WP2 Summary Talk

Form Factor Contributions beyond NNLO

Tim Engel
Albert-Ludwigs-Universität Freiburg

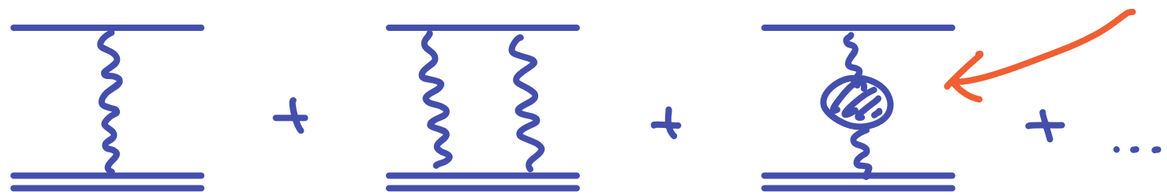
8/6/2023

Overview

$$d\sigma^{(3)}_{e^+e^-\to\gamma^*} = \underbrace{\int d\Phi_n\, \mathcal{M}^{(3)}_n}_{VVV} + \underbrace{\int d\Phi_{n+1}\, \mathcal{M}^{(2)}_{n+1}}_{rVV} + \underbrace{\int d\Phi_{n+2}\, \mathcal{M}^{(1)}_{n+2}}_{rrV} + \underbrace{\int d\Phi_{n+3}\, \mathcal{M}^{(0)}_{n+3}}_{rrr}$$

fully differential !

motivation MUonE [Abbiendi et al. 17] → talk G. Abbiendi



mmt @ 1%

calculate @ 10 ppm

EW@NLO ~ 20% [Alacevich, Calame, Chiesa, Montagna, Nicrosini, Piccinini 19]

QED@NNLO ~ 2% [Calame, Chiesa, Hasan, Montagna, Nicrosini, Piccinini 20] [Banerjee, TE, Signer, Ulrich 20] [Broggio et al. 22]

talk M. Rocco

QED@N^{3}LO ~ ?

parton showers ↝ talk C.C. Calame

Overview

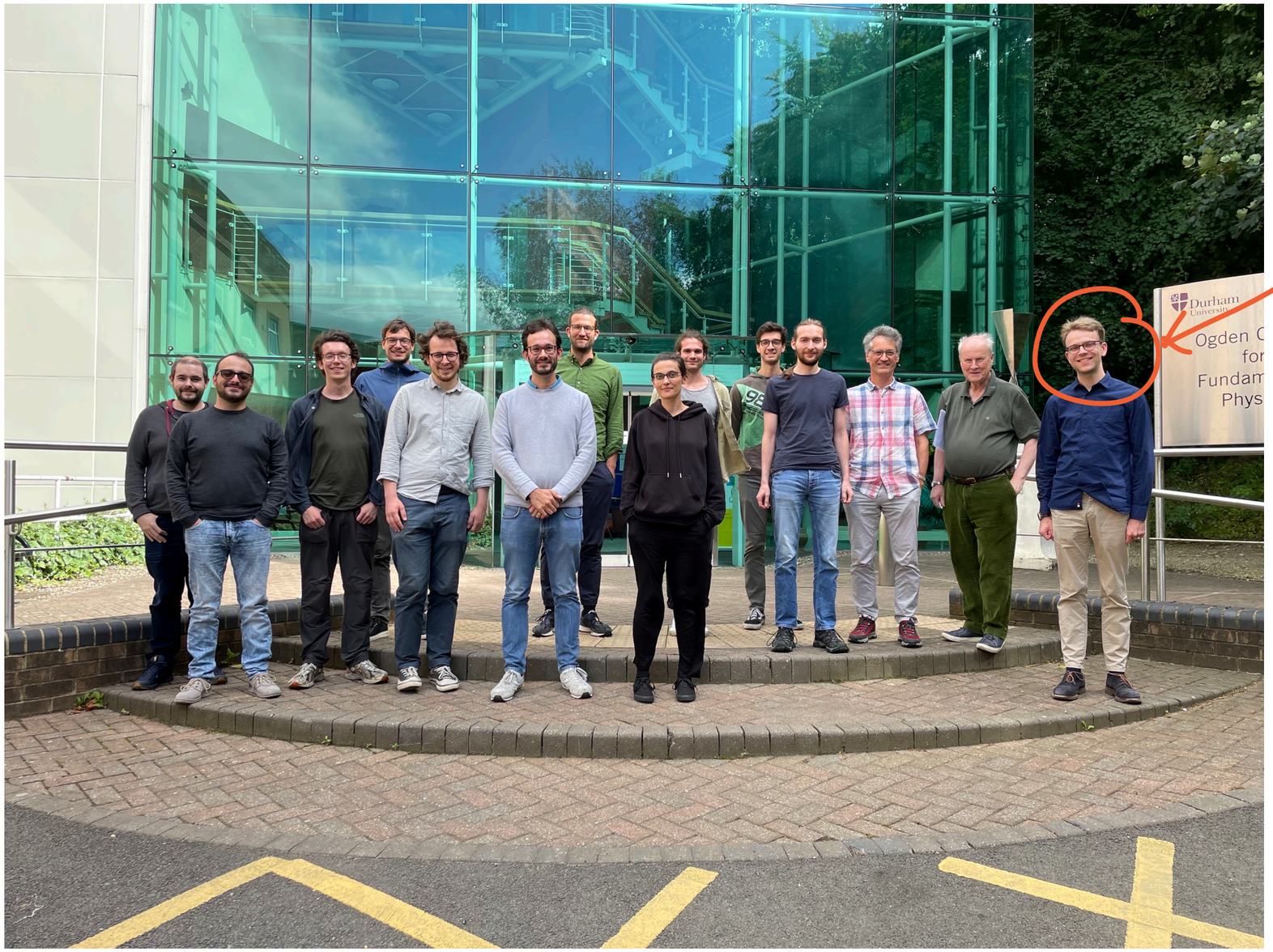
$$d\sigma^{(3)}_{e^+e^-\to\gamma^*} = \underbrace{\int d\Phi_n \mathcal{M}^{(3)}_n}_{VVV} + \underbrace{\int d\Phi_{n+1} \mathcal{M}^{(2)}_{n+1}}_{rVV} + \underbrace{\int d\Phi_{n+2} \mathcal{M}^{(1)}_{n+2}}_{rrV} + \underbrace{\int d\Phi_{n+3} \mathcal{M}^{(0)}_{n+3}}_{rrr}$$

