MITP Workshop: Electroweak corrections at current and future accelerators

McMule feels weak – EW corrections for MOLLER (& P2)

Sophie Kollatzsch & David Radic

Paul Scherrer Institute / University of Zurich

McMule :: Fixed-order Monte Carlo framework for lepton processes at low energies

matrix elements $\longrightarrow$ **McMule** $\longrightarrow$ **physical cross section**

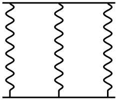
matrix elements: by us or others

McMule: integrator (generator WIP); phase space generation, subtraction, stabilisation, integration, event generation, ...

physical cross section: for any physical observable: acceptance cuts, real photon emission, ...

we provide (and WIP) NNLO QED for

$ee \to ee$ :: $ep \to ep$ :: $eC \to eC$



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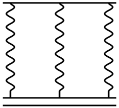
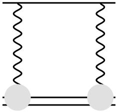


NNLO pointlike

NLO w simple/better TPE model



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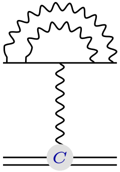


and EW NNLO+NLL for logs $\log\left(\frac{m_e^2, s, t, \ldots}{M_Z^2, M_W^2, \ldots}\right)$ in $ee \to ee$ in LEFT

challenges to overcome

$$\sigma = \int \mathrm{d}\Phi_2 \, \Bigg|$$

$$\Bigg|^2$$

$$+ \int \mathrm{d}\Phi_3 \, \Bigg| \qquad \Bigg|^2$$

$$+ \int \mathrm{d}\Phi_4 \, \Bigg| \qquad \Bigg|^2$$

$$+ \ldots$$

$$\sigma = \int \mathrm{d}\Phi_2 \left| \quad + \quad \right|^2$$

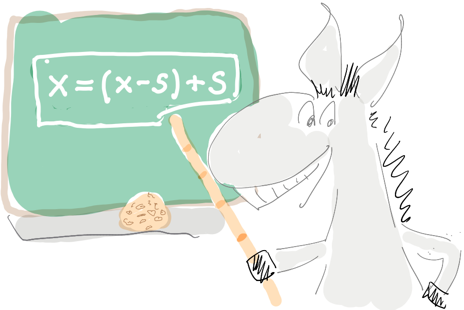
$$+ \int \mathrm{d}\Phi_3 \left| \quad \right|^2$$

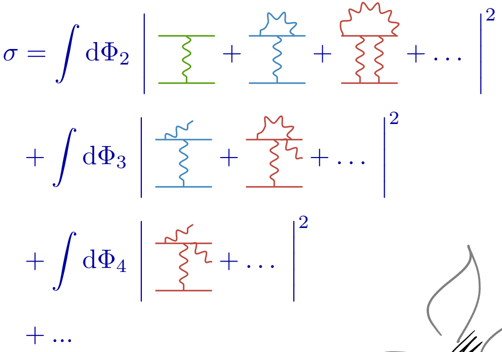
challenges to overcome

- divergent phase space (PS) int
  $\Longrightarrow$ FKS$^\ell$ subtraction

$$\int \mathrm{d}\Phi_2 \Big(\quad + \int \mathrm{d}\Phi_\gamma \mathrm{CT} \Big)$$

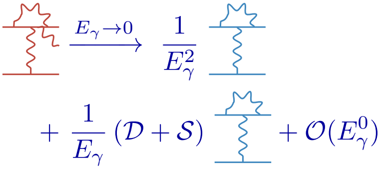
$$+ \int \mathrm{d}\Phi_2 \int \mathrm{d}\Phi_\gamma \Big(\quad - \mathrm{CT} \Big)$$





challenges to overcome

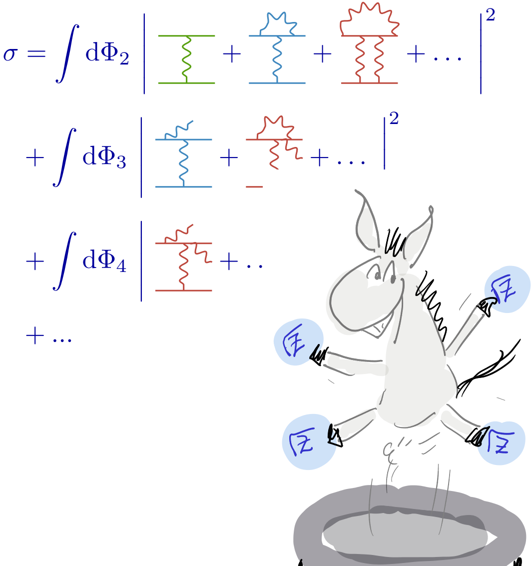
- divergent phase space (PS) int
  $\Longrightarrow$ FKS$^\ell$ subtraction
- numerical instabilities in PS int
  $\Longrightarrow$ next-to-soft stabilisation
  $+$ OpenLoops [Buccioni et al 17,19]



$+$ polarisation terms

[Low 58; Burnett, Kroll 67; Balsach 23;...]

challenges to overcome

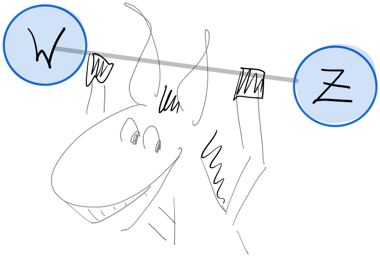


- divergent phase space (PS) int
  $\implies$ FKS$^\ell$ subtraction
- numerical instabilities in PS int
  $\implies$ next-to-soft stabilisation
  $+$ OpenLoops [Buccioni et al 17,19]
- loop amplitudes with $m \neq 0$
  $\implies$ massification
  [Penin 05; Mitov et al 06; Becher et al 07; ...]

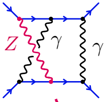
$$\mathcal{M}(m) = \mathcal{M}(0) \times \left(\sqrt{Z(m)}\right)^{\#\text{ legs}} + \mathcal{O}(m)$$

iff $m^2 \ll$ all other scales

...cannot recover helicities $\sim m$



EFT framework



complicated

$$\log \frac{m}{M} \gg 1$$

McMule framework

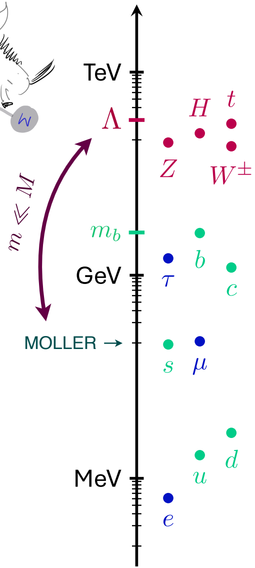
massification (SCET)

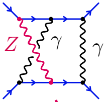
FKS^{ℓ}

LBK (HQET)

flexible & fully differential!

include EW effects via …





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$$\log \frac{m}{M} \gg 1$$

McMule framework

massification (SCET)

FKS^ℓ

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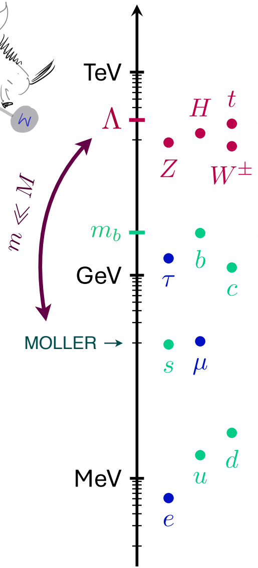
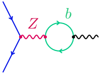
include EW effects via **low-energy effective field theory (LEFT)**



matching + RG running

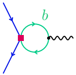


$\mathcal{L}_{\mathrm{SM}}$

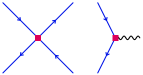
$L_i = \gamma_{ij} L_j$

$$\mathcal{L}_{\mathrm{LEFT}} = \mathcal{L}_4 + \sum L_i\, \mathcal{O}_i$$

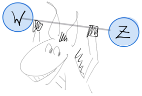
QED + QCD

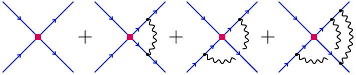


$\mathcal{L}_{\mathrm{LEFT},\not b}$ (w/o b quark)



	LL	NLL	$\mathrm{N^2LL}$
LO	1		
NLO	$\alpha \log$	α	
$\mathrm{N^2LO}$	$\alpha^2 \log^2$	$\alpha^2 \log$	α^2
⋮	⋮	⋮	⋮





$+\ \mathcal{O}(\Lambda^{-3})$

we use the `San Diego` conventions

$\rightharpoonup$ basis definition, evanescent operators, ...

