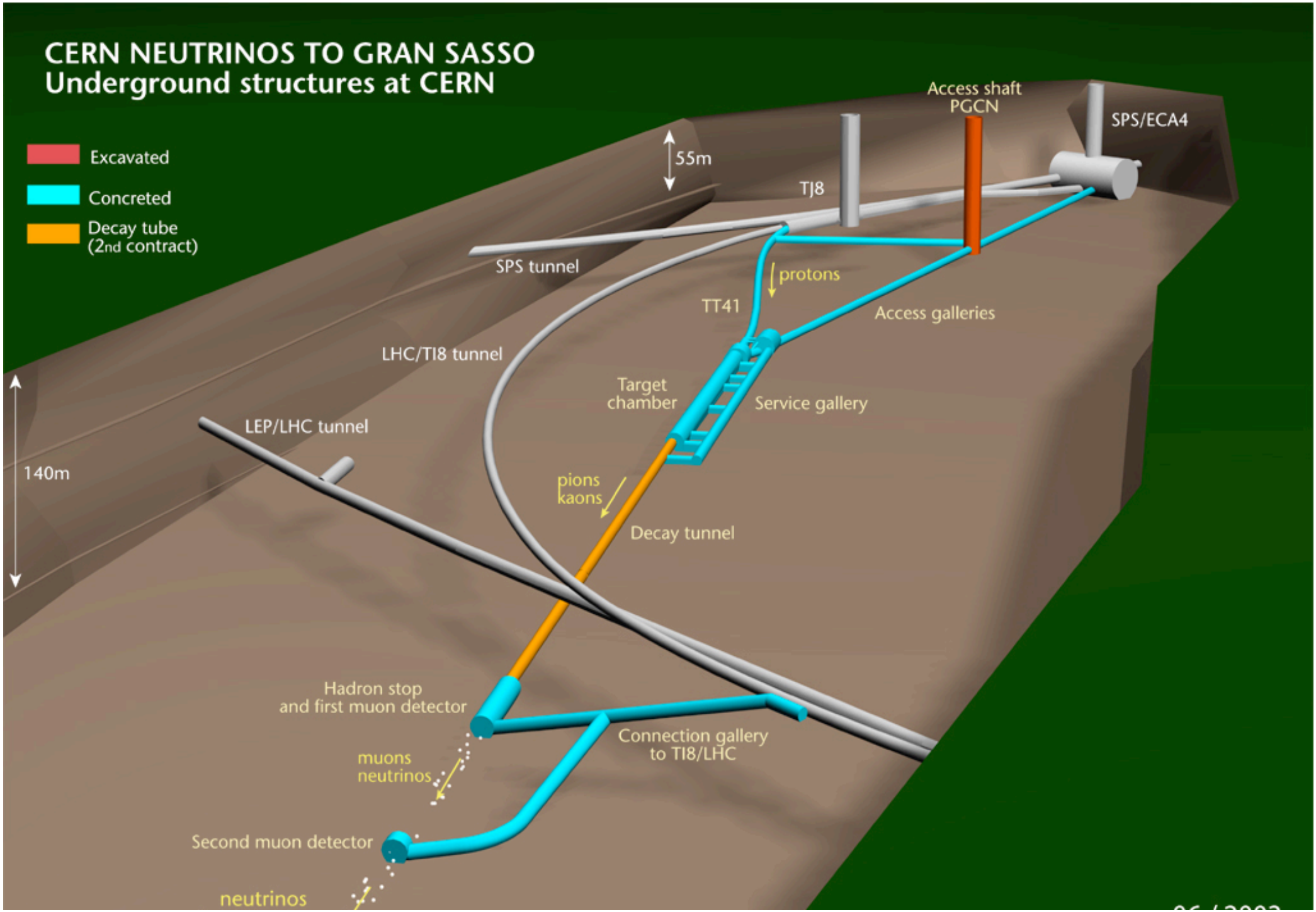
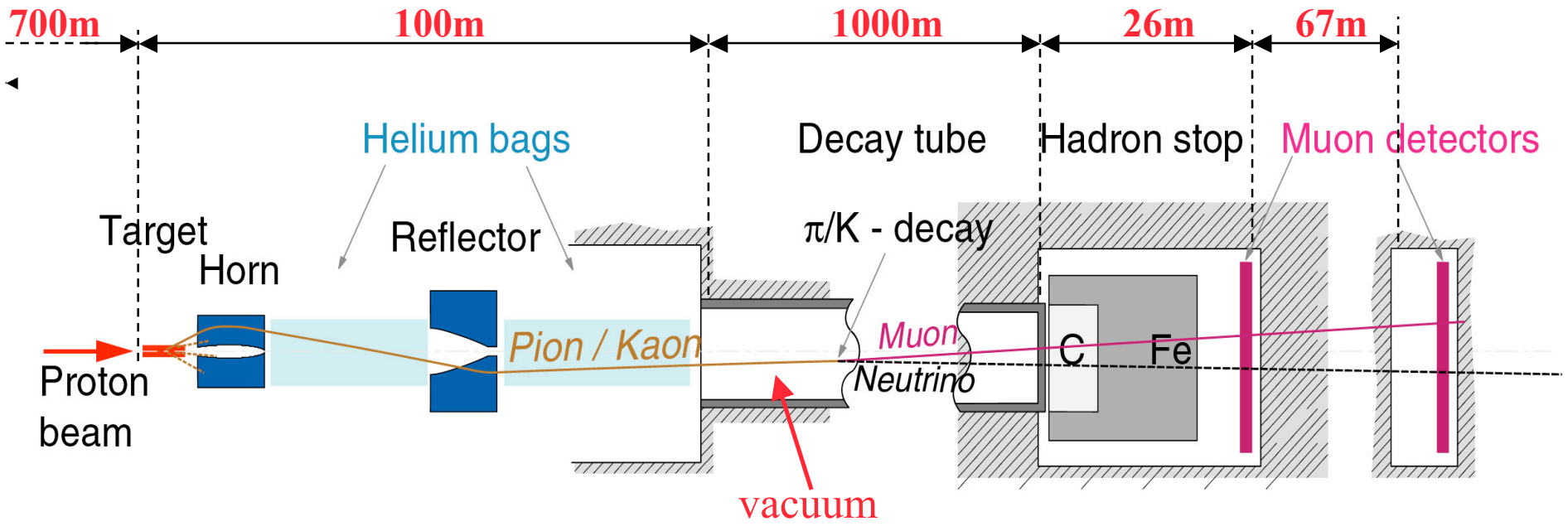
CNGS Project: Secondary Beam

1. Layout
2. Beam Instrumentation
3. Commissioning Plans for the Secondary Beam


CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN
Excavated
Concreted
Decay tube
(2nd contract)
55m
Access shaft
PGCN
SPS/ECA4
TJ8
SPS tunnel
protons
TT41
Access galleries
LHC/TI8 tunnel
Target
chamber
Service gallery
LEP/LHC tunnel
140m
pions
kaons
Decay tunnel
Hadron stop
and first muon detector
Connection gallery
to TI8/LHC
muons
neutrinos
Second muon detector
neutrinos

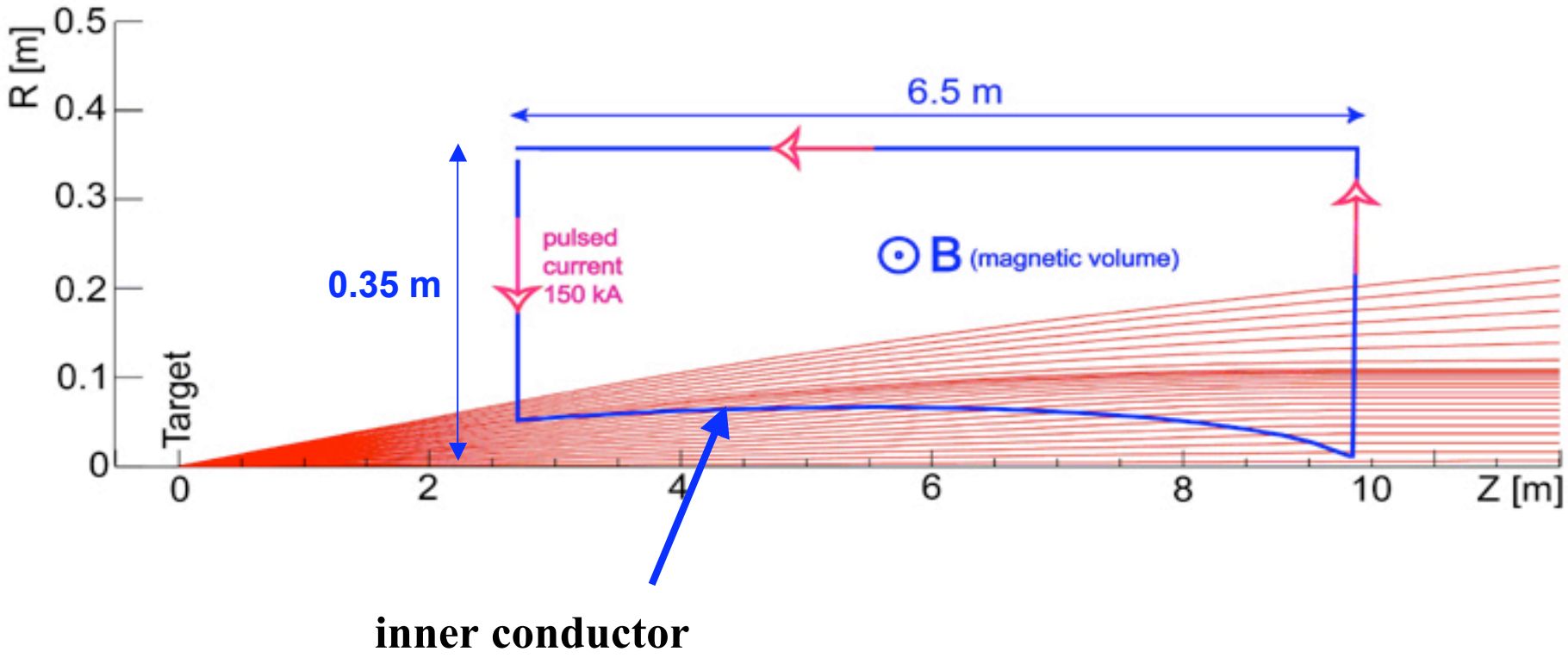
CNGS Layout



$p + C \rightarrow$ (interactions) $\rightarrow \pi^+, K^+ \rightarrow$ (decay in flight) $\rightarrow \mu^+ + \nu_\mu$

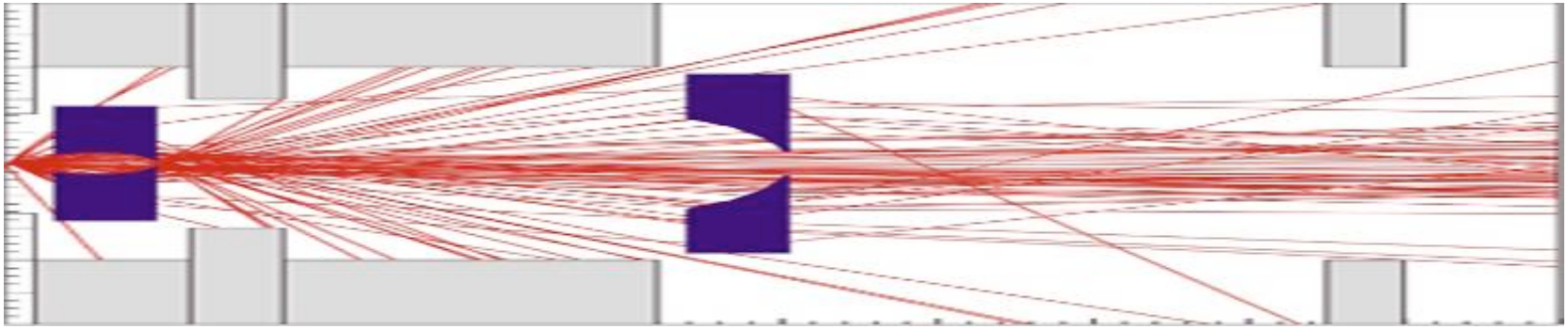
Horn and Reflector: Secondary Beam Focusing

Principle of Focusing:

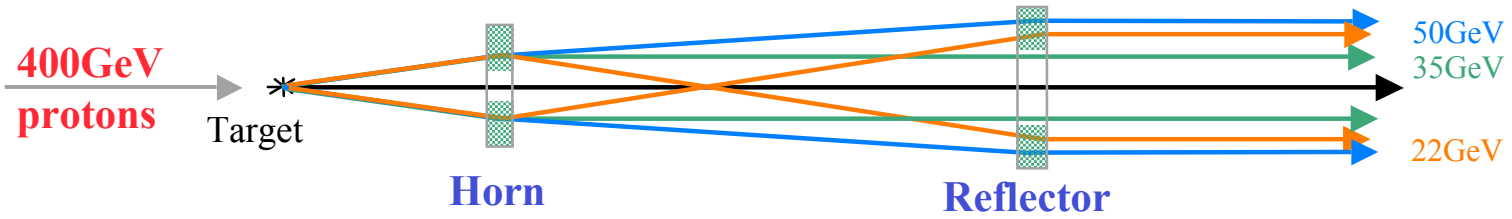


Horn AND Reflector

Focalising many particles:

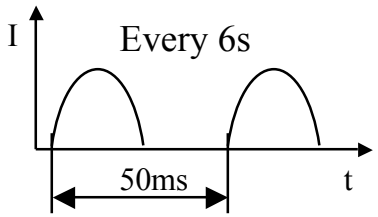


Focalising particles of all energies:



Horn & Reflector

- Length (magnetic volume): 6.65 m
- Total length: 7.45 m
- Diameter: 70 cm
- Material: Al alloy 6082
- Water cooling: distributed spray nozzles



