Review dei generatori ad elementi di matrice tree-level

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From Tevatron to LHC

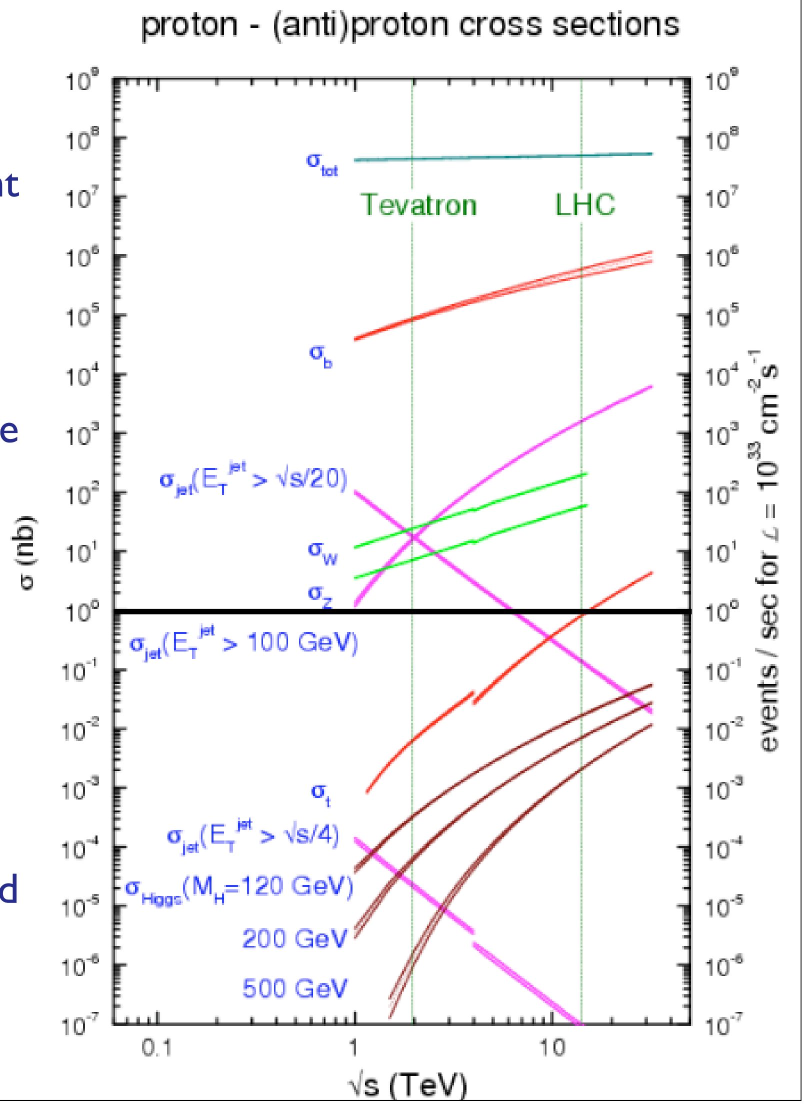
- Yields increased by order of magnitudes wrt Tevatron.
- Events with vectors bosons, tops and heavy and light jets with rates >1 Hz.
- Higgs physics down order of magnitudes.
- Need to understand QCD backgrounds well!

QCD factorization theorem for short-distance inclusive processes:

$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_a(x_1, \mu_F^2) f_b(x_2, \mu_F^2) \times \hat{\sigma}_{ab\to X}(x_1, x_2, \alpha_S(\mu_R^2), \frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2})$$

Two ingredients necessary:

1. Parton Distribution functions (from exp).
2. Short distance coefficients as an expansion in α_S and possibly with resum. of large logs (from th).



How to improve our predictions?

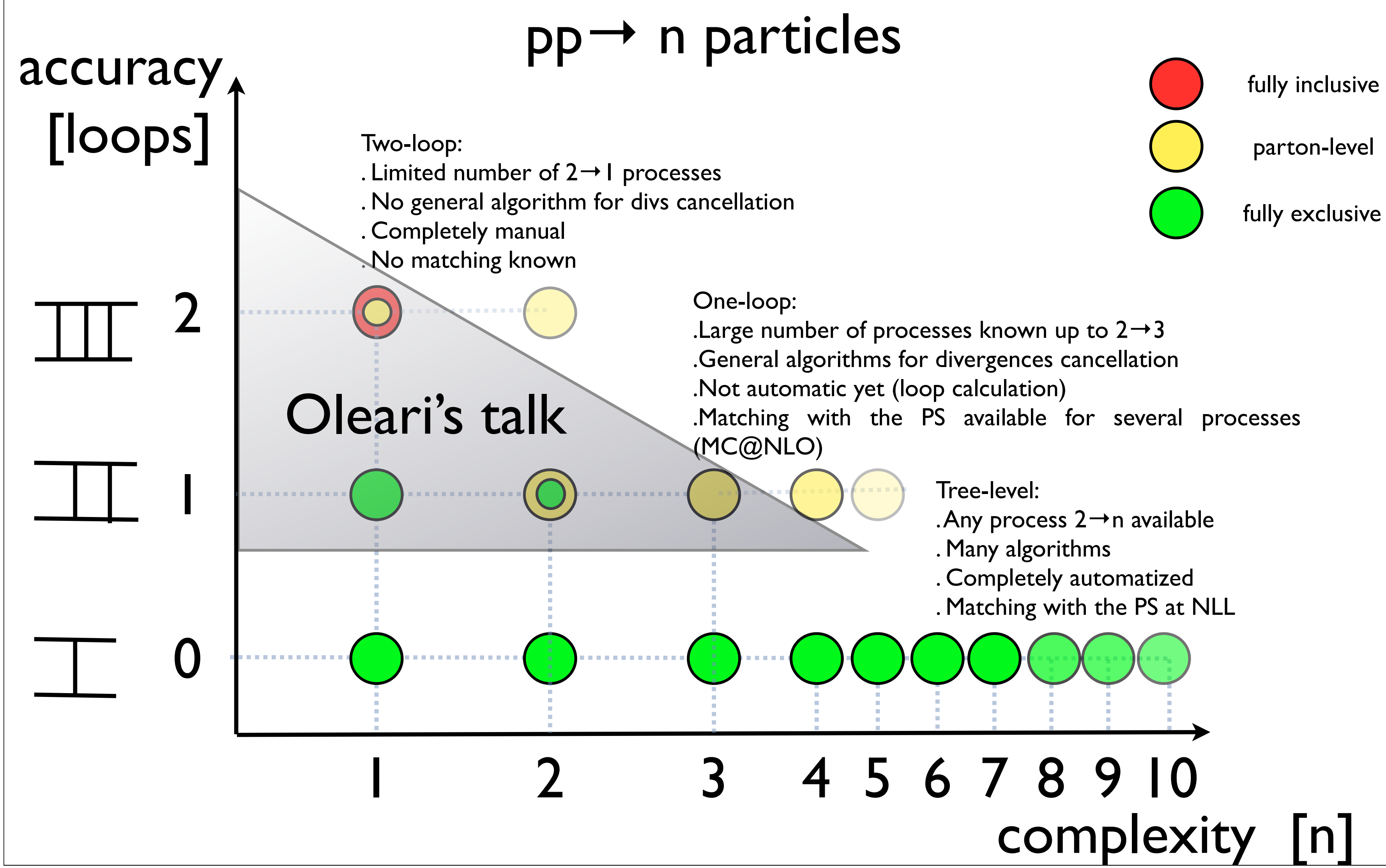
Standard ways:

- Include higher order terms in our fixed-order calculations (LO→NLO→NNLO...)
  $\Rightarrow \hat{\sigma}_{ab\to X} = \sigma_0 + \alpha_S \sigma_1 + \alpha_S^2 \sigma_2 + \ldots$
- Describe final states with high multiplicities using parton showers.

