# The “solar flare” of 14th, July, 2000. Observation from the detector “L3+Cosmics”

P. Ladron de Guevara

on behalf of the

L3+C collaboration.

XXX REUNION BIENAL DE LA RSEF

Ourense, 12-16 Septiembre, 2005

# GROUND LEVEL ENHANCEMENTS (GLE s)

**Solar protons are accelerated in high energy solar process such as:**

* Solar flares (SF s)
* Coronal mass ejections (CME s)

**- Solar protons with energies > 100 MeV produce secondaries that can be observed at ground level (Ground Level Enhancements, GLE s)**

* First GLE observed : 1946
From then… ~ 60 GLEs detected (Worldwide network of **neutron monitors**, NMs)

**More than 100 NMs distributed at different geomagnetic latitudes**
**→ Geomagnetic spectrometer (started by Simpson,1950)**

## From the Neutron Monitors (NMs) observations:

**(primaries energy threshold set by rigidity of the site)**

* **The Sun can accelerate protons at least up to GeV energies**
* **Huancayo NM** (Peru) : **solar protons > 13 GeV** (29/Sept/1989)

## Modelling on data:

**(Ref. [1-3])**

Description of the proton beam approaching the Earth :

- particle trajectory tracing.
- model of magnetospheric magnetic field
- data from several NMs for the same GLE

**(Ref 4)**

* Steep spectrum ( index ~ -6)
* Anisotropic beams
* Delayed components

**Problems**

- Isolated NMs are not sensitive in detecting a directionally narrow beam, or excesses for E>5 GeV (statistics !!)
- Add EAS arrays (E > 5 GeV)
- Add underground muon telescopes if proton momentum high enough (??)

## Muon telescopes (directional) (Ref [5-8])

•**Embudo** => solar protons from 20-30 GeV (1989) (35 mwe,New Mexico)

* **Baksan** => solar protons > 500 GeV (?) (1989) (signal delayed 2 hrs after the impulsive flare phase )

**L3+C is a muon telescope**

**Of interest :**

**-the limit in primary energy**

**-the (an)isotropy of the proton beams**

**-the spectral index**

**-the existence of delayed components**

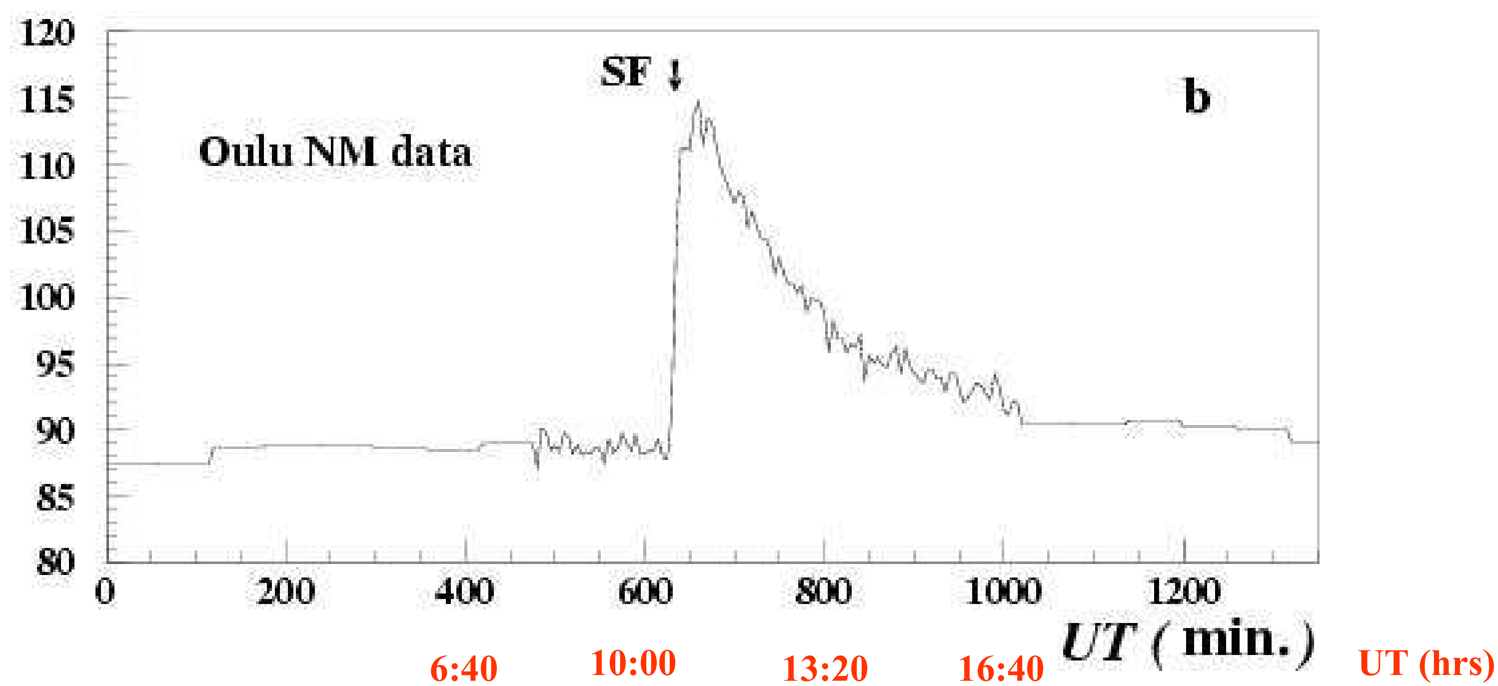
**One GLE happened during L3+C operation, the 14th July, 2000**

(“Bastille Day” event) named as **SF20000714** ( **Ref [9-11]** )

* Solar flare and CME associated.
* X5.7/3B from 9077 sunspot region (X class SF, x-ray wavelenght 5.7 Amstrongs)
* 10:24 UT X-ray flare peak
* 10:30 UT proton flux rapidly increased up to E> 100 MeV, observed by satellite GOES-8
* During this period a full halo, earth directed CME was developped and observed by SOHO/LASCO (Solar and Heliospheric Observatory/Large Angle Spectrometric Coronograph )

