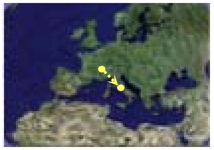


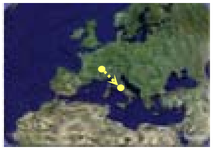
CERN Neutrinos to Gran Sasso (CNGS): Commissioning and First Operation

Edda Gschwendtner

AB/ATB/EA

on behalf of the CNGS project and commissioning teams

1. Introduction
2. Proton Beam Line Commissioning
3. Secondary Beam Line Commissioning
4. CNGS Operation
5. First Events at Gran Sasso (OPERA)



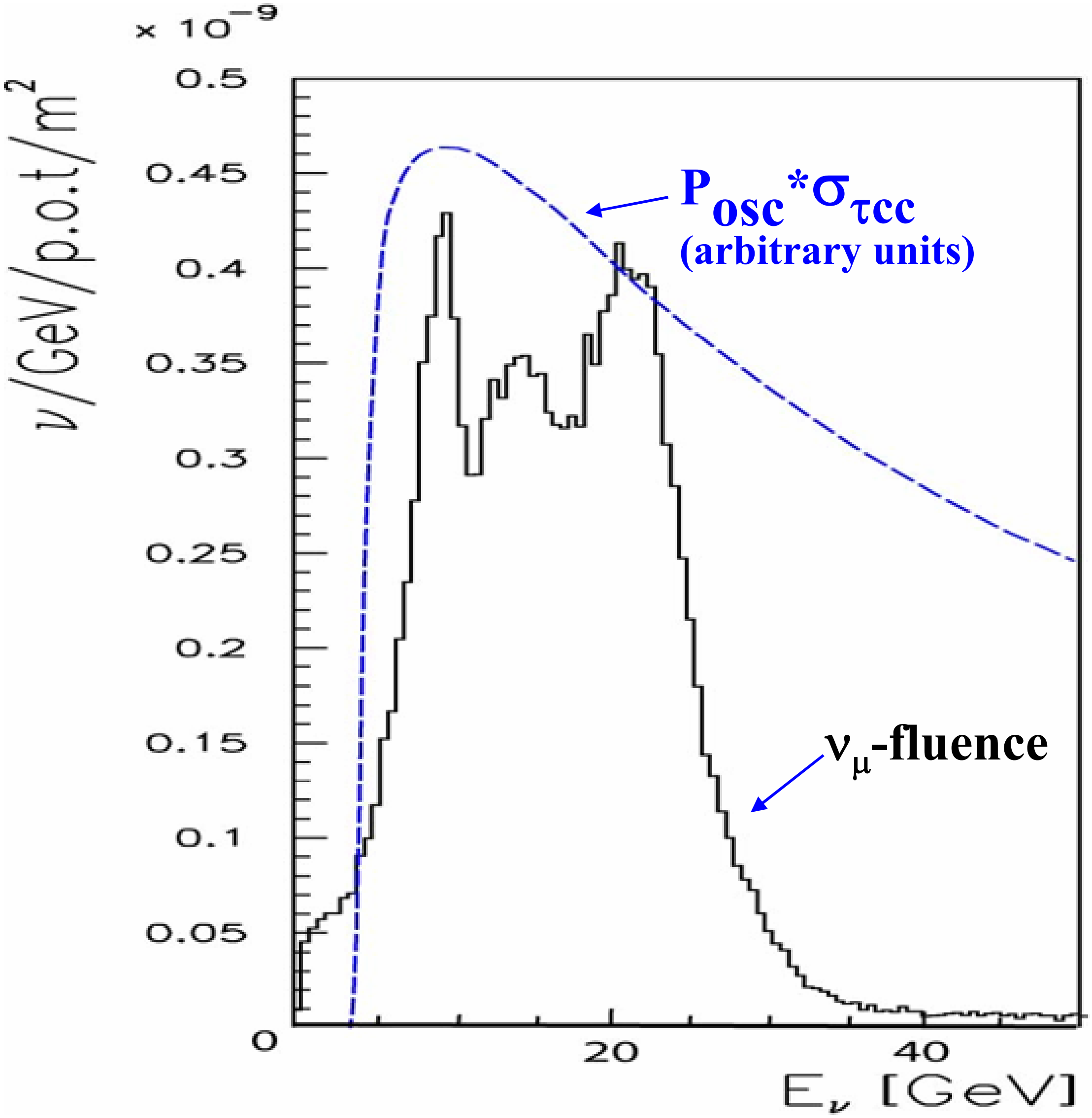
CNGS Project

CNGS (CERN Neutrinos to Gran Sasso)

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

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

ν_τ – Appearance Experiment



- **Beam optimization:**
  - ➔ **Intensity: as high as possible**
  - ➔ **Neutrino energy: matched for ν_μ-ν_τ appearance experiments**
- **Product of**
  1. **Oscillation probability $\nu_\mu - \nu_\tau$**
  2. **Production cross-section ν_τ with matter**
  3. **ν_μ –fluence(E)**

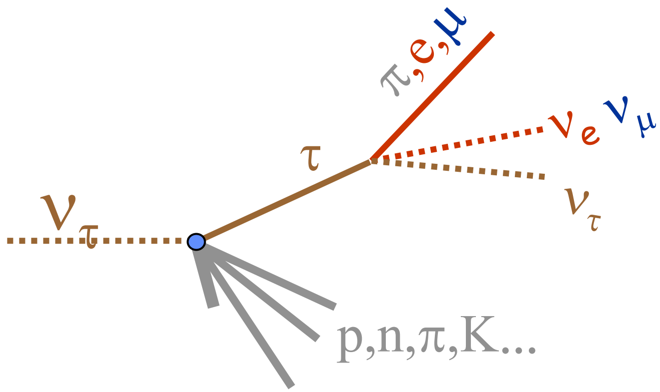
  + Detection efficiency in the experiment

Detecting ν_τ at Gran Sasso

Look for the τ lepton :

➔ **extremely difficult:**

τ travels only less than 1 mm before decaying



5 years CNGS operation, 1800 tons target:

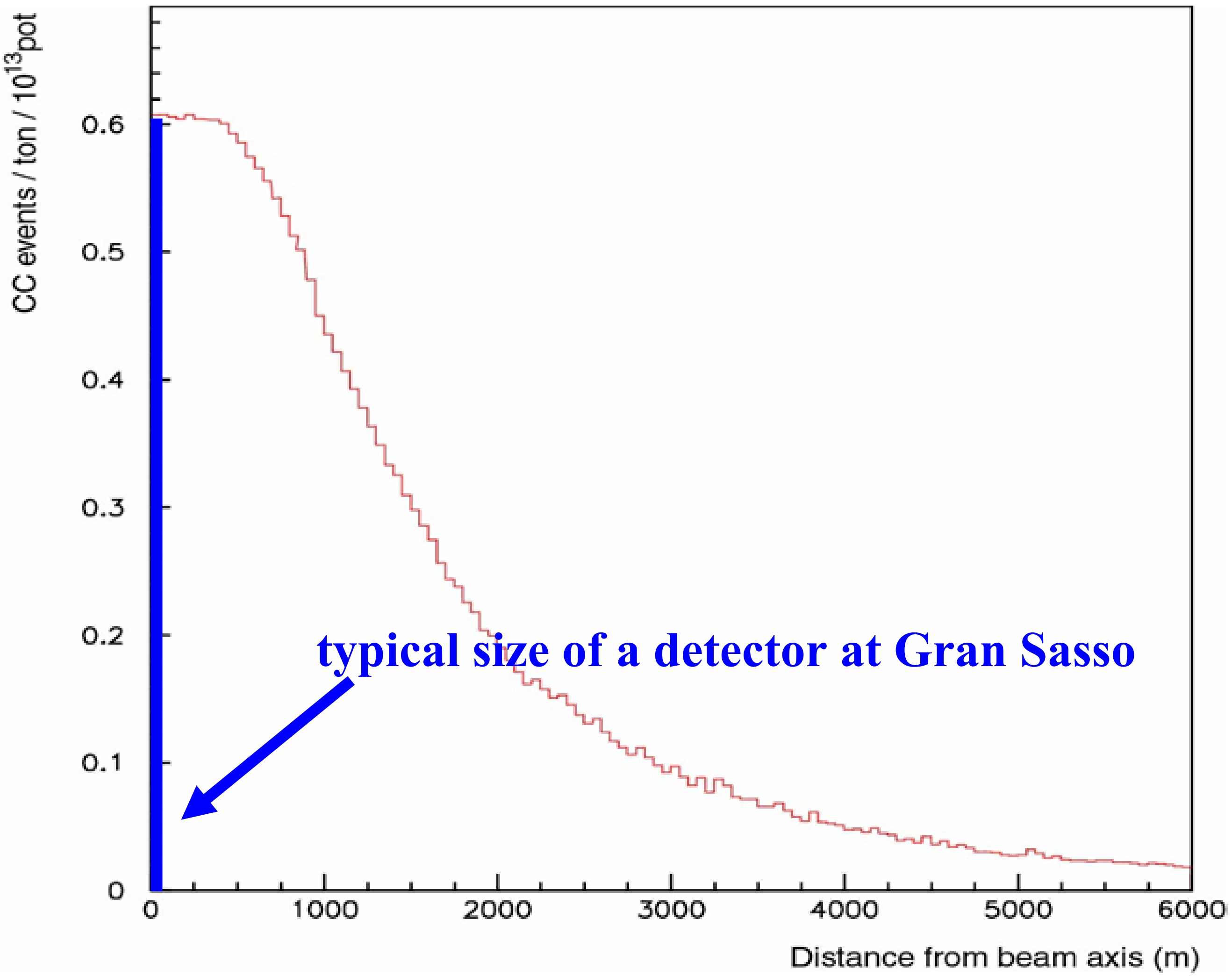
- **30000 neutrino interactions**
- **~150 ν_τ interactions**
- **~15 ν_τ identified**
- **< 1 event of background**

Approach:

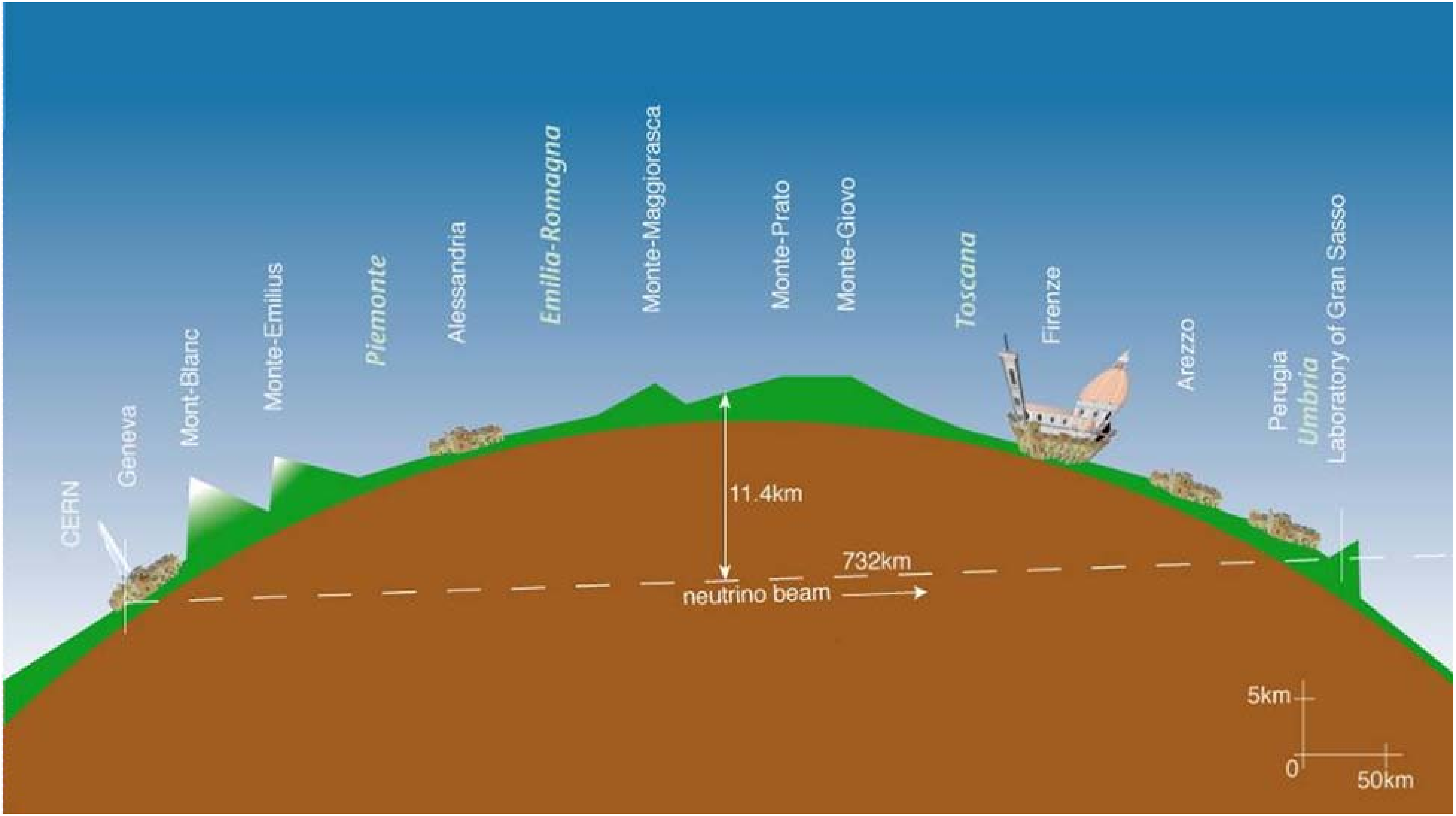
➔ **very good position resolution (see the decay 'kink'): OPERA**

(ICARUS: see status report at the next SPSC 3 Oct. 2006)

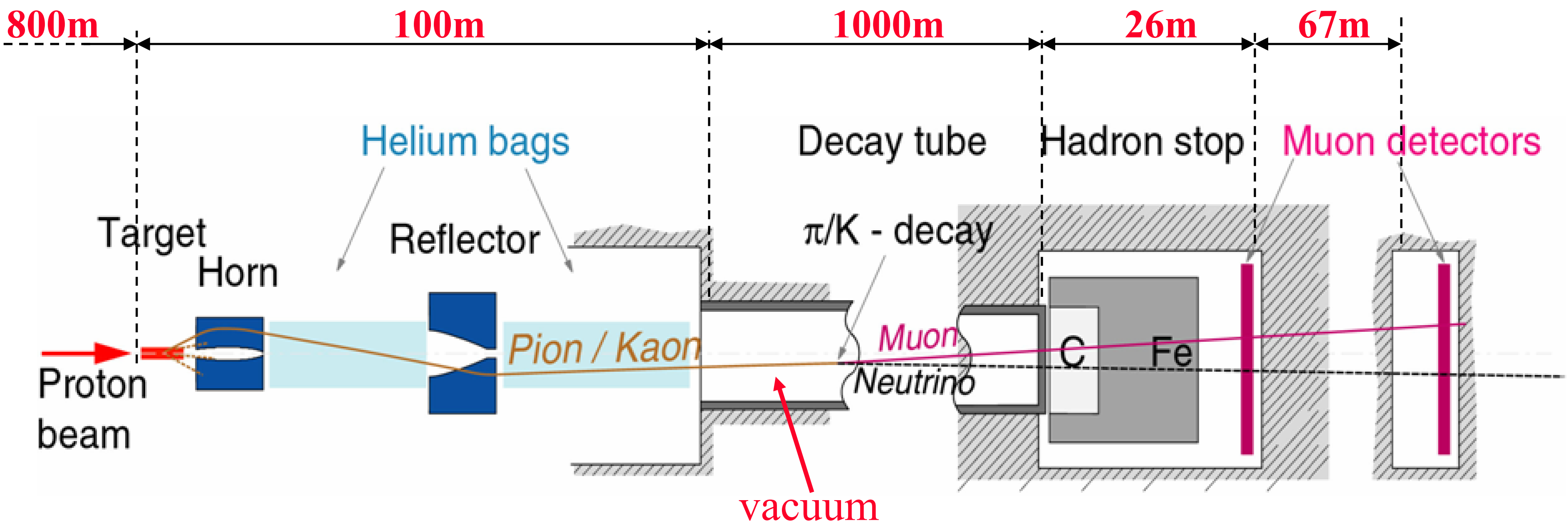
Radial Distribution of the ν_μ-Beam at GS



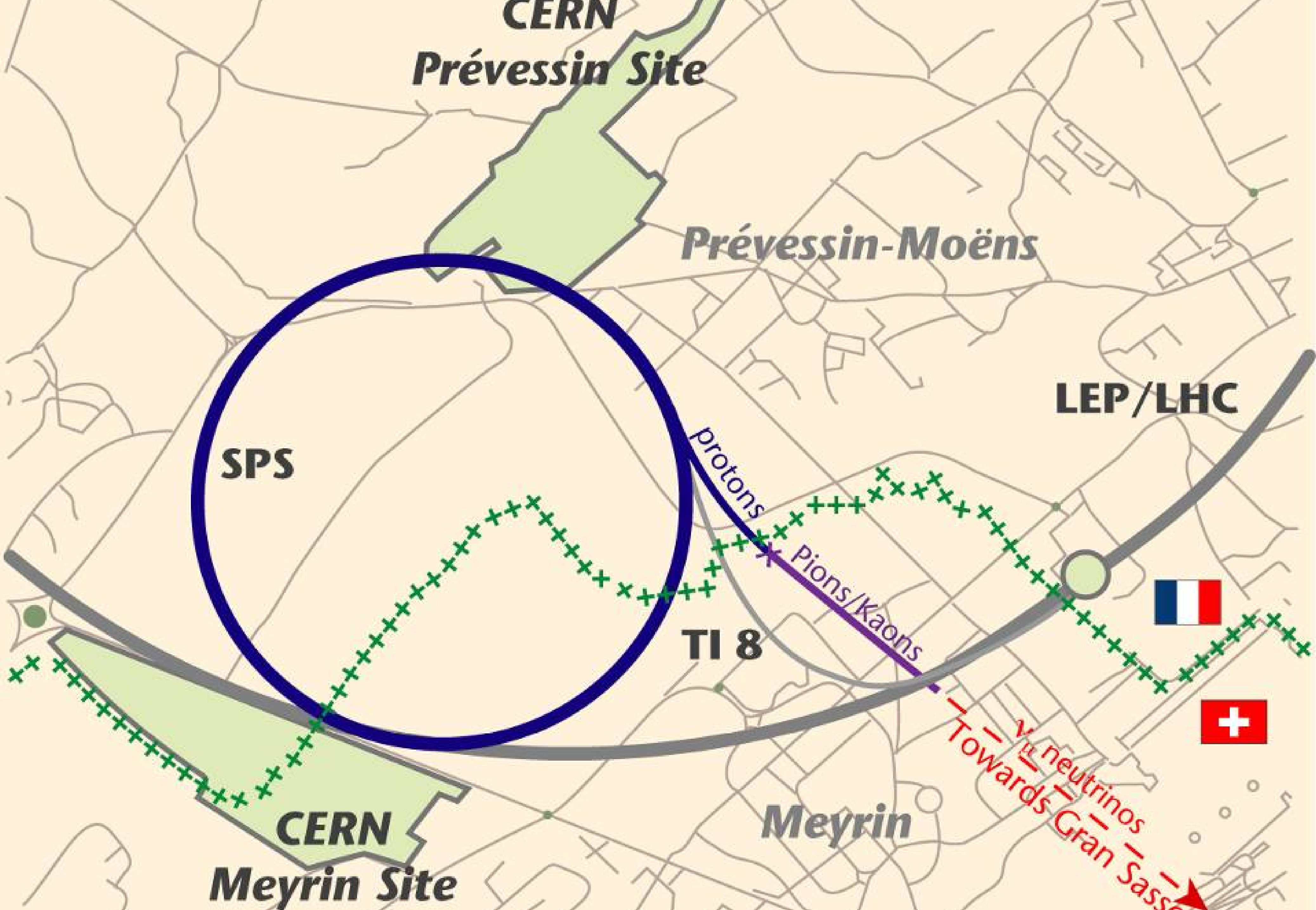
CERN Neutrinos to Gran Sasso



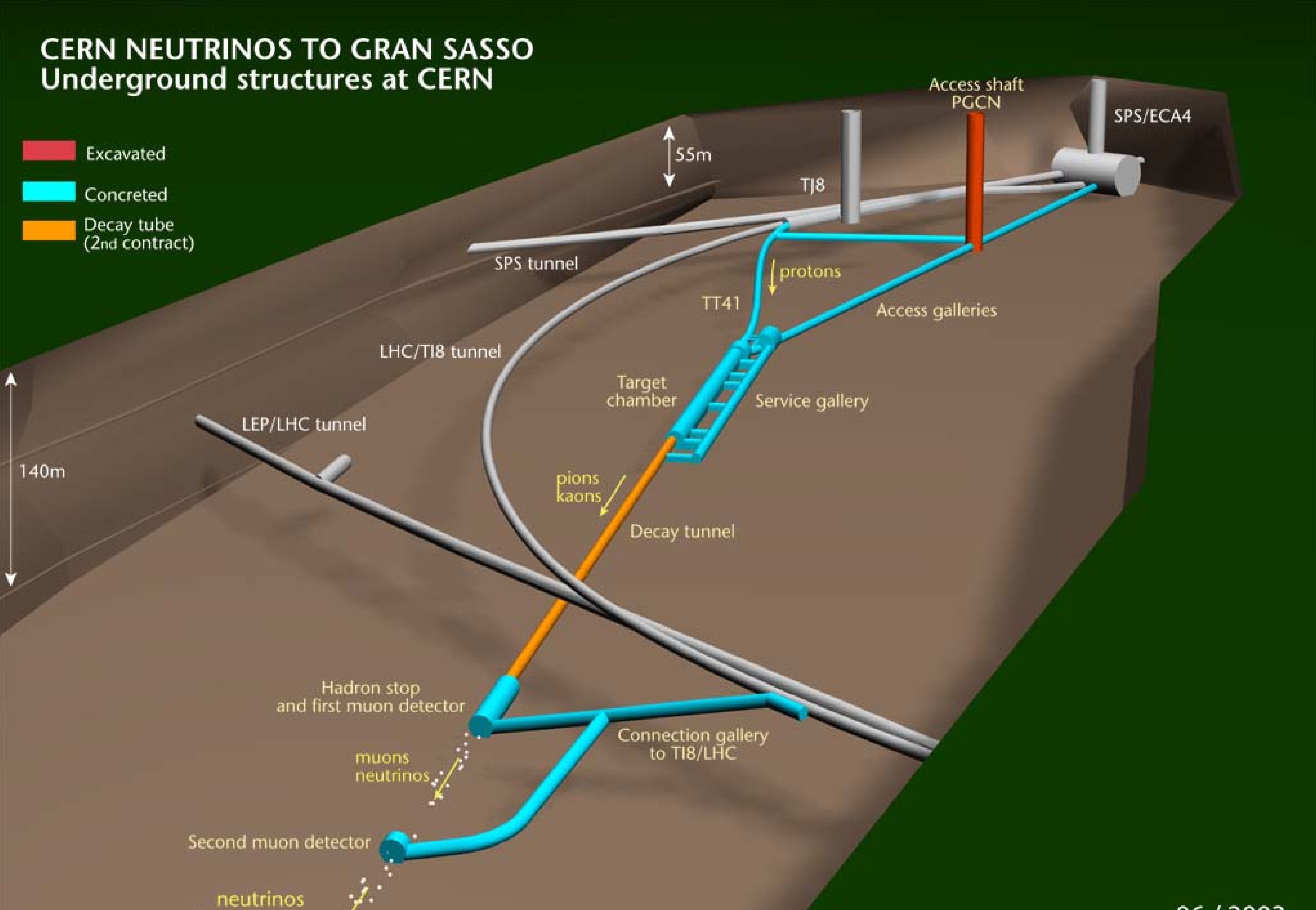
CNGS Layout

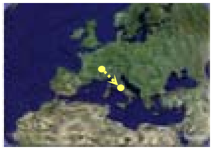


$$p + C \rightarrow \text{(interactions)} \rightarrow \pi^+,\ K^+ \rightarrow \text{(decay in flight)} \rightarrow \mu^+ + \nu_\mu$$



CERN
Prévessin Site
Prévessin-Moëns
LEP/LHC
SPS
protons
Pions/Kaons
TI 8
ν_μ neutrinos
Towards Gran Sasso
Meyrin
CERN
Meyrin Site


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



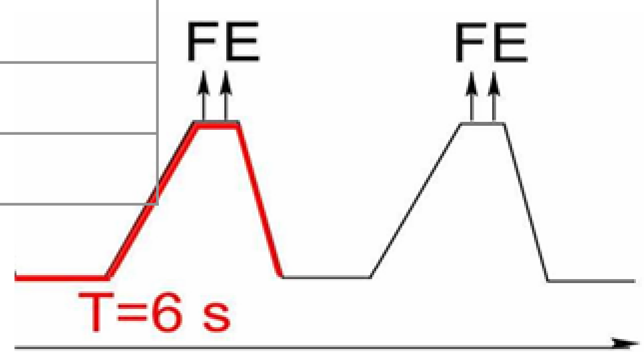
CNGS Proton Beam Parameters

Beam parameters	Nominal CNGS beam
Nominal energy [GeV]	400
Normalized emittance [μm]	H=12 V=7
Emittance [μm]	H=0.028 V= 0.016
Momentum spread Δp/p	0.07 % +/- 20%
# extractions per cycle	2 separated by 50 ms
Batch length [μs]	10.5
# of bunches per pulse	2100
Intensity per extraction [10^{13} p]	2.4
Bunch length [ns] (4σ)	2
Bunch spacing [ns]	5
Beta at focus [m]	hor.: 10 ; vert.: 20
Beam sizes at 400 GeV [mm]	0.5 mm
Beam divergence [mrad]	hor.: 0.05; vert.: 0.03

