



## **Final Report for the LAL Pulsed Laser Injected Cavity Experiment (PLIC)**

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### **Abstract**

The main deliverables of the original HEPOL task within the Diagnostics (DIAG) work package are described and references to key references are provided. The main sub-tasks include: a high-finesse stable two-mirror cavity in pulsed regime, laser-beam waist reduction using a non-planar four-mirror cavity, and polarimetry studies. The task evolved within the period into the “pulsed laser injected cavity” (PLIC) programme.

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## 1 High Finesse Stable Two-mirror Cavity in Pulsed Regime

Year 2005 was devoted to the choice and ordering of the electronics, laser and optics equipments. The mechanical design of the two-mirror confocal cavity was also finished in 2005. The full system consisting of Ti:sapphire pulsed laser beam of 1ps pulse width and 76 MHz repetition rate, a Fabry-Perot cavity of Finesse  $\sim 3000$  and an electronic feedback (Pound-Drever-Hall method) was set up in 2006. The cavity of finesse 3000 was locked during summer 2007. From end 2007 to march 2008, we were delayed by asbestos problems in the hall where our optical room was located. We had to move to another building and build a new clean room. Our experimental setup was remounted at the beginning of March 2008.

During September 2008 we locked our pulsed laser beam to a Fabry-Perot cavity of Finesse 30000. This is, to our knowledge, the highest finesse ever achieved in laser pulsed regime. It was possible to reach such high finesse because of:

- High mechanical stability and flexibility provided by our optical mounting systems which had been designed and built in our Laboratory Workshop.
- Very low noise levels of the analogue electronic devices designed and realized within our group.
- High flexibility and high precision of the digital feedback that had been designed and operated within our group.
- Expertise acquired within our group in mode-locked laser dynamics.

The achievement of this experimental result is our main EUROTEV deliverable because it demonstrates the capability of passive Fabry-Perot optical resonators to stack laser pulses with a power enhancement factor of 10000. Our group is presently optimising the locking stability and preparing a final publication on this topic.

## 2 Laser Beam Waist Reduction: Non-Planar four-mirror cavity

An extensive numerical study of the stability and eigen mode polarisation of four-mirror cavities was carried out during the period 2005-2006. From this study it became apparent that a tetrahedron non-planar configuration was the optimal choice for laser electron Compton scattering at ILC.

An experimental study of four-mirror bow-tie cavities had been carried out already in 2007 in order to provide a very small laser waist inside the cavity. Two geometrical configurations were compared: planar (2D) and non-planar (3D).

Although we were able to verify successfully the mode characteristics and the theoretical model used to describe the non-standard 3D resonator, we observed some optical aberrations when the cavity geometry was pushed toward the instability limit (i.e. very small mode waist limit). In order to investigate these aberrations, we rebuilt a new 3D cavity using 2 inch mirror diameters (instead of standard 1 inch mirrors that we used before). We confirm the observation of aberrations in the very divergent limit: the fundamental mode is elliptic (more precisely generalised astigmatism) with an S shape in the plane transverse to the propagation axis. A publication is foreseen to report our experimental results.

This phenomenon may have some effects on the geometrical factor of the laser-electron Compton luminosity. We therefore started a challenging model study in order to quantify this effect.

### 3 Polarimetry Studies

During the years 2007-2008, a member of our group, Marie Jacquet, has performed a detailed experimental study of the systematic uncertainty on the HERA electron beam measurement related to the laser polarisation uncertainty. She used the experimental data recorded by the cavity polarimeter of HERA and she demonstrated that a few per thousand level of systematic uncertainty on the measurement of the electron beam polarisation can be reached already with a Fabry-Perot cavity. She indicates a few improvements which would allow to reach the per thousand level of accuracy. Her work has been submitted as a EUROTEV note.

