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MadGraph/MadEvent 4

SUSY, new models, matching and more!

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Overview of talk

- MadGraph and MadEvent – what are they?
- What's new in MG/ME v. 4?
- How to generate processes and events online
- New models in MG/ME v. 4: MSSM, 2HDM, HEFT
- Implement your own model in MG/ME
- Matching of matrix elements and parton showers
- Ongoing developments

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MadGraph: What is it ?

- By T. Stelzer and W.F. Long [Phys. Commun. 81 (1994) 357-371]
- Given a process (specified in simple syntax), produces Feynman diagrams and a Fortran subroutine that computes the squared amplitudes by calls to the HELAS helicity amplitude library
- Reads particles.dat and interactions.dat files to know the particle content and interaction vertices of the model
- Produces info on the structure of Feynman diagrams to help phase-space integration
- Sums over protons (initial state), jets and leptons (final state)
- Manages processes with up to 7-8 final states particles

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MadEvent: What is it ?

- By F. Maltoni and T. Stelzer [JHEP 0302:027, 2003]
- Multi-purpose event generator
- Uses as input the process-dependent information (matrix elements and phase space mappings) produced by MadGraph
- The only event generator to exploit the powerful and general phase-space integration method named Single-Diagram-Enhanced multichannel integration:
  - ➔ Uses the squared diagrams as basis for multi-channel integration
  - ➔ Interference terms cannot introduce new poles

$$f_i = \frac{|A_{\rm tot}|^2}{\sum_i |A_i|^2} |A_i|^2$$

- Trivially parallelizable technique makes cluster use efficient

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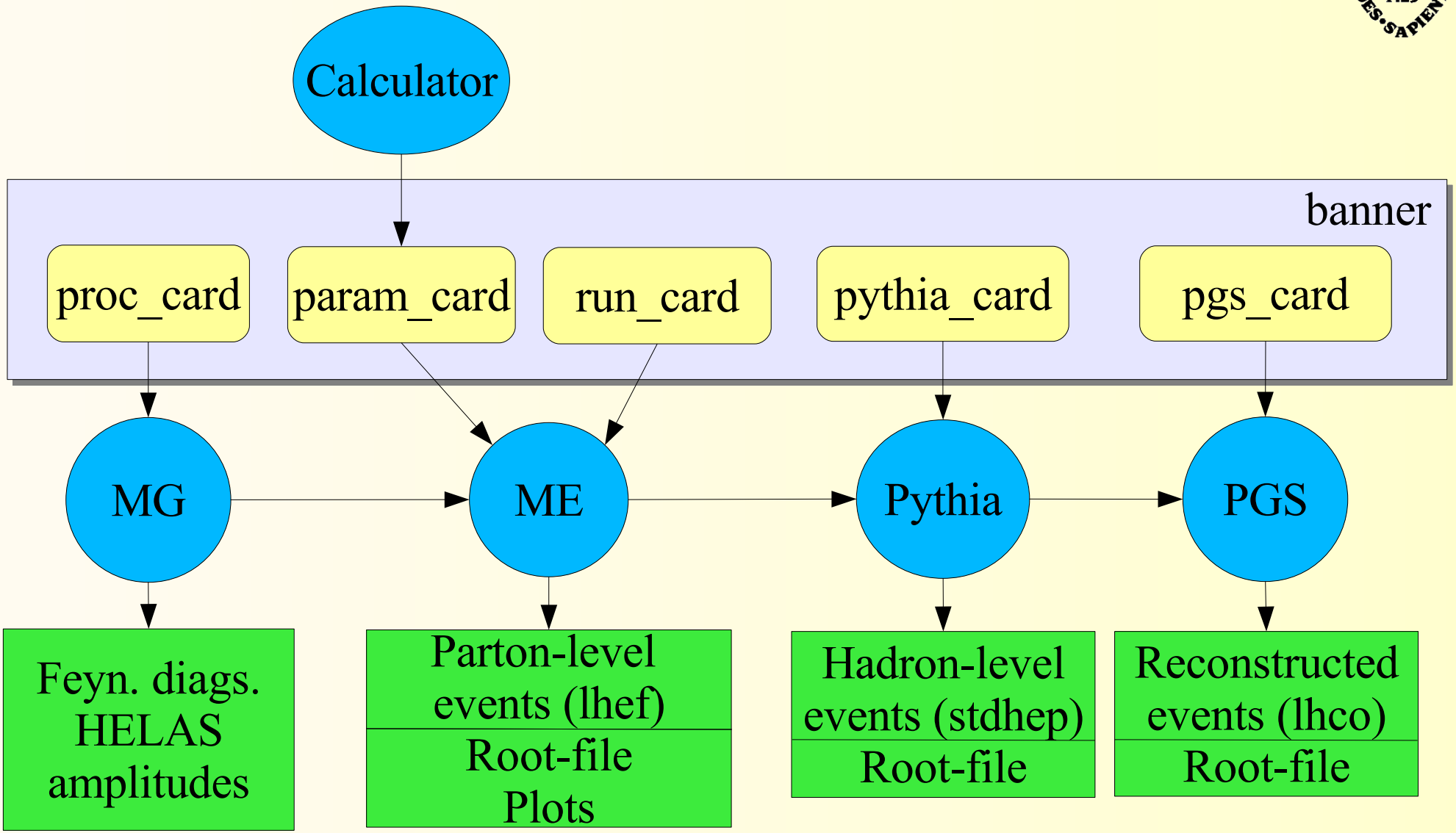
What is new in MG/ME 4?

