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$H^o \rightarrow ZZ^* \rightarrow \ell^+\ell^- \ \ell^+\ell^-$: Search for $140 < M_{H^o} < 180$ GeV

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$H^0 \to ZZ^* \to \ell^+\ell^-\ell^+\ell^-$: Search for $140 < M_{H^0} < 180$ GeV

Below the ZZ threshold of the Higgs decay mode, we can search for the Higgs through the ZZ^* channel

$$p + p \to H^0 + X \to ZZ^* + X \to 4 \text{ leptons} + X,$$

where the Z^* is virtual with mass $< (M_{H^0} - M_{Z^0})$. At $10^{33}/cm^2/s$ luminosity, we can search the Higgs mass through this channel down to 140 GeV with significant signal/background ratio. Our muon system is designed to work at higher luminosity, therefore at $10^{34}/cm^2/s$ luminosity, we can search the Higgs mass through

$$ZZ^* \to \mu^+\mu^-\mu^+\mu^-$$

channel down to 130 GeV. Note that for $150GeV < M_{H^0} < 180\ GeV$, $ZZ^* \to \ell^+\ell^-\ell^+\ell^-$the only channel to search for the Higgs with reliable and clean signals.

We studied ZZ^* signal and background events using the Monte Carlo program ISAJET (version 6.36). The background events come from following proposses:

$$pp \to 2 - \text{jets} + X \to 4 \text{ leptons} + X$$

$$pp \to Z\gamma^* + X \to 4 \text{ leptons} + X$$

$$pp \to Z + Q\bar{Q} + X \to 4 \text{ leptons} + X$$

The event selection criteria is following:

- electron/muon rapidity, $|\eta_\ell| < 2.5$;
- $p_T^\ell > 5$ GeV, and at least 2 leptons with $p_T > 10$ GeV;
- isolation cut: $(\sum E_T - E_T^\ell)_{R=0.3} < 5GeV + E_T^\ell/10$;

- $86GeV < M_{\ell_1^+\ell_2^-} < 96GeV$, $10GeV < M_{\ell_3^+\ell_4^-} < 90GeV$.

The overall acceptance for Higgs is 42% after the above cuts. Large QCD events are rejected by the isolation cut and the requirement $M_{\ell\ell} > 10$ GeV when applied to all four leptons. The remaining background come from $ZX, Zq\bar{q}$ events. In these events, the first pair of leptons comes from a real Z^0, one cannot use the Z^0 mass as a constraint, and the leptons from heavy quarks have little hadronic energy around them and thus are similar to the leptons from the virtual Z^*.

The simulation for electrons, we assumed the EM calorimeter has resolutions

$$\Delta E/E = 2\%/\mathrm{sqrt}E \oplus 0.5\% \qquad \mathrm{for}BaF_2\mathrm{option}$$

and

$$\Delta E/E = 7.5\%/\mathrm{sqrt}E \oplus 0.5\% \qquad \mathrm{for}LAr\mathrm{option}$$

. The calorimeter cracks didn't take into account. For BaF_2 option, the crack (for central tracker cable going out) is about 2.7%. The event vertex uncertainty and the shower position uncertainty in the EM calorimeter are assumed 1 mm.

The simulation for muons, we used the muon energy loss spectra in the calorimeter with different angle and incident muon energies to calcilate the muon energy losses. Total muon energy is determined as following:

$$E^{\mu}_{total} = P_{\mu-chamber} + \Delta E$$

where $P_{\mu-chamber}$ is the muon momentum measured in the muon chambers out side of the calorimeter, ΔE is the muon energy loss inside the calorimeter. For muon system the momentum resolution vs. η for different muon momenta is shown in Fig. 1; For muon energy loss corrections we determined that if $\Delta E < 1.27 \times E_{peak}$(dE/dxloss), we used E_{peak} to correct for the muon energy loss; otherwise we used calorimeter measured ΔE assuming calorimetry energy resolution of $\Delta E/E = 50\%/\sqrt{E} + 2\%$. For the Higgs mass reconstruction, we assumed the central tracker can determine the event vertex with $\sigma_z \sim 1\ mm$, and the track anguler resolution

of few milli-radians. For $10^{34}/cm^2/s$ luminosity case, if we loss the muon anglular information from the central tracker, and only use the tracking information from the muon chambers, we included the multiple scattering contributions from the calorimeters to the muon angular resolution. The mass resolutions for $ZZ^* \rightarrow \mu^+\mu^-\mu^+\mu^-$ get 5-7% worse compared with that of using central tracker information.

