Hadronic Final State Working Group

Theory Talks

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14th International Workshop on
Deep Inelastic Scattering

Tsukuba, Japan, April 20 - 24, 2006

Topics were discussed

- Perturbative QCD
  - Fix order calculations (N^kLO, k = 0,1,2)
    - Automated Matrix Element generators (*J. Alwall, M. Worek*)
    - Numerical calculation of one-loop integrals (*A. Daleo*)
    - Inclusive hadron electroproduction at NLO (*B. Kniehl*)
    - NLO correction to Higgs production (*C. Oleari*)
    - Status of NNLO (*V. Del Duca*)
  - Tools for experimentalist, jet algorithm
    - Jet algorithm with flavour information (*G. Salam*)
    - fastJet algorithm (*M. Cacciari*)
    - fastNLO project (*M. Wobisch*)
  - Parton Shower Monte Carlos (LO, NLO)
    - Shower algorithm, matching at LO level (*L. Lönnblad*)
    - Matching at NLO level (*S. Frixione, P. Nason*)

Topics were discussed

- Approximated Cross Sections
  - High energy limit of scattering processes (*Jeppe R. Andersen*)
  - Soft-gluon corrections in hard-scattering processes through NNNLO (*Nicolaos Kidonakis*)
- Resummation
  - Problems in resumming interjet *Et* flows with *kt* clustering (*Mrinal Dasgupta*)
  - Threshold Resummation for Higgs Production in Effective Field Theory (*Feng Yuan*)

Matrix elements at Tree Level

Hellac automated matrix element generator (*Malgorzata Worek*)

