CNGS Run 2007
and
Ensuring Safe and Reliable Operation of CNGS as of 2008

Edda Gschwendtner

On behalf the

CNGS Secondary Beam Working Group

Outline

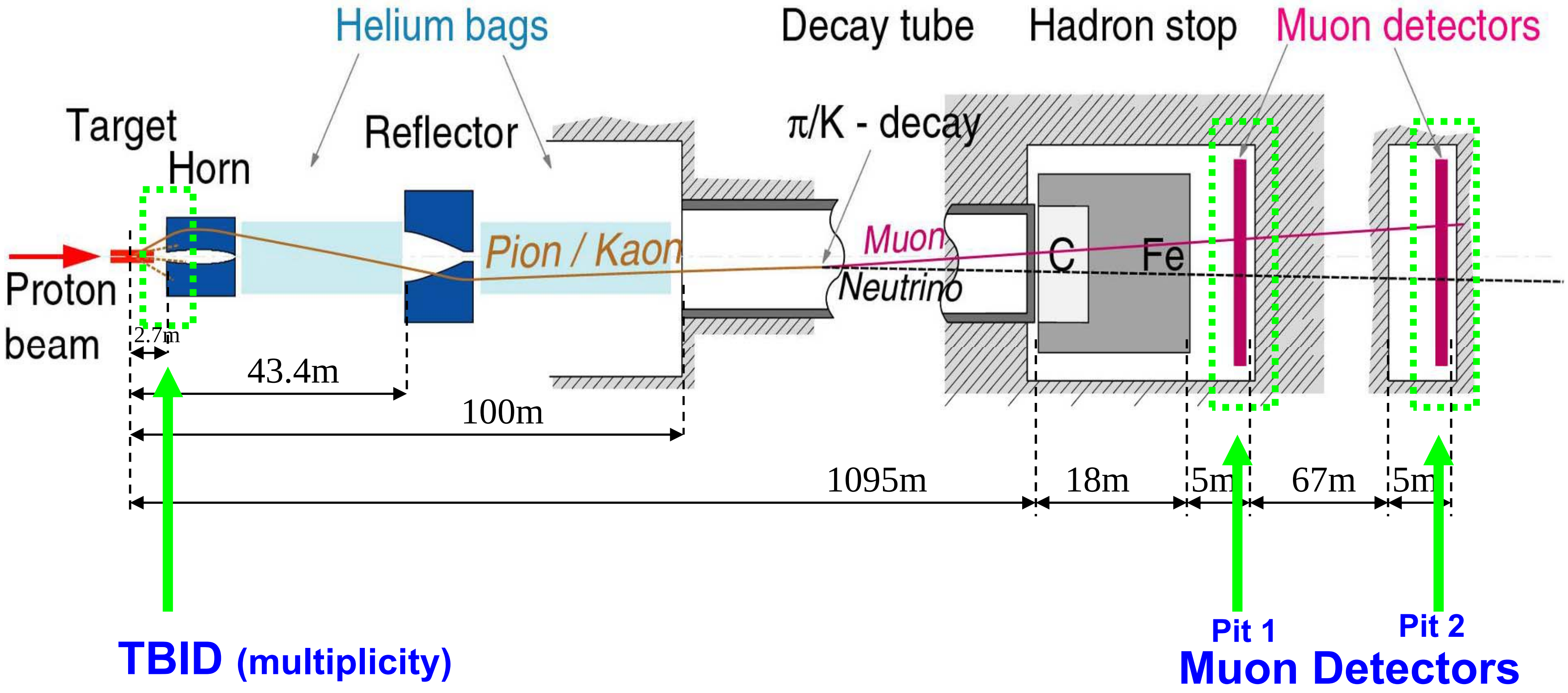
- Introduction to CNGS and OPERA
- CNGS Run 2007
  - Beam Performance
  - Results
  - Radiation Effects on Electronics
- Modifications for 2008
  - Strip-line
  - Shielding Modifications
- Operational Aspects

CNGS Challenges

- **High Intensity, High Energy Proton Beam (500kW, 400GeV/c)**
  - *Proton beam: Tune!!*
  - Induced radioactivity
    - In components, shielding, fluids, etc…
  - Intervention on equipment 'impossible'
    - Remote handling by overhead crane
    - Replace broken equipment, no repair
    - Human intervention only after long 'cooling time'
  - Design of equipment: compromise
    - E.g. horn inner conductor: for neutrino yield: thin tube, for reliability: thick tube
- **Intense Short Beam Pulses, Small Beam Spot (up to $3.5x10^{13}$ per 10.5 μs extraction, < 1 mm spot)**
  - *Proton beam: Interlock!!*
  - Thermo mechanical shocks by energy deposition (designing target rods, thin windows, etc…)

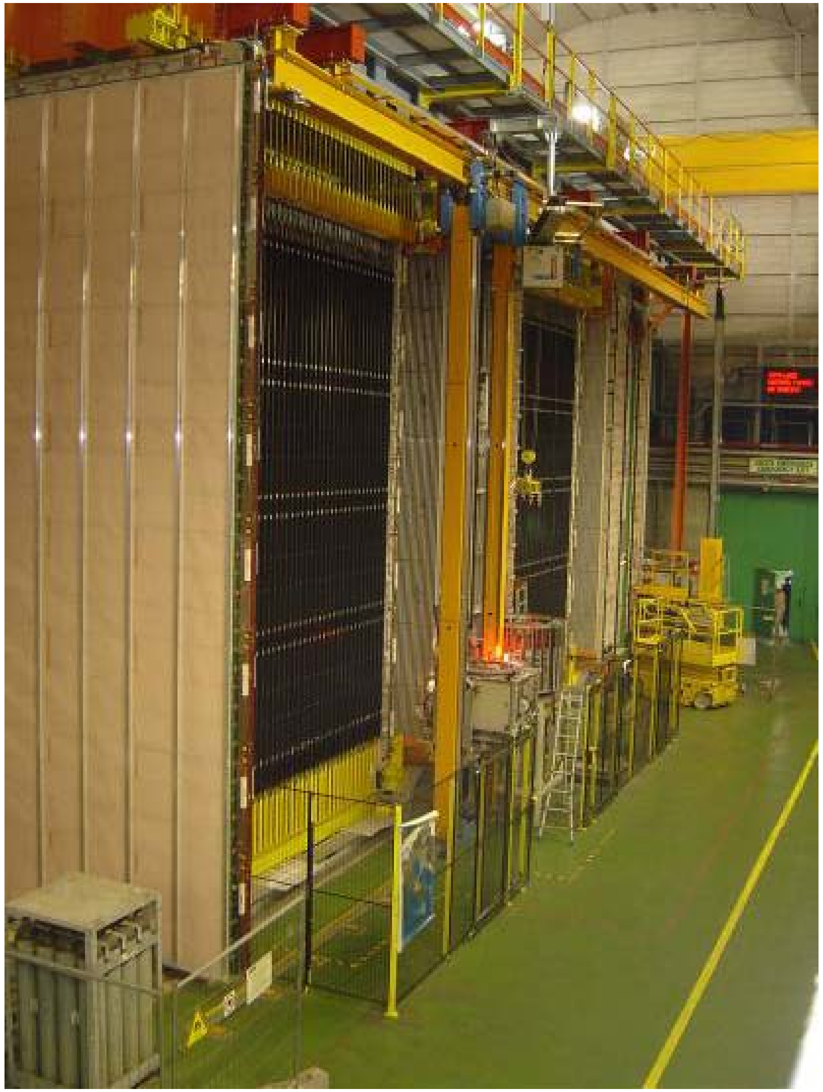
→ **most challenging zone: Target Chamber** (target–horn–reflector)

CNGS Facility



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

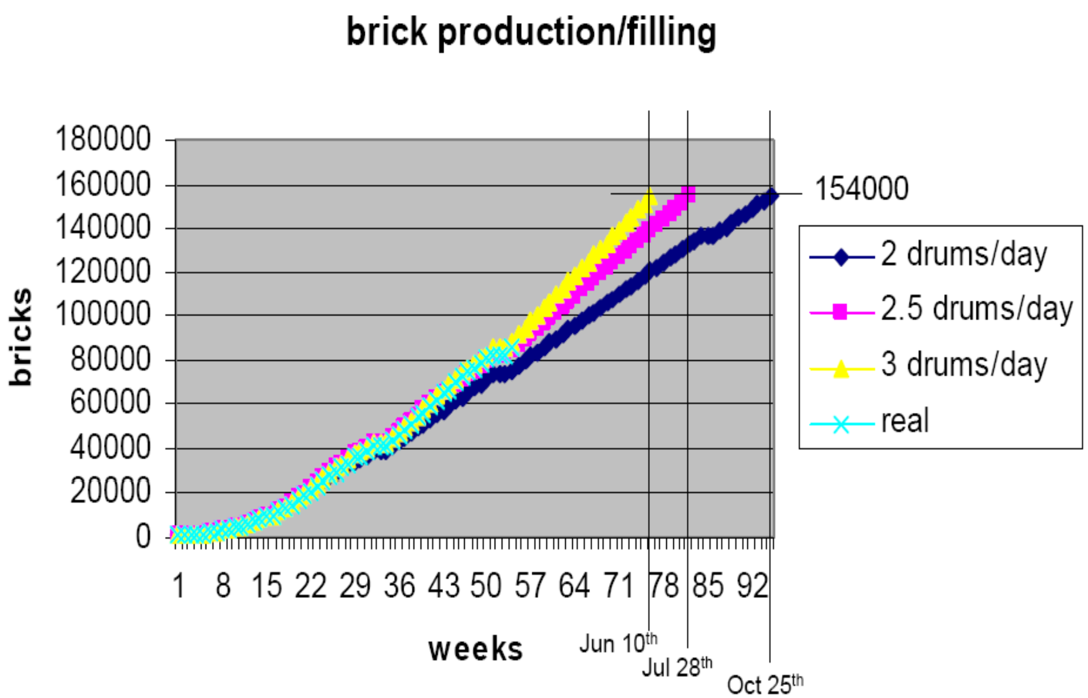
OPERA



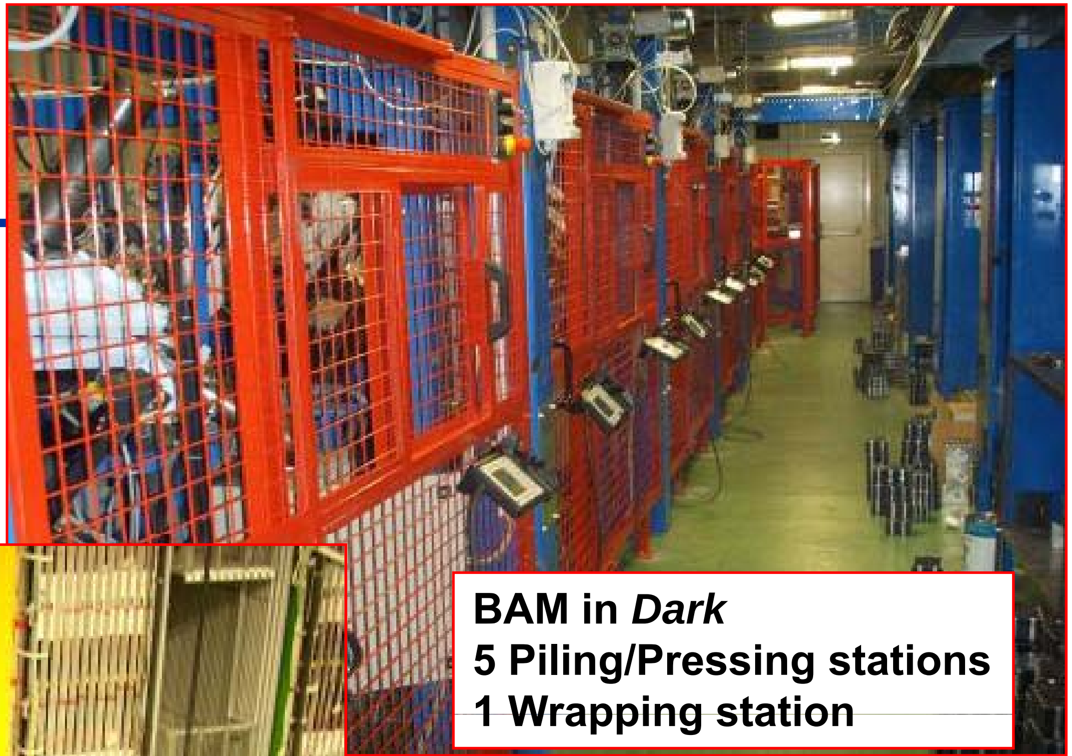
11th January 2008:

- **85202 bricks (out of 154000) are produced**
- **Production is stabilized at a rate of 3 drums/day (700 bricks).**

  → Finished by 10th June 2008.



