Marie-Curie Workshop 2014

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"A few tips" for the writing of IEF Marie Curie proposal

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Outline

- General advises about the form
- General advises about the content
- A few tips, section per section…

General advises about the form

- Make it easily understandable to a non-specialist (scientist from an other field) => *use buzzwords, repeat them all along the proposal, put special attention on introduction/conclusion*
- Make it easily readable for your referee => !!*strictly follow the template!!, use bullet points, put buzzwords in bold/italic and repeat them*
- Be positive and enthusiastic => *don't hesitate to blah-blah*
- *Make your proposal look nice => put figures, colors, start page, nice acronym…*

General advises about the content

- Try to show that you are the right person to carry out the project (experience, CV, and so on…) and that the host institute is the best place for that (leading lab in the field, recognized researchers, timeliness and relevance of the project)
- Ask your host institute for information (excellence in the research field, number of publications/patents, transfer of technology, contact with industrial sector, spin-off)
- If you have the chance to have EU advisors in your lab, ask for their help (the more the better ;))

Useful tips, section per section

<u>*Last year*</u>

- Science and Technology quality (0,25)
- Training (0,15)
- Researcher (0,25)
- Implementation (0,15)
- Impact (0,2)

38 pages

→

<u>*This year*</u>

- Excellence
- Impact
- Implementation
- Researcher (CV)

Only 16 pages…

2. Excellence

2.1 ***Quality, innovative aspects and credibility of the research*** *(including inter/multidisciplinary aspects)*

You should develop your proposal according to the following lines:

- Introduction, state-of-the-art, objectives and overview of the action
- Research methodology and approach: highlight the type of research and innovation activities proposed
- Originality and innovative aspects of the research programme: explain the … expected to make to advancements within … ovel concepts, approaches or methods that

What are the stakes and challenges of your research field ?
Describe the context … field

What people do at the moment to answer these challenges?
Describe the state … and the current li…

What are your research objectives?
Bullet points with 3 or 4 objectives
!!don't explain yet how to reach them!!

2. Excellence

B1 Research and technological quality

B1-1 Research and technological quality

Stakes and challenges of attosecond science

Exploring and understanding the ultrafast behavior of matter remains a permanent *multidisciplinary challenge in many scientific fields such as physics, chemistry and biology*. In order to observe extremely brief phenomena such as molecular bonds formation, ultrafast processes in photosynthesis or electronic bond hardening in transition metals, it is necessary to develop measurement devices with ever increasing time resolution.
Attosecond science is currently lifting the veil on *the most transient processes ever observed*. Over the last decade, light burst of attosecond duration ($1\,as = 10^{-18}\,s$) has been used as ultrafast tool to observe for the first time the motion of individual electrons in atoms [1, 2], molecules [3] or solids [4]. This proposal takes place in this context and aims to contribute to *the rising of an bright attosecond light source generated by the interaction of a ultra-intense laser with a plasma mirror* [5].

Generating attosecond pulses: from gas to plasma?

The method aiming at generating attosecond light bursts is of the utmost importance. So far the most accomplished technique has consisted in inducing nonlinear interaction of an ultrashort laser pulse with a gently ionized gas of atoms or molecules [6] at moderate intensity ($I \approx 10^{14}\,W.cm^{-2}$, see Fig. 1). This process has enabled to produce XUV bursts of less than 100 as [7] and probe ultrafast electronic phenomena, such as electron tunneling in atoms [8] or electronic motion in condensed matter [4]. If attosecond pulse generation from gas medium represents today the state-of-the-art technique (particularly because it takes full advantage of the most advanced laser technologies, such as sub-cycle control of the light field waveform [1], the necessary radiative recombination at the root of the attosecond emission *prevents to exploit ultrahigh light intensity* provided by the actual largest laser facilities. Despite all the efforts the energy of the attosecond emission from gas media is therefore still limited to the μJ level [9], with efficiency around 10^{-5}.

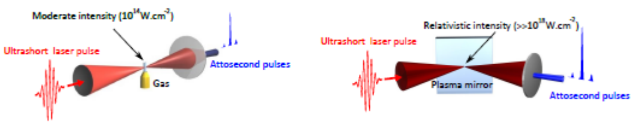

Figure 1: Attosecond pulse generation from gas media (left) or from plasma mirrors (right)

Attosecond pulse generation from plasma mirrors, which is the object of this proposal, is more and more presented as *a credible alternative for the generation process*. This mechanism consists in focusing an ultrashort laser pulse onto a solid target at relativistic intensity ($I >> 10^{18}\,W.cm^{-2}$, see Fig. 1). The huge amplitude of the laser electric field completely ionizes the target and *creates a plasma mirror which oscillates at speed of light and radiates very bright XUV pulses of attosecond duration*. This generation technique presents many advantages which could overcome the limitations of the generation in gas media [10]:

- The laser field strength can be virtually increased without any limitation, which promises an strong enhancement of the attosecond generation efficiency by many orders of magnitude: together with using laser energy at the Joule level or more, this mechanism could lead to *very energetic isolated attosecond pulses*, way above mJ level (that is more than a thousand times what can be obtained from attosecond generation in gas media).
- It appears to be possible to obtain very short isolated attosecond pulses *in a wide range of photon energy*, from 10 eV to a few keV, which would make this very versatile source perfectly adapted to many types of ultrafast dynamic measurements.

