NLO QCD Corrections to J/ψ Inclusive Production in Photon-Photon Collision

Based on arXiv: 1608.06231

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Outline

Introduction

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- CERN LEPII $\gamma\gamma \to J/\psi + X$ data provide direct evidence for CO mechanism. But the importance of CO mechanism in this process is still being researched.

J/ψ Inclusive Production in Photon-Photon Collision

- Experimental Data
  - LEPII $\gamma\gamma \to J/\psi + X$ Data
- Theoretical Calculations
  - Three Classes of Subprocesses
  - The LO Calculations
  - The NLO Corrections
  - $J/\psi + c\bar{c}$ Final State Subprocess

LEPII $\gamma\gamma \to J/\psi + X$ Data

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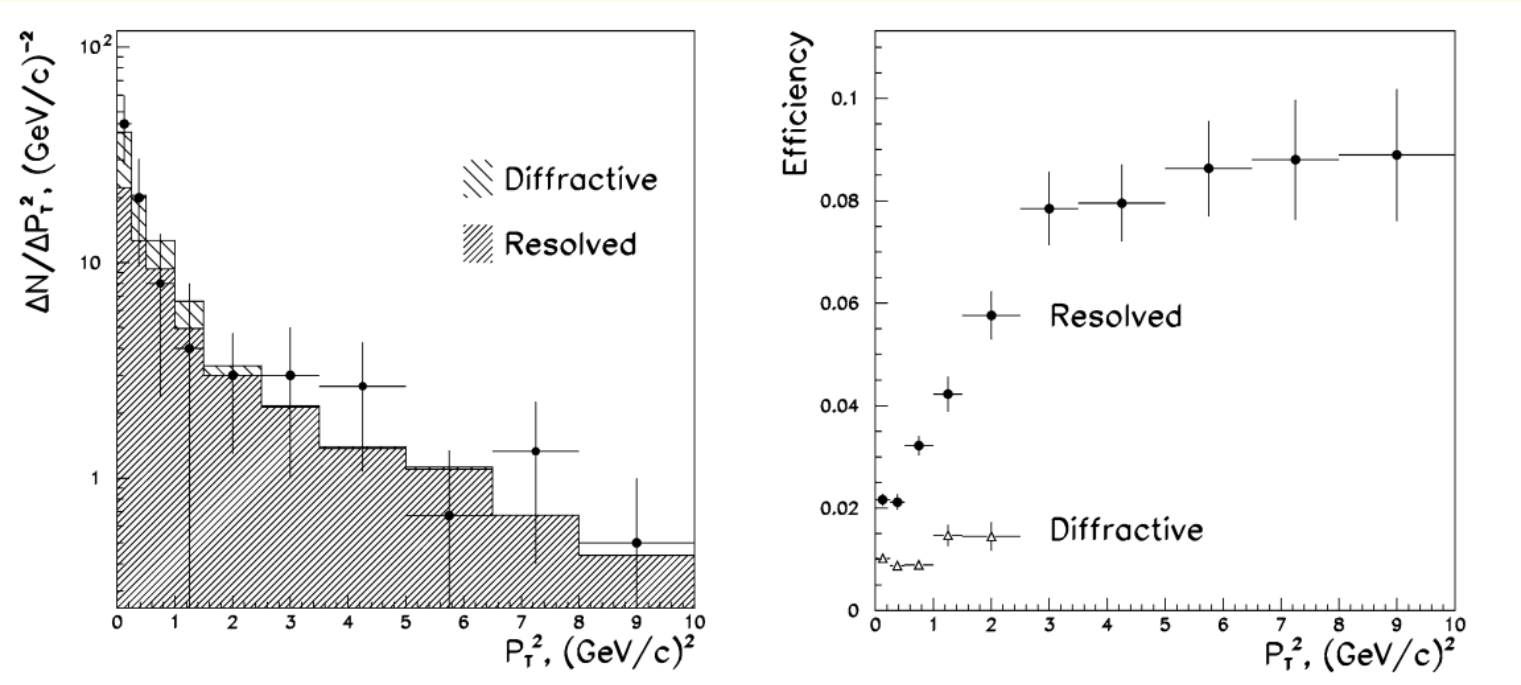

Figure: "DELPHI Collaboration, Phys. Lett. B 565(2003)76-86".

The requirement of at least 4 reconstructed tracks suppress the $J/\psi + \gamma$ final state.

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$$gg \to c\bar{c}\left[{}^3S_1^{(1)}\right] g, c\bar{c}\left[{}^3P_J^{(1)}\right] g, c\bar{c}[8]g,$$
$$gq \to c\bar{c}\left[{}^3P_J^{(1)}\right] q, c\bar{c}[8]q,$$
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- DELPHI $(6.4 \pm 2.0)\text{pb}$
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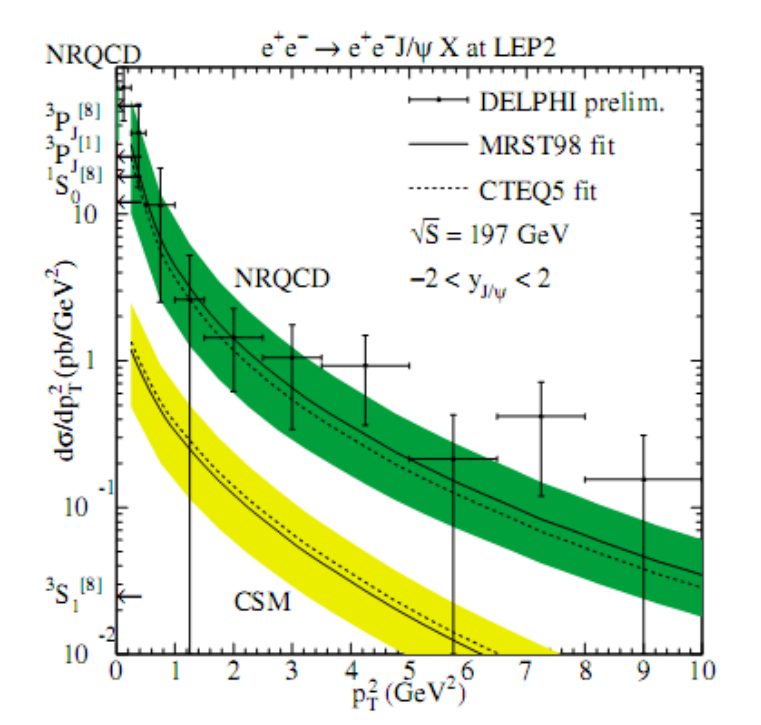

