Threshold Production of Gluino Pairs at the LHC

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Outline

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1. Introduction
2. Gluino bound states
3. Threshold production

Introduction

- If SUSY is realized the precise determination of the properties of the 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 unaccesible information

Gluino Properties

Important gluino properties relevant for this talk:

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

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

- only have strong interactions, main decay channel $\tilde{g} \to \tilde{q}q$

Consider in the following production of gluino bound states and production of gluino pairs in the threshold region

Outline

Introduction

- Gluinos can form bound states (aka gluinonium) if certain conditions are fulfilled
  - single gluino decays have to be suppressed $m_{\tilde{g}} \lesssim m_{\tilde{q}}$
  - gluinonium width smaller than level spacing
- These conditions can be fulfilled and are even realised in some SPS points.
  - single gluino dacay width of $\mathcal{O}(10\text{ MeV})$
  - level spacing and gluinonium decay width have to be checked
- Consider only production of pseudo-scalar states, higher spin states are suppressed
- Consider only color singlett configuration

Theoretical framework

- bound state properties
  – energy levels and wave functions –
  can be described in the framework of NRQCD
- have to be supplemented with a one-loop calculation for $pp \to (\tilde{g}\tilde{g})$
- master formula for S-waves

$$\hat{\sigma} = \frac{C_A^2 \pi^2 \alpha_s^2}{4} \frac{|R(0)|^2}{s(2m_{\tilde{g}})^3} (1+\mathcal{O}(\alpha_s)) \quad \Gamma = \frac{C_A^2}{2} \frac{\alpha_s^2}{m_{\tilde{g}}^2} |R(0)|^2 (1+\mathcal{O}(\alpha_s))$$

- production of higher spin states suppressed

Energy levels and wave functions

Energy levels and wave functions can be obtained from the QCD potential between two octett states

$$V = \frac{C_A \alpha_s(\mu^2)}{r} \left\{ 1 + \frac{\alpha_s(\mu^2)}{4\pi} \left[a_1 + 2\gamma_E \beta_0 + 2\beta_0 \ln(\mu r) \right] + V_{NNLO} \right\} + V_{nc}$$

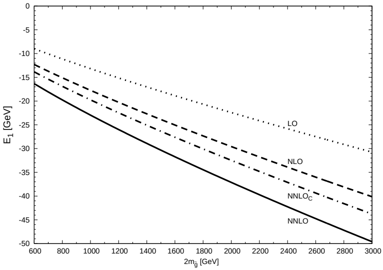
which – up to NNLO– can be obtained from the potential of triplet states

at leading order:

$$E_n = -\frac{m_{\tilde{g}} C_A^2 \alpha_s^2}{4n^2} \qquad |\Psi_n(0)|^2 = \frac{m_{\tilde{g}}^3 C_A^3 \alpha_s^3}{8\pi n^3}$$

Ground State Energy and Level Splitting

ground state energy (pole mass)



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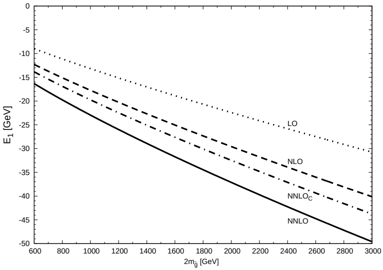

- no good convergence of the perturbation series

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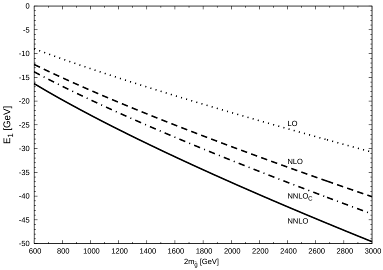

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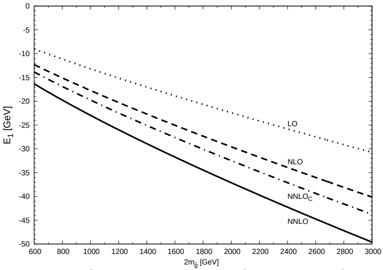
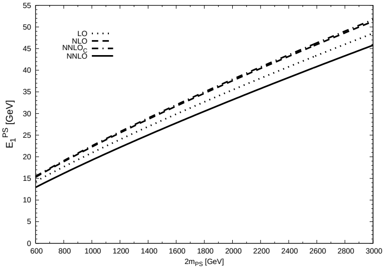


ground state energy (PS mass)



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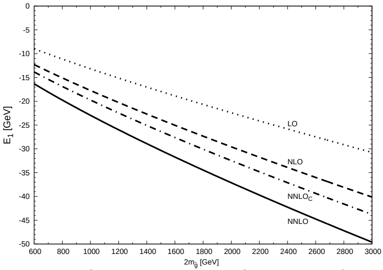

