International Linear Collider (ILC) Valencia Workshop 2006

ECFA Study

Physics and Detectors for a Linear Collider

international linear collider

Summary of the Generators Working Group Parallel Session

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Short introduction: the models implemented.

In CalcHEP there are implemented

- The Standard Model,
- MSSM based on SuSpect/Isajet/SoftSUSY/SPHENO (MicrOMEGAs group)
- NMSSM based NMHDecay (MicrOMEGAs group + C.Hugonie)
- MSSM with CP violation based on CPSuperHiggs(MicrOMEGAs + S.Kraml)
- The Little Higgs model (A.Birkedal et al; A.Belyaev et al)
- The extra dimension LZP model (G. Servant, K. Agashe)
- The LeptoQuark model (A.Belyaev et al)

Implementation of new model is simplified by LanHEP package

A. Semenov. Nucl.Inst.\&Meth. A393 (1997) p. 293.
http://theory.sinp.msu.ru/~semenov/lanhep.html

Short introduction: Batch calculations

Batch *non-interactive session can be realized by the following trick:*

In the end of interactive session launched with option "+blind", for example,

```
n_calchep  +blind
```

program writes on the screen the sequence of pressed keys. Let we have generated 123 events using CalcHEP menus. Then after the end of session we find on screen:

```
"[[[[[[[[[{[[[{{123{[[[{0"
```

In principle, one can decode it, `{ - Enter ;` `[ - Down arrow`

To force CalcHEP to repeat this session one can call

```
n_calchep -blind "[[[[[[[[[{[[[{{123{[[[{0"
```

Now one can replace "123" to `$1` *and save this line in a file to get a shell script for event generation.*

Several such scripts are written and disposed in `$CALCHEP\bin`.

Event generation in CalcHEP_2.5

CalcHEP_2.5 - is a new version which is in progress. Beta release of it is presented on CalcHEP site. It contains a script for generation of events in cycle over subprocesses.

Interface with Showering and Hadronization event Generators

This interface is based on Les Houches Accord for event generators Boos et al, hep-ph/0109068. Here Fortran interface is assumed and information is passed via COMMON BLOCKs.

Particle decays and Double Les Houches Accord.

Events with new particles passed to SHG have to be accompanied with information about decays. For instance, one can use SUSY Les Houches Accord (P. Skands et al, hep-ph/0311123). Here information is passed via text file using PDG numbers for particle identification.

Fusion of collision and decay events in CalcHEP.

Apart of well known problem of lost of spin correlation the passing decay information via SLHA gets a flat momenta distributions and has a problem with color rearrangement. For example, ISAJET generates t-quark decays which leads to a crash in PYTHIA at the color rearrangement step. Also it will produce wrong mass distribution for $f\bar{f}$ pairs.

If parton events are passed to SHG by external program, the same program should be able to generate decay events and implement them decays before passing event to SHG.

Other new facilities.

Polarized beams. There is a possibility to calculate matrix element for polarized massless incoming particles. Polarized particle should be marked by the % symbol when we define the process.

$$E\%, e\% \rightarrow 2*x \quad or \quad A\%, A\% \rightarrow 2*x$$

In numerical session one can specify left/right contents of incoming beams.

