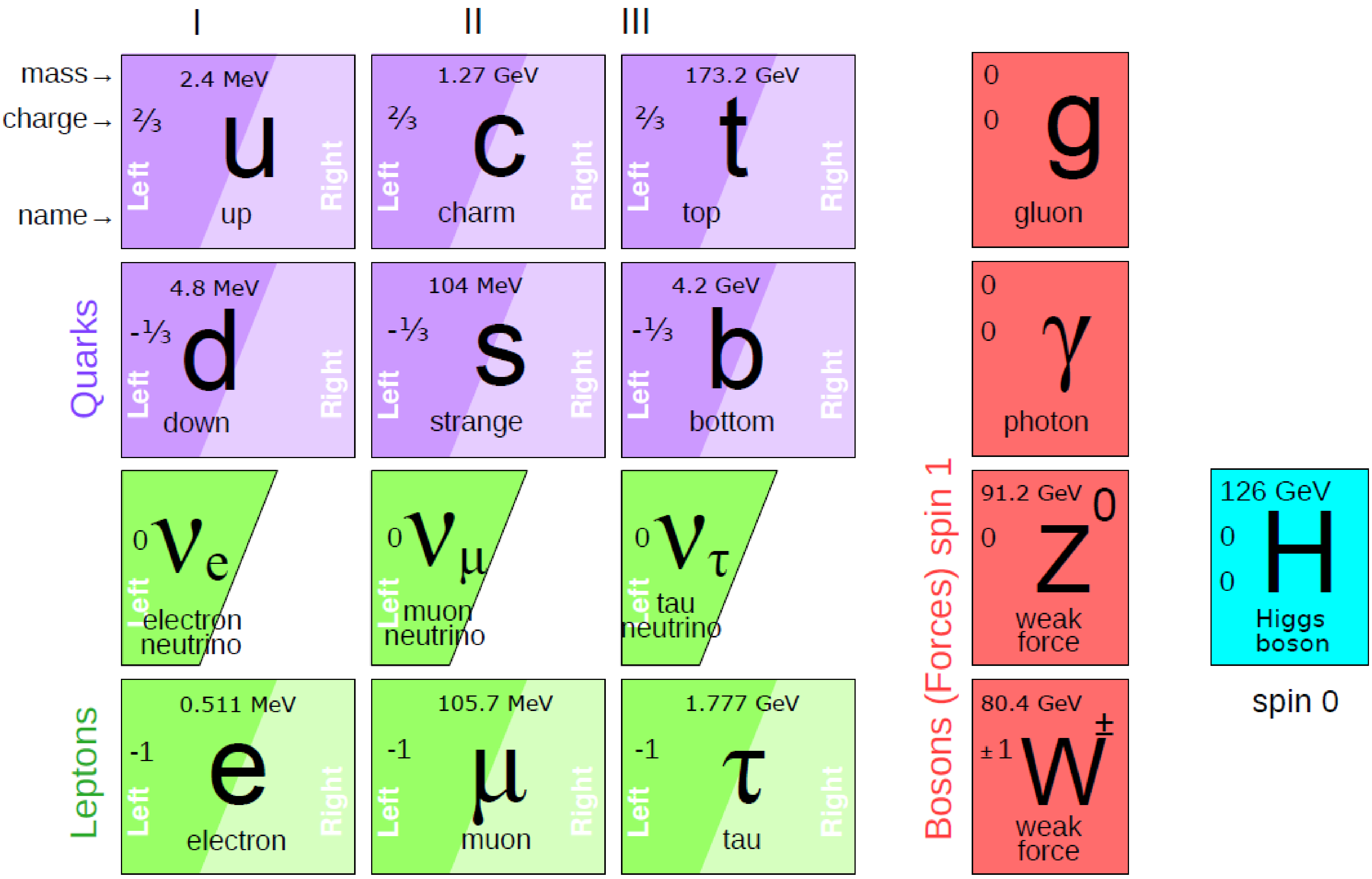
HIGGSOV MEHANIZAM i MASE BOZONA STANDARDNOG MODELA

- HIGGSOV MEHANIZAM U SM-u
- MASE BAŽDARNIH BOZONA
- MASA HIGGSA

Three Generations of Matter (Fermions) spin ½



	I	II	III	Bosons (Forces) spin 1	
mass → charge → name →	2.4 MeV ⅔ u Left up Right	1.27 GeV ⅔ c Left charm Right	173.2 GeV ⅔ t Left top Right	0 0 g gluon	
Quarks	4.8 MeV -⅓ d Left down Right	104 MeV -⅓ s Left strange Right	4.2 GeV -⅓ b Left bottom Right	0 0 γ photon	
	0 ν_e Left electron neutrino	0 ν_μ Left muon neutrino	0 ν_τ Left tau neutrino	91.2 GeV 0 Z^0 weak force	126 GeV 0 0 H Higgs boson spin 0
Leptons	0.511 MeV -1 e Left electron Right	105.7 MeV -1 μ Left muon Right	1.777 GeV -1 τ Left tau Right	80.4 GeV ±1 $W^\pm$ weak force	

ABELOVSKI HIGGSOV MEHANIZAM Originalni U(1)-simetrični Lagrangian s kompleksnim skalarnim poljem

$$\mathcal{L}_{\Phi} = \mathcal{L}_{\Phi,\mathrm{kin}} + \mathcal{L}_{\Phi,\mathrm{pot}}$$

two real scalar fields ϕ and η,

$$\Phi(x) = \frac{1}{\sqrt{2}} \boxed{\phi(x)}\, \underset{\uparrow}{e^{i\eta(x)}}$$

odrotiramo

$$\mathcal{L}_{\Phi,\mathrm{kin}} = (D_\mu \Phi)^* \, (D^\mu \Phi) \ ,$$

$$-\mathcal{L}_{\Phi,\mathrm{pot}} = V(\Phi) = \mu^2 |\Phi|^2 + \lambda |\Phi|^4$$

$$V(\phi) = \frac{\mu^2}{2}\phi^2 + \frac{\lambda}{4}\phi^4$$

$$(D_\mu \Phi)^* \, (D^\mu \Phi) \rightarrow \frac{1}{2}(\partial_\mu \phi)^2 + \frac{1}{2} e^2 q^2 \phi^2 A_\mu A^\mu \ ,$$

$$\phi(x) = v \ + \ H(x)$$

Higgs’64: Goldstoneov teorem ne vrijedi za slomljenu lokalnu simetriju

$$-\mathcal{L}_{\text{Higgs}} = \frac{1}{2} m_H^2 H^2 + \frac{\kappa}{3!} H^3 + \frac{\xi}{4!} H^4 \ ,$$

$$m_H^2 = 2\lambda v^2, \quad \kappa = 3\frac{m_H^2}{v}, \quad \xi = 3\frac{m_H^2}{v^2} \ .$$

- Skalarna čestica dobije masu

Englert & Brout’64: i vektorsko polje pribavlja masu

$$\mathcal{L}_{\rm Higgs-photon} = \frac{1}{2}m_A^2 A_\mu A^\mu + e^2q^2vHA_\mu A^\mu + \frac{1}{2}e^2q^2H^2A_\mu A^\mu$$

$$m_A^2 = e^2q^2v^2 \ .$$

- **Weinberg’67: Generiranje mase kiralnih fermiona lomljenjem baždarne simetrije**

$$\psi = (\psi_L, \psi_R)^T,$$

$$\mathcal{L}_{\rm fermion\ \ mass} = y_\psi \psi_L^\dagger \, \Phi \, \psi_R + {\rm c.c.} \ ,$$

$$\mathcal{L}_{\rm fermion\ \ mass} = m_\psi \psi_L^\dagger \psi_R + \frac{m_\psi}{v} H \, \psi_L^\dagger \psi_R + {\rm c.c.} \ ,$$

$$m_\psi = y_\psi \frac{v}{\sqrt{2}} \ .$$

London-Anderson-Englert-Brout Higgs-Guralnik-Hagen-Kibble-Weinberg

- **Englert-Brout:** prvi realistični modeli s elementarnim skalarom, Lorentzovom simetrijom i neabelovskim baždarnim poljima
- **Higgs:** uz jedno kompleksno skalarno polje predviđa opservabilni bozon po analogiji sa supravodljivošću
- **Weinberg:** uz dublet kompleksnih skalara demonstrira "čaroliju" jednog SM-higgsa

