Production & Decay

On Higgs Physics in photon-photon Collisions

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§ $H \to \gamma\gamma$: QCD & EW

§§ $\gamma\gamma \to b\bar{b}$ $(J_z = 0)$

Large Double & Single QCD Logarithms resummation !

§§§ DL in $H \to \gamma\gamma$

+ Akhoury, Melnikov, Kotsky, Wang

The talk is based on papers

1) <u>K. Melnikov + O. Yakovlev</u>
" $H \to \gamma\gamma$: 2-loop QCD " , PLB

2) <u>K. Melnikov + O. Yakovlev</u> , PRD
" $H \to \gamma\gamma$: $\mathcal{O}(G_F m_H^2)$ rad corr. "

3) <u>M. Kotsky + O. Yakovlev</u> PLB ('98)
" On Double Log resumm. in $H \to \gamma\gamma$ "

4) <u>R. Akhoury, H. Wang, O. Ya.</u>
" On DL & SL logs in
$\gamma\gamma \to b\bar{b}$ ($J_z = 0$) " (soon)
to be publ.

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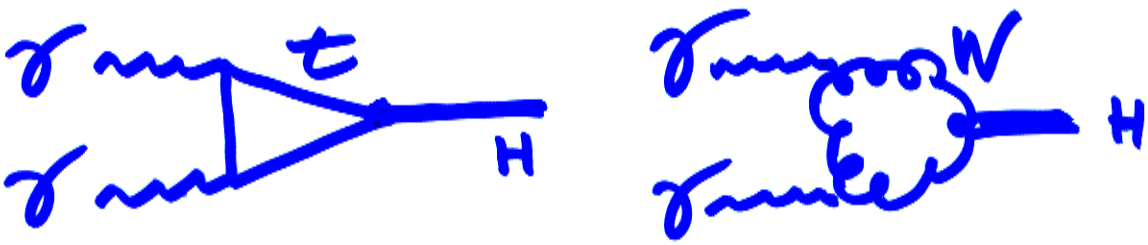
* see also indep. analysis
by Melles, Stirling on DL in $\gamma\gamma \to q\bar{q}$

The photon mode of LC extremely important tool for study Higgs physics.

The production goes



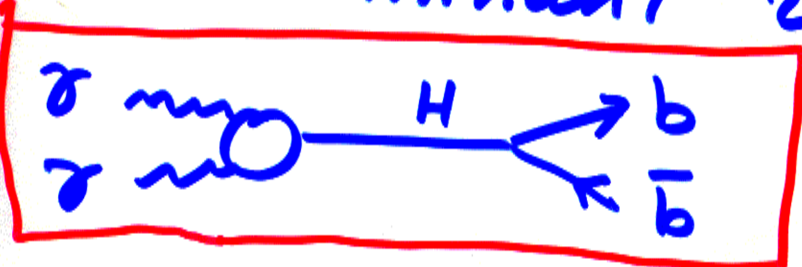
The First question:

How large are
1) QCD 2-loops ?
2) EW 2-loops ?

* That is important because of $H \to \gamma\gamma$ can be a counter of new heavy particles! $m_X > \sqrt{s}$, $m_X \gg \sqrt{s}$

I will give an answer to 2 questions.

The second question:
for intermediate-mass Higgs
the dominant reaction



How large is a background?

$J_z=0$

$\sim \frac{m}{\sqrt{s}}$ $(J_z=0)$

More specifically:
there are large QCD logarithms
How to resum them?

$$\sum_n \left[\alpha_s \ln^2(S/m_b)\right]^n \cdot a_n \qquad \text{D.L.}$$

$a_n - ?$

$$+ \left[\alpha_s \ln(S/m_b)\right]^k b_n \qquad b_n - ?$$

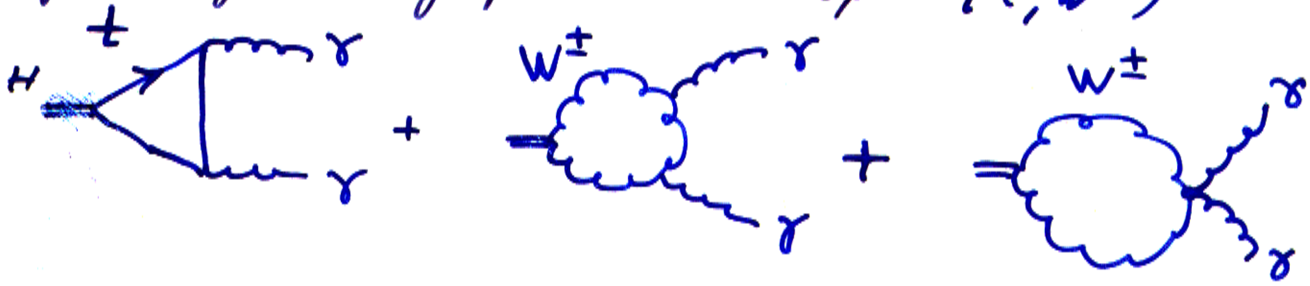
Single Logs

§ Born and one-loop levels.

- at the tree levell vertex $H\gamma\gamma$ is absent in SM

$= \emptyset$

- at the one loop level $H\gamma\gamma$ vertex is mediated by charge heavy particle loops $(t, W^{\pm})$



- it is useful to describe $H\gamma\gamma$-vertex with help of effective Lagrangian

$$\mathcal{L}_{eff} = \frac{\alpha}{4\pi V} F_{\mu\nu} F^{\mu\nu} H \cdot \underline{F(s)}$$

Here $F(s)$ is formfactor, it contains all informa[tion] about particles in loop.

- 1-loop contributions

$$\begin{cases} F_t = -2\tau\left(1-(1-\tau)\cdot f(\tau)\right) \\ F_w = 3\tau - 3\tau(\tau-2) f(\tau) + \underline{2} \end{cases}$$

by J. Ellis, Gaillard, Nanopoulos.

