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Central Laser Facility

# Temporal and spectral characterization of Ultra-Short High Power Laser Pulses


***Mario Galletti***

*Marco Galimberti  Danilo Giulietti*


*Within a collaboration with SPARC_LAB*

IN SUPREMÆ DIGNITATIS 1343

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# Summary

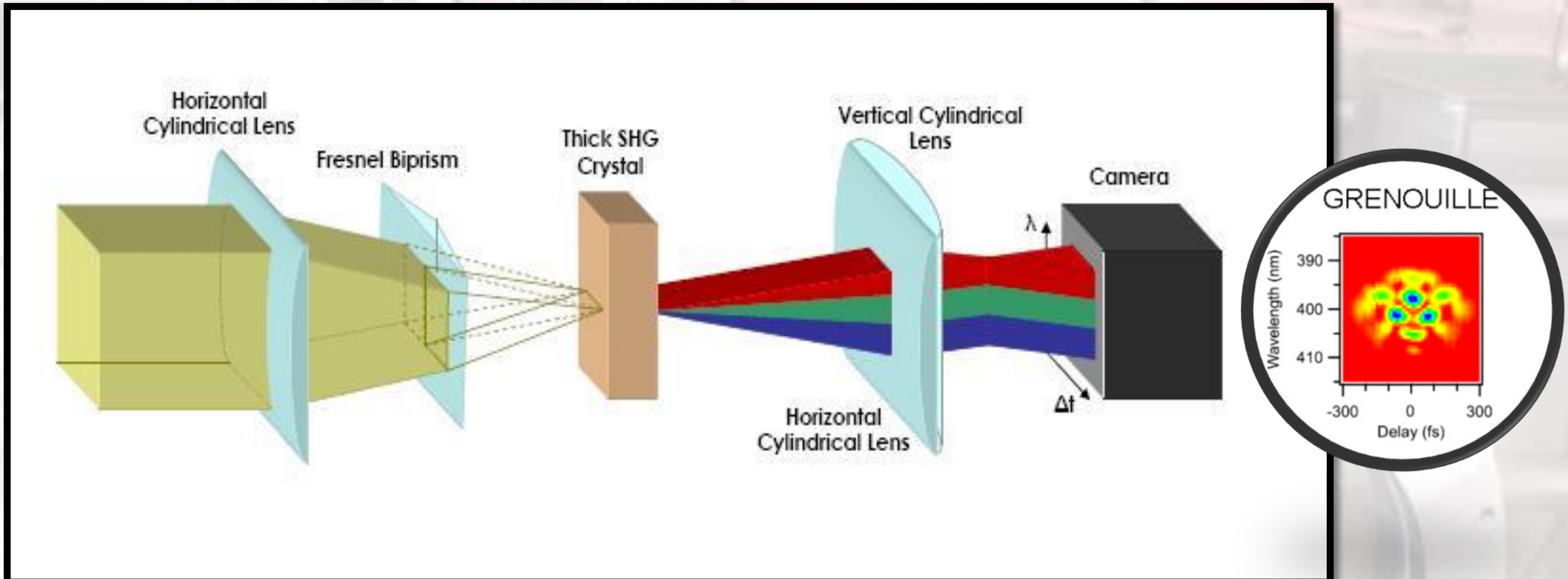
- Measurements’ Importance
- Laser Diagnostic: GRENOUILLE
- Previous Algorithm: BASIC FROG, GP, COMPOSITE.
- The DEVELOPED ALGORITHM
- Characterization of VULCAN DATA
- Characterization of FULL POWER GEMINI DATA
- Conclusions

# Measurements' Importance

The characterization of the laser pulse is essential for studying many physical process:

- ✓ The *PHOTO-DISSOCIATION* is more efficient in the case of using a chirped pulse;
- ✓ The *NON-LINEAR PHENOMENA* like self-focusing, self-phase modulation, etc. which modify the laser beam;
- ✓ The *TEST OF THEORETICAL MODELS* about the laser physics and the *PRODUCTION OF SHORTER PULSES;*
- ✓ The detection of the laser paramenter, after passing a material, for understanding its *STRUCTURAL CHARACTERISTICS*;
- ✓ The *VALUATION OF THE PULSE TEMPORAL SHAPE* (pedestal,pre-pulses,etc.) for the employment of this type of pulses in plasma physics (laser-plasma interaction, fusion, etc.).