Figure 2 shows $H^0 \rightarrow ZZ^* \rightarrow \mu^+\mu^-\mu^+\mu^-$ for the Higgs masses, 140, 150, 160, and 180 GeV superimposed with background. Number of events are normalized to total number of events per year (10^7 sec.) at the $10^{33}/cm^2/s$ luminosity. It is clear that for $M_{H^0} = 170\ GeV$, we need longer time or higher luminosity for detection sensitivity.

Figure 3 shows $H^0 \rightarrow ZZ^* \rightarrow e^+e^-e^+e^-$ for the Higgs masses, 140, 150, 160, and 180 GeV superimposed with background. Fig. 3a is BaF_2 EM calorimeter option, assuming the resolution of $\Delta E/E = 2\%/sqrtE \oplus 0.5\%$; Fig. 3b is LAr EM calorimeter option, assuming the resolution of $\Delta E/E = 7.5\%/sqrtE \oplus 0.5\%$. Number of events are normalized to total number of events per year (10^7 sec.) at the $10^{33}/cm^2/s$ luminosity.

Figure 4 shows $H^0 \rightarrow ZZ^* \rightarrow e^+e^-\mu^+\mu^-$ for the Higgs masses, 140, 150, 160, and 180 GeV superimposed with background. Fig. 4a is the BaF_2 EM calorimeter option and Fig. 3b is the LAr EM calorimeter option The normalizations are the same as Fig. 2 and Fig. 3.

Triggers

As complete, I put modified L trigger section here, and I hope we will change it with GEM trigger section*

The GEM trigger system has three levels. The Level-1 trigger uses several thousand channels of information, including coarse tower sums from the hadron and

electromagnetic calorimeters, and rough tracks from fast muon trigger detectors (Resistive Plate Counters for the barrel and PAD chambers for the end-caps). The Level-1 trigger decision is performed for each beam crossing. The number of events accepted by Level-1 does not exceed 2×10^5 Hz.

The Level-2 trigger reduces the data rate by another factor of 200. Finer tower sums from the electromagnetic and hadron calorimeters, and more accurate measurement of muon momenta will be available at this level. The finer granularity of the Level-2 trigger is important for the selection of interesting events with isolated leptons and jets, or multileptons. The Level-2 trigger rate is expected to be less than 10^3 Hz.

The Level-3 trigger reconstructs events using the full digitized data from $\approx 10^6$ channels, including the complete information from the muon chambers and inner silicon tracker. The Level-3 trigger processes up to 1 kHz of events, using parallel computing techniques. The rate accepted by Level-3, and written to permanent storage, will typically be up to 10 Hz.

Electron-Photon Trigger Strategy

The Level-1 Trigger:

Because of the huge QCD jet production cross-section at the SSC ($\sigma \approx 100$ mb, i.e. 100 MHz), the primary goal of the Level-1 trigger is to reduce the trigger rate from QCD jets.

L*'s Level-1 trigger for isolated photons or electrons is based on sums of transverse energies in groups of cells in the electromagnetic calorimeter(EM), with a typical group covering 0.2×0.2 in $\Delta\eta \times \Delta\phi$ (e.g. 5 by 5 BaF_2 crystals). Each group of EM cells is matched with an overlapping hadron calorimeter 'tower' (a group of HCAL cells) behind it. An HCAL veto, requiring that the sum of the transverse energies measured in the matching HCAL tower is less than 10% of the sum of the transverse energy in the EM cell-group, is used to reject the huge QCD

background.

A Monte Carlo simulation was carried out to calculate the Level-1 trigger rate. The PYTHIA 5.4 program [?] was used to generate QCD jets. The response of the electromagnetic calorimeter and hadronic calorimeter was computed for each particle in the jets by assuming:

- electrons and photons deposit all of their energy in the electromagnetic calorimeter;
- hadrons deposit a fraction of their energy which is distributed according to the predictions of the GEANT (full shower) simulation[1].

