Stato dei generatori MC per i processi di fondo teorico

Fabio Maltoni

Center for Particle Physics Phenomenology,
Università di Louvain, Belgio

III Workshop Italiano sulla Fisica di ATLAS e CMS, Bari 20-22 Ottobre 2005

From Tevatron to LHC

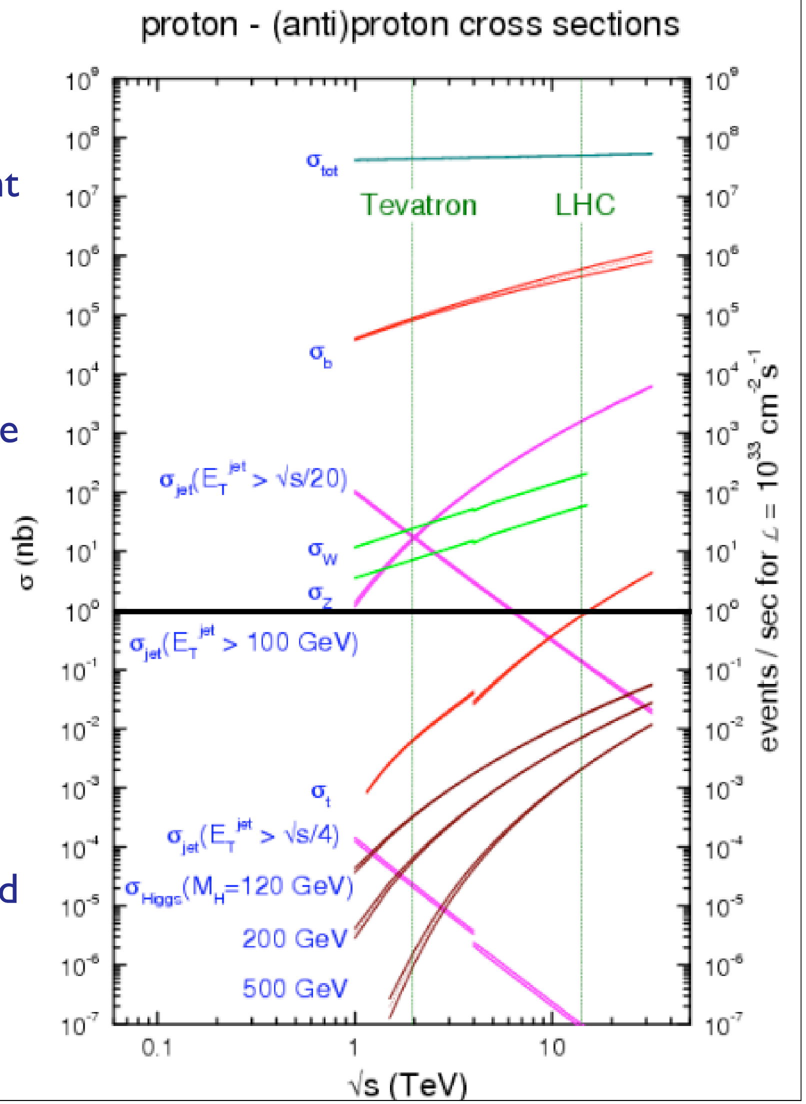
- Yields increased by order of magnitudes wrt Tevatron.
- Events with vectors bosons, tops and heavy and light jets with rates >1 Hz.
- Higgs physics down order of magnitudes.
- Need to understand QCD backgrounds well!

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.

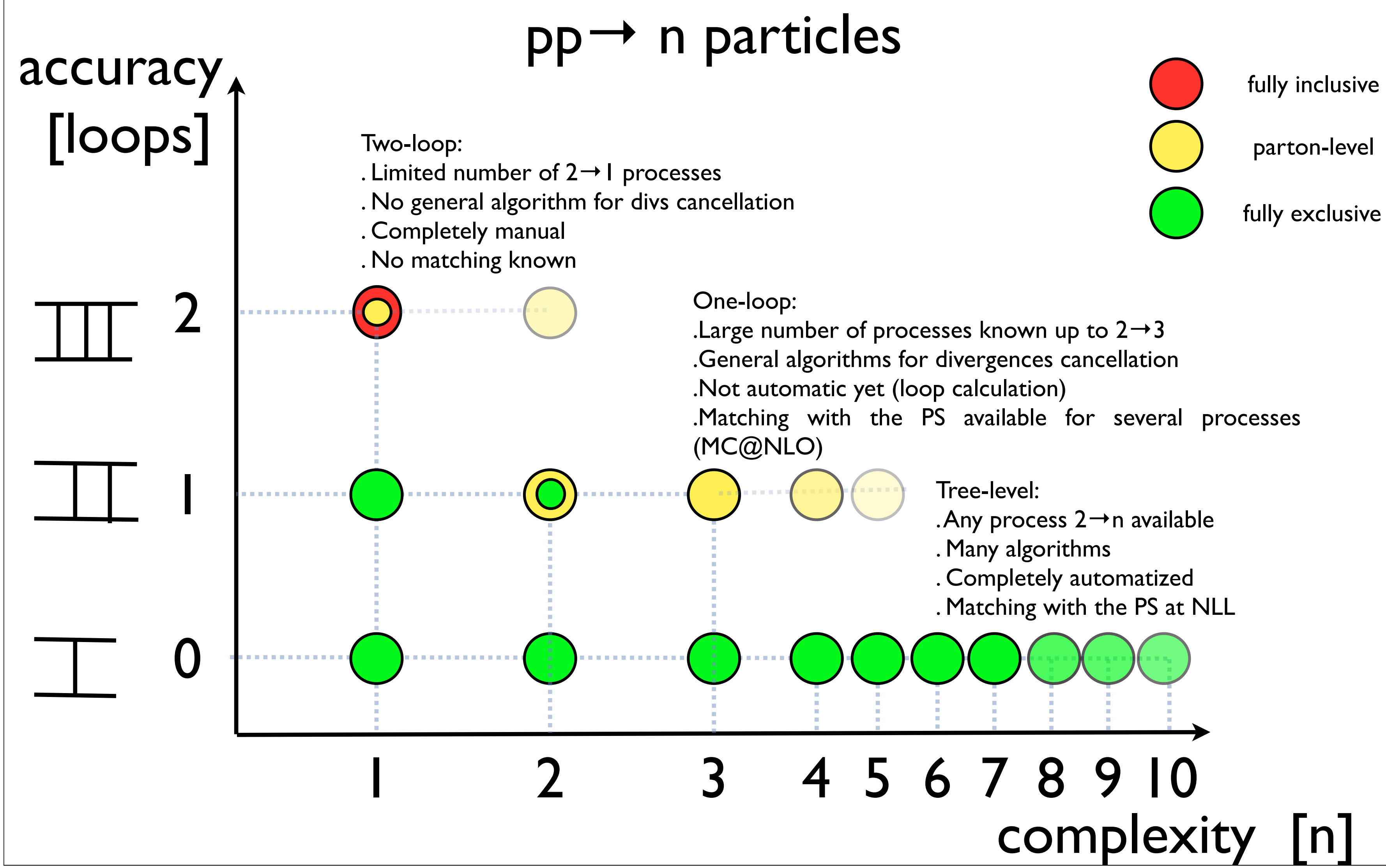
New trend:

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

Outline

- Progress in low multiplicity:
  - from NLO to NNLO
  - from NLO to MC@NLO
- Progress in high multiplicity:
  - the new matrix element generators
  - matching matrix elements with parton showers
- Conclusions and Discussions

