

①

# EVENT GENERATORS

について\*

2001年 12月 1日

ICFP ハドロン コライダー 研究会にて



小田切 宏輔 (KEK)

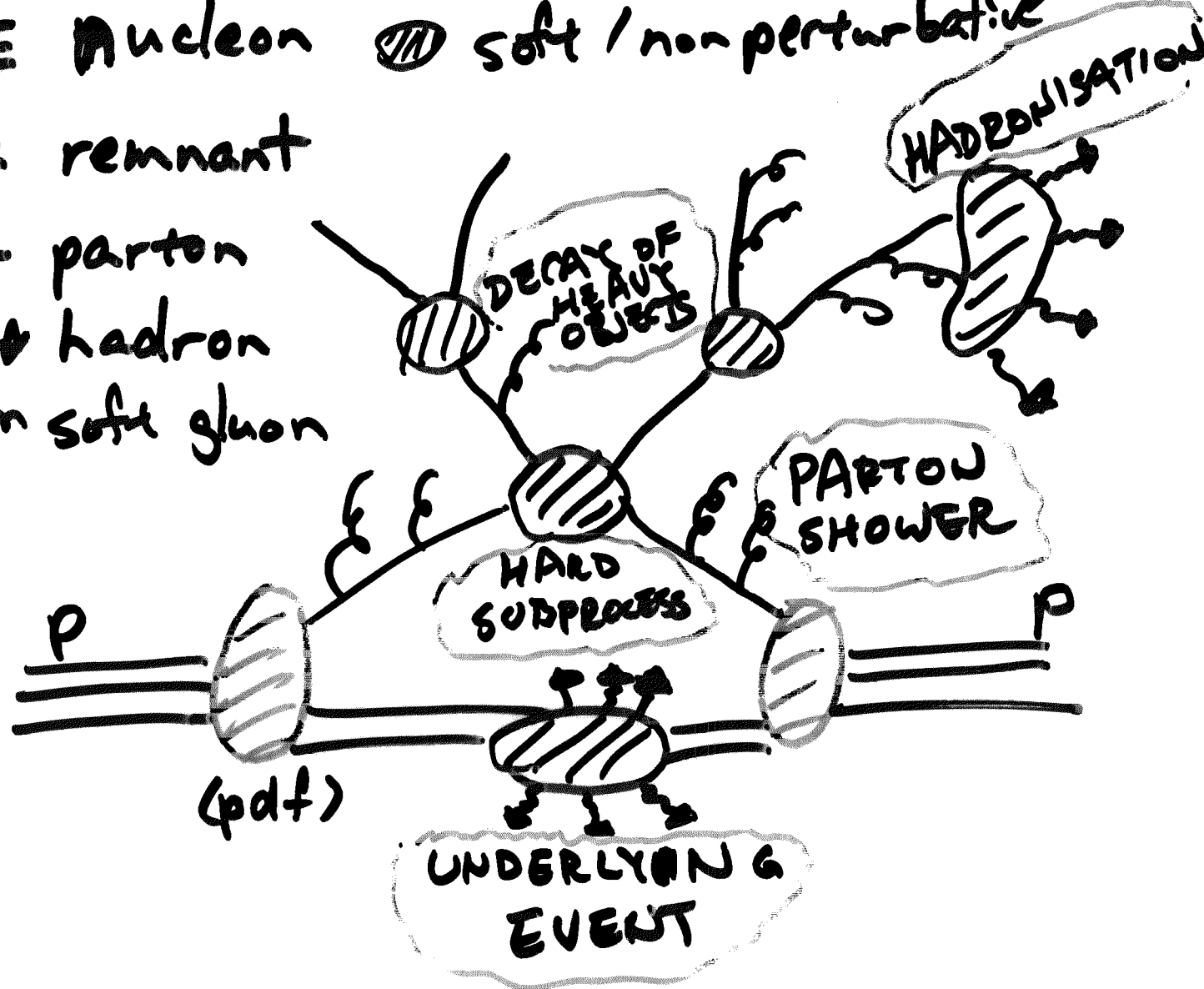
\* 主に HERWIG

しかも ハドロンコライダーに  
話を限る

# MONTE CARLO EVENT GENERATOR $\chi$

- $\star KE^{\vee}$
- $\equiv$  nucleon
- $=$  remnant
- parton
- $\rightarrow$  hadron
- on soft gluon

-  hard / perturbative
-  soft / non-perturbative



いさく物理を  $\chi$  に  $\chi$  にした  
 FORTRAN / C++ (C++) で書かれた  
 プログラム

強調  $\rightarrow$  MC は 単なる 道具 に 非ず  
 (歴史 的 に も)

詳しい人のための話を  
あきら. hopefully,  
↑

③

あまり詳しくない人のために一言で  
いうならば

PARTON LEVEL  
の DIFFERENTIAL CROSS SECTION  
から 実際にはかれる

EXPLICIT に  
HADRON LEVEL  
の FINAL STATE を 作る.

逆に見  
非ず  
←

いや 作るためのモデルです。  
QCDの。

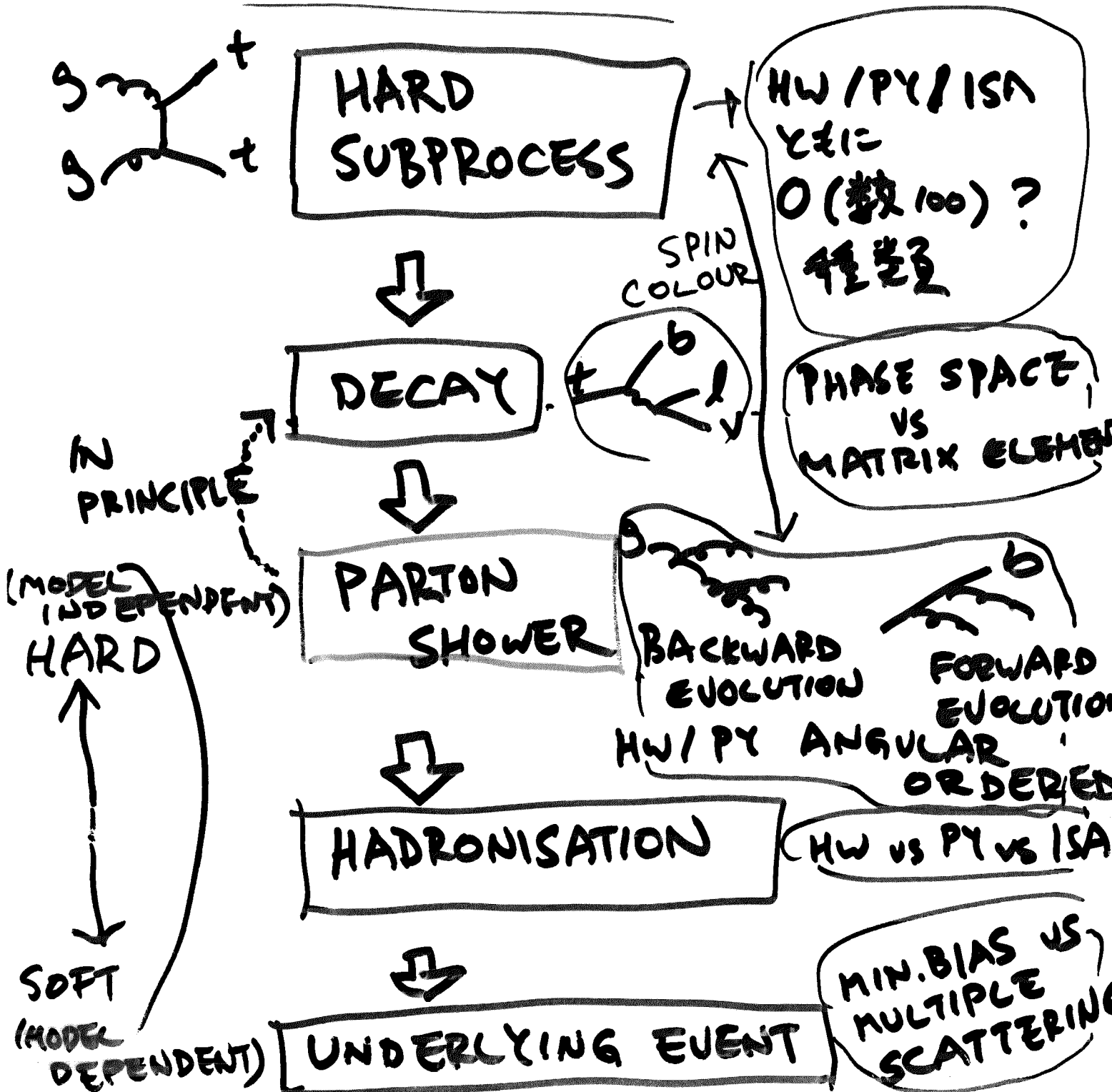
2大 ジェネレータ  
+1  
(独断偏見?)

