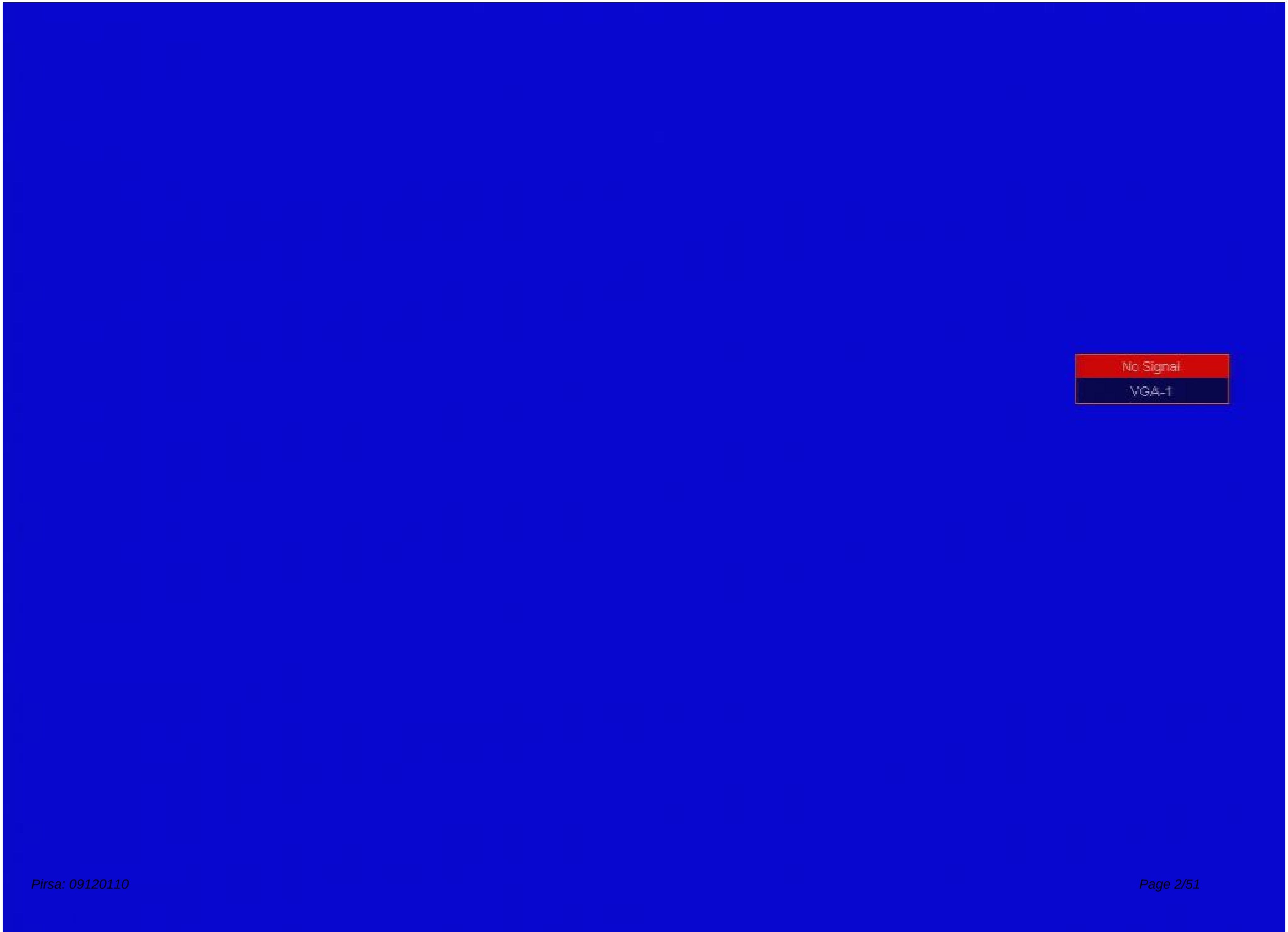
Title: Bound states at the LHC

Date: Dec 15, 2009 01:00 PM

URL: http://pirsa.org/09120110

Abstract: When a pair of particles is produced close to threshold, they may form a bound state if the potential between them is attractive. Can we use such bound states to obtain information about new colored particles at the LHC? I will discuss the relevant issues using examples from the MSSM and other beyond the standard model scenarios.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Bound states at the LHC

Yevgeny Kats
Harvard University

arXiv:0912.0526 (with Matthew D. Schwartz)

Particle Physics Seminar, Perimeter Institute, 15 Dec 2009

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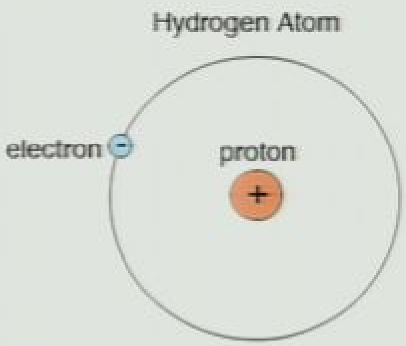
This talk is about...

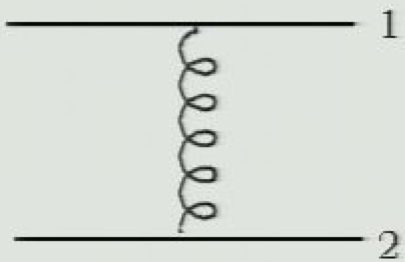
- Bound states of pair-produced colored particles. Examples from the MSSM.
- Using signals from bound state annihilation for getting information about the new physics (and in which kind of scenarios this is possible).
- A detailed analysis: gluinonium at the LHC
- Bound states in other theories

Bound states



$$V(r) = -\frac{\alpha}{r}$$

Binding energy	Bohr radius	Wavefunction at the origin
$E_b = \frac{\alpha^2 m_e}{2}$	$a_0 = \frac{1}{\alpha m_e}$	$\lvert\psi(\mathbf{0})\rvert^2 = \frac{1}{\pi a_0^3}$



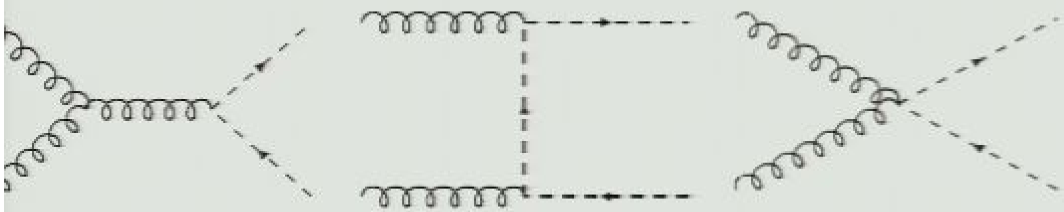
$$V(r) = -C\frac{\overline{\alpha}_s}{r} \qquad C = \frac{1}{2}\left(C_1 + C_2 - C_{(12)}\right)$$

quadratic Casimirs

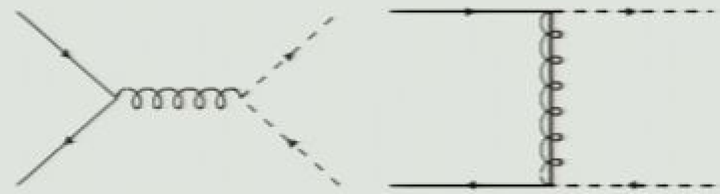
Assumptions: $a_0 \ll \frac{1}{\Lambda_{\rm QCD}}\,, \quad \overline{\alpha}_s \ll 1\,, \quad v^2 = C^2\overline{\alpha}_s^2 \ll 1$

Binding energy	Bohr radius	Wavefunction at the origin
$E_b = \frac{C^2\overline{\alpha}_s^2 m}{4}$	$a_0 = \frac{2}{C\overline{\alpha}_s m}$	$\lvert\psi(\mathbf{0})\rvert^2 = \frac{1}{\pi a_0^3} = \frac{C^3\overline{\alpha}_s^3 m^3}{8\pi}$

Pair production of colored particles in the MSSM

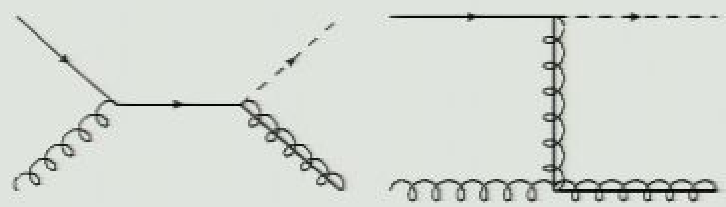


$$g + g \longrightarrow \tilde{q}_i + \bar{\tilde{q}}_i$$

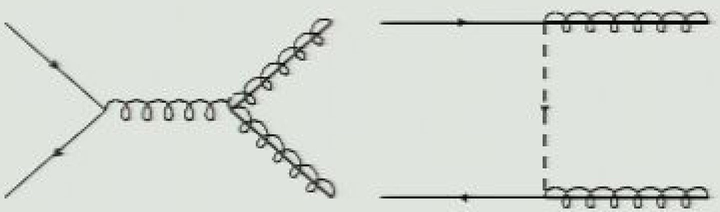


$$q_i + \bar{q}_j \longrightarrow \tilde{q}_k + \bar{\tilde{q}}_l$$

$$g + g \longrightarrow \tilde{g} + \tilde{g}$$



$$q_i + g \longrightarrow \tilde{q}_i + \tilde{g}$$



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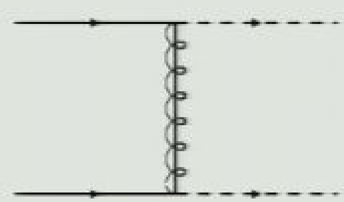

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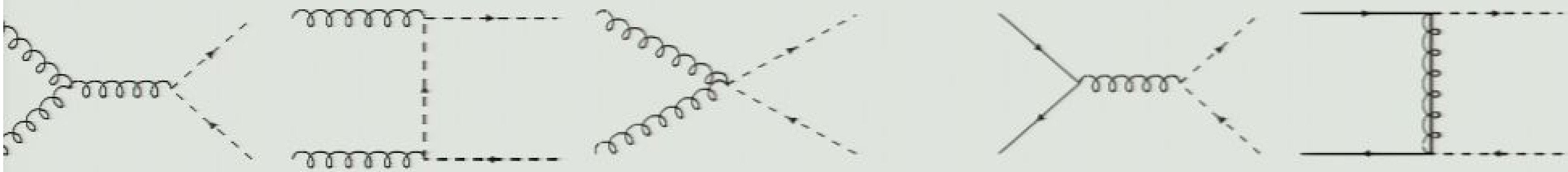

$$g + g \longrightarrow \tilde{q}_i + \bar{\tilde{q}}_i$$

$$\mathbf{3} \otimes \overline{\mathbf{3}} = \mathbf{1} \oplus \mathbf{8}$$

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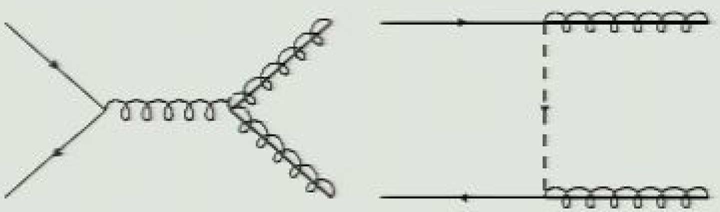

$$q_i + \bar{q}_i \longrightarrow \tilde{g} + \tilde{g}$$

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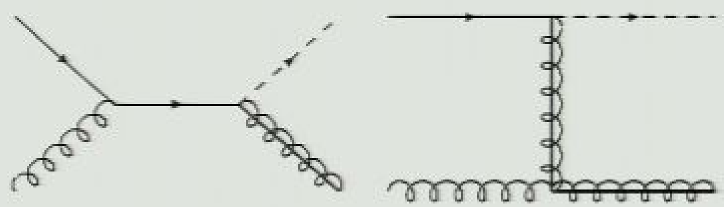

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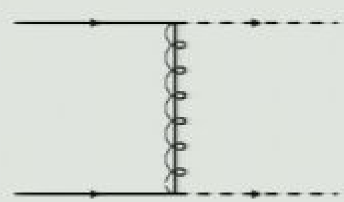

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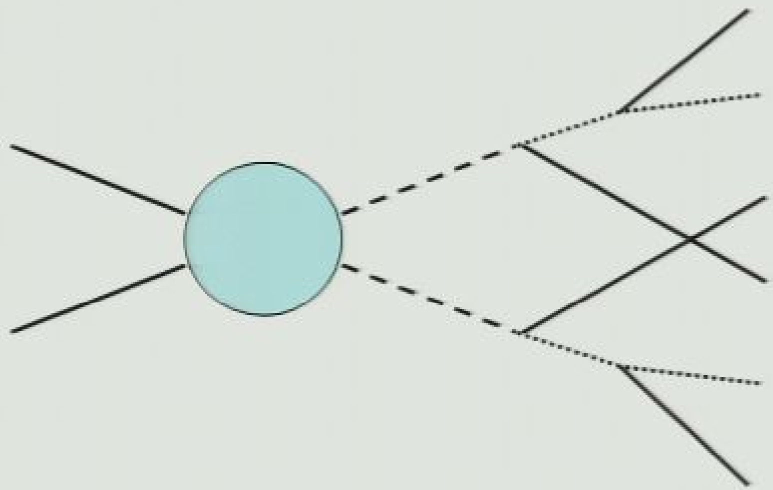
Why care about bound states?

