Alessandro Dallocchio 13-03-2008

LHC Collimation PHASE II
3^{rd} Design Meeting - 28/02/2008

Present: Noel Hilleret, Gonzalo Arnau Izquierdo, Wihelmus Vollenberg, Arnaud Pierre Bouzoud, Oliver Aberle, Gilles Favre, Paolo Chiggiato, Roger Perret, Alessandro Bertarelli (chairman), Alessandro Dallocchio (scientific secretary).

1. Follow up of design solutions (A. Bouzoud)

Bouzoud showed the preliminary design solution based on the idea of a jaw coupled with a rigid support beam ensuring high geometrical stability.
As shown in Figure 1 and Figure 2 cooling system is brazed on the jaw that is simply supported at the extremities and is free to expand.
The c-shaped beam is simply supported on the shafts independently from the jaw.
Jaw and support beam are connected in the middle via a control system that compensate potential deflection of the jaw.

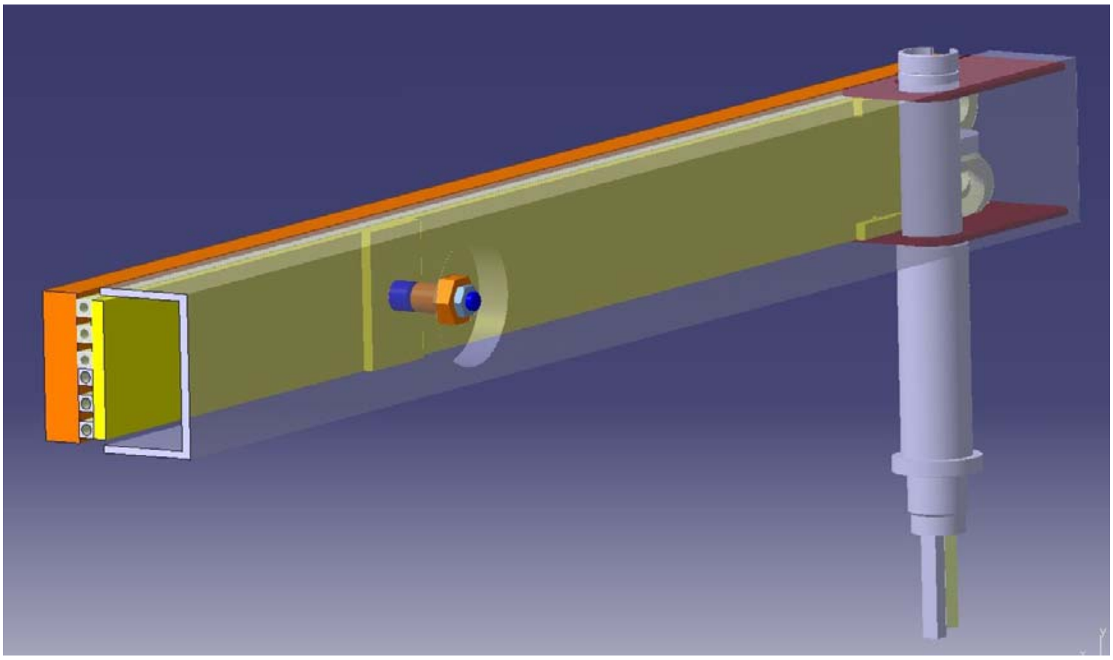

Figure 1: Cutaway of the jaw assembly. Collimation jaw is the component in orange on which the cooling pipes are brazed; yellow plate is brazed and allows the connection at the extremities with the support shafts. Grey component is the rigid c-shaped support beam linked to the jaw via a control system placed in the middle useful to compensate jaw deflection and to maximize its flatness.