	QCD
HERWIG	◎
PYTHIA	○
ISAJET	△

定例に定例  
↓

# EVENT GENERATION の流れ

## また、この流れ

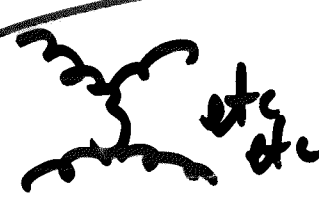


# HARD SUBPROCESS について

HW / PY / ISA などに

決山 ありませう

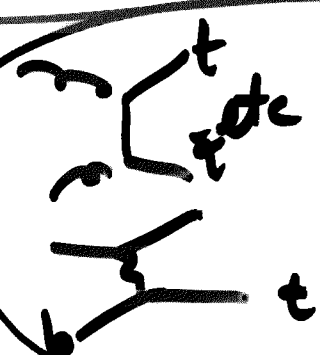
例として HERWIG などは




etc etc QCD 2→2




8/2, w DRELL-YAN



etc HEAVY QUARKS



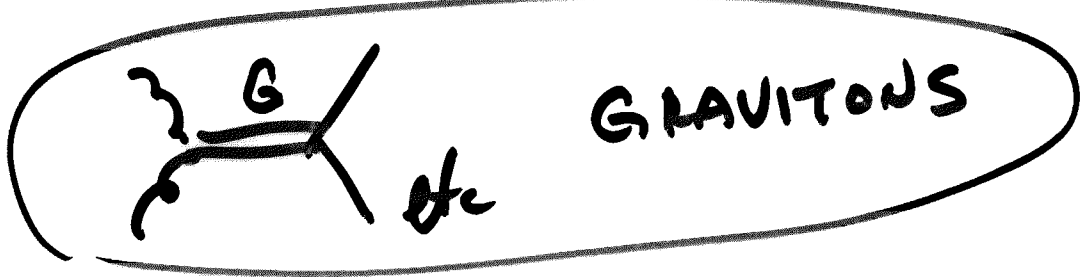
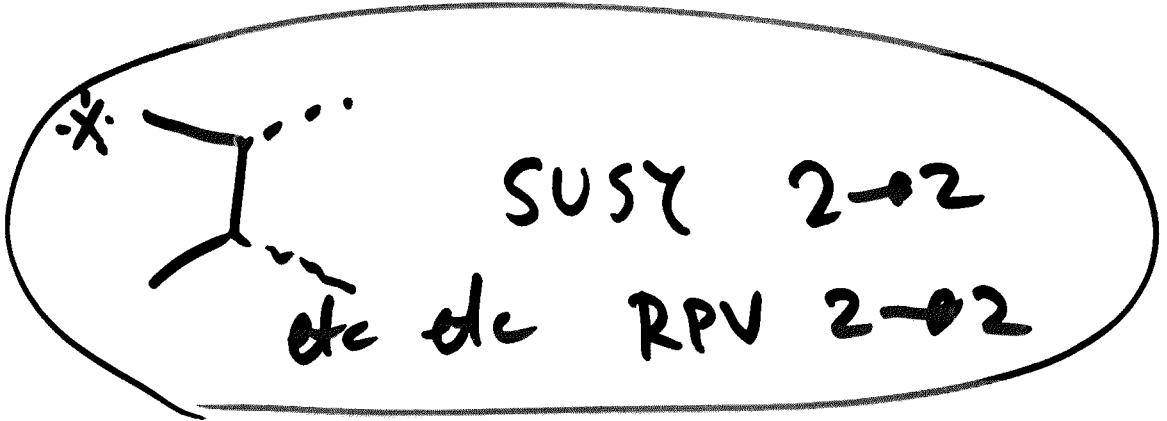
HIGGS 2→1



etc etc 2→2

etc etc 2→3

Q  
etc  
xx  
ep



+ GAUGE BOSON PAIR,  
PHOTON + JET  
~~GAUGE BOSON PAIR~~ GAUGE BOSON + JET  
HIGGS + JET  
COLOUR SINGLET EXCHANGE  
etc.  $\Sigma = \Sigma \text{ ? } \text{IL } \text{A} \text{ ?}$   
ホ-ムページを御参照あれ

\* SUSY について 先日 の SUBGROUP MEETING で 話した 内容を 持ちこて来ている。

HERWIG の ホーム ページ

[http://hepwww.rl.ac.uk/theory/  
seymour/herwig/](http://hepwww.rl.ac.uk/theory/seymour/herwig/)

REFERENCE

G. CORCELLA, I. G. KNOWLES, G. MARCHESINI,  
S. MORETTI, K. ODAGIRI, P. RICHARDSON,  
M. H. SEYMOUR AND B. R. WEBBER,

"HERWIG 6: AN EVENT GENERATOR  
FOR HADRON EMISSION REACTIONS  
WITH INTERFERING GLUONS  
(INCLUDING SUPERSYMMETRIC  
PROCESSES)",

JHEP 0101 (2001) 010.

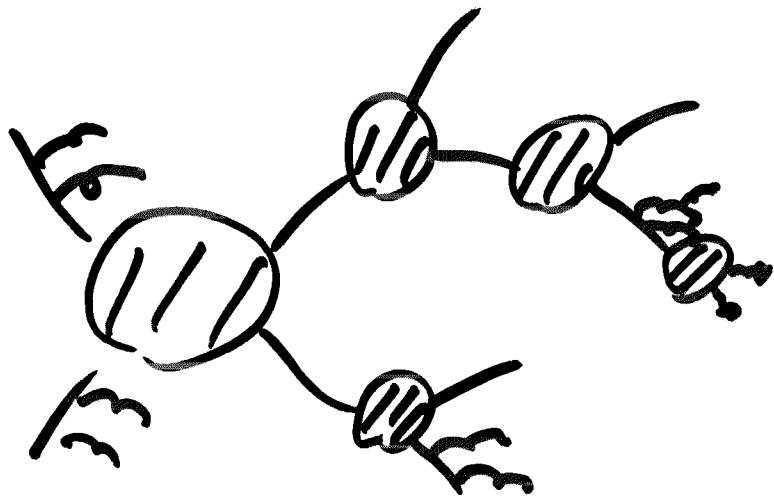
v6.3 RELEASE NOTE - hep-ph/0107071

DECAY について

特筆事項無し.

HW に SUSY 3-body ME decay  
及び CASCADE DECAY の  
SPIN CORRELATION が 入 っ け ば .

(SUSY SUB GROUP での TALK  
参 照 )

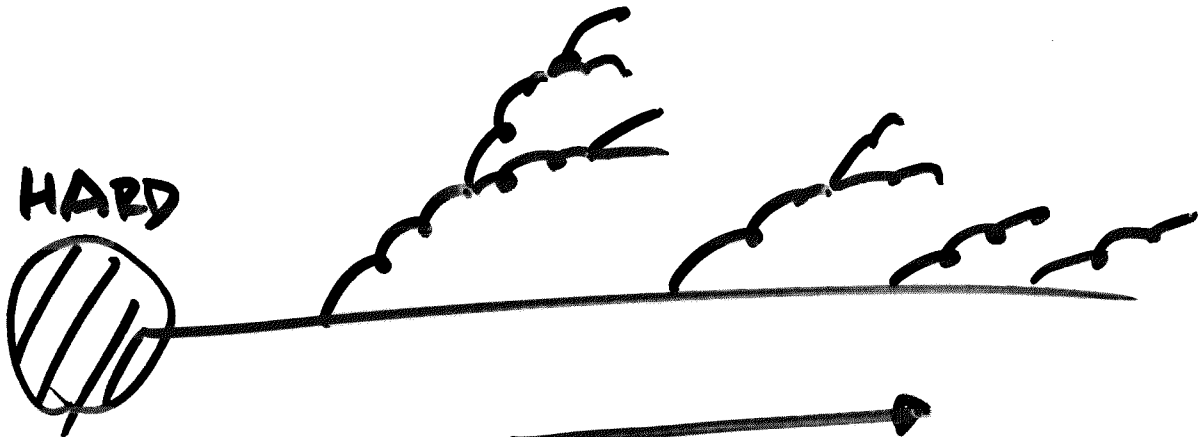


(いまだ和風な ジョネーション )



# PARTON SHOWER $\rightarrow$ PFC

COLLINEAR  $\rightarrow$  SOFT EMISSIONS



PROCESS

→  
DECREASING  
VIRTUALITY  
&  
EMISSION ANGLE  
(ANGULAR ORDERING)

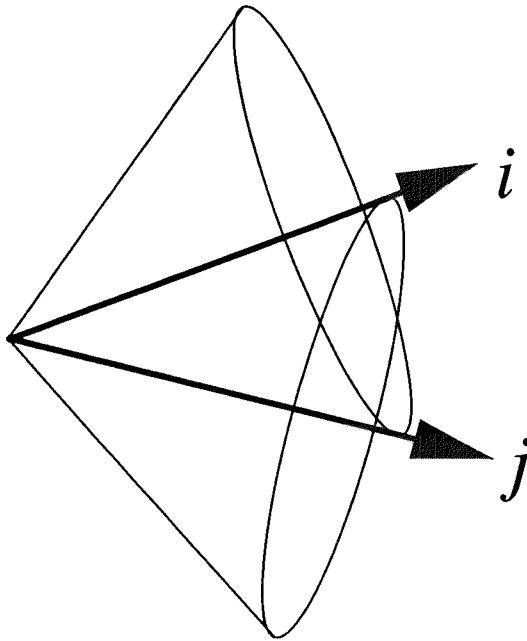
以下 トリパ 教授を  
Bryan Webber の  
Run II  
Fermilab MC Workshop (Apr 2000)  
の トリパ から 拝借  
(KEKの ATLAS Japan ガルゴ  
アの トリパ の 講義 に 参考 しました)

[http://www-theory.fnal.gov/  
runiimc/](http://www-theory.fnal.gov/runiimc/)

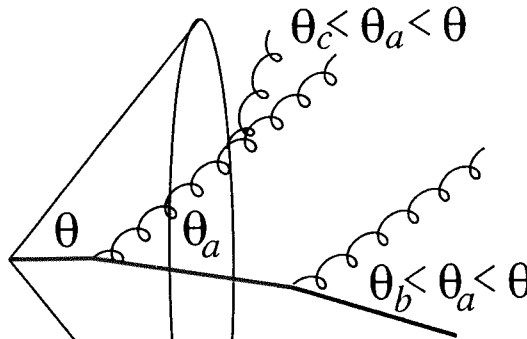
Parton Shower & Collinear splitting ④  
 色相干性は角順序でシミュレートされる, soft emission は 21.25%

● Colour coherence is simulated by angular ordering:

❖ Angular region for shower from parton  $i$  is cone bounded by direction of  $j$  (and vice-versa), where  $i$  and  $j$  are colour-connected:



❖ Angles within shower decrease away from hard subprocess:



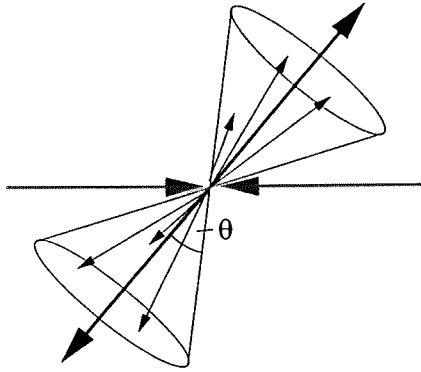
これは soft / collinear での IR sum ではない

❖ This suppresses soft gluon/hadron production (MLLA/LPHD).

