Higgs production in the MSSM at NLO

Alejandro Daleo

Institut für Theoretische Physik

ETH Zürich

(SUSY-QCD corrections to $gg \to H^0$ in the MSSM)

in collaboration with C. Anastasiou, S. Beerli, S. Bucherer and Z. Kunszt

(hep-ph/0611236, hep-ph/0703282, arXiv:0803.3065 and in preparation)

INTRODUCTION

HIGGS SEARCHES ARE PRIORITY AT LHC

- FOLLOWING DISCOVERY WE HAVE TO UNDERSTAND WHICH HIGGS WE FOUND

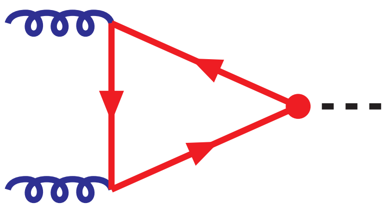
SIGNAL CROSS SECTION WILL BE MEASURED AT $\pm 10\%$ OR BETTER

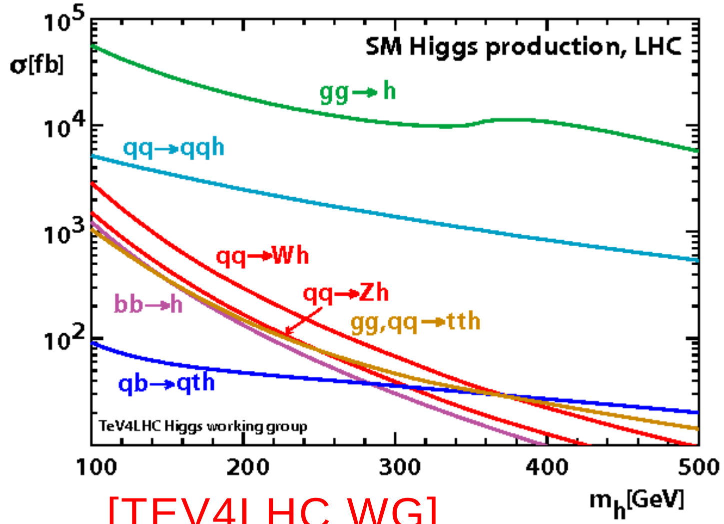
- A PRECISION TEST OF THE STANDARD MODEL

IMPORTANT TO HAVE THEORETICAL PREDICTIONS MATCHING THIS PRECISION

DOMINANT PRODUCTION MECHANISM IS GLUON FUSION

- LOOP INDUCED, MEDIATED BY HEAVY QUARKS IN THE SM





[TEV4LHC WG]

EXTENSIONS OF THE SM MIGHT CHANGE THE PHENOMENOLOGY SIGNIFICANTLY

- NEW PARTICLES AFFECTING HIGGS PRODUCTION AND DECAYS
- COUPLING STRUCTURE MIGHT HIGHLIGHT CONTRIBUTIONS UNIMPORTANT IN THE SM
- EXTENDED HIGGS SECTORS COULD BE STUDIED AT THE LHC

MSSM: ARCHETYPE FOR BSM HIGGS PRODUCTION

MSSM IS A PROTOTYPICAL AND THOROUGHLY STUDIED BSM BENCHMARK SCENARIO

MANY INTERESTING FEATURES AFFECTING HIGGS PRODUCTION

- NEW COLORED PARTICLES, SQUARKS AND GLUINO, MEDIATING THE $gg \to h$ PROCESS
- CURRENT LIMITS DO NOT RULE OUT LIGHT $(100 - 200\,GeV)$ SQUARKS
- BOTTOM-HIGGS COUPLINGS ENHANCED AT LARGE $\tan\beta$
- HEAVY NEUTRAL HIGGS MIGHT BE ALSO SEEN AT THE LHC

HOWEVER, NO COMPLETE NLO CALCULATION UNTIL NOW:

- FULL SUSY-QCD NLO CORRECTIONS IN LARGE MASS LIMIT
  HARLANDER, STEINHAUSER (2004), HARLANDER, HOFMANN (2005)

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EXPECTED TO WORK UP TO 10-20%
MISSING BOTTOM CONTRIBUTIONS
DOESN'T WORK FOR HEAVY HIGGS

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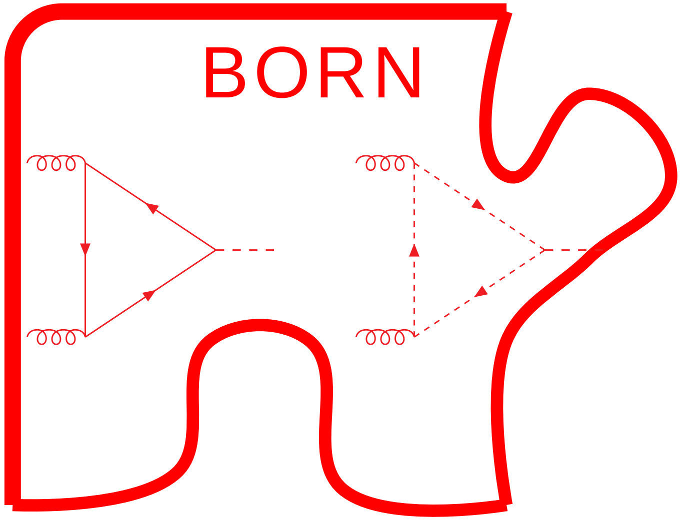
- FULL SUSY-QCD NLO CORRECTIONS IN LARGE MASS LIMIT
  HARLANDER, STEINHAUSER (2004), HARLANDER, HOFMANN (2005)
- 2 LOOP VIRTUAL SQUARK CONTRIBUTIONS, NO MIXING (QUARTIC COUPLINGS)
  ANASTASIOU, BEERLI, BUCHERER, AD, KUNSZT (2006), BERNREUTHER *et al.* (2006)
- COMPLETE NLO CORRECTIONS FOR SQUARK CONTRIBUTIONS, NO MIXING
  MÜHLLEITNER, SPIRA (2006)
- ANALYTIC RESULTS FOR REAL RADIATION SQUARK CONTRIBUTIONS, NO MIXING
  BONCIANI, DEGRASSI, VICINI (2007)
- COMPLETE VIRTUAL CORRECTIONS FOR $gg \to h$ IN THE MSSM
  ANASTASIOU, BEERLI, AD (2008)