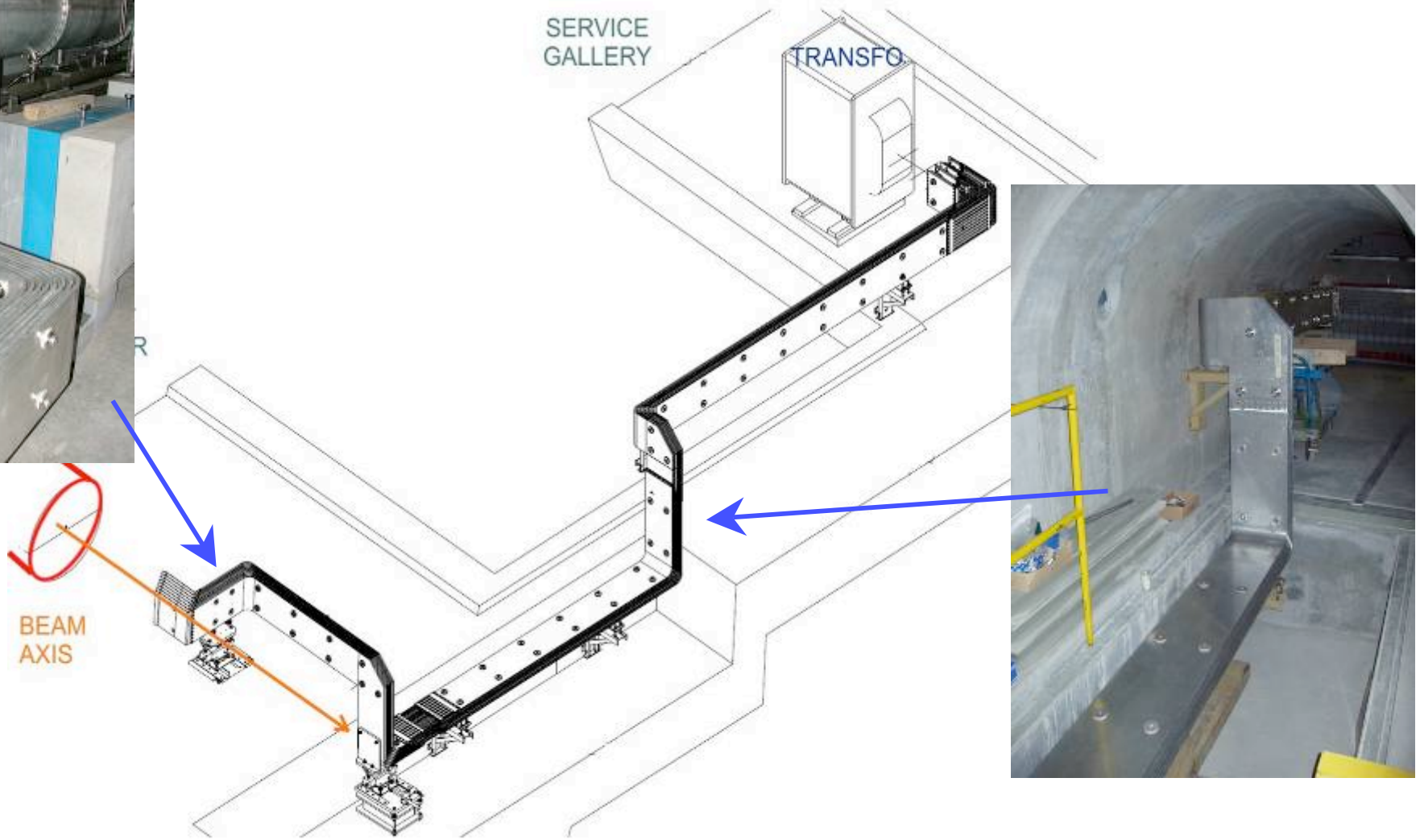
Main Parameters

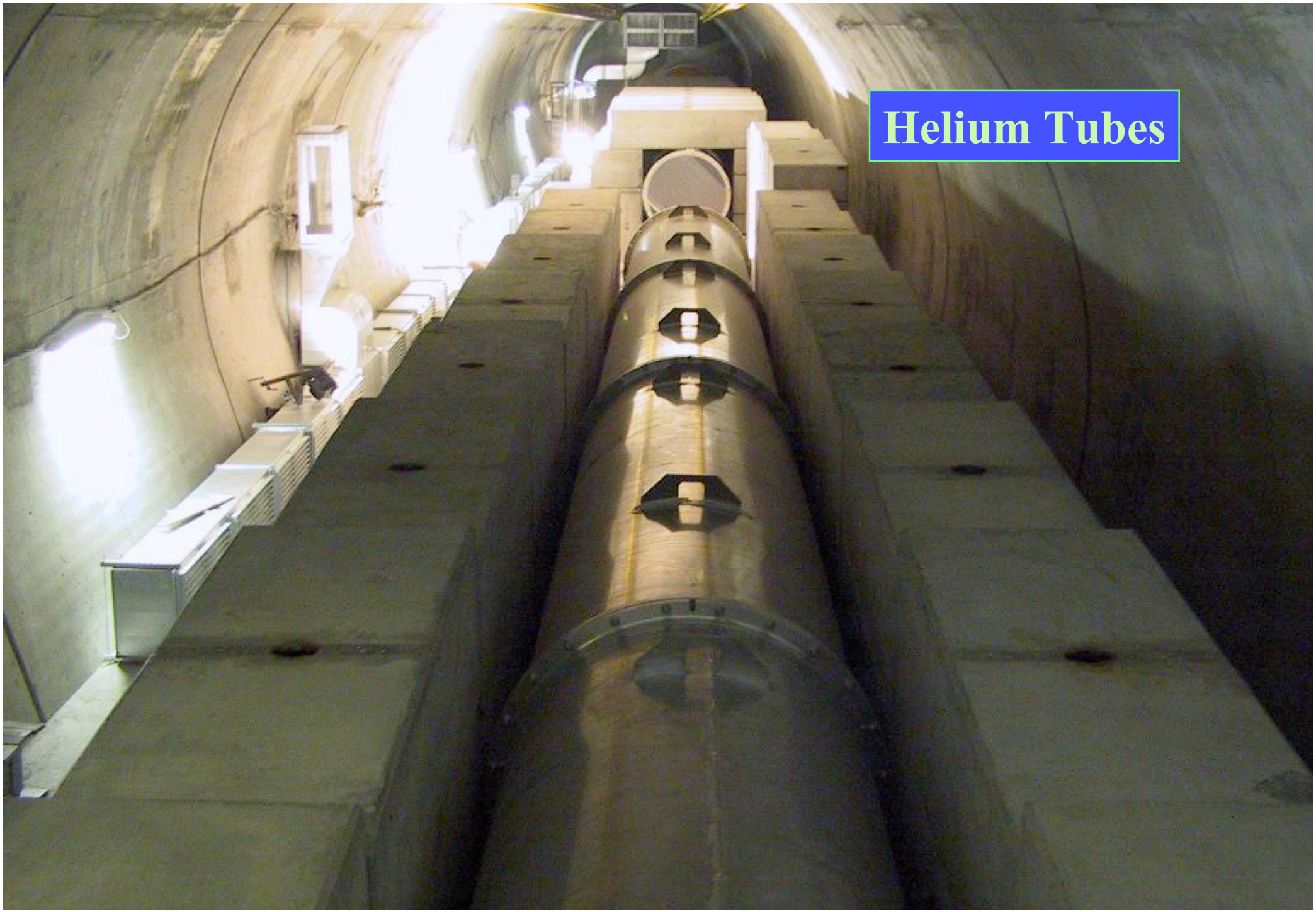
	Unit	HORN System	REFLECTOR System
Load Peak current	kA	150	180
Transformer ratio		16	32
Primary current peak	A	9375	5625
Load inductance	µH	2,7 x 16 x 16 = 691	1,5 x 32 x 32 = 1540
Total inductance with 4 cables	µH	1210	2046
Load resistance	mΩ	0,6 x 16 x 16 = 154	0,21 x 32 x 32 = 215
Total resistance with 4 cables	mΩ	328	495
Total capacitance for one pulse	µF	4080	4080
Pulse duration	ms	7,5	10
Charging voltage	V	7700	6300
Total stored energy	kJ	2 x 119 = 238	2 x 80 = 160
Load max. voltage	V	280	150
Mean power dissipated by current only (2 pulses)	kW	16	10,5
Total power dissipated (with beam)	kW	26	16,5
Water flow for delta T=5C	l/min	70	70
Pressure	bar	1,2	1,2

Horn

Installation of the horn in the target chamber

Horn & Reflector Powering



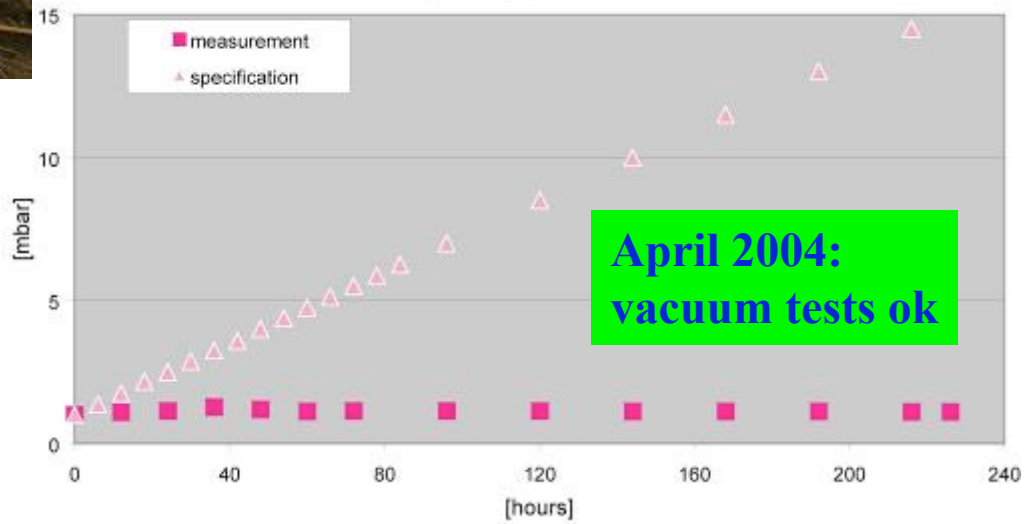

Helium Tubes


Decay Tube

Decay Tube

- steel pipe
- 1mbar
- 994m long
- 2.45m diameter
- entrance window: 3mm Ti
- exit window: 50mm carbon steel, water cooled

Decay tube: pressure increase vs. time



April 2004: vacuum tests ok

Shutter

Decay tube is closed with
- 3mm Titanium window

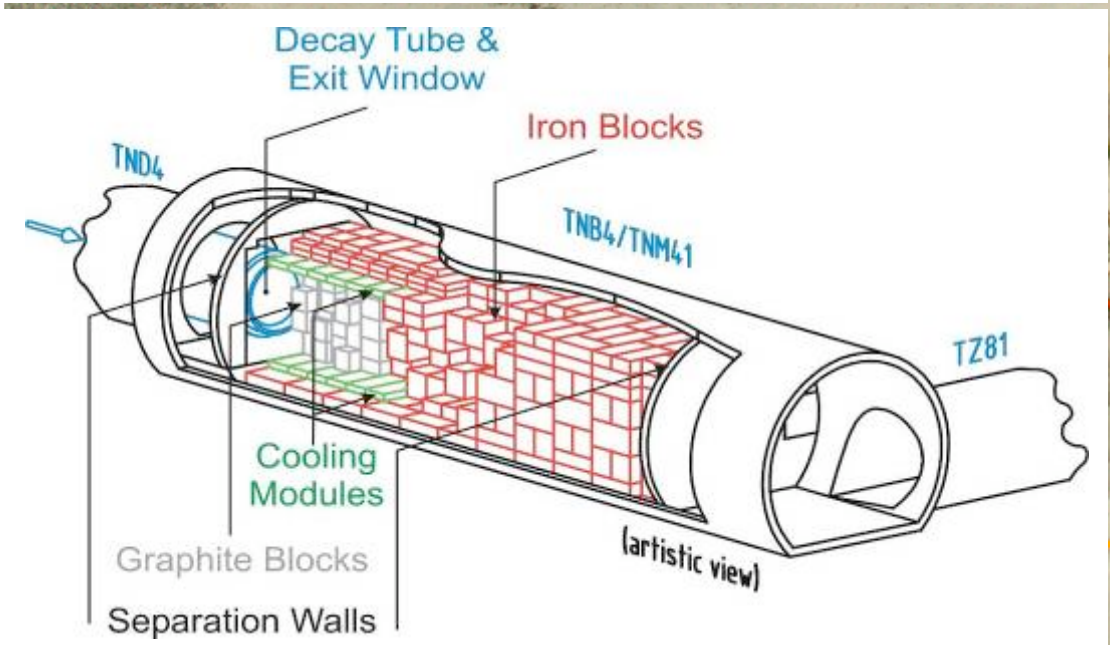
Must be protected by a '**shutter**' when access
- Hardware Interlocked!!!

Hadron Stop

graphite

cooling modules

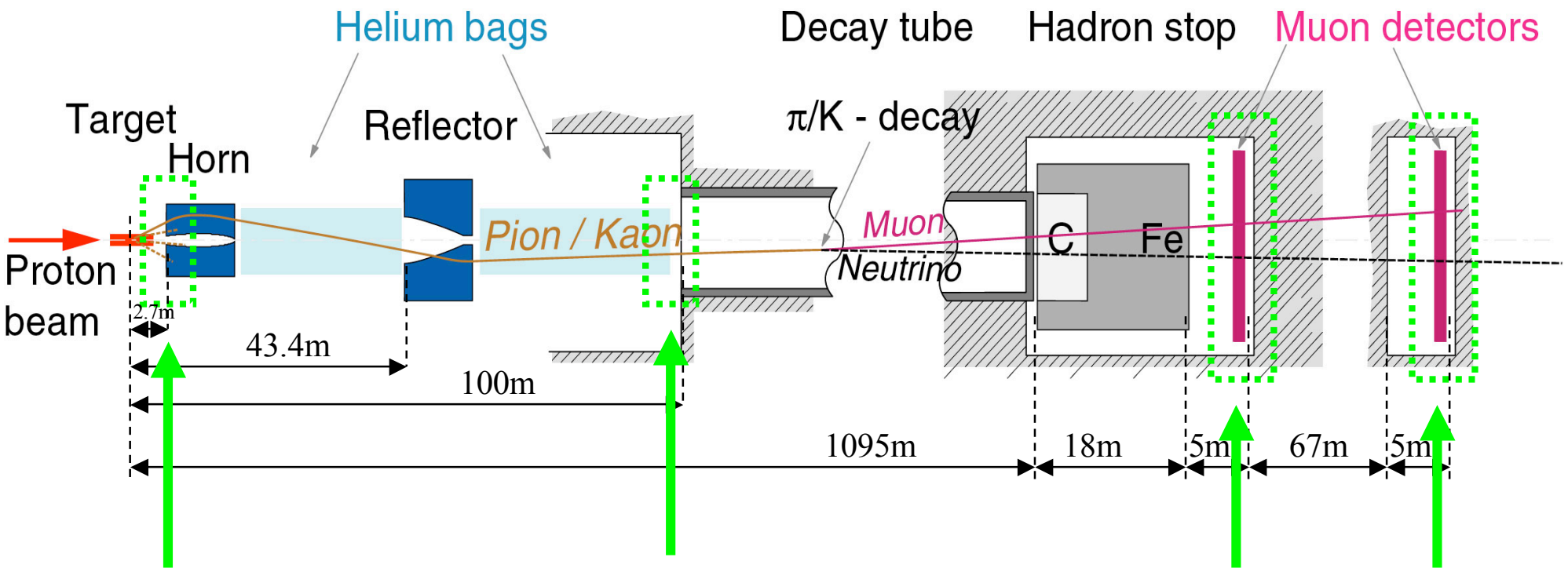
- Cooling modules: stainless steel tubes in Al blocks
- Several temperature sensors (both in target chamber and in hadron stop)