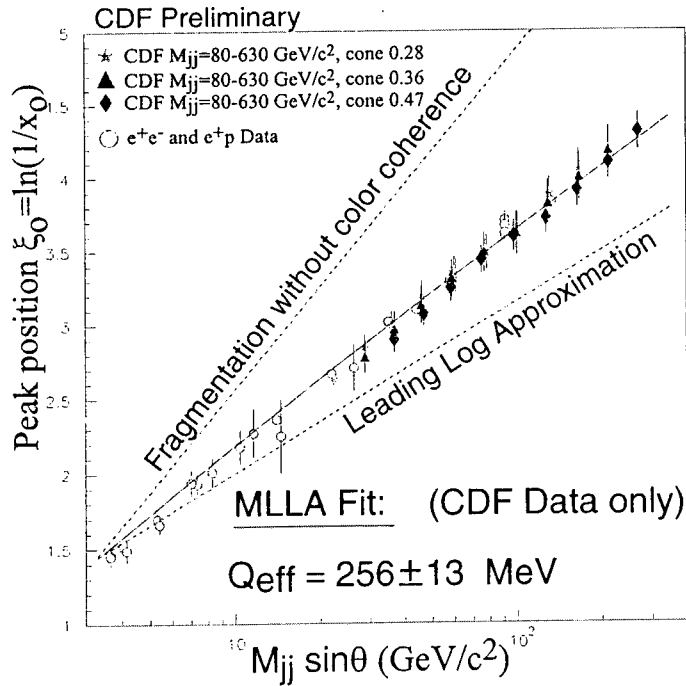
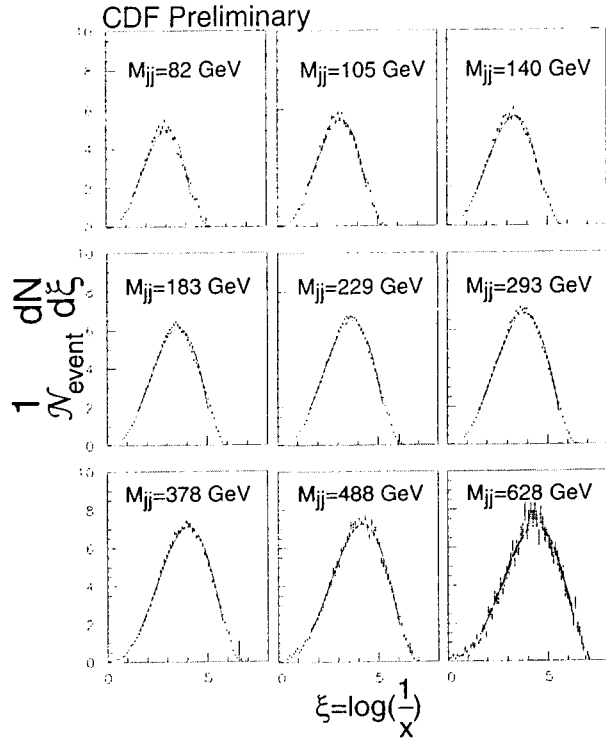
HERWIG / PYTHIA にて  $\lambda \rightarrow 21.3$

● Beautifully confirmed by Tevatron dijet data

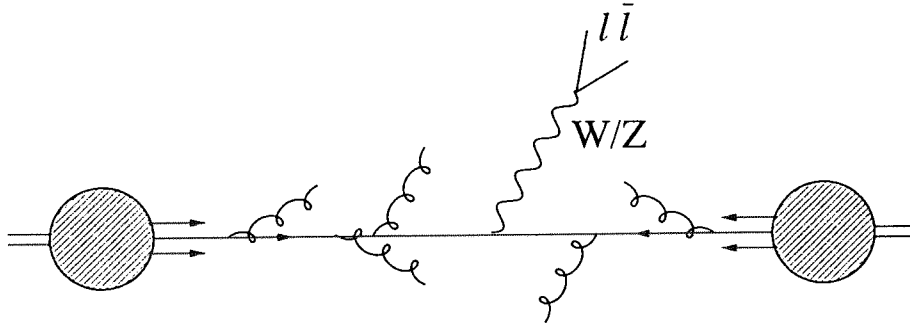
CDF Collaboration



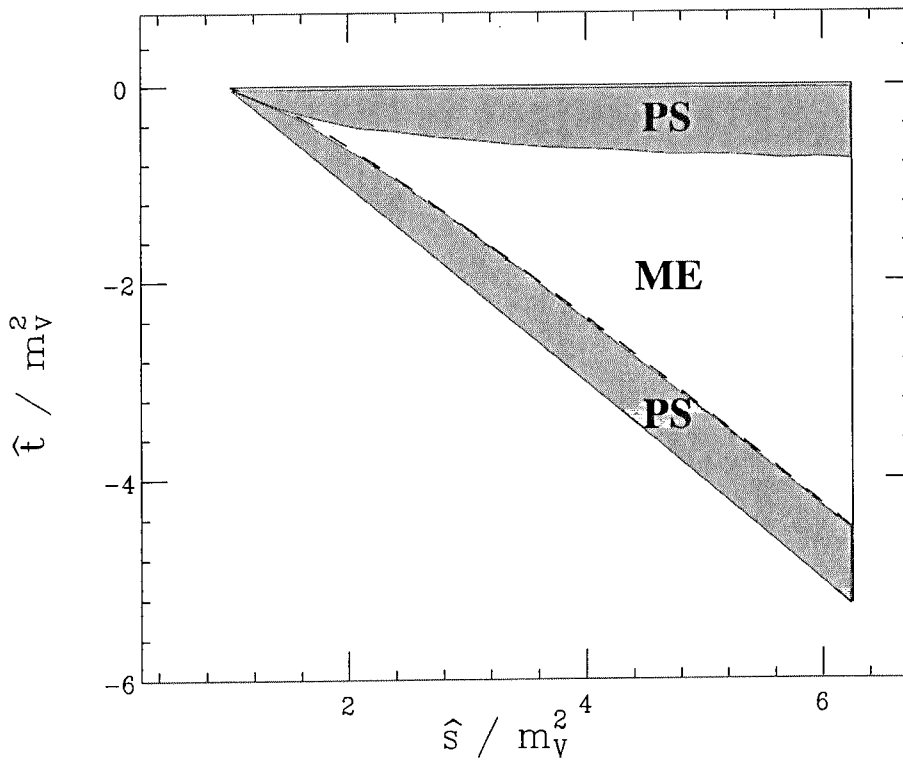
$$x = p_{had}/E_{jet}$$



- Parton showers inside cones do not populate whole phase space. We also have to include matrix element corrections (talk by Gennaro Corcella)
- For example, in W/Z hadroproduction

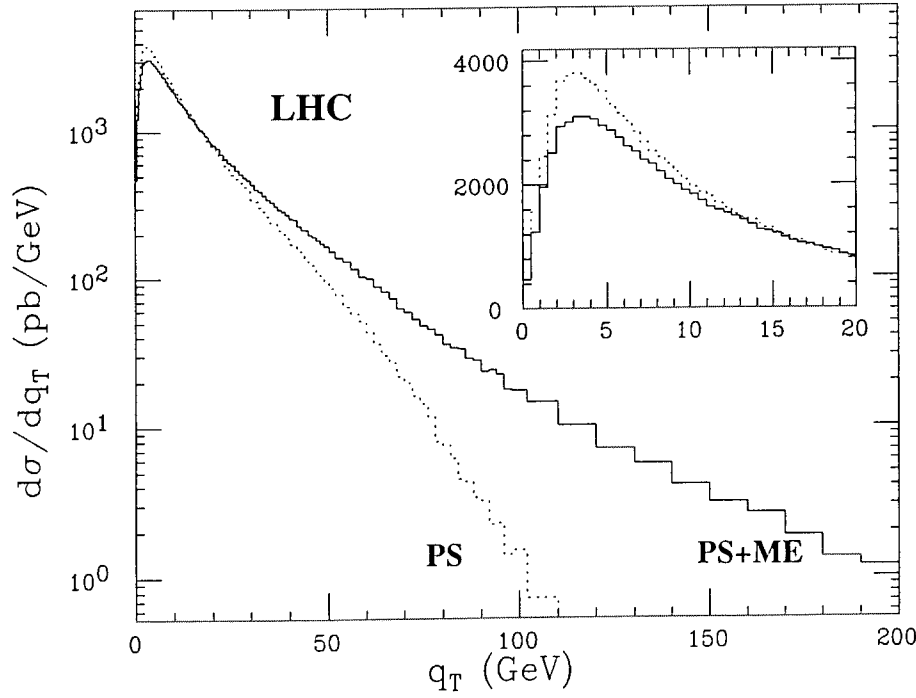
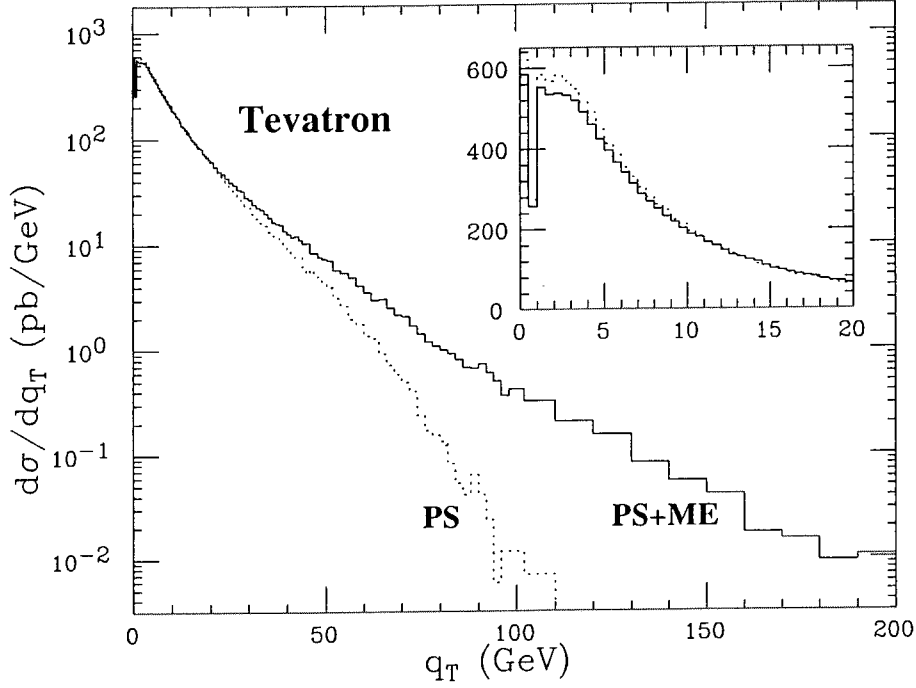


