Precise measurement of the η_c mass and width in radiative J/Ψ decays

Pablo Roig LPT (CNRS), Orsay (France)

Collaboration with Nora Brambilla and Antonio Vairo
(Work in progress)

Orsay, 29/07/10

SUMMARY:

- Radiative transitions: Basics
- Experimental data on $J/\Psi \to \eta_c \gamma$
- EFT framework: pNRQCD
- Lineshape in $J/\Psi \to \eta_c \gamma$ using pNRQCD
- Summary

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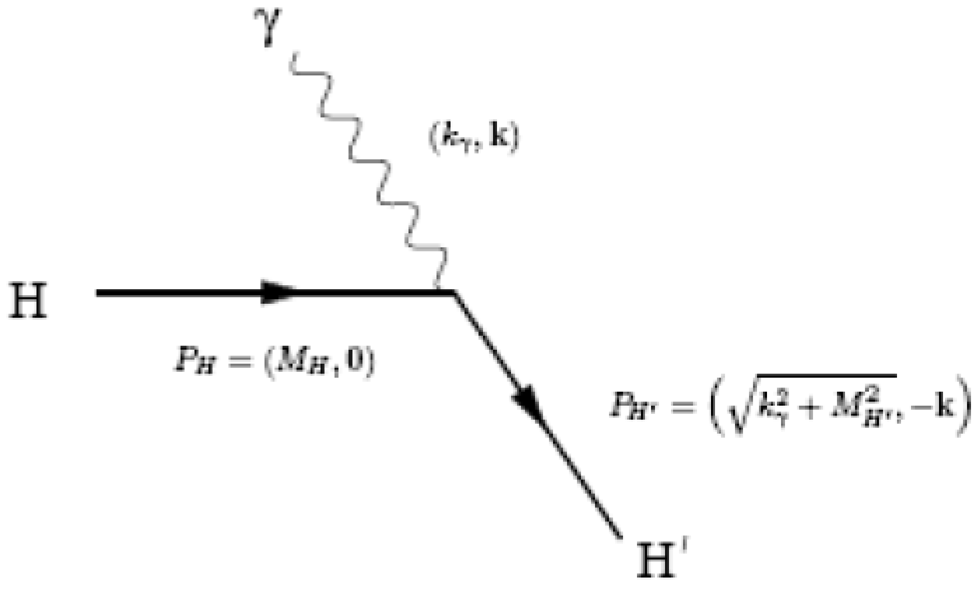
Radiative transitions: Basics

There are two dominant single-photon transition processes:

i) Electric dipole transitions (E1)

ii) Magnetic dipole transitions (M1)



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In the non-relativistic limit

$$\Gamma_{n^3S_1 \to n'^1S_0\,\gamma} = \frac{4}{3}\,\alpha\,e_Q^2\,\frac{k_\gamma^3}{m^2}\left|\int_0^\infty dr\,r^2\,R_{n'0}(r)\,R_{n0}(r)\,j_0\left(\frac{k_\gamma r}{2}\right)\right|^2$$

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If $k_\gamma \langle r \rangle \ll 1$ → $j_0(k_\gamma r/2) = 1 - (k_\gamma r)^2/24 + \ldots$

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- n = n' Allowed transitions
- n ≠ n' Hindered transitions

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Experimental data on $J/\Psi \to \eta_c \gamma$

• Only one direct experimental measurement existed for long time:
$\Gamma(J/\Psi \to \gamma\, \eta_c) = (1.14 \pm 0.23)$ keV ***(Crystal Ball '86)***

• There were also several measurements of the BR($J/\Psi \to \gamma\, \eta_c \to \gamma\, \phi\, \phi$) and one independent measurement of BR($\eta_c \to \phi\, \phi$) ***(Belle '03)***
From them, one obtained $\Gamma(J/\Psi \to \gamma\, \eta_c) = (2.9 \pm 1.5)$ keV

• Recently, CLEO found $\Gamma(J/\Psi \to \gamma\, \eta_c) = (1.85 \pm 0.08 \pm 0.28)$ keV ***(CLEO '08)***

•The combination of these independent measurements leads to
$\Gamma(J/\Psi \to \gamma\, \eta_c) = (1.44 \pm 0.18)$ keV **with a 13% error**

$m_{\eta_c} = (2977.3 \pm 1.3)$ MeV from $\Gamma(J/\Psi, \Psi(2S) \to \gamma\, \eta_c)$ vs.
$m_{\eta_c} = (2982.6 \pm 1.0)$ MeV from $\gamma\, \gamma$ or $p\bar{p}$ production

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Experimental data on $J/\Psi \to \eta_c \gamma$

η_c line shape in the CLEO analysis

CLEO PRL 102(09)011801

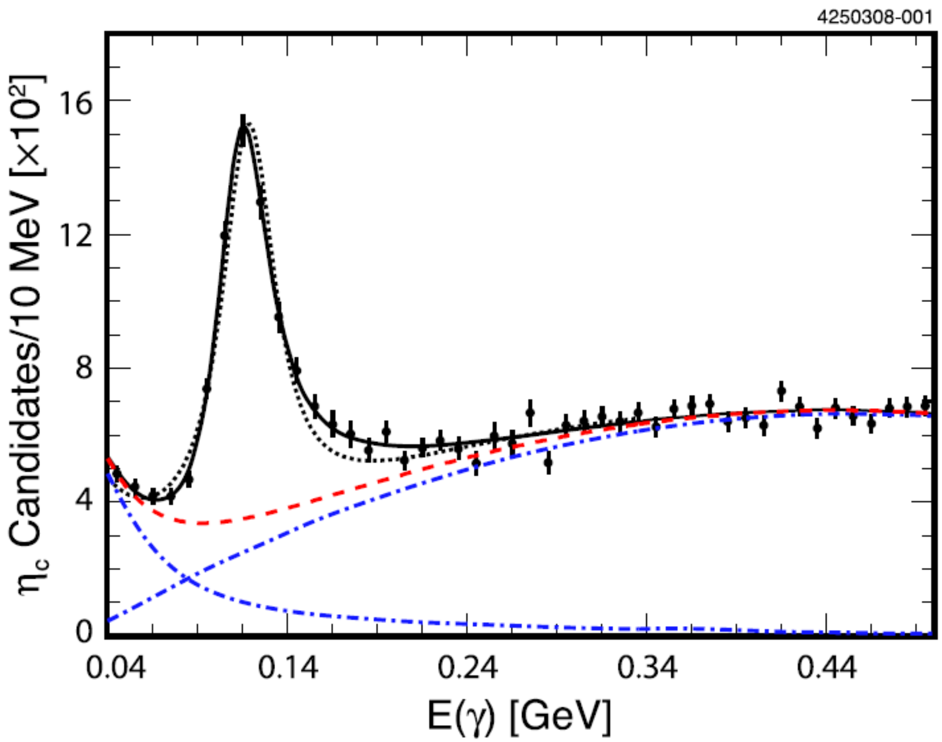

FIG. 1: Fits to the photon spectrum in exclusive $J/\psi \to \gamma\eta_c$ decays using relativistic Breit-Wigner (dotted) and modified (solid) signal line shapes convolved with a 4.8 MeV wide resolution function. Total background is given by the dashed line. The dot-dashed curves indicate two major background components described in the text.

- **Input**: two background sources
- a MC modeled background for spurious $J/\Psi \to X$:

$$bkg(1)(E) = \mathbf{N}[\exp(-5.720E) + 10.441\exp(-33.567E)]$$

- a freely fit background for $J/\Psi \to \pi^0 X$ and non-signal $J/\Psi \to X$:

$$bkg(2)(E) = \mathbf{A} + \mathbf{B}\ E + \mathbf{C}\ E^2$$

- a theoretical line shape

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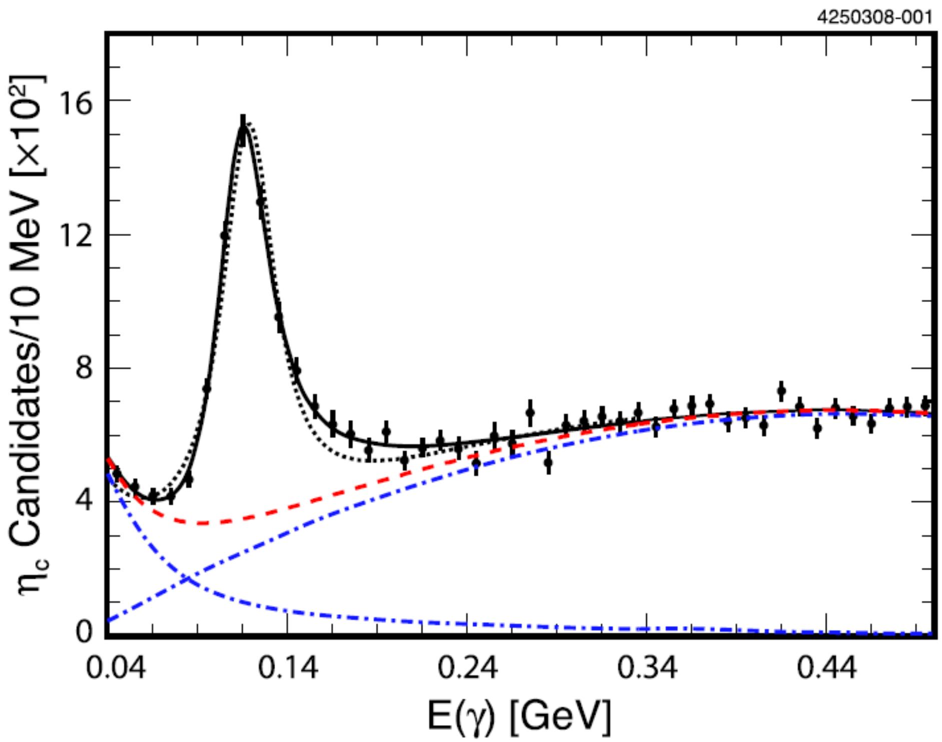

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- $J/\Psi \rightarrow \pi^0 X$ and non-signal $J/\Psi \rightarrow X$:

bkg(2)(E) = **A** + **B** E + **C** E^2

- a theoretical line shape given by $E^3 \times BW^{rel}(E) \times \text{damping}(E)$, where

- $BW^{rel}(E)^{-1}$ =

$(M^2_{J/\Psi} - 2\, M_{J/\Psi}E - M^2_{\eta_c})^2 + (M^2_{J/\Psi} - 2 M_{J/\Psi}E)^2 \Gamma_{\eta_c}$

- damping(E) =

$\exp[-E^2/(8 \times ([65.0 \pm 2.5]\ \text{MeV})^2)]$

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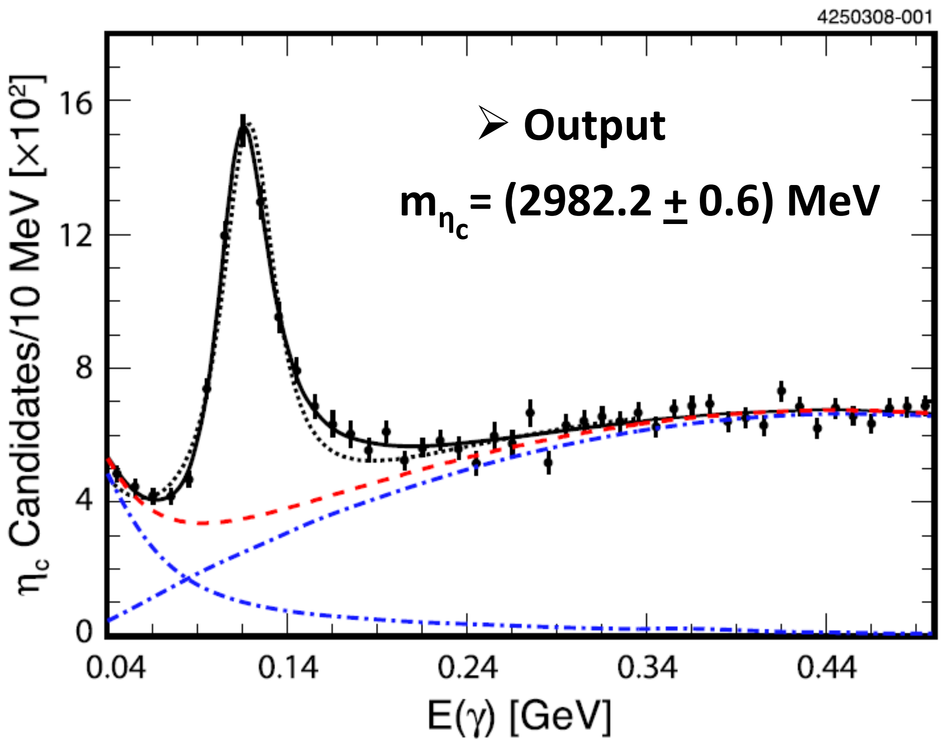

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One gets this shape assuming harmonic oscillator wf's and keeping the interaction unexpanded. Then, it should be ~ 1/r ~ p ~ 800 MeV!!!!