Number of Graphs

P. Draggiotis, R. Kleiss Eur. Phys. J. C23, 701 (2002)

QCD with 1 fermion pairs

N=8	N=9	N=10	N=11	N=12	N=13
15495	231280	4016775	79603720	1773172275	43864374400

QCD with 3 (identical) fermion pairs

N=8	N=9	N=10	N=11	N=12	N=13
4362	59424	946050	17258640	355273170	8151299520

roughly grows like **n!**

Matrix elements at Tree Level

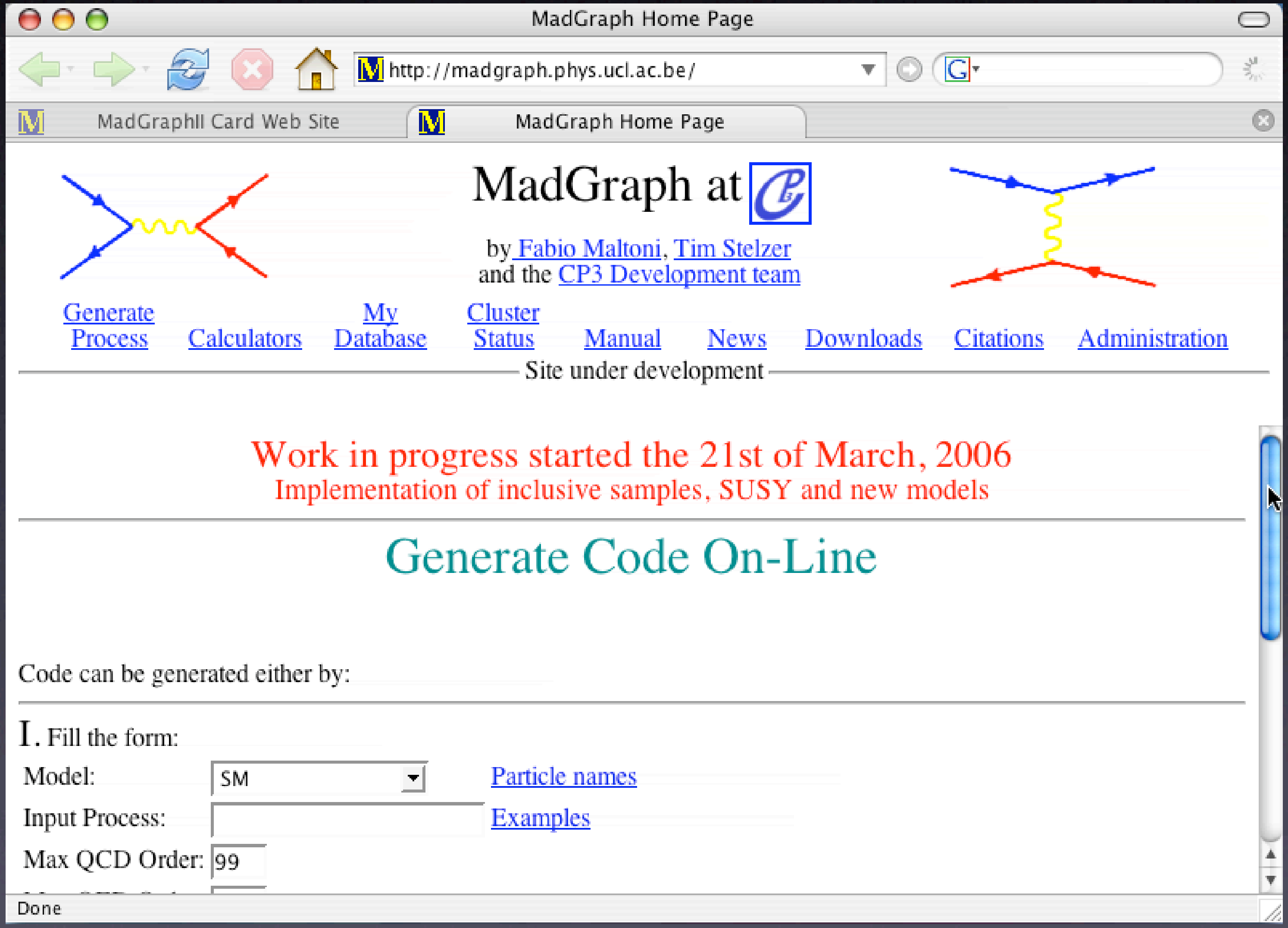
Hellac automated matrix element generator (*Malgorzata Worek*)

- It use an iterative algorithm based on the Dyson-Schwinger equations
- Computes any Standard Model processes
- Helicity, flavor and color sums are performed by Monte Carlo summation
- Computational efficiency is significantly improved : $\mathcal{O}(N!) \longrightarrow \mathcal{O}(N^3)$
- Interfaced to parton shower algorithms
- Unweighted event generation with color flow information

Matrix elements at Tree Level

MadGrap/MadEvent automated matrix element generator (*Johan Alwall*)

- Generates events for any tree level process in SM, MSSM, 2HDM, effHiggs, ...
- Generates unweighted events
- Interfaced to parton shower algorithms
- User friendly graphical and web interface
- Implements the CKKW matching scheme



NLO level

FastNLO: Fast pQCD calculations (*Marcus Wobisch*)

- It is a complementary project to the existing NLO programs
