



ЦЕРН, 17 Септември 2012

# Участието на ИЯИЯЕ, БАН в експеримента CMS и търсене на Higgs бозон

Владимир Генчев

ИЯИЯЕ, БАН, София

# Съдържание

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**Физическа мотивация**

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# Стандартен Модел

(„Периодична таблица“ на елементарните частици)  
 SM се базира на  $SU_C(3) \times SU_L(2) \times U_Y(1)$  калибровъчна група  
 структура: QED, EW, QCD

поколения	лептони		кварки	
I	e	$\nu_e$	uuu	ddd
II	$\mu$	$\nu_\mu$	ccc	sss
III	$\tau$	$\nu_\tau$	ttt	bbb
ел. заряд Q	-1	0	2/3	-1/3

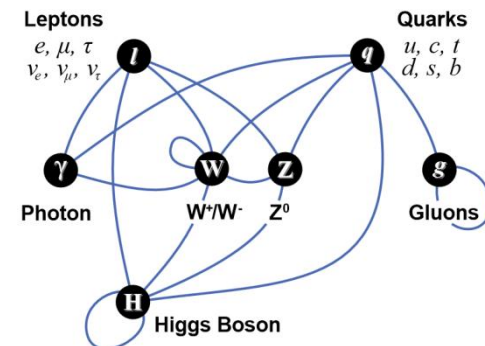
$\neq S$

бозони
$\gamma$
g
$W^\pm$ Z
Higgs ?

$C_a$  – октет на цветните заряди  $\rightarrow SU_C(3)$

$I_3 = \pm 1/2 \rightarrow SU_L(2)$

$Q = I_3 + (1/2)Y$  ( $Y = 1$  – лептони,  $Y = 1/3$  - кварки)  $\rightarrow U_Y(1)$



# Физическа мотивация

SM съдържа явно спорни моменти

(защо има 6 кварка? защо има само 3 фамилии кварки и лептони?)

SM има липсващи елементи

(механизъм за генериране на масите на познати частици)

SM е логически незавършен

(гравитацията не е инкорпорирана)

SM дава безсмислици при LHC енергии

(вероятността за някои процеси  $> 1$  при енергии над 1 TeV)

Какво е масата? Защо някои частици нямат маса?

$$(M_\gamma = 0, M_W, M_Z \sim 100 \text{ GeV})$$

От какво е направена 96% от Вселената (невидима енергия/материя)?

Предпочитание на Природата... защо няма антиматерия?

На какво е приличала материята в първите мигове на Вселената?

(кварк-глюонна плазма?)

Програмата на LHC трябва да отговори на тези въпроси.

Необходимо бе:

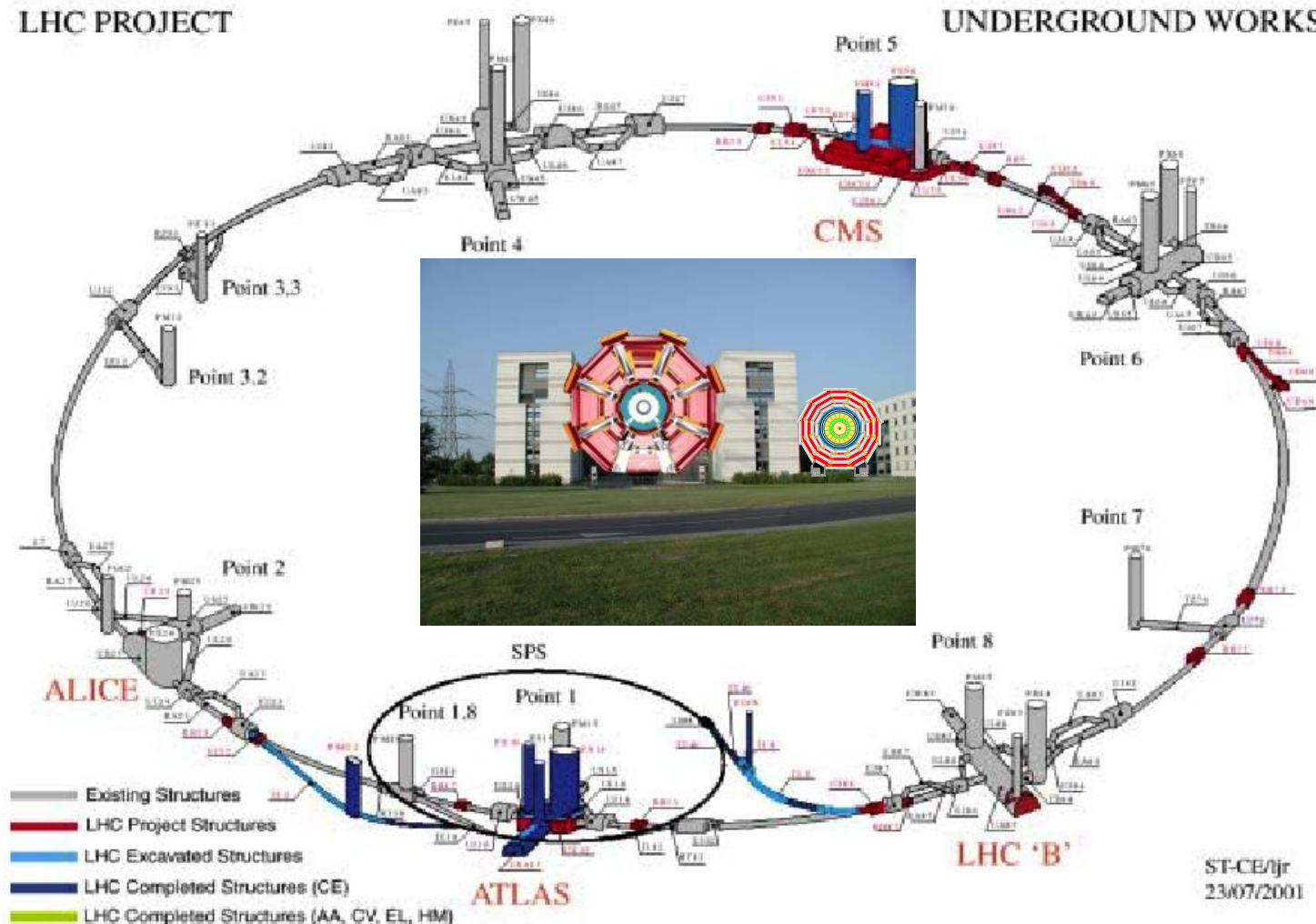
Да се открие Higgs

Да се излезе извън SM: (SUSY, допълнителни размерности)

# Детектори

LHC PROJECT

UNDERGROUND WORKS



# ИЯИЯЕ, БАН В CMS

Expression of Interest for a Compact Muon Solenoid Detector for LHC

CMS

**1991**

Institut für Hochenergiephysik der Österreichischen Akademie der Wissenschaften, Vienna, AUSTRIA

Université Libre, Bruxelles, BELGIUM  
Vrije Univ., Brussel, BELGIUM

Université Catholique de Louvain, Louvain-la-Neuve, BELGIUM  
Univ. Instelling Antwerpen, Wilrijk, BELGIUM  
Univ. de l'Etat Mons, Mons, BELGIUM

Physics, Acad. Sci. Byelorussia, Minsk, BYELORUSSIA

Institute of Nuclear Research & Nuclear Energy, Sofia, BULGARIA  
Univ. of Sofia, Sofia, BULGARIA

Institute of Physics, Czechoslovak Academy of Sciences, Praha, CFSR

Inst. of Chemistry and Physics, Tallinn, ESTONIA

SEFT, Helsinki, FINLAND  
Physics Department, Univ. of Helsinki, Helsinki, FINLAND  
Univ. of Technology, Helsinki, FINLAND  
Univ. of Technology, Tampere, FINLAND  
Åbo Akademi, Turku, FINLAND

Laboratoire de Physique des Particules (LAPP), Annecy-le-Vieux, FRANCE  
Inst. Nat. Phys. Nucl. et Phys. Part., Lyon-Villeurbanne, FRANCE  
Ecole Polytechnique, Palaiseau, FRANCE  
CEN-Saclay, Gif-sur-Yvette, FRANCE

Tbilisi State University, Tbilisi, GEORGIA

Universität Aachen, Aachen, GERMANY  
Universität Kiel, Kiel, GERMANY

University of Ioannina, Ioannina, GREECE  
Nucl. Research Center Demokritos, Attiki, Athens, GREECE  
University of Athens, Athens, GREECE

Central Research Institute for Physics, Hung. Acad. Sci., Budapest, HUNGARY

Dipartimento di Fisica dell'Università and Sezione dell'INFN, Milano, ITALY  
Università di Padova, Padova, ITALY  
Università di L'Aquila, Coppito, ITALY

Dipartimento di Fisica dell'Università and Sezione dell'INFN, Genova, ITALY

Inst. of Experimental Physics, University of Warsaw, Warszawa, POLAND  
Institute for Nuclear Studies, Warszawa, POLAND

CIEMAT, Madrid, SPAIN

CERN, Geneva, SWITZERLAND

JINR, Dubna, RUSSIA  
ITEP, Moscow, RUSSIA  
INR, Moscow, RUSSIA  
IHEP, P'ovino, RUSSIA

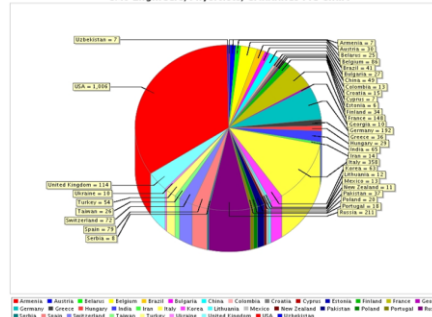
Imperial College, London, U.K.  
Rutherford Appleton Laboratory, Didcot, U.K.

Univ. of California, Davis, USA  
Univ. of California, Riverside, USA  
Univ. of California, Los Angeles, USA

