The **MERcury Intense Target Experiment** – or **nTOF11**

I. Efthymiopoulos – CERN, AB Dept.

(for the MERIT collaboration)

20m/sec Hg jet achieved on February 14, 2007
MERIT Collaboration – ORNL test setup

MUTAC Review
BNL – April 18, 2007
Outline

- Reminder: scientific goals & layout of the experiment
- Schedule
- Construction of experimental components
  - Solenoid & Hg loop
    - MIT combined tests → Van Graves’s talk
  - Cryogenics
- Activities at CERN
- Safety
- Beam issues & particle detectors
The MERIT experiment

A proof-of-principle test of a target station suitable for a Neutrino Factory or Muon Collider source using a 24-GeV proton beam incident on a target consisting of a free mercury jet that is inside a 15-T capture solenoid magnet.

Proposal submitted to INTC – May 2004
Experiment approved as nTOF11

Participating Institutes
- BNL, MIT, ORNL, Princeton University
- KEK
- CERN, RAL

Spokespersons
- H. Kirk (BNL), K. McDonald (Princeton Univ.)

From previous tests @ CERN + BNL
MERIT Experiment – Profile

**Target**
- 1-cm diameter Hg jet, jet velocity \(\cong 20\text{m/s}\)
- Hg jet/proton beam configuration:
  - Hg-jet ↔ solenoid axis = 33 mrad
  - proton beam ↔ Hg-jet axis = 67 mrad
  - beam ↔ Hg-jet interaction length = \(~30\text{cm} (2\ \lambda_I)\)

**Proton beam**
- 24(14) GeV/c extracted from PS
  - Max. intensity \(3 \times 10^{13} \text{ protons/pulse}\)
  - Beam spot \(r \leq 1.2\ \text{mm rms}\)
  - Variable pulse length \(0.134 \div 500\ \mu\text{sec}\)
  - \(~100\) high-intensity pulses
  - \(3 \times 10^{15}\) protons on target in total (radiation limit)
MERIT Experiment – Target & Solenoid

Hg-jet hydraulic system

Hg container

Solenoid

Target chamber

Proton Beam
MERIT Experiment – Scientific Goals

Important milestone towards the production of 1-4MW pion production targets

1. Study MHD effects on Hg-jet with normal target size and velocity
2. Study jet disruption (cavitation?) by varying the PS spill structure

**MERIT: 180 J/g**
- 28TP@24GeV protons
- 1cm diam. Hg-jet
- 1.2×1.2 mm² beam size rms

Jet dispersal at t=100μs with magnetic field varying from 0 to 10 Tesla

R.Samulyak-BNL

Ifthymiopoulos, CERN
Build.180: Cryogenics assembly and surface tests

Build.272: Offices & Control Room

TT4 tunnel:
- preparation area for Hg-loop
- storage for short-term cooling

TT2/TT2A: MERIT

PS ring
MERIT Experiment – Layout

Material access shaft

Racks & electronics

Personnel access

Solenoid & Hg loop

Beam dump

Upstream beam elements (new)
- Quadrupoles for final focusing
- Collimator
- Beam profile measurement
- Beam intensity measurement

N2 Exhaust line
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- Safety

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MERIT Experiment – Status

Since MUTAC’06 significant progress has been made in all aspects of the experiment

- Construction is basically completed for all experiment’s components
- Delays have been accumulated due to technical problems:

<table>
<thead>
<tr>
<th>Milestone</th>
<th>MUTAC’06</th>
<th>Update</th>
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<tbody>
<tr>
<td>DVB delivery</td>
<td>Sep.’06</td>
<td>Nov.’06</td>
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<tr>
<td>Hg-loop test @ ORNL</td>
<td>Oct.’06</td>
<td>Completed Feb.’07</td>
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<tr>
<td>Solenoid test @ MIT</td>
<td>Mar.’06</td>
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<td>Combined test @ MIT</td>
<td>Dec.’06</td>
<td>Mar.’07</td>
</tr>
<tr>
<td>Shipment to CERN</td>
<td>Dec.’06</td>
<td>14 Mar.’07</td>
</tr>
</tbody>
</table>

