DETECTION OF HEAVY PARTICLES ...Quarks and Higgs

Yuzo Asano   University of Tsukuba

Abstract

Possibilities of detecting heavy particles (quarks and Higgs) by SSC is examined in three different modes: jets only; jets and leptons; and leptons only. The background estimation is not complete, but some hints of suppressing the background by kinematical cuts are obtained.

Introduction

It is generally taken for granted that lepton identification is essetial for detection of new particles. Good momentum resolution up to a few TeV, and pseudo rapidity coverage up to 3 is required. Jet analysis is also very important. One of the new aspect in SSC data analysis is to find out the origin of the jet by measuring all possible physical quantities: paticle multiplicity in the event (e.g.,Higgs and Z have lower multiplicity), number of jets (as we see later this is a measure of hardness of collision), fatness of the jet, energy flow, energy deposition around a lepton track (lepton isolation), angular correlation, etc. The group of K. Kondo at Univ. of Tsukuba, for example, tries to distinguish quark- and gluon-jets by fitting the moments of particle-momenta with suitable distribution functions. In this case, too, a fast and reliable event generator is essentially important. In this talk, some of the physical quantities which help identify the origin of the jets are investigated, and requirements for the lepton detctor are made clear in the process of reconstructing the Higgs particle of 500 GeV/c^2.

SSC-detector

In Fig.1, an example of proposed SSC-detector is shown. There are many other proposals of different types, but essential points are as follows:

1) Tracking.

The tracking is thought to be important in measuring relatively low momenta of particles and matching the tracks which enter the calorimeter or muon chamber. The proposed momentum resolution is 10-50%P_t.

2)Super conducting solenoid coil.

The radius is about 2m, field strength is 1.7-2 Tesla.

3)Calorimeter.

Electro-magnetic and hadronic shower calorimeters. There are many possibilities, but proposed detector elements are roughly classified as ioniaztion chamber and scintillation counter. The electro-magnetic calorimeter has energy resolution of 15-20%/sqr(E), the hadron calorimeter has 35-50%/sqr(E). The granularity in phi- and pseudo-rapidity space is (0.03-0.06)x(0.03-0.06).

4)Muon chamber.

In the central region (pseudo-rapidity 0-1.5), there are two different proposals: one of them proposes to use the toroidal field of 2 Tesla, the other proposes to use only the return field. The required resolution is analysed in more detail later. The forward region is covered by the magnetized iron, as the solenoidal coil gives a poor bending power in this region.

Heavy quark reconstruction.

In Fig.2, a copy of transparecy is shown. This is from the talk at KEK on Sept. 7 '88. In this analysis, heavy down-quark of mass 500 GeV/c^2 is reconstructed through top and W reconstruction by reconstructing 8 jets, without lepton detection. The contents are hopefully self-explanatory. The cut conditions which were used in the reconstruction are:

*n_{jet} is greater than 6.
*P_{jet} is greater than 30 GeV/c.
*E_{Tjet} is greater than 20 GeV.
*cos(jet opening angle from W) is greater than 0.7.
*reconstructed m_W is between 40 and 100 GeV/c^2.
*reconstructed P_W is greater than 1000 GeV/c.
*cos(jet opening angle from top) is greater than 0.8.
*reconstructed top mass is between 20 and 60 GeV/c^2.

Note that the mass of top quark was assumed to be 40 GeV/c^2 at that time. Later it was assumed to be 200 GeV/c^2.

In Fig.3, assumed detector resolution and conclusions are shown.

The tt-bar background is further analysed in the talk at Sendai on Nov. 15 '88. In Fig.4, the number of tt-bar events which survived the cut conditions above at each cut point is shown as a function of P_T of the top quarks at generation time. The number drops abruptly for P_T below 300 GeV/c. A large contribution comes from the number of jets which survive the cut conditions. The requirement that the number of 'good jets' must be larger than 6 reduces the QCD background substantially, especially for lower P_T events, as Fig.5 shows. Fig.6 shows the tt-bar jet cross-section as a function of P_T of the top quark at generation time. Fig.7 is a copy of transparecy showing a conclusion about (tt-bar) jet background.

Higgs reconstruction through detection of 4 leptons.

Neutral Higgs particle of 500 GeV/c^2 decaying into two Z's is reconstructed by detecting 4 muons. This study is done in order to make clear the requirements (resolution and coverage) for the muon detector. The cut conditions on the muons are as follows:

(1) Pseudo rapidity must be within +-3.
(2) P_T must be larger than 20 GeV/c.
(3) P must be larger than 30 GeV/c.
(4) The number of muons which pass the conditions above must be greater than or equal to 4.
(5) Cosine of the opening angle between a pair of muons with opposite charge must be greater than 0.
(6) There must be at least two such pairs whose invariant mass lie within 88 and 100 GeV/c^2 (Z0 mass is assumed to be 94 GeV/c^2).
(7) The Higgs mass is reconstructed out of all combinations of the above pairs.

Fig.8 shows the reconstruction efficiency as a function of the type of resolution which is listed below. In the figure, the efficiency in the case of detecting two mu's and two jets is also shown for the resolution type 10, 11 and 'mixed' case. The 'mixed' case means the nuon momentum is measured by the tracking chamber up to psudo-rapidity y_b=1.6, and it is measured by the iron-toroid magnet for the pseudo-rapidity between 1.6 and 3. This clearly demonstrates that the tracking chamber is very important in the central region, and that the mu-mu+2 jet mode is more advantageous in reconstruction efficiency.
Fig.9 shows the reconstructed Higgs mass in the case of a perfect

detector resolution. Fig.10 shows the reconstructed Z0 mass and Higgs mass in the case of detector resolution type 6 (like the central tracker at 90 degree). Fig.11 shows the same things in the case of detector resolution type 12 (20%).
Fig.12 shows the reconstructed Higgs mass on the Z0-pair background for the integrated luminosity of 10^{40}, in the cases of detector resolution type 1 (perfect resolution) and 4 (0.3 P_T). Fig.13 shows the same things in the cases of detector resolution type 10 (iron toroid --- muon momentum vector is measured at the exit of iron filter) and 11 (iron toroid --- muon momentum vector is not measured at the exit of iron filter). It is clear that the resolution is very important, and that the luminosity is essential. Fig.14 shows the Higgs-reconstruction efficiency as a function of pseudo-rapidity coverage of the central tracker. This shows that the central tracker coverage up to y=1.5 - 2 is very important.

Although Z0-pair background is seen to be not serious as in the figures 12 and 13 in the case of detecting 4 leptons, the QCD-background may be serious. Some of the cuts which suppress this background is investigated. Fig.15 shows the cumulative percentage of transverse energy deposited within the cone of delta R=0.6 from a muon track (lepton isolation). It is seen that Higgs and Z0-pair events are very isolated, but the tt-bar events (here top mass of 200 GeV/c^2 is assumed) are not, especially when the generated top quark has a large transverse momentum (i.e., when the collision is hard). The rejection factor of 300 is expected. Fig.16 shows the distribution of the number of muons passing cuts in an event. The decay in flight of charged kaons and pions are included. Higgs events have 60 % efficiency if the cut is made at 4 (pseudo-rapidity coverage up to 3). This efficiency drops to 1/3 if the coverage is limited to y=1.6. This demonstrates the necessity of forward muon detector. On the other hand, top-pair events have only 0.6% of efficiency; thus the rejection of 100 is expected.

Higgs reconstruction through 2 leptons and 2 jets.

