GR@PPA Event Generator

GRACE-based event generators for hadron collision interactions

Shigeru Odaka
KEK/IPNS
shigeru.odaka@kek.jp

GR@PPA

GRace @ Proton-Proton/Anti-proton

An extension of GRACE to hadron-collision interactions

$$\frac{d\sigma_{h_1h_2\to A+X}(s)}{d\Phi_A} = \sum_{a,b,i}\int_0^1 dx_1 \int_0^1 dx_2 f_{h_1\to a}(x_1,\mu_F^2) f_{h_2\to b}(x_2,\mu_F^2)\delta(\hat{s}-x_1x_2s)\frac{d\hat{\sigma}_{ab\to A_i}(\hat{s})}{d\hat{\Phi}_{A_i}}$$

Flavor sum

Parton distribution function (PDF)

GRACE

Initial state: variable flavor/momentum according to PDF
Final state: generalization of quarks and gluons as "jets"

General features

Derivation of many subprocesses from a base process

C/P inversions, flavor/mass/coupling exchanges

➔ Reduction of the program size

e.g., all $Z + 1$ jet production processes are derived from $u\bar{u} \to Z + g$ and $ug \to Z + u$.

Multi-process support

Automatic event mixing

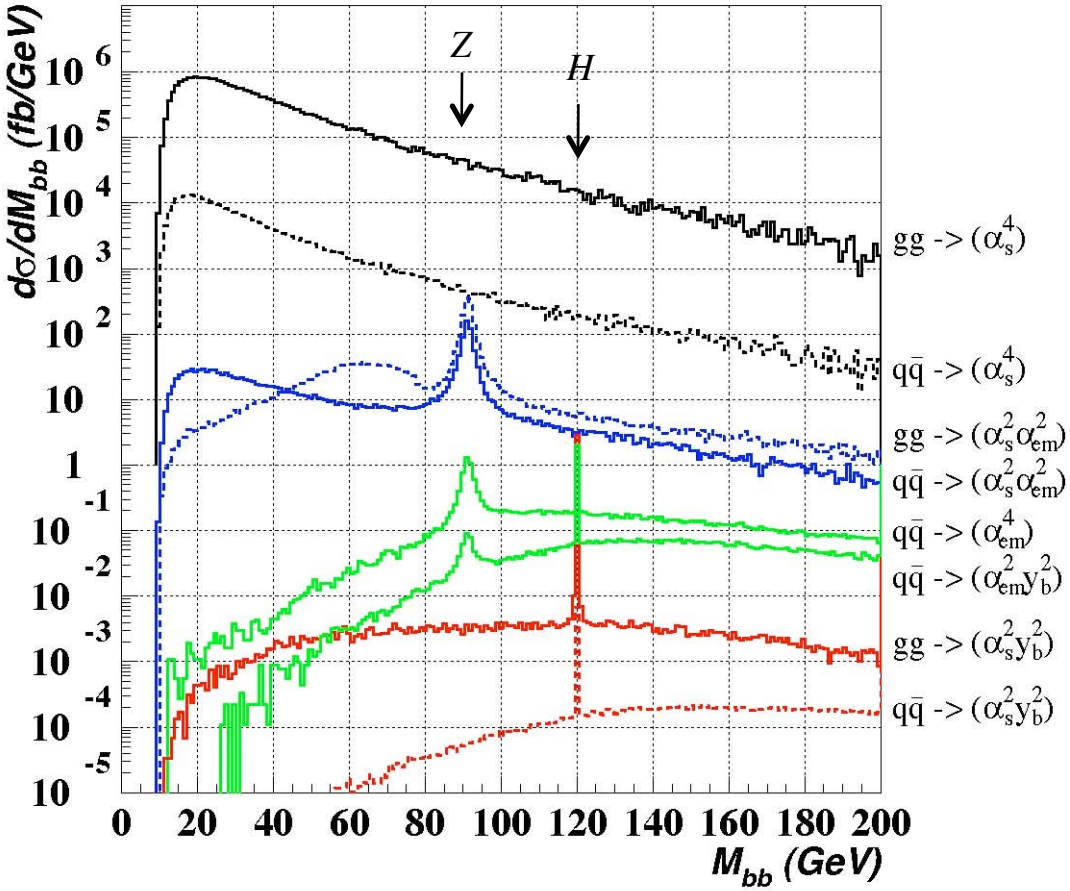
Interface to general-purpose event generators

GR@PPA is a parton-level event generator.