Usual signature of a pair of MSSM particles



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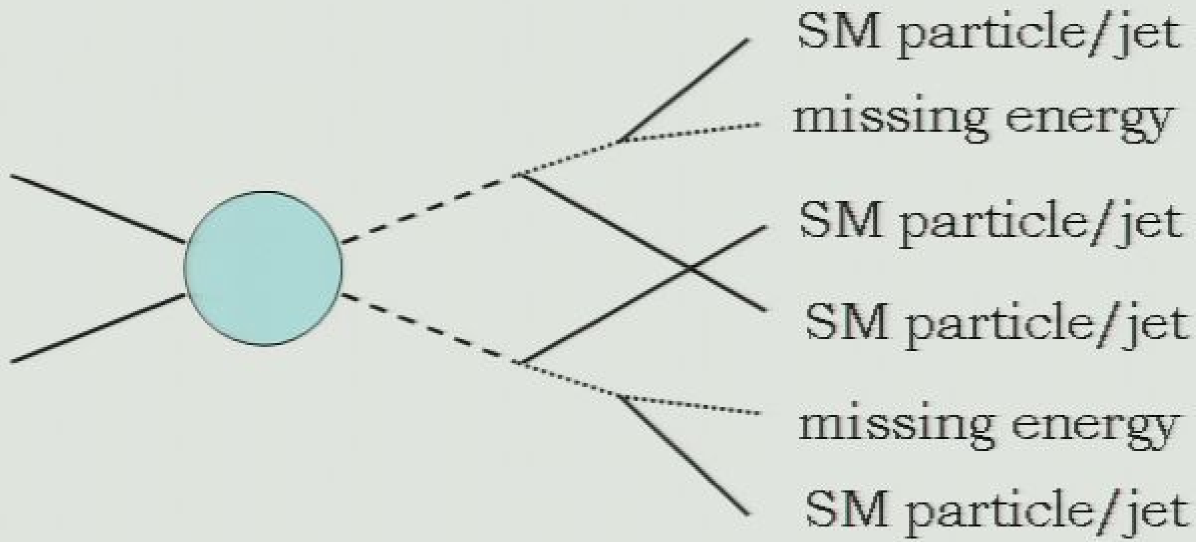
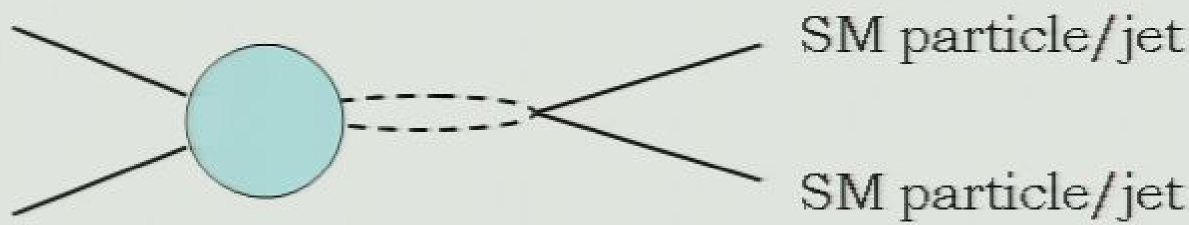
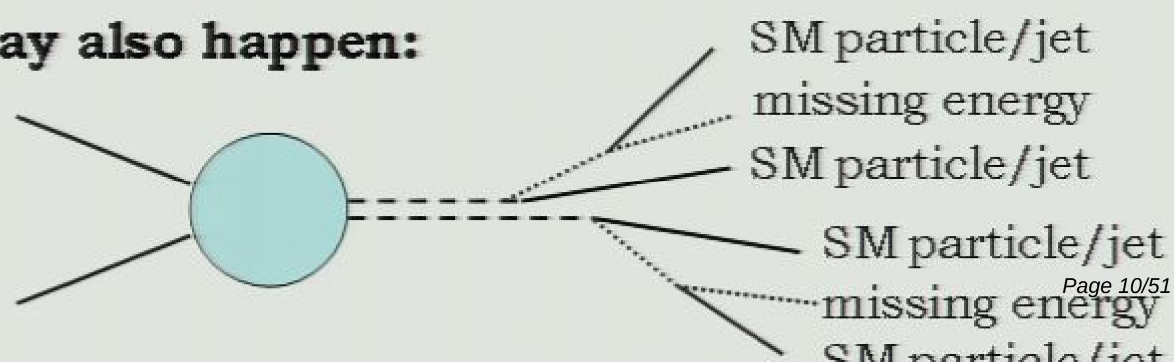


Bound state annihilation

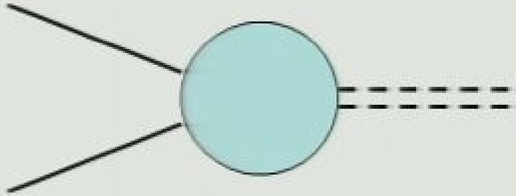


However, the following may also happen:

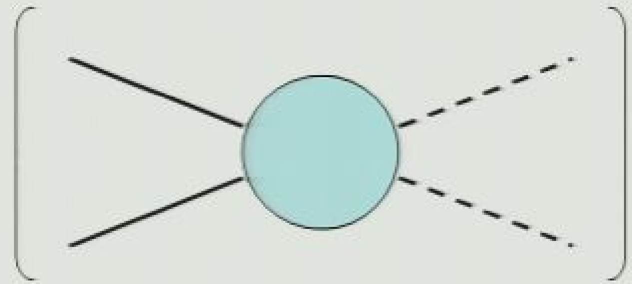


How to compute bound state processes

Matrix elements for bound state production or annihilation:



$$= \frac{\psi(\mathbf{0})}{\sqrt{m}}$$



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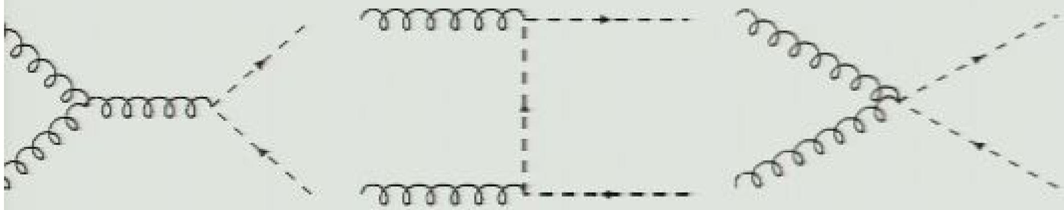
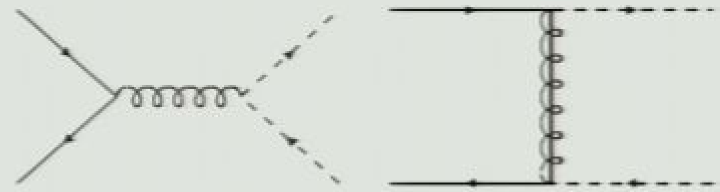


$$g + g \longrightarrow \tilde{q}_i + \bar{\tilde{q}}_i$$



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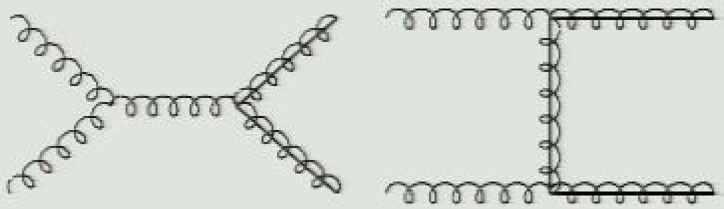

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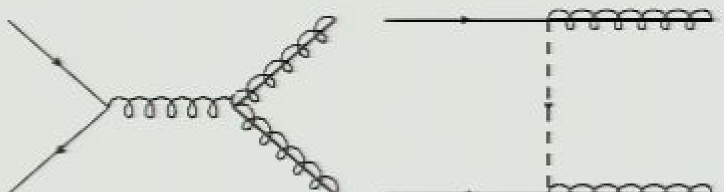

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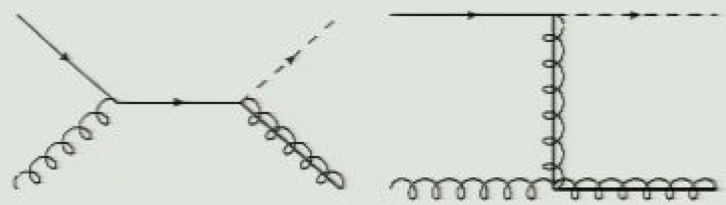

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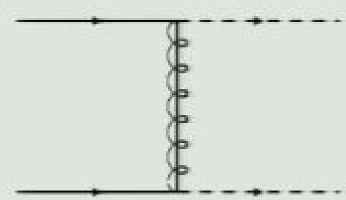

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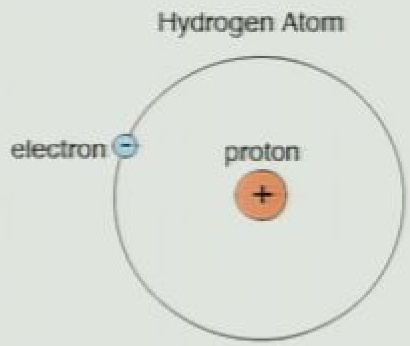
Bound states



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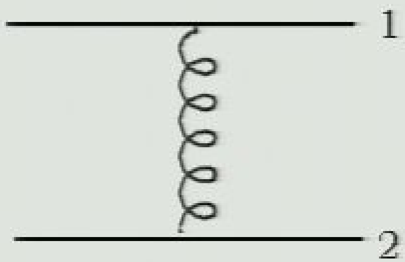

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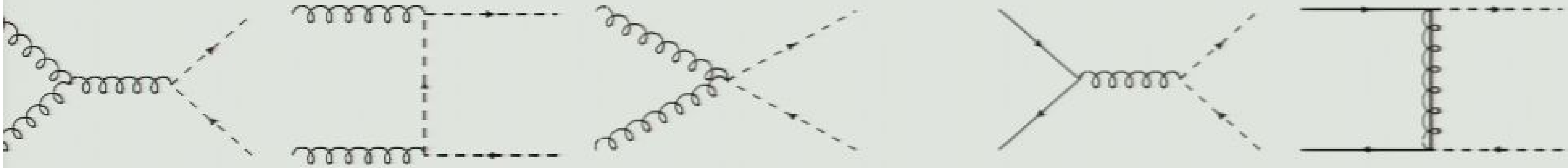

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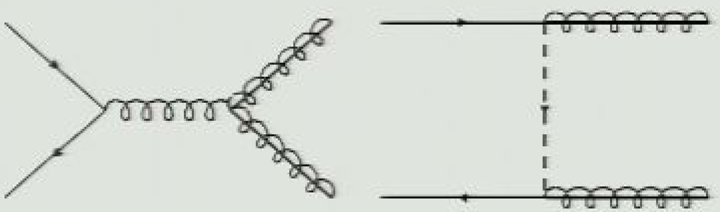

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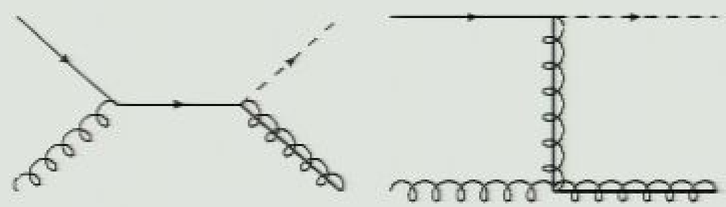

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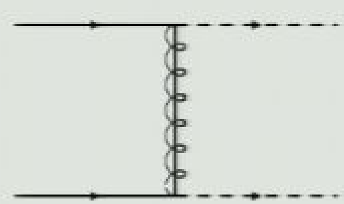

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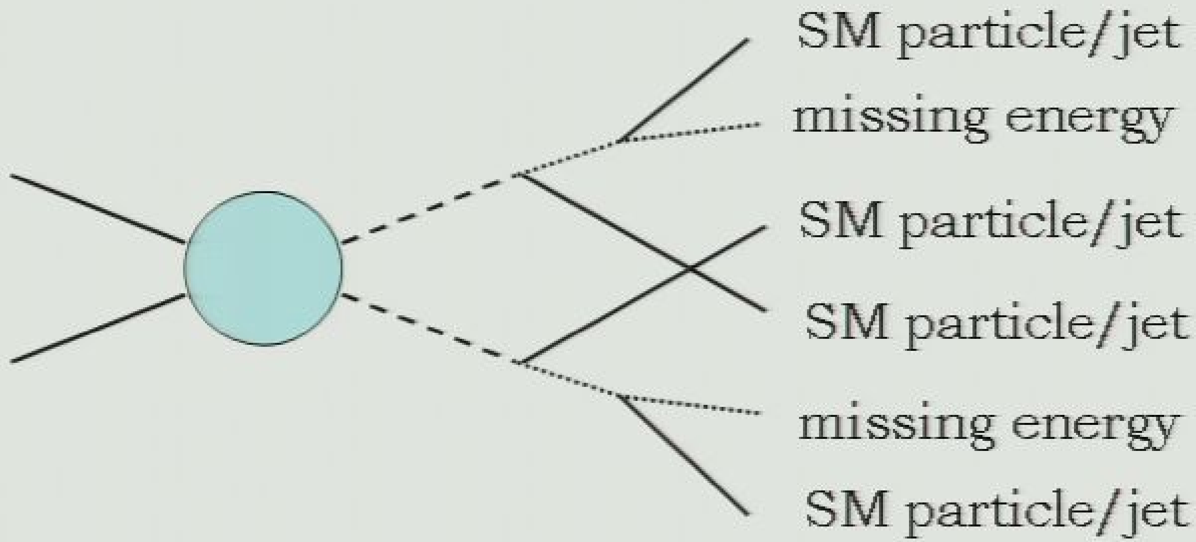
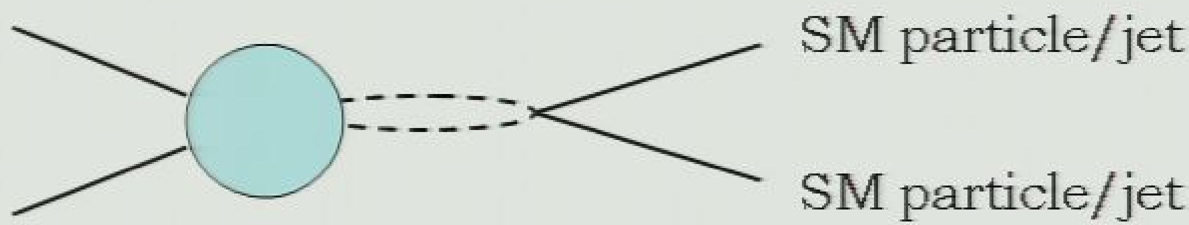


Bound state annihilation



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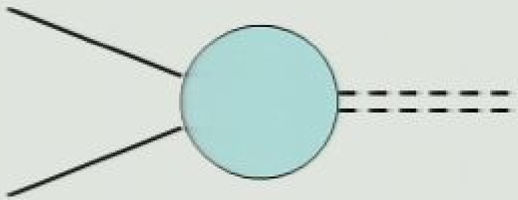

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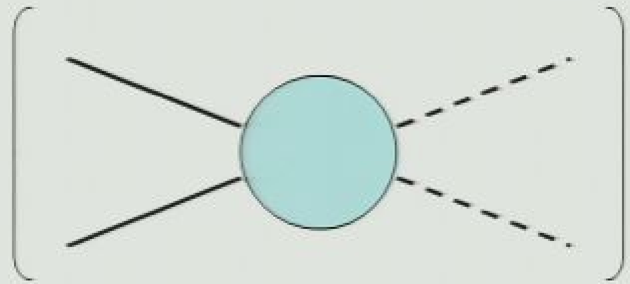

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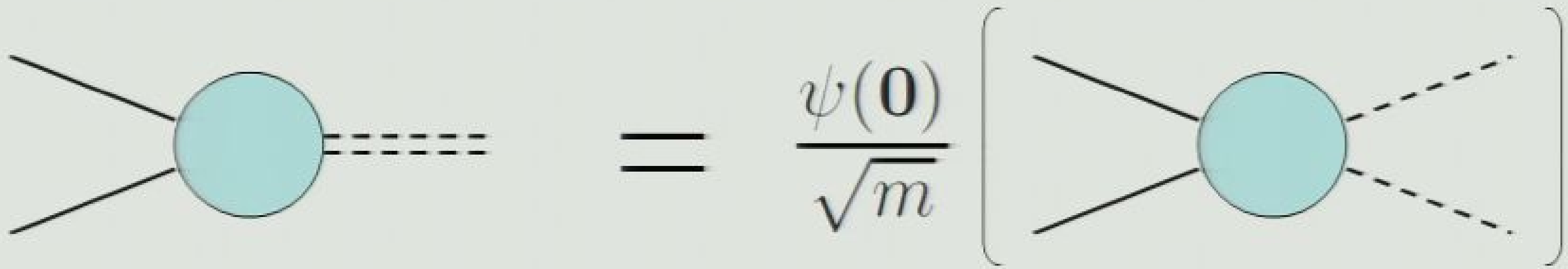

A more general formalism:

$$\left[-\frac{\nabla^2}{m} + V(r) - E\right] G(\mathbf{x}, E) = \delta^{(3)}(\mathbf{x}) \qquad E_n = \frac{E_b}{n^2}$$

$$G(\mathbf{0}, E) = -\frac{m^2}{4\pi}\left[\sqrt{-\frac{E}{m}} - C\overline{\alpha}_s \ln\left(\frac{|C|\overline{\alpha}_s}{2}\sqrt{-\frac{m}{E}}\right) - \frac{2}{\sqrt{m}}\sum_{n=1}^{\infty}\frac{E_n}{\sqrt{-E} - \mathrm{sign}(C)\sqrt{E_n}}\right]$$

For finite width: $E \to E + i\Gamma$

For $\Gamma \to 0$, below threshold:

$$\mathrm{Im}\, G(\mathbf{0}, E) = \sum_n M_n |\psi_n(\mathbf{0})|^2\, \Phi_1$$

where $\Phi_1 = 2\pi\,\delta(\hat{s} - M_n^2)$, $M_n = 2m - E_b/n^2$

For the general case, see toponium ($t\overline{t}$) demonstration.

