Signals of single particle production at the earliest LHC

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Based on

R. Barbieri and R. T., arXiv:1008.5302 [hep-ph]

Outline

1. Motivations
   - How to bring out the best from the early LHC
2. "Early birds"
   - What kind of new particles?
3. Scalar resonance
   - The reference Lagrangian
   - Phenomenology
4. Heavy quark
   - The reference Lagrangian
   - Phenomenology
5. Summary
   - Summary and conclusions

The early LHC: the criterion of "simplicity"

Some "simple" questions

1. *Can the LHC discovery new physics in its early stage?*

Our "simple" answers

1. *Yes... if we are lucky*

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The early LHC: the criterion of "simplicity"

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3. *What kind of "new physics" is accessible to the LHC in its early stage ($\sqrt{s} = 7$ TeV and $\int \mathcal{L} = 1$ fb^{-1})?*

Our "simple" answers

1. *Yes... if we are lucky*
2. *E.g. in the single resonant production of new particles*
3. *Charge, spin, SM representation are constrained by the required production rates and by general principles (simplicity at first!)*

The early LHC: the criterion of "simplicity"

Some "simple" questions

1. *Can the LHC discovery new physics in its early stage?*
2. *How new physics can shows up?*
3. *What kind of "new physics" is accessible to the LHC in its early stage ($\sqrt{s} = 7$ TeV and $\int \mathcal{L} = 1\ fb^{-1}$)?*
4. *What is the best way to present the experimental data in order to quickly test many new physics models and understand if a signal is there?*

Our "simple" answers

1. *Yes... if we are lucky*
2. *E.g. in the single resonant production of new particles*
3. *Charge, spin, SM representation are constrained by the required production rates and by general principles (simplicity at first!)*
4. *The data have to be presented with a minimum of biases coming from model building: simple phenomenological Lagrangians can be the guiding line for the experimental analysis making a signal of new physics to simply emerge*

Our approach

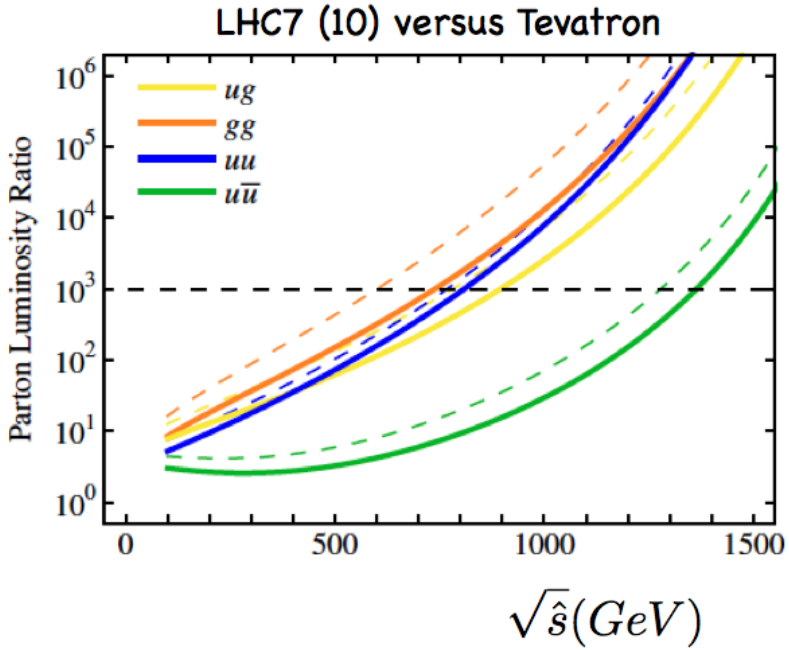
- We base our considerations on simple phenomenological Lagrangians, fulfilling reasonable consistency conditions
- We are generally guided by the possible existence of composite states produced by a putative strong dynamics responsible for ElectroWeak Symmetry Breaking
- We aim also at a neat and simple definition of the interactions responsible for the signals under discussion, to be used as a possible guide for the presentation of the data
- The interpretation of a possible positive signal in terms of more elaborate and more defined theoretical models is eased by this way of presenting the data.

The goal of my talk

Apply this approach to the single resonant production of new particles

A matter of parton luminosities

- Single production of a relatively narrow resonance is the most obvious candidate for a copious production at the LHC also in its early stage
- One of the most studied cases (mostly in the leptonic channel) is the vector resonance, either neutral or charged, produced in the $q\bar{q}$ channel
  See the *Review on Z' searches* in PDG and for recent results see *E. Salvioni, A. Strumia, G. Villadoro and F. Zwirner, arXiv:0911.1450 [hep-ph]*
- In competition with the Tevatron (with its high integrated luminosity) the $q\bar{q}$ channel at the LHC is definitely less favorable relative to the gg, qg and qq channels in view of the corresponding parton luminosities



C. W. Bauer et al., arXiv:0909.5213 [hep-ph]

We concentrate our attention to the gg, ug and uu production mechanisms

The nature of the new particles

- Considering for simplicity the lowest possible spin and QCD representation of the new particles candidates the gg, qg and qq production mechanisms suggest a small set of possible new states

The possibilities

1. gg-**channel**: *a spin-less totally neutral scalar* S;
2. qg-**channel**: *a* $J = 1/2$ *color-triplet "heavy quark", either "*U*" or "*D*";*
3. qq-**channel**: *a spin-less color-triplet or color-sextet scalar* ϕ*, with various possible charges.*

- We assume that one single new particle is available at a time, which therefore can only decay into SM particles
- We concentrate our attention to the first two cases since the scalar triplet or sextet (see *C. W. Bauer et al., arXiv:0909.5213 [hep-ph]*) can only decay into a pair of jets, whereas we find relatively more promising the final states containing at least one photon
- The resonances in the qq channel suffer also of problems with flavor physics

Scalar resonance: the Lagrangian

A reasonable reference Lagrangian for a scalar singlet S is given by

The reference Lagrangian for a scalar singlet

$$\mathcal{L}_S = c_3 \frac{g_S^2}{\Lambda} G^a_{\mu\nu} G^{\mu\nu\, a} S + c_2 \frac{g^2}{\Lambda} W^i_{\mu\nu} W^{\mu\nu\, i} S + c_1 \frac{g'^2}{\Lambda} B_{\mu\nu} B^{\mu\nu} S + \sum_f c_f \frac{m_f}{\Lambda} \bar{f} f S \,, \quad (1)$$