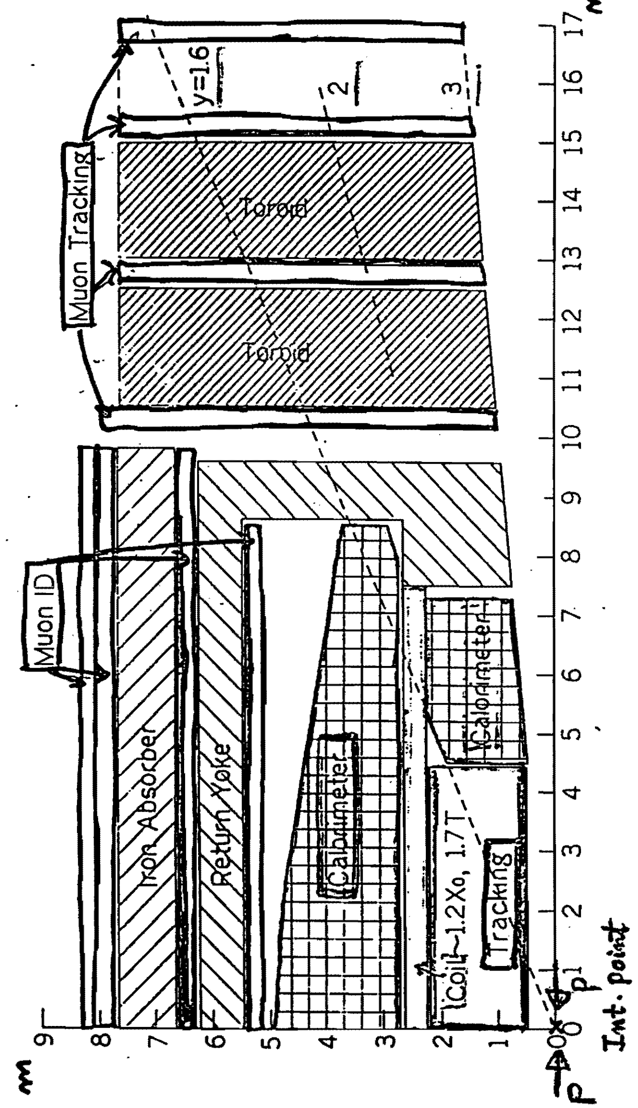
Neutral Higgs decaying into 2 Z0's is reconstructed by detecting 2 muons and 2 jets. Fig.17 shows Z0 reconstruction by 2 jets. Fig. 18 shows the reconstructed Higgs for the integrated luminosity of 5×10^{39}. A comparison with Fig.12 shows the advantage in efficiency. Fig.19 shows the W-pair background for the luminosity of 10^{38}. If more cuts are imposed, this background is not serious. Other QCD background needs more study.

Conclusion.

1) Lepton id is very important.
   Good resolution up to a few Tev and at low momentua.
   Good coverage up to pseudo-rapidity 3.
2) Lepton isolation, number of jets, particle multiplicity etc, are very powerful cuts.
3) To study QCD background and jets, a reliable and fast event generator is essentially needed.
4) For neutral Higgs reconstruction, a good detection efficiency and high luminosity are needed in 4-lepton mode. In 2-lepton + 2 jet mode, QCD background needs more study, but very promising efficiencywise.

Fig. 1

August 1989 SM



An example of SSC detector (quadrant)

~30,000 ton

Fig. 2

Heavy Quark Detection at SSC

Sept. 7 '88
Yuzo Asano Univ. of Tsukuba

From unitarity, $M_F \lesssim 550\ GeV/c^2$

for $M_X \approx M_Y = M_F$ (X Y) pair

$\rho = 1.02 \pm 0.02 \longrightarrow |M_X^2 - M_Y^2|^{1/2} \lesssim 350\ GeV/c^2$

CROSS SECTION →

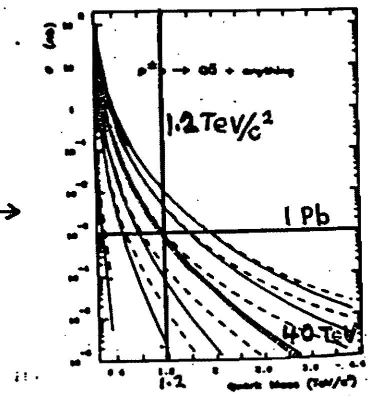


FIG. 163. Integrated cross sections for pair production of heavy quarks in proton-proton (solid lines) and proton-antiproton (dashed lines) collisions, according to the parton distributions of Set 2, at √s = 2, 10, 20, 40, 70, and 100 TeV.

EHLQ (1984)

$\lesssim 1.2\ TeV/c^2$ for 1 Pb

If $\int \mathcal{L} = 10^{40}\ cm^{-2}$

number of quarks $\sim 10^4$

Assume, $m_Y = 500\ GeV/c^2$, $m_t = 40\ GeV/c^2$

- Kim and Takikawa

  $p + p \rightarrow Y + \bar{Y} + anything$
  - $\hookrightarrow \bar{t} + W^+$
    - $\hookrightarrow e^+ + \nu$
    - $\hookrightarrow \geq 2$ jets
  - $\hookrightarrow t + W^-$
    - $\hookrightarrow 2$ jets
    - $\hookrightarrow \geq 2$ jets

  efficiency ~0.4%

- Similar channel with lepton detection ~0.2%

TRIED, $p + p \rightarrow Y + \bar{Y} + anything$
- $\hookrightarrow \bar{t} + W^+$
  - $\hookrightarrow 2$ jets
  - $\hookrightarrow 2$ jets
- $\hookrightarrow t + W^-$
  - $\hookrightarrow 2$ jets
  - $\hookrightarrow 2$ jets

} 8 jets without lepton detection

Fig. 3

Assumed Detector: $\frac{\Delta E}{E} = 20\%/\sqrt{E}$ for e and γ $\Delta\eta = 0.06$ $|\eta| \leq 3$

$\frac{\Delta E}{E} = 50\%/\sqrt{E}$ for hadrons $\Delta\phi = 0.06$

jet finding radius $R_{jet} = 0.6$

Reconstruct W → Reconstruct t → Reconstruct Y
from (hadron) calorimeter only.

cuts, as follows...

Conclusion

- Signal seen : efficiency ~ 2.5%
  (accurate mass determination is difficult)

- Back ground :
  - W^+W^- OK.
  - To be done:
    - $t\bar{t}$, min. bias) probably OK but, can't tell definitely.
    - others: To be done

how to cope with difference in $\int \mathcal{L}$ as much as

× 3000 $t\bar{t}$

× 10^9 min. bias ??

