Gluino Pair Production at Threshold

Peter Marquard

Institute for Theoretical Particle Physics
Karlsruhe Institute of Technology

in collaboration with

M. Kauth, J.H. Kühn, M. Steinhauser

SPONSORED BY THE
Federal Ministry of Education and Research

Karlsruhe Institute of Technology

Computational Theoretical Particle Physics
SFB TR9

ICHEP 2012, Melbourne

Motivation

- If SUSY is realized the precise determination of the properties of SUSY particles is an important task
- Gluinos decay through cascades into the LSP + multiple jets $\rightarrow$ direct determination of gluino properties difficult
- Investigation of bound states of gluinos if they exist and a precise analysis of the behaviour at threshold might provide otherwise inaccessible information

Gluino Properties

- Gluinos only have strong interactions, main decay channel $\tilde{g} \rightarrow \tilde{q} + q$ if kinematically allowed

Gluino Properties

- Gluinos only have strong interactions, main decay channel $\tilde{g} \rightarrow \tilde{q} + q$ if kinematically allowed
- if $m_{\tilde{g}} \leq m_{\tilde{q}}$ gluino decays into squarks impossible $\rightarrow$ small decay width $\rightarrow$ formation of bound states possible.

Gluino Properties

- Gluinos only have strong interactions, main decay channel $\tilde{g} \rightarrow \tilde{q} + q$ if kinematically allowed
- if $m_{\tilde{g}} \leq m_{\tilde{q}}$ gluino decays into squarks impossible $\rightarrow$ small decay width $\rightarrow$ formation of bound states possible.
- if $m_{\tilde{g}} > m_{\tilde{q}}$ then the decay $\tilde{g} \rightarrow \tilde{q} + q$ is possible $\rightarrow$ no boundstates
- but, if gluino width $\Gamma_{\tilde{g}} = \mathcal{O}(\text{GeV})$ visible threshold effects (cmp $t\bar{t}$ system)

Gluino Properties cont'd

- Gluinos are color octetts
- Gluino pairs can form several color states according to

$$8 \otimes 8 = 1 \oplus 8_S \oplus 8_A \oplus 10_A \oplus \overline{10}_A \oplus 27$$

Gluino Properties cont'd

- Gluinos are color octetts
- Gluino pairs can form several color states according to

$$8 \otimes 8 = \underbrace{1 \oplus 8_S \oplus 8_A}_{\text{attractive}} \oplus 10_A \oplus \overline{10}_A \oplus \underbrace{27}_{\text{repulsive}}$$

Gluino Properties cont'd

- Gluinos are color octetts
- Gluino pairs can form several color states according to

$$8 \otimes 8 = \underbrace{1 \oplus 8_S \oplus 8_A}_{\text{attractive}} \oplus 10_A \oplus \overline{10}_A \oplus \underbrace{27}_{\text{repulsive}}$$

- if the gluino width is small enough, gluinos may form meson-like boundstates
- Consider in the following production of gluino pairs in the threshold region

Scenarios

Consider three MSUGRA scenarios:

- Scenario P (SPS 4):

$$m_{\tilde{g}} = 734\,\mathrm{GeV} \quad \bar{m}_{\tilde{q}} = 714\,\mathrm{GeV} \quad \Gamma_{\tilde{g}} = 1.24\,\mathrm{GeV} \quad \tilde{g} \to \tilde{b}\bar{b}$$

Scenarios

Consider three MSUGRA scenarios:

- Scenario P (SPS 4):

$$m_{\tilde{g}} = 734\,\mathrm{GeV} \quad \bar{m}_{\tilde{q}} = 714\,\mathrm{GeV} \quad \Gamma_{\tilde{g}} = 1.24\,\mathrm{GeV} \quad \tilde{g} \to \tilde{b}\bar{b}$$

- Scenario X:

$$m_{\tilde{g}} = 1300\,\mathrm{GeV} \quad \bar{m}_{\tilde{q}} = 1360\,\mathrm{GeV} \quad \Gamma_{\tilde{g}} = 1.83\,\mathrm{GeV} \quad \tilde{g} \to \tilde{t}\bar{t}$$

Scenarios

Consider three MSUGRA scenarios:

- Scenario P (SPS 4):

$$m_{\tilde{g}} = 734\,\mathrm{GeV} \quad \bar{m}_{\tilde{q}} = 714\,\mathrm{GeV} \quad \Gamma_{\tilde{g}} = 1.24\,\mathrm{GeV} \quad \tilde{g} \to \tilde{b}\bar{b}$$

- Scenario X:

$$m_{\tilde{g}} = 1300\,\mathrm{GeV} \quad \bar{m}_{\tilde{q}} = 1360\,\mathrm{GeV} \quad \Gamma_{\tilde{g}} = 1.83\,\mathrm{GeV} \quad \tilde{g} \to \tilde{t}\bar{t}$$

- Scenario Y:

$$m_{\tilde{g}} = 1370\,\mathrm{GeV} \quad \bar{m}_{\tilde{q}} = 1235\,\mathrm{GeV} \quad \Gamma_{\tilde{g}} = 10\,\mathrm{GeV} \quad \tilde{g} \to \tilde{t}\bar{t}$$

Theoretical framework

- Threshold phenomena best described using non-relativistic QCD (NRQCD)
- Master formula for partonic cross section