- But thanks to the fast shipment of components (air-cargo) some time was saved
- We are still on time for the installation, but we have lost a big part of our contingency
Beam setting-up for MERIT

**Note:**
- There is no nTOF run scheduled for 2007
- We potentially have the possibility to request additional beam time
## MERIT Experiment – Schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
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</thead>
<tbody>
<tr>
<td>Hg-loop at MIT</td>
<td>0 d</td>
<td>Mon Feb 26</td>
<td>Mon Feb 26</td>
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<tr>
<td>Combined tests at MIT</td>
<td>3 d</td>
<td>Mon Feb 26</td>
<td>Thu Mar 1</td>
</tr>
<tr>
<td>Transport (Hg loop + solenoid)</td>
<td>7.2 d</td>
<td>Wed Mar 14</td>
<td>Mon Mar 26</td>
</tr>
<tr>
<td>Hg loop + solenoid at CERN</td>
<td>0.8 d</td>
<td>Mon Mar 26</td>
<td>Mon Mar 26</td>
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<tr>
<td>- Magnet tests at bat.189</td>
<td>14.4 d</td>
<td>Mon Mar 26</td>
<td>Fri Apr 20</td>
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<tr>
<td>Installation</td>
<td>1.5 d</td>
<td>Mon Mar 26</td>
<td>Tue Mar 27</td>
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<td>Connection to the cryo system</td>
<td>4 d</td>
<td>Wed Mar 28</td>
<td>Tue Apr 4</td>
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<td>Room temp tests</td>
<td>2.4 d</td>
<td>Tue Apr 3</td>
<td>Tue Apr 15</td>
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<tr>
<td>Cold tests / recycling</td>
<td>7.2 d</td>
<td>Tue Apr 10</td>
<td>Fri Apr 20</td>
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<tr>
<td>Pre-installation safety review</td>
<td>4 d</td>
<td>Fri Mar 30</td>
<td>Thu Apr 5</td>
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<tr>
<td>PS start with beam</td>
<td>53.6 d</td>
<td>Mon Apr 16</td>
<td>Tue Jul 17</td>
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<tr>
<td>SPS start with beam</td>
<td>40.8 d</td>
<td>Tue May 8</td>
<td>Tue Jul 17</td>
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<tr>
<td>Installation in TT2/T2A</td>
<td>5.6 d</td>
<td>Mon Apr 23</td>
<td>Tue May 1</td>
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<tr>
<td>Lowering of material</td>
<td>0.8 d</td>
<td>Mon Apr 23</td>
<td>Mon Apr 23</td>
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<tr>
<td>Position solenoid + Hg loop to T2A</td>
<td>0.8 d</td>
<td>Tue Apr 24</td>
<td>Tue Apr 24</td>
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<tr>
<td>Position beam elements</td>
<td>1 d</td>
<td>Wed Apr 25</td>
<td>Thu Apr 26</td>
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<tr>
<td>Installation cryo and racks in T2</td>
<td>1 d</td>
<td>Fri Apr 27</td>
<td>Mon Apr 30</td>
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<tr>
<td>Close shaft - activate access system</td>
<td>0.8 d</td>
<td>Tue May 1</td>
<td>Tue May 1</td>
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<td>Commissioning</td>
<td>12 d</td>
<td>Tue May 1</td>
<td>Mon May 21</td>
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<tr>
<td>Cryogenics + solenoid + ps</td>
<td>3.2 d</td>
<td>Tue May 1</td>
<td>Fri May 4</td>
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<tr>
<td>Hg-loop + optic diagnostics</td>
<td>4 d</td>
<td>Mon May 7</td>
<td>Fri May 11</td>
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<td>Insert Hg-loop into solenoid</td>
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<td>Mon May 14</td>
<td>Tue May 15</td>
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<td>Combined tests</td>
<td>3.2 d</td>
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<td>all systems operational readiness</td>
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<td>Finalize installation</td>
<td>12 d</td>
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<td>Fri Jun 8</td>
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<tr>
<td>Fine-tune beam diagnostics</td>
<td>12 d</td>
<td>Mon May 21</td>
<td>Fri Jun 8</td>
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<tr>
<td>Fine-tune particle detectors</td>
<td>12 d</td>
<td>Mon May 21</td>
<td>Fri Jun 8</td>
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<tr>
<td>precise alignment</td>
<td>2.4 d</td>
<td>Tue Jun 5</td>
<td>Thu Jun 7</td>
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<tr>
<td>Fine-tune all systems</td>
<td>12 d</td>
<td>Mon May 21</td>
<td>Fri Jun 8</td>
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<tr>
<td>Waiting for beam</td>
<td>5.6 d</td>
<td>Fri Jun 8</td>
<td>Mon Jun 18</td>
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<tr>
<td>Commissioning with beam</td>
<td>7.2 d</td>
<td>Tue Jun 19</td>
<td>Fri Jun 29</td>
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<tr>
<td>MERIT run</td>
<td>8.8 d</td>
<td>Thu Jun 3</td>
<td>Tue Jul 17</td>
</tr>
</tbody>
</table>
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      - MIT combined tests ➔ Van Graves’s talk
    - Cryogenics
  - Activities at CERN
  - Safety
  - Beam & particle detectors
Hg loop system

