On Radiative Corrections to polarized DIS

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Outline

- Introduction
- Radiative Corrections (RC) in general
- Computer codes for RC
- SANC project
- Electroweak RC to inclusive DIS
- RC to semi-inclusive processes
- Outlook

Introduction

Andrej Arbuzov

* **Graduated from the Moscow State University, 1992**

* **Work at the Bogoliubov Lab of theoretical physics,
Joint Institute for Nuclear Research, Dubna since 1992**

* **PhD, 1996, (adviser: E. Kuraev)**

* **PostDoc positions: Uni. di Torino (1998-2000), Uni. of Alberta (2000-2002)**

* **Interests: particle phenomenology, precision calculations,
electroweak rad. corr., (multi)loop calculations,
Bhabha scattering, DIS, muon decay, tagged photons, . . .**

* **Some work for: LEP, HERA, VEPP-2M (and other meson factories),
TWIST (TRIUMF), NOMAD, PIBETA, LHC, LC** *etc.*

Radiative Corrections in general

RC: QCD, QED, EW, vacuum polarization, . . .

Typical size of EW and QED RC	**a few percent**
in certain cases we have	**several 10s percent (DIS)**
in rather special cases we have up to	**several 1000s percent**

RC: perturbative calculations + phenomenological input

$$\text{Size of RC}: \qquad \delta^{\text{RC}} \sim \text{Const} \times \frac{\alpha}{\pi} \times \left(\ln\frac{Q^2}{m^2},\ \ln(1-y),\ \frac{1}{1-y},\ \frac{M_Z}{\Gamma_Z},\ \ldots\right) \times \text{Cuts}$$

The Leading Logarithmic approximation $\mathcal{O}(\alpha^n \ln^n(Q^2/m^2))$ gives a fast estimate of RC. For many case it gives the bulk of the effect.

There is a continuous progress in RC calculations. But we see many places, where the theory is *behind* the experiment.

Uncertainty of theoretical predictions (including RC calculations) is an important ingredient of the experimental systematic error, $\delta^{\text{theor.}} \lesssim \delta^{\text{syst.}}/3$

Computer codes for theoretical predictions

General purpose: GRACE, CompHEP, SANC, PYTHIA, LEPTO, . . .
Specific (RC): ZFITTER, POLRAD, HECTOR, RADGEN, . . .
Dedicated: the concrete experimental MC

Codes: semi-analytic $\leftrightarrow$ Monte Carlo

Implementation of RC into the codes . . .   bugs

The strategy: looking for compromise . . .

Estimates of the theoretical accuracy for concrete experimental conditions . . .

The main problem is misunderstanding and misuse . . .

The SANC project

Support of Analytic and Numeric calculations
for experiments at Colliders

An automatized three level computer system for precision calculations of pseudo– and realistic observables for HEP experiments

SANC team: D. Bardin, L. Kalinovskaya, P. Christova, A. Arbuzov, S. Bondarenko, G. Nanava, A. Andonov; G. Passarino, W. von Schlippe