— 361 —

Fig. 4

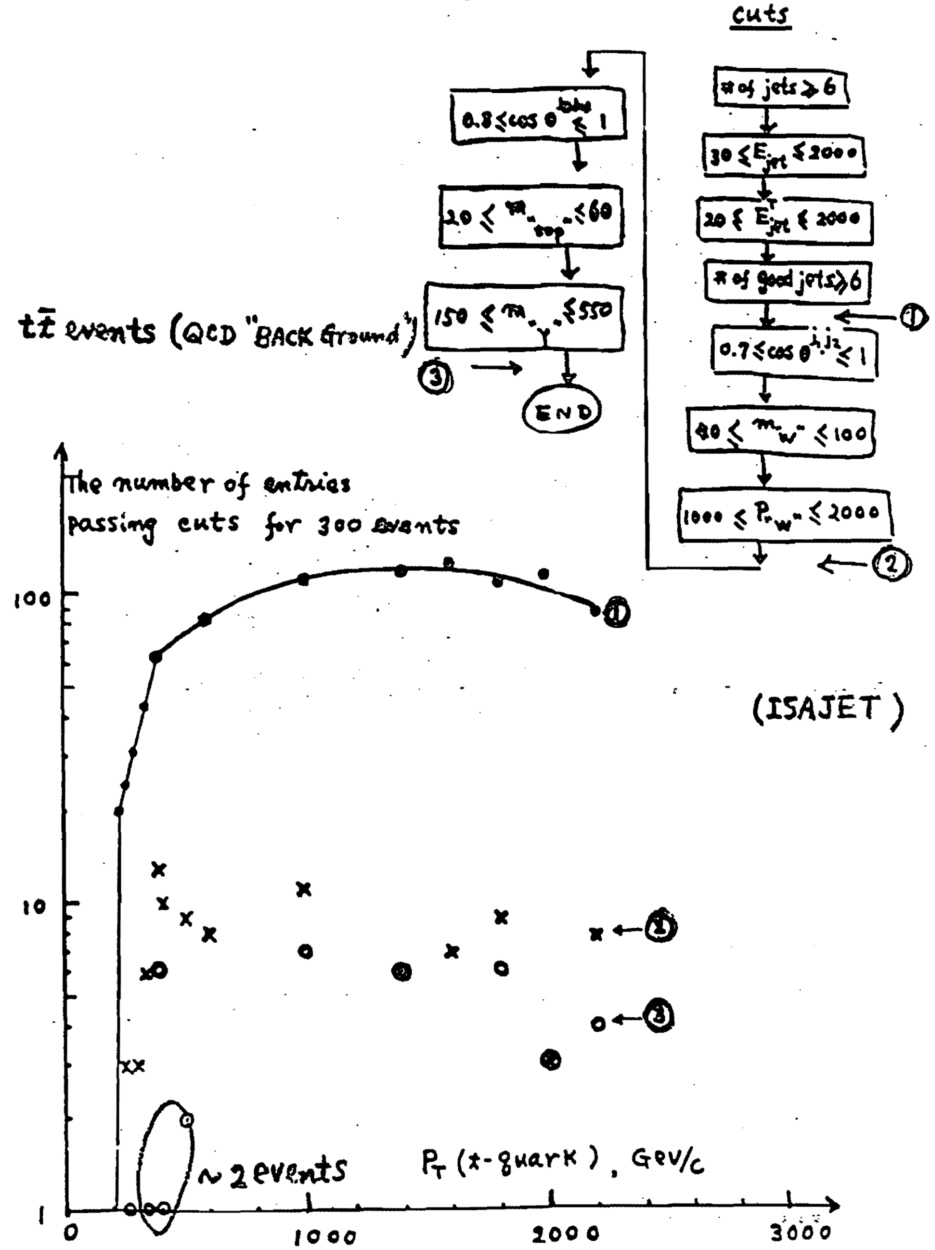


Fig. 5

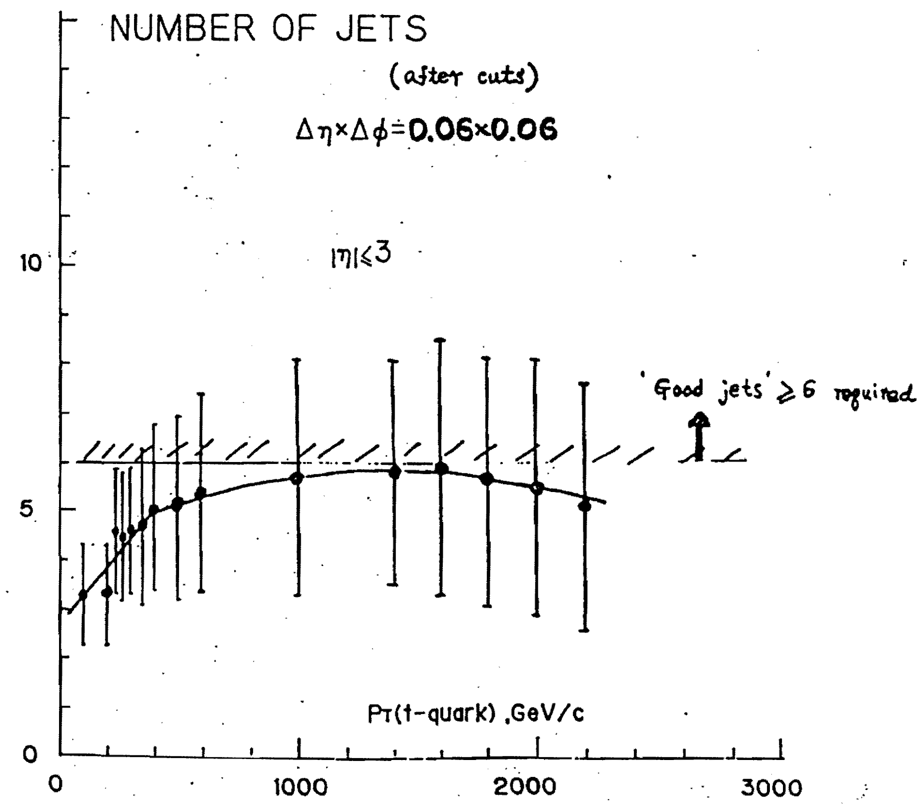

NUMBER OF JETS
(after cuts)
Δη×Δφ=0.06×0.06
|η|≤3
'Good jets' ≥ 6 required
Pт(t-quark) ,GeV/c
0
5
10
0
1000
2000
3000

Fig. 6

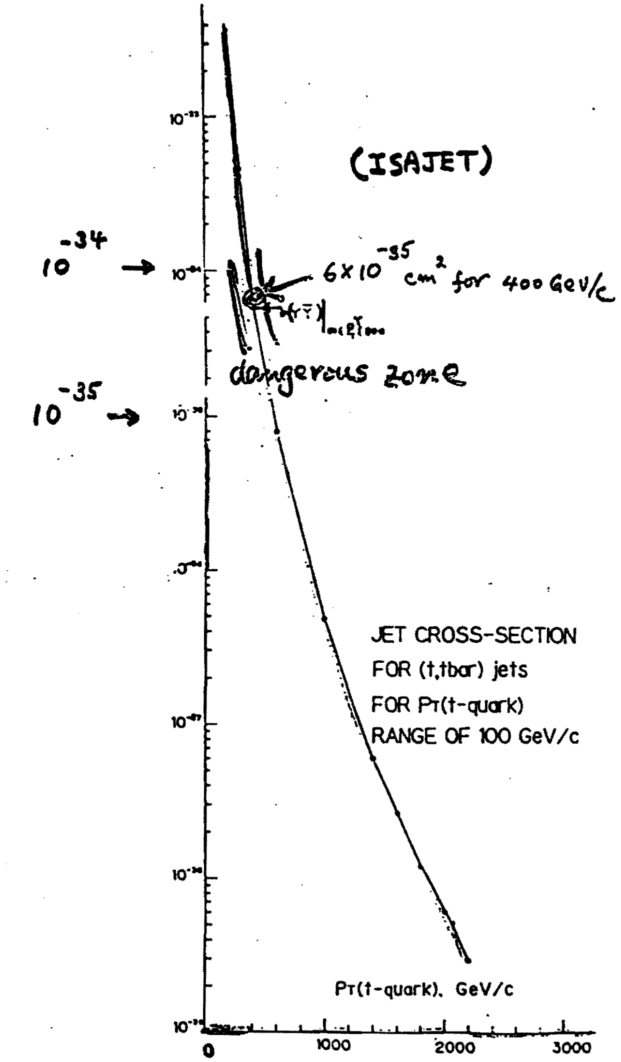

(ISAJET)
10^-34 →
10^-35 →
6×10^-35 cm^2 for 400 GeV/c
dangerous zone
JET CROSS-SECTION
FOR (t,tbar) jets
FOR Pт(t-quark)
RANGE OF 100 GeV/c
Pт(t-quark), GeV/c
0
1000
2000
3000