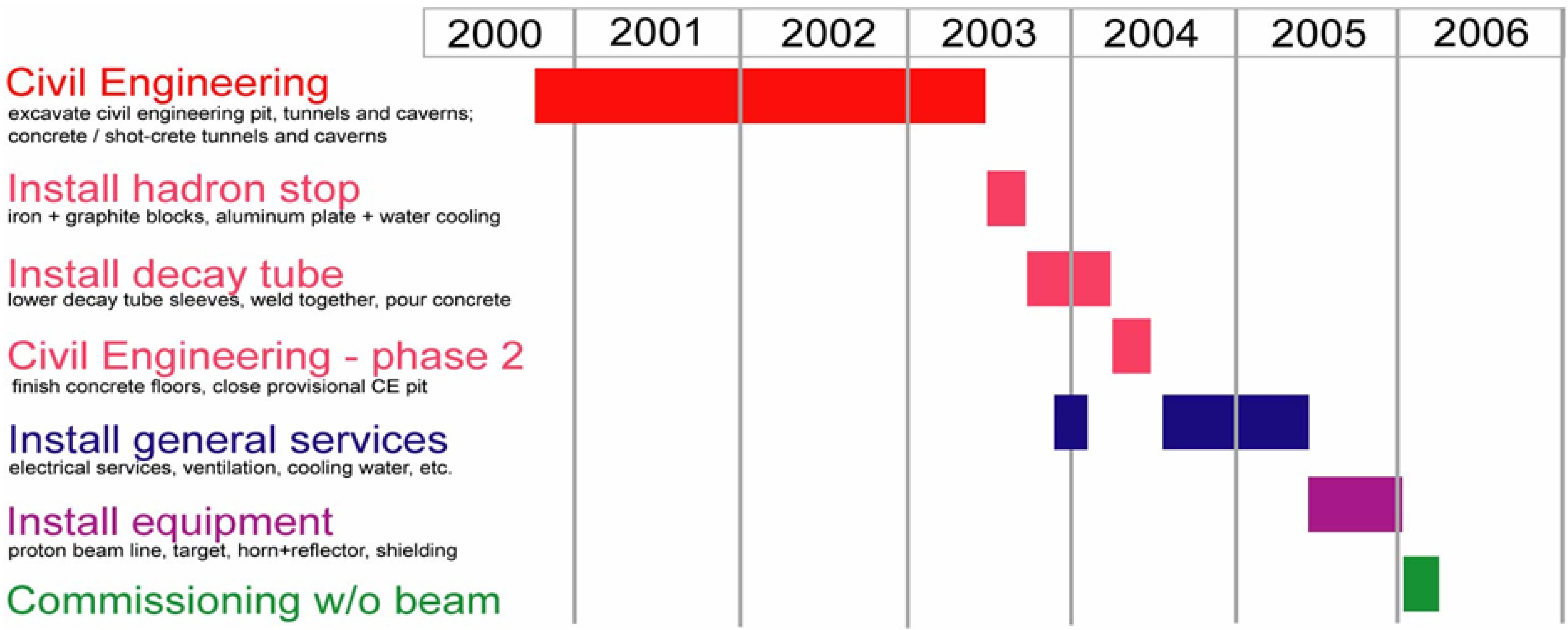
500kW beam power

Upgrade phase: 3.5 10^{13} p

Expected beam performance: 4.5 x 10^{19} protons/year on target

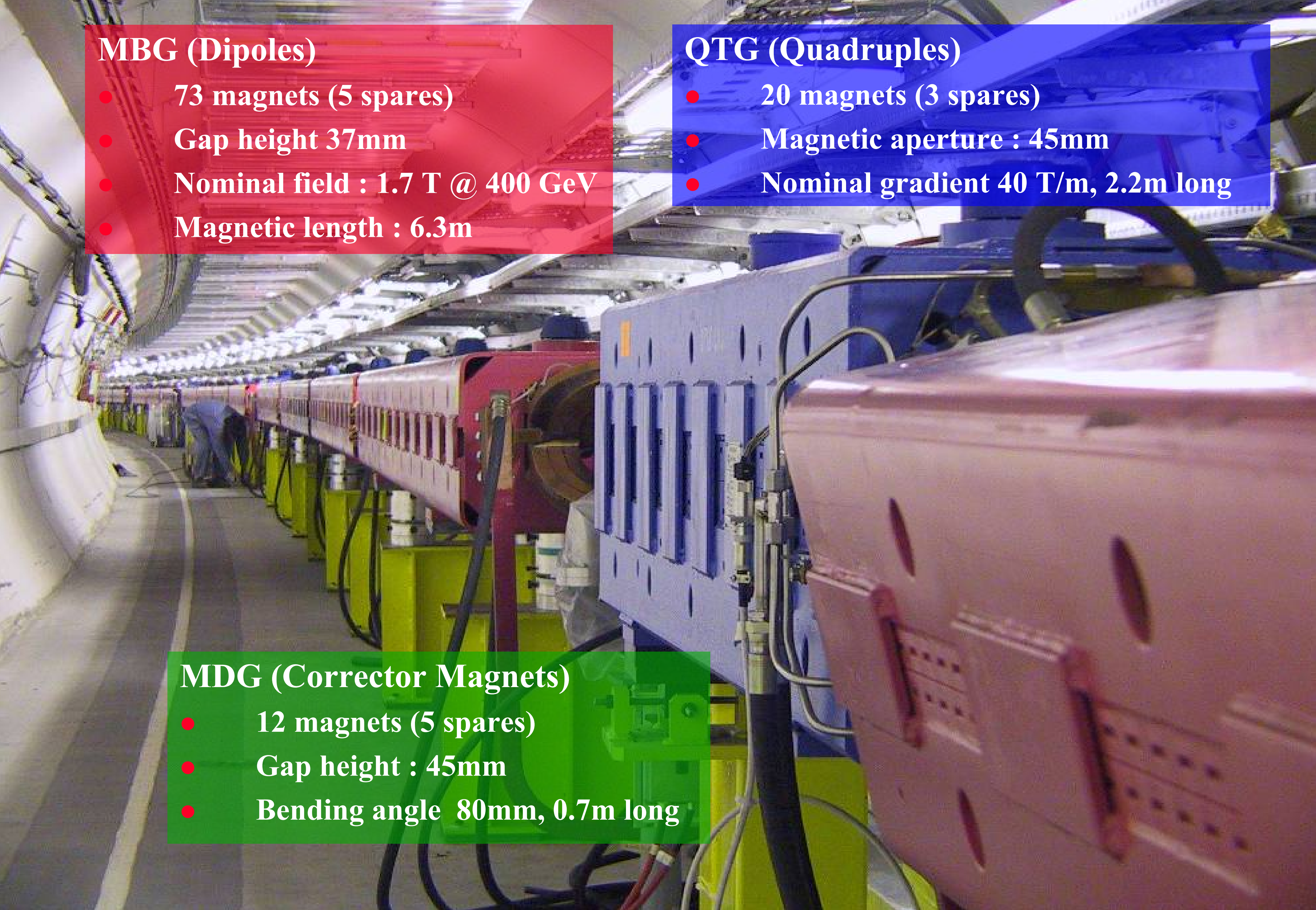


Schedule

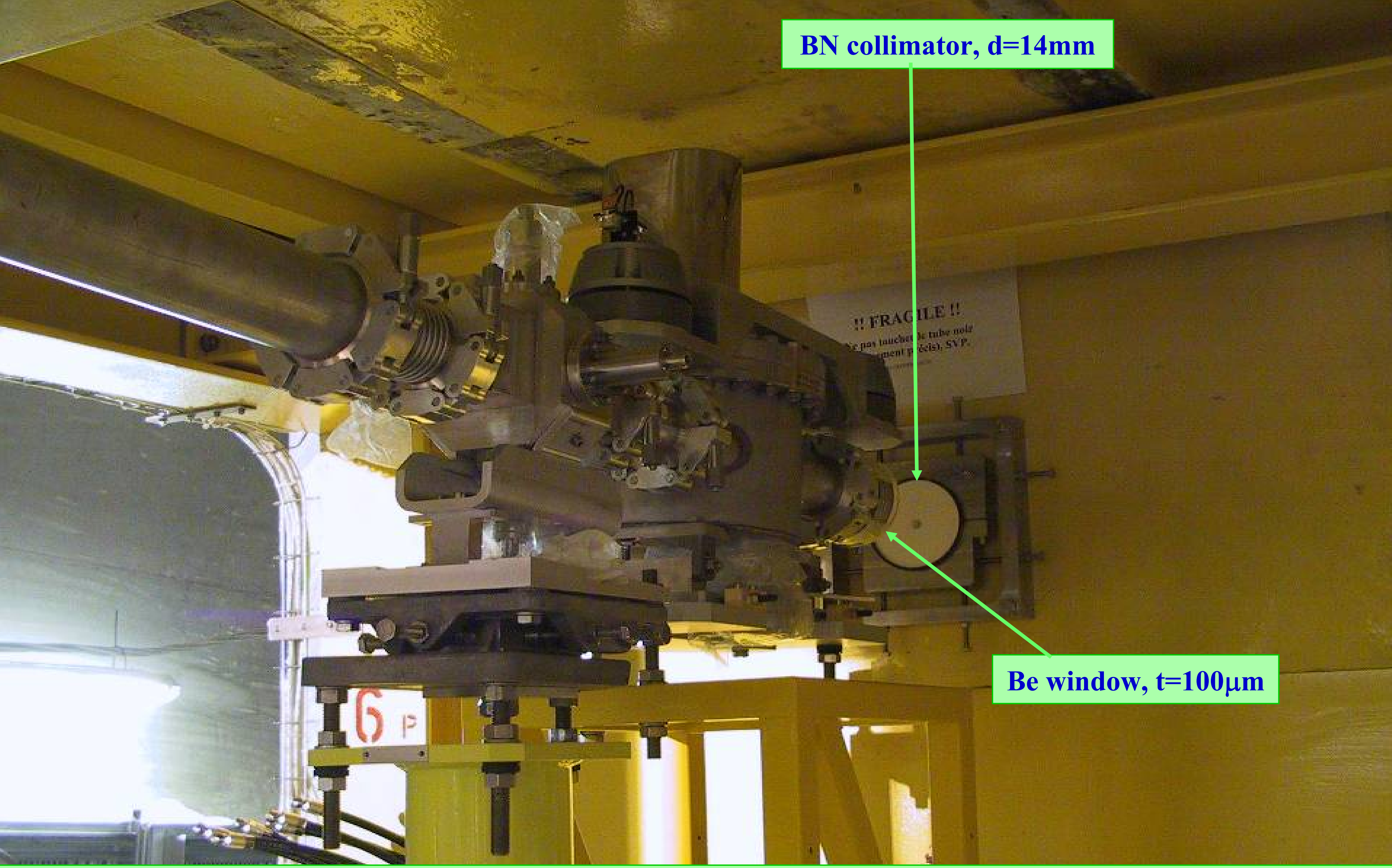


First beam: **10 July 2006**

Proton Beam Line Commissioning


MBG (Dipoles)
73 magnets (5 spares)
Gap height 37mm
Nominal field : 1.7 T @ 400 GeV
Magnetic length : 6.3m
QTG (Quadruples)
20 magnets (3 spares)
Magnetic aperture : 45mm
Nominal gradient 40 T/m, 2.2m long
MDG (Corrector Magnets)
12 magnets (5 spares)
Gap height : 45mm
Bending angle 80mm, 0.7m long

Final focusing onto the target (recuperated magnets)



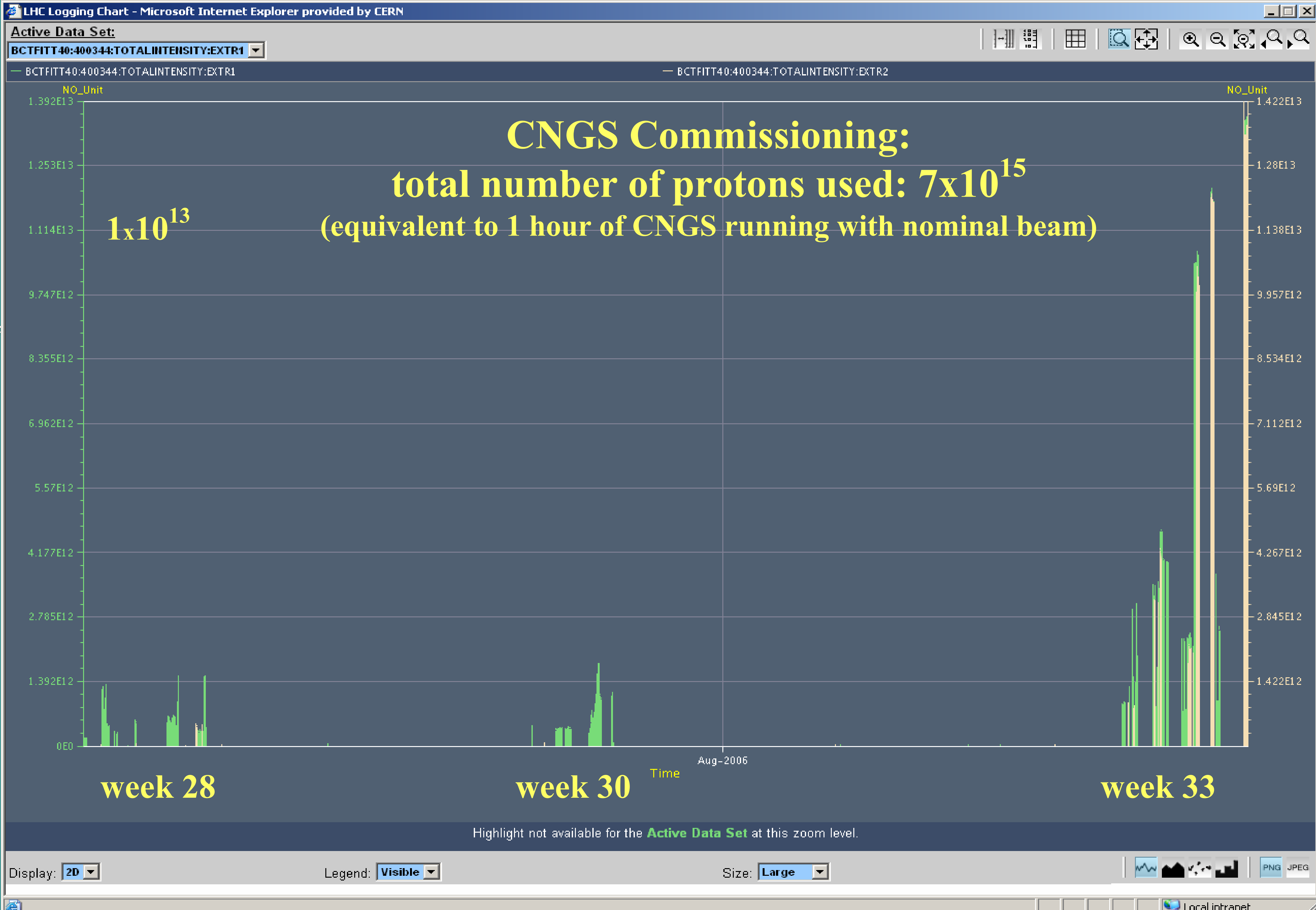
Proton beam: last beam position / beam profile monitors upstream of the target station collimator and shielding

Commissioning Plan

- **Hardware commissioning** **Feb. – April 2006**
  - ➔ **Beam instrumentations**
  - ➔ **Power supplies**
  - ➔ **Magnets (polarities)**
  - ➔ **Vacuum system**
  - ➔ **(April / May: Target / Horn exchange excercises 'real')**

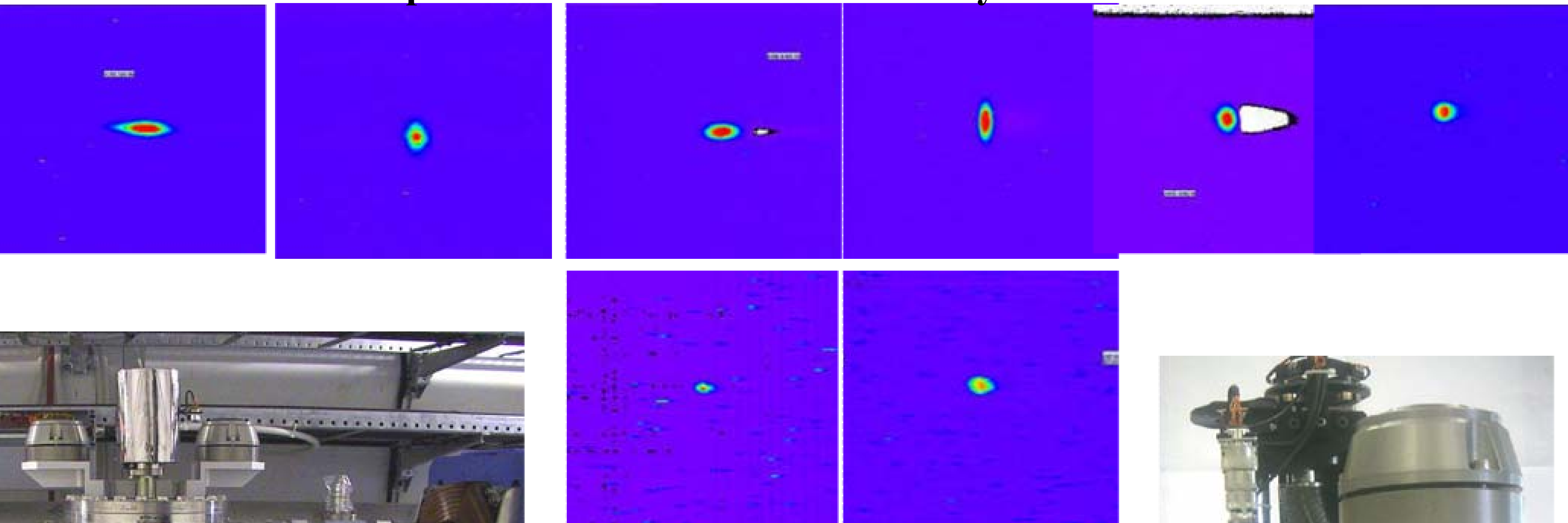
- **'Dry runs' from CCC** **April – May 2006**
  - ➔ **Timing**
  - ➔ **Controls**
  - ➔ **Interlocks**
  - ➔ **Beam permit**
  - ➔ **Magnets (currents & polarities)**

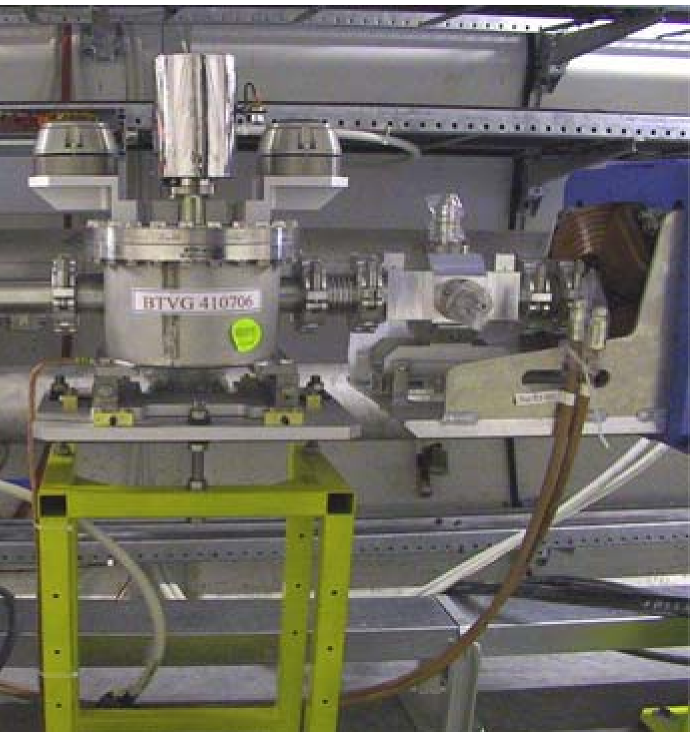
- **Commissioning with beam** **2006: weeks 28, 30 and 33**


LHC Logging Chart - Microsoft Internet Explorer provided by CERN
Active Data Set:
BCTFITT40:400344:TOTALINTENSITY:EXTR1
— BCTFITT40:400344:TOTALINTENSITY:EXTR1
— BCTFITT40:400344:TOTALINTENSITY:EXTR2
NO_Unit
NO_Unit
CNGS Commissioning:
total number of protons used: 7x10^15
(equivalent to 1 hour of CNGS running with nominal beam)
1x10^13
1.392E13
1.253E13
1.114E13
9.747E12
8.355E12
6.962E12
5.57E12
4.177E12
2.785E12
1.392E12
0E0
1.422E13
1.28E13
1.138E13
9.957E12
8.534E12
7.112E12
5.69E12
4.267E12
2.845E12
1.422E12
Aug-2006
Time
week 28
week 30
week 33
Highlight not available for the Active Data Set at this zoom level.
Display: 2D
Legend: Visible
Size: Large
PNG
JPEG
Local intranet

FIRST SHOT 11 July 2006

1st shot down proton beam line: beam is already well centered on screens



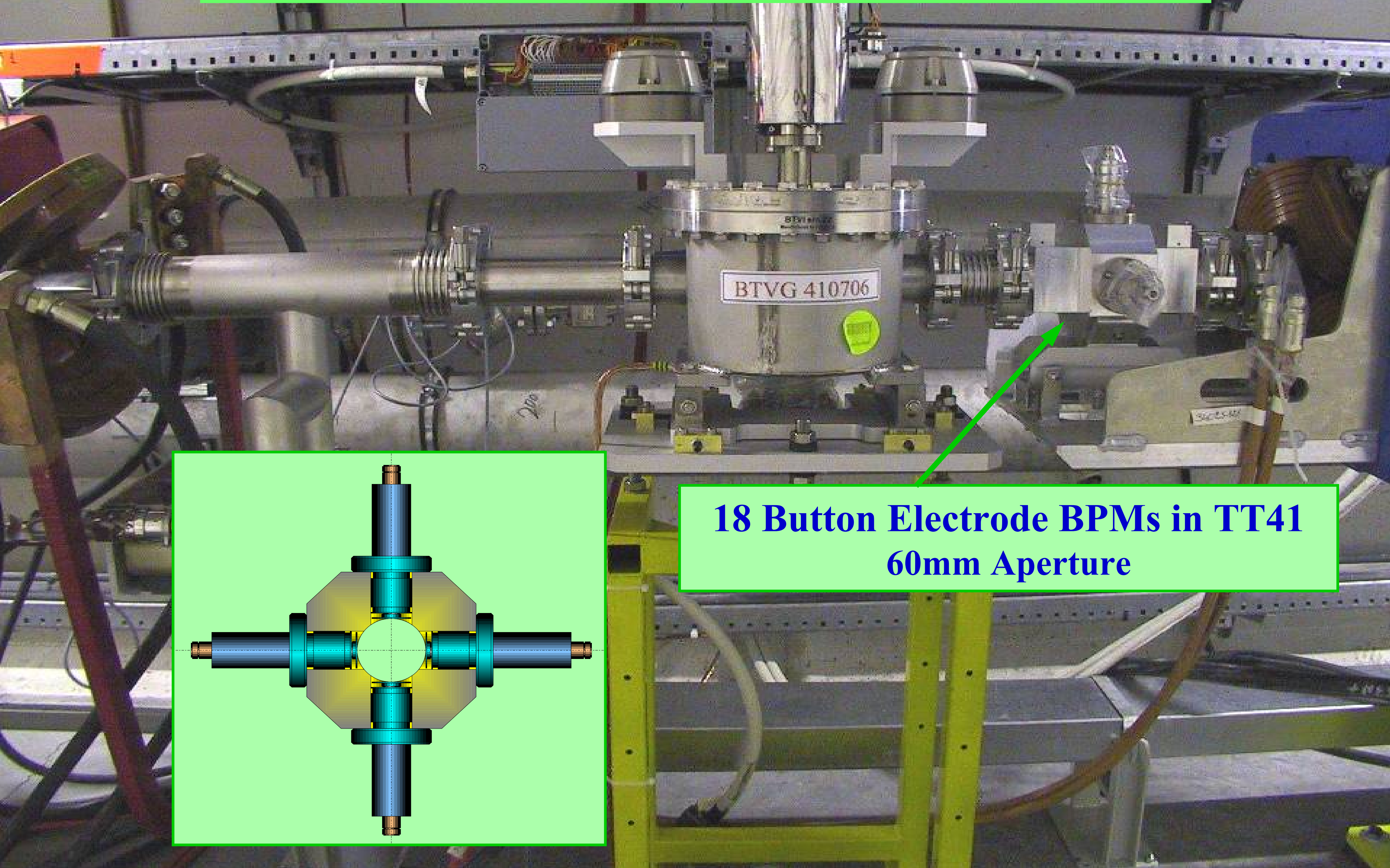


8 profile monitors (BTVG):

Optical Transition Radiation screens:

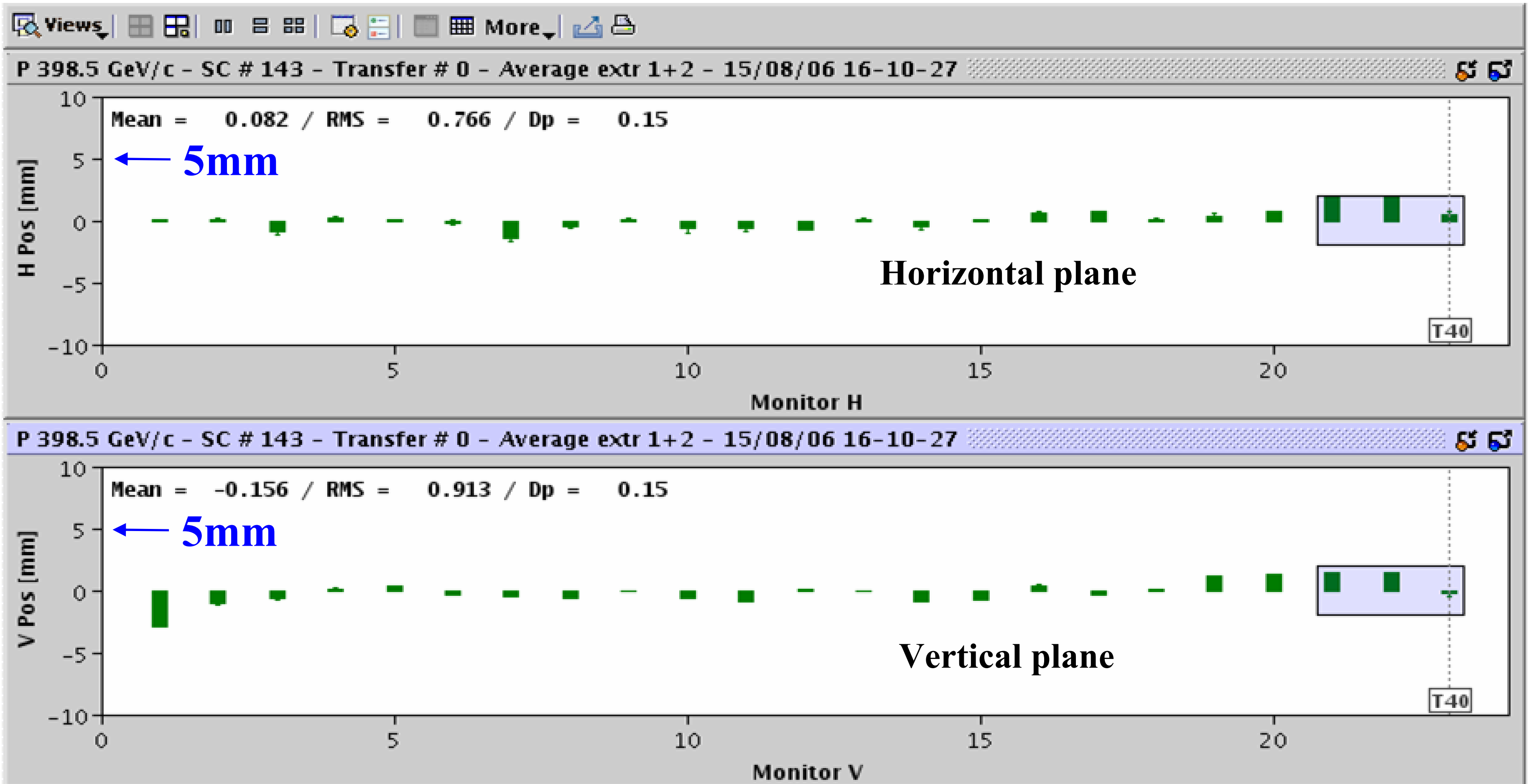
- **75 µm carbon**
- **12 µm titanium screens**

CNGS Beam Position Monitors



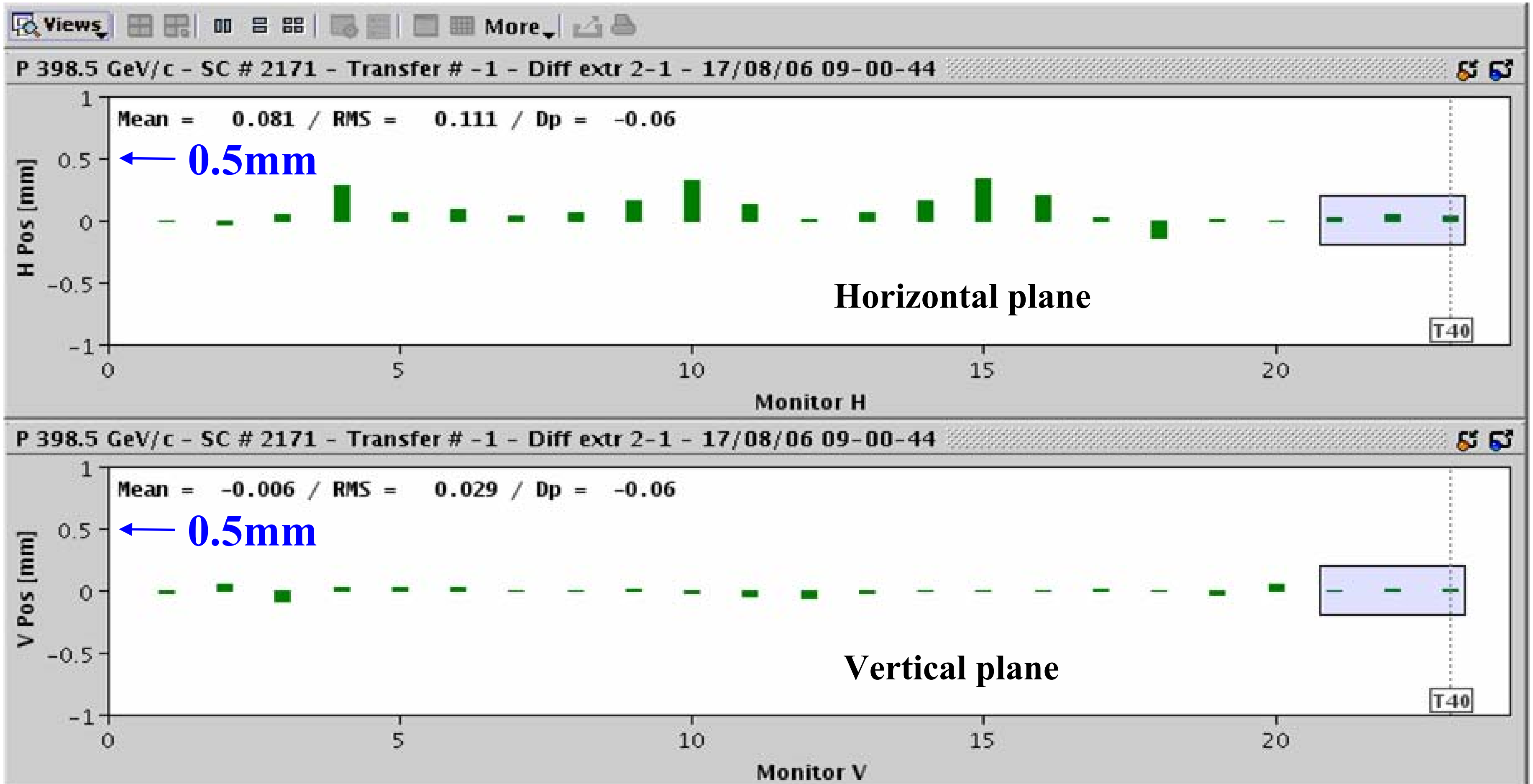
Trajectory along the Beam Line

Average of two extractions. 1E13 protons per batch



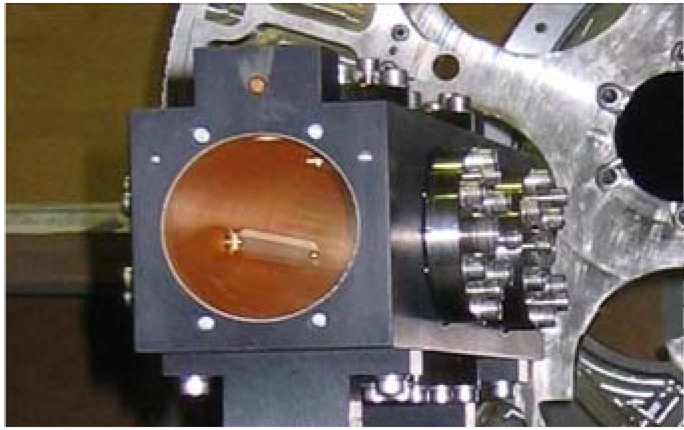
Trajectory Difference btw. 2 Extractions

energy difference of $6 \cdot 10^{-5}$

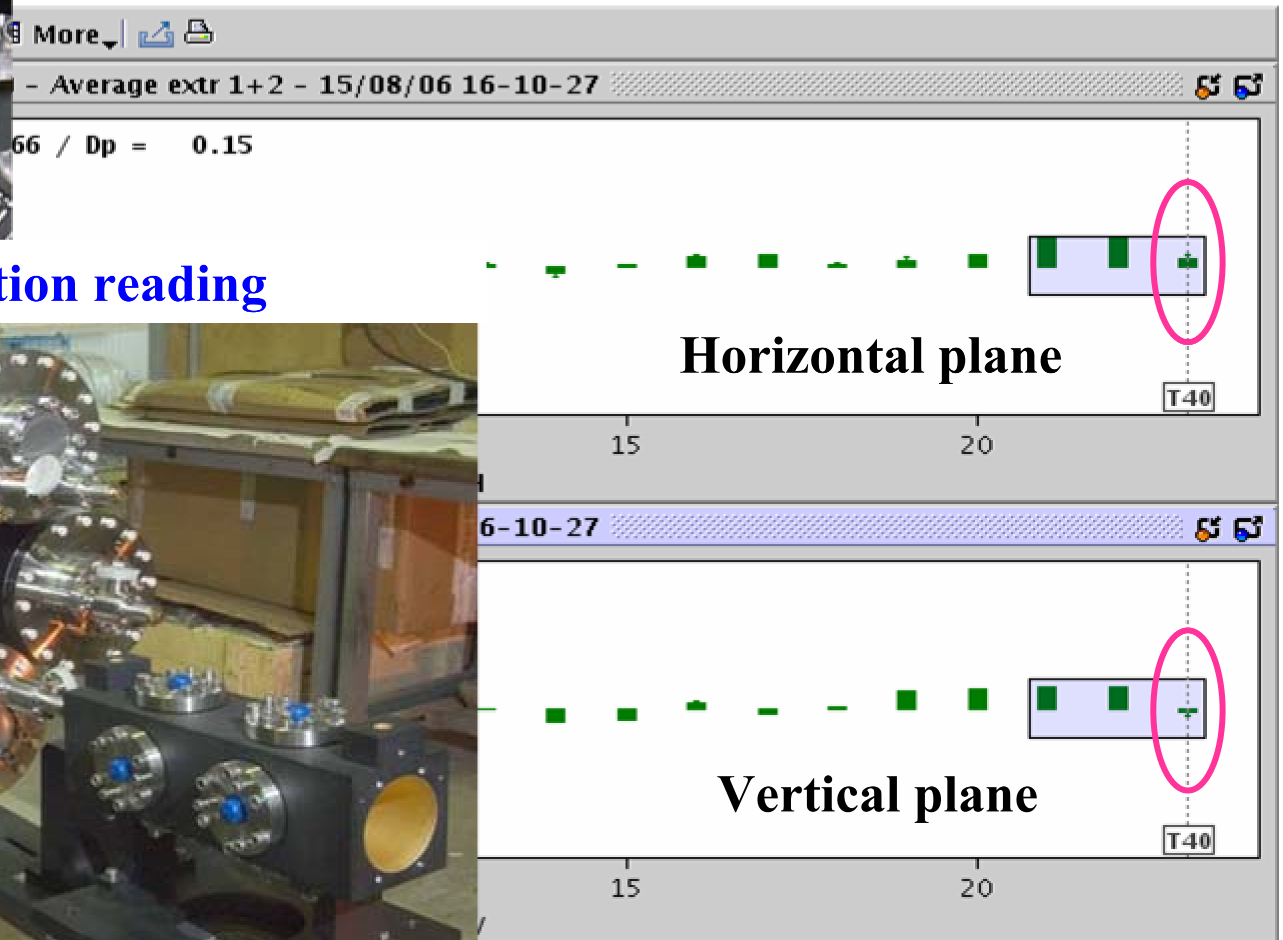


➔ **Beam position stability onto the target over the 3 first days: ~50 µm rms**

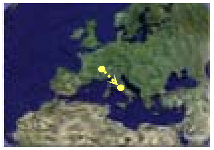
CNGS Target Beam Position Monitor



Stripline coupler pick-up, operated in air

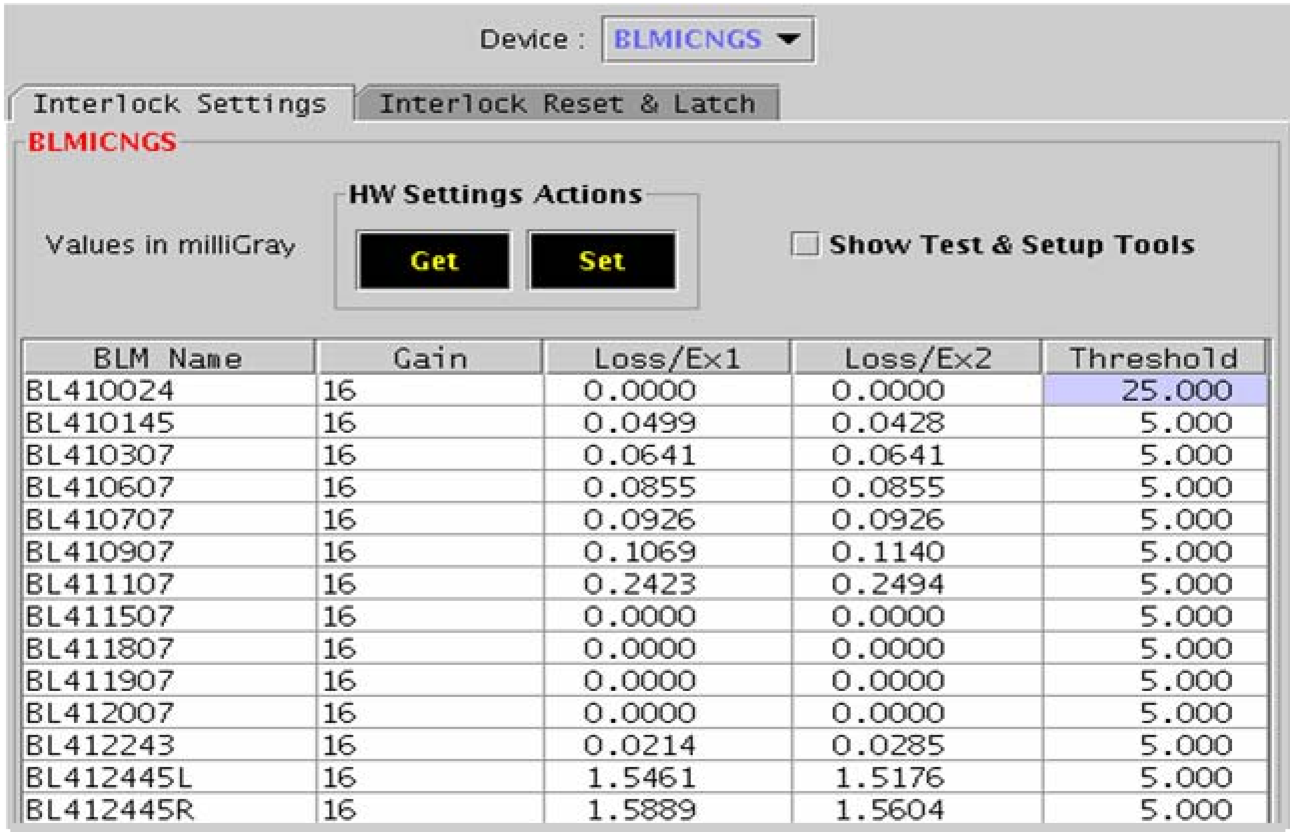


➔ very reliable position reading



Beam Losses along the Proton Line

TT41: ALL screens OUT, at the exception of the target one



Device : BLMICNGS

Interlock Settings | Interlock Reset & Latch

BLMICNGS

Values in milliGray

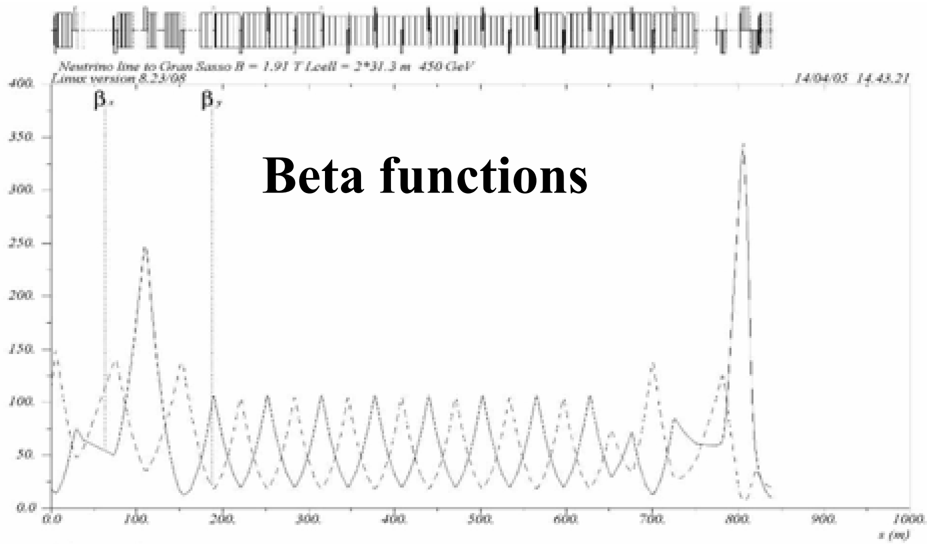
HW Settings Actions: Get | Set

Show Test & Setup Tools

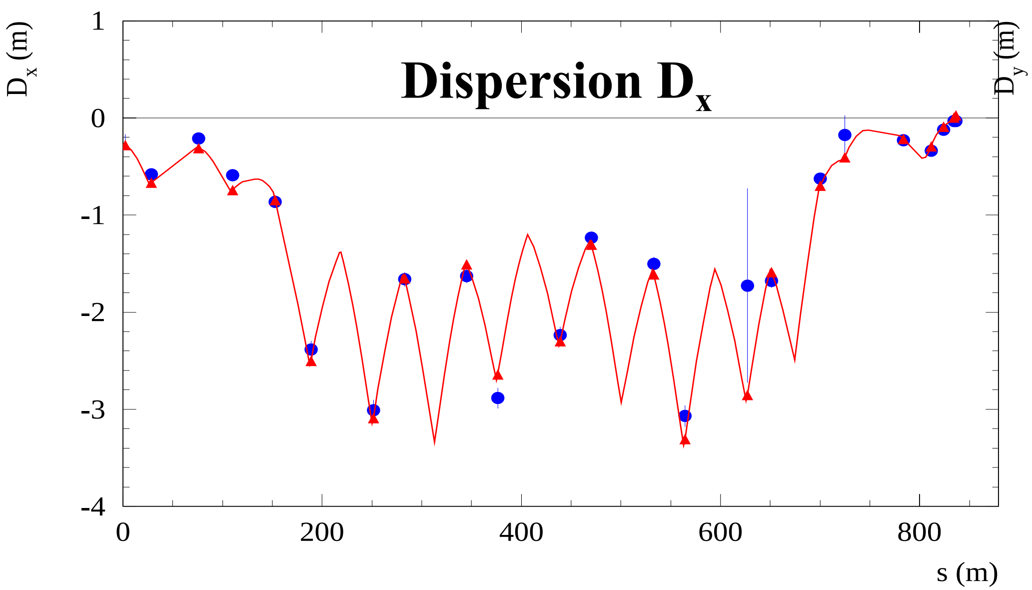
BLM Name	Gain	Loss/Ex1	Loss/Ex2	Threshold
BL410024	16	0.0000	0.0000	25.000
BL410145	16	0.0499	0.0428	5.000
BL410307	16	0.0641	0.0641	5.000
BL410607	16	0.0855	0.0855	5.000
BL410707	16	0.0926	0.0926	5.000
BL410907	16	0.1069	0.1140	5.000
BL411107	16	0.2423	0.2494	5.000
BL411507	16	0.0000	0.0000	5.000
BL411807	16	0.0000	0.0000	5.000
BL411907	16	0.0000	0.0000	5.000
BL412007	16	0.0000	0.0000	5.000
BL412243	16	0.0214	0.0285	5.000
BL412445L	16	1.5461	1.5176	5.000
BL412445R	16	1.5889	1.5604	5.000

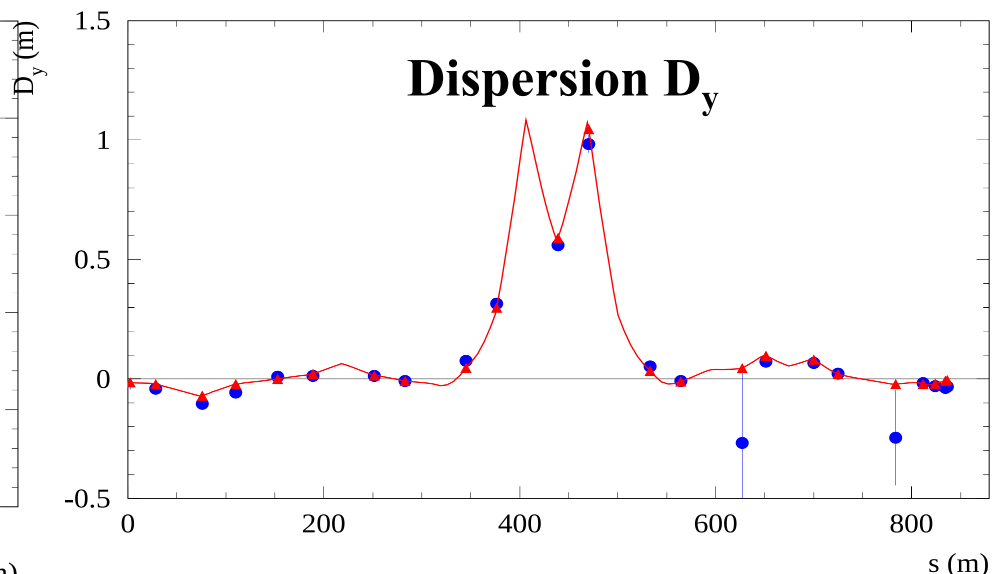
CNGS BLMs with double extraction $1 \cdot 10^{13}$

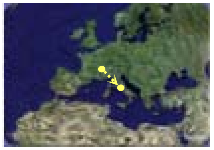
Optics Check



good agreement with theory

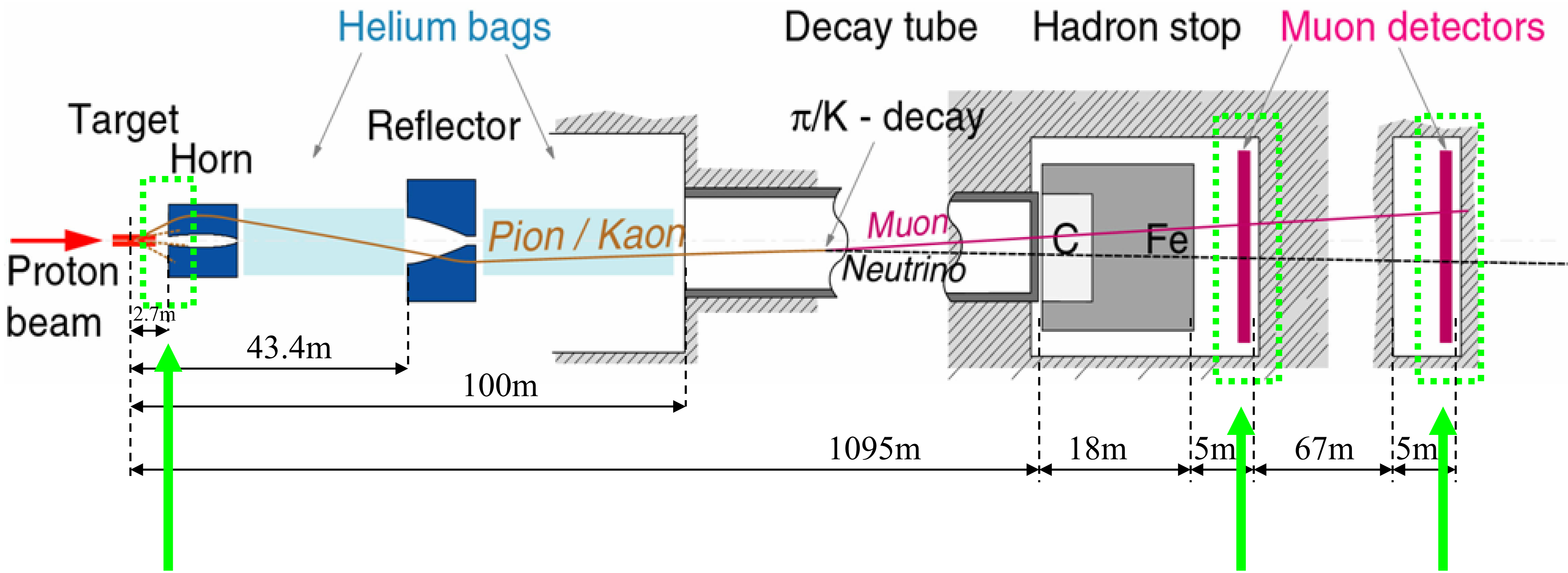






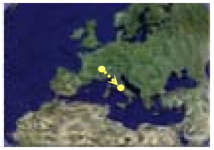
Secondary Beam Line Commissioning

CNGS Secondary Beam Layout



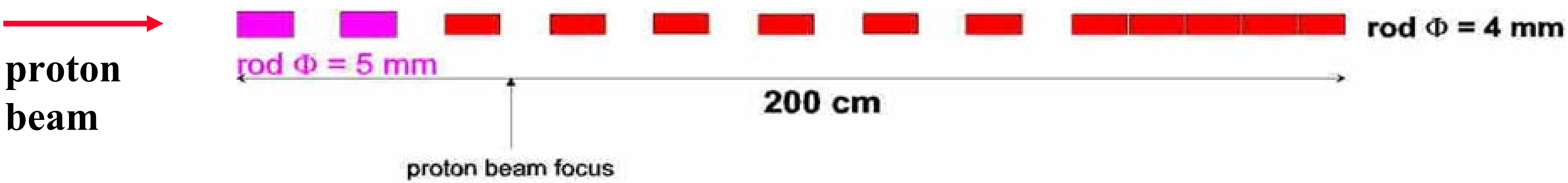
TBID / 2 Ionization Chambers **Muon Detectors**