Hadron Stop
finished Sept. 2003

2. Secondary Beam Instrumentation

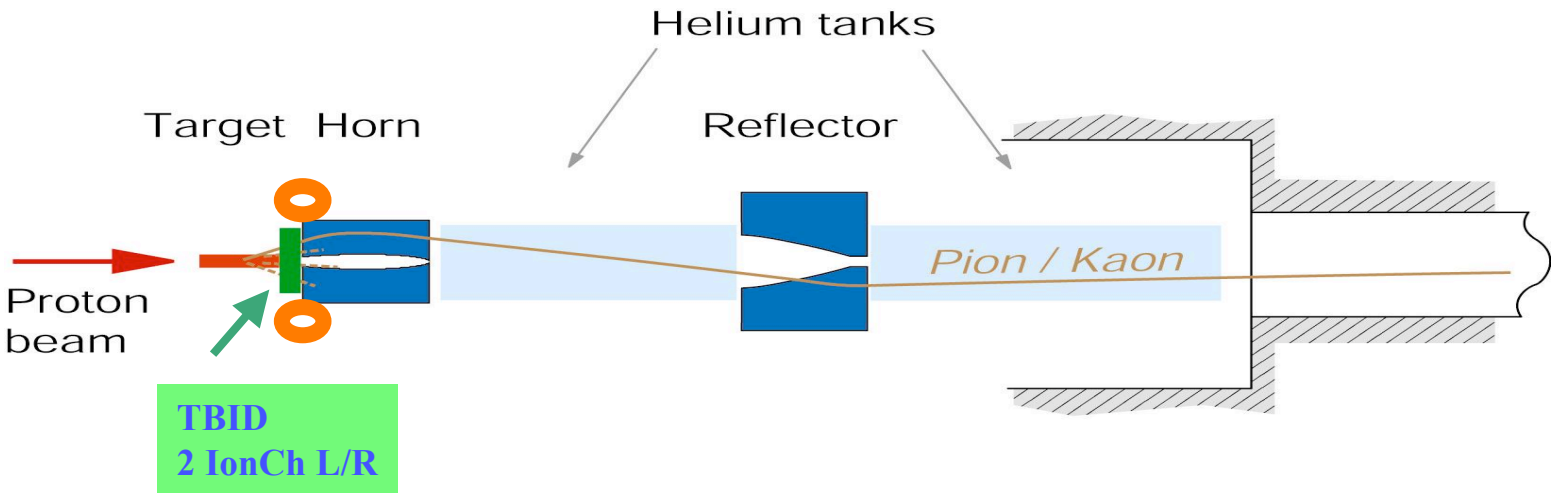
CNGS Secondary Beam Instrumentation



TBID: Target Beam Instrumentation Downstream

IonCh: Ionization Chamber

TBID + 2 Ionization Chambers

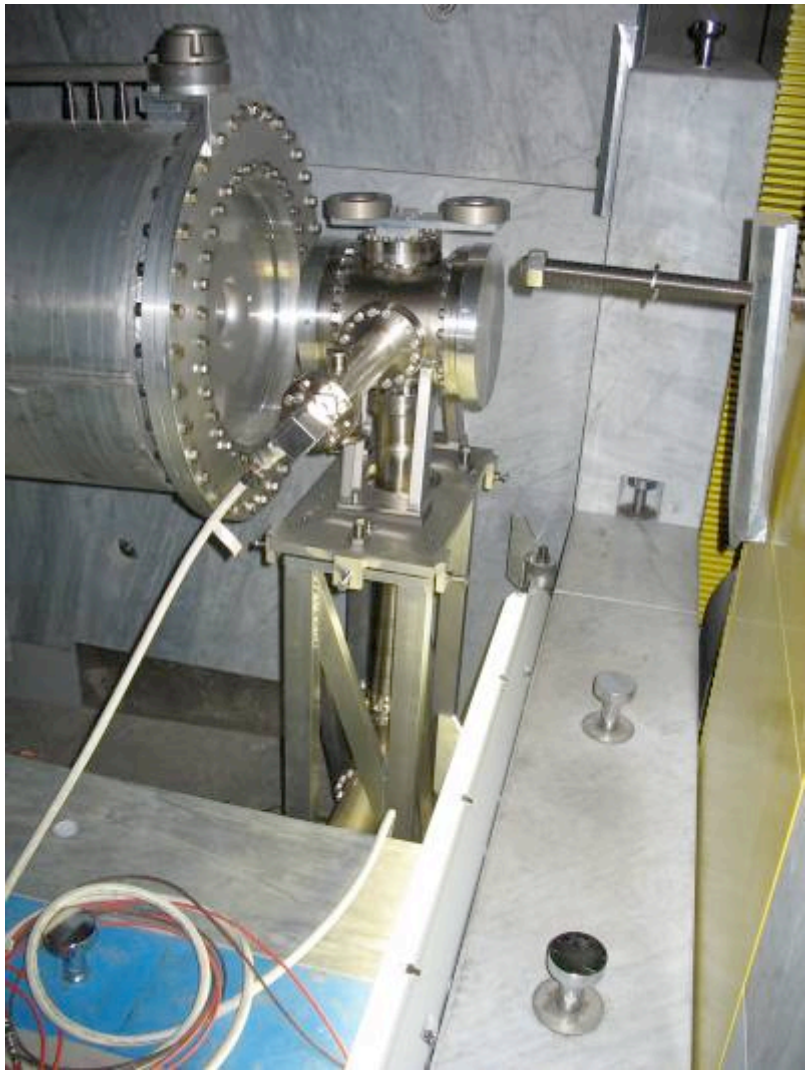


Purpose:

- ➔ **Check efficiency with which protons are converted into secondaries**
  - **Multiplicity (Compare with BFCT upstream of the target)**
  - **Misalignment of the Beam**

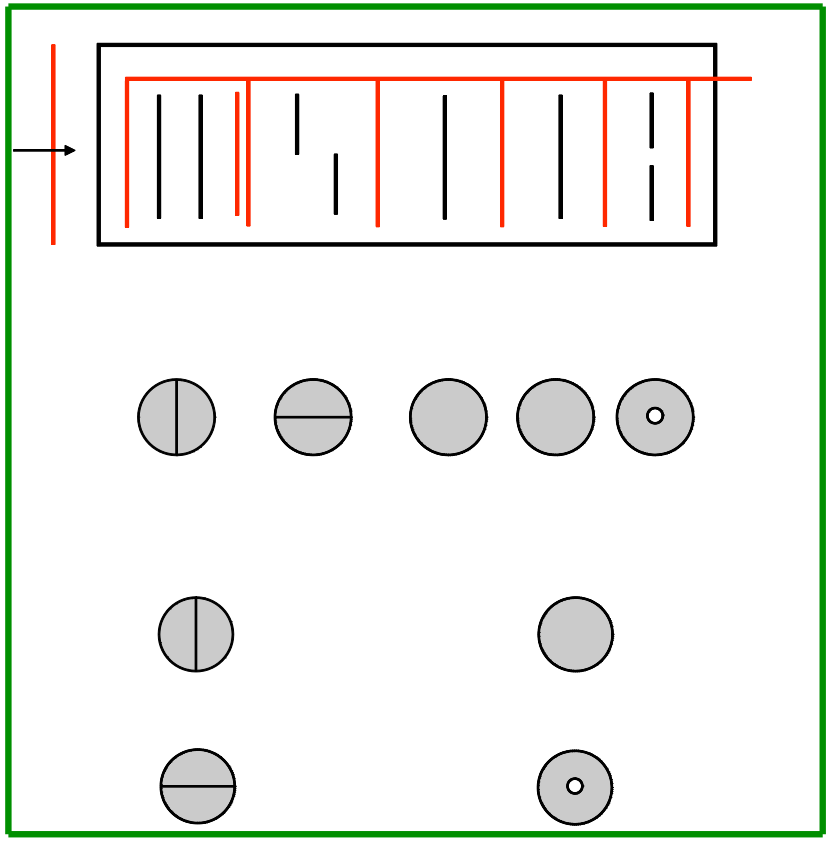
Ionization Chamber used as back-up

TBID

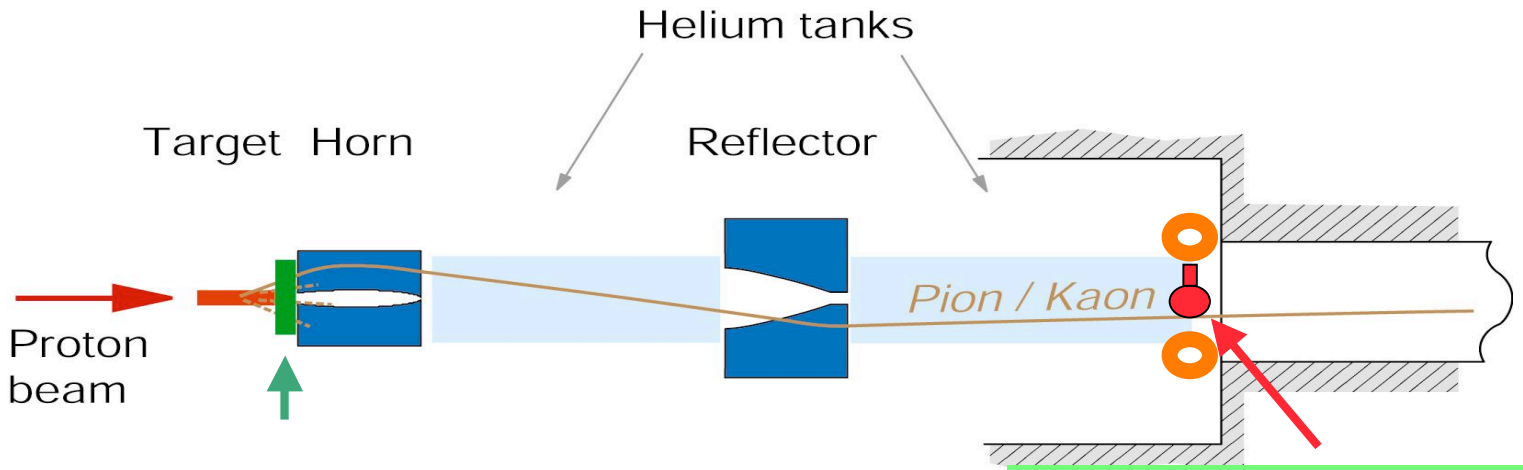


TBID Monitor

- Secondary emission monitor
- 12 µm Ti foils
- better than 10^{-4} mbar vacuum



Cross-Hair + 2 Ionization Chambers



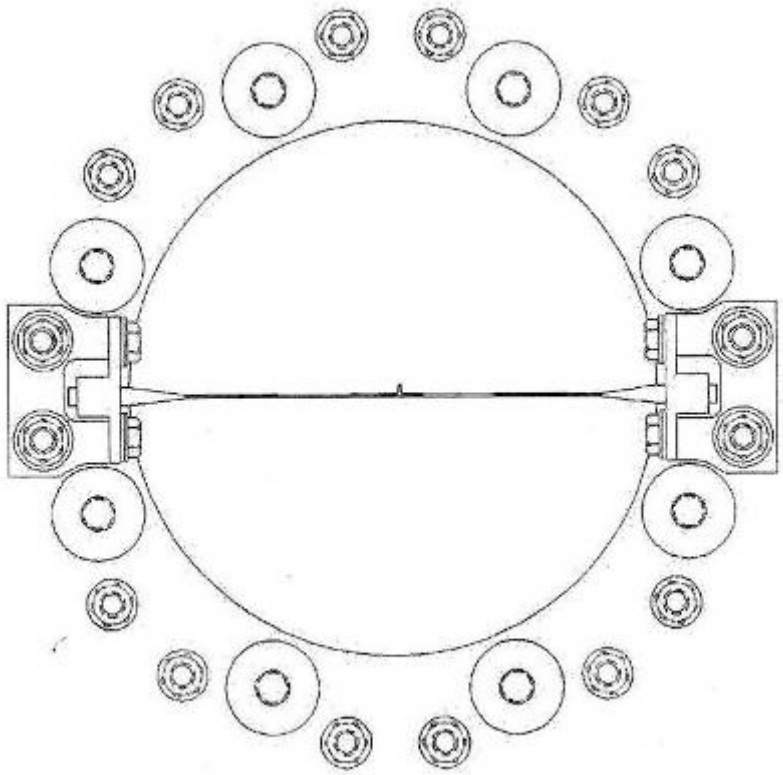
Cross-Hair observed by 2 IonCh L/R

Motivation for cross-hair and 2 ionization chambers

- **CNGS proton beam direction is important**
- **additional, more accurate information on proton beam angle (works only without target and with horn/reflector off)**
- **angular accuracy achieved by BPMs (11 m apart) is limited**
- **target chamber is > 100 m long… bigger lever arm**
- **additional "active" detector is difficult / expensive**

NuMI/Fermilab invention

Cross-Hair



beam ⊗

Cross-hair beam view
(schematic)

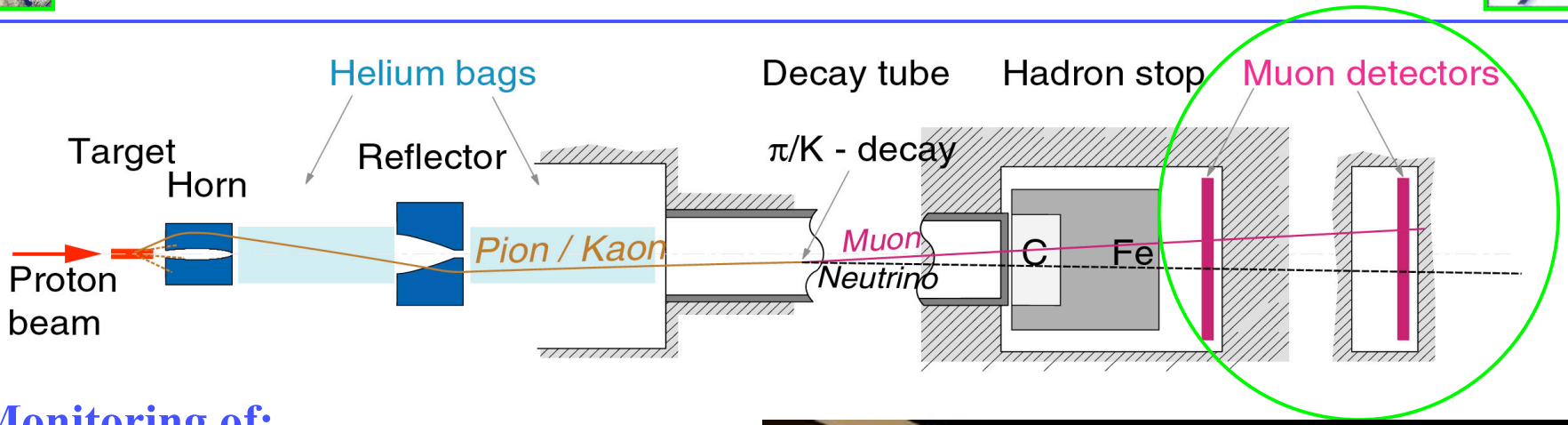
Layout:

- 4mm wide
- appendix 10mm long
- 20mm thick along the beam-axis

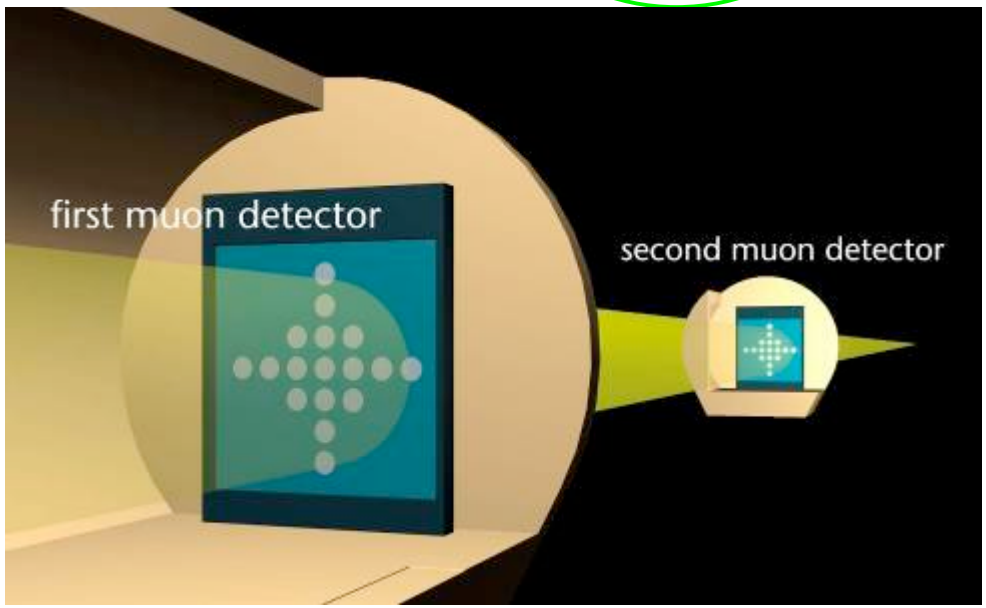
Installation slightly off-axis (10mm):

- ➔ gives the sign of the offset
- ➔ avoids over-heating the metal when beam on axis

Muon Monitors

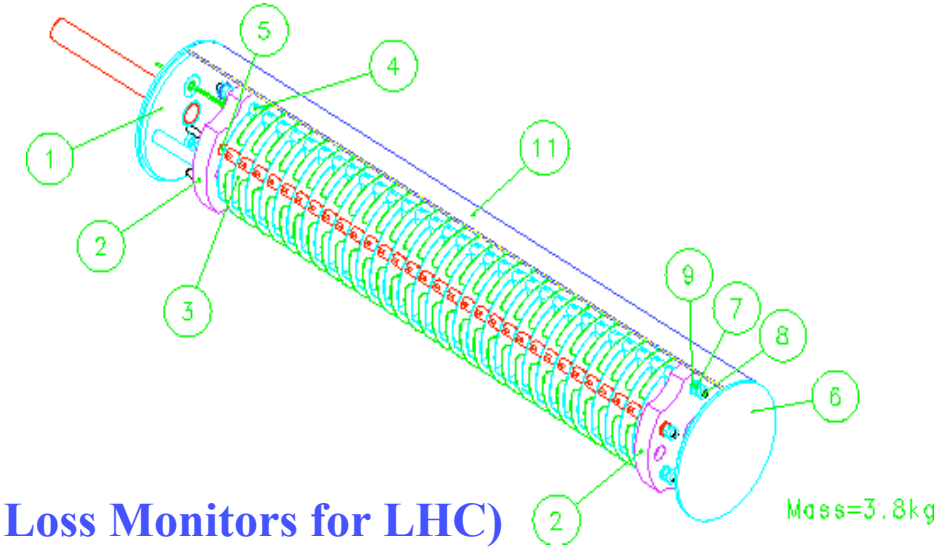


- **Monitoring of:**
  - ➔ **muon intensity**
  - ➔ **muon beam profile shape**
  - ➔ **muon beam profile centre**
- **Muon intensity:**
  - ➔ **Up to 7.7x10^7 per cm^2 and 10.5µs**
- **Monitors:**
  - ➔ **2 muon detectors with each 17 fixed monitors + 1 movable monitor (ionization chambers)**



