PLASMONX: project status

Danilo Giulietti

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On behalf of the PLASMONX Team

PLASMONX
LINEE GUIDA E MILESTONES

*COMMISSIONING FLAME

*SITE

*T.S. & EXTERNAL INJECTION

*SUPPORTO SPERIM. & TEORICO

*FORMAZIONE

*INSERIMENTO INTERNAZIONALE

*WORKSHOP @ LNF, PRIMAVERA 2010

Contents

- FLAME lab general layout;
- An overview of the laser system;
- FLAME target area for laser-only experiments;
- Primo esperimento Italiano di LPA
- Self-injection Test Experiment;
- External injection;
- Agenda July ’09 – March 2010
- RICHIESTE FINANZIARIE
- Conclusions

The FLAME laboratory

27th March 2007 –
beginning of construction

23rd June 2008 –
Building completed

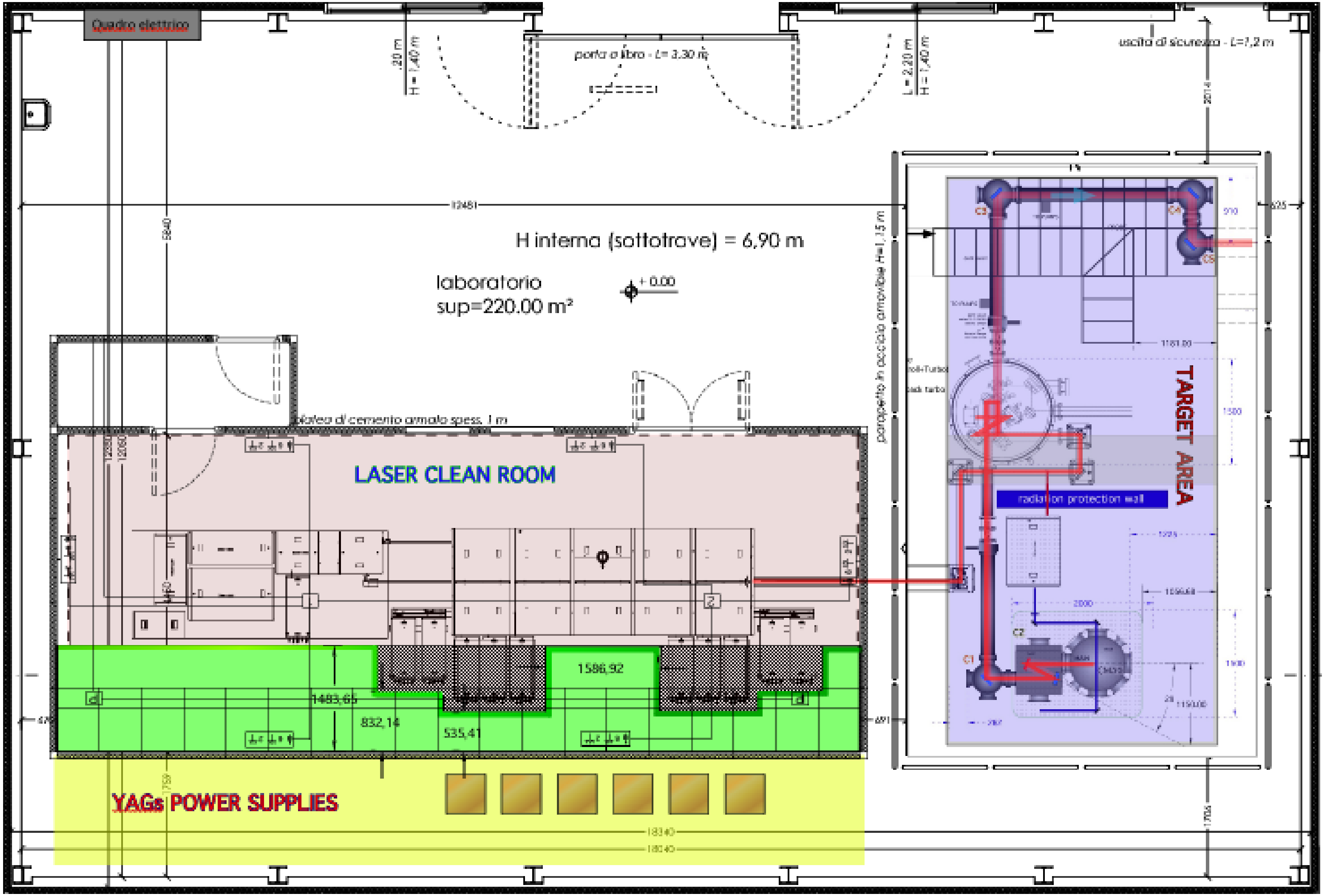
The FLAME laboratory - update

12th March 2009 –
delivery of laser

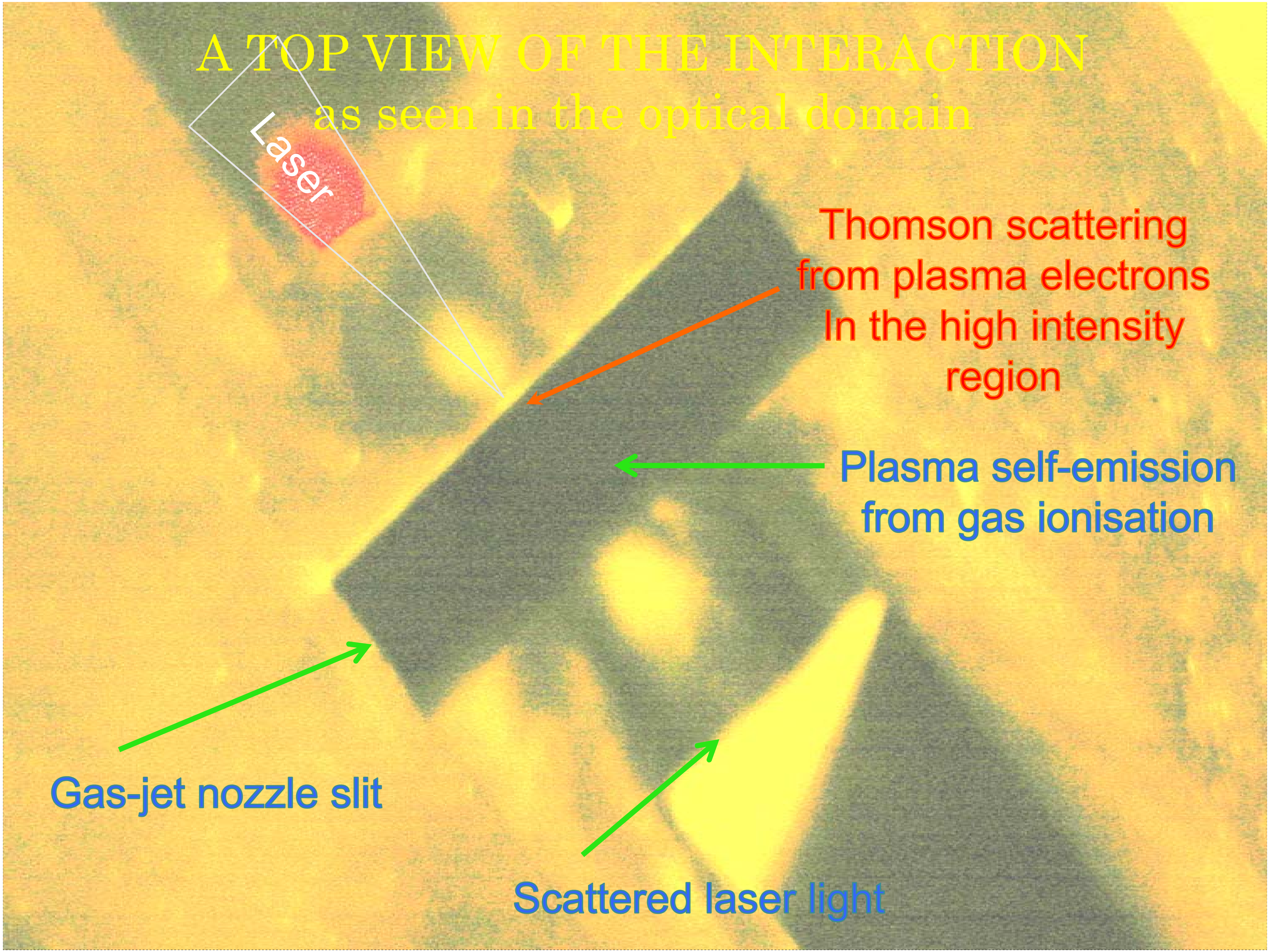
18th May 2009 –
start of Installation of clean room

10th June 2009 –
“Cold” laser installation

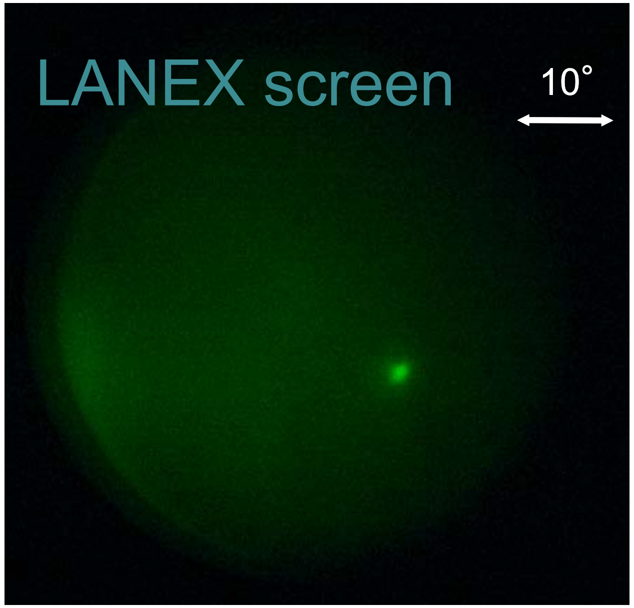
The FLAME laboratory – general layout

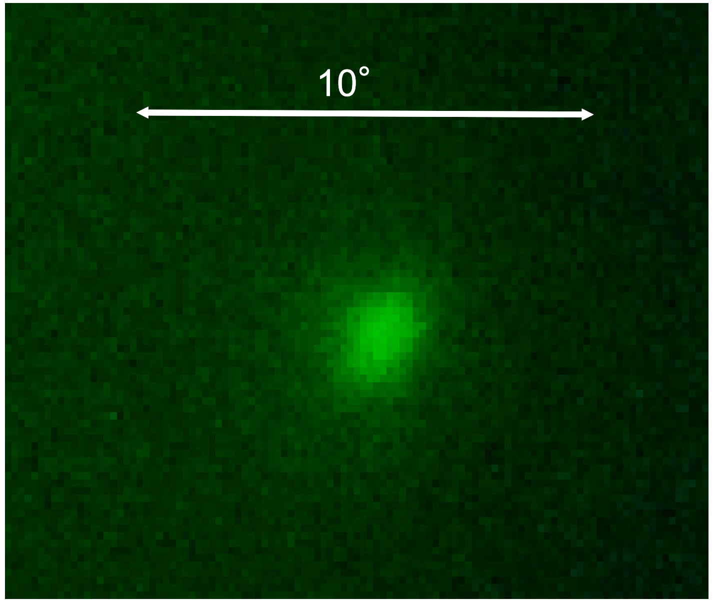


A TOP VIEW OF THE INTERACTION
as seen in the optical domain



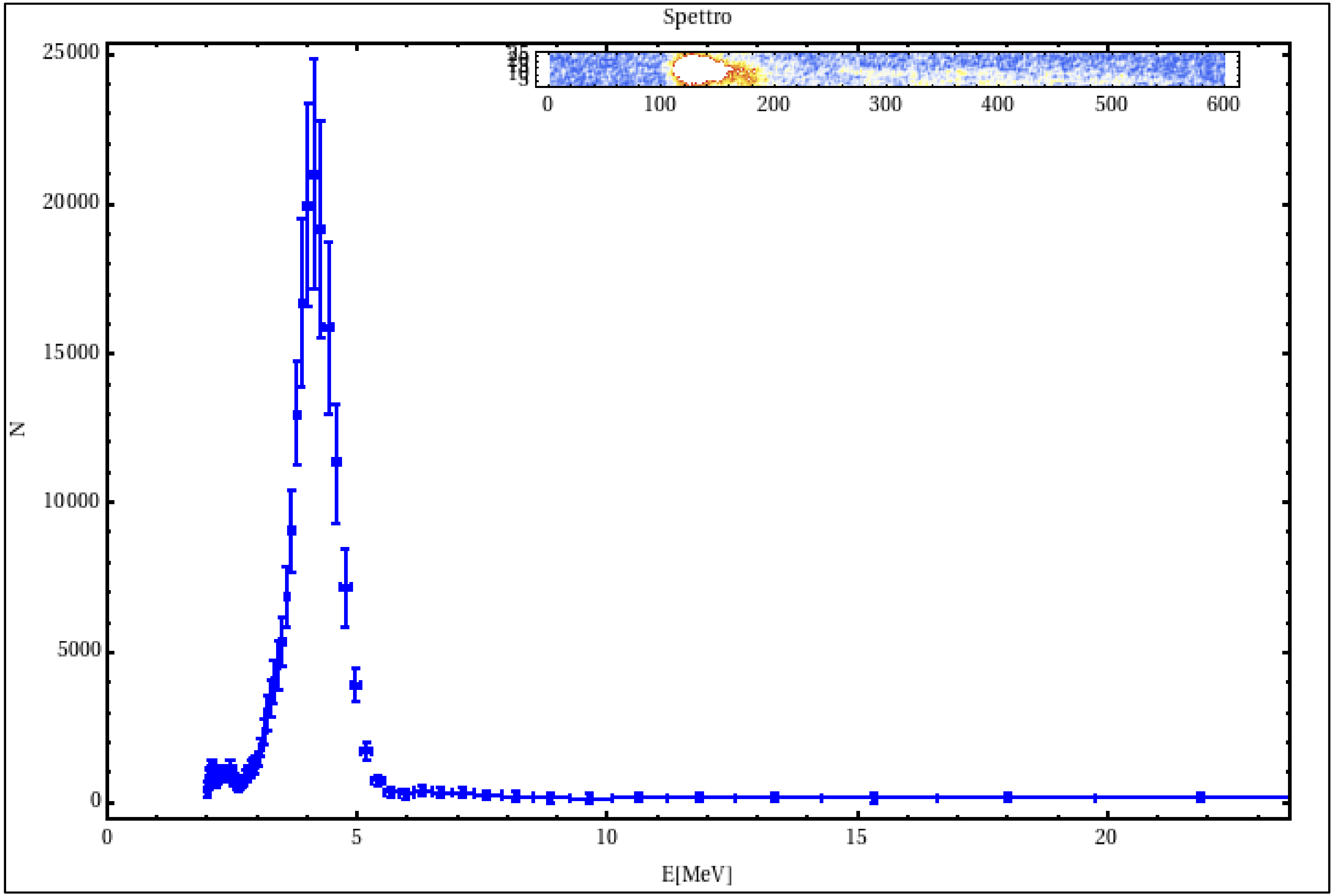
ELECTRON BEAM
He@50 bar





The LANEX screen shows a collimated electron beam.

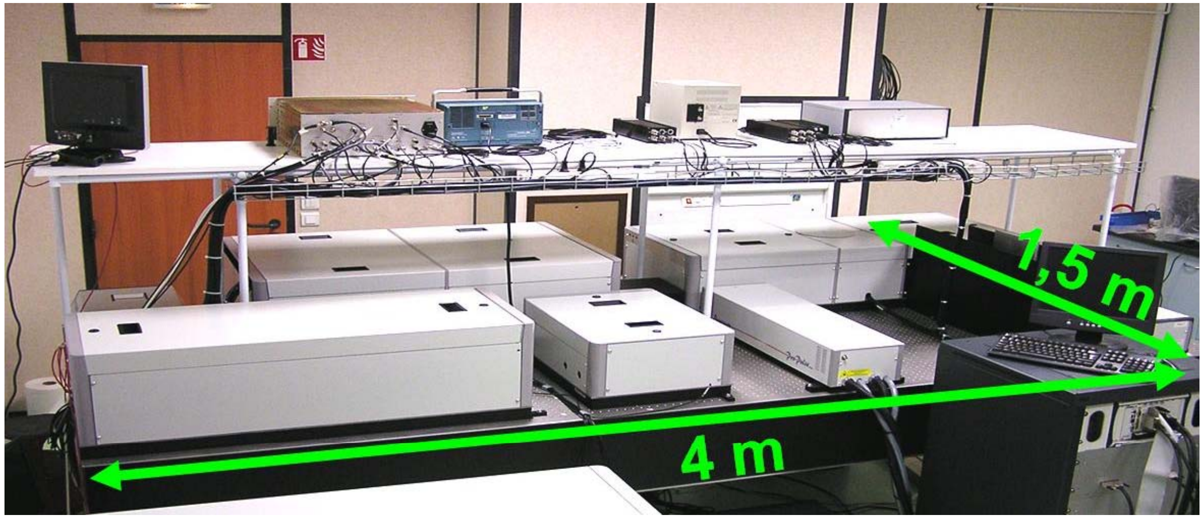
Electron spectrum



FLAME LASER

FLAME laser: specifications

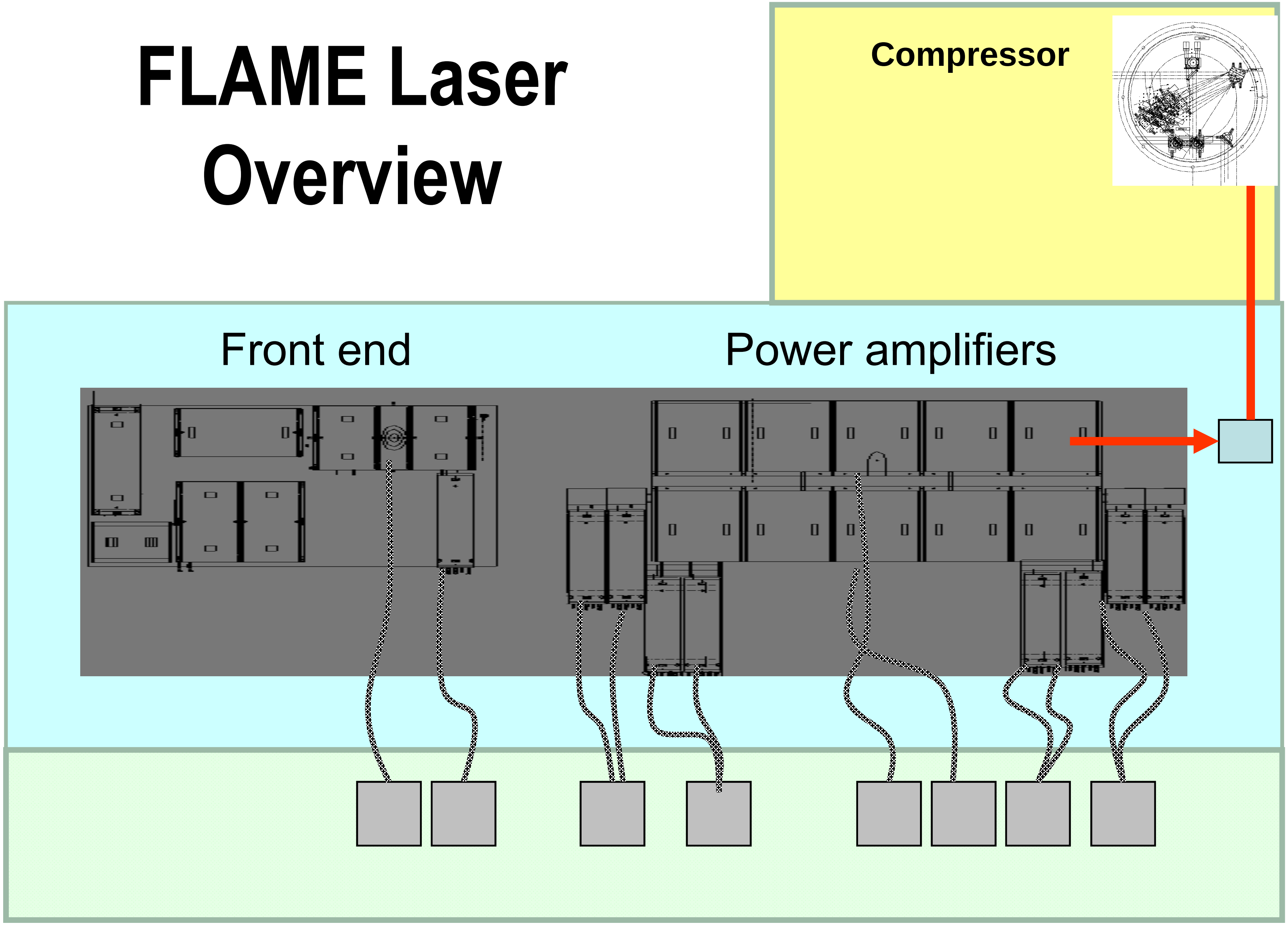
Repetition Rate	10 Hz
Energy (after compression)	up to 6 J (typ. exp. 5.6J)
Wavelength	800 nm
Pulse duration	down to 20 fs (typ.23 fs)
Peak power	up to 300 TW
ASE contrast	$< 10^{10}$
Pre-pulse contrast	$< 10^{-8}$