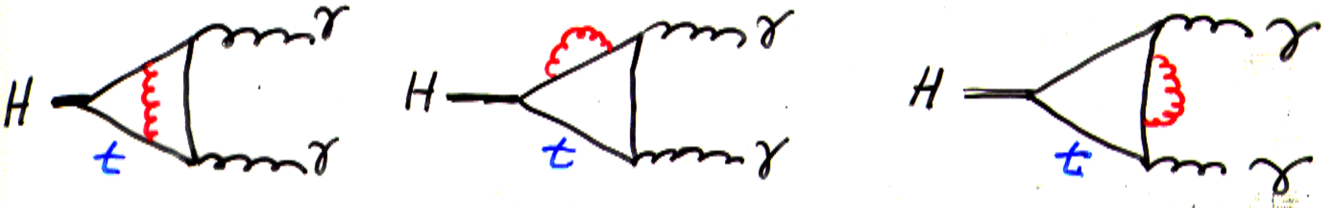
Vainstein
Shifman
Voloshin
Zakharov (1979)

Here $\tau = 4m^2_{t,W}/m_H^2$;

$$f(\tau) = \begin{cases} \arcsin^2\left(\frac{1}{\sqrt{\tau}}\right) & \tau > 1 \\ -\frac{1}{4}\left(\log \frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}} - i\pi\right)^2 & \tau < 1 \end{cases}$$

- it is interesting here at $m_H \sim 600$ GeV top contribution compensates W-contribution.

§ QCD correction to $H \to \gamma\gamma$ decay



Melnikov, O. Yakovlev '95 →

{Zerwas, Spira

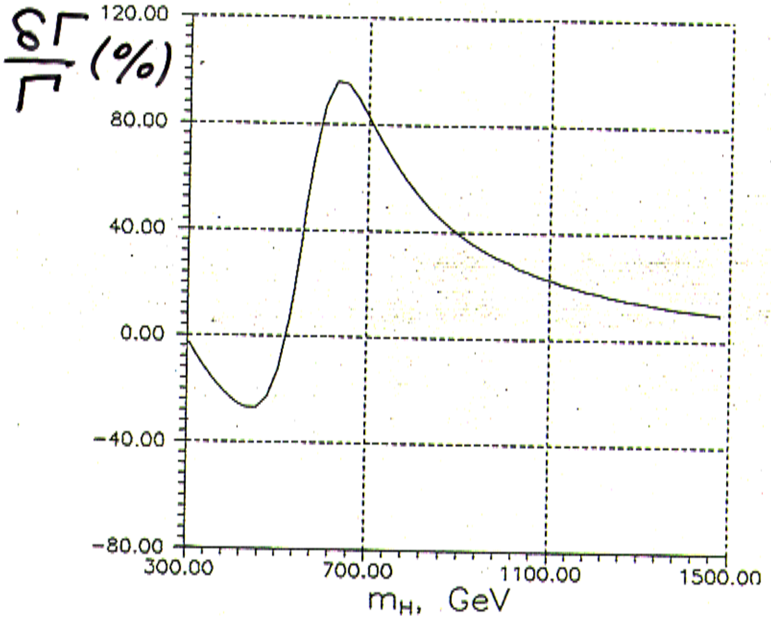


Fig. 6. Radiative correction to the $H\gamma\gamma$ width (%) m_t = 150 GeV.

1. The Correction is small at $s \leq 2m_t$ (1-3%)
   large at $s \geq 2m_t$ (20-80%
2. The compensation of t- and W- loops contribut. in Born amplitude, $m_H \simeq 600$ GeV.
3. ... large corr-n to the Yukawa coupling
   $g_{Ht\bar{t}} = \frac{m_t}{v}$ • can be absorbed in running mass $m(\mu)$
4. Double logarithms at $m_H \gg m_t$

$$F = F^\circ \left(1 - \frac{1}{6}\left(\frac{\alpha_s C_F}{4\pi} \ln^2\left(\frac{m_t^2}{m_H^2}\right)\right) + \ldots\right)$$

Melnikov '95, O. Yakovlev

- NON-SUDAKOV TYPE
- RESUMMATION ??? → YES, IT CAN BE DONE.

$$H \to \gamma\gamma : O(G_F m_H^2)$$

TWO-LOOP EW CORRECTION

- formal $m_H \to \infty$ approximation
- only W-loop contribute: $F_W = 2,\ F_t = 0$
- Equivalence Theorem:
  in the limit $m_H >> m_W$, leading contribution is obtained by replacing the gauge bosons $Z, W^\pm$ by corresponding Goldstone bosons z, w, which can be taken to be massless. (Cornwal et al '74)

We use $U(1)$ gauged σ- model instead of Standard Model:

$$\begin{aligned} L &= -\frac{1}{4}F_{\mu\nu}^2 + (D\omega)(D\omega)^* + \frac{1}{2}(\partial z)^2 - \frac{1}{2}(\partial H)^2 \\ &- \frac{1}{2}M^2H^2 - \frac{M^2}{4v^2}(\pi^2 + H^2)^2 - \frac{M^2}{v}(\pi^2 + H^2)H \end{aligned}$$

here $D = \partial - ieA$ and $\pi = (w^+, w^0, w^-)$ are Goldstones.

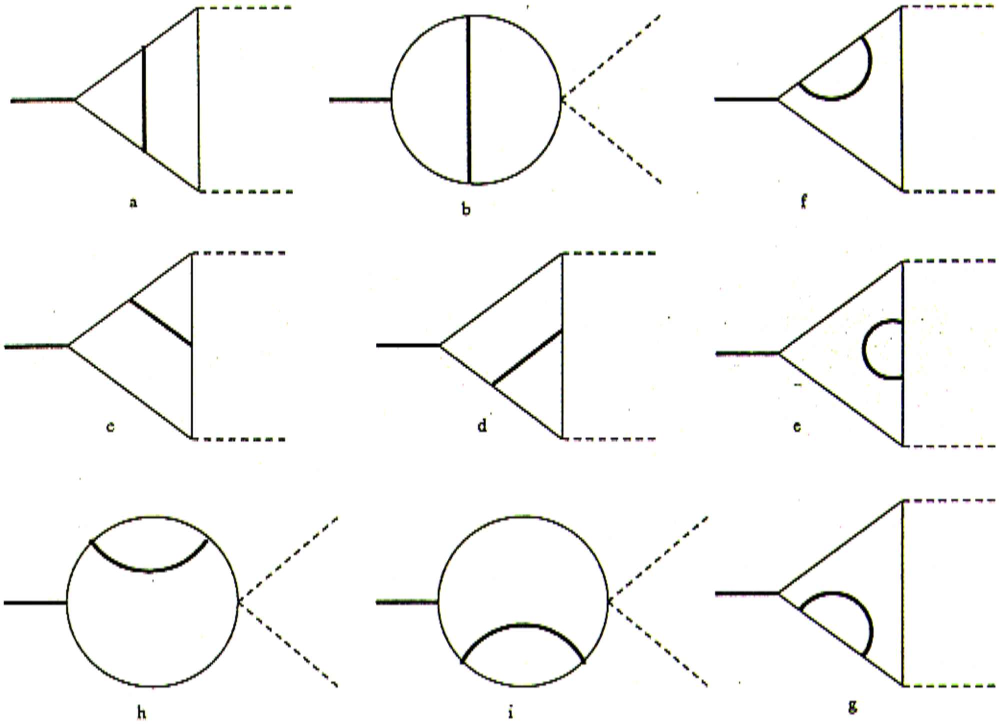


Figure 1: Two loop diagrams, part 1.