• A GLE event produced. The earliest increase occurred at 10:30 UT.
• > 20 NMs observed flux increases in the range of 2 % => 60 %

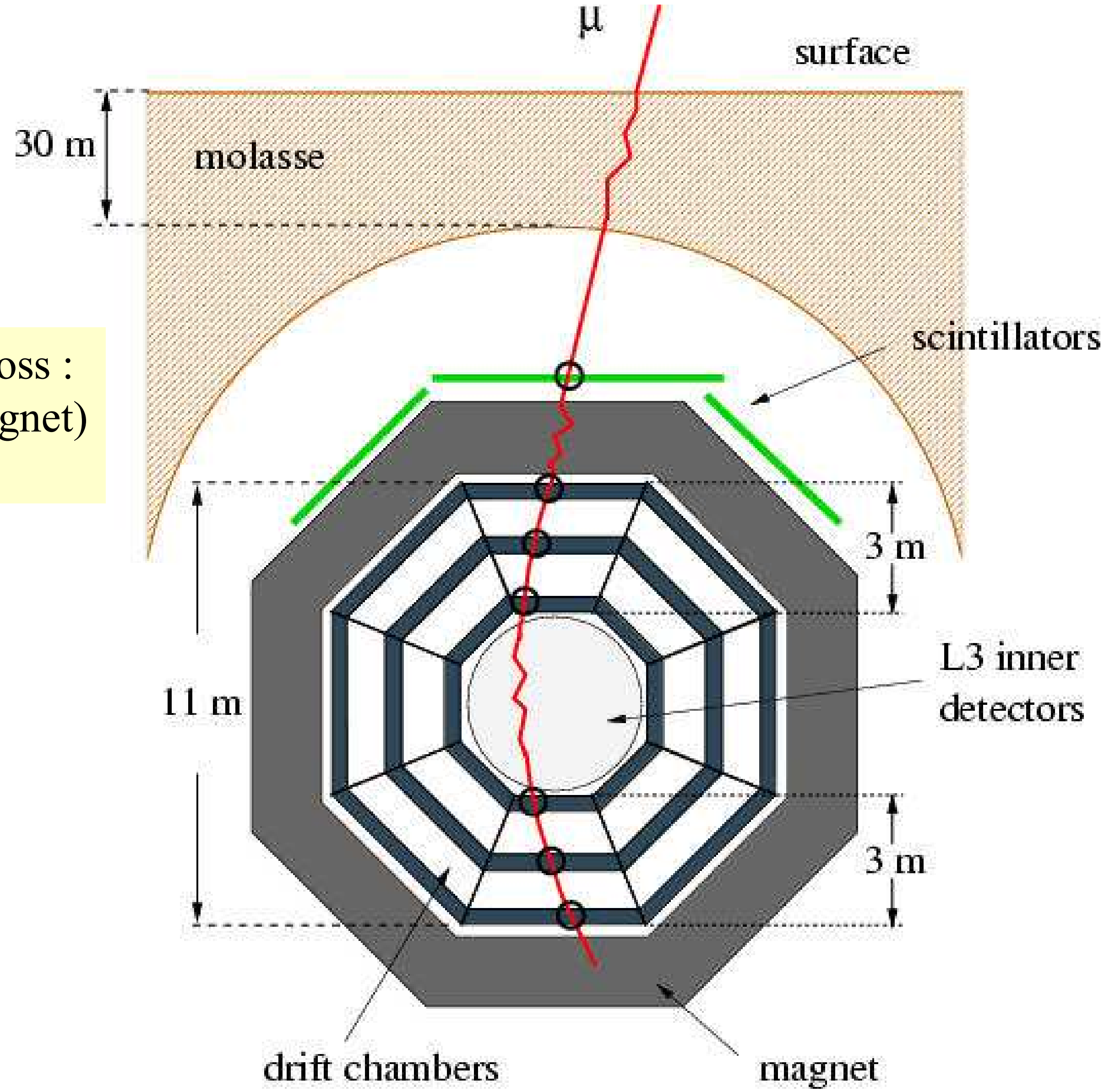
* Reconstructed from ~20 NMs data, the solar protons have anisotropic incident direction, energy threshold up to 6.7 GeV, soft spectrum with a power law index of –6 during the rising phase, -7 at 11 h, -8 at 12 h.
* Particle arrival was anisotropic and changed with time.



# Analysis of data from L3+C during 14th/July/2000

## L3+C schematic setup and momentum measurement.

Mean energy loss :
(molasse + magnet)
15 GeV



# L3+C ( Ref [12] )

angular resolution ~ 0.3 $^0$
momentum resolution ~ 5 % (from 15 GeV-25 GeV)
momentum threshold ~ 15 GeV/c
sensitive volume 1000 m $^3$
magnetic field 0.5 T

Coordinates : 6.02 $^0$ E, 46.25 $^0$ N , 450 m. asl
30 m. underground
Magnetic rigidity cutoff ~ 5 GV

**Event selection** :

- Only a single muon track is present in the muon chamber.
- Track composed of at least 3 segments of hits in P-chambers (wires parallel to magnetic field) and 2 segments of hits in Z-chambers (wires perpendicular to magnetic field)
- Back-tracking from muon chambers to the surface succesful, to ensure a good pointing.
- Only muons with surface energies from 15 GeV to 25 GeV were consider at first step.

**Live-time binning:**

* 83.9 s (~1.4 min) live-time bin as the basic time unit in searching for possible signals.
* The different time windows used in the search are multiples of the above.