Front end @

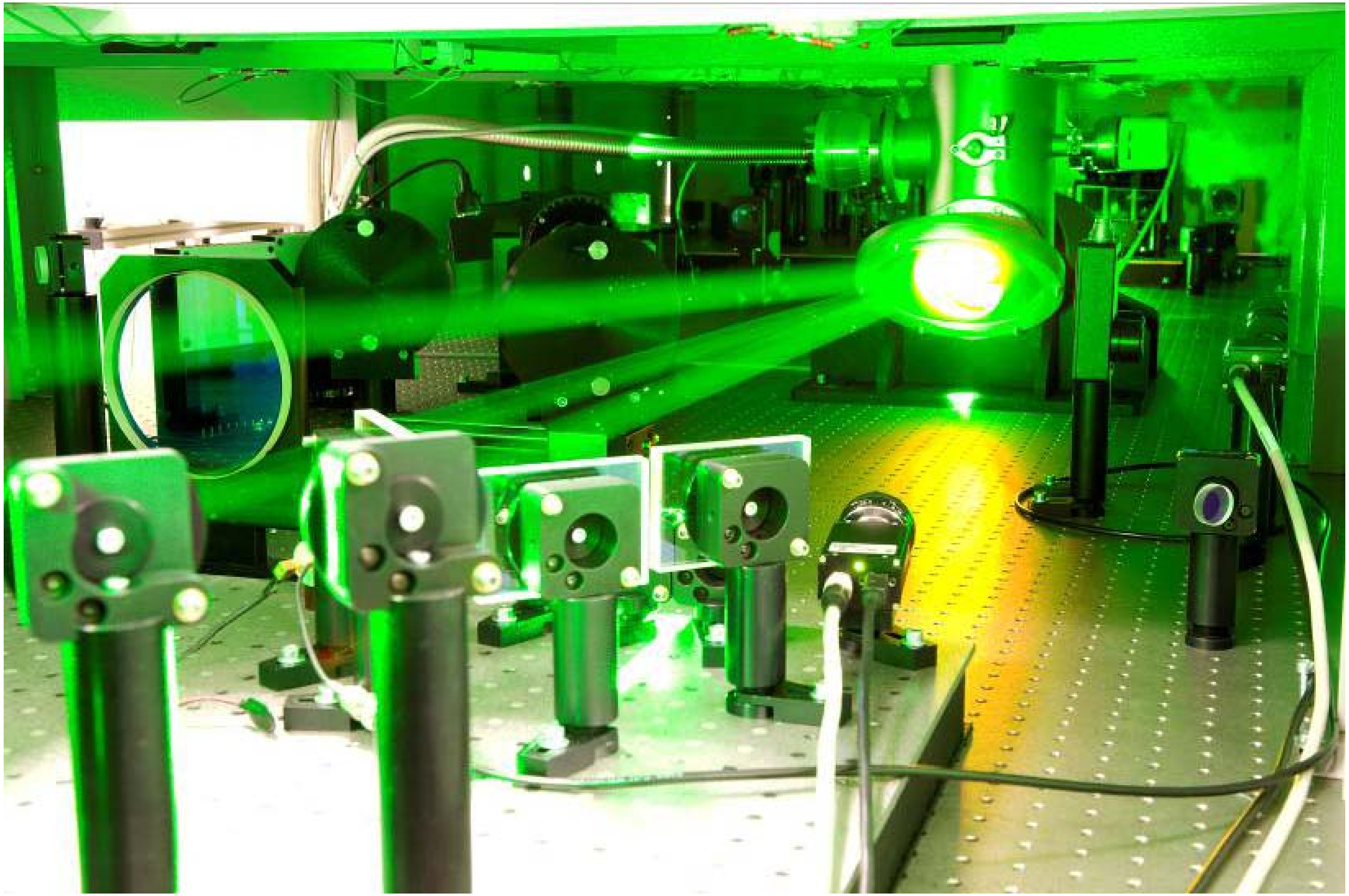
Amplitude TECHNOLOGIES

FLAME Laser Overview



Amplitude TECHNOLOGIES

AMPLIFIER #3 – THE POWER AMPLIFIER



Amplitude
TECHNOLOGIES

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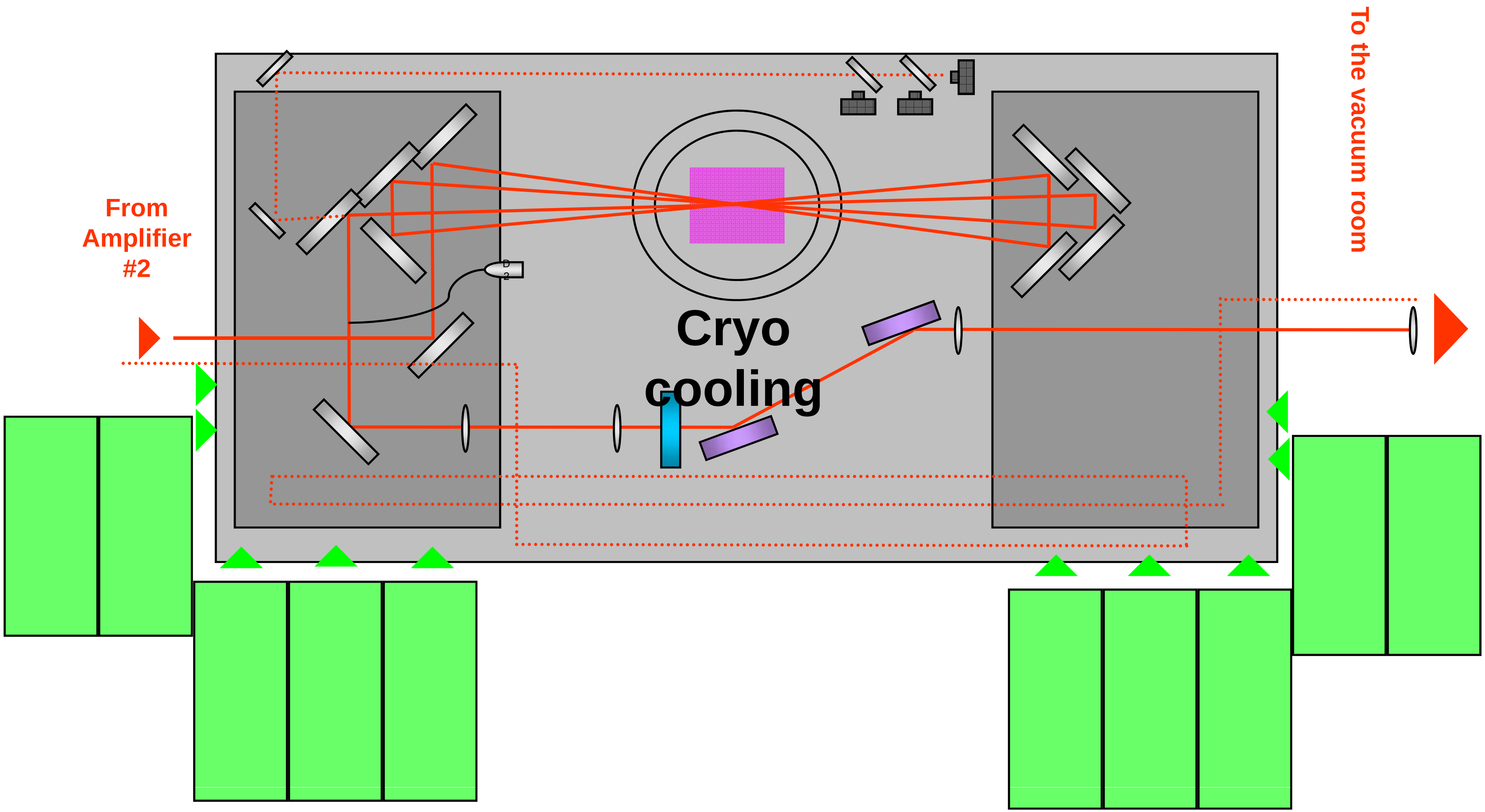
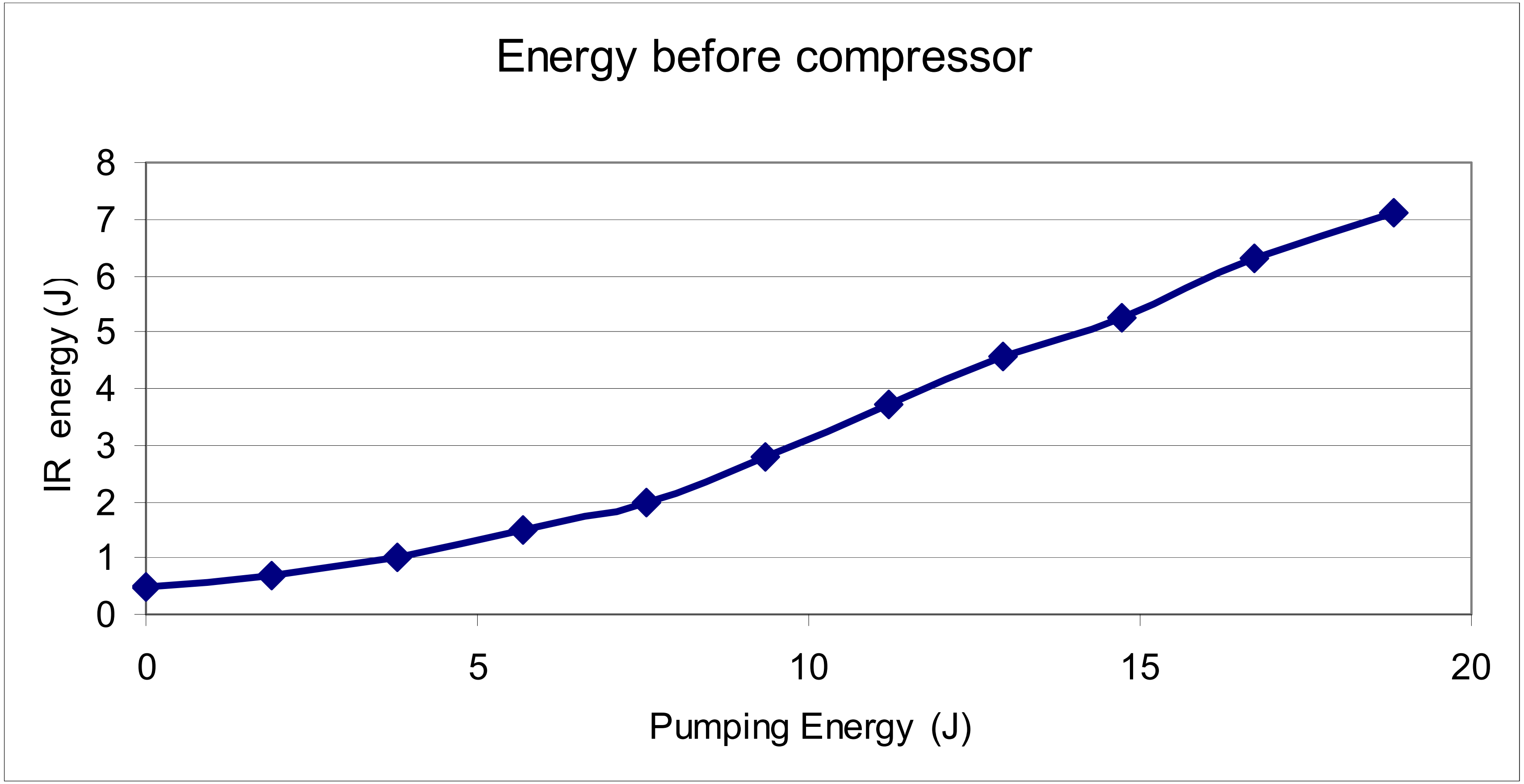
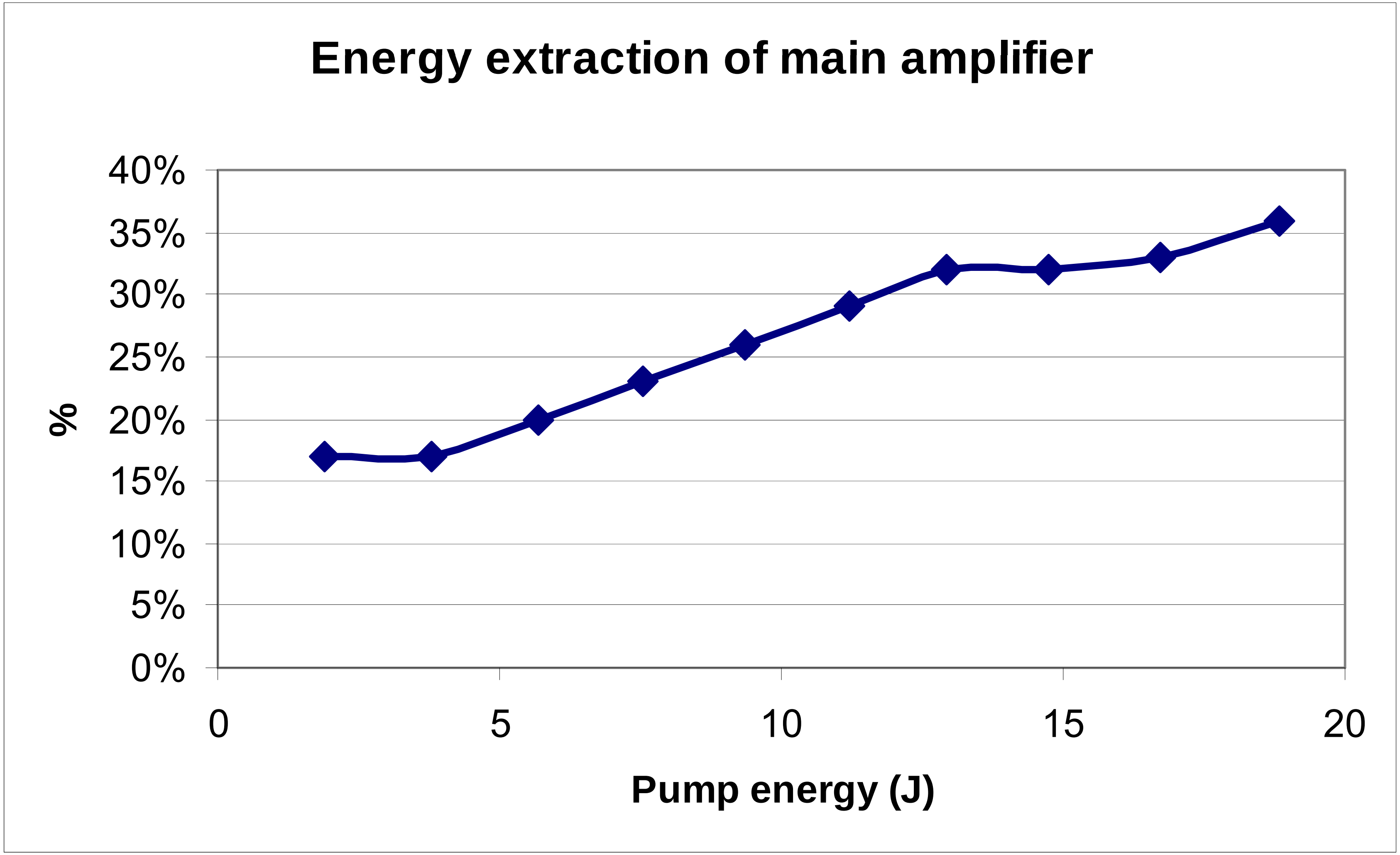


