기초과학연구원
Institute for Basic Science

Model Independent Constraints on Charges of New Particles

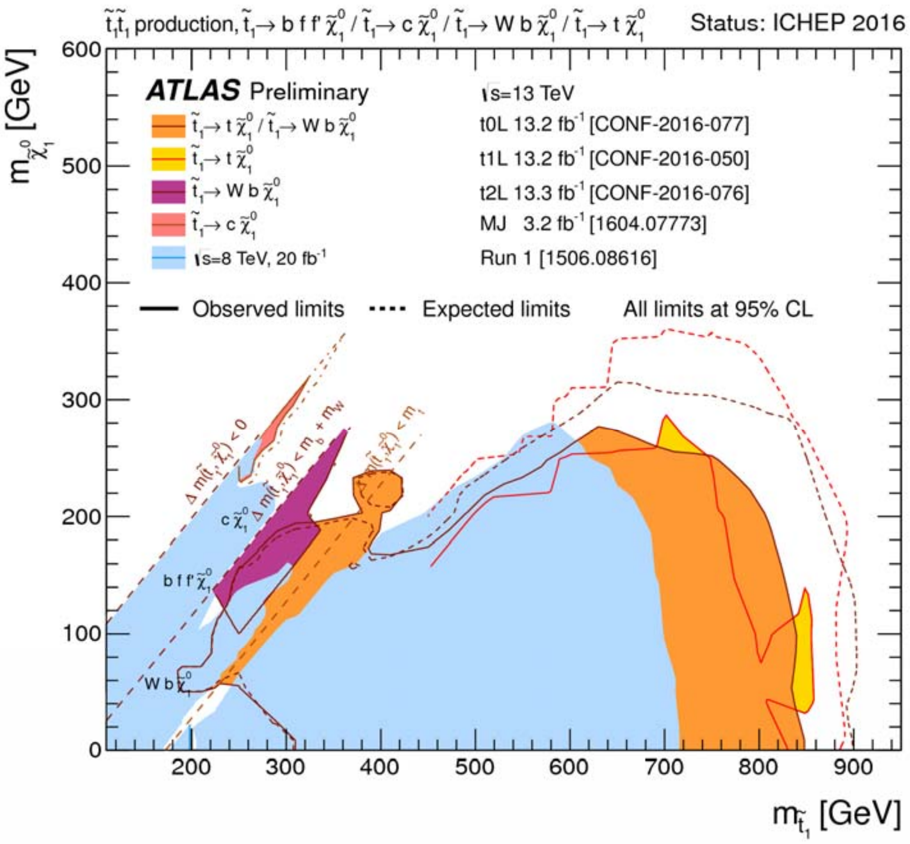
Tae Hyun Jung

CTPU - IBS

2016.12.08 @ IBS

References
THJ, D. Chway, R. Dermíšek, and H. D. Kim, Phys.Rev.Lett. 117 (2016) no.6, 061801
THJ, W. S. Cho, D. Chway, R. Dermíšek, and H. D. Kim, arXiv:1611.xxxx

LHC search for light stop



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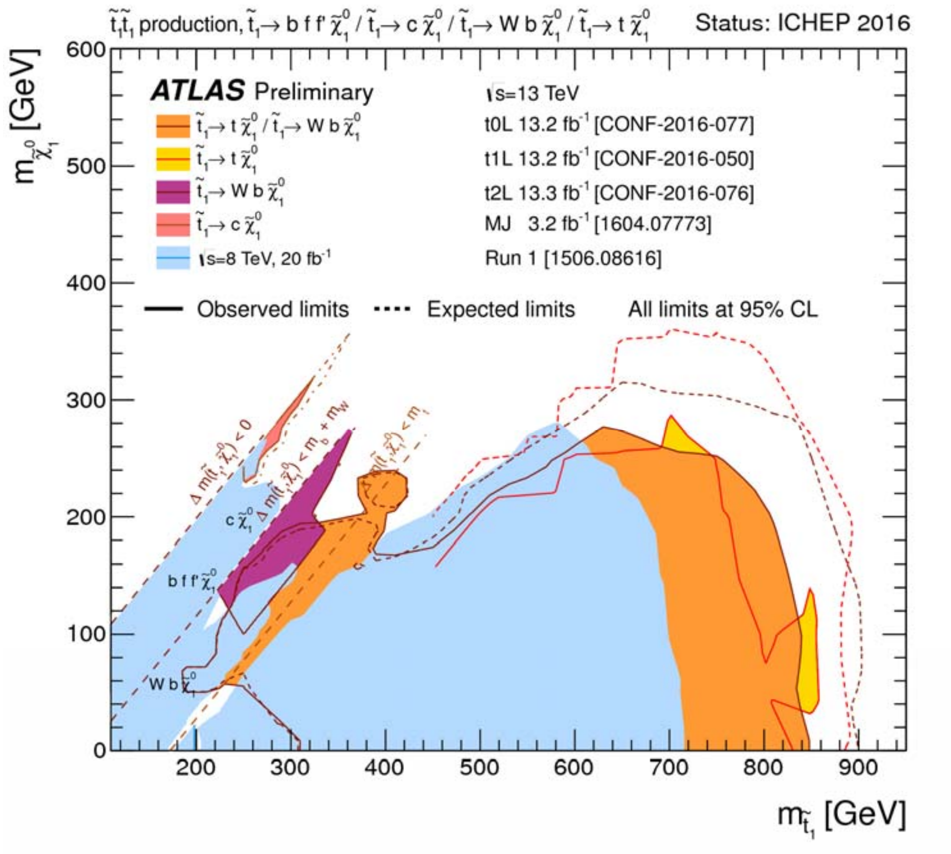
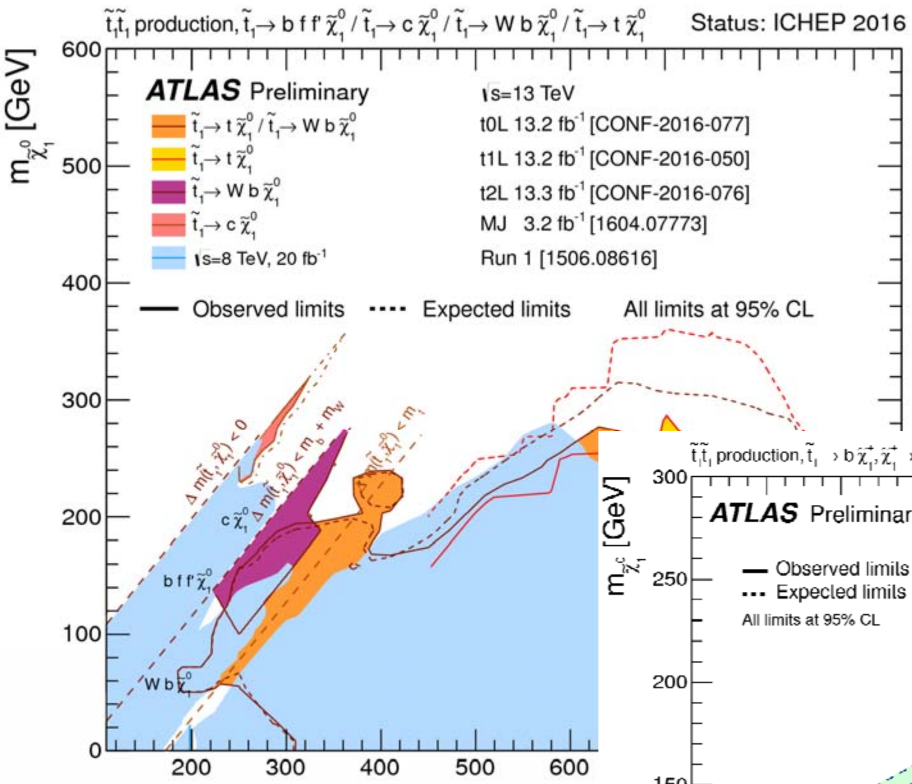
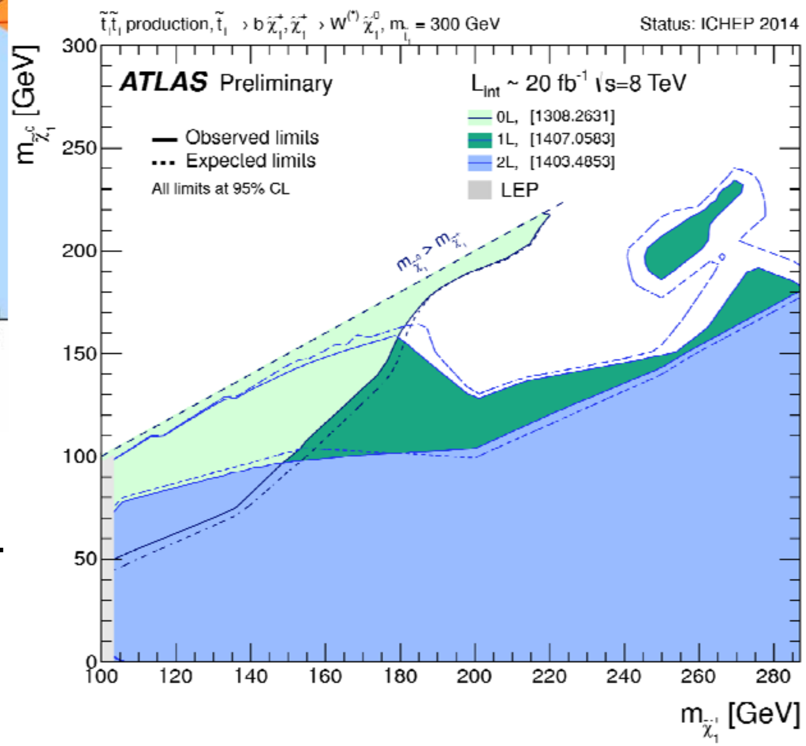