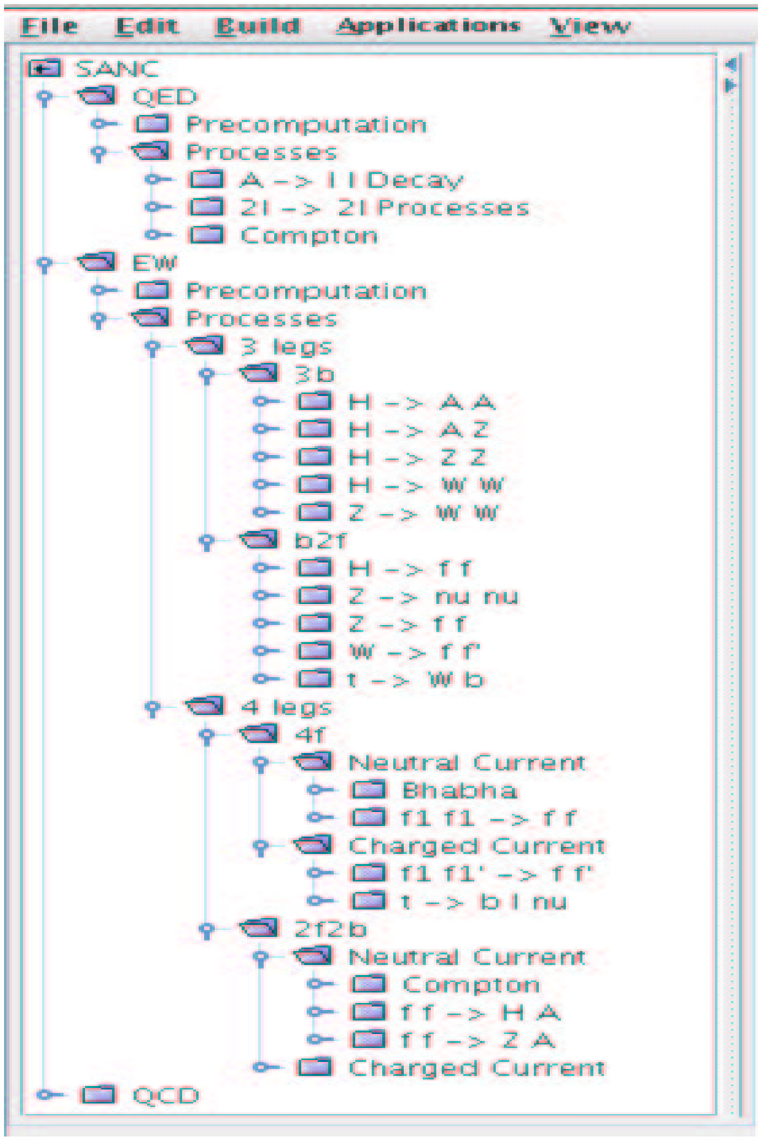
“Roots” of SANC: book “*The Standard Model in the Making*” by D. Bardin and G. Passarino; computer codes for HEP such as TOPAZ0, ZFITTER, HECTOR *etc.*

The main goal of SANC project is the creation of a software product, accessible via Internet for the automatic computation of pseudo- and realistic observables with one-loop precision for various processes of elementary particle interactions, such as: $1 \to 2,\ 1 \to 3,\ 2 \to 2,\ 1 \to 4,\ 2 \to 3,$ *etc.*

SANC can be accessed at `http://brg.jinr.ru`, `http://pcjinr01.cern.ch`

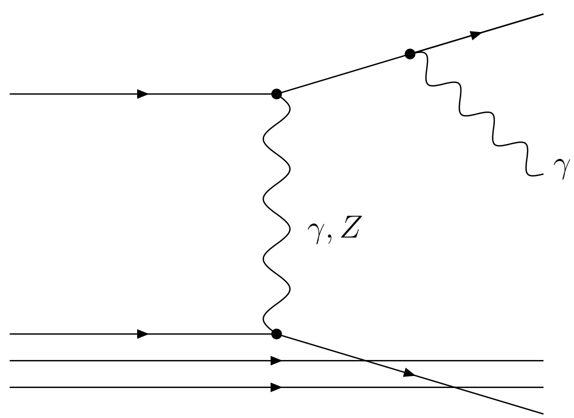
SANC User's guide (prepared for CPC): hep-ph/0411186

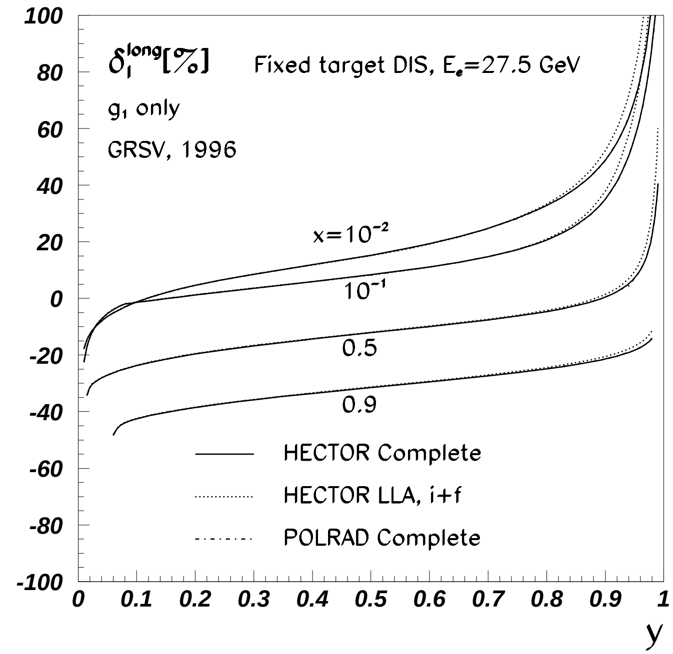
List of processes available in SANC v.0.41