fully differential !

challenges

- calculation of $\mathcal{M}^{(3)}_n$
- calculation of $\mathcal{M}^{(2)}_{n+1}$
- numerical (in)stability of $\mathcal{M}^{(1)}_{n+2}$
- IR subtraction scheme @ N^3LO

N^3LO kick-off workshop/thinkstart (3.8 – 5.8 2022, IPPP Durham)



organiser
Y. Ulrich

Why we think it's possible

$$d\sigma^{(3)}_{e^+e^-\to\gamma^*} = \underbrace{\int d\Phi_n \mathcal{M}^{(3)}_n}_{VVV} + \underbrace{\int d\Phi_{n+1} \mathcal{M}^{(2)}_{n+1}}_{RVV} + \underbrace{\int d\Phi_{n+2} \mathcal{M}^{(1)}_{n+2}}_{RRV} + \underbrace{\int d\Phi_{n+3} \mathcal{M}^{(0)}_{n+3}}_{RRR}$$

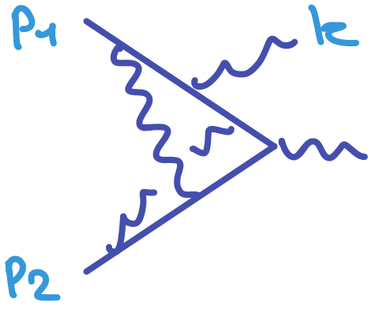
fully differential !

challenges

- calculation of $\mathcal{M}^{(3)}_n$ ✓ [Fael, Lange, Schönwald, Steinhauser 2x22, 23]
  ↳ workstop talk F. Lange
- calculation of $\mathcal{M}^{(2)}_{n+1}$ ⊗
- numerical (in)stability of $\mathcal{M}^{(1)}_{n+2}$ ☺
  ⇝ OpenLoops [Buccioni, Lang, Lindert, Maierhöfer, Pozzorini, Zhang, Zoller 19]
  ⇝ NTS stabilisation [Banerjee, TE, Schalch, Signer, Ulrich 21]
- IR subtraction scheme @ N^3LO ✓ [TE, Signer, Ulrich 20]

⇝ fully-differential N^3LO calculation within reach !

