Helmholtz International School - Workshop
"Calculations for Modern and Future Colliders"

SANC: present and future

Evgeny Uglov
on behalf of SANC group

July 18, 2009
JINR, Dubna, Russia

SANC group

Project title: SANC

Support of Analytic and Numeric Calculations for experiments at colliders

D.Yu. Bardin, L.V. Kalinovskaya, P.Ch. Christova, V.A. Kolesnikov, L.R. Rumyantsev, R.R. Sadykov, A.A. Sapronov, E.D. Uglov — DLNP, JINR, Dubna, Russia;
A.B. Arbuzov, S.G. Bondarenko — BLTP, JINR, Dubna, Russia;
W. von Schlippe — PNPI, RAN, Gatchina, Russia;

In collaboration with:

B.A. Nikolov, K.S. Jordanova, A.D. Andonov
— University of Shoumen, Shoumen, Bulgaria;

S. Jadach, M. Skrzypek, W. Placzek, Z. Was
— IFJ, PAN, Krakow, Poland.

SANC Project: phases, goals, availability

First phase (2001–2005) — creation a computer system `SANC v1.10` intended for a semi-automatic complete calculations at the one-loop precision level: EW + QCD (QED - education purpose) of the realistic and pseudo-observables (event distributions and decay rates), practically for all 3-particle decays and many 4-particle (sub-) processes.

NB: Complete NLO calculations: all diagrams for a given process.

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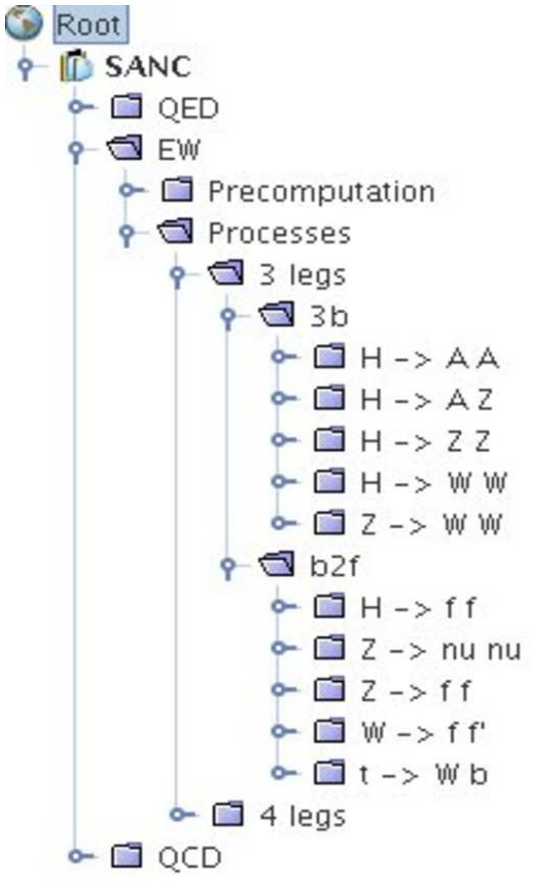
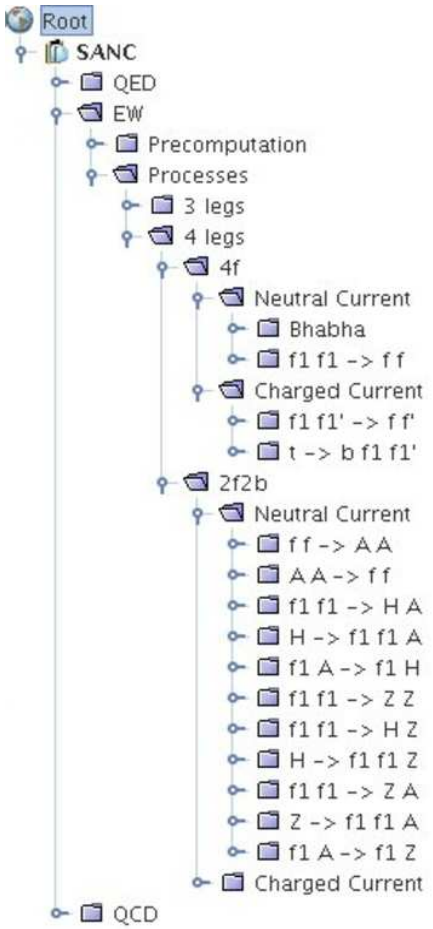
Second phase (2006–2009) — begin to be used for physical applications: LHC hot processes.

Accessible from servers:
in Dubna *http://sanc.jinr.ru/* and CERN *http://pcphsanc.cern.ch/*.

1. A. Andonov, *et al.*, Comput. Phys. Comm. **174** (2006) 481–517.
2. D. Bardin, *et al.*, Comput. Phys. Comm. **177** (2007) 738–756.
3. A. Andonov, *et al.*, arXiv:0812.4207 [physics. comp-ph].

SANC V1.10: Available processes

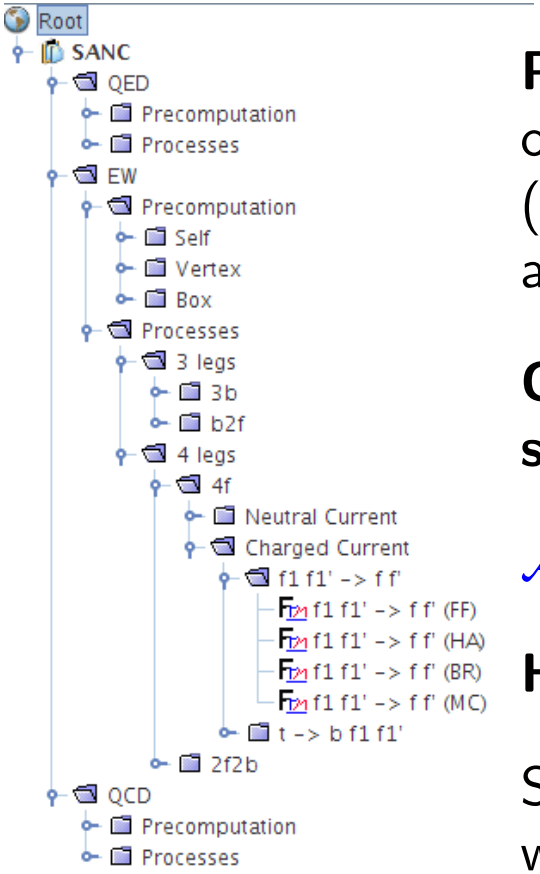




Notation for folders:
b – any boson; $f(f_1)$ – any fermion (massless) fermion; A – a photon;
for files: the same but t, b mean top and bottom quarks.