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
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)
Tree-level:
.Any process 2→n available
. Many algorithms
. Completely automatized
. Matching with the PS at NLL
2
1
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/

In questo talk menzionerò soprattutto i prodotti "made in Italy"! Italian

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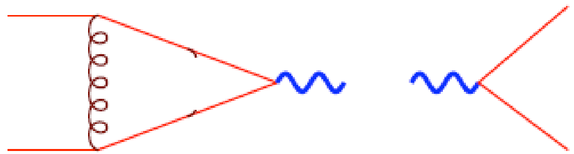
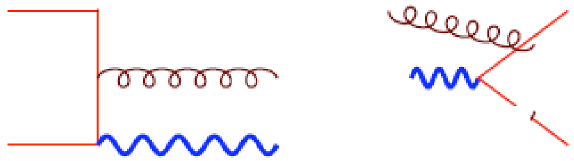
Elements of pp→W NLO calculation

- Virtual

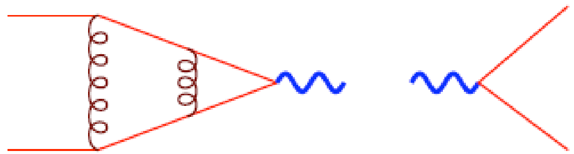


- Real



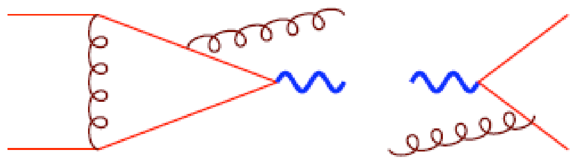
Elements of pp→W NNLO calculation

- Virtual-Virtual



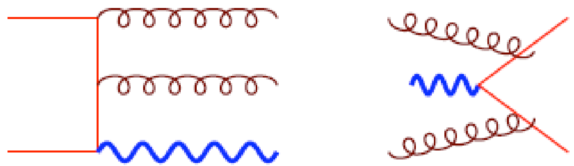
+ 100 terms

- Real-Virtual



+ 300 terms

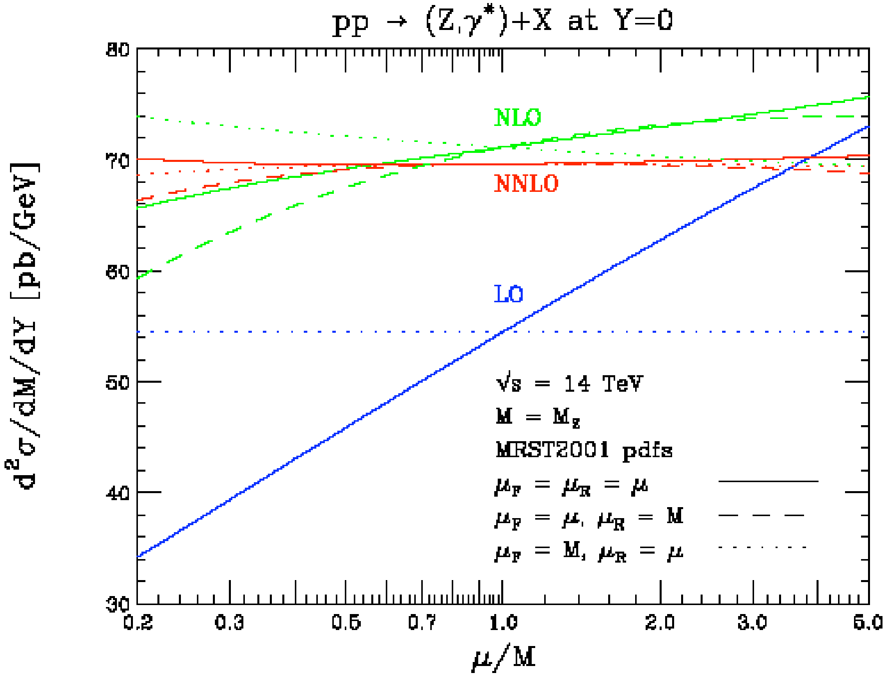
- Real-Real



+ 500 terms

⇒ Need clever algorithms to handle!

Fully inclusive results

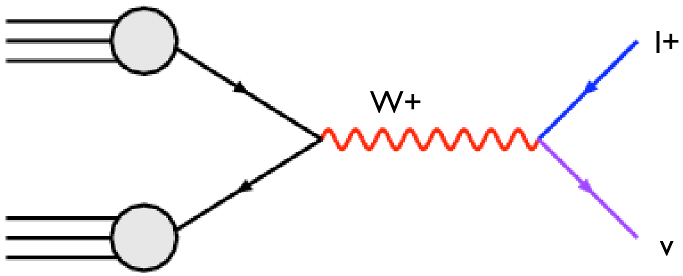


- Precision predictions at NNLO
- Also miss qualitative effects at lower orders
  - Few initial channels open; sensitivity to pdfs underestimated
  - Few jets in final state
  - Jets modeled by too few partons
  - Incorrect kinematics, e.g., no p_T

[Anastasiou, Dixon, Melnikov, Petriello. 2004]

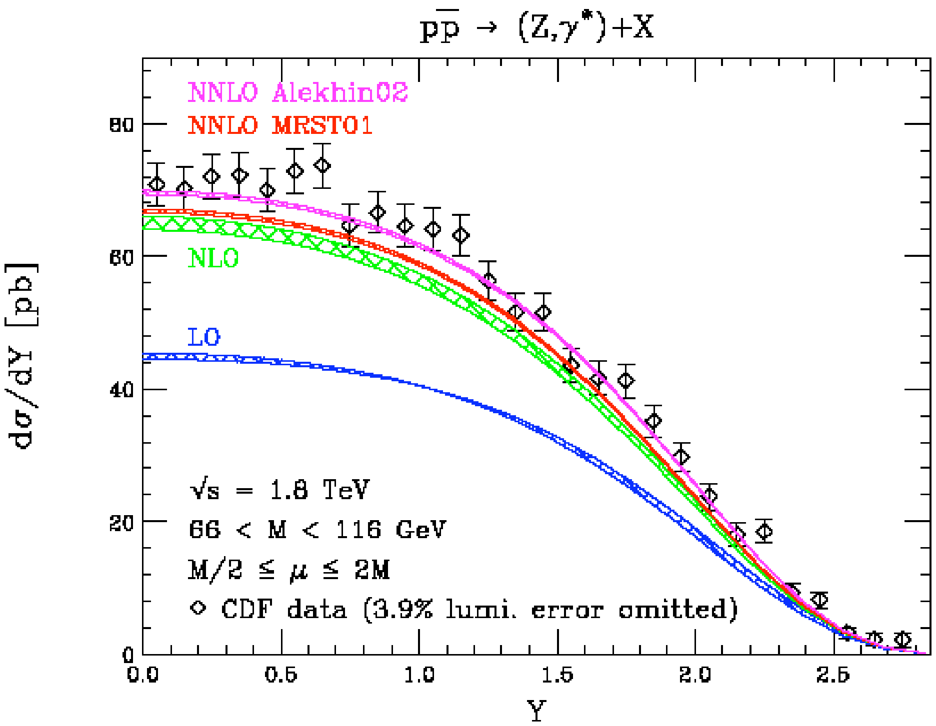
If theory is accurate enough, one can use σ(W) to:

0. Indirectly measure Γ_W
   (from R= σ(W) BR(W→lν) / σ(Z) BR(Z→ll))
1. Extract direct information on the PDF
2. Measure the collider luminosity
3. Extract parton-parton luminosity (=luminosity+PDF)
   ⇒ Use W and Z as standard candles!!



