Joint Research Activities on

Charge production with Photo-injectors (PHIN)

Andrea Ghigo on behalf of PHIN collaboration

CARE collaboration meeting CERN 2-4 December 2008

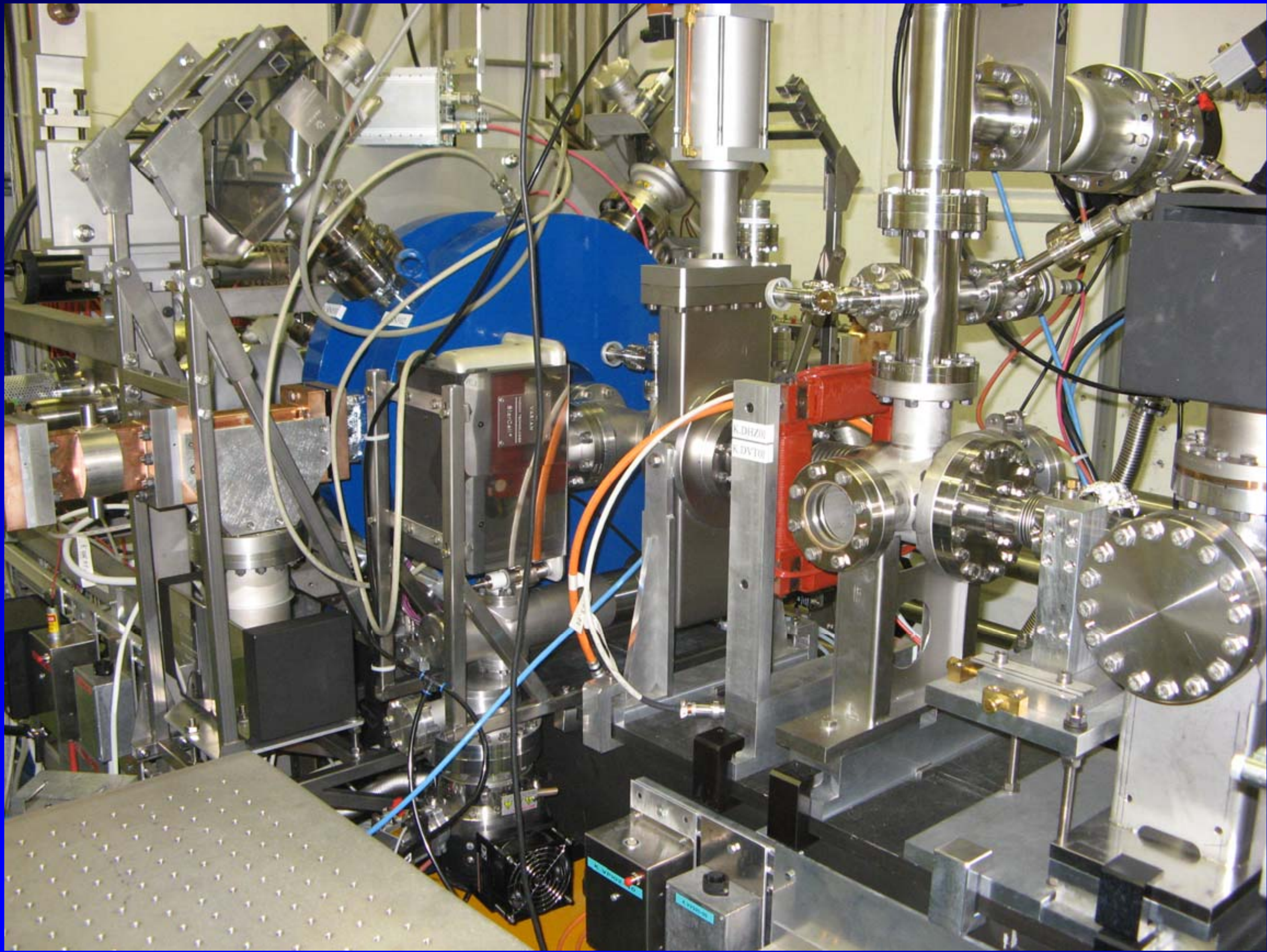
Coordinator: A. Ghigo **Deputy Coordinator: L.Rinolfi**

Institute	Acronym	Country	PHIN Scientific Contact	Associated to
CCLRC Rutheford Appletone Lab. (22)	**CCLRC-RAL**	**UK**	**G.Hirst**	
CERN Geneva (19)	**CERN**	**CH**	**R.Losito**	
CNRS-IN2P3 Orsay (3)	**CNRS-LAL**	**F**	**G. Bienvenu**	**CNRS**
CNRS Lab. Optique Appl. Palaiseau (3)	**CNRS-LOA**	**F**	**V. Malka**	**CNRS**
ForschungsZentrum ELBE (10)	**FZR-ELBE**	**D**	**J. Teichert**	
INFN-Lab. Nazionali di Frascati (11)	**INFN-LNF**	**I**	**A. Ghigo**	**INFN**
INFN- Milan (11)	**INFN-MI**	**I**	**I. Boscolo**	**INFN**
Twente University- Enschede (13)	**TEU**	**NL**	**P.Van der Slot**	

PHIN JRA addressed to

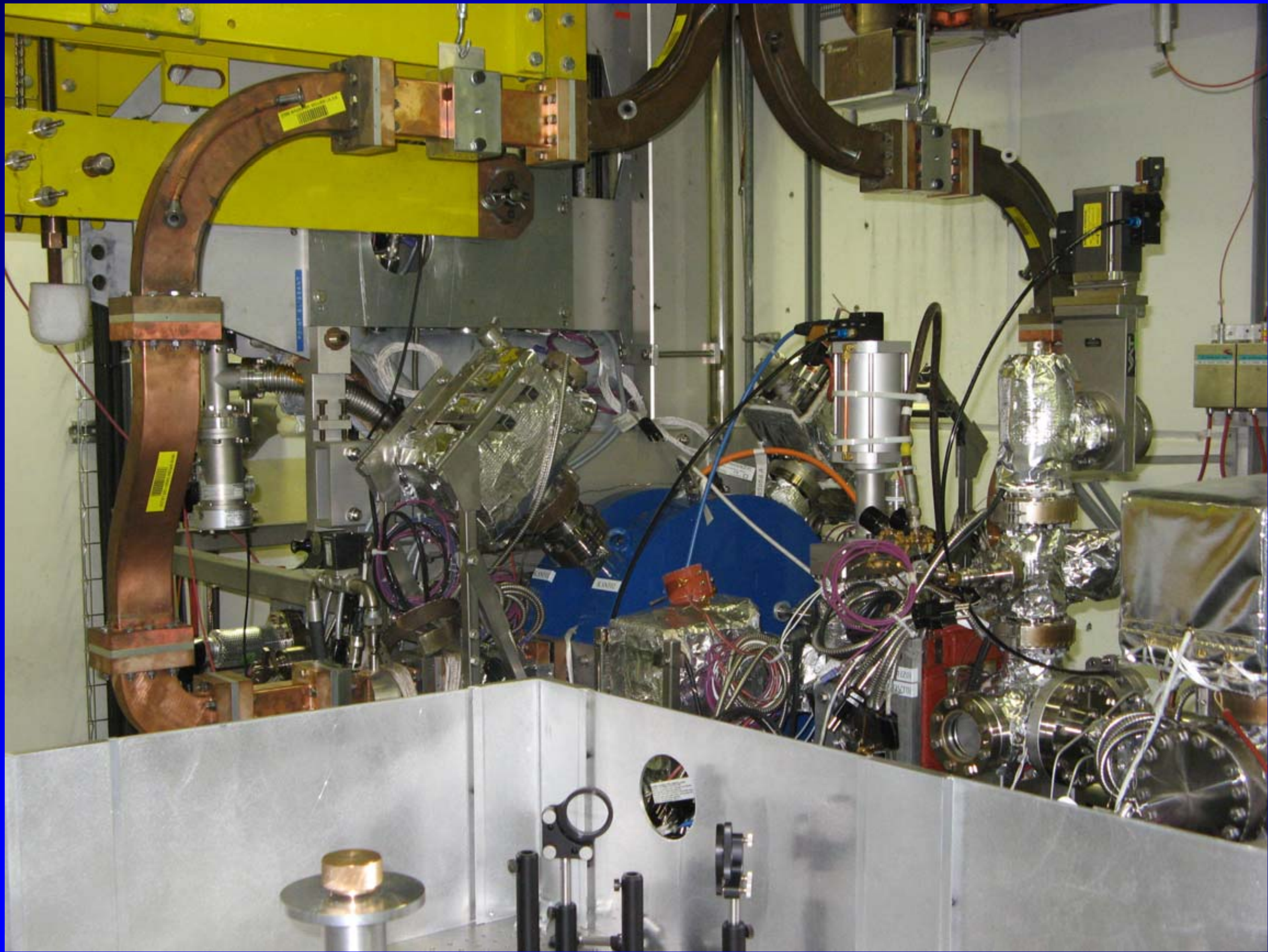
- **Development of the high charge e^- beam (drive beam) for the RF power source of the two-beam linear collider CLIC-CTF3 (CERN).**
- **Realisation of the first high power photoinjector that uses a photocathode, laser driven, in a superconducting RF gun for application in ELBE (Rossendorf).**
- **Realisation of high brightness high energy laser driven plasma photoinjector (LOA-Palaiseau)**
- **Realisation of new electron source for NEPAL (PHIL) (LAL-Orsay) test stand.**
- **Improve the brightness of SPARC (INFN-Frascati / Milano) photoinjector by longitudinal laser pulse shaping.**
- **Improve the performance of TEU-FEL (Twente) photoinjector by studying cathodes composition and adding cathode diagnostics**

