T.K. Kroc, FNAL
4/13/06

TTF2/DESY Trip Report

People met:
Albrecht Leuschner – Radiation Protection Department
Michael Schmitz – Machine Department
Siegfried Schreiber – Machine department

Trip objective:
The purpose of the trip was to learn as much as possible about their experience with shielding for radiation protection and beam dump designs. By drawing on their experience to this point, we should be able to focus our attention on other areas. Or at least not spend time in fruitless areas.

The trip was a very useful endeavor. In my search for materials describing the TTF facility, it has been difficult to determine which documents described the actual facility and which ones described proposals and investigations for things that never got built. I now know what is there. The face-to-face contact with Albrecht and Michael will make it easier to continue to work with them in my work on the design of the FNAL shielding and dumps. In addition, I was able to show Michael the type of drawings that some Fermilab people are interested in getting in a CAD format. Previous exchanges had resulted in exchanges of layouts in this format (a 3D viewer that did not provide the draftsman with the information he needed.)

Publications received:
"Calculation of Hadron Yields Around Thick Targets and Doses Behind Concrete Shielding of High Energy Electron Accelerators" by Dinter, et.al., NIM-A, 455 (2000) 460-469.
"Design of a Beam Dump for the TTF-FEL Phase II (TTF2) Project", by Maslov, et.al., DESY, December 1999, TESLA-FEL 99-06.

Questions for the trip:(questions developed before the trip are in italics; answers follow)

- *Look at design, construction, operation of dump*
    - *Has operations exposed any shortcoming in design?*
        - Operations have not reached the design parameters of the dump, by several orders of magnitude. According to Seigfried, this is just because they have not completed development of feed-forward systems and machine protection systems such as loss monitor interlocks.
        - Beam loading is considerable and feed forward systems need very sophisticated logic to account for many different scenarios of beam variations. For instance, the machine can withstand 25 % variation from bunch to bunch, but only 5% for the average of 10 bunches, and .5% over 100 bunches (numbers are illustrative not quantitatively correct). Another scenario is how to deal with sparks or other beam deflection events within a bunch train; how to deal with the effects quickly enough to protect equipment.
        - Another issue to be dealt with is triggering the loss monitor system. Noise issues such as dark current probably require the loss monitors to be triggered. Once you commit to triggering, then how do you ensure that they are triggered correctly to ensure the machine is protected at all times?
    - *Can we use the dump design for our facility without modification?*
        - Although operations have not tested the capabilities of the dump, Michael is not satisfied with the design of the dump. There is inadequate diagnostics in the dump area, particularly beam size. Michael is concerned that the beam size is not known at the window and on the dump face. If the beam size is too small it could limit the lifetime of either component. For this reason, he would like to have a design that would eliminate the window and allow the dump to be in the vacuum.
    - *What is the status of 2GeV/130 kW system?* (64 μA ave. current @ 10 Hz)
        - These are the parameters that the present dump has been designed for (including the 40 cm extension shown in top right of fig. 1).

- *Compare layout of beamline components, warm and cold sections to ours*
  - *How does this impact magnitude of losses?*
    - Most, if not all radiation (prompt and due to activation) is due to dark current, not direct beam loss.
      - The two primary sources of dark current are the gun and an accelerating cavity at the high energy end of the second (first?) cryostat resulting in a high energy dark current.
      - They were not aware of the dark current issue at the beginning of the project.
  - *Do loss locations impact shielding design?*
    - The enclosure was laid out before the beam line was finalized. This resulted in a labyrinth being located near a bunch compressor section. Because of this, there is difficulty with radiation, particularly thermal neutrons at the exit of the labyrinth.
- *Compare regulatory limits for radiation exposure.*
  - German limits are:
    - Radiation workers are allowed 6 mSv/yr with no medical oversight (.6 Rad/yr)
    - Radiation workers can also accumulate 20 mSv/yr with annual medical oversight (2 Rad/yr)
    - The exposure to the general public is 1 mSv/yr (.1 Rad/yr)
- *Compare shielding design*
  - *What did you use to estimate exposure at energies above 300 MeV?*
    - For exposure at directions transverse to the beam line, they used "Calculation of Hadron Yields Around Thick Targets and Doses Behind Concrete Shielding of High Energy Electron Accelerators" by Dinter, et.al., NIM-A, 455 (2000) 460-469. This looks like it will be very helpful to provide a starting point for our calculations at the higher energies.
    - For straight-ahead (down the photon line into the experimental area), they used FLUKA calculations.
- *Look at differences in occupancy in the surrounding environment*
  - The 1st half of the accelerator is in an enclosure that is within an experimental hall (similar to how the FNAL ILC test facility will be). The east wall of the enclosure has a 2 m passageway between it and the outside wall of the hall.
  - The second half of the accelerator is in a prototype of the TESLA enclosure and is covered by 4m of earth.
  - So the general layout is similar to what will be at Fermilab, at least at the low energy end.
- *How have their radiation surveys compared to their design predictions?*
  - Predictions have been good for all areas in front of the dump.
  - Again, they do not know the optics of the line in front of the dump well enough.
  - They have encountered a couple of situations relating to radiation.