Distributions at NNLO

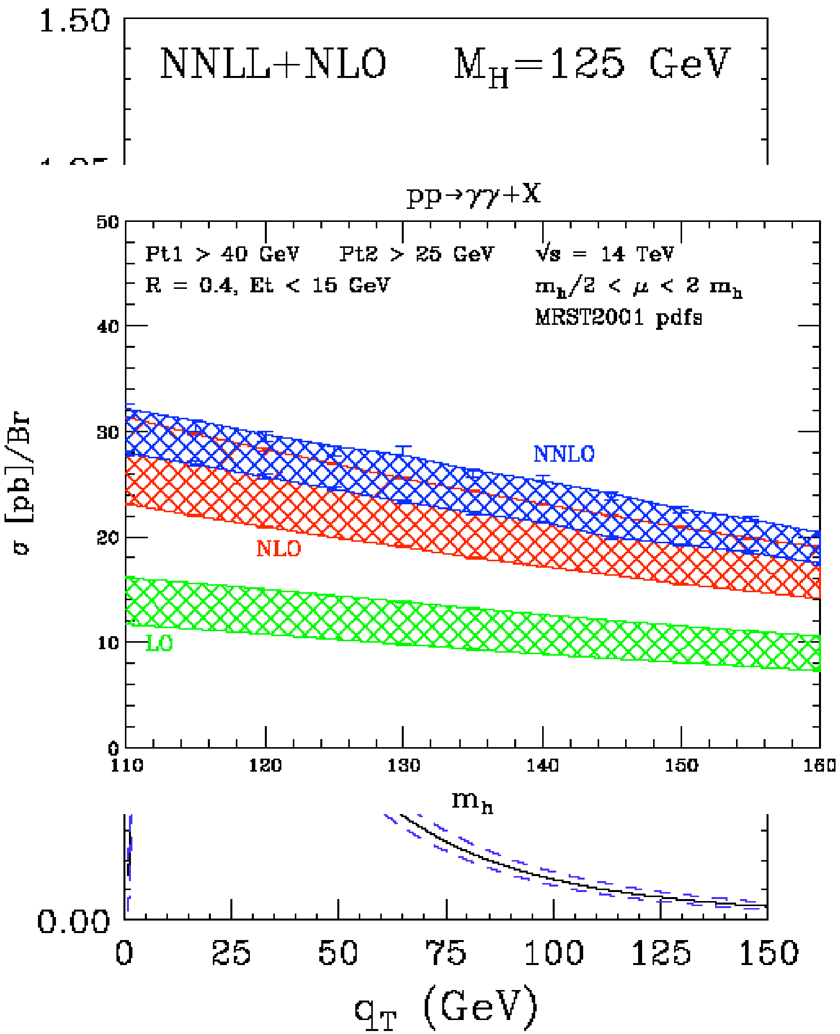
[Anastasiou, Dixon, Melnikov, Petriello. 2004]



- NNLO corrections increase NLO result by 3-5%
- Scale variations 3-6% at NLO, $< 1\%$ at NNLO
- Drell-Yan now a high precision probe of QCD

- Spin correlations are important! [Frixione, Mangano, 2004]
- Exclusive NNLO calculation WITH spin correlations is desirable!
- EW corrections are important: combination with QCD desirable.

GG → H → γγ



Dominant production mechanism at hadron colliders.
The story of the most accurate prediction in QCD:

QCD corrections:
[Daswon.1991] [Djouadi, Graudenz, Spira, Zerwas. 1991]
[Kramer, Laenen, Spira.1998] [Catani, De Florian, Grazzini.2001]
[Harlander, Kilgore.2001,2002] [Anastasiou, Melnikov.2002]
[Ravindran,Smith,Van Neerven. 2003]
[Catani, De Florian, Grazzini, Nason.2003]

Two-loop EW corrections:
[Djouadi, Gambino, Kniehl. 1998]
[Aglietti, Bonciani, Degrassi,Vicini. 2004]
[Degrassi, FM. 2004]

PDF evolution at NNLO (“Guinness of QCD”):
[Moch,Vogt,Vermaseren, 2004]

Best QCD predictions at present:
> Fully exclusive (PS interfaced) prediction at NLO+NLL[Frixione, Webber, 2003]
> Fully exclusive prediction at NNLO (first ever) [Anastasiou, Melnikov, Petriello. 2004]
> Resummed pt distribution at NLO+NNLL [Bozzi, Catani, De Florian, Grazzini, 2005]

(NLO) MC's integrators

- Now used only for at least NLO calculations or analytically resummed results
- Provide essential information on the normalization of the cross section
- Produce distributions of any quantity of interest but not events (due to negative weights)
- Inclusive approach (NO EVENTS)
- Predictions are at parton level only. No showering, hadronization or detector effects.
- Jets contain at most two partons.

An experimenter's wishlist

- Hadron collider cross-sections one would like to know at NLO

Run II Monte Carlo Workshop, April 2001

Single boson	Diboson	Triboson	Heavy flavour
$W + \leq 5j$	$WW + \leq 5j$	$WWW + \leq 3j$	$t\bar{t} + \leq 3j$
$W + b\bar{b} + \leq 3j$	$WW + b\bar{b} + \leq 3j$	$WWW + b\bar{b} + \leq 3j$	$t\bar{t} + \gamma + \leq 2j$
$W + c\bar{c} + \leq 3j$	$WW + c\bar{c} + \leq 3j$	$WWW + \gamma\gamma + \leq 3j$	$t\bar{t} + W + \leq 2j$
$Z + \leq 5j$	$ZZ + \leq 5j$	$Z\gamma\gamma + \leq 3j$	$t\bar{t} + Z + \leq 2j$
$Z + b\bar{b} + \leq 3j$	$ZZ + b\bar{b} + \leq 3j$	$WZZ + \leq 3j$	$t\bar{t} + H + \leq 2j$
$Z + c\bar{c} + \leq 3j$	$ZZ + c\bar{c} + \leq 3j$	$ZZZ + \leq 3j$	$t\bar{b} + \leq 2j$
$\gamma + \leq 5j$	$\gamma\gamma + \leq 5j$		$b\bar{b} + \leq 3j$
$\gamma + b\bar{b} + \leq 3j$	$\gamma\gamma + b\bar{b} + \leq 3j$		
$\gamma + c\bar{c} + \leq 3j$	$\gamma\gamma + c\bar{c} + \leq 3j$		
	$WZ + \leq 5j$		
	$WZ + b\bar{b} + \leq 3j$		
	$WZ + c\bar{c} + \leq 3j$		
	$W\gamma + \leq 3j$		
	$Z\gamma + \leq 3j$		