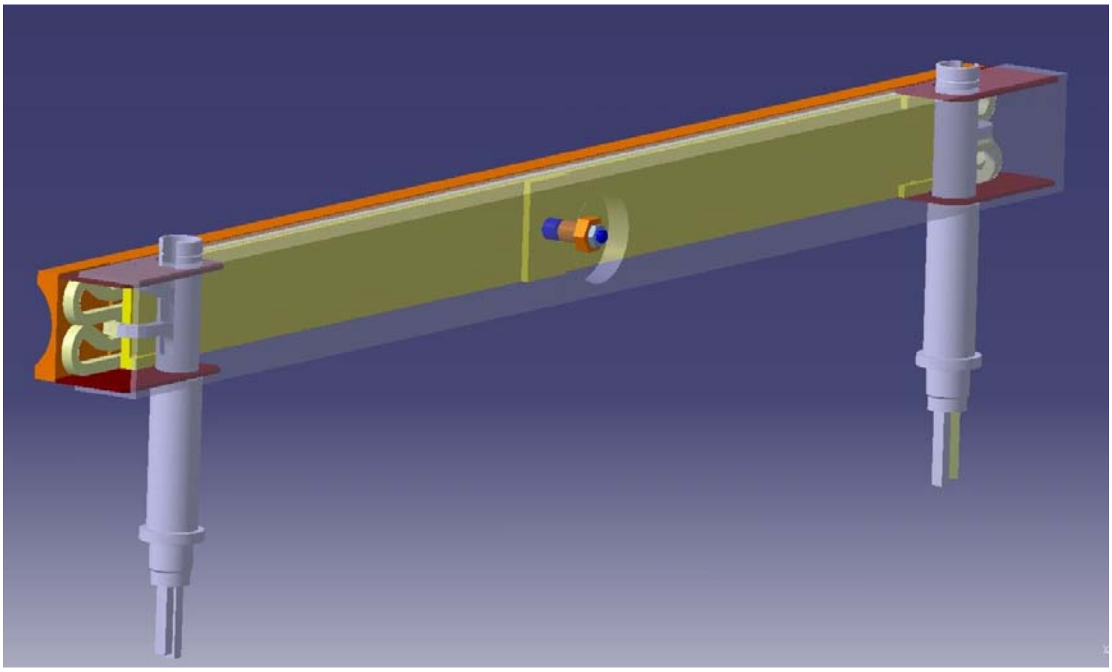

Figure 2: 3D view of the jaw assembly.

2. Discussion on the possibility of having welded or brazed connections inside vacuum tank

Bertarelli explained the necessity of having a more efficient design of the cooling system:

- Design principle based on *jaw + rigid support beam* can work correctly only if the rigid support beam is thermally stabilized; thus, it is clear the importance of having a cooling system also on this component.
- Phase II collimation probably requires the use of high density materials for the collimation jaw in order to increase cleaning efficiency. Therefore, heat load deposited on collimators will be higher proportionally to the jaw density (as a rough estimation).
- Experience acquired with collimation phase I shows that the solution of cooling pipes brazed on the collimation jaws creates lots of problems: given that it is really difficult to obtain pipes with flat external surfaces, thus the brazing will be of low quality.

On the strength of these considerations *Bertarelli* focused on the potential advantages given by the opportunity of having welded or brazed connections inside vacuum tank. This could lead to a more efficient and powerful cooling system for the jaw as well as for rigid support beam (cooling pipes can be machined directly on a solid component). Furthermore, an efficient cooling system limits the maximum temperature with clear advantages both in terms of degassing problem as well as for the geometrical stability.
Hilleret asked about temperature gradients on collimators; *Bertarelli* explained that it is not possible to have this information at this stage of the project, however in case of Phase I collimators, maximum temperature gradients was found on the jaw (about 40°C) while a $\Delta T \sim 2°C$ was detected between water and internal surface of cooling pipes.

Hilleret said that in principle it is possible to have welded and brazed connection inside vacuum: only brazing under vacuum and electron beam welding are allowed, all other types of connection are forbidden. *Hilleret* explained that detailed technical motivations are necessary in order that connections inside vacuum could be definitively accepted.
Moreover, given the potential risk of vacuum leaks introduced by the use of welded or brazed connections, great attention must be paid to safety aspects (thickness of cooling pipes, corrosion, speed of water…) and appropriate inspections must be foreseen on the connections (radiography…). A vacuum pressure of 10^{-8}torr is required close to the magnets (this indicative value must be verified).
Hilleret remarked that double wall solution is not strictly required at the moment.
An issue was raised: if pipe connections will be placed near to the support shafts at jaw extremities, stresses due to thermal deformation must be carefully checked.

