Performance of the CERN neutrino beam to Gran Sasso (CNGS). Effects of alignment errors at Gran Sasso and at the beam monitors

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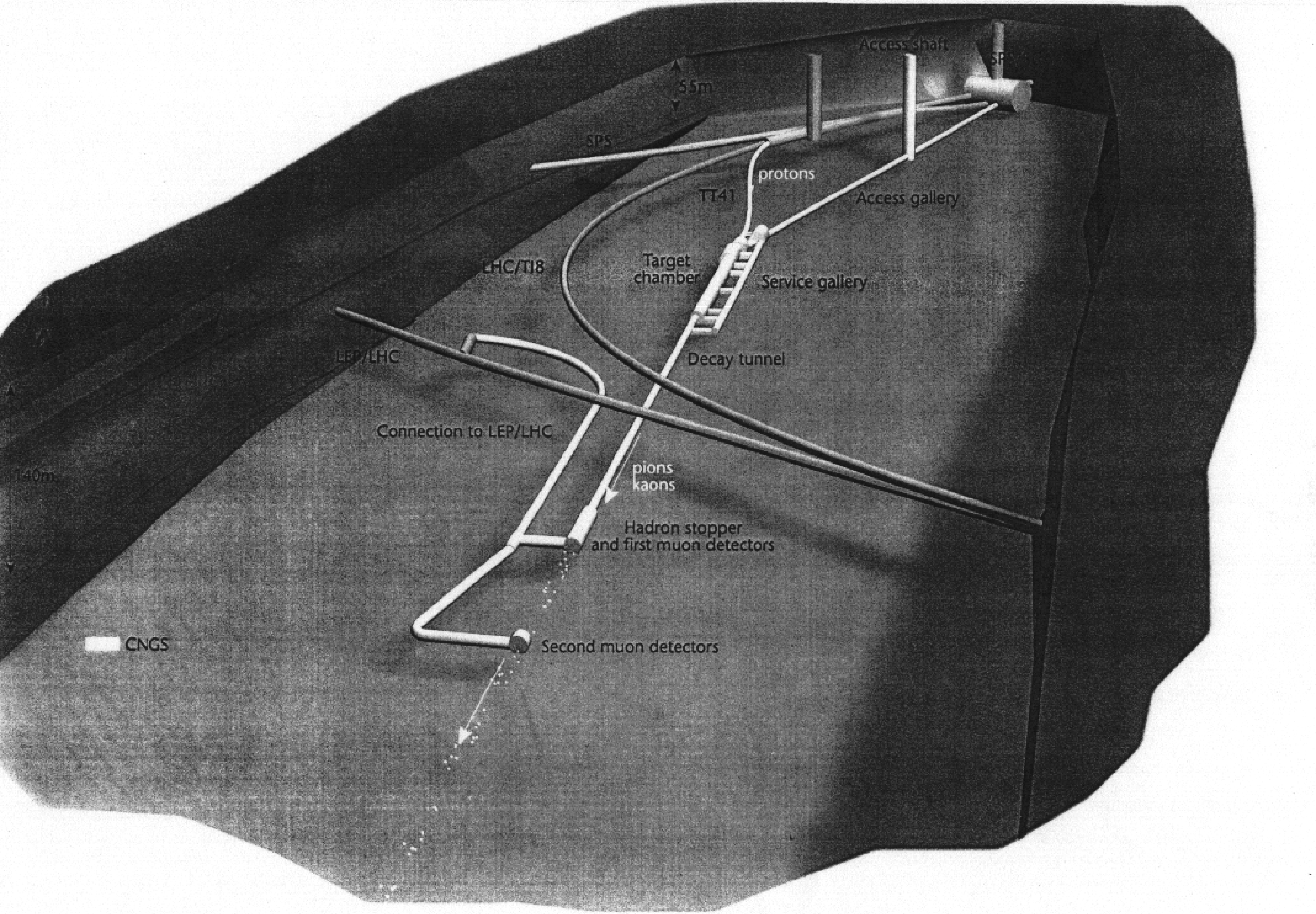
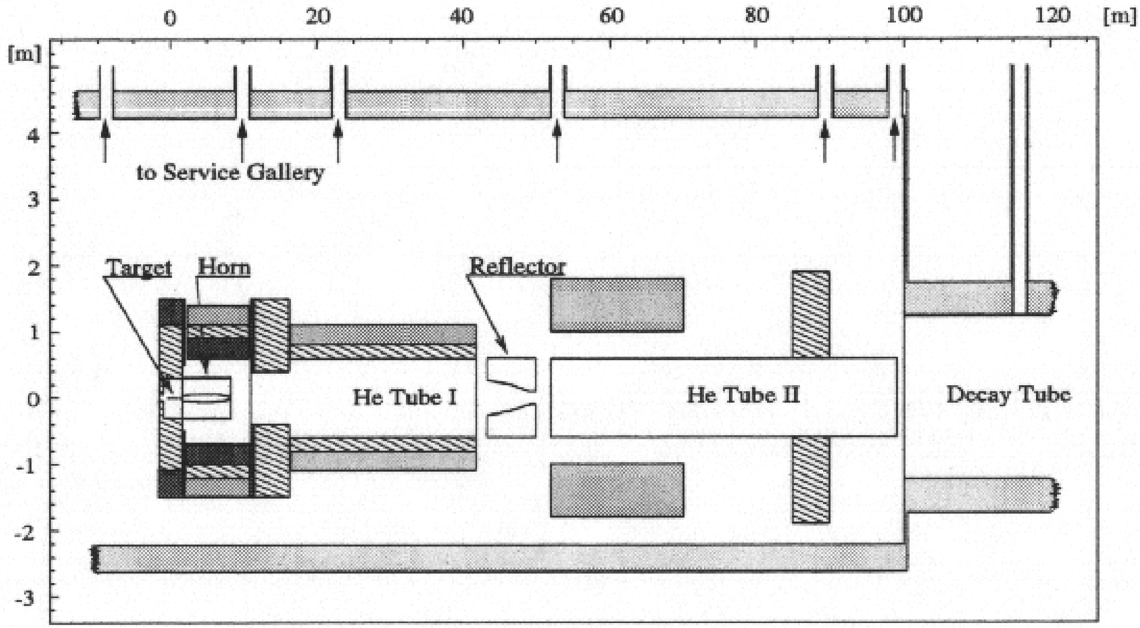
Outline