SPONTANO NARUŠENJE NEABELOVE SIMETRIJE SM-a

$$SU(2)_W \otimes U(1)_Y \longrightarrow U(1)_{e.m.}$$

Bezmaseni baždarni bozoni   simetrične faze

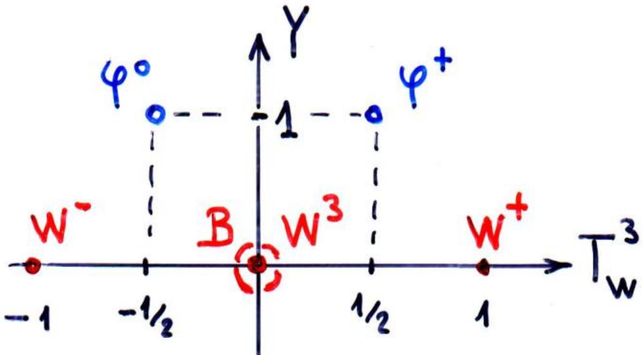
W^i (i=1,2,3), B

Higgsovo polje nosi kvantne brojeve "W" & Y

$\Phi = \begin{pmatrix} \varphi^+ \\ \varphi^0 \end{pmatrix}$ dublet kompleksnih skalarnih polja

$$\varphi^+ = \frac{1}{\sqrt{2}} (\varphi_1 + i \varphi_2)$$

$$\varphi^0 = \frac{1}{\sqrt{2}} (\varphi_3 + i \varphi_4)$$



SKALARNI POTENCIJAL

$$\mathcal{L}_\Phi = (\mathcal{D}_\mu \Phi)^\dagger (\mathcal{D}^\mu \Phi) - V(\Phi) + \mathcal{L}_{\text{Yukawa}}$$

$$\mathcal{L} \supset \tfrac{1}{2}\partial_\mu \phi_i \partial^\mu \phi_i$$

$$V(\Phi) = -\mu^2 \Phi^\dagger \Phi + \lambda(\Phi^\dagger \Phi)^2$$

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi_1 + i\phi_2 \\ \phi_3 + i\phi_4 \end{pmatrix}$$

$$\Phi^\dagger \Phi = \frac{1}{2}(\phi_1^2 + \phi_2^2 + \phi_3^2 + \phi_4^2)$$

Minimum potencijala za $\boxed{\Phi^\dagger \Phi = \frac{\mu^2}{2\lambda}}$

IZBOR

$V(\Phi) = -\mu^2 \Phi^\dagger \Phi + \lambda (\Phi^\dagger \Phi)$

Potencijal izražen tim poljima ima minimum za

$$\frac{\partial V}{\partial \phi^{+*}} = -\mu^2 \phi^+ + 2\lambda(|\phi^+|^2 + |\phi^0|^2)\phi^+ = 0$$

$$\frac{\partial V}{\partial \phi^{0*}} = -\mu^2 \phi^0 + 2\lambda(|\phi^+|^2 + |\phi^0|^2)\phi^{\cancel{+}0} = 0,$$

dakle za

$$\underbrace{\Phi^\dagger \Phi = |\phi^+|^2 + |\phi^0|^2 = \frac{\mu^2}{2\lambda} = \frac{v^2}{2}.}$$

Budući da se za $(-\mu^2) < 0$ minimum potencijala postiže za:

$$|\langle 0\,|\Phi|\,0\rangle| = \begin{pmatrix} 0 \\ \frac{v}{\sqrt{2}} \end{pmatrix}, \qquad v \equiv \sqrt{\frac{\mu^2}{\lambda}}$$

možemo pisati

$$V(\Phi) = -\frac{\lambda}{4}\left(\Phi^\dagger\Phi - \frac{v^2}{2}\right)^2 .$$

Potencijal $V(\Phi)$ je invarijantan na lokalne (baždarne) transformacije

$$\Phi(x) \to \Phi'(x) = e^{i\vec{\alpha}(x)\cdot\vec{\tau}/2}\Phi(x),$$

a isto će se postići i za kinetički član kad u njemu zamijenimo obične derivacije kovarijantnim

$$\begin{aligned} \mathcal{L}_{\mathrm{S}} &= (D_\mu\Phi)^\dagger(D^\mu\Phi) - V(\Phi)\,, \\ D_\mu\Phi &= \left(\partial_\mu - \frac{1}{2}ig\vec{\tau}\cdot\vec{W}_\mu - \frac{1}{2}ig'B_\mu\right)\Phi\,. \end{aligned} \tag{6.40}$$

Četiri realna skalarna polja
s odgovarajućom normalizacijom

- **Kinetički član** $\mathcal{L} \supset \frac{1}{2}\partial_\mu \phi_i \partial^\mu \phi_i$
- **Maseni član** $V \supset \frac{1}{2} m^2 \phi^2$

$$V = -\frac{\mu^2}{2}\left(\phi_1^2 + \phi_2^2 + (h+v)^2 + \phi_4^2\right) + \frac{\lambda}{4}\left(\phi_1^2 + \phi_2^2 + (h+v)^2 + \phi_4^2\right)^2$$

Odabir (VEV) orijentacije za $\Phi = \frac{1}{\sqrt{2}}\begin{pmatrix} \phi_1 + i\phi_2 \\ \boxed{v + h} + i\phi_4 \end{pmatrix}$

$$\langle \phi_3 \rangle \equiv v = \sqrt{\frac{\mu^2}{\lambda}}, \qquad \langle \phi_1 \rangle = \langle \phi_2 \rangle = \langle \phi_4 \rangle = 0$$

Realno polje iščezavajuće VEV $\langle h \rangle = 0$ pribavlja masu $m_h = \sqrt{2\lambda v^2}$

Izbor unitarnog baždarenja:

$$\Phi = \frac{1}{\sqrt{2}} \left(\begin{array}{c} 0 \\ v + h \end{array} \right)$$

- Na drugi način, SU(2) rotacijom

$$\Phi = \frac{1}{\sqrt{2}} \exp\left(\frac{i\xi^a \sigma^a}{v} \right) \left(\begin{array}{c} 0 \\ v + h \end{array} \right)$$

To linear order, $\xi^1 = \phi_2$, $\xi^2 = \phi_1$, and $\xi^3 = -\phi_3$

- odn. baždarnim transformacijama

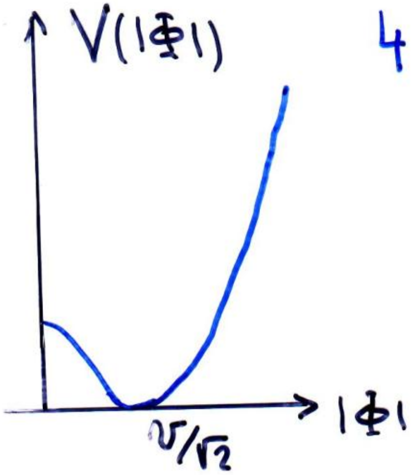
$$\Phi \to \exp\left(i\lambda_L^a(x) \frac{\sigma^a}{2} \right) \Phi$$

uz

$$\lambda_L^a(x) = -2\xi^a / v$$

Mase bozona izborom unitarnog baždarenja

Spontano lomljenje: $\begin{pmatrix}\varphi^+\\ \varphi^0\end{pmatrix} \xrightarrow{e^{i\vec{\tau}\vec{\vartheta}(x)}} \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v+H(x)\end{pmatrix}$