- Phase space for W + jet

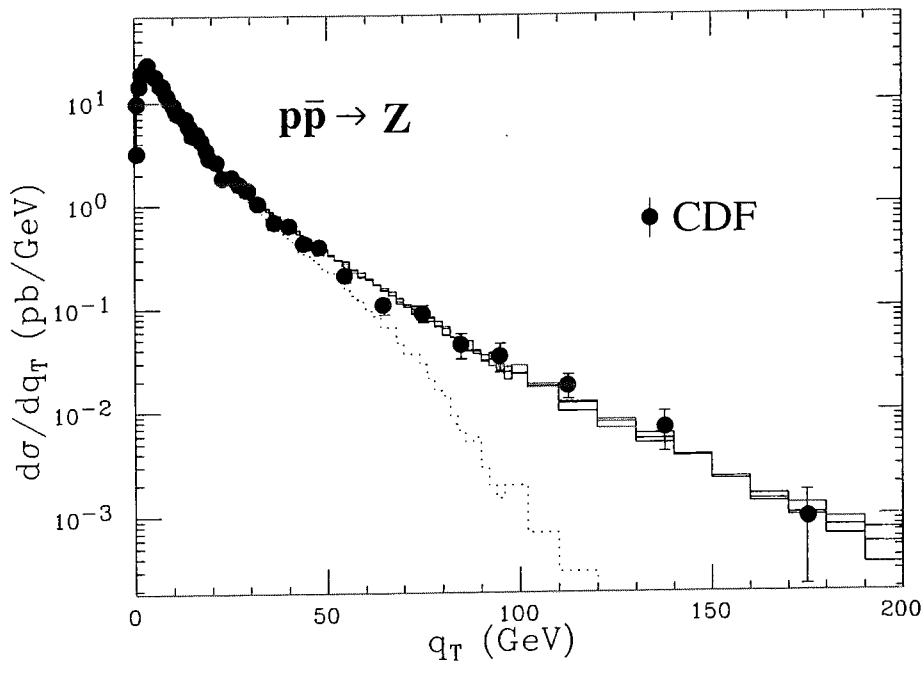
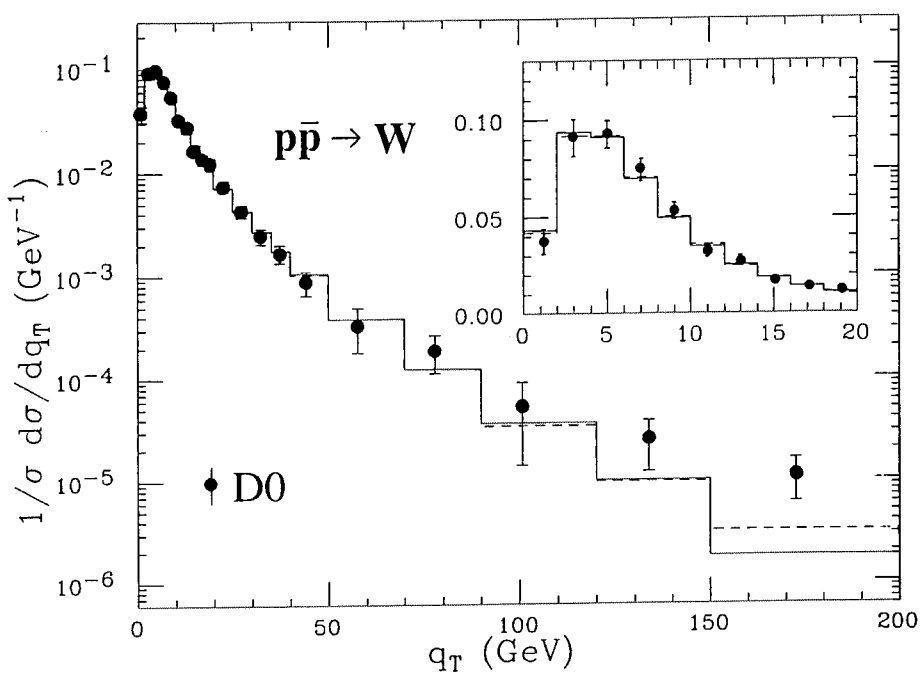


- ME corrections essential for W/Z production at large transverse momentum (important background to new physics):

G Corcella & MH Seymour, Nucl Phys B565(2000)227



● Comparisons with Tevatron data:



# HADRONISATION

PARTON SHOWER を

SHOWER CUT-OFF まで止める

HERWIG の場合

QUARK MASSES

GLUON EFFECTIVE MASS = 0.75 GeV

QUARK VIRTUALITY CUTOFF  
= 0.48 GeV

GLUON VIRTUALITY CUTOFF  
= 0.10 GeV

SCALE まで

HADRONISATION が始まる

理想的には物理的に INDEPENDENT

実際は LOW TO FAVOURED

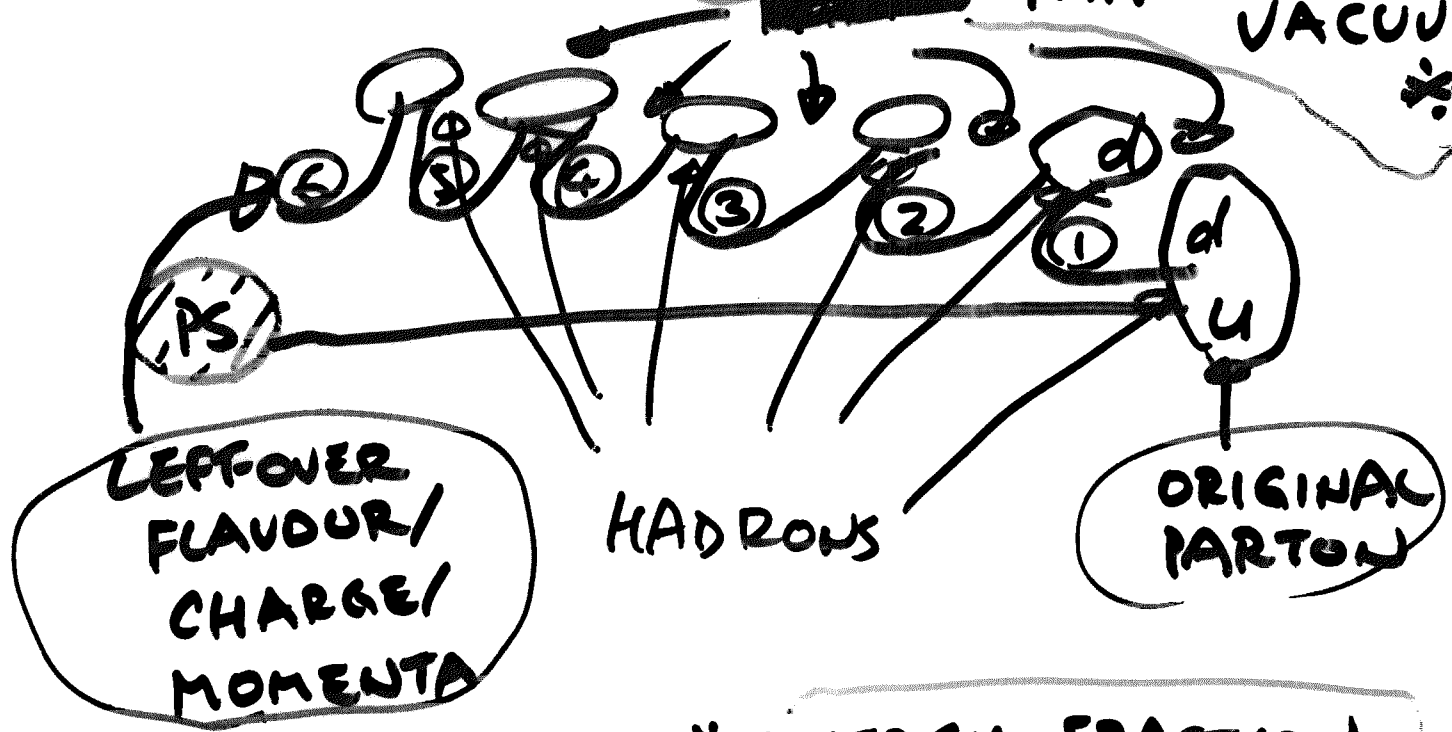
⇒ PERTURBATIVE PHASE MUCH BETTER & VALID TO LOW SCALE UNDERSTOOD.