HIGGS PRODUCTION IN THE MSSM: OVERVIEW

- BORN

$gg \rightarrow h$ MEDIATED BY HEAVY QUARK AND SQUARK LOOPS



HIGGS PRODUCTION IN THE MSSM: OVERVIEW

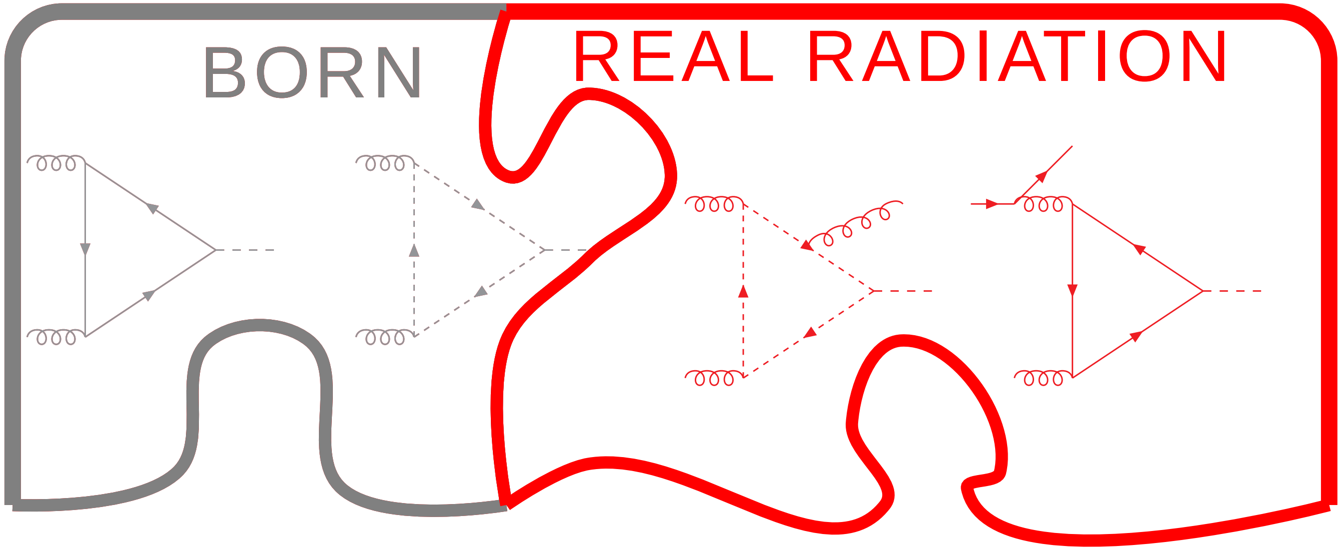
- BORN

$gg \to h$ MEDIATED BY HEAVY QUARK AND SQUARK LOOPS

- REAL RADIATION

ANALYTIC EXPRESSIONS

IR SINGULARITIES: SUBTRACTION METHOD

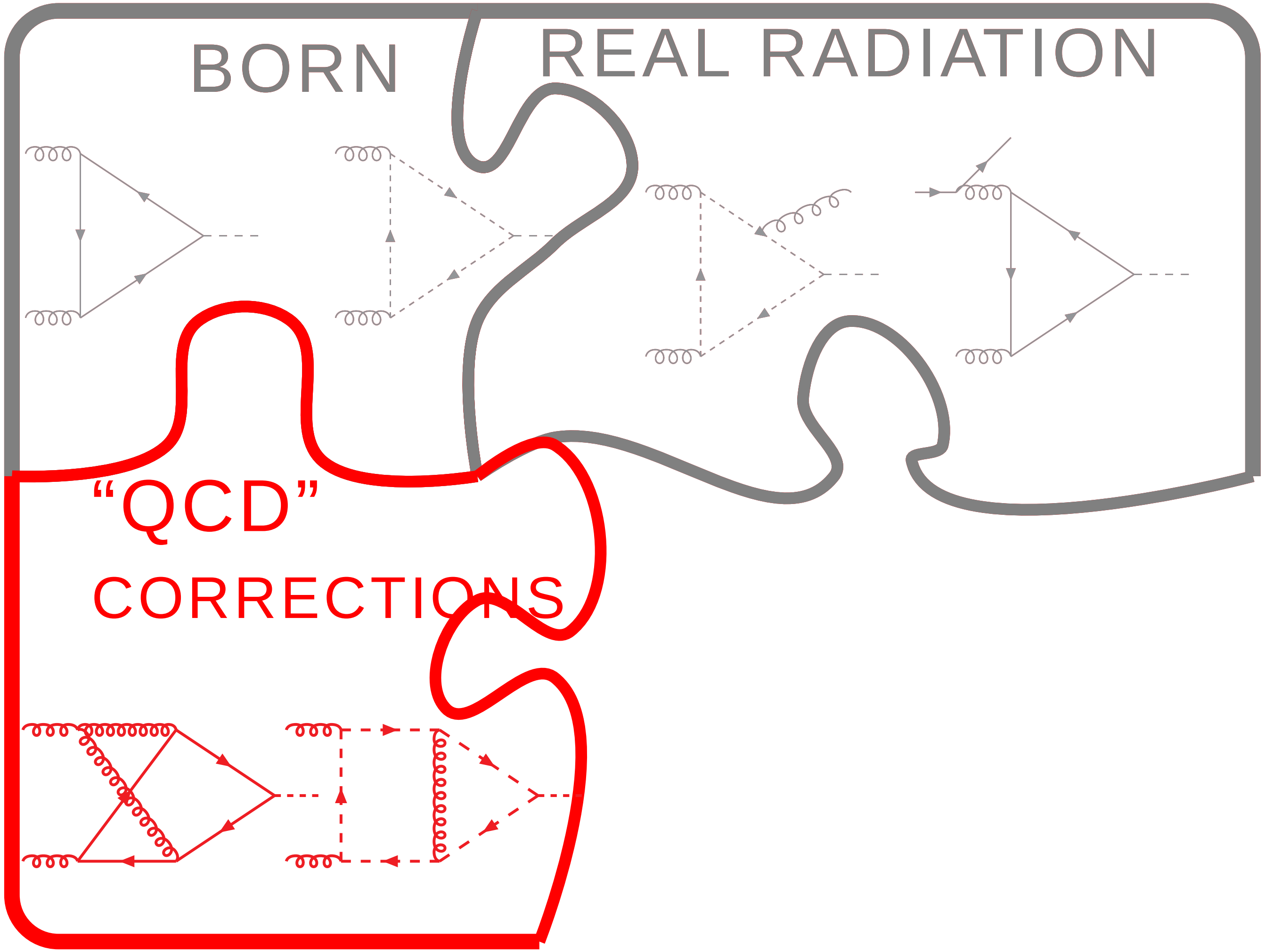


Higgs production in the MSSM: overview

- BORN
$gg \to h$ MEDIATED BY HEAVY QUARK AND SQUARK LOOPS

- REAL RADIATION
ANALYTIC EXPRESSIONS
IR SINGULARITIES: SUBTRACTION METHOD

- "QCD" CORRECTIONS:
COMPUTED ANALYTICALLY
INVOLVE ONLY GLUON INSERTIONS
ONE MASS RUNNING IN THE LOOPS

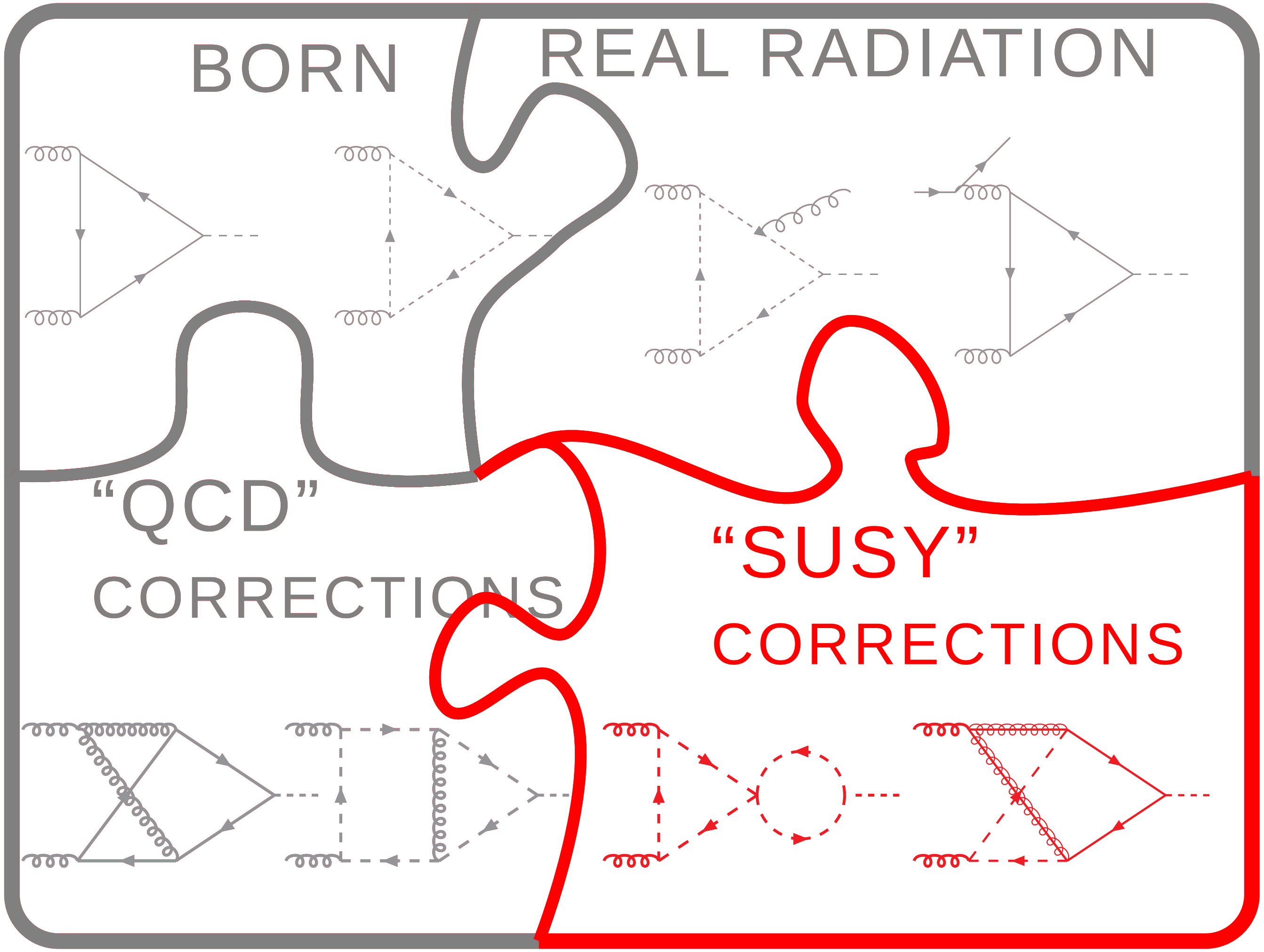


HIGGS PRODUCTION IN THE MSSM: OVERVIEW

- BORN
  $gg \longrightarrow h$ MEDIATED BY HEAVY QUARK AND SQUARK LOOPS
- REAL RADIATION
  ANALYTIC EXPRESSIONS
  IR SINGULARITIES: SUBTRACTION METHOD

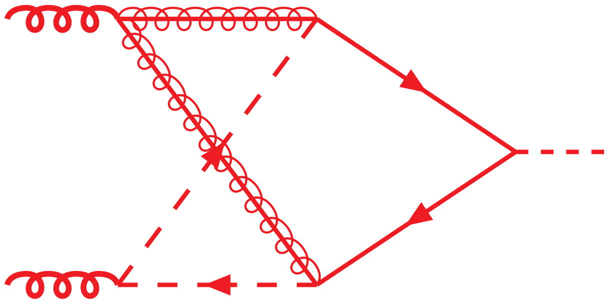
- “QCD” CORRECTIONS:
  COMPUTED ANALYTICALLY
  INVOLVE ONLY GLUON INSERTIONS
  ONE MASS RUNNING IN THE LOOPS

- “SUSY” CORRECTIONS:
  LAST MISSING PIECES
  CONTAIN SUSY VERTICES
  SEVERAL MASSES IN THE LOOPS
  MOST DIFFICULT INTEGRALS



A TECHNICAL STOP: BACK TO COMPUTING LOOP INTEGRALS

WE LOOK FOR A METHOD TO COMPUTE THINGS LIKE



$= ???$

MORE GENERALLY, WE HAVE THE USUAL WISH LIST:

- ABLE TO DEAL WITH UV AND IR SINGULAR INTEGRALS (COMPUTE COEFFICIENTS IN ϵ EXPANSION)
- ABLE TO HANDLE ALL KINEMATICAL REGIONS, MASSES, THRESHOLDS, ETC
- EASY TO AUTOMATE
- REASONABLE ACCURACY AND SPEED (REASONABLE IS PROCESS DEPENDENT!)

