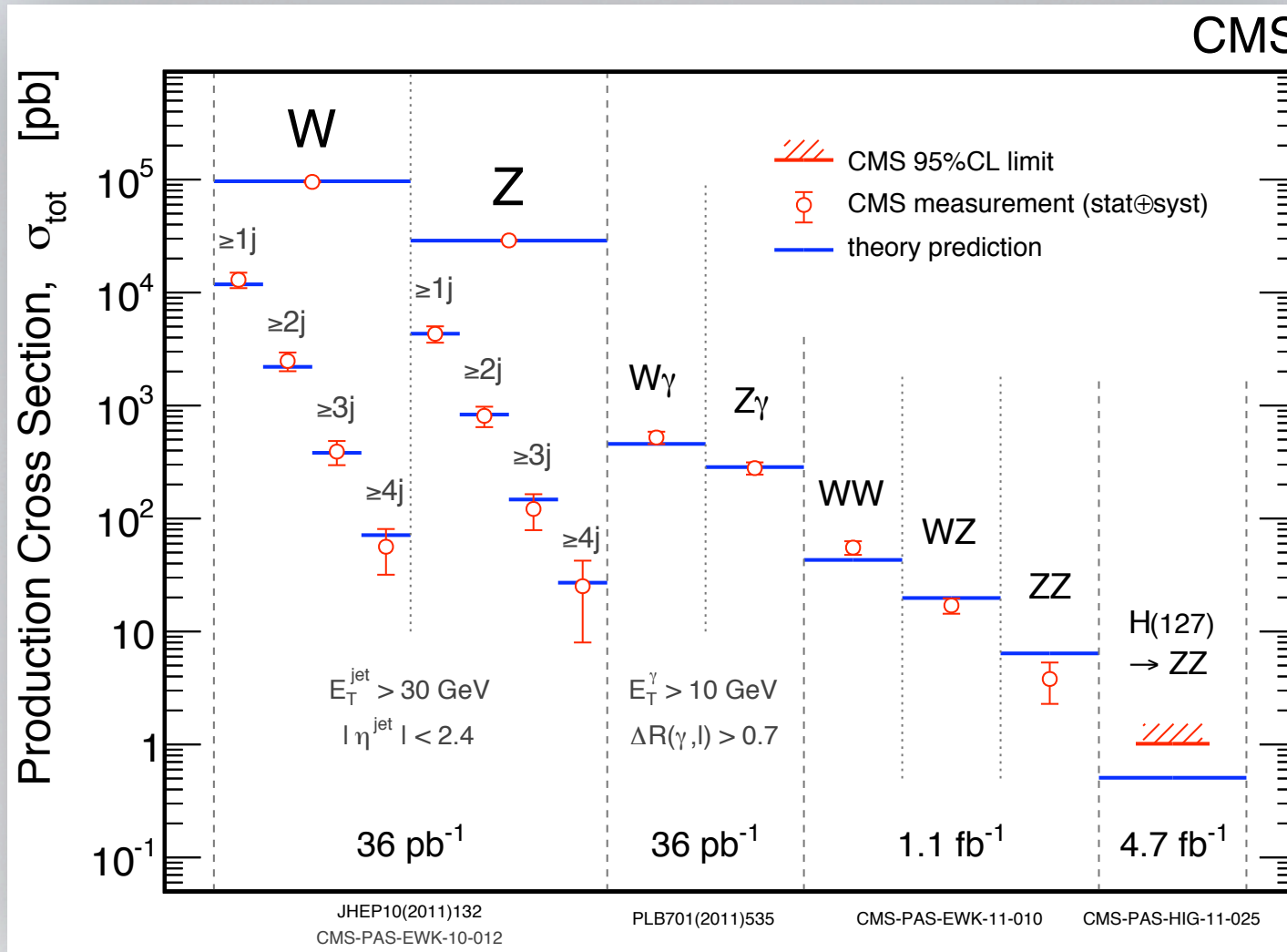


# CMS u punom sjaju...





# Testiranje teorije elektroslabih interakcija

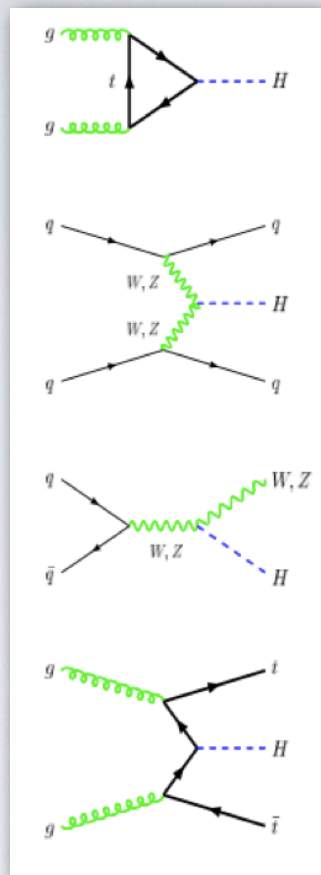


**Neverovatan uspeh Standardnog modela!!!**

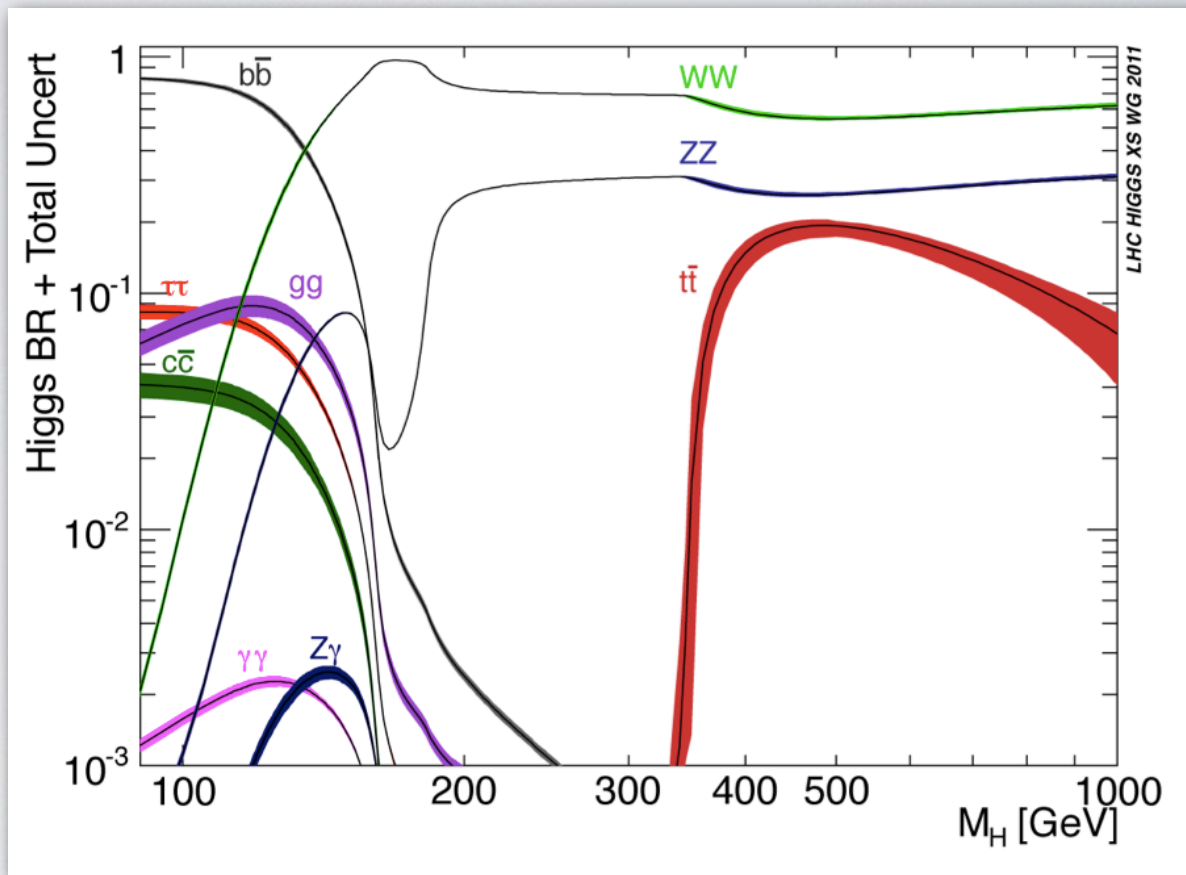
(posledica investiranog ogromnog teorijskog i eksperimentalnog rada)

# Produkcija Higgs bozona i načini raspada

## Produkcija



## Načini raspada i njihove verovatnoće



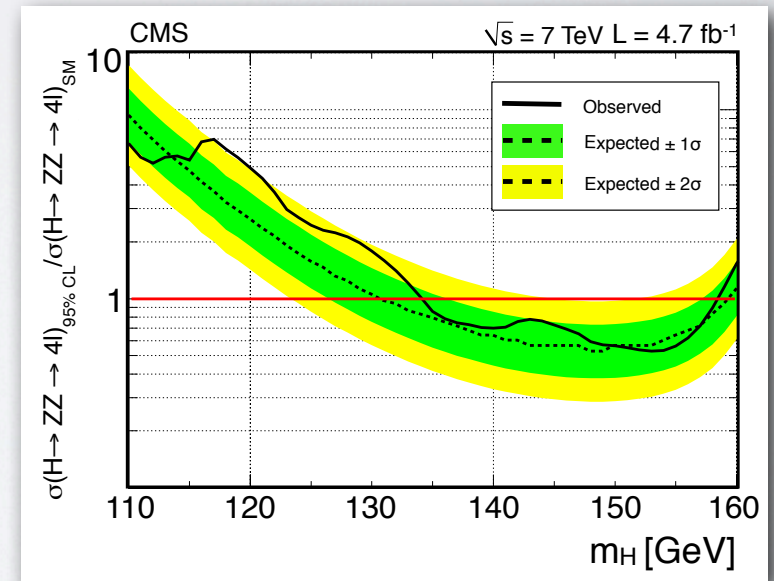
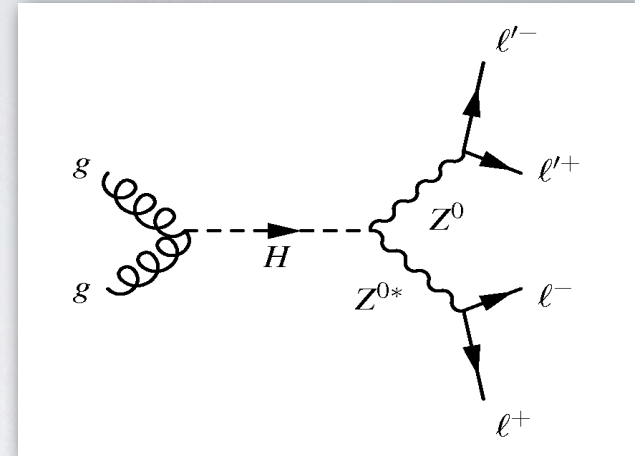
Glavni kandidati sa detekciju Higgs-a:

Male mase:  $H \rightarrow \gamma\gamma$ ,  $H \rightarrow ZZ$

Srednje-visoke mase:  $H \rightarrow WW$ ,  $H \rightarrow ZZ$

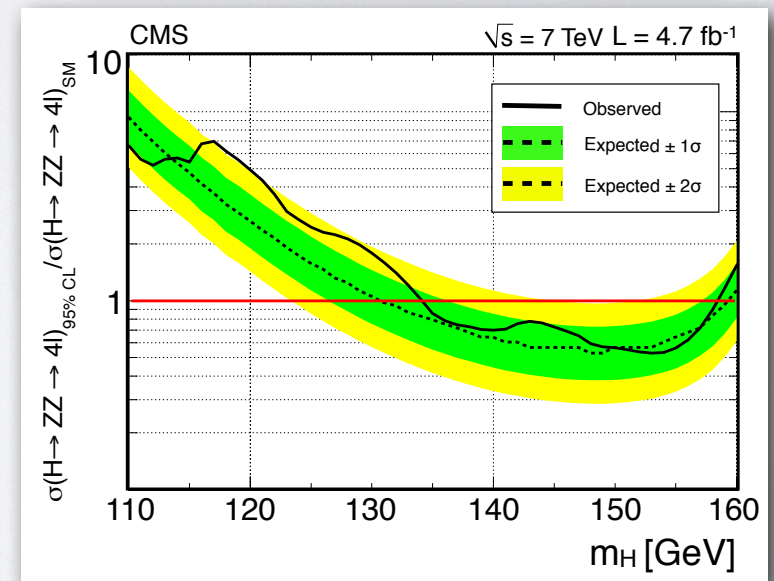
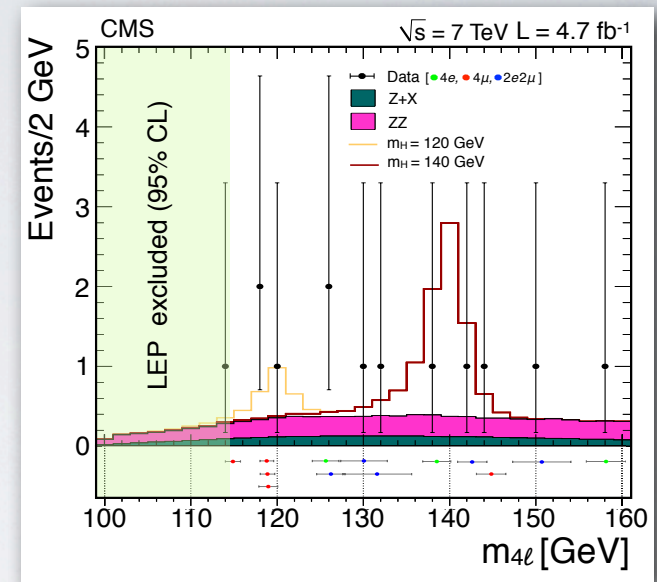
# H → ZZ → 4l

- Zlatan kanal
  - Lako prepoznatljiv zapis u detektoru
  - ➡ profitira zbog izvanredne rezolucije
  - **Uska rezonanca** u spektru mase Četiri leptona
- Pozadinski procesi (šum)
  - “Nerazlučivi” šum:  $pp \rightarrow ZZ^* \rightarrow 4l$
  - “Razlučivi” šum:  $pp \rightarrow Z + \text{jets}$
- Osetljivost analize
  - $115 < m_H < 600 \text{ GeV}$
- Bitni aspekti
  - Precizna rekonstrukcija leptona
  - Precizna procena šuma
  - **Optimalno iskorišćenje kinematičke informacije**



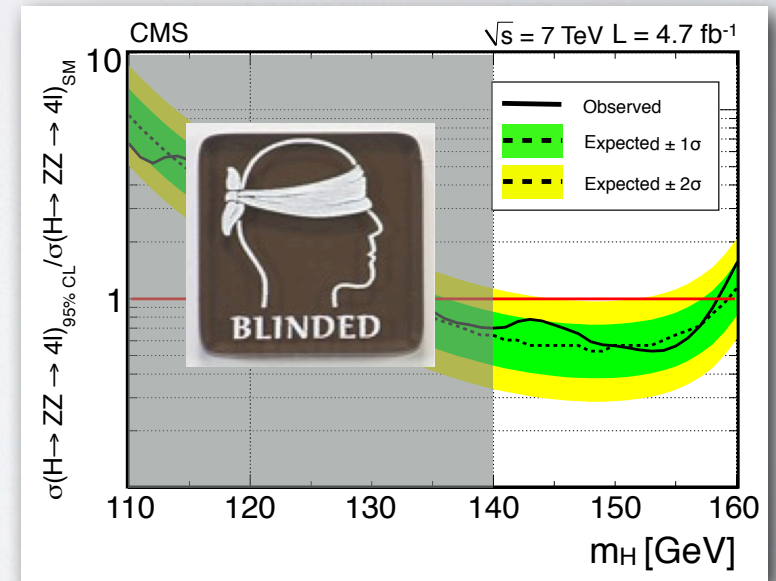
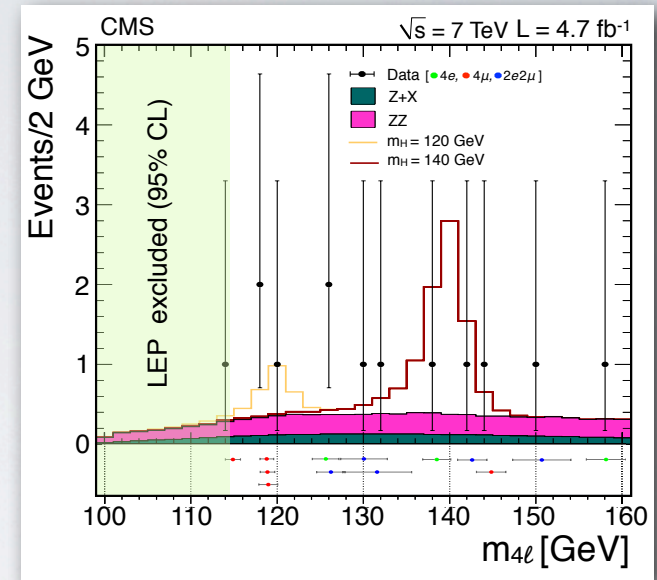
# H → ZZ → 4l

- Zlatan kanal
  - Lako prepoznatljiv zapis u detektoru
  - ➡ profitira zbog izvanredne rezolucije
  - Uska rezonanca u spektru mase Četiri leptona
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  - Precizna procena šuma
  - Optimalno iskorišćenje kinematičke informacije



# H → ZZ → 4l

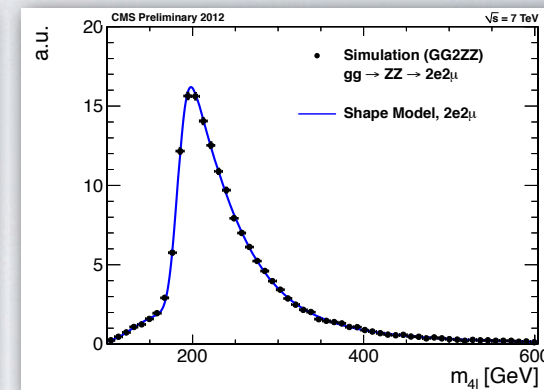
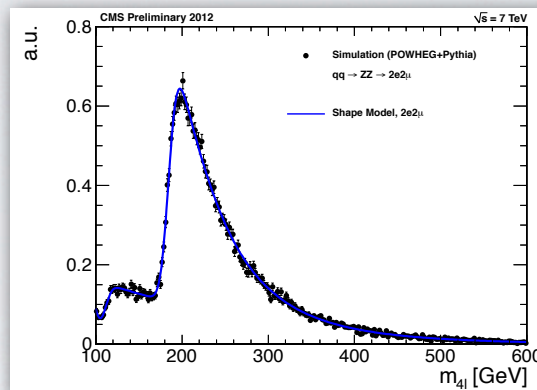
- Zlatan kanal
  - Lako prepoznatljiv zapis u detektoru
  - ➡ profitira zbog izvanredne rezolucije
  - Uska rezonanca u spektru mase Četiri leptona
- Pozadinski procesi (šum)
  - “Nerazlučivi” šum:  $pp \rightarrow ZZ^* \rightarrow 4l$
  - “Razlučivi” šum:  $pp \rightarrow Z + jets$
- Osetljivost analize
  - $115 < m_H < 600$  GeV
- Bitni aspekti
  - Precizna rekonstrukcija leptona
  - Prezicna procena šuma
  - Optimalno iskorišćenje kinematičke informacije



# Model pozadinskih procesa (šuma)

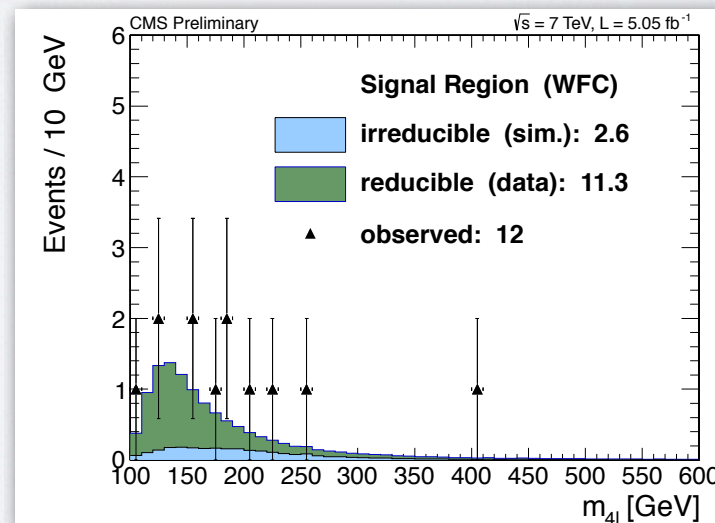
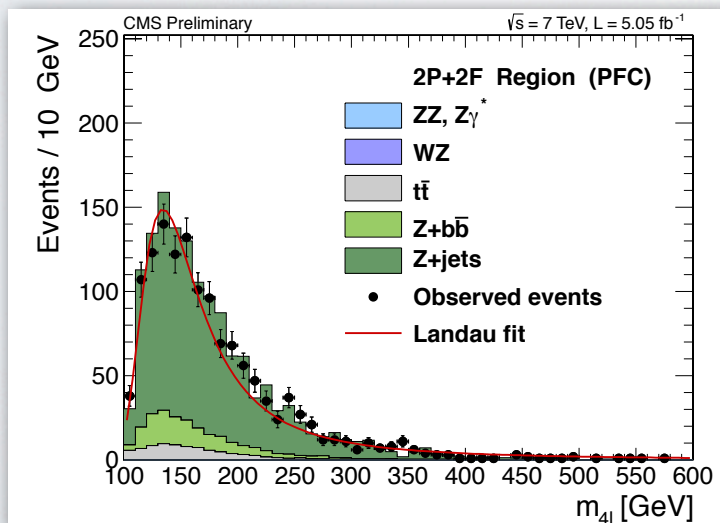
- ‘Nerazlučivi’ šum

- Procena na osnovu simulacije
- Dodatna korekcija na osnovu izmerenih razlika između simulacije i podataka



- ‘Razlučivi’ šum na osnovu merenja u stvarnim podacima

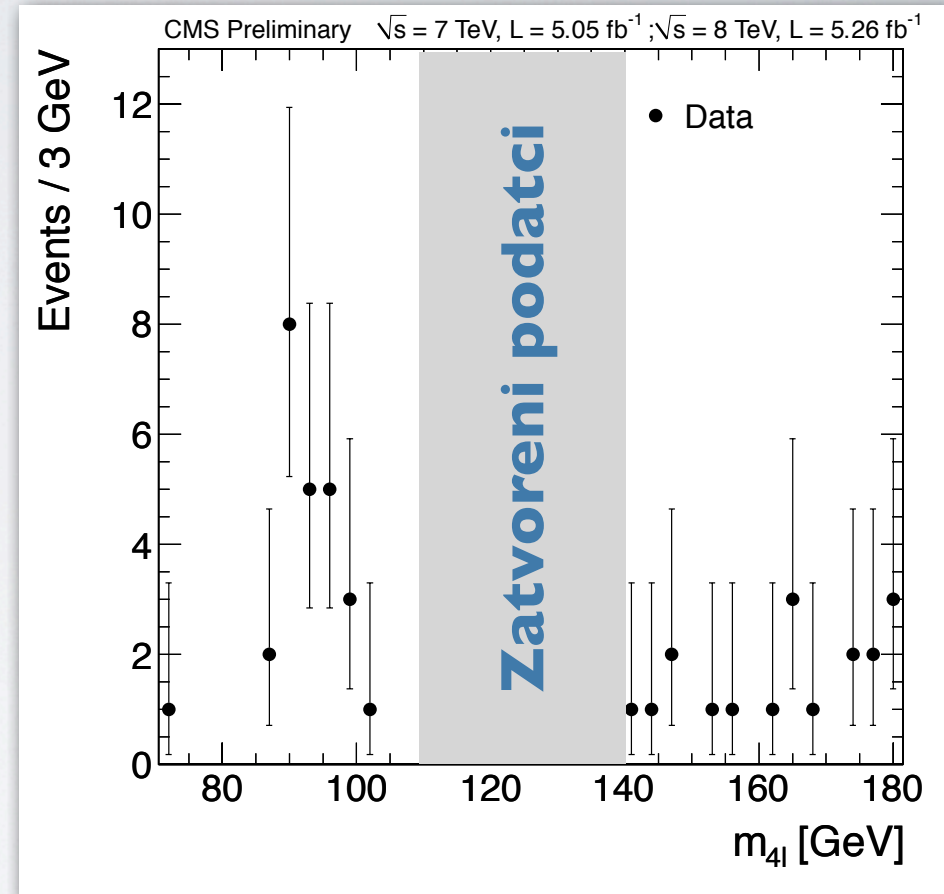
- Ekstrapolacija iz dela podataka obogaćenog pogrešno identifikovanim leptonima
- Totalna neodređenost ispod 50%



