MCGPJ and ReneSANCe MC event generators: status and perspectives

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OUR WAY TO HIGH PRECISION

MOTIVATION

- Analyze advantages and problems in existing codes
- Extended features, e.g., polarization and new processes
- Look for new analytic results that can be implemented
- Optimization of MC generators, e.g., in extreme kinematical regions
- Re-estimation of theoretical uncertainties
- Preparation for new experiments

MCGPJ

Monte-Carlo Generator with Photon Jets (MCGPJ)
[A.A., G.Fedotovich, F.Ignatov, E.Kuraev, A.Sibidanov, EPJC 46 (2006) 3]
is based on [A.A. et al., JHEP 10 (1997) 006; JHEP 10 (1997) 001]

Non-collinear regions are treated in $\mathcal{O}(\alpha)$ and collinear ones in the leading logarithmic approximation. A matching to recover the complete $\mathcal{O}(\alpha)$ correction is realized.

Advantages: universal treatment of collinear radiation for various processes; possibility to add new channels; a good precision ($\sim 0.2\%$) for sufficiently inclusive (IR-safe) observables

Drawbacks: approximate kinematics for multi-photon events leads to lower precision in some cases; there are a few negatively weighted events

More about MCGPJ in Fedor Ignatov's talks.

RENESANCE

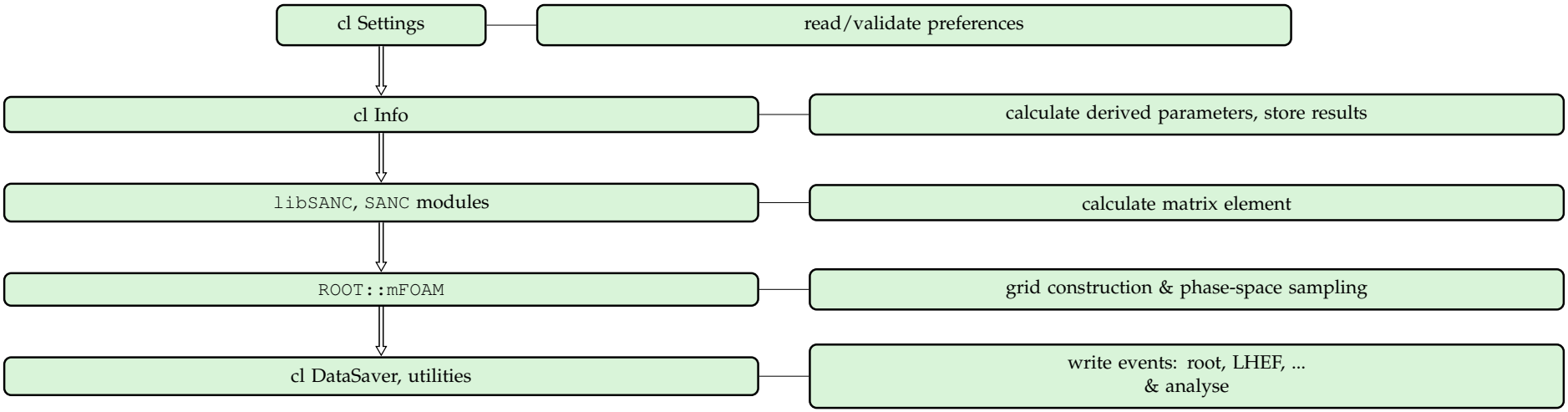
Renewed SANC Monte Carlo event generator (ReneSANCe) is a program for simulation of processes at e^+e^- colliders. Primarily it is devoted to FCC-ee and CEPC physics but not only.

- The following processes are fully implemented:
  - Bhabha scattering ($e^+e^- \to e^-e^+$)
  - Higgs-strahlung ($e^+e^- \to ZH$)
  - s-channel ($e^+e^- \to \mu^-\mu^+, \tau^-\tau^+$)
- Based on the SANC modules
- Complete one-loop and some higher-order electroweak radiative corrections
- All particle masses and polarizations
- Effectively operates in collinear regions and in a wide range of center-of-mass energies
- New processes can be easily added

[R.Sadykov, V.Yermolchyk, Comput.Phys.Comm. 256 (2020) 107445]

CODE STRUCTURE

Languages: `C++, C, FORTRAN`



`ReneSANCe v1.2.1` is available for downloading at
`http://sanc.jinr.ru/download.php`
`https://renesance.hepforge.org`

mFOAM: [S.Jadach et al., CPC 177 (2007) 441; CPC 152 (2003) 55]