History of GR@PPA

- Jan. 2000: NLO Working Group was established.
- Oct. 2000: ACAT2000 (FNAL)
  - Talk by S. Odaka, *Integration of GRACE and PYTHIA*
- Feb. 2001: Tsuno named the 4*b* event generator as GR@PPA_4b.
- Apr. 2002: GR@PPA_4b 1.0 released
  - All $b\bar{b}b\bar{b}$ production processes including those mediated by *Z* and *H*
  - Interface to PYTHIA 6.1
  - S. Tsuno *et al.*, Comput. Phys. Commun. 151 (2003) 216; hep-ph/0204222
- Apr. 2003: GR@PPA_4b 2.0 released
  - LHA interface supported
- Feb. 2004: GR@PPA_ALL 2.6 released
  - *W* + (0-3) jets, *Z* + (0-2) jets, diboson (W^+W^-, *ZW*, *ZZ*), top pair were added.
- Feb. 2006: GR@PPA 2.7 released
  - *W* + 4 jets, *Z* + (3-4) jets, diboson + (1-2) jets, top pair + 1 jet, QCD (2-4) jets were added.
  - S. Tsuno *et al.*, Comput. Phys. Commun. 175, 665 (2006); hep-ph/0602213

GR@PPA_4b


Z
H
$d\sigma/dM_{bb}$ (fb/GeV)
M_{bb} (GeV)
gg -> (α_s^4)
qq̄ -> (α_s^4)
gg -> ($\alpha_s^2\alpha_{em}^2$)
qq̄ -> ($\alpha_s^2\alpha_{em}^2$)
qq̄ -> (α_{em}^4)
qq̄ -> ($\alpha_{em}^2 y_b^2$)
gg -> ($\alpha_s^2 y_b^2$)
qq̄ -> ($\alpha_s^2 y_b^2$)

$\sqrt{s} = 14\ TeV$ at LHC (CTEQ6L, $p_T > 20\ GeV, |\eta| < 2.5, \Delta R < 0.4$)

