scminami group

Automatic Feynman Amplitudes Computation and its Application to High Energy Physics (HEP)

Review Committee Meeting of KEK
Large Scale Simulation Program

December 12 - 13, 2002

scminami group

- Head : prof.**Y.Shimizu**
- members : KEK and Universities
- members : theorists, experimentalists, computer-scientists
- International collaboration : France, Russia, Poland, Italy, ...
- Systematic development for tools and systems for HEP

Introduction

- Systems for Automatic Computation of cross sections → essential tools in HEP
- Complicated calculation

  EW, susy : many particles and vertices

  SM: particles=24, vertices=139

  MSSM: particles=55, vertices=3553

  final states: multi-body

  high statistics: higher-order(loops)

→ **Beyond man-power**

Sugawara, ICHEP2000

Automatic Computation

⇒ Automatic calculation of cross sections in HEP.
⇒ Large scale computation beyond man-power.
⇒ Essential tools for current and future HEP.

1. Automatic computation systems working in the world

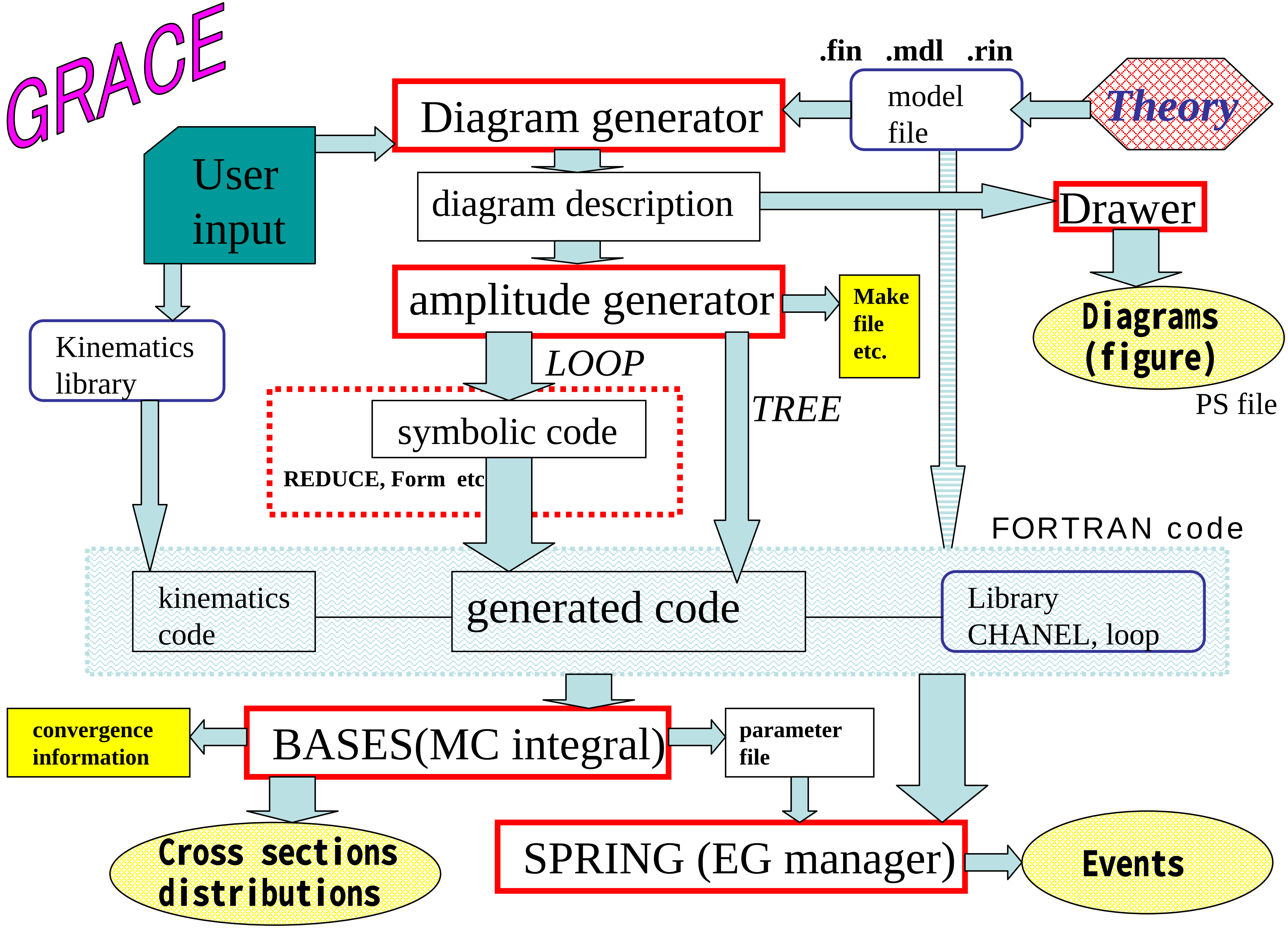
   ALPHA(Italy), **CompHEP**(Russia), **FDC**(China), **FeynArts/FeynCalc series**(Germany), **GEFICOM**(Germany/Russia), **GRACE**(Japan), **MadGraph**(USA), **NIKHEF setup**(Holland) ...