3. Jaw material

Discussion leaded to this consideration: at this stage of the project it is necessary to keep on two different solutions: metallic materials like Cu-Diamond composites (high electrical conductivity) as well as ceramic materials (low electrical conductivity). A definitive choice will be taken on the base of RF impedance requirements.

4. Outcomes from material R&D brainstorming discussion – 21/02/2008

Presents: A. Dallocchio, A. Bertarelli, G. A. Izquierdo, S. Heikkinen, F. Cerutti, G. Favre, A. Bouzoud, Peter Sievers.

Cerutti presented the results of energy deposition on a multi-layer jaw. A 95cm long jaw was simulated considering a particle beam with Gaussian tail distribution during normal working condition (no direct beam impact).
Three materials were taken into account (Be, Ti, Fe) in order to have “light”, “medium” and “heavy” materials with respect to density, radiation length and interaction length. Given a fixed length for each material (Be 40cm, Ti 25cm, Fe 30cm) the aim of this study is to minimize the peak of energy deposition (ideal situation would be a longitudinally constant absorption of energy). Different configurations were simulated (from 3 to 13 layers).
Remarks:

- Number of lost protons is only related to the total length of each material regardless of different multi-layer configurations.
- Peak of energy deposition can be reduced (4-layers solution gives 20% of reduction of peak dose).

More details can be found on Cerutti’s presentation.

Bertarelli proposed a new solution for the design of collimation jaw. As shown in Figure 3, a series of grooves have been machined on the jaws; in this way a 360° cleaning can be performed by one collimator with potential advantage in terms of collimation efficiency. Moreover, in case of accident, jaw can be vertically moved in order to present a "fresh" undamaged groove to the beam.
This solution has some problems:

- no vertical degree of freedom
- alignment could be really difficult

However, this idea will be presented at next specification meeting and a tracking simulation will be required in order to verify if the cleaning efficiency could be increased by this solution.

Final discussion leads to the following conclusion: design of Phase II collimators must give priority to the cleaning efficiency and to RF impedance requirements in order to achieve the main target of this project: LHC nominal performances. Upon this consideration, the robustness of collimators in case of abnormal beam losses can be considered, at this stage of the project, of minor importance.

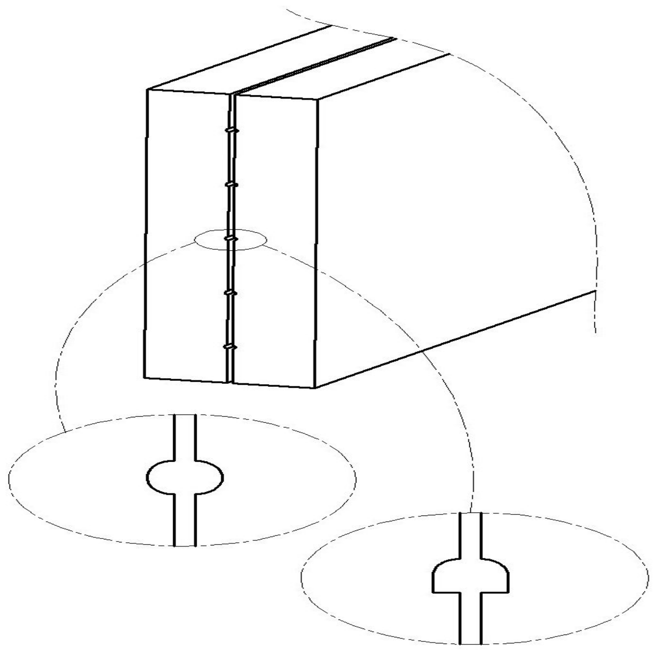

Figure 3: Scheme of "360° collimation jaws".

5. Outcomes from material R&D brainstorming discussion – 06/03/2008

Presents: A. Dallocchio, A. Bertarelli, G. A. Izquierdo, S. Heikkinen, R. Perret, W. Vollenberg, A. Bouzoud, I. Wevers.