# GRating-Eliminated No-nonsense Observation of Ultrafast Incident Laser Light E-fields

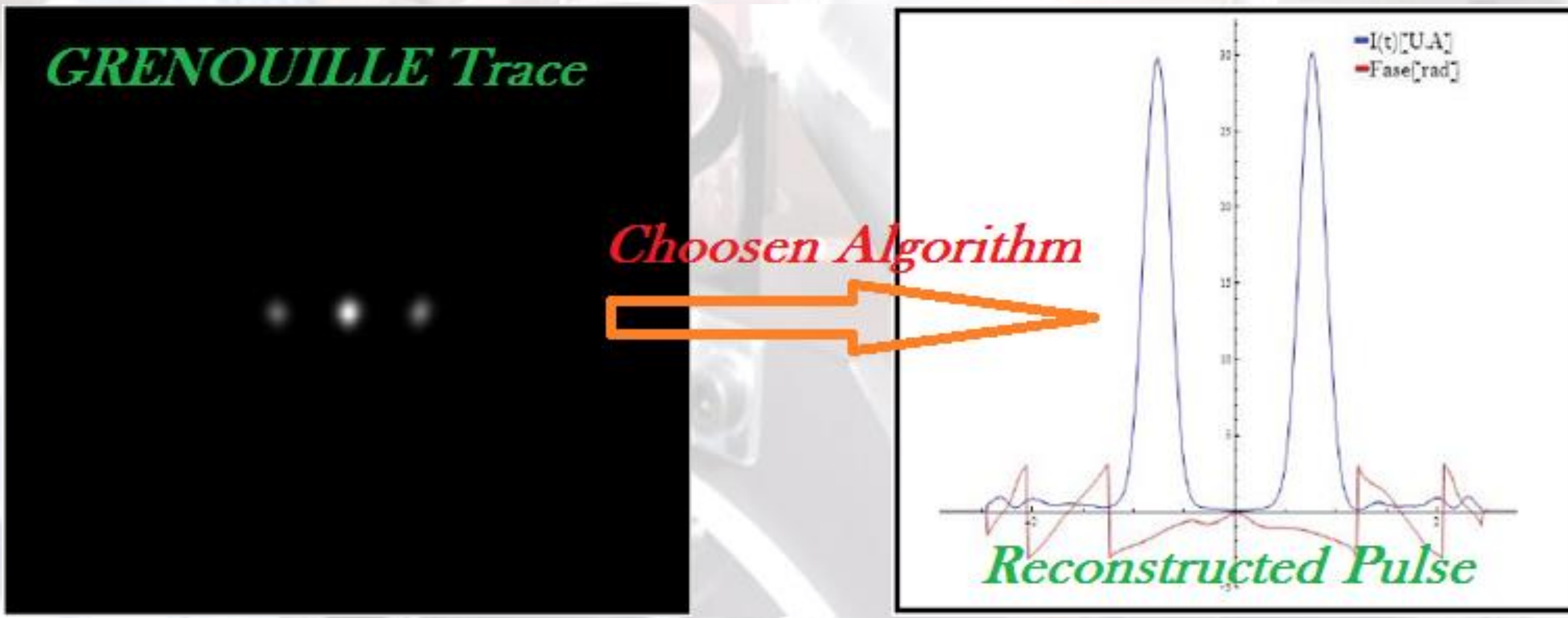



GRENOUILLE IS A SPECTRALLY RESOLVED AUTOCORRELATION.

**Patrick O'Shea, Mark Kimmel, Xun Gu, and Rick Trebino,**
*Highly simplified device for ultrashort-pulse measurement,*
*OPTICS LETTERS / Vol. 26, No. 12 / June 15, 2001*

# *Previous algorithm*

In order to characterize a pulse one must use a pulse retrieval algorithm, in which the GRENOUILLE TRACE serves as an input data.




***M.Galletti, M.Galimberti, D.Giulietti,***
*Sviluppo di un software di riscostruzione e caratterizzazione di impulsi laser ultracorti di alta potenza, Master Thesis, 15 Dec. 2014, Pisa*

# Previous algorithm

- **BASIC FROG** based on an iterative loop, where after calculating $I_{GREN}$ from an initial guess of E(t), it substitutes the magnitude $I_{GREN}$ with the magnitude $I_{EXP}$ and makes the inverse-FT to conclude the loop;

**K. W. DeLong and R. Trebino,** *Improved ultrashort pulse-retrieval algorithm for frequency-resolved optical gating, Vol.11, No.9, Sept.1994, JOSA A*

- **GENERAL PROJECTION** based on a 1-D minimization algorithm;
- **COMPOSITE ALGORITHM** based on the mix of the previous two algorithm with other minimization algorithms.

**K. W. DeLong, D. N. Fittinghoff, R. Trebino, B. Kohler and K. Wilson,** *Pulse retrieval in frequency-resolved optical gating based on the method of generalized projections, OPT. LETT./ Vol.19, No.24/ Dec. 15, 1994*

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# Ultra-Short Pulse Reconstruction Software

The algorithm is based on the *1-D "CONIUGATE GRADIENT" MINIMIZATION METHOD*. It consists of 2 main parts:

1. *EXPERIMENTAL IMAGE CAPTURE,* image that will be compared with (involves determining the $\chi^2$ "distance") a calculated one

$$I_{GRENOUILLE}^{SHG} = \left|\int_{-\infty}^{\infty} E(t)E(t-\tau)e^{-iwt}dt\right|^2,$$

the latter produced by a reasonable initial pulse guess;

2. *AN ITERATIVE LOOP* (includes a minimization algorithm) that proposes to vary the arbitrary initial pulse for decreasing of the $\chi^2$, succeeding so to obtain a reconstructed pulse as similar as possible to the real one.

# Ultra-Short Pulse Reconstruction Software

The experimental image is not ready to be processed, so before processing in the first part of the algorithm, the images have been:

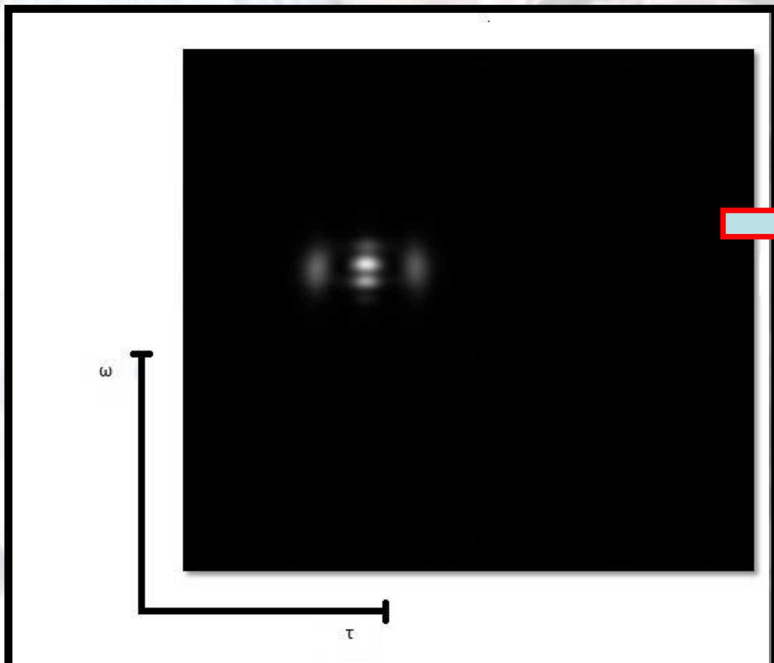
1.1 SUBTRACTED from the background;

1.2 RE-SCALED to have the needed dimension to be reconstructed;

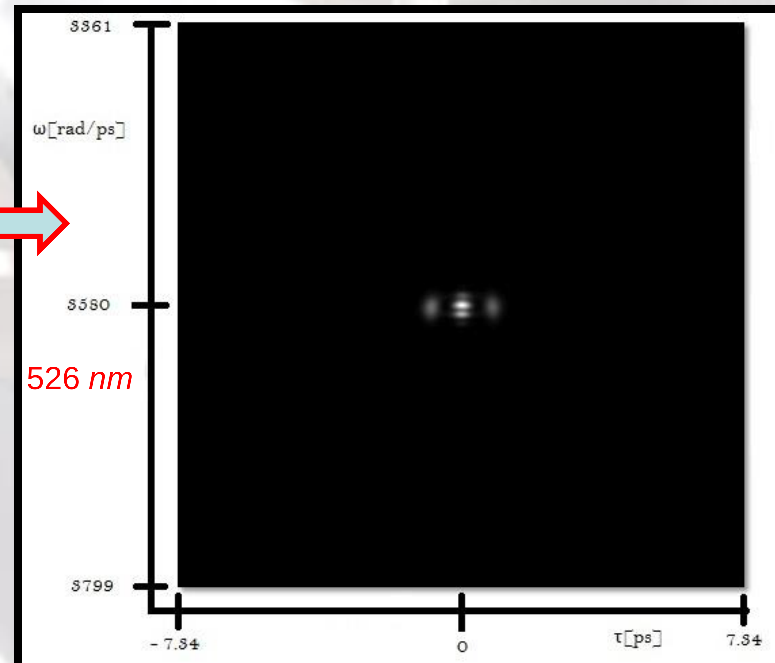
1.3 CENTERED in the maximum of I(t).

