Valeri Falaleev
FNAL, 6-9 September 2000

Proposal for the muon monitoring system at CNGS

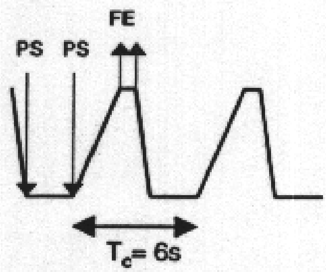
Beam monitoring requirements

Neutrino flux at Gran Sasso integrated over a year should be within 10% of what is achievable

Muon monitoring system (together with other beam monitors) should be able to detect any beam elements imperfection which leads to more them 5% drop of neutrino flux at Gran Sasso.

Main features of the beam

• Proton beam momentum	400 GeV/c
• Proton intensity/burst	up to 2.4×10^{13}
• Burst duration	10.5 μs
• Time between bursts	50 msec
• Minimum repetition time	6 s
• Expected integrated number of protons per year	4.5×10^{19}



SPS cycles for dedicated CNGS running

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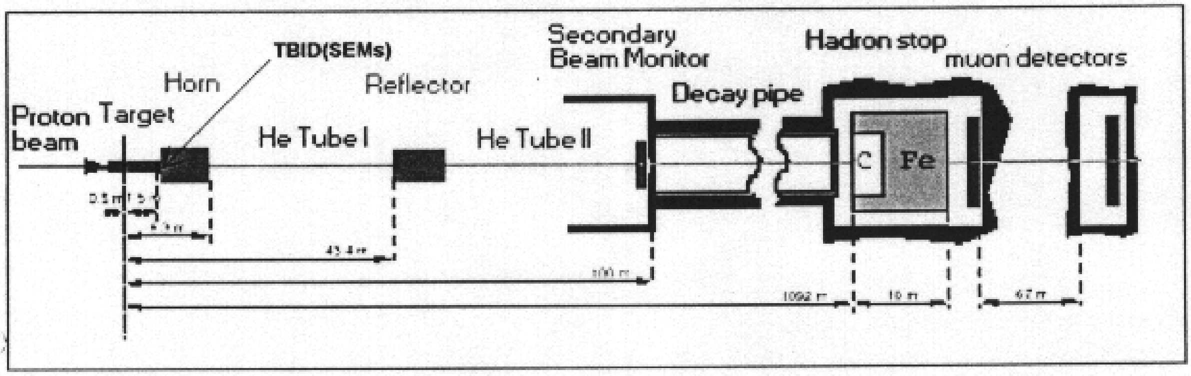
Muon monitoring station



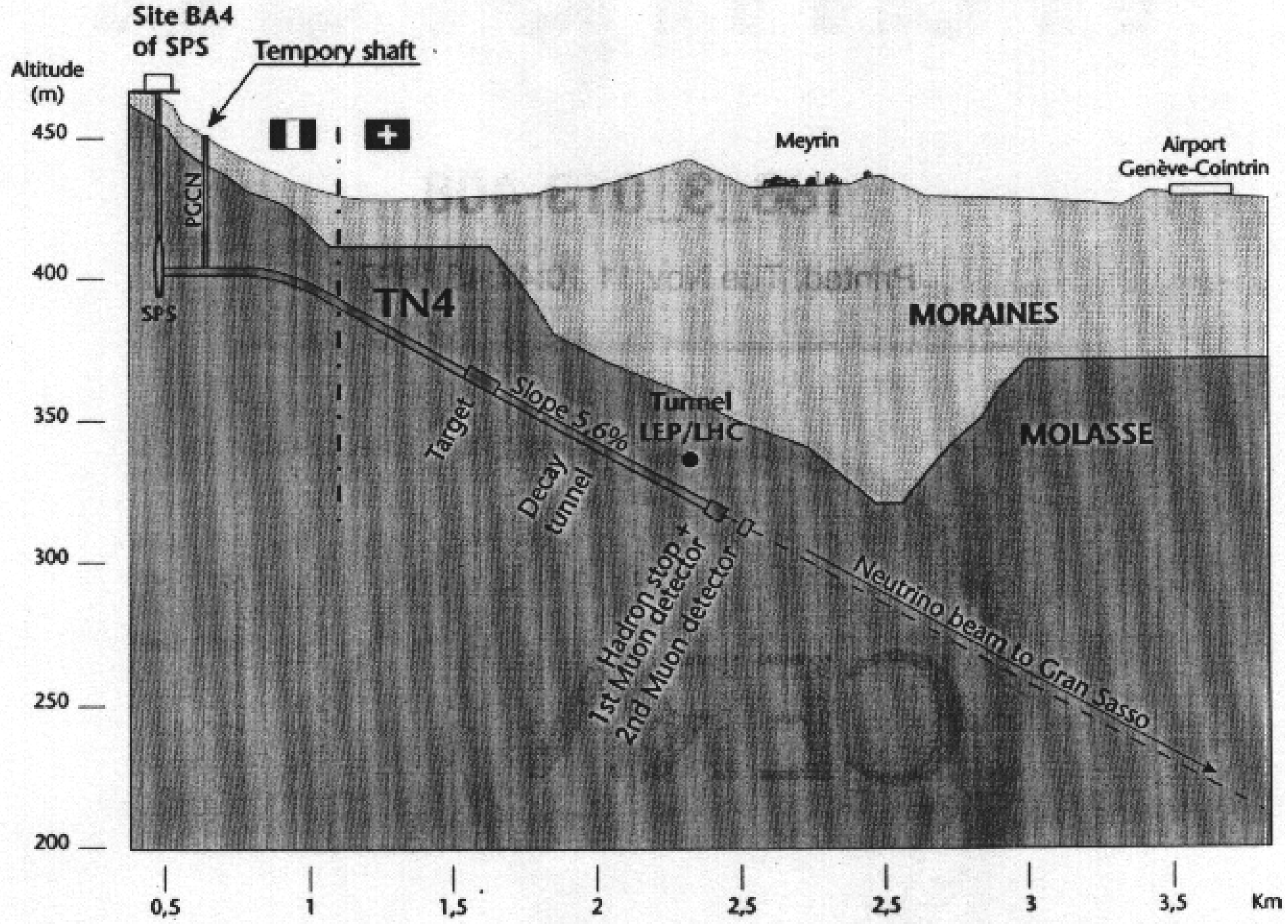
2 muon chambers:

- 3.2m of graphite and 15m of iron in front of the first muon chamber
- 5 x 6 x 6 m first muon chamber
- 67m of 'molasse'
- 5 x 6 x 6 m second muon chamber

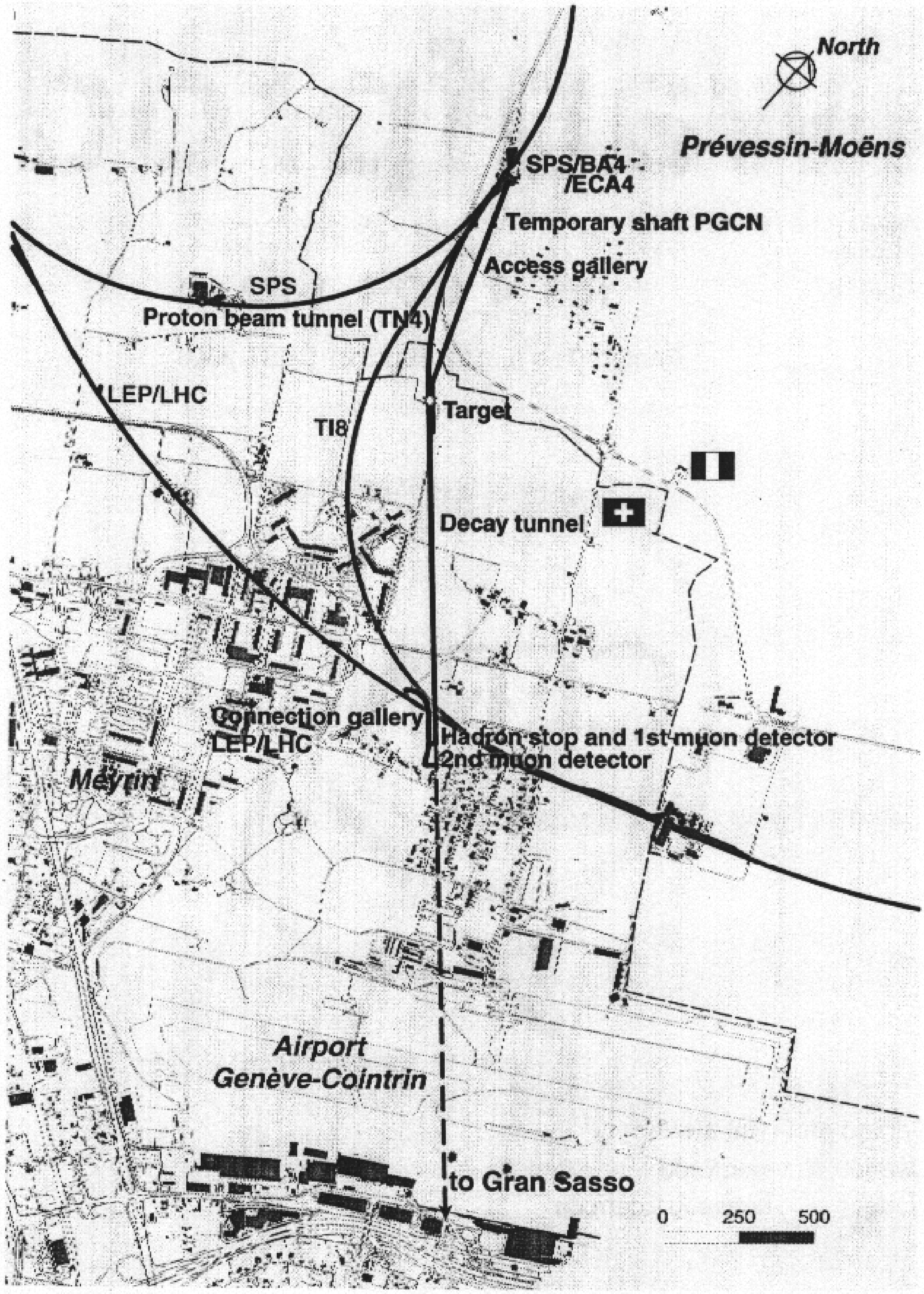
Maximal muon fluxes :

