CNGS Project: Status report

OUTLINE

1. Project Overview
2. Civil Engineering work
3. Proton beam line studies
4. Equipment design, procurement and installation progress
5. 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
CNGS: the main components

700 m  100 m  1000m  67 m

<table>
<thead>
<tr>
<th>Target Horn</th>
<th>Helium bags</th>
<th>Proton beam</th>
<th>Reflector</th>
<th>Pion / Kaon</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>100 m</th>
<th>Decay tube</th>
<th>π/K - decay</th>
<th>Hadron stop</th>
<th>Muon detectors</th>
</tr>
</thead>
</table>

Vacuum

$$p + C \rightarrow (interactions) \rightarrow \pi^+, K^+, (\mu^+) \rightarrow (decay \ in \ flight) \rightarrow \mu^+ + \nu_\mu$$
2. Civil Engineering work

Under the responsibility of N. Lopez, TS/CE
Proton beam tunnel - April 2003
survey of tunnels (TS-SU):

106 survey points sealed in all of CNGS

- all points measured in vertical plane (altimetry)
  (2mm absolute accuracy)

- 2/3 of all points measured in XY plane
  (5mm absolute accuracy)

Pointing accuracy to Gran Sasso from CERN surveyors: < 50m
Beam size at Gran Sasso: 1 $\sigma$ about 1km
Decay tube

TS seminar on 21\textsuperscript{st} April 2004
by Natacha Lopez
CNGS Decay tunnel

998 m long, evacuated 1-2 Torr
2.45 m diameter
18 mm thick

Steel sleeves of 6m to target chamber
18m steel sleeves down the decay tunnel
decay tube sleeves fully produced, keep arriving
target chamber: assembling the 18m long section
Welding inside decay tube
Decay tube outlook:

11 Feb. 2004: 57% completed - 576 metres installed. Alignment re-checked by TS/SU

Decay tube installation expected end: mid-March 2004
-> followed by vacuum tests (by the contractor)
What’s next for the Civil Engineering?

Last civil engineering phase: May – July 2004

- finishing concrete floors,
- closing off the PGCN pit,
- various minor work
3. Proton beam line studies

- Layout
- Parameters
- Optics
- Trajectory correction scheme
- Beam stability

Collaboration with W. Herr, AB/ABP
Transfer line layout: half cell
Last 200m

Beam in TT41

Final focusing

Target T40
## 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} p]</td>
<td>2.4</td>
</tr>
<tr>
<td>Bunch length [ns] (4σ)</td>
<td>2</td>
</tr>
<tr>
<td>Bunch spacing [ns]</td>
<td>5</td>
</tr>
</tbody>
</table>

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

![Diagram showing beam extractions]

T=6 s
Expected number of protons delivered on CNGS target:

For 1 year of CNGS operation (200 days):

4.5 x 10^{19} protons on target / year ("nominal")

based on 1998 performance:
4.8x10^{13} protons in SPS, 55% overall efficiency;
(+ mixed cycles with LHC and other fixed target experiments)

higher proton intensities (very much requested by OPERA and ICARUS):

High Intensity Protons Working Group
Machine studies

AB/RF
AB/ABP
Optics at Target

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 mrad

Possible to increase beam size to 0.7
Trajectory correction scheme

AIM:

- Is the proposed scheme sufficient?
- Can we save some correctors or monitors?
- What happens if something goes wrong (w.r.t. faulty correctors or monitors)

Took into account:

Beam line errors (quad displacement, beam position monitor, dipole field and tilt, extraction from SPS)
**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: $\pi/2$

 Produce $\pi$ bumps which may not be visible as the trajectory is heavily under-sampled.  
Problem worse when some BPMs are malfunctioning
Vertical bump along beam line

Vertical bump as seen on BPMs

Vertical bump after correction along beam line
Vertical bump before correction as seen on BPMS (+ 1 BPM)

Same, after correction along beam line

Same, after correction with additional corrector

- Reading of the positions in both planes (X, Y) for all BPMs
# Trajectory correction scheme

