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INTENSE LASER IRRADIATION LAB,
PISA



CONSIGLIO NAZIONALE DELLE RICERCHE

FLAME: impulsi laser ad alta intensità a LNF

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**ON BEHALF OF THE
FLAME COMMISSIONING
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CONTENTS

- ULTRAINTENSE LASERS: CURRENT STATUS
- FLAME: STATUS
- TEST EXPERIMENT ON LPA w. SELF-INJECTION
- CONCLUSIONS



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CRITICAL TECHNOLOGY ISSUES

BANDWIDTH 1/2

Chirped pulse amplification requires large bandwidth gain medium;

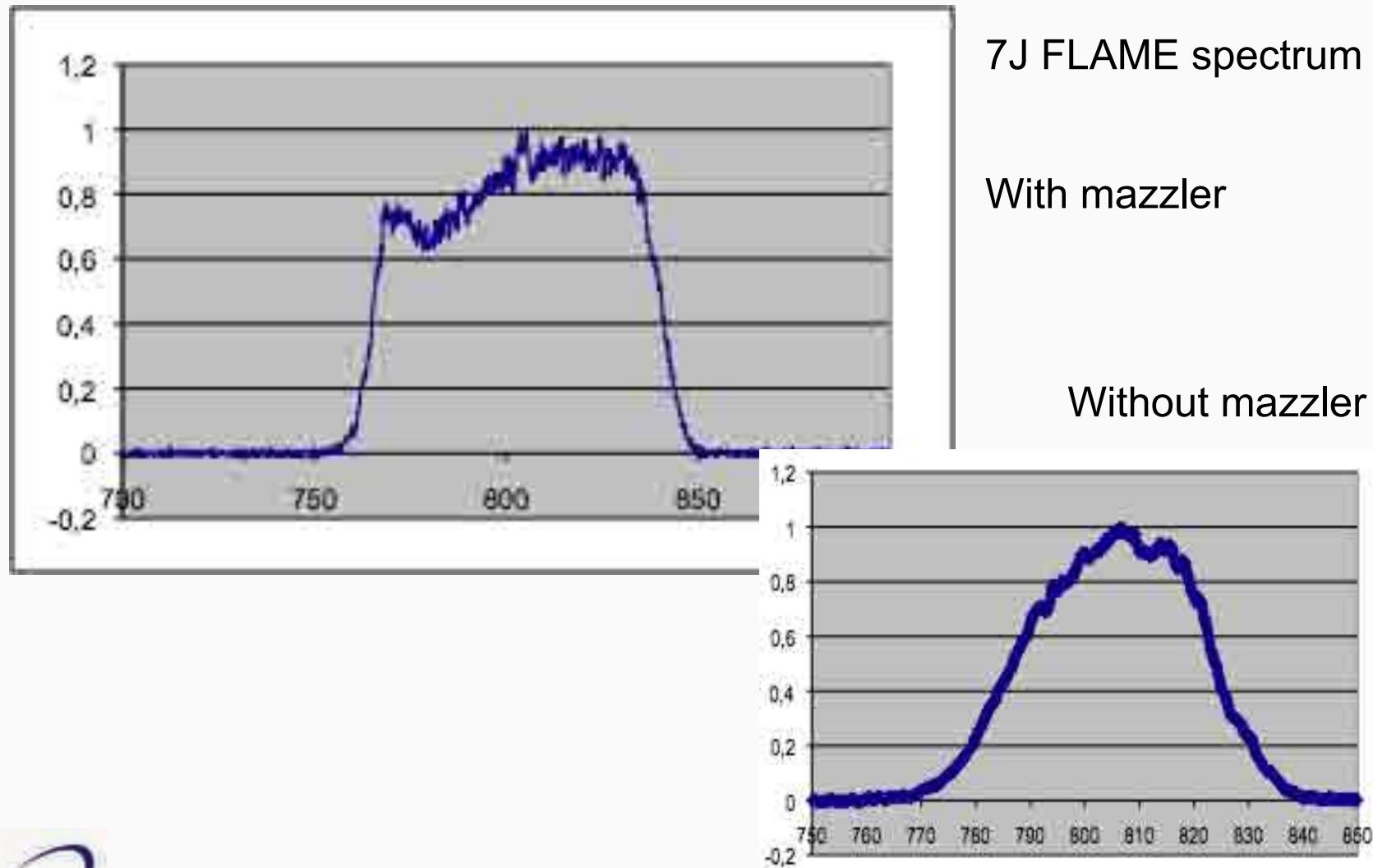
Ti:Sa combined with bandwidth and phase control devices (dazzler, mazzler) are used to overcome gain narrowing and keep flat phase distribution over a 70-80 nm bandwidth;

Optical parametric CPA is rapidly being developed for a new generation of ultra-high bandwidth (up to 3x Ti:Sa) front-end;



CRITICAL TECHNOLOGY ISSUES

BANDWIDTH 2/2

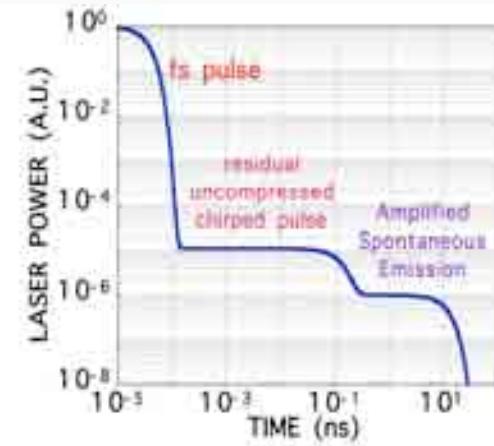
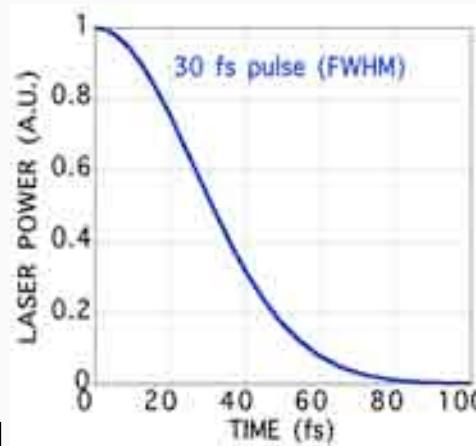




CRITICAL TECHNOLOGY ISSUES

CONTRAST

Temporal contrast (ASE) in excess of 10 orders of mag. required for peak intensities on target of $>10^{22}$ W/cm².



Established techniques include

- electro-optic devices (Pockel cells) for prepulse reduction;
- moderate gain in front end and saturable amplifier for ASE management;
- Other advanced techniques (e.g cross polarized wave generation) again for front-end contrast enhancement;



CRITICAL TECHNOLOGY ISSUES

BEAM QUALITY 1/2

A high beam quality is required to achieve high laser intensity in the focal spot.

Strehl ratio (energy in the focal spot/total energy) and M^2 (deviation from the Gaussian shape) are used to measure beam quality;

Multi-pass and regenerative amplification implies large number of reflections off mirrors, passes through optics, gain medium and air;

Small imperfections of optics and air turbulence impose white-spectrum spatial scale distortions of the phase-front.



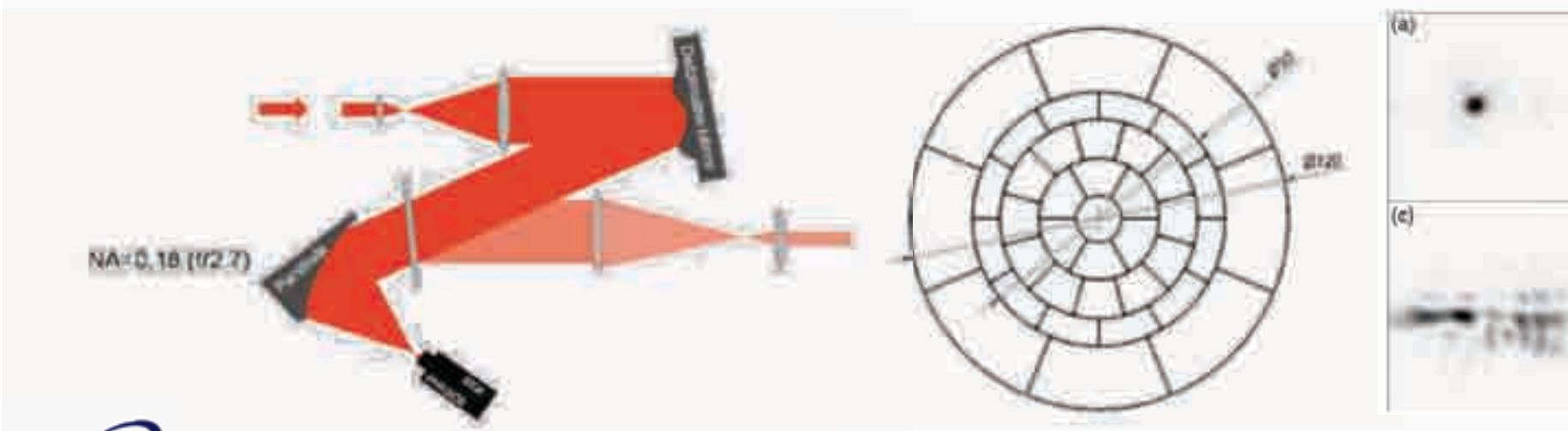
CRITICAL TECHNOLOGY ISSUES

BEAM QUALITY 2/2

Active spatial phase control technique can be used to correct moderate distortions;

Sensors are used to measure intensity and phase map of the beam;

Deformable mirrors are used to correct the measured wave front distortions in a close loop;



S.-W. Bahk et al., Optics Letters **29**, 2837 (2004)



TREND IN ULTRAINTENSE LASERS

Laser technology is rapidly progressing towards higher peak power and higher repetition rate:

Systems undergoing commissioning will include (e.g.):

- 1.3 PW, 30 fs, 1 Hz repetition rate (LBNL, USA) => **10 GeV e⁻**
- 1 PW, < 30 fs, 1 Hz repetition rate (CLPU, Salamanca, Spain)
- 10 PW \approx 500 fs (CLF, Rutherford Appleton Lab, UK)

Still based upon Chirped Pulse Amplification and using flash-lamp pumped, frequency doubled Nd:YAG pump lasers.

