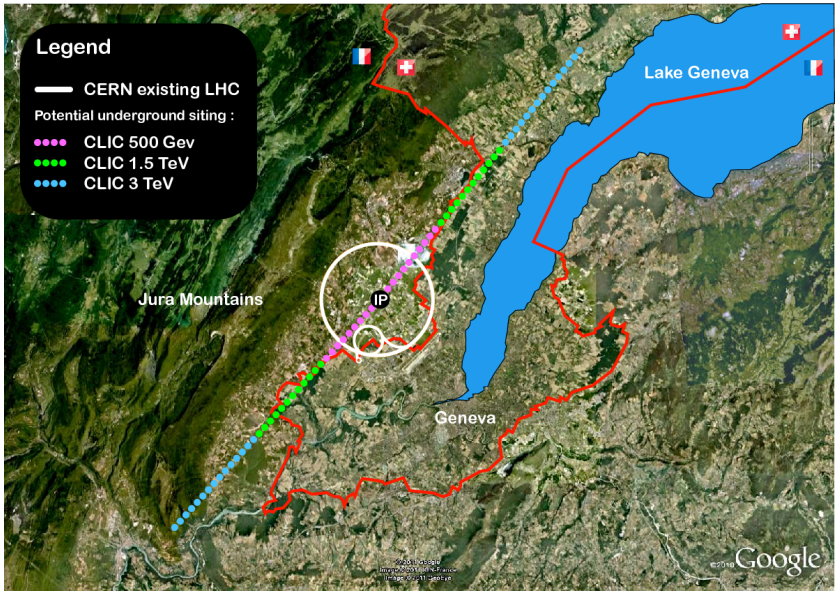
Leptonic decay of the Z boson for polarized Higgs-strahlung

Aliaksei Hurynovich, Vitaly Yermolchyk

INP BSU, JINR

XXth Workshop on High Energy Spin Physics (DSPIN-2026), 7-11 Sep 2026, Dubna, Russia