# Rezultati

## Region niskih masa

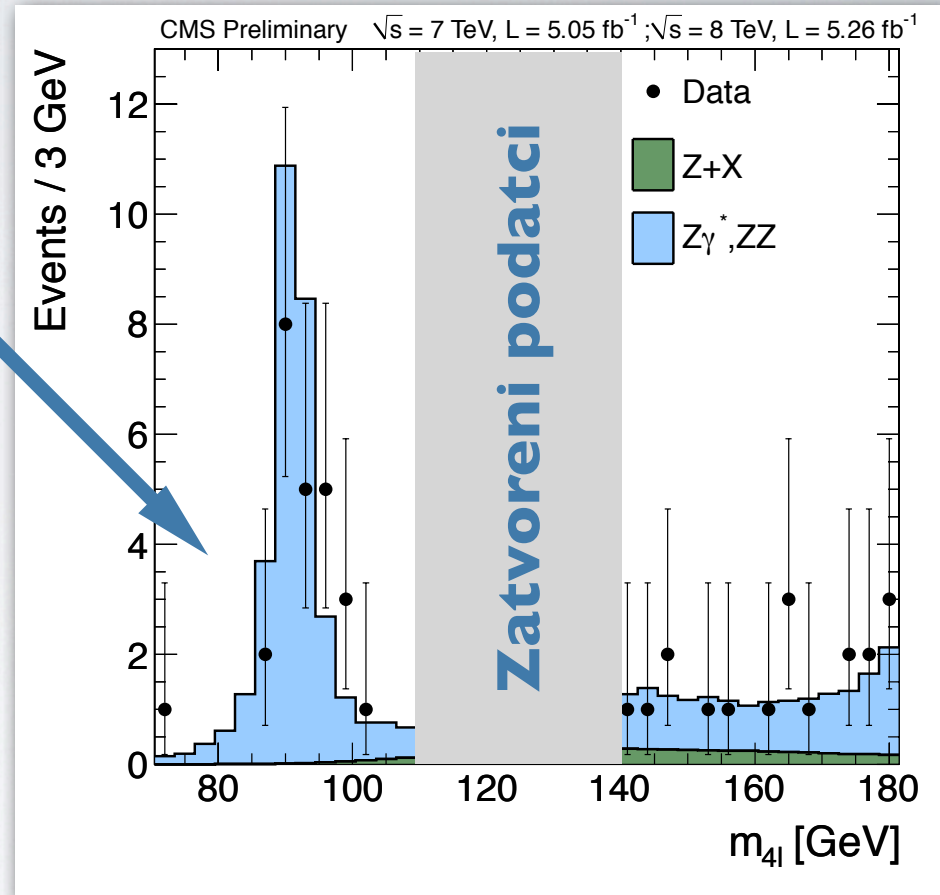
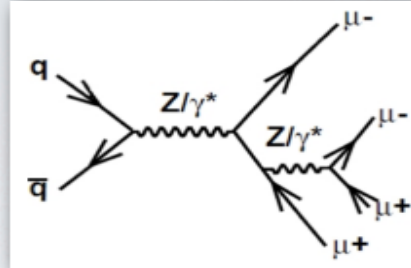
- Izmereni podatci
- **Zatvoreni**



# Rezultati

## Region niskih masa

- Izmereni podatci
- **Zatvoreni**
- Procenjeni pozadiski događaji

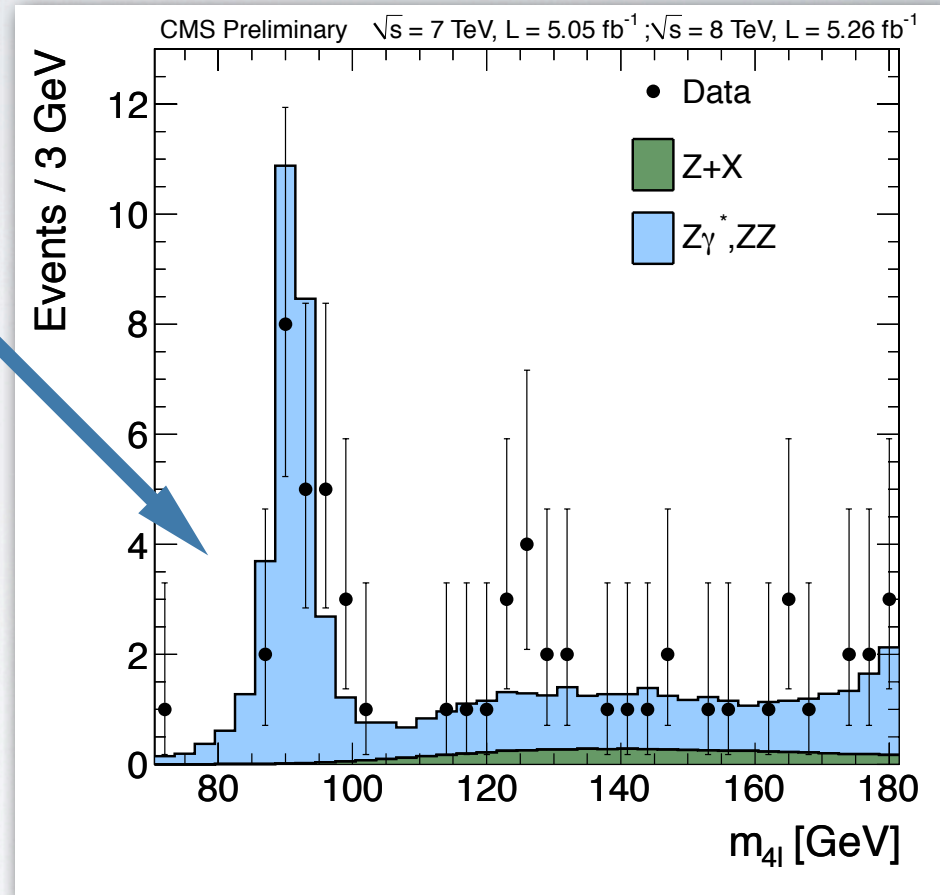
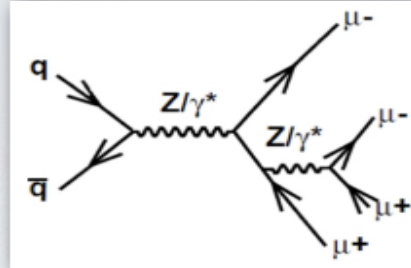




# Rezultati

## Region niskih masa

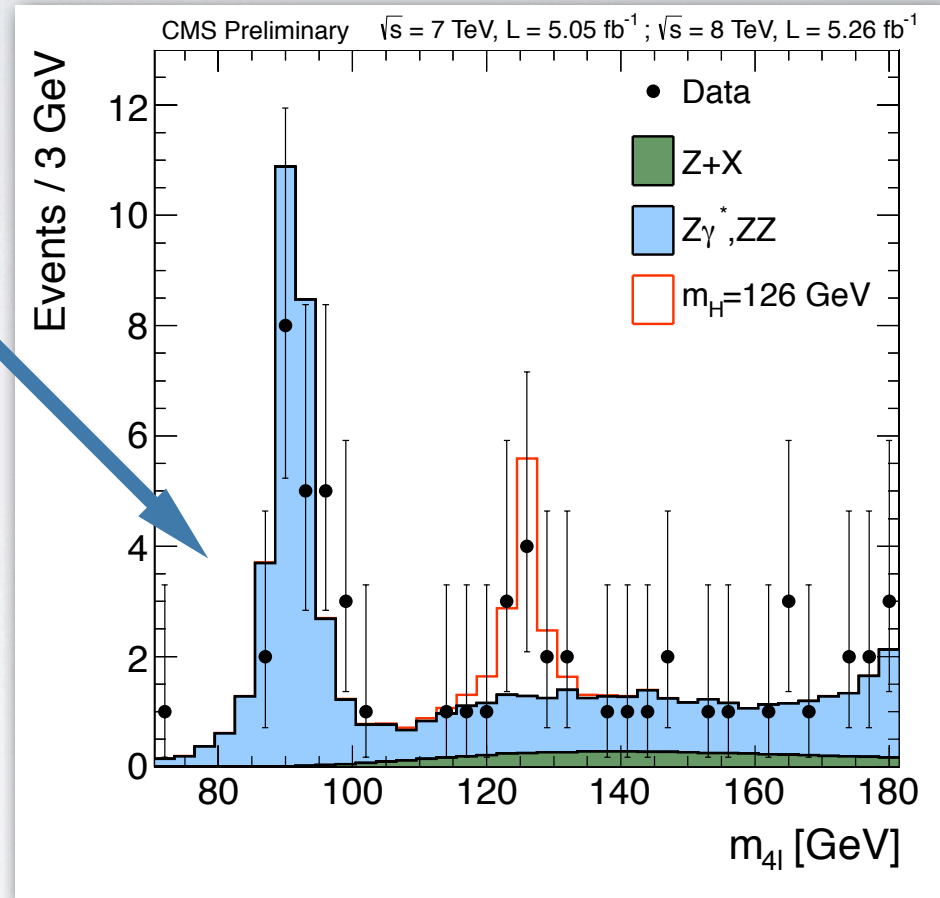
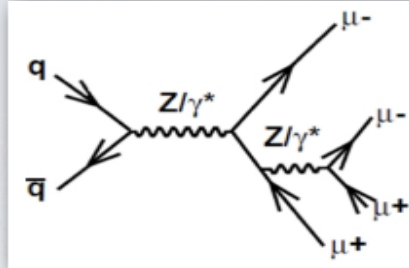
- Izmereni podatci
- **Otvoreni**
- Procenjeni pozadinski događaji