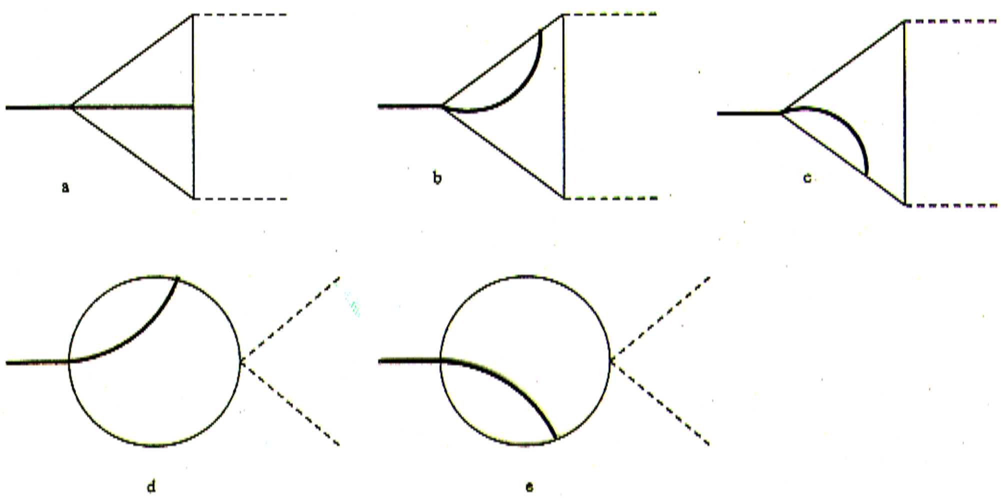


Figure 2: Two loop diagrams, part 2.

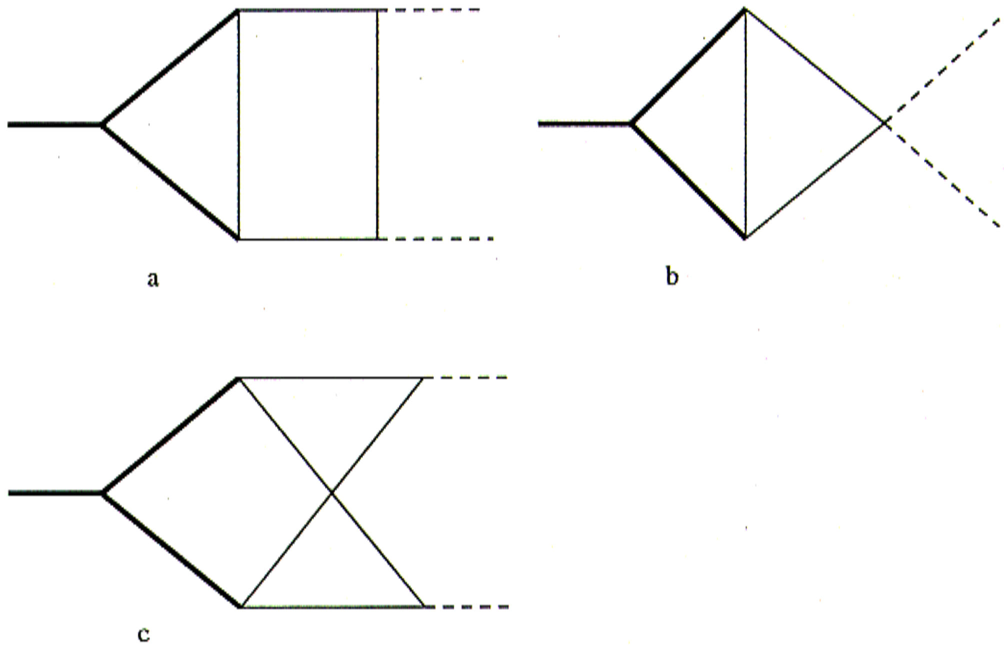


Figure 3: Two loop diagrams, part 3.

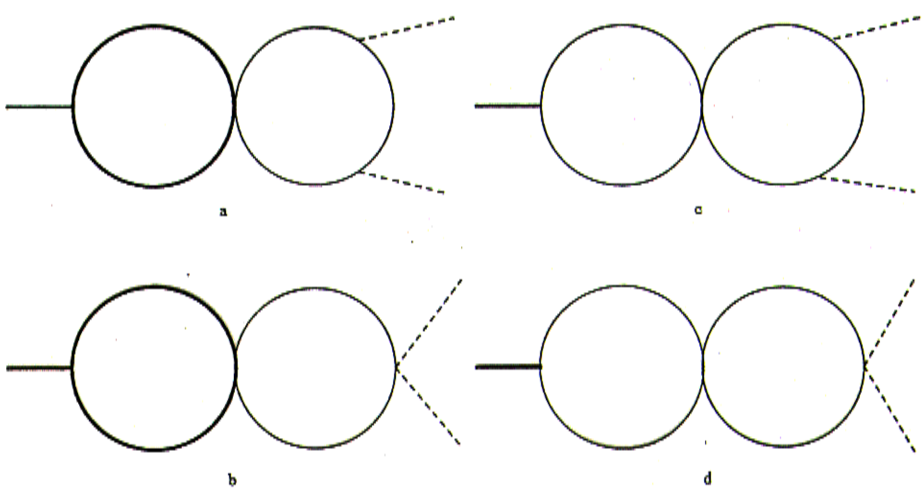


Figure 4: Two loop diagrams, part 4.