CLIC - Compact linear collider



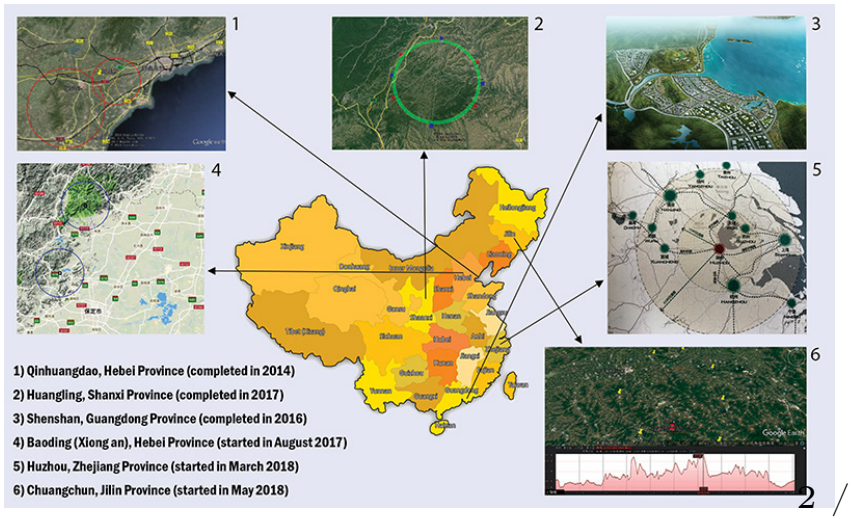
ILC - International linear collider



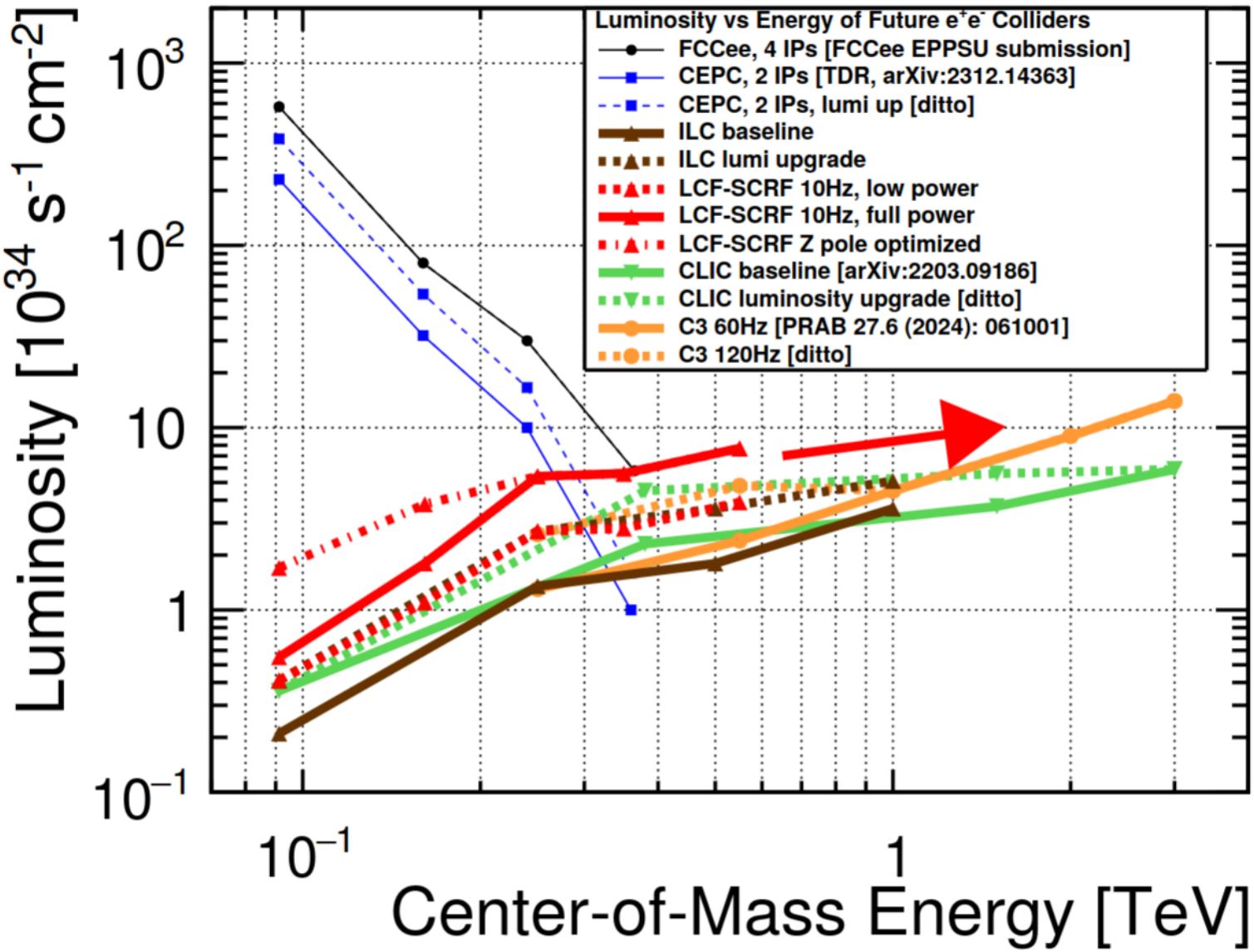
FCC - Future Circular Collider



CEPC - Circular e^+e^- Collider



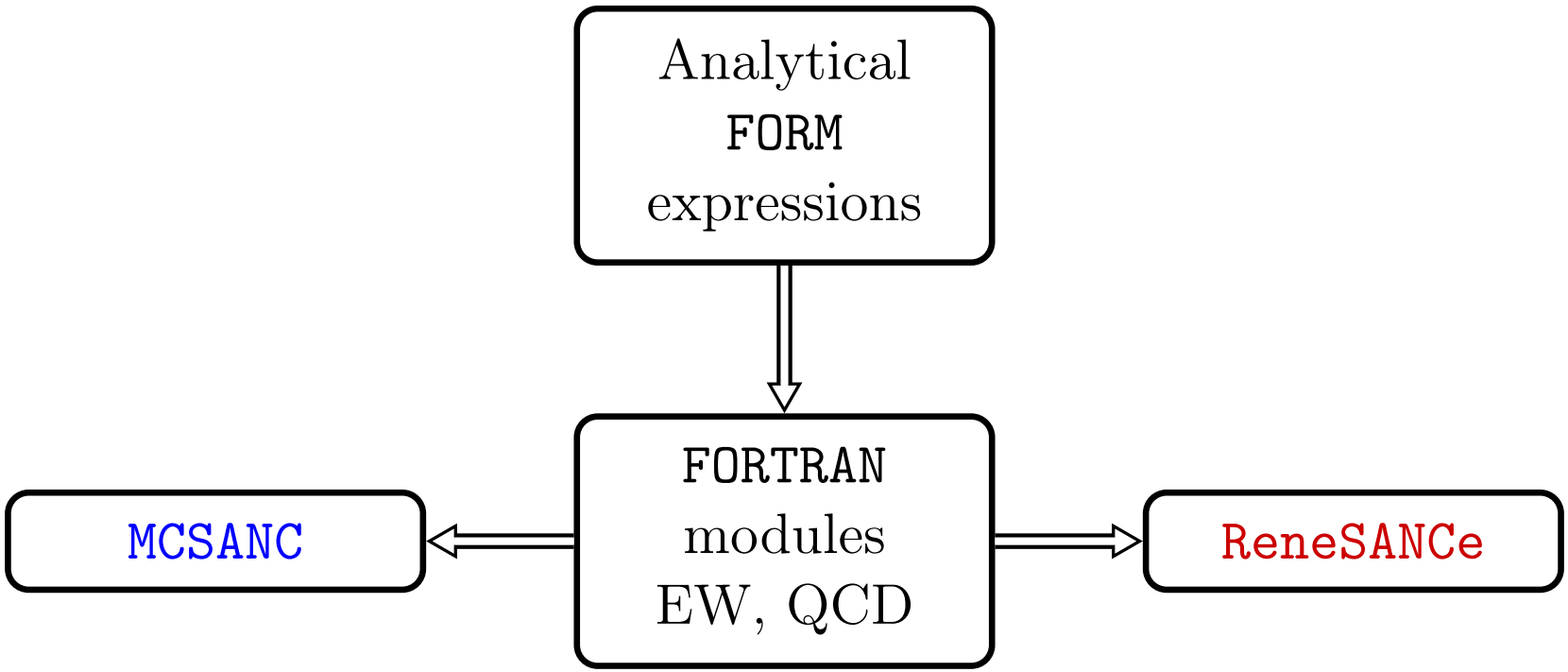
Luminosity [M.Peskin Eur. Phys. J. Plus 141, 346 (2026)]