Muon Monitor Layout

- **17 fixed monitors (Ionization Chambers)**
  - Possibility to double number of monitors
- **1 movable chamber behind fixed monitors for relative calibration**
- **Movement by stepping motors**



BLMs (Beam Loss Monitors for LHC)

- **Parallel electrodes separated by 0.5 cm**
- **Stainless steel cylinder**
- **Al electrodes**
- **N_2 gas filling at 100 mbar over pressure**
- **Diameter=8.9cm, length=60cm, 1.5 litre**

3. Commissioning Plans for the Secondary Beam

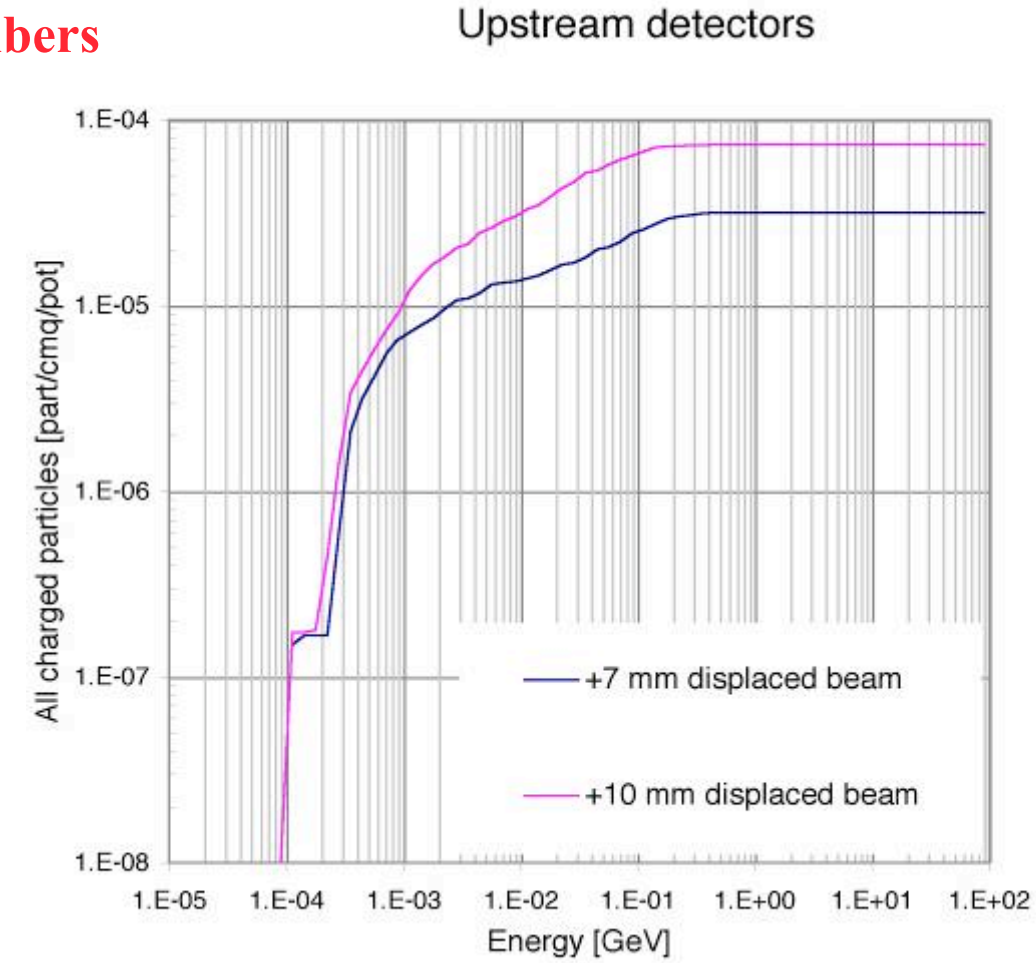
Secondary Beam Commissioning Steps

- **Target Out – Horns Off – TED Out**
  - ➔ **Check p-beam angle**
    - Collimator's Ionization Chambers
    - Cross-Hair with Ionization Chambers
    - Muon monitors
- **Target In – Horns Off – TED Out**
  - ➔ **p-beam scan across the target**
    - Observe rates in Ionization Chambers
    - Observe rates in TBID
    - Observe rates in muon monitors
- **Target In – Horns In – TED Out**
  - ➔ **Initial calibration of monitors**
  - ➔ **Check for different beam settings**
    - Muon monitors

Target Out – Horns Off – TED Out

- **Check proton beam angle**
  - ➔ **Collimator's ionization chambers**

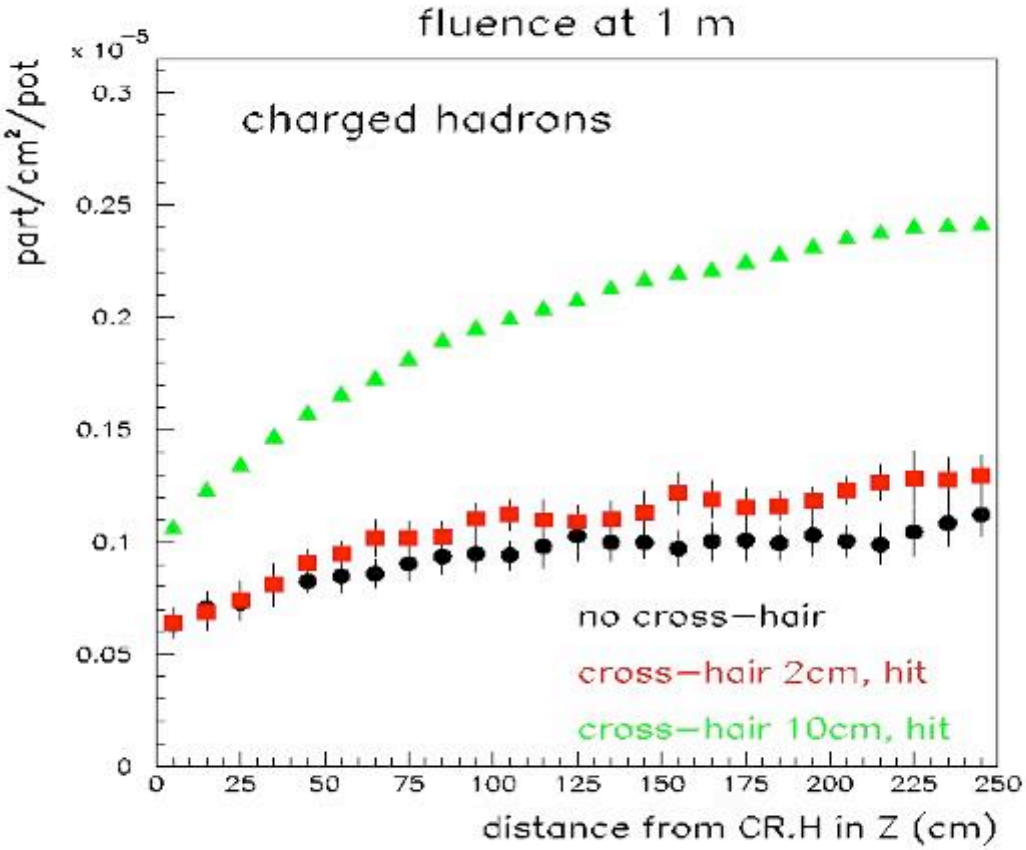
Beam displacement	Charged particles [part/cm^2/10^{12}pot]
0mm	0
5mm	0
7mm	3.2 _ 10^7
10mm	7.4 _ 10^7



Target Out – Horns Off – TED Out

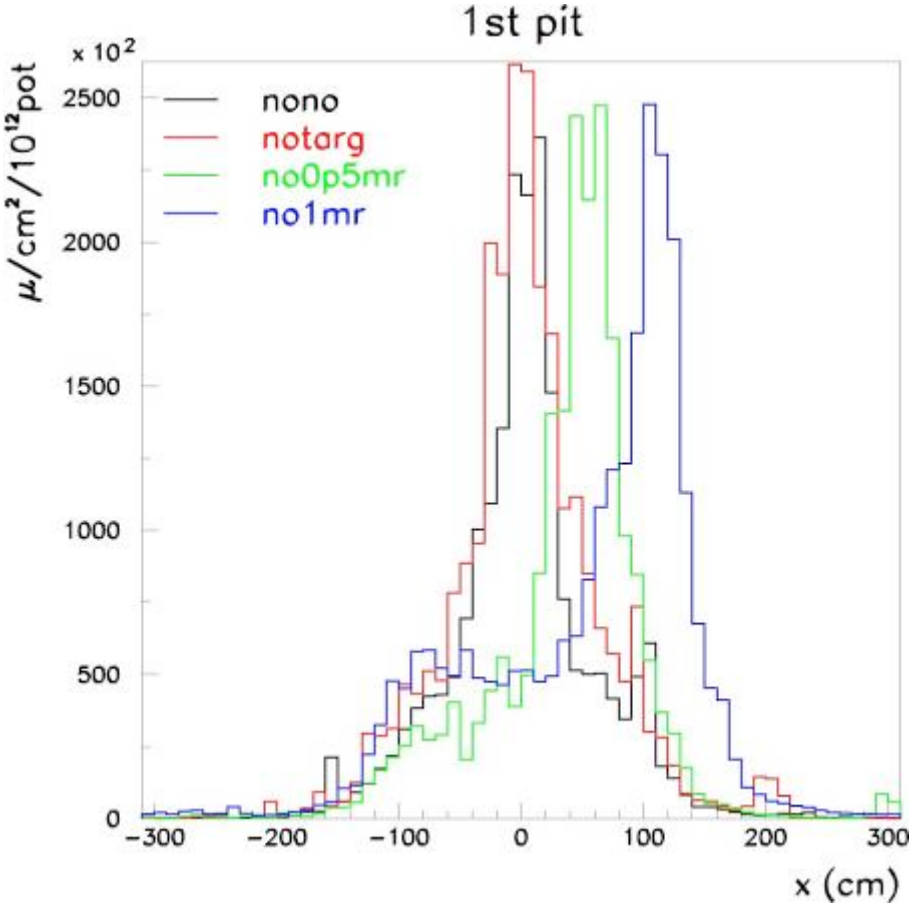
- **Check proton beam angle**
  - ➔ **Cross-hair and its ionization chambers**

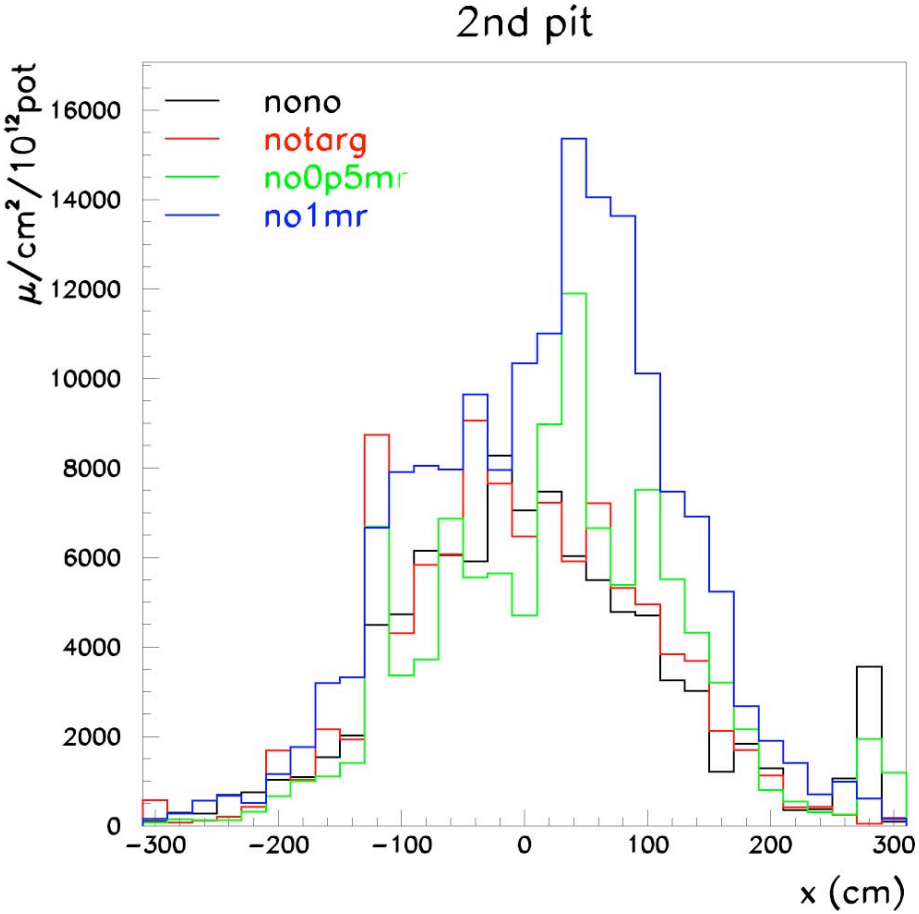
Beam displacement	Charged hadrons [part/cm^2/10^{12}pot]
No X-hair	0.9 _ 10^6
Hit X-hair (10cm)	2 _ 10^6



Target Out – Horns Off – TED Out

- **Check proton beam angle**
  - ➔ **Muon monitors**





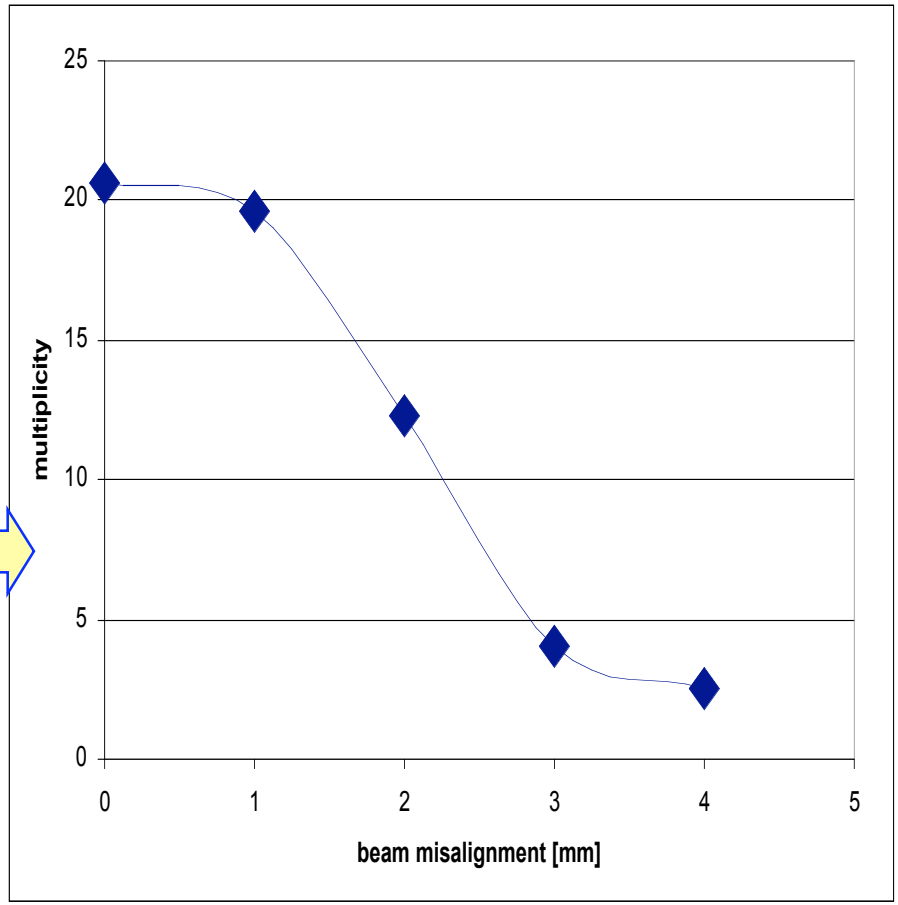
Target In – Horns Off – TED Out

- **Proton beam scan across the target**
  - ➔ Observe rates in **TBID**

Number of particles/primary proton hitting the TBID in different injection conditions

multiplicity

	0 mm	1 mm	2 mm	3 mm	4 mm
All particles	75.8	42.5	26.2	7.6	4.1
Charged particles	20.6	19.6	12.3	4.0	2.5
Electrons	12.6	11.8	7.0	1.6	0.5
Charged hadrons	7.9	7.7	5.3	2.4	1.9