POWER AMPLIFIER – output energy



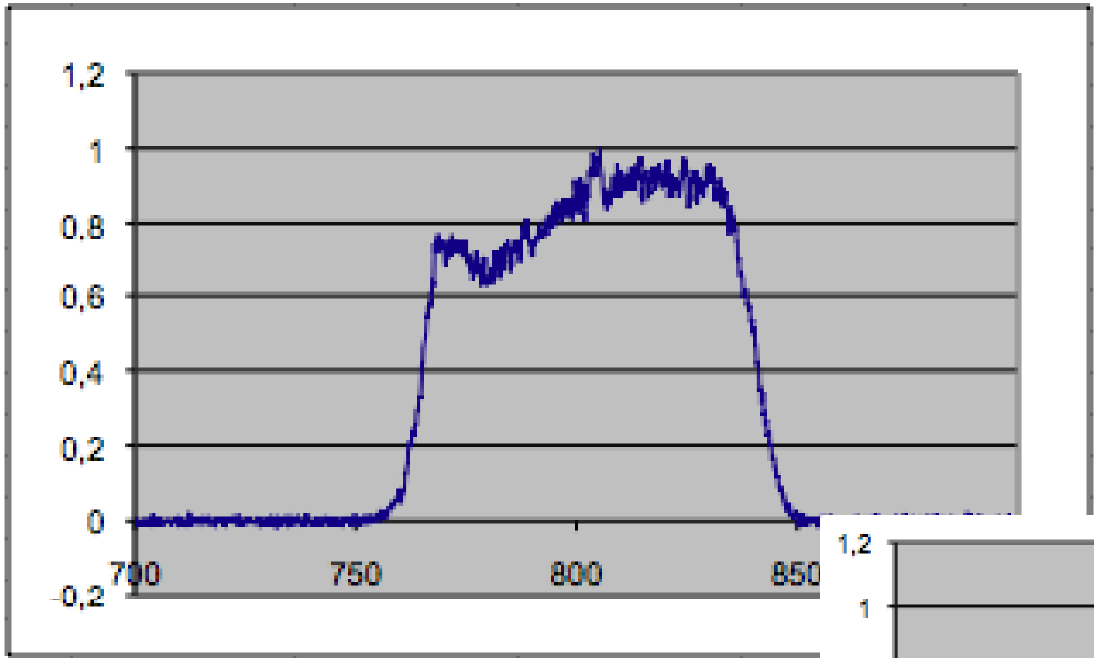
POWER AMPLIFIER – extraction efficiency



Amplitude TECHNOLOGIES

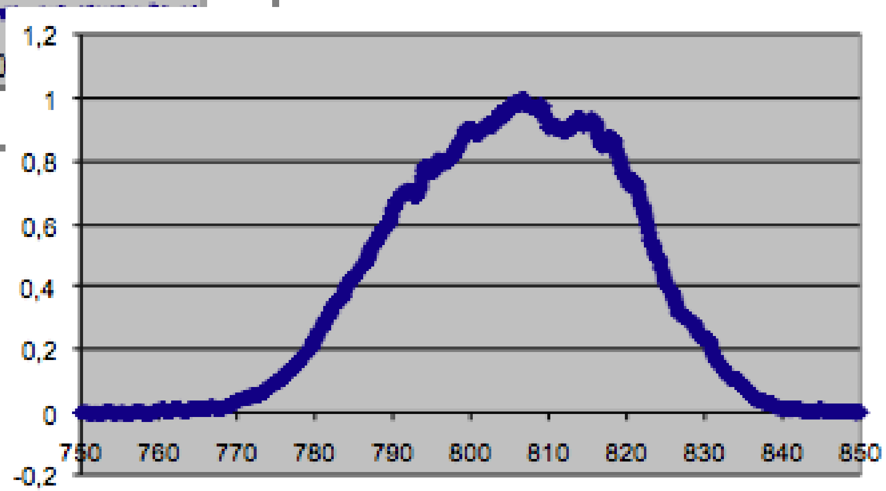
POWER AMPLIFIER - spectrum

7J spectrum



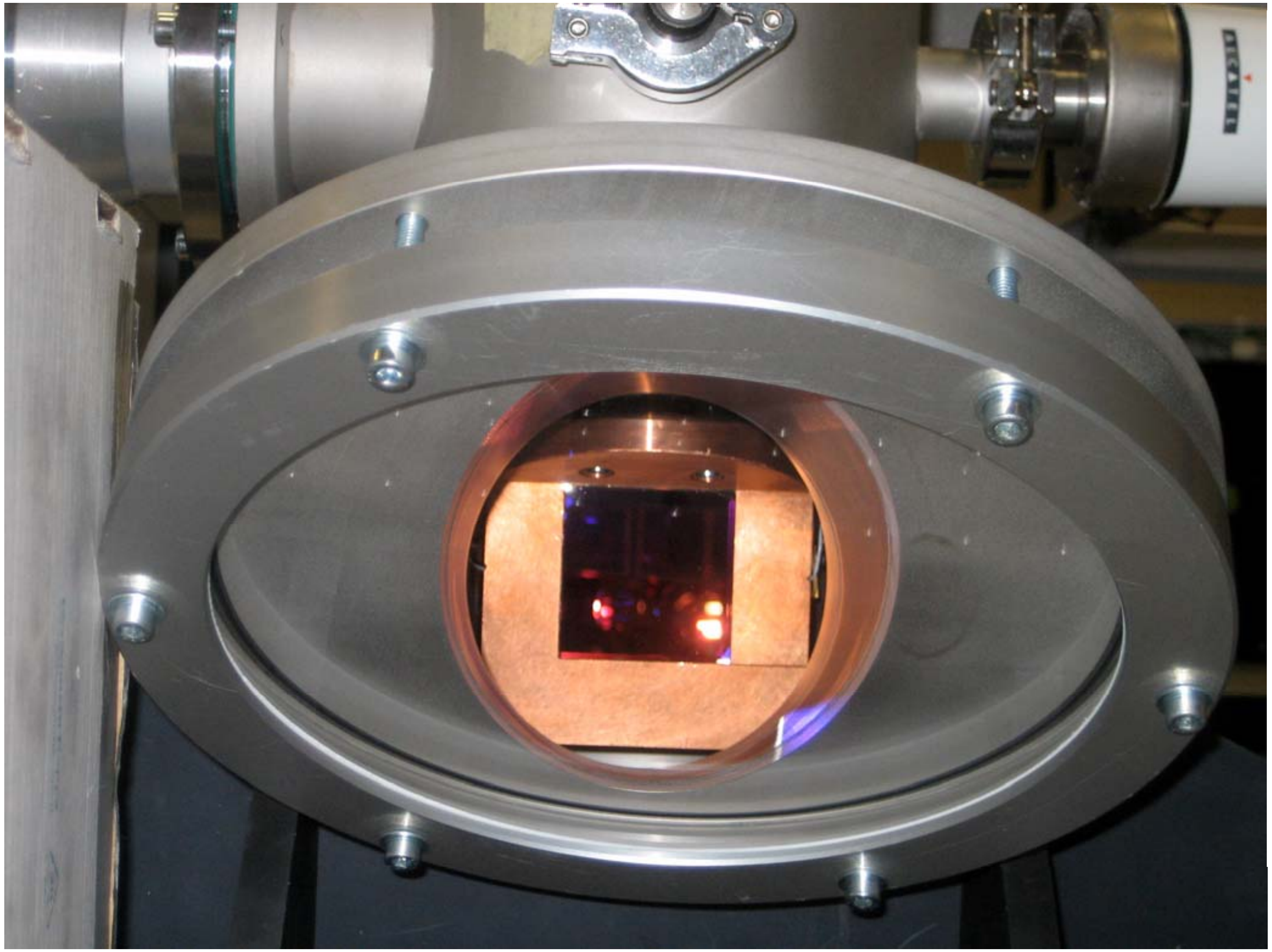
With mazzler

Without mazzler

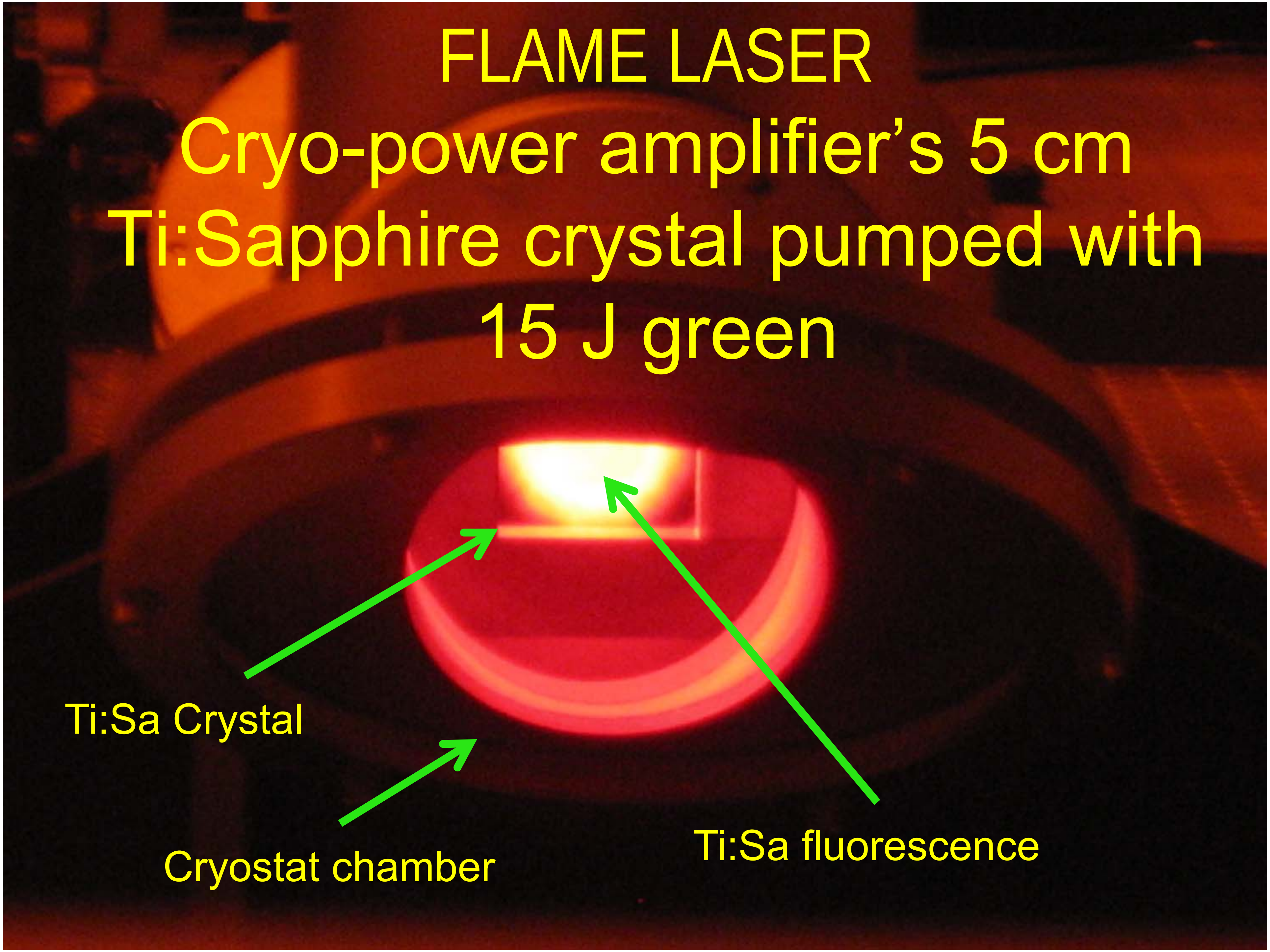


POWER AMPLIFIER

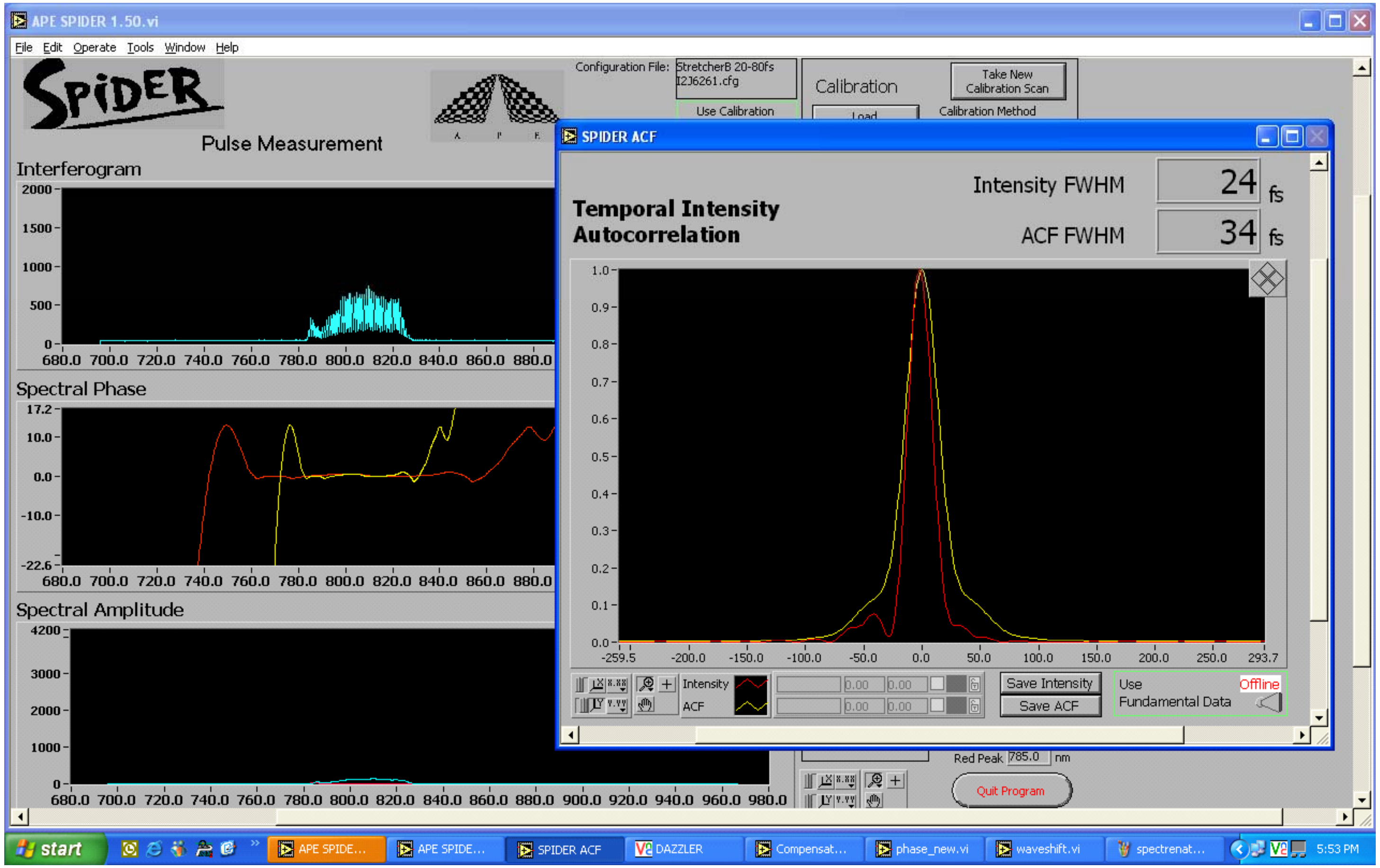
Pictures of the Ti:Sa crystal inside the cryostat



Amplitude TECHNOLOGIES


FLAME LASER
Cryo-power amplifier’s 5 cm
Ti:Sapphire crystal pumped with
15 J green
Ti:Sa Crystal
Cryostat chamber
Ti:Sa fluorescence

THE COMPRESSOR: spectral control



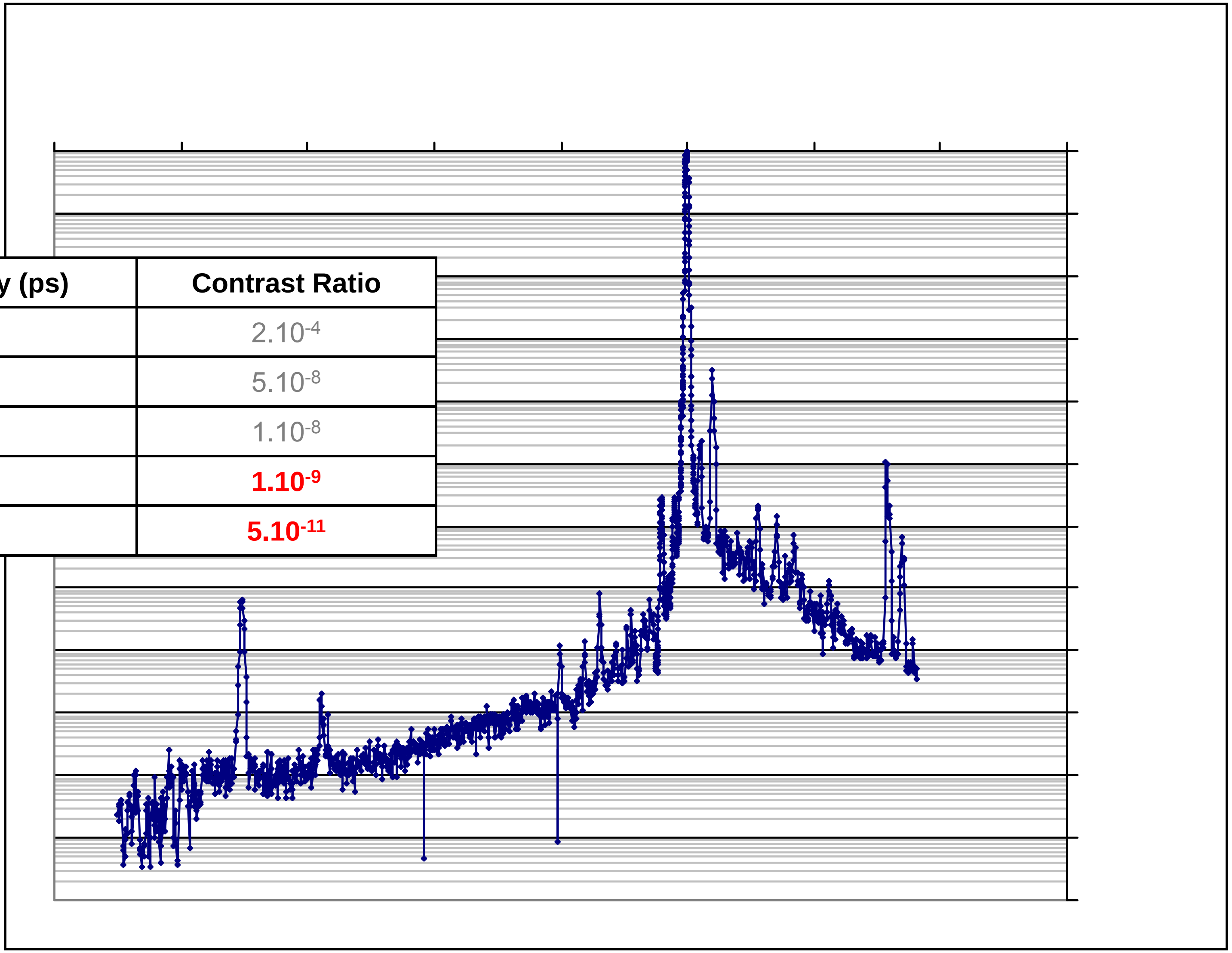
Pulse duration with the test compressor

Spider measurments

- natural duration < 55 fs
- corrected duration < 25 fs

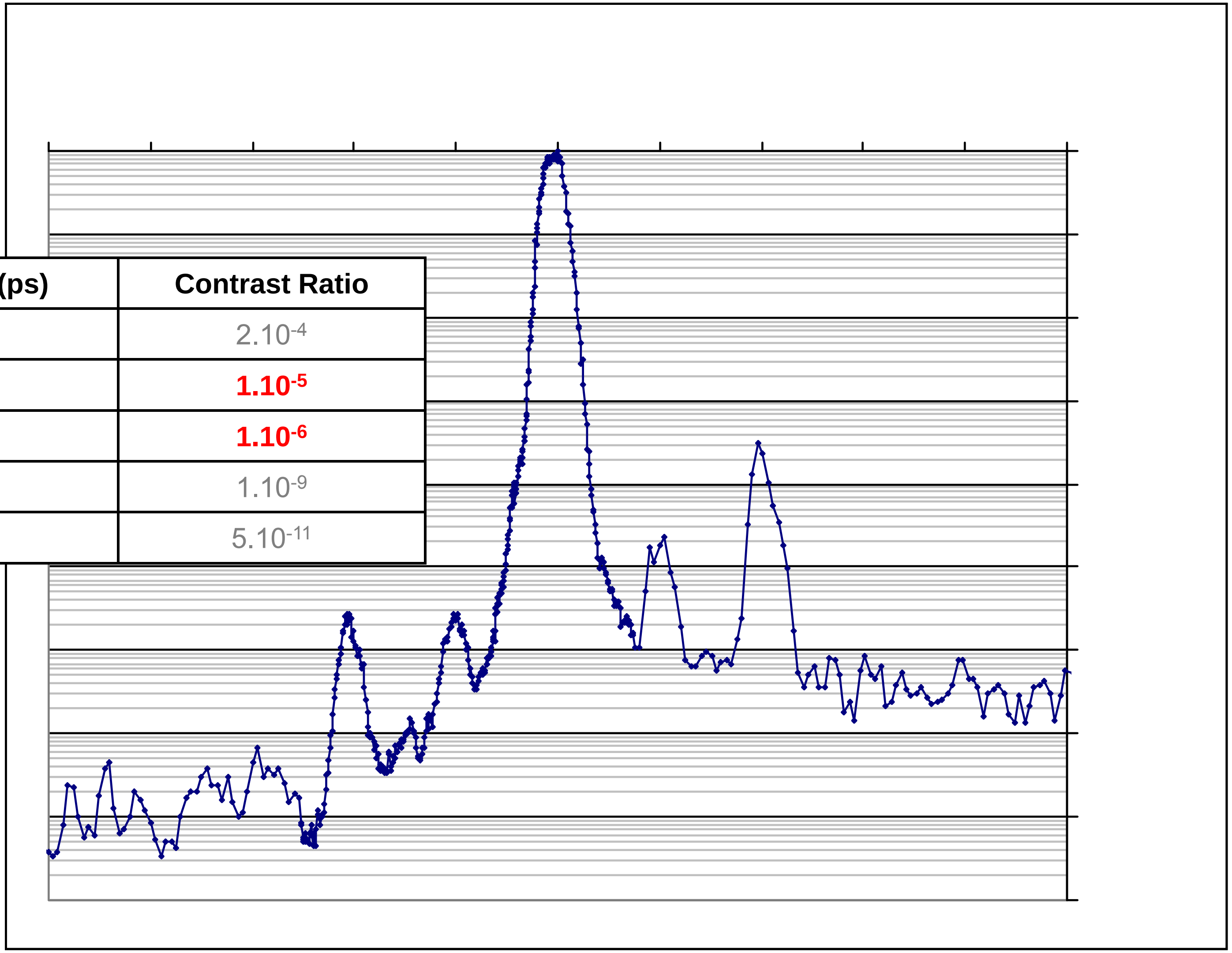
Amplitude TECHNOLOGIES

THE COMPRESSOR sub-ns contrast



Time Delay (ps)	Contrast Ratio
-1	2.10^{-4}
-5	5.10^{-8}
-10	1.10^{-8}
-150	**1.10^{-9}**
-450	**5.10^{-11}**

THE COMPRESSOR: ps contrast



Time Delay (ps)	Contrast Ratio
-1	2.10^{-4}
-5	**1.10^{-5}**
-10	**1.10^{-6}**
-150	1.10^{-9}
-450	5.10^{-11}

Amplitude TECHNOLOGIES

SUMMARY OF FLAME LASER

Summary of performances before shipping

- Energy before compression @ 7 J
- Vacuum compressor transmission > 70%
- Pulse duration @ < 25 fs
- ASE Contrast ratio @ 5.10^{-10}
- RMS Pulse Stability @ 0.8 %

➢ Enhancement of pumping configuration/extraction efficiency;

➢ Full vacuum compression test to be performed at LNF;

ENHANCING LASER FLEXIBILITY

POLARIZATION CONTROL (S, P, CIRCULAR)
Established contact with manufacturer (limiting factor: diameter and thickness of required crystals);

FREQUENCY CONVERSION (400 nm operation)
Same as above plus recent involvement in « Happie », LASERLAB Joint Research Activity (IPCF-CNR Subcontractor of LULI);

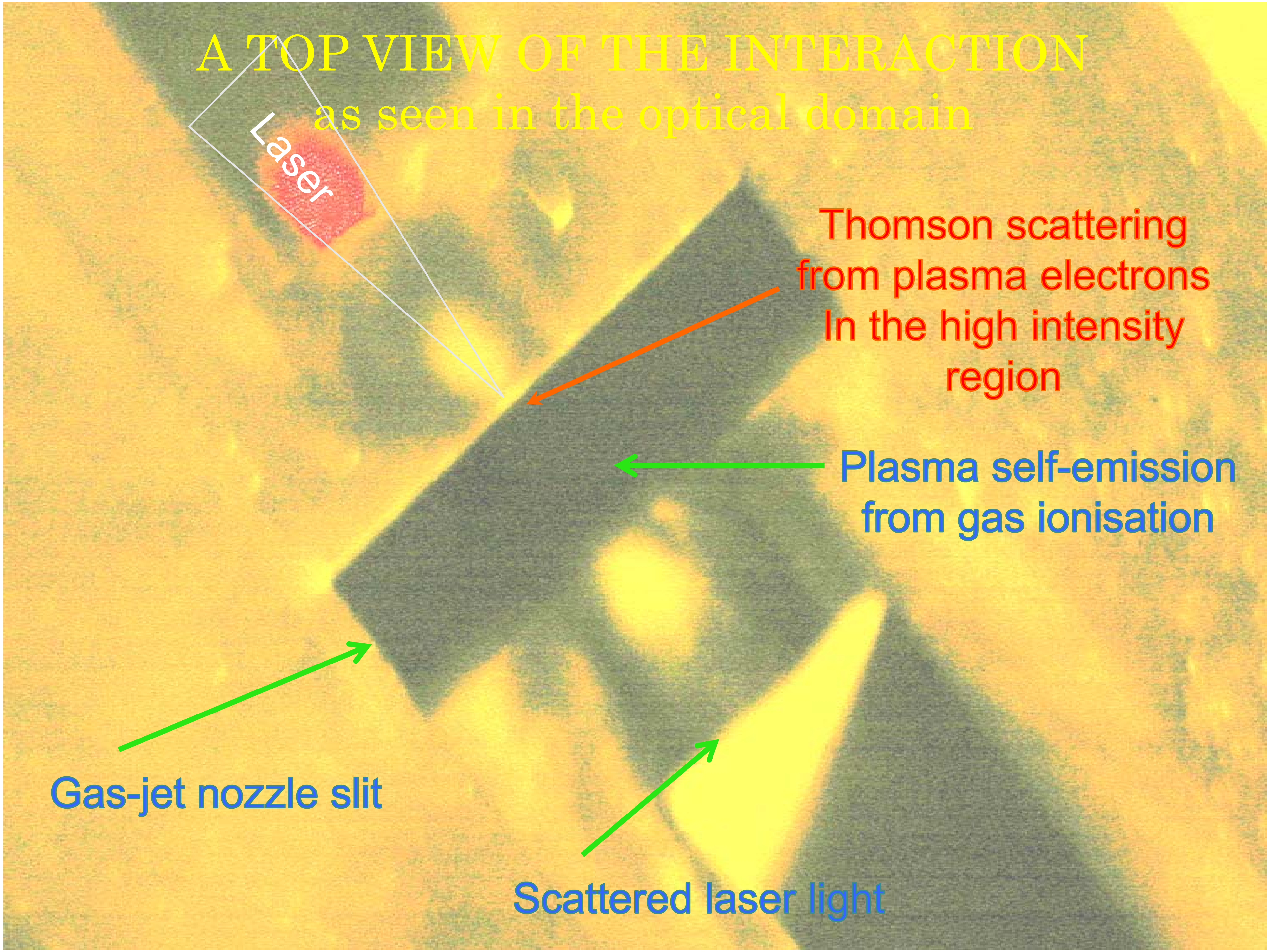
CONSTRAST ENHANCEMENT (plasma mirror, frequency doubling); collaboration with CEA-Saclay

ADAPTIVE OPTICS for focal spot quality control and tailoring, collaboration with CLPU-Salamanca

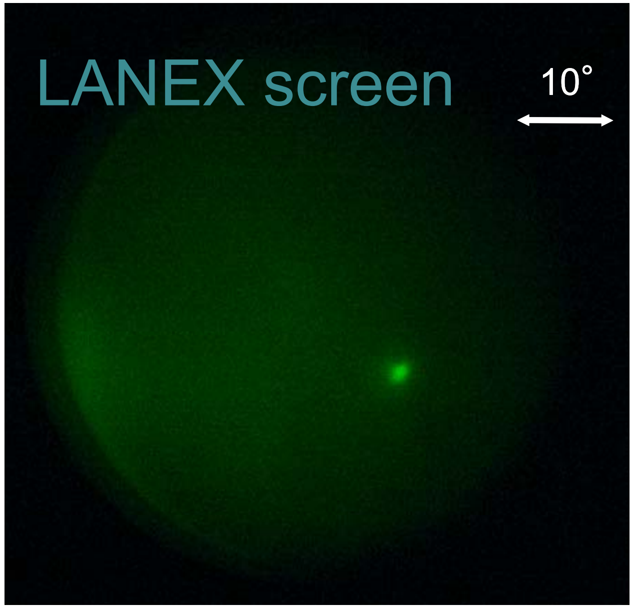
ULTRA-HIGH intensities ($\approx 10^{21}$ W/cm^2) with ellipsoidal plasma mirror …

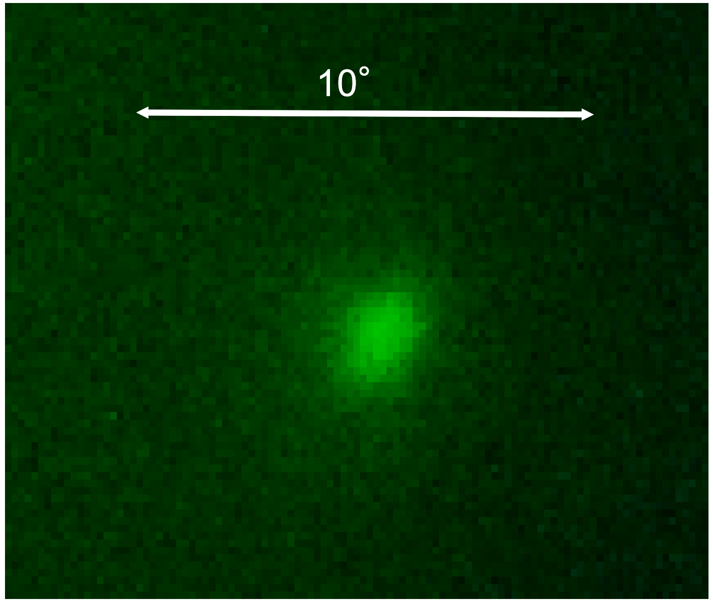
And more ….