TBID: Target Beam Instrumentation Downstream



CNGS Target Elements

10 cm long graphite rods, Ø = 5mm and/or 4mm



Note: - target rods thin / interspaced to “let the pions out”

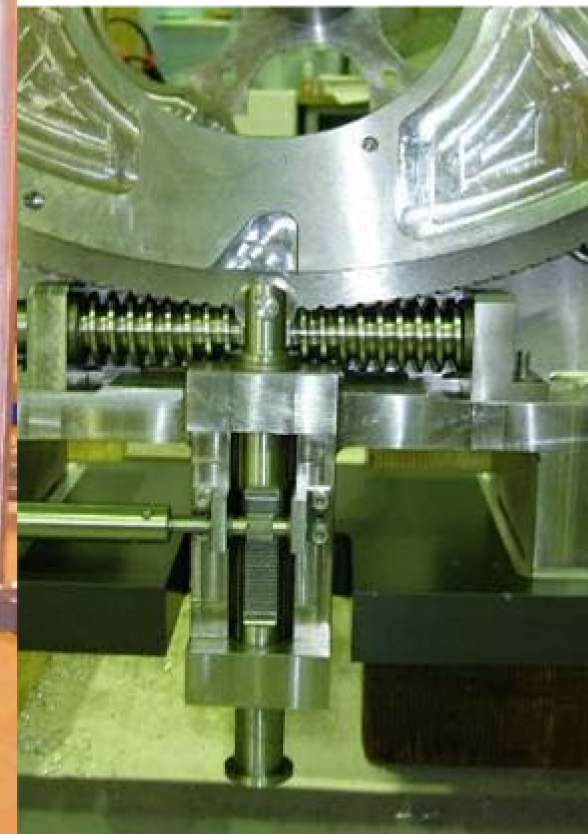
- **target shall be robust to resist the beam-induced stresses**

- **target is air-cooled (particle energy deposition)**

Target Units

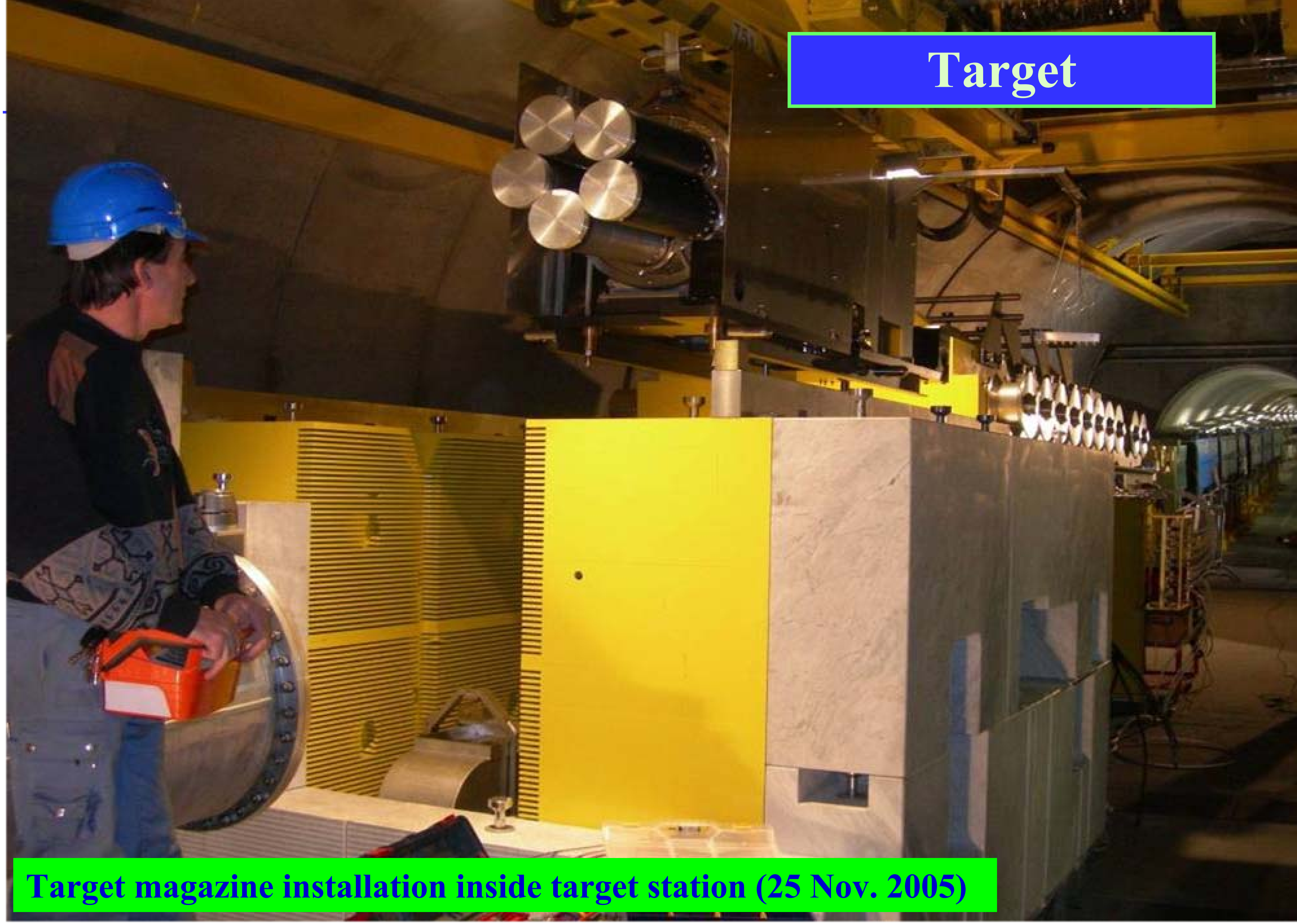
Ten targets (+1 prototype) have been built. They are assembled in two magazines.

Target Magazine



indexing finger

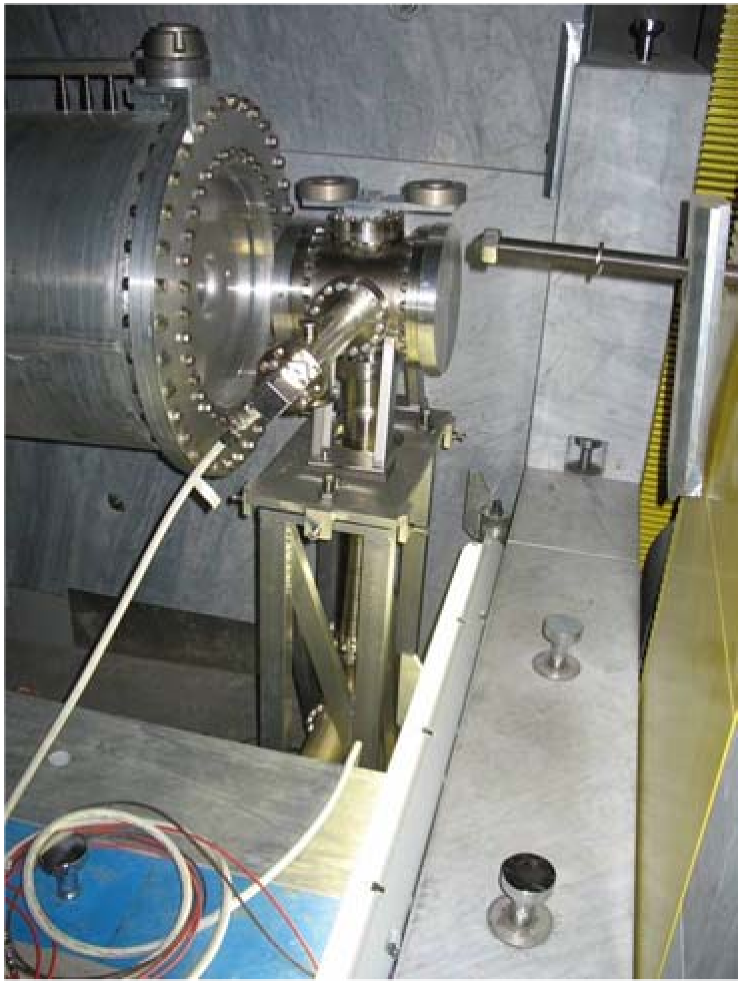
Target



Target magazine installation inside target station (25 Nov. 2005)

TBID (Target Beam Instrumentation Downstream)

- **Check efficiency of particle production in the target**
  - **Multiplicity (Compare with BFCT upstream of the target)**
  - **Misalignment of the Beam vs. Target**

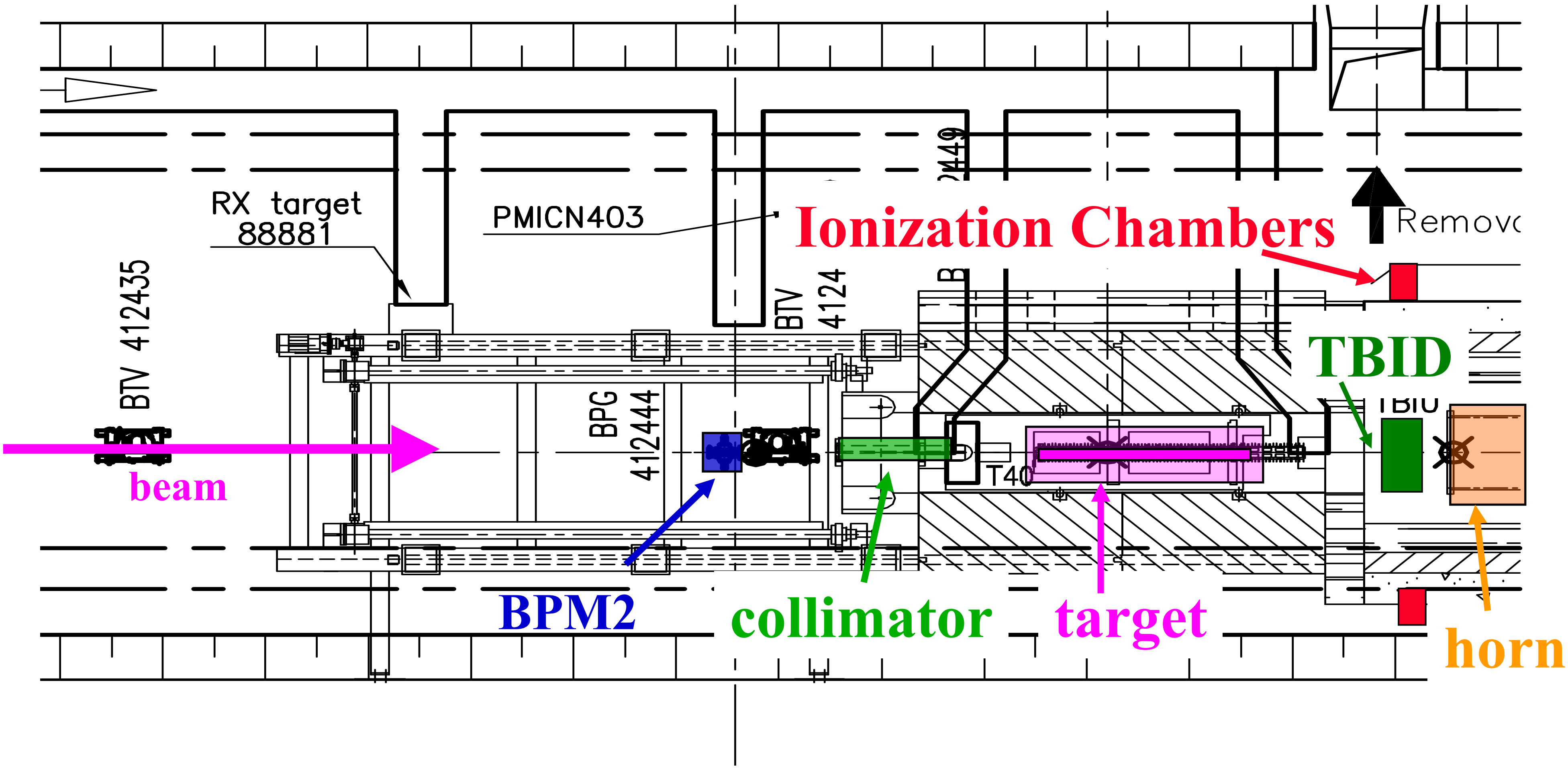


TBID Monitor

- **Secondary emission monitor**
- **12 μm Ti foils**
- **diameter = 145mm**
- **better than 10^{-4} mbar vacuum**

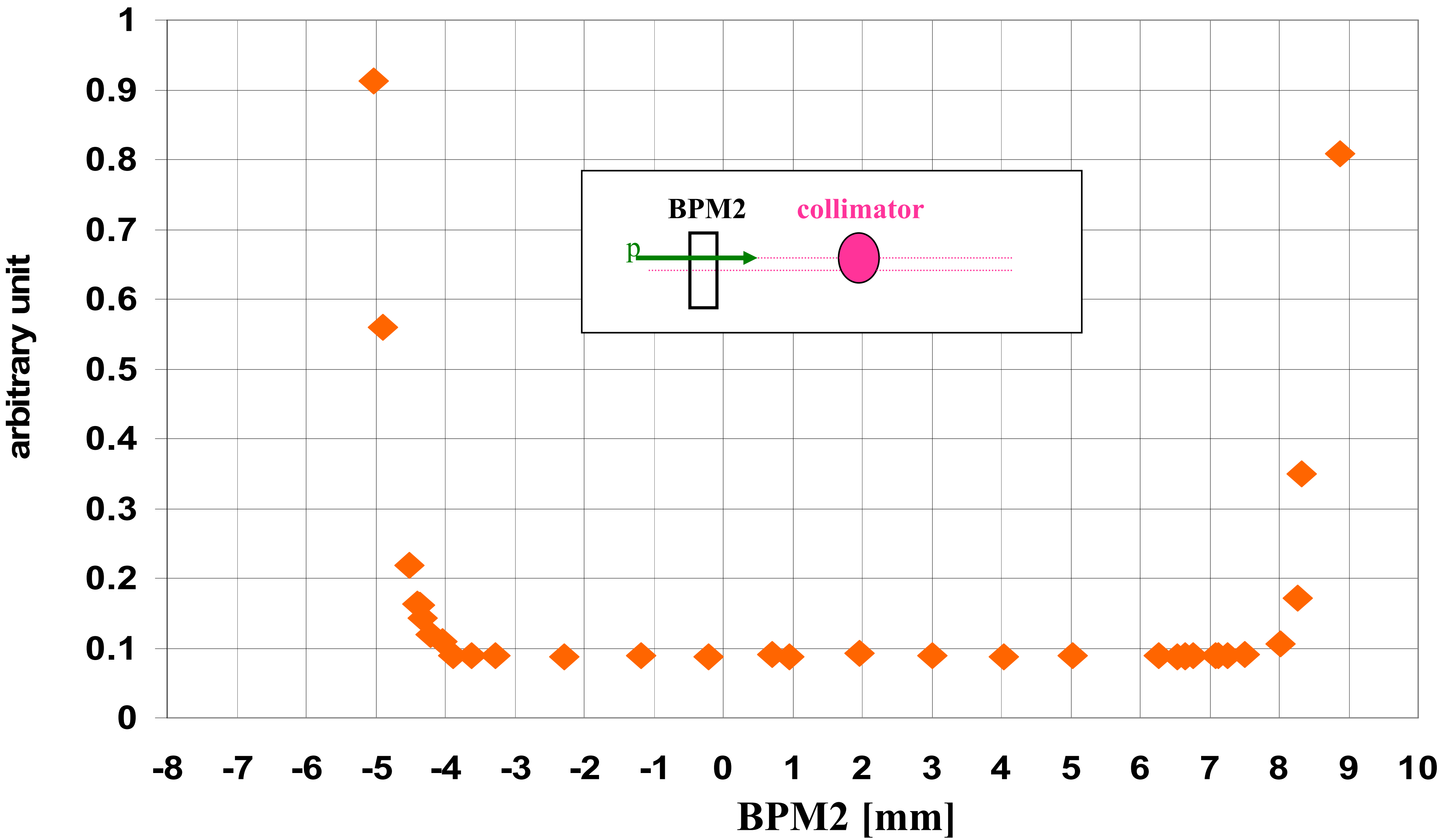
TBID Monitor might not survive if high intensity beam misses the target
→Ionization Chambers as back-up (SPS-type BLMs)

Target Region Layout

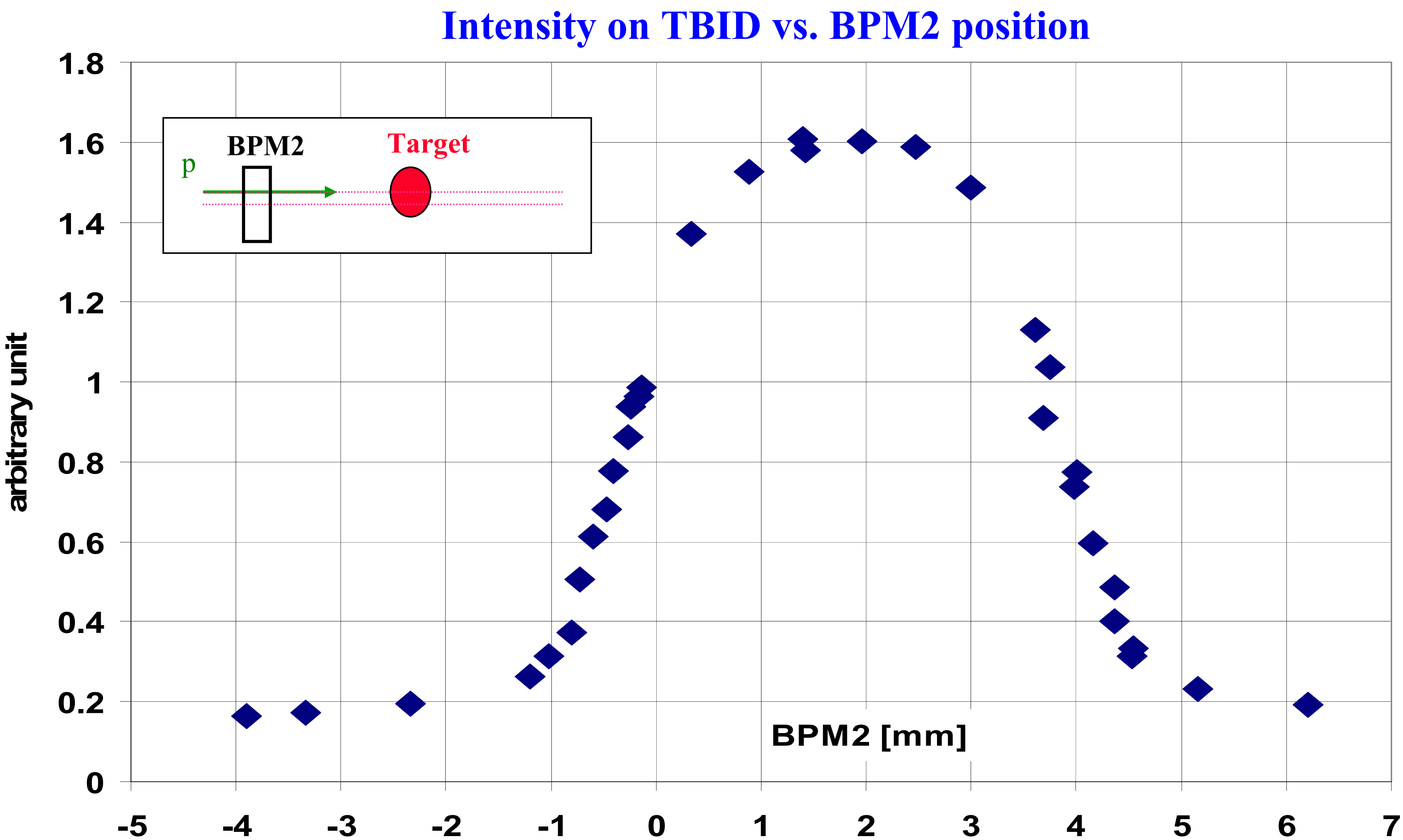


Horizontal Beam Scan, Target Out

Intensity on TBID vs. BPM2



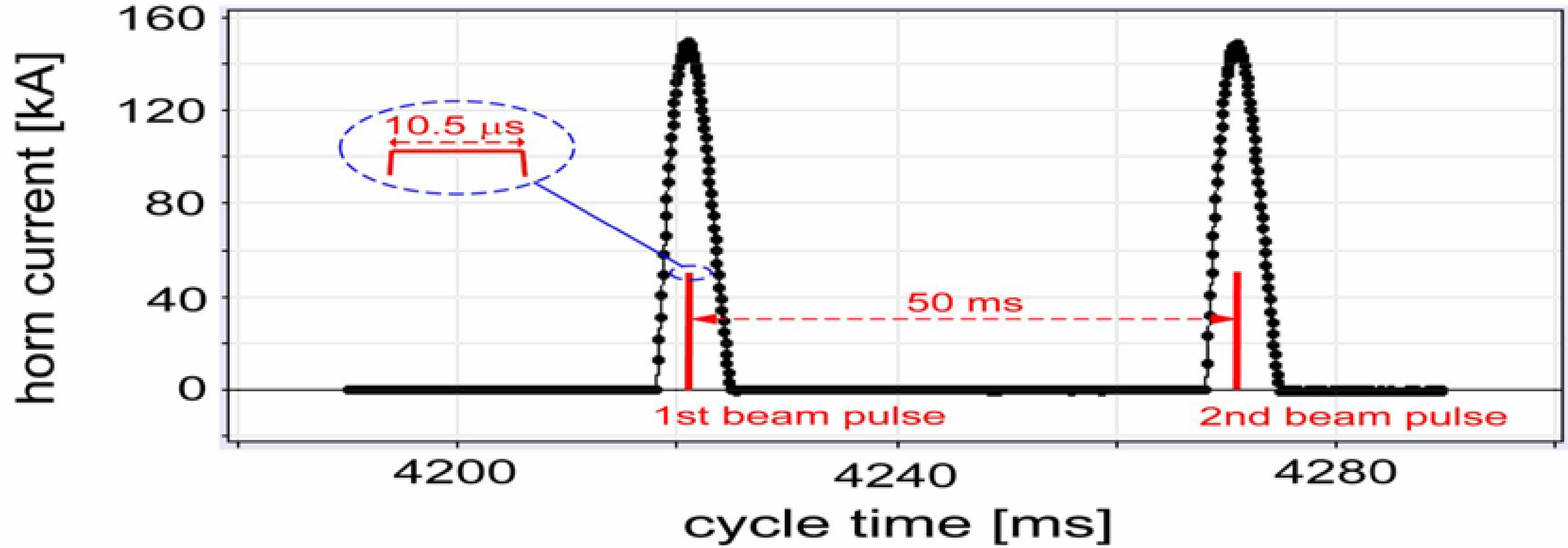
Horizontal Beam Scan, Target IN



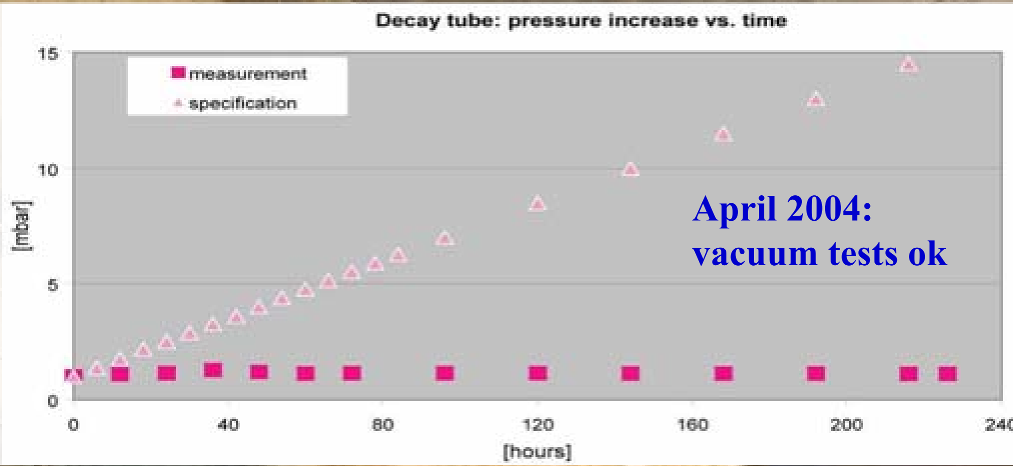
Horn

Installation of the horn in the target chamber

Horn/Reflector Power System



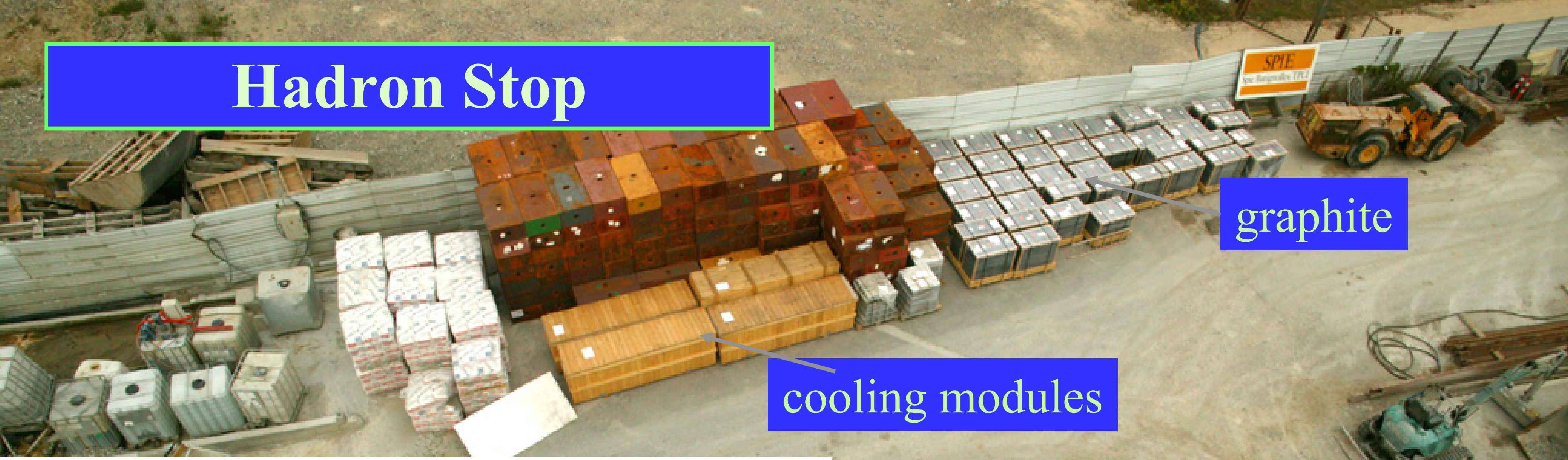
	Unit	HORN System	REFLECTOR System
Load Peak current	kA	150	180
Pulse duration	ms	6.5	9.8
Transformer ratio		16	32
Primary peak current	A	9375	5646
Charging voltage	V	6300	5800
Water flow for delta T=5C	l/min	75	48
Pressure	bar	1.2	1.2