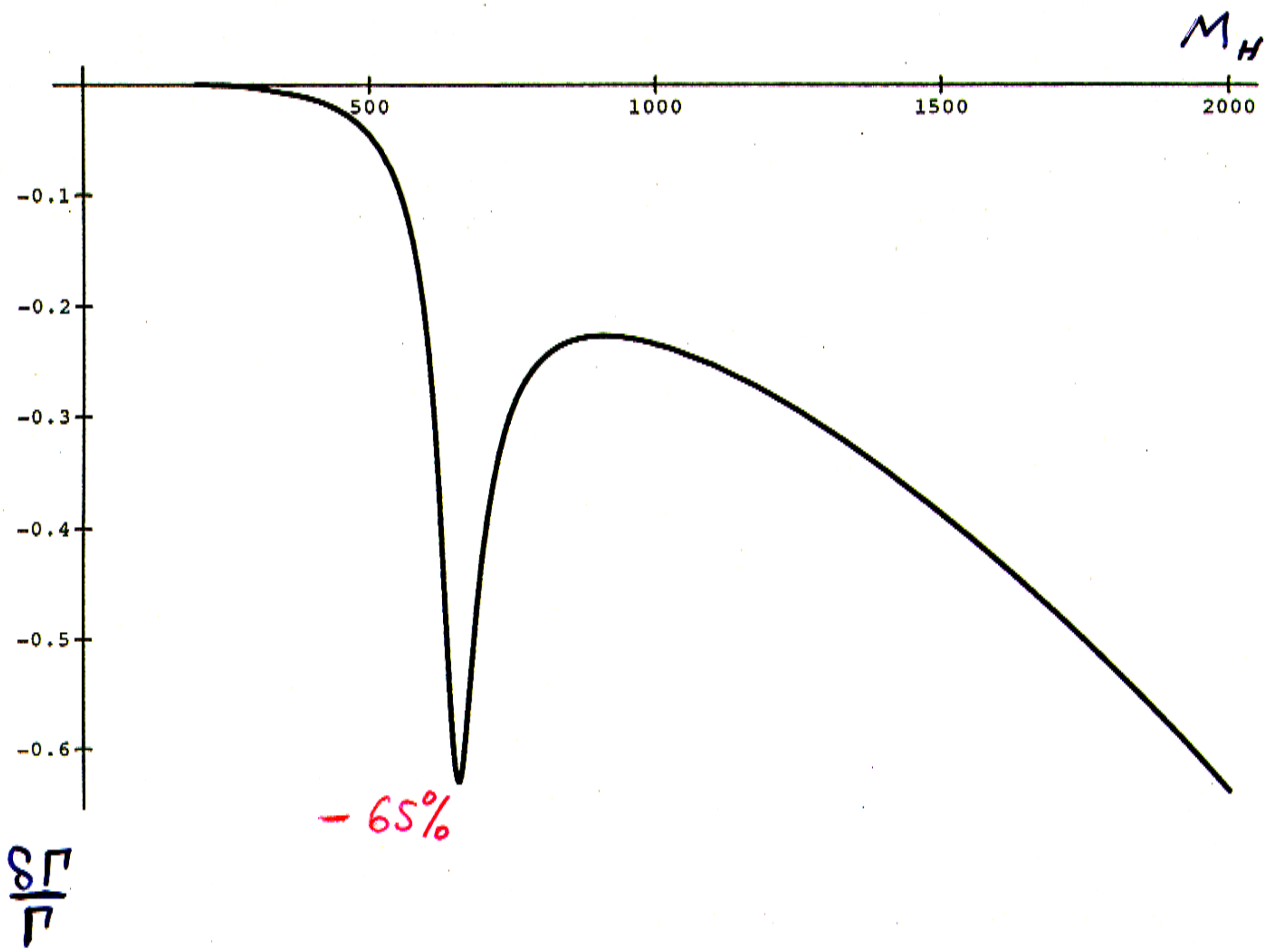


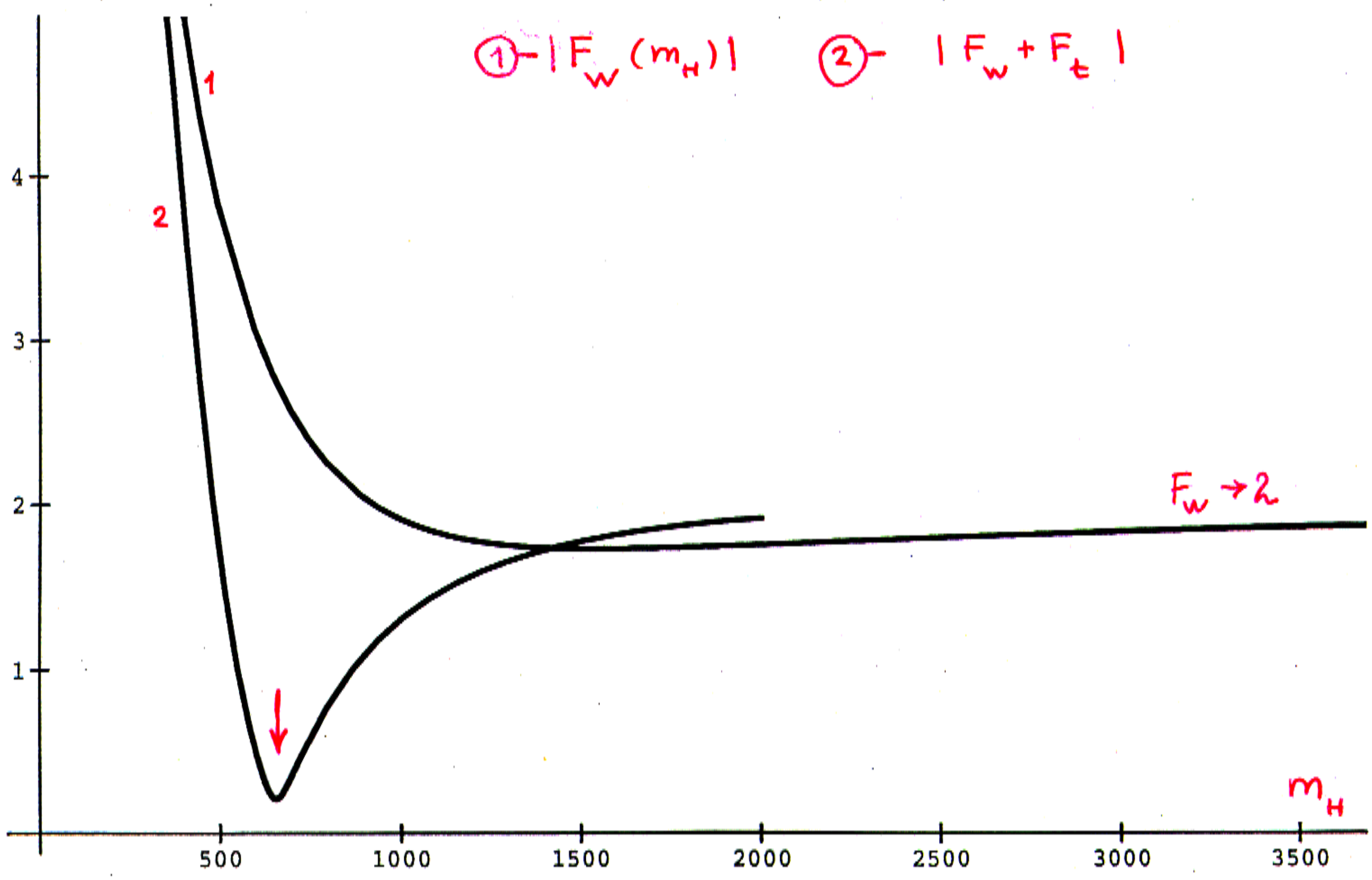
Figure 6: Relative two-loop electroweak correction to the decay width $H \to \gamma\gamma$ as a function of M_H (GeV).

at $m_H \simeq 600$ GeV

- Contributions of **W** and **t** have different signs and tempt to compensate each other (in real and imaginary parts!)

