The Project PITZ 2 - Development of Optimized Photo Injectors for Free Electron Lasers

(16. November 2004)

0. Preface

In this paper we describe the PITZ2 project for the installation of the necessary hardware to study the beam emittance conservation principle and to optimize the electron source for the VUV-FEL at TTF2 and the XFEL. The planning is for the years 2004 to 2006. Since the latest component, the CDS booster cavity, will not be ready before autumn 2006 the time in between will be used to operate the PITZ facility with the preliminary booster (called TESLA booster). Subsequently, the diagnostics elements for measuring the beam properties will be upgraded in between the running periods so that end of 2006 the whole facility will be operational. With this scenario it is possible to do first studies on the emittance conservation principle already in an early stage of the PITZ upgrade and also commission most of the diagnostics elements with beam before the installation of the CDS booster, saving time for the later running with the complete PITZ2 setup.

In May 2004 the first PITZ2 project proposal was submitted to the directorate and the DESY project commission. The current PITZ2 project proposal is an updated version of the older one, following more closely to the new project planning regulations in force at DESY which have been changed since May. In addition, a more detailed time and resource planning has been worked out using the MS Project planning tool. The resources requested with the first proposal have not been fully allocated to the project up to now. This especially concerns the required physicist manpower for the physical design of PITZ2 components (from the job announcement in spring 2004 only one qualified physicist could be hired) as well as the resources in the construction department on the technical design of diagnostics components for PITZ2. This resulted in mainly two consequences:

a) the startup of PITZ2 with the TESLA booster cavity will only happen with a minimal version of diagnostics (this stage of PITZ is often called ‘PITZ1.5’),
b) the major project goals are delayed by about half a year (e.g. in the first project proposal the installation of the CDS booster and the major parts of diagnostics had been foreseen for spring 2006, now it will happen in autumn 2006).

The operation of the PITZ2 facility with the CDS booster and the complete set of diagnostics for optimizing the injector for the VUV-FEL and the XFEL and for extending the XFEL parameter range will be a follow-up project starting in 2007. This will be described in a separate project proposal to be prepared in 2006.

Content:

In Section 1 of this PITZ2 proposal the goals of the project are described. Section 2 contains the technical description of the PITZ2 setup. The project organization is explained in Section 3 and Section 4 shows the time planning. The resources are discussed in Section 5 and in Section 6 a risk analysis is given. The detailed time and resources planning is listed in the attachments. The time planning highlighting the different milestones is shown in Appendix 1 (outline level 2). Appendix 2 shows the detailed time planning with the required resources (all subtasks). In Appendix 3 the resources contributing to the project are listed[1]. Appendix 4 shows the allocation of working time of the different employees to the project over the period of 3 years[2] and Appendix 5 lists the tasks per resource.

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[1] For calculating the over all personnel costs of the project a unified average cost rate of 30 €/h is assumed for all employees.

[2] The MS Project printout shows the maximum resources usage during the displayed time interval. Since the planning is not on weeks basis for all tasks (some tasks for the same resources are planned over several months), over

1. Goals of the Project

1.1 Introduction

The **P**hoto **I**njector **T**est facility at DESY **Z**euthen (PITZ) was built in order to test and optimize sources of high brightness electron beams for future free electron lasers and linear colliders. The focus is on the production of intense electron beams with very small transverse emittance and reasonably small longitudinal emittance which are required in order to meet the high-gain conditions of FEL operation. The challenge of PITZ is the production of such beams with very high quality by applying the most advanced techniques in combination with key parameters of projects based on TESLA technology like the VUV-FEL, the European XFEL, and the proposed BESSY-FEL. In autumn 1999 the decision for building this facility was taken and in January 2002 the first photo electrons were produced. Since then, several operation periods have followed and the first beam measurements have been presented at the conferences EPAC2002 [1], FEL2002 [2], PAC2003 [3], and FEL2003 [4]. In summer and autumn 2003, a full characterization and optimization of the existing electron source was done at PITZ. On November 21st, 2003, the electron gun was transported to Hamburg and in January 2004, the rf gun was installed at the VUV-FEL and then taken into operation.

During the optimization procedure in 2003 a minimum normalized vertical emittance of 1.5 π mm mrad was achieved (geometrical average of both transverse planes 1.7 π mm mrad). This is well below the startup-requirements of the VUV-FEL for a radiation wavelength of 30 nm which is 3 π mm mrad. On the other hand, a normalized transverse emittance of 0.9 π mm mrad has to be achieved in both transverse planes for the European XFEL. This requires a big step forward in the electron source development: as a comparison, the current world record is 1.2 π mm mrad in one of the transverse planes.

1.2 The PITZ2 Longer Term Strategy

The second stage of PITZ, called PITZ2, is a large extension of the facility and its research program. The concept of PITZ2 is to basically resemble the VUV-FEL and the XFEL[3] up to that critical beam energy where emittance becomes a constant of motion for the rest of acceleration. In this way, the VUV-FEL and the XFEL will be relieved from the time consuming studies on improvement of electron beam quality, while all results achieved at PITZ can readily be transferred to both facilities, thus improving their performances. In addition, PITZ2 will be able to study injector schemes beyond the VUV-FEL and baseline XFEL demands, e.g. upgrades of the European XFEL and studies for the proposed BESSY-FEL.

The future program at PITZ will comprise the following main aspects:

1) The key technical element of PITZ2 is a **booster cavity**, which allows accelerating the beam to ~ 30 MeV, an energy necessary to prove the basic principles of conserving small transverse emittance. According to simulations, a minimum normalized transverse beam emittance can be conserved by locating a booster cavity at the position of the beam envelope waist, together with a proper choice of rf gun and solenoid parameters. Future FEL proposals rely on this technique [5, 6, and 7]. A proof of this concept and experimental optimization are the main objectives of PITZ2. The experimental study will be done in two stages. First, a TESLA prototype cavity (normal conducting, copper) will be used together with a subsequently upgraded diagnostics beamline. Later, this preliminary booster will be replaced by a normal conducting cavity specially designed for PITZ, which will reach higher beam energies (CDS booster, see section 2.1.1).

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allocation during the shutdown periods is not a problem. It can be compensated by under allocation before or after the shutdown.

