$R_{\gamma\gamma}$ and $R_{Z\gamma}$ in the Inert Doublet Model

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Abstract

Analysis of the 125 GeV Higgs boson's decay rates to $\gamma\gamma$ and $Z\gamma$ in the Inert Doublet Model is presented. We study the constraints on the masses of the scalars (in particular the Dark Matter candidate) and their couplings to the Higgs boson, coming from the $h \to \gamma\gamma$ data.

Inert Doublet Model

IDM is a 2HDM with two scalar doublets Φ_S, Φ_D, invariant under D-symmetry: $\Phi_D \xrightarrow{D} -\Phi_D$, $\Phi_S \xrightarrow{D} \Phi_S$, $\Phi_{SM} \xrightarrow{D} \Phi_{SM}$.

- D-symmetric scalar potential
- Only Φ_S couples to fermions (Model I)
- Vacuum state: $\langle \Phi_S \rangle = \frac{v}{\sqrt{2}}$, $\langle \Phi_D \rangle = 0$

The particle spectrum consists of:

- h – SM-like Higgs boson ($M_H \approx 125$ GeV)
- 4 dark scalars: H, A, $H^\pm$
  couplings: $\lambda_3 \sim hH^+H^-$, $\lambda_{345} \sim hHH$

The lightest D-odd particle (H) stable $\Rightarrow$ a good Dark Matter candidate.

IDM is in agreement with theoretical and experimental constraints: vacuum stability, perturbative unitarity, existence of inert vacuum, electroweak precision tests, LEP, DM data.

LHC and $R_{\gamma\gamma}$, $R_{Z\gamma}$

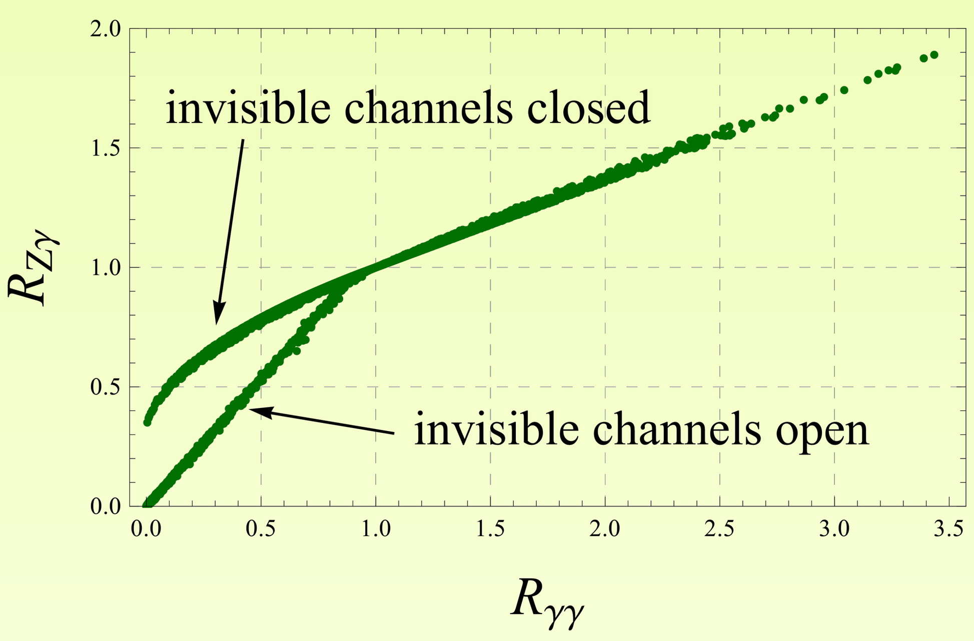
$$R_{XX'} = \frac{\sigma(pp \to h \to XX')^{\text{IDM}}}{\sigma(pp \to h \to XX')^{\text{SM}}} \approx \frac{\text{Br}(h \to XX')^{\text{IDM}}}{\text{Br}(h \to XX')^{\text{SM}}},\; XX' = \gamma\gamma,\, Z\gamma.$$

$$\text{ATLAS} : \quad R_{\gamma\gamma} = 1.65 \pm 0.24(\text{stat})^{+0.25}_{-0.18}(\text{syst}),$$
$$\text{CMS} : \quad R_{\gamma\gamma} = 0.79^{+0.28}_{-0.26}.$$

$R_{\gamma\gamma}$ and $R_{Z\gamma}$ can be modified with respect to the SM ($R_{\gamma\gamma} = R_{Z\gamma} = 1$) due to:

- charged scalar $H^\pm$ loop
- invisible decays

$R_{\gamma\gamma}$ and $R_{Z\gamma}$ are positively correlated, their maximal values are: $R^{\max}_{\gamma\gamma} \approx 3.5$, $R^{\max}_{Z\gamma} \approx 1.9$.