### 4 Conclusion

We have been able to demonstrate for the first time that a picosecond laser oscillator can be used to fill a high finesse Fabry-Perot cavity. We have also built for the first time a non-planar four-mirror cavity and we demonstrated experimentally the advantages of this geometry for laser Compton scattering applications.

New funding from the French ANR agency has been obtained to pursue our R&D activity in 2009-2011. Our new goal is to build a 3D high finesse four-mirror cavity and to install it at the ATF (Accelerator Test Facility) of the KEK laboratory in order to produce the highest gamma ray flux ever achieved. Within this context, a design study of the implementation of a non-planar four-mirror cavity at ATF is being carried out.

Our expertise acquired within EUROTEV has led us to contribute to new projects in the context of compact monochromatic X-ray sources for medical and cultural applications. Collaboration with Le Louvre museum and with the cancer centre IGS has already started.

### Acknowledgement

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### References

Our work has been reported at various occasions. We just mention the 2008 communications here:

- 1 *Activités expérimentales autour des cavités Fabry-Perot au LAL*, LAL-SOLEIL seminars, Orsay mars 2008.
- 2 *FINALI Al*.
- 3 *Polarisation effects in four-mirror cavities*, Workshop POSIPOL08, Hiroshima, 16-19 juin 2008.
- 4 *Status of the LAL R&D on cavity locking in pulsed regime*, Workshop POSIPOL08, Hiroshima, 16-19 juin 2008.
- 5 *4 mirror(s) high finesse optical cavity to produce high gamma ray flux at ATF.*, 2<sup>nd</sup> FJPPL Workshop Paris 15 may 2008
- 6 *Fabry-Perot cavity R&D at Orsay*, Workshop on Compton X/g rays: Physics and Applications , Alghero (Porto Conte) Italy, 7-12 septembre 2008

- 7 *Fabry-Perot cavity in pulsed regime & Polarimetry*, EUROTEV Scientific workshop, Upsala 26-28 August 2008.
- 8 *Cavités en modes pulsés*, FEMTO2008, French thematic school « Optique et phénomènes ultra-rapides », septembre 2008 Mittelwihr (Haut-Rhin) France.
- 9 A. Variola, *Fabry-Perot cavity R&D at Orsay*, CLIC08 Workshop, CERN 14-17 October 2008.
- 10 F. Zomer, *Les cavités laser pour une source Compton inverse*, AGLAE2 steering comity meeting, C2RMF Le Louvre, Paris 2009.

**One article has been published**

F. Zomer, V. Soskov and A. Variola, *On the nonparaxial modes of two-dimensional nearly concentric resonators*, **Appl. Opt.** 46 (2007) 6159-6866

**We also contributed to:**

G. Moortgat et al., *The role of polarized positrons and electrons in revealing fundamental interactions at the Linear Collider*, **Phys. Rep.** 460 (2008) 131

**One Eutotev note has been submitted**

M. Jacquet, *Laser beam polarisation measurement at the per mille in an accelerator environment*,

**One Physics preprint**

S. Araki et al., *Conceptual proposal of a polarised positron source based on laser Compton scattering*, (2005) **physics/0509016**.

**A monographie in French**

R. Chiche et al., *Les cavités Fabry-Perot en mode pulsé et leurs récentes applications*, monographie to appear in Femto 2008 : Optique et phénomènes ultra-rapides, Publications de l'Université de Saint-Étienne

**Two out reach communications have been published :**

An ILC news: [http://www.linearcollider.org/newsline/readmore\\_20070719\\_ftr1.html](http://www.linearcollider.org/newsline/readmore_20070719_ftr1.html)

A "success story": *LAL towards record power amplification* in the Lyrtech Compagny web site: <http://www.lyrtech.com/>

**An article has also been submitted to Applied Optics:**

F. Zomer, N. Pavloff, V. Soskov, A. Variola and Y. Fedala, *Polarization induced instabilities in external four-mirror Fabry-Perot cavities*.

Two proceedings have been written and two experimental articles are foreseen in the course of 2009.