- Required flow: 1.57 lt/s
- Mercury inventory: ~23 lt
- Piston velocity: 3.0 cm/s
- Hg jet duration of 12s
- Drive cylinders:
  - 15-cm diam
  - 45 lt/min
  - 20 MPa (200 bar)

Geneva’s jet d’eau

Hg-loop assembled - during water tests @ORNL

April 2007
Hg loop system

Hg-nozzle

Syringe system

Hydraulic pump unit
Optical diagnostics

Primary container mock-up @ BNL

80 us/frame, 16 frames
pulsed NIR light
SMD camera
Solenoid

- first test at MIT in March 2006
- 15T magnetic field reached!
Combined tests & MIT

- Details & results in Van’s talk…
Transport to CERN

- Leaving MIT on Wednesday March 14th
- {solenoid, Hg-loop, optical diagnostics}

- Arrival at CERN on Monday March 19th
Transport to CERN

- Hg volume was sent to CERN separately
  - 23-Lt in 11 drums transported according to safety rules for chemically hazardous material
Cryogenics – Surface tests

- Installation in build.180 for surface tests completed
  - System fully commissioned with dummy load

- Process control implemented
- Remote operation from control room tested
- Interlock with solenoid power supply defined
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Cryogenics – Surface tests

- Due to the leaks in the solenoid observed during the MIT tests, it was decided to proceed with the **full commissioning** of the solenoid and the cryogenics **at surface** before installation in the tunnel.
Cryogenics – Surface tests

Status

- CERN Safety inspection for the solenoid & cryogenics done
  - safety valves set
  - operation mode accepted

- First cool-down started on **Friday April 13**
  - No leaks at warm observed
  - Leaks at cold were observed when filled with LN
  - Icing due to insufficient insulation was observed as well
Cryogenics – Surface tests

...Status

- Further tests ongoing to diagnose the exact location of the leaks
  - we do suspect failure of the insulating silicon-rubber material in the current leads and instrumentation connections
  - a possible solution is under consideration, to be reviewed by US and CERN cryo experts and safety officials

- Improvements in the insulation to minimize formation of ice need to be done as well

Detection and correction of the leaks and making the solenoid operational with the cryogenics system is on the critical path that may have implications for the installation schedule
Transport & Installation