[3] The injector concept is basically the same for the VUV-FEL and the European XFEL.

2) For a complete characterization of the electron beam parameters at higher energies, new **diagnostic** elements have to be developed and installed. This includes devices that allow efficient and precise measurements of longitudinal and transverse phase space parameters for the full range of beam energies (see section 2.1.2).
3) A stable and reliable **laser system** with the required flat-top temporal and transverse laser beam profiles (~ 20 ps FWHM, ≤ 2 ps rise/fall time, homogeneous transverse profile with variable diameter) has to be developed and installed. Since the development of the central laser system with the required temporal profile is leaded by the Max-Born-Institute and is funded externally by the BMBF, this subtask is not included in this project proposal. The installation of the laser optical beamline for producing the required transverse profile on the photo cathode and the diagnostics of the laser system is under the responsibility of DESY and therefore included in this project proposal.
4) Further **optimization** of all other subsystems is needed in order to reach the required electron beam parameters. Extensive **beam dynamics studies** are needed for this. Detailed beam dynamics features have to be implemented in the simulation tools in order to obtain good agreement between measurements and simulation. Extensive parameter studies have then to be performed by simulations in order to find the global optimum conditions for a given set of boundary conditions. This optimum then has to be confirmed and re-optimized experimentally in a broad measurement program[4]. This optimization procedure has to be repeated when major boundary conditions change significantly (e.g. laser profiles, achievable gun or booster gradients, solenoid or booster positions).
5) **Improved rf guns** have to be designed, built, tested and delivered for the VUV-FEL and the XFEL. For obtaining the emittance requested for the XFEL the gun cavity must be operated at a gradient of 60 MV/m (currently ~45 MV/m have been reached, limited by the 5 MW klystron). Besides the availability of a 10 MW klystron, this especially requires additional cooling on the front and end surface of the rf gun body as well as a modified water distribution. DESY will built gun cavity prototype number 4 with improved water cooling system which will also serve as a spare copy for the operation of the VUV-FEL. In addition, a gun cavity development has started at BESSY. They will design a normal conducting, high duty cycle rf gun (1 kHz repetition rate, 75 kW average power) for their FEL proposal. This rf gun will be tested at PITZ with the existing rf system. Although this test can only run at the repetition rate of 10 Hz currently, this test is important since the required average power can be reached by simply increasing the rf pulse length. Since for the European XFEL the increase of the repetition rate is under discussion, this development and test is also of importance for DESY. If the test is successful a copy of this design can later be built by DESY for further usage at the DESY facilities.
6) To reach the required beam parameters, further developments on **photo cathodes** and improvements of the photo cathode handling system are necessary. This work will include the characterization of the cathodes before and after usage at PITZ using the modern synchrotron facilities technology available at BESSY. Since this subtask will mainly be done by our colleagues from INFN Milan and is funded by the EU, it is not included in this project proposal.
7) The exploration of the **parameter space** for the XFEL user operation should be started. The target parameters for the XFEL assume a nominal value of the bunch charge of 1nC and it must be guaranteed that the required beam emittance and peak current to safely reach 1Å wavelength can be achieved. That is why PITZ is important for the XFEL

[4] In this project proposal the manpower required for the beam dynamic simulations for preparing the different measurement programs, for the analysis of the measured data and for the interpretation of the measurements by comparing with detailed simulations is considered in those tasks where the PITZ facility is operated. On average, about 90% of the pure operation time of the machine is added for these preparation, analysis and feedback tasks.

project. Additionally, in view of the broad spectrum of experiments one can foresee for the XFEL facility, operation with quite different sets of bunch parameters is conceivable. For instance: snapshots of molecules (e.g. in the field of biology) may have photon pulses of 10fs or less desirable. In this context it could be highly interesting to study the possibility of operating with low-charge, but extremely short bunches. A reduced emittance could be a possible benefit in this case. On the other side, there will be experiments which desire to have as many photons as possible in a single, possibly longer, high-charge bunch. Extensive studies of the injector with varying bunch parameters are necessary to explore this range of possibilities, to be accompanied by theoretical and simulation studies. Since first the baseline parameters of the XFEL have to be demonstrated, considerations on this parameter studies will not start before the end of 2006. Therefore, only a small amount of manpower is included in this proposal as a pre-study for the next PITZ project proposal starting in 2007.

8) Future plans for PITZ also include conceptual studies on **ballistic bunching**, an alternative compression method which allows to achieve FEL specified bunch density distributions avoiding unwanted coherent synchrotron radiation (CSR) effects. This work requires the reliable operation of a booster and will not start before 2006. Therefore, only a small amount of manpower is included in this proposal as a pre-study for the next PITZ project proposal starting in 2007.

1.3 Concrete Goals of this Project Proposal

The major goals to be fulfilled within this project proposal until the end of 2006 are as follows:

1) The TESLA booster cavity will be prepared, installed, commissioned and operated at PITZ.
2) The CDS booster cavity will be designed, built and installed at PITZ.
3) Most of the diagnostics elements necessary for the complete characterization of the electron beam at different beam energies will be designed, built and installed at PITZ (details and exceptions are explained in section 2.1.2).
4) The beam dumps necessary for the operation of the facility at full specification (charge per pulse, pulse train length, repetition rate, beam energy) will be designed, built and installed at PITZ.
5) Two 10 MW klystrons will be installed and operated at PITZ.
6) First experience will be gained with operating a rf gun at a gradient above the limit of a 5 MW klystron. It will get clear if dramatic problems to operate a rf gun at 60 MV/m have to be solved or if just the water cooling has to be adapted.
7) The BESSY high duty cycle rf gun will be tested. This will give further hints for the design of a rf gun to fulfill the XFEL parameter requirements.
8) The DESY gun cavity prototype number 4 will be designed, built, and operated. Besides an improved cooling concept, this cavity will also serve as a spare copy for the operation of the VUV-FEL.
9) The TESLA booster will be operated with a subsequently upgraded diagnostics section. This will allow to do first tests of the emittance conservation principle already in an early stage of the PITZ upgrade. It will also allow to commission most of the diagnostics elements with beam before the installation of the CDS booster. This will save time for the later running with the complete PITZ2 setup.
10) The injector setup will be optimized within the parameter range possible for the TESLA booster (limitation on e.g. accelerating gradient, field uniformity, pulse train length, repetition rate). Mainly depending on the actual limitation of the booster accelerating gradient which can not be predicted, this optimization might have a direct influence on the

injector parameters used for the running of the VUV-FEL (rf gradient and rf phase in the gun; transverse and longitudinal laser parameters; solenoid strength and position; rf gradient, rf phase and position of the booster cavity). Even when the TESLA booster gradient is limited to <<12 MV/m an impact on the running of the VUV-FEL might be obtained by comparing the measurements with simulations and extrapolating the results.