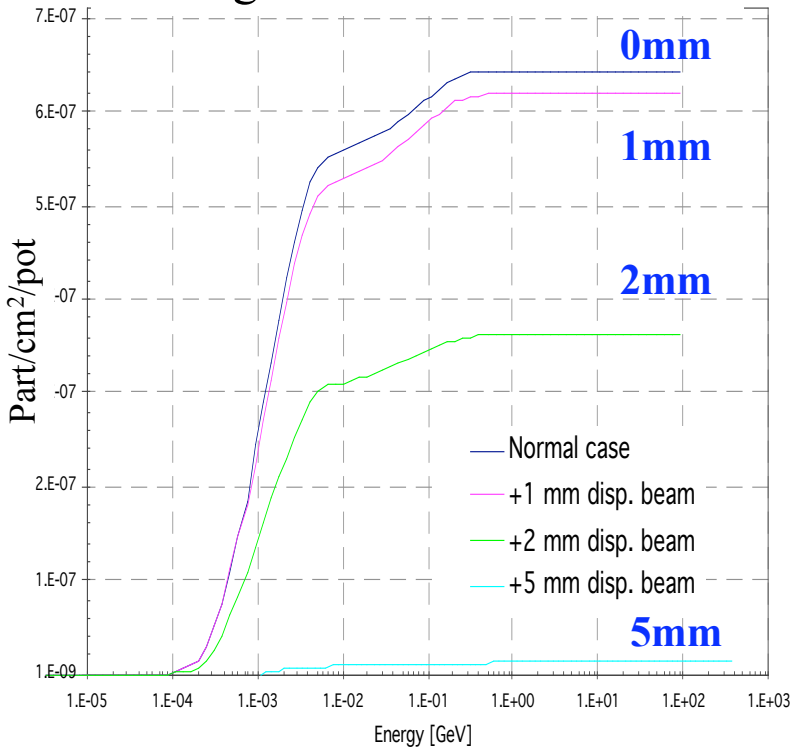


Target In – Horns Off – TED Out

- **Proton beam scan across the target**
  - ➔ Observe rates in **Ionization Chambers** at the TBID
    - **scan p-beam:**
      - **position: ±5mm**
      - **angle: ± 0.5mrad**

Beam displacement	Charged particles [part/cm^2/10^{12}pot]
0mm	6.4 _ 10^5
1mm	6.2 _ 10^5
2mm	3.7 _ 10^5
5mm	1.4 _ 10^4

Charged particle fluence for misaligned beam in the IonCh BLM



Target In – Horns On – TED Out

- **Observe signals on muon monitors**

- **Initial calibration of monitors in both muon chambers (10^3-10^8 μ/cm^2 in 10μs) (with horn/reflector "on" for higher muon flux)**
  - **Check/adjust cross-calibration of μ–monitoring by scanning the motorized monitor across the grid of fixed monitors**

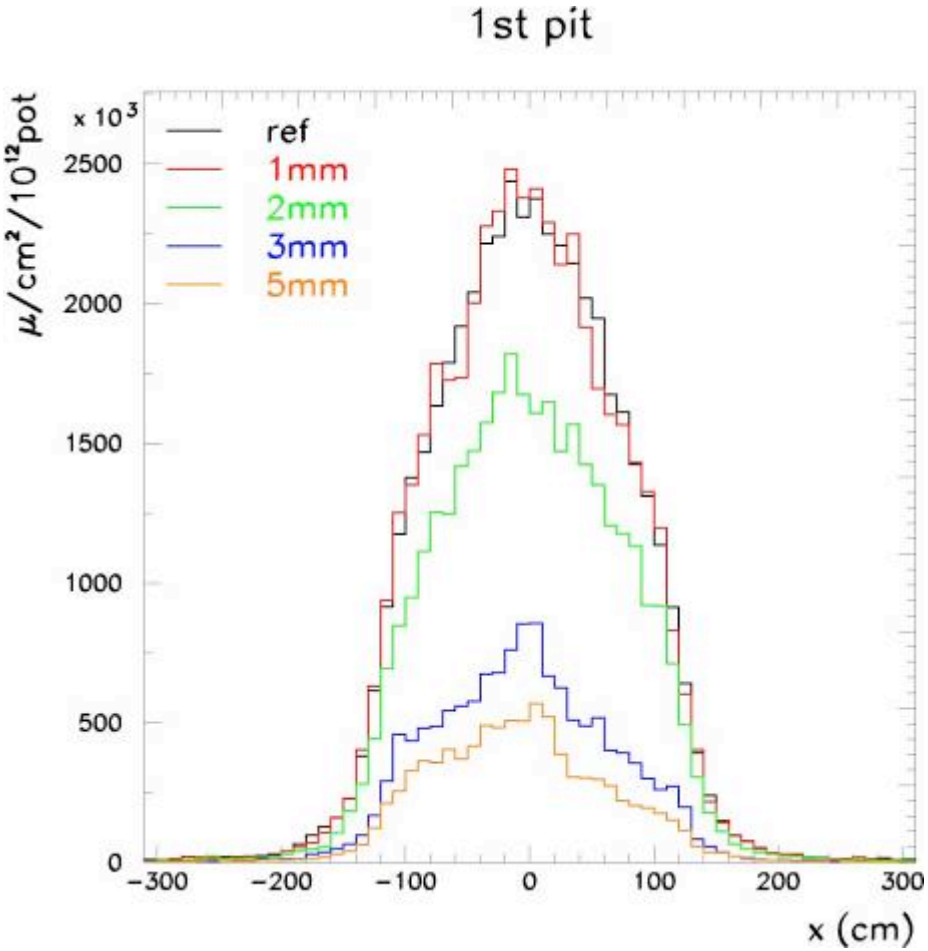
- Check **muon monitors** (TBID & IonCh) for
  - **Target in**
  - **Horn off/on**
  - **Horn & reflector off/on**
  - **Horn & reflector on with negative polarity**
  - **Horn & reflector on with 10% less current**

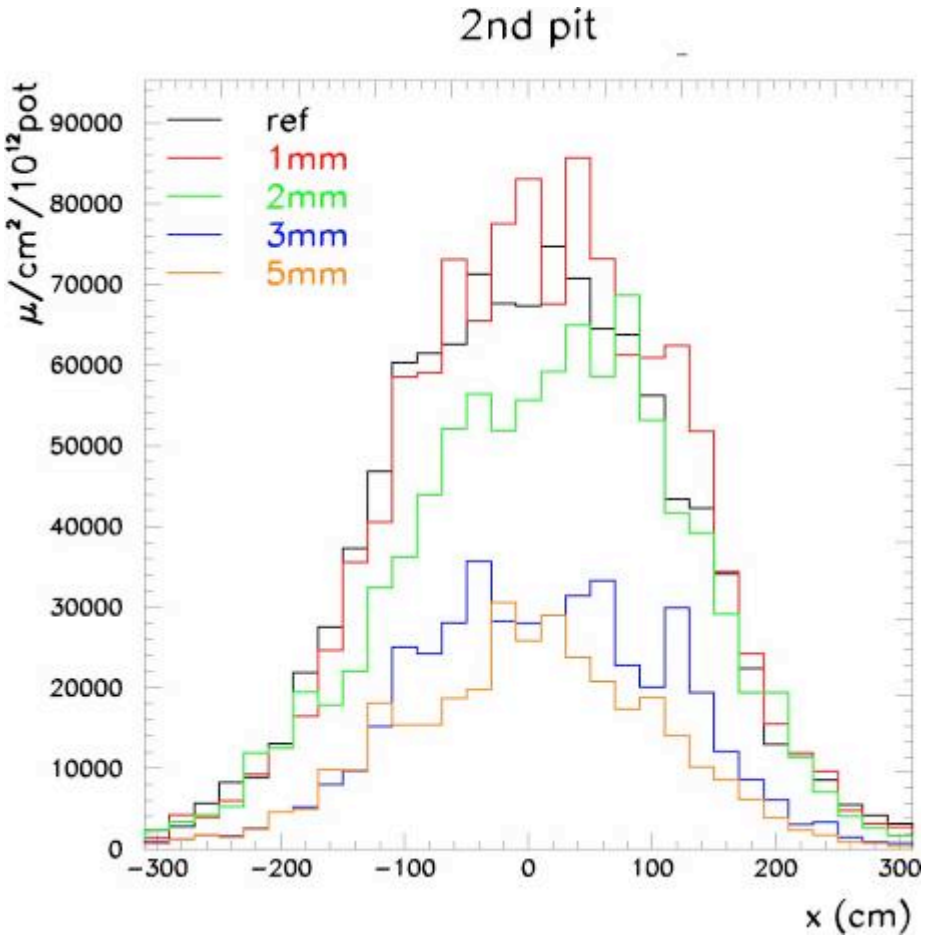
Configuration	1st muon pit	2nd muon pit
	[muons/cm^2/10^{13}pot]	
Target IN Magn. Field ON	2.3_ 10^7	3.6_ 10^5
Target IN Magn. Field OFF	1.2_ 10^6	1.7_ 10^5
Target OUT Magn. Field OFF	1.3_ 10^6	3.2_ 10^4

Target In – Horns On – TED Out

- **Parallel proton beam misalignment**

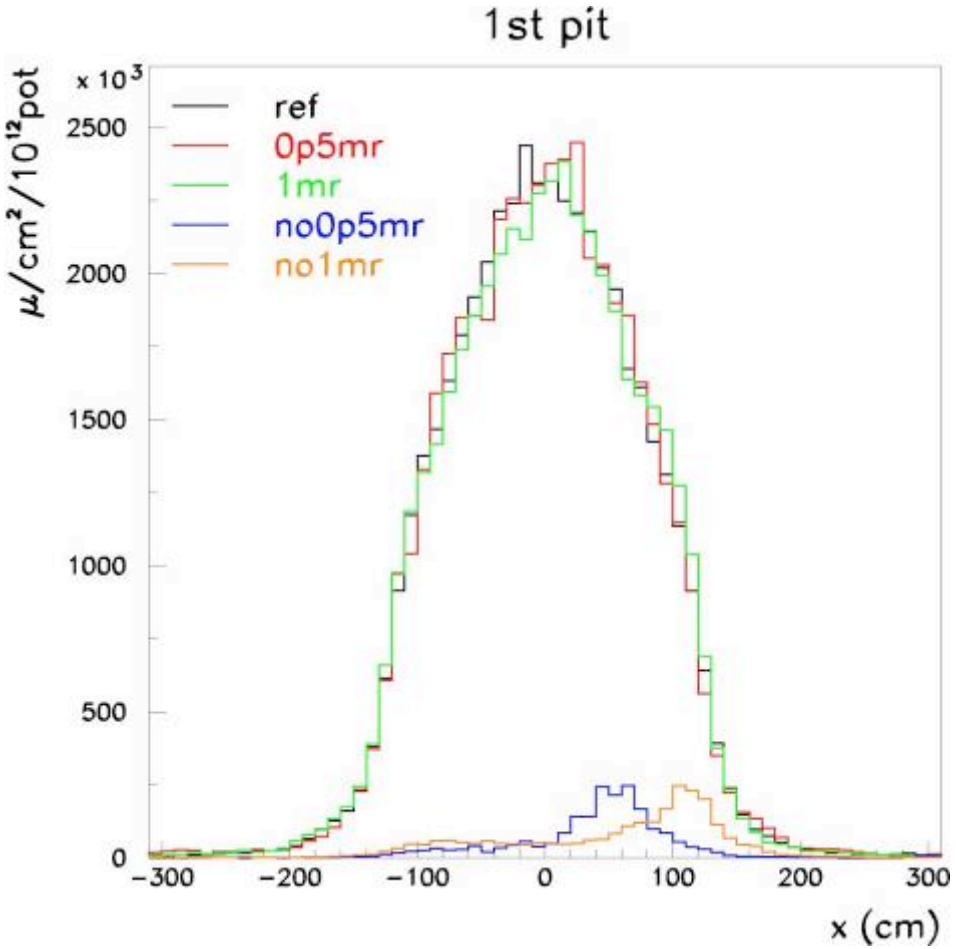
  ➔ **Muon monitors**

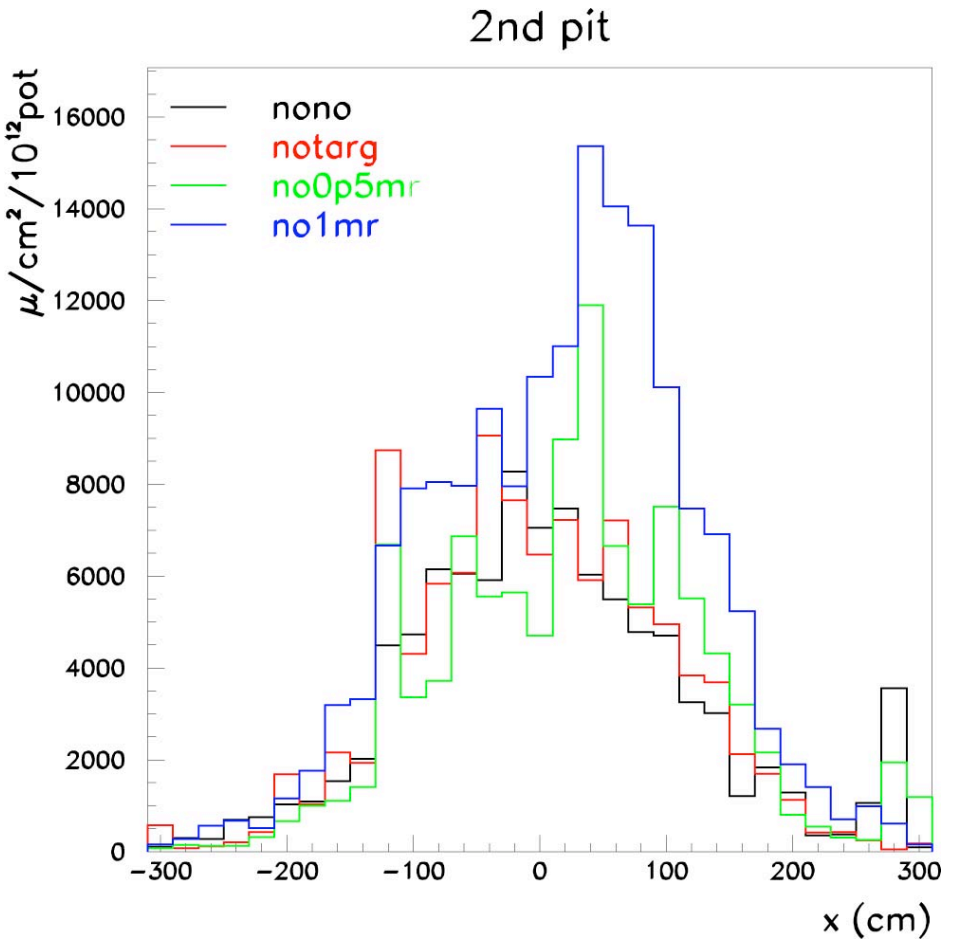




Target In – Horns On – TED Out

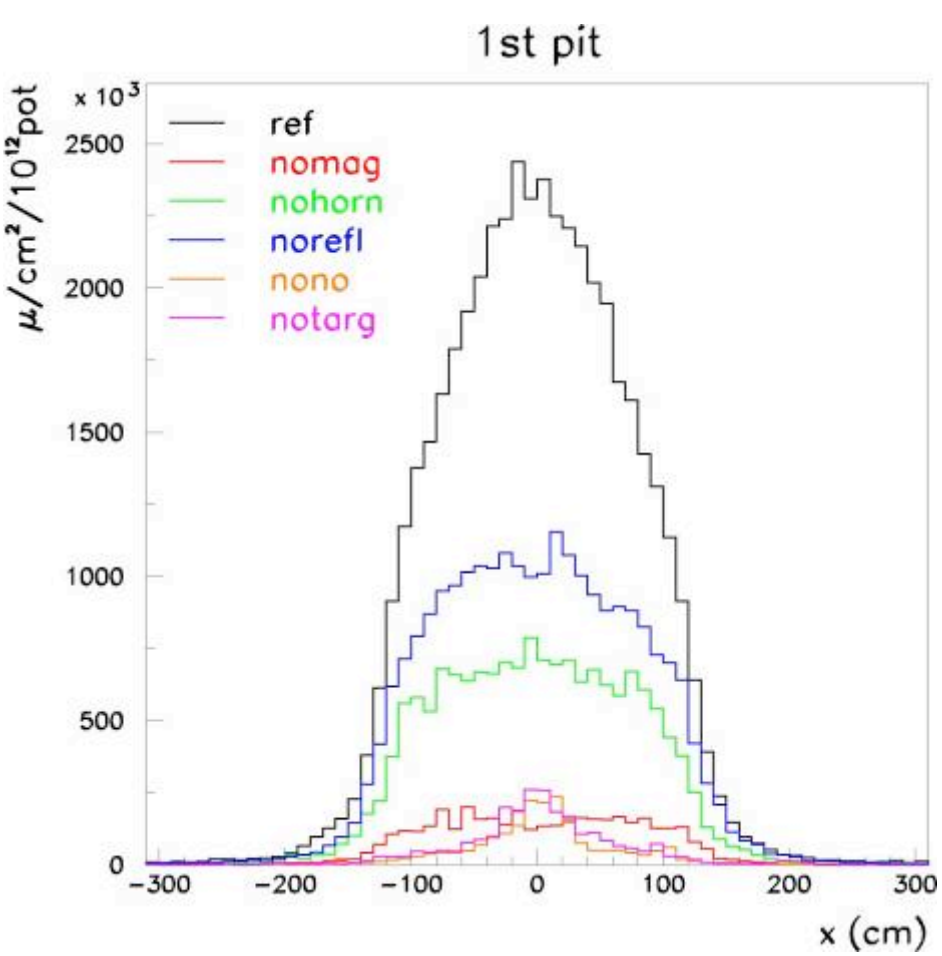
- **Angular proton beam misalignment**
  - ➔ **Muon monitors**