ELI Pillars (Czech Rep., Romania, Hungary ...)

Da <http://www.laserlab-europe.eu/>

Research Topics

KEY APPLICATIONS

Atomic and Molecular Spectroscopy and Chemical Dynamics

Biophysics and Optical Life Sciences

Intense Laser and Particle Beams Interactions

Laser Cooling, Trapping and BEC

Laser-Particle Acceleration and Applications

Laser-Plasma Physics, Fusion Science and Applications

Laser Remote Sensing, Analytical Chemistry and Combustion Diagnostics

Materials Processing

Multiphoton Processes, including High-Order Harmonics, with Applications

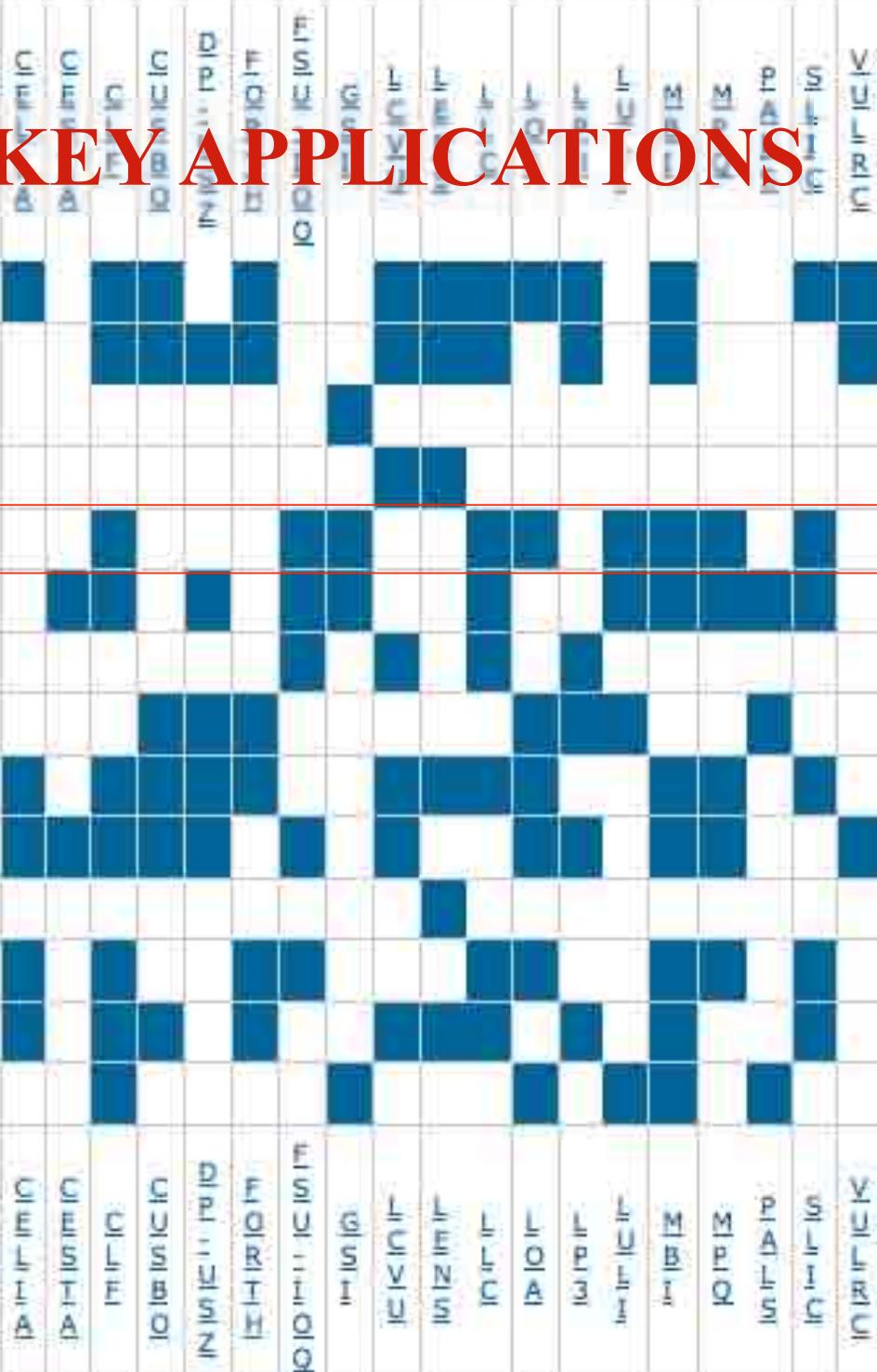
Quantum Electronics and Novel Laser Development

Spectroscopy under High Pressure Conditions

Time-Resolved X-Ray Science

Ultrafast Dynamics of Molecules, Liquids and Semiconductor Materials

X-Ray Laser Physics





FUTURE OF LPA

Laser Acceleration and its Future

Toshiki Tajima^{*†}

Faculty of Physics, Ludwig-Maximilian University and Max Planck Institute for Quantum Optics, Garching, Germany

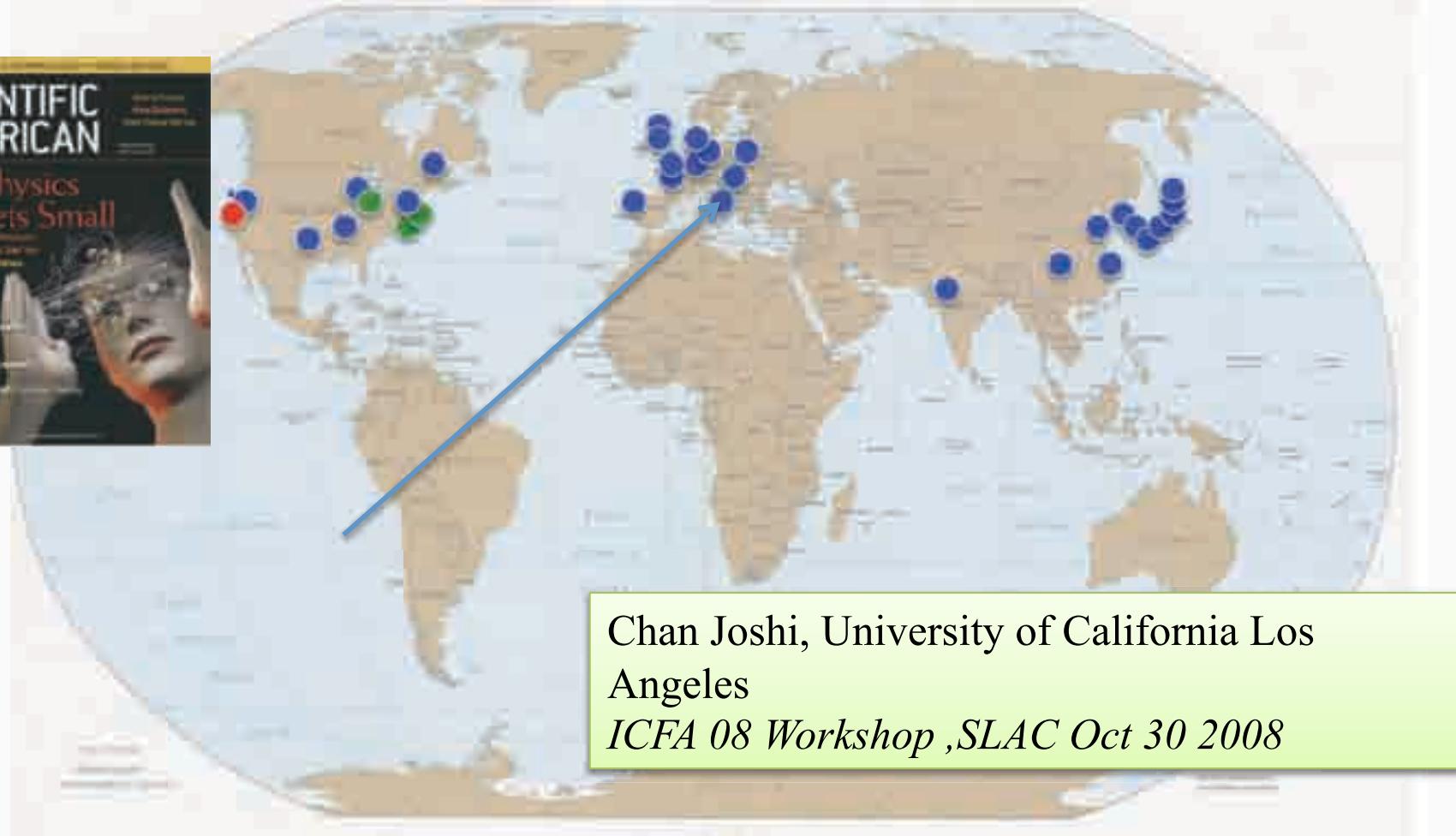
Abstract. Laser acceleration is based on the concept to marshal collective fields that may be induced by laser. In order to exceed the material breakdown field by a large factor, we employ the broken-down matter of plasma. While the generated wakefields resemble with the fields in conventional accelerators in their structure (at least qualitatively), it is their extreme accelerating fields that distinguish the laser wakefield from others, amounting to tiny emittance and compact accelerator. The current research largely falls on how to master the control of acceleration process in spatial and temporal scales several orders of magnitude smaller than the conventional method. The efforts over the last several years have come to a fruition of generating good beam properties with GeV energies on a table top, leading to many applications, such as ultrafast radiolysis, intraoperative radiation therapy, injection to X-ray free electron laser, and a candidate for future high energy accelerators.