Status of the CTF3 photoinjector



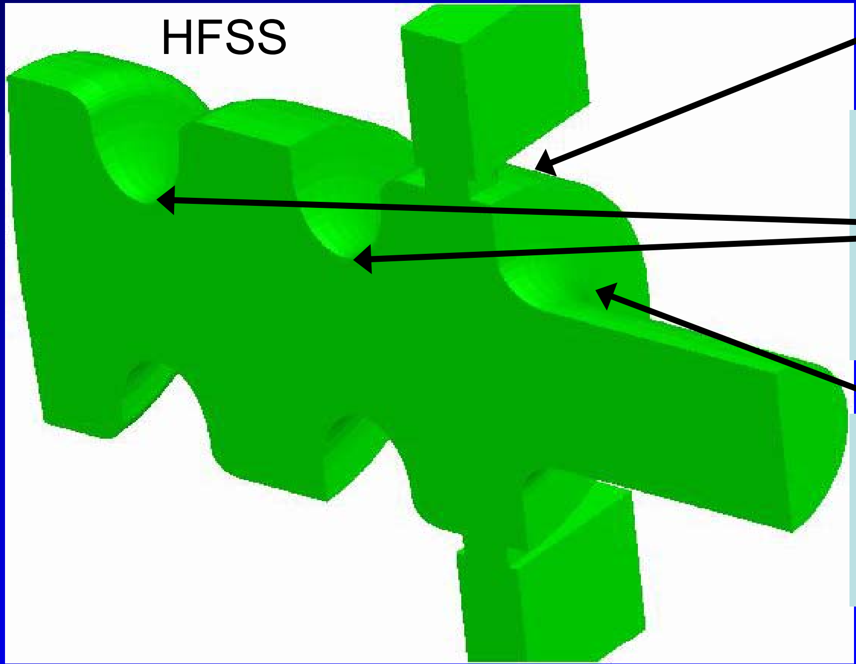
16 September 2008

Status of the CTF3 photoinjector



17 November 2008

Construction of 2 photo-injectors: one for CTF3 and one for LAL



Hole coupling:
•overcoupled
•symmetrical

Elliptical irises to reduce Surface electrical field

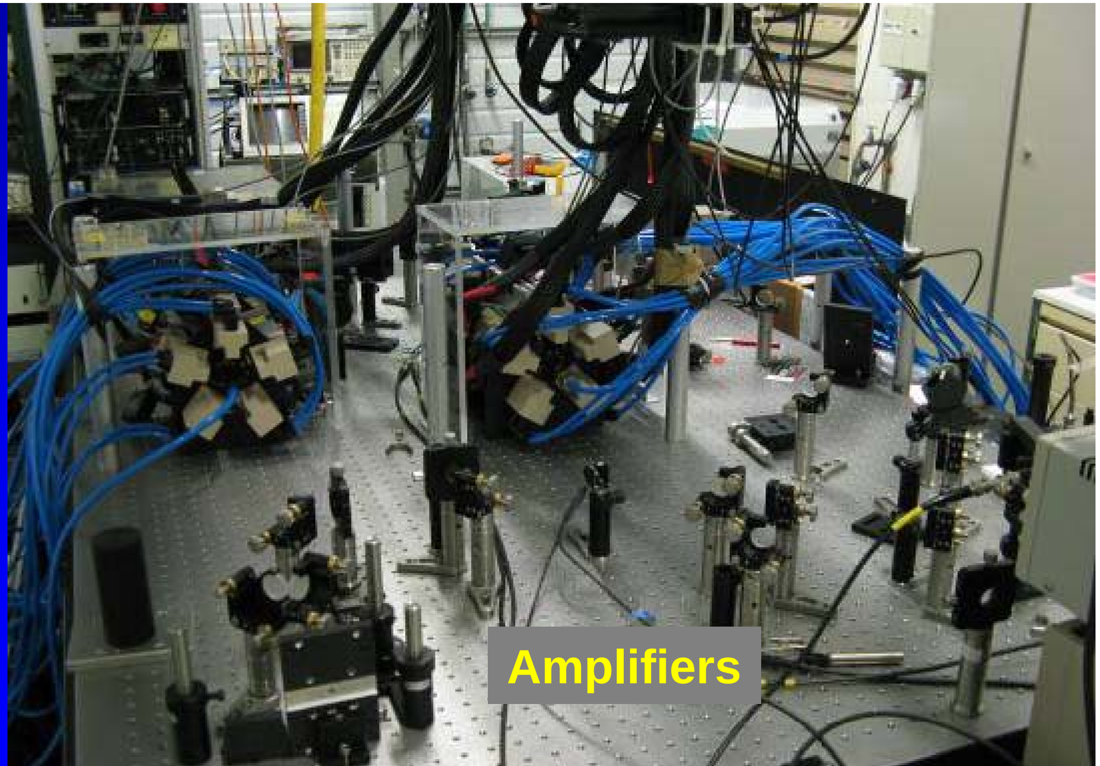
Racetrack shape of the coupling cell

29 April 2008 – LAL (photo G. Bienvenu)

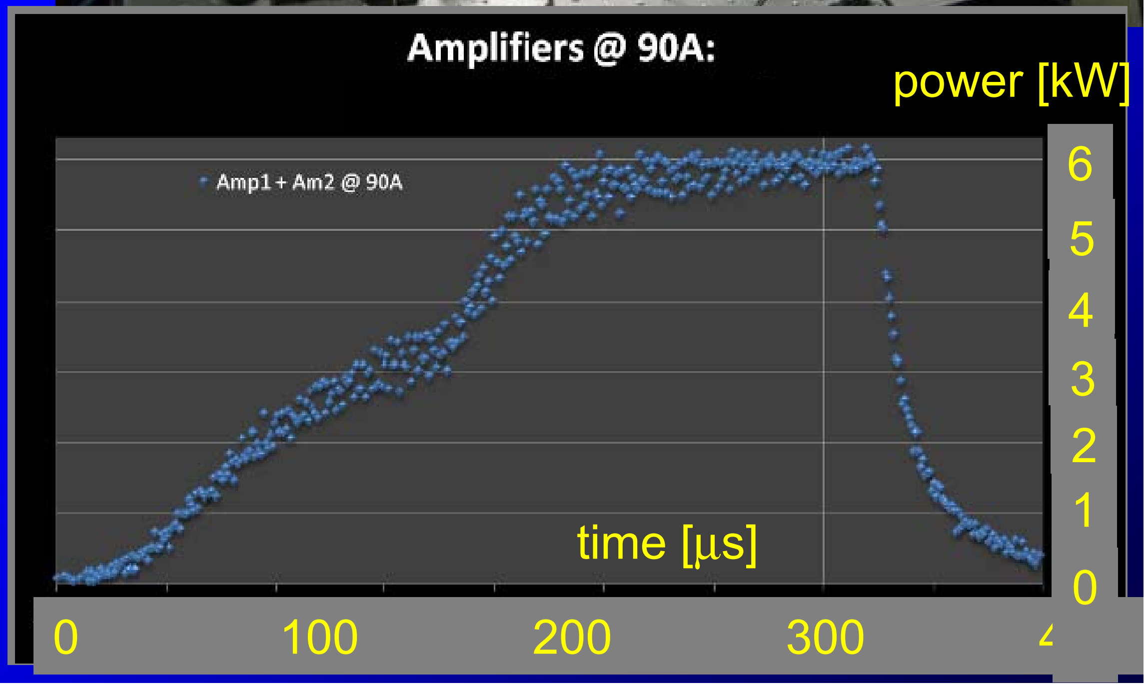
F_r = 3.0 GHz
R_s = 6 MΩ
Q = 14530

P = 10 MW (vacuum)
P = 30 MW with beam
Injection during the rise time

CTF3 - LASER



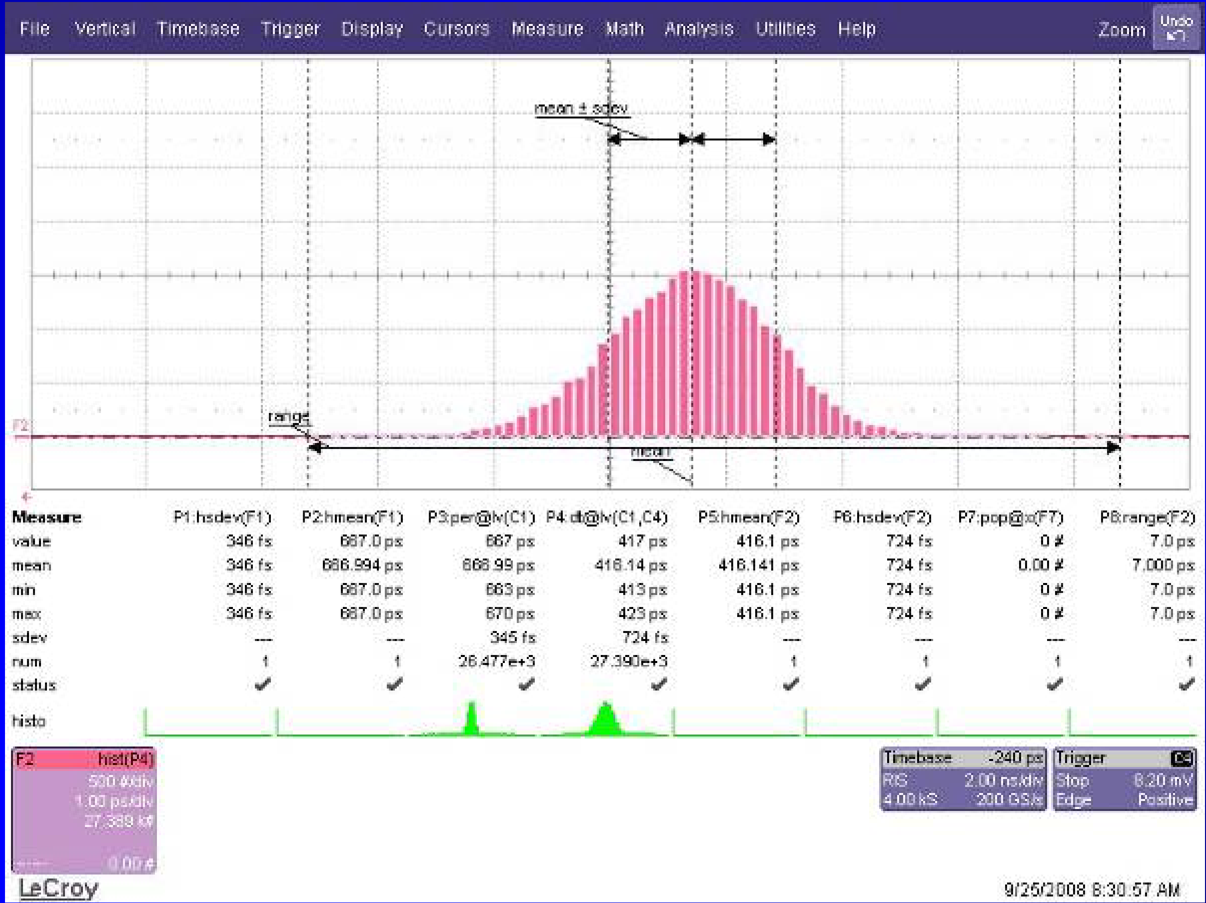
CTF3 High Power LASER
CCLRC-RAL design and realization.
CERN-INFN commissioning
- **1st Amplifier reach nominal power and gain [3.5kW]**
  - **Pulse duration < 10ps**
  - **Jitter< 1 ps**
- **2nd Amplifier reaches half nominal power.**



On site synchronization measurements

Lecroy SDA (16GHz, 60GS/s+ NewFocus Photodetector25GHz)

After on site investigation, oscillator cavity perturbations due to thermal effects were suspected



HighQ expert came and fixed the settings of the oscillator end-cavity mirror (semiconductor saturable absorber mirror "SESAM"): 50C Degree

Problem has been fixed

$$J_{real} = \sqrt{(J_{meas})^2 - (JNF)^2}$$

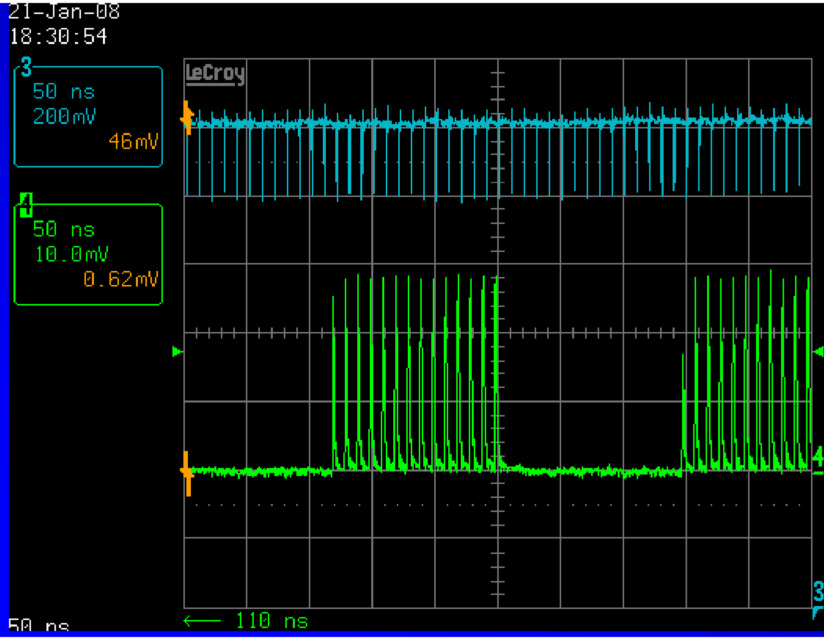
JNF: jitter noise floor ~ 350 fs
Jmeas: 724fs

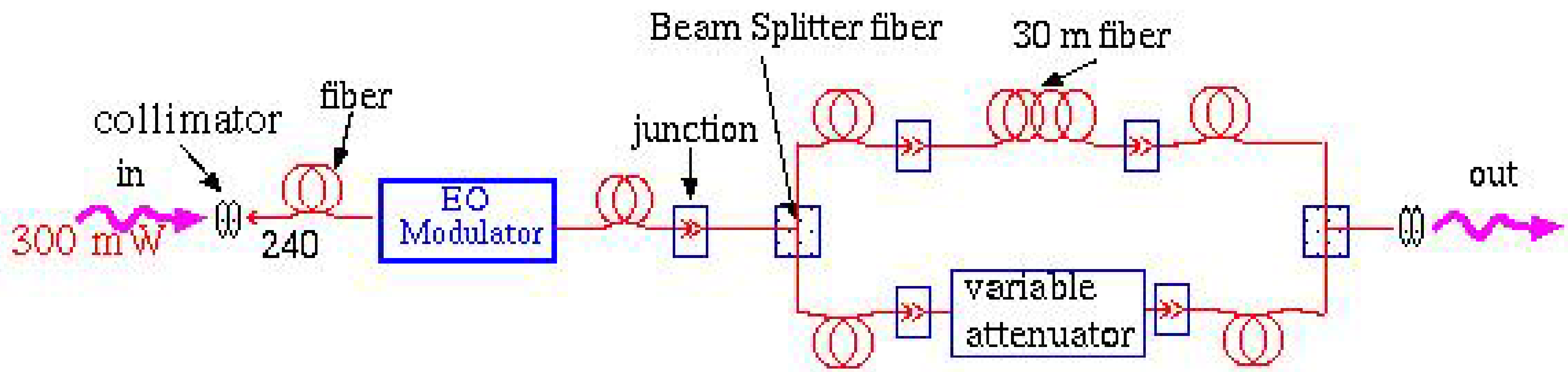
J_{real} ~ 634 fs (rms jitter required <1ps)

Phase coding system

Trains of the right length are generated

Pin 300 mW expected Pout 10.7 mW
Measured: Pout about 7 mW

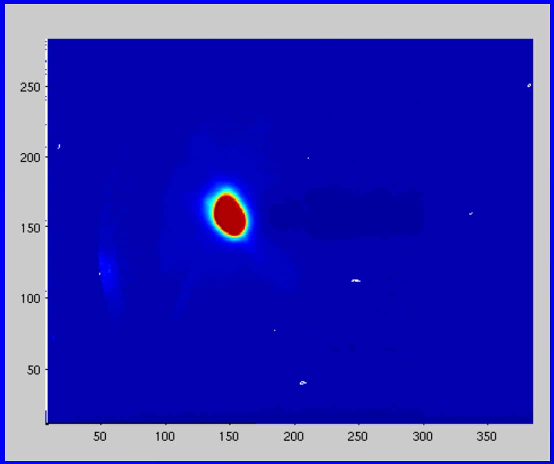




CCLRC assesments	1	4.5	0.5	0.5	0.5	0.5	0.5	loss dB
	0.8	0.35	0.9	0.9	0.9	0.9	0.9	P_o/P_i
Milano measurenents	ok	7.3	ok	>0..5	ok	ok	>0..5	
		0.18		<0.9			<0.9	