Bouzoud showed the new design solution for the cooling system based on the possibility of having welded or brazed connections inside vacuum tank. Cooling pipes have been directly machined on the jaw thus obtaining 8 pipes instead of the 6 pipes of previous solution with an increasing of the cooling surface (see Figure 5 and Figure 1). The circuit is watertight thanks to a back plate micro-brazed under vacuum on the jaw (see Figure 6). Wide brazing surface should avoid any problem of leakage. Circular pipes can be now used.
Perret proposed to change the dimension of cooling pipes: from 6 x 5 to 5 x 9 → from 8 pipes to 6 larger pipes in order to increase the cooling surface (5*mm* is the pipe dimension in the Y-direction while 9*mm* is the pipe dimension in the X-direction, see Figure 6). *Perret* proposed to increase also the dimension of the circular pipes in order to increase the water flow: from 6*mm* of internal diameter to 8*mm* (2*mm* is the thickness of the pipe).
Bertarelli remarked that distance between jaw surface and walls of cooling pipes is 26*mm*, this distance could be probably reduced having a thinner jaw (this point will be verified once energy deposition maps will be available).

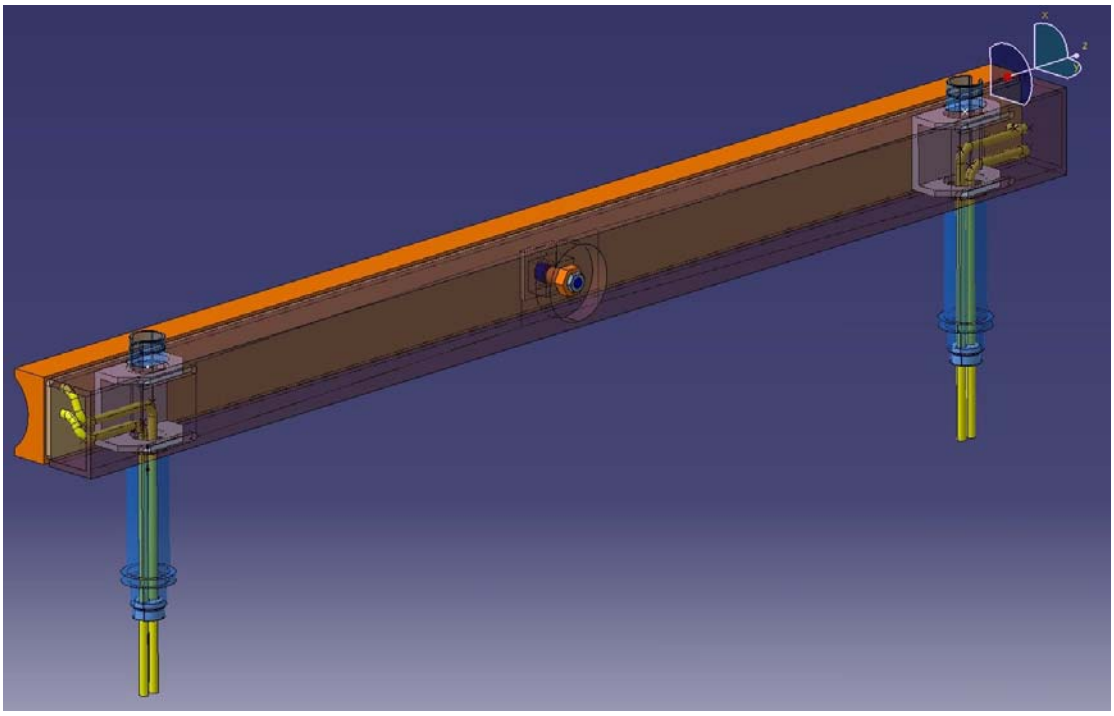

Figure 4: 3D view of the jaw assembly with new design of cooling system that has been machined directly on the jaw; pipes have circular cross-section.