How to compute bound state processes

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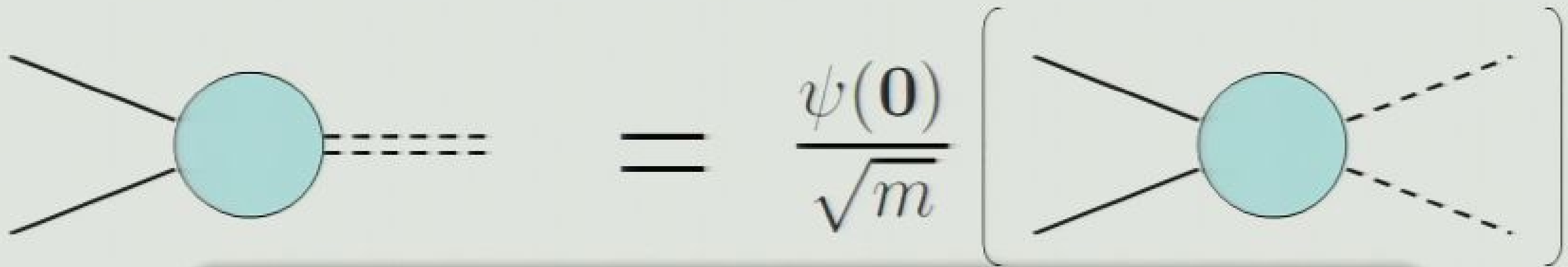

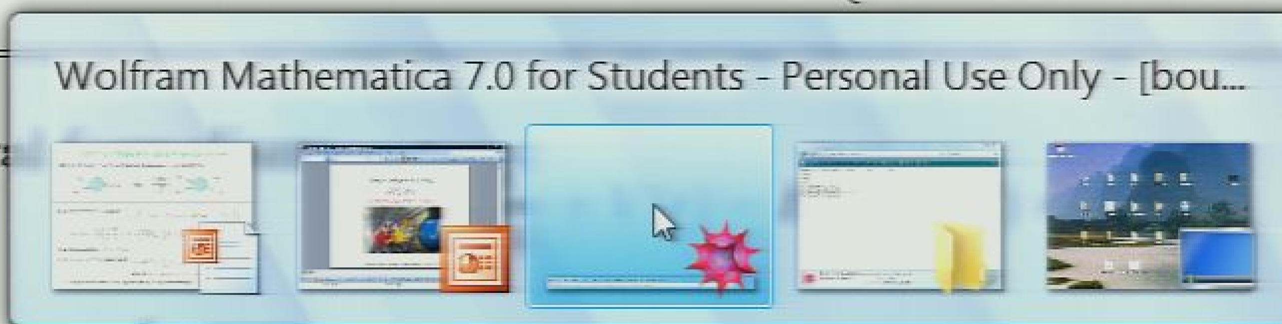

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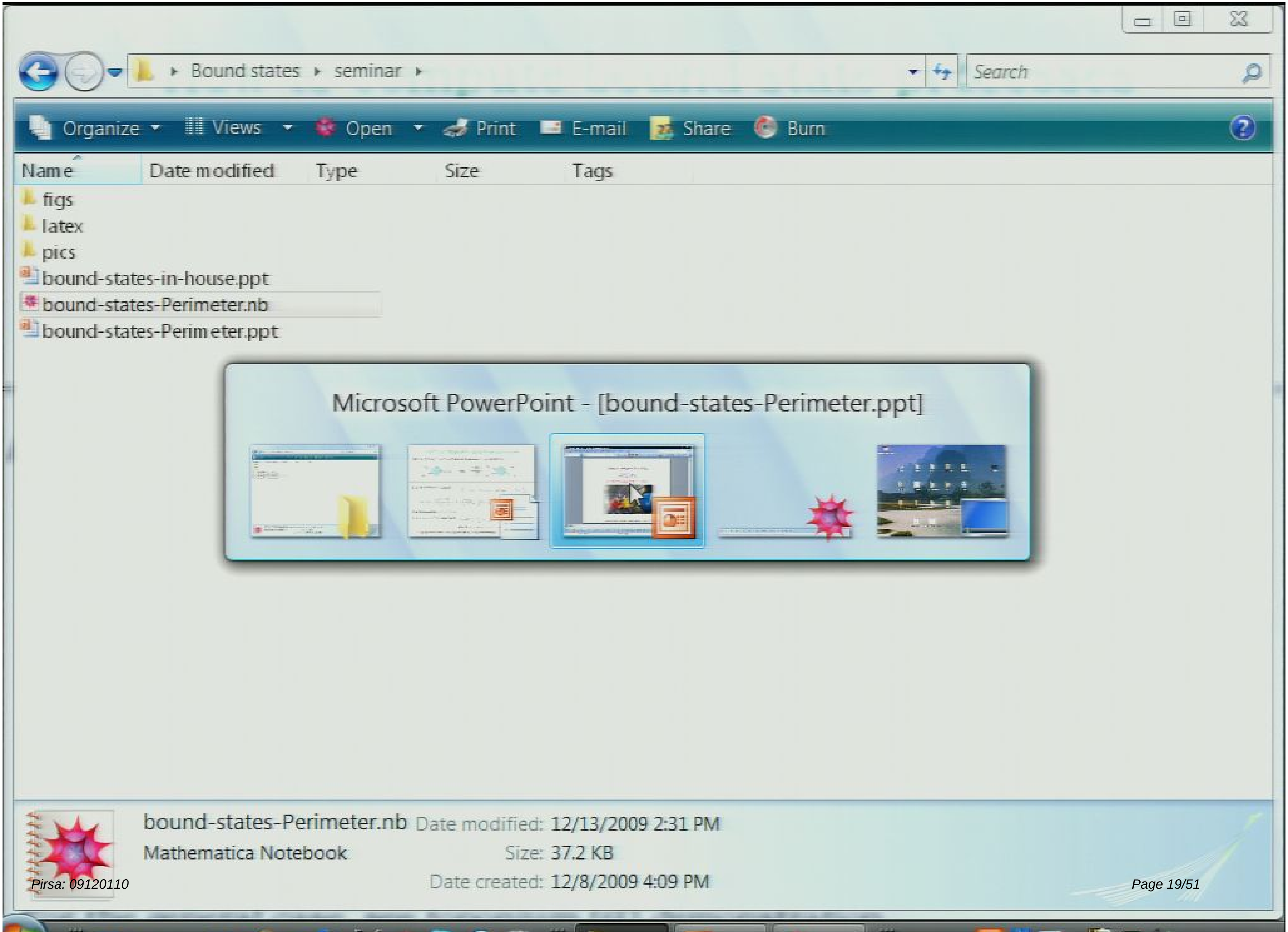
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Date created: 12/8/2009 4:09 PM

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Slide Show

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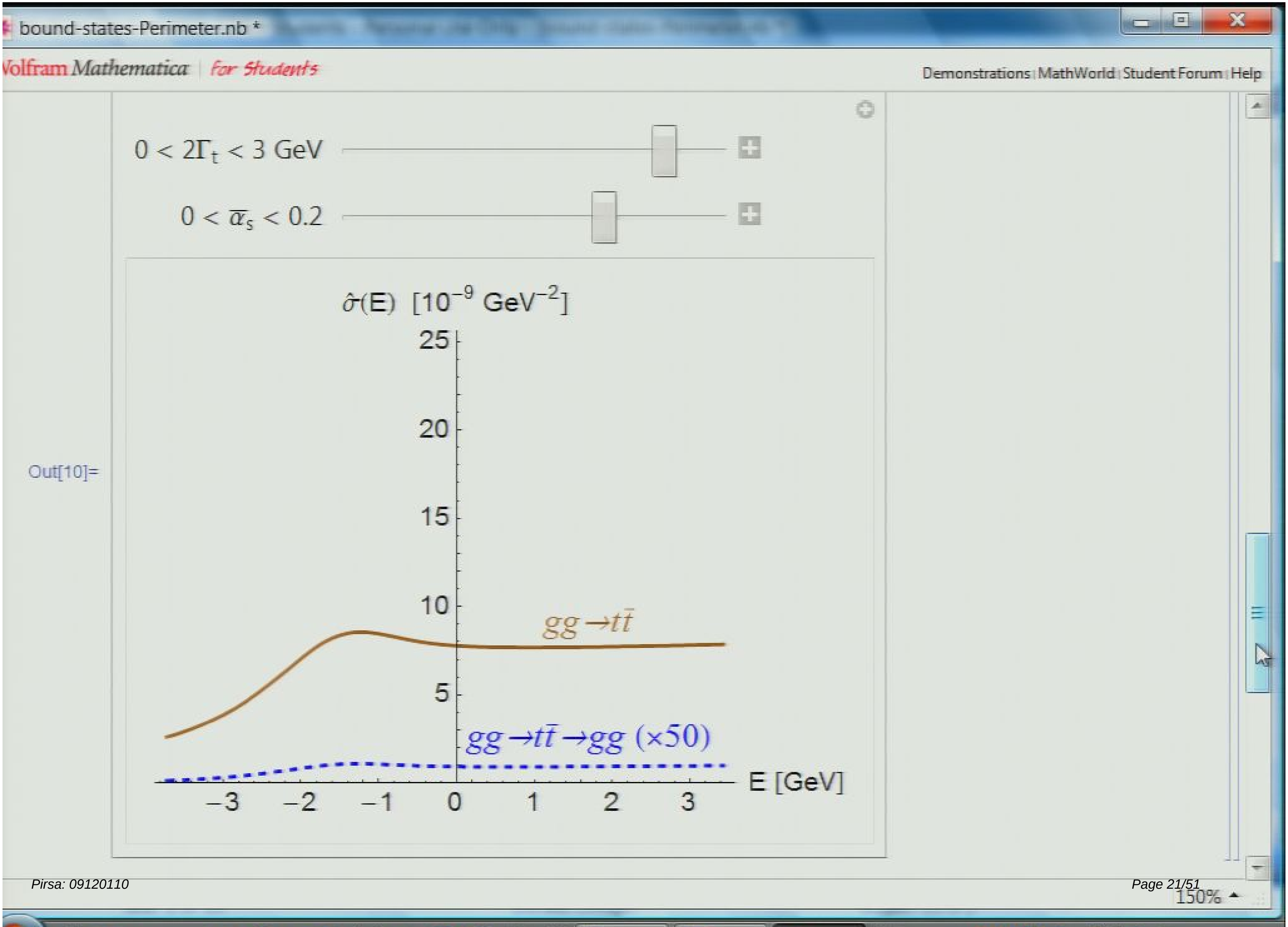
...es at the LHC

Yevgeny Kats
Harvard University

arXiv:0912.0526 (with Matthew D. Schwartz)