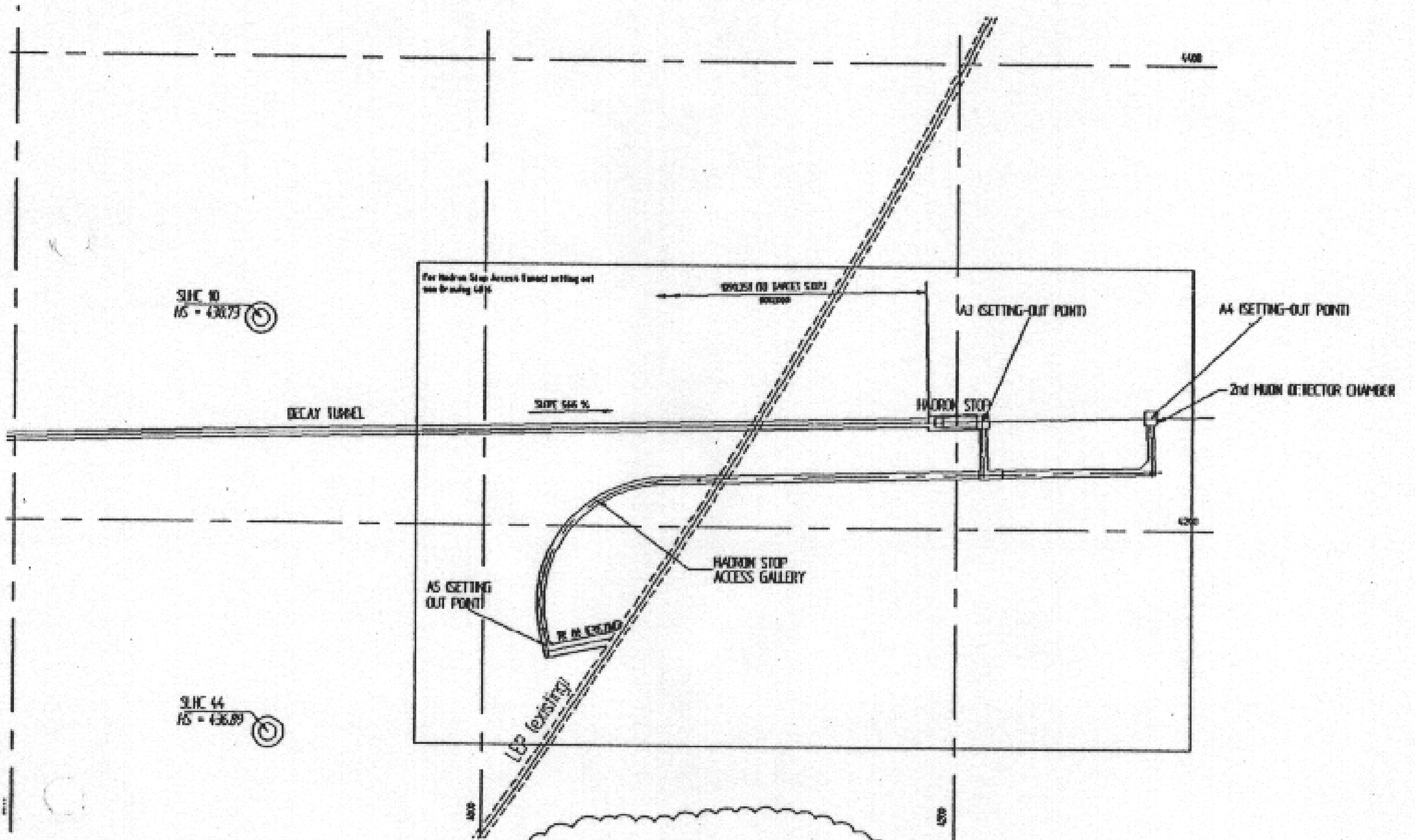
5×10^7 particles/cm^2/10µs in muon chamber 1

7×10^5 particles/cm^2/10µs in muon chamber 2



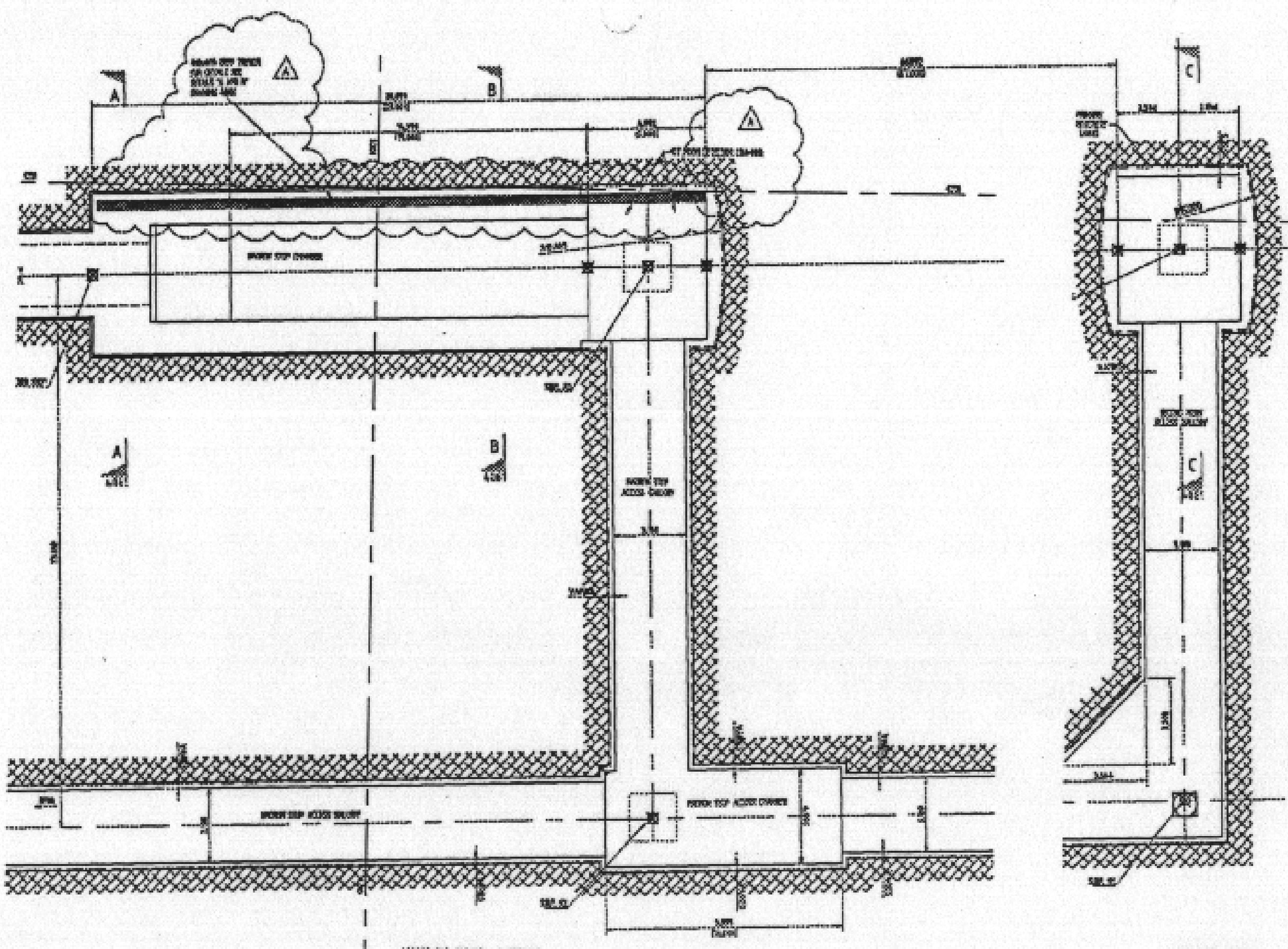
Site BA4
of SPS
Tempory shaft
Altitude
(m)
450
400
350
300
250
200
PGCN
SPS
TN4
Meyrin
Airport
Genève-Cointrin
MORAINES
MOLASSE
Tunnel
LEP/LHC
Target
Slope 5,6%
Decay
tunnel
Hadron stop +
1st Muon detector
2nd Muon detector
Neutrino beam to Gran Sasso
0,5
1
1,5
2
2,5
2,5
3
3,5
Km


North
Prévessin-Moëns
SPS/BA4
/ECA4
Temporary shaft PGCN
Access gallery
SPS
Proton beam tunnel (TN4)
LEP/LHC
Target
TI8
Decay tunnel
Connection gallery
LEP/LHC
Hadron stop and 1st muon detector
2nd muon detector
Meyrin
Airport
Genève-Cointrin
to Gran Sasso
0
250
500



PLAN OF HADRON STOP, 2ND MUON DETECTOR AND HADRON STOP ACCESS GALLERY
(Scale 1 : 1250)

(SCALE 1 : 1250)



HADRON STOP, ACCESS GALLERY AND CHAMBERS
1 : 100

SECOND MUON DETECTOR CHAMBER
1 : 100

(SCALE 1 : 100)

Rev. Index	Date	Drawn	Drg. Check	Approved By	Notes
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-					