Fig. 7

$(t\bar{t})$ jet background

- $P_T \gg 400$ GeV/c : cross section too small
- $P_T \sim 400$ GeV/c :

  $\int \mathcal{L} = 10^{40}$ に対する background events

  $$\sim \frac{2\,\text{events}}{300\,\text{trials}} \times (6\times10^{-35}) \times 10^{40} \times 2$$

  ↑ σ for $\Delta P_T=100$ ↑ $\int \mathcal{L}$ ↑ $\Delta P_T=200$

  $$\sim \underline{8\times10^{3}}$$

- $P_T \lesssim 200$ GeV/c :

  { # of 'good jets' ≥ 6 cut → rejection ×100
  { cross section ×100

  とほぼ cancel

Signal 15 events/$5.6\times10^{36}\,\text{cm}^{-2}$

$$\rightarrow 15\times\frac{10^{40}}{5.6\times10^{36}} = \underline{3\times10^{4}}$$

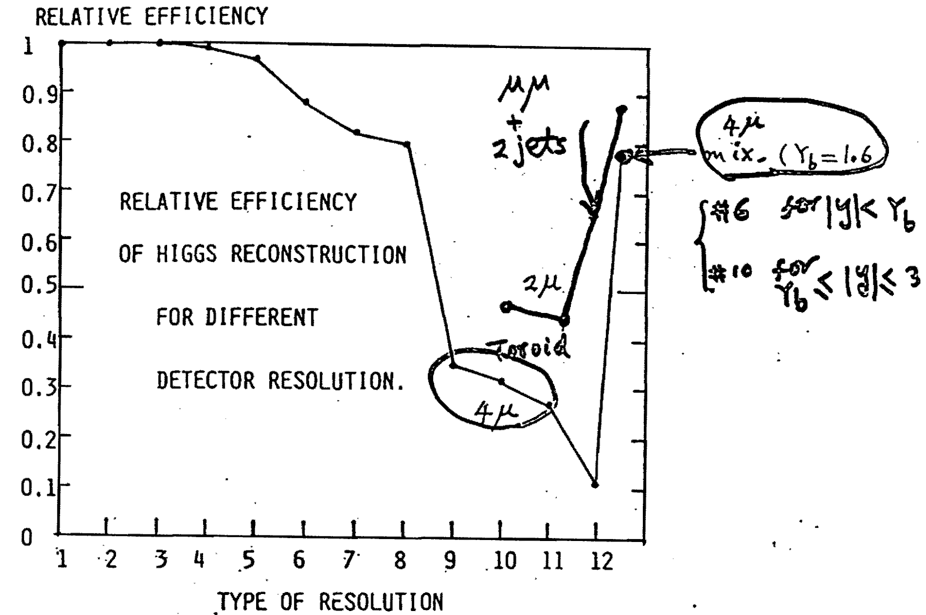
結論 QCD background は, signal とほぼ同数

従って, jet analysis [multiplicity, energy flow, etc.] により

更に数倍の rejection があれば,

十分 business になりうる。

Fig. 8



TYPE NO.	RESOLUTION ΔP/P
1	Perfect
2	2%
3	0.15/sqrt(E)
4	$0.3P_T$
5	4%
6	0.14P+0.01
7	$0.54P_T$
8	0.02 for ABS(y) .LT.1, 0.02+(ABS(y)-1)*0.06 for |y| .GT.1 and .LT.3
9	$0.1+0.1P_T$ (TeV/c)
10	Toroid case 3 (Amako program #3...muon vector is measured at the exit of the filter.)
11	Toroid case 2 (Amako program #2...only position of the mu is measured at the exit of the filter.)
12	20%

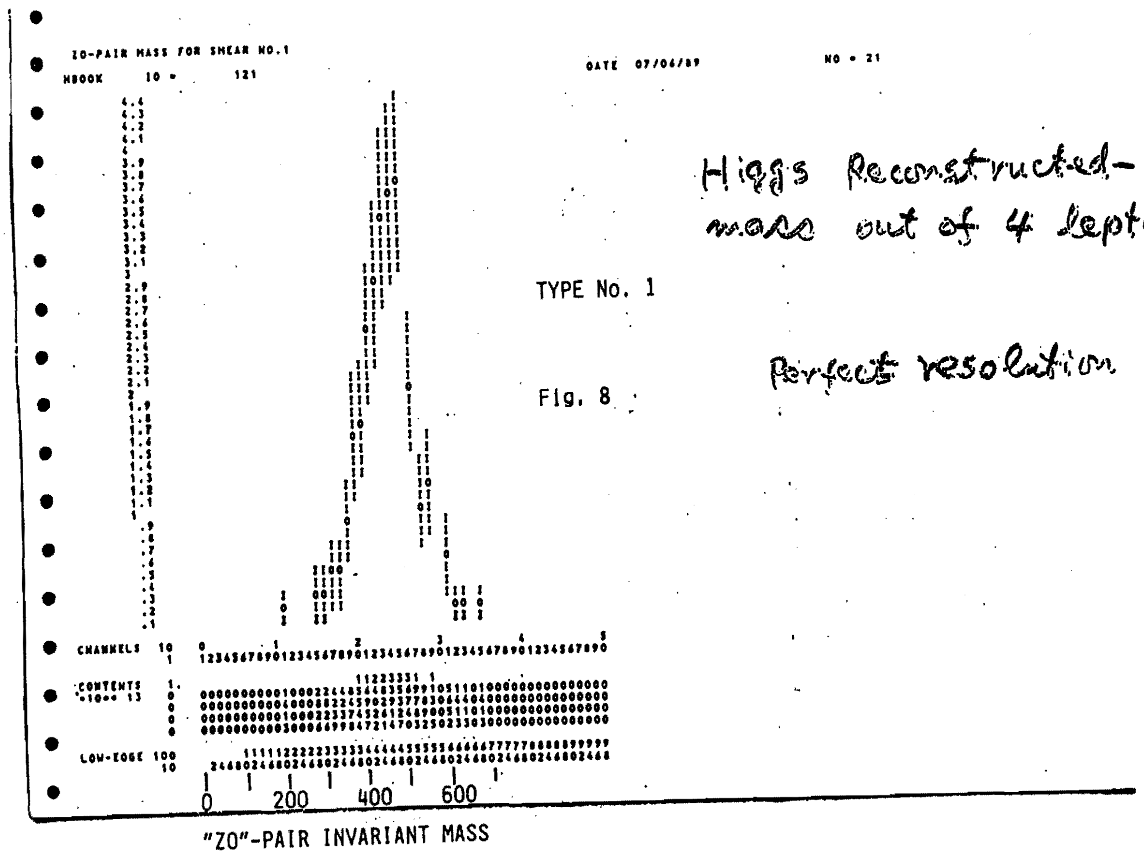
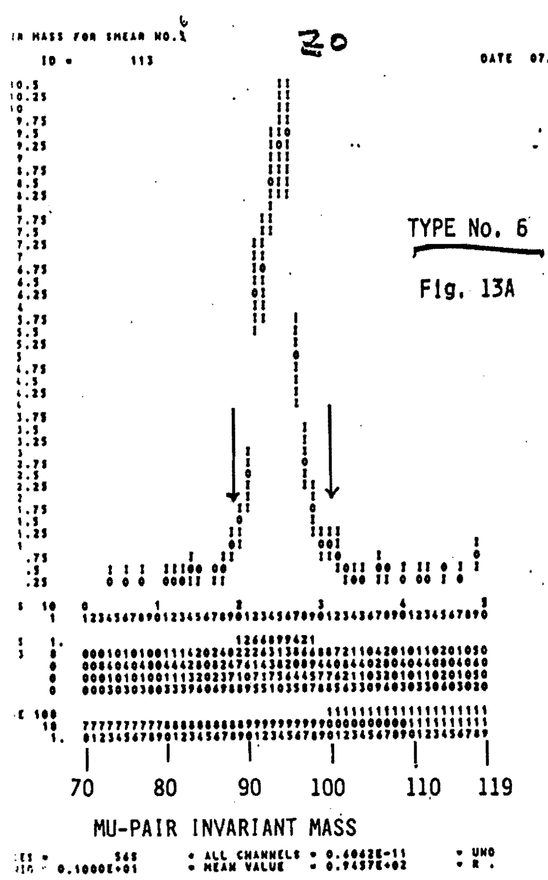