SECTOR DECOMPOSITION + CONTOUR DEFORMATION

LAZOPOULOS, MELNIKOV, PETRIELLO (2007)

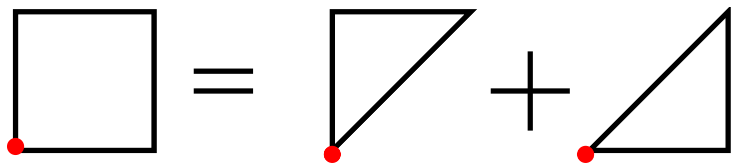
ANASTASIOU, BEERLI, AD (2007)

First ingredient: Sector Decomposition

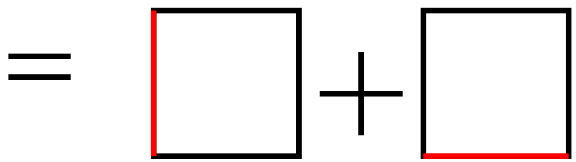
(Hepp; Binoth&Heinrich)

Aim: to disentangle singularities in Feynman parameters

$$\int_0^1 \frac{x^\epsilon\, y^\epsilon\, dx\, dy}{(x+y)^2} \to \left(\int_{x>y} + \int_{y>x}\right) \frac{x^\epsilon\, y^\epsilon\, dx\, dy}{(x+y)^2}$$



$$\int_{x>y} \frac{x^\epsilon\, y^\epsilon\, dx\, dy}{(x+y)^2} \xrightarrow{y \to xy} \int_0^1 \frac{x^{-1+2\epsilon}\, y^\epsilon\, dx\, dy}{(1+y)^2}$$



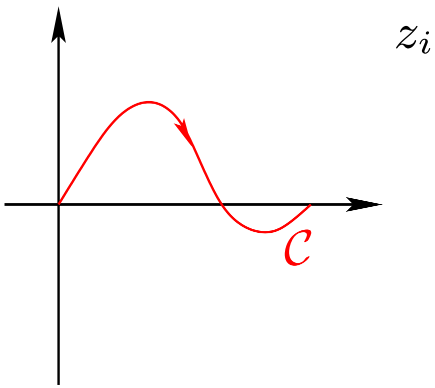
$$\int_0^1 dx x^{-1+\epsilon} f(x) = \frac{f(0)}{\epsilon} + \int_0^1 dx x^\epsilon \frac{f(x) - f(0)}{x}$$

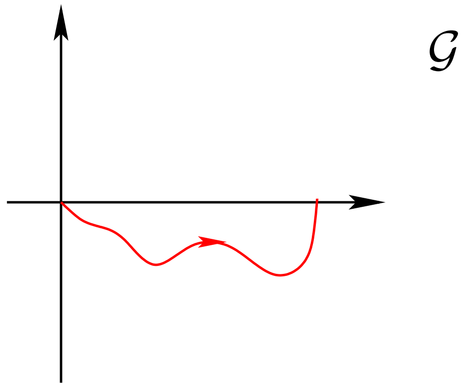
SECOND INGREDIENT: CONTOUR DEFORMATION

(NAGY & SOPER)

- INTRODUCED BY NAGY AND SOPER, TO TREAT NUMERICALLY THE INTEGRATION OVER FEYNMAN PARAMETERS IN LOOP INTEGRALS
- USED BY BINOTH *et al.* TO EVALUATE NUMERICALLY INFRARED FINITE LOOP INTEGRALS
  BINOTH, GUILLET, HEINRICH, PILON, SCHUBERT (2005)
- *enforce* THE $i\delta$ PRESCRIPTION IN THE PROPAGATORS

$$\int_0^1 dx_1 \cdots dx_n \frac{\mathcal{F}(\vec{x},\epsilon)}{[\mathcal{G}(\vec{x},M_i^2,s_{kl}) - i\delta]^\alpha} \longrightarrow \int_{\mathcal{C}} dz_1 \cdots dz_n \frac{\mathcal{F}(\vec{z},\epsilon)}{[\mathcal{G}(\vec{z},M_i^2,s_{kl})]^\alpha}$$





$$z_i = x_i - i\lambda x_i(1-x_i)\frac{\partial \mathcal{G}_s}{\partial x_i} \qquad \mathcal{G}_s(\vec{x}) - i\,\delta \longrightarrow \mathcal{G}_s(\vec{z}) = \mathcal{G}_s(\vec{x}) - i\lambda \sum_i x_i(1-x_i)\left(\frac{\partial \mathcal{G}_s}{\partial x_i}\right)^2 + \mathcal{O}(\lambda^2)$$

A brief detour: evanescent couplings in DRED

SUSY and DREG do not get along very well, DRED is the default scheme for MSSM, but both schemes should give identical results after redefinitions of couplings and masses

However, for arbitrary (no SU(2) or SUSY) quark and squarks Higgs couplings:

$$C_1^{\text{DREG}} - C_{1,\text{NAIVE}}^{\text{DRED}} = \left(\frac{\alpha_s}{2\,\pi}\right)^2 N_C\,T_F\,\frac{1}{s}\sum_q m_q^2 \left(4\,h_f(q) - \sum_{i=1,2} h_s(q,i,i)\right)$$

difference does not vanish in the SM!!
in the MSSM it only vanishes when considering complete $SU(2)$ doublets:

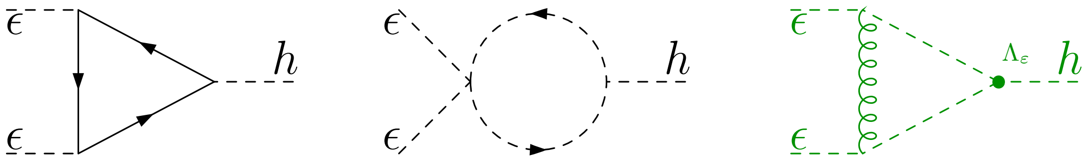
$$m_q^2 \left(4\,h_f(q) - \sum_{i=1,2} h_s(q,i,i)\right) = \begin{cases} m_Z^2\,\sin(\alpha+\beta) & q=t \\ -m_Z^2\,\sin(\alpha+\beta) & q=b \end{cases}$$

There's a missing contribution originated in evanescent couplings in DRED

- in DRED spacetime is $d = 4 - 2\,\epsilon < 4$ dimensional
- gluons split into
  - physical d dimensional gluons $G_\mu^a(x)$
  - ϵ components $G_i^a(x) \equiv \varepsilon_i^a(x)$
- $\varepsilon_i^a(x)$ behave as scalars under Lorentz transformations and
- as scalars in the adjoint representation under color ones

A BRIEF DETOUR: EVANESCENT COUPLINGS IN DRED

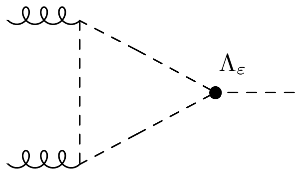
ε-SCALARS BEHAVE IN A FUNNY WAY: A NEW COUPLING ARISES RADIATIVELY



$$\mathcal{L}_\varepsilon = \Lambda_\epsilon \, \epsilon \cdot \epsilon \, h$$

$$\delta\Lambda_\varepsilon = \frac{\alpha_s}{2\,\pi} \frac{1}{\epsilon} \frac{1}{v} \left\{ T_F \sum_q m_q^2 \left(4\, h_f(q) - \sum_{s=1}^{2} h_s(q,s,s) \right) - \left(\frac{3}{2} N_C - T_F \right) v \, \Lambda_\varepsilon \right\}$$

AND ITS RENORMALIZATION



$$\longrightarrow C_1^\Lambda = \frac{\alpha_s}{2\pi} N_C \frac{\Lambda_\varepsilon \, v}{s} \epsilon$$

CANCELS THE MISMATCH BETWEEN DRED AND DREG

SU(2) SYMMETRY REQUIRES $\mathcal{L}_\varepsilon = \lambda_\epsilon \, \epsilon \cdot \epsilon \, |\mathcal{H}|^2 \longrightarrow \lambda_\epsilon \, v \, \epsilon \cdot \epsilon \, h = \Lambda_\epsilon \, \epsilon \cdot \epsilon \, h$