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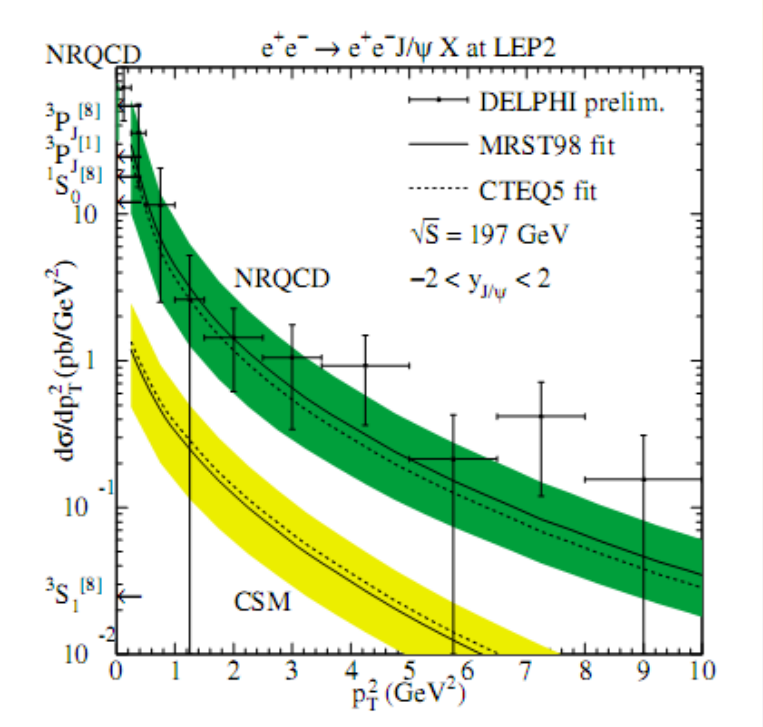

The LO results indicate that DELHPI data are not explainable by the CS model alone, and the CO mechanism is evidently necessary. But investigations on NLO corrections and NLO subprocesses are still needed to clarify the situation.

[1] Michael Klasen *et al.*, Nucl. Phys. B 609 (2001).

[2] Michael Klasen *et al.*, Phys. Rev. Lett. 89, 032001(2002).

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For the single-resolved channel, the NLO corrections in CS model are moderate. But the discrepancy between DELPHI data and CS model prediction is too large to be removed.

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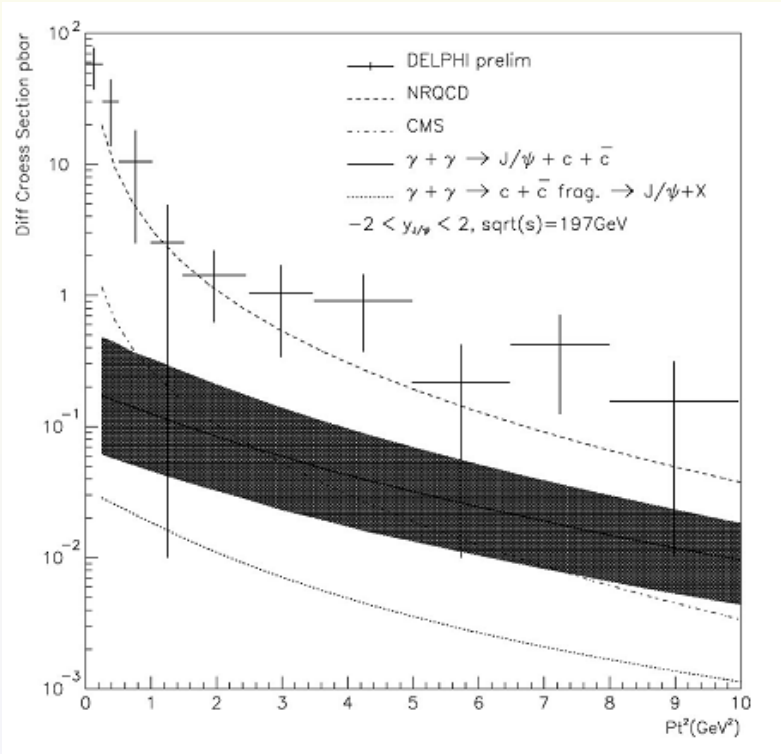
On the other hand, a new process, $J/\psi + c\bar{c}$ final state process is very necessary to be included in the full NLO calculation. And the experimentally distinguishable final state also make this process worth to study.

$J/\psi + c\bar{c}$ Final State Subprocess

C.F. Qiao and J.X. Wang are the first two to notice the importance of $\gamma\gamma \to J/\psi + c\bar{c}$ process[1].

A comparison is also made between pure fragmentation result and full calculation in [1]. It is found that this process cannot be mimicked by simple fragmentation scheme.



After including this process, the CO mechanism is still necessary but with a shrunken contribution to explain the DELPHI experimental result.

[1] C.F. Qiao and J.X. Wang, Phys. Rev. D 69, 014015(2004).

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These researches indicate that the contributions of single-resolved and double-resolved are significantly less important than the direct one with in the CS prescription. The CO mechanism is still needed to explain experimental data.

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To seek further clarification, NLO corrections for these processes, especially for $\gamma\gamma \to J/\psi + c\bar{c}$, are very necessary.

NLO QCD Corrections to $\gamma\gamma \to J/\psi + c\bar{c}$

- Formalism and Calculation
- Numerical Results

Formalism and Calculation

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- The overall differential cross section can be written as

$$d\sigma = \int dx_1 dx_2 f_\gamma(x_1) f_\gamma(x_2) d\hat{\sigma}(\gamma\gamma \to c\bar{c}[^3S_1] + c\bar{c}) \langle \mathcal{O}^{J/\psi}(^3S_1) \rangle$$

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- The quarkonium spin projection operator is

$$v(P/2)\bar{u}(P/2) = \frac{1}{4\sqrt{2}E(E+2m_c)}(\frac{\not{P}}{2} - m_c) \not{\epsilon}_S^*(\not{P} + 2E)(\frac{\not{P}}{2} + m_c)$$