Particle Physics Seminar, Perimeter Institute, 15 Dec 2009

Slide 1 of 23 | Default Design | English (U.S.)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Wolfram Mathematica | For Students
Demonstrations | MathWorld | Student Forum | Help
0 < 2Γt < 3 GeV
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Out[10]=
σ̂(E) [10^-9 GeV^-2]
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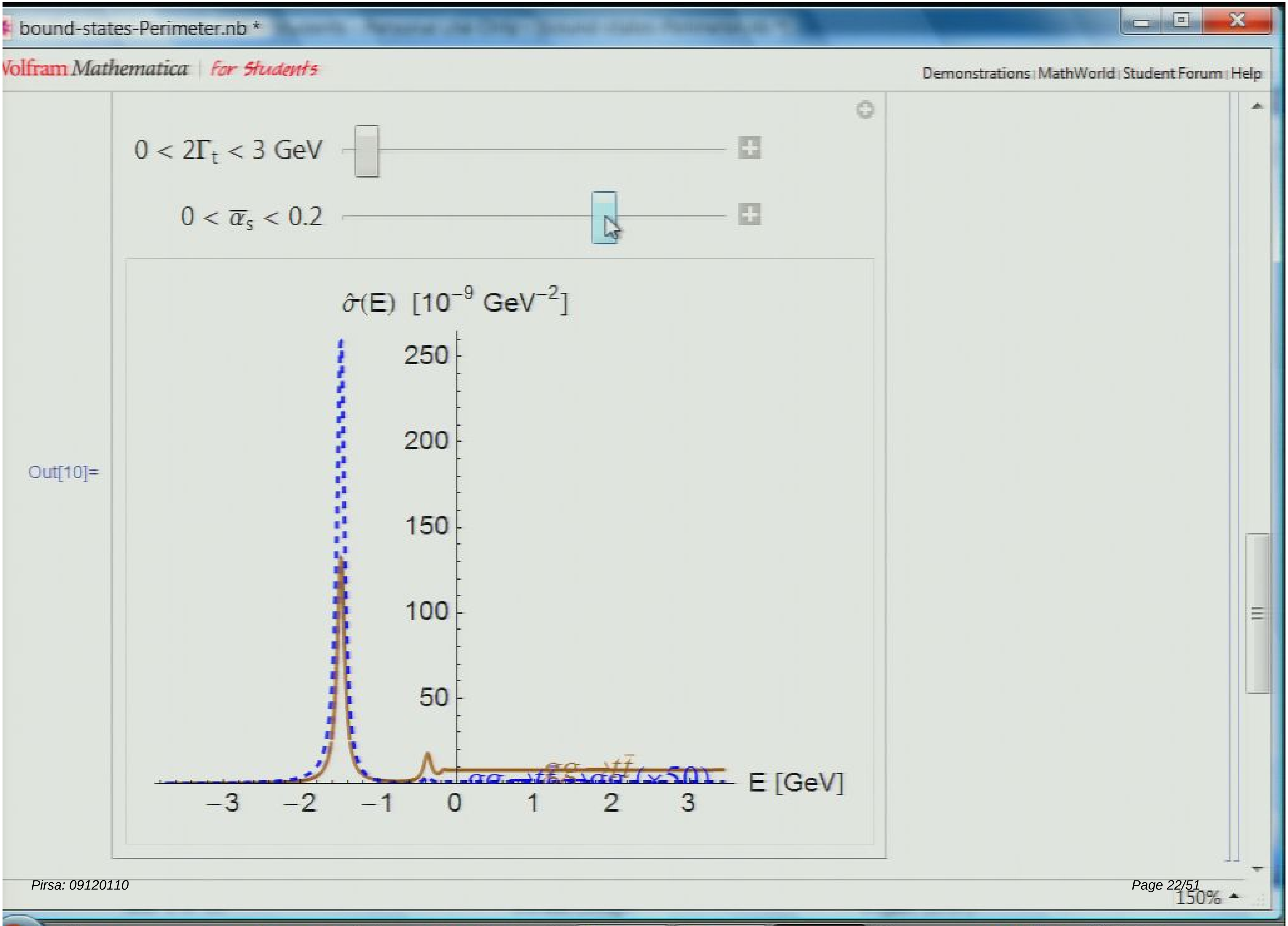
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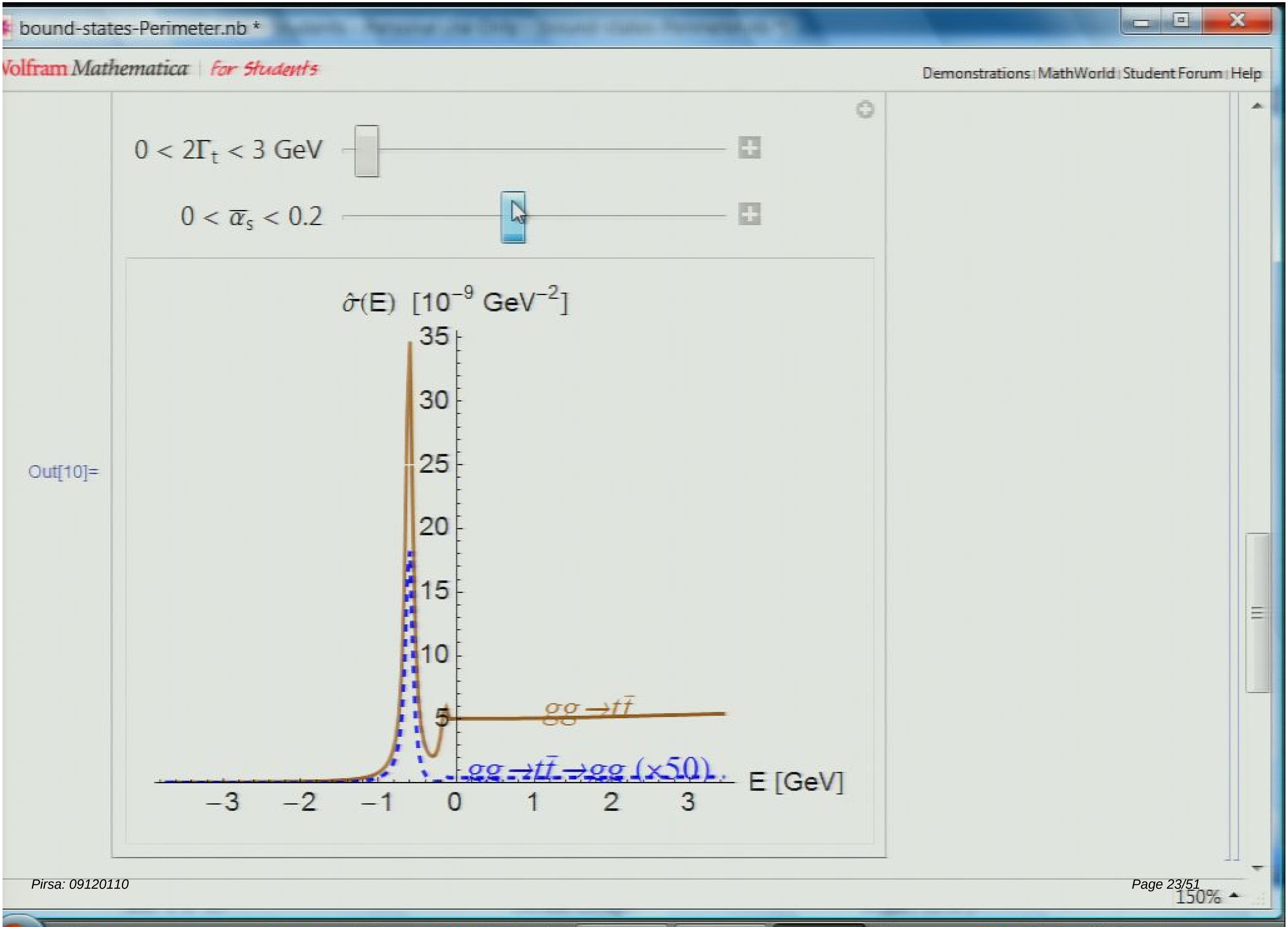
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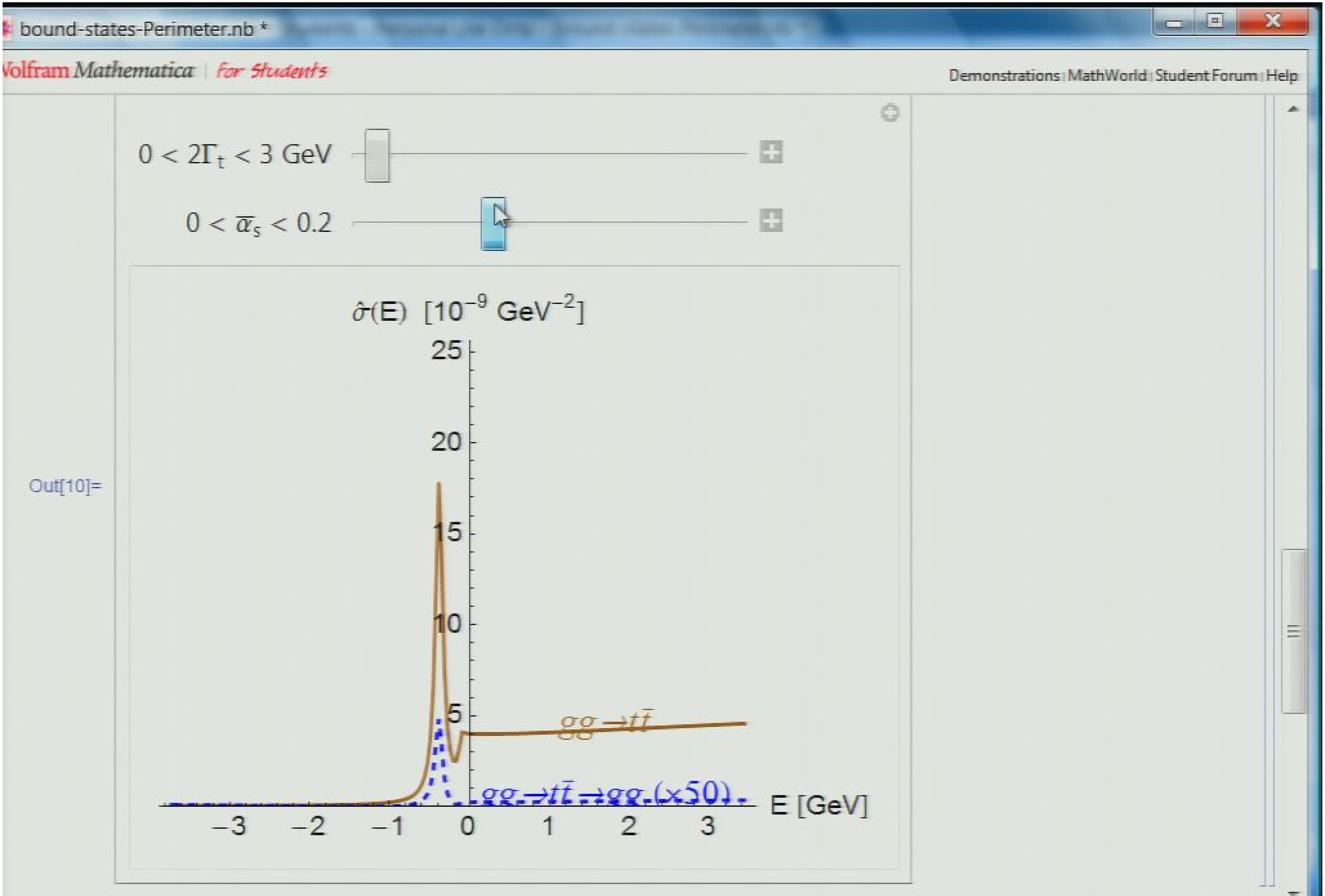

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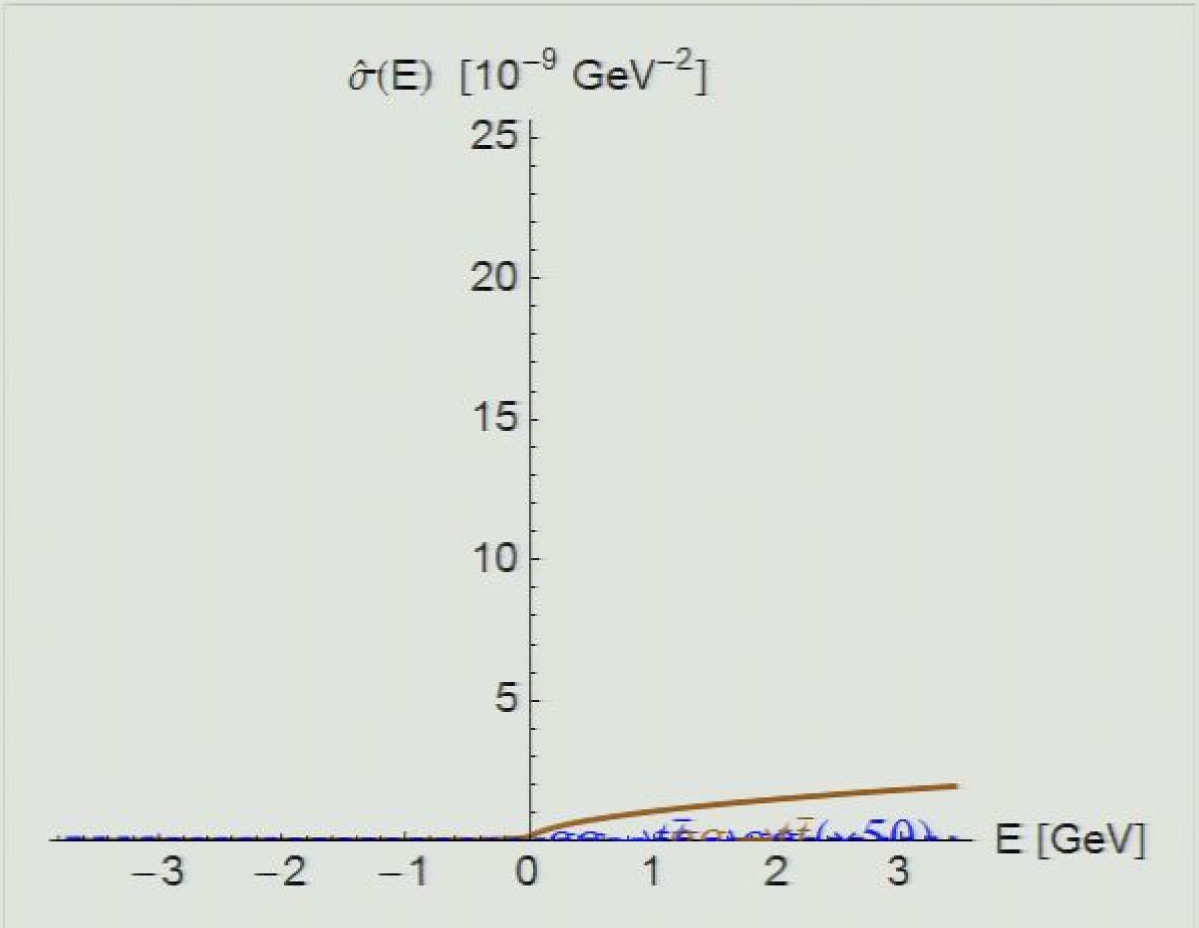
$0 < 2\Gamma_t < 3$ GeV

$0 < \bar{\alpha}_s < 0.2$

Out[10]=



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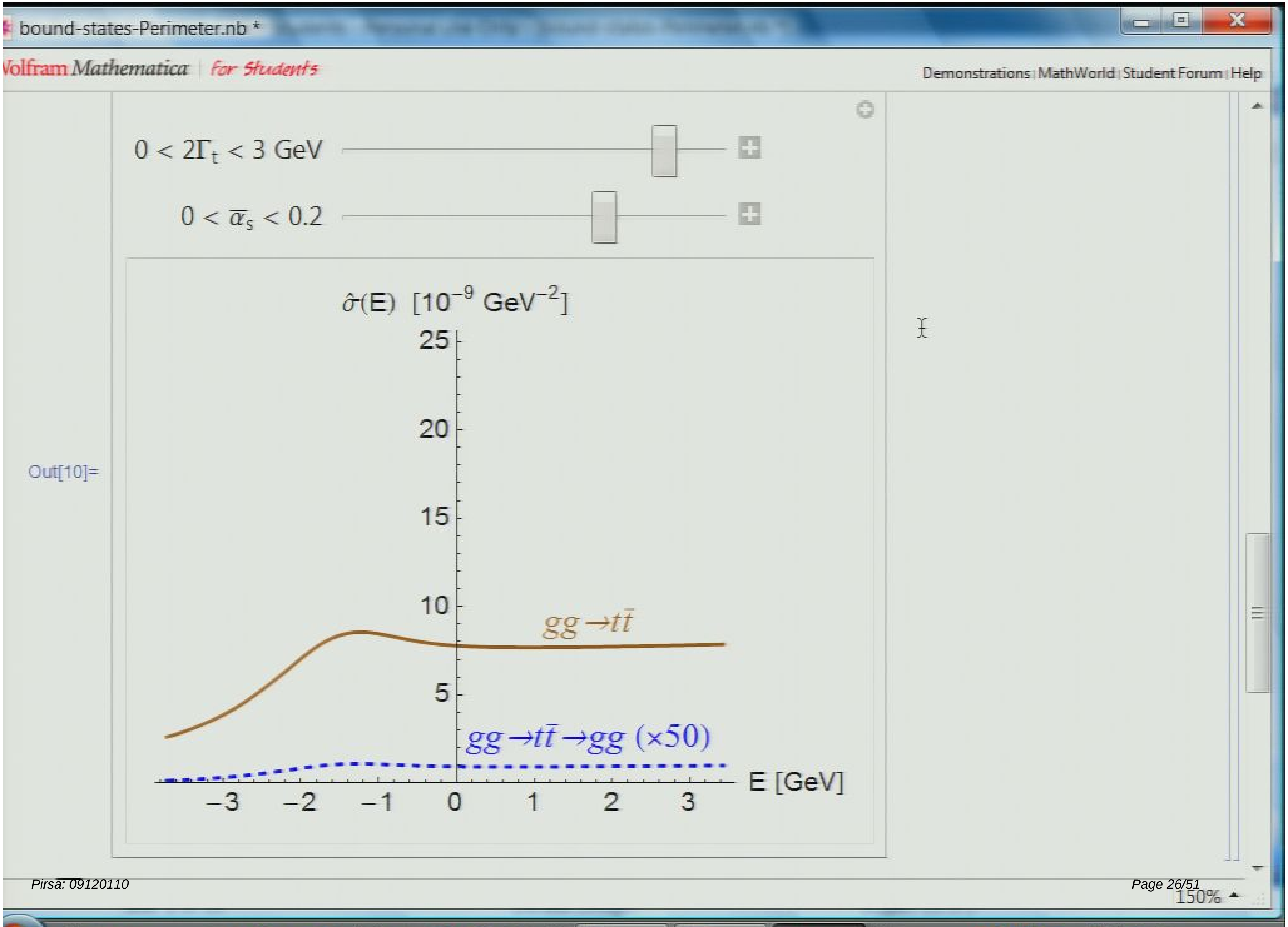

bound-states-Perimeter.nb *
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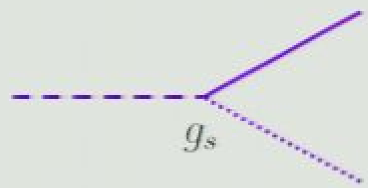
Demonstrations | MathWorld | Student Forum | Help
$0 < 2\Gamma_t < 3$ GeV
$0 < \bar{\alpha}_s < 0.2$
Out[10]=
$\hat{\sigma}(E)$ $[10^{-9}\ \mathrm{GeV}^{-2}]$
25
20
15
10
5
$gg \to t\bar{t}$
$gg \to t\bar{t} \to gg\ (\times 50)$
E [GeV]
−3
−2
−1
0
1
2
3
150%

Scales in the problem

Binding energy: $E_b \sim \overline{\alpha}_s^2 m$

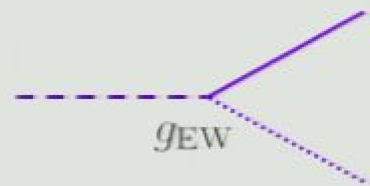
Bound state annihilation rate: $\Gamma_{\text{ann}} \sim \frac{\alpha_s^2}{m^2}|\psi(\mathbf{0})|^2 \sim \alpha_s^2 \overline{\alpha}_s^3 m$

Single-particle decay rate:



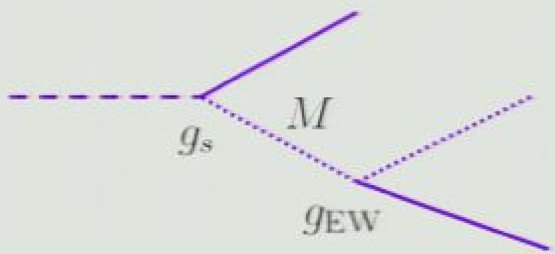
$\tilde{g} \to \tilde{q}\overline{q}$

$\Gamma_{\text{decay}} \sim \alpha_s m$



$\tilde{q} \to q\,\chi$

$\Gamma_{\text{decay}} \sim \alpha\, m \sim \alpha_s^2 m$



$m_{\tilde{q}} \gtrsim m_{\tilde{g}}: \quad \tilde{g} \to \chi q \overline{q}$

$$\Gamma_{\text{decay}} \sim \alpha_s \alpha\, m \left(\frac{m}{M}\right)^4 \sim \alpha_s^3 m \left(\frac{m}{M}\right)^4$$

$$\Gamma_{\tilde{g}} \sim \frac{\alpha \alpha_s m_{\tilde{g}}}{16\pi \sin^2\theta_W}\left(\frac{m_{\tilde{g}}}{m_{\tilde{q}}}\right)^4$$

Binding fraction

In the case when narrow bound states do exist,
what fraction of all the pairs forms bound states?