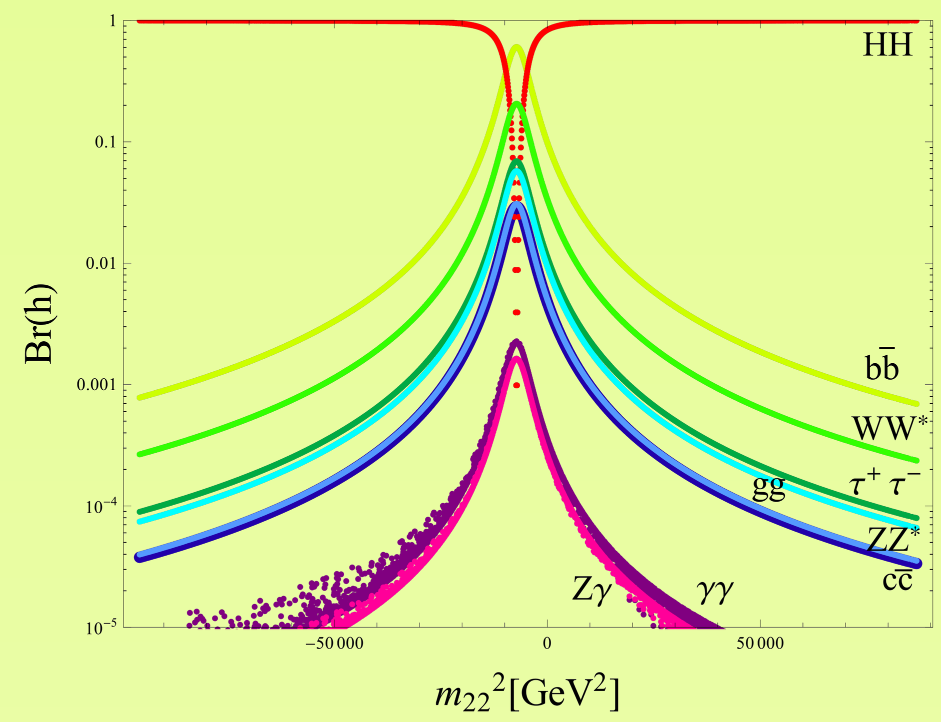


Summary

- $R_{\gamma\gamma}$ and $R_{Z\gamma}$ are positively correlated.
- $R_{\gamma\gamma} > 1 \Rightarrow M_{H,H^\pm,A} \gtrsim 63$ GeV, $\lambda_3 < 0$.
- Lower bound on $R_{\gamma\gamma}$ $\Rightarrow$ upper bounds on M_H, $M_{H^\pm}$ and λ_3.
- $R_{\gamma\gamma} > 1.2 \Rightarrow M_{H,H^\pm} < 154$ GeV and $-1.45 < \lambda_3 < -0.18$.
- $1 > R_{\gamma\gamma} > 0.7$ constraints strongly λ_{345}.
- $1 > R_{\gamma\gamma} > 0.7$ is incompatible with WMAP for $M_H \lesssim 53$ GeV.
- $1 > R_{\gamma\gamma} > 0.7$ limits DM-nucleon scattering cross-section stronger than XENON100 for low and medium DM masses.