2. Technical Description

2.1 Experimental Setup with Booster Cavity

The upgrade of the photo injector test facility at Zeuthen (PITZ2) includes the development of an accelerating section with booster cavity and an extended beam diagnostics section for detailed studies and full characterization of the electron source. An overview of the PITZ2 setup is shown in Figure 1.

2.1.1 Accelerating Section

The accelerating section of PITZ2 consists of a gun cavity with an upgraded gradient of above 40 MV/m (the goal for the XFEL is a gun gradient of 60 MV/m), and a booster cavity. Being a key technical element, the booster cavity for PITZ2 must have a special design allowing a maximum energy gain without degrading the electron beam quality. The positron pre-accelerator cavity with the so called cut disk structure (CDS) which was planned to be used for the TESLA positron injector provides a good starting point for finding an optimal solution for a normal conducting PITZ booster. A design group at INR Troitsk has done a detailed physical design of the CDS booster for PITZ. The final design report is ready now. The fabrication design, the construction, the tuning and the commissioning of this booster cavity is part of this PITZ2 proposal. The maximum attainable energy gain of the booster depends on the available rf power and the requested accelerating gradient. Further depending on the detailed design of the booster cavity geometry, this results in a certain number of accelerating cells. A booster cavity with 14 accelerating cells, a maximum accelerating gradient of 14 MV/m, and an energy gain of up to about 23 MeV is foreseen to be built now. With an energy gain in the improved gun cavity of about 5-6 MeV the total electron beam energy will be about 30 MeV.
Since the construction and tuning of the CDS booster cavity will last until autumn 2006, the start-up of PITZ2 will take place with a normal conducting TESLA prototype cavity (TESLA booster). This booster is limited in its surface quality and cooling capacity, resulting in a reduced accelerating gradient and average rf power. Nevertheless, this booster can be used to commission most part of the diagnostics for PITZ2 and to do first tests on the emittance conservation principle.

2.1.2 Diagnostics Section

For the full characterization of the electron source detailed measurements of transverse and longitudinal phase space properties have to be done. The increased beam energy requires various new diagnostics elements. A list of the diagnostic tools to be designed and built for PITZ2 is given below:

- The beam offset at different positions along the beamline has to be known in order to steer the beam onto the ideal orbit as well as for lattice devices alignment studies. For these purposes 11 Beam Position Monitors (BPMs) have to be installed.
- 3 Faraday Cups (FC) allow absolute bunch charge measurements, at the same time they serve as beam collector.
- For a non-interceptive beam current measurement 6 commercial Integrating Current Transformers (ICTs) will be used.

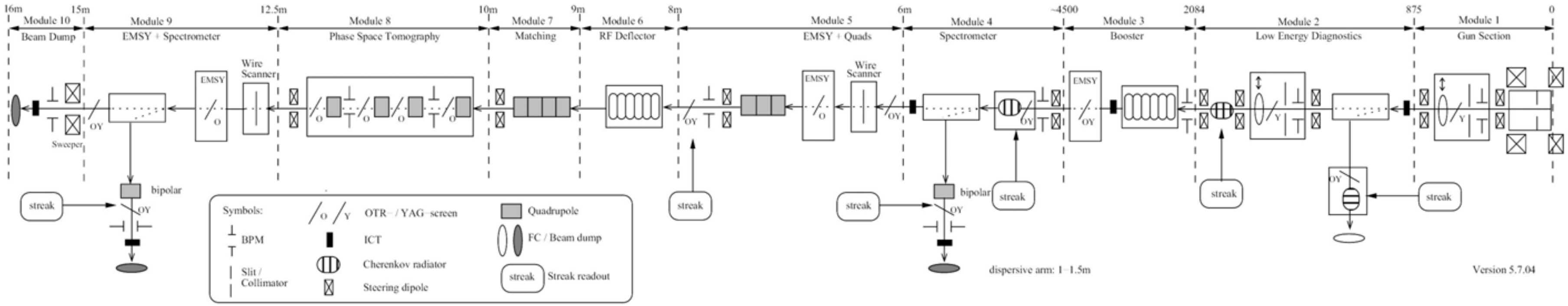

Figure 1: *PITZ2 general layout. The acceleration sections consist of the gun cavity and the booster cavity. The gun is followed by a rotating steerer and a diagnostics cross consisting of a Beam Position Monitor (BPM), a YAG screen, and a removable Faraday Cup (FC) (serving for charge measurement and as low energy beam dump). A low energy diagnostics module follows, consisting of an ICT, a dipole spectrometer, a second rotating steerer, and a second diagnostics cross which contains in addition a collimator for dark current absorption. A Cherenkov radiator with streak camera readout for bunch length measurements is positioned afterwards, as well as in the first dispersive section, exchangeable with OTR and YAG screens. At the end of module 2 two additional rotating steerers are installed in order to place the electron beam on the electrical axis of the booster cavity which follows in module 3. A BPM is placed right before the booster cavity. The high energy diagnostics also starts on that module with an ICT and an Emittance Measurement System (EMSY). Module 4 includes another rotating steerer, a BPM, a screen with the possibility of choosing a streak camera readout, a first high energy spctrometer and another ICT. Module 5 starts with a screen (OTR as well as YAG) for observing the beamlets of the upstream EMSY system. Then a wire scanner and a second EMSY follow in analogy to the first one. Between EMSY and its screen of observation a quadrupole triplet (for the beam focusing) as well as another rotating steerer and a BPM will be positioned. Module 6 consists of the rf deflecting cavity. In order to do the beam tomography described in the text, one still needs a matching section in front of the tomography module consisting of 4 quadrupole magnets and 4 OTR screens. This module must contain at least 2 additional BPMs. At the end of the beam pipe a second wire scanner and the third EMSY will be installed, followed by the second high energy spectrometer in order to allow a beam longitudinal phase space measurement at this position. It follows a screen, a sweeper for distributing the beam over the beam dump surface, an ICT for the beam current measurement, and finally the beam dump. The dispersive arms that belong to the two last spectrometers consist of a quadrupole, a screen, a BPM, an ICT, and finally a beam dump, which can absorb the whole beam energy. Furthermore, there will be a possibility for using the streak camera in the dispersive areas.*