- Web-oriented, modular software structure
- New models
  - SUSY, 2HDM and Higgs EFT
  - Framework for easy user model implementation
- Multiple/inclusive processes in single run
- Pythia (hadronization) and PGS (detector sim.) packages for complete event simulation on-line
  - Root files created at all stages (parton, hadron, detector)
- Three dedicated clusters (UIUC, UCL and Rome)
- Private process database for each user
- Matching with Pythia parton showers (still beta)

SLAC MG/ME 4 generation structure



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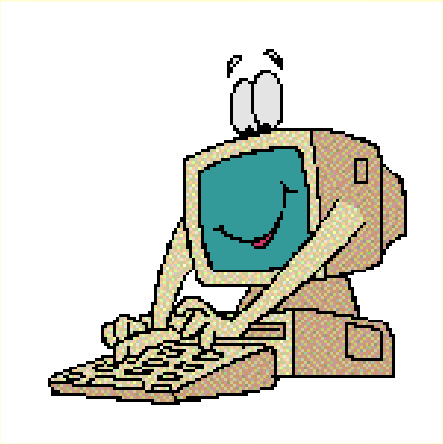
MG/ME new structure

- Whole chain on web or downloaded and run locally
- Cards filled on the web or uploaded (reusable)
- Modular structure – easy to interface to other applications / add new functionality

So what about using it?
Let me show you!



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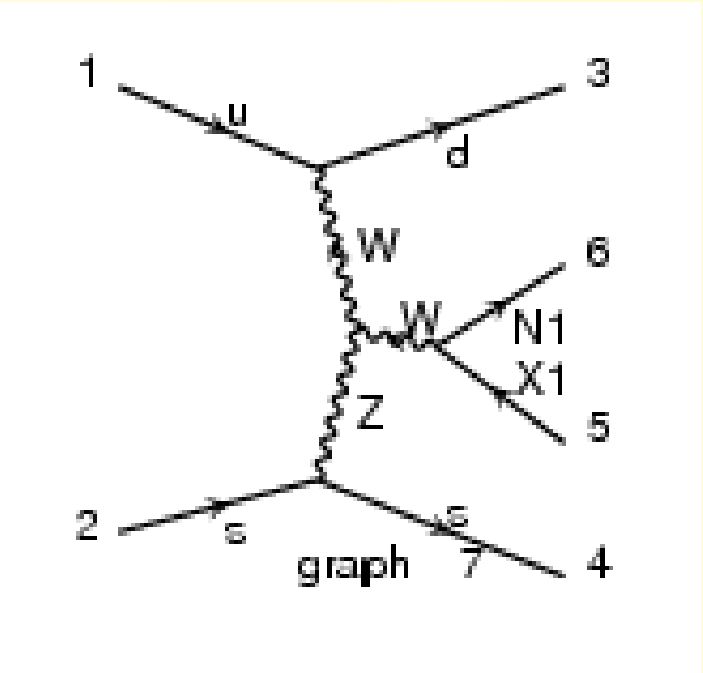
New models: MSSM