Brick Assembly Machine, BAM



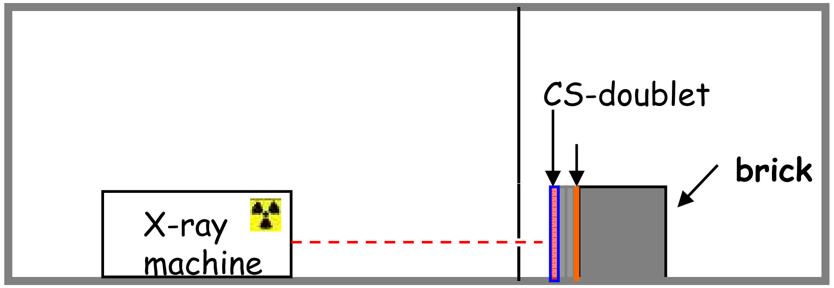
BAM in *Dark*
5 Piling/Pressing stations
1 Wrapping station

Brick Manipulator System, BMS

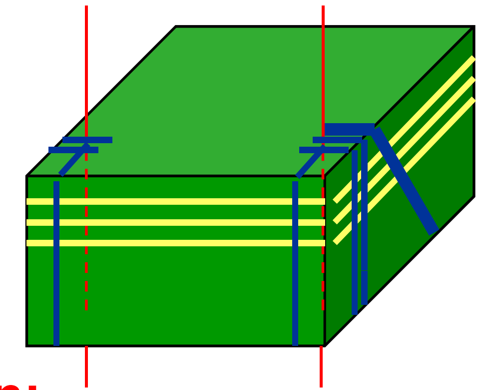
Drum loader
(1 drum = 234 bricks)

Emulsion Scanning Systems

CSd alignment &
CSd brick connection



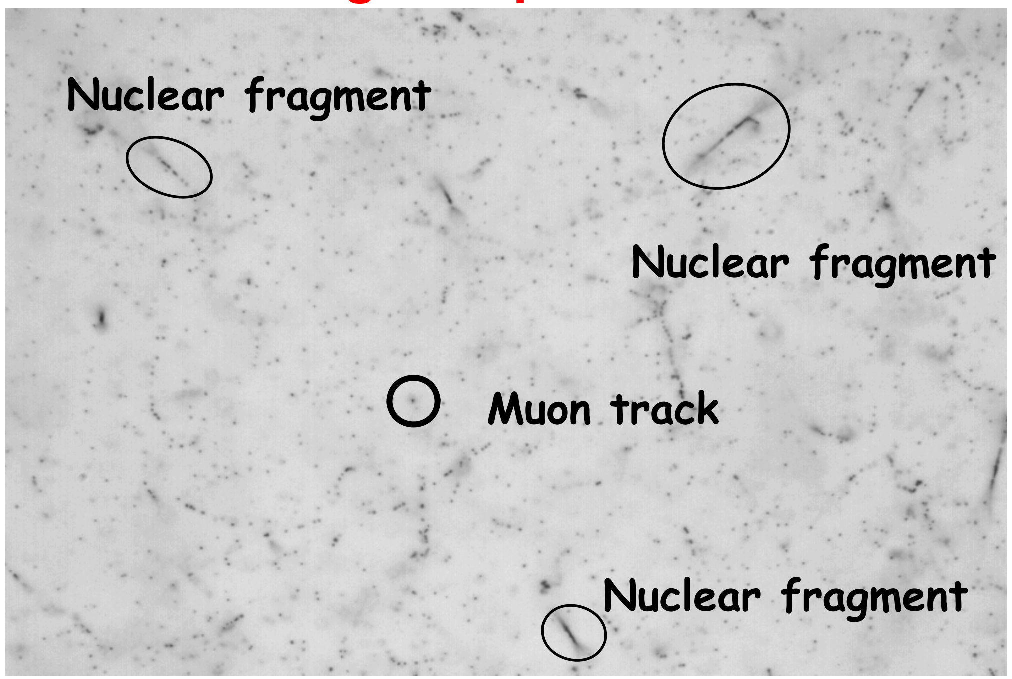
Brick films alignment
- 6 lines for alignment (crossing point)
- 1 line (inclined) for plate numbering



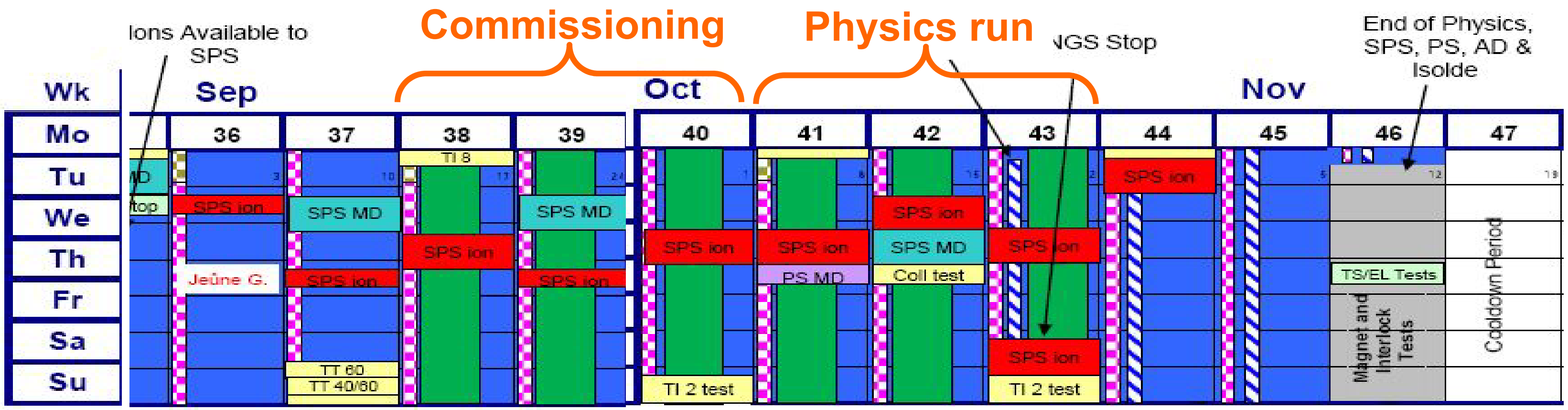
Scanning in Europe:

- **E**uropean **S**canning **S**ystem at 20 cm^2/h
- at LNGS: CSd scanning for quick confirmation of neutrino interaction
- ~30 ESS distributed at 11 labs for scanning bricks to locate vertex interaction
  → Bari, Bern, Bologna, LNGS, Lyon, Napoli, Salerno, Neuchatel, Roma, LNF, Padova

Scanning in Japan:



CNGS Run 2007



Commissioning (week 38-40):

- Setting up of SC
- Interlock tests
- Extraction
- Horn/reflector tests
- Stripline modification
- Setting up of secondary beam
  - Alignment horn vs. target vs reflector
  - TBID calibrations
  - Study neutrino/antineutrino behavior
- Increase of intensity

→ Total: $0.5 \cdot 10^{17}$ pot

Physics run (week 41-43):

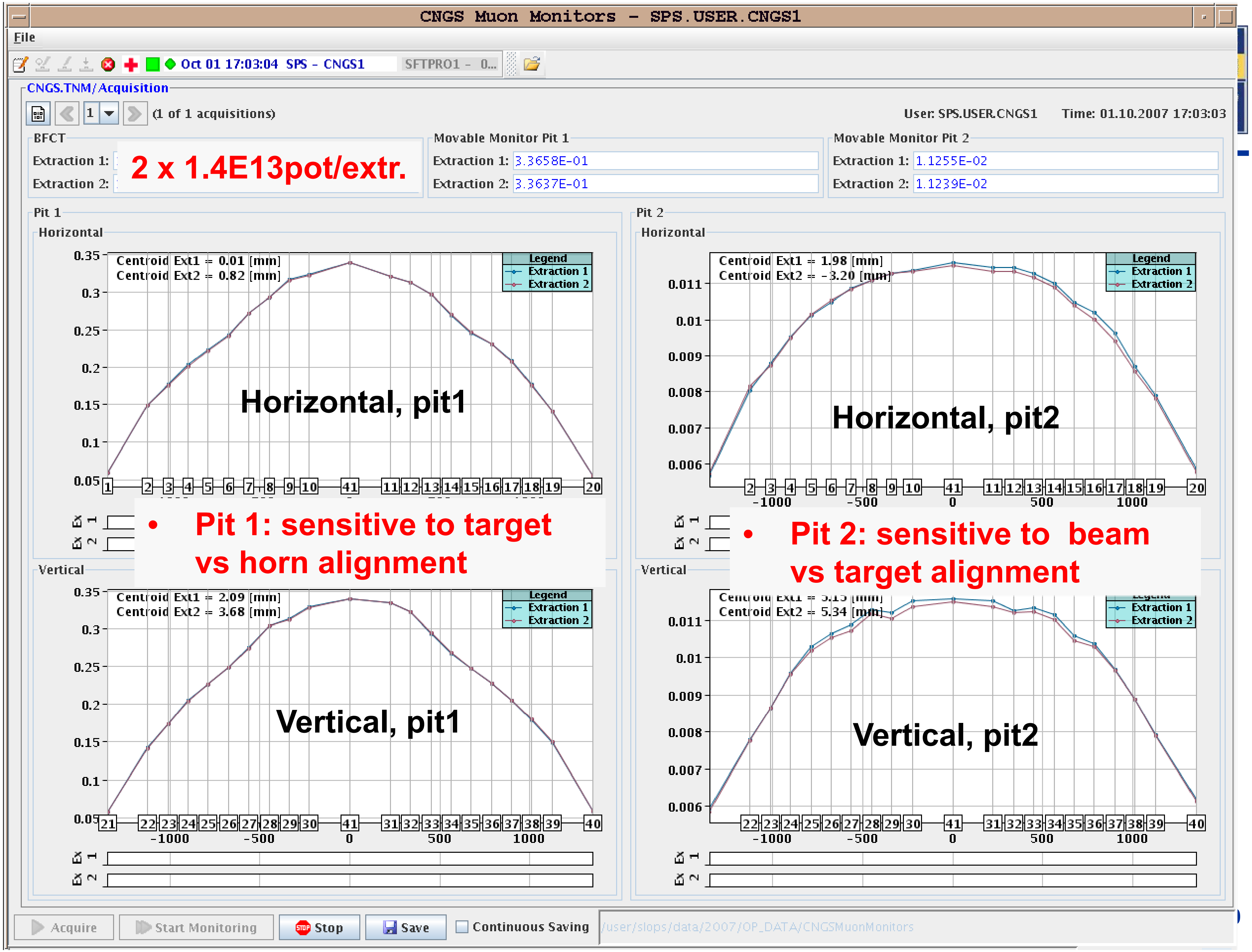
- Start Friday, October 5^{th}, 5:30 pm
- Stop of beam 5 days prior than planned due to failures in the ventilation caused by radiation effects in the electronics
  - Many efforts and modifications for CV done
  - However, failure in switching to access mode in a safe manner