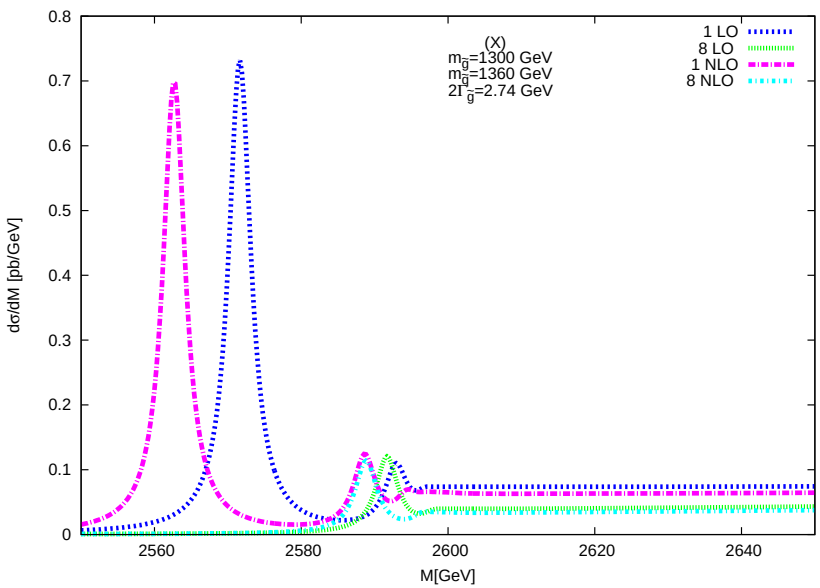
$$M_{(\tilde{g}\tilde{g})}\frac{d\hat{\sigma}}{dM_{(\tilde{g}\tilde{g})}} = \mathcal{F}(PP \to \tilde{g}\tilde{g}X)\frac{1}{m_{\tilde{g}}^2}\mathrm{Im}G(M + i\Gamma)$$

- $\mathcal{F}(PP \to \tilde{g}\tilde{g}X)$ contains the hard kernel
- Threshold behaviour encoded in Green's function $G(M + i\Gamma)$
- Take into account contributions from all colour states

Green's function

Green's function can be calculated in NRQCD

$$G(M+i\Gamma) = \frac{ivm_{\tilde{g}}^2}{4\pi} + \frac{C^{[R]}\alpha_s(\mu)m_{\tilde{g}}^2}{4\pi}\left[\log\frac{i\mu}{2m_{\tilde{g}}v} + \psi^{(0)}(1-\kappa) + \frac{\alpha_s(\mu)}{4\pi}g_{NLO}\right], \quad \kappa = i\frac{C^{[R]}\alpha_s(\mu)}{2v}$$



perturbative Green's function has double and higher poles $\rightarrow$ resummation

Production Channels

Green's function sensitive to color configuration $\rightarrow$ hard part has to be calculated for specific color states

Production Channels

Green's function sensitive to color configuration $\rightarrow$ hard part has to be calculated for specific color states

- $1, 8_S, 27$
  $gg \rightarrow \tilde{g}\tilde{g}$ at tree level, squarks enter at 1-loop

Production Channels

Green's function sensitive to color configuration $\rightarrow$ hard part has to be calculated for specific color states

- $1, 8_S, 27$
  $gg \rightarrow \tilde{g}\tilde{g}$ at tree level, squarks enter at 1-loop
- 8_A
  $q\bar{q} \rightarrow \tilde{g}\tilde{g}$ at tree level, suppressed if $m_{\tilde{g}} = m_{\tilde{q}}$
  $\mathcal{F}(q\bar{q} \rightarrow \tilde{g}\tilde{g}) \propto \frac{1-r}{1+r}, \quad r = m_{\tilde{q}}^2/m_{\tilde{g}}^2$

Production Channels

Green's function sensitive to color configuration $\rightarrow$ hard part has to be calculated for specific color states

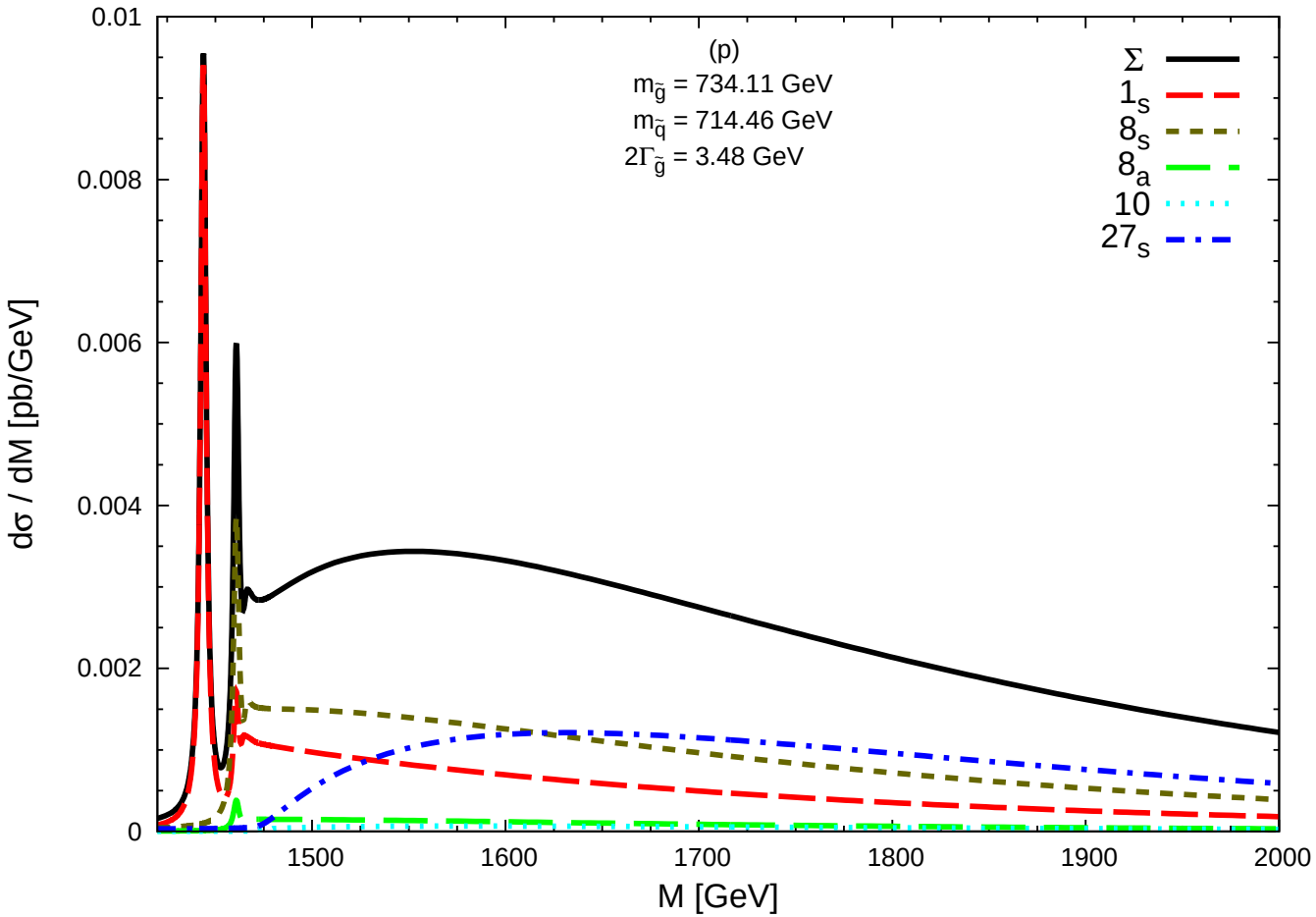
- $1, 8_S, 27$
  $gg \rightarrow \tilde{g}\tilde{g}$ at tree level, squarks enter at 1-loop
- 8_A
  $q\bar{q} \rightarrow \tilde{g}\tilde{g}$ at tree level, suppressed if $m_{\tilde{g}} = m_{\tilde{q}}$
  $\mathcal{F}(q\bar{q} \rightarrow \tilde{g}\tilde{g}) \propto \frac{1-r}{1+r}, \quad r = m_{\tilde{q}}^2/m_{\tilde{g}}^2$
- 10
  only accessible via real radiation at NLO
  $q\bar{q} \rightarrow g\tilde{g}\tilde{g}, qg \rightarrow q\tilde{g}\tilde{g}, \bar{q}g \rightarrow \bar{q}\tilde{g}\tilde{g}$