Motivation

- The dominant cross section at about 250 GeV for Higgs boson production at e^+e^- colliders is Higgstrahlung ($e^+e^- \to HZ$).
- Using only the observed Z boson, it is possible to measure the absolute Higgstrahlung cross section and, using the best-defined Z's with decay to $\mu^+\mu^-$, to measure the Higgs mass to 10 MeV (10^{-4} precision).
- Linear colliders can support longitudinal beam polarization both for electrons and positrons, an advantage in studying the chiral couplings of the SM. Unsurprisingly, the use of beam polarization turns out to give a significant advantage.

The SANC framework and products family



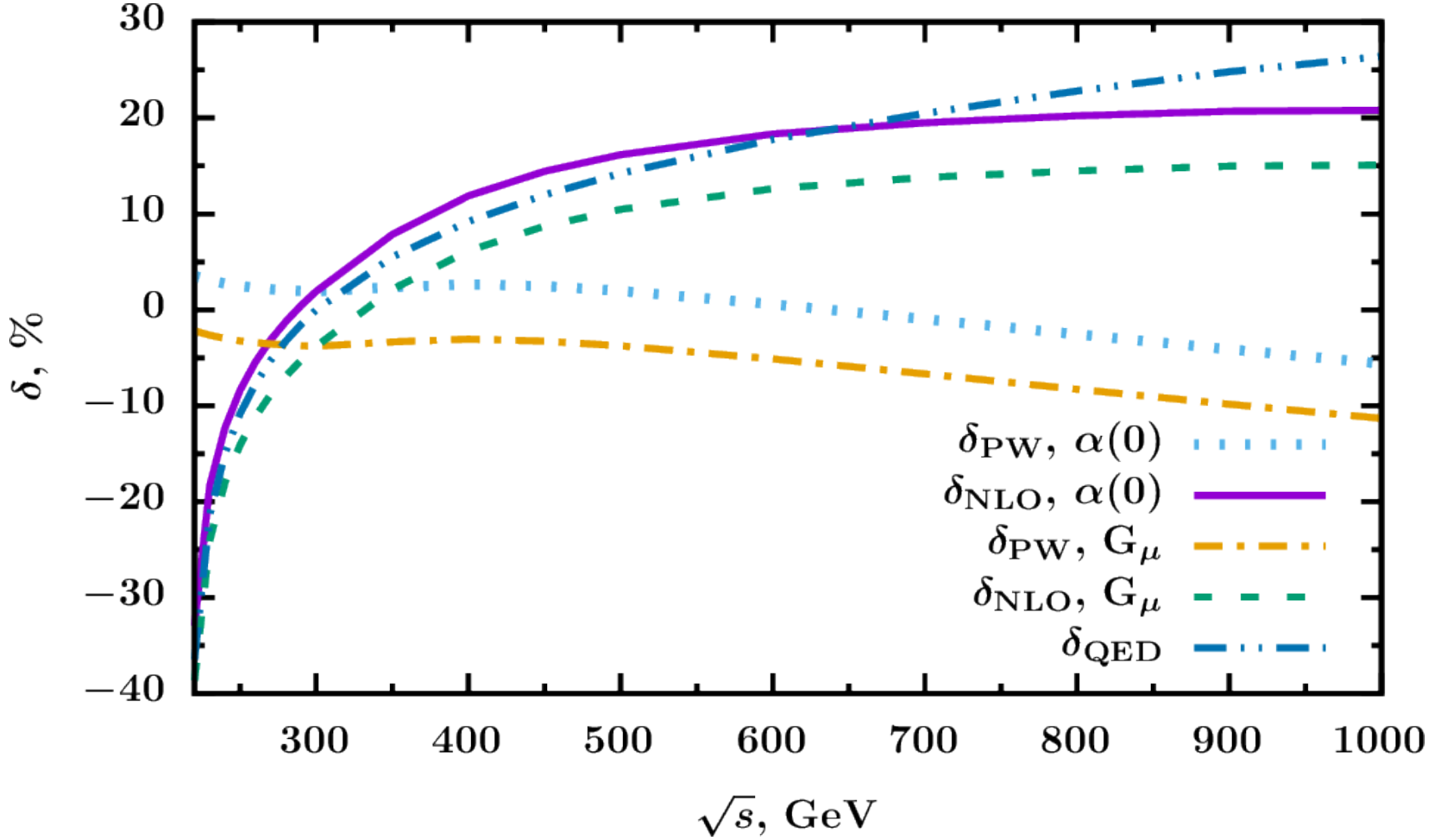
Publications:

SANC – Comput.Phys.Commun. 174 (2006), 481-517.
MCSANC (pp-mode) – Comput.Phys.Commun. 184 (2013),2343-2350; JETP Letters 103 (2016), 131-136.
ReneSANCe – Comput.Phys.Commun. 256 (2020), 107445.

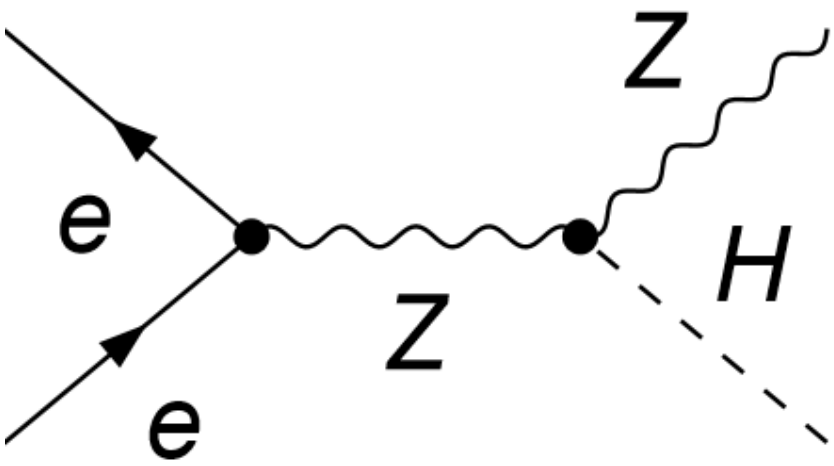
SANC products are available at http://sanc.jinr.ru/download.php

$e^+e^- \to ZH$, energy dependence

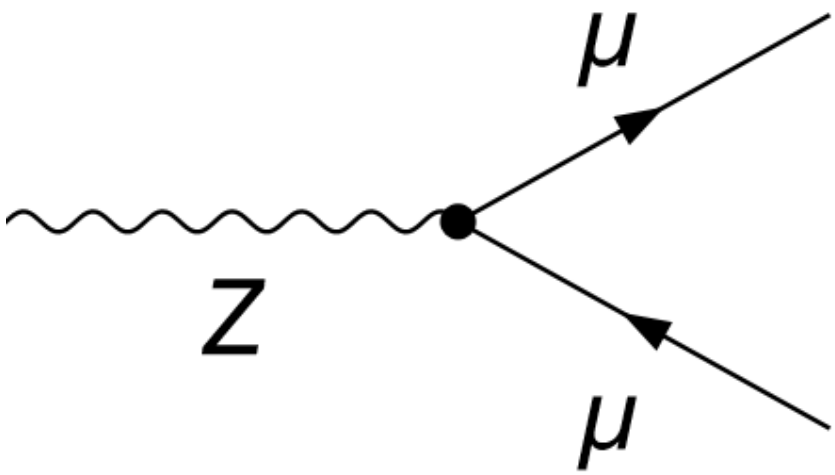
The relative corrections in parts as a function of the c.m.s. energy.



