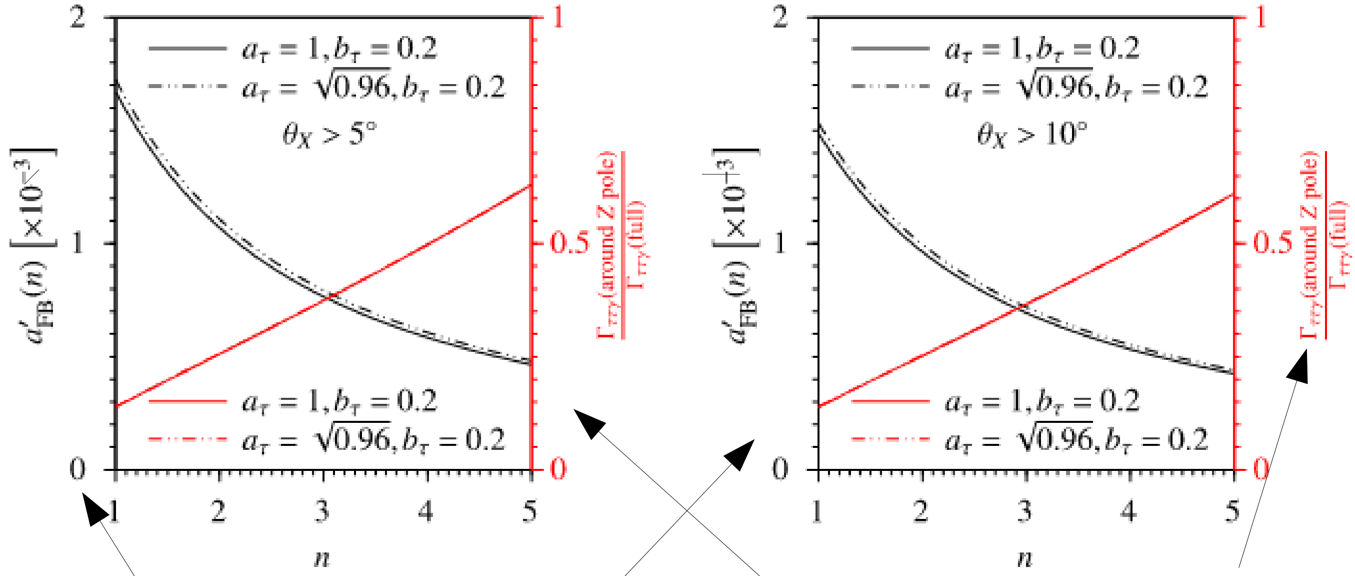
# Asymmetry around $Z$ pole vis-á-vis reduction in decay rate

Considering only those events surrounding $Z$ pole $\Longrightarrow$ drastic reduction in phase space




asymmetry***10**(+3)**

part of the BR that is resonant withing 1,2 , n widths

**From these plots we see that around 15% of BR is resonant withing 1 width of Z0 mass, while 60% is within 5 widths of Z0 mass. We get some different numbers from simple, non-interference considerations:**

From Dibya as well: H- tau tau gamma is 0.06 of the total Higgs-> tau tau. This includes both resonant and non-resonant. Since Higgs-> tau tau is 0.063 of Higgs→anything ( if I remember well):
Higgs-> tau tau gamma is 36* 10**(-4) of Higgs→anything