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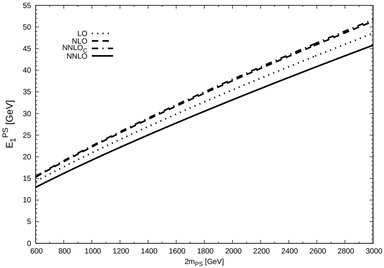
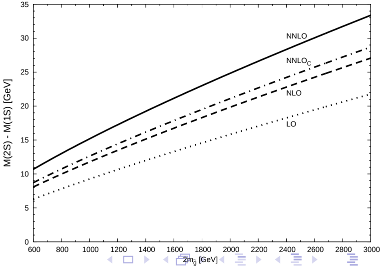
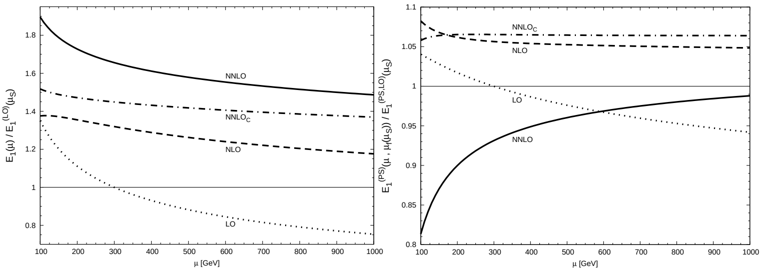


level splitting



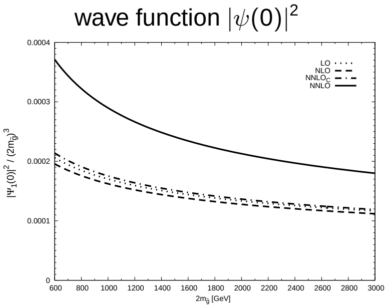
Energy Levels – scale dependence

scale-dependence pole mass scale-dependence PS mass



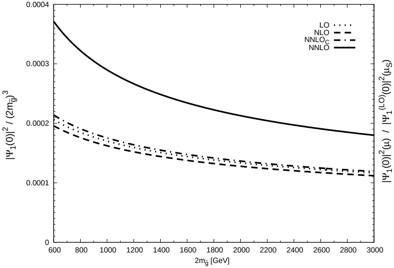
- reduced scale dependence in both mass schemes
- large contribution from non-coulombic terms in the potential

Wave Function

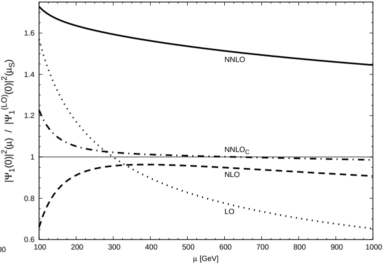


Wave Function

wave function $|\psi(0)|^2$



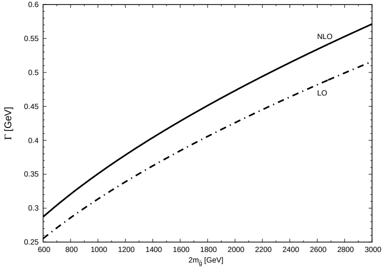
scale-dependence



- good convergence of coulombic terms
- large contribution from non-coulombic terms in the potential

Decay Width & Production Cross Section

gluinonium decay width



- gluinonium annihilation decay width much smaller than level spacing
- bound states are realized and might be detectable

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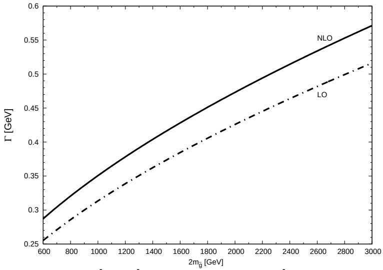
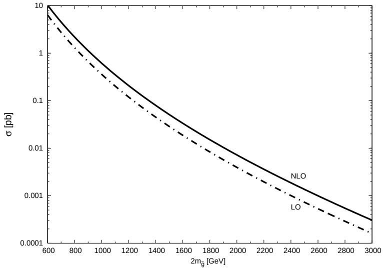


production cross section



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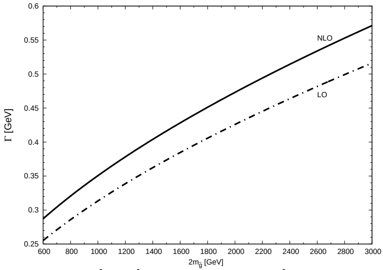

