CNGS Project: Status report

1. Project Overview
2. Proton beam layout and equipment status
3. Proton beam dynamics
4. Target and secondary beam equipment readiness
5. Commissioning preparation
6. Outlook
1. Project Overview

(see http://cern.ch/cngs)

CNGS - a long base-line neutrino beam facility (732 km)

send $\nu_\mu$ beam $\rightarrow$ detect $\nu_\tau$ appearance

CNGS project at CERN: production of the $\nu_\mu$ beam

using protons from the existing accelerator chain

At Gran Sasso:

OPERA detecting $\nu_\tau$
CNGS: the main components

\[ p + C \rightarrow (\text{interactions}) \rightarrow \pi^+, K^+, (\mu^+) \rightarrow (\text{decay in flight}) \rightarrow \mu^+ + \nu_{\mu} \]
2. Proton beam line layout and equipment status
Proton beam line overview
TT41 extraction point to beam dump

- TA40
- TT40
- SPS extraction point
- CNGS&LHC beam
- SPS beam
- TT40
- Safety beam stopper
- MBHC 13mrad
- MBHA 15mrad
- MBSG 25mrad
- TT41 extraction point to beam dump
- to CNGS target
- to LHC

Beam Dump TED

SPS
Transfer line layout: half cell

5.6% slope

Electrical distribution box

Magnet Interlock box

BPM control box
Main dipole magnet status

MBG
73 magnets (78 ordered)
Nominal field : 1.7 T @ 400 GeV
Magnetic length : 6.3 m
Gap height 37 mm

ALL RECEIVED and stored
Main quadrupole magnet status

QTG  20 magnets (23 ordered)
Magnetic aperture : 45 mm
Nominal gradient 40 T/m, 2.2 m long

All QTG received

All QTG installed in TT41 and aligned
Quadrupole installation in TT41

23 August 2005
Dipole corrector magnet status

MDG 12 magnets (17 ordered)
Gap height : 45 mm
Bending angle  80 µrad, overall length: 700mm

All MDG magnets received

Chambers to be inserted in 4 MDGH (at CERN)
MDGH and MDGV
Dipole corrector magnets
Last 200m

Beam

Target T40

Strong correctors
2 MDSH
2 MDSV

Final focusing
6 QTL
2 QTS

23 August 2005 Malika Meddahi
Beam line instrumentation

- 18 beam position monitors in proton beam line (BPG) + 4 in common line with LHC (BPK)
- 1 coupler in air on target table (BPKG)
- 8 proton beam profile monitors (BTVG)
- 18 beam loss monitors (BLM)
- 1 beam current transformer (BFCT) (+1 BFCT in common line with LHC)
Beam Position Monitoring

Beam Position Measurement Requirements

<table>
<thead>
<tr>
<th>source</th>
<th>rms uncertainty</th>
<th>tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPM (global accuracy)</td>
<td>0.25 mm</td>
<td>± 0.5 mm</td>
</tr>
<tr>
<td>Alignment</td>
<td>0.20 mm</td>
<td>± 0.4 mm</td>
</tr>
<tr>
<td>Total</td>
<td>0.32 mm</td>
<td>± 0.6 mm</td>
</tr>
</tbody>
</table>

Intensity Range: \(1 \times 10^{12}\) to \(3.5 \times 10^{13}\)

4 Stripline Couplers in TT40 will see both LHC & CNGS beams

Original

Modified

18 Button Electrode
BPGs in TT41
60mm Aperture
Target Beam Position Monitor

Target Beam Position Measurement Requirements

Final standard BPG of the proton beam line & target BPKG

⇒ used to provide position at the target
⇒ setting up performed using final beam line BPG
⇒ aiming at target rods verified & tracked using target BPKG
⇒ accuracy of measurement ±0.2mm in ±2mm central region.
⇒ accuracy of measurement ±0.5mm outside ±2mm central region.

<table>
<thead>
<tr>
<th>error source</th>
<th>rms uncertainty</th>
<th>tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPM (global accuracy)</td>
<td>0.1 mm &amp; ≤± 0.15 mm</td>
<td>± 0.2 mm &amp; ≤± 0.3 mm</td>
</tr>
<tr>
<td>Alignment</td>
<td>0.10 mm</td>
<td>± 0.2 mm</td>
</tr>
<tr>
<td>Total</td>
<td>0.14 mm</td>
<td>≤± 0.35 mm</td>
</tr>
</tbody>
</table>
BPKG - special beam position monitor on target table
Stripline Coupler Pick-up operated in air
Beam Profile monitors

75 µm carbon and 12 µm titanium screens
5 to 10 % precision requested

23 August 2005
Beam Loss Monitoring

Beam losses will be detected using:

⇒ 18 standard 1 litre, SPS, nitrogen filled ionisation chambers
⇒ 30 parallel plates with 5mm separation - ionisation length of 19cm
⇒ efficiency of ~1250 pairs per primary charge
Beam Current Transformers

Two Monitors — one at the beginning & one at the end of the line
Absolute Accuracy of 1% for the Intensity Range: $1 \times 10^{12}$ to $3.5 \times 10^{13}$

First BCT sees both LHC & CNGS beams

• Has to fulfill additional requirement of LHC bunch by bunch capability (i.e. 25ns resolution)
3. Proton beam dynamics
## Nominal beam parameters

<table>
<thead>
<tr>
<th>Beam parameters</th>
<th>Nominal CNGS beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal energy [GeV]</td>
<td>400</td>
</tr>
<tr>
<td>Normalized emittance [µm]</td>
<td>H=12   V=7</td>
</tr>
<tr>
<td>Emittance [µm]</td>
<td>H=0.028   V= 0.016</td>
</tr>
<tr>
<td>Momentum spread Δp/p</td>
<td>0.07 % +/- 20%</td>
</tr>
<tr>
<td># extractions per cycle</td>
<td>2 separated by 50 ms</td>
</tr>
<tr>
<td>Batch length [µs]</td>
<td>10.5</td>
</tr>
<tr>
<td># of bunches per pulse</td>
<td>2100</td>
</tr>
<tr>
<td>Intensity per extraction $[10^{13} \text{p}]$</td>
<td>2.4</td>
</tr>
<tr>
<td>Bunch length [ns] $(4 \sigma)$</td>
<td>2</td>
</tr>
<tr>
<td>Bunch spacing [ns]</td>
<td>5</td>
</tr>
</tbody>
</table>

Upgrade phase: $3.5 \times 10^{13} \text{p}$
Nominal parameters:

- Beta at focus: 10 m, 20 m
- Beam size $\sigma$ at 400 GeV: 0.5 mm
- Beam divergence $\sigma'$ at 400 GeV: 0.05, 0.03 mrad

Possible to increase further the beam size
**Trajectory correction scheme**

2-in-3 scheme: 2 consecutive half cells per plane out of 3 are equipped with Beam Position Monitors (BPMs) and correctors. Phase advance per cell: $\pi/2$

Beam line errors (quad displacement, beam position monitor, dipole field and tilt, extraction from SPS)

<table>
<thead>
<tr>
<th></th>
<th>Max. RMS</th>
<th>Max. Excursion (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X before trajectory.</td>
<td>3.6</td>
<td>15.</td>
</tr>
<tr>
<td>Correction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X after trajectory</td>
<td>0.7</td>
<td>2.7</td>
</tr>
<tr>
<td>correction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y before trajectory.</td>
<td>3.2</td>
<td>8.</td>
</tr>
<tr>
<td>Correction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y after trajectory.</td>
<td>0.6</td>
<td>2.5</td>
</tr>
<tr>
<td>correction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: max. trajectory excursion allowed: 4 mm

The implemented correction scheme is sufficient
Beam stability at the target

- Target resistance to non-centered beam

Beam line imperfections (quad displacement, beam position monitor, main dipole field and tilt, extraction, power supply precision)

Horizontal spot size is dominated by extraction errors

Vertical spot size is not increased, vertical beam position is determined by trajectory errors.
<table>
<thead>
<tr>
<th>Type of error</th>
<th>Error magnitude</th>
<th>Horizontal $\sigma_x$ at target (mm)</th>
<th>Horizontal $\sigma'_x$ at target (µrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet errors</td>
<td>As in specs.</td>
<td>0.12 mm</td>
<td>11 µrad</td>
</tr>
<tr>
<td>Horizontal extraction angle</td>
<td>10 µrad r.m.s.</td>
<td>0.11 mm</td>
<td>5 µrad</td>
</tr>
<tr>
<td>Horizontal extraction position</td>
<td>0.5 mm r.m.s.</td>
<td>0.32 mm</td>
<td>21 µrad</td>
</tr>
<tr>
<td>Nominal beam [r.m.s.]</td>
<td></td>
<td>0.53 mm</td>
<td>53 µrad</td>
</tr>
<tr>
<td>Effective beam [r.m.s.]</td>
<td></td>
<td>0.64 mm</td>
<td>57 µrad</td>
</tr>
</tbody>
</table>
MKE - extraction kicker

23 August 2005
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<table>
<thead>
<tr>
<th>± 1% MKE field ripple</th>
<th>± 1.5% MKE field ripple</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{x_{\text{at}}} ) target (mm)</td>
<td>0.2</td>
</tr>
<tr>
<td>( \sigma'<em>{x</em>{\text{at}}} ) target (µrad)</td>
<td>8</td>
</tr>
<tr>
<td>2( \sigma_{x_{\text{at}}} ) target (mm)</td>
<td>0.4</td>
</tr>
</tbody>
</table>

LHC: 7 µs
CNGS: 10.5 µs

Fast rise and fall time required by CNGS only

2 such pulses needed, 50ms apart

Post-kick ripple also very important!!
Aperture studies

For nominal beam parameters and expected errors
  -> no beam loss is expected.