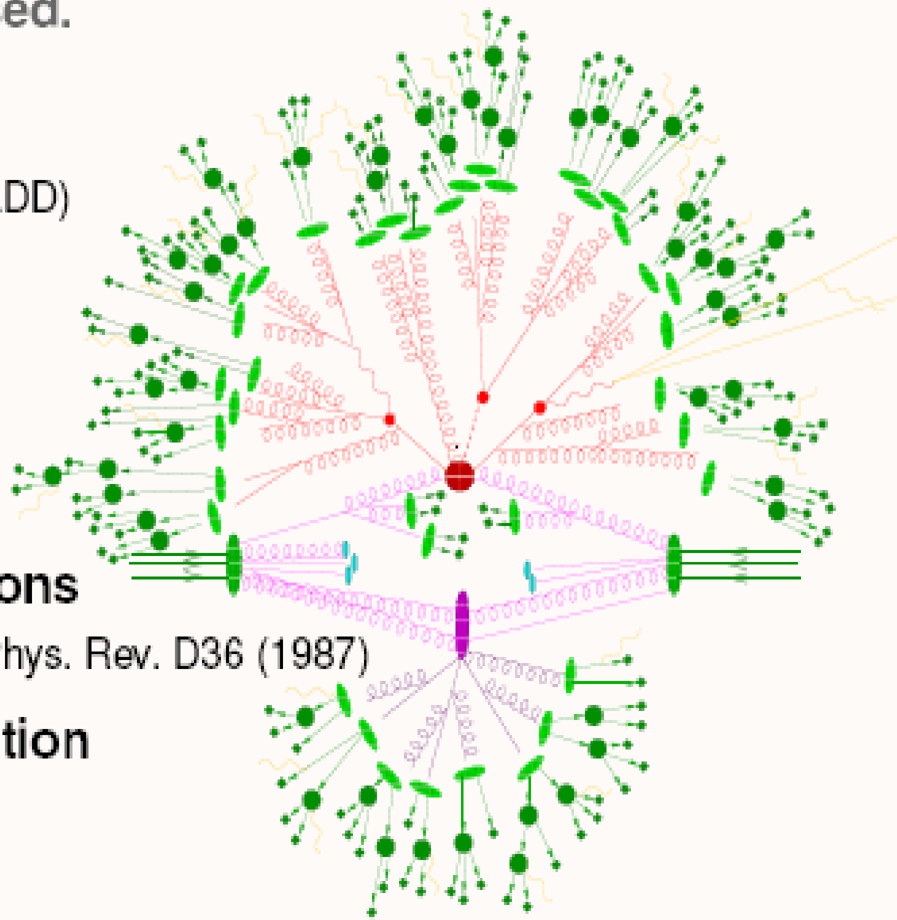
Spin 3/2 and spin 2 massive particles are available in CalcHEP now. Spin 2 can be interesting for models with extra dimensions.

What is SHERPA

T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann and J. W., JHEP **0402** 056 (2004).

➔ **SHERPA version 1.0.8 has been released.**

- **ME generator AMEGIC++**
  (at tree level, provides HP and HD in SM, MSSM, ADD)
- **IS and FS shower module APACIC++**
  (virtuality ordered, PYTHIA-like showers)
- **Combination of ME and PS according to CKKW**
- **Simulation of multiple parton interactions**
  main ideas based on T. Sjöstrand and M. van Zijl, Phys. Rev. D36 (1987)
- **Interface to PYTHIA's string hadronization**
- **Interface to PYTHIA's hadron decays**



➔ **Sherpa is the event generation framework:**

- initialization of the different phases
- interplay of the various stages
- steering the event generation

BSM physics with SHERPA

Tanju Gleisberg

———

Institute for Theoretical Physics
Dresden University of Technology

CERN, Theory Division

- Event generation with Sherpa
- The matrix element generator AMEGIC++
- BSM Models
  - MSSM, ADD, Anomalous gauge couplings
  - Implementation of new models

MSSM

MSSM implementation

- MSSM spectrum taken from SLHA input files
  (→ masses etc. governed by external codes)
- General Feynman rules (unitary gauge, conserved R-party) according to J. Rosiek, Phys.Rev.D41:3436, 1990
- The violated fermion flow of Majorana fermions is cured by using appropriate Feynman rules
  - Implemented the approach of Denner *et al.* Nucl.Phys.B387, 1992
  - The relative sign of interfering Feynman graphs is determined avoiding the usage of charge-conjugated matrices
  - Instead an orientation (fermion flow) for each appearing fermion line is defined

Application area

- Calculation of total and partial widths of sparticles
- Sparticle production processes at LHC and ILC
- AMEGIC++ can provide SUSY signals and associated SM/SUSY backgrounds