BUT THIS OPERATOR BREAKS SUSY IN A NON-SOFT WAY $\rightarrow$ FORBIDDEN IN THE MSSM

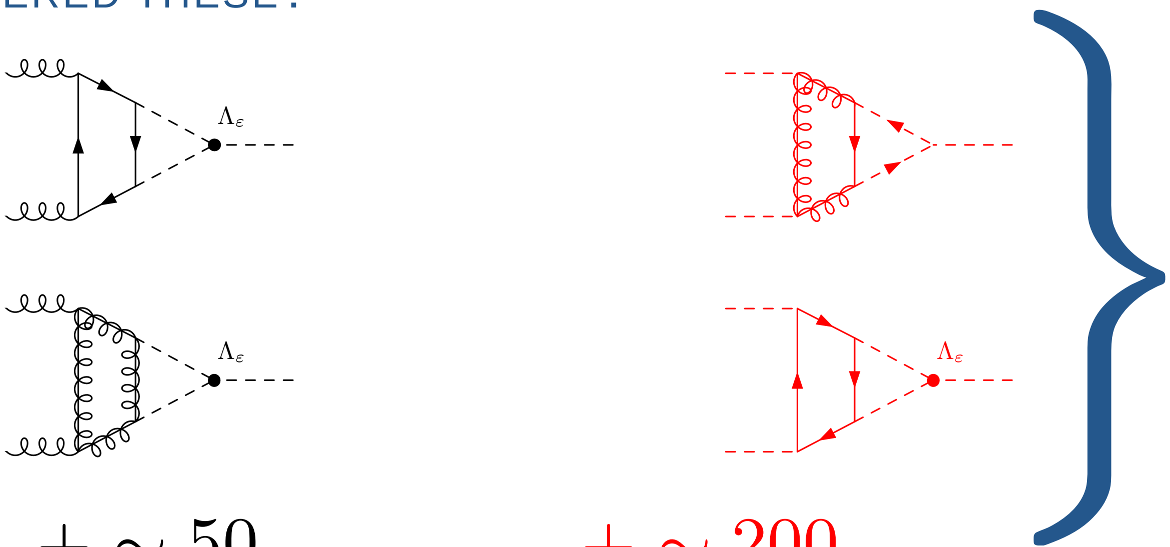
HOWEVER NO PROBLEM AT ALL:

$$\sum_{q=t,b} m_q^2 \left(4\, h_f(q) - \sum_{s=1}^{2} h_s(q,s,s) \right) = 0$$

RECAP

- HIGGS–ε-SCALAR COUPLING REQUIRED WHENEVER SUSY OR SU(2) ARE ABSENT
- NOTABLY THE CASE OF THE SM!
- NOT PRESENT IN THE MSSM
- HOWEVER THEY WILL POP OUT WHEN NEGLECTING TERMS (LIKE BOTTOM-HIGGS COUPLINGS) IN THE LAGRANGIAN
- HUNDREDS OF NEW (UNDESIRED) DIAGRAMS TO CHECK...

WHO ORDERED THESE?



$+ \sim 50$ $\quad + \sim 200$ $\quad = \mathcal{O}(\epsilon)$

A SCENARIO IN THE MSSM

MSSM HAS AN ENORMOUS PARAMETER SPACE, HOPELESS TO STUDY IT ALL

TRY TO STUDY GENERIC FEATURES INSTEAD AND IDENTIFY REGIONS WITH INTERESTING PHENOMENOLOGY

WE FOCUSED ON SCENARIOS THAT

- CONTAIN ONE LIGHT STOP
- WITH LARGE MASS SPLITTINGS BETWEEN SQUARKS (STOPS)
- REQUIRE RELATIVELY LARGE $\tan\beta$

THIS FEATURES APPEAR FOR INSTANCE IN SCENARIOS THAT MINIMIZE THE FINE-TUNING (KITANO AND NOMURA, 2006) FOR INSTANCE THROUGH "MIRAGE" (COMBINED MODULI AND ANOMALY) MEDIATED SUSY BREAKING

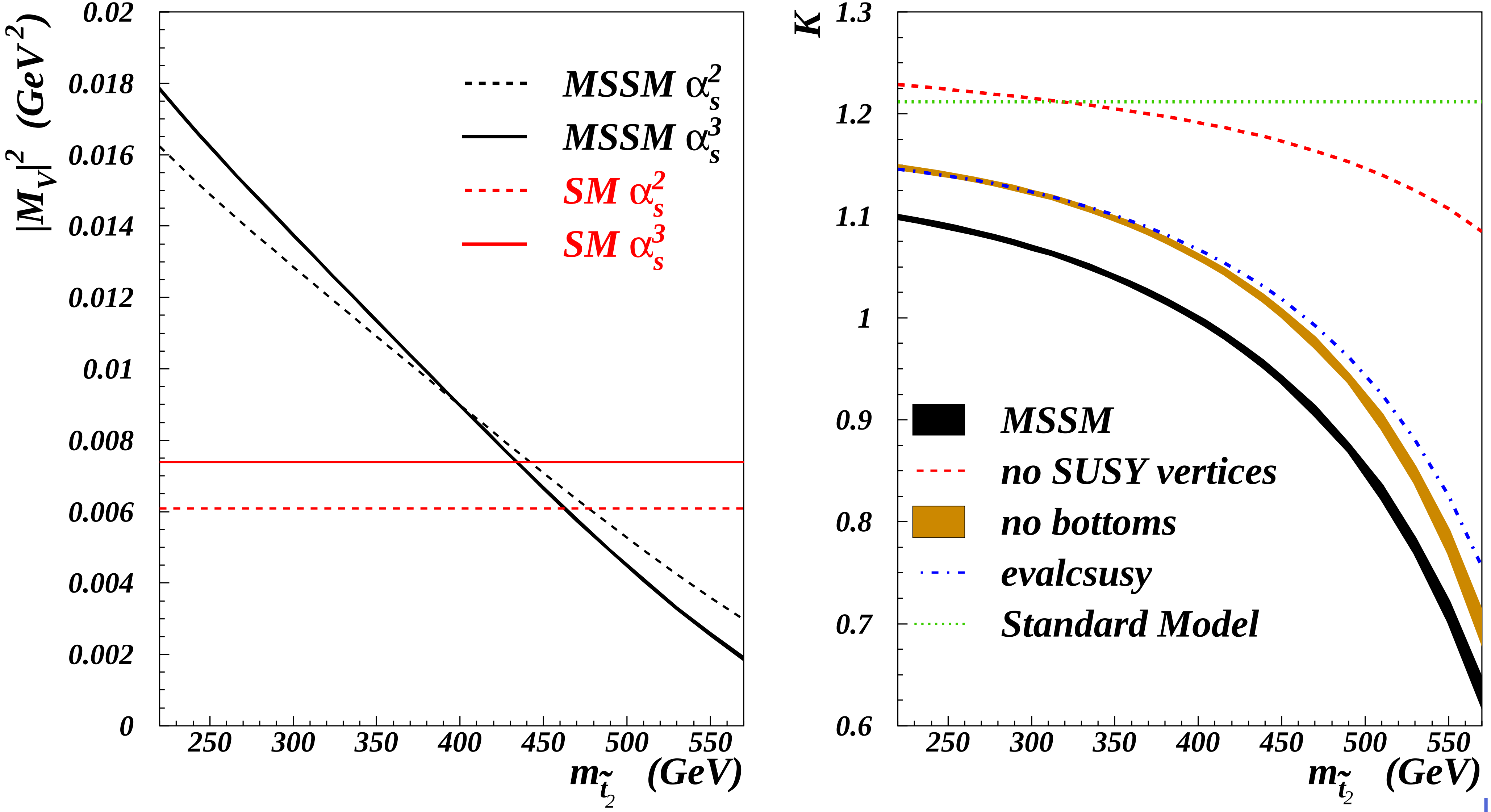
RESEMBLES THE "GLUOPHOBIC" SCENARIO CONSIDERED BY HARLANDER AND STEINHAUSER

IN THE FOLLOWING PLOTS, WE FIX THE LOW ENERGY SPECTRUM

$$\begin{array}{ll}
m_{\tilde{t}_1} = 150\,\text{GeV} & 220\,\text{GeV} < m_{\tilde{t}_2} < 570\,\text{GeV} \\
m_{\tilde{b}_1} = 350\,\text{GeV} & m_{\tilde{b}_2} = 370\,\text{GeV} \\
m_{\tilde{g}} = 500\,\text{GeV} & \\
m_h = 115\text{GeV} & 280\text{GeV} < m_H < 450\text{GeV} \\
\tan\beta = 20 & \mu = 300\,\text{GeV}
\end{array}$$

RESULTS: VIRTUAL CORRECTIONS (INCLUDING AN IR (CATANI) COUNTERTERM)

LIGHT HIGGS ($m_h = 115\,\mathrm{GeV}$)



complete PRELIMINARY results for higgs production in the MSSM at NLO

thanks to Stefan Bucherer!

