Automated NLO QCD+EW corrections and the complex-mass scheme

within MG5_aMC

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Outline

- **NLO QCD+EW automating with MG5_aMC**
  - Our **approach** to this problem
  - Some results and **sub-leading NLO EW** contributions

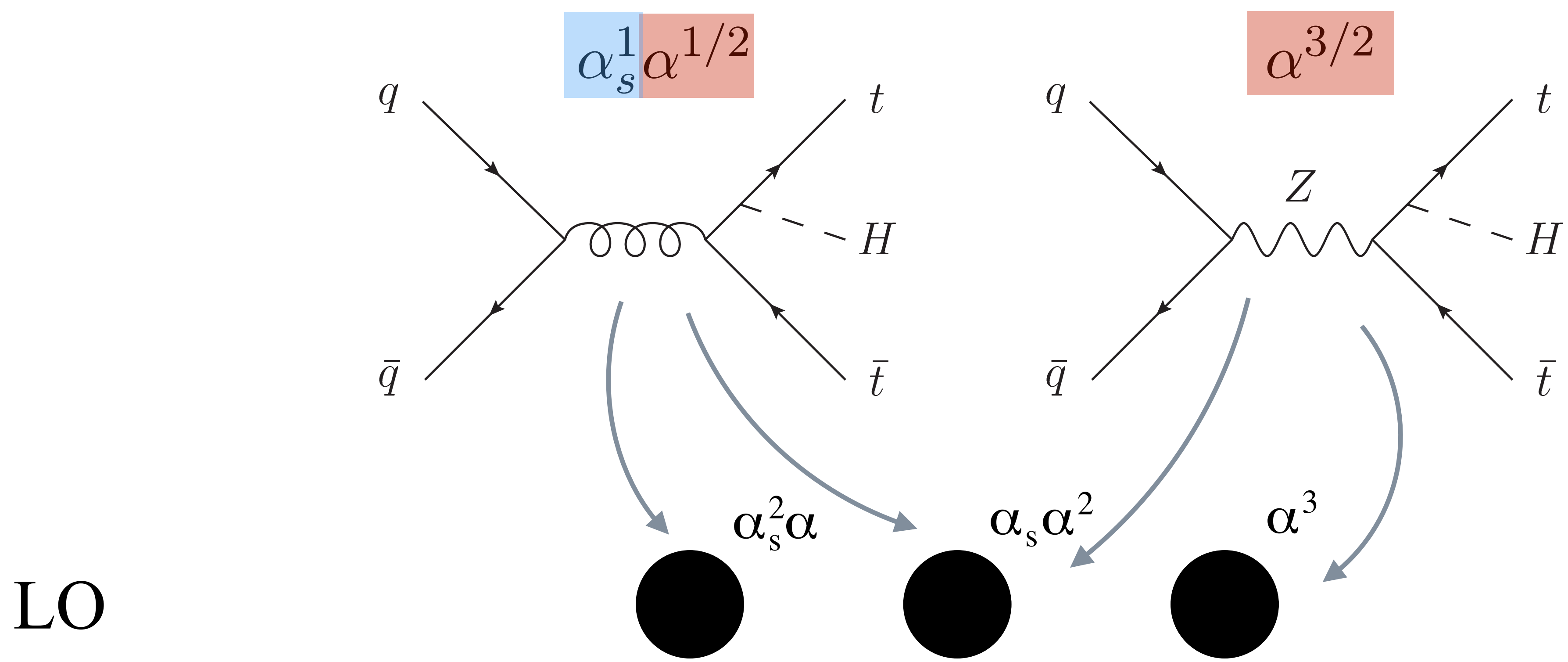
- **Subtleties in the complex-mass (CM) scheme**
  - Underlying **principles** of the CM renormalisation scheme
  - **Analytic continuation** of the two-point function
  - Implication of setting $|\alpha|$
  - Mixed scheme: **CM +On-Shell (OS)** renormalisation

Mixed NLO QCD+EW
with
MG5_aMC v3.0 beta

[Frederix, Frixione, VH, Pagani, Shao '18]

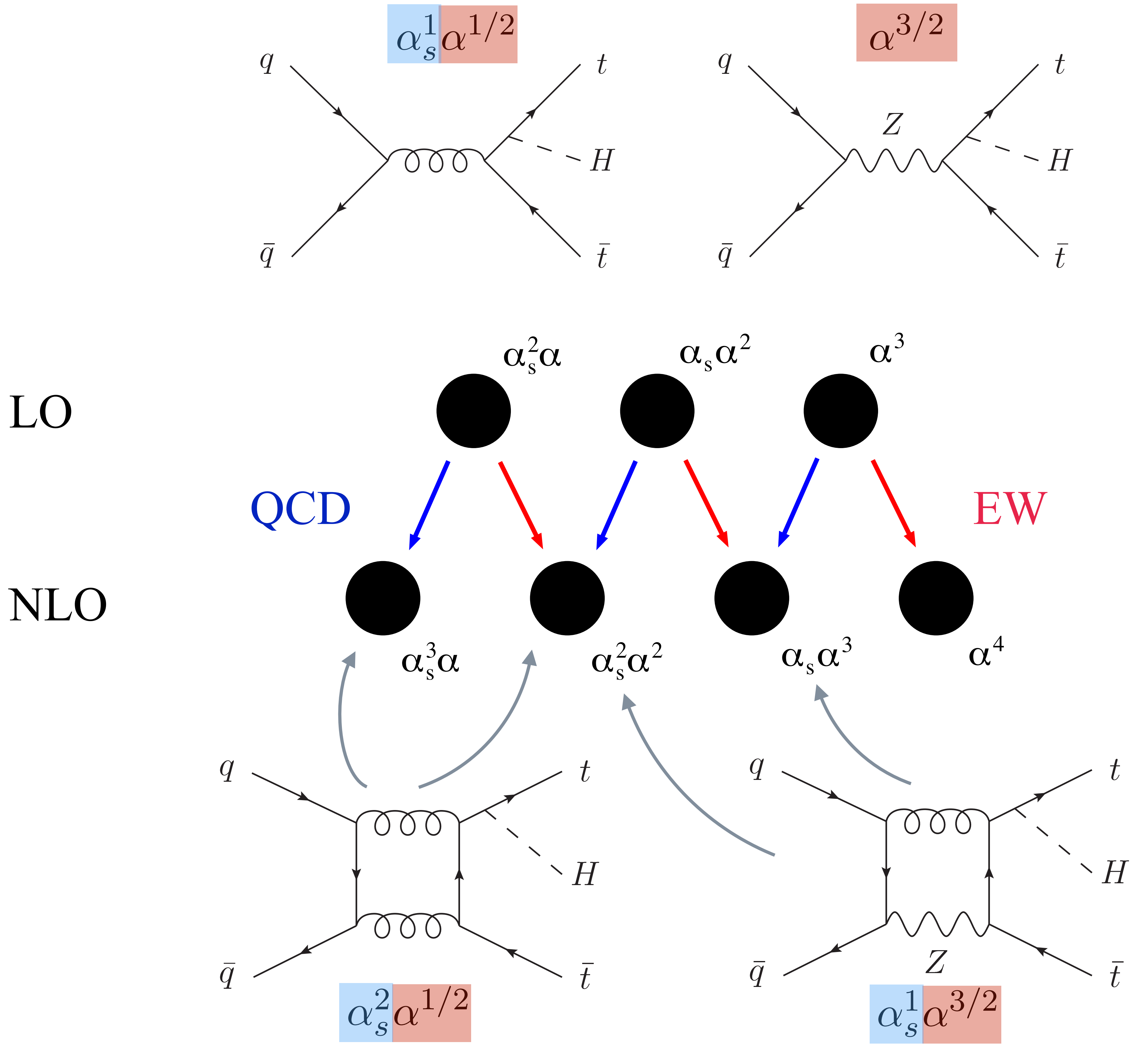
General structure of NLO EW-QCD

The ttH case: [Frixione, VH, Pagani, Shao, Zaro, '15]