If these predictions would appear to be verified, *attosecond pulse generation from plasma mirrors would surely become the new generation source, providing attosecond light bursts with unprecedented brightness and duration.*

State of the art of plasma attosecond pulse generation and objectives of the proposal

During the last ten years, pioneer proofs of concept have been done regarding the relevance of overdense plasmas as a alternative (or a complement) to gas media for attosecond pulse generation. Among them (i) the actual attosecond duration measurement of the emission [11], which demonstrates its intrinsically phase-locked nature, and (ii) the conversion into high energy X-rays [12], reaching now the keV level.
However, if these results strengthen the relevance of this generation mechanism, there is still some way to go before having a source available for further attosecond science experiments. Indeed no one managed so far to fulfill the required interaction conditions [10, 13, 14] and to generate attosecond pulses from plasma mirrors with two-cycle CEP stable laser pulses at relativistic intensity.

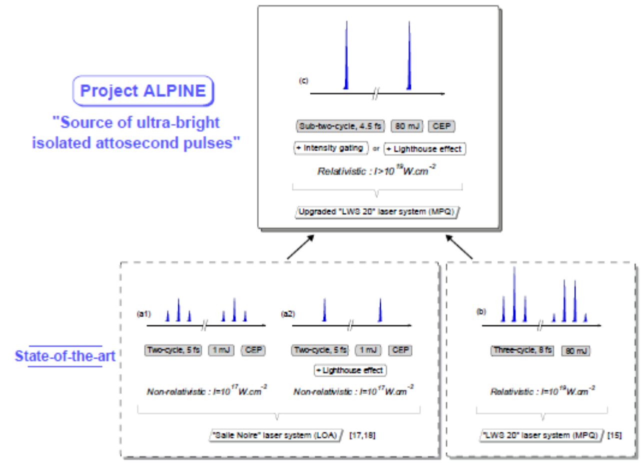

Figure 2: Project ALPINE, a source of ultra-bright isolated attosecond pulses

Aim of the project

The aim of the project ALPINE is then *to scale waveform-controlled laser-matter interaction to relativistic intensity, in order to generate isolated attosecond light pulses of unprecedented brightness*. This project will be done at the Max Planck Institut für Quantenoptik (MPQ) with the Light Wave Synthesizer 20 TW (LWS 20) laser system, which delivers sub-5 fs laser pulses with 20 TW peak power. The demonstration of this "new generation attosecond source" relies on four objectives to be achieved:

Objective 1: The generation of attosecond pulses in the relativistic regime with two-cycle laser pulses.

It is necessary to combine *relativistic intensity* on target, i.e. $I > 1.3 \times 10^{18}\,W.cm^{-2}$, together with the use of *few-cycle driving laser* pulses. Indeed relativistic intensity allows generating high energy, ultra-short duration pulses (through the so-called "relativistic oscillating mirror" mechanism) while the use of few-cycle (two or less) driving laser pulse will lead to the emission of a very low number of attosecond pulses (potentially isolated isolated pulse if laser intensity is strong enough), which is crucial for future temporally resolved experiments. Merging these two conditions is a serious challenge as well as an absolute necessity for the

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development of the new generation of attosecond sources. This idea is presented on Fig 2.
If attosecond pulse generation from plasma mirrors with respectively relativistic intensity [12, 15, 16] and two-cycle laser pulses [17] have been separately demonstrated, these two experimental conditions have never been put together. Only Heissler et al [15] from MPQ have already approached this challenging conditions, by demonstrating relativistic emission with only three-cycle laser pulses. Our goal is then to demonstrate the generation of attosecond pulses by focusing a two-cycle laser pulses onto a plasma mirror at relativistic intensity.

Objective 2: The sub-cycle control of the emission with the laser CEP
Two-cycle laser pulse has the particularity to have its intensity envelop which varies almost as fast as the electric field. The consequence is that the waveform strongly depends on the phase of the electric field with respect of the envelop: this so-called Carrier-to-Envelop Phase (CEP) has necessarily to be stabilized from one shot to the next (the CEP is random if no special care is taken), so that repeatable interaction conditions can be ensured during the experiment. Even more so controlling the CEP of the laser has a substantial effect of the properties of attosecond emission. Having two-cycle driving laser pulses with stable and controllable CEP is the key to precisely control the plasma electron trajectories and consequently the temporal structure of the attosecond emission [1, 17].
Plasma mirrors experiments driven by CEP-stabilized few-cycle laser pulse are very demanding, and I have had the chance to obtain during my PhD the first results in these experimental conditions [17, 18]. It has then been demonstrated that plasma mirror emission can be controlled with attosecond precision. However, the results have been achieved two orders of magnitude below the relativistic intensity, in a regime where the generated attosecond pulses have weak energy and low frequencies. If these proofs-of-concept have open the door to attosecond plasma control, I aim at reproducing such experiments with state-of-the-art laser systems allowing to reach the relativistic regime with the same level of temporal control of the attosecond emission. This will in particular demand a strong effort on CEP stabilization of high peak power laser systems.