1. Branching ratio = 100% ?
2. Other channel? (chargino, RPV, ...)

LHC search for light stop





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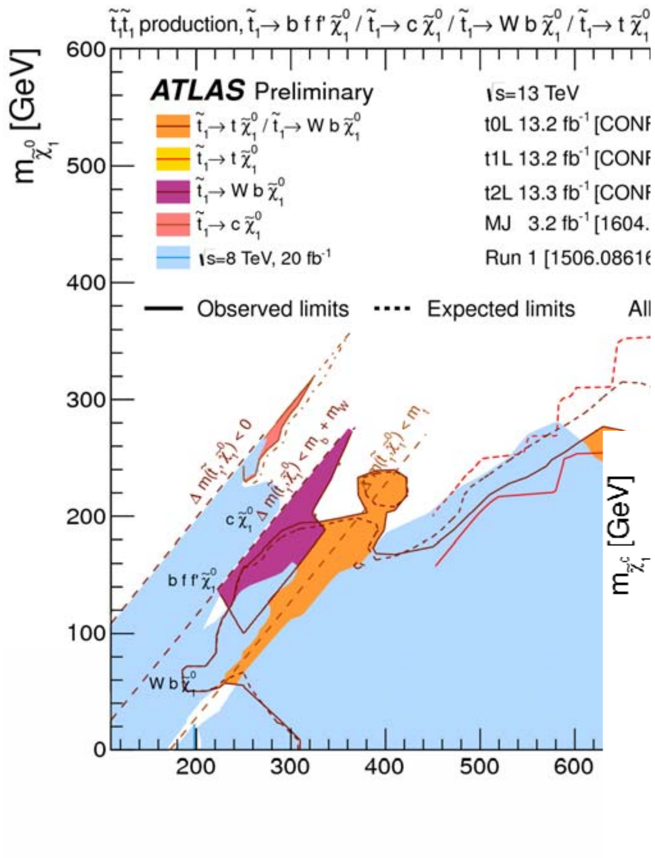

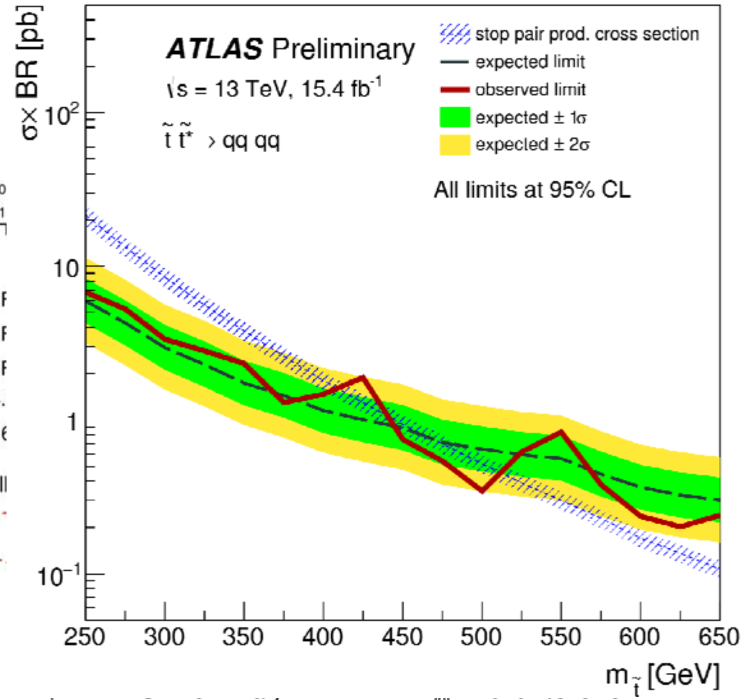

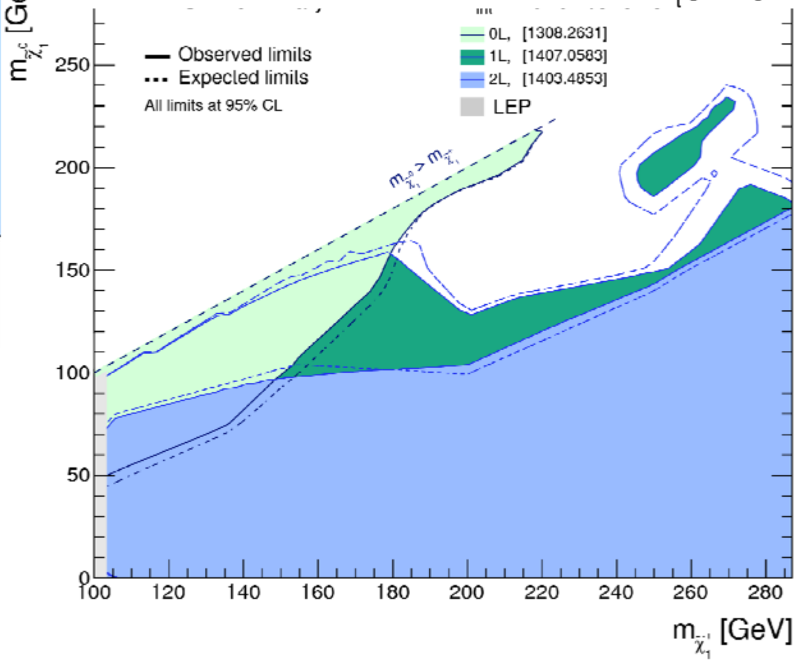

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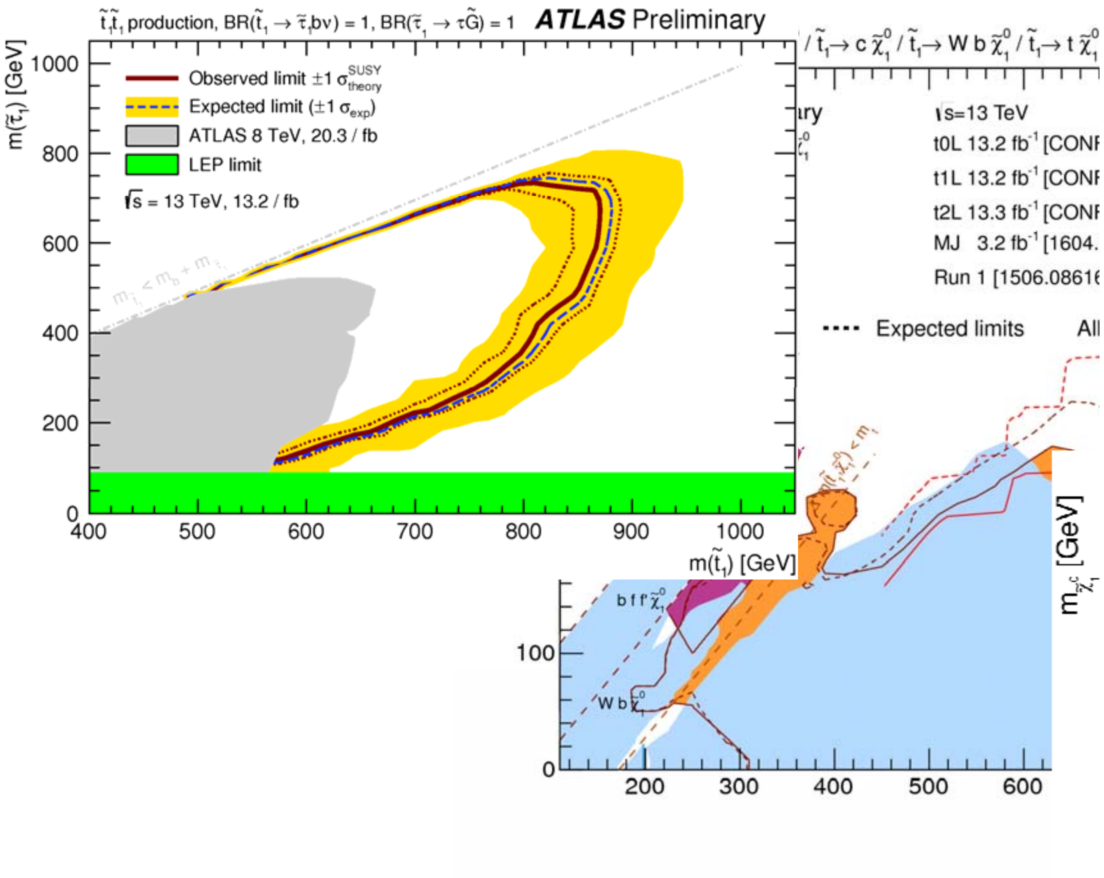