→ Total: $7.9 \cdot 10^{17}$ pot

CNGS Extraction and Transfer

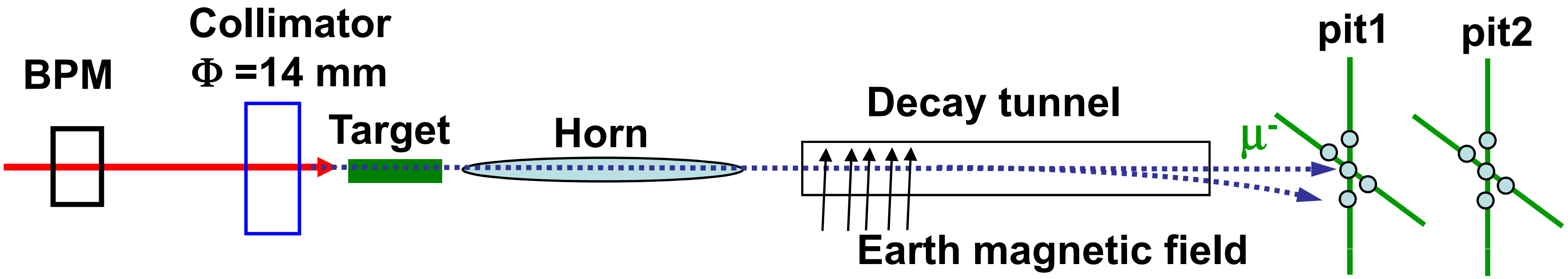
courtesy of J. Wenninger

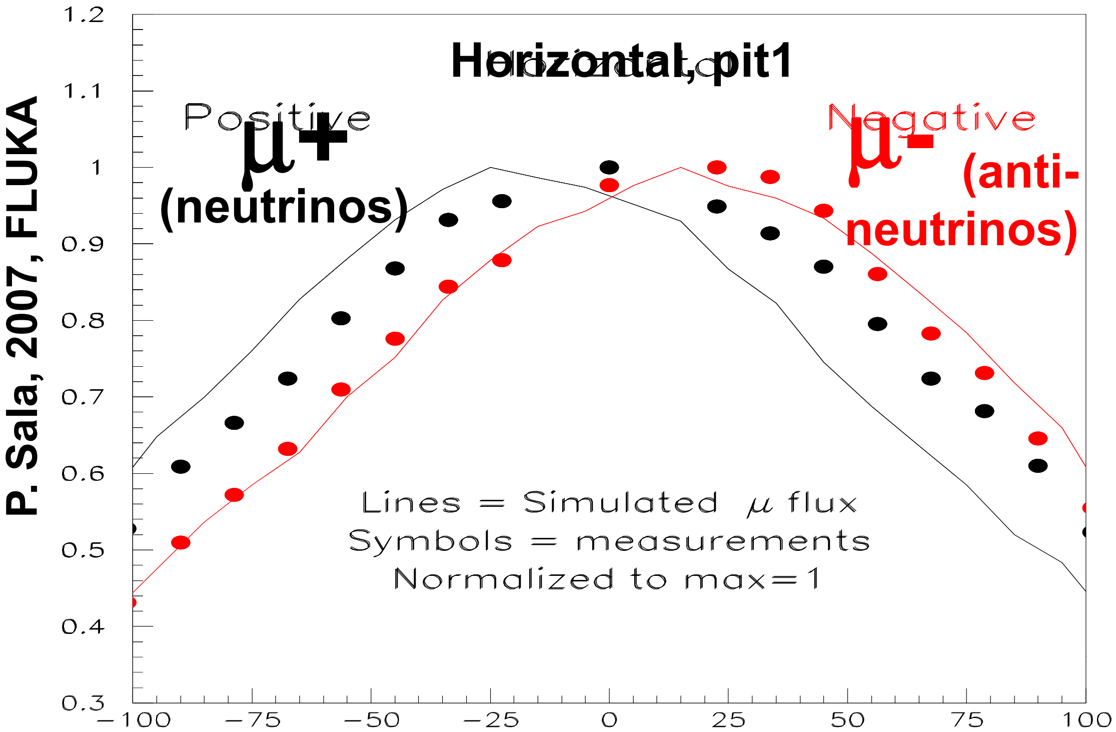
- **Extraction line and equipment very stable with respect to 2006.**
  - **Setting of main magnets and major corrections fully reproducible.**
  - **Interlock settings for all dipoles and quadrupole converters reproducible.**
- **Excellent beam stability**
  - **All 23 BPM measurements are well within the design tolerance of ± 4mm.**
  - **All extractions hit the target within tolerance (below ± 0.5mm).**
  - **Stable beam losses.**
- **Beam Intensity**
  - **SC of 39.8s with 1 long FT, CNGS1, CNGS2, CNGS3, 1 MD**
  - **45400 extractions in 23700 cycles.**
  - **Average intensity on target of $1.7 \cdot 10^{13}$ protons per extraction.**
  - **Maximum intensity: $2 \cdot 10^{13}$ protons per extraction.**


CNGS Muon Monitors – SPS.USER.CNGS1
File
Oct 01 17:03:04 SPS - CNGS1
SFTPRO1 - 0...
CNGS.TNM/Acquisition
(1 of 1 acquisitions)
User: SPS.USER.CNGS1
Time: 01.10.2007 17:03:03
BFCT
Extraction 1:
Extraction 2:
2 x 1.4E13pot/extr.
Movable Monitor Pit 1
Extraction 1: 3.3658E-01
Extraction 2: 3.3637E-01
Movable Monitor Pit 2
Extraction 1: 1.1255E-02
Extraction 2: 1.1239E-02
Pit 1
Horizontal
Centroid Ext1 = 0.01 [mm]
Centroid Ext2 = 0.82 [mm]
Legend
Extraction 1
Extraction 2
Horizontal, pit1
Pit 2
Horizontal
Centroid Ext1 = 1.98 [mm]
Centroid Ext2 = -3.20 [mm]
Horizontal, pit2
• Pit 1: sensitive to target vs horn alignment
• Pit 2: sensitive to beam vs target alignment
Vertical
Centroid Ext1 = 2.09 [mm]
Centroid Ext2 = 3.68 [mm]
Vertical, pit1
Centroid Ext2 = 5.34 [mm]
Vertical, pit2
Acquire
Start Monitoring
Stop
Save
Continuous Saving
/user/slops/data/2007/OP_DATA/CNGSMuonMonitors

Neutrino/Antineutrino Behavior

p + C → (interactions) → $\pi^{+(-)}$, $K^{+(-)}$ → (decay in flight) → $\mu^{+(-)} + \nu_{\mu(\bar{\ })}$



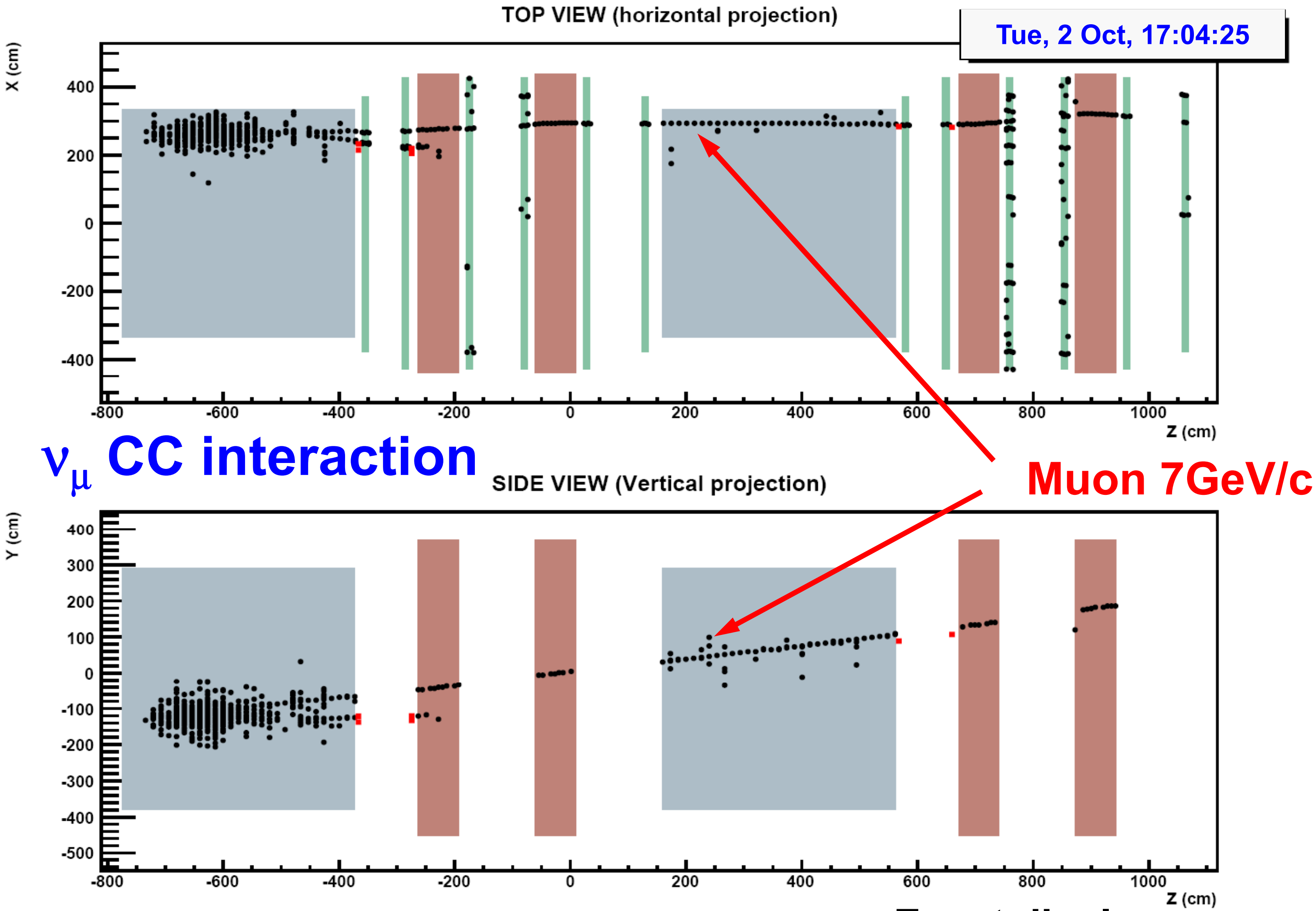


Comparison of measurements with first preliminary simulations:

- Earth magnetic field: 0.4 Gauss
- Shielding of iron wall of decay tube not yet included!