**Institute of Nuclear Research & Nuclear Energy, Sofia, BULGARIA**  
**Univ. of Sofia, Sofia, BULGARIA**

CMS Эксперимент

CMS Engineers, Physicists, Graduates Pie Chart

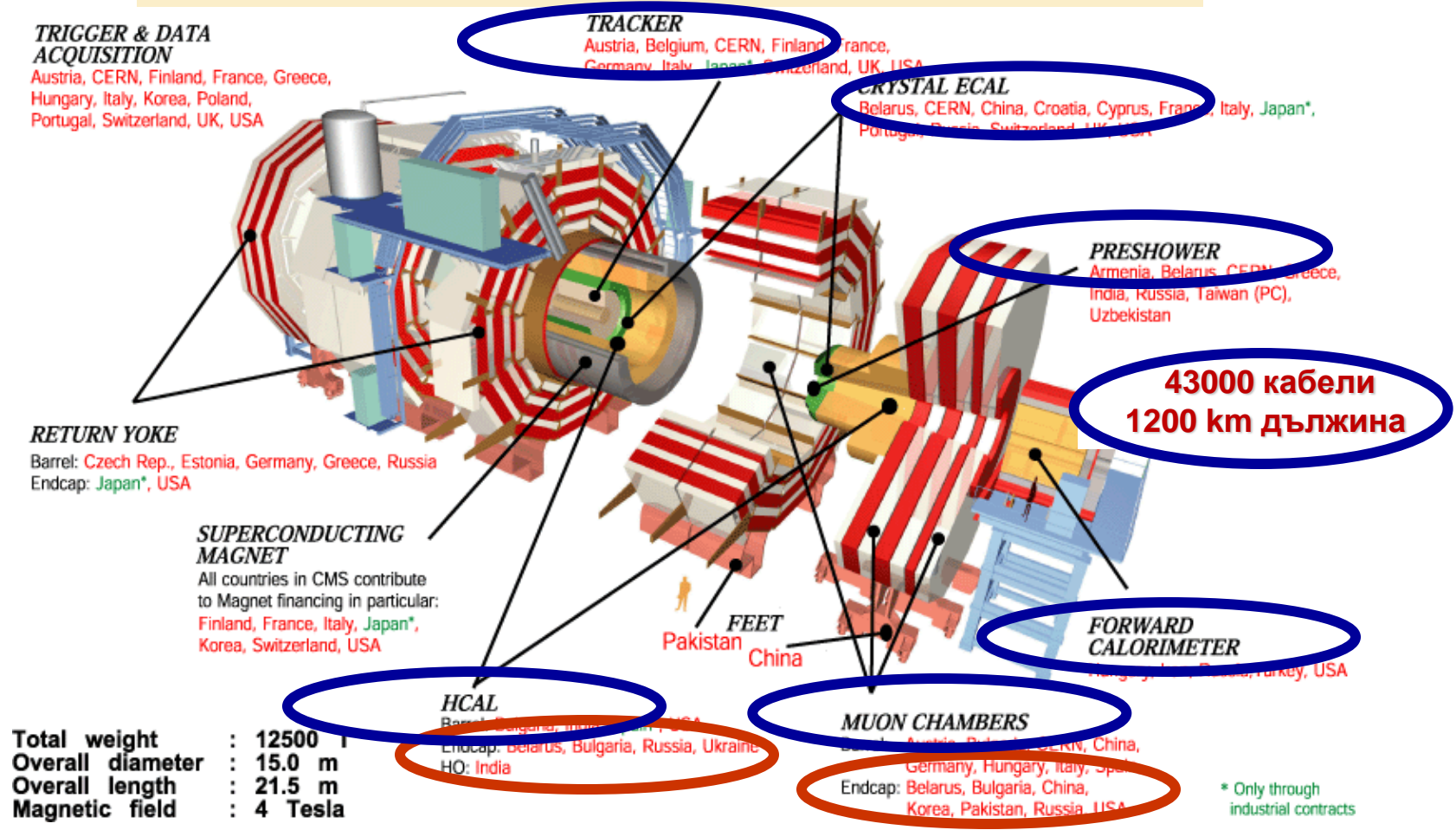


AACHEN-1, AACHEN-3A, AACHEN-3B, ADANA-CUKUROVA, ANKARA-METU, ANTWERPEN, ATHENS, ATOMKI, AUCKLAND, BARI, BEIJING-IHEP, BOGAZICI, BOLOGNA, BOSTON-UNIV, BRISTOL, BROWN-UNIV, BRUNEL, BRUSSEL-VUB, BRUXELLES-ULB, BUDAPEST, CALTECH, CANTERBURY, CARNEGIE-MELLON, CATANIA, CCCS-UWE, CERN, CHANDIGARH, CHEJU, CHICAGO, CHONNAM, CHUNGBUK, CHUNGLI-NCU, COLORADO, CORNELL, DEBRECEN-IHEP, DELHI-UNIV, DEMOKRITOS, DESY, DONGSHIN, DUBLIN-UCD, DUBNA, EINDHOVEN, FAIRFIELD, FERMI-LAB, FIRENZE, FLORIDA-FIU, FLORIDA-STATE, FLORIDA-TECH, FLORIDA-UNIV, FRASCATI, GENOVA, GHENT, HAMBURG-UNIV, HEFEI-USTC, HELSINKI-HIP, HELSINKI-UNIV, HEPHY, IOANNINA, IOWA, IPM, ISLAMABAD-NCP, JOHNS-HOPKINS, KANGWON, KANSAS-STATE, KANSAS-UNIV, KARLSRUHE-IKIP, KHARKOV-ISC, KHARKOV-KIPT, KHARKOV-KSU, KONKUK-UNIV, KOREA-UNIV, KYUNGPOOK, LAPP, LAPPEENRANTA-LUT, LIP, LIVERMORE, LONDON-IC, LOUVAIN, LYON, MADRID-CIEMAT, MADRID-UNIV, MARYLAND, MEXICO-IBEROAM, MEXICO-IPN, MEXICO-PUEBLA, MEXICO-UASLP, MILANO-BICOCCA, MINNESOTA, MINSK-INP, MINSK-NCPHEP, MINSK-RIAPP, MINSK-UNIV, MISSISSIPPI, MIT, MONS, MOSCOW-INR, MOSCOW-ITEP, MOSCOW-LEBEDEV, MOSCOW-MSU, MOSCOW-RDIP, MUMBAI-BARC, MYASISHCHEV, NAPOLI, NEBRASKA, NICOSIA-UNIV, NORTHEASTERN, NORTHWESTERN, NOTRE DAME, NUST, OHIO-STATE, OVIEDO, PADOVA, PAVIA, PEKING-UNIV, PERUGIA, PISA, POLYTECHNIQUE, PRINCETON, PROTVINO, PSI, PUERTO RICO, PURDUE, PURDUE-CALUMET, RAL, RICE, RIE, RIO-CBPF, RIO-UERJ, ROCHESTER, ROCKEFELLER, ROMA-1, RUTGERS, SACLAY, SANTANDER, SAO PAULO, SEONAM, SEOUL-EDU, SEOUL-SNU, SHANGHAI-IC, SKK-UNIV, SOFIA-CLMI, **SOFIA-INRNE**, SOFIA-UNIV, SPLIT-FESB, SPLIT-UNIV, ST-PETERSBURG, STRASBOURG, SUNY-BUFFALO, TAIPEI-NTU, TALLINN, TASHKENT, TBILISI-IHEPI, TBILISI-IPAS, TENNESSEE, TEXAS-TAMU, TEXAS-TECH, TIFR-EHEP, TIFR-HECR, TORINO, TRIESTE, UCDAVIS, UCLA, UCRI-VARSIDE, UCSB, UCSD, UNIANDES, VANDERBILT, VILNIUS-ACADEMY, VILNIUS-UNIV, VINCA, VIRGINIA-TECH, VIRGINIA-UNIV, WARSAW-IHP, WARSAW-INS, WARSAW-ISE, WAYNE, WISCONSIN, WONKWANG, YEREVAN, ZAGREB-RUDJER, ZURICH-ETH, ZURICH-UNIV

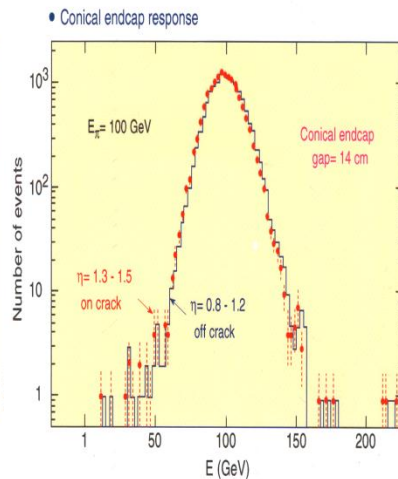
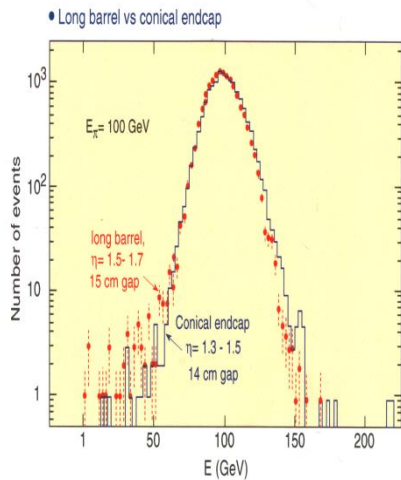
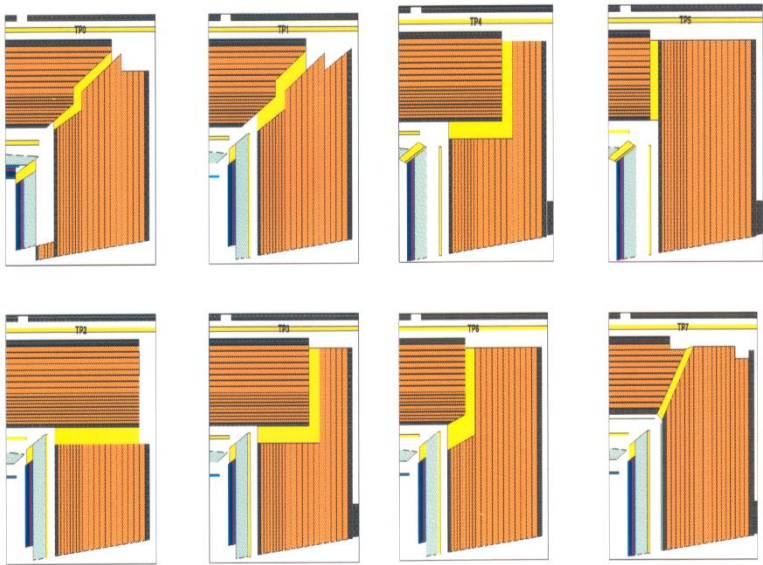
39 Страни, 169 Института  
3170 учени и инженери  
(800 PhD студенти)

# CMS детектор

**39 страни, 193 Института, 3300 учени**



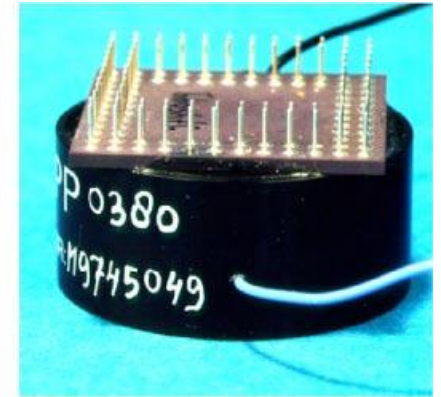
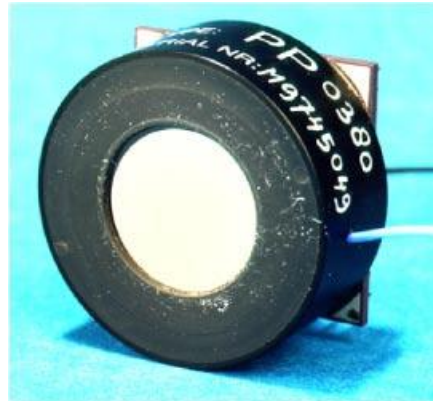
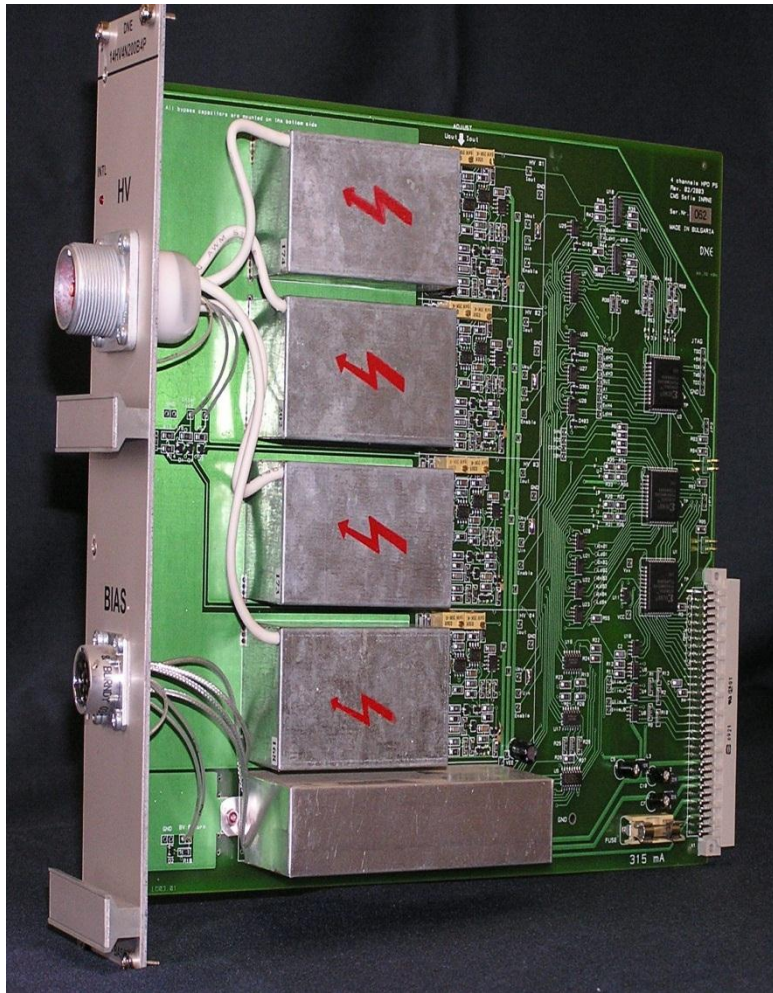
# Адронен калориметър



**700 T**



# HCAL HV захранване



# RPC производство и тестване



# CMS в действие

**23.11.2009** – запускане на 0.45 и 1.18 TeV

**30.03.2010** – запускане на 3.5 TeV

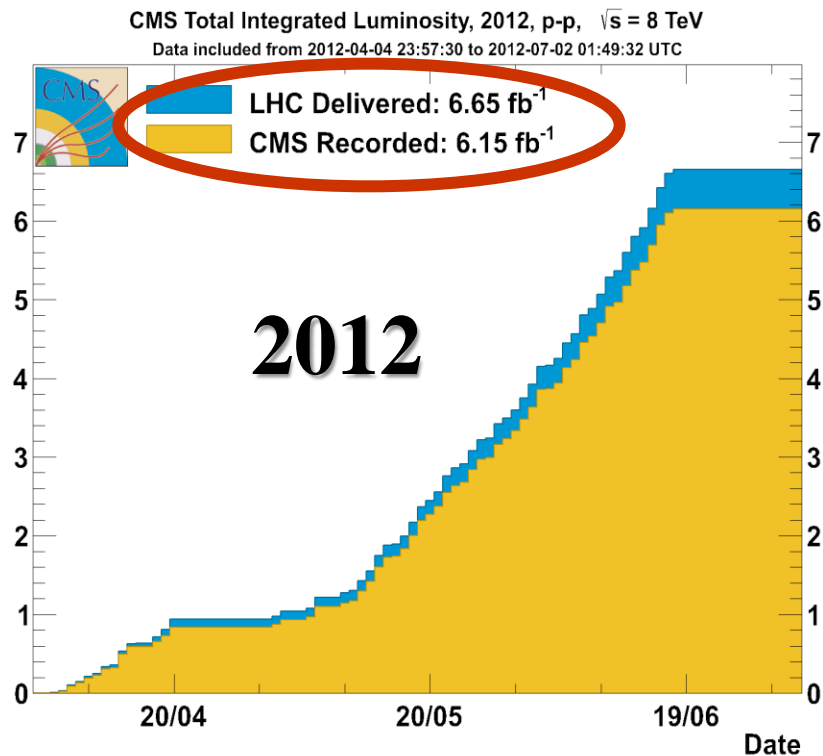
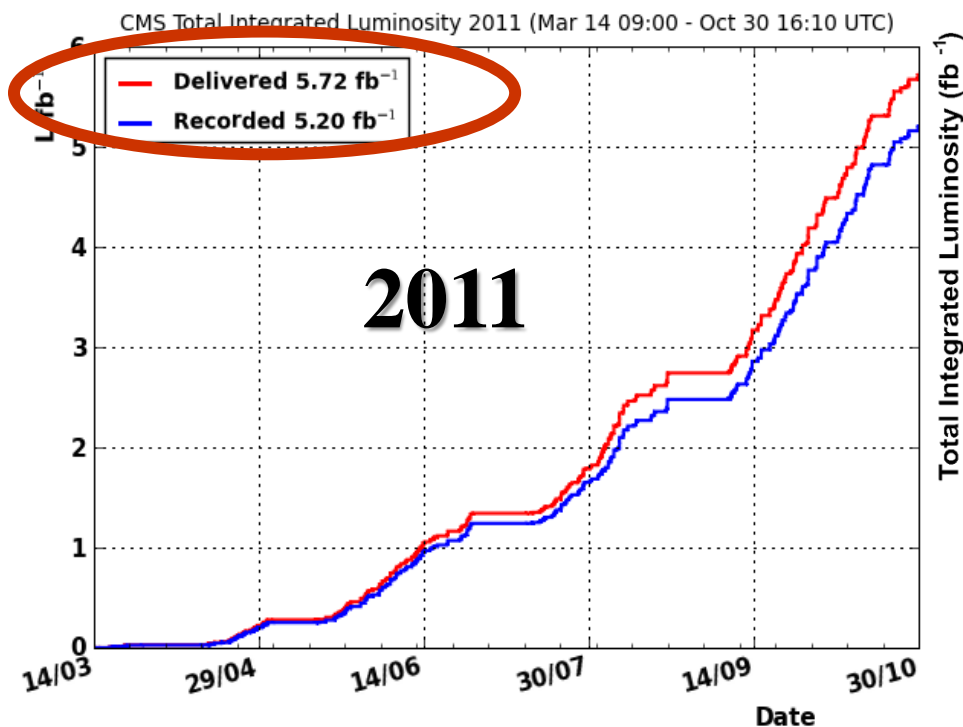
**08.11.2010** – тежки йони 2.76 TeV/nucleon

