Introduction of GR@PPA event generator

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- Introduction
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- Application of the LO generators in hadron collisions
- Summary

Introduction

GRACE :

1) An automatic source code generator to calculate Feynman diagrams.

2) Using CHANNEL/BASES/SPRING libraries.

In principle, GRACE provides a framework of a phase space integration and (unweighted) event generation at once for any processes even in the higher order.

But once we want to make the processes in the hadron collisions, we encounter huge number of diagrams, which consume much CPU time…

GR@PPA :

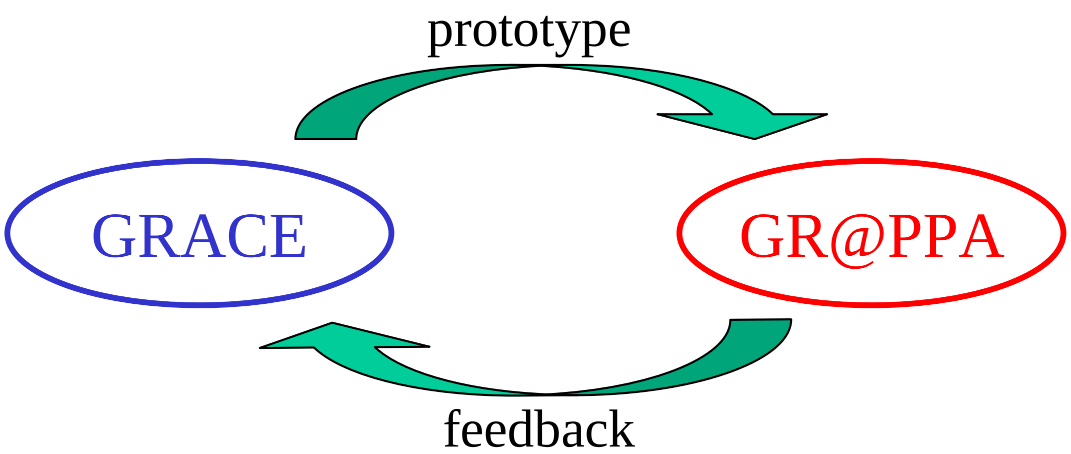
1) Event generator for hadron collisions.

2) Generic treatment of parton flavor in GRACE output code.

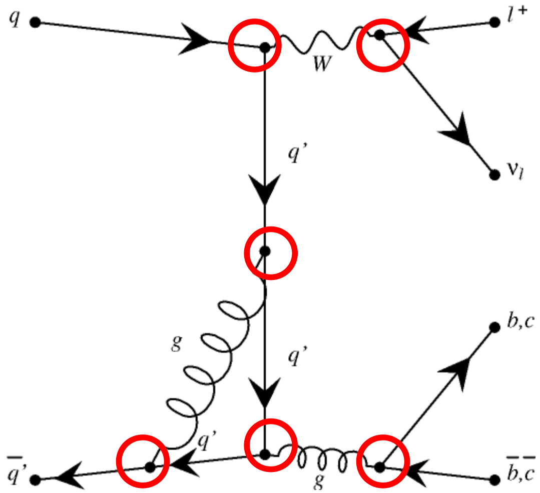
3) Previous work can be seen in bbbb process; CPC 151(2003)216.

Quarks and leptons can be treated as the generic fermion with mass and charge differences, so that event generation cycle can be much faster that the automated processes of GRACE.

Schematic view



Symbolic treatment of flavor(mass) & coupling.



- user defined process
- user customizable
- running not so fast

Suitable for study of specified signals rather than background estimation.

- process specific
- optimized kinematics
- easy to use
- running fast

Suitable for mass production of background or specified signals.

GR@PPA generator

Process :

$$p\,p(\bar{p}) \rightarrow j\,W + k\,Z/\gamma^* + l\,H + m\,\gamma + n\,\text{jets} + X;$$

$$(j + k + l + m + n \leq 6,\ \ j,k,l,m,n = 1,2,3,\ldots)$$

(ALPGEN = 8)

ex. W + jets process :

	GRACE	GR@PPA	
W + 1 jet :	288	6	diagrams
+ 2 jets:	4752	64	
+ 3 jets:	37264	596	
+ 4 jets:	∞	4456	

Current processes

Boson(s) + n jets :

W + n jets	(n = 0,1,2,3,4)
WW + n jets	(n = 0,1,2)
Z/γ^* + n jets	(n = 0,1,2,3)
Z/γ^* Z/γ^* + n jets	(n = 0,1,2)
Z/γ^* W + n jets	(n = 0,1,2)

Note that the bosons are decayed into fermions, so that the decay correlation is reproduced correctly.