- Description of the secondary beam layout
- CNGS performance at Gran Sasso
- Effects of various systematic errors:
  - ◇ Proton beam uncertainties: angular and spatial displacements
  - ◇ Wrong alignment of the beam to Gran Sasso
  - ◇ Horn and Reflector displacements
- Conclusions


Access shaft
55m
SPS
protons
TT41
Access gallery
Target chamber
Service gallery
LHC/TI8
LEP/LHC
Decay tunnel
Connection to LEP/LHC
140m
pions
kaons
Hadron stopper
and first muon detectors
CNGS
Second muon detectors

Description of the CNGS beam elements



- Two co-axial lenses as focusing elements (horn and reflector) at 1.7m and 43.35m respectively, focusing 21, 35(h35) and 50(R50) GeV/c rays
- He tubes, collimators

CNGS beam detectors

- one hadron monitor at 100m (ionization devices) in front of the decay tunnel, hadron stopper, two muon monitoring pits (with silicon detector devices) at $\sim$ 1.12km and 1.19km with 67m of Molasse between them, and muon monitor at GS

Horns focusing

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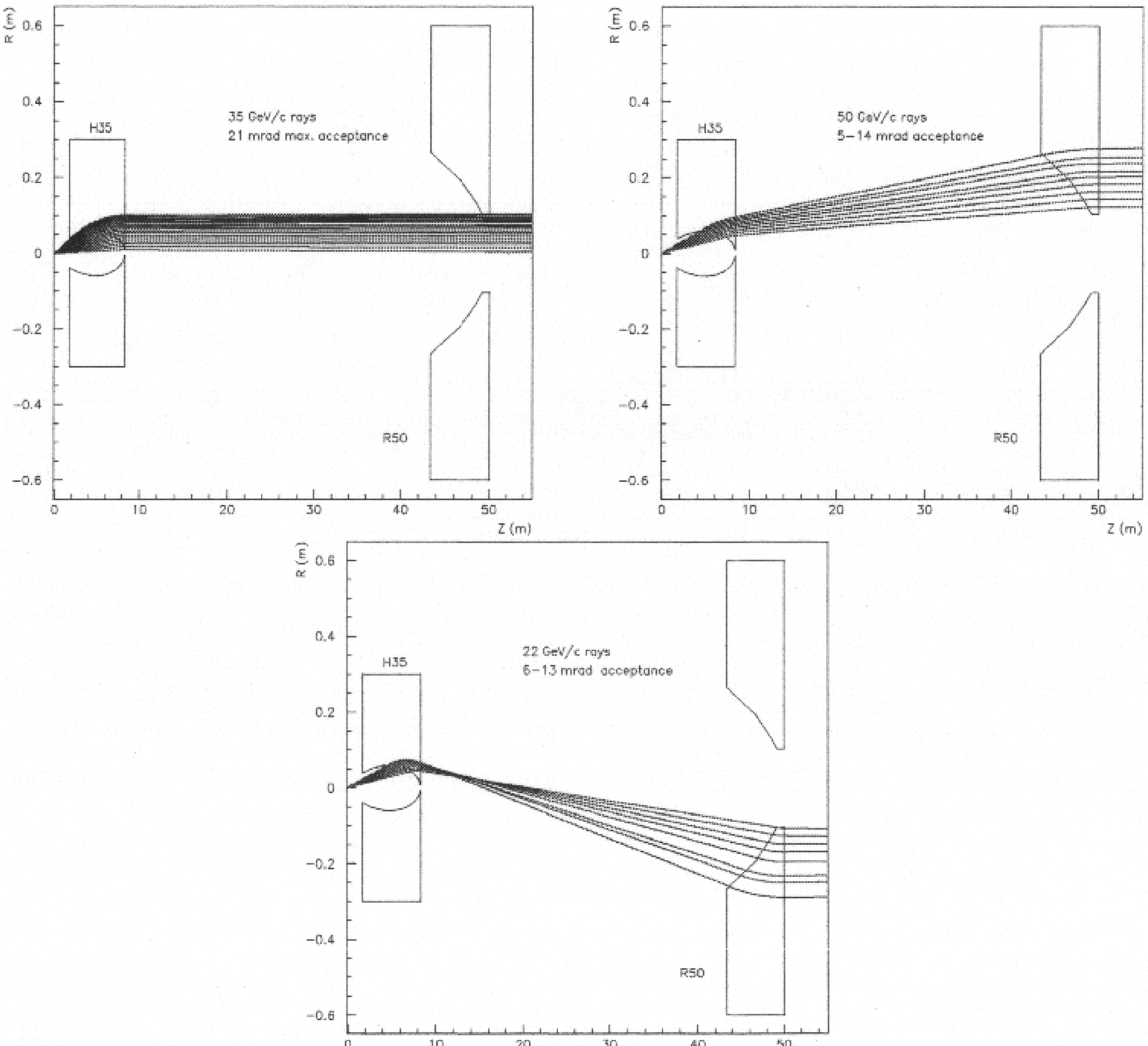
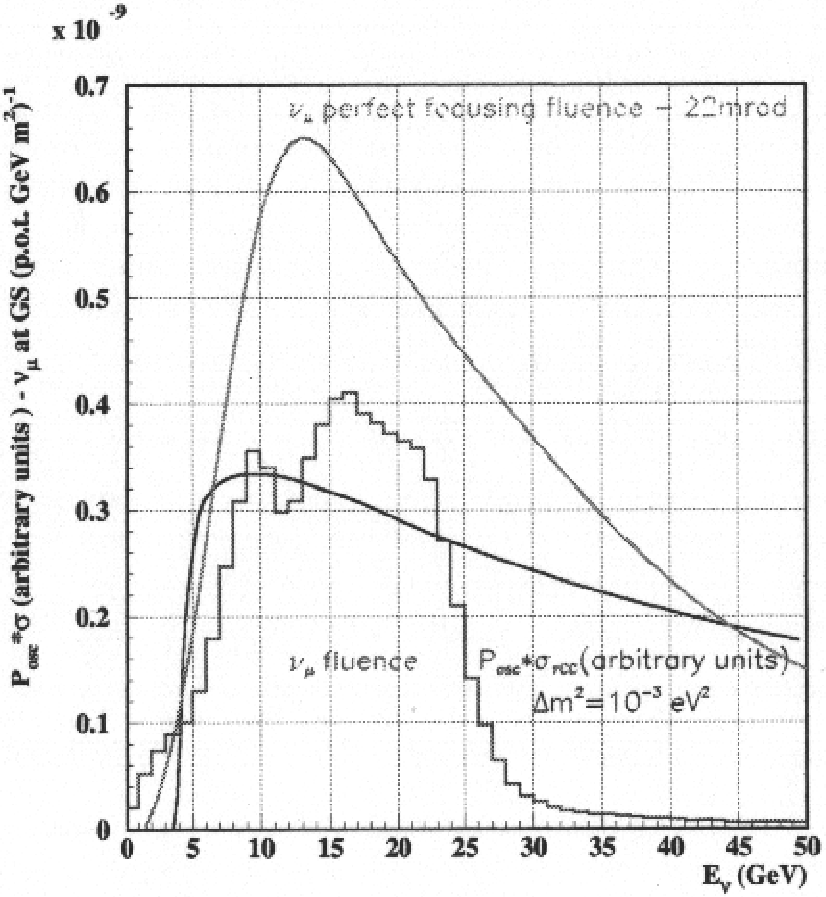
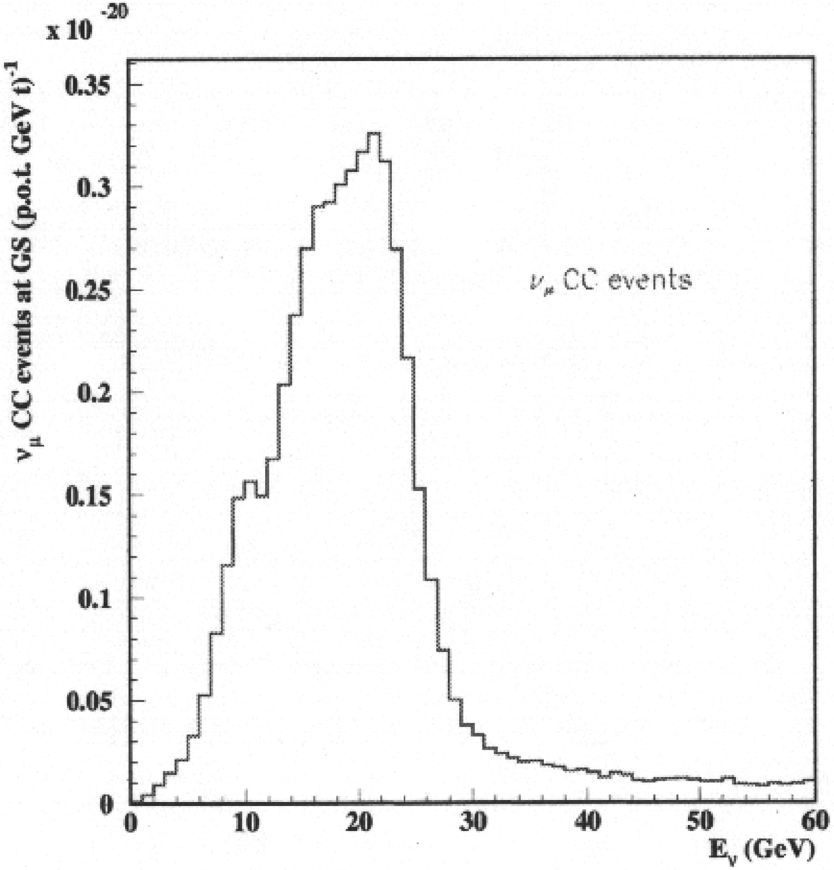