**22.04.2011** – нов световен рекорд за светимост

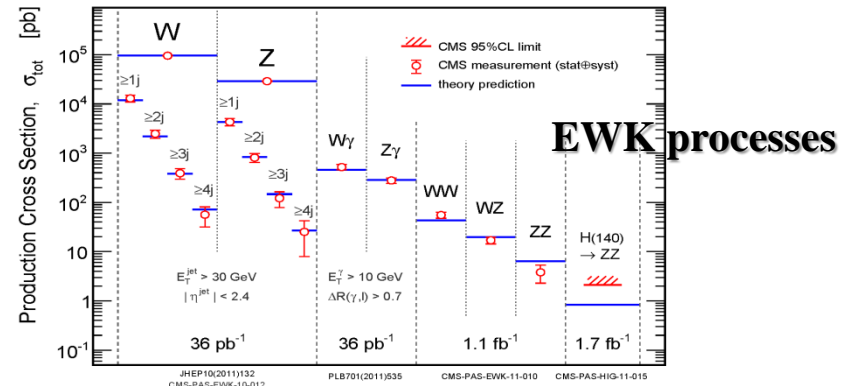
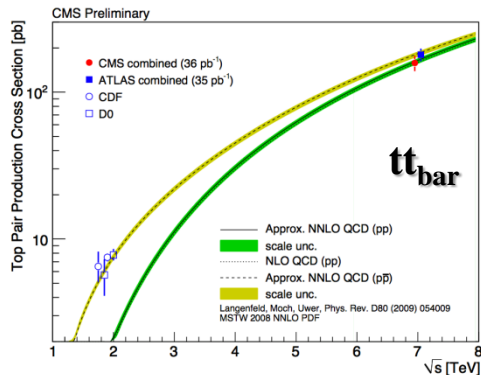
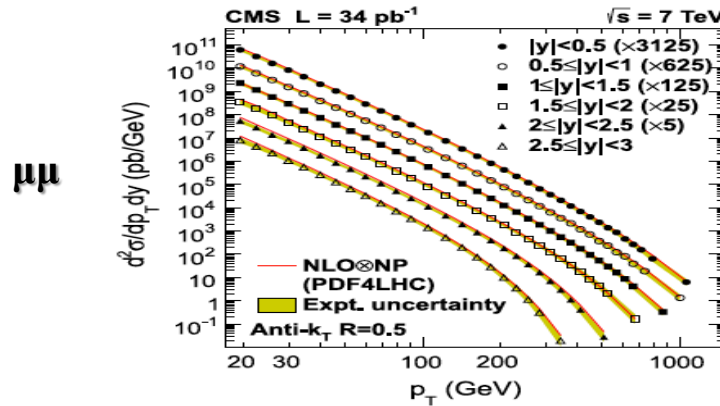
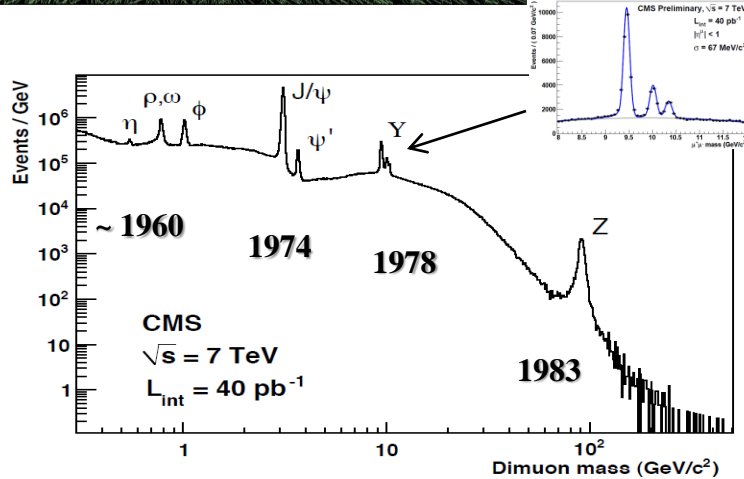
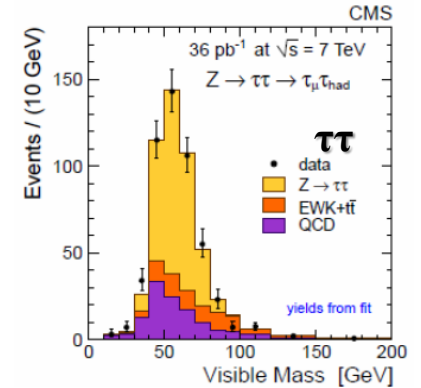
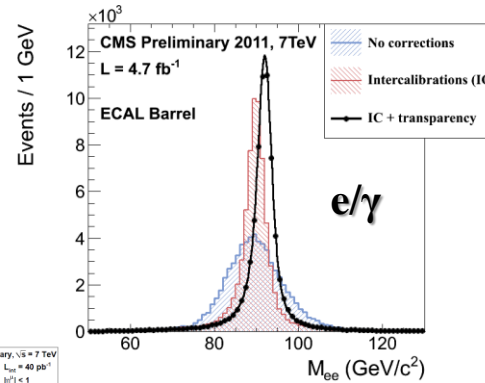
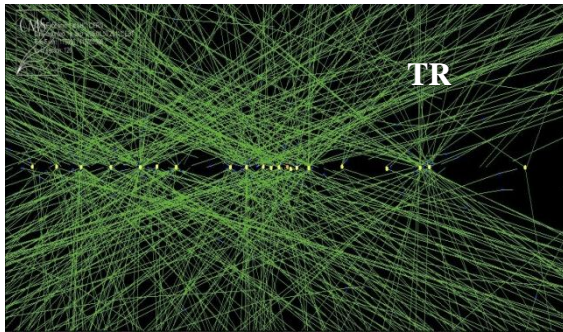
до края на 2011 – светимост  $3.54 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

**05 Април 2012** - запускане на 4.0 TeV, светимост  $6.8 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

**04 Юли 2012** – CERN



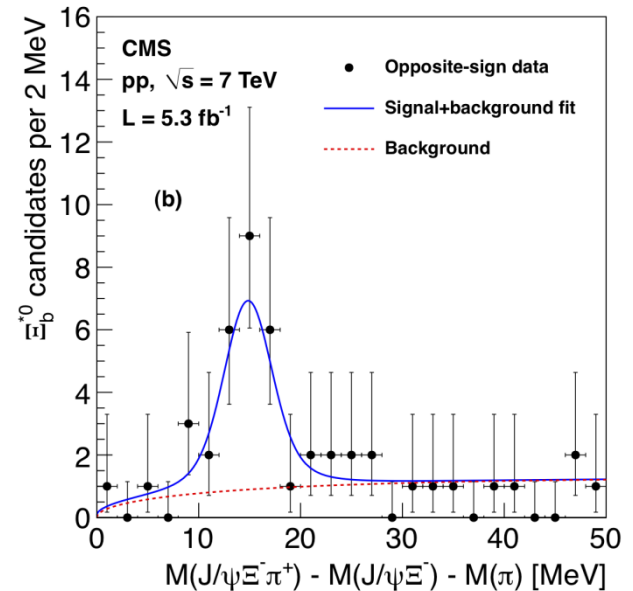
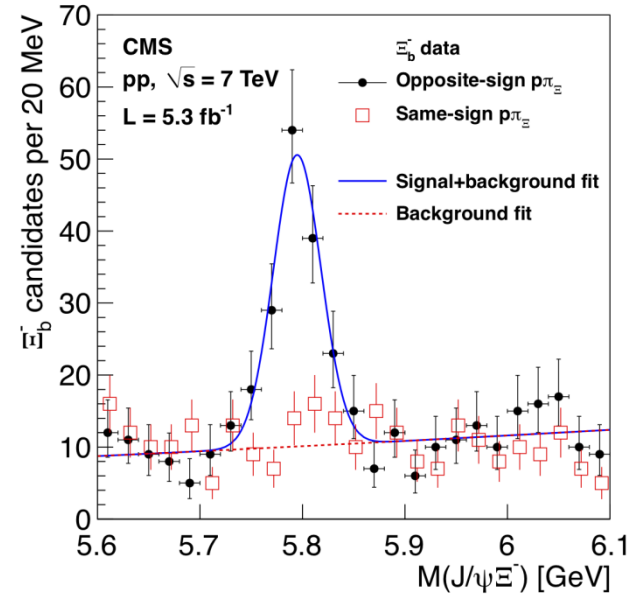
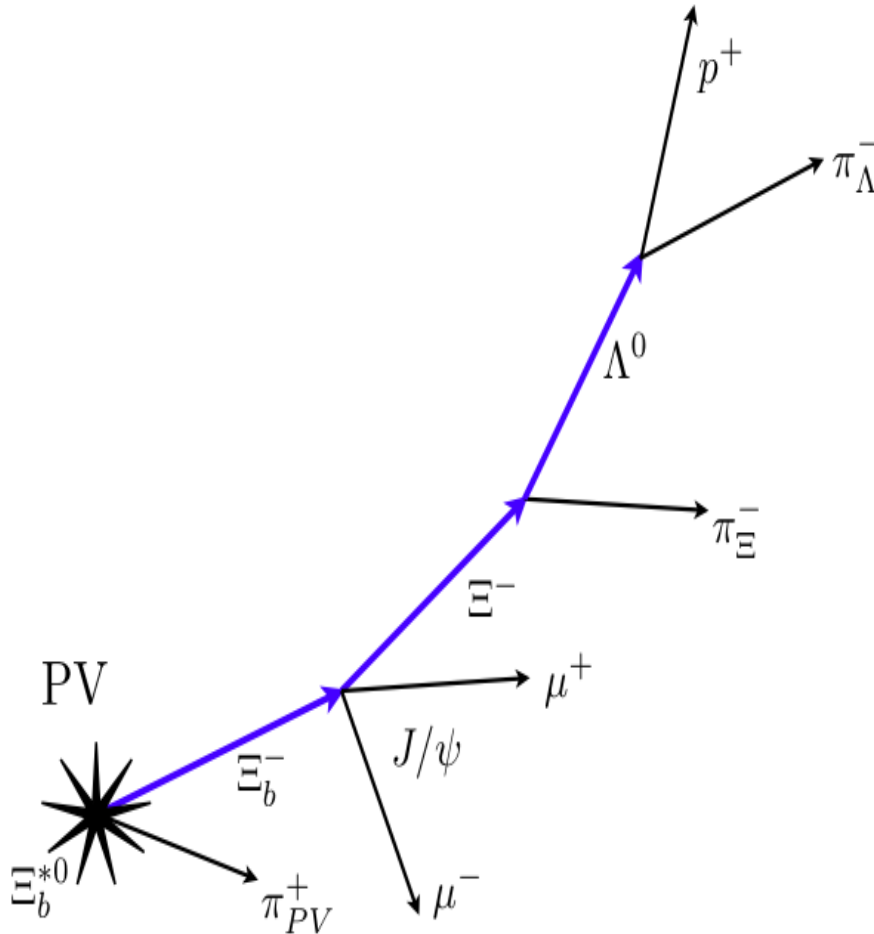
# CMS в действие