- Produce Exact pQCD Results, Goal: Systematic Precision of 0.1%
- Can be used for any Observable in Hadron-Induced Processes (Hadron-Hadron, DIS, Photoproduction, Photon-Photon, Diffraction)
- Can be used in any Order pQCD
- Concept requires existing Flexible Computer Code (e.g. NLOJET++)
- Save no Time during First Computation (may take Days, Weeks, Months, … to achieve High Statistical Precision)
- Any further Computation is done in Milliseconds

NLO level

FastNLO: Fast pQCD calculations (*Marcus Wobisch*)

- Choose Interpolation Eigenfunctions $E^{(i)}$ (EFs)

$$f(x) = \sum_i f(x^{(i)})\, E^{(i)}(x)$$

- Interpolate PDFs f(x) between Fixed Values $f(x^{(i)})$

$$\sigma_{hh} = \sum_{i,j} f_a(x_1^{(i)}, \mu_f)\, f_b(x_2^{(j)}, \mu_f) \sum_n \alpha_s^n(\mu_r) \sum_{\text{PDFflavors } a} \sum_{\text{PDFflavors } b} c_{a,b,n}(\mu_r, \mu_f) \otimes E_a(x_1^{(i)}, \mu_f) \otimes E_b(x_2^{(j)}, \mu_f)$$

time-consuming

Multiply PDFs / alpha-s later

Compute once!
& Store in Table

Status of NNLO

- The NNLO is relevant where NLO fails to do its job
  - In measurement of α_s the scale variation is the main source of the uncertainty
  - NLO correction is huge: Higgs production
  - NLO effectively is LO: energy distribution in jet cone