PRIMO ESPERIMENTO TUTTO ITALIANO DI LPA A PISA


A TOP VIEW OF THE INTERACTION
as seen in the optical domain
Laser
Thomson scattering
from plasma electrons
In the high intensity
region
Plasma self-emission
from gas ionisation
Gas-jet nozzle slit
Scattered laser light

ELECTRON BEAM
He@50 bar





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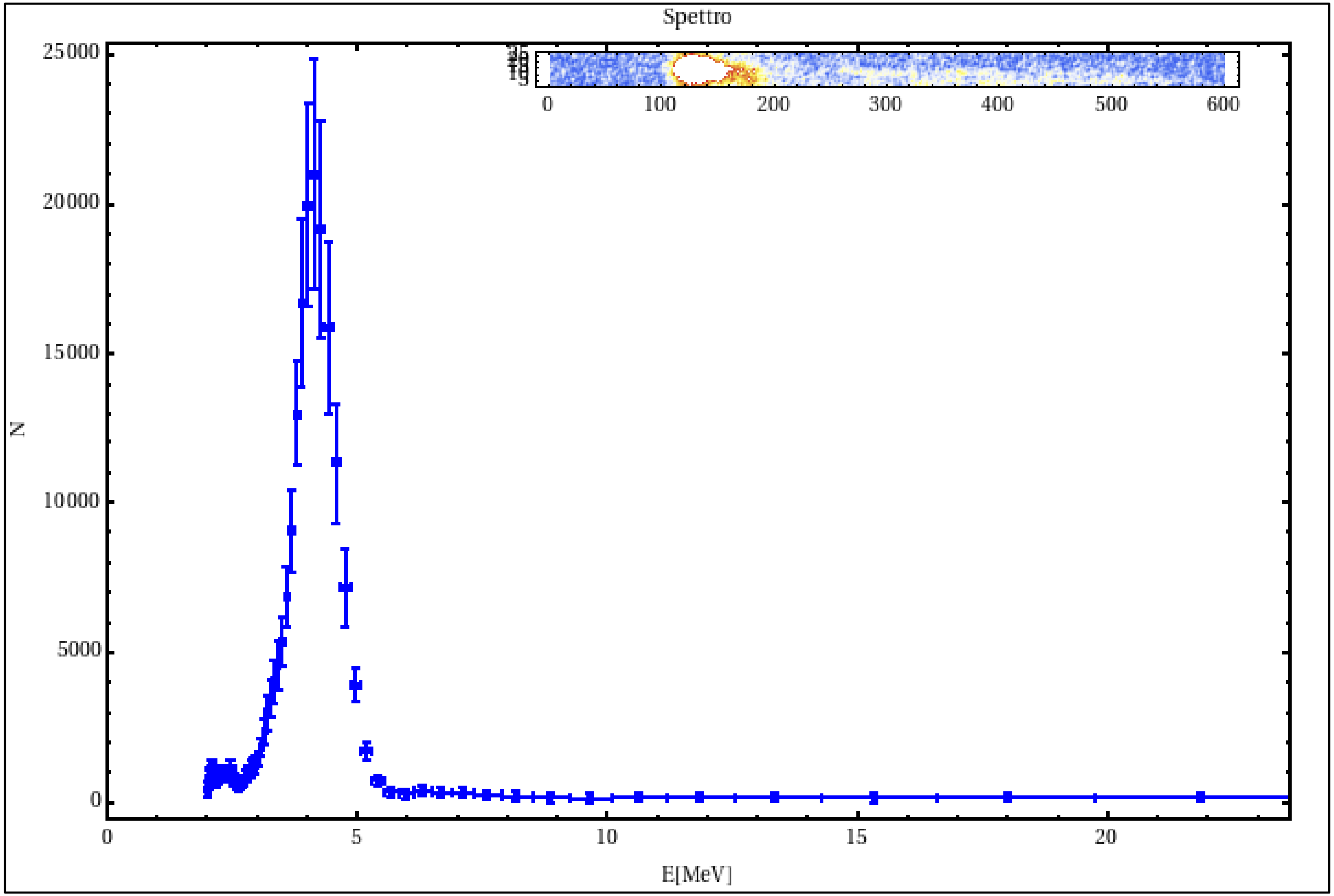
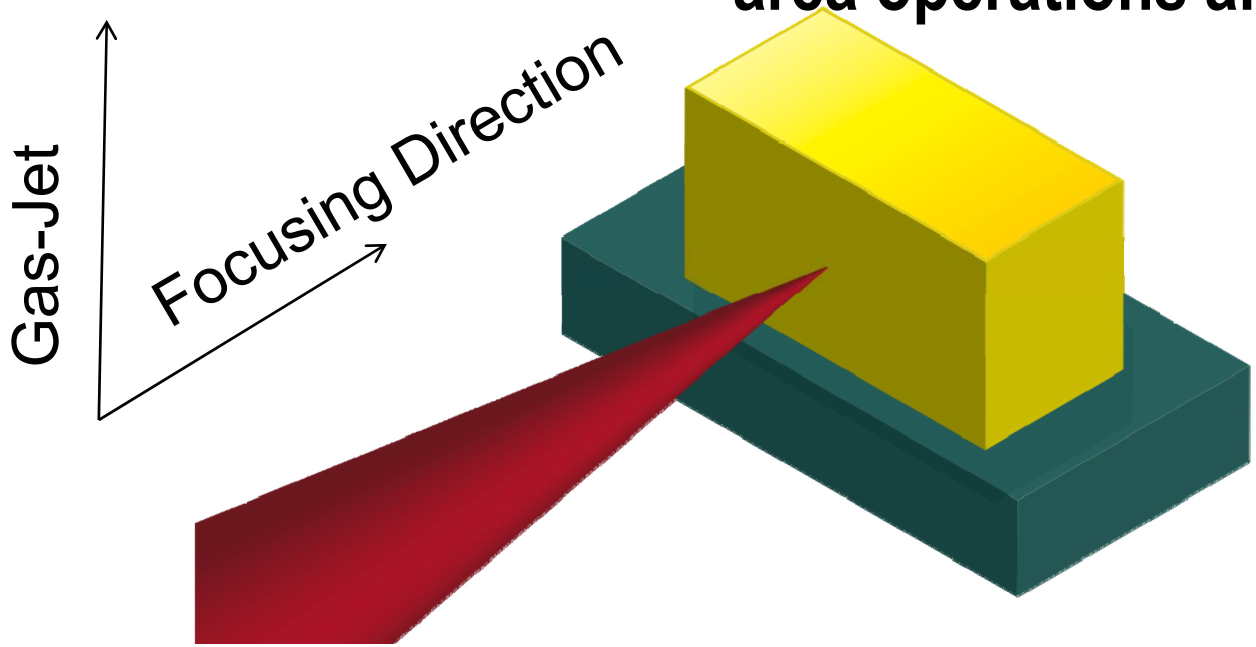


Self-Injection test experiment (SITE)

THE “TEST” SELF-INJECTION EXPERIMENT

<u>MAIN TASK</u>: establish performance of the FLAME laser system in real experimental conditions and test target area operations and procedures

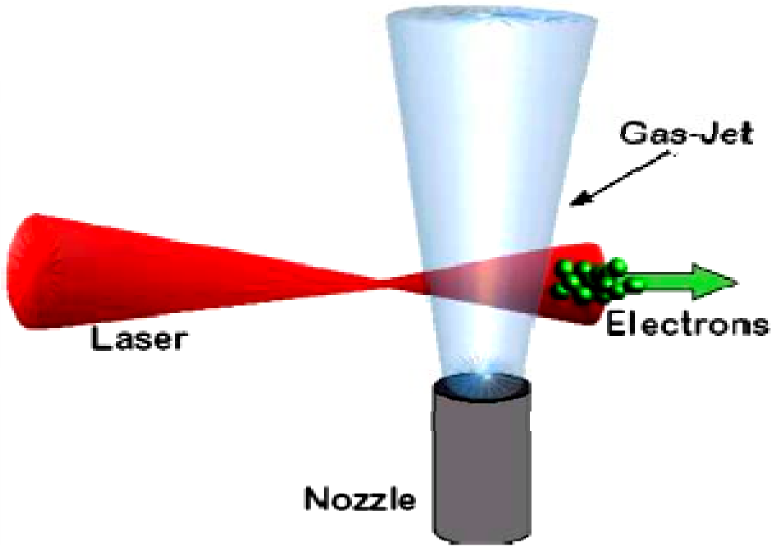


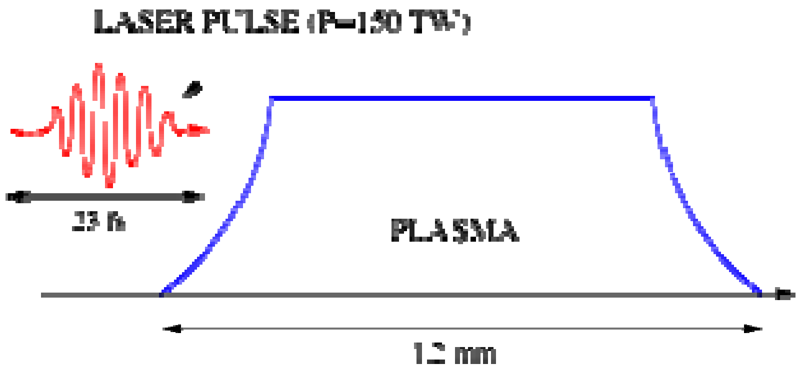
A supersonic gas–jet is used as a target. gas–jet targets have been successfully used and tested in the CEA-Saclay and “pilot| Pisa esperiment and offer ideal conditions for both self-injection measurements and laser pulse characterisation via optical probing

A.Giulietti et al. Phys.Rev.Lett, 105002, 2008.

Self-injection simulations
(di C. BENEDETTI ET AL.,)

- (Half power) FLAME laser
  - P =150 TW, $\tau_{fwhm} = 24$ fs
  - waist: $w_0 = 8 \div 40$ ($1/e^2$ radius of the laser intensity profile, $w_{fwhm} \simeq 1.2\, w_0$)
  - norm. vector potential $a_0 \equiv \frac{eA_{laser}}{mc^2} = 8.5 \cdot 10^{-10} \sqrt{I[\text{W/cm}^2](\lambda[\mu\text{m}])^2} \geq 2$



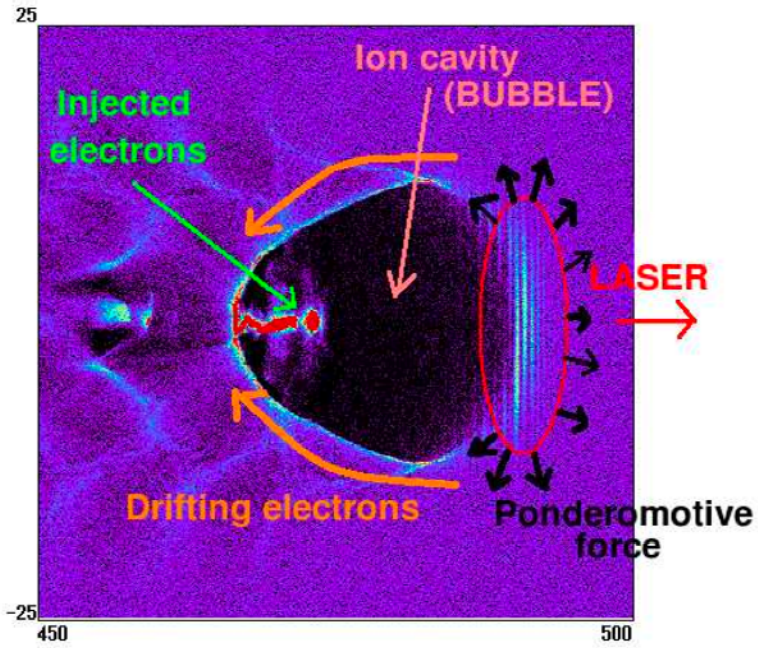


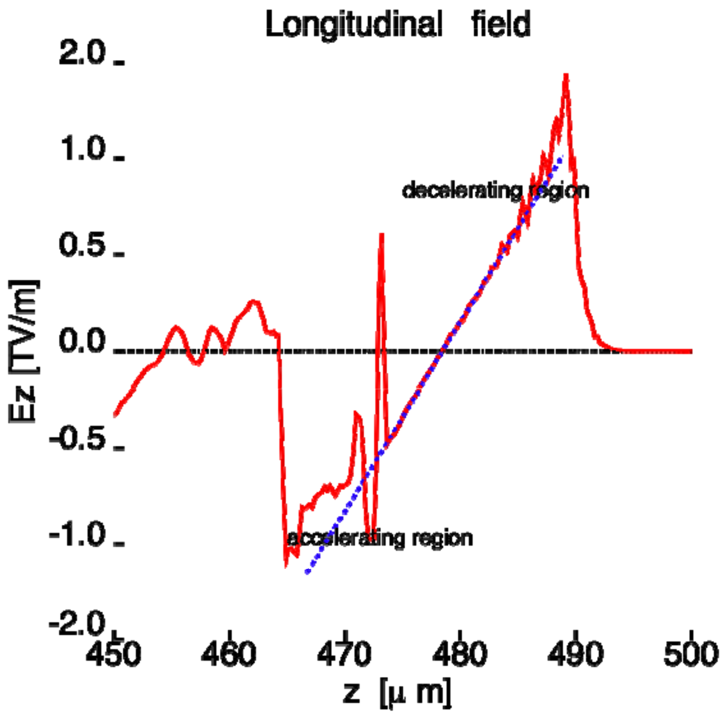
- Two regimes:

1. $w_0 < \lambda_p \Rightarrow$ **Nonlinear 3D regime (bubble)**
2. $w_0 > \lambda_p \Rightarrow$ **Nonlinear "1D-like" regime** (+ properly modulated gas-jet)

SIMULAZIONI self-injection
(di C. BENEDETTI ET AL.,)

• **Nonlinear 3D regime (bubble)** [a]





• $R_{bub} \simeq O(\lambda_p)$ $E_z^{(max)} \simeq 100\sqrt{n_0[\text{cm}^{-3}] \times a_0}$ [V/m]

• $\begin{cases} v_{elect} \simeq c \\ v_{bub} \simeq c(1 - 3\omega_p^2/(2\omega_0^2)) < v_{elect} \Rightarrow \text{acc. length is finite + monochromaticity} \end{cases}$

[a] S. Gordienko and A. Pukhov, Phys. Plas. 12 (2005) / W. Lu *et al.* PRSTAB 10 (2007)

SIMULAZIONI ALADYN
(di C. BENEDETTI ET AL.,)

Studies for the SITE

- **Nonlinear 3D regime (bubble)**: phenomenological theory [*W. Lu & al., PRSTAB 10 (2006)*]
  - "stability" of the bubble: $k_p R_{bub} \simeq k_p w_0 \simeq 2\sqrt{a_0}$
  - dephasing length: $L_d = \frac{2}{3}\frac{\omega_0^2}{\omega_p^2} R_{bub}$
  - pump depletion: $L_{pd} = \frac{\omega_0^2}{\omega_p^2} c\tau_{fwhm}$, shuld be $L_{pd} >$ min(L_{gasjet}, L_d)
  - $e-$energy (dephasing): $W[\text{GeV}] \simeq 1.7 \times \left(\frac{P[\text{TW}]}{100}\right)^{1/3} \left(\frac{10^{18}}{n_p[\text{cm}^{-3}]}\right)^{2/3} \left(\frac{0.8}{\lambda_0[\mu\text{m}]}\right)^{4/3}$
  - charge injected: $Q[\text{pC}] \simeq 400 \times \left(\frac{0.8}{\lambda_0[\mu\text{m}]}\right) \left(\frac{P[\text{TW}]}{100}\right)^{1/2}$
- **Nonlinear 3D regime (bubble)** for a FLAME-like laser: $P = 200$ TW, $\tau_{fwhm} = 30$ fs

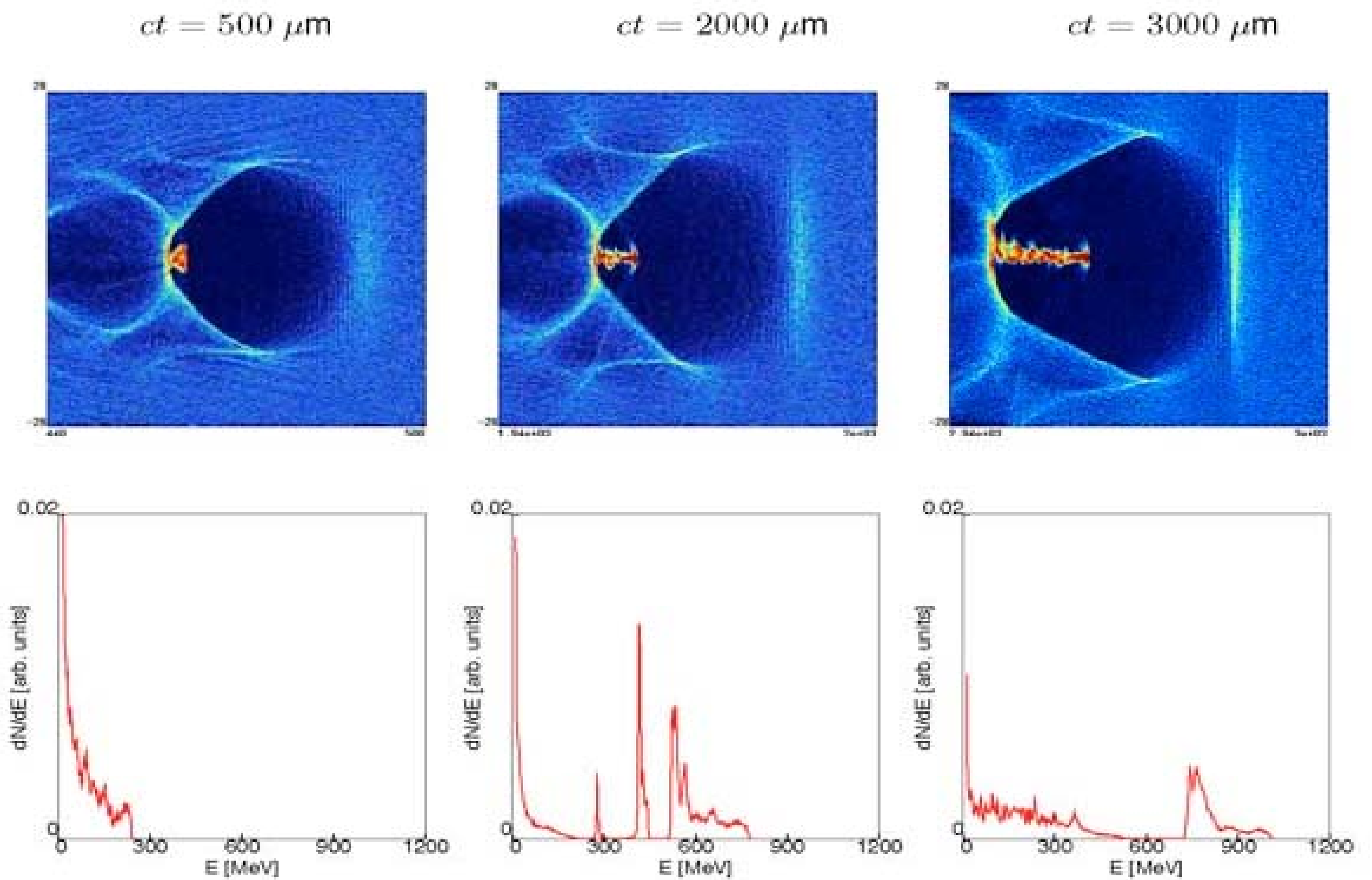
Taking the waist w_0 as a free parameter ($R_{bub} \simeq w_0$), we have

- $n_p\ [\text{cm}^{-3}] \simeq 8.7 \cdot 10^{21}/(w_0[\mu\text{m}])^3$
- $L_d[\mu\text{m}] \simeq 0.13 \times (w_0[\mu\text{m}])^4$
- $L_{pd}[\mu\text{m}] \simeq 1.8 \times (w_0[\mu\text{m}])^3$
- $W[\text{MeV}] \simeq 79 \times \frac{L_{gasjet}[\mu\text{m}]}{(w_0[\mu\text{m}])^2}\left(1 - \frac{3.75\times(L_{gasjet}[\mu\text{m}])}{(w_0[\mu\text{m}])^4}\right)$ (for $L_d \geq L_{gasjet}/2$)
- $Q \simeq 0.5 \div 0.6$ nC

