CPP2010 summary

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CPP2010
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A Starting Point

- Lyon 1990 (AIHENP)

People from various nations surprisingly found that all the members are involved in the same problem.

Since then, 20 years passed …

Experiments in energy frontier

- LHC(2009～)
  p(7TeV)+p(7TeV) （Now, ３．５＋３．５）

- ILC(20xx～)
  e^+e^- W=250GeV～500GeV～1TeV～?

- Toward the Theory of Everything

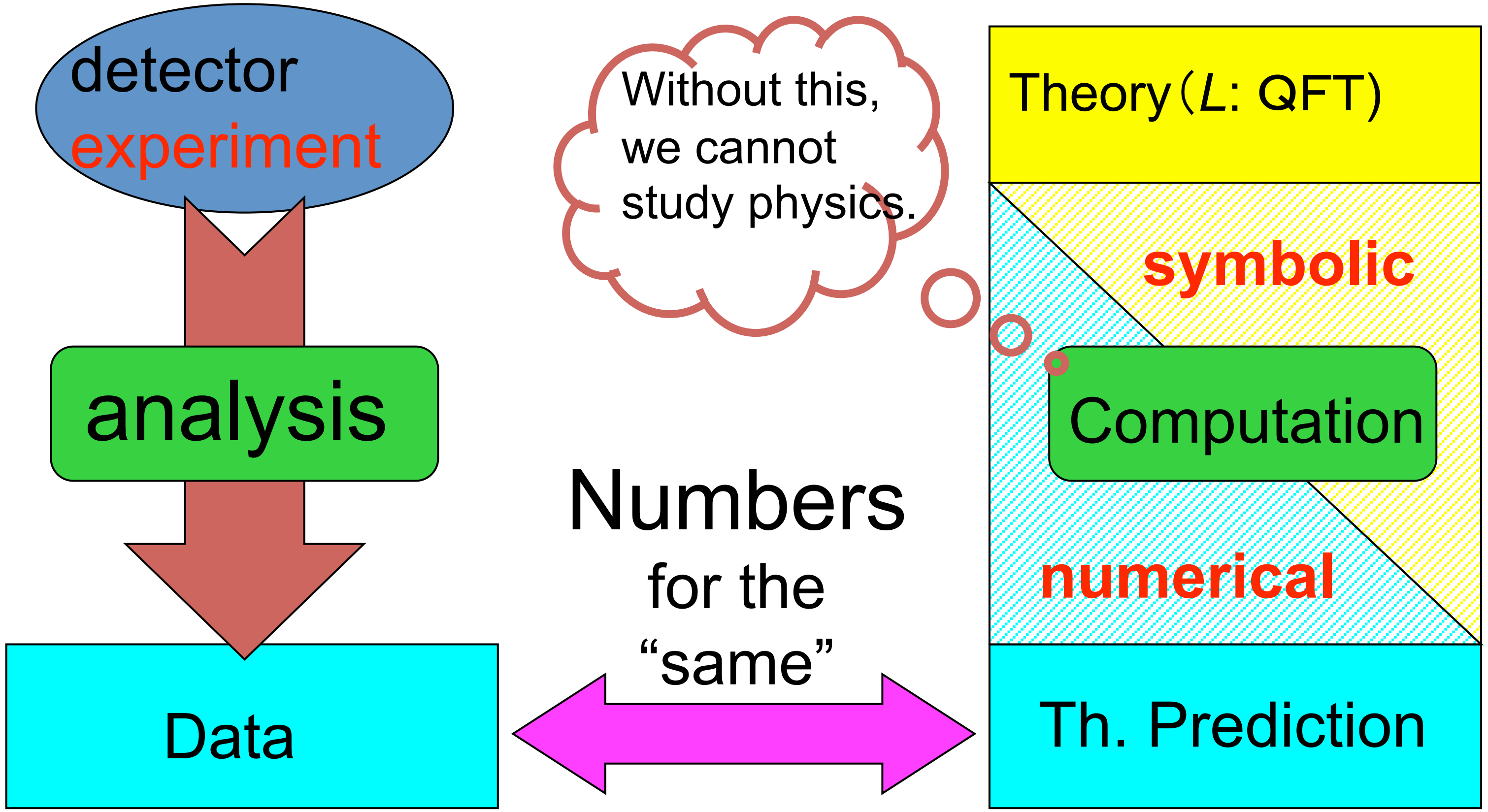
Higgs processes, Full 1-loop RC available

$e^+e^- \to \nu\bar{\nu}H$	GRACE, PLB559(2003)252 Denner et al., NPB660(2003)289
$e^+e^- \to t\bar{t}H$	GRACE, PLB571(2003)163 You et al., PLB571(2003)85 Denner et al., PLB575(2003)290
$e^+e^- \to ZHH$	GRACE, PLB576(2003)152 Zhang et al., PLB578(2004)349
$e^+e^- \to e^+e^-H$	GRACE, PLB600(2004)65
$e^+e^- \to \nu\bar{\nu}\gamma$ $\quad \nu = \nu_\mu, \nu_e$	GRACE, NIM A534(2004)334
$e^+e^- \to \nu\bar{\nu}HH$	GRACE, Talk by Y.Yasui at Durham(Sep.2004)

ILC: essential

ALL done by automation

Theory and Experiment



Human's Properties (H.Takahashi-sensei)

- 第１条 人間は気まぐれである
- 第２条 人間はなまけものである
- 第３条 人間は不注意である
- 第４条 人間は根気がない
- 第５条 人間は単調を嫌う
- 第６条 人間はのろまである
- 第７条 人間は論理的思考力が弱い
- 第８条 人間は何をするかわからない

(8) It is impossible to predict what a human will do.

Automatic Computation

"Render unto Computer the things which are Computer's"

Lagrangian in the standard model

$$L = L(QCD) + L(EW)$$

Quantum field theory

strong

$$L(QCD) = -\frac{1}{4} G^{a}_{\mu\nu} G^{\mu\nu\, a} + \sum_{q} \bar{q}(i\gamma^{\mu} D_{\mu} - m)q + L(g.f.)$$

Electro-weak

$$L(EW) = -\frac{1}{4} F^{a}_{\mu\nu} F^{\mu\nu a} + \sum \bar{L} i\gamma^{\mu} D_{\mu} L + \sum \bar{R} i\gamma^{\mu} D_{\mu} R$$

$$+ (D_{\mu}\phi)^{*}(D^{\mu}\phi) - V(\phi) - \sum_{up} f_{u} \bar{L}_{u} \tilde{\phi} R_{u} - \sum_{down} f_{d} \bar{L}_{d} \phi R_{d}$$

$$+ L(g.f.)$$

g.f.=gauge fixing term & ghost term

How to solve QFT

- Strong coupling region(large g) :
  Non-perturbative; Lattice QCD
- Weak coupling region(small g) : perturbative

$$F = F_0 + g^2 F_1 + g^4 F_2 + g^6 F_3 + \cdots$$

Lowest order term (tree) may not have sufficient accuracy. Then We need higher order term(loop).

How to compute?

- Method based on Feynman diagrams
  → This talk

  Procedure : Well established

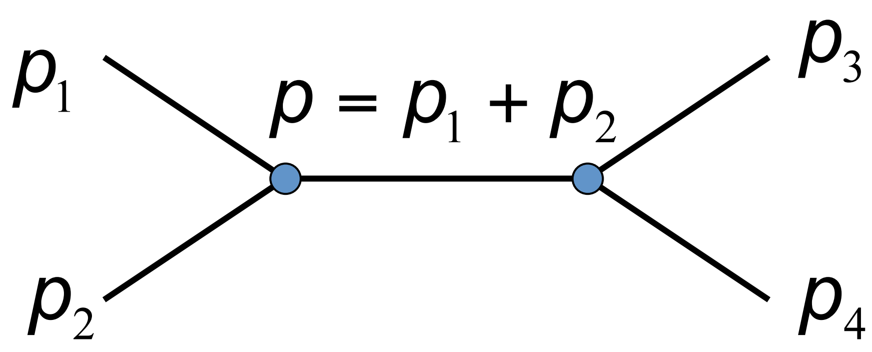
"...religious battle between Feynmanians and Unitarians..." Joey Huston

Coverage is extending

- Non-feynman diagramatic methods
  -- ALPHA(ALPGEN)・・ tree : Finie freedom → amplitude
  -- unitarity method ・・ effective in some cases
  e.g. Multi-gluon amplitude in QCD

Feyman diagrams

tree

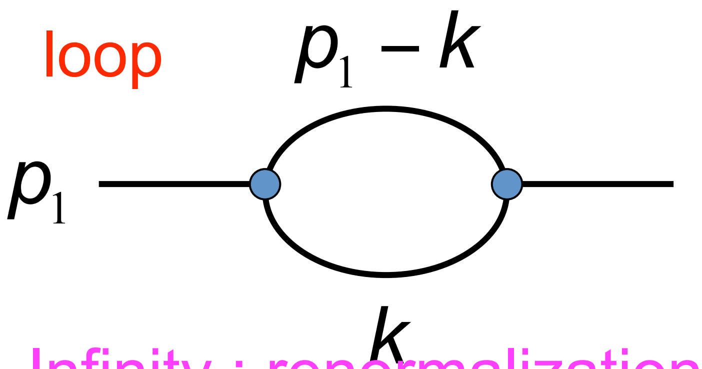


Amplitude T

$$F(p_1)F(p_2)V(p_1,p_2)D(p)$$
$$\times V(p_3,p_4)F(p_3)F(p_4)$$

Product of the functions
for each components

loop



Amplitude T

$$\int F(p_1)VD(p_1 - k)D(k)VF(p_1)d^4k$$

Products of functions

Integrals over indefinite momenta

Hard calculation

Infinity : renormalization

Discover new particles implicitly

Automatic computations and event generators, tree level

Dubinin's Talk

From Lagrangian to Feynman rules

- LanHEP (native symbolic language)
- FeynRules (Mathematica)

Tree level hard process integrand generator

- CompHEP,(Squared amplitude, many models including MSSM), CalcHEP (SM, MSSM, + many)
- Grace (Helicity amplitudes, SM),
- FDC (Wang)
- COMIX (multi-leg tree level event generator, color reccursive relation, many legs)
- AMEGIC++ (parton level generator)
- HELAC/Phegas (dyson-schwinger)
- O'Mega (alpha algorithm)

Jimbo's Talk

Wang's Talk

General purpose mainly tree level (all decay, 2->2, 2->3, some 2->4, ISR, PS and Hadronisation)

- Pythia++, Ariadne, MC++
- Herwig++
- Isajet

General purpose event generators based on automatic integrand callculations

- Whizard (O'Mega)
- Sherpa (using Comix and AMEGIC++, CKKW, Pythia (or Pythia like)
- Madgraph, MadEvent
- Graceful (based on Grace, interfaced to Pythia) in progress …

Specific set of event generators

- Gr@ppa (Grace for matrix elements and Pythia/Herwig for parton shower/Hadronization)
- AlpGen (multi parton generation)

Parton shower matching

- CKKW, POWHEG, MLM, Subtraction method (matrix element matching with shower MC)

Event database:

- MC database (CompHEP)
- JETWEB

Denis Perret-Gallix
IN2P3/CNRS France

Automatic computations and event generators, NLO,…

- RESBOS (Q_t resummation NLO/NNLO, no parton shower necessary) lepton distributions in Drell-Yan-like processes); inclusive with respect to hadronic radiation

NLO hard process

NLO event generators (specific processes)

- MC@NLO (Herwig + Subtraction methods: H, single Boson, single top, lepton pairs, H +W/Z, …)
- MCFM (full spin correlation, Wbb, …)
- BlackHat (one-loop, W/Z+3,4 jets)
- NLOjet++ (Catani-Seymour dipole subtraction method)
- Rocket (N-gluon amplitude, 2-q +N-g, W +2-q + N-g, W +4 q +Ng… N> 20)
- CutTools (one-loop amplitudes at integrand level)
- JETRAD (inclusive 1 and 2 jet production)
- JETI
- FeynCalc (Mathematica/Form Passarino-Veltman reduction of one-loop amplitudes to standard scalar integrals) FeynArt, FeynRules, …
- Grace one-loop
- FDC (loop)
- Golem (one-loop amplitude up-to six legs)
- PhoX family JetPhox (inclusive γ/hadron+jet, Diphox (hadron production of 2γ, hadron+γ, hadron+hadron)