# HADRONISATION OF $e^+e^-$ 1

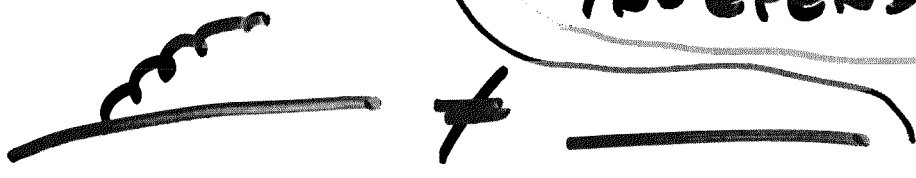
## ISAJET — INDEPENDENT FRAGMENTATION

(DI)QUARK PAIR FROM VACUUM \*



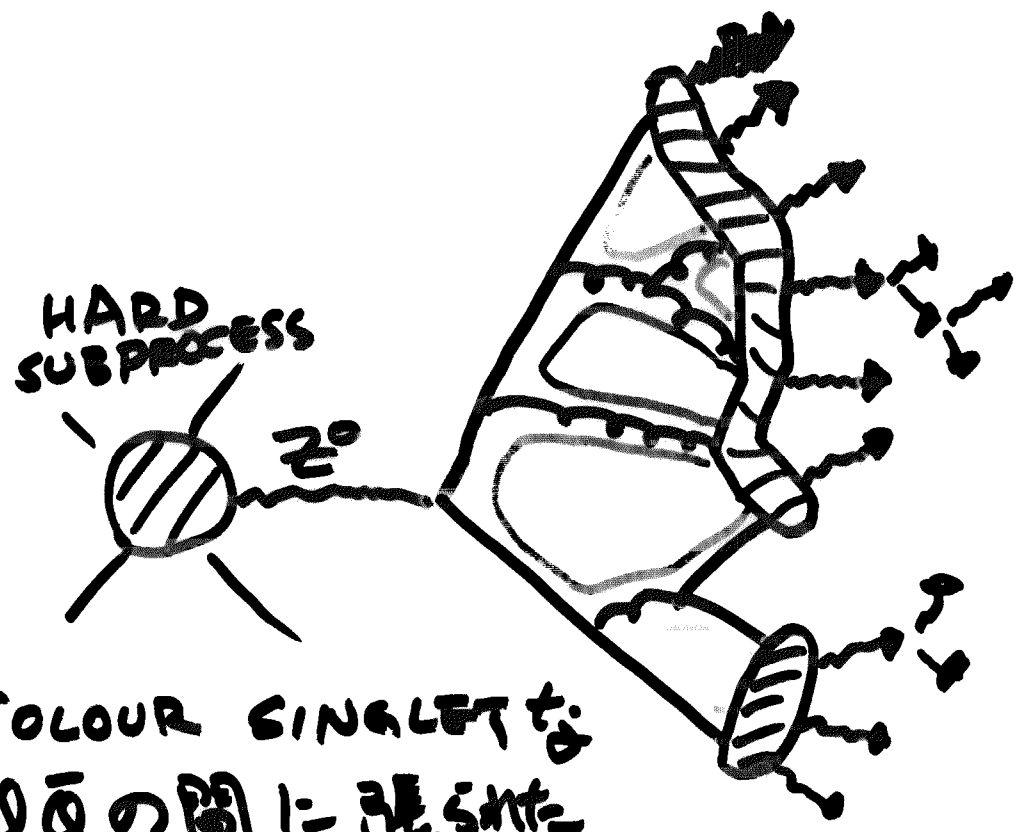
PROBLEM WITH COLLINEAR PARTONS

\* ENERGY FRACTION FOLLOWS THE FRAGMENTATION FUNCTION (ENERGY INDEPENDENT)



# HADRONISATION のモデル 2

## PYTHIA - STRING MODEL



単一の  
弦の  
場合は  
INDEPENDENT  
FRAGMENTATION  
になる

COLOUR SINGLET な  
( $N_c$ )  $Q\bar{Q}$  の間に張られた

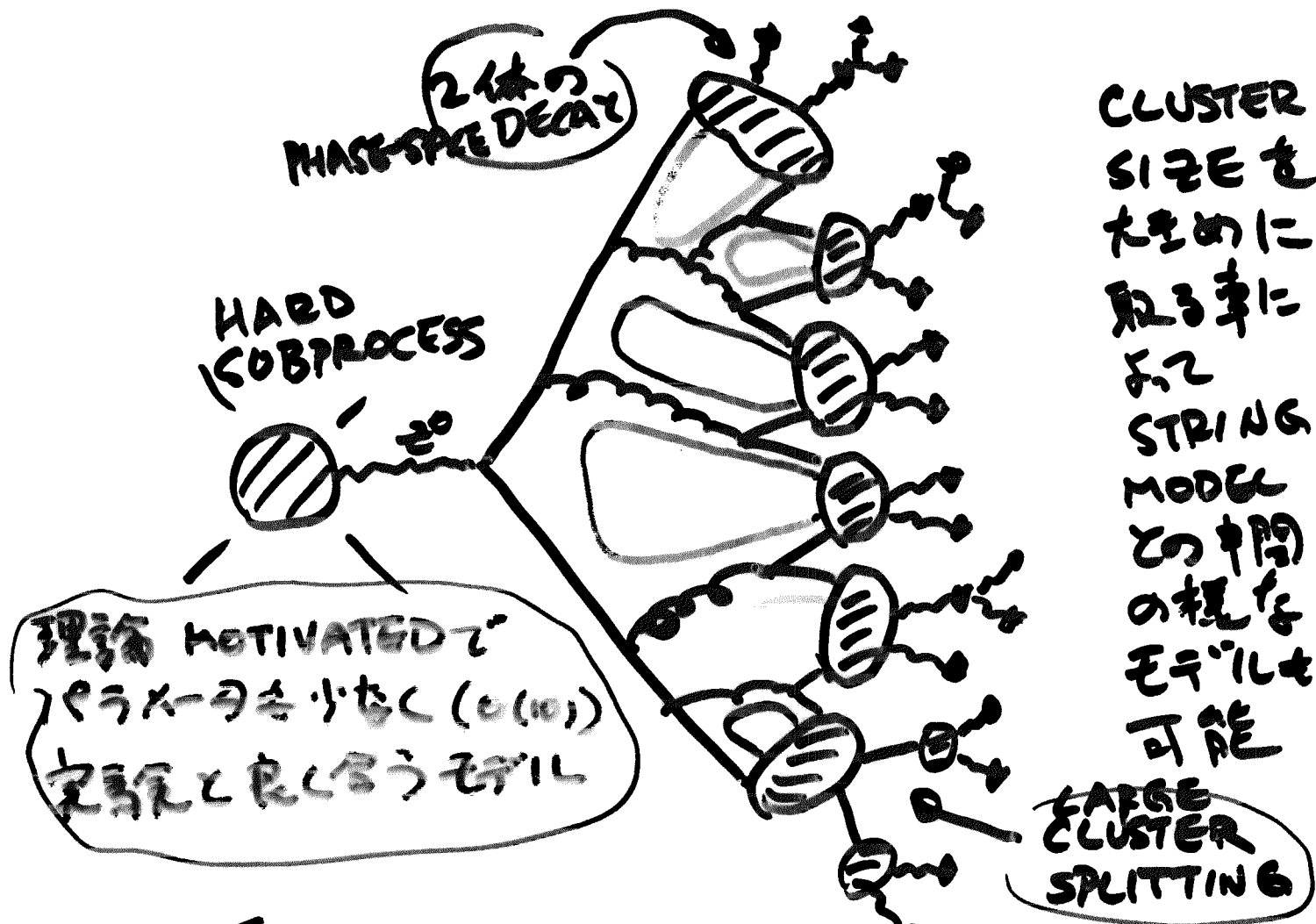
SPACE-LIKE な 一様な エネルギー密度  
を持つ COLOUR STRING から 弦の

QUANTUM TUNNELLING で ハドロン  
生成

→ 実際は 沢山 ( $O(50)?$ ) の  $1/5 \times 1/5$   
が必要.

# HADRONISATION のモデル 3

## HERWIG - CLUSTER HADRONISATION MODEL



← FORCED NONPERTURBATIVE  
 GLUON SPLITTING  
 により  $O(\sqrt{E_0})$  (= cut-off for P.S.) 位の  
 大きさの COLOUR SINGLET CLUSTER  
 が定義される

P.S. 2<sup>nd</sup> 生成された PARTON の PRECONFINEMENT

による COLOUR SINGLET CLUSTER の  
存在は理論的には

D. AMATI & G. VENEZIANO, PL883 (1979) 87;  
A. BASSETTO, M. CIAFALONI & G. MARCHESINI, " 207;  
G. MARCHESINI, L. TRENTADUE & G. VENEZIANO,  
NPB181 (1980) 335.

2<sup>nd</sup> 予言されており、実験的にも検証  
されている

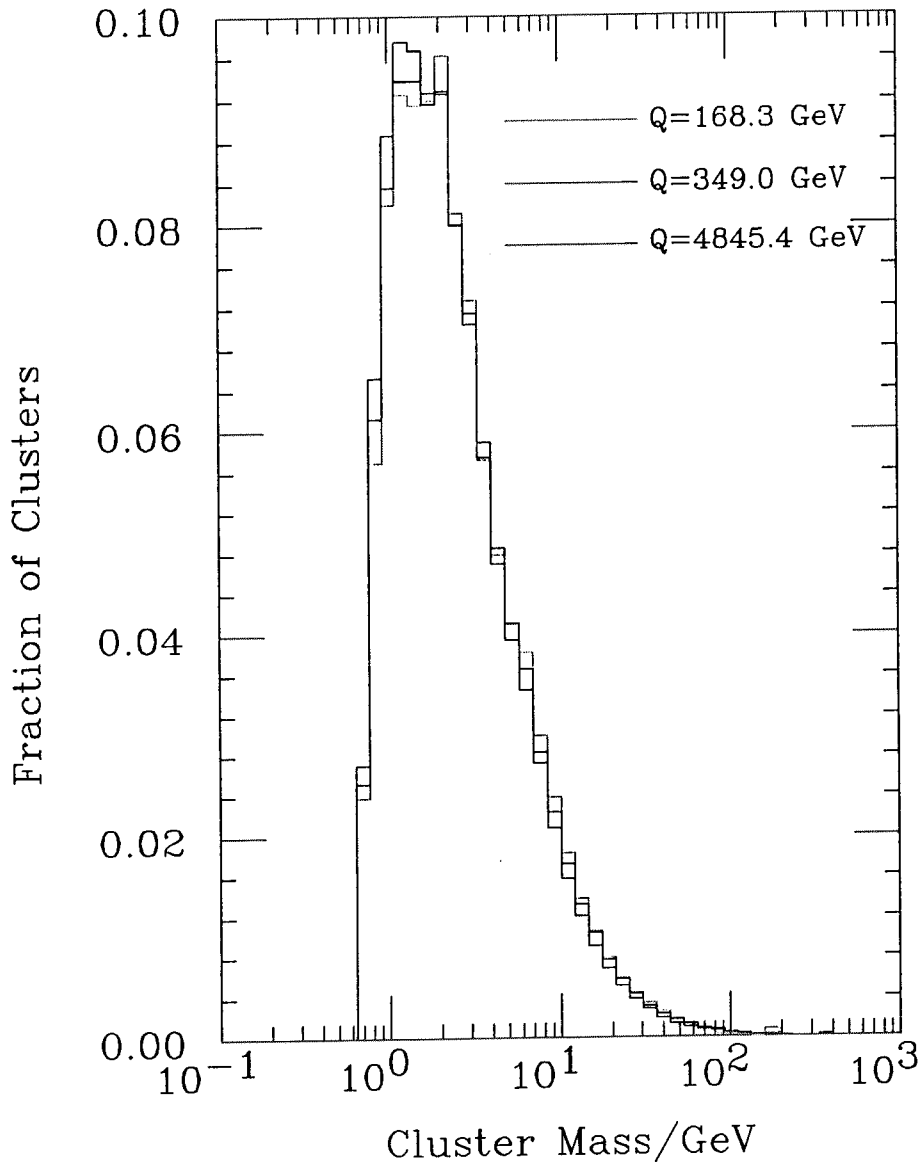
o "SUBCLUSTERS IN JETS"

