EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/86-155
9 October 1986

# SEARCH FOR NARROW SIGNALS IN THE $\gamma$-SPECTRUM FROM $p\bar{p}$ ANNIHILATION AT REST

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**ABSTRACT**

The $\gamma$-spectrum originating from $p\bar{p}$ annihilations at rest in liquid hydrogen was measured with two BGO spectrometers. A total of $24 \times 10^6$ $\gamma$'s were accumulated. No narrow peaks indicating exotic states such as baryonium were observed. The upper limit for the branching ratio $p\bar{p} \rightarrow \gamma + X$ with $1040 \leq m_X \leq 1770$ MeV/$c^2$ and with $\Gamma_X \leq 25$ MeV/$c^2$ is less than $10^{-3}$ with more than 99.96% confidence.

(Submitted to Physics Letters B)

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Several experiments have reported narrow peaks in the $\gamma$-spectra related to $p\bar{p}$ annihilation at rest in liquid hydrogen, which were tentatively attributed to new exotic states such as baryonium [1-3]. The peak energies were around 105 MeV [1, 2], 175 MeV, 220 MeV, 400 MeV, and 550 MeV [1, 3], with yields of several per mille. None of the signals in the different experiments exceeded a level of $3\sigma$. However, the fact that the signals showed up in experiments with rather different detectors and set-ups at roughly the same energies resulted in a seemingly much higher confidence.

This situation called for high-statistics experiments in order to clarify definitely the question of the existence of such peaks.

We report on an experiment carried out at the low-energy antiproton ring (LEAR) at CERN. Antiprotons of 320 MeV/c momentum were stopped in a liquid-hydrogen target of 20 cm length and 5 cm diameter. The antiprotons were measured with a 1 mm thick counter of 2 cm diameter located immediately at the entrance of the target. They were distinguished from reaction pions by pulse-height discrimination. The beam diameter was 4 mm (FWHM). The thickness of the moderator was chosen such as to stop the antiprotons in the centre of the target. The $\gamma$-rays produced in the $p\bar{p}$ annihilation were measured with two independent systems of bismuth germanate (BGO) crystals, each one consisting of seven hexagonal prisms of 20 cm length and 5.4 cm inner diameter, mounted at a distance of 50 cm from the target. Charged particles were identified by plastic scintillators placed in front of the BGO systems. A total of $5.5 \times 10^9$ antiprotons (corrected for a dead-time of about 10% in the data-taking system) were stopped within one and a half days of running time. The set-up, the procedures of calibration and stabilization, and the detector performances are discussed in detail elsewhere [4–6].

The conditions for identifying a $\gamma$ were as follows: i) no charged particle entered the detector, ii) the central module of a detector had to contain at least 15% of the total measured energy, iii) if a peripheral module contained most of the energy, the central module had to contain most of the remaining energy. Under these conditions the resolution of the detectors was $\Delta E/E = 0.04/(E[\mathrm{GeV}])^{1/4}$ (FWHM).

The time of arrival of the $\gamma$-ray in the detector with respect to the beam telescope counter was measured using constant-fraction techniques and additionally correcting off-line for time walk. A time resolution of 1.6 ns (FWHM) was achieved. A time-delayed spectrum was obtained by allowing only for events 5.2 ns after the prompt events ($t = 0$). This spectrum contains about 4% of all events, has exponential shape and does not show any sharp structure.

In order to obtain the spectrum due to prompt events alone, only times $t \leq 2.6$ ns were allowed. The resulting prompt spectra of the two detectors were then added to give the spectrum of fig. 1. This spectrum contains $23.95 \times 10^6$ $\gamma$'s, corresponding to almost 10 times the statistics of ref. [1].

The continuous $\gamma$-spectrum was approximated by a smooth function derived from a Monte Carlo simulation of the spectrum as described in ref. [7] and subtracted from the spectrum of fig. 1, resulting in the residual spectrum of fig. 2. For normalization we assume 3.8 $\gamma$'s per annihilation [7].