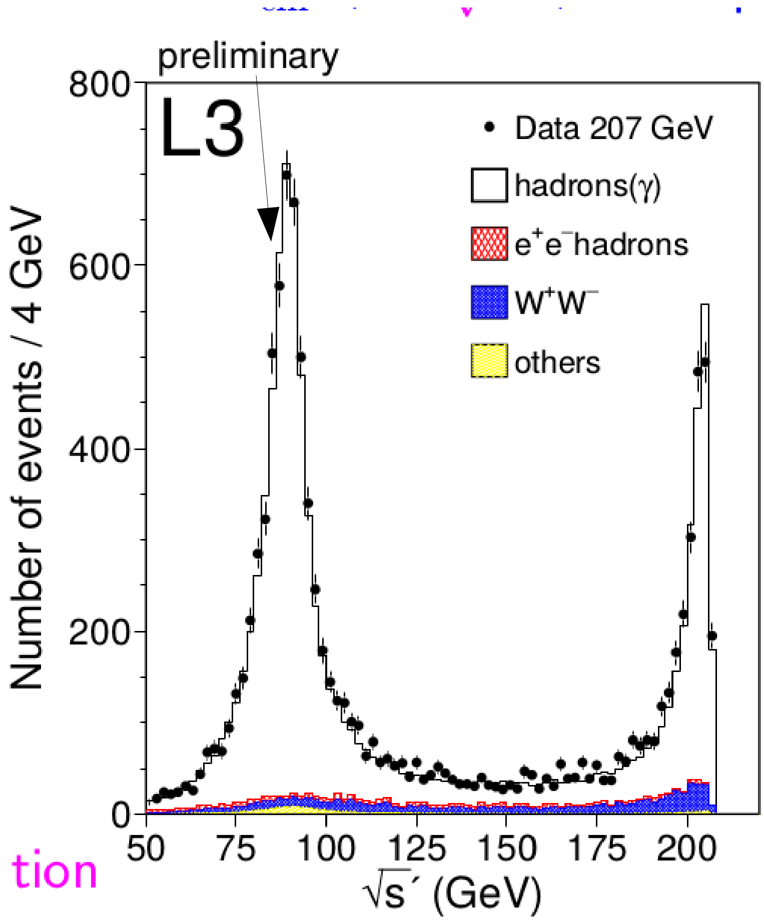
**Reference ( arXiv: 1610.07922 [hep-ph]) in the ATLAS paper.**
$B(H \to Z\gamma)$ **= (1.54 ± 0.09) × 10−3. From LEP that Z-> tau tau is 3%.**
**Thus the resonant part is 1,54*0.001*0.03=4.6*10**(-5)**
**of Higgs->anything.**
**While total resonant and non-resonant part is 36*10**(-4) .**
**That means that the purely resonant part is around**
**1.3% of the total Higgs-> tau tau gamma.**

But from Dibya plots above the resonant part looks like much more than 1.3% of the total Higgs-> tau tau gamma. Which
might mean that it is "pushed up" by the interference terms. Or a mistake somewhere ??? **see the next page**

There are two things to understand:
1) why the Z0 peak in resonant H→ tau+ tau- gamma where tau+ tau- come from Z* is so much wider than the normal Breit-Wigner ?

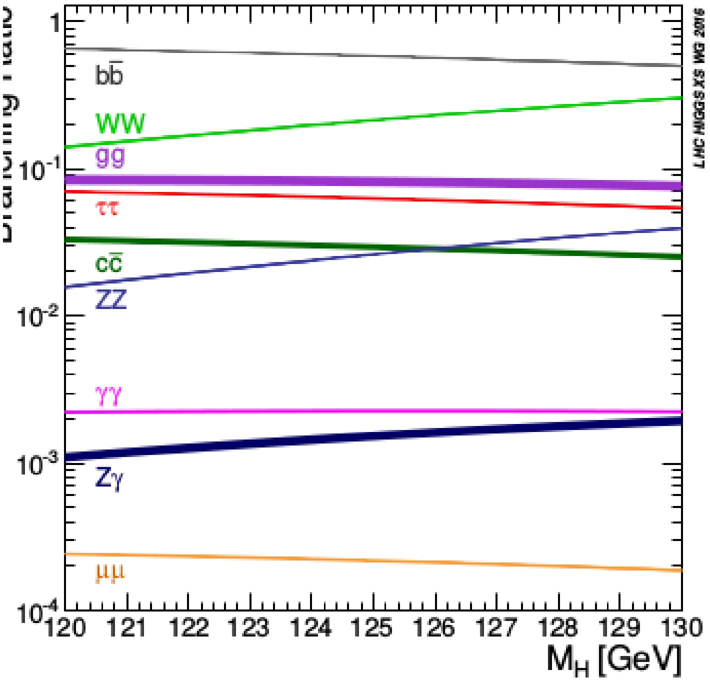
2) Why the resonant BR  H→ tau tau gamma is of the order of 3.6*10**(-3)*[0.1-0.6] thus [0.36-2.2]*10**(-3) much larger than  $B(H \to Z\gamma)$ = (1.54 ± 0.09) × 10−3 * 0.03 thus 4.6*10**(-5) ?