2. Examples of Achievements

   - 4-fermion generators(76 processes) for LEP-2 experiments(**ALPHA**,**CompHEP**, **GRACE**).
   - $e^-e^+ \to$ 6-fermion(**ALPHA**,**GRACE**), $e^-e^+ \to \tilde{\chi}_1^0\tilde{\chi}_1^0 q_1\bar{q}_2 q_3\bar{q}_4$ (**GRACE**), $\gamma\gamma \to$ 4-fermion(**CompHEP**).
   - $ep \to el^+l^-X$(**GRACE**).
   - $p\bar{p} \to Wb\bar{b}j$(**CompHEP**), $pp \to W^+W^-b\bar{b}j$ (**MadGraph**), $gg, q\bar{q} \to 8g$(**ALPHA**).
   - 1-loop calculation for $e^-e^+ \to W^-W^+$, $\gamma\gamma \to W^+W^-$, $W^+W^- \to W^+W^-$ (**FeynArts/FeynCalc**,**GRACE**), $e^-e^+ \to W^+\mu^-\bar{\nu}_\mu$ (**GRACE**).
   - Hadronic Higgs decay in $O(\alpha_s^2)$, $O(\alpha\alpha_s)$ corrections to $Z \to b\bar{b}$, etc. (**GEFICOM**).
   - 4-loop β-function($\sim$50,000 diagrams) (**NIKHEF setup**).

system components

- Diagram generation for the input process
- Amplitude/Matrix element generation
- Kinematics and Integration (efficiency)
- Event generation (efficiency & weight)
- Peripheral tools: rule generator, diagram selection, QED radiation, PDF, loop integral library, multi-process, color flow and interface for hadronization, etc.


GRACE
.fin .mdl .rin
Diagram generator
model file
Theory
User input
diagram description
Drawer
amplitude generator
Make file etc.
Diagrams (figure)
PS file
Kinematics library
LOOP
TREE
symbolic code
REDUCE, Form etc
FORTRAN code
kinematics code
generated code
Library CHANEL, loop
convergence information
BASES(MC integral)
parameter file
Cross sections distributions
SPRING (EG manager)
Events

GRACE

GRACE: the Generator of Generators

for the analysis of HEP experiments

more than 100 citations

Children of GRACE

- grc4f : $e^+e^- \rightarrow$ 4fermions (LEPII)
- susy23 : $e^+e^- \rightarrow$ 23 susy processes (LEPII)
- grape: $ep \rightarrow e\, l\, l\, N$ (HERA)
- gr@ppa: $pp \rightarrow bbbb$ X (CDF/LHC)

etc.

GRACE 1-loop

Many 2 to 2 processes have been checked.