Calculation

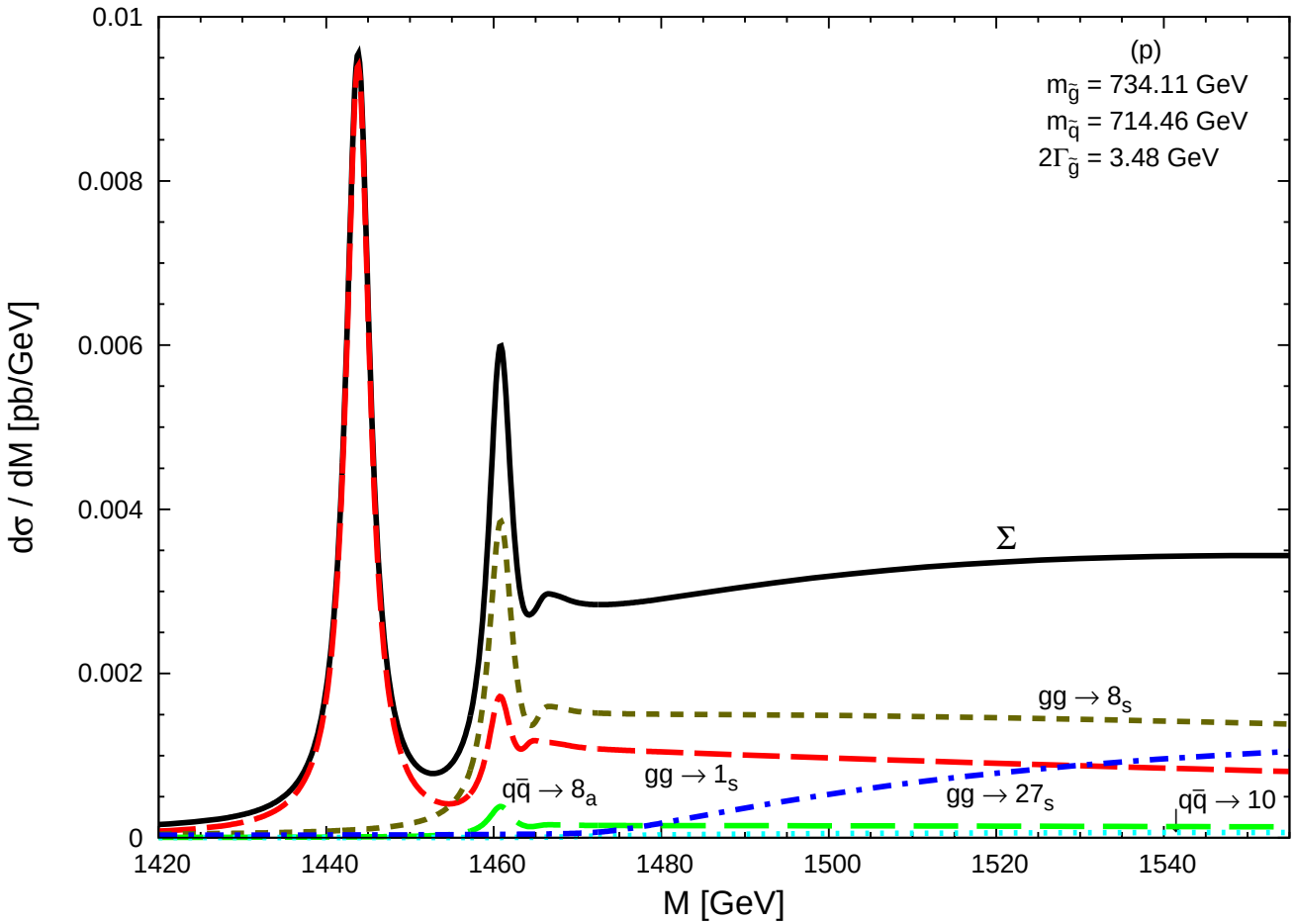
Building blocks:

- Green's function at NLO
- Hard kernel: evaluation of the process $pp \to \tilde{g}\tilde{g}X$ at threshold in perturbation theory at NLO separately for each color configuration
- Inclusion of real radiation for all production channels @NLO to cancel infrared singularities
- Renormalization in the $\overline{\mathrm{DR}}$ scheme
- PDFs: MSTW2008 NLO