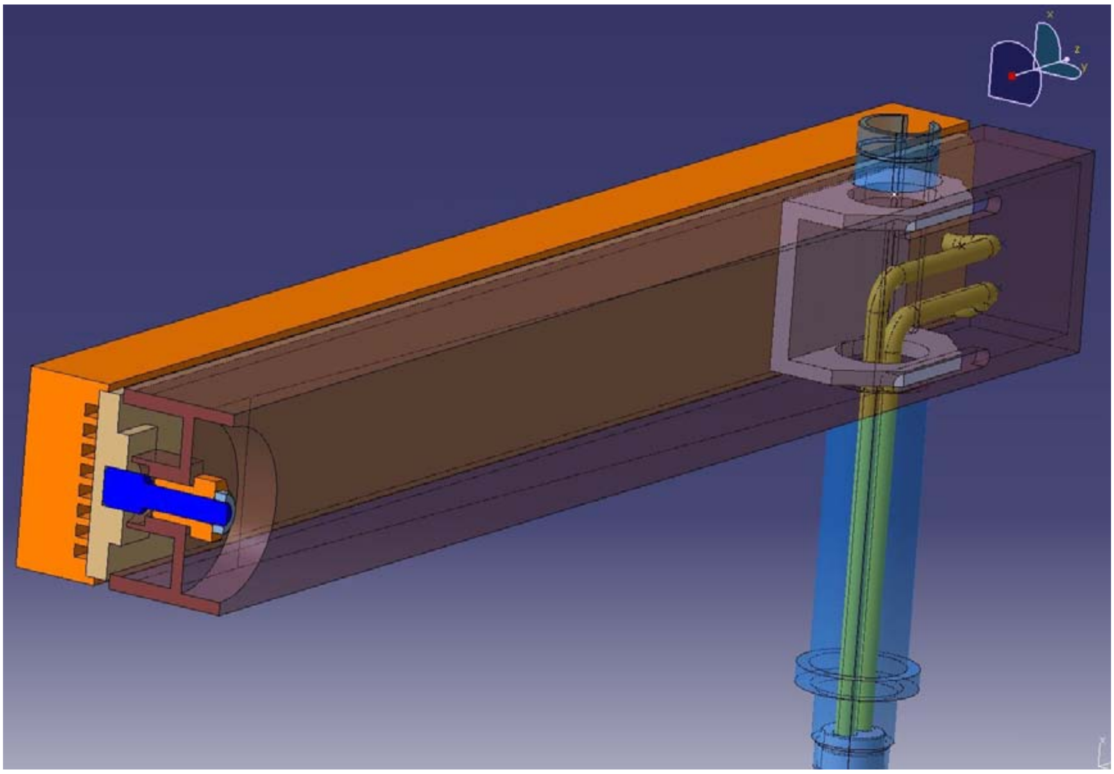

Figure 5: Cutaway of the jaw assembly. Cooling circuit has been machined on the jaw with a brazed back-plate ensuring that the system is watertight.

