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Update at 192-202 GeV of the analysis of single photon events with missing energy.

Preliminary

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Abstract

An update of a study of the production of single photon events at $\sqrt{s} = 192 - 202$ GeV has been made with the data collected with the DELPHI detector. The analysis uses an integrated luminosity of 229 pb^{-1}. No excess of events beyond that expected from the Standard Model was observed and limits are set on new physics. A new limit on the gravitational scale is also determined.

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1 Introduction

This paper describes the update of a study of the production of single photon events [1] with 229 pb^{-1} of data collected by DELPHI during 1999 at $\sqrt{s} = 192 - 202$ GeV (average $\sqrt{s}$ =197.6 GeV).

The physics motivations and the procedure to select the events have been discussed in detail in [1]. Several other results have also been published on this topic by DELPHI and other LEP collaborations [2].

2 The single photon selection

The general criteria for the selection of events are based mainly on the three electromagnetic calorimeters (STIC, FEMC and HPC) and the tracking system of the DELPHI detector [3]. The basic selection criteria of events are: no charged tracks detected and no electromagnetic showers apart from the shower from the single photon candidate. Scintillation counters and silicon microvertex detectors are used to veto on charged particles. The details of the selection were described in [1].

The selection of events in the FEMC is not identical to the previous selection since it has been extended to lower photon energies. A sufficient rejection of QED background at these photon energies was obtained by using the scintillator counters [4] mounted on the LEP beampipe and by a new theta-dependent energy cut.

3 Single photon cross section

The energy spectrum ($x_\gamma = E_\gamma/E_{beam}$) of the 540 selected single photon events is shown in Figure 1 together with the expected contributions from known sources. The $\nu\bar{\nu}\gamma$ process was simulated by the KORALZ [5] program and then passed through the extensive detector simulation package of DELPHI [6].

The number of events and cross sections obtained from these event samples after correcting for background and efficiencies are given in Tables 2 and 1. The main source of background is the QED process $e^+e^- \rightarrow e^+e^-\gamma$ [7] where the two electrons escape undetected along the beampipe but also the contribution from other processes such as $\gamma\gamma$ collisions, $e^+e^- \rightarrow \gamma\gamma\gamma$, off-energy electrons [8], cosmic events, $e^+e^- \rightarrow \mu^+\mu^-\gamma$ and $e^+e^- \rightarrow \tau^+\tau^-\gamma$ have been estimated. The contribution from various sources to the systematic error amounts to $\pm 8\%$, $\pm 8\%$ and $\pm 9\%$ for the HPC, FEMC and STIC analysis respectively. The dominant uncertainty comes from the estimation of trigger and detection efficiencies.

Figure 2 shows the expected behaviour of the cross section, for three neutrino families, compared with the values measured with the HPC detector at different LEP energies. The new points at $\sqrt{s} = 192 - 202$ GeV are in a good agreement with the expectation of the Standard Model.

Averaging the three independent measurements done with the three different calorimeters at $\sqrt{s} = 192 - 202$ GeV, $N_\nu = 2.78 \pm 0.13(stat) \pm 0.14(syst)$, with the measurement at 183 and 189 GeV, the number of light neutrino generations becomes:

$$N_\nu = 2.82 \pm 0.09(stat) \pm 0.14(syst)$$

4 Limits on the production of an unknown neutral state

The observed single photon events have been used to set a limit on the production cross section of a new hypothetical particle, X, produced in association with a photon and being stable or decaying to invisible decay products. Limits are calculated from the recoil mass distribution (Figure 3) at $\sqrt{s} = 192 - 202$ GeV of the 428 single γ events in the angular region $12^\circ - 168^\circ$ and the 173 events in the angular region $45^\circ - 135^\circ$ while taking into account the expected background. The limit is valid when the intrinsic width of the X particle is negligible compared to the detector resolution (the recoil mass resolution varies between 10 GeV at the Z^0 peak to 1 GeV at high masses). The upper limit at the 95% confidence level of the cross section for $e^+e^- \rightarrow \gamma$+X is given in Figure 3 for photons in the HPC region and in the FEMC+HPC region. In the latter case an assumption of an ISR-like photon angular distribution has been made to correct for losses between the calorimeters.