[Jenkins, Manohar, Stoffer 18]
[Dekens, Stoffer 19]

power counting ...

dipole (dim. 5) **4-fermion (dim. 6)**

$$\mathcal{L}_{\text{LEFT}} \supset L_{\substack{e\gamma \\ pr}} (\bar{e}_{Lp}\, \sigma^{\mu\nu}\, e_{Rr})\, F_{\mu\nu} + \text{h.c.} + L^{V,LL}_{\substack{ee \\ prst}} (\bar{e}_{Lp}\, \gamma^{\mu}\, e_{Lr})(\bar{e}_{Ls}\, \gamma_{\mu}\, e_{Lt})$$

loop-induced & of dim. 6 when derived from the SM!

$\mathcal{O}(\Lambda^{-2}) \;\Rightarrow$ only **single-insertions** of higher-dim. operators (naively counted as $\sim \alpha^2$)

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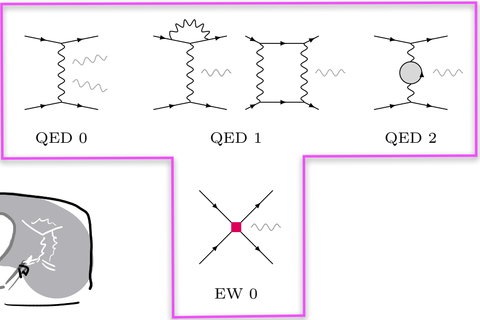
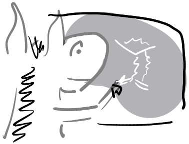
LO





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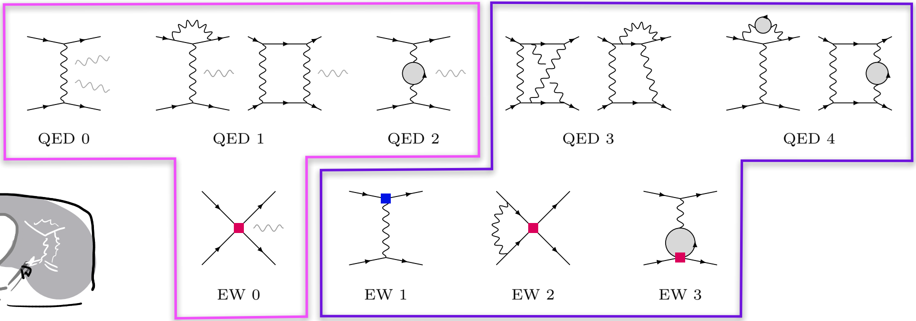
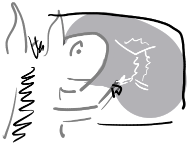


NLO



scattering cross section w/ one initial-state polarisation:

$$\mathrm{d}\sigma_{L/R} = \sum_{i=0}^{\infty} \alpha^{i+2}\, \mathrm{d}\sigma^{(i)} + \sum_{j=0}^{\infty} \lambda\, \alpha^{j+1}\, \mathrm{d}\sigma^{(j,1)}_{L/R} + \mathcal{O}(\lambda^2)$$

EW

QED

$$\boxed{\mathrm{d}\sigma^{(i)}_L = \mathrm{d}\sigma^{(i)}_R = \mathrm{d}\sigma^{(i)}}$$

bookkeeping parameter for insertion of higher-dim. operator

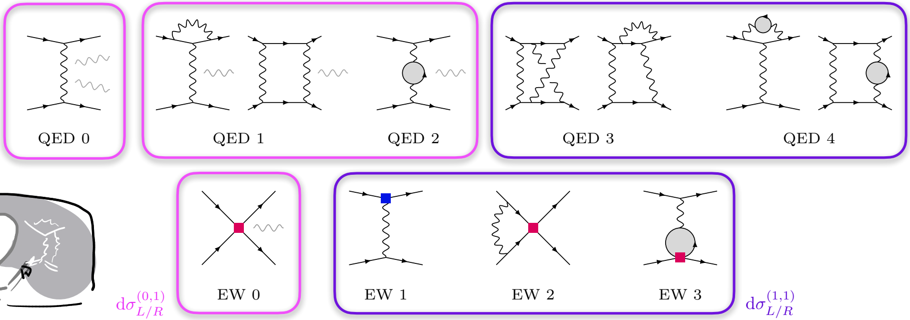
left-right asymmetry

$$A_{LR} = \frac{\mathrm{d}\sigma_L - \mathrm{d}\sigma_R}{\mathrm{d}\sigma_L + \mathrm{d}\sigma_R}$$

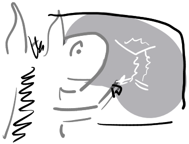
$$A_{LR}^{\text{full}} = \frac{[\text{best}]}{[\text{best}]} \quad \textbf{vs.} \quad A_{LR}^{\text{exp}} = \left[\begin{matrix}\text{expanded}\\ \text{in } \alpha \text{ \& } \lambda\end{matrix}\right]$$

$\mathrm{d}\sigma^{(1)}$

$\mathrm{d}\sigma^{(0)}$



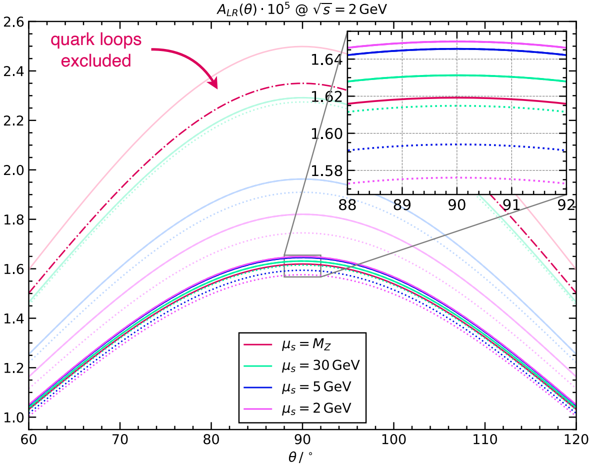
$\mathrm{d}\sigma^{(2)}$



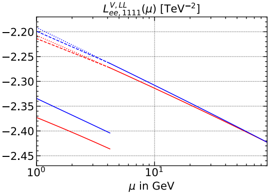
$\mathrm{d}\sigma^{(0,1)}_{L/R}$

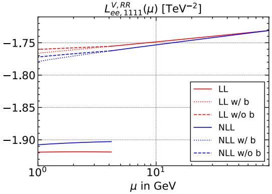
$\mathrm{d}\sigma^{(1,1)}_{L/R}$

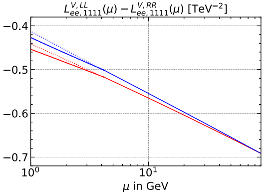
[SK, Moreno, DR, Signer 25]



tree-level (light colors) and one-loop (dark colors) in RG improved perturbation theory at LL (solid lines) and NLL (dotted lines) accuracy







2-loop anomalous dimensions in LEFT for the **4-fermion sector** (NDR)

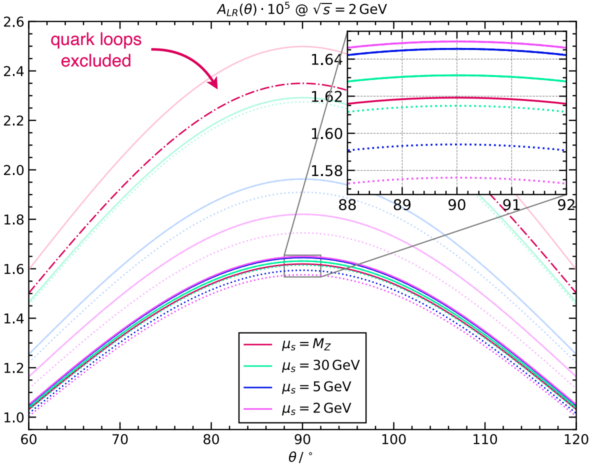
NLL results generated with `DsixTools`

[Celis, Fuentes-Martin, Vicente, Virto 17]

[Fuentes-Martin, Ruiz-Femenia, Vicente, Virto 21]

we go LEFT

[SK, Moreno, DR, Signer 25]



tree-level (light colors) and one-loop (dark colors) in RG improved perturbation theory at LL (solid lines) and NLL (dotted lines) accuracy

...running from M_Z to $\sqrt{s}$ reduces the one-loop corrections from $\sim 40\%$ to $\sim 15\%$ at LL accuracy

...switching from LL to NLL has a notable impact

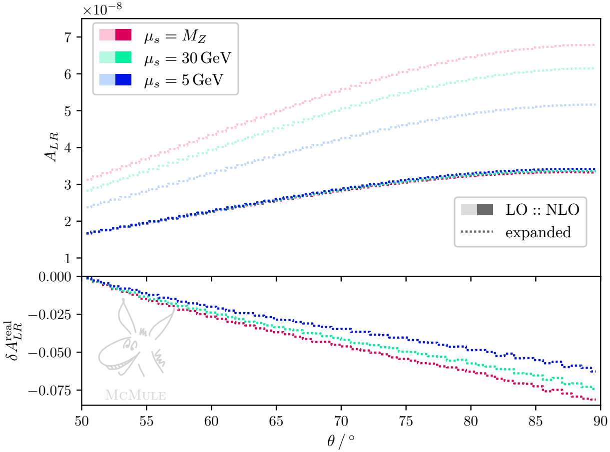
take-home message:

\# 1 use LEFT

resummation is important

some examples for MOLLER
based on [SK, Moreno, DR, Signer 25]

$\sqrt{s} = 106\,\mathrm{MeV}, \theta = \frac{1}{2}\left(\pi - |\theta_3 - \theta_4|\right), 50^\circ \le \theta_\ell \le 130^\circ$, 90% long. pol.