Objective 3: Generation of ultra-bright isolated attosecond pulse on plasma mirrors
Having isolated attosecond pulses [7, 19] is generally much more convenient for the study of ultrafast phenomena. Unfortunately the interaction of an intense laser with a plasma mirror generally produces a bunch of attosecond pulses, one per laser cycle [11]. It is hence preferable to use few-cycle laser pulses to reduce as much as possible the number of consecutive attosecond pulses, as mentioned above. However it is usually still not enough to obtain an isolated pulse [17].
If different techniques of isolating attosecond pulses have already been demonstrated in gas media [7, 19, 20, 21], so far only one has been successfully applied on plasma mirrors, by the former research group of the applicant [18]. I managed to apply the very new "lighthouse technique" [22], which has enabled to generate a bunch of isolated attosecond pulses by rotating in time the wavefront of the laser, in order to send each attosecond pulse in different directions. During the duration of the proposal, I plan to scale the generation of isolated attosecond pulses to the unexplored relativistic regime, by testing several isolating techniques in order to find the most suitable and efficient one. I will particularly try three techniques: relativistic intensity gating [10] and lighthouse technique [18], with a backup onto polarization gating [23] if the two firsts appeared to be inefficient.

Objective 4: The access to high average power sources with attosecond stability
Having an attosecond source delivering high average power photons flux is essential for applications. Indeed high average power allows integrating signals which are generally weak, and to have access to statistics of the generally highly non-linear studied processes. This is obtained by running the laser-plasma experiment at the maximum repetition rate offered by the driving laser system, which implies a particular effort on designing the suitable solid target.
So far, most plasma mirror experiments have been performed using large scale facility delivering pulses on a single-shot basis. These laser facilities have enabled to investigate some fundamental aspects of the plasma attosecond pulse generation (see above), but will never be adapted for further applications of the attosecond source due to there lack of average power. Some smaller laser facilities have however recently managed to performed attosecond pulse generation at very high repetition rate [24] by using high velocity optically monitored solid target. My aim is to drive relativistic interaction at the full operation speed (10 Hz) of the laser system LWS 20 at MPQ, with a double perspective: (i) taking advantage of the possibility to integrate signal over numerous successive shots to get quick and clear access to the complex physics of the

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How to reach these objectives?
Keep the same bullet points with 3 or 4 objectives and get into more technical details on how to reach them

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interaction process, and (ii) preparing further application experiments requiring high repetition rate source with attosecond temporal stability (10 nm in the spatial domain).

B1-2 Appropriateness of research methodology and approach

This project will be carried out using the state-of-the-art Light Wave Synthesizer 20 TW (LWS 20) laser system. It is based on Optical Parametric Chirped-Pulse Amplification (OPCPA, two-color amplification) technology and provides two-cycle (5 fs) pulses with 100 mJ at 10 Hz repetition rate. This unique laser system is today the only capable to deliver two-cycle pulses at relativistic intensity, and hence to fully validate the relevance of very bright isolated attosecond pulse generation from plasma mirrors.
I present here how I plan to approach my research objectives (this work schedule is illustrated in a Gantt chart in B4-3):

Objective 1: The generation of attosecond pulses in the relativistic regime with two-cycle laser pulses.
This part will consist in the characterization and optimization of the generated attosecond emission, by playing onto laser and plasma parameters. The principal aimed characteristics of the attosecond emission as well as the related laser and plasma parameters are presented on Fig 3: (i) the appearance of relativistic harmonics above the plasma maximum frequency, characteristic of relativistic laser intensity (this will be feed-backed onto the focus size and position and onto pulse compression), (ii) the shape of these harmonics, especially the appearance of a continuum, generally associated to isolated pulses (I will particularly look for the influence of the laser CEP, see below), and also (iii) the conversion efficiency (according to previous theoretical and experimental studies, I will concentrate on the plasma gradient shape, which will be controlled by a light prepulse with controllable delay and intensity).

