ОБЗОР ФИЗИКИ НА БОЛЬШОМ АДРОННОМ КОЛЛАЙДЕРЕ

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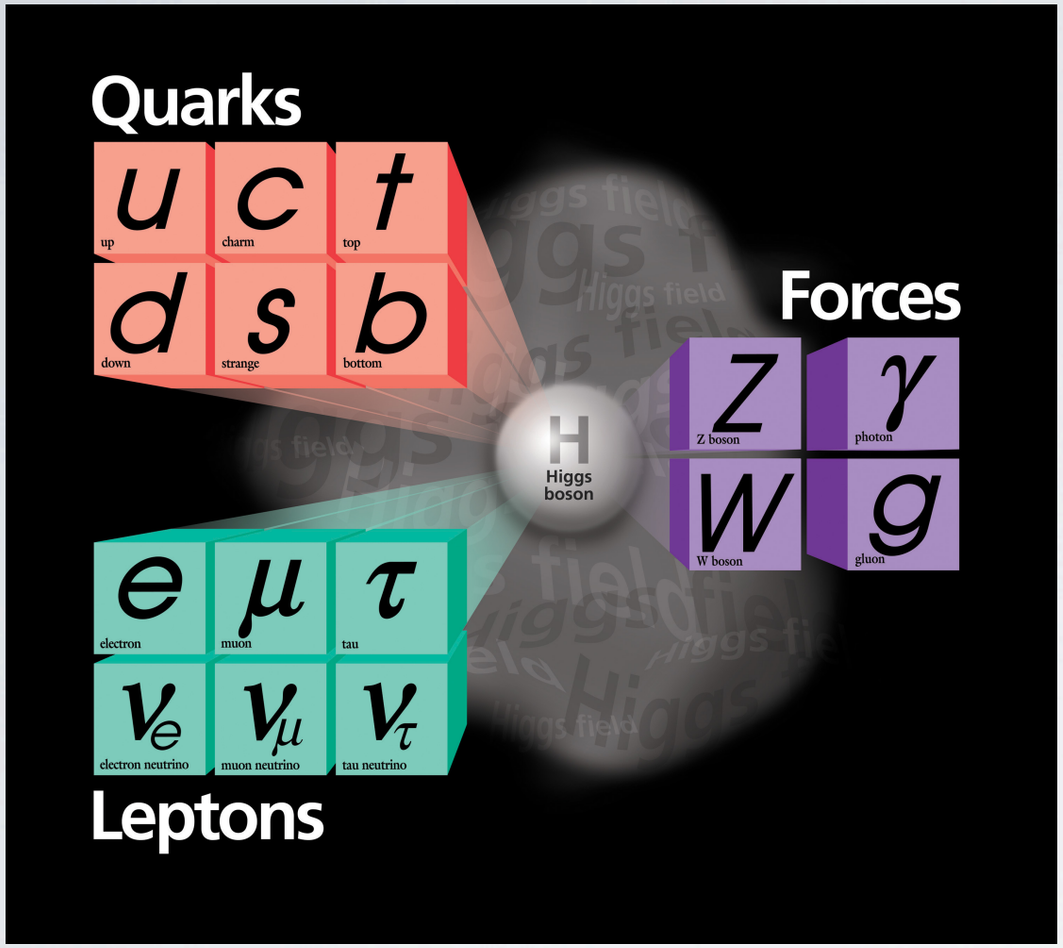
СОДЕРЖАНИЕ

“Переоткрытие” Стандартной Модели
Поиски бозона Хиггса
Поиски новой физики за пределами Стандарной Модели
Суперсимметрия?
Дополнительные размерности?

СТАНДАРТНАЯ МОДЕЛЬ



e.g. LEP and SM

Quantity	Value	Standard Model	Pull
m_t [GeV]	$172.7 \pm 2.9 \pm 0.6$	172.7 ± 2.8	0.0
M_W [GeV]	80.450 ± 0.058	80.376 ± 0.017	1.3
	80.392 ± 0.039		0.4
M_Z [GeV]	91.1876 ± 0.0021	91.1874 ± 0.0021	0.1
Γ_Z [GeV]	2.4952 ± 0.0023	2.4968 ± 0.0011	−0.7
Γ(had) [GeV]	1.7444 ± 0.0020	1.7434 ± 0.0010	—
Γ(inv) [MeV]	499.0 ± 1.5	501.65 ± 0.11	—
$\Gamma(\ell^+\ell^-)$ [MeV]	83.984 ± 0.086	83.996 ± 0.021	—
$\sigma_{\rm had}$ [nb]	41.541 ± 0.037	41.467 ± 0.009	2.0
R_e	20.804 ± 0.050	20.756 ± 0.011	1.0
R_μ	20.785 ± 0.033	20.756 ± 0.011	0.9
R_τ	20.764 ± 0.045	20.801 ± 0.011	−0.8
R_b	0.21629 ± 0.00066	0.21578 ± 0.00010	0.8
R_c	0.1721 ± 0.0030	0.17230 ± 0.00004	−0.1
$A_{FB}^{(0,e)}$	0.0145 ± 0.0025	0.01622 ± 0.00025	−0.7
$A_{FB}^{(0,\mu)}$	0.0169 ± 0.0013		0.5
$A_{FB}^{(0,\tau)}$	0.0188 ± 0.0017		1.5
$A_{FB}^{(0,b)}$	0.0992 ± 0.0016	0.1031 ± 0.0008	−2.4
$A_{FB}^{(0,c)}$	0.0707 ± 0.0035	0.0737 ± 0.0006	−0.8
$A_{FB}^{(0,s)}$	0.0976 ± 0.0114	0.1032 ± 0.0008	−0.5
$\bar{s}_\ell^2(A_{FB}^{(0,q)})$	0.2324 ± 0.0012	0.23152 ± 0.00014	0.7
	0.2238 ± 0.0050		−1.5
A_e	0.15138 ± 0.00216	0.1471 ± 0.0011	2.0
	0.1544 ± 0.0060		1.2
	0.1498 ± 0.0049		0.6
A_μ	0.142 ± 0.015		−0.3
A_τ	0.136 ± 0.015		−0.7
	0.1439 ± 0.0043		−0.7
A_b	0.923 ± 0.020	0.9347 ± 0.0001	−0.6
A_c	0.670 ± 0.027	0.6678 ± 0.0005	0.1
A_s	0.895 ± 0.091	0.9356 ± 0.0001	−0.4
g_L^2	0.30005 ± 0.00137	0.30378 ± 0.00021	−2.7
g_R^2	0.03076 ± 0.00110	0.03006 ± 0.00003	0.6
$g_V^{\nu e}$	-0.040 ± 0.015	-0.0396 ± 0.0003	0.0
$g_A^{\nu e}$	-0.507 ± 0.014	-0.5064 ± 0.0001	0.0
A_{PV}	-1.31 ± 0.17	-1.53 ± 0.02	1.3
Q_W(Cs)	-72.62 ± 0.46	-73.17 ± 0.03	1.2
Q_W(Tl)	-116.6 ± 3.7	-116.78 ± 0.05	0.1
$\frac{\Gamma(b\to s\gamma)}{\Gamma(b\to Xe\nu)}$	$3.35^{+0.50}_{-0.44} \times 10^{-3}$	$(3.22 \pm 0.09) \times 10^{-3}$	0.3
$\frac{1}{2}(g_\mu - 2 - \frac{\alpha}{\pi})$	4511.07 ± 0.82	4509.82 ± 0.10	1.5
τ_τ [fs]	290.89 ± 0.58	291.87 ± 1.76	−0.4

СМ: замечатальная и хорошо проверенная экспериментально теория

СТАНДАРТНАЯ МОДЕЛЬ: ПРОБЛЕМЫ

Где бозон Хиггса?

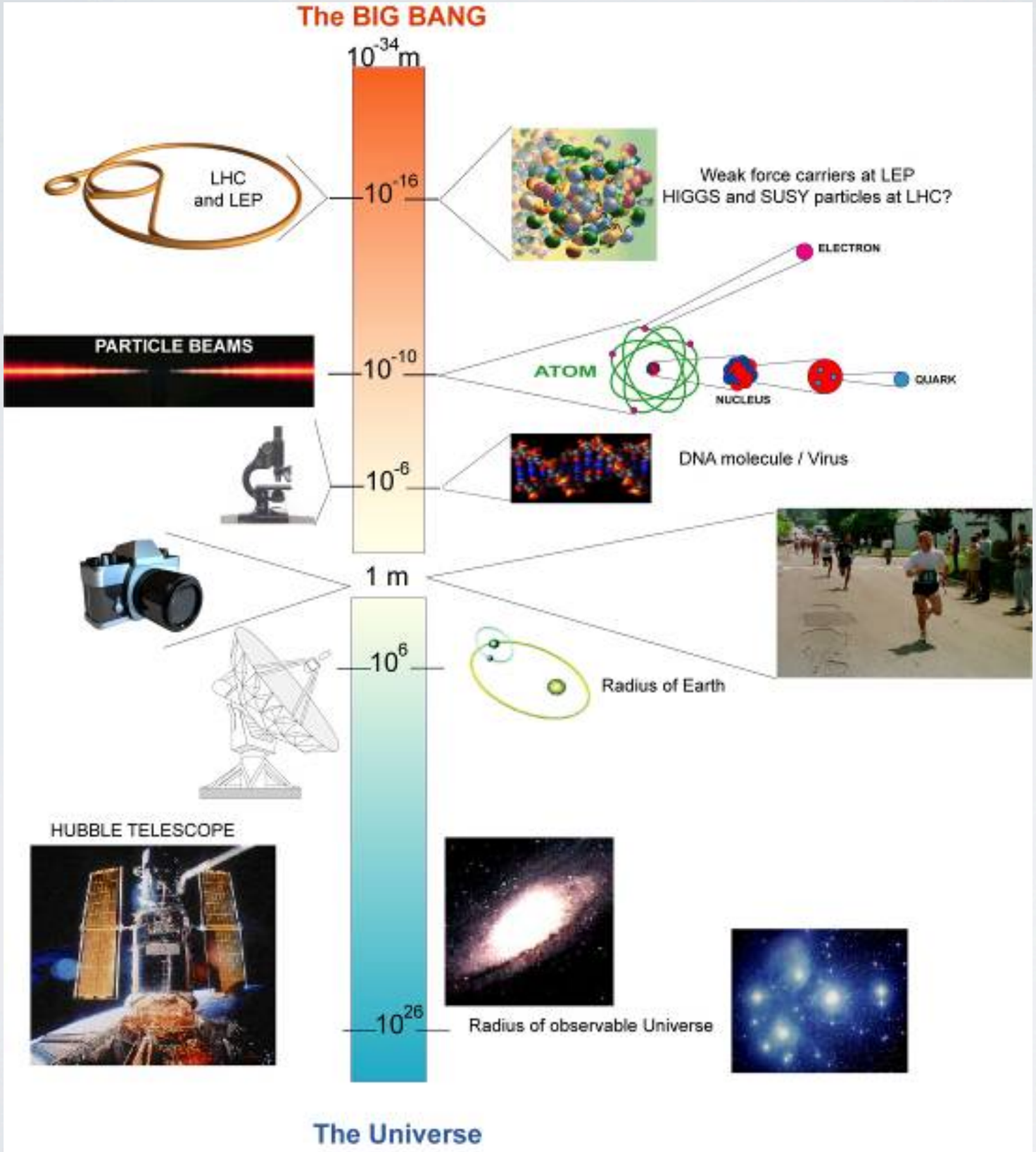
Происхождение масс и их иерархия?
Присхождение CP-нарушения?

Новые состояния кварк-глюонной материи?

Слишком много параметров: 22

Как включить гравитацию?