# *Ultra-Short Pulse Reconstruction Software*

GRENOUILLE Trace of a ***DOUBLE PULSE*** made using a Michelson interferometer with a ***100 FS*** *Ti:Sa laser*, ***80 MHZ, 1053 NM.***




EXPERIMENTAL *GRENOUILLE TRACE*




*MODIFIED EXPERIMENTAL TRACE*

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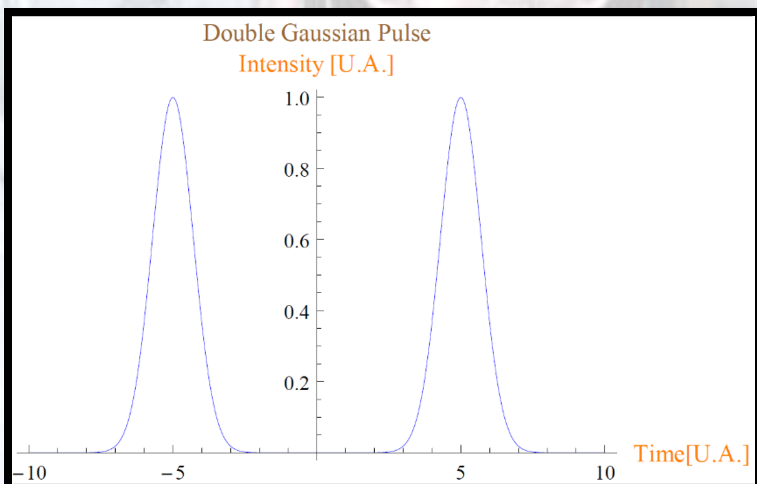
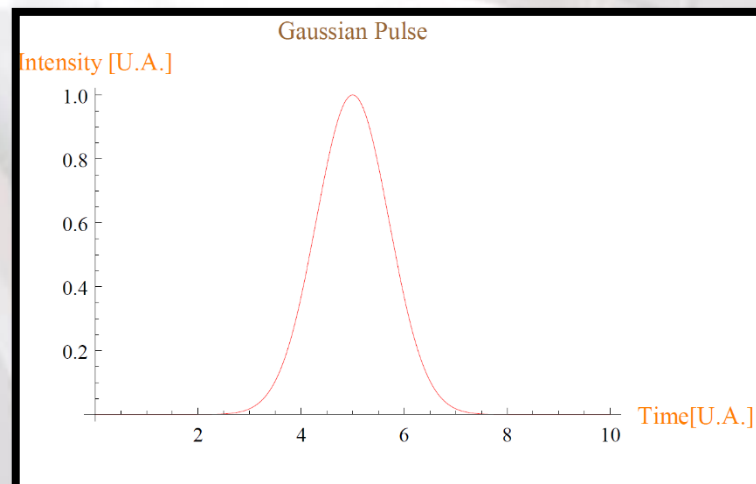
# Ultra-Short Pulse Reconstruction Software

The first part ends with:

**1.4** ***CHOICE OF THE FIELD*** $E(t)$, in this case:




**1.5** ***SAMPLING*** of the field, $E_j$;

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# Ultra-Short Pulse Reconstruction Software

The second part starts with the iterative loop that consists in:

**2.1** **CALCULATION** of the GRENOUILLE signal, of the "distance" $\chi^2$,of the $\chi^2$ gradient with respect to $E_j$ and of $\chi^2$ minimum in the gradient direction.

The "distance" $\chi^2$ is made up by 2 parts: one is **THE "REAL DISTANCE"** between the sperimental and the analytical image, and the other was added to maintain the **TEMPORAL BARYCENTER** in the middle of the analytical one so as to permit a better reconstruction of the GRENOUILLE trace.

**2.2** **UPDATING** of the new $E_j$ with the minimum position.

The steps are repeated until reaching conditions for which the reconstructed pulse does not vary significantly.

***M.Galletti, M.Galimberti, D.Giulietti,***
*Ultra-Short Pulse Reconstruction Software*
*in High Power Laser System, NIMB May 2015*

