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NEW TOOLS FOR AUTOMATIC CROSS SECTION CALCULATION

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In this contribution the matrix element generator `AMEGIC++` will be presented. It automatically generates Feynman diagrams, helicity amplitudes, and suitable phase space mappings for processes involving multi-particle final states within the Standard Model and some of its popular extensions.

Due to the rising energy frontier in high-energy collider experiments, potential signals and their backgrounds for interesting or new phenomena involve an increasing number of final state particles and their correlations. To describe the production process of a number of particles, in a quantum mechanically correct treatment, at least at leading order, the corresponding amplitudes have to be constructed. This usually results in a potentially very large number of terms, such that their automated construction and evaluation becomes mandatory. Apart from handling the sheer number of amplitudes, which grows factorially or worse with the number of final state particles, the integration over the multidimensional phase space of the final state represents a formidable task. In the past years various solutions, implemented as different codes, to surmount these problems, have been found. Codes, which incorporate the full Standard Model, are:
`CompHEP` [1], which relies on the traditional method of constructing and summing Feynman diagrams, where completeness relations are used to square the total amplitude. The integration is achieved through one phase space mapping selected by the user. `MadGraph/MadEvent` [2], which constructs Feynman diagrams and employs the method of helicity amplitudes through the `HELAS` library [3] for their evaluation. The phase space integration is achieved through a single-diagram enhanced mapping.There, each diagram gives rise to one parametrisation of phase space, their interplay is steered dynamically in order to minimise the overall variance. `Alpgen` [4] uses the (extended) α-formalism [5] to construct the amplitudes. This formalism is based on the Schwinger-Dyson method to recursively define one-particle off-shell Greens functions, which are then numerically evaluated through a specific representation of their ingredients. This approach significantly tames the factorial growth of the number of terms to be calculated with the number of final state particles. In `Alpgen` a huge number of processes at hadron colliders is implemented ready to use, the amplitudes are supplemented with suitable, predefined phase space mappings. The `HELAC/PHEGAS` package [6] also employs the Schwinger-Dyson method, however, in a slightly different fashion. The phase space mappings are constructed automatically after Feynman diagram-like topologies underlying

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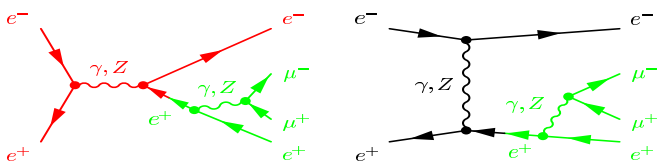

Figure 1. Common parts of the amplitudes (in green) can be factored out, reducing the number of complex multiplications, leading to "super-amplitudes".

$e^+e^- \to$	Feynman diagrams	"Super-amplitudes"
e^+e^-	4	4
$e^+e^-\mu^+\mu^-$	50	10
$e^+e^-e^+e^-$	144	9
$e^+e^-e^+e^-\mu^+\mu^-$	3690	261
$e^+e^-e^+e^-e^+e^-$	13896	323

Table 1. Effect of factoring out common parts of the amplitudes, leading to "super-amplitudes".

the amplitudes have been defined.

In this talk, however, the focus will be on `AMEGIC++` [7] which constructs Feynman diagrams and helicity amplitudes in the fashion of [8] In order to reduce the factorial growth, symbolical manipulations are performed, cf. Fig. 1, which significantly limit the number of terms to be evaluated, see also Table 1. The helicity method has been extended to spin-2 particles allowing `AMEGIC++` to include some models featuring graviton resonances [9]. The phase space mappings are generated automatically from the Feynman diagrams. The integration is performed using standard multi-channel methods [10]. `AMEGIC++` has been tested for a plethora of processes. For e^+e^- colliders, there is an ongoing study in the framework of the ECFA-DESY workshop to validate such tools for six-body final states; results of such a comparison of `AMEGIC++` with `HELAC/PHEGAS` [11] are presented in the left panel of Table 2 and in its right panel, relative deviations are displayed. Obviously the errors are distributed statistically, hence the results of the two codes are in perfect agreement. In the framework of the MC4LHC workshop [12] in a similar fashion, different programs for the calculation of cross sections in proton-proton collisions have been compared; exemplary results can be found in Table 3. Furthermore, some results for production cross sections of exotic particles in the framework of supersymmetric extensions of the Standard model and of models for extra dimensions are presented in Figs 2. In the left plot the cross section for the production of up-type squarks by laser-backscattered photons (with corresponding Compton spectrum) at an e^+e^--collider is depicted, displaying also the contributions due to the hadronic structure of the photons. In the right panel of this figure, the production cross section for graviton resonances in the ADD model [13], also at an e^+e^--collider, is exhibited in dependence on the c.m.-energy of the incoming e^+e^--pair.