A_{LR} expanded in α & λ

accidental cancellation of IR divergences

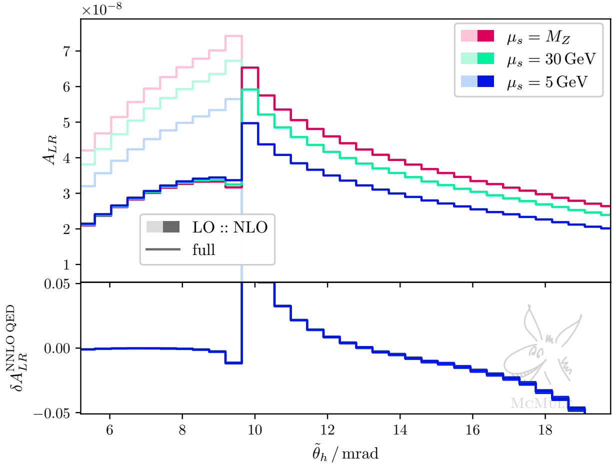
$$\delta A_{LR}^{\mathrm{real}} = \frac{\text{real+virtual} - \text{virtual}}{\text{virtual}}$$

. . . can be $\sim 7.5\%$ (or more)

2 use McMule

real corrections are important and cannot be neglected scattering angle of more-energetic electron $\tilde\theta_h$

$A_{LR} = \frac{\text{best}}{\text{best}}$ incl NNLO QED



3 use McMule

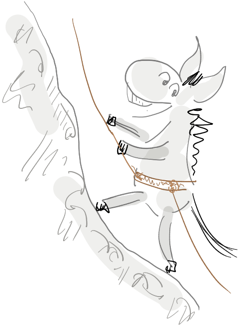
fully differential implementation is required

$$\delta A_{LR}^{\text{NNLO QED}} = \frac{\text{w NNLO} - \text{w/o NNLO}}{\text{w/o NNLO}}$$

...can be $\sim 5\,\%$

4 use McMule

NNLO QED can be important



higher orders within LEFT

NNLO+NLL in LEFT + **matching onto the SM(EFT) at two loops**

NNLO+NLL in LEFT + matching onto the SM(EFT) at two loops

significant progress on **2-loop anomalous dimensions** in the literature ✓

- **NDR** vs. **HV**? scheme dependencies?

4-fermion sector (NDR) ⟶ `DsixTools`
[Aebischer, Morell, Pesut, Virto 25]

?

full LEFT (HV)
[Naterop, Stoffer 25 (dim.-five)]
[Naterop, Stoffer 25 (dim.-six BNV)]
[Naterop, Stoffer 26 (dim.-six)]

compute all relevant **matrix elements in LEFT** up to dimension 6

- automation via in-house **Mathematica routines** interfacing various software packages
- analytic results for 2-loop master integrals known with full mass dependence

  … or use expanded results from `AsyInt` [Zhang 24]

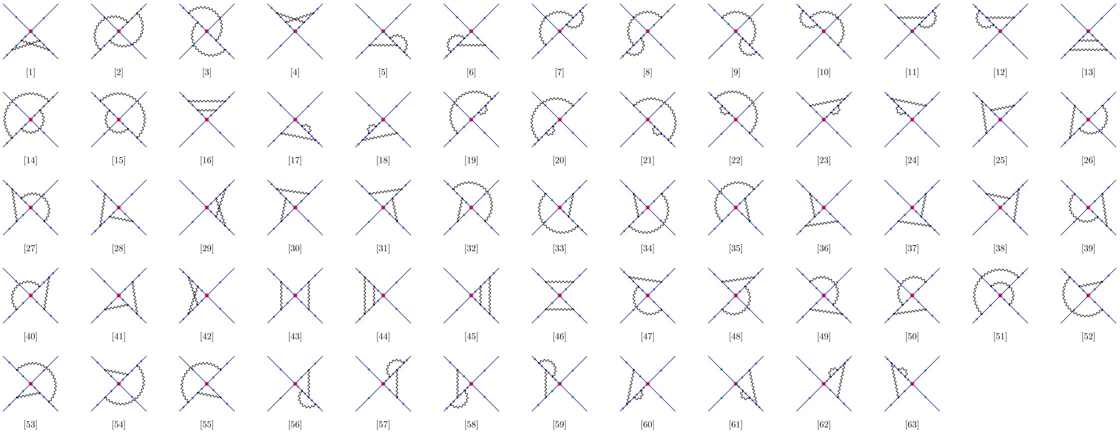
⇒ **no showstoppers!**

virtual-virtual bosonic corrections in LEFT

```
In[4]:= InitModel["LEFT"]
        Initialize model: LEFT
```

workflow :: ... QGRAF → Mathematica → FORM → Kira → Reduze 2 ...

```
In[5]:= Diagrams[{"e", "e"}, {"e", "e"}, 2, Dim → {6}, Filter → {"Single4Fermion", "nf0"}] // Paint[#, Size → {5, 13}] &
```



WIP

NNLO+NLL in LEFT + **matching onto the SM(EFT) at two loops**

… scheme choices?

renormalization beyond one loop?

γ_5 **treatment?**

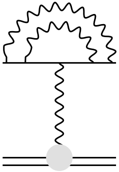
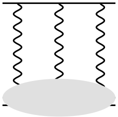
separate evanescent sector from physical sector

⋮

status of $ep \to ep$

what we can do

how we deal with protons [Engel, Hagelstein, Rocco, Sharkovska, Signer, Ulrich 23]

NNLO $\supset$  ✓ $+$ 

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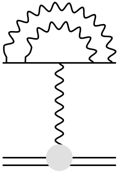
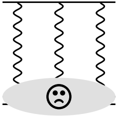
NNLO $\supset$  ✓ $+$ 

what we can do

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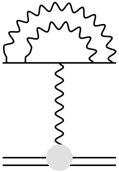
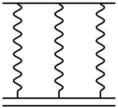
NNLO $\supset$  ✓ + 

pointlike approximation
$e\mu \to e\mu$
with $m_\mu \to m_p$

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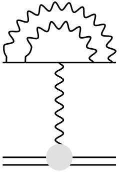
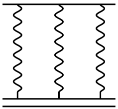
NNLO $\supset$



$\checkmark$ $+$



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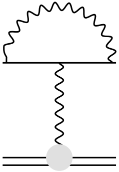

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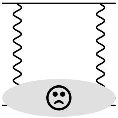

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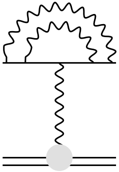
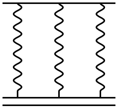
NNLO $\supset$  ✓ $+$ 