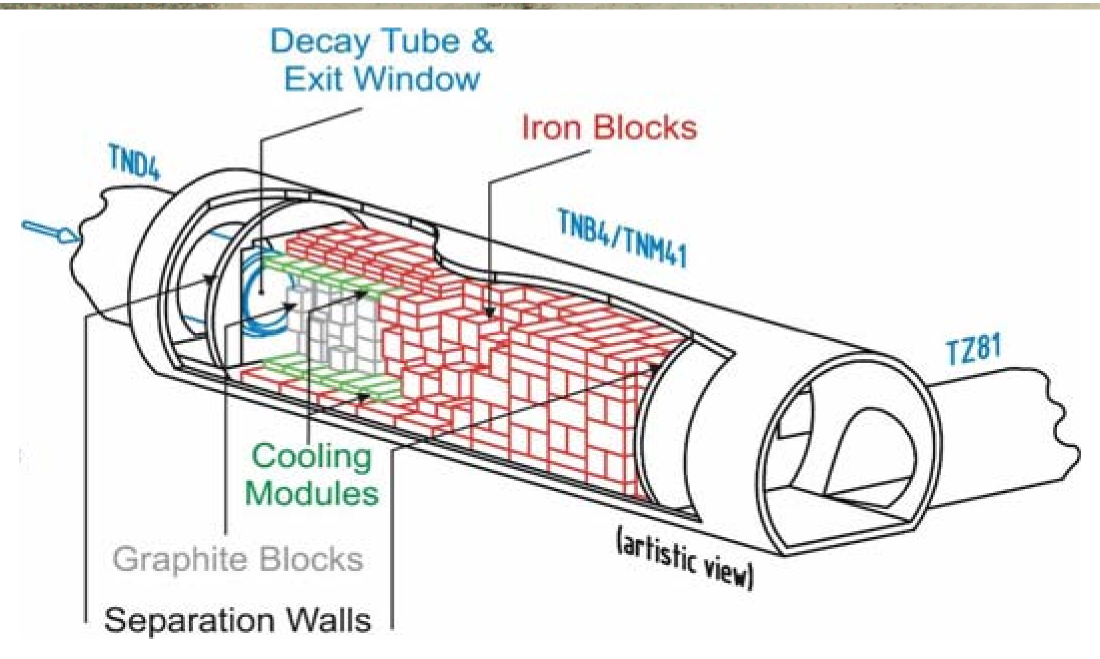
Decay Tube

- steel pipe
- 1mbar
- 994m long
- 2.45m diameter, t=18mm, surrounded by 50cm concrete
- entrance window: 3mm Ti
- exit window: 50mm carbon steel, water cooled

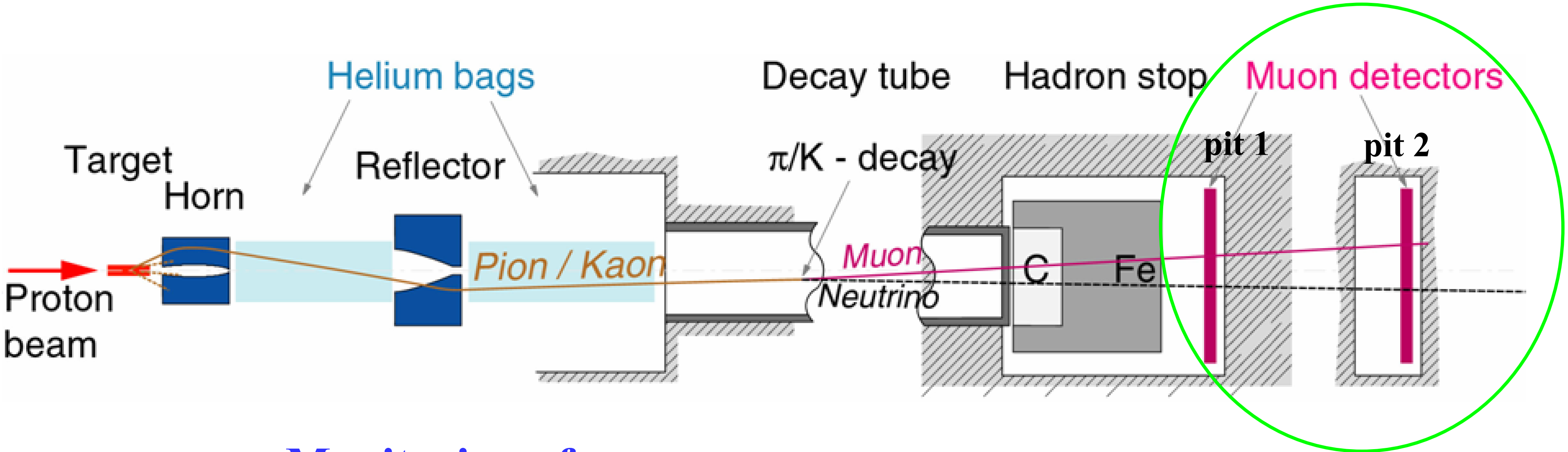
Hadron Stop



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



Muon Monitors

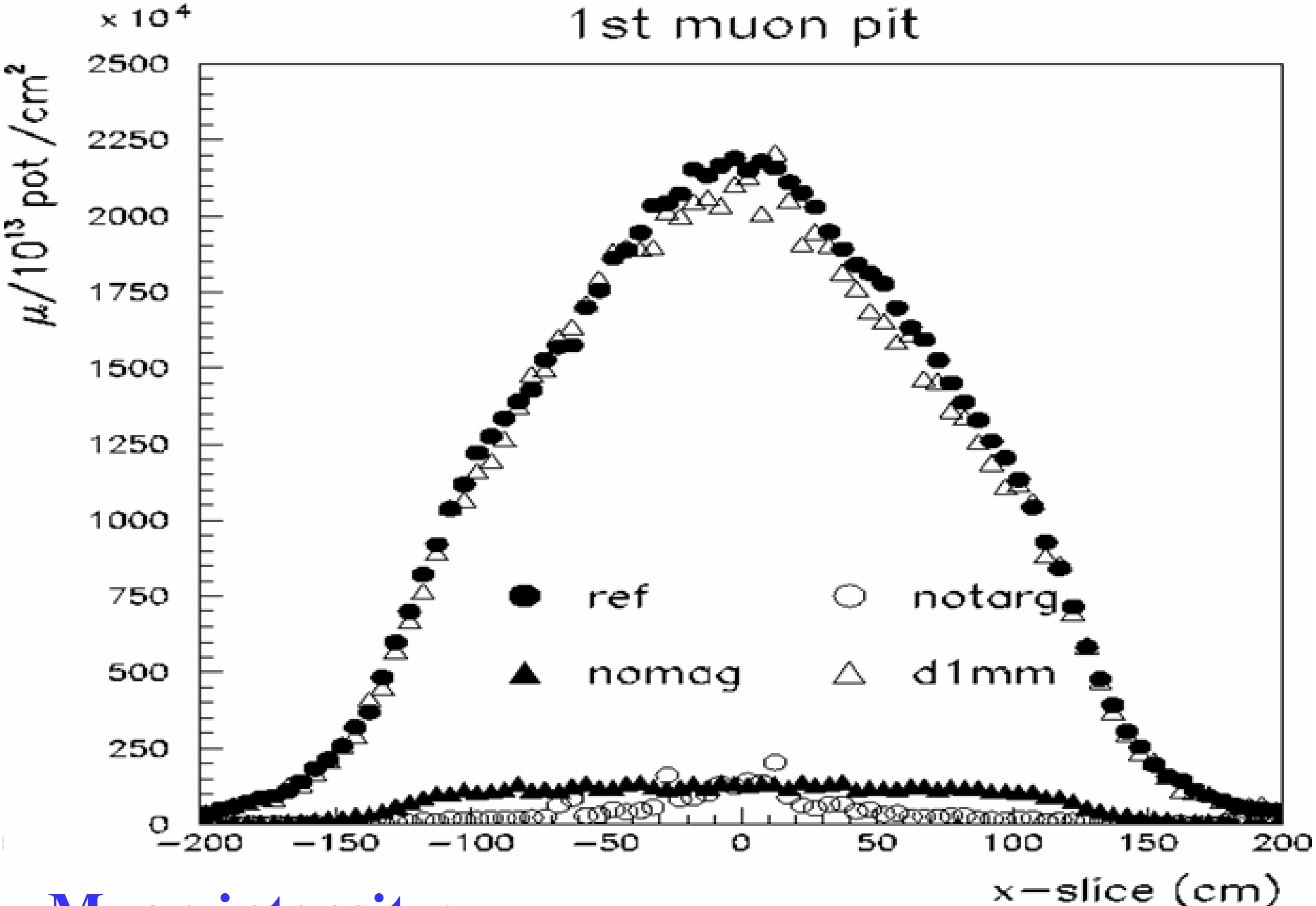


Monitoring of:

- **muon intensity**
- **muon beam profile shape**
- **muon beam profile centre**

Muon energy filter due to 67m rock in between pit 1 and pit 2.

Expected Muon Signals (FLUKA)

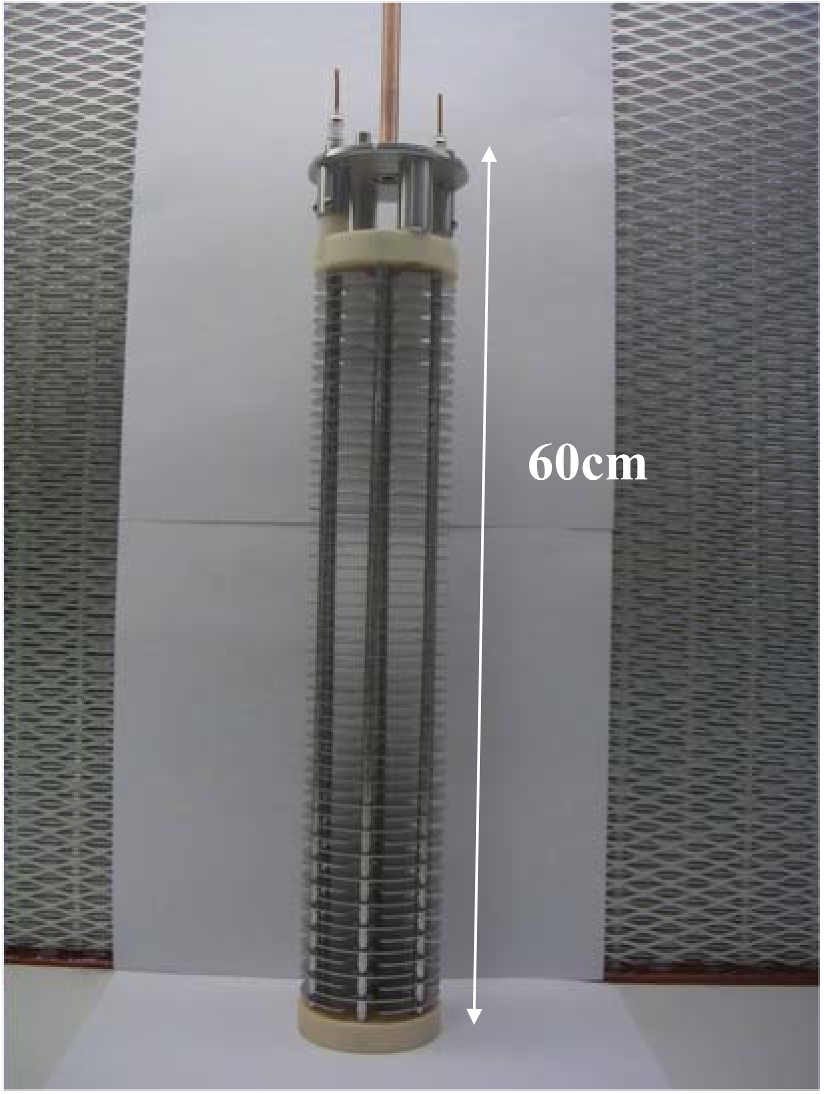


Muon intensity:

Up to ~8×10^7 per cm^2 and 10.5μs

→ Detector choice: ionization chambers

Muon Monitor Layout



LHC type Beam Loss Monitors

- Parallel electrodes separated by 0.5 cm
- Stainless steel cylinder
- Al electrodes
- N_2 gas filling at 100 mbar over pressure
- Diameter=8.9cm, active length=34.5cm, 1.5 litre

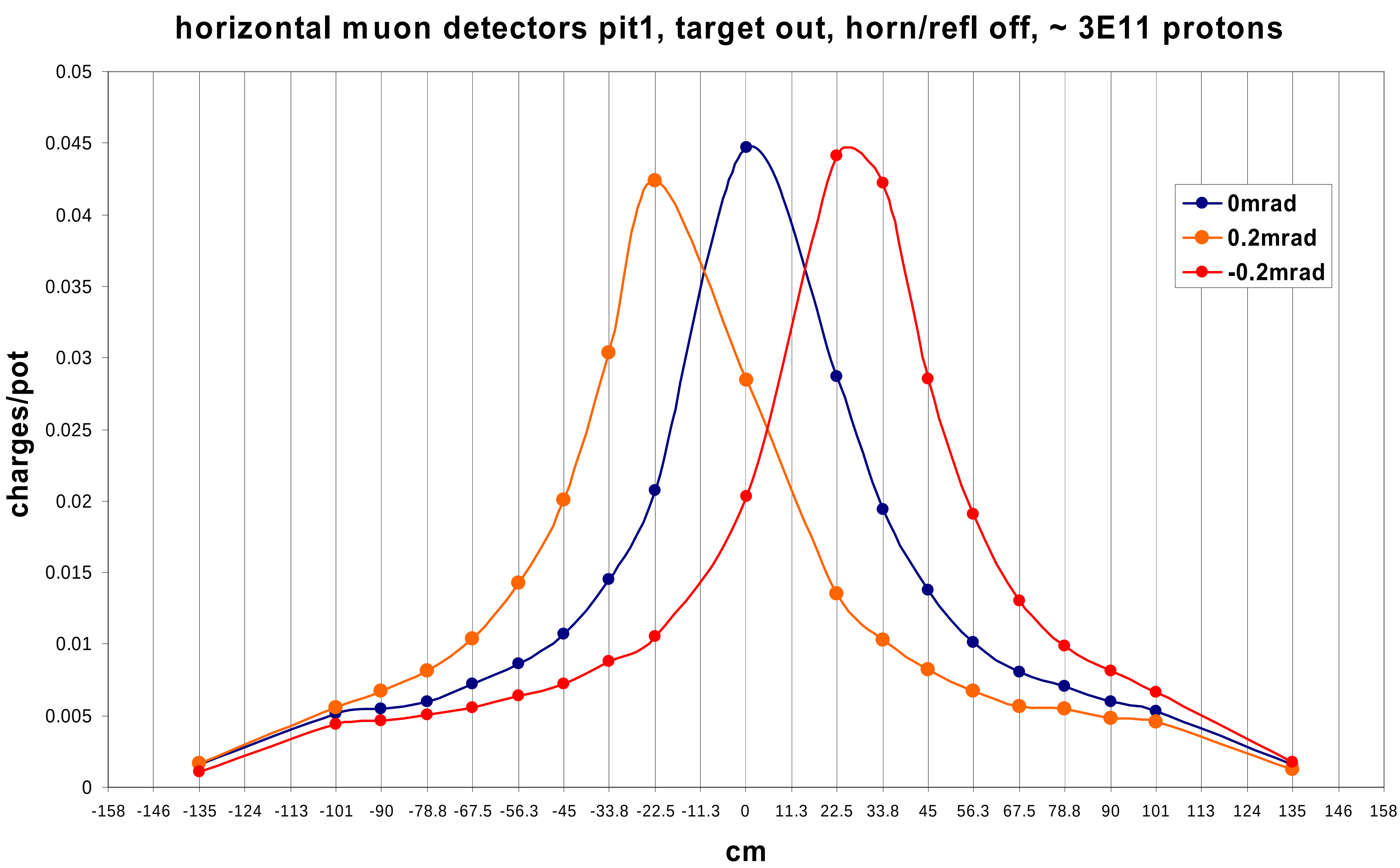
- Dynamic range: 10^5
- Specs accuracies: 10% absolute, 3% relative, 1% cycle by cycle, 5% per year

CNGS installation:

- 2 x 37 fixed monitors (Ionization Chambers)
- 2 x 1 movable chamber behind fixed monitors for relative calibration
- Movement by stepping motors

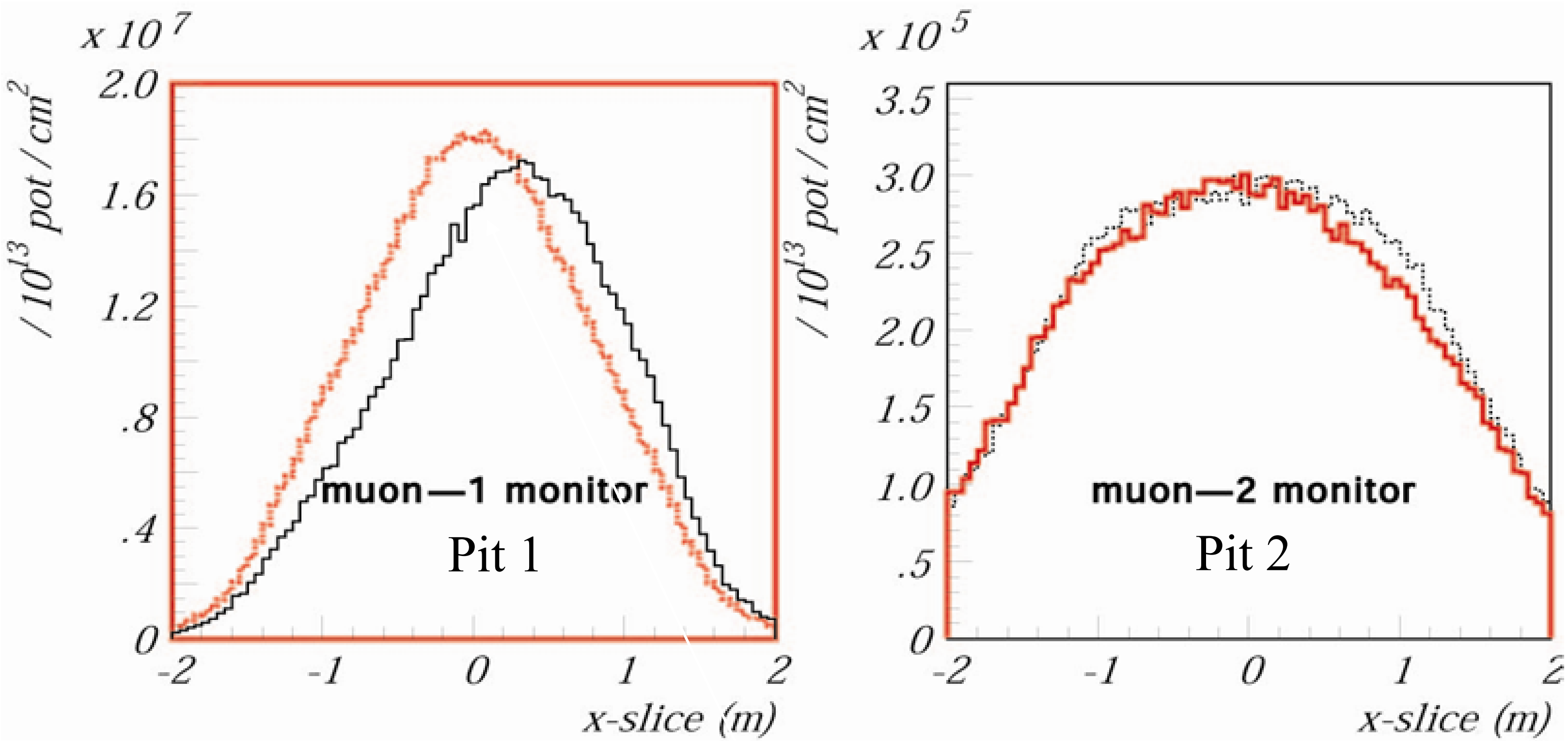

270cm
11.25cm

Horizontal Angular Scan, Target Out



Target vs. Horn Alignment

Note SL-2001-016-EA

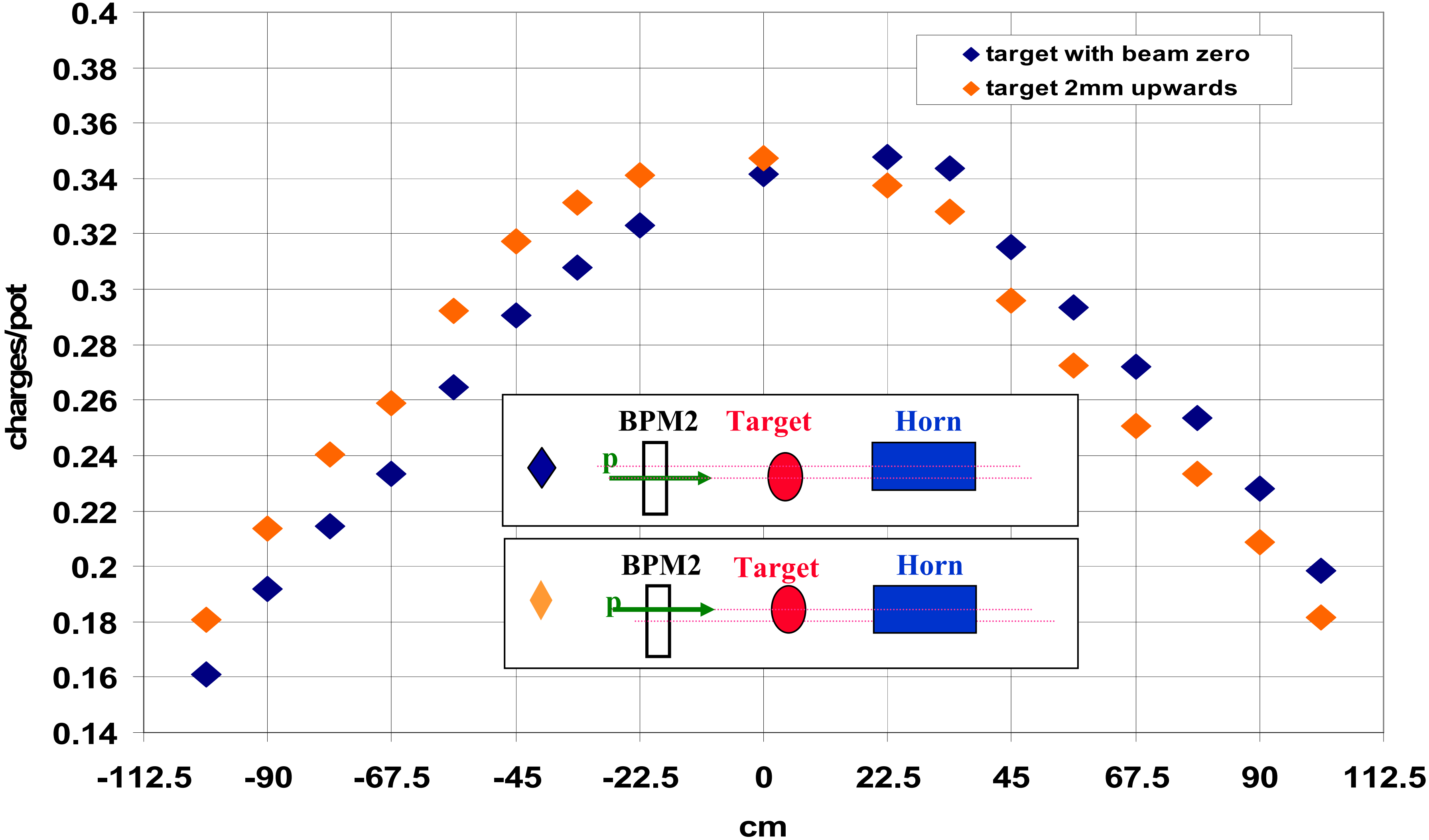


target vs. horn misalignment: 3 mm → 10.1 cm shift in Muon Pit1
6 mm → 19.1 cm
9 mm → 24.3 cm