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

NEUTRINO — CIVIL ENGINEERING

HADRON STOP AND SECOND MUON DETECTOR
GENERAL ARRANGEMENT
SHEET 1 OF 3

CONSULTANCY SERVICES

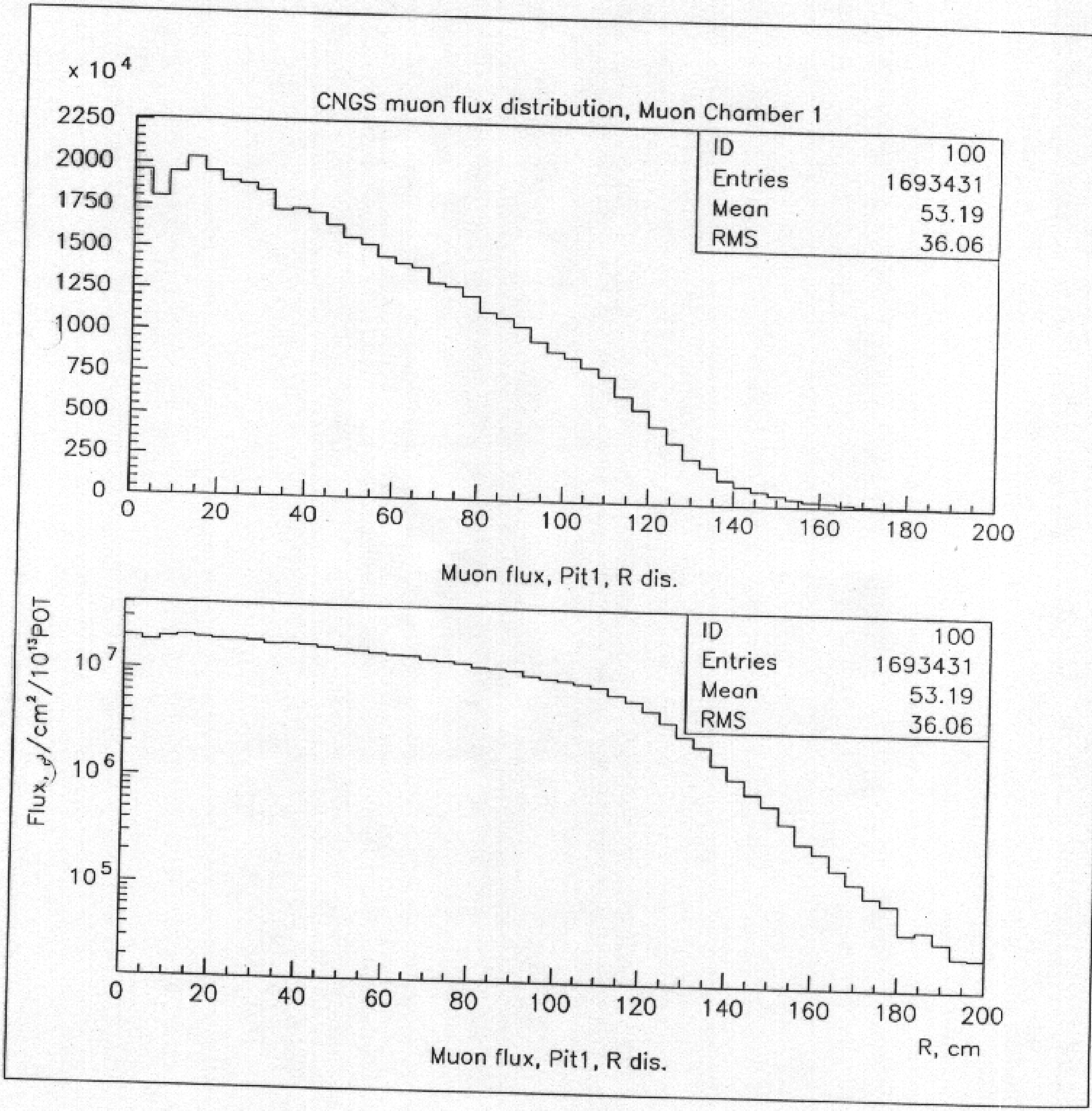
GIBB

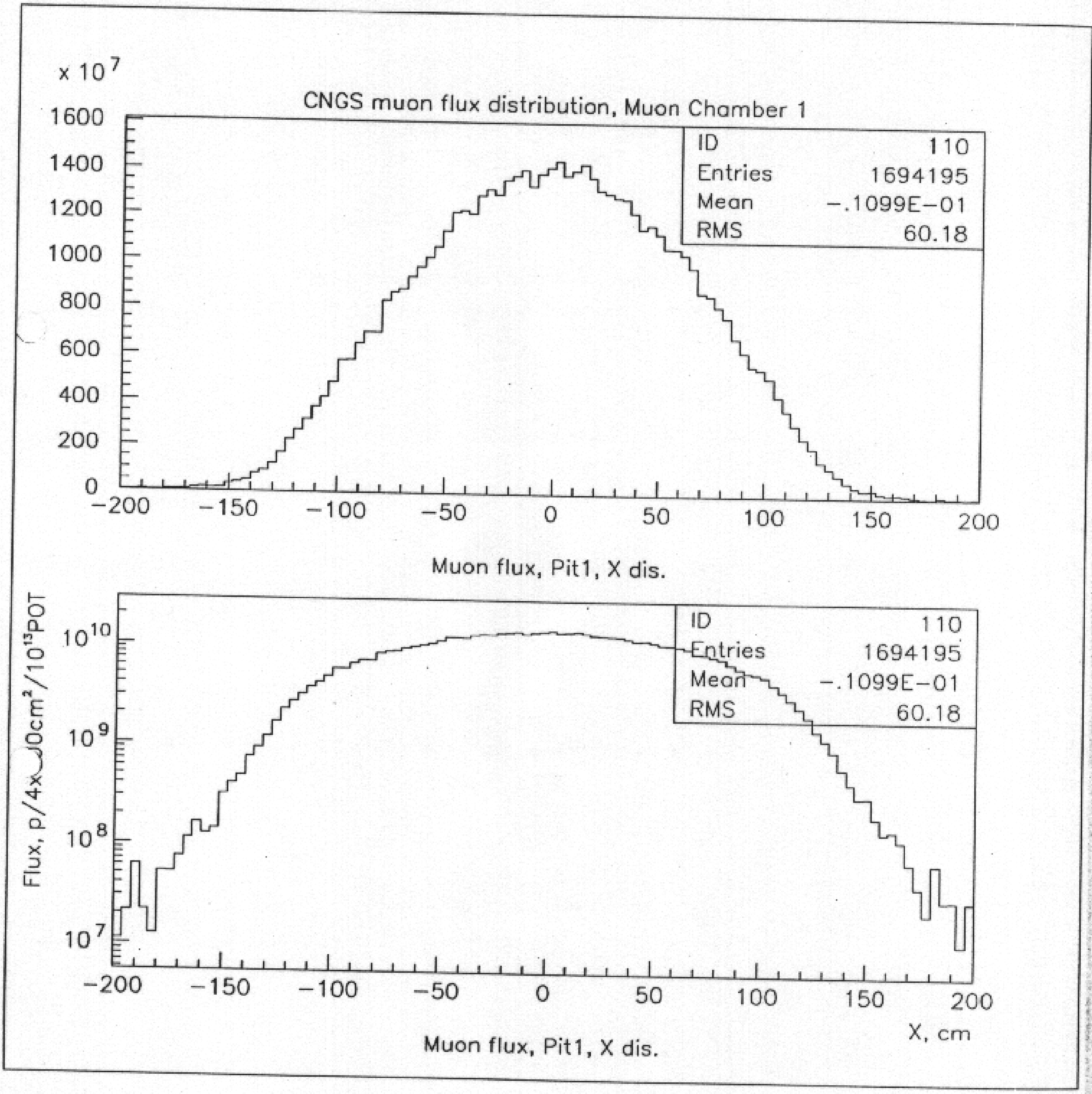
Scale : 1 : 100

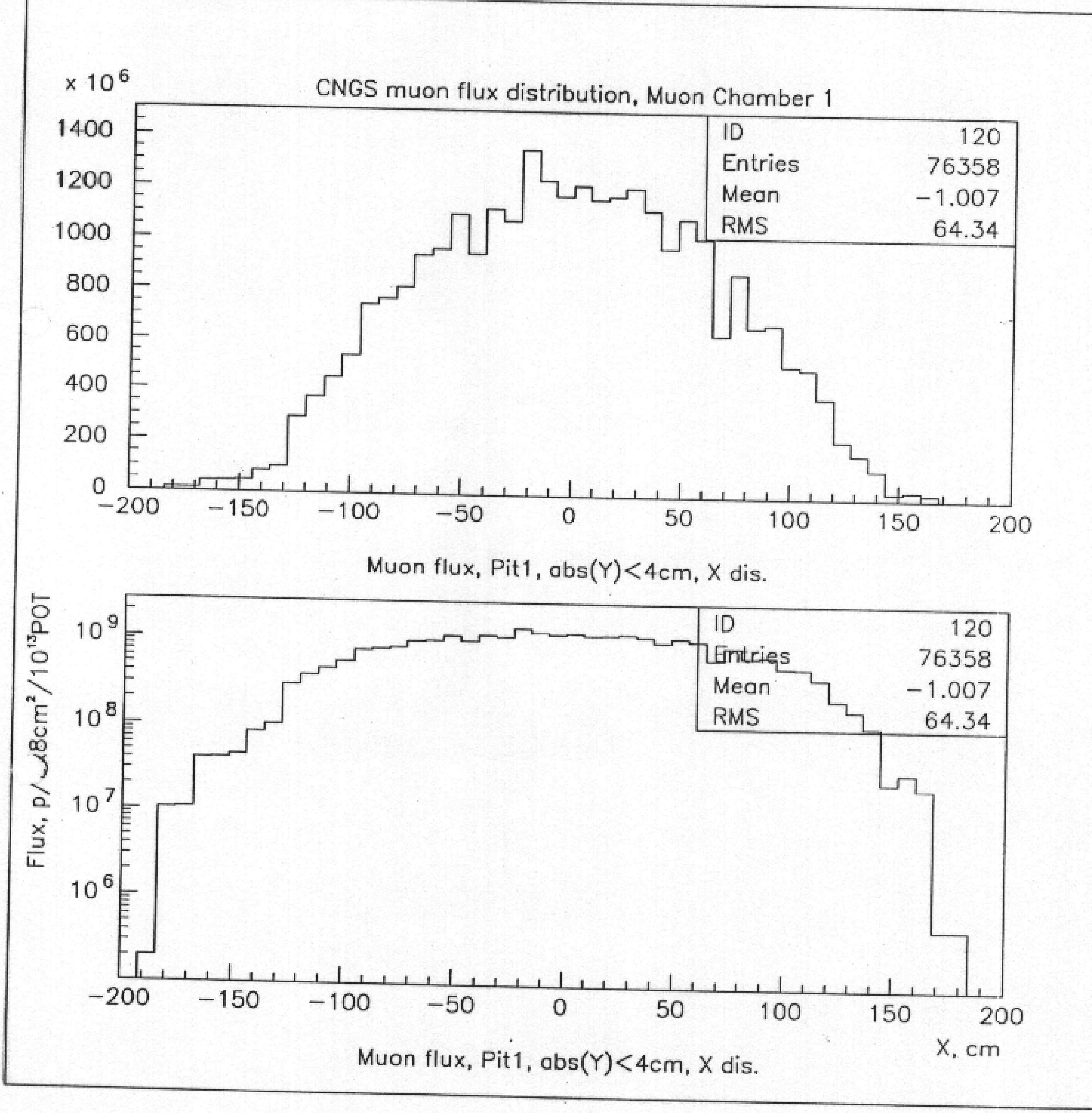
P C A A

DRG. No.