Formalism and Calculation

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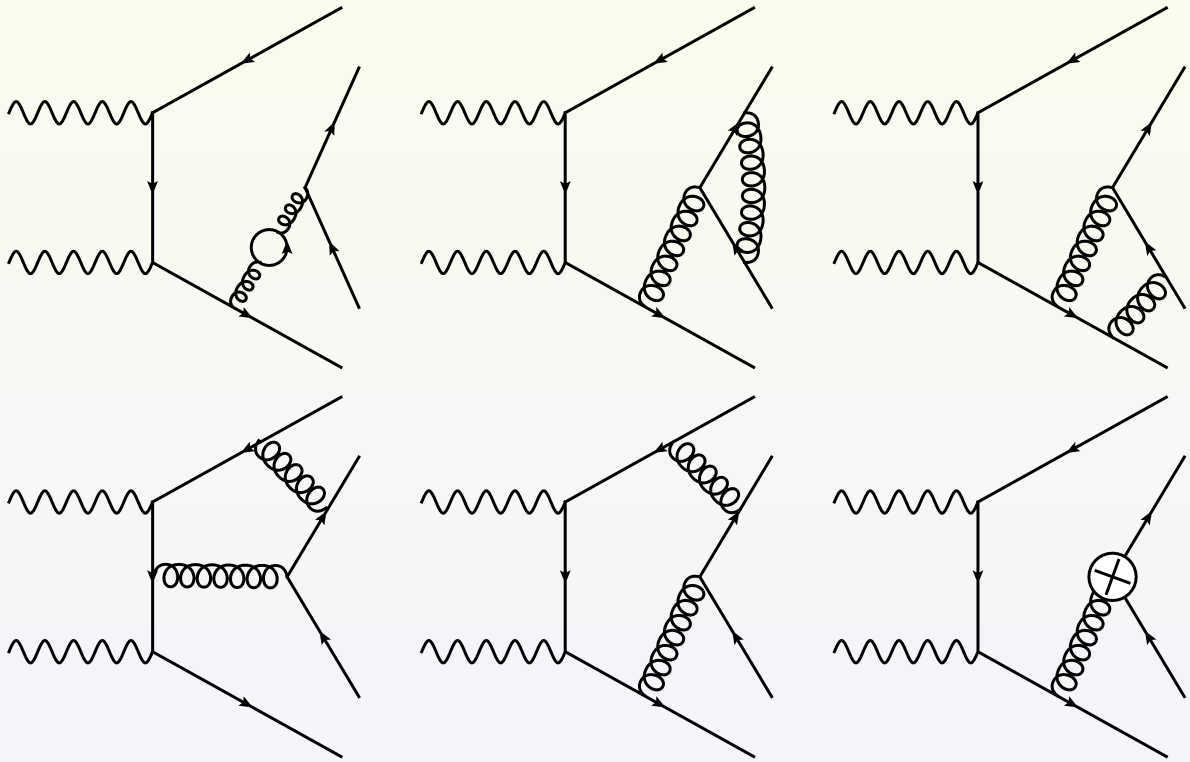
  Selfenergies, Triangles, Boxes, Pentagons, Hexagons and Counter terms



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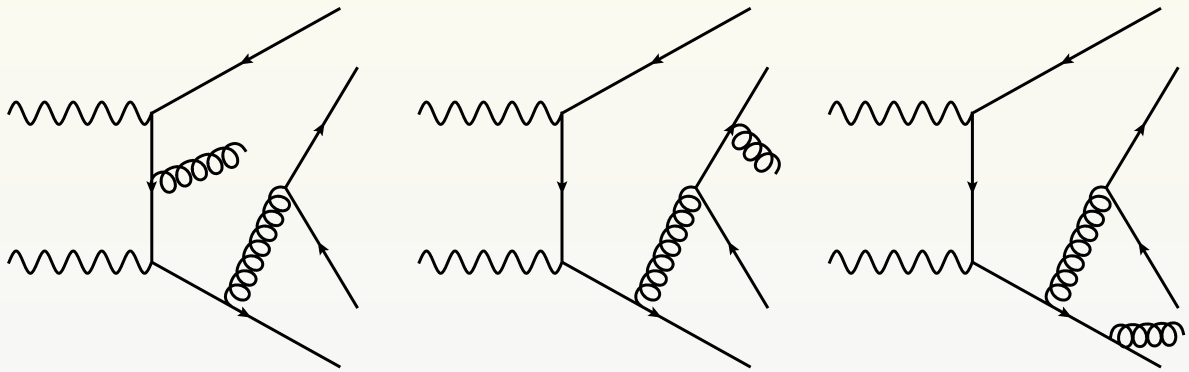
$$\gamma\gamma \to J/\psi + c\bar{c} + g$$



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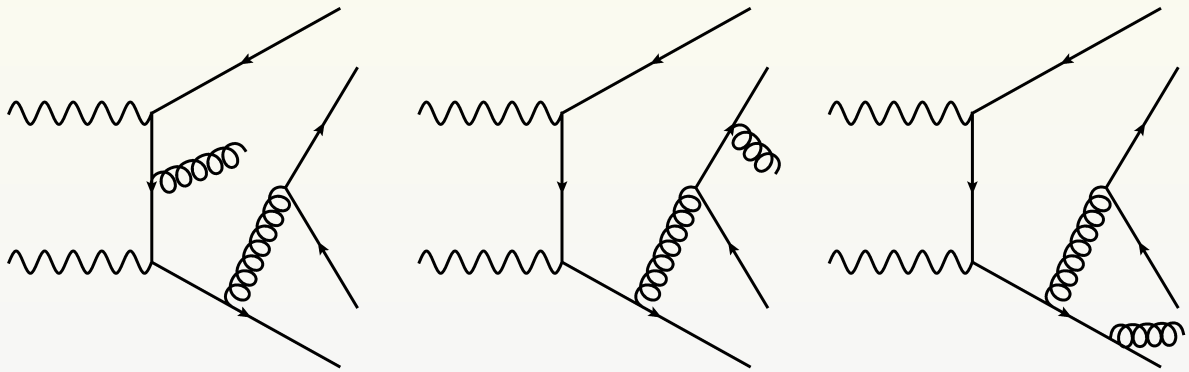

According to B. W. Harris and J. F. Owens, "Two cutoff phase space slicing method", Phys. Rev. D 65, 094032 (2002),

$$d\sigma_{real} = d\sigma^{IR}_{soft}|_{p^0_g<\delta} + d\sigma^{IR-free}_{hard}|_{p^0_g>\delta}$$

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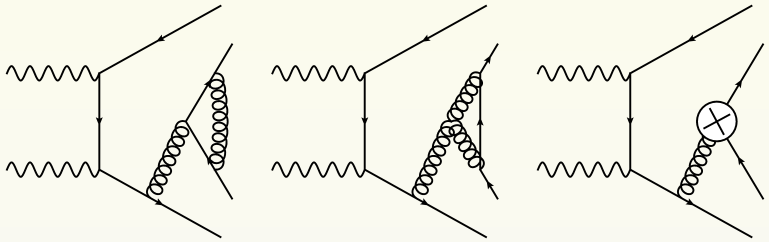

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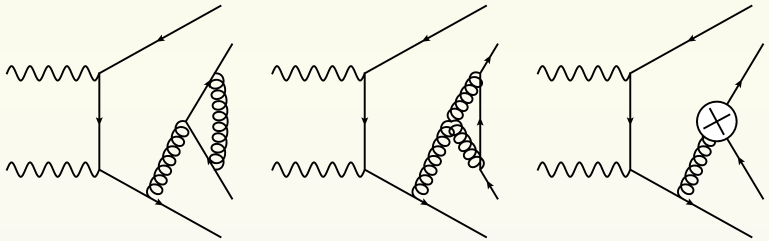
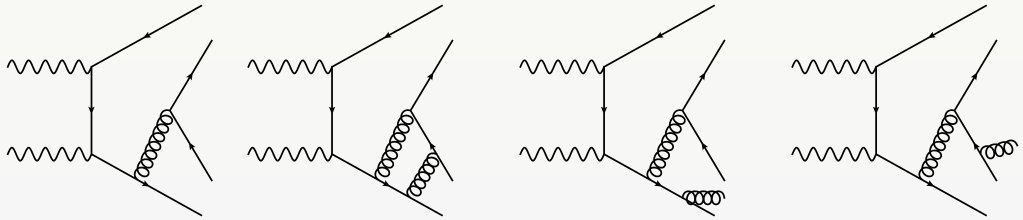