Very roughly (ignoring the luminosity fall-off with energy etc.):

$$\frac{\sigma^{\rm bound}}{\sigma^{\rm cont}} \sim \frac{\int \hat{\sigma}^{\rm bound}(\hat{s})\, {\rm d}\sqrt{\hat{s}}}{\int \hat{\sigma}^{\rm cont}(\hat{s})\, {\rm d}\sqrt{\hat{s}}} \sim C^3 \overline{\alpha}_s^3 \sim \text{ few } \%$$

where we used

$$\hat{\sigma}^{\rm bound}(\hat{s}) \sim \frac{\alpha_s^2}{m^4} |\psi(\mathbf{0})|^2 \, \delta\left(\sqrt{\hat{s}} - 2m\right) \qquad |\psi(\mathbf{0})|^2 = \frac{C^3 \overline{\alpha}_s^3 m^3}{8\pi}$$

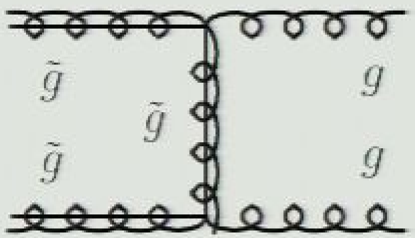
$$\hat{\sigma}^{\rm cont}(\hat{s}) \sim \frac{\alpha_s^2}{\hat{s}}$$

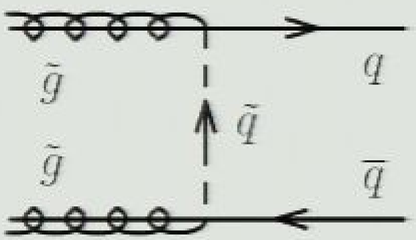
Gluinonium

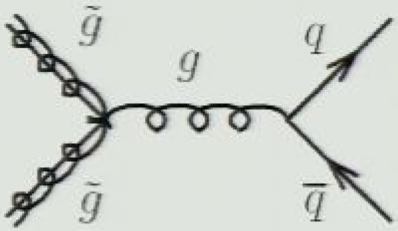
$$8 \otimes 8 = 1 \oplus 8_S \oplus 8_A \oplus 10 \oplus \overline{10} \oplus 27$$

Keung, Khare '84
Kühn, Ono '84
Goldman, Haber '85
Kartvelishvili, Tkabladze, Chikovani, '89
Chikovani, Kartvelishvili, Shanidze, Shaw '96
Bouhova-Thacker, Kartvelishvili, Small '04, '06
Cheung, Keung '05
Hagiwara, Yokoya '09
Kauth, Kühn, Marquard, Steinhauser '09

$$C_1 = 3, \qquad C_{8_S} = C_{8_A} = \frac{3}{2}$$







$$|\psi(\mathbf{0})|^2 = \frac{C^3 \overline{\alpha}_s^3 m^3}{8\pi}$$

color	J^{PC}	production channel	annihilation channels	BR$(t\bar{t})$ $m_{\tilde{q}} \sim m_{\tilde{g}}$	BR$(t\bar{t})$ $m_{\tilde{q}} \gg m_{\tilde{g}}$
$\mathbf{1}, \mathbf{8_S}$	0^{-+}	gg	$gg, t\bar{t}$	$5\% - 0.5\%$	0
$\mathbf{8_A}$	1^{-+}	$q\bar{q}$	$q\bar{q}$	not produced	1/6

$$\Gamma(\mathbf{1} \to gg) = \frac{18\pi\alpha_s^2}{m_{\tilde{g}}^2} |\psi_{\mathbf{1}}(\mathbf{0})|^2 = \frac{243}{4} \alpha_s^2 \overline{\alpha}_s^3 m_{\tilde{g}} \qquad \Gamma(\mathbf{8_S} \to gg) = \frac{9\pi\alpha_s^2}{2m_{\tilde{g}}^2} |\psi_{\mathbf{8_S}}(\mathbf{0})|^2 = \frac{243}{128} \alpha_s^2 \overline{\alpha}_s^3 m_{\tilde{g}}$$

$$\Gamma(\mathbf{8_A} \to q\bar{q}) = \sum_{\tilde{q}} \left(\frac{m_{\tilde{q}}^2 - m_{\tilde{g}}^2}{m_{\tilde{q}}^2 + m_{\tilde{g}}^2} \right)^2 \frac{\pi\alpha_s^2}{2m_{\tilde{g}}^2} |\psi_{\mathbf{8_A}}(\mathbf{0})|^2 = \sum_{\tilde{q}} \left(\frac{m_{\tilde{q}}^2 - m_{\tilde{g}}^2}{m_{\tilde{q}}^2 + m_{\tilde{g}}^2} \right)^2 \frac{27}{128} \alpha_s^2 \overline{\alpha}_s^3 m_{\tilde{g}}$$

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$$\hat{\sigma}^{\text{cont}}(\hat{s}) \sim \frac{\alpha_s^2}{\hat{s}}$$

Gluinonium

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

♥ ♥ ♥ ⊘ ⊘ ⊘

Keung, Khare '84
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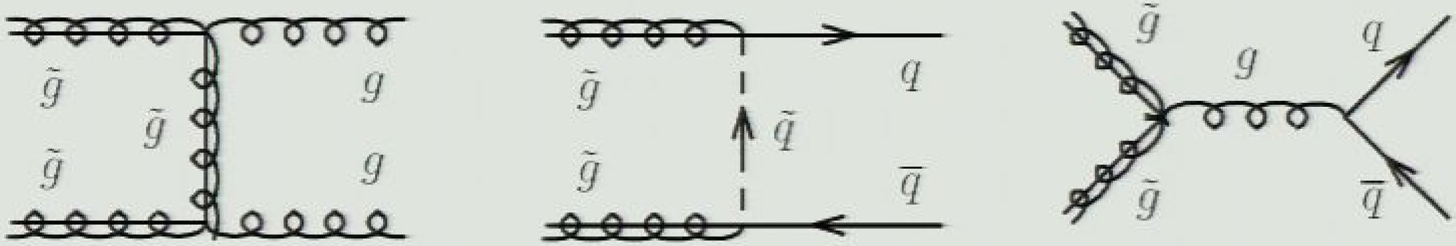
$$C_{\mathbf{1}} = 3\,, \qquad C_{\mathbf{8_S}} = C_{\mathbf{8_A}} = \frac{3}{2}$$



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$$\Gamma(\mathbf{8_A} \to q\bar{q}) = \sum_{\tilde{q}} \left(\frac{m_{\tilde{q}}^2 - m_{\tilde{g}}^2}{m_{\tilde{q}}^2 + m_{\tilde{g}}^2} \right)^2 \frac{\pi\alpha_s^2}{2m_{\tilde{g}}^2} |\psi_{\mathbf{8_A}}(\mathbf{0})|^2 = \sum_{\tilde{q}} \left(\frac{m_{\tilde{q}}^2 - m_{\tilde{g}}^2}{m_{\tilde{q}}^2 + m_{\tilde{g}}^2} \right)^2 \frac{27}{128}\alpha_s^2 \overline{\alpha}_s^3 m_{\tilde{g}}$$

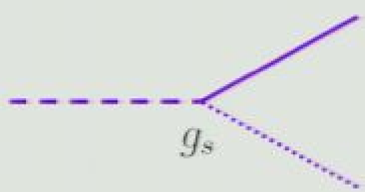
Gluino at benchmark points

Model	$m_{\tilde g}$	$m_{\tilde t}$	$E_b^{\mathbf{1}}$	$E_b^{\mathbf{8}}$	$2\,\Gamma_{\tilde g}$	$\Gamma_{\mathbf{1}}^{\text{ann}}$	$\Gamma_{\mathbf{8_S}}^{\text{ann}}$	$\Gamma_{\mathbf{8_A}}^{\text{ann}}$
SPS 1a	607	400	18	5.3	11	0.46	0.018	0.0005
SPS 1b	938	660	25	7.4	20	0.53	0.021	0.0006
SPS 2	782	950	22	6.5	0.0052	0.50	0.020	0.0082
SPS 3	935	648	25	7.4	23	0.53	0.021	0.0006
SPS 4	733	545	21	6.1	4.2	0.49	0.019	0.0003
SPS 5	722	262	20	6.1	23	0.49	0.019	0.0016
SPS 6	720	503	20	6.1	11	0.49	0.019	0.0005
SPS 7	950	807	25	7.5	8.4	0.53	0.021	0.0002
SPS 8	839	978	23	6.8	0.034	0.51	0.020	0.0017
SPS 9	1182	930	30	8.8	9.1	0.57	0.023	0.0003
Toy models	300	300	11	3.1	0	0.37	0.015	0
	300	∞	11	3.1	0	0.35	0.014	0.019
	800	800	22	6.6	0	0.50	0.020	0
	800	∞	22	6.6	0	0.50	0.020	0.027

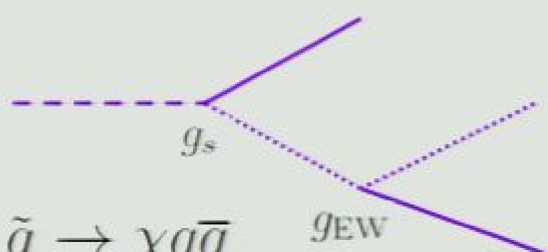
All the units in the table are GeV.

mSUGRA focus point (SPS 2)

GMSB w/ neutralino NLSP (SPS 8)



$\tilde g \to \tilde q \bar q$



$\tilde g \to \chi q \bar q$

Gluinonium signals at the LHC

$m_{\tilde{g}}$ GeV	$m_{\tilde{q}}$ GeV	$\mathbf{1}, \mathbf{8_S} \to gg$ fb	$\mathbf{1}, \mathbf{8_S} \to t\bar{t}$ fb	$\mathbf{8_A} \to q\bar{q}$ fb	$\mathbf{8_A} \to t\bar{t}$ fb	any $\to gg, q\bar{q}$ fb	any $\to t\bar{t}$ fb
300	300	13000	780	0	0	13000	780
300	∞	14000	0	1200	240	15000	240
800	800	38	0.28	0	0	38	0.28
800	∞	38	0	13	2.6	51	2.6

$$\mathcal{L}_{gg\Phi_1} \propto \frac{1}{m_{\tilde{g}}} \epsilon^{\mu\nu\rho\sigma} \Phi_{\mathbf{1}} G^a_{\mu\nu} G^a_{\rho\sigma} \qquad \mathcal{L}_{q\bar{q}\Phi_1} \propto \frac{m_q}{m_{\tilde{g}}} \Phi_{\mathbf{1}}\, i\bar{q}\gamma^5 q$$

$$\mathcal{L}_{gg\Phi_{8_S}} \propto \frac{1}{m_{\tilde{g}}} \epsilon^{\mu\nu\rho\sigma} d^{abc}\, \Phi^a_{\mathbf{8_S}} G^b_{\mu\nu} G^c_{\rho\sigma} \qquad \mathcal{L}_{q\bar{q}\Phi_{8_S}} \propto \frac{m_q}{m_{\tilde{g}}} \Phi^a_{\mathbf{8_S}} \left(T^a\right)^j_i\; i\bar{q}^i \gamma^5 q_j$$

$$\mathcal{L}_{q\bar{q}V^\mu_{8_A}} \propto \left(V^\mu_{\mathbf{8_A}}\right)^a \left(T^a\right)^j_i\; \bar{q}^i \gamma_\mu q_j$$

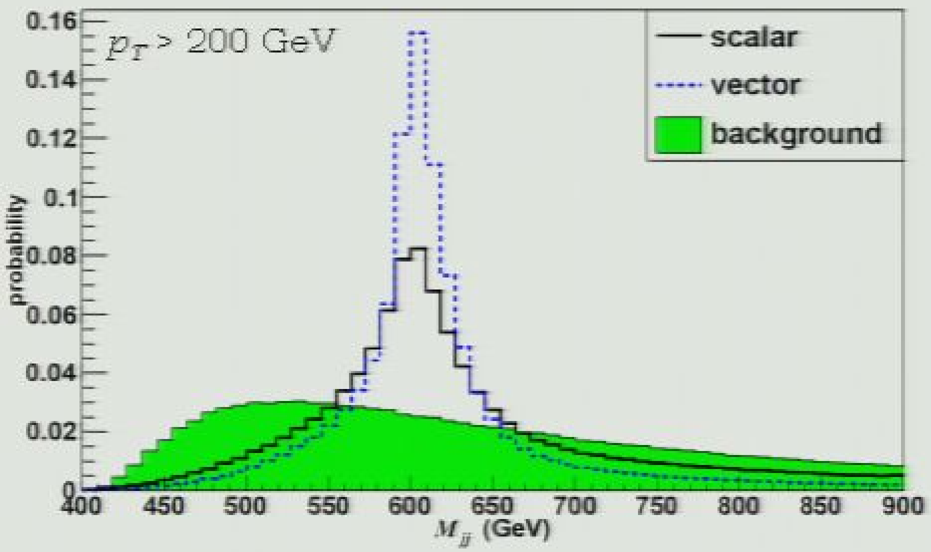
Pythia 8: pseudoscalar Higgs and Z' with modified couplings (ignoring color) with 14 TeV LHC, LO MSTW2008 pdfs, SISCone jet algorithm.

Dijet channel

Signal: $\mathbf{1} \to gg\,,\ \mathbf{8_S} \to gg,\ \ \mathbf{8_A} \to q\bar{q}$

Background: $\ gg \to gg,\ qg \to qg$, etc.

