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e^+e^- physics: what needs to be done

MG/FR meeting, Bonn, 16/11/2021

Most relevant papers:

- 1804.10017

  Automation of fixed-order $\alpha_S^k \alpha^p$ results. No QED ISR

- 1909.03886, 1911.12040, 2105.06688

  NLL-accurate QED PDFs. Blueprint for FFs

- 2108.10261

  beamstrahlung and LO+LL ISR implementation in MG5_aMC

Being done:

- Extension of 2108.10261 to NLO+NLL ISR

  by looking at observable cross sections

Lessons learned/observations:

1.

We had to give up on event projection for QED ISR

$e^{\pm}$ PDFs are essentially δ functions

2.

We need an UFO for the SM in $\overline{\mathrm{MS}}$

3.

It is easy to obtain results for $\mu^{\pm}$ PDFs

muon-collider phenomenology

More on 1.

- No event projection $\Longrightarrow$ no matching to MCs (as is done currently)
- In any case, MC-matching would not be NLL accurate
- May consider ISR PDFs $+$ FSR MC-matching?

  $\longrightarrow$ ISR's $\log p_T$ not resummed

Bottom line: some form of QED ISR matching is needed.
Matching without event projection, or with a modified event projection?
Must talk to MC authors. Experiments want final-state γ's

In addition to the above:

- We still don't have showers from non-leading amplitudes, (N)LO$_i$, $i \geq 2$

  Methods of 2106.13471 may provide a general framework for both QCD and QED

More on 2.

- A prescription by means of which one ends up with a factor $\alpha(0)^l \alpha_{G_F}^k \alpha(m_Z)^{n-l-k}$ is not suited to automation
- Even if it were, it stems from a framework where there was a single mass scale (m_Z)
- Several of us are on record (1612.06548) with the proposal of a much simpler, elegant, and universal solution: $\overline{\mathrm{MS}}$
- And that was before we knew anything about NLL QED PDFs
- Added benefit: to address another relic of the past, the $\alpha(0)$ scheme (which, incidentally, works only for FSR)

$\alpha(0)$ scheme: Buscar el Levante por el Ponente

(aka: UV by means of IR)

- The photon splits: IR singularity cancelled by that of self-energy. S-matrix residues are IR-finite in $\overline{\mathrm{MS}}$-like schemes
- The photon can't split: self-energy IR singularity uncancelled. Compensated by IR-divergent S-matrix residues in on-shell schemes

This technical difference is related to a more fundamental one,
ie the identification of two objects which are best kept distinct:
the short-distance photon and the observable photon

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We don't travel any longer to Japan going west (and in 20-meter wooden ships).
We don't need any longer to use the $\alpha(0)$ scheme

Our proposal (1612.06548):

A photon is taggable (i.e. can be subject to physical cuts) only if it emerges from a fragmentation process

Thus:

- A fragmentation function (FF) $D_\gamma^{(a)}$ must be introduced for each possible $a \to \gamma$ "hadronisation", with a any "parton"
- Key: this includes $D_\gamma^{(\gamma)}$ for $\gamma \to \gamma$ (turns a short-distance photon into a taggable photon)
- Note: $D_\gamma^{(q)}$ is necessary already at NLO EW when applying an E_γ cut

From the purely perturbative FF evolution:

$$D_{\gamma}^{(\gamma)}(z,\mu) = \frac{\alpha(0)}{\alpha(\mu)}\delta(1-z) + \cdots$$

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Bottom line:

- UFO for SM in the $\overline{\mathrm{MS}}$: look for early 90's results (Degrassi, Sirlin, ...)
- Well-defined project: implement FFs (following 1804.10017 for FKS) for leptons and photons

For the future:

- Incoming lepton polarisations?

  Most likely one can follow 1909.03886, 1911.12040, 2105.06688

- Resummation of soft non-collinear logs in $e^{\pm}$ PDFs

ASIDE

ATLAS has generated large samples (30M) of FxFx $V + j$ events, with and without an H_T bias. They want to use the former to improve the statistics in production, and the latter serves as a closure test

Initially the closure test was failing, and it took a long time (and specifically a lot of Rikkert's) to figure out the problem(s). Some observations:

- The accuracy for the closure test to pass depends on the largest parton multiplicity: at 1% one is limited to $V + 1p$, at 0.1% to $V + 2p$, and at 0.01% to $V + 3p$. Pragmatically acceptable, but it is misleading
- " the running time for Z+3jets with 0.1 per mille accuracy is incredibly high (up to 6 weeks running over 32 cores)"
- "It is very complicated to recover broken jobs (actually we do it by hand so maybe to introduce a functionality which does it automatically might be good and very user friendly)"