ZO-PAIR MASS FOR SHEAR NO.1
DATE 07/06/89
Higgs Reconstructed-mass out of 4 leptons
TYPE No. 1
Fig. 8
Perfect resolution
CHANNELS
CONTENTS
LOW-EDGE
0
200
400
600
"ZO"-PAIR INVARIANT MASS

Fig. 9


ZO
DATE 07/06/89
TYPE No. 6
Fig. 13A
70
80
90
100
110
119
MU-PAIR INVARIANT MASS

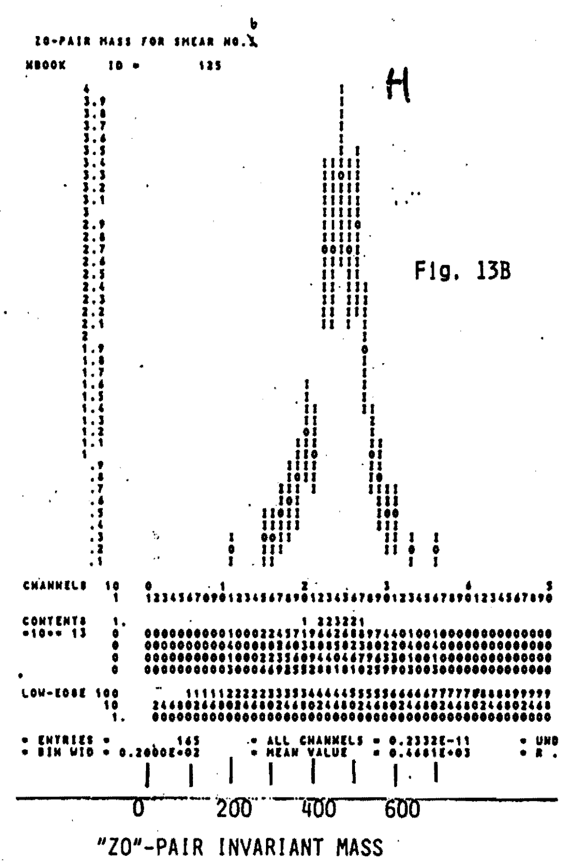
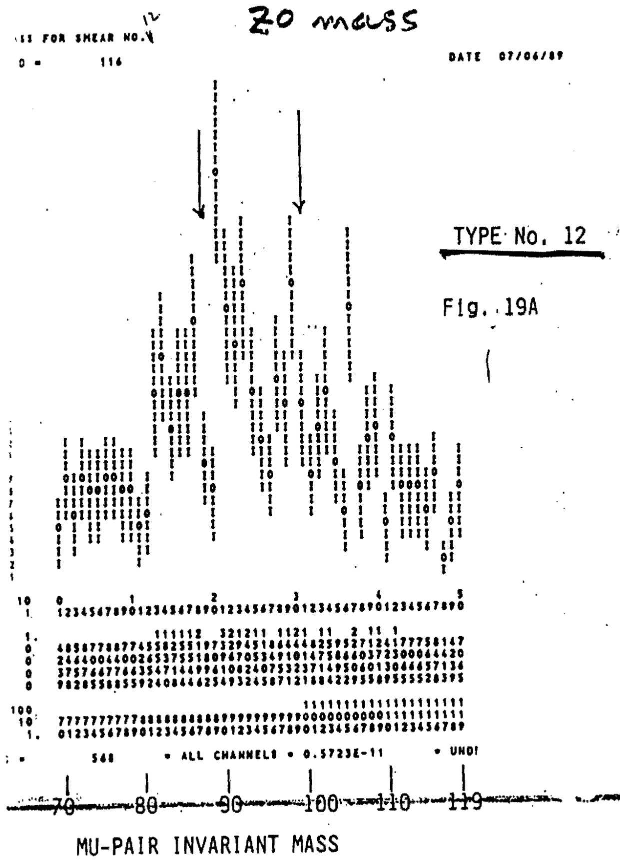

ZO-PAIR MASS FOR SHEAR NO.
HBOOK
H
Fig. 13B
CHANNELS
CONTENTS
LOW-EDGE
ENTRIES
BIN WID
ALL CHANNELS
MEAN VALUE
0
200
400
600
"ZO"-PAIR INVARIANT MASS

Fig. 10


Z0 mass
TYPE No. 12
Fig. 19A
70
80
90
100
110
119
MU-PAIR INVARIANT MASS

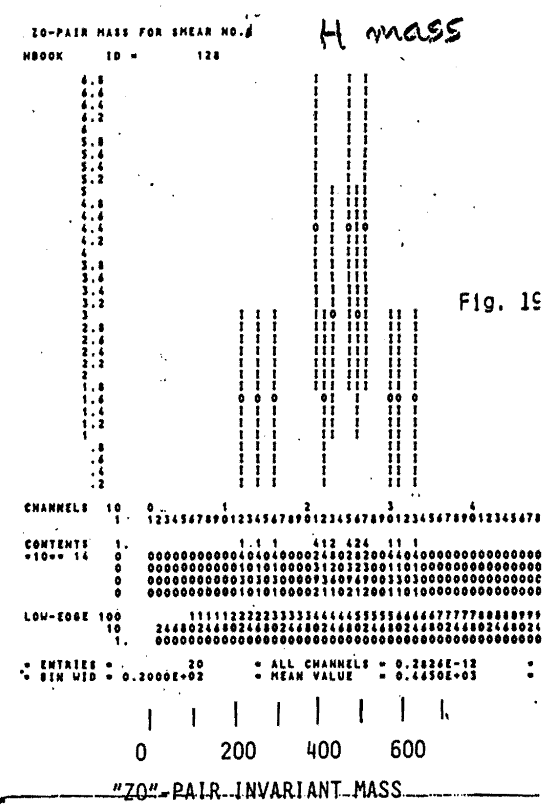
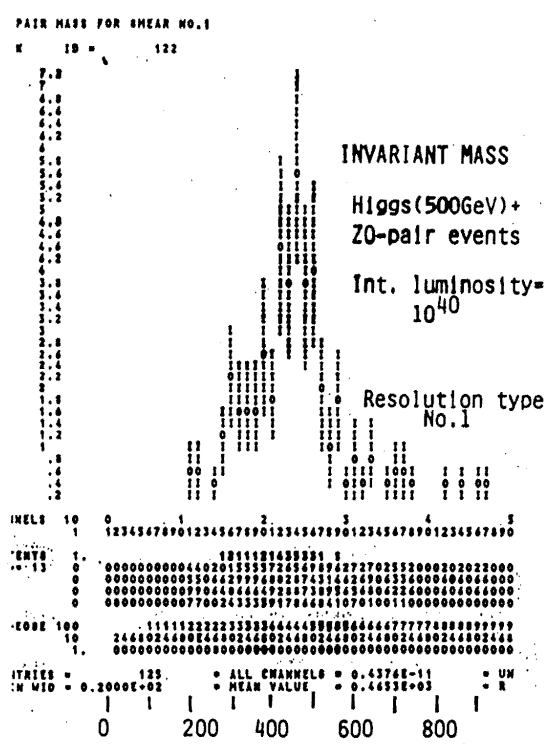

