Search for electric and strong charged particles in di-photon channel

Dongjin Chway (Seoul National University)

Large Charge arXiv:1512.08221 (PRL 117 (2016) no.6, 061801)

DC, Radovan Dermisek, Tae Hyun Jung, and Hyung Do Kim

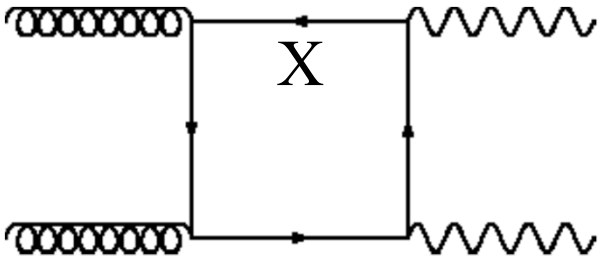
Top Quark arXiv:1609.?????

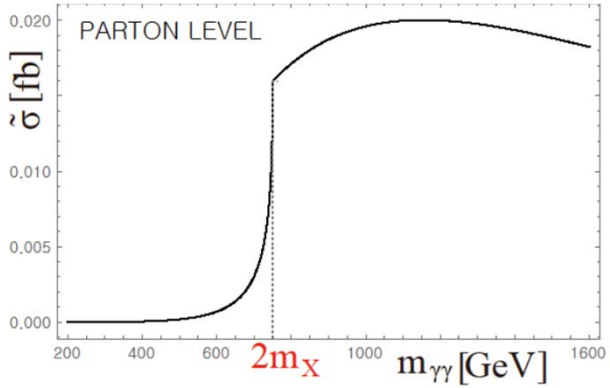
Won Sang Cho, DC, Radovan Dermisek, Tae Hyun Jung, Hyung Do Kim, and Dongsub Lee

1st IBS-Honam Focus Program 2016 Aug. 31

Motivation

- Model independently, any particle charged under $SU(3)_C$ and $U(1)_{EM}$ mediates $gg \to \gamma\gamma$ through loops.





$$\propto C_X \equiv N_X T_{R_X} Q_X^2$$

Number of copies — SU(3) Dynkin index — Electric charge

Exclusion for the combined charge!!

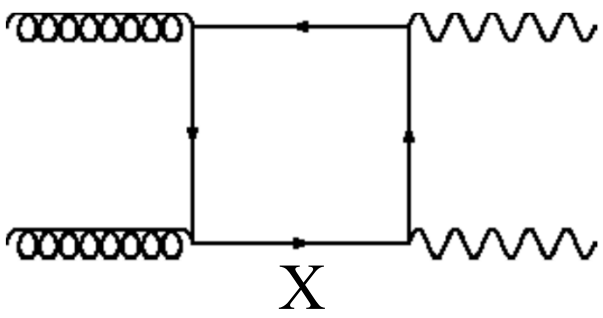
e.g. $C_{top} = 2/9$

- Good resolution in binning $\gamma\gamma$ invariant mass

Top mass measurment

Top mass is an important parameter in EW precision tests and Higgs stability.

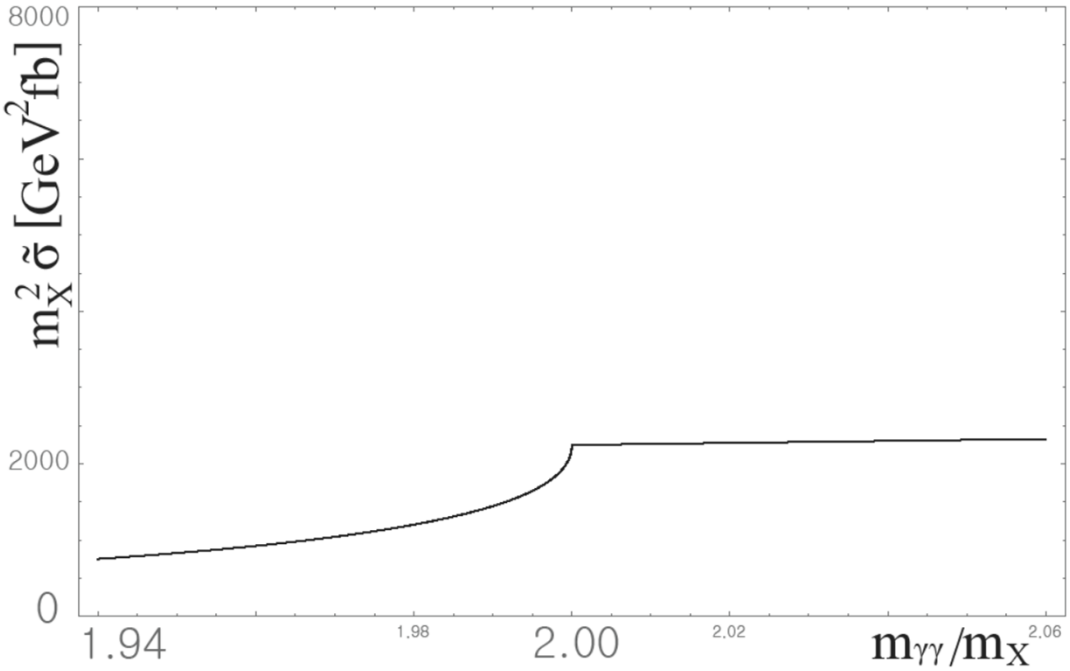
One Loop



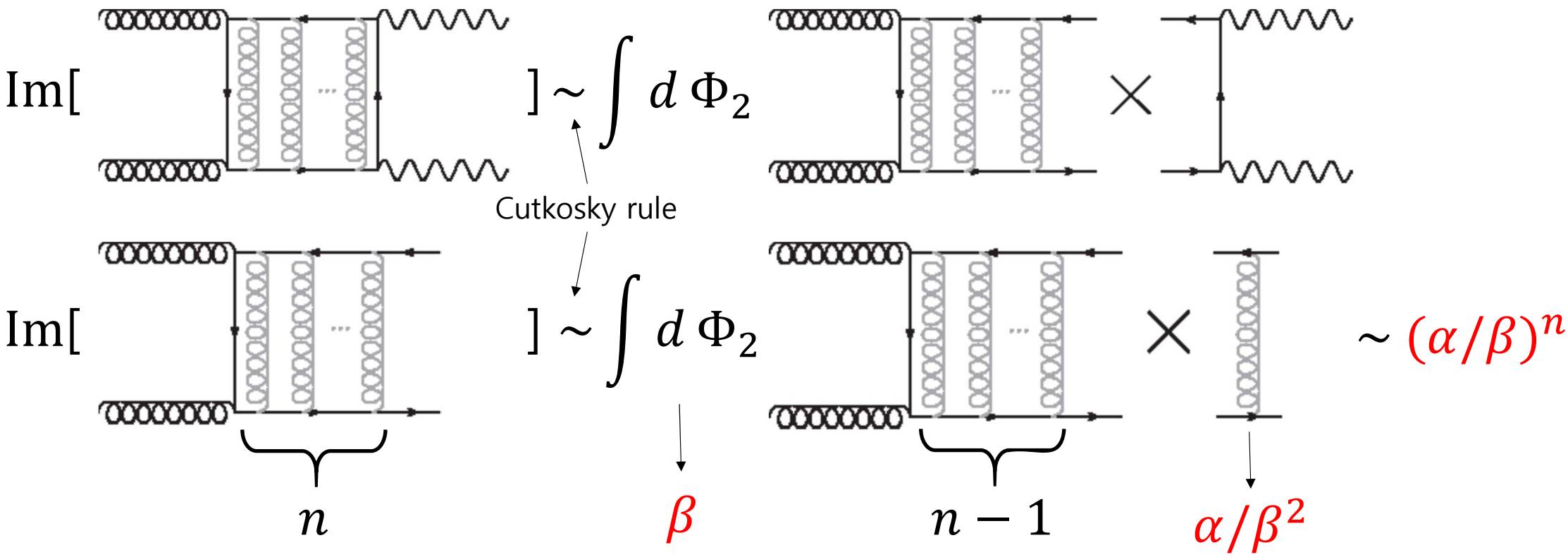
$$\propto C_X \equiv N_X T_{R_X} Q_X^2$$