УСКОРИТЕЛИ ЧАСТИЦ



СОВРЕМЕННЫЕ КОЛЛАЙДЕРЫ

Фермилаб Тэватрон (Чикаго)

$p\bar{p}$: 1 ТэВ x 1 ТэВ $E^L = 2 \cdot 10^3$ ТэВ

BNL RHIC (Нью-Йорк)

AA: 100 ГэВ/н x 100 ГэВ/н $E^L = 20$ ГэВ/н

ЦЕРН БАК (Женева)

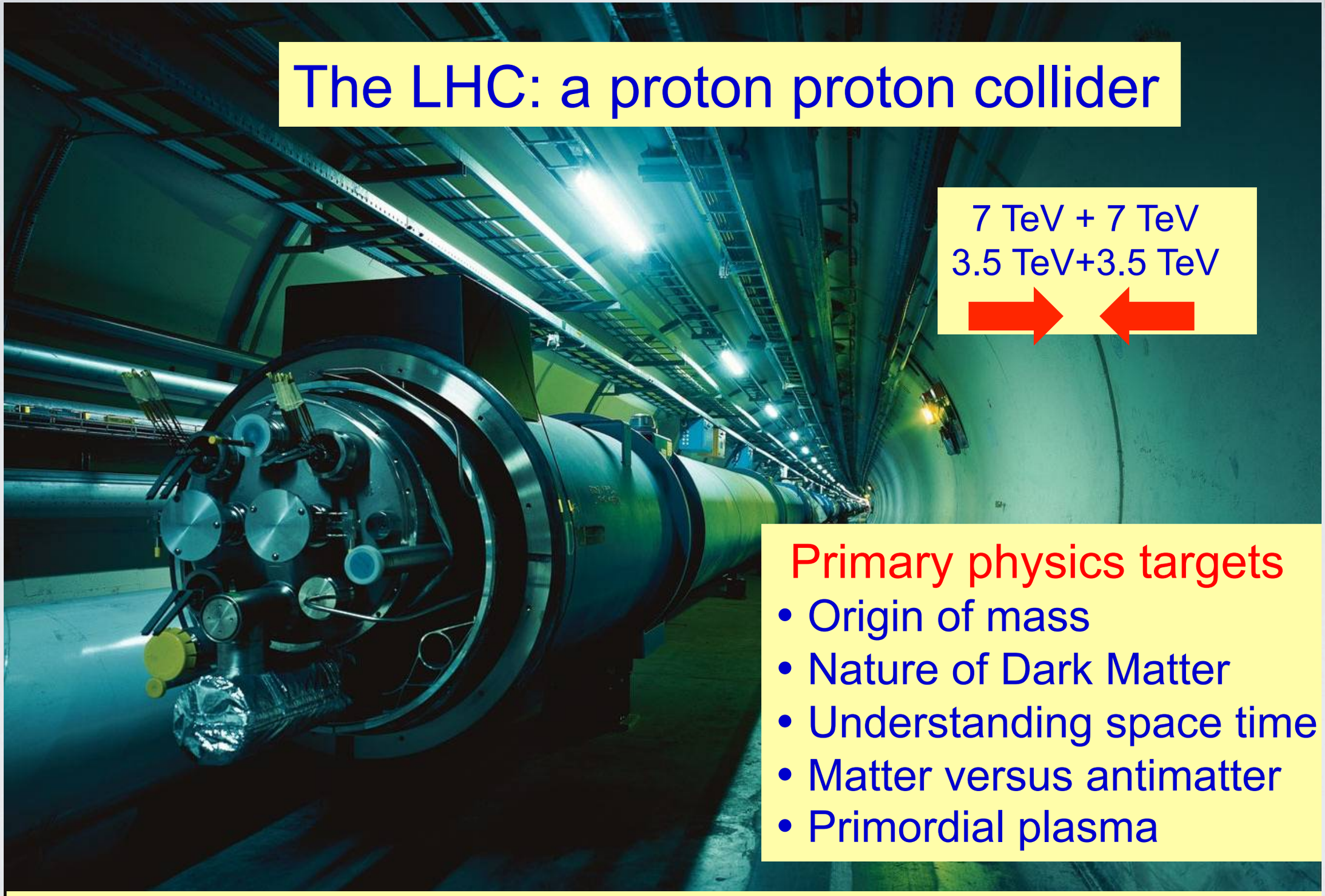
pp: 3.5 ТэВ x 3.5 ТэВ $E^L = 2 \cdot 10^4$ ТэВ

7 ТэВ x 7 ТэВ $E^L = 10^5$ ТэВ

AA:

БОЛЬШОЙ АДРОННЫЙ КОЛЛАЙДЕР

БОЛЬШОЙ АДРОННЫЙ КОЛЛАЙДЕР



The LHC: a proton proton collider

7 TeV + 7 TeV
3.5 TeV+3.5 TeV

Primary physics targets

- Origin of mass
- Nature of Dark Matter
- Understanding space time
- Matter versus antimatter
- Primordial plasma

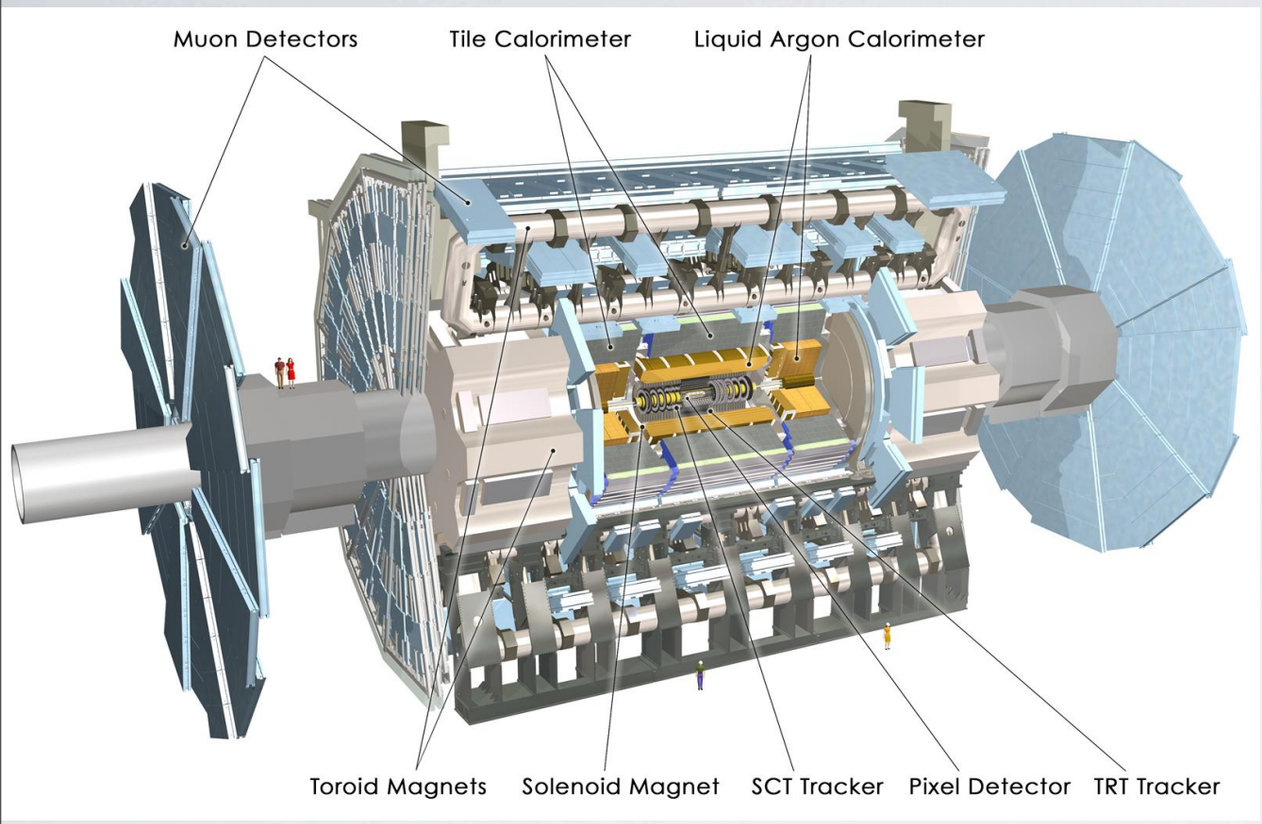
The LHC will determine the Future course of High Energy Physics

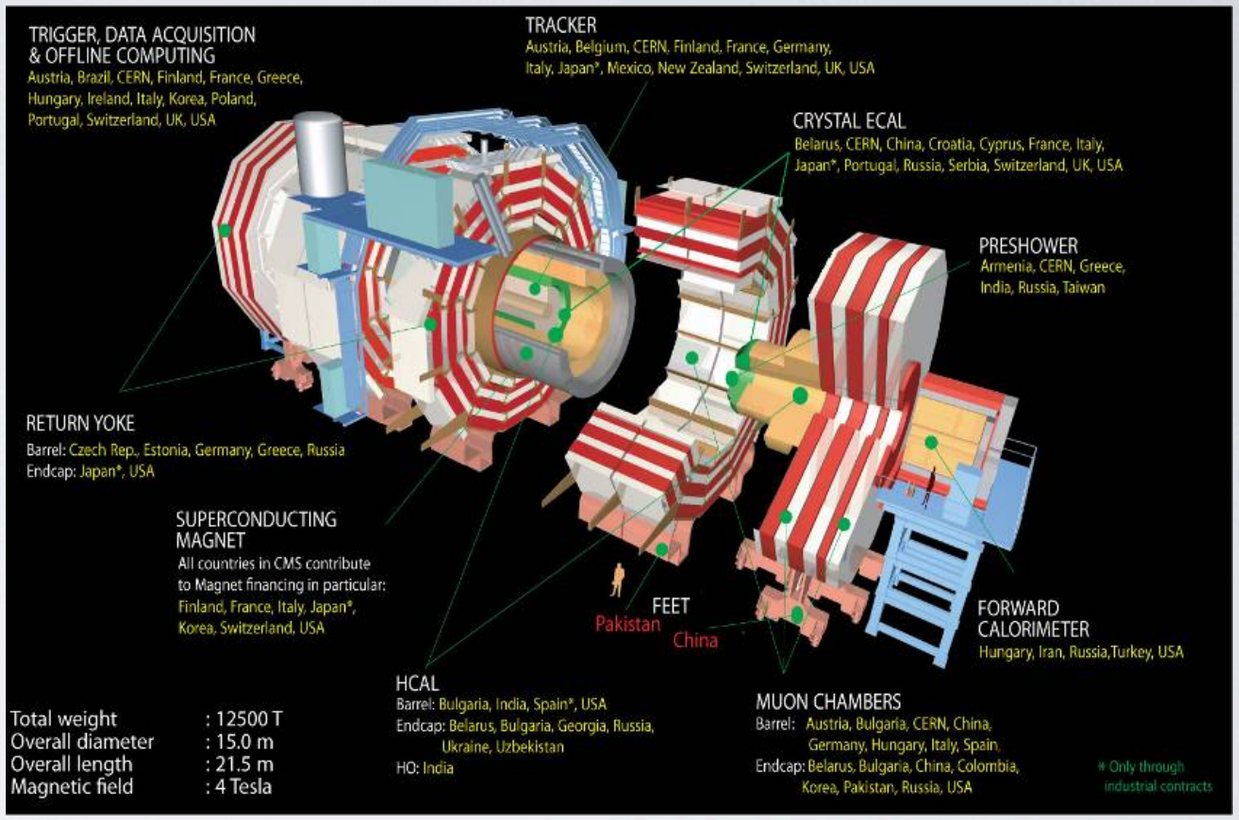
The LHC started at 7 TeV Centre of Mass Energy on 30/3/10