Gluino mass: 300 GeV



Gluinonium signals at the LHC

$m_{\tilde{g}}$ GeV	$m_{\tilde{q}}$ GeV	$\mathbf{1}, \mathbf{8_S} \to gg$ fb	$\mathbf{1}, \mathbf{8_S} \to t\bar{t}$ fb	$\mathbf{8_A} \to q\bar{q}$ fb	$\mathbf{8_A} \to t\bar{t}$ fb	any $\to gg, q\bar{q}$ fb	any $\to t\bar{t}$ fb
300	300	13000	780	0	0	13000	780
300	∞	14000	0	1200	240	15000	240
800	800	38	0.28	0	0	38	0.28
800	∞	38	0	13	2.6	51	2.6

$$\mathcal{L}_{gg\Phi_1} \propto \frac{1}{m_{\tilde{g}}} \epsilon^{\mu\nu\rho\sigma} \Phi_1 G^a_{\mu\nu} G^a_{\rho\sigma}$$

$$\mathcal{L}_{q\bar{q}\Phi_1} \propto \frac{m_q}{m_{\tilde{g}}} \Phi_1 \, i\bar{q}\gamma^5 q$$

$$\mathcal{L}_{gg\Phi_{8_S}} \propto \frac{1}{m_{\tilde{g}}} \epsilon^{\mu\nu\rho\sigma} d^{abc} \, \Phi^a_{8_S} G^b_{\mu\nu} G^c_{\rho\sigma}$$

$$\mathcal{L}_{q\bar{q}\Phi_{8_S}} \propto \frac{m_q}{m_{\tilde{g}}} \Phi^a_{8_S} \left(T^a\right)_i^j \; i\bar{q}^i \gamma^5 q_j$$

$$\mathcal{L}_{q\bar{q}V^{\mu}_{8_A}} \propto \left(V^{\mu}_{8_A}\right)^a \left(T^a\right)_i^j \; \bar{q}^i \gamma_\mu q_j$$

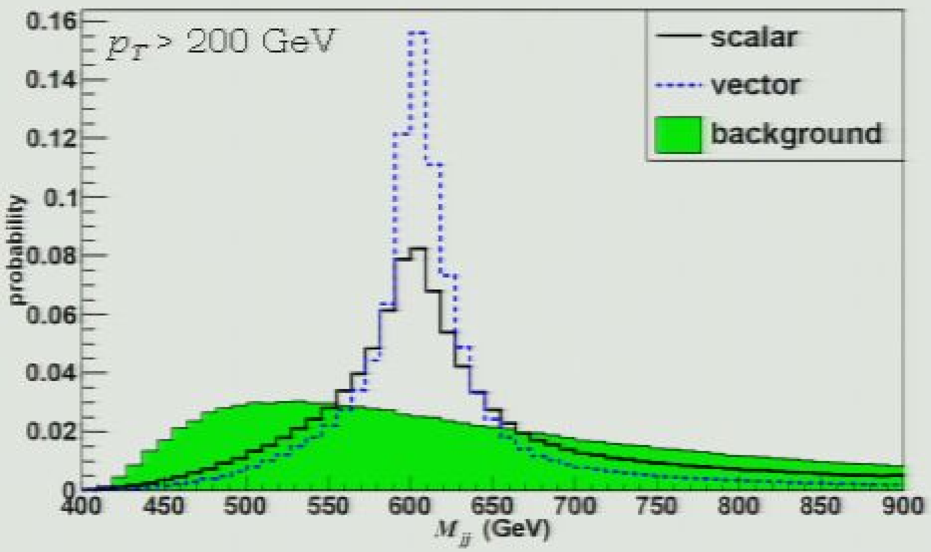
Pythia 8: pseudoscalar Higgs and Z' with modified couplings (ignoring color) with 14 TeV LHC, LO MSTW2008 pdfs, SISCone jet algorithm.

Dijet channel

Signal: $\mathbf{1} \to gg$, $\mathbf{8_S} \to gg$, $\mathbf{8_A} \to q\bar{q}$

Background: $gg \to gg$, $qg \to qg$, etc.

Gluino mass: 300 GeV



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Background: $\ gg \to gg,\ qg \to qg$, etc.

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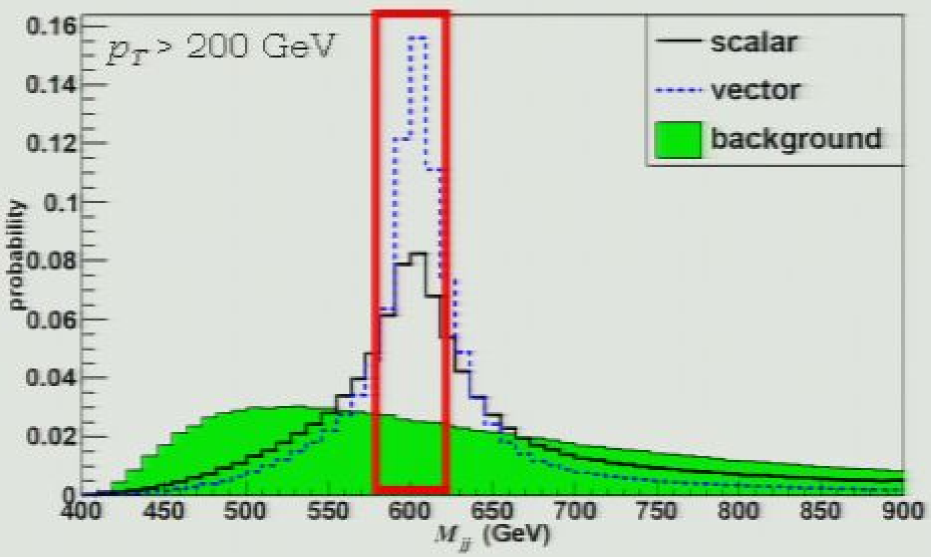
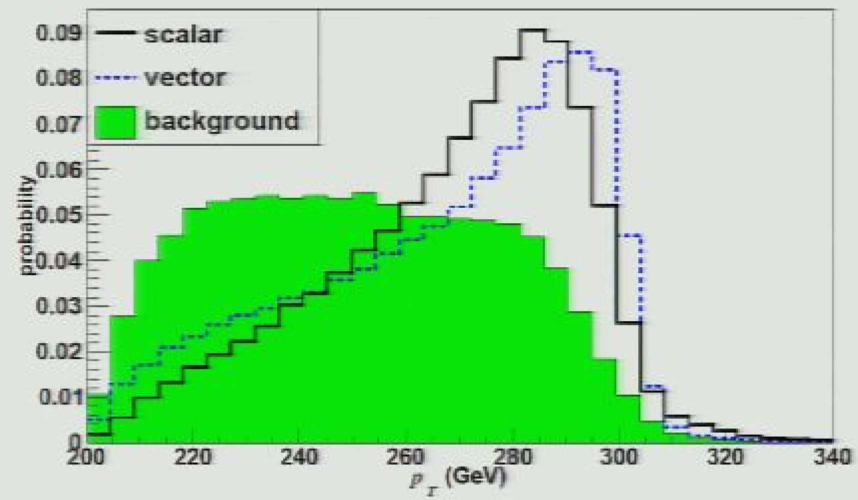
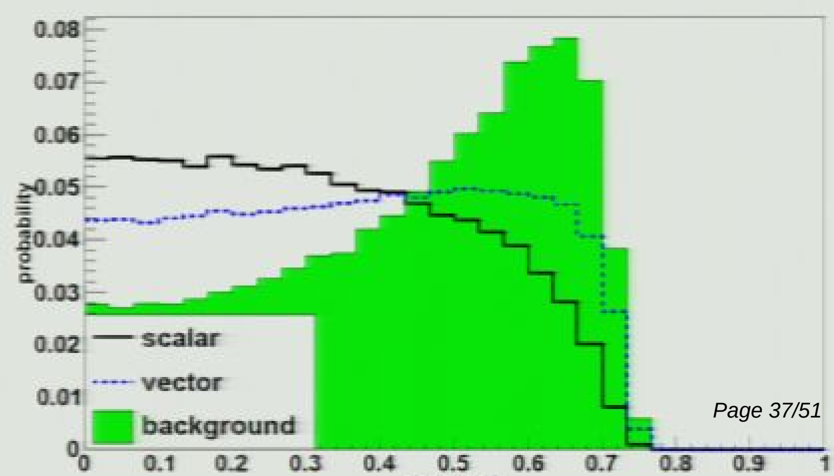




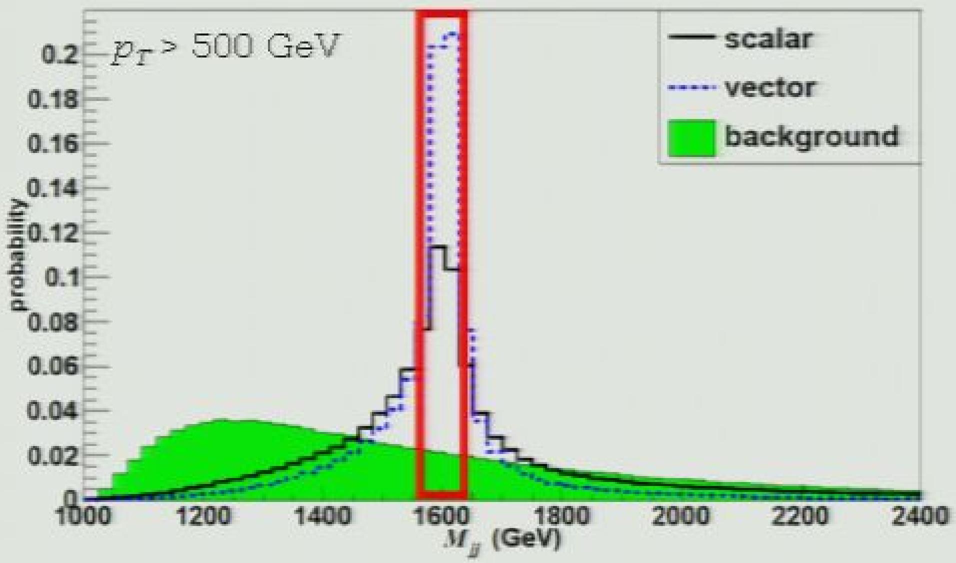


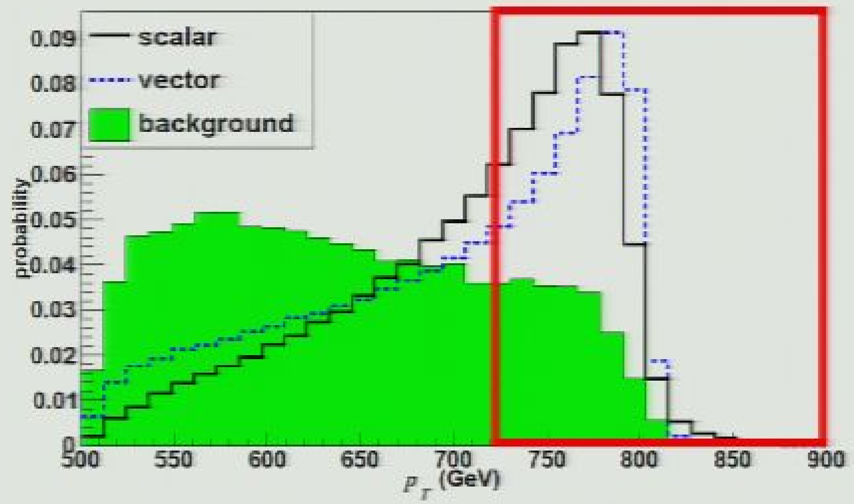
Dijet channel

Signal: $\mathbf{1} \to gg\,,\ \mathbf{8_S} \to gg,\ \ \mathbf{8_A} \to q\bar{q}$

Background: $gg \to gg,\ qg \to qg$, etc.

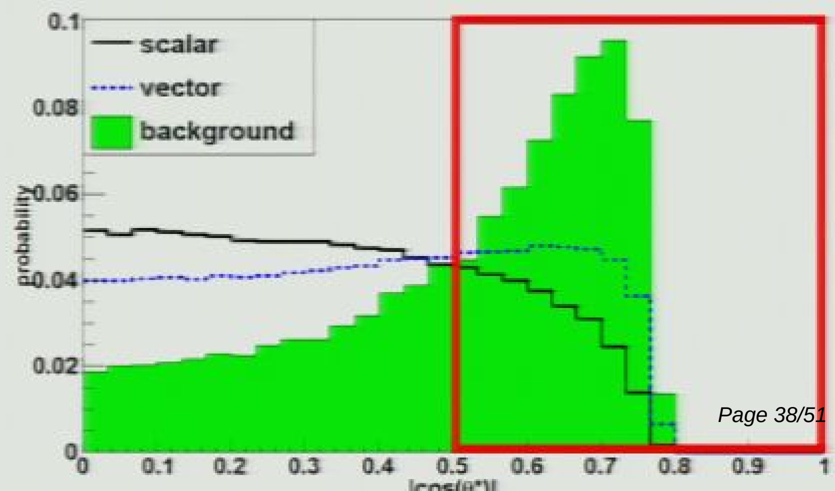
Gluino mass: 800 GeV



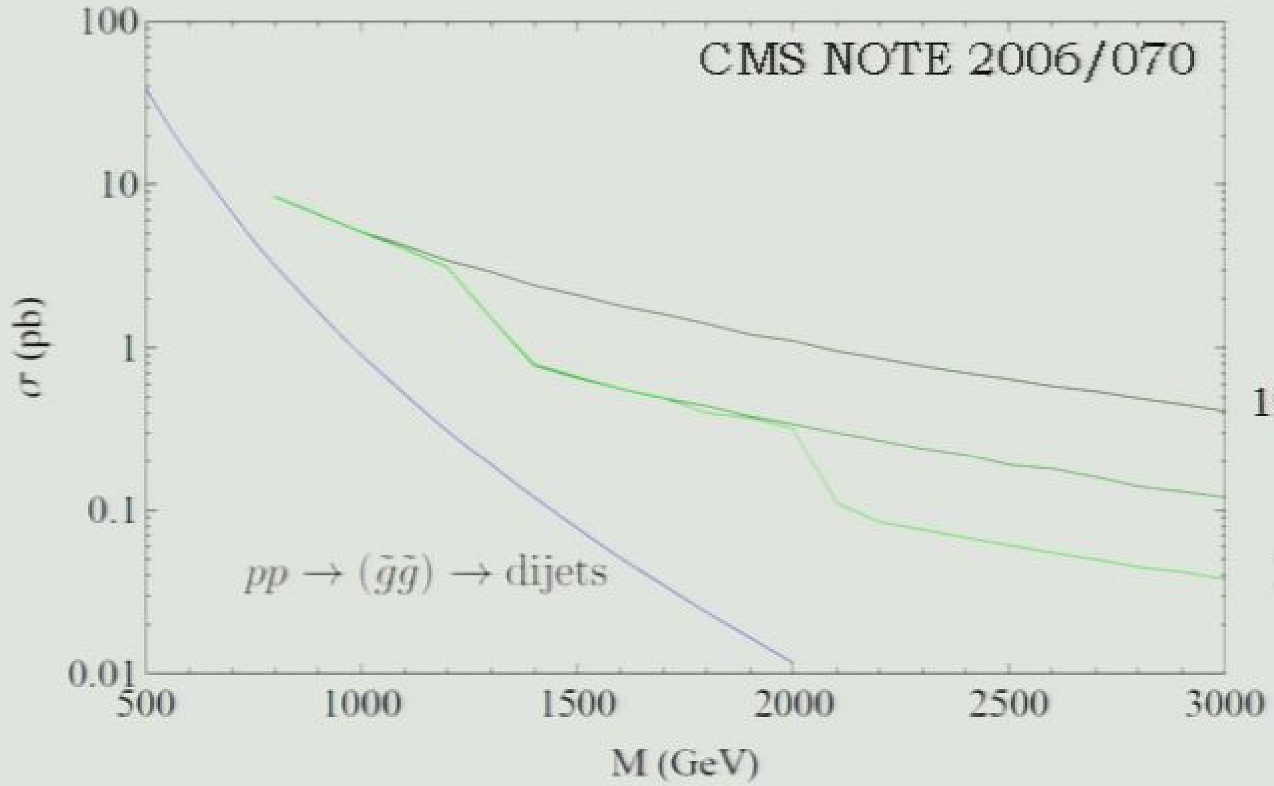


3σ at 10^3-10^4 fb^{-1}

$$\frac{S}{B} \sim 0.05\%$$



Will ATLAS and CMS look for our dijets?