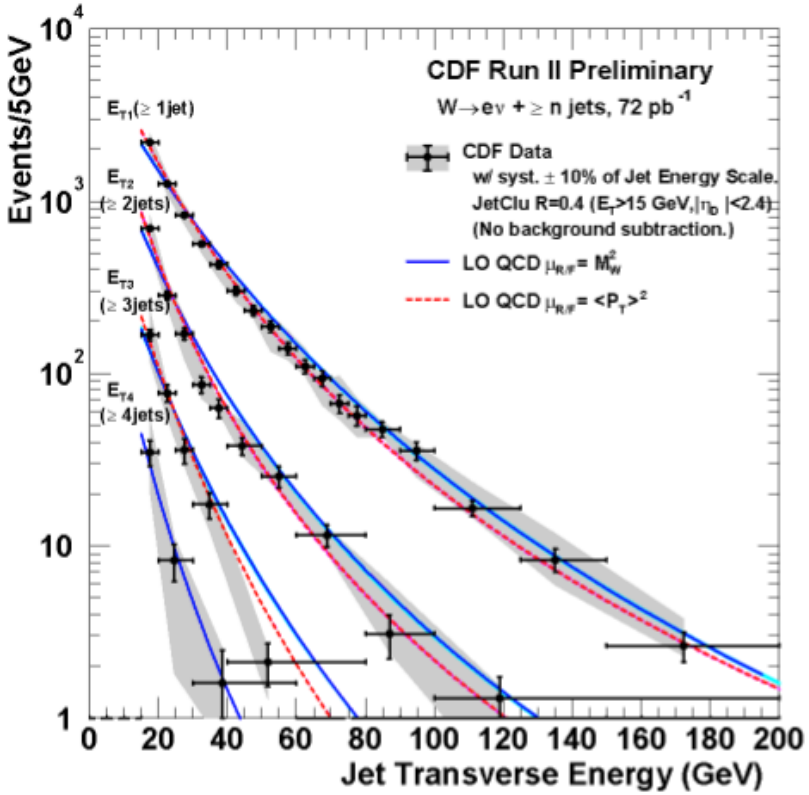
Condition given at the MC4LHC WS 2003

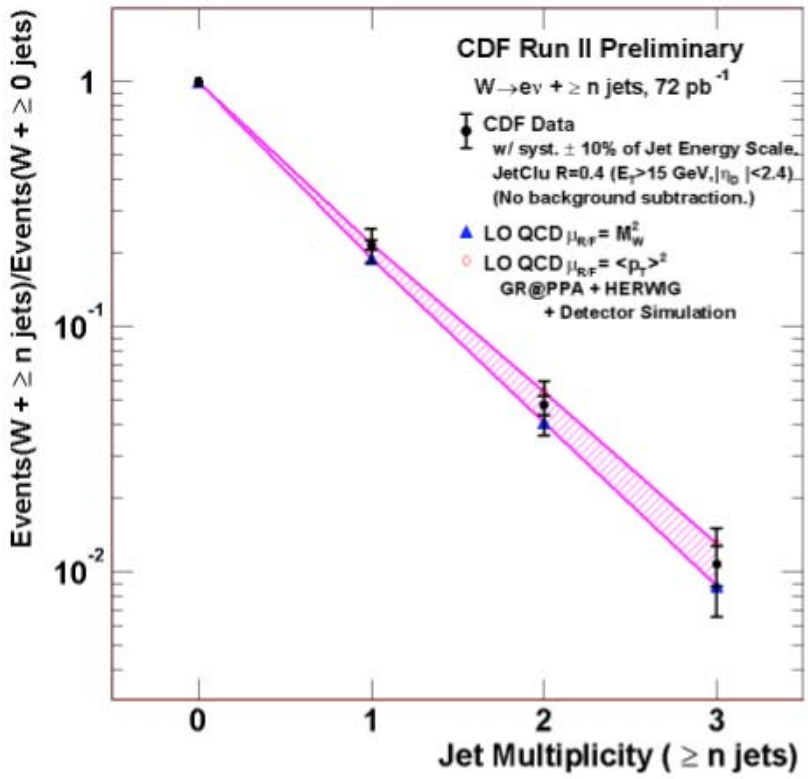
Cross section (pb)	Number of jets				
$W^-(e^-\nu_e)$ + n jets	0	1	2	3	4
ALPGEN	3904(6)	1013(2)	364(2)	136(1)	53.6(6)
MadEvent	3902(5)	1012(2)	361(1)	135.5(3)	53.6(2)
GR@PPA	3905(5)	1013(1)	361.0(7)	133.8(3)	53.8(1)

$W^+(e^+\nu_e)$ + n jets	0	1	2	3	4
ALPGEN	5423(9)	1291(13)	465(2)	182.8(8)	75.7(8)
MadEvent	5433(8)	1277(2)	464(1)	182(1)	75.9(3)
GR@PPA	5434(7)	1273(2)	467.7(9)	181.8(5)	76.6(3)

W + jets at Tevatron Run II

PhD thesis of S. Tsuno (U. Tsukuba)





GR@PPA has some advantages against other event generators:

Heavy particle decays in matrix elements

Top pair production is a six-body process.

➔ Exact spin/phase-space effects at the tree level

Support of multi-jet production processes

However,

Reliable only in those events having a large separation between jets, due to a double-count problem

Double-count problem

A double counting of parton radiation effects in matrix elements (ME) and parton showers (PS) or PDF

The problem exists even if we do not apply PS, since the same radiation effects are included in PDF.

Several solutions (ME-PS matching) have been proposed and implemented in event generators.

ME correction in PYTHIA/HERWIG

CKKW method in Sherpa and MLM prescription in AlpGen for multi-jet productions

a subtraction method in MC@NLO

a suppression method in POWHEG

NLO Working Group (NLO-WG)

http://atlas.kek.jp/physics/nlo-wg/index.html

A collaboration of people from Minami-Tateya group
and ATLAS-Japan group

Goal
Development of NLO event generators for multi-particle production processes at hadron collisions based on GRACE

Dream
Automatic generation of NLO event generators

The purpose of GR@PPA is to establish a framework for the event generation.

NLO event generators necessarily include radiative processes.
➔ The double counting is a problem which must be solved in NLO event generators.

Our solution to the problem

Leading-Log (LL) subtraction

The doubly counted radiation contributions are numerically subtracted from matrix elements of radiative processes.

$$\left|M_{A+1}\left(\hat{s}_{A+1},\hat{\Phi}_{A+1}\right)\right|^2 - \left|M_A\left(\hat{s}_A,\hat{\Phi}_A\right)\right|^2 \times f_{LL}\left(Q^2, z=\hat{s}_A/\hat{s}_{A+1}\right)$$

radiation factor

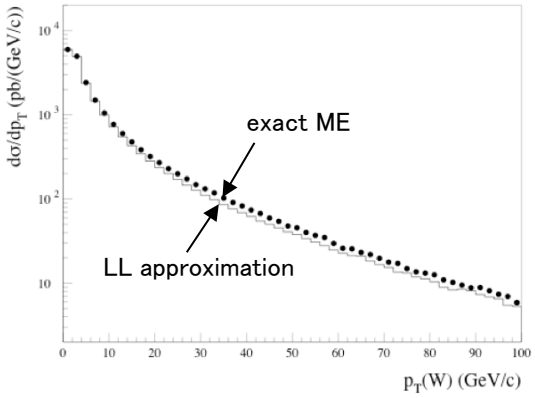
leading-log approximation

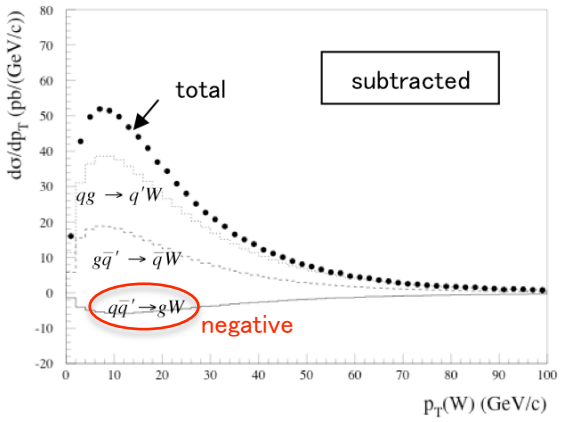
Subtracted are the divergent terms of radiative processes.
PS regularizes the divergence as an effect of multiple radiation.
➔ Everything is finite after the subtraction.