Spectra at Gran Sasso

ν_μ fluence, the product of probability of $\nu_\mu \rightarrow \nu_\tau$ and ν_τ CC cross section , and ν_μ CC events spectra:





CNGS performance at Gran Sasso

Predicted performance of the CNGS reference beam with the horn running at 150kA:

Energy region E_{ν_μ} [GeV]	1 - 30	1 - 100
ν_μ [m^{-2}/pot]	7.1×10^{-9}	7.45×10^{-9}
ν_μ CC events/pot/kt	4.70×10^{-17}	5.44×10^{-17}
$\langle E \rangle_{\nu_\mu\, fluence}$ [GeV]		17
fraction of other neutrino events:		
ν_e/ν_μ	0.8 %	
$\overline{\nu}_\mu/\nu_\mu$	2.0 %	
$\overline{\nu}_e/\nu_\mu$	0.05 %	

Expected number of ν_τ CC events /kt/year at GS:

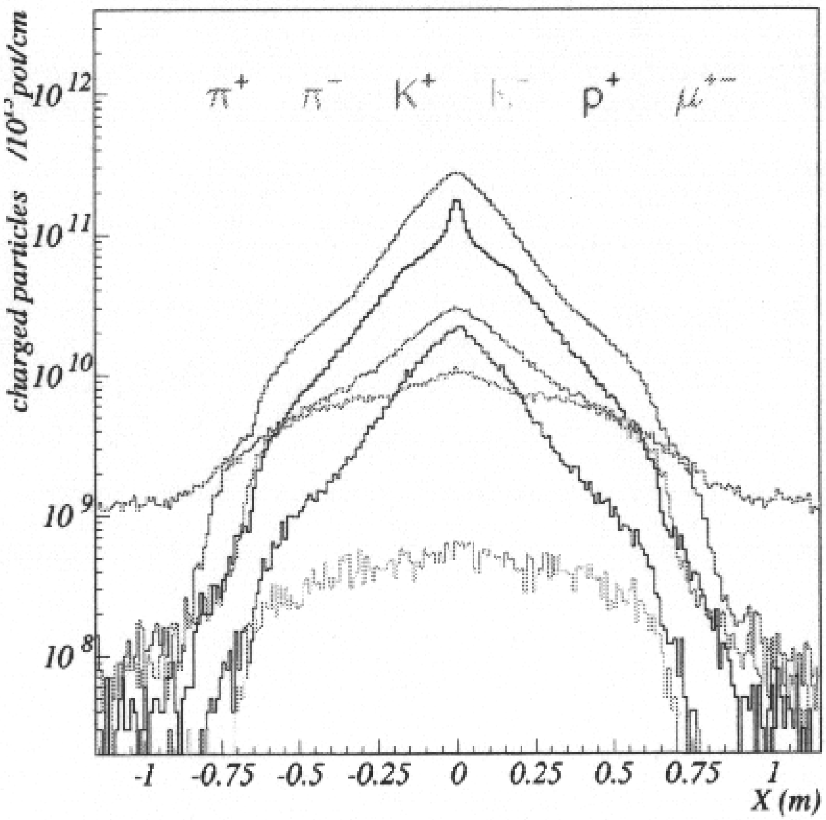
Energy region E_{ν_τ} [GeV]	1 - 30	1 - 100
$\Delta m^2 = 1 \times 10^{-3}\,\mathrm{eV}^2$	2.34	2.48
$\Delta m^2 = 3 \times 10^{-3}\,\mathrm{eV}^2$	20.7	21.4
$\Delta m^2 = 5 \times 10^{-3}\,\mathrm{eV}^2$	55.9	57.7
$\Delta m^2 = 1 \times 10^{-2}\,\mathrm{eV}^2$	195	202