CTF3 Photoinjector commissioning

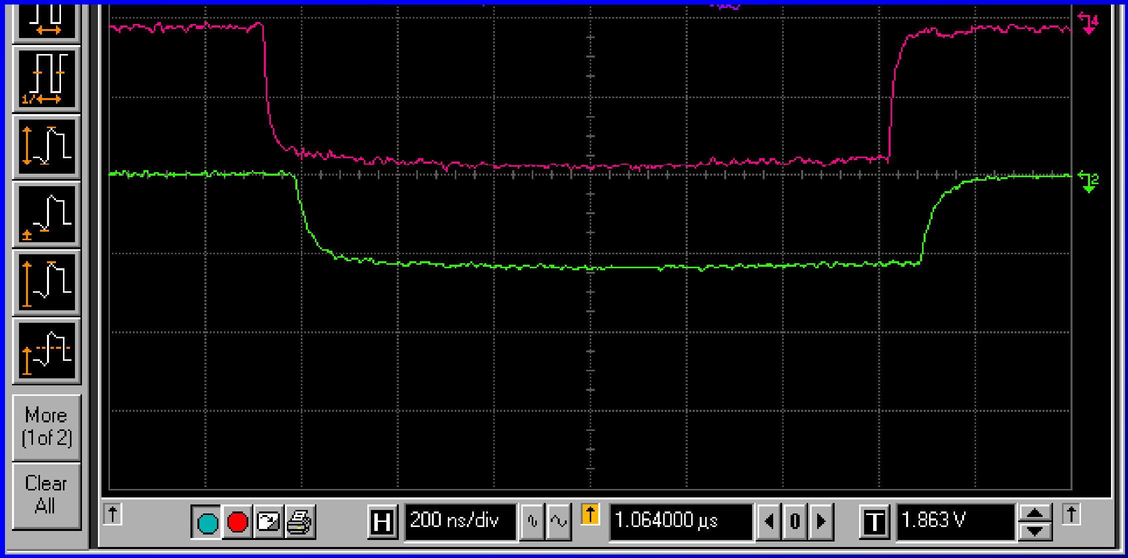
first MTV screen
beam spot 1.55 m
downstream of RF gun:
FWHM ~ 5 mm



Beam current – 1.3 μs train (2000 bunches)

Beam Position Monitor
Sum Signal

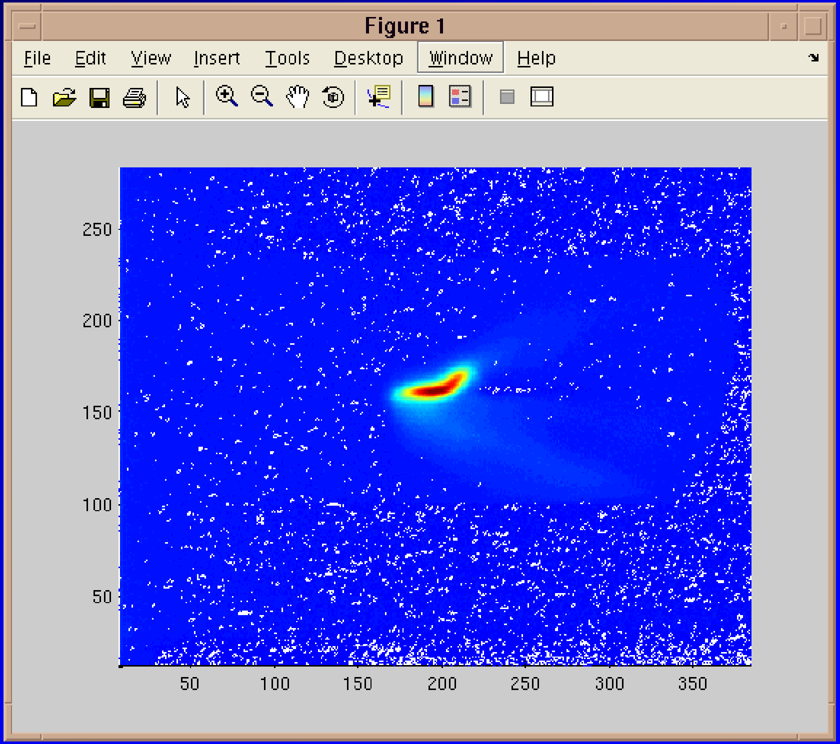
Faraday Cup

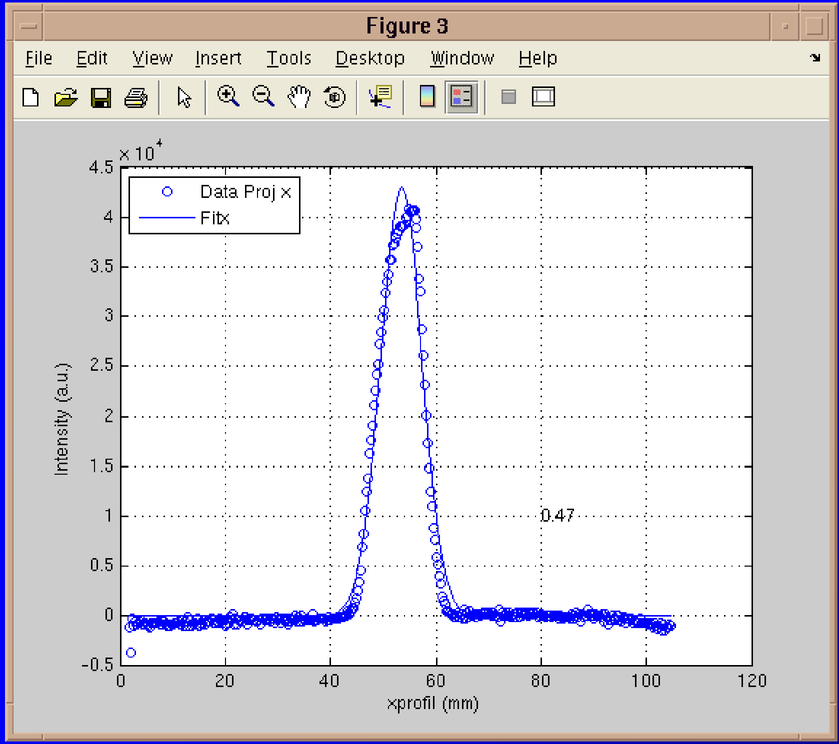


electron beam train-to-train
intensity fluctuations (BPM):
r.m.s < 6% (5 minutes)

laser beam train-to-train
UV energy fluctuations
in laser room:
r.m.s < 3% (500 trains)

Energy measurement, 90 deg. Spectrometer



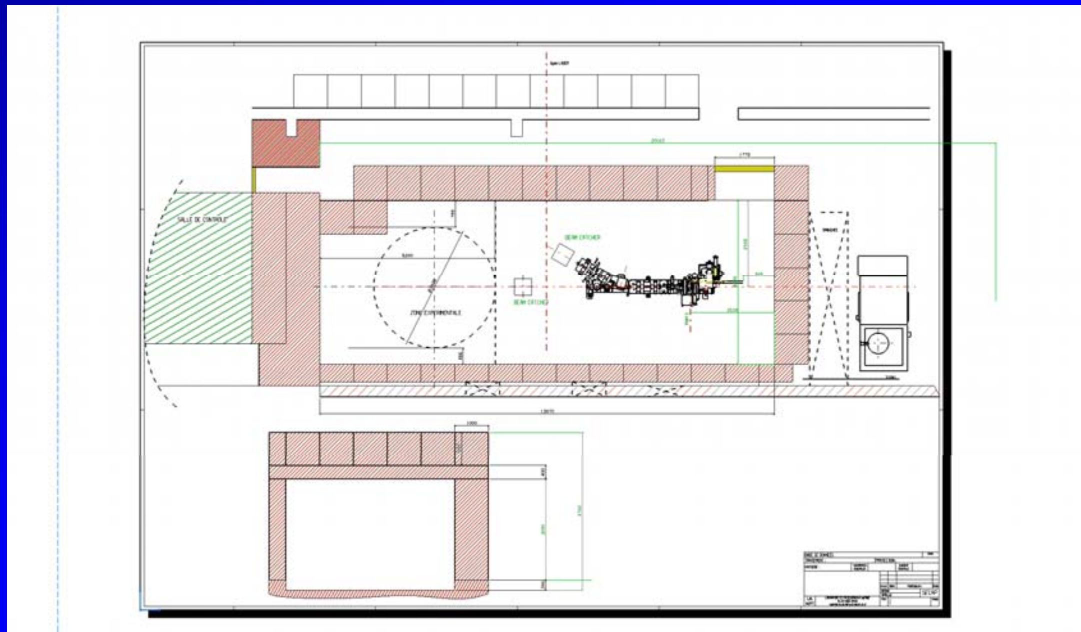


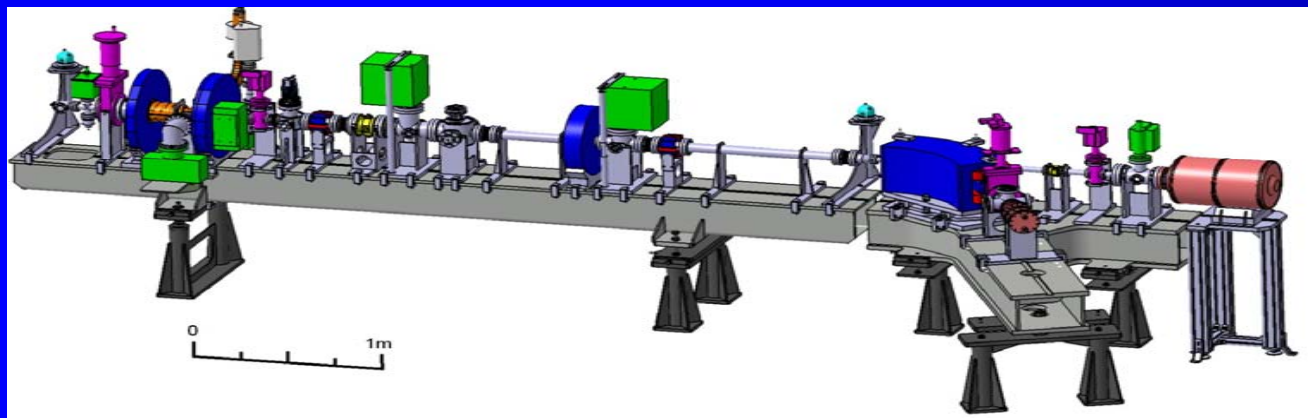
Measured nominal energy with small energy spread (calibration to be checked)

5.3 MeV with 27 keV (0.5 %) r.m.s. energy spread

Construction of a test beamline at LAL

Layout of the accelerator area





Construction of a test beamline at LAL

The civil engineering begun in October 2006

Holes are drilled in the floor, pillars are set-up, then a concrete floor is built