Keywords: laser acceleration, collective fields, relativistic coherence, wakefields, collective deceleration



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PLASMA ACCELERATION SITES



● Laser Wake Expts

● Electron Wake Expts

● e-/e+ hi γ Wake Expts

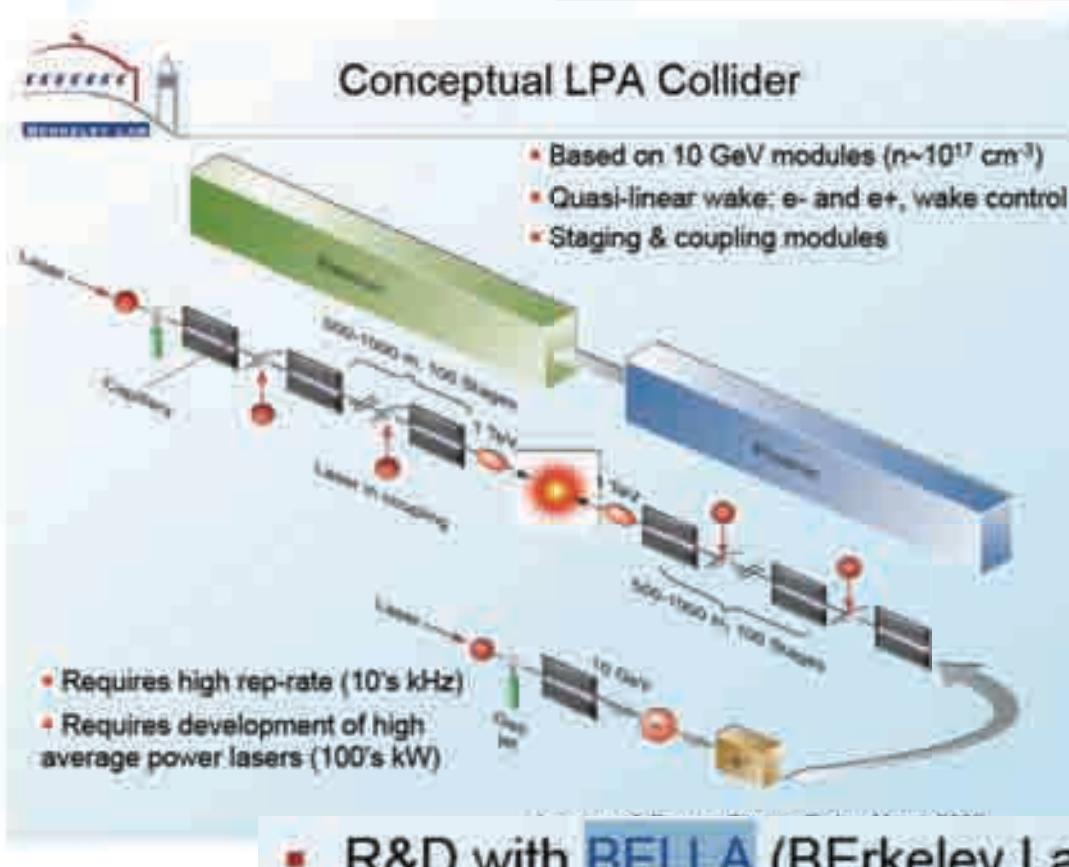
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CONCEPT OF TeV LPA COLLIDER



Carl B. Schroeder

and the Members of the
LOAIS Program
Lawrence Berkeley National Laboratory

- R&D with **BELLA** (BErkeley Lab Laser Accelerator):
 - 10 GeV LPA stage
 - Positron acceleration in quasi-linear regime
 - Beam-plasma interactions

● Laser Wake Expts

● Electron Wake Expts

● e-/e+ hi γ Wake Expts



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FLAME LASER



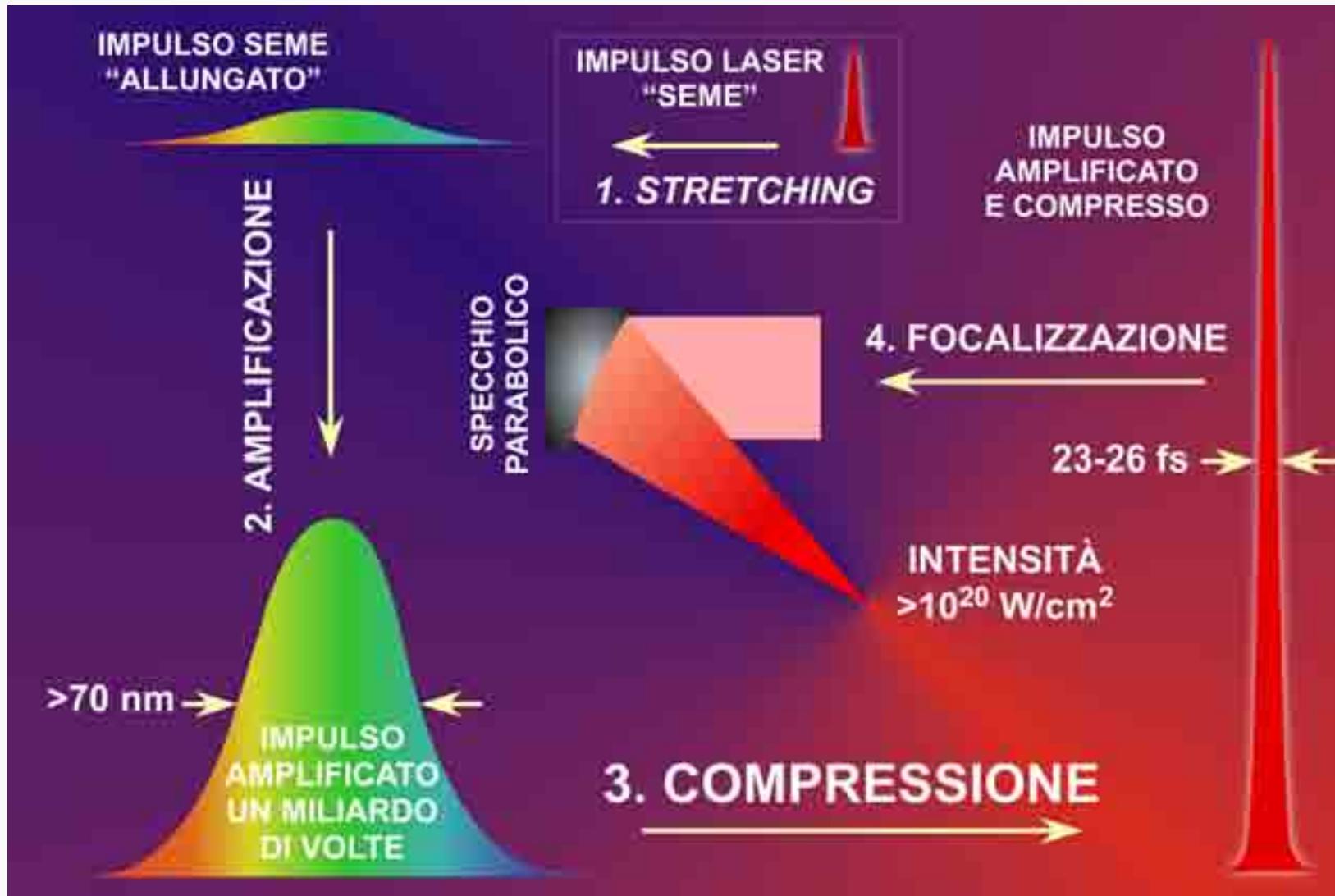
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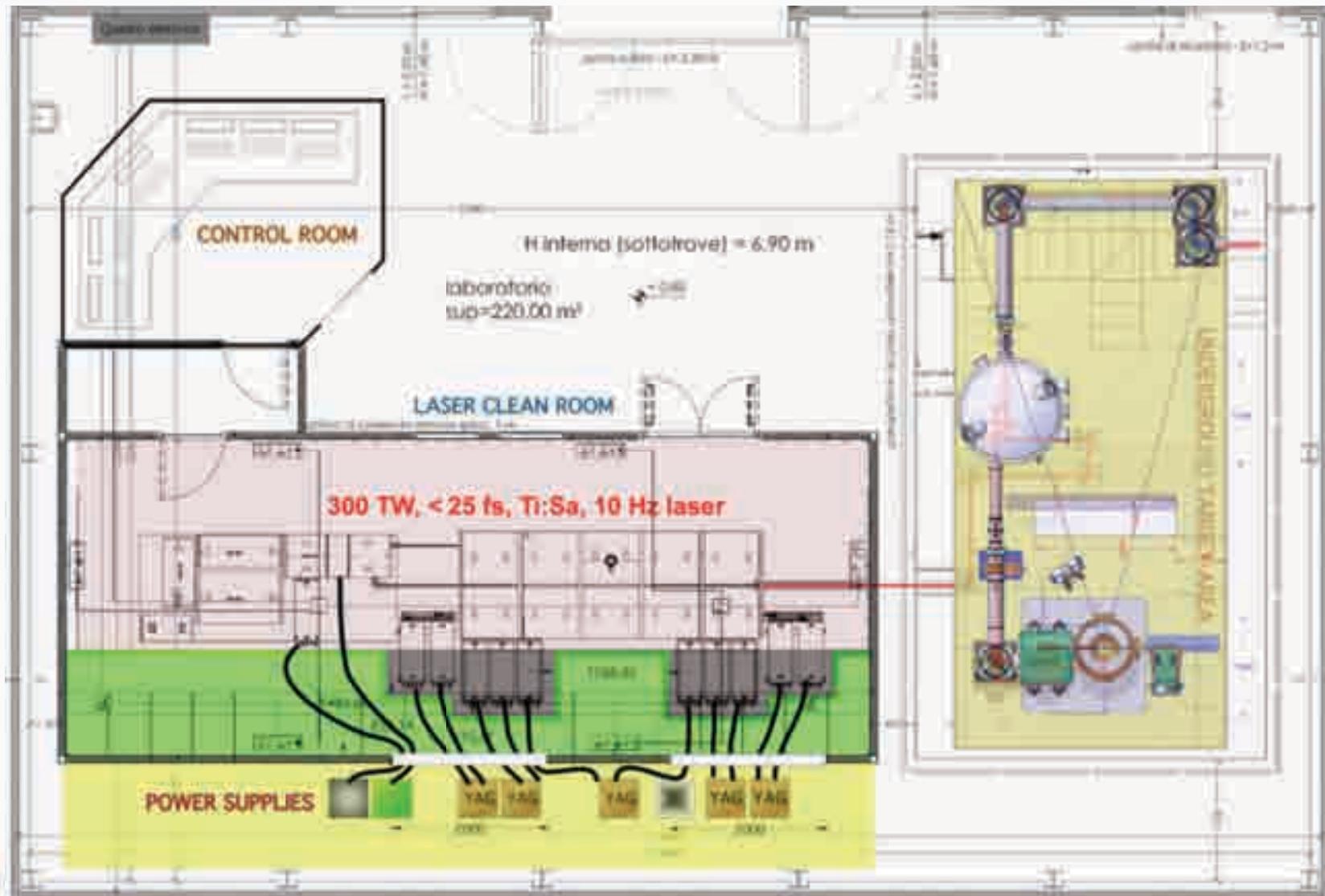
SCHEMATIC BLOCK DIAGRAM