The residual spectrum exhibits two prominent structures originating from slow $\pi^-$ of the annihilation stopping in the hydrogen. The subsequent charge exchange results in a uniform distribution of $\gamma$'s between 55 and 83 MeV. The radiative capture results in a peak at 129.5 MeV. The yield of this peak is $(2.56 \pm 0.17) \times 10^{-3}$ and corresponds to expectation.

The spectrum does not show any other structures of significance. If narrow peaks are attributed to the production of narrow exotic states through the reaction $pp \rightarrow \gamma + X$, upper limits for the branching ratios $B_{\gamma X}$ can be obtained from the spectrum. Since very narrow states seem to be unlikely we give upper limits for two cases: i) the $\gamma$-peak width is just the detector resolution, ii) the $\gamma$-peak width is composed of the detector resolution and the broadening introduced by the width of the state ($\Gamma = 25$ MeV/$c^2$). The upper limits for $B_{\gamma X}$ at the 95% confidence level as a function of the mass $m_X$ of the state are shown in fig. 3 for the two cases.

We conclude that the production of exotic states with $1040 \leq m_X \leq 1070$ MeV/$c^2$ and $\Gamma_X \leq$ 25 MeV/$c^2$ with yields $Y \geq 10^{-3}$ is ruled out by this experiment with a confidence of more than 99.96% *).

Thus, if exotic states in the measured mass range exist, they are much broader than 25 MeV/$c^2$ or are produced with much lower yields than $10^{-3}$ and/or must be searched for in other reactions.

This experiment was supported by the Swiss National Science Foundation, the Swedish Research Council, and the Greek Administration for Research and Technology. We wish to thank CERN for the support and the hospitality we have received. We are also indebted to K. Agehed and A. Engström (Stockholm), K. Iconomou (Thessaloniki), and H. Krause (Basle) for mechanical-engineering support.

*) This is at variance with the results of the previous experiments. This must be the result of the different experimental conditions, and the peaks found earlier suggest systematic effects as the origin. In contrast to the previous experiments [1, 3], which had to be performed with poor beam conditions, we have now: i) a very clean low-momentum $\bar{p}$ beam which requires almost no moderator; ii) an almost massless surrounding of the target; iii) detectors with a volume more then 10 times smaller than the previously used detectors; iv) no lead collimators or lead shielding.

## REFERENCES


[1] B. Richter at al., Phys. Letters **126B** (1983) 284.

[2] R. Brando et al., Phys. Letters **139B** (1984) 133.

[3] P. Pavlopoulos et al., Phys. Letters **72B** (1978) 415.

[4] L. Adiels et al., Nucl. Instrum. Methods **A244** (1986) 380.

[5] C. Findeisen, PhD Thesis, University of Basle (1986).

[6] S. Carius, PhD Thesis, Royal Institute of Technology, Stockholm (1986).

[7] G. Backenstoss et al., Nucl. Phys. **228B** (1983) 424.

**Figure captions**

Fig. 1 : $\gamma$-spectrum from $p\bar{p}$ annihilations at rest in liquid hydrogen. The spectrum contains $23.95 \times 10^6$ $\gamma$'s.

Fig. 2 : $\gamma$-spectrum after subtracting a smooth background as described in the text. The two structures are due to the reactions $\pi^- + p \rightarrow \pi^0 + n$ and $\pi^- + p \rightarrow \gamma + n$.

Fig. 3 : 95% confidence upper limits for the production of narrow exotic states through the reaction $p\bar{p} \rightarrow \gamma + X$ for $\Gamma_X$ much smaller than the detector resolution and for $\Gamma_X = 25$ MeV/$c^2$.