QCD jets :

n jets	(n = 2,3)
bbbb	
t t	

In tt proc., 3-body decay are considered, that is, calculating 6-body kinematics.

Only LO is available now…

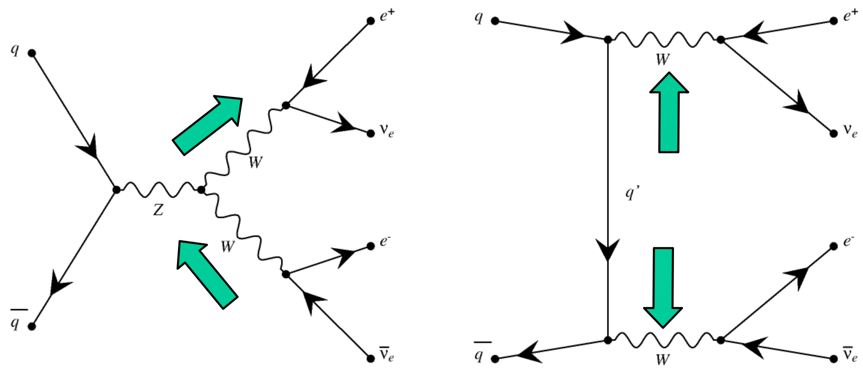
Ever growing processes if users request!!

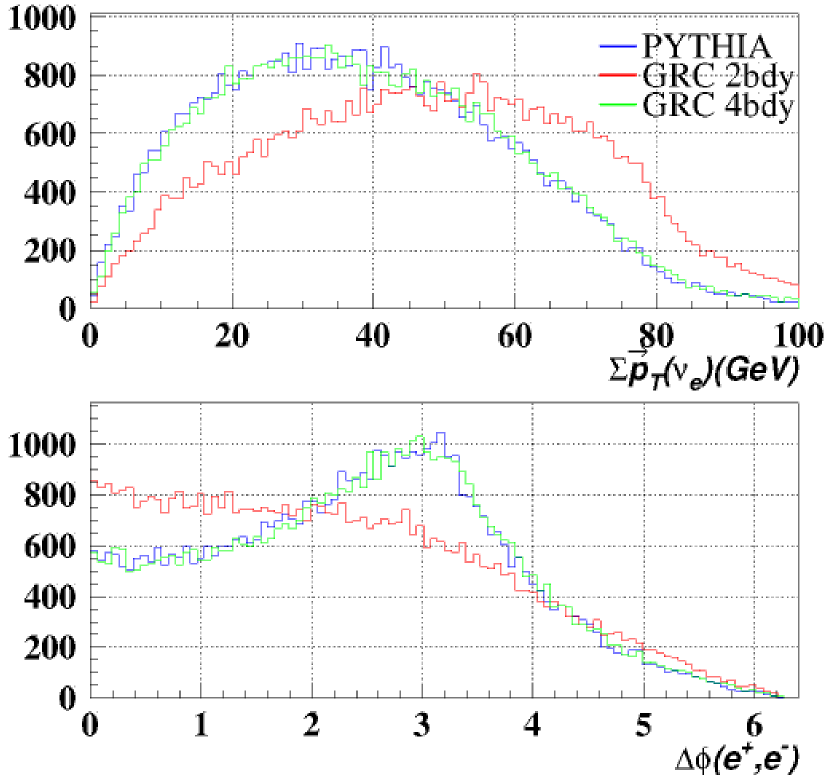
Double resonance proc.

Memo:

$$\delta(q^2 - M_W^2) \Rightarrow \frac{1}{\pi}\int \frac{dq^2}{(q^2 - M_W^2)^2 + M_W^2 \Gamma_{W(tot)}^2} \times \Gamma_{W(part.)}$$

The 2-body ME including decay kinematics is not enough to reproduce decay correlation.