Hagiwara, Plehn, Rainwater, Stelzer + Alwall

- CP and R-parity conserving MSSM
- Sfermion mixing and Yukawa couplings for 3rd gen.
- Uses SUSY Les Houches input files – independent of SUSY breaking scheme
- Detailed comparison of cross sections between SMadGraph, Omega and Amegic++ (hep-ph/0512260)
- Input files for the 10 SPS points available



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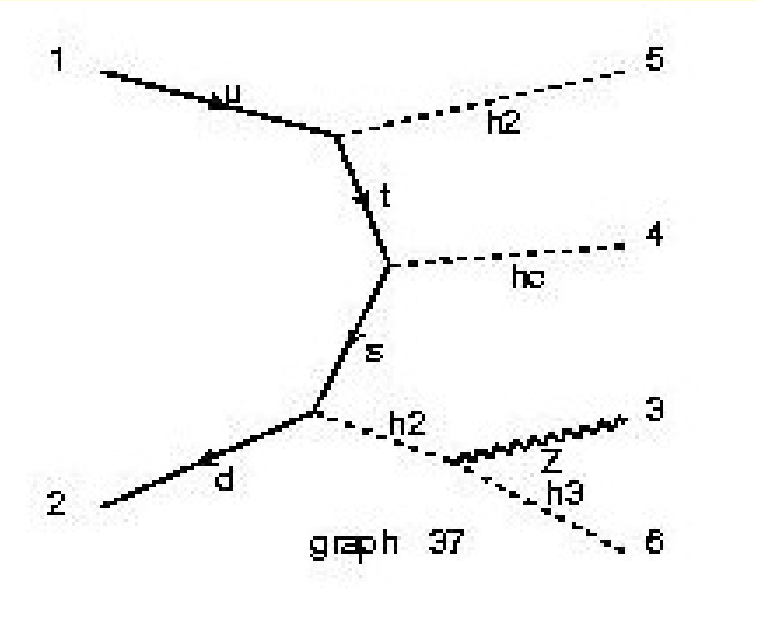
General 2HDM

de Visscher, Herquet

- Completely general 2HDM, with FCNC and CP violation
- New tree-level calculator (Herquet) with a web interface, TwoHiggsCalc, to generate the param_card for MadEvent
- Generic basis or Higgs basis, intensive use of recent basis invariance techniques (e.g. hep-ph/0504050)
- Tested in the SM & MSSM limit
- Sample files for various cases
- Simplified version without FCNC and off-diag. CKM elements



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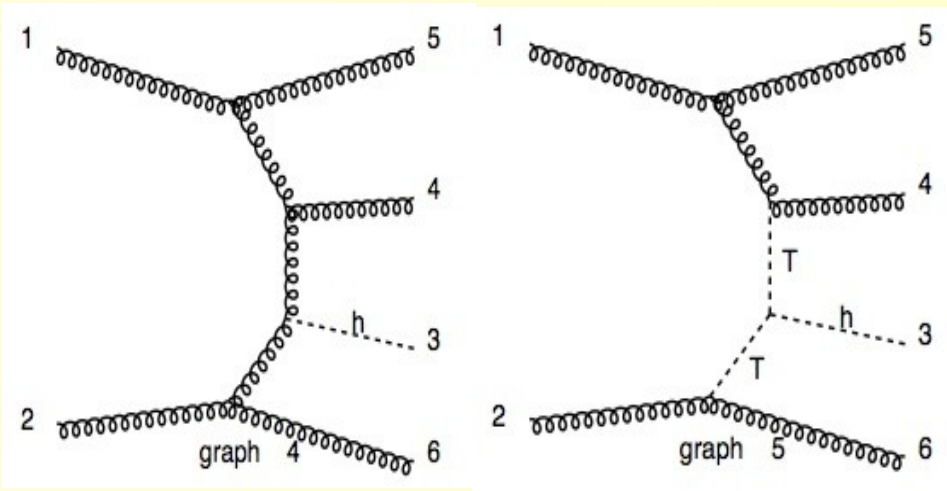
Higgs EFT

Frederix

- Effective couplings of Higgs to gluons
  - Uses effective non-propagating tensor particle to allow Higgs couplings to more than 3 gluons
  - Several new HELAS subroutines
  - Works for scalar and pseudo-scalar neutral Higgs bosons



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User model generation

de Vissher

- General framework for user-defined models
  - User only needs to introduce
    - New particles
    - New interactions
    - New parameters (read from param_card.dat)
    - Expressions for the new couplings

    A Perl script takes care of generating all files needed by MadEvent!
  - Easy to look at interesting subspaces of larger models
  - Used at Stanford, Berkeley, KEK, UCL, ...