The answer to the first question comes from studying qq gamma at LEP2 where the radiative return to Z is visible (analogy of the resonant part). The Z peak is much wider than normal BW, these comes from interference effects with the non-resonant part.




The answer to the second question might be that in the process H→ Z* gamma → tau+tau- gamma  the  Z* was "forced" to go tau+ tau-  thus the BR  of Z→ tau+ tau- =0.03 does not apply.  This is physically not true as coupling constant is a coupling constant both for a real and a virtual process. Maybe it was forgotten in Dibya calculations? I see it on the next page however.
However, ff this is true the process H→ Z* gamma → tau+ tau- gamma effectively has much higher BR than  $B(H \to Z\gamma)$ = (1.54 ± 0.09) × 10−3 * 0.03 with Z→ mu+ mu- for example.  **We can  propose  to search for this process, and our mass calculator will have much wider application. Possibly a good news. However. BR calculation should be checked, as most likely we have a mistake, see next page.**

**Anna L 27/03/2023**




From the Yellow Report.
H→ Z gamma→ tau tau gamma has BR =4.6*10**(-5)

From Dibya, seems that coupling to tau is correctly in place. However the total BR H→ tau tau gamma=3.6*10**(-3)

### 3.2 Decay amplitude

Using the form factors $A_{2,3}^{\mathcal{V}\gamma}$ for the loop contributions, the decay amplitude for the decay $H \to \tau^+\tau^-\gamma$ is given by,

$$\mathcal{M}_{\tau\tau\gamma} = \mathcal{M}_{\tau\tau\gamma}^{(\mathrm{Yuk})} + \mathcal{M}_{\tau\tau\gamma}^{(Z\gamma)} + \mathcal{M}_{\tau\tau\gamma}^{(\gamma\gamma)}, \tag{3.2}$$

where

$$\mathcal{M}_{\tau\tau\gamma}^{(\mathrm{Yuk})} = -e\,\frac{m_\tau}{v}\,\epsilon_\alpha^*(p_0)\,\overline{u}(p_-)\Bigg[\gamma^\alpha\left(\frac{\not{q}_- + m_\tau}{q_-^2 - m_\tau^2 + i\,m_\tau\Gamma_\tau}\right)\left(a_\tau + i\,\gamma^5 b_\tau\right) + \left(a_\tau + i\,\gamma^5 b_\tau\right)\left(\frac{-\not{q}_+ + m_\tau}{q_+^2 - m_\tau^2 + i\,m_\tau\Gamma_\tau}\right)\gamma^\alpha\Bigg]v(p_+), \tag{3.3a}$$

$$\mathcal{M}_{\tau\tau\gamma}^{(Z\gamma)} = \frac{g_z}{2\,v}\epsilon_\alpha^*(p_0)\Big(A_2^{Z\gamma}\left[(p_H - p_0)^\alpha\; p_0^\beta - (p_H\cdot p_0)\; g^{\alpha\beta}\right] + A_3^{Z\gamma}\,\epsilon^{\alpha\beta\rho\sigma}\,p_{H\rho}\,p_{0\sigma}\Big) \times \left(\frac{-g_{\beta\mu} + \dfrac{(p_H - p_0)_\beta\,(p_H - p_0)_\mu}{m_Z^2}}{(p_H - p_0)^2 - m_Z^2 + i\,m_Z\Gamma_Z}\right)\left[\overline{u}(p_-)\,\gamma^\mu\left(c_V^\tau - c_A^\tau\gamma^5\right)v(p_+)\right], \tag{3.3b}$$

$$\mathcal{M}_{\tau\tau\gamma}^{(\gamma\gamma)} = -\frac{e}{v}\,\epsilon_\alpha^*(p_0)\Big(A_2^{\gamma\gamma}\left[(p_H - p_0)^\alpha\; p_0^\beta - (p_H\cdot p_0)\; g^{\alpha\beta}\right] + A_3^{\gamma\gamma}\,\epsilon^{\alpha\beta\rho\sigma}\,p_{H\rho}\,p_{0\sigma}\Big) \times \left(\frac{-g_{\beta\mu}}{(p_H - p_0)^2}\right)\left[\overline{u}(p_-)\,\gamma^\mu\,v(p_+)\right], \tag{3.3c}$$

with $p_H$, $p_+$, $p_-$ and $p_0$ denoting the 4-momenta of the initial Higgs, the final $\tau^+$, $\tau^-$ and $\gamma$ respectively, $q_\pm = p_\pm + p_0$ denoting the 4-momenta of the propagating $\tau^\pm$, $e$ denoting the