RENESANCE: FEATURES

- Events with unit weights
- Initial and final state particle polarization
- Complete one-loop EW corrections
- LL QED; and higher order weak corrections through $\Delta\rho$
- Different EW schemes can be chosen
- Output in the Standard Les Houches Format
- Simple installation & usage
- Processes:
  - $e^+e^- \to e^-e^+$
  - $e^+e^- \to \mu^-\mu^+, \tau^-\tau^+$
  - $e^+e^- \to ZH$
- Tuned comparisons showed agreement with `CalcHEP`, `WHIZARD`, `GraceLoop` and `aITALC` (where possible)

RENESANCE: EXAMPLE OF RESULTS

PRELIMINARY: $\mu^+e^- \to \mu^+e^-(\gamma)$

P_{μ^+}, P_{e^-}	$0, 0$	$-1, -1$	$-1, +1$	$+1, -1$	$+1, +1$
σ^{Born}, μb	1265.0629(3)	1275.3(1)	1254.8(1)	1254.8(1)	1275.3(1)
δ^{QED}, %	4.76(1)	4.77(1)	4.75(1)	4.75(1)	4.75(1)
δ^{VP}, %	0.940(1)	0.943(1)	0.936(1)	0.936(1)	0.943(1)
$\delta^{\text{ho}}(\Delta\alpha^2)$, %	0.006(1)	0.006(1)	0.006(1)	0.006(1)	0.006(1)

Table: Integrated Born cross section and relative corrections for the c.m. energy $\sqrt{s} = 0.405541$ GeV (MUonE) for different polarization degrees of the initial particles in the $\alpha(0)$ EW scheme, θ_e, θ_μ <100 mrad, E_e >0.2 GeV

RENESANCE: PLANS

- New processes:
  - $\mu^{\pm}e^{-} \to e^{-}\mu^{\pm}$ (soon)
  - $e^{+}e^{-} \to \gamma\gamma$
  - $e^{+}e^{-} \to \gamma Z$ (soon, arXiv:2111.11490)
  - $e^{+}e^{-} \to t\bar{t}$
  - $e^{-}e^{-} \to e^{-}e^{-}$
- Further tuned comparisons, in particular, for μe scattering
- Resonance approximation for decays of τ, Z, t, and H
- QED showers
- EW Sudakov logarithms

MCSANC

MCSANC is a Monte Carlo integrator.

In allows to evaluate the same processes as ReneSANCe and some more, e.g. Drell-Yan.

It is based on the same SANC modules (matrix elements and form factors).

But it is much faster and stable in extreme kinematical regions.

Cross-checks between Monte Carlo generators and integrators help a lot to exclude bugs and adjust the technical precision.

[A.A., D.Bardin et al., JETP Lett. 103 (2016) 131; CERN YR 3 (2020) 213; J.Phys.Conf.Ser. 1525 (2020) 012012]

ISR IN e^+e^- ANNIHILATION

Initial state radiation (ISR) in e^+e^- annihilation is the source of large corrections. It should be treated with care.

Recent analytic results [1-4] for $\mathrm{d}\sigma/\mathrm{d}s'$ can be implemented in computer codes, e.g., in ZFITTER

and serve as benchmarks

N.B. Having precise analytic results is crucial for verification of technical precision of Monte Carlo codes

and for estimates of theoretical precision in general

[1] J.Blümlein, A.De Freitas and W. van Neerven, "Two-loop QED Operator Matrix Elements with Massive External Fermion Lines," Nucl. Phys. B 855 (2012) 508

[2] J.Blümlein et al., "The $O(\alpha^2)$ initial state QED corrections to $e^+e^- \to \gamma^*/Z_0^*$," Nucl. Phys. B 956 (2020) 115055

[3] J.Ablinger et al., "Subleading Logarithmic QED Initial State Corrections to $e^+e^- \to \gamma^*/Z^{0*}$ to $O(\alpha^6 L^5)$," Nucl. Phys. B 955 (2020) 115045

[4] J.Blümlein et al., "The QED initial state corrections to the forward-backward asymmetry of $e^+e^- \to \gamma^*/Z^{0*}$ to higher orders," Phys. Lett. B 816 (2021) 136250

OUTLOOK

- MCGPJ is a working tool with a good but limited accuracy
- ReneSANCe is a new MC event generator for e^+e^- colliders with polarized or unpolarized beams
- Muon-electron scattering in ReneSANCe: article is in preparation
- Analytic results, semi-analytic codes, and Monte Carlo integrators are very useful for cross-checks and benchmarks
- Analytic results for two-loop (virtual) corrections should be supplemented by single and double hard radiation of photons and light pairs
- Higher-order corrections ($\sim \mathcal{O}(\alpha^3)$) can be implemented with approximations, e.g., with showers or collinear jets like in MCGPJ