η_c mass and width in radiative J/Ψ decays

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Experimental data on J/Ψ → $\eta_c\,\gamma$

η_c line shape in the KEDR analysis

KEDR arXiv:1002.2071

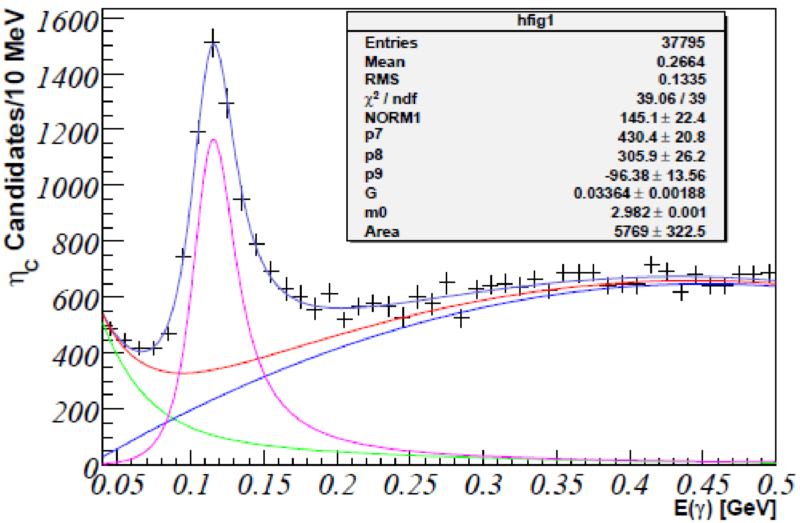

Fig. 1. Fit of CLEO data using $d\Gamma/d\omega \sim \omega^3\omega_0^2/(\omega\omega_0+(\omega-\omega_0)^2)BW(\omega)$.

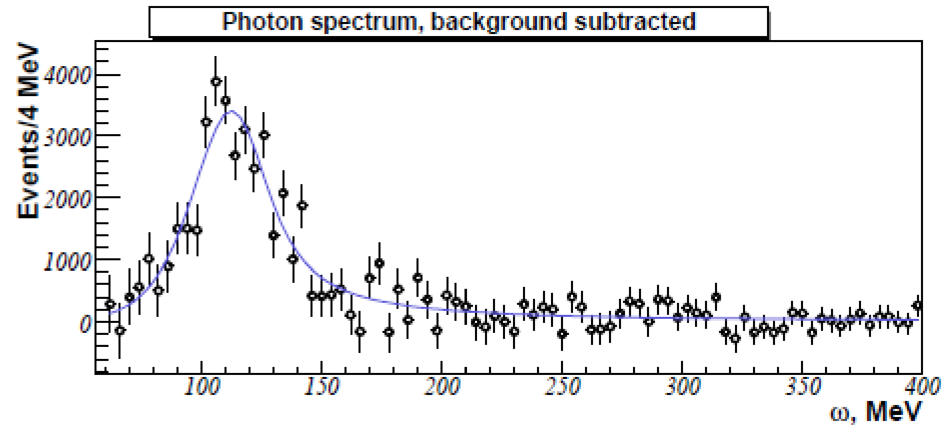

Fig. 5. Fit of the inclusive photon spectrum with $f(\omega)=\omega_0^2/(\omega\omega_0+(\omega-\omega_0)^2)$.

➢ **Input**: as before, but also damping'(E) $=E^2_{peak}/[E\,E_{peak}+(E-E_{peak})^2]$

➢ **Output**:

m_{η_c}	Γ_{η_c}
(2979.7 ± 1.6) MeV	(26.9 ± 4.8) MeV
(2979.4 ± 1.5) MeV	(27.8 ± 5.1) MeV

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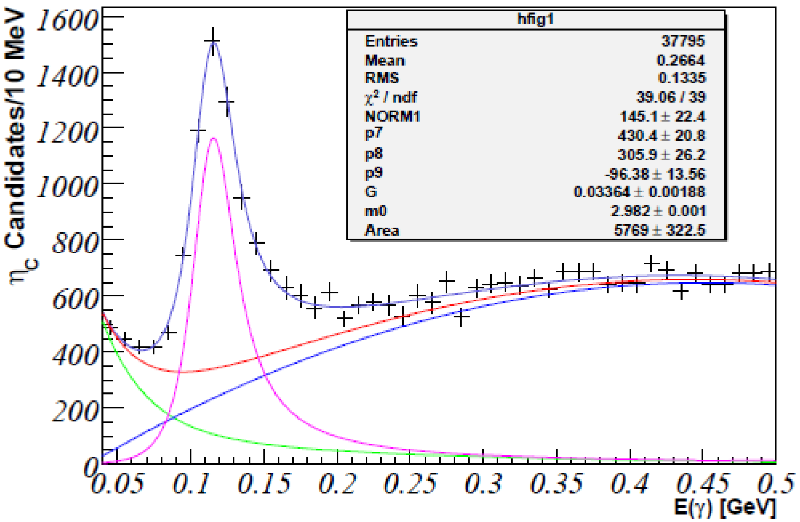
η_c line shape in the KEDR analysis

KEDR arXiv:1002.2071



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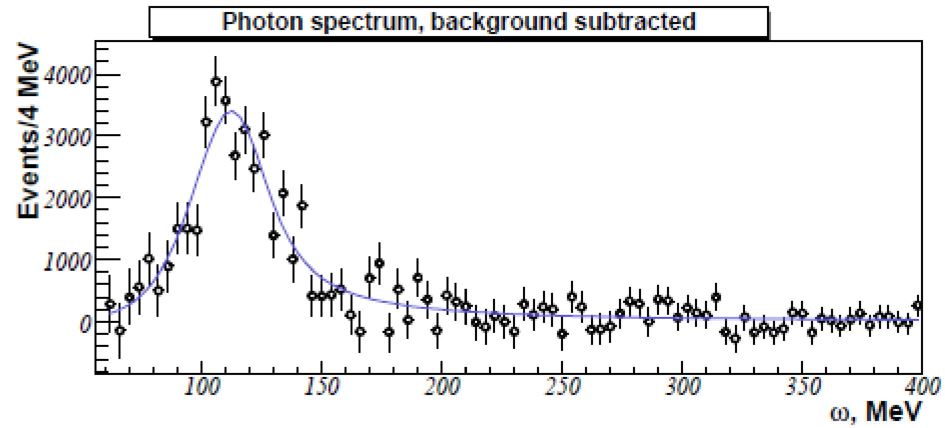

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(2979.7 ± 1.6) MeV	(26.9 ± 4.8) MeV
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- **Output** CLEO:

m_{η_c} = (2982.2 ± 0.6) MeV

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EFT framework: pNRQCD

● The LO NR expressions for the M1 transitions do not account well enough for the data.

● So one needs to supplement them with higher order corrections.

● EFT provide a systematic and controlled way of doing that.

● In the case of Quarkonia they are NRQCD (Caswell, Lepage '86) (Bodwin, Braaten and Lepage '95), pNRQCD (Pineda, Soto '97) (Brambilla, Pineda, Soto, Vairo '99) that exploit the hierarchy of scales the problem has.

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Scales:

- $\langle p\rangle \sim 1/\langle r\rangle \sim m_c v \sim$ (0.7-1) GeV $\gg \Lambda_{QCD}$
- $E_{J/\Psi} \equiv M_{J/\Psi} - 2m_c \sim m_c v^2 \sim$ 400 MeV - 600 MeV $\ll 1/\langle r\rangle$
- $M_{J/\Psi} - M_{\eta_c} \sim m_c v^4 \sim$ 120 MeV $\ll E_{J/\Psi}$
- 0 MeV $\leq E \leq$ (400 – 500) MeV $\ll 1/\langle r\rangle$

($E \sim m_c v^2$ if allowed) ($E \sim m_c v^4$ if hindered)

- $\Gamma_{\eta_c} \sim$ 30 MeV $\ll m_c v^4$

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It follows that the system is

(i) non-relativistic,

(ii) weakly-coupled at the scale $1/<r>$: $v \sim \alpha_s$,

(iii) that we may multipole expand in the external photon energy.

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An **EFT approach**: **degrees of freedom**

Degrees of freedom at scales lower than mv:

• c-$\bar{c}$ states, with energy $\sim \Lambda_{QCD}$, $m_c v^2$ and momentum $\leq m_c v \Rightarrow$ (i) singlet S (ii) octet O

• Gluons with energy and momentum $\sim \Lambda_{QCD}$, $m_c v^2$

• Photons of energy and momentum lower than $m_c v$

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EFT framework: pNRQCD

(Brambilla, Pineda, Soto, Vairo '06)

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An EFT approach: the Lagrangian

$$\mathcal{L} = \mathcal{L}_{\rm pNRQCD} + \mathcal{L}_\gamma$$

- $$\mathcal{L}_{\rm pNRQCD} = -\frac{1}{4}F^a_{\mu\nu}F^{\mu\nu\,a} - \frac{1}{4}F^{\rm em}_{\mu\nu}F^{\mu\nu\,{\rm em}} + {\rm Tr}\left\{{\rm S}^\dagger\left(i\partial_0 - h_s\right){\rm S} + {\rm O}^\dagger\left(iD_0 - h_o\right){\rm O}\right\} + \dots$$

$$h_s = {\rm Re}\,h_s + i{\rm Im}\,h_s, \quad {\rm Re}\,h_s = \mathbf{p}^2/m_c + {\rm Re}\,V_s, \quad \langle H|{\rm Im}\,h_s|H\rangle = -\Gamma_H/2$$

  - Pineda Soto NP PS 64(98)428, Brambilla et al NPB 566(00)275 Brambilla et al PRD 67(03)034018

- $$\mathcal{L}_\gamma = {\rm Tr}\left\{\overbrace{V_A^{\rm em}\,{\rm S}^\dagger\mathbf{r}\cdot ee_Q\mathbf{E}^{\rm em}{\rm S}}^{\rm E1} + \overbrace{\frac{1}{2m_c}V_1\left\{{\rm S}^\dagger,\boldsymbol{\sigma}\cdot ee_Q\mathbf{B}^{\rm em}\right\}{\rm S}}^{\rm M1} + \dots\right\}$$

$$V_A^{\rm em} = 1 + \dots, \qquad V_1 = 1 + \dots$$

  - Brambilla Jia Vairo PRD 73(06)054005

EFT framework: γpNRQCD

(Brambilla, Jia and Vairo '06)