Recent Progress

$$e^+e^- \to \nu\bar{\nu}H$$

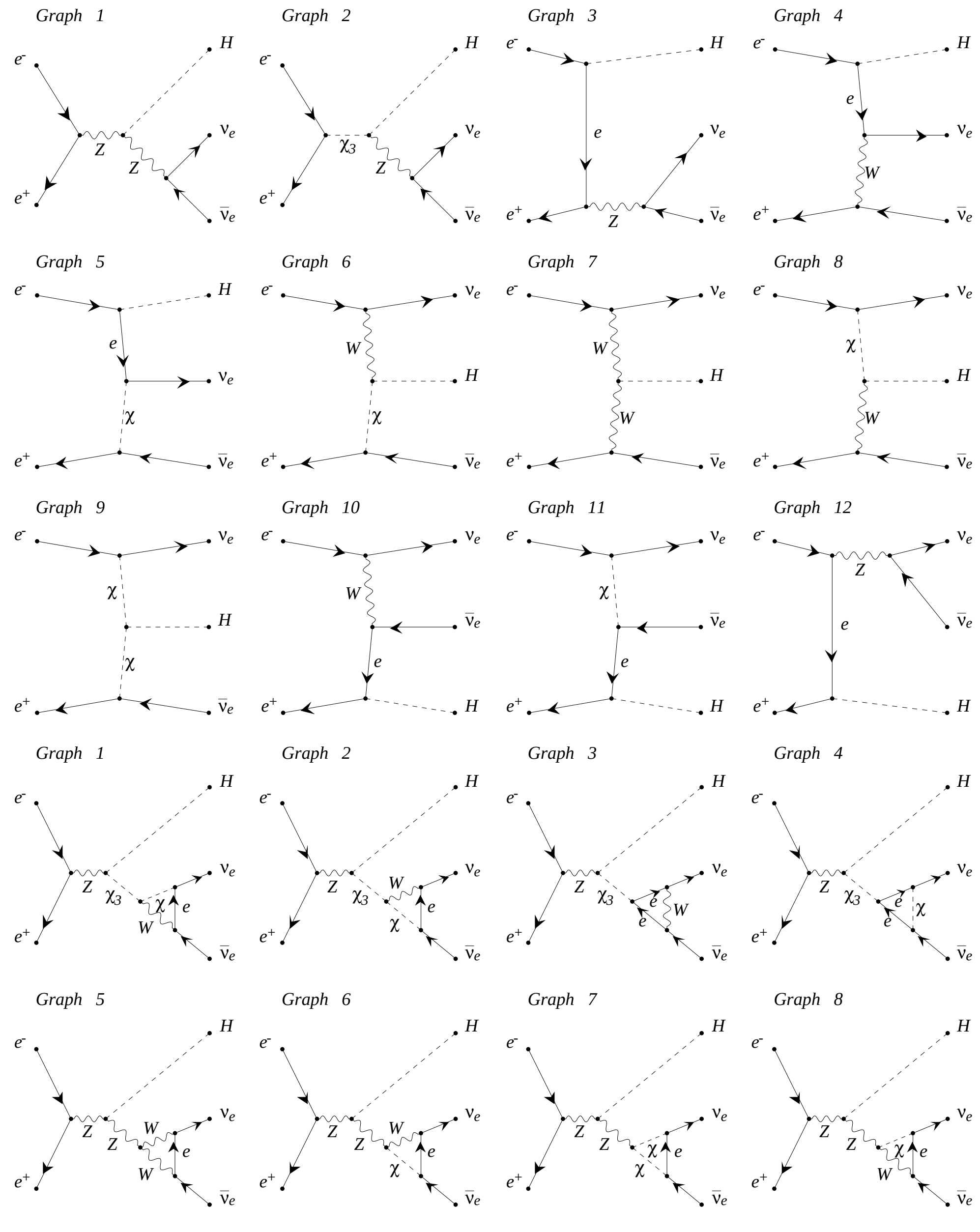
tree:2(12) 1-loop:249(1350)