Electroweak RC to inclusive (polarized) DIS

- were studied for many years, there is a number of computer codes: **POLRAD**, **(pol)HECTOR** (semi-analytic), **RADGEN** (MC) and many other
- Recent analytical results for higher order RC: J. Blümlein, H. Kawamura, hep-ph/0409289
- Implementation of RC in the codes ...





1) QED RC to the lepton line,
2) vacuum polarization,
3) QED & QCD RC to the quark line,
4) QED RC due to the interference,
5) EW effects $\mathcal{O}(Q^2/M_Z^2)$

A comparison of results obtained by the codes `POLRAD` and `HECTOR` is given for the kinematic regime of the HERMES experiment. *"This does not replace future comparisons in the real experimental applications."* [Acta Phys. Polon.'1997]

The Leading Logarithmic Approximation

$$\frac{\mathrm{d}^2\sigma^{\mathrm{LLA}}_{\mathrm{rad}}}{\mathrm{d}x\mathrm{d}y} = \frac{\mathrm{d}^2\sigma_{\mathrm{ini}}}{\mathrm{d}x\mathrm{d}y} + \frac{\mathrm{d}^2\sigma_{\mathrm{fin}}}{\mathrm{d}x\mathrm{d}y} + \frac{\mathrm{d}^2\sigma_{\mathrm{Comp}}}{\mathrm{d}x\mathrm{d}y},$$

$$\frac{\mathrm{d}^2\sigma_{\mathrm{ini,fin}}}{\mathrm{d}x\mathrm{d}y} = \frac{\alpha}{2\pi}\left(\ln\frac{Q^2}{m_l^2} - 1\right)\int\limits_0^1 \mathrm{d}z\frac{1+z^2}{1-z}\left\{\Theta(z-z_0)\ \mathcal{J}\ \frac{\mathrm{d}^2\sigma_{\mathrm{Born}}}{\mathrm{d}x\mathrm{d}y}\bigg|^{\mathrm{ini,fin}}_{x=\hat{x},y=\hat{y},S=\hat{S}} - \frac{\mathrm{d}^2\sigma_{\mathrm{Born}}}{\mathrm{d}x\mathrm{d}y}\right\},$$

$$\text{Initial State Radiation}: \quad \hat{s} = zs, \quad \hat{y} = \frac{y+z-1}{z}, \quad \hat{Q}^2 = zQ^2, \quad \hat{x} = \frac{\hat{Q}^2}{\hat{y}\hat{s}};$$