End of civil engineering in March 2007

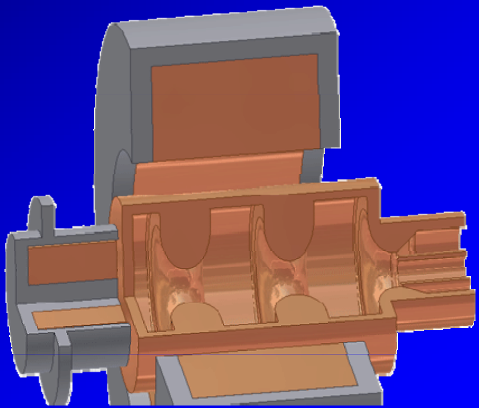
SERA

Construction of a test beamline at LAL

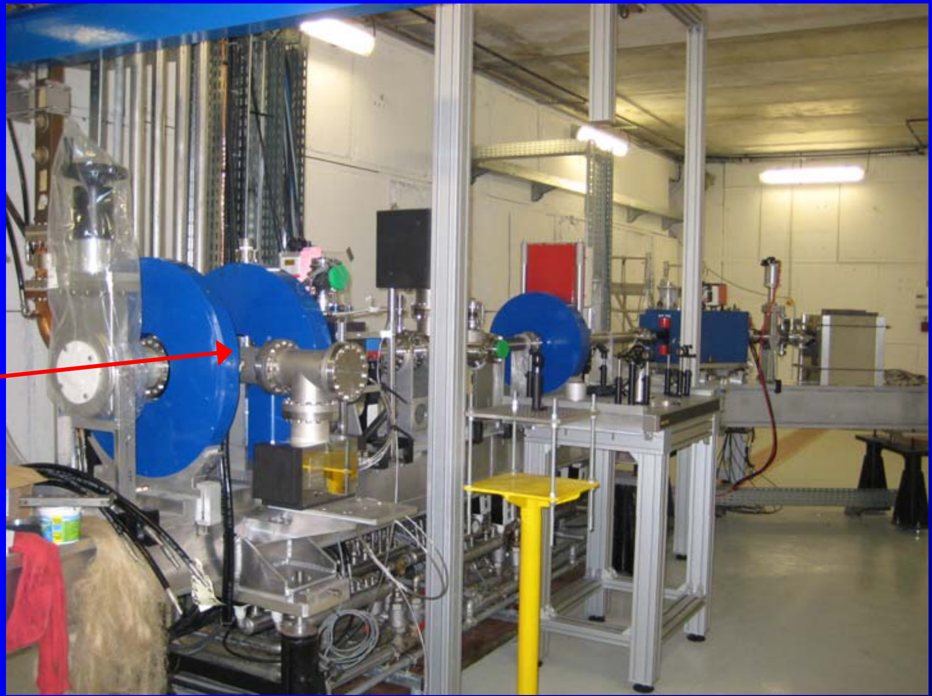
PHIN

Most of the beamline was installed in July 2008

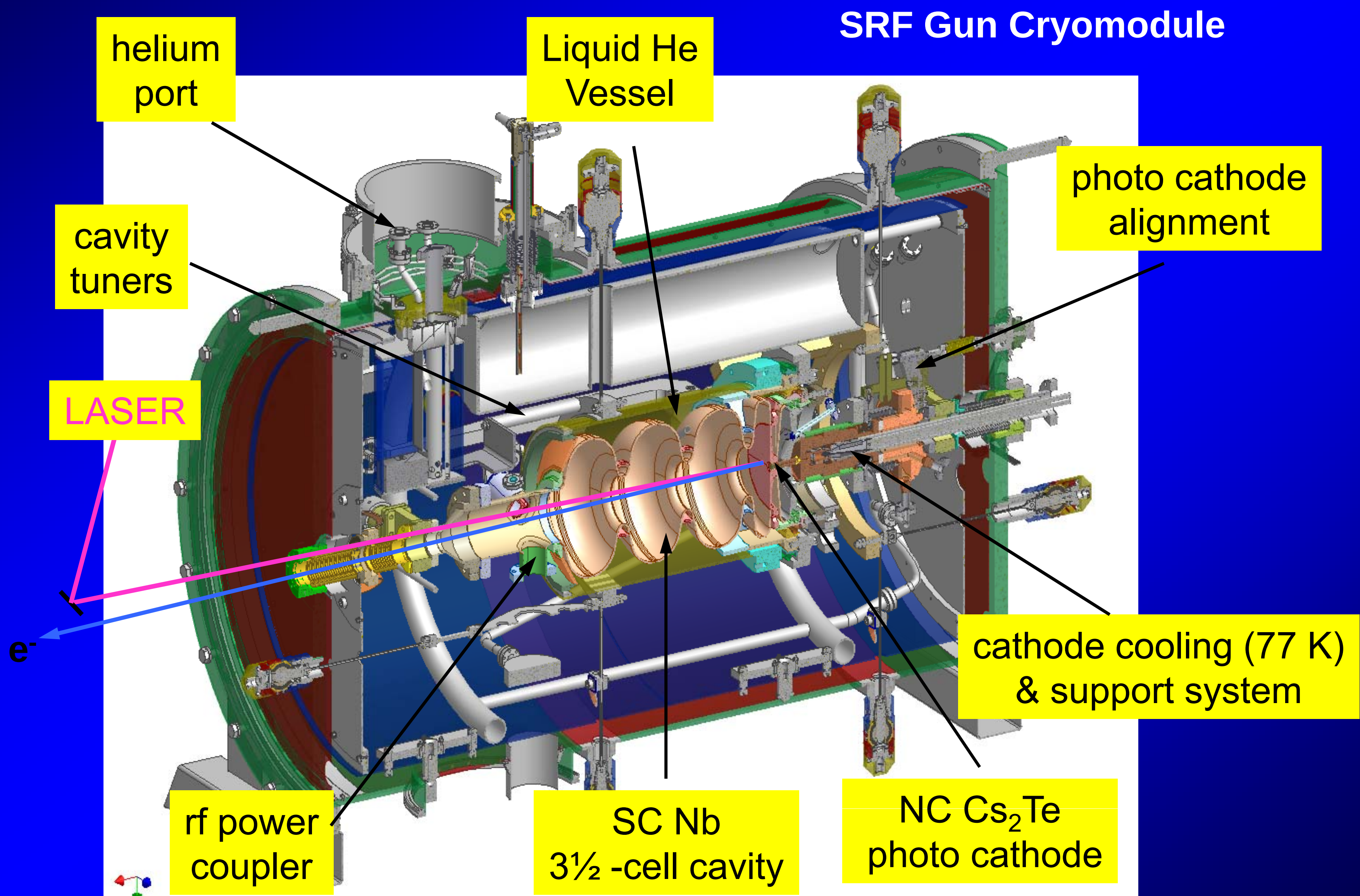
AlphaX RF gun



- 3 GHz
- 2,6 cells
- waveguide coupling
- compatible with NEPAL beamline

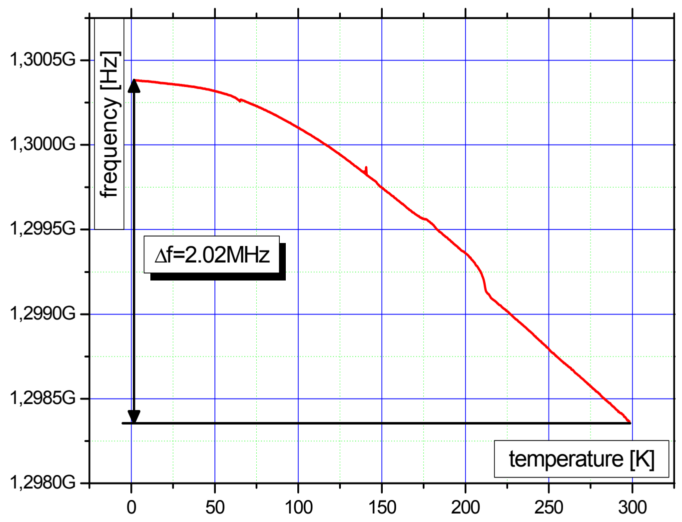


The Superconducting RF Photoinjector at ELBE



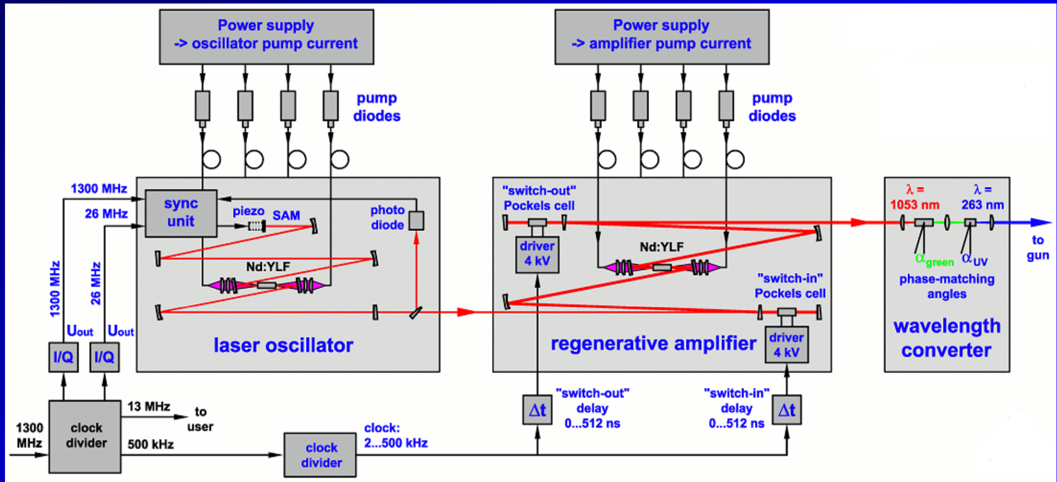
COMMISSIONING – FIRST COOL-DOWN

first cool-down 1 – 2 August 2007



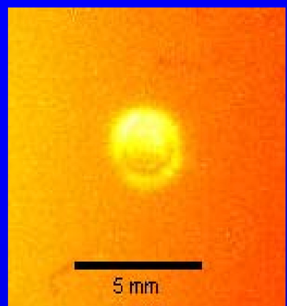
COMMISSIONING – UV LASER INSTALLATION

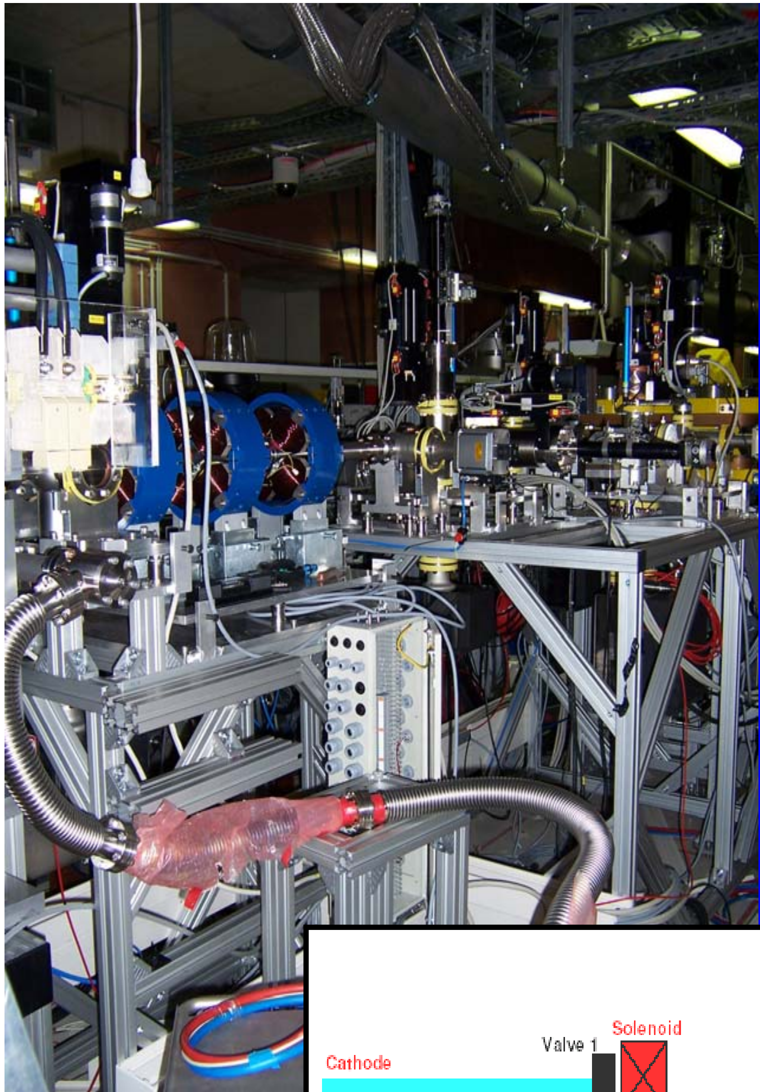
500 kHz Laser system developed by MBI



262 nm CW laser mit 0.5 W /UV)
Nd:YLF oscillator +
Nd:YLF regenerative amplifier
two-stage frequ. conv. (LBO, BBO)
15 ps FWHM Gaussian

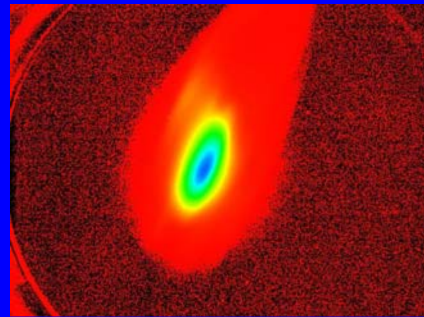
Laser pulse lateral:
shaped with aperture to Ø 2.7 mm
circular flat top





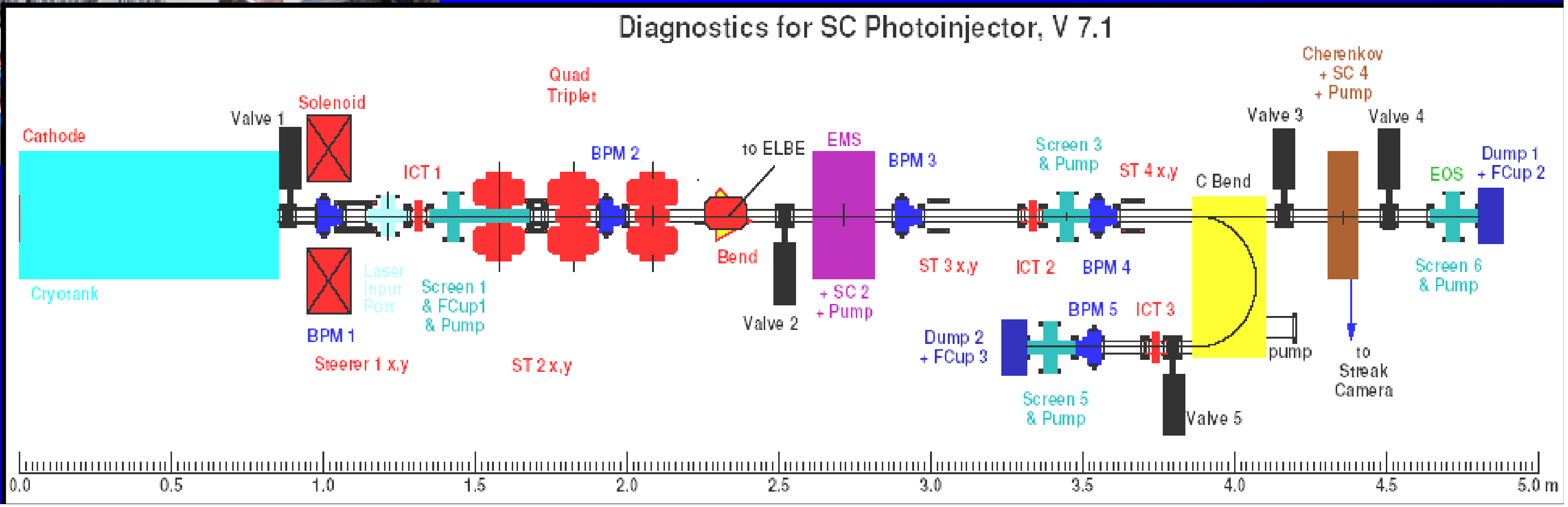
COMMISSIONING - DIAGNOSTICS BEAMLINE

Beam spot on the first YAG screen in the BESSY diagnostics beamline



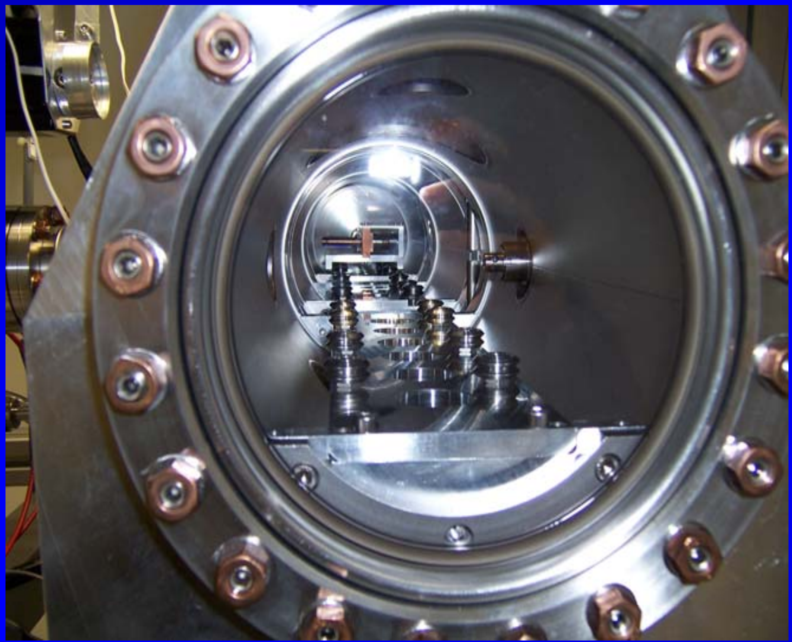
ELBE shut-down, Oct. 15 – 26, 2007
Installation of BESSY diagnostics beamline