SANC client download

Precomputation, amplitudes, form factors



Precomputation: to precompute as many one-loop diagrams and derived quantities (renormalization constants, etc) as possible (to save CPU time)

Covariant Amplitudes (CA) and scalar Form Factors (FF) — $\mathcal{F}_i$

$$\mathcal{A} \propto \gamma_\mu \mathcal{F}_1 + \sigma_{\mu\nu} q_\nu \mathcal{F}_2$$

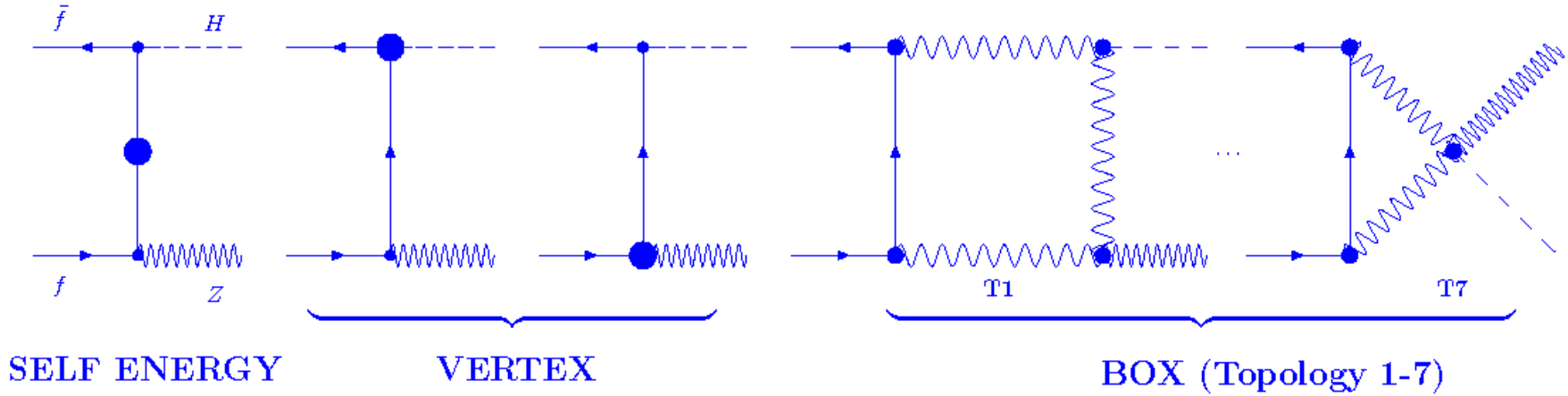
Helicity Amplitudes (HA) — $\mathcal{H}_{\{\lambda_i\}}(\mathcal{F}_i)$

Standard approach: $O \propto |\mathcal{A}|^2$
while in terms of HAs: $O \propto \sum_{\{\lambda_i\}} |\mathcal{H}_{\{\lambda_i\}}|^2$

inclusive **Accompanying Bremsstrahlung (BR)**
fully-differentional **Monte-Carlo generator (MC)**

Building Block Ideology of SANC

$HZf\bar{f} \longrightarrow 0$ process:



R_ξ–gauge invariance

From analytic results to numbers

- **Virtual corrections:**

$$d\Gamma(d\sigma) \sim \sum_{\lambda_i\lambda_j\lambda_k\lambda_l} \left| \mathcal{H}\left(\mathcal{F}^{\text{Born+1loop+2loop}}\right)_{\lambda_i\lambda_j\lambda_k\lambda_l} \right|^2$$

- **Real corrections:**
  - **Soft bremsstrahlung**
  - **Hard bremsstrahlung**
    either from semi-analytic or MC calculations

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- **s2n package to generate FORTRAN codes**

  SANC includes its own FORTRAN library for numerical calculation of Passarino–Veltman functions and use LoopTools as an alternative

  T. Hahn and M. Perez-Victoria; http://www.feynarts.de/looptools/

Types of SANC outputs

- **Standard SANC Form and Fortran Modules (SSFM)**
- **Standard standalone SANC MC integrators**
- **Standalone SANC MC generators**

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  Contribution to **tuned comparison**, an impact on competition of precision MC generators at the LHC
  DY CC & NC (EW + QCD) NLO:
  Les Houches Workshop Proceedings, 2006, 2008 and Tevatron for LHC Report, 2007.
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- **Standalone SANC MC generators**
  a) $H \to 4\mu$ decay in the single Z pole approximation;
  b) NC and CC Drell–Yan processes;
  c) $t \to bl\nu$ decay;

For more information about SSFM and MC generators see ATL-COM-PHYS-2008-176.

SANC Fortran packages

Fortran modules are presented in form of Fortran packages, that provide environment in which they could be tested.

The adopted form of presentation of the differential cross section at the one-loop level in obvious notation is:

$$d\hat{\sigma}^{1-\mathrm{loop}} = d\hat{\sigma}^{\mathrm{Born}} + d\hat{\sigma}^{\mathrm{Virt+Soft}}(\bar{\omega}) + d\hat{\sigma}^{\mathrm{Hard}}(\bar{\omega}) + d\hat{\sigma}^{\mathrm{Subt}}$$

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Each fortran package contains

- documentation,
- declaration, initialization and various input files,
- libraries,
- main file,
- **SSFM: files containing subroutines**

SANC Fortran packages download

SANC Modules.

SANC NC package (Neutral Current processes modules).

The previous versions of SANC NC package you can find in SANC Archives.

- 15/12/2008 SANC NC v1.20 package (354 Kb tgz-file) [last stable version]

In v1.20 package the modules for new processes are added. Details are in the file CHANGES.

- 13/02/2008 SANC NC v1.10 package (300 Kb tgz-file) [stable version]

In v1.10 package the f1f1HZ processes are added. For description of the f1f1HZ processes please refer to the paper D. Bardin et al., Comput. Phys. Comm. 177 (2007) 738-756. Details are in the file CHANGES.

This package is intended for calculation of the 1-loop radiative correction to Drell-Yan Neutral Current processes at partonic level. For a Technical Description of this module please refer to the paper Eur. Phys. J. C54 (2008) 451.

SANC CC package (Charged Current processes modules).

The previous versions of SANC CC package you can find in SANC Archives.

- 16/06/2009 SANC CC v1.30 package (236 Kb tgz-file) [last stable version]

In v1.30 package the modules for new processes are added. Details are in the file CHANGES.