# $\Xi_b^{*0}$ - НОВА ЧАСТИЦА

$\Xi_b^0$  барион съдържа **b**, **s** и **u** кварки

$\Xi_b^-$  барион съдържа **b**, **s** и **d** кварки

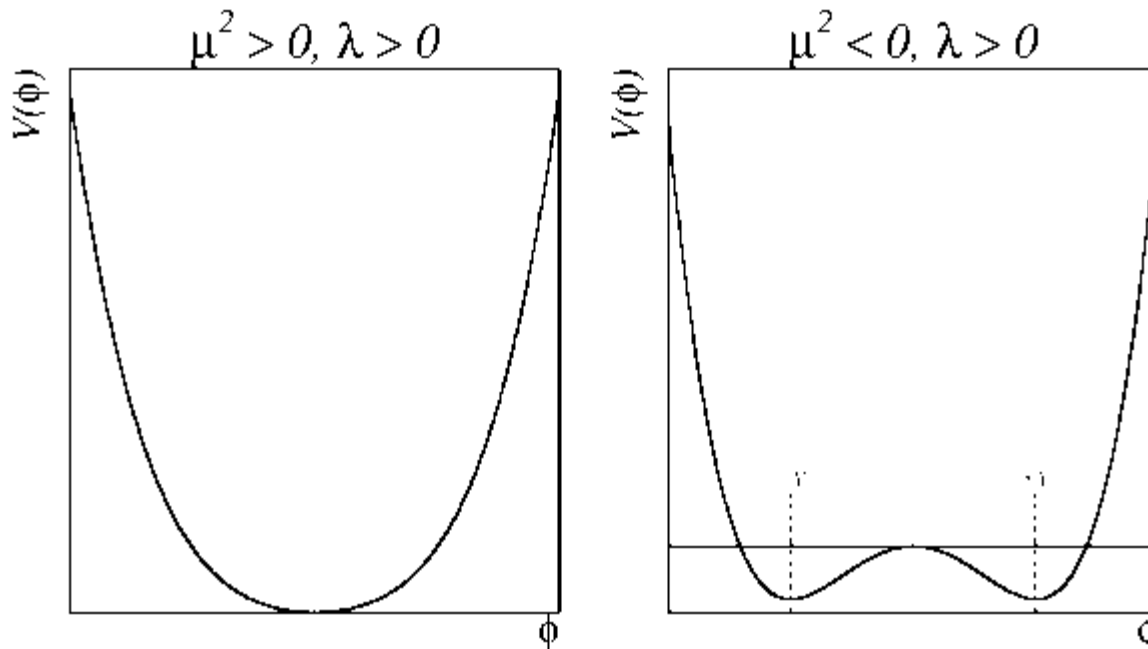


# Спонтанно нарушение на симетрията

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \Phi)^2 - V(\Phi) ; V(\Phi) = (\frac{1}{2}\mu^2\Phi^2 + \frac{1}{4}\lambda\Phi^4)$$

$\mu$  – маса на полето,  $\lambda$  – self coupling параметър

симетрия  $\Phi(x) = -\Phi(x)$



R. Durka

**Вакуума не съответства на нулевото  
значение на полето**

**min.  $\Phi = \pm v = \pm\sqrt{-\mu^2/\lambda}$   
(VEV) - очаквана  
вакуумна стойност**

# Реално скаларно поле на Higgs

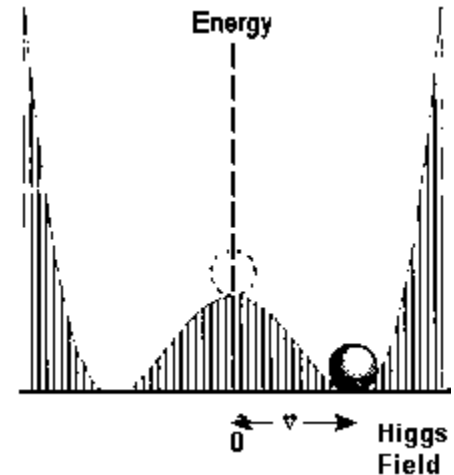
- проблеми: - имагинерна маса  
 - вакуума съдържа ненулево поле

$$\Phi(x) = v + \eta(x)$$

$v$  – вакуумна съставляваща

$\eta(x)$  – поле на Higgs бозона  $H$

$$\mathcal{L} = (\frac{1}{2}(\partial_\mu \eta)^2 - \lambda v^2 \eta^2) - \lambda v \eta^3 - \lambda/4 \eta^4$$

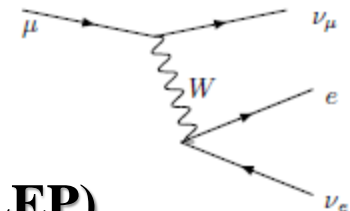


- вакуума има нулево значение за полето (реален вакуум)
- полето има масов член  $\lambda v^2 \eta^2 = 1/2 m_H^2 \eta^2 \rightarrow m_H = \sqrt{2\lambda v^2}$

$$M_W = \frac{1}{2} v g_2 = (\sqrt{2} g_2^2 / 8 G_F)^{1/2} \rightarrow v = 1 / (\sqrt{2} G_F)^{1/2}$$

$$G_F = 1.16637 \times 10^{-5} \text{ GeV}^{-2} \rightarrow v = 246 \text{ GeV}$$

$m_H = \sqrt{2\lambda v^2}$  – свободен параметър;  $m_H > 114.4 \text{ GeV}$  (LEP)



# История

Higgs механизъм – механизъм на

**Englert – Brout – Higgs – Guralnik – Hagen – Kibble**

**F. Englert and R. Brout (1964). "Broken Symmetry and the Mass of Gauge Vector Mesons". *Physical Review Letters* 13(9): 321–323.**

**Peter W. Higgs (1964). "Broken Symmetries and the Masses of Gauge Bosons". *Physical Review Letters* 13(16): 508–509**

**G. S. Guralnik, C. R. Hagen, and T. W. B. Kibble (1964). "Global Conservation Laws and Massless Particles". *Physical Review Letters* 13(20): 585–587**





# Защо Higgs?

- **Higgs pointed out a massive scalar boson**

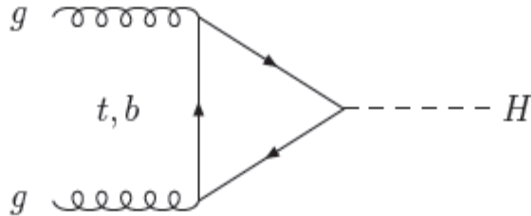
$$\{\partial^2 - 4\varphi_0^2 V''(\varphi_0^2)\}(\Delta\varphi_2) = 0, \quad (2b)$$

Equation (2b) describes waves whose quanta have  
(bare) mass  $2\varphi_0\{V''(\varphi_0^2)\}^{1/2}$ .

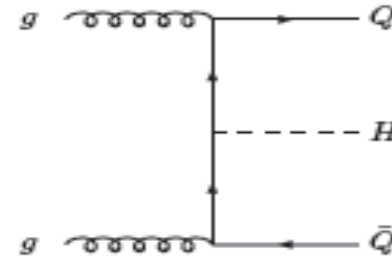
- “... an essential feature of [this] type of theory ... is the prediction of incomplete multiplets of vector and scalar bosons”
- Englert, Brout, Guralnik, Hagen & Kibble did not comment on its existence

# Higgs

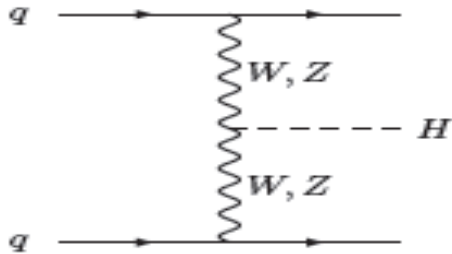
**GF**



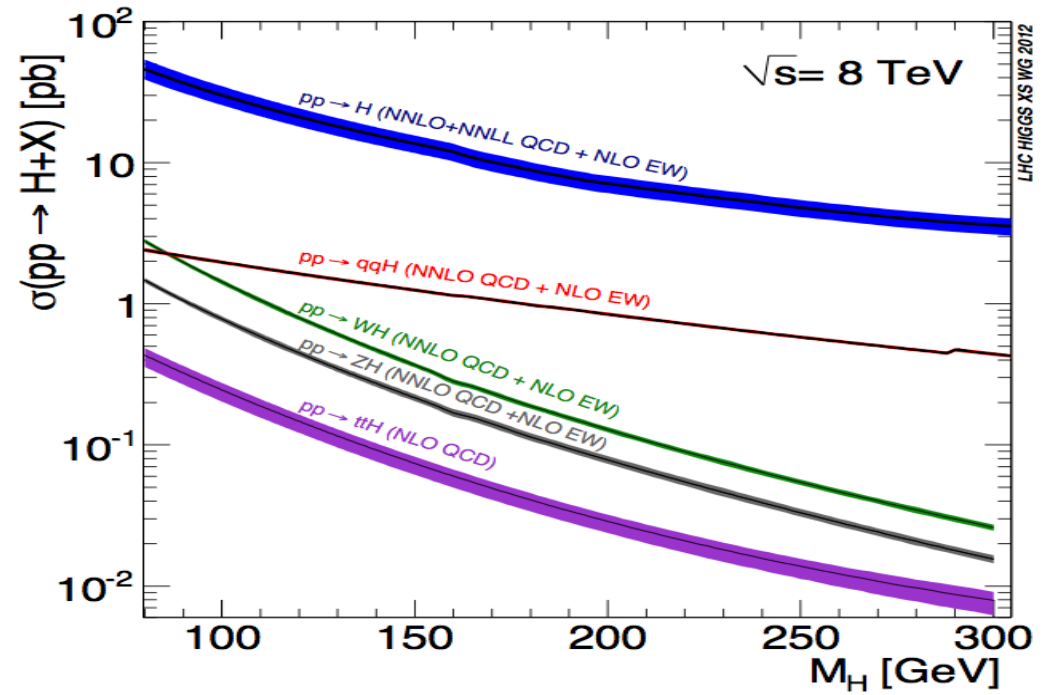
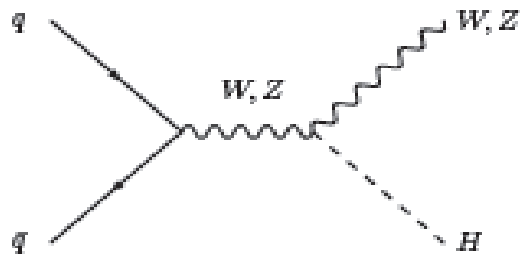
**QH**



**VBF**

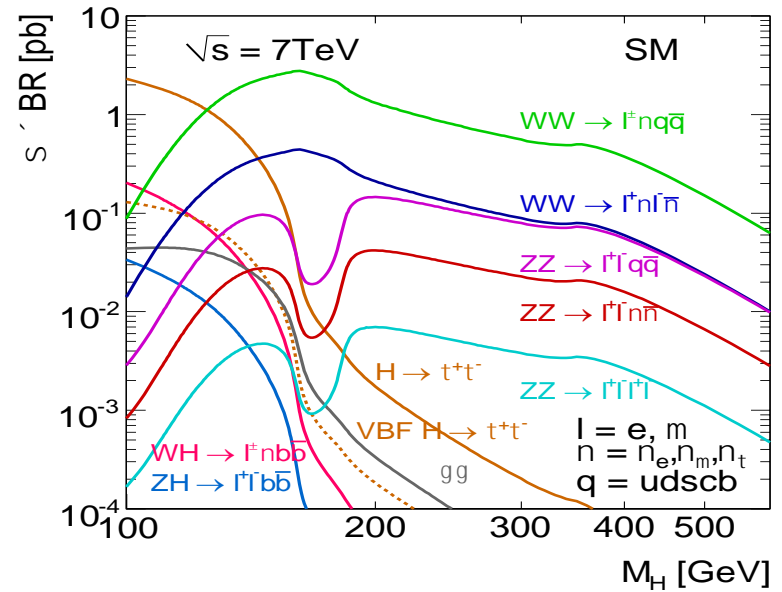
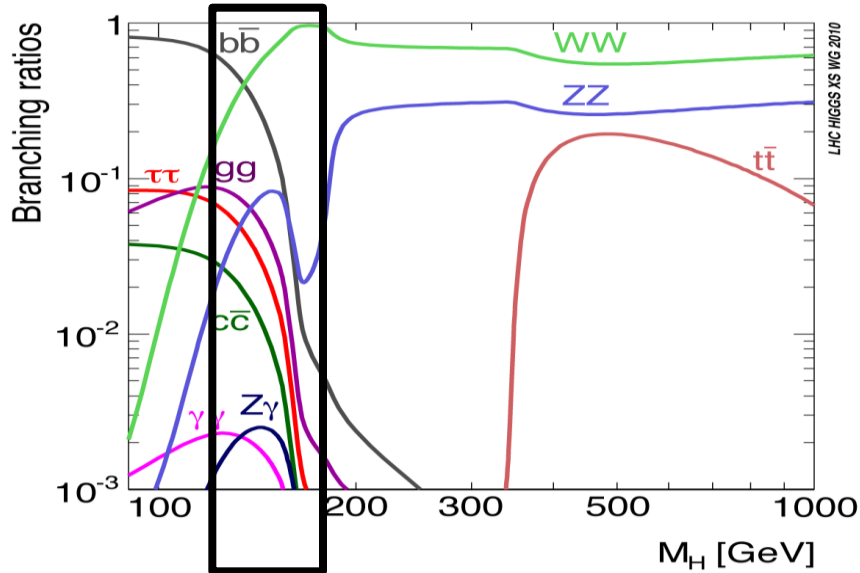