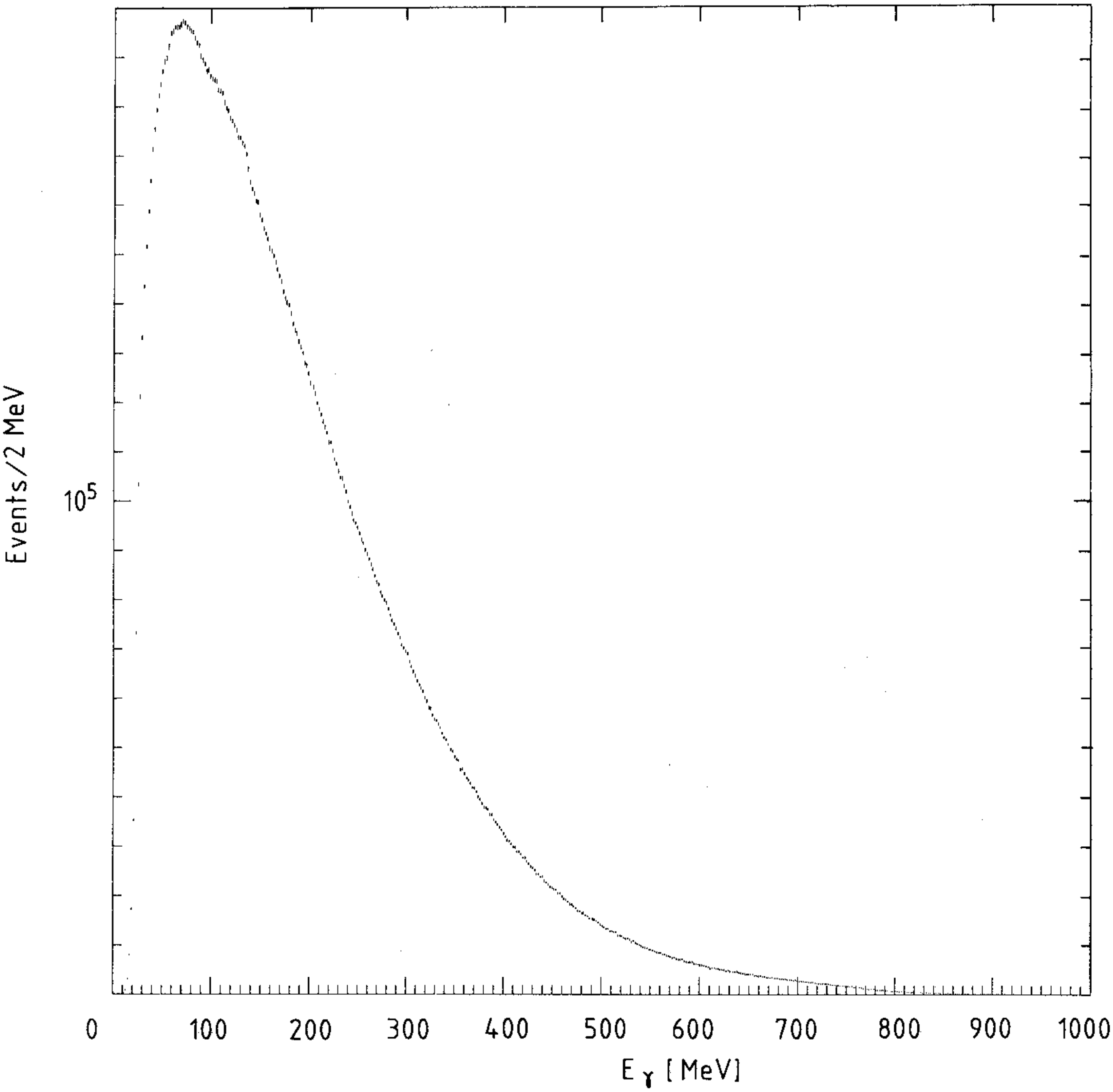
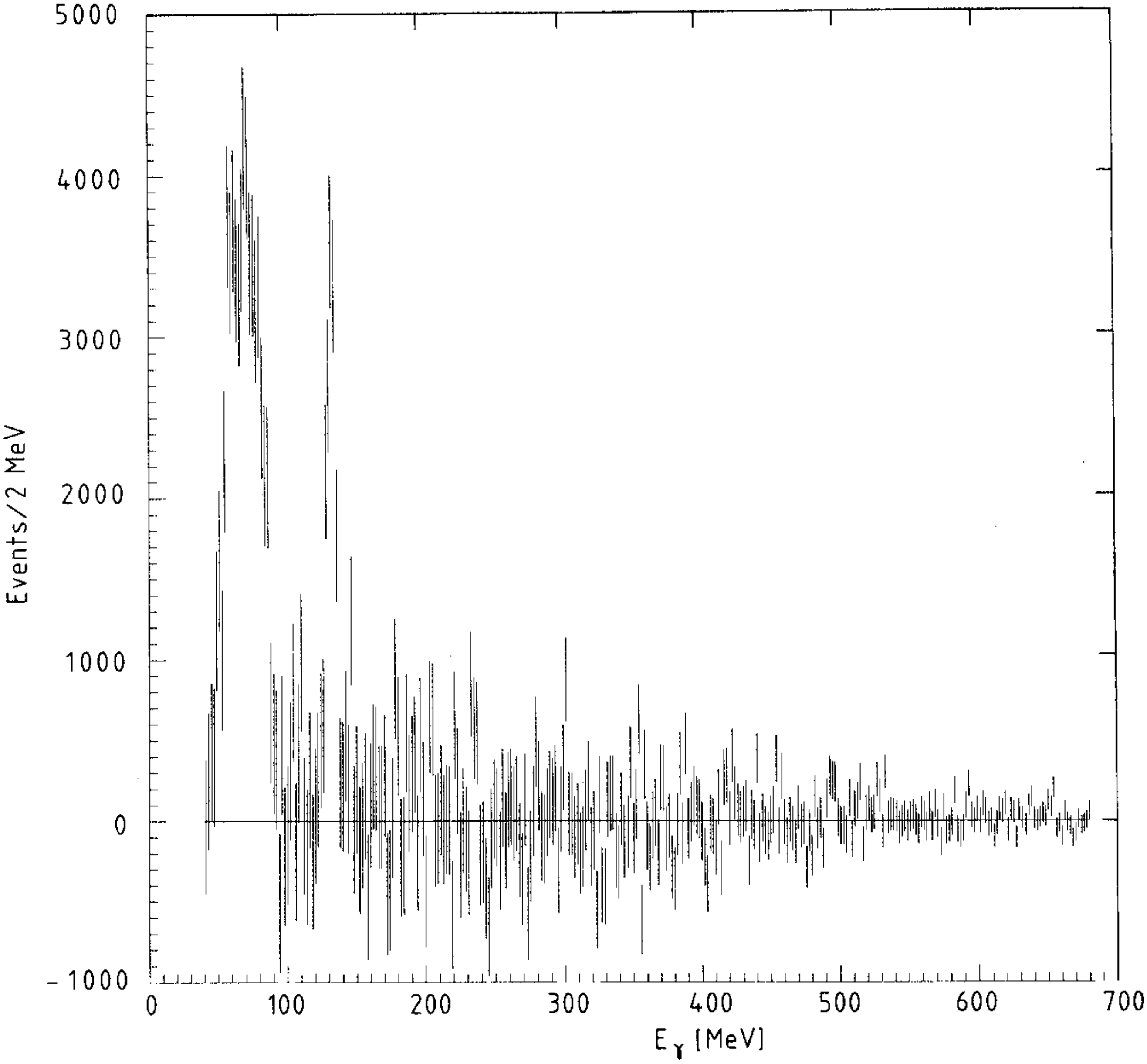
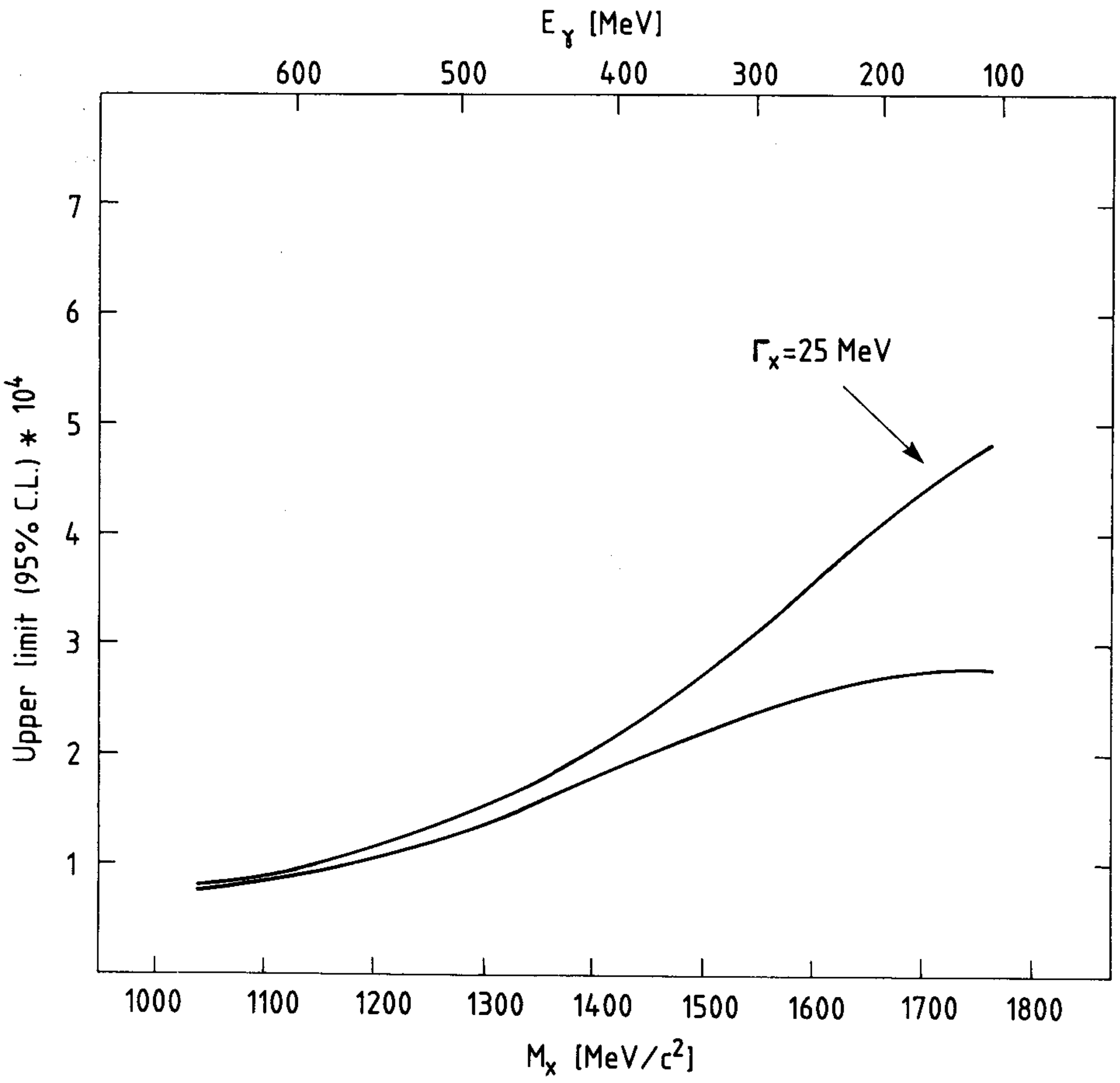

Events/2 MeV
10^5
0
100
200
300
400
500
600
700
800
900
1000
E γ [MeV]

**Fig. 1**



5000
4000
3000
2000
1000
0
-1000
Events/2 MeV
0
100
200
300
400
500
600
700
$E_\gamma$ [MeV]


**Fig. 2**



E_γ [MeV]
600
500
400
300
200
100
Upper limit (95% C.L.) * 10^4
7
6
5
4
3
2
1
Γ_x=25 MeV
1000
1100
1200
1300
1400
1500
1600
1700
1800
M_x [MeV/c^2]


Fig. 3