New trend:

Match fixed-order calculations and parton showers to obtain the most accurate predictions in a detector simulation friendly way

Status



pp→ n particles
accuracy [loops]
fully inclusive
parton-level
fully exclusive
Two-loop:
. Limited number of 2→1 processes
. No general algorithm for divs cancellation
. Completely manual
. No matching known
2
Oleari's talk
One-loop:
.Large number of processes known up to 2→3
.General algorithms for divergences cancellation
.Not automatic yet (loop calculation)
.Matching with the PS available for several processes (MC@NLO)
1
Tree-level:
.Any process 2→n available
. Many algorithms
. Completely automatized
. Matching with the PS at NLL
0
1 2 3 4 5 6 7 8 9 10
complexity [n]

Available Tools: references

- Les Houches Guide Book to MC generators for Hadron Collider Physics, hep-ph/0403045
- Links and descriptions of the codes at http://www.ippp.dur.ac.uk/HEPCODE/

Note One: In this talk I will give only a very partial and (italian) biased presentation of the available tools!

Note Two: I'll assume we have learned what a parton shower is this morning.

Outline

- What's a matrix-element based generator?
- Matching matrix elements with parton showers
- ME generators for new physics
- Conclusions & Discussion

What's a matrix-element based generator?

$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_a(x_1, \mu_F^2) f_b(x_2, \mu_F^2) \times \hat{\sigma}_{ab\to X}(x_1, x_2, \alpha_S(\mu_R^2), \frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2})$$

- Matrix element calculators provide our first estimation of rates for inclusive final states.

- Extra radiation is included: it is described by the PDF's in the initial state and by the definition of a final state parton, which at LO represents all possible final state evolutions.

- Due to the above approximations a cross section at LO can strongly depend on the factorization and renormalization scales.

- Any tree-level calculation for a final state F can be promoted to the exclusive F + X through a shower. However, a naive sum of final states with different jet multiplicities would lead to double counting.

The technical challenges

How do we calculate a LO cross section for 3 jets at the LHC?

I. Identify all subprocesses (gg→ggg, qg→qgg....) in

$$\sigma(pp \to 3j) = \sum_{ijk} \int f_i(x_1) f_j(x_2) \hat{\sigma}(ij \to k_1 k_2 k_3)$$

easy

II. For each one, calculate the amplitude:

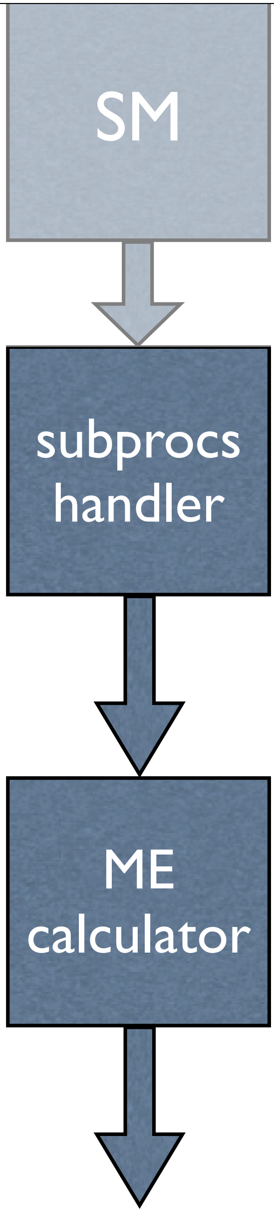
$$\mathcal{A}(\{p\},\{h\},\{c\}) = \sum_i D_i$$

difficult

III. Square the amplitude, sum over spins & color, integrate over the phase space (D ~ 3n)

$$\hat{\sigma} = \frac{1}{2\hat{s}} \int d\Phi_p \sum_{h,c} |\mathcal{A}|^2$$

very hard



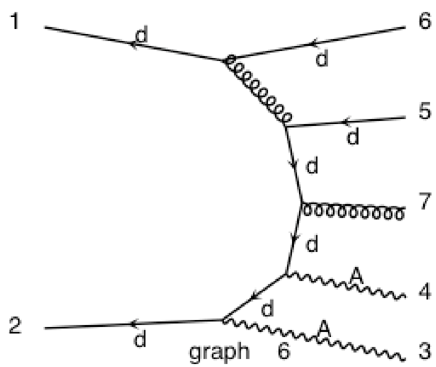
General structure

Includes all possible subprocess leading to a given multi-jet final state automatically or manually (done once for all)

d~ d -> a a u u~ g
d~ d -> a a c c~ g
s~ s -> a a u u~ g
s~ s -> a a c c~ g

<u>“Automatically”</u> generates a code to calculate |M|^2 for arbitrary processes with many partons in the final state.

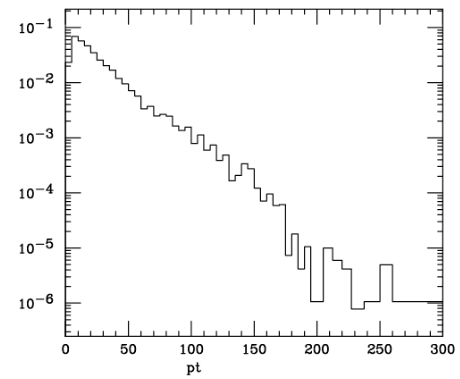
Most use Feynman diagrams w/ tricks to reduce the factorial growth, others have recursive relations to reduce the complexity to exponential. ☺



General structure

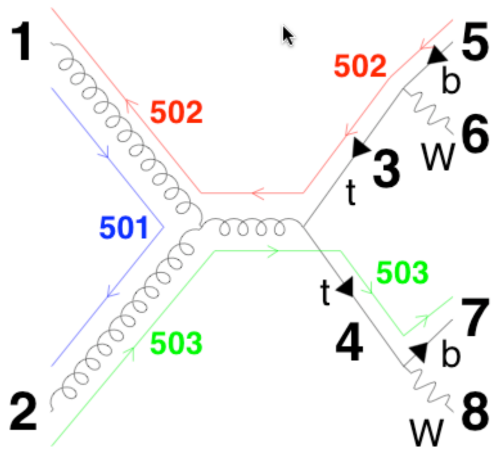
x section

Integrate the matrix element over the phase space using a multi-channel technique and using parton-level cuts.