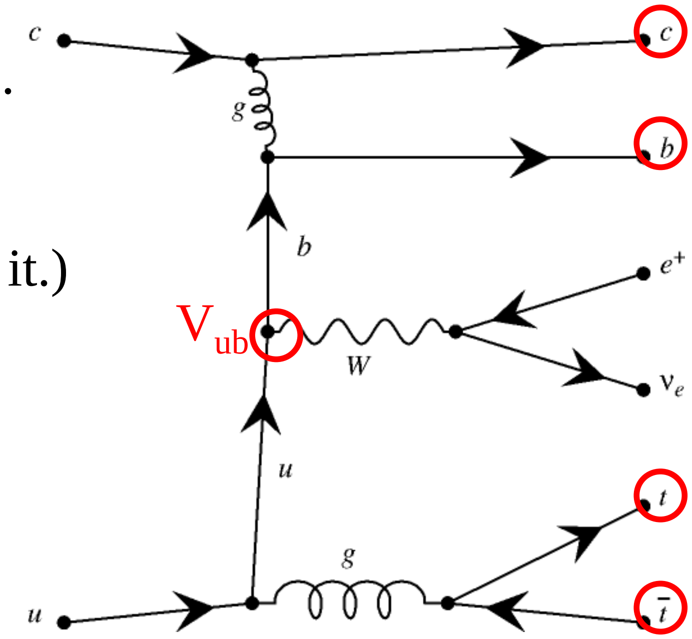


Decay products do not know the spin info. of the mother bosons.

In this case, we calculate the full 4-body ME. PYTHIA also calculates 4-body ME for di-boson productions.

Fermion masses and 3 x 3 CKM

One of remarkable features is that heavy flavor jets(b,t) are produced by the same algorithm to make light flavor jets(g,u,d,s,c). Thus, the odd number of heavy flavor jets is also produced in multi-jet events (Note ALPGEN, MadEvent is hard to make it.)



Tricky example: (background of ttH prod.)

$$c+u \rightarrow W^+(e^+\nu_e)+\underline{t+\bar{t}+b+c}$$

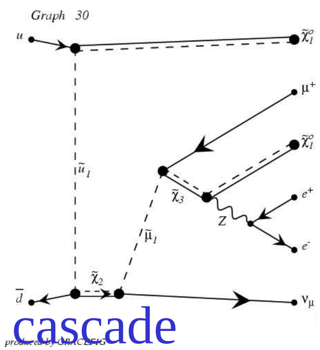
All massive fermions.

The flavors of jets are simply controlled by the input arguments.

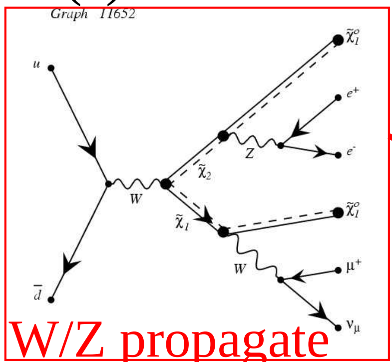
SUSY process

We can also make SUSY processes.

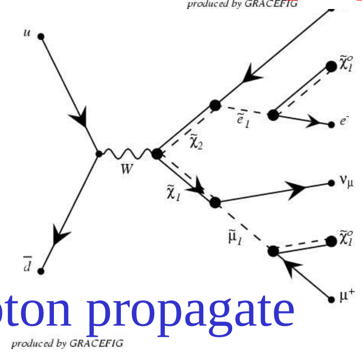
Ex. SUSY golden channel at Tevatron/LHC(?)



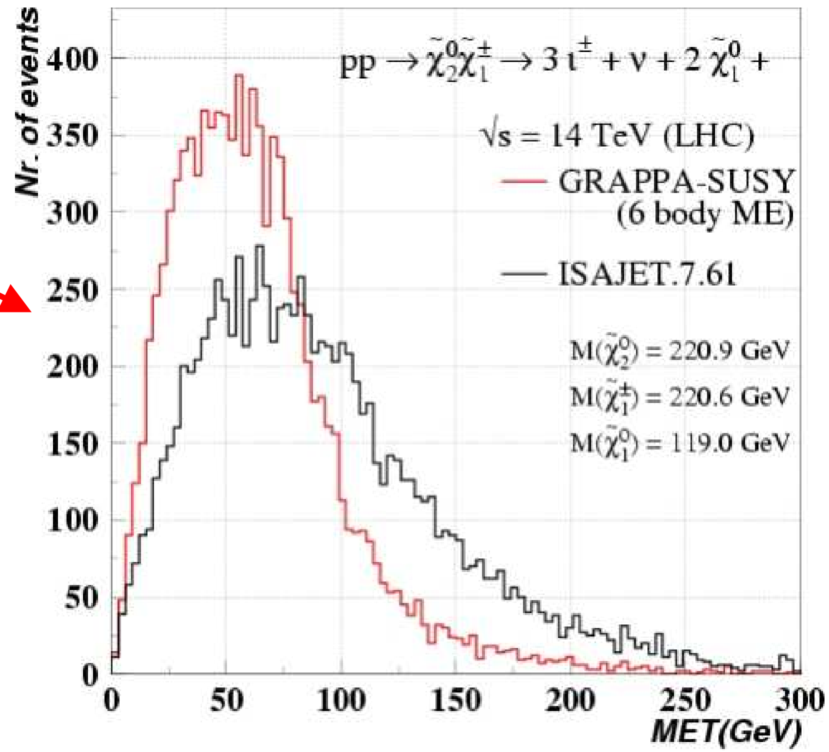
cascade



W/Z propagate



slepton propagate



If you use GRACE, you have 23750 diagrams!!