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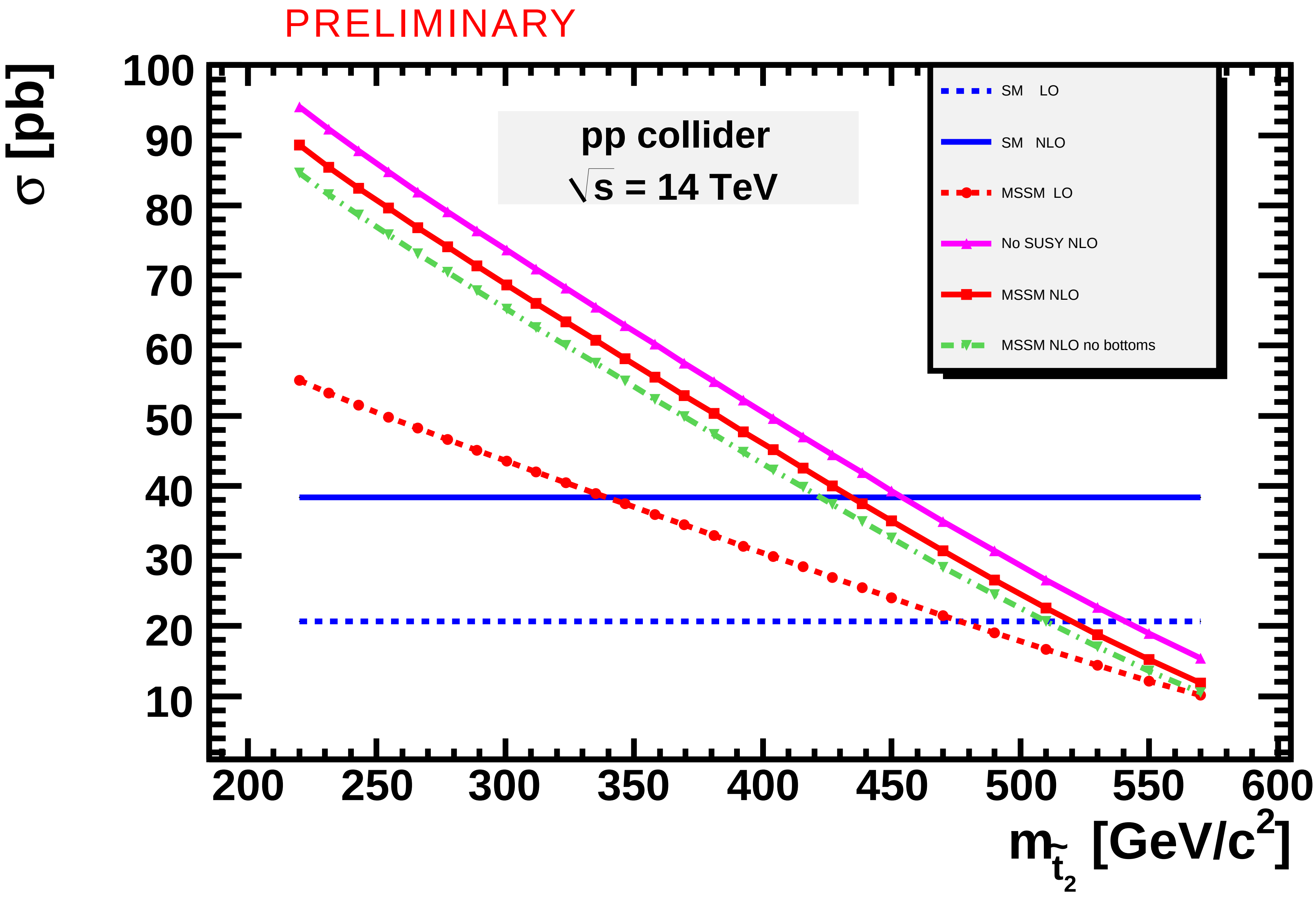

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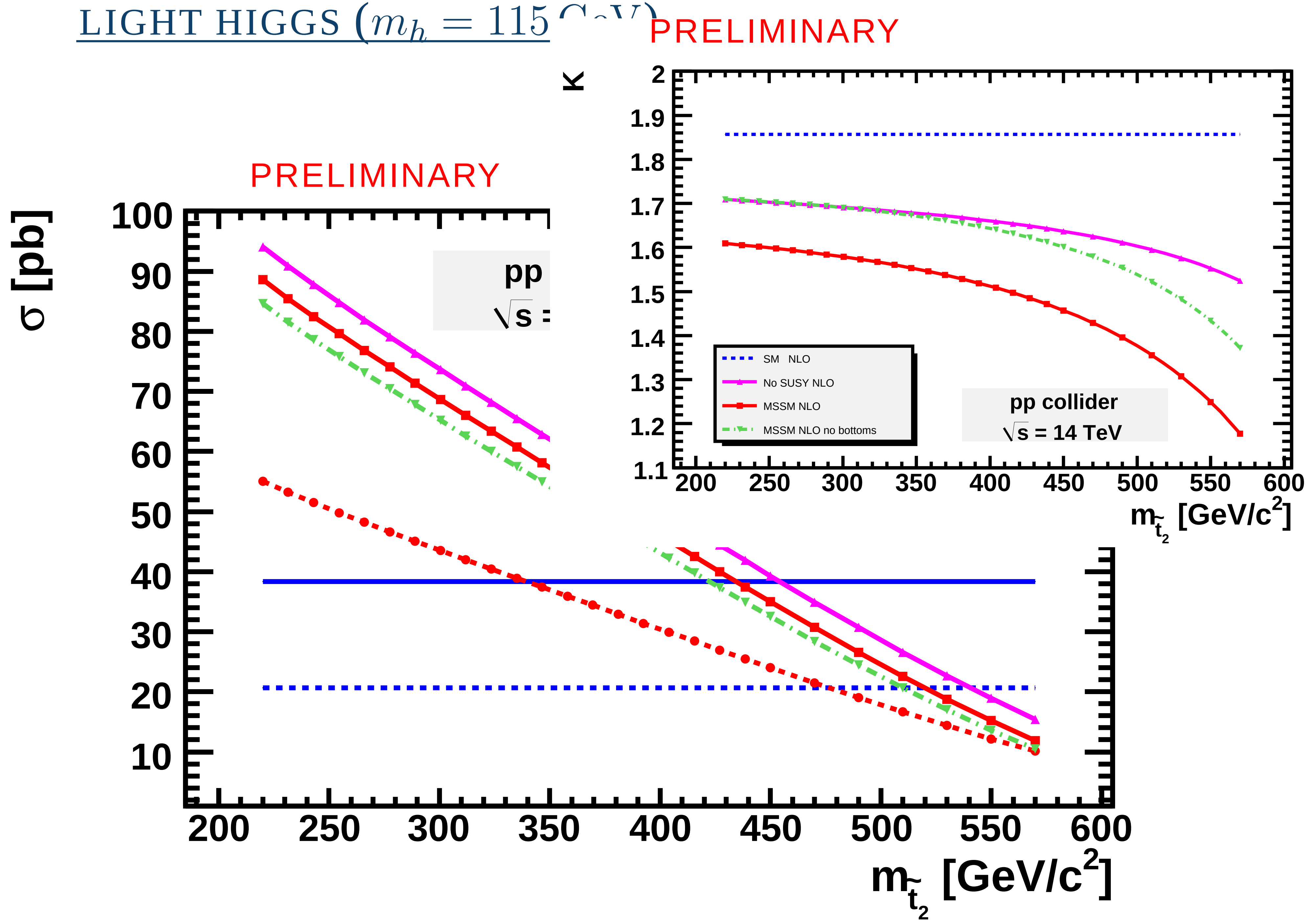
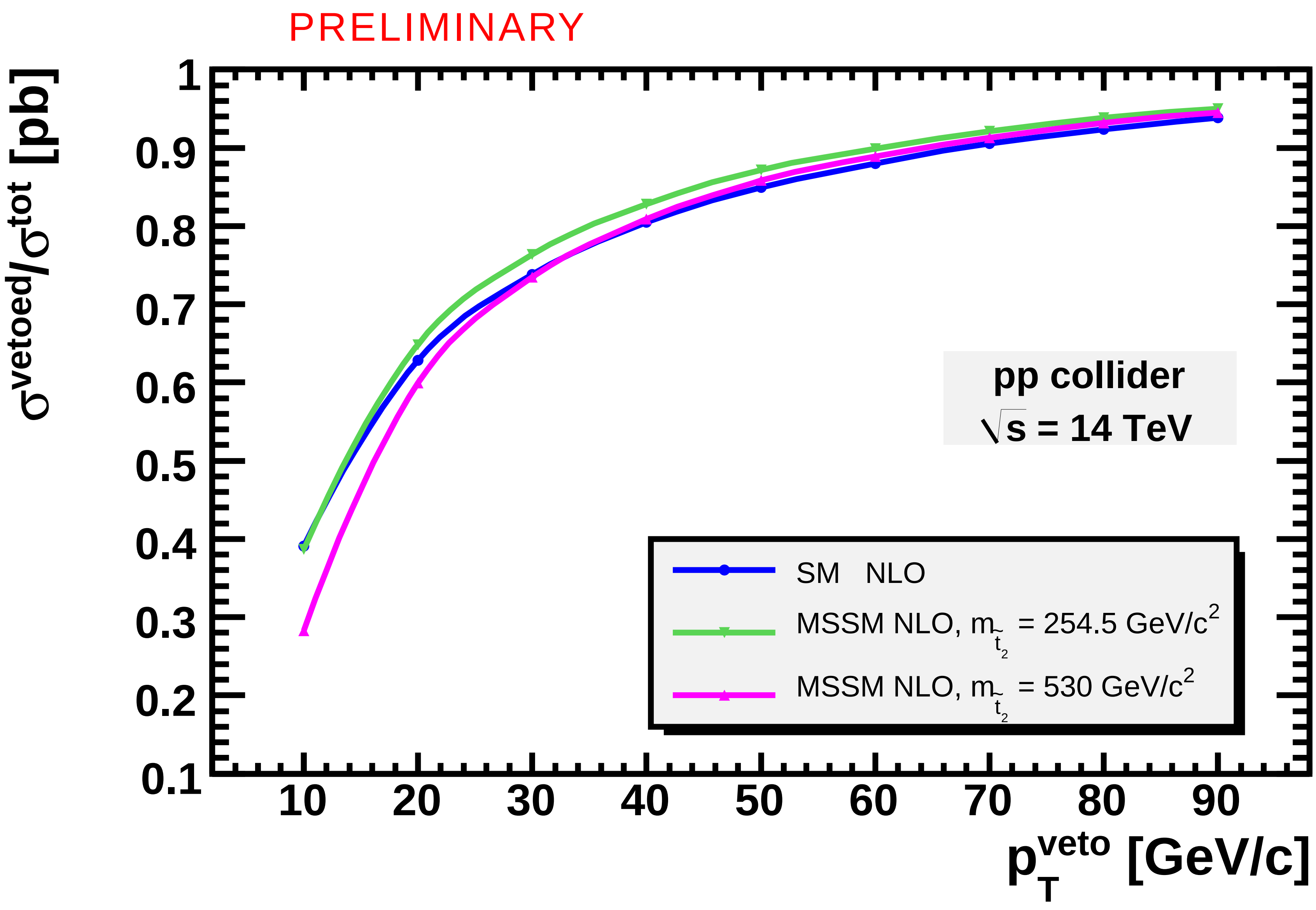
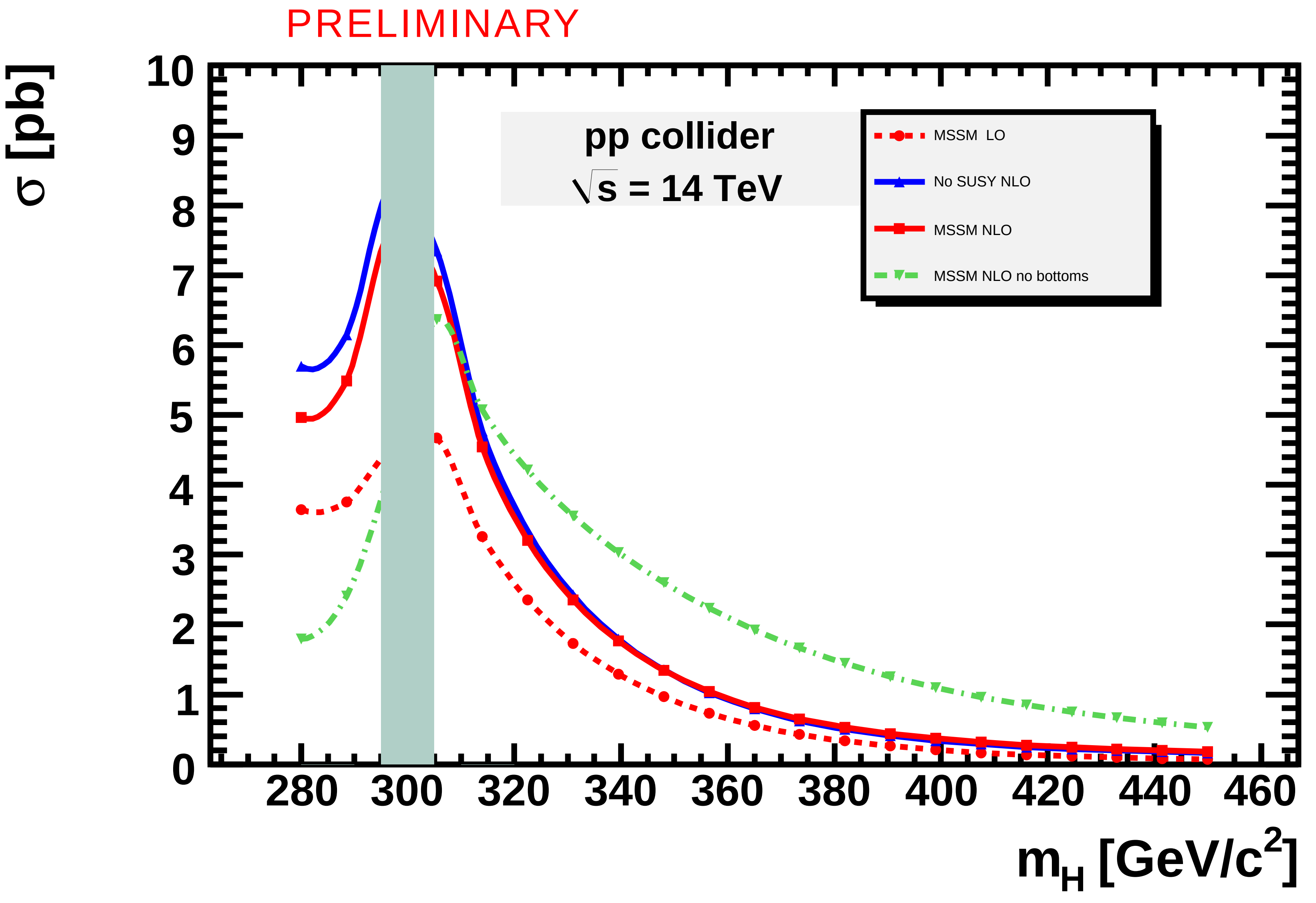