For the most critical parameters
  -> a margin of a factor 2 found

Upper limits for possible injection errors have been established.
4. Target and secondary beam equipment readiness
"Graphite rods", $L = 10 \text{ cm}$, $\Phi = 5 / 4 \text{ mm}$

The **target unit** is conceived as a **static sealed system** filled with 0.5 bar of He.

**MATERIALS**

- **Tube:** Al-Mg alloy
- **Windows:** Be by Brush & Wellman
- **Target Support:** Carbon Fiber reinforced Carbon
- **Target rod:** Fine-grain graphite, sintered carbon, C-C composite
The target units
Target rods: alignment

![Graph showing the alignment of target rods with laser tracker and metrology data.]
Target Magazine + BPKG

Indexing finger
Target Station - Shielding

Beam direction

Target enclosure
Horn system

Design criteria:
>95% probability to work for $5 \times 10^7$ pulses

Pulsed devices:
150kA / 180 kA, 1 ms

Length: 6.5 m
Diameter: 70 cm
Weight: 1500 kg

Water-cooled:
Distributed nozzles
The CNGS horn “today”
Glass Disk - the remaining big issue

Received from LAL

Glass plate broken
Problem = conceptual

After modification

Cracks discovered ~weeks after electrical tests

23 August 2005

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Muon Monitoring

Muon detectors

Access very rare
LHC type beam loss monitor
- Parallel electrodes separated by 0.5cm
- Stainless steel cylinder
- Al electrodes
- $\text{N}_2$ gas filling at 1-1.1 bar
Monitor Layout

- 17 fixed monitors mounted on cross shaped structure (Al)
  - Possibility to double number of monitors
- 1 movable chamber behind fixed monitors for relative calibration
- Movement by stepping motors

Radiation hard camera 5m upstream
5. Commissioning preparation
First checks of CNGS beam extraction done in September 2004

First and last opportunity to check the CNGS beam extraction before the start up in May 2006

• Tests the extraction channel with CNGS beam and double pulse extraction

• MKE kicker magnets & circulating SPS beam

• BPKG test in air
CNGS beam extracted from SPS into TT40
(observed in 3 OTR screens)

8 September 2004
During 2004, high intensity tests allow to reproduce the previous 1996 record in terms of intensity per cycle: $4.8 \times 10^{13}$ protons, with record value of $5.3 \times 10^{13}$ protons.

Beam losses and induced radiation are the most critical issues for the whole complex (extraction in the PS, low energy losses in the SPS, SPS extraction losses).

Reduction of the beam losses is the operation goal in order to deliver the committed number of protons in a reliable and sustainable way.
MKE - extraction kicker, AB/BT

Measured extraction kicker field

CERN SPS CNGS extraction kick MKE LSS

Flat top ripple in specs

post-kick ripple reduced
## Extraction kick pulse parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requested</th>
<th>Achieved No damper</th>
<th>Achieved with damper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise time</td>
<td>1.05 µs</td>
<td>1.05 µs</td>
<td>1.05 µs</td>
</tr>
<tr>
<td>Fall time</td>
<td>1.05 µs</td>
<td>1.05 µs</td>
<td>1.05 µs</td>
</tr>
<tr>
<td>Usable batch length</td>
<td>2×10.5 µs</td>
<td>2×10.4 µs</td>
<td>2×10.5 µs</td>
</tr>
<tr>
<td>Flat top field ripple</td>
<td>&lt; 2%</td>
<td>&lt; 2%</td>
<td>&lt; 2%</td>
</tr>
<tr>
<td>Post kick pulse ripple</td>
<td>&lt; 2%</td>
<td>&lt; 4%</td>
<td>&lt; 2%</td>
</tr>
</tbody>
</table>
Commissioning schedule

- Hardware commissioning  Feb. - April 2006
  Beam instrumentations
  Power supplies
  Magnets (polarities)
  Vacuum system

- “Dry runs”  April - May 2006
  Timing
  Controls
  Interlocks
  Beam permit
  Magnets (current & polarities)

- Commissioning with beam  2006: weeks 22, 25 and 27
Week 22: low intensity, up to target
Week 25: low to medium intensity, secondary beam
Week 27: high intensity, full facility
Commissioning team, mandate, list of subjects to be addressed were defined.