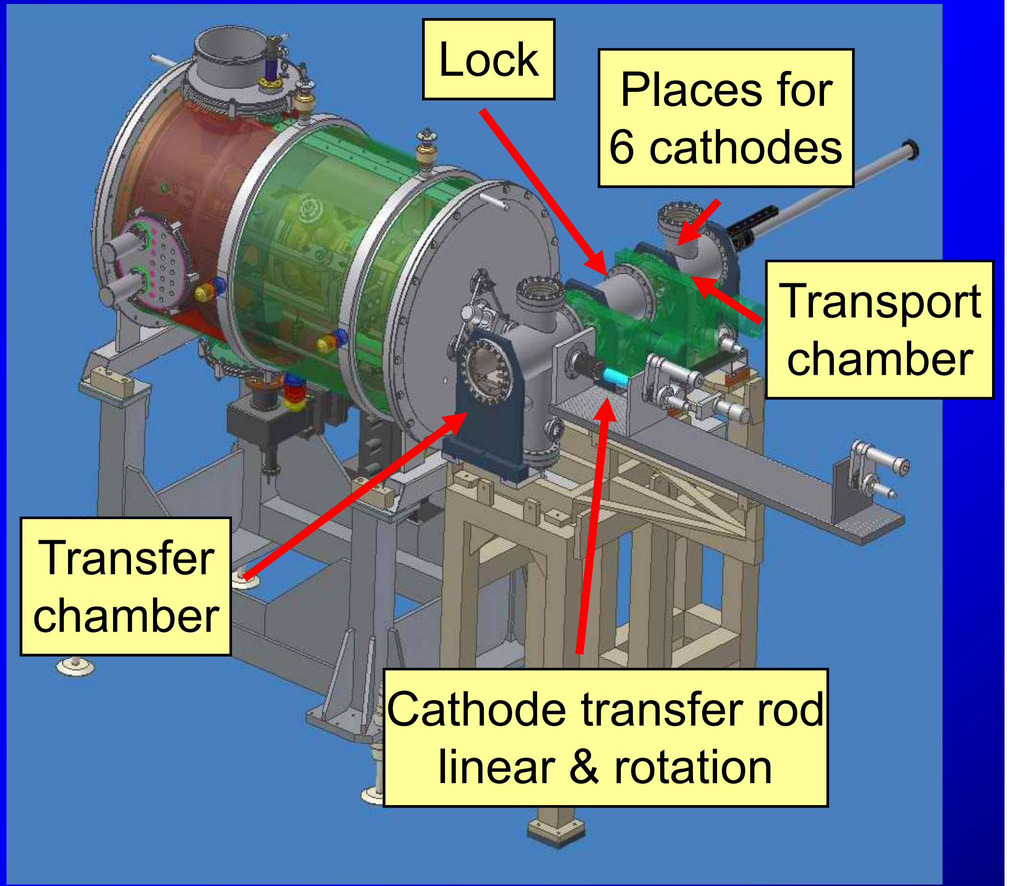
- **Emittance measurement (slit mask)**
- **C bend (E, ΔE)**
- **Cherenkov radiatior with optical beamline and streak camera**



COMMISSIONING - CATHODE TRANFER SYSTEM INSTALLATION

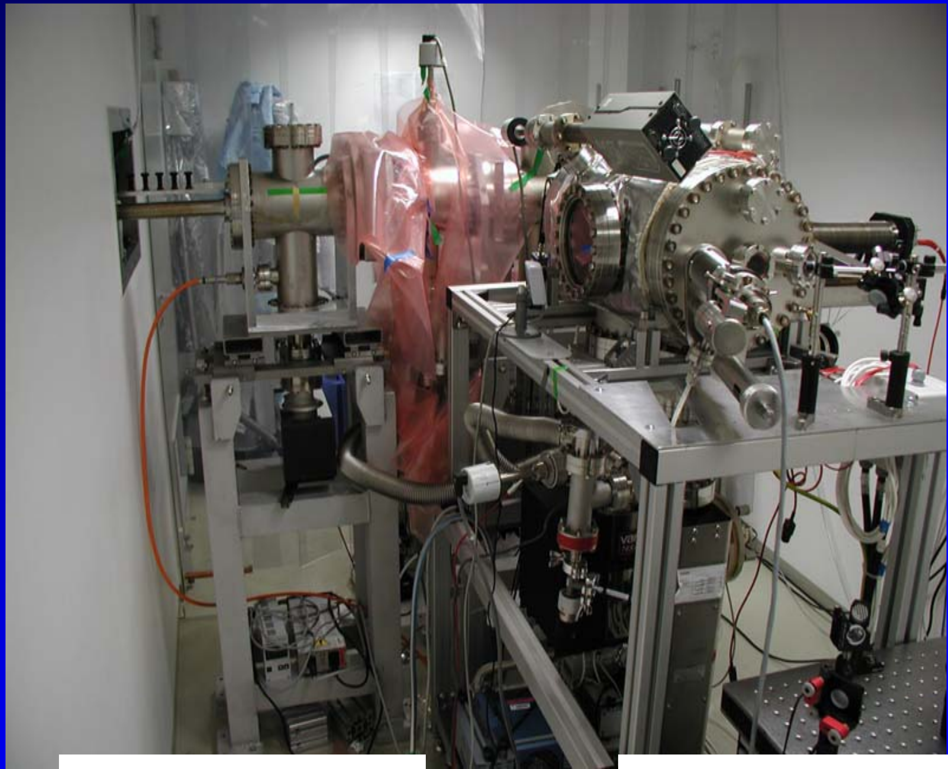
installation in the shut-downs
of ELBE in Jan. + March 08
at the SRF gun



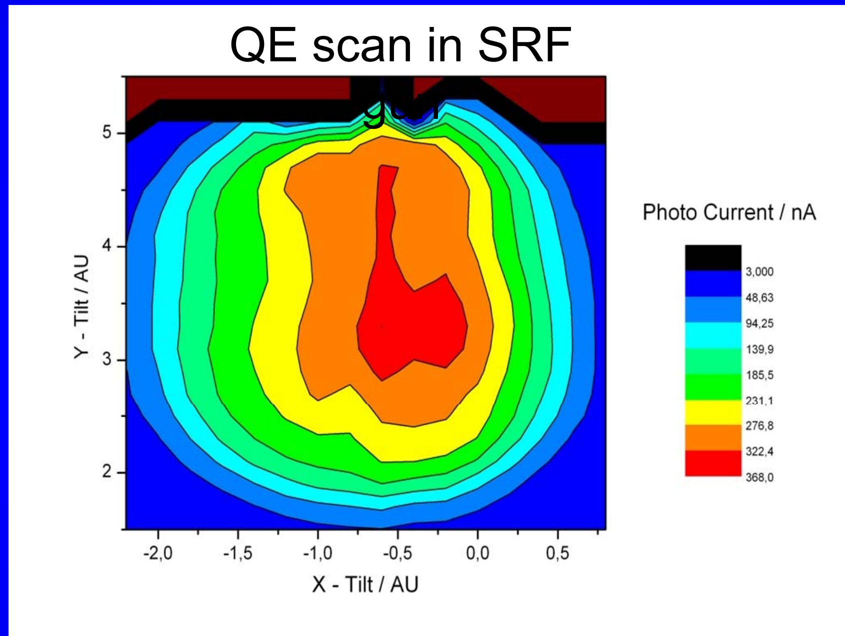


Cs_2Te PHOTO CATHODES

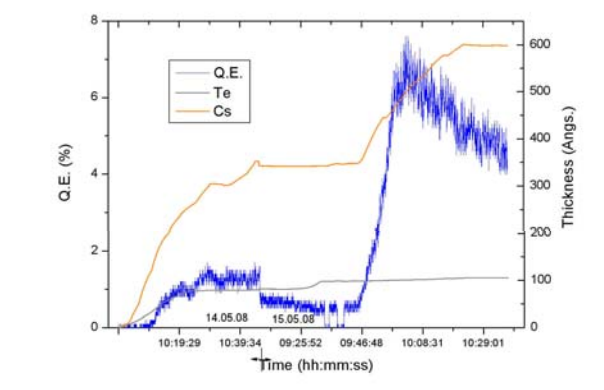
Photo cathode preparation lab at FZD



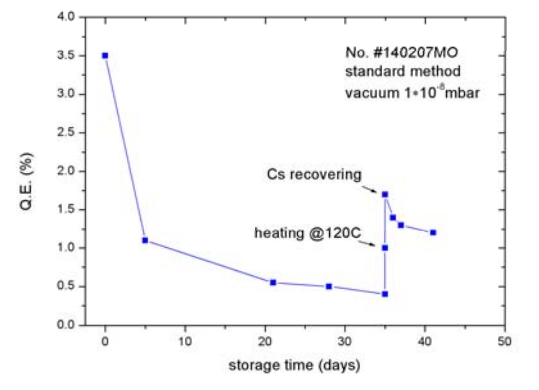
May 08: First set of Cs_2Te cathodes in the SRF gun



preparation process



storage & recovery

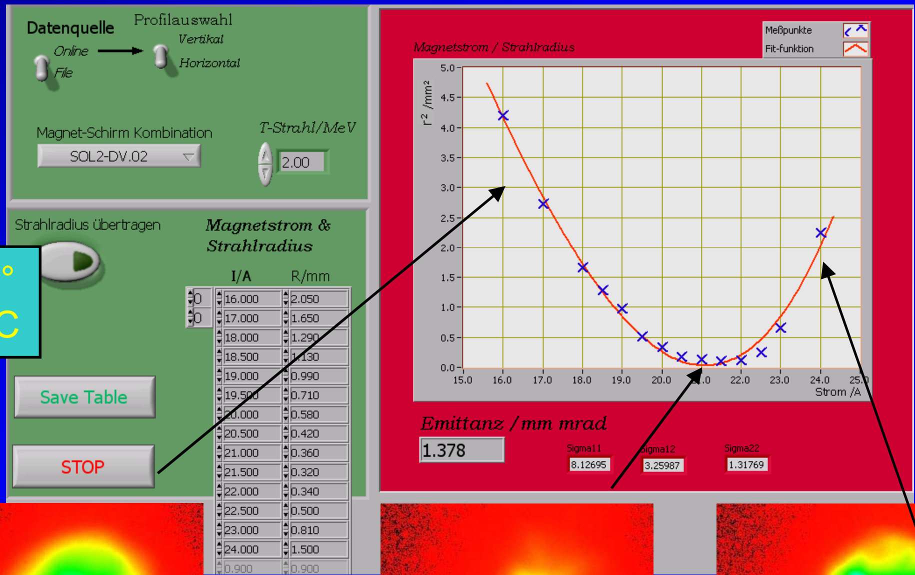


CARE collaboration meeting
CERN 2-4 December 2008

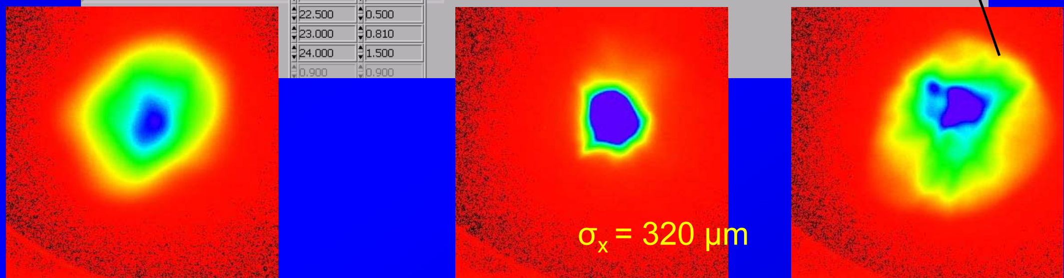
BEAM PARAMETER MEASUREMENTS

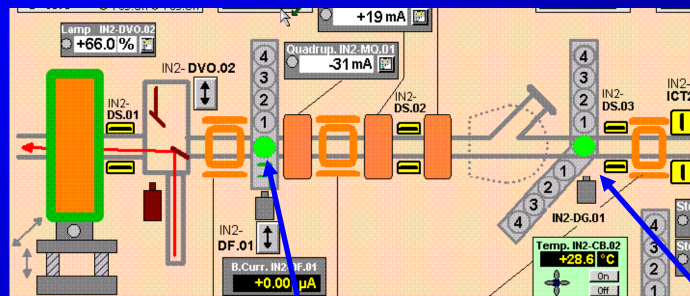
Transverse Emittance – Solenoid scan

- not suitable for space-charge dominated beams,
- preliminary method as long as the analysis tools for the installed slit mask method are under development