- The transverse electron beam distribution at 16 longitudinal positions along the beamline has to be determined by means of observation screens and CCD cameras. The increased beam energy allows to use Optical Transition Radiation (OTR) screens. However, Yttrium:Aluminum:Garnet (YAG) screens are suitable for measurements of low intensity and low energy beams (for example, behind a slit-mask or directly after the gun).
- For cross-checking the profile measurements 2 wire scanner stations will be installed.
- For the bunch length measurements as well as for the corresponding longitudinal phase space analysis, OTR screens or Cherenkov radiators with streak camera readout are needed at 6 different locations along the beamline.
- The transverse projected emittance will be measured using Emittance Measurement Systems (EMSYs), composed of slit masks and/or hole masks (pepper pot), and screens 1.5−2 m downstream which are observed by CCD cameras. In addition, the gradient of a quadrupole is varied and the corresponding beam size variation is measured on screens (quadrupole scan). Later, Twiss parameter analysis yields a beam emittance computation. In order to observe the beam emittance evolution along the beamline, 3 EMSYs have to be installed: at the place of the smallest emittance (approximately at z=6 m), as well as at the beginning and at the end of the high energy beamline (i.e. at z=4 m and z=13 m).
- For measuring the beam momentum distribution 3 spectrometers are required, each consisting of a dipole magnet and a screen in the dispersive section (1 dipole in the low energetic part, 1 dipole each at the beginning and the end of the high energetic part). The image can be recorded by a conventional CCD camera as well as by a streak camera.
- The slice emittance can be measured by using off-crest acceleration in the booster and a quadrupole in the dispersive arm. Therefore, both high energetic dispersive arms are equipped with a quadrupole. A better slice emittance measurement is possible using a rf deflecting cavity. This device will be realized in collaboration with external partners and with funding from the EU and an own DESY contribution. The EU project (EUROFEL) is foreseen to start in January 2005 and will last 3 years. From the currently existing time schedule there, it is not yet clear if the rf deflector will be installed at PITZ until the end of 2006.
- A complete phase space analysis can be done using a set of 4 quads and view screens (4 monitor method). This phase space tomography module will be realized in collaboration with CCLC Daresbury. This task is again part of the EUROFEL proposal starting in January 2005 and lasting 3 years. From the currently existing time schedule there, it is not yet clear if the tomography module will be installed at PITZ until the end of 2006.
- Moreover, beam phase space analysis becomes possible using one out of two OTR screens placed one behind the other. Beam energy, intensity and divergence can be determined by analyzing the interference pattern of forward and backward scattered radiation [8]. This method will be tested at one of the coupled OTR stations in the tomography module after this is installed and commissioned.
- For centering the beam at beam optical elements and compensating kinks in the beamline 9 rotating steerer magnets will be built and installed at PITZ.
- Because of the high beam density of a low emittance electron source electromagnetic sweepers will be needed in front of the beam dumps.

All magnets and diagnostics elements mentioned above (screen stations, Faraday cups, BPMs, ICTs, and EMSYs) have to be developed in order to fit the requirements of increased beam energy and improved measurement accuracy. Some new diagnostics elements (e.g. EMSY) can be designed by changing the existing construction and adapting the inner components to higher beam energies. An overview of the general diagnostics layout for PITZ2 is shown in Fig. 1. The setup consists of separated modules that may be positioned and eventually exchanged independently from each other.

In addition to what is shown in Figure 1, a small setup mainly for the conditioning of gun cavities to obtain reliable operation at the given gradients and repetition rates will be installed in the tunnel. This is very important because the experience shows that the conditioning, especially for reaching high accelerating gradients and high average power is very time consuming (many months). Since a second rf system is available anyhow, with this small setup two rf cavities can be conditioned in parallel which significantly reduces the overall downtime for pure conditioning of gun cavities. The small setup can simply re-use the very first PITZ1 setup which we got from Hamburg and just needs an actuator for inserting a Mo cathode and a copy of the existing gun setup. This gun conditioning setup also acts as a spare gun setup when the rf guns are exchanged between Hamburg and Zeuthen.
Since the resources required by the first proposal for PITZ2 were not allocated to the project up to now (missing physicists for the physical design of PITZ2 components and missing construction engineers for the technical design of diagnostics elements) the startup with the booster cavity in spring 2005 will happen with a minimal version of the diagnostics. This reduced setup for the start of PITZ2 (often called PITZ1.5) is shown in Figure 2. It will be upgraded subsequently when the further diagnostics elements are ready as described in the time planning in Section 4 (even more details in Appendix 1 and Appendix 2).