simulations

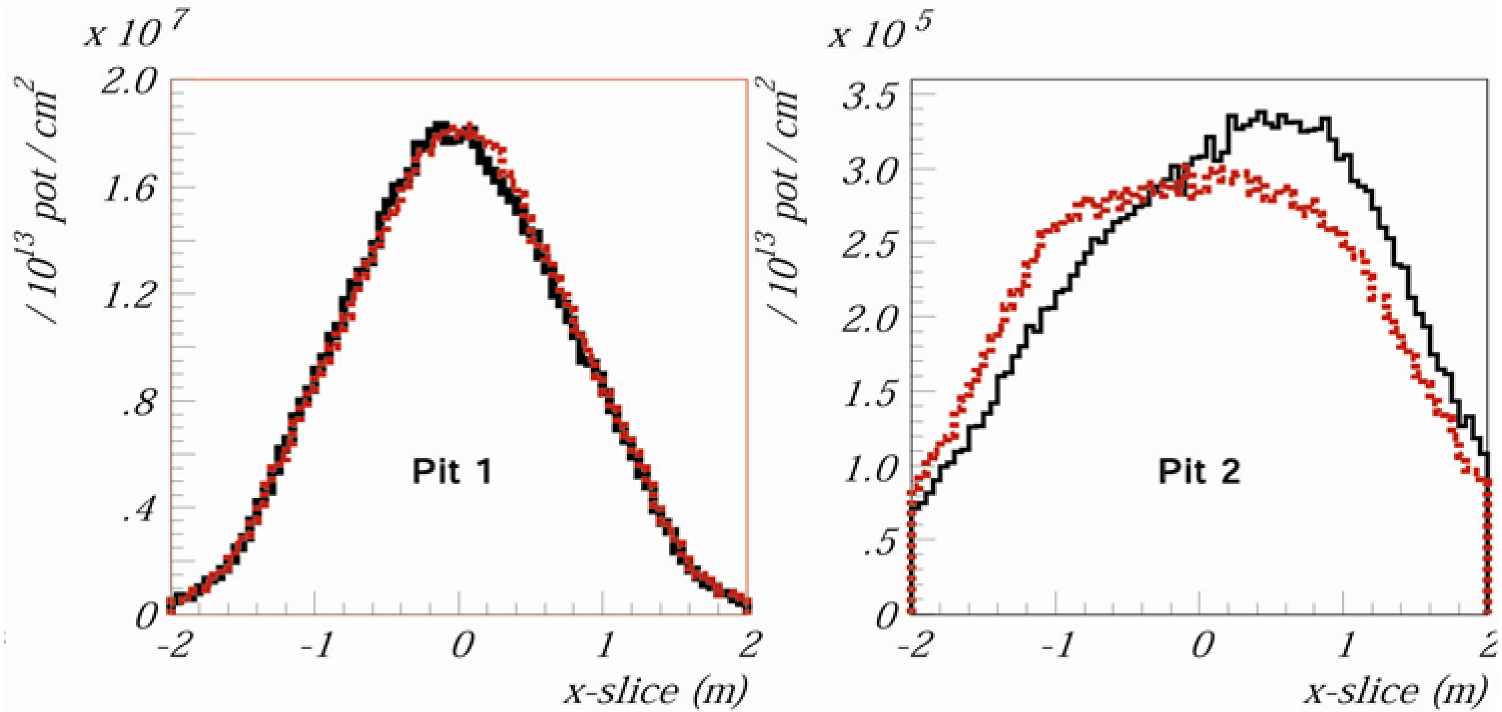
Vertical Target vs. Horn Alignment

Muon pit 1: more sensitive to target vs. horn alignment



Beam vs. Target Alignment

Note SL-2001-016-EA

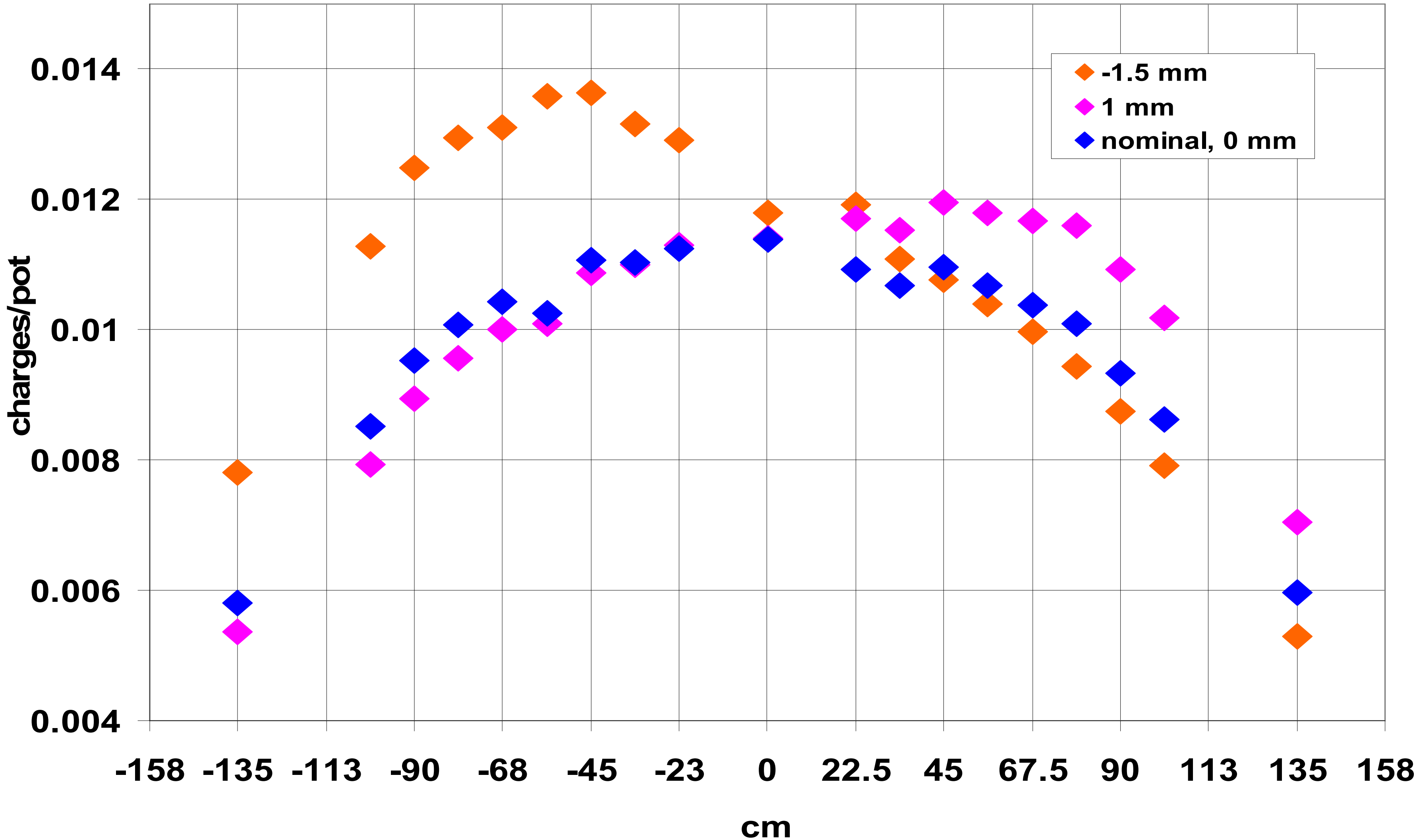


beam vs. target misalignment: 0.5 mm → 7.3 cm shift in Muon Pit2
1.0 mm → 14.8 cm

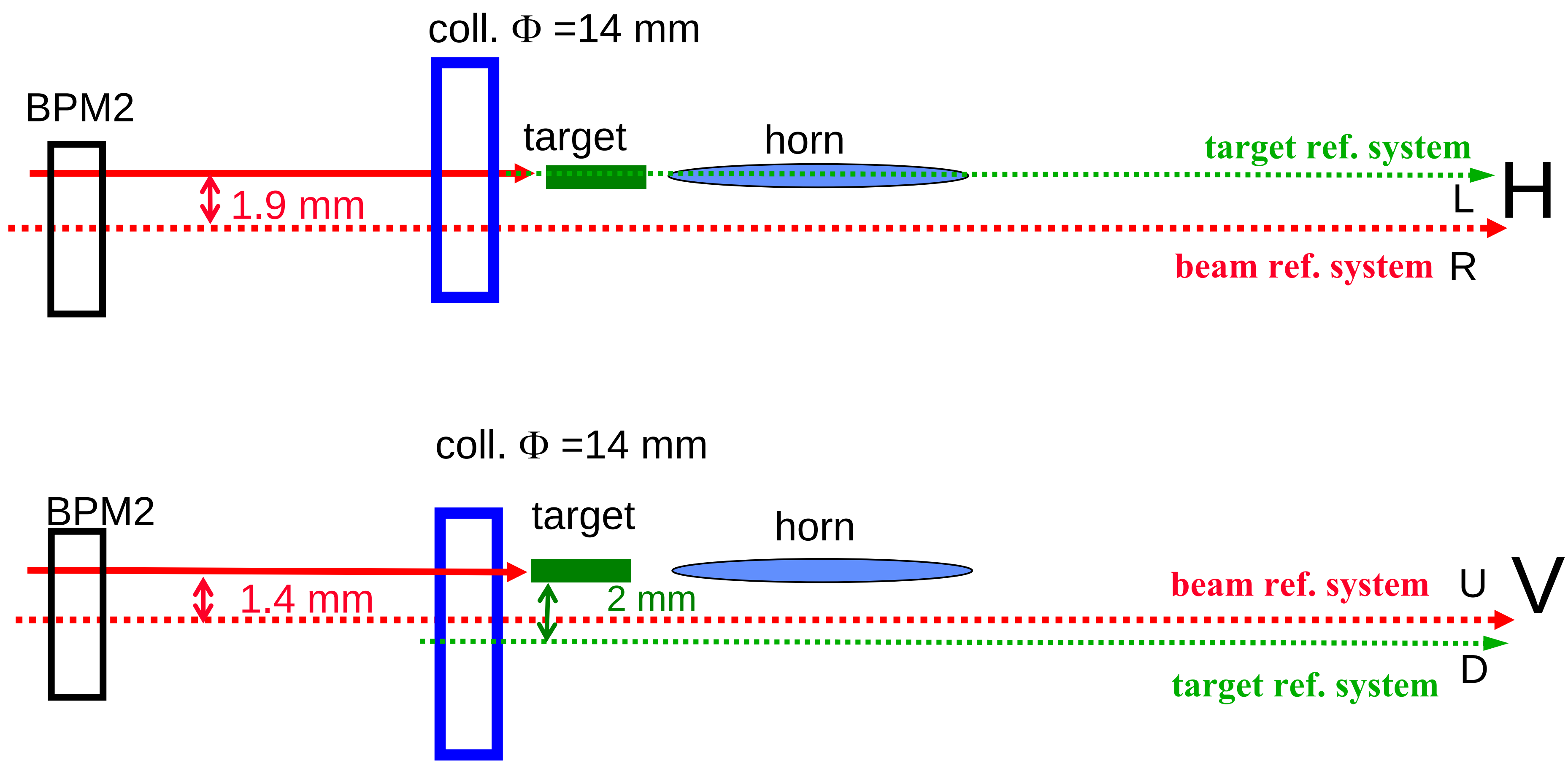
simulations

Vertical Beam vs. Target Alignment

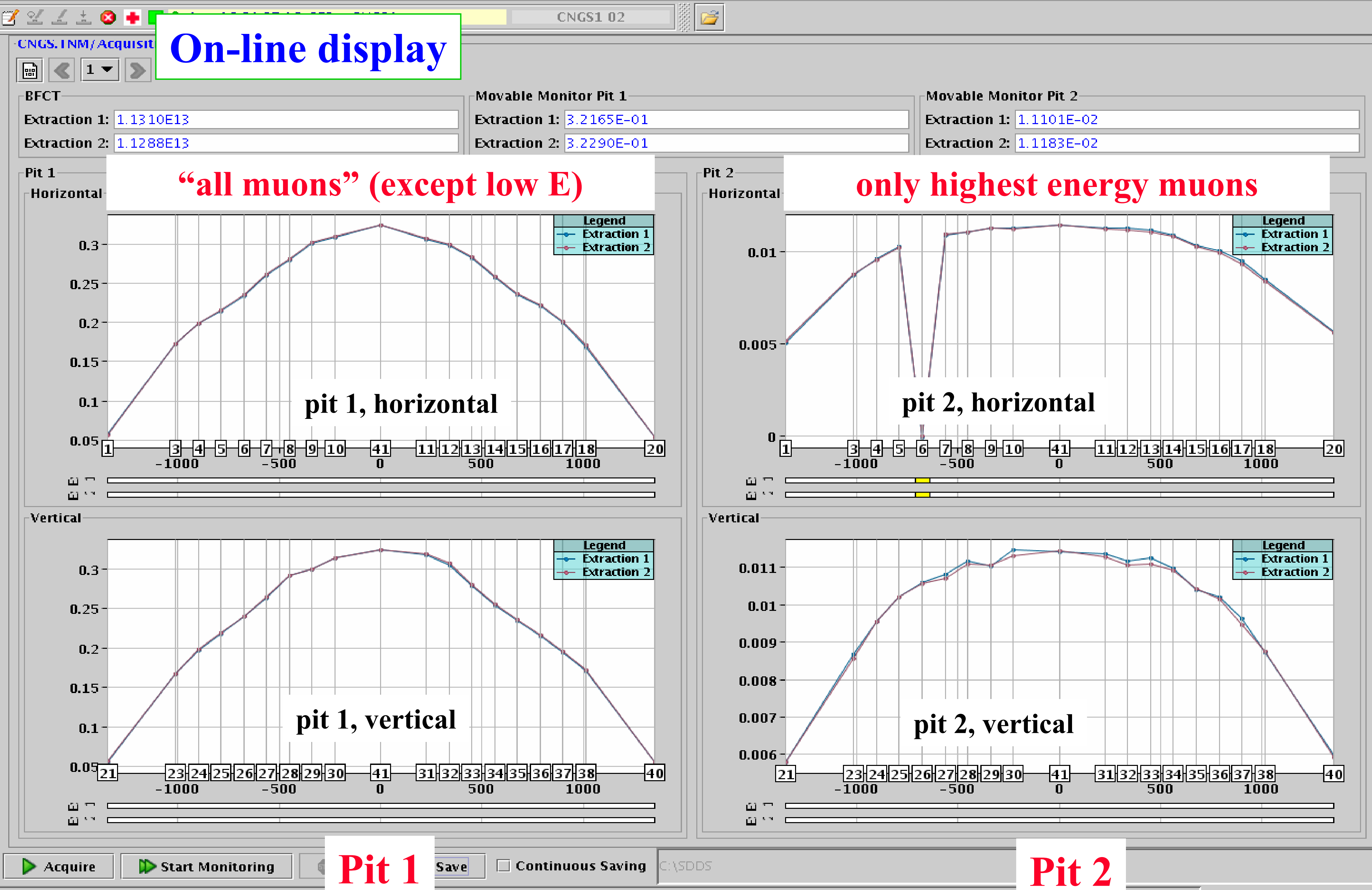
Muon pit 2: more sensitive to beam vs. target alignment



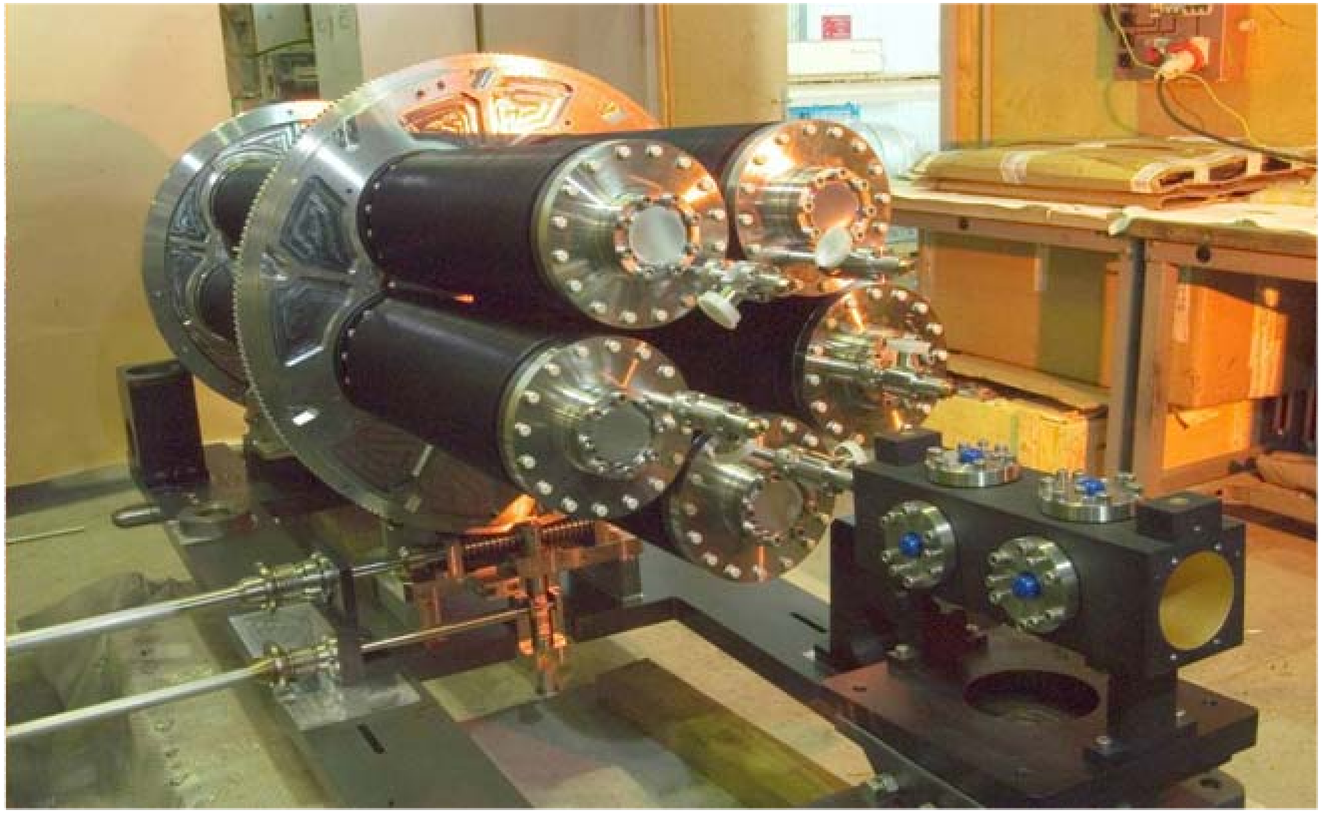
Final Alignment



On-line display



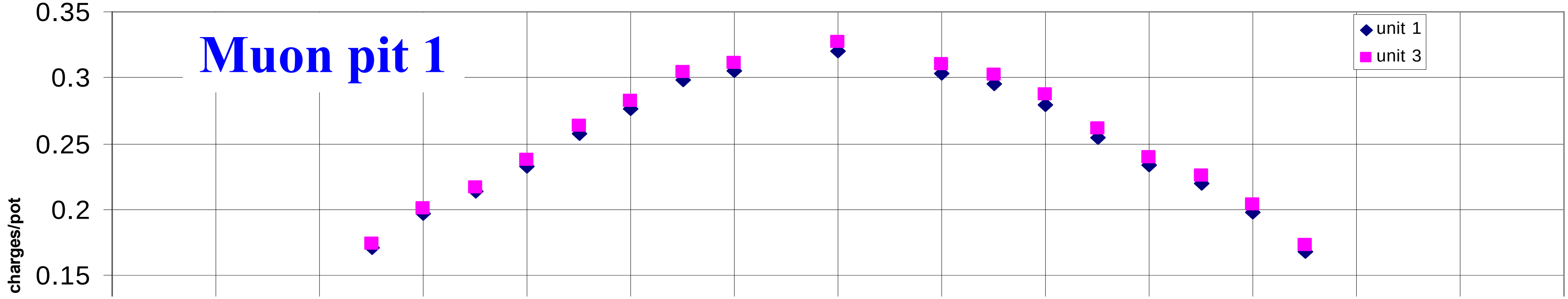
Target Unit Tests



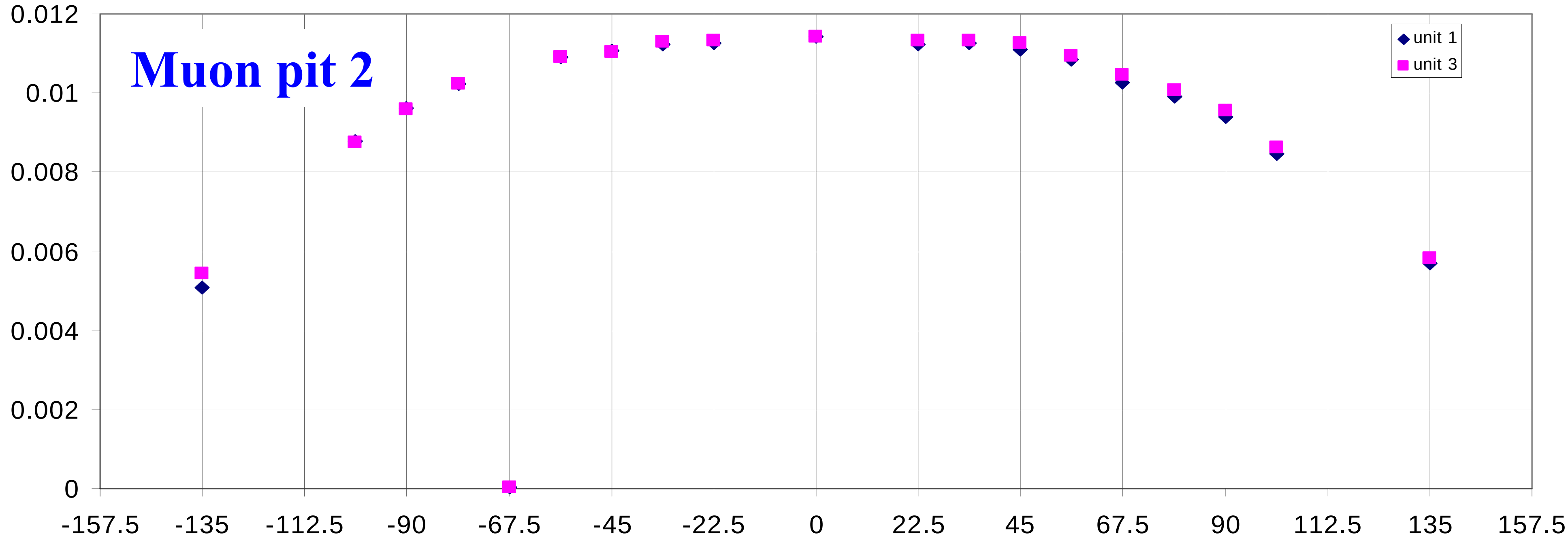
unit 1 : polycrystalline graphite by Carbone-Lorraine 2020 PT
density 1.76 g/cm3