        - Again, the enclosure was laid out before the beam line was finalized. This resulted in a labyrinth being located near a bunch compressor section. Because of this, there is difficulty with radiation, particularly thermal neutrons at the exit of the labyrinth.
        - There are a couple of sources of dark current that are large sources of radiation.
        - The roof of the enclosure is a single layer of blocks so the cracks are not sealed. Access to the roof is not permitted while the accelerator is in operation.
        - Surveys of the last 2 meters of beam pipe before the dump window indicate that beam is scraping there. The survey shows larger readings farther away from the dump than at the dump face. This leads Albrecht and Michael to question whether the beam is even hitting the dump; driven by their lack of diagnostics in that area. Siegfried, on the other hand, feels this occurred for a short time during December.
- *Where is the shielding around the dump?*
    - While it is not shown in the drawings, there are several meters of concrete surrounding the electron dump. In fact the top of the shielding serves as the floor of the enclosure for the photon line and its components.
- *Why material choice for dump (i.e. carbon for primary energy deposition)?*
    - Mainly dependent on beam spot size. The design is for a minimum beam spot size of 2 mm. If one can generate and guarantee a large beam spot size, one can do something simpler such as a solid aluminum or copper dump.
    - They have not used pyrolytic graphite as mentioned in a couple of their publications. While its anisotropic thermal conductivity would be advantageous in the dump design, it is unknown what the lifetime of that anisotropy would be under the stresses imposed by use in the dump.
- *Why not have the dump in vacuum?*
    - Graphite is not a good vacuum material.
    - On the other hand, Michael would like to put the dump in vacuum, maybe its own vacuum area, defined by a window or differential pumping.
        - He is looking at new designs.
        - The method for fabricating the present dump was to shrink fit the aluminum sleeve around the graphite. He would like to braze the graphite into a copper sleeve for better thermal connection.
        - But how to fabricate it and how to account for the different thermal expansion properties?
- *Activation of dump materials?*
    - Not much information at this point. They do have activation of the beam pipe upstream of the window as noted above.

- *What are the interlocks of the final bending magnets?*
    - The control system looks at a dipole at the beginning of the by-pass line, D1Dump, and D6Dump (fig. 2). The system can react at the 10 Hz level, not individual pulses. In the event of a trip, the klystrons, source and RF for the laser are all turned off.
    - The ratio of these has to be within certain tolerances for beam to be enabled. However, this is not working well as the settings are not repeatable. They do not know the value of the absolute settings as a function of the beam energy. I wonder if it is due to hysteresis in the iron-core dipoles.
    - They do have horizontal and vertical steering at the beginning of the dump line. However, the vertical steering is the trim on the bend magnet. The operators have not been confident enough to actually use it (again, maybe due to the uncertainty of hysteresis effects).
    - In the case where all the bending magnets were to be left off, allowing beam to enter the photon line, there is a permanent magnet dipole that would direct beam into a lead stop. Albrecht showed me FLUKA simulations that showed the level of radiation that would enter the experimental area.
- To save money on designs, they have the same steering magnets throughout the accelerator. Because of this, the steering in the low-energy end is much too strong and can deflect the beam into the beam pipe over a very short distance which could result in damage to the beam pipe.

More on the beam dump:

These paragraphs will summarize and expand on the issues of the design of the beam dump.

The beam dump was originally designed for 50 kW. It has a graphite core within an aluminum outer sleeve. The core was inserted into the ring by heating the sleeve, inserting the core, and allowing the sleeve to contract around it. Powdered graphite was applied to the outer surface of the core to facilitate the insertion. Michael Schmitz is concerned about the magnitude and uniformity of the thermal contact between the core and the sleeve.