The subtracted cross section may become negative, but it is not a serious problem unless the fraction becomes large.

W + 1 jet @LHC

p_T > 1 GeV/*c* for numerical stability





Limited

PS implementation is limited by a certain energy scale (μ_{PS}).
➔ Subtraction should also be limited by μ_{PS}.

Identity between PS and PDF.
➔ $\mu_{PS} = \mu_F$ (factorization scale)

⇨ Limited Leading-log (LLL) subtraction

Y. Kurihara et al., Nucl. Phys. B654 (2003) 301; hep-ph/0212216
S. Odaka and Y. Kurihara, Eur. Phys. J. C 51 (2007) 867; hep-ph/0702138

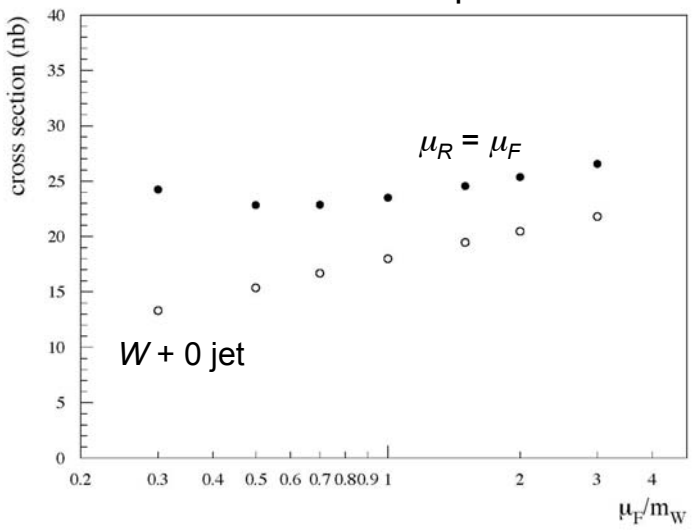
W production @LHC

"*W* + 0 jet" + "*W* + 1 jet"
with LLL subtraction

Good stability against the variation of the factorization scale

Showing a good matching between ME and PDF

Factorization-scale dependence



Parton showers

The matching between the radiation factor and PS is crucial.
➔ custom-made PS (QCDPS)

A forward-evolution PS in the initial state (space-like)
Based on a primitive definition of the Sudakov form factor at the leading order (LO)
An x-deterministic evolution technique to overcome the low-efficiency problem
Equivalent to the QCD evolution in LO PDFs

Y. Kurihara et al., Nucl. Phys. B654 (2003) 301; hep-ph/0212216

An appropriate definition of the branch kinematics (model) is crucial to achieve a good matching in transverse activities; *e.g.*, recoil p_T.

⇨ p_T-prefixed branch kinematics

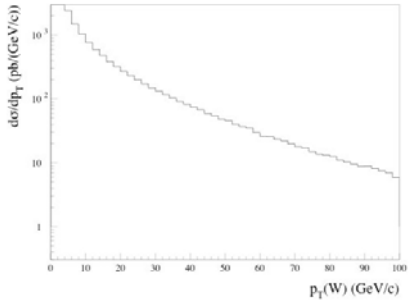
S. Odaka and Y. Kurihara, Eur. Phys. J. C 51 (2007) 867; hep-ph/0702138
S. Odaka, arXiv:0907.5056; to be published in Mod. Phys. Lett. A

We have also developed a backward-evolution PS with the same kinematics model (QCDPSb), and a PS for the final state (QCDPSf) for consistency.