5 Limits on the production of gravitons

If there are extra compact dimensions of space in which only gravity can propagate, gravitational interactions could be unified with gauge interactions already at the weak scale [9, 10]. The consequence of this model is that at LEP gravity could manifest itself by the production of gravitons (G), which themselves would be undetectable by the experiments. Instead single photons from the $e^+e^- \rightarrow \gamma G$ reaction are observable.

In these gravitational models, a fundamental mass scale, M_D, is introduced, which is related to the gravitational constant, the size of the compactified space and the number of dimensions, n, in addition to the usual 4 dimensional space. The differential cross-section for the $e^+e^- \rightarrow \gamma G$ process has been calculated by [10].

After the sensitivity had been optimised for each calorimeter, the single photon sample at $\sqrt{s} = 196 - 202$ GeV consisted of 51 events with a photon in the HPC with $6 < E_\gamma < 50$ GeV and 73 events with a photon in the FEMC with $10 < E_\gamma < 50$ GeV. The numbers of events expected in the Standard Model were 63.1 and 72.7 for the two calorimeters respectively. A cross-section limit of

$$\sigma < 0.17 \text{ pb} \quad \text{at 95\% C.L.} \tag{1}$$

results in limits on the fundamental mass scale of $M_D > 1.25$ TeV and $M_D > 0.79$ TeV for 2 and 4 extra dimensions (Figure 4).

6 Limits on compositeness

The model used in this analysis [11] considers leptons, quarks and weak bosons as composite particles. Some of the predicted new particles contribute to the cross section of the process $e^+e^- \rightarrow \gamma + \textit{invisible particles}$. Calculating the cross sections with the hypothesis that a composite boson exists with mass between $m_D = 5 \cdot m_{Z^0}$ and $m_D = 7 \cdot m_{Z^0}$ and summing the contributions to the cross sections coming from direct production of $U^0\bar{U}^0$ pairs and the exchange of $U^\pm$, a limit can be obtained on m_U from the measured

$\sigma(e^+e^- \to \gamma + inv.)$ after subtracting the contribution expected from neutrino production in the Standard Model.

The cross section limit obtained at $\sqrt{s} = 196 - 202$ GeV from the FEMC and the HPC data is the same as in the graviton analysis ($\sigma < 0.17$ pb) and this limit translates into a limit on the mass of the U boson which ranges between

$$m_U > 78 - 87 \text{ GeV/c}^2 \quad \text{at 95\% C.L.}$$

varying m_D in the range indicated above.

7 SUSY particles

7.1 Limits on the gravitino mass

The cross section for the process $e^+e^- \to \tilde{G}\tilde{G}\gamma$ has been computed under the assumption that all other supersymmetric particles are too heavy to be produced [12] and lower limits on the mass of such a light gravitino has been extracted previously at LEP [1, 13]. The largest sensitivity is obtained with photons at low energy and/or low polar angle. Since the signal cross section grows as the sixth power of the center-of-mass energy, the highest sensitivity is also found at the highest available beam energy.

Combining the data at $\sqrt{s} = 196 - 202$ GeV from the FEMC and the HPC, the same limit of $\sigma < 0.17$ pb at 95% C.L. was obtained as in the graviton analysis. This corresponds to a lower limit on the gravitino mass which is

$$m_{\tilde{G}} > 10.0 \cdot 10^{-6} \text{ eV/c}^2 \quad \text{at 95\% C.L.}$$

Since the supersymmetry-breaking scale $|F|^{\frac{1}{2}}$ is related to the gravitino mass by $|F| = \sqrt{\frac{3}{8\pi}/G_N} \cdot m_{\tilde{G}}$, the limit on this scale is $|F|^{\frac{1}{2}} > 205$ GeV.

8 Conclusions

With the 229 pb^{-1} of data collected by DELPHI in 1999 at a center-of-mass energy of 192-202 GeV, an update of the analysis of single and photon events with missing energy has been made.

The measured single photon cross section is in agreement with the expectations from the Standard Model process $e^+e^- \to \nu\bar{\nu}\gamma$.

The absence of an excess of events has been used to set limits on the production of a new unknown model-independent neutral state, a W-type U-boson as described by a compositeness model, a light gravitino and neutralinos. A new limit on the gravitational scale is also determined.