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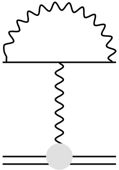
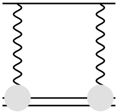
$e\mu \to e\mu$

with $m_\mu \to m_p$

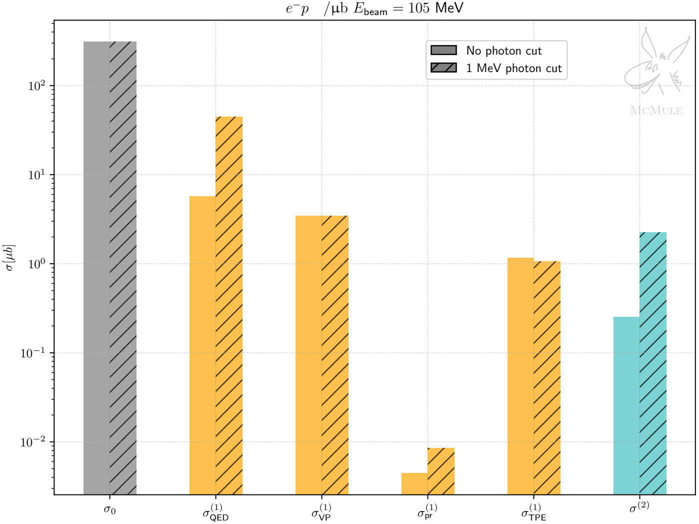
NLO $\supset$  ✓ $+$ 

two-photon-exchange (TPE) as simple model

ongoing :: implement state-of-the-art TPE, including inelastic TPE

MAGIX example :: $ep \to ep$

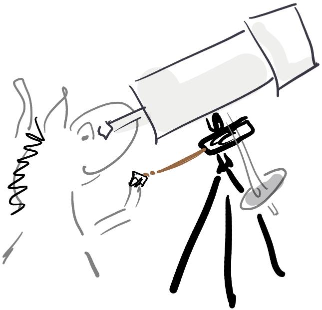
$E_{\rm in} = 105\,\mathrm{MeV}, 15^\circ \le \theta_e \le 150^\circ, 73.5\,\mathrm{MeV} \le p_e \le 105\,\mathrm{MeV}, E_\gamma \le 1\,\mathrm{MeV}$



NNLO effects can be larger than TPE !

5 use McMule

similar studies needed for EW effects for P2



outlook

McMule's future is (not) weak

focus on EW for $ee \to ee$ & **repeat QED approach for EW $ep \to ep$**

- NLO+LL $\to$ NNLO+NLL
- heavy BSM $\subset$ LEFT

- simple TPE model at NLO
  we have methods to deal with dispersive input
  [Fang, SK, Rocco, Signer, Ulrich, Zoller 25]
- pointlike NNLO via $ee \to \mu\mu$

. . . and make McMule even better

- integrator $\to$ generator ongoing, see talk by [Y. Ulrich]
- combine with parton shower / soft photon resummation
- make McMule ready for high energies $\to$ FCC-ee, . . .

to take home

1 use LEFT $\implies$ resummation & systematic higher orders, heavy BSM for free

2 use McMule $\implies$ real corrections, cuts, NNLO effects

McMule team

f.l.t.r.: A.Signer (Zurich & PSI), F.Hagelstein (Mainz), M.Ronchi (Mainz), M.Rocco (Turin)
S.Kollatzsch (Zurich & PSI), Y.Ulrich (Liverpool), S.Gündogdu (Zurich & PSI),
D.Radic (Zurich & PSI), J.Wilson (Liverpool), S.Zanoli (Oxford), Y.Fang (Zurich & PSI)
not shown: P.Banerjee (Chennai), A.Coutinho (IFIC) V.Sharkovska (Zurich & PSI),
G.Billis (PSI), T.Oruç (ETHZ)

use McMule!

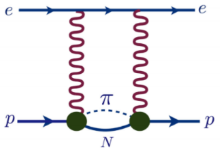
Interest? Get in touch!

McMule

mule-tools.gitlab.io

see talk by [A. Signer]

plan: include state-of-the-art TPE models

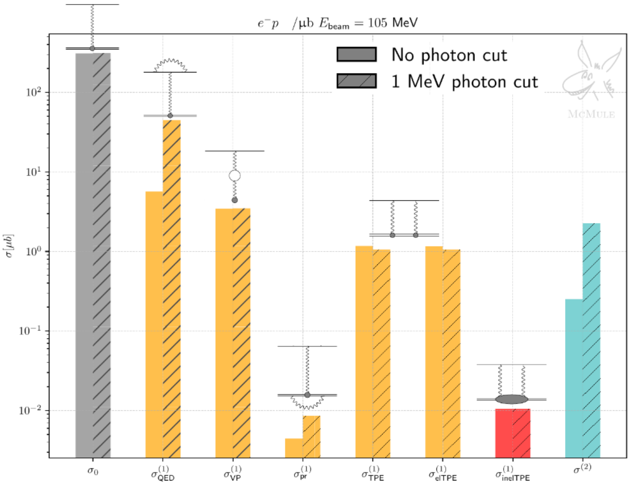


[Tomalak, Pasquini, Vanderhaeghen, 1708.03303]

so far 'only' virtual part

Ooops, recall message # 3

⇒ work on real counterpart

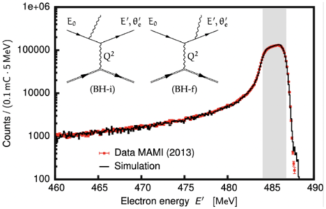


see talk by [A. Signer]

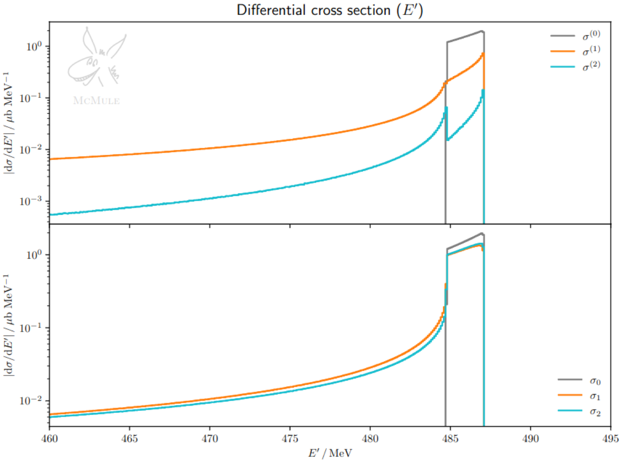
full NLO for $e^- p \to e^- p \gamma$

($\supset$ NNLO for $e^- p \to e^- p$)

$E = 495$ MeV



[Mihovilovic et al. 1905.11182]



10% correction in the tail

left-right asymmetry – full vs. expanded

$$\boxed{\mathrm{d}\sigma^{(j,1)}_{L\pm R} \equiv \mathrm{d}\sigma^{(j,1)}_{L} \pm \mathrm{d}\sigma^{(j,1)}_{R}}$$

$$A_{LR}^{\text{LO full}} = \frac{\lambda\,\mathrm{d}\sigma^{(0,1)}_{L-R}}{2\left(\alpha\,\mathrm{d}\sigma^{(0)} + \alpha^2\,\mathrm{d}\sigma^{(1)}\right) + \lambda\,\mathrm{d}\sigma^{(0,1)}_{L+R}}$$

$$A_{LR}^{\text{NLO full}} = \frac{\lambda\,\mathrm{d}\sigma^{(0,1)}_{L-R} + \alpha\,\lambda\,\mathrm{d}\sigma^{(1,1)}_{L-R}}{2\left(\alpha\,\mathrm{d}\sigma^{(0)} + \alpha^2\,\mathrm{d}\sigma^{(1)} + \alpha^3\,\mathrm{d}\sigma^{(2)}\right) + \lambda\,\mathrm{d}\sigma^{(0,1)}_{L+R} + \alpha\,\lambda\,\mathrm{d}\sigma^{(1,1)}_{L+R}}$$

$$A_{LR}^{\text{LO exp}} = \frac{\lambda}{\alpha}\,\frac{\mathrm{d}\sigma^{(0,1)}_{L-R}}{2\,\mathrm{d}\sigma^{(0)}}$$

$$A_{LR}^{\text{NLO exp}} = \frac{\lambda}{\alpha}\,\frac{\mathrm{d}\sigma^{(0,1)}_{L-R}}{2\,\mathrm{d}\sigma^{(0)}} + \lambda\,\frac{\mathrm{d}\sigma^{(0)}\,\mathrm{d}\sigma^{(1,1)}_{L-R} - \mathrm{d}\sigma^{(1)}\,\mathrm{d}\sigma^{(0,1)}_{L-R}}{2\,(\mathrm{d}\sigma^{(0)})^2}$$

LEFT operators up to dimension 6

dipoles

$(\nu\nu)X + \text{h.c.}$

$\mathcal{O}_{\nu\gamma}$	$(\nu_{Lp}^T\, C\, \sigma^{\mu\nu}\, \nu_{Lr})\, F_{\mu\nu}$	`"\[Nu]\[Gamma]"`