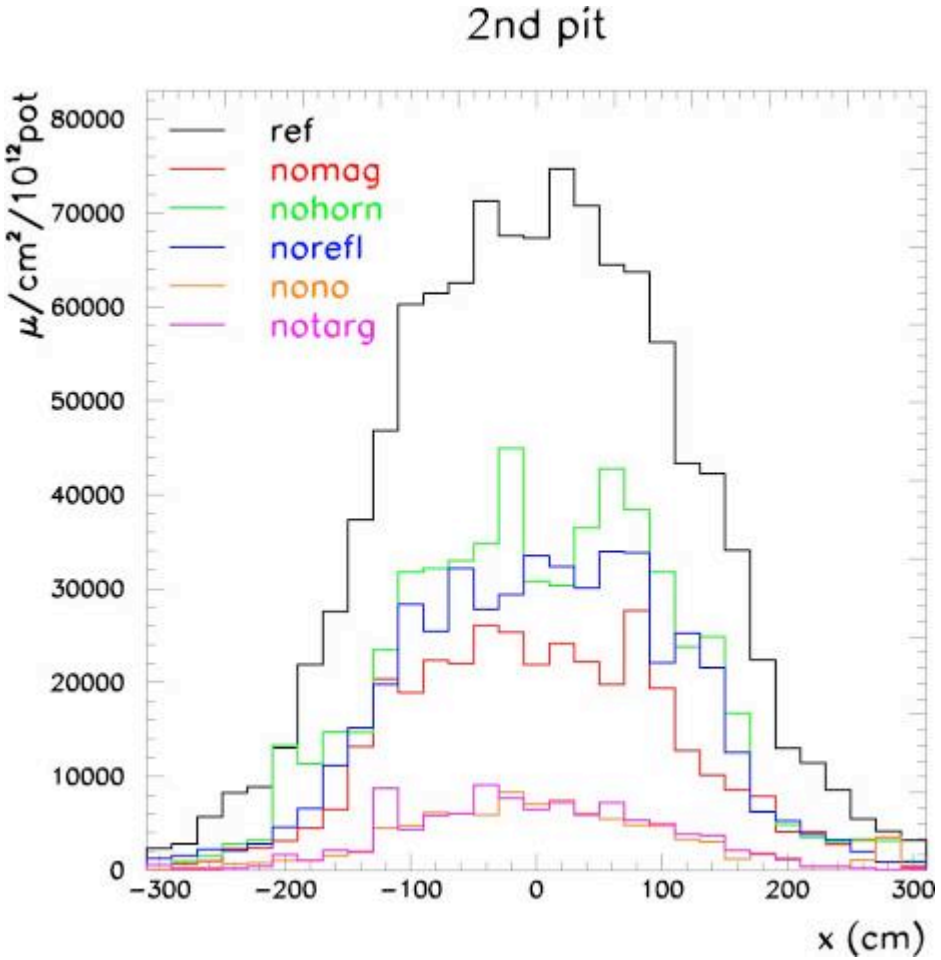




Target In – Horns On – TED Out

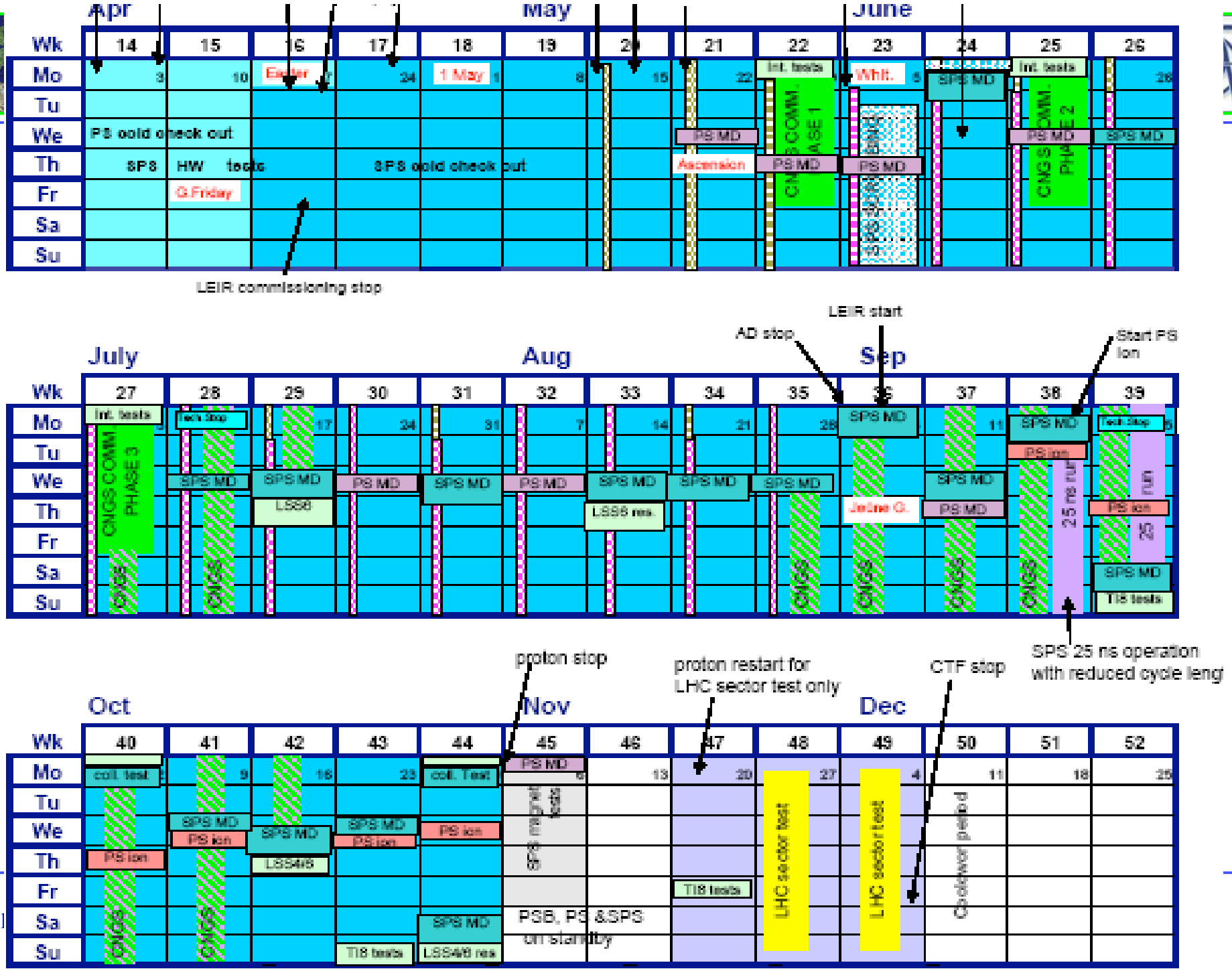
- **Target, horn, reflector: On/Off**
  - ➔ **Muon monitors**





Outlook

- **Installation complete**
- **Manipulation / Exchange exercises of components in Target Chamber in progress**
- **Commissioning with beam:**
  - ➔ **to start week 22 (29 May 2006)**
- **CNGS beam operational after week 27 (July 2006)**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Int. tests
CNGS COMM. PHASE 1
CNGS COMM. PHASE 2
PS MD
SPS MD
LEIR commissioning stop
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Int. tests
CNGS COMM. PHASE 3
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PS MD
LSS6
LSS6 mk.
Jaime G.
PS ion
25 ns run
TI8 tests
LEIR start
AD stop
Start PS Ion
SPS 25 ns operation with reduced cycle leng
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coll. test
PS ion
LSS4/5
TI8 tests
LSS4/5 mk
PSB, PS &SPS on standby
proton stop
proton restart for LHC sector test only
CTF stop
LHC sector test
Cryo-lower period

Additional Slides

CNGS Project

CNGS (CERN Neutrino Gran Sasso)

- A long base-line neutrino beam facility (732km)
- send ν_μ beam produced at CERN
- detect ν_τ appearance in OPERA experiment at Gran Sasso

➔ direct proof of ν_μ - ν_τ oscillation (appearance experiment)

Radiological Issues

- **Beam on:**
  - ➔ **< 100Sv/h outside the horn shielding**
  - ➔ **< 2Sv/h in service gallery**
- **Beam off- immediately afterwards**
  - ➔ **100mSv/h**

Access is controlled with 'radiation veto'?!

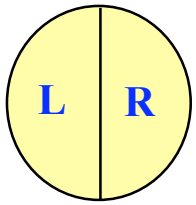
For intervention: dose rate < 2mSv/intervention (CERN rule)

Examples:

- ➔ **1 week shutdown to change a motor of the target**
- ➔ **1 month shutdown to exchange the horn**
  - **Only possible because most is remotely handled!**

Left/Right Asymmetry

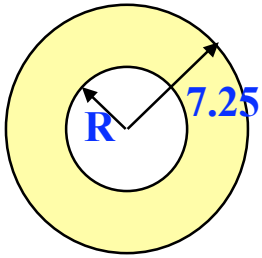
All charged particles



	TBID positive [part/cm^2/primary]	TBID negative [part/cm^2/primary]
	> $E_{cut\ off}$ (~1MeV)	> $E_{cut\ off}$ (~1MeV)
0 mm	9.3E-2	9.3E-2
1 mm	8.8E-2	8.7E-2
2 mm	5.8E-2	5.3E-2
3 mm	2.4E-2	1.4E-2
5 mm	1.7E-2	5.0E-3
7 mm	6.1E-2	4.9E-2
10 mm	12.5E-2	11.0E-2

Halo

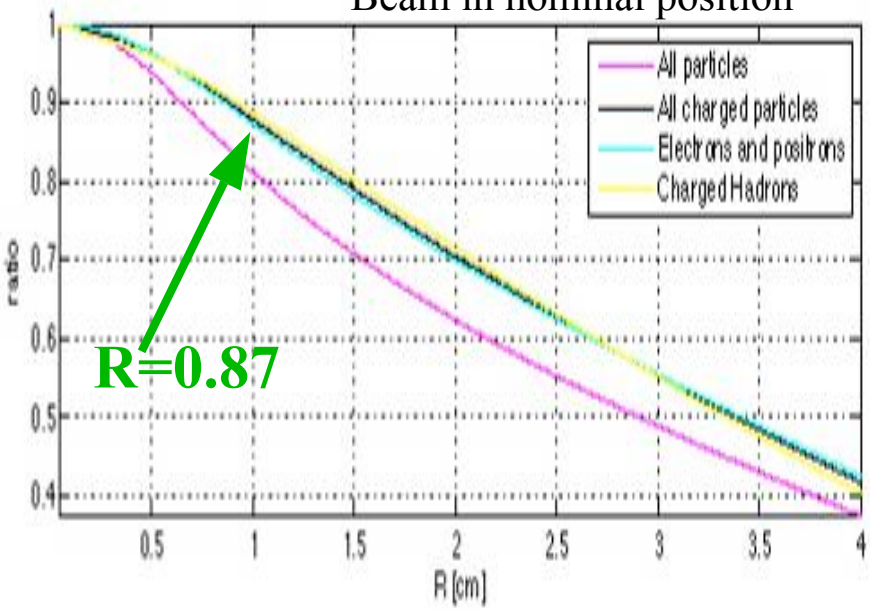
$$\text{Ratio} = \frac{\text{number of particles } (7.25 - R)}{\text{Total \#}}$$



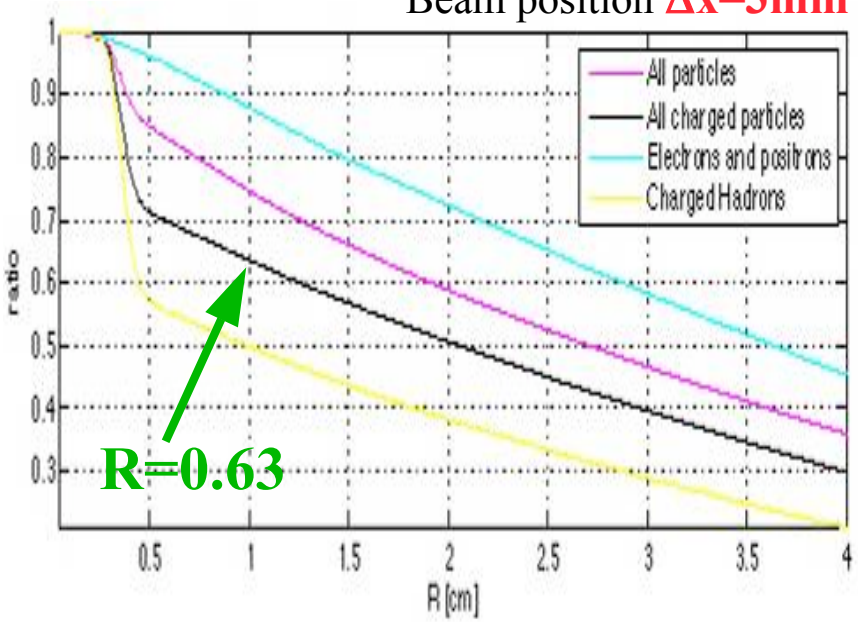
- $R \approx 0.9$ cm $\Rightarrow$ ratio = 90 %
- $R \approx 3.4$ cm $\Rightarrow$ ratio = 50 %