Jimbo's Talk

Wang's Talk

Reiter's Talk

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SUSY specific and Cosmology

Spectrum calculations (RGE codes)

- Isasusy
- Softsusy
- Spheno
- Suspect

Amplitude calculation Tree level

- Grace/Susy (MSSM)

One-loop dedicated

- Prospino
- Hprod

One-loop General

- Grace-susy One-loop
- FormCalc
- SloopS

Cosmology

- Micromegas: relic density computation based on LANHEP, CALCHEP
- DarkSusy
- NeutDriver
- IsaRed

Decay code

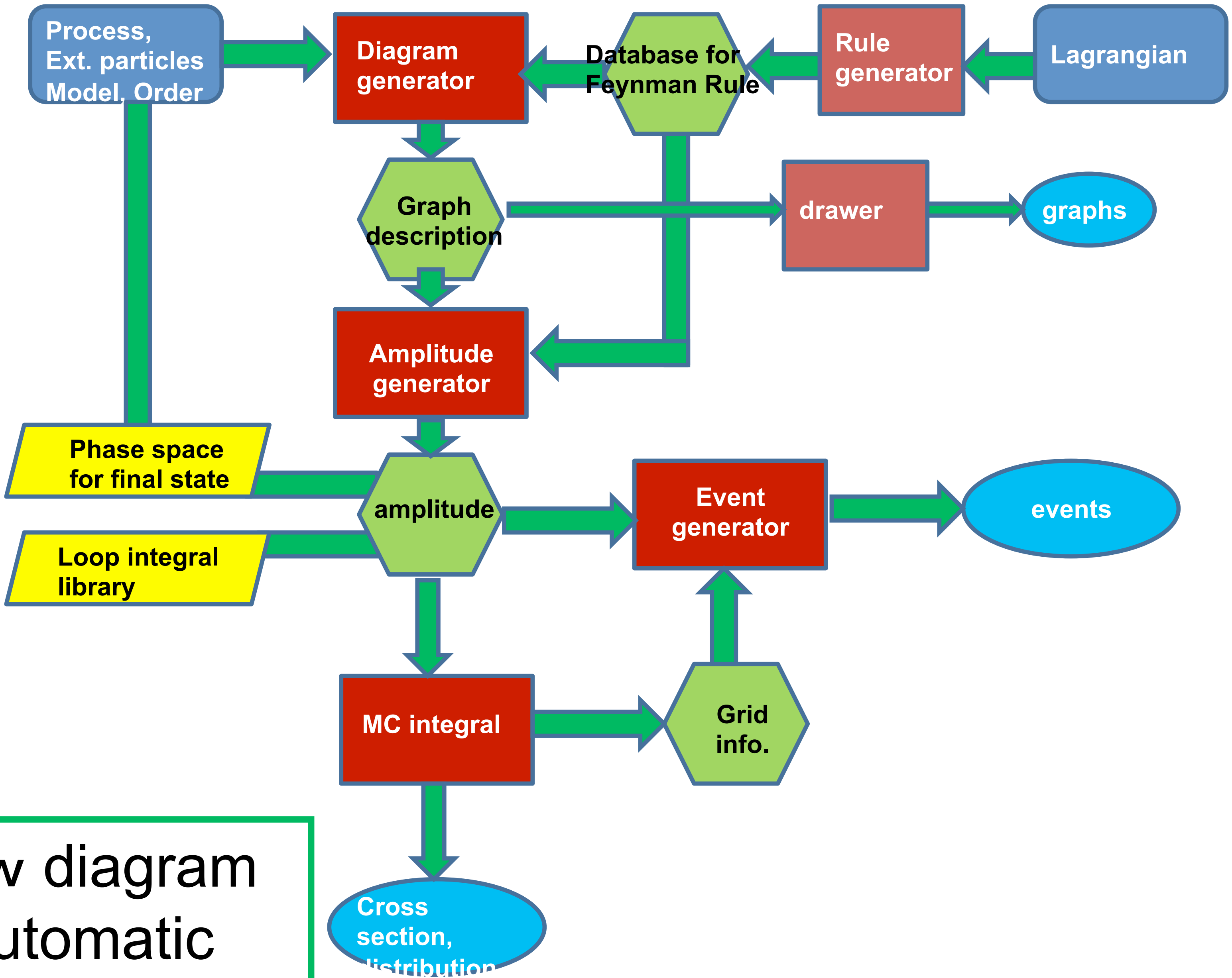
- HDECAY
- NMHDECAY
- SDECAY

Fitters

- Fittino
- Sfitter

SLHA

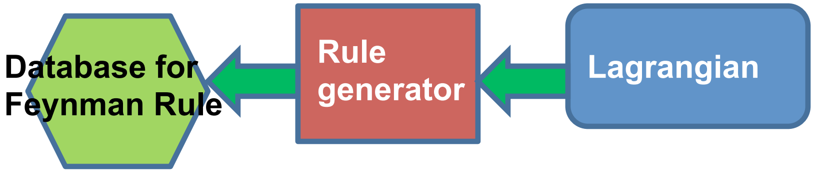
Kon/Jimbo's Talk



Flow diagram of automatic computation

From Lagrangian to Feynman Rule

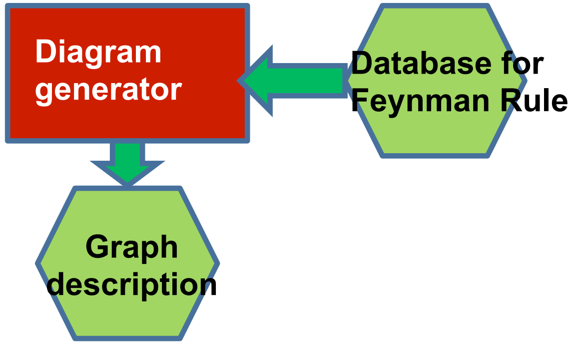
＊LanHEP（A. Semenov）
http://theory.sinp.msu.ru/~semenov/lanhep.html
＊FDC（J.-X. Wang）
www.ihep.ac.cn/lunwen/wjx/public_html



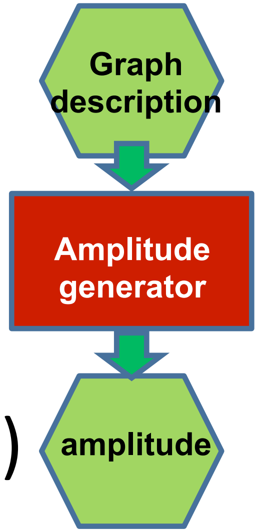
LanHEP+CompHEP(Dubinin's talk)
Add a new interaction easily to the SM.
→ BMS study

Graph generation

＊QGRAF（P. Nogueira）
http://cfif.ist.utl.pt/~paulo/qgraf.html
＊GRACE（T.Kaneko）
＊FeynArts （ T. Hahn ）
＊FDC（J.-X. Wang）
www.ihep.ac.cn/lunwen/wjx/public_html



Importance of symbolic manipulation system
FORM (Vermaseren's talk)



GRAPH to Amplitude

Complex processes: Produced code is huge!
(Number of diagrams and each diagram itself.)
Required robust and powerful system.

QED : number of diagrams

Process	Loop	diagrams	Process	Loop	diagrams
e-->e	1	1	e-e- ->e-e-	1	10
	2	3		2	94
	3	18	e+e- ->e+e-	1	10
	4	153		2	94
	5	1638		3	1136
	6	20898	e+e- ->e+e-γ	1	72
γ-->γ	1	1	e+e- ->e+e-γγ	0	40
	2	3		1	564
	3	18	e+e- ->e+e-e+e-	0	36
	4	153		1	552
e+e- -->γ	1	1	e+e- ->e+e-μ+μ-	0	36
	2	7		1	552
	3	72	e+e- ->e+e-μ+μ-γ	0	252
	4	891	e+e- ->e+e-2(μ+μ-)	0	1728
	5	12672	γγ -> γγ	1	6
	6	202770		2	60

T.Kaneko, S.Kawabata, Y.Shimizu, CPC 43 (1987) 279
also T.Sasaki, J.Comput. Phys. 22 (1976) 189

Cross section

$$d\sigma = (factors)\times\left|\sum T\right|^2\times(p.s.)$$

$$(p.s.) = (2\pi)^4\,\delta\Big(\sum_{final} p_j - P_0\Big)\prod_{final}\frac{d^3 p_j}{2E_j(2\pi)^3}$$

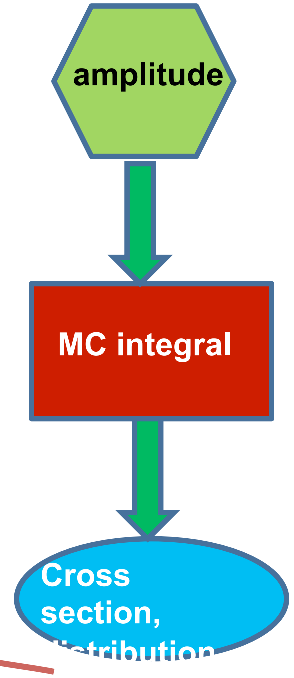
LHC,ILC → multi-body final states are important

multiple integration : Numerial integration (adaptive MC)

Integrand : several singularity originating from physical reasons (Infrared, collinear, resonance, forward angle, gauge cancelation, …)

How to choose variables ? (e.g., Dubinin's talk)

MonteCarlo integraion

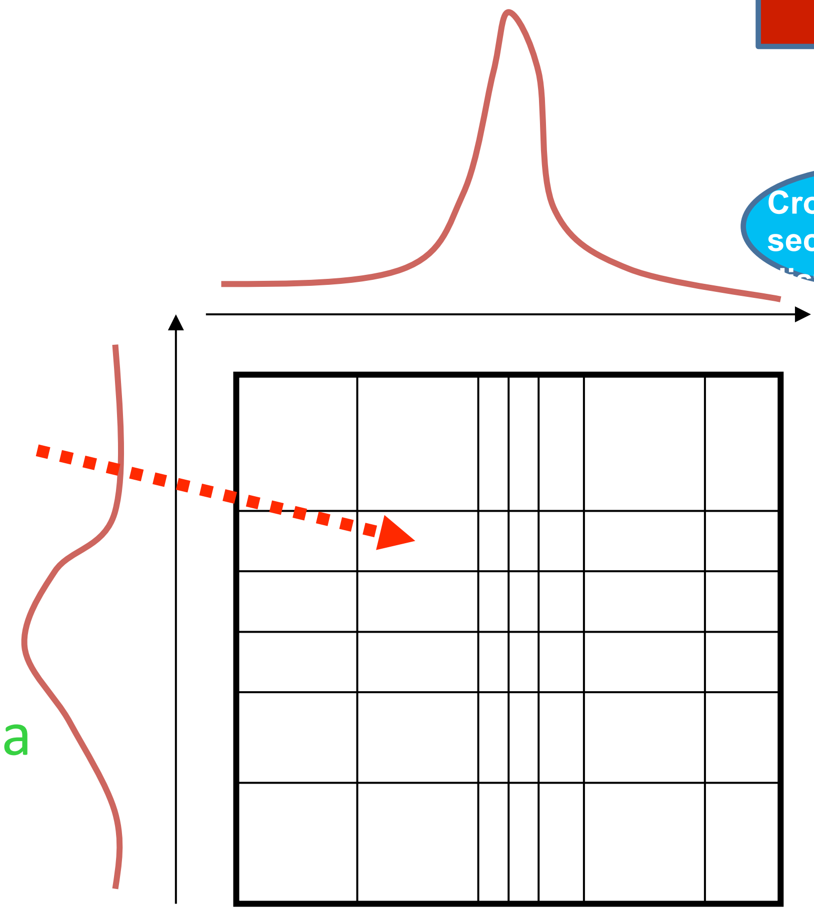


VEGAS, BASES

importance and stratified sampling

adjust grid so that weights in each hypercube are uniform

→Only possible when each singularity is assigned to a specific variable



Loop integral

Reduction momentum or Feyman x ?