Z decay



$e^+e^- \to Z^*H$



$Z^* \to \mu^+\mu^-$

Amplitude representation

Helicity amplitudes approach

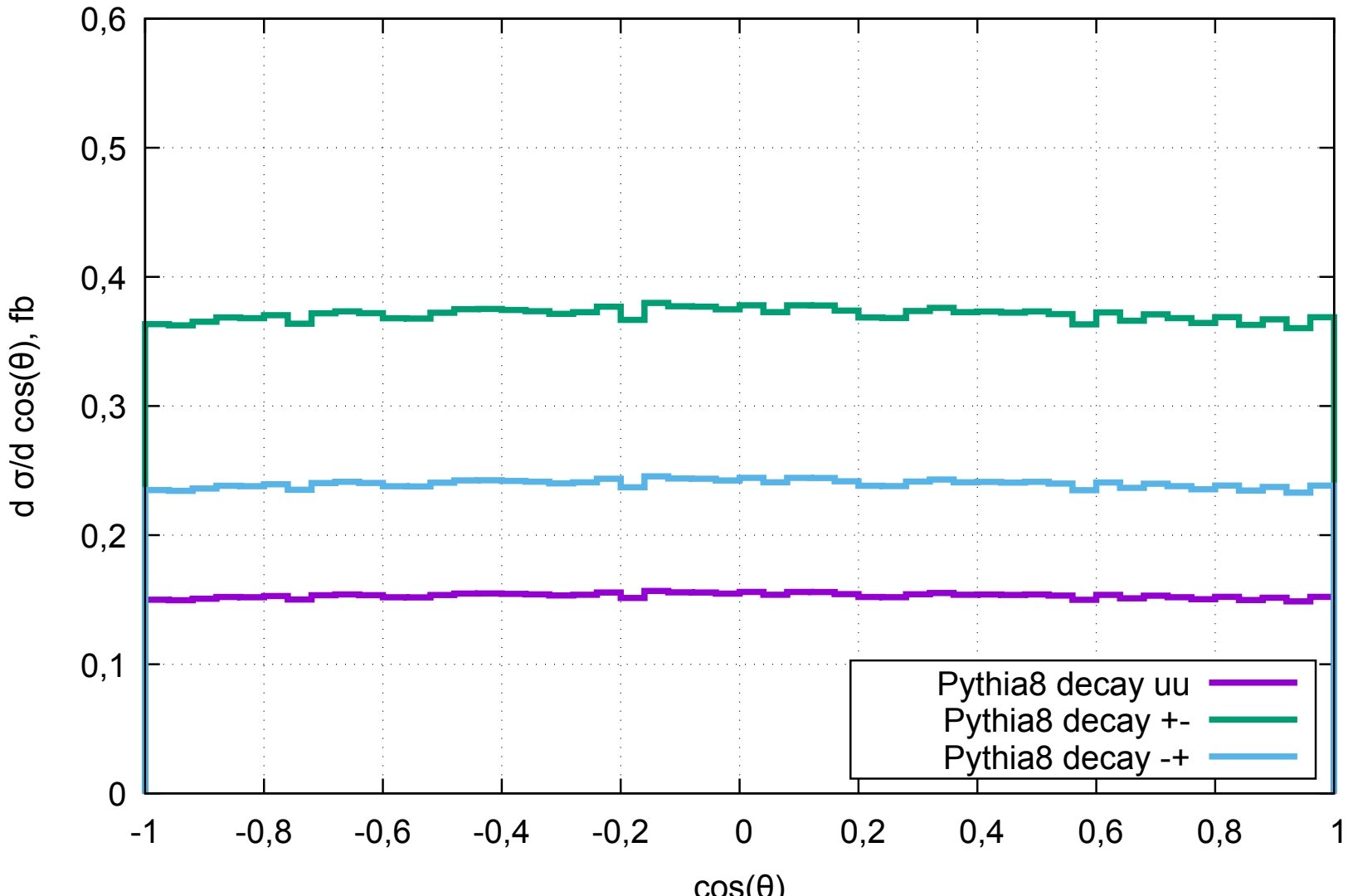
- any initial (not only longitudinal) polarization,
- polarization of final states,
- spin correlations, polarization transfer from the initial to the final state.