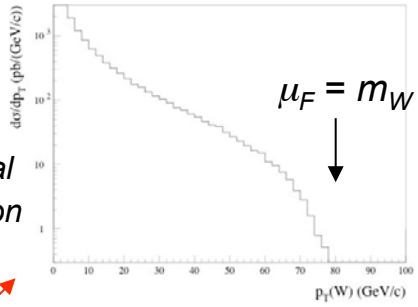
Concept of NLO event generation

p_T spectrum of W bosons as a sample

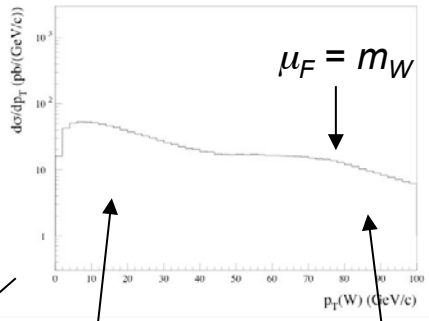
Radiation by W + 1 jet ME



LLL (Limited Leading-Log) terms



LLL-subtracted W + 1 jet ME



− *numerical subtraction*

=

matching

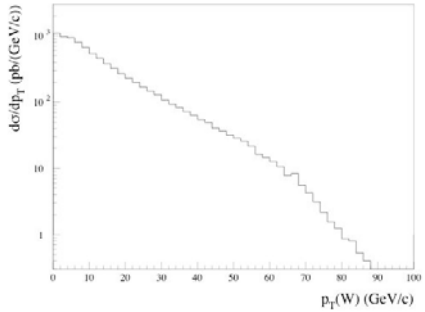
Non-LL

Non-LL + hard LL

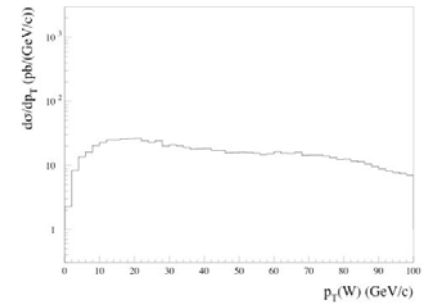
⊗PS

Non-rad.⊗PS

(Born + virtual/soft/collinear corrs.) ⊗ LLL



+



=

NLO event generator with PS

GR@PPA new version

Implementation of the matching method and PS

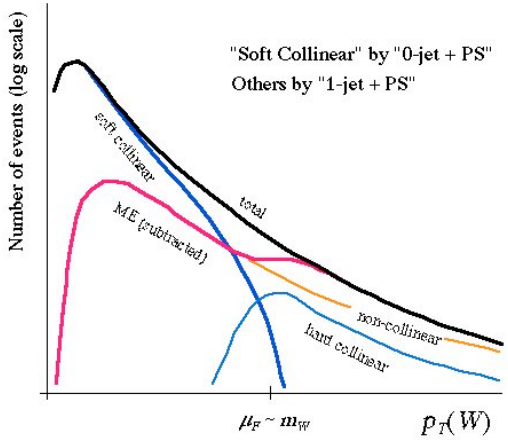
for single and double weak-boson productions

⇨ GR@PPA 2.8

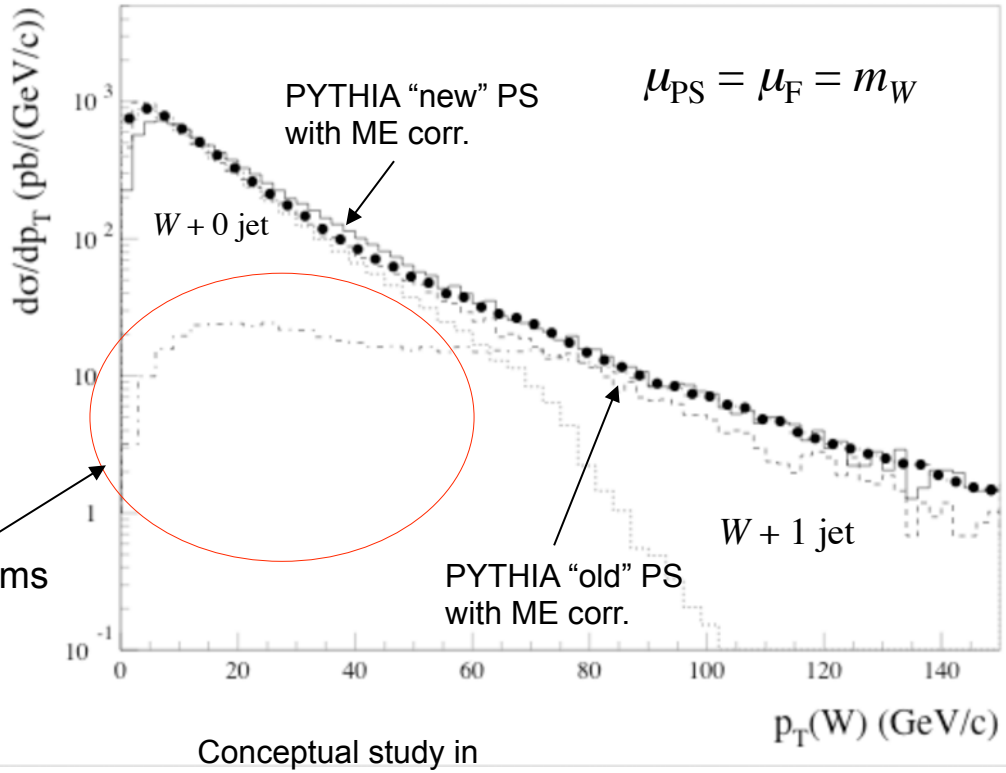
MEs in GR@PPA are still at the tree level;

i.e., no virtual corrections.