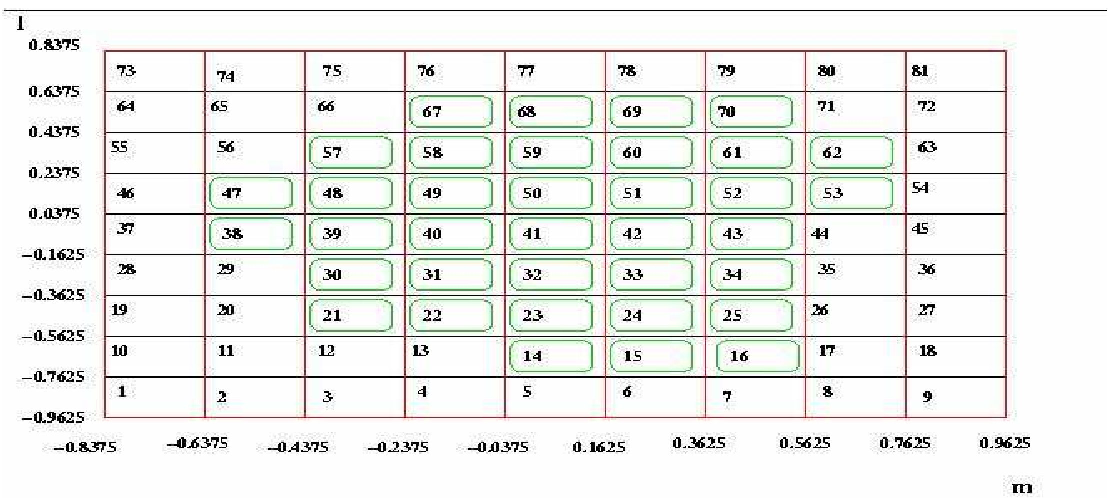
# The goal is the detection of an excess in flux in any direction.

We divide the space according to the direction cosines:

**l**= sin θ . cos Φ  θ : zenith, Φ : azimuth of the muon at surface.
**m**= sin θ . sin Φ

The squared area of **l** and **m** was divided in a **10 x 10** grid.

Ignoring the cells with poor acceptance, 41 sky cells remain for investigation.




l= sin(Θ) cos(ϕ)  m=sin(Θ) sin(ϕ)

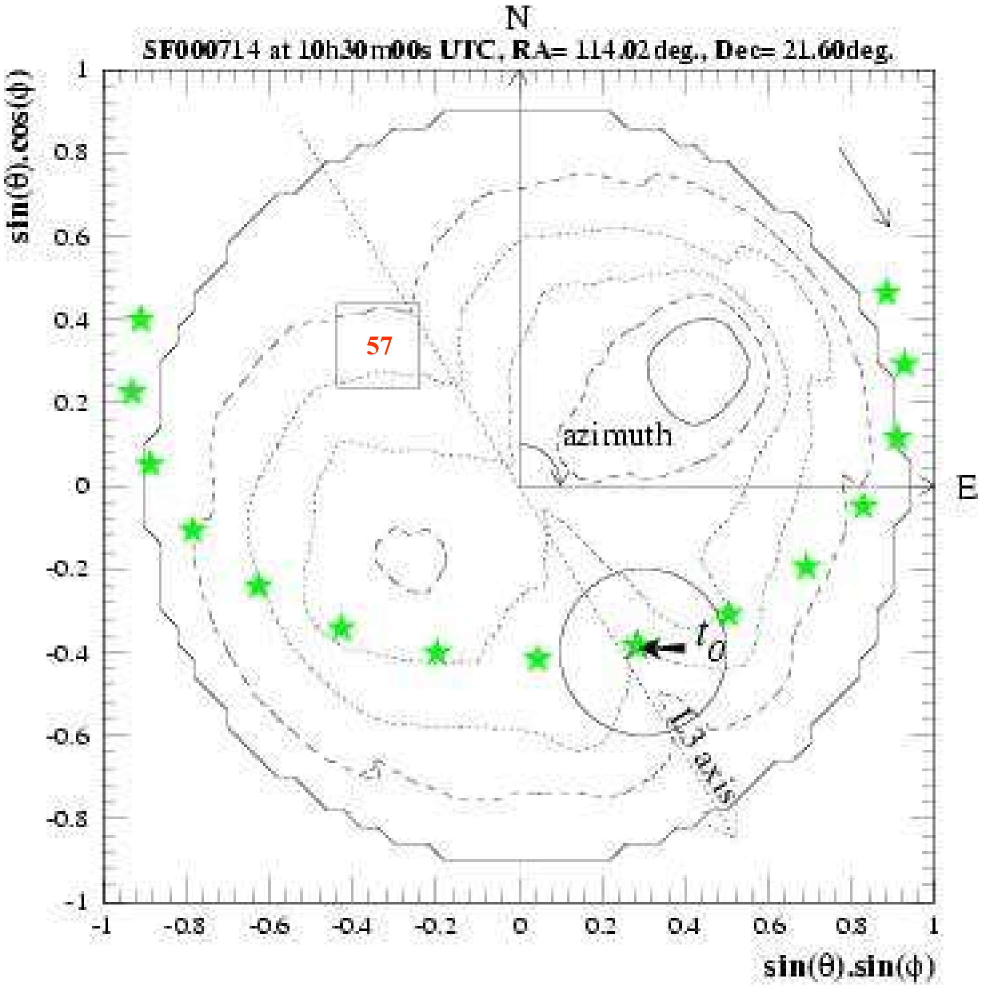
Position of the cells in l, m space.
In green the cells with <evts / bin> > 5.0