4 skalarnih polja

1 realno skalarno polj

3 polja odlaze u longitudinalne komp. W^+, W^- i Z bozona

$$W_\mu^\pm = \frac{1}{\sqrt{2}}\left(W_\mu^1 \mp i W_\mu^2\right)$$

$$Z_\mu = -B_\mu \sin\Theta_W + W_\mu^3 \cos\Theta_W$$

$$A_\mu = B_\mu \cos\Theta_W + W_\mu^3 \sin\Theta_W$$

ostaje bezmasen

Predikcija masa baždarnih bozona:

Uvrštavanjem kovarijantne derivacije

$$D_\mu \Phi = \left(\partial_\mu - \frac{i}{2} g \vec{\tau} \cdot \vec{W}_\mu - \frac{i}{2} g' B_\mu \right) \Phi$$

u $\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + H \end{pmatrix}$

u kinetički član Higgsovog polja $(D_\mu \Phi)^\dagger (D^\mu \Phi)$

$$M_W^2 = \frac{g^2 v^2}{4}$$

$$M_Z^2 = \frac{1}{4} (g^2 + g'^2) v^2$$

Mase baždarnih bozona iscrpnije

- **Iz kovarijantnog kinetičkog člana**

$$\mathcal{L} \supset (\mathcal{D}_\mu \Phi)^\dagger (\mathcal{D}^\mu \Phi) \qquad \mathcal{D}_\mu = \partial_\mu - i\frac{g'}{2}B_\mu - i\frac{g}{2}W^a_\mu \sigma^a$$

sa skalarom u unitarnom baždarenju:

$$\mathcal{D}_\mu \Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} -\frac{i}{2}g(W^1_\mu - iW^2_\mu)(v+h) \\ \partial_\mu h + \frac{i}{2}(gW^3_\mu - g'B_\mu)(v+h) \end{pmatrix}$$

$$(\mathcal{D}_\mu \Phi)^\dagger (\mathcal{D}^\mu \Phi) = \frac{1}{2}(\partial_\mu h)(\partial^\mu h) + \frac{1}{8}g^2(v+h)^2(W^1_\mu - iW^2_\mu)(W^{1\mu} + iW^{2\mu})$$

nabijeni

$$+\frac{1}{8}(v+h)^2\left(-g'B_\mu + gW^3_\mu\right)^2$$

neutralni

Identifikacija nabijenih bozona

$$W_\mu^1\sigma^1 + W_\mu^2\sigma^2 = \frac{1}{2}(W_\mu^1 - iW_\mu^2)(\sigma^1 + i\sigma^2) + \frac{1}{2}(W_\mu^1 + iW_\mu^2)(\sigma^1 - i\sigma^2)$$

$$= \sqrt{2}\frac{W_\mu^1 - iW_\mu^2}{\sqrt{2}}\sigma^+ + \sqrt{2}\frac{W_\mu^1 + iW_\mu^2}{\sqrt{2}}\sigma^-$$

$$(\sigma^1 + i\sigma^2) = 2\sigma^+ = 2\begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}, \qquad (\sigma^1 - i\sigma^2) = 2\sigma^- = 2\begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix}$$

- Iz očuvanja električnog naboja pri djelovanju na lijeve fermionske dublete

$$\begin{array}{lcccc}
\frac{W_\mu^1 - iW_\mu^2}{\sqrt{2}}(\bar{u}\ \bar{d})\,\sigma^+\gamma^\mu P_L\begin{pmatrix} u \\ d \end{pmatrix} & = & \frac{W_\mu^1 - iW_\mu^2}{\sqrt{2}}\bar{u}\gamma^\mu P_L d & \Rightarrow & \boxed{\frac{W_\mu^1 - iW_\mu^2}{\sqrt{2}} = W_\mu^+} \\
\frac{W_\mu^1 + iW_\mu^2}{\sqrt{2}}(\bar{u}\ \bar{d})\,\sigma^-\gamma^\mu P_L\begin{pmatrix} u \\ d \end{pmatrix} & = & \frac{W_\mu^1 + iW_\mu^2}{\sqrt{2}}\bar{d}\gamma^\mu P_L u & \Rightarrow & \boxed{\frac{W_\mu^1 + iW_\mu^2}{\sqrt{2}} = W_\mu^-}
\end{array}$$

Masa W bozona

$$\boxed{M_W^2 = \frac{g^2v^2}{4}}$$

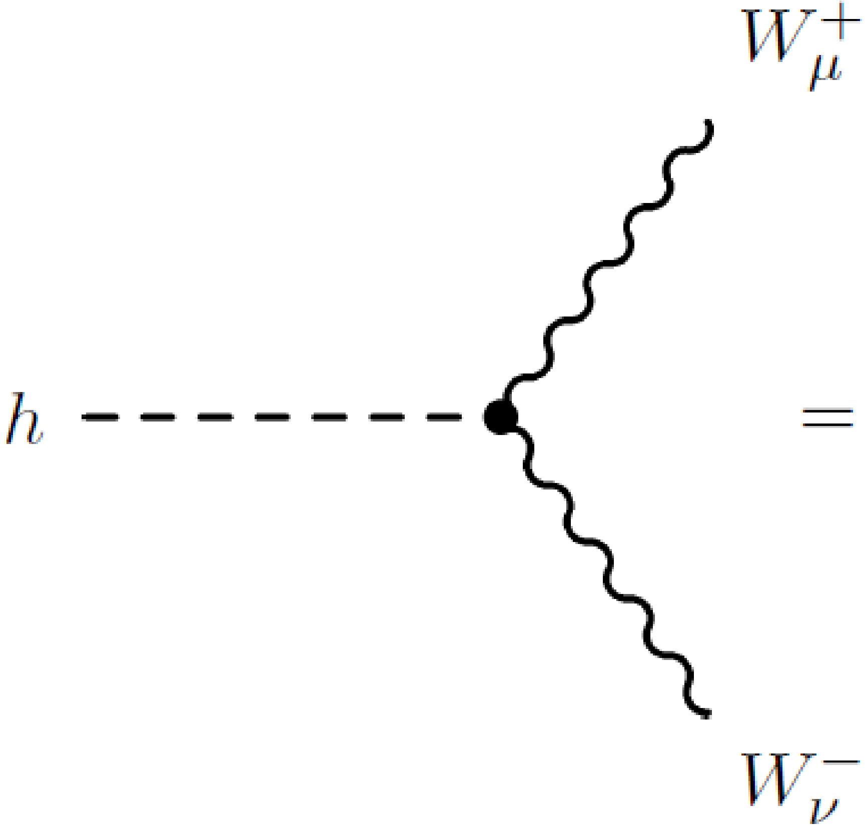
$$\begin{aligned}
\mathcal{L} &\supset \frac{1}{8}g^2(v+h)^2(W_\mu^1 - iW_\mu^2)(W^{1\mu} + iW^{2\mu}) \leftarrow \text{nabij.}\\
&= \frac{1}{4}g^2(v+h)^2 W_\mu^+ W^{-\mu}\\
&= \boxed{\frac{g^2v^2}{4}} W_\mu^+ W^{-\mu} + \underbrace{\frac{g^2v}{2} h W_\mu^+ W^{-\mu} + \frac{g^2}{4} hh W_\mu^+ W^{-\mu}}_{}
\end{aligned}$$

- Jednoznačno predviđene interakcije s higgsom daju Feynmanova pravila:

$$hW_\mu^+ W_\nu^- : \qquad i\frac{g^2v}{2} g_{\mu\nu} = igM_W g_{\mu\nu} = 2i\frac{M_W^2}{v} g_{\mu\nu},$$