Structure of NLO EW-QCD corrections

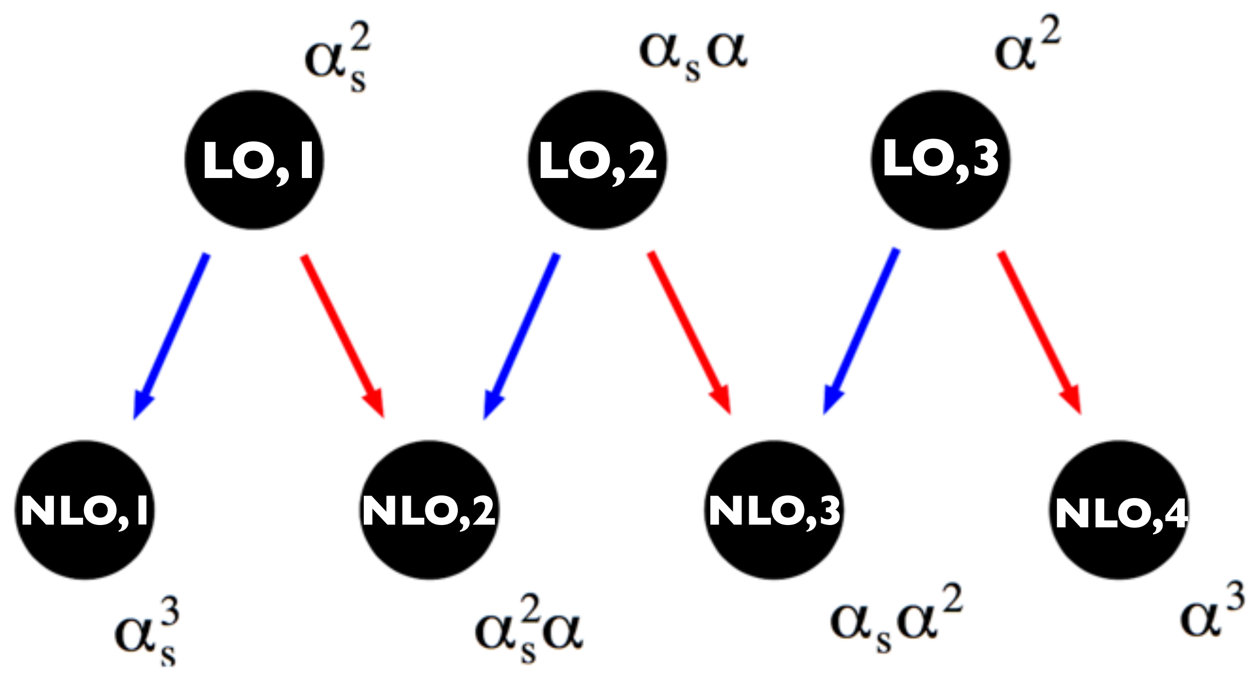
The ttH case: S.Frixione, V.Hirschi, D. Pagani, H.-S. Shao, M. Zaro [arXiv:1504.03446]



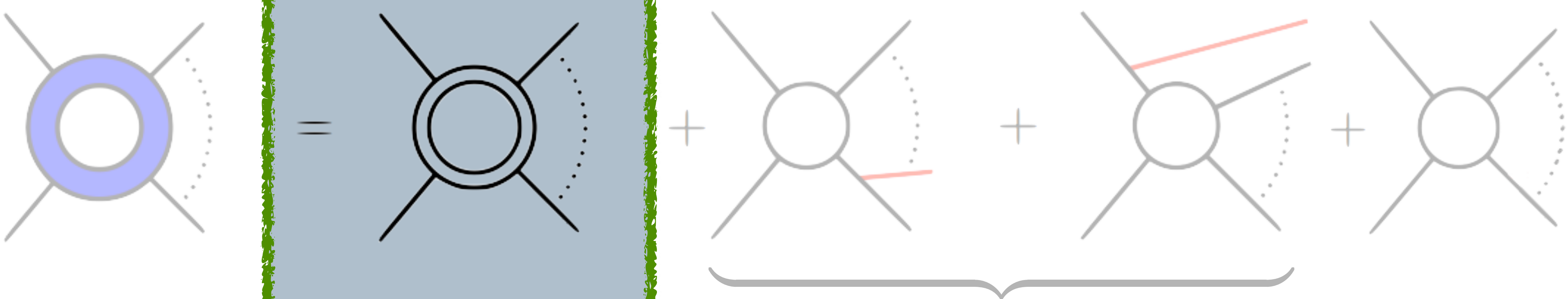
Notation for an observable Σ

$$
\begin{aligned}
\Sigma^{(\mathrm{LO})}(\alpha_S,\alpha) &= \alpha_S^2\,\Sigma_{2,0} + \alpha_S\alpha\,\Sigma_{2,1} + \alpha^2\,\Sigma_{2,2} \\
&\equiv \Sigma_{\mathrm{LO},1} + \Sigma_{\mathrm{LO},2} + \Sigma_{\mathrm{LO},3} \\
\Sigma^{(\mathrm{NLO})}(\alpha_S,\alpha) &= \alpha_S^3\,\Sigma_{3,0} + \alpha_S^2\alpha\,\Sigma_{3,1} + \alpha_S\alpha^2\,\Sigma_{3,2} + \alpha^3\,\Sigma_{3,3} \\
&\equiv \Sigma_{\mathrm{NLO},1} + \Sigma_{\mathrm{NLO},2} + \Sigma_{\mathrm{NLO},3} + \Sigma_{\mathrm{NLO},4}
\end{aligned}
$$

Usually, $\Sigma_{\mathrm{NLO},1}$=NLO QCD, $\Sigma_{\mathrm{NLO},2}$=NLO EW (weak+QED)



MadLoop @ EW loops



$$\sigma^{\text{NLO}} = \int_m d^{(d)}\sigma^V + \int_{m+1} d^{(d)}\sigma^R + \int_m d^{(4)}\sigma^B$$

Virtual part | Real emission part | Born

MadLoop | MadFKS | Solved

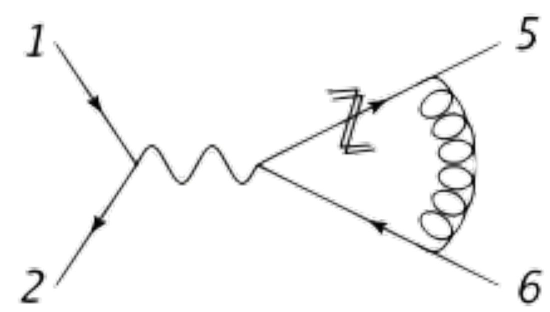
- Hand-written dedicated **UFO Model** for **QCD+EW** corrections
- G_μ and $\alpha(M_Z^2)$ **renormalization scheme,** not $\alpha(0)$
- **Complex mass scheme** for handling unstable particle
- Work within the **Feynman gauge**, yielding **polynomial** numerators

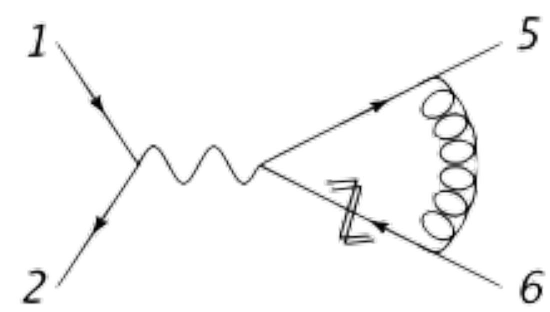
MadLoop @ EW loops

- No external tool for loop diagram generation:
  Reuse MG5_aMC efficient tree level diagram generation.

- Cut loops have two extra external particles

Trees ($e^+e^- \rightarrow$ u u~ u u~) $\equiv$ Loops ($e^+e^- \rightarrow$ u u~)

$\equiv$ 

$\equiv$ 

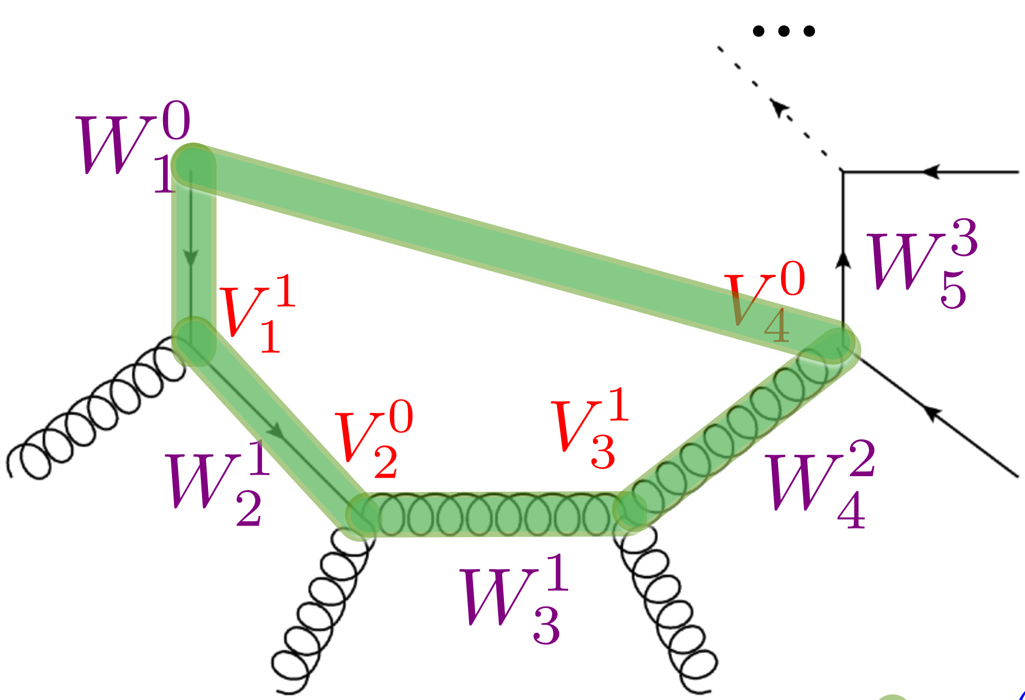
Using open-loops technique

[S. Pozzorini & al. hep-ph/1111.5206]

- Lite-Motive: Be Numerical where you can and analytical where you should.

$$\mathcal{N}(l^\mu) = \sum_{r=0}^{r_{max}} C^{(r)}_{\mu_0\mu_1\cdots\mu_r} l^{\mu_0} l^{\mu_1} \cdots l^{\mu_r}$$