To accommodate increased beam energy, an extension was added to the upstream end to ensure that all the energy was captured. Both the original and extension dumps have external water cooling from a helical coil around the dump. A slow sweeping magnet was added to distribute the beam power across the face of the dump. The magnet was made from a spare sextupole magnet with the 3 pairs of poles energized 120º out of phase from each other. The frequency is 1 Hz and therefore deposits pulse trains at new points on the face but is not fast enough to spread out pulses within a train.

The dump is separated from the vacuum of the accelerator. The exit window of the accelerator is shown in figure 3. They flow dry nitrogen in the area between the window and the dump. This is done to prevent the generation of corrosive compounds. They do not appear to do anything to monitor activation of the gas.

In both the performance of the dump and that of the window, the beam spot size is critical to their longevity. Michael is not confident that they have enough diagnostics to ensure that the beam does not get too small and could damage either the window or dump. If the beam size is too small, one can not do anything to mitigate the instantaneous temperature rise in the dump. Michael suggested that we consider a fast sweeping system that could distribute energy within a pulse train and would then eliminate the concern about beam spot size.

Michael would like to redesign the dump. He would like braze the graphite into a copper sleeve. There are a number of engineering challenges to doing this properly. He would like to eliminate the window by including the dump in the accelerator’s vacuum while maintaining the external water cooling.

Another possibility would be to design a window that could be an OTR screen and use the OTR image to monitor the beam spot size.

Conclusions:

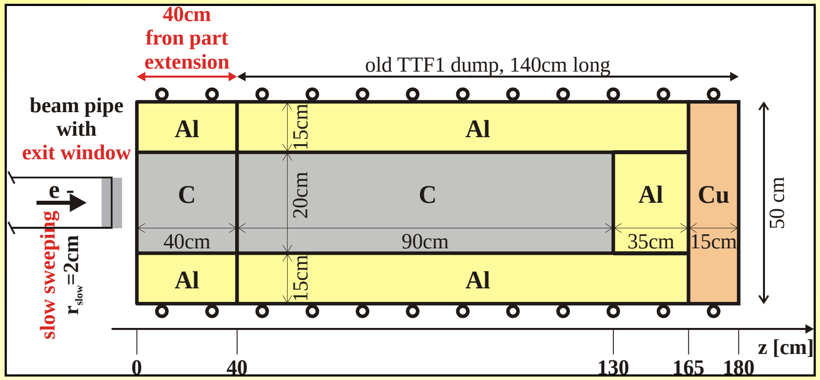
- The design of the dump will not be straight forward. While the TTF experience has not shown any short-comings, they are not completely confident of their design. We should consider other options in addition to their design.
- We should have adequate beam diagnostics to ensure proper targeting on the dump.
- A passive beam emittance degrader before the dump would be ideal.
- We should pay special attention to dark current. It is a wild card in both operations and in shielding design.

B: Absorber

- re-use old TTF1 dump and modify by:
  40cm front part extension
  ⇒ average heating in Al reduced
  slow beam sweeping r_{slow} = 2cm
  ⇒ average heating in C and Al reduced
- beam spot at dump entrance $\sigma_x \cdot \sigma_y \geq 1mm^2$
  ⇒ instantaneous heating in C max. ≈ 250K
- max. temperatures just after bunch train
  in graphite ≤ 400°C (+200K w/o sweep)
  in aluminum ≤ 250°C
- dump operates at normal atmosphere
- design on basis of 2GeV / 130kW
  ⇒ limit for P_{ave} at const. power density:

E_0 [GeV]	0.4	0.8	1.2	1.6	2
limit of P_{ave} [kW]	87	108	120	125	130

- 2 (1 + 1 spare) modified absorbers ready
  1 absorber is installed in place



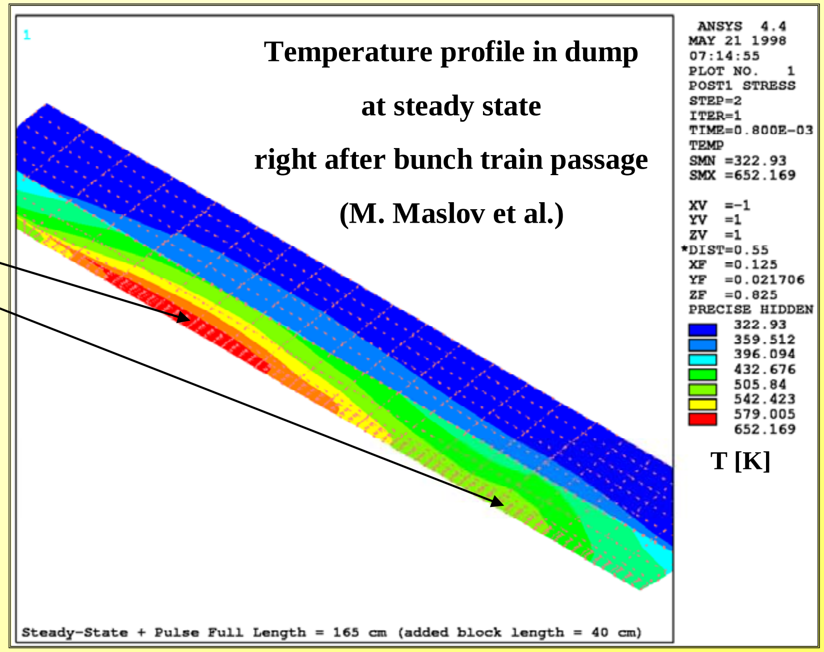
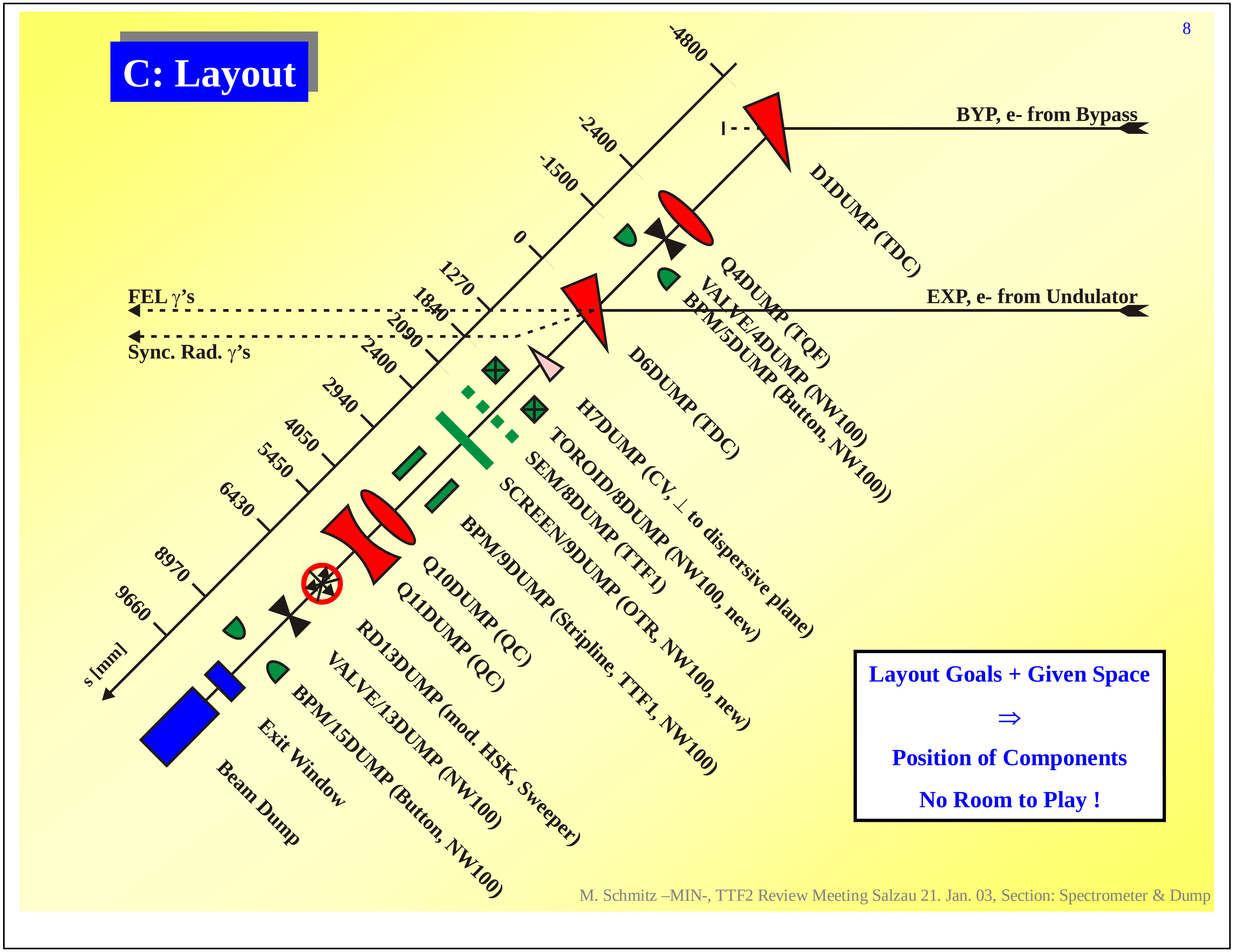