W production @LHC



My prospect at PhysSim WS at KEK in 2004



Non-collinear terms

Conceptual study in

S. Odaka and Y. Kurihara, Eur. Phys. J. C 51 (2007) 867; hep-ph/0702138

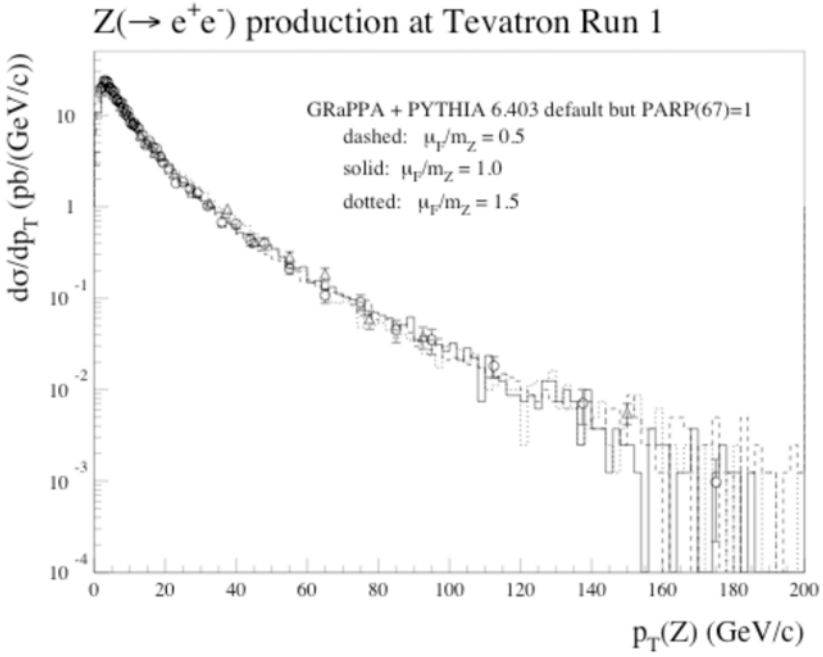
Low-Q simulations by PYTHIA/HERWIG are yet to be applied.

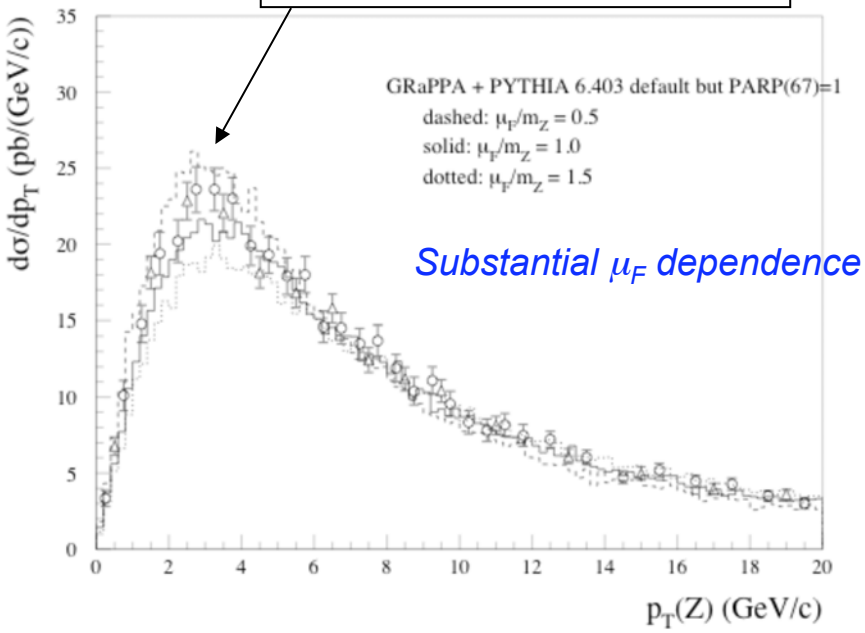
Z production at Tevatron

GR@PPA 2.8 + PYTHIA 6.4

PYTHIA for simulating soft PS ($1.0 < Q < 4.6$ GeV), primordial k_T ($<k_T> = 2.0$ GeV/c), hadronization, and decays

This determines the peak position.





Substantial μ_F dependence

Circles: CDF, Phys. Rev. Lett. 84, 845 (2000)

Triangles: D0, Phys. Rev. D 61, 032004 (2000) × 1.12

D0 data and simulations are normalized to the total cross section of CDF.