Note that decay correlation appears in 6-body ME.

Automatic generation system in GRACE at hadron collisions (in future)

GRACE has two generation cycles.

User input

Graph generation

Makes graph structure based on the initial/final state particles(flavor) and coupling order.

The extension will be done in this "graph generation" cycle.

Ex. u-quark => proton, gluon => jet

Code generation

Makes (fortran) code based on this graph structure.

If necessary, PDF is embedded into the kinematics.

Recipe for automatic "graph" generation

0) Start with current GRACE system.
    Initial and final state is well-defined.

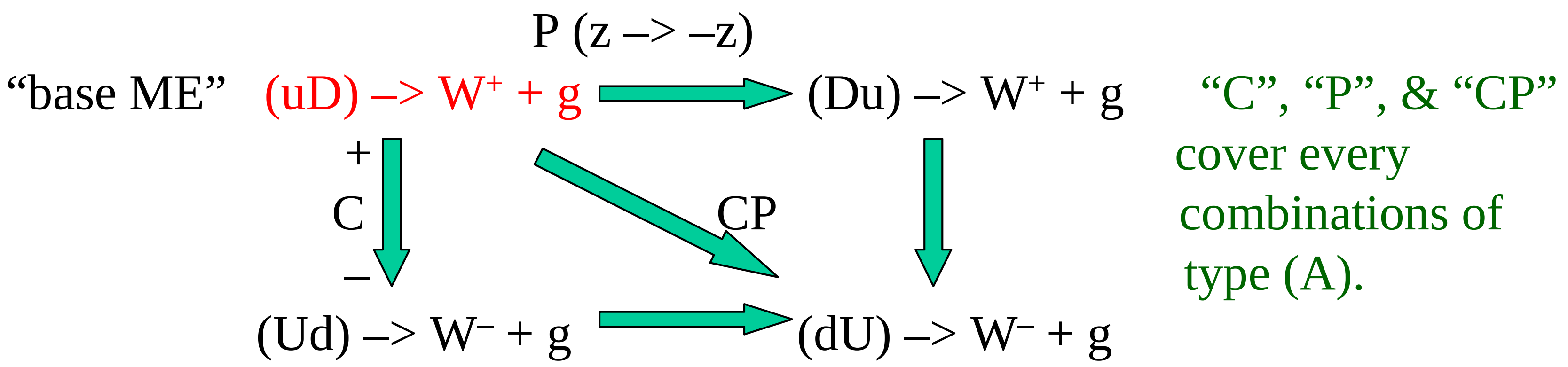
1) For example, let's make "W + 1 jet" process. => pp –> W + jet

2) Then, find all possible combinations of the sub-processes.

Initial partons : (uD) , (dU) , (Du) , (Ud) , … (A)
(ug) , (dg) , (gu) , (gd) , (Ug), (Dg) , (gU) , (gD) … (B)

Final partons : u , d , U, D, g

3) Now, consider "Charge" and "Parity" transformation:



then, DO diagram reduction except "base ME".

Rule of base ME : positive (≥ 0) side.

$$
\overbrace{\begin{matrix} +4/3 \\ +3/3 \\ +2/3 \\ +2/3 \\ +1/3 \\ +1/3 \\ 0 \\ 0 \\ 0 \\ -1/3 \end{matrix} \begin{pmatrix} (uu) \\ (uD) \\ (ug) \\ (DD) \\ (Dg) \\ (ud) \\ (gg) \\ (uU) \\ (dD) \\ (UD) \end{pmatrix}}^{\text{initial}} \quad \overbrace{+ \; n \begin{pmatrix} W+ \\ Z \\ H \end{pmatrix} + \; m \begin{pmatrix} u \\ D \\ g \\ d \\ U \end{pmatrix} \begin{matrix} +2/3 \\ +1/3 \\ 0 \\ -1/3 \\ -2/3 \end{matrix}}^{\text{final}}
$$

$$\Sigma(n) + \Sigma(m)$$

Under charge & particle/anti-particle conservations.