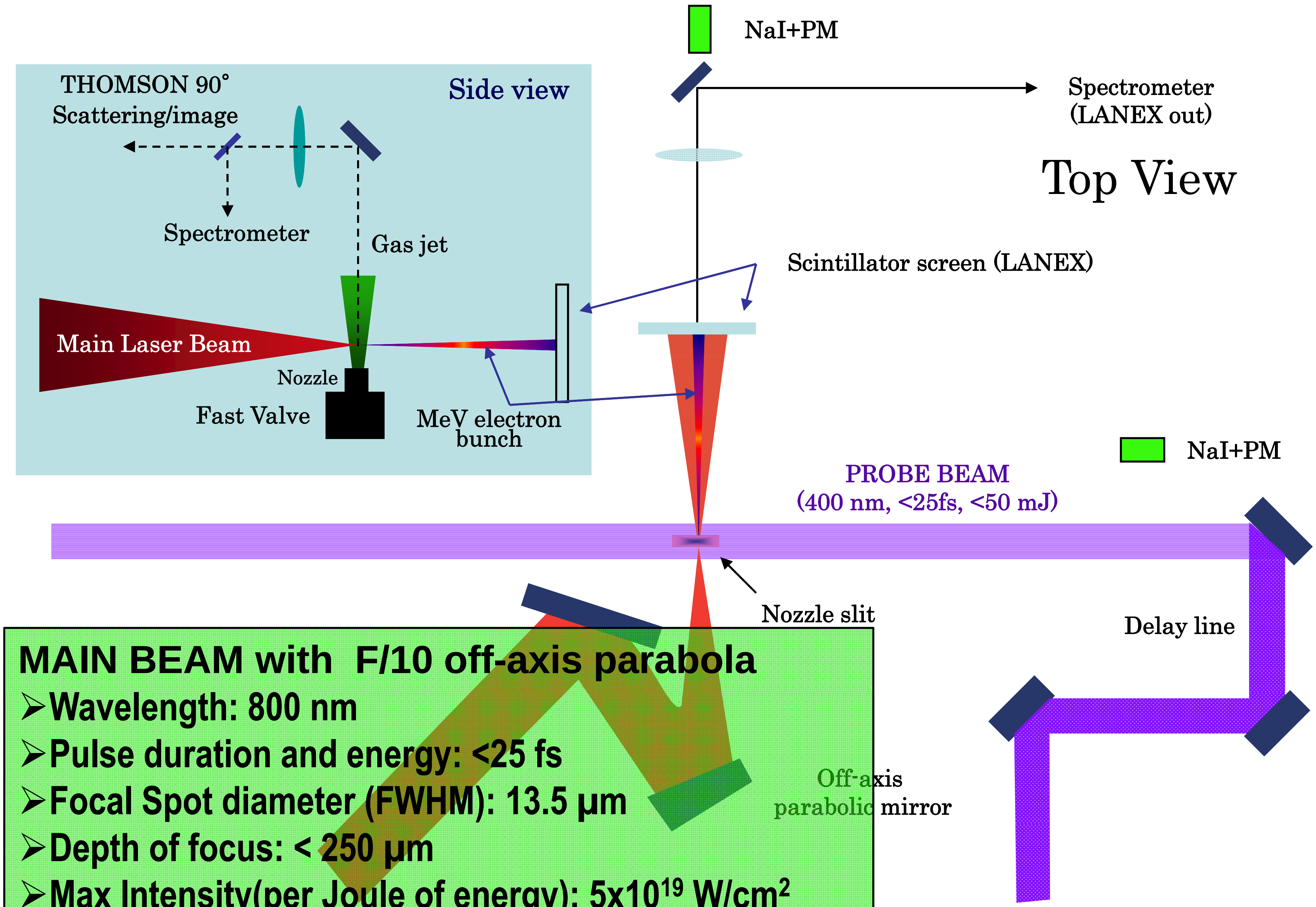
SIMULAZIONI ALADYN
(di C. BENEDETTI ET AL.,)

Studies for the SITE

- 3D sim. "GeV-class" ($L_{gasjet} = 4$ mm)



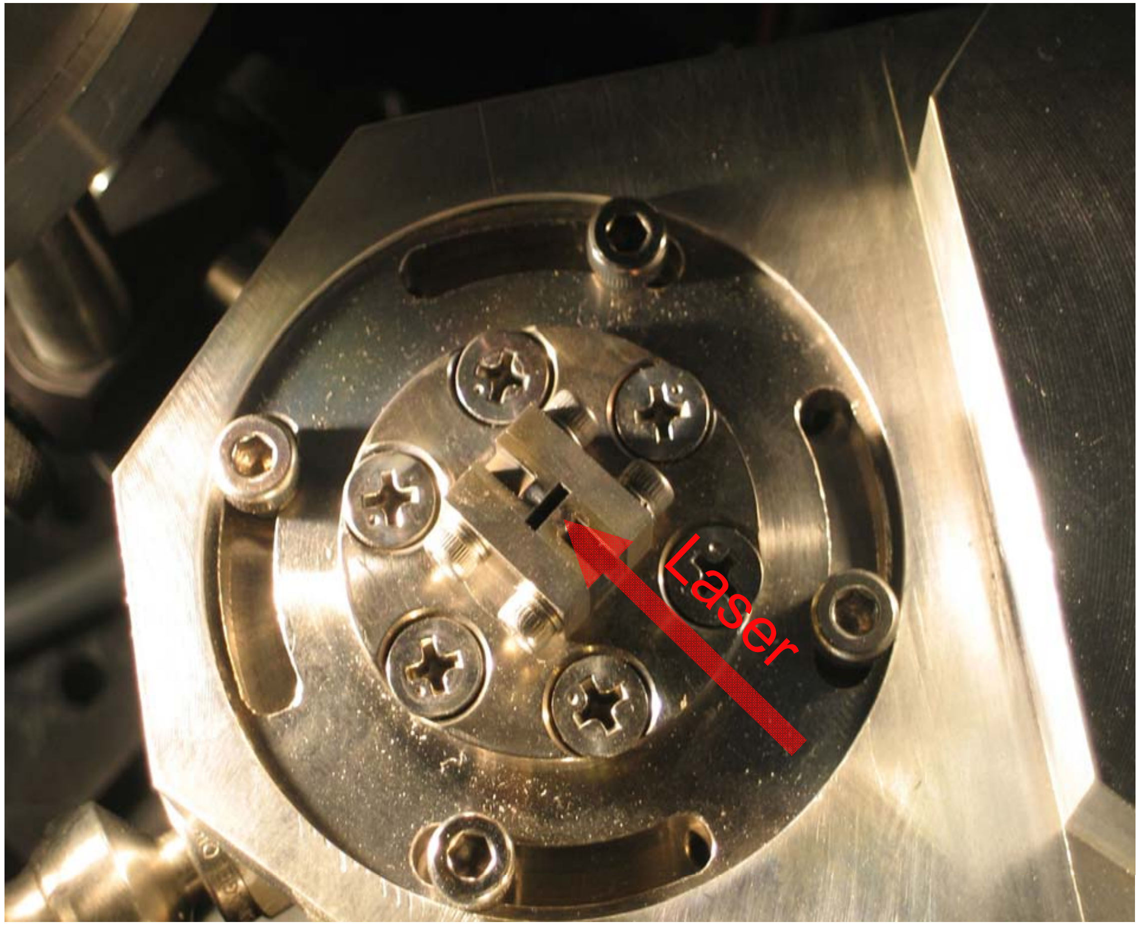
Planned experimental set up



MAIN BEAM with F/10 off-axis parabola

- Wavelength: 800 nm
- Pulse duration and energy: <25 fs
- Focal Spot diameter (FWHM): 13.5 μm
- Depth of focus: < 250 μm
- Max Intensity(per Joule of energy): 5×10^{19} W/cm^2

Pulsed gas-Jet nozzle



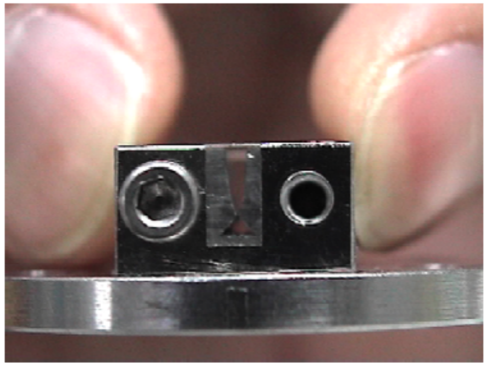
Nozzle size: 4mm x 1.2mm or 10 mm x 4 mm

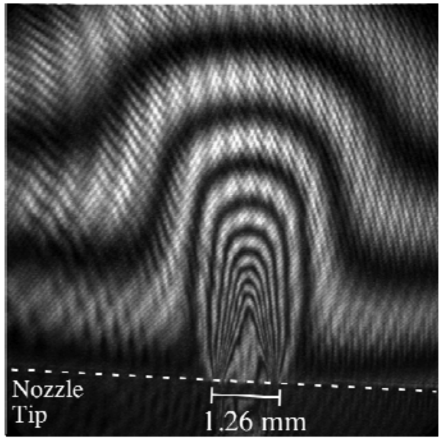
<u>Possible application of a continuous gas-jet under consideration (v. talk L. Gialanella, Ven 20. H.11.10)</u>

High-density well-defined gas jet (1)
Shockwave free supersonic nozzle

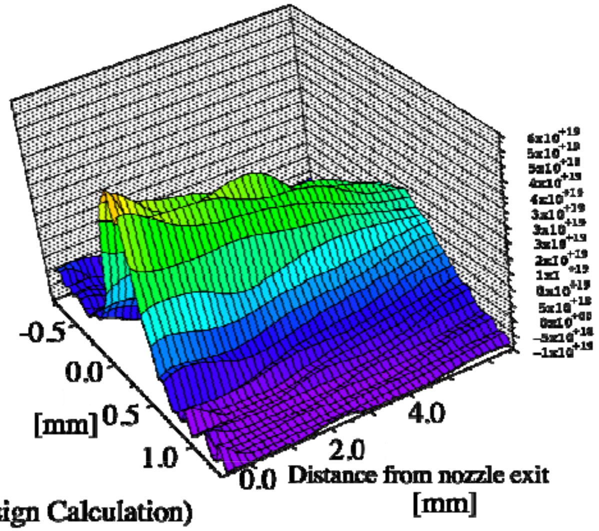
Gas-Jet nozzle

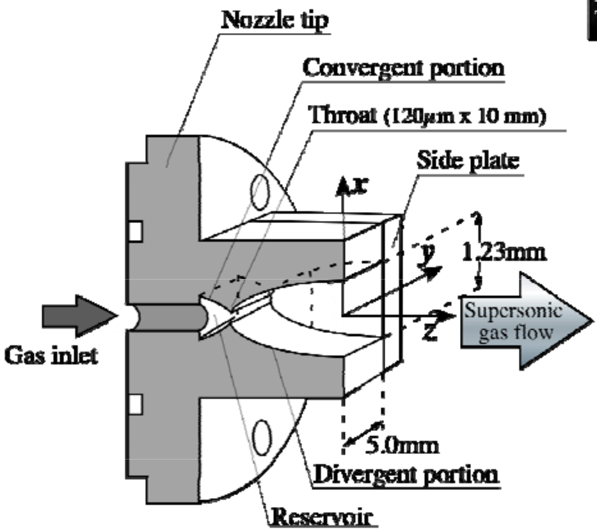
Nuclear Engineering Research Laboratory
Graduate School of Engineering
University of Tokyo



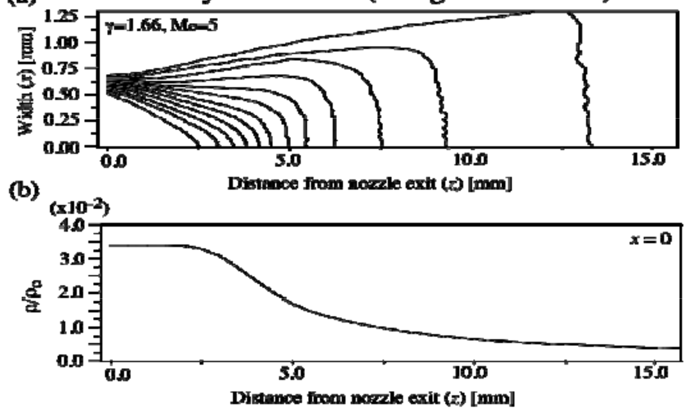


Measured Density Distribution



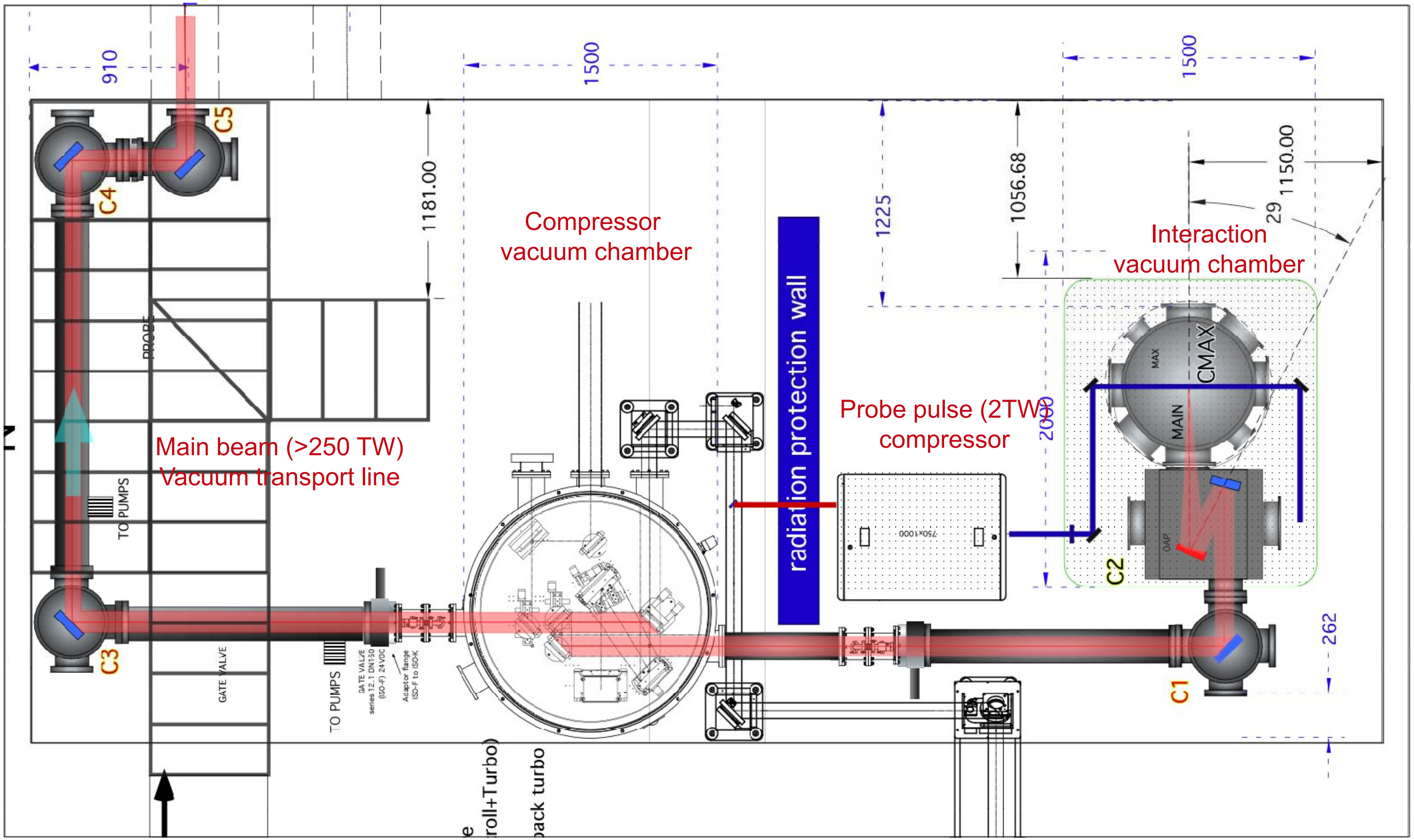


Density Distribution(Design Calculation)