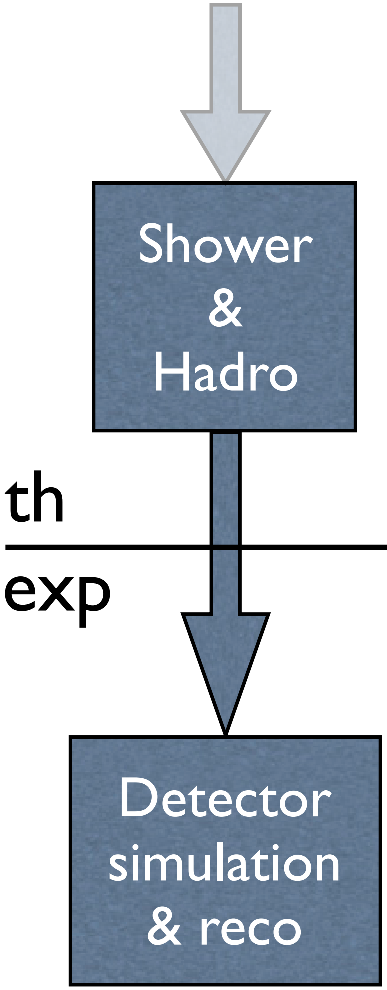


parton-level events

Events are obtained by unweighting. These are at the parton-level. Information on particle id, momenta, spin, color is given in the Les Houches format.

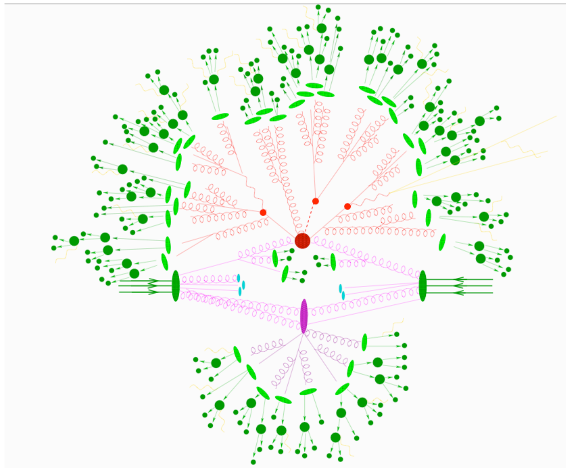


General structure

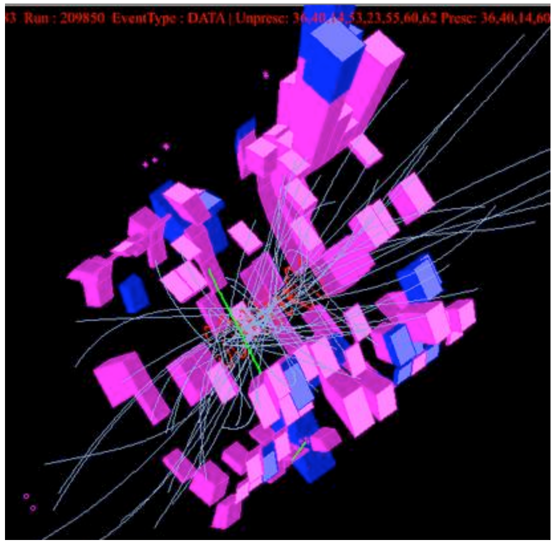


Events in the LH format are passed to the showering and hadronization⇒

high multiplicity hadron-level events



Events in stdhep format are passed through fast or full simulation, and physical objects (leptons, photons, jet, b-jets, taus) are reconstructed.

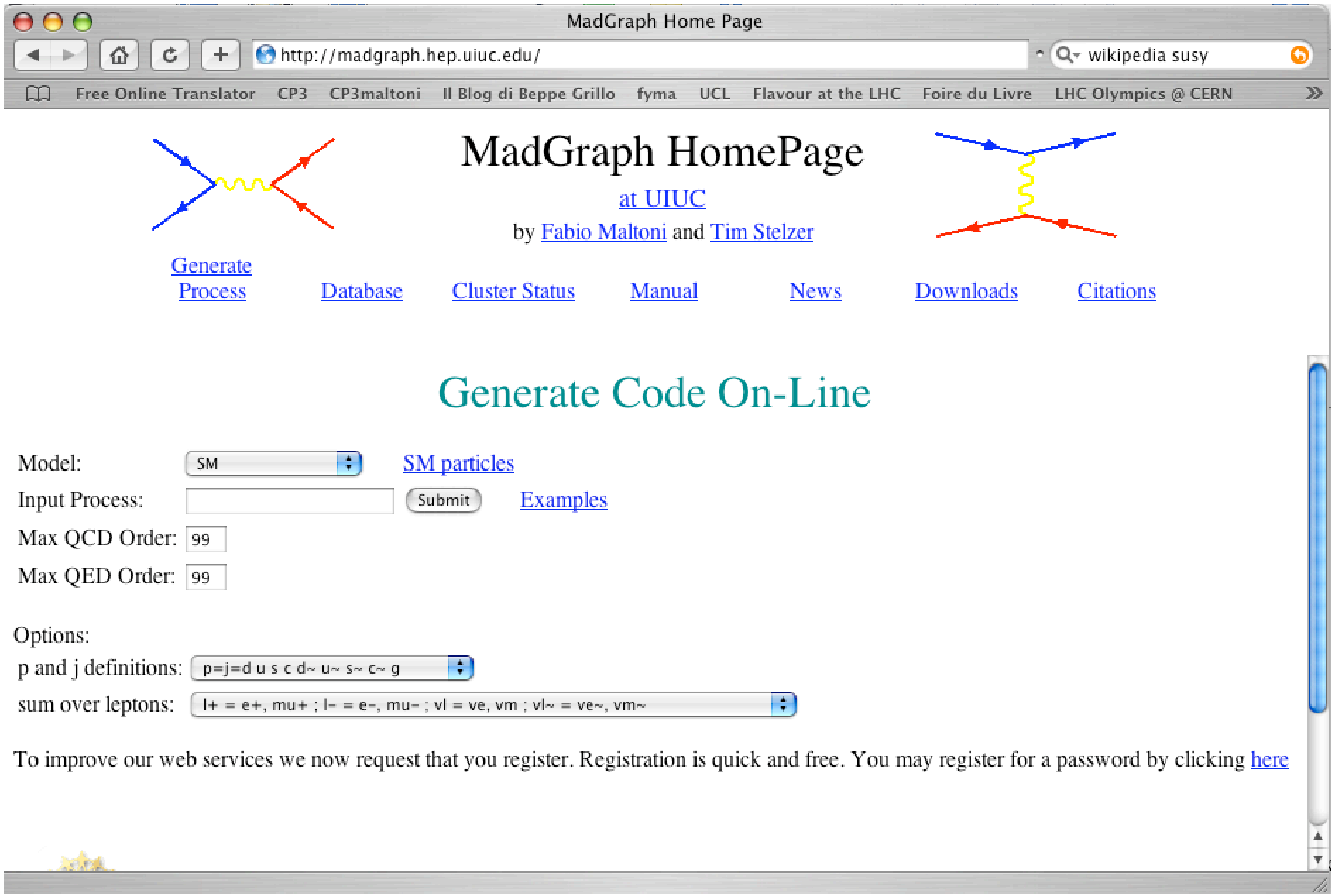


Types of SM codes available

Several codes exist for the SM, built using different philosophies

TYPE	Characteristics	Examples
"One" Process	Highly dedicated, manual work, optimized, specific problems addressed	VecBos TopRex
		Phase
Library	Semi automatic, modular structure, author-driven efficient	Gr@PPA
		AlpGen
Multi-purpose	High automatization, user-driven, huge versatility	Sherpa CompHep MadGraph Whizard