W + 1 jet	3	
W + 2 jets	14	base MEs
W + 3 jets	20	

Recipe of automatic "code" generation

1) Make kinematics.

The dimension of numerical integration is

$$N = \underbrace{2}_{x1,x2} + \underbrace{3\,(n-1)}_{\text{n-body}} + \underbrace{1}_{\text{ini. Flav.}} + \underbrace{1}_{\text{jets}} \ \underbrace{(+\ 1)}_{\text{decay}} .$$

2) Decide initial flavors by weight of PDF of the initial hadron.

3) Decide final state flavors if the graph has "jet".

The "jet" flavors are characterized by the number of W bosons.

(the jet flavor is decided by the weight of $|CKM|^{2n}$, where n is # of W's.)

4) Find singularities.

This generalization is not so difficult.

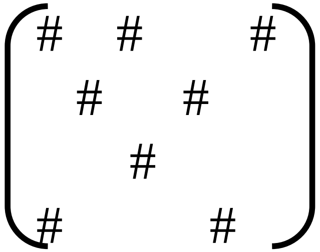
That's it (!?).

Generation speed

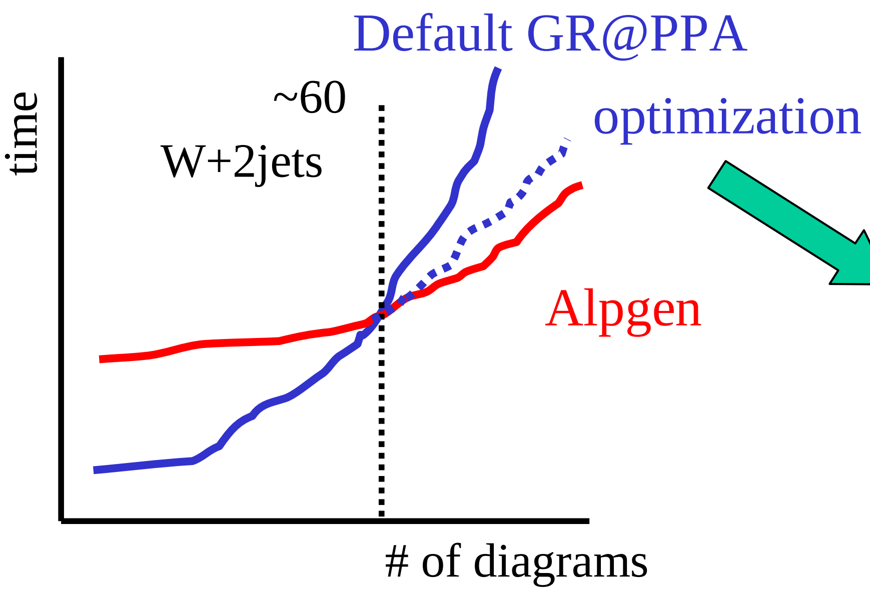
Generation speed is also important factor…

Amplitude is calculated by looped over

$$|Amp|^2 = \{ \Sigma(\text{helicity}) \times \Sigma(\text{color}) \times (\#\ \text{of diagrams}) \}^2$$



But most of elements are null (sparse matrix) if massless particles(photon or gluon or massless fermion) appear.



We sacrifices CPU time to assign all finite-mass fermions, event u- or d-quarks.

Example : q + g –> W + q + g + g

(helicity state) : 128

(non-zero state) : 64

CPU time : 40 % up.

(depends on number of gluons.)

Application of LO-QCD generator at hadron colliders

The lowest order(LO) calculation only gives rough estimation at hadron collisions.

- no scale stability
- no infrared/collinear safety

⇒ NLO may solve it.

Thus the application is limited in hadron colliders.

Here, I would like to show some practical examples to use the LO generators.