# Rezultati

## Region niskih masa

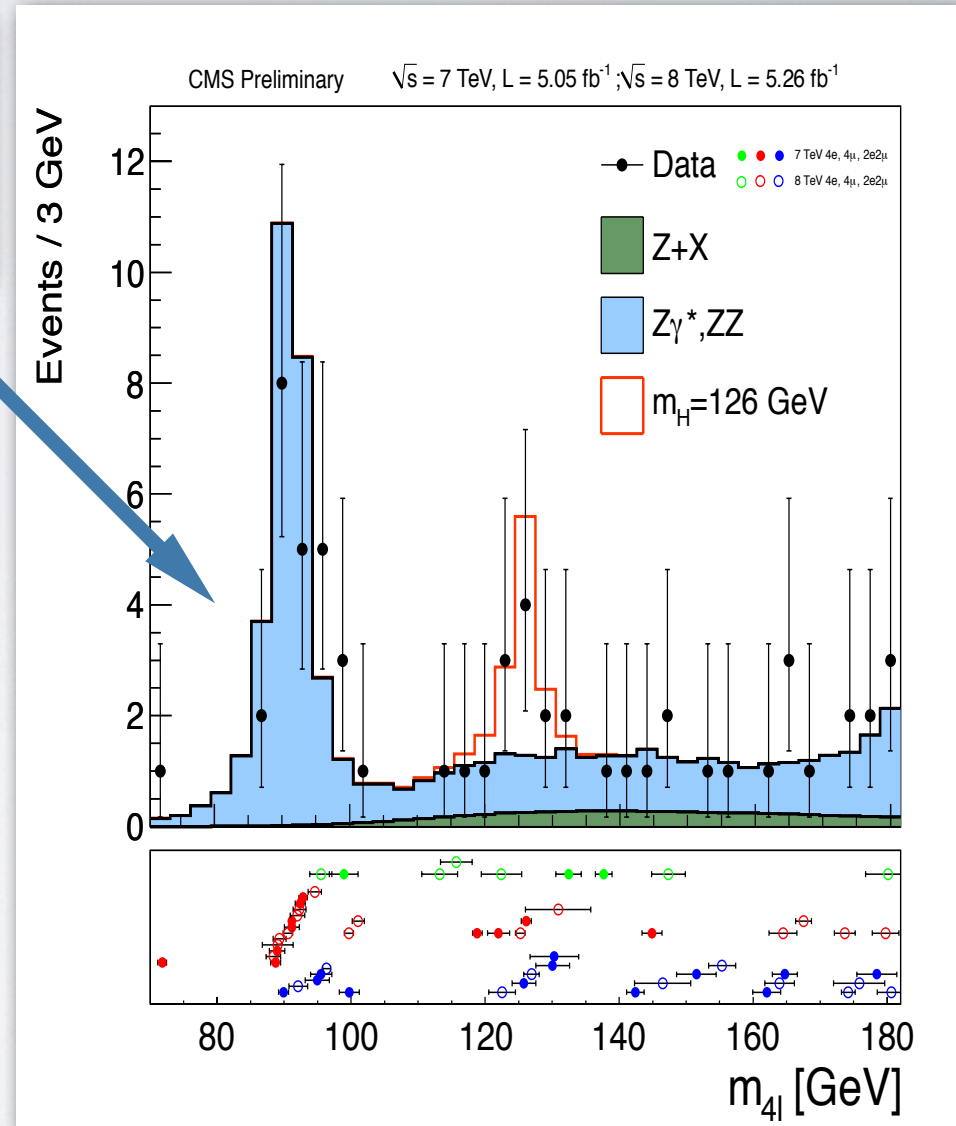
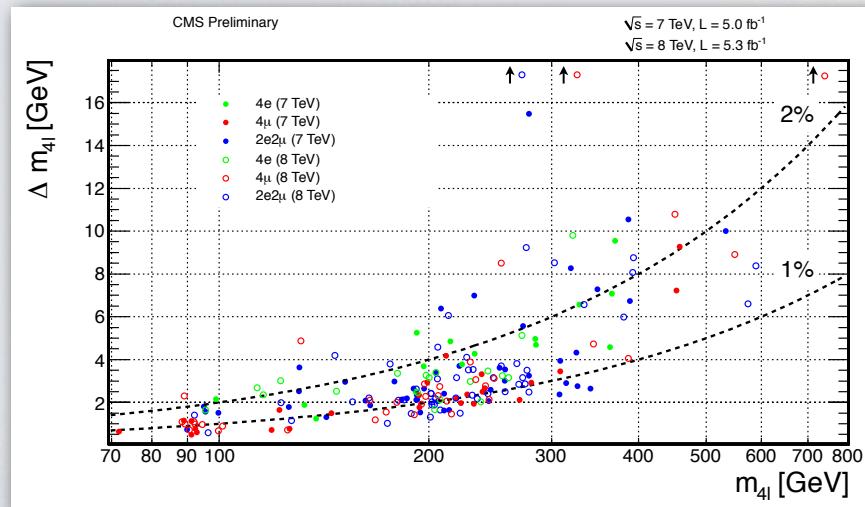
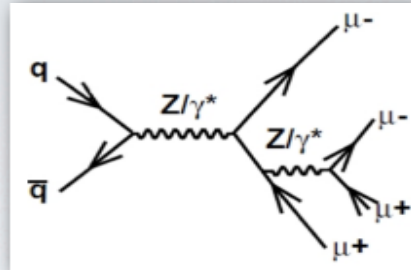
- Izmereni podatci
- **Otvoreni**
- Procenjeni pozadinski događaji
- Očekivan signal na  $m_H = 126 \text{ GeV}$



# Rezultati

## Region niskih masa

- Izmereni podatci
- **Otvoreni**
- Procenjeni pozadinski događaji
- Očekivan signal na  $m_H = 126 \text{ GeV}$
- Preciznost merenja mase

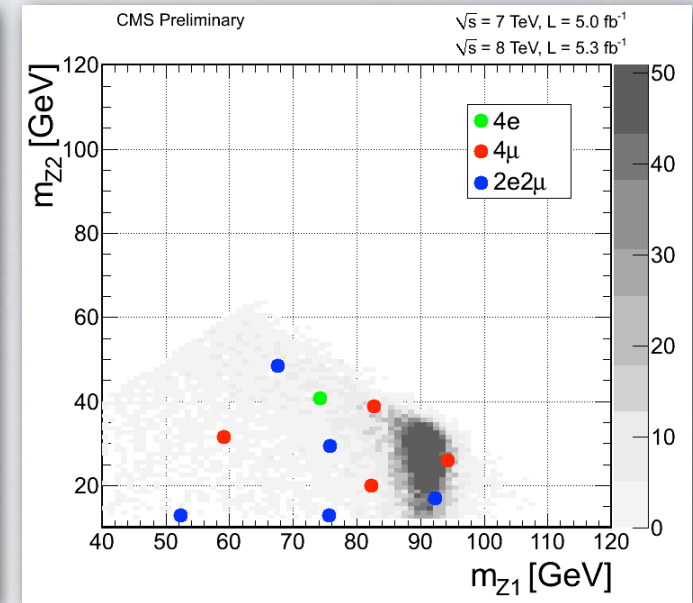
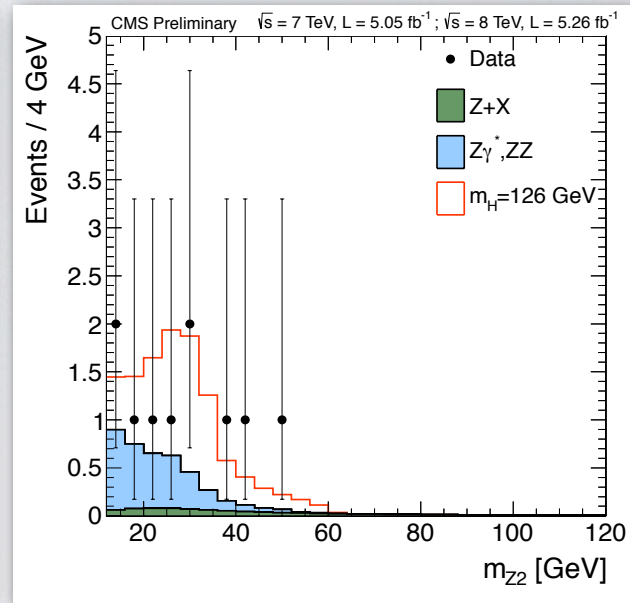
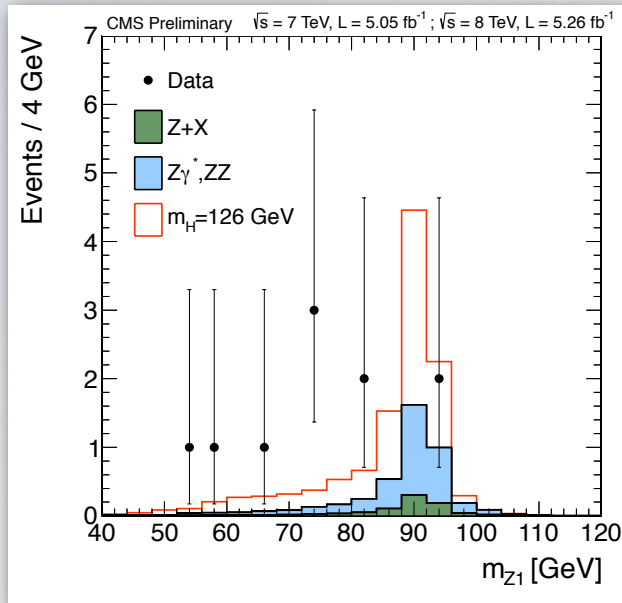


# “ Noć otvaranja”



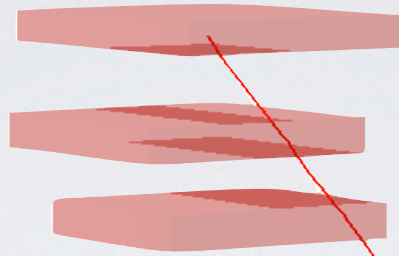
# Mase leptonskih parova

- Rekonstruisane mase leptonskih parova (kandidati za Z bozone)
- $121 \leq m_{4l} \leq 131$  GeV



➡ Mase  $Z_1$  i  $Z_2$  bozona su niže od očekivanih i za signal i za šum...?

# 3D slika događaja ( $H \rightarrow ZZ \rightarrow 2e2\mu$ )

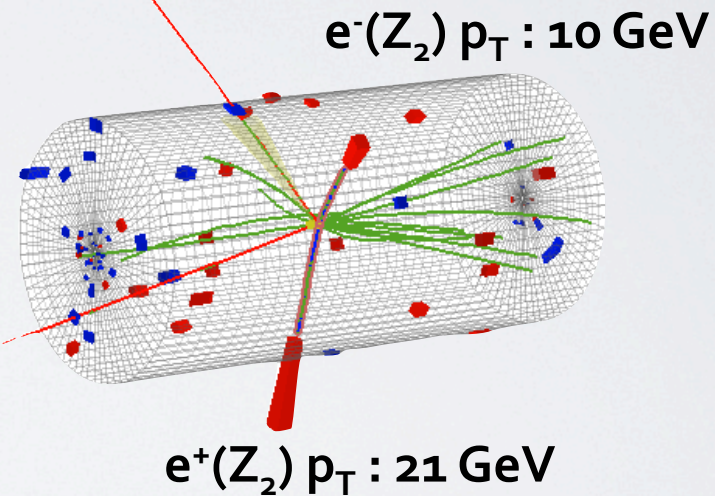
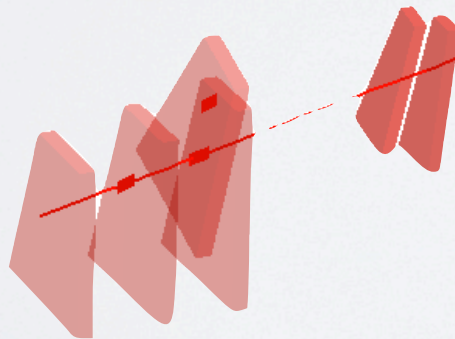