CDF Note 4083, 3615, 3467, 3466

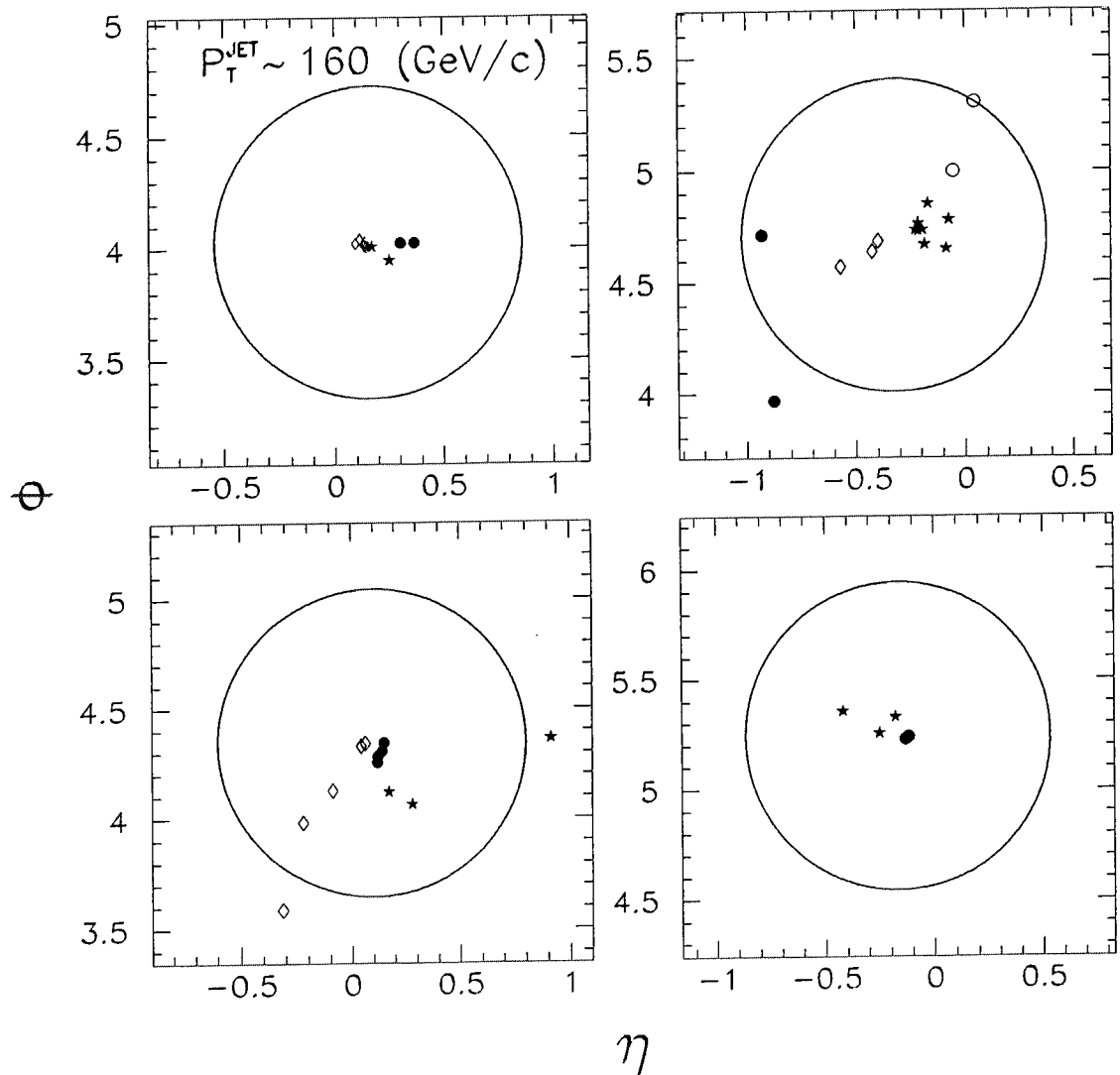
o CDF QCD PAGE

[http://www-cdf.fnal.gov/physics/  
new/qcd/qcd99-pub-welcome.html](http://www-cdf.fnal.gov/physics/new/qcd/qcd99-pub-welcome.html)

● Cluster mass spectrum is universal

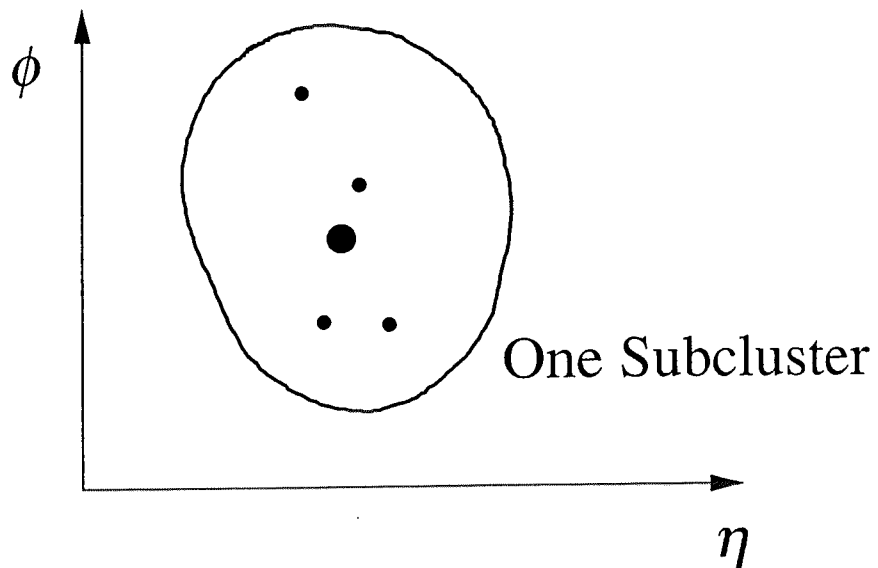


## CDF Preliminary



Distributions of tracks in a jet are displayed in  $\eta$ - $\phi$  space. The transverse momentum of the jet is approximately 160 GeV/c. We display 4 typical jets. Tracks associated with a subcluster are indicated by the same symbol. The subclusters have been determined using the  $k_{\perp}$  algorithm. The jet cone radius is 0.7.

## Definition of $\bar{r}_{\text{RMS}}$

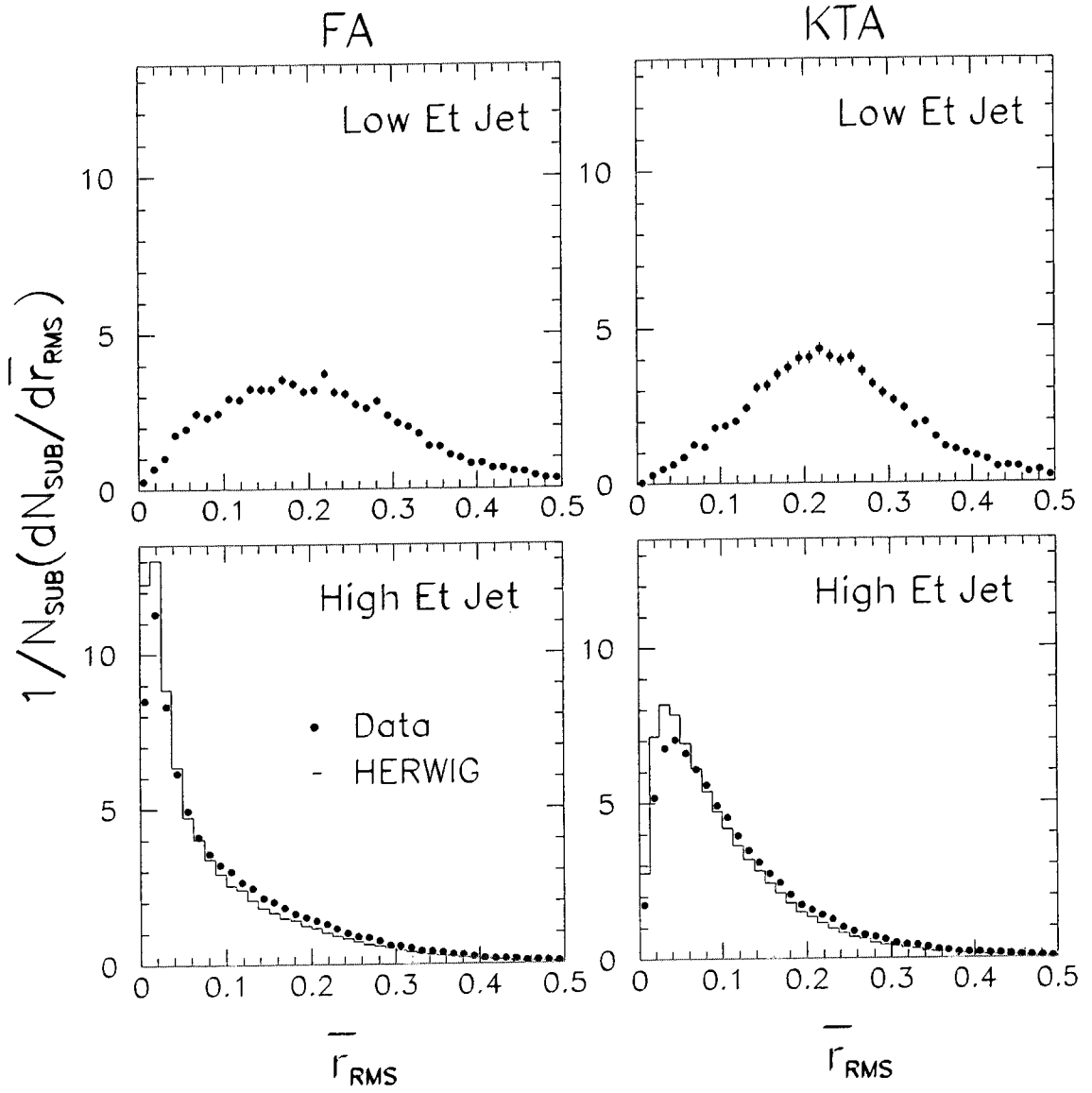


- Subcluster Axis  $(\bar{\eta}, \bar{\phi})$
- Track  $(\eta_i, \phi_i)$

$$\bar{r}_{\text{RMS}} = \frac{1}{n} \sqrt{\sum_{i=1}^n (\phi_i - \bar{\phi})^2 + (\eta_i - \bar{\eta})^2}$$

n: number of tracks in a subcluster

# CDF Preliminary



The RMS distribution of tracks in a subcluster for high  $E_T$  jet and low  $E_T$  jet.