THE EFFECT OF A p_t VETO



HEAVY HIGGS


PRELIMINARY
σ [pb]
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320
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360
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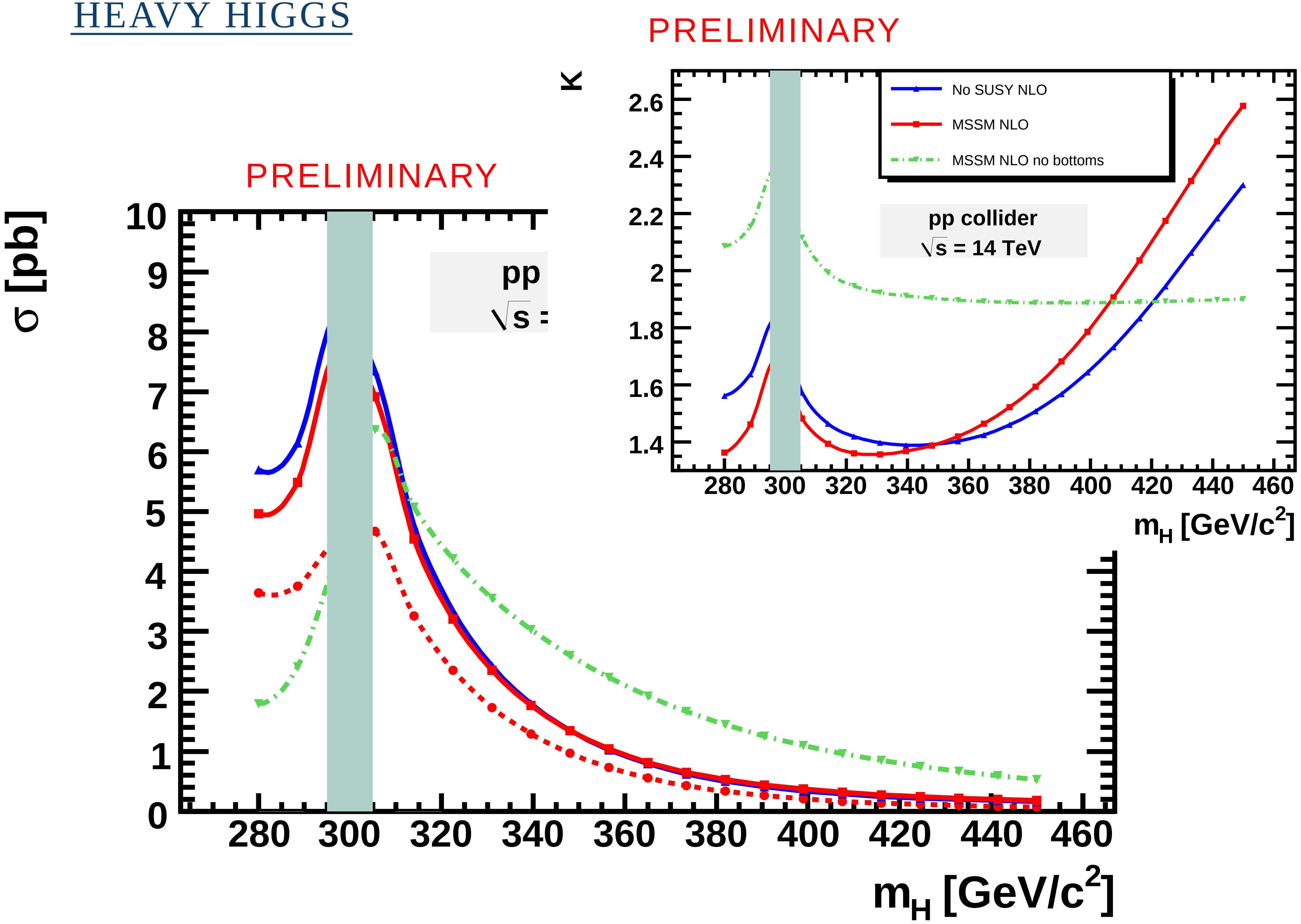
400
420
440
460
m_H [GeV/c^2]
pp collider
√s = 14 TeV
MSSM LO
No SUSY NLO
MSSM NLO
MSSM NLO no bottoms

HEAVY HIGGS



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No SUSY NLO
MSSM NLO
MSSM NLO no bottoms
pp collider
√s = 14 TeV
m_H [GeV/c^2]

SUMMARY

COMPLETE CALCULATION FOR HIGGS PRODUCTION IN GLUON FUSION IN MSSM AT NLO

- FULL SUSY-QCD CORRECTIONS AT $\mathcal{O}(\alpha_s^3)$
- INCLUDES TOP AND BOTTOM CONTRIBUTIONS
- LIGHT AND HEAVY NEUTRAL HIGGSES

TODAY:

- A NEW METHOD TO COMPUTE LOOP INTEGRALS INVOLVING SEVERAL SCALES AND IR SINGULARITIES
  - GREAT POTENTIAL FOR MULTILOOP CALCULATIONS
- DRED AND EVANESCENT COUPLINGS
  - NEW EXAMPLE IN WHICH ε-SCALARS PLAY AN IMPORTANT ROLE
- THE RESULTS
  - STUDIED AN APPEALING (FROM THE MODEL BUILDER'S PERSPECTIVE) SCENARIO
  - INCLUDE ALL SUSY-QCD CORRECTIONS FOR LIGHT AND HEAVY HIGGSES, AS WELL AS THE EFFECT OF LIGHTER QUARKS (BOTTOMS)
  - BOTH SUSY AND BOTTOM SECTORS GIVE $\sim 20\%$ CORRECTIONS
  - FINDING THE HIGGS, IF AN MSSM ONE, CAN PROBE TO BE VERY HARD!