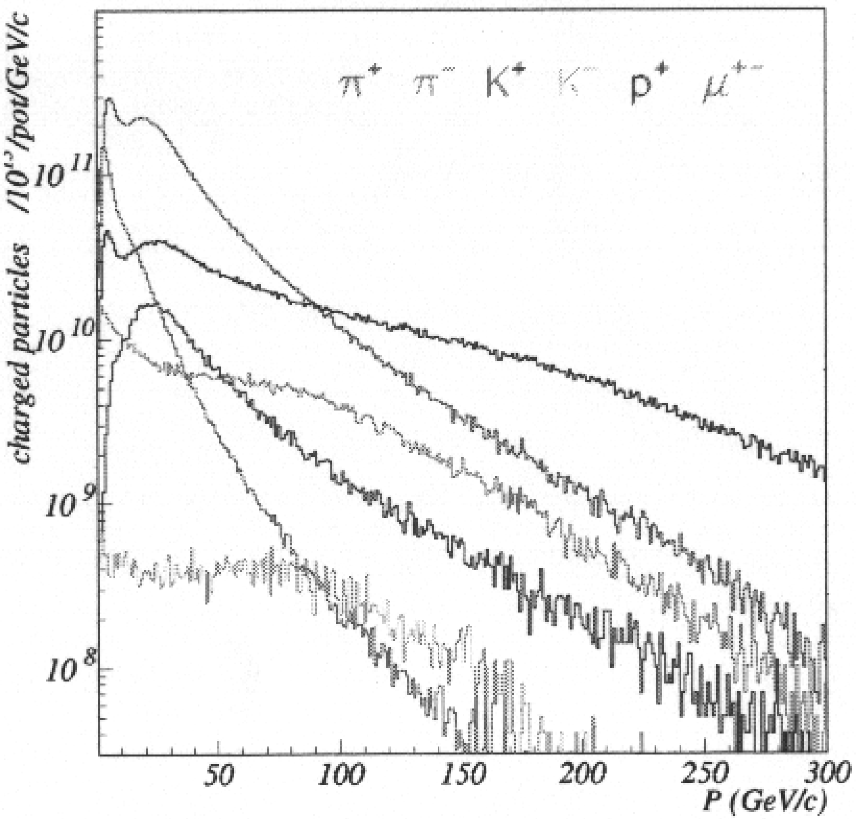
CNGS beam profile

Ref. beam	<X>-axis projection (mm)	$\sigma_{<X>}$ (mm)	total intensity (ch. part. /10^{13}pot)	peak intensity (ch. part. /10^{13}pot)/cm
Hadron detector	0.3	0.2	1.8 10^{13}	5.00 10^{11}
Muon pit-1	1.0	0.5	5.9 10^{11}	0.45 10^{10}
Muon pit-2	-3.0	2.0	2.5 10^{10}	0.01 10^{10}

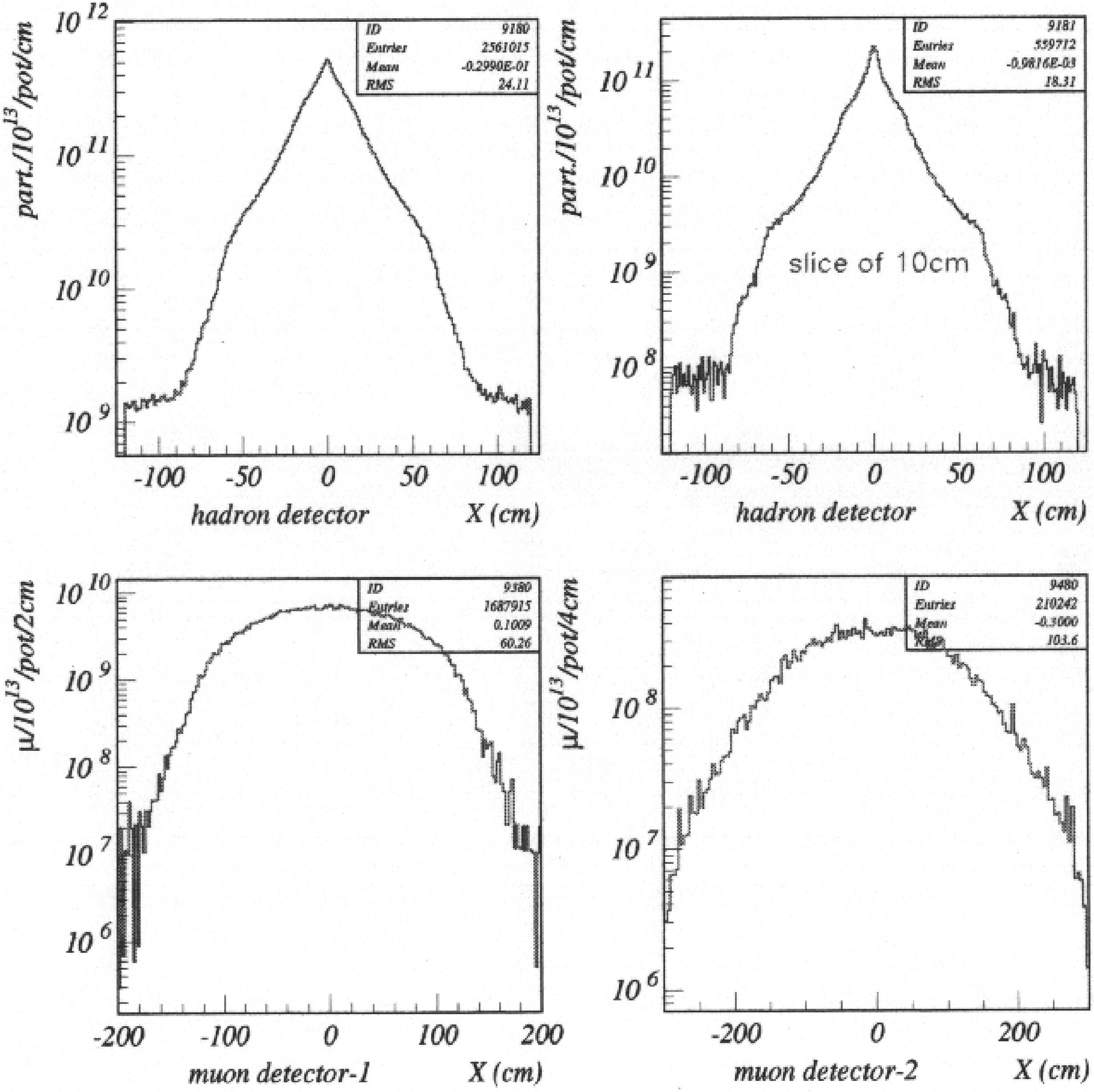
(preliminary results -no electrons)