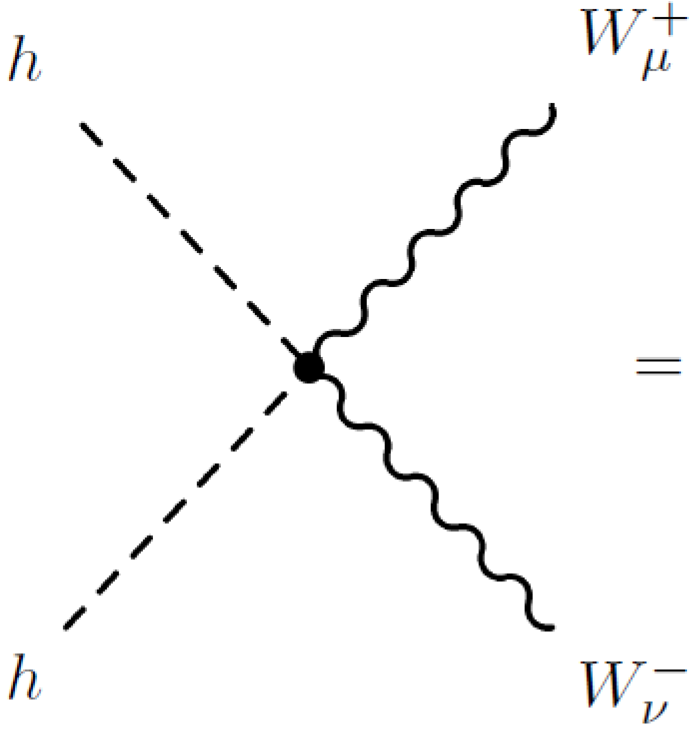
$$hhW_\mu^+ W_\nu^- : \qquad i\frac{g^2}{4} \times 2!\, g_{\mu\nu} = 2i\frac{M_W^2}{v^2} g_{\mu\nu},$$

Feynmanovo pravilo za vrh hWW



$$= i\frac{g^2 v}{2} g_{\mu\nu} = 2i\frac{M_W^2}{v} g_{\mu\nu}$$

Feynmanovo pravilo za vrh hhWW (s kombinatorijskih 2!)



$$= i\frac{g^2}{4} \cdot 2g_{\mu\nu} = 2i\frac{M_W^2}{v^2}g_{\mu\nu}$$

Masa Z bozona

-prepoznavanjem

$$\boxed{M_Z^2 = \frac{(g^2+g'^2)v^2}{4}}$$

$$\begin{aligned}
(gW_\mu^3 - g'B_\mu) &= \sqrt{g^2+g'^2}\left(\frac{g}{\sqrt{g^2+g'^2}}W_\mu^3 - \frac{g}{\sqrt{g^2+g'^2}}B_\mu\right) \\
&\equiv \sqrt{g^2+g'^2}\,(c_W W_\mu^3 - s_W B_\mu) \\
&\equiv \sqrt{g^2+g'^2}\,Z_\mu,
\end{aligned}$$

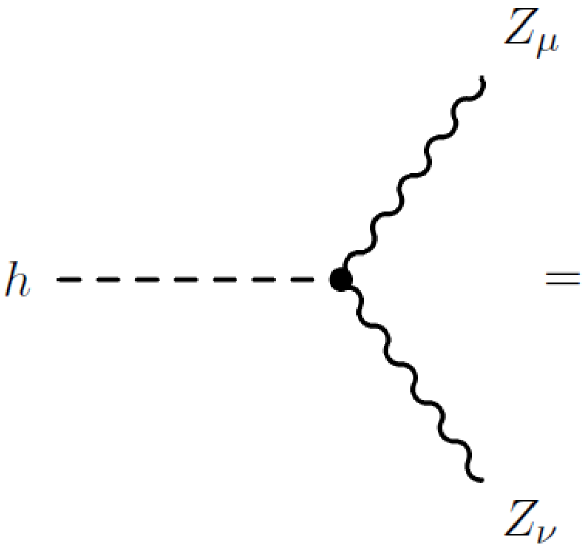
$$\begin{aligned}
\mathcal{L} &\supset \frac{1}{8}(v+h)^2\left(-g'B_\mu + gW_\mu^3\right)^2 \\
&= \frac{1}{8}(g^2+g'^2)(v+h)^2 Z_\mu Z^\mu \\
&= \boxed{\frac{(g^2+g'^2)v^2}{\underset{=4\cdot 2}{8}}} Z_\mu Z^\mu + \frac{(g^2+g'^2)v}{4} h Z_\mu Z^\mu + \frac{(g^2+g'^2)}{8} hh Z_\mu Z^\mu
\end{aligned}$$

- **Feynmanova pravila interakcija s higgsom:**

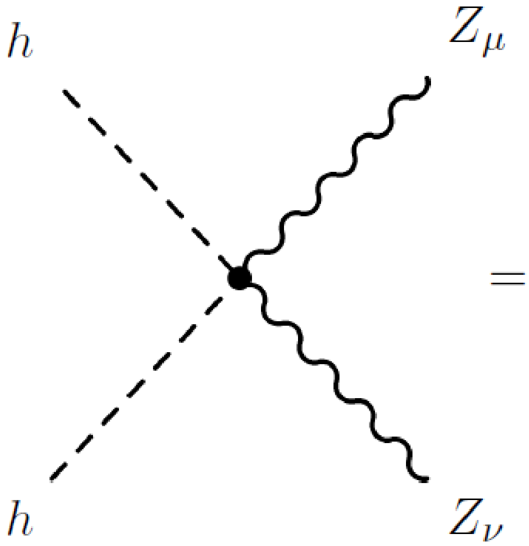
$$hZ_\mu Z_\nu : \qquad i\frac{(g^2+g'^2)v}{4} \times 2!\,g_{\mu\nu} = i\sqrt{g^2+g'^2}M_Z g_{\mu\nu} = 2i\frac{M_Z^2}{v}g_{\mu\nu}$$

$$hhZ_\mu Z_\nu : \qquad i\frac{(g^2+g'^2)}{8} \times 2! \times 2!\,g_{\mu\nu} = 2i\frac{M_Z^2}{v^2}g_{\mu\nu},$$

Feynmanova pravila za hZZ i hhZZ

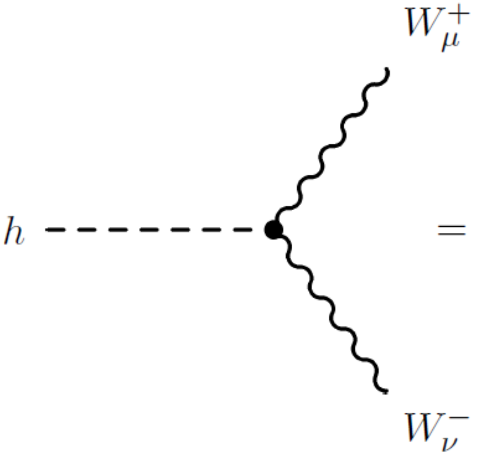


$$= i\frac{(g^2 + g'^2)v}{4} \cdot 2g_{\mu\nu} = 2i\frac{M_Z^2}{v}g_{\mu\nu}$$

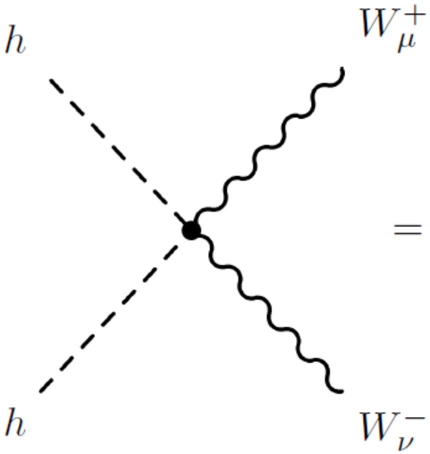


$$= i\frac{(g^2 + g'^2)}{8} \cdot 2 \cdot 2g_{\mu\nu} = 2i\frac{M_Z^2}{v^2}g_{\mu\nu}$$