- at $m_H \gg m_W, m_t$

$$F_W = 2 \; ; \; F_t = 0$$

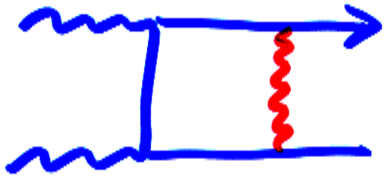


Formfactors F_W, F_t as a function of m_H.

- $\Gamma(H \to \gamma\gamma)$ is suppressed at $m_H \sim 600$ GeV.

Double logarithms in $\gamma\gamma \to b\bar{b}$

* first noticed by G. Jikia '95
  in direct calculations

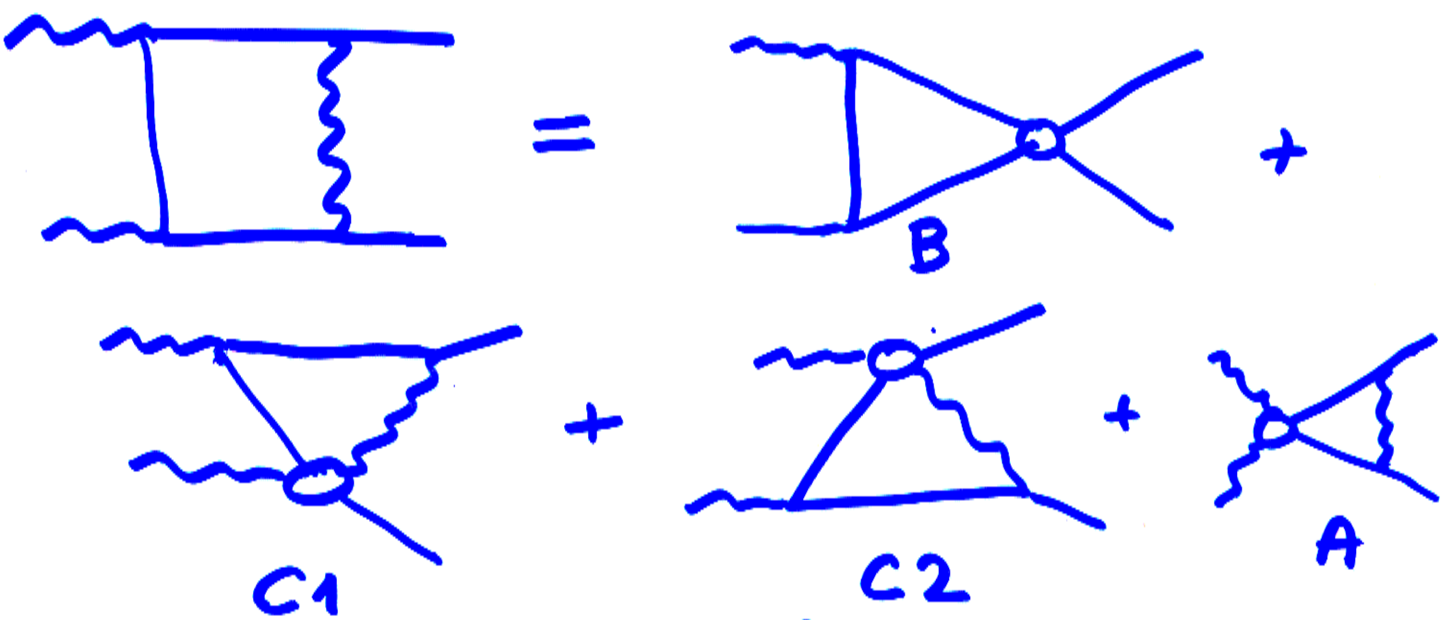


($J_z = 0$) $\alpha_s \ln^2 s/m_b^2$

100%- important!

* The origin
  understood by {V. Fadin, V. Khoze, A. Martin '96

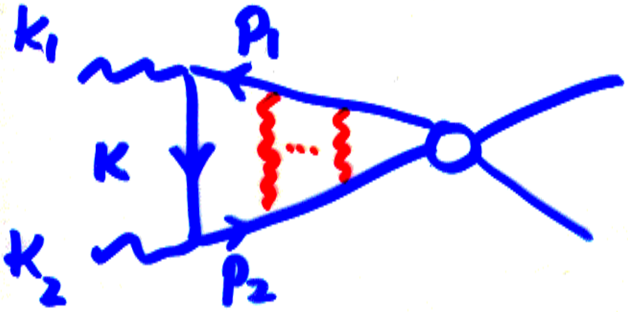
keyword: „triangle topology":

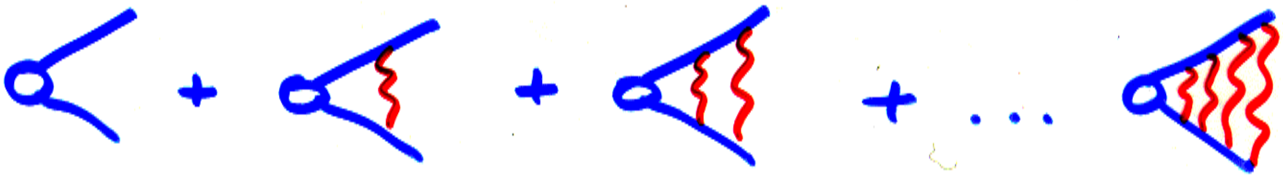


$$M \simeq \underbrace{3 \cdot \alpha_s \log^2 \frac{s}{m^2}}_{B+C1+C2} + \underbrace{\alpha_s \ln^2 s/\lambda}_{A}$$