● HERWIG's adjustable parameters:

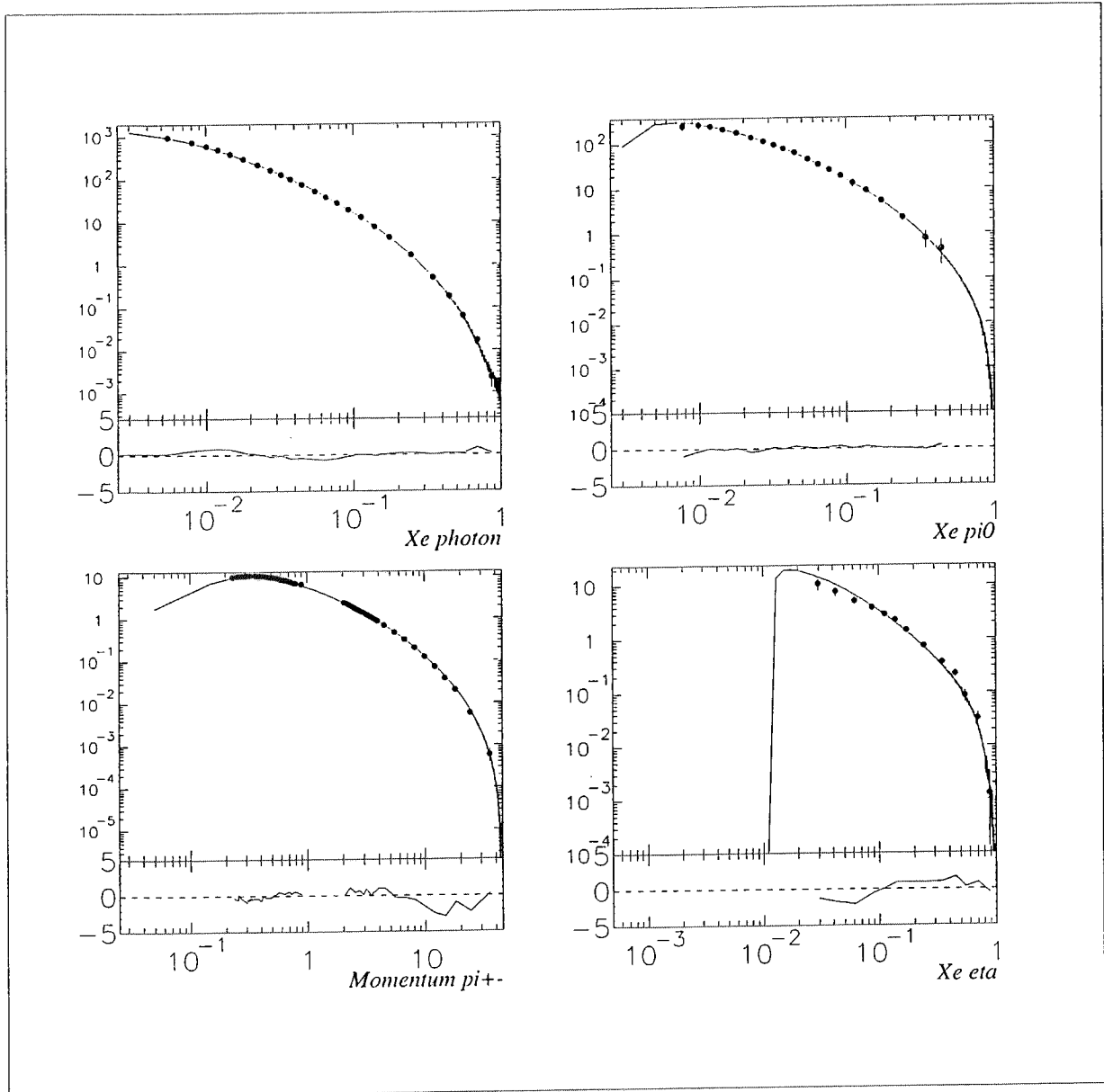
Parameter	Affects	Default	OPAL
QC DLAM	$\Lambda \sim \Lambda_{\overline{MS}}^{(5)}$	0.180	D
RMASS(13)	cutoff " $m_g$ "	0.750	D
CLMAX	cluster mass limit	3.35	D
CLPOW	cluster splitting	2.0	D
PSPLT(1)	cluster spectrum (udsc)	1.0	D
PSPLT(2)	cluster spectrum (b)	1.0	0.33
CLSMR(1)	cluster decay (udsc)	0.0	0.40
CLSMR(2)	cluster decay (b)	0.0	D
PWT(3)	s quark weight	1.0	—
PWT(7)	diquark weight	1.0	—
SNGWT	baryon weight (1)	1.0	—
DECWT	baryon weight (10)	1.0	0.7

For details see <http://home.cern.ch/webber/hwtune.html>

- LEP and Tevatron data are reproduced well overall, with some discrepancies near kinematic boundaries. Baryon and heavy flavour yields are less well described.
- Strongest constraints are from LEP1 data ( $Z^0$  decay):