} Charged particles

Beam in nominal position

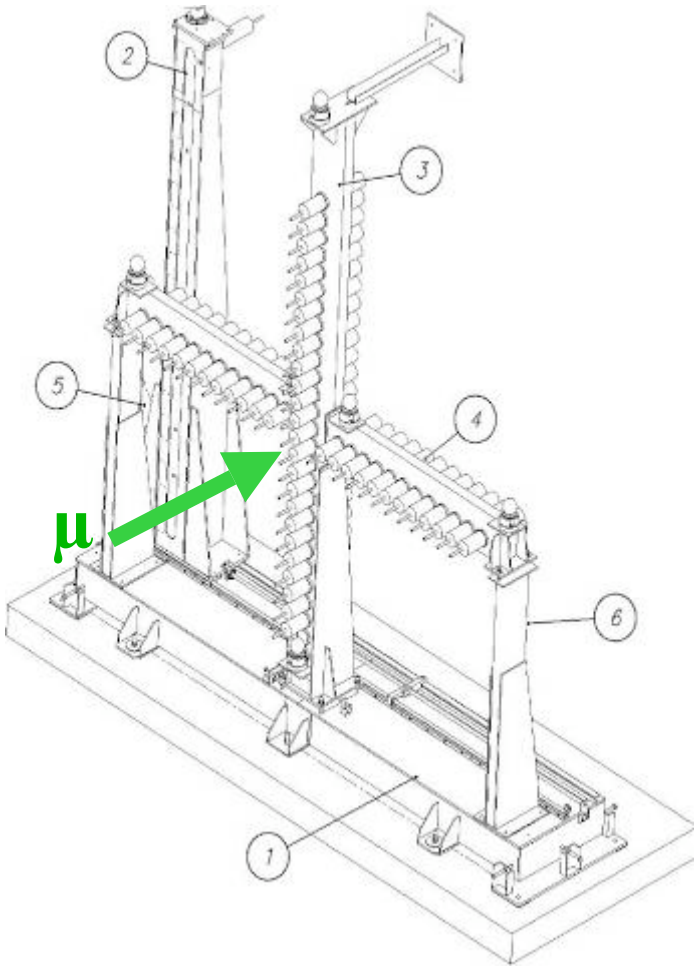


Beam position Δx=3mm



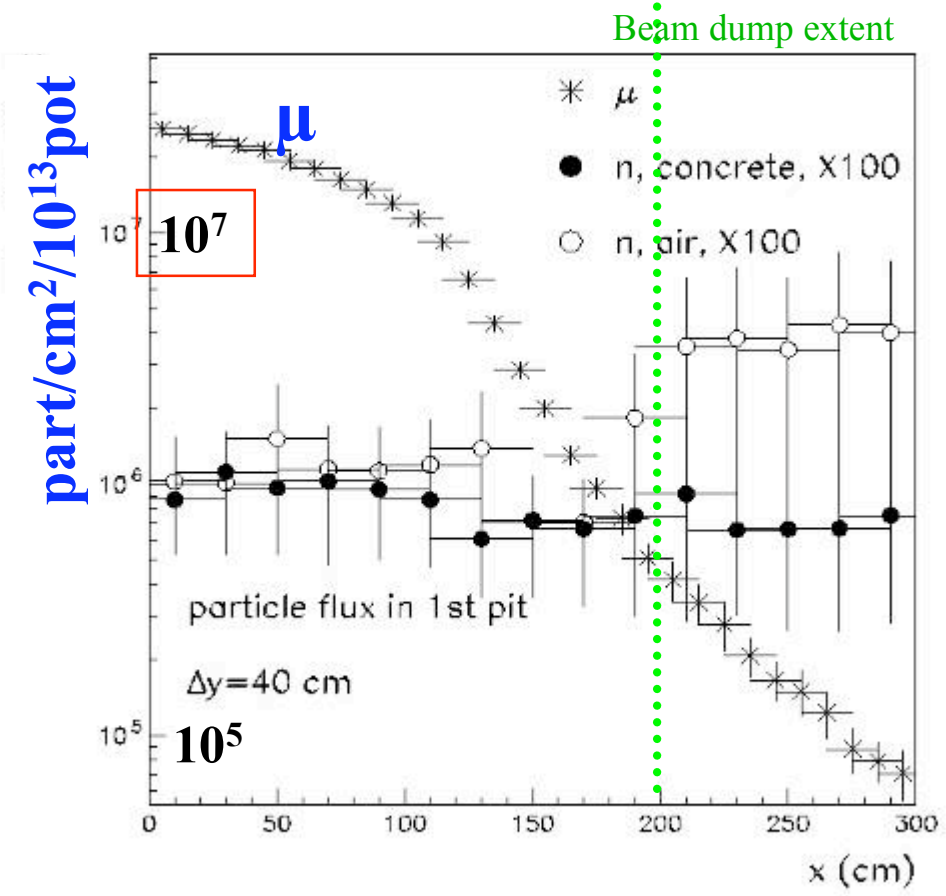
Moving the beam horizontally: the ratio falls off when R = Δx.

Muon Monitor



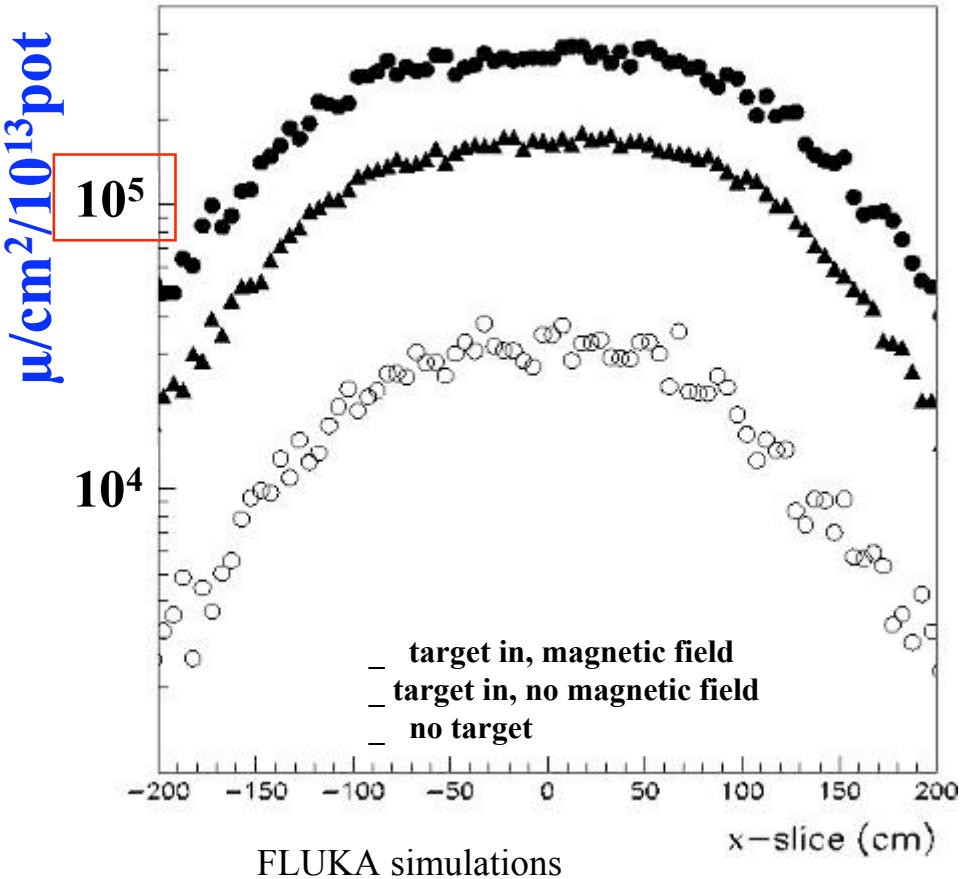
Muon Profiles

1st muon pit



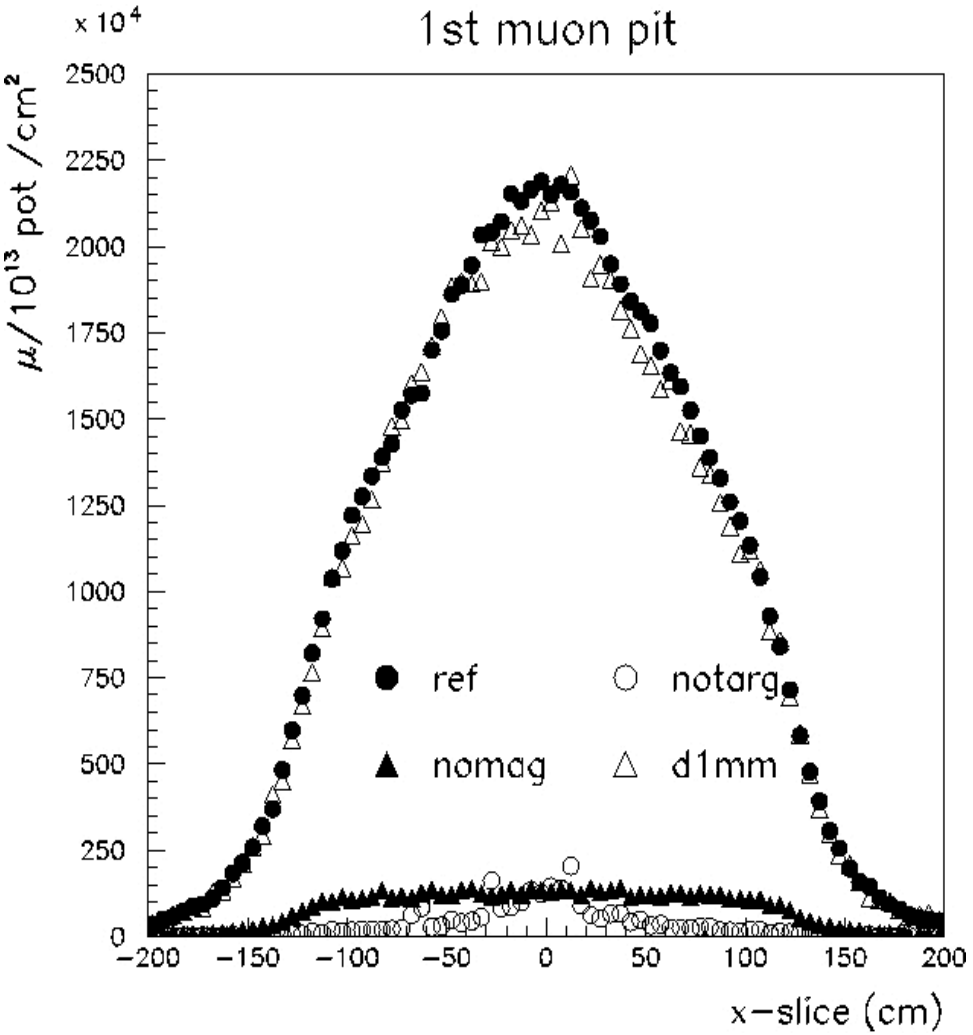
An updated calculation of neutron fluence in the CNGS first muon pit,
A. Ferrari, A. Guglielmi, P.R. Sala

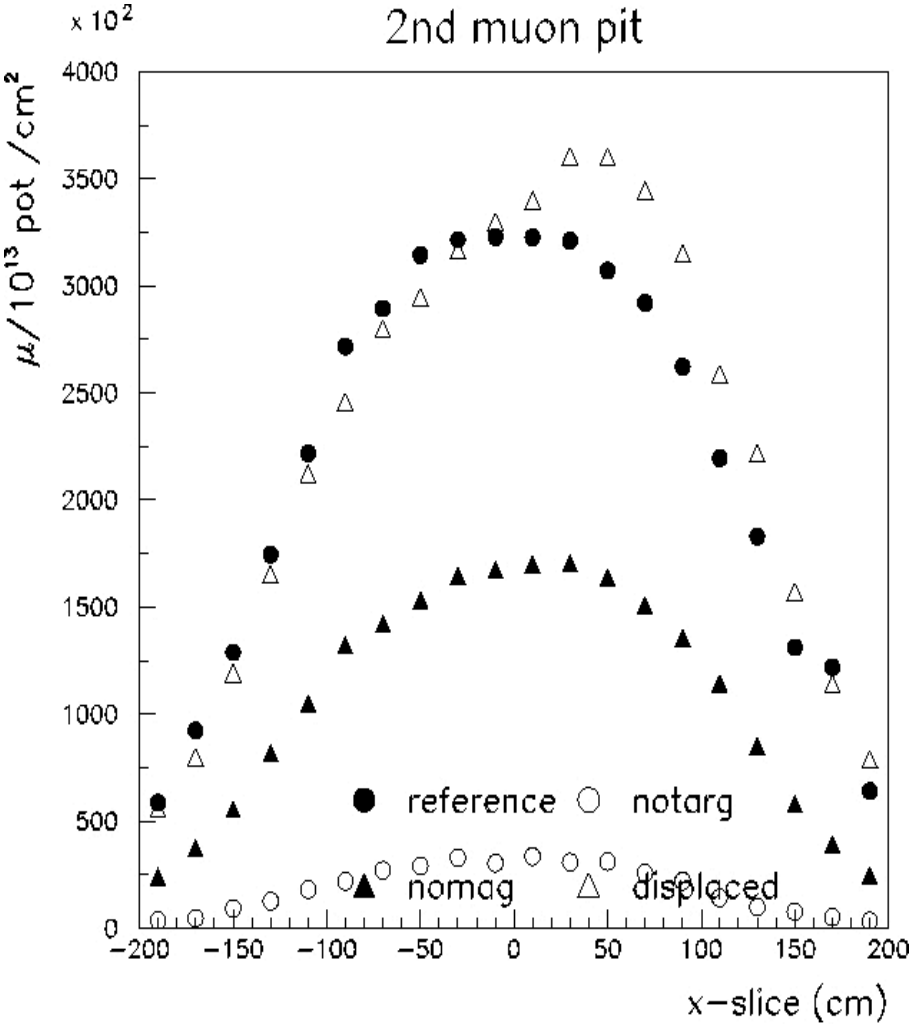
2nd muon pit



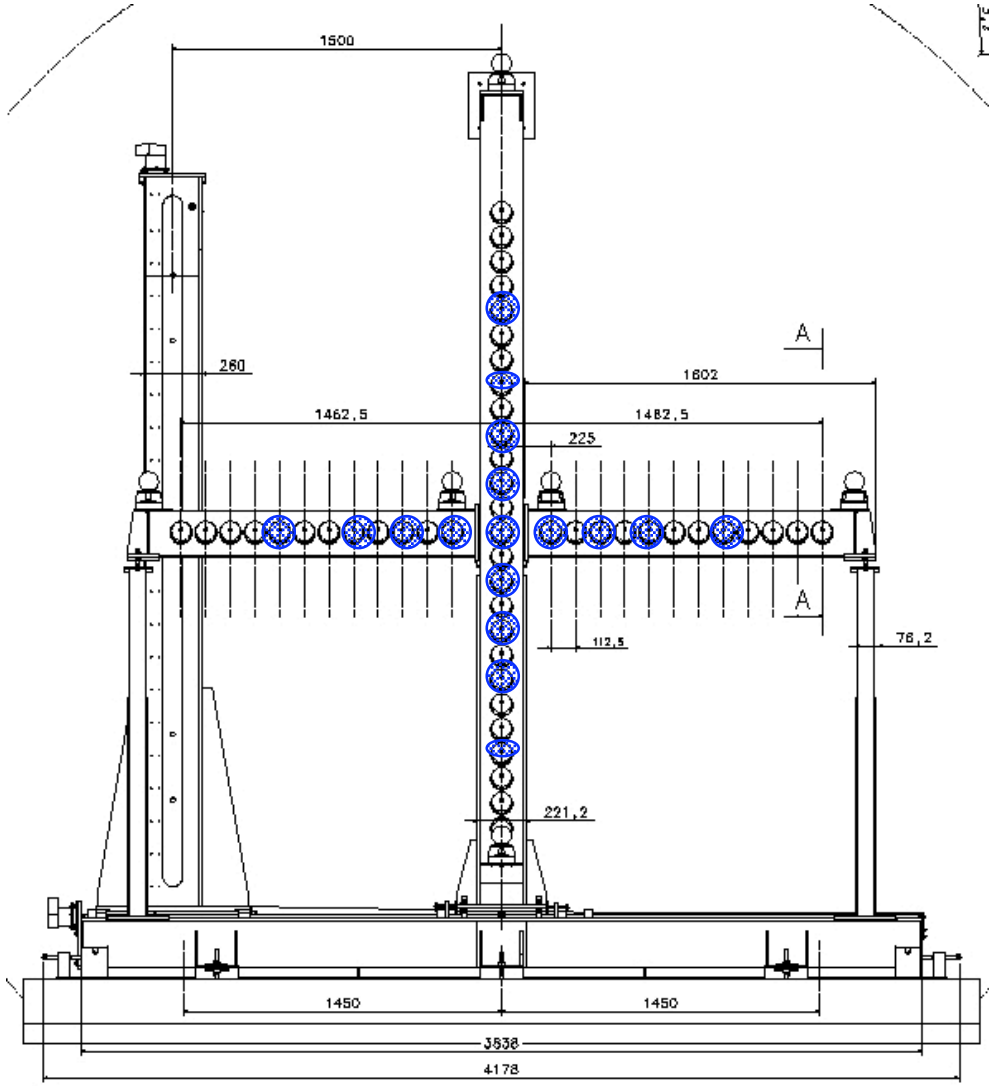
FLUKA simulations
(P. Sala, not published)