User model generation (cont.)

particles.dat

```
#Name anti_Name  Spin    Linetype Mass Width Color Label Model
#xxx   xxxx      SFV      WSDC     str  str   STO    str  PDG code

#MODEL EXTENSION
tp       tp~      F        S      TPMASS TPWID  T    TP    8
zp       zp       V        W      ZPMASS ZPWID  S    ZP   32
# END
```

interactions.dat

```
#   USRVertex
tp tp g  GG     QCD
tp t  zp GTPZP QED
t  tp zp GTPZP QED
```

couplings.f

```
c************************************
c UserMode couplings
c************************************

      GTPZP(1)=dcmplx(ee*param1,Zero)
      GTPZP(2)=dcmplx(ee*param1,Zero)
```

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Matching of ME and Pythia

Alwall-Höche

Matching of jet-production by matrix elements and parton showers

- Combine ME parton-level jet production with parton showers without double-counting
- Very important for W/Z+jets backgrounds at hadron colliders, but also to understand jet structure of signals (e.g. when using jet veto)
- Make signal "parton shower-like" by
  - Clustering by k_T algorithm
  - Reweighting of α_s with scale in each vertex and suppression by Sudakov to account for non-emission

Matching of ME and Pythia

With MadEvent:

- CKKW-like with Sherpa showers (Höche-Alwall)
  (analytic Sudakovs, veto on showers above cutoff scale)
- MLM-like with Pythia showers (Alwall)
  (Sudakov suppression from parton showers by rejecting event with too hard shower emissions)
  - Alpgen style: cone jet clustering and matching
  - "CKKW" style: k_T jet clustering and matching
- Comparison of pp → W+jets with Alpgen, Ariadne, Helac and Sherpa underway
- Ongoing work with SCET in MadEvent+Pythia (Schwartz)

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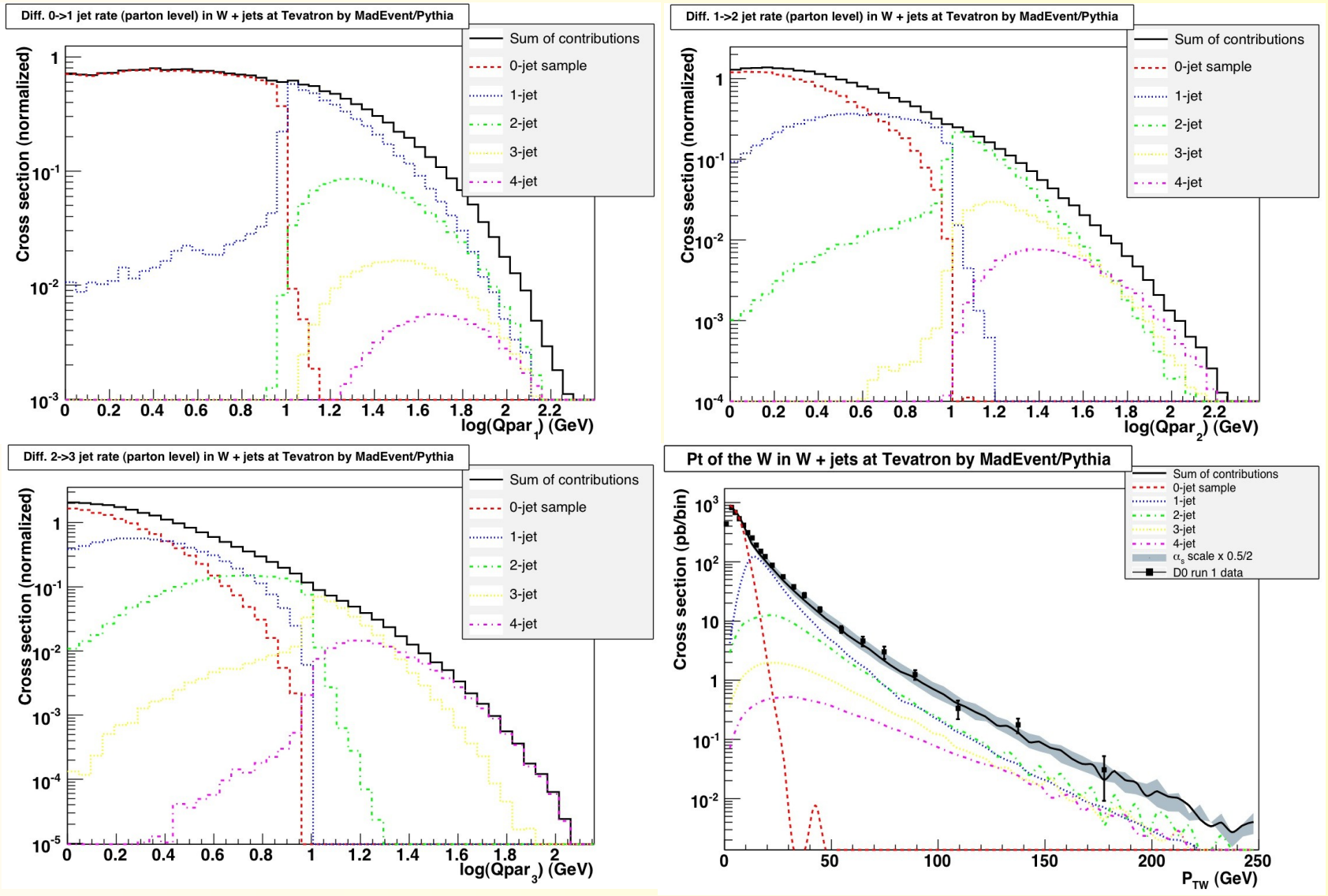
Matching of ME and PS