- A coupling to the SM Higgs of the form $m_S S H^\dagger H$ could also be present, as it would actually be induced by radiative corrections. In a wide range of M_S and Λ it is however consistent to assume that such coupling is irrelevant.
- NDA suggests $c_i \approx \frac{1}{4\pi}$ but can easily be larger
- We take as reference values $\Lambda = 3$ TeV (reminiscent of a possible strong interaction responsible for EWSB at $\Lambda \approx 4\pi v$) and $c_i = 1$
- Our results can be simply generalized to different values of the parameters

Scalar resonance: decay widths and branching ratios

The phenomenology of the new particle is now a function of the production rate and of the decay branching ratios (for a fixed mass M_S)

Partial widths

$$\Gamma\left(S \to gg\right) = \frac{2 g_S^4 M_S^3}{\pi \Lambda^2}$$

$$\Gamma\left(S \to W^+W^-\right) = \frac{g^4 \sqrt{M_S^2 - 4M_W^2}\left(M_S^4 - 4M_S^2 M_W^2 + 6M_W^4\right)}{2\pi M_S^2 \Lambda^2}$$

$$\Gamma\left(S \to ZZ\right) = \frac{\left(g^2 \cos^2\theta_W + g'^2 \sin^2\theta_W\right)^2 \sqrt{M_S^2 - 4M_Z^2}\left(M_S^4 - 4M_S^2 M_Z^2 + 6M_Z^4\right)}{4\pi M_S^2 \Lambda^2}$$

$$\Gamma\left(S \to Z\gamma\right) = \frac{\sin^2\theta_W \cos^2\theta_W \left(g'^2 - g^2\right)^2 \left(M_S^2 - M_Z^3\right)^2}{2\pi M_S^3 \Lambda^2}$$

$$\Gamma\left(S \to \gamma\gamma\right) = \frac{e^4 M_S^3}{\pi \Lambda^2}\,,$$

$$\Gamma\left(S \to t\bar{t}\right) = \frac{3 m_t^2 \left(M_S^2 - 4m_t^2\right)\sqrt{M_S^2 - 4m_t^2}}{8\pi M_S^2 \Lambda^2}$$

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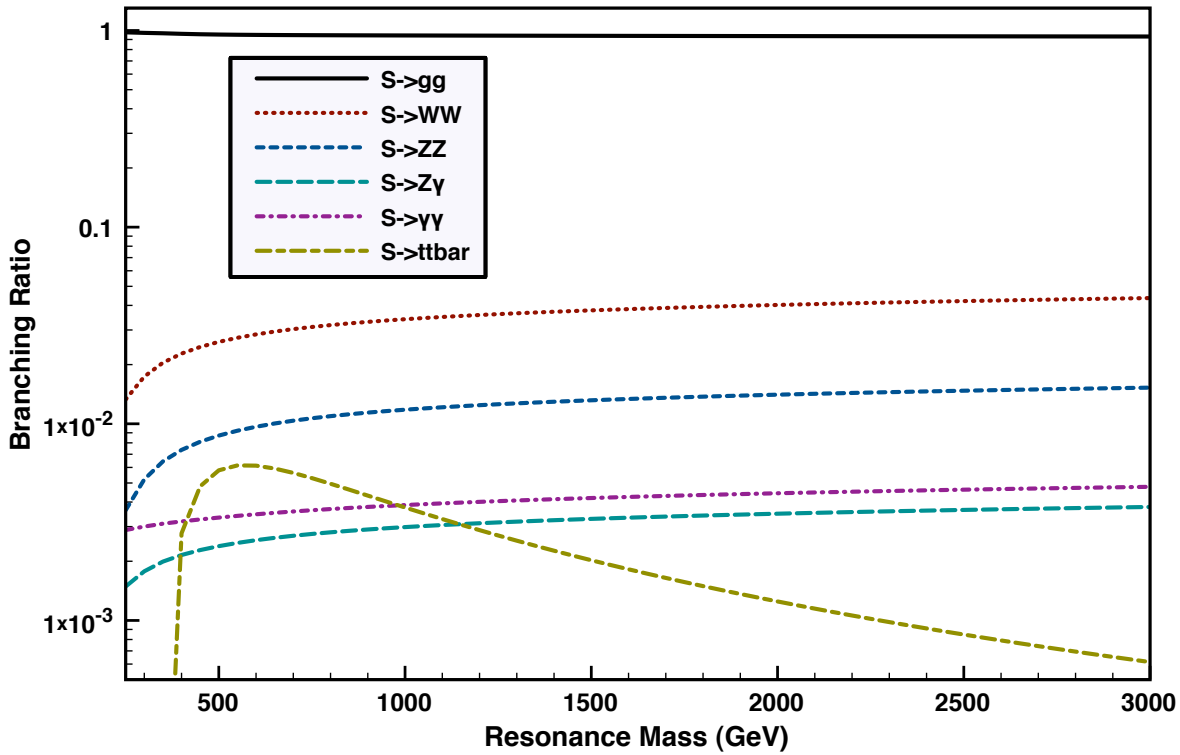
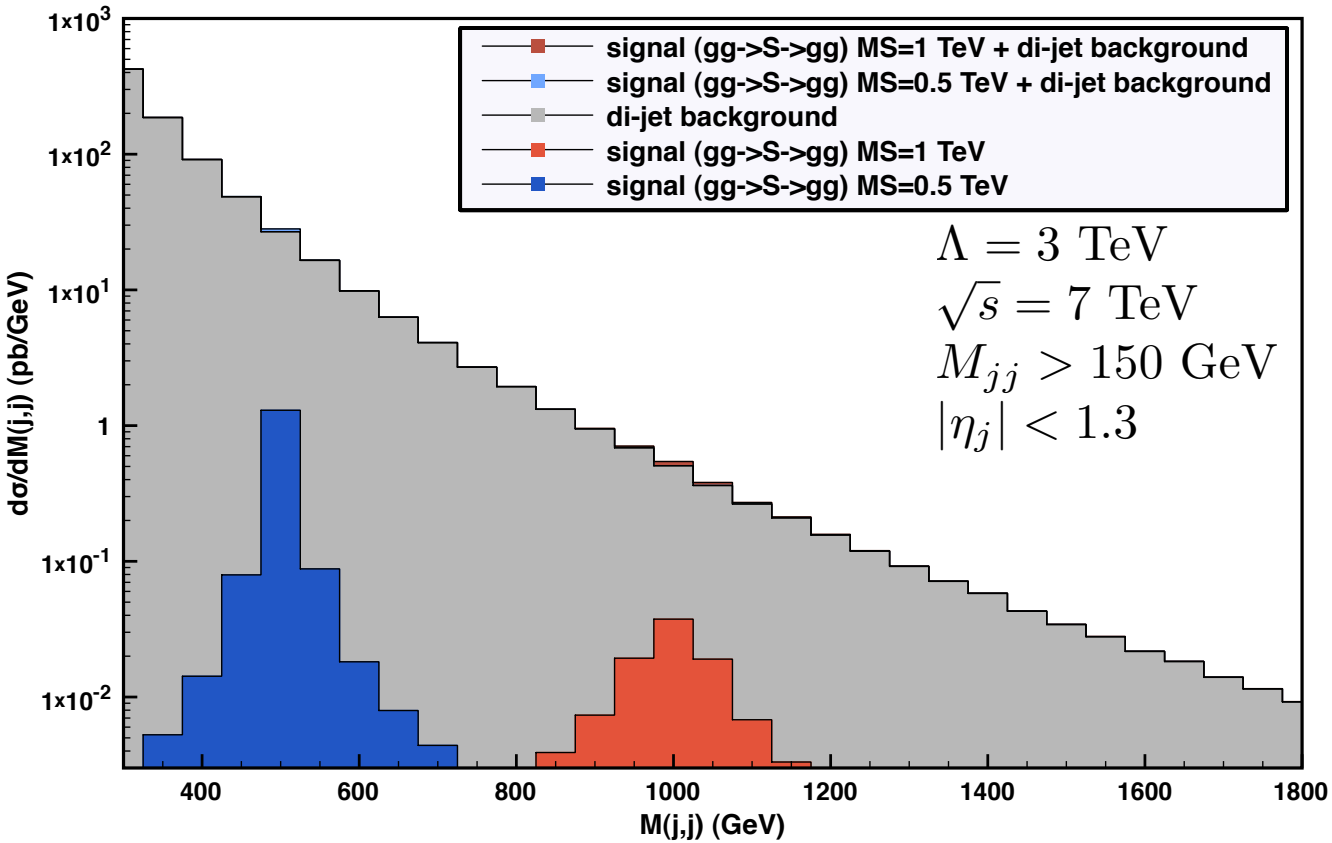


