

Monte Carlo generators

&

radiative corrections

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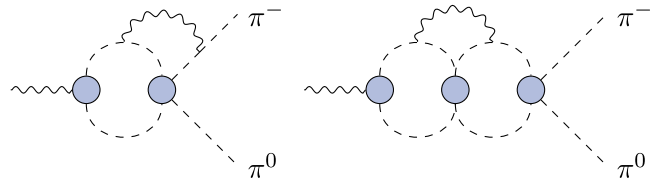
Recap I : iso spin breaking for $\pi\pi$ scattering

Watson theorem:
same phase of $e^+e^- \rightarrow \pi\pi$
and $\pi\pi \rightarrow \pi\pi$ if only
 $\pi\pi$ inter. states

$\rightarrow$ control rescattering effects

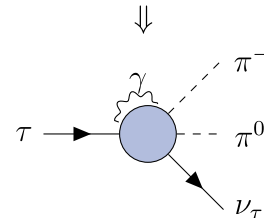
Higher order corrections

Work in progress: FSR



- Matching to χ PT of all (sub)amplitudes
- improved estimate of **uncertainties**

$\rightarrow$ see Monnard PhD thesis and Jacobo's talk at KEK



Recap II: Radio Monte Carlo 2

review & improve MC

Phase I $\nearrow$ $\nwarrow$ Phase II

Big question $\gamma^n \pi \pi$

$n=1 \leadsto F \times \text{eQED}$

$n=2 \leadsto F \times \text{eQED}, F_S \text{QED}$
 $G_{\text{VMD}}, \dots$

$n > 2$??

Pisa consensus:

$\overline{I} \dots \leadsto \overline{I} \dots$

beyond?



PH.2 :: ... to Improving MCs

o **fixed-order**: NNNLO for $2 \rightarrow 2$ (through $e^+e^- \rightarrow \gamma^*$ @ NNNLO)

NNLO for $2 \rightarrow 3$ (through $e^+e^- \rightarrow \gamma^*\gamma$ @ NNLO)

$\hookrightarrow$ Sophie's and Pau's talks later today

o **hadrons**: FsQED, GVMD used and compared in [2409.03469] [↗](#)

$\hookrightarrow$ Fulvio's talk later today

FSC for $2 \rightarrow 3$ needs improvement/better understanding

o **all-order**: combine higher fixed orders with CS/PS/YFS, e.g.

o NLOPS for $XX\gamma$ (BABAYAGA)

o EEX+NNLO (McMULE)

o improved CEEX+NNLO (PHOKHARA)

o NLO+YFS w/ improved VP (SHERPA)

Recap III : McMele

NULO ISC almost done

→ corrections look large...

→ limits to applicability

calculation of $ee \rightarrow \pi\pi$ with a focus on automation

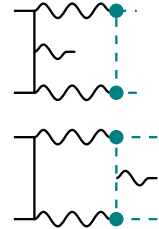
(Openloops / EFT / threshold)



a mule never stops – outlook

pions

- $q_e^3 q_\pi^2$ contributions for $ee \rightarrow \pi\pi\gamma$ in FsQED in preparation
- RMCL2 plan (Pisa consensus) :: FsQED also beyond $q_e^3 q_\pi^2$
- rescattering corrections ...?



radiative NNLO

- finish $ee \rightarrow \gamma\gamma^*$ investigations & add VP (to be solved: collinear emission & higher energies)
- full $ee \rightarrow \mu\mu\gamma$ with (virtual)² from [Badger et al 23]'s $pp \rightarrow 2j + \gamma$



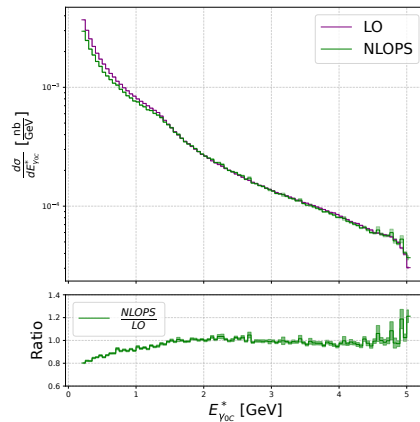
Recap IV Baba Yaga @ NLO

- support for $ee \rightarrow \pi\pi$
using FxQED, FsQED, GUM0
& parton shower

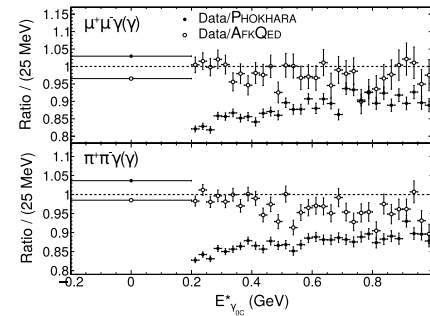
- goal: NLO PS for 2γ
 $\rightarrow$ allows for estimates
of more radiation

Preliminary results of the simulation (I)

- $e^+e^- \rightarrow \mu^+\mu^-\gamma$



- (BaBar Coll.), arXiv:2308.05233



Recap ν : Fast evaluation for MC

Phokhara gets CEEEX
(VIP)

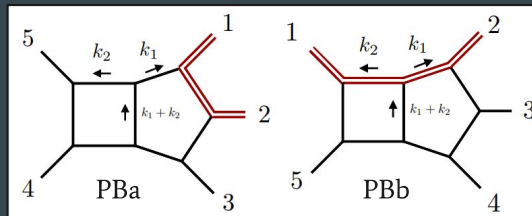
NLO needs amplitudes

$\rightarrow$ needs integrals

numerical evaluation

Two-loop $pp \rightarrow tt + \text{jet}$

Test the integrator with something similar to $e^+e^- \rightarrow x^+x^-\gamma$.



- Evaluated random benchmark points.
- Big speed up (x1000 in double, x10 in quad), compared with DiffExp.
- Opens the door to on-the-fly evaluation!

Figure from
[2404.12325]

		$\mathcal{T}_A, \mathcal{T}_R$	$\mathcal{R}$	$\langle \tau \rangle$ [s]	DiffExp $\langle \tau \rangle$ [s]
PB _A	double	$10^{-12}, 10^{-12}$	10	0.0881	580.85
	quad	$10^{-28}, 10^{-28}$	27	51.588	795.516
PB _B	double	$10^{-12}, 10^{-12}$	10	0.100	555.438
	quad	$10^{-28}, 10^{-28}$	27	89.088	826.219

Things to talk about I

- can we agree on notation? NLO vs. one extra photon
- who is doing what? when do we expect results?
within RMCL2? outside RMCL2?
- can we ensure that everyone uses canonical versions of code? e.g. v. 9 with fixes (which?) in VP
- what technical requirements do we have for MC?

Things to talk about II

- how do we treat structure-dependent corrections?
is the Pisa consensus sensible?  

- what is the impact of radiation beyond NLO, i.e. $ee \rightarrow t\bar{t}\gamma\gamma$
loops vs. new topologies?

- Fedor: what about interference of ISC & FSC?


- what is the impact of 3π & 4π scattering on 2π MC