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	HPC	FEMC	STIC
$\sqrt{s}$:	192-202 GeV	192-202 GeV	192-202 GeV
θ_γ:	$45^\circ - 135^\circ$	$12^\circ - 32^\circ$, $148^\circ - 168^\circ$	$3.8^\circ - 8.0^\circ$, $172^\circ - 176.2^\circ$
x_γ:	> 0.06	> 0.1	> 0.3
$N_{observed}$:	173	255	112
$N_{background}$:	0.5	23.8	3.6
$N_{e^+e^-\to\nu\bar{\nu}\gamma}$:	172	229	120

Table 1: Number of selected and expected single photon events in the 1999 DELPHI data.

		191.6 GeV	195.5 GeV	199.5 GeV	201.5 GeV
		26.3 pb^{-1}	77.5 pb^{-1}	84.6 pb^{-1}	40.8 pb^{-1}
STIC	σ_{meas} (pb)	1.32±0.37	1.33±0.22	1.00±0.19	0.75±0.25
$3.8^\circ - 8^\circ$	$\sigma_{\nu\bar{\nu}\gamma(\gamma)}$ (pb)	1.32	1.29	1.22	1.21
$172^\circ - 176.2^\circ$	N_ν	3.01±0.37	3.09±0.51	2.45±0.48	1.87±0.63
FEMC	σ_{meas} (pb)	2.12±0.42	1.73±0.22	2.03±0.23	2.11±0.33
$12^\circ - 32^\circ$	$\sigma_{\nu\bar{\nu}\gamma(\gamma)}$ (pb)	2.14	2.09	1.96	1.97
$148^\circ - 168^\circ$	N_ν	2.97±0.58	2.49±0.32	3.11±0.35	3.22±0.50
HPC	σ_{meas} (pb)	2.13±0.44	1.42±0.21	1.86±0.22	1.61±0.30
$45^\circ - 135^\circ$	$\sigma_{\nu\bar{\nu}\gamma(\gamma)}$ (pb)	1.93	1.83	1.78	1.73
	N_ν	3.31±0.68	2.33±0.34	3.14±0.37	2.79±0.52

Table 2: Measured and calculated cross-section with the three calorimeters for $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$ (KORALZ with three neutrino generations) and the number of neutrino generations calculated from the cross-sections.. The errors are statistical only.