$$\begin{aligned}\mathcal{L}_{\gamma\,\mathrm{pNRQCD}} = \int d^3r\ \mathrm{Tr}\Big\{ & V_A^{\mathrm{em}}\ \mathrm{S}^\dagger \mathbf{r}\cdot ee_Q \mathbf{E}^{\mathrm{em}}\mathrm{S} \\
&+ \frac{1}{2m}\, V_S^{\frac{\sigma\cdot B}{m}}\ \left\{\mathrm{S}^\dagger, \boldsymbol{\sigma}\cdot ee_Q\mathbf{B}^{\mathrm{em}}\right\}\mathrm{S} \\
&+ \frac{1}{16m}\, V_S^{(r\cdot\nabla)^2\frac{\sigma\cdot B}{m}}\ \left\{\mathrm{S}^\dagger, \mathbf{r}^i\mathbf{r}^j(\boldsymbol{\nabla}^i\boldsymbol{\nabla}^j\boldsymbol{\sigma}\cdot ee_Q\mathbf{B}^{\mathrm{em}})\right\}\mathrm{S} \\
&+ \frac{1}{2m}\, V_O^{\frac{\sigma\cdot B}{m}}\ \left\{\mathrm{O}^\dagger, \boldsymbol{\sigma}\cdot ee_Q\mathbf{B}^{\mathrm{em}}\right\}\mathrm{O} \\
&+ \frac{1}{4m^2}\, \frac{V_S^{\frac{\sigma\cdot(r\times r\times B)}{m^2}}}{r}\ \left\{\mathrm{S}^\dagger, \boldsymbol{\sigma}\cdot\left[\hat{\mathbf{r}}\times(\hat{\mathbf{r}}\times ee_Q\mathbf{B}^{\mathrm{em}})\right]\right\}\mathrm{S} \\
&+ \frac{1}{4m^2}\, \frac{V_S^{\frac{\sigma\cdot B}{m^2}}}{r}\ \left\{\mathrm{S}^\dagger, \boldsymbol{\sigma}\cdot ee_Q\mathbf{B}^{\mathrm{em}}\right\}\mathrm{S} \\
&- \frac{1}{16m^2}\, V_S^{\frac{\sigma\cdot\nabla\times E}{m^2}}\ \left[\mathrm{S}^\dagger, \boldsymbol{\sigma}\cdot\left[-i\boldsymbol{\nabla}\times, ee_Q\mathbf{E}^{\mathrm{em}}\right]\right]\mathrm{S} \\
&- \frac{1}{16m^2}\, V_S^{\frac{\sigma\cdot\nabla_r\times r\cdot\nabla E}{m^2}}\ \left[\mathrm{S}^\dagger, \boldsymbol{\sigma}\cdot\left[-i\boldsymbol{\nabla}_r\times, \mathbf{r}^i(\boldsymbol{\nabla}^i ee_Q\mathbf{E}^{\mathrm{em}})\right]\right]\mathrm{S} \\
&+ \frac{1}{4m^3}\, V_S^{\frac{\nabla_r^2\sigma\cdot B}{m^3}}\ \left\{\mathrm{S}^\dagger, \boldsymbol{\sigma}\cdot ee_Q\mathbf{B}^{\mathrm{em}}\right\}\boldsymbol{\nabla}_r^2\mathrm{S} \\
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$$\mathcal{L}_{\gamma\,\mathrm{pNRQCD}} = \int d^3r\ \mathrm{Tr}\left\{ V_A^{\mathrm{em}}\ \mathrm{S}^\dagger \mathbf{r}\cdot ee_Q \mathrm{E}^{\mathrm{em}} \mathrm{S} \right.$$ **E1 at O(1)**

$$\left. + \frac{1}{2m} V_S^{\frac{\sigma\cdot B}{m}} \left\{ \mathrm{S}^\dagger, \boldsymbol{\sigma}\cdot ee_Q \mathrm{B}^{\mathrm{em}} \right\} \mathrm{S} \right\} \cdot$$ **M1 at O(1)**

The matching procedure gives the coefficients V that appear at a given order in the v-expansion

For the **M1 potential (≡V1):**

V1=(hard)x(soft);

(hard)=c_F^{em}=1+2$\alpha_S(m_c)/3\pi$+...

(soft) = 1

No large quarkonium anomalous magnetic moment

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EFT framework: γpNRQCD

M1 at O(v^2)

$$\frac{1}{4m^2}\frac{V_S^{\frac{\sigma\cdot(r\times r\times B)}{m^2}}}{r}\left\{S^\dagger,\boldsymbol{\sigma}\cdot[\hat{\mathbf{r}}\times(\hat{\mathbf{r}}\times ee_Q\mathbf{B}^{em})]\right\}S$$

($\equiv V_2$)

To all orders:

(hard) = 2 c_F- c_S = 1; (soft) = r^2 V_s'/2

(due to reparametrization/Poincaré invariance) (Brambilla, Gromes, Vairo '03)

V_2 = r^2 V_s'/2

V_3 = 0 (No scalar interaction)

$$\frac{1}{4m^2}\frac{V_S^{\frac{\sigma\cdot B}{m^2}}}{r}\left\{S^\dagger,\boldsymbol{\sigma}\cdot ee_Q\mathbf{B}^{em}\right\}S \qquad \frac{1}{4m^3}V_S^{\frac{\nabla_r^2\sigma\cdot B}{m^3}}\left\{S^\dagger,\boldsymbol{\sigma}\cdot ee_Q\mathbf{B}^{em}\right\}\boldsymbol{\nabla}_r^2 S$$

($\equiv V_3$) ($\equiv V_4$)

(hard) = 1(due to reparametrization invariance)(Manohar '97)

V_4 = 1 + O(α_S soft contributions)

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Lineshape in $J/\Psi \to \eta_c \gamma$ using pNRQCD

$$\Gamma_{J/\Psi\to\eta_c\gamma} = \int \frac{d^3k}{(2\pi)^3}(2\pi)\,\delta\left(E_p^{J/\Psi} - k - E_k^{\eta_c}\right)|\langle\gamma(k)\eta_c|\mathcal{L}_\gamma|J/\Psi\rangle|^2$$

Up to $O(v^2)$ this transition is completely accessible to perturbation theory

$$\Gamma_{J/\psi\to\eta_c\gamma} = \frac{16}{3}\alpha e_c^2 \frac{k_\gamma^3}{M_{J/\psi}^2}\left[1 + C_F\frac{\alpha_s(M_{J/\psi}/2)}{\pi} + \frac{2}{3}\frac{\langle 1S|3V_S^{(0)} - rV_S^{(0)\prime}|1S\rangle}{M_{J/\psi}}\right]$$
$$= \frac{16}{3}\alpha e_c^2 \frac{k_\gamma^3}{M_{J/\psi}^2}\left[1 + C_F\frac{\alpha_s(M_{J/\psi}/2)}{\pi} - \frac{2}{3}(C_F\alpha_s(p_{J/\psi}))^2\right],$$

The normalization scale for α_s is the charm quark mass (in the contribution inherited from the quark magnetic moment) and the typical momentum transfer (for that one coming from the Coulomb potential).

$$\alpha_s(M_{J/\psi}/2) \approx 0.35 \qquad p_{J/\psi} \approx mC_F\alpha_s(p_{J/\psi})/2 \approx 0.8\ \text{GeV}$$

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Lineshape in $J/\Psi \to \eta_c \gamma$ using pNRQCD

$$\Gamma_{J/\psi\to\gamma\eta_c} = \frac{16}{3}\alpha e_c^2 \frac{k_\gamma^3}{M_{J/\Psi}^2}\left(1 + \frac{4}{3}\frac{\alpha_s(M_{J/\Psi}/2)}{\pi} - \frac{2}{3}\frac{\langle 1|rV_s'|1\rangle}{M_{J/\Psi}} + 2\frac{\langle 1|V_s|1\rangle}{M_{J/\Psi}}\right)$$

- If $V_s = -\frac{4}{3}\frac{\alpha_s(\mu)}{r}$: $-\frac{2}{3}\frac{\langle 1|rV_s'|1\rangle}{M_{J/\Psi}} + 2\frac{\langle 1|V_s|1\rangle}{M_{J/\Psi}} = -\frac{32}{27}\alpha_s(\mu)^2 < 0$
- *If* $V_s = \sigma r$: $-\frac{2}{3}\frac{\langle 1|rV_s'|1\rangle}{M_{J/\Psi}} + 2\frac{\langle 1|V_s|1\rangle}{M_{J/\Psi}} = \frac{4}{3}\frac{\sigma}{M_{J/\Psi}}\langle 1|r|1\rangle > 0$

  A scalar interaction would add a negative contribution $-2\langle 1|V^{\text{scalar}}|1\rangle/M_{J/\Psi}$.

$\Gamma(J/\psi \to \eta_c\gamma) = (1.5 \pm 1.0)$ keV

Experimentally $\Gamma(J/\Psi \to \gamma\eta_c) = (1.44 \pm 0.18)$ keV

However, the theoretical (EFT) description of the decay $J/\Psi \to \gamma\,\eta_c$ is not a priori what should be directly compared to CLEO data

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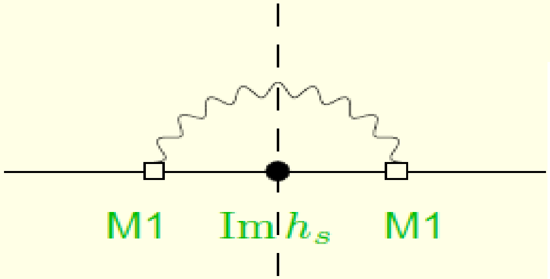
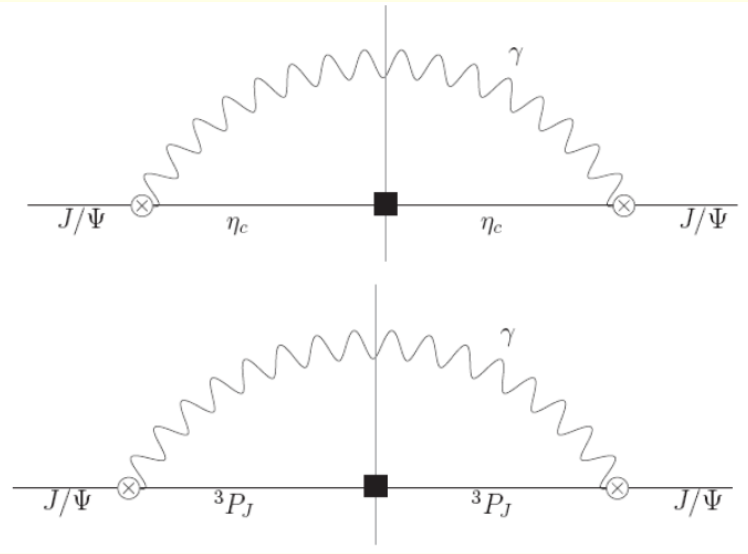
Lineshape in J/Ψ → η_c γ using pNRQCD

$J/\psi \to X\,\gamma$ for 0 MeV $\leq E_\gamma \lesssim$ 500 MeV

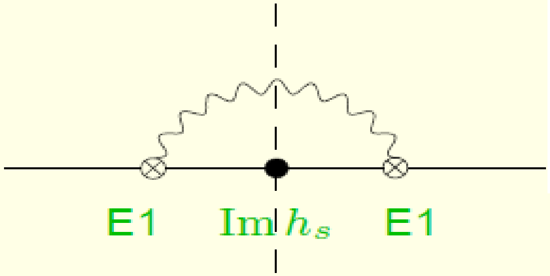
Three main processes contribute to $J/\psi \to X\,\gamma$ for 0 MeV $\leq E_\gamma \lesssim$ 500 MeV:

- $J/\psi \to \eta_c\,\gamma \to X\,\gamma$





- $J/\psi \to \chi_{c0,2}(1P)\,\gamma \to X\,\gamma$



- fragmentation and other background processes, included in the bkg functions.

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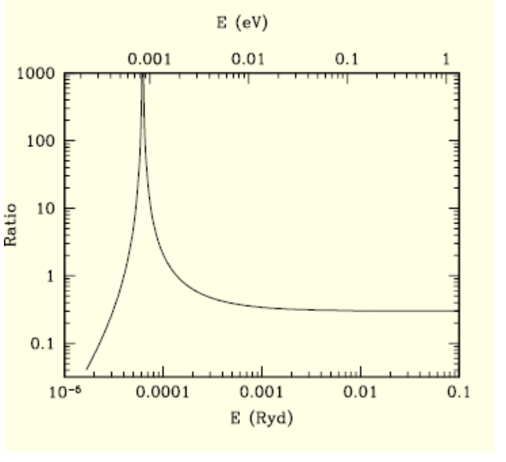
Lineshape in $J/\Psi \to \eta_c \gamma$ using pNRQCD

$$\frac{d\Gamma^{\rm mag}_{J/\Psi\to\eta_c\gamma}}{dk_\gamma} = \frac{4}{3}\frac{c_F^{em\,2}\alpha e_Q^2}{m^2}\frac{k_\gamma^3}{\pi}\frac{\frac{\Gamma_{\eta_c}}{2}}{\left(E_{J/\Psi}-k_\gamma-E_{\eta_c}\right)^2+\frac{\Gamma_{\eta_c}^2}{4}}$$

$$\frac{d\Gamma^{\rm el}_{J/\Psi\to\eta_c\gamma}}{dk_\gamma} = \frac{8}{9}\frac{\alpha e_Q^2}{\pi}k_\gamma\left|\phi_{J/\Psi}(0)\right|^2\frac{\left|a_e(k_\gamma)\right|^2}{m^4}\left[C_A\Im m f_1\left(^3P_0\right)+5C_A\Im m f_1\left(^3P_2\right)\right]$$