$\mu^+(Z_1) p_T : 43 \text{ GeV}$

8 TeV DATA

4-lepton Mass : 126.9 GeV

$\mu^-(Z_1) p_T : 24 \text{ GeV}$

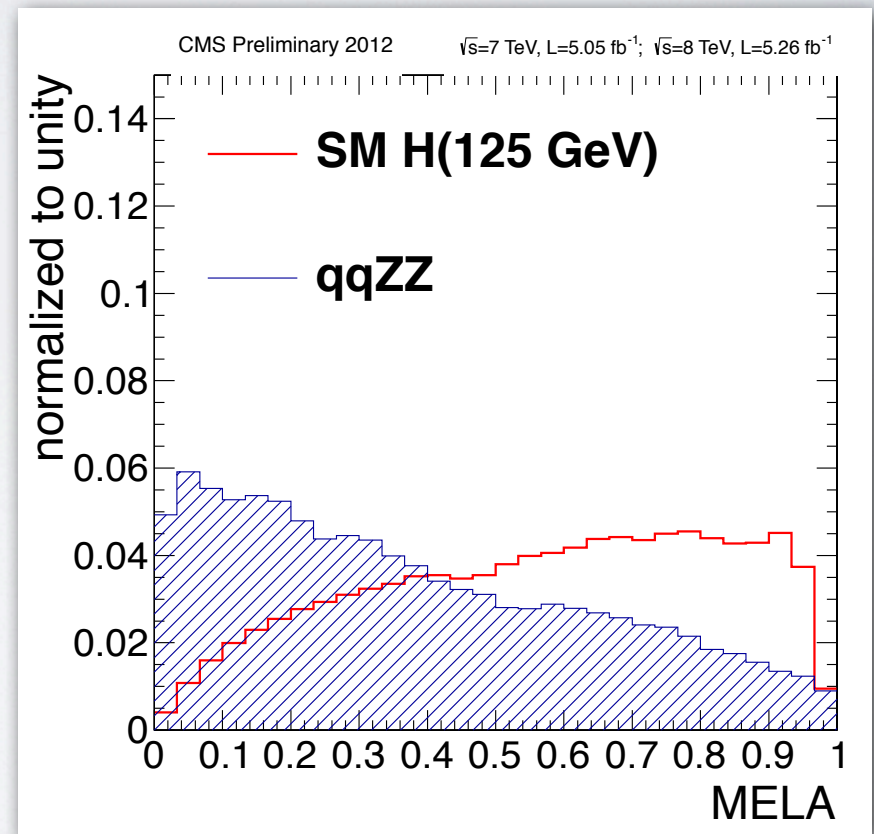
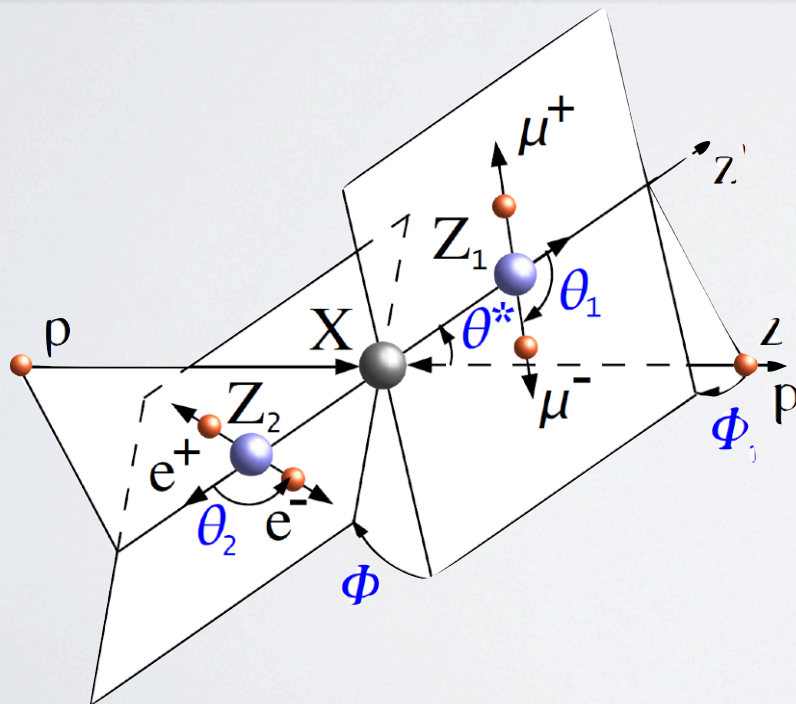


CMS Experiment at LHC, CERN  
Data recorded: Mon May 28 01:35:47 2012 CEST  
Run/Event: 195099 / 137440354  
Lumi section: 115

# Kinematička analiza

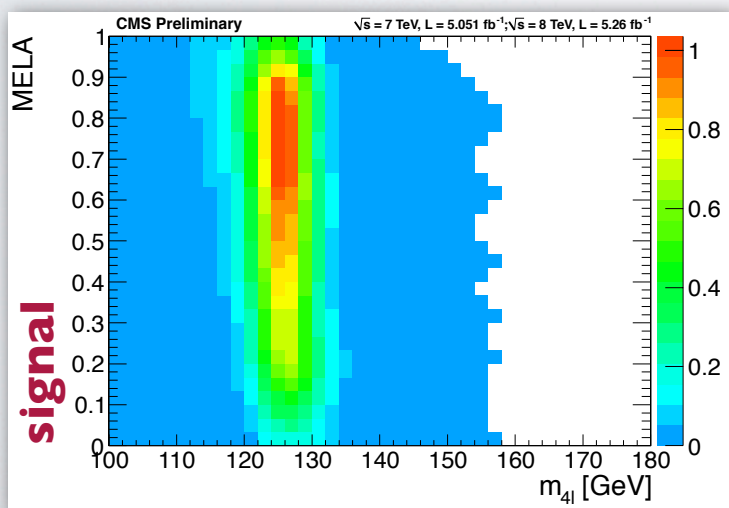
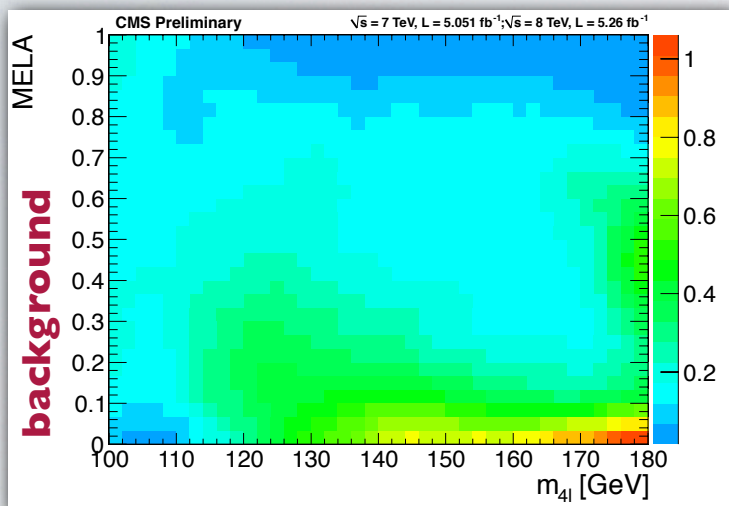
- **M**atrix **E**lement **L**ikelihood **A**nalysis (MELA):
  - Kinematika raspada opisana sa 5 uglova i 2 mase
  - Značajno bolja diskriminacija između signala i pozadinskih procesa (šuma)

$$\text{MELA} = \left[ 1 + \frac{\mathcal{P}_{\text{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\text{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})} \right]^{-1}$$



# Kinematička analiza

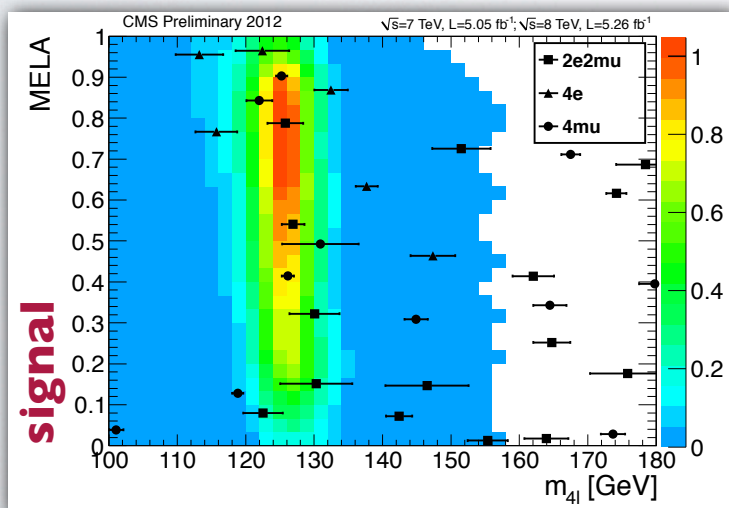
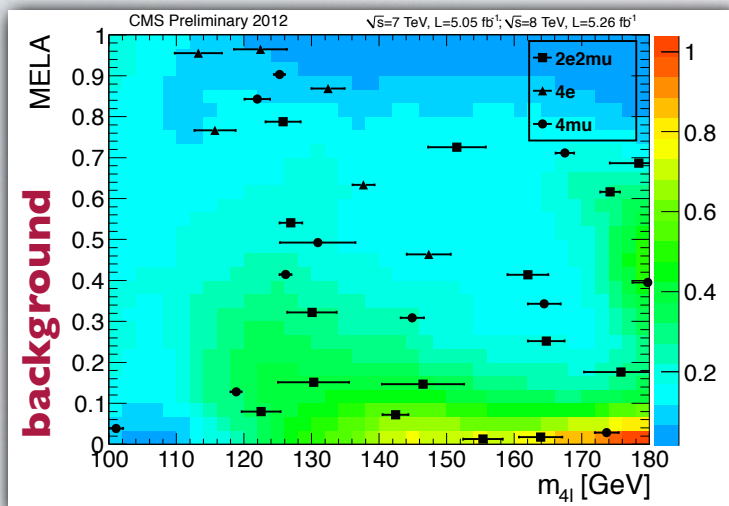
- Analiza podataka na osnovu 2D distribucije kinematičkih varijabli





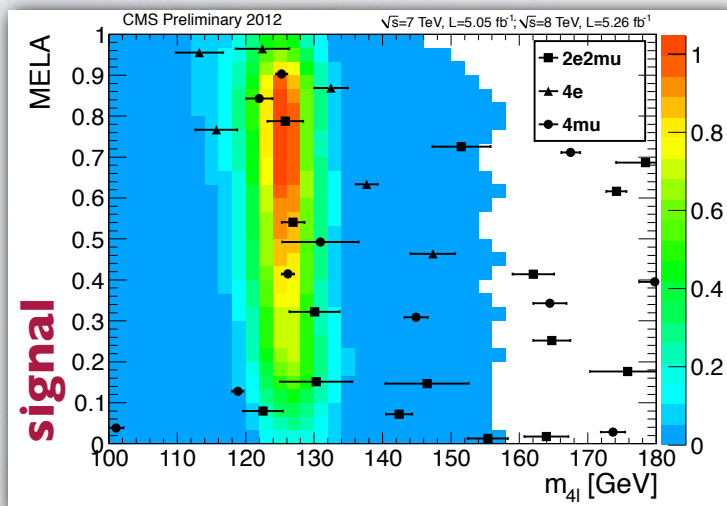
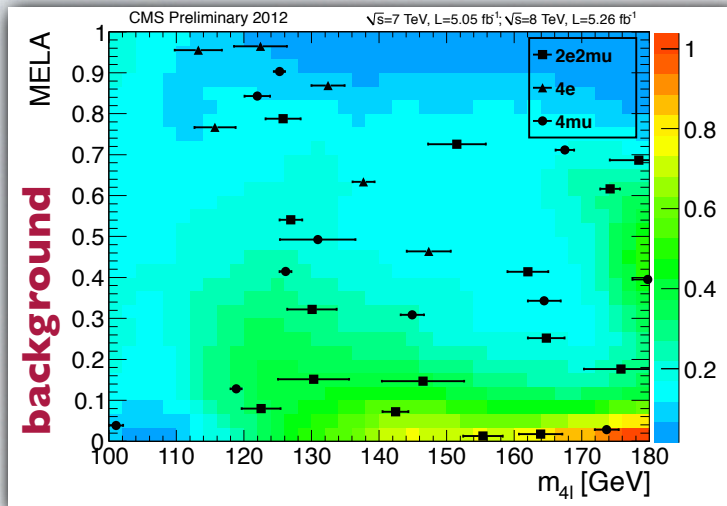
# Kinematička analiza