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

Note: max. trajectory excursion allowed: 4 mm

The proposed correction scheme is sufficient
Beam stability at the target

AIM:

Investigate the beam spot stability at the target
→ Target resistance to non-centered beam

Took into account:

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

Result:

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 ($\mu$rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet errors</td>
<td>As in specs.</td>
<td>0.12 mm</td>
<td>11 $\mu$rad</td>
</tr>
<tr>
<td>Horizontal extraction angle</td>
<td>10 $\mu$rad r.m.s.</td>
<td>0.11mm</td>
<td>5 $\mu$rad</td>
</tr>
<tr>
<td>Horizontal extraction position</td>
<td>0.5 mm r.m.s.</td>
<td>0.32 mm</td>
<td>21 $\mu$rad</td>
</tr>
<tr>
<td>Nominal beam [r.m.s.]</td>
<td></td>
<td>0.53 mm</td>
<td>53 $\mu$rad</td>
</tr>
<tr>
<td>Effective beam [r.m.s.]</td>
<td></td>
<td>0.64 mm</td>
<td>57 $\mu$rad</td>
</tr>
</tbody>
</table>
MKE - extraction kicker, AB/BT

( Note: two such pulses are needed, 50 ms apart)
## Magnet and extraction errors

<table>
<thead>
<tr>
<th>± $1%$ MKE field ripple</th>
<th>$\sigma_{x\text{at target}}$ (mm)</th>
<th>$\sigma'_{x\text{at target}}$ (µrad)</th>
<th>$2\sigma_{x\text{at target}}$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>± $1.5%$ MKE field ripple</td>
<td>0.24</td>
<td>12</td>
<td>0.48</td>
</tr>
<tr>
<td>± $2%$ MKE field ripple</td>
<td>0.32</td>
<td>16</td>
<td>0.64</td>
</tr>
<tr>
<td>± $3%$ MKE field ripple</td>
<td>0.48</td>
<td>24</td>
<td>0.96</td>
</tr>
</tbody>
</table>
Margin on the target rods:

Nominal beam size = 0.53 mm

± 1.5% MKE field ripple (v.s. ± 1%):

On target rods (4 mm diameter):

\[ 2.0 \text{ mm} - (3\sigma_{\text{beam}} + 0.48\text{mm}) = -0.07\text{mm} \]
\[ 0.40\text{mm} \quad -0.01\text{mm} \]

Going beyond:

• loose in particle production
• induce more activation in target and shielding
• increase rod stresses
Non centered beam on target

- Beam eccentricity is critical as it induces large transversal oscillations
- Second pulse hits when thermal equilibrium from first pulse is not reached yet, hence building up overall stresses.
- Problem arises from one shot
- Eccentricity must remain below admissible stress i.e. < 0.4mm (graphite, ultimate intensity)
- For nominal intensity: marginal with 0.5 mm

L. Bruno, AB/ATB
A. Bertarelli, TS/MME
What really matters in terms of accurate alignment and tuning:

- Beam hits the target within the requested specs

Small effect at Gran Sasso from
- Proton beam lateral displacement (0.5mm)
- Proton beam angular displacement (0.5 mrad)
- Horn lateral displacement (3mm)
- Reflector lateral displacement (10mm)
More results in

Aperture* and Stability studies for the CNGS proton beam line
AB-Note 2003-20 ABP, W. Herr and M. Meddahi
https://edms.cern.ch/document/383852/1

Trajectory correction studies for the CNGS proton beam line
SL-Note 2002-015 AP, W. Herr and M. Meddahi
https://edms.cern.ch/document/355912/1

* Fraction of particles lost for different aperture misalignments and momentum offsets studied:
  For nominal parameters no particle losses are observed.
Equipment design, procurement and installation progress

Magnet production

Proton beam instrumentation (Target region)

Target

Horns

On going installation

Muon detectors
MBG magnet production - 50 out of 78 have arrived at CERN

12 February 2004

K. Schirm, AT/MAS
QTG series being produced at Novosibirsk

T. Zickler, AT/MEL
Corrector magnets

Price enquiry launched
Contract will be placed in March 2004
All magnets delivered by end 2004

17 magnets
Bending angle: 80 μrad
Gap height: 45 mm

T. Zickler, AT/MEL

Refurbishment of recuperated magnets

D. Smekens, AT/MEL

Magnet accessories

S. Koczorowski, AT/MEL
Beam monitoring (AB/BDI)

Problem: fast extracted, very intense proton beam, focused into a very small beam spot is too hot for standard Ti windows

⇒ SEM monitors don’t work

Question: beam position monitor operated in air?