Status of NNLO

Analytic method:

- first method
- flexible enough to include a limited class of acceptance cuts by modeling cuts as ``propagators”

Sector decomposition method:

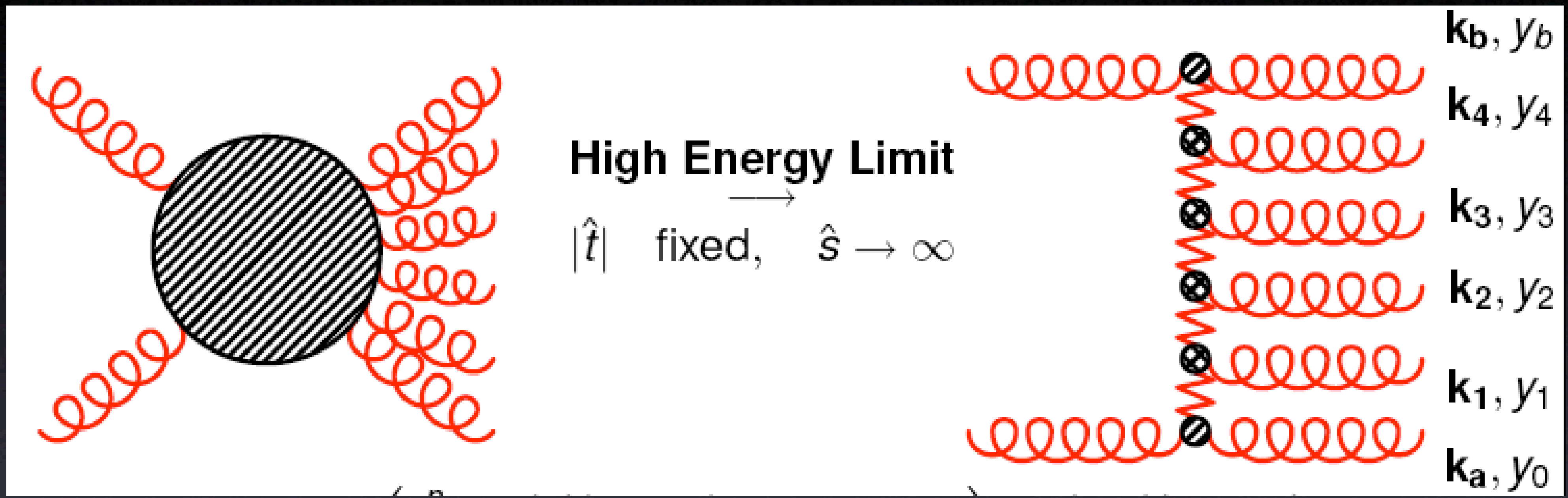
- flexible enough to include any acceptance cuts
- cancellation of divergences is performed numerically
- cannot handle processes with many particles

Subtraction method (under development):

- process independent
- can be automated
- using the subtraction terms the parton shower can be improved

Approximated Cross Sections

High energy limit of scattering processes (*Jeppe R. Andersen*)



In the fully inclusive case: $d\sigma(p_a, p_b) = \Gamma_a(\mathbf{p}_a)\, \underbrace{f(\mathbf{p}_a, -\mathbf{p}_b, \Delta)}\, \Gamma_b(\mathbf{p}_b)$

Solution of the BFKL eq.