- The access shaft was opened on November 22, 2006
- It can remain open even when PS starts with beam
  - but not during the whole run
Transport & Installation

transport test with dummy load

access ramps TT2/TT2A
Power supply

- Recuperated from the old SPS West Area extraction
- “pulsed” mode: 7kA / 30 min ; 5MW
- Installed (along with its transformer) in bat 193
- Refurbished to convert it to PS standards and controls
Experimental area

cable passage holes

beam fixed jaw collimator

beam dump
Experimental area

Auxiliary works:

- The **power supply** work is advancing well
  - Controls, interlocks and timing issues defined
  - Work on AC part is advancing as scheduled

- Installation of **services** (electricity, networking, etc.) is ongoing

- Installation of the **cryogenics line** completed as well as the preparation for the dewar platform on the surface

- **Platforms and pedestals** for the crates in the TT2 tunnel done

- **ODH monitoring** installation completed

- **Access** doors and interlocks defined and work ongoing

Significant progress over the last months, works proceed as scheduled
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  - Cryogenics
- Activities at CERN
- Safety
- Beam & particle detectors
Safety for MERIT experiment

1. Preliminary hearings with safety officials at CERN before the proposal submission and approval of the experiment

2. Safety reviews of the major sub-systems of the experiment, in time with their production
   - Cryostat and cryogenics – **February 3, 2006**
   - Hg-system – **June 20, 2006**

3. Safety pre-installation review **March 30, 2007**
   - Experience from the combined tests & MIT

4. Safety inspections in-situ
   - Transport, installation, Hg-handling, cryogenics, electrical safety, etc.
   - Access, interlocks, monitoring systems, etc.
**Solenoid & Cryogenics Review**

http://indico.cern.ch/conferenceDisplay.py?confId=673

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Description</th>
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<tbody>
<tr>
<td>09:00-09:30</td>
<td><strong>Introduction</strong></td>
<td>ILias Efthymiopoulos (CERN), Adrian Fabich (CERN)</td>
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<tr>
<td>09:00</td>
<td>Introduction</td>
<td>Ilas Efthymiopoulos (CERN), Adrian Fabich (CERN)</td>
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<tr>
<td>09:20</td>
<td>Discussion</td>
<td>Ilas Efthymiopoulos (CERN), Adrian Fabich (CERN)</td>
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<td>09:30-10:40</td>
<td><strong>Solenoid</strong></td>
<td>Peter Titus (MIT)</td>
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<td>09:30</td>
<td>Solenoid description</td>
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<td>10:10</td>
<td>Discussion</td>
<td>Peter Titus (MIT)</td>
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<td>10:45</td>
<td>break</td>
<td>Ilas Efthymiopoulos (CERN), Adrian Fabich (CERN)</td>
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<td>11:00-12:10</td>
<td><strong>Cryogenics system</strong></td>
<td>Friedrich Haug (CERN)</td>
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<td>11:00</td>
<td>Description</td>
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<td>11:40</td>
<td>Discussion</td>
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<td>12:10</td>
<td>lunch</td>
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<td>13:15-14:15</td>
<td><strong>Closed/open session</strong></td>
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<td>14:30-15:30</td>
<td><strong>feedback session</strong></td>
<td>reviewers</td>
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<tr>
<td>14:30</td>
<td>feedback session</td>
<td>reviewers</td>
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**MERIT safety review**

| Description | MERIT solenoid and cryogenics system is reviewed. Participation upon invitation. |

**Friday 03 February 2006**

**April 2007**

I.Efthymiopoulos, CERN
**Mercury System Review**

http://indico.cern.ch/conferenceDisplay.py?confId=1785

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**"MERIT safety review of the mercury system"**