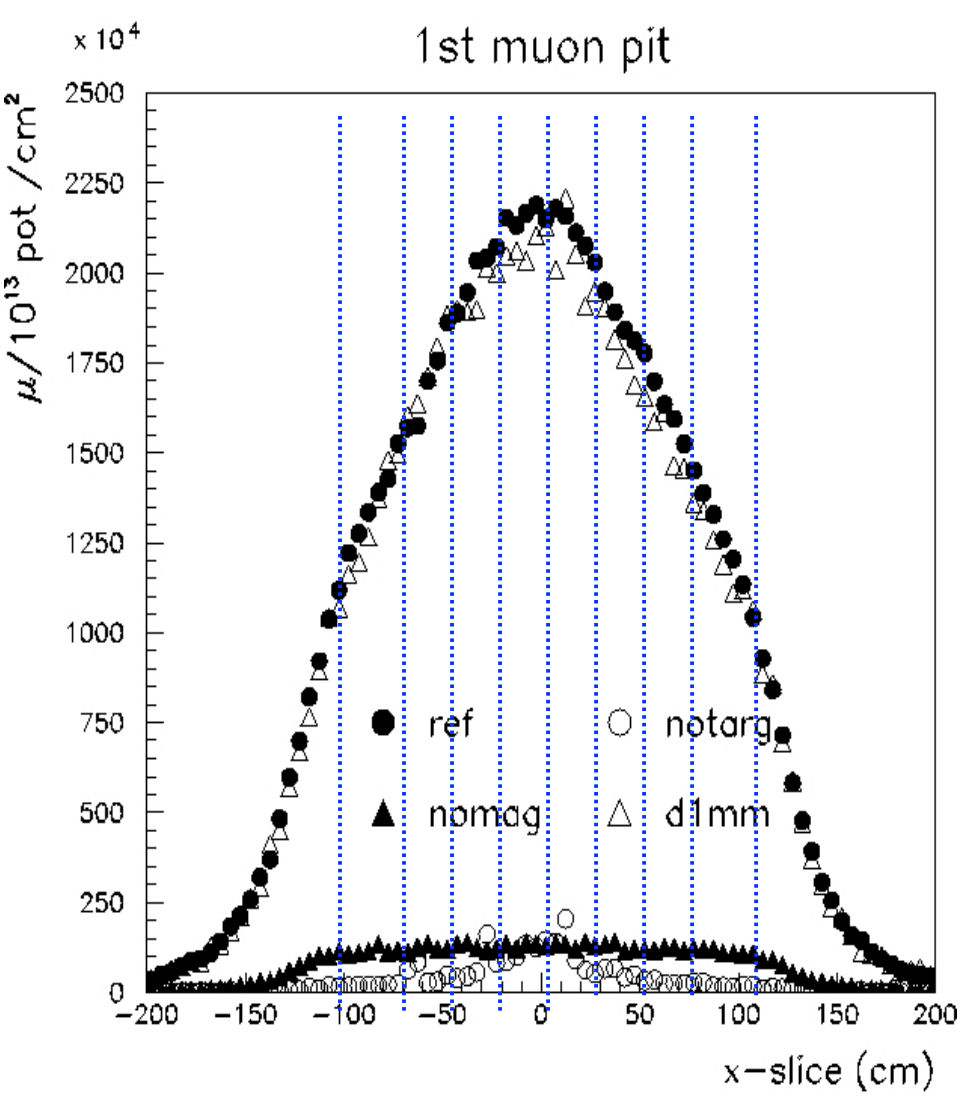
Muon Monitor



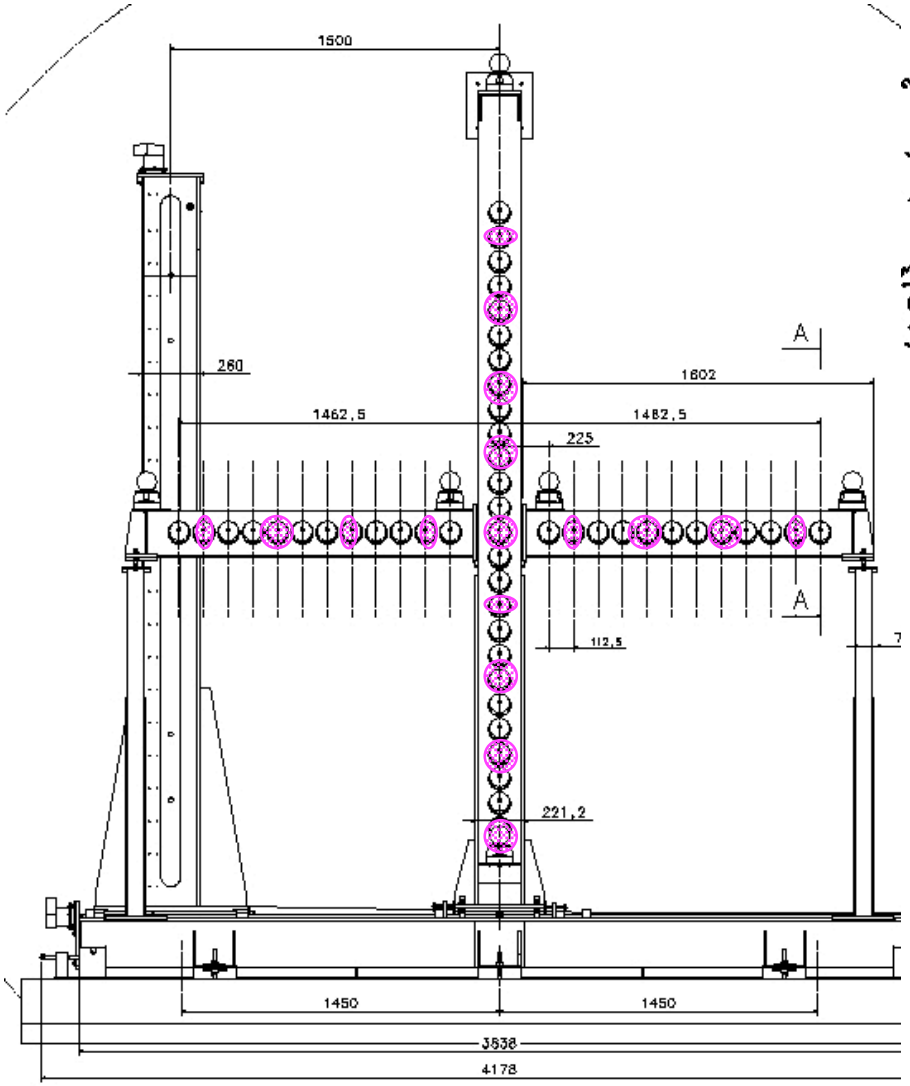


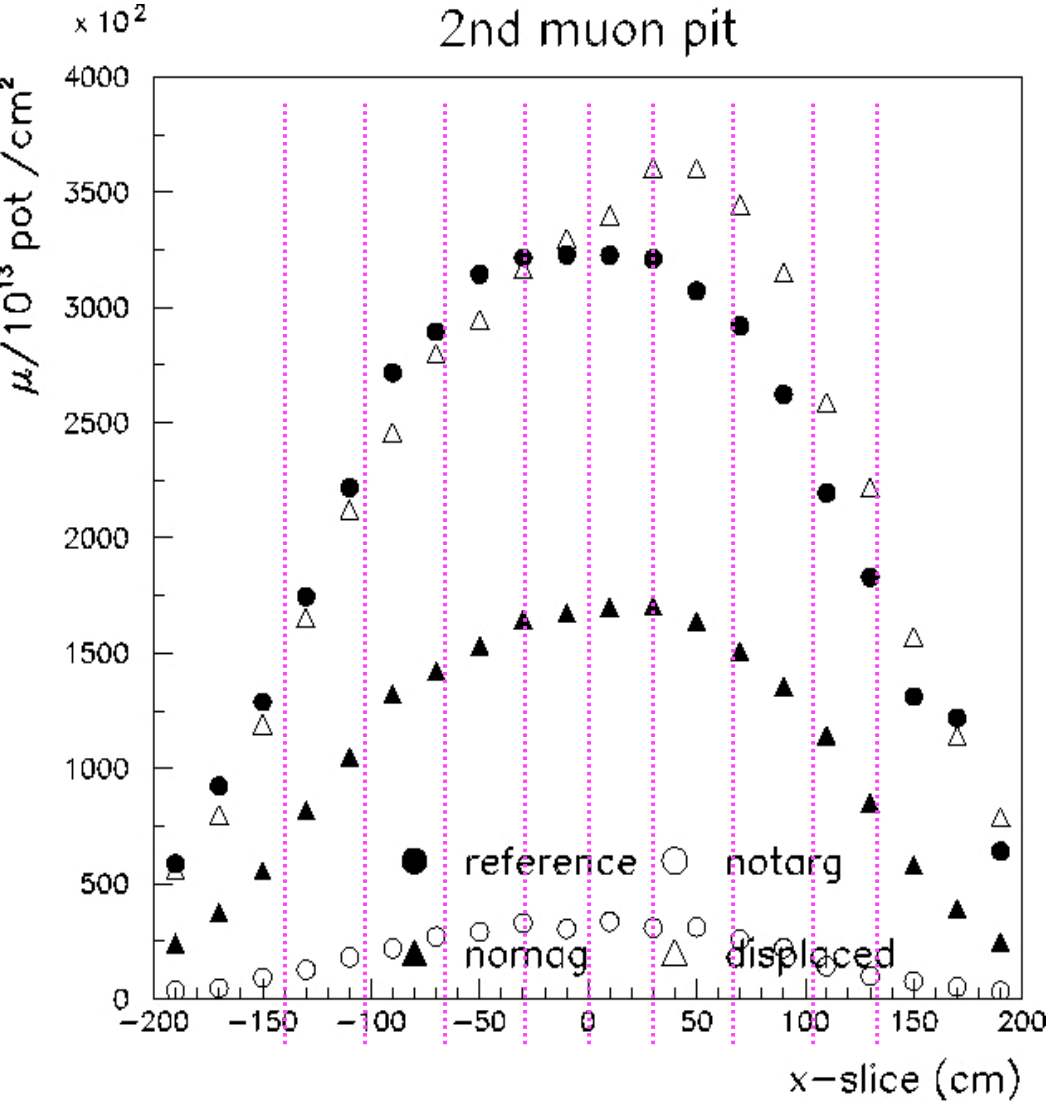
Muon Pit 1


1500
260
1462,5
1482,5
225
1602
A
A
112,5
76,2
221,2
1450
1450
3536
4178


1st muon pit
x 10^4
μ/10^13 pot /cm^2
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
ref
notarg
nomag
d1mm
−200
−150
−100
−50
0
50
100
150
200
x−slice (cm)

Muon Pit 2


1500
260
1462,5
1482,5
1602
225
A
A
112,5
221,2
1450
1450
3536
4178


2nd muon pit
x 10²
μ/10¹³ pot /cm²
4000
3500
3000
2500
2000
1500
1000
500
0
−200
−150
−100
−50
0
50
100
150
200
x−slice (cm)
reference
notarg
nomag
displaced

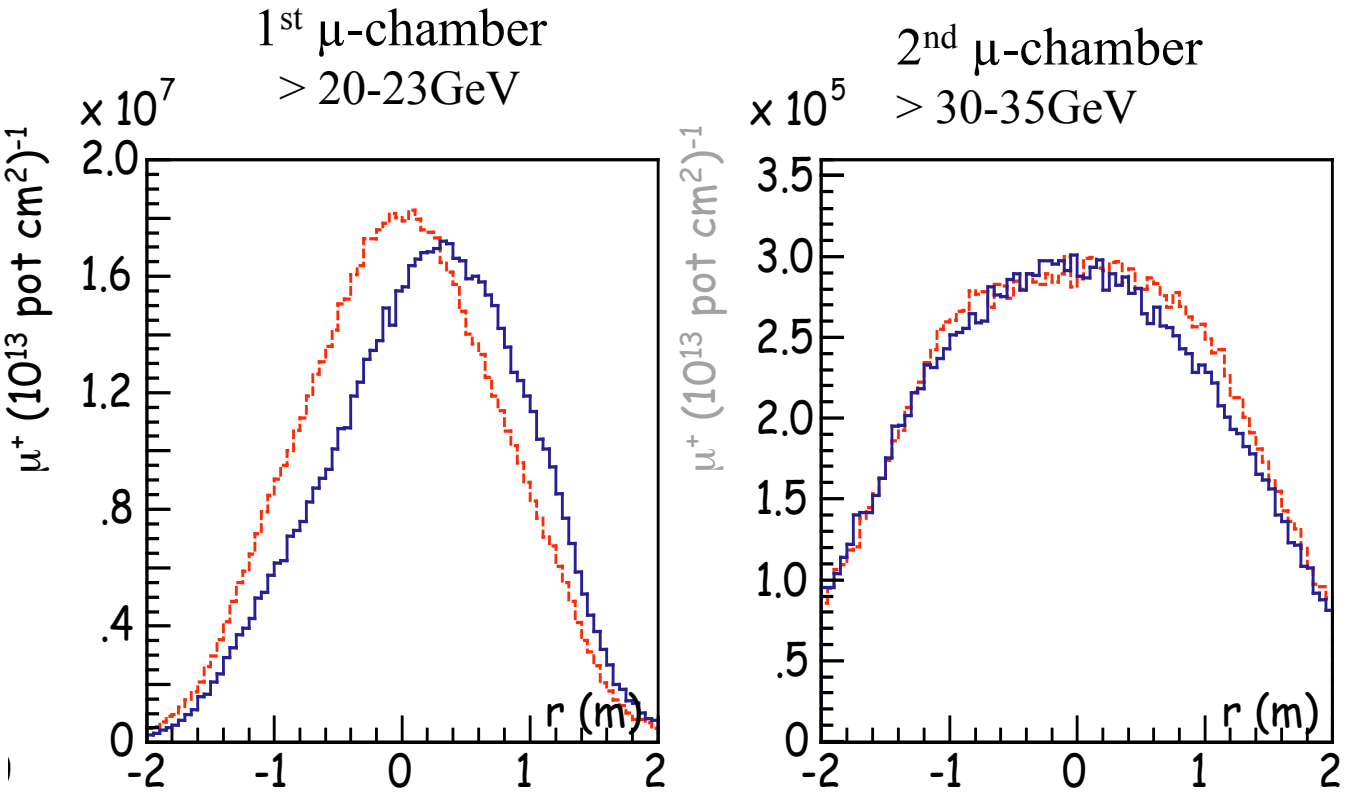
Muon Profiles

Example: 6 mm horn neck lateral displacement

Mis-aligned case

Aligned case

fast simulation



Raise intensity gradually

- **Check linearity of all monitors vs. BFCT**
- **Repeat calibration of the muon monitors with the moving monitor at different beam intensities**

CNGS Performance

For CNGS performance, the main issues are

- ➔ the geodesic alignment wrt. Gran Sasso
- ➔ the beam must hit the target very accurately !!
- ➔ for target resistance and environmental reasons!

Examples:	effect on cc events
horn off axis by 6mm	< 3%
reflector off axis by 30mm	< 3%
proton beam on target off axis by 1mm	< 3%
CNGS facility misaligned by 0.5mrad (beam 360m off)	< 3%

Commissioning Plans

- **Hardware commissioning** — **Feb. – April 2006**
  - → **Beam instrumentations**
  - → **Power supplies**
  - → **Magnets (polarities)**
  - → **Vacuum system**
- **'Dry runs'** — **April – May 2006**
  - → **Timing**
  - → **Controls**
  - → **Interlocks**
  - → **Beam permit**
  - → **Magnets (currents & polarities)**
- **Commissioning with beam** — **2006: weeks 22, 25 and 27v**

SPS Cycles for CNGS

CNGS protons: 400 GeV from SPS

SPS cycles for CNGS: 2x10.5 μs extr., Δt=50ms / 6 s cycle

- **SPS Cycle Proposal for 2006**
  - ➔ **Commissioning:**

    12s FT + 6s CNGS
  - ➔ **Run 1**

    12s FT + 6s CNGS + 4.8s MD
  - ➔ **Run 2**

    12s FT + 3x6s CNGS + 4.8s MD