MSSM: Validation

Comparison of Automated Tools for Phenomenological Investigations of SuSy

SMadGraph, **O'Mega/Whizard**, **Amegic++/Sherpa**

Hagiwara, Kilian, Krauss, Ohl, Plehn, Rainwater, Reuter, Schumann,
Phys. Rev. D 73, 055005 (2006)

- All SUSY vertices were checked testing several hundred $2 \to 2$ processes

$$\begin{matrix} e^+e^-,\ e^-\bar{\nu}_e,\ e^-e^-,\ \tau^+\tau^-,\ \tau^-\bar{\nu}_\tau,\ u\bar{u},\ d\bar{d}, \\ uu,\ dd,\ b\bar{b},\ b\bar{t},\ W^+W^-,\ W^-Z,\ W^-\gamma, \\ ZZ,\ Z\gamma,\ \gamma\gamma,\ gW^-,\ gZ,\ g\gamma,\ gg,\ ug,\ dg \end{matrix} \longrightarrow$$

All combinations of SUSY partners or Higgs boson

- Results are listed under

`http://www.sherpa-mc.de/susy_comparison/susy_comparison.html`

Conclusion and outlook

- Sherpa is ready for BSM studies at LHC and ILC (signals and background)
- MSSM and ADD are fully implemented and tested
- Further models are almost ready (however some more test and completion necessary): Anomalous gauge couplings, RPV Susy, Models with Gravitinos (Spin 3/2), UED, RS1, ...
- User extendible as long as Lorentz-/Dirac-structures of propagators and vertices are available
(in principle there is no limit, however this part is quite involved!)

- The latest SHERPA version (1.0.8) is available from our homepage:

http://www.sherpa-mc.de

Coming soon: version 1.0.9

Merging MEs and the parton shower with SHERPA

[ILC Workshop Valencia 2006]

Jan Winter [a]

CERN PH TH *and* Institute for Theoretical Physics, TU Dresden

- **Challenge: appropriate treatment of multijets**
- **CKKW method overview**
- **Survey of application examples**
- **Current developments**

[a] SHERPA authors: T. Gleisberg, S. Höche, F. Krauss, F. Siegert, S. Schumann, J. W.

http://www.sherpa-mc.de/

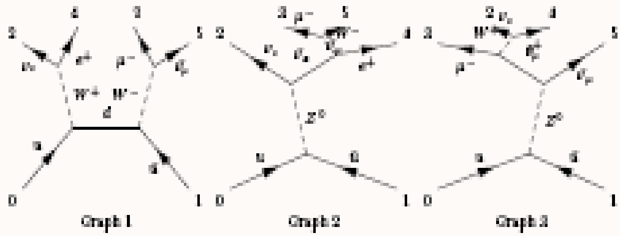
Multiparton MEs

✓ exact at some fixed order (FO) in the coupling

✓ quantum interferences & spin correlations & mass/offshell effects

✓ exact phase space filling: correct high energetic/wide angle configurations

✗ factorial growth of calculational work
complicated phase-space structures
lack of bulk of radiation: multiple soft/coll emissions



Parton showers (PSs)

✓ free colour particle radiates partons perturbatively

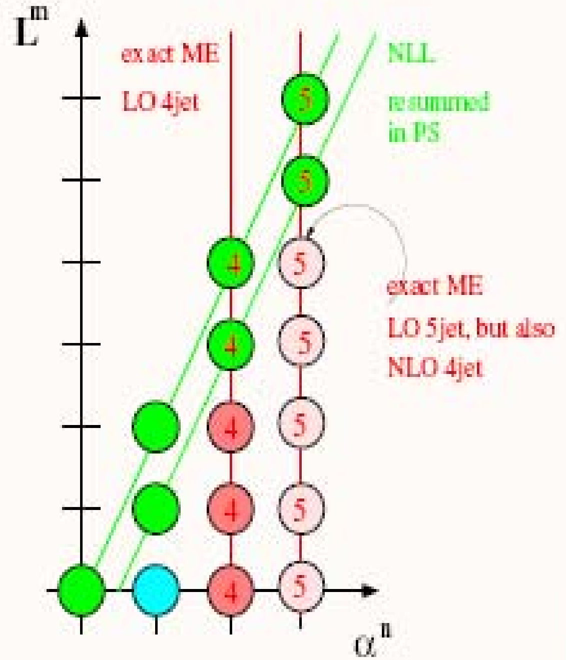
✓ mainly in the coll/soft limit: AO resummation/LL exponentiation ⇒ tower of logs