It should be noted that `AMEGIC++` is an integral part of a full-fledged event generator called `SHERPA` [14]. The connection to its internal parton shower [15] is achieved

final state	QCD	AMEGIC++ [fb]	HELAC [fb]
$b\bar{b}u\bar{d}d\bar{u}$	yes	49.74(21)	50.20(13)
	no	49.42(44)	50.55(26)
$b\bar{b}u\bar{u}gg$	–	9.11(13)	8.832(43)
$b\bar{b}gggg$	–	24.09(18)	23.80(17)
$b\bar{b}u\bar{d}e^-\bar{\nu}_e$	yes	17.486(66)	17.492(41)
	no	17.366(68)	17.353(31)
$b\bar{b}e^+\nu_e e^-\bar{\nu}_e$	–	5.954(55)	5.963(11)
$b\bar{b}e^+\nu_e\mu^-\bar{\nu}_\mu$	–	5.865(24)	5.868(10)
$b\bar{b}\mu^+\nu_\mu\mu^-\bar{\nu}_\mu$	–	5.840(30)	5.839(12)

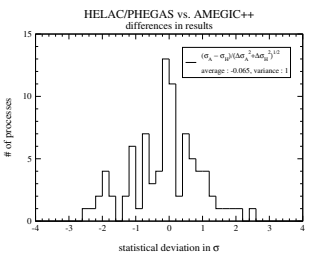

Table 2. Some cross sections for processes with six-body final states in e^+e^- collisions (left panel). In the right figure, relative deviations of all cross sections calculated independently by AMEGIC++ and HELAC/PHEGAS are shown, proving that the results of the two codes coincide.

X-sects (pb)	Number of jets					
$e^-\bar{\nu}_e$ + n QCD jets	0	1	2	3	4	5
Alpgen	3904(6)	1013(2)	364(2)	136(1)	53.6(6)	21.6(2)
CompHEP	3947.4(3)	1022.4(5)	364.4(4)			
MadEvent	3902(5)	1012(2)	361(1)	135.5(3)	53.6(2)	
Amegic++/Sherpa	3908(3)	1011(2)	362(1)	137.5(5)	54(1)	

X-sects (pb)	Number of jets				
$e^-\bar{\nu}_e$ + bb	0	1	2	3	4
Alpgen	9.34(4)	9.85(6)	6.82(6)	4.18(7)	2.39(5)
CompHEP	9.415(5)	9.91(2)			
MadEvent	9.32(3)	9.74(1)	6.80(2)		
Amegic++/Sherpa	9.37(1)	9.86(2)	6.87(5)		

Table 3. Compilation of results for cross sections of some selected processes at the LHC.

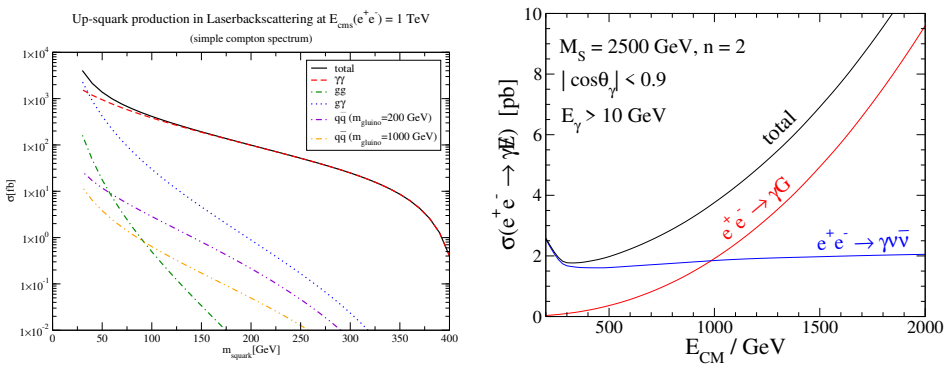

Figure 2. Production of squarks at a photon collider (by laser-backscattering off an e^+e^- collider) including the effect of the photons hadronic structure (left plot). In the right plot the production cross section for real ADD-gravitons is shown, in dependence of the c.m.-energy of the colliding e^+e^--pair.

according to the merging prescription of [16] rendering it an unique tool. It is anticipated that SHERPA will also contain a new version of the cluster hadronisation, presented in [17]. Taken together, AMEGIC++ within this framework represents a powerful tool for studying various relevant production processes within and beyond the Standard Model and for physics simulations at current and future colliders.

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