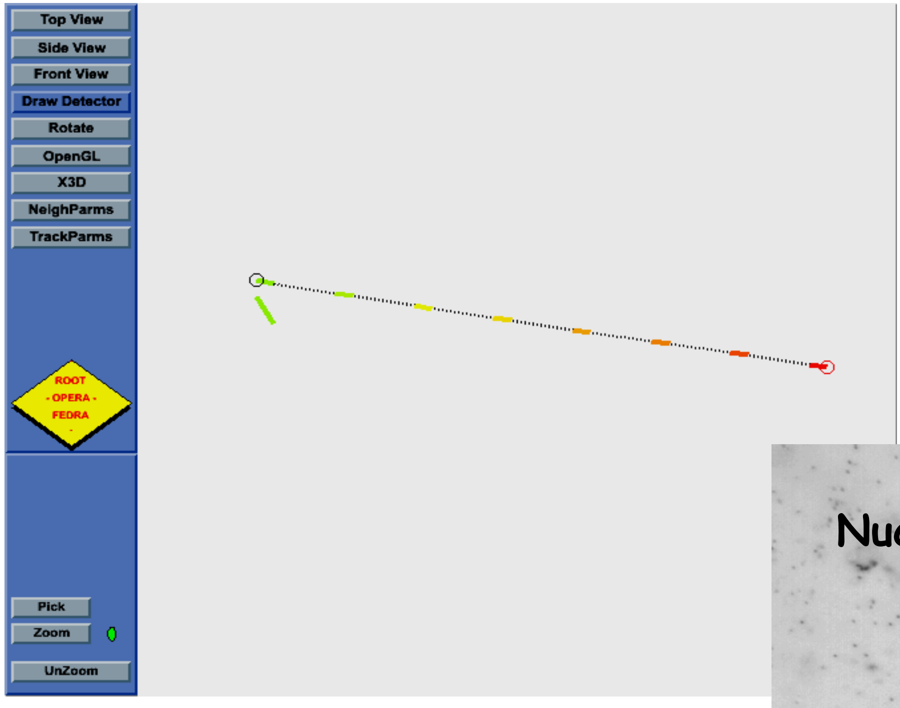
  → deflection is bigger in simulations

First CNGS Neutrino Interaction inside an OPERA Brick

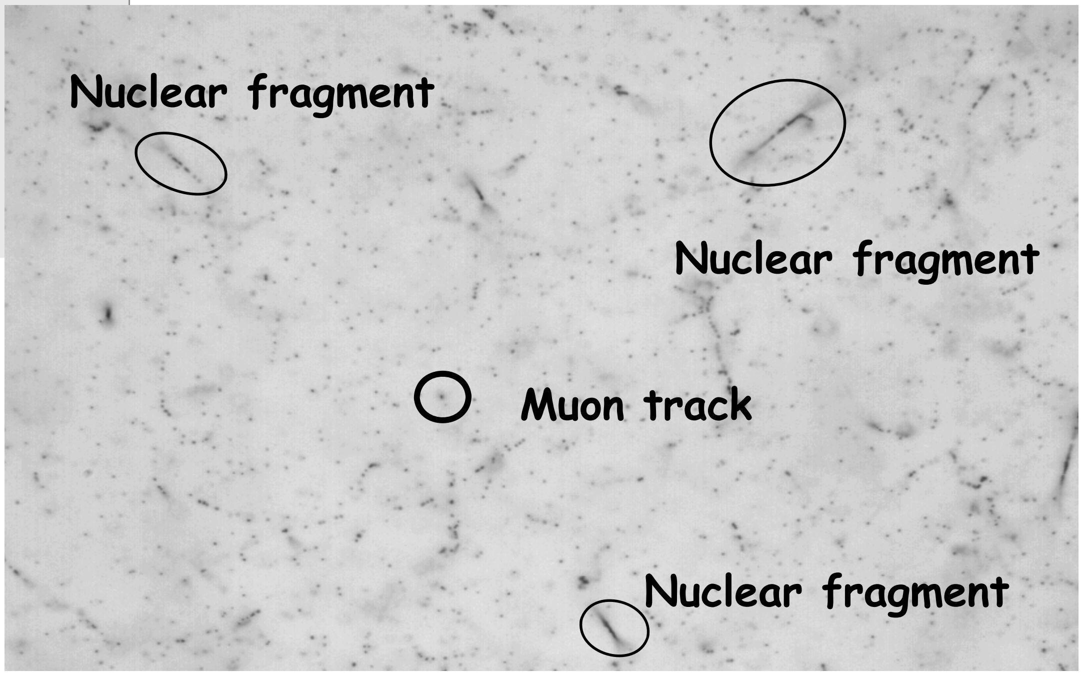


Event display

Events inside Bricks

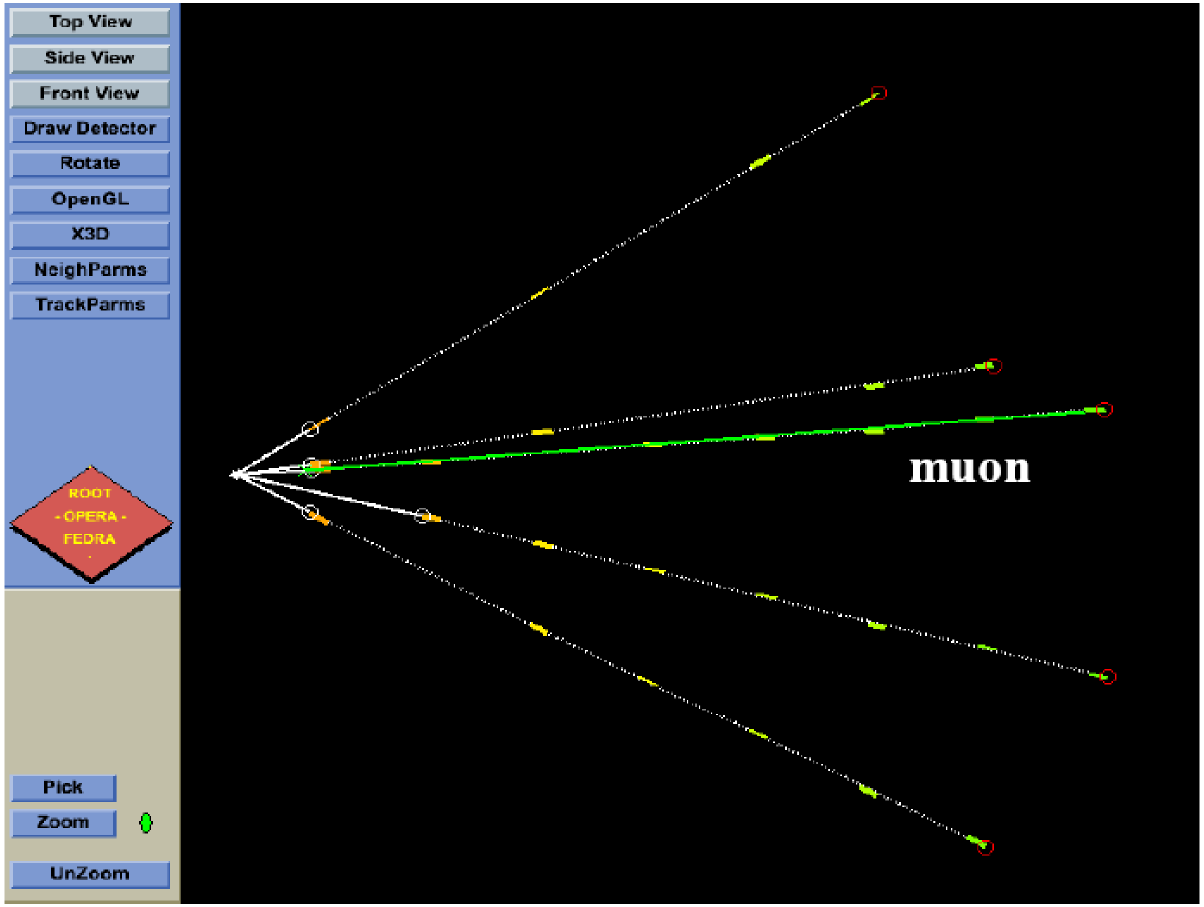


Vertex found- quasi elastic event



CNGS Events inside Bricks

Event: 186970035



IP (micron)
2.03 µm
4.16 µm
3.05 µm
2.72 µm
14.89 µm

CNGS Run 2007 – Summary

- **Successful Repair and Modification of the Horn and Reflector in 2007**
  (As a consequence of a water leak in the reflector cooling circuit in 2006)

→ Restart of the CNGS facility as scheduled on 17 September 2007 for six weeks

- **CNGS beam performance: very good**
  In total: $8.5 \cdot 10^{17}$ protons on target
  → 38 OPERA events in bricks
  → More than 400 events from interactions outside OPERA detector

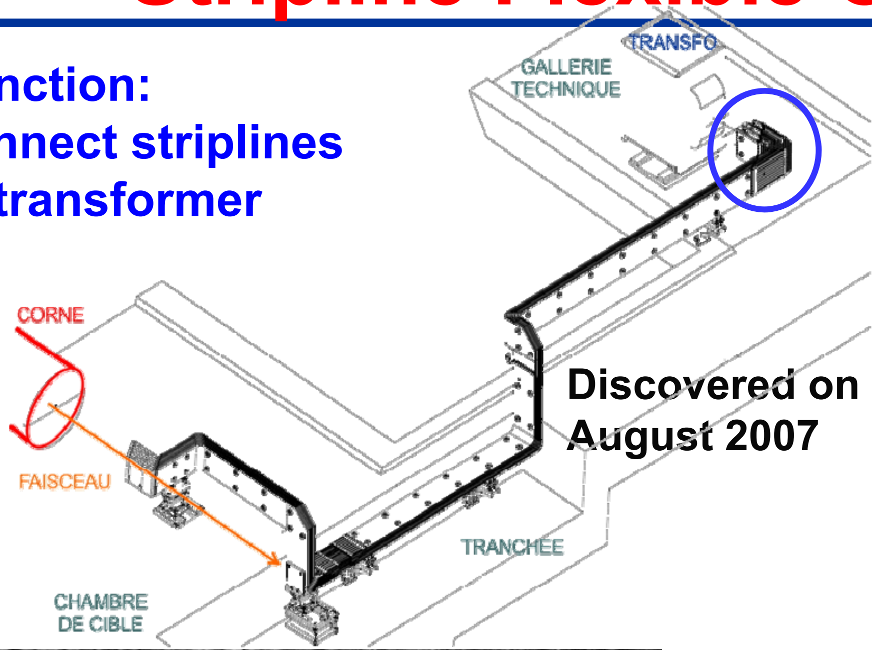
- **Failures in the ventilation system due to radiation effects in electronic**
  → Consequences on
    - **safety of installed equipment – possible temperature rise**
    - **access system – switch between beam and access mode**

  → Stop of CNGS beam 5 days ahead of time

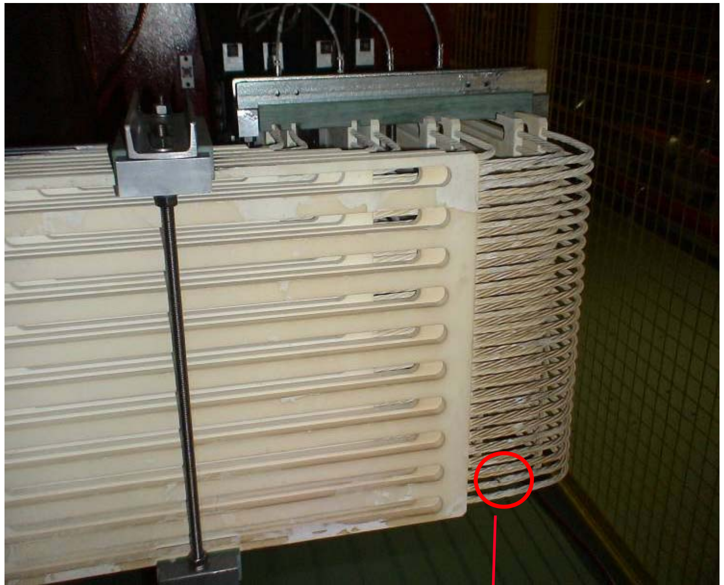
- **Other issue: Broken cable in one of the flexible junctions in the reflector striplines**

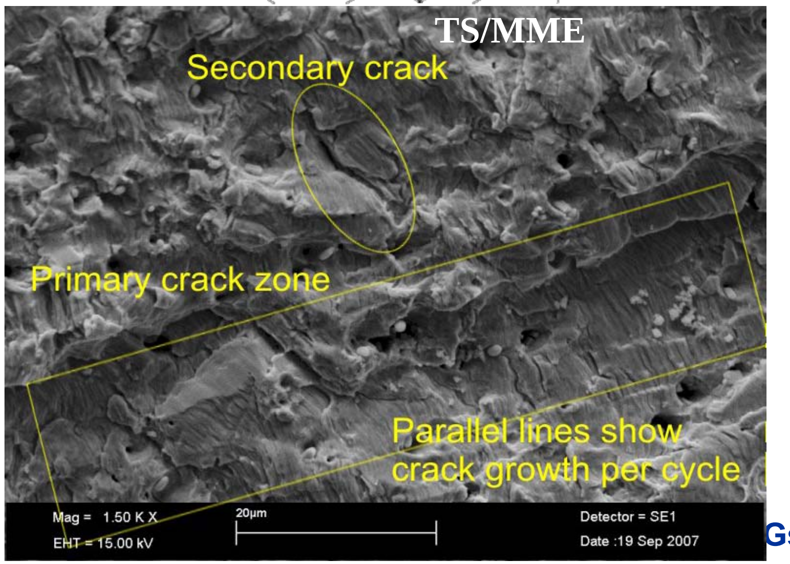
Modification 2008: Stripline Flexible Connection I

Function: connect striplines to transformer



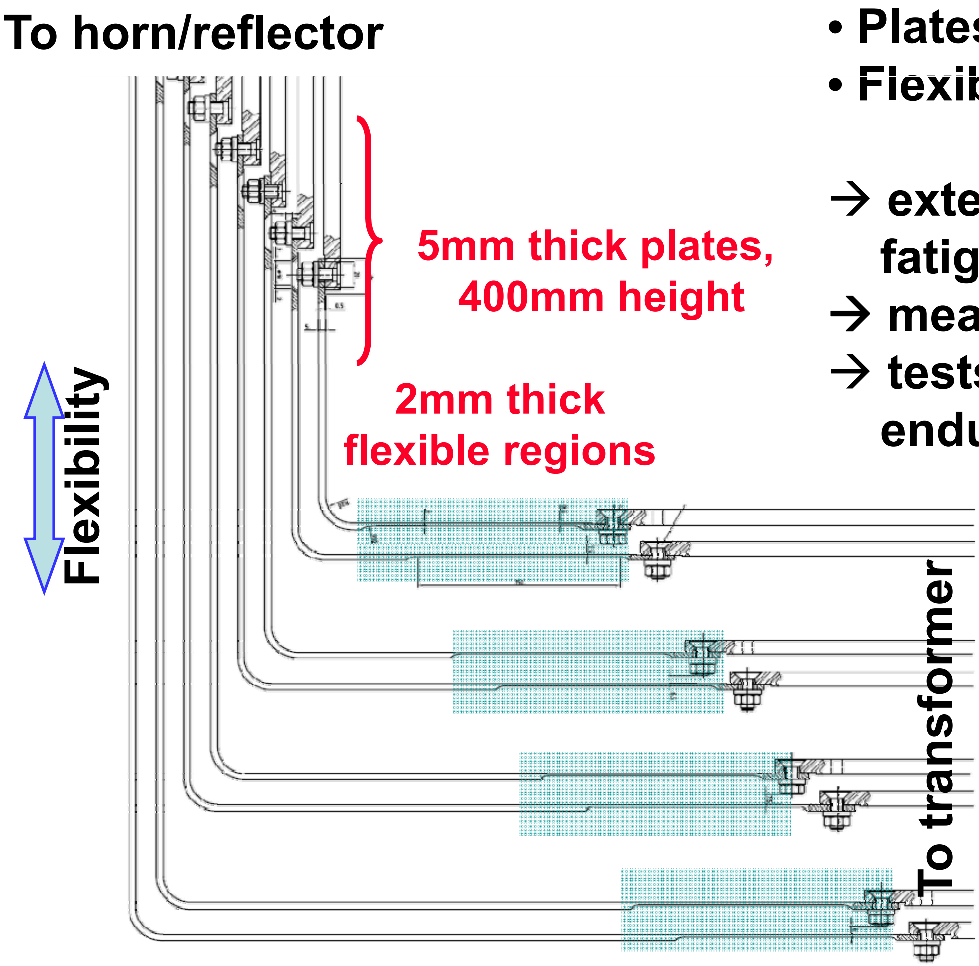
Discovered on Reflector August 2007





Twisted & brazed cables, Ag-Cu. Fatigue (pulses) on strands plus force from thermal expansion stripline caused cracks & fatigue failure.