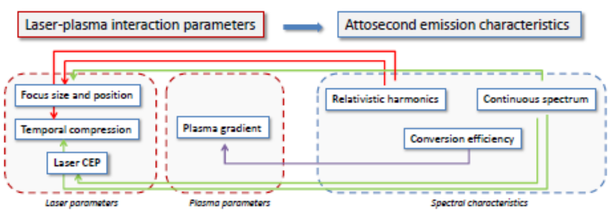

Figure 3: Attosecond emission optimization as a function of laser-plasma parameters

Objective 2: The sub-cycle control of the emission with CEP stabilization
The sub-cycle control of the emission, which is an essential feature for future applications, is ruled by the stability of the laser CEP. The CEP stabilization of LWS 20 will be implemented in two phases (see also Fig 4).

- *Phase stabilization of the laser "front-end".* The first step will be to stabilize the MHz Ti:Sapphire oscillator CEP (1). This is no strong difficulty here, and this will be implemented with the help of the oscillator supplier (Femtolaser). The second step will be to measure and stabilize the laser beam after amplification (kHz repetition rate), and preferably after the spectral enlargement provided by the hollow core fiber (2). The CEP will be measured by spectral interferometry, and the feedback loop will also be done on the oscillator laser pump.
- *Phase measurement and stabilization of the OPA stages.* After the two OPA stages, CEP drift introduced by amplification and propagation will be measured still by spectral interferometry. At that stage, it could also be possible to monitor the CEP by measuring the interference fringes between the seed amplified by the "first color amplification (a)" (phase ϕ_{CEP}) and the idler generated by the

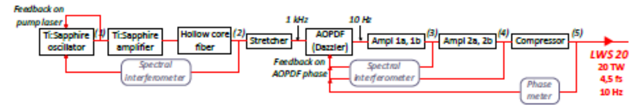

Figure 4: CEP measurement and stabilization of LWS 20

"second color amplification (b)" (phase $2\phi_{CEP}$). The slow CEP drift will then be compensated with the acousto-optic programmable dispersive filter (AOPDF) of the laser system. This will be tested after both amplification stage. Finally, the group is also currently setting-up a phase meter using asymmetries of high-energy photoelectrons along the polarization axis. These different technique will allow us to stabilize (or in the worse case to measure) the CEP during laser-plasma interaction.

Objective 3: Generation of ultra-bright isolated attosecond pulse on plasma mirrors
I will focus first on the intensity gating technique, which has never been demonstrated and is achievable with the characteristics of LWS 20. This technique simply lies on the physics of generation and requires no preliminary laser shaping. I will also explore the lighthouse technique at relativistic intensity, which will provides several isolated attosecond pulses in an ultralarge range of wavelength. Finally, in the case none of them gives sufficient results, I want to try polarization gating as a fallback position.

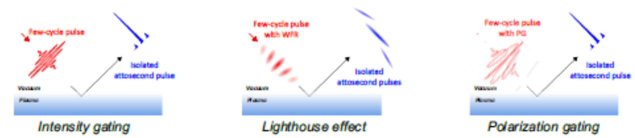

Figure 5: Different techniques for isolating attosecond pulses

- *Technique 1: Intensity gating technique (Fig 5 left).* In the relativistic regime, Particle In Cell (PIC) simulations and analytic models predict that the spectrum of each attosecond pulses depends on the amplitude of the generating laser optical pulse. It means that optical cycles with large amplitude will generate higher energy XUV photons. If the laser pulse is short enough, the attosecond pulse generated by the optical cycle with the largest amplitude contains high frequency in its spectrum. Then a proper filtering of the "low" frequencies of the train enables to isolate one attosecond pulse. Therefore this technique simply consists in focusing a two-cycle laser pulse with the highest intensity.

- *Technique 2: Attosecond lighthouse effect (Fig 5 middle).* This technique consists in a angular separation of the attosecond pulses of the train. By inducing a fast rotation in time of the laser wavefronts in the interaction zone, it introduces a slight angle between each attosecond pulses. If this angle is higher than the divergence of the XUV emission, after propagation the attosecond pulses will be separated in space. This technique has the great advantage to produce not only one isolated pulses but as many as the number of generating optical cycles. However it requires to introduce wave front rotation at focus, which can be done with a angular dispersive object (like a prism or a grating) and a focusing optic.

- *Fallback position: Polarization gating technique (Fig 5 right).* This technique relies on the dependance of the emission efficiency as a function of the laser polarization. In the relativistic regime, simulations show that linear polarization is more efficient than circular polarization by orders of magnitude. Technically, it is possible to generate a laser pulse with linear polarization over only one optical cycle, while the rest of the pulse is circularly polarized, by combining a quartz plate with a $\lambda/4$ plate.

2. Excellence

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Why are these objectives original and relevant?
Confront with the state-of-the-art

3. Impact

3. Impact

Some ideas, you could mention

- The impact of the fellowship on your career development
  - On your future career, in terms of visibility in the scientific community (creation of a research network, improvement of your oral skills via conferences and workshops, development of “project leader” skills)
- Your impact of your research activity on European society
  - Regarding the industrial sector (public/private partnership, transfer of technology, patents)
  - Through your mobility, you promote collaborations and cooperations in the European research community (be concrete, give some researcher or laboratory’s name)
  - Contribution to the European excellence and competitiveness
  - Propose some outreach activities: press articles for each striking results, etc..