1-loop

$$\int d^n\ell \frac{\{1, \ell^\mu, \ell^\mu \ell^\nu, \ell^\mu \ell^\nu \ell^\rho, \cdots\}}{(\ell^2 - m_1^2 + i\varepsilon)((\ell + p_1)^2 - m_2^2 + i\varepsilon)((\ell + p_{12})^2 - m_3^2 + i\varepsilon)\cdots}$$

Loop integrals

1-loop
Many good libraries and formulas

e.g.
Golem
Kaneko: analytical formulas by hypergeometric functions   clear and well-organized structure

Main target : 2-LOOP

Sector Decomposition(Ueda)

- Sector decomposition disentangles overlapping singularities in multi-dimensional integration

$$\int_0^1 dx \int_0^1 dy \frac{f(x,y)}{(x+y)^{2-\epsilon}}$$

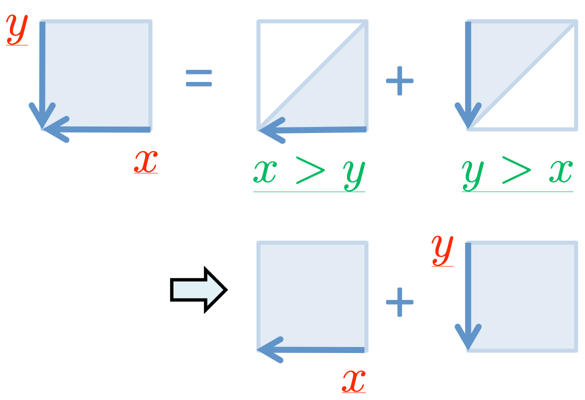
$f(x,y)$: finite $\quad \epsilon \longrightarrow +0$

singular when simultaneously $x, y \longrightarrow 0$

Split integration domain

$$= \int_0^1 dx \int_0^x dy \frac{f(x,y)}{(x+y)^{2-\epsilon}} + \int_0^1 dy \int_0^y dx \frac{f(x,y)}{(x+y)^{2-\epsilon}}$$

$x > y$ $\qquad$ $y > x$



Remap to [0:1]

$y \longrightarrow x\tilde{y}$

Similarly $x \longrightarrow \tilde{x}y$

$$\int_0^1 dx \int_0^1 x d\tilde{y} \frac{f(x, x\tilde{y})}{(x + x\tilde{y})^{2-\epsilon}}$$

Factor out x

$$= \int_0^1 dx \int_0^1 d\tilde{y} \frac{1}{x^{1-\epsilon}} \frac{f(x, x\tilde{y})}{(1+\tilde{y})^{2-\epsilon}} + \int_0^1 d\tilde{x} \int_0^1 dy \frac{1}{y^{1-\epsilon}} \frac{f(\tilde{x}y, y)}{(1+\tilde{x})^{2-\epsilon}}$$

singular behavior is factorized as powers of one variable

non-singular $x \longrightarrow 0$

$$\int_0^1 dx \frac{f(x)}{x^{1-\epsilon}} = \int_0^1 dx \frac{f(0)}{x^{1-\epsilon}} + \int_0^1 dx \frac{f(x) - f(0)}{x^{1-\epsilon}} = \frac{f(0)}{\epsilon} + \int_0^1 dx\, x^{\epsilon} \frac{f(x) - f(0)}{x}$$

singular when $x \longrightarrow 0$ $\qquad$ pole $\qquad$ non-singular at $x \longrightarrow 0$

Test Implementation(Ueda)

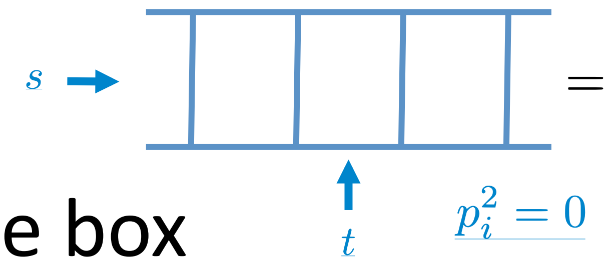
- Our test implementation
  - Dual cone construction
    - Convex hull - Incremental algorithm
  - Triangulation
    - Our own simple algorithm; Neither unique, nor optimum
  - Written in Python (and very slow)

# of generated sectors

Diagram	A	B	C	S	X	our method
Box	12	12	12	12	12	12
Double box	755	586	586	362	293	266
Triple box	M	114256	114256	22657	10155	6568
D420	8898	564	564	180	F	168

Our method gives less number of sectors than other methods !!

An Example Calculation(Ueda)



$$= \Gamma(4+3\epsilon)\left[\sum_{i=0}^{6}\frac{C_i}{\epsilon^i} + \mathcal{O}(\epsilon)\right]$$

- On-shell triple box

Taking symmetries into account, Strategy X and our method generate

Strategy X : 4143 terms
Out method : 2670 terms
(ratio ~1.55)

	Strategy X		Our method		Exact value
C_6	0.098765(±0.000004)	1.4s	0.098765(±0.000003)	0.7s	0.098765
C_5	-0.767001(±0.000027)	10.7s	-0.767001(±0.000033)	4.4s	-0.767001
C_4	1.977227(±0.000156)	2.9m	1.977224(±0.000326)	1.1m	1.977227
C_3	-0.753089(±0.001144)	26.6m	-0.753088(±0.001192)	10.1m	-0.753080
C_2	-4.749675(±0.006682)	2.5h	-4.749694(±0.003523)	1.3h	-4.749610
C_1	2.016040(±0.042107)	6.9h	2.016607(±0.014341)	4.1h	2.016790
C_0	21.673992(±0.268047)	16.4h	21.692735(±0.067518)	9.9h	21.692455

s = -1, t = -3, integrated by Cuba1.7 (Vegas) 10Mpts, Xeon X5560 (2.80GHz) x 8cores

16.4h / 9.9h ~1.66

Analytical result: V.A. Smirnov, Phys.Lett.B567 (2003) 193

XLOOPS-GiNaC(Do)

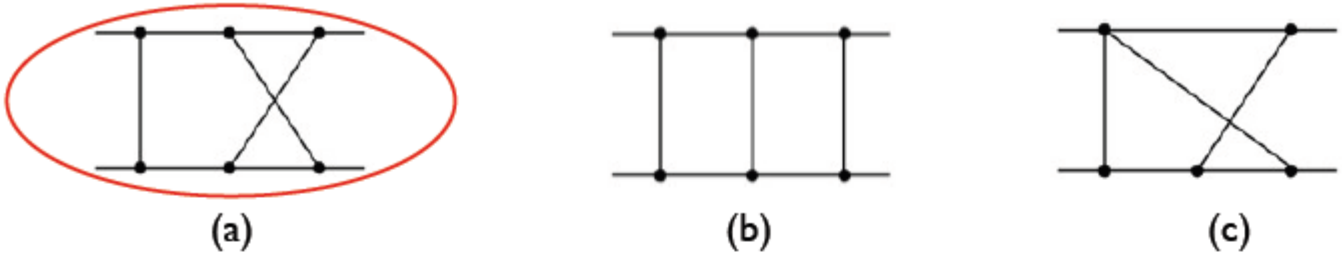
Gram determinant problem free.
Tensor integrals are automatically decomposed into integrals of components of internal momenta. No matrix inversion!

Complex mass is possible.

Numerial comparison in one-loop, two-loop in progress.

2-loop in XLOOPS-GiNaC(Do)

- We are interested in a subgroup of Scalar Two-loop box integral (crossed and planar topologies)



$$S_0 = 4 \int_0^\infty dl_\perp dk_\perp \int_{-\infty}^{\infty} \frac{dl_0 dl_1 dl_2 dk_0 dk_1 dk_2}{P(l)P(l+k)P(k)}$$

$$P(l) \;=\; \prod_i^{N_l} \left[(l+q_i)^2 - m_i^2 + i\eta\right] \;,\; P(k) = \prod_n^{N_k} \left[(k+q_n)^2 - m_n^2 + i\eta\right]$$

$$P(l+k) = \prod_j^{N_{lk}} \left[(l+k+q_j)^2 - m_j^2 + i\eta\right]$$

Kreimer Phys.Lett.B347, 1995; Kreckel, Eur.Phys.J.C6 1998

Direct computation method(Yuasa)

Analytical computation
-> epsilon infinitesimal
-> complex analysis

$$I = \lim_{\varepsilon \to 0} \int_0^1 dx \int_0^{1-x} dy \frac{1}{D(x,y) - i\varepsilon}$$

Sometimes D=0 in the integral region

$$\Re(I(\varepsilon_l)) = \int_0^1 dx \int_0^{1-x} dy \frac{D(x,y)}{D(x,y)^2 + \varepsilon_l^{\,2}},$$

$$\Im(I(\varepsilon_l)) = \int_0^1 dx \int_0^{1-x} dy \frac{\varepsilon_l}{D(x,y)^2 + \varepsilon_l^{\,2}}$$

Keep epsilon FINITE
Denominator > 0
Numerical integration

$$\varepsilon_l = \frac{\varepsilon_0}{c^l}, \qquad c > 1$$

Extrapolate $I(\varepsilon_l)$
and get the result when ε becomes 0
using ε-algorithm by P.Wynn.

ε-algorithm: a math-magic

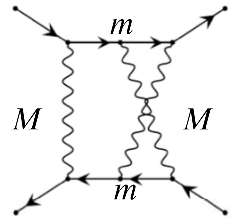
2.5
2.666666667
2.708333333
2.716666667
2.718055556
2.718253968
2.718278770

e=2.718281828

$$\tau_{\kappa,\lambda+1} = \tau_{\kappa+1,\lambda-1} + \frac{1}{\tau_{\kappa+1,\lambda} - \tau_{\kappa,\lambda}}$$

YUASA

Two-loop non-planar box



$$\mathcal{I} = -\int_0^1 dx_1\, dx_2\, dx_3\, dx_4\, dx_5\, dx_6\, dx_7\, \delta(1 - \sum_{\ell=1}^{7} x_\ell) \frac{\mathcal{C}}{(\mathcal{D} + i\epsilon\mathcal{C})^3},$$