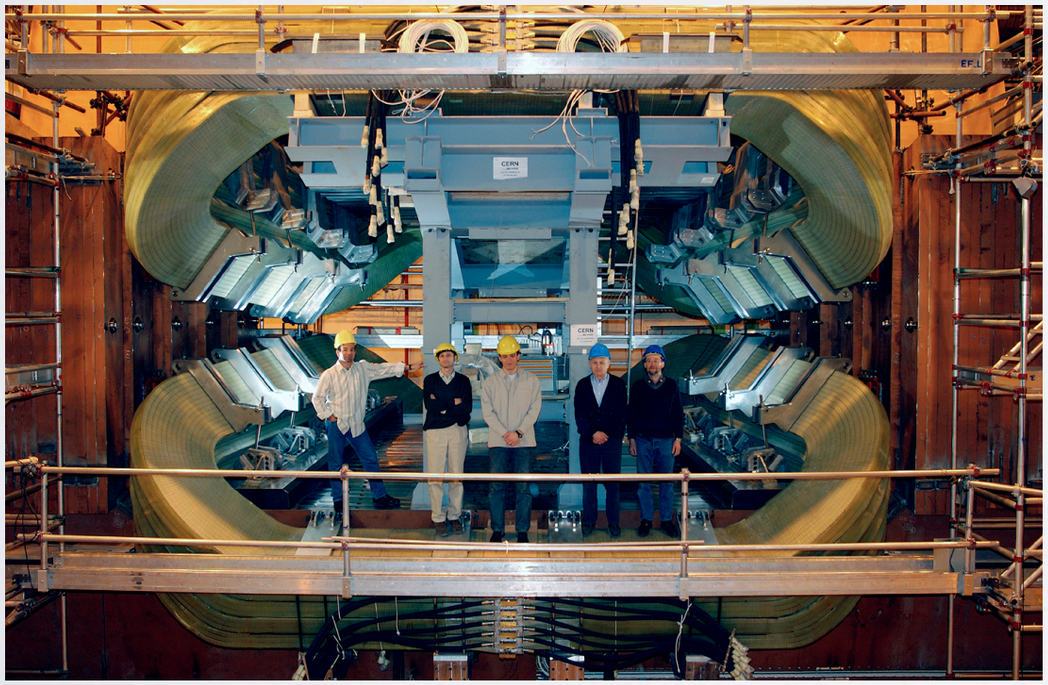
ЭКСПЕРИМЕНТЫ НА БАК

Experiments at the LHC

ЭКСПЕРИМЕНТЫ НА БАК

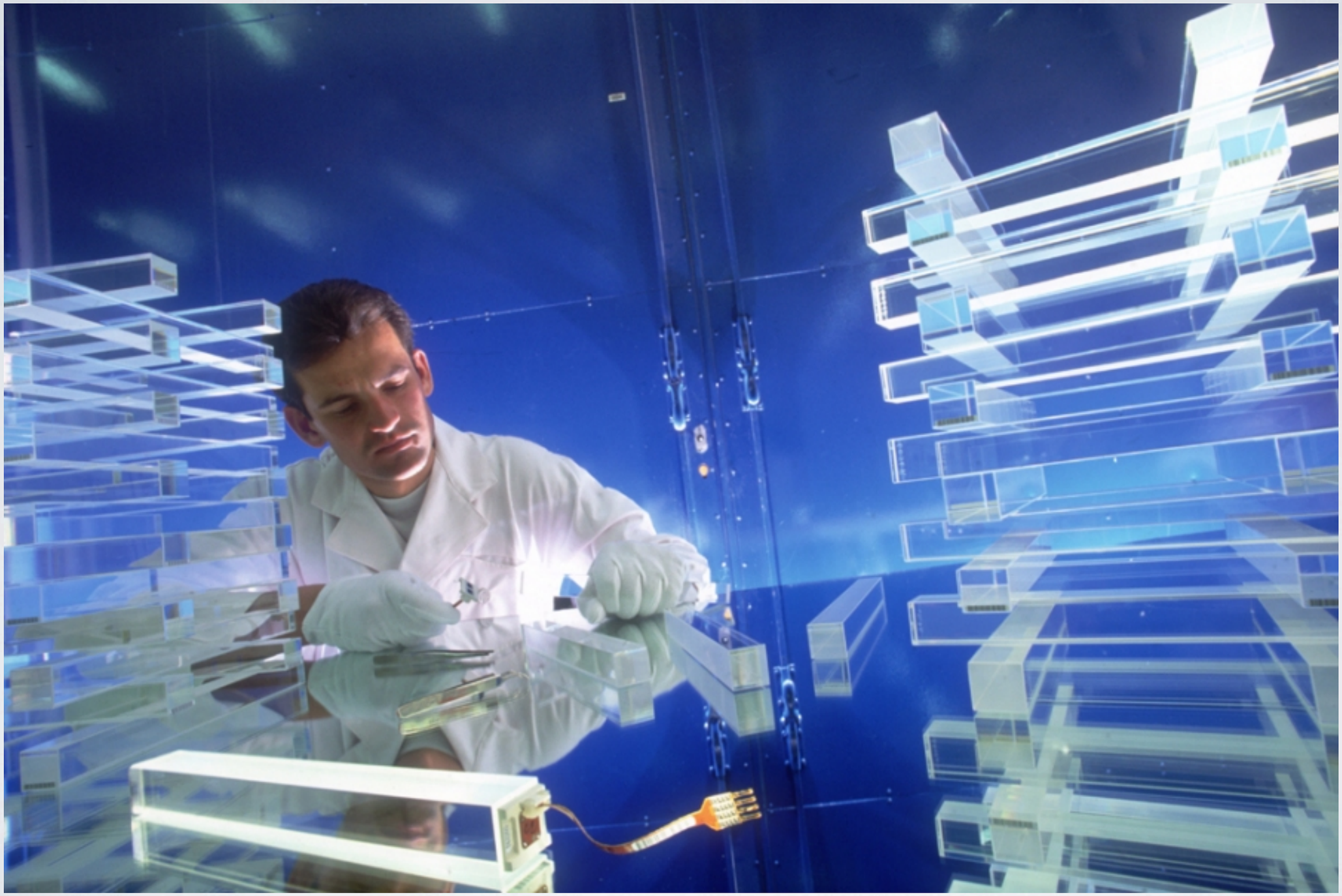




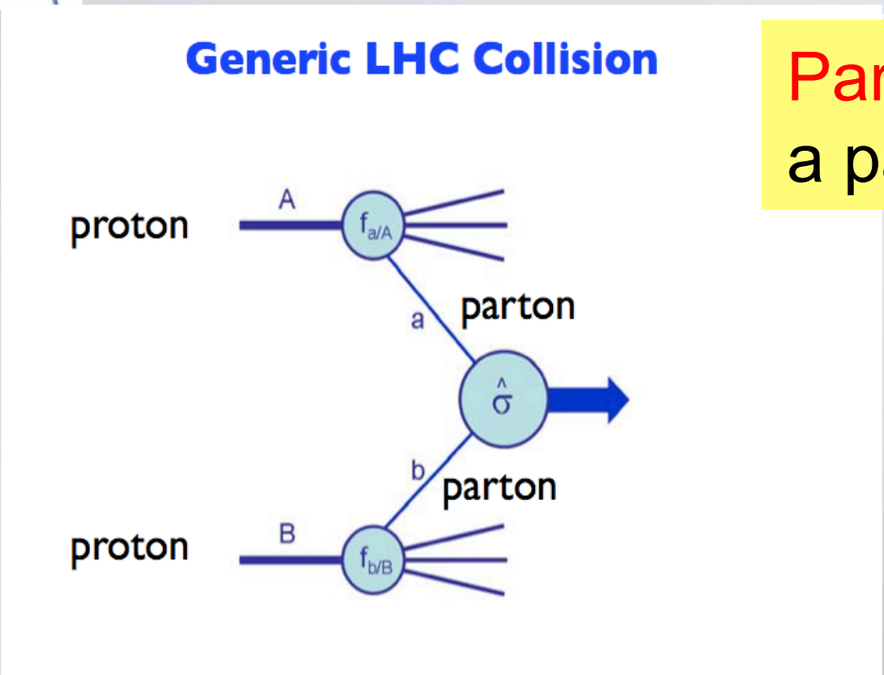


КОНВЕРСИЯ ВПК ДЛЯ БАК (CMS)

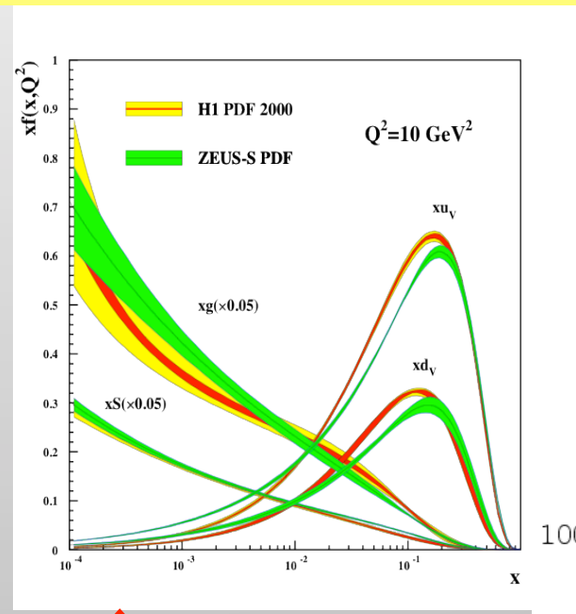
КОНВЕРСИЯ ВПК ДЛЯ БАК : КРИСТАЛЛЫ ДЛЯ CMS ECAL

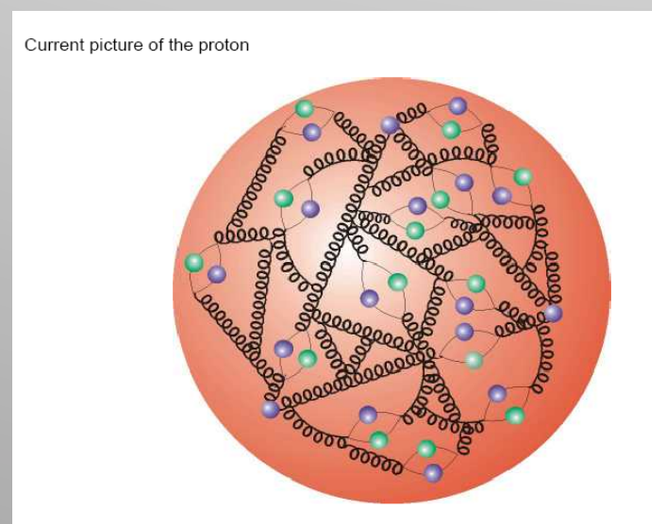


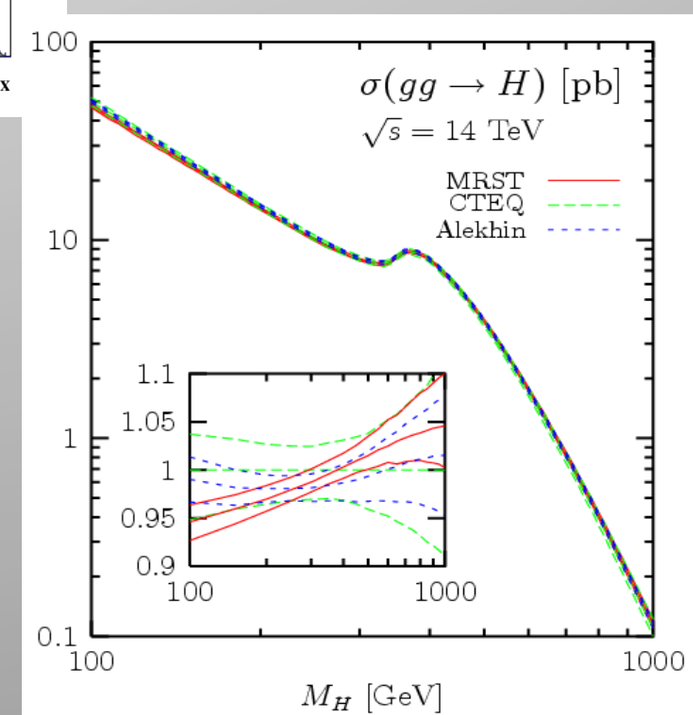
PP-СОУДАРЕНИЯ НА БАК



Parton Distribution Functions: the probability of finding a parton with momentum fraction x in the proton