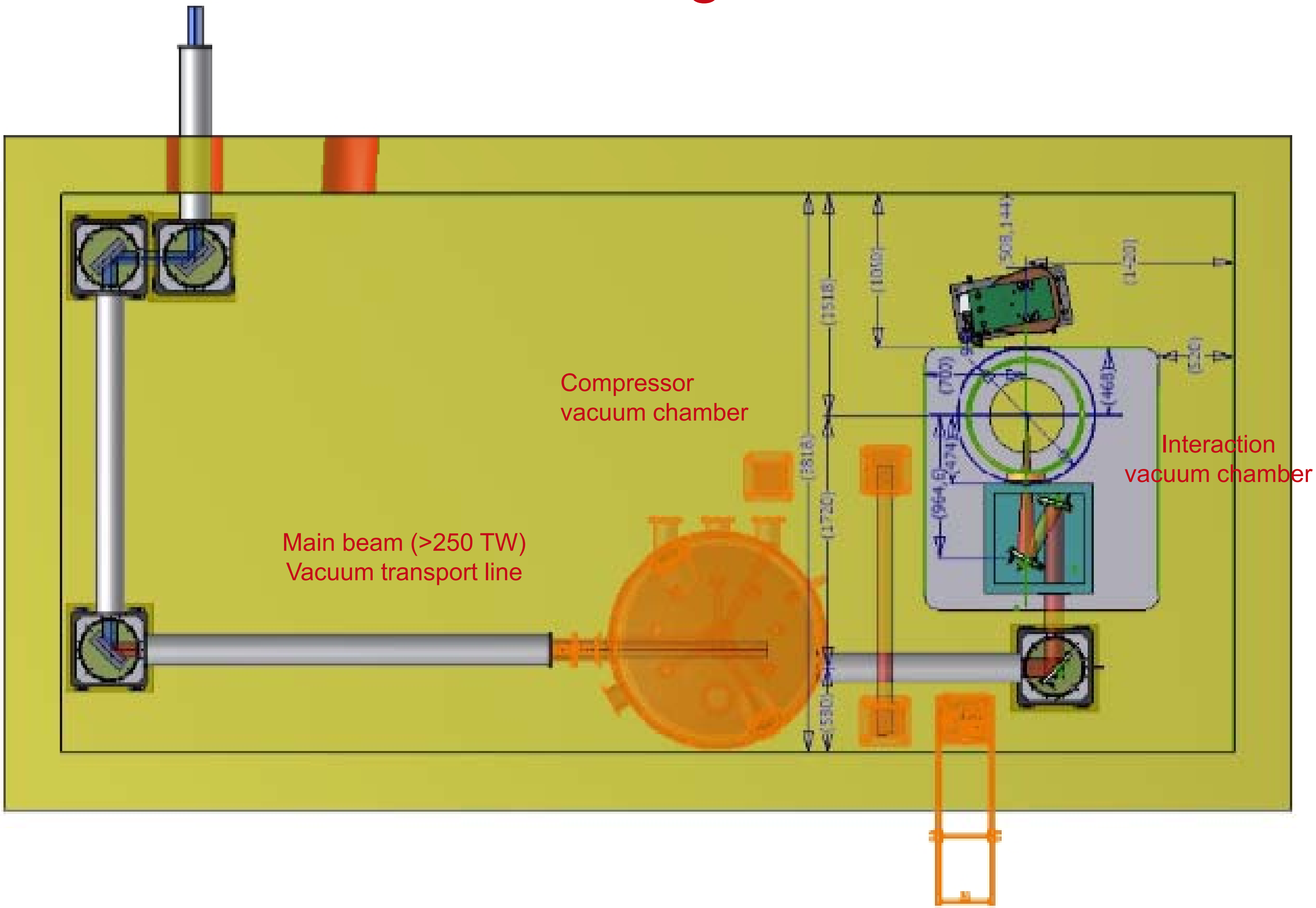


Courtesy of T. Hosokai, Tokyo Institute of Technology

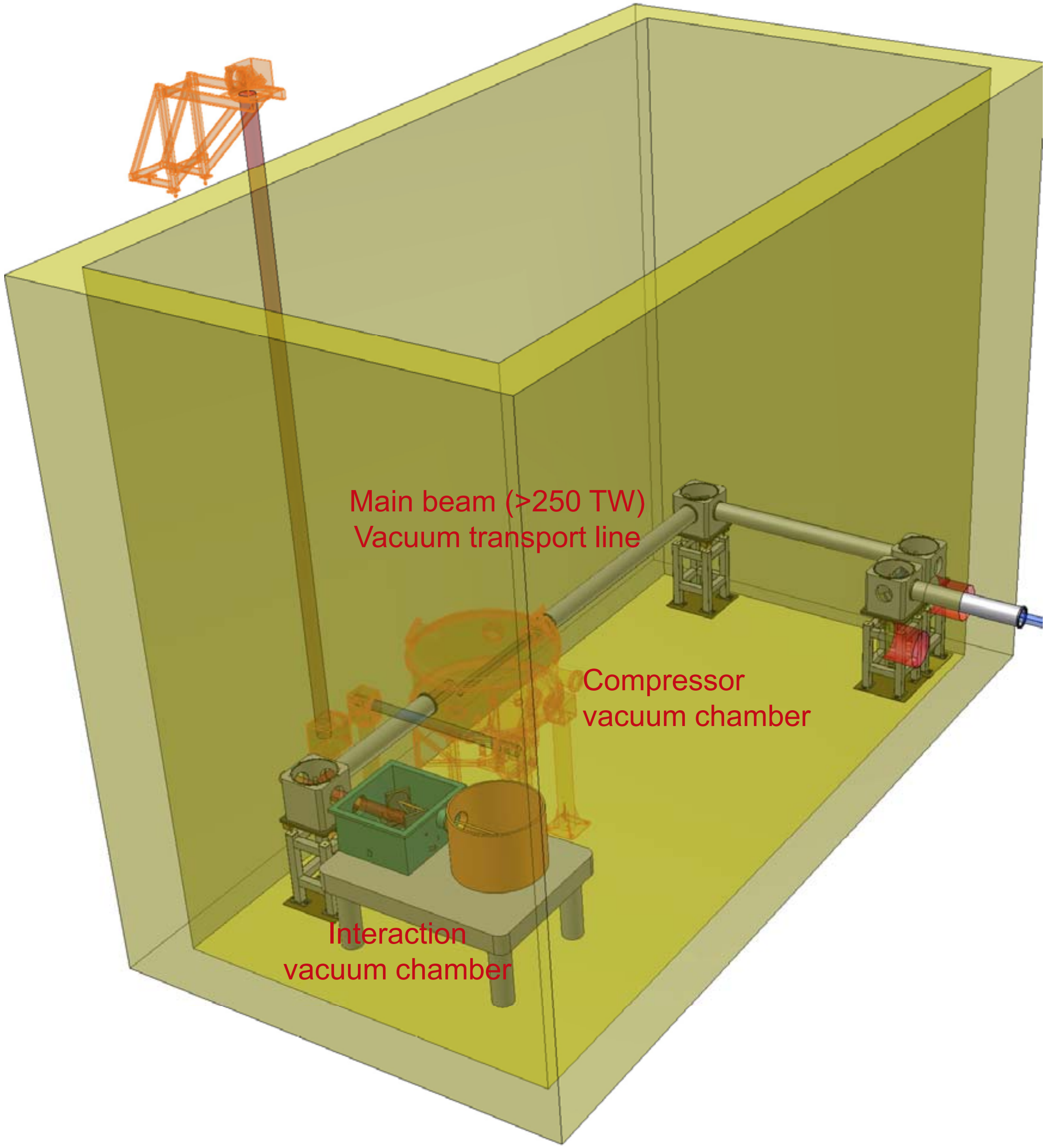
FLAME Target Area



FLAME Target Area

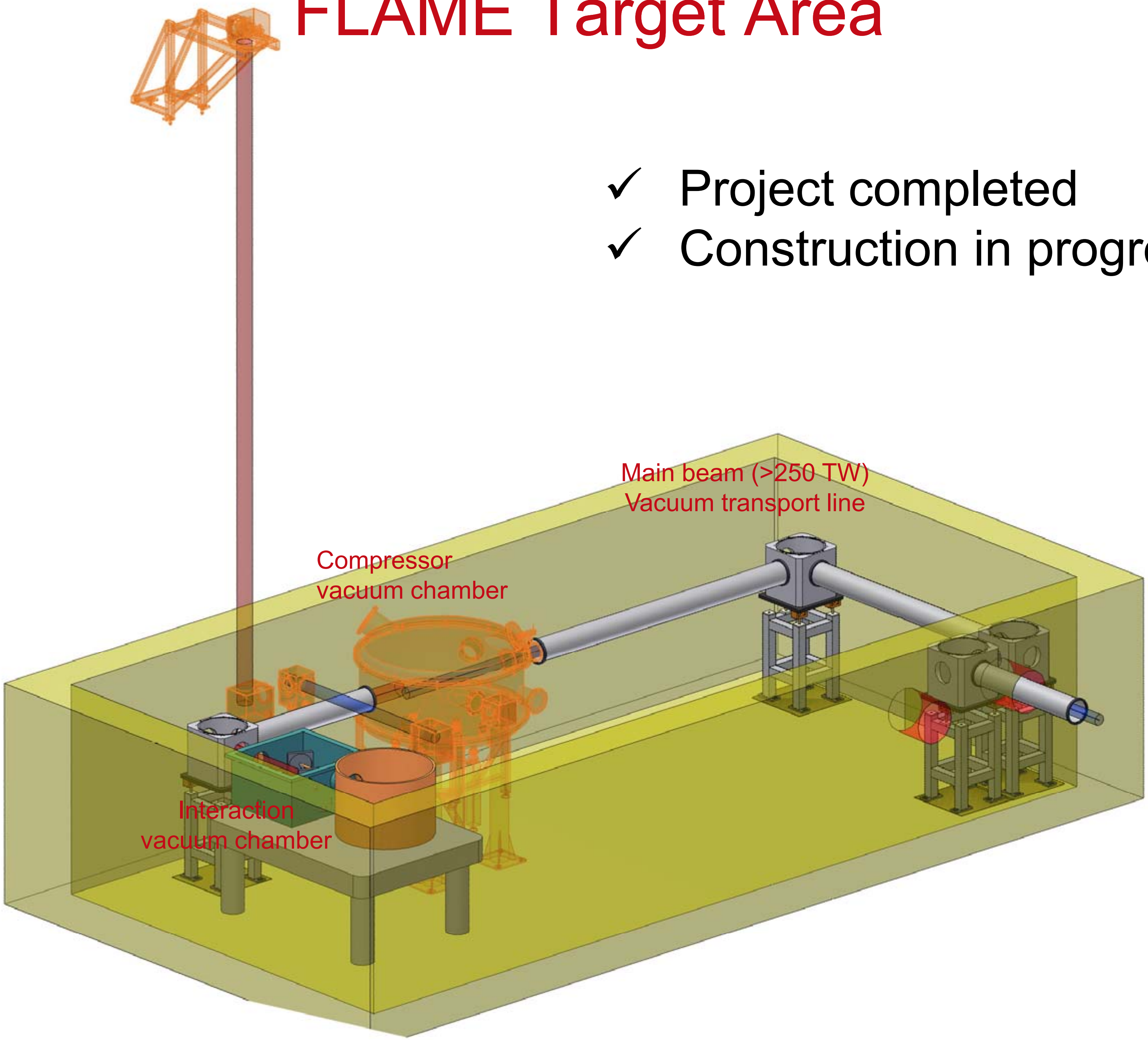


FLAME Target Area



FLAME Target Area

- ✓ Project completed
- ✓ Construction in progress



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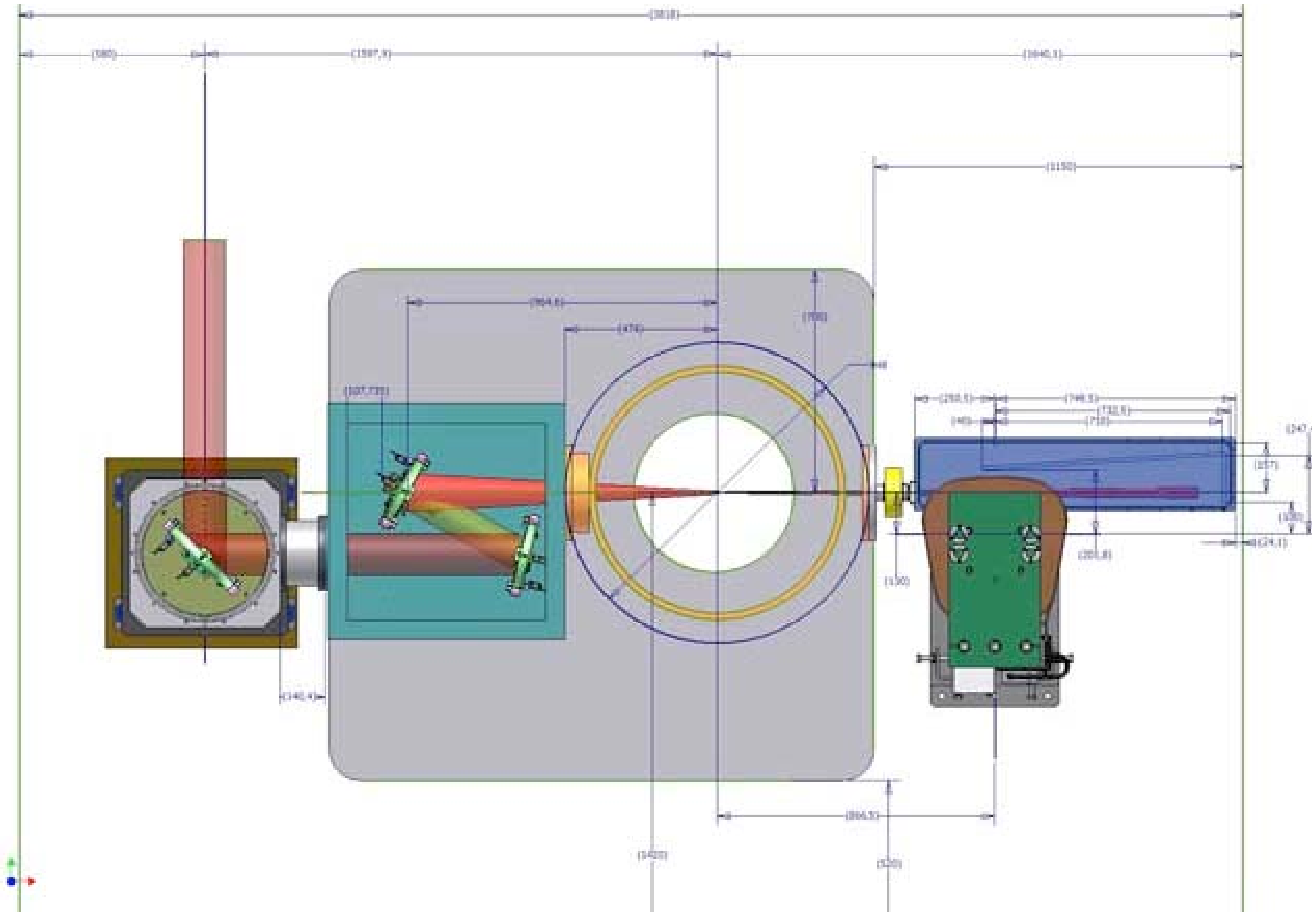


Spettrometro per elettroni

Finalita': misura spettro energetico elettroni accelerati

Energia massima:

- Primi test di prova con p ≈10 MeV, esperimenti a piena potenza possono raggiungere l'energia di 10 GeV

- L'accelerazione di ioni prevede la produzione di protoni con T≈10Mev

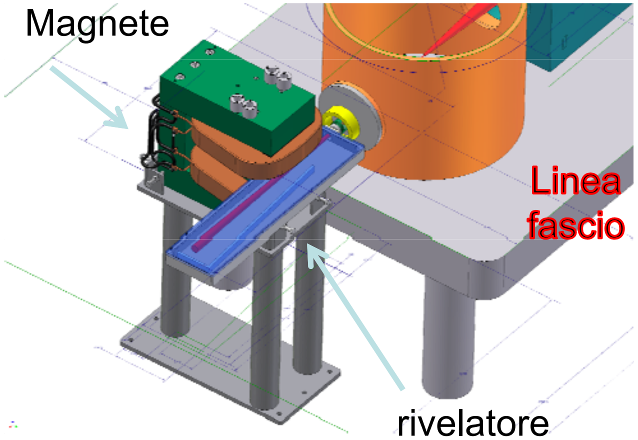
Risoluzione:

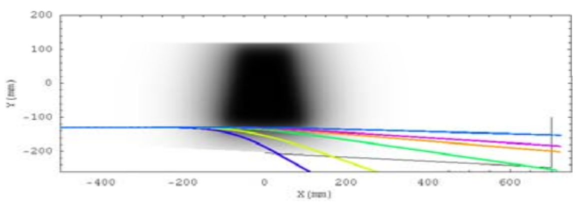
≈1% su largo range

Forma del fascio iniziale:

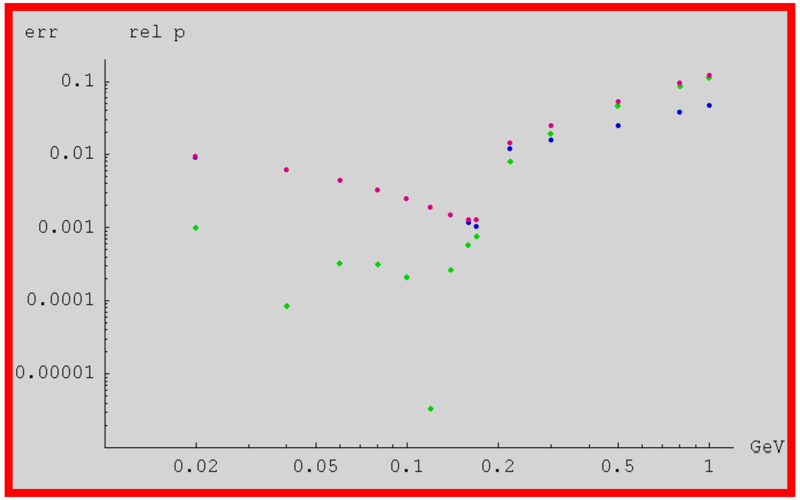
-Sorgente puntiforme con 1mrad dispersione angolare iniziale

Il Prototipo





Principio funzionamento: traiettorie per differenti valori di momento



Prestazioni previste del prototipo

Errore relativo vs momento

Contact: R. Faccini et al. ,,,

“TEST” EXPERIMENT DIAGNOSTICS

OPTICAL DIAGNOSTICS FOR LASER PROPAGATION STUDIES

Thomson scattering

Femtosecond optical probing

Transmitted and scattered beam spectroscopy

ELECTRON DIAGNOSTICS FOR ELECTRON ACCELERATION MEAS.

Establish self-injection acceleration conditions

Provide benchmarking for modelling

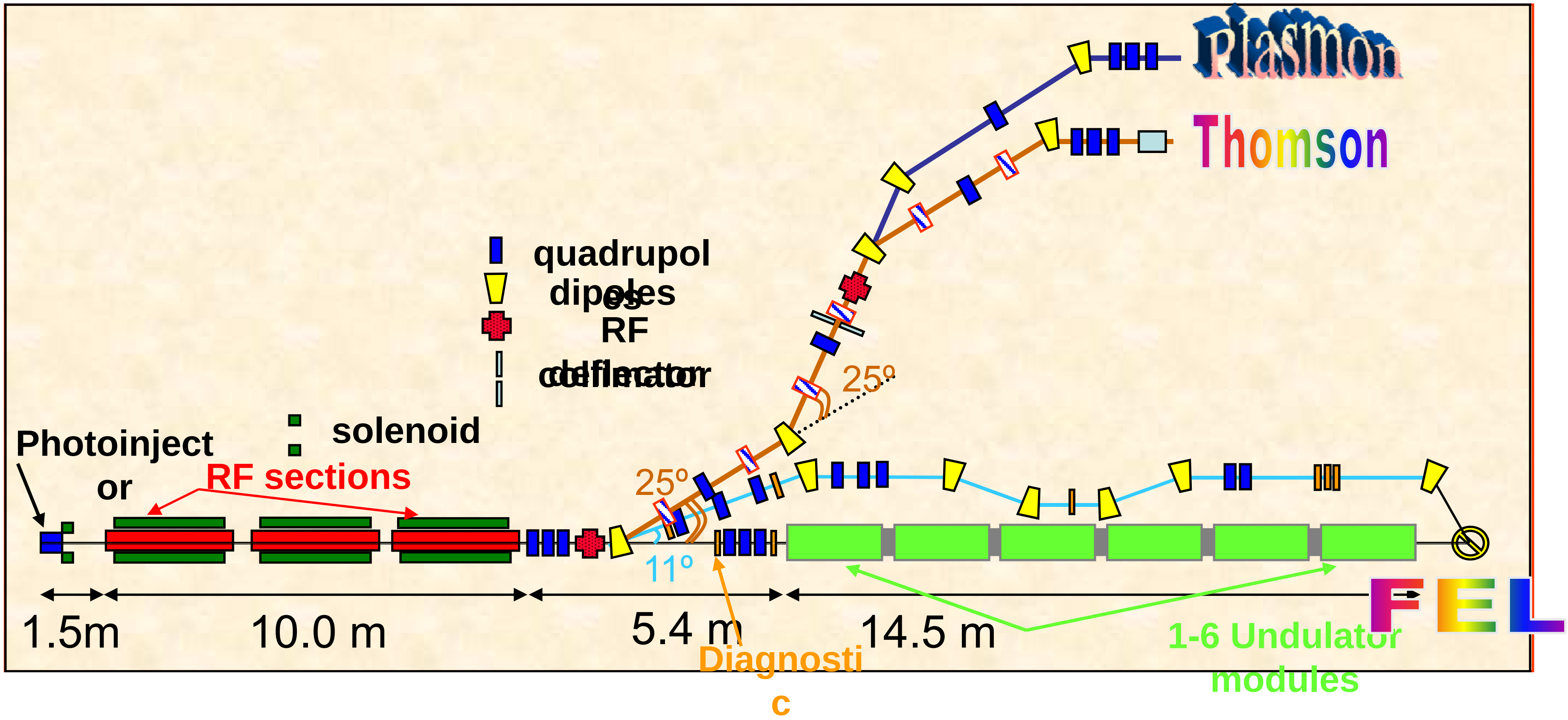
Agenda for next 6-8 months

• Completion and commissioning of subsystems:
*Clean room, Cooling network, Ethernet (before end of July ‘09)
• Full laser installation (Sept. 15^{th} – December 2009, in phases;)
• Assembling of transport line from optical compressor to experimental target chamber (July – September ‘09)
• Assembling of self injection test experiment diagnostics (September – December ’09)
• Laser on (gas-jet) target at >50 TW lavel Feb-March 2010.

Conclusions

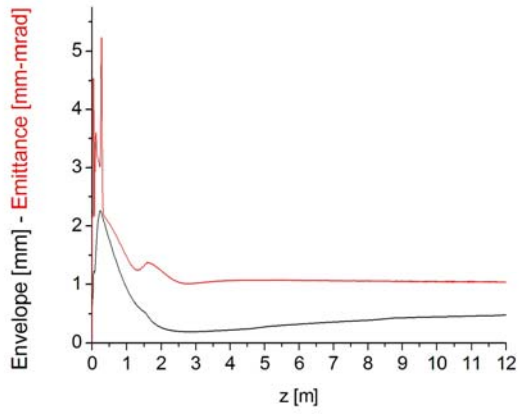
- Installation of main subsystems in progress
  Clean room, Laser, Cooling, Conditioning;
- Components of beam transport line in production;
- Design of test experiment completed;
- Construction of electron spectrometer in progress;
-

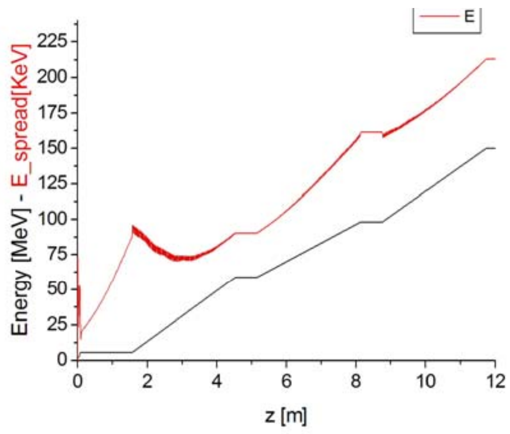
Schematic layout of electron beam lines for FEL, Plasma Acceleration and Thomson Source experiments



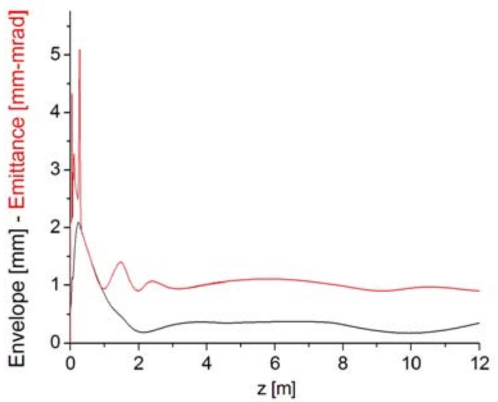
Last-beam line 30-150MeV

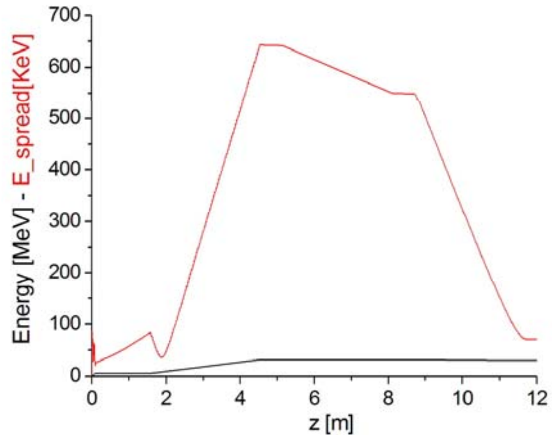
Runs with the GA to **minimize** the Δ*E*/*E*, the **emittance** and to reach the **needed energy**





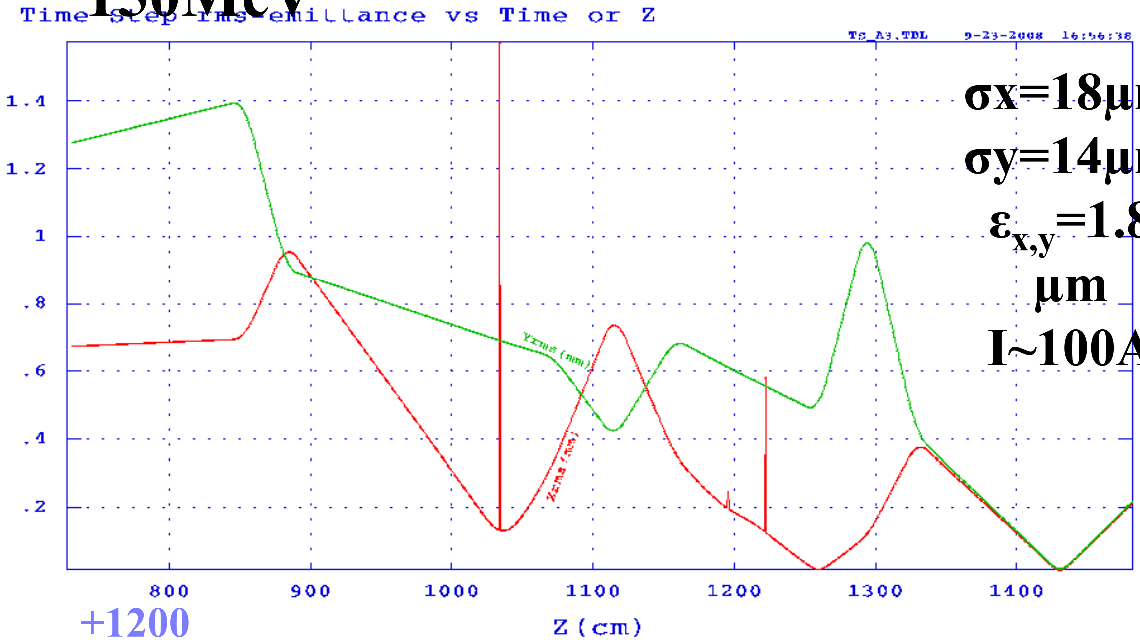
Δγ/γ [%]	**=0.1416E+00**
<E>[eV]	=0.1505E+09
σ_x[mm]	=0.4825E+00
ε[mm*mrad]	**=0.1041E+01**
<I> [A]	=0.9848E+02





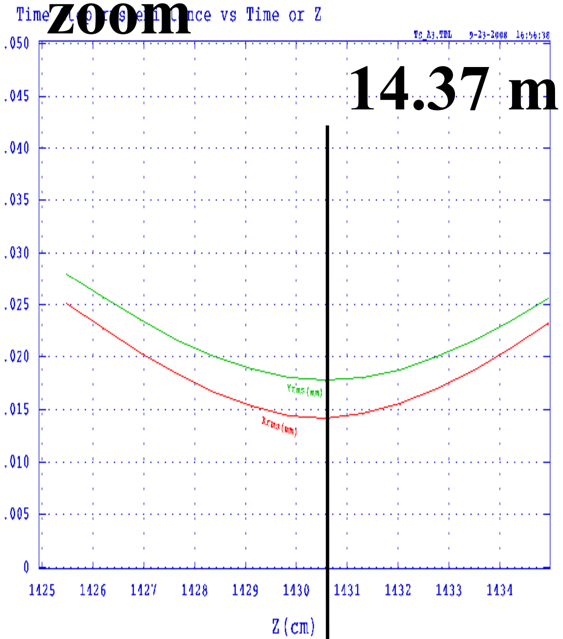
Δγ/γ [%]	**=0.2324E+00**
<E>[eV]	=0.3051E+08
σ_x[mm]	=0.3501E+00
ε[mm*mrad]	**=0.9015E+00**
<I> [A]	=0.8973E+02