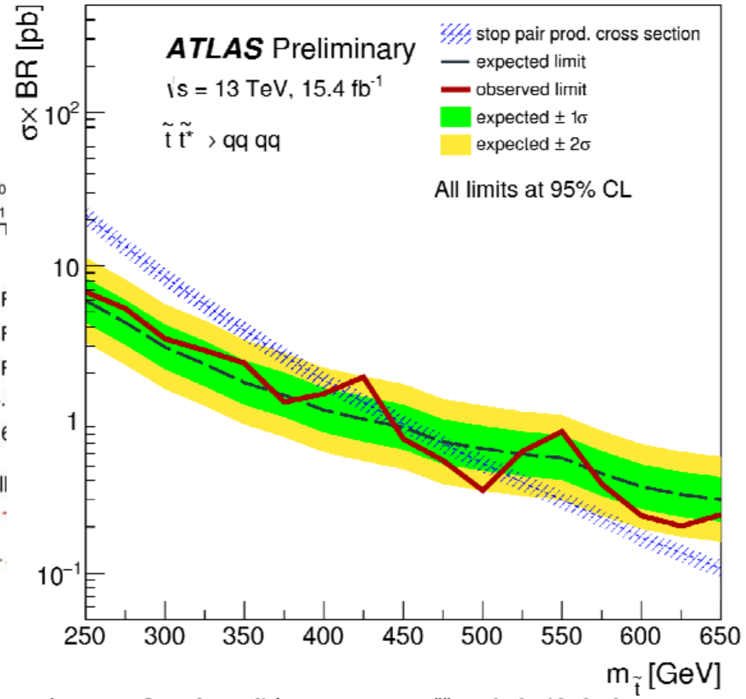

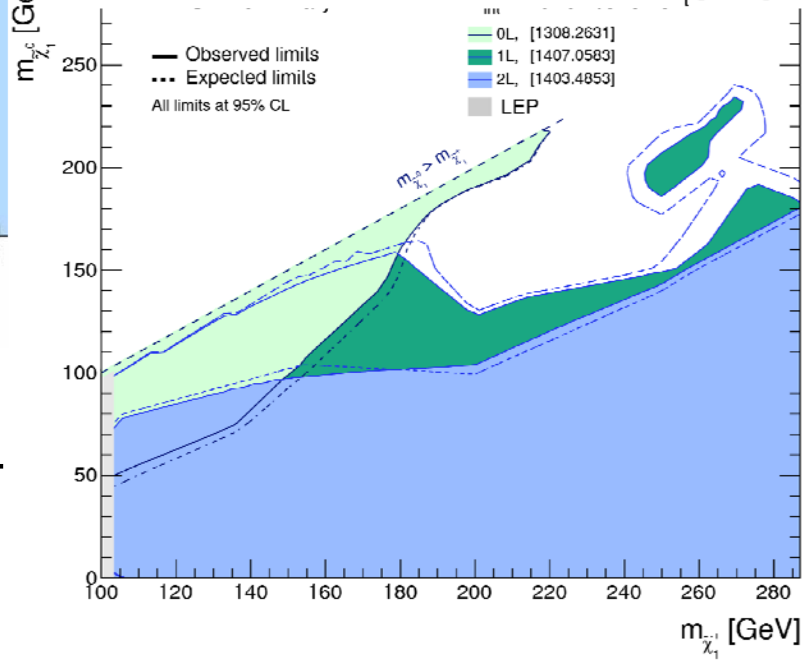

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2. Other channel? (chargino, RPV, ...

-> blind spot??

Is there any model-independent (decay channel independent) bound of color and electromagnetic charged particles? (not only for stop)

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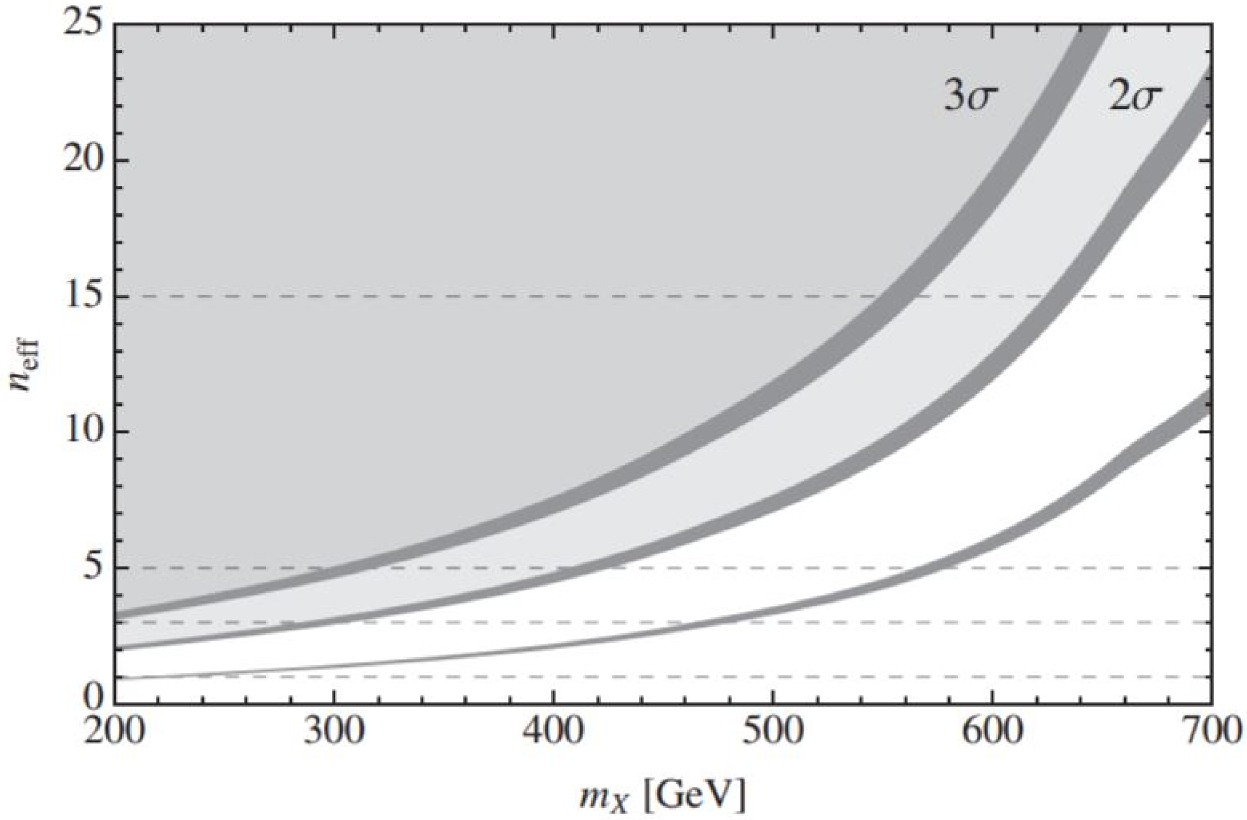
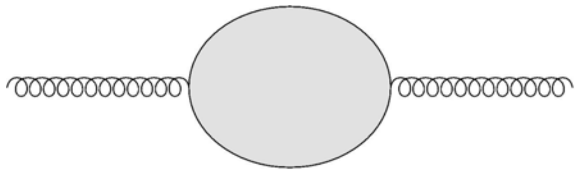
Running of QCD coupling (2j/3j)



D. Becciolini, M. Gillioz, F. Sannino, M. Nardecchia, and M. Spannowsky (2015)

-HERA, Tevatron, LHC run I

n_{eff}=effective # of quarks
(=1 for one Dirac quark in fundamental rep.)



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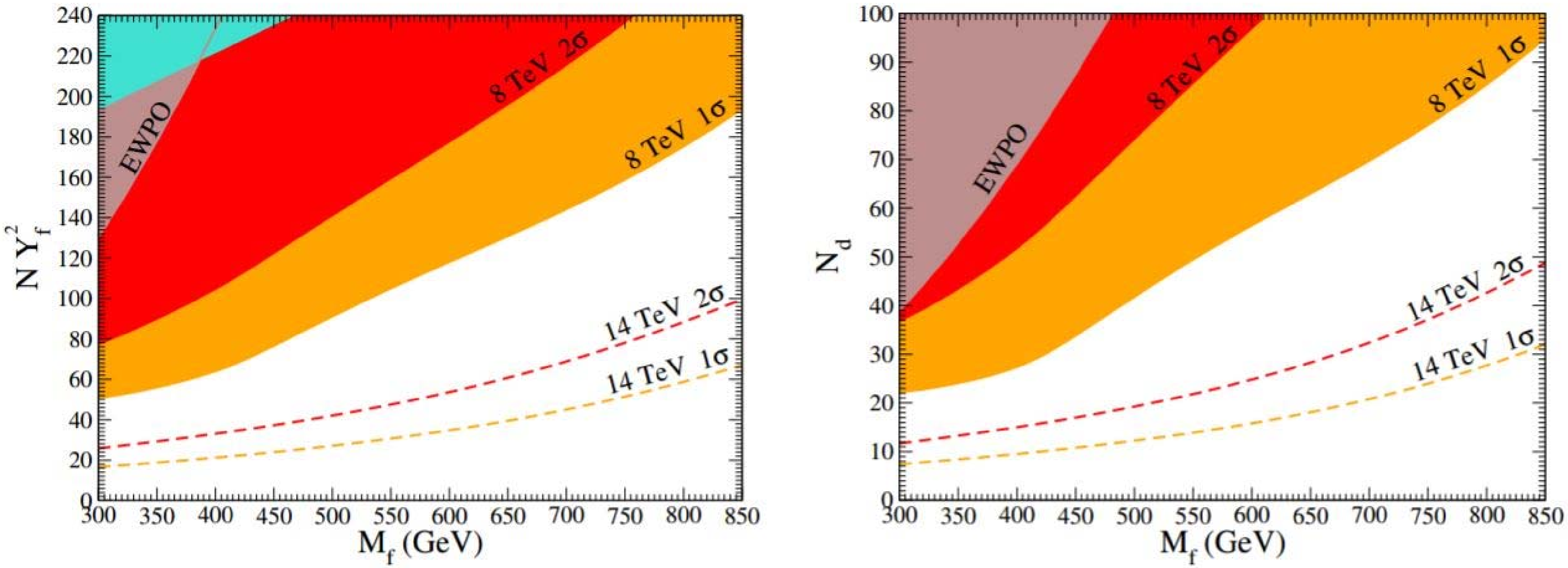
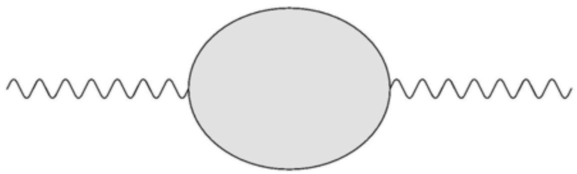
Running of EW coupling (Drell-Yan)