unit 3: carbon-carbon composite by Carbone-Lorraine A035
density >1.75 g/cm3

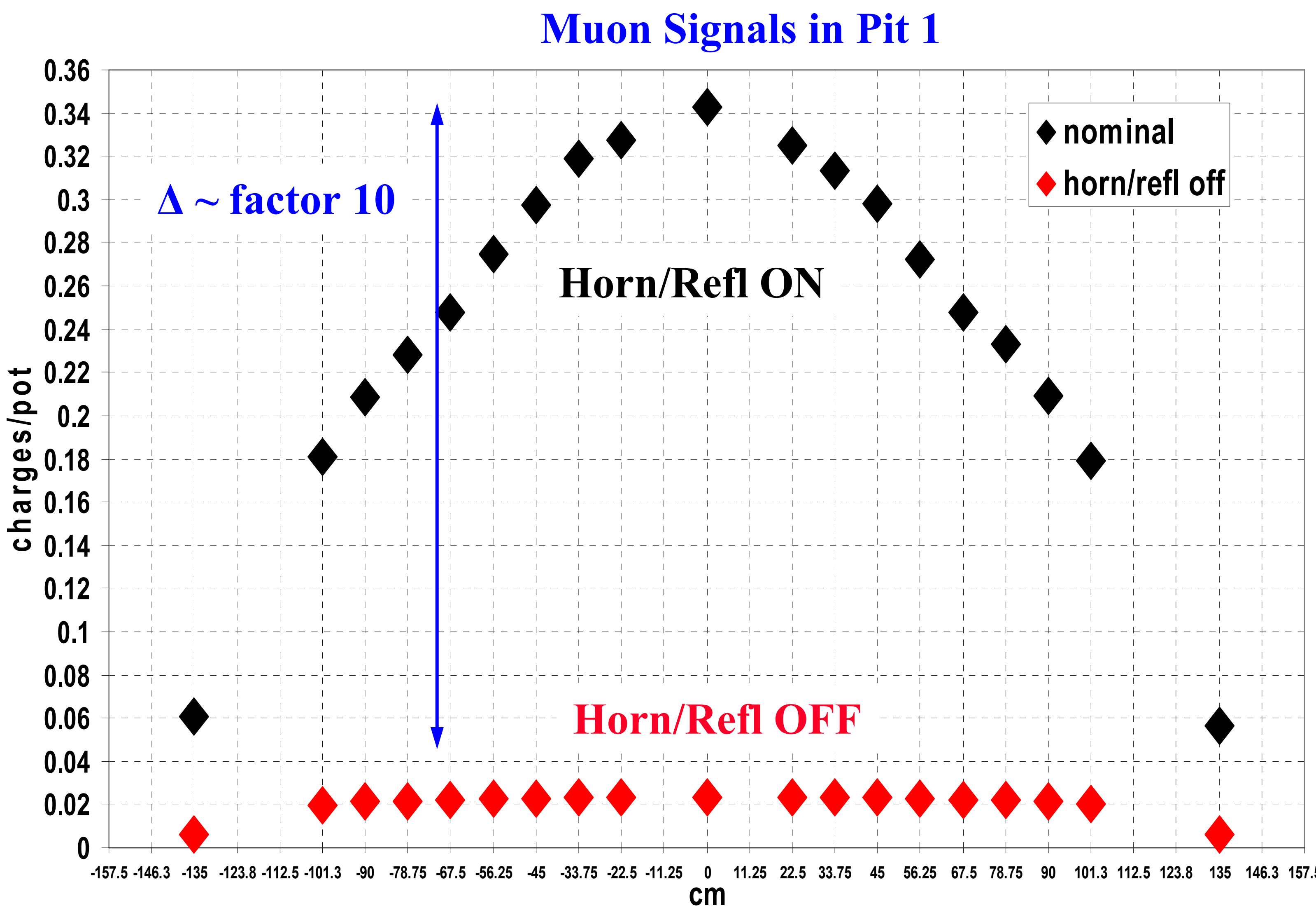
Comparison Unit 1 and Unit 3



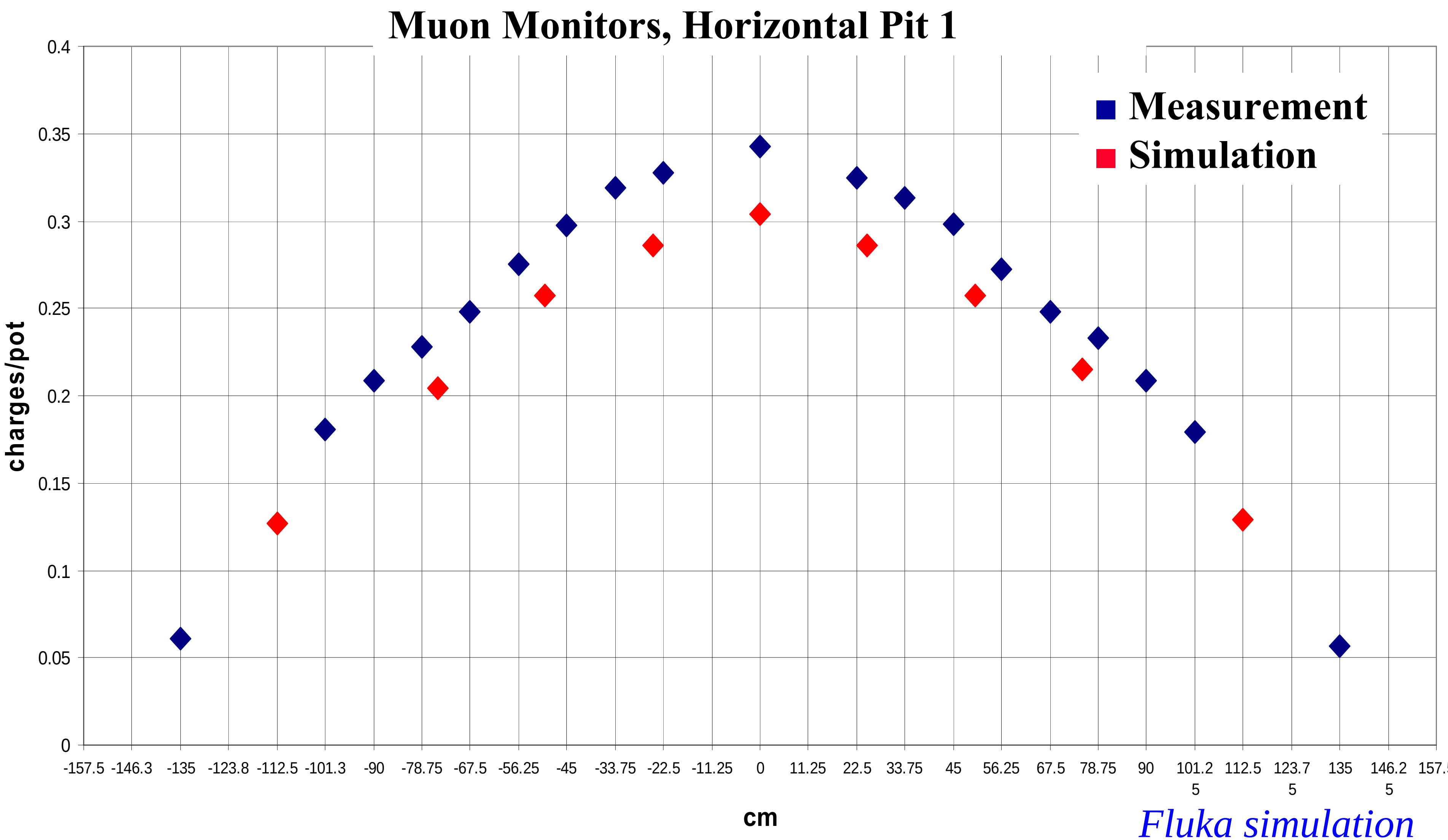
Average of 2 extraction, ~1.2E13 protons



Check Horn/Reflector On/Off

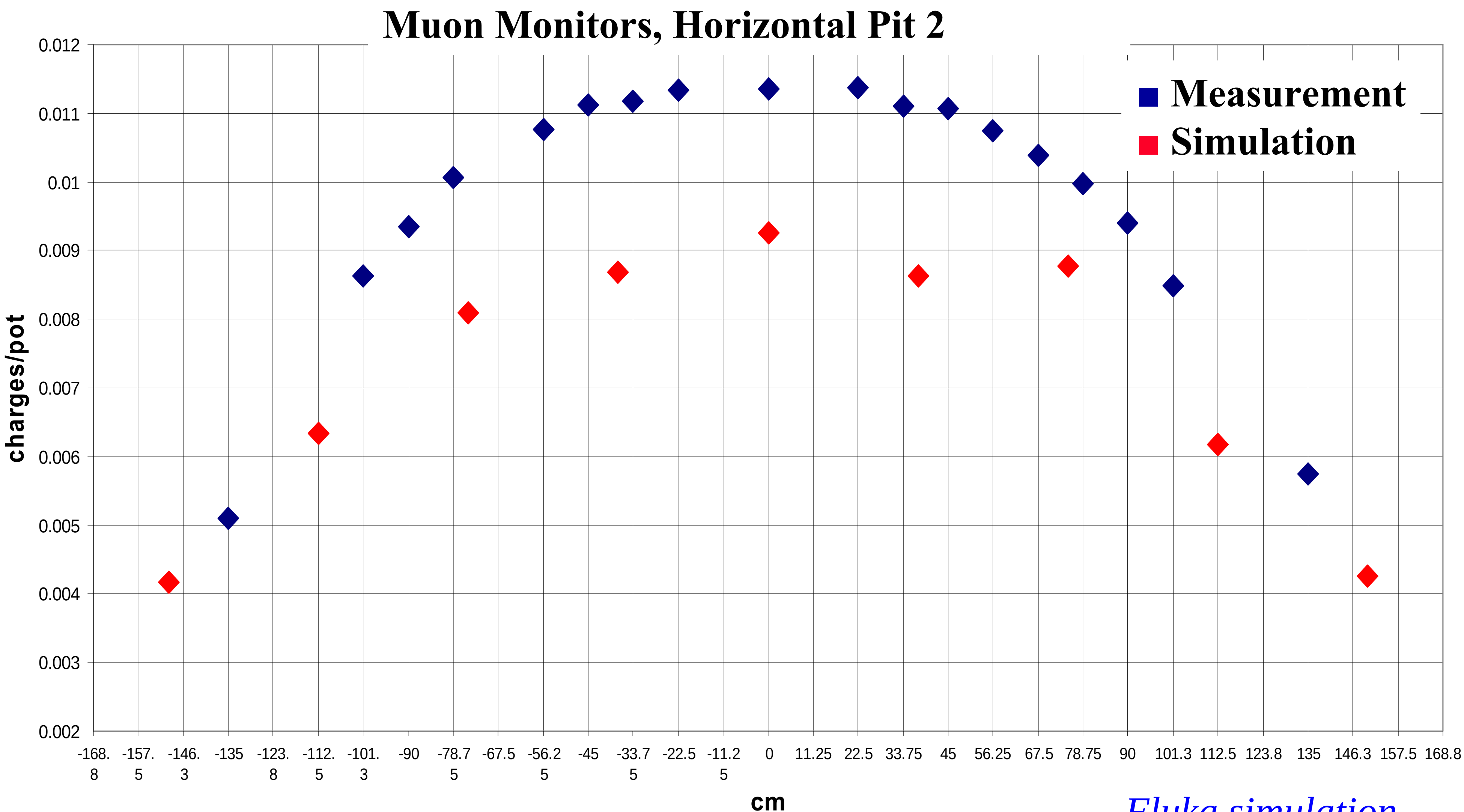


CNGS Quality Check (Preliminary)

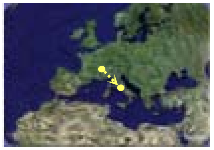


Fluka simulation

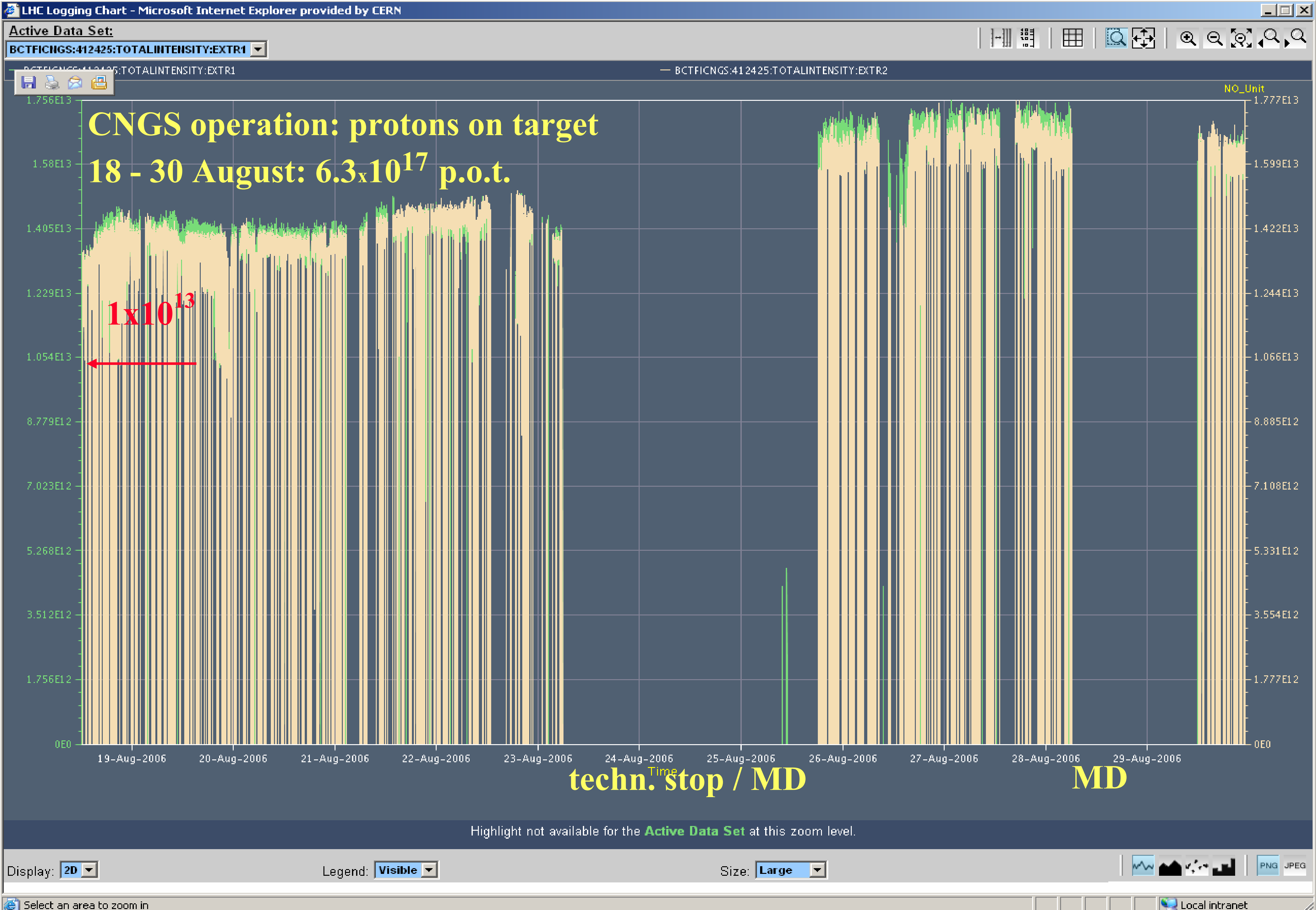
CNGS Quality Check (Preliminary)



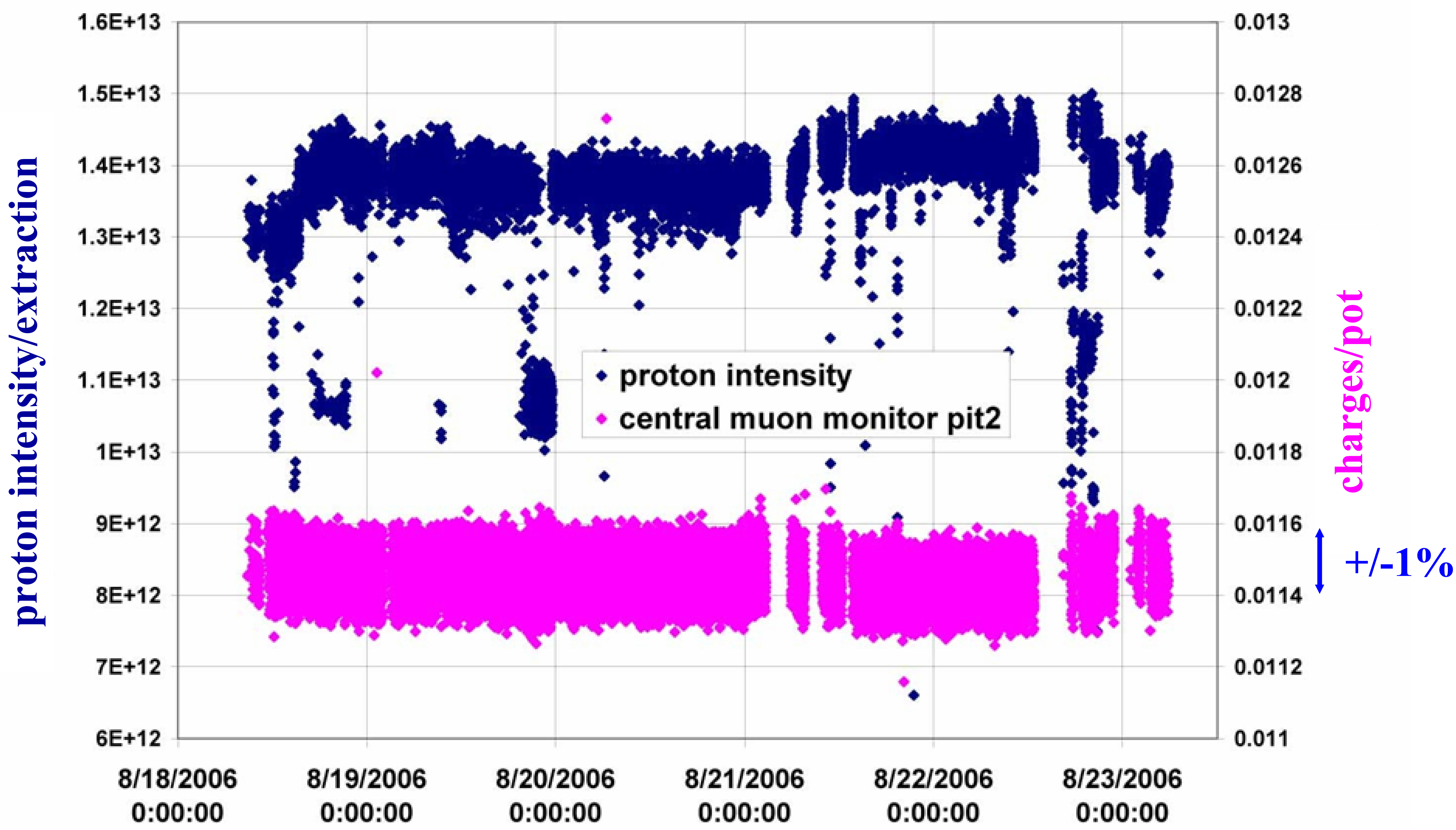
Fluka simulation



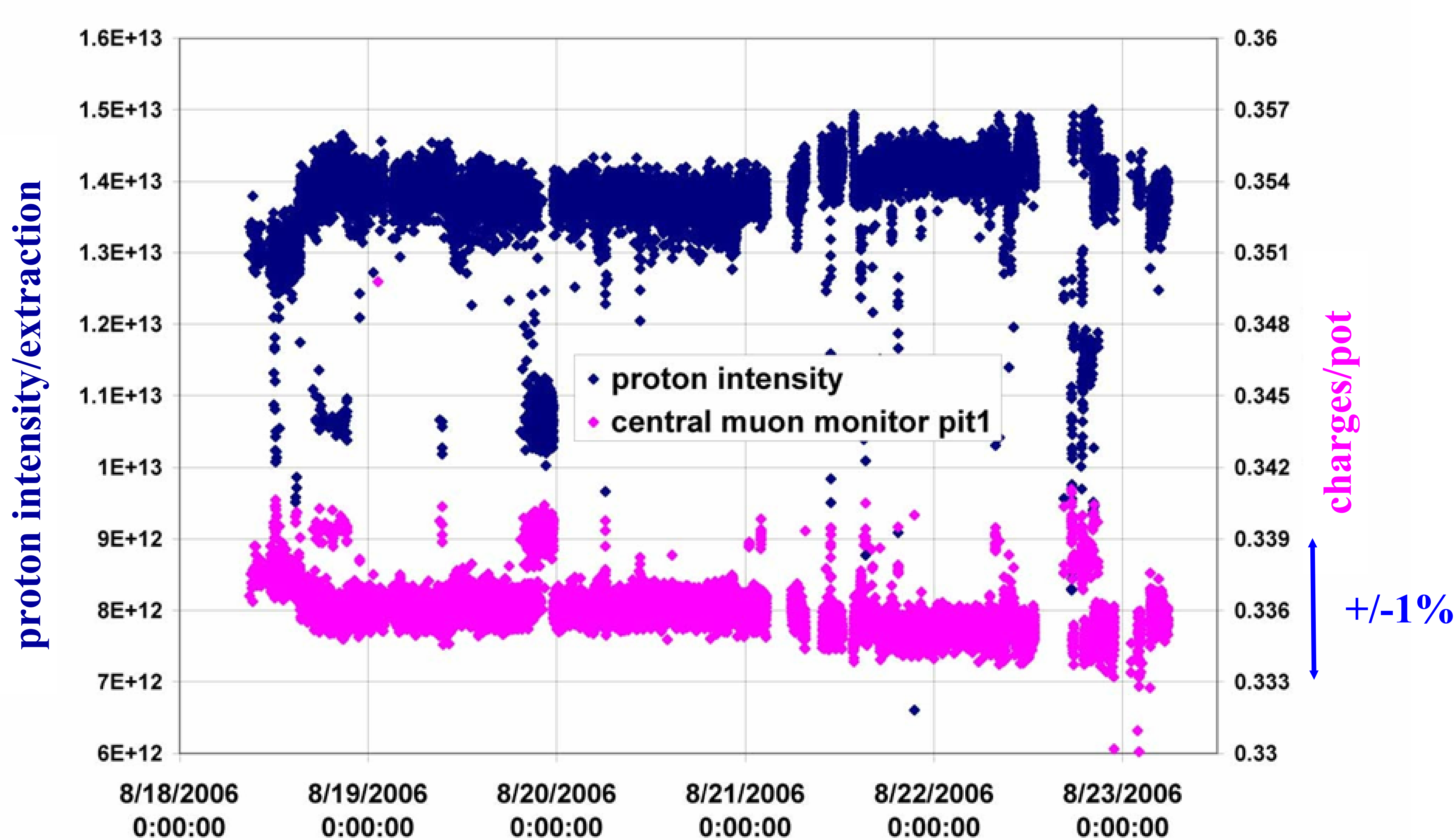
CNGS Operation

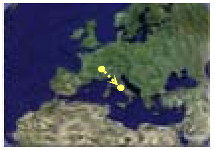

LHC Logging Chart - Microsoft Internet Explorer provided by CERN
Active Data Set:
BCTFICNGS:412425:TOTALINTENSITY:EXTR1
BCTFICNGS:412425:TOTALINTENSITY:EXTR2
NO_Unit
CNGS operation: protons on target
18 - 30 August: 6.3x10^17 p.o.t.
1x10^13
1.756E13
1.58E13
1.405E13
1.229E13
1.054E13
8.779E12
7.023E12
5.268E12
3.512E12
1.756E12
0E0
1.777E13
1.599E13
1.422E13
1.244E13
1.066E13
8.885E12
7.108E12
5.331E12
3.554E12
1.777E12
0E0
19-Aug-2006
20-Aug-2006
21-Aug-2006
22-Aug-2006
23-Aug-2006
24-Aug-2006
25-Aug-2006
26-Aug-2006
27-Aug-2006
28-Aug-2006
29-Aug-2006
Time
techn. stop / MD
MD
Highlight not available for the Active Data Set at this zoom level.
Display: 2D
Legend: Visible
Size: Large
PNG
JPEG
Select an area to zoom in
Local intranet