- 05/12/2008 SANC CC v1.20 package (160 Kb tgz-file) [stable version]

In v1.20 package the modules for new processes are added. Details are in the file CHANGES.

- 28/10/2008 SANC CC v1.11 package (131 Kb tgz-file) [stable version]

In v1.11 package some bugs in the QCD soft-virtual part are fixed. Details are in the file CHANGES.

This package is intended for calculation of the 1-loop radiative correction to Drell-Yan Charged Current processes at partonic level, see A. Arbuzov et al., Eur. Phys. J. C46 (2006) 407.

SANC MC generators

The sanc_**_foam_v1.** packages are intended for generation of unweighted events of the DY processes in NC and CC sector.

- **use SSFM,**
- **one-loop EW radiative corrections,**
- **hadronic level,**
- **based on `FOAM` algorithm,**
- **Les Houshes Accord format of the output data – gives the possibility to link output to general purpose programs such as PYTHIA and HERWIG in order to take into account partonic showers.**

SANC MC generators download

SANC Generators.

Drell-Yan Neutral Current processes generator.

The previous versions of SANC NC generator you can find in SANC Archives.

- 23/05/2008 SANC NC DY FOAM v1.10 package (345 Kb tgz-file) [last stable version]

In v1.10 package the Les Houches format event files is introduced. Details are in the file CHANGES.

- 22/02/2008 SANC NC DY FOAM v1.01 package (584 Kb tgz-file) [stable version]

In v1.01 package the modules are taken from the sanc_nc_v1.01 package. Details are in the file CHANGES.

This SANC generator is intended for generation of unweighted events of the Drell-Yan Neutral Current processes at hadronic level taking into account the 1-loop EW radiative correction using the FOAM algorithm. Please read the instructions (in tgz file) for using this package.

Drell-Yan Charged Current processes generator.

The previous versions of SANC CC generator you can find in SANC Archives.

- 15/04/2008 SANC CC DY FOAM v1.00 package (235 Kb tgz-file) [last stable version]

This SANC generator is intended for generation of unweighted events of the Drell-Yan Charged Current processes at hadronic level taking into account the 1-loop EW radiative correction using the FOAM algorithm. Please read the instructions (in tgz file) for using this package. In v1.00 package the modules are taken from the sanc_cc_v1.02 package.

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Applications

- One-loop EW & QCD corrections: modules
- Multichannel approach
- Top-physics
  → **Talk of V.Kolesnikov (SANC)**
- Drell–Yan processes: tuned comparison
- Interfacing SANC with PYTHIA and HERWIG
  → **Talk of R.Sadykov (SANC)**
- 4b physics
- SANC for COMPASS: virtual Compton effect

One-loop EW & QCD corrections: modules

Export of modules: WINHAC and EW modules of SANC

The first example of the application of SANC EW modules into another code was their implementation into MC generator WINHAC ($pp \to \mu^+\nu_\mu X$) , written by our partners from IFJ, Krakow.

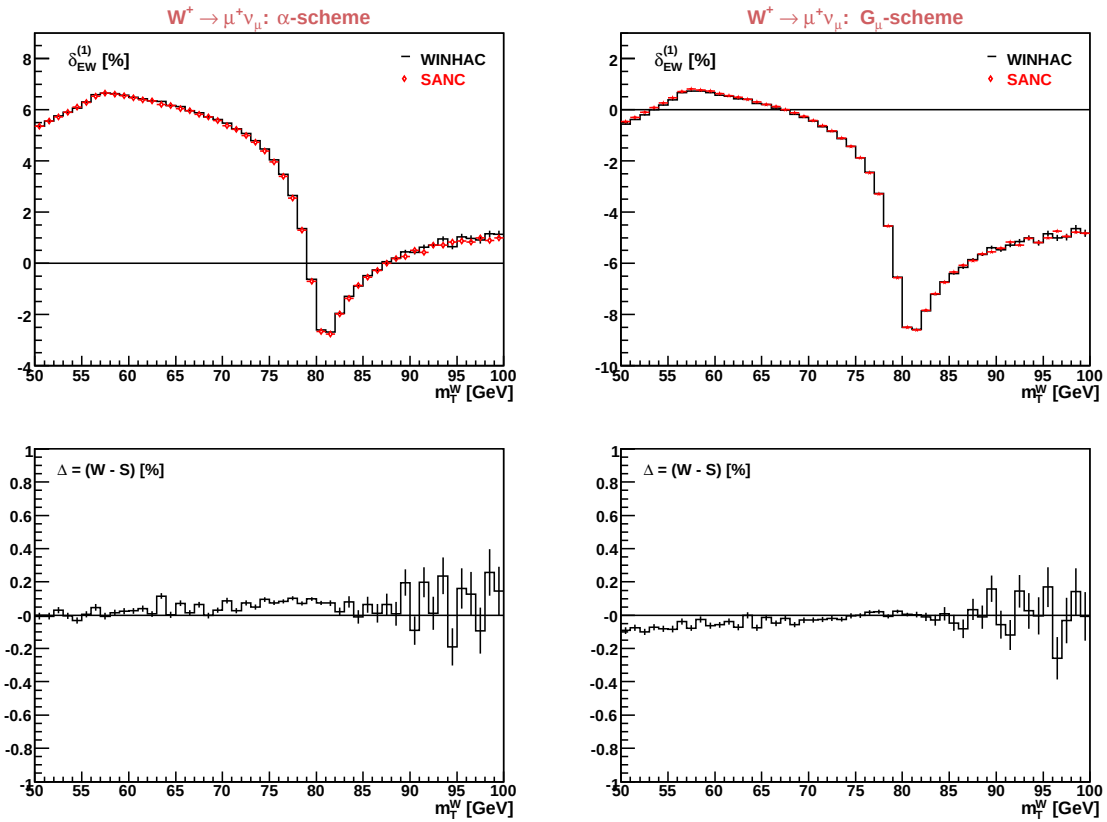
Next step is to implement SANC EW modules into MC generator ZINHAC ($pp \to \mu^+\mu^- X$).

Presently, a possibility of implementation of SANC EW modules to the program RESBOS is under discussion.

D. Bardin, S. Bondarenko, S.Jadach, L. Kalinovskaya, W. Placzek, *Implementation of SANC EW corrections in WINHAC Monte Carlo generator.* Acta Physica Polonica, **40** (2009) 75–92. arXiv: 0806.3822 [hep-ph].