... includes pentagon diagrams

$e^+e^- \to \nu\bar{\nu}H$

tree diagrams and

first 8 one-loop diagrams



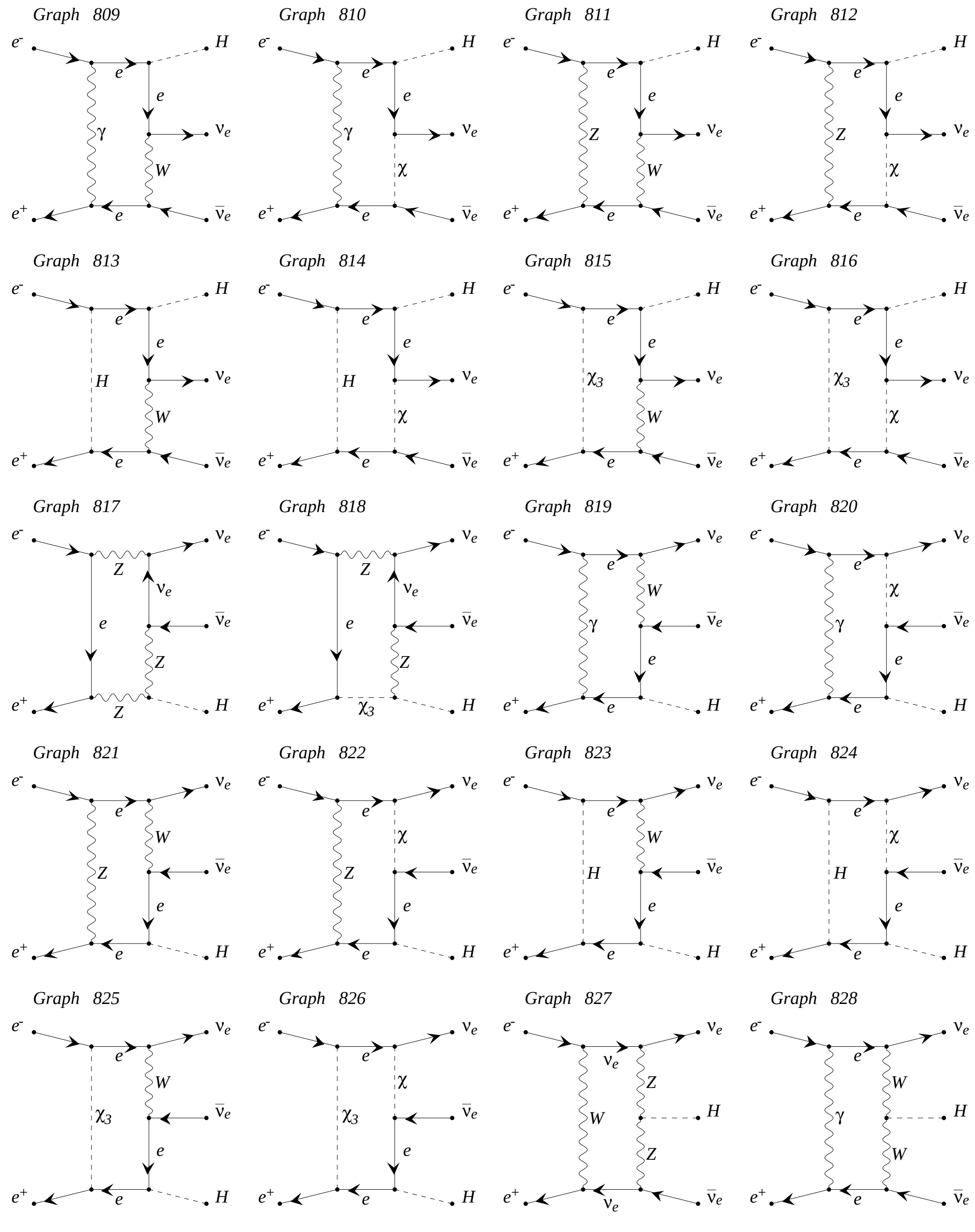