$$f(\mathbf{p}_a, -\mathbf{p}_b, \Delta) = \sum_{n=0}^{\infty} \int d\mathcal{P}_n \mathcal{F}_n J_n$$

$$\mathcal{F}_n \sim \prod_{i=1}^{n} V(\mathbf{q}_i, \mathbf{q}_{i+1})$$

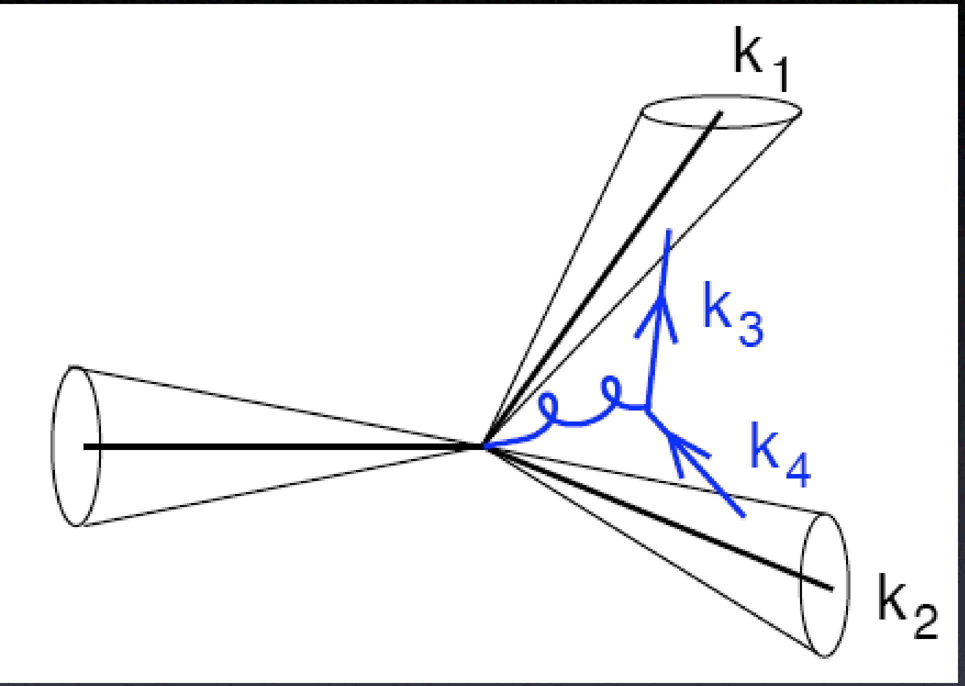
A Monte Carlo technique has been developed to solve the BFKL eq. at NLL level and keep the final state information fully exclusive in such a way that the momentum conservation is maintained.

Jets Algorithms

Infrared Safe definition of jet flavour (*Gavin Salam*)

The physical meaning of the quark and gluon jet is obvious but with normal jet algorithm the sum of the parton flavors in the jet is infrared unsafe:

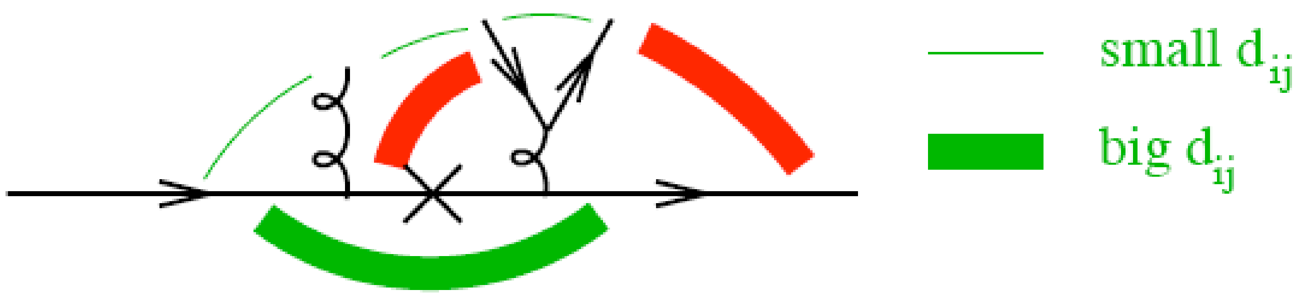
Soft gluon $\longrightarrow$ large angle $q\bar{q}$ is clustered into different jets and contaminates jet flavor