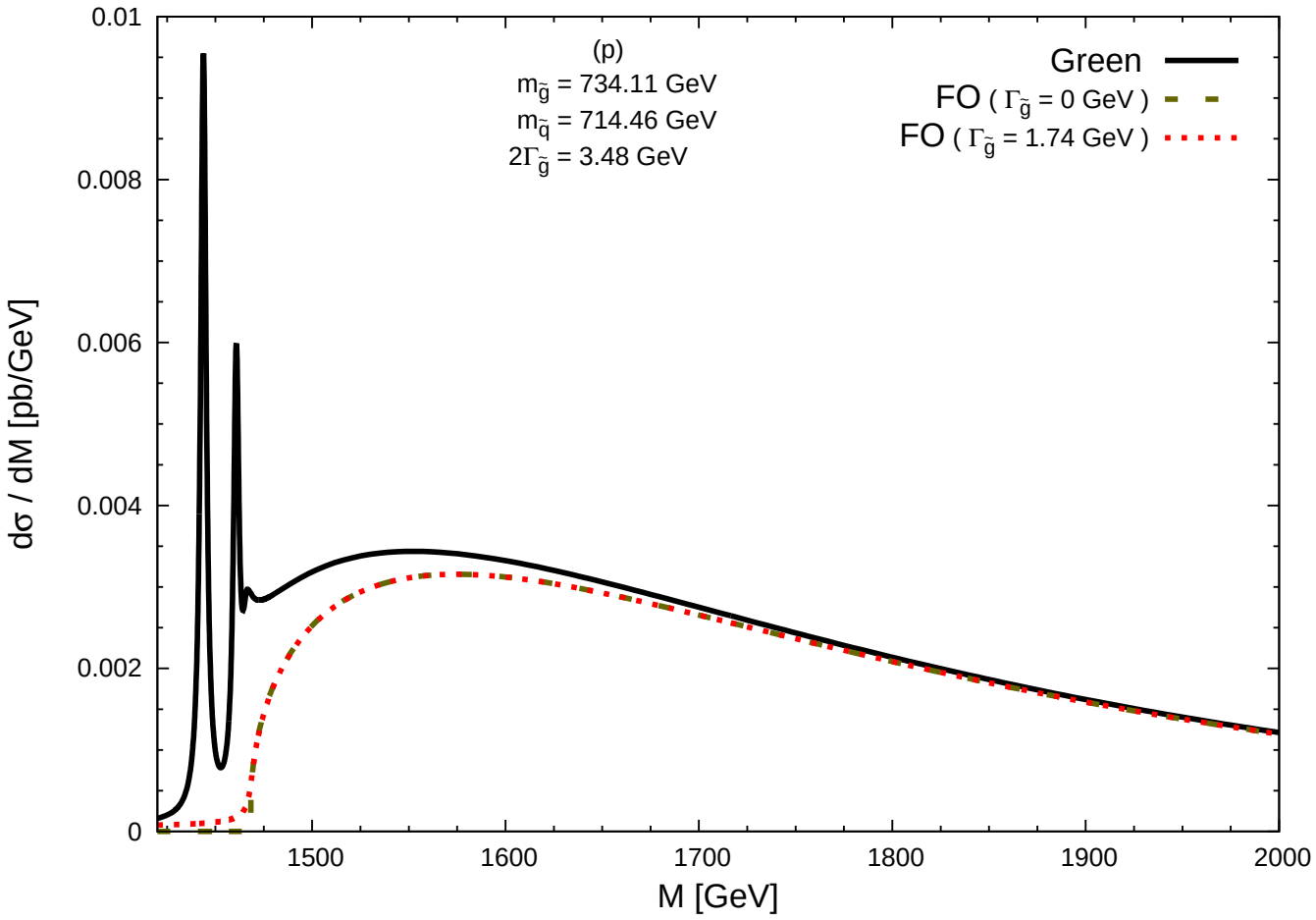
Scenario P – differential cross section



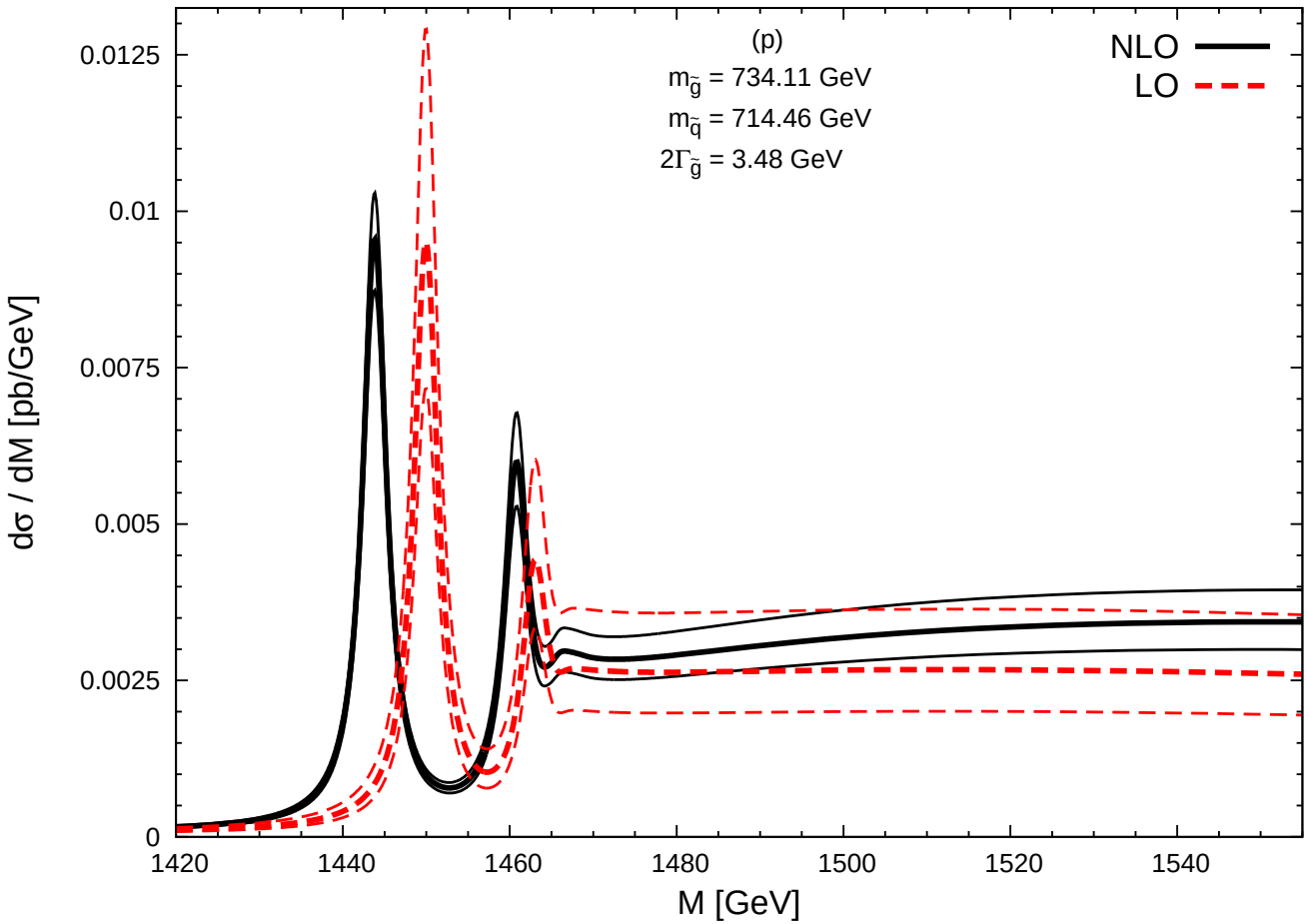