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FLAME – TOP VIEW



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FLAME: A FEW CHALLENGES ...

- FLAME to operate a 250 TW, 10 Hz system
- Basic issues/challenges (project driven):
 - Pulse contrast ($>10^{10}$)
 - Pulse duration (<30 fs)
 - Performance stability to compare with LINAC
 - Mechanical stability (2 μm at focal spot)
 - ...

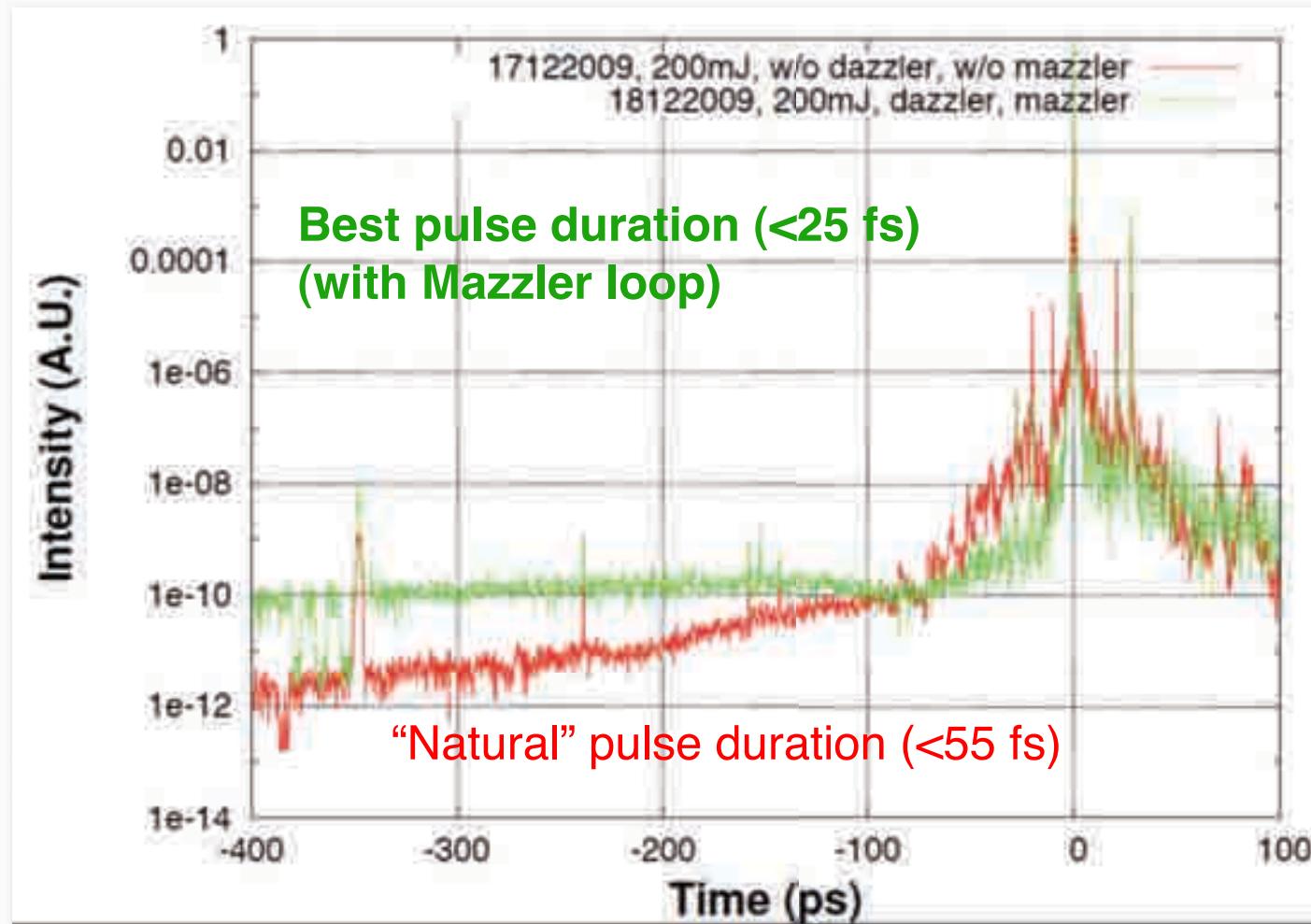


PROJECT LASER REQUIREMENTS

Parametro	Unità	Expected Value	PROBE BEAM PARAMETERS	
Rep Rate	Hz	10	Laser Wavelength	800 nm
Pulse Duration	fs	20	Pulse Energy	50 mJ
<i>Output energy (before compression)</i>	mJ	8000	Pulse Duration (FWHM)	30 fs
Output energy	mJ	5000	Beam Size	10 mm
Pulse Energy Adj.	mJ	5000-10	Repetition Rate	10 Hz
Pulse Duration Adj.	fs	20-3000	Beam Quality after compression (M^2) (Ideal=1 typ>1)	Not greater than 1.5
Energy Stability (RMS)	%	<1.5	Energy Stability	2%
Spatial beam quality	M2	1.5	Pointing stability (at focusing)	<2 μ rad
Pointing Stability	μ rad	<2	OPERATION CONDITIONS	
ns prep. contrast (replica)	ratio	1.00E+07	System warm-up time	<3 hours
ps prepulse contrast	ratio	1.00E+06	Temperature Stability in room	<3 deg
ASE contrast	ratio	1.00E+09	Stable operation period (unserviced)	> 3 hours
contrast @ 1ps	ratio	1.00E+03	Half life of grating efficiency	>2 years
contrast @ 5ps	ratio	1.00E+05	HOUSEKEEPING	
contrast 10-20 ps	ratio	5.00E+06	Energy monitor (at all amplifier stages)	Always on
Oscillator Timing Jitter	fs	1000	Spectrum monitor at before regen. amp.	Always on
Peak Power	TW	2.50E+02	Temporal/spectral pulse monitor (SPIDER)	Always on
beam size	mm	1.00E+02	CCD beam pointing monitor and control	Always on
Warm-up time	hrs	3	2D CCD Beam profiling (at all amps.)	Always on
Stability of Operation	hrs	6	Equivalent Plane Monitoring (after compr.)	Always on
Gratings Half-Life	yrs	2	USER CONTROL	
			Adjustable Pulse energy range	5 - 0.01 Joule
			Adjustable Pulse duration (compressor)	30 - 3000 fs