$t_o$ : flare time

**Square:**
Cell with coordinates:
**19.6$^0$ < Zenith<38.2$^0$**
**298.5$^0$<Azim.<331.5$^0$**
**( cell 57 )**

**Contour lines:**
**Equal acceptance**

**Star marks:**
**Sun direction every hour**



# The search of flux excess

**Two kinds of methods used :**

**1) "Free" search. ("running means" method).**

*** Fix parameter : time start of the search ( 22:00 UT in 13th July)**

*** Free parameter: time window, tw (related to the unknown duration of the excess)**

*** Two alternative background determinations:**

**a) Computed from 12 h. before the S-F start time. (fixed background) from 13/July 22:00 UT to 14/July 10:00 UT)**

**b) Computed as the mean of two backgrounds, 3h. of livetime before and after the region of the "signal"**

*** Notice:**

**In a) the background is unique and assumed to be extrapolable to the S-F region.**

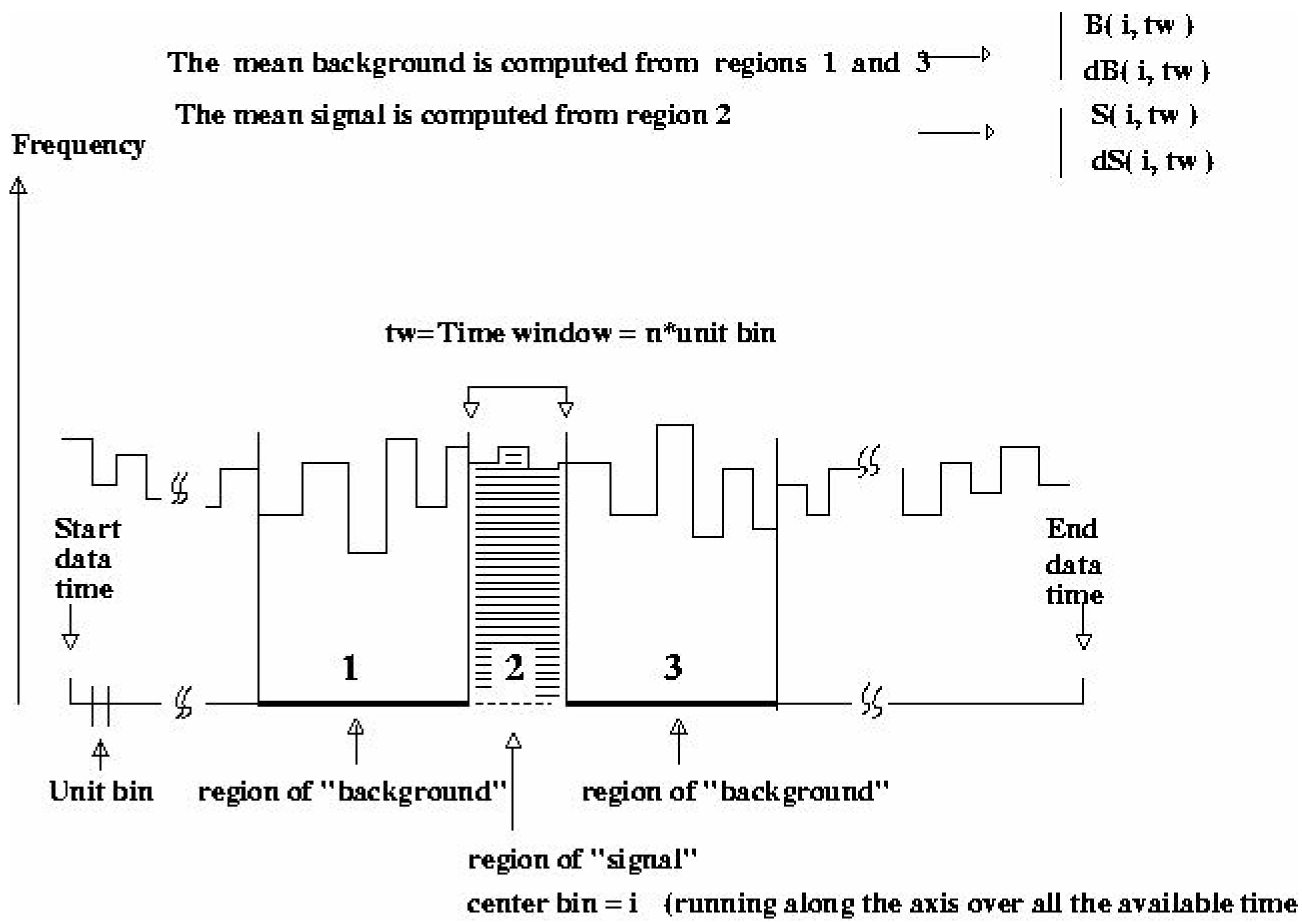
**In b) the background changes with the position and size of the time window and**

**- has the trend to dilute the "excess" if the time window is larger than the "signal"**

**- the statistical error is greater than for a) (by sqrt(2) )**

**...but reduces the influence of the local fluctuations.**

# The running means principle, method 1.b, variable background.



## •"Running means" principle: ( in a given directional cell )

** pick a time window tw centered on the time t and compute :

$$nsd = ( S(t,tw) - B(t,tw) ) / \sigma( B(t,tw) )$$

**S(t,tw)** is the number of entries in the interval with length **tw** and center at **t**.
**B(t,tw)** is the background and **σ( B(t,tw) )** stands for its mean standard deviation.

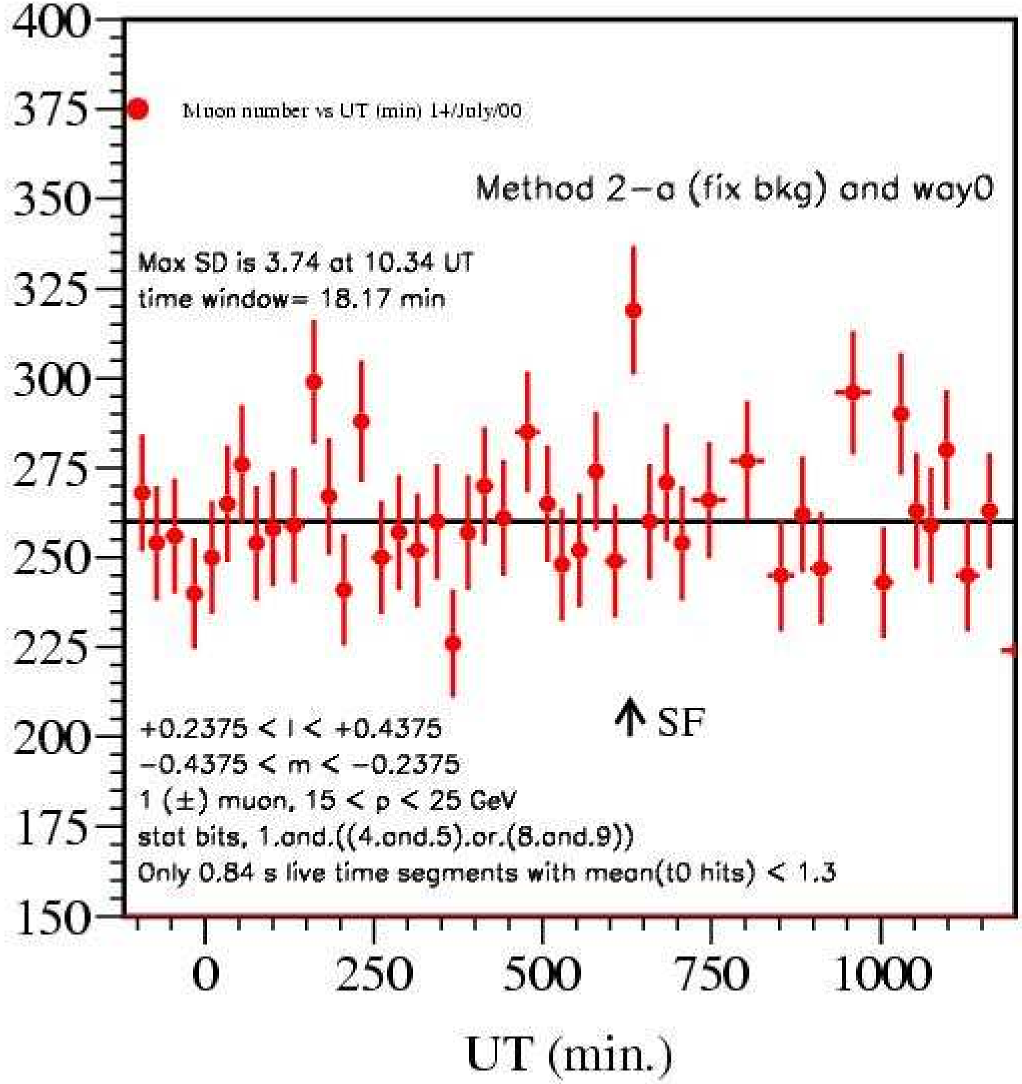
** run over tw (from 1.398 m. to 139.8 m.) and over t (the full day) to get **nsd** and find **the absolute maximum of nsd** and its corresponding **t, tw**
( 3 values per directional cell )