- Analiza podataka na osnovu 2D distribucije kinematičkih varijabli

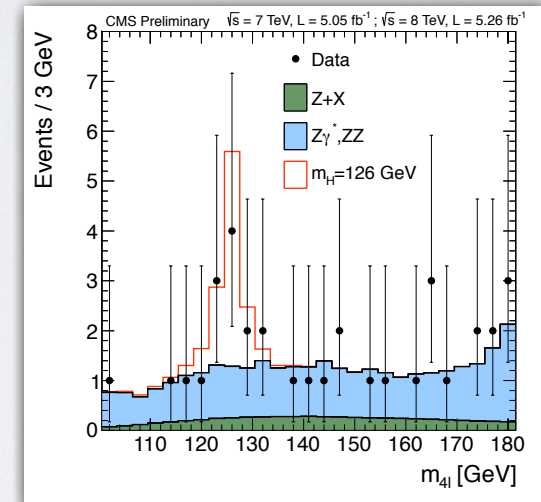
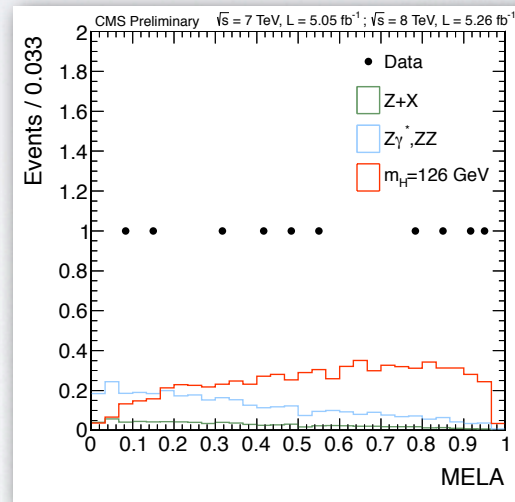


# Kinematička analiza

- Analiza podataka na osnovu 2D distribucije kinematičkih varijabli

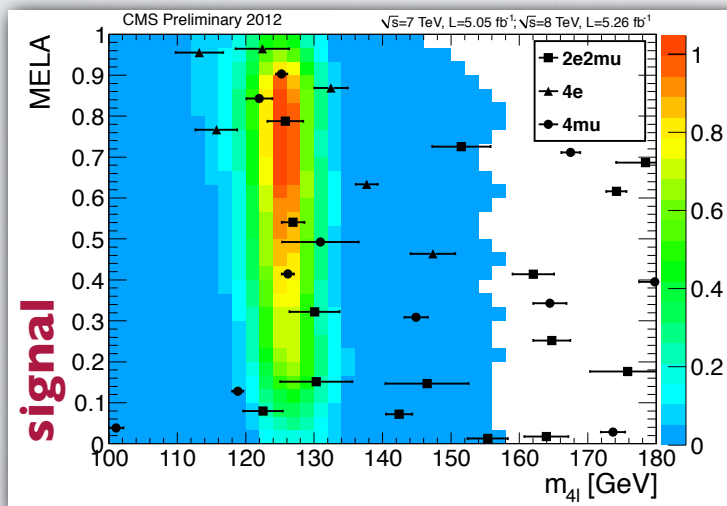
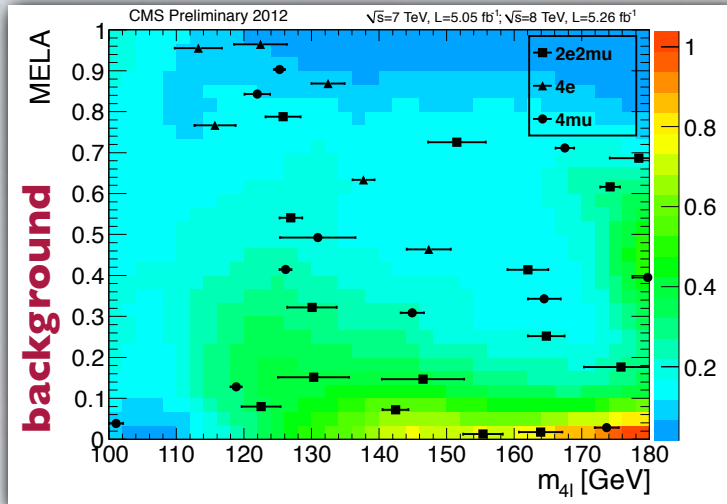


ilustracija:  
projekcija u regionu  
 $m(4l)$  121-131 GeV

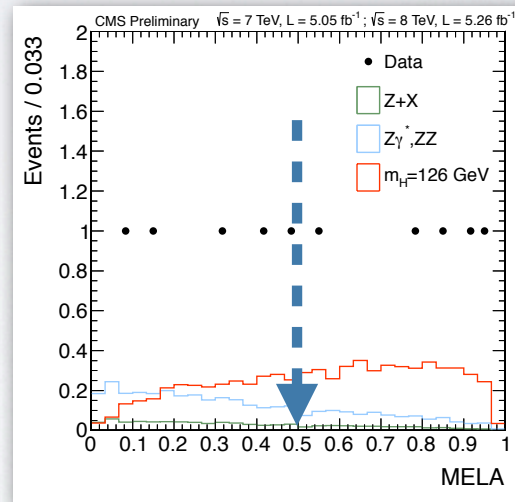


# Kinematička analiza

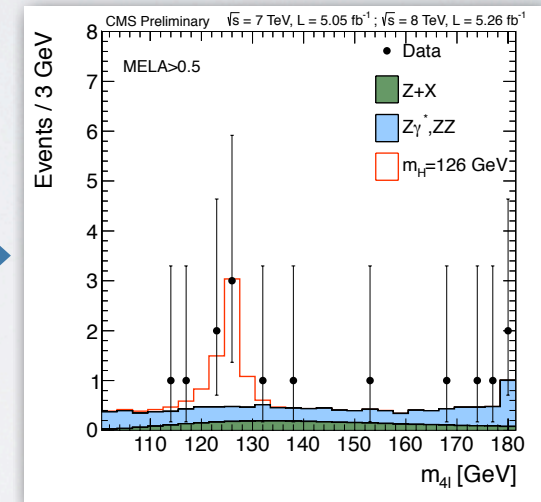
- Analiza podataka na osnovu 2D distribucije kinematičkih varijabli



ilustracija:  
projekcija u regionu  
 $m(4l)$  121-131 GeV



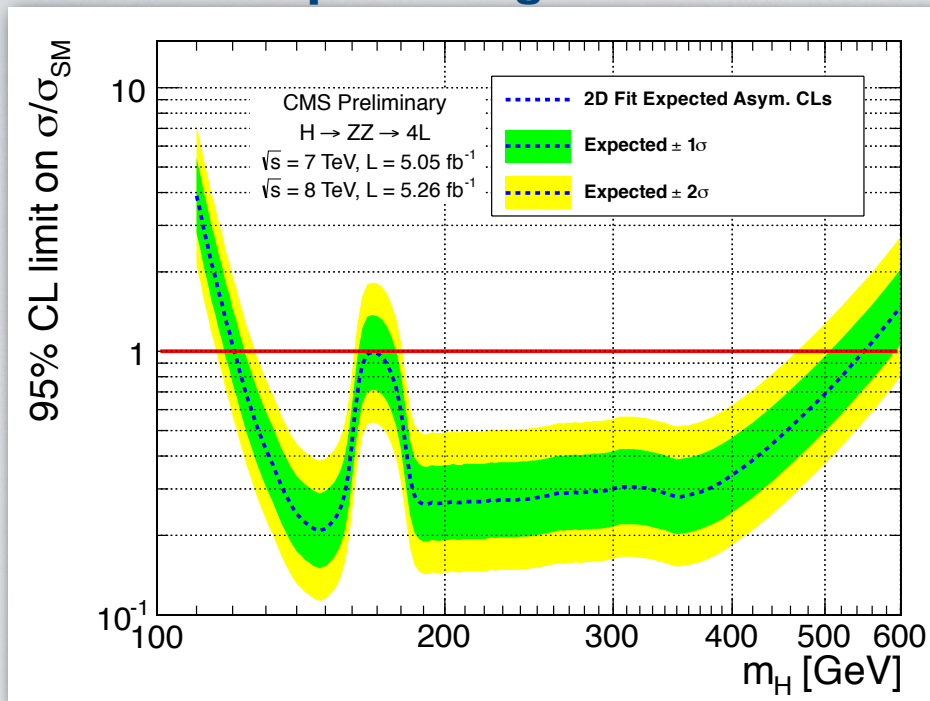
ilustracija:  
 $m(4l)$  sa selekcijom **MELA > 0.5**



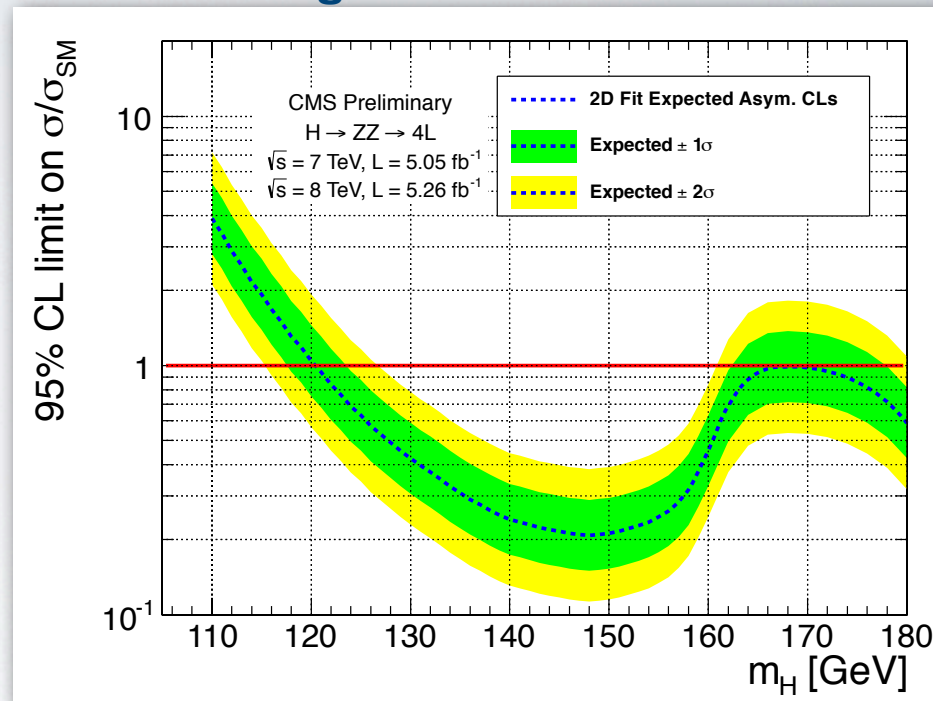
registrovani događaji konzistentni sa Higgs-om