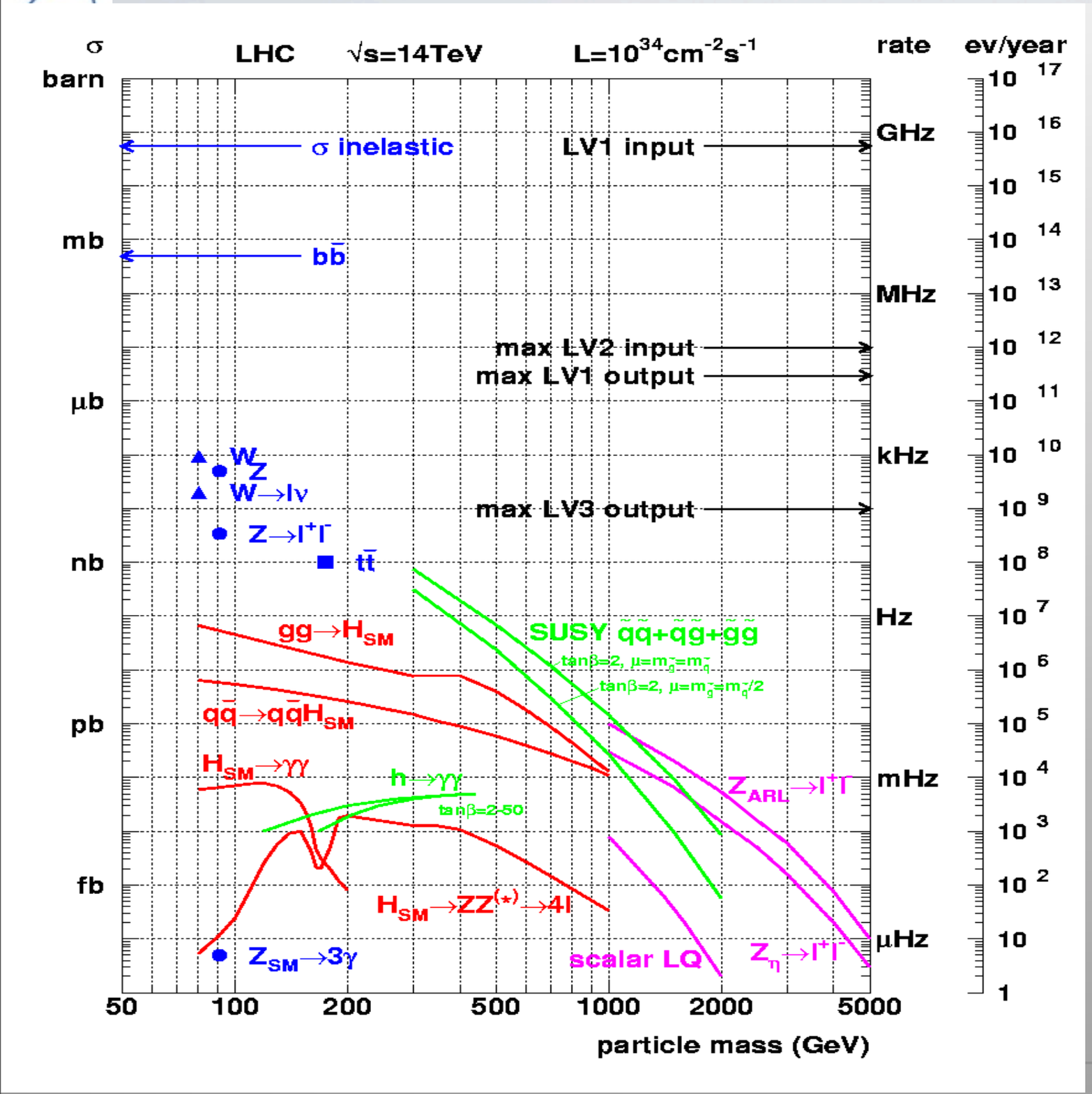






Structure function measurements eg from HERA

СЕЧЕНИЯ РАССЕЯНИЯ НА БАК

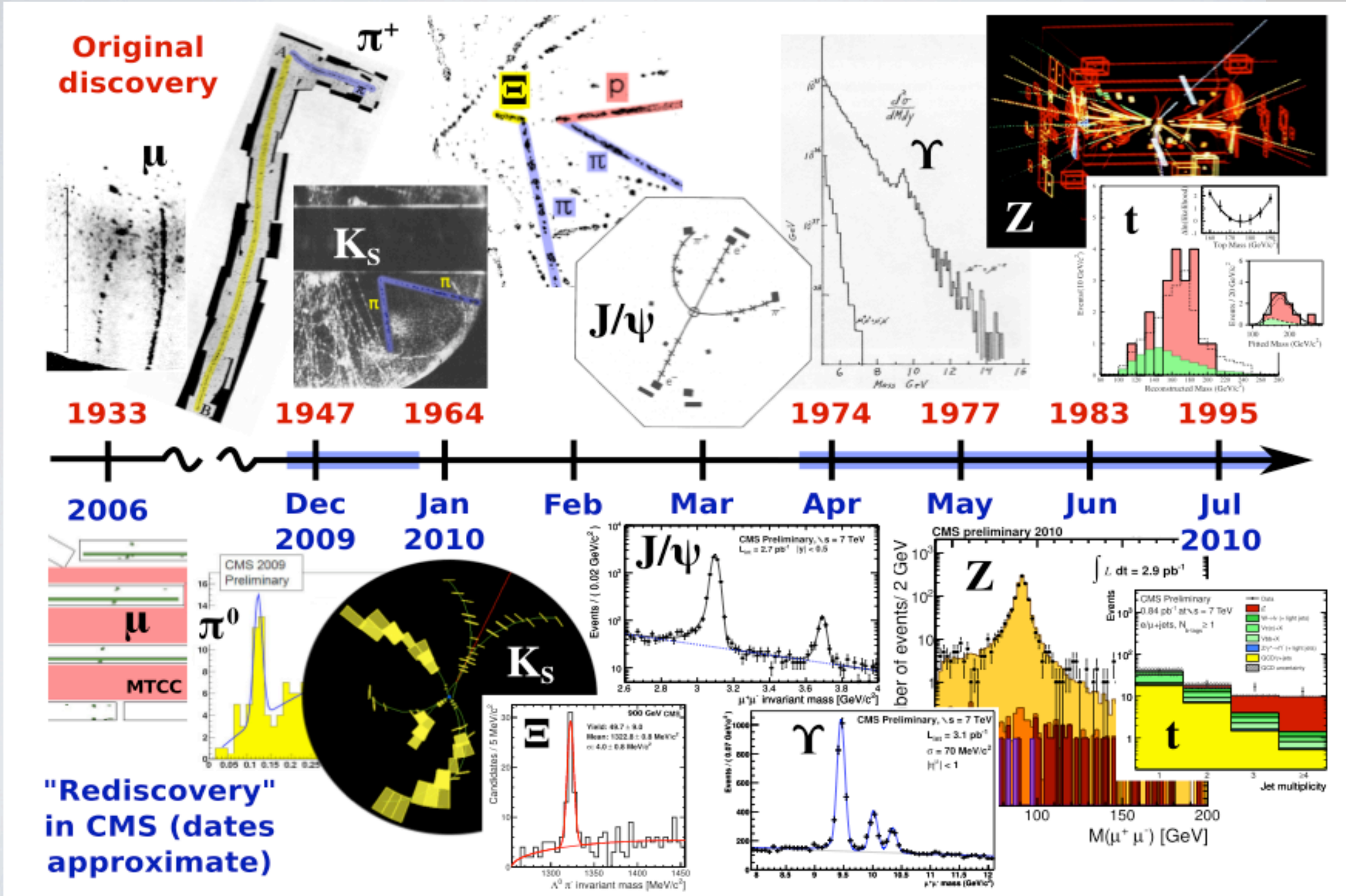


"Well known" processes, don't need to keep all of them …

New Physics!!

This we want to keep!

“ПЕРЕ-ОТКРЫТИЕ” СТАНДАРТНОЙ МОДЕЛИ



БАК: ПРОВЕРКА СМ ПРИ НОВЫХ ЭНЕРГИЯХ

Главные цели БАК:
новые частицы и взаимодействия
за пределами Стандартой Модели

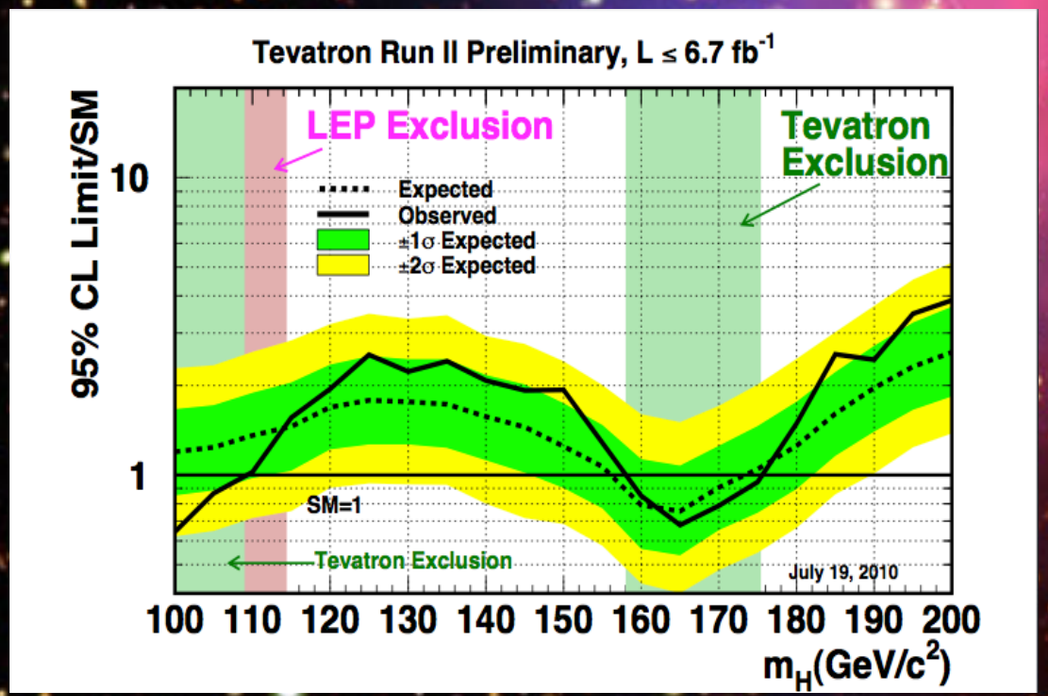
а также:
проверка СМ при новых энергиях
поиски новой динамики СМ

The Origin of Mass

Some particles have mass, some do not

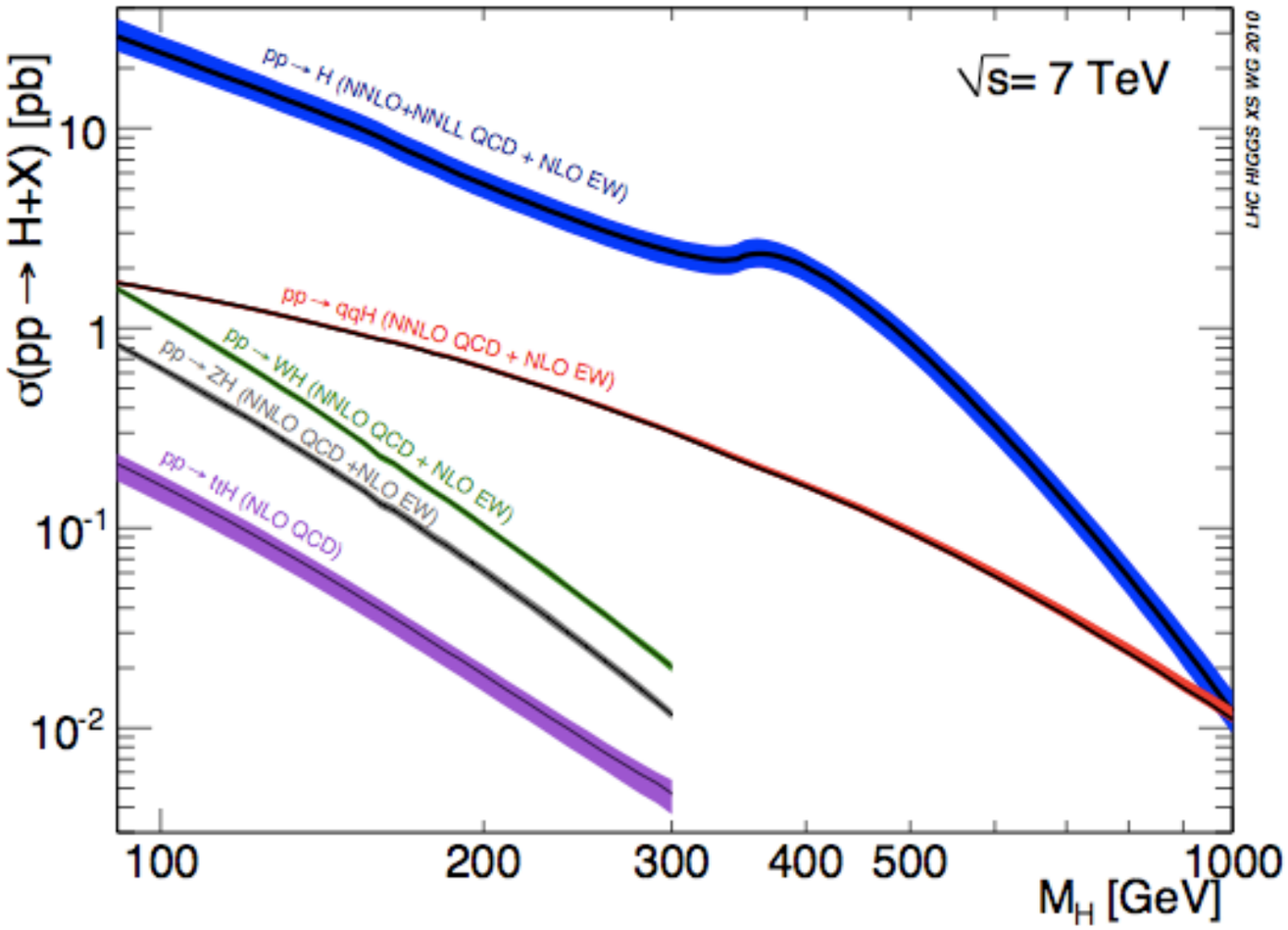
Where do the masses come from?

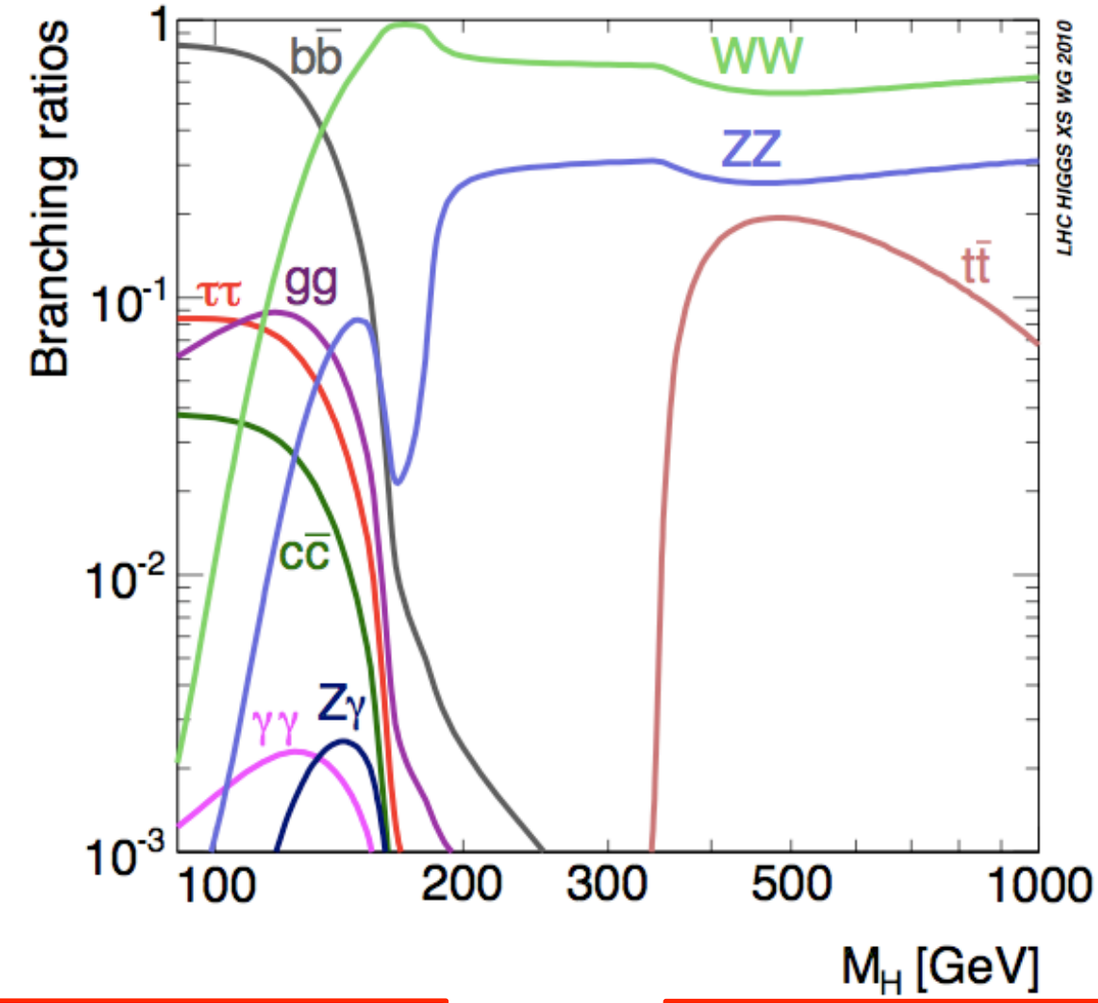
Explanation of Profs P. Higgs
R. Brout en F. Englert
⇒ A new field and particle



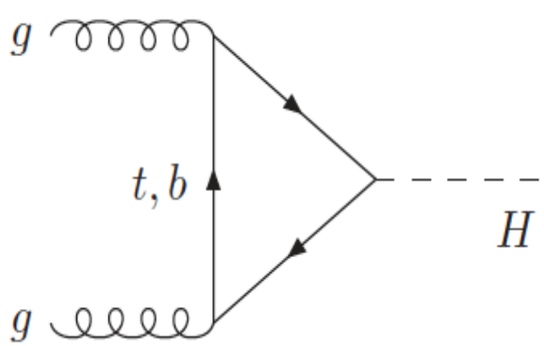
The key question:
Where is the Higgs?