RVV: the numerical approach



} analytic approach with $p_i^2 = m^2 \neq 0$ <u>not</u> feasible

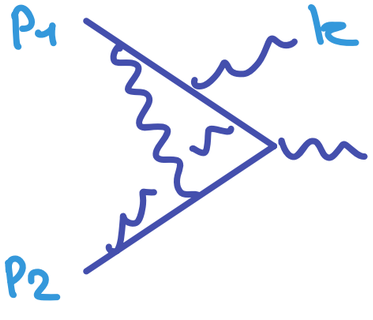
4 scales
elliptic

<u>but</u> many promising numerical tools available :

- DiffExp [Hidding 21]
- AMFlow [Liu, Ma 23]
- SecDec [Borowka, Heinrich, Jones, Kerner, Schlenk, Zirke 15]
- feyntrop [Borinsky, Munch, Tellander 23]
- dispersive approach ⇝ workshop talk A. Gurgone
- ...

RVV: the analytic approach

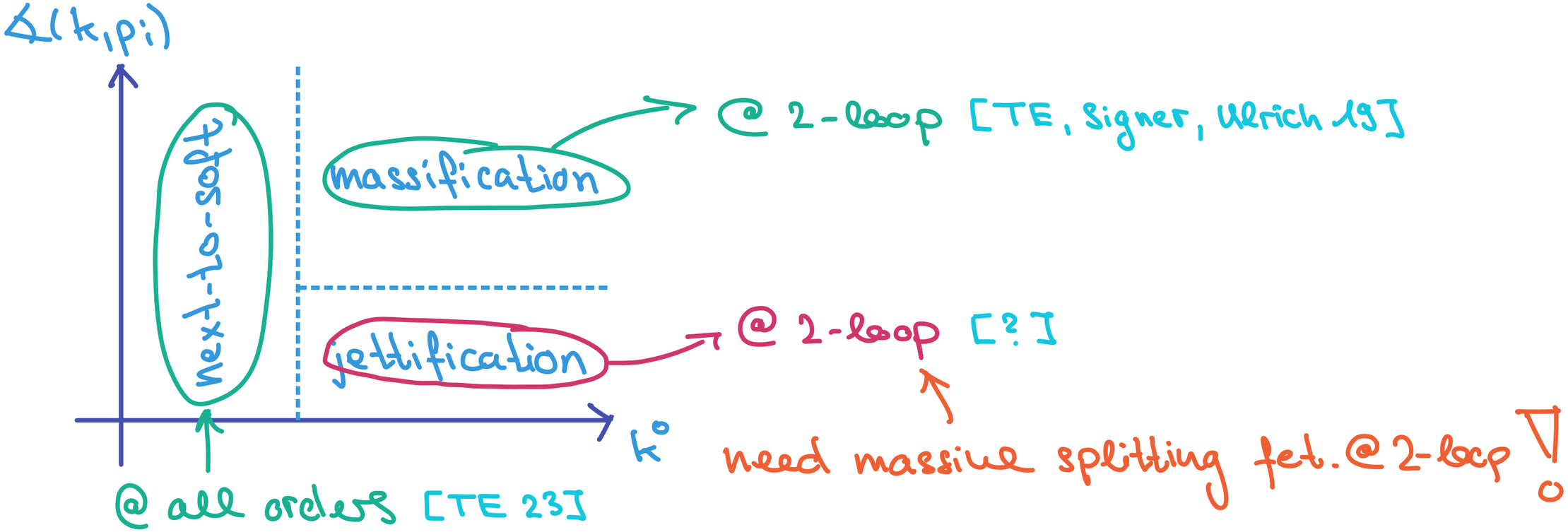
known for $m=0$ ⇝ talk R. Moodie



three (main) scale hierarchies:

$m^2 \ll Q^2$ $\quad$ $\underbrace{k\cdot p_i \sim m^2 \ll Q^2}_{\text{collinear}}$ $\quad$ $\underbrace{k \ll Q, m}_{\text{soft}}$

idea exploit factorisation theorems in SCET / HQET



Conclusions

WP2 assessment

Fully-differential N^3LO calculation feasible :

- calculation of $\mathcal{M}_n^{(3)}$ ✓
- numerical (in)stability of $\mathcal{M}_{n+2}^{(1)}$ ✓
- IR subtraction scheme @ N^3LO ✓
- calculation of $\mathcal{M}_{n+1}^{(2)}$ ✗ $\left\{ \begin{array}{l} \text{numerical but exact approach} \\ \text{analytic but approx. approach} \end{array} \right.$