# Odbacivanje hipoteze (očekivanje)

## Kompletan region masa



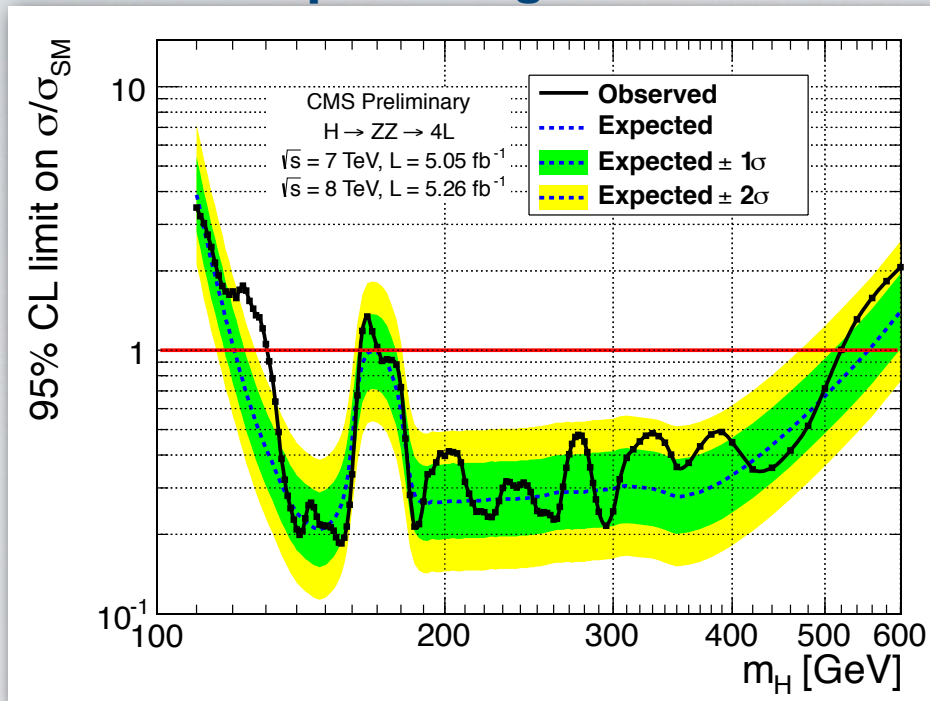
## Region niskih masa



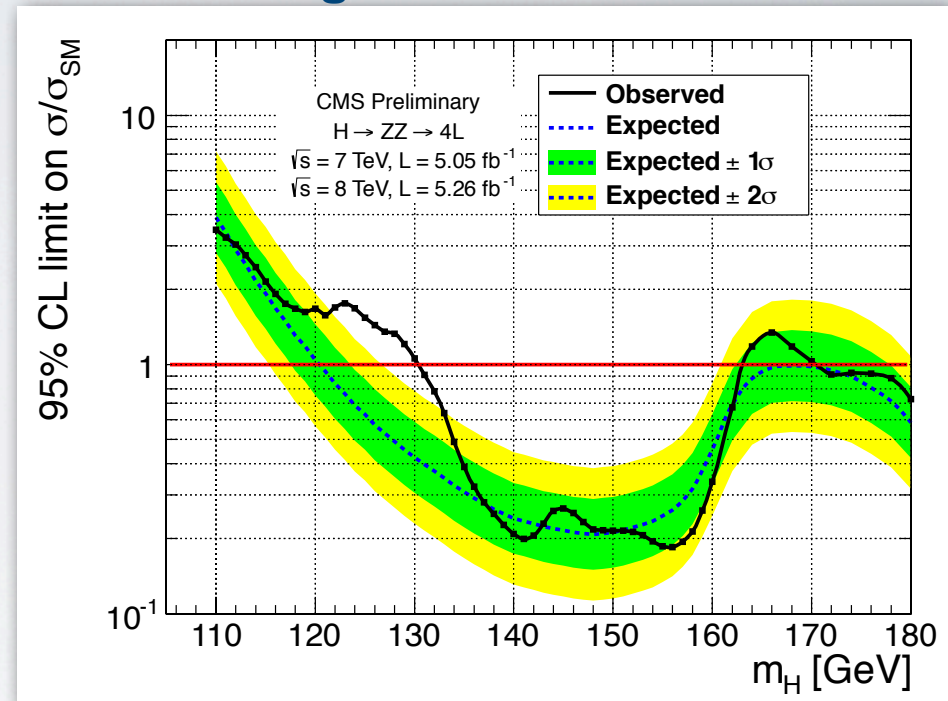
očekivano odbacivanje hipoteze sa 95% CL: **121-570 GeV**

# Odbacivanje hipoteze (merenje)

## Kompletan region masa



## Region niskih masa



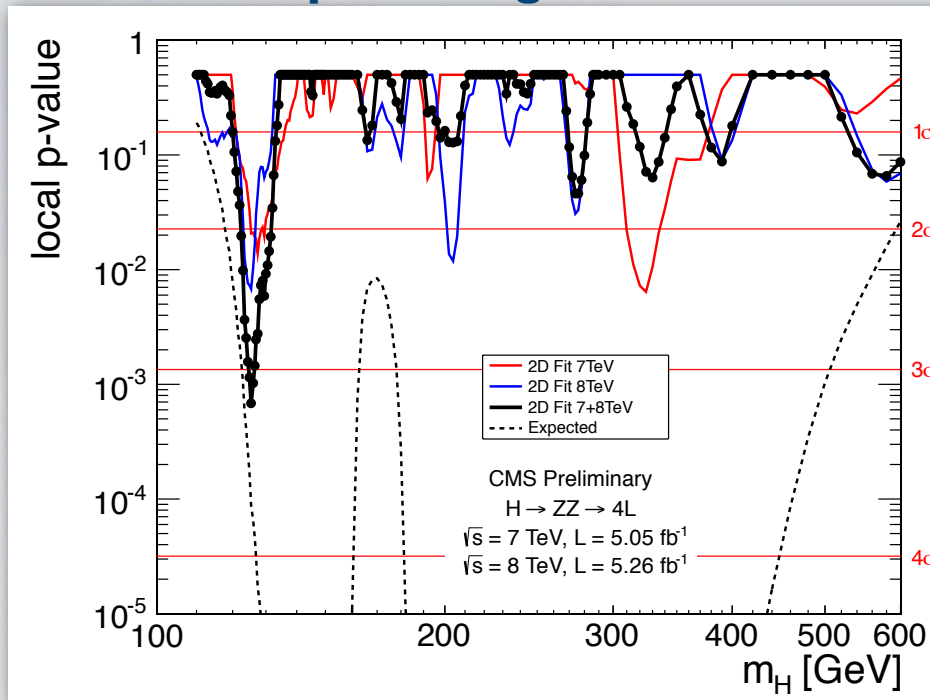
očekivano odbacivanje hipoteze sa 95% CL: **121-570 GeV**

izmereno sa 95% CL: **[131-162], [172-525] GeV**

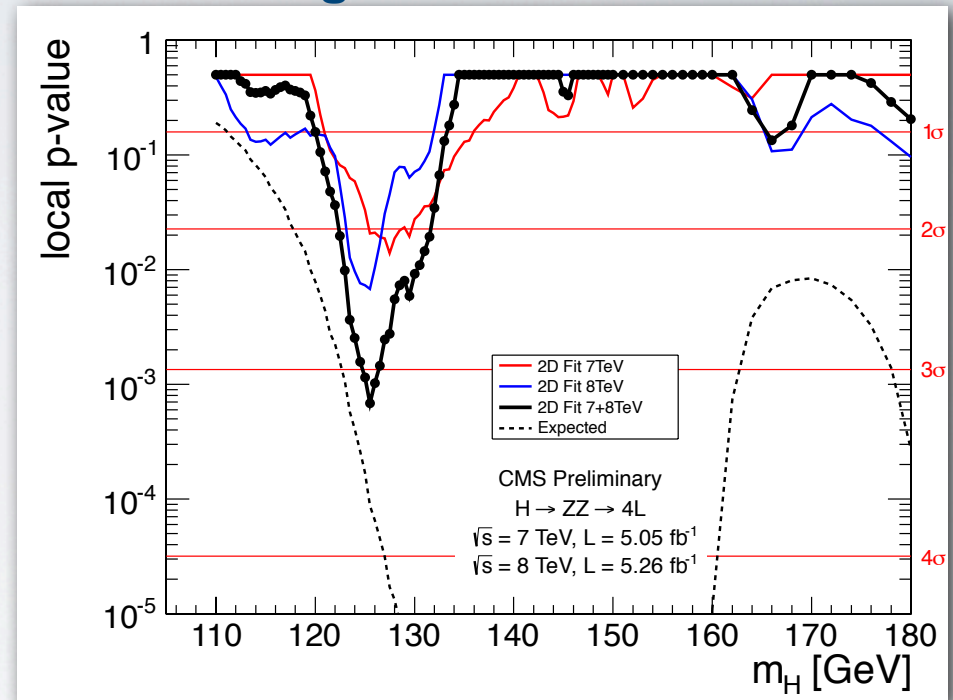
registrovan **višak** događaja u regionu oko  **$m_{4l} \sim 125 \text{ GeV}$** !

# Višak događaja (7 TeV i 8 TeV)

## Kompletan region masa



## Region niskih masa

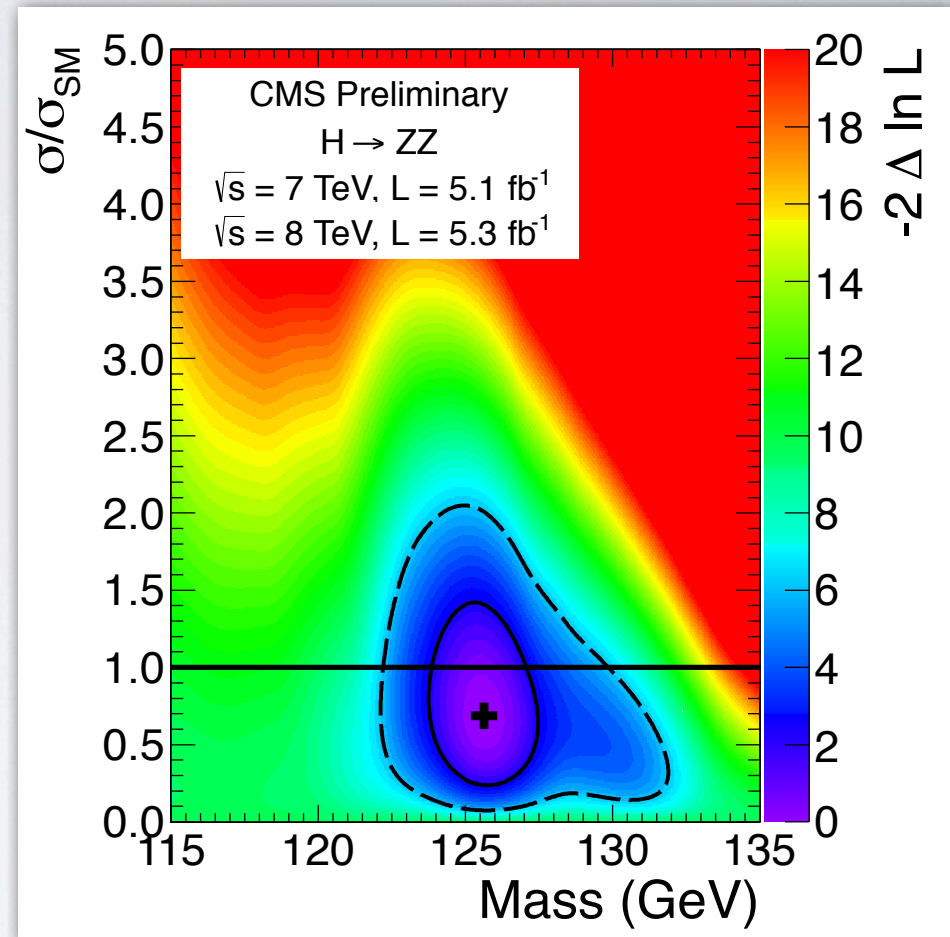


Očekivana statistička značajnost na 125.5 GeV: **3.8σ**

Izmerena statistička značajnost na 125.5 GeV: **3.2σ**

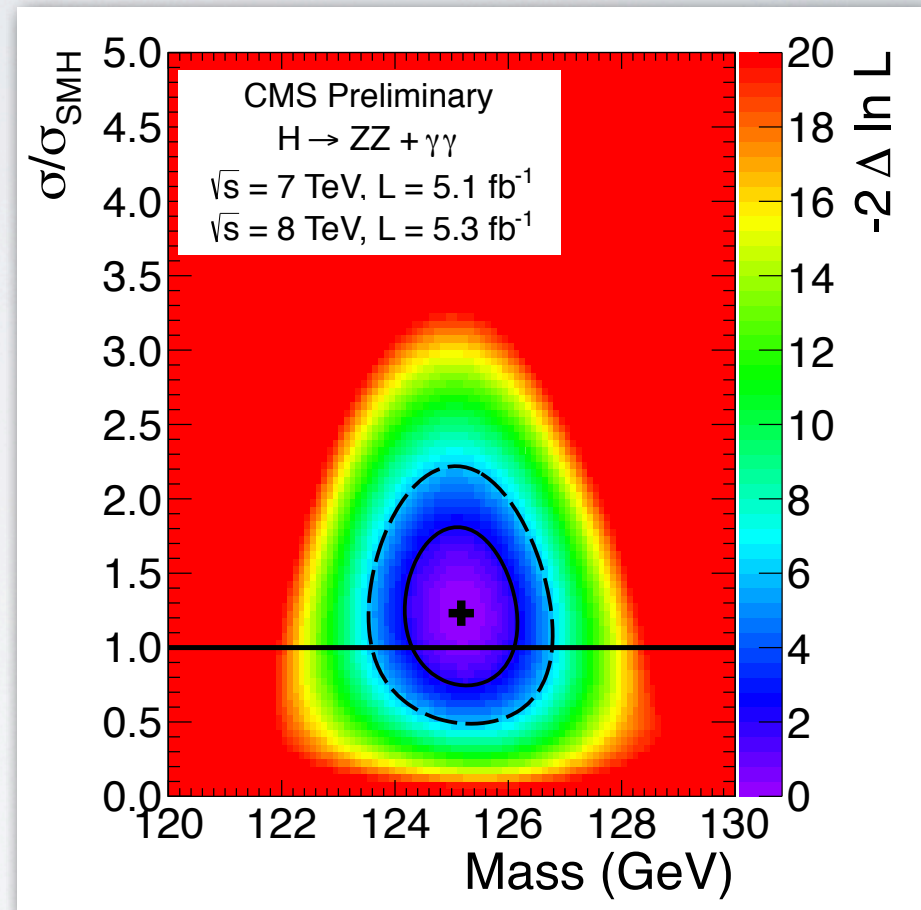
# Masa bozona i jačina signala ( $H \rightarrow ZZ \rightarrow 4l$ )