The total response of each EM and HCAL group was obtained by summing the responses to the individual particles in the jets, event by event.

The requirements of the Level-1 trigger are:

- N electromagnetic clusters (EMC) with transverse energy larger than E_{Tcut}^{N} within the full calorimeter coverage $|\eta| < 3.8$, i.e.

  $$E_T^{cluster} > E_{Tcut}^{N},$$

  where E_{Tcut}^{N} equals 50, 15 and 5 GeV for $N = 1$, 2 or 3, and >3 respectively;
- the sum of the transverse energies in the matching hadron calorimeter tower E_T^{tower} is less than 10% of the sum of the transverse energy in the electromagnetic cluster, i.e.

  $$E_T^{tower} < 0.1 \times E_T^{cluster}.$$

Table 1 lists the E_{Tcut}^{N} values and expected trigger rates from QCD jets as a function of the number of EMC's. The total QCD trigger rate is approximately 35 kHz.

[1]The GEANT distributions were expressed as parametrized curves for this simulation.

Table 1: Level-1 EM Trigger Rate (Hz) from QCD Jets, After HCAL Veto

N (EMC)	1	2 or 3	> 3
E^N_{Tcut} (GeV)	50	15	5
Level-1 (kHz)	7.1	14.3	17.6

The numerical values of these cuts were chosen after extensive preliminary studies, and were cross-checked to insure that the cuts are loose enough to allow all of the interesting physics events, such as $H^0 \rightarrow \gamma\gamma$ and $H^0 \rightarrow e^+e^-e^+e^-$, to survive. The study shows that with the cut values specified above, the acceptances of a 150 GeV Higgs decay to 4 electrons and an 80 GeV Higgs decaying to $\gamma\gamma$ are 98.4% and 85% respectively.

The Level-2 Trigger:

At the Level-2 trigger, isolated electromagnetic clusters (IEMC) are selected by requiring that the transverse energy of the electromagnetic cluster ($E_T^{cluster}$) is larger than E_{Tcut}, and the sum of all transverse energies in a cone of radius R=0.3, excluding the electromagnetic cluster, is less than an isolation energy cut (E_{Icut}). After analyzing the results of the simulations, we chose $E_{Tcut} = 20\ GeV$ and $E_{Icut} = 10\ GeV$, i.e.

$$E_T^{cluster} > 20\ GeV,\ and$$

$$\sum_{R<0.3} E_T - E_T^{cluster} < 10\ GeV.$$

The total trigger rate from QCD jets is reduced by the Level-2 trigger to ≈ 135 Hz. The reduction of the acceptance by Level-2 conditions is less than 1% for the decay of a 150 GeV Higgs to 4 electrons and an 80 GeV Higgs decay to 2 photons.

The Level-3 Trigger:

The Level-3 trigger applies the cut on matching charged track momenta with

the energy in each electromagnetic calorimeter cluster, and then performs the physics event selection cuts (as described in Section 1.1). Table 2 lists the rates at each level of the trigger for the QCD and Drell-Yan processes calculated above. The final electromagnetic trigger rate after the Level-3 trigger is expected to be less than 4 Hz.

Table 2: EM Trigger Rate (Hz) for different physics processes

Process	Level-1	Level-2	Level-3
QCD Jet	35000	~135	~0
$q\bar{q} \rightarrow e^+e^-$	2	2	2

Muon Trigger

Generic muon rates for GEM detector were calculated with GEANT simulations and ISAJET Monte Carlo event generators. Table 1 lists the physics processes included in our calculations.