C. Gross, O. Lebedev,
and J. M. No, rXiv:1602.03877



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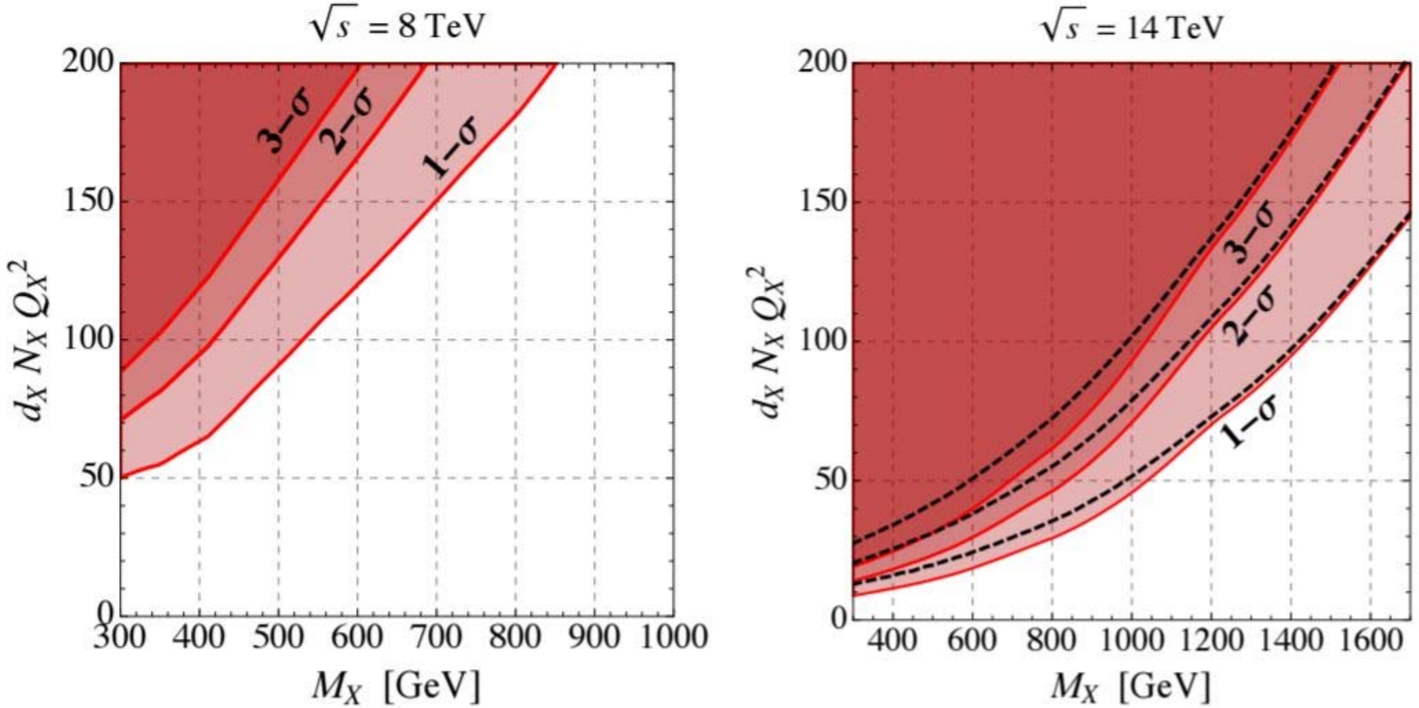
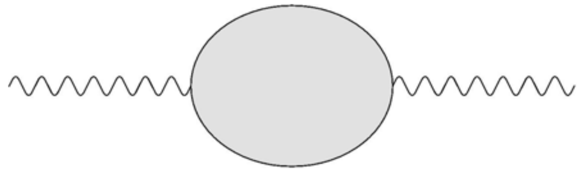


$d_X N_X$=# of vector-like fermion pairs
Q_X=charge

conclusion : $d_X N_X Q_X^2 \leq 15\sim20$ for 14 TeV
for m_X=300 GeV

F. Goertz, A. Katz, M. Son,
and A. Urbano, arXiv:1602.04801.



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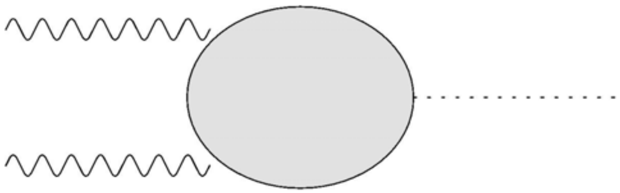
Higgs production and decay rate



It depends on Yukawa coupling

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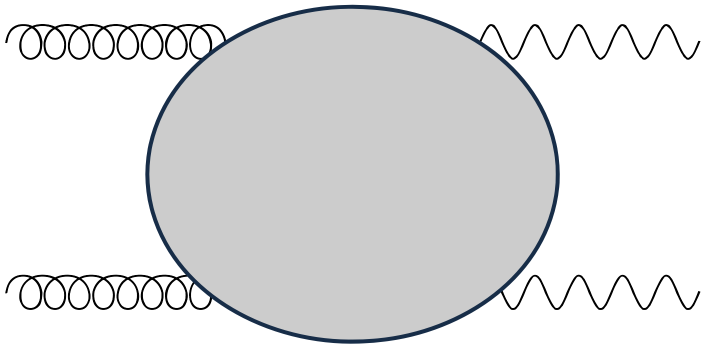
My suggestion is …

THJ, D. Chway, R. Dermíšek, and H. D. Kim, Phys.Rev.Lett. 117 (2016) no.6, 061801

$gg \to \gamma\gamma$



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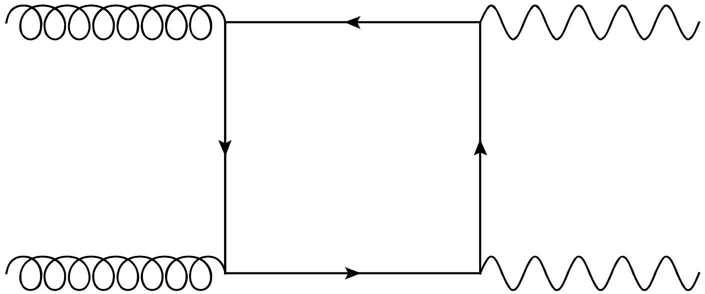

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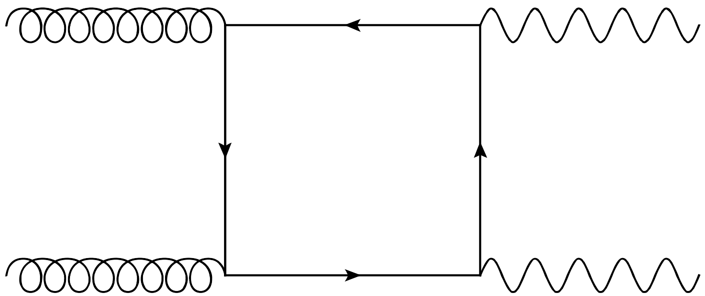

Drastic enhancement near $m_{\gamma\gamma} = 2m_X$

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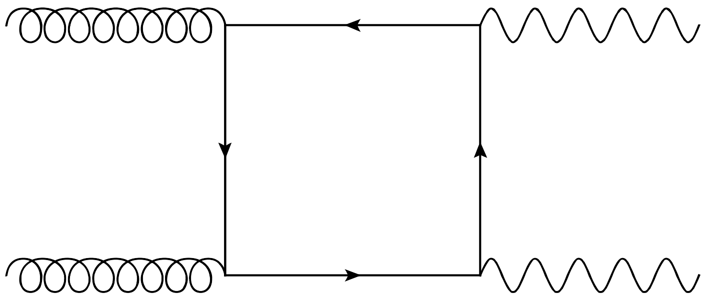