# Results:

**Only two cells (CR arrival directions) have been found with coincident t, tw from methods a) and b) in the interval from 10:00 to 11:00**

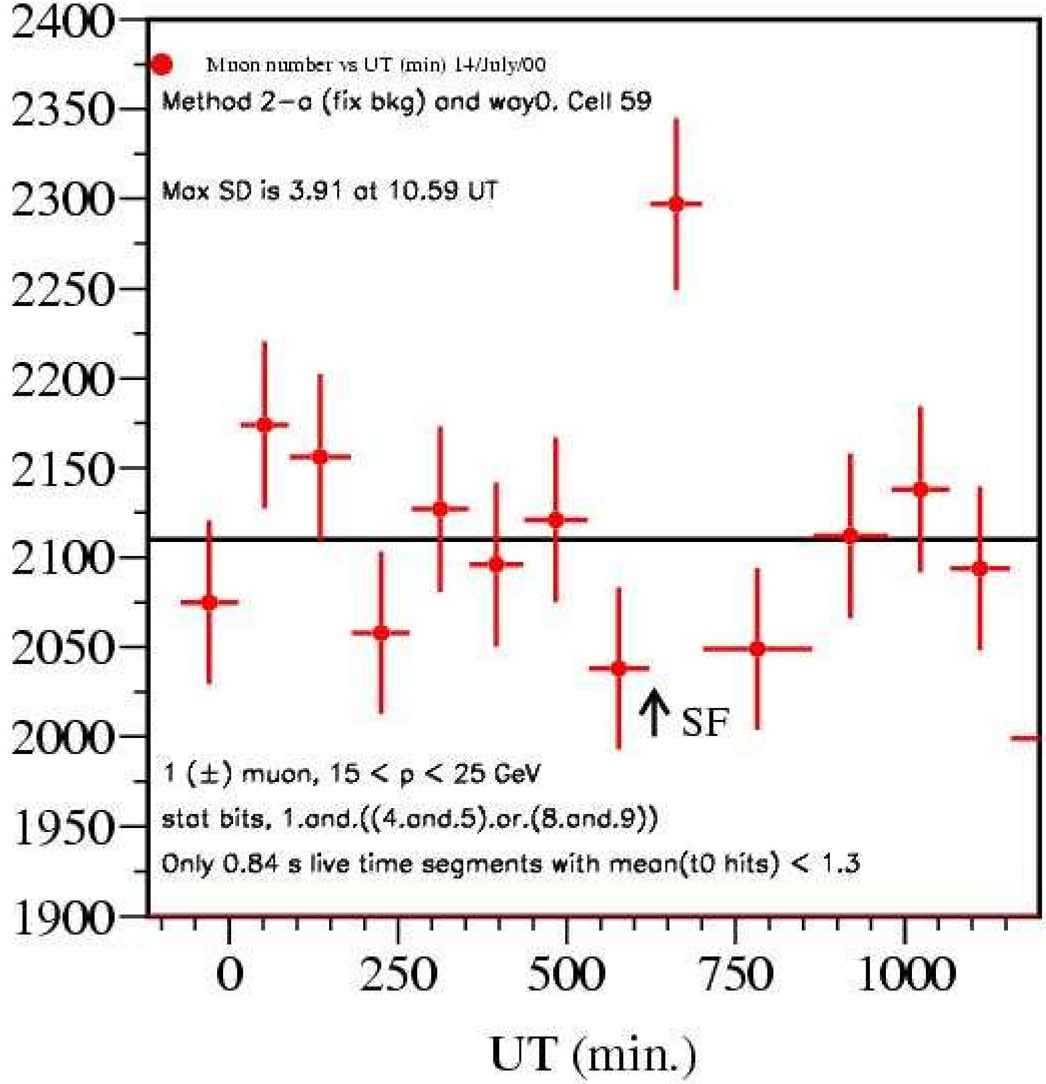
| | Method 1a (fixed background) | | | | | Method 1b) (variable background) | | |
|---|---|---|---|---|---|---|---|---|
| Cell | bakground | excess | max σ | time-window | time (UT) | background | excess | max σ |
| 57 | 259.7 | 59.3 | 3.74 | 18.18 min | 10:34 | 260.8 | 58.2 | 2.65 |
| 59 | 2109.5 | 187.5 | 3.91 | 60.13 min | 10:59 | 2094.9 | 202.1 | 3.14 |

## Cell 57



Muon number vs UT (min) 14/July/00
Method 2−a (fix bkg) and way0
Max SD is 3.74 at 10.34 UT
time window= 18.17 min
↑ SF
+0.2375 < l < +0.4375
−0.4375 < m < −0.2375
1 (±) muon, 15 < p < 25 GeV
stat bits, 1.and.((4.and.5).or.(8.and.9))
Only 0.84 s live time segments with mean(t0 hits) < 1.3
400
375
350
325
300
275
250
225
200
175
150
0
250
500
750
1000
UT (min.)