**VH**



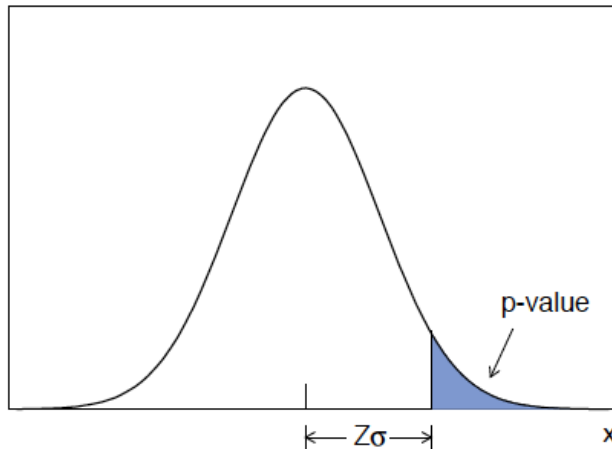
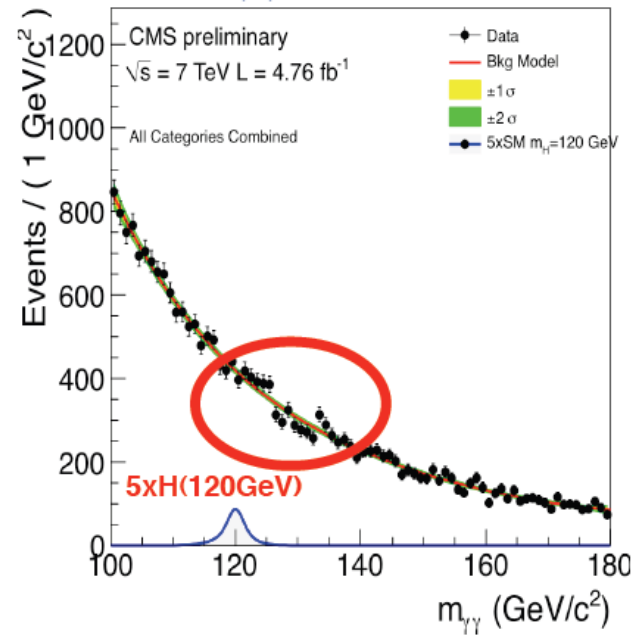
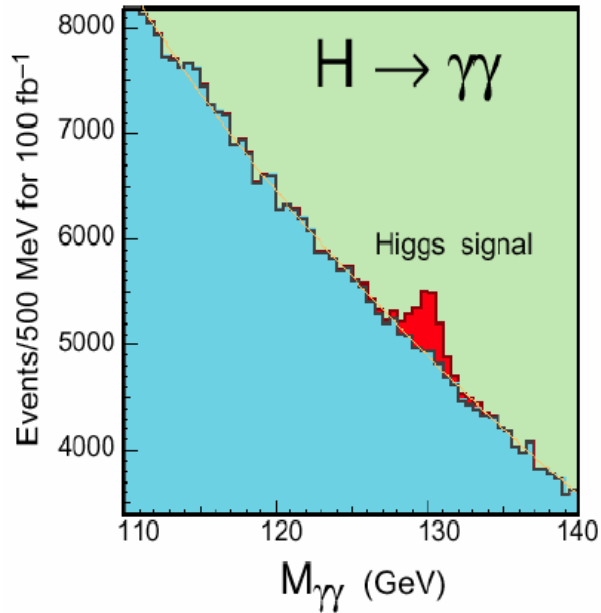
**Фон:  $H \rightarrow WW, ZZ, \gamma\gamma$  главно от  $qq$  аниhilация**

# Канали на разпад



Канали на разпад	Масова област (GeV/c <sup>2</sup> )	m <sub>H</sub> разрешение
H → γγ	4 110 - 150	1.2 – 2.7 %
H → ZZ → 4l	3 110 - 600	1 – 2 %
H → bb	5 110 - 145	20 %
H → ττ	9 110 - 135	10 %
H → WW → 2l2ν	5 110 - 600	20 %
H → ZZ → 2l2τ	8 190 - 600	10 – 15 %
H → ZZ → 2l2q	6 130 – 164 (200 – 600)	3 %
H → ZZ → 2l2ν	2 250 - 600	7 %

# Статистическа значимост



## Нормално разпределение

$$f(z) = 1/\sqrt{2\pi\sigma^2} e^{-(z^{**2}/2)}$$

$$Z\sigma = CL \text{ (confidence level)}$$

Нека  $\sigma = 1$  и  $Z = 4.45$  (99.9992%)

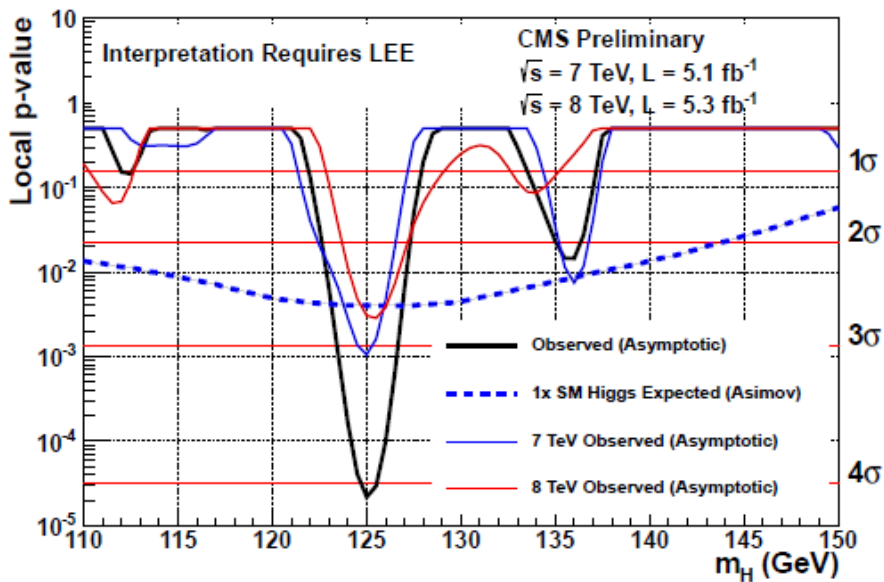
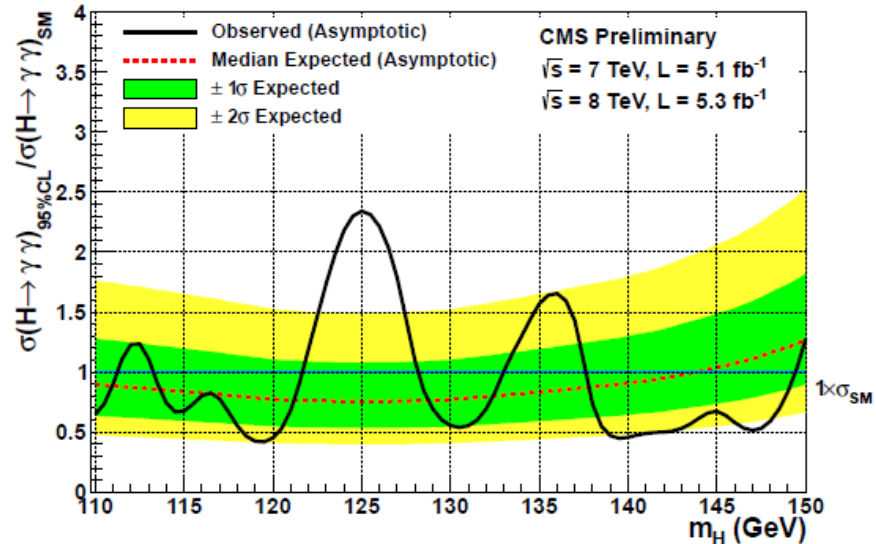
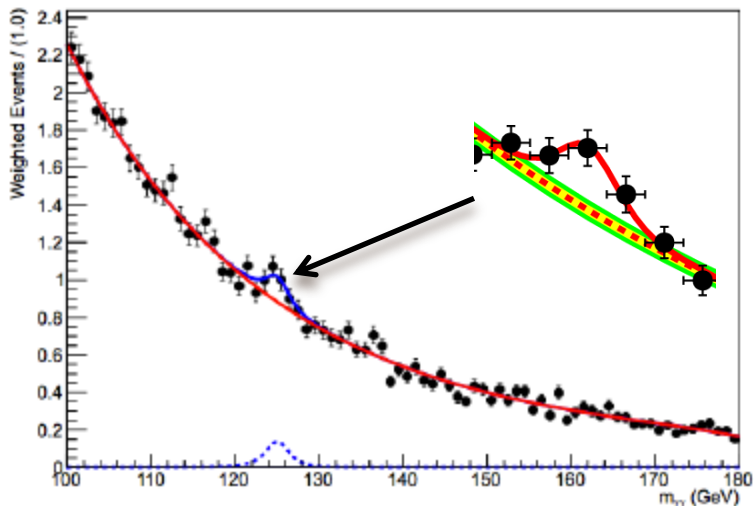
$$p\text{-value} (Z \geq 4.45) = 1/\sqrt{2\pi} \int_{4.45}^{\infty} e^{-(z^{**2}/2)} dz$$

$$= 0.000004$$

Вероятността фонвата флуктоация да даде сигнал

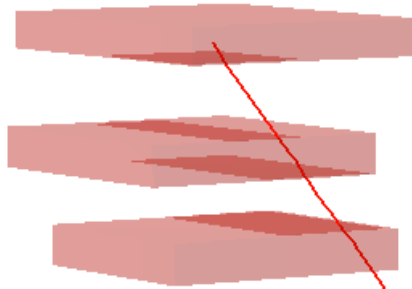
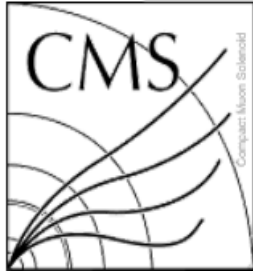
# Леки Higgs $H \rightarrow \gamma\gamma$

$H \rightarrow \gamma\gamma$  - 2011+2012



**4.1  $\sigma$  за  $M_H = 125$  GeV**

# Леки Higgs $H \rightarrow ZZ \rightarrow 4l$

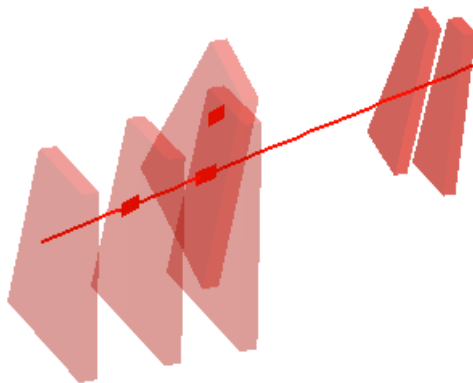


$\mu^+(Z_1) p_T : 43 \text{ GeV}$

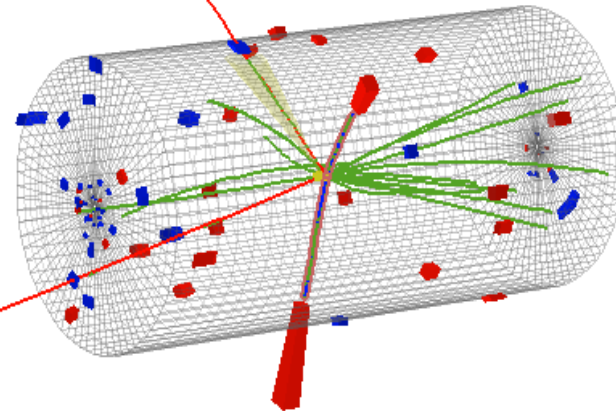
8 TeV DATA

4-lepton Mass : 126.9  
GeV

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



$e^-(Z_2) p_T : 10 \text{ GeV}$



$e^+(Z_2) p_T : 21 \text{ GeV}$

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

# Леки Higgs $H \rightarrow ZZ \rightarrow 4l$

CMS Experiment at LHC, CERN  
Data recorded: Thu Oct 13 03:39:46 2011 CEST  
Run/Event: 178421 / 87514902  
Lumi section: 86