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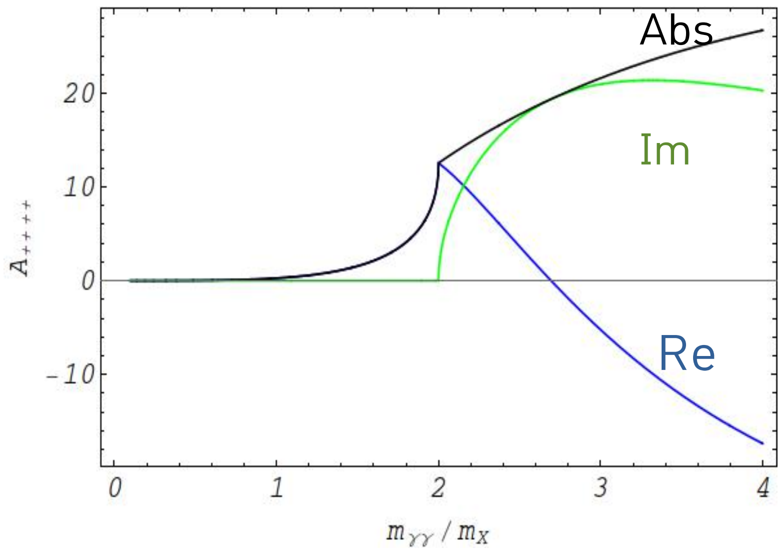

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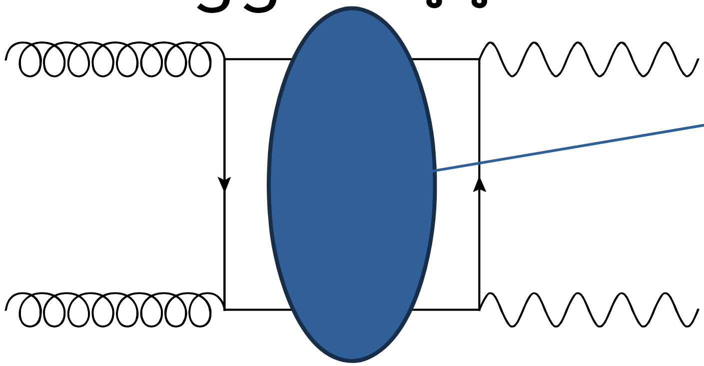
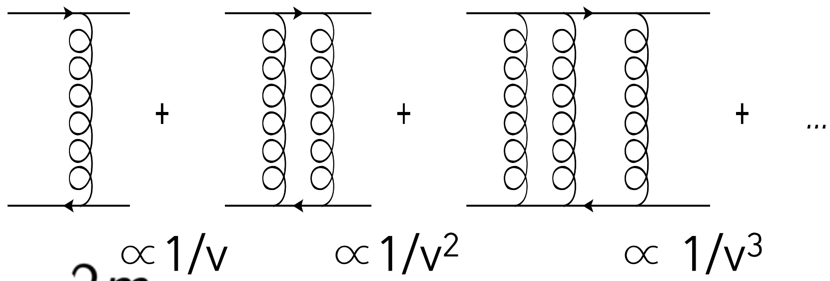


Non-perturbative effect near $m_{\gamma\gamma} = 2m_X$
(resummation of ladder diagrams)



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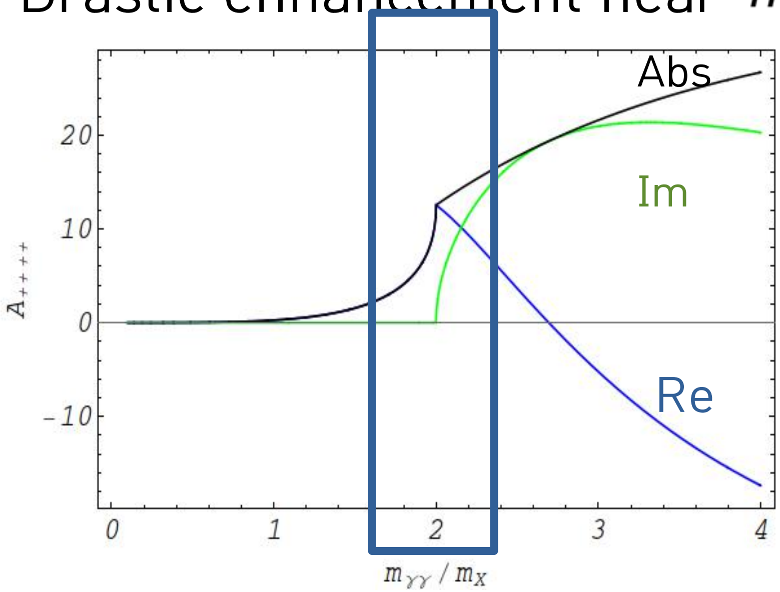

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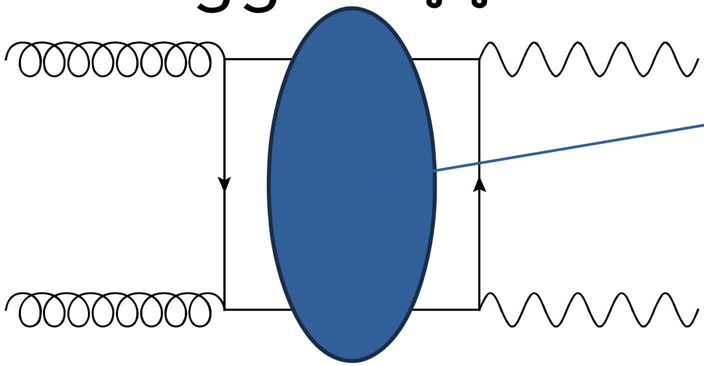

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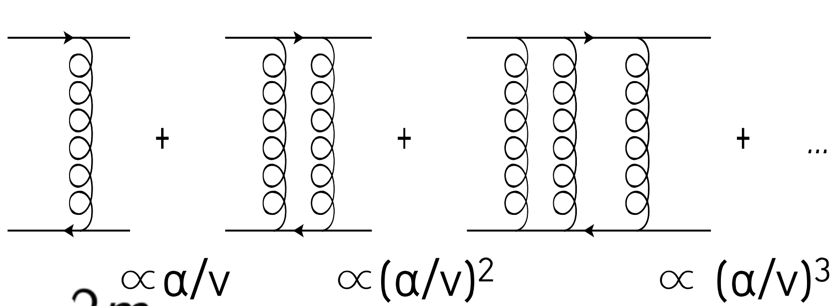

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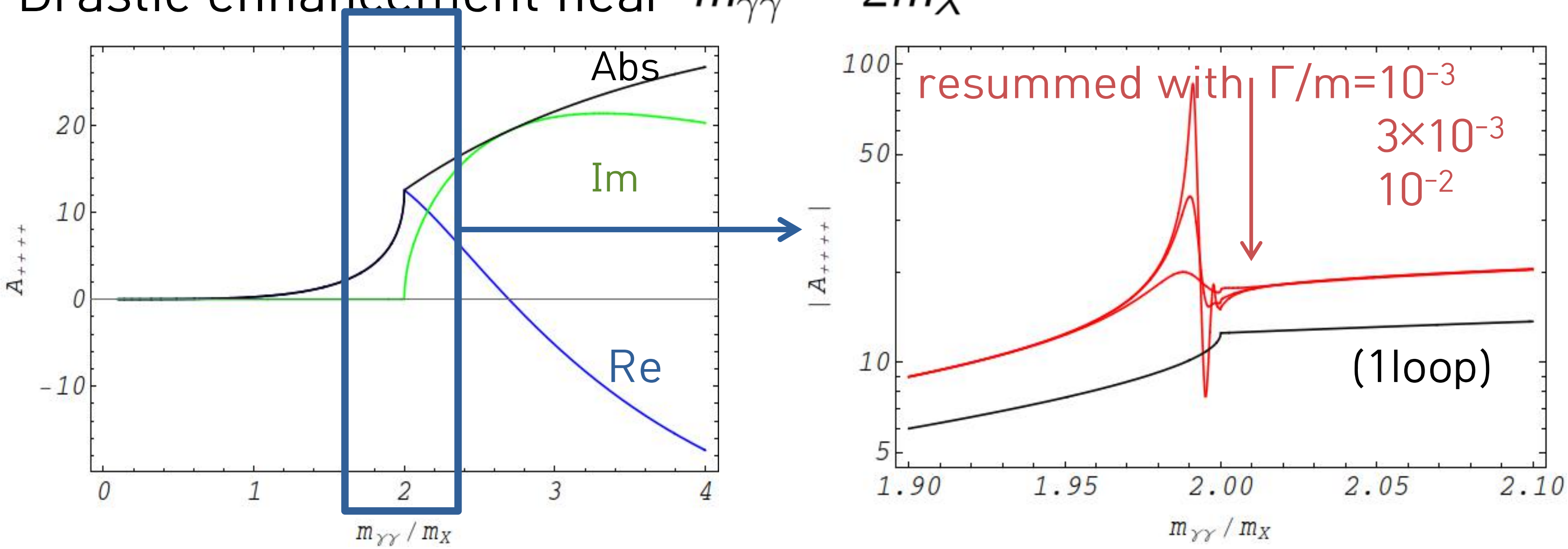