**Cell 59**


Muon number vs UT (min) 14/July/00
Method 2−a (fix bkg) and way0. Cell 59
Max SD is 3.91 at 10.59 UT
1 (±) muon, 15 < p < 25 GeV
stat bits, 1.and.((4.and.5).or.(8.and.9))
Only 0.84 s live time segments with mean(t0 hits) < 1.3
SF
2400
2350
2300
2250
2200
2150
2100
2050
2000
1950
1900
0
250
500
750
1000
UT (min.)

## 2) “Guided” search. This search uses our knowledge of the 14th July 2000 GLE event.

**We search for protons with higher energies than established until now**

**The analysis of NMs data ( Ref [5] )** shows a soft solar proton spectrum (g= - 6) and became softer with time => the higher the solar proton energy, the shorter the signal duration time

⇒We search for short signals.

⇒We concentrate on a short period starting from 10:20 UT (the onset time of the type II radio burst) and around the peak time of the increase seen by the NMs. (~ 10:UT=> ~12:00 UT)

### Background:

From GOES-8 **(Ref [9])** => Event rate of protons with energies > 100 MeV stable during the 12 hours before 10:00. The background is extracted from this range, the same as for method 3a) above.

### Search of excess :

1- Check of possible excesses during the peak time of NMs only.

2- Search for an excess using a bin (tw) unit (83.9 s live-time) starting from 10:20 UT

3- When found, (at 10:24 UT in cell 57 only), add the next bins up to the point that the excess start to decrease.

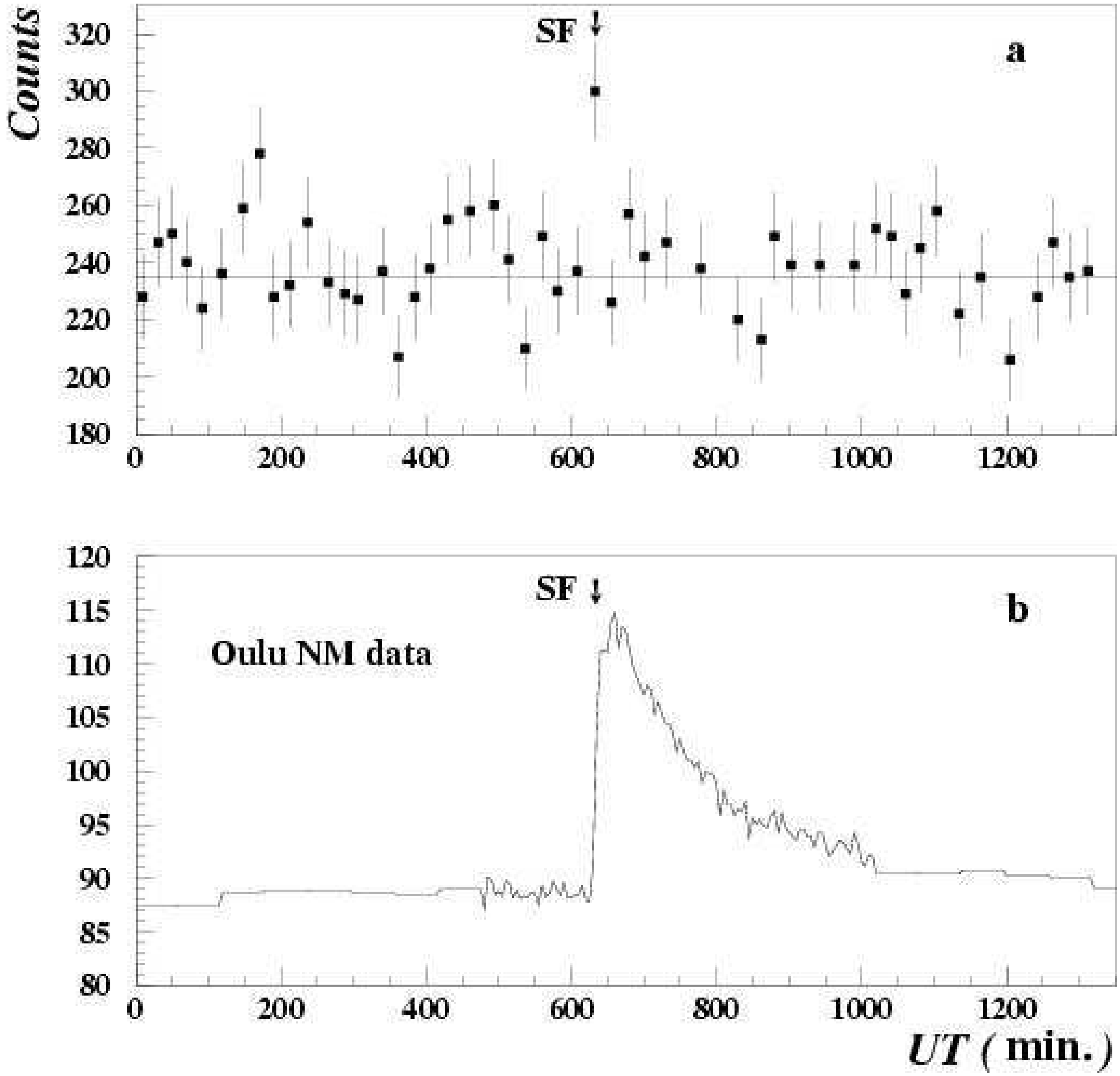
4- 11 live-time units were so gathered amounting to a tw = 16.78 min.