## CNGS COMMISSIONING GOALS

<table>
<thead>
<tr>
<th>GOAL</th>
<th>PARAMETERS</th>
<th>Beam instrumentation</th>
<th>Commissioning Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Proton beam parameters on target</td>
<td>Proton beam intensity monitor BFCT412425</td>
<td>Intensity: $2.4 \times 10^{13}$ per extraction or maximum available from injector.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proton beam profile monitor BTVG412445</td>
<td>Beam sizes: $0.45 \text{ mm} &lt; \sigma_{x,y} &lt; 0.7 \text{ mm}$ for nominal target unit.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proton beam position monitor at BFKG412449</td>
<td>Proton beam position stability better than $\pm 0.5 \text{ mm}$ (upper value).</td>
</tr>
<tr>
<td>2</td>
<td>Proton beam direction on target</td>
<td>Proton beam position monitors BPG412424 and BPG412444</td>
<td>Proton beam direction established within better than $0.2 \text{ mr}$ of the known direction to Gran Sasso detectors.</td>
</tr>
<tr>
<td>3</td>
<td>Proton beam position along TT41</td>
<td>Proton beam position monitors along TT41</td>
<td>Trajectory excursion less than $\pm 4 \text{ mm}$.</td>
</tr>
<tr>
<td>4</td>
<td>Muon detector parameters</td>
<td>Muon monitors in TNM41 and TNM42</td>
<td>Intensity per proton and profile within $\pm xx%$ (TBA by SWS) of simulated values.</td>
</tr>
<tr>
<td>5</td>
<td>Proton beam losses</td>
<td>Beam loss monitors</td>
<td>No more than $1E-3$ at extraction. None along TT41 beam line.</td>
</tr>
<tr>
<td>6</td>
<td>Proton beam tails</td>
<td>Proton beam profile monitors</td>
<td>tbd</td>
</tr>
</tbody>
</table>
Commissioning with beam

Step 1:
Low intensity: $10^{12}$ p/extraction, 1 extraction per cycle then 2
High intensity: $10^{13}$ p/extraction, 2 extractions per cycle, few batches
   a. Target OUT - Horns OFF - TED IN
   b. Target OUT - Horns OFF - TED OUT

Step 2: Low intensity: $10^{12}$ p/extraction, 2 extractions per cycle
   c. Target IN - Horns OFF - TED OUT
   d. Target IN - Horns ON - TED OUT
   e. Combination of Horn ON/OFF, Reflector ON/OFF, Horn+Reflector ON/OFF

Step: High intensity: $10^{13}$ p/extraction, 2 extractions per cycle:
   f. All parameters at optimized values, high intensity
6. Outlook
Target Chamber: Shielding
Target Chamber: Helium Tanks

Alu Helium tube sleeve
20 July 2005: last element of He tube installed

23 August 2005
CNGS schedule

<table>
<thead>
<tr>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
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<tbody>
<tr>
<td>Civil Engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>excavate civil engineering pit, tunnels and caverns; concrete / shotcrete tunnels and caverns</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Install hadron stop</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>iron + graphite blocks, aluminum plate + water cooling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install decay tube</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lower decay tube sleeves, weld together, pour concrete</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Civil Engineering - phase 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>finish concrete floors, close provisional CE pit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install general services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>electrical services, ventilation, cooling water, etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>proton beam line, target, horn+reflector, shielding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commissioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

First beam to Gran Sasso*:
* pending details in SPS schedule for 2006

"today"

May 2006

23 August 2005

Malika Meddahi
Summary

-> Procurement of last equipment is being complete

-> Installation is well underway

-> Commissioning with beam:
    to start week 22 (29 May 2006)

-> CNGS beam operational after week 27 (July 2006)
Muon Monitors

Monitoring of:
- muon intensity
- muon beam profile shape
- muon beam profile centre

Muon intensity:
- Up to $7.7 \times 10^7$ per cm$^2$ and 10.5 μs

Dynamic range: $10^5$

Accuracies:
- absolute 10%
- relative 3%
- reproducibility: cycle to cycle 1%, one year 5%
An updated calculation of neutron fluence in the CNGS first muon pit, A. Ferrari, A. Guglielmi, P.R. Sala
Muon Monitors

Muon Profiles in Pit 2

FLUKA simulations
(P. Sala, not published)

target in, magnetic field
target in, no magnetic field
no target
Muon Information from Gran Sasso

- With sufficient beam intensity
  - measure muons from interactions in Gran Sasso rock
  - later: receive time stamp of muons

- Expected muon fluence for the nominal CNGS beam intensity (FLUKA)
  - $43.6 \mu/m^2/10^{19}$ pot
  - $0.98 \mu/m^2/day$ or
  - $196 \mu/m^2/y$

- Muon spectrum peaks at low energies: $<p> = 16.2 GeV/c.$