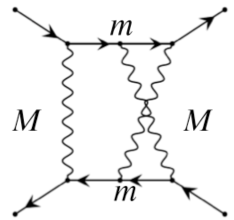
$$\begin{aligned}
\mathcal{D} &= -\mathcal{C} \sum x_\ell m_\ell^2 \\
&+ \{s(-x_1x_5x_6 + x_2x_3x_4 + x_2x_3x_5 + x_2x_3x_6 + x_2x_3x_7 + x_2x_6x_7 + x_3x_4x_5) \\
&+ t(x_1(x_4x_7 - x_5x_6)) \\
&+ p_1^2(x_1(x_2x_4 + x_2x_5 + x_2x_6 + x_2x_7 + x_4x_5 + x_5x_6)) \\
&+ p_2^2(x_1(x_3x_4 + x_3x_5 + x_3x_6 + x_3x_7 + x_5x_6 + x_6x_7)) \\
&+ p_3^2(x_1x_5x_6 + x_1x_5x_7 + x_2x_4x_7 + x_2x_5x_7 + x_3x_5x_6 + x_3x_5x_7 + x_4x_5x_7 + x_5x_6x_7) \\
&+ p_4^2(x_1x_4x_6 + x_1x_5x_6 + x_2x_4x_6 + x_2x_5x_6 + x_3x_4x_6 + x_3x_4x_7 + x_4x_5x_6 + x_4x_6x_7)\}
\end{aligned}$$

and

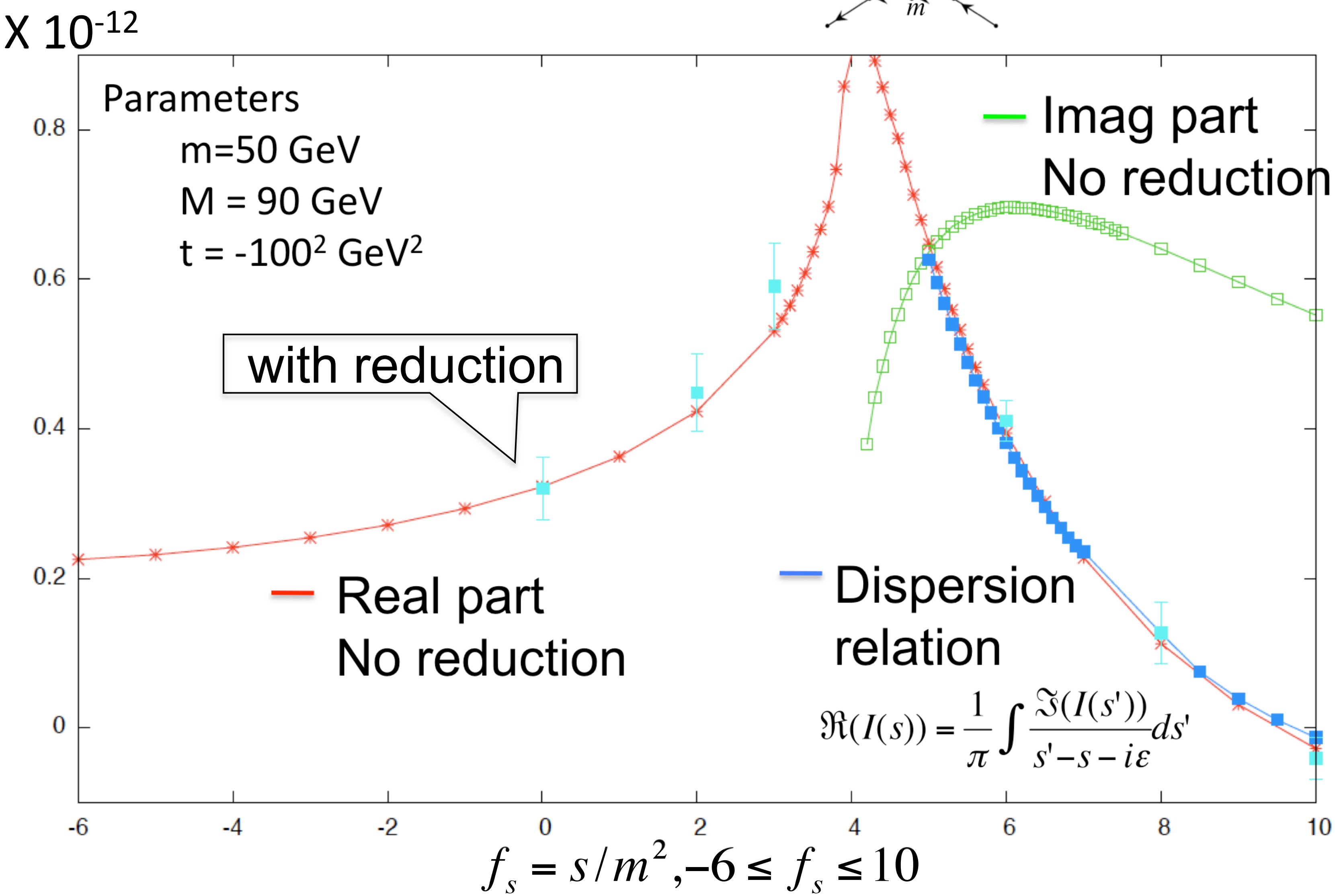
$$\mathcal{C} = (x_1 + x_2 + x_3 + x_4 + x_5)(x_1 + x_2 + x_3 + x_5 + x_6 + x_7) - (x_1 + x_2 + x_3)^2.$$

Here, $s = (p_1 + p_2)^2 = (p_3 + p_4)^2$, $t = (p_1 + p_3)^2 = (p_2 + p_4)^2$ and $p_1 + p_2 + p_3 + p_4 = 0.$

Example of direct computation method
two-loop non-planar box with masses



YUASA



ε-δ method(de Doncker)

$$\frac{1}{D - i\delta}$$

original direct method
Keep delta finite

$$\left(\frac{1}{D - i\delta}\right)^{K+\varepsilon}$$

Also keep n-dimension
as n=4+2epsilon

$$\frac{1}{\varepsilon}C_{-1} + C_0 + O(\varepsilon)$$

Extract infrared pole
numerically with delta
regularization

Precision control

Long digit computation is required:

- To get the precise results
- To avoid instabilities

Singularity

REAL: e.g., IR divergence, Landau singularity, …

INSTABILITY: e.g. Gram-determinant in numerator reduction

Gram-det.=0 … skip calculation (measure=0)

Gram-det. is not 0 but very small

→ stabilized by the long digit computation

(e.g. , Le,D.N. : small DetG expansion or using quadruple precision)

An example : Long digit computation is reqired

- f = 333.75*(b**6)
  + (a**2)*{11*(a**2)*(b**2) - (b**6)- 121*(b**4) - 2}
  + 5.5*(b**8) + a/(2*b),
  where a=77617.0、b=33096.0.
  by C. Hu, S. Xu and X. Yang
- f = 1.172603940053178631858834904520180
  w/ Quadruple precision
- Analytical result = - 54767/66192
  = - 0.827396059946821368141165095479816
- Using the new Octuple precision library in **HMLib**:
  f = - 0.827396059946821368141165095479816
  with lost bits = 121

Exflib(Fujiwara)

Key features

- 60 – 20,000 decimal digit arithmetic
- range : $10^{-10^{18}}$ – $10^{10^{18}}$
- basic four rules, built-in functions
- polymorphic interface in C++, FORTRAN90
- instruction level optimization in assembly language

64-bit unsigned integer array

Data structure of exfloat

s	e_b	f_1	f_2	f_3	$\cdots$	f_n
1	63	64	64	64		64

$$(-1)^s \times 2^{e_b - \mathrm{BIAS}} \times \left(1 + \sum_{i=1}^{n} \frac{f_i}{2^{64i}}\right)$$

A mult-precision library

HMLIb: New FORTRAN Library for High-speed Multiprecision operations

- Library in FORTRAN ← available for any architectures
- Based on Integer operations→ fast & "lost bits" information for subtraction.
- For the octuple floating point operations:
  based on IEEE754,
  1 bit for sign,15bits for exponent,
  240 bits for mantissa.
- For example
  call Q4ADDSUB(A,B,C,I,IBIT) :
  for add/sub in Quad.

  Number of lost digit is reported!
- MULT/DIV,SQRT,LOG,ATAN2 … are also available

Hardware: quadruple precision

GRAPE-DR

512PE(90nm,200mm^2) 200MHz
400Gflops/chip(Single Precision)
200 Gflops/chip(Double Precision)

5GFLOPS in quad-precision

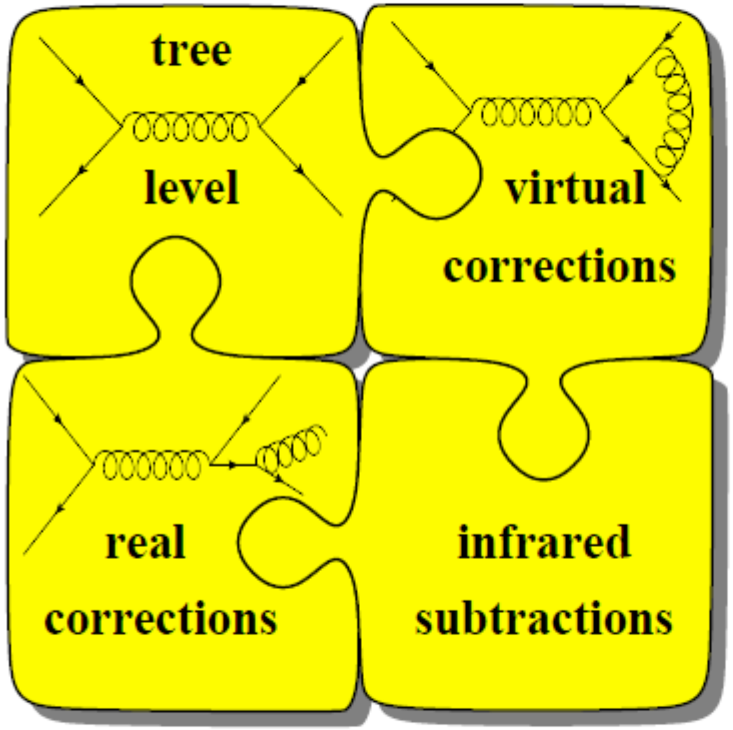
GRAPE-MP (semi-custom)
Chip for quad-precision