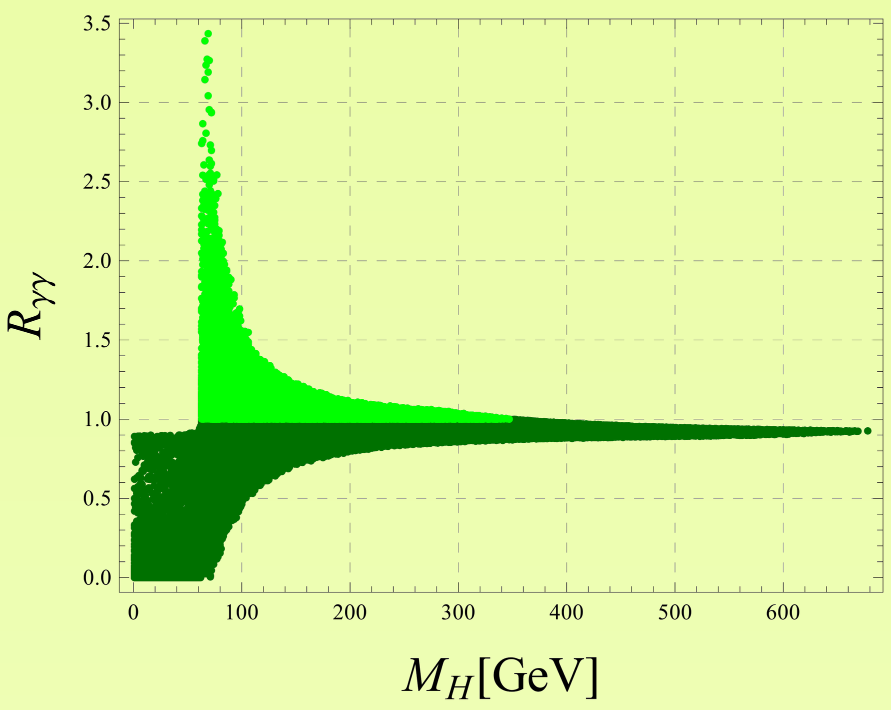
$R_{\gamma\gamma} > 1$

The invisible Higgs decays' partial widths are big in comparison with the SM decays' widths:



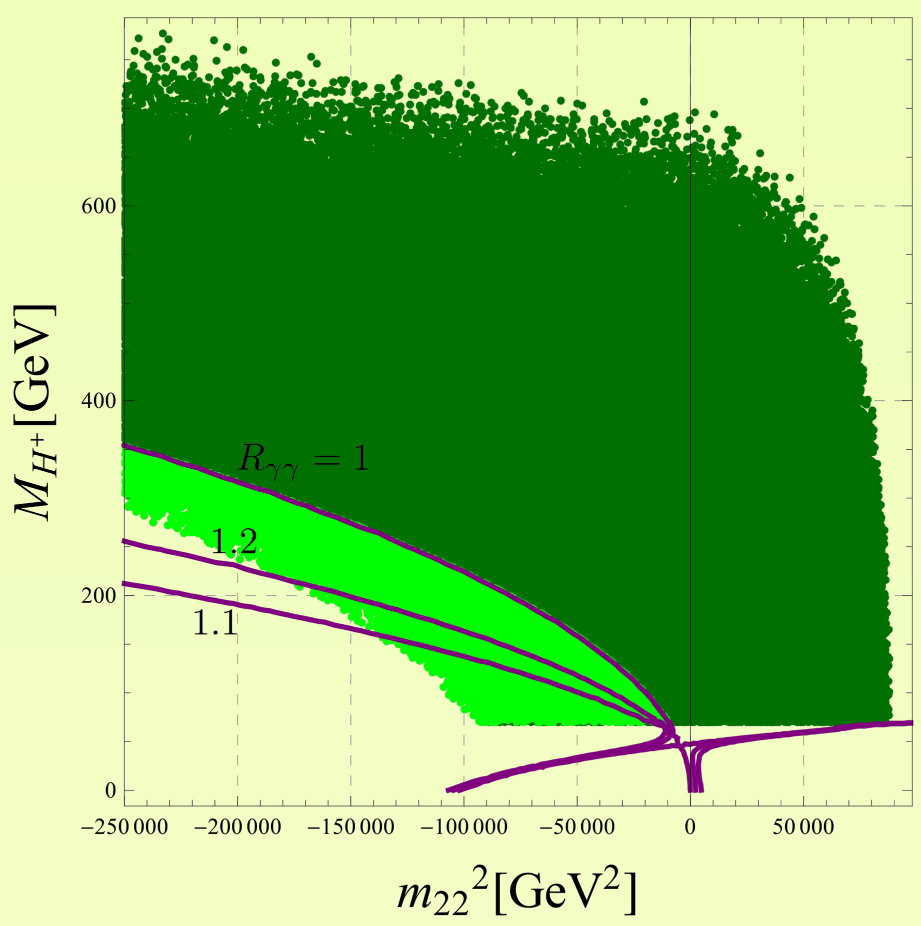
For $M_H < M_h/2$, the total width is so big that $R_{\gamma\gamma} > 1$ is impossible.