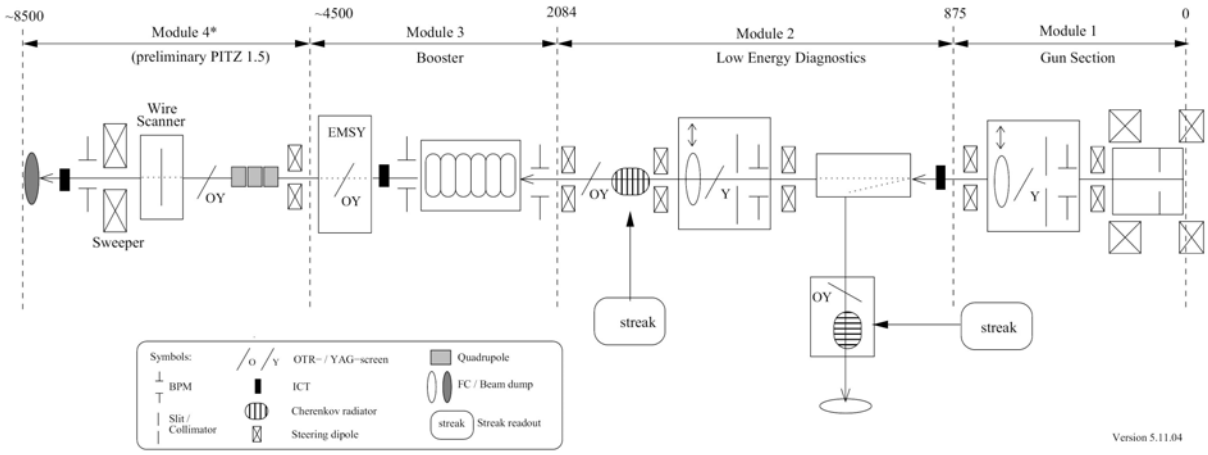

Figure 2: *Schematic setup of PITZ1.5 in spring 2005. The first part from the gun to the booster cavity is identical to the setup shown for PITZ2 in Figure 1. After the TESLA booster cavity a modified EMSY station and a quadrupole triplet from PITZ1 will be re-used. A wire scanner station for both transverse coordinates will be installed to cross check the beam size measurements of the screen station before. The sweeper before the preliminary beam dump will be installed if the possible energy gain and rf pulse length from the booster require this.*

2.2 Development of the Laser System

A stable and reliable laser system with the required flat-top temporal laser beam profile (~ 20 ps FWHM, ≤ 2 ps rise/fall time) will be developed by the Max-Born-Institute (MBI, Berlin-Adlershof). This development is funded externally by the BMBF and is not included in this project proposal.
For transporting the laser beam from the laser hut to the photo cathode, a special laser beam line has to be developed in order to obtain transverse homogeneous laser distributions with variable diameter on the photo cathode. This development started in 2003 in cooperation between DESY and the MBI and will be continued in 2004 and 2005. The MBI has done the optics design for improving the imaging of the laser spot on the photo cathode. DESY is responsible for the technical design, the construction and the installation at PITZ.
DESY is also responsible for the diagnostics of the laser system: transverse profile, temporal profile, intensity. Several of the these diagnostics will be upgraded in detail during the period of

this project proposal (e.g. improvements on the virtual cathode, the continuous laser power measurement, the laser pulse length measurement). All these steps will lead to a more characterized laser system as an important ingredient for a reliable photo injector operation and a valuable comparison with electron beam dynamic simulations. In addition, DESY has also to take care of the continuous operation of the laser system and the exchange of wear parts (e.g. flashlamps).

3. Project Organization

The different tasks of the project are grouped into work packages with a corresponding work package leader. Sometimes a work package leader is also a group leader of a technical group in Zeuthen. Resources from a technical group may not only be allocated to one single work package but also to different work packages (matrix structure). The project organization is done as follows:

1) Project Leader: Frank Stephan
2) A) Project Coordination and Technical Coordination: Jürgen Bähr
   B) Resources Coordination: Anne Oppelt (with help from Katrin Varschen)
3) Work Packages:
   a) Mechanics and Vacuum, WP-Leader: Alexander Donat,
      installation work in the accelerator tunnel; general technical design work for tools and supports; design, operation and maintenance of the vacuum system.
   b) Electronics (incl. RF), WP-Leader: Holger Leich,
      installation, operation and upgrade of the rf system; development, installation and operation of the timing system, the interlock system and the llrf system.
   c) Controls, WP-Leader: Gunter Trowitzsch,
      operation; firmware; DAQ and run controls; controls for rf; new servers; video system; GUI and documentation; adjustments between Hamburg and Zeuthen.
   d) Infrastructure, WP-Leader: Herbert Schulze,
      water cooling upgrade; upgrade of the electrical power station; operation, maintenance and extension of the water, SF6 and electrical systems.
   e) Optics, WP-Leader: Jürgen Bähr,
      operation and upgrade of the laser system; extension of the streak camera and TV systems; extension of the controls for the laser and streak systems.
   f) Beam Dynamics and Operation, WP-Leader: Mikhail Krasilnikov,
      simulations for the PITZ2 design; design, construction and installation of all magnets systems; operation of the facility; participation at and service for TTF.
   g) Gun, Booster and Diagnostics, WP-Leader: Anne Oppelt,
      design, construction and tuning of the gun and both booster cavities; all electron beam diagnostics for PITZ2 including mechanics, electronics and BIS; RF deflector.
   h) Beam Dump and Protection, WP-Leader: Sabine Riemann,
      preparation of the preliminary and final beam dumps; design and construction of the beam protection system.

In Appendix 3 the resources contributing to the project are listed. They are grouped by the resource group which they belong to.
In Appendix 2 the full list of tasks is grouped to the work packages and the resources used per task are listed as well. For details on the principles used for the project planning with MS project please see Sections 5.4 and 5.5.

4. Time Planning

The time planning with the intermediate milestones (larger text size, underlined) is shown in Appendix 1 (Gantt chart with outline level 2). The full time planning is shown in Appendix 2 together with the resources required for each task. The evolution of the project can be described as follows:

After the gun cavity prototype number 2 (G2) was send to Hamburg for installation into TTF2 end of 2003, the gun prototype number 1 (G1) was installed at PITZ in January 2004. It was used for doing high power rf tests (peak and average) and further optimizing the emittance from the rf gun. Since the delivery of the 10 MW multi beam klystron was delayed further and further (problems during acceptance tests required a modification of the tubes in the company, now the first 10 MW klystron will come in the first week of 2005), the operation had to be done with the available 5 MW klystron. In parallel, the second rf system was prepared for driving the booster cavity. It got into operation on October 8th, 2004. In 2004 the laser beamline to the photo cathode was continuously upgraded. The preliminary version of the improved beamline got into operation on June 18th, 2004. This together with the slightly increased accelerating gradient in the gun cavity resulted in a new record emittance at PITZ: a minimum normalized emittance in one plane of 1.3 π mm mrad and a minimum geometrical average of both transverse planes of 1.6 π mm mrad was achieved (before it was 1.5 π mm mrad in one plane and was 1.7 π mm mrad for the geometrical average, the world record in one plane is 1.2 π mm mrad). The final version of the improved laser beamline will be ready on March 4th, 2005. In parallel to these advances from the rf and operation point of view, the physical design, technical design and construction of the first elements of the new diagnostics beamline for PITZ 2 took place in 2004, concentrating on the elements necessary for PITZ1.5 as explained before. Starting from December 6th, 2004, and lasting until March 4th, 2005, a large shutdown will take place at PITZ for the installation of an extended water cooling system as well as for the installation of the TESLA booster cavity and the other components for PITZ1.5 (see Figure 2).