Charged particles X-axis projection, momenta at hadron monitor:





CNGS beam profile



Alignment errors considered

We are studying the effects of the following possible errors of the CNGS beam at the hadron and muon detectors and at Gran Sasso:

- target, horn, reflector, μ-monitors, detectors on axis: primary p^+-beam displaced parallel to the axis by dX =
  - ◇ 0.1mm, 0.5mm, 1mm: expected 0.1mm
- angular rotations of the primary p^+-beam:
  - ◇ 0.2mrad, 0.5mrad: expected 0.1mrad
- reduction of primary p^+-beam divergences by factor of 2
- wrong pointing error to Gran Sasso 0.5mrad: expected 0.05mrad
- horn and reflector displacements of
  - ◇ 1mm, 2mm, 3mm, 6mm: expected 0.1mm
  - ◇ the horn cases are equivalent to primary p^+-beam + target displacements in respect to the other elements

dX = 0.1mm, 0.5mm, 1mm

displacements:

cases	0.1mm	0.5mm	1mm
Hadron (mm)	0.1	1.5	3.9
Muon1 (mm)	0.2	-2.7	-13.1
Muon2 (mm)	1.2	63.2	89.4

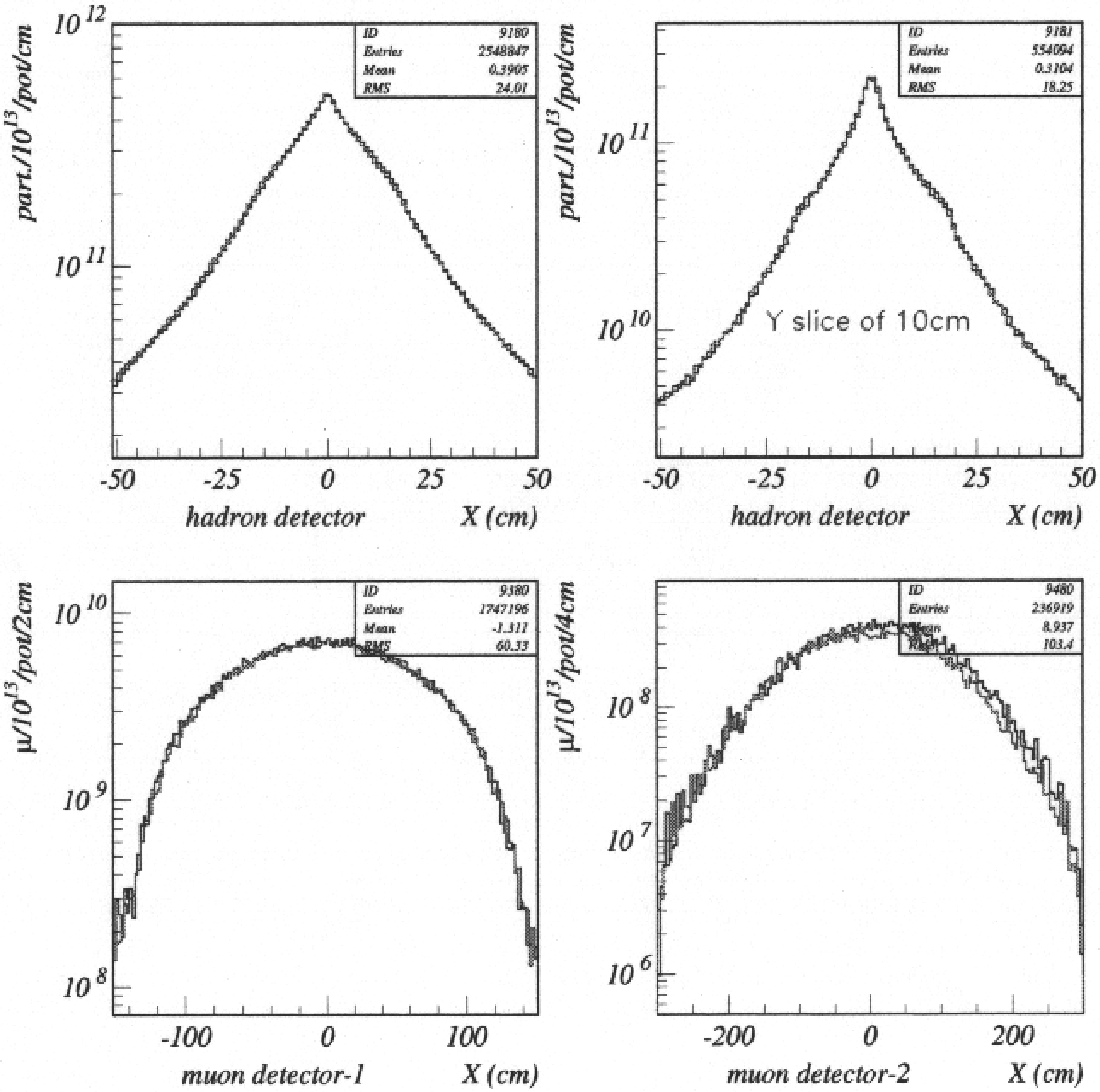
- Muon detector-2 is more sensitive to proton beam displacements

