GRACE の使い方（とか？）

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GRACE-School　2009

GRACE とは？

Lagrangean

↓

GRACE

Feynman rule

↓

散乱振幅

↓

散乱断面積

(kinematics,数値積分)

↓

イベント生成

↓

周辺機器

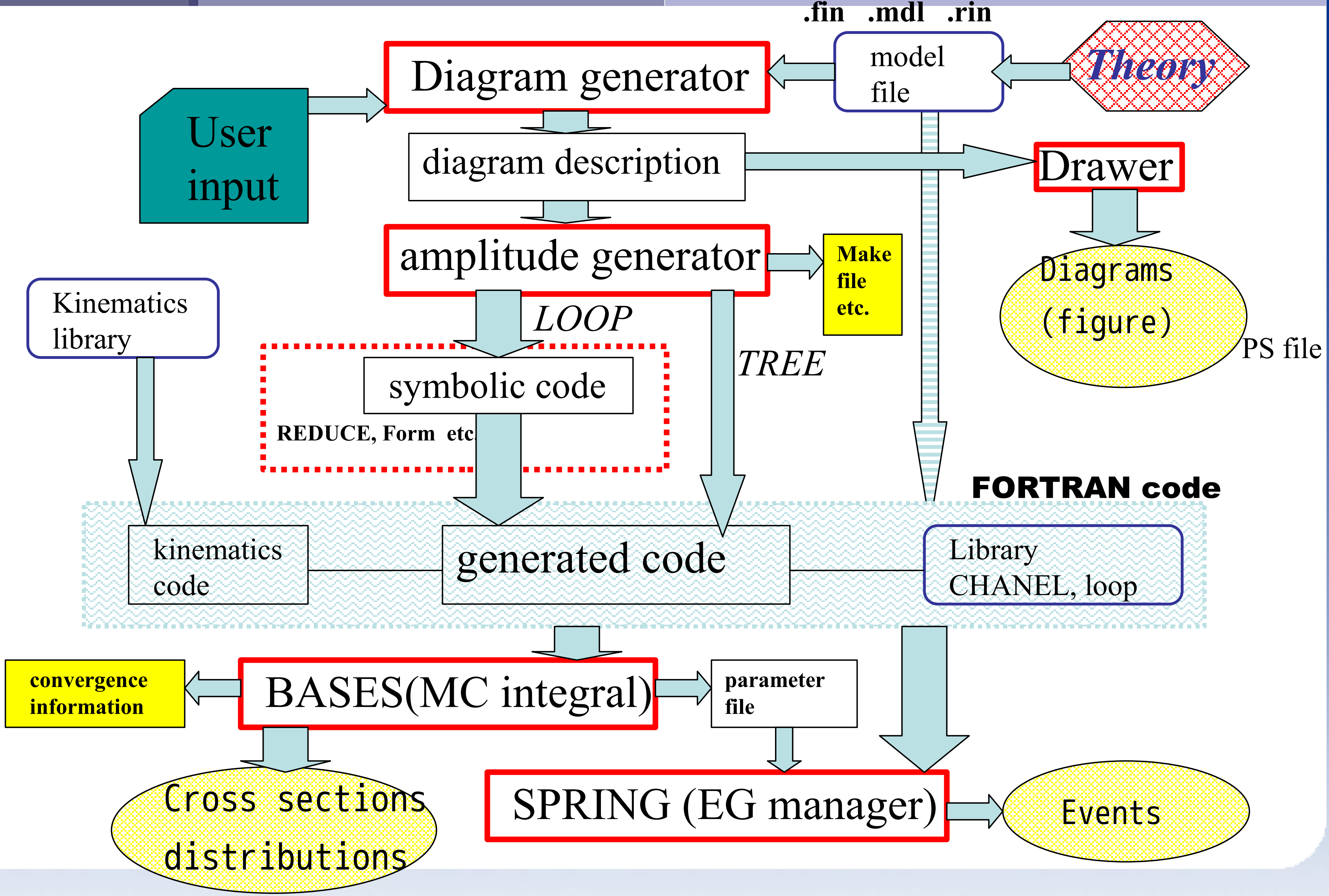
散乱振幅計算の２つの方法

- 散乱振幅の２乗を数式的に計算する。
  - 偏極の和　→　トレース

- 散乱振幅を、数値的に計算する。
  - スピノール
  - 偏極ベクトル　　　→　数値化
  - プロパゲーター

GRACEの方法

GRACE とは？



.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

Model file: particle definition

```
%=======================================
% gauge bosons
%---------------------------------------
 Particle=W-plus["W+"]; Antiparticle=W-minus["W-"];
     Gname={"W", "W^+", "W^-"};
     PType=Vector; Charge=1; Color=1; Mass=amw; Width=agw;
     PCode=2; KFCode=24; Gauge="wb";
 Pend;
%
 Particle=Z["Z0"];      Antiparticle=Particle;
     Gname={"Z^0"};
     PType=Vector; Charge=0; Color=1; Mass=amz; Width=agz;
     PCode=4; KFCode=23; Gauge="zb";
 Pend;
%
 Particle=photon["A"];    Antiparticle=Particle;
     Gname={"\gamma"};
     PType=Vector; Charge=0; Color=1; Mass=ama; Width=0;
     PCode=1; Massless; KFCode=22; Gauge="ab";
 Pend;
%
 Particle=gluon["g"]; Antiparticle=Particle;
     Gname={"g"};