Nearly perfect through the entire measurement range

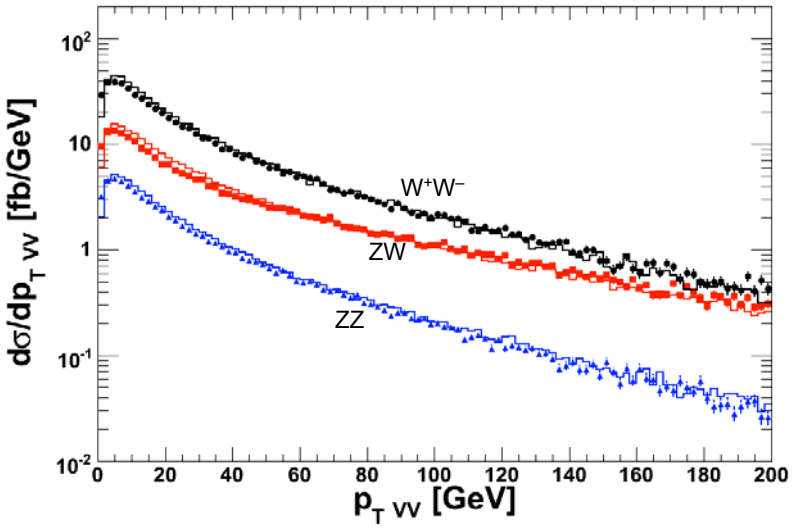
No tunable parameter in GR@PPA

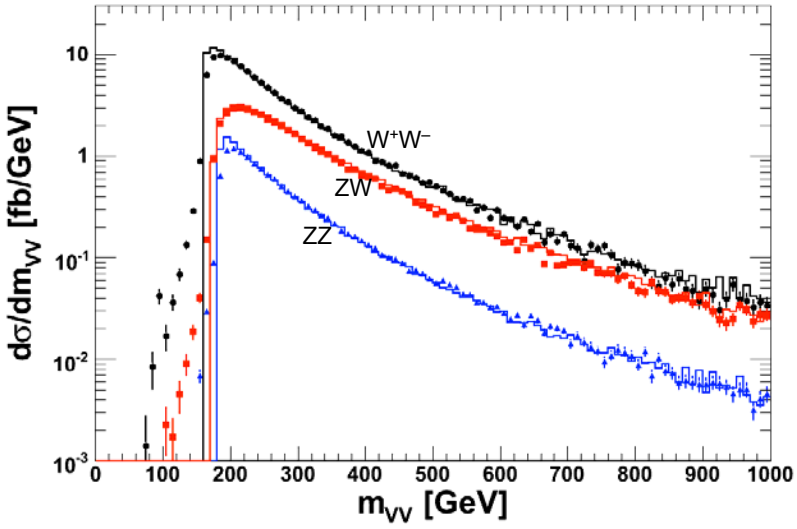
Diboson (double weak-boson) production @LHC

Comparison with MC@NLO

Plots: GR@PPA 2.8 + Pythia 6.4

Histograms : MC@NLO3.31+Herwig6.510.3+Jimmy4.31.3





Reasonable agreement

GR@PPA is yet to be at NLO.

Zero decay widths in these MC@NLO simulations.

Summary

- NLO Working Group at KEK
  - Established in 2000,
  - Aiming at developing NLO event generators for multi-particle production processes at hadron collisions based on GRACE.
  - GR@PPA event generators have been developed in order to establish a framework of the event generation.
  - GR@PPA is still at the tree level, but supporting many multi-particle production processes.
- GR@PPA 2.8 is almost ready to release;
  - Implementing an initial-state jet matching (ME-PS matching) for single W and Z productions and diboson (W^+W^-, ZW and ZZ) productions,
  - Including a forward-evolution PS and a backward-evolution PS for the initial state, as well as a PS for the final state.
  - The simulation surprisingly well reproduces the Z-boson p_T spectrum measured at Tevatron.
  - An important step towards NLO event generators

Next

Jet matching in γ production processes

QED final-state matching together with QCD

⇨ GR@PPA 2.9 ?

NLO event generator

Consistent application of virtual corrections to non-radiative processes

⇨ GR@PPA 3.x ?

Further automatization

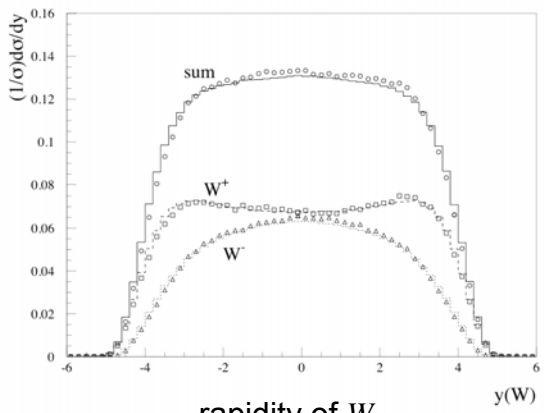
To reduce mistakes in the coding

⇨ GR@PPA 4.x ?