The function $a_e(k_\gamma)$ has been discussed in (Manohar, Ruiz-Femenia '03, Ruiz-Femenia '07, '09). (Voloshin '03) gave a closed analytical form for it.
We have checked the results in these papers for the orthopositronium decay spectrum in (p)NRQED. (Caswell, Lepage '86)

ortoPositronium $\to 3\gamma$



η_c mass and width in radiative J/Ψ decays

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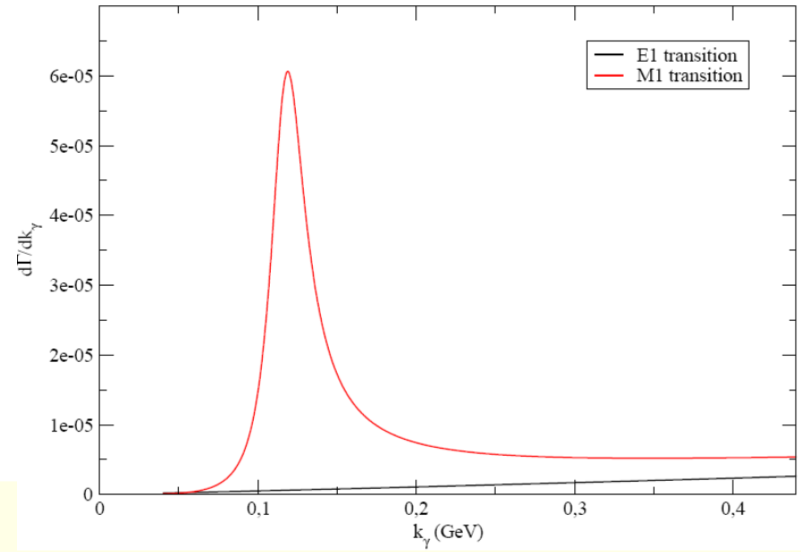
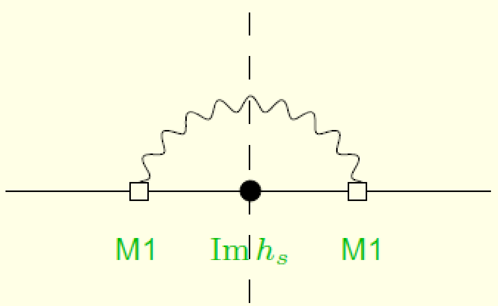
Lineshape in J/Ψ → $\eta_c\,\gamma$ using pNRQCD



$$\frac{d\Gamma}{dE_\gamma} = \frac{64}{27}\frac{\alpha}{M_{J/\psi}^2}\frac{E_\gamma}{\pi}\frac{\Gamma_{\eta_c}}{2}\frac{E_\gamma^2}{(M_{J/\psi}-M_{\eta_c}-E_\gamma)^2+\Gamma_{\eta_c}^2/4}$$

$J/\psi \to \eta_c\,\gamma \to X\,\gamma$



- For $\Gamma_{\eta_c} \to 0$ one recovers $\Gamma(J/\psi \to \eta_c\,\gamma) = \frac{64}{27}\alpha\frac{E_\gamma^3}{M_{J/\psi}^2}$
- The non-relativistic Breit–Wigner distribution goes like:

$$\frac{E_\gamma^2}{(M_{J/\psi}-M_{\eta_c}-E_\gamma)^2+\Gamma_{\eta_c}^2/4} = \begin{cases} 1 & \text{for } E_\gamma \gg m_c\alpha_s^4 \sim M_{J/\psi}-M_{\eta_c} \\ \frac{E_\gamma^2}{(M_{J/\psi}-M_{\eta_c})^2} & \text{for } E_\gamma \ll m_c\alpha_s^4 \sim M_{J/\psi}-M_{\eta_c} \end{cases}$$

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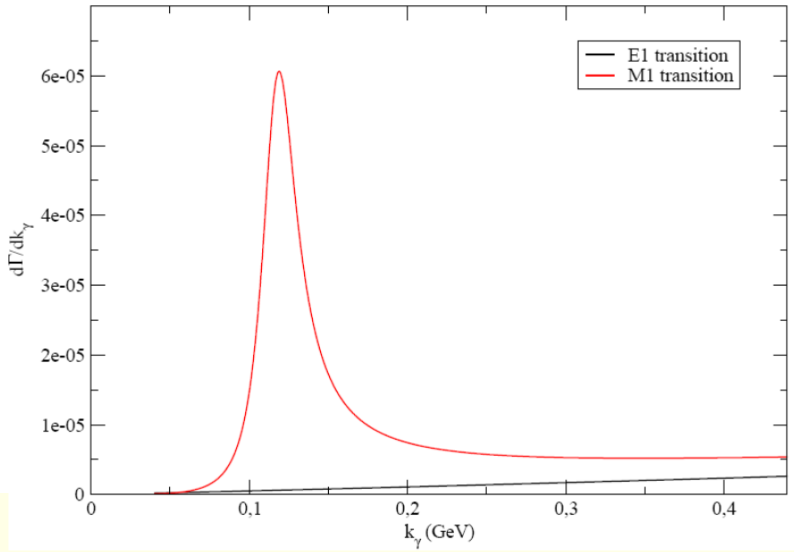
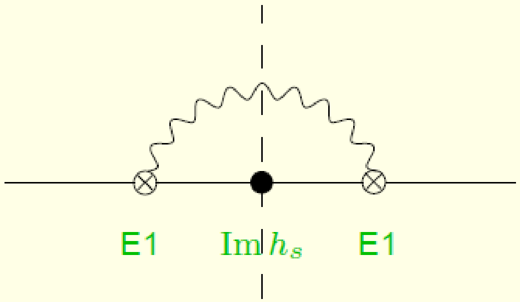
Lineshape in $J/\Psi \to \eta_c \gamma$ using pNRQCD



$$\frac{d\Gamma}{dE_\gamma} = \frac{32}{81}\frac{\alpha}{M_{J/\psi}^2}\frac{E_\gamma}{\pi}\left[\frac{21\,\alpha_s^2}{2\,\pi\,\alpha^2}\right]|a(E_\gamma)|^2$$

$J/\psi \to \chi_{c0,2}(1P)\,\gamma \to X\,\gamma$



- $a(E_\gamma) = \frac{(1-\nu)(3+5\nu)}{3(1+\nu)^2} + \frac{8\nu^2(1-\nu)}{3(2-\nu)(1+\nu)^3}\,{}_2F_1(2-\nu,1;3-\nu;-(1-\nu)/(1+\nu))$
  $\nu = \sqrt{-E_{J/\psi}/(E_\gamma - E_{J/\psi})}$

◦ Voloshin MPLA 19(04)181

- $|a(E_\gamma)|^2 = \begin{cases} 1 & \text{for } E_\gamma \gg m_c\alpha_s^2 \sim E_{J/\psi} \\ E_\gamma^2/(2E_{J/\psi})^2 & \text{for } E_\gamma \ll m_c\alpha_s^2 \sim E_{J/\psi} \end{cases}$

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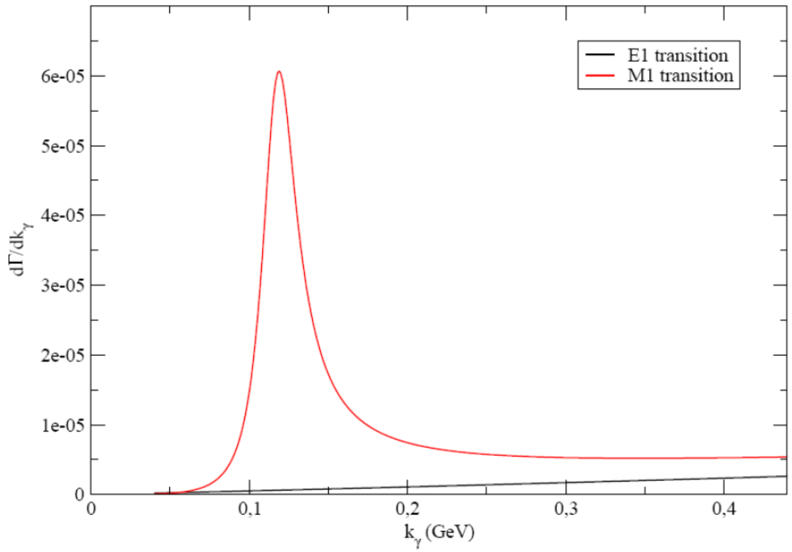
Lineshape in J/Ψ → $\eta_c\,\gamma$ using pNRQCD



- The two contributions are of equal order for $m_c\alpha_s \gg E_\gamma \gg m_c\alpha_s^2 \sim -E_{J/\psi}$;
- the magnetic contribution dominates for $-E_{J/\psi} \sim m_c\alpha_s^2 \gg E_\gamma \gg m_c\alpha_s^4 \sim M_{J/\psi} - M_{\eta_c}$;
- it also dominates by a factor $E_{J/\psi}^2/(M_{J/\psi} - M_{\eta_c})^2 \sim 1/\alpha_s^4$ for $E_\gamma \ll m_c\alpha_s^4 \sim M_{J/\psi} - M_{\eta_c}$.

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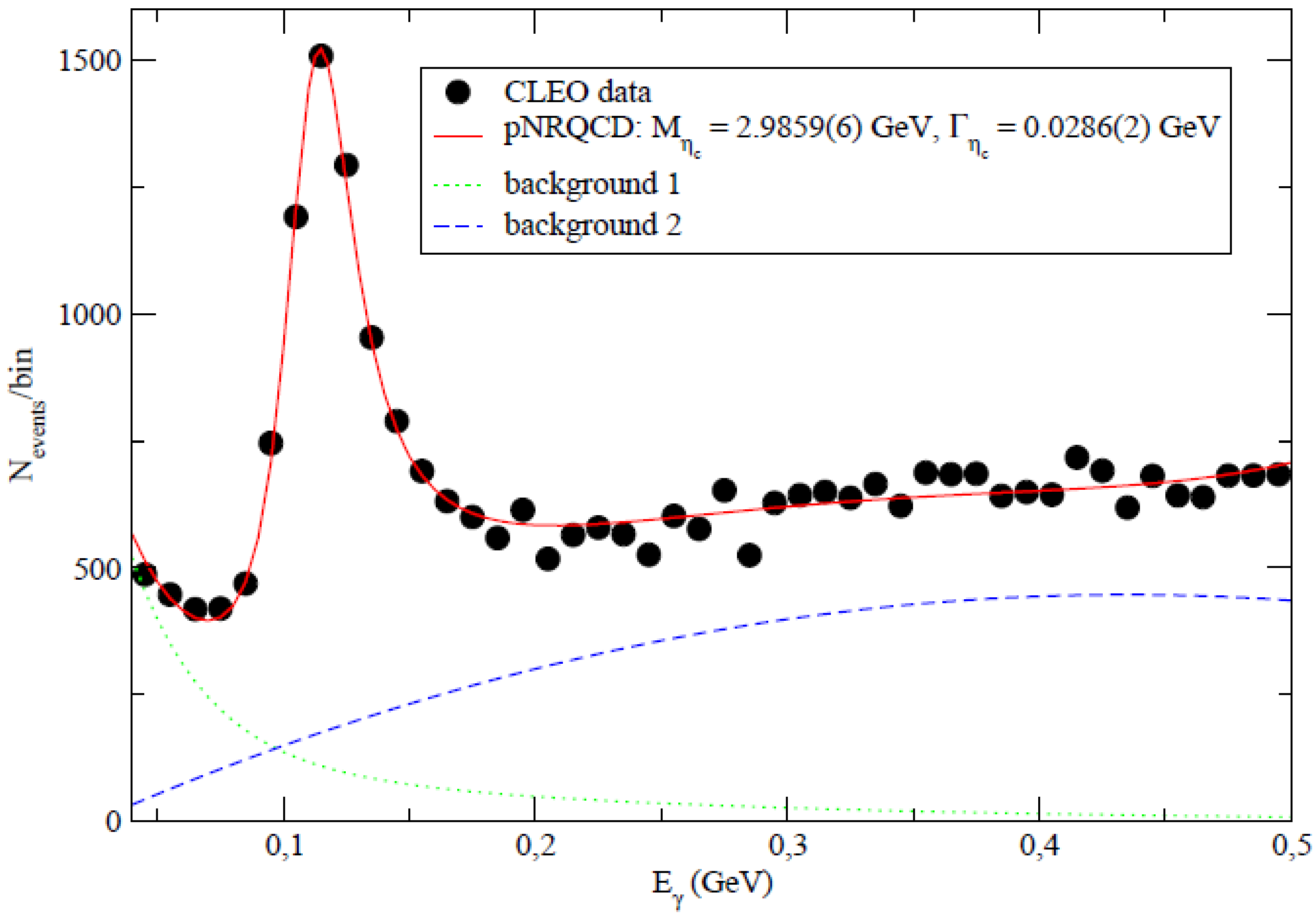
Lineshape in $J/\Psi \rightarrow \eta_c \gamma$ using pNRQCD



- Besides M_{η_c} and Γ_{η_c} the fitting parameters are the overall normalization N, the signal normalization, and the background parameters a, b and c.