Number of copies SU(3) Dynkin index Electric charge e.g. $C_{top} = 2/9$

Parton level cross section of gg to di-photon

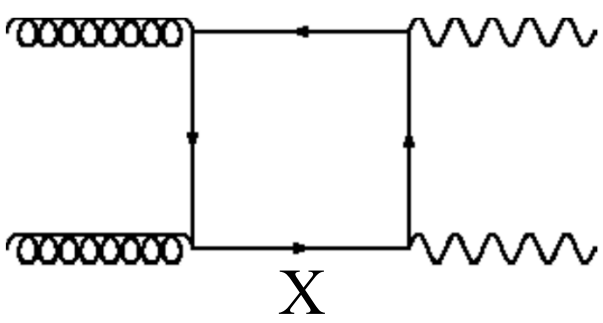


Higher loop

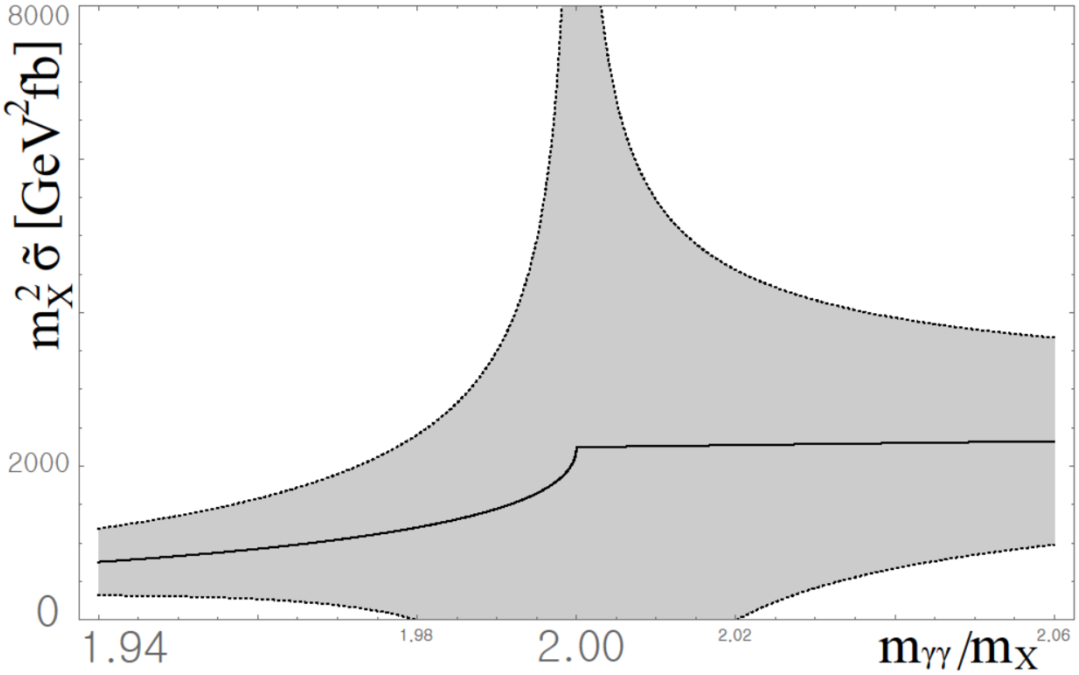


β : Velocity of the loop particle

One Loop

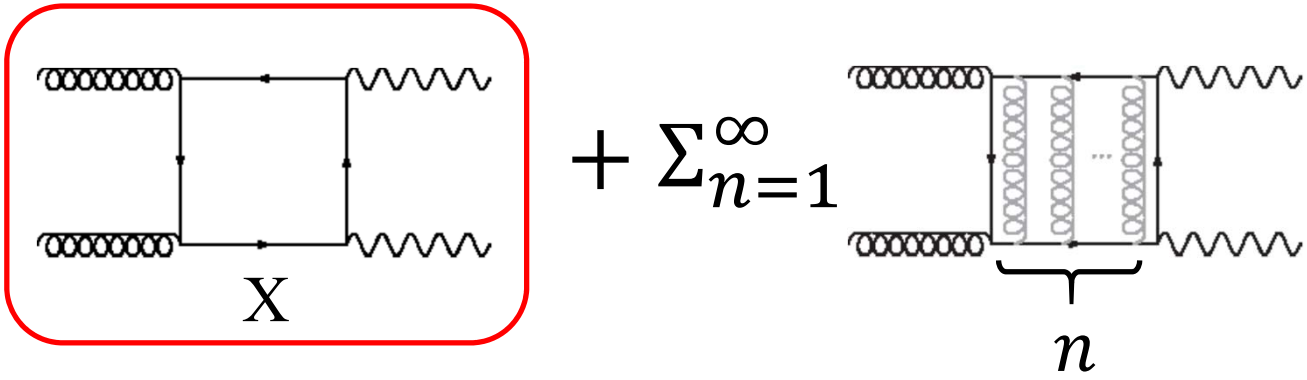


Parton level cross section of gg to di-photon

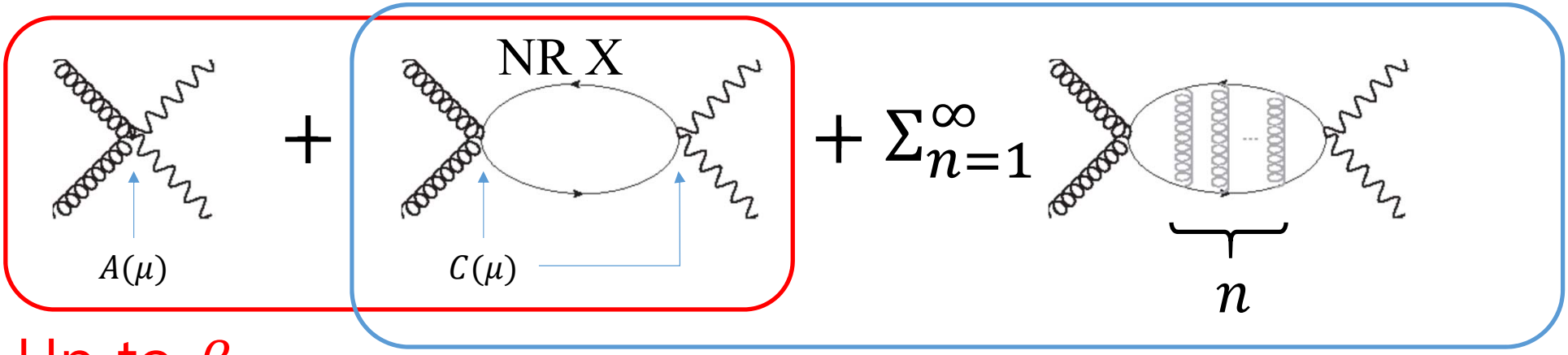


The shaded area shows $\left(\frac{\alpha}{\beta}\right)$ Error to one loop result

Threshold Resummation



EFT (Relativistic part of X particle is integrated out)



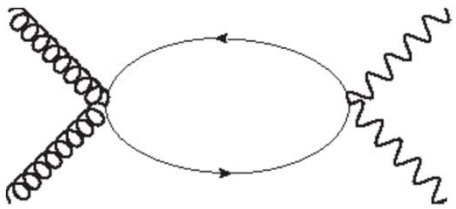
Up to β

Self-consistency equation leads to
Schroedinger equation of Coulomb potential

Free Green Function

Non-relativistic limit of a fermion propagator

$$S\left(\left\{m+\frac{E}{2}+k^0,\vec{k}\right\}\right)\approx\frac{i(1+\gamma^0)/2}{k^0+\frac{E}{2}-\frac{\vec{k}^2}{2m}}$$

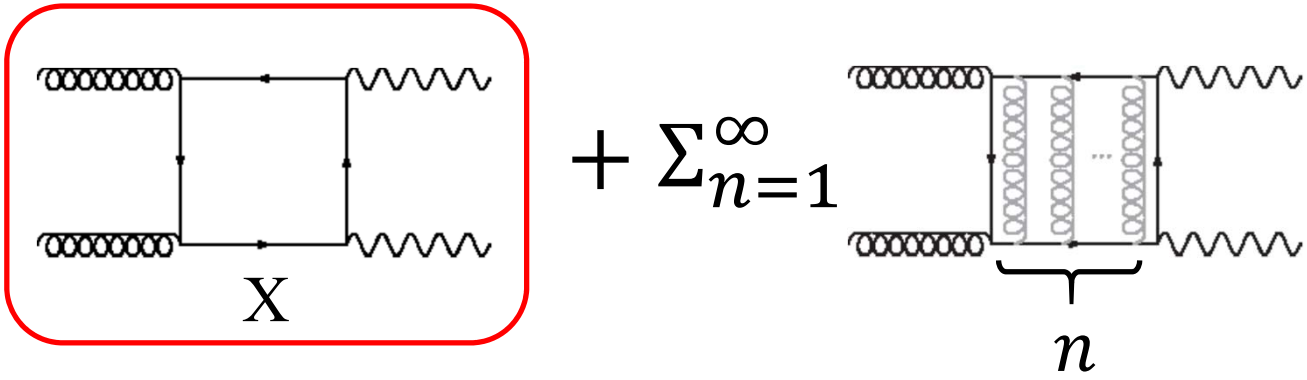


$$\propto\int d^4k\,\frac{1}{k^0+\frac{E}{2}-\frac{\vec{k}^2}{2m}}\;\frac{1}{-k^0+\frac{E}{2}-\frac{\vec{k}^2}{2m}}\propto\int d^3\vec{k}\,\frac{1}{E-\frac{\vec{k}^2}{m}}=G_0(\vec{0})$$