- The total width scales as $1/\Lambda^2$ and the results can be simply generalized to different values of Λ
- We made a preliminary phenomenological study of the di-jet, $\gamma\gamma$ and γZ decay channels

Scalar resonance in the di-jet channel



The discovery in the di-jet channel with a small statistics ($\lesssim 1$ fb^{-1}) seems strongly disfavored by the high SM background

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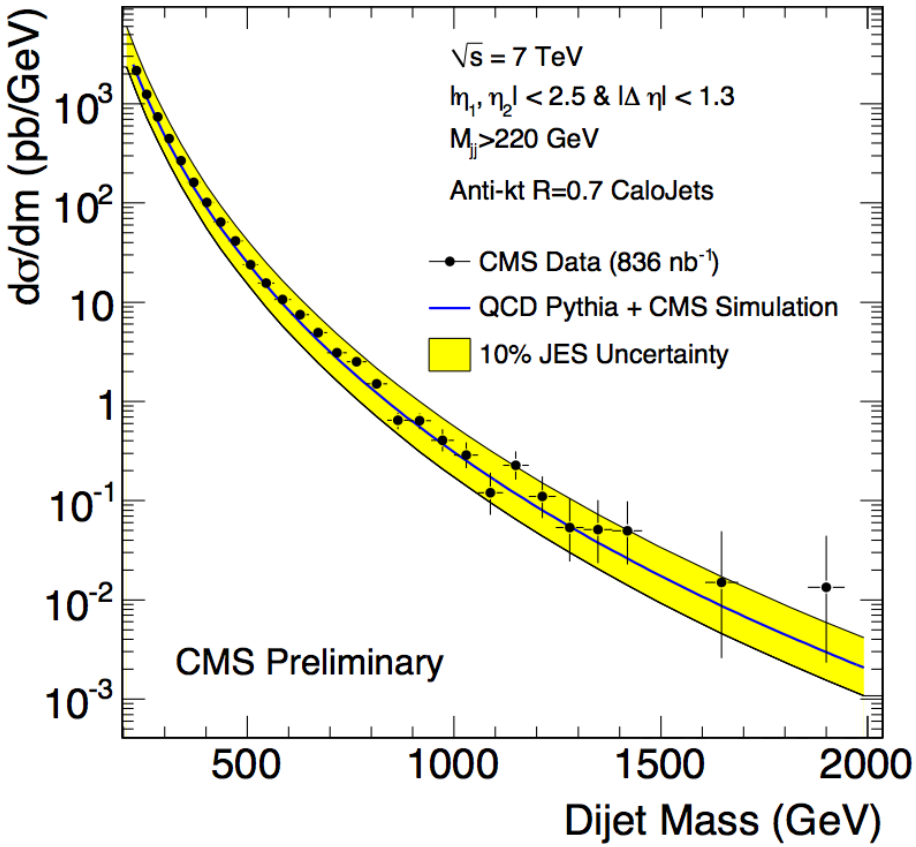
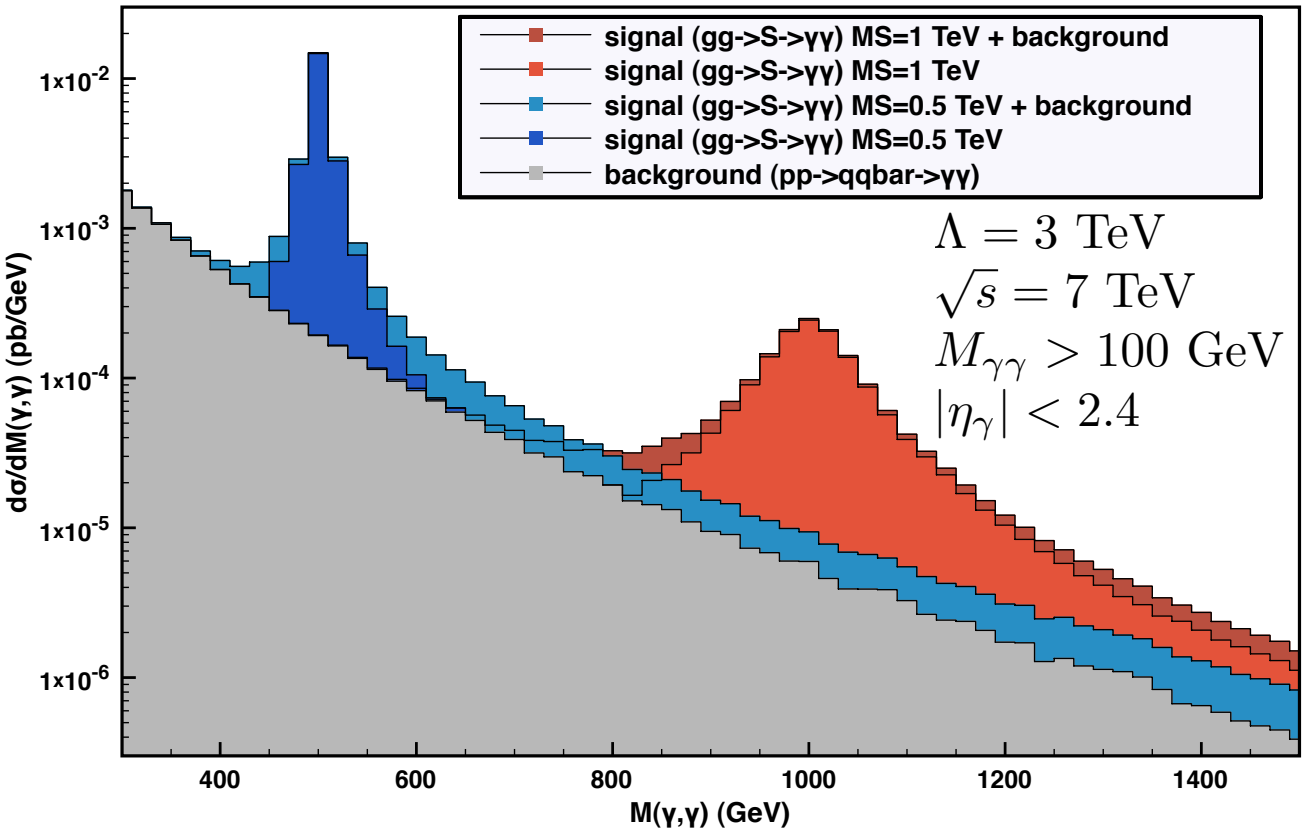