Table 3: **Simulated MC Events in Various Physics Processes**

process	P_T^{jet}**(GeV)**	cross section(mb)	N_{MC}
Minimal bias	4-20	7.4×10^1	1000k
$PP \rightarrow$ 2 jets (q, g)	20-9000	0.2×10^1	9700k
$PP \rightarrow t\bar{t}$	10-5000	1.6×10^{-5}	1150k
$PP \rightarrow W + X \rightarrow \mu\nu X$	10-5000	3.1×10^{-5}	1770k
$PP \rightarrow Z + X \rightarrow \mu^+\mu^- X$	10-5000	3.1×10^{-6}	800k
$PP \rightarrow \gamma(Z) + X \rightarrow \mu^+\mu^- X$	10-5000	5.1×10^{-6}	432k

Fig. 5 shows the total rates in the inner layer muon chambers as functions of

muon transverse momentum, p_T, rapidity range $|\eta| < 2.5$. Spectra from different physics processes were plotted to show their relative contributions. It is clear that the muons come from QCD two jet events dominates the rate.

Fig. 6 shows the total rates versus the rapidity, η, with different muon p_T cut.

The Integrated Rate in several η regions are listed in Table 2. The multi-muon event rates are listed in Table 3. All these rate calculations are assumed the SSC standard luminosity, $10^{33}/cm^2/s$.

Table 4: **Integrated Rate (Hz) in Several η Regions**

Region	$\|\eta\| < 2.5$	$\|\eta\| < 1.5$	$1.5 < \|\eta\| < 2$	$2 < \|\eta\| < 2.5$	di-muon $\|\eta\| < 2.5$
no p_T cut	2467k	1042k	660k	760k	230k
$p_T > 5$ GeV	9.31k	4.84k	2.23k	2.23	91
$p_T > 10$ GeV	1.92k	1.08k	440	403	19
$p_T > 15$ GeV	630	372	136	120	9.9
$p_T > 20$ GeV	280	166	52	58	6.3
$p_T > 25$ GeV	140	50	26	24	

Table 5: **Multi-Muon Event Rate (Hz) for $|\eta| < 2.5$**

multi-μ state	1μ/event	2μ/event	3μ/event	4μ/event	$> 4\mu$/event
no p_T cut	1274k	144.7k	42.7k	19.3k	24.1k
$p_T > 5$ GeV	9.14k	88	1.84	0.17	0.022
$p_T > 10$ GeV	1.91k	17.4	0.52	0.14	0.016
$p_T > 15$ GeV	629	8.36	0.30	0.12	0.014
$p_T > 20$ GeV	280	4.95	0.20	0.092	0.013

The GEM muon trigger system is designed to handle level-1 trigger rate at few tens of kHz level, and to reduce the trigger rate by a factor of 100 at level-2 trigger. Level-3 trigger rate should be less than few Hz. The GEM fast muon trigger is formed from roads in three layers of Resistive Plate Counters "RPC's" in the barrel region, and of Cathod Strip Chamber (PAD chamber) in the end-cap regions. Both trigger devices have a response time of less than 15 nanoseconds, which allows the Level-1 trigger decision is performed for each beam crossing.

From Table 4, we see that the muons with $p_T > 5\ GeV$ have a rate of 9.3 kHz, and with $p_T > 25 GeV$, have a rate of 140 Hz. This result implies that at the high luminosity hadron colliders, muons certainly offer an advantage over electrons/photons due to the low particle rate outside of the calorimeter. We can trigger on muons at level-1 with the p_T cut as low as 5 GeV at the $10^{33}/cm^2/s$ luminosity. Even the luminosity is a factor of 10 higher, we can increase the muon trigger threshold to 25 GeV.