Additional slides

A (LONG) DETOUR: THE RÔLE OF REGULARIZATION SCHEMES

SUSY AND DREG DO NOT GET ALONG VERY WELL $\longrightarrow$ DRED IS THE DEFAULT SCHEME FOR MSSM

HOWEVER (WITH DESPAIR) WE FOUND

$$\mathcal{M}^0_{\text{VIRTUAL}} = \epsilon^a_\mu(p_1)\,\epsilon^b_\nu(p_2)\,\frac{\delta_{ab}}{v}\left(g^{\mu\nu} - \frac{p_2^\mu\,p_1^\nu}{p_1\cdot p_2}\right) C_1$$

$$C_1^{\text{DREG}} - C_1^{\text{DRED}} = \left(\frac{\alpha_s}{2\,\pi}\right)^2 N_C\,T_F\,\frac{1}{s}\sum_q m_q^2\left(4\,h_f(q) - \sum_{i=1,2} h_s(q,i,i)\right)$$

SOMETHING FISHY HERE...

- RESULTS DISAGREE IN THE SM WHERE DREG IS CERTAINLY CORRECT!!

- WITHOUT SUSY RELATING h_f AND h_s, DIFFERENCE IS ARBITRARY

- IN THE MSSM, THE DIFFERENCE ONLY VANISHES WHEN CONSIDERING COMPLETE $SU(2)$ DOUBLETS (I.E. TOPS AND BOTTOMS):

$$m_q^2\left(4\,h_f(q) - \sum_{i=1,2} h_s(q,i,i)\right) = \begin{cases} m_Z^2\,\sin(\alpha+\beta) & q=t \\ -m_Z^2\,\sin(\alpha+\beta) & q=b \end{cases}$$

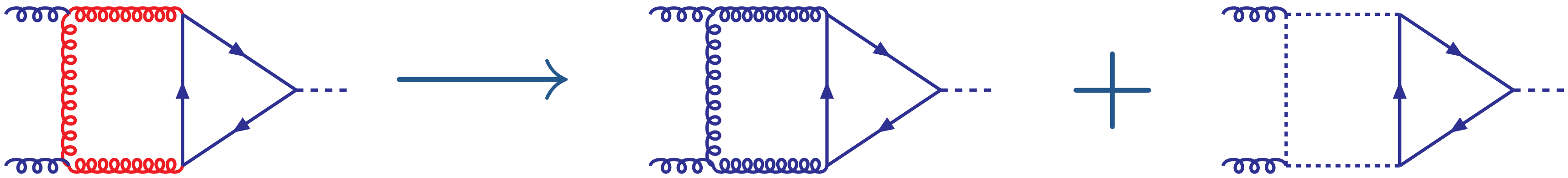
D TERMS IN THE SUPERPOTENTIAL

WHERE DOES IT COME FROM?? WHAT DO WE DO WITH IT??!!

A (LONG) DETOUR: THE RÔLE OF REGULARIZATION SCHEMES

ORIGIN OF THE MISMATCH IS OBVIOUS:

INTERNAL GLUONS ARE 4-DIMENSIONAL IN DRED BUT d-DIMENSIONAL IN DREG



AND THE $4-d$ COMPONENTS OF THE GLUON ARE VERY PECULIAR:

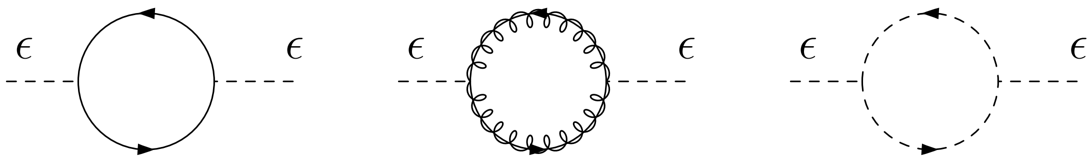
- SPACETIME IS $d = 4 - 2\epsilon < 4$ DIMENSIONAL
- GLUONS SPLIT INTO
  - PHYSICAL d DIMENSIONAL GLUONS $G^a_\mu(x)$
  - ϵ COMPONENTS $G^a_i(x) \equiv \varepsilon^a_i(x)$
- $\varepsilon^a_i(x)$ BEHAVE AS SCALARS UNDER LORENTZ TRANSFORMATIONS AND
- AS SCALARS IN THE ADJOINT REPRESENTATION UNDER COLOR ONES

THEY DON'T BEHAVE AS NORMAL COMPONENTS OF A GAUGE FIELD AND

THEY AREN'T PROTECTED BY GAUGE SYMMETRIES!!

Evanescent couplings in DRED

Without the protection of gauge symmetry, all kind of nasty things happen at one loop:



$$\delta m_\varepsilon^2 = -\frac{\alpha_s}{4\pi}\frac{1}{\epsilon}\left\{T_F\sum_q\left(4\,m_q^2 - 2\sum_{i=1,2} m_{\tilde{q}_i}^2 \qquad\right) + N_C\,\left(\qquad 2\,m_{\tilde{g}}^2\right)\right\}$$

A mass for the ε-scalars is generated radiatively...
actually it even requires renormalization at one-loop

In absence of SUSY, also a-priori identical couplings become independent

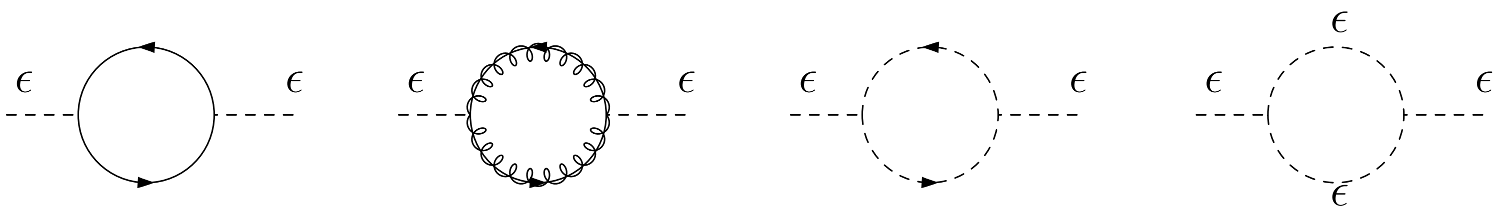
$$g\,\bar{\psi}\,\gamma_\mu\,T_a\,\psi\,G_a^\mu \qquad g_\varepsilon\bar{\psi}\,\gamma_i\,T_a\,\psi\,\varepsilon_a^i \qquad g \neq g_\varepsilon \text{ at one loop}$$

and new “gauge” couplings are allowed

$$H^{abcd}\,\varepsilon_a\cdot\varepsilon_b\,\varepsilon_c\cdot\varepsilon_d$$

EVANESCENT COUPLINGS IN DRED

WITHOUT THE PROTECTION OF GAUGE SYMMETRY, ALL KIND OF NASTY THINGS HAPPEN AT ONE LOOP:



$$\delta m_\varepsilon^2 = -\frac{\alpha_s}{4\,\pi}\,\frac{1}{\epsilon}\,\left\{T_F\sum_q\left(4\,m_q^2-2\sum_{i=1,2}m_{\tilde{q}_i}^2-2\,m_\varepsilon^2\right)+N_C\,\left(3\,m_\varepsilon^2+2\,m_{\tilde{g}}^2\right)\right\}$$

A MASS FOR THE ε-SCALARS IS GENERATED RADIATIVELY...
ACTUALLY IT EVEN REQUIRES RENORMALIZATION AT ONE-LOOP

IN ABSENCE OF SUSY, ALSO A-PRIORI IDENTICAL COUPLINGS BECOME INDEPENDENT

$$g\,\bar{\psi}\,\gamma_\mu\,T_a\,\psi\,G_a^\mu \qquad g_\varepsilon\bar{\psi}\,\gamma_i\,T_a\,\psi\,\varepsilon_a^i \qquad g\neq g_\varepsilon$$ AT ONE LOOP

AND NEW “GAUGE” COUPLINGS ARE ALLOWED

$$H^{abcd}\,\varepsilon_a\cdot\varepsilon_b\,\varepsilon_c\cdot\varepsilon_d$$

Evanescent couplings in DRED

How seriously do we have to take evanescent couplings?

A naive approach would be to “forget” about operators involving ε-scalars

But this leads to very unpleasant consequences:

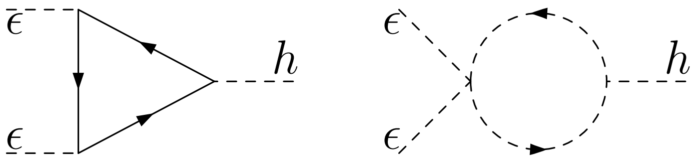
- Breakdown of unitarity (van Damme and ’t Hooft, 1985)
- Loose equivalence between DREG and DRED (Jack, Jones and Roberts, 1994; Jack and Jones, 1994)
- Breakdown of factorization (Signer and Stockinger, 2006)
- Non consistent results for RGE and decoupling relations (Harlander et al., 2006, 2007)

So we should better learn to live with them!!