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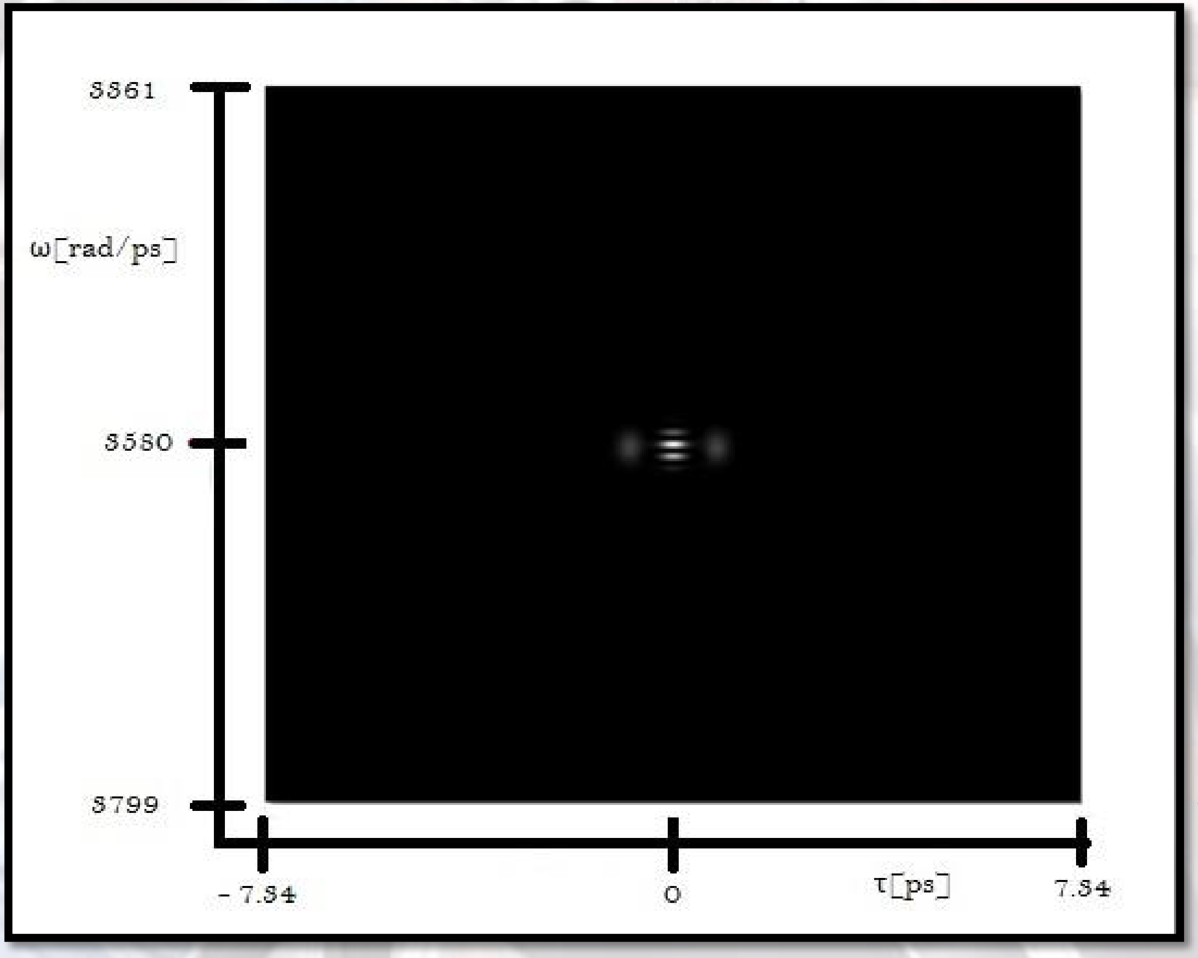
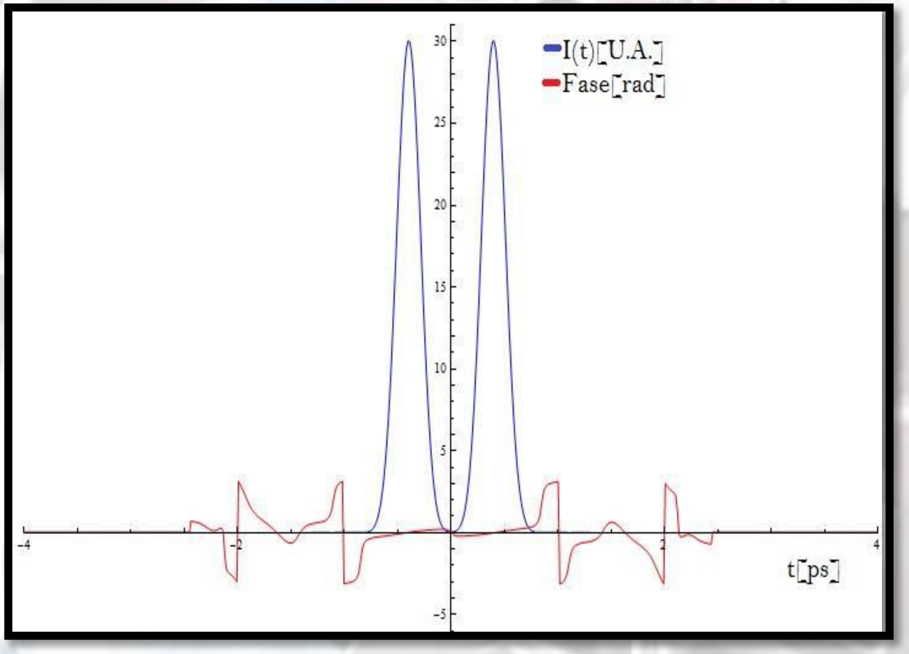
# Ultra-Short Pulse Reconstruction Software

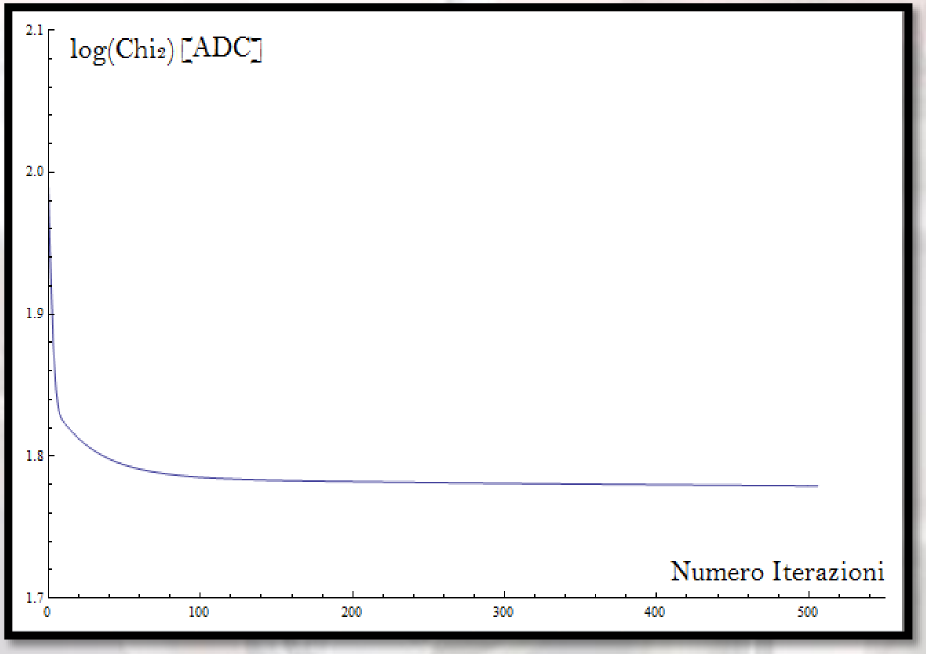



- The choice of the ***INITIAL FIELD WAS A DOUBLE PULSE*** with the parameters different from the real one.