Resummation of DL

Lets focus on the topology B





$$= \rightarrow \; S(p_1^2, p_2^2) = \mathrm{Exp}\left[-\frac{\alpha_s}{2\pi} C_F \ln\frac{s}{p_1^2} \ln\frac{s}{p_2^2}\right]$$

similar to Poggio, Quinn, Carrazone '75

Then, using Sudakov Variables

$$K = \alpha k_1 + \beta k_2 + k_\perp$$

$$k^2 = s\alpha\beta - k_\perp^2$$

$$p_1^2 = (k_1 + k)^2 = s\beta$$

$$p_2^2 = (k_2 + k)^2 = s\alpha \qquad x = \frac{m^2}{s}$$

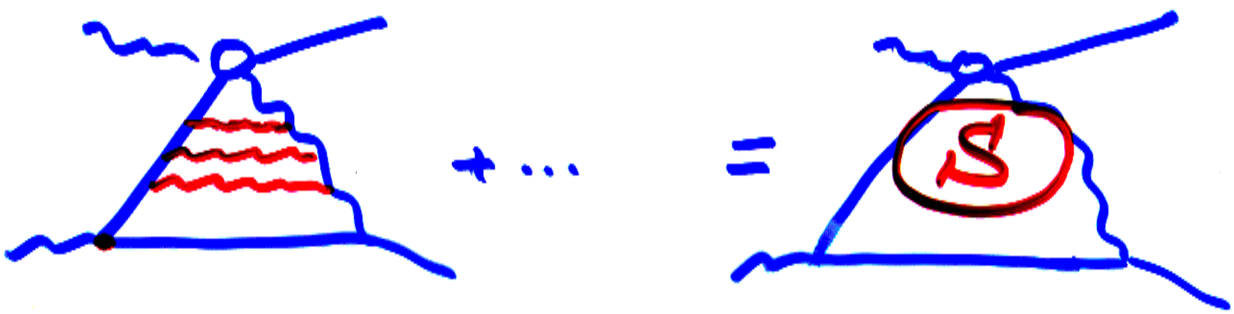
$$M \simeq \int_{-1}^{1}\!\!\int \frac{d\alpha}{\alpha}\frac{d\beta}{\beta}\,\Theta(\alpha\beta - x)\,\mathrm{Exp}\left[-\frac{\alpha_s C_F}{2\pi}\ln\alpha \ln\beta\right]$$

The result : (O.Ya + Kotsky)
(Melles + Stirling)

$$M = M_0 \cdot \sum_{n=0}^{\infty} \frac{2\,\Gamma(n+1)}{\Gamma(2n+3)} (-\rho)^n$$

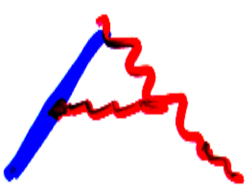
$$\rho = \frac{\alpha_s C_F}{2\pi} \ln^2 s/m^2$$ (show Fig $M(\rho)$)

Next : topology C



$S \equiv$ Sudakov form factor

Color : $C_F \to C_A/2$



$$M_c = M_0^c \cdot \sum_{n=0}^{\infty} \frac{2\,\Gamma(n+1)}{\Gamma(2n+3)} (-\rho_c)$$

$$\rho_c = \frac{C_A \alpha_s}{4\pi} \ln^2 s/m^2 \ !$$

Next-to-Leading Log (NLL) accuracy (result only)

* $M =$  ← QCD dynamics.

* $\begin{cases} L = \ln s/m^2 \\ \rho = \dfrac{\alpha_s C_F}{2\pi} L^2 \end{cases}$ * $\begin{cases} \text{take} \\ S_{NLL}(p_1^2, p_2^2) \end{cases}$

* $$\boxed{M = M_{LL}(\rho) + \frac{1}{L} M_{NLL}(\rho)}$$

double log's NLL

we get:

$$\boxed{M_{LL} = M_0 \cdot \sum_{n=0}^{\infty} \frac{2\Gamma(n+1)}{\Gamma(2n+3)} (-\rho)^n} \;!$$

$$\boxed{M_{NLL} = M_0 \cdot \sum_{n=0}^{\infty} \frac{\Gamma(n+1)}{\Gamma(2n+2)} \cdot (-\rho)^n \cdot \left(-3 + \frac{\rho\beta_0}{C_F} \frac{n}{2n+2}\left(\frac{n+2}{2n+3} - \frac{\ln s/\mu^2}{L}\right)\right)}$$

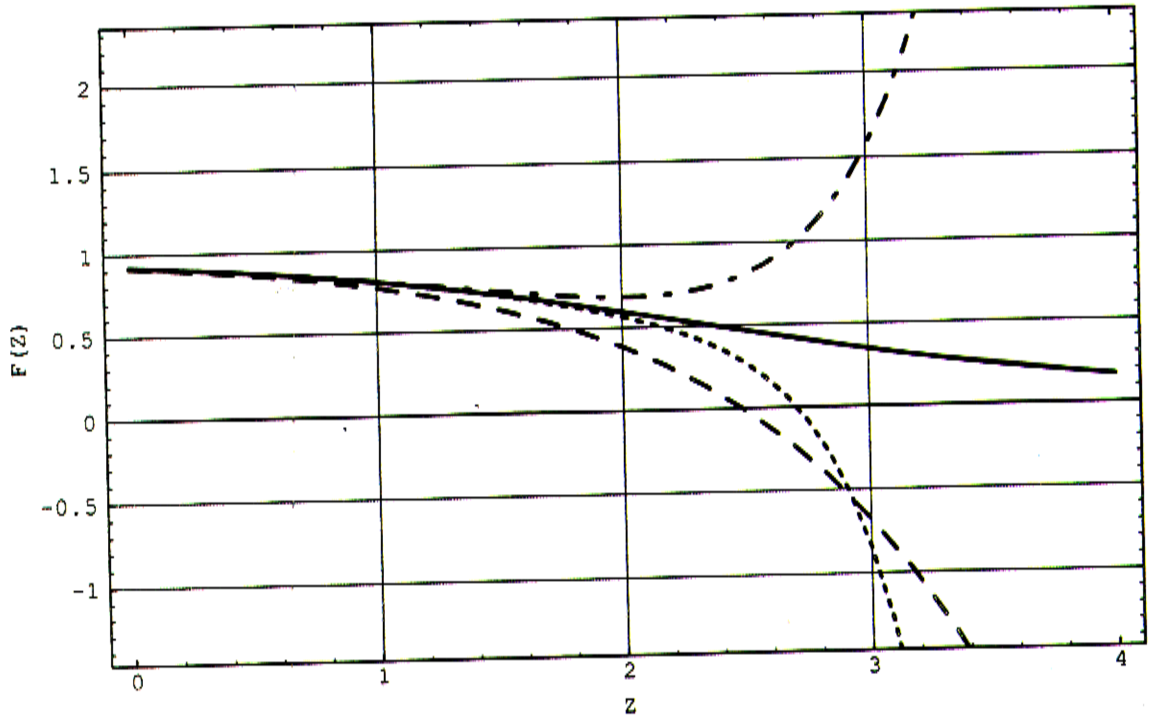
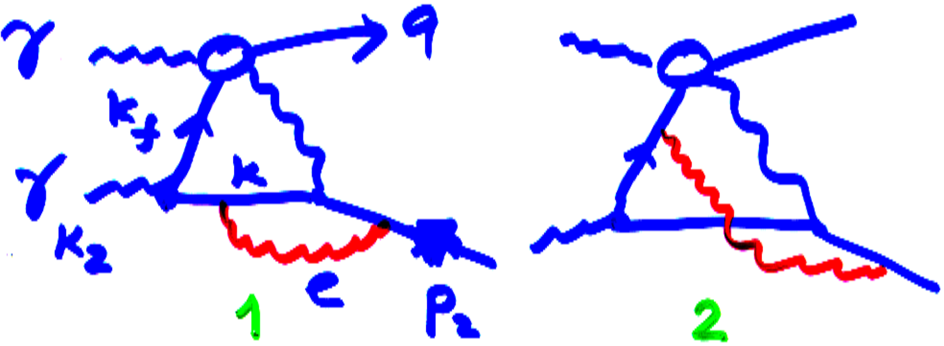