Resummation Procedure

1. Integrate out relativistic mode of the particle
(matching between NR QCD $\leftrightarrow$ Full Lagrangian)

2. Replace NRQCD ladder diagrams by Green's function solution of Non-relativistic Schrodinger equation

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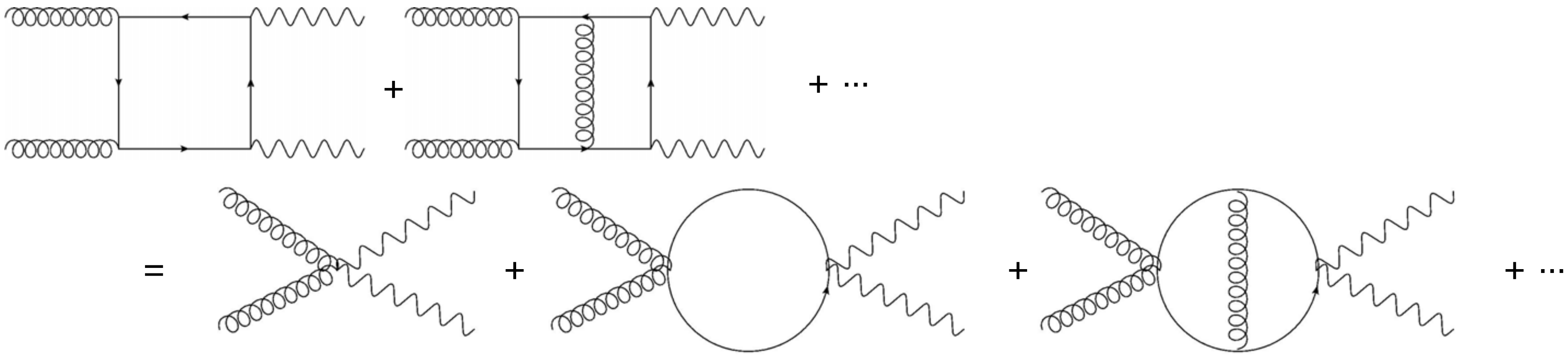

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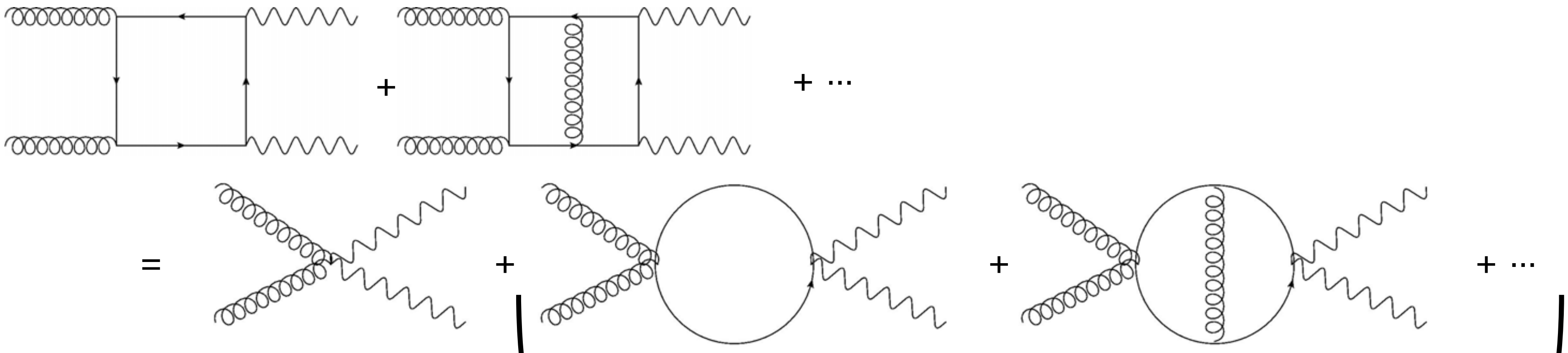


2. Replace NRQCD ladder diagrams by Green's function solution of Non-relativistic Schrodinger equation

V.S. Fadin and V.A. Khoze (1987, 1988)
M.J. Strassler and M.E. Peskin (1991)
K. Melnikov, M. Spira and O.I. Yakovlev (1994)

$G(\mathbf{0}, \mathbf{0}; E)$, E=sqrt{S}-2m_X

$$\left(\frac{\nabla^2}{m} + V(r) - E\right) G(\mathbf{r}, \mathbf{r}'; E) = \delta(\mathbf{r} - \mathbf{r}').$$

Calculation order

There are different types of higher order corrections.

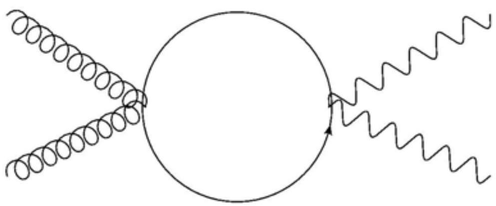
1. overall coupling : $\alpha(\mu_{\mathrm{hard}})^2 \alpha_s(\mu_{\mathrm{hard}})^2$ → LO with $\mu_h = E_{\gamma\gamma}$
2. QCD potential : $V_{\mathrm{QCD}}(r;\ \mu_s)$ → NLO
3. matching between NRQCD and full Lagrangian → part of NLO (LL)
4. running of NRQCD couplings → part of NLO (LL)

$$\left(\frac{\nabla^2}{m} + V(r) - E\right) G(\mathbf{r}, \mathbf{r}'; E) = \delta(\mathbf{r} - \mathbf{r}').$$

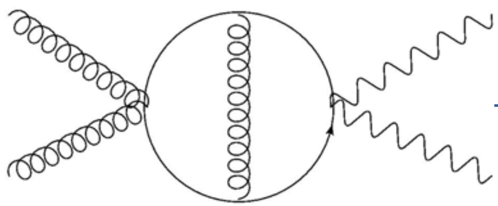
$$G(0,0;E) = -\frac{m^2}{4\pi}\left[\sqrt{-\frac{E}{m}} - C\overline{\alpha}_s \ln\left(\frac{|C|\overline{\alpha}_s}{2}\sqrt{-\frac{m}{E}}\right) - \frac{2}{\sqrt{m}}\sum_{n=1}^{\infty}\frac{E_n}{\sqrt{-E} - \mathrm{sign}(C)\sqrt{E_n}}\right]$$

(if $V(r)=C\alpha_s/r$)

bound state



LO



"part" of NLO

Higher order

There are different types of higher order corrections.

1. overall coupling : $\alpha(\mu_{\mathrm{hard}})^2 \alpha_s(\mu_{\mathrm{hard}})^2$ → LO with $\mu_h = E_{\gamma\gamma}$
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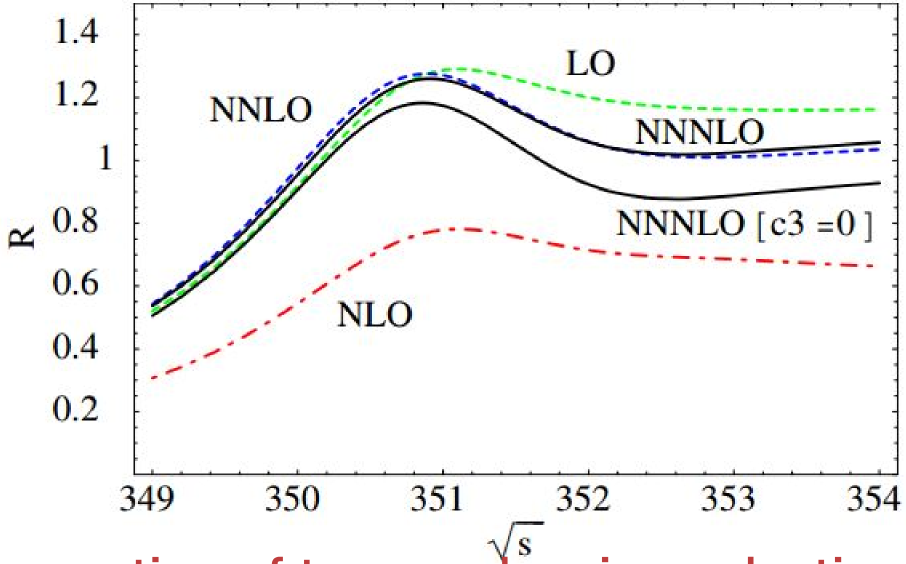
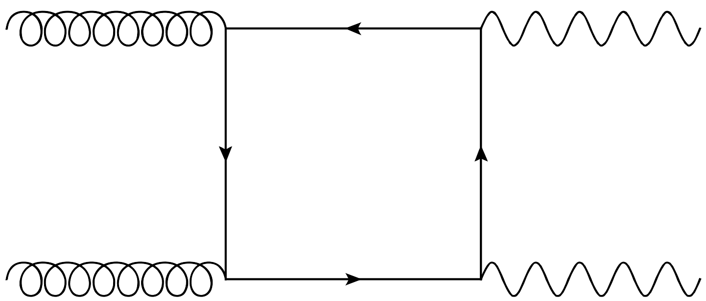


cross section of top quark pair production at ILC
(imaginary part of Green's function)