-160°
20 pC





screen DV01

screen DV02

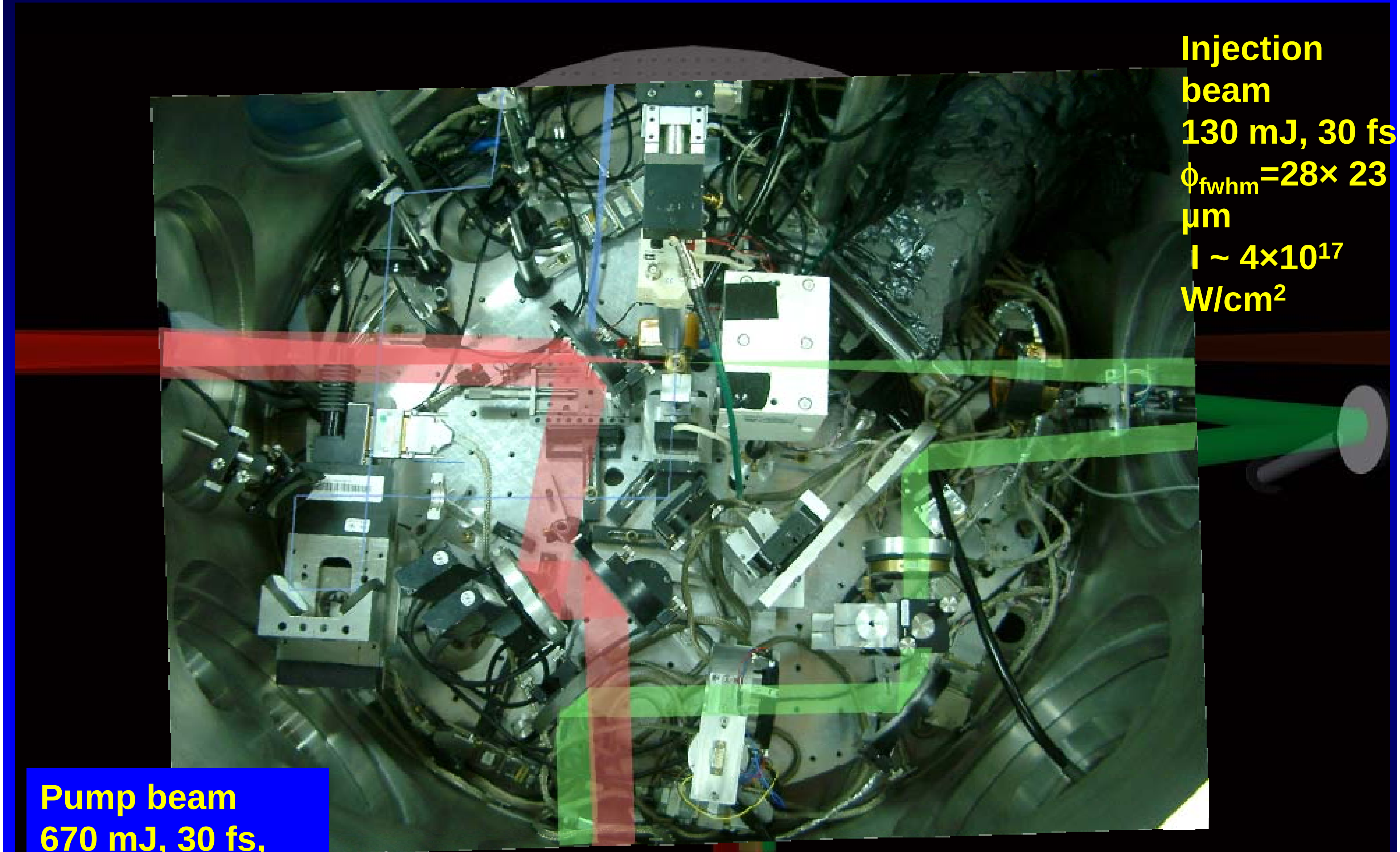
Measurement: 5 MV/m gradient, 2 MeV energy
laser: 15 ps FWHM Gaussian, 2.7 mm diam. sharp edges
launch phase & pulse energy variation

LOA has completed all their deliverables

Laser plasma acceleration has demonstrated

- Energy gains of 1 MeV to 200 MeV
- E-fields of 1 GV/m to 1000 GV/m
- Good e-beam quality : Emittance < 3πmm.mrad
- Charge at high energy
- Quasi monoenergetic

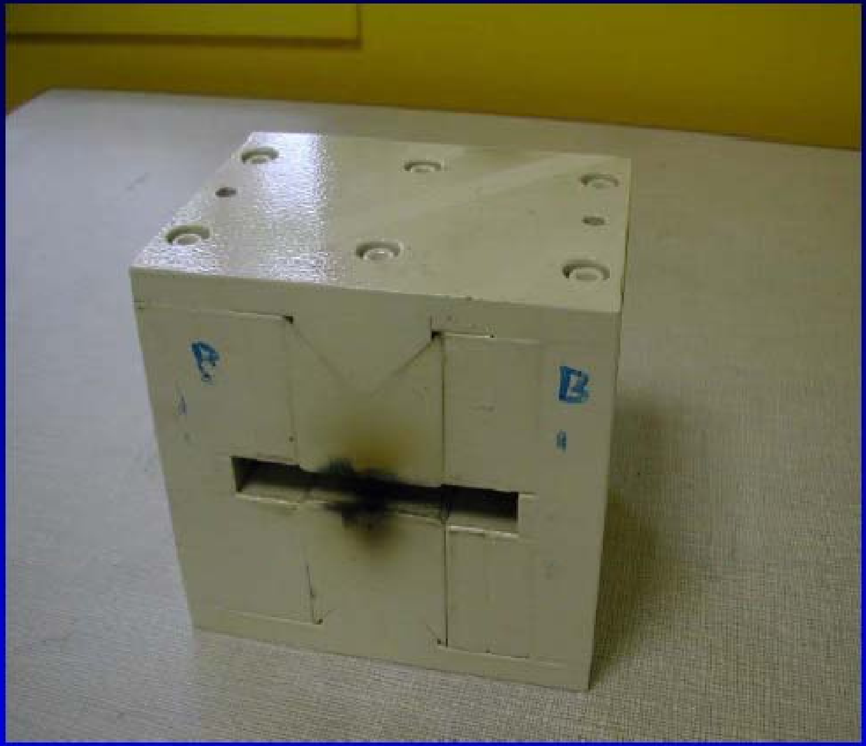
Experimental set up



Injection beam
130 mJ, 30 fs
ϕ_{fwhm}=28× 23 µm
I ~ 4×10^{17} W/cm^2

Pump beam
670 mJ, 30 fs,
ϕ_{fwhm}=21×18 µm
I ~ 4×10^{18} W/cm^2

LOA Energy spectrometer permanent magnets

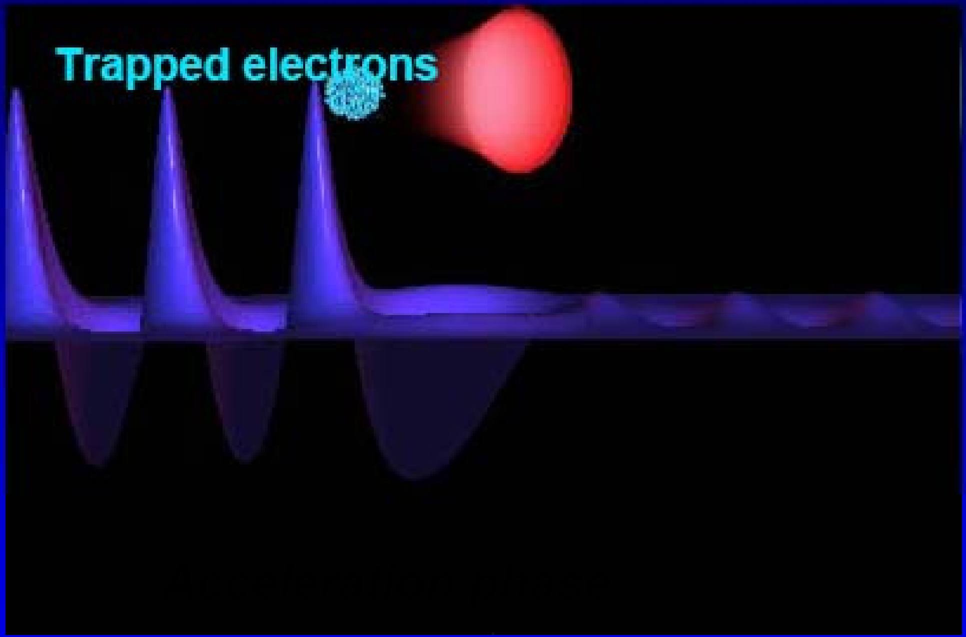


10 cm magnet

40 cm new magnet for GeV e beam

Controlling the injection

A second laser beam is used to heat electrons

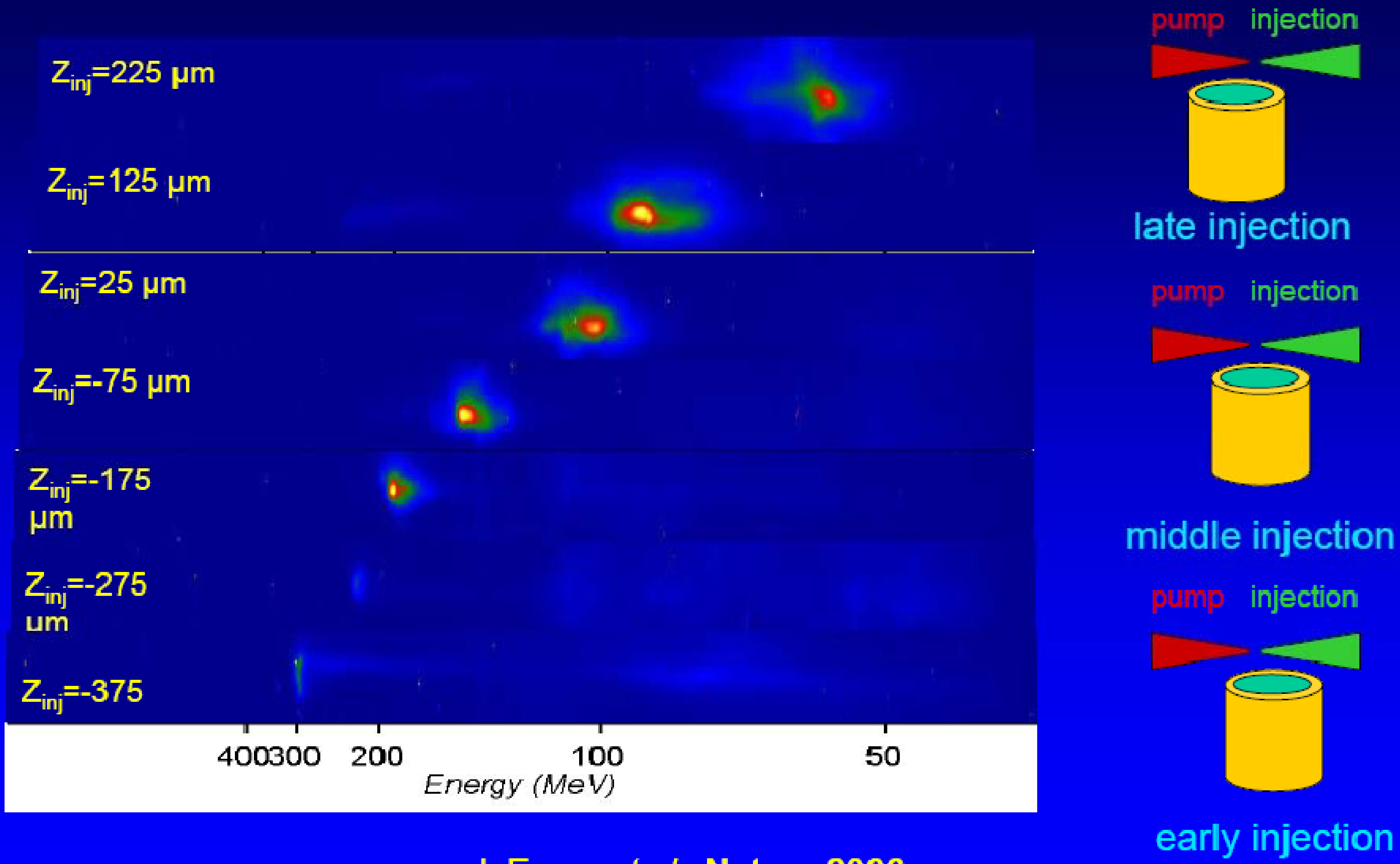


Ponderomotive force of beatwave: $F_p \sim 2a_0a_1/\lambda_0$ (a_0 et a_1 can be "weak")