Differential jet rate for $0 \to 1$, $1 \to 2$, $2 \to 3$ jets and W pt in $p\bar{p} \to W+jets$

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Work in progress

- More complete models: UED (Alves) Under testing
- Specification of complete decay chains (Stelzer-Alwall) Under testing
  - Allows for large number of final state particles
  - Keeps full spin correlations (still amplitude-squared!)
- Generic width calculator and decay tool for new models (Reece) Under testing
- Interfaces to CMS and Atlas software suites
- New HELAS routines for effective vertices (Hagiwara)
- SCET for alternative ME-PS matching (Schwartz)
- Inclusion of MadEvent in MARMOSET (Alwall-Thaler)

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Summary

- MadGraph/MadEvent 4 – an integrated tool to generate any process, signal or background!
- Several new models (MSSM, 2HDM, HEFT), and easy to implement your own model!
- From model to detector in one run – as easy locally as on the web!
- Fast – thanks to efficient and cluster-oriented generation
- Clusters found at:
  - UCL: http://madgraph.phys.ucl.ac.be/
  - Rome: http://madgraph.roma2.infn.it/
  - UIUC: http://madgraph.hep.uiuc.edu/
- We are continuously improving MG/ME

Try it out – we are grateful for any feedback!

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Backup slides

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Calculators

- SLHA-like model parameter input format (param_card)
- Can be used by other event generators (e.g. Pythia)
- Need to calculate dependent parameters (e.g. weak sector) and decay widths (to get branching ratios right)
- MSSM
  - Takes SLHA files from any SUSY spectrum generator
- 2HDM
  - Enter potential parameters and Yukawa couplings
  - Choice between Higgs basis and general basis
  - Calculates masses, mixings, couplings and decay widths

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2HDM Calculator

Higgs Basis (more info)

$$V = \mu_1 H_1^\dagger H_1 + \mu_2 H_2^\dagger H_2 - \left(\mu_3 H_1^\dagger H_2 + \text{h.c.}\right) + \lambda_1 \left(H_1^\dagger H_1\right)^2 + \lambda_2 \left(H_2^\dagger H_2\right)^2 + \lambda_3 \left(H_1^\dagger H_1\right)\left(H_2^\dagger H_2\right) + \lambda_4 \left(H_1^\dagger H_2\right)\left(H_2^\dagger H_1\right) + \left[\left(\lambda_5 H_1^\dagger H_2 + \lambda_6 H_1^\dagger H_1 + \lambda_7 H_2^\dagger H_2\right)\left(H_1^\dagger H_2\right) + \text{h.c.}\right]$$

lambda1	1
lambda2	1
lambda3	1
lambda4	0
lambda5	0
Norm of lambda6	0
Norm of lambda7	0
Phase of lambda6	0
Phase of lambda7	0
Mass of Charged Higgs (GeV)	300