4. Implementation

- Show that your research project is coherent and feasible
- Define work packages correspondingly to the research objectives that you defined in the “Excellence” paragraph
- Make a nice Gantt chart!

4. Implementation

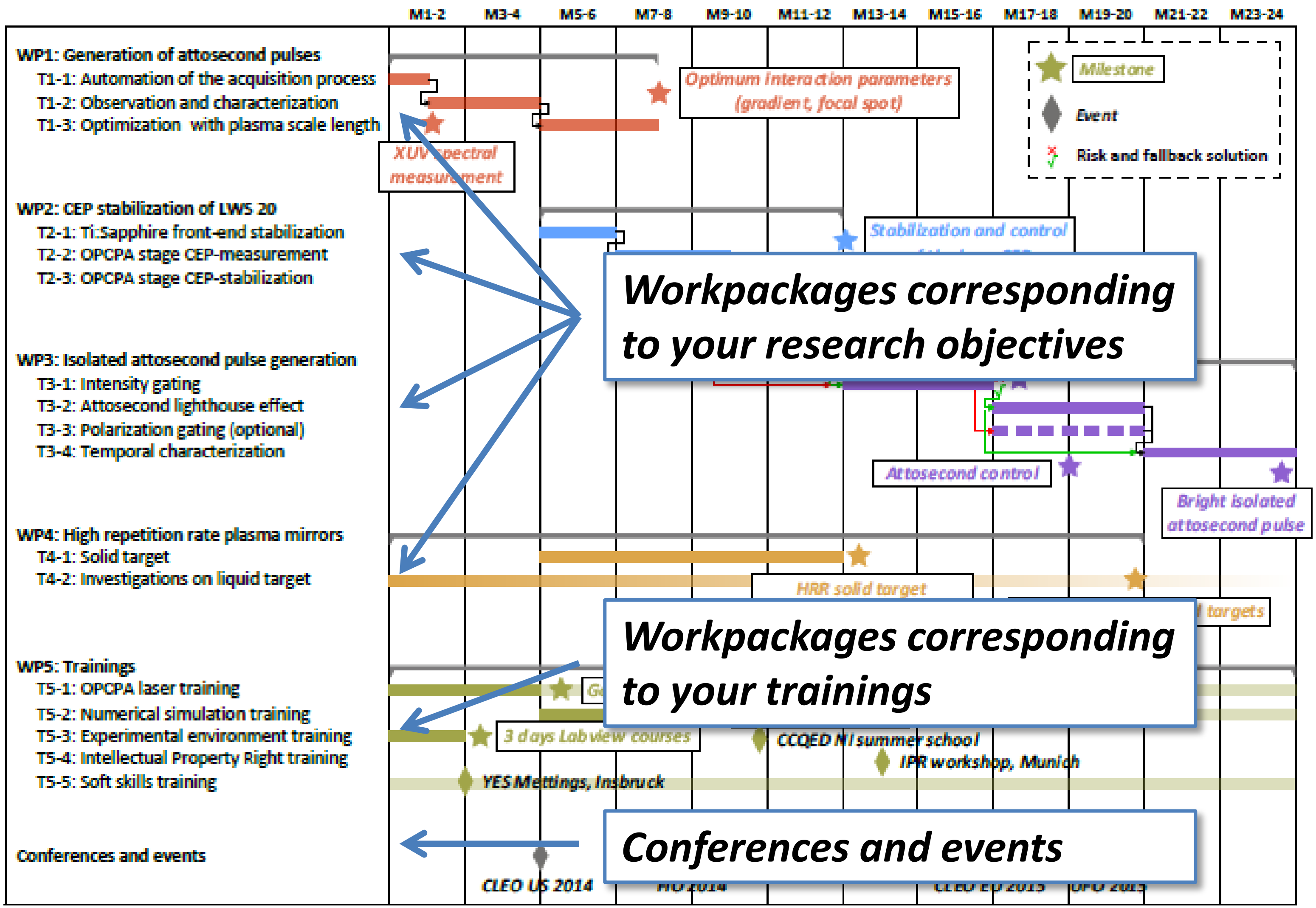
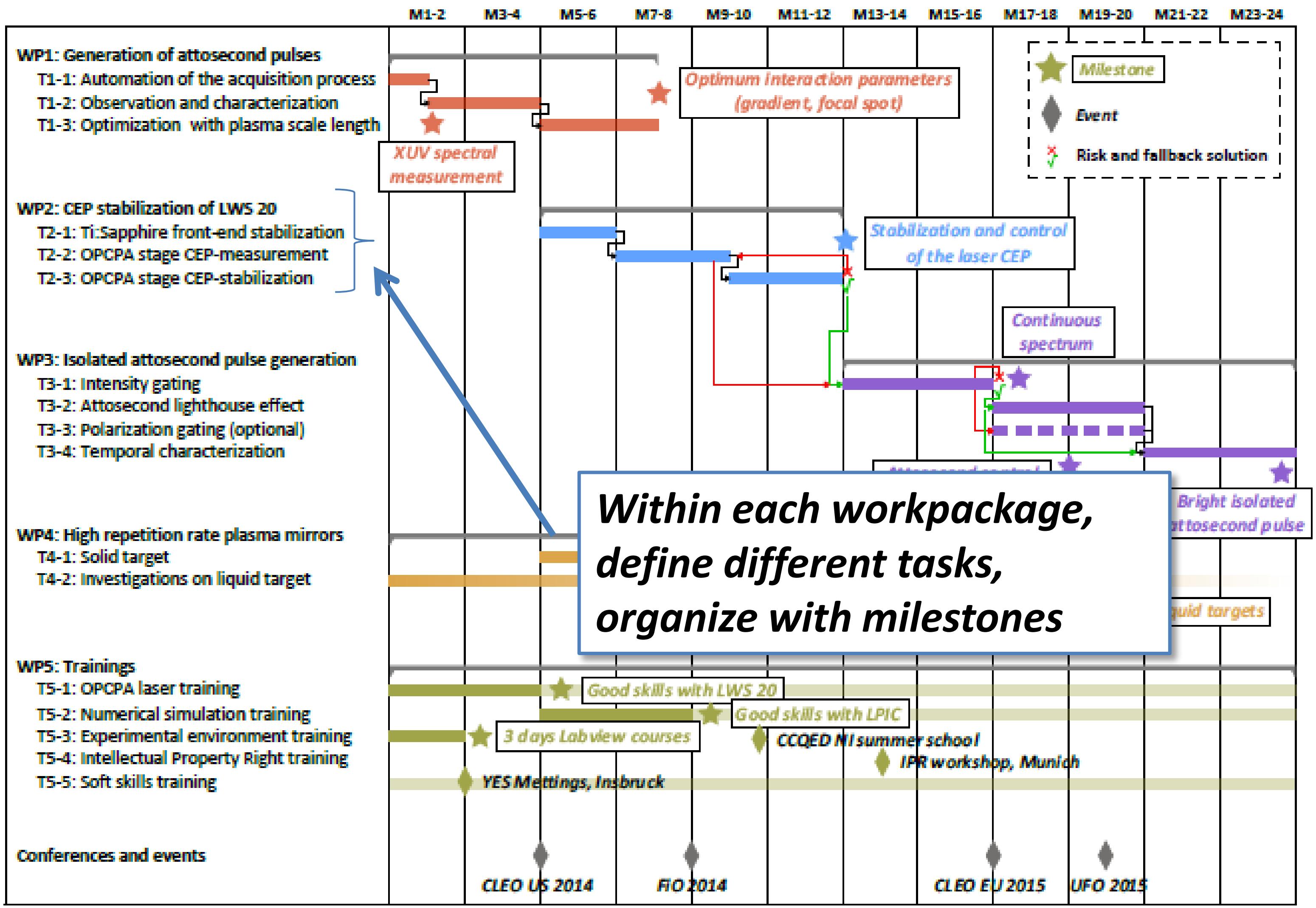