In January and February 2005 the first 10 MW klystron will be installed and commissioned at PITZ. On March 7th, 2005, PITZ1.5 will get into operation: On the one hand side, one will be able to power the gun with the 10 MW klystron in order to reach higher accelerating gradient on the cathode (goal for XFEL: 60 MV/m). On the other hand side, one will be able to operate the booster with the gun to commission the diagnostics and gain first operation experience with the booster. On May 13th, 2005, this first operation period with the 10 MW klystron and the gun will be finished, followed by a shutdown to install gun prototype number 3 (G3). Because G1 has known problems with its copper quality (leak tightness) and the amount of dark current it produces, it will not be qualified for an installation into TTF. That is different for G3. Its copper quality is ok and it is expected that also the level of dark current is much lower (comparable to G2). On June 10th, 2005, conditioning and characterization of G3 will start. Depending on the results it might be a replacement gun for G2 at TTF. Mid of October 2005 the operation of G3 will be stopped to install the BESSY gun. Its design is finished now and the negotiations with the producer have started. The BESSY gun will be ready for conditioning on November 18th, 2005 and it will be operated and characterized until March 2006.

In March 2006 the gun cavity prototype number 4 (G4) will be installed at PITZ. The design for this cavity will start in December 2004 and will be finished in June 2005. The production will need about half a year so that there is sufficient time left for the tuning and final cleaning and assembly. In April 2005 also a significant part of the diagnostics for PITZ2 will be installed so that G4 will be ready for conditioning on April 21st, 2006. From March 2005 until September 2006 the PITZ facility will be operated with the TESLA booster cavity and different gun cavities and the diagnostics beamline will be continuously upgraded. The construction and tuning of the CDS booster cavity will last until September 2006. In October 2006 it will be installed in PITZ and some remaining parts from the diagnostics beamline upgrade will follow, so that the CDS

booster cavity is ready for conditioning on November 14th, 2006. The rest of 2006 will be needed for the conditioning of the CDS booster.
The major **critical path** in all that timing scenario is also visible in Appendix 1. It is the interplay between the shutdown periods to exchange the rf guns and upgrade the diagnostics beamline on the one hand side and the operation and characterization periods to gain experience with high gun gradients (goal for XFEL: 60 MV/m), to commission the new diagnostics elements and to do first test on the emittance conservation principle on the other hand side. The critical elements in this critical path are the availabilities of the 10 MW klystron, of the different parts of the diagnostics beamline and of the CDS booster cavity at the required times.

5. Resources and Financial Planning

5.1 Resources and Finances for Infrastructure for PITZ2

First of all, what is needed are all the rooms and buildings currently used by PITZ (all the rooms behind the key code entering door, the laser and optics lab, the llrf lab and the rooms in the technical groups which are currently used for PITZ, e.g. vacuum lab, rf test area) and the offices needed for our existing and new personnel (permanent staff, post-docs, PhD students and guests).
The installation of the second rf system for the booster and the request on higher cooling capacity require also an increase in the available electrical power. The upgrade of the electrical power installation at Zeuthen for PITZ and the computer center (total about 572 k€) was approved by the DESY directorate. It will be realized in the years 2004 (350 k€) and 2005 (222 k€) and will be paid from the infrastructure budget in DESY Zeuthen.
Also the upgrade of the water cooling system which is needed for PITZ2 is already partly approved by the DESY directorate. The upgrade will happen in two stages: First, the upgrade to operate the PITZ2 system with 10 Hz will happen in 2004 (500 k€) and 2005 (445 k€). These costs are approved by the DESY directorate and are now accounted on the PITZ budget. Secondly, the further upgrade of the cooling system to operate the PITZ2 system with short rf pulses at 50 Hz repetition rate requires additional investments of about 475 k€. The decision on these additional costs has to be taken in spring 2005.
For the installation of the rf system of the deflecting cavity either the construction of a second floor in a limited area of the klystron hall is necessary or the usage of a storage room in the building of the purchase department will be changed accordingly (100 k€ planned for 2006).

5.2 Resources and Finances for the Laser and the Laser Beamline Development at the MBI

For the complete replacement of flash-lamp pumped amplifiers by diode-pumped amplifiers, stabilization of the flat top pulses, development of a remote controllable power unit for the diode amplifiers, the development of a more robust laser rf system against electromagnetic noise and improved high voltage units for the pockels cells a contract between DESY Zeuthen and MBI (contract number 2 - Z) was approved by the DESY directorate. Within this contract a payment of 300 k€ to MBI has happened in 2003, 225 k€ will be paid in 2004, and the rest of 172 k€ will be paid in 2005.

5.3 External funding expected for PITZ

From the FP6 of the European Union we will get money for the I3 (integrated infrastructure initiative) research activity R5 “Development of an Optimized Radio Frequency Photo Injector for X-ray Free Electron Lasers” (in this proposal this budget is called ‘EU1-I3’). The pure DESY part of this support accounts to 414 k€ in the period from March 1st, 2004, to February 28th, 2007. This is 325 k€ for personnel costs, 12 k€ for hardware, 8 k€ for travel and 20% overhead. In addition, 100 k€ are allocated for new methods of bunch length measurements, 44 k€ will go to INRNE Sofia for the production, installation and commissioning of three EMSY stations for higher beam energy, 40 k€ will be used for buying NEWPORT hardware for the EMSY stations, and 200 k€ will go to the MBI for the development and test of optical sampling of the laser pulse length. Also 100 k€ will go to BESSY for the development and test of a new high duty cycle gun cavity and 150 k€ will go to LAL-Orsay for the construction and installation of the main parts of 2 high energy spectrometer arms. Finally, 216 k€ will go to INFN-LASA Milan for studies on cathode performance, new cathode production procedures and improvements on cathode handling and 90 k€ will go to INFN-LNF Frascati for beam dynamics studies and participation in the running of the facility.