     PType=Vector; Charge=0; Color=8; Mass=amg; Width=0;
     PCode=8; Massless; KFCode=21;
     Gauge="gl"; PSelect="gluon";
 Pend;
```

Model file: particle interaction

```
 Vertex={u-bar, u, Z}; ELWK=1; FName=czuu(2,1/3);
          Vend;
 Vertex={c-bar, c, Z}; ELWK=1; FName=czuu(2,2/3);
          Vend;
 Vertex={t-bar, t, Z}; ELWK=1; FName=czuu(2,3/3);
          Vend;
 Vertex={d-bar, d, Z}; ELWK=1; FName=czdd(2,1/3);
          Vend;
 Vertex={s-bar, s, Z}; ELWK=1; FName=czdd(2,2/3);
          Vend;
 Vertex={b-bar, b, Z}; ELWK=1; FName=czdd(2,3/3);
          Vend;
%-------------------------------------------------
% FFV (FFg)
%-------------------------------------------------
 Vertex={u-bar, u, gluon}; QCD=1; FName=cguu(2,1/3);
          FType="V"; Vend;
 Vertex={d-bar, d, gluon}; QCD=1; FName=cgdd(2,1/3);
          FType="V"; Vend;
 Vertex={c-bar, c, gluon}; QCD=1; FName=cguu(2,2/3);
          FType="V"; Vend;
 Vertex={s-bar, s, gluon}; QCD=1; FName=cgdd(2,2/3);
          FType="V"; Vend;
 Vertex={b-bar, b, gluon}; QCD=1; FName=cguu(2,3/3);
          FType="V"; Vend;
 Vertex={t-bar, t, gluon}; QCD=1; FName=cgdd(2,3/3);
          FType="V"; Vend;
```