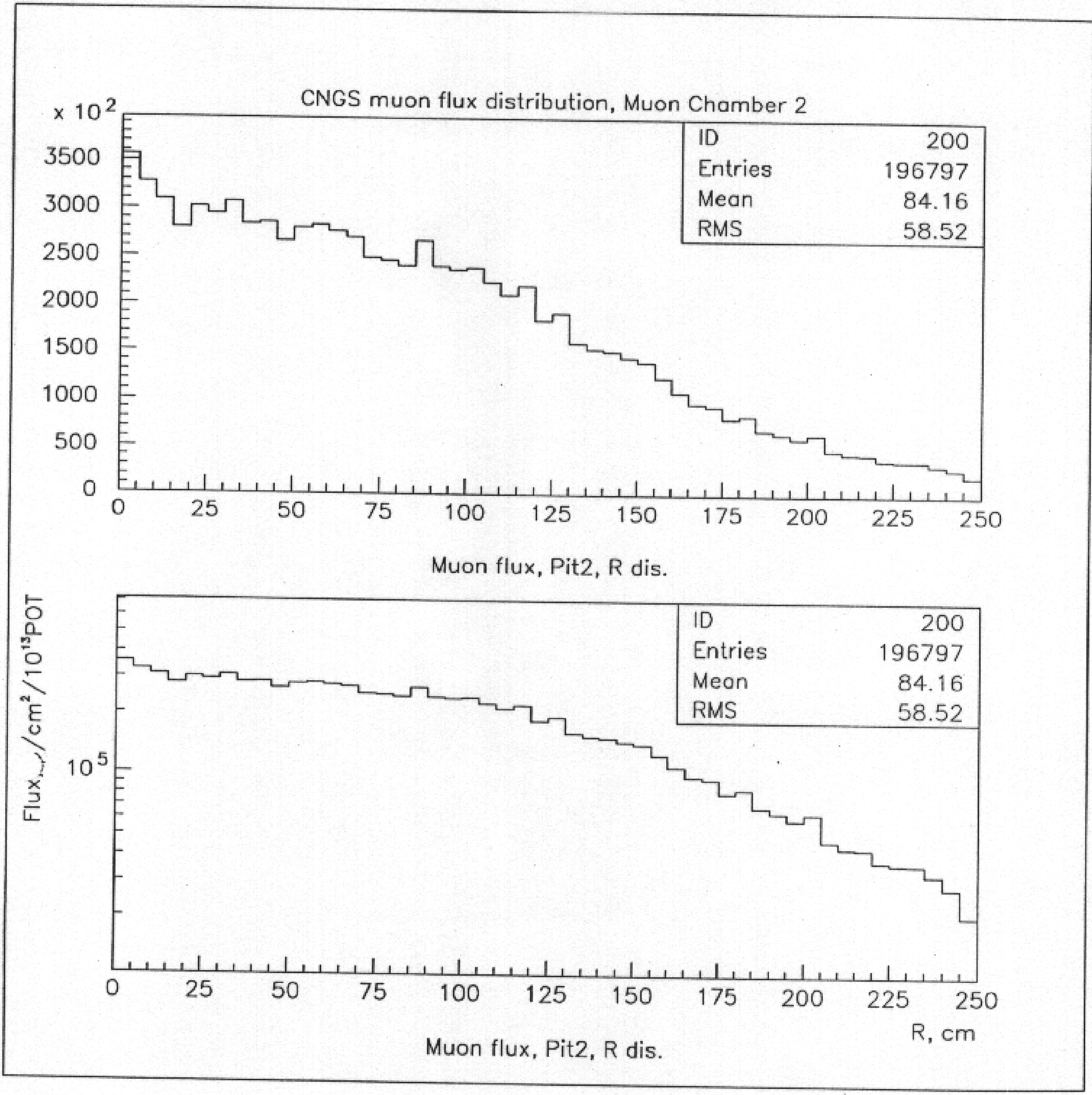
T - G N G S K 1 1 0 0 4 0 6 0 1 A

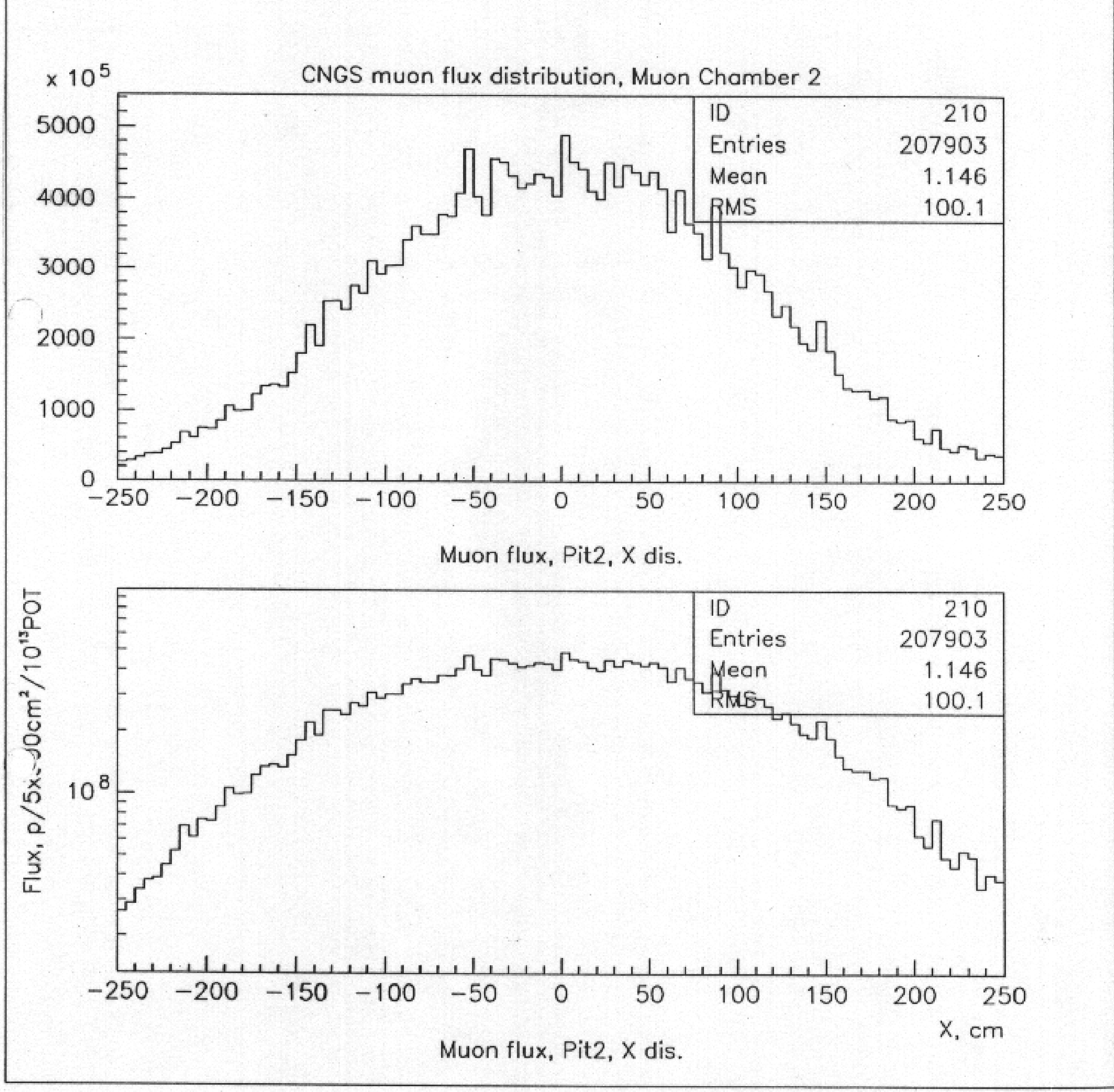

x 10^4
CNGS muon flux distribution, Muon Chamber 1
2250
2000
1750
1500
1250
1000
750
500
250
0
ID 100
Entries 1693431
Mean 53.19
RMS 36.06
0 20 40 60 80 100 120 140 160 180 200
Muon flux, Pit1, R dis.
Flux, μ/cm²/10¹³POT
10^7
10^6
10^5
ID 100
Entries 1693431
Mean 53.19
RMS 36.06
0 20 40 60 80 100 120 140 160 180 200
R, cm
Muon flux, Pit1, R dis.


x 10^7
CNGS muon flux distribution, Muon Chamber 1
ID 110
Entries 1694195
Mean -.1099E-01
RMS 60.18
Muon flux, Pit1, X dis.
Flux, p/4x_0cm²/10¹³POT
ID 110
Entries 1694195
Mean -.1099E-01
RMS 60.18
X, cm
Muon flux, Pit1, X dis.

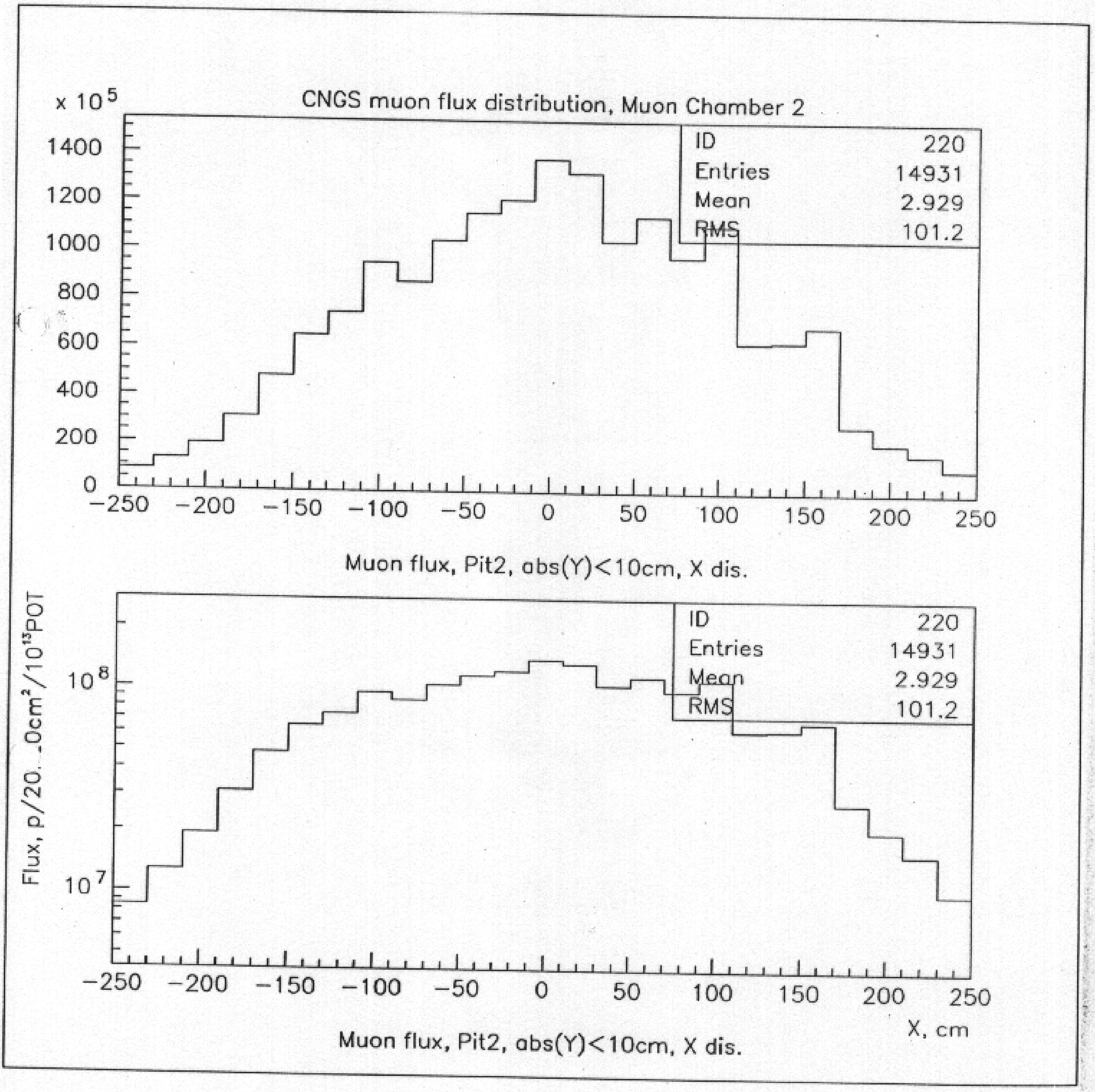


CNGS muon flux distribution, Muon Chamber 1
x 10^6
ID 120
Entries 76358
Mean −1.007
RMS 64.34
Muon flux, Pit1, abs(Y)<4cm, X dis.
Flux, p/8cm²/10¹³POT
ID 120
Entries 76358
Mean −1.007
RMS 64.34
X, cm
Muon flux, Pit1, abs(Y)<4cm, X dis.


CNGS muon flux distribution, Muon Chamber 2
x 10^2
ID 200
Entries 196797
Mean 84.16
RMS 58.52
3500
3000
2500
2000
1500
1000
500
0
0 25 50 75 100 125 150 175 200 225 250
Muon flux, Pit2, R dis.
Flux/cm²/10¹³POT
10^5
ID 200
Entries 196797
Mean 84.16
RMS 58.52
0 25 50 75 100 125 150 175 200 225 250
R, cm
Muon flux, Pit2, R dis.



CNGS muon flux distribution, Muon Chamber 2
x 10^5
ID 210
Entries 207903
Mean 1.146
RMS 100.1
Muon flux, Pit2, X dis.
Flux, p/5x50cm²/10¹³POT
ID 210
Entries 207903
Mean 1.146
RMS 100.1
X, cm
Muon flux, Pit2, X dis.



x 10^5
CNGS muon flux distribution, Muon Chamber 2
ID 220
Entries 14931
Mean 2.929
RMS 101.2
0
200
400
600
800
1000
1200
1400
−250 −200 −150 −100 −50 0 50 100 150 200 250
Muon flux, Pit2, abs(Y)<10cm, X dis.
Flux, p/20.._0cm²/10¹³POT
ID 220
Entries 14931
Mean 2.929
RMS 101.2
10^8
10^7
−250 −200 −150 −100 −50 0 50 100 150 200 250
X, cm
Muon flux, Pit2, abs(Y)<10cm, X dis.

Features and special requirements

- **Access to the equipment is rare and difficult**
  ⇒ High reliability and redundancy
- **Wide dynamical range (10^5)**
  The flux in the muon chambers can vary:
  - two order of magnitude because on the proton beam intensity variation;
  - two order of magnitude from chamber 1 to chamber 2;
  - an order of magnitude because of the different detector position in the same pit.
  ⇒ Detector elements with different sensitivity. Wide dynamic range electronics
- **Big area to cover**
  ⇒ Use of low cost materials or measurement of the flux in several points and interpolation between them
- **Limited feed-back from the experiments**
  ⇒ **Permanent cross-check of the beam detectors data and periodical (or permanent) geodetic monitoring**

Another important factor affecting the choice

- **Positive experience in utilisation of silicon counters (solid state detectors) for neutrino beams monitoring at CERN (more than 20 years history, last time used for CHORUS and NOMAD in 94-98)**

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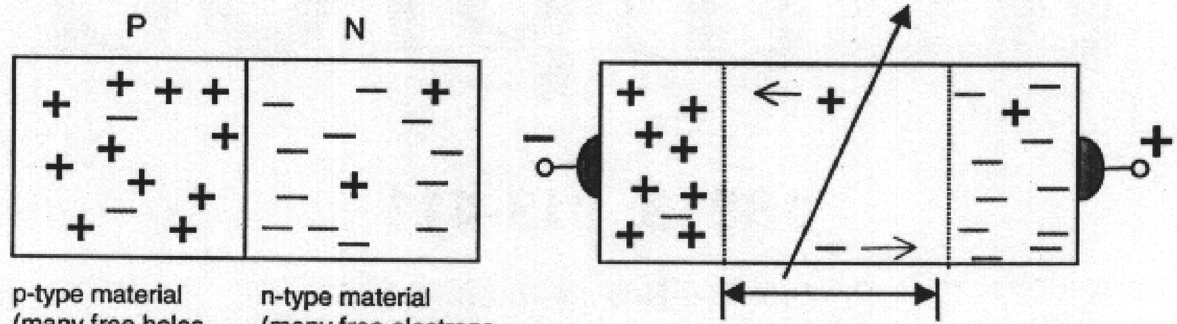
Semiconductor junction detector as particles flux monitor



p-type material (many free holes, practically no free electrons)

n-type material (many free electrons, practically no free holes)

Depletion region contains almost no free carriers of either sign (insulator)

Junction detectors with reverse bias behave much like solid state ionization chamber

Mean energy deposition of a "standard MIP" in Si is 3.5 MeV/cm

3.62 eV needs in average to produce an electron-hole pair

~ 10^4 electrons-holes pairs/particle

- **The detector is not counting the particles, but measuring the total charge.**
- **Signal rise time is ~1 ns and usually each bunch seen by the detector independently.**
- **Integrated charge is proportional to the particles flux**