Currently, a proposal for the call on design studies within FP6 is under negotiation with the European Union (in this proposal this budget is called "EU2-EUROFEL"). Since the contract is not yet signed and the total budget has to be reduced by 10 % in the next days, the amounts allocated to the different institutes and the different tasks are still subject of change. The contract should start on January 2005 and will last 3 years. Probably DESY will get about 350 k€ (gun cavity, tomography, rf deflector, reliability studies), INFN will ask for about 650 k€ and URLS will ask for about 100 k€ (in both requests a total sum of about 300 k€ is included for design and construction of the rf deflecting cavity for PITZ), ENEA will ask for about 100 k€ (nothing special for PITZ), CEA will ask for about 290 (nothing special for PITZ), CNRS will ask for about 130 k€ (nothing special for PITZ), ELETTRA will ask for about 130 k€ (nothing special for PITZ), TUD will ask for about 140 k€ (simulations not only but also for PITZ), BESSY will ask for about 170 k€ (cathode materials, gun cavity, not only but also for PITZ), MBI will ask for about 110 k€ (aspheric lenses for improvements in the laser transmission line at PITZ), and Daresbury will ask for about 130 k€ (tomography for PITZ).

From the "HGF Impulsfond" DESY will get consumables for the period from October 1^{st}, 2003, to September 30^{th}, 2006, i.e. 35 k€ in 2003, 80 k€ in 2004, 80 k€ in 2005 and 60 k€ in 2006. The other collaboration partners in this proposal are TU Darmstadt (55 k€ for personnel per year), University of Hamburg (45 k€ for personnel per year), and Humboldt University Berlin (45 k€ for personnel and 15 k€ for consumables per year).

In the year 2005 Zeuthen will get 1500 k€ "Ausbaumittel" from the HGF for PITZ. In the frame of this project proposal 1035 k€ are already allocated for different investments (see Section 5.4 and Appendix 5). Beyond that, investments for development work towards higher repetition rate rf systems are not considered in this project proposal for example.

5.4 Investments for PITZ2

The required investments for PITZ2 in the years 2004 to 2006 are included in the MS Project planning printed in Appendix 2. The whole project is split into work packages which are further split into tasks (this can be summary task, detailed work tasks, pure investments, or mixtures of these). In any case no task is extended over the change of a year to allow a yearly accounting. Subsequent tasks with similar general content are numbered with a, b, c, … For pure investments (no manpower is needed) the task name is the name of the investment and the time interval of this task is the year where the investment takes place (e.g. "pulse power amplifier" and "IGCT backup switch" and so on in the work package "electronics" under the sub-task "install and commission RF2"). If a work task also needs investments, then the amount of investments is added to the list of manpower resources required for this task (e.g. the task "design+construct tools+supports" in the work package "mechanics and vacuum" not only needs the construction engineers and the mechanical workshop for fulfilling this task but to some extend also needs to buy profile systems from e.g. Rose&Krieger).

Because different sources of money are needed and available for the PITZ project, the investments are distributed to the different money sources. The available money resources are:

- the Zeuthen budget for PITZ, called “Budget PITZ”, used for most of the investments also including the water system upgrade, 1660 k€ in 2004, 1442 k€ in 2005, 713 k€ in 2006.
- the Zeuthen budget for infrastructure, called “Budget Infrastructure”, only used for the power station upgrade, 350 k€ in 2004, 222 k€ in 2005, 0 k€ in 2006.
- the EU funding from the integrated infrastructure initiative, called “EU1-I3”, used for the subcontracts within this activity, 158 k€ in 2004, 96 k€ in 2005, 30 k€ in 2006.
- the EU funding from the EUROFEL proposal, called “EU2-EUROFEL”, used for the production of gun prototype number 4 and parts of the rf system for the rf deflector, the contract of this proposal is not yet signed and therefore still might be subject for changes, 0 k€ in 2004, 40 k€ in 2005, 310 k€ in 2006.
- the HGF Impulsfond des HGF Präsidenten, called “HGF Impuls”, used for the building of the CDS booster, 30 k€ in 2004, 120 k€ in 2005, 60 k€ in 2006.
- the HGF Ausbauinvestitionen, called “HGF Ausbau”, up to now only available in 2005 and used for the 10 MW klystron, magnets, power supplies, diagnostics, and the conditioning test stand, 0 k€ in 2004, 1035 k€ in 2005, 0 k€ in 2006.

The investments paid by the different money resources are listed in Appendix 5. Summarizing all investments over the full project duration results in 6.3 M€.
Comparing the required investments with the available money sources it can be said that thanks to HGF Ausbauinvestitionen the major investment problem from the first PITZ2 proposal is solved. Taking into account that the water cooling system upgrade is now accounted in the PITZ budget and that the corresponding money will be transferred from infrastructure budget allocated in the past, **all the required investment resources are allocated as needed.**
If in 2005 it will be decided that a further upgrade of the water cooling system to operate the PITZ2 system with short rf pulses at 50 Hz repetition rate should be done, the required additional investments of about 475 k€ have to come from external resources like e.g. HGF.