Solution: modify distance measure for quarks to reflect divergences

[Banfi, GPS & Zanderighi, hep-ph/0601139]

$$d_{ij}^{(F)} = 2(1-\cos\theta_{ij}) \times \begin{cases} \max(E_i^2, E_j^2)\,, & \text{softer of } i,j \text{ is quark-like,} \\ \min(E_i^2, E_j^2)\,, & \text{softer of } i,j \text{ is gluon-like,} \end{cases}$$

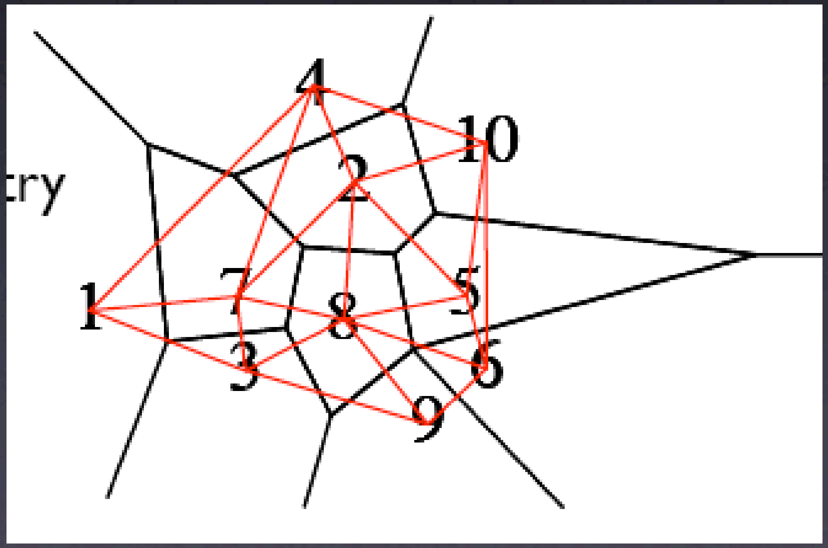


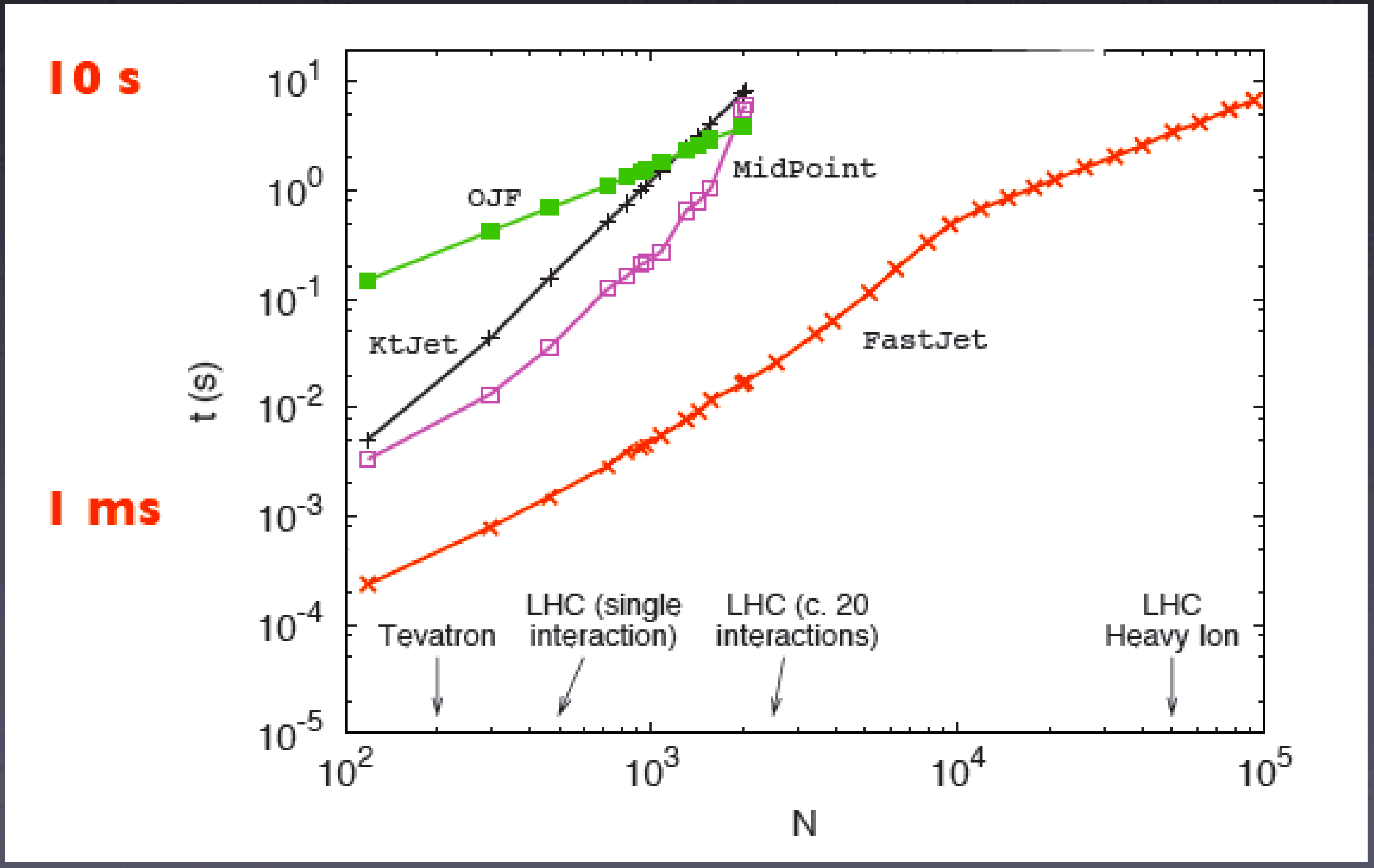
Jet Algorithms

FastJet algorithm (*Matteo Cacciari*)

The main problem of the jet clustering algorithm implementations is to find the nearest neighbor to a particle

The solutions: Store the clustering information (distance between the particle) in a clever way → Voronoi Diagram