$\propto\beta$

※Note that $\left(-\frac{\nabla^2}{m}-E\right)\int d^3\vec{k}\frac{1}{E-\frac{\vec{k}^2}{m}}\,e^{i\vec{k}\cdot\vec{x}}=\delta^3(\vec{x})$

Threshold Resummation



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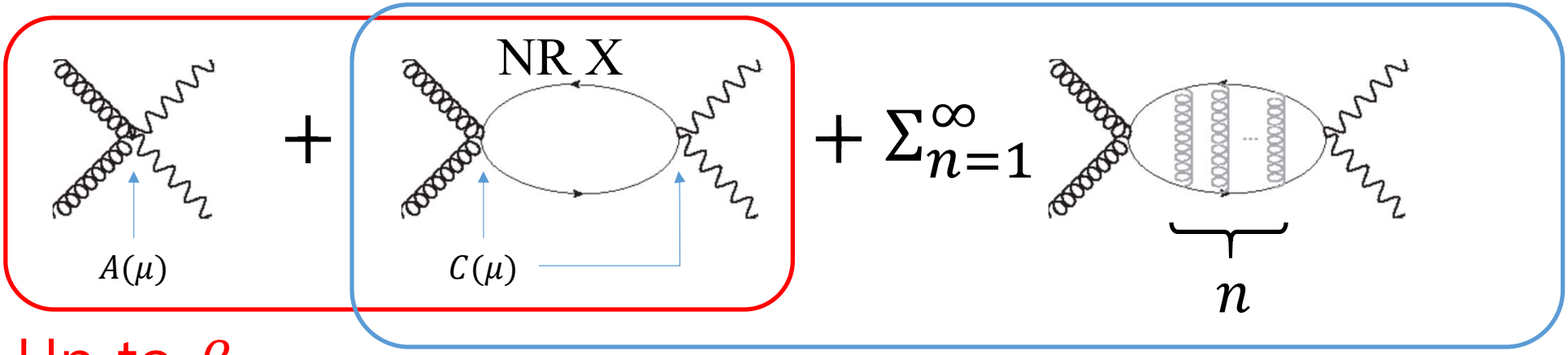
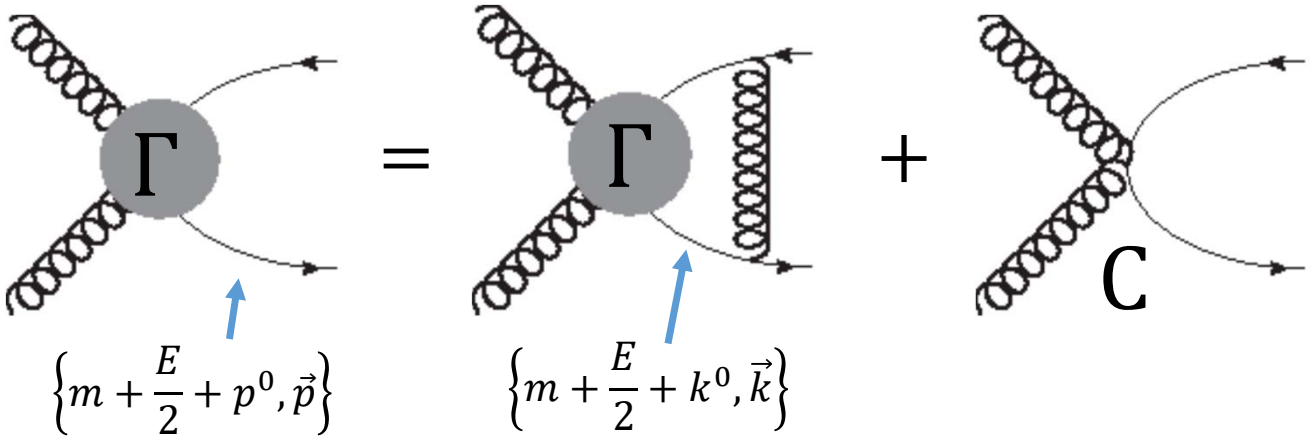


Up to β

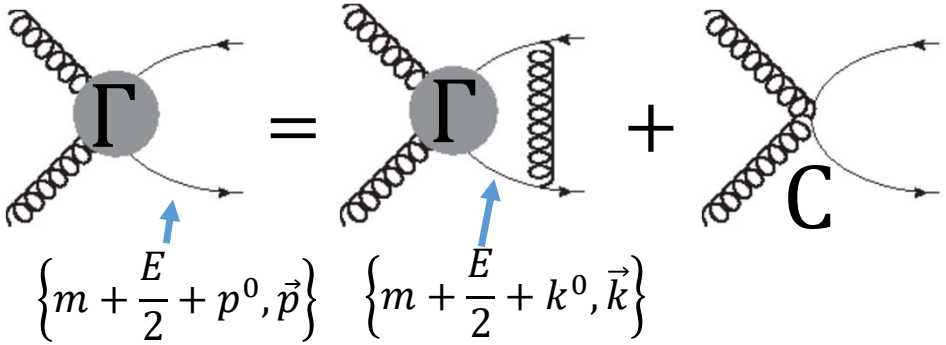
Self-consistency equation leads to
Schroedinger equation of Coulomb potential

Self-Consistency



$$\Gamma(E,\vec{p}) = C + \int d^3\vec{k}\;\Gamma(\mathrm{E},\vec{\mathrm{k}})\mathrm{G}_0(E,\vec{\mathrm{k}})\frac{\mathrm{C}_2\alpha_s}{\left(\vec{p}-\vec{k}\right)^2}$$

Strassler, Peskin (91)



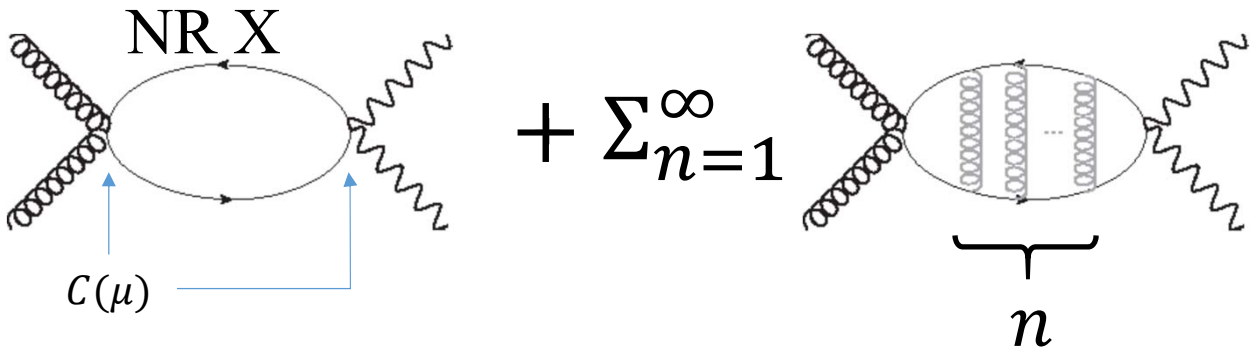
$$\Gamma(E,\vec{p}) = C + \int d^3\vec{k}\,\Gamma(\mathrm{E},\vec{\mathrm{k}})\mathrm{G}_0(E,\vec{\mathrm{k}})\frac{\mathrm{C}_2\alpha_s}{(\vec{p}-\vec{k})^2}$$

$$\frac{\Gamma(E,\vec{p})}{C}G_0(E,\vec{p}) = G_0(E,\vec{p}) + G_0(E,\vec{p})\int d^3\vec{k}\,\frac{\Gamma(\mathrm{E},\vec{\mathrm{k}})}{\mathrm{C}}\mathrm{G}_0(E,\vec{\mathrm{k}})\frac{\mathrm{C}_2\alpha_s}{(\vec{p}-\vec{k})^2}$$

$$G(E,\vec{p}) = G_0(E,\vec{p}) + G_0(E,\vec{p})\int d^3\vec{k}\,G(E,\vec{\mathrm{k}})\frac{\mathrm{C}_2\alpha_s}{(\vec{p}-\vec{k})^2}$$

$$\left(-\frac{\nabla^2}{m}-\frac{\mathrm{C}_2\alpha_s}{r}-E\right)G(E,\vec{x}) = \delta^3(\vec{x})$$