One-loop EW & QCD corrections: modules

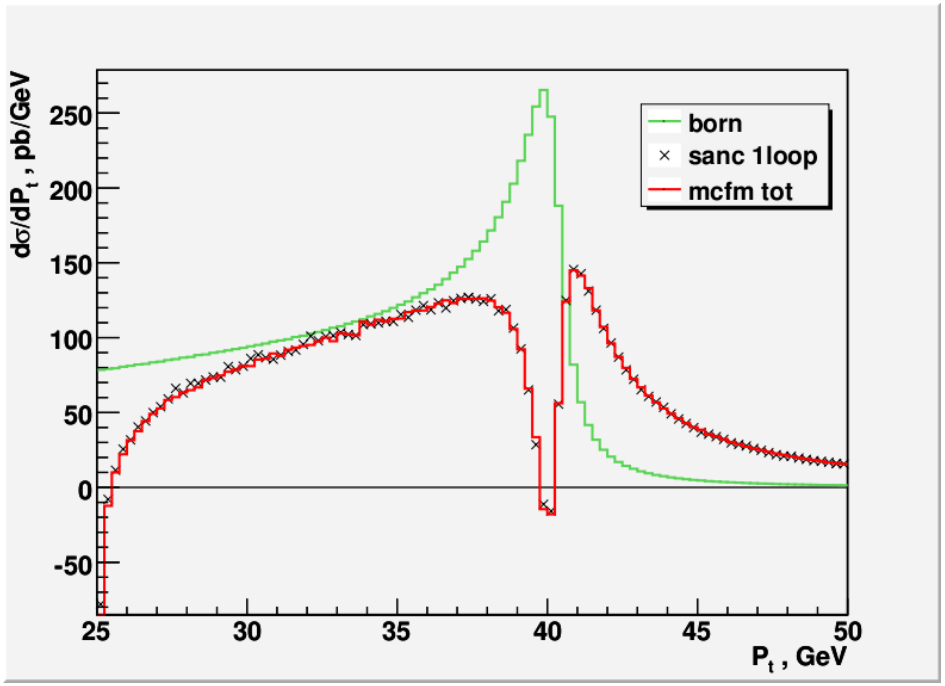
Distributions of EW NLO corrections in variable M_T^W, computed by SANC (points) and WINHAC (solid lines) for the process $pp \to \mu^+ \nu_\mu X$ within two calculative schemes and their absolute difference $\Delta = \mathrm{W} - \mathrm{S}$.



The comparison of two calculations shows an agreement at the level of .1%, that means the correctness of implementation of SANC into WINHAC framework.

One-loop EW & QCD corrections: modules

Comparison of two calculations results by SANC and by the code MCFM, realized mainly as one of cross-checks of QCD results of SANC modules.



Distribution in $P_T^{\mu^+}$ in the DY-like CC process.

The comparison demonstrates an impressive agreement proving correctness QCD modules of SANC and reality of an "unphysical deep" in the distribution in the vicinity of W resonance, which is getting smeared if the multiple soft gluon and $q\bar{q}$ pairs (parton showers) is taken into account.

A. Andonov, A. Arbuzov, S. Bondarenko, P. Christova, V. Kolesnikov, G. Nanava, R. Sadykov, *NLO QCD corrections to Drell-Yan processes in the SANC framework*. Jan 2009. 16pp. arXiv:0901.2785 [hep-ph], to be published Yad. Phys.

Drell–Yan processes: tuned comparison

The main emphasis of **international collaboration** was done on active participation of SANC group in several Workshops on tuned comparison of EW corrections for Drell–Yan CC and NC processes representing great interest for LHC physics (measurements of luminosity, W mass, structure functions, etc.).

SANC collaborated with groups of IFJ, PAN, Krakow, leaded by Prof. S. Jadach; University of Pavia, Italy, leaded by Prof. G. Montagna (program HORACE); University of Buffalo, NY, USA, leaded by Prof. D. Wackeroth (programs Z(W)GRADE) and with Prof. S. Dittmaier (MPI, Munich) & Prof. M. Kramer (Aachen), Germany.

C.Buttar *et al.*, *Tuned comparison of electroweak corrections to Drell–Yan-like W- and Z-production — a status report.* Published in Les Houches Workshop Proceedings, Apr. 13th. 2006; arXiv:hep-ph/0604120.

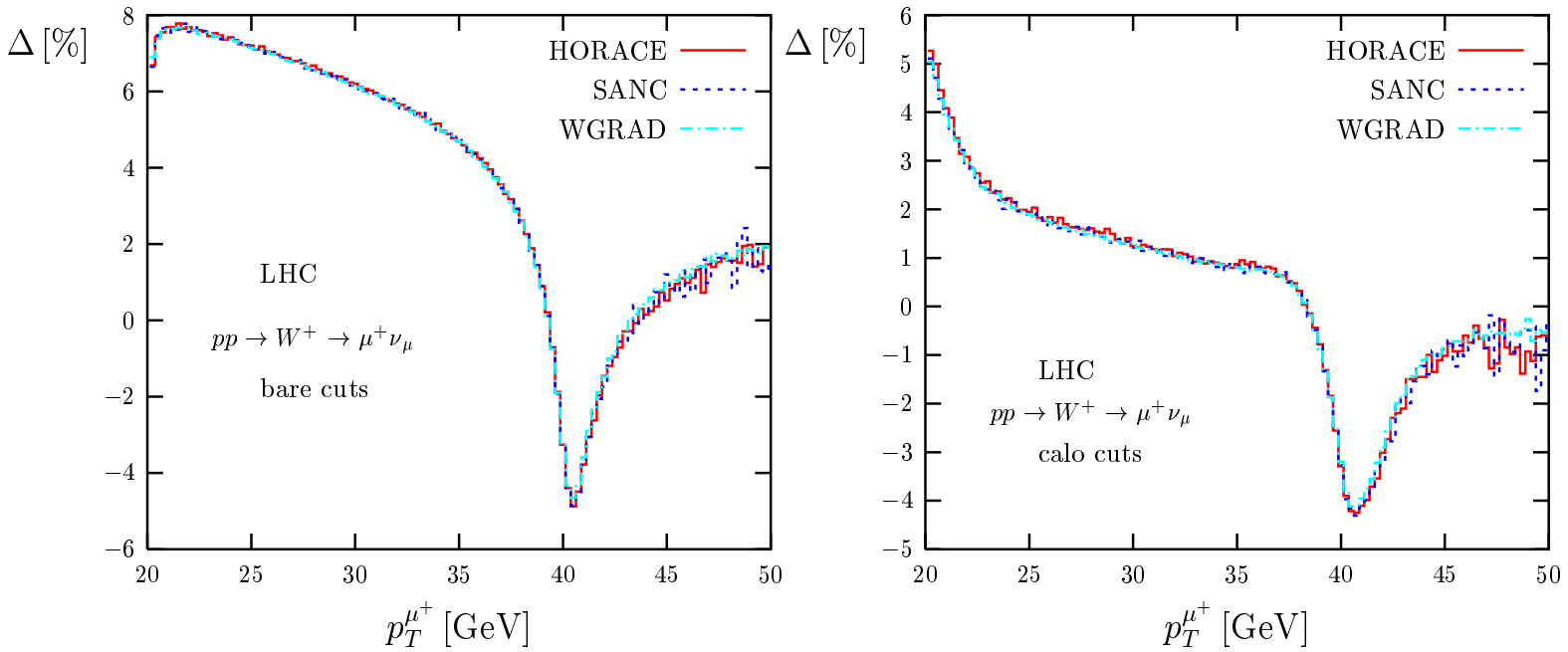
C.E. Gerber *et al.*, *Tevatron-for-LHC Report: Top and Electroweak Physics. By TeV4LHC-Top and Electroweak Working Group.* FERMILAB-CONF-07-052-E-T, May 2007. 206pp. arXiv:0705.3251 [hep-ph].