Generic Basis (more info)

$$V = \mu_1 \phi_1^\dagger \phi_1 + \mu_2 \phi_2^\dagger \phi_2 - \left(\mu_3 \phi_1^\dagger \phi_2 + \text{h.c.}\right) + \frac{1}{2}\lambda_1 \left(\phi_1^\dagger \phi_1\right)^2 + \frac{1}{2}\lambda_2 \left(\phi_2^\dagger \phi_2\right)^2 + \lambda_3 \left(\phi_1^\dagger \phi_1\right)\left(\phi_2^\dagger \phi_2\right) + \lambda_4 \left(\phi_1^\dagger \phi_2\right)\left(\phi_2^\dagger \phi_1\right) + \left[\left(\frac{1}{2}\lambda_5 \phi_1^\dagger \phi_2 + \lambda_6 \phi_1^\dagger \phi_1 + \lambda_7 \phi_2^\dagger \phi_2\right)\left(\phi_1^\dagger \phi_2\right) + \text{h.c.}\right]$$

Tan(beta)=v2/v1	1
Phase of v2	0
Norm of mu3	0
lambda1	1
lambda2	1
lambda3	1
lambda4	0
Norm of lambda5	0
Norm of lambda6	0
Norm of lambda7	0
Phase of lambda5	0
Phase of lambda6	0
Phase of lambda7	0

Yukawa parameters

Higgs basis (more info)

$$\mathcal{L}_Y = \frac{\overline{Q_L}\sqrt{2}}{v}\left[(M_d H_1 + Y_d H_2) d_R + (M_u \tilde{H}_1 + Y_u \tilde{H}_2) u_R\right] + \frac{\overline{E_L}\sqrt{2}}{v}\left[(M_e H_1 + Y_e H_2) e_R\right]$$

Generic Basis (more info)

$$\mathcal{L}_Y = \frac{\overline{Q_L}\sqrt{2}}{v}\left[(\Delta_d \phi_1 + \Gamma_d \phi_2) d_R + (\Delta_u \tilde{\phi}_1 + \Gamma_u \tilde{\phi}_2) u_R\right] + \frac{\overline{E_L}\sqrt{2}}{v}\left[(\Delta_e \phi_1 + \Gamma_e \phi_2) e_R\right]$$

Yukawa couplings to the second Higgs doublet of the down type quarks (norm and phase)

Y1D/G1D	0	0	Y1S/G1S	0	0	Y1B/G1B	0	0
Y2D/G2D	0	0	Y2S/G2S	0	0	Y2B/G2B	0	0
Y3D/G3D	0	0	Y3S/G3S	0	0	Y3B/G3B	0	0

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The cards

- The proc_card:

```
pp > W+jjj
QCD=3
QED=1
sm
```

  - Defines the process(es), order in couplings and model.
- The param_card:

```
Block MASS
        4      1.40000000E+00
```

  - Defines the model parameters (masses, widths and couplings) in SUSY Les Houches-like format
- The run_card:

```
 1 = lpp1 !  beam 1 type
 1 = lpp2 !  beam 2 type
7000 = ebeam1 ! beam 1 energy
7000 = ebeam2 ! beam 2 energy
```

  - Defines the collider, cuts, parton densities and scales
- The pythia_card and pgs_card determine the operation of Pythia and PGS.