  - ii Infrared singularities involved in virtual corrections and real emissions are canceled each other



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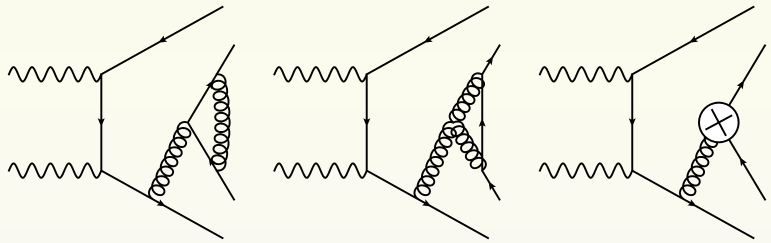

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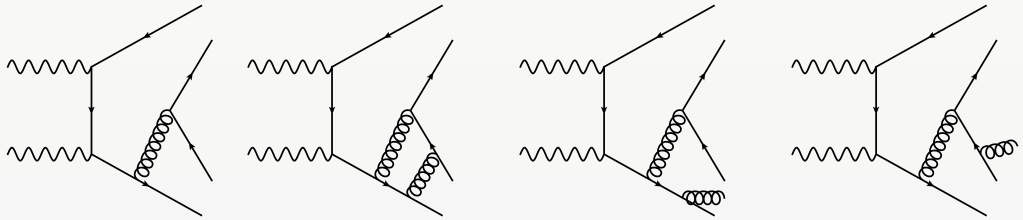
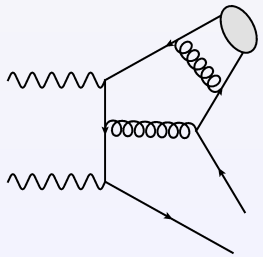


  - iii Coulombic singularities are attributed to NRQCD long-distance matrix elements



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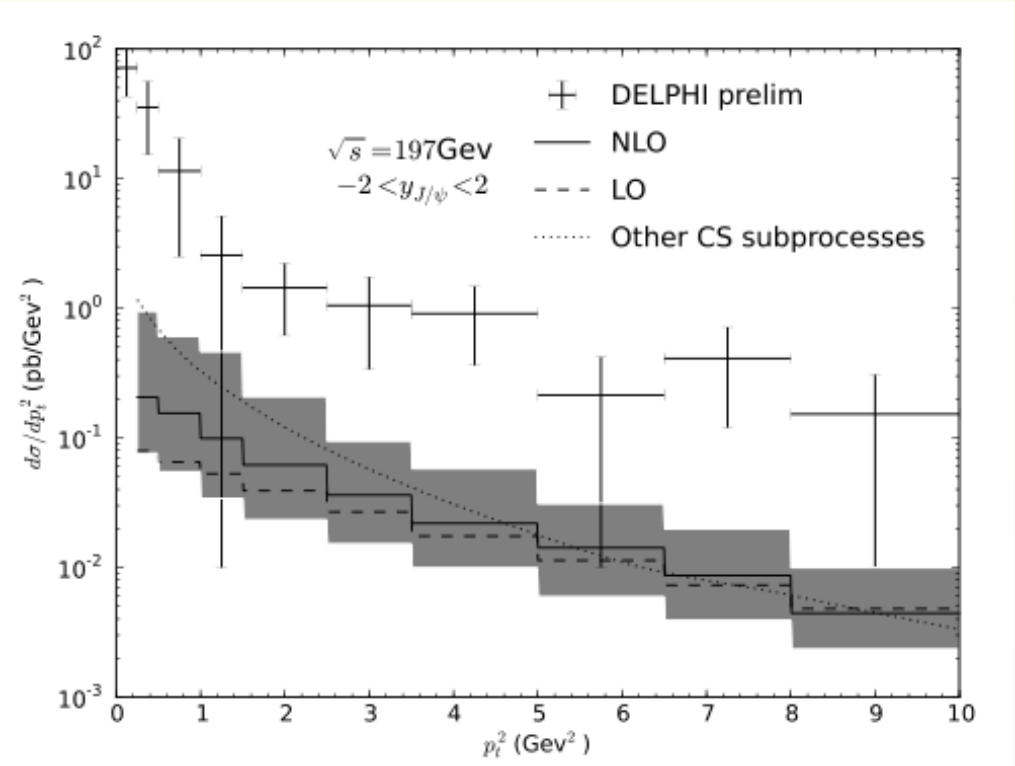

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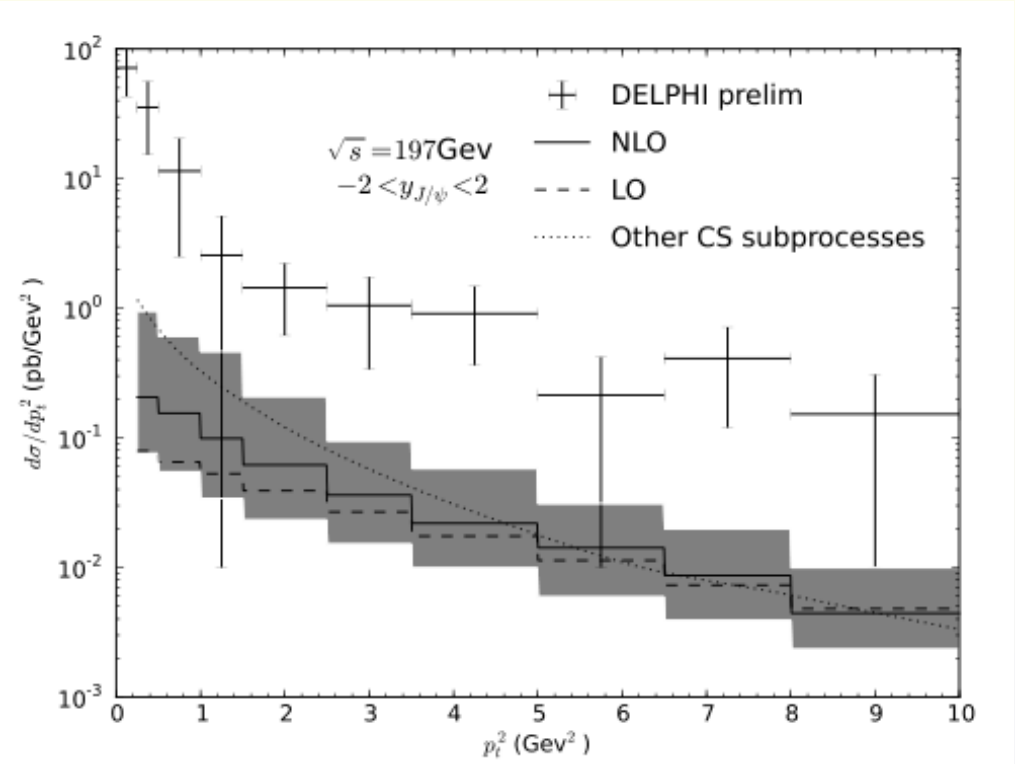

The shaded band is the NLO result of $\gamma\gamma \to J/\psi + c\bar{c}$ process with its upper bound obtained at $r = 0.5$, $m_c = 1.4$GeV and lower bound at $r = 2$, $m_c = 1.6$GeV. The solid and dashed lines represent the NLO and LO results with $r = 1$, $m_c = 1.5$GeV.