95% CL exclusion

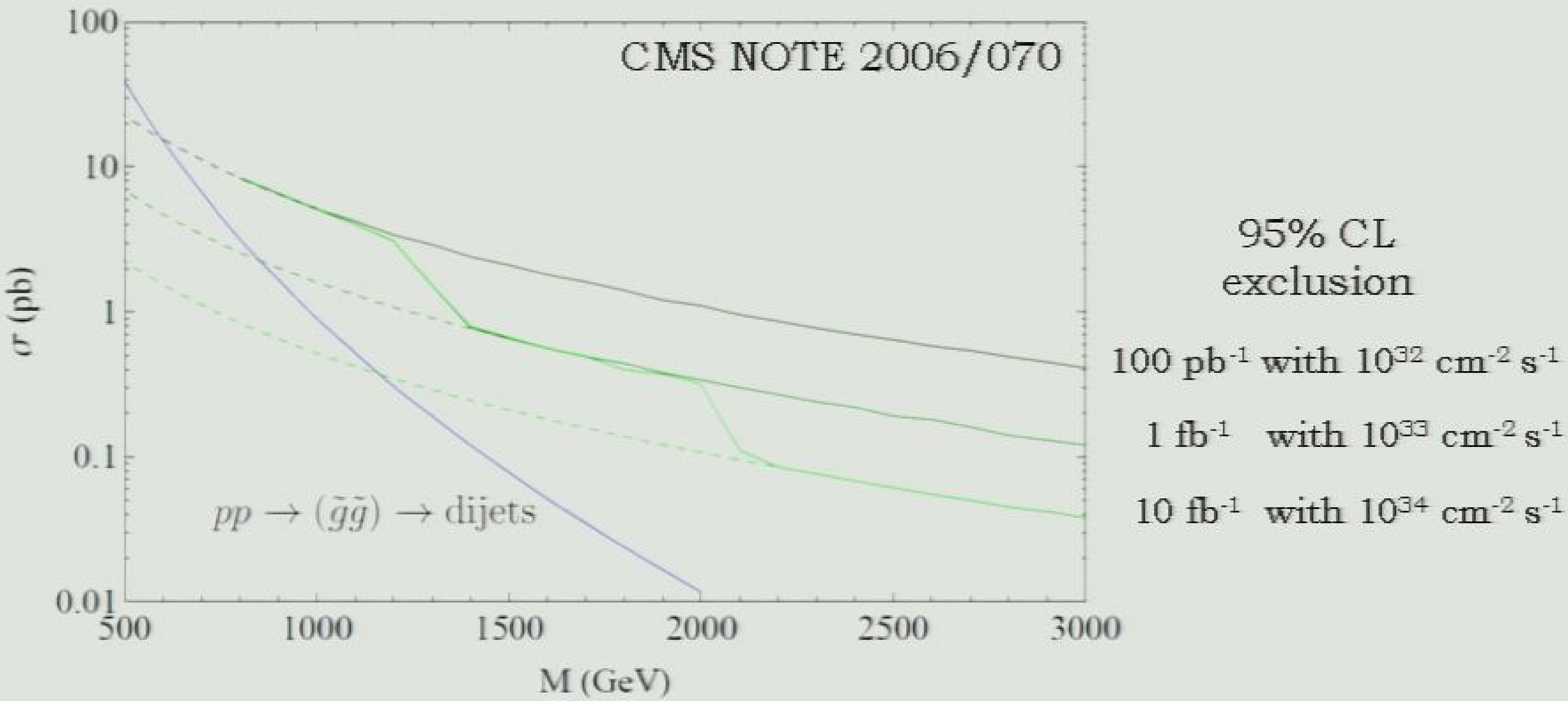
100 pb^{-1} with 10^{32} cm^{-2} s^{-1}

1 fb^{-1} with 10^{33} cm^{-2} s^{-1}

10 fb^{-1} with 10^{34} cm^{-2} s^{-1}

By default, the dijet signal from light gluinonium will suffer from **prescaling** at ATLAS and CMS.

Will ATLAS and CMS look for our dijets?



By default, the dijet signal from light gluinonium will suffer from **prescaling** at ATLAS and CMS.

Prescaling can be reduced by adjusting the triggers, especially if the expected mass is known in advance.

$t\bar{t}$ channel

Signal: $\mathbf{1} \to t\bar{t}$, $\mathbf{8_S} \to t\bar{t}$, $\mathbf{8_A} \to t\bar{t}$ Background: $gg \to t\bar{t}$, $q\bar{q} \to t\bar{t}$, ...

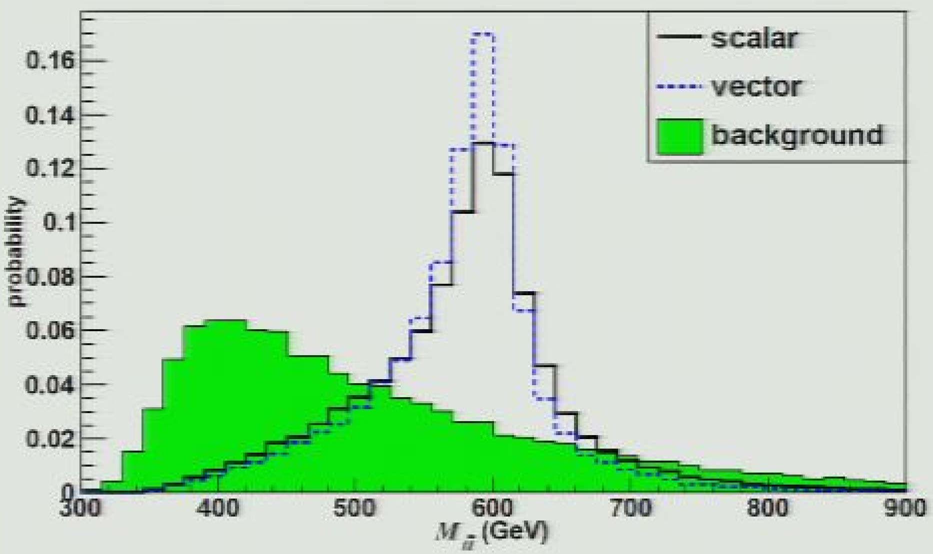
Top decay channels: $t \to W^+ b \to j\,j\,j$, $t \to W^+ b \to \ell^+ \overline{\nu}_\ell\, j$

The twice-leptonic channel has 2 or more missing particles.

The twice-hadronic channel has large QCD background.

We use the semileptonic channel with $\ell = e$ or μ. ATL-PHYS-PUB-2006-033 CMS PAS TOP-09-009

Gluino mass: 300 GeV



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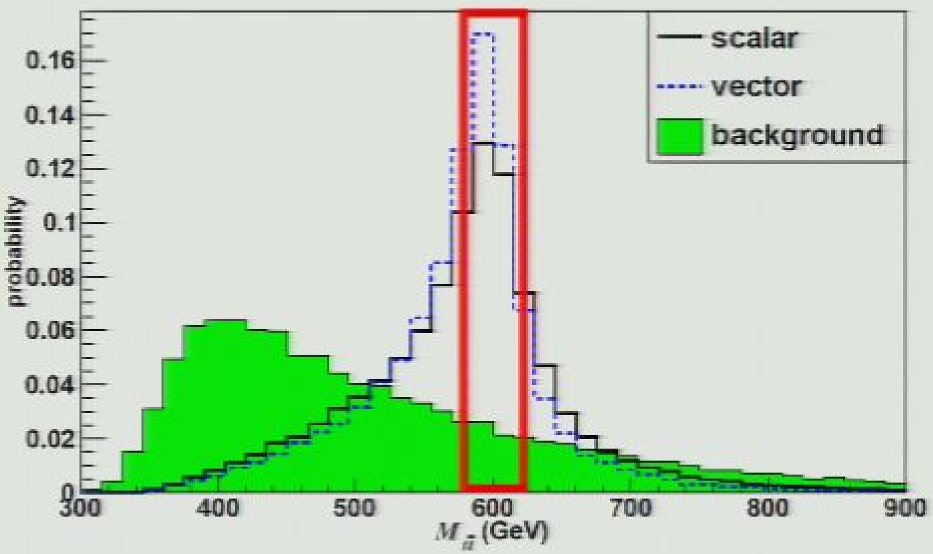
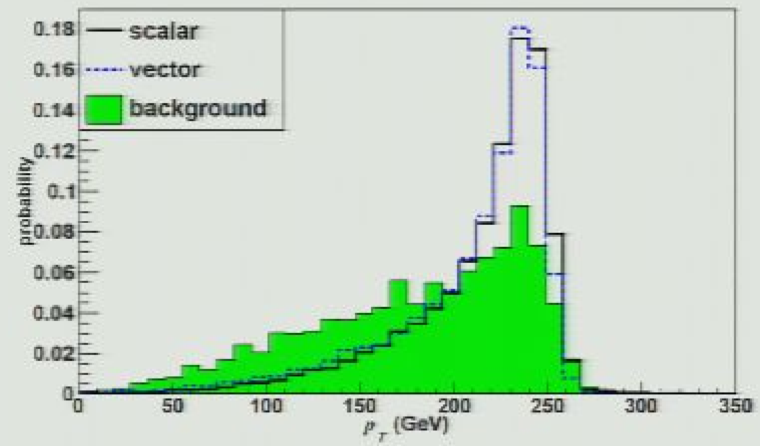
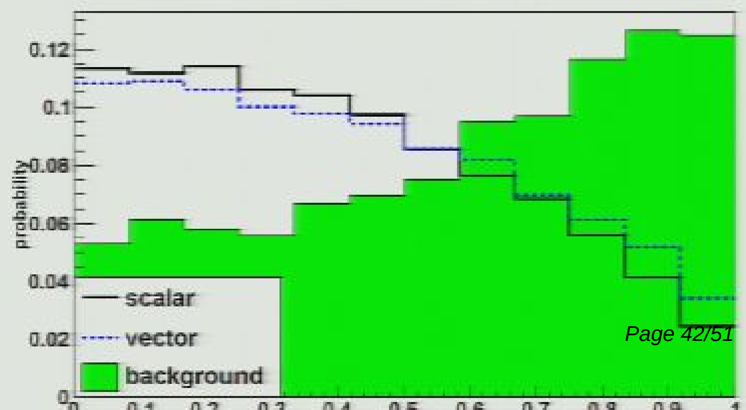
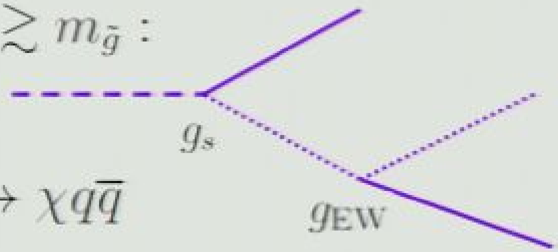




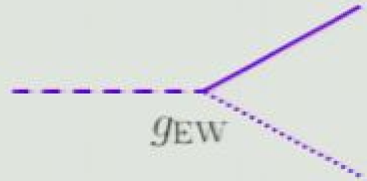


Gluinonium vs. squarkonium

$m_{\tilde{q}} \gtrsim m_{\tilde{g}}:$



$\tilde{g} \to \chi q \bar{q}$



$\tilde{q} \to \tilde{q}' W \qquad \tilde{q} \to q\,\chi$

$\Gamma_{\tilde{q}} \sim \alpha\, m \sim \alpha_s^2 m$

$$\Gamma_{\tilde{g}} \sim \frac{\alpha \alpha_s m_{\tilde{g}}}{16\pi \sin^2\theta_W}\left(\frac{m_{\tilde{g}}}{m_{\tilde{q}}}\right)^4$$

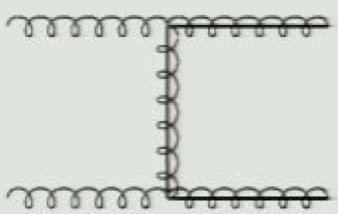
Problem 1: Squarks decay too fast.

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

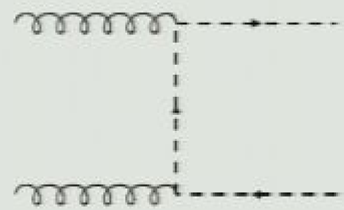
$$\mathbf{3} \otimes \overline{\mathbf{3}} = \mathbf{1} \oplus \mathbf{8}$$

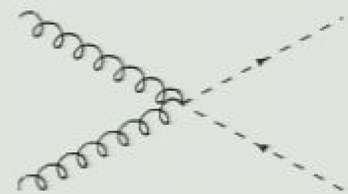
$C_{\mathbf{1}} = 3. \qquad C_{\mathbf{8_S}} = C_{\mathbf{8_A}} = \frac{3}{2}$

$C_{\mathbf{1}} = \frac{4}{3}$



$$|\psi(\mathbf{0})|^2 = \frac{C^3 \overline{\alpha}_s^3 m^3}{8\pi}$$





$$\Gamma(\mathbf{1} \to gg) = \frac{18\pi\alpha_s^2}{m_{\tilde{g}}^2}|\psi(\mathbf{0})|^2 = \frac{243}{4}\alpha_s^2 \overline{\alpha}_s^3 m_{\tilde{g}}$$

$$\Gamma(\mathbf{1} \to gg) = \frac{4\pi\alpha_s^2}{3m_{\tilde{q}}^2}|\psi(\mathbf{0})|^2 = \frac{32}{81}\alpha_s^2 \overline{\alpha}_s^3 m_{\tilde{q}}$$

Problem 2: Squarkonium cross-sections are much smaller

A second chance for the squarkonium

The lightest stop might be sufficiently long-lived.

Not generic in mSUGRA.

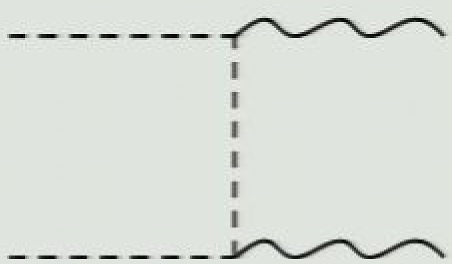
Yes in "compressed supersymmetry" models

or models with electroweak-scale baryogenesis.

In these models, narrow stoponium will exist.

Herrero, Méndez, Rizzo '88
Drees, Nojiri '94, '94
Martin '08
Martin, Younkin '09

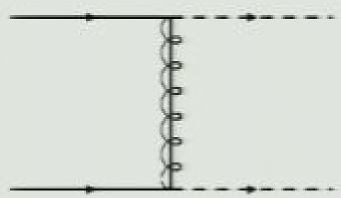
Squarks are charged and can annihilate into $\gamma\gamma$:



$$\frac{\Gamma_{(\tilde{t}\bar{\tilde{t}})\to\gamma\gamma}}{\Gamma_{(\tilde{t}\bar{\tilde{t}})\to gg}} = \frac{8}{9}\frac{\alpha^2}{\alpha_s^2} \simeq 0.005$$

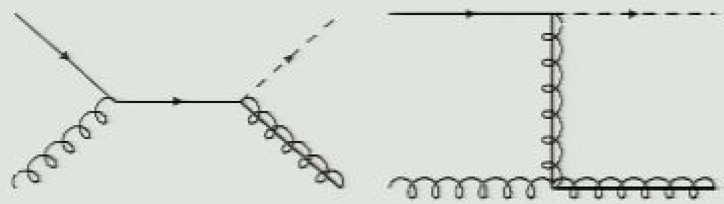
Stoponium signal is viable at a sufficiently large luminosity.

No second chance for di-squarks or squark-gluino bound states



$$q_i + q_j \longrightarrow \tilde{q}_i + \tilde{q}_j$$

$$\mathbf{3} \otimes \mathbf{3} = \overline{\mathbf{3}} \oplus \mathbf{6}$$



$$q_i + g \longrightarrow \tilde{q}_i + \tilde{g}$$

$$\mathbf{3} \otimes \mathbf{8} = \mathbf{3} \oplus \overline{\mathbf{6}} \oplus \mathbf{15}$$

- The squarks decay too fast, like we discussed for the squarkonium.
- Di-stops and stop-gluino bound states cannot be produced because this would require having top quarks in the proton pdfs.