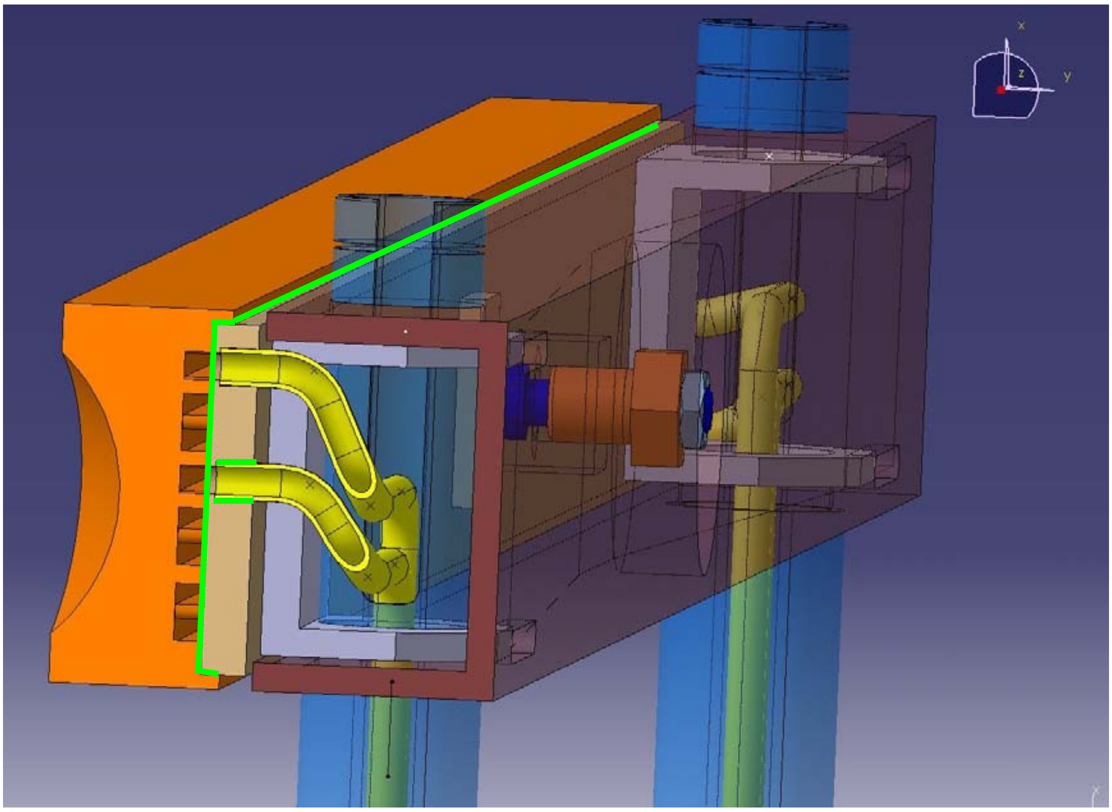

Figure 6: 3D view of the jaw assembly. Brazed surfaces are highlighted.

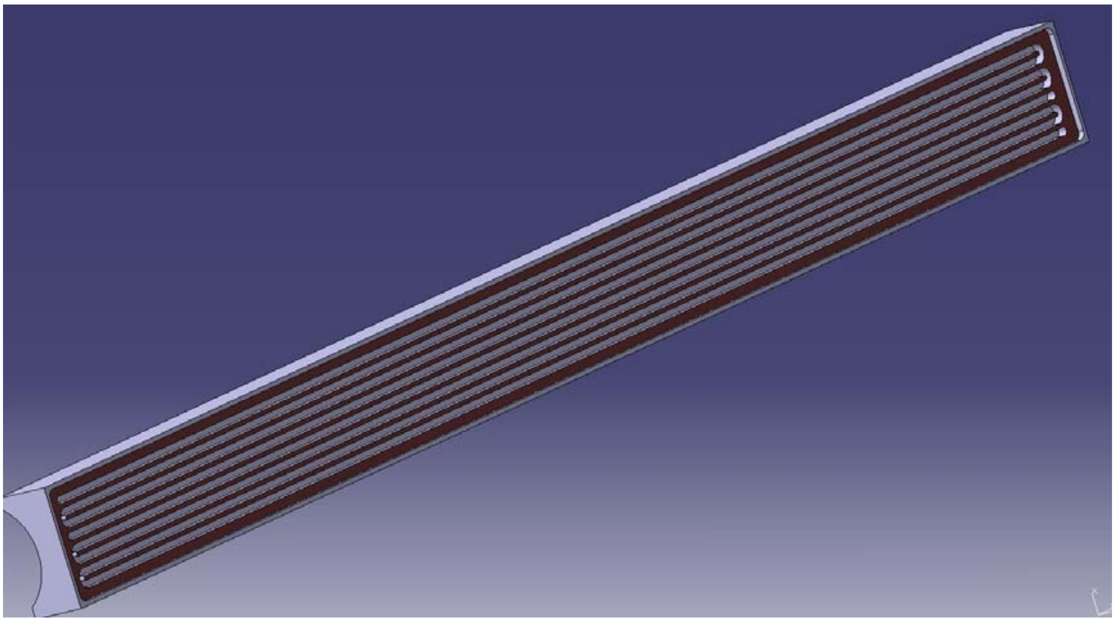

Figure 7: Cooling circuit is directly machined on the jaw. The brown surface can be used for the brazing.