Scenario P – differential cross section



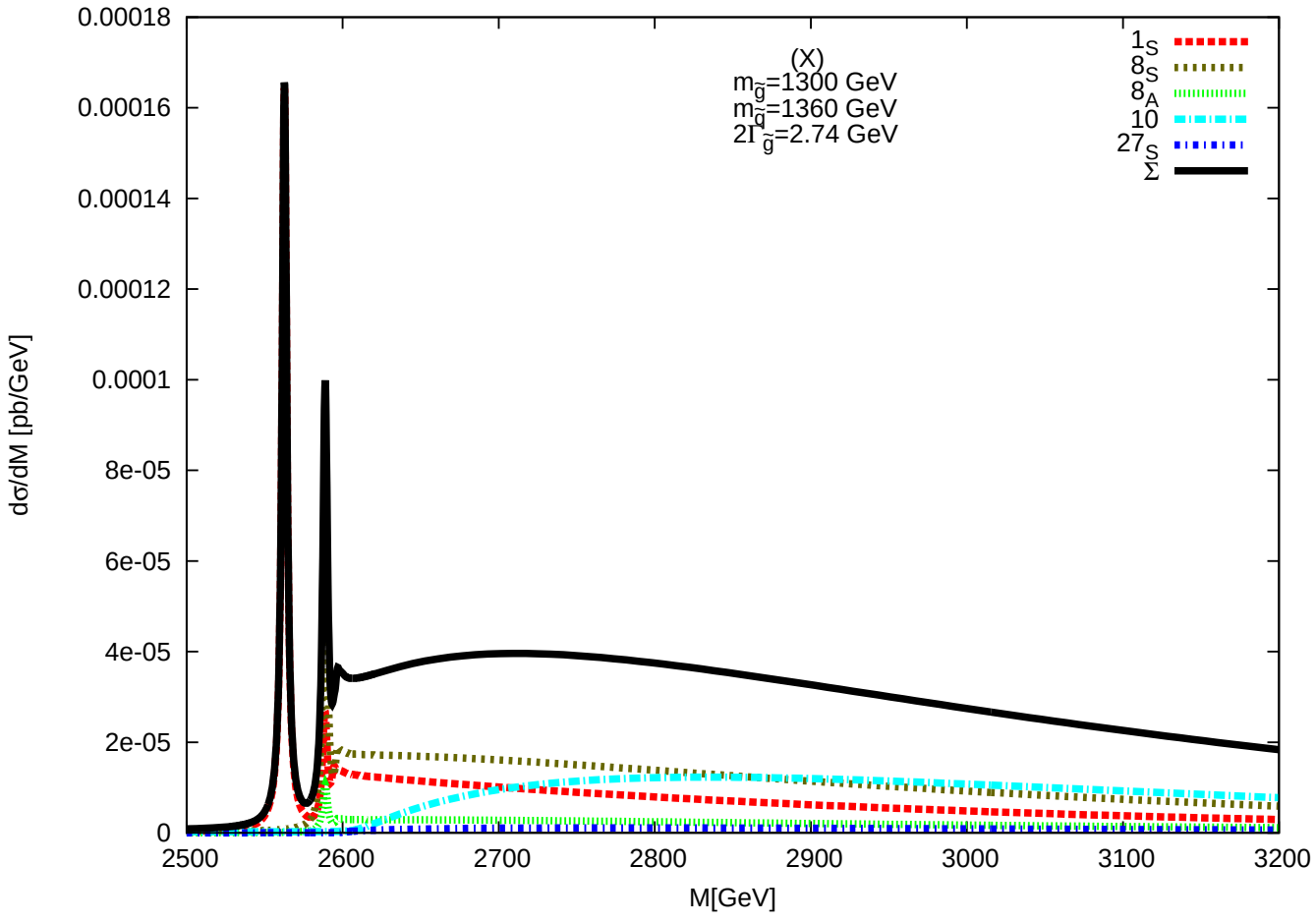
Scenario P – comparison with fixed order calculation