Madgraph


MadGraph Home Page
http://madgraph.hep.uiuc.edu/
wikipedia susy
Free Online Translator
CP3
CP3maltoni
Il Blog di Beppe Grillo
fyma
UCL
Flavour at the LHC
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MadGraph HomePage
at UIUC
by Fabio Maltoni and Tim Stelzer
Generate Process
Database
Cluster Status
Manual
News
Downloads
Citations
Generate Code On-Line
Model:
SM
SM particles
Input Process:
Submit
Examples
Max QCD Order:
99
Max QED Order:
99
Options:
p and j definitions:
p=j=d u s c d~ u~ s~ c~ g
sum over leptons:
l+ = e+, mu+ ; l- = e-, mu- ; vl = ve, vm ; vl~ = ve~, vm~
To improve our web services we now request that you register. Registration is quick and free. You may register for a password by clicking here

Madgraph

[F.M., Stelzer]
[Hagiwara, Plehn, Rainwater]
[Alwall, de Visscher, Frederix, Herquet]

- The new web generation:
  - User inputs model/parameters/cuts.
  - Code runs in parallel on modest farms.
  - Returns cross section, plots, parton-level events.
  - News: BSM physics (MSSM, 2HDM,...) + returns Pythia and PGS events!
- Advantages:
  - Reduces overhead to getting results
  - Events can easily be shared/stored
  - Quick response to user requests and to new ideas!

http://madgraph.hep.uiuc.edu U.S.
http://madgraph.roma2.infn.it Italian
http://madgraph.phys.ucl.ac.be Belgian (restricted)

Alpgen

[Mangano,Moretti,Piccinini, Pittau, Polosa]

Up to now available processes (in `ALPGEN v2.0`)

- $(W \to f\bar{f}') + N$ jets, $N \leq 6$, $f = l, q$
- $(Z/\gamma^* \to f\bar{f}) + N$ jets, $N \leq 6$, $f = l, \nu$
- $(W \to f\bar{f}')Q\bar{Q} + N$ jets, $(Q = b, t)$, $N \leq 4$, $f = l, q$
- $(Z/\gamma^* \to f\bar{f})Q\bar{Q} + N$ jets, $(Q = c, b, t)$, $N \leq 4$, $f = l, \nu$
- $(W \to f\bar{f}') + c + N$ jets, $N \leq 5$, $f = l, q$
- $n\ W + m\ Z + l\ H + N$ jets, $n + m + l \leq 8$, $N \leq 3$
- $Q\bar{Q} + N$ jets, $(Q = c, b, t)$, $N \leq 6$
- $Q\bar{Q}Q'\bar{Q}' + N$ jets, $(Q, Q' = c, b, t)$, $N \leq 4$
- $Q\bar{Q}H + N$ jets, $(Q = b, t)$, $N \leq 4$
- N jets, $N \leq 6$
- $N\ \gamma + N$ jets, $N \geq 1$, $N + M \leq 8$, $M \leq 6$
- $gg \to H + N$ jets $(m_t \to \infty)$
- single top

Features:

- Matrix-element based MC
- No Feynman diagrams
- Large library of processes (extendable)
- Optimized for multi-jet production
- ME+PS MLM-matching implemented

⇒Produces inclusive samples

http://home.cern.ch/mlm/alpgen

Aside: Complexity of QCD amplitudes

$$\mathcal{A}_n(g_1,\ldots,g_n) = g^{n-2} \sum_{\sigma\in S_{n-1}} \mathrm{Tr}(\lambda^{a_1}\lambda^{a_{\sigma_2}}\cdots\lambda^{a_{\sigma_n}})A_n(1,\sigma_2,\ldots,\sigma_n)$$

n	full Amp	partial Amp	BG
4	4	3	3
5	25	10	10
6	220	36	35
7	2485	133	70
8	34300	501	126
9	559405	1991	210
10	10525900	7335	330
11	224449225	28199	495
12	5348843500	108280	715
	$(2n)!$	3.8^n	n^4

Conclusion: twistors technique have not helped improving practical calculations yet!

- New twistor tree-level BCF relations perform WORSE than the "old" Berends-Giele recursive relations for the partial amplitudes. [Dinsdale, Wernick, Weinzierl, 2006]

- In any case the calculation through partial amplitudes is not as efficient as the direct calculation of the full amplitude at fixed color through numerical recursive relations [Moretti, Caravaglios, Mangano, Pittau, 1998; Draggiotis, Kleiss, Papadopoulos, 1998], which has only an exponential growth.

- Similar results can be obtained through the BG and an improved handling of color [FM, Paul, Stelzer, WIlenbrock 2003].