Strassler, Peskin (91)



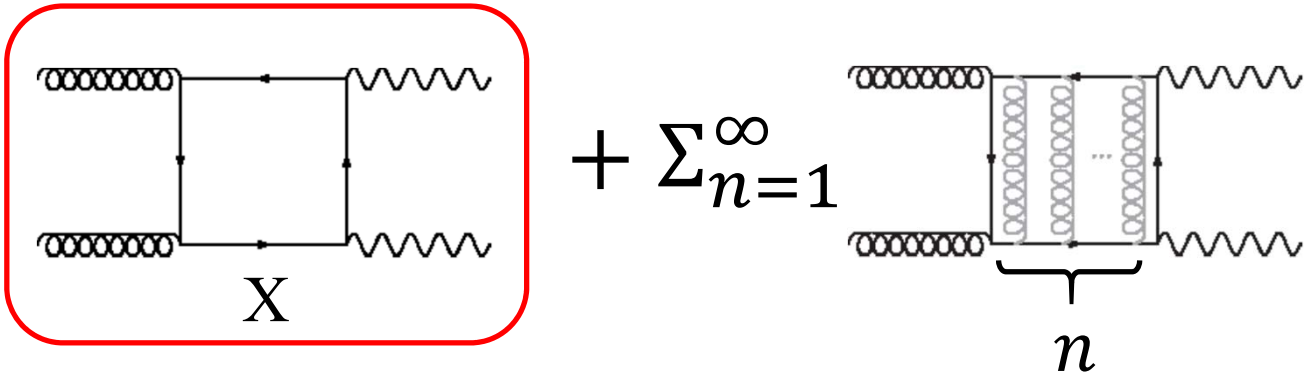
$$= \quad \Gamma$$

$$= \int d^3\vec{k}\, \mathrm{C}\, \frac{\mathrm{G}(\mathrm{E},\vec{\mathrm{k}})}{G_0(E,\vec{k})}\, \mathrm{G}_0(E,\vec{\mathrm{k}})\, C_{X\bar{X}\gamma\gamma}$$

$$= C C_{X\bar{X}\gamma\gamma} G(E,\vec{x}=\vec{0})$$

$$\frac{\Gamma(E,\vec{p})}{C} G_0(E,\vec{p}) = G(E,\vec{p})$$

Threshold Resummation



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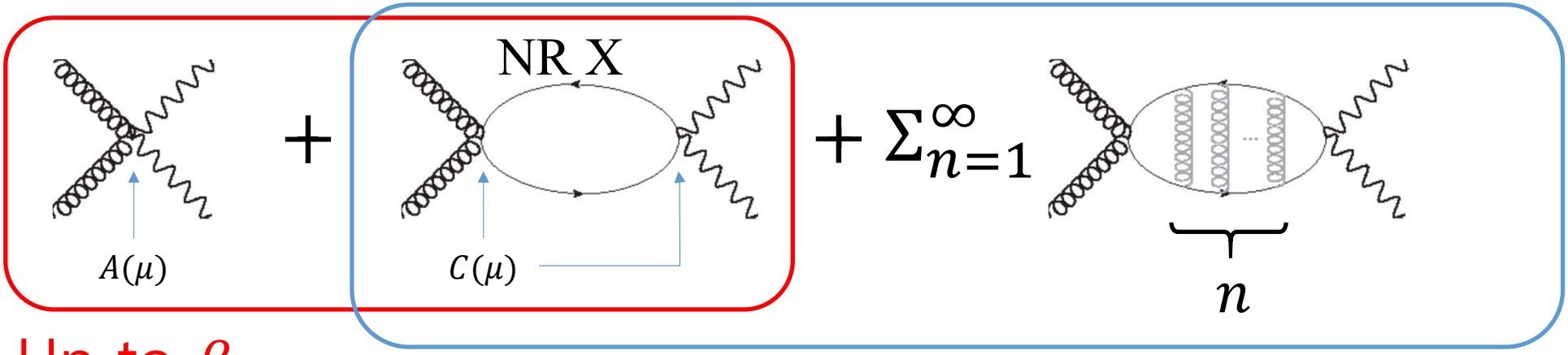


Up to β

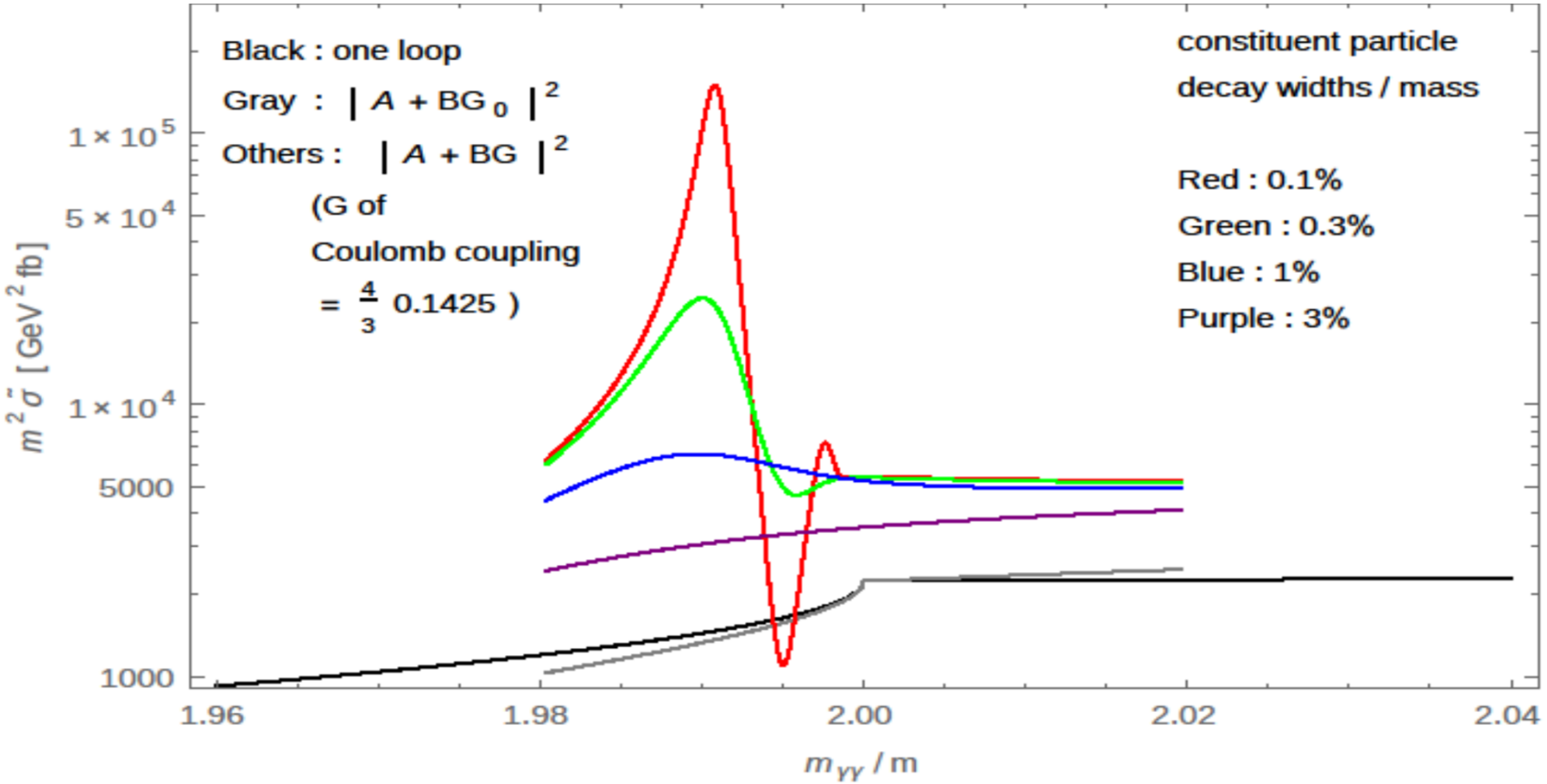
Self-consistency equation leads to
Schroedinger equation of Coulomb potential

Melnikov, Spira, Yakovlev (94)