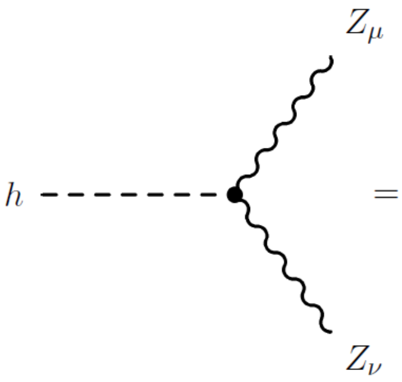
Feynmanova pravila (s dodatnim faktorima 2 za 2 identična h/Z)



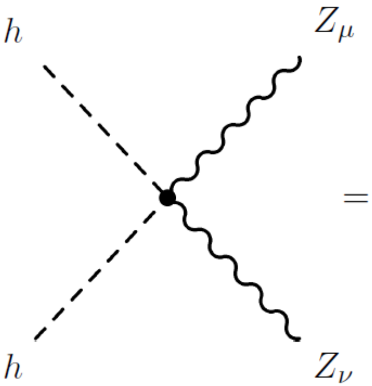
$$= i\frac{g^2 v}{2} g_{\mu\nu} = 2i\frac{M_W^2}{v} g_{\mu\nu}$$



$$= i\frac{g^2}{4} \cdot 2g_{\mu\nu} = 2i\frac{M_W^2}{v^2} g_{\mu\nu}$$



$$= i\frac{(g^2 + g'^2)v}{4} \cdot 2g_{\mu\nu} = 2i\frac{M_Z^2}{v} g_{\mu\nu}$$



$$= i\frac{(g^2 + g'^2)}{8} \cdot 2 \cdot 2g_{\mu\nu} = 2i\frac{M_Z^2}{v^2} g_{\mu\nu}$$

Kovarijantna derivacija SM-a izražena fizikalnim bozonima

$$\mathcal{D}_\mu = \partial_\mu - i g_s G^a_\mu t^a - i\frac{g}{2}\left(W^+_\mu T^+ + W^-_\mu T^-\right)$$

$$- i Z_\mu \left(g c_W T^3 - g' s_W Y\right) - i A_\mu \left(g s_W T^3 + g' c_W Y\right)$$

- **Uz definicije** $s_W = g'/\sqrt{g^2+g'^2},\ c_W = g/\sqrt{g^2+g'^2},$

$$\left(g s_W T^3 + g' c_W Y\right) = \frac{gg'}{\sqrt{g^2+g'^2}}\left(T^3+Y\right) \equiv eQ, \qquad e = \frac{gg'}{\sqrt{g^2+g'^2}} = g s_W = g' c_W,$$

$$\left(g c_W T^3 - g' s_W Y\right) = \frac{g^2+g'^2}{\sqrt{g^2+g'^2}} T^3 - \frac{g'^2}{\sqrt{g^2+g'^2}} Q = \sqrt{g^2+g'^2}\left(T^3 - s_W^2 Q\right)$$

$$\boxed{- i\frac{e}{s_W c_W} Z_\mu \left(T^3 - s_W^2 Q\right) - i e A_\mu Q}$$

Određivanje skale elektroslabog faznog prijelaza:

Skalu lomljenja simetrije moglo se utvrditi i prije mjerenja $M_{W,Z}$ masa

- (V-A) teorija slabih međudjelovanja predviđa na niskim energijama

$$\left.\frac{G_F}{\sqrt{2}} = \frac{g^2}{8M_W^2} = \frac{1}{2v^2}\right\} \Rightarrow \boxed{v = (\sqrt{2}\,G_F)^{-1/2} = 246\,\mathrm{GeV}}$$

& mjeren $G_F \simeq 1.17 \cdot 10^{-5}\,\mathrm{GeV}^{-2}$

ŠTO JE S MASOM HIGGSA?

Bila je neodređena sve do otkrića Higgsolike rezonancije na 126 GeV na LHC-u (4.7.2012.): λ = 0.13 *1

$$V(\Phi) = -\frac{\lambda}{4}\left(\Phi^{\dagger}\Phi - \frac{v^2}{2}\right)^2$$

Masa Higgsove čestice ostaje neodređena :

$$V(\Phi) = \frac{1}{2}(2\mu^2)\,H(x)^2 + \cdots \Rightarrow \boxed{M_H = \sqrt{2}\mu = \sqrt{2\lambda}\, v}$$

ovisnost o jakosti samointerakcije λ

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*1 Slabo vezanje

SAMOINTERAKCIJE HIGGSA

-minimizacijom potencijala i unitarno bažd.

$$\mu^2 = \lambda v^2 \qquad \Phi^\dagger\Phi = \frac{1}{2}(h+v)^2$$

$$\mathcal{L}_V = -V(\Phi) = \mu^2\Phi^\dagger\Phi - \lambda(\Phi^\dagger\Phi)^2$$

$$= \boxed{-\lambda v^2} h^2 \boxed{- \lambda v h^3 - \frac{\lambda}{4} h^4} + \text{const.}$$

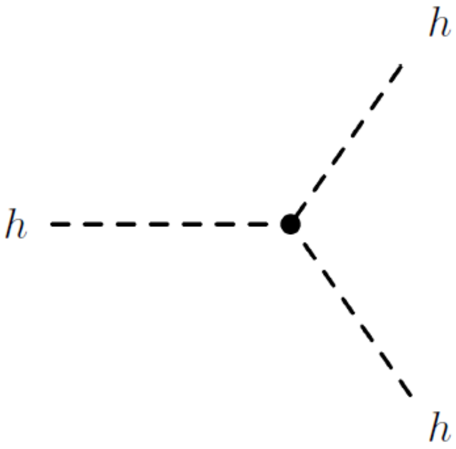
- **Član mase i Feynmanova pravila interakcija**

$$\boxed{-\lambda v^2 = -m_h^2/2}$$

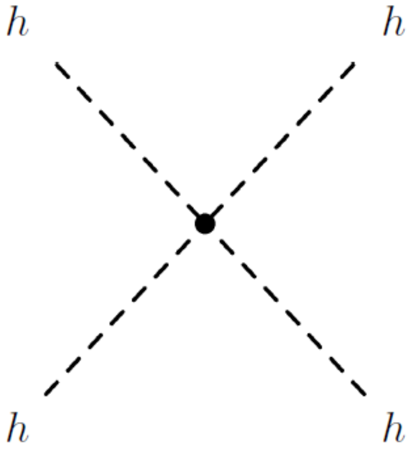
$$hhh: \quad -i\lambda v \times 3! = -6i\lambda v = -3i\frac{m_h^2}{v}$$

$$hhhh: \quad -i\frac{\lambda}{4} \times 4! = -6i\lambda = -3i\frac{m_h^2}{v^2}$$