150MeV



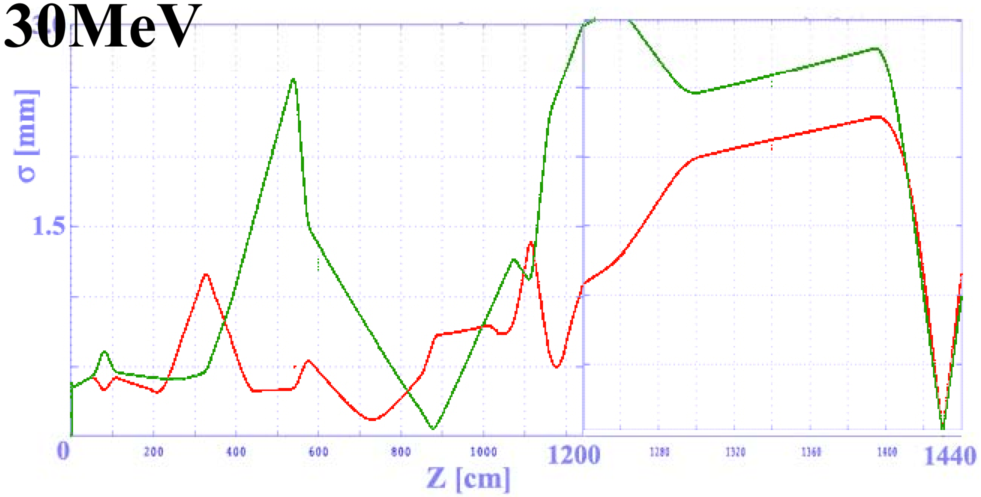
σx=18μm
σy=14μm
$\varepsilon_{x,y}$=1.8 μm
I~100A

zoom



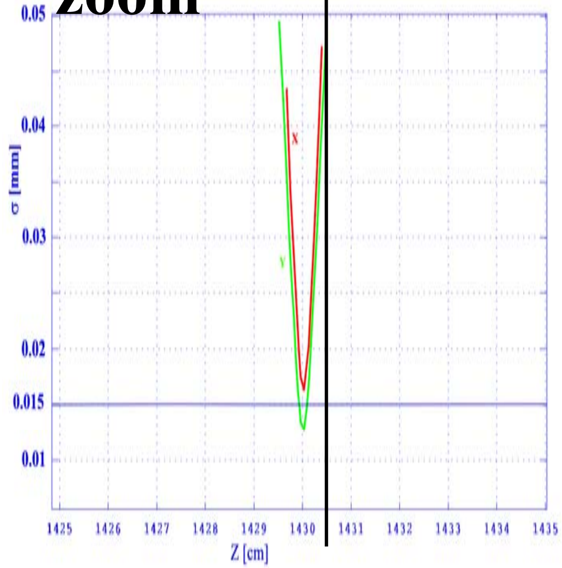
14.37 m

30MeV

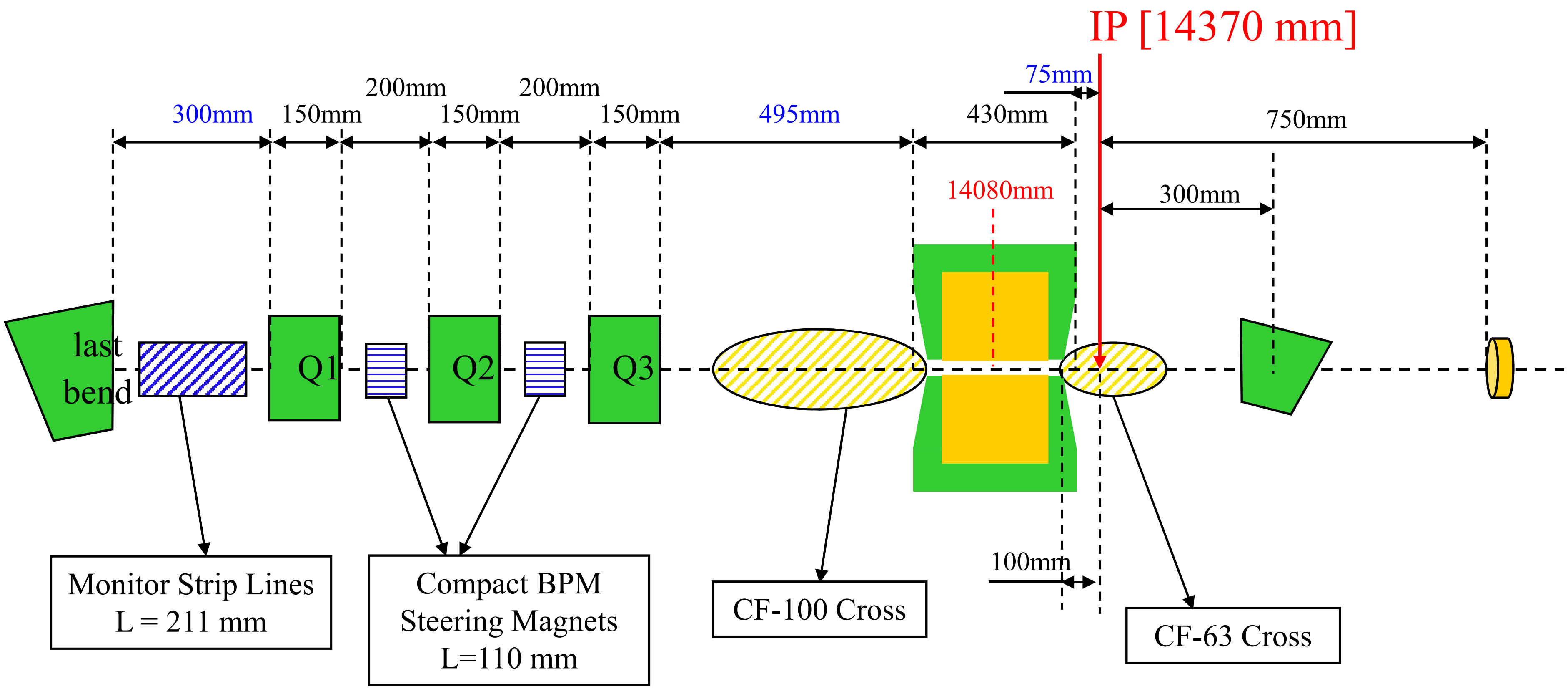


σx=14μm
σy=12.5 μm
$\varepsilon_{x,y}$=4 μm
I~90A

zoom

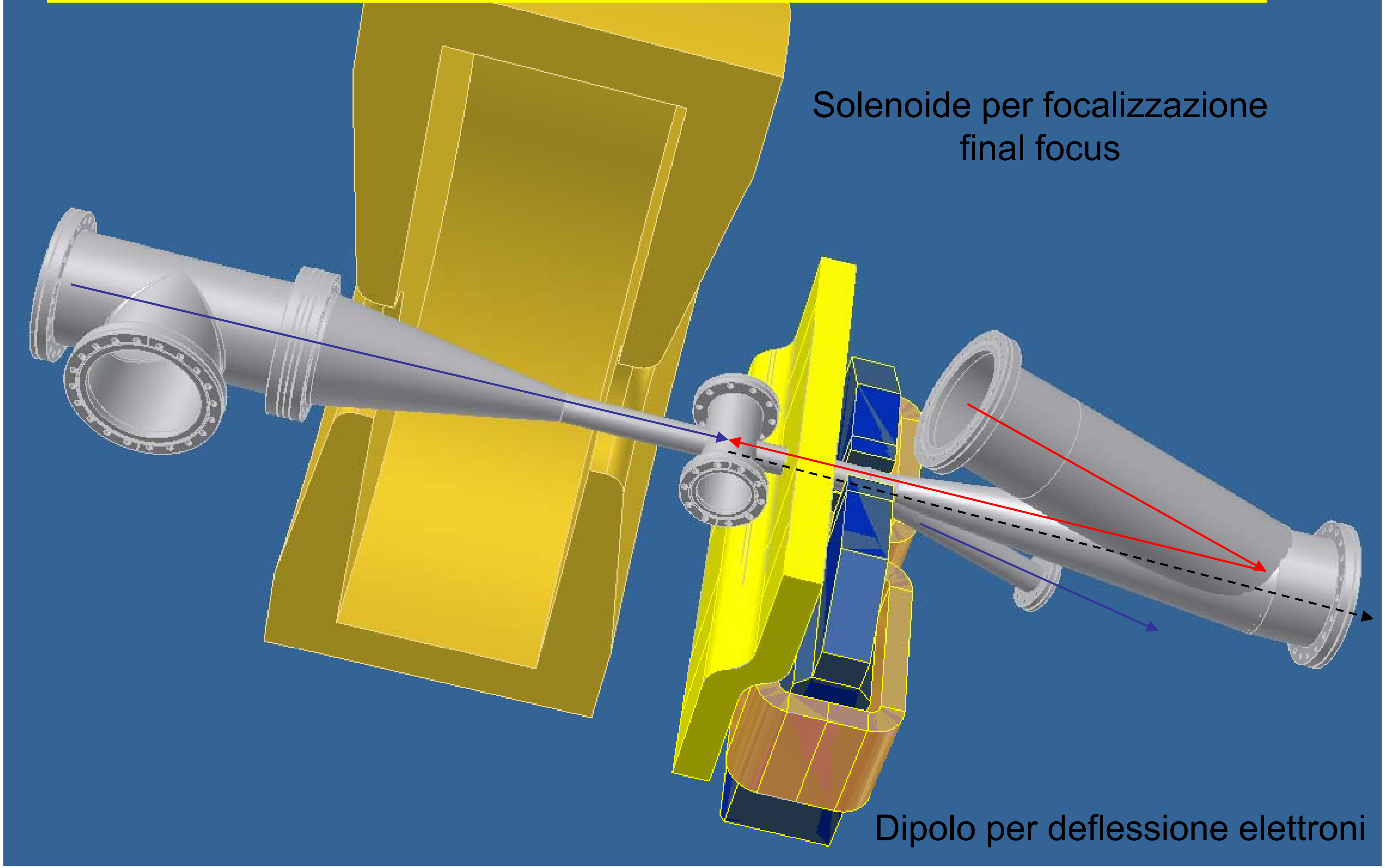


Block diagram with dimensions; scattering area with final focusing magnetic elements, diagnostic devices



every magnetic element has been designed and specified to the engineering level; the acquisition procedure of the magnetic elements has started

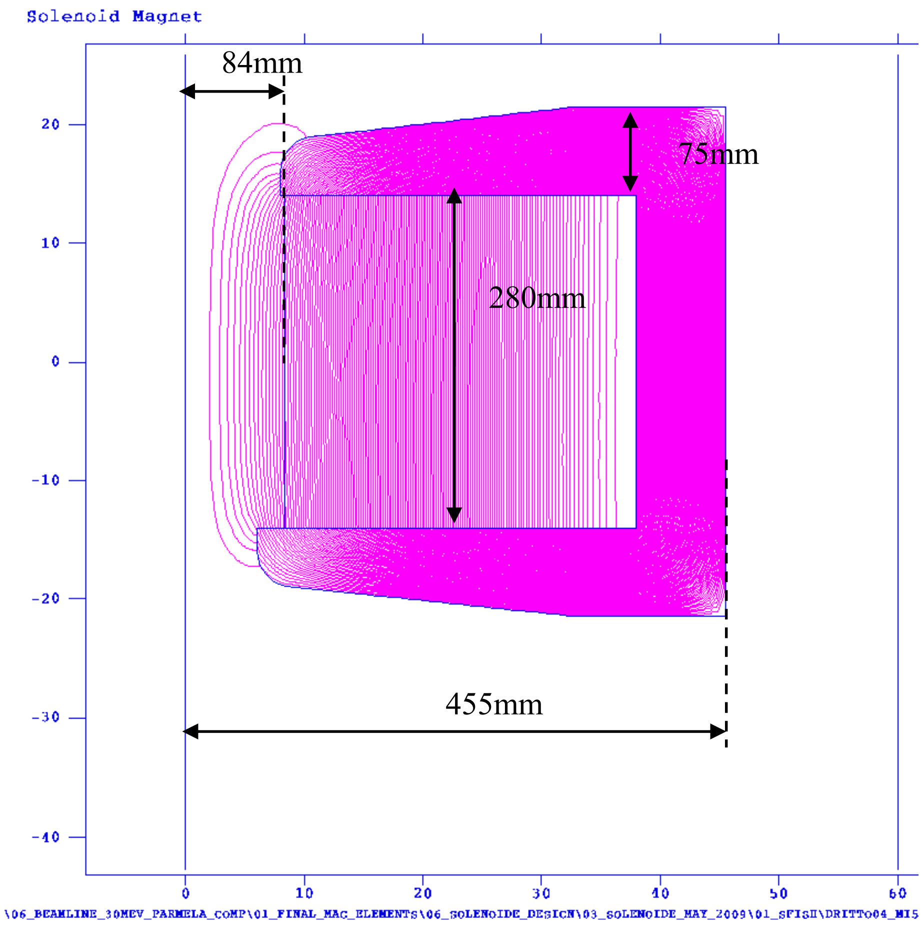
Schema camera interazione Sorgente Thomson: in blu il fascio di elettroni, in rosso il fascio laser, in nero i raggi X



Focusing solenoid

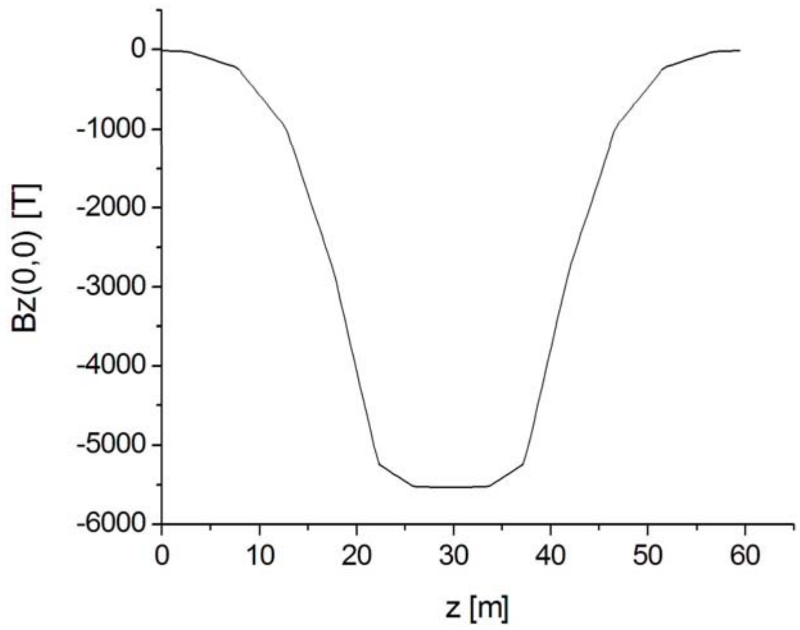
Maximum field = 1.0 [T]

(J = 3A*mm^2)

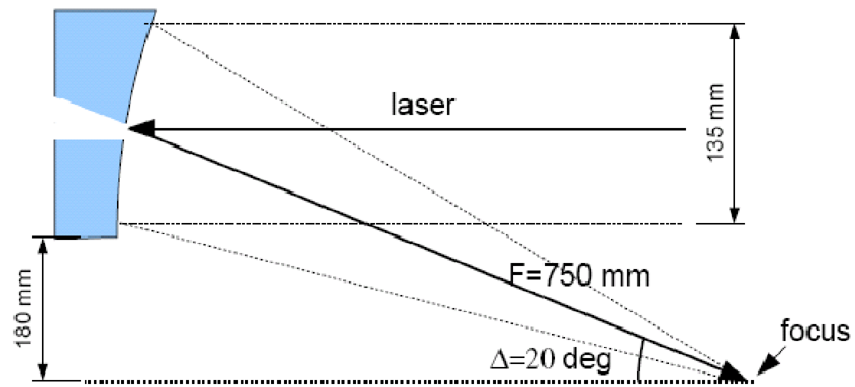


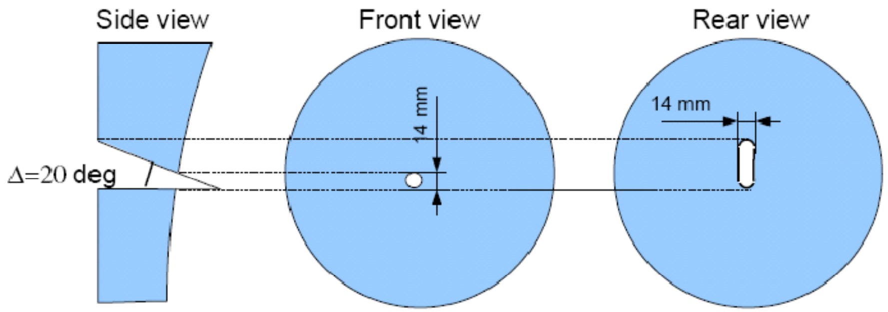
Dumping dipole

200 mm length, center at **300 mm from (IP)**, J=2.5A*mm^2 **no shield** since the fringing field results in a beam **deviation** at the IP of the order of **50µm**

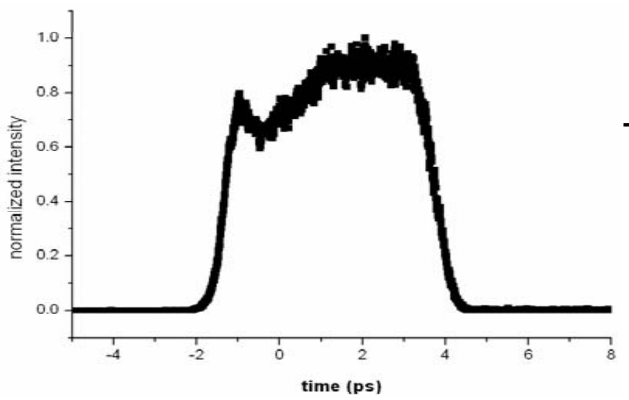


Plane mirror supports



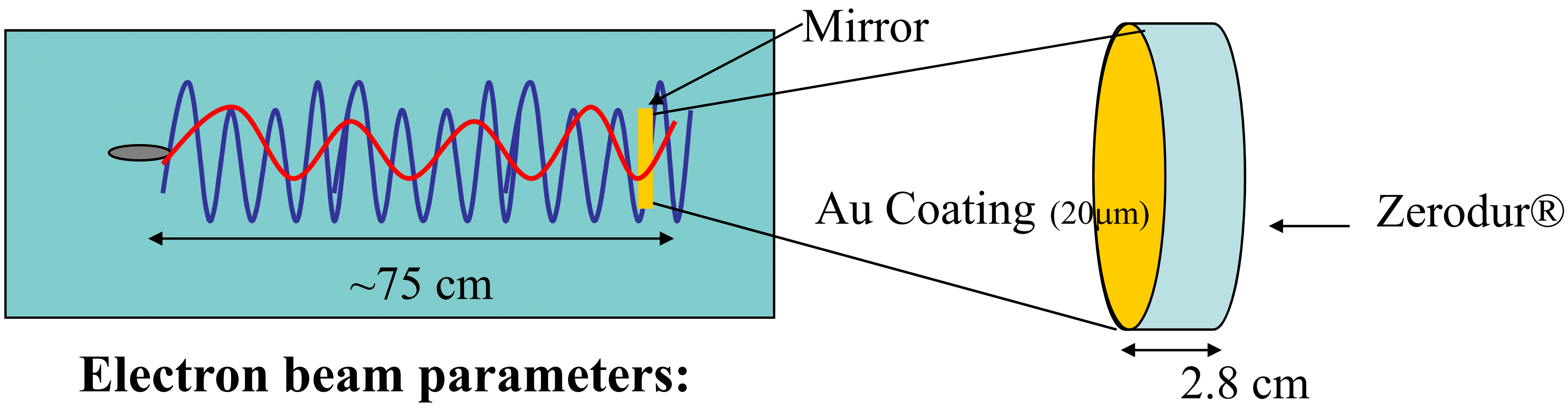


Simulation - Laser temporal profile at IP



Delivery from the company within the end of July 2009

Electron beam on the Mirror (accidental no beam deflection)

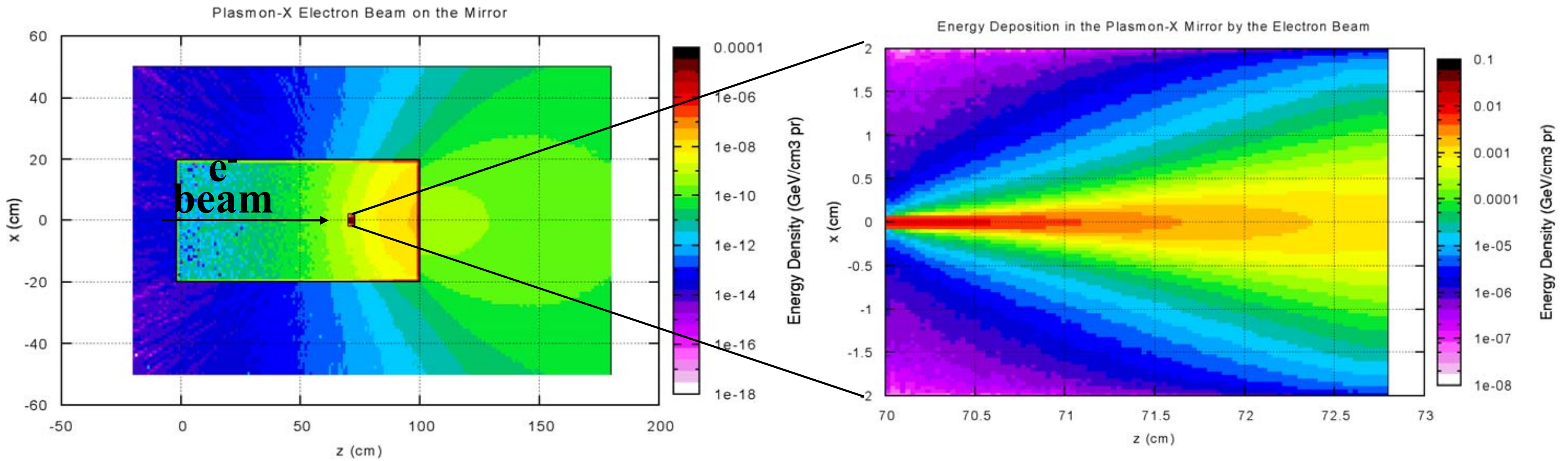


Electron beam parameters:

1.0nC; 30 MeV; $\Delta E/E=0$; $\varepsilon_{x,n}$= 2 mm-mrad;

r_{beam}=5 mm at IP, x'=2.2 mrad

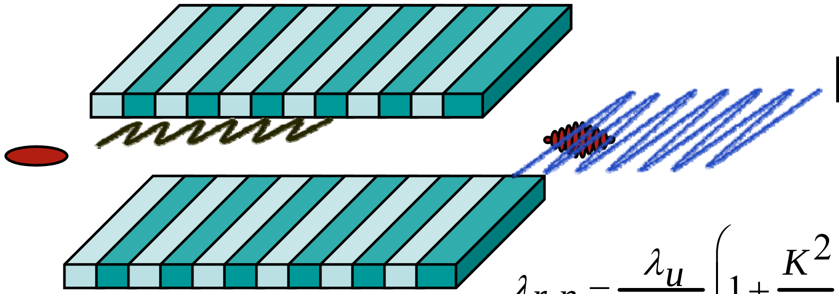
10 different FLUKA runs with 10^6 particle each



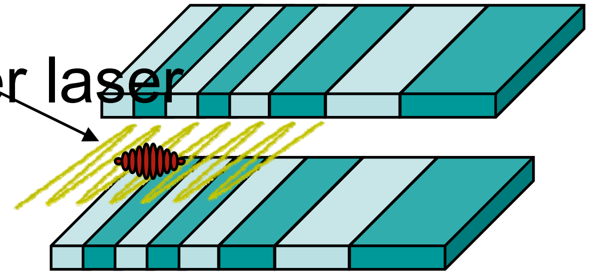
IFEL Interaction

In an FEL energy in the e-beam is transferred to a radiation field

In an IFEL the electron beam absorbs energy from a radiation field.



$$\lambda_{r,n} = \frac{\lambda_u}{2\gamma^2 n}\left(1 + \frac{K^2}{2}\right)$$



Somewhat arbitrary separation line. Include in IFEL all optical manipulation schemes: bunchers, modulators, laser heater, etc.