Test board

GRAPE-MP project is working

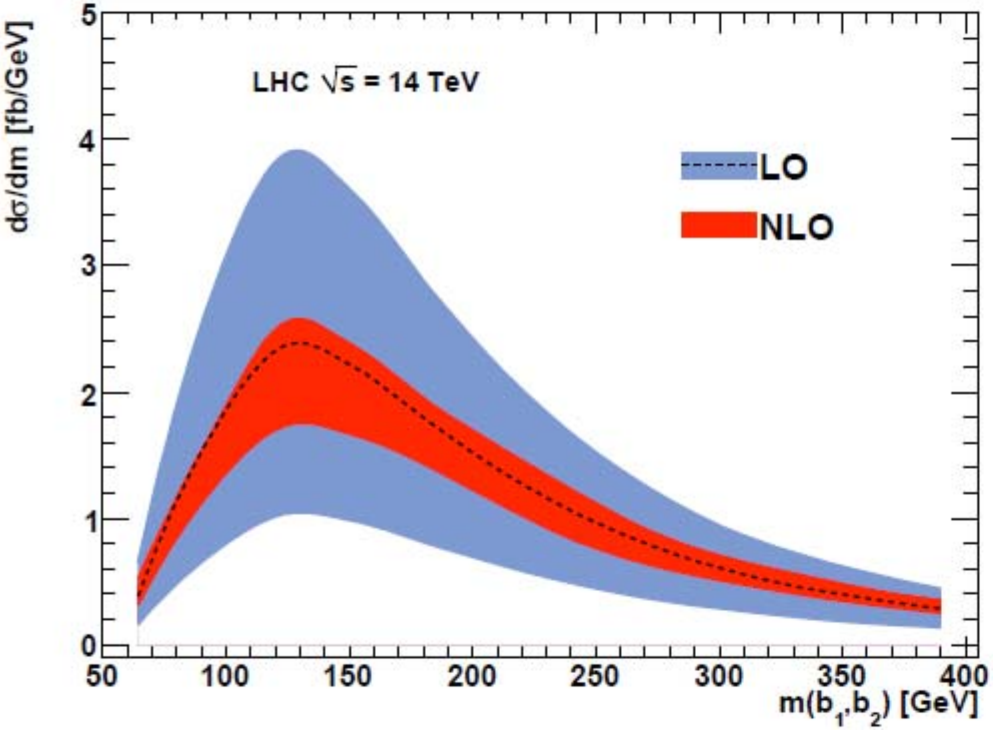
Physcal results

NLO by GOLEM/SAMURAI



$q\bar{q} \to b\bar{b}b\bar{b}$: Results

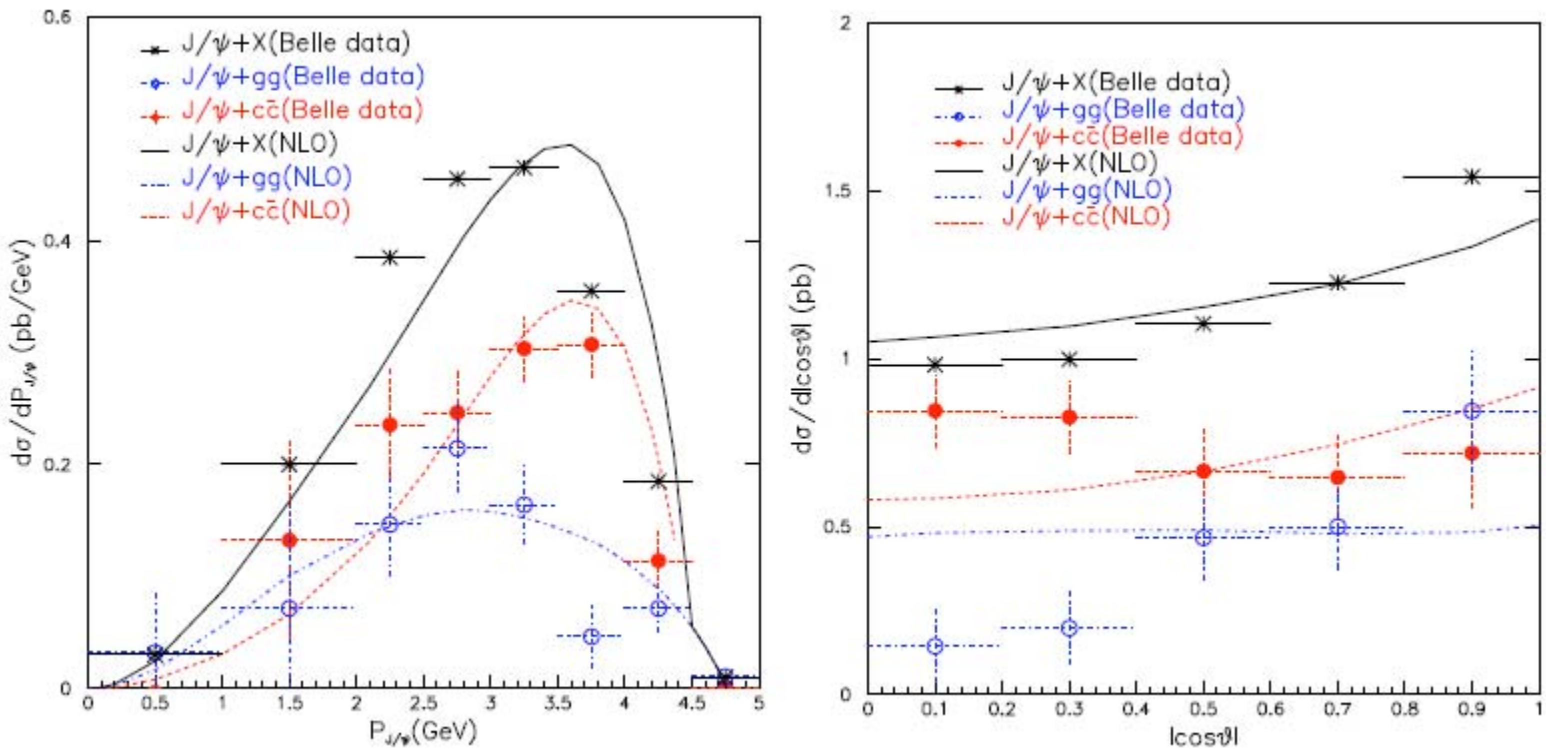
m_{bb} of leading b-jets



$\sqrt{s} = 14$ TeV, $\mu_R = \frac{1}{2}\sqrt{\sum_j p_T^2(b_j)}$, $\mu_F = 100$ GeV, $m_b = 0$

- significant reduction of scale dependence
- plateau region around $x = 0.5$
- stabilization of result
- error bands: $\mu_0/4 < \mu_R < 2\mu_0$
- complete analysis after inclusion of all channels

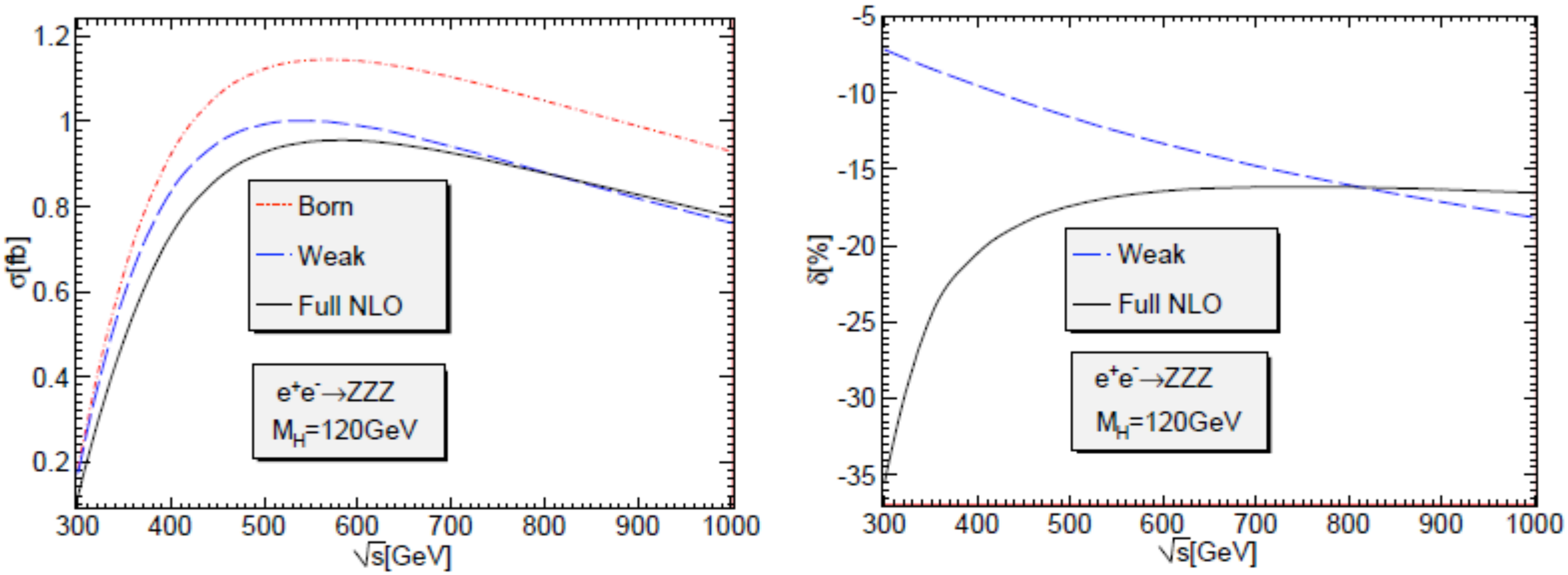
Heavy quarkonium production: FDC-LOOP (Wang)



Momentum distribution of inclusive J/ψ production with $\mu = \mu^*$ and $m_c = 1.4$ GeV is taken for the $J/\psi cc$ channel. The contribution from the feed-down of ψ' has been added to all curves by multiplying a factor of 1.29.

EW 1-loop tri-boson production(Le)

$e^+e^- \to ZZZ$: Total Xsection



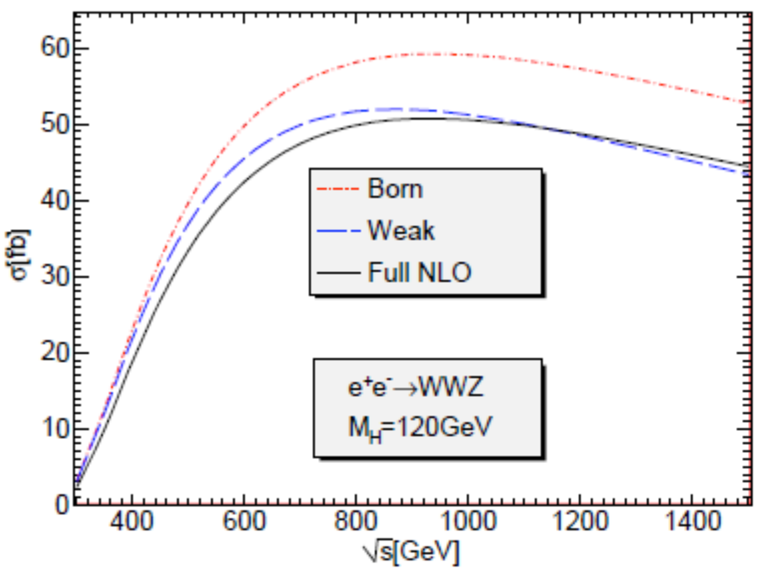
Input parameters: $\alpha_{G_\mu} = \sqrt{2} G_\mu s_W^2 M_W^2/\pi = \alpha(0)(1+\Delta r)$

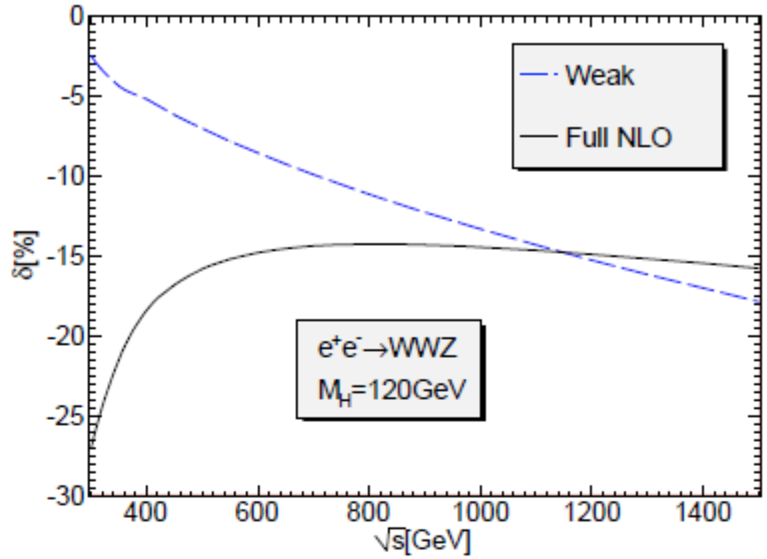
$$\delta Z_e^{G_\mu} = \delta Z_e - \frac{1}{2}(\Delta r)_{1-\text{loop}}.$$

- Total Xsection peak about 1fb is at $\sqrt{s} \approx 550$GeV.
- The weak correction goes from -12% to -18% when $\sqrt{s}$ increases from 500GeV to 1TeV.

EW 1-loop tri-boson production(Le)

$e^+e^- \to W^+W^-Z$: Total Xsection





- Total Xsection peak about 50fb (50 times larger than σ_{ZZZ}) is at $\sqrt{s} \approx 900\text{GeV}$.
- Large Sudakov corrections at high energies: $\alpha \log(M_W^2/s)$, $\alpha \log^2(M_W^2/s)$.
- The weak correction goes from -7% to -18% when $\sqrt{s}$ increases from 500GeV to 1.5TeV.