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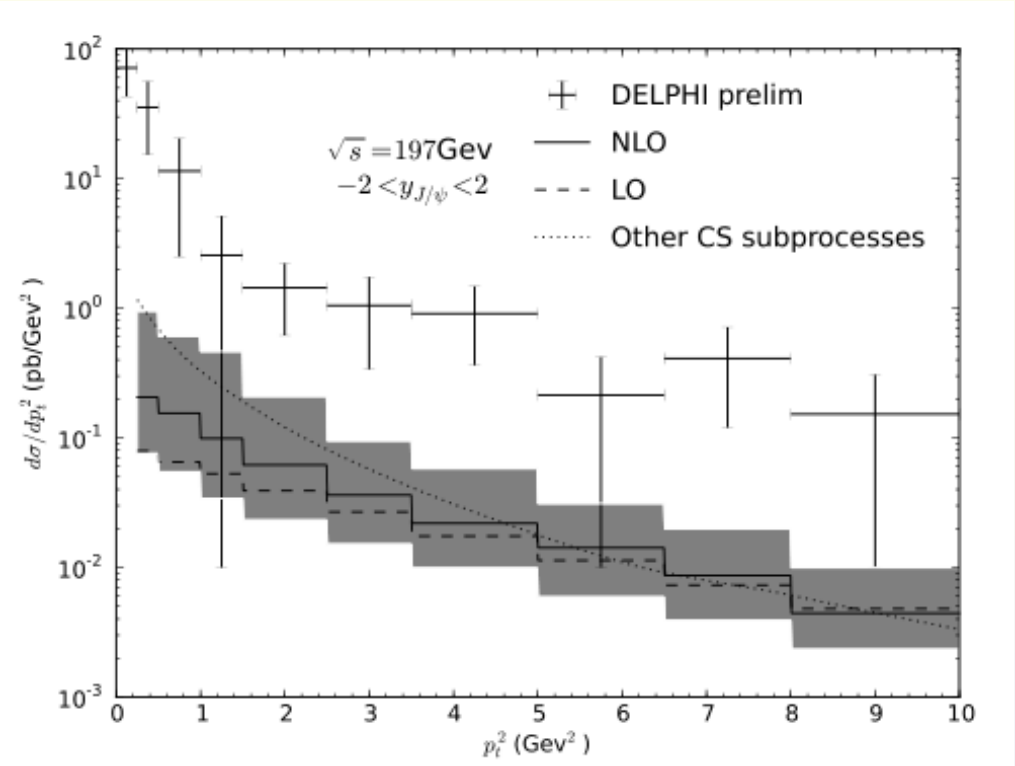

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The NLO correction is moderate but not big enough to remove the huge discrepancy between CS model prediction and experimental observation.

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  While integrated over the range $1 \leq p_t^2 \leq 10\text{GeV}^2$,

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The result of DELPHI and other CS processes read (6.4 ± 2.0)pb and $0.39^{+0.16}_{-0.09}$pb, respectively. The CO mechanism is still needed to explain the DELPHI data.

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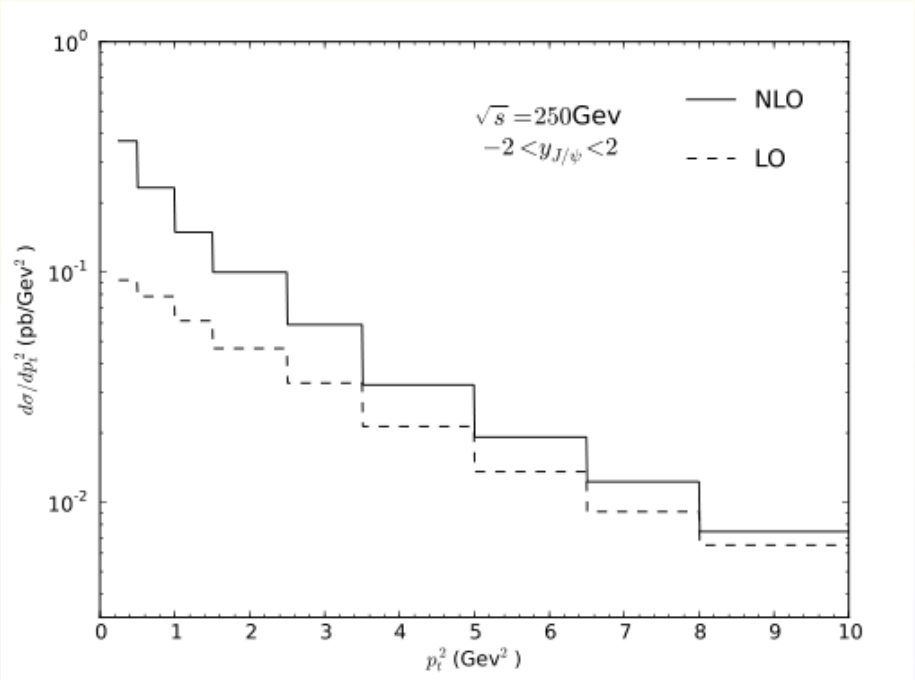