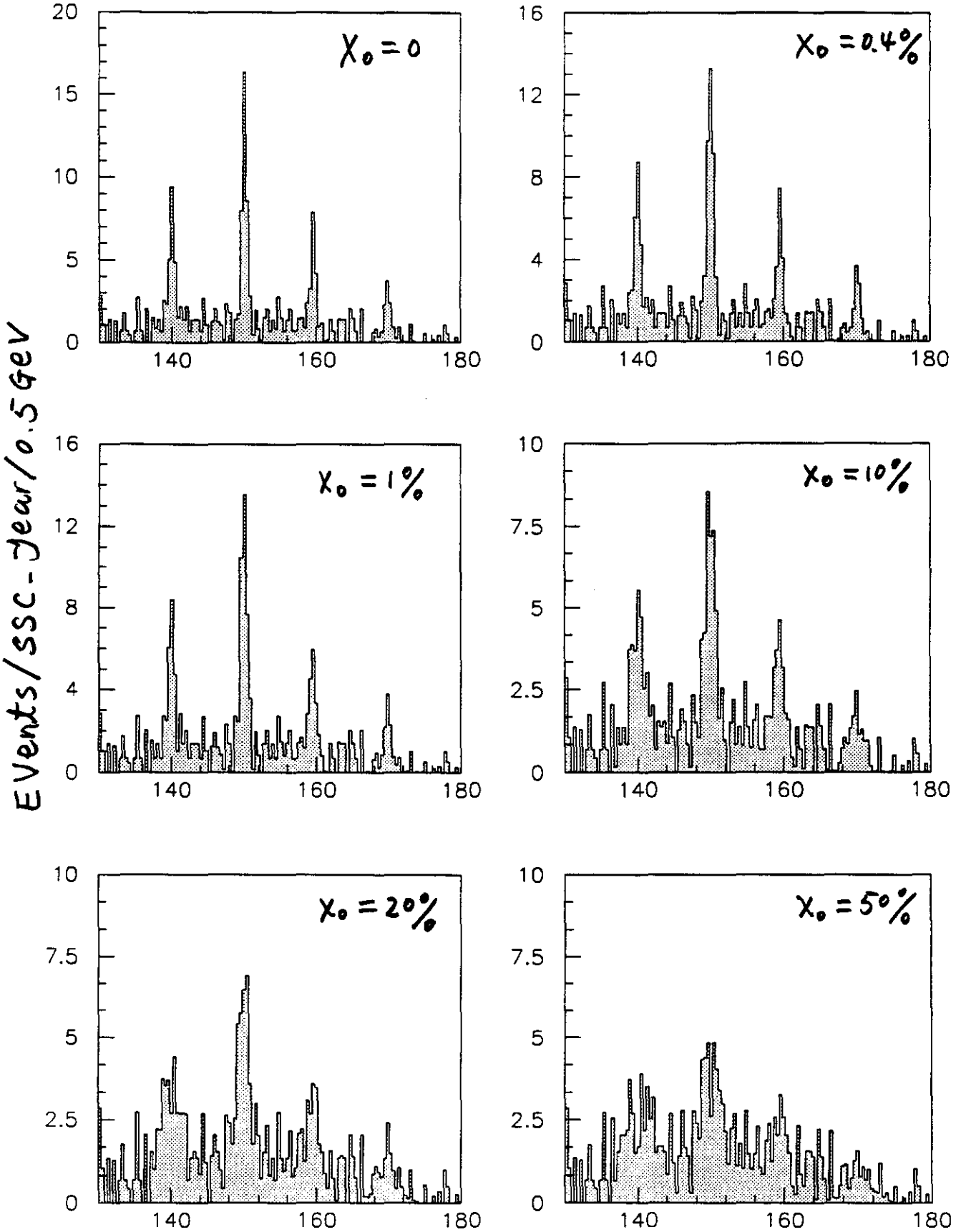
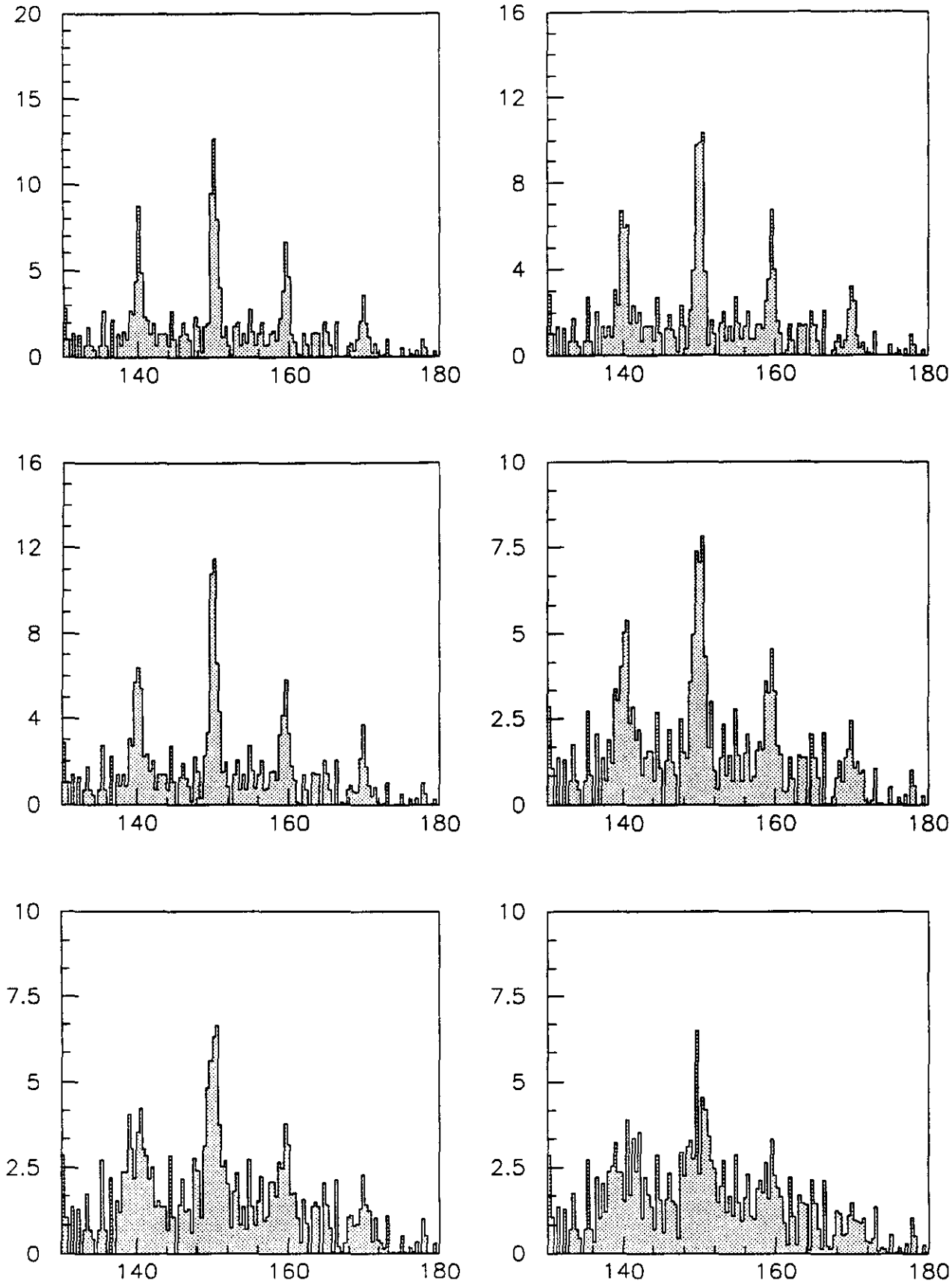
To trigger events of the type $H^0 \rightarrow 2\mu + 2\ other fermions$, we require 1 muon track in the region of $\mid \eta \mid < 2.5$ at the Level-1 trigger. In the central detector we consider roads which are formed by 3 neighboring 3 cm strips thus allowing for momenta down to $p_T = 8\ GeV$. The trapezoidal strips in the end-cap detector are radially oriented and have a width of 3*0.5 cm (the PAD chamber strip width=0.5 cm, and typically a charged particle fires three strips). Integrating the rates from Fig. 6 down to the minimum p_T allowed by the strip configuration yields a total Level-1 trigger rate of less than 10 kHz.

The Level-2 trigger requires the event to have a second muon track. From Table 5, di-muon events with $p_T^\mu > 10\ GeV$ have rate less than 20 Hz at the $10^{33}/cm^2/s$. We can certainly handle such rate for level-2 trigger even at higher luminosities.

At the Level-3 trigger, the muon momentum can be calculated with close to the final accuracy by using the chamber drift time information. For the Higgs searches, we require the invariant mass of the two candidate tracks to be $m_Z \pm 5$

GeV and are left with a rate of only a few Hz.

Higgs → $ZZ^* \rightarrow \mu\mu\mu\mu$



Higgs → $ZZ^* \rightarrow \mu\mu\mu\mu$ (with MS smearing)