CMS PAS EXO-10-010

The discovery in the di-jet channel with a small statistics ($\lesssim 1$ fb^{-1}) seems strongly disfavored by the high SM background and by the by the large Jet Energy Scale systematic uncertainty

Scalar resonance in the $\gamma\gamma$ channel

The $\gamma\gamma$ channel is much more promising due to the low SM background



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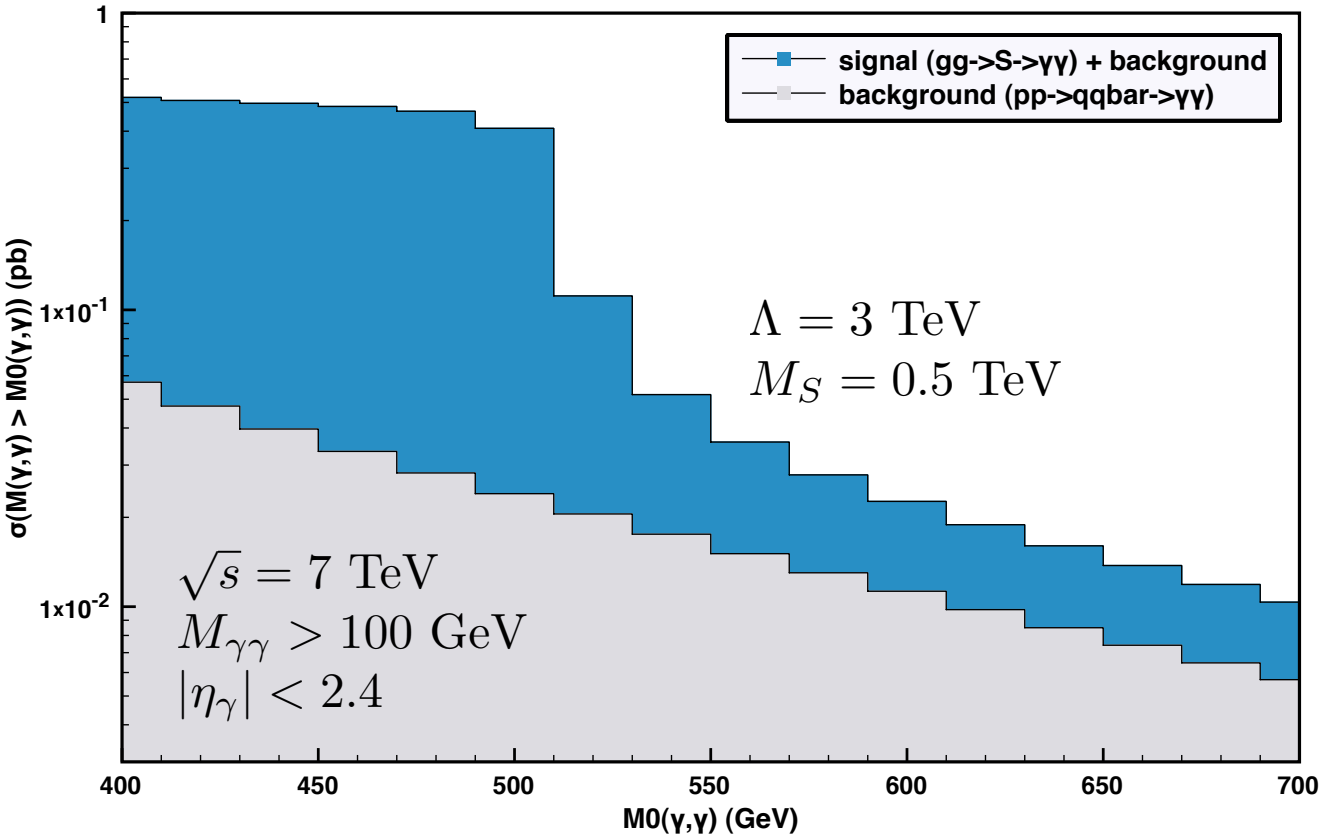

