Report from MC tools Working Group

Presented by Bin Gong

On behalf of MC tools Working Group

Institute of High Energy Physics, CAS

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Outline

Group Members I

At present, we have 12 affiliations and 23 core members in total.

1. CCNU (Central China Normal University)
   Xin-Qiang Li
2. HBU (Hebei University)
   Tai-Fu Feng and Shu-Min Zhao
3. HZNU (Hangzhou Normal University)
   Qing-Jun Xu
4. IHEP (Institute of High Energy Physics, CAS)
   Yu Feng, BG, Zhao Li and Jian-Xiong Wang
5. PKU (Peking University)
   Qiang Li and Hua-Sheng Shao
6. SDU (Shandong University)
   Shou-Shan Bao, Hong-Lei Li, Shi-Yuan Li and Zong-Guo Si

Group Members II

7. SJTU (Shanghai Jiao Tong University)
   Jian-Hui Zhang
8. SYSU (Sun Yat-Sen University)
   Hong-Hao Zhang
9. UCAS (University of Chinese Academy of Science)
   Qi-Shu Yan and Xiao-Ran Zhao
10. USTC (University of Science and Technology of China)
    Lei Guo, Wen-Gan Ma and Ren-You Zhang
11. ZJU (Zhejiang University)
    Bo Feng
12. ZZU (Zhengzhou University)
    Guo-Li Liu

Brief Introduction

- The importance of MC tools can never be overestimated.
- a bridge between experiments and theories
- combine both theoretical and experimental knowledge into powerful tools
- development of MC tools thought as theoretical work
- can provide the most comprehensive information needed by experimental groups (X-sections, differential distributions, angular correlations, etc...)
- high precision MC tools are needed for future high energy physics

Current MC tools

After more than 40 years of development, there are lots of useful MC tools. I list some of most popular ones here:

- Pythia, Herwig, Sherpa: general purpose, parton shower/hadronization
- Grace@loop, MadGraph 5, GoSam, BlackHat: one-loop
- Alpgen, BlackHat, Whizard: multi final states
- Delphes, PGS: detector simulation

The world record is W+5j@NLO (BlackHat+Sherpa)

Our aims

- physical study with current MC tools for future high energy physics at the early (CDR/TDR) stage Qiang Li, Bin Zhang, *et al.*
- develop high precision MC toolkits and general-purpose MC generators Jian-Xong Wang, BG, Zhao Li
- explore new technology for amplitudes computation (method for multi-loops and multi-legs) Bo Feng, Jian-Hui Zhang
- tighten the connections with other MC groups
- foster young talents to carry on the project

Activities since last workshop

Beside usual communications, seminars are held monthly at ITP/KITPC:

- March 8, "Jet/Parton Matching" Qiang Li from PKU
- April 10, "IR Regularization: Paradise and Purgatory" Zhao Li from IHEP
- May 8, "Automation of Next-to-leading Order Computations with MadGraph5_aMC@NLO" Hua-Sheng Shao from PKU/CERN
- June 12, "Recent developments in computing loop amplitudes" Jian-Hui Zhang from SJTU
- July 4, "Current status and future development of FDC" BG from IHEP

aim of physical study at early stage

As mentioned above, at the early (CDR/TDR) stage, we will explore the physical potential of colliders with CURRENT MC tools. Namely, we will

- provide important information for detector designs
- explore the event shape of SM processes
- explore the feasibility of various new physics

Benchmark processes

(Tong-Guang Cheng, Sergei Chekanov, Bo Feng, Bin Gong, Tao Han, Gang Li, Liang Li, Qiang Li, Zhao Li, Meenakshi Narain, Sanjay Padhi, Meade Patrick, Jimmy Proudfoot, Hui-Lin Qu, Man-Qi Ruan, Da-Yong Wang, Jian-Xiong Wang, Ke-Chen Wang, Lian-Tao Wang, Yi-Wen Wen, Yong-Cheng Wu, Ke-Ping Xie,Qi-Shu Yan, Da-Neng Yang, Gao Yu, Bin Zhang, Jian-Hui Zhang, Xiao-Ran Zhao, Zhi-Jie Zhao)