**Monday 19 June 2006**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Presenter</th>
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<tr>
<td>09:00</td>
<td>Introduction (15’) presentation</td>
<td>Ilias Efthymiopoulos (CERN)</td>
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<td>09:15</td>
<td>Discussion (15’)</td>
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<td>09:30</td>
<td>Layout and construction of the Hg system (30’) presentation</td>
<td>Van Graves (ORNL)</td>
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<td>10:00</td>
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<td>10:30</td>
<td>break</td>
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<tr>
<td>11:00</td>
<td>Operation and handling (30’) presentation</td>
<td>Phil Spampinato (ORNL)</td>
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<td>Discussion (30’)</td>
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<td>12:15</td>
<td>lunch (..)</td>
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<td>13:30</td>
<td>Transport and decommissioning (30’) presentation</td>
<td>Van Graves (ORNL)</td>
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<td>14:00</td>
<td>Discussion (30’)</td>
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<td>14:30</td>
<td>Closed session (1h00’) review panel</td>
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<td>15:30</td>
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<td>16:00</td>
<td>Discussion - feedback (1h00’)</td>
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Pre-installation Review

http://indico.cern.ch/conferenceDisplay.py?confId=13152

Friday 30 March 2007

10:30 Welcome (20 min) 
Ilias Efthymiopoulos (CERN)

10:35 Status of the Experiment (19 min) 
Adrian Fabich (CERN)

Brief overview of the experiment focusing on the items that won’t be discussed in detail during the meeting. Go through the installation and commissioning schedule.

10:50 Mercury handling operations (30 min) 
Harold Kirk (Brookhaven National Laboratory (BNL))

Description of the mercury system - “as built”. Results from standalone and combined tests at MIT. Mercury loading and unloading operations. Plans at CERN.

11:20 Solenoid - experience from the tests at MIT (20 min) 
Kirk McDonald (Princeton University)

Present the operation and experience from the standalone and combined tests at MIT.

11:40 Discussion (20 min)

14:30 Installation plans (30 min) 
Michael Lazzaroni

Go through the installation procedure foreseen. Address the issues of lowering of material from the shaft, manipulations inside the tunnels etc.

15:00 Cryogenics installation and operation (30 min) 
(tbc)

Update on the cryogenics installation and operation.

15:20 Discussion (40 min)
MERIT Safety Reviews

Chairman
- Ghislain Roy (CERN-AB/DSO)

Mercury experts & Chemical Safety
- Friedrich Groeschel (PSI)
- Bernie Riemer (ORNL)
- Jonathan Gulley (CERN/SC)

Radiation protection (CERN-SC/RP)
- Marco Silari
- Thomas Otto
- Pierre Carbenez

Mechanical safety (CERN-SC/GS)
- Benoit Delille
- Andrea Astone

General Safety (CERN-SC/GS)
- Bruno Pichler
- Karl Gunnar Lindell
- Ralf Trant

Fire protection (CERN-SC/GS)
- Fabio Corsanego
Safety issues

- MERIT Presentations in:
  - **AB Installation Committee (ABIC)**
    - interface with PS/SPS and CERN services teams
      - permission to work in TT2/TT2A tunnel during PS/SPS operation
  - **AB Safety Committee (ABSC)**
    - Presented safety structure of the experiment and proposal for review program of various components
  - **AB Technical Committee (ATC)**
    - discussed status of the experiment, schedule, AB & CERN resources, safety…
  - **Radiation Protection Committee (RPC)**
    - Presentation to French and Swiss authorities; authorization to run obtained

- **ISIEC form** for the experiment submitted
  - Ardian Fabich (CERN) nominated as GLIMOS *(Group Liaison In Matters Of Safety)*

A very good and continuous contact with the CERN safety officials has been established

The “**safety file**” for MERIT sets the example on how safety should be handled for experiments at CERN
Dismantling

- At the end of the run the experiment will remain in place for a **cool-down time** until the machine shutdown (November '07)
  - The Hg will be emptied and stored in the flasks in TT2 tunnel

- During the **2008 shutdown** the experiment will be removed from the tunnel
  - All equipment will be stored at CERN for **one year cool down**
  - At the end of that period radioactivity will be minimal for all components which allows classifying them as **“exempted” packages** for shipment