- A discovery for a scalar singlet with a mass in the range 500 GeV $\lesssim M_S \lesssim 1$ TeV seems possible with a modest luminosity of about 10 to 100 pb^{-1}
- Obviously for a given integrated luminosity the absence of a signal in the $\gamma\gamma$ channel is easily translated in a lower bound on $\frac{\Lambda}{c_1+c_2}$

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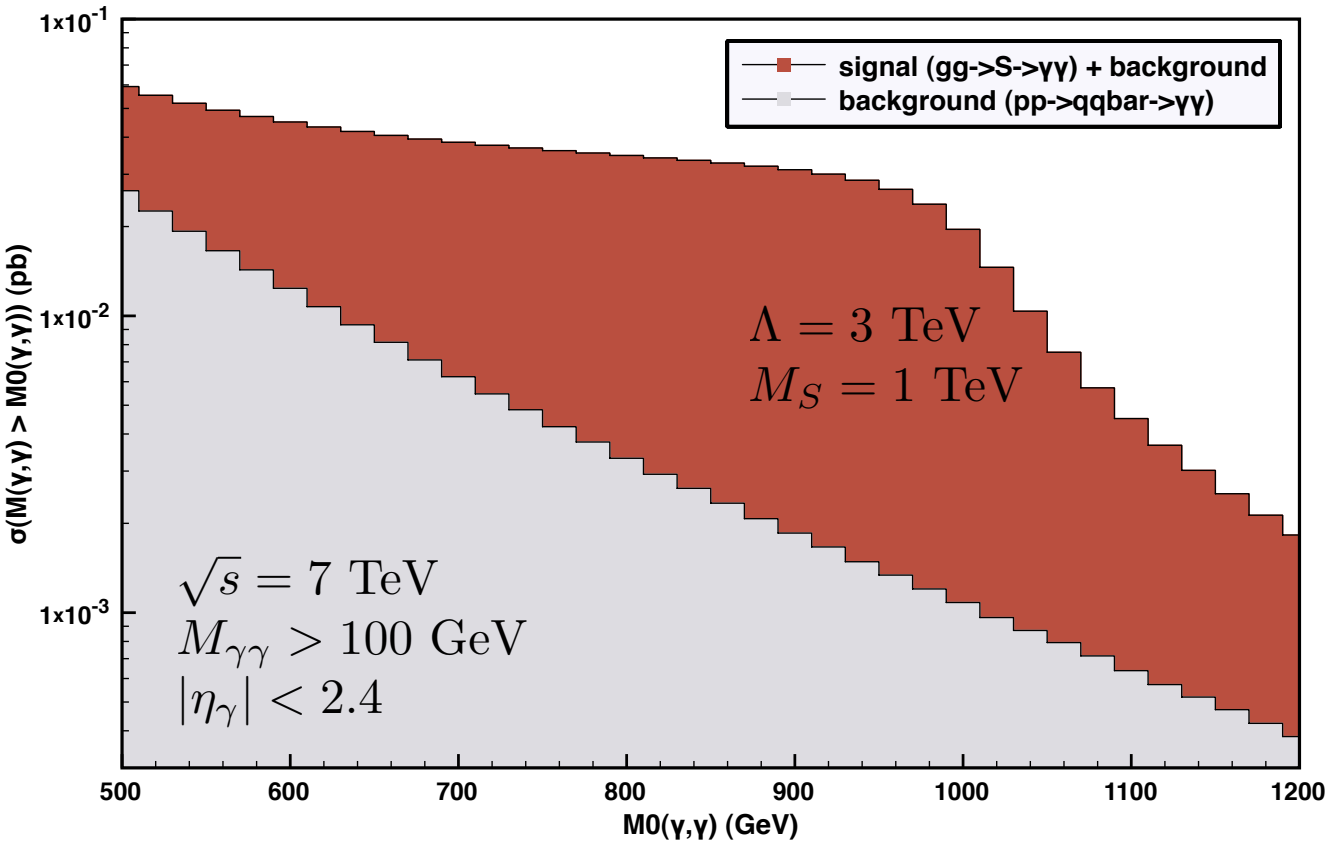

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Heavy quark: the Lagrangian

A reasonable reference Lagrangian for an heavy quark U is given by

The reference Lagrangian for a heavy quark

$$\mathcal{L}_U = c_G \frac{g_S}{\Lambda} \bar{U}_L \sigma^{\mu\nu} T^a u_R G^a_{\mu\nu} + c_B \frac{g'}{\Lambda} \bar{U}_L \sigma^{\mu\nu} u_R B_{\mu\nu} + h.c.\,, \tag{2}$$

- The U field transforms as a $(3,1)_{2/3}$ representation of the SM group
- Problem with the flavor if we pretend that the U couples to the physical u-quark but has no (significant) coupling to the c-quark (not to cause unobserved $\Delta C = 2$ flavor changing effects)
- Possible solution to this problem: introduce three U fields, one per generation and assume that the Lagrangian (2) respects a global $SU(3)_R$ acting on the standard three u-type quarks
- These considerations don't affect the phenomenology we are interested in
- As in the case of the scalar we have done a preliminary phenomenological study with the reference values $\Lambda = 3$ TeV and $c_G = c_B = 1$

Heavy quark: decay widths and branching ratios

As in the case of the scalar, the phenomenology depends only on the production rate and on the decay branching ratios (for a fixed mass M_U)