Light Higgs at LHC:CompHEP (Dubinin)

Example: regularization of the amplitude pp → γ + 3 jet (QCD misidentification (or fake) background [jet ⇨ γ] to the light Higgs boson signal at the LHC in the channel $\gamma\gamma$+ jets). 50 partonic subprocesses in the «hash-model» format, each of them includes 30-40 diagrams with 10-20 singularities. Total number of QCD diagrams about 2000

	subprocess	σ, [pb]	$\frac{\sigma}{\sigma_{max}}$
1	$u\#, u\# \to A, G, u\#, u\#$	514.1	0.36
2	$u\#, U\# \to A, G, u\#, U\#$	123.2	0.09
3	$u\#, U\# \to A, G, d\#, D\#$	0.3	0
4	$u\#, U\# \to A, G, G, G$	2.4	0
5	$u\#, d\# \to A, G, u\#, d\#$	208.1	0.15
6	$u\#, D\# \to A, G, u\#, D\#$	101.4	0.07
7	$u\#, G \to A, u\#, u\#, U\#$	52.5	0.04
8	$U\#, G \to A, u\#, d\#, D\#$	30.3	0.02
9	$u\#, G \to A, G, G, u\#$	1397.7	1
10	$U\#, u\# \to A, G, u\#, U\#$	125.7	0.09
11	$U\#, u\# \to A, G, d\#, D\#$	0.3	0
12	$U\#, u\# \to A, G, G, G$	2.4	0
13	$U\#, U\# \to A, G, U\#, U\#$	19.1	0.01
14	$U\#, d\# \to A, G, U\#, d\#$	41.9	0.03
15	$U\#, D\# \to A, G, U\#, D\#$	17.2	0.01
16	$U\#, G \to A, u\#, U\#, U\#$	8.5	0.01
17	$U\#, G \to A, U\#, d\#, D\#$	4.5	0
18	$U\#, G \to A, G, G, U\#$	196.5	0.14
19	$d\#, u\# \to A, G, u\#, d\#$	206.9	0.15
20	$d\#, U\# \to A, G, U\#, d\#$	41.9	0.03
21	$d\#, d\# \to A, G, d\, d\#$	49.7	0.03
22	$d\#, D\# \to A, G, u\#, U\#$	0.1	0
23	$d\#, D\# \to A, G, d\#, D\#$	23.3	0.02
24	$d\#, D\# \to A, G, G, G$	0.4	0
25	$d\#, G \to A, u\#, U\#, d\#$	23.9	0.02

	subprocess	σ, [pb]	$\frac{\sigma}{\sigma_{max}}$
	$d\#, G \to A, d\#, d\#, D\#$	8.0	0
	$d\#, G \to A, G, G, d\#$	195.2	0.14
	$D\#, u\# \to A, G, u\#, D\#$	98.7	0.07
	$D\#, U\# \to A, G, U\#, D\#$	17.6	0.01
	$D\#, d\# \to A, G, u\#, U\#$	0.1	0
	$D\#, d\# \to A, G, d\#, D\#$	23.2	0.02
	$D\#, d\# \to A, G, G, G$	0.4	0
	$D\#, D\# \to A, G, D\#, D\#$	9.0	0
	$D\#, G \to A, u\#, U\#, D\#$	9.6	0
	$D\#, G \to A, d\#, D\#, D\#$	2.8	0
	$D\#, G \to A, G, G, D\#$	69.1	0.05
	$G, u\# \to A, u\#, u\#, U\#$	53.3	0.04
	$G, u\# \to A, u\#, d\#, D\#$	29.7	0.02
	$G, u\# \to A, G, G, u\#$	1400.0	1
	$G, U\# \to A, u\#, U\#, U\#$	9.5	0
	$G, U\# \to A, U\#, d\#, D\#$	4.5	0
	$G, U\# \to A, G, G, U\#$	198.6	0.14
	$G, d\# \to A, u\#, U\#, d\#$	23.8	0.02
	$G, d\# \to A, d\#, d\#, D\#$	7.7	0
	$G, d\# \to A, G, G, d\#$	190.9	0.13
	$G, D\# \to A, u\#, U\#, D\#$	9.9	0
	$G, D\# \to A, G, G, D\#$	2.9	0
	$G, D\# \to A, G, G, D\#$	68.8	0.05
	$G, G \to A, G, u\#, U\#$	277.9	0.20
	$G, G \to A, G, d\#, D\#$	69.5	0.05
	$pp \to A, j, j, j$	5970.4	

CompHEP (Dubinin)

New Features in CompHEP 4.4 (Interfaces)

- CompHEP->PYTHIA (CPYTH) (ready)
- CompHEP->PYTHIA-TAUOLA (ready)
- CompHEP->HERWIG (ready)
- CompHEP->HERWIG++ (in progress)
- Interfaced to Exp. Collaboration SW:

  SIMDET(ILC), CMKIN(CMS), ATHENA(ATLAS) and D0 (Tevatron) Run II software.
- Macros of interface to ROOT graphics (in progress)
- Output Events are ready for LCG MCDB Data Base

Event generator

Strong request from experimentalists

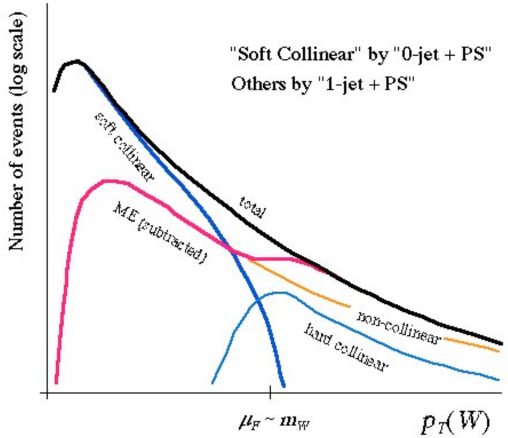
Cross section calculation etc. by theorists in NOT enough!

Generate 4-vectors of final state particles, hopefully in equal weights

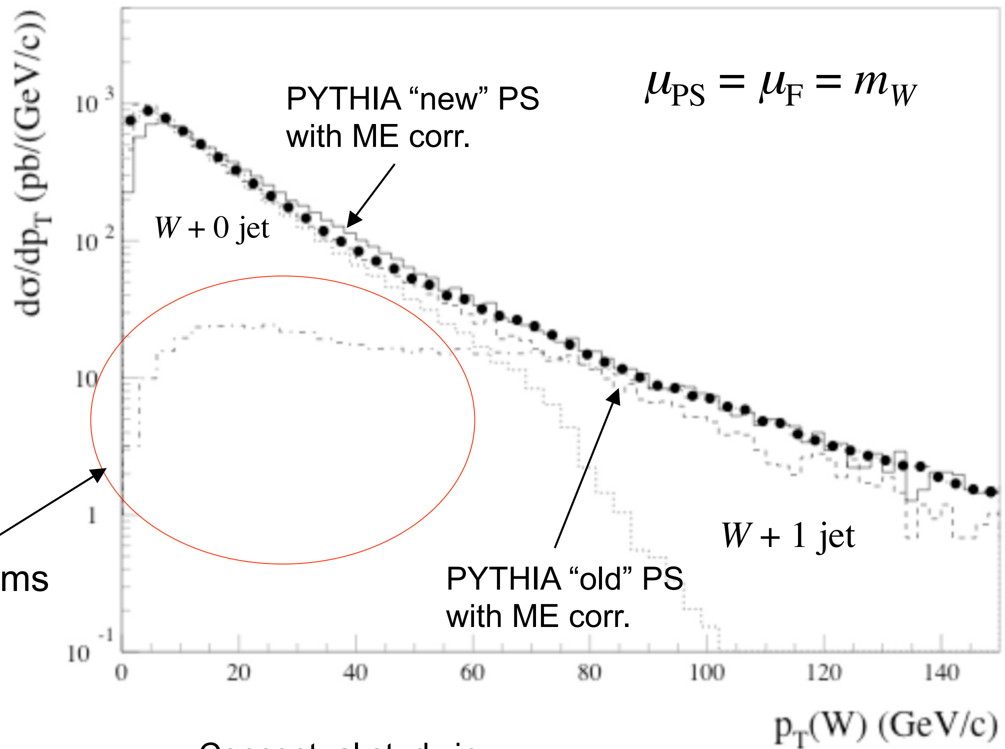
“Requirement” list, or, what EG (Kurihara)

- What is a “must” for EG at LHC-era?
  - σ_{tree} x (K-factor) → NLO ME
  - ME/PS Matching
  - Fast & Stable Numerical Calculation
  - High Generation Efficiency
  - Fully Exclusive
  - Non-p Effects if necessary
  - LHA-Compliant Interface

W production @LHC(ODAKA)



My prospect at PhysSim WS at KEK in 2004



Conceptual study in

S. Odaka and Y. Kurihara, Eur. Phys. J. C 51 (2007) 867; hep-ph/0702138

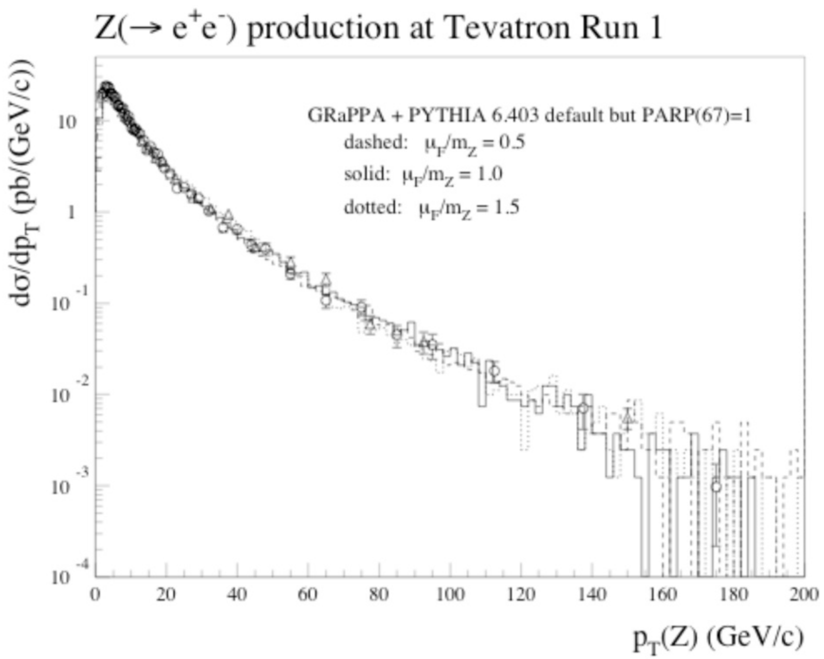
Low-Q simulations by PYTHIA/HERWIG are yet to be applied.

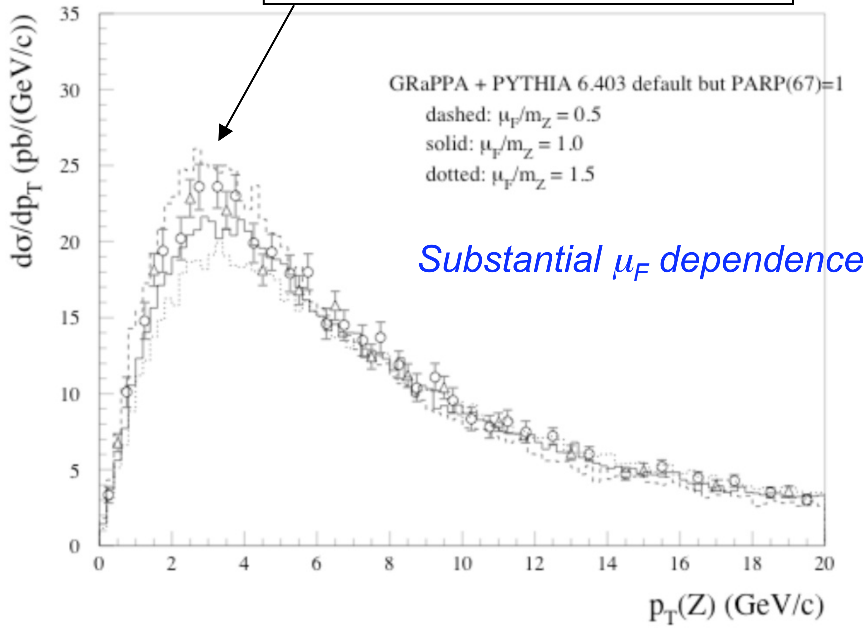
Z production at Tevatron (ODAKA)

GR@PPA 2.8 + PYTHIA 6.4

PYTHIA for simulating soft PS ($1.0 < Q < 4.6$ GeV), primordial k_T ($<k_T> = 2.0$ GeV/c), hadronization, and decays

This determines the peak position.





Circles: CDF, Phys. Rev. Lett. 84, 845 (2000)

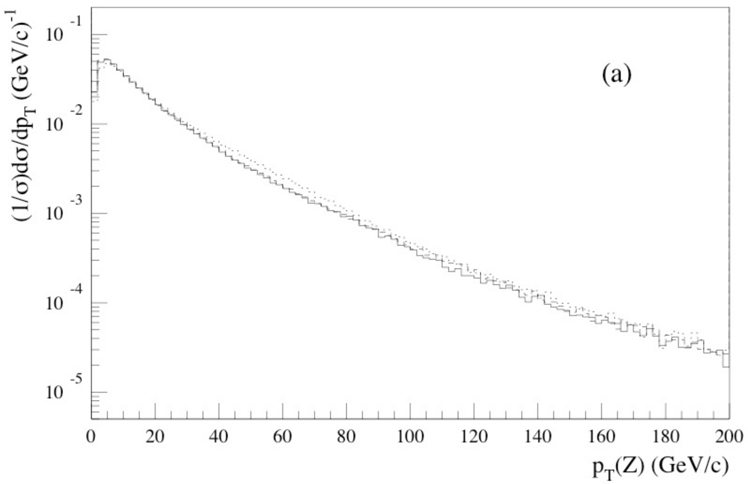
Triangles: D0, Phys. Rev. D 61, 032004 (2000) × 1.12

D0 data and simulations are normalized to the total cross section of CDF.