Figure 3: The relative contribution of the two-loop (dashed curve), the three-loop (dashed-dotted curve), the four-loop (dotted curve) and the exact in DLA result for the formfactor (31) (solid curve) as a function of Z. All results are normalized on the one-loop result. The one-loop contribution corresponds to one in such a normalization.

Cancellations

The general mechanism of canc-ns is a „dipole mechanism".

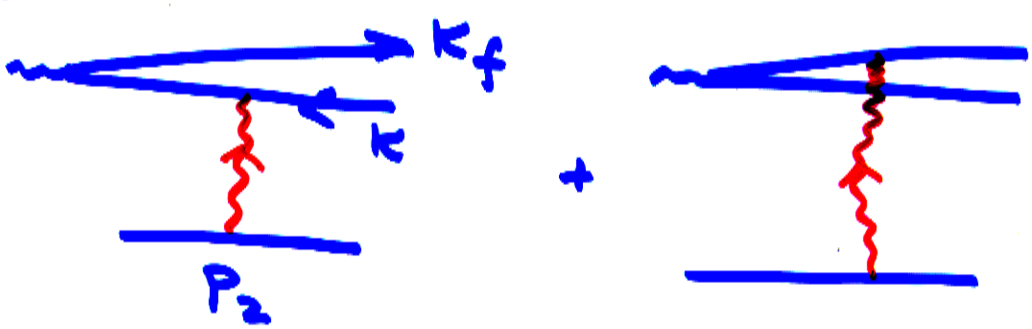
* Simple example



ℓ, k - soft

It could be shown that only region which gives DL : $k \parallel k_f$
(otherwise NO DL in diag. 1)

Then



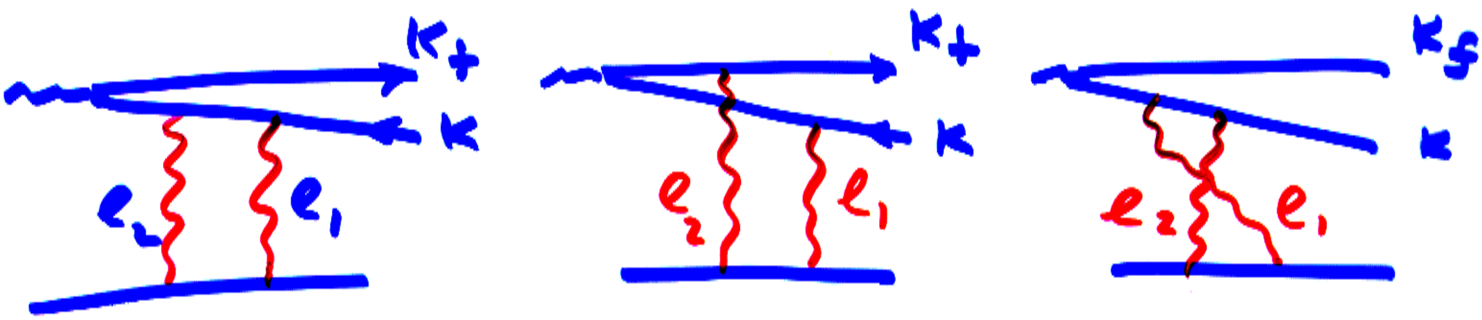
$$\frac{2k^\mu}{2k\ell} \cdot p_2^\mu + \frac{2k_f^\mu}{-2k_f\ell}\, p_2^\mu = 0$$

$$\frac{k^\mu}{k\ell} = \frac{n^\mu}{n\ell} \quad \Rightarrow \qquad n^\mu = \frac{k^\mu}{|k|} \quad n^2 = 1$$

$$\frac{n p_2}{n\ell} - \frac{n p_2}{n\ell} = \emptyset$$

** More complicated example

$k_f \parallel k$



$$\frac{1}{n(\ell_1+\ell_2)}\,\frac{1}{n\ell_1} - \frac{1}{n\ell_1\, n\ell_2} + \frac{1}{n(\ell_1+\ell_2)\, n\ell_2}$$

$$= \emptyset$$

The interaction of collinear $b\bar{b}$ with soft gluons leads to suppression !