⇒ a challenge for AB / BDI
Electromagnetic Stripline Coupler Pick-up

Electrostatic Button Pick-up

Test Set-up at PS Booster

T. Bogey
R. Jones
Preliminary Results

**Button Electrode Monitor**
⇒ *Very sensitive to air ionisation*

**Stripline Coupler Monitor**
⇒ *less sensitive to air ionisation than button*
⇒ *Position measurement possible BUT work still required*
Target Station

Target Team, led by L. Bruno (AB/ATB)

TS/MME, led by G. Patti

All target slides courtesy of L. Bruno, G. Patti
T40 Layout
Schematic Vertical view

Target enclosure
Crane limit
Shield
Steel frame
Proton beam

Target assembly

“Handled” structure
Fixed structure
The target magazine is mechanically coupled to the BPKG monitor. They are aligned in the lab and are remotely handled as a single component (the « alignment table »). They rest on the « base table », bearing the displacement mechanisms.
The target unit is conceived as a **static sealed system** filled with inert gas. The tube has annular fins to enhance convective heat transfer. **Light materials** are used to limit the heat load.

**MATERIALS**

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube</td>
<td>Al-Mg alloy</td>
</tr>
<tr>
<td>Windows</td>
<td>Be by Brush &amp; Wellman</td>
</tr>
<tr>
<td>Target Support</td>
<td>Carbon Fiber reinforced Carbon</td>
</tr>
<tr>
<td>Target rod</td>
<td>Fine-grain graphite, hexagonal boron nitride, CFC</td>
</tr>
</tbody>
</table>
• Engineering design of the Target station
• Study of alternative target materials (boron nitride)
• Laboratory tests, beam tests for both graphite and boron nitride are under way
• Revolving target magazine (4 in-situ spares)
Magnetic Horn: Principle of focusing

35 GeV positively charged particles leaving the target

inner conductor
CNGS -- focusing devices

(S. Rangod, PH/TA3
collaboration with LAL, IN2P3, Paris)

- Design criteria:
  - >95% probability to work for 5x10^7 pulses
  - length: 6.5 m
  - diameter: 70 cm
  - weight: 1500 kg

- Pulsed devices:
  - 150kA / 180 kA, 1 ms
  - water-cooled:
    - distributed nozzles

---

length: 6.5 m
diameter: 70 cm
weight: 1500 kg

Pulsed devices:
150kA / 180 kA, 1 ms
water-cooled:
distributed nozzles
New power transformer

New capacitor bank

G. Maire, PH/TA3
Hadron stop – artistic view
11 July 2003 - near the CE shaft

graphite
cooling modules
Installation done by CE contractor
Preparation, Supervision: M. Clément, A. Pardons, with AB/ATB/EA team

Hadron stop - 28 July 2003
Access gallery TZ80 to muon chambers
TS/EL, TS/CV
CNGS Muon Monitoring

Muon detectors 67m

Access very rare
17 BLM (fixed cross centered on beam axis)
1 moveable monitor

SPS Type Beam Loss Monitor
Ionisation Chamber

**PS Booster Beam Loss Monitor Tests**
- Confirmed that response time not an issue for CNGS (50ms between trains)
- More experiments and theoretical work required
OUTLOOK

CNGS schedule
(schematic, simplified version)

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

First beam to Gran Sasso: May 2006
On behalf of the CNGS Project Team

THANK YOU
to the many colleagues who are contributing to the CNGS project