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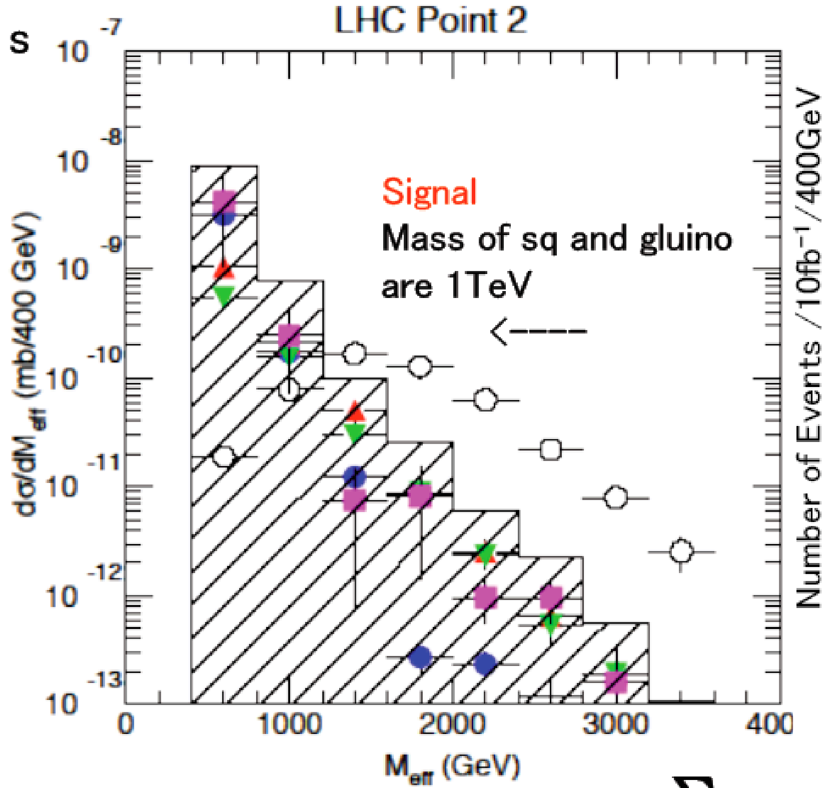
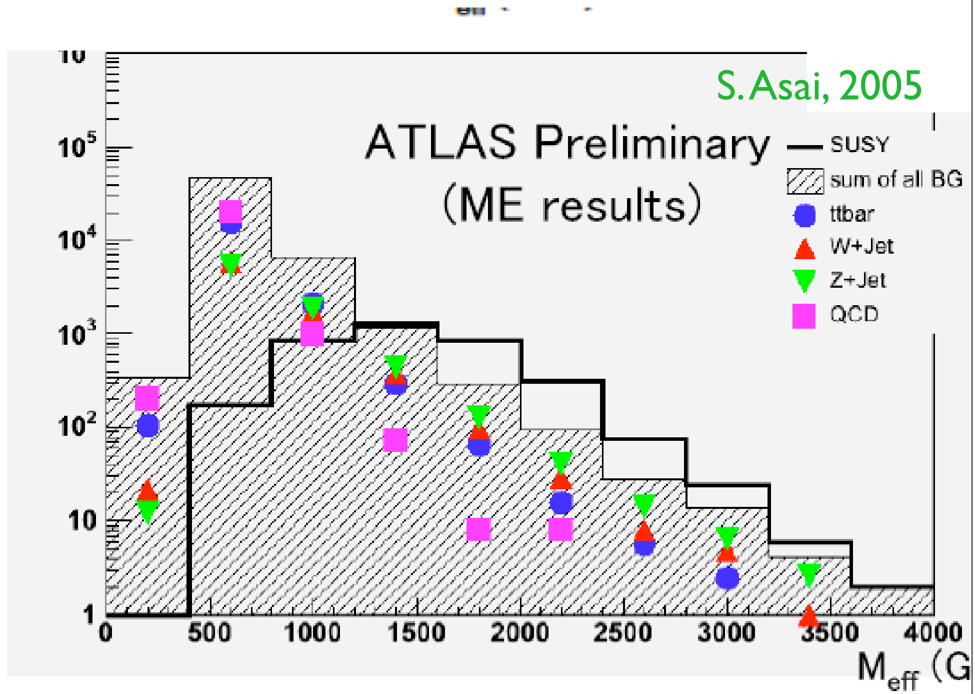
First example: Inclusive SUSY searches at the LHC



$$= \not{E}_T + \sum P_T$$

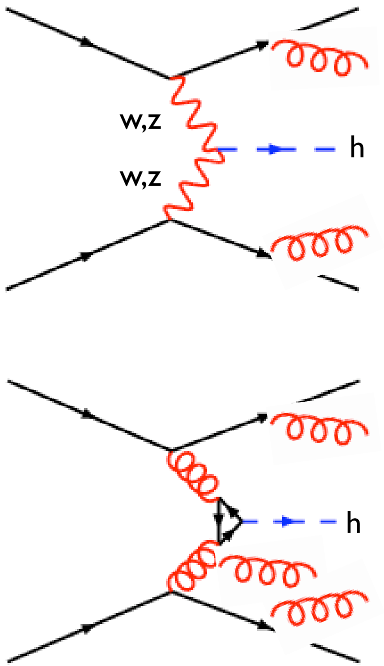


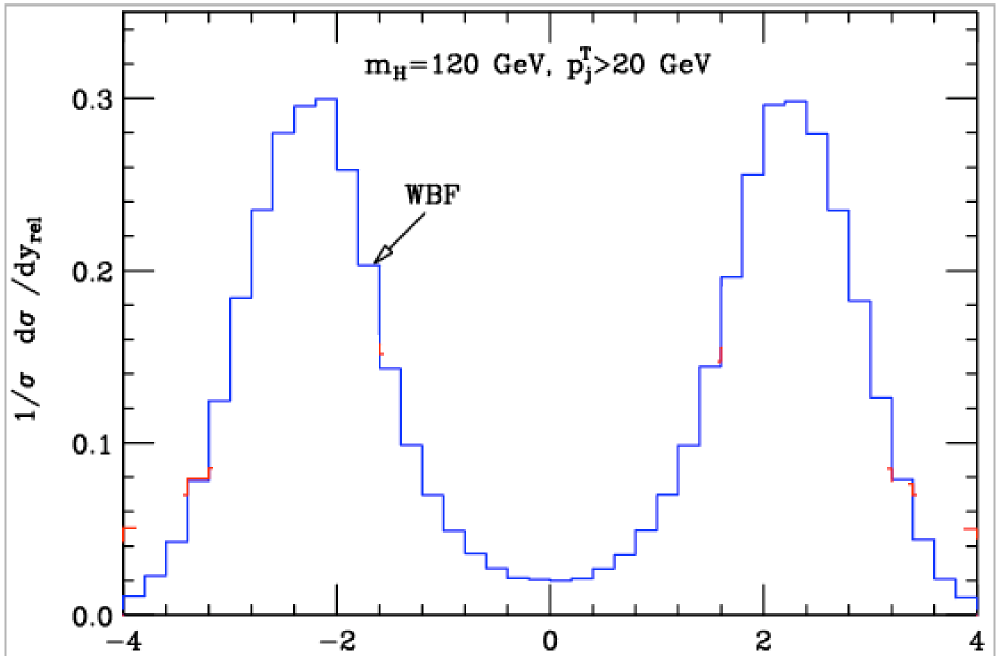
Alpgen+Pythia

Ht or Meff receive large contributions from W or Z plus few jets. A stardad Shower MC, like Pythia or Herwig, can underestimate the multijet rates by a factor of ~10. The matched prediction is clearly much better, even though it still affected by the typical uncertainity of a LO order calculation, typically a factor of ~2, even though...

Second Example: Couplings extraction from VBF

Vector boson fusion will play a crucial role in studying the Higgs properties, in many decay channels (ZZ,WW,ττ,ϒϒ). Typical signature is two forward jets and a “rapidity gap”. Central jet veto will be essential to select not only signal from background, but also VBF from QCD production.





Del Duca et al. 2004

Central jet veto will be essential to select not only signal from background, but also VBF from QCD production. Matched description needed. Comparison with NLO results possible. Impact of minimum bias, underlying event, forward low-et jets difficult to predict ⇒ data modeling will be needed.

ME/PS matching

ME	Shower MC
1. parton-level description	1. hadron-level description
2. fixed order calculation	2. resums large logs
3. quantum interference exact	3. quantum interference through AA
4. valid when partons are hard and well separated	4. valid when partons are collinear and/or soft
5. needed for multi-jet description	5. nedeed for realistic studies

Approaches are complementary!