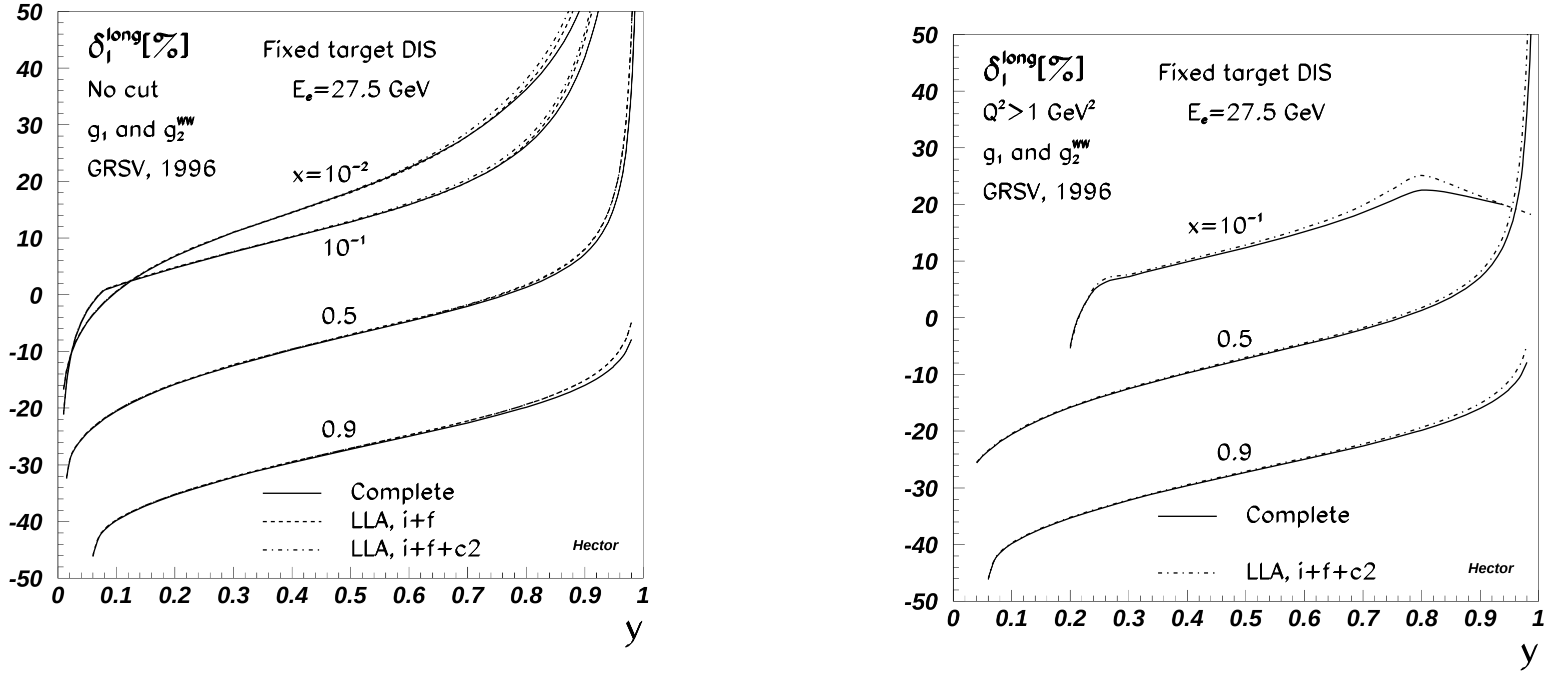
$$\text{Final State Radiation}: \quad \hat{s} = s, \quad \hat{y} = \frac{y+z-1}{z}, \quad \hat{Q}^2 = \frac{Q^2}{z}, \quad \hat{x} = \frac{\hat{Q}^2}{\hat{y}\hat{s}};$$

The Compton sub-process is peaked at $y_l \to 1$:

$$\frac{\mathrm{d}^2\sigma^{U}_{\mathrm{Comp}}}{\mathrm{d}x_l\mathrm{d}y_l} = \frac{\alpha^3}{Sx_l^2}\frac{1+(1-y_l)^2}{1-y_l}\int\limits_{x_l}^{1}\mathrm{d}z\int\limits_{(Q_h^2)^{\min}}^{(Q_h^2)^{\max}}\frac{\mathrm{d}Q_h^2}{Q_h^2}\left[\frac{1+(1-z)^2}{z}F_2^{\gamma\gamma}(x_h,Q_h^2) - zF_L^{\gamma\gamma}(x_h,Q_h^2)\right],$$

$$\frac{\mathrm{d}^2\sigma^{L}_{\mathrm{Comp}}}{\mathrm{d}x_l\mathrm{d}y_l} = \left(-2\lambda_l\lambda_N^L\right)\frac{\alpha^3}{Sx_l^2}\frac{1-(1-y_l)^2}{1-y_l}\int\limits_{x_l}^{1}\mathrm{d}z\int\limits_{(Q_h^2)^{\min}}^{(Q_h^2)^{\max}}\frac{\mathrm{d}Q_h^2}{Q_h^2}\frac{1-(1-z)^2}{z}x_h g_1^{\gamma\gamma}(x_h,Q_h^2),$$