produced by GRACEFIG

$e^+e^- \to \nu\bar{\nu}H$

... and

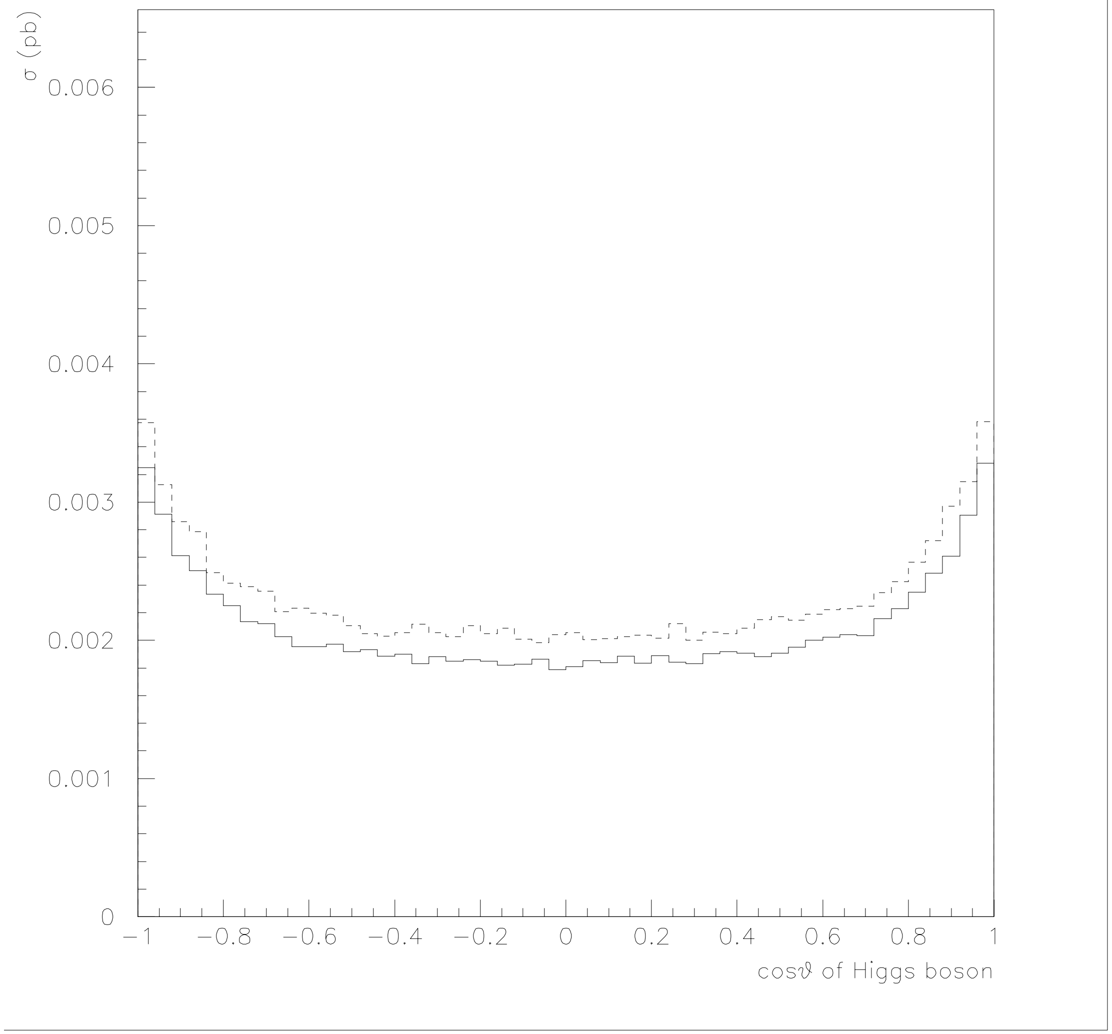
some one-loop diagrams

(pentagons)