Boost electrons locally and injects them

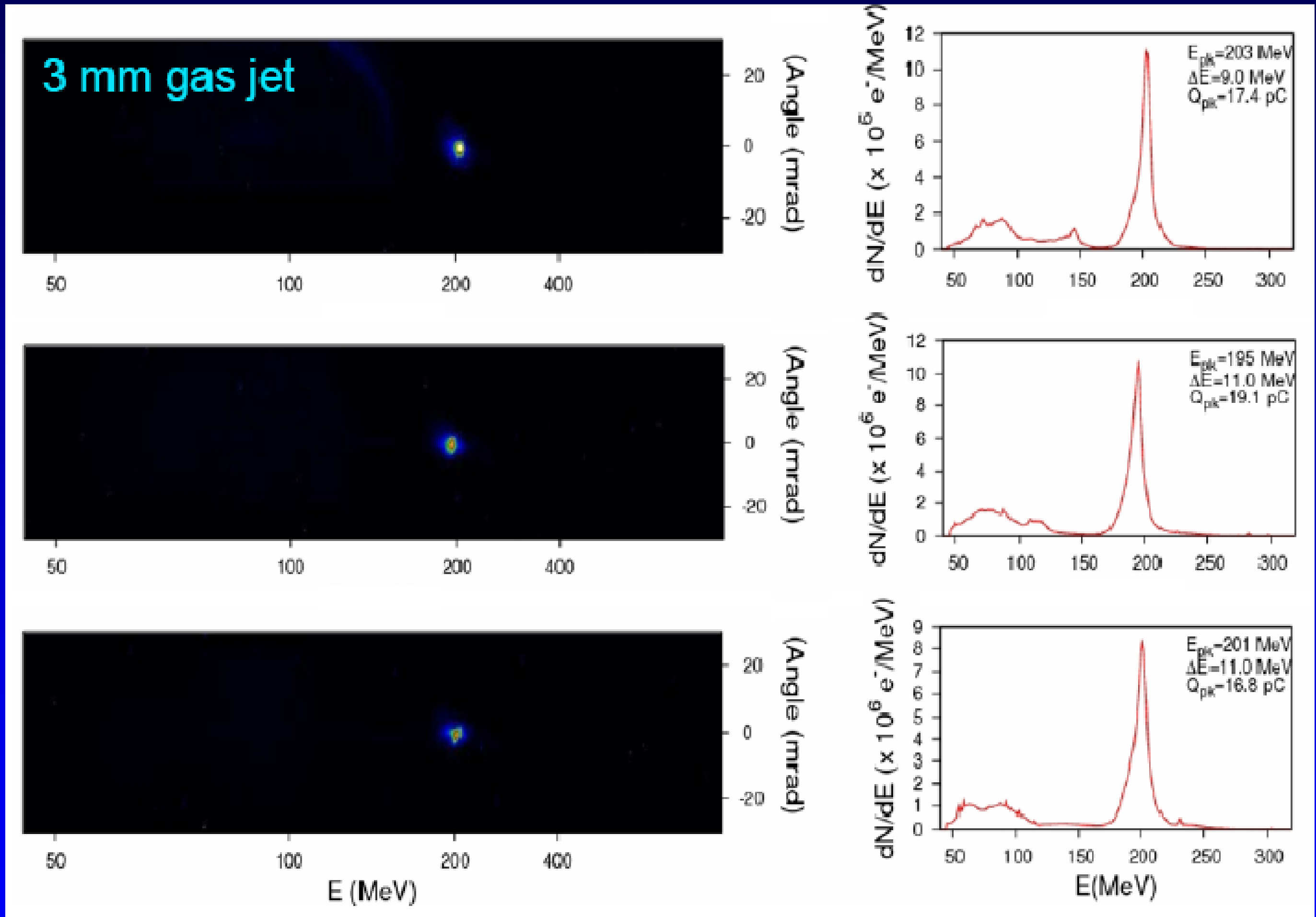
INJECTION IS LOCAL and IN FIRST BUCKET

Tunable monoenergetic bunches



J. Faure *et al*.. **Nature 2006**

Stable monoenergetic beams at 200 MeV



Statistics (30 shots):

E = 206 +/- 11 MeV

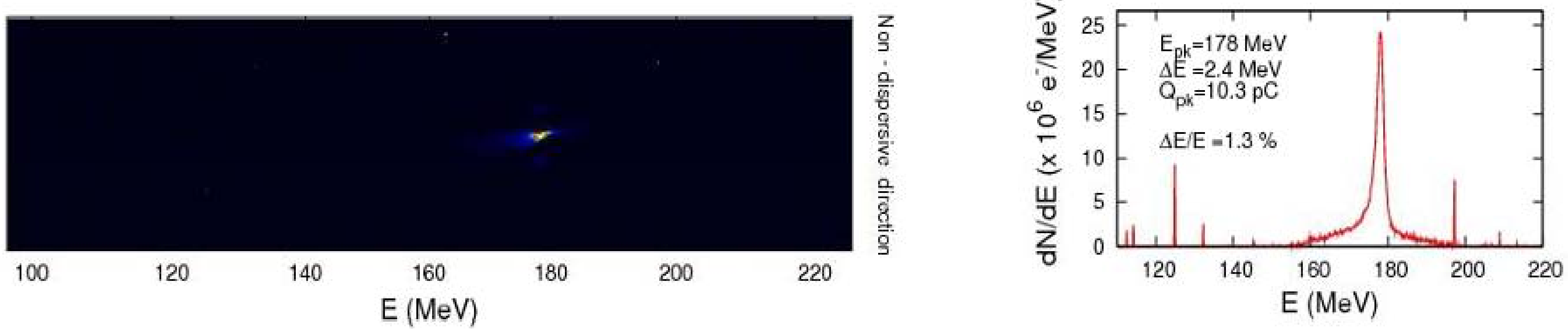
Qpk = 16.5+/- 4.7 pC

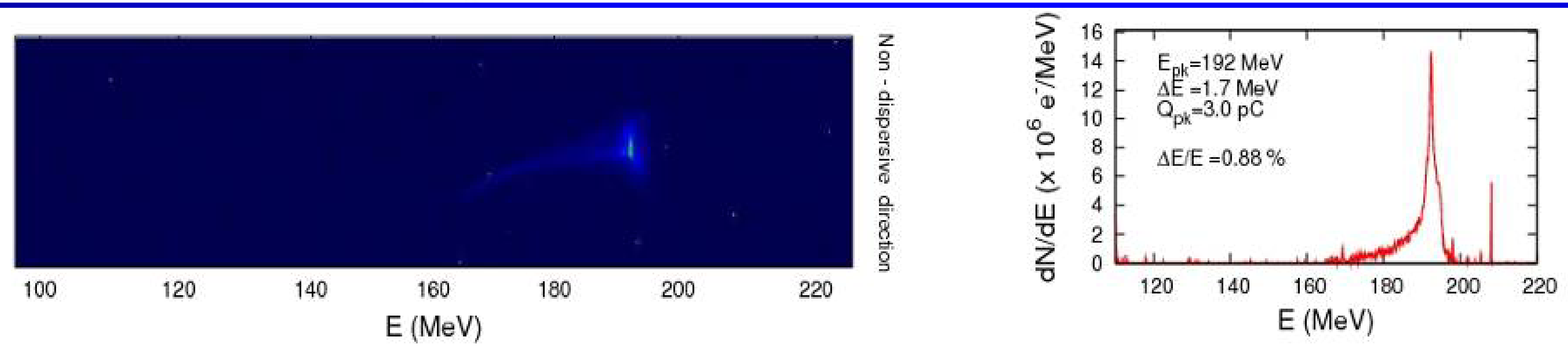
δE = 14 +/- 3 MeV

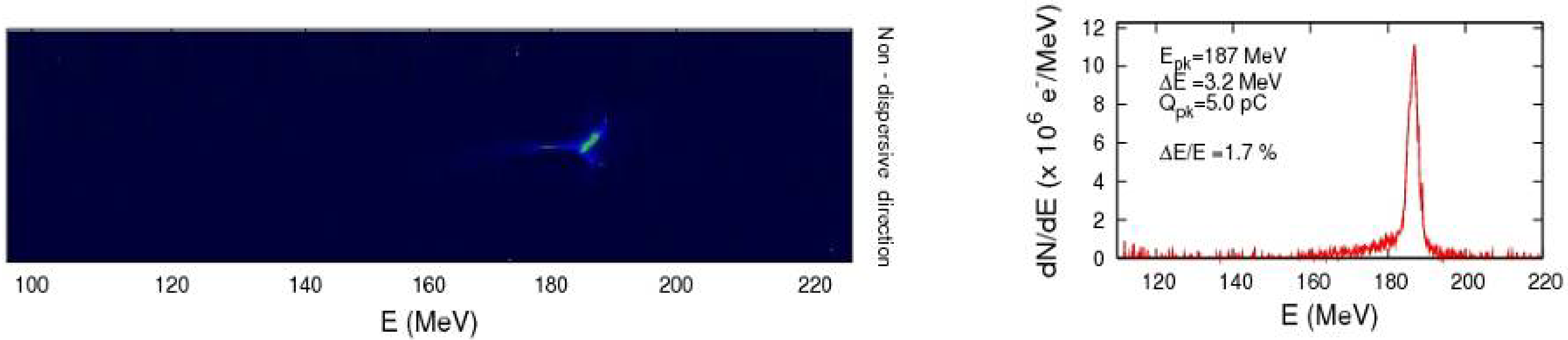
δE/E = 6%

Collaboration with LLR* for resolving small energy spread beams

1% energy spread beams







Conclusion

Two laser beams allows control of many e-beam parameters

- Good beam quality √
  - **Monoenergetic**, collimated beam √
  - $\delta E/E$ down to 5 % , dE ~ 5-20 MeV, charge 10's pC √
- Beam is stable √
- Energy is tunable: 20-300 MeV √
- Charge is tunable: 1 to 100 pC √
- Energy spread is tunable: 5 to 20 % √
- Low energy spread beams at $\Delta E/E$=1% √

WHAT'S NEXT ?

- Push energy limit (>1 GeV)
- Measure the bunch duration

(simulation and exp data indicates τ_{bunch}<10fs)

- Measure the emittance => EUCARD
- Increase injected charge: larger a_1 ?

LOA/CARE_PHIN : contribution 04-08

21 in refereed journals : 2 nature, 1 PRSTAB, 1 EuroPhys Lett, 1 PRL, etc..

50 Invited talks in International Conference

7 proceedings

Thanks to CARE the LOA group got several prizes :

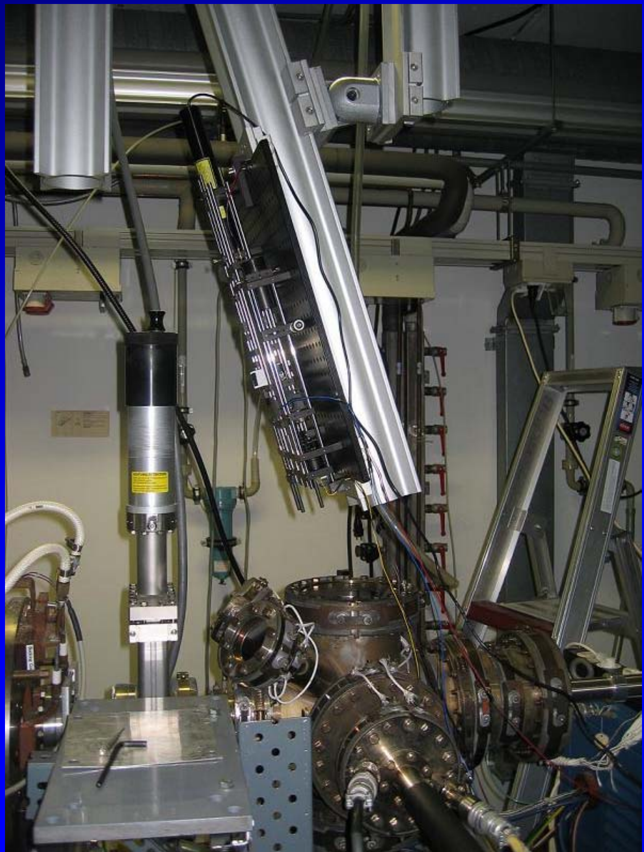
Fresnel Prize to Jerome Faure
EPS PhD prize to Yannick Glinec
IEEE Prize to Victor Malka
La Recherche Magazine prize to V. Malka, J. Faure and E. Lefebvre

And ERC senior grant to V. Malka

Many thanks to the "accelerators" community for their supports and for hosting our approach in their program at a early, at a time where nothing (or quite) Was yet achieved.