Benchmark processes can provide important information to evaluate the physical potentials of future colliders. Here we list a few benchmark processes, which are important and should be carefully studied in CDR and TDR stages.
For CEPC we have:

- beams (radiation, matter-beam interaction, beam distribution functions)
- Higgs production with polarized and unpolarized beams
- $Z + \gamma(s)$
- WW/ZZ, TGC measurements
- multi vector boson scattering and QGC measurements

And SPPC simulations (where we focus on):

- event shape of the SM at 100 TeV collisions
  - jets, boosted $W/Z/H/top$ Qi-Shu Yan, Shuo Yang
  - $W/Z(s)$, multi vector boson final states Qiang Li's group
  - single top and multi tops Zong-Guo Si
  - (multi) Higgs boson(s) Qi-Shu Yan, Qiang Li, Chien-Yi Chen (BNL)
  - VBF Bin Zhang
  - $t\bar{t}H, t\bar{t}HH, t\bar{t} \to HH$ Liang Li
- benchmark new physics processes at 100 TeV collisions
  - spin 0 particle search: new Higgs bosons (neutral/charged/multi-charged), stop/sbottom quarks, sleptons Yong-Chen Wu, Ning Chen
  - spin 1/2 particle search: new quarks/leptons, charginos Bin Zhang
  - spin 1 particle search: W'/Z', KK W/Z Ke-Ping Xie
  - spin 3/2 particle search: gravitino
  - spin 2 particle search: KK gravitons Chien-Yi Chen
  - Dark matter search

To fulfil the need of detector design, these benchmark processes should help to address the following detector issues:

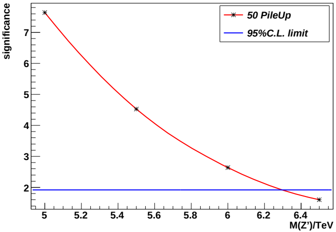
based on Delphes3 by Jimmy Proudfoot, Sanjay Padhi, Meenakshi Narain *et al.*

- possible detector research and developments
  - overall strategies; vector detector technologies; large tracking detectors, calorimetry; forward calorimeter; muon detection technologies
- simulation studies and tools
  - event generation and samples; simulations and reconstruction tools; pileup mitigation and effects
- machine and detector interface
  - large additional radiations; timing and beam crossing
- baseline detector studies
  - detector performance; particle ID-electrons, muons, taus and photons; jet tagging; energy and momentum resolutions; flavor tagging; sub-jet studies and calorimeter segmentations; particle flow; tau tagging

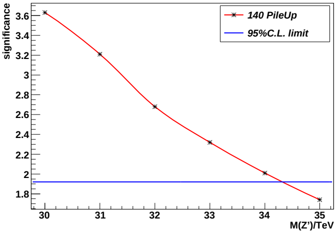
Sequential Z' (by Ke-Ping Xie and Qiang Li)

A Monte-Carlo feasibility study of searching Sequential Standard Model Z' via its decay into $\mu^+\mu^-$ has been performed at *pp* colliders.

obtained exclusion limit on Z'_{SSM} as 6.3/34.3 TeV, as shown in the figure



(a) $\sqrt{s} = 14\ \mathrm{TeV}, \mathcal{L} = 300\ \mathrm{fb}^{-1}$



(b) $\sqrt{s} = 100\ \mathrm{TeV}, \mathcal{L} = 1000\ \mathrm{fb}^{-1}$

Statistical significance in the most sensitive mass window with given *pp* collision energy and luminosity.

Triple-W Production and Anomalous $WWWW$ Couplings (by Yi-Wen Wen, Hui-Lin Qu, *et al.*)

The large collision energy offers us an opportunity to probe the quartic couplings of the non-Abelian gauge theory. Triple gauge boson production can be used to test the robustness of the Standard Model.