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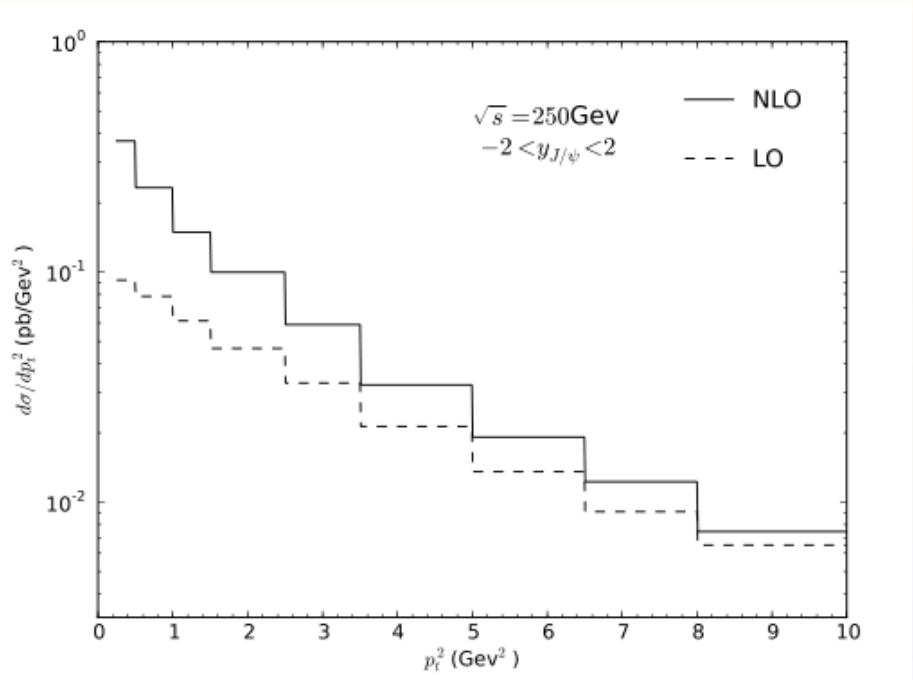

The p_t^2 distribution of $J/\psi + c\bar{c}$ production through $\gamma\gamma$ collision at CEPC. The solid and dashed lines represent the NLO and LO results with $r = 1, m_c = 1.5\text{GeV}$.

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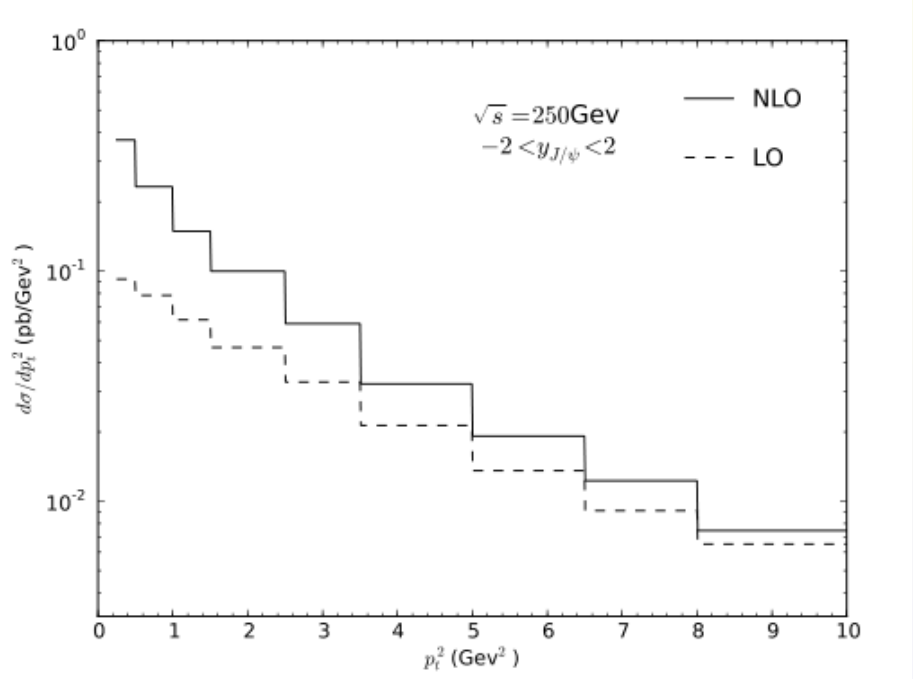

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$J/\psi + ggg$ Final State Subprocess

- $\gamma\gamma \to J/\psi + gg$ Process and Furry's Theorem
- Feynman Diagrams
- Numerical Results

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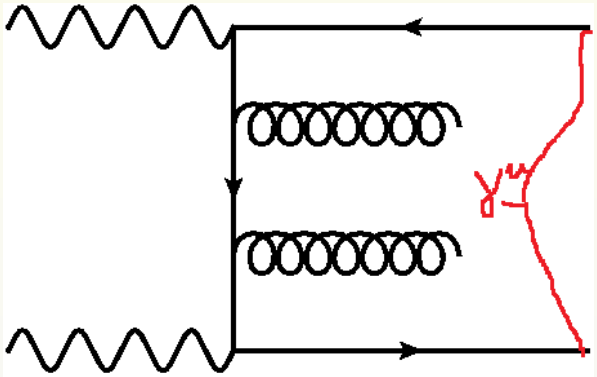

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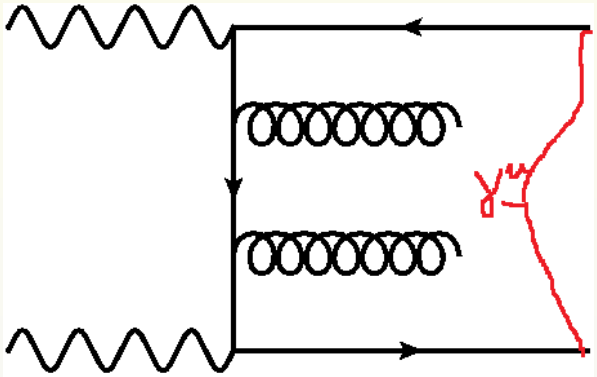