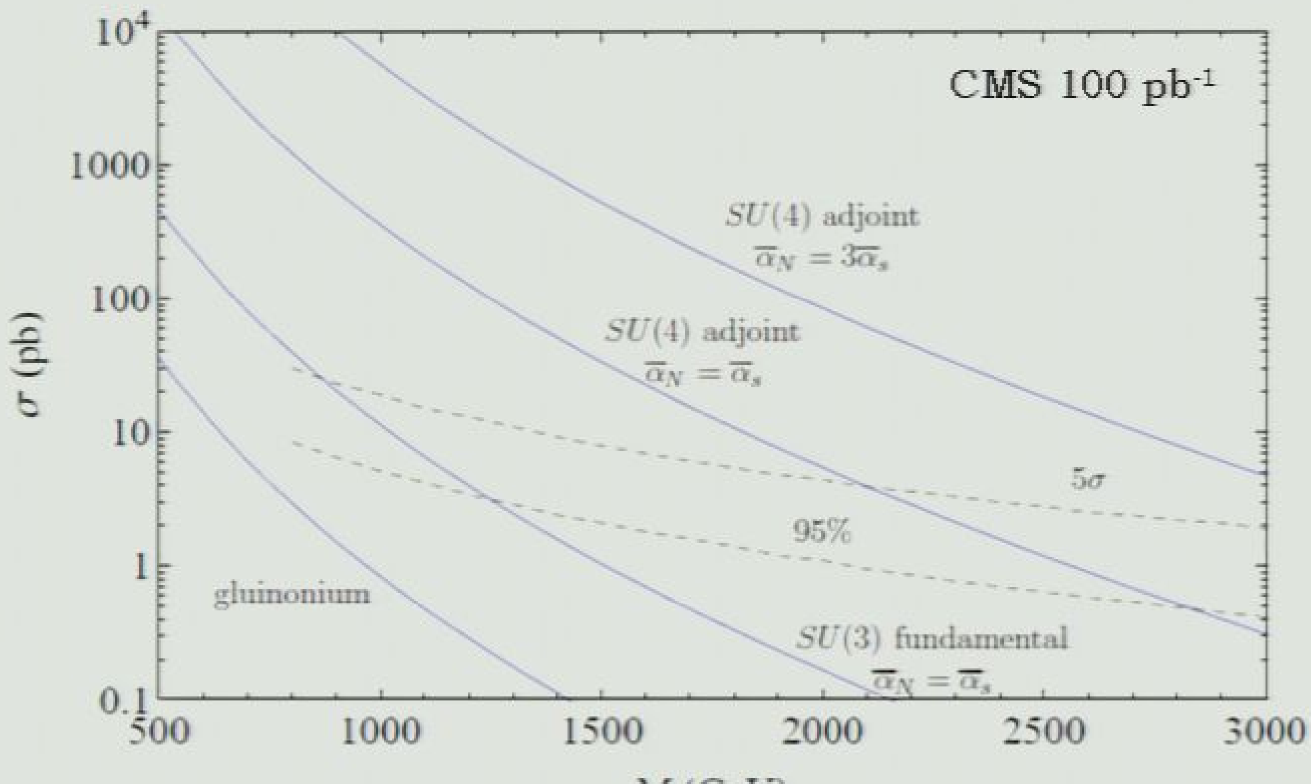
Bound states with new forces

For QCD bound states: $V(r) = -C\frac{\overline{\alpha}_s}{r}$ $\frac{\sigma^{\text{bound}}}{\sigma^{\text{cont}}} \sim (C\overline{\alpha}_s)^3$

Suppose the new colored particles are charged also under representation R of a new SU(N) with coupling constant α_N.

Then $C\,\overline{\alpha}_s \rightarrow C\,\overline{\alpha}_s + C_R\overline{\alpha}_N$.

Example: "gluinos" that are charged also under a new group:



Conclusions – MSSM

Gluinonium

- Exists, if the gluino is not too heavy compared to the lightest squark.
- The annihilation into dijets and/or $t\bar{t}$ can probably be detected if the gluino is not much heavier than 300 GeV, once the systematics of the background are under control.

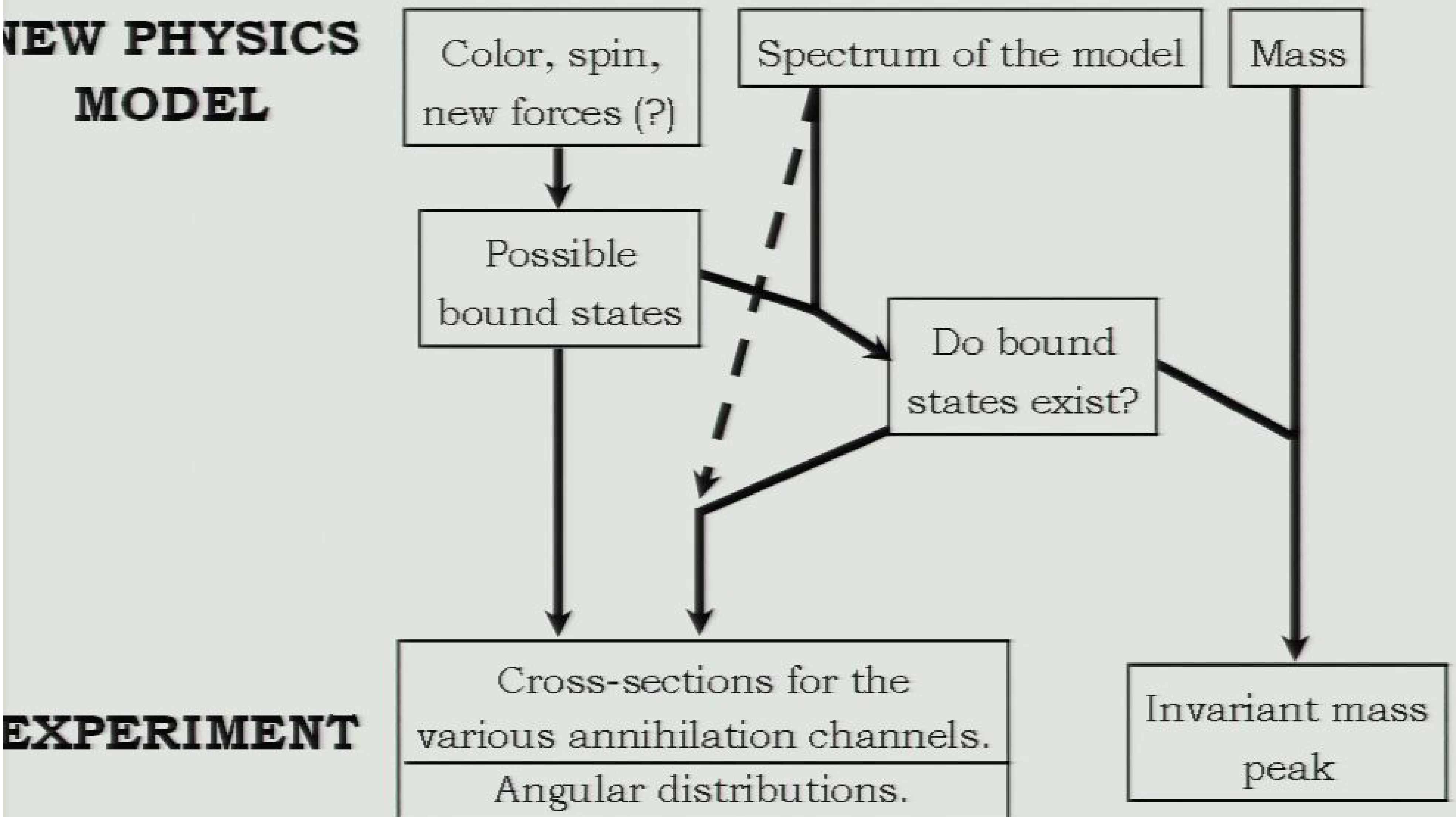
Stoponium

- Can exist if the lighter stop is very light.
- Cannot be seen in dijet or $t\bar{t}$ channels, but can be seen in $\gamma\gamma$.

Other flavors of squarkonia | **Di-squarks** | **Squark-gluino bound states**

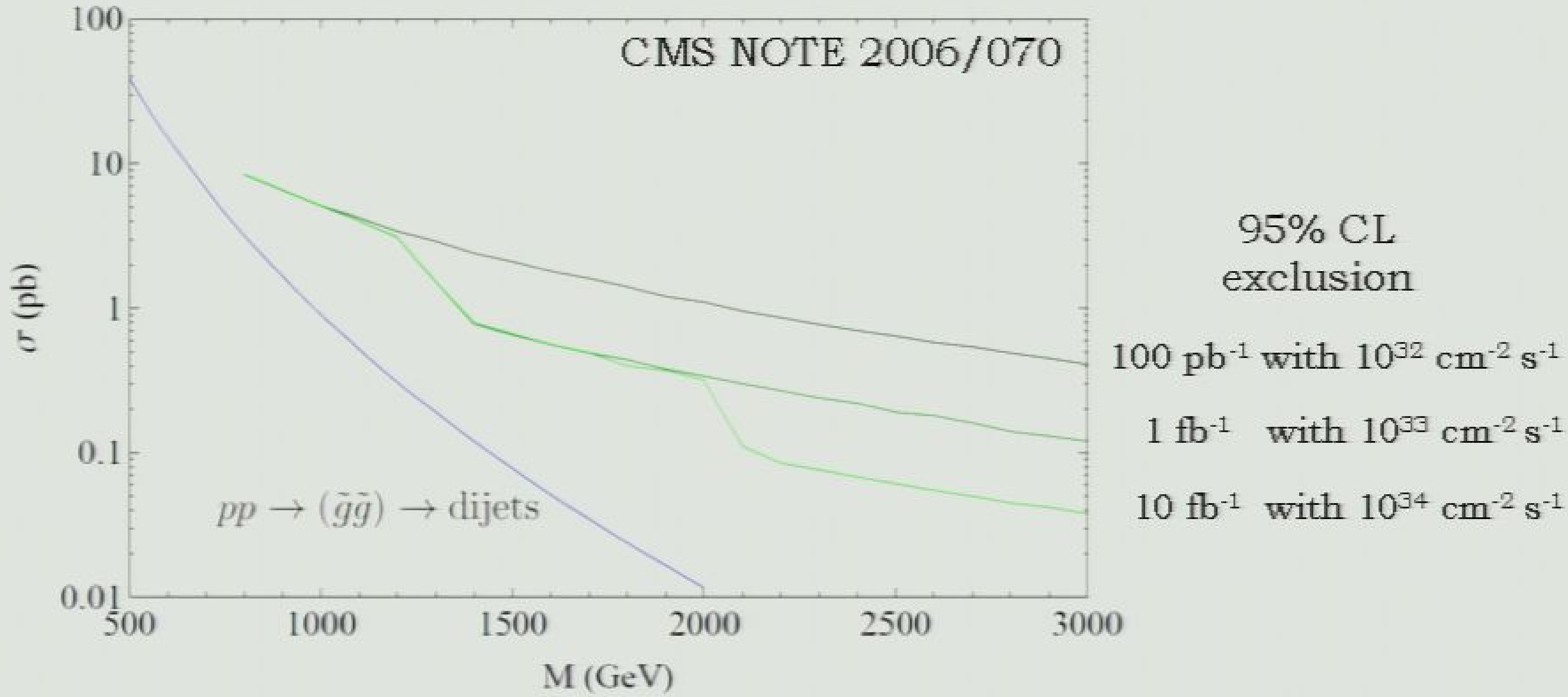
- Unlikely to exist for any MSSM spectrum (like the toponium).

Conclusions – general



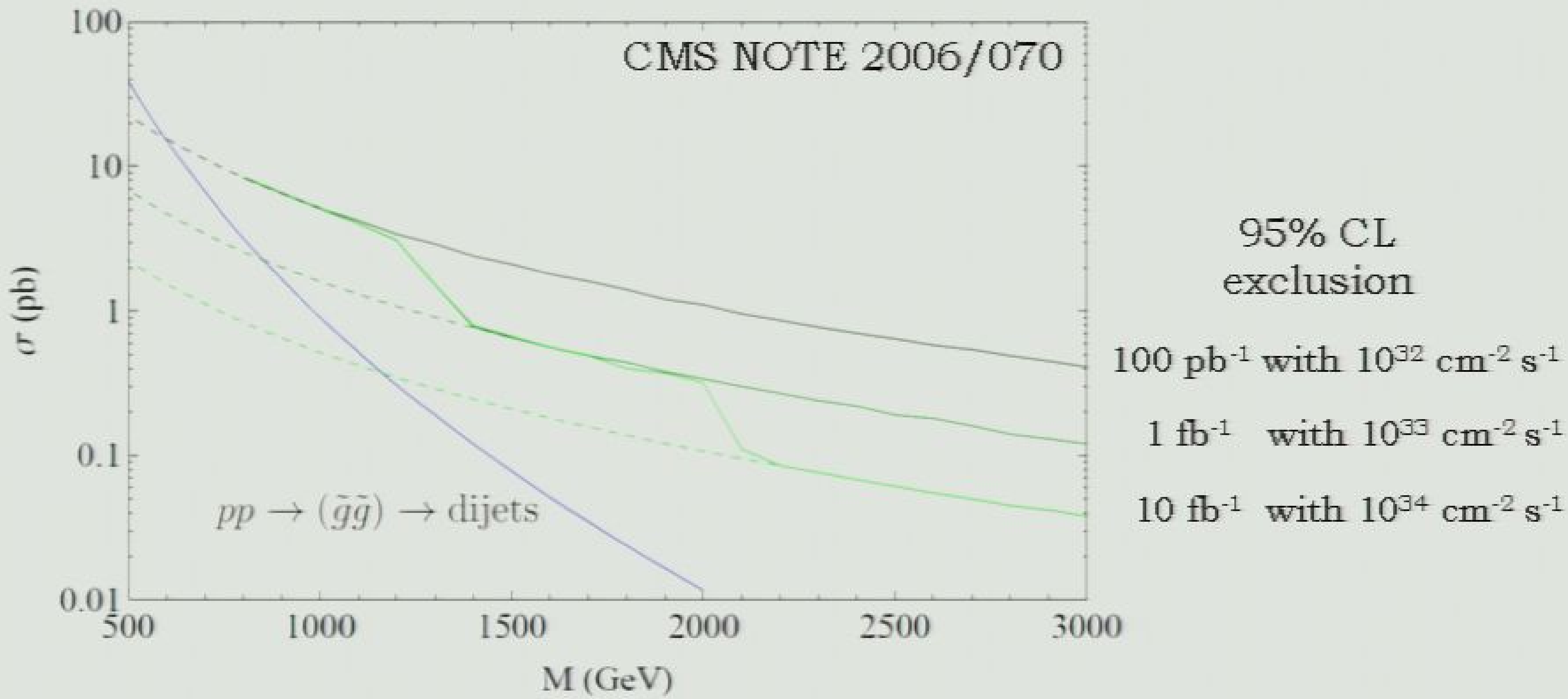
Hope we'll find you, guys ;)

Will ATLAS and CMS look for our dijets?



By default, the dijet signal from light gluinonium will suffer from **prescaling** at ATLAS and CMS.

Will ATLAS and CMS look for our dijets?



By default, the dijet signal from light gluinonium will suffer from **prescaling** at ATLAS and CMS.

Prescaling can be reduced by adjusting the triggers, especially if the expected mass is known in advance.