$(\bar{L}R)X + \text{h.c.}$

$\mathcal{O}_{e\gamma}$	$(\bar{e}_{Lp}\, \sigma^{\mu\nu}\, e_{Rr})\, F_{\mu\nu}$	`"e\[Gamma]"`
$\mathcal{O}_{u\gamma}$	$(\bar{u}_{Lp}\, \sigma^{\mu\nu}\, u_{Rr})\, F_{\mu\nu}$	`"u\[Gamma]"`
$\mathcal{O}_{d\gamma}$	$(\bar{d}_{Lp}\, \sigma^{\mu\nu}\, d_{Rr})\, F_{\mu\nu}$	`"d\[Gamma]"`
$\mathcal{O}_{uG}$	$(\bar{u}_{Lp}\, \sigma^{\mu\nu} t^\alpha\, u_{Rr})\, G^\alpha_{\mu\nu}$	`"uG"`
$\mathcal{O}_{dG}$	$(\bar{d}_{Lp}\, \sigma^{\mu\nu} t^\alpha\, d_{Rr})\, G^\alpha_{\mu\nu}$	`"dG"`

3-gluon

X^3

$\mathcal{O}_G$	$f^{\alpha\beta\gamma}\, G_\mu^{\alpha\,\nu}\, G_\nu^{\beta\,\rho}\, G_\rho^{\gamma\,\mu}$	`"G"`
$\mathcal{O}_{\tilde{G}}$	$f^{\alpha\beta\gamma}\, \tilde{G}_\mu^{\alpha\,\nu}\, G_\nu^{\beta\,\rho}\, G_\rho^{\gamma\,\mu}$	`"Gt"`

4-fermion (fermion-number-conserving)

$(\bar{L}L)(\bar{L}L)$

$\mathcal{O}_{\nu\nu}^{V,LL}$	$(\bar{\nu}_{Lp}\, \gamma^\mu\, \nu_{Lr})(\bar{\nu}_{Ls}\, \gamma_\mu\, \nu_{Lt})$	`"VLL\[Nu]\[Nu]"`
$\mathcal{O}_{ee}^{V,LL}$	$(\bar{e}_{Lp}\, \gamma^\mu\, e_{Lr})(\bar{e}_{Ls}\, \gamma_\mu\, e_{Lt})$	`"VLLee"`
$\mathcal{O}_{\nu e}^{V,LL}$	$(\bar{\nu}_{Lp}\, \gamma^\mu\, \nu_{Lr})(\bar{e}_{Ls}\, \gamma_\mu\, e_{Lt})$	`"VLL\[Nu]e"`
$\mathcal{O}_{\nu u}^{V,LL}$	$(\bar{\nu}_{Lp}\, \gamma^\mu\, \nu_{Lr})(\bar{u}_{Ls}\, \gamma_\mu\, u_{Lt})$	`"VLL\[Nu]u"`
$\mathcal{O}_{\nu d}^{V,LL}$	$(\bar{\nu}_{Lp}\, \gamma^\mu\, \nu_{Lr})(\bar{d}_{Ls}\, \gamma_\mu\, d_{Lt})$	`"VLL\[Nu]d"`
$\mathcal{O}_{eu}^{V,LL}$	$(\bar{e}_{Lp}\, \gamma^\mu\, e_{Lr})(\bar{u}_{Ls}\, \gamma_\mu\, u_{Lt})$	`"VLLeu"`
$\mathcal{O}_{ed}^{V,LL}$	$(\bar{e}_{Lp}\, \gamma^\mu\, e_{Lr})(\bar{d}_{Ls}\, \gamma_\mu\, d_{Lt})$	`"VLLed"`
$\mathcal{O}_{\nu edu}^{V,LL}$	$(\bar{\nu}_{Lp}\, \gamma^\mu\, e_{Lr})(\bar{d}_{Ls}\, \gamma_\mu\, u_{Lt}) + \text{h.c.}$	`"VLL\[Nu]edu"`
$\mathcal{O}_{uu}^{V,LL}$	$(\bar{u}_{Lp}\, \gamma^\mu\, u_{Lr})(\bar{u}_{Ls}\, \gamma_\mu\, u_{Lt})$	`"VLLuu"`
$\mathcal{O}_{dd}^{V,LL}$	$(\bar{d}_{Lp}\, \gamma^\mu\, d_{Lr})(\bar{d}_{Ls}\, \gamma_\mu\, d_{Lt})$	`"VLLdd"`
$\mathcal{O}_{ud}^{V1,LL}$	$(\bar{u}_{Lp}\, \gamma^\mu\, u_{Lr})(\bar{d}_{Ls}\, \gamma_\mu\, d_{Lt})$	`"V1LLud"`
$\mathcal{O}_{ud}^{V8,LL}$	$(\bar{u}_{Lp}\, \gamma^\mu\, t^\alpha\, u_{Lr})(\bar{d}_{Ls}\, \gamma_\mu\, t^\alpha\, d_{Lt})$	`"V8LLud"`

$(\bar{R}R)(\bar{R}R)$

$\mathcal{O}_{ee}^{V,RR}$	$(\bar{e}_{Rp}\, \gamma^\mu\, e_{Rr})(\bar{e}_{Rs}\, \gamma_\mu\, e_{Rt})$	`"VRRee"`
$\mathcal{O}_{eu}^{V,RR}$	$(\bar{e}_{Rp}\, \gamma^\mu\, e_{Rr})(\bar{u}_{Rs}\, \gamma_\mu\, u_{Rt})$	`"VRReu"`
$\mathcal{O}_{ed}^{V,RR}$	$(\bar{e}_{Rp}\, \gamma^\mu\, e_{Rr})(\bar{d}_{Rs}\, \gamma_\mu\, d_{Rt})$	`"VRRed"`
$\mathcal{O}_{uu}^{V,RR}$	$(\bar{u}_{Rp}\, \gamma^\mu\, u_{Rr})(\bar{u}_{Rs}\, \gamma_\mu\, u_{Rt})$	`"VRRuu"`
$\mathcal{O}_{dd}^{V,RR}$	$(\bar{d}_{Rp}\, \gamma^\mu\, d_{Rr})(\bar{d}_{Rs}\, \gamma_\mu\, d_{Rt})$	`"VRRdd"`
$\mathcal{O}_{ud}^{V1,RR}$	$(\bar{u}_{Rp}\, \gamma^\mu\, u_{Rr})(\bar{d}_{Rs}\, \gamma_\mu\, d_{Rt})$	`"V1RRud"`
$\mathcal{O}_{ud}^{V8,RR}$	$(\bar{u}_{Rp}\, \gamma^\mu\, t^\alpha\, u_{Rr})(\bar{d}_{Rs}\, \gamma_\mu\, t^\alpha\, d_{Rt})$	`"V8RRud"`