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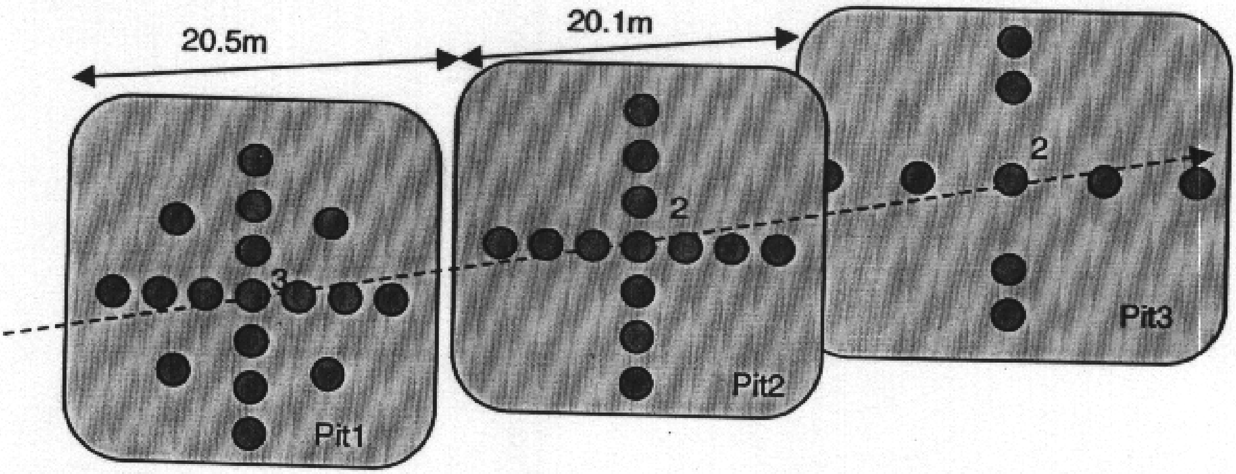
Use of SSDs in the WANF (CHORUS & NOMAD run)

- 43 detectors mounted inside of the water-tight boxes and installed on the support plates



3 muon pits, 63 detectors :
5 in Ref. Box
Pit1 - 19 fixed + 5 in Cal. Box
Pit2 - 14 fixed + 5 in Cal. Box
Pit3 - 10 fixed + 5 in Cal. Box

A remotely controlled girder ("lift") equipped with a calibration box was able be positioned in front of any point of support plate. There was a space on each lift to transport at the same time a second box of the same type (reference box)

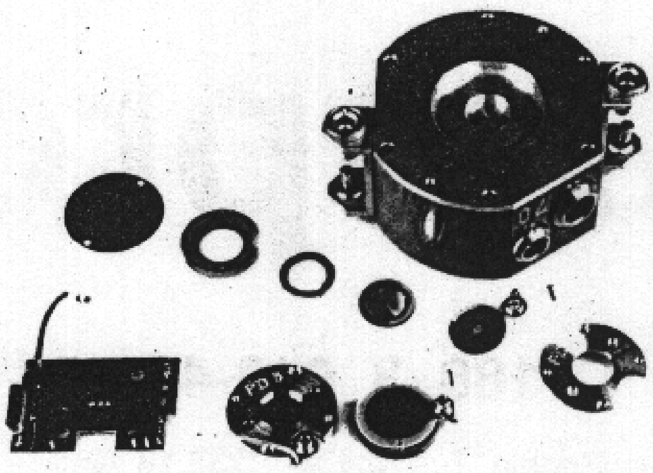


Fig. 7.3 The disassembled detector mounting together with the tight box. The detector shown here, has an active area of 2 cm².

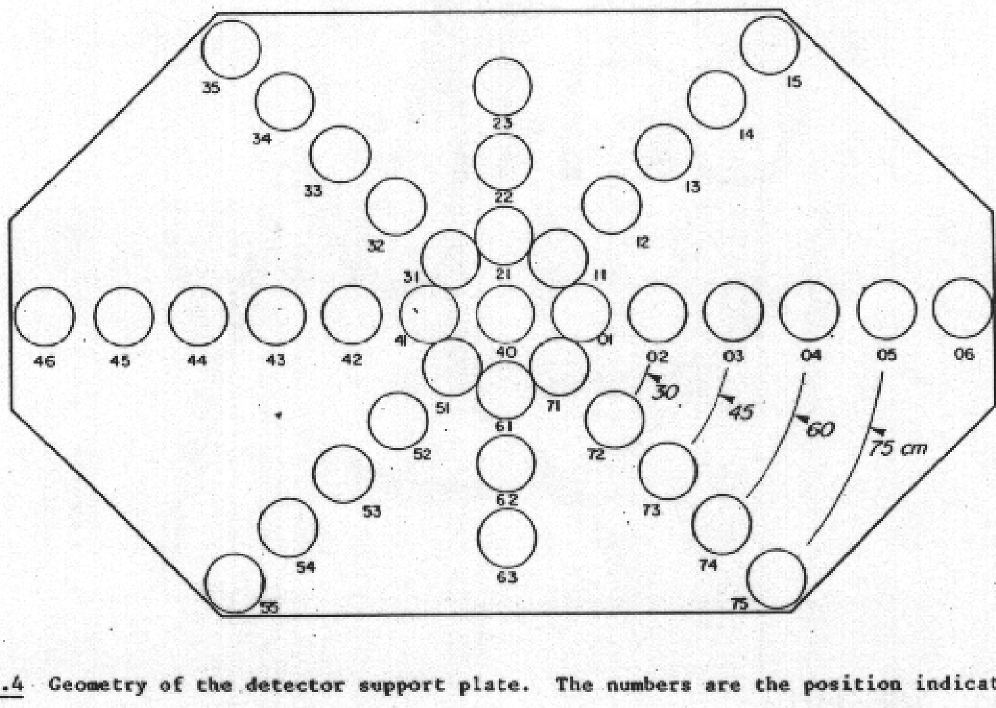


Fig. 7.4 Geometry of the detector support plate. The numbers are the position indicators.

Other main features of the system

- Permanent leakage current compensation
  up to the 10 μA maximum current.
  Changing of the detectors with higher current.
- Permanent detectors calibration, which allowed to keep flux measurement resolution of individual detectors in the range of 1%.
- Individual bias voltages.
- A good electronics linearity and resolution (better than 0.5% in average).
- Charge sensitive amplifiers with variable gain (the gain changed from 1 to 500) with direct coupling to the detectors.
- Adaptation of the detectors size to the measured flux.

Muon flux profiles

- The beam centre and width were determined by the fixed detectors for each spill with a precision of ±2 mm for pits 1 and 2, and ±3 mm for pit 3.
- Independent beam scans were done by calibration boxes moved either horizontally or vertically.

Advantage: independent on the relative SSD calibrations
Disadvantage: average flux only
Precision: ±1 mm

The strong points

1. Wide dynamical range (more than 10^5).
2. Simple maintenance (no gas, no HT, detectors are easy to change or move).
3. System is easy for modifications.
4. Two practically independent source of beam profile information: fixed detectors and beam scan with calibration boxes.
5. Good relative short-term flux measurement resolution (better than 1%) of individual counters.
6. Simple relative counters calibration.
7. Possibility of absolute muon flux measurement.

The weak points

1. Slow sensitivity change.
2. Rise of leakage current.
3. Relatively high cost.

Proposal

A measurement system based on the solid state detectors is a perfect tool for muon flux monitoring. It proved its capacity during long WANF life and proposed to use in CERN Neutrino beam to Gran Sasso

Muon monitoring system for CNGS

WANF type SSD based monitoring system with modifications taking into account the WANF experience

How to avoid the WANF monitoring system weaknesses

1. Slow sensitivity change
   - Can be compensated by periodical calibration.
   - Not so important for relative measurements (correct beam profiles).
   - Compensation of long term sensitivity variation can be achieved by external calibration.
   - The problem becomes more complicated, if the absolute muon flux measurement are needed.
2. Rise of leakage current
   - Automatic leakage current compensation up to certain limit
   - Main reasons of detectors replacements in the WANF during 94-98 run:
     - use of very old detectors
     - high humidity in the pits
     - mistakes in detector data analysis
   - Use AC coupling to the electronics
   - Preliminary detector selection
3. Relatively high cost

   Re-use of the WANF detectors

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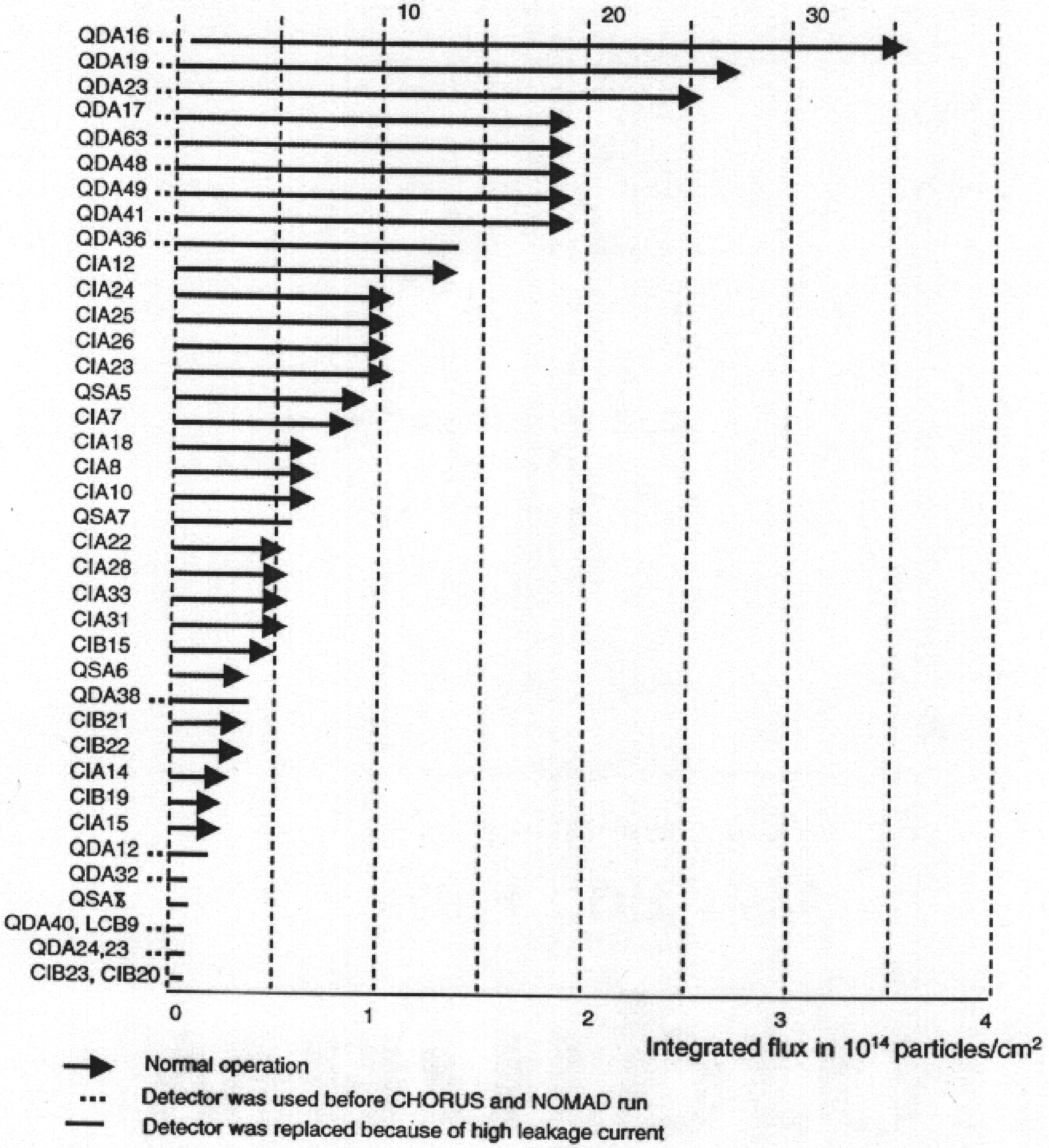
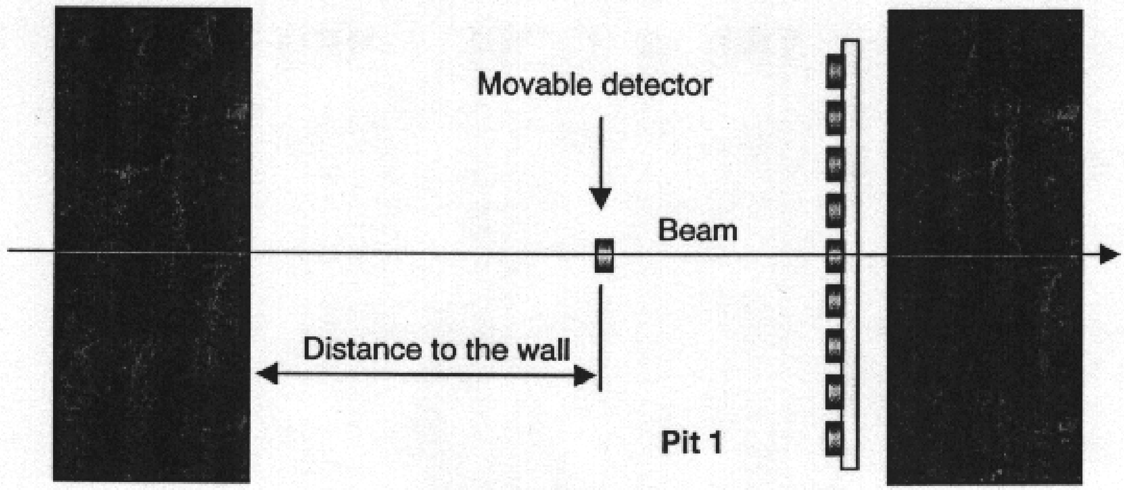
The total muon dose received by the silicon detectors during WANF operation for CHORUS and NOMAD