Modification 2008: Stripline Flexible Connection II



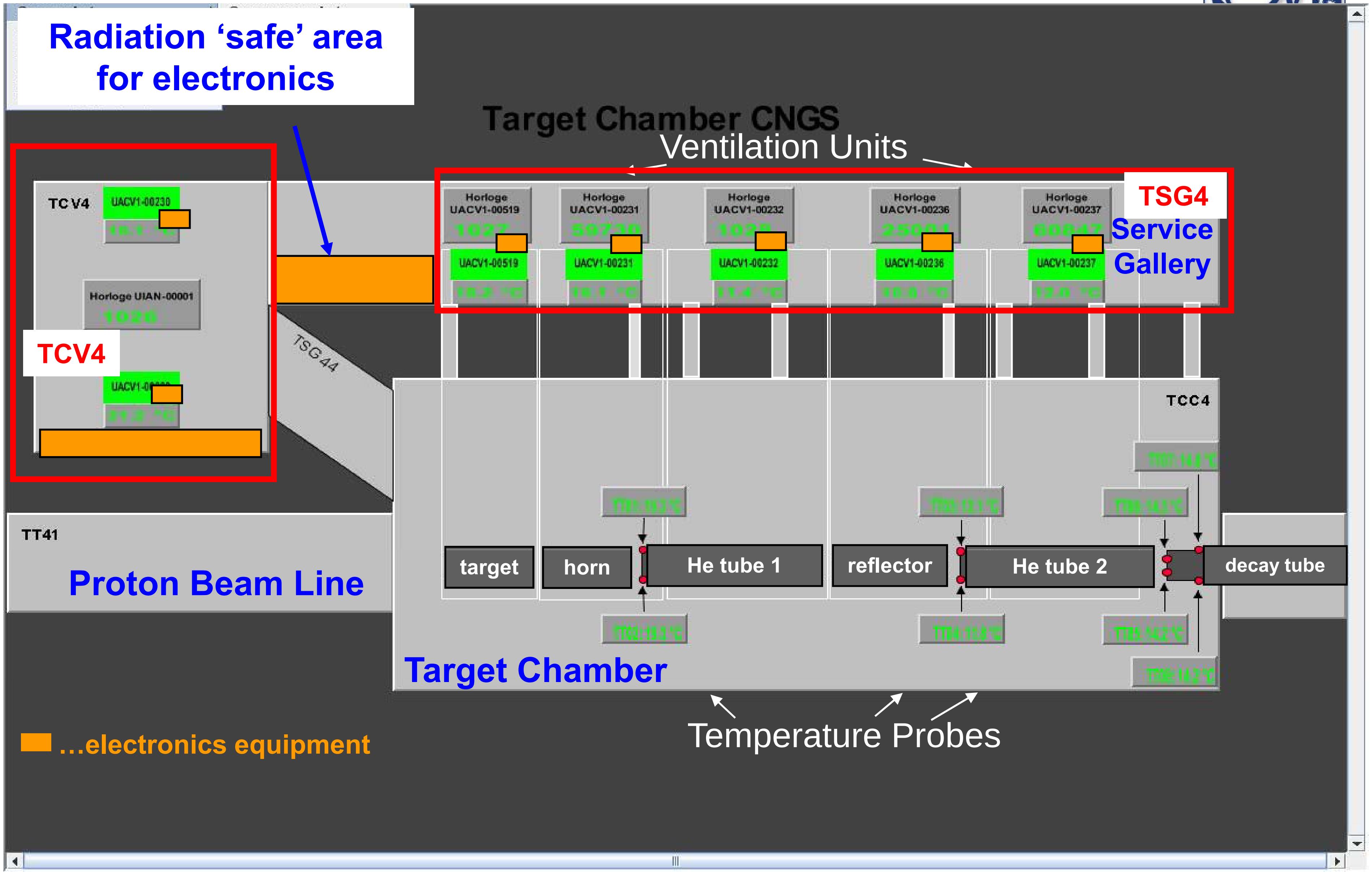
New Design to ensure reliability

- Plates instead of twisted cables, no brazing
- Flexible part to absorb thermal expansion

→ extended calculations (magnetic, thermal, fatigue)
→ measurement of thermal expansion
→ tests (prototype, metallurgy, installation, endurance)

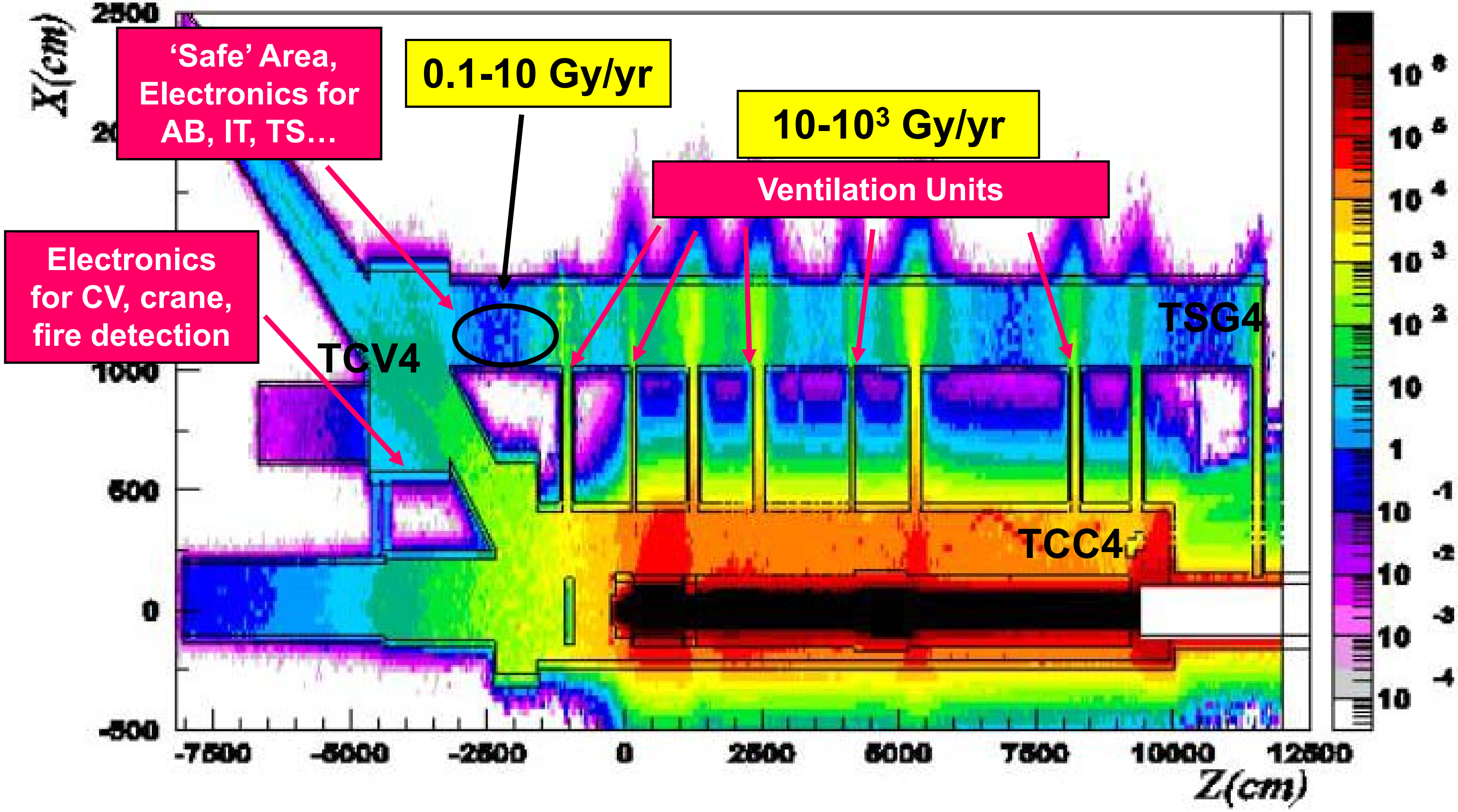
→Installation (horn & reflector): May 2008

CNGS Electronics Layout



Present Situation: Expected Dose Levels

Gy/yr for a nominal CNGS year of 4.5 10^{19} pot

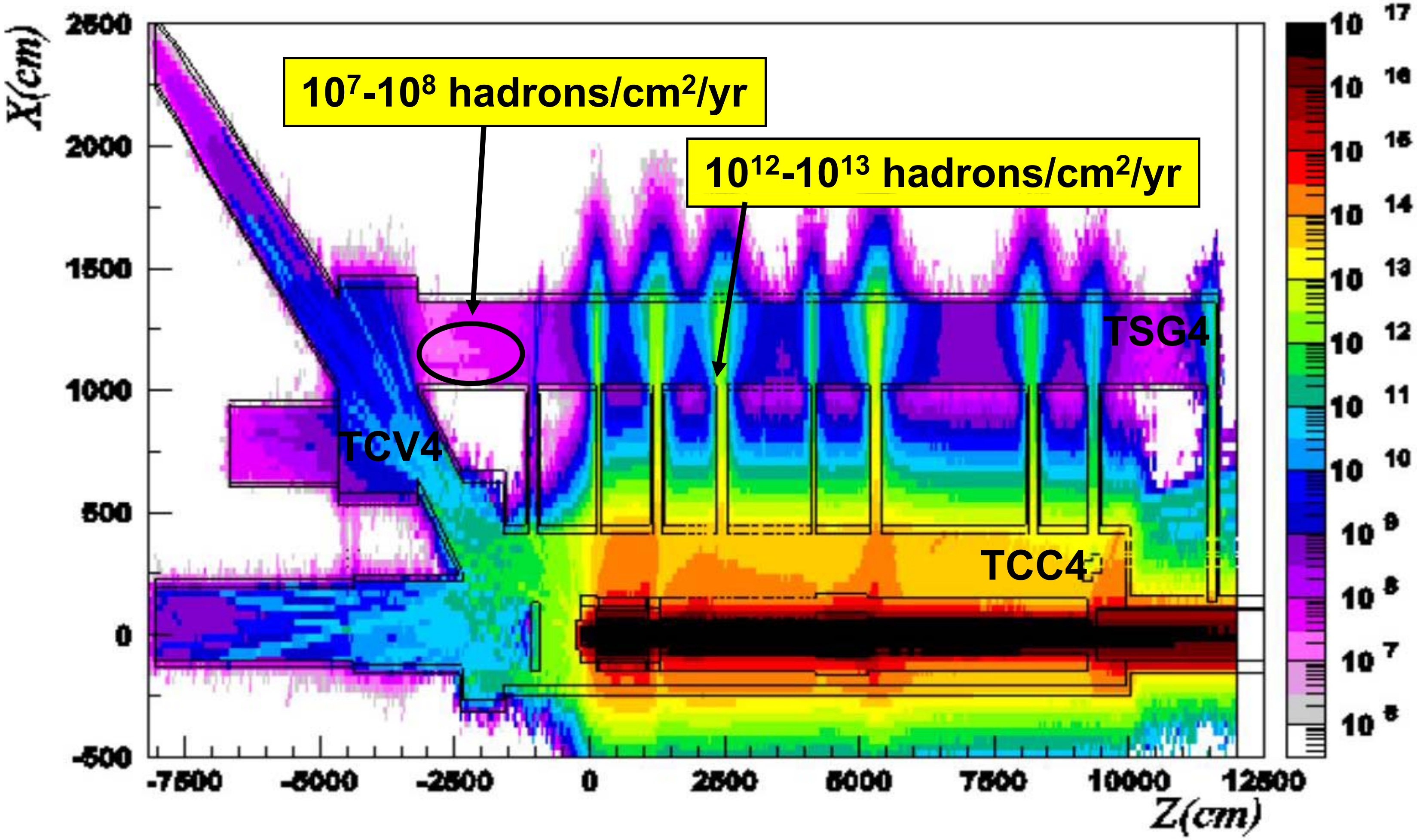


A. Ferrari, L.Sarchiapone et al, 2007, FLUKA

Commercial electronics typically does not fail below 10 Gy

Present Situation:
Expected High Energy Hadron Fluence

Energetic (> 20 MeV) hadron fluence (cm^{-2} yr^{-1}) for a nominal CNGS year of 4.5 10^{19} pot



A. Ferrari, L.Sarchiapone et al, 2007, FLUKA

→ **Single Event Effects on electronics (bit flip, single event upsets...)**

Modifications 2008: Radiation on Electronics

- Electronics with failures installed in Service Gallery TSG4 and Ventilation Chamber TCV4
  - Direct view to target chamber (ventilation ducts, etc…)
  - Radiation levels there: too high for commercial components:

- No failures in electronics upstream of TSG4 in ‘safe area’
  - Radiation levels there: ok for beam intensities during 2007 run
    - However, failures probably would have happen for a longer CNGS run.