7 TeV DATA

**4 $\mu$ + $\gamma$  Mass : 126.1 GeV**

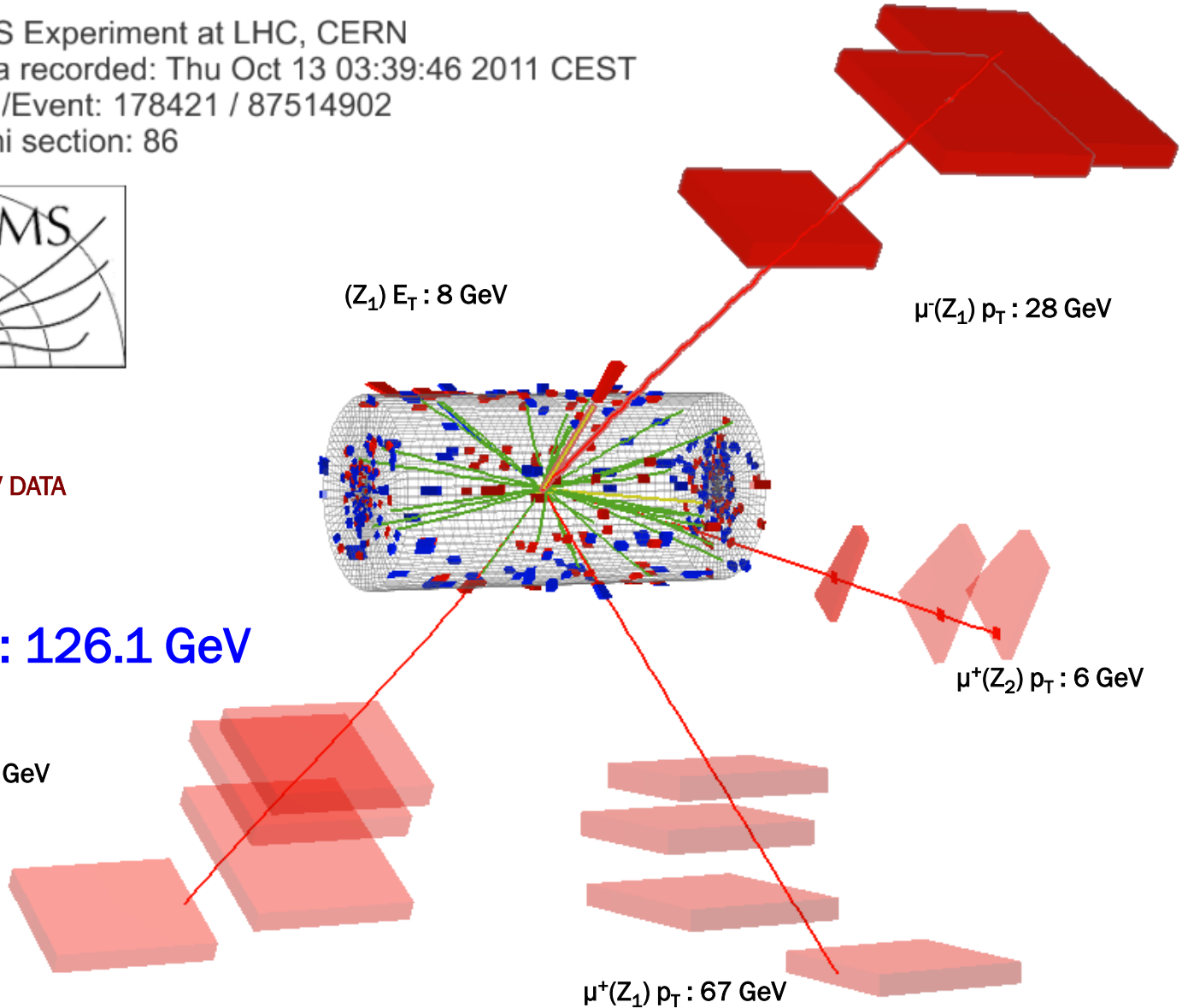
$\mu^-(Z_2) p_T : 14 \text{ GeV}$

$(Z_1) E_T : 8 \text{ GeV}$

$\mu^-(Z_1) p_T : 28 \text{ GeV}$

$\mu^+(Z_2) p_T : 6 \text{ GeV}$

$\mu^+(Z_1) p_T : 67 \text{ GeV}$



# Леки Higgs $H \rightarrow ZZ \rightarrow 4l$



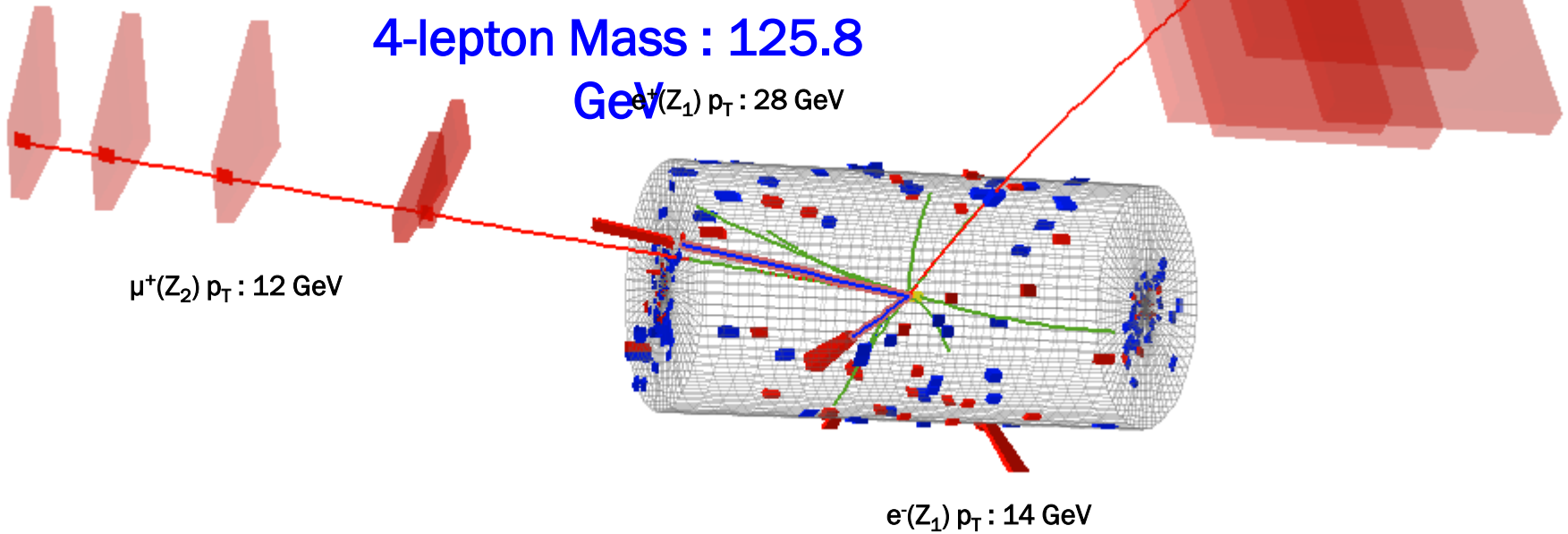
CMS Experiment at LHC, CERN  
Data recorded: Tue Oct 4 00:10:13 2011 CEST  
Run/Event: 177782 / 72158025  
Lumi section: 99

$\mu^-(Z_2) p_T : 15 \text{ GeV}$

7 TeV DATA

4-lepton Mass : 125.8

GeV  $e^+(Z_1) p_T : 28 \text{ GeV}$

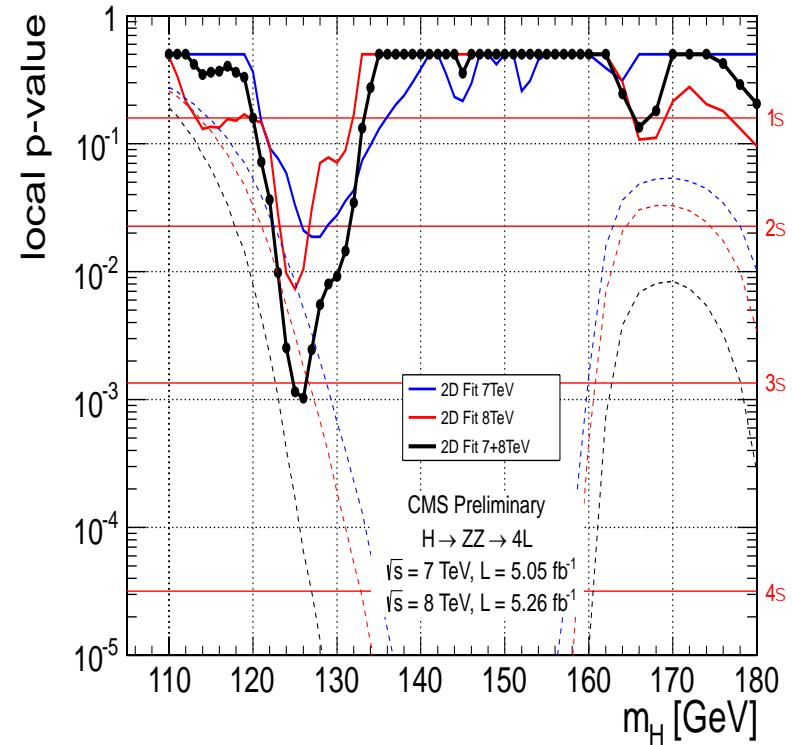
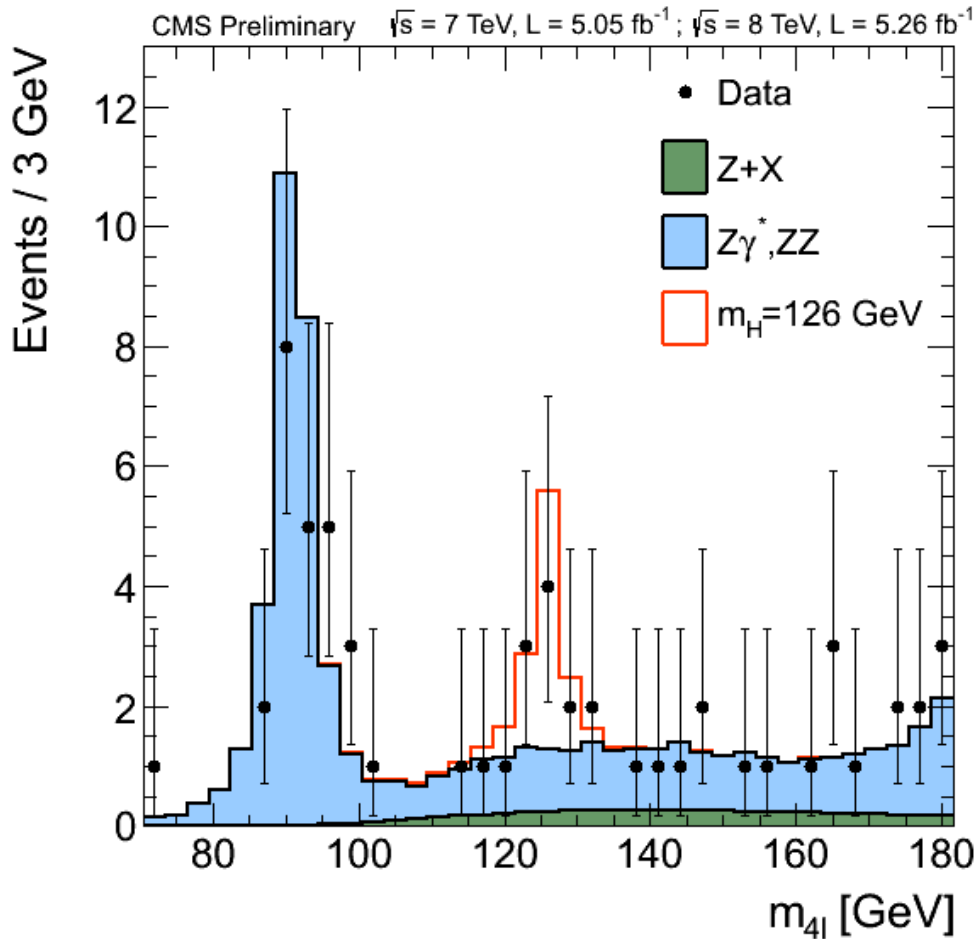


$\mu^+(Z_2) p_T : 12 \text{ GeV}$

$e^-(Z_1) p_T : 14 \text{ GeV}$

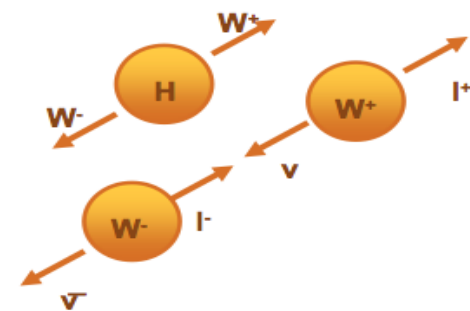
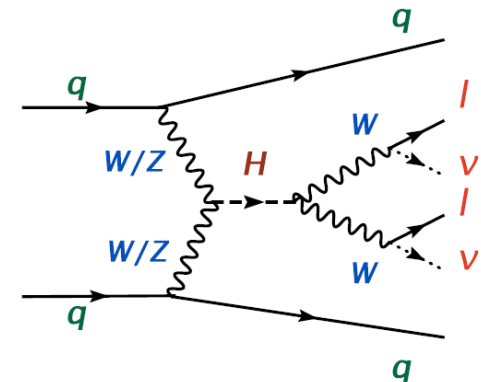
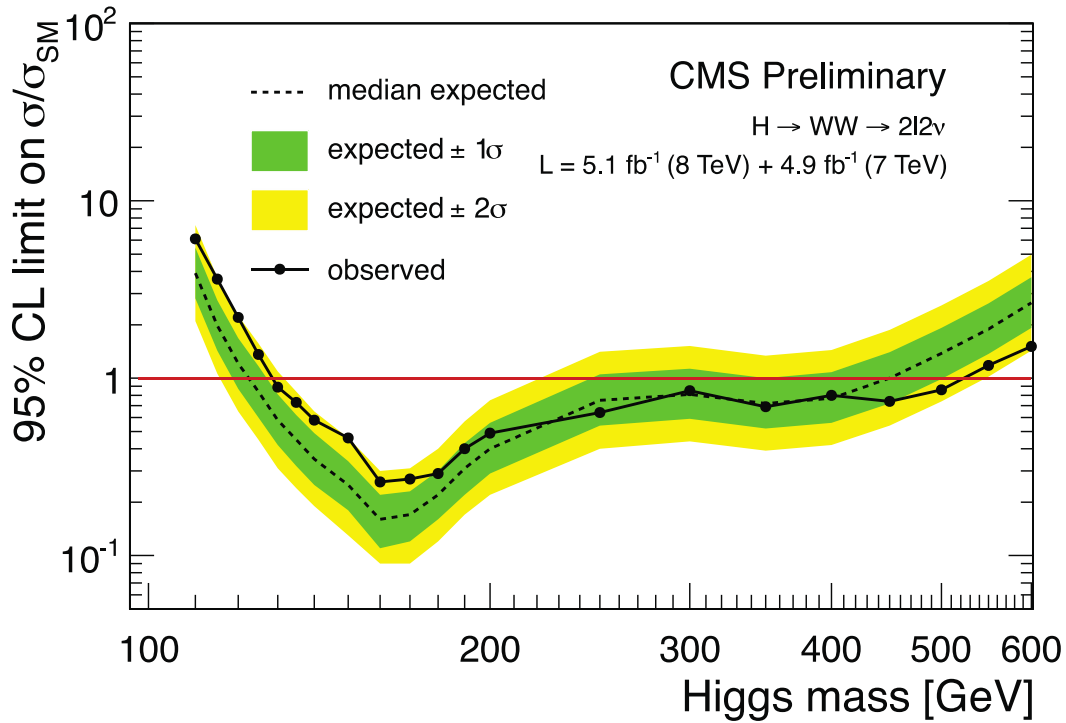