Effect of a cut on Q^2

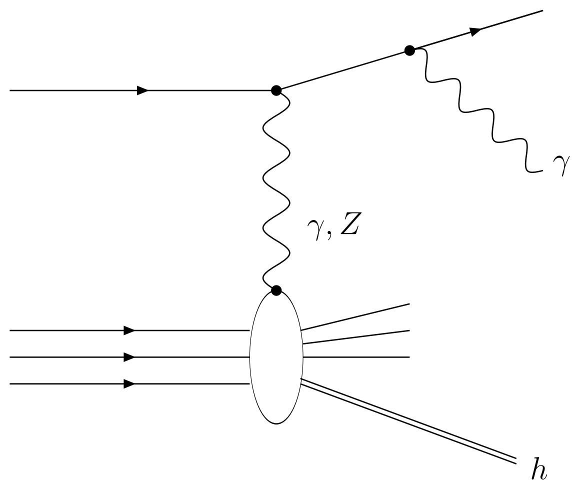


N.B. $Q^2 = xyS$.

Figures are taken from D. Bardin *et al.*, Nucl. Phys. B506 (1997) 295.

Check the Kinoshita–Lee–Nauenberg theorem conditions to get an idea about the size of RC

RC to semi-inclusive DIS



Δq extraction from identified hadron double-spin asymmetries

$$A_1 = \frac{\sigma_{\gamma N}^{\uparrow\downarrow} - \sigma_{\gamma N}^{\uparrow\uparrow}}{\sigma_{\gamma N}^{\uparrow\downarrow} + \sigma_{\gamma N}^{\uparrow\uparrow}} \approx \frac{\Sigma_q e_q^2(\Delta q + \Delta\bar{q})}{\Sigma_q e_q^2(q + \bar{q})}$$

RC to the quark (parton) block become much more important than in inclusive DIS!

$\Delta G/G$ from charm photo–production also can get *additional* QED RC

Generalized parton distributions and fragmentation functions with $p_\perp$ dependence are required to proceed in the systematic way (*our near future*).

At present we use certain approximations . . .

Important: a treatment of the quark mass singularities, $\ln(Q^2/m_q^2)$, is required.
ISR and FSR logs *should be hidden* into PDF's and fragmentation functions, respectively, while the Compton peak can remain and enhance the value of RC.

The task: calculation of QED RC to the quark line (QPM) as a part of coefficient functions. This will give us immediately the answer about the magnitude of the effect. Actually, all formulae are known, our problem is just to get numbers under the COMPASS conditions.

N.B. The first set of *parton distributions incorporating QED contributions* is released [MRST hep-ph/0411040]; lead to isospin violation, i.e. $u^p \neq d^n$, and to the appearance of *new* photon parton distributions $\gamma(x, Q^2)$ of proton and neutron

Implementation of RC into Monte Carlo

- **Virtual RC including vacuum polarization (*universal*)**
- **Soft photon RC (exponentiation . . .) (*universal**)**
- **Hard photon RC depend on particle registration conditions**

(Numerical) cancellation of auxiliary† parameter for soft–hard separation (Bardin–Shumeiko approach in semi-analytic codes)

RC factors, $\mathrm{d}^2\sigma_{\mathrm{RC}}(x,Q^2)/\mathrm{d}^2\sigma_{\mathrm{Born}}(x,Q^2)$ **to be applied to each event, generated according to the Born formula. This is valid both for Model Independent and QPM approaches.**

Generation of real hard photons

Reconstruction of *true* hadronic variables $x,\ Q^2$ (arguments of PDF's) — a change of the *internal* kinematics, not the *observed* one

(Re-)weighted events . . .

Mapping of RC for quick use, but it should be different for different observables

Outlook

- **QCD, QED & EW RC to polarized DIS are important for precision analysis of experimental data**
- **There is a number of well-tested codes for RC to inclusive DIS (& (quasi-)elastic), our tasks here are 1) to avoid their misunderstanding and misuse and 2) to derive the value of the theoretical uncertainty**
- **RC to semi-inclusive polarized DIS should be re-estimated taking into account concrete experimental conditions**
- **A combined approach with generalized structure functions will be developed**
- **A. Arbuzov will work for COMPASS within the Dubna group not only on RC, but also on data analysis** *etc.*
- *Never make a calculation until you know the answer*
  (Wheeler's first moral principle)