Partial widths

$$\Gamma(U \to ug) = \frac{4\alpha_S M_U^3}{3\Lambda^2}$$

$$\Gamma(U \to uZ) \approx \frac{\alpha M_U^3 \tan^2\theta_W}{\Lambda^2}$$

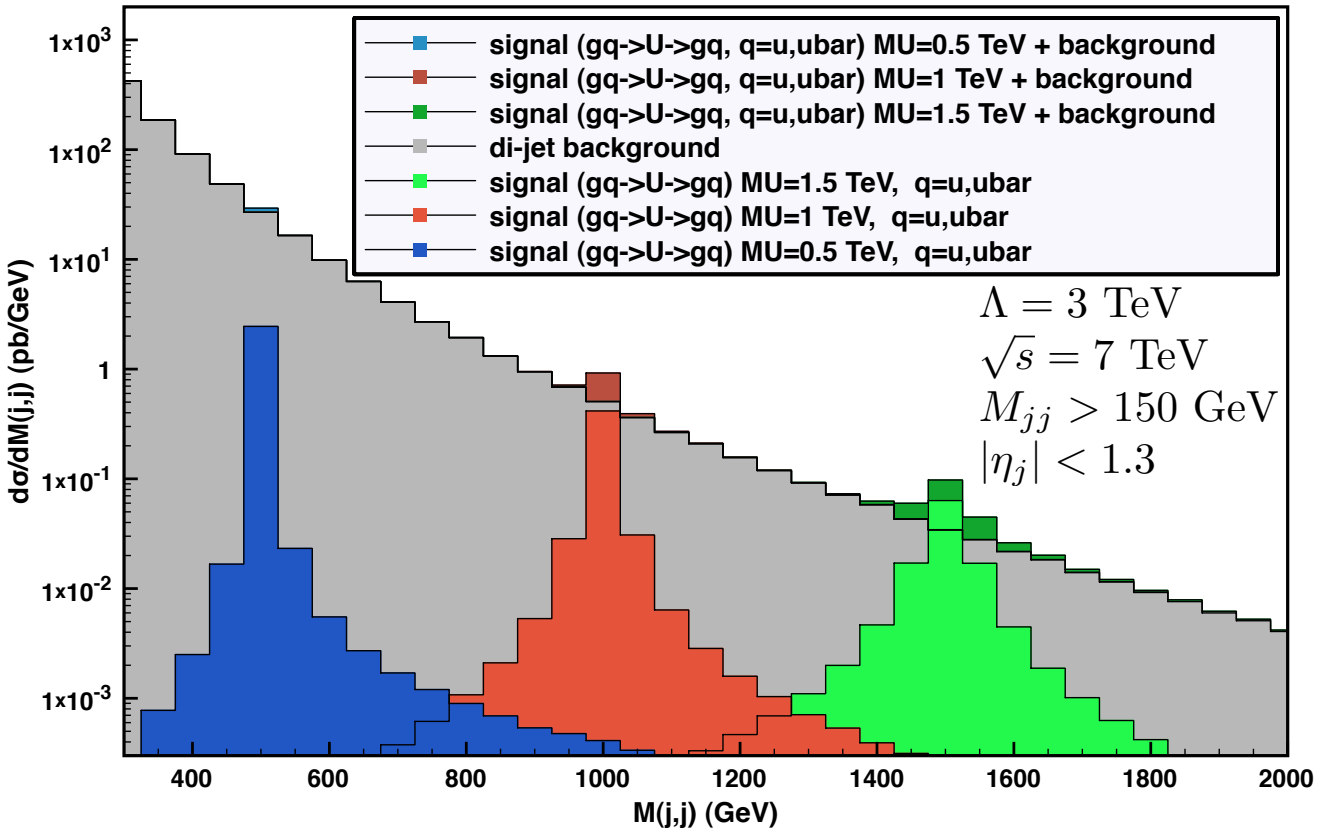
$$\Gamma(U \to u\gamma) = \frac{\alpha M_U^3}{\Lambda^2}$$

Total width

$$\Gamma_U \approx \frac{M_U^3 \alpha_S}{\Lambda^2}\left(\frac{4}{3} + \frac{\alpha}{\alpha_S \cos^2\theta_W}\right) \tag{4}$$

- With our choice of the parameters $2 \lesssim \Gamma_U \lesssim 30$ GeV for $0.5 \lesssim M_U \lesssim 1.5$ TeV
- BR$(U \to ug) \approx 92\%$, BR$(U \to u\gamma) \approx 6\%$ and BR$(U \to uZ) \approx 2\%$

Heavy quark in the di-jet channel



The discovery in the di-jet channel with a small statistics ($\lesssim 1$ fb^{-1}) seems strongly disfavored by the dominant SM background and by the by the large Jet Energy Scale systematic uncertainty

Heavy quark in the $\gamma + jet$ channel

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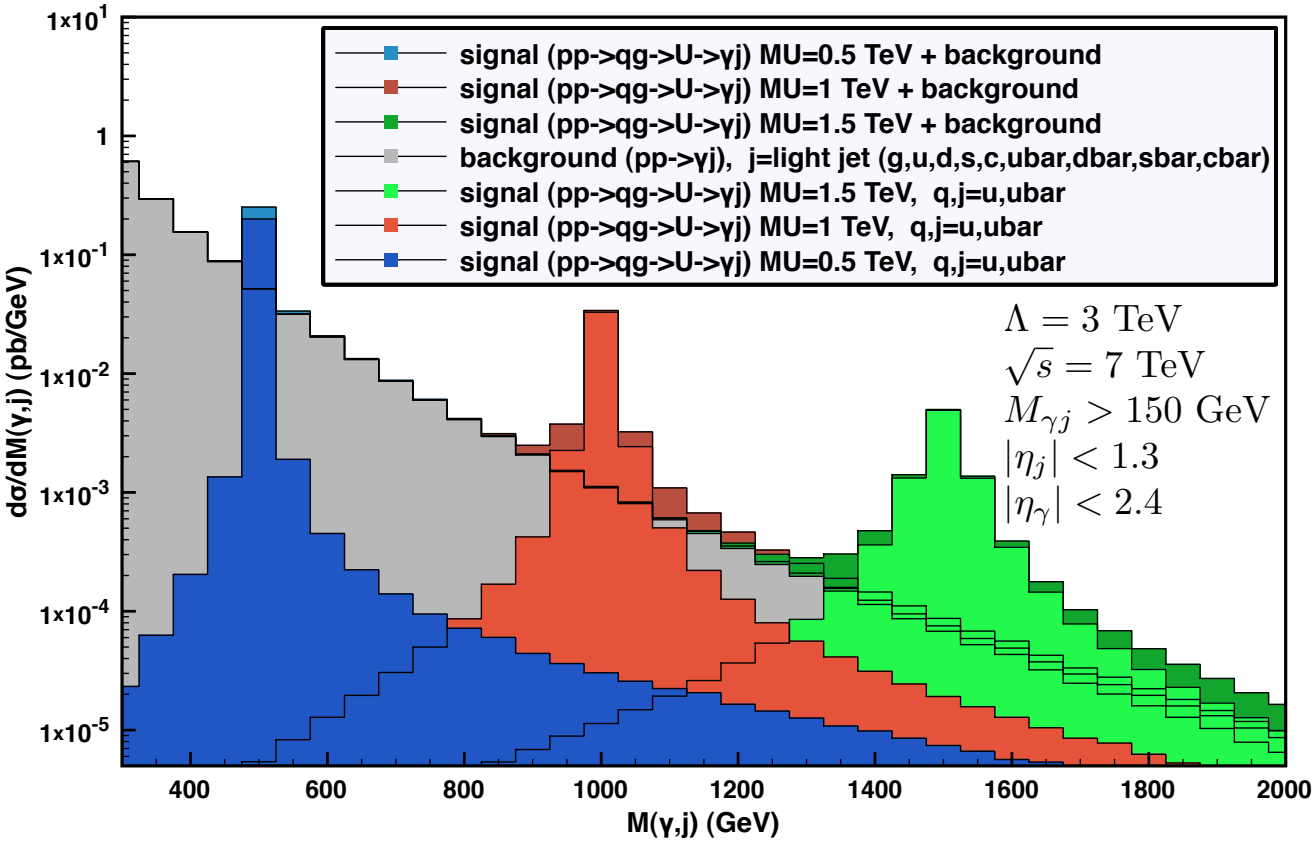