H mass
0
200
400
600
"Z0"-PAIR INVARIANT MASS

Fig. 11


INVARIANT MASS
Higgs(500GeV)+
Z0-pair events
Int. luminosity=
10^40
Resolution type
No.1
0
200
400
600
800

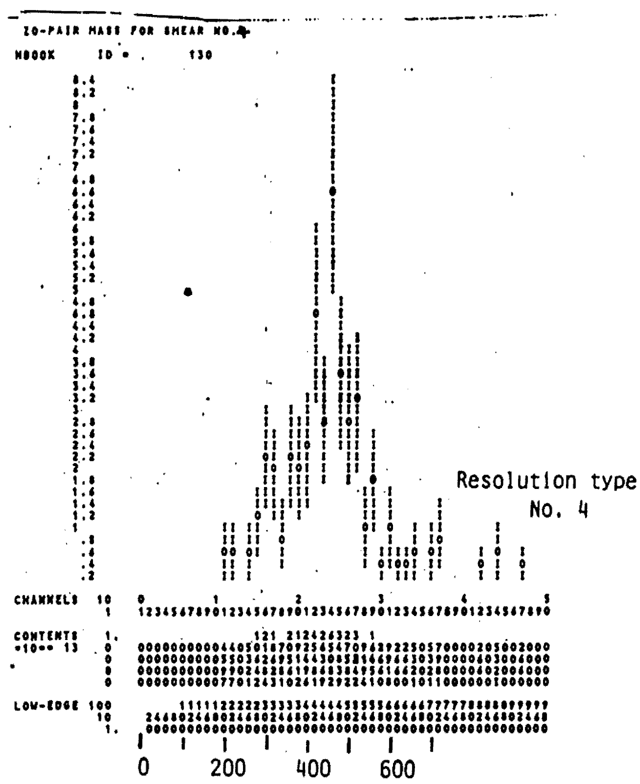

Resolution type
No. 4
0
200
400
600

Fig. 12

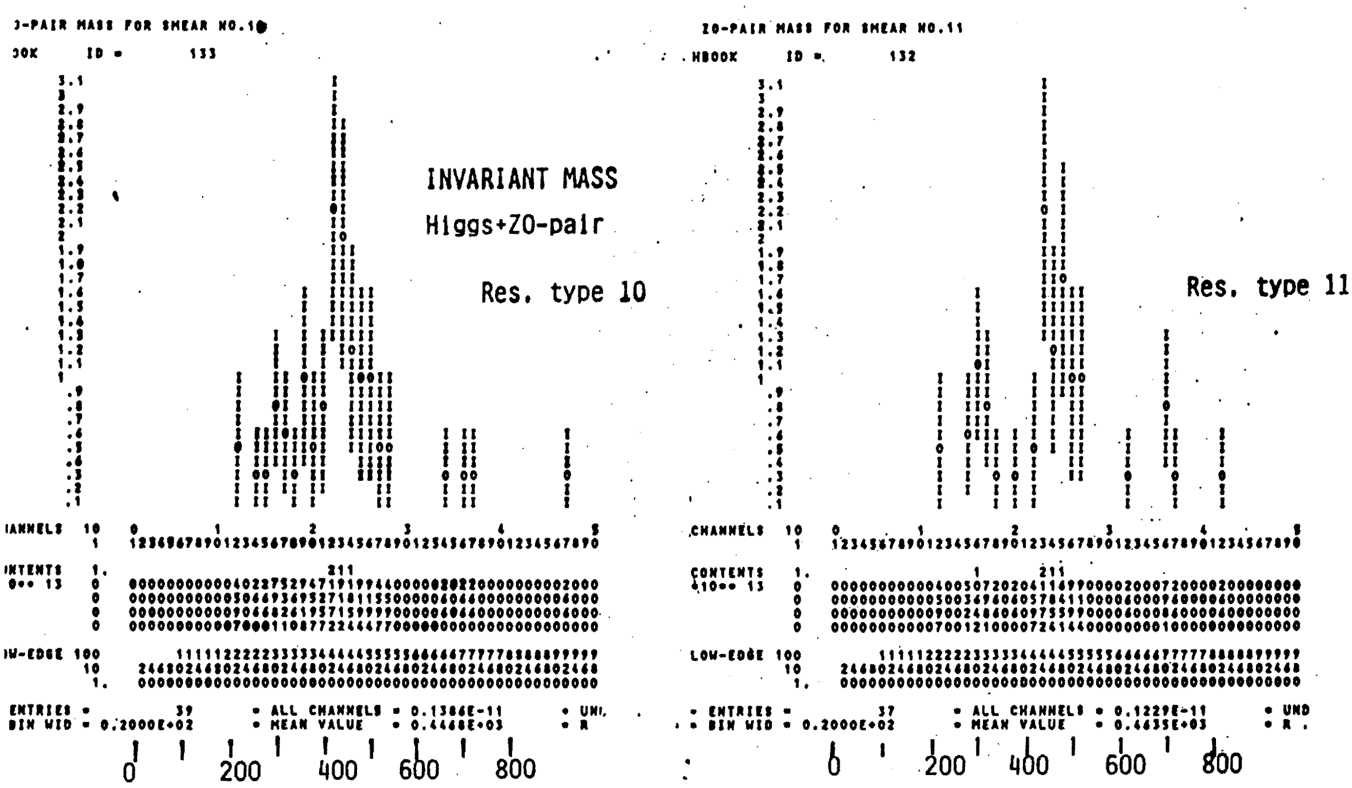

INVARIANT MASS
Higgs+ZO-pair
Res. type 10
Res. type 11
0 200 400 600 800
0 200 400 600 800