$(\bar{L}L)(\bar{R}R)$

$\mathcal{O}_{\nu e}^{V,LR}$	$(\bar{\nu}_{Lp}\, \gamma^\mu\, \nu_{Lr})(\bar{e}_{Rs}\, \gamma_\mu\, e_{Rt})$	`"VLR\[Nu]e"`
$\mathcal{O}_{ee}^{V,LR}$	$(\bar{e}_{Lp}\, \gamma^\mu\, e_{Lr})(\bar{e}_{Rs}\, \gamma_\mu\, e_{Rt})$	`"VLRee"`
$\mathcal{O}_{\nu u}^{V,LR}$	$(\bar{\nu}_{Lp}\, \gamma^\mu\, \nu_{Lr})(\bar{u}_{Rs}\, \gamma_\mu\, u_{Rt})$	`"VLR\[Nu]u"`
$\mathcal{O}_{\nu d}^{V,LR}$	$(\bar{\nu}_{Lp}\, \gamma^\mu\, \nu_{Lr})(\bar{d}_{Rs}\, \gamma_\mu\, d_{Rt})$	`"VLR\[Nu]d"`
$\mathcal{O}_{eu}^{V,LR}$	$(\bar{e}_{Lp}\, \gamma^\mu\, e_{Lr})(\bar{u}_{Rs}\, \gamma_\mu\, u_{Rt})$	`"VLReu"`
$\mathcal{O}_{ed}^{V,LR}$	$(\bar{e}_{Lp}\, \gamma^\mu\, e_{Lr})(\bar{d}_{Rs}\, \gamma_\mu\, d_{Rt})$	`"VLRed"`
$\mathcal{O}_{ue}^{V,LR}$	$(\bar{u}_{Lp}\, \gamma^\mu\, u_{Lr})(\bar{e}_{Rs}\, \gamma_\mu\, e_{Rt})$	`"VLRue"`
$\mathcal{O}_{de}^{V,LR}$	$(\bar{d}_{Lp}\, \gamma^\mu\, d_{Lr})(\bar{e}_{Rs}\, \gamma_\mu\, e_{Rt})$	`"VLRde"`
$\mathcal{O}_{\nu edu}^{V,LR}$	$(\bar{\nu}_{Lp}\, \gamma^\mu\, e_{Lr})(\bar{d}_{Rs}\, \gamma_\mu\, u_{Rt}) + \text{h.c.}$	`"VLR\[Nu]edu"`
$\mathcal{O}_{uu}^{V1,LR}$	$(\bar{u}_{Lp}\, \gamma^\mu\, u_{Lr})(\bar{u}_{Rs}\, \gamma_\mu\, u_{Rt})$	`"V1LRuu"`
$\mathcal{O}_{uu}^{V8,LR}$	$(\bar{u}_{Lp}\, \gamma^\mu\, t^\alpha\, u_{Lr})(\bar{u}_{Rs}\, \gamma_\mu\, t^\alpha\, u_{Rt})$	`"V8LRuu"`
$\mathcal{O}_{ud}^{V1,LR}$	$(\bar{u}_{Lp}\, \gamma^\mu\, u_{Lr})(\bar{d}_{Rs}\, \gamma_\mu\, d_{Rt})$	`"V1LRud"`
$\mathcal{O}_{ud}^{V8,LR}$	$(\bar{u}_{Lp}\, \gamma^\mu\, t^\alpha\, u_{Lr})(\bar{d}_{Rs}\, \gamma_\mu\, t^\alpha\, d_{Rt})$	`"V8LRud"`
$\mathcal{O}_{du}^{V1,LR}$	$(\bar{d}_{Lp}\, \gamma^\mu\, d_{Lr})(\bar{u}_{Rs}\, \gamma_\mu\, u_{Rt})$	`"V1LRdu"`
$\mathcal{O}_{du}^{V8,LR}$	$(\bar{d}_{Lp}\, \gamma^\mu\, t^\alpha\, d_{Lr})(\bar{u}_{Rs}\, \gamma_\mu\, t^\alpha\, u_{Rt})$	`"V8LRdu"`
$\mathcal{O}_{dd}^{V1,LR}$	$(\bar{d}_{Lp}\, \gamma^\mu\, d_{Lr})(\bar{d}_{Rs}\, \gamma_\mu\, d_{Rt})$	`"V1LRdd"`
$\mathcal{O}_{dd}^{V8,LR}$	$(\bar{d}_{Lp}\, \gamma^\mu\, t^\alpha\, d_{Lr})(\bar{d}_{Rs}\, \gamma_\mu\, t^\alpha\, d_{Rt})$	`"V8LRdd"`
$\mathcal{O}_{uddu}^{V1,LR}$	$(\bar{u}_{Lp}\, \gamma^\mu\, d_{Lr})(\bar{d}_{Rs}\, \gamma_\mu\, u_{Rt}) + \text{h.c.}$	`"V1LRuddu"`
$\mathcal{O}_{uddu}^{V8,LR}$	$(\bar{u}_{Lp}\, \gamma^\mu\, t^\alpha\, d_{Lr})(\bar{d}_{Rs}\, \gamma_\mu\, t^\alpha\, u_{Rt}) + \text{h.c.}$	`"V8LRuddu"`

$(\bar{L}R)(\bar{L}R) + \text{h.c.}$

$\mathcal{O}_{ee}^{S,RR}$	$(\bar{e}_{Lp}\, e_{Rr})(\bar{e}_{Ls}\, e_{Rt})$	`"SRRee"`
$\mathcal{O}_{eu}^{S,RR}$	$(\bar{e}_{Lp}\, e_{Rr})(\bar{u}_{Ls}\, u_{Rt})$	`"SRReu"`
$\mathcal{O}_{eu}^{T,RR}$	$(\bar{e}_{Lp}\, \sigma^{\mu\nu}\, e_{Rr})(\bar{u}_{Ls}\, \sigma_{\mu\nu}\, u_{Rt})$	`"TRReu"`
$\mathcal{O}_{ed}^{S,RR}$	$(\bar{e}_{Lp}\, e_{Rr})(\bar{d}_{Ls}\, d_{Rt})$	`"SRRed"`
$\mathcal{O}_{ed}^{T,RR}$	$(\bar{e}_{Lp}\, \sigma^{\mu\nu}\, e_{Rr})(\bar{d}_{Ls}\, \sigma_{\mu\nu}\, d_{Rt})$	`"TRRed"`
$\mathcal{O}_{\nu edu}^{S,RR}$	$(\bar{\nu}_{Lp}\, e_{Rr})(\bar{d}_{Ls}\, u_{Rt})$	`"SRR\[Nu]edu"`
$\mathcal{O}_{\nu edu}^{T,RR}$	$(\bar{\nu}_{Lp}\, \sigma^{\mu\nu}\, e_{Rr})(\bar{d}_{Ls}\, \sigma_{\mu\nu}\, u_{Rt})$	`"TRR\[Nu]edu"`
$\mathcal{O}_{uu}^{S1,RR}$	$(\bar{u}_{Lp}\, u_{Rr})(\bar{u}_{Ls}\, u_{Rt})$	`"S1RRuu"`
$\mathcal{O}_{uu}^{S8,RR}$	$(\bar{u}_{Lp}\, t^\alpha\, u_{Rr})(\bar{u}_{Ls}\, t^\alpha\, u_{Rt})$	`"S8RRuu"`
$\mathcal{O}_{ud}^{S1,RR}$	$(\bar{u}_{Lp}\, u_{Rr})(\bar{d}_{Ls}\, d_{Rt})$	`"S1RRud"`
$\mathcal{O}_{ud}^{S8,RR}$	$(\bar{u}_{Lp}\, t^\alpha\, u_{Rr})(\bar{d}_{Ls}\, t^\alpha\, d_{Rt})$	`"S8RRud"`
$\mathcal{O}_{dd}^{S1,RR}$	$(\bar{d}_{Lp}\, d_{Rr})(\bar{d}_{Ls}\, d_{Rt})$	`"S1RRdd"`
$\mathcal{O}_{dd}^{S8,RR}$	$(\bar{d}_{Lp}\, t^\alpha\, d_{Rr})(\bar{d}_{Ls}\, t^\alpha\, d_{Rt})$	`"S8RRdd"`
$\mathcal{O}_{uddu}^{S1,RR}$	$(\bar{u}_{Lp}\, d_{Rr})(\bar{d}_{Ls}\, u_{Rt})$	`"S1RRuddu"`
$\mathcal{O}_{uddu}^{S8,RR}$	$(\bar{u}_{Lp}\, t^\alpha\, d_{Rr})(\bar{d}_{Ls}\, t^\alpha\, u_{Rt})$	`"S8RRuddu"`

$(\bar{L}R)(\bar{R}L) + \text{h.c.}$

$\mathcal{O}_{eu}^{S,RL}$	$(\bar{e}_{Lp}\, e_{Rr})(\bar{u}_{Rs}\, u_{Lt})$	`"SRLeu"`
$\mathcal{O}_{ed}^{S,RL}$	$(\bar{e}_{Lp}\, e_{Rr})(\bar{d}_{Rs}\, d_{Lt})$	`"SRLed"`
$\mathcal{O}_{\nu edu}^{S,RL}$	$(\bar{\nu}_{Lp}\, e_{Rr})(\bar{d}_{Rs}\, u_{Lt})$	`"SRL\[Nu]edu"`

LEFT operators up to dimension 6

4-fermion (fermion-number-violating)

$\Delta L = 4 + \text{h.c.}$

$\mathcal{O}_{\nu\nu}^{S,LL}$	$(\nu_{Lp}^T\, C\, \nu_{Lr})(\nu_{Ls}^T\, C\, \nu_{Lt})$	"SLL\[Nu]\[Nu]"

$\Delta B = -\Delta L = 1 + \text{h.c.}$

$\mathcal{O}_{ddd}^{S,LL}$	$\varepsilon_{abc}\,(d_{Lp}^{aT}\, C\, d_{Lr}^b)(\bar{e}_{Rs}\, d_{Lt}^c)$	"SLLddd"
$\mathcal{O}_{udd}^{S,LR}$	$\varepsilon_{abc}\,(u_{Lp}^{aT}\, C\, d_{Lr}^b)(\bar{\nu}_{Ls}\, d_{Rt}^c)$	"SLRudd"
$\mathcal{O}_{ddu}^{S,LR}$	$\varepsilon_{abc}\,(d_{Lp}^{aT}\, C\, d_{Lr}^b)(\bar{\nu}_{Ls}\, u_{Rt}^c)$	"SLRddu"
$\mathcal{O}_{ddd}^{S,LR}$	$\varepsilon_{abc}\,(d_{Lp}^{aT}\, C\, d_{Lr}^b)(\bar{e}_{Ls}\, d_{Rt}^c)$	"SLRddd"
$\mathcal{O}_{ddd}^{S,RL}$	$\varepsilon_{abc}\,(d_{Rp}^{aT}\, C\, d_{Rr}^b)(\bar{e}_{Rs}\, d_{Lt}^c)$	"SRLddd"
$\mathcal{O}_{udd}^{S,RR}$	$\varepsilon_{abc}\,(u_{Rp}^{aT}\, C\, d_{Rr}^b)(\bar{\nu}_{Ls}\, d_{Rt}^c)$	"SRRudd"
$\mathcal{O}_{ddd}^{S,RR}$	$\varepsilon_{abc}\,(d_{Rp}^{aT}\, C\, d_{Rr}^b)(\bar{e}_{Ls}\, d_{Rt}^c)$	"SRRddd"