uu→WWg: Input file

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Model="sm.mdl";
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Process;
   ELWK={2,2};
   QCD={3,1};
   Initial={u u-bar};
   Final  ={gluon, w-plus, w-minus};
   Expand=Yes;
   Block=No;
   AnyCT=Yes;
   Kinem="2301";
Pend;
```

Name of model file

loop order

tree order

Order of α

Order of α_s

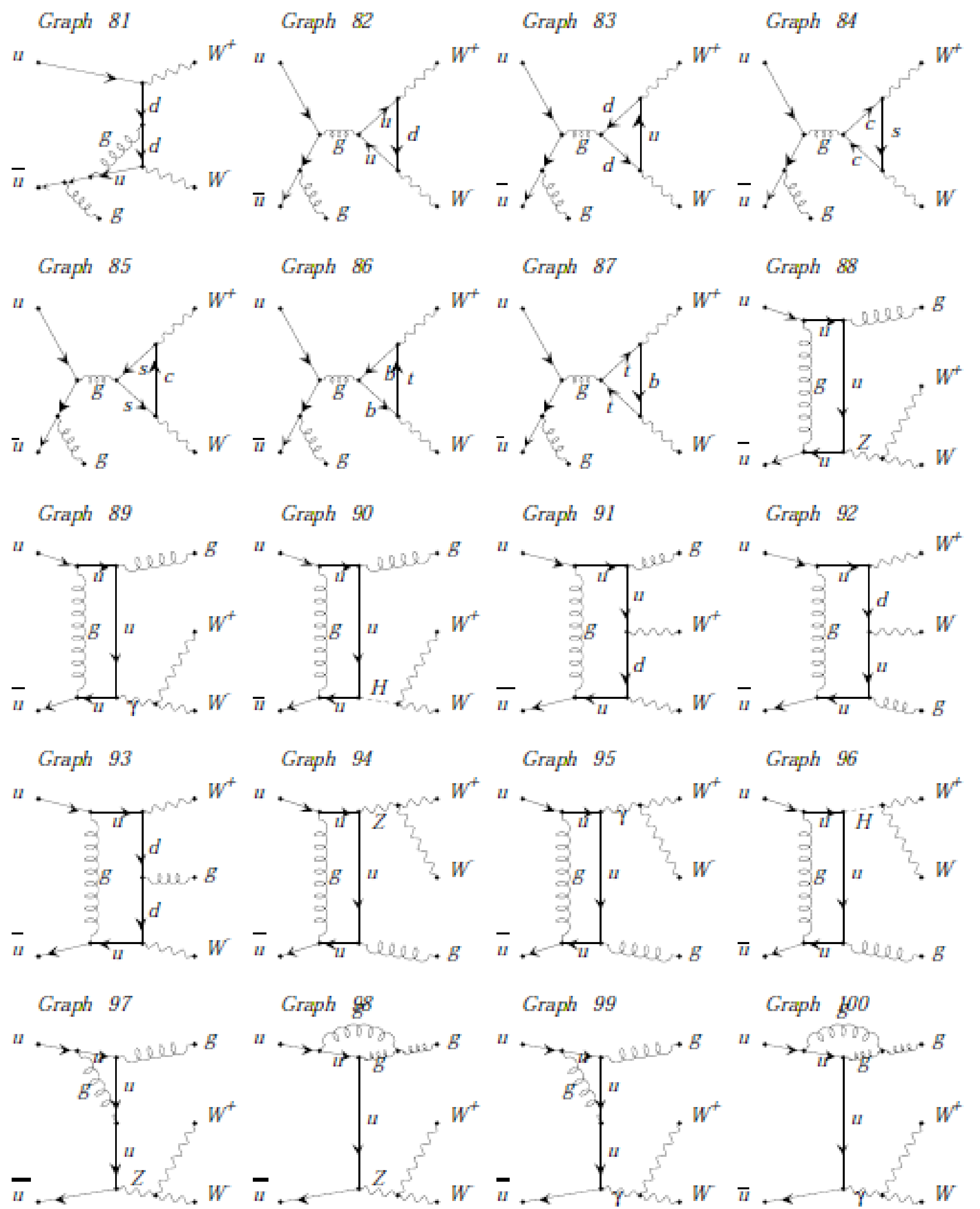
initial state particles

final state particles

kinematics number

Diagrams

uU→WWg



FORTRAN source code

```
      subroutine atrg2
      implicit real*8(a-h,o-z)

      include 'incltrl.h'
      include 'inclk.h'
      include 'incltrp.h'
*-----------------------------------------------------------------------
      common /amwork/cftrl3q,av4,av5,extrl3q,pttrl3q
      common /amwori/lt4,lt5
*     880 (880) + 32 (32) bytes used

      integer     lt4(0:3),lt5(0:3)
      real*8      extrl3q(2),pttrl3q(4,3)
      complex*16 cftrl3q(2,4)
      complex*16 av4(lextrn*lintrn*lepexa)
      complex*16 av5(lintrn*lextrn*lepexv)
      complex*16 atmp
      real*8      cwgt(0:1)