Figure 1



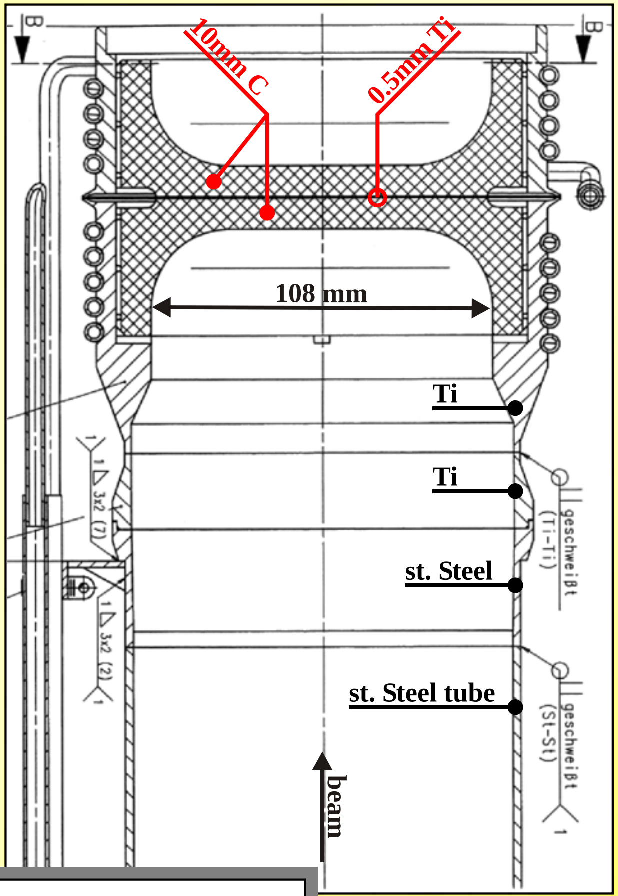
C: Layout
8
-4800
-2400
-1500
0
1270
1840
2090
2400
2940
4050
5450
6430
8970
9660
s [mm]
BYP, e- from Bypass
EXP, e- from Undulator
FEL γ's
Sync. Rad. γ's
D1DUMP (TDC)
Q4DUMP (TQF)
VALVE/4DUMP (NW100)
BPM/5DUMP (Button, NW100))
D6DUMP (TDC)
H7DUMP (CV, ⊥ to dispersive plane)
TOROID/8DUMP (NW100, new)
SEM/8DUMP (TTF1)
SCREEN/9DUMP (OTR, NW100, new)
BPM/9DUMP (Stripline, TTF1, NW100)
Q10DUMP (QC)
Q11DUMP (QC)
RD13DUMP (mod. HSK, Sweeper)
VALVE/13DUMP (NW100)
BPM/15DUMP (Button, NW100)
Exit Window
Beam Dump
Layout Goals + Given Space
⇒
Position of Components
No Room to Play !
M. Schmitz –MIN-, TTF2 Review Meeting Salzau 21. Jan. 03, Section: Spectrometer & Dump

Figure 2

B: Beam Exit Window (2)

4.) DESY exit window construction (T. Wohlenberg)

- take geometry from Protvino design, but
  braze Ti and C together instead of pressing
  - pressed: ≈ 0.14 – 0.25 W/(cm²·K)
  - brazed: ≥ 0.8 W/(cm²·K)
  - ⇒ improved and long term stable thermal contact
- all brazing pre-tests were successful
- construction finished
  all parts manufactured for 2 windows
  - ⇒ brazing of 1. final window starts now
- venting the small volume between dump and window
  with dry nitrogen gas, ≈ 1-10 l/day
  - ⇒ protection of atmosphere side of window against
    aggressive substances like ozone or NO_x
- 1 complete Protvino window is at DESY and serves
  as fall back solution



DESY Construction
Ti-C contacts are brazed

Figure 3