Processes	Cross section[fb]	Events cut-based Pileup 50 s1	Events cut-based Pileup 50 s2	Events cut-based Pileup 140 s1	Events cut-based Pileup 140 s2
WWW	15.6	4758	1416	3855	1156
WZ	2570	92185	1670	82060	1696
$t\bar{t}W$	89.7	8607	2539	9930	3211
ZZ	2674	26633	481	24226	1283
$t\bar{t}Z$	454	15240	4408	18180	5034
WWZ	14.1	1164	317	993	255
Significance		12.5	14.6	10.5	10.8

Event numbers and significances of WWW production in trilepton decay channel at future pp collider with $\sqrt{s} = 100$ TeV and integrated luminosity of 3000 fb^{-1}.

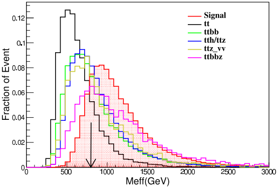
Processes	Cross section[fb]	Events			
		Pileup 50		Pileup 140	
		cut-based	BDT	cut-based	BDT
WWW	26	6465	12156	7794	13485
$t\bar{t}W$	7684	35961	65928	60396	100047
$WWjj$	535	30507	41124	71610	75708
$WZjj$	16250	209820	437775	429195	693225
Significance		12.3	16.4	10.4	14.4

Event numbers and significances of WWW production in same sign dilepton decay channel at future pp collider.

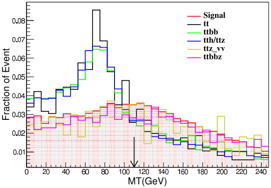
pile-up effects are important!

Sbottom Searches (by Yong-Chen Wu, Shu-Fang Su, Tao Han, Bin Zhang)

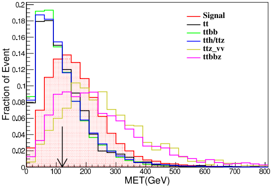
sbottom pair production via $4b + 2j + \ell +$ missing energy



(a) M_{eff}



(c) M_T



(b) $\not{E}_T$

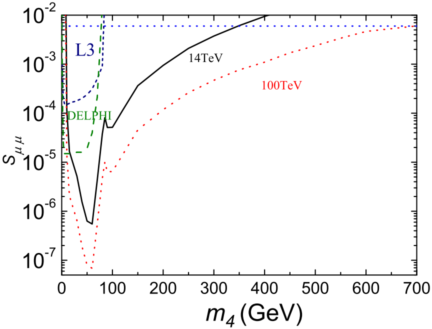
The distributions of observables M_{eff}, $\not{E}_T$, and M_T (defined by transverse mass of lepton and missing transverse momentum) are demonstrated.

Process	No-Cuts	Cut1	Cut2	Cut3	Cut4
Signal	400000	72562	60516	40111	11938
fb	3293(153.7)	597.37	498.20	330.21	98.28(93.6)
ttbar	2000000	9784	2074	853	39
fb	7181000(47.9)	35129.5	7446.7	3062.7	140.03(143.9)
ttbb	400000	16245	7039	2675	173
fb	341200(88.4)	13856.9	6004.3	2281.8	147.6(182.1)
tth/ttz	400000	42190	20790	8189	382
fb	8387(68.9)	884.62	435.9	171.7	8.01(86.0)
ttbbz	80000	4261	3057	2448	734
fb	155.8(158.8)	8.30	5.95	4.77	1.43(136.2)
ttz_vv	400000	2560	1283	1104	352
fb	2524(74.3)	16.15	8.10	6.97	2.22(61.0)
$S/\sqrt{B}$	$L = 100 fb^{-1}$	26.74	42.26	44.41	56.81(7.5)

The significance and cut efficiencies are displayed for both signal and background events. The numbers in red is the ratio compared with the case at LHC 14 TeV.

cut1: 3 b-jets tagging   cut2: $M_{eff} \geq 800$ GeV
cut3: $\not{E}_T \geq 120$ GeV   cut4: $M_T \geq 110$ GeV

Exotic Leptons detection (by Bin Zhang)



2σ sensitivity for $S_{\mu\mu}$ versus m_4 at the LHC or 100TeV collider with 100 fb^{-1} integrated luminosity.

100TeV *pp* collider has strong ability to test massive Majorana neutrinos (can detect the mass less than 800 GeV).