J. Campbell

Theoretical status

- Much smaller jet multiplicities, some categories untouched

Single boson	Diboson	Triboson	Heavy flavour
$W+\leq 2j$	$WW+\leq 0j$	$WWW+\leq 3j$	$t\bar{t}+\leq 0j$
$W+b\bar{b}+\leq 0j$	$WW+b\bar{b}+\leq 3j$	$WWW+b\bar{b}+\leq 3j$	$t\bar{t}+\gamma+\leq 2j$
$W+c\bar{c}+\leq 0j$	$WW+c\bar{c}+\leq 3j$	$WWW+\gamma\gamma+\leq 3j$	$t\bar{t}+W+\leq 2j$
$Z+\leq 2j$	$ZZ+\leq 0j$	$Z\gamma\gamma+\leq 3j$	$t\bar{t}+Z+\leq 2j$
$Z+b\bar{b}+\leq 0j$	$ZZ+b\bar{b}+\leq 3j$	$WZZ+\leq 3j$	$t\bar{t}+H+\leq 0j$
$Z+c\bar{c}+\leq 0j$	$ZZ+c\bar{c}+\leq 3j$	$ZZZ+\leq 3j$	$t\bar{b}+\leq 0j$
$\gamma+\leq 1j$	$\gamma\gamma+\leq 1j$		$b\bar{b}+\leq 0j$
$\gamma+b\bar{b}+\leq 3j$	$\gamma\gamma+b\bar{b}+\leq 3j$		
$\gamma+c\bar{c}+\leq 3j$	$\gamma\gamma+c\bar{c}+\leq 3j$		
	$WZ+\leq 0j$		
	$WZ+b\bar{b}+\leq 3j$		
	$WZ+c\bar{c}+\leq 3j$		
	$W\gamma+\leq 0j$		
	$Z\gamma+\leq 0j$		

+ a few other results:
H+≤2b
Z+b+ ≤1j
t+q
tW
(W,Z)+2j (EW)

J. Campbell

MCFM British + U.S. + a touch of Italian

(Campbell, Ellis + collaboration by F.M. + F. Tramontano, S. Willenbrock)

$p\bar{p} \to W^{\pm}/Z$	$p\bar{p} \to W^{+} + W^{-}$
$p\bar{p} \to W^{\pm} + Z$	$p\bar{p} \to Z + Z$
$p\bar{p} \to W^{\pm} + \gamma$	$p\bar{p} \to W^{\pm}/Z + H$
$p\bar{p} \to W^{\pm} + g^{\star}\,(\to b\bar{b})$	$p\bar{p} \to Zb\bar{b}$
$p\bar{p} \to W^{\pm}/Z + 1$ jet	$p\bar{p} \to W^{\pm}/Z + 2$ jets
$p\bar{p}(gg) \to H$	$p\bar{p}(gg) \to H + 1$ jet
$p\bar{p}(VV) \to H + 2$ jets	$p\bar{p} \to t + q$
$p\bar{p} \to H + b$	$p\bar{p} \to Z + b$

☞ Sizeable library of processes, relevant for signal and background studies.

☞ Cross sections and distributions at NLO are provided, including spin correlations.

☞ Easy and flexible choice of parameters/cuts.

- Version 4.1 available at:

  `http://mcfm.fnal.gov`

When should they ...

...be used?

1. When a precise knowledge of a NLO "observable" is needed
2. The measurement is inclusive enough for hadronization effects not to be important
3. To study the "theoretical" uncertaintes of a measurement:
   - ☞scale variation
   - ☞PDF errors

...not be used?

1. When the observable is not really at NLO for that code!
2. As "blind" overall k-factor estimators for LO codes.

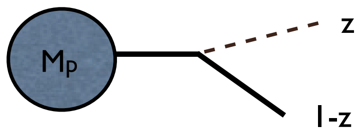
Parton Shower MC event generators

- General-purpose tools
- Complete exclusive description of the events
- hard scattering, showering & hadronization, underlying event
- Presently based on a library of simple $2 \rightarrow n$, with $n \leq 3$, hard processes

Parton Shower MC event generators

ME involving q →q g (or g → gg) are strongly enhanced when they are close in the phase space:

$$\frac{1}{(p_q+p_g)^2} \simeq \frac{1}{2E_qE_g(1-\cos\theta)}$$



Both soft and collinear divergences: very different nature!

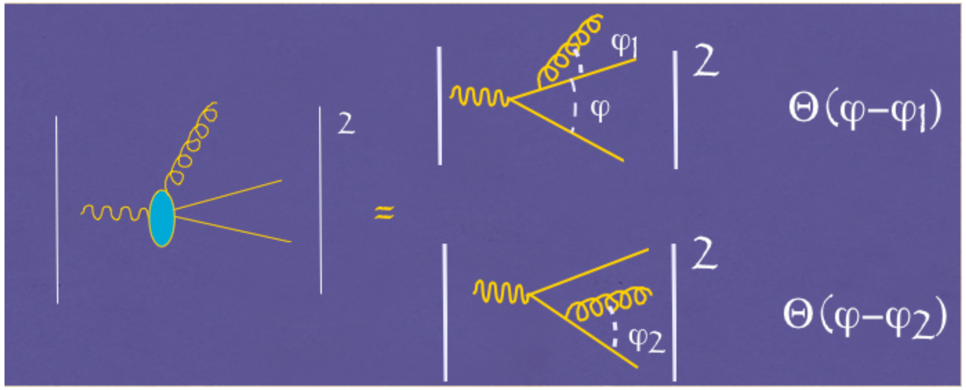
Collinear factorization:

$$|M_{p+1}|^2 d\Phi_{p+1} \simeq |M_p|^2 d\Phi_p \frac{dt}{t}\frac{\alpha_S}{2\pi}P(z)dzd\phi$$

1. Allows for a parton shower (Markov process) evolution
2. The evolution resums the dominant leading-log contributions

Parton Shower MC event generators

How do we describe the soft gluons?



Solution: during the collinear evolution we impose angular ordering

Beware that it's an approximation:

☞lack of radiation at large angle

☞incoherent emission between partons

→ Poor description of hard multi-jet events

Parton Shower MC event generators

available programs:

ISAJET

PYTHIA 7

HERWIG ++

ARIADNE

SHERPA

Comments:

Well-known and widely used

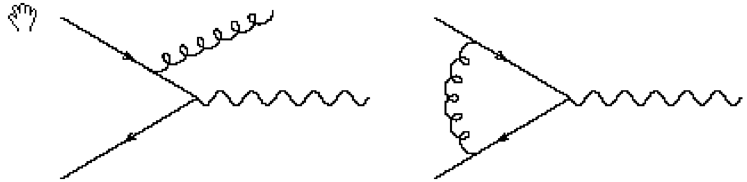
Different evolution and ordering variables, models, various choices

New C++ version are under development

MC@NLO

Italian + British
[Frixione, Webber + Nason+...]

Compute all NLO diagrams before starting the shower



. . . . . .