$$\mathcal{O} = \sum r_n \alpha_S^n \quad \Rightarrow \quad \mathcal{O} = \sum c_n \alpha_S^n \log^{2n}(q/q_0) + \text{NLL} + \ldots$$

Combine advantages, remove weaknesses.

Beware of double counting, preserve universality of hadronization.

α_S vs. Log



CKKW – key feature of SHERPA

- Method has been implemented within SHERPA in full generality.

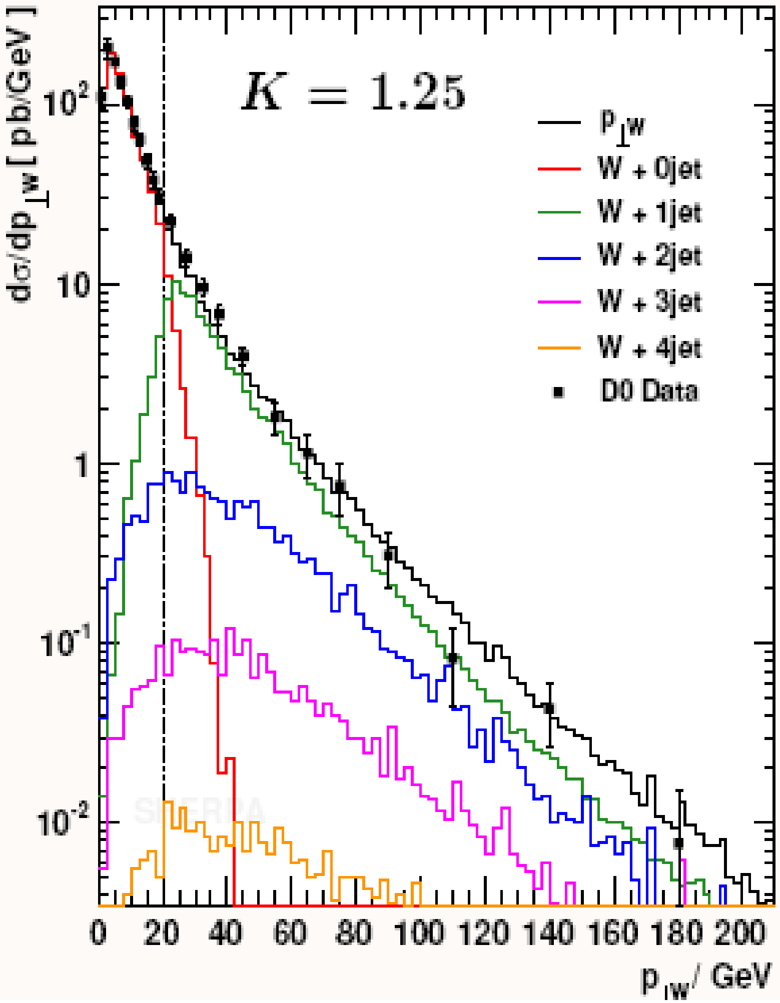
S. Catani, F. Krauss, R. Kuhn and B. Webber, JHEP **0111** (2001) 063

F. Krauss, JHEP **0208** (2002) 015

- Process-independent implementation.