$\Delta L = 2 + \text{h.c.}$

$\mathcal{O}_{\nu e}^{S,LL}$	$(\nu_{Lp}^T\, C\, \nu_{Lr})(\bar{e}_{Rs}\, e_{Lt})$	"SLL\[Nu]e"
$\mathcal{O}_{\nu e}^{T,LL}$	$(\nu_{Lp}^T\, C\, \sigma^{\mu\nu}\, \nu_{Lr})(\bar{e}_{Rs}\, \sigma_{\mu\nu}\, e_{Lt})$	"TLL\[Nu]e"
$\mathcal{O}_{\nu e}^{S,LR}$	$(\nu_{Lp}^T\, C\, \nu_{Lr})(\bar{e}_{Ls}\, e_{Rt})$	"SLR\[Nu]e"
$\mathcal{O}_{\nu u}^{S,LL}$	$(\nu_{Lp}^T\, C\, \nu_{Lr})(\bar{u}_{Rs}\, u_{Lt})$	"SLL\[Nu]u"
$\mathcal{O}_{\nu u}^{T,LL}$	$(\nu_{Lp}^T\, C\, \sigma^{\mu\nu}\, \nu_{Lr})(\bar{u}_{Rs}\, \sigma_{\mu\nu}\, u_{Lt})$	"TLL\[Nu]u"
$\mathcal{O}_{\nu u}^{S,LR}$	$(\nu_{Lp}^T\, C\, \nu_{Lr})(\bar{u}_{Ls}\, u_{Rt})$	"SLR\[Nu]u"
$\mathcal{O}_{\nu d}^{S,LL}$	$(\nu_{Lp}^T\, C\, \nu_{Lr})(\bar{d}_{Rs}\, d_{Lt})$	"SLL\[Nu]d"
$\mathcal{O}_{\nu d}^{T,LL}$	$(\nu_{Lp}^T\, C\, \sigma^{\mu\nu}\, \nu_{Lr})(\bar{d}_{Rs}\, \sigma_{\mu\nu}\, d_{Lt})$	"TLL\[Nu]d"
$\mathcal{O}_{\nu d}^{S,LR}$	$(\nu_{Lp}^T\, C\, \nu_{Lr})(\bar{d}_{Ls}\, d_{Rt})$	"SLR\[Nu]d"
$\mathcal{O}_{\nu edu}^{S,LL}$	$(\nu_{Lp}^T\, C\, e_{Lr})(\bar{d}_{Rs}\, u_{Lt})$	"SLL\[Nu]edu"
$\mathcal{O}_{\nu edu}^{T,LL}$	$(\nu_{Lp}^T\, C\, \sigma^{\mu\nu}\, e_{Lr})(\bar{d}_{Rs}\, \sigma_{\mu\nu}\, u_{Lt})$	"TLL\[Nu]edu"
$\mathcal{O}_{\nu edu}^{S,LR}$	$(\nu_{Lp}^T\, C\, e_{Lr})(\bar{d}_{Ls}\, u_{Rt})$	"SLR\[Nu]edu"
$\mathcal{O}_{\nu edu}^{V,RL}$	$(\nu_{Lp}^T\, C\, \gamma^{\mu}\, e_{Rr})(\bar{d}_{Ls}\, \gamma_{\mu}\, u_{Lt})$	"VRL\[Nu]edu"
$\mathcal{O}_{\nu edu}^{V,RR}$	$(\nu_{Lp}^T\, C\, \gamma^{\mu}\, e_{Rr})(\bar{d}_{Rs}\, \gamma_{\mu}\, u_{Rt})$	"VRR\[Nu]edu"

$\Delta B = \Delta L = 1 + \text{h.c.}$

$\mathcal{O}_{udd}^{S,LL}$	$\varepsilon_{abc}\,(u_{Lp}^{aT}\, C\, d_{Lr}^b)(d_{Ls}^{cT}\, C\, \nu_{Lt})$	"SLLudd"
$\mathcal{O}_{duu}^{S,LL}$	$\varepsilon_{abc}\,(d_{Lp}^{aT}\, C\, u_{Lr}^b)(u_{Ls}^{cT}\, C\, e_{Lt})$	"SLLduu"
$\mathcal{O}_{uud}^{S,LR}$	$\varepsilon_{abc}\,(u_{Lp}^{aT}\, C\, u_{Lr}^b)(d_{Rs}^{cT}\, C\, e_{Rt})$	"SLRuud"
$\mathcal{O}_{duu}^{S,LR}$	$\varepsilon_{abc}\,(d_{Lp}^{aT}\, C\, u_{Lr}^b)(u_{Rs}^{cT}\, C\, e_{Rt})$	"SLRduu"
$\mathcal{O}_{uud}^{S,RL}$	$\varepsilon_{abc}\,(u_{Rp}^{aT}\, C\, u_{Rr}^b)(d_{Ls}^{cT}\, C\, e_{Lt})$	"SRLuud"
$\mathcal{O}_{duu}^{S,RL}$	$\varepsilon_{abc}\,(d_{Rp}^{aT}\, C\, u_{Rr}^b)(u_{Ls}^{cT}\, C\, e_{Lt})$	"SRLduu"
$\mathcal{O}_{dud}^{S,RL}$	$\varepsilon_{abc}\,(d_{Rp}^{aT}\, C\, u_{Rr}^b)(d_{Ls}^{cT}\, C\, \nu_{Lt})$	"SRLdud"
$\mathcal{O}_{ddu}^{S,RL}$	$\varepsilon_{abc}\,(d_{Rp}^{aT}\, C\, d_{Rr}^b)(u_{Ls}^{cT}\, C\, \nu_{Lt})$	"SRLddu"
$\mathcal{O}_{duu}^{S,RR}$	$\varepsilon_{abc}\,(d_{Rp}^{aT}\, C\, u_{Rr}^b)(u_{Rs}^{cT}\, C\, e_{Rt})$	"SRRduu"

LEFT operators up to dimension 6

on-shell redundant

$(\nu\nu)D^2$ + h.c.

$\mathcal{O}_{\nu D}$	$\nu_{Lp}^T\, C\, (i\slashed{\partial})^2\, \nu_{Lr}$	"\[Nu]D"

$(\bar{L}R)D^2$ + h.c.

$\mathcal{O}_{eD}$	$\bar{e}_{Lp}\, (i\slashed{D})^2\, e_{Rr}$	"eD"
$\mathcal{O}_{uD}$	$\bar{u}_{Lp}\, (i\slashed{D})^2\, u_{Rr}$	"uD"
$\mathcal{O}_{dD}$	$\bar{d}_{Lp}\, (i\slashed{D})^2\, d_{Rr}$	"dD"

$(\bar{L}L)D^3$

$\mathcal{O}^L_{\nu D}$	$\bar{\nu}_{Lp}\, (i\slashed{\partial})^3\, \nu_{Lr}$	"L\[Nu]D"
$\mathcal{O}^L_{eD}$	$\bar{e}_{Lp}\, (i\slashed{D})^3\, e_{Lr}$	"LeD"
$\mathcal{O}^L_{uD}$	$\bar{u}_{Lp}\, (i\slashed{D})^3\, u_{Lr}$	"LuD"
$\mathcal{O}^L_{dD}$	$\bar{d}_{Lp}\, (i\slashed{D})^3\, d_{Lr}$	"LdD"

$(\bar{R}R)D^3$

$\mathcal{O}^R_{eD}$	$\bar{e}_{Rp}\, (i\slashed{D})^3\, e_{Rr}$	"ReD"
$\mathcal{O}^R_{uD}$	$\bar{u}_{Rp}\, (i\slashed{D})^3\, u_{Rr}$	"RuD"
$\mathcal{O}^R_{dD}$	$\bar{d}_{Rp}\, (i\slashed{D})^3\, d_{Rr}$	"RdD"