ν_τ *CC events at* $\Delta m^2 = 3.2\ 10^{-3} eV^2$*, full mixing /kt/year at GS:*

cases	Ref.	0.1mm	0.5mm	1mm
ν_τ CC	24.4	24.4	24.4	24.5

- there is no change in ν_τ CC events at GS and particle intensities are similar at beam detectors
- there is 10% increase in $\bar{\nu}_\mu$ CC events when dX = 1mm at GS

Profiles: std beam vs dX = 1mm



angular rotations, divergence, wrong pointing

displacements, and ν_τ *CC events at* $\Delta m^2 = 3.2\ 10^{-3} eV^2$*,*
full mixing /kt/year at GS:

cases	angular rotation 0.2mrad	divergence $\sigma_{x,y} * 2$, $\sigma_{\theta x,y}/2$
Hadron (mm)	3.9	0.1
Muon1 (mm)	1.4	-2.4
Muon2 (mm)	22.9	-7.9
ν_τ CC	24.3	24.3

Also, angular rotation 0.5mrad, and wrong pointing 0.5mrad ($\sim$ 360m at GS) with 3-4% reduction of ν_τ CC events at GS

- there is no significant change in ν_τ CC events, and particle intensities are slightly smaller at the extreme cases
- there is 10% increase in $\bar{\nu}_\mu$ CC events at GS

horn and refl. dX= 1mm, 2mm, 3mm, 6mm

horn:

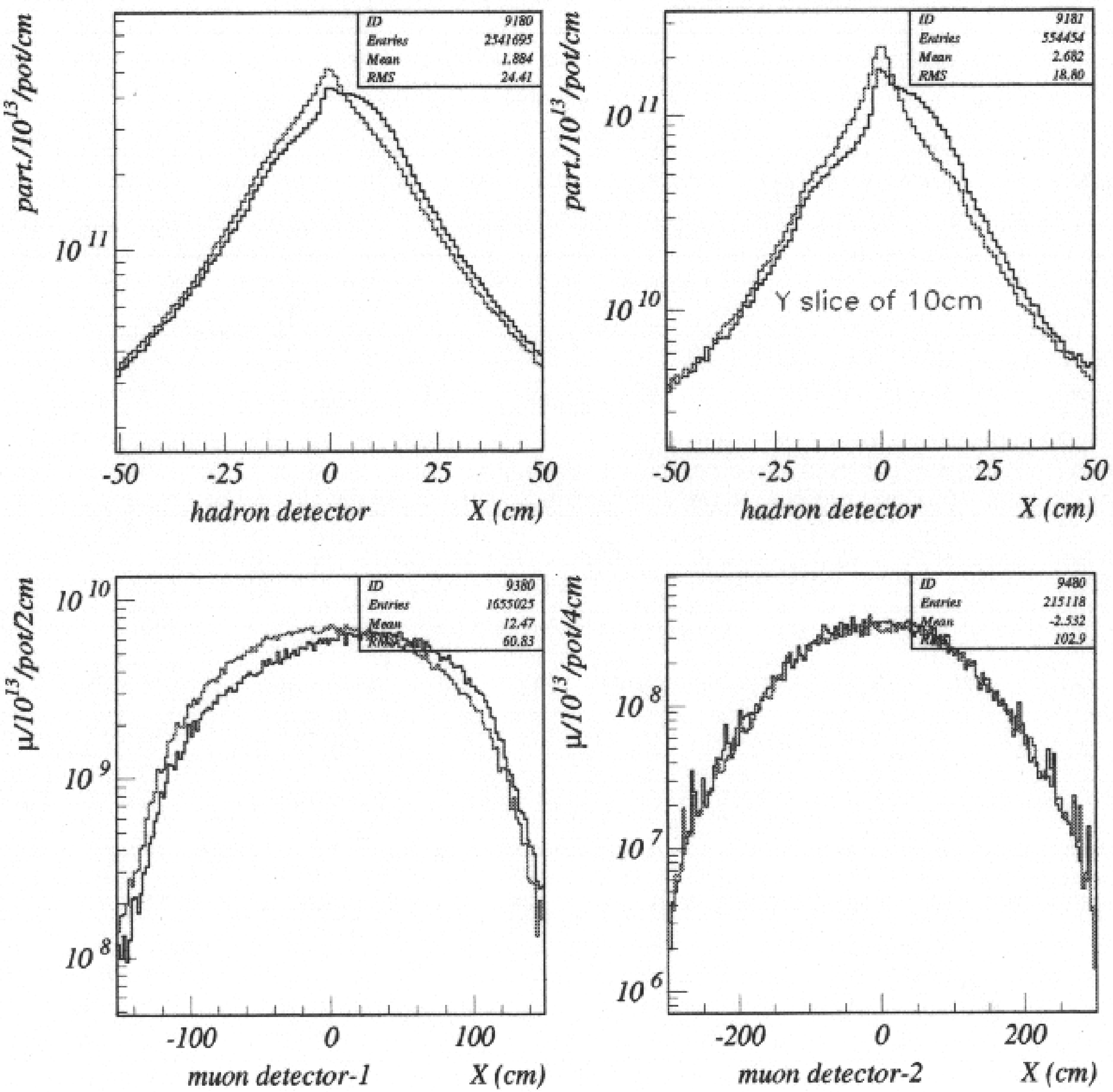
cases	1mm	2mm	3mm	6mm
Hadron (mm)	3.4	6.7	9.9	18.8
Muon1 (mm)	24.9	50.4	70.1	124.5
Muon2 (mm)	3.2	-28.4	7.2	-25.3
ν_τ CC	24.2	24.2	24.3	23.7

reflector:

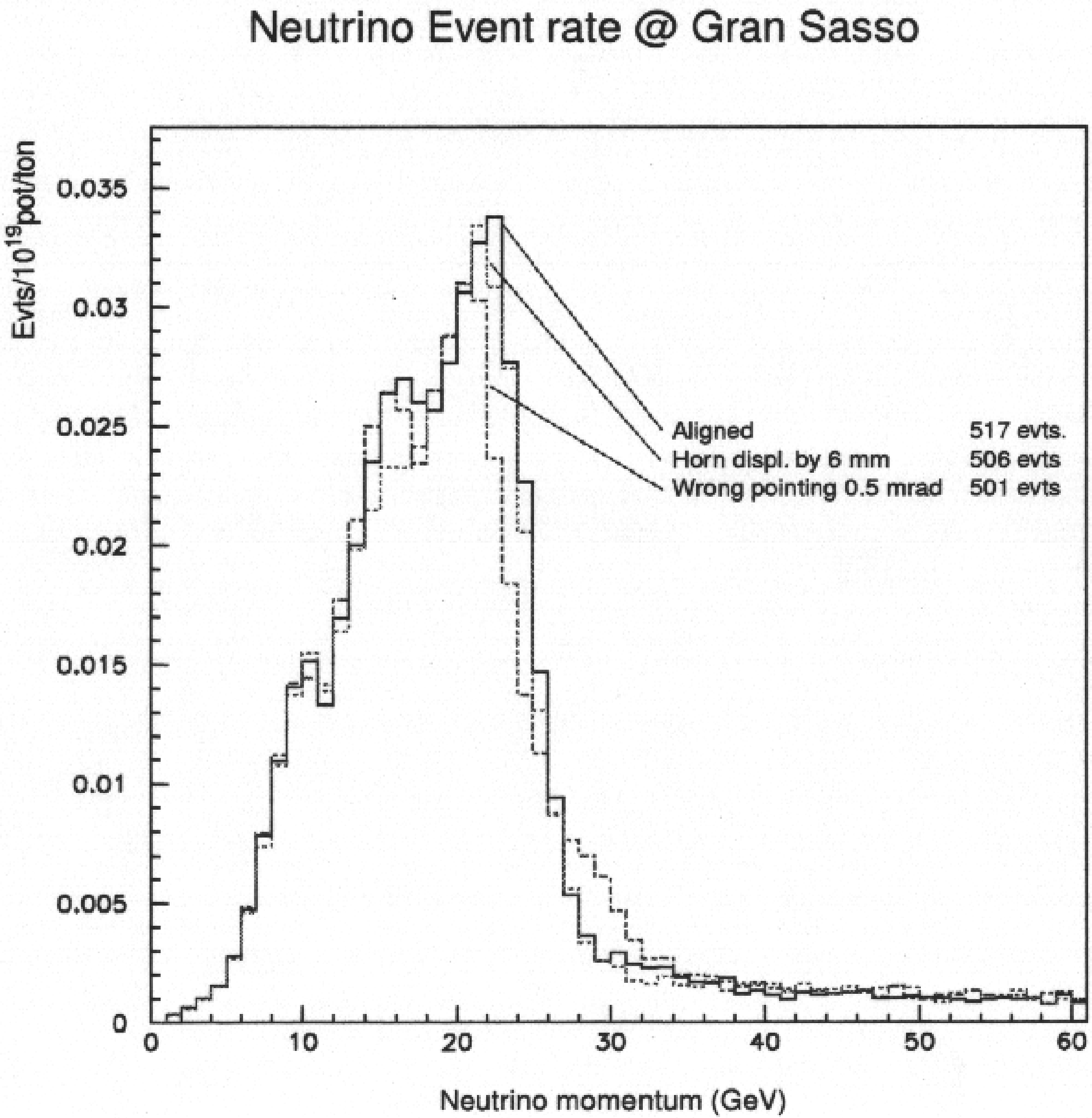
cases	1mm	2mm	3mm	6mm
Hadron (mm)	0.9	1.6	2.7	5.2
Muon1 (mm)	8.1	7.3	13.2	32.9
Muon2 (mm)	-1.2	-11.0	-16.1	-40.6
ν_τ CC	24.2	24.3	24.2	24.3