БОЗОН ХИГГСА: ОБРАЗОВАНИЕ И РАСПАДЫ

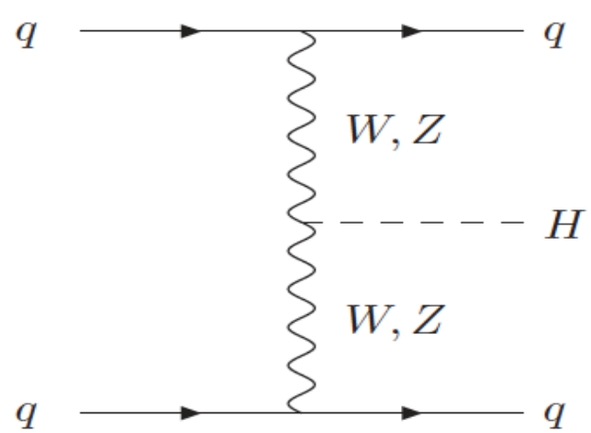




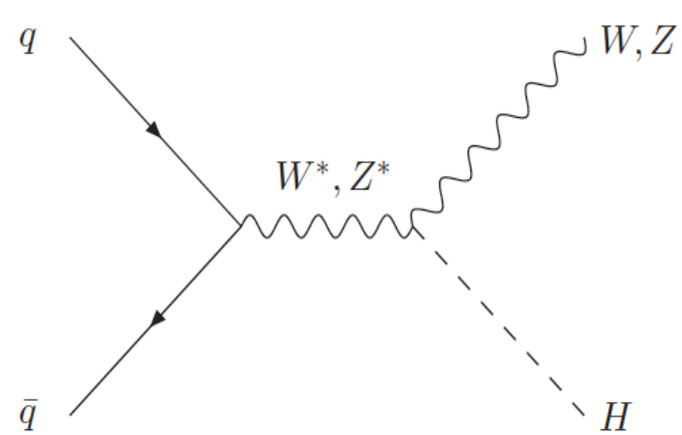
gluon-fusion



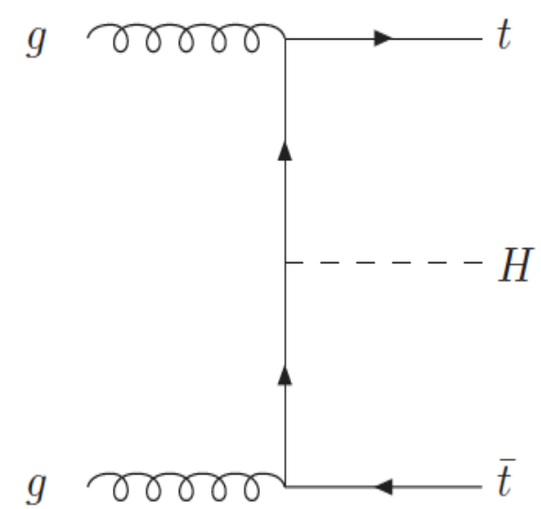
VBF



VH



ttH

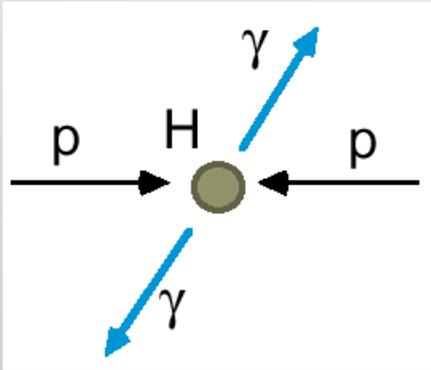


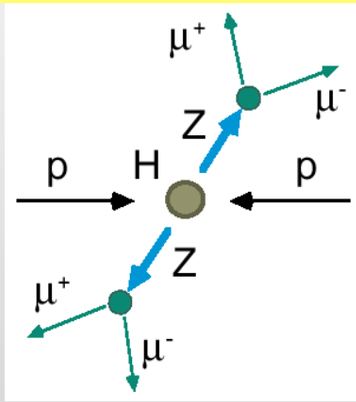
ПОИСКИ БОЗОНА ХИГГСА

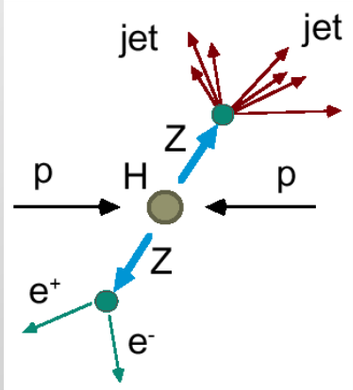
Low M_H < 140 GeV/c²

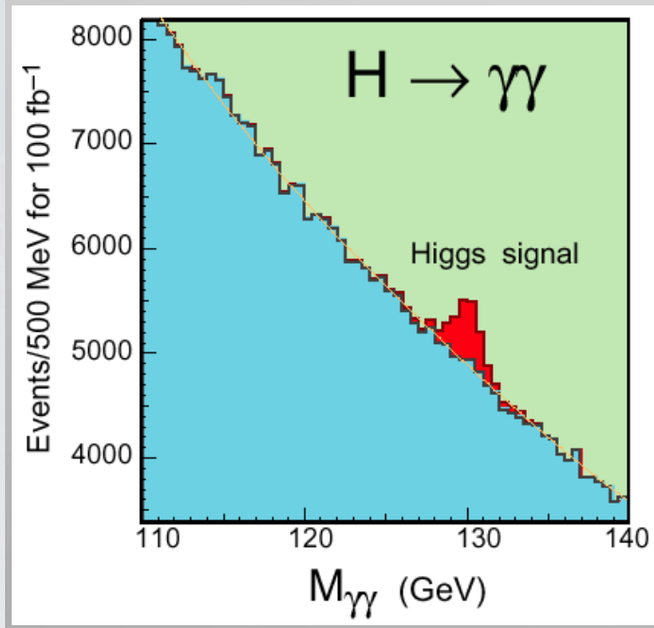
Medium 130<M_H<500 GeV/c²

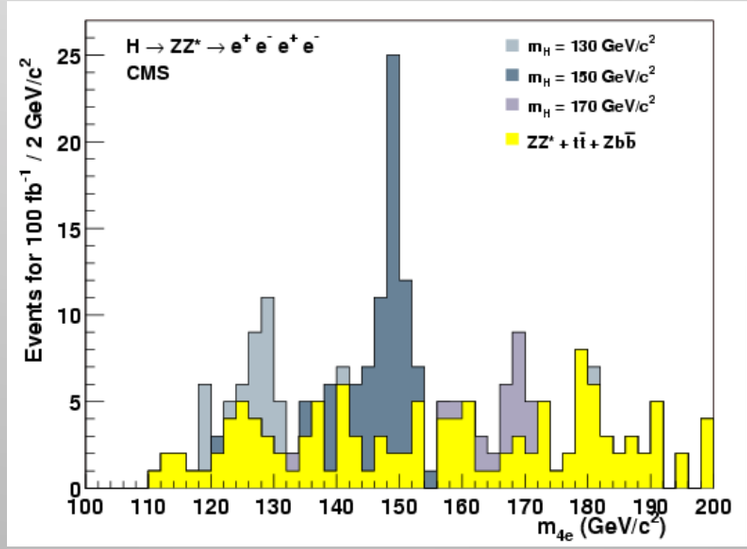
High M_H > ~500 GeV/c²

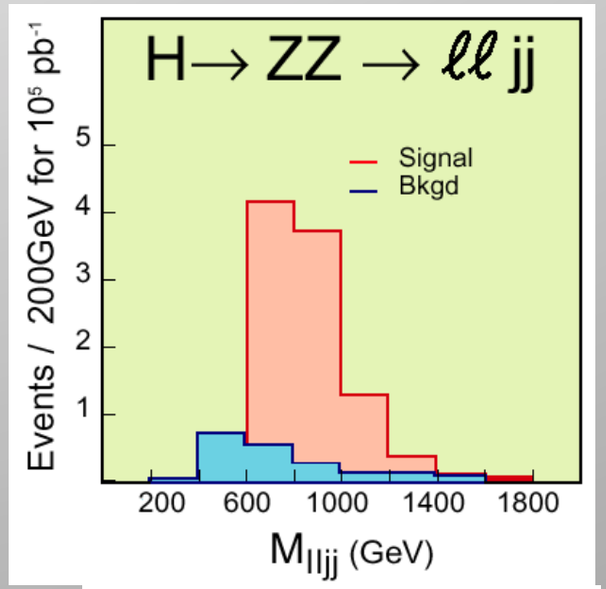


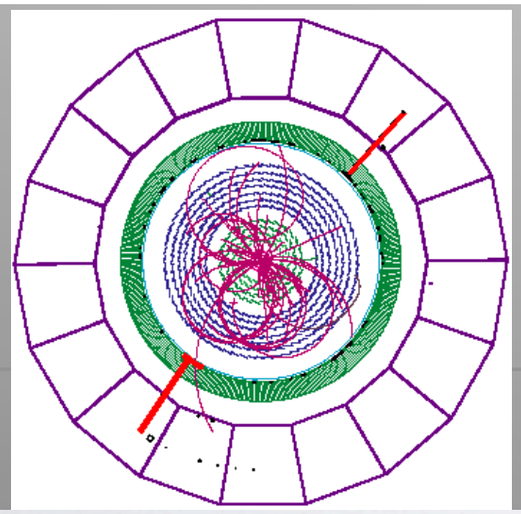


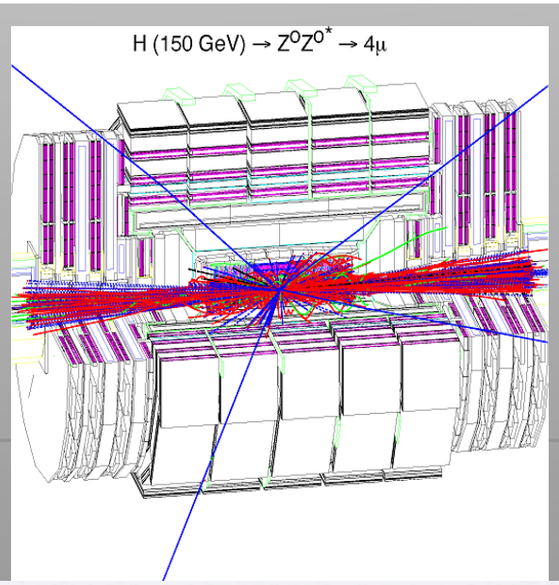


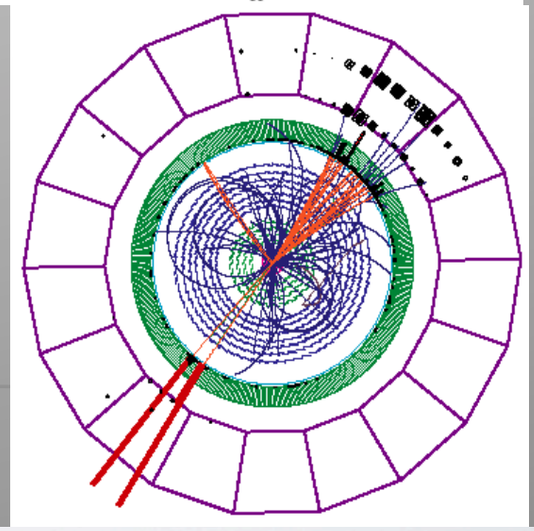










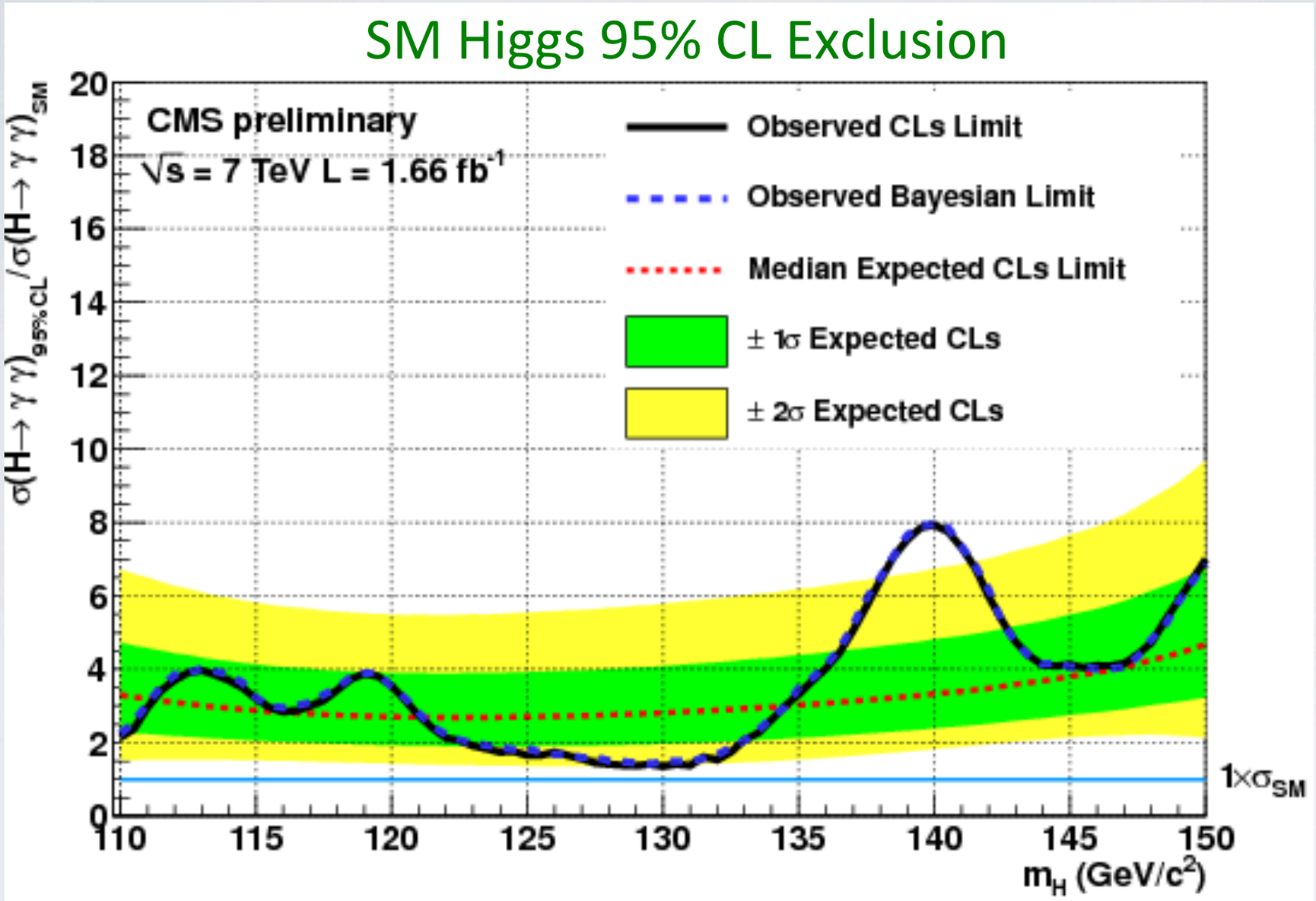


КАНАЛЫ РАСПАДА БОЗОНА ХИГГСА (CMS)

Channel	Mass Range (GeV)	Dataset (fb^{-1})
$H \rightarrow \gamma\gamma$	[110-150]	1.7
$qq \rightarrow VH;\ H \rightarrow bb$	[110-135]	1.1
$H \rightarrow \tau\tau$	[110-145]	1.6