produced by GRACEFIG

$$e^+e^- \to \nu\bar{\nu}H$$

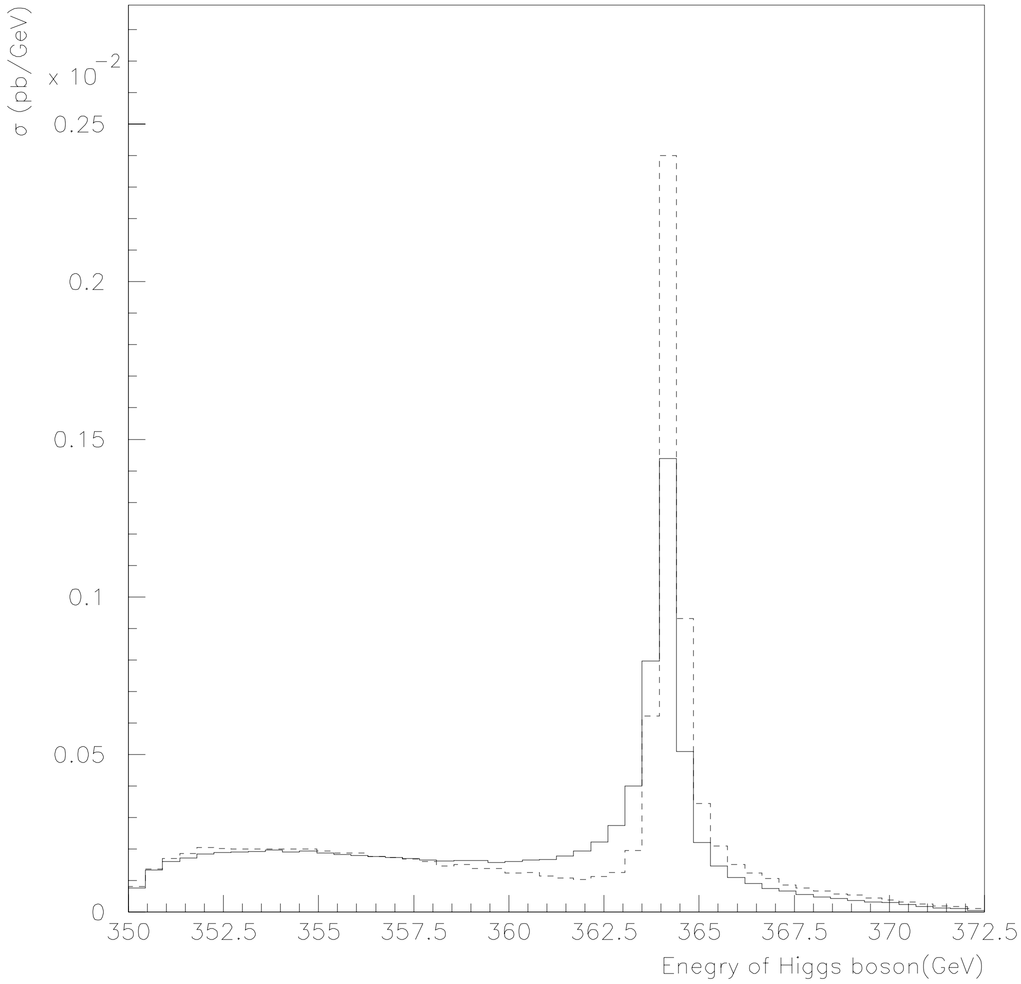


angular distribution of Higgs boson

dash=tree

solid=tree+loop +radiation

$$e^+e^- \to \nu\bar{\nu}H$$



energy distribution of Higgs boson

dash=tree

solid=tree+loop +radiation

GRACE SUSY (tree/1loop)

- many particles and vertices
- *system check*: ALL 6-external-particle 582,102 processes are examined by gauge invariance.
- 1-Loop

  ee→tt : MSSM 540×2,SQCD 20×2

  ee→WW : MSSM 936×3

  ee→h^0Z : MSSM 1265×1

  ee→H^+H^- : MSSM 732×3

Higher Loops

- 1-Loop, 2-Loop,...

  Huge number of diagrams
  ⇒ CPU power, memory size, disk size, ...

- For the check of system, quadruple precision is very important.
  (Indispensable feature of super computer)

Multi-particle final states

- cross sections ... phase space integral
- event generation ... weight=1 generators are favored
- singularities
  resonance pole, t-channel
  soft singularity, collinear singularity

  loop integrals

Monte Carlo Integral

MC integral :