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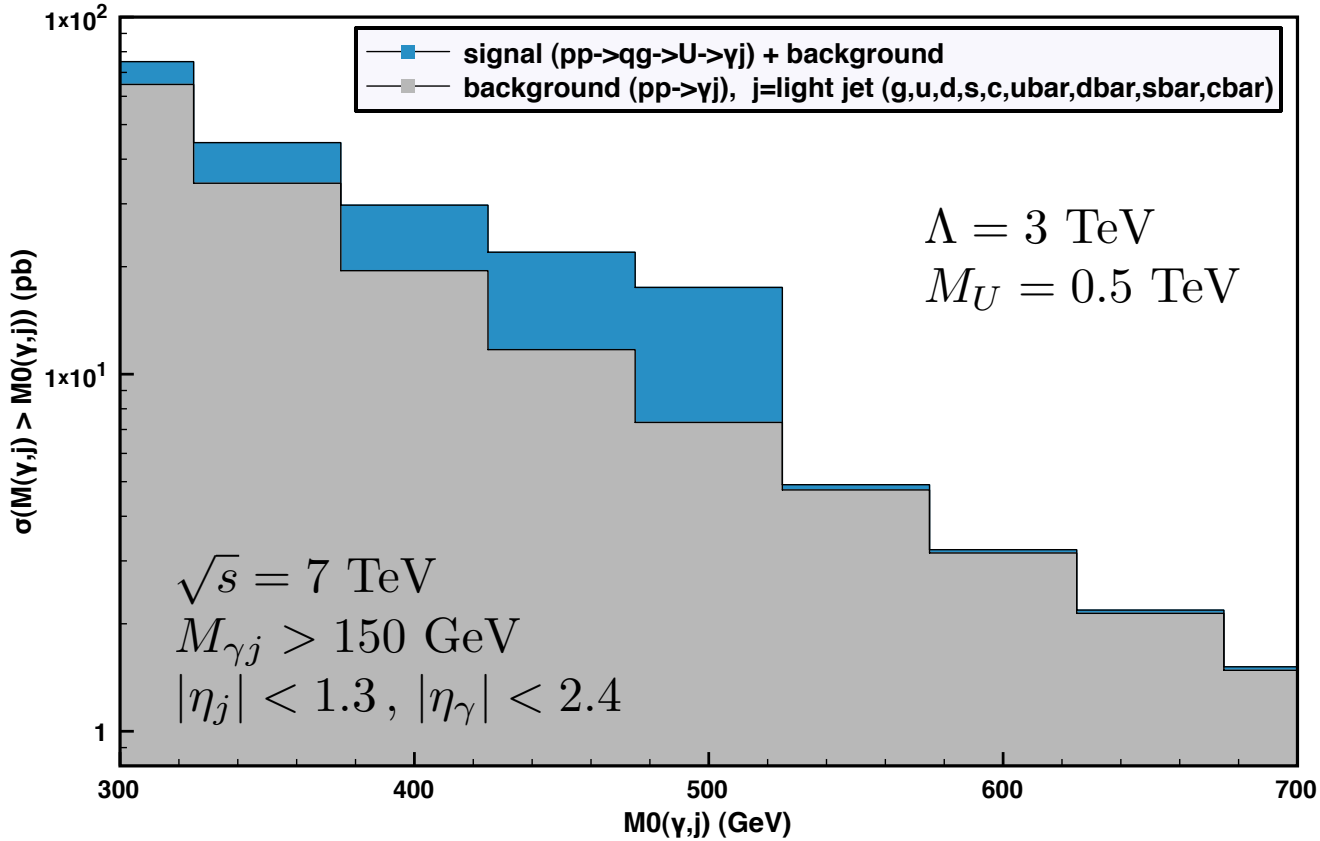