- $R_{\gamma\gamma} > 1 \Rightarrow M_H,\ M_{H^\pm},\ M_A \gtrsim 63$ GeV.



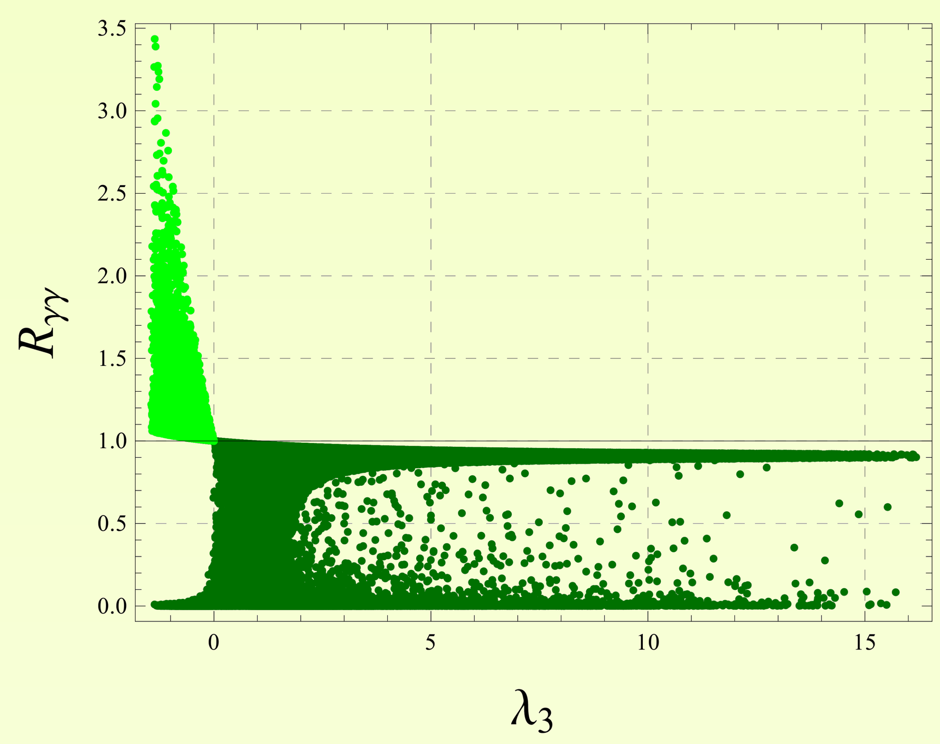
Setting a lower bound on $R_{\gamma\gamma}$ constraints $M_{H^\pm}$ (and therefore also M_H).

- $R_{\gamma\gamma} > 1.2 \Rightarrow M_H, M_{H^\pm} < 154$ GeV.



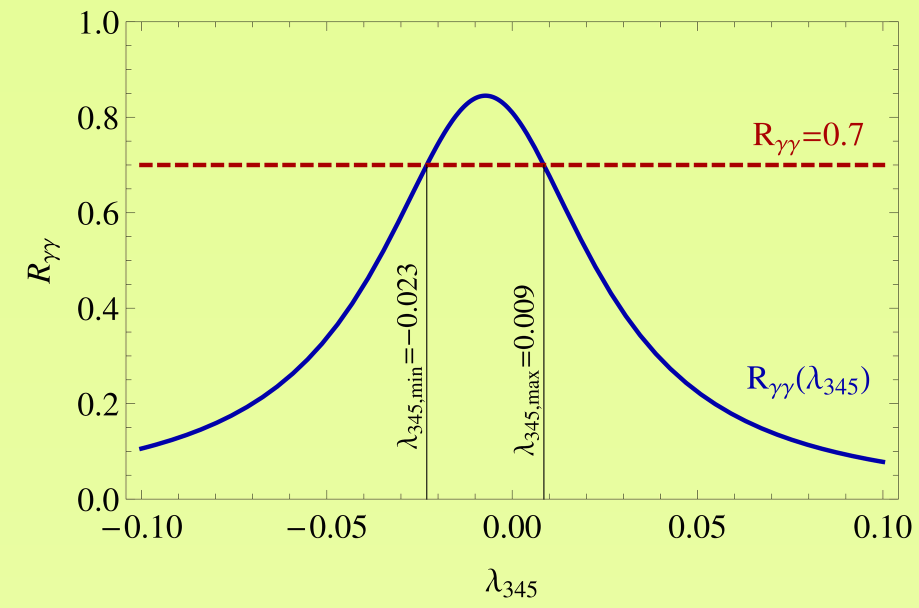
$R_{\gamma\gamma} > 1$ is possible when SM contribution and the $H^\pm$ loop interfere constructively $\Rightarrow \lambda_3 < 0$. A lower limit on $R_{\gamma\gamma}$ further constraints λ_3.