$H \rightarrow WW \rightarrow 2l\ 2\nu$	[110-600]	1.5
$H \rightarrow ZZ \rightarrow 4l$	[110-600]	1.7
$H \rightarrow ZZ \rightarrow 2l2\tau$	[180-600]	1.1
$H \rightarrow ZZ \rightarrow 2l2j$	[226-600]	1.6
$H \rightarrow ZZ \rightarrow 2l2\nu$	[250-600]	1.5

red: most sensitive channels

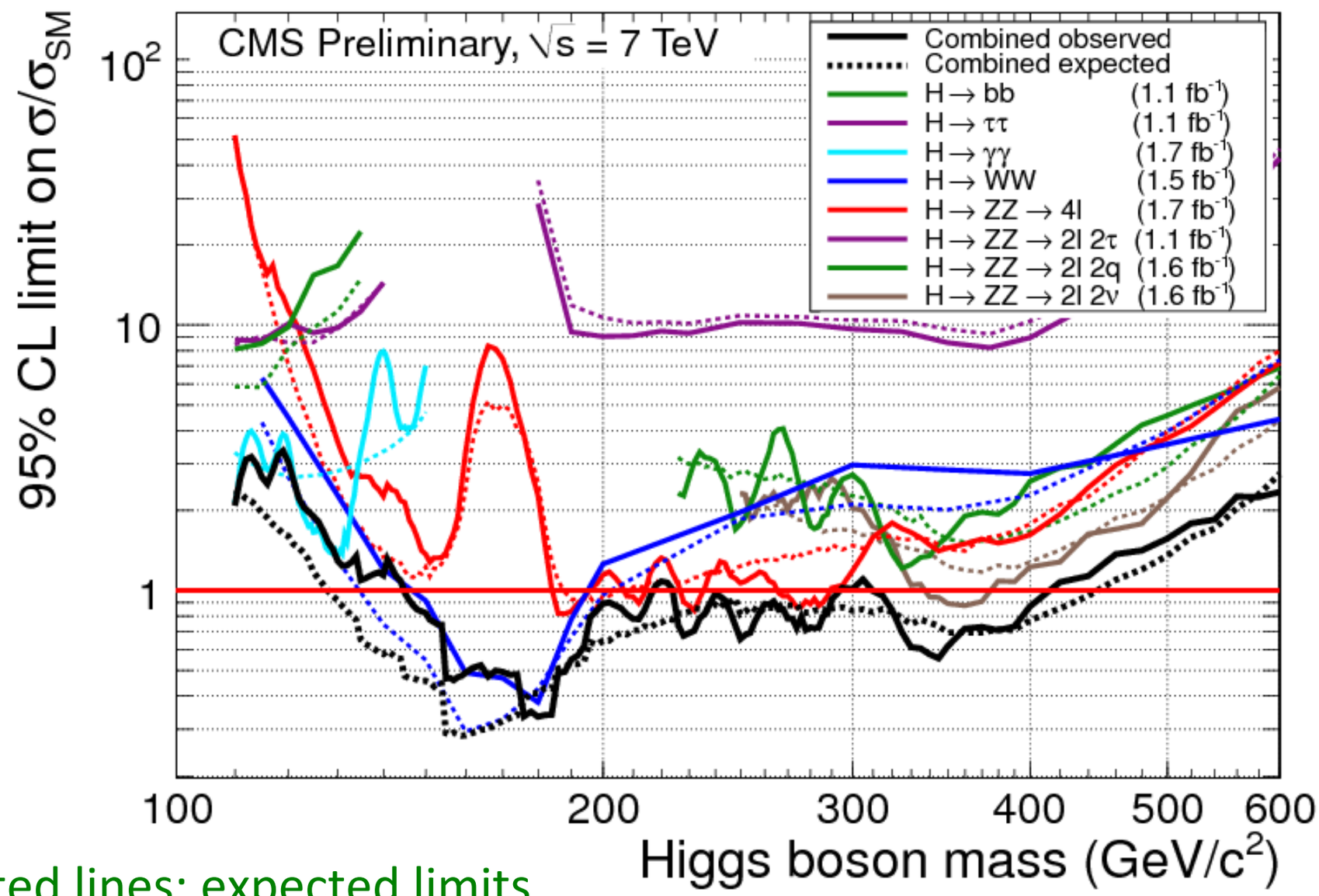
РАСПАД БОЗОНА ХИГГСА В ФОТОНЫ (CMS)



Slight excess at 140 GeV

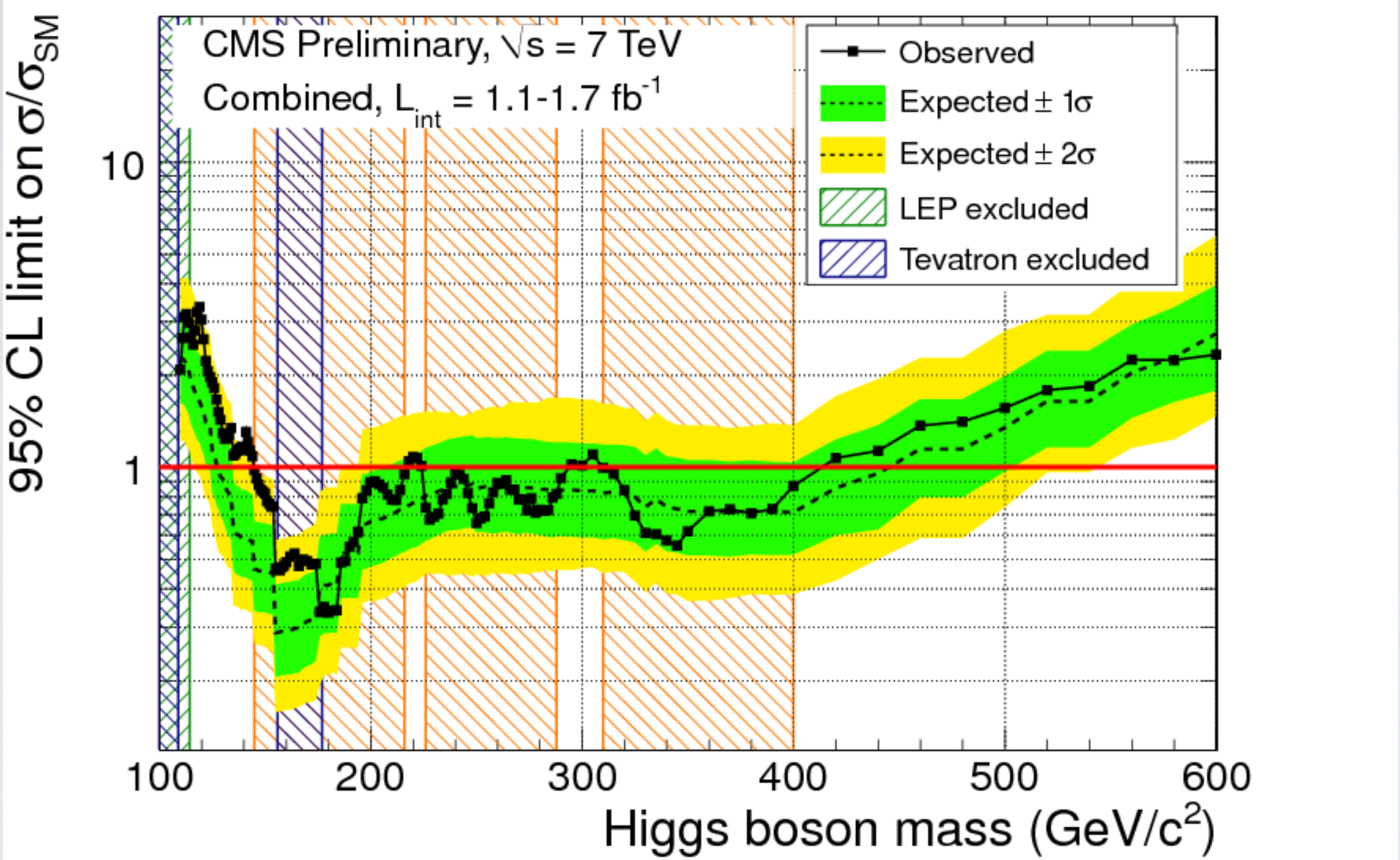
КАНАЛЫ РАСПАДА БОЗОНА ХИГГСА (CMS)

- All channels are combined to obtain the final Confidence Level for exclusion/discovery
- SM cross sections and Branching Ratios are assumed
- Baseline method for CL evaluation is modified frequentist (CLs)



Dotted lines: expected limits
Solid lines: observed limits

БОЗОН ХИГГСА: ОГРАНИЧЕНИЯ НА МАССЫ

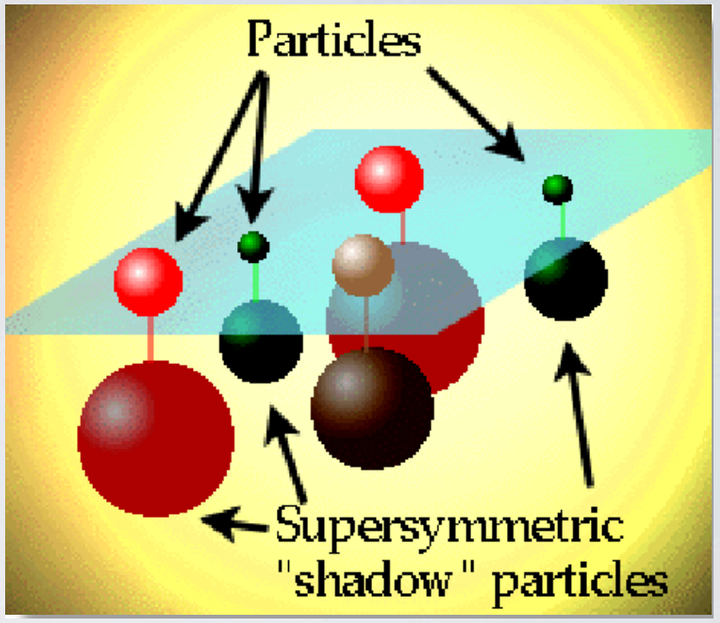


Expected 95% CL exclusion M_H 130 – 440 GeV

Observed 95% CL exclusion M_H 145-216, 226-288, 310-400 GeV

НОВАЯ ФИЗИКА? СУПЕРСИМЕТРИЯ?