Problems

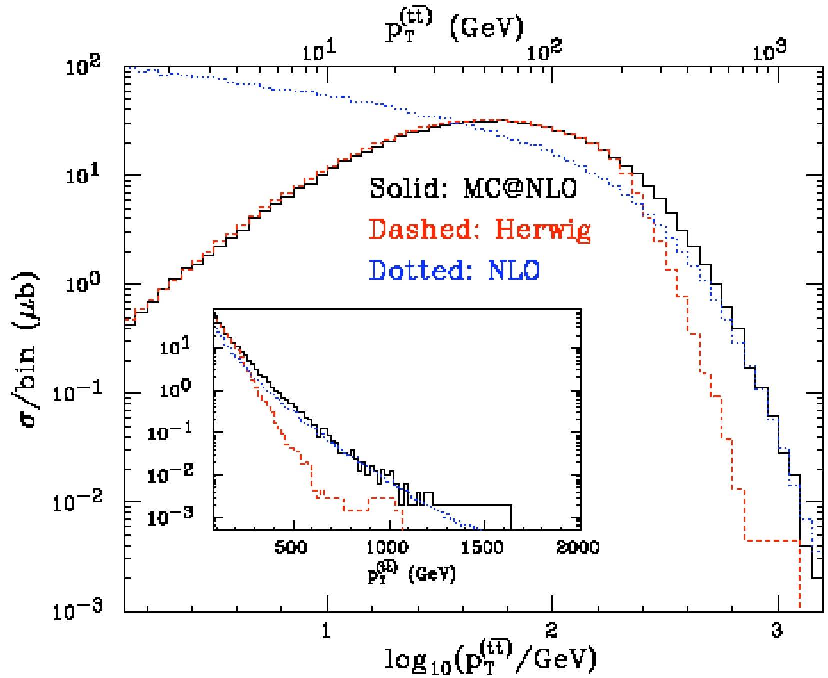
- Double counting (the shower can generate the same diagrams)
- The diagrams are divergent

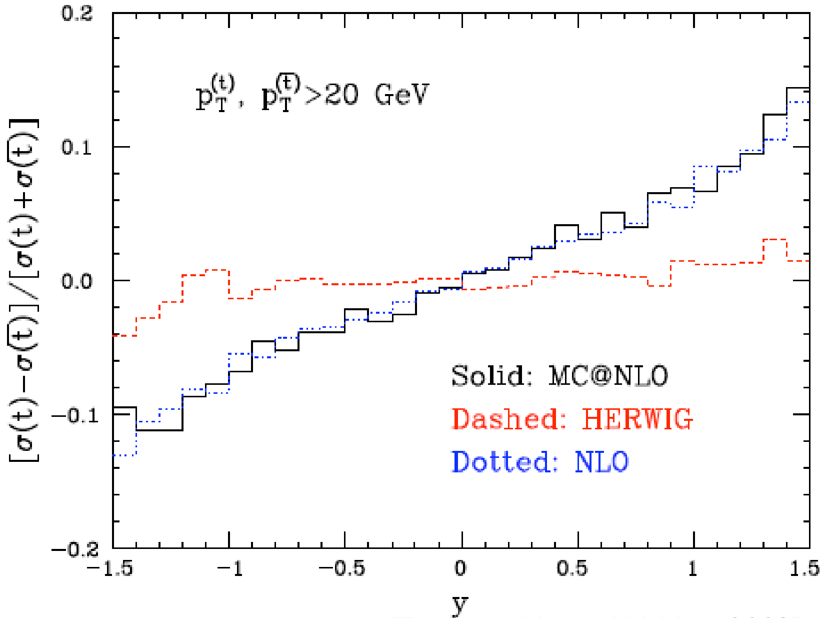
Solution (MC@NLO)

Remove the divergences locally by adding and subtracting the MC result that one would get after the first emission (yes, this is sufficient!)

MC@NLO

Italian + British





[Frixione, Nason, Webber, 2003]

- MC@NLO rate = NLO rate $\Longrightarrow$ K-factors are included consistently
- MC@NLO- and MC-predicted shapes are identical where MC does a good job
- $\mathcal{S}$+0 jet and $\mathcal{S}$+1 jet treated exactly, $\mathcal{S}+n$ jets $(n > 1)$ better than in MC's

This is our "best" tool!

MC@NLO

Italian + British

IPROC	Process
−1350−IL	$H_1H_2 \to (Z/\gamma^* \to) l_{\rm IL}\bar{l}_{\rm IL} + X$
−1360−IL	$H_1H_2 \to (Z \to) l_{\rm IL}\bar{l}_{\rm IL} + X$
−1370−IL	$H_1H_2 \to (\gamma^* \to) l_{\rm IL}\bar{l}_{\rm IL} + X$
−1460−IL	$H_1H_2 \to (W^+ \to) l^+_{\rm IL}\nu_{\rm IL} + X$
−1470−IL	$H_1H_2 \to (W^- \to) l^-_{\rm IL}\bar{\nu}_{\rm IL} + X$
−1396	$H_1H_2 \to \gamma^*(\to \sum_i f_i\bar{f}_i) + X$
−1397	$H_1H_2 \to Z^0 + X$
−1497	$H_1H_2 \to W^+ + X$
−1498	$H_1H_2 \to W^- + X$
−1600−ID	$H_1H_2 \to H^0 + X$
−1705	$H_1H_2 \to b\bar{b} + X$
−1706	$H_1H_2 \to t\bar{t} + X$
−2850	$H_1H_2 \to W^+W^- + X$
−2860	$H_1H_2 \to Z^0Z^0 + X$
−2870	$H_1H_2 \to W^+Z^0 + X$
−2880	$H_1H_2 \to W^-Z^0 + X$

- Works identically to HERWIG: the very same analysis routines can be used
- Reads shower initial conditions from an event file (as in ME corrections)
- Exploits Les Houches accord for process information and common blocks
- Features a self contained library of PDFs with old and new sets alike
- LHAPDF will also be implemented

Present limitations of NLO calculations

- Any new process is a whole new project!
- Technology well known but no complete automatization achieved yet.
- Matching in MC@NLO is tailored to a specific subtraction scheme and to HERWIG.

The desirables for NLO calculations

- Automatization of the whole calculation:
  - New techniques and algorithms being tested for loop calculations
  - Real corrections can be automatized but no practical implementation ready yet.
- Other matching prescriptions with other showers than HERWIG being proposed/under development.
- Proof of a matching with no negative weights available [Nason, 2004] but no practical implementation available yet.
- It would be nice to have a matching scheme based on the dipole subtraction method => all available NLO codes could be immediately interfaced to a PS!

Outline

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  - from NLO to MC@NLO
- Progress in high multiplicity:
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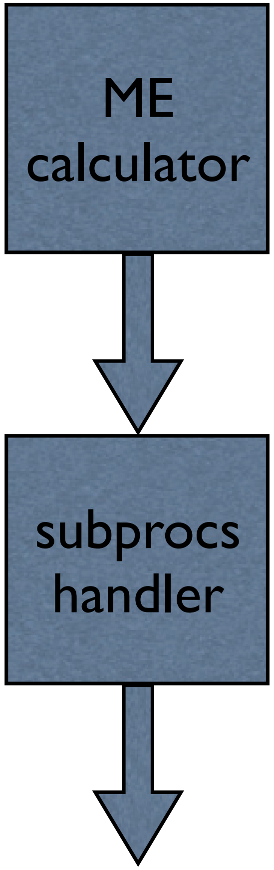
Matrix-element based MC event generators

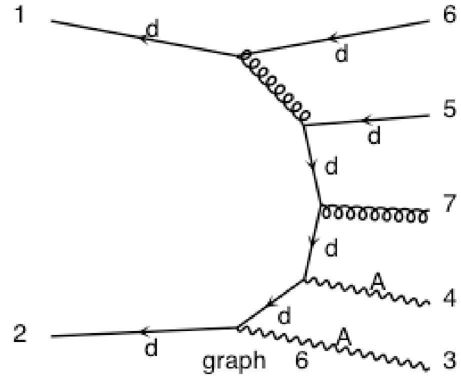
- New generation of codes
- Multi-parton matrix elements for arbitrary tree-level processes
- Integration over phase space can be done efficiently $\rightarrow$ event generators for partons

General structure



"Automatically" generates a code for |M|^2 for arbitrary processes with many partons in the final state. Most use Feynman diagrams w/ tricks