- How to get these coefficients? (Wavefunction and 4-momenta indices now omitted)



$$W_j^{(r)} = \sum_{i=0}^{r} w_j^i l^i \qquad V_j^{(r=0,1)} = \sum_{i=0}^{r} v_j^i l^i$$

$$W_1^{(0)} = w_1^0 = 1$$

$$W_2^{(1)} = (v_1^1 l + v_1^0) w_1^0$$

$$W_3^{(1)} = v_2^0 W_2^{(1)} = v_2^0 (v_1^1 l + v_1^0) w_1^0$$

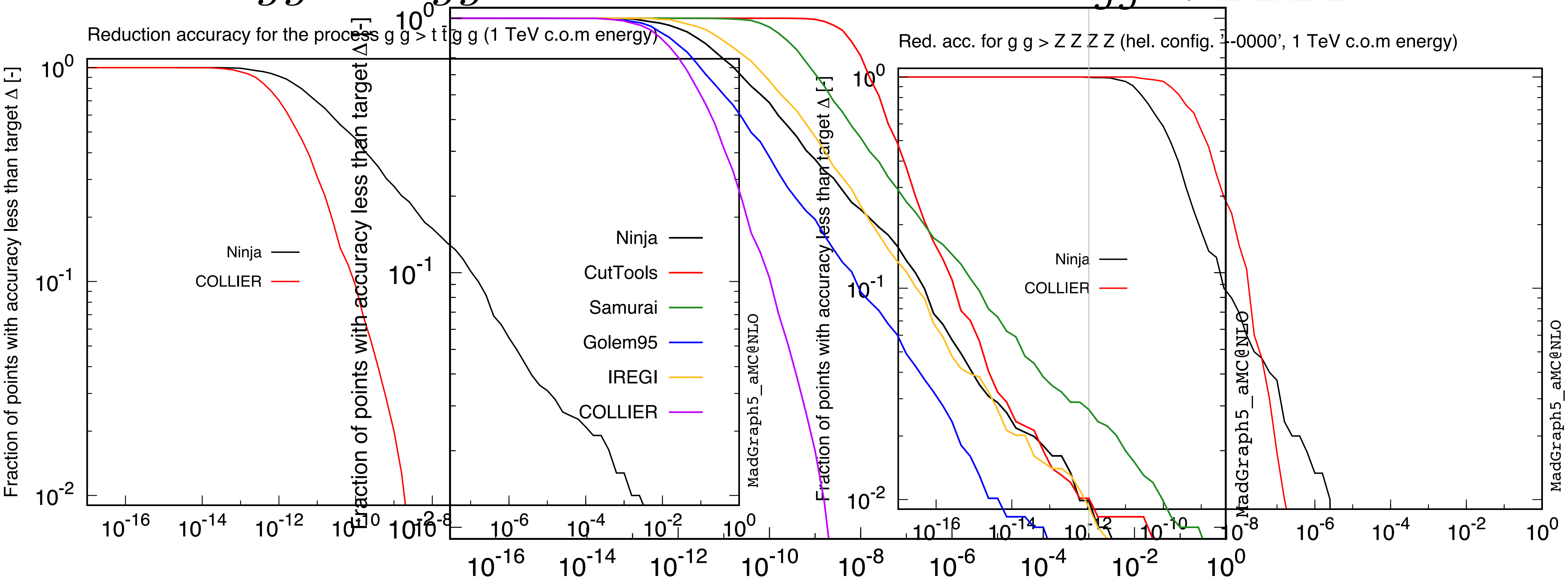
$$W_4^{(1)} = V_3^{(1)} W_2^{(1)} = (v_3^1 l + v_3^0) v_2^0 (v_1^1 l + v_1^0) w_1^0$$

... or end of loop and $C^{(2)} = v_3^1 v_2^0 v_1^1 w_1^0, C^{(1)} = v_2^0 w_1^0 (v_3^1 v_0^1 + v_3^0 v_1^1), C^0 = \cdots$

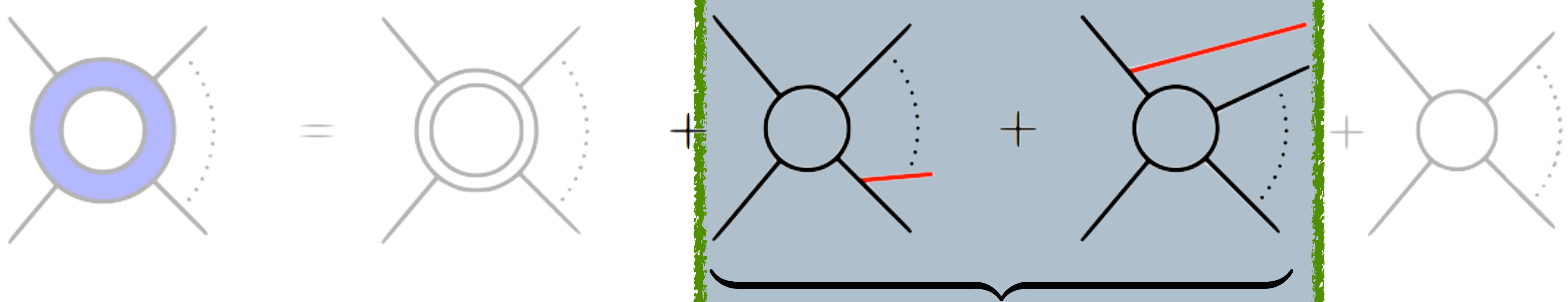
Reduction

- OPP integrand-level:
  - CUTTOOLS G.Ossola, C.G.Papadopoulos, R.Pittau [arXiv:0711.3596]
  - NINJA T.Peraro [arXiv:1403.1229], V.H., T.Peraro [arXiv:1604.01363]
- Tensor Integral Reduction:
  - COLLIER A. Denner, D. Dittmaier, L. Hofer [arXiv:1604.06792]
- Alternatives: IREGI, GOLEM95, PJFRY++, SAMURAI

$gg \to t\bar{t}gg$ $gg \to ZZZZ$



MadFKS: QED subtraction



$$\sigma^{\mathrm{NLO}} = \int_m d^{(d)}\sigma^V + \int_{m+1} d^{(d)}\sigma^R + \int_m d^{(4)}\sigma^B$$

Virtual part — Real emission part — Born

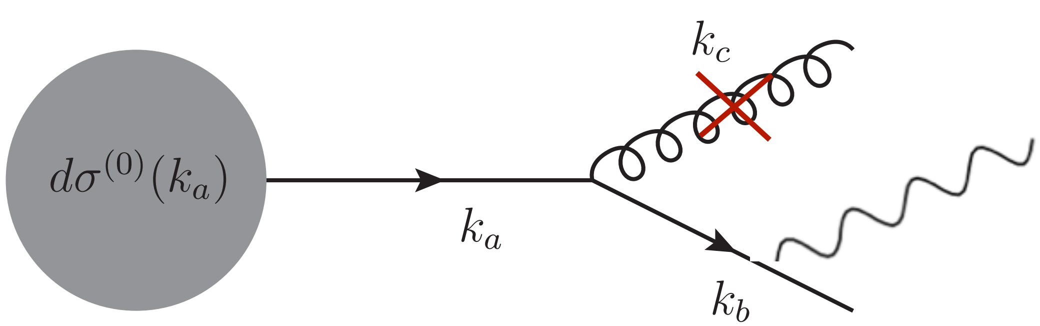
MadLoop — MadFKS — Solved

Full NLO EW-QCD corrections

[Frederix, Frixione, VH, Pagani, Shao '18]

- Improved **MadFKS** to subtract **QED singularities**

Isn't that just a **trivial modification** of the **counterterms**?