5.5 Manpower needed for PITZ2

The manpower resources required for PITZ2 in the years 2004 to 2006 are included in the MS Project planning printed in Appendix 2. For details on the definition of work packages and tasks please see Sections 3 and 5.4. In Appendix 3 the persons from the different technical and physics groups mainly from Zeuthen but also from Hamburg are listed which are required to participate in the project. The names of the persons appear in bold writing if in any of the time intervals within the years from 2004 to 2006 the allocated working time is above the maximum given in column 8 of Appendix 3. This over allocation is also visible in Appendix 4 where the working time of the different employees for the project over the period of 3 years is displayed with a resolution of a month. This MS Project printout shows the maximum resources usage during the displayed time interval. Since the planning is not on weeks basis for all tasks (some tasks for the same resources are planned over several months), over allocation during the shutdown periods at PITZ is not a problem. It can be compensated by under allocation before or after the shutdown. Anyhow, the precision of our planning with MS Project is about ±10%. Over or under allocation of manpower resources of ±20% was accepted for short periods. From Appendix 5 one can see which tasks the different people work on.
The main results from a detailed analysis of this data can be summarized as follows:

1) Hiring Sergiy Khodyachykh from the last job announcement in spring 2004 was the first step in the right direction but is by far not sufficient (5 other very good candidates from this job announcement preferred positions in industry or in a research field closer to their previous subject). In addition to the current status, 2 post-docs and 2 PhD students are needed as soon as possible. For the post-docs a job announcement is currently running. One diploma student currently working on PITZ will become PhD student beginning of

2005. **The financing of the post-doc and PhD student manpower can be done from the money available from the EU-I3 project and the household of Zeuthen.**
In the next two years the number of permanent people working for PITZ must be increased from currently 3 to 4. In the years 2007 and 2008 another permanent position should be made available for PITZ. According to the size of the PITZ project, its strong relation to significant hardware investments, its important and partially leading role in the international electron source development 5 permanent positions are fully justified and required on the longer term. This is also true when comparing with other important experimental groups in Zeuthen. **These permanent people are not yet allocated to PITZ in the household of Zeuthen but are required to have a continuous success of the facility.**

2) For the subject mechanics/vacuum the current situation with construction/vacuum engineers is very tide. The planning is without any spare time and the experience shows that the time required for fulfilling a task is nearly always increasing when the detailed side conditions get clearer during the detailed technical design. Even without taking this into account Mr. Tönse (who got an offer for extending his current contract until the end of 2005) is booked to 50% already for the year 2006. **This shows that there is a need for one additional construction engineer on top of the current planning in 2006. The financing of this person is still open.** In addition, because of the tight planning used, there is the danger of slippage of milestones due to missing hardware components to be installed at PITZ. That is why, the diagnostics elements are mentioned in the critical path discussed in Section 4.
In addition, also the capacity of the mechanical workshop has to be increased compared to the current situation. On average we up to now had about 2.5 to 3 persons from the mechanical workshop working permanently for PITZ. **For the years 2005 and 2006 we need on average about 3.5 to 4 persons from the mechanical workshop working permanently for PITZ.**
3) **For the work package controls the employees finishing their contracts during the project period have to be replaced.**
4) **The financing of the AGW Bagrat Petrosyan who was paid from the EU-I3 money in 2004 is not ensured for the years 2005 and 2006. This money must come from the Zeuthen household.**

As obvious from the statements above the financing situation on personnel costs is much worse in comparison to the investment costs after we obtained the HGF Ausbauinvestitionen. Therefore, it will be tried to shift part of the budget (e.g. 100 k€) from the EUROFEL proposal from hardware to manpower. Whether this try will be successful can not yet be stated but should get clear towards the beginning of December 2004.
For calculating the overall personnel costs of the project an unified average cost rate of 30 €/h is assumed for all employees. With this assumption the overall personnel costs for the full project duration is 6.4 M€.

6. Risk Analysis

The biggest risk is to not fund the PITZ2 effort as requested because this clearly will lead to a delay in the development and optimization of minimum emittance electron sources for the VUV-FEL and the European XFEL. Such a delay will lead to reduced performance of both facilities and finally can also prevent the operation of the XFEL as it is discussed right now (e.g. high accelerating gradients at the gun and high repetition rates with emittances of 0.9 π mm mrad from the injector).
Since the time planning on the physical design, technical design and construction of mechanical components for PITZ 2 is very tide and does not include any spare time there is a significant risk

that the delivery of e.g. diagnostics elements is delayed if unforeseen detailed problems arise during the physical and technical design phase. To try to prevent this the physicists and engineers need to stay in close contact on the technical development and have to report to the project coordinator and project leader on a regular, short time scale. In addition, it is indispensable that the physicist and engineers manpower listed above is available for the project.
As we have seen in the past, there is also the risk that the number of well qualified physicists ready to take a position at Zeuthen is not sufficient compared to our requests. If this turns out from the currently running job announcement, we have to continue with another job announcement and a delay of some parts of the project probably can not be prevented.
If it turns out that for an operation of the rf gun cavity at an accelerating gradient of 60 MV/m major problems arise, we will react on this. The kind of reaction will depend of the kind of problem showing up. If for example, the lifetime of the photo cathodes will get too short, the cathode development will be strengthened on e.g. cathode surface protection layers. Or if it turns out that the dark current form the gun body is too high, the cavity fabrication technique and cavity geometry have to be re-considered. During the duration of this PITZ2 project it will get clear if these kind of developments are necessary and if yes, this work will be started.

7. References

[1] F. Stephan et al. "First Measurements at the Photo Injector Test Facility at DESY Zeuthen", Proc. EPAC 2002, Paris, June 2002.

[2] J. Bähr et al. "First Beam Measurements at the Photo Injector Test Facility at DESY Zeuthen", Proc. FEL 2002, Chicago, September 2002.

[3] M. Krasilnikov et al. "Experimental Characterization of the Electron Source at the Photo Injector Test Facility at DESY Zeuthen", Proc. PAC 2003, Portland, June 2003.

[4] M. Krasilnikov et al. "Characterization of the Electron Source at the Photo Injector Test Facility at DESY Zeuthen", Proc. FEL 2003, Tsukuba, Japan.

[5] M. Ferrario et al. "HOMODYN study for the LCLS rf photo-injector", NLNF-00/004(P) and SLAC-PUB 9400, Contribution to the 2nd ICFA Advanced Accelerator Workshop, Los Angeles, November 1999.

[6] M. Ferrario, K. Flöttmann, B. Grigoryan, T. Limberg, Ph. Piot, "Conceptual Design of the TESLA XFEL Photo Injector", TESLA-FEL 2001-3. See also references mentioned in this paper for a path to the underlaying theory.

[7] L. Serafini "New perspectives and programs in Italy for advanced applications of high brightness beams", ICFA AABD Workshop, Chia Laguna, Sardenia, July 2002.

[8] X.K. Maruyama et al., NIM A272 (1988) 237.