In general, all operators allowed by the symmetries of the Lagrangian will be generated radiatively and might require renormalization

Evanescent couplings in DRED

Let's look at $\epsilon\epsilon \longrightarrow h$ ($\epsilon\epsilon \longrightarrow hh$ yields similar results):



$$\frac{\alpha_s}{2\,\pi}\,\frac{1}{\epsilon}\,\frac{1}{v}\,\left\{T_F\sum_q m_q^2\left(4\,h_f(q)-\sum_{s=1}^{2}h_s(q,s,s)\right)\right.\qquad\qquad\left.\right\}$$

However here we have to be more careful than before,
SU(2) symmetry requires

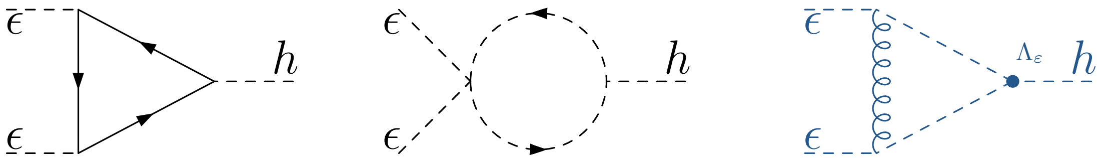
$$\lambda_\epsilon\,\epsilon\cdot\epsilon\,|\mathcal{H}|^2 \longrightarrow \lambda_\epsilon\,v\,\epsilon\cdot\epsilon\,h = \Lambda_\epsilon\,\epsilon\cdot\epsilon\,h$$

But this operator would break SUSY in a non-soft way!!!
Actually, if SUSY is only softly broken, there's no issue at all:

$$\sum_{q=t,b} m_q^2\left(4\,h_f(q)-\sum_{s=1}^{2}h_s(q,s,s)\right)=0$$

EVANESCENT COUPLINGS IN DRED

LET'S LOOK AT $\epsilon\epsilon \longrightarrow h$ ($\epsilon\epsilon \longrightarrow hh$ YIELDS SIMILAR RESULTS):



$$\delta\Lambda_\varepsilon = \frac{\alpha_s}{2\,\pi}\,\frac{1}{\epsilon}\,\frac{1}{v}\,\left\{T_F\,\sum_q m_q^2\,\left(4\,h_f(q) - \sum_{s=1}^{2} h_s(q,s,s)\right) - \left(\frac{3}{2}\,N_C - T_F\right)\,v\,\Lambda_\varepsilon\right\}$$

HOWEVER HERE WE HAVE TO BE MORE CAREFUL THAN BEFORE,
SU(2) SYMMETRY REQUIRES

$$\lambda_\epsilon\,\epsilon\cdot\epsilon\,|\mathcal{H}|^2 \longrightarrow \lambda_\epsilon\,v\,\epsilon\cdot\epsilon\,h = \Lambda_\epsilon\,\epsilon\cdot\epsilon\,h$$

ON THE OTHER HAND, IF

- SUSY IS ABSENT (QCD!!), OR
- WE NEGLECT THE BOTTOM QUARKS (AND THUS SU(2) INVARIANCE)

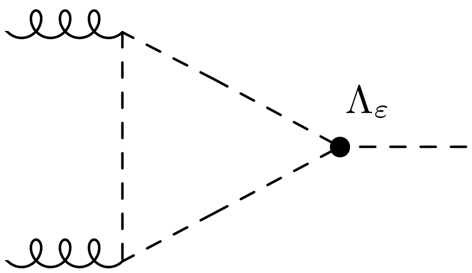
THE HIGGS–ϵ-SCALAR COUPLING IS LEGIT AND CRUCIAL!

Evanescent couplings in DRED

Back to our problem (let's forget about SUSY and SU(2) for a minute):

$$C_1^{\mathrm{DREG}} - C_1^{\mathrm{DRED}} = \left(\frac{\alpha_s}{2\,\pi}\right)^2 N_C\,T_F\,\frac{1}{s}\sum_q m_q^2\left(4\,h_f(q) - \sum_{i=1,2} h_s(q,i,i)\right)$$

But the evanescent Higgs–ϵ-scalar coupling enters the game:



$$\longrightarrow\; C_1^{\Lambda} = \frac{\alpha_s}{2\pi}\,N_C\,\frac{\Lambda_\varepsilon\,v}{s}\,\epsilon$$

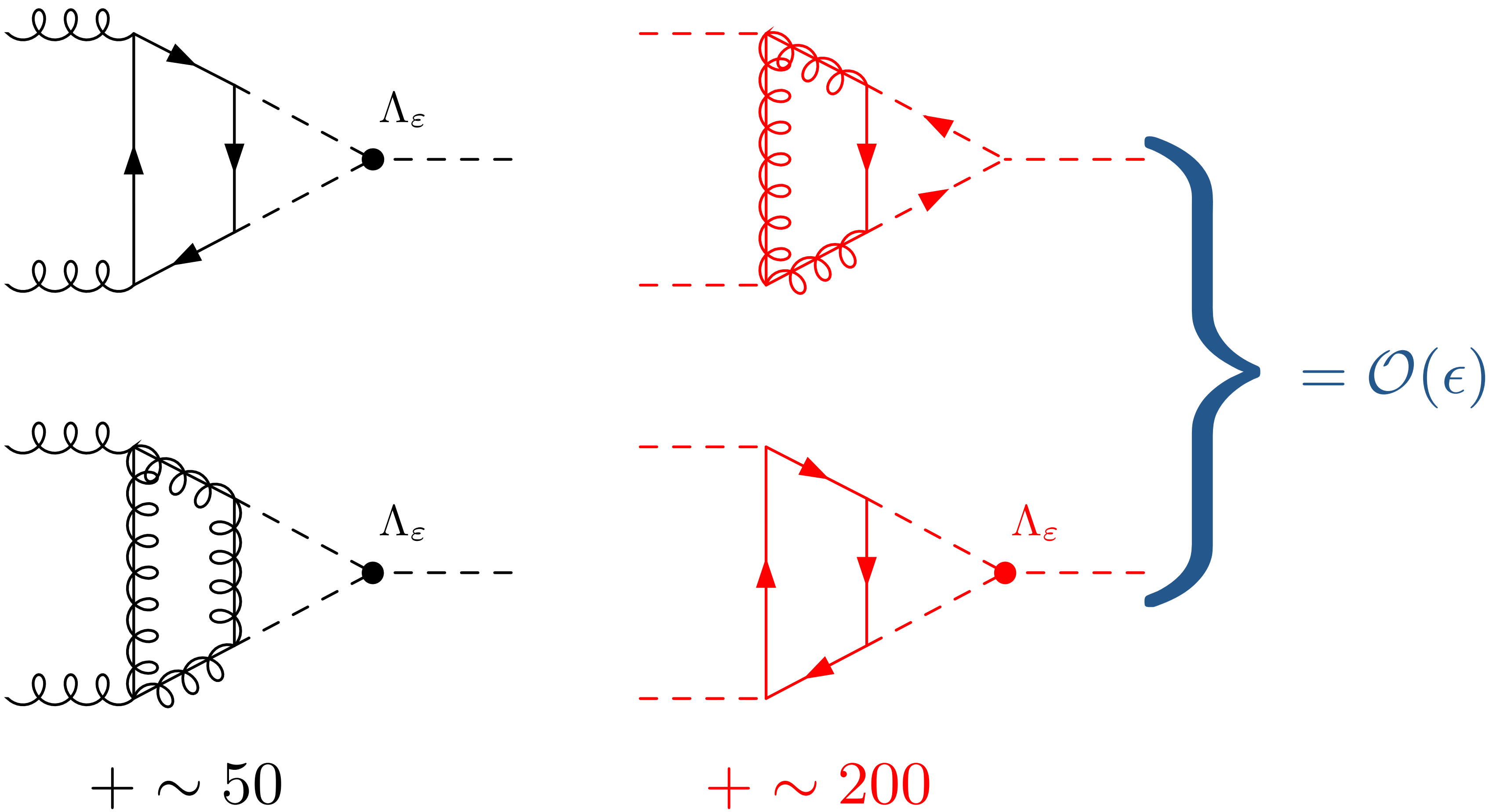
And after renormalization we get an additional contribution in DRED:

$$C_1^{\Lambda,r} = \left(\frac{\alpha_s}{2\,\pi}\right)^2 N_C\,T_F\,\frac{1}{s}\sum_q m_q^2\left(4\,h_f(q) - \sum_{i=1,2} h_s(q,i,i)\right)$$

DRED and DRED yield identical results!

EVANESCENT COUPLINGS IN DRED

WE GOT WHAT WE WANTED. . . BUT WHO ORDERED THESE?



RECAP

- HIGGS–ε-SCALAR COUPLING REQUIRED WHENEVER SUSY OR SU(2) ARE ABSENT
- NOTABLY THE CASE OF THE SM!
- NOT PRESENT IN THE MSSM
- HOWEVER THEY WILL POP OUT WHEN NEGLECTING TERMS (LIKE BOTTOM-HIGGS COUPLINGS) IN THE LAGRANGIAN
- HUNDREDS OF NEW (UNDESIRED) DIAGRAMS TO CHECK...