**M.Galletti, M.Galimberti, D.Giulietti,** *Sviluppo di un software di riscostruzione e caratterizzazione di impulsi laser ultracorti di alta potenza, Master Thesis, 15 Dec. 2014, Pisa*

# Ultra-Short Pulse Reconstruction Software

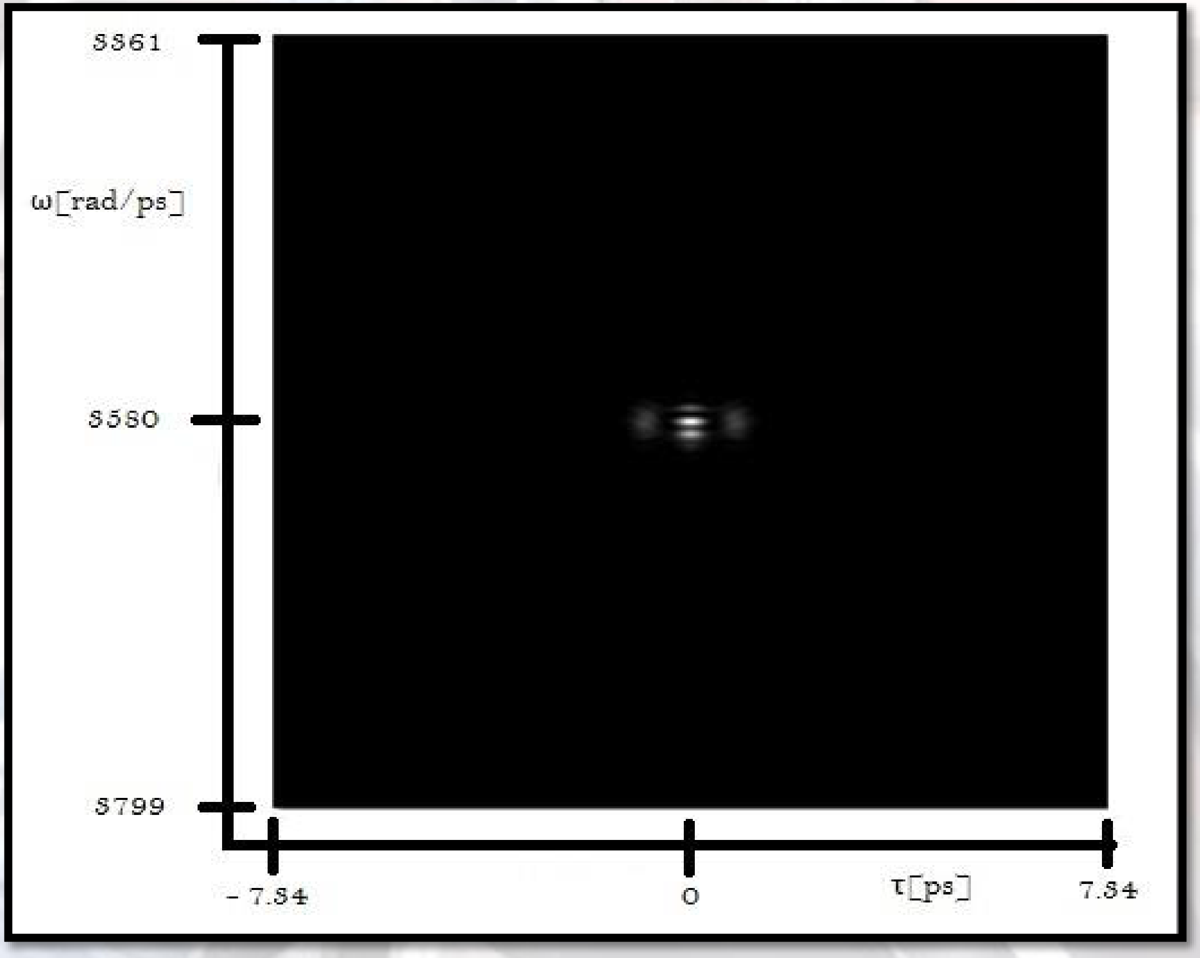



→ The phase is reported even where the intensity is zero and it doesn't have a real physical sense and it is not treated with the unwrapping technique;

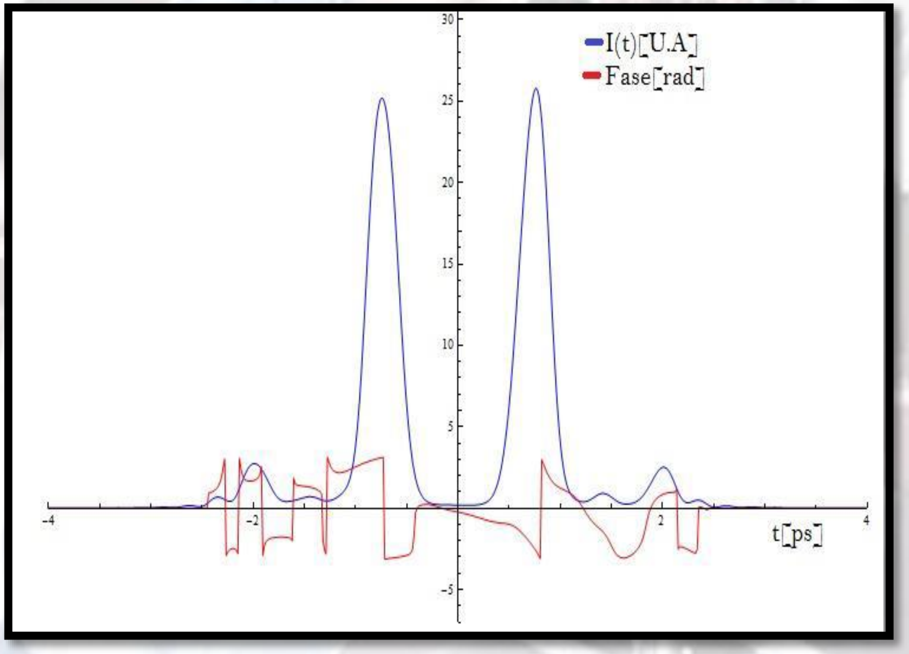
→ The *CONVERGENCE IS REACHED IN A REALLY FAST WAY* (60 iterations).