CONTRAST MEASUREMENTS

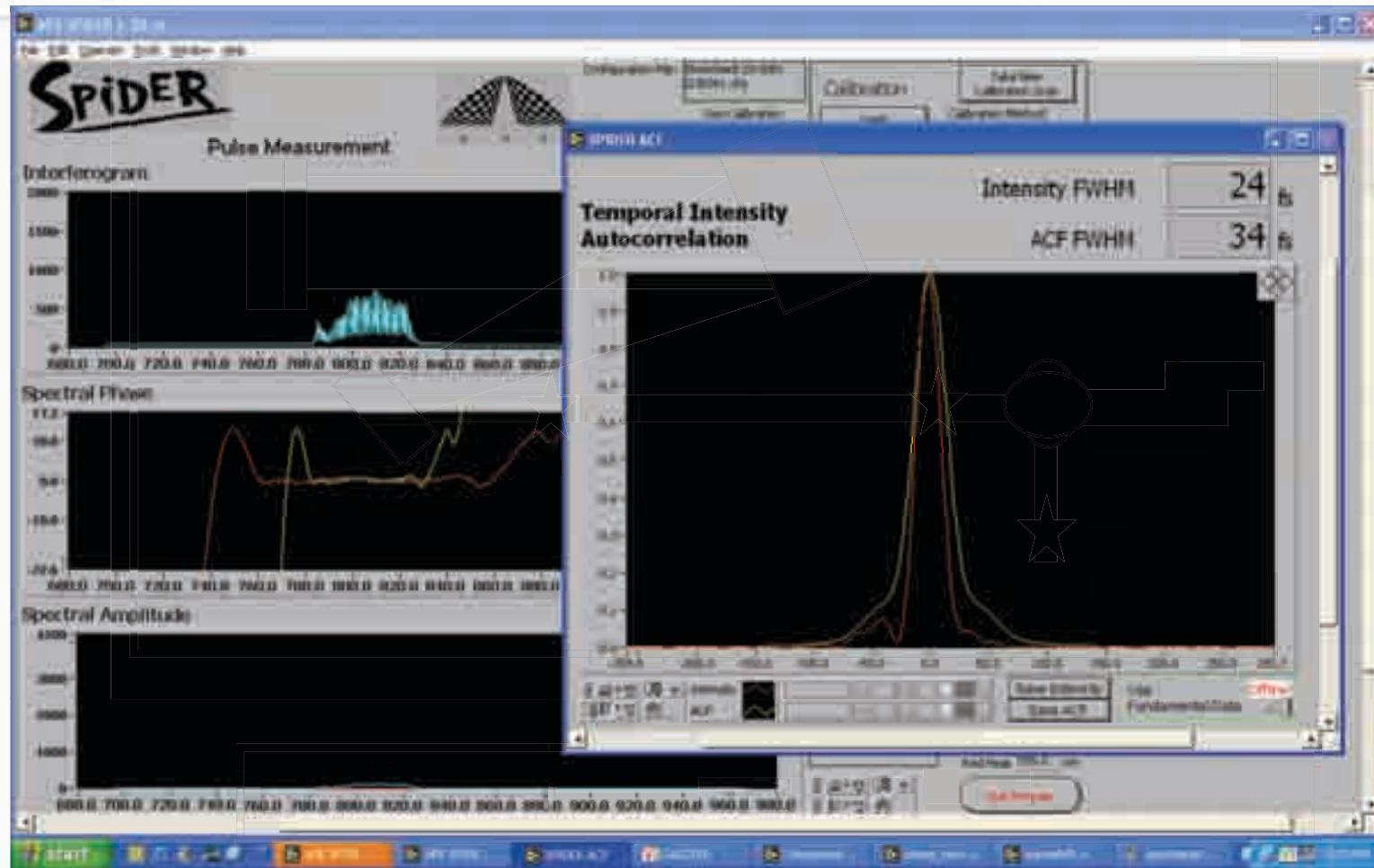


- Contrast level @ 200mJ well within specs;



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COMPRESSION COMPLETED



Pulse duration with the **test** compressor
Spider measurements
• natural duration < 55 fs
• corrected duration < 25 fs



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SUMMARY OF FLAME LASER

Summary of performance (to date)

- Energy before compression @ 7 J
- Vacuum compressor transmission > 70%
- Pulse duration down to 23 fs
- ASE Contrast ratio: better than 2×10^9
- Pre-Pulse Contrast better than 10^8
- RMS Pulse Stability @ 0.8 %
- Pointing Stability (incl. path) < 2 μ rad

➤ Enhancement of pumping configuration/extraction efficiency;
➤ Full vacuum compression test to be performed at LNF shortly;



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SELF-INJECTION TEST EXPERIMENT (SITE)



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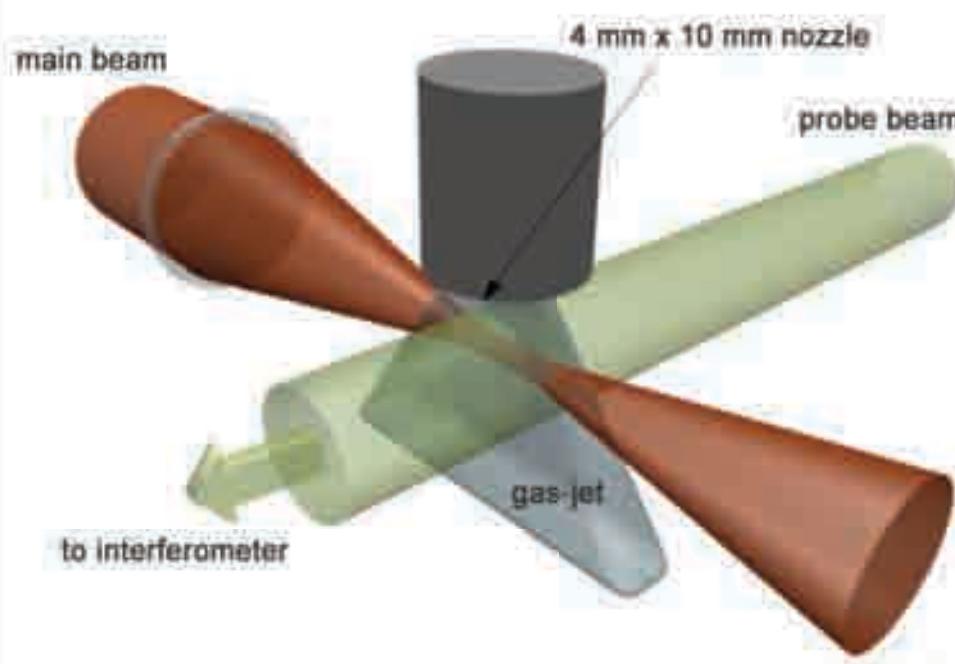
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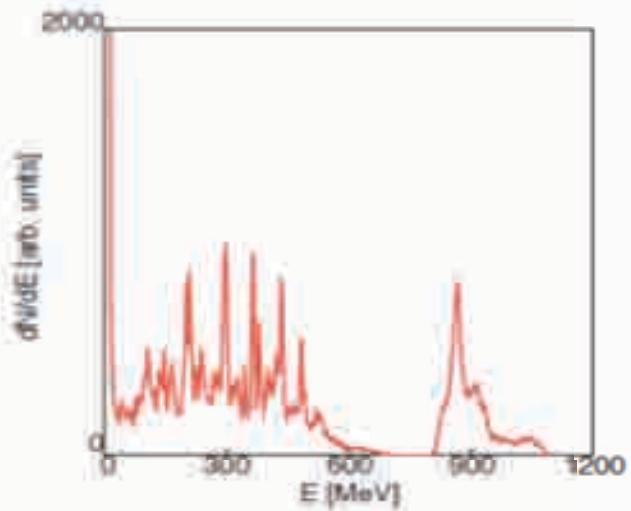
GeV ELECTRON ACCELERATION

Main set up parameters

$L_{\text{gas jet}}$ [mm]	n_e [e/cm ³]	τ [fs]	I_0 [W/cm ²]	w_0 [μ m]
4	$3 \cdot 10^{18}$	30	$5.2 \cdot 10^{19}$	16



Calculated electron spectrum



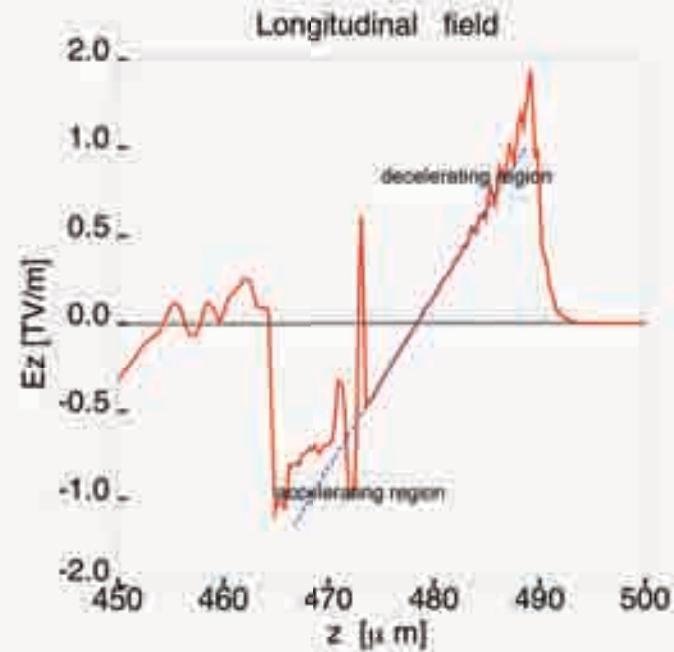
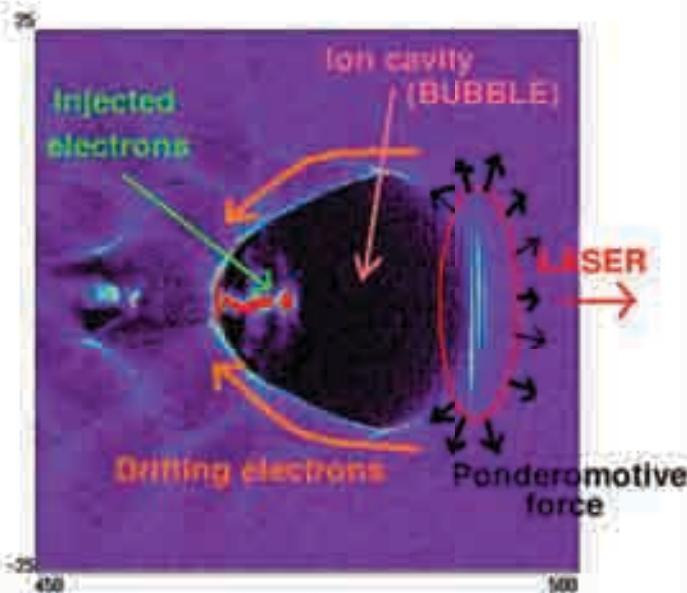
Goal: 0.9 GeV in 4 mm