Undulator magnetic field to couple high power radiation with relativistic electrons

$K_l =$

$$\gamma_r^2 \cong \frac{\lambda_w}{2 \cdot \lambda} \cdot \left(1 + \frac{K^2}{2}\right)$$

Significant energy exchange between the particles and the wave happens when the resonance condition is satisfied.

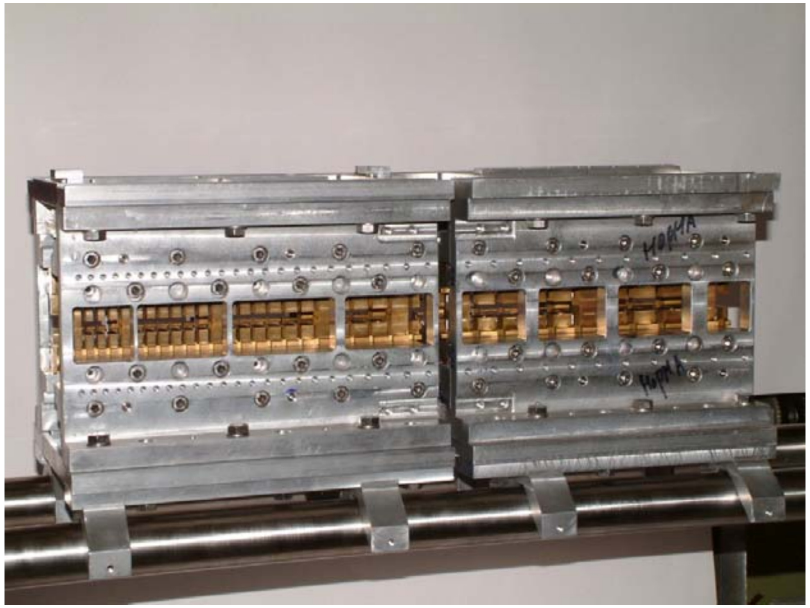
For large acceleration -> need for undulator tapering

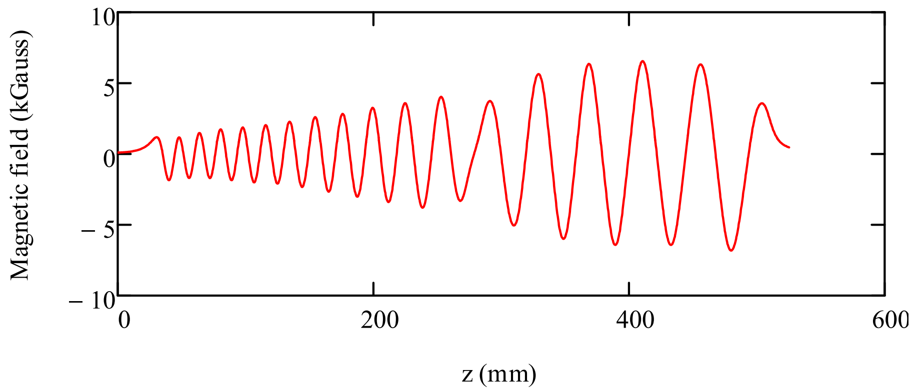
UCLA tapered undulator @ LNF

Use ***unique*** capabilities of SPARC + FLAME.

- High brightness beam
- High power laser in same facility.
- UCLA has already available and could loan the strongly

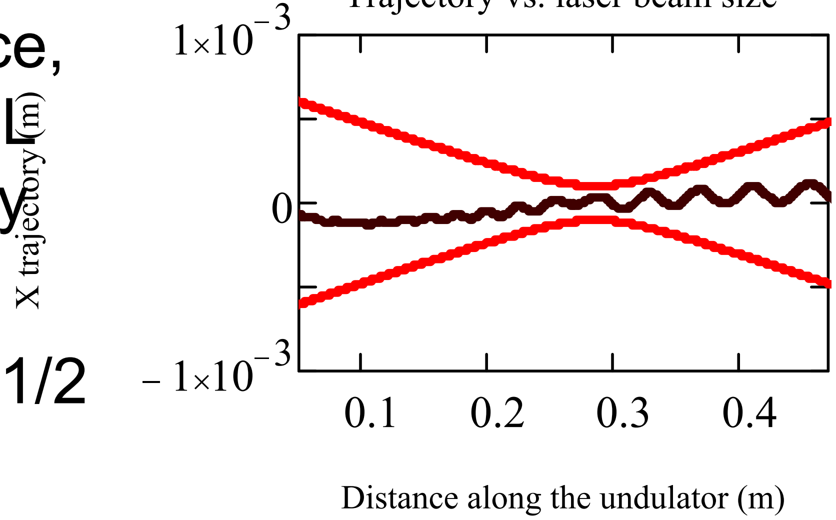
	Initial	Final
Period	1.5 cm	5.0 cm
Field Amplitude	0.12 T	0.6 T
Peak K parameter	0.2	2.8
gap	12 mm	12 mm





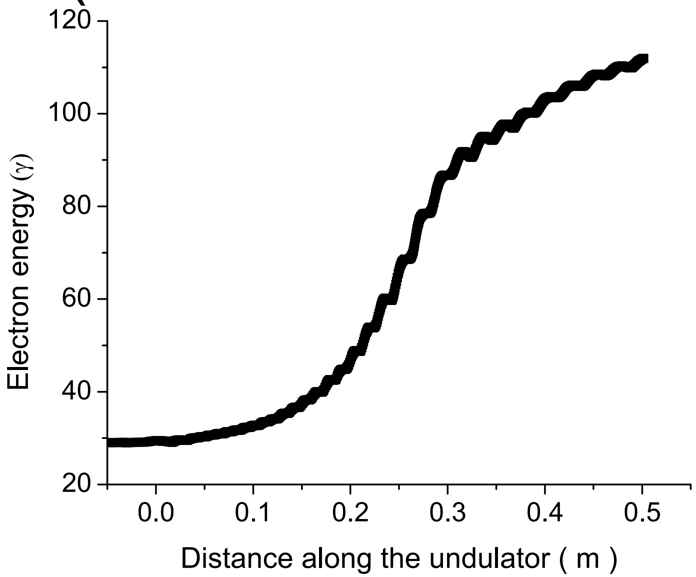
IFEL@LNF experiment

Because of wavelength difference, simply scaling the Neptune IFEL experiment is already extremely interesting.



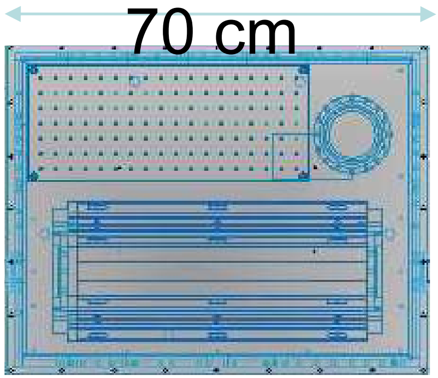
4.5 MeV -> 50 MeV) x (10.6/0.8) ^1/2

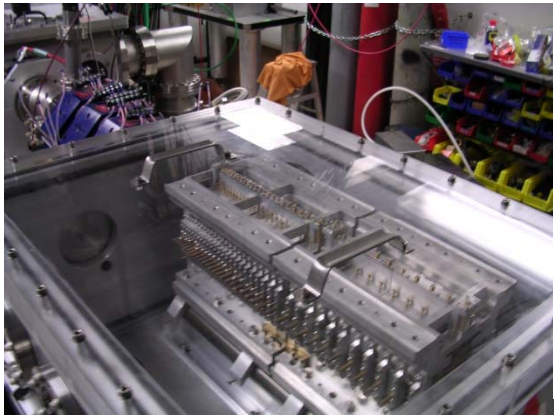
(52 MeV -> 180 MeV)

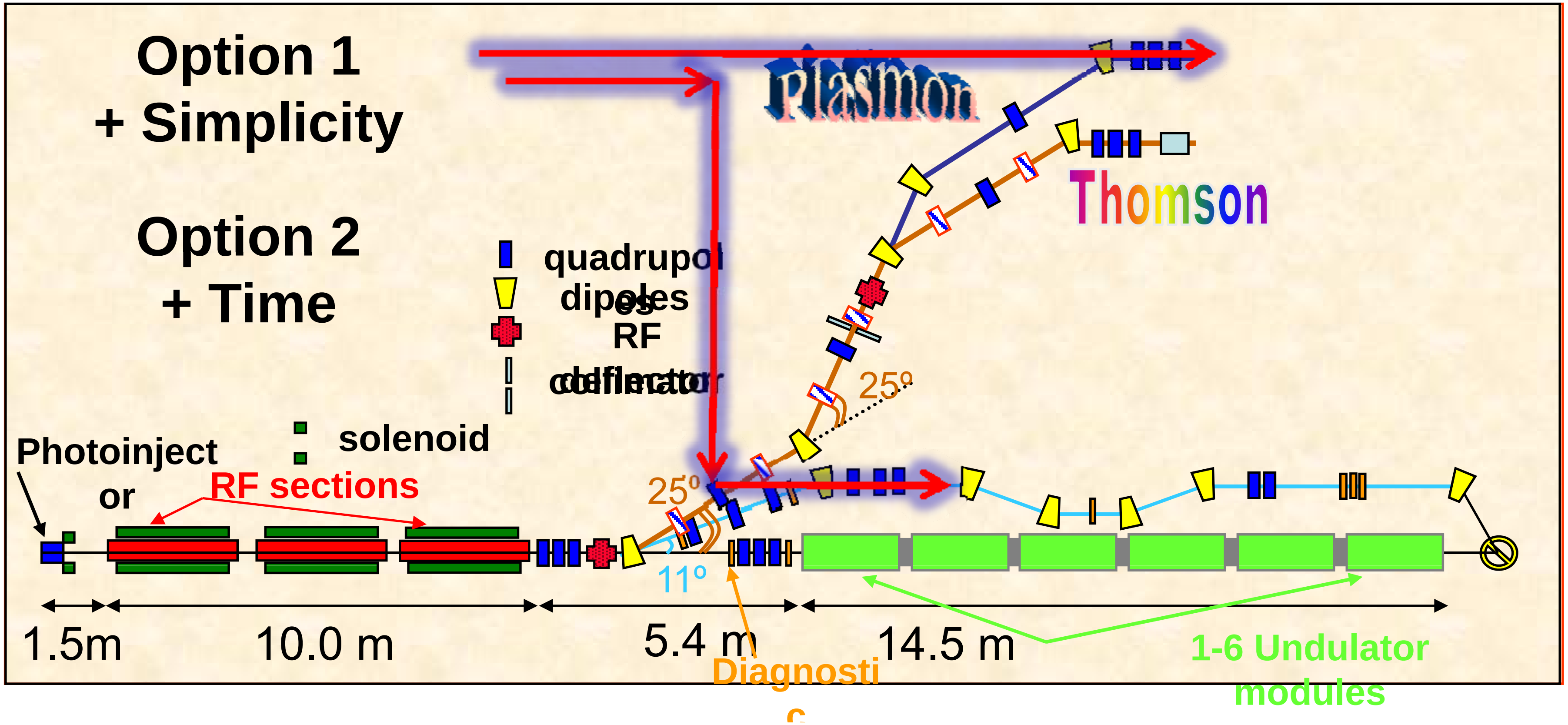


Initial energy	52 MeV
Final energy	180 MeV
Avg gradient	260 MV/m
Final energy spread	1 %
Laser wavelength	800 nm
Laser power	5 TW
Laser spot size (w_0)	0.2 mm

Layout


70 cm



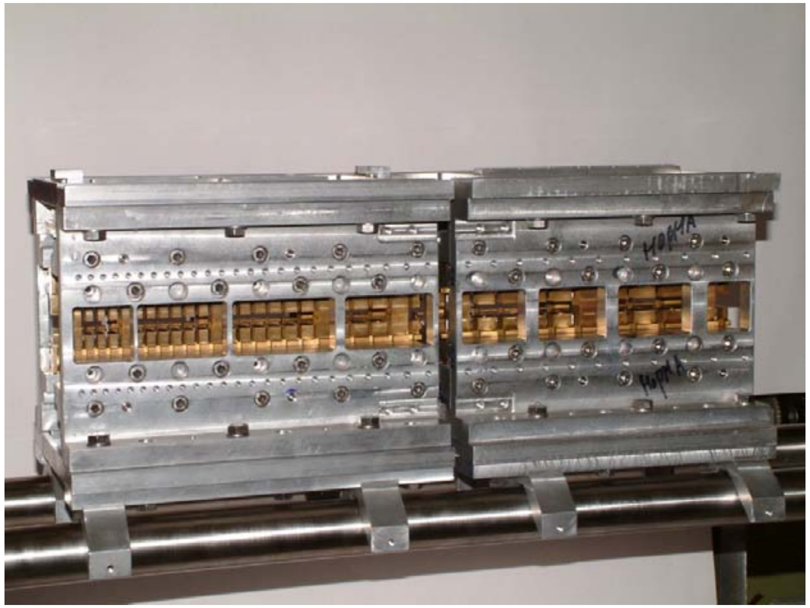

Option 1
+ Simplicity
Option 2
+ Time
Plasmon
Thomson
quadrupol
dipoles
RF
deflector
collimator
solenoid
Photoinject
or
RF sections
25°
25°
11°
1.5m
10.0 m
5.4 m
14.5 m
Diagnosti
c
1-6 Undulator
modules

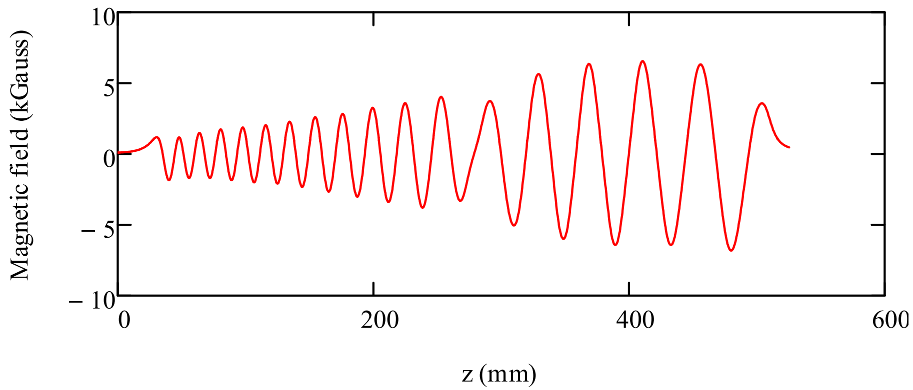
UCLA tapered undulator @ LNF

Use ***unique*** capabilities of SPARC + FLAME.

- High brightness beam
- High power laser in same facility.
- UCLA has already available and could loan the strongly

	Initial	Final
Period	1.5 cm	5.0 cm
Field Amplitude	0.12 T	0.6 T
Peak K parameter	0.2	2.8
gap	12 mm	12 mm





A new helical undulator for a phase-2 IFEL acceleration experiment at SPARC

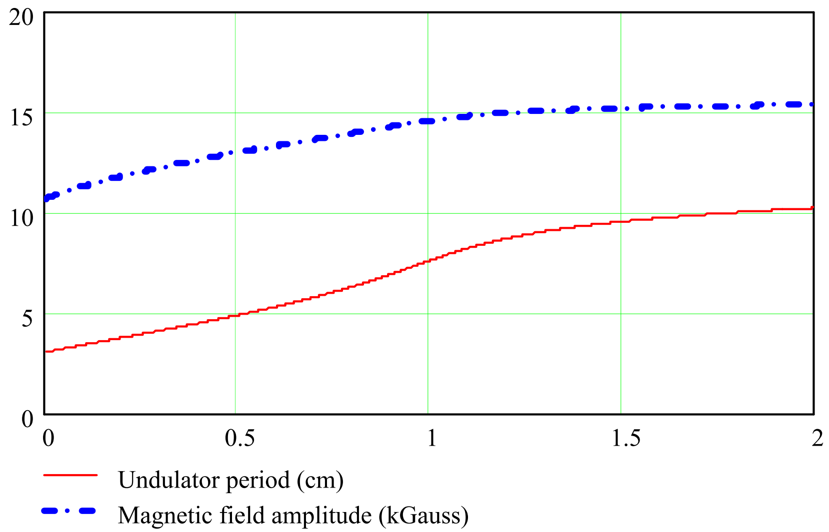
Assume typical parameters for SPARC / FLAME

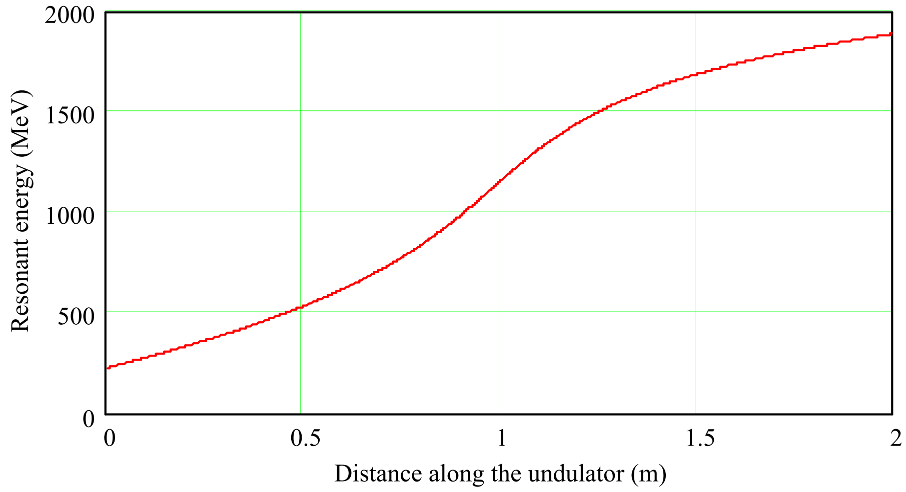
Aim at maximum final energy with 2 m long undulator

Parameter	Fixed Value
Initial *e*-beam energy (γ value)	180 MeV
Initial *e*-beam intrinsic energy spread	0.1% (1σ)
Initial *e*-beam current	1 kA
Laser wavelength	800 nm
Laser peak power	20 TW
Nominal length of wiggler, L_w	200 cm
Rayleigh range	20 cm
Location of laser waist inside wiggler	100 cm
Resonant phase angle ψ for wiggler	*var*

Tapering optimization

- Helical undulator to maximize energy exchange (interaction always ON).
- Keep magnetic field amplitude well under the Halbach limit for a gap = 6 mm to ensure technical feasibility.
- Starting from initial energy 180 MeV
- Final energy spread <0.6 %, to be decreased with appropriate choice of resonant phase exit.





SITUAZIONE DELLE PROPOSTE DEL PROGETTO STRATEGICO "NUOVE TECNICHE DI ACCELERAZIONE" PER IL BILANCIO 2009

- per Sigla -

NOTE	SIGLA	Sez.	INTERNO		ESTERO		CONSUMO		SEM	TRASPORTI		PUB	CALCOLO		MAN.		INVENTARIO		APPARATI		TOT. PARZIALI		GENERALE
			Assegn.	S.J.	Assegn.	Sub-Jud	Assegn.	Sub-Jud		Assegn	S.J.		Assegn.	S.J.	Ass.	S.J.	Assegn.	Sub-Jud	Assegn.	Sub-Jud	Assegn.	Sub-Jud	
	NTA-PLASMONX	BO	7		5		2														14		**14**
	NTA-PLASMONX	LNF	10		8		9												96		123		**123**
	NTA-PLASMONX	MI	15		12		5														32		**32**
	NTA-PLASMONX	MIB	7		3		3														13		**13**
	NTA-PLASMONX	NA	3		2		3														8		**8**
	NTA-PLASMONX	PI	20		7		40								10				90		167		**167**
	Totale Sigla		62		37		62								10				186		357		**357**

PREVENTIVO GLOBALE DI SPESA PER L'ANNO 2010

In K€

Struttura	A carico dell'I.N.F.N.									A carico di altri enti
	interno	estero	consumo	trasporti	manutenzione	inventario	apparati	licenze-SW	**TOTALI**	
BO	5.00	5.00	11.00						**21.00**	
LNF	10.00	20.00	9.00			34.00	59.50		**132.50**	
LNS	10.00	5.00	3.00	2.00					**20.00**	
MI	20.00	15.00	5.00				65.00		**105.00**	
MIB	8.00	2.00	3.00			5.00			**18.00**	
NA	12.00	20.00	15.00	2.00	4.00	41.00		4.00	**98.00**	
PI	35.00	15.00	33.00	2.00	15.00	102.00	15.00	8.00	**225.00**	
RM1	5.00	5.00	30.00			56.00			**96.00**	
Totali	**105.00**	**87.00**	**109.00**	**6.00**	**19.00**	**238.00**	**139.50**	**12.00**	***715.50***	

Mod. EC/EN 4 (a cura del responsabile nazionale)