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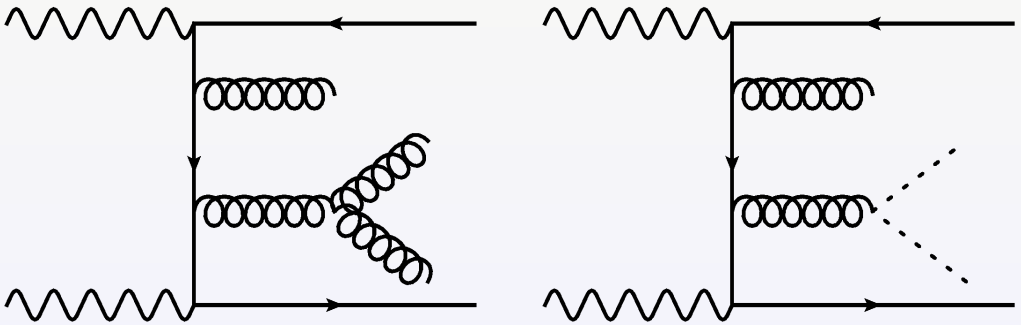
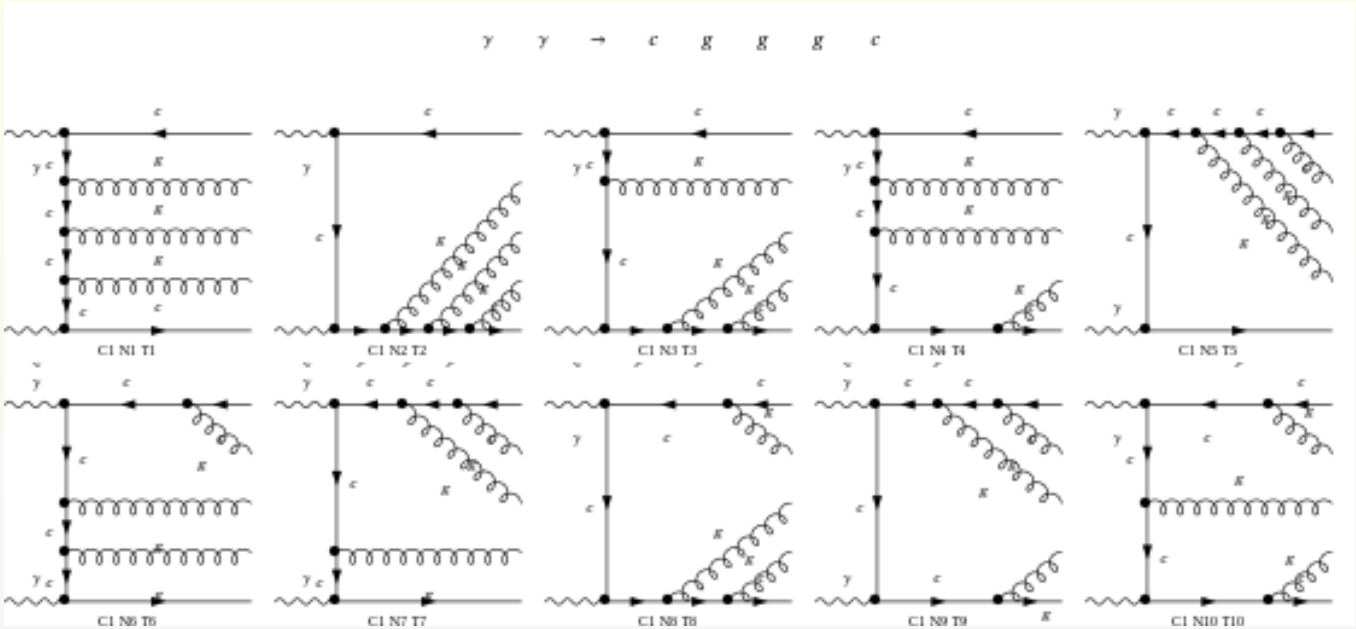


This was also verified by explicit calculation.

Feynman Diagrams

So, the Feynman diagrams of this process are



Other diagrams can be obtained by exchange gluons and photons.

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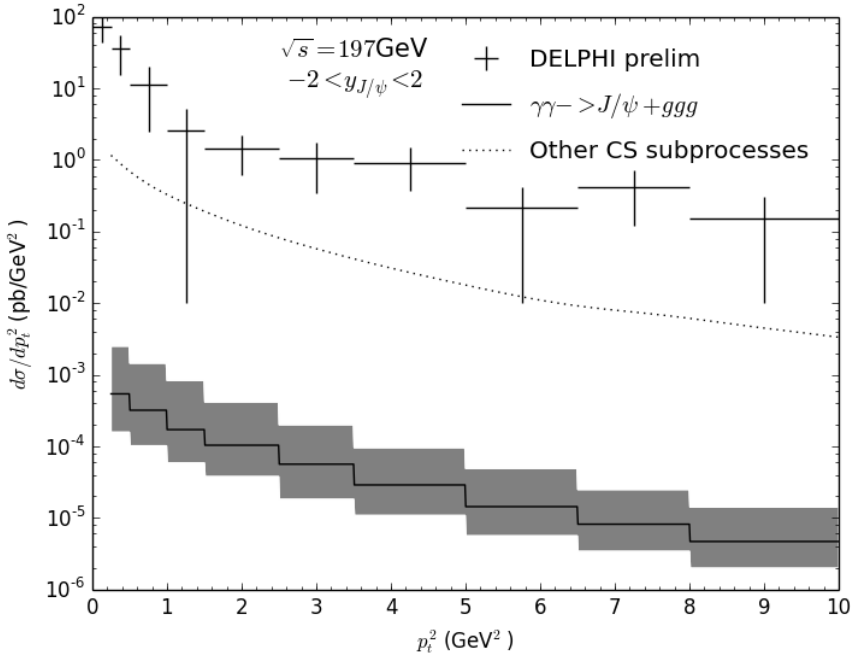

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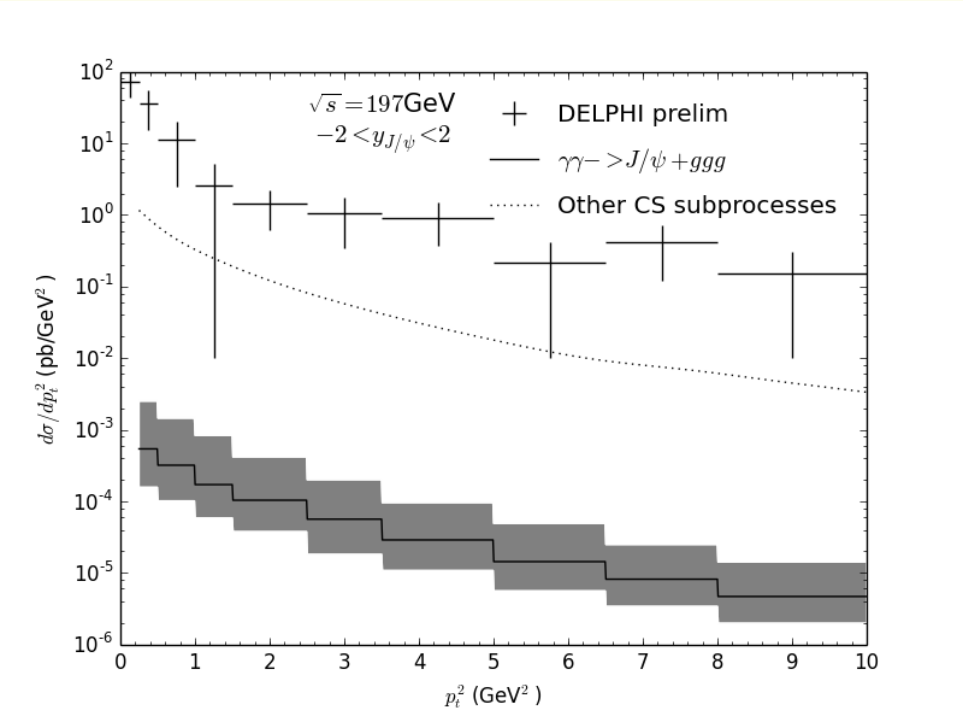

The shaded band is the cross section of $\gamma\gamma \to J/\psi + ggg$ process with its upper bound obtained at $r = 0.5$, $m_c = 1.4$GeV and lower bound at $r = 2$, $m_c = 1.6$GeV. The solid lines represent the results with $r = 1$, $m_c = 1.5$GeV.