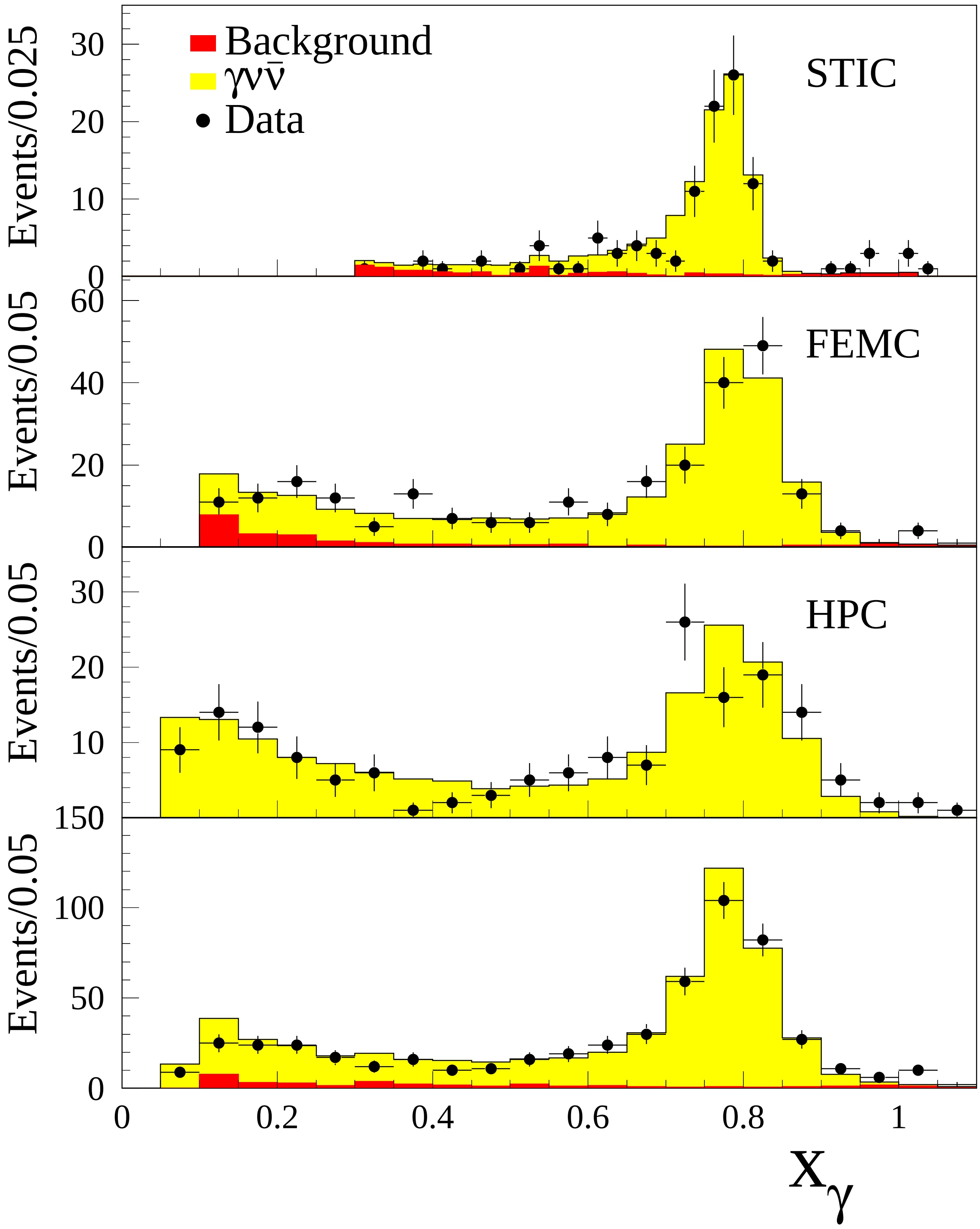

Figure 1: x_γ of selected single photons at 192-202 GeV in the three calorimeters STIC, FEMC and HPC. The bottom plot shows the combined spectrum. The light shaded area is the expected distribution from $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ and the dark shaded area is the total background from other sources.