$$k_b = z k_a + k_T + \beta_b \hat{n}$$

$$k_c = (1-z) k_a - k_T + \beta_c \hat{n}$$

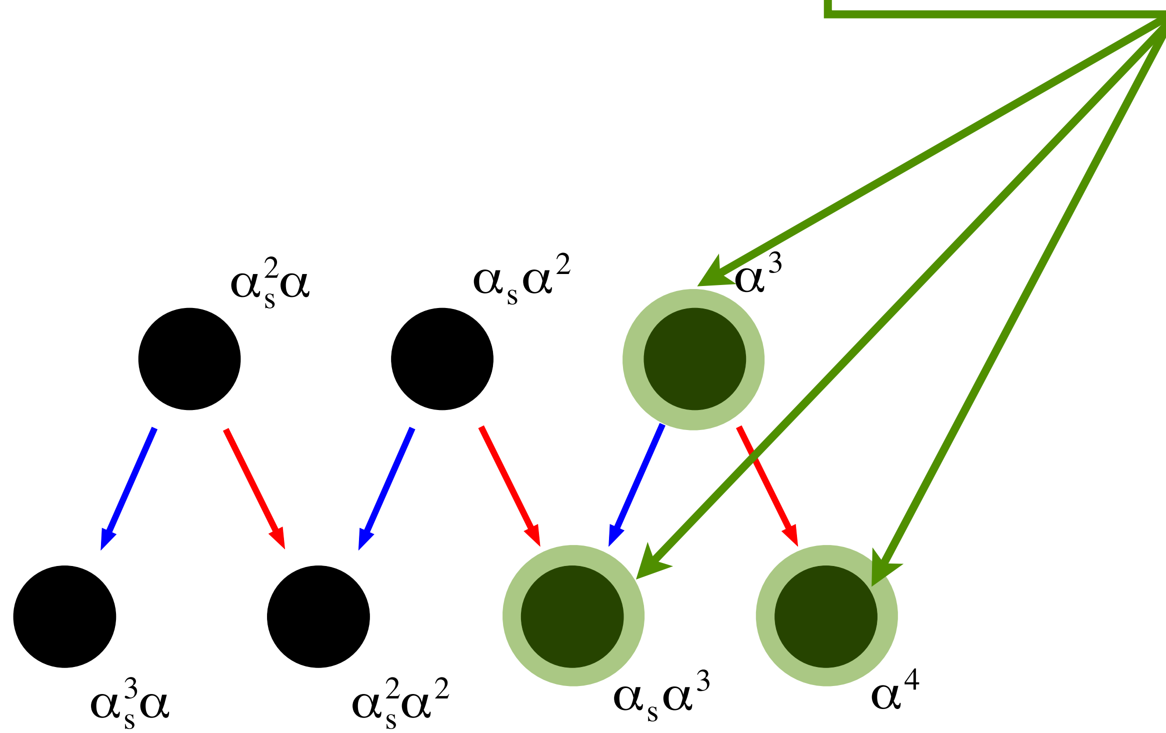
$$d\sigma^{(1,R)} = \frac{\overset{\alpha}{\cancel{\alpha_s}}}{2\pi} \int dk_T^2 \int_0^1 dz \, \overset{Q_f}{\cancel{C_F}} \frac{1+z^2}{1-z} \frac{1}{k_T^2} d\sigma^{(0)}(k_a) + \mathcal{R}$$

For ttH/V **mostly yes**... but jets complicate things

Full NLO EW-QCD corrections

S.Frixione, V.H, D. Pagani, H.-S. Shao, M. Zaro [arXiv:1504.03446]

- We can **compute all NLO contribs**, incl. **subleading corrections**

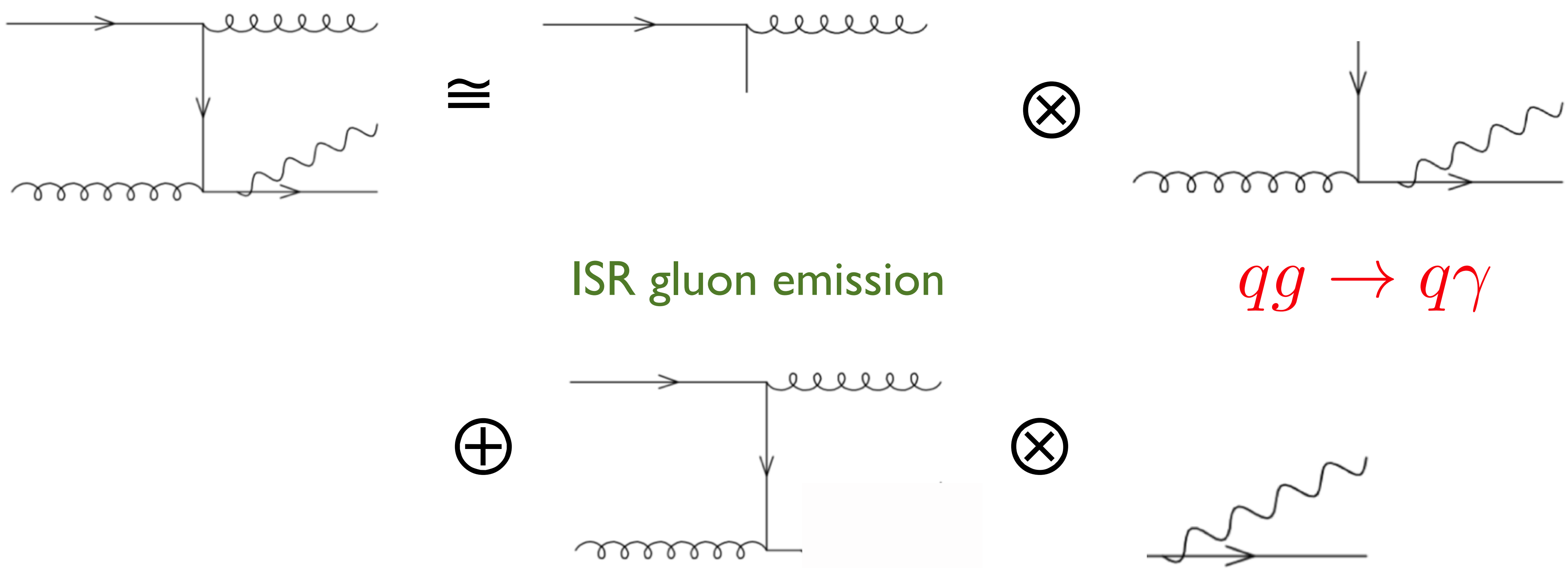


- Attack **dijet** so as to address most **remaining difficulties at once**

ALL DIJET NLO EW-QCD CORRECTIONS

S.Frixione, V.H, D. Pagani, H.-S. Shao, M. Zaro [arXiv:1504.03446]

- QCD still requires soft/collinear gluon limit to be regular



ISR gluon emission

$qg \to q\gamma$

$qg \to qg$

FSR photon emission

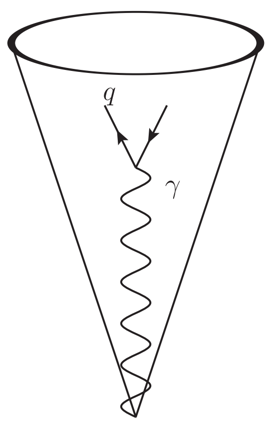
- More book-keeping → requires full automation
- Must include both gluons and photons in jets → democratic jet clustering
- Need to define hadronic jet→ requires IR-safe definition of photon jets

All NLO EW-QCD corrections

S.Frixione, V.H, D. Pagani, H.-S. Shao, M. Zaro [arXiv:1504.03446]

- Issues with democratic jets:
  Experimentalist typically do not consider photon-jets as jets

Solution: cluster democratically, but discard jets where $E_\gamma > z_{cut} E_{jet}$



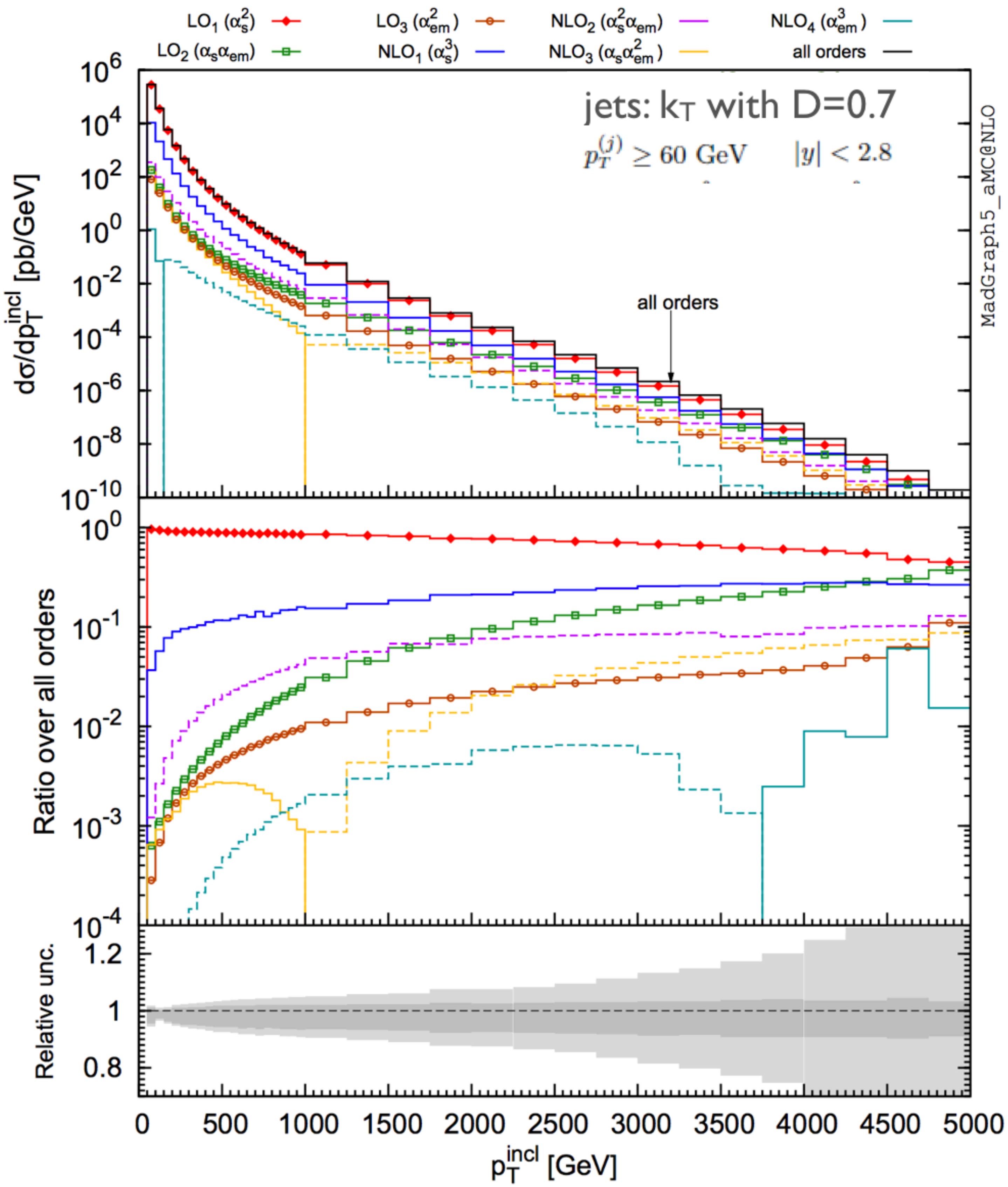
However: E_γ is not a well-defined quantity in pQED $(\gamma \to q\bar{q})$

This is a problem only at $\Sigma_{\mathrm{NLO},3}$ and beyond (at least two EW couplings are needed): in principle it can be ignored at NLO EW.