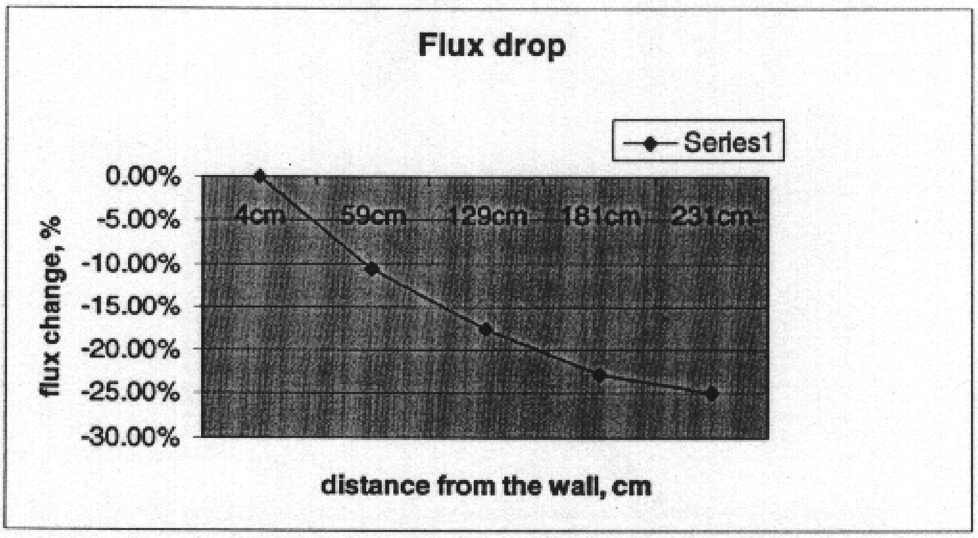


Total integrated proton intensity during WANF operation for CHORUS and NOMAD is 7.1×10^{19} POT

Other innovations

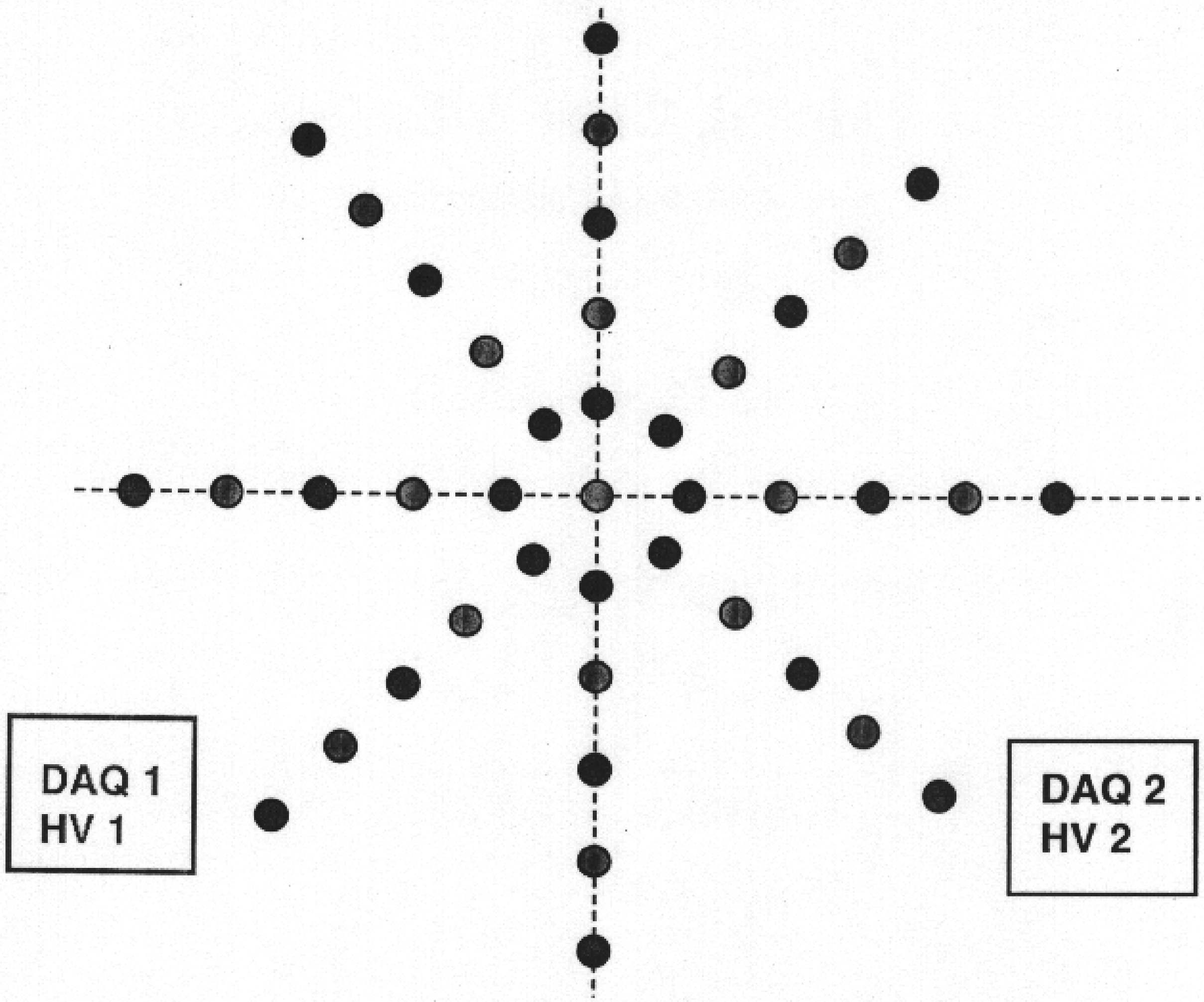
1. Both muon chambers are big (5 m) and have the same size to avoid effect of low energy electrons





2. The calibration box will be positioned not in front but behind of the fixed detectors to avoid the 'Cal. Box.' effect

3. Requested redundancy can be achieved by splitting the monitoring system into two independent ones



4. 'Transparent' detector boxes and support structure

Detector performance (first estimation)

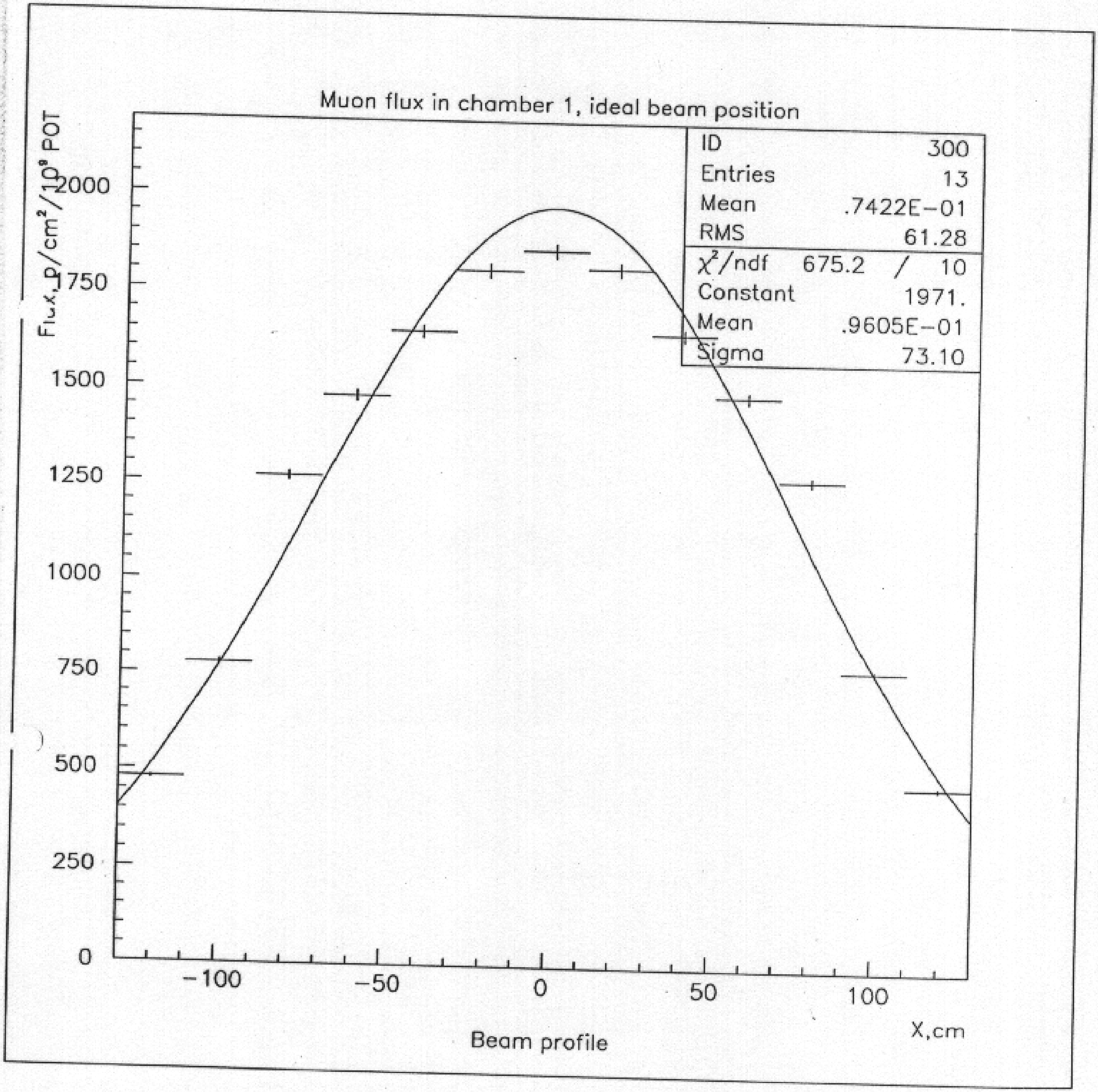
Detector in Muon Chamber 1

Step	Detectors Precision	Precision at nominal position	HORN 6mm shift (error of sampling)
20 cm	1%	1.5 mm	1.5 cm
	2%	3.0 mm	1.5 cm
40 cm	1%	2.5 mm	1 cm
	2%	4.0 mm	1 cm