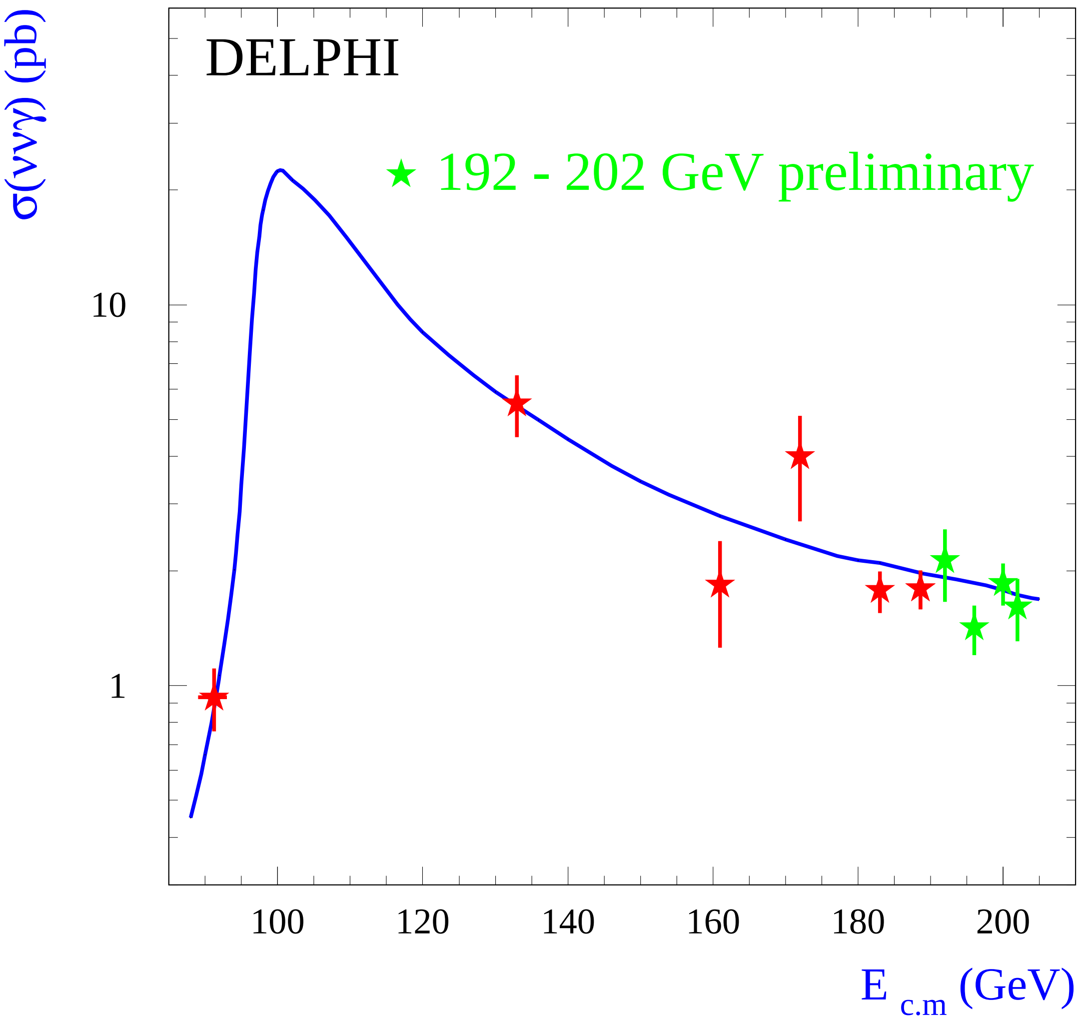

Figure 2: The measured cross-sections in the HPC for E_γ >6 GeV at different $\sqrt{s}$ compared to the expected $\sigma(\nu\bar{\nu}\gamma)$ (for three neutrino generations).

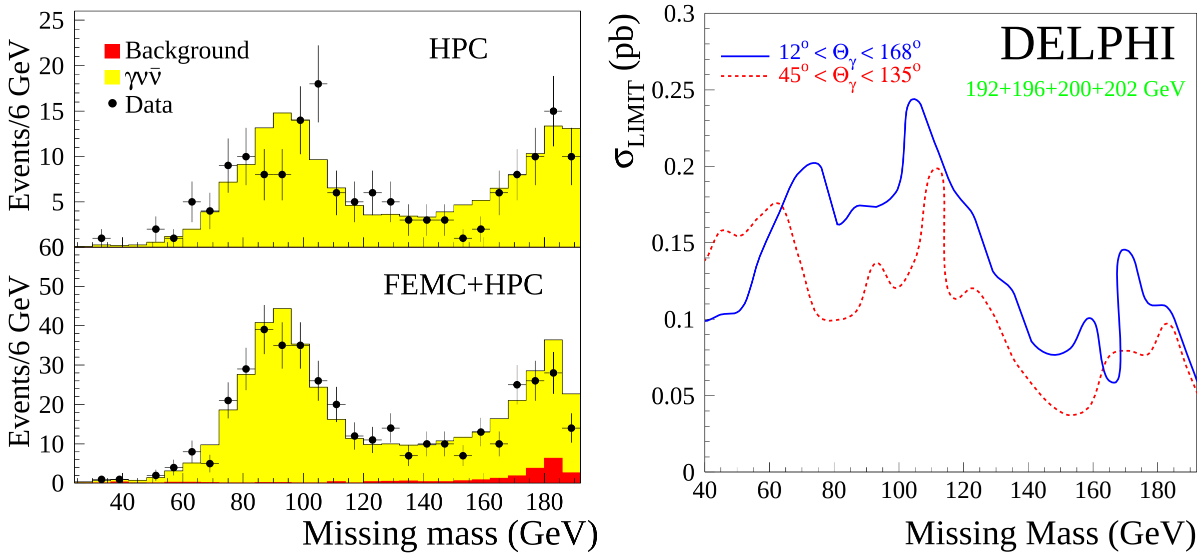

Figure 3: Left: The distributions of the missing mass for the events at 192-202 GeV in the HPC and in the FEMC+HPC. The light shaded area is the expected distribution from $e^+e^- \to \nu\bar{\nu}\gamma$ and the dark shaded area is the total background from other sources. Right: upper limit at 95% C.L. (within the solid angles described) for the production of a new unknown stable neutral object .