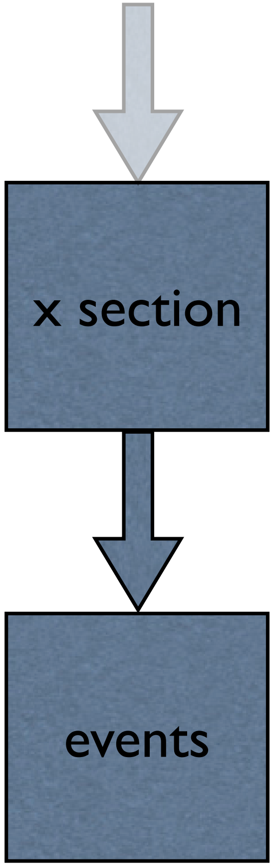
to reduce the factorial growth



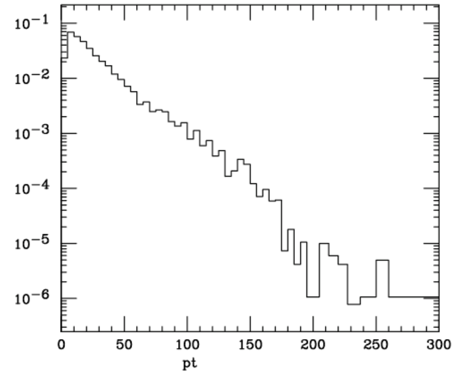
Includes all possible subprocess leading to a given multi-jet final state automatically or manually (done once for all)

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

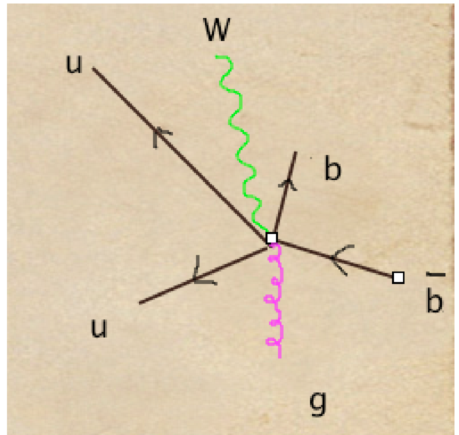
General structure



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



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.



Different philosophies

Several codes exist, 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	AcerMC Gr@PPA AlpGen
Multi-purpose	High automatization, user-driven, huge versatility	Comphep MadEvent Amegic

Alpgen

Italian

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

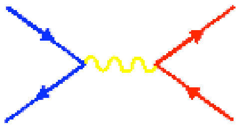
Features:

- 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

Madgraph

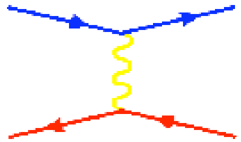
Italian + U.S.



MadGraph HomePage

at UIUC

by Fabio Maltoni and Tim Stelzer



Generate Process | Database | Cluster Status | FAQ | News & Developments | Citations

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Generate Code On-Line

Model: SM | SM particles

Input Process: [ ] Submit

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

Support for this web site has been provided by the National Science Foundation through grant PHY-0426272

Madgraph Italian + U.S.

- Madgraph/MadEvent is a web based multi-purpose generator.
- Generates unweighted parton-level events in the Les Houches Accord (and also root format).
- Codes for specific processes are generated on air upon user request and stored in DB
- Pythia and Herwig interfaces for showering and hadronization are available.

Madgraph Italian + U.S.

Latest developments:

- Web based generation:
  - User inputs cuts/parameters
  - Code runs in parallel on modest farms (US and IT).
  - Returns cross section, plots, root file (M. Zanetti), and 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

ME/PS matching

ME

1. parton-level description
2. fixed order calculation
3. valid when partons are hard and well separated
4. necessary in multi-jet configurations

Shower MC

1. hadron-level description
2. resums large logs
3. valid when partons are collinear and/or soft
4. necessary for simulations for hadronization and detectors

Approaches are complementary!

But double-counting has to be avoided!

The MLM matching recipe

- Generate events with the ME, using hard partonic cut, e.g., $p_T > p_{Tmin}$, DeltaR$_{jj}$ > DeltaR$_{MIN}$
- Shower the event and jet-cluster it (e.g. ,with a cone algorithm)
- Require the original partons are 1-1 associated to the jets.

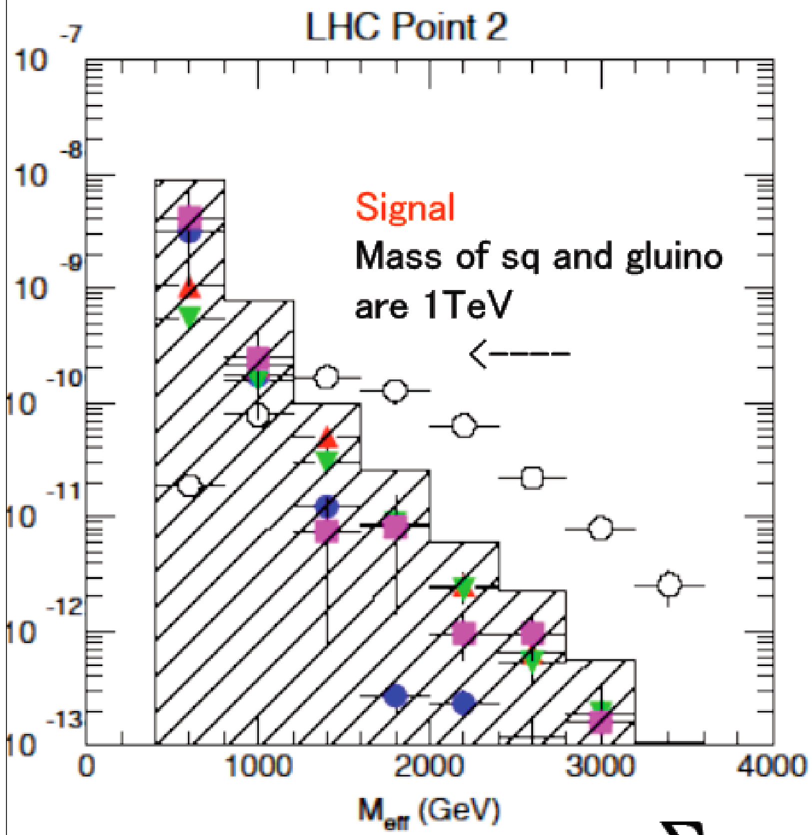
Main features of the ME-PS matching

- The matching (a la CKKW) has been rigourly proved 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 virtual contributions are included, information on the normalization of the cross section is not available and it has to be obtained from a NLO calculation.