! Validation

- $W/Z+$jets @ Tevatron/LHC
  F. Krauss, A. Schälicke, S. Schumann,
  Phys. Rev. D **70** (2004) 114009, D **72** (2005) 054017
- WW production @ Tevatron
  T. Gleisberg et al., Phys. Rev. D 72 (2005) 034028
- ongoing: detailed comparison to ARIADNE & MLM merging
  1st results in "HERA and the LHC" proceedings
- ongoing: pure jets, $Zb\bar{b}+X$, $gg \to H+X$, VBF



HELAC - A package to compute helicity amplitudes and cross sections

(Progress Report)

Malgorzata Worek
ITP Karlsruhe

- Reliable cross section computation and event generation for multiparticle processes with **10-12** particles
  - Matrix element computation algorithm based on **Dyson-Schwinger** equations
  - Including: EW, QCD, masses, CKM matrix, running couplings, PDF sets, ...
  - Free from the task of calculating Feynman Diagrams
  - **MC summation** over colours and helicities
  - Much improvement in computational efficiency $\sim 3^n$
  - Successfully implemented in Fortran 95 program (gfortran, g95, lahey 95)
- Results & Comparisons
- Summary & Outlook

In collaboration with:
C. G. Papadopoulos
NCSR "Demokritos", INP Athens

Results & Comparisons

Process	$\sigma_{MC} \pm \varepsilon$ (nb)	ε (%)
$gg \to 7g$	$(0.53185 \pm 0.01149) \times 10^{-2}$	2.1
$gg \to 8g$	$(0.33330 \pm 0.00804) \times 10^{-3}$	2.4
$gg \to 9g$	$(0.13875 \pm 0.00430) \times 10^{-4}$	3.1 !!!

- Comparison of the computational time for $|M|^2$
- t_{EXACT} - time for the processes with summation over all possible colour flows for colour ordered amplitudes
- t_{MC} - time for the processes with the Monte Carlo summation over 'real' colours for full amplitudes

Process	t^{CF}_{EXACT}	t_{MC}	t_{EXACT}/t_{MC}
$gg \to 2g$	0.315×10^{0}	0.554×10^{0}	0.57
$gg \to 3g$	0.329×10^{1}	0.143×10^{1}	2.30
$gg \to 4g$	0.383×10^{2}	0.372×10^{1}	10.29
$gg \to 5g$	0.517×10^{3}	0.105×10^{2}	49.24
$gg \to 6g$	0.987×10^{4}	0.362×10^{2}	272.65 !!!
$gg \to u\bar{u}$	0.260×10^{0}	0.466×10^{0}	0.56
$gg \to gu\bar{u}$	0.196×10^{1}	0.123×10^{0}	1.59
$gg \to 2gu\bar{u}$	0.166×10^{2}	0.348×10^{1}	4.77
$gg \to 3gu\bar{u}$	0.171×10^{3}	0.129×10^{2}	13.25
$gg \to 4gu\bar{u}$	0.197×10^{4}	0.307×10^{2}	64.17
$gg \to c\bar{c}c\bar{c}$	0.697×10^{1}	0.605×10^{1}	1.15
$gg \to gc\bar{c}c\bar{c}$	0.568×10^{2}	0.217×10^{2}	2.62
$gg \to 2gc\bar{c}c\bar{c}$	0.619×10^{3}	0.401×10^{2}	15.44

Results & Comparisons

ILC

- Determination of Higgs potential - self couplings of H have to be checked
- Higgs bosons emerge in Higgs-strahlung-like topologies abd decay into $b\bar{b}$
- Final states $e^+e^- \to \mu^+\mu^- 4b$, $Z \to \mu^+\mu^-$
- Contributions mediated by Higgs bosons included or neglected factor ~3-4
- QCD effects checked as well

Triple Higgs coupling

Final state	QCD	AMEGIC++ [fb]	HELAC [fb]
$\mu^-\mu^+b\bar{b}b\bar{b}$	yes	2.560(26)e-02	2.583(26)e-02
	yes	3.096(60)e-02	3.019(43)e-02
	no	1.711(55)e-02	1.666(28)e-02
	no	2.34(12)e-02	2.36(10)e-02

Backgrounds to triple Higgs coupling

Final state	QCD	AMEGIC++ [fb]	HELAC [fb]
$\mu^-\mu^+b\bar{b}b\bar{b}$	yes	7.002(32)e-03	7.044(22)e-03
	yes	6.308(24)e-03	6.364(21)e-03
	no	2.955(11)e-03	2.972(12)e-03
	no	3.704(15)e-03	3.695(13)e-03

The GraphShot project

- A FORM code to generate and manipulate the amplitudes in the SM
- A link to FORTRAN libraries for numerical computation
- Authors: G.Passarino, S.Actis, C.Sturm, S.U.