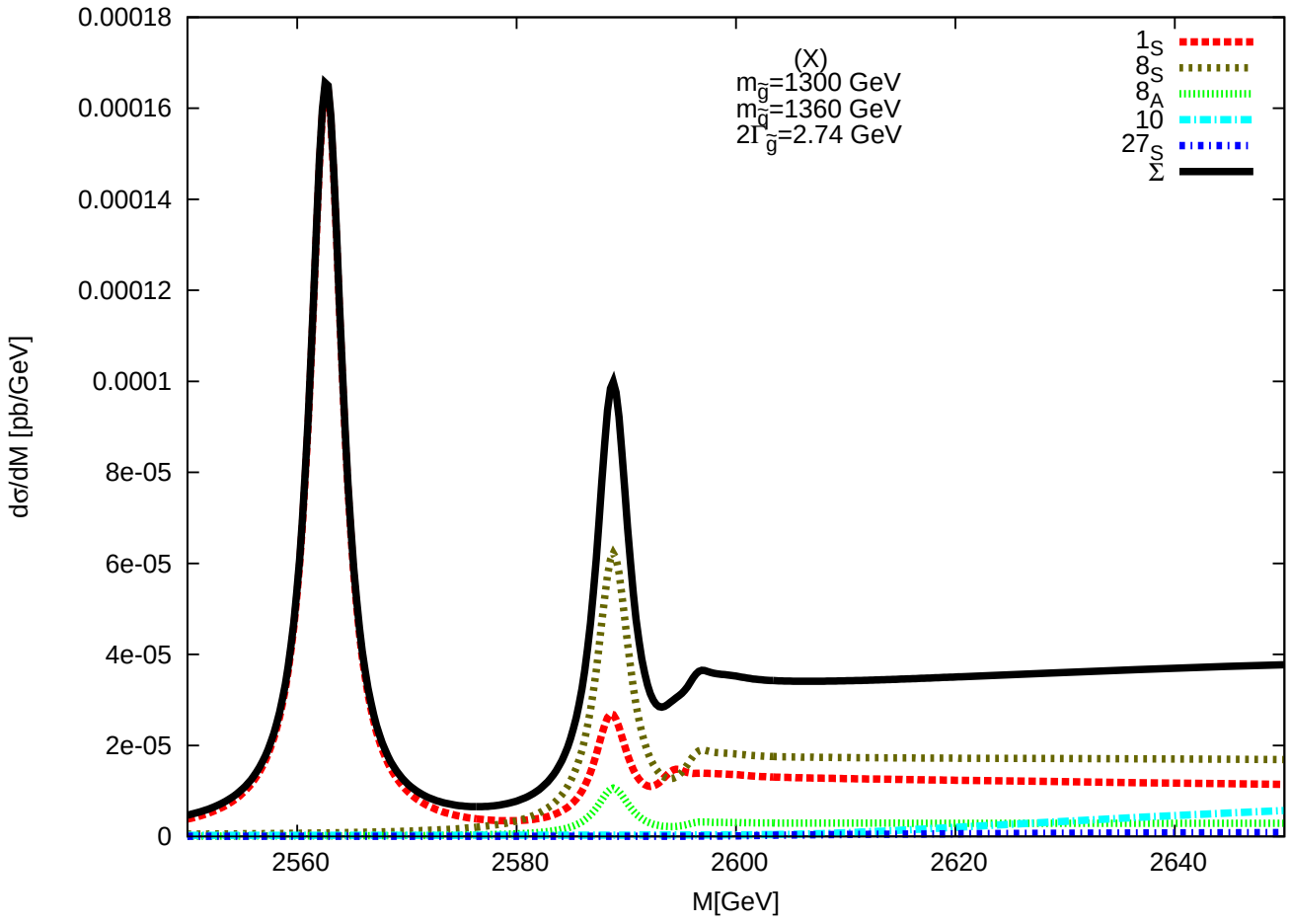
Scenario P – scale dependence



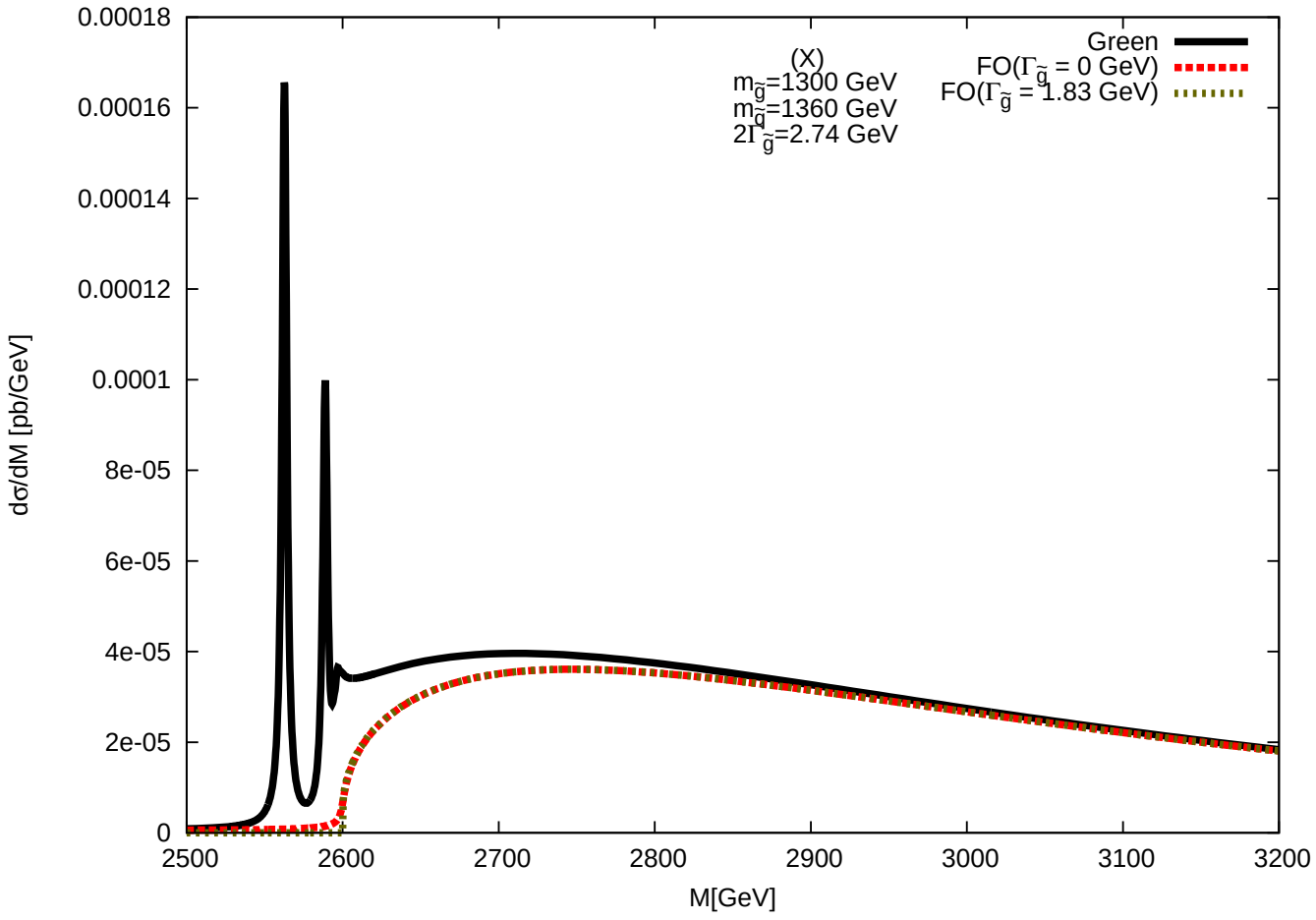
Scenario X – differential cross section



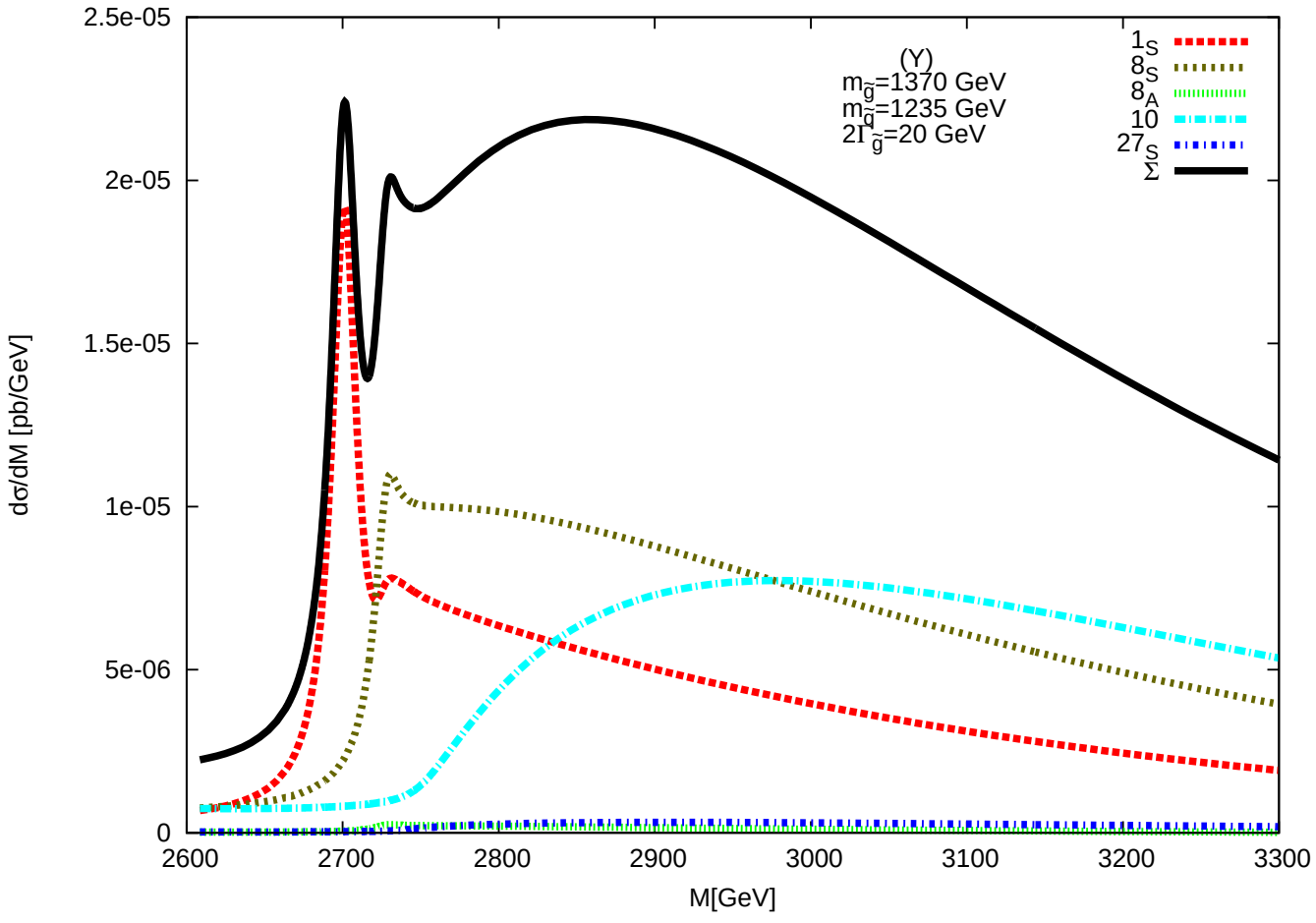
Scenario X – differential cross section



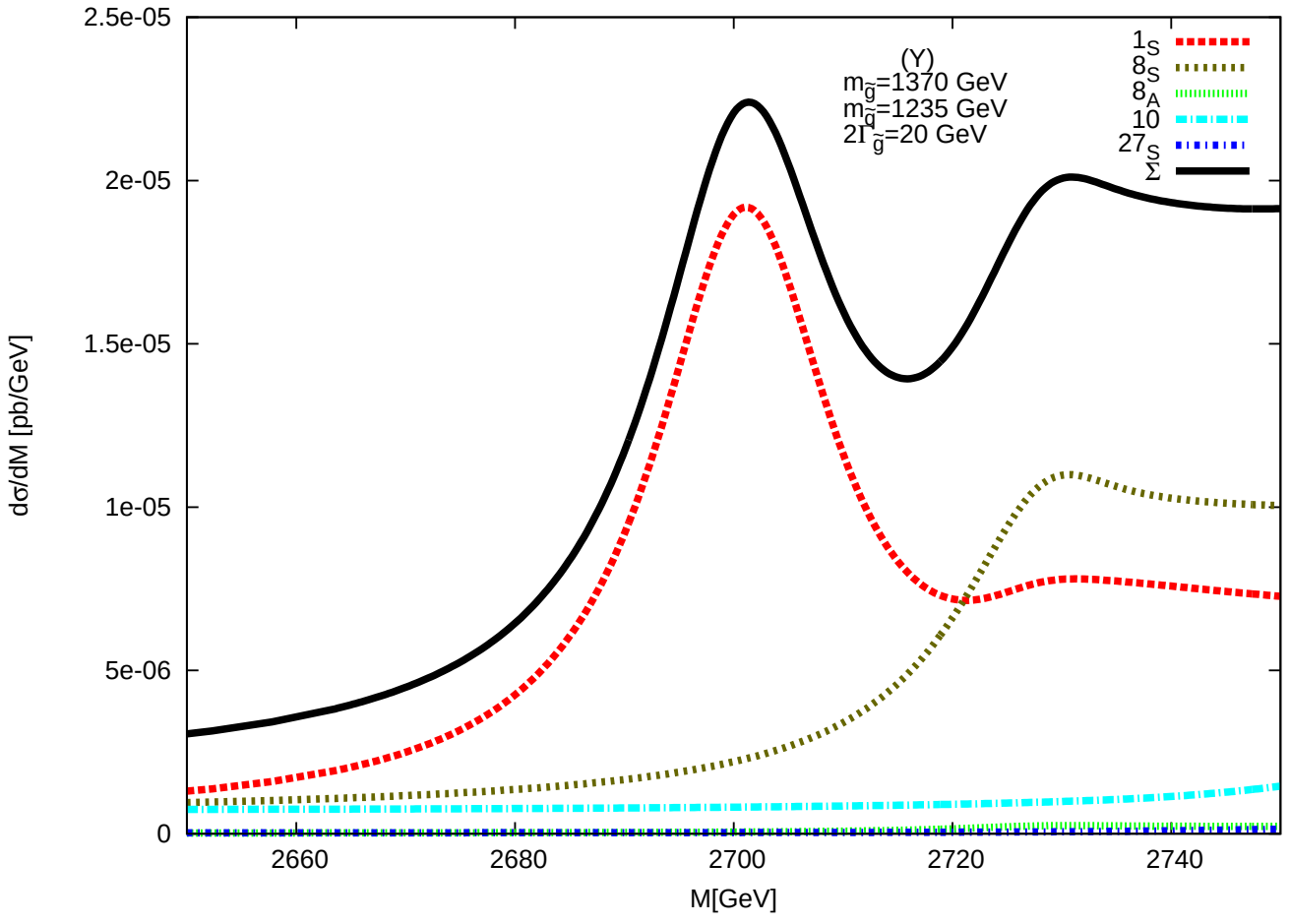