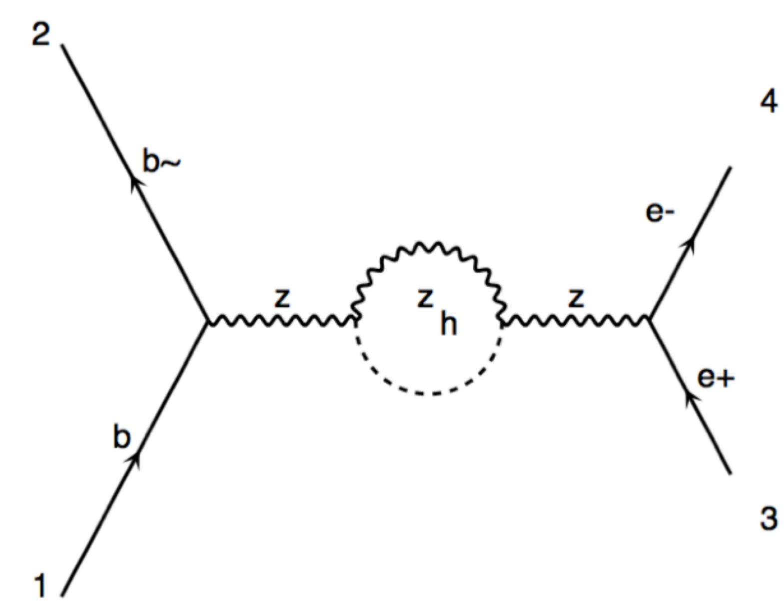
[When not using the $\alpha(0)$ scheme, the use of **fragmentation functions** to **define taggable short-distance** photon offers a general solution.]

COMPLETE DIJET QCD+EW NLO CORRECTIONS

R. Frederix, S. Frixione, V. H., D. Pagani, H-S.Shao, M.Zaro [arXiv:1612.06548]



- All $\mathcal{O}(\alpha_s^m, \alpha^n), m+n=2,3$ contributions to dijet. Use G_μ scheme
- Necessitated large computing resources, 219 subprocesses
- This process involves the whole particle spectrum of the SM. Yes, even the Higgs.



Complete NLO QCD+EW Automation

[Frederix, Frixione, VH, Pagani, Shao '18]

Current syntax (leading terms, i.e. NLO QCD)

```
MG5_aMC> generate a b > c d e f [QCD]
```

Will become (or something similar):

```
MG5_aMC> generate a b > c d e f QCD=n QED=m [QCD QED]
```

in order to include in the computation all the terms that factorise:

$$\begin{array}{lllll} \text{LO} & \alpha_s^k \alpha^p\,, & k \leq n\,, & p \leq m\,, & k+p=b \\ \text{NLO} & \alpha_s^k \alpha^p\,, & k \leq n+1\,, & p \leq m+1\,, & k+p=b+1 \end{array}$$

then

```
MG5_aMC> output
MG5_aMC> launch NLO
```

Complete NLO QCD+EW Automation

[Frederix, Frixione, VH, Pagani, Shao '18]

- **Subleading** EW corrections **can matter.**

	$pp \to t\bar{t}$	$pp \to t\bar{t}Z$	$pp \to t\bar{t}W^+$	$pp \to t\bar{t}H$	$pp \to t\bar{t}j$
LO_1	$4.3803 \pm 0.0005 \cdot 10^2$ pb	$5.0463 \pm 0.0003 \cdot 10^{-1}$ pb	$2.4116 \pm 0.0001 \cdot 10^{-1}$ pb	$3.4483 \pm 0.0003 \cdot 10^{-1}$ pb	$3.0278 \pm 0.0003 \cdot 10^2$ pb
LO_2	$+0.405 \pm 0.001$ %	-0.691 ± 0.001 %	$+0.000 \pm 0.000$ %	$+0.406 \pm 0.001$ %	$+0.525 \pm 0.001$ %
LO_3	$+0.630 \pm 0.001$ %	$+2.259 \pm 0.001$ %	$+0.962 \pm 0.000$ %	$+0.702 \pm 0.001$ %	$+1.208 \pm 0.001$ %
LO_4					$+0.006 \pm 0.000$ %
NLO_1	$+46.164 \pm 0.022$ %	$+44.809 \pm 0.028$ %	$+49.504 \pm 0.015$ %	$+28.847 \pm 0.020$ %	$+26.571 \pm 0.063$ %
NLO_2	-1.075 ± 0.003 %	-0.846 ± 0.004 %	-4.541 ± 0.003 %	$+1.794 \pm 0.005$ %	-1.971 ± 0.022 %
NLO_3	$+0.552 \pm 0.002$ %	$+0.845 \pm 0.003$ %	$+12.242 \pm 0.014$ %	$+0.483 \pm 0.008$ %	$+0.292 \pm 0.007$ %
NLO_4	$+0.005 \pm 0.000$ %	-0.082 ± 0.000 %	$+0.017 \pm 0.003$ %	$+0.044 \pm 0.000$ %	$+0.009 \pm 0.000$ %
NLO_5					$+0.005 \pm 0.000$ %

(Monte-Carlo statistical error reported in the above chart)

Complex mass scheme

A. Denner, S.Dittmaier, M.Roth, L.Wieder [hep-ph/9904472 , hep-ph/0505042]

Complex mass scheme

A. Denner, S.Dittmaier, M.Roth, L.Wieder [hep-ph/9904472 , hep-ph/0505042]

- Complex mass scheme to handle unstable particle resonances

$$i\frac{\not{p}+\bar{M}}{p^2-\bar{M}^2+i\Gamma\bar{M}} \xrightarrow{m_{cms}\equiv\sqrt{\bar{M}^2-i\Gamma\bar{M}}} i\frac{\not{p}+m_{cms}}{p^2-m_{cms}^2}$$

- The CM scheme is a modification of the OS scheme.

$$\Sigma_{\mathrm{R}}(p^2) = \Sigma_{\mathrm{U}}(p^2) - \delta M^2 + \left(p^2 - M^2\right)\delta Z$$

$$\Re\left[\Sigma_{\mathrm{R}}(p^2)\right]\Big|_{p^2=M^2} = 0\,,$$

$$\lim_{p^2\to M^2}\frac{1}{p^2-M^2}\Re\left[\Sigma_{\mathrm{R}}(p^2)\right] = 1\,,$$

$$\Re\left[\Sigma_{\mathrm{R}}(p^2=M^2)\right] = 0 \quad\Longrightarrow\quad \delta M^2 = \Re\left[\Sigma_{\mathrm{U}}(p^2=M^2)\right]$$

$$\Re\left[\Sigma'_{\mathrm{R}}(p^2=M^2)\right] = 0 \quad\Longrightarrow\quad \delta Z = -\Re\left[\Sigma'_{\mathrm{U}}(p^2=M^2)\right]$$

OS scheme

Complex mass scheme

A. Denner, S.Dittmaier, M.Roth, L.Wieder [hep-ph/9904472 , hep-ph/0505042]

$$\bar{M}^2 - i\bar{\Gamma}\bar{M} \equiv m^2 = M_0^2 - \delta m^2$$

$$\Sigma_{\mathrm{R}}(p^2) = \Sigma_{\mathrm{U}}(p^2) - \delta m^2 + \left(p^2 - m^2\right)\delta z$$

$$\Sigma_{\mathrm{R}}(p^2 = \bar{M}^2 - i\bar{\Gamma}\bar{M}) = 0 \quad \Longrightarrow \quad \delta m^2 = \Sigma_{\mathrm{U}}(p^2 = \bar{M}^2 - i\bar{\Gamma}\bar{M})$$

$$\Sigma'_{\mathrm{R}}(p^2 = \bar{M}^2 - i\bar{\Gamma}\bar{M}) = 0 \quad \Longrightarrow \quad \delta z = -\Sigma'_{\mathrm{U}}(p^2 = \bar{M}^2 - i\bar{\Gamma}\bar{M})$$