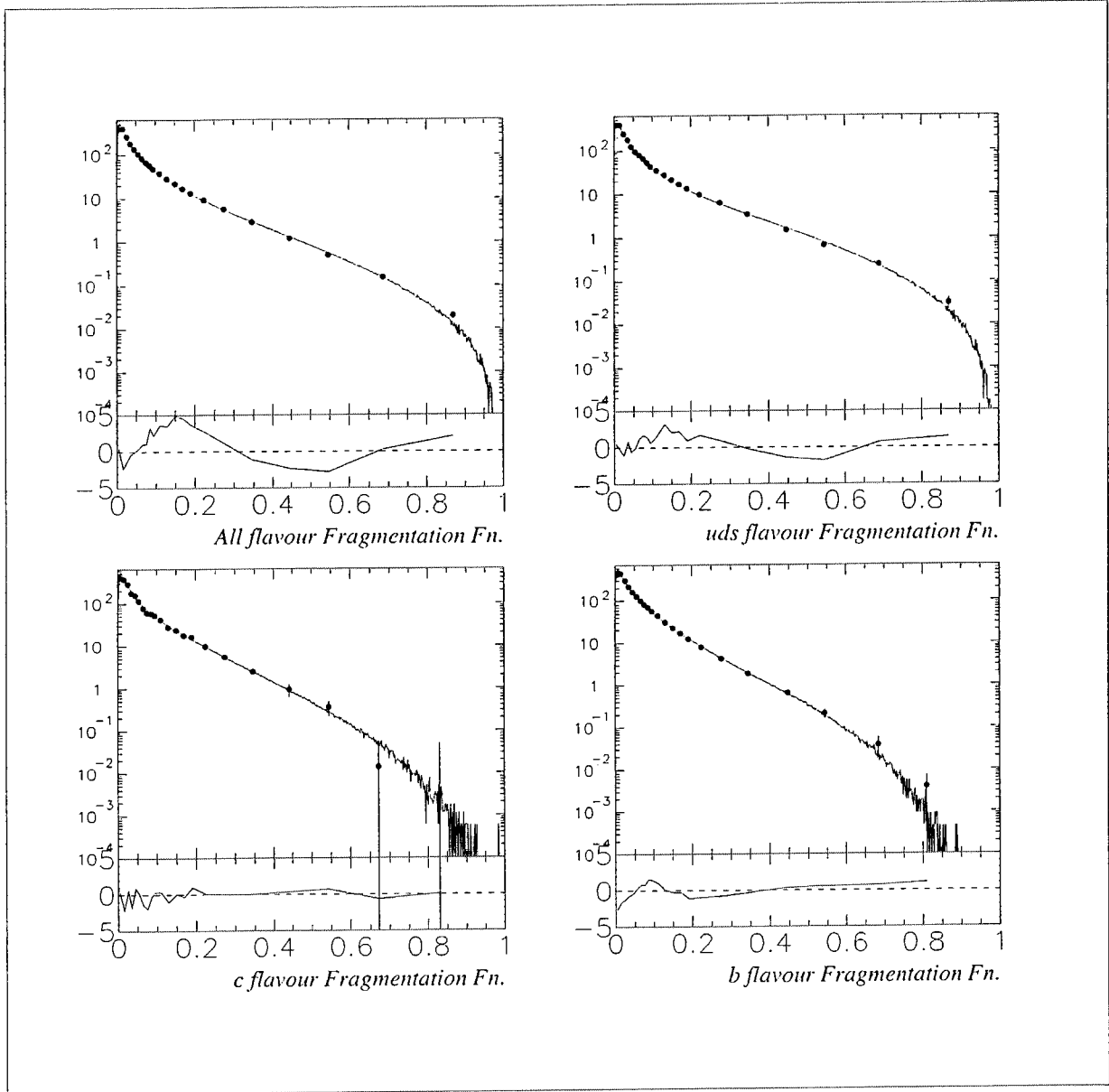
# ● Identified particle spectra

OPAL Collaboration



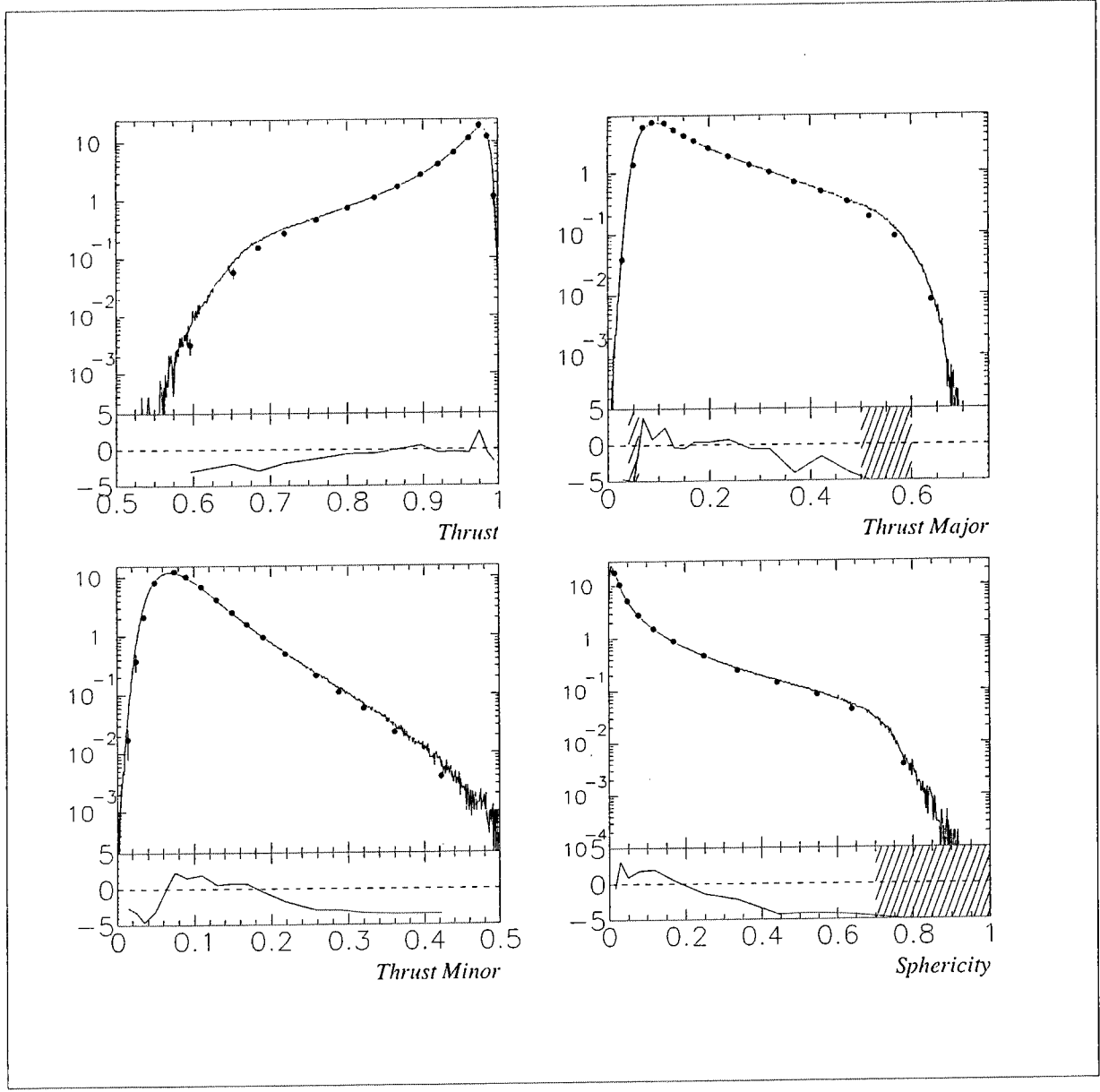
# ● Quark fragmentation functions

OPAL Collaboration



● Event shapes

OPAL Collaboration



# ● Identified particle yields in $Z^0$ decay

OPAL Collaboration

Particle	$J^P$	Experiment	Reference	Rate/event Measured	Rate/ev HW6.1 default	Rate/ev HW6.1 tuned
All charged		M,A,D,L,O	[13, 17, 33, 35, 36] [57, 62, 69, 89]	$20.924 \pm 0.117$	20.453*	21.137
$\gamma$	$1^-$	A,O	[32, 94]	$21.27 \pm 0.60$	20.056	20.657
$\pi^0$	$0^-$	A,D,L,O	[30, 51, 57, 63, 94]	$9.59 \pm 0.33$	9.549	9.772
$\pi^\pm$	$0^-$	A,O	[34, 77]	$17.04 \pm 0.25$	16.308	17.410
$\eta$	$0^-$	A,L,O	[32, 27, 63, 94]	$0.956 \pm 0.049$	0.625*	0.808*
$\rho(770)^0$	$1^-$	A,D	[27, 43]	$1.295 \pm 0.125$	1.000	1.201
$\rho(770)^\pm$	$1^-$	O	[94]	$2.40 \pm 0.43$	1.930	2.305
$\omega(782)$	$1^-$	A,L,O	[27, 65, 94]	$1.083 \pm 0.088$	0.972	1.182
$\eta'(958)$	$0^-$	A,L,O	[32, 65, 94]	$0.152 \pm 0.030$	0.100	0.113
$f_0(980)$	$0^+$	D,L,O	[43, 61, 93]	$0.142 \pm 0.011$	0.010*	0.006*
$a_0(980)^\pm$	$0^+$	O	[94]	$0.27 \pm 0.11$	0.021	0.030
$\phi(1020)$	$1^-$	A,D,O	[27, 55, 93]	$0.097 \pm 0.007$	0.128*	0.135*
$f_2(1270)$	$2^+$	D,L,O	[43, 61, 93]	$0.168 \pm 0.021$	0.169	0.173
$f_2'(1525)$	$2^+$	D	[54]	$0.020 \pm 0.008$	0.012	0.024
$K^\pm$	$0^-$	A,D,O	[34, 41, 77]	$2.319 \pm 0.079$	2.102	2.383
$K^0$	$0^-$	S,A,D,L,O	[21, 37, 43, 60, 88, 14]	$2.027 \pm 0.025$	1.971	2.262*
$K^*(892)^\pm$	$1^-$	A,D,O	[32, 37, 43, 76]	$0.731 \pm 0.058$	0.545*	0.735
$K^*(892)^0$	$1^-$	A,D,O	[27, 38, 55, 78]	$0.761 \pm 0.032$	0.548*	0.735
$K_2^*(1430)^0$	$2^+$	D,O	[55, 78]	$0.106 \pm 0.060$	0.072	0.113
$D^\pm$	$0^-$	A,D,O	[20, 46, 90]	$0.184 \pm 0.018$	0.276*	0.273*
$D^0$	$0^-$	A,D,O	[20, 46, 90]	$0.473 \pm 0.026$	0.491	0.499
$D_s^\pm$	$0^-$	A,O	[29, 90]	$0.129 \pm 0.013$	0.127	0.129
$D^*(2010)^\pm$	$1^-$	A,D,O	[20, 46, 95]	$0.182 \pm 0.009$	0.153*	0.159
$D_s^{*\pm}$	$0^-$	O	[96]	$0.096 \pm 0.046$	0.045	0.046
$J/\Psi$	$1^-$	A,D,L,O	[26, 42, 66, 72, 84]	$(5.44 \pm 0.29)10^{-3}$	0.00186*	0.00183*
$\Psi(3685)$	$1^-$	D,L,O	[42, 66, 84]	$(2.29 \pm 0.41)10^{-3}$	0.0009*	0.0009*
$p$	$\frac{1}{2}^+$	A,D,O	[34, 41, 77]	$0.991 \pm 0.054$	1.521*	0.836
$\Delta^{++}$	$\frac{3}{2}^+$	D,O	[50, 86]	$0.088 \pm 0.034$	0.295*	0.144
$\Lambda$	$\frac{1}{2}^+$	A,D,L,O	[21, 37, 40, 60, 91]	$0.373 \pm 0.008$	0.642*	0.399*
$\Sigma^+$	$\frac{1}{2}^+$	O	[92]	$0.099 \pm 0.015$	0.133	0.082
$\Sigma^0$	$\frac{1}{2}^+$	A,D,O	[32, 49, 92]	$0.074 \pm 0.009$	0.100	0.068
$\Sigma^-$	$\frac{1}{2}^+$	O	[92]	$0.083 \pm 0.011$	0.109	0.072
$\Xi^-$	$\frac{1}{2}^+$	A,D,O	[32, 37, 48, 91]	$0.0262 \pm 0.0010$	0.0776*	0.0549*
$\Sigma(1385)^\pm$	$\frac{3}{2}^+$	A,D,O	[32, 48, 91]	$0.0471 \pm 0.0046$	0.2135*	0.1100*
$\Xi(1530)^0$	$\frac{3}{2}^+$	A,D,O	[32, 48, 91]	$0.0058 \pm 0.0010$	0.0364*	0.0218*
$\Omega^-$	$\frac{3}{2}^+$	A,D,O	[32, 49, 91]	$0.00125 \pm 0.00024$	0.00967*	0.00586*
$\Lambda_c^+$	$\frac{1}{2}^+$	D,O	[52, 90]	$0.077 \pm 0.016$	0.014*	0.008*

Table 1: Particle Production rates at 91.21 GeV compared with default and OPAL-tuned versions of HERWIG61. The experiments are Aleph(A), Delphi(D), L3(L), Opal(O), MK2(M), and SLD(S). Particle and anti-particle rates are summed and sequential particle decay is activated. \* indicates that the rate differs from measurement by more than three standard deviations.

# SUBSUMMARY

- MC EVENT GENERATOR は 種々雑多な物理を 融合した QCD のモデル (であり) HERWIG, PYTHIA, ISAJET などがある
- 2+1 次 GENERATOR に含まれる HARD PROCESS に 大差はない。
- 同じく DECAY。但し HW 6.4 では CASCADE DECAY の場合の SPIN CORRELATION
- PARTON SHOWER は HERWIG が 最も CONSISTENT (COLOUR COHERENT) 次いで PYTHIA (ANGULAR ORDERED), ISAJET。
- HADRONISATION は HERWIG が 少ない パラメータで 良く 定量化 と言う。また SUBCLUSTER など JET の 細部の 性質を 良く 表わしている。