$(\bar{L}L)XD$

$\mathcal{O}^L_{D\nu\gamma}$	$(\bar{\nu}_{Lp}\, i\overleftarrow{\slashed{\partial}}\, \sigma^{\mu\nu}\, \nu_{Lr})\, F_{\mu\nu}$	"LD\[Nu]\[Gamma]"
$\mathcal{O}^L_{\nu D\gamma}$	$(\bar{\nu}_{Lp}\, \sigma^{\mu\nu} i\slashed{\partial}\, \nu_{Lr})\, F_{\mu\nu}$	"L\[Nu]D\[Gamma]"
$\mathcal{O}^L_{\nu\gamma D}$	$(\bar{\nu}_{Lp}\, \gamma^\mu\, \nu_{Lr})(\partial^\nu F_{\mu\nu})$	"L\[Nu]\[Gamma]D"
$\mathcal{O}^L_{De\gamma}$	$(\bar{e}_{Lp}\, i\overleftarrow{\slashed{D}}\, \sigma^{\mu\nu}\, e_{Lr})\, F_{\mu\nu}$	"LDe\[Gamma]"
$\mathcal{O}^L_{eD\gamma}$	$(\bar{e}_{Lp}\, \sigma^{\mu\nu} i\slashed{D}\, e_{Lr})\, F_{\mu\nu}$	"LeD\[Gamma]"
$\mathcal{O}^L_{e\gamma D}$	$(\bar{e}_{Lp}\, \gamma^\mu\, e_{Lr})(\partial^\nu F_{\mu\nu})$	"Le\[Gamma]D"
$\mathcal{O}^L_{Du\gamma}$	$(\bar{u}_{Lp}\, i\overleftarrow{\slashed{D}}\, \sigma^{\mu\nu}\, u_{Lr})\, F_{\mu\nu}$	"LDu\[Gamma]"
$\mathcal{O}^L_{uD\gamma}$	$(\bar{u}_{Lp}\, \sigma^{\mu\nu} i\slashed{D}\, u_{Lr})\, F_{\mu\nu}$	"LuD\[Gamma]"
$\mathcal{O}^L_{u\gamma D}$	$(\bar{u}_{Lp}\, \gamma^\mu\, u_{Lr})(\partial^\nu F_{\mu\nu})$	"Lu\[Gamma]D"
$\mathcal{O}^L_{Dd\gamma}$	$(\bar{d}_{Lp}\, i\overleftarrow{\slashed{D}}\, \sigma^{\mu\nu}\, d_{Lr})\, F_{\mu\nu}$	"LDd\[Gamma]"
$\mathcal{O}^L_{dD\gamma}$	$(\bar{d}_{Lp}\, \sigma^{\mu\nu} i\slashed{D}\, d_{Lr})\, F_{\mu\nu}$	"LdD\[Gamma]"
$\mathcal{O}^L_{d\gamma D}$	$(\bar{d}_{Lp}\, \gamma^\mu\, d_{Lr})(\partial^\nu F_{\mu\nu})$	"Ld\[Gamma]D"
$\mathcal{O}^L_{DuG}$	$(\bar{u}_{Lp}\, i\overleftarrow{\slashed{D}}\, \sigma^{\mu\nu} t^\alpha\, u_{Lr})\, G^\alpha_{\mu\nu}$	"LDuG"
$\mathcal{O}^L_{uDG}$	$(\bar{u}_{Lp}\, \sigma^{\mu\nu} t^\alpha i\slashed{D}\, u_{Lr})\, G^\alpha_{\mu\nu}$	"LuDG"
$\mathcal{O}^L_{uGD}$	$(\bar{u}_{Lp}\, \gamma^\mu\, t^\alpha\, u_{Lr})(D^\nu G^\alpha_{\mu\nu})$	"LuGD"
$\mathcal{O}^L_{DdG}$	$(\bar{d}_{Lp}\, i\overleftarrow{\slashed{D}}\, \sigma^{\mu\nu} t^\alpha\, d_{Lr})\, G^\alpha_{\mu\nu}$	"LDdG"
$\mathcal{O}^L_{dDG}$	$(\bar{d}_{Lp}\, \sigma^{\mu\nu} t^\alpha i\slashed{D}\, d_{Lr})\, G^\alpha_{\mu\nu}$	"LdDG"
$\mathcal{O}^L_{dGD}$	$(\bar{d}_{Lp}\, \gamma^\mu\, t^\alpha\, d_{Lr})(D^\nu G^\alpha_{\mu\nu})$	"LdGD"

$(\bar{R}R)XD$

$\mathcal{O}^R_{De\gamma}$	$(\bar{e}_{Rp}\, i\overleftarrow{\slashed{D}}\, \sigma^{\mu\nu}\, e_{Rr})\, F_{\mu\nu}$	"RDe\[Gamma]"
$\mathcal{O}^R_{eD\gamma}$	$(\bar{e}_{Rp}\, \sigma^{\mu\nu} i\slashed{D}\, e_{Rr})\, F_{\mu\nu}$	"ReD\[Gamma]"
$\mathcal{O}^R_{e\gamma D}$	$(\bar{e}_{Rp}\, \gamma^\mu\, e_{Rr})(\partial^\nu F_{\mu\nu})$	"Re\[Gamma]D"
$\mathcal{O}^R_{Du\gamma}$	$(\bar{u}_{Rp}\, i\overleftarrow{\slashed{D}}\, \sigma^{\mu\nu}\, u_{Rr})\, F_{\mu\nu}$	"RDu\[Gamma]"
$\mathcal{O}^R_{uD\gamma}$	$(\bar{u}_{Rp}\, \sigma^{\mu\nu} i\slashed{D}\, u_{Rr})\, F_{\mu\nu}$	"RuD\[Gamma]"
$\mathcal{O}^R_{u\gamma D}$	$(\bar{u}_{Rp}\, \gamma^\mu\, u_{Rr})(\partial^\nu F_{\mu\nu})$	"Ru\[Gamma]D"
$\mathcal{O}^R_{Dd\gamma}$	$(\bar{d}_{Rp}\, i\overleftarrow{\slashed{D}}\, \sigma^{\mu\nu}\, d_{Rr})\, F_{\mu\nu}$	"RDd\[Gamma]"
$\mathcal{O}^R_{dD\gamma}$	$(\bar{d}_{Rp}\, \sigma^{\mu\nu} i\slashed{D}\, d_{Rr})\, F_{\mu\nu}$	"RdD\[Gamma]"
$\mathcal{O}^R_{d\gamma D}$	$(\bar{d}_{Rp}\, \gamma^\mu\, d_{Rr})(\partial^\nu F_{\mu\nu})$	"Rd\[Gamma]D"
$\mathcal{O}^R_{DuG}$	$(\bar{u}_{Rp}\, i\overleftarrow{\slashed{D}}\, \sigma^{\mu\nu} t^\alpha\, u_{Rr})\, G^\alpha_{\mu\nu}$	"RDuG"
$\mathcal{O}^R_{uDG}$	$(\bar{u}_{Rp}\, \sigma^{\mu\nu} t^\alpha i\slashed{D}\, u_{Rr})\, G^\alpha_{\mu\nu}$	"RuDG"
$\mathcal{O}^R_{uGD}$	$(\bar{u}_{Rp}\, \gamma^\mu\, t^\alpha\, u_{Rr})(D^\nu G^\alpha_{\mu\nu})$	"RuGD"
$\mathcal{O}^R_{DdG}$	$(\bar{d}_{Rp}\, i\overleftarrow{\slashed{D}}\, \sigma^{\mu\nu} t^\alpha\, d_{Rr})\, G^\alpha_{\mu\nu}$	"RDdG"
$\mathcal{O}^R_{dDG}$	$(\bar{d}_{Rp}\, \sigma^{\mu\nu} t^\alpha i\slashed{D}\, d_{Rr})\, G^\alpha_{\mu\nu}$	"RdDG"
$\mathcal{O}^R_{dGD}$	$(\bar{d}_{Rp}\, \gamma^\mu\, t^\alpha\, d_{Rr})(D^\nu G^\alpha_{\mu\nu})$	"RdGD"

X^2D^2

$\mathcal{O}_{\gamma D}$	$(\partial_\mu F^{\mu\nu})(\partial^\rho F_{\rho\nu})$	"\[Gamma]D"
$\mathcal{O}_{GD}$	$(D_\mu G^{\alpha,\mu\nu})(D^\rho G^\alpha_{\rho\nu})$	"GD"