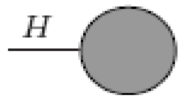
GraphShot: a code to compute Feynman amplitudes

1. The Feynman rules

- The SM Lagrangian $\longrightarrow$ normal rules for propagators and vertices

- Special rules:
  - Higgs vacuum expectation value

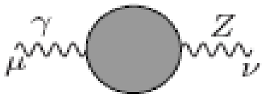
normal : 

$= \;\; 0$ special : 

$= \;\; 0$

  - Z-Photon exchange ($g \to g\,(1+\Gamma)$):

normal : $\Gamma = 0$

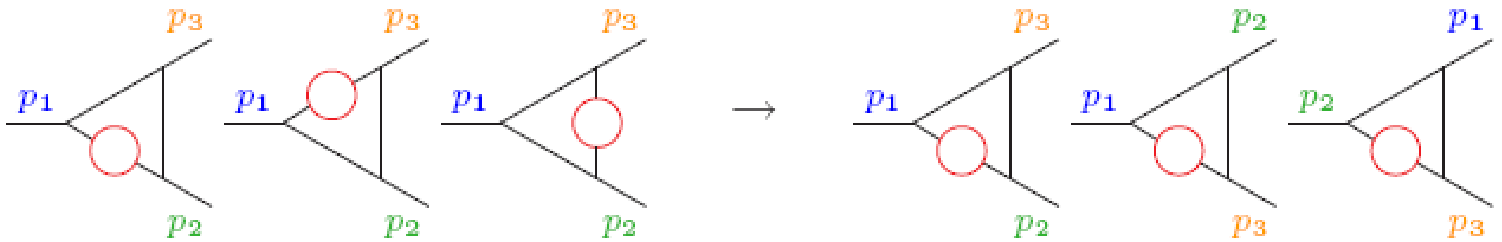
special : 

$= \;\; \mathcal{G}_d^{AZ}(p^2)\,\delta_{\mu\nu} + \mathcal{G}_{pp}^{AZ}(p^2)\,p_\mu p_\nu\,, \qquad \mathcal{G}_d^{AZ}(0) = 0$

- Renormalization $\longrightarrow$ $\overline{MS}$ scheme
  - Counterterms for couplings, masses, fields, ...
  - Finite Feynman amplitudes

2. Generate the amplitude

- Group the diagrams into families, paying attention to:
  - Permutation of external legs



  - Combinatorial factors (Goldberg strategy)
- Combine the topologies and the Feynman rules
- Introduce projectors
- Compute the trace of Dirac matrices

$$\Downarrow$$

All loop momenta are contracted with other momenta

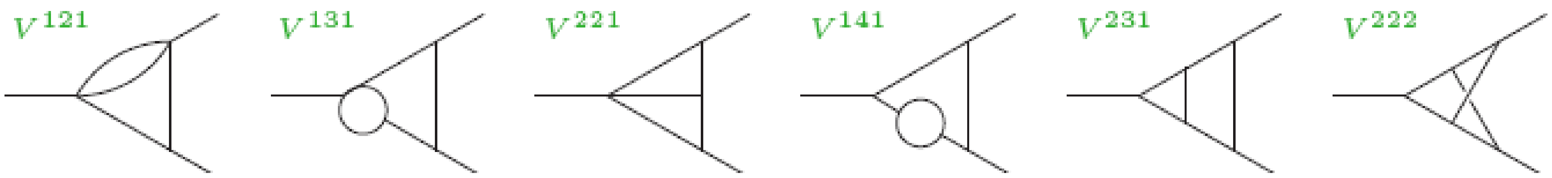
3. Reduction to Master Integrals

- Recursive application of:
  - Obvious reduction:

$$\frac{2\,q.p}{(q^2+m^2)\,[(q+p)^2+M^2]} = \frac{1}{q^2+m^2} - \frac{1}{(q+p)^2+M^2} - \frac{p^2-m^2+M^2}{(q^2+m^2)\,[(q+p)^2+M^2]}$$