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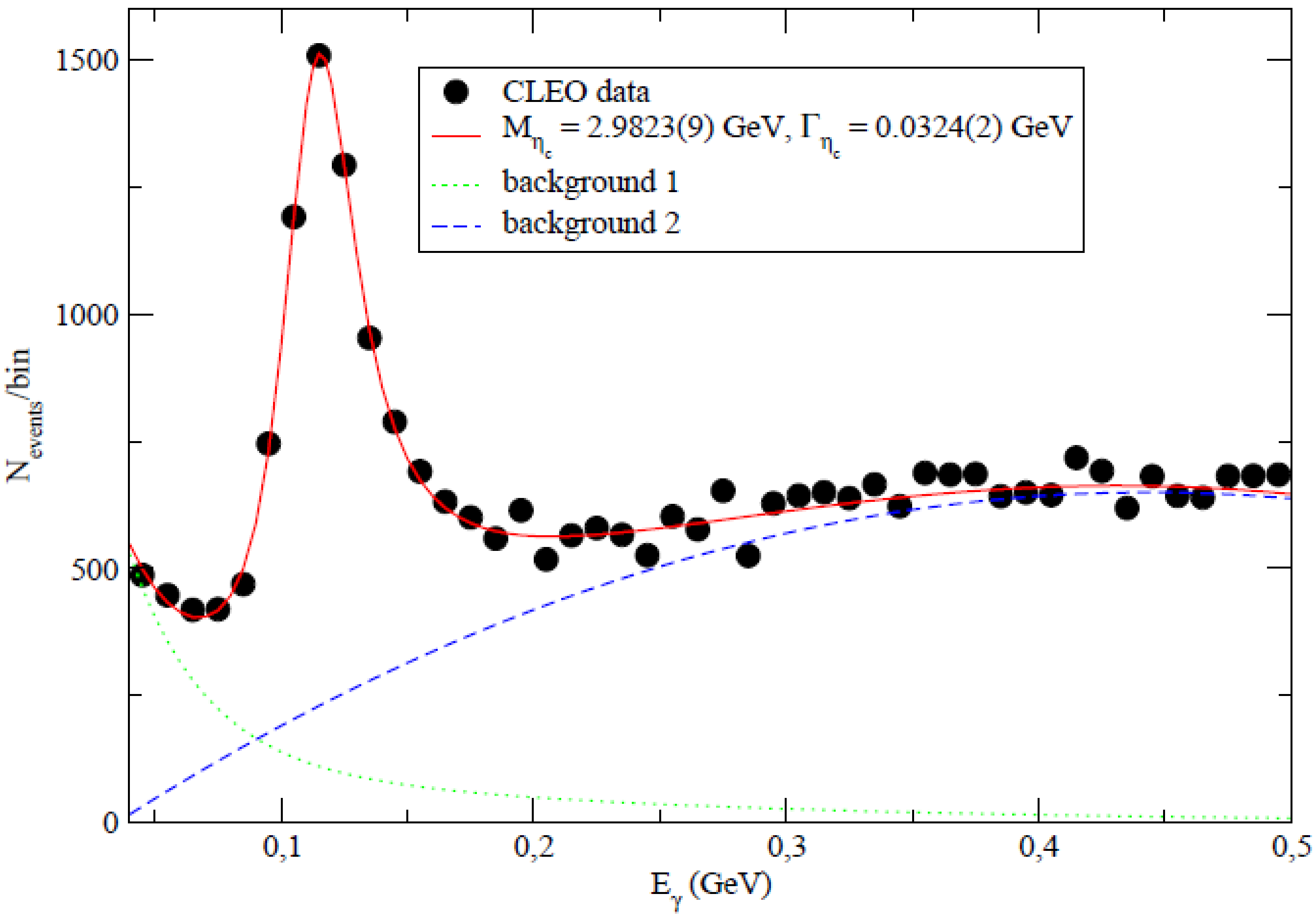
CLEO way



η_c mass and width in radiative J/Ψ decays

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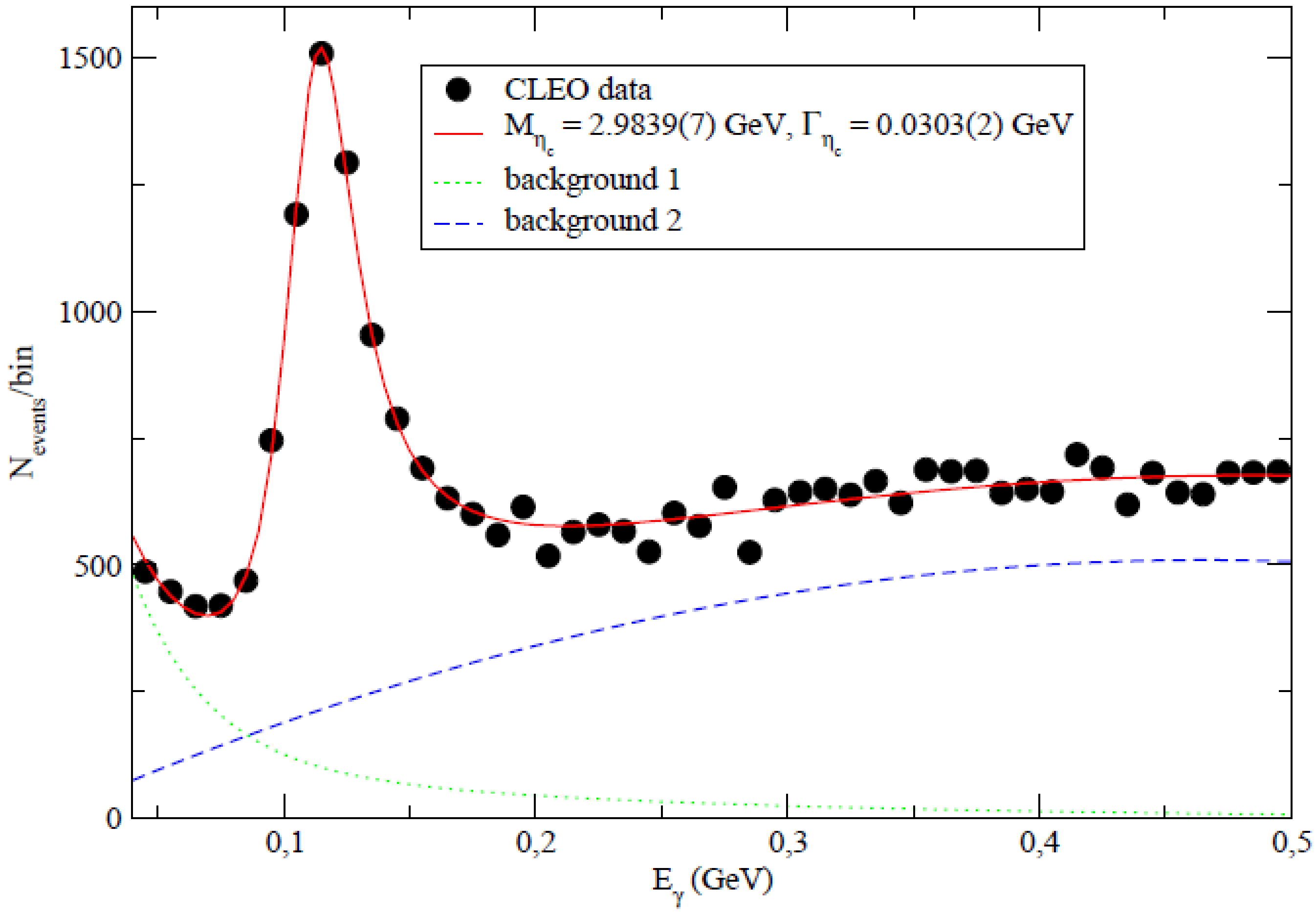
CLEO way without exponential suppression



η_c mass and width in radiative J/Ψ decays

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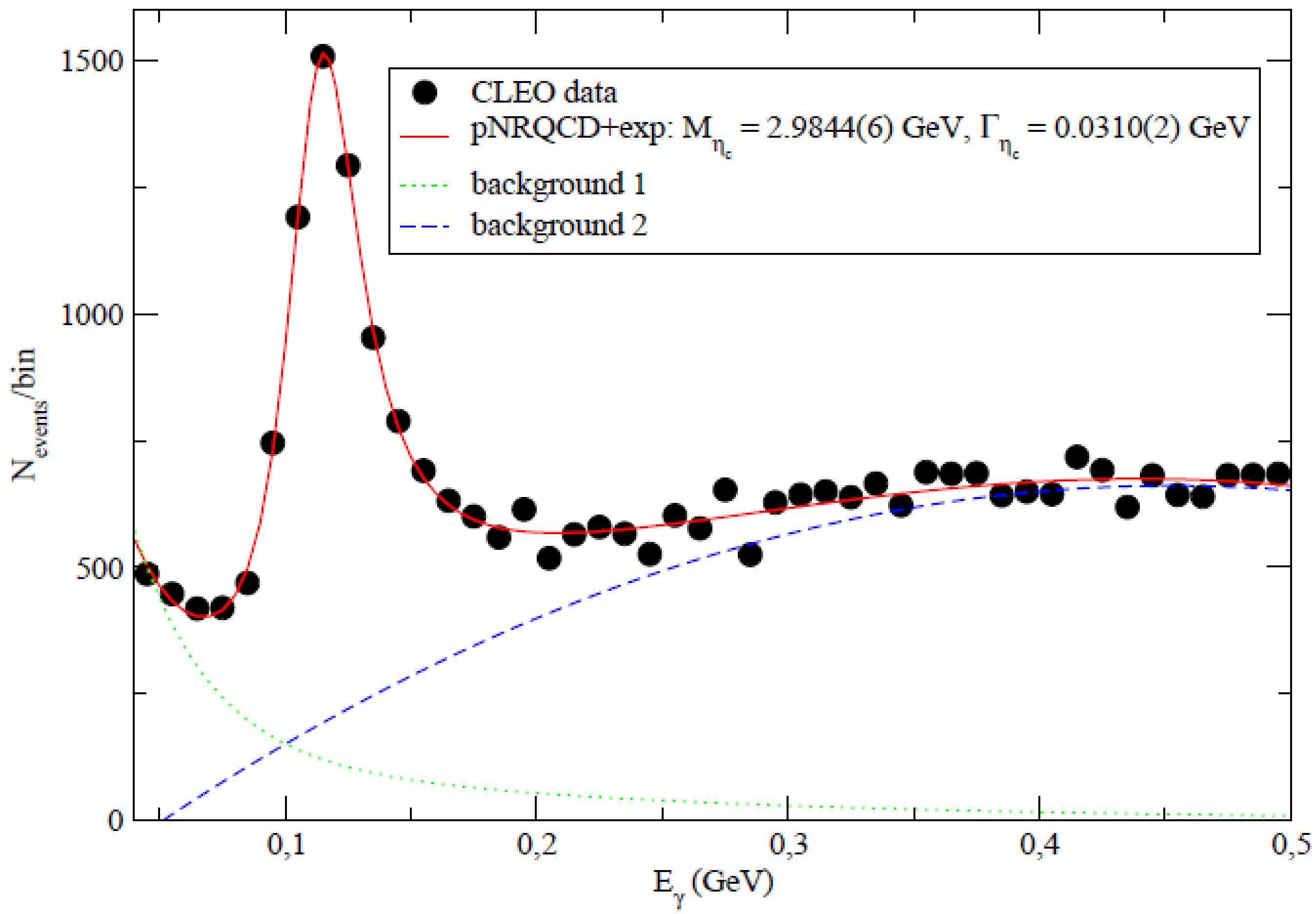
pNRQCD plus exponential suppression



η_c mass and width in radiative J/Ψ decays

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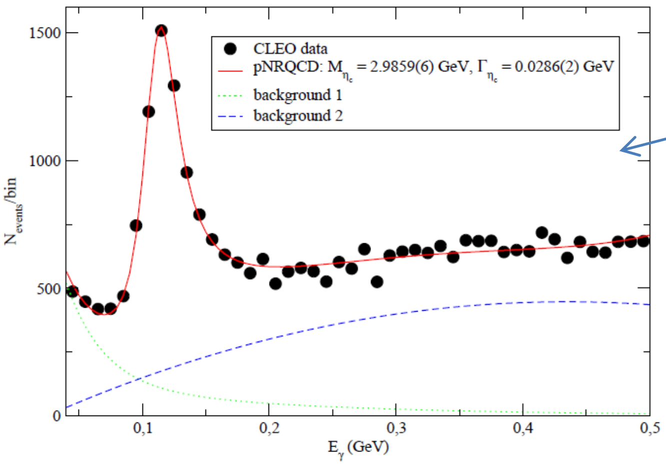
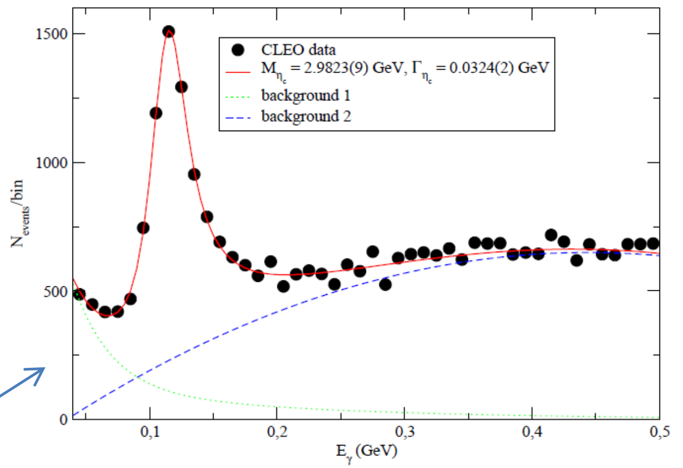
Lineshape in $J/\Psi \rightarrow \eta_c \gamma$ using pNRQCD





Differences with the CLEO fit

- No damping functions, which do not seem to have a theoretical justification. They account for about 50% difference in the η_c mass.
- Damping functions require a larger background above the η_c peak. The absence of the damping functions accounts for a background about 30% smaller than in the CLEO analysis.
- The use of the non-relativistic Breit–Wigner $\times E_\gamma^3$ distribution instead of the relativistic Breit–Wigner $\times E_\gamma^3$ distribution used in the CLEO analysis accounts for about 50% difference in the η_c mass.