C.Buttar *et al.*, *Standard Model Handles and Candles Working Group: Tools and Jets Summary Report.* Mar 2008. 94pp. Published in Les Houches 2007, Physics at TeV colliders 121–214 arXiv:0803.0678 [hep-ph].

A. Arbuzov, *Description of Charged Current Drell-Yan process in SANC.* Talk at "W-mass workshop", Department of Physics, University of Milano, March 17-18, 2009;
URL: *http://wwwteor.mi.infn.it/∼vicini/wmass.html.*

Drell–Yan processes: tuned comparison

Typical "triple" comparison of results of calculations by SANC, HORACE and Z(W)GRADE of EW corrections to Drell–Yan charged current processes, done within the framework of Workshop *TEV4LHC'06*.



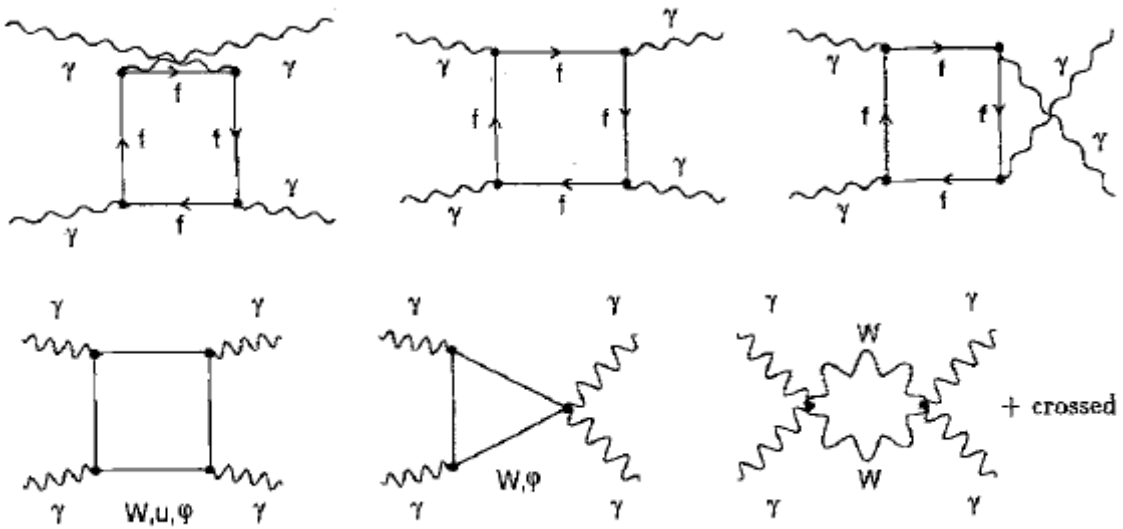
The following set-up was used:

$P_T(l,\nu) > 20$ GeV, $|\eta(l)| < 2.5$; $\alpha(0)$ EW scheme; PDF=MRST2004QED; NLO QED DIS subtraction scheme.

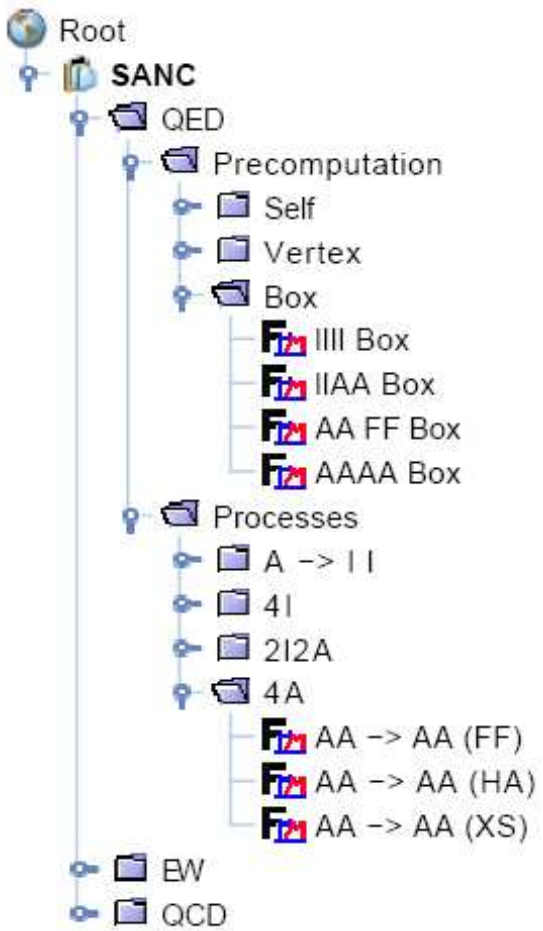
4b physics

Among number of 4b processes high priority deserve processes with $\gamma\gamma$ and gg (interest for physics at LHC) in the initial state:

$$\gamma\gamma(gg) \to \gamma\gamma(ZZ,\ Z\gamma\ , H\gamma,\ \text{etc.})$$



graphs for $\gamma\gamma \to \gamma\gamma$



ArXiv: hep-ph/0611188

4b physics: Helicity Amplitudes $\gamma\gamma \to \gamma\gamma$

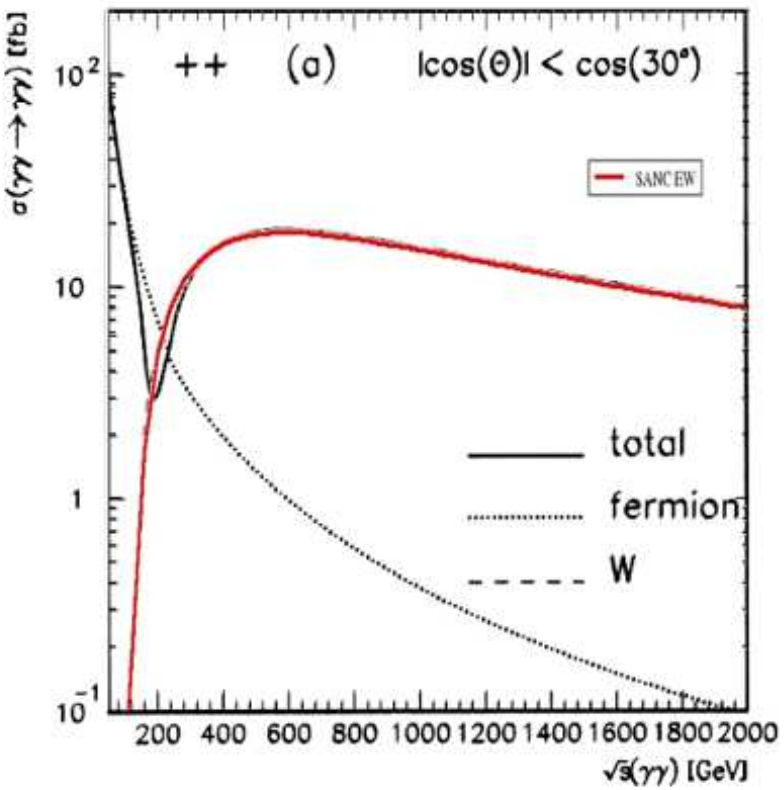
$$
\begin{aligned}
H^{++++}_{fermion}(s,t,u) &= -1 + \frac{u-t}{s}\left[B_0(u,m_f) - B_0(t,m_f)\right] + \left[\frac{4m_f^2}{s} + 2\left(\frac{tu}{s^2} - \frac{1}{2}\right)\right]\left[uC_0(u,m_f) + tC_0(t,m_f)\right] \\
&\quad -2m_f^2 s\left(\frac{m_f^2}{s} - \frac{1}{2}\right)\left[D_0(s,t,m_f) + D_0(s,u,m_f) + D_0(t,u,m_f)\right] \\
&\quad -tu\left(\frac{4m_f^2}{s} + \frac{tu}{s^2} - \frac{1}{2}\right) D_0(t,u,m_f); \\
H^{++--}_{fermion}(s,t,u) &= 1 - 2m_f^4\left[D_0(s,t,m_f) + D_0(s,u,m_f) + D_0(t,u,m_f)\right]; \\
H^{+++-}_{fermion}(s,t,u) &= 1 - m_f^2\left(s^2+t^2+u^2\right)\left[\frac{1}{tu}C_0(s,m_f) + \frac{1}{su}C_0(t,m_f) + \frac{1}{st}C_0(u,m_f)\right] \\
&\quad -m_f^2\left[\left(2m_f^2 + \frac{st}{u}\right)D_0(s,t,m_f) + \left(2m_f^2 + \frac{su}{t}\right)D_0(s,u,m_f) + \left(2m_f^2 + \frac{ut}{s}\right)D_0(u,t,m_f)\right].
\end{aligned}
$$

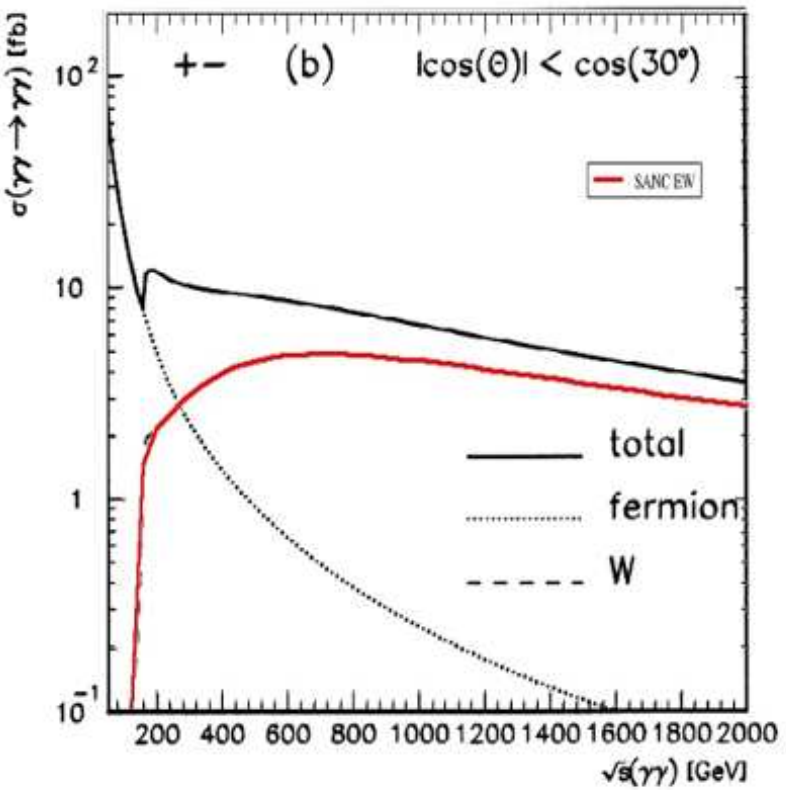
Comparison with M.Bohm Z.Phys. C63, 219-225 (1994) and G.Jikia arXiv:hep-ph/9312228

$$
\begin{aligned}
H^{++++}_{boson}(s,t,u) &= 1 - \frac{u-t}{s}\left[B_0(u,M_W) - B_0(t,M_W)\right] - \left[\frac{4M_W^2}{s} + 2\left(\frac{tu}{s^2} - \frac{4}{3}\right)\right]\left[uC_0(u,M_W) + tC_0(t,M_W)\right] \\
&\quad + \left[2M_W^2 s\left(\frac{M_W^2}{s} - \frac{4}{3}\right) + \frac{2}{3s^2}\right]\left[D_0(s,t,M_W) + D_0(s,u,M_W) + D_0(t,u,M_W)\right] \\
&\quad + tu\left(\frac{4M_W^2}{s} + \frac{tu}{s^2} - \frac{4}{3}\right) D_0(t,u,M_W).
\end{aligned}
$$