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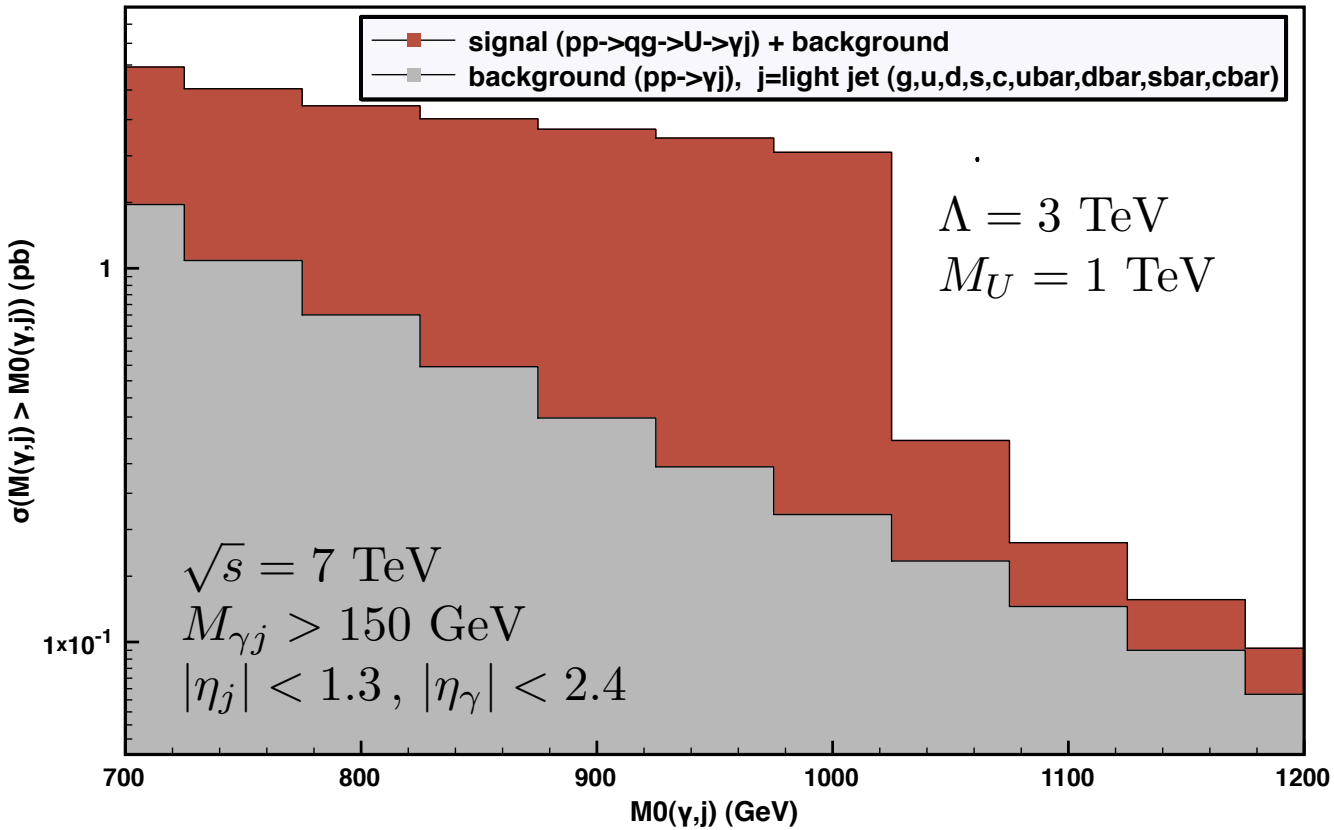

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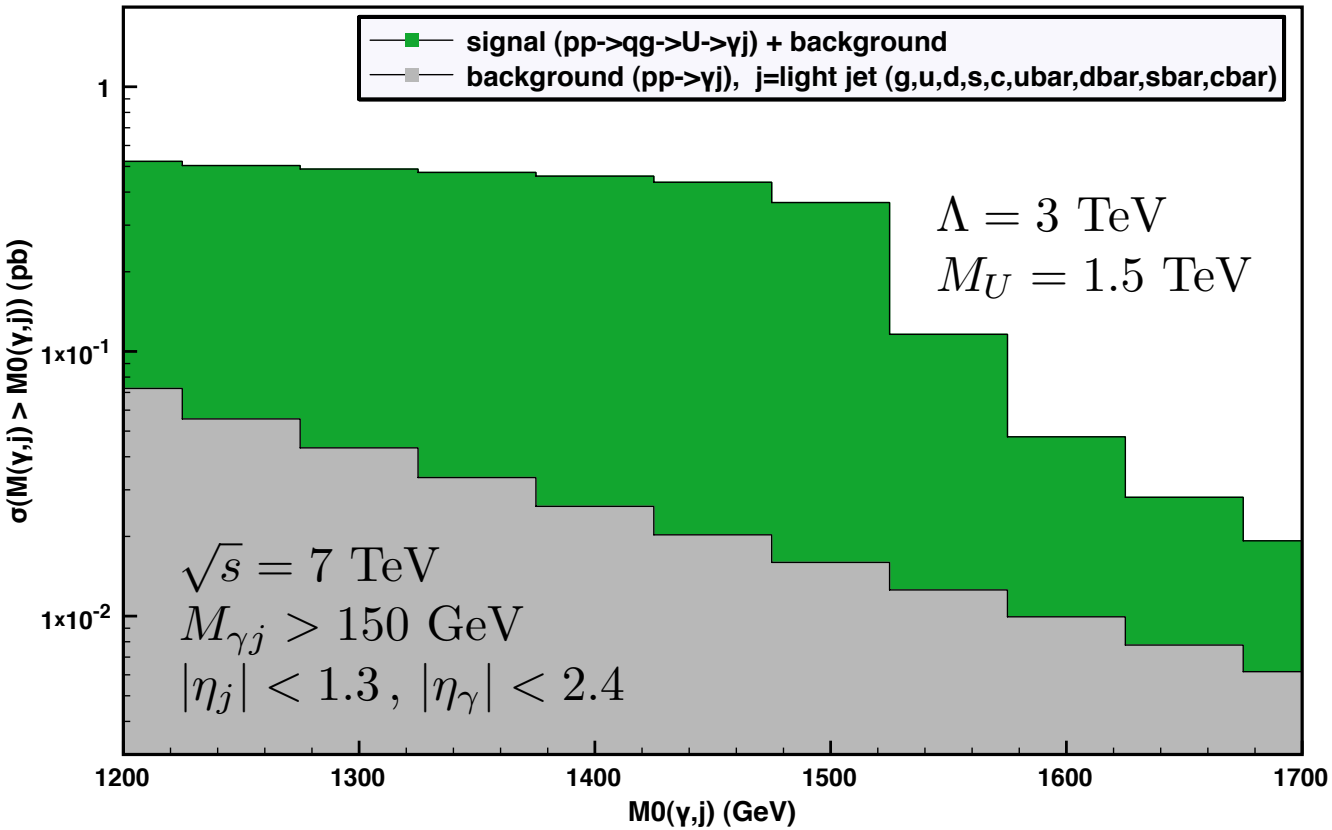

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Summary

- In view of the lack so far of a thorough experimental exploration of the energy range at or well above the Fermi scale, an open attitude is best to take in the expectation for possible signals of new physics at the LHC
- We have studied the possibility to observe at the early LHC relatively narrow resonances that can have, in a wide region of the parameters, important production rates
- These particles could be composite particles arising from a strong dynamics responsible for EWSB. They might be visible in $\gamma\gamma$ or in $\gamma + jet$ channels at 7 TeV with less than 100 pb$^-1$
- We have at least defined simple single interactions responsible for their production, useful to guide (without prejudices) the experimental analysis and the presentation of the experimental results.

I would like to thanks Riccardo Barbieri and Michelangelo Mangano.