Victor Malka

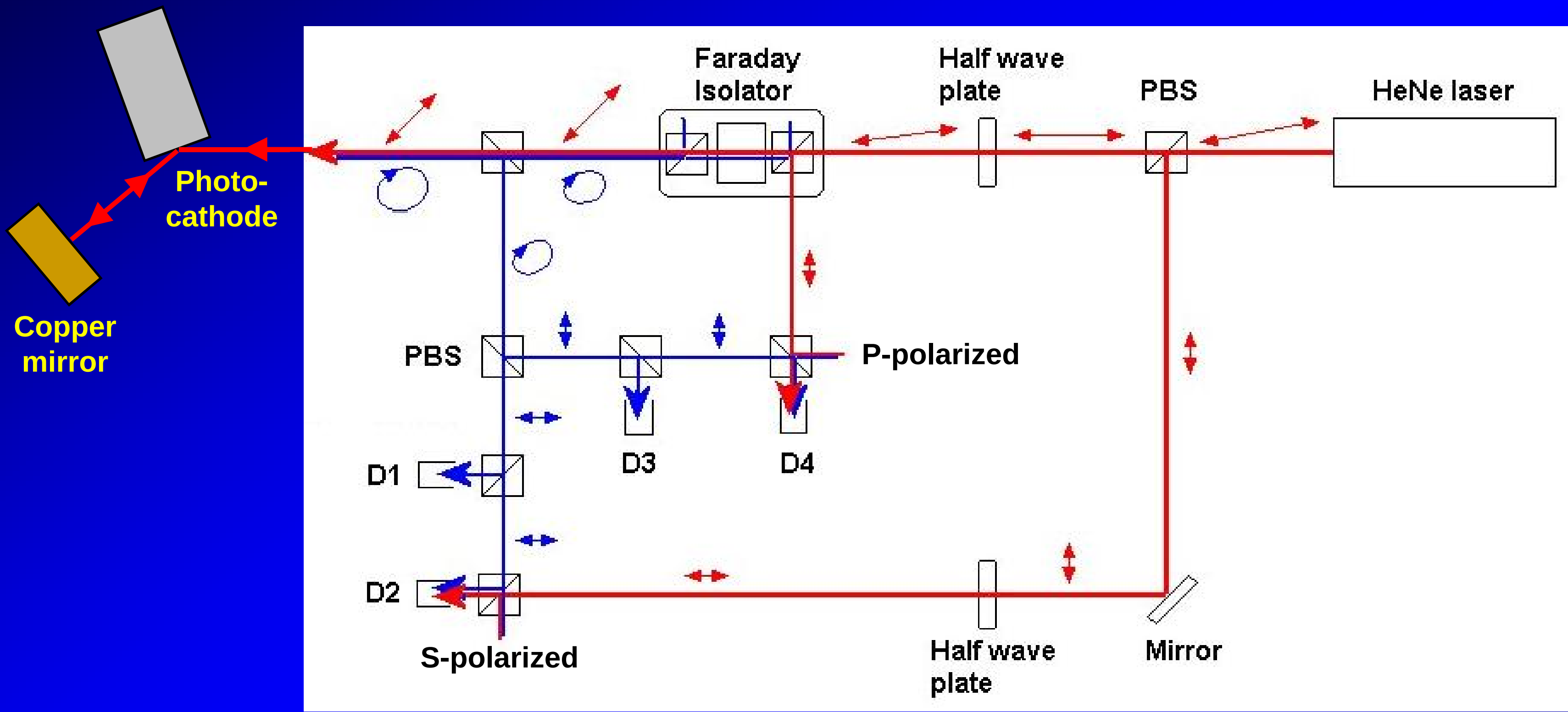
Cesium-telluride PVD diagnostics @University of Twente



Ellipsometer mounted above photocathode preparation chamber

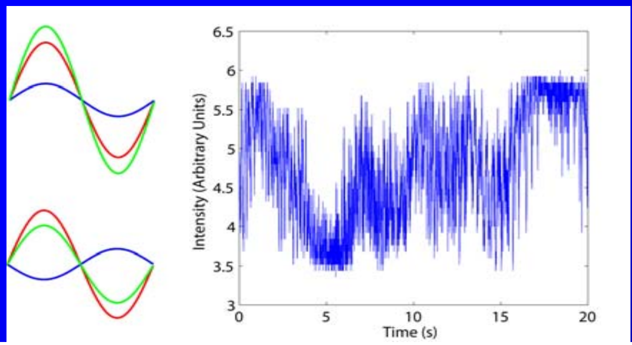
- Diagnostics for cesium-telluride Physical Vapour Deposition (PVD) based on ellipsometry
- Interferometric ellipsometry attempted => failed due to vibration of deposition surface
- Alternative method Rotating Compensator Ellipsometry attempted => successful, interpretation of results remains a challenge

Interferometric Ellipsometry



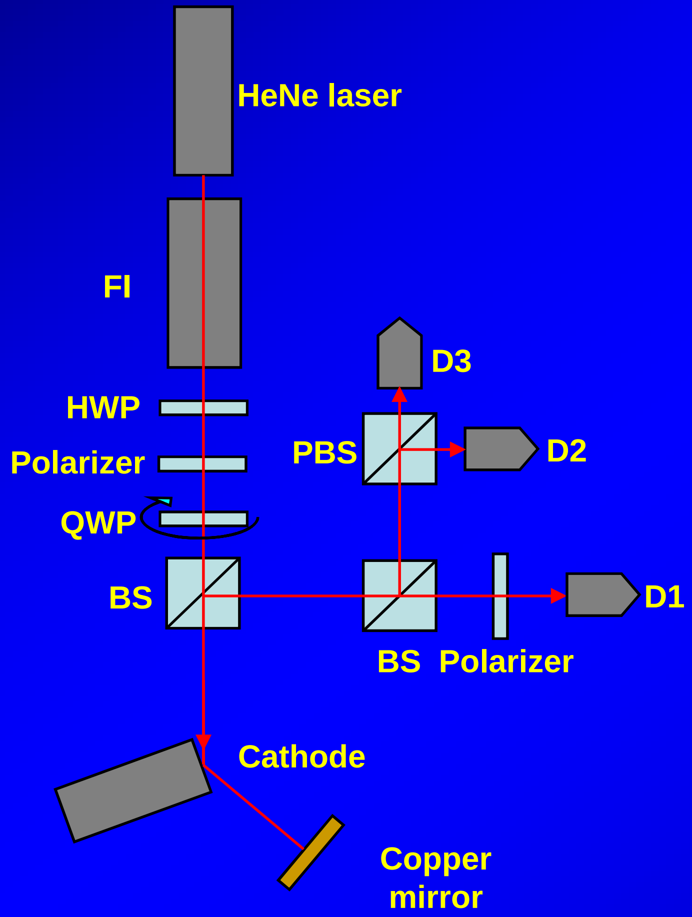
- D1 & D3 measuring <u>amplitude</u> of reflected beam
- D2 & D4 measuring interference between reflected beam and reference beam, giving information about the <u>phase</u> of the reflected beam.

•Vibrations make interference signal unstable.



<u>Conclusion</u>: interferometric ellipsometry in this case seems impractical, requires major changes to the deposition system to work.

Rotating Compensator Ellipsometry

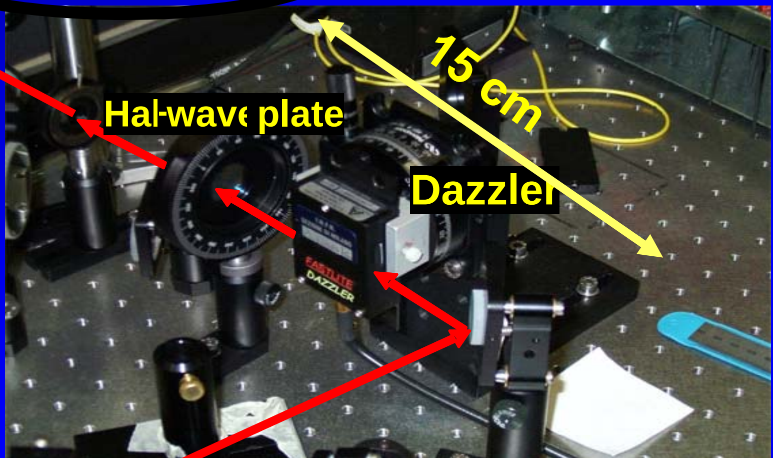


- Incident beam polarization is manipulated by rotating a quarter wave plate (QWP)
- Reflected beam is measured after a polarizer
- Intensity after the polarizer is measured as a function of QWP angle
- Fourier and Mueller matrix analysis give sample properties psi and delta
- => method successful

INFN laser longitudinal pulse shaping R&D

Dazzler (LNF) & LC-SLM (Mi)

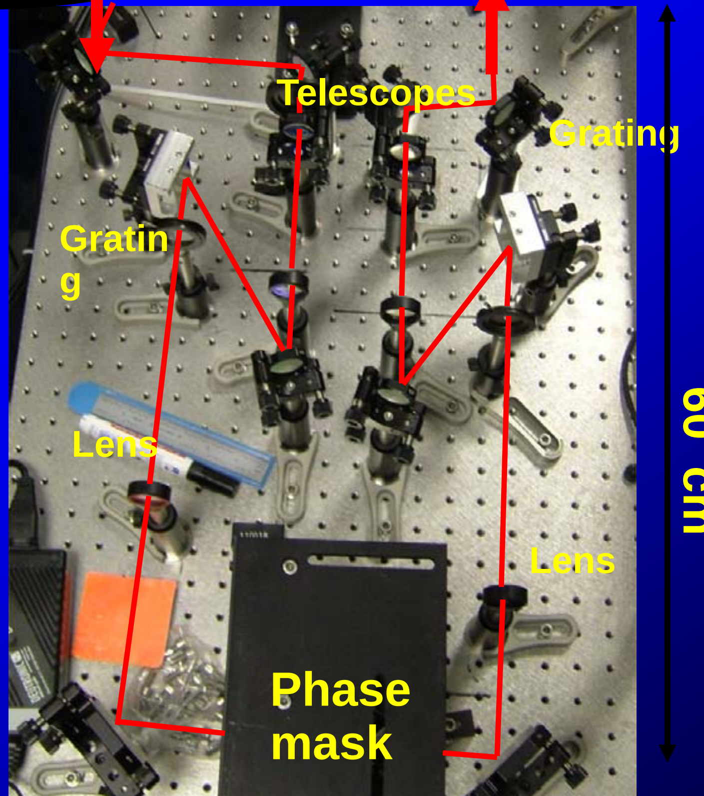
Into amplifier



From oscillator

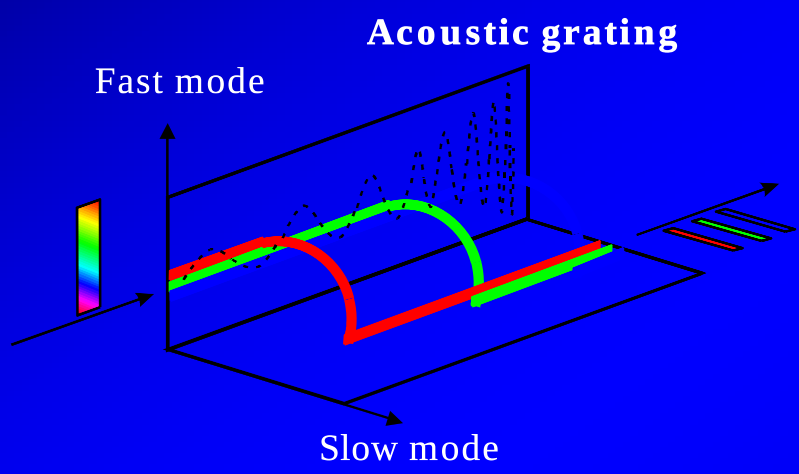
From oscillator

Into amplifier



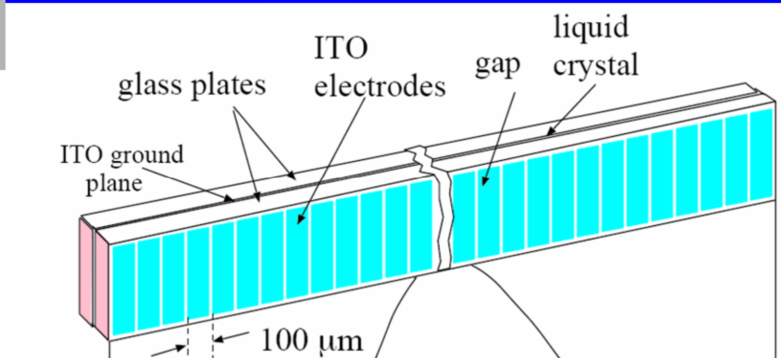
IR programmable pulse shapers

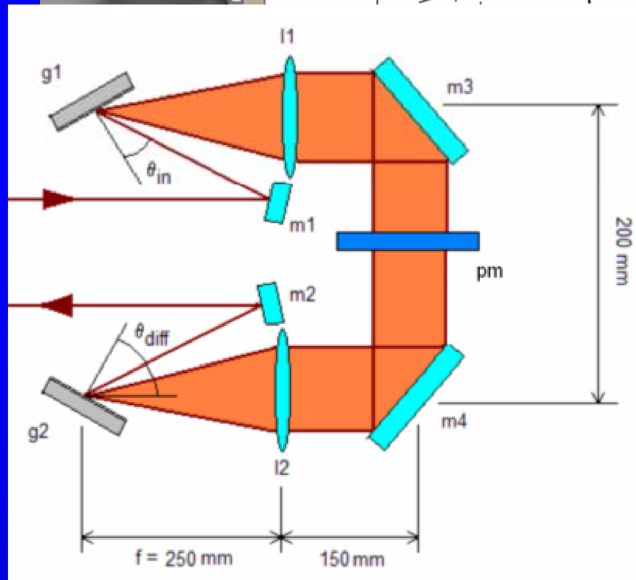
DAZZLER



Acousto-optic interaction in a TeO_2 crystal

LC-SLM





$\theta_{in} = 40^{\circ}$

$\theta_{d} = 69.6^{\circ}$

$f = 250\,mm$

$g = 2000\,l/mm$

$1nm \rightarrow 1.4mm\,(14\,pixels)$