5- The fit of the background with the 16.78 min bin compared to the the excess allowed to measure a 4.2 $\sigma$ effect

6- It was also checked whether there were other possible excesses appearing at delayed times. 5 16.78 min. live-time bins were examined from 9:52 UT to 11:51 UT over the 41 cells and no other excess than the one reported was found.

**Cell 57**

Bkg=235
Excess=65
σ=4.2
tw=16.7min.
time=10:33 UT



**Resumee**

The “free” and “guided” searches are coincident in finding an excess at very close time and time-window in cell **57** , with directions:

**$19.6^0$ < Zenith<$38.2^0$**
**$298.5^0$<Azim.<$331.5^0$**

Free search : time: 10:34 UT with time-window = 18.18 min (3.74 σ)
Guided search : time: 10:33 UT with time-window = 16.78 min (4.22 σ)

**From Monte-Carlo simulation, the probability for the excess of 4.2 σ in one of the 41 sky cells being due to a background fluctuation is ~ 1 %**

**(small significance !!)**

**No excess was found for muons at > 25 GeV in the cell 57.**

**Assuming the muon excess being produced by protons associated to the GLE:**
**What is the primary energy of such protons ?**

**MC simulation (Air simulation code CORSIKA)**

***Primary proton spectrum with exponent of –6 above 20 GeV**
***Primary protons assumed to be incident along the directions that make the produced muons to appear in cell 57.**

**(85 % of the produced muons come from the region 40-100 GeV with most probable energy of 70 GeV)**

# Upper limit of the solar flare induced proton flux

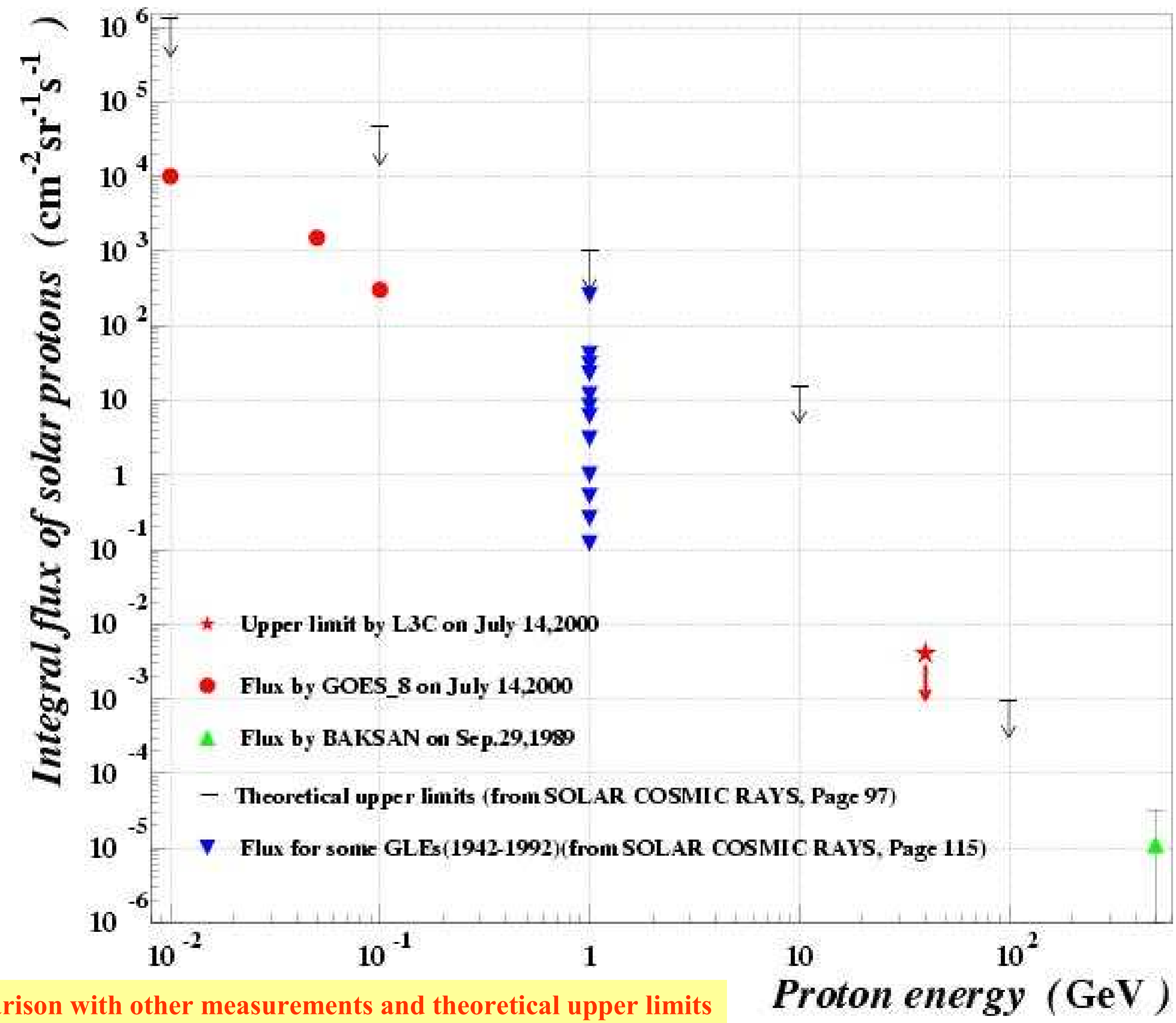
*The MC produced muons on the surface are recorded
*Large enough area centered around the μ–chambers was set to ensure less of 1 % loss of muons.
*Muons were traced through the molasse and μ-chambers and its tracks reconstructed.

## Background:

Same procedure as for the “signal”, but using the primary ray spectrum power law index –2.7

Comparison between observed data and simulated data gives un upper limit of the flux:

**$I(E_p > 40\ \text{GeV}) < 2.8 \times 10^{-3}\ \text{cm}^{-2}\ \text{sec}^{-1}\ \text{sr}^{-1}$ (90% c. l.)**




Comparison with other measurements and theoretical upper limits

# Conclusions

* In the GLE event of the 14th July 2000 a 4.2 $\sigma$ excess of muons with $E_\mu$ = 15-25 GeV in a particular sky region was observed which lasted from 10:24 UT to 10:42 UT.