See: L.A. Gizzi et al., EPJ-ST, 175, 3-10 (2009)



NUMERICAL SIMULATIONS

- Nonlinear 3D regime (bubble) ^a



- $R_{bub} \simeq O(\lambda_p) \quad E_z^{(max)} \simeq 100\sqrt{n_0[\text{cm}^{-3}] \times a_0} \quad [\text{V/m}]$
- $\begin{cases} v_{elect} \simeq c \\ v_{bub} \simeq c(1 - 3\omega_p^2/(2\omega_0^2)) < v_{elect} \Rightarrow \text{acc. length is finite + monochromaticity} \end{cases}$

^aS. Gordienko and A. Pukhov, Phys. Plas. 12 (2005) / W. Lu et al. PRSTAB 10 (2007)

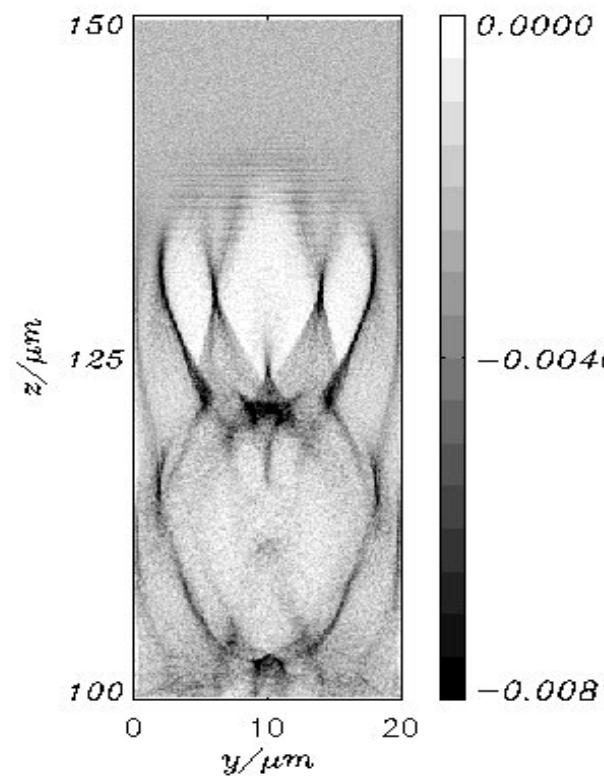


PSC RUNS FOR S.I.T.E.

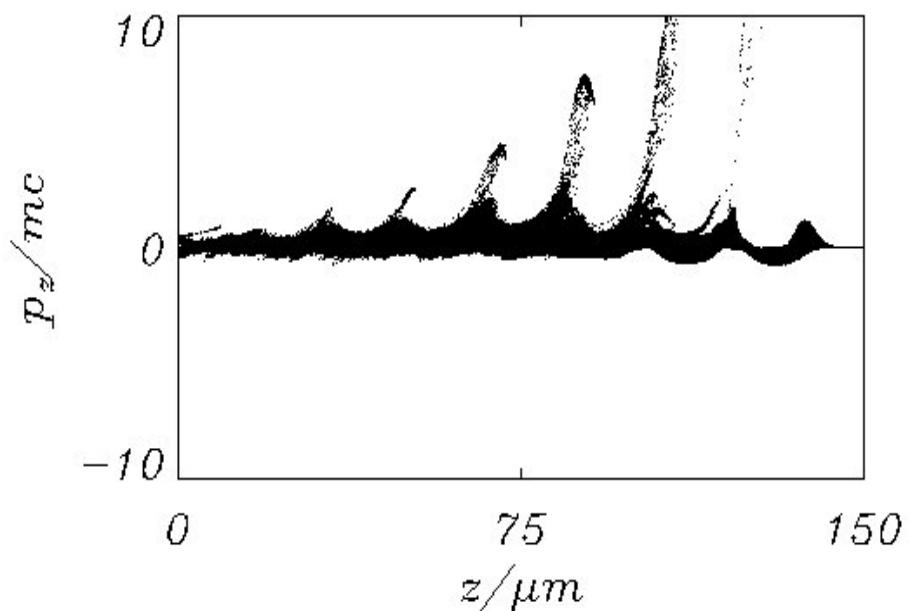
IN PROGRESS ...

by N.Pathak, L.Labate, T. Levato ...

$t=555.052\text{fs}$
 $x=9.94975\mu\text{m}$
 $\max=0.00000$
 $\min=-0.0161144$



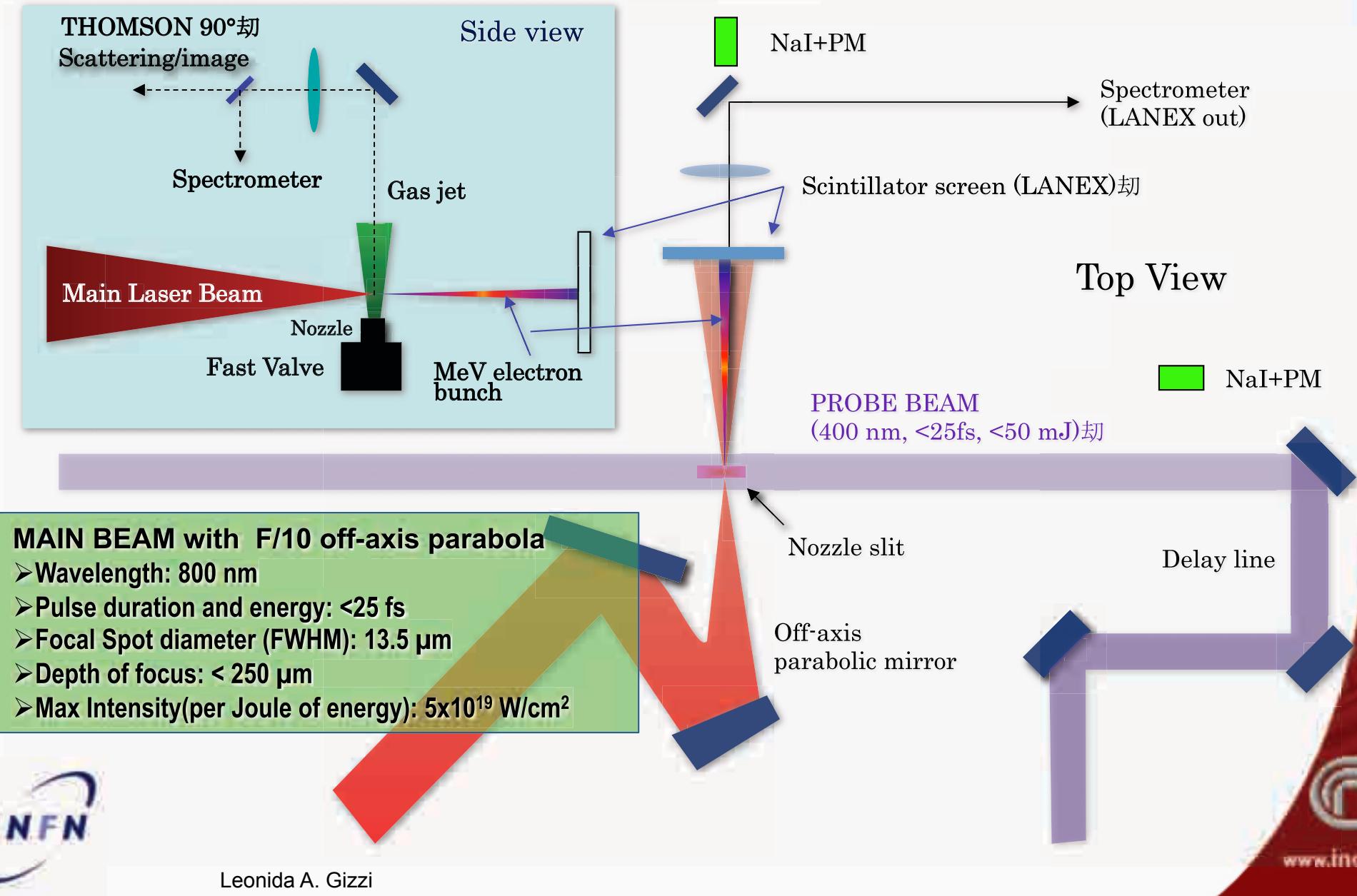
$t=555.051\text{fs}$
 $x=9.84925-10.0503\mu\text{m}$
 $y=-0.100503-20.1005\mu\text{m}$
 $p_x=-1.00000-1.00000mc$
 $p_y=-10.0000-10.0000mc$
 $m=1.00000m_e$
 $q=-1.00000e^-$
 $N=8.47818e+08$



Need to run for longer axial and transverse length



SCHEMATIC EXPERIMENTAL SET UP





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FLAME TARGET AREA (FOR S.I.T.E.)