Muon Monitor Stability Pit 2

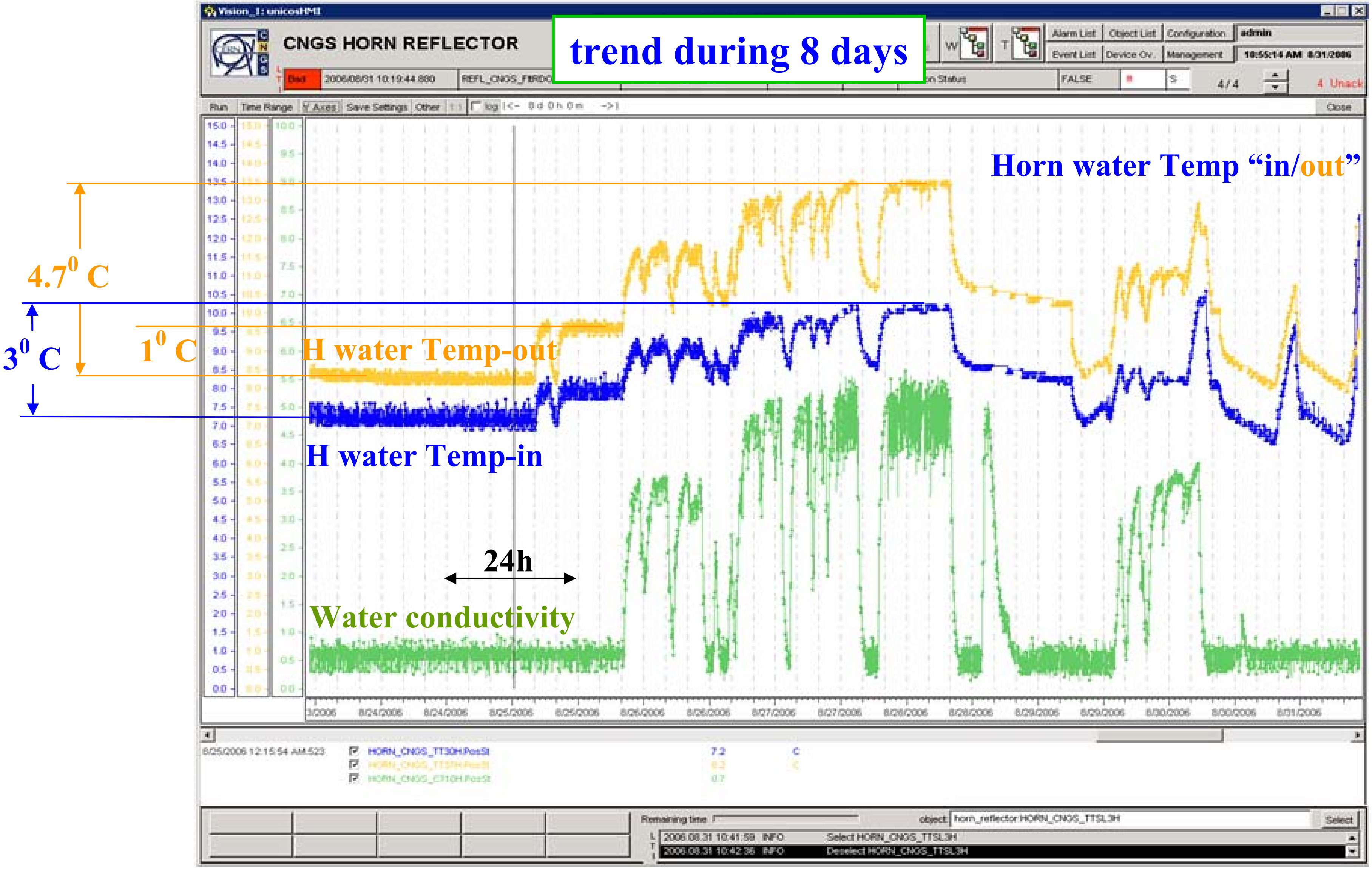


Muon Monitor Stability Pit 1

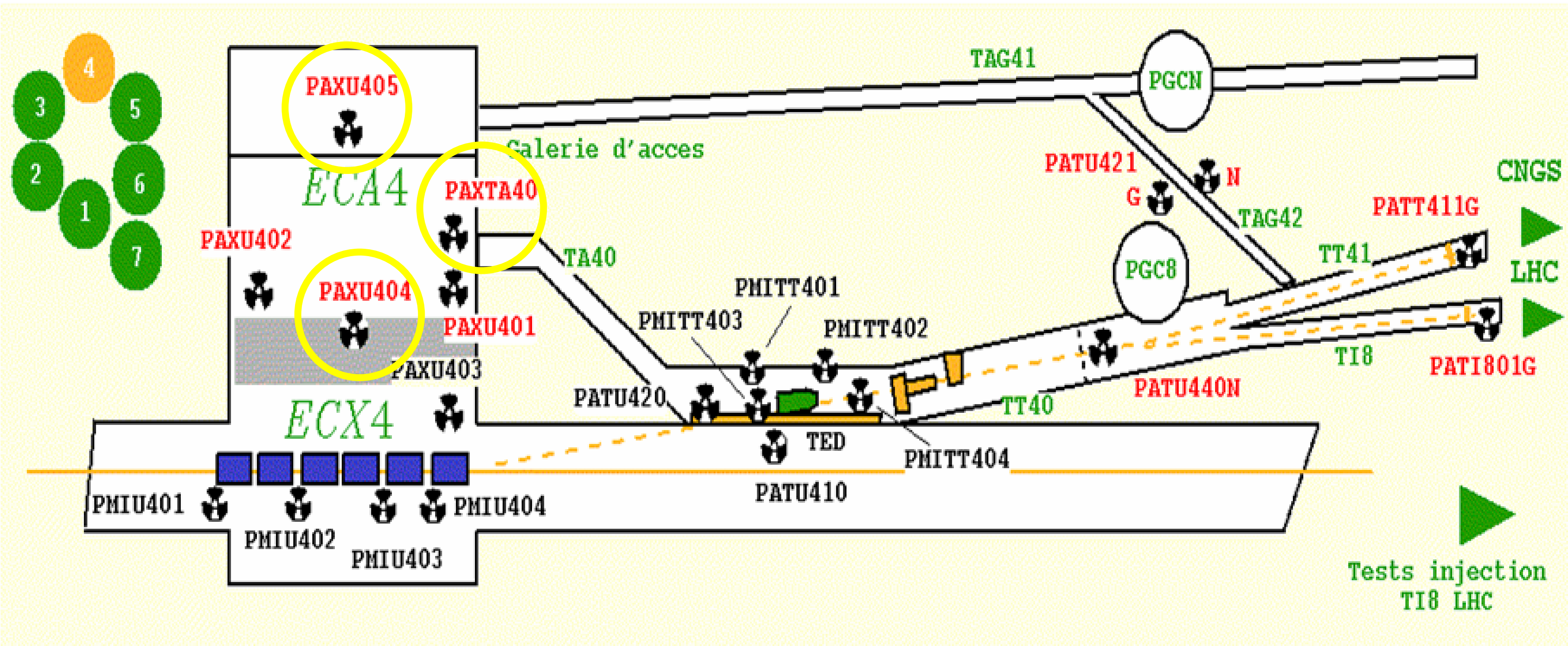




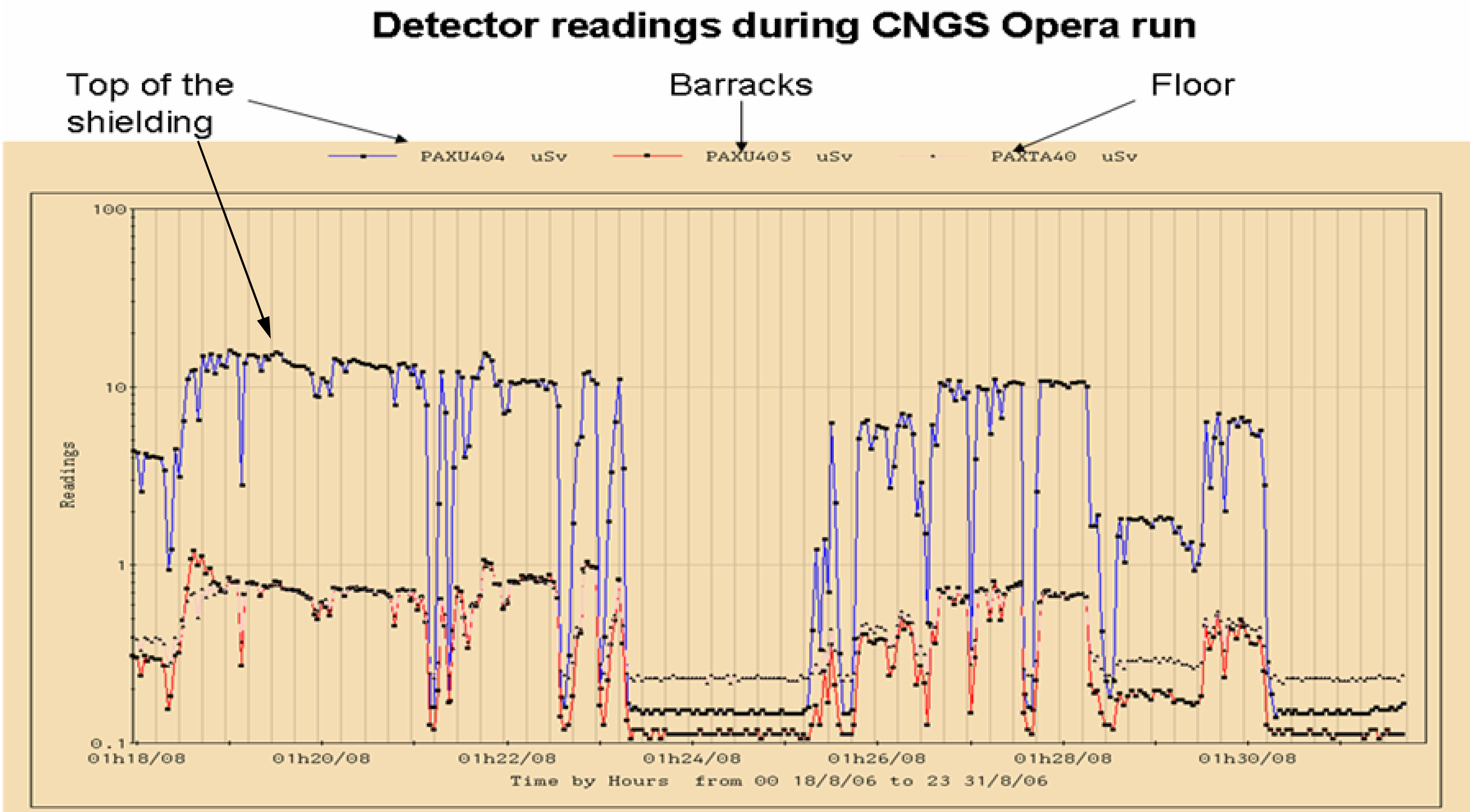
Horn Cooling



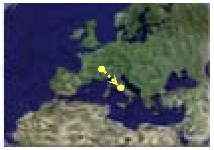
Radiation Detectors in ECA4



Radiation Detectors in ECA4



The monitors show maximum radiation values of 1 μSv/h in accessible regions.
Based on beam loss studies and simulations this corresponds to a beam loss of 0.05 %.

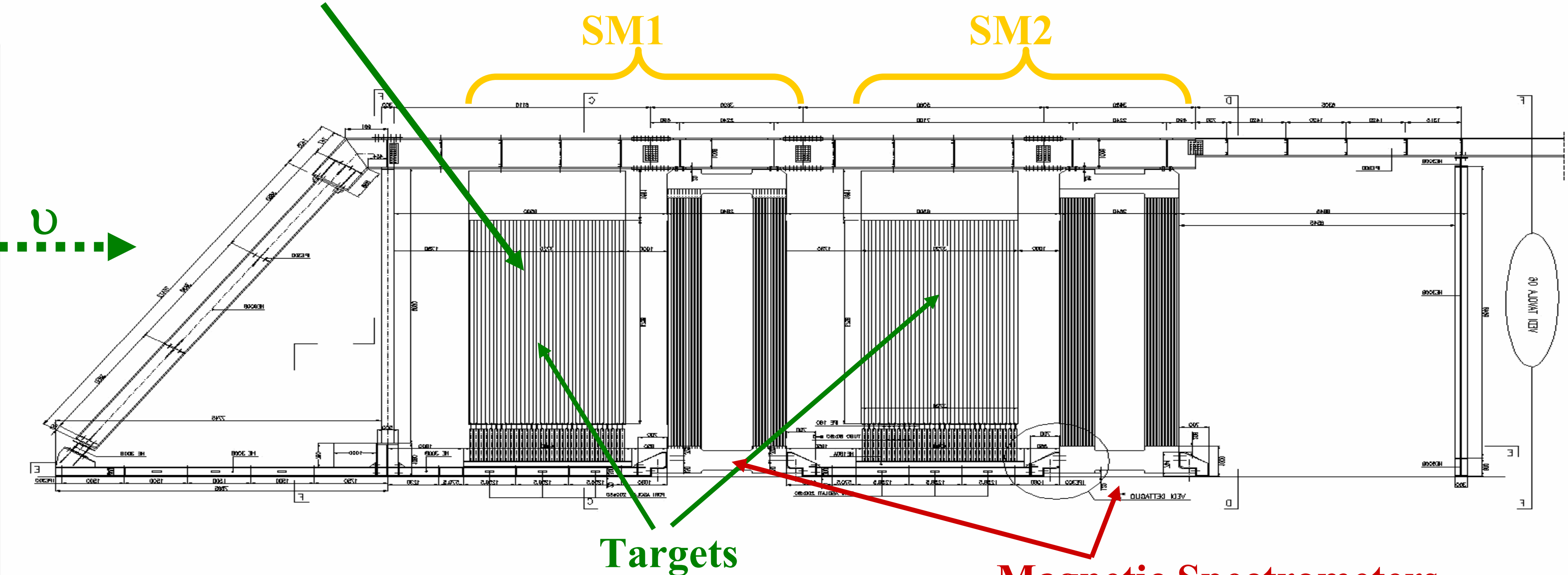


First OPERA Events

Structure of the OPERA Experiment

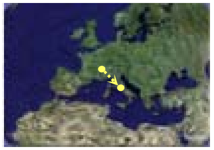
Basic unit: brick: 56 Pb sheets + 56 emulsion sheets

31 target planes / supermodule (in total: 206336 bricks, 1766 tons)



Proposal: July 2000,
installation at LNGS started in May 2003
First observation of CNGS beam neutrinos : August 18th, 2006

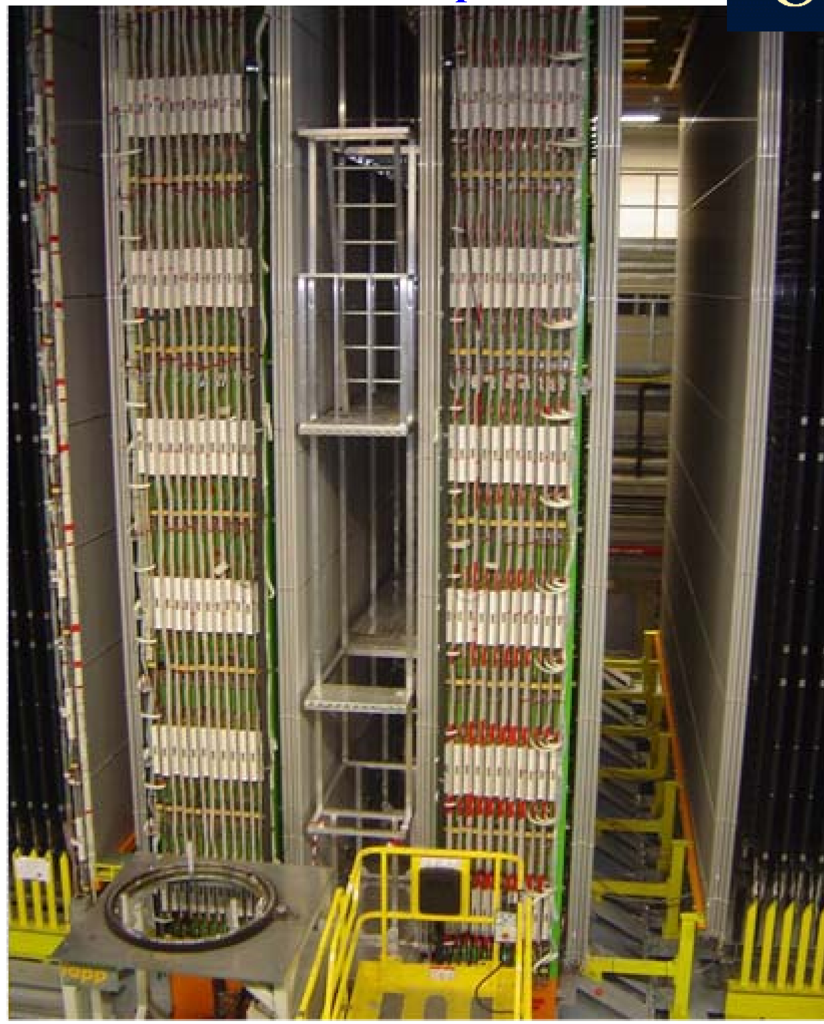
OPERA in Pictures



Second Super-module

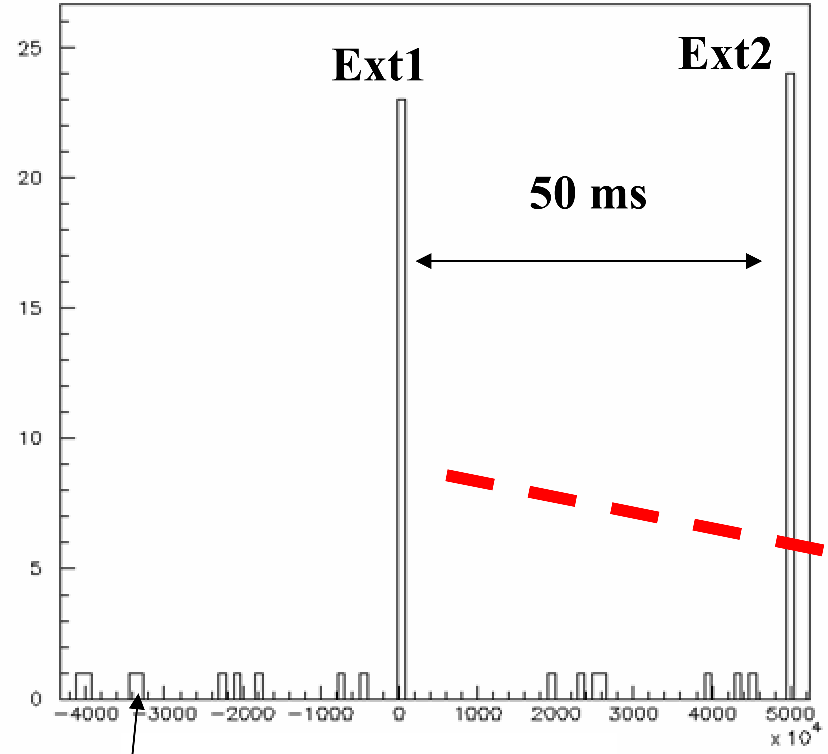
Scintillator planes 5900 m²
8064 7m long drift tubes

Details of the first spectrometer



3050 m² Resistive Plate Counters
2000 tons of iron for the two magnets

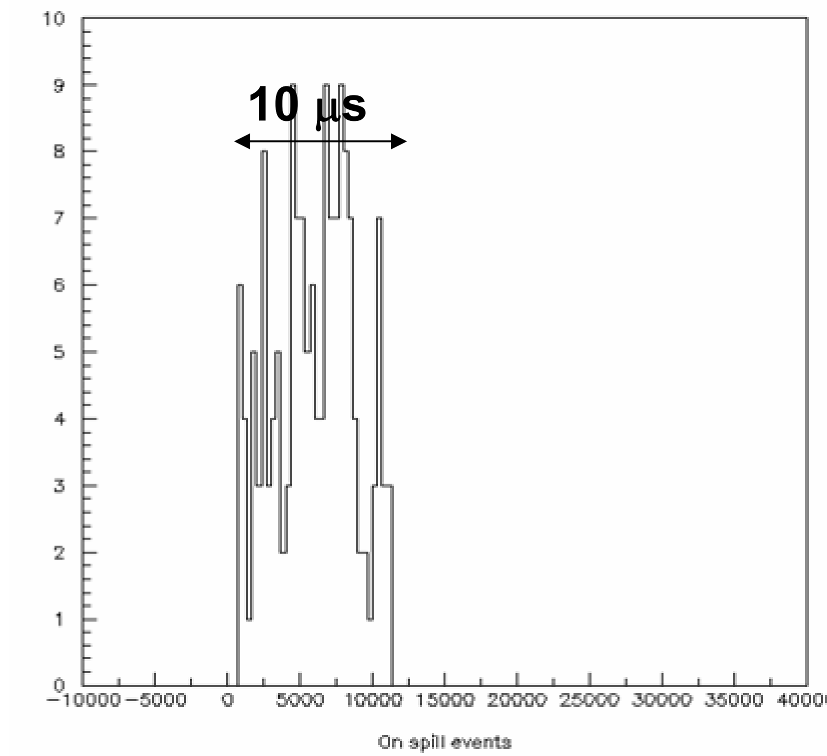
Event Selection by Using GPS Timing Info



Δt first extraction (ns)

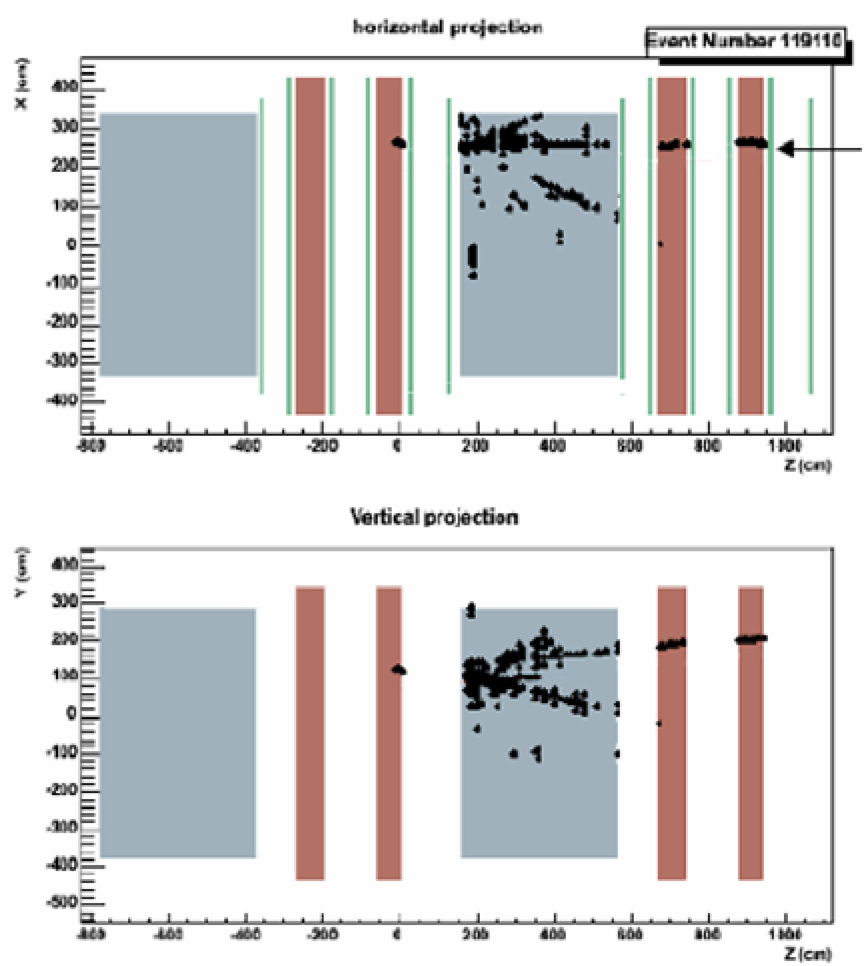
Cosmic rays background events

Zoom on the spill peaks

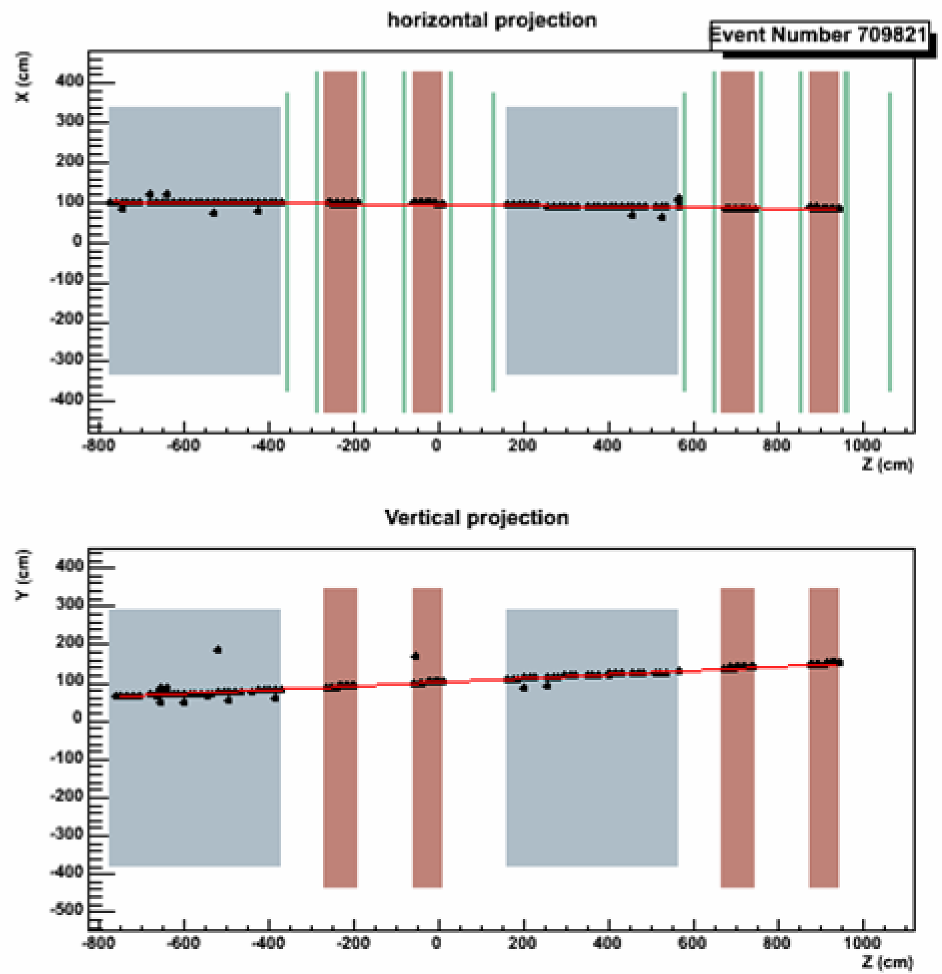


Δt closest extraction (ns)

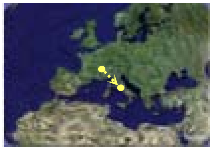
Beam Events



CC event in the first magnet



Muon from CC interaction in the material in front of the detector (BOREXINO, rocks)



Summary

- CNGS construction started 2000
- Installation finished beginning 2006
- Detailed hardware commissioning
- 'Dry runs'
  - ➔ Allowed early debugging of all systems
- CNGS has been successfully commissioned

→ CNGS is operational

- The most difficult part (high intensity operation) starts now
  - ➔ Very high radiation levels
  - ➔ Fatigue from beam impact (shocks) on equipment
  - ➔ Fatigue from pulsing
  - ➔ …

MANY THANKS

to all involved in the project’s success!