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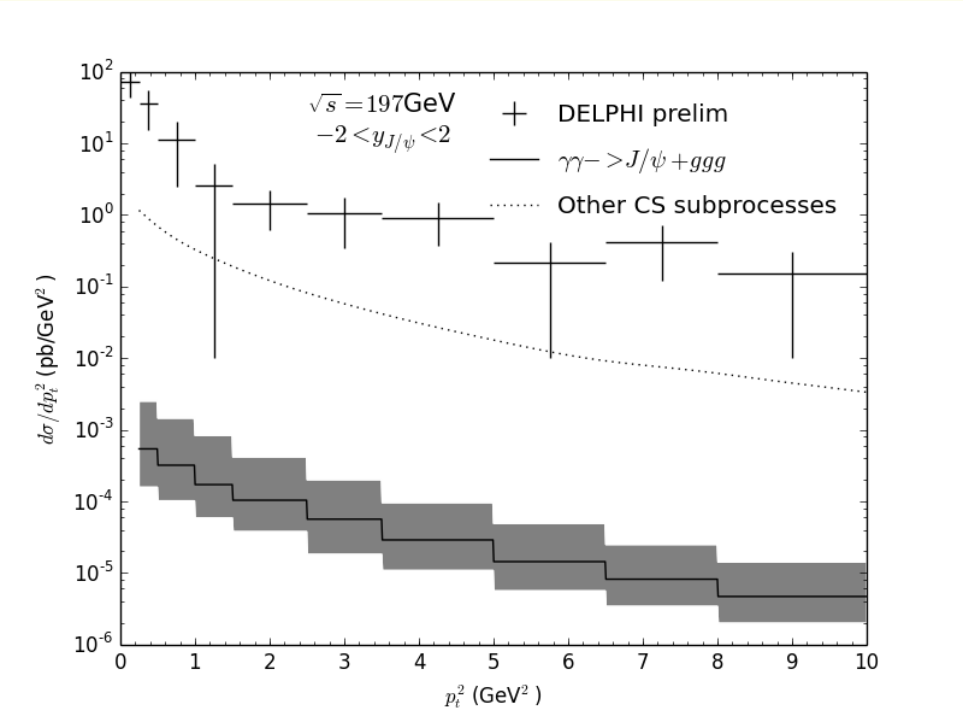

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Integrated over the range $1 \leq p_t^2 \leq 10\text{GeV}^2$,

σ(fb)	$m_c = 1.4$GeV	$m_c = 1.5$GeV	$m_c = 1.6$GeV
$r = 0.5$	1.32	0.82	0.54
$r = 1$	0.52	0.33	0.22
$r = 2$	0.26	0.17	0.12

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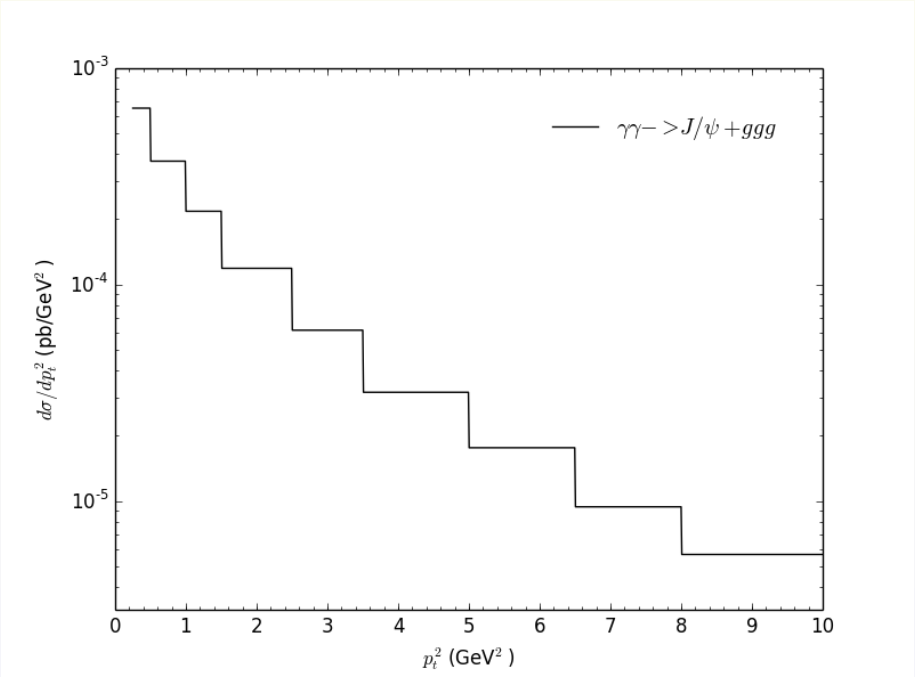

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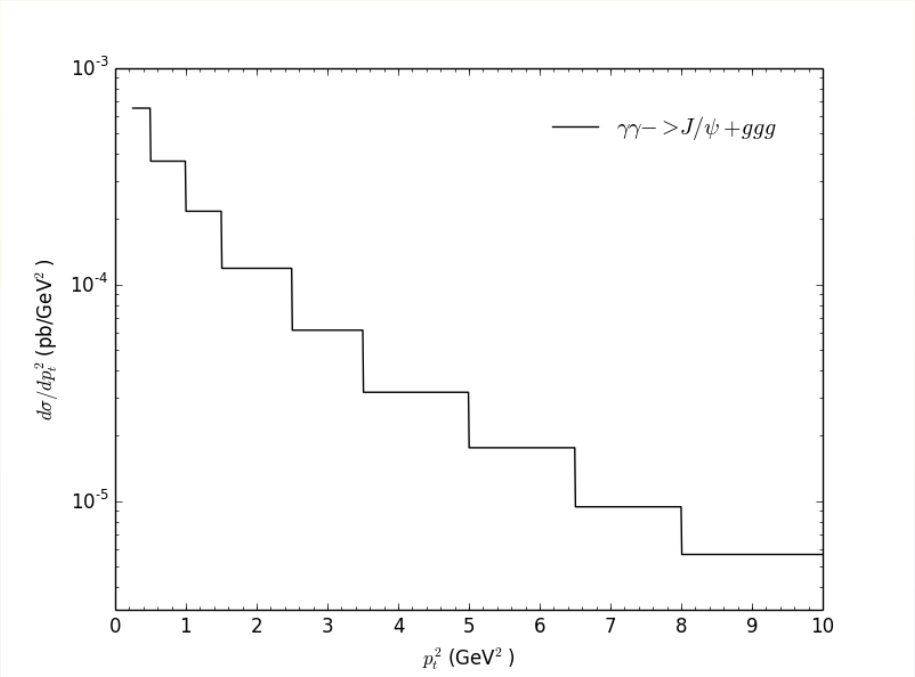

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- According to Furry's theorem, CS process $\gamma\gamma \to J/\psi + gg$ is forbidden. The cross section of $\gamma\gamma \to J/\psi + ggg$ is relatively small.