M.~Beneke, Y.~Kiyo and K.~Schuller
arXiv:0801.3464

Background Amplitude



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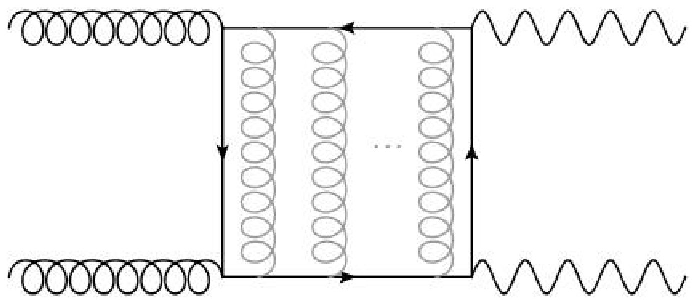


light quarks(u, d, s, ...)

new particle

$$\propto C_X = N_X S_2 Q^2$$

# of ptc

Dynkin index

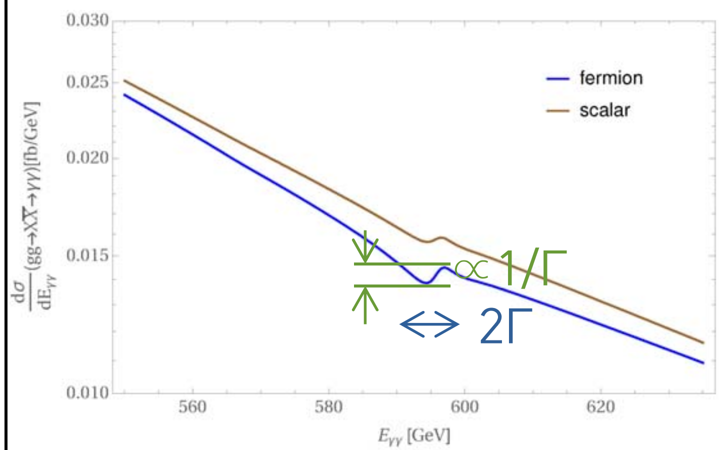
electric charge

Background Amplitude

m_X=300 GeV
CTEQ6L

<table>
<tr><th></th><th>bound state</th><th>overall shape (loop function)</th></tr>
<tr>
<td>interference
btw light quarks
and new particle</td>
<td>

$\Gamma/m=7\times10^{-3}$, $C_F=2/9$ ($C_S=4/9$)



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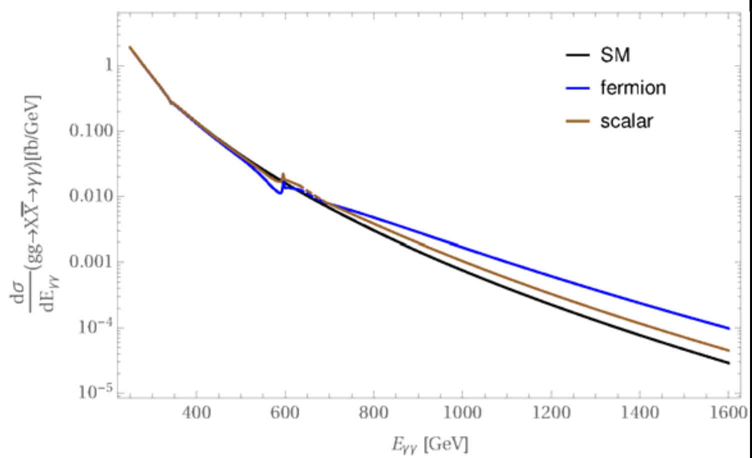
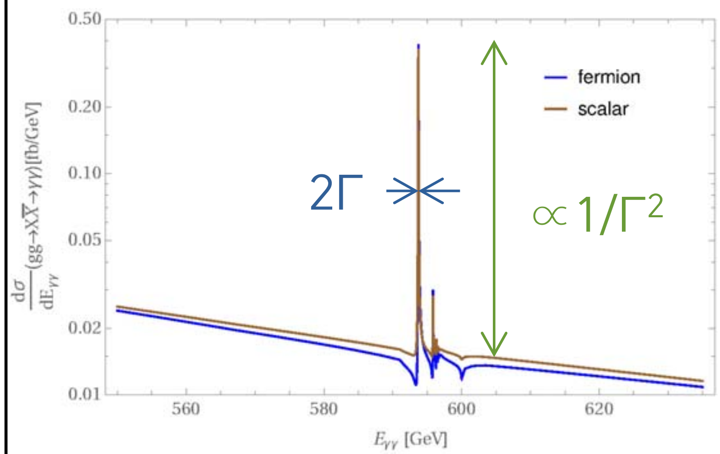
<td>

$\Gamma/m=10^{-2}$, $C_F=1$ ($C_S=2$)



</td>
</tr>
<tr>
<td>square
of new particle</td>
<td>

$\Gamma/m=10^{-4}$, $C_F=2/9$ ($C_S=4/9$)



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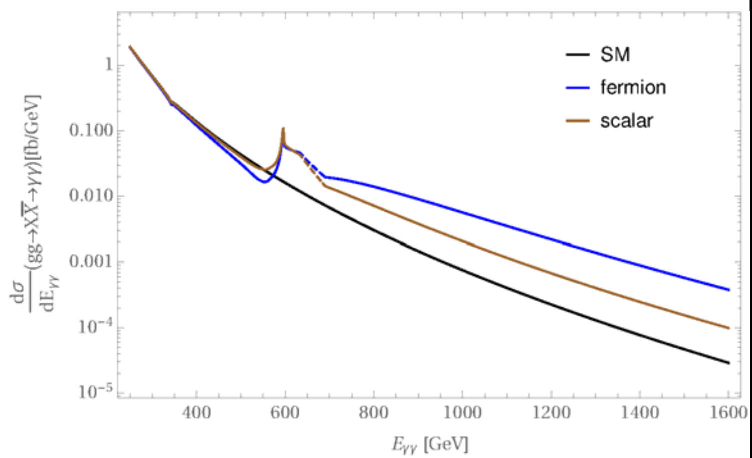
<td>

$\Gamma/m=10^{-2}$, $C_F=3$ ($C_S=6$)



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Background Amplitude

	bound state	overall shape (loop function)
interference btw light quarks and new particle	pros Once we find something, it can be used for precise mass measurement cons 1. bin size < Γ	pros 1. less-dependent on Γ 2. less-dependent on bin size cons 1. mass is hard to be determined due to systematic uncertainy
square of new particle	pros 1. Clear resonance 2. NWA available cons $\Gamma/m < 10^{-3}$	pros 1. less-dependent on Γ 2. less-dependent on bin size cons 1. C_X should be very large. (No model)

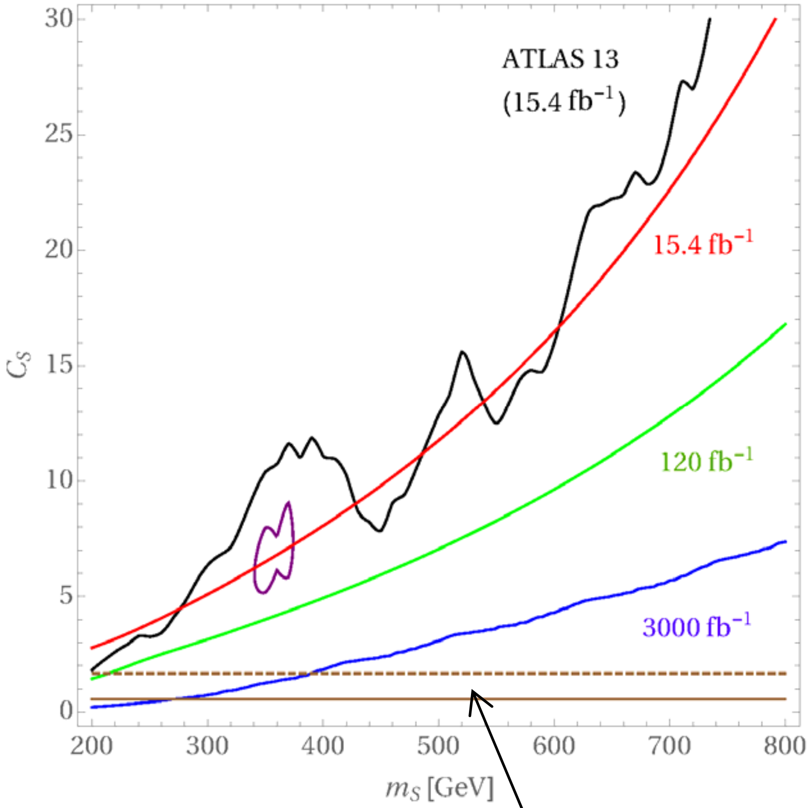
Exclusion Plot
(only statistics)