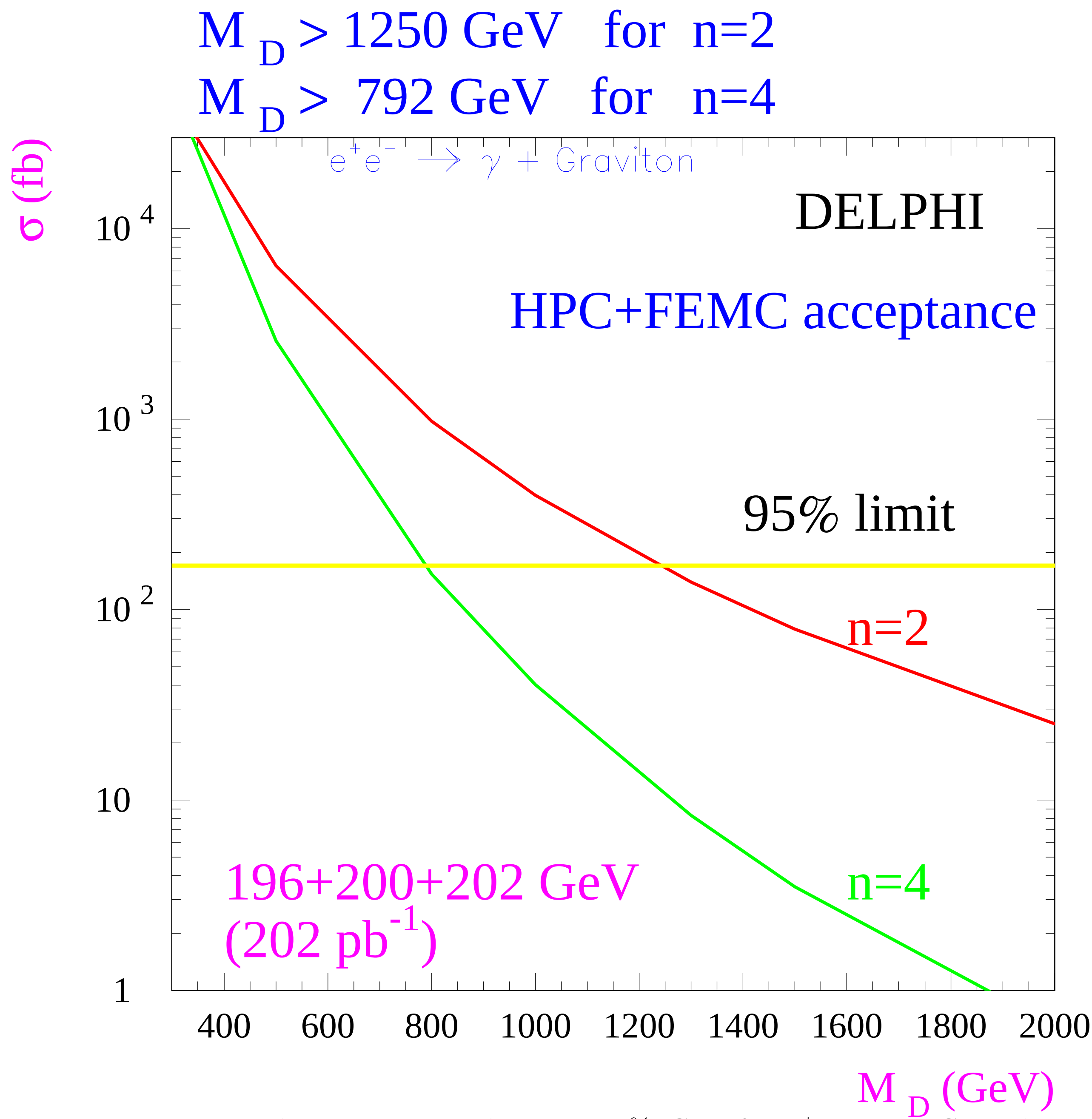

Figure 4: The cross-section limit at 95% C.L. for $e^+e^- \rightarrow \gamma G$ production at $<\sqrt{s}>$=198.4 GeV and the expected cross-section for 2 and 4 extra dimensions.