Figure 7: Gantt chart of the ALPINE project

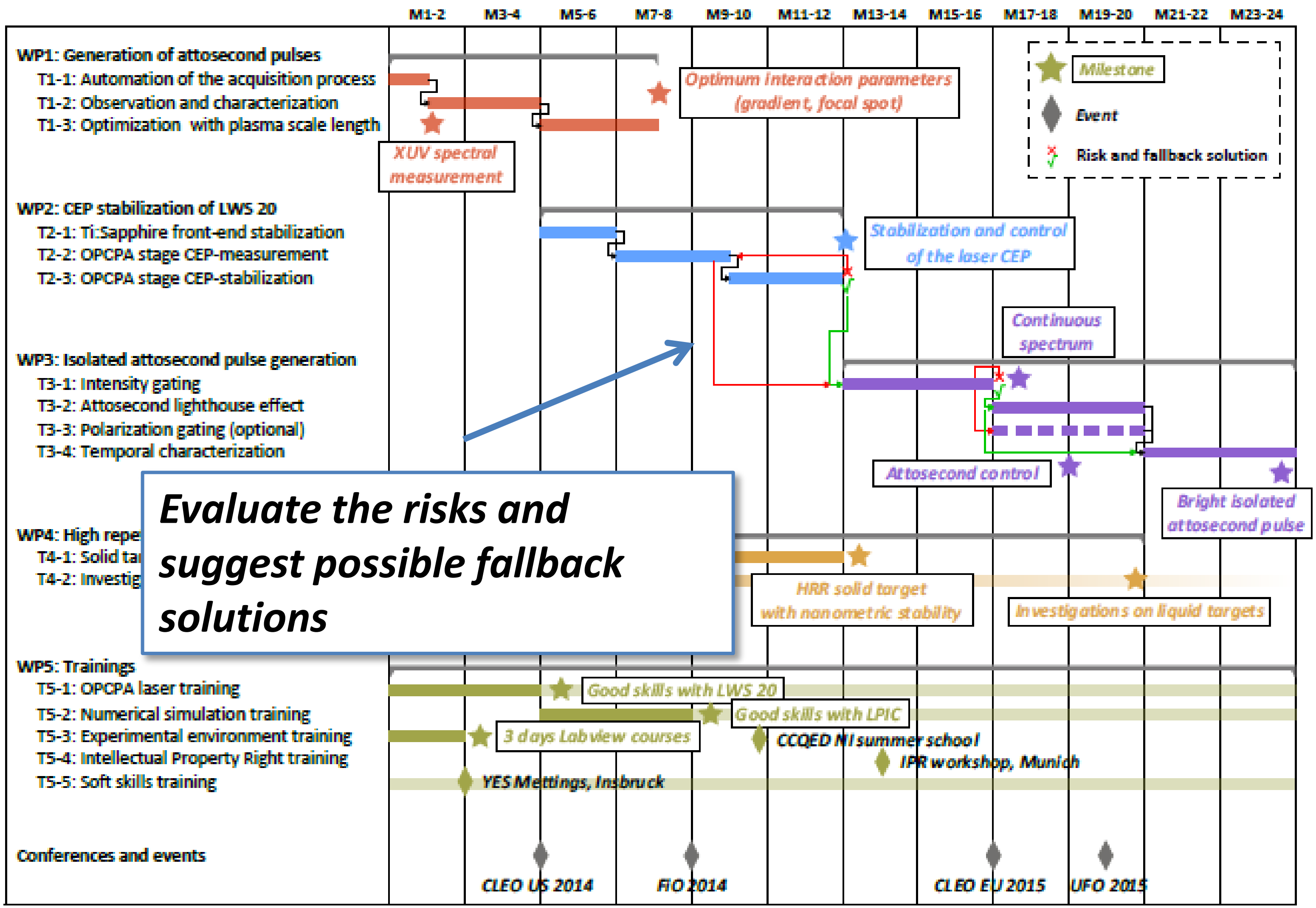
4. Implementation



Within each workpackage, define different tasks, organize with milestones

Figure 7: Gantt chart of the ALPINE project

4. Implementation



Evaluate the risks and suggest possible fallback solutions

Figure 7: Gantt chart of the ALPINE project

4. Implementation

Risk: 1/5 *Impact*: 2/5

- Task 1-3: Optimization of the signal strength with plasma scale length (3 months)

  Methodology: Plasma scale length has been theoretically and experimentally pointed out as having a strong influence on the attosecond emission efficiency, especially when the interaction is driven by few-cycle laser pulses. In our experiment, the plasma length will be tuned by ionizing the target before the arrival of the main pulse using a laser prepulse with variable delay

  Risk: 2/5 *Impact*: 3/5

→ Milestones: (1) XUV spectral measurement, (2) Identification of the optimum interaction parameters

Work Package 2: CEP stabilization of LWS 20

Duration

- Task 2-1: CEP stabilization of the Ti:Sapphire front-end (2 months)

  Objectives and methodology: The first step of the CEP-stabilization of the laser system is to stabilize the output of the laser front-end. First I will upgrade the oscillator in order to lock the CEP via a feedback onto pump-laser amplitude. Then slow-CEP-drift of the amplified pulse will be monitored at the output of the first amplifier with an f-to-2f interferometer. If the CEP appears to be stable enough (0.3 rad) over a few seconds, the f[...]ed after the hollow core fiber, where slow-CEP-drift will be corrected [...]amplitude of the oscillator.

  Risk, Impact

  Risk: 0/5 *Impact*: 1/5

- Task 2-2: CEP measurement of the OPCPA amplification stages (3 months)

  Objectives and methodology: The second step consists in measuring the laser CEP at the output of the two consecutive pairs (1 and 2) of OPCPA amplification stages. Two methods will be tested:

  ◦ Spectral interferometry, either by frequency doubling the amplified seed after amplification of the whole spectrum, or by combining the seed of the 2ω amplification stage (ϕ_{CEP}) with the idler of the 3ω amplification stage ($2\phi_{CEP}$). This method is easy to implement but only provides the relative CEP of the pulse.