Fig. 13

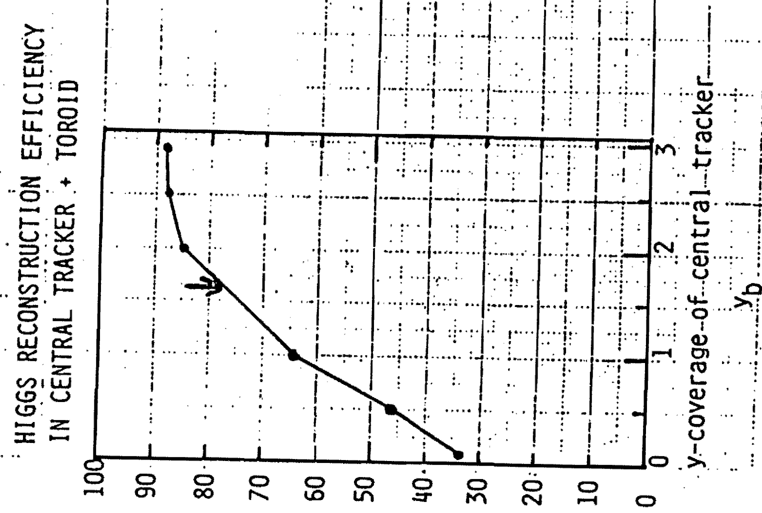
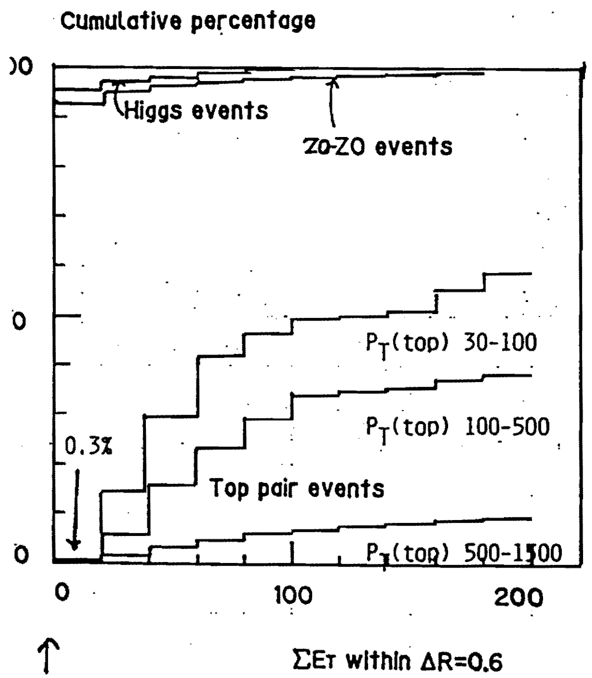

HIGGS RECONSTRUCTION EFFICIENCY
IN CENTRAL TRACKER + TOROID
100 90 80 70 60 50 40 30 20 10 0
0 1 2 3
y-coverage-of-central-tracker
y_b

Fig. 14

Fig. 15

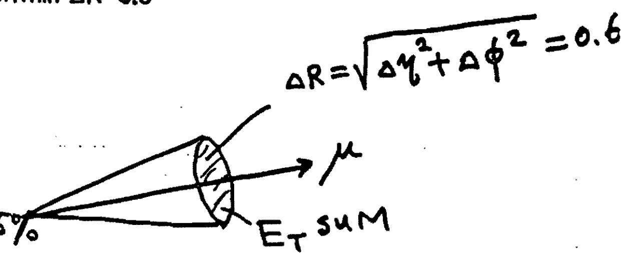
MUON ISOLATION



$m_T = 200$

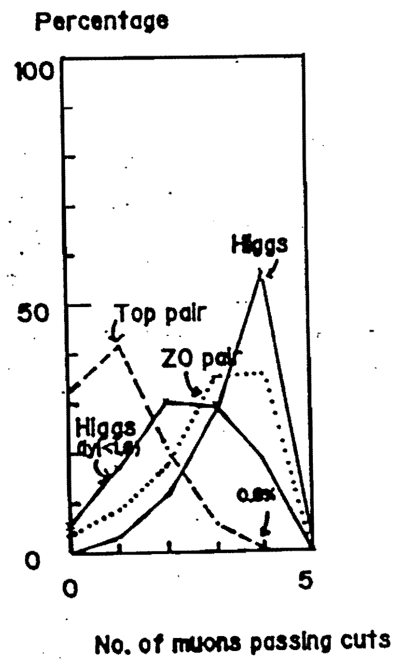
↑

(E_T SUM)が ある値より
小さい 確率



例えば、20 GeV Cut
をすれば、 Higgsは95%
とれるが、 $t\bar{t}$ events は、
0.3%しか 混入しない。

Fig. 16



$m_t = 200$

Decay included.

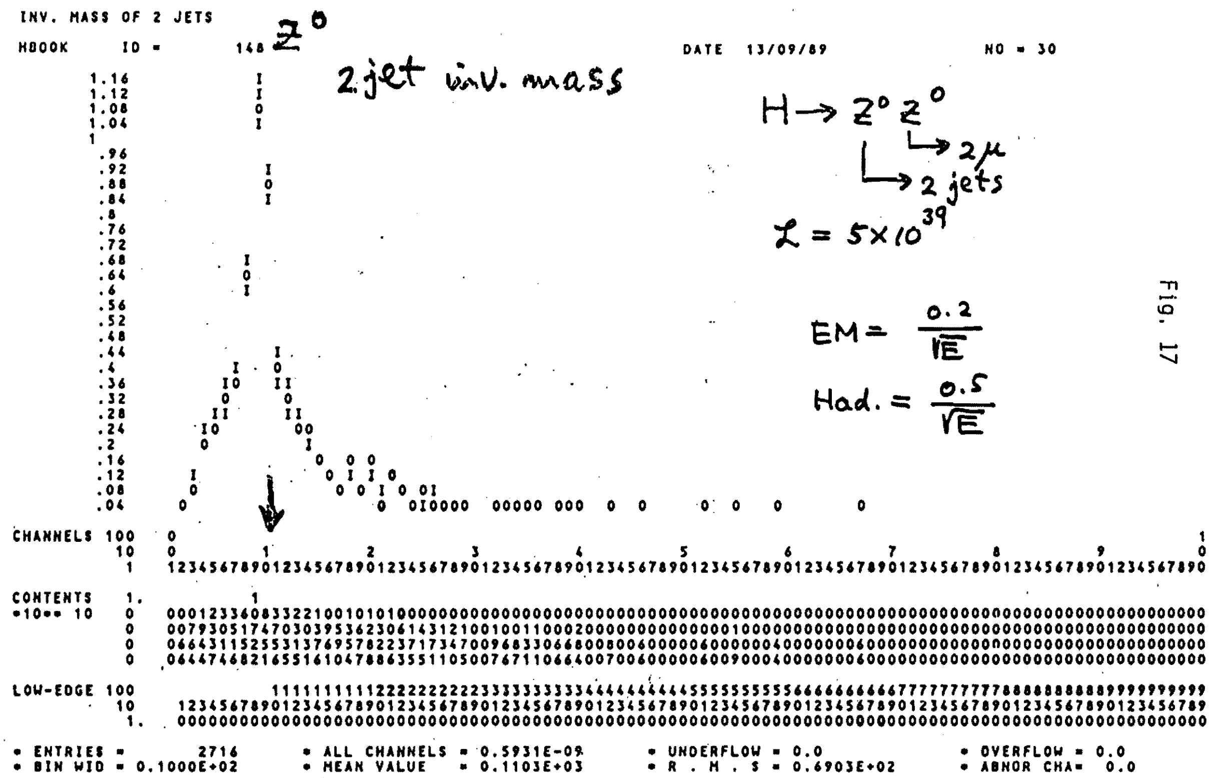

INV. MASS OF 2 JETS
HBOOK ID = 148
DATE 13/09/89
NO = 30
Z^0
2 jet inv. mass
$H \to Z^0 Z^0$
$\to 2\mu$
$\to 2$ jets
$\mathcal{L} = 5 \times 10^{39}$
$EM = \frac{0.2}{\sqrt{E}}$
$Had. = \frac{0.5}{\sqrt{E}}$
CHANNELS 100
10
1
CONTENTS 1.
*10** 10
LOW-EDGE 100
10
1.
* ENTRIES = 2716
* ALL CHANNELS = 0.5931E-09
* UNDERFLOW = 0.0
* OVERFLOW = 0.0
* BIN WID = 0.1000E+02
* MEAN VALUE = 0.1103E+03
* R . M . S = 0.6903E+02
* ABNOR CHA= 0.0