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CONCLUSIONS

● Radiative decays of quarkonia are/will be subject of research in CLEO-c, BaBar, Belle, BES-III.

● One can take advantage of the hierarchy of scales the problem has and develop an EFT approach (pNRQCD) able to study them systematically.

● Within pNRQCD at $O(v^2)$ one obtains Γ(**$J/\Psi \to \gamma\ \eta_c$) in agreement** with experiment.

● A description of the lineshape of this process is currently in progress: Γ(**$J/\Psi \to \gamma\ \eta_c$) and m_{η_c}**.

● We find that the M1 contribution overcomes completely that of E1.

● Getting the br from the lineshape is not straightforward.

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SKIPPED SLIDES

Outlook

- We plan to include the first relativistic correction of order E_γ/m_c ($\sim \alpha_s^4$ around the η_c peak). Note that relativistic corrections of order $\langle p\rangle^2/m_c^2$ are reabsorbed in the overall normalization while corrections coming form the multipole expansion are of order $E_\gamma^2\langle r\rangle^2$ ($\sim \alpha_s^6$ around the η_c peak) and therefore suppressed in the peak region.

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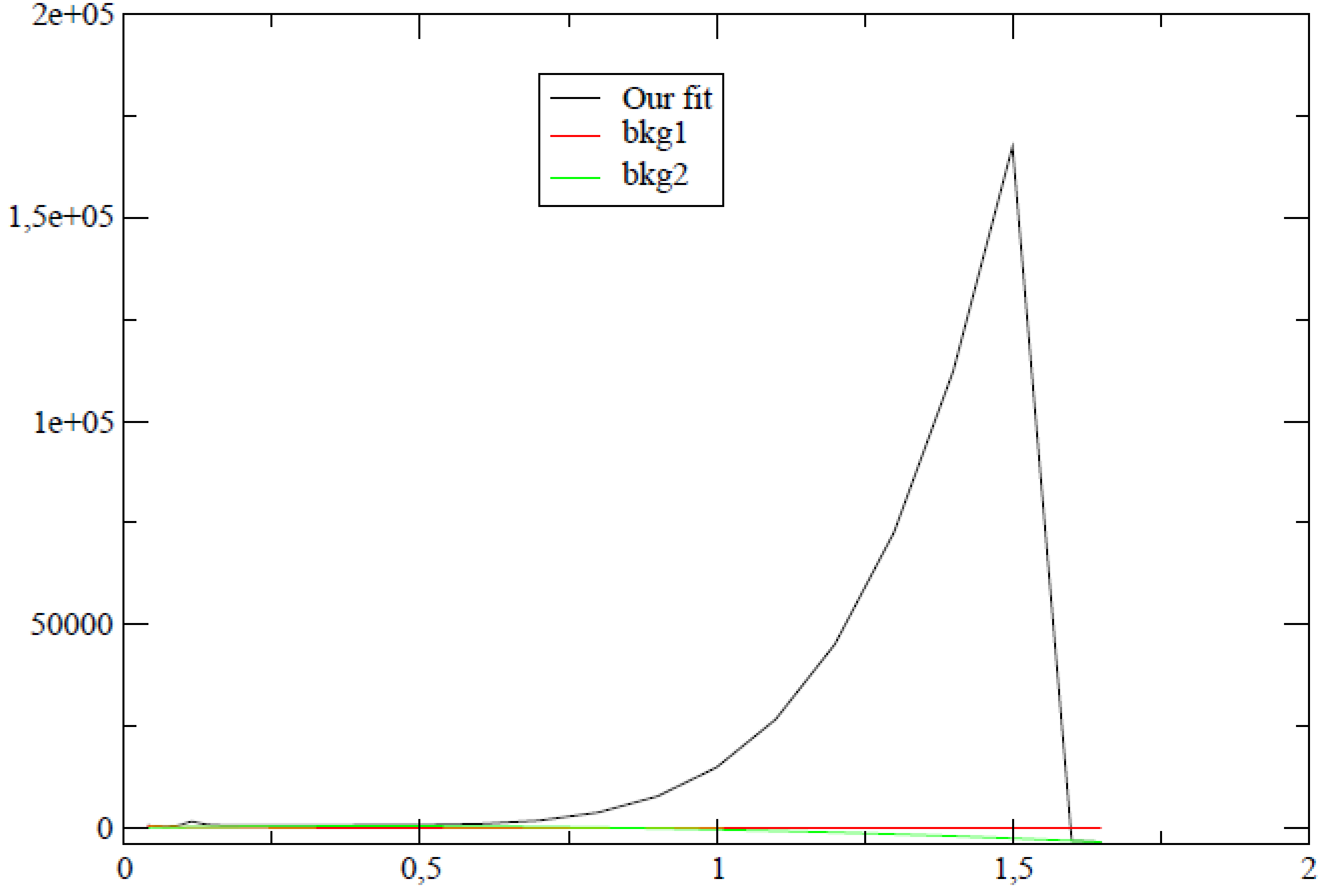
Our bad high-energy behaviour



η_c mass and width in radiative J/Ψ decays

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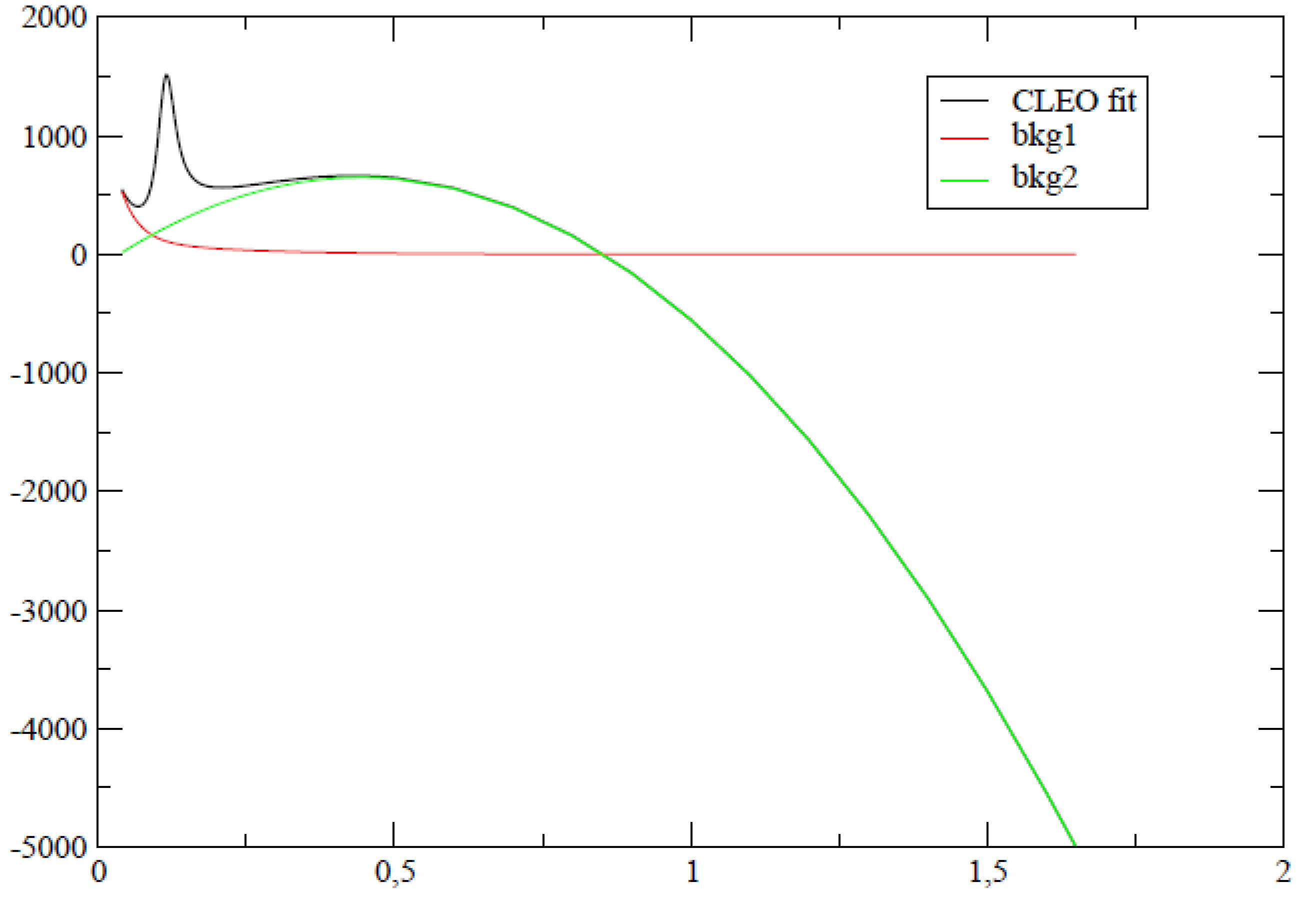
CLEO bad high-energy behaviour