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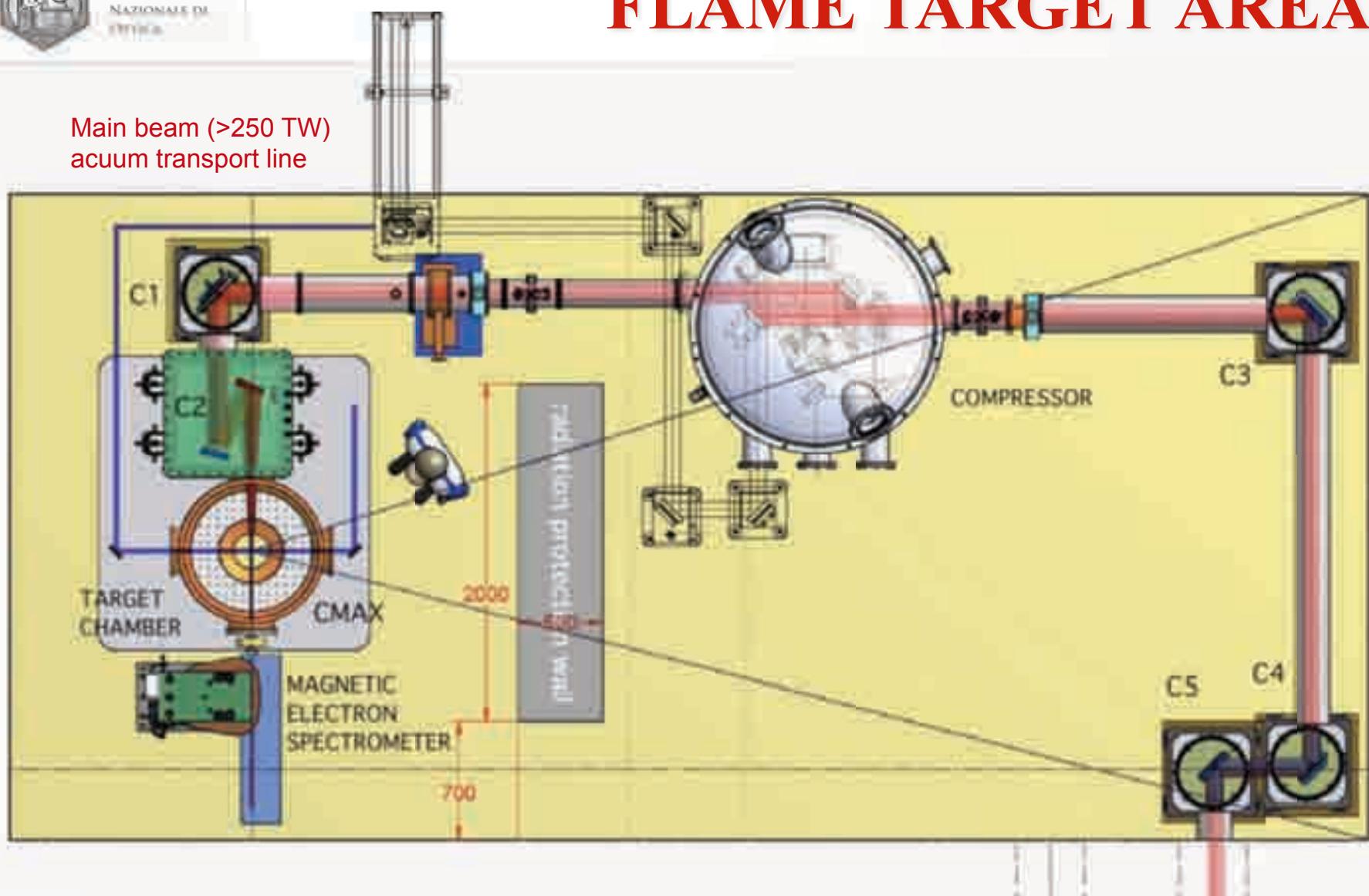
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FLAME TARGET AREA

Main beam (>250 TW)
accum transport line



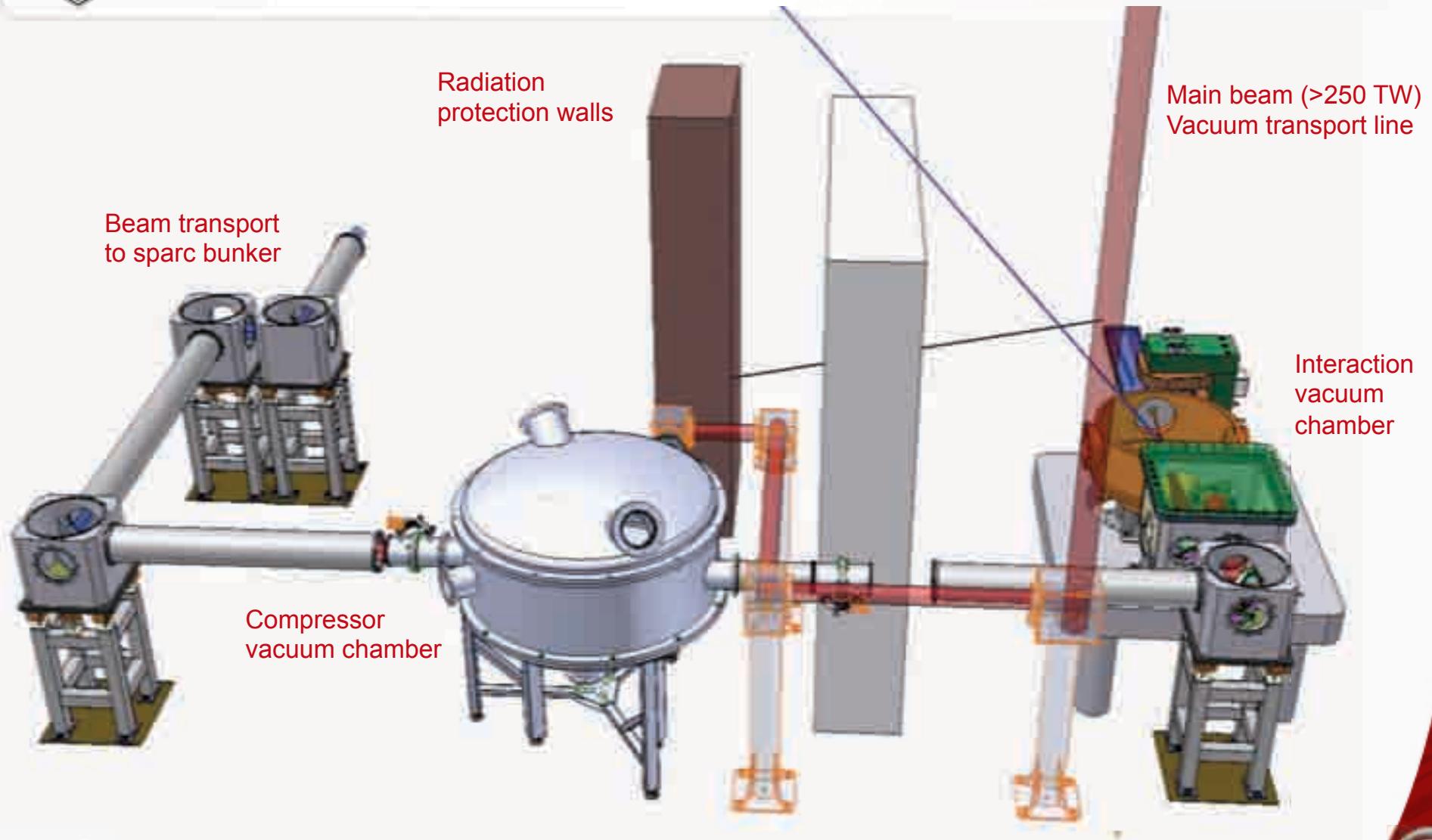
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FLAME TARGET AREA





FLAME TARGET AREA

Main beam (>250 TW)
Vacuum transport line

Radiation
protection walls

Main
turning
mirror

Off-axis
parabola

Interaction
vacuum chamber

Interaction point

Electron
spectrometer



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FLAME TARGET AREA (SITE)