Scenario X – comparison with fixed order calculation



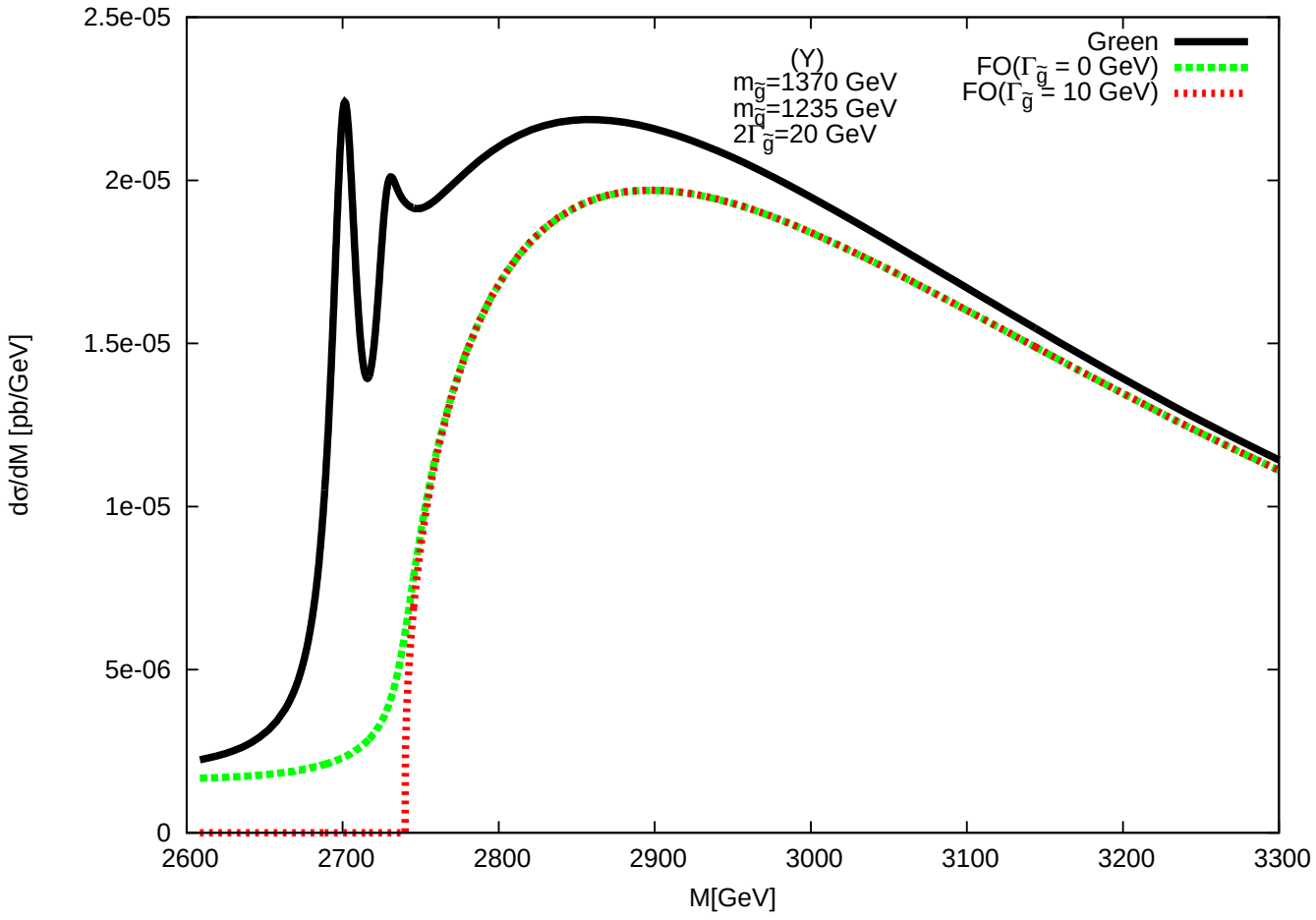
Scenario Y – differential cross section



Scenario Y – differential cross section



Scenario Y – comparison with fixed order calculation



Conclusions

- gluinos form bound states if single gluino decays are suppressed
- improved analysis of threshold production of gluino pairs including NLO effects
- full color correlation taken into account
- comparison with fixed-order calculation gives a measure for the increase of the cross section due to threshold effects