1) shape analysis

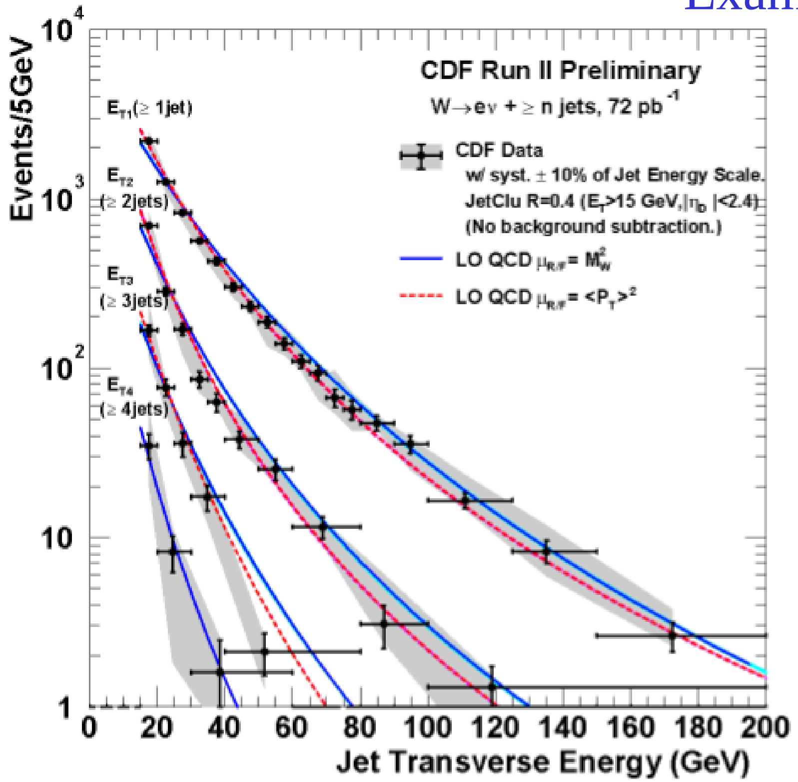
⇒ used as the fitting of background shape.

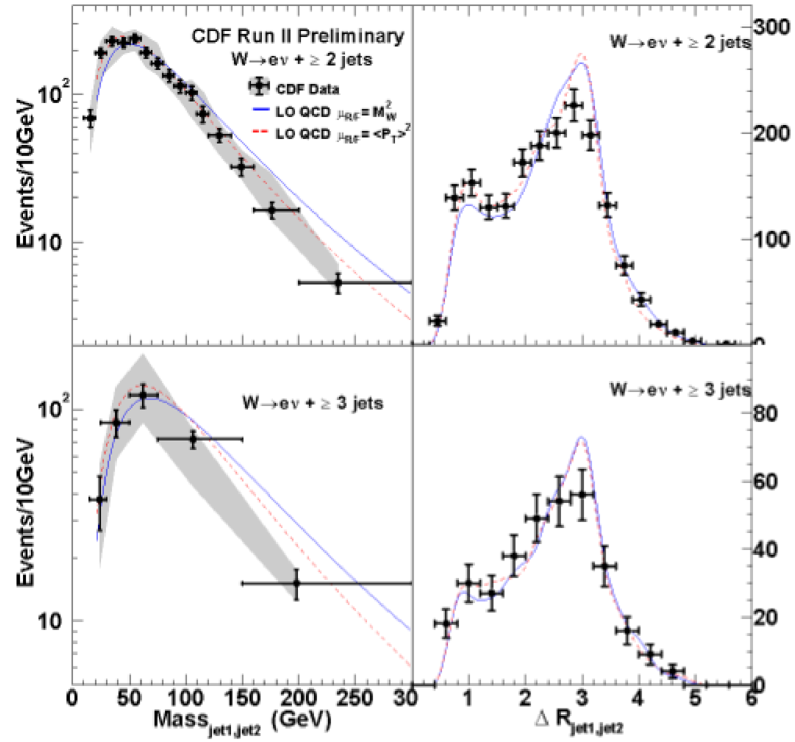
2) ratio analysis

⇒ used as the overall estimation of background content.

Shape analysis

Example : W + jets events at CDF Run II.





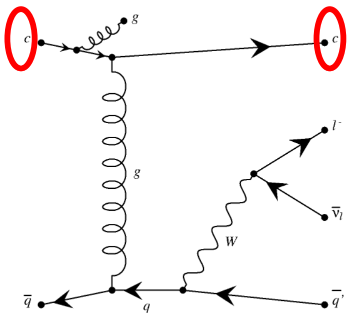
- Jet is clustered by fixed cone algorithm (JetClu) with $R_c = 0.4$.
- Systematics of jet => parton ~ 10 % .
- Two enery scale $\mu_{R/F} = M_W^2$, $<p_T>^2$.
- Normalized by data .

Heavy flavor fraction

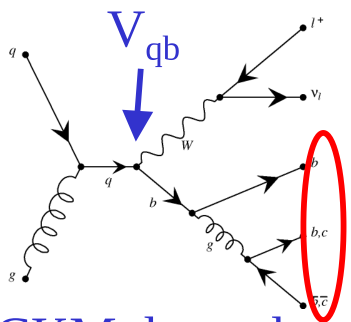
The overall prediction does not make sense in LO calculation. However, the ratio of physics observables is well-motivated and predictable.