•The probability of finding such an excess in this search as a fluctuation of the background is ~ 1%

•It was time-coincident with the peak increase observed by 20 different NMs during the impulsive phase of the solar flare, at 10:30 UT

* If the excess was really induced by solar protons the observation might indicate that solar protons with energies higher than 40 GeV were generated in this event.

•The upper limit of a solar proton beam entering the upper atmosphere around the space direction

$19.6^0 <$ Zenith $< 38.2^0$

$298.5^0 <$ Azim. $< 331.5^0$

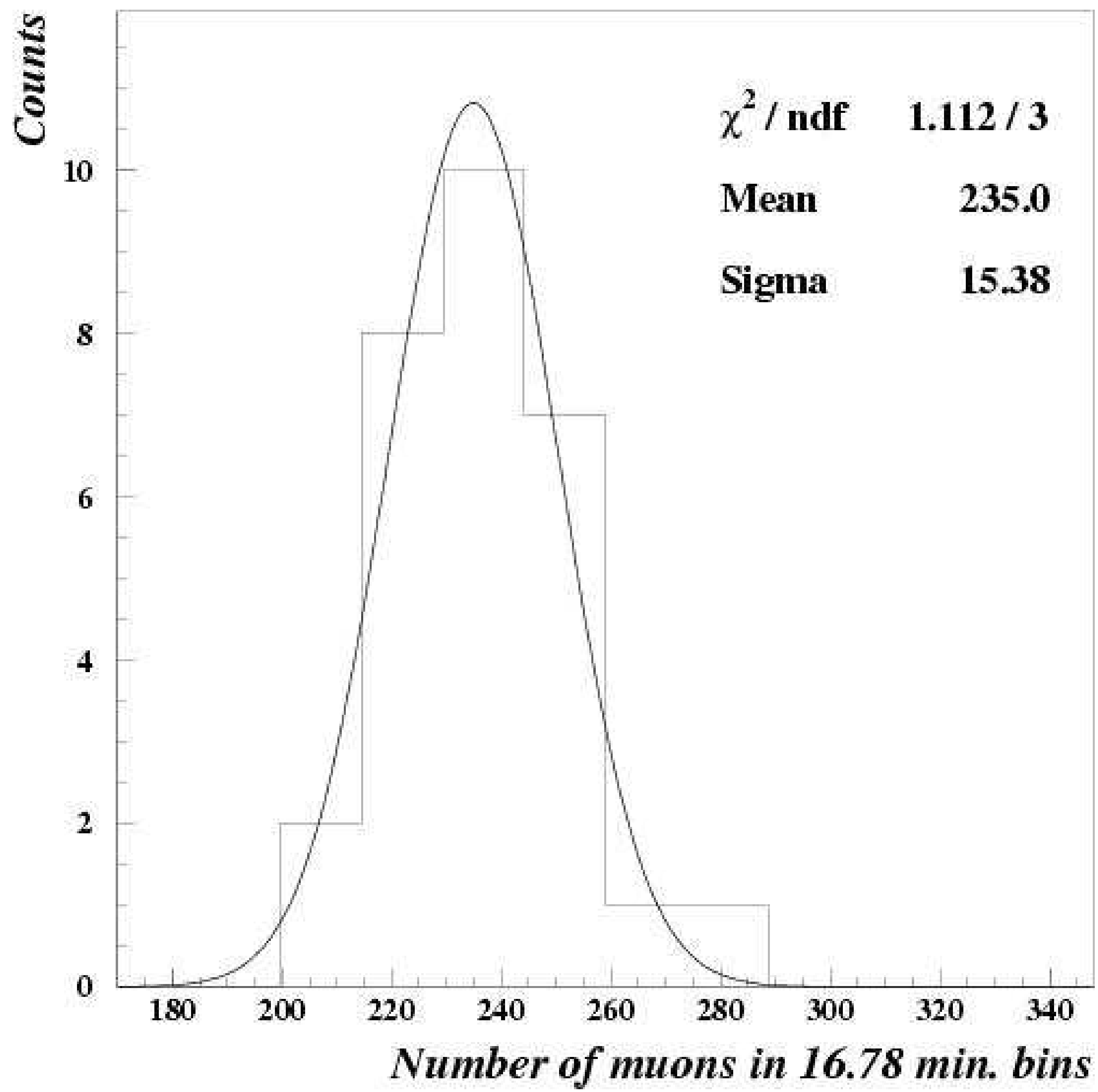
and corresponding to the excess was determined to be :

$$I(Ep > 40\ GeV) < 2.8 \times 10^{-3}\ cm^{-2}\ sec^{-1}\ sr^{-1}\ \ (90\%\ c.\ l.)$$

# References

1- M.L. Duldig, Proceedings of 27th ICRC, 3363 (2001)
2- V.V. Pchelkin et al., Proceedings of the 27th ICRC ,3379, ( 2001 ).
3- E.V. Vashenyuk et al., Proceedings of 27$^{th}$ ICRC, 3383, ( 2001 ).
4- N.A. Tsyganenko, Planet Space Sci. 37,5, ( 1989 ).
5- A.T. Filippov et al., 22nd ICRC, Dublin,3,113,( 1991 ).
6- E.N. Alexeyev et al., Geomagn. Aeron.,32,192, ( 1992 ).
7- E.N. Alexeyev et al., Geomagn. Aeron.,34,143, ( 1994 ).
8- S.N. Karpov et al., Nuo. Cim.,21C,551, ( 1998 ).
9- http://crlhir.crl.go.jp/ dimages/gpa1day/proton/20000714.gif
10- http://crlhir.crl.go.jp/tserdin/plain_report/20000714_forecast.ht1m
11- A.V. Belov et al.,Proceedings of 27th ICRC, 3446,( 2001 ).
12- O. Adriani et al., Nucl. Instr. And Methods in Physics Research, A488,209,(2002).

# End of talk. Thank you !!



Counts
$\chi^2$ / ndf 1.112 / 3
Mean 235.0
Sigma 15.38
0
2
4
6
8
10
180
200
220
240
260
280
300
320
340
Number of muons in 16.78 min. bins