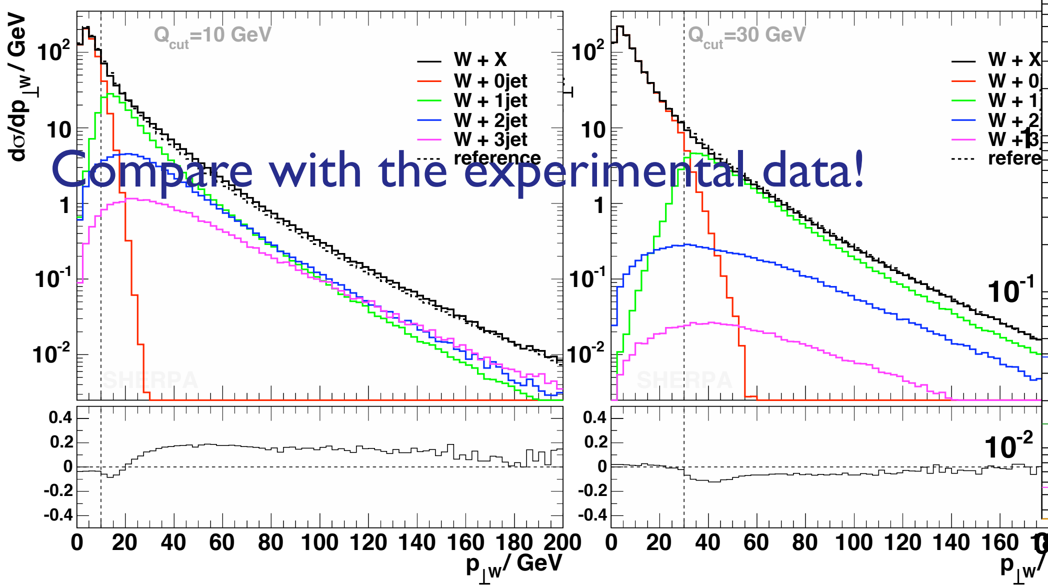
But double-counting has to be avoided!

CKKW algorithm in a nutshell

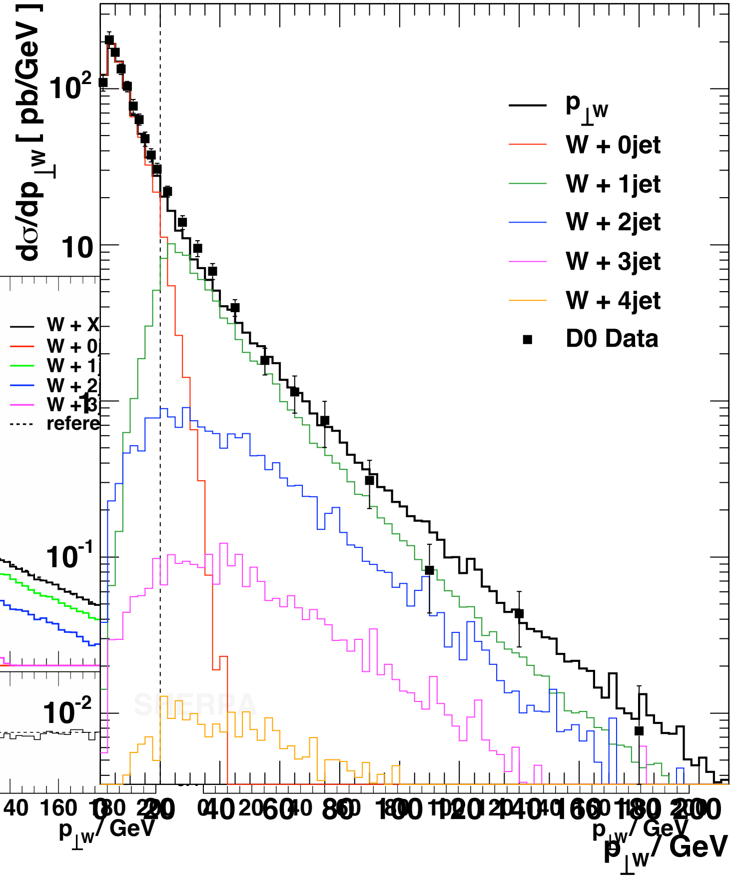
- Select a jet multiplicity with probability $P_n = \frac{\sigma_n}{\sum_{i=0}^{N} \sigma_i}$ with $y_{cut} = Q^2_{\mathrm{jet}}/Q^2$
- Generate final state p^i using the exact ME
- Find the probability w that "the event comes from a parton shower" (=kt cluster the event, generate a parton history, and perform a reweighting of coupling constants)
- Accept or reject the event based on w
- Pass the event to the parton shower, vetoing emissions above Q^2_{jet}

CKKW at work: pt distribution of the W

Check independence on the choice of the resolution scale



Compare with the experimental data!



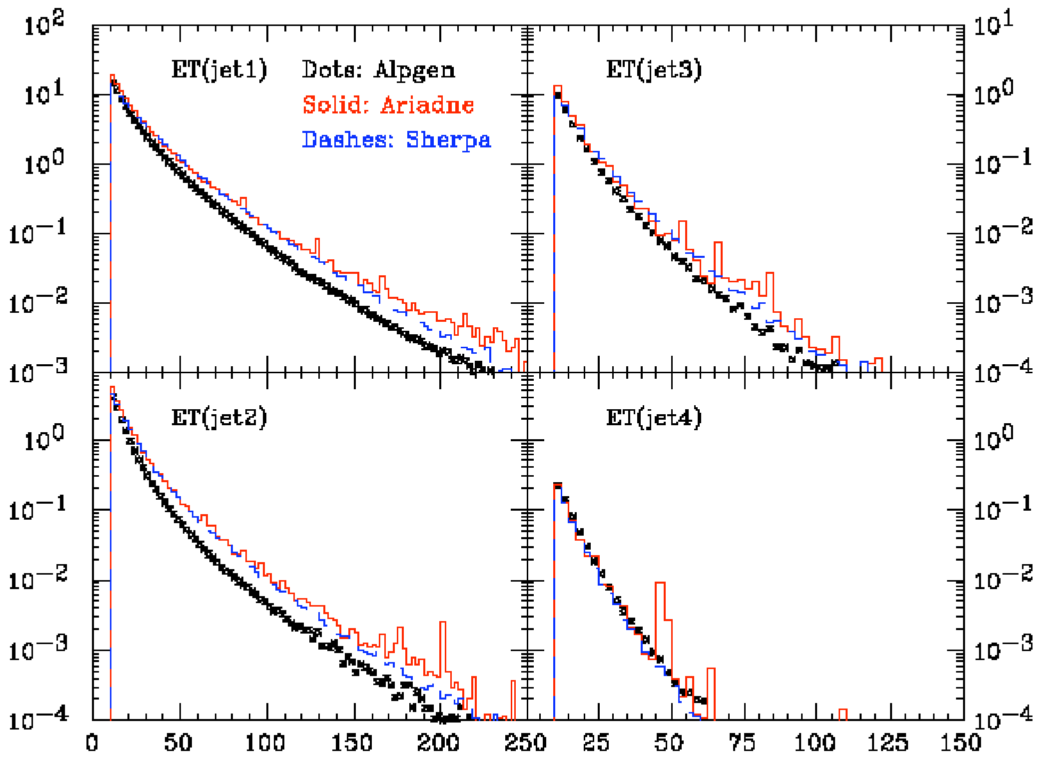
[Sherpa collaboration]

The MLM matching algorithm

- Generate events with the ME, using hard partonic cut, e.g., $p_T > p_{Tmin}$, DeltaR$_{jj}$ > DeltaR$_{MIN}$
- (Reweight the event to optimize scale choices)
- Shower the event and jet-cluster it (e.g. , with a cone algorithm)
- Require the original partons to be one-to-one associated to the jets.