Identical structure for all orders:

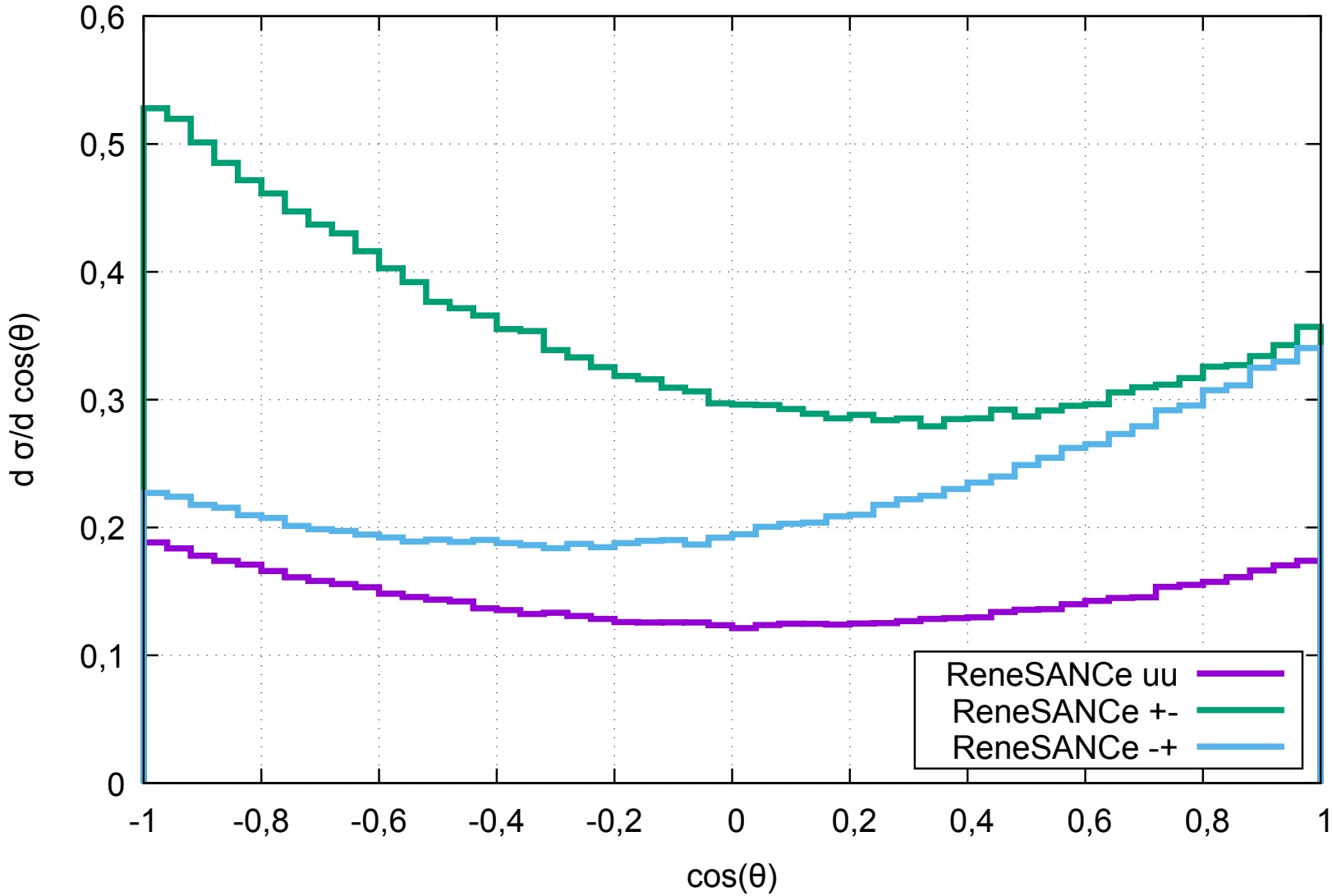
$$\mathcal{H} = \sum Str_i \mathcal{F}_i(s,t,u)$$

Spin-tensor structures is constructed of Dirac spinors, γ-matrices and momenta (like $Str_1 = \bar{v}\left(\not{p}_3\gamma^\mu\gamma^\nu + \gamma^\mu p_4^\nu - \gamma^\nu p_3^\mu + (\not{p}_3 - \not{p}_4)\delta^{\mu\nu}\right)\bar{u}$). Form-factors $\mathcal{F}_i$ are scalar functions that depend only on the Mandelstam variables.

$e^+e^- \to H\mu^+\mu^-$: Born with different polarizations of initial state. Z decay using Pythia. No spin correlations!



$e^+e^- \to H\mu^+\mu^-$: Born with different polarizations of initial state. Z decay using ReneSANCe



Corrections in decay

The calculations are organized in a way to control consistency of result.

- All calculations at the one-loop precision level are realized in the R_ξ gauge with three calibration parameters: ξ_A, ξ_Z and $\xi \equiv \xi_\mathsf{W}$.
- To parameterize ultraviolet divergences, dimensional regularization is used.
- Loop integrals are expressed in terms of standard scalar Passarino-Veltman functions: A_0, B_0, C_0, D_0.