Nearly perfect through the entire measurement range

No tunable parameter in GR@PPA

Z production @LHC (ODAKA)

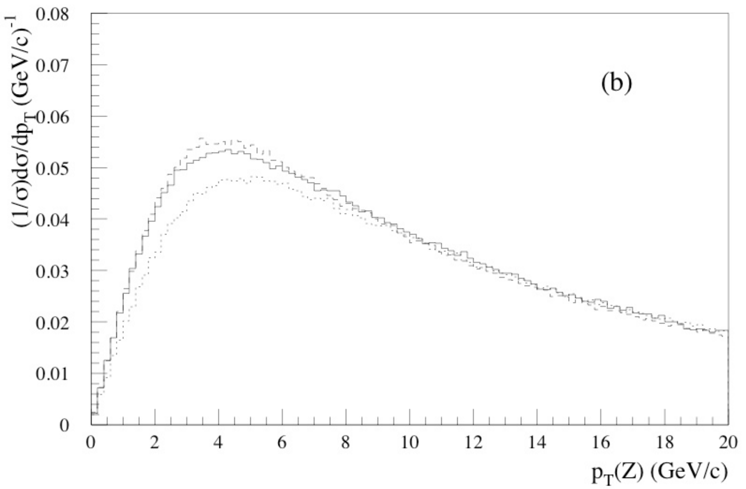


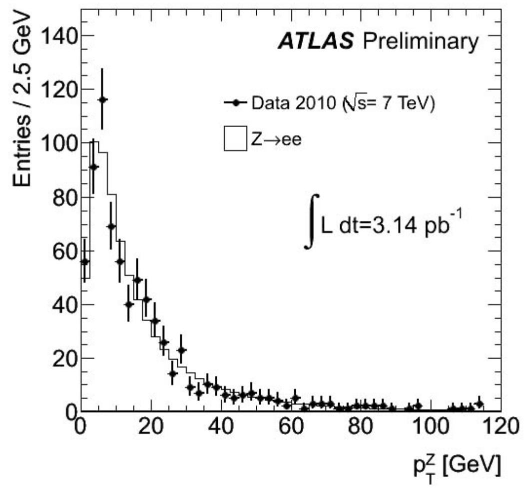
Solid: GR@PPA 2.8 + PYTHIA 6.421

Dashed: PYTHIA 6.421 built-in with new PS

Dotted: HERWIG 6.510

We will be able to plot measurement results soon.

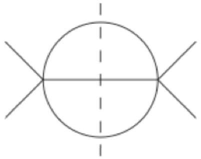




Heavy quark mass effect on photon SF (Sasaki)

Master integral for 3-body phase-space

- The easiest master integral



$$= \int dPS^{(3)}$$

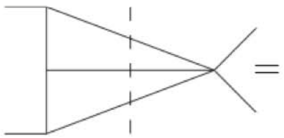
$$= S^{2\epsilon}\,\frac{s}{128\pi^3}\left(1-\frac{4m^2}{s}\right)^{\frac{5}{2}}\left\{1-\epsilon\left[3\log\left(1-\frac{4m^2}{s}\right)+2\log s-\psi^{(0)}\left(\frac{3}{2}\right)+\psi^{(0)}\left(\frac{1}{2}\right)\right]+\mathcal{O}(\epsilon^2)\right\}\quad S_1\left(\frac{s}{4m^1}\right)$$

$$S_1(a)=\frac{1}{4(1-a)^{\frac{5}{2}}}\Big\{-3a^2\log[a(1-a)]+2a^2\log[a+\sqrt{1-a}-1]-a^2(\tanh^{-1}\sqrt{1-a}) +a\sqrt{1-a}+2\sqrt{1-a}-4a(1-a)\log[-a+\sqrt{1-a}+1]+2a\log[a(1-a)]\Big\}$$

can be evaluated analytically

$$\beta_{12}=\beta_{12}(t,u)$$

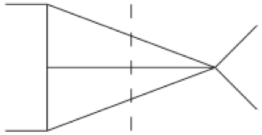
- Other master integrals are difficult to calculate analytically



$$=\frac{1}{(4\pi)^D}\frac{1}{\Gamma(D-3)}(s-q^2)^{3-D}\int_0^{\pi}d\theta\sin^{D-3}\theta\int_0^{\pi}d\phi\sin^{D-4}\phi\int_0^{(s-q^2)(1-\frac{4m^2}{s})}dt\int_{q^2t/(s-q^2)}^{(s-4m^2)-t}du$$

$$\left(1-\frac{4m^2}{s-t-u}\right)^{\frac{D-3}{2}}\left\{(s-t-u)\,t\,\Big[(s-q^2)u-q^2t\Big]\right\}^{\frac{D-4}{2}}\frac{-2}{s-t-q^2}\,\frac{1}{\{1+\beta_{12}\cos\theta\}}$$

Heavy quark mass effect on photon SF (Sasaki)



$$= \frac{s}{128\pi^3}\left(1-\frac{4m^2}{s}\right)^{\frac{5}{2}} \times \frac{-1}{s\left(1-\frac{4m^2}{s}\right)^{\frac{1}{2}}}(1-x) \times S_{D0d}\left(\frac{4m^2}{s}, x\right)$$

$$S_{D0d}(a,x) \equiv \int_0^1 dy \int_0^1 dz \frac{1-y}{\sqrt{\widetilde{A}}} \log\left|\frac{2A+B+2\sqrt{A(A+B+C)}}{-2A+B+2\sqrt{A(A-B+C)}}\right|$$

$$\widetilde{A} \;=\; \Big[1-y(1-a)\Big]^2 + 2(1-x)(1-a)\Big[-(1-a)y^2z + y(1+a-az) + z - 1\Big] + (1-x)^2(1-a)^2\Big[1-(1-y)$$

$$A = s^2 \frac{1-a}{(1-x)^2} \frac{(1-y)z}{a+(1-a)(1-y)z}\left\{\Big[1-y(1-a)\Big]^2 + 2(1-x)(1-a)\Big[-(1-a)y^2z + y(1+a-az) + z - 1\Big] + (1-x)^2(1-a)^2\Big[1-(1-y)z\Big]^2\right\}$$

$$B = 2s^2\sqrt{\frac{(1-a)(1-y)z}{a+(1-a)(1-y)z}} \frac{(1-a)(1-x)(1-y)z + (1-a)(x+y) + a}{(1-x)^2[1-y(1-a)]}\left\{\Big[1-y(1-a)\Big]^2 - (1-x)(1-a)\Big[(1-y)(1-z) - y\right\}$$

$$\sqrt{A+B+C} = \frac{s}{(1-x)}\Big[(1-a)(1-x)(1-y)z + (1-a)(x+y) + a\Big] + \frac{s}{(1-x)[1-y(1-a)]} \quad \sqrt{\frac{(1-a)(1-y)z}{a+(1-a)(1-y)z}}$$

$$\times\left\{\Big[1-y(1-a)\Big]^2 - (1-x)(1-a)\Big[(1-y)(1-z) - y\{a+(1-a)(1-y)z\}\Big]\right\}$$

- Most of the master integrals for real emission are hard to be calculated analytically

- Numerical analysis of these master integrals are in progress.

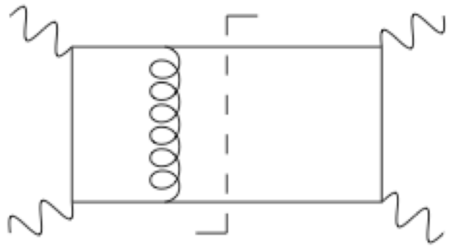
Heavy quark mass effect on photon SF (Sasaki)

- The heavy quark mass effects on the photon structure functions are investigated in parton model up to the NLO
- Using Cutkosky rule and reduction method, structure functions are expressed in terms of the master integrals.
- The master integrals for virtual corrections are evaluated