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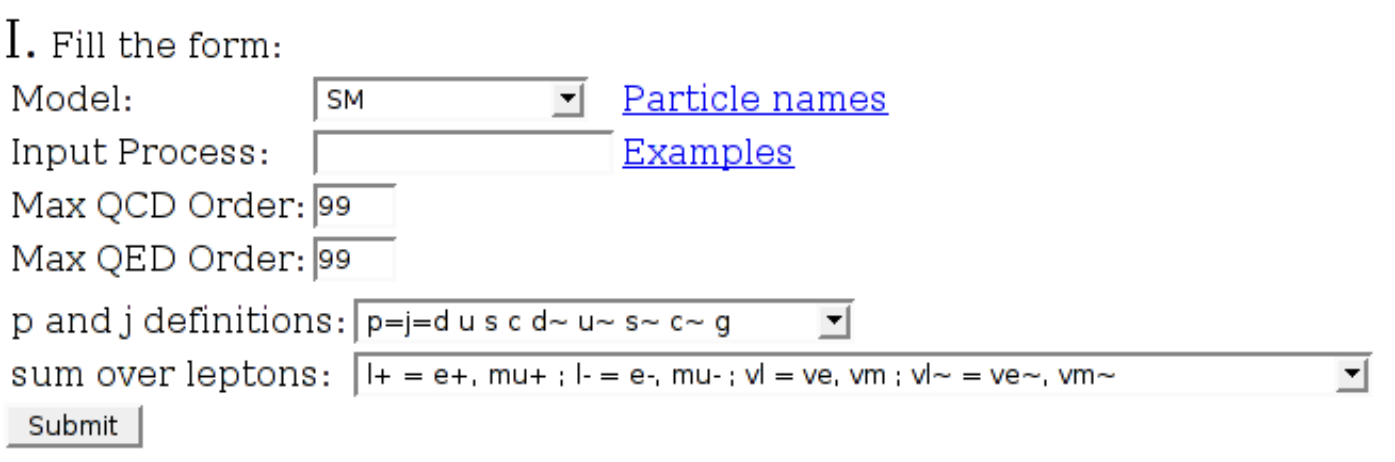
MG/ME step by step

- Surf on one of our cluster (register, it's free!):
  - http://madgraph.phys.ucl.ac.be
  - http://madgraph.hep.uiuc.edu (still old version)
  - http://madgraph.roma2.infn.it
- Select a model, input a process and define max QCD/QED order and p,j,l definitions (proc_card)



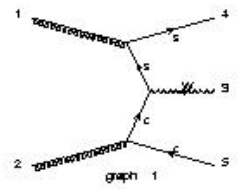
MG/ME step by step

- MadGraph returns a list of subprocesses with related Feynman diagrams and HELAS amplitudes
- Either you generate events online on our clusters or you download the stand-alone code

MadEvent Card for pp>w+jj

Created: Mon Jun 19 16:15:24 CEST 2006

Process: pp>w+jj
QCD=99
QED=99
Model: sm



Links	Status
Process Information	Generation Complete
Code Download	Available
On-line Event Generation	Available (access restricted)
Results and Event Database	No runs available

Notes:

Last Update: Mon Jun 19 16:15:26 CEST 2006

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MG/ME step by step

- 4 “cards” (txt files) are needed for events generation
  - param_card : LHA compliant file with values for all the model parameters, should ALWAYS be produced by a “Calculator”
  - run_card : Collider parameters, # events, scales, cuts, ...
  - pythia_card : Pythia configuration (showering ...)
  - pgs_card : PGS configuration (detector type, ...)
- All these cards can be filled online (with web form) or by manually editing text files

Cards for input parameters			
Model	Run	Pythia	PGS
param_card.dat	run_card.dat	pythia_card.dat	pgs_card.dat

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MG/ME step by step

- During event generation, MadEvent returns the current status of the computation

Run Name	Cards	Status	Results	Jobs on the cluster			
				Queued	Running	Done	Total
Web	param_card run_card	Running 2nd Refine	5669.739± 35.407(pb)	3	7	0	12

- When the run is finished, a full detailed set of output is available

Links	Events	Tag	Run	Collider	Cross section (pb)	Events
results plots banner	parton-level rootfile hadron-level (Pythia) reconstructed objects (PGS)	fermi	run1	p p 7000 x 7000 GeV	.57088E+04	10004

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MG/ME step by step

Graph	Cross Sect(pb)	Error(pb)	Events (K)	Eff	Unwgt	Luminosity
Sum	5700.109	12.197	3536	4.0		
P_gu_w+dg	1582.500	7.536	321	2.7		2.47
P_ug_w+dg	1580.600	7.688	323	2.8		2.74
P_dxg_w+uxg	631.410	3.878	46	1.3		2.46
P_gdx_w+uxg	630.880	2.927	129	1.7		7.07
P_udx_w+gg	152.470	0.867	47	1.2		19.10
P_dxu_w+gg	150.450	1.261	32	1.5		2.21
P_gg_w+uxd	145.470	0.688	48	1.0		16.90
P_gg_w+scx	145.440	0.897	30	1.1		14.40
P_uu_w+ud	95.099	0.510	69	1.4		24.20