- horn dX=6mm: there is 3% reduction of ν_τ CC at GS

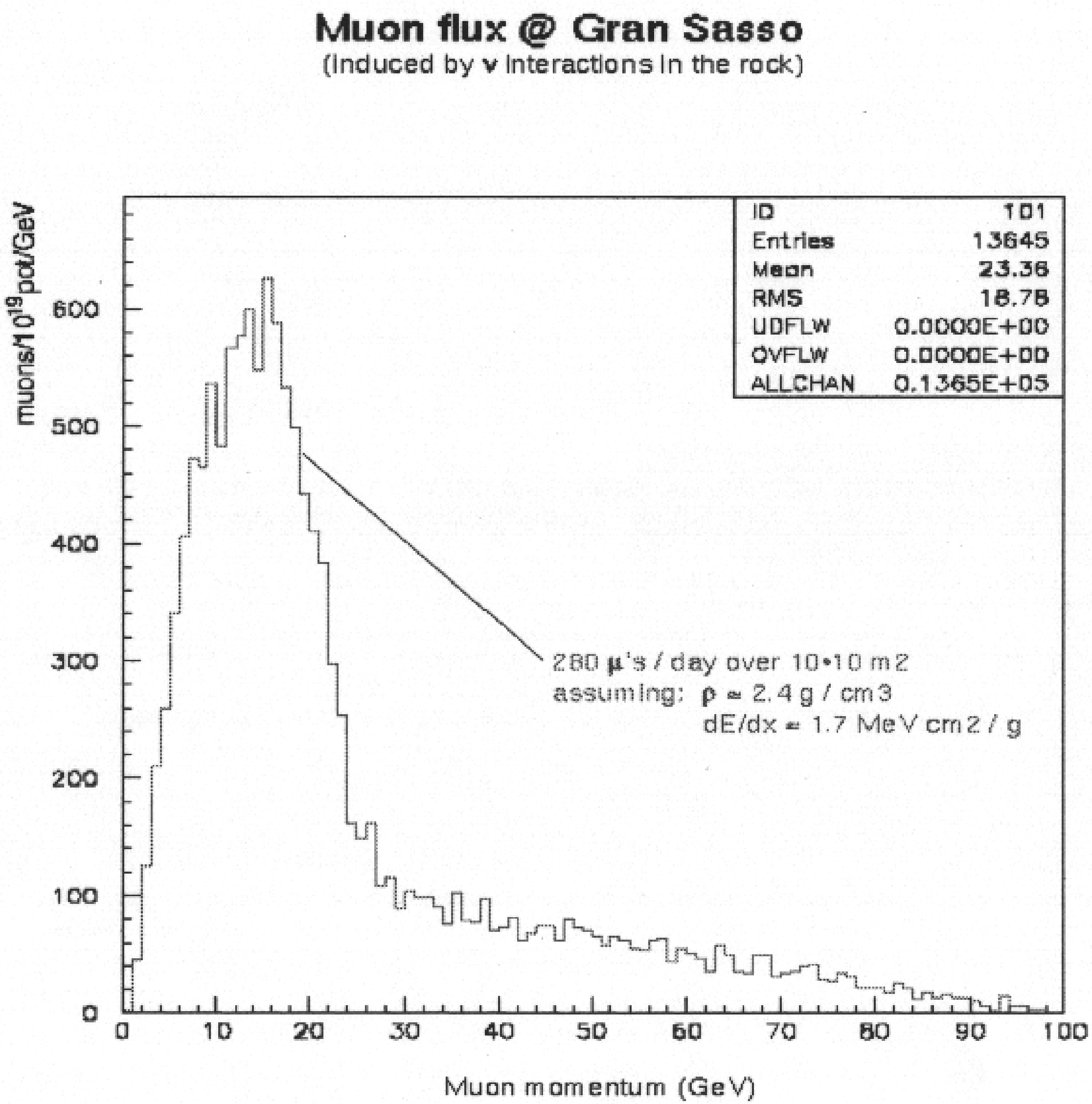
Profiles: std beam vs horn dX = 6mm



ν_μ CC events in alignment errors

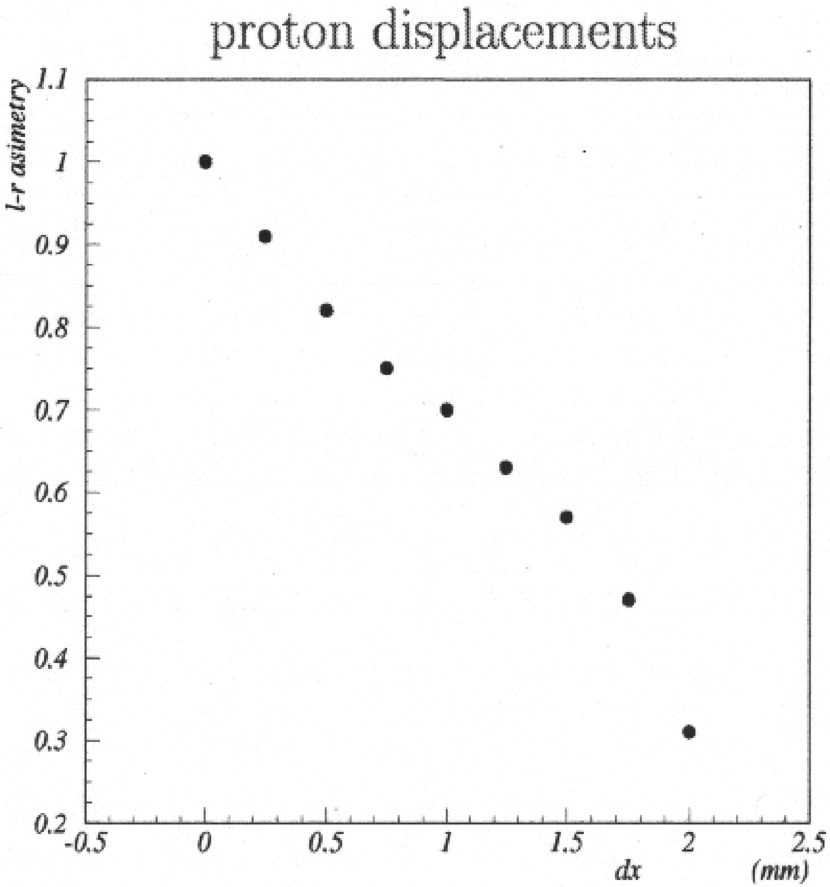


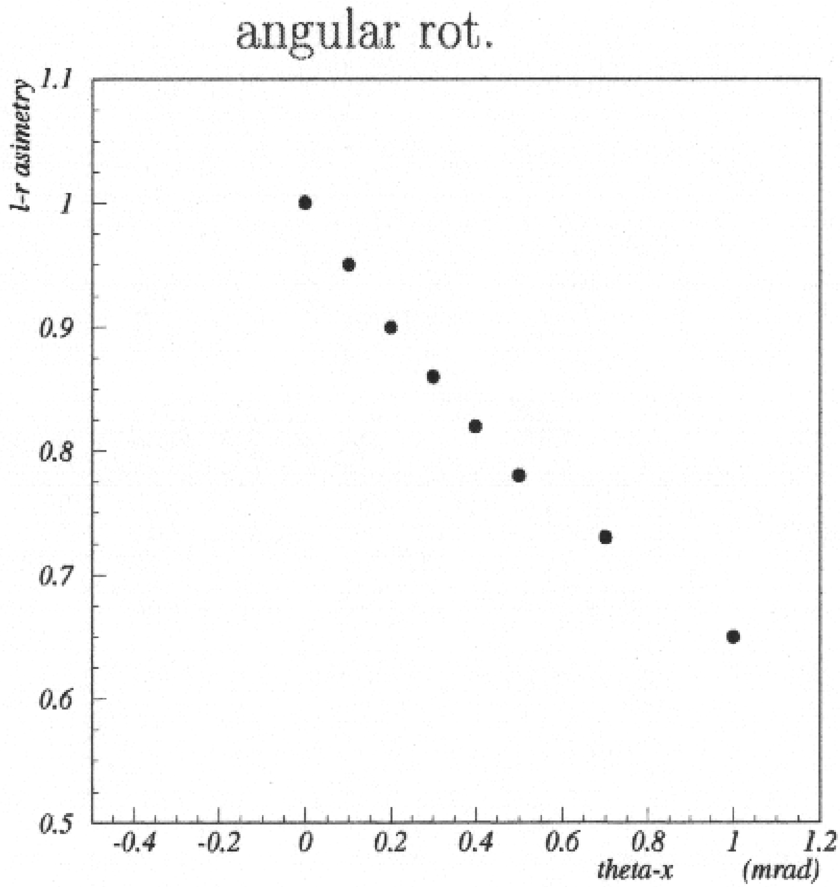
μ-monitor at Gran Sasso



target monitor

monitoring 15cm after the target:





- left-right asymmetry (-X,Y)/(+X,Y) is sensitive to +X alignment errors 15cm downstream of the target

Conclusions

- The overall alignment to GS should be left below 0.1mrad or 60m at GS
- Proposed monitors give good control of the beam
- The fluence at GS is insensitive to all reasonable alignment errors