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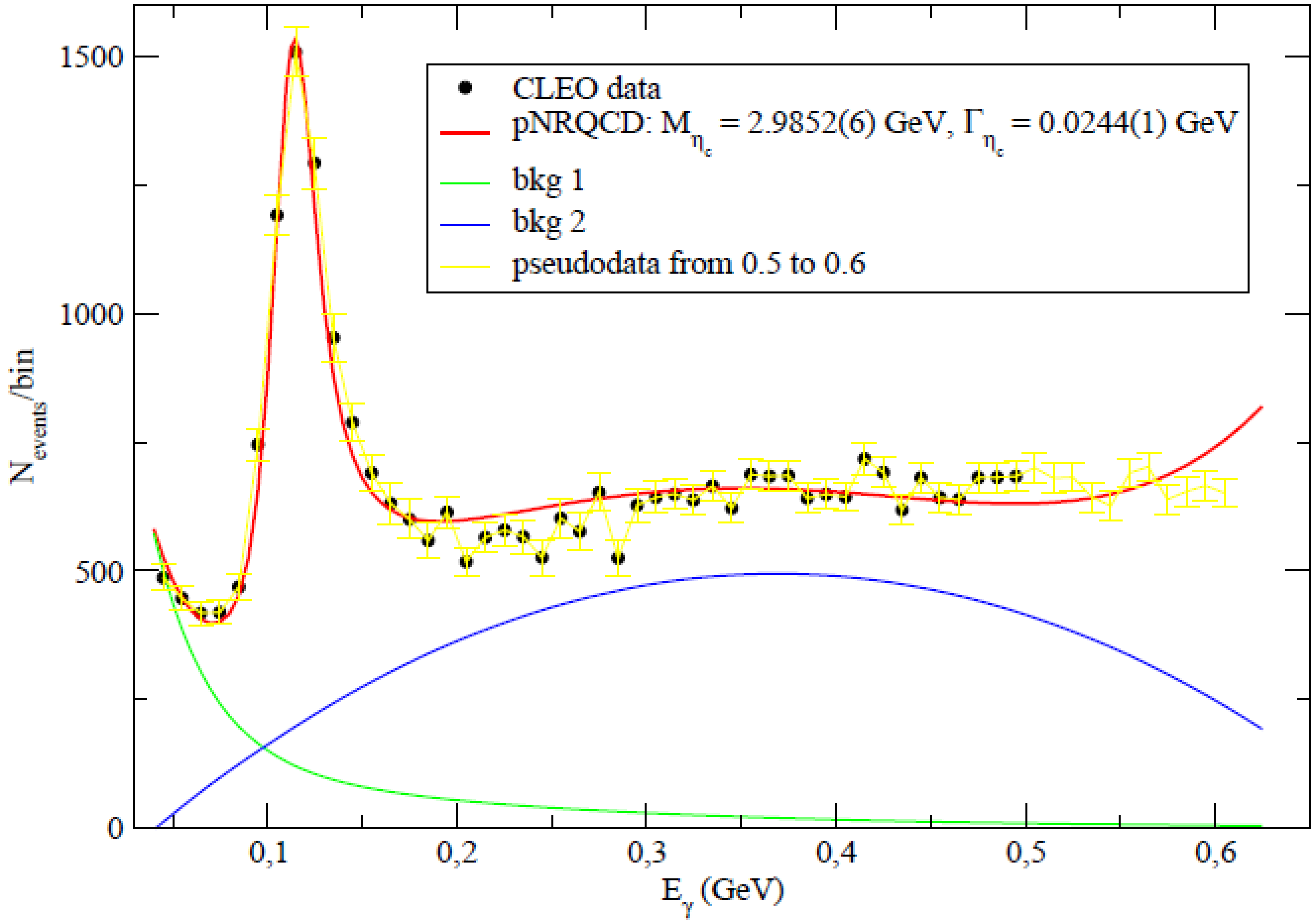
Our fit including pseudodata



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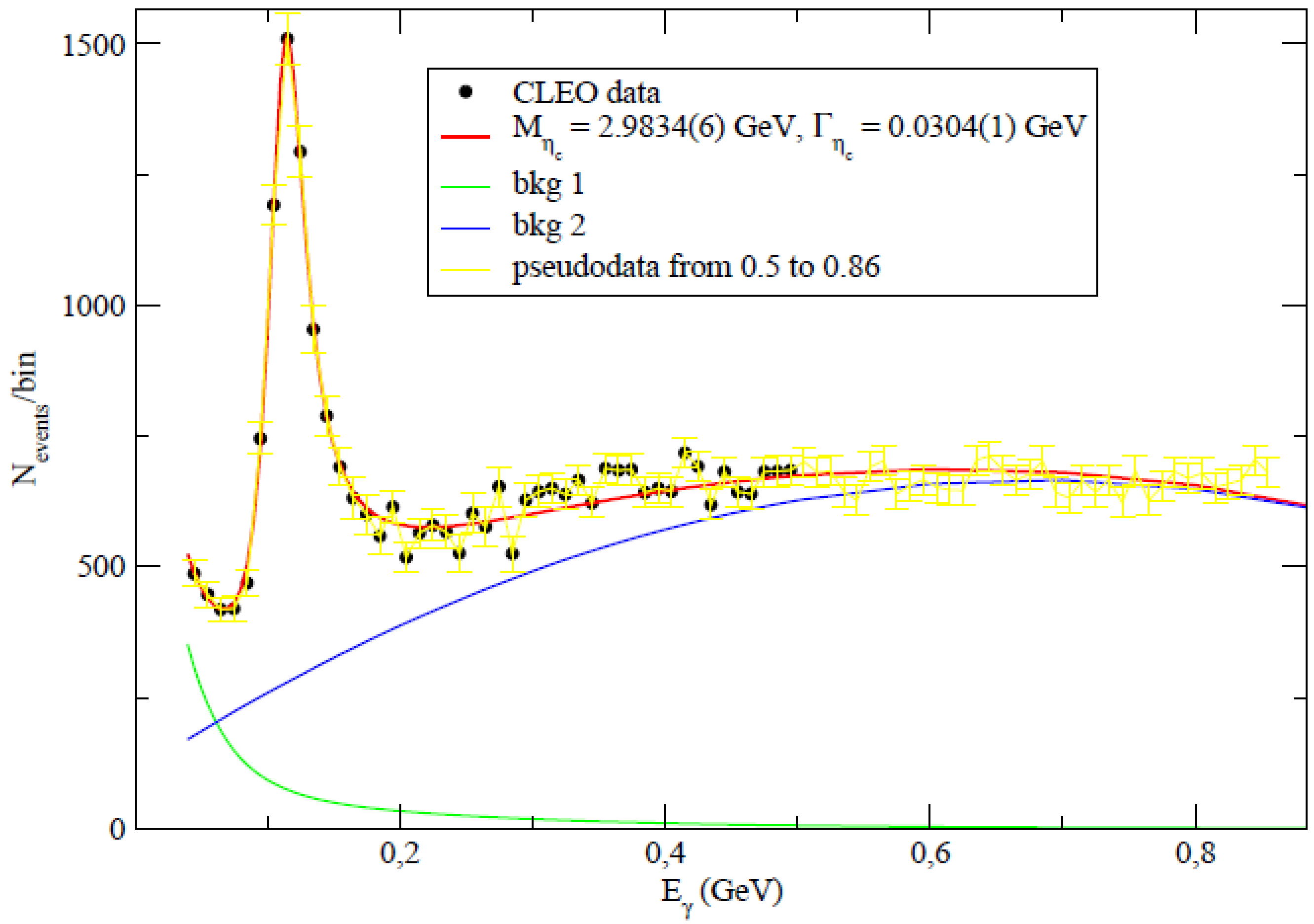
CLEO way with pseudodata



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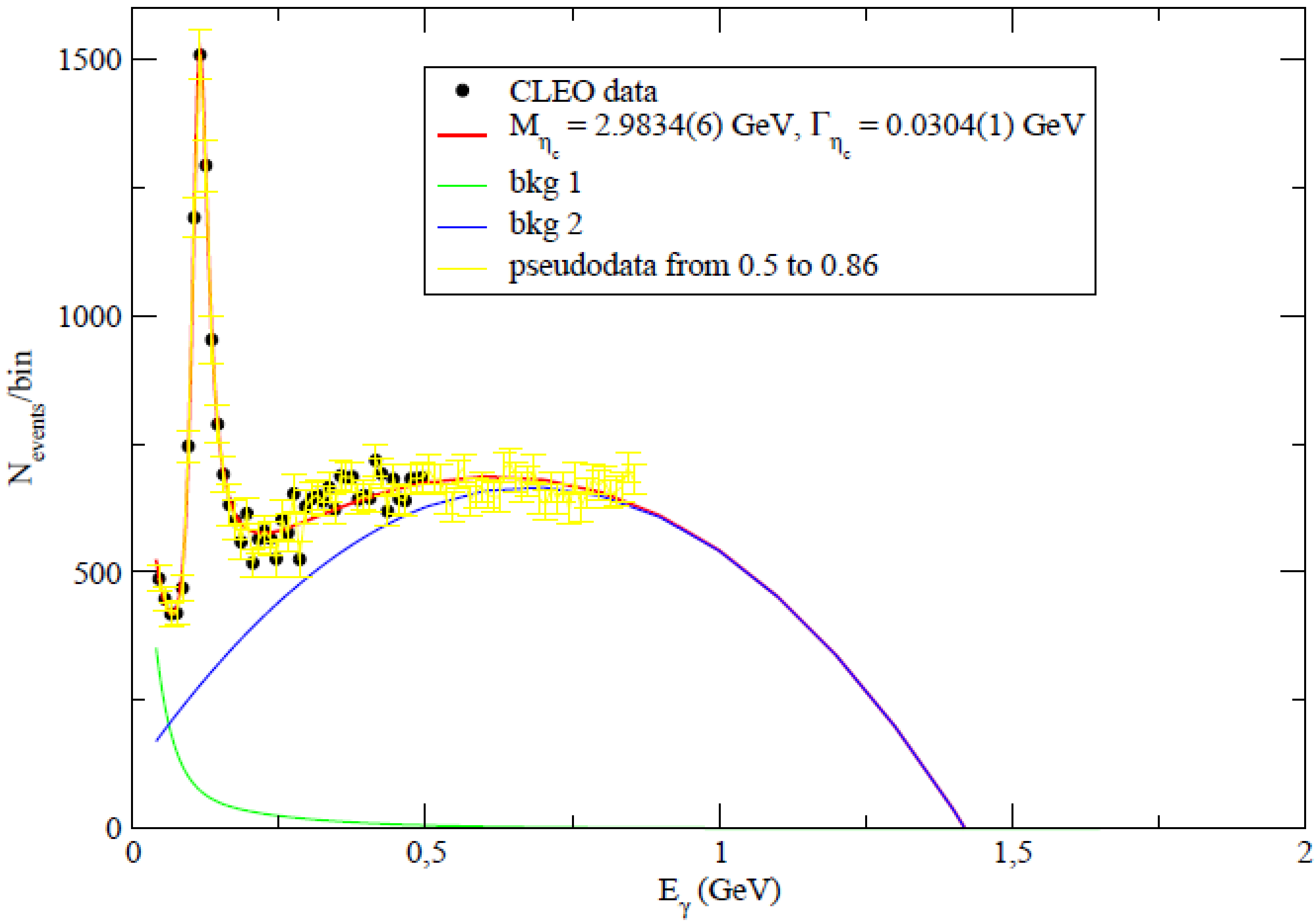

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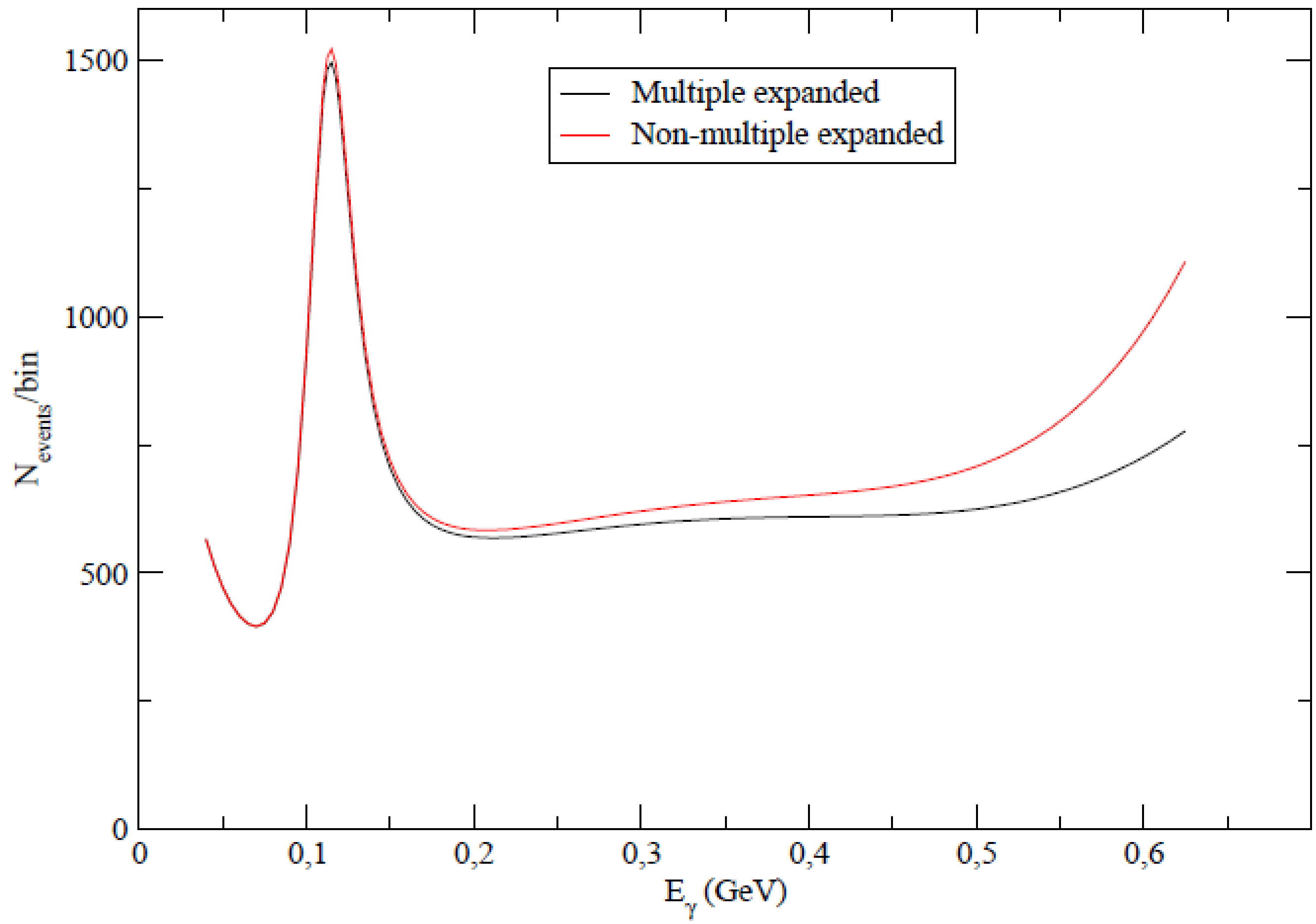
Multiple expanding or not multiple expanding?