4

From Dibya, we need to know what BR corresponds to each of these terms separately for btau=0 before proceeding.

$$\left|\mathcal{M}_{\tau\tau\gamma}\right|^2 = \left|\mathcal{M}_{\tau\tau\gamma}^{(\mathrm{Yuk})}\right|^2 + \left|\mathcal{M}_{\tau\tau\gamma}^{(Z\gamma)}\right|^2 + \left|\mathcal{M}_{\tau\tau\gamma}^{(\gamma\gamma)}\right|^2 + 2\,\mathrm{Re}\left(\mathcal{M}_{\tau\tau\gamma}^{(\gamma\gamma)}\,\mathcal{M}_{\tau\tau\gamma}^{(Z\gamma)*}\right) + 2\,\mathrm{Re}\left(\mathcal{M}_{\tau\tau\gamma}^{(\mathrm{Yuk})}\,\mathcal{M}_{\tau\tau\gamma}^{(Z\gamma)*}\right) + 2\,\mathrm{Re}\left(\mathcal{M}_{\tau\tau\gamma}^{(\mathrm{Yuk})}\,\mathcal{M}_{\tau\tau\gamma}^{(\gamma\gamma)*}\right),$$

Source of forward-backward asymmetry
Has term linear in $b_\tau$

M Y2 Z2 G2 2GZ

TBR= C *( $|\mathscr{M}_{\tau\tau\gamma}|^2$ ) = [ $\left|\mathscr{M}^{(\mathrm{Yuk})}_{\tau\tau\gamma}\right|^2 + \left|\mathscr{M}^{(Z\gamma)}_{\tau\tau\gamma}\right|^2 + \left|\mathscr{M}^{(\gamma\gamma)}_{\tau\tau\gamma}\right|^2 + 2\,\mathrm{Re}\left(\mathscr{M}^{(\gamma\gamma)}_{\tau\tau\gamma}\,\mathscr{M}^{(Z\gamma)*}_{\tau\tau\gamma}\right) + 2\,\mathrm{Re}\left(\mathscr{M}^{(\mathrm{Yuk})}_{\tau\tau\gamma}\,\mathscr{M}^{(Z\gamma)*}_{\tau\tau\gamma}\right) + 2\,\mathrm{Re}\left(\mathscr{M}^{(\mathrm{Yuk})}_{\tau\tau\gamma}\,\mathscr{M}^{(\gamma\gamma)*}_{\tau\tau\gamma}\right)$ ]* C= 3.6* 10**(-3)

2YZ 2YG

$$\frac{(Y^2+Z^2+G^2+2\,GZ+2\,YZ+2\,YG)}{M}=1$$

$$\frac{Z^2}{M}=\frac{4.6*10^{-5}}{3.6*10^{-3}}=1.3*10^{-2}, \quad \frac{G^2}{M}\sim\frac{1.0*10^{-4}}{3.6*10^{-3}}\sim 3*10^{-2} \quad \rightarrow \frac{2\,GZ}{M}\sim 4*10^{-2}$$

$$\frac{(Y^2+2\,YZ+2\,YG)}{M}=0.9$$

Say : $\frac{Y^2}{M}=0.5$

$$\rightarrow \frac{Y^2 Z^2}{M^2}=0.65*10^{-2} \rightarrow \frac{Y^2*G^2}{M^2}=2*10^{-2} \quad \rightarrow YZ/M=0.8*10^{-1} \;,\; YG/M=1.4*10^{-1}$$

$$\frac{(2\,YZ+2\,YG)}{M}\sim 0.44 \quad \textit{should be } 0.40 \textit{ but not so bad.}$$

We get that the resonant part $\frac{(Z^2+2\,YZ)}{M}=1.7*10^{-1}$

is around 17% of the whole amplitude, in contradiction with Dibya result presented as such.
We are using here Dibya result for the total.
Of course this is a simplification “averaging” the real and imaginary parts of amplitudes.