VEGAS, BASES

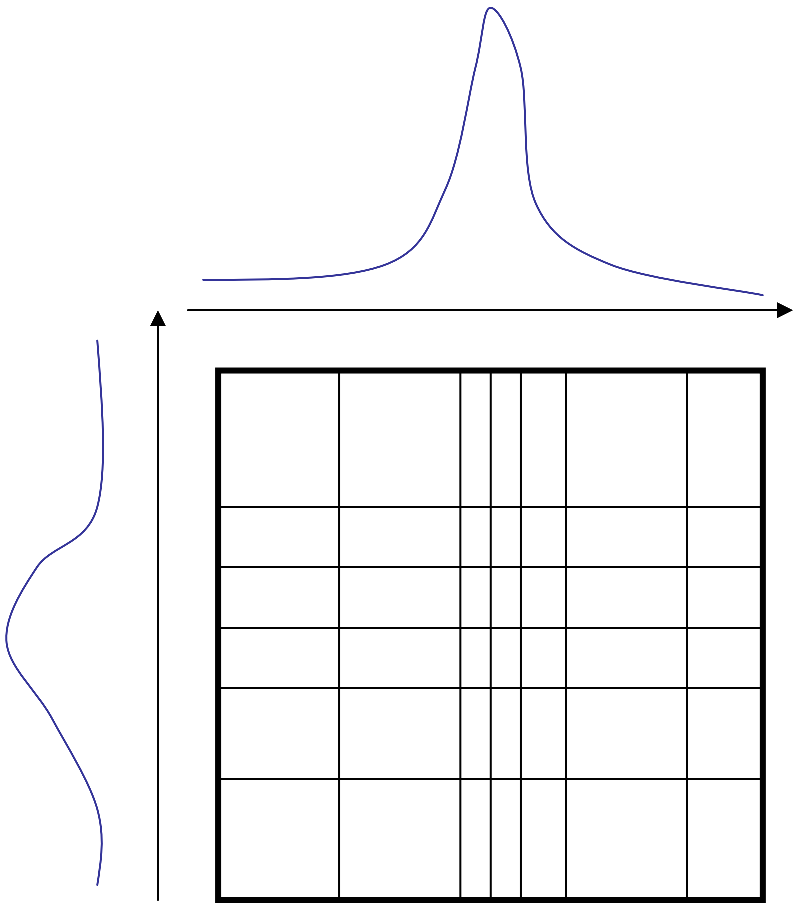
importance and

stratified sampling

only effective if

each singularity is

factorizable



singular numerical integral

- VEGAS, BASES ... requires expert technique to choose integral variables
- Existence of “good” variable set is unknown.

⇒Kinematics database, division of phase space ,.... etc.

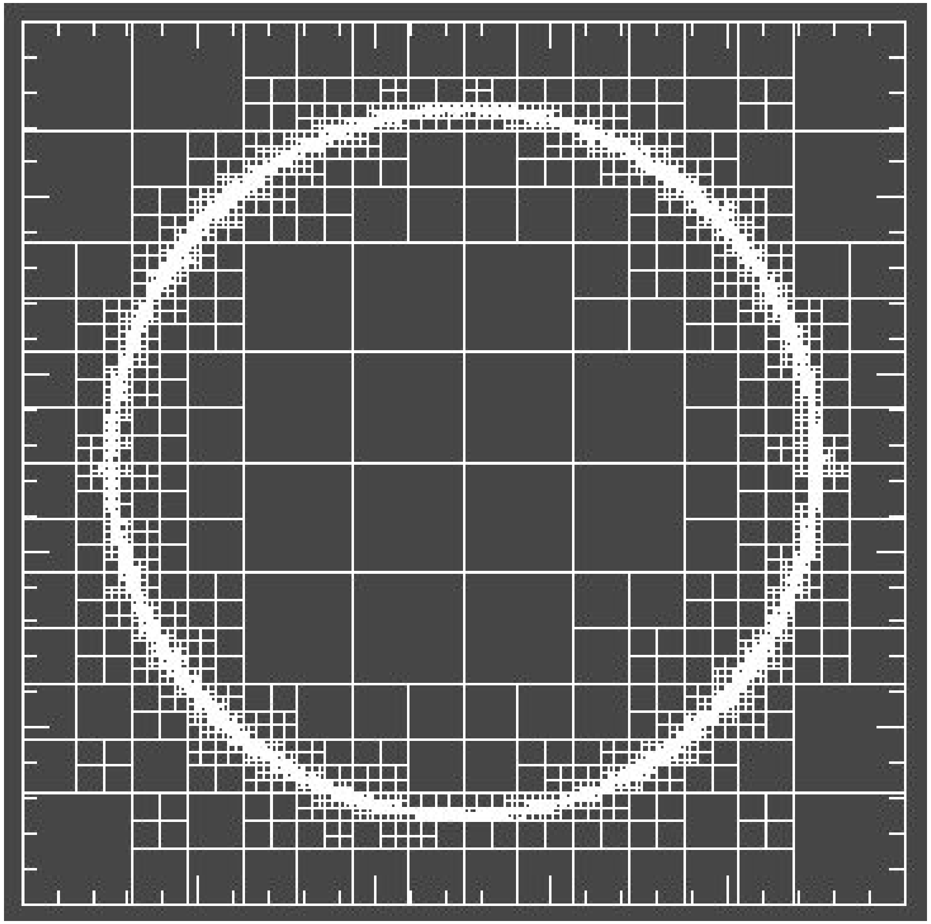
⇒ Numerical integral package for a general singular integrand is WANTED.