- We end with integrals up to rank 3:
  - 1-loop functions
  - 2-loop self-energies (4 topologies)

  - 2-loop vertices (6 topologies)



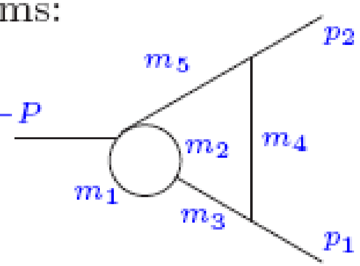
- For all, few scalar products are remaining

4. Analytical cancellations of divergences

Extraction of the UV poles

- 2-loop diagrams:

$V^{131} =$



$$= \frac{1}{\pi^4}\int \frac{d^n q_1\, d^n q_2}{\underbrace{[1]\,[2]}_{x}\,[3]\,[4]\,[5]}, \quad \text{with } [1]\dots[5] \to y_1, y_2, y_3$$

$[1] = q_1^2 + m_1^2$

$[2] = (q_1 - q_2)^2 + m_2^2$

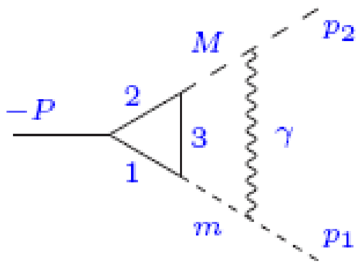
$[3] = q_2^2 + m_3^2$

$[4] = (q_2 + p_1)^2 + m_4^2$

$[5] = (q_2 + P)^2 + m_5^2$

Infrared singularities

$V_{\rm IR}^{231} =$



$$= \frac{1}{\pi^4}\int \frac{d^n q_1\, d^n q_2}{\underbrace{[1]\,[2]\,[3]}_{x_1, x_2}\,[4]\,[5]\,[6]}, \quad \text{with } [1]\dots[6] \to y_1, y_2, y_3$$

$[1] = q_1^2 + m_1^2$

$[2] = (q_1 + p_1)^2 + m_2^2$

$[3] = (q_1 - q_2)^2 + m_3^2$

$[4] = (q_2 + p_1)\cdot(q_2 - p_1)$

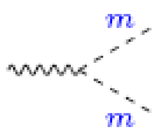
$[5] = (q_2 + p_1)^2$

$[6] = (q_2 + p_1)\cdot(q_2 + p_1 + 2p_2)$

- Small momenta singularity $(q_2 + p_1 = 0)$

Collinear divergencies

- They come from the coupling of light particles (m) with massless particles



5. Numerical computation

Write the **finite part** in one of the following forms:

1) $\int dx \, \frac{Q(x)}{V(x)}$ $V(x)$ polinomial positive definite

2) $\frac{1}{B} \int dx \, Q(x) \ln^n V(x)$ B constant $\neq 0$.

3) $\int dx \, \frac{Q(x)}{V(x)} f\left(\frac{V(x)}{P(x)}\right)$ $f(0) = 0,$ $f(x) = ln^n(1+x),\ Li_n(x),\ S_{n,p}(x)$

State of the art

- Algebraic manipulation → implemented for 1-,2-,3-point 1-,2-loop functions
- Fortran codes → available for 1-,2-,3-point 1-,2-loop functions, massive and IR (link to Graphshot to be done)
- Extraction of collinear logs → partially done
- Future extension → 1-loop multi-leg processes

Applications

- First (partial) application: recent computation of $\sin^2\theta_{\rm eff}$
- Process under examination: $H \to \gamma\gamma$