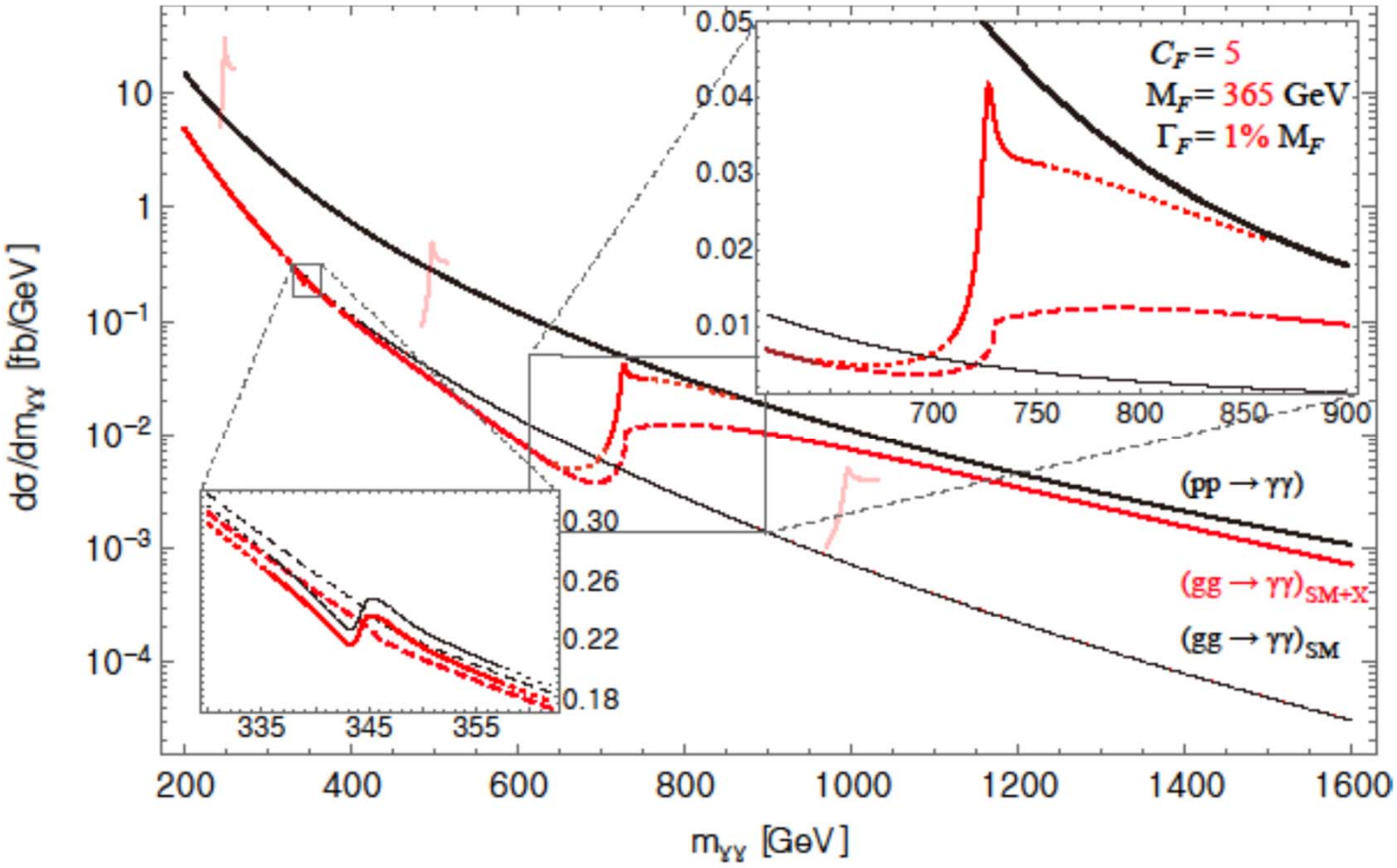
$$\mathcal{M}^{\lambda_1\lambda_2\lambda_3\lambda_4} = \mathcal{M}^{\lambda_1\lambda_2\lambda_3\lambda_4}_{\text{One Loop}} - B^{\lambda_1\lambda_2\lambda_3\lambda_4}G_0 + B^{\lambda_1\lambda_2\lambda_3\lambda_4}G(0, \Delta E + i\Gamma_X)$$

Fadin, Khoze (87)

$$G(0,\Delta E) = \frac{m_X^2}{4\pi}\left(\sqrt{-\frac{\Delta E}{m_X}} - C_2(X)\overline{\alpha_s}\ln\left(\frac{\sqrt{m_X\Delta E}}{\mu}\right) - \frac{2}{\sqrt{m_X}}\Sigma_{n=1}^{\infty}\frac{\mathrm{E_n}}{\sqrt{-\Delta E} - sign\left(C_2(X)\right)\sqrt{E_n}}\right)$$



Exclusion



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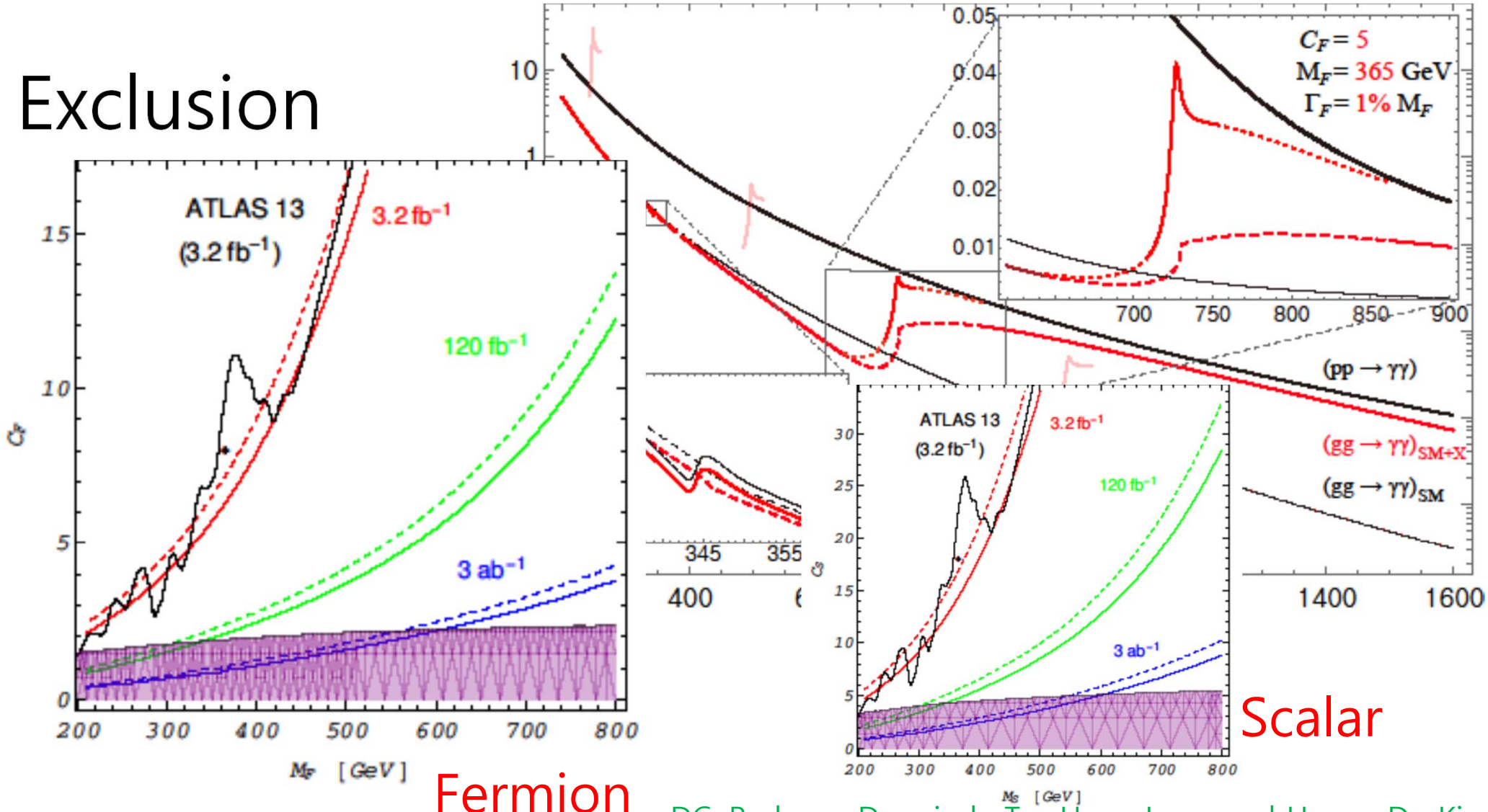
PRL 117 (2016) no.6, 061801)