4b physics

Cross section in monochromatic collisions for $\gamma\gamma \to \gamma\gamma$ process:
(Legend: red solid line is SANC EW NLO, black ones - G.Jikia)





Comparison with G.Jikia arXiv: hep-ph/9710459

SANC: future plans

- Tuned comparisons and Workshops, e.g. W-mass Workshop
- Single-top production → **Talk of P.Christova (SANC)**
- NLO QCD with PYTHIA and HERWIG
- Re-weighting of events due to missing EW NLO corrections
  PYTHIA + FOTOS (ATLAS software) = no EW and QCD NLO
  → **Talk of R.Sadykov (SANC)**
- Single-resonance approach to complex processes
- New fermion–boson and purely boson processes
  → **Talk of W. von Schlippe (SANC)**
- R&D and realization of SANC2 phase of the project
- Implementation of 5-particle processes

Scientific Knowledge Services

In SANC we faced a problem of integrating components with different nature:

- symbolical and numerical algorithms,
- data,
- user interfaces.

To resolve these problems we need to develop a flexible system architecture to provide interaction of SANC2 components.

This lead us to the idea of developing general interface for these components — **Scientific Knowledge Service (SKS)** interface.

SANC2 stages

- **Framework**

  SANC project has already a developed computer framework, that provides computations in HEP for experiments.

  Currently this framework is based on **FORM** computer language, that is specialized for symbolical computations in HEP, but it is not suitable for building complex systems.

  That is why the first task is to write a wrapper around FORM and SANC framework using a high level program language. We propose to use **Ruby** for this purpose as modern, dynamically progressing high level program language. **SKS** interface for this framework will be developed as well.

SANC2 stages

- **Framework**
- **Database policy**

Using the computer **Framework** the SANC group has already computed observables for a lot of HEP processes.

The results are stored in the database of the current SANC computer system as **FORM codes** and as **FORTRAN modules** ready for use in MC generators by other groups.

They also should be adopted to the new environment as **SKS**.

SANC2 stages

- **Framework**
- **Database policy**
- **MC generators.**

  The SANC group also has started building its own MC generators.

  Currently each new generator is written from modules (s2n).

  The task is to develop the general component for such generators and implement it as **SKS**.

SANC2 stages

- **Framework**
- **Database policy**
- **MC generators.**
- **Education.**

The computations in HEP are very complex, which makes the mentioned SANC framework difficult to use.

There is a need to develop learning **SKS**, that can be used as a tutorial to the framework and as an introduction to the Quantum Field Theory computations for students and PhDs.

MCSANC - generator interface for SANC

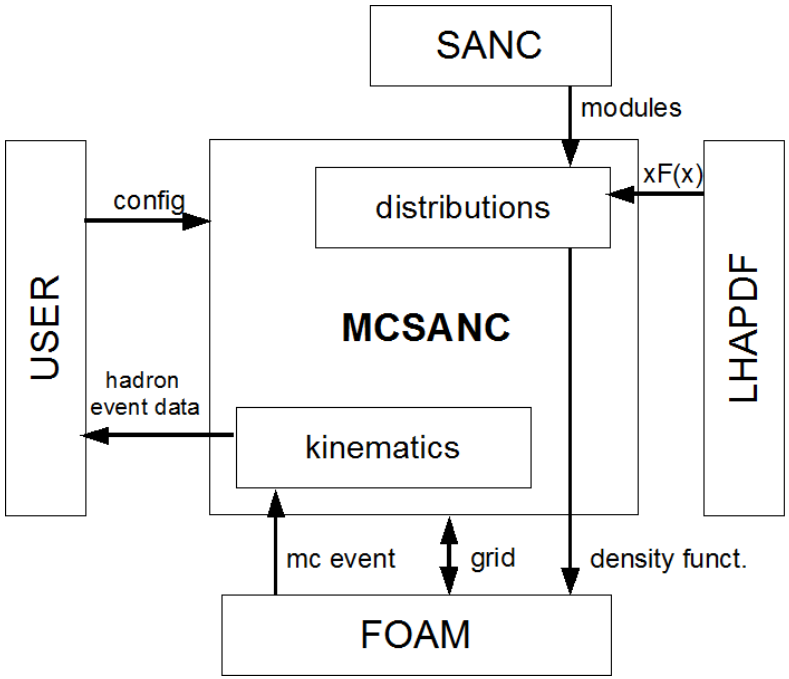
The processes calculated in SANC at 1-loop level are all using same set of methods and data blocks. Thus their implementation as event generators is convinient to be done in a single envelope. For this purpose a simple toolkit is being developed, aiming for the following tasks:

- Provide a transparent way to manipulate the processes requested by the user.
- Simplify the run configuration using config-files.
- Provide a unified interface to SANC package modules.
- Interface with FOAM general purpose Monte-Carlo generator, its persistency.
- Output data format manipulation
- other...

Thanks to A.Sapronov (SANC)

MCSANC - structure

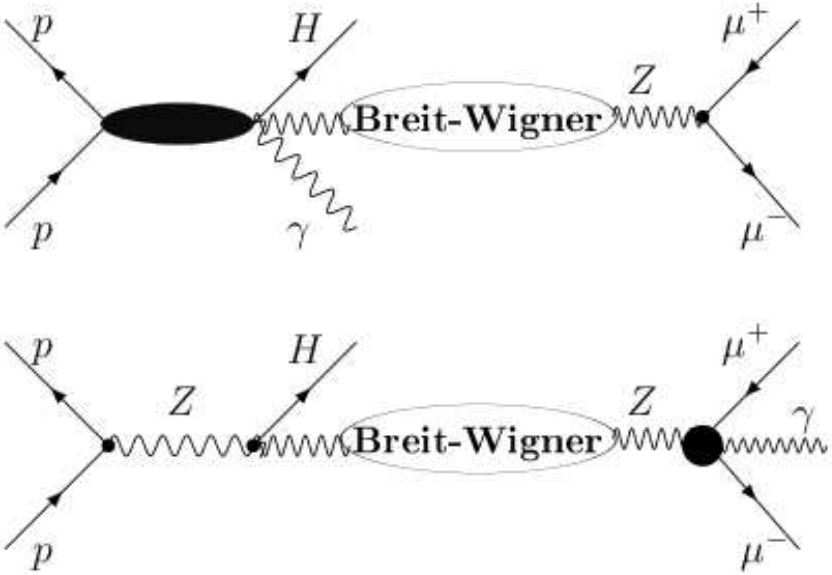
MCSANC is a small set of C++ classes, uses autotools to compile (standard ./configure script)



This approach of general interface was tested in comparison with stand-alone realization of Drell-Yan process

Process $pp \to HZ(\mu^+\mu^-)$ EW NC

Currently a generator for $pp \to HZ(\mu^+\mu^-)$ EW NC process at NLO level is being created using this approach. For implementation of 5-particle process the cascade approximation is exploited.
→ **Talk of V.Kolesnikov (SANC); also V.Kuksa, CALC2009**.