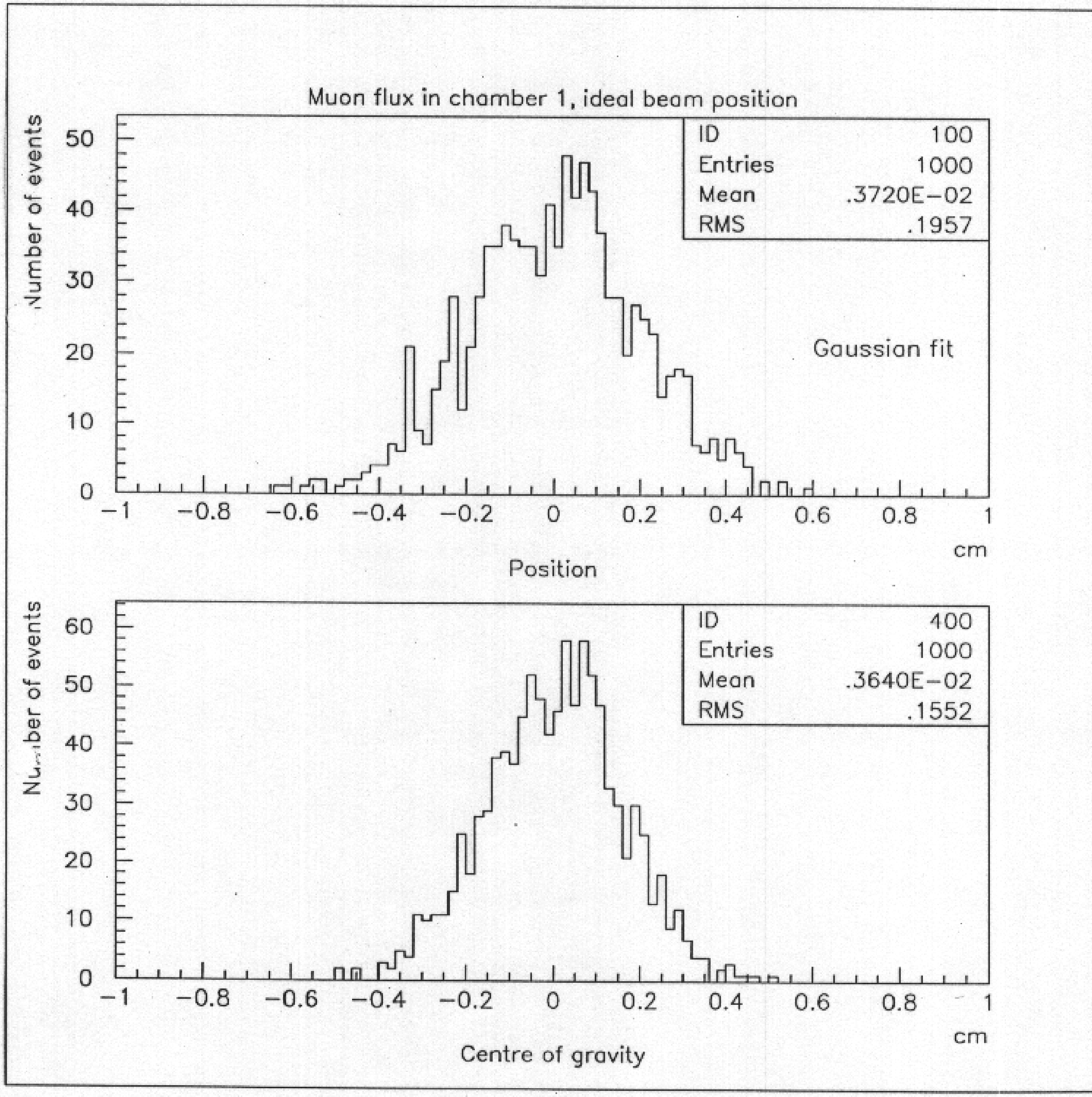
Detector in Muon Chamber 2

Step	Detectors Precision	Precision at nominal position
30 cm	1%	2.5 mm
	2%	4.0 mm
60 cm	1%	3.5 mm
	2%	5.0 mm

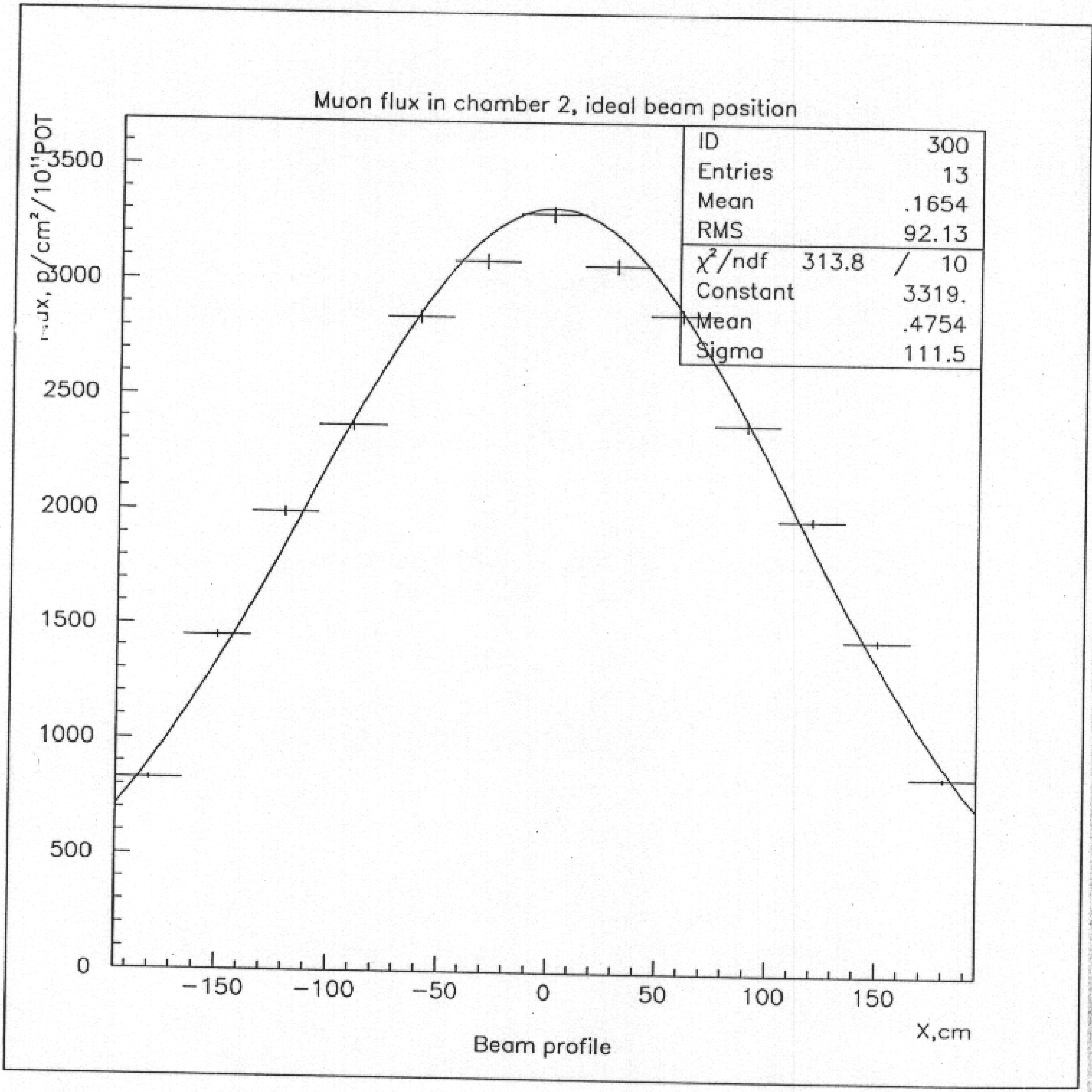
Final number and positions of the detectors is under study.



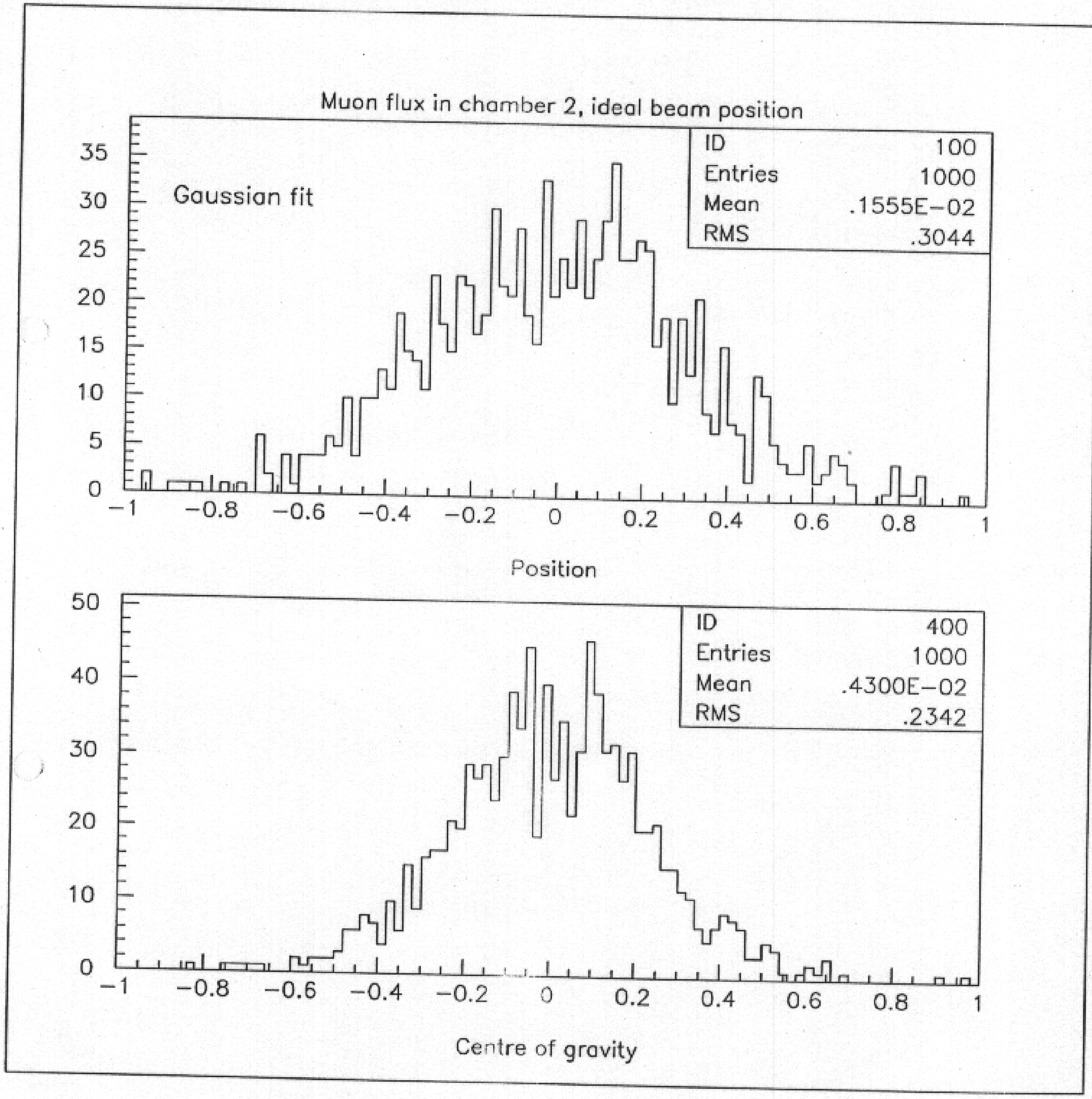
Muon flux in chamber 1, ideal beam position
Flux, p/cm²/10⁹ POT
0
250
500
750
1000
1250
1500
1750
2000
-100
-50
0
50
100
X,cm
Beam profile
ID 300
Entries 13
Mean .7422E-01
RMS 61.28
χ²/ndf 675.2 / 10
Constant 1971.
Mean .9605E-01
Sigma 73.10