According to the design principle of a RIGID support beam that should stabilize the jaw, three materials have been proposed for the c-shaped beam: Mo, Ti, Invar (low coefficients of thermal expansion and high mechanical properties). Molybdenum seems to be the most promising (high modulus of stabilization EK/α).
Bertarelli asked if it is possible to have a thick coating of copper on the c-shaped beam in order to increase its thermal stabilization; *Vollenberg* said that it is possible but this aspect should be verified in detail.
A discussion started about the design of the cooling circuit for the c-shaped beam.
Dallocchio proposed to increase the inertia of the c-shaped beam that must have a higher stiffness with respect to the jaw; moreover, if the beam is thick enough, cooling pipes can be directly machined on the component.
Perret proposed a different solution: separate cooling circuit clamped on the c-shaped beam; this should leave more possibility on the choice of the material regardless of coefficient of thermal expansion and without any brazing.
Dallocchio raised an issue: how to implement the idea of a multi-layer jaw.
The proposed solution foresees a “jaw base” on which plates made up of several materials can be brazed according to the energy deposition studies (multi-layer solution) see Figure 8.
GLIDCOP has been firstly proposed as a material for the “jaw base” but this can create problems because of the big difference between CTE of Cu-diamond and GLIDCOP.
Bertarelli proposed to use Molybdenum for the “jaw base”, given its high thermal stability and its low CTE. This solution creates a problem: stiffness of the “jaw base” could become too high thus contrasting the action of the c-shaped beam.
Perret proposed a solution for this problem: cooling circuit on the “jaw base” can be divided into two separated circuits closed by two back-plates thus leaving a free region in the middle of the “jaw base”. This central region can be opportunely weakened in order to reduce the “jaw base” stiffness. The aim is to obtain a jaw with low stiffness coupled with a very rigid c-shaped beam that gives geometrical stability to the system. Figure 8 shows a scheme of the proposed solution.

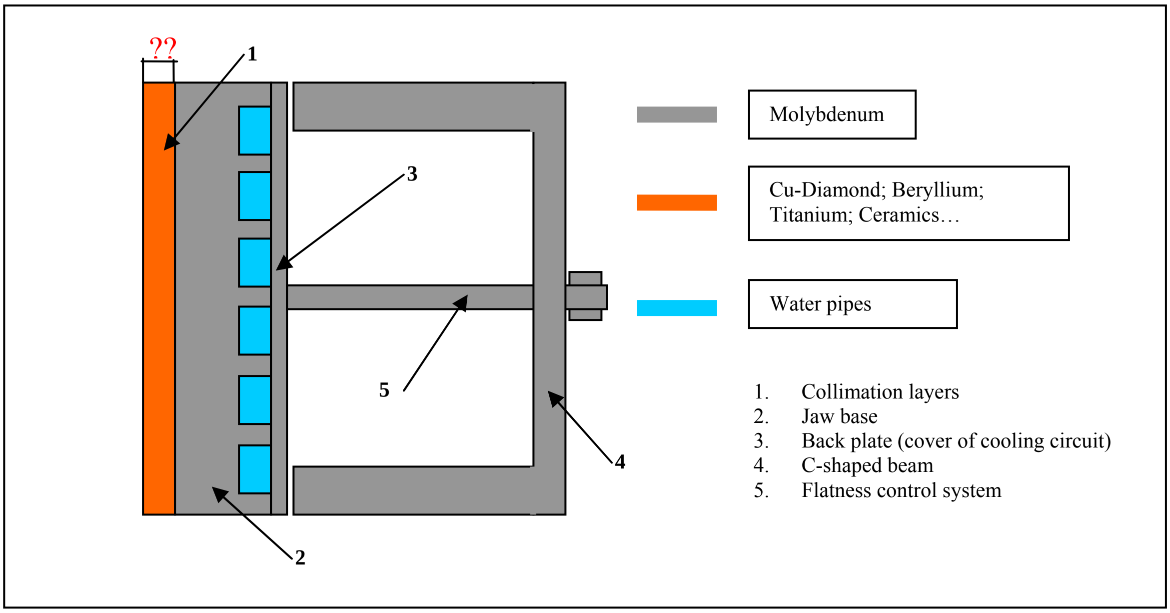

Figure 8: Scheme of the proposed solution.

6. Action list

- Follow up of design solution.
  (A. Bouzoud)

- Preparation of a list with specification requirements on Cu-Diamond composite to be given to Ludger Weber (EPFL) in order to start a more detailed study on this potential material for collimator jaw.
  (G. Izquierdo)

- Verify potential problems relative to machining and brazing of Molybdenum
  (G. Favre)

Next Phase II Design meeting will be on March 14th, 2008.
Room 376-1-016

Next brainstorming discussion on materials will be on March 19th, 2008.
Room 376-1-016