Суперсимметрия:
симметрия между бозонами и фермионами



Q |boson> = |fermion>
Q |fermion> = |boson>

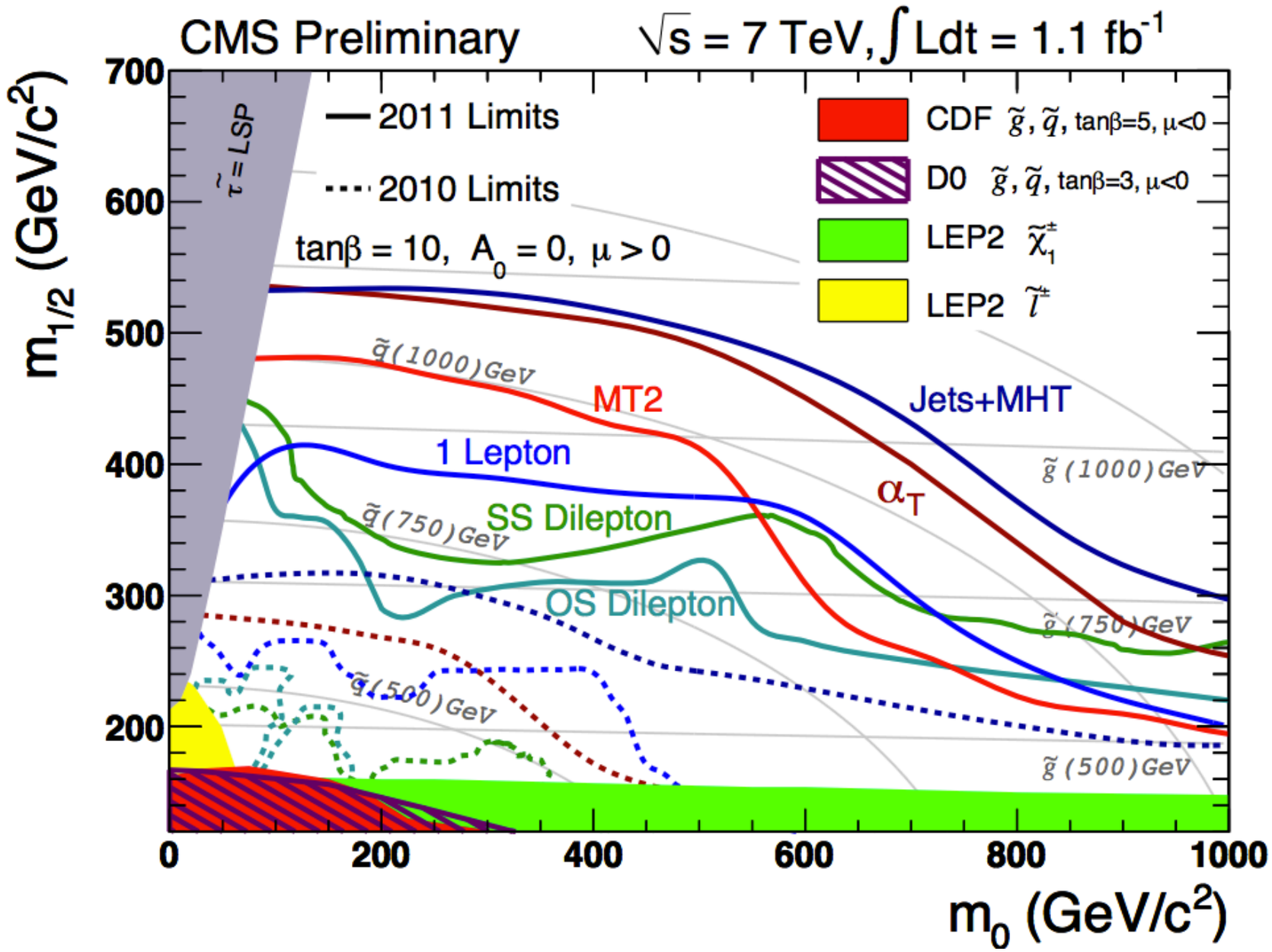
Простейшее обобщение СМ:
Минимальная суперсимметричная Стандарная Модель (MSSM)

“Зоопарк” частиц MSSM

Суперполя	Бозоны	Фермионы	$SU_C(3)$	$SU_L(2)$	$U_Y(1)$
Gauge G^a V^K $V_{\boxed{W}}$	gluon: g^a,a=1,2,3 weak: W^K ($W_{\boxed{W}}$,Z) hypercharge: B($_{\boxed{W}}$)	gluino: $\tilde{g}^a$ wino, zino: $\tilde{w}^K(\tilde{w}^{\pm},\tilde{z})$ bino: $\tilde{b}(\tilde{\gamma})$	8 1 1	0 3 1	0 0 0
Matter L_i $\boxed{W}_i$	sleptons $\begin{cases}\tilde{L}_i = (\tilde{\nu},\tilde{e})_L \\ \tilde{\varepsilon}_i = \tilde{e}_R\end{cases}$	leptons $\begin{cases}L_i = (\nu,e)_L \\ \varepsilon_i = e_R\end{cases}$	1 1	2 1	-1 2
Matter Q_i U_i D_i	squarks $\begin{cases}\tilde{Q}_i = (\tilde{u},\tilde{d})_L \\ \tilde{U}_i = \tilde{u}_R \\ \tilde{D}_i = d_R\end{cases}$	quarks $\begin{cases}Q_i = (u,d)_L \\ U_i = u_R^C \\ D_i = d_R^C\end{cases}$	3 3* 3*	2 1 1	1/3 -4/3 2/3
Higgs H_1 H_2	two higgs doublets H_1 H_2	higgsions $\begin{cases}\tilde{H}_1 \\ \tilde{H}_2\end{cases}$	1 1	2 2	-1 1

ПОИСКИ СУПЕРСИММЕТРИИ НА БАК

- Limits have been obtained in the constrained MSSM



- Squarks and gluinos up to 1 TeV and beyond are excluded at 95% CL

ДОПОЛНИТЕЛЬНЫЕ ИЗМЕРЕНИЯ?

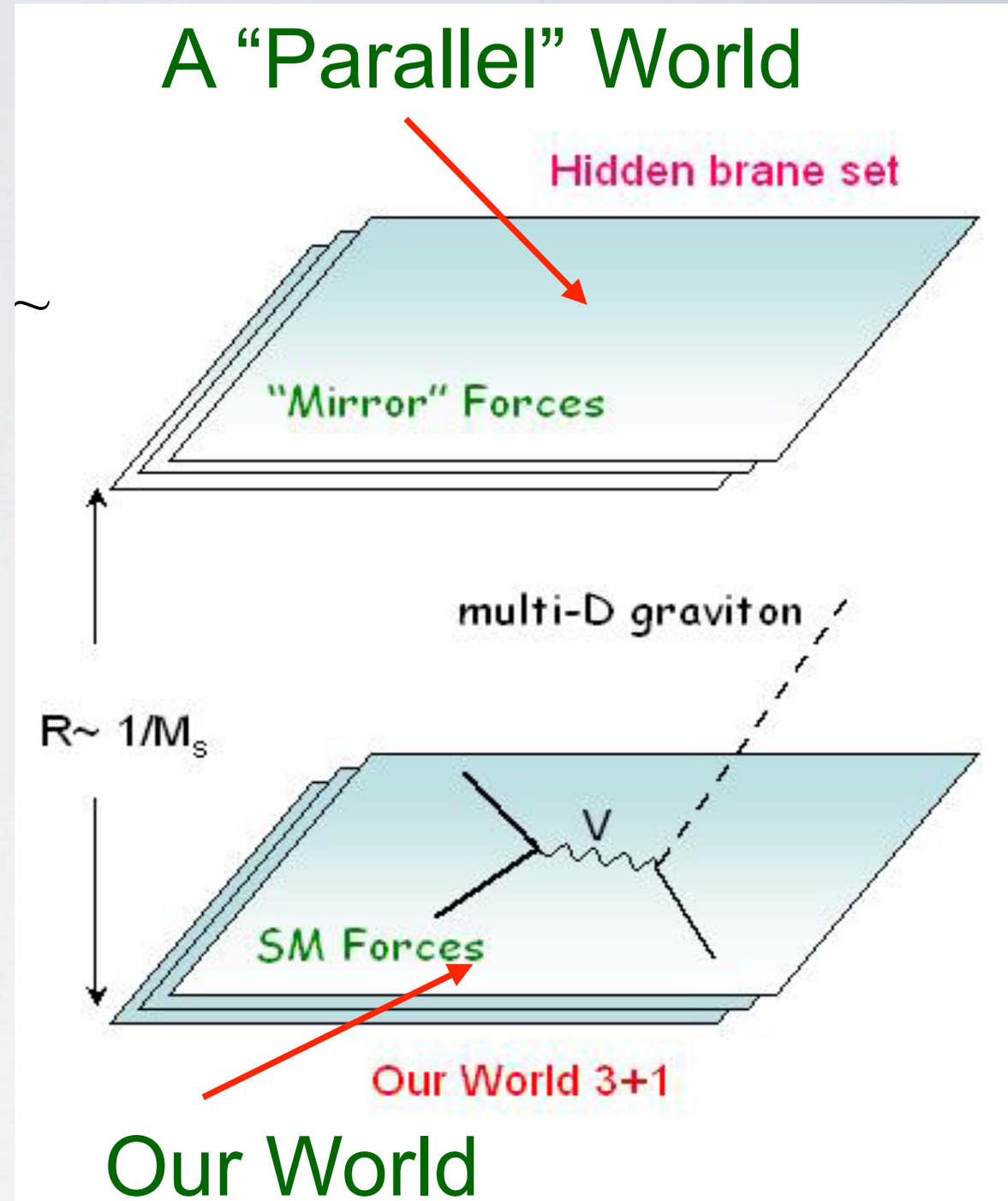
Arcani-Hamed, Dimopulos & Dvali (1999)
Randall & Sunodrum (1999)

multi-dimensional gravity:
solving hierachy scale problem

новая масса Планка: M_D
новая длина Планка: L_D $L_D = \left(\frac{G_D \hbar}{c^3}\right)^{1/(n+2)}$
новая гравитационная
константа Ньютона: $G_D = \frac{(2\pi)^{n-1}\hbar^{n+1}}{4c^{n-1}M_D^{n+2}}$

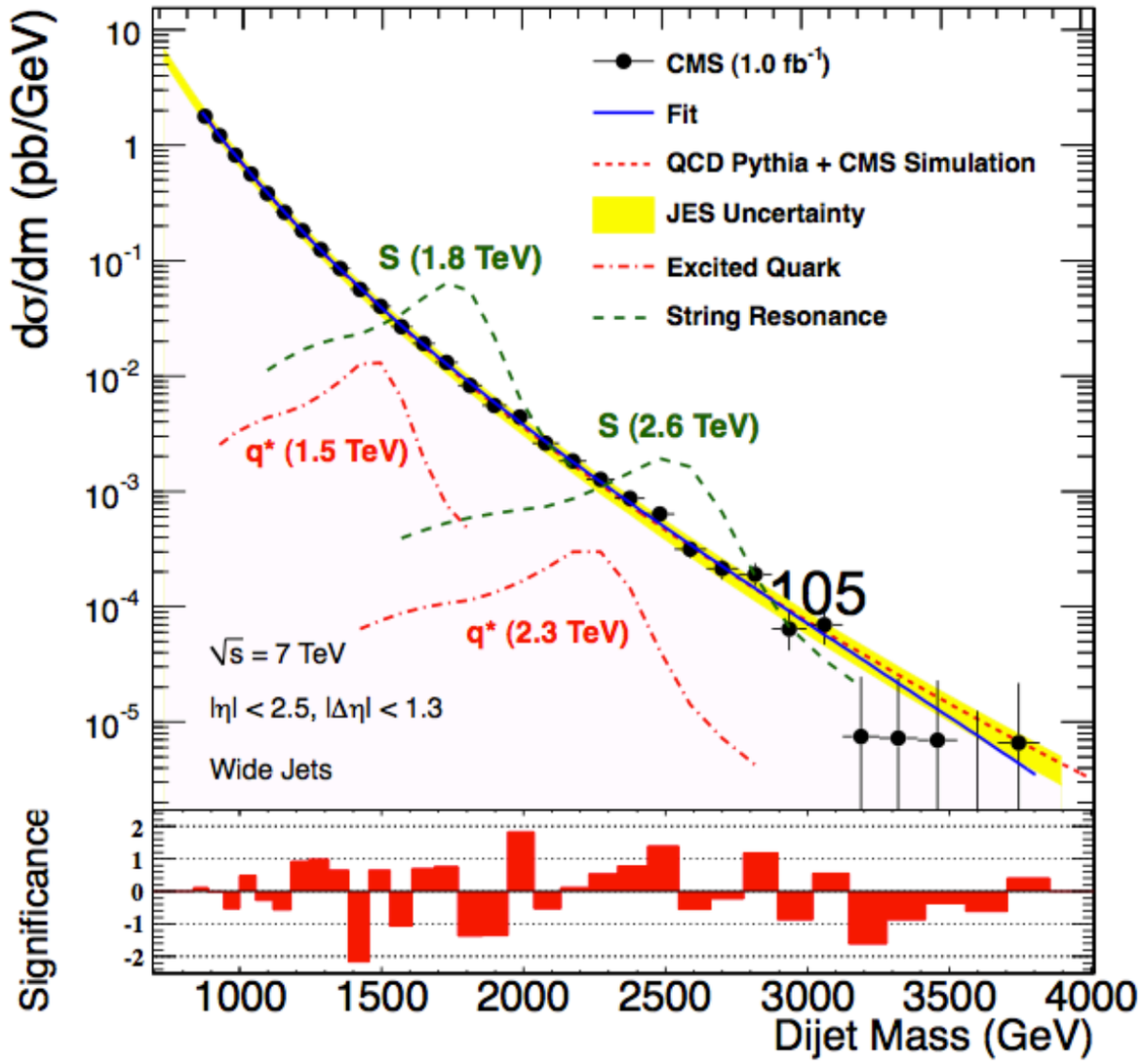
Радиус Шваршильда R_S:

$$R_S = \frac{1}{\sqrt{\pi}}\left(\frac{8\Gamma[(n+3)/2]}{(n+2)}\,\frac{G_D\sqrt{s}}{c^4}\right)^{1/(n+1)}$$