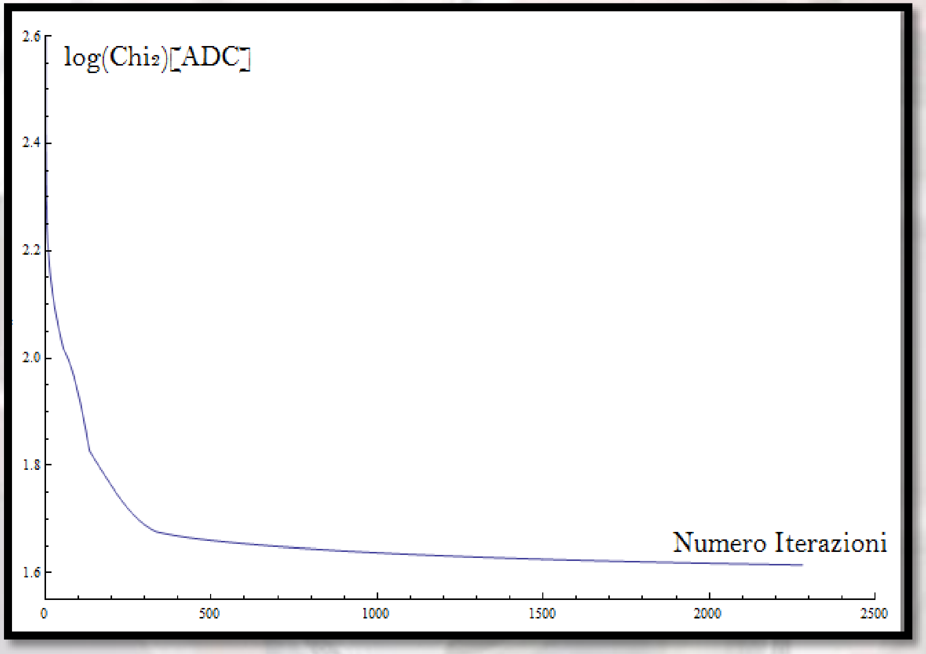
# Ultra-Short Pulse Reconstruction Software




- The choice of the ***INITIAL FIELD WAS A GAUSSIAN PULSE*** with FWHM larger than the temporal lenght of the real double pulse.
- The ***GAUSSIAN PULSE IS THE MOST GENERAL ONE***. It can be applied to most of the pulses deriving its parameters from the experimental traces.

# Ultra-Short Pulse Reconstruction Software



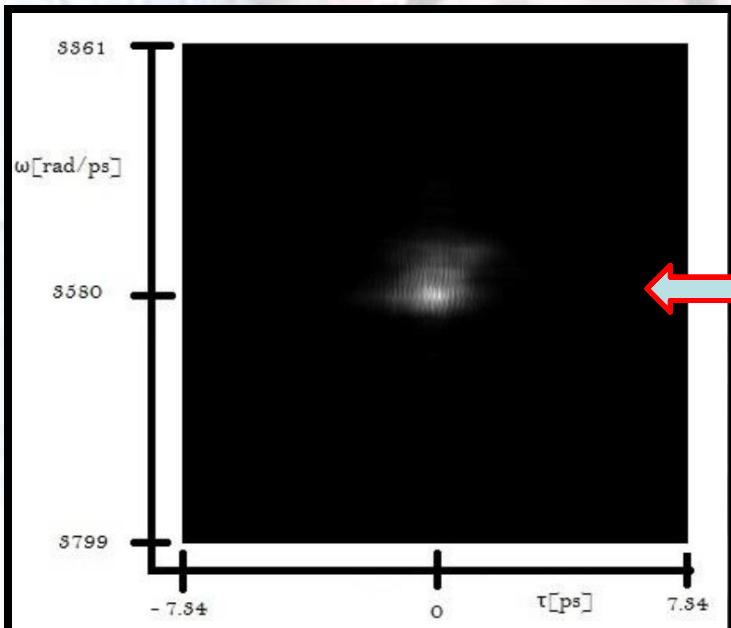




→ The phase is reported even where the intensity is zero and it doesn't have a real physical sense and it is not treated with the unwrapping technique;

→ The *CONVERGENCE IS REACHED IN A FAST WAY* (300 iterations), moreover we reach a lower "distance" value than before.

# *Vulcan Measurements*

In this experimental research was analyzed for the first time, in Target Area Petawatt of Vulcan (*GW*), the laser pulse (*MJ, 2 HZ, 1053 NM*) with a *DIFFERENT TECHNIQUE* from the AC.



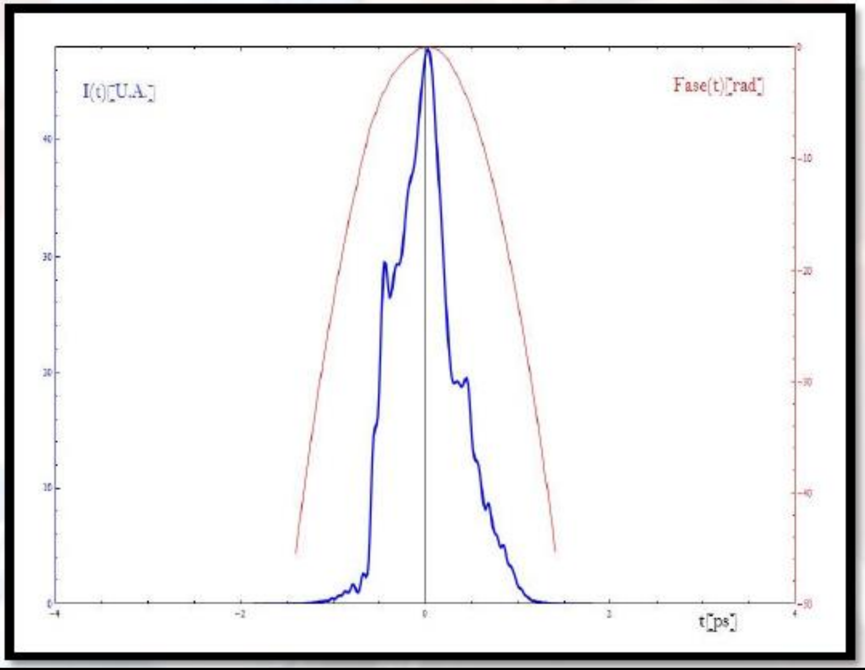

| Images | FWHMAC pulse (ps) | FWHMGR pulse (ps) |
|---|---|---|
| GR_25 | | 0.717 |
| GR_26 | | 1.0038 |
| AC_14 | 0.7662 | |
| AC_13 | 1.0071 | |

The results show an excellent agreement between the two type of measurements.