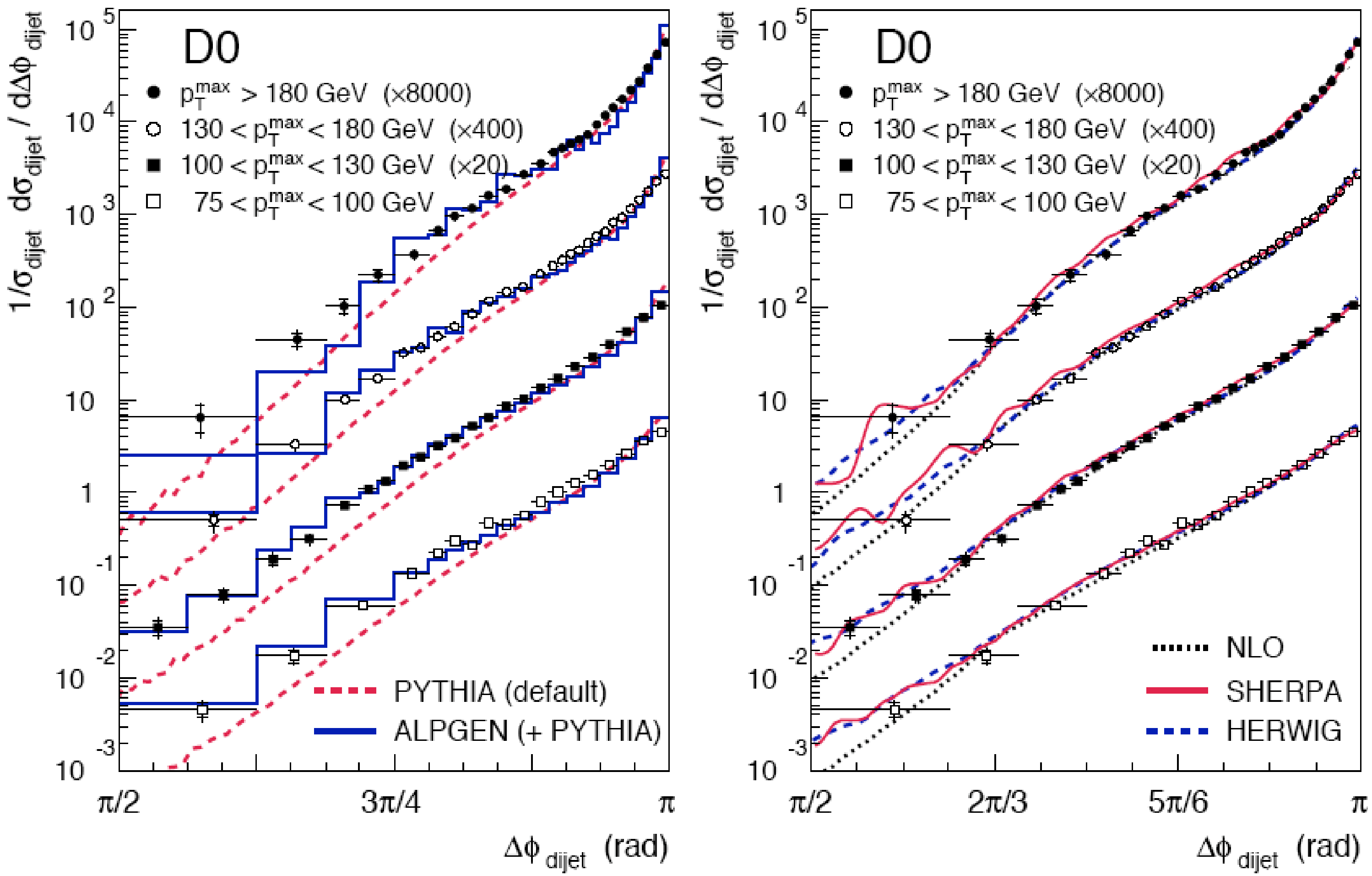
Comparison among various matching/ parton showers

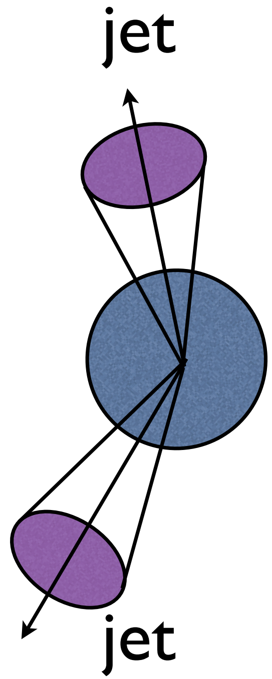
Hoeche et al., 2006



- Impressive agreement on the inclusive W pt distribution
- Reasonable agreement for the rapidity distributions
- Differences in the leading jets Et distributions
- Tevatron data will help.

Angular decorrelations pp→2j events





More later ⇒ Andrea Messina's talk

To remember about the ME-PS matching

- The matching (à la CKKW) has been rigourslyproved in e+e- collisions and it is believed to be true also in pp collisions.
- It provides an algorithm to generate multi-jet inclusive samples, that are accurate in all the areas of the phase space avoiding double-counting.
- Since no exact virtual contributions are included the normalization of the cross section is uncertain and it has to be obtained from a NLO calculation.
- On the other hand, shapes are (so far) in very good agreement with NLO.

Status & Directions in the ME-PS matching

- Various studies comparing the various options for matching (MLM or CKKW) have been performed:
  [Mrenna & Richardson, 2003;Hoeche et al., 2006].
- Two codes released with matching implemented (Alpgen and SHERPA). Other coming in the future (Herwig, MadGraph,...).
- Activities in progess:
  - Comparison with NLO results.
  - Thourough testing of ambiguities in the prescriptions.
  - Validation with Tevatron data.