# Леки Higgs $H \rightarrow ZZ \rightarrow 4l$



**$3.2 \sigma$  за  $M_H = 125 \text{ GeV}$**

# $H \rightarrow WW \rightarrow 2l2\nu$

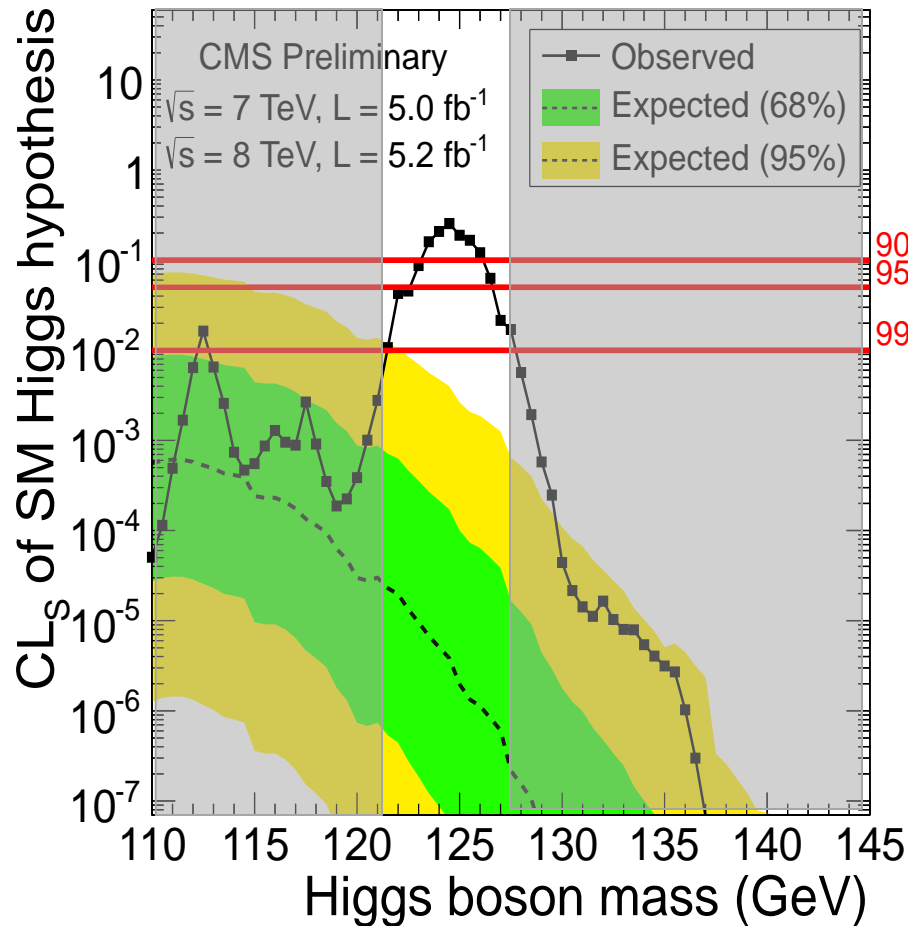


**Област на изключване:**

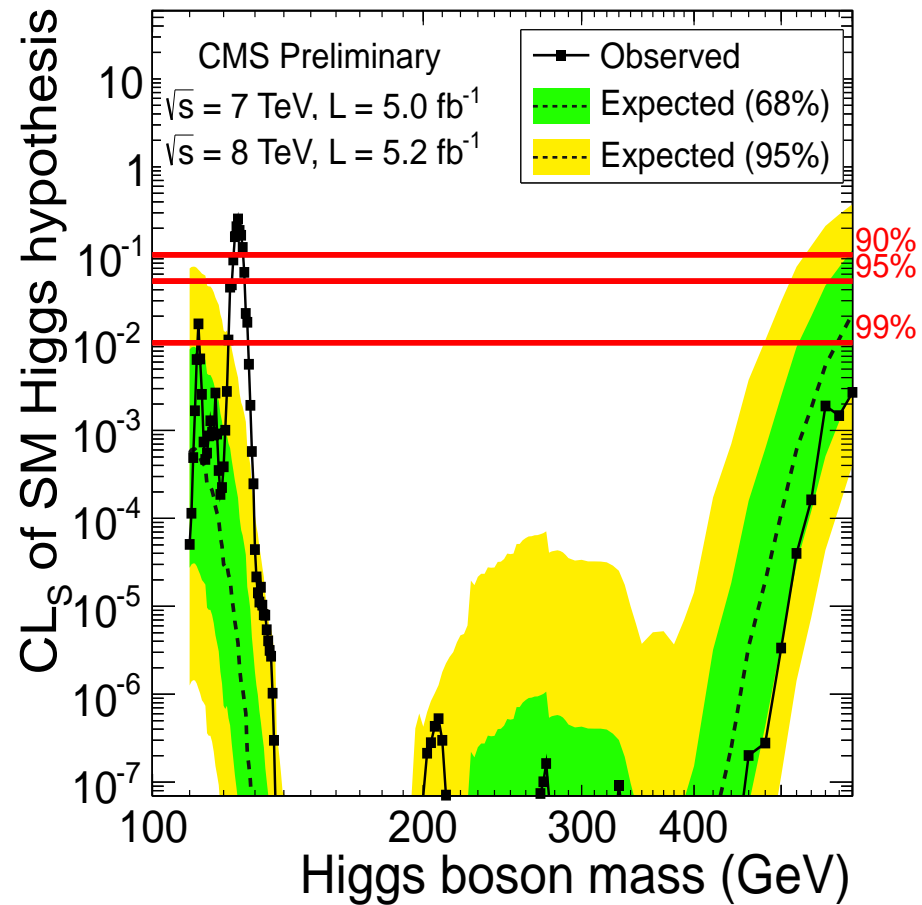
**очаквана: 123 - 450 GeV**

**наблюдавана: 129 - 520 GeV**

# Комбинирани данни



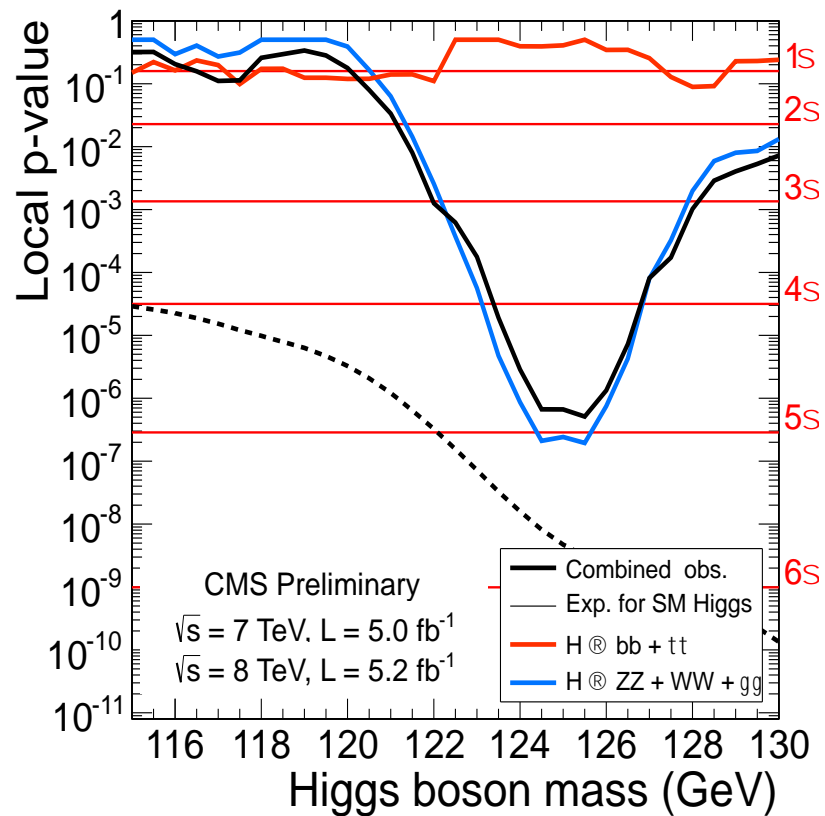
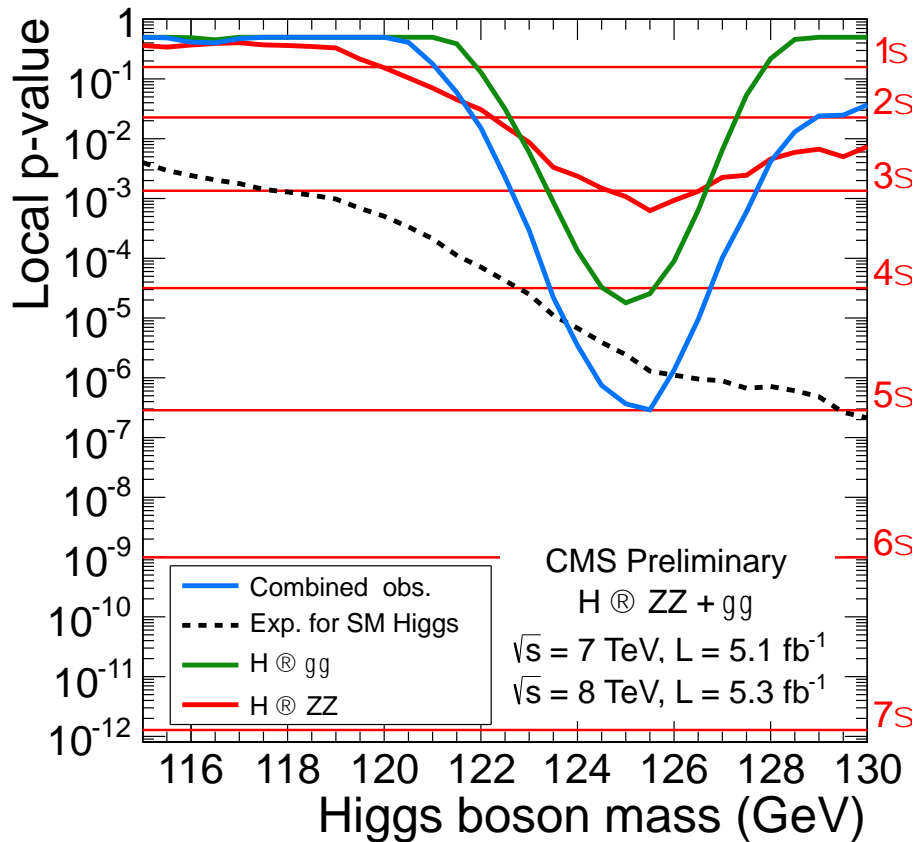
**Наблюдавана област на изключване:**



**95 % 110 – 121.5 GeV**

**127 – 600 GeV**

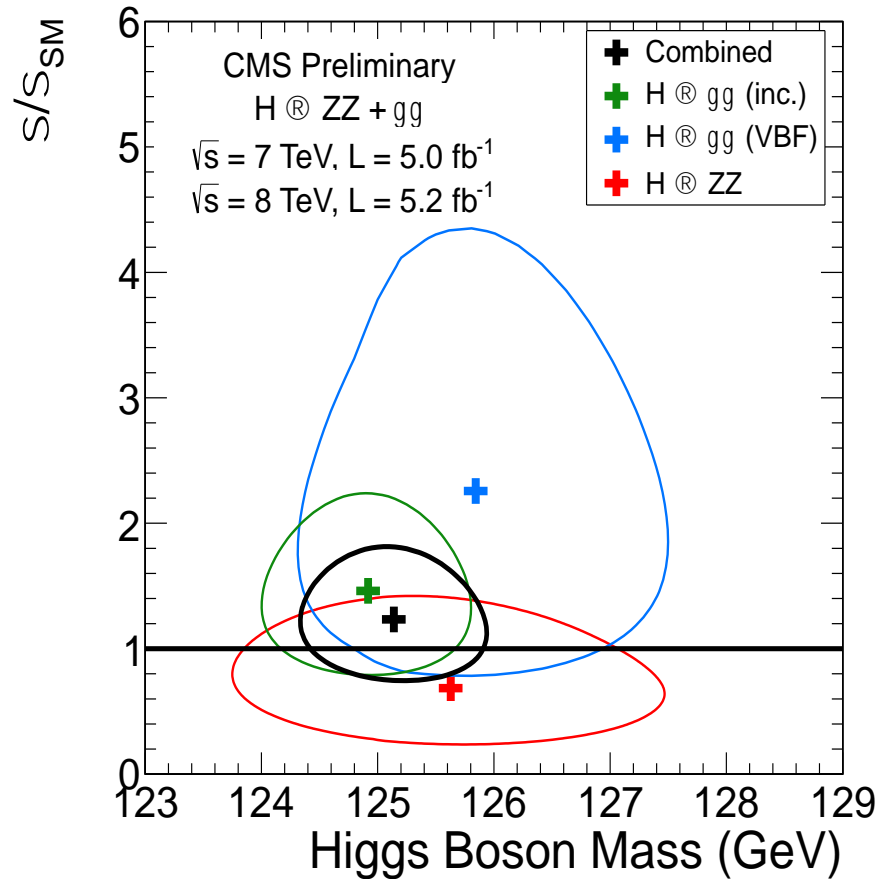
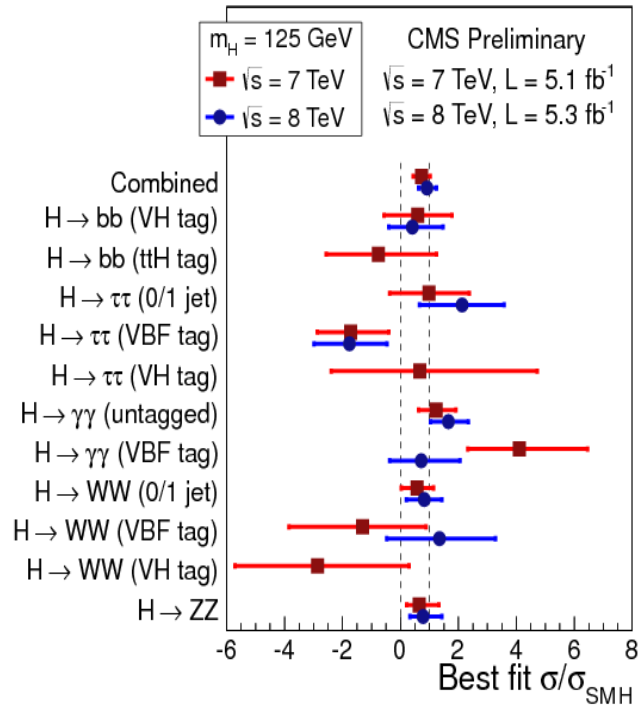
# P-value за малките маси