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VERT. AND HORIZ. SHIELDING





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MAIN BEAM OPTICS IN PLACE

45 AND 15° TURNING MIRROR MOUNTED



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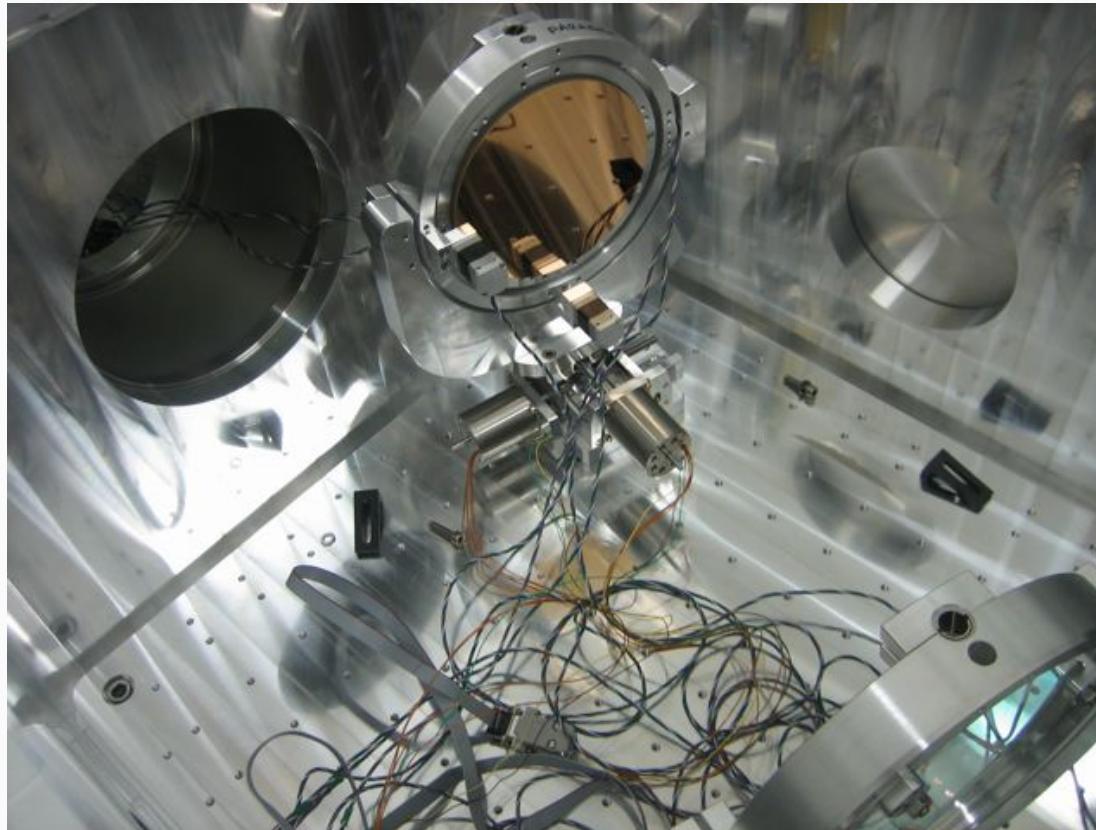
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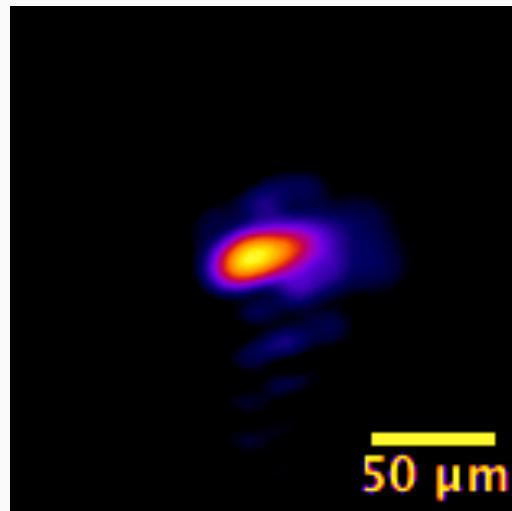
FOCUSING LASER

1 m focal length, 15° Off Axis Parabola (SORL)

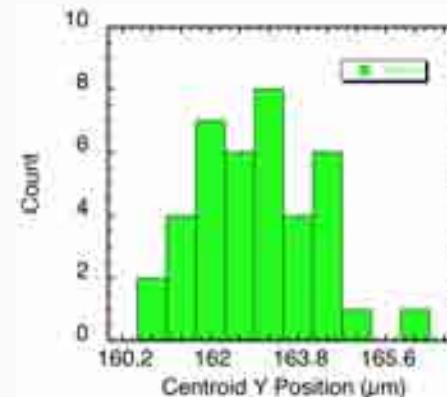
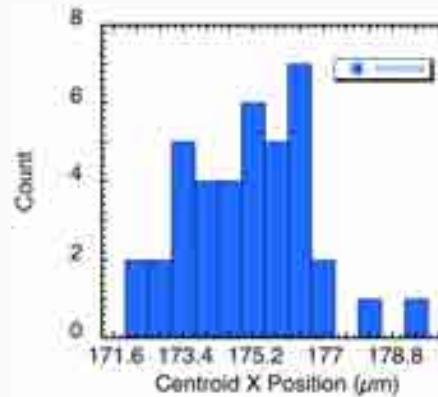




LASER AT TARGET CHAMBER CENTER



Pointing stability at TCC

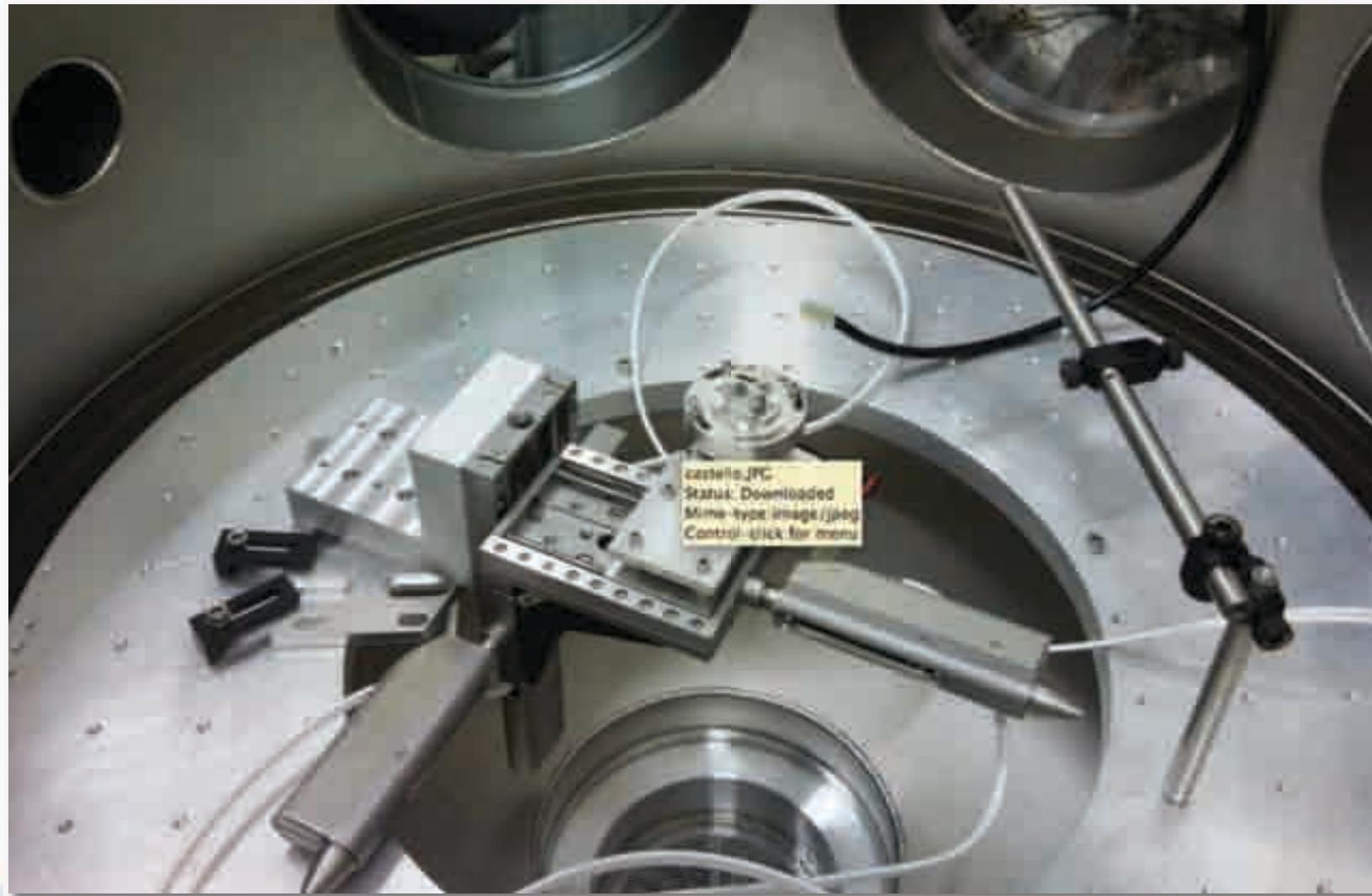


	Centroid Y	Centroid X
Minimum	160,89799	172,12
Maximum	166,22099	179,614
Points	39	39
Mean	162,9351	175,0372
Median	162,995	175,244
RMS	162,93927	175,04455
Std Deviation	1,18026	1,6241748
Variance	1,3930138	2,6379437
Std Error	0,18899286	0,26007611



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GAS JET TARGET IN PLACE



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AGENDA FOR NEXT WEEKS

- Full power FLAME test: transport, compression, OAP focusing (no target);
- Laser performance test at output: far field, contrast, width, phase distortion, measurements ... prepare for adaptive optics;
- Completion and test of HW and SW control and diagnostics;
- Completion of hardware and registration for radioprotection, safety and control of operations;
- Laser on (gas-jet) target at >50 TW level.



PLANNED ACTIVITY 2/2

ATTIVITA COMMISSIONING FLAME E PLASMONX 2010-2011	LUG.	AGO.	SET.	OTT.	NOV.	DIC.	1° TRI '11	2° TRI '11	3° TRI '11	4° TRI '11
Acceleration with self-injection (SITE) - Laser Beam and Plasma Diagnostics										
Acceleration with self-injection (SITE) - Bunch production and characterisation with 1.2 mm gas-jet										
Acceleration with self-injection (SITE) - Bunch production and characterisation with 4.0 mm gas-jet,										
Acceleration with self-injection (SITE) - Bunch stability and control vs laser stability										
Commissioning FLAME: Assessment and validation of laser performance at interaction focus point										
Thomson Scattering: Installation of additional e-beam line and delivery of laser beamline										
FAST: Installation of laser-linac sync										
Thomson Scattering: integration of target chambre components and X-ray source optimisation										
Thomson Scattering: X-ray beam to users (BEATS)										
FLAME target area Maintenance + set up and preliminary tests for solid target experiments										
Ion acceleration (LILIA) at FLAME target area										



SUMMARY

- FLAME commissioning entering experiment phase;
- Requirements on peak power, contrast, stability are challenging;
- Measurements to date show that parameters are within specs;
- Radiation protection measures in place – awaiting authorization
- Rapidly approaching self-injection LPA measurements



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THE END



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