Feynmanova pravila u unitarnom baždarenju za samointerakcije



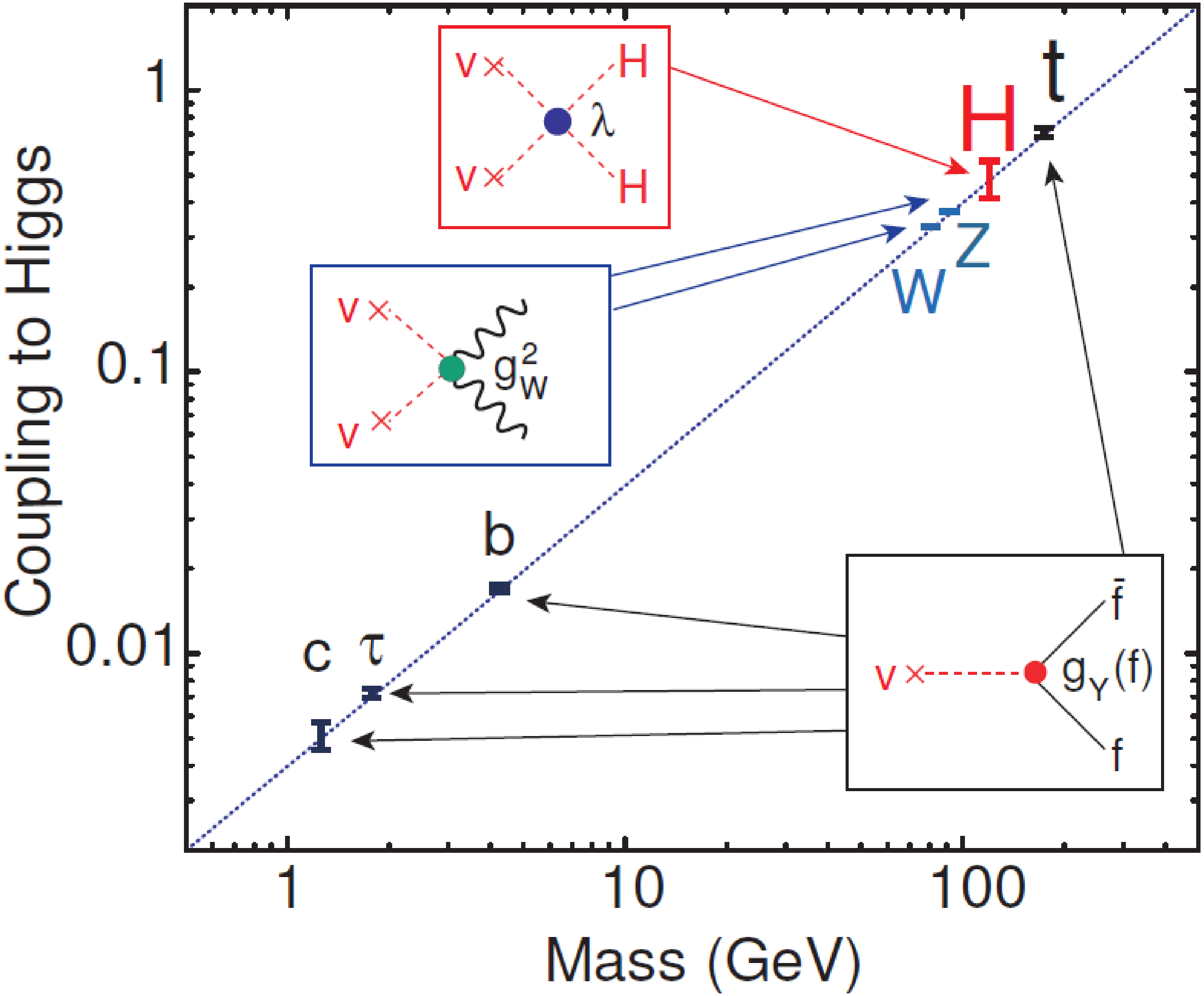
$$= -i\lambda v \cdot 3! = -6i\lambda v = -3i\frac{m}{v}$$



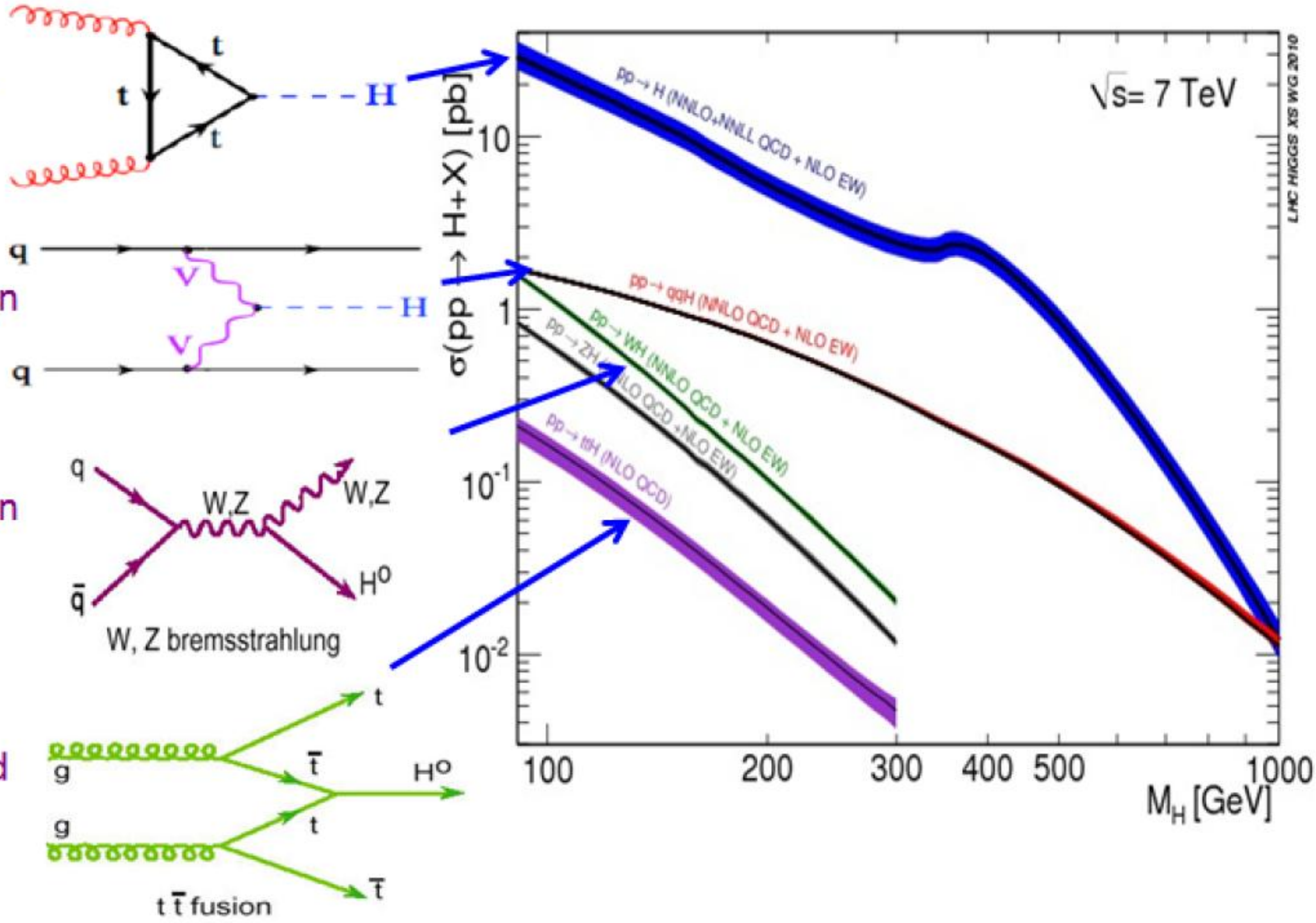
$$= -i\frac{\lambda}{4} \cdot 4! = -6i\lambda = -3i\frac{m_h^2}{v^2}$$

- Standardni model zahtijeva uvođenje tad još neotkrivenog Higgsovog polja
- To je SKALARNO POLJE koje prožima sav prostor
- Mogućnost pobuđenja tog polja (produkcija Higgsove čestice) na LHC-u