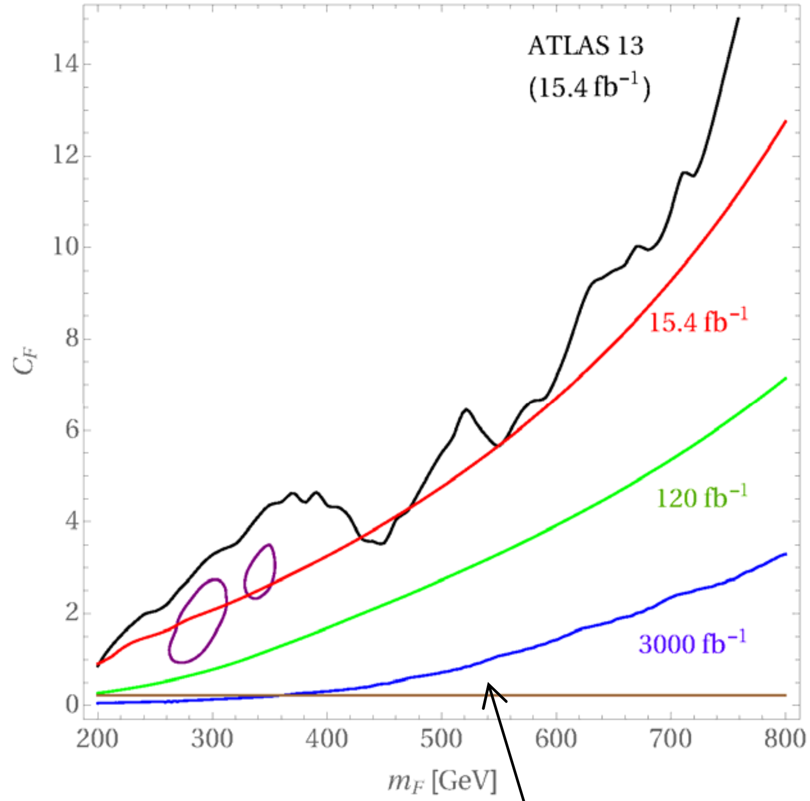
Current exc. : Compare maximum likelihood of SM with SM+X by using **current ATLAS data**
(Assumption : 1.$d(\sigma(pp \rightarrow \gamma\gamma) - \sigma(gg \rightarrow \gamma\gamma))/dE_{\gamma\gamma} = N(1-x^{1/3})^b x^a / L$ where $x=E_{\gamma\gamma}/\mathrm{sqrt}\{S\}$)
(= smooth function)
2. K factor of $\sigma(gg \rightarrow \gamma\gamma)$ times cut selection efficiency = 1

Expected exc. : Fitted values of a and b for current data was assumed to be real values

Exclusion Plot
(only statistics)

bin size=20 GeV
$\Gamma/m=10^{-2}$





At 3 ab^{-1}
one stop : m_s<200 GeV
one generation of squark : m_s<280 GeV
three generation of squark : m_s<380 GeV

one more quark : m_F<350 GeV

y axis : $C_X = N_X S_2 Q^2$

# of ptc

Dynkin index

electric charge

Exclusion Plot
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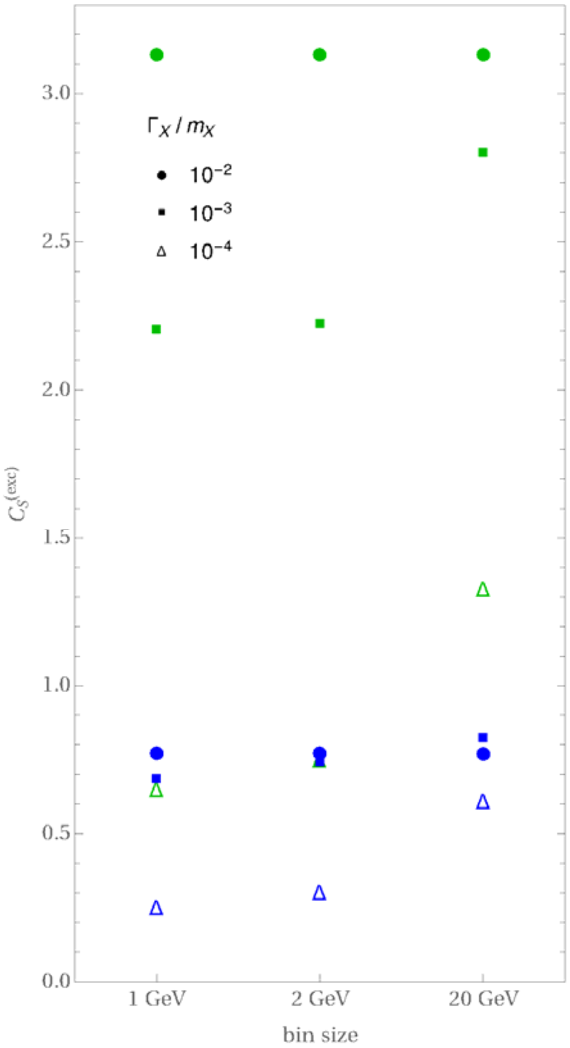
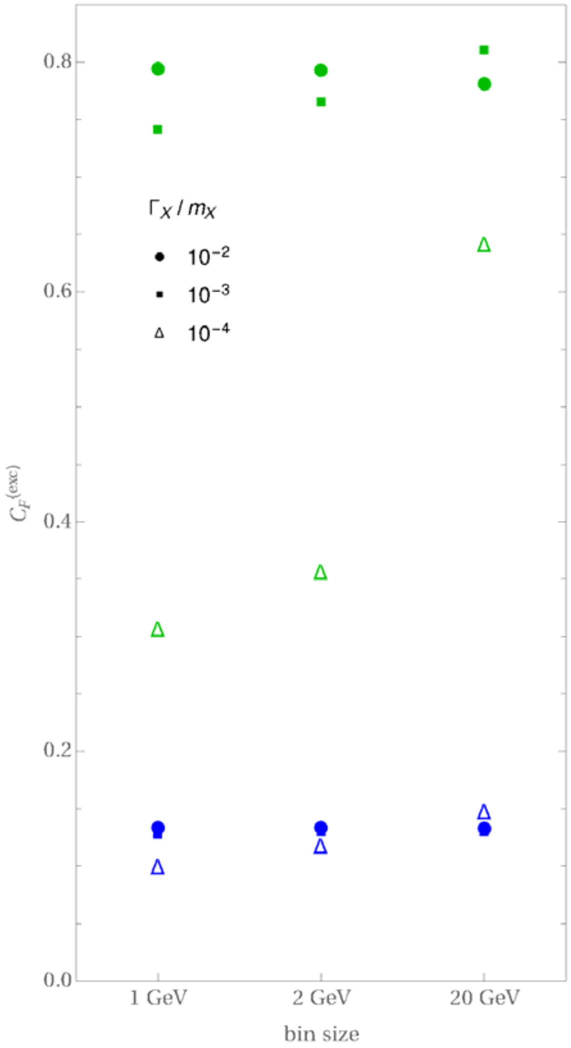
m_X=300 GeV





x axis : bin size

y axis : expected upper bound of C_X

Summary

- By looking at $gg \to \gamma\gamma$ interaction, we could get model independent bound on color and electromagnetic chargs of new particles. (decay channel independent)

- Usual NWA approach to stoponium study is applicable only for very very small decay width ($<10^{-4}$m). For large decay width we have to take interference effects correctly.

- The constraints for fermions are stronger than scalar case.

- As a benchmark point, stop with $m_S<200$ GeV for $\Gamma/m=10^{-2}$ and $m_S<300$ GeV for $\Gamma/m=10^{-4}$ expected to be excluded at HL-LHC.

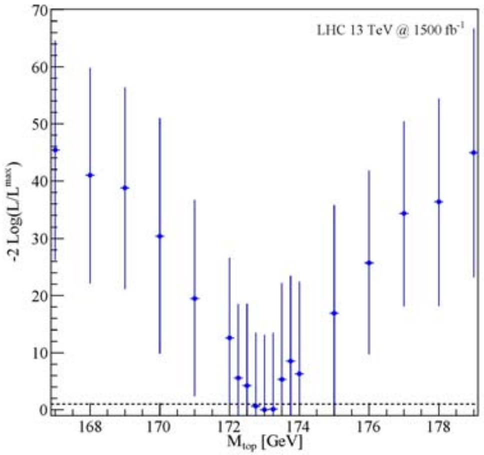
- In addition, top quark mass and decay width can be precisely determined : see Won Sang's talk this afternoon.

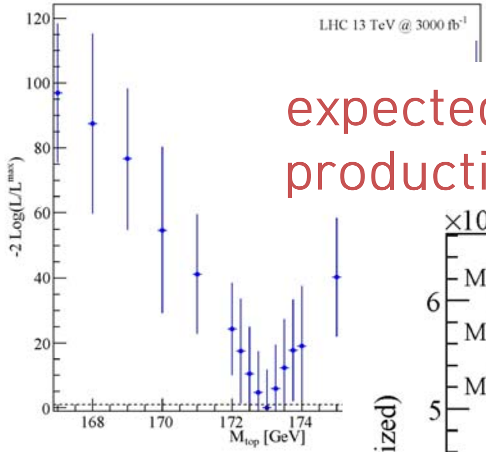
Thank you

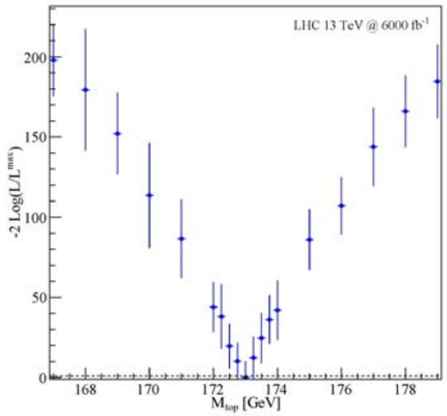
back up

Top quark mass measurement

We generate many pseudo experiment and then get average value and standard deviation of maximized log likelihood and best fit value for top quark mass.







expected precision from direct production at 3 ab^{-1} : 300~400 MeV