*-----------------------------------------------------------------------

* Denominators of propagators
      aprop = 1.0d0
      call smprpd(pphase,aprop,vntrl3,
     &        amuq**2,0.0d0)

* Internal momenta
      call smintf(amuq,pftrl3,vntrl3,extrl3q,pttrl3q,cftrl3q)

* Vertices (6)
      call smffv(lextrn,lintrn,lepexa,extr2q,extrl3q,amuq,amuq,cguq,
     &           cftr2q,cftrl3q,pttr2q,pttrl3q,eqtrl4e,lt4,av4)
      call smffv(lintrn,lextrn,lepexv,extrl3q,extr4t,amuq,amdq,cwuq,
     &           cftrl3q,cftr4t,pttrl3q,pttr4t,eqtr9b,lt5,av5)

      call smconf(lt4,lt5,2,1,extrl3q,av4,av5,lt,av)

      sym = - 1.0d0
      aprop         = sym/aprop

      indexg(1) = 1
      indexg(2) = 4
      indexg(3) = 2
      indexg(4) = 3

      if(jcpol(4).ne.0) call smcpol(2, lt, av)

      call atmpord(lt, av, indexg, agcwrk)

      ancp(jgraph) = 0.0d0
*     nbase = 2
      do 500 ih = 0 , ltrag-1
         atmp        =   agcwrk(ih)*aprop
         agc(ih,0) = agc(ih,0) + (-1/6.d0)*atmp
         agc(ih,1) = agc(ih,1) + (1/2.d0)*atmp
         ancp(jgraph) = ancp(jgraph) + atmp*conjg(atmp)
  500 continue