MC Generator Development

Why do we need new MC generators of our own?

- As end users, you will not be able to know details of generators (you are unable to custom them).
- Current MC tools are not so powerful as you thought (not enough for Z/H factory, CEPC/SPPC)
- We are not too far away, but will never catch up if we stop
- Future high energy physics needs more powerful MC generators (two and even higher loops/more than 10 legs)

Aims and Plan for MC Generator Development (Jian-Xiong Wang, BG, Zhao Li)

- middle-term aim: develop a MC generator at one-loop level (something like Madgraph5 but capable of more legs)
- long-term aim: develop an even higher precision MC generator (capable of two/higher loops), at least fulfil the need of Z&H factory/CEPC/SPPC
- The generator will be developed based on FDC package, which is already a NLO ME generator
- The first step of the plan is to improve current FDC package.

Brief introduction of FDC

FDC (Feynman Diagram Calculation) Project has been continued for more than twenty years. The package includes following basic functional modules:

- prepare Lagrangian and deduce Feynman rules for first principle model
- generate all possible Feynman diagrams for given processes in a given model (compatible with phenomenological models)
- manipulate amplitude of the process analytically
- generate Fortran codes for final numerical results
- integrate over phase space and/or generate events (BASES/Pythia)

- Also some additional modules:
  - FDC-MSSM: extended to implement SUSY models, able to construct Lagrangian and deduce Feynman rules for supersymmetry models.
  - FDC-PWA: a Partial Wave Analysis tool for experiments, fulfil the need of BESII, appreciated by BESII data analysis group
- Extended to one-loop level in 2007, with an upgrade in 2011
  - The IBP (Integration By Part) reduction method for loop integrals is implemented.
  - The two-cutoff phase space slicing method (PSS) is realized to deal with IR divergence in real corrections.
  - Two different way of amplitude calculation is realized: square the amplitude analytically; generate numerical result (in Fortran code) of amplitude then square it
- Many complicated but important processes in quakonium physics at QCD NLO have been studied with FDC.

Automatic Amplitude Computation

- Tree Level: almost all the MC tools are capable of this (according to the multiplicity)
- One Loop Level:
  - traditional Passarino-Veltman reduction method
  - IBP method: reduction at integral level, FDC here
  - OPP method: reduction at integrand level, Madgraph5 here
  - (generalized)-unitary cut method: no Feynman diagram approach, very promising for multi final state processes, BlackHat here
- Two/Higher Loop Level: computing technology still under research

Recent Research Plan of MC Generator Development

- automatic deduction of counter-terms at one-loop level, for MSSM and all other models (current counter-terms for SM are input manually)
- implement new technologies (unitary cut method) in amplitude calculation (avoid Feynman diagrams, capable of multi-legs, less numerical problem)
- new method to deal with real correction processes (FKS substraction/sector decomposition, avoid unphysical cut of PSS, quick convergence in phase integration)
- more automatic and user-friendly
- aim: a MC generator no worse than Madgraph5 (but capable of more legs)
- based on above, we can develop even higher precision general-purpose MC generators for Z&H factories and CEPC/SPPC

Others

Besides physical study and MC generator development, we will also need the following:

- explore new amplitude computation technology (especially for two/higher loops)
- strengthen the connection with other MC groups (via organizing annual schools, workshops and conferences, running visiting programs, etc). We should know more about others, on matter from an end user's view or from a developer's view.
- As a project of two or more decades, more active people are needed, in various fields (experts in theory, experiments, computations, programming). Need more collaboration among the institutes inside working group. Also have to foster young talents to take over the long-period task.

Summary

- Regional MC group is necessary for future high energy physics
- It is a long-term and highly non-trivial task to development MC generators. We need more people in various fields.
- At present, main task of MC tools working group is to provide powerful tools for other sub-working groups to develop CDR/TDR. We need various activities (annual schools, workshops, conference, visiting programs) to train young talents in order to complete the task.
- The middle-term and long-term aim is to develop high precision general-purpose MC generators for Z&H factories and CEPC/SPPC.

Thanks for your attention!