**Мах. локална значимост ( $H \rightarrow ZZ + \gamma\gamma$ ) = 5.0  $\sigma$**

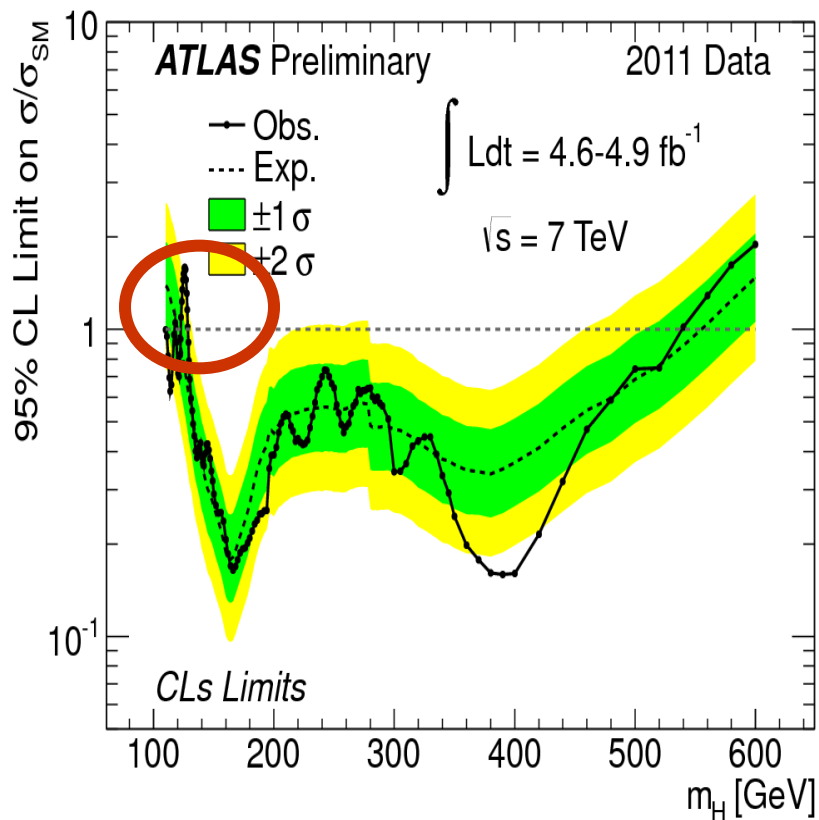
**Мах. локална значимост ( $H \rightarrow ZZ + \gamma\gamma + WW$ ) = 5.1  $\sigma$**

# Характеристики на Higgs: маса



$$m_x = 125.3 \pm 0.6 \text{ GeV}$$

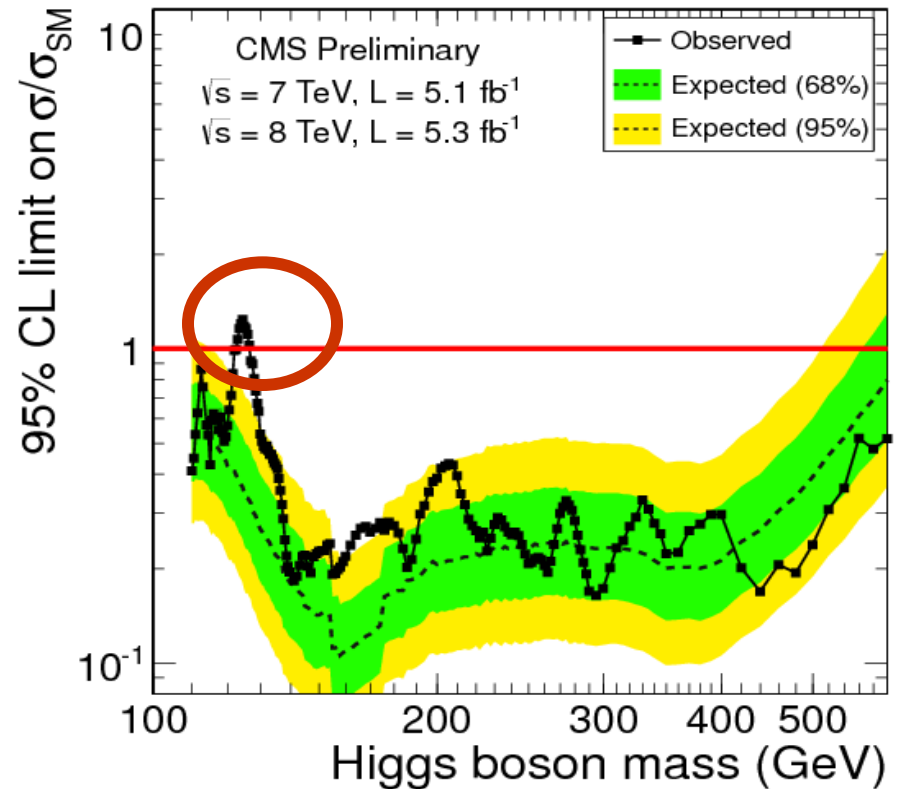
# CL<sub>S</sub> 3a SM Higgs



**ATLAS изключва:**

**< 121.8; > 130.7; < 523 GeV**

**$m_x = 126.5 \text{ GeV} / 5 \sigma$**



**CMS изключва:**

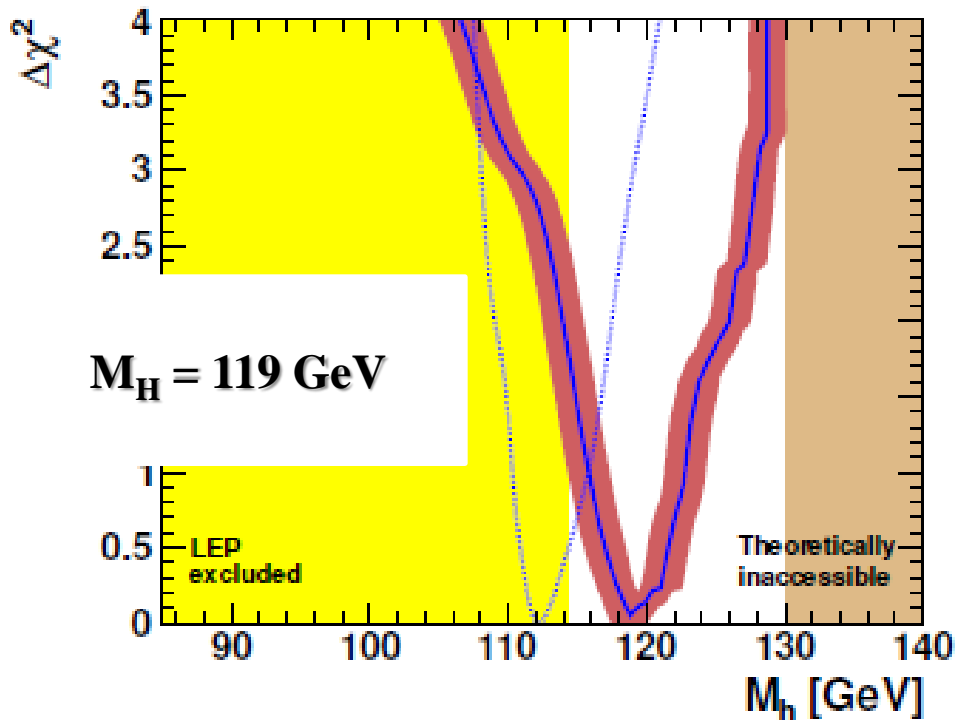
**< 121.5; > 127.5; < 600 GeV**

**$m_x = 125.3 \text{ GeV} / 5.1 \sigma$**

# Теория

От LEP:  $M_H > 114.4 \text{ GeV}$

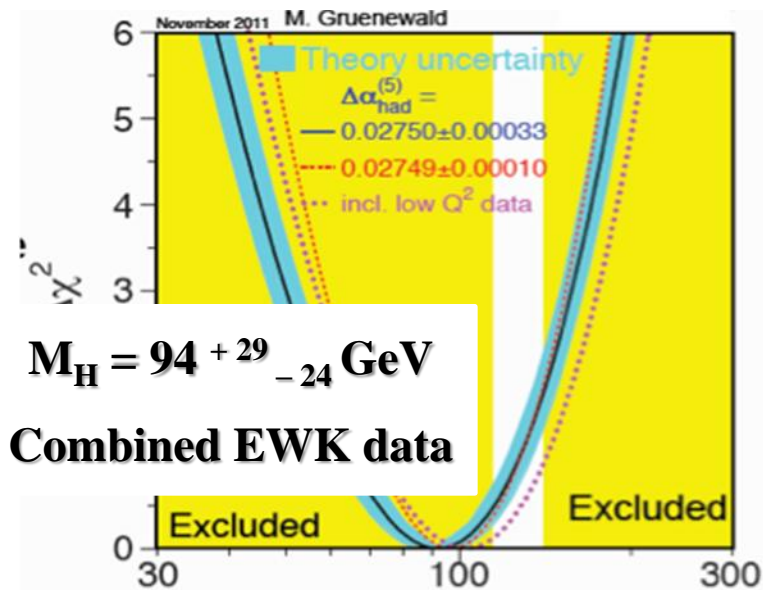
O. Buchmueller et al. hep-ph 1110.3568, 2011



$M_H = 119 \text{ GeV}$

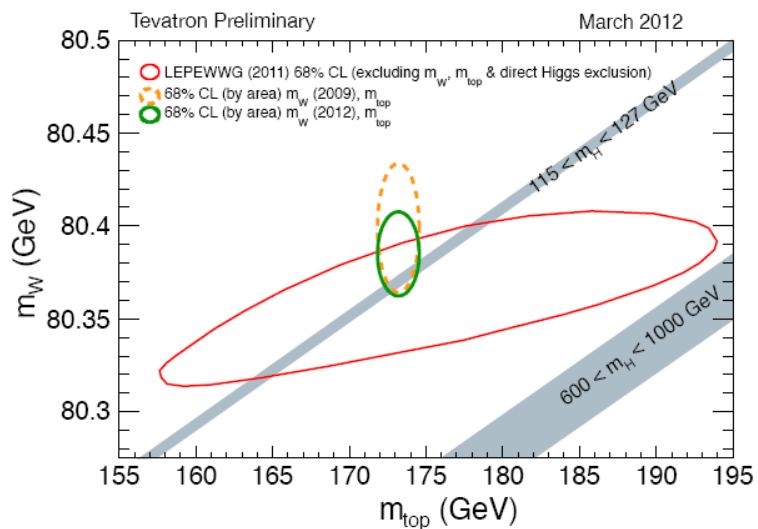
Tevatron March 2012

$M_W = 80385 \pm 15 \text{ MeV}$



$M_H = 94^{+29}_{-24} \text{ GeV}$

Combined EWK data



# Заклучение

**Изключена е областта за съществуването на SM Higgs бозон при 95 % CL: [110 – 121.5] и [127.5 – 600]**

**Наблюдава се състояние от 5.1  $\sigma$  при  $\sim 125$  GeV**

**Две разпада (високо разрешение и висока чувствителност) дават основен принос:**

-  $X \rightarrow \gamma\gamma$  с 4.1  $\sigma$

-  $X \rightarrow 4l$  с 3.2  $\sigma$

- двете наблюдавани състояния са при една и съща маса

- фитът дава  $m_x = 125.3 \pm 0.6$  GeV

**Естествената интерпретация, че това състояние се дължи на раждането на Higgs бозон, съвпада (в рамките на статистическата точност) с наблюденията при всички канали на разпад**