Exclusion

$C_X \equiv N_X T_{R_X} Q_X^2$



Fermion

Scalar

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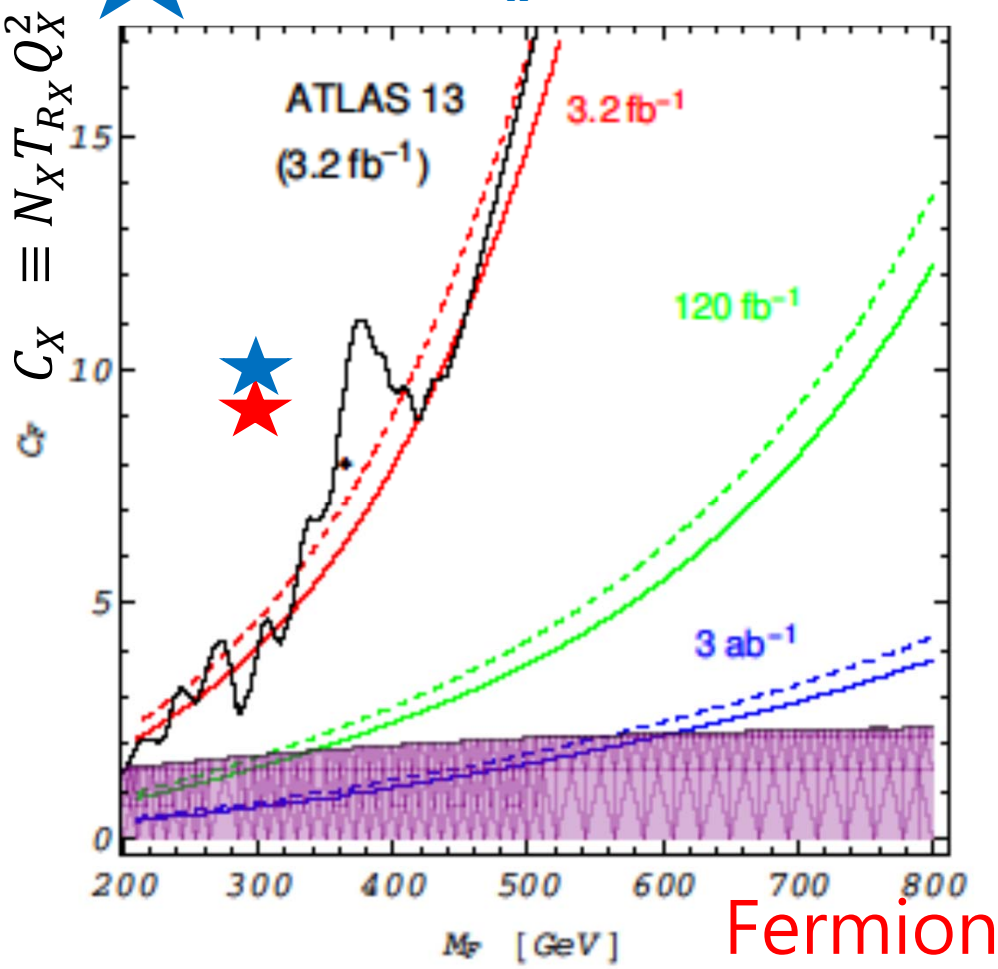
: $N_X = 1, T_{R_X} = 3,\ Q_X^2 = 3$

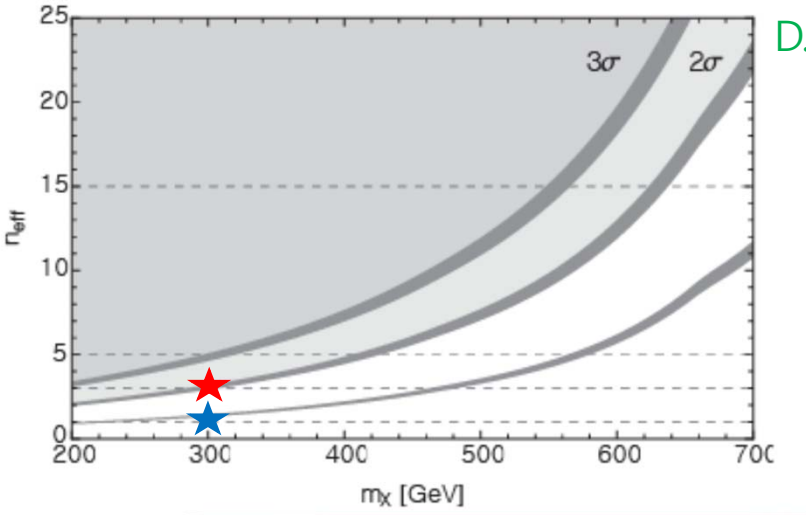
: $N_X = 1, T_{R_X} = 1/2,\ Q_X^2 = 20$



Fermion

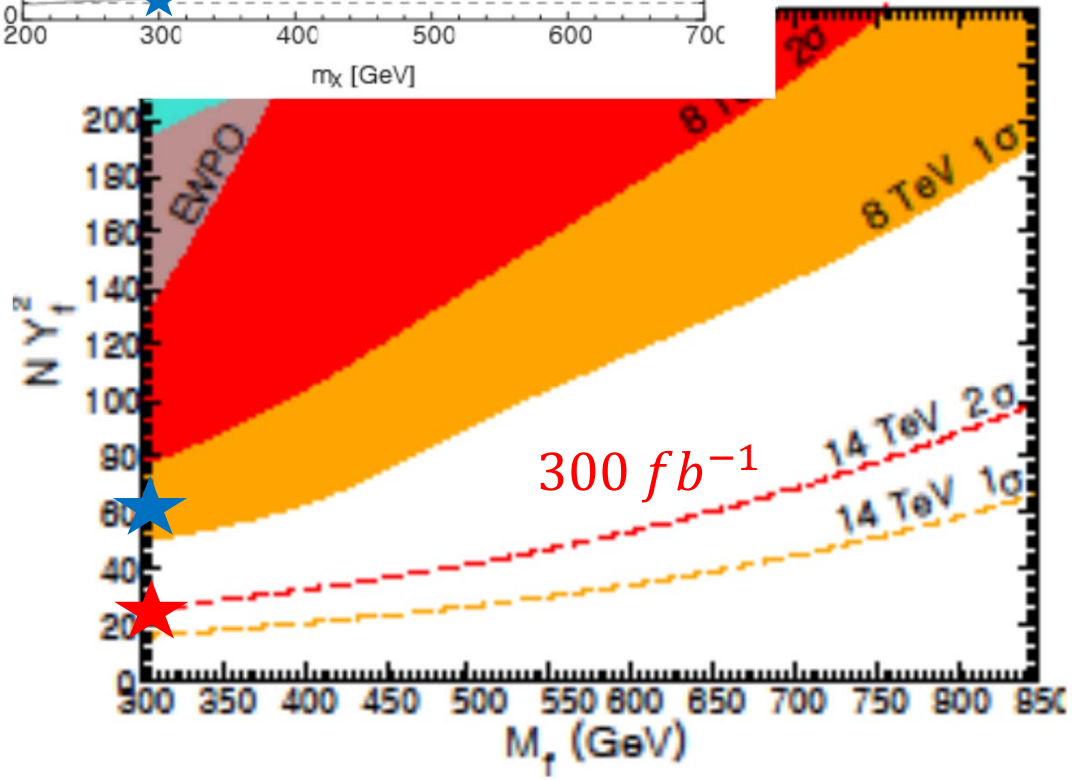
PHYSICAL REVIEW D 91, 015010 (2015)