These features make it possible to carry out several important checks at the level of analytical expressions, e.g., checking the gauge invariance by reducing the dependence on the gauge parameter, checking cancellation of ultraviolet poles, as well as checking various symmetry properties and the Ward identities.

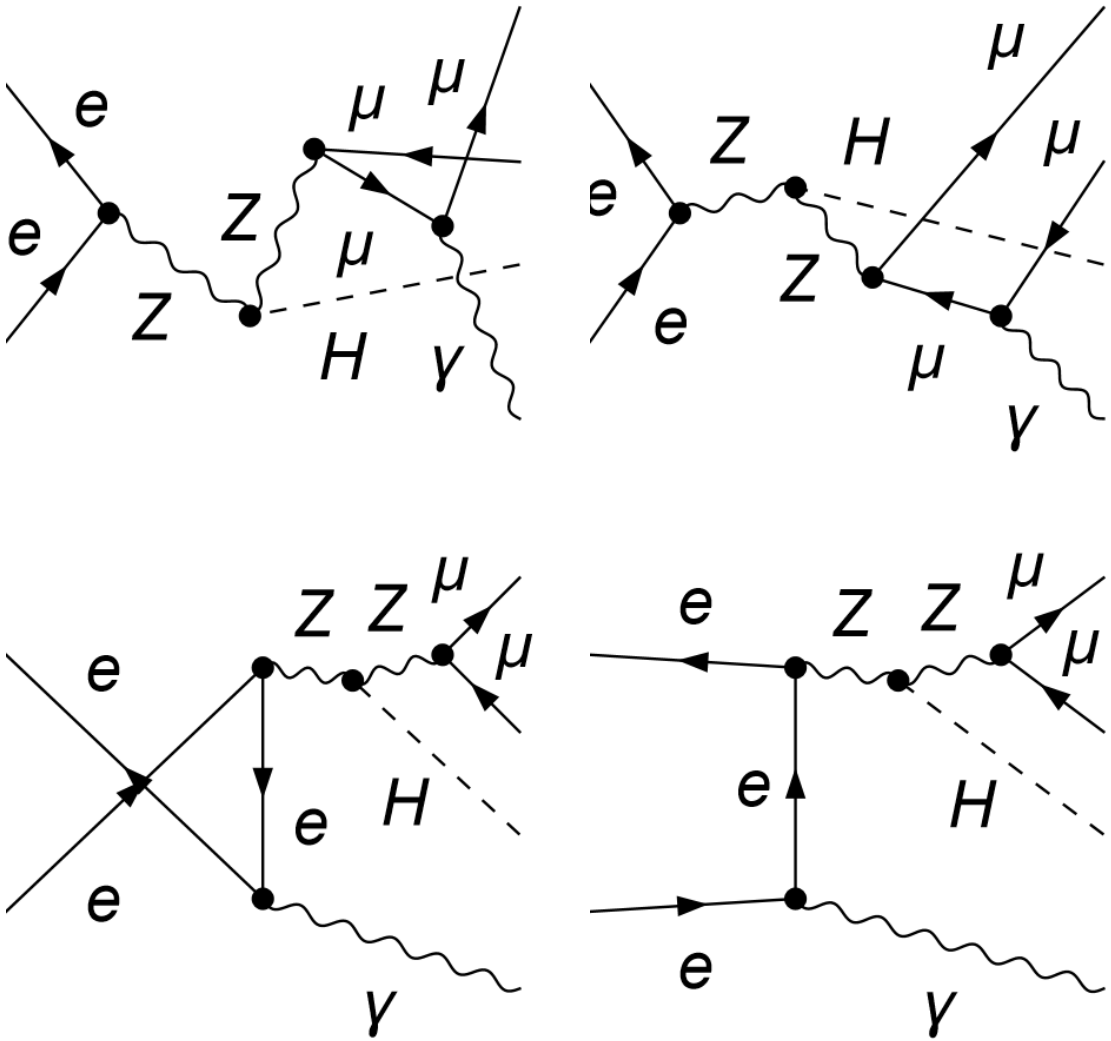
Cross-section structure

The cross-section of processes at one-loop can be devided into four parts:

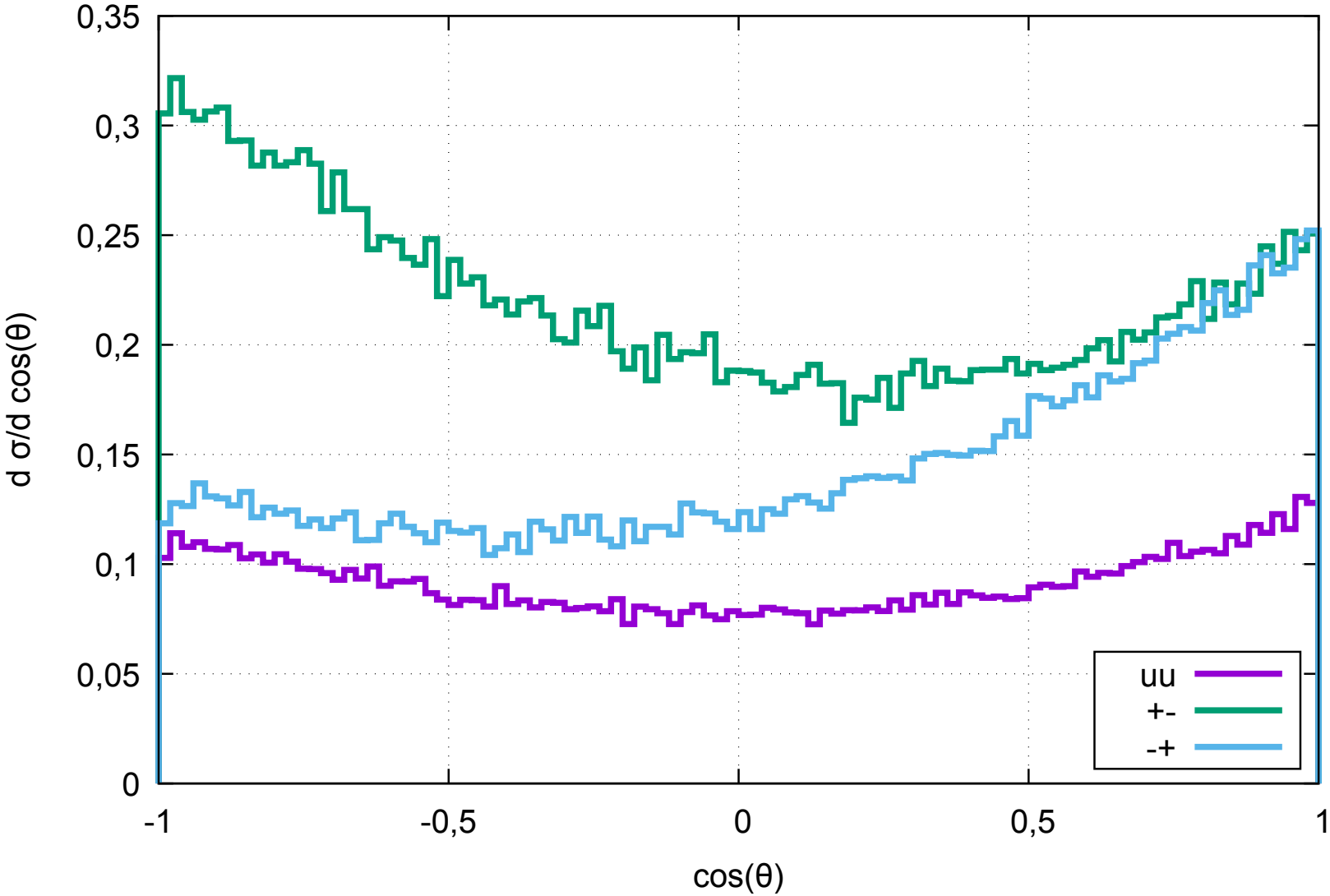
$$\sigma^{\text{1-loop}} = \sigma^{\text{Born}} + \sigma^{\text{virt}}(\lambda) + \sigma^{\text{soft}}(\lambda, \omega) + \sigma^{\text{hard}}(\omega),$$

Contributions due to:
σ^{Born} **— Born level cross-section,**
σ^{virt} **— virtual(loop) corrections,**
σ^{soft} **— soft photon Bremsstrahlung,**
σ^{hard} **— hard photon Bremsstrahlung (with energy** $\mathbf{E}_\gamma > \omega$**).**
Auxiliary parameters λ **("photon mass") and** ω **cancel out after summation.**

Hard Bremsstrahlung: precise kinematics $2 \to 4$



Angle dependence for $e^+e^- \to \mu^+\mu^- H\gamma$, $\sqrt{s} = 250$ GeV, $E_\gamma > 0.0125$ GeV



Conclusions

- Decays of unstable particles in `ReneSANCe` are under development
  - Full spin correlations
  - Factorized loop corrections
  - Accurate kinematics for hard Bremsstrahlung
  - Speed optimization is still required
  - Some problems with the tensor multiplication library have already been fixed

Thank you for your attention!