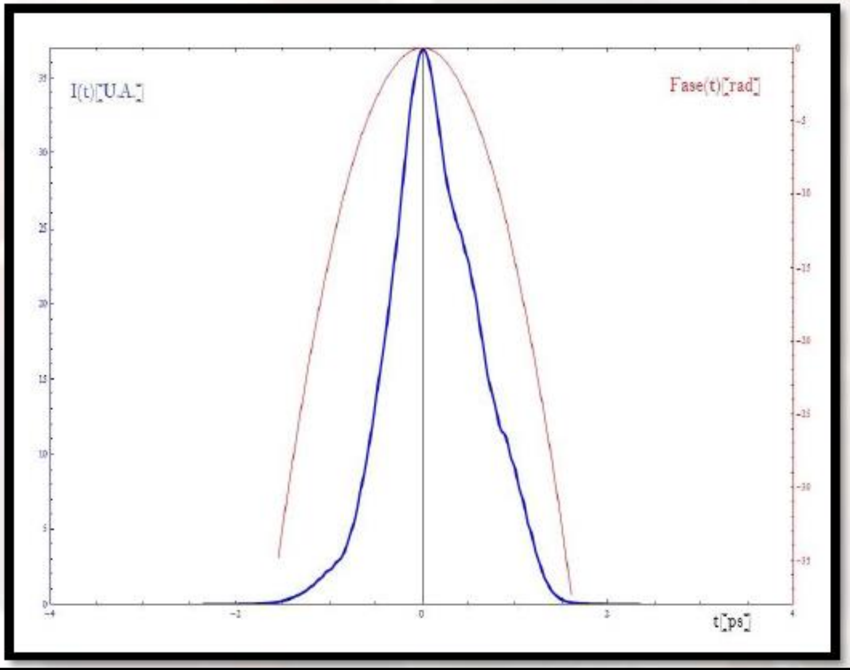
# Vulcan Measurements

The *RETRIEVED TEMPORAL SHAPE* are that expected.

GR_25




GR_26




***M.Galletti, M.Galimberti, D.Giulietti,***
*Ultra-Short Pulse Reconstruction Software*
*in High Power Laser System, NIMB May 2015*

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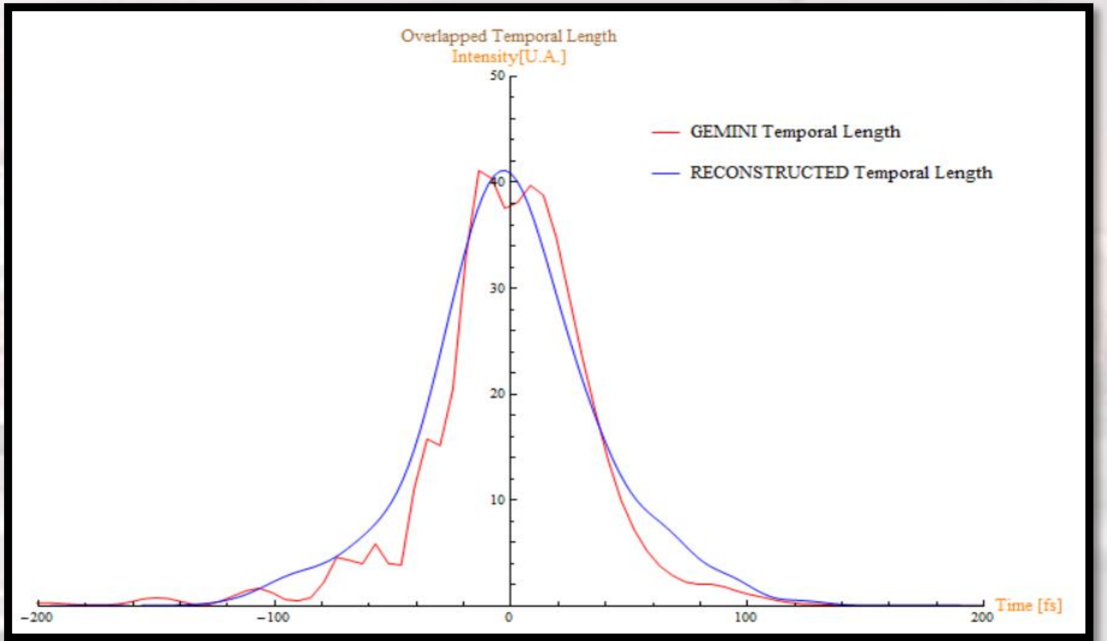
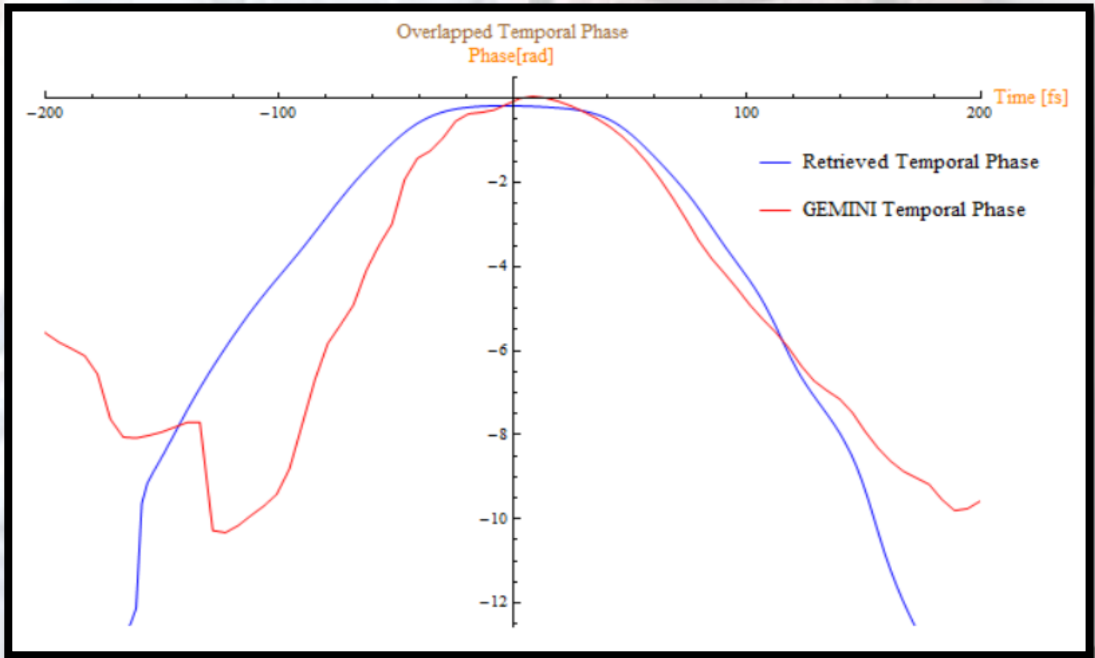
# *Gemini Full Power Measurements*

This is a GRENUILLE trace of a GEMINI pulse.