D. Becciolini *et al.*



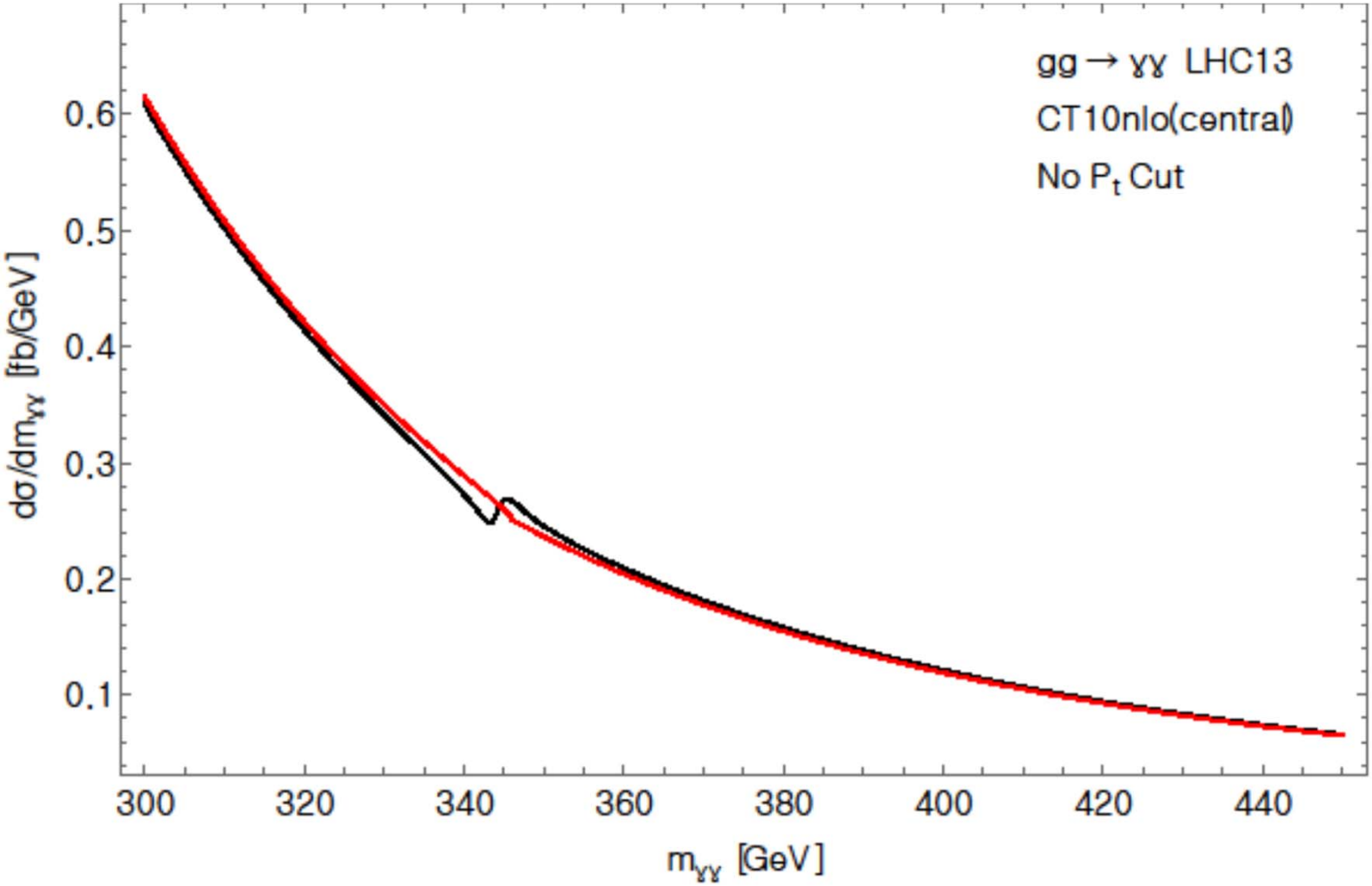
arXiv:1602.03877

C. Gross *et al.*

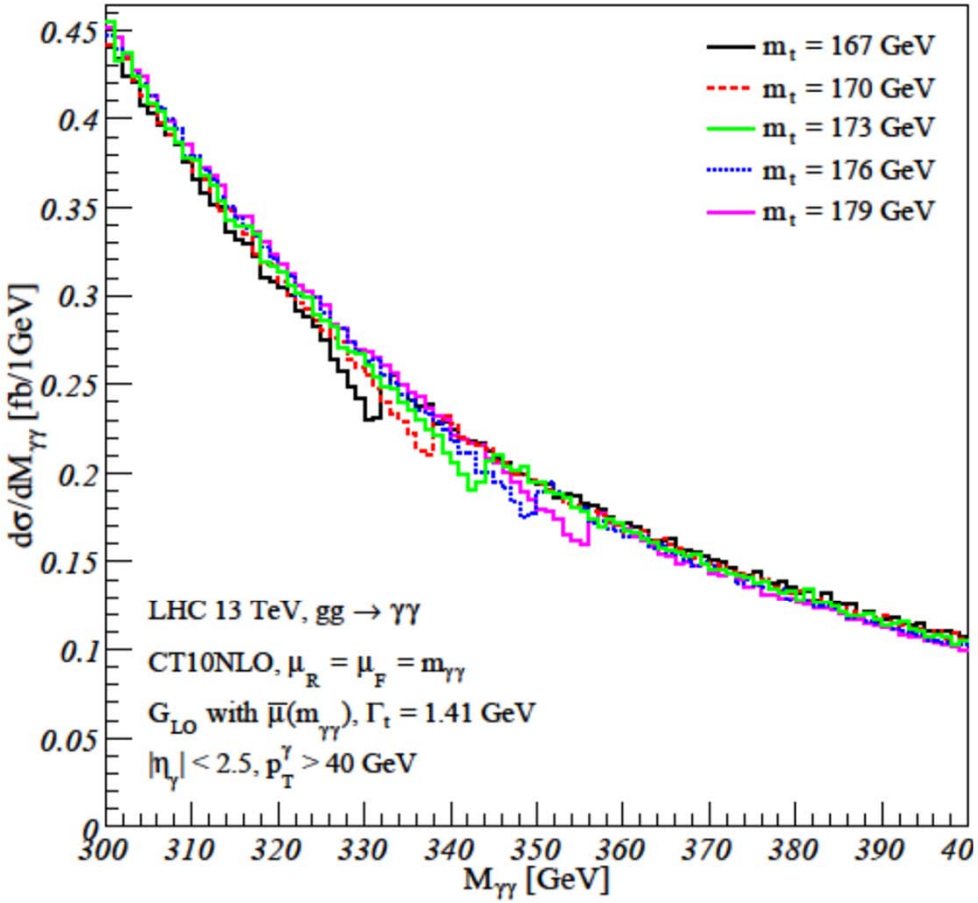


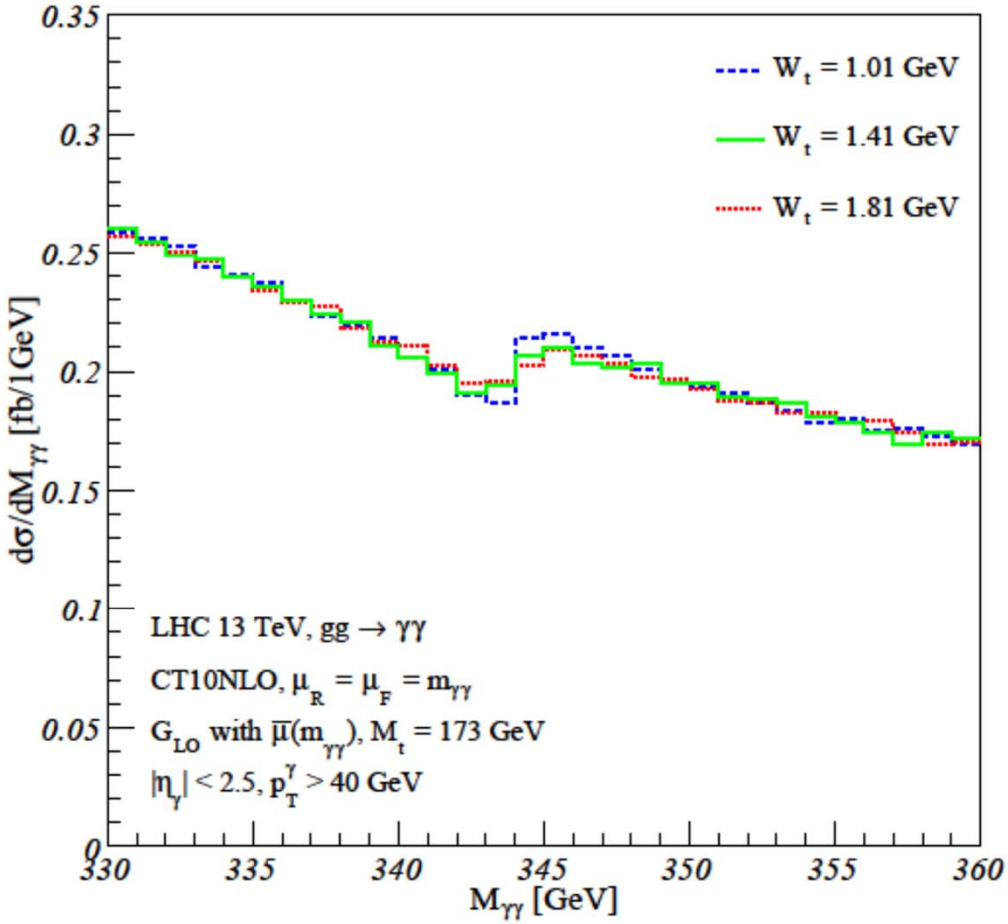
Top search

$C_{top} = 2/9$



Top search


m_t = 167 GeV
m_t = 170 GeV
m_t = 173 GeV
m_t = 176 GeV
m_t = 179 GeV
LHC 13 TeV, gg → γγ
CT10NLO, $\mu_R = \mu_F = m_{\gamma\gamma}$
G_{LO} with $\bar{\mu}(m_{\gamma\gamma})$, Γ_t = 1.41 GeV
$|\eta_\gamma| < 2.5$, $p_T^\gamma > 40$ GeV
$d\sigma/dM_{\gamma\gamma}$ [fb/1GeV]
$M_{\gamma\gamma}$ [GeV]