Vezanja Higgsovih bozona u SM



Produkcija Higgsovih bozona



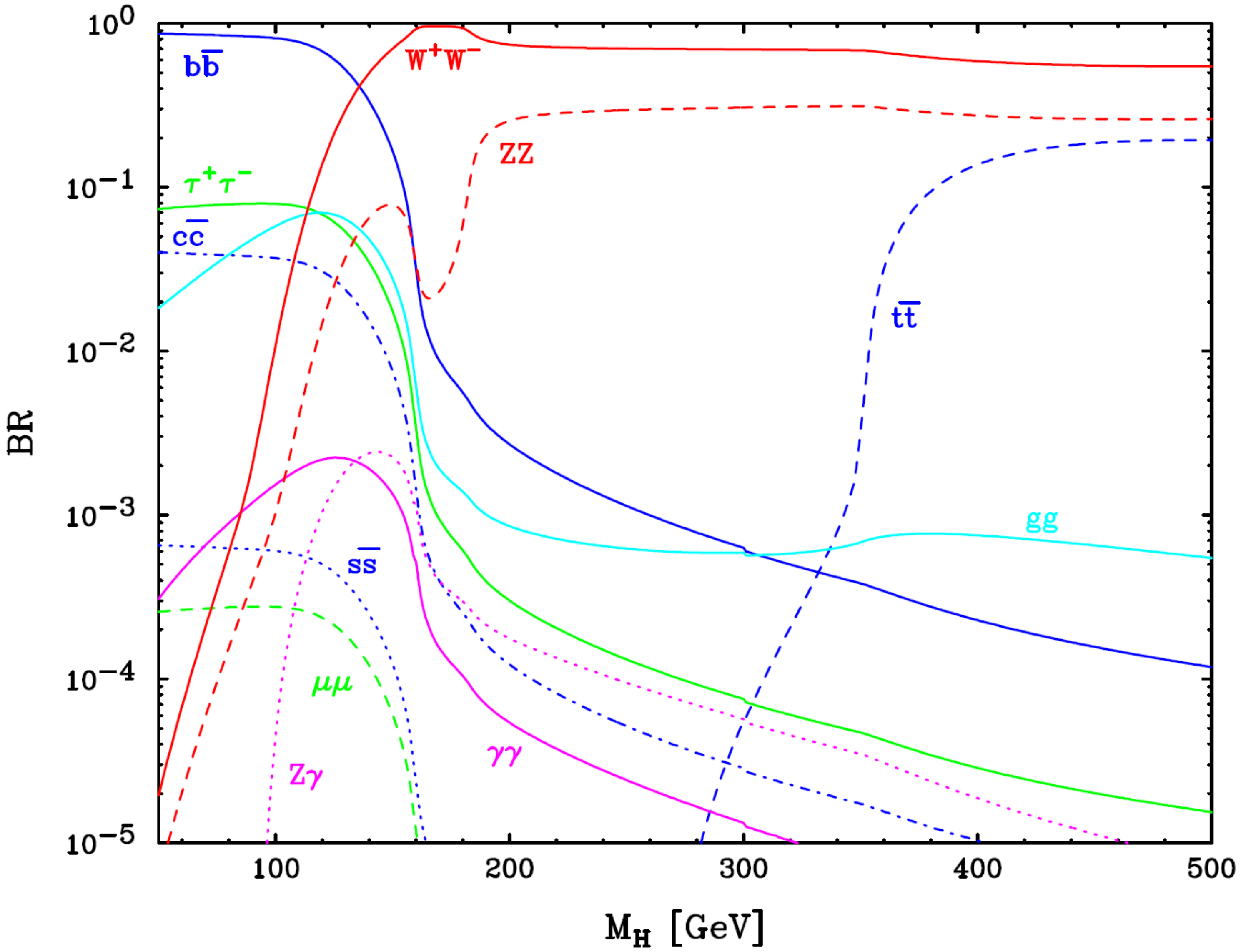
„gluon fusion“

„vector boson fusion“

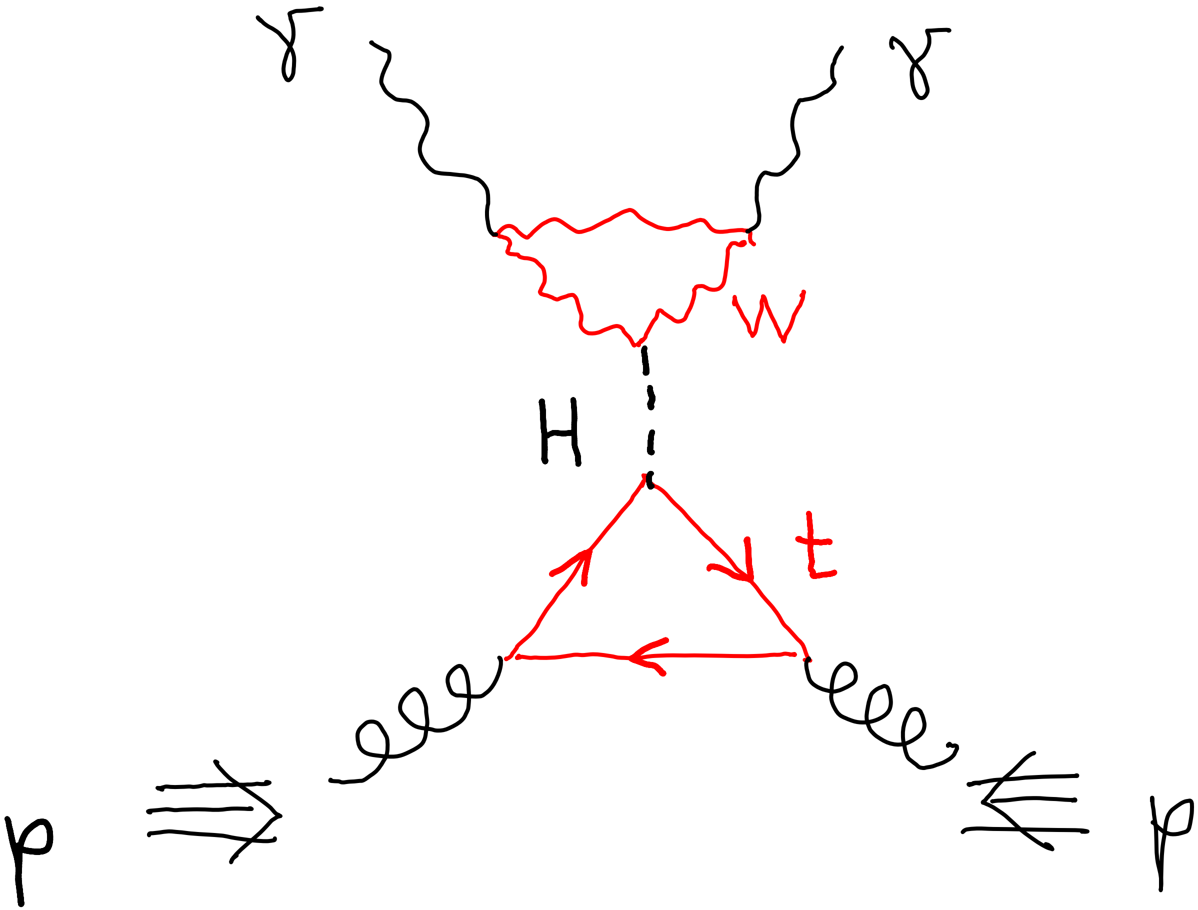
„vector boson radiation“

„tt associated production“

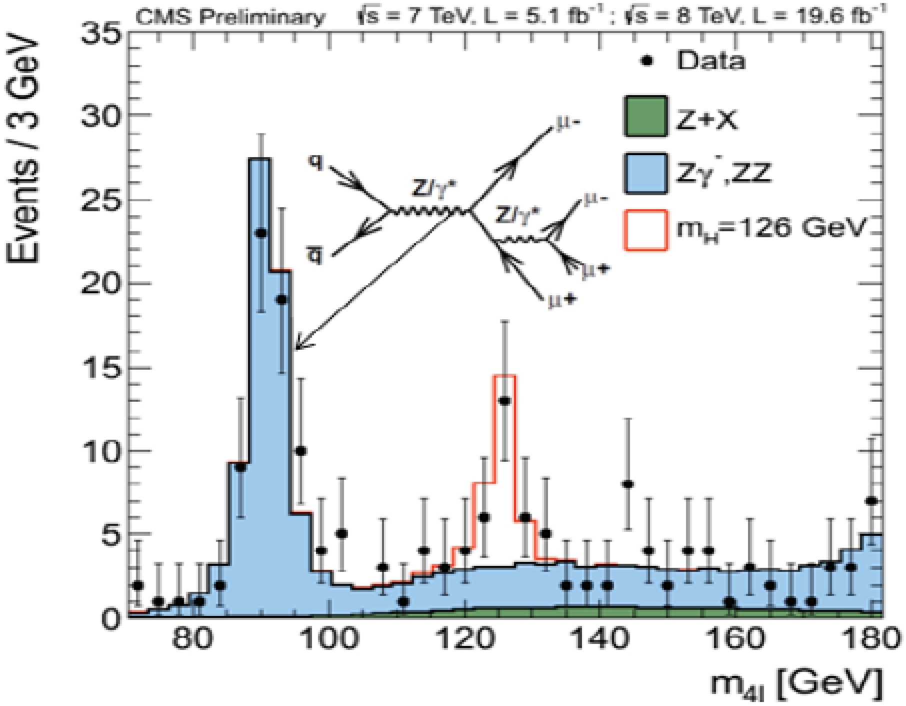
Raspadi Higgsovog bozona

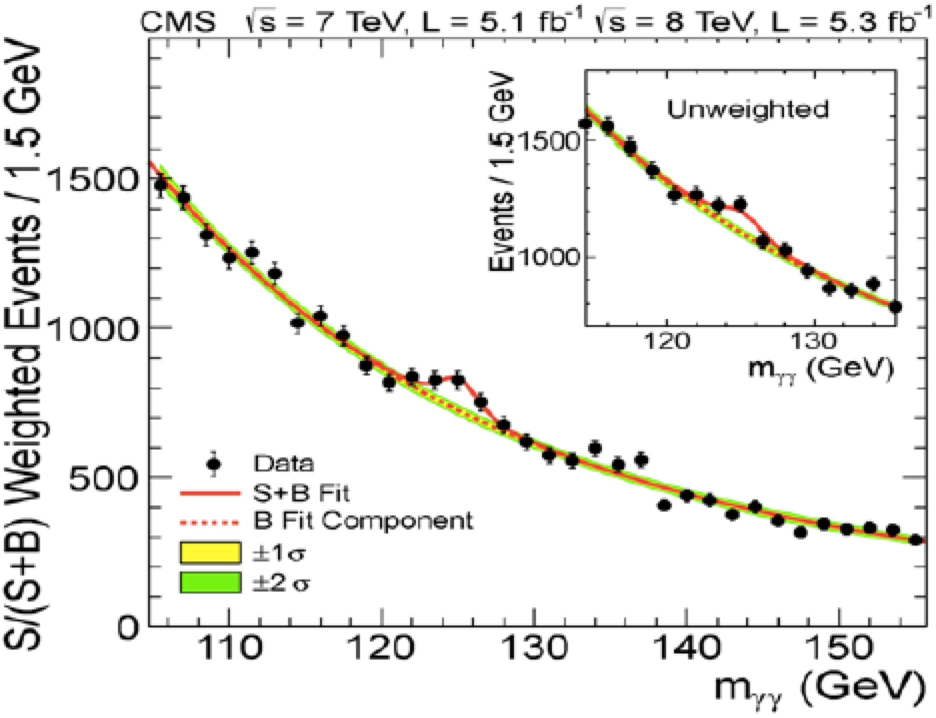


Virtualna fizika u eri LHC-a:
Produkc. i raspad kvantnom petljom

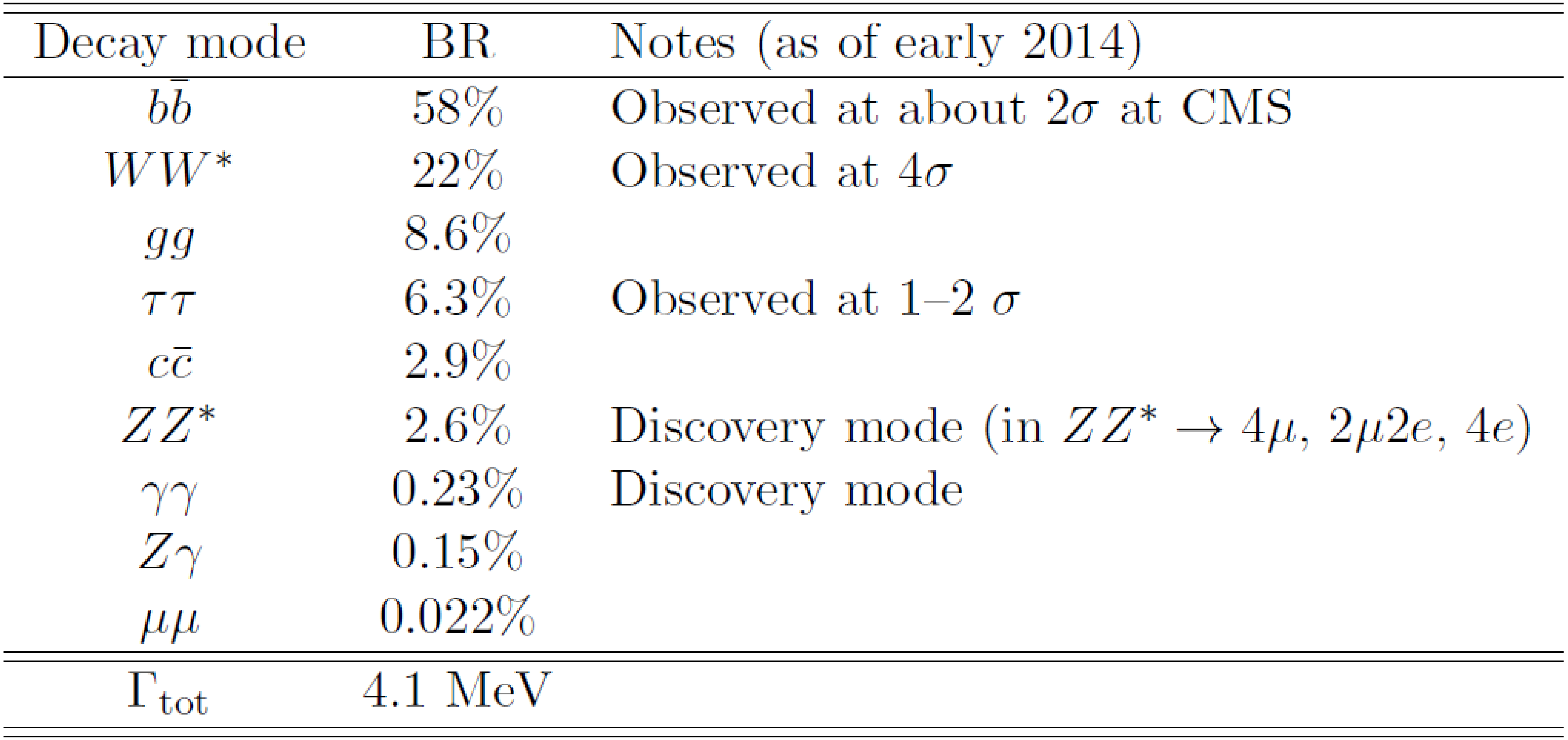


Pojačanje spektra na invarijantnoj masi 126 GeV





Omjeri grananja za Higgsov bozona SM-a mase 126 GeV



Decay mode	BR	Notes (as of early 2014)
$b\bar{b}$	58%	Observed at about 2σ at CMS
WW^*	22%	Observed at 4σ
gg	8.6%	
$\tau\tau$	6.3%	Observed at 1–2 σ
$c\bar{c}$	2.9%	
ZZ^*	2.6%	Discovery mode (in $ZZ^* \to 4\mu$, $2\mu 2e$, $4e$)
$\gamma\gamma$	0.23%	Discovery mode
$Z\gamma$	0.15%	
$\mu\mu$	0.022%	
Γ_{tot}	4.1 MeV	

NAKON OTKRIĆA HIGGSA

Zagonetka finog podešavanja za tri parametra Higgsovog potencijala

$$V = \text{const.} + m_H^2 |H|^2 + \lambda |H|^4$$

- Problem kozmološke konstante
- Problem prirodnosti higgsa
- Problem vakuumske stabilnosti