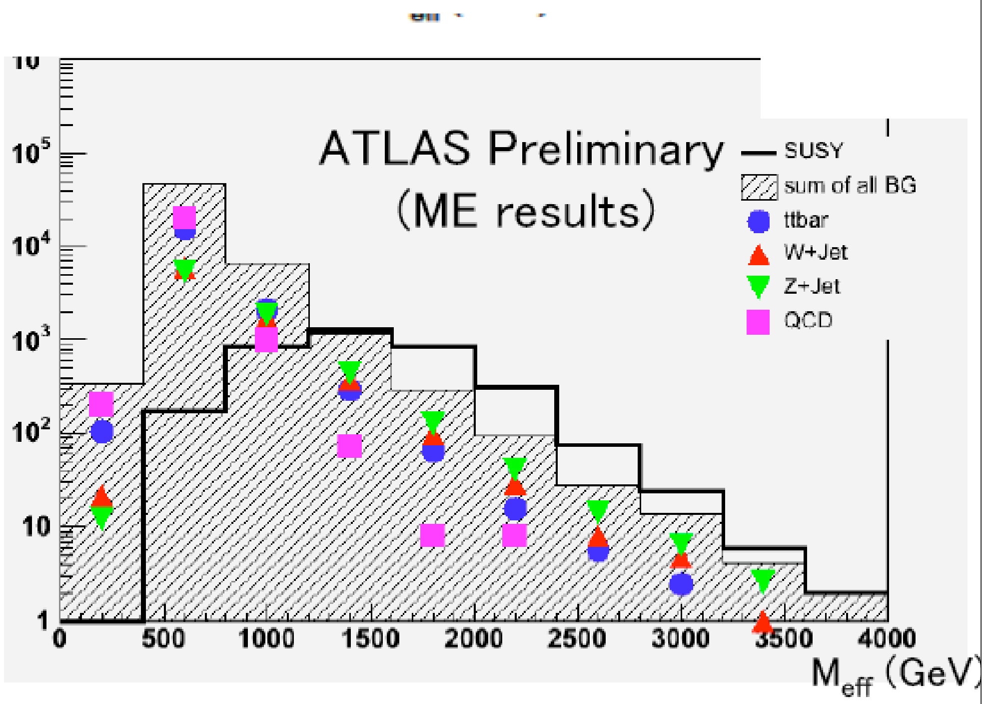
Alpgen

Italian

A nice application:



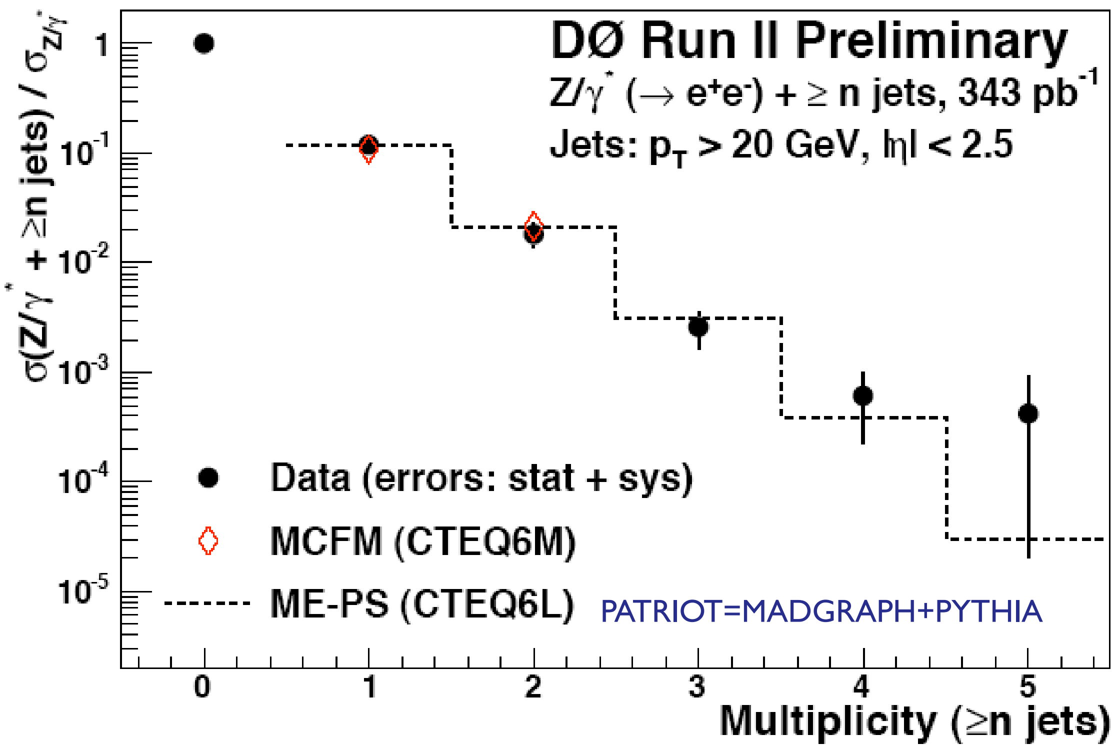
$= \not{E}_T + \sum P_T$



S. Asai, 2005

Madgraph Italian + U.S.

A nice application:



Status of the ME-PS matching

- Various studies comparing the various options for matching (MLM or CKKW) have been performed (Mrenna & Richardson, Mangano & Krauss).
- A couple of codes available with matching implemented (Alpgen and SHERPA). Other coming in the future (Herwig, MadGraph/MadEvent).
- Detailed comparison with NLO codes in progress.
- Thourough testing of ambiguities in the prescription to be done.
- More validation against hadron collider data needed.

Conclusions

- Tremendous development in the last three/four years, still in progress;
- Predictions for signals (and backgrounds) available at an unprecedented level of accuracy;
- Many new tools have become available that mirror the accuracy with which we now can make predictions at pp colliders;
- Choosing the best MC for a given analysis is not always obvious ⇒

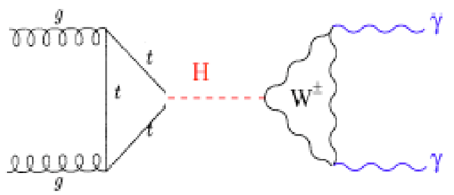
  collaboration between theorists and experimentalists is essential.

Three very different interesting examples

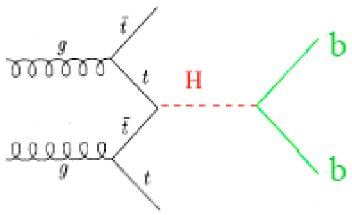
Each channel contributes ~ 2σ to total significance → observation of all channels important to extract convincing signal in first year(s)

The 3 channels are complementary → robustness:

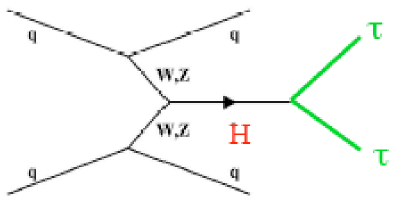
$H \to \gamma\gamma$



$t\bar{t}H \to t\bar{t}\,b\bar{b} \to bl\nu\ bjj\ b\bar{b}$

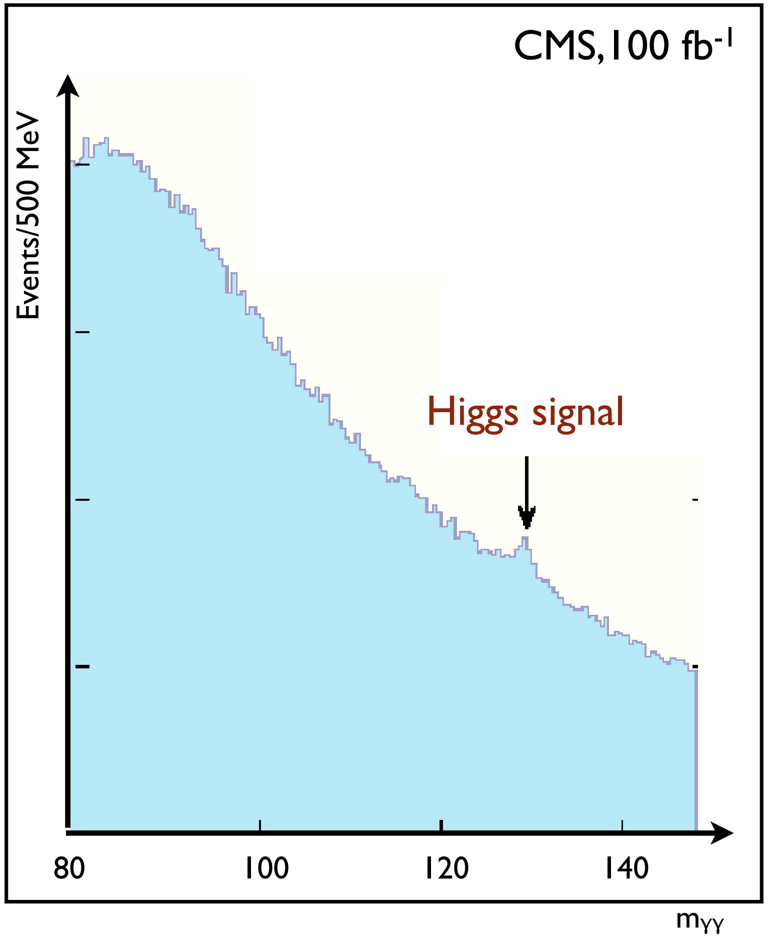


$qqH \to qq\tau\tau$



Fabiola Giannotti, lepton-photon 2005

$gg \to H \to \gamma\gamma$



Huge background from QCD.

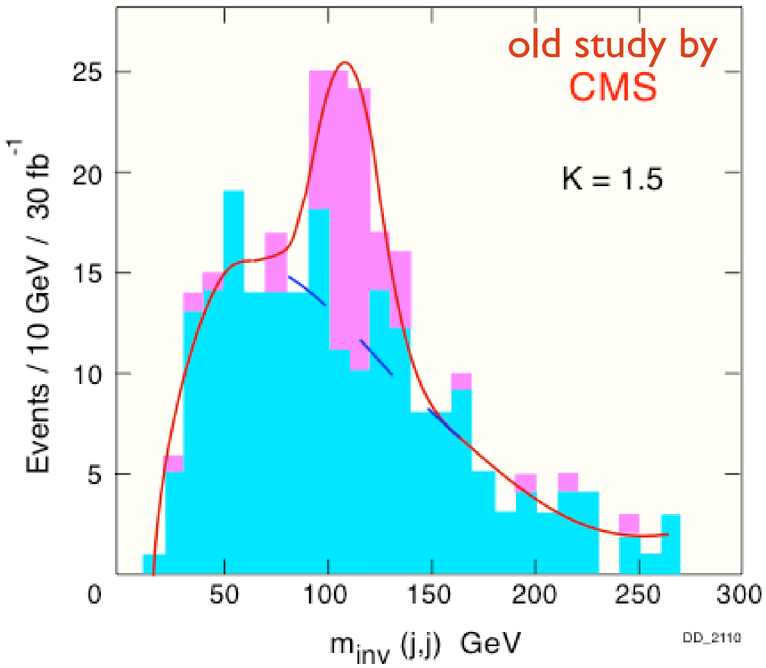
$q\bar{q} \to \gamma\gamma$ known at NLO (DIPHOX) including fragmentation contributions
[Binoth, Guillet, Pilon, Werlen. 2000]

$gg \to \gamma\gamma$ direct known at NLO (two-loop)
[Bern, Dixon, Schmidt. 2002]

This is an example of a discovery that does not need an accurate theoretical prediction for the background. Data modeling will suffice.

On the other hand, extraction of information about couplings to top and W needs accurate predictions for both the cross section and the branching ratio.

ttH production



Signal cross section of ~1 pb, known at NLO.
K-factor of order 1.
[Beenakker,Dittmaier,Kramer,Plumper,Spira,Zerwas.2002] [Dawson,Jackson,Orr,Reina,Wackeroth.2003]

Typical signature 4b+2j+l+mEt: very difficult!

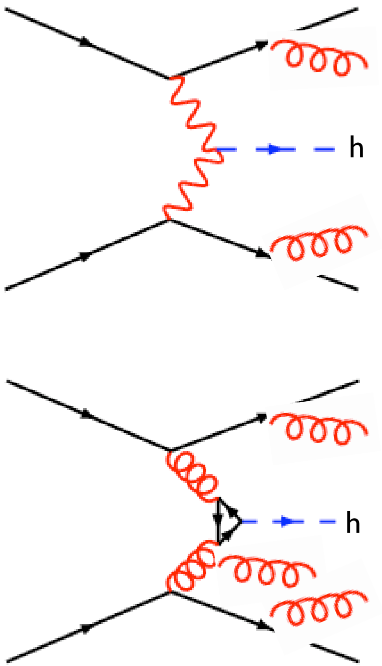
Key issues:
1. Combinatorics
2. b-tagging
3. Invariant mass resolution
4. Background modeling: ttbb,ttjj are known only at LO⇒normalization very uncertain.

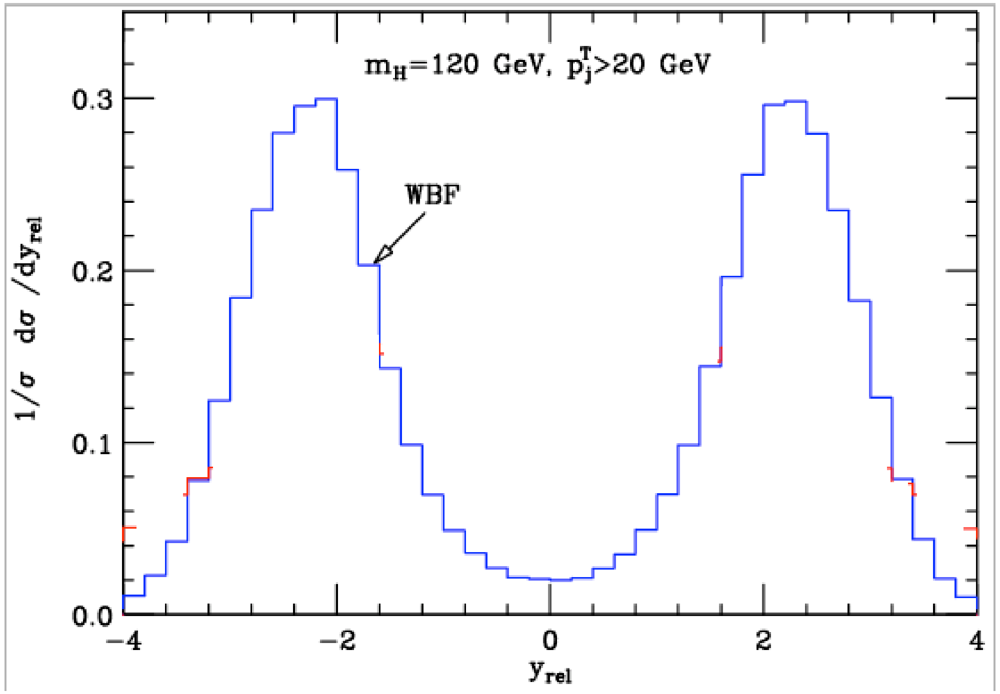
Extremely good knowledge of the detector necessary.

On-going CMS analysis: not ready yet.

Couplings extraction from WBF

Vector boson fusion will play a crucial role in studying the Higgs properties, in many decay channels (ZZ,WW,ττ,γγ). 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.





Central jet veto will be essential to select not only signal from background, but also VBF from QCD production. Impact of minimum bias, multi-parton scattering, forward low-et jets difficult to predict ⇒ data modeling will be needed.

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