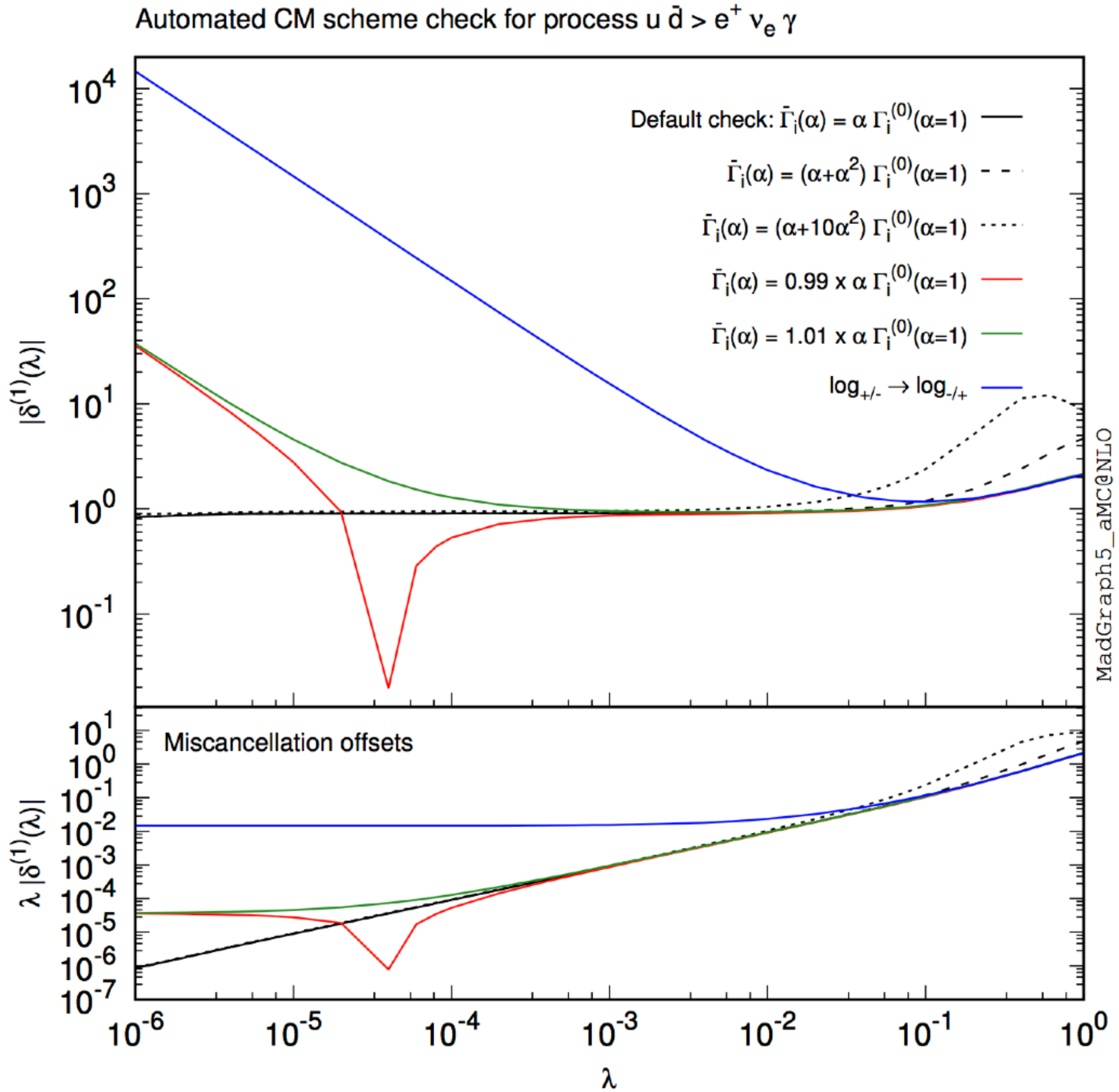
$$\Im[m^2] = -\bar{\Gamma}\bar{M} = -\Im[\delta m^2] = -\Im[\Sigma_{\mathrm{U}}(p^2 = \bar{M}^2 - i\bar{\Gamma}\bar{M})]$$

CM scheme

- The CM scheme re-organises the perturbative expansion:

$$\begin{aligned}
&(m^2 + \delta m^2) - (M^2 + \delta M^2) = \\
&\quad = \left(\bar{M}^2 - i\bar{\Gamma}\bar{M} + \Sigma_{\mathrm{U}}(p^2 = \bar{M}^2 - i\bar{\Gamma}\bar{M})\right) - \left(M^2 + \Re\left[\Sigma_{\mathrm{U}}(p^2 = M^2)\right]\right) = \\
&\quad = \left(\bar{M}^2 - M^2\right) + \left(\Sigma_{\mathrm{U}}(p^2 = \bar{M}^2 - i\bar{\Gamma}\bar{M}) - i\bar{\Gamma}\bar{M} - \Re\left[\Sigma_{\mathrm{U}}(p^2 = M^2)\right]\right) \\
&\quad \overset{\mathrm{NLO}}{=} \mathcal{O}(\alpha^2)\,.
\end{aligned}$$

Testing the complex mass scheme



$$\Delta^{(0)} = \lim_{\lambda\to 0}\left(\left.\frac{\mathcal{M}^{(0)}_{\rm CM}-\mathcal{M}^{(0)}_{\rm ZW}}{\lambda\mathcal{M}^{(0)}_{\rm ZW}}\right|_{\alpha=\lambda\alpha^{\rm ref}}\right) \equiv \lim_{\lambda\to 0}\delta^{(0)}(\lambda)$$

$$\Delta^{(1)} = \lim_{\lambda\to 0}\left(\left.\frac{\mathcal{M}^{(1)}_{\rm CM}+\mathcal{M}^{(0)}_{\rm CM}-\mathcal{M}^{(1)}_{\rm ZW}-\mathcal{M}^{(0)}_{\rm ZW}}{\lambda^2\mathcal{M}^{(0)}_{\rm ZW}}\right|_{\alpha=\lambda\alpha^{\rm ref}}\right) \equiv \lim_{\lambda\to 0}\delta^{(1)}(\lambda)$$

$$\mathcal{M}^{(L)}_{\rm ZW}(\{p_k\}) = \left.\mathcal{M}^{(L)}_{\rm OS}(\{p_k\})\right|_{\{\Gamma_r=0\}}$$

ANALYTIC CONTINUATION OF THE BUBBLE

- Example: $\Sigma^{\gamma W}_{\mathrm{U},T}(\bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W) \supset B_0\left(p^2, 0, \bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W\right)\Big|_{p^2\to\bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W}$
- **Exact result**:

$$\frac{1}{i\pi^2} B_0\left(p^2, 0, \bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W\right)\Big|_{p^2\to\bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W} = \frac{1}{\epsilon} + 2 + \log\frac{\mu^2}{\bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W}$$

- The **Taylor expansion** is not correct in this case:

$$\rightarrow \quad B_0\left(p^2, 0, \bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W\right) = B_0\left(\bar{M}_W^2, 0, \bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W\right) + \left(\frac{p^2 - \bar{M}_W^2}{\bar{M}_W^2}\right) B_0'\left(\bar{M}_W^2, 0, \bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W\right) + \mathcal{O}\left(\left(\frac{p^2 - \bar{M}_W^2}{\bar{M}_W^2}\right)^2\right)$$

Taylor lead to ($p^2 \to \bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W$):

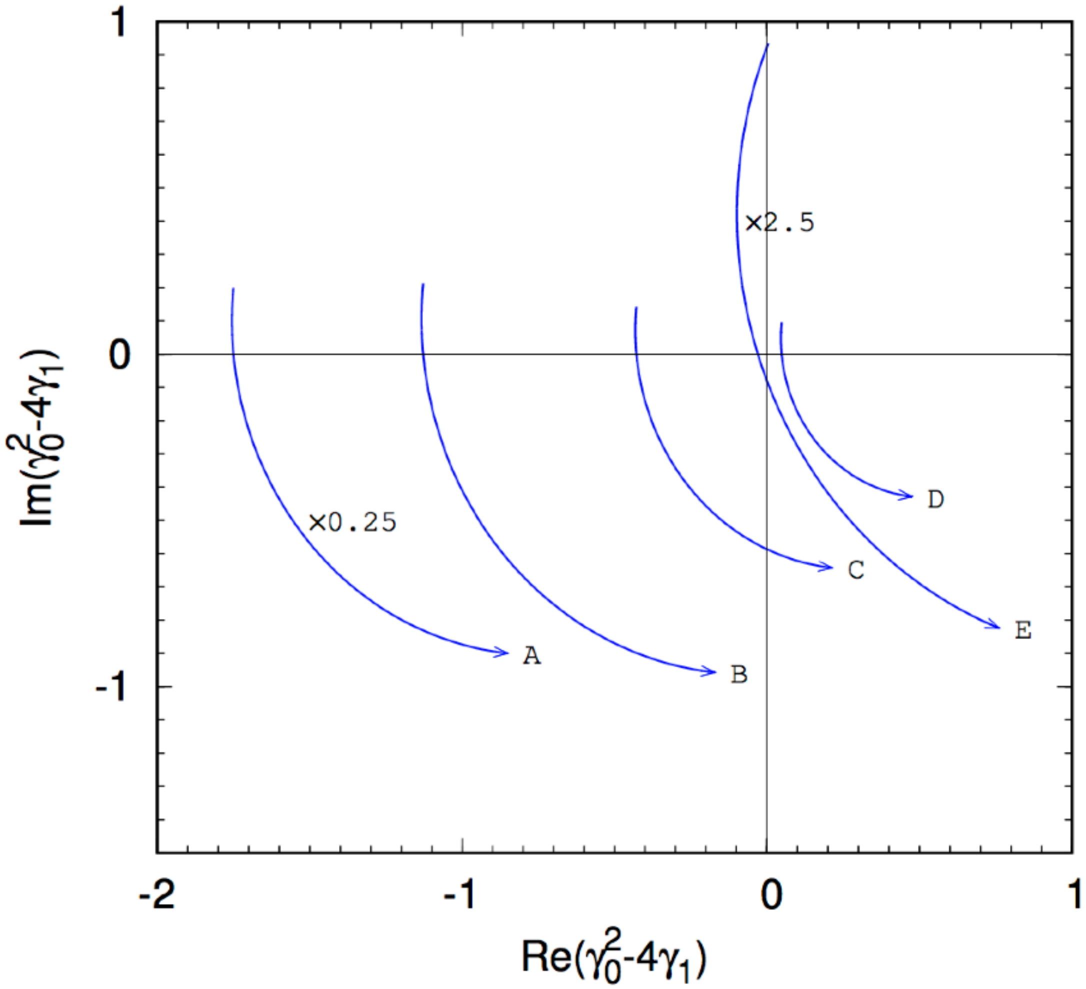
$$\rightarrow \quad \Sigma^{\gamma W}_{\mathrm{U},T}(\bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W) - \Sigma^{\gamma W,(1)}_{\mathrm{U},T}(\bar{M}_W^2 - i\bar{\Gamma}_W\bar{M}_W) = \boxed{\frac{\pi^2\bar{\Gamma}_W}{\bar{M}_W}} + \mathcal{O}\left(\left(\frac{\bar{\Gamma}_W}{\bar{M}_W}\right)^2\right)$$