Heavy flavor fraction in W + jets evts:

$$N_{W+bb} = f_{bb} \times N_{W+jets}$$

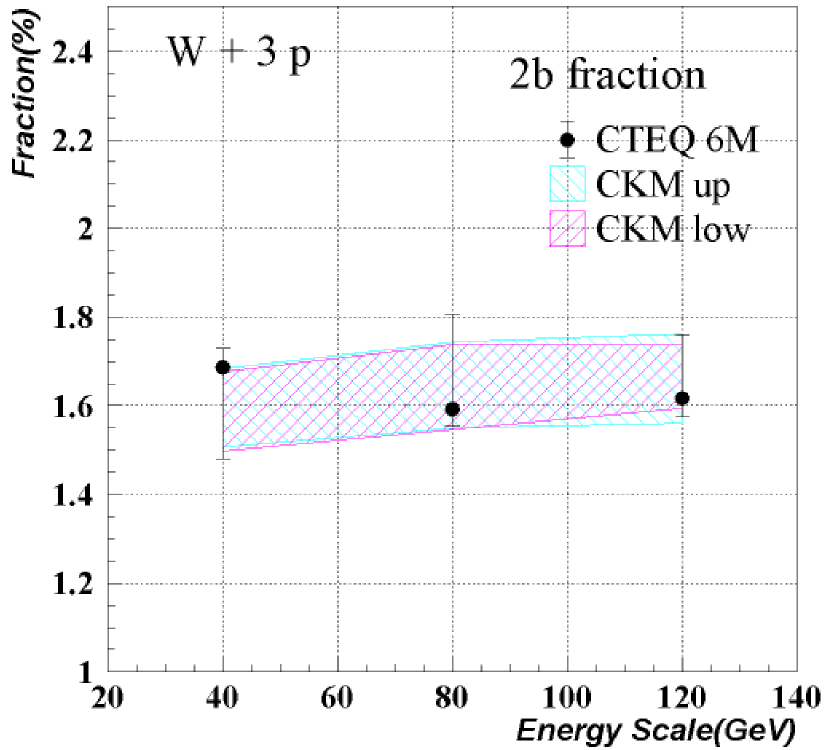


PDF dependence



CKM dependence

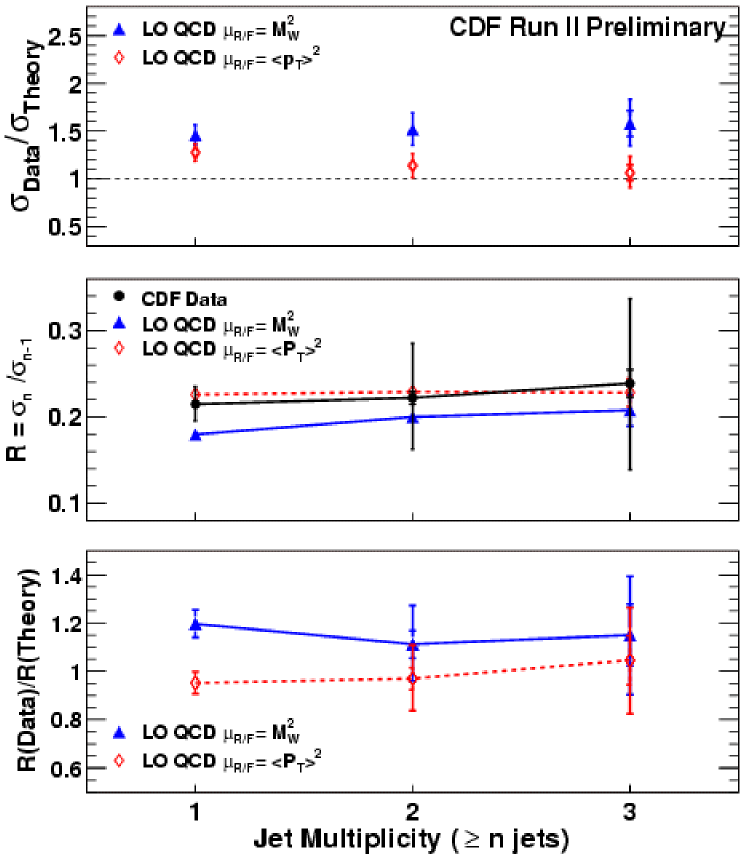
2b fraction in W + 3 jets events

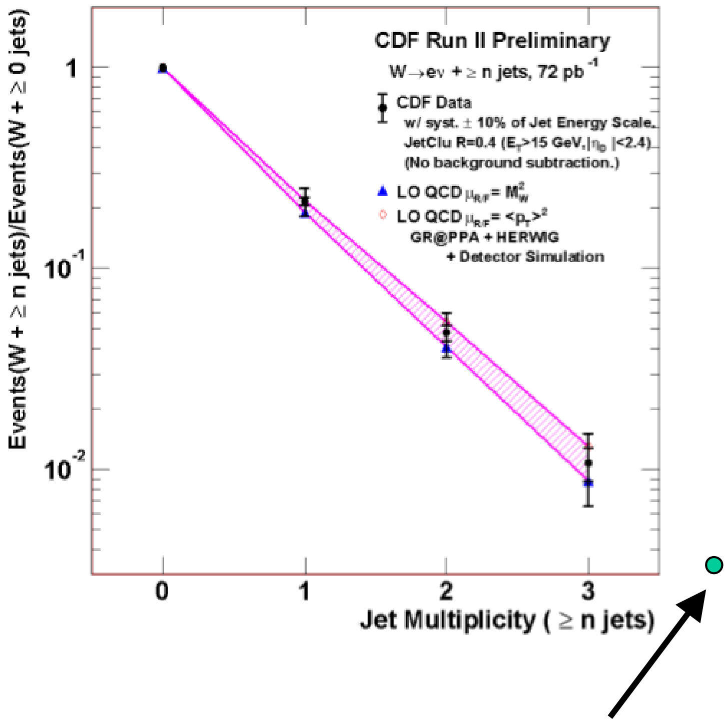


Expects no scale dependence and calculation order if we require high pT jets.

Looking at ratio

Our ME-PS is not out-of-tune.





How many 4 jets??

Inclusive to exclusive measurement

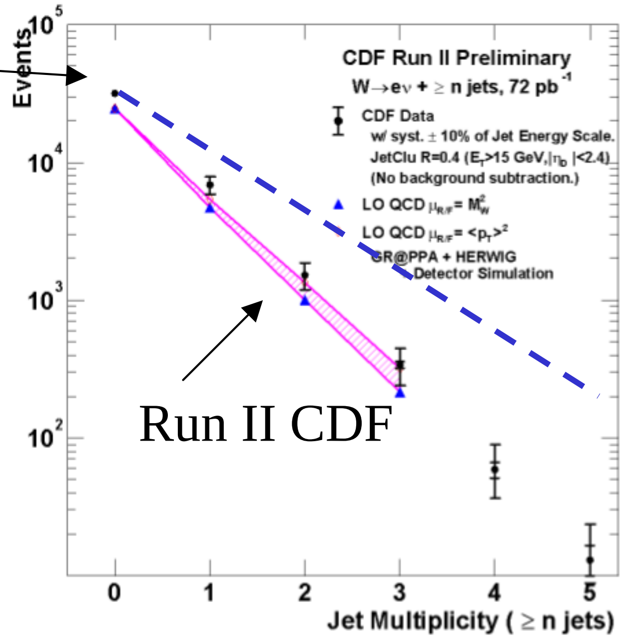
Even if ME+PS describes real data well, the systematics of the “inclusive” jet analysis may be worse at LHC energy region.

This decline is not steep than Tevatron.

Expected W+jets prod. in LHC.

Jet/pb	0	1	2	3	4
W	9327	2304	829	319	129
Wbb	9.34	9.85	6.82	4.18	2.39

MC4LHC 2003



At CDF, we are studying

1) kt-clustering in jet production
   (but inclusive-kt-cluster)
2) CKKW
   (CKKW-MadEvent produced by Steve.)

Summary

We have developed a newly event generator, GR@PPA, which is based on the automatic Feynman amplitude calculation system, GRACE. GR@PPA is developed for usability of GRACE system in hadron collisions. Both of them complementary feedback each other.

Some LO processes which will be important processes in Tevatron/LHC are included in GR@PPA generator. And GR@PPA also has a possibility to add NLO processes. The processes ever-increase if users require them.

We are also thinking the extension of GRACE system for hadron collisions.

Some practical examples to use the LO calculation were shown. At LHC era, the inclusive measurement may be worse than Tevatron. Experimental and theoretical scheme is needed precisely to measure/count jets.

Pay attention to Tevatron !!