- Statistička “likelihood” analiza kompletnog seta podataka
- Globalni minimum
  - $m_{4l} = 125.6 \pm 1.2 \text{ GeV}$
  - $\mu = 0.7 \pm 0.4$  (jačina signala)
- Elipse pokazuju konture statističke zbačajnosti 68% i 95% CL



# Masa bozona i jačina signala

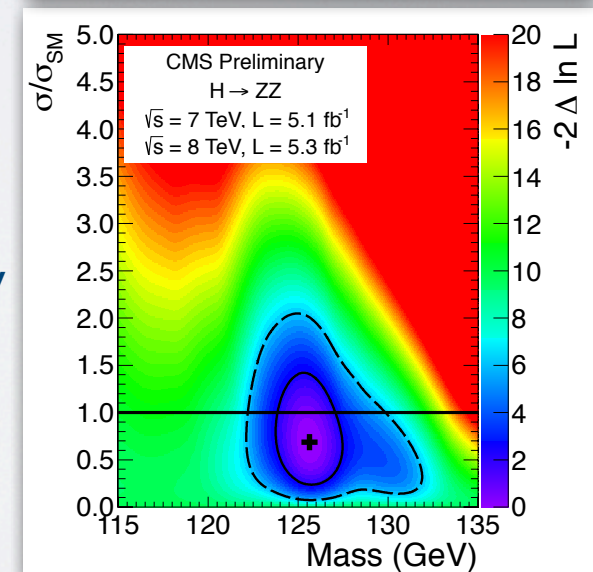
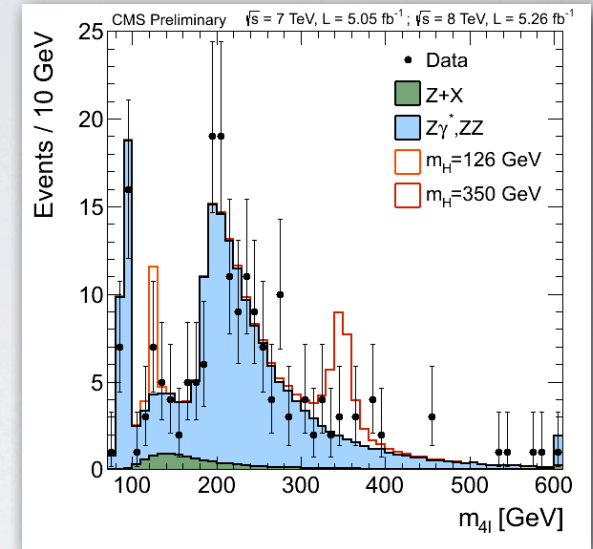
- Statistička “likelihood” analiza kompletnog seta podataka
- Globalni minimum
  - $m_{4l} = 125.3 \pm 0.6 \text{ GeV}$
  - $\mu = 1.3 \pm 0.5$  (jačina signala)
- Elipse pokazuju konture statističke zbačajnosti 68% i 95% CL





# Zaključci

- LHC eksperimenti su postigli **impresivne rezultate** u rekordno kratkom periodu!
- Analiza događaja  $H \rightarrow ZZ \rightarrow 4l$ 
  - Re-analizirani 7 TeV ( $5.1 \text{ fb}^{-1}$ ), dodati 8 TeV podatci ( $5.3 \text{ fb}^{-1}$ )
  - **Značajno inapređena** analiza
- Registrovani signal je u skladu sa predviđanjima SM
- Anatomija registrovanih događaja
  - Višak događaja registrovan za stat. značajnošću  **$3.2\sigma$** 
    - ➔ **Indikacija postojanja rezonance 4 lepton**
  - Signal odbačen sa 95% CL u regionima 131-162 i 172-530 GeV
  - Procena mase  $m_{4l} = 125.6 \pm 1.2 \text{ GeV}$
  - Procena jačine signala  $\mu = 0.7 \pm 0.4$



# Zaključci i pogled u budućnost

- Kombinacija svih analiza Higgs događaja:

➡ Otkriće novog bozona mase  
 **$125.3 \pm 0.6 \text{ GeV}$**  sa stat. značajnošću  **$5.0 \sigma$**  !

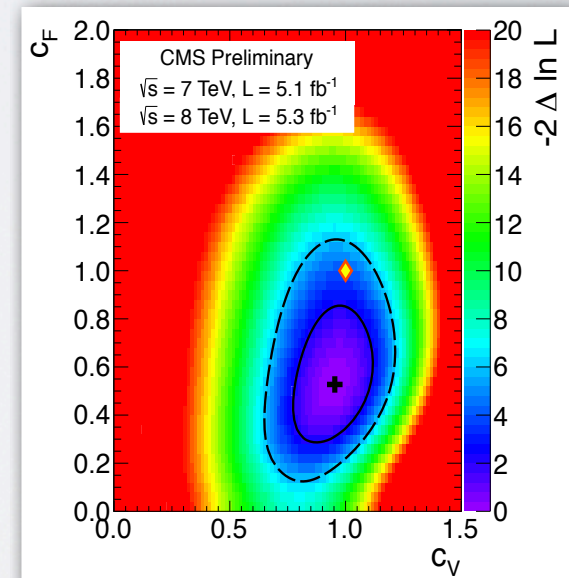
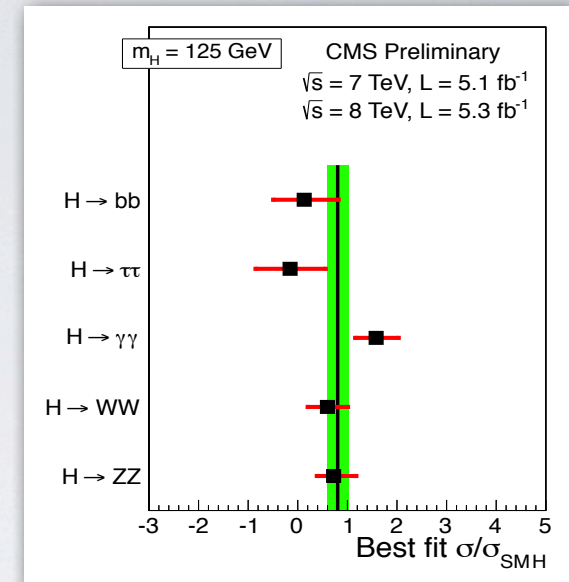
- Ali, da li je ovo zaista “onaj” Higgs bozon?

- Dobro slaganje većine analiziranih kanala raspada ( $\gamma\gamma$  signal prejak and  $\tau\tau$  signal preslab?)
- Tenzija “efektivnih” sprezanja fermiona i vektorskih bozona (slaganje u okviru 95% CL)

➡ **Samo novi podatci mogu da daju odgovor!**

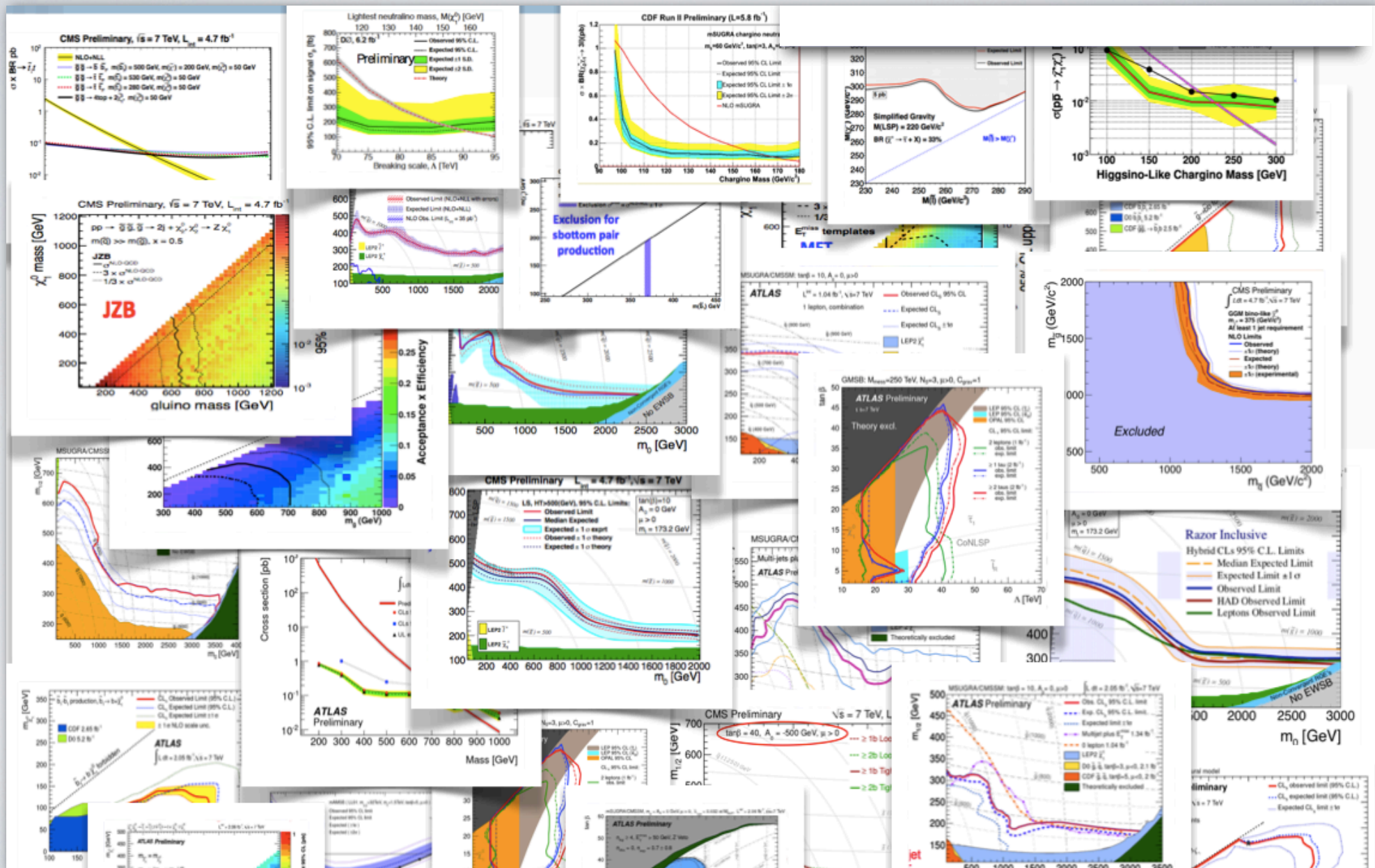
- Proučavanje osobina novog bozona (masa, širina raspda, konstante sprejanja, kvantni brojevi itd.)
- Uzbudljiva vremena su ispred nas (nova otkrića?)

➡ **Studenti pridružite nam se!**



# Backup slides

# Searches for New Physics - SUSY



# Searches for New Physics - Exotica