ANALYTIC CONTINUATION: GENERAL CASE

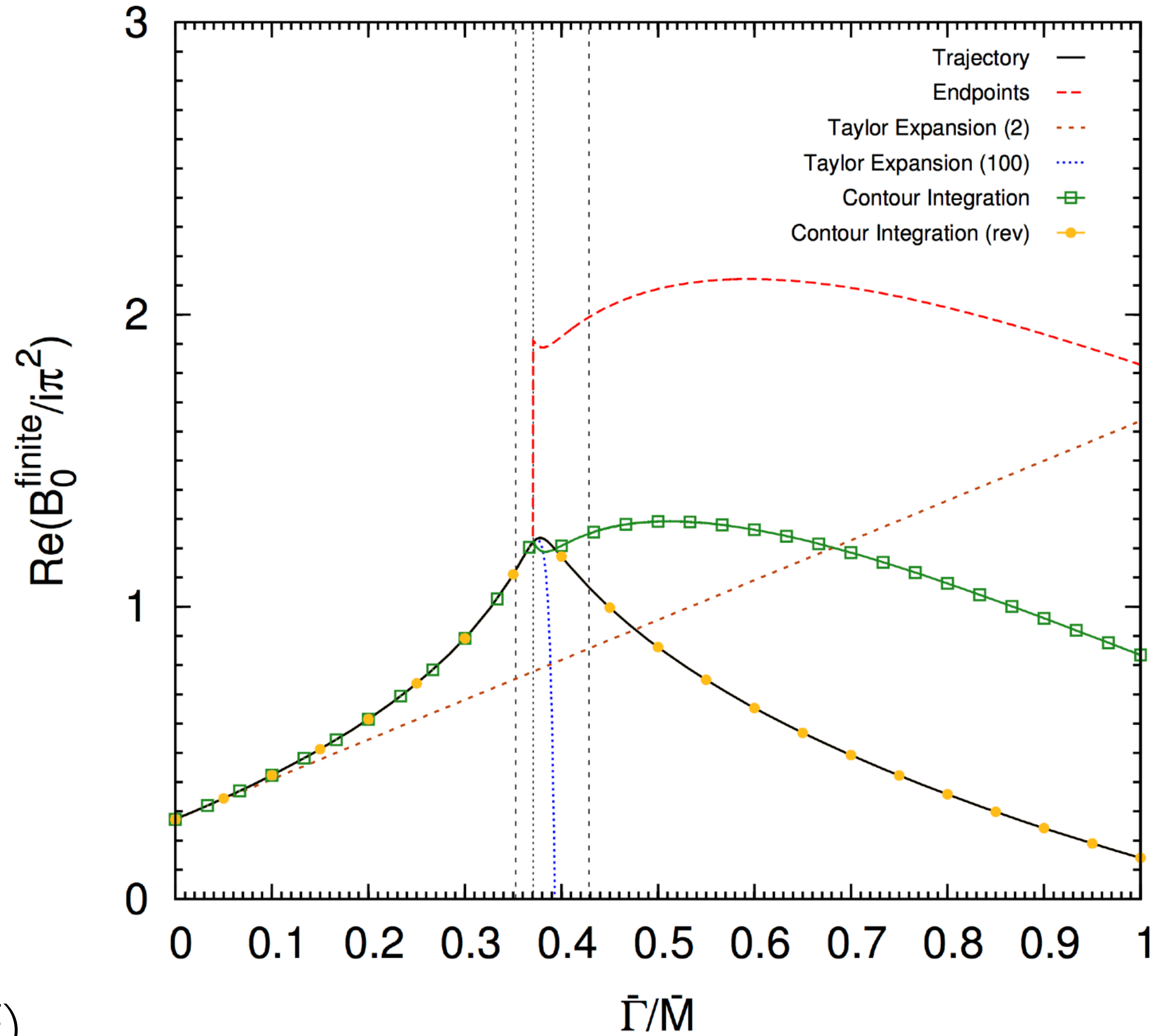
$$\frac{1}{i\pi^2} B_0(p^2, \mu_1^2, \mu_2^2) = \frac{1}{\epsilon} + 2 - \log \frac{p^2 - i0}{\mu^2} + \sum_{i=\pm} \left[\gamma_i \log \frac{\gamma_i - 1}{\gamma_i} - \log(\gamma_i - 1) \right]$$

$$\gamma_\pm = \frac{1}{2}\left(\gamma_0 \pm \boxed{\sqrt{\gamma_0^2 - 4\gamma_1}}\right), \quad \gamma_0 = 1 + \frac{\mu_1^2}{p^2} - \frac{\mu_2^2}{p^2}, \quad \gamma_1 = \frac{\mu_1^2}{p^2} - \frac{i0}{p^2}$$

	$\bar{M}^2/\bar{M}_1^2$	$\bar{M}_2^2/\bar{M}_1^2$	$\bar{\Gamma}_1/\bar{M}_1$	$\bar{\Gamma}_2/\bar{M}_2$
A	0.5	1	0.1	0.1
B	1.88	1	0.1	0.1
C	2.8	1	0.1	0.1
D	4.2	1	0.1	0.1
E	5.9	2	0.8	0.1



ANALYTIC CONTINUATION: General case

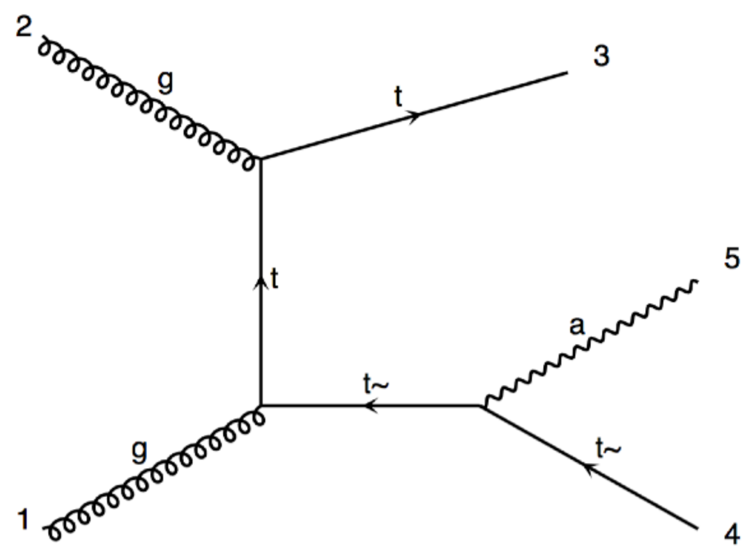


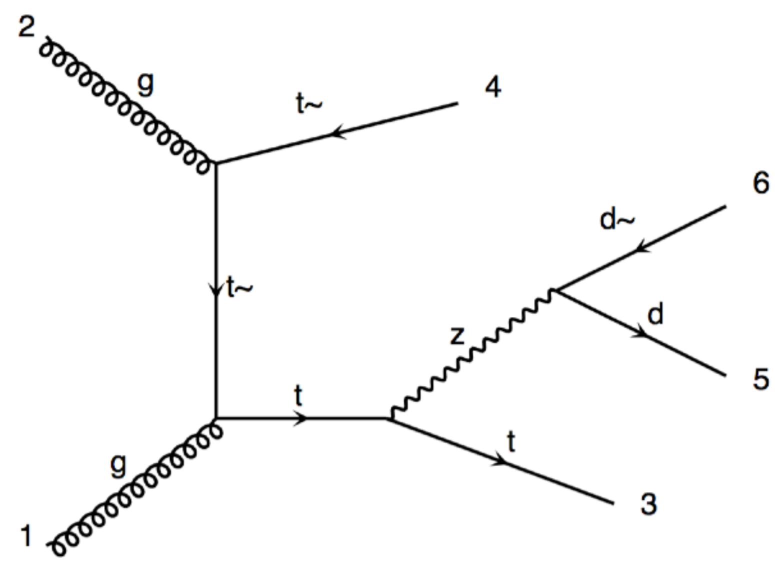
Config. E)

Mixed OS and CM scheme

- One cannot handle a process like $pp \to Z e^+ e^-$

- But what about $pp \to t\bar{t}j$?