Each beam will deliver ***15 JOULES*** to target in a pulse of ***61 FEMTOSECONDS*** (i.e. a peak power of about ***PW***), with a shot rate of ***ONE SHOT PER 20 SECONDS***.

# Gemini Full Power Measurements




The GEMINI temporal length is 61 fs while the **RECONSTRUCTED TEMPORAL LENGTH IS 64.29 FS**.

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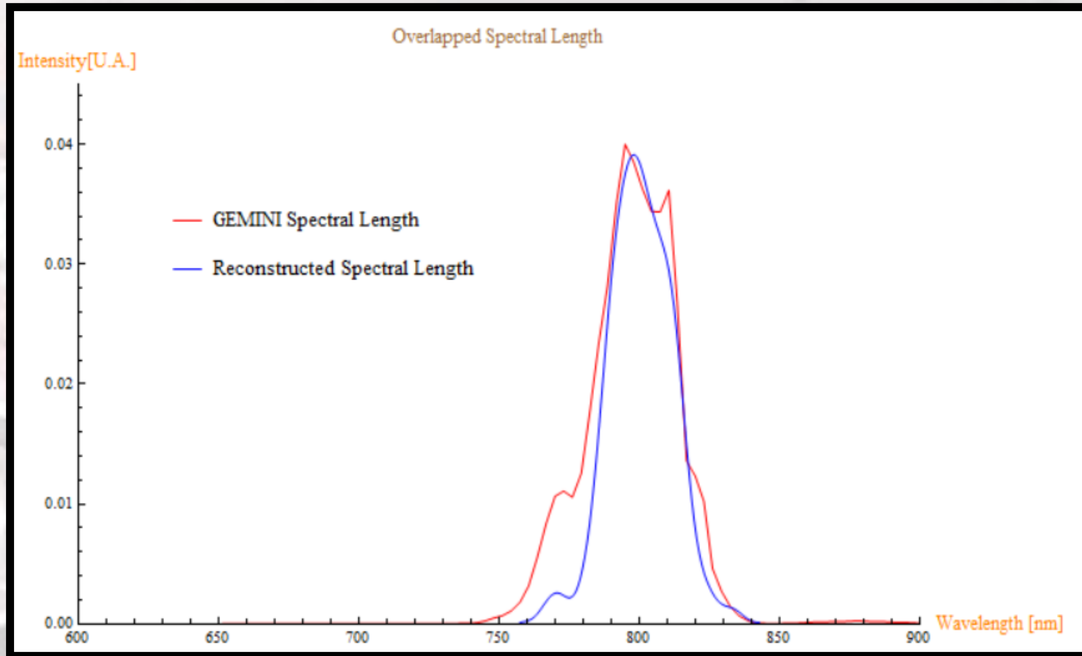
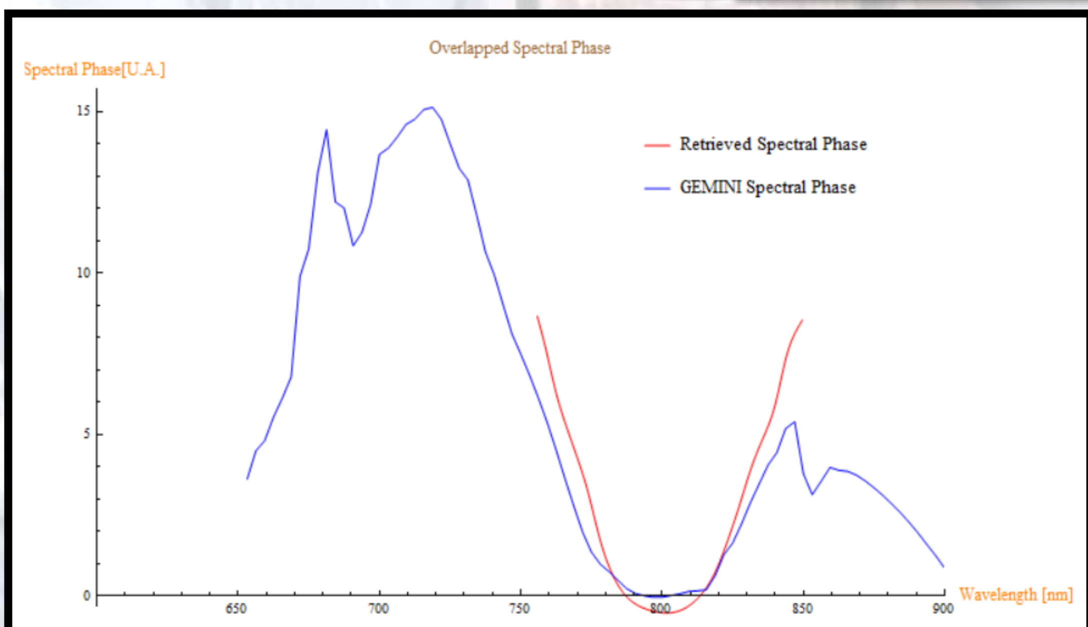
# Gemini Full Power Measurements




The GEMINI spectral length is 29,5 nm while the *RECONSTRUCTED SPECTRAL LENGTH IS 29,7 NM*.

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# Conclusions 1/2

- The algorithm will be improved with functions analyzing information derived by other diagnostic tool (like *SPIDER*) so as to obtain more precise pulse characterization.

- The improved algorithm can be made faster and it could be used to make *ON-LINE MEASUREMENTS*.

# Conclusions 2/2

- Our purpose is to make temporal and spectral characterization of *FLAME PULSES*.

*FLAME LASER* is based upon Ti:Sa, CPA system that will deliver *30 FS, 800 NM (BW 60 NM), 200 TW,* laser pulses with a *10 HZ* repetition rate.

The system has a *CONTRAST RATIO >10^8.*

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# *Thank you for your attention!!*

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