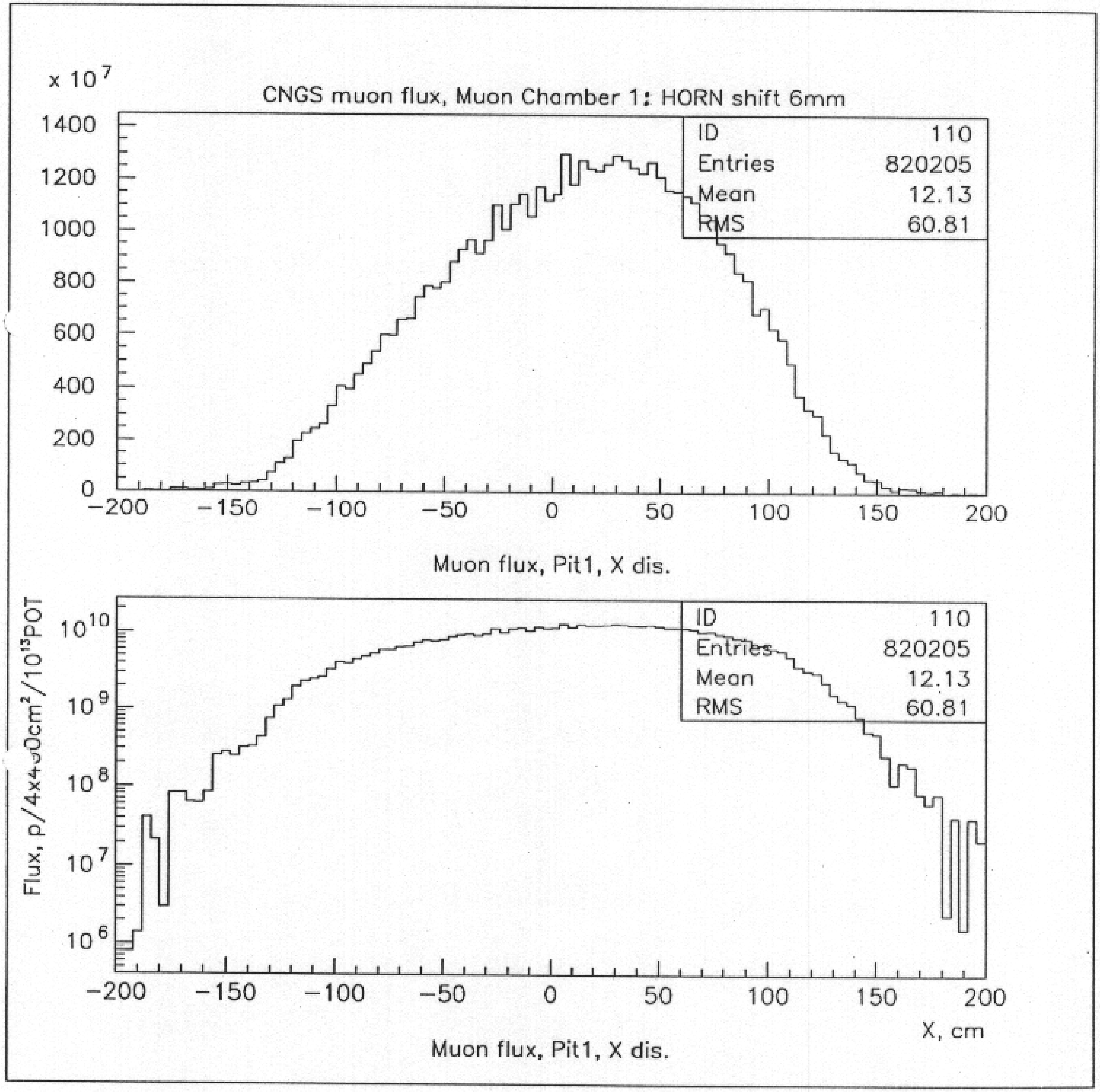


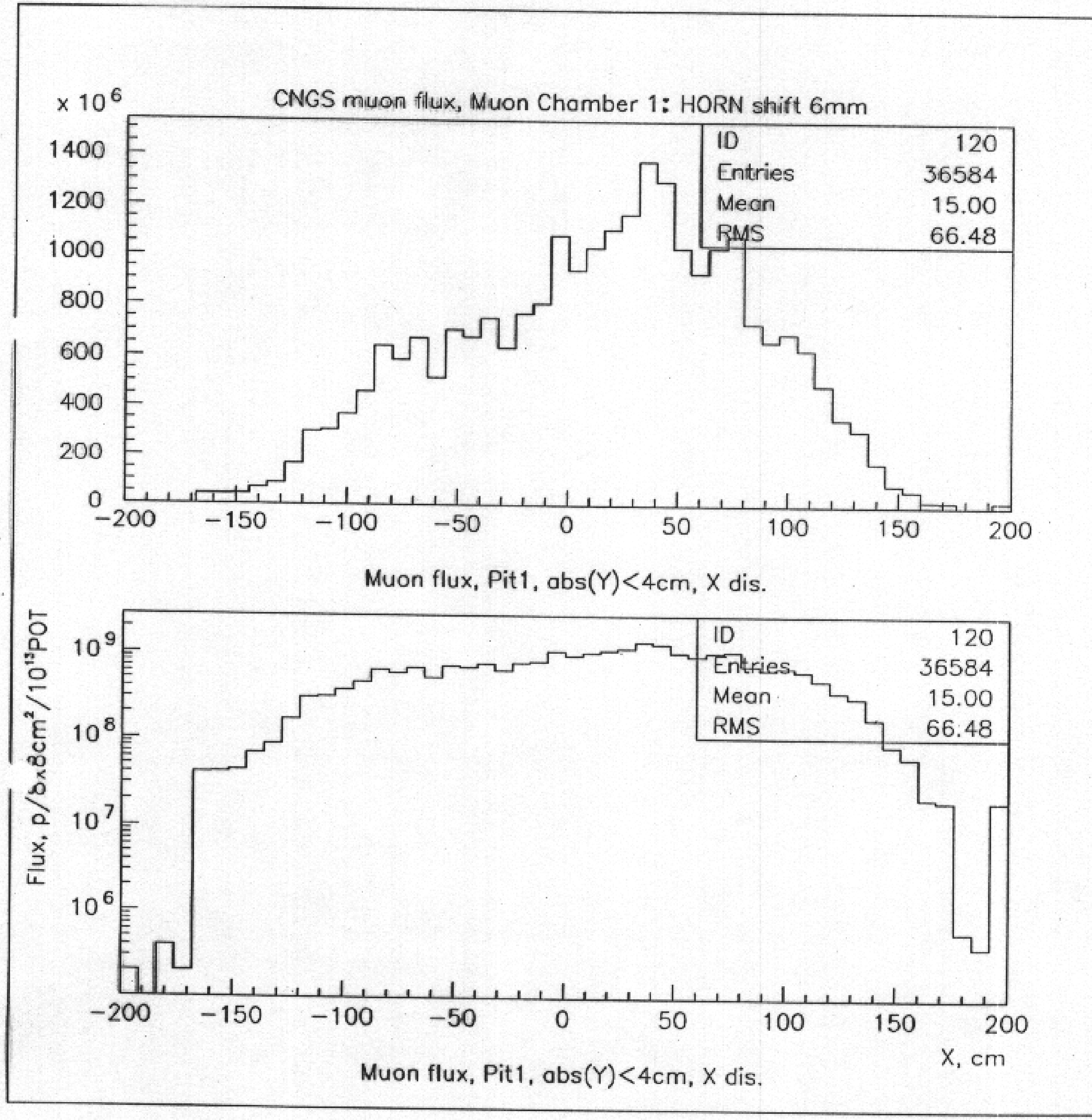
Muon flux in chamber 1, ideal beam position
ID 100
Entries 1000
Mean .3720E-02
RMS .1957
Gaussian fit
Number of events
Position
cm
ID 400
Entries 1000
Mean .3640E-02
RMS .1552
Number of events
Centre of gravity
cm



Muon flux in chamber 2, ideal beam position
ID 300
Entries 13
Mean .1654
RMS 92.13
χ²/ndf 313.8 / 10
Constant 3319.
Mean .4754
Sigma 111.5
Flux, p/cm²/10¹¹POT
X,cm
Beam profile

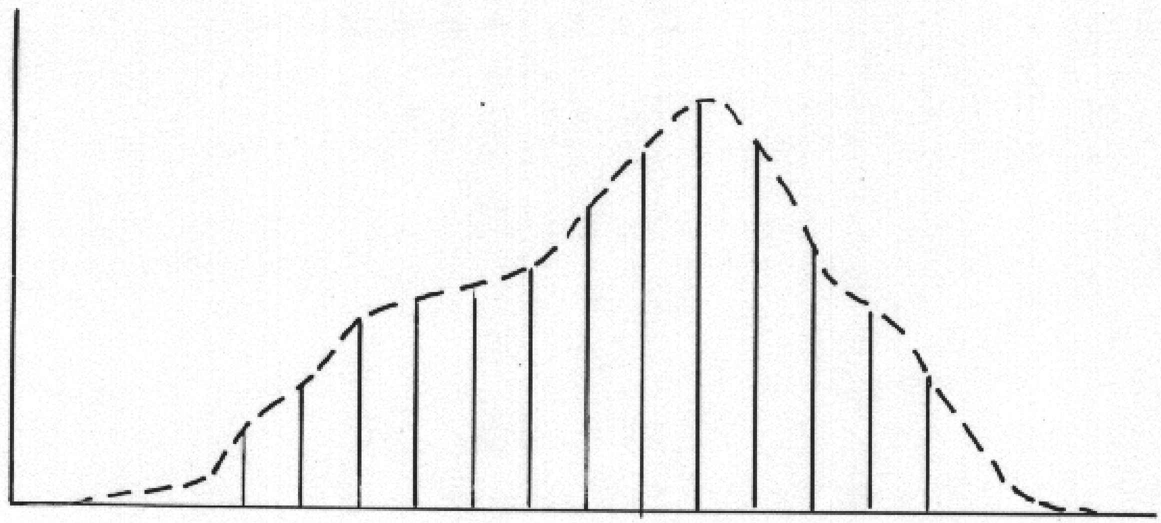

Muon flux in chamber 2, ideal beam position
Gaussian fit
ID 100
Entries 1000
Mean .1555E-02
RMS .3044
35
30
25
20
15
10
5
0
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1
Position
ID 400
Entries 1000
Mean .4300E−02
RMS .2342
50
40
30
20
10
0
Centre of gravity


x 10^7
CNGS muon flux, Muon Chamber 1: HORN shift 6mm
ID 110
Entries 820205
Mean 12.13
RMS 60.81
1400
1200
1000
800
600
400
200
0
−200
−150
−100
−50
0
50
100
150
200
Muon flux, Pit1, X dis.
Flux, p/4x4 cm²/10¹³POT
ID 110
Entries 820205
Mean 12.13
RMS 60.81
10^10
10^9
10^8
10^7
10^6
−200
−150
−100
−50
0
50
100
150
200
X, cm
Muon flux, Pit1, X dis.



CNGS muon flux, Muon Chamber 1: HORN shift 6mm
x 10^6
ID 120
Entries 36584
Mean 15.00
RMS 66.48
Muon flux, Pit1, abs(Y)<4cm, X dis.
Flux, p/8x8cm²/10¹³POT
ID 120
Entries 36584
Mean 15.00
RMS 66.48
X, cm
Muon flux, Pit1, abs(Y)<4cm, X dis.

Mean from sample 13.5c



Potential problems

1. Very high ionization density

Anomalously high signal was observed in CERN PS neutrino beam for relatively thick detectors ($>500\mu$) at intensity 1.2×10^7 muon/cm^2.
The PS beam was formed from 18 bunches. The bunches have a duration of 10 ns and an interval of 100 ns between bunches

1) The CNGS beam will consist of the 2-3 ns bunches each 5 ns.
2) We will use relatively thin ($\leq$100 μ) detectors
3) More study needed

2. Very high integrated dose

Proton intensity integrated during WANF operation for CHORUS and NOMAD (7.1×10^{19} POT) will be exceeded in one year of the CNGS operation in dedicated mode (7.6×10^{19} POT).

Additional study of radiation hardness will be extremely useful

Conclusion

Monitoring system based on silicon counters fulfils all CNGS muon monitoring requirements.

Additional study at high fluxes and total integrated doses will be useful to obtain an assurance of the system