DICE, MILX, FOAM, ParInt,…

DICE

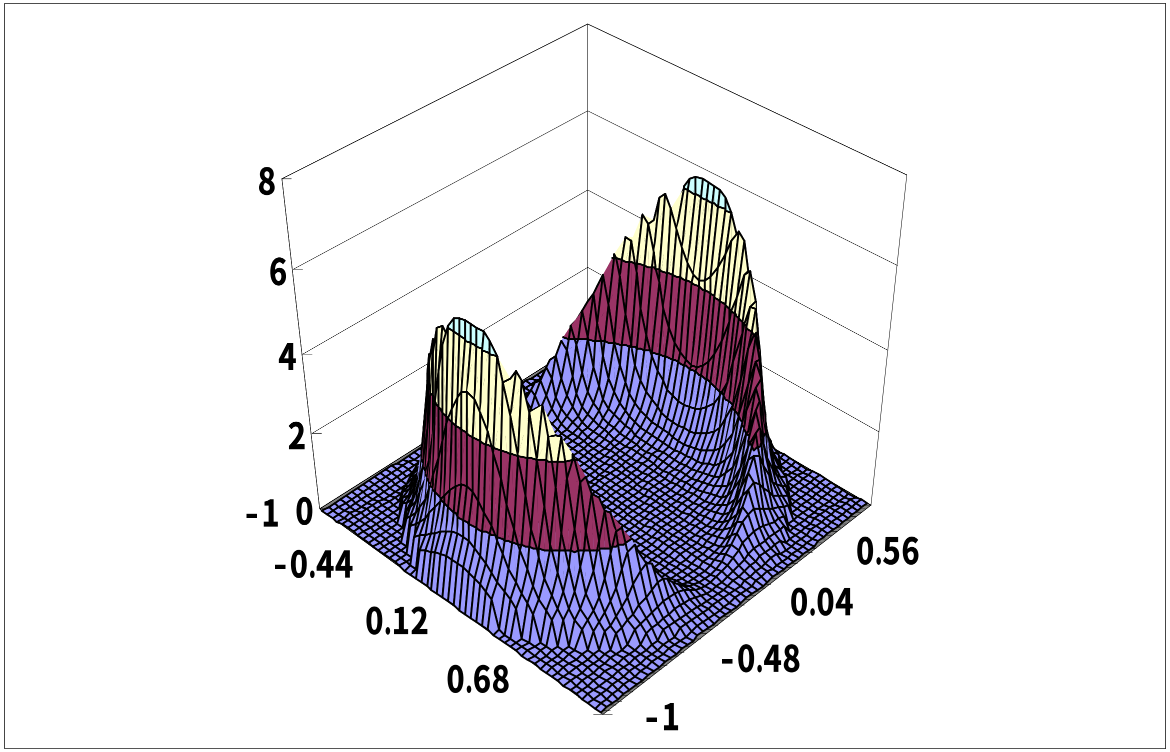
- Basic idea

  iteratively divide the hyper-cubes only those give dominant contribution to the integral



DICE vs ParInt

$$I_2 = \iint\limits_{-1<x,y<1} dxdy \frac{\varepsilon y^2 \theta(1-x^2-y^2)}{(x^2+y^2-a^2)^2+\varepsilon^2}$$



DICE vs ParInt

$$I_2 = \iint_{-1<x,y<1} dxdy \frac{\varepsilon y^2 \theta(1-x^2-y^2)}{(x^2+y^2-a^2)^2+\varepsilon^2}$$

a=0.8

ε	ParInt 1.1	DICE v1.3	Exact
10^{-1}	2.6436±0.0018 0.66s 4E5	2.6440±0.0002 2.36s 6E6	2.6436
10^{-2}	3.1056±0.0006	3.1058±0.0003	3.1056
10^{-3}	3.1530±0.0001	3.1532±0.0003	3.1530
10^{-4}	3.1577±0.0003	3.1578±0.0003	3.1577
10^{-5}	3.1582±0.0002	3.1583±0.0003	3.1582
10^{-6}	3.1583±0.0001 243s 2E9	3.1578±0.0003 2058s 6E9	3.1583

CPU Time, Sampling points

DICE

$$e^+e^- \to \mu^+\mu^-\gamma \qquad \sqrt{s} = 70\,\mathrm{GeV} \qquad k_{cut} = 0.1\,\mathrm{GeV}$$

KECSC : Naive Kinematics, 4-dim integral
for DICE 0.1% Acc. required
vu-user/user =98.22 %

DICE 0.1% naive kin.	2.9106±0.0029 E-2 nb	171d 2h
DICE 1% naive kin.	2.8517±0.0256 E-2 nb	1d 20h
BASES 1% good kin.	2.9203±0.0016 E-2 nb	5m47s / hp9000
ParInt 1% naive kin.	2.9140±0.0291 E-2 nb	1h59m/AMD800MHz

conclusion

If we require the precise understanding of the present and future HEP, the large scale computation is unavoidable.

Combination of the automated systems and the computational power is one of the essential element of the HEP.