- Transport back to US is defined & agreed with CERN officials
  - **Hg volume**: transported by air-cargo using the existing packaging
    - radioactivity will be minimal and chemical hazards precede
  - **Hg loop**: transported by air-cargo
    - Classified as “mercury wet” material (< 1lt of Hg)
  - **Solenoid & other heavy material** will be packaged and send separately
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Beam setup for cavitation studies

- Operate the PS machine in harmonic-16
  - Fill the machine in bunch pairs

**PUMP**: 6 bunches, $15 \times 10^{12}$ protons

**PROBE**: 2 bunches, $5 \times 10^{12}$ protons

- $d_n = n$ experiment = 0, 2, 4, 6, 8, 16, 18, 20, 22, 24, 32, 40, 48, 56, ...
- Setup time is scheduled to provide all the requested configurations
  - Understand possible instabilities and intensity limits due to inhomogeneous intensity distribution
  - Similar requirements as for the HI CNGS beams

April 2007
I. Efthymiopoulos, CERN
Beam pulse Priorities

General approach
- Repeat each parameter configuration twice
- Increase intensity gradually (up to $2.5 \times 10^{13}$ protons/pulse)
- Do basic program, MHD first
- Each proton pulse configuration is performed at $B=15$ T (solenoid) and $B=0$ T (horn)
- Consider effort for PS operation to change settings

Schedule
1. Beam setup – understand beam optics, parameters and tuning
2. MHD studies (i.e. magnetic field scans)
3. Beam position scan along the target
4. Pulse structure studies
   1. Cavitation
5. Spot size sensibility
6. Intensity; aim to >3.2 TP !!!

- Operation scenarios with real time estimates are being worked out
Beam Instrumentation

Beam profile measurement
- MTV screens
  - “almost” readily available
  - Minor effort / minimum budget

Transverse beam parameters
- Position & spot size → MTV screens
- Direction → 2× MTV screens & collimator
- Divergence → not a direct measurement
  - Rely on beam simulations
  - Estimate from spot size monitors

Longitudinal beam parameters
- Measured by pick-ups in the PS & TT2 line upstream of MERIT

Beam intensity
- Beam transformer at beginning of line and just upstream of experiment
- Measurement of intensity per bunch

Logging of all beam parameters and instrumentation possible
Particle Detectors

- Measure particle production in “pump-probe” method for cavitation studies: i.e. detect particle production per bunch
- Place detectors around the target at various locations
  - Detectors: pCVD diamonds, pin diodes, ACEM detectors
- Monitor the beam-target interaction

**Particle fluxes** - $3 \times 10^{13}$ protons (MARS Simulation)

- Charged hadrons (E>200 KeV)
- Neutrons (E>100 KeV)

S. Striganov - FNAL
Particle Detectors

Diamond detectors
- Same principle as a PIN-diode, with reverse bias voltage and separation of electron-hole pairs, created by traversing MIPs.
- Previously tested in conditions similar to that of MERIT with good results.
- Will be used at LHC for the fast beam abort system around the experiments ACEM
- Aluminum Cathode Electron Multiplier—Built like a photo multiplier, but with an aluminum foil functioning as a secondary electron emitter as cathode. See [1].
- Used in PS & PSB machines as beam loss monitors
Summary

- The experiment is in good track. Construction is completed and results from the tests so far are very encouraging.
  - The important milestone of combined tests at MIT was met in March’07

- The focus now moves to CERN with the installation and commissioning activities
  - Despite of the delays and technical problems, we remain on time for the July run with beam (3rd - 17th) but with very limited contingency
  - Correcting the leaks of the solenoid remains critical and will focus our attention in the coming week

- Safety has been handled very seriously; continuous contact and collaboration with CERN officials has been established
  - Several reviews organized – no show stopper identified
  - Our primary goal remains to perform a successful and safe experiment

We are looking forward for an exciting summer at CERN with good physics results to verify the liquid target concept