Рассеяние на прицельных расстояниях b ~ R_S
-> образование черных микро-дыр! время жизни << 10^{-30} sec

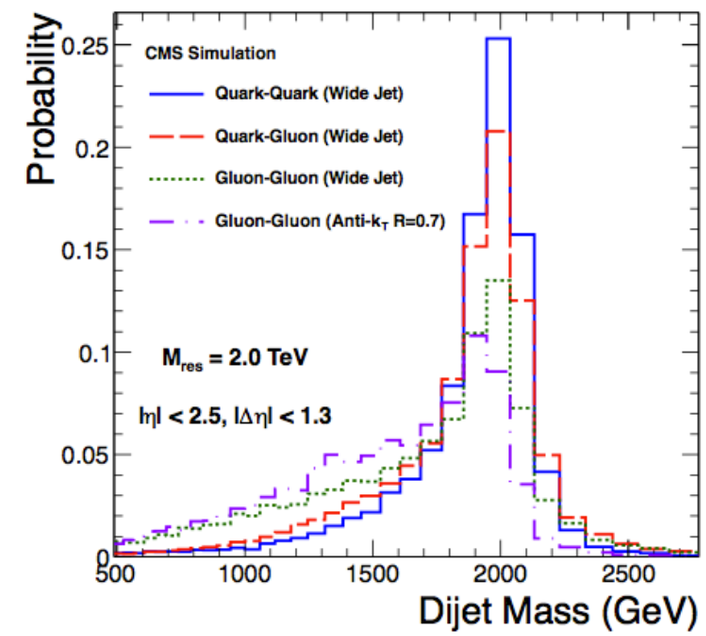
МАССЫ ДВУХ СТРУЙ (CMS)



Parametrization of the data:

$$\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2 + P_3 \ln(m/\sqrt{s})}}$$

Signal shape



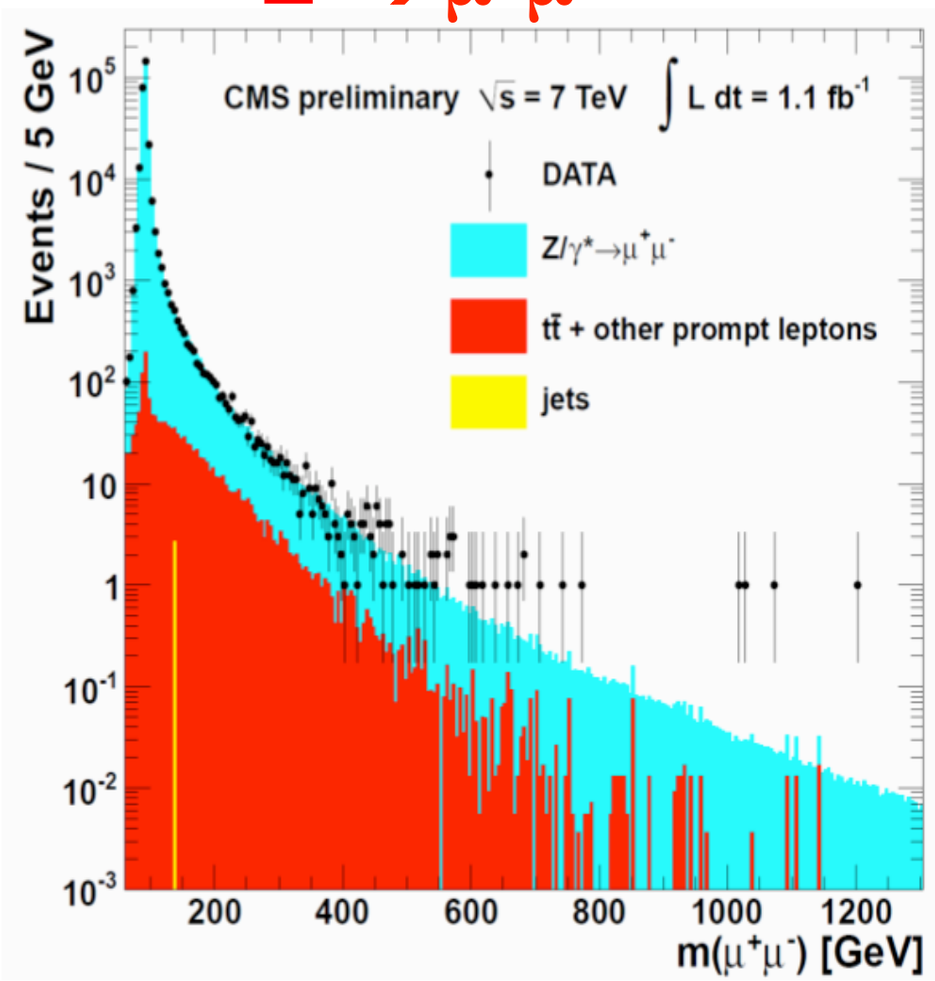
Lower limit on the mass in different models

Model	Excluded Mass (TeV)	
	Observed	Expected
String Resonances	4.00	3.90
E_6 Diquarks	3.52	3.28
Excited Quarks	2.49	2.68
Axigluons/Colorons	2.47	2.66
W′ Bosons	1.51	1.40

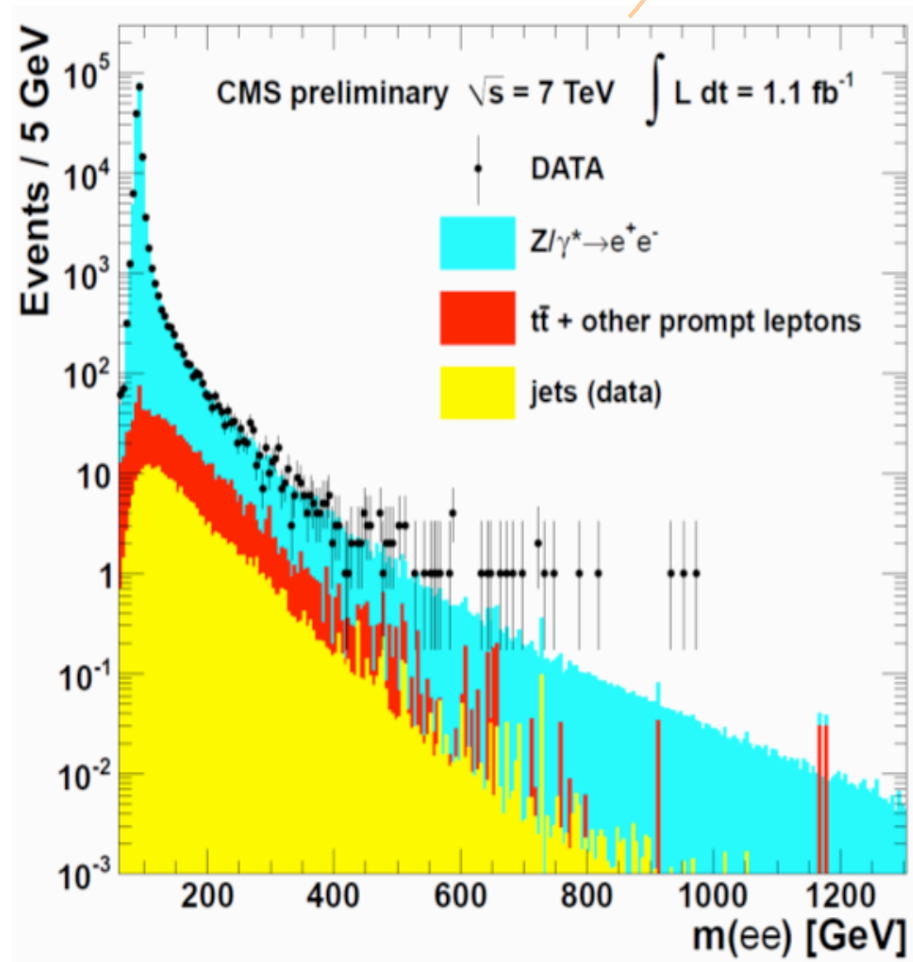
МАССЫ ДВУХ ЛЕТОНОВ (CMS)

- Di-muon and di-electron mass spectra

Z' →μ⁺μ⁻



Z' →e⁺e⁻



Model	95% CL lower limit on the mass
Sequential Standard Model Z'_{SSM}	1940 GeV
Super-String inspired models, Z'_{ψ}	1620 GeV
RS Kaluza-Klein Gravitons for (k/M_{Pl}) 0.05-0.1	1450-1780 GeV

БАК: БЛИЖАЙШИЕ ПЕРСПЕКТИВЫ

физика БАК 2011: 5 Фб$^{-1}$

2012: 10 Фб$^{-1}$?

2012: увеличение до 8-10 ТэВ?

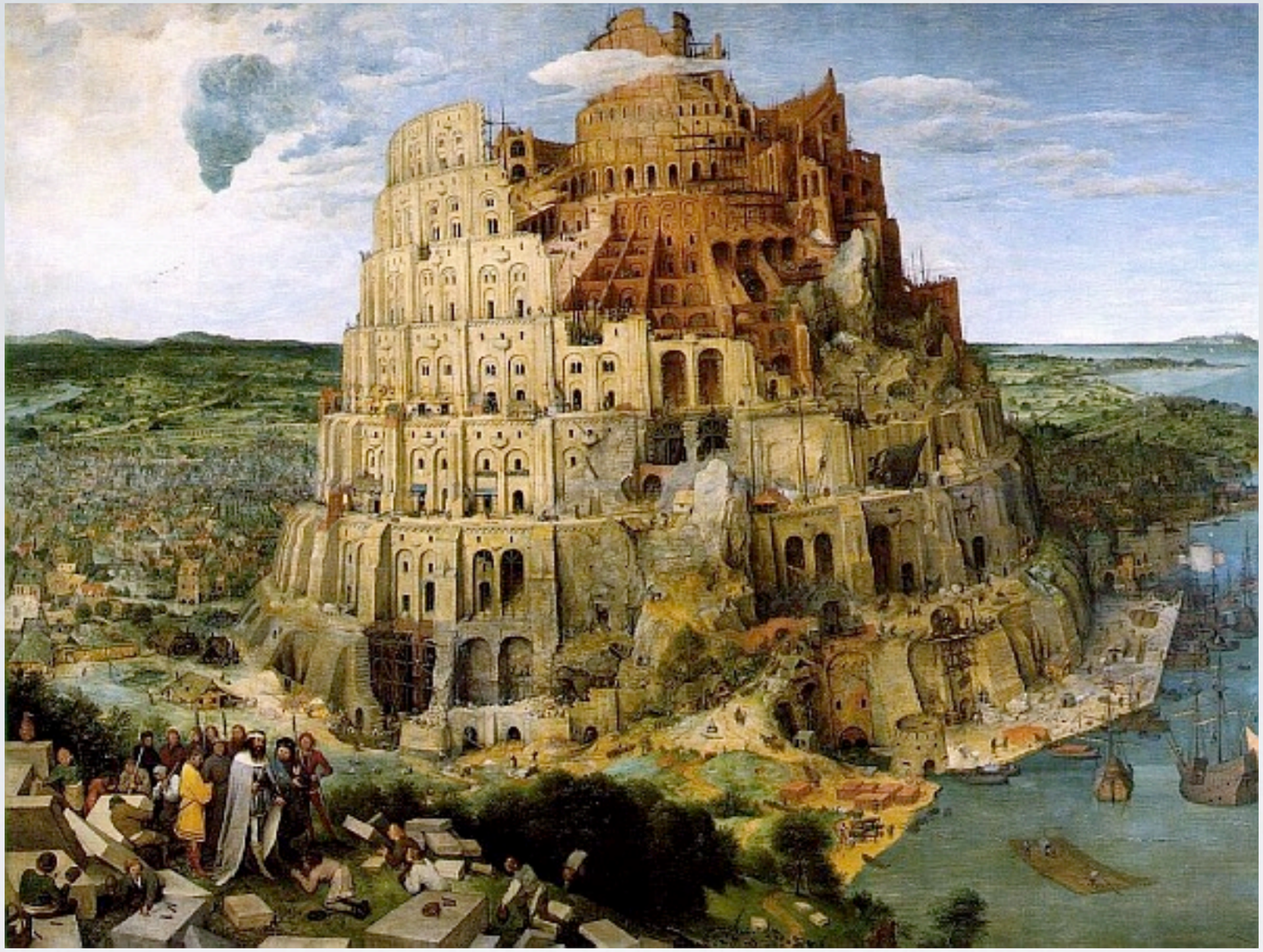
2012: все возможные массы бозона Хиггса СМ

сильные ограничения на MSSM

сюрпризы?

ЦЕРН БАК: МНОГО НОВОСТЕЙ ВПЕРЕДИ!

БАК: “ВАВИЛОНСКАЯ БАШНЯ”



Pieter Bruegel de Oude "Babylon tower" 1563

ЦЕРН: уникальные возможности!