Fig. 17

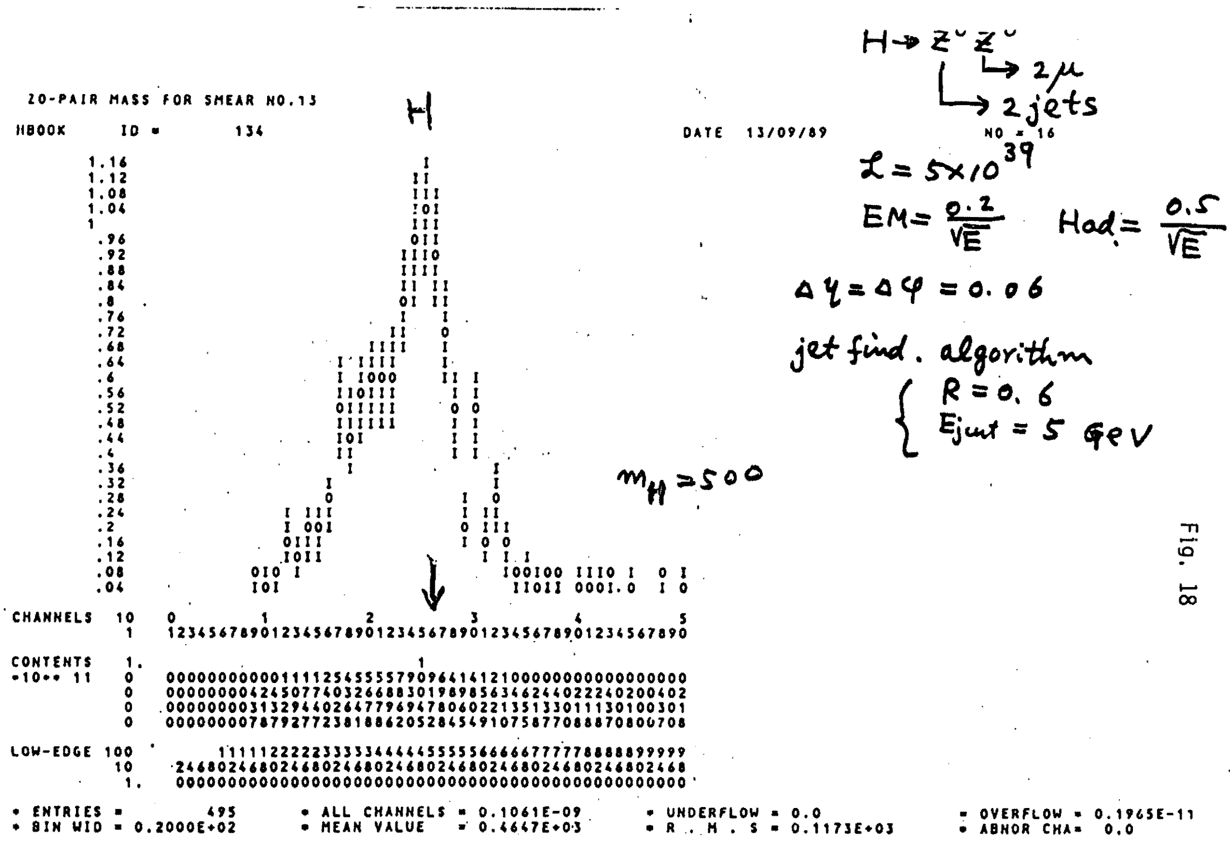

ZO-PAIR MASS FOR SMEAR NO.13
HBOOK ID = 134
DATE 13/09/89
NO = 16
H
$H \to Z^0 Z^0$
$\to 2\mu$
$\to 2$ jets
$\mathcal{L} = 5 \times 10^{39}$
$EM = \frac{0.2}{\sqrt{E}}$
$Had = \frac{0.5}{\sqrt{E}}$
$\Delta \eta = \Delta \varphi = 0.06$
jet find. algorithm
$R = 0.6$
$E_{jcut} = 5$ GeV
$m_H = 500$
CHANNELS 10
1
CONTENTS 1.
*10** 11
LOW-EDGE 100
10
1.
* ENTRIES = 495
* ALL CHANNELS = 0.1061E-09
* UNDERFLOW = 0.0
* OVERFLOW = 0.1965E-11
* BIN WID = 0.2000E+02
* MEAN VALUE = 0.4647E+03
* R . M . S = 0.1173E+03
* ABNOR CHA= 0.0

Fig. 18

```
 ZO-PAIR MASS FOR SHEAR NO.13
HBOOK      ID =        134                                      DATE  13/09/89            NO =  16
      3.7                 I I I            I
      3.6                 I I I            I
      3.5                 I I I            I
      3.4                 I I I            I
      3.3                 I I I            I
      3.2                 I I I            I
      3.1                 I I I            I
      3                   I I I            I
      2.9                 I I I            I
      2.8                 I I I            I
      2.7                 I I I            I
      2.6                 I I I            I
      2.5                 I I I            I
      2.4                 I I I            I
      2.3                 I I I            I
      2.2               I 0 0I0     I I I  0
      2.1               I I III     I I I  I
      2                 I I III     I I I  I
      1.9               I I III     I I I  I
      1.8               I I III     I I I  I
      1.7               I I III     I I I  I
      1.6               I I III     I I I  I
      1.5               I I III     I I I  I
      1.4               I I III     I I I  I
      1.3               I I III     I I I  I
      1.2               I I III     I I I  I
      1.1               0 I I0I     0 0 0  I
      1                 I I III     I I I  I
       .9               I I III     I I I  I
       .8               I I III     I I I  I
       .7               I I III     I I I  I
       .6               I    I      I I I
       .5               I    I      I I I
       .4               I    I      I I I
       .3               I    I      I I I
       .2               I    I      I I I
       .1               I    I      I I I
CHANNELS 10  0        1         2         3         4         5
          1  12345678901234567890123456789012345678901234567890

CONTENTS  1.            1 2 212     1 1 1  2
*10** 11  0  00000000000001010100000000000001000000000000000000
          0  00000000000704047400000707070040000000000000000000
          0  00000000000000000000000000000000000000000000000000
          0  00000000000204042400000202020040000000000000000000

LOW-EDGE 100      111112222233333444445555566666777778888899999
          10  2468024680246802468024680246802468024680246802468
          1.  0000000000000000000000000000000000000000000000000

* ENTRIES =          13      * ALL CHANNELS = 0.1391E-09      * UNDERFLOW = 0.0              * OVERFLOW = 0.0
* BIN WID = 0.2000E+02       * MEAN VALUE   = 0.3977E+03      * R . M . S = 0.1290E+03       * ABNOR CHA=  0.0
```

W-pair Background

$\mathcal{L} = 10^{38}$

(entry = 13)

Fig. 19