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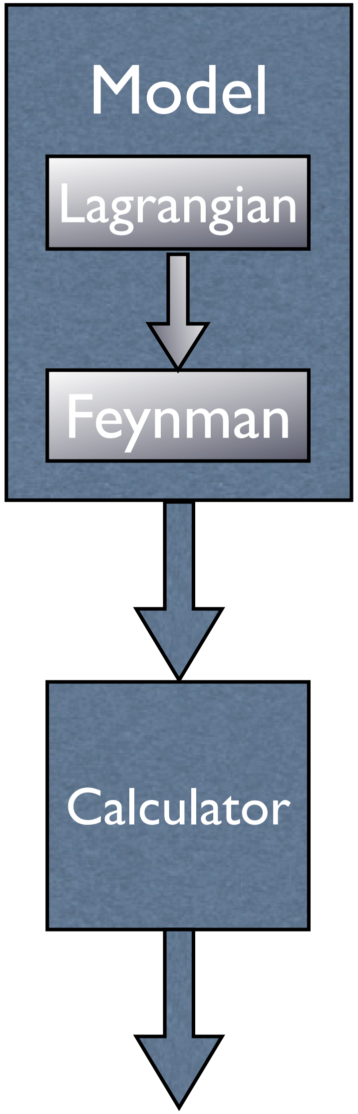
Add-on for BSM



Invent a model, renormalizable or not, with new physics. Write the Lagrangian and the Feyman Rules.

SUSY, Little Higgs, Higgsless, GUT, Extra dimensions (flat, warped, universal,...)

Parameters Calculator. For example, Masses and widths of heavy states (such as Higgs-bosons). These are passed in the LH format.

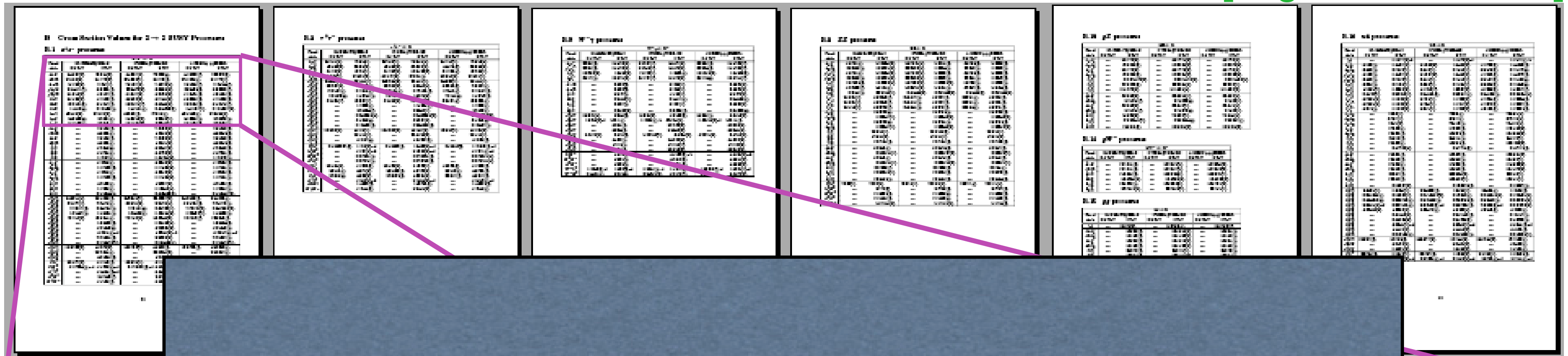
FeynHiggs, ISAJET, NMHDecay, SOFTSUSY, SPHENO, SUSPECT, SDECAY...

Status and directions of the BSM ME generators (I)

- Given the large number of possibilities, an automatic approach is the only practical one.
- Advanced implementations exist mainly for SUSY (Pythia,ISAJET, Sherpa, CompHep, Madgraph,Sherpa,Whizard).

MadGraph/Sherpa/Whizard SUSY comparison

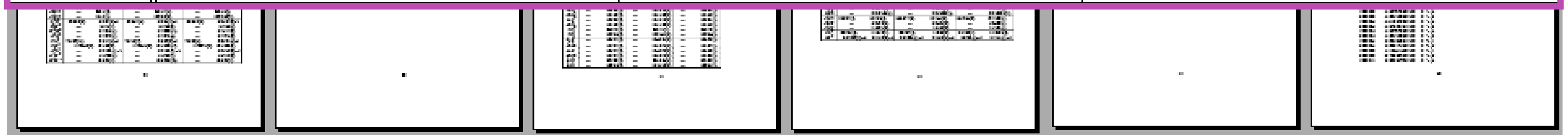
[Hagiwara et al. 2005]



~500 processes to check all Feynman rules
(CP and R-conserving, CKM=MSN=1)

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

Final state						ERPA TeV
$\tilde{e}_L\tilde{e}_L^*$						570(8)
$\tilde{e}_R\tilde{e}_R^*$						78(1)
$\tilde{e}_L\tilde{e}_R^*$						3744(7)
$\tilde{\mu}_L\tilde{\mu}_L^*$						2638(7)
$\tilde{\mu}_R\tilde{\mu}_R^*$						1085(6)
$\tilde{\tau}_1\tilde{\tau}_1^*$						1399(6)
$\tilde{\tau}_2\tilde{\tau}_2^*$	19.0161(6)	6.5047(2)	19.0174(7)	6.5045(3)	19.0163(2)	6.50473(7)
$\tilde{\tau}_1\tilde{\tau}_2^*$	1.4118(4)	0.21406(1)	1.41191(5)	0.214058(8)	1.41187(1)	0.214067(2)
$\tilde{\nu}_e\tilde{\nu}_e^*$	493.35(2)	272.15(2)	493.38(2)	272.15(1)	493.358(5)	272.155(3)
$\tilde{\nu}_\mu\tilde{\nu}_\mu^*$	14.8632(4)	2.9231(1)	14.8638(6)	2.9232(1)	14.8633(1)	2.92309(3)
$\tilde{\nu}_\tau\tilde{\nu}_\tau^*$	15.1399(5)	2.9246(1)	15.1394(8)	2.9245(1)	15.1403(2)	2.92465(3)



Status and directions of the BSM ME generators (II)

- Surging of interest on distinguishing among models (inverse-problem) (Example: UED vs. SUSY with spin [Smillie & Webber, 2005])
- Only one tool exists to pass from a Lagrangian to the Feynman rules automatically (LanHep) as a add-on to CompHep. For simple signatures ($2 \to 2$) CompHep is still the easiest way to go.
- In any case this is not the whole story: Spectrum and width calculators are needed (human or machine!). Specific issues, such long decay chains preserving spin correlations (Herwig and Sherpa), need to be addressed.
- Collaboration with model experts is mandatory to help develop intuition/ signatures/analysis...

Simplest Strategy:
develop tools that can be directly used by both model builders and experimentalists

Conclusions

- Tremendous development in the last ~5 years, still in progress;
- Many new tools have become available ⇒ A little bit of confusion but also a much larger spectrum of applications/studies/analysis possible. (Example: ME methods in top mass measurements).
- Generation of inclusive-matched (multi-jet) samples is at a mature stage. Studies on systematics, comparison among various approaches and NLO, and data validation have started.
- Most BSM ME generators are at present "limited" to SUSY.
Room and need for improvements.
- The modular structure of the ME generators offers a natural ground for collaboration between theorists (both model builders and the MC/QCD community) and experimentalists!