      return
      end
```

GRACEをつかってみよう

- uU → dD　　　　(大文字は反粒子を表す)

①in.prcを用意する。
②$grc　と打つ。　　　(グラフを生成する。)
③$gracefig　と打つ。 (グラフを見ることができる。)
④$grcfort　と打つ。 (FORTRANコードが生成される。)
⑤$make gauge と打つ。
　(gaugeチェックのための実効モジュールが生成される。)
⑥$gauge　と打つ。
　(gaugeチェックを数値的に行うことができる。)
⑦$make integ と打つ。
　(散乱断面積の計算のための実効モジュールが生成される。)
⑧$integ　と打つ。
　(散乱断面積が計算される。数値積分。)

GRACEの粒子の表

Bosons	name	description
W^+	W-plus	Weak boson with charge +1
W^-	W-minus	Weak boson with charge -1
Z^0	Z	Neutral weak boson
γ	photon	Photon
g	gluon	Gluon

Fermions	name	description
e^-	electron	Electron
e^+	positron	Positron
μ^-	muon	Muon
μ^+	anti-muon	Anti-muon
τ^-	tau	Tau lepton
τ^+	anti-tau	Anti-tau lepton
ν_e	nu-e	Electron neutrino
$\bar{\nu}_e$	nu-e-bar	Anti-electron neutrino
ν_μ	nu-mu	Muon Neutrino
$\bar{\nu}_\mu$	nu-mu-bar	Anti-muon neutrino
ν_τ	nu-tau	Tau neutrino
$\bar{\nu}_\tau$	nu-tau-bar	Anti-tau neutrino

Quarks	name	description
u	u	Up quark
$\bar{u}$	u-bar	Anti-up quark
d	d	Down quark
$\bar{d}$	d-bar	Anti-down quark
s	s	Strange quark
$\bar{s}$	s-bar	Anti-strange quark
c	c	Charm quark
$\bar{c}$	c-bar	Anti-charm quark
b	b	Bottom quark
$\bar{b}$	b-bar	Anti-bottom quark
t	t	Top quark
$\bar{t}$	t-bar	Anti-top quark

Scalars	name	description
ϕ	Higgs	Higgs scalar
χ^+	chi-plus	Charged Goldstone boson with charge +1
χ^-	chi-minus	Charged Goldstone boson with charge -1
χ^3	chi-3	Neutral Goldstone boson

Ghosts	name	description
c^+	C-plus	Faddeev-Popov ghost associated with W^-
$\bar{c}^-$	C-plus-bar	Anti-Faddeev-Popov ghost associated with W^-
c^-	C-minus	Faddeev-Popov ghost associated with W^+
$\bar{c}^+$	C-minus-bar	Anti-Faddeev-Popov ghost associated with W^+
c^Z	C-Z	Faddeev-Popov ghost associated with Z^0
$\bar{c}^Z$	C-Z-bar	Anti-Faddeev-Popov ghost associated with Z^0
c^γ	C-A	Faddeev-Popov ghost associated with photon
$\bar{c}^\gamma$	C-A-bar	Anti-Faddeev-Popov ghost associated with photon
c^g	C-g	Faddeev-Popov ghost associated with gluon
$\bar{c}^g$	C-g-bar	Anti-Faddeev-Popov ghost associated with gluon

生成されるFORTRANファイル(主なもの)

- gauge.f　gaugeチェック
- mainbs.f　積分のmainプログラム
- func.f　被積分関数（散乱振幅）
- amps.f　個々のグラフの振幅を計算
- ampsum.f　振幅の和をとる（自乗する）
- kinit.f　kinematicsの初期化
- kinem.f　kinematicsを与えるプログラム
- kfill.f　ヒストグラムのfilling
- gfinit.f　偏極・グラフの選択
- setmas.f　粒子の質量・結合定数の設定

kinematicsとは何か？

- 終状態3体反応の自由度を数える

  P → p1+p2+p3

  Total　　　　　　　　　: 4×3=12

  質量条件　　　　　　　: 3

  エネルギー運動量保存: 4

  残り　　　　　　　　　: 12-3-4=5

  (方位角の対称性　　　: 1　　　　)

  (残り　　　　　　　　: 5-1=4　　)

- 5(4)つの乱数→　３つの4元運動量

  これを与えるアルゴリズムをkinematicsと呼ぶ。

  　(積分の能率は、この良し悪しで決まる)

- 「問題」　n体終状態での自由度は？

kinematicsの選び方

- 散乱振幅の振る舞いの「肝」は、プロパゲータの分母！

code number	contents
1201	1-body $\to$ 2 body decay
1301	1-body $\to$ 3 body decay Sequential decay $1 \to 2 + (3+4) \to 2+3+4$ can be treated.
2201	2-body $\to$ 2 body in CM frame t- and u-channel singularities can be treated.
2301	2-body $\to$ 3 body in CM frame , Sequential decay type $1+2 \to 3+(4+5) \to 3+4+5$. Resonance on particles 4 and 5 can be treated.
2302	2-body $\to$ 3 body in CM frame , Radiative processes $1+2 \to 3(\gamma)+4+5$, both initial and final radiation can be treated.
2303	2-body $\to$ 3 body in CM frame , Double-radiative processes $1+2 \to 3(\gamma)+4(\gamma)+5$
2304	2-body $\to$ 3 body in CM frame , Three photon processes $1+2 \to 3(\gamma)+4(\gamma)+5(\gamma)$
2401	2-body $\to$ 4 body in CM frame, a pair of sequential decay type $1+2 \to (3+4)+(5+6) \to 3+4+5+6$ t-channel singularity can be treated.
2402	2-body $\to$ 4 body in CM frame, 'fusion' type $1+2 \to (3+A)+(4+B); A+B \to 5+6$

GRACEを使ってみよう（その２）

- uU → uU

  QCD, Electro/weak, Gauge set
- uU → uU gluon

  QCD, IR divergence
- uU → uU Higgs

  Electro/weak, Graph selection, PDF
- qQ → e ν_e C s

  Electro/weak 4-fermion

GRACEを使ってみよう（宿題）

- qQ → qQ Higgs (w-fusion)
- PP →gluino gluino (SUSY粒子生成）
- ν_e g → ν_e dD (ニュートリノ・陽子散乱）
- eE → eE squark Squark (2-photon process)