W_t = 1.01 GeV
W_t = 1.41 GeV
W_t = 1.81 GeV
LHC 13 TeV, gg → γγ
CT10NLO, $\mu_R = \mu_F = m_{\gamma\gamma}$
G_{LO} with $\bar{\mu}(m_{\gamma\gamma})$, M_t = 173 GeV
$|\eta_\gamma| < 2.5$, $p_T^\gamma > 40$ GeV
$d\sigma/dM_{\gamma\gamma}$ [fb/1GeV]
$M_{\gamma\gamma}$ [GeV]

Next order

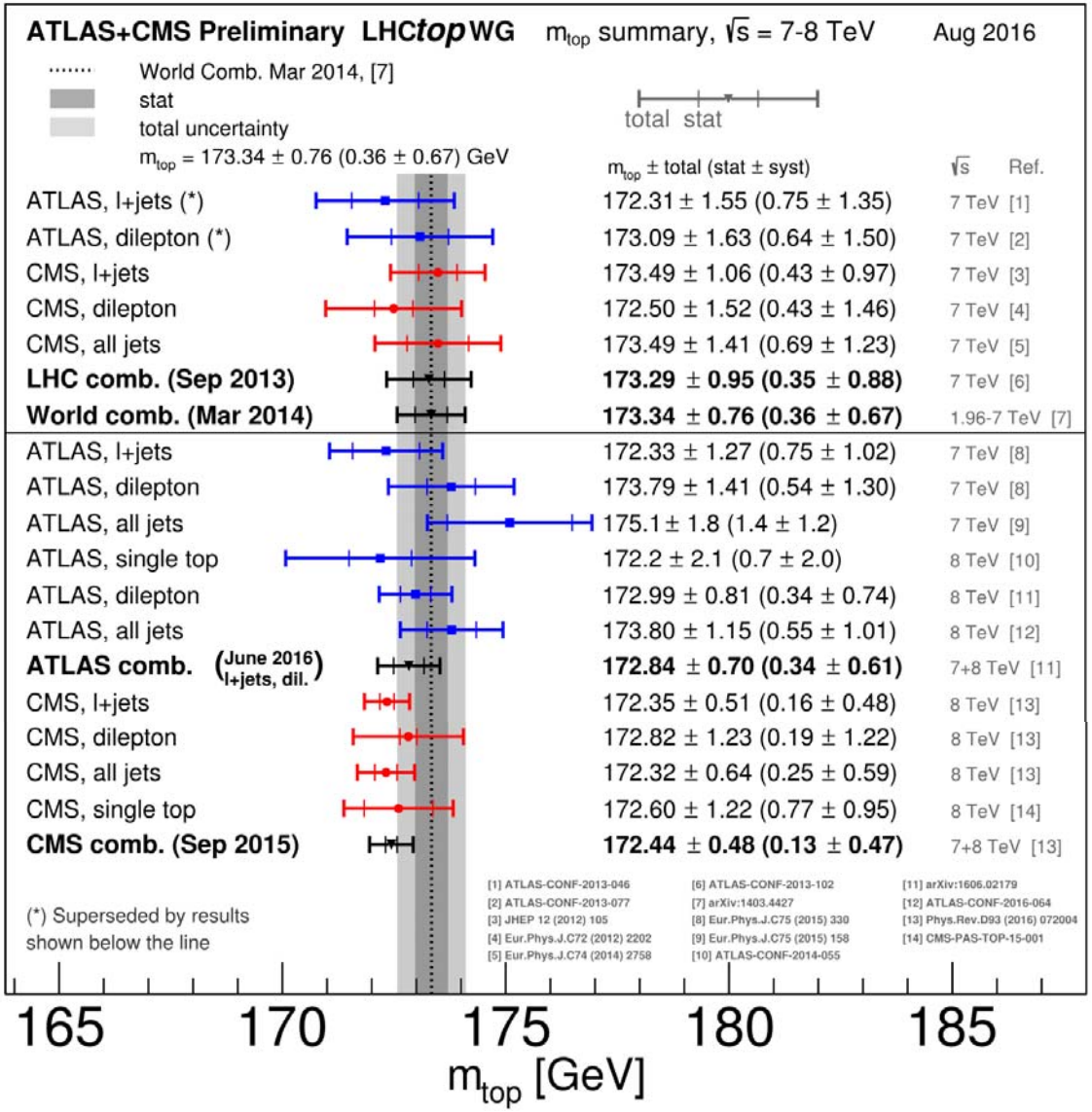
- Vertex and Green function corrections next order in α and β.
- Soft gluon or photon
- NRQCD is the tool as the case of $t\bar{t}$ production NNLO calculations.

Summary

- We obtained model independent exclusion plot of strong and electric combined charge.

- Continuing analysis on di-photon will help pin down the top quark mass.

Appendix


ATLAS+CMS Preliminary LHCtopWG
m_{top} summary, $\sqrt{s}$ = 7-8 TeV
Aug 2016
World Comb. Mar 2014, [7]
stat
total uncertainty
m_{top} = 173.34 ± 0.76 (0.36 ± 0.67) GeV
total stat
m_{top} ± total (stat ± syst)
$\sqrt{s}$
Ref.
ATLAS, l+jets (*) 172.31 ± 1.55 (0.75 ± 1.35) 7 TeV [1]
ATLAS, dilepton (*) 173.09 ± 1.63 (0.64 ± 1.50) 7 TeV [2]
CMS, l+jets 173.49 ± 1.06 (0.43 ± 0.97) 7 TeV [3]
CMS, dilepton 172.50 ± 1.52 (0.43 ± 1.46) 7 TeV [4]
CMS, all jets 173.49 ± 1.41 (0.69 ± 1.23) 7 TeV [5]
LHC comb. (Sep 2013) 173.29 ± 0.95 (0.35 ± 0.88) 7 TeV [6]
World comb. (Mar 2014) 173.34 ± 0.76 (0.36 ± 0.67) 1.96-7 TeV [7]
ATLAS, l+jets 172.33 ± 1.27 (0.75 ± 1.02) 7 TeV [8]
ATLAS, dilepton 173.79 ± 1.41 (0.54 ± 1.30) 7 TeV [8]
ATLAS, all jets 175.1 ± 1.8 (1.4 ± 1.2) 7 TeV [9]
ATLAS, single top 172.2 ± 2.1 (0.7 ± 2.0) 8 TeV [10]
ATLAS, dilepton 172.99 ± 0.81 (0.34 ± 0.74) 8 TeV [11]
ATLAS, all jets 173.80 ± 1.15 (0.55 ± 1.01) 8 TeV [12]
ATLAS comb. (June 2016) (l+jets, dil.) 172.84 ± 0.70 (0.34 ± 0.61) 7+8 TeV [11]
CMS, l+jets 172.35 ± 0.51 (0.16 ± 0.48) 8 TeV [13]
CMS, dilepton 172.82 ± 1.23 (0.19 ± 1.22) 8 TeV [13]
CMS, all jets 172.32 ± 0.64 (0.25 ± 0.59) 8 TeV [13]
CMS, single top 172.60 ± 1.22 (0.77 ± 0.95) 8 TeV [14]
CMS comb. (Sep 2015) 172.44 ± 0.48 (0.13 ± 0.47) 7+8 TeV [13]
(*) Superseded by results shown below the line
[1] ATLAS-CONF-2013-046
[2] ATLAS-CONF-2013-077
[3] JHEP 12 (2012) 105
[4] Eur.Phys.J.C72 (2012) 2202
[5] Eur.Phys.J.C74 (2014) 2758
[6] ATLAS-CONF-2013-102
[7] arXiv:1403.4427
[8] Eur.Phys.J.C75 (2015) 330
[9] Eur.Phys.J.C75 (2015) 158
[10] ATLAS-CONF-2014-055
[11] arXiv:1606.02179
[12] ATLAS-CONF-2016-064
[13] Phys.Rev.D93 (2016) 072004
[14] CMS-PAS-TOP-15-001
165
170
175
180
185
m_{top} [GeV]