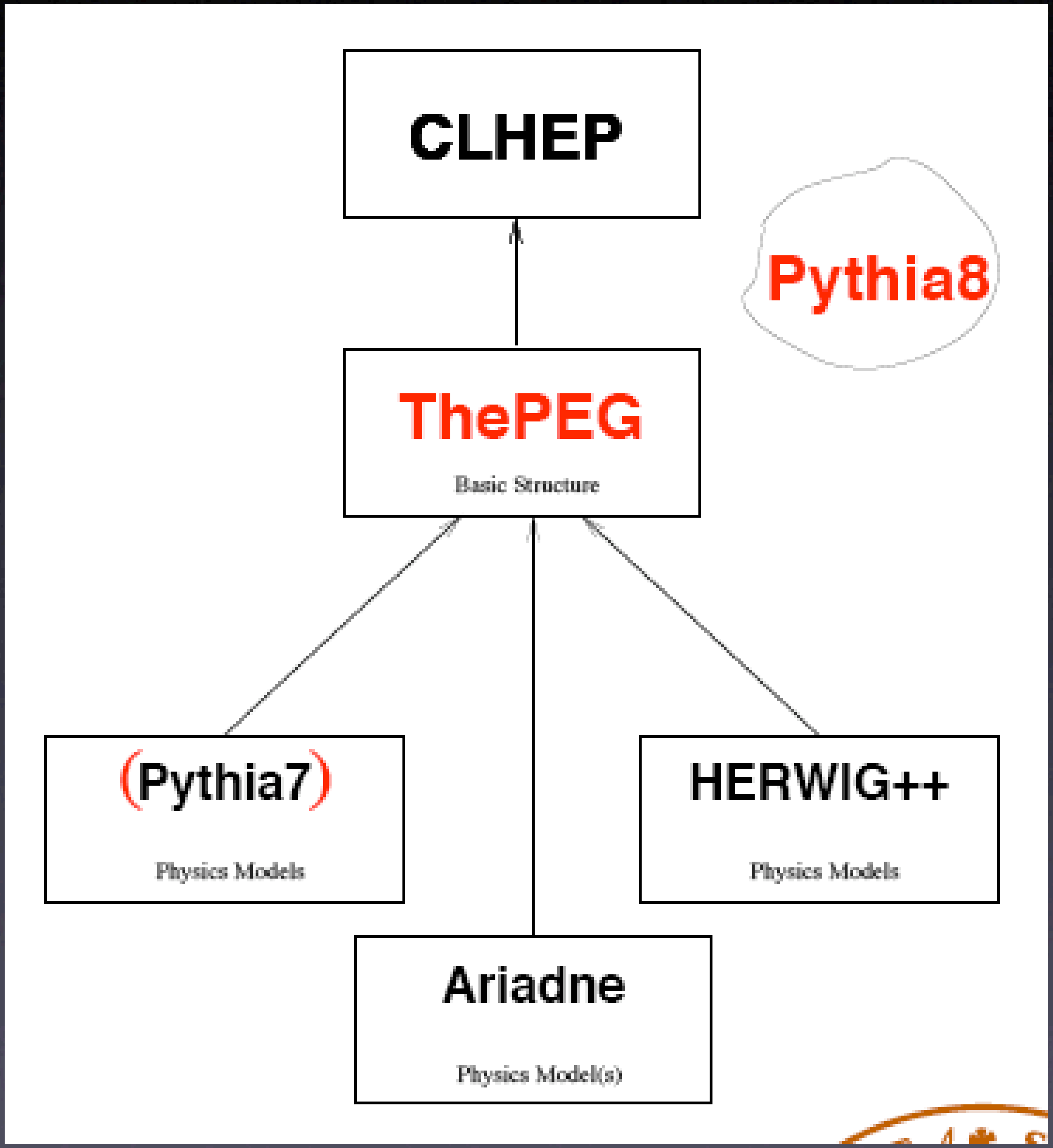
Speed improvement:

$$\mathcal{O}(N^3) \longrightarrow \mathcal{O}(N \log N)$$

Parton Shower

ThePEG, Herwig++ and Ariadne (*Leif Lönnblad*)

- ThePEG is an general framework for implementing models for event generations
- PYTHIA7 includes some basic matrix elements, couple of PDF parameterizations, remnant handling, initial- and final-state parton showers, Lund string fragmentation and particle decays.
- HERWIG++ includes a new parton shower algorithm, improved cluster fragmentation, improved hadron decays. Mainly e+e−, but also Drell-Yan in hadron collisions.



Parton Shower

Current activities on ThePEG, Herwig++, Ariadne

THEPEG:

- Documentation
- Basic CKKW ME/PS matching facilities
- Interface to external ME generators
- Spin and Helicity stuff ready

HERWIG++:

- Initial state PS (with CKKW)
- SUSY/BSM stuff
- Multiple Interactions à la JIMMY
- All the rest. . .

ARIADNE:

- Dipole shower with CKKW.
- LDC model with multiple interactions.

NLO with Parton Shower

NLO with parton showers with positive weight (*Paolo Nason*)

- Proof of concept: MC+NLO with positive weight possible and easy
- Final state radiation easy; Initial state radiation presents no problems
- Interface to different SMC's under studies
- Formulation of general method for NLO processes under work
- Implemented for $pp \to ZZ$ process

The NLO generation of the hardest emission is performed according to

$$d\sigma = \bar{B}(v, \mu_v) d\Phi_v \left[\Delta(v, 0) + \Delta(v, k_T(v, r)) \frac{R(v, r)}{B(v)} d\Phi_r \right] ,$$

where

$$\bar{B}(v) = B(v) + V(v) + \int d\Phi_r \, [R(v, r) - C(v, r)]$$

$$\Delta(v, p_\mathrm{T}) = \exp\left[-\int \frac{R(v, r)}{B(v)} \theta(k_T(v, r) - p_\mathrm{T}) d\Phi_r \right] ,$$

MC@NLO

(*Stefano Frixione*)

1. Choose your favorite MC, and compute analytically the NLO cross section". This is an observable-independent, process-independent procedure, which is done once and for all.