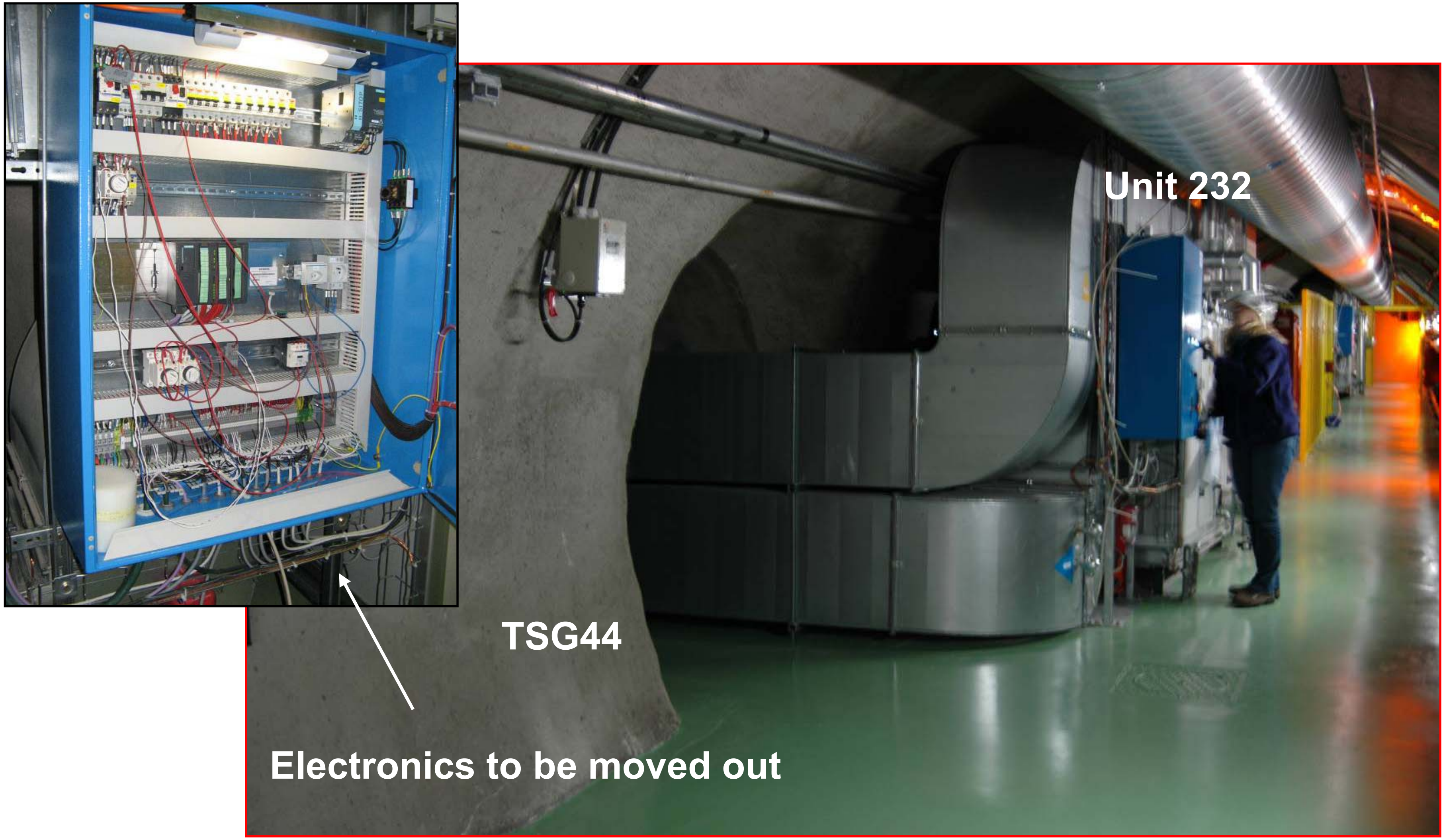
→ Move electronics out of downstream TSG4 and out of TCV4

→ Create ‘radiation safe’ area

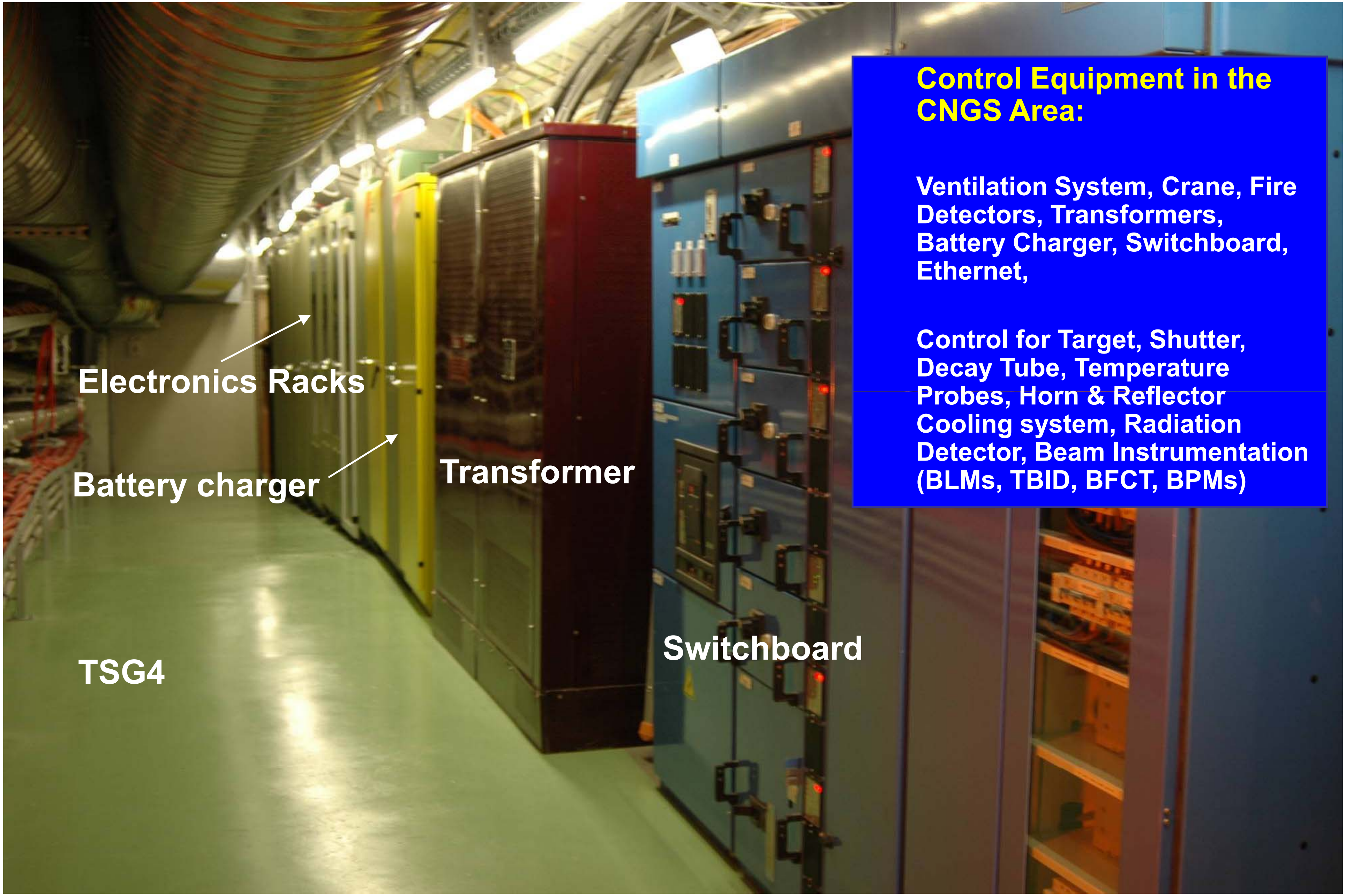
- adding adequate shielding and move all the electronics in there
- Address the sensitivity to radiation of the installed electronics and investigate upgrade possibilities to radiation-tolerant components
- Assure a mean time between failures of at least 1 year → redundancy and preventive maintenance actions
- Install radiation monitoring system for electronics as in LHC

→ We aim for beam on 28 May 2008

Ventilation Units in TSG4



‘Safe’ Area for Electronics



Control Equipment in the CNGS Area:

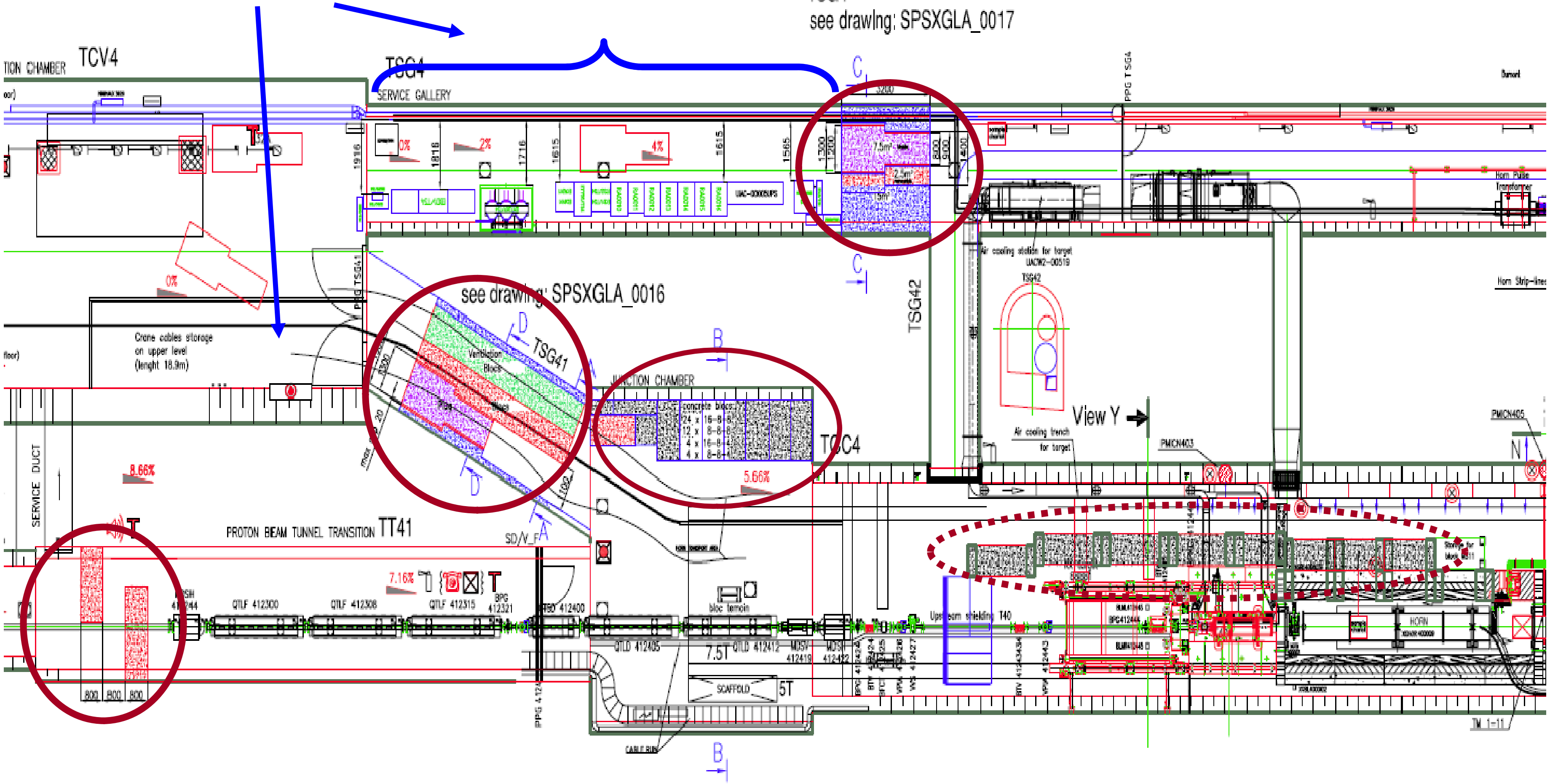
Ventilation System, Crane, Fire Detectors, Transformers, Battery Charger, Switchboard, Ethernet,

Control for Target, Shutter, Decay Tube, Temperature Probes, Horn & Reflector Cooling system, Radiation Detector, Beam Instrumentation (BLMs, TBID, BFCT, BPMs)