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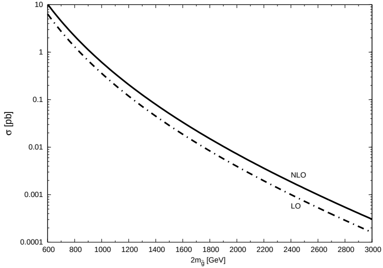
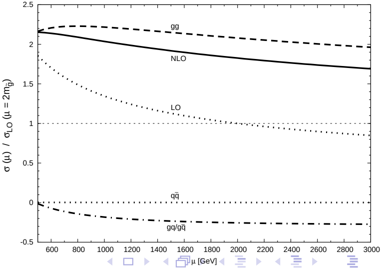


scale dependence



Outline

Introduction

- if $m_{\tilde{g}} > m_{\tilde{q}}$ then the decay $\tilde{g} \rightarrow \tilde{q} + q$ is possible
  $\rightarrow$ no boundstates
- if gluino width $\Gamma_{\tilde{g}} = \mathcal{O}(\text{GeV})$ visible threshold effects (cmp $t\bar{t}$ system)
- conditions are easily met by typical SUSY scenarios

Theoretical framework

- Threshold phenomena best described by using NRQCD
- Master formula

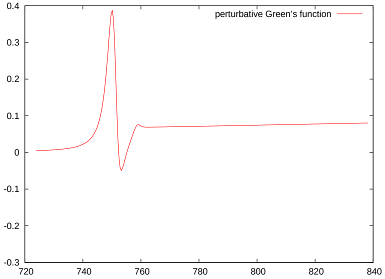
$$M_{(\tilde{g}\tilde{g})}\frac{d\sigma}{dM_{(\tilde{g}\tilde{g})}} = \mathcal{F}(PP \to \tilde{g}\tilde{g}X)\frac{1}{m_{\tilde{g}}^2}\mathrm{Im}G(M + i\Gamma)$$

- $\mathcal{F}(PP \to \tilde{g}\tilde{g}X)$ contains the hard part
- Threshold behavior encoded in Green's function $G(M + i\Gamma)$
- Take into account contributions from all color states
- Improve an work by Hagiwara and Yokoya

Green's function

Green's function can be calculated in NRQCD

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



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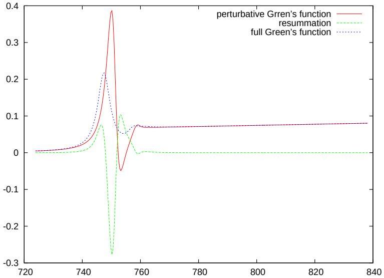

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Production Channels

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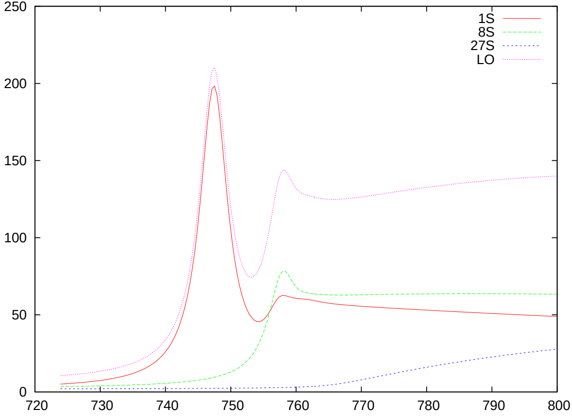
- 10
  only accessible via real radiation at NLO
  $q\bar{q} \rightarrow g\tilde{g}\tilde{g}, qg \rightarrow q\tilde{g}\tilde{g}, \bar{q}g \rightarrow \bar{q}\tilde{g}\tilde{g}$

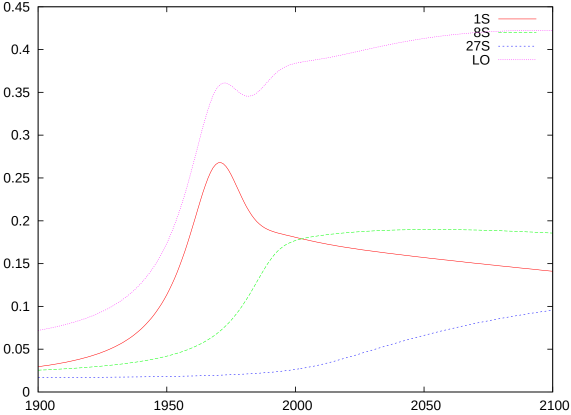
Cross Section @ threshold

$Md\sigma/dM[pb]$, only including gg channels, preliminary
$m_{\tilde{g}} = 381$ GeV, $\bar{m}_{\tilde{q}} = 344$ GeV, $\Gamma_{\tilde{g}} = 2.6$ GeV



Cross Section @ threshold

$Md\sigma/dM[pb]$, only including gg channels, preliminary
$m_{\tilde{g}} = 1000$ GeV, $\bar{m}_{\tilde{q}} = 987$ GeV, $\Gamma_{\tilde{g}} = 15$ GeV



Conclusions

- gluino bound states
  - gluinons form bound states if single gluino decays are suppressed
  - resonance might be detectable if sufficient detector resolution
- threshold production
  - improved analysis of threshold production of gluino pairs at threshold including NLO effects
  - full color correlation taken into account