  ◦ Phase tagging using asymmetries of high-energy photoelectrons along the polarization axis. Despite its complexity, this technique provides full characterization of the pulse (CEP, pulse duration and peak intensity)

  Risk: 3/5 *Impact*: 2/5

- Task 2-3: CEP stabilization of the OPCPA amplification stages (3 months)

  Objectives and methodology: These measurements will allow us quantifying the temporal drift of the laser CEP introduced by the optical parametric amplification stages. At this stage of the laser system, the repetition rate is 10 Hz. As the stabilization is done by compensating afterward the slow CEP drift, it is necessary that the time scale of this drift be of the order of 1 second or more. If yes, the feedback will be applied using the acousto-optic programmable dispersive filter (AOPDF) situated before the OPCPA stages. This AOPDF (Dazzler) will also be used for controlling the relative CEP. If not, I will measure the CEP of each laser pulse and relate it to the XUV spectral measurement. In case of success, the control of the CEP of such a high power laser system will be a pioneer result for the high field laser-matter interaction community.

  Risk: 3/5 *Impact*: 4/5

Milestones

→ Milestones: CEP stabilization of LWS 20

Work Package 3: Isolated attosecond pulse generation

- Task 3-1: Intensity gating (4 months)

  Objectives and methodology: I will first try to demonstrate isolated attosecond pulse generation with intensity gating. This gating technique consists in driving the interaction with the highest intensity

and shortest laser pulse. Special cares will be taken to precisely control the plasma gradient, which is a key parameter of the interaction. I will study the spectral response of the emission as a function of laser CEP. I expect to see spectral modulations, characteristic of a train of pulse, alternated with continuum in the relativistic part of the spectrum, characteristic of isolated pulses. Energy contained in the emission will be measured using an calibrated XUV photodiode. In case of success, this will be the most important result of the project. The study of the effect of the laser CEP on the emission spectrum will give tremendous understanding of the relativistic interaction.

Risk: 4/5 *Impact*: 5/5

- Task 3-2: Attosecond lighthouse effect (4 months)

  Objectives and methodology: I also want to study the attosecond lighthouse effect with LWS 20. The improvement with respect to my previous work on this subject during my PhD is that LWS 20 gives access to the relativistic regime, and consequently to high energy attosecond pulses. To do so, I will introduce a thin wedge in the beam path, and the wavefront rotation at focus will be monitored by imaging the laser focus onto a 2D optical spectrometer. Lighthouse effect will be observed in the spatial domain (with two grazing incidence silicon plates followed by a large surface Micro Channel Plate) and in the spectral domain (with the XUV spectrometer). The observation of a bunch of relativistic isolated attosecond pulse will have very strong impact, especially for future XUV-pump XUV-probe time resolved measurements.

  Risk: 3/5 *Impact*: 5/5

- Task 3-3: Temporal characterization (4 months)

  Objectives and methodology: Temporal measurement of the isolated attosecond pulses generated by intensity gating and lighthouse technique (or polarization gating as a fallback position) will be done by XUV autocorrelation, which allows direct determination of the temporal characteristics of the pulse, by measuring the second-order autocorrelation trace of the attosecond pulse. MPQ has a strong experience in this challenging technique since its research team have consequently measured train of attosecond pulses generated from gas media and plasma mirrors using XUV autocorrelation. This temporal measurement combined with energy measurement will be the final achievement of this proposal by demonstrating the generation of very bright isolated attosecond pulses.

  Risk: 4/5 *Impact*: 5/5

→ Milestones: (1) Observation of continuous spectrum as a function of laser CEP, (2) Demonstration of attosecond control of the plasma emission, (3) Demonstration of the generation of bright isolated attosecond pulses

Work Package 4: Development of high repetition rate plasma mirrors with attosecond stability

- Task 4-1: Solid target (8 months)

  Objectives and methodology: This task will consist in developing a high repetition rate solid target with sub-10 nm stability. The aim is to ensure a temporal stability of less than 100 as to the plasma mirror source. It is a necessary condition to achieve this synchronization for future interaction experiments between this source and for instance the IR field or an other XUV attosecond source. This target will require strong efforts to get fast acquisition and data treatment from the monitoring system, and fast feedback using high frequency piezo actuators.

  Risk: 2/5 *Impact*: 2/5

- Task 4-2: Investigations on liquid target (16 months)

  Objectives and methodology: I also plan to investigate liquid target for high repetition rate laser-plasma interaction as an complement of solid target. My future research team at MPQ has started such investigation that I want to push forward. These target can offer a major advantage over solid target since it does not need target replacement. It is then particularly adapted for applications , which require ultrahigh repetition rate and long lifetime. The main difficulty is to provide a stability of the liquid flow at micrometric level. I will carry out bibliographic work and discussions with fluid mechanics

Conclusion

- To do
  - Stick to the template and make it easy to evaluate!
  - Show that you and the host are the best choices
  - Explain what you will bring to Europe
- To avoid…
  - Miss any of the required points of the guidelines!
  - Put unnecessary information
  - Fail in explaining how MC fellowship will develop your scientific career

Good luck!