The process is build from two parts, tied up using Z mass spreaded with Breit-Wigner distribution.

This gives a linearized expression for 5-particle process cross section.

$$\sigma_{f_1\bar{f}_1\to \mathrm{H}(f\bar{f})} = \frac{\sigma^{\mathrm{Born}}_{f_1\bar{f}_1\to \mathrm{H}Z}\Gamma^{\mathrm{Born}}_{Z\to f\bar{f}}}{\Gamma_Z}\times \left(1+\delta^{\mathrm{1loop}}_{f_1\bar{f}_1\to \mathrm{H}Z}+\delta^{\mathrm{1loop}}_{Z\to f\bar{f}}\right)$$

where:

$$\delta^{\mathrm{1loop}} = \Gamma^{\mathrm{1loop}}/\Gamma^{\mathrm{Born}} - 1$$

Process $pp \to HZ(\mu^+\mu^-)$: tree level

The cascade approximation approach was tested in comparison with CompHEP(v4.5.1) calculations at parton and handron levels in LO.

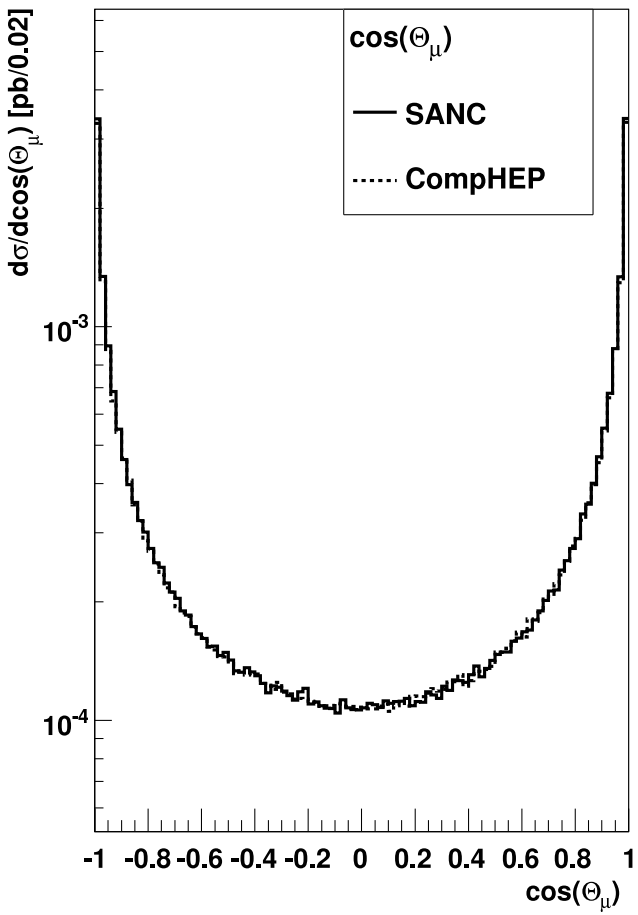
$\sqrt{s}, GeV$	500.	1000.
$\sigma[u\bar{u} \to HZ(\mu^+\mu^-)], pb$		
CompHEP	0.00077363(9)	0.00016990(8)
SANC	0.00078961(1)	0.00017357(1)
$\sigma[d\bar{d} \to HZ(\mu^+\mu^-)], pb$		
CompHEP	0.00099791(14)	0.00021901(6)
SANC	0.00101774(1)	0.00022372(1)

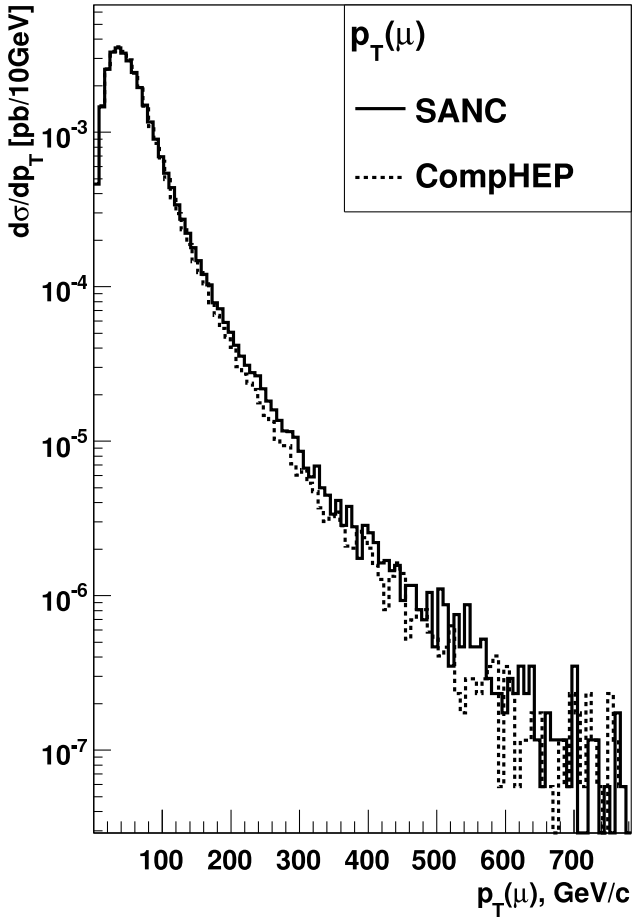
Hadron level:
$\sqrt{s} < 210. GeV$, CTEQ6M

$pp \to HZ(\mu^+\mu^-)$	σ, pb
CompHEP	0.02864(2)
SANC	0.02906(3)

The difference between precise calculation by CompHEP and cascade approximation approach is less than $\sim 1.5\%$ for parton and hadron levels.

Process $pp \to HZ(\mu^+\mu^-)$: tree level distributions





Conclusions

- SANC project:
  Became familiar with main concept, levels of calculations, SANC Outputs types
- Modules SSFM:
  Knew present status of applications
- Future plans:
  Welcome to SANC2 stages and new calculations

Demonstration

Export SSFM from SANC client!

See attached AVI...