2. Implement the NLO matrix elements of the process according to the subtraction-based formalism of FKS. This is the only non-trivial step necessary in order to add new processes.

3. Add and subtract the MC counterterms, computed in step 1, to what computed in step 2. The resulting expression allows one to generate the hard kinematic configurations, which are eventually fed into the MC showers as initial condition.

IPROC	IV	IL_1	IL_2	Spin	Process
–1350–IL				✓	$H_1H_2 \to (Z/\gamma^* \to) l_{\rm IL} l_{\rm IL} + X$
–1360–IL				✓	$H_1H_2 \to (Z \to) l_{\rm IL} l_{\rm IL} + X$
–1370–IL				✓	$H_1H_2 \to (\gamma^* \to) l_{\rm IL} l_{\rm IL} + X$
–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				×	$H_1H_2 \to \gamma^* (\to \sum_i f_i f_i) + X$
–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				×	$H_1H_2 \to t\bar{t} + X$
–2000–IC				×	$H_1H_2 \to t/\bar{t} + X$
–2001–IC				×	$H_1H_2 \to \bar{t} + X$
–2004–IC				×	$H_1H_2 \to t + X$
–2600–ID	1	7		×	$H_1H_2 \to H^0 W^+ + X$
–2600–ID	1	i		✓	$H_1H_2 \to H^0 (W^+ \to) l^+_i \nu_i + X$
–2600–ID	-1	7		×	$H_1H_2 \to H^0 W^- + X$
–2600–ID	-1	i		✓	$H_1H_2 \to H^0 (W^- \to) l^-_i \bar{\nu}_i + X$
–2700–ID	0	7		×	$H_1H_2 \to H^0 Z + X$
–2700–ID	0	i		✓	$H_1H_2 \to H^0 (Z \to) l_i l_i + X$
–2850		7	7	×	$H_1H_2 \to W^+ W^- + X$
–2850		i	j	✓	$H_1H_2 \to (W^+ \to) l^+_i \nu_i (W^- \to) l^-_j \bar{\nu}_j + X$
–2860		7	7	×	$H_1H_2 \to Z^0 Z^0 + X$
–2870		7	7	×	$H_1H_2 \to W^+ Z^0 + X$
–2880		7	7	×	$H_1H_2 \to W^- Z^0 + X$

MC@NLO

Current activities:

- Adding new processes such as dijets, Higgs through VBF, Wt-mode in single top, anomalous couplings in WZ, spin correlations in $t\bar{t}$ and single top
- general formulation of positive MC@NLO according to Nason's algorithm

Conclusion/Comments/Outlook

- At Born level we are very successful
  - we can calculate basically any process based on several theory (SM, MSSM, ...)
  - Don't forget this is *JUST* LO QCD ➡ Large scale uncertainty
  - In order to have an automated NLO code we need color and helicity correlated TREE level matrix elements

Conclusion/Comments/Outlook

We have good chance to build automated NLO program

- we have to deal with the IR singularities:
  I think the best method is the dipole subtraction scheme → computed in NLOJET++
- we need automated matrix element generator at one-loop level

Conclusion/Comments/Outlook

Why only positive weights?

- One of the reason is about 20 years old; detector simulation algorithms are too slow
- The other is more physiological than practical; in the detector every event is unweighted
- I cannot see any physical reason not to use negative weights

Conclusion/Comments/Outlook

It is clear that without negative weights we cannot improve parton shower algorithm:

- we cannot do the matching to NLO in the proper way
- no way to treat the color properly and go beyond the $1/N_c^2$ approximation
- no way to include higher order effects

➡ hep-ph/0601021