Ultraviolet divergence are canceled

Infrared divergence are remained

should be canceled when contribution of real gluon emission diagrams is added

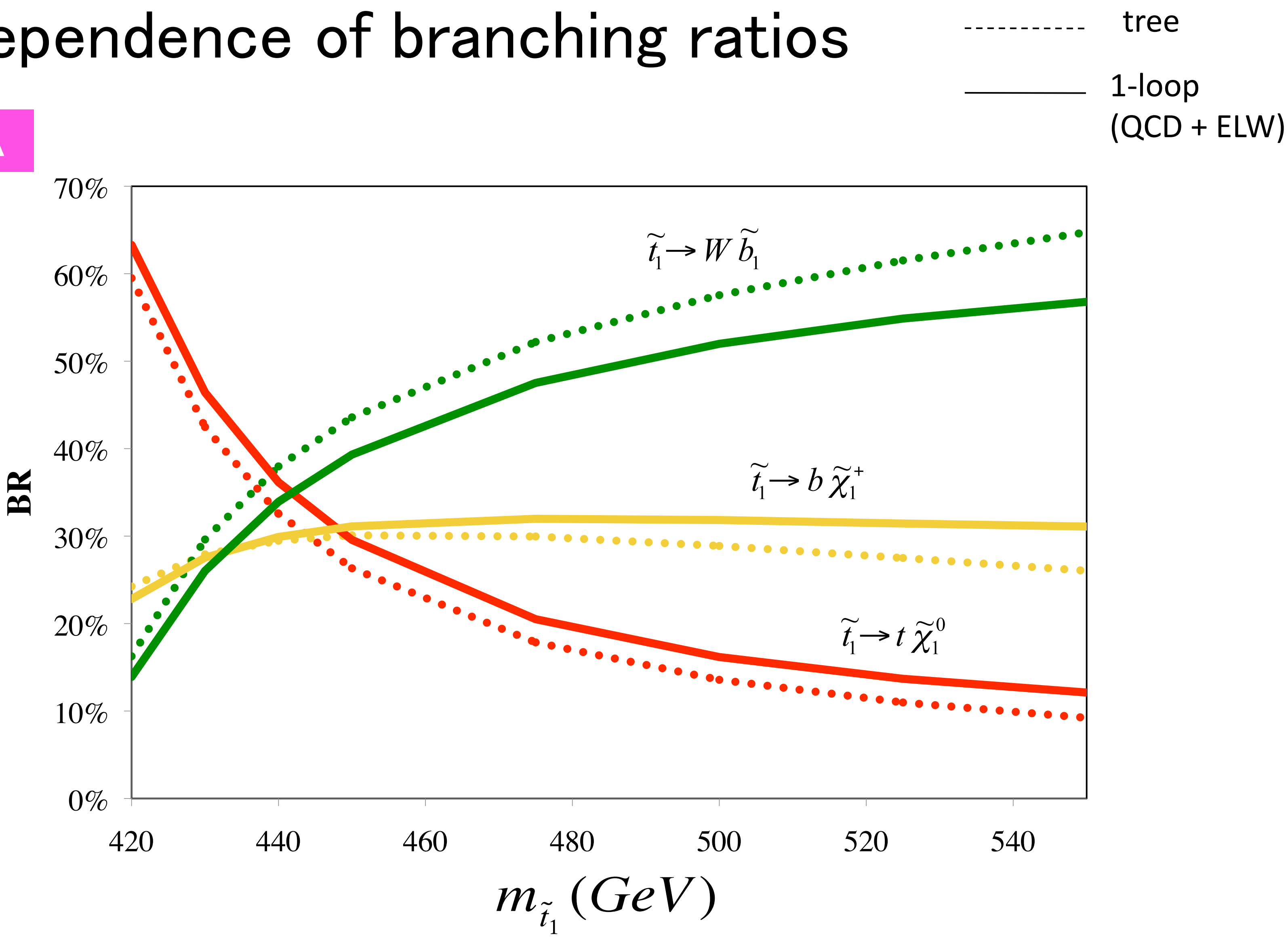


- Analysis of the real gluon emission diagrams in progress

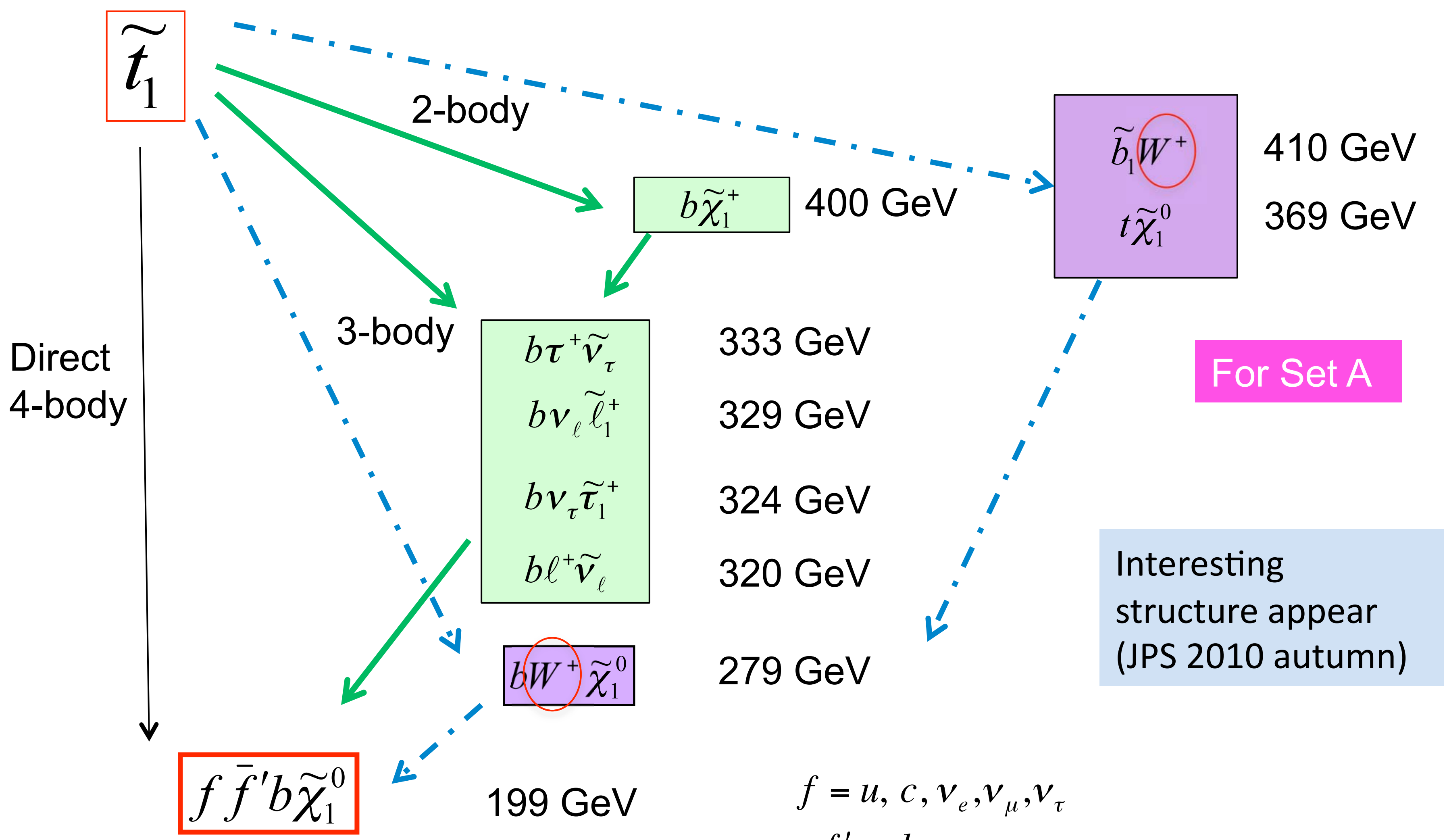
MSSM 1-loop corrections (Kon)

$m_{\tilde{t}_1}$ dependence of branching ratios

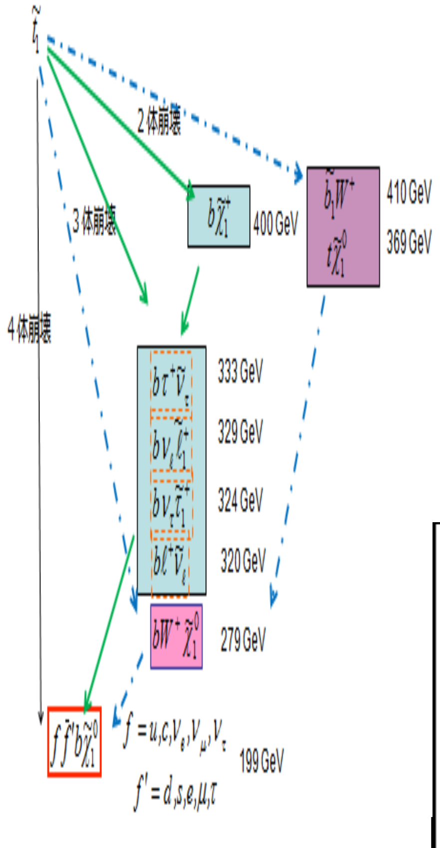
For Set A



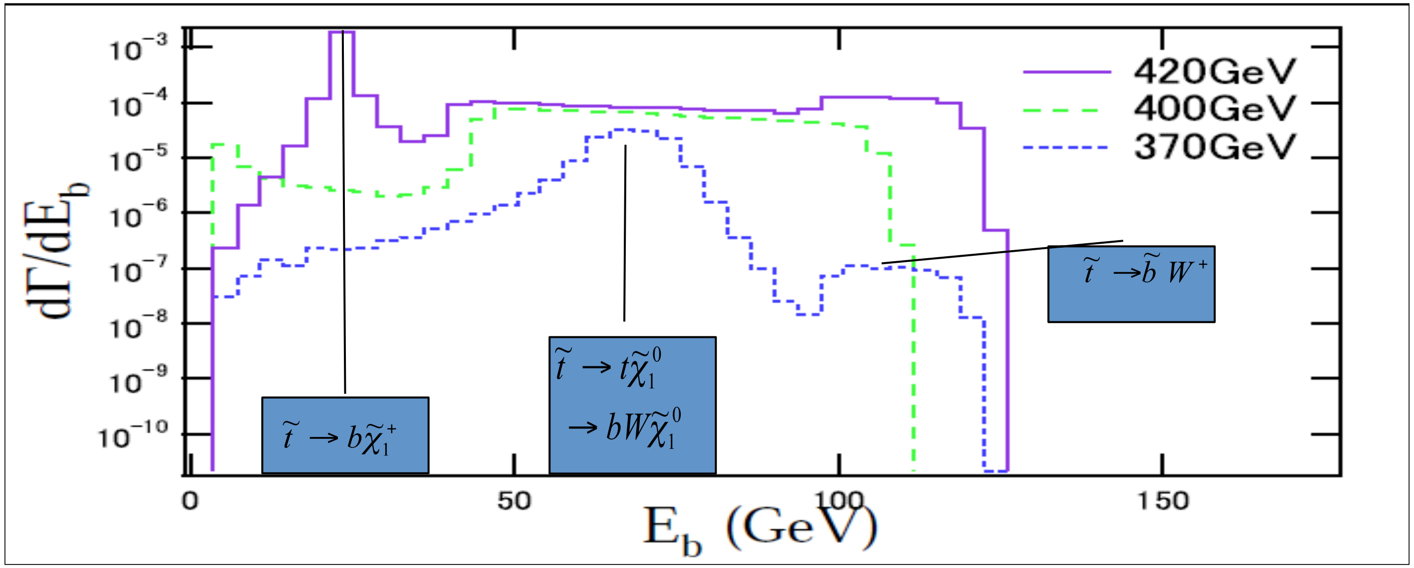
Analysis of 4-body decays for a parameter set (Kon)



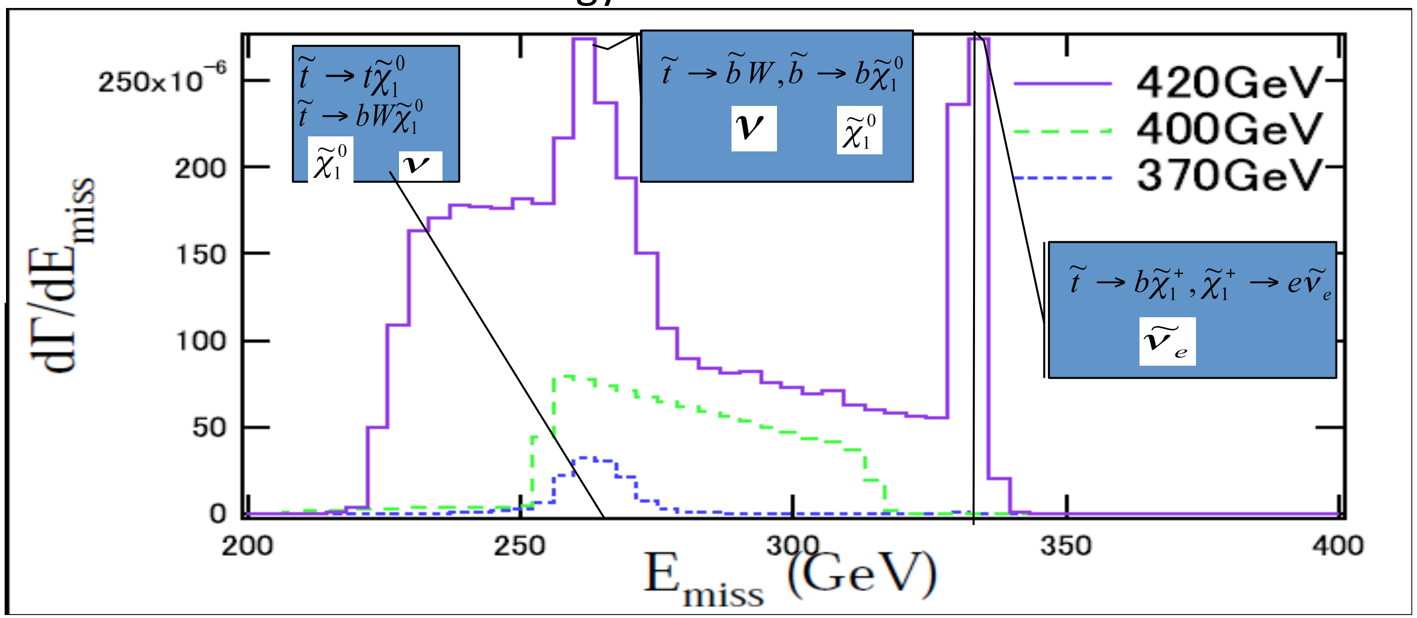
$$\tilde{t} \rightarrow e^{+}\nu_e b\tilde{\chi}_1^0$$



Energy distribution of b-quark



Invisible energy distribution



How to confirm

Systematic check of the computation : Large scale, hard to check

UV cancelation

IR cancelation

Interchange ordering

Gauge invariance check

… NLG mode (Jimbo's talk, Le's talk) : useful

New: Sfermion sector

Final words

- "Computation" is essential for the comparison between experiment and theory
  -> Study SM, and also BMS
- Automatic computation is an indispensable tool for current and future HEP
  -> produce theoretical prediction with enough accuracy
  -> computers are the 'detectors' for theorists
- Armored by the automated system, we have obtained important physical results and also have contributed to the event generator development.

Final words(cont.)

- Acceleration of hardware and parallelization, high-speed algorithm, symbolic systems, reliability, … are important for ultra-size computation.

(8) It is impossible to predict what a human will do.

FUTURE: Let’s make unpredictable progress by human power.