New Shielding Layout

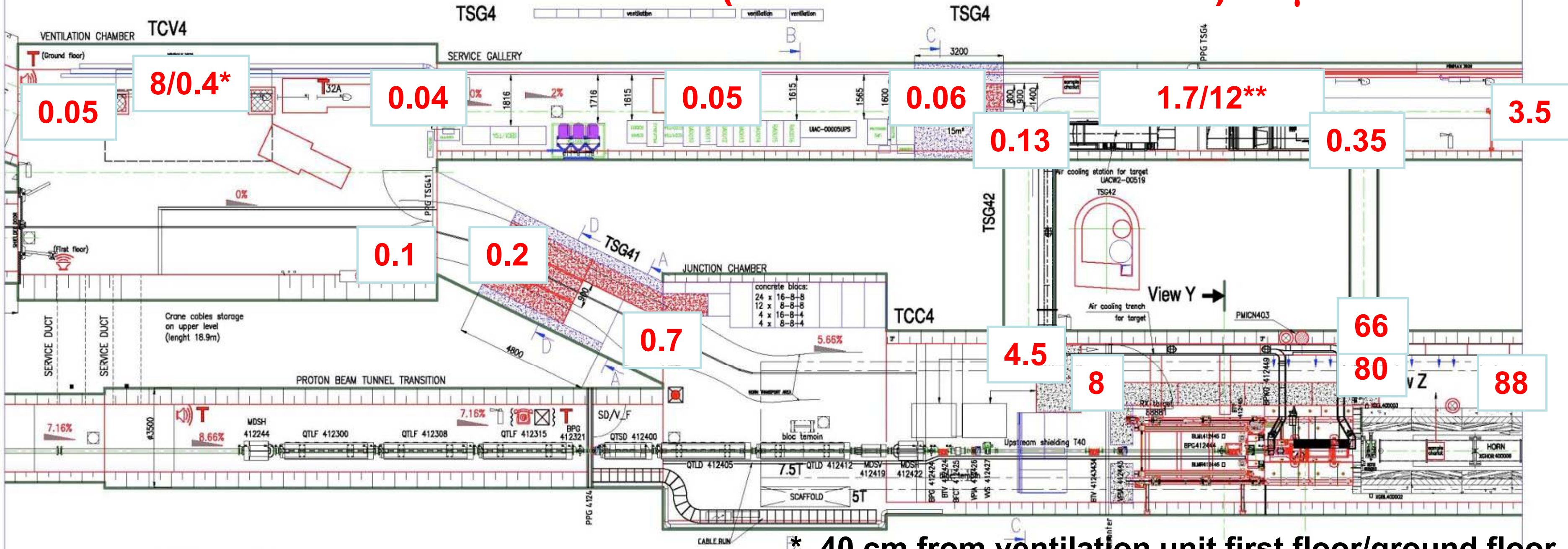
Radiation safe area

Radiation reduction at order of ~10^4



CNGS Dose Measurements

measurement from 20/11/2007 (1 month after beam off) in µSv/hr



* 40 cm from ventilation unit first floor/ground floor

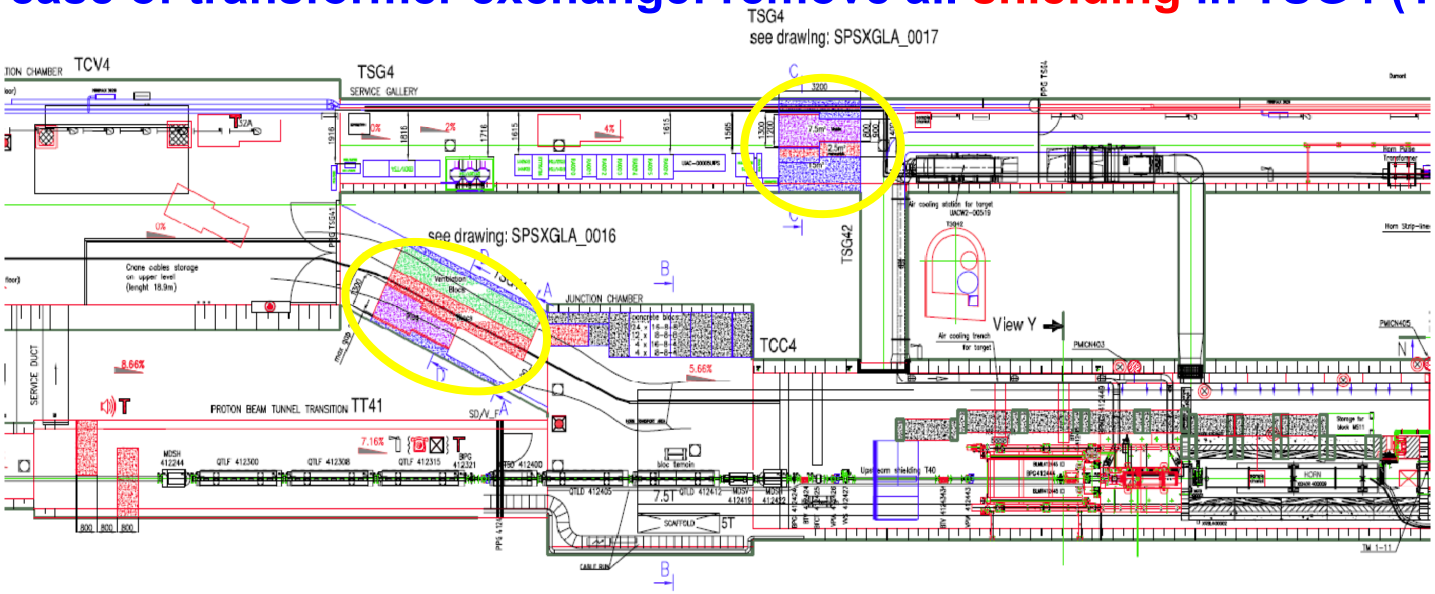
** in the aisle/contact ventilation unit

- **No work close to the "hot" areas in TCC4**
- **Planning and execution of the works in-situ**
  - same procedures as with the horn repairs
  - Optimization of design and execution taking into account RP and safety constraints
  - Detailed planning of activities in parallel to dose planning
  - Supervision of the works/workers in-situ
  - use of appropriate materials for RP and waste handling

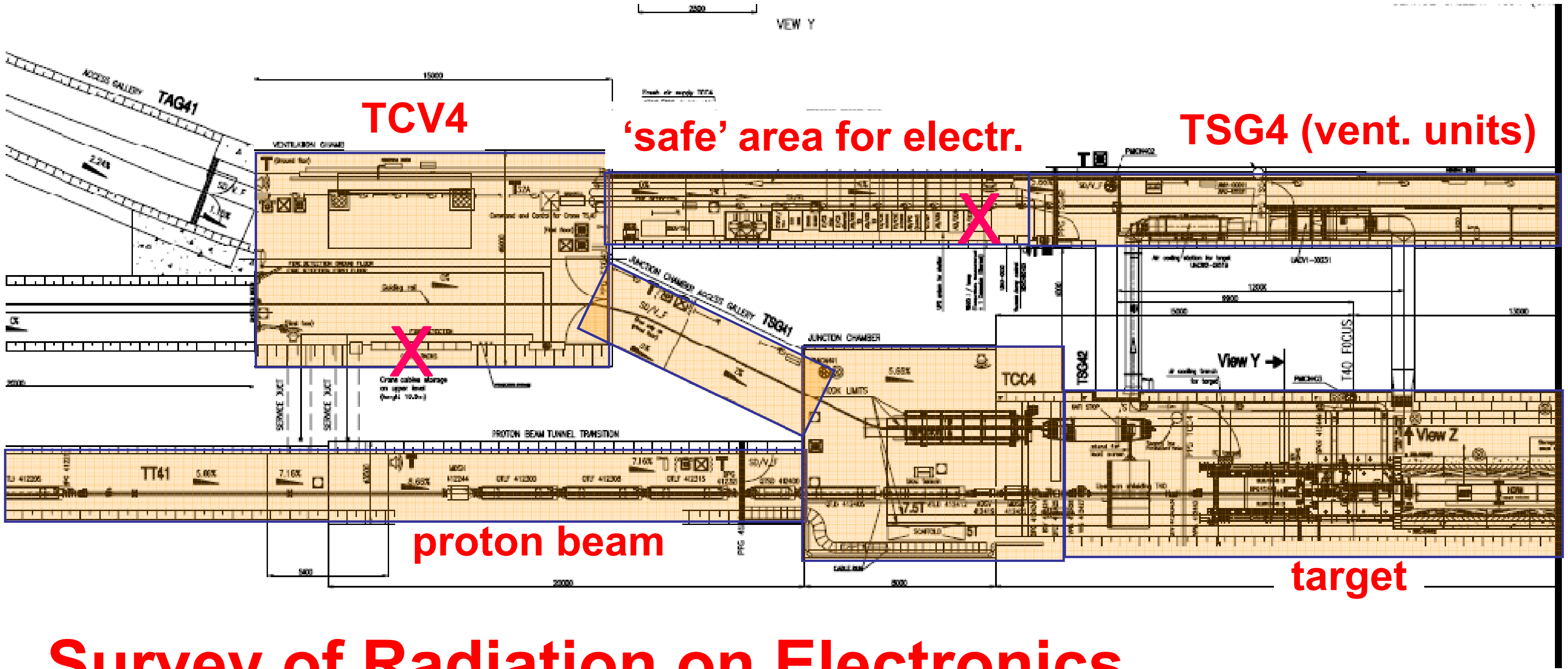
Operational Aspects

Strict access procedures:

- **Minimum 1day waiting time for access**
  - change to access mode in ventilation → reliable system!
  - RP: air and dust probes, dose map, etc…
- **For any access to CNGS: shielding plugs must be opened (~2hrs).**
- **In case of horn/reflector/target exchange: remove entire shielding in TSG41 (1-2 weeks).**
- **In case of transformer exchange: remove all shielding in TSG4 (1-3 days)**



Operational Aspects



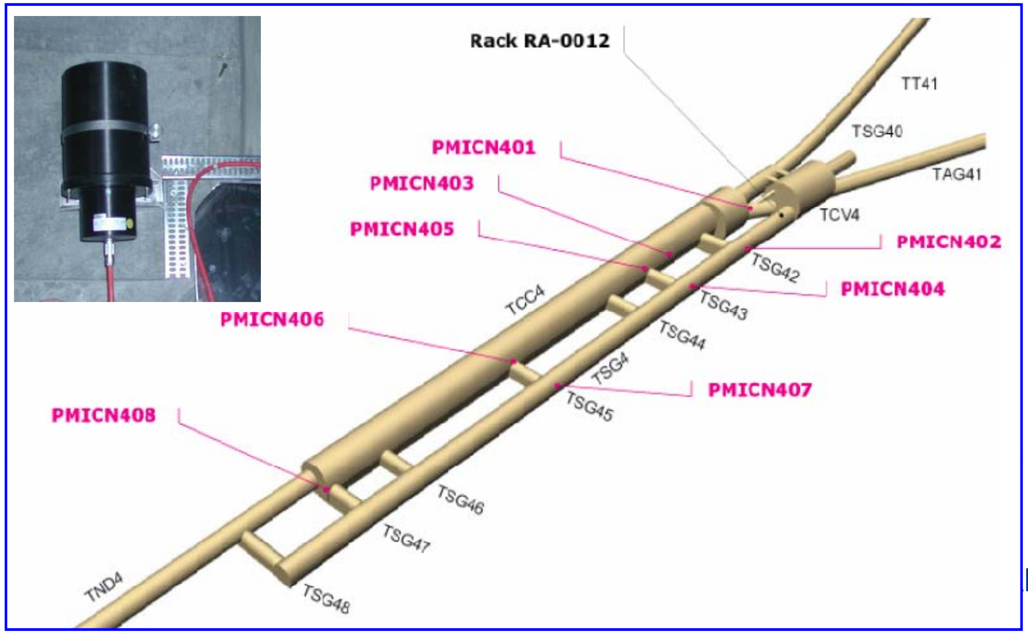
Survey of Radiation on Electronics

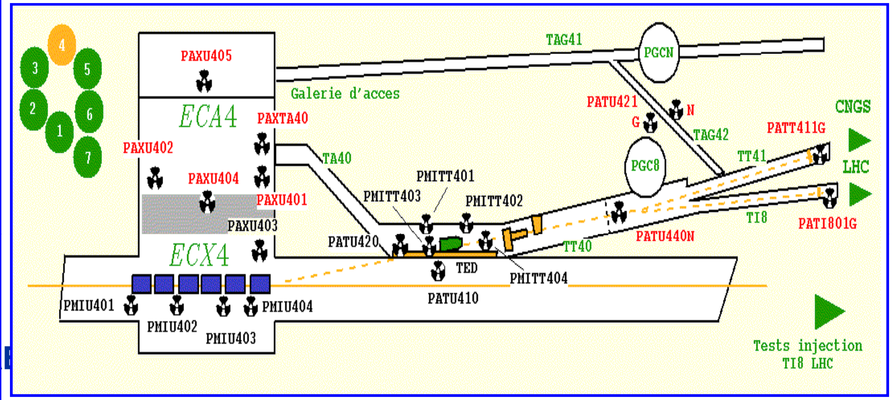
→ **dose, 1 MeV neutron equivalent fluence and high energy hadron fluence measurements:**

- **Last period of 2007 run: 2 RadMon monitors X**
- **2008: > 5 RadMon distributed in CNGS area**

Operational Aspects

- **Continuous radiation monitoring of prompt radiation, released radioactivity and induced radioactivity**
  → **warning, interlocks**
  - **Ramses detectors:**
    - **Stray radiation monitoring stations: gamma & neutron monitors**
    - **Induced activity monitors**
    - **Ventilation monitoring station: gas monitor & aerosol sampler**
    - **Hand & foot monitor**
    - **Tools & material controller**
  - **ARCON system**
  - **Remote radiation survey mounted on overhead crane**





Operational Aspects

- In order to take into account the new shielding layout update of
  - Access procedures
  - Horn/target exchange procedures
  - Intervention/maintenance procedures

- No significant changes in the operational aspects
  - Main effect on time needed to remove additional shielding.
  - However, time-consuming manipulation only done when exchange of horns/target is planned.

    → Marginal compared to cool-down time.

Summary

- Very good beam performance during CNGS run 2007
- Radiation effects in electronics
  - Move electronics
  - Create 'radiation safe area' by adding shielding
- Protection of humans, electronics and equipment is assured
  - Updated access procedures, radiation monitors, preventive maintenance, shielding, interlocks

MANY THANKS!!!!

to all people for their contributions to the operation and shutdown activities of CNGS!