- Can one set $\Gamma_{Z/W} \neq 0$ and $\Gamma_t = 0$? Yes, but care is needed:

Mixed OS and CM scheme

- One must carefully remove the absorptive part only:

$$\delta Z_t^{L/R} \supset \delta_{(W+,b)} Z_t^{L/R} = -\boxed{\tilde{\Re}}\left[\Sigma^{t,L/R}_{(W+,b)}(M_t^2)\right] - M_t \frac{\partial}{\partial p^2}\boxed{\tilde{\Re}}\left[\Sigma^{t,R}_{(W+,b)}(p^2) + \Sigma^{t,R}_{(W+,b)}(p^2) + 2\Sigma^{t,S}_{(W+,b)}(p^2)\right]\Big|_{p^2=M_t^2}$$

$$\Sigma^{t,S}_{(W+,b)}(p^2) = 0\,,$$

$$\Sigma^{t,L}_{(W+,b)}(p^2) = \boxed{\frac{\alpha}{2\pi}\frac{1}{s_W^2}}\left[\frac{1}{4}\frac{1}{\epsilon_{\mathrm{UV}}} + \kappa^L_{\Re,\mathrm{fin}}(p^2) + \cancel{i\kappa^L_{\Im,\mathrm{fin}}(p^2)}\right]\,,$$

$$\Sigma^{t,R}_{(W+,b)}(p^2) = \boxed{\frac{\alpha}{2\pi}\frac{M_t^2}{m_W^2 s_W^2}}\left[\frac{1}{8}\frac{1}{\epsilon_{\mathrm{UV}}} + \kappa^R_{\Re,\mathrm{fin}}(p^2) + \cancel{i\kappa^R_{\Im,\mathrm{fin}}(p^2)}\right]\,,$$

- Anti-top wf renormalisation not obtained by complex conjugation!

$$\delta Z_{\bar{t}}^{L/R} \neq \delta Z_t^{L/R\star}$$

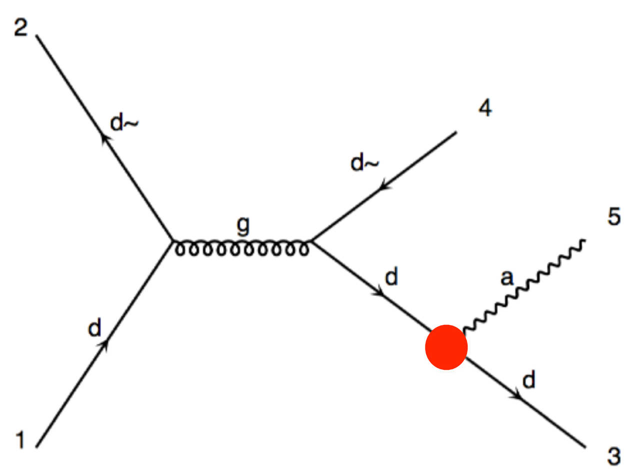
How to handle the complex phase of α ?

- In the G_μ -scheme for example, **α** is defined as:

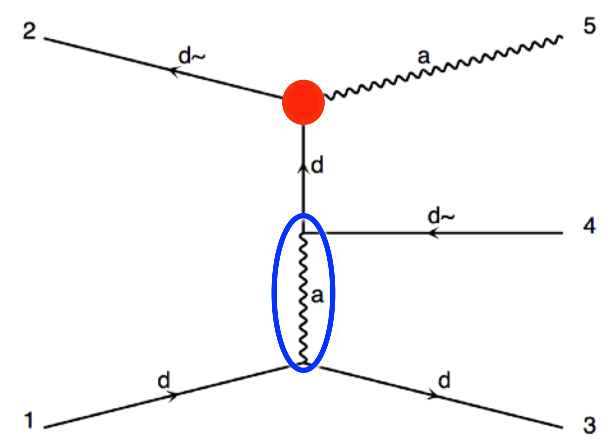
$$\alpha^{(CMS,G_\mu)} = \frac{\sqrt{2}G_f}{\pi}\frac{M_W^{(CMS)2}(M_Z^{(CMS)2} - M_W^{(CMS)2})}{M_Z^{(CMS)2}} \longrightarrow$$ Should be complex!

- In practice the complex phase is often irrelevant because the matrix elements factorize |**α**|. But, in subleading blobs, one can have:

Reals:



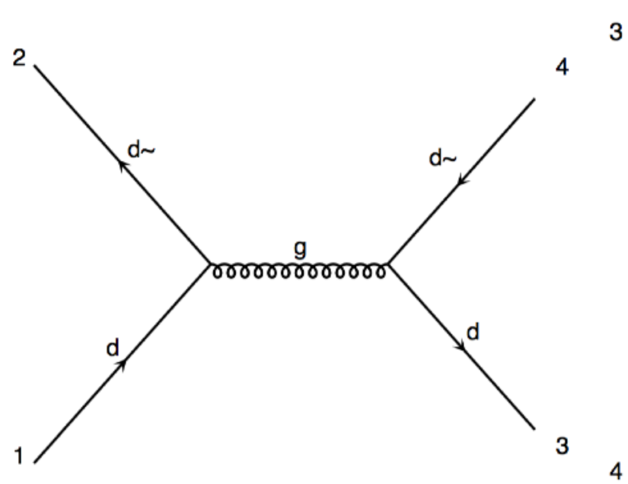
X



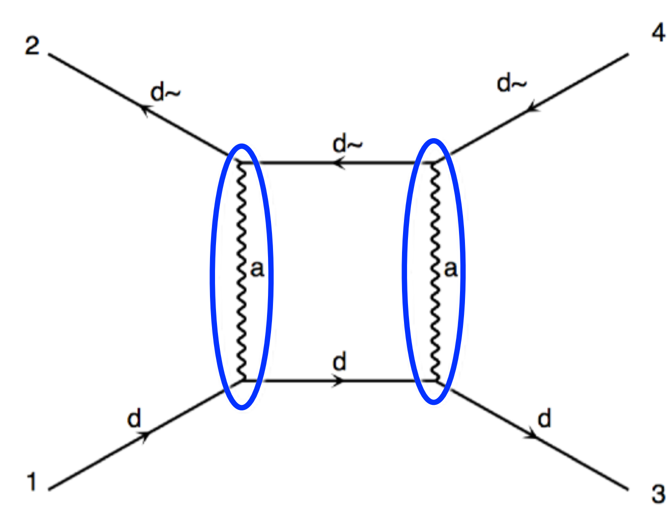
~ $|\alpha|\, Re(\alpha)$

$\neq$

Virtuals:



X



~ $|\alpha|^2$

~ $Re(\alpha)^2$

How to handle the complex phase of α ?

- We **must set α→|α|** to setup IR factorization.
  - → This can induce **gauge violations** whenever sensitive to complex phase of α
  - → And correspondingly, a potential **dependance** on **how one writes EW couplings**.

→ It is always possible to assign a phase to G_μ so as to make α real (this is what is effectively done in the $\alpha(M_Z)$ scheme)

step 1 : $\alpha^{(CMS,G_F)} = \left|\left((\sqrt{2}/\pi)\,|G_F|/M_Z^{(CMS)2}\right) M_W^{(CMS)2}\left(M_Z^{(CMS)2} - M_W^{(CMS)2}\right)\right|$

step 2 : $G_F^{-1} = \left((\sqrt{2}/\pi)\frac{1}{\alpha^{(CMS,G_F)}}/M_Z^{(CMS)2}\right) M_W^{(CMS)2}\left(M_Z^{(CMS)2} - M_W^{(CMS)2}\right)$

$$\rightarrow\ \overline{G}_\mu^{(G_\mu)} = G_\mu^{(G_\mu)}\ e^{\,i\mathrm{Arg}\left[\frac{m_Z^2}{m_W^2(m_Z^2-m_W^2)}\right]}$$

TL;DL

- Computation of **all NLO QCD+EW** now available in **MG5_aMC.**
- **Complex mass-scheme** is an essential component in the computation of EW corrections. **Subtelties:** complex phase of expansion parameters, analytic continuation, mixed-case with OS scheme, ….
- **Outlook**
  - Use of **fragmentation functions** for (anti-)tagging short-distance photons; though **not necessary for leading NLO EW**
  - study solutions for **matching** mixed QCD+EW fixed order predictions to parton showers.
  - study the possibility of automatically generating UFO@NLO **BSM** models suited for QCD+EW NLO predictions.