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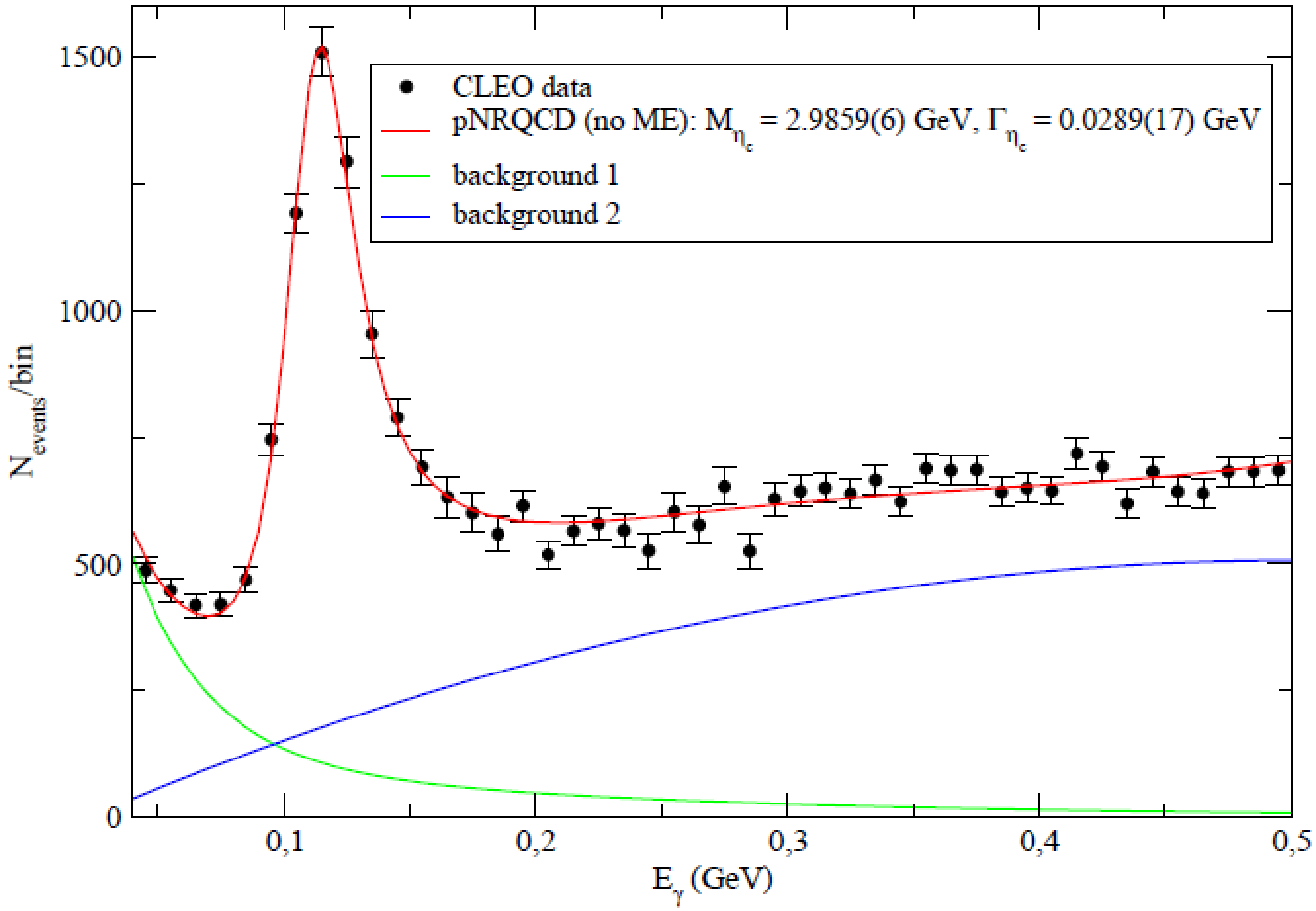
Not multiple expanding



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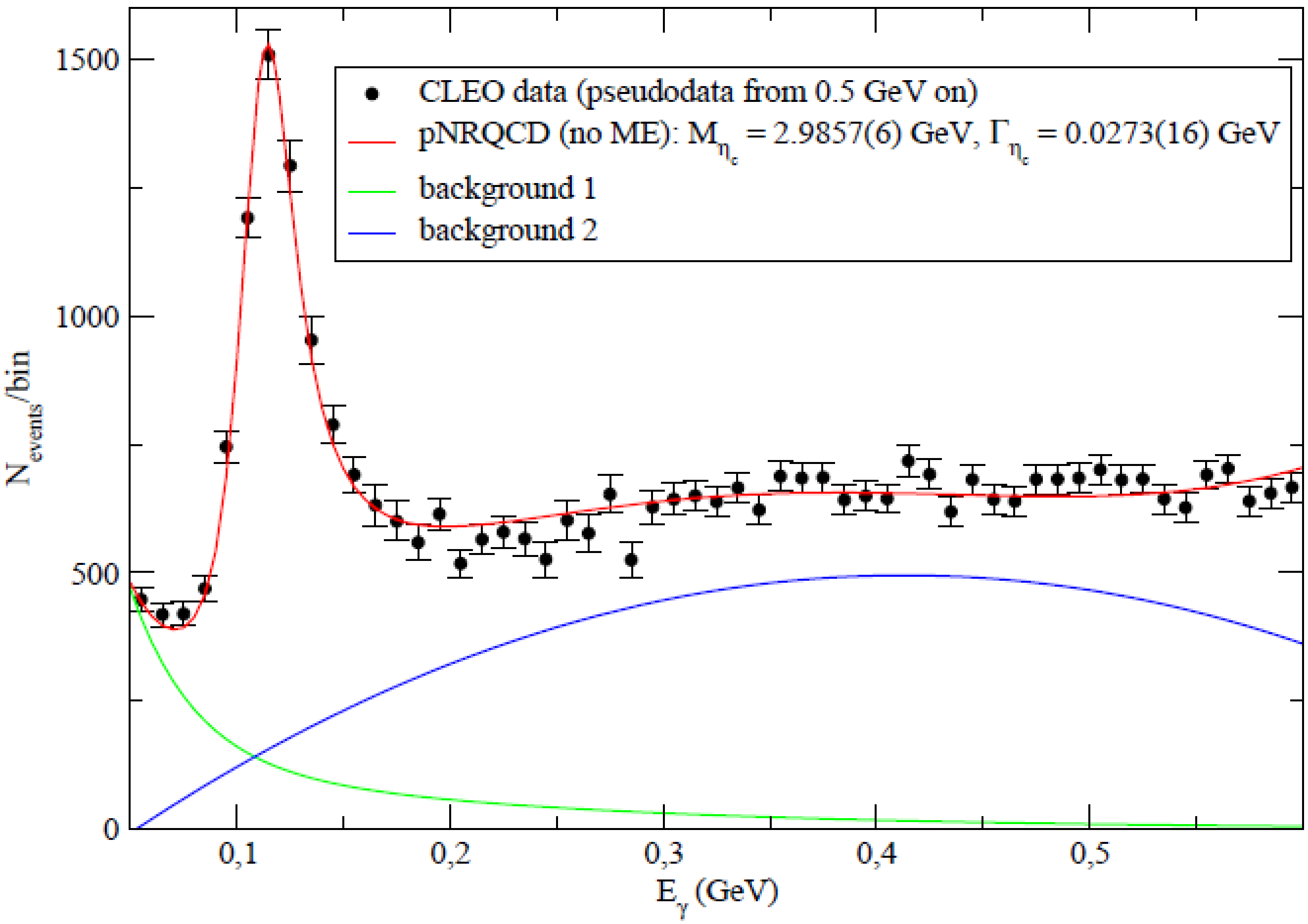
Not multiple expanding with pseudodata



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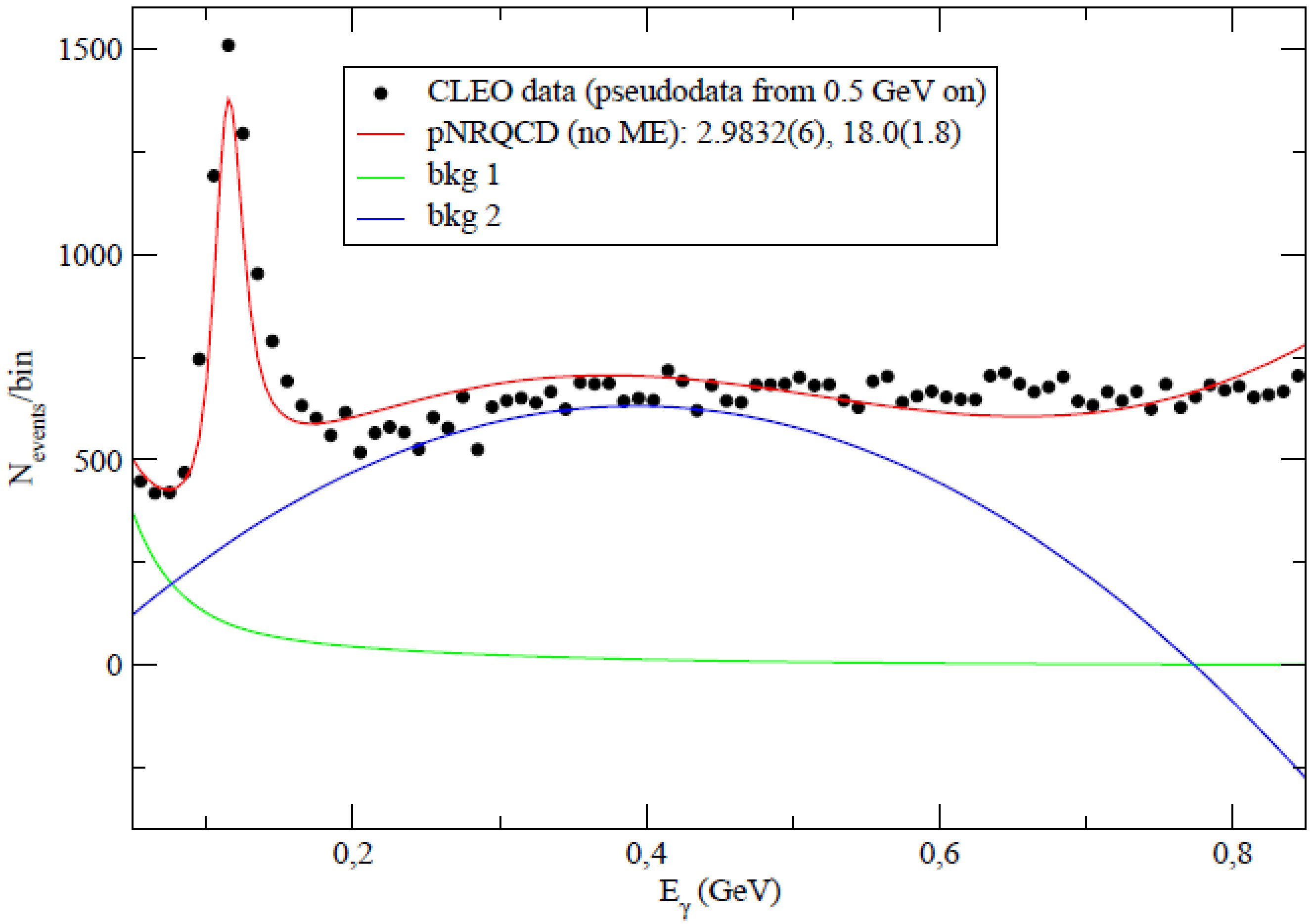
Not multiple expanding with pseudodata



η_c mass and width in radiative J/Ψ decays

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