AB/OP - AB/CO - AB/PO – AB/ATB - RP/SL - PH/DT1 - TS/MME – TS/CV – TS/IC

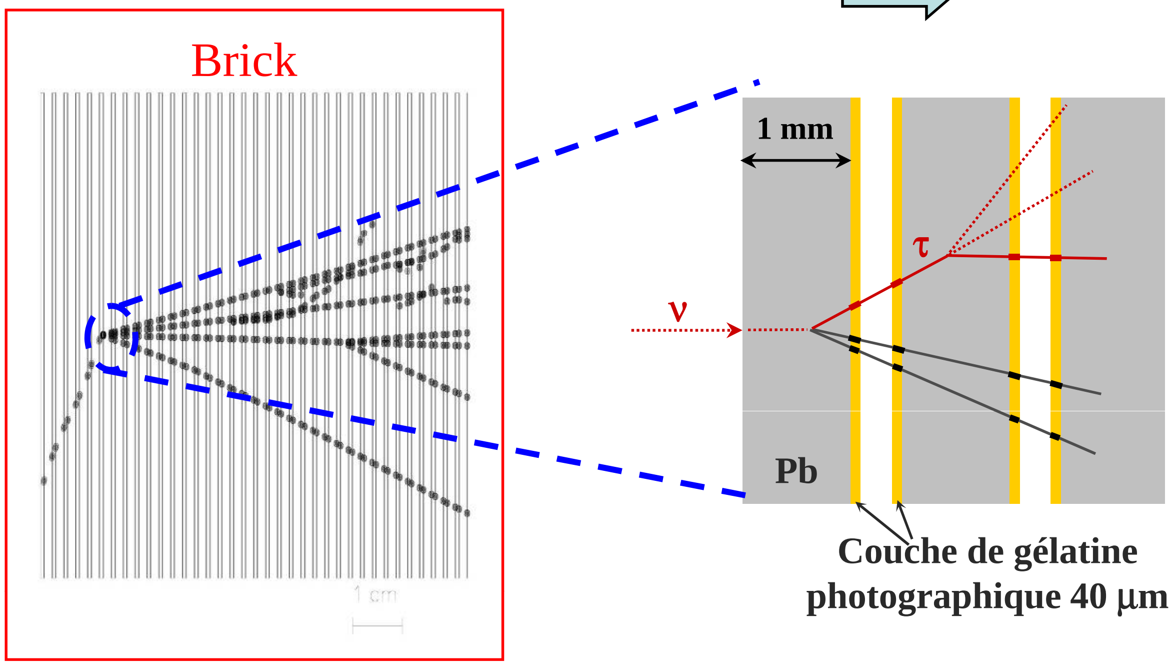
Spare Slides

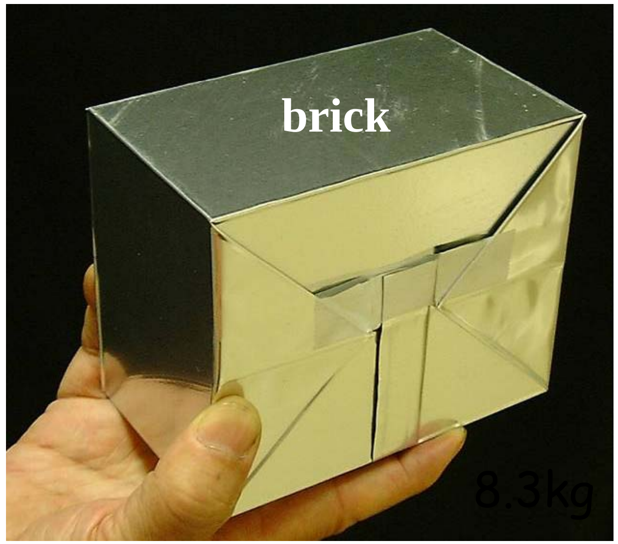
OPERA Experiment

Basic unit: brick:

56 Pb sheets + 56 photographic films (emulsion sheets)

lead plates: massive target
emulsions: micrometric precision

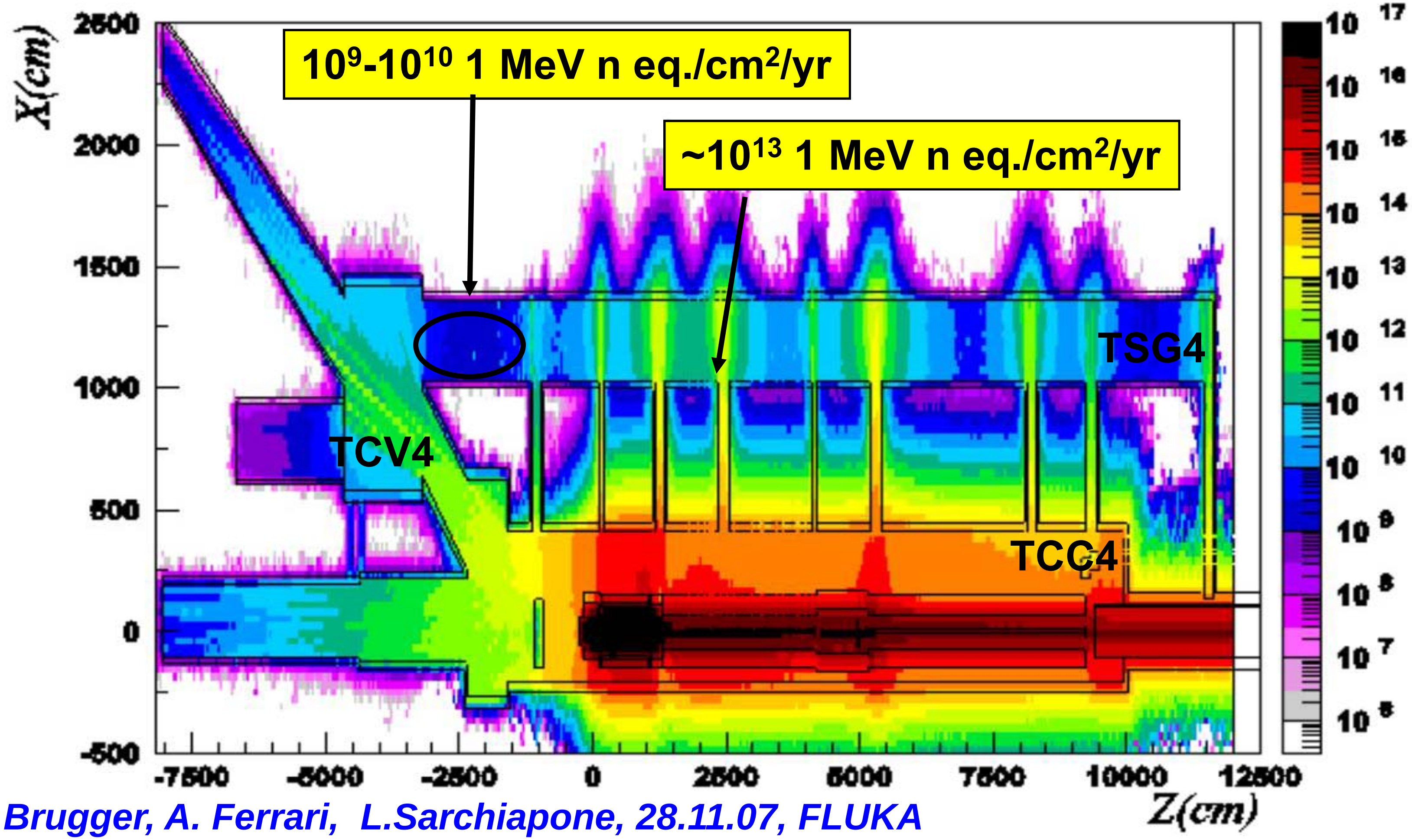




10.2 x 12.7 x 7.5 cm^3

Expected Neutron Fluence

1 MeV eq. neutron fluence (cm^{-2} yr^{-1}) for a nominal CNGS year of 4.5 10^{19} pot



M. Brugger, A. Ferrari, L.Sarchiapone, 28.11.07, FLUKA

CNGS Performance

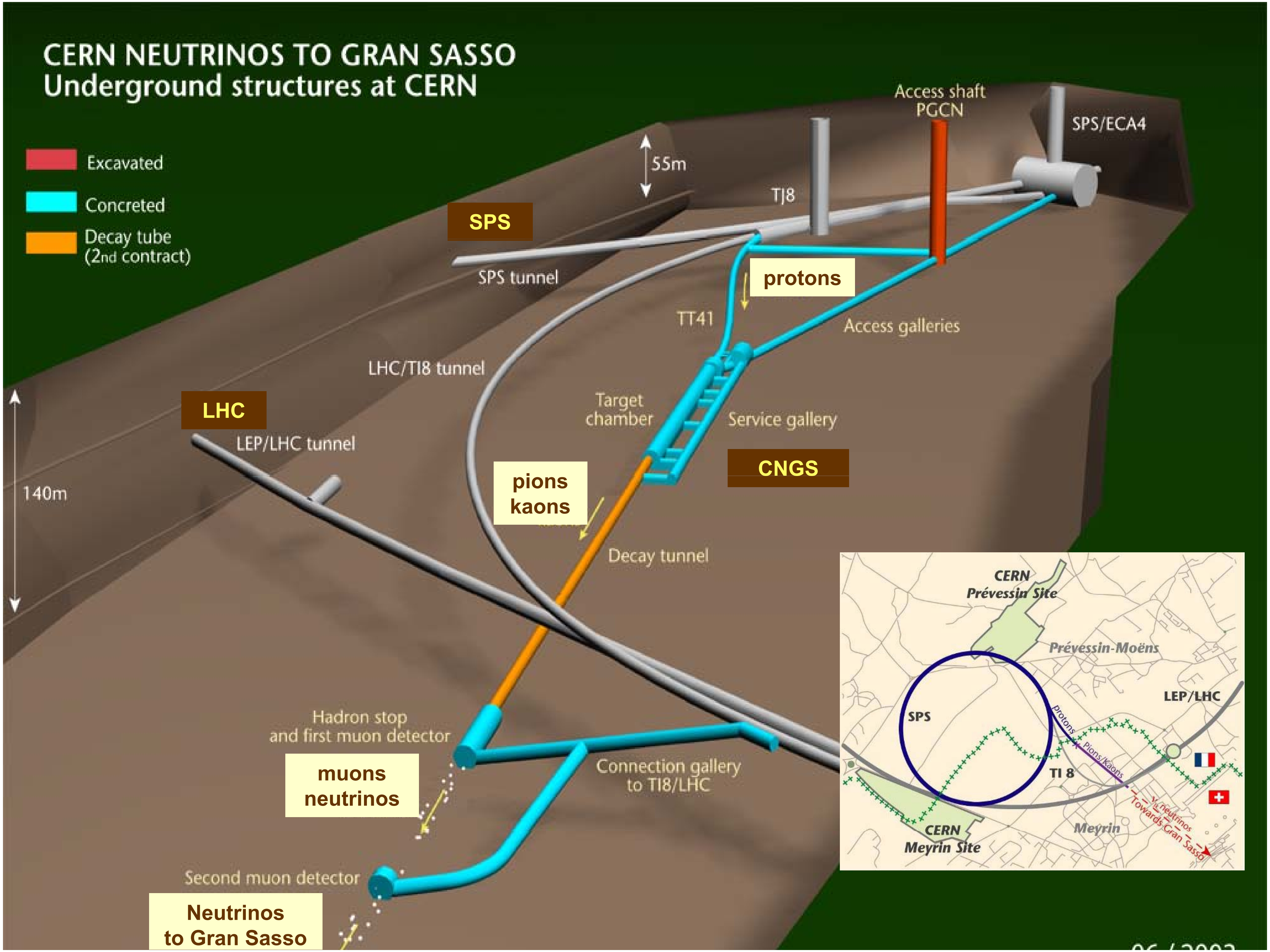
For CNGS performance, the main issues are

– the geodesic alignment wrt. Gran Sasso

Examples:	effect on ν_τ 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%

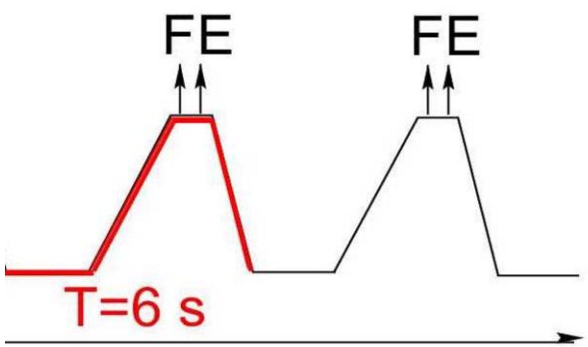
– the beam must hit the target very accurately

– horn and reflector tables NOT motorized


CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN
Excavated
Concreted
Decay tube
(2nd contract)
SPS
SPS tunnel
55m
TJ8
Access shaft
PGCN
SPS/ECA4
protons
TT41
Access galleries
LHC/TI8 tunnel
LHC
LEP/LHC tunnel
Target
chamber
Service gallery
CNGS
140m
pions
kaons
Decay tunnel
Hadron stop
and first muon detector
muons
neutrinos
Connection gallery
to TI8/LHC
Second muon detector
Neutrinos
to Gran Sasso
CERN
Prévessin Site
Prévessin-Moëns
LEP/LHC
SPS
Protons
Pions/Kaons
TI 8
Towards Gran Sasso
CERN
Meyrin Site
Meyrin

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



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