- $R_{\gamma\gamma} > 1.2 \Rightarrow -1.45 < \lambda_3 < -0.18$.

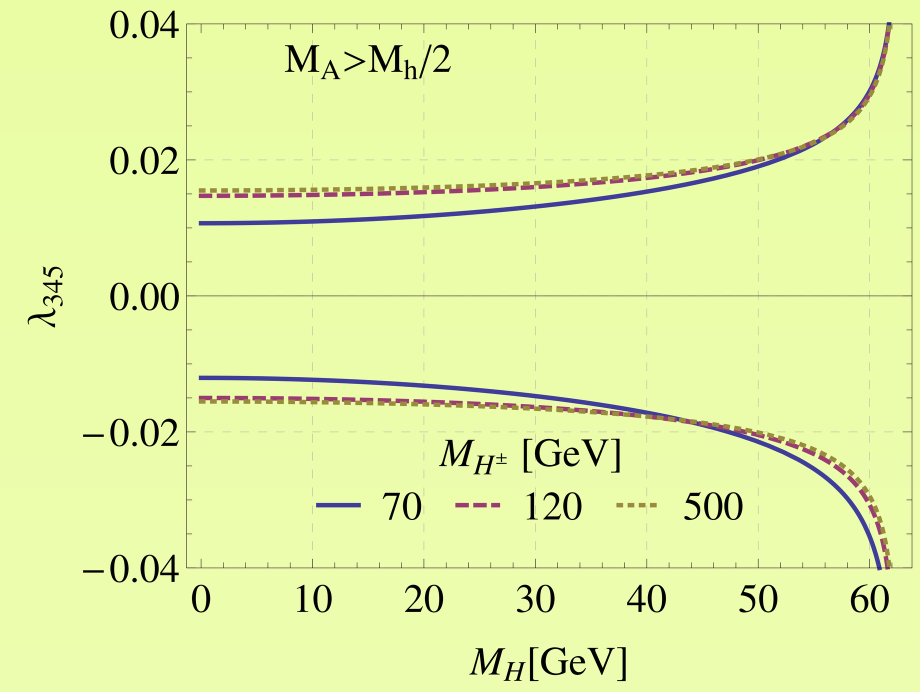


$R_{\gamma\gamma} < 1$

Setting a lower limit on $R_{\gamma\gamma}$ constrains λ_{345}:

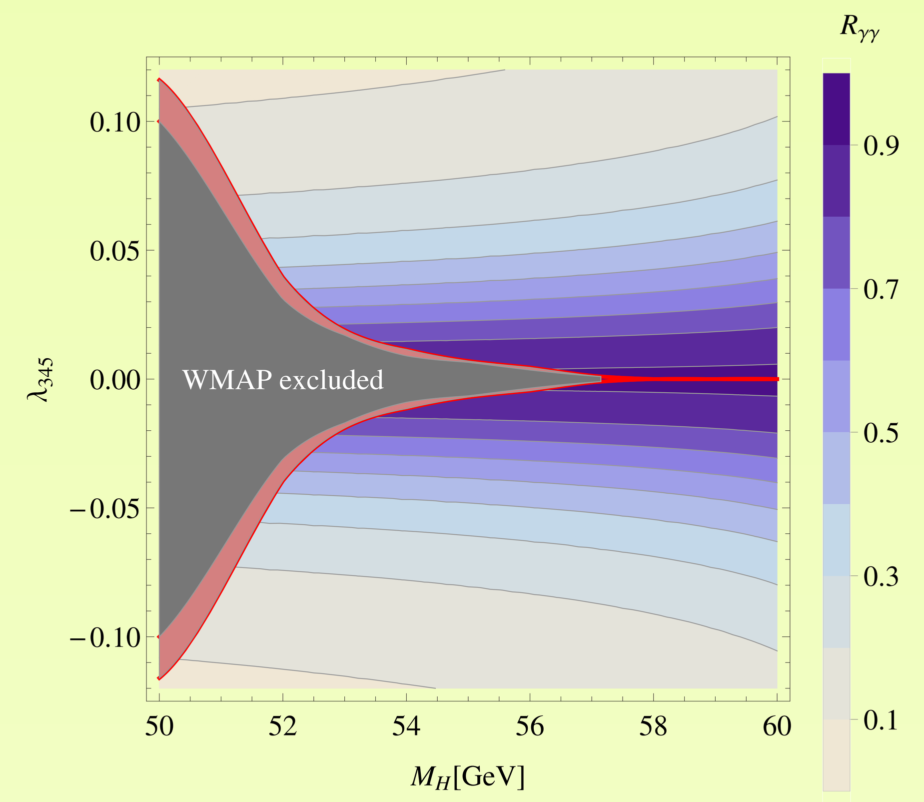


Upper and lower limits on λ_{345} as functions of M_H:



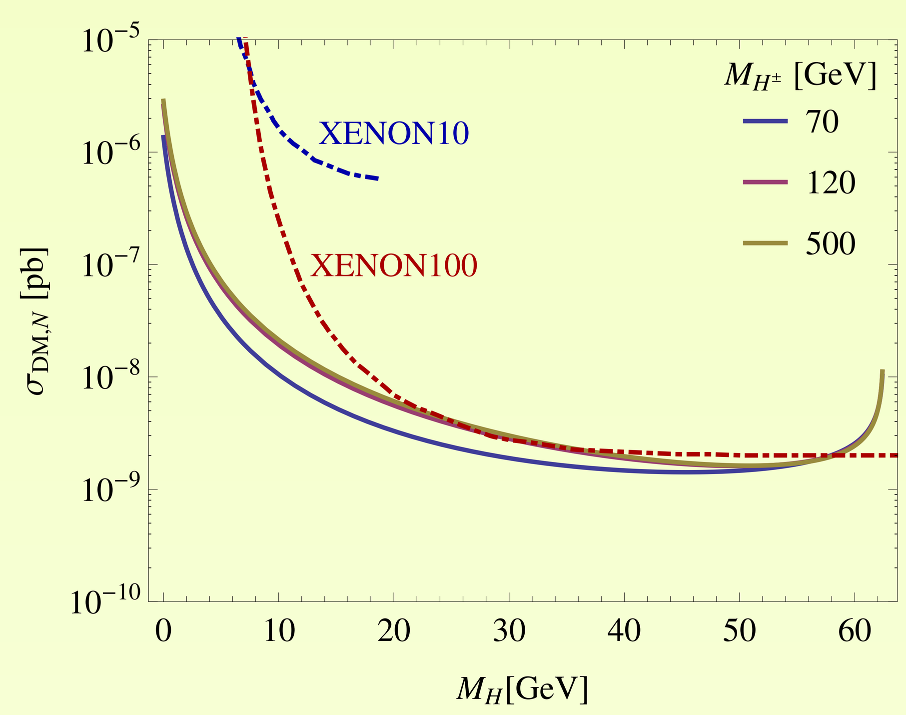
Comparison with WMAP data

- λ_{345} is constrained by the relic abundance of the DM, $\Omega_{DM}h^2$ (WMAP and Planck).
- H constituting 100% of the DM (red band) is incompatible with $1 > R_{\gamma\gamma} > 0.7$ for $M_H \lesssim 53$ GeV.



Comparison with XENON100

- DM-nucleon scattering cross section $\sigma_{\text{DM},N} \sim \lambda^2_{345}$.
- $R_{\gamma\gamma}$ bounds on λ_{345} translated to the $(\sigma_{\text{DM},N},\ M_H)$ plane:



- Upper limits are stronger than those provided by XENON100.

References

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