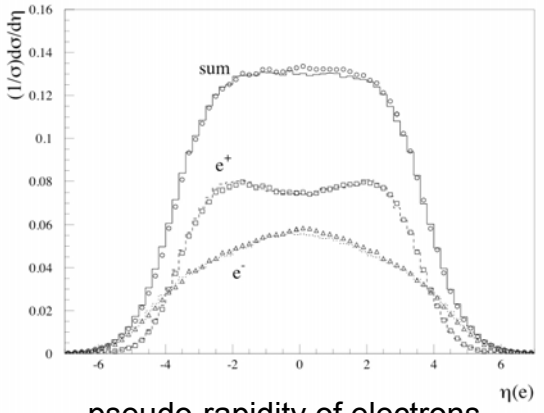
W production @LHC

Comparison with PYTHIA

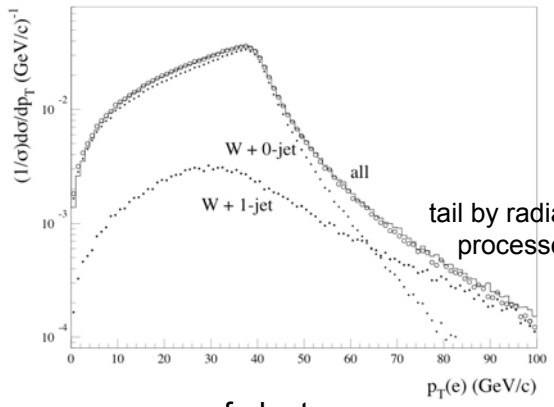
Plots: GR@PPA, Histograms: PYTHIA



rapidity of W

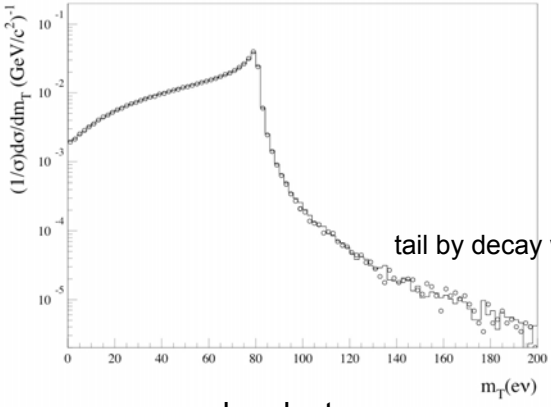


pseudo-rapidity of electrons



tail by radiative processes

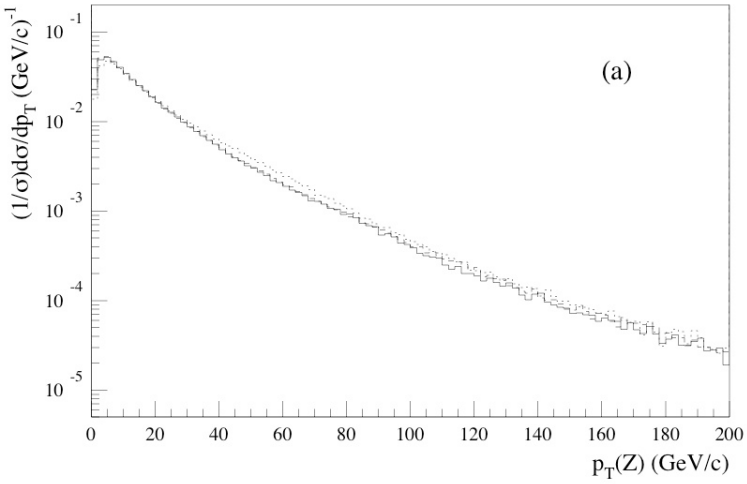
p_T of electrons



tail by decay width

m_T by electrons

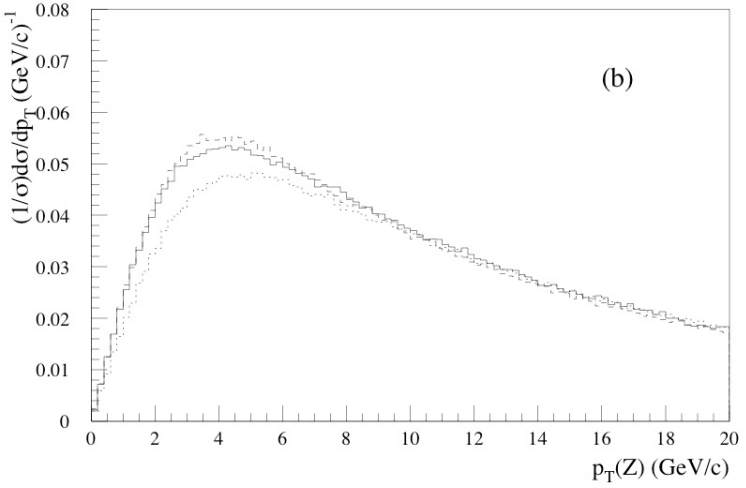
Z production @LHC



Solid: GR@PPA 2.8 + PYTHIA 6.421

Dashed: PYTHIA 6.421 built-in with new PS

Dotted: HERWIG 6.510



We will be able to plot measurement results soon.