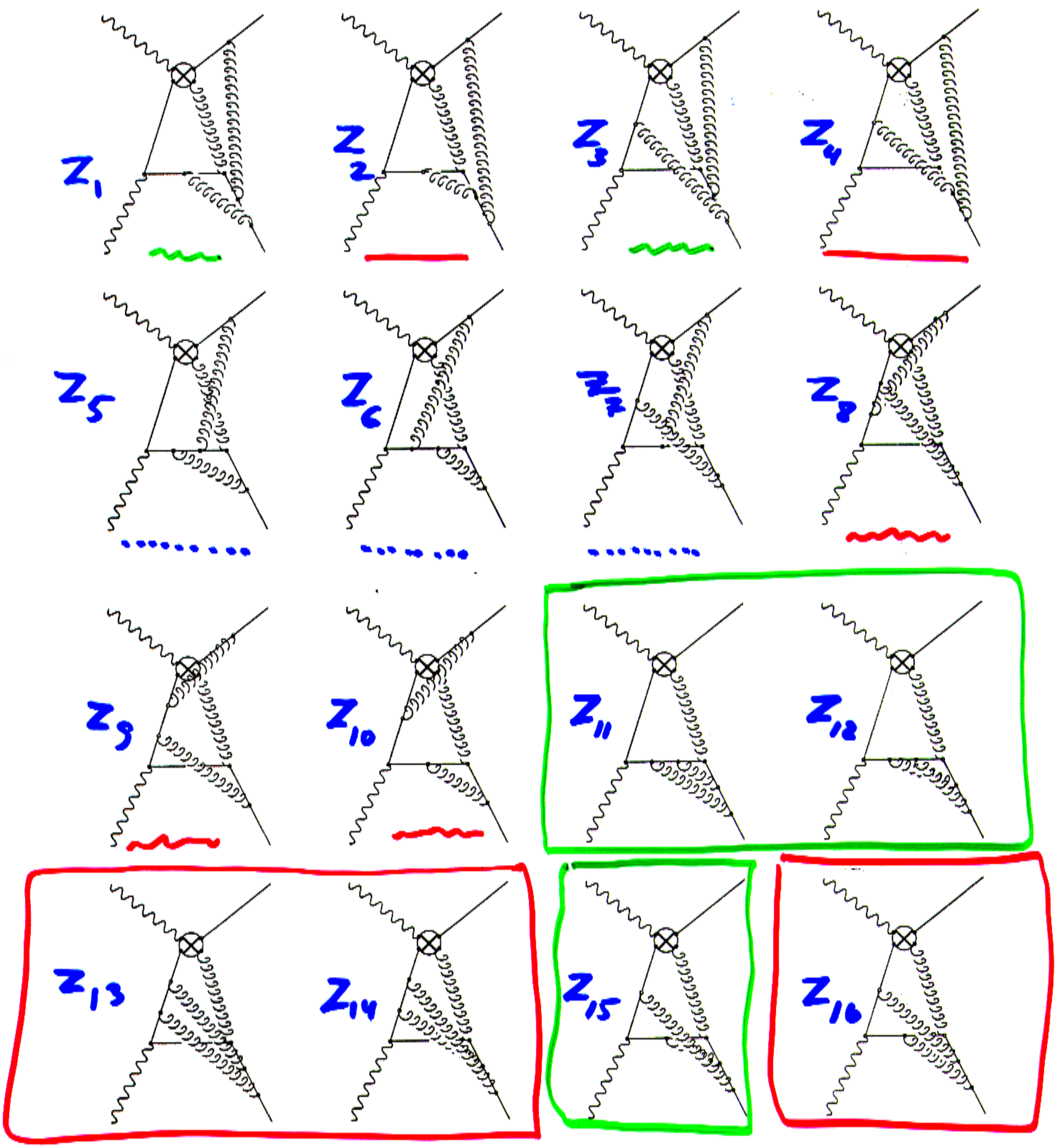


Figure 2: The abelian diagrams of the topology C.

4) $z_1 + z_3 = 0$

3) $z_{10} + z_8 + z_9 = 0$

5) $z_2 + z_4 = 0$

2) $z_{11} + z_{12} + z_{15} = 0$

6) $z_5 + z_6 + z_7 = 0$

1) $z_{13} + z_{14} + z_{16} = 0$

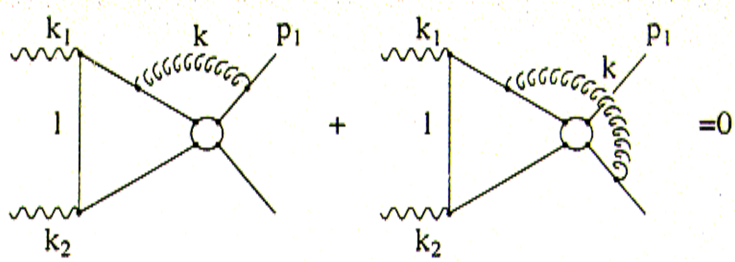


Figure 3: Example of cancellation dictated by dipole mechanism.

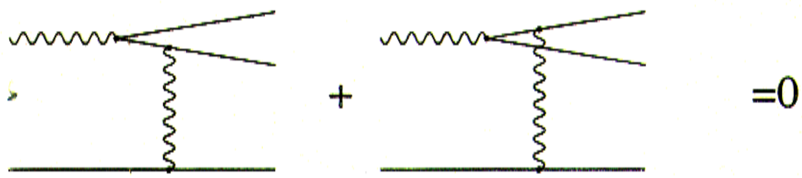


Figure 4: The general mechanism of the DL cancelation in the group 1 and 2 is the dipole interaction of the collinear pir of quarks with one soft gluon.

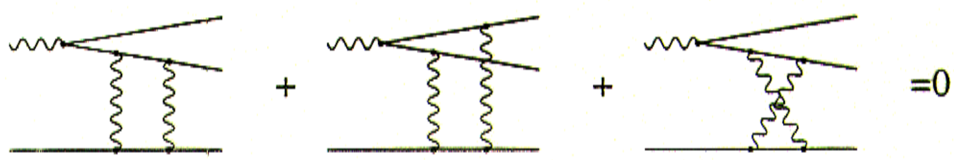


Figure 5: The general mechanism of the DL cancelation in the group 1 and 2 is the dipole interaction of the collinear pir of quarks with two soft gluons.

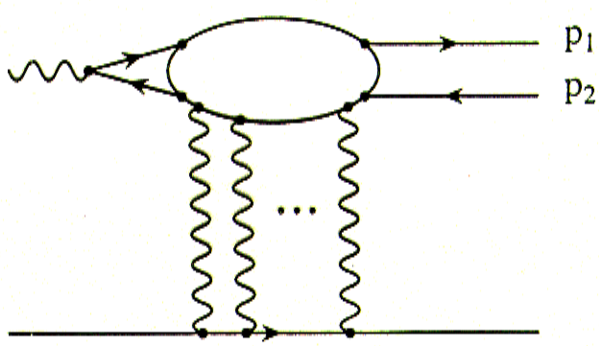


Figure 6: The general mechanism of the DL cancelation in the group 1 and 2 is the dipole interaction of the collinear pir of quarks with many soft gluons.

Conclusions

1) DL and SL have been resummed in a very simple way

2) It has been proven: cancellations of MANY (∞) high order diagrams

3) QCD effects are under control in

a) $\gamma\gamma \to b\bar{b}$ ($J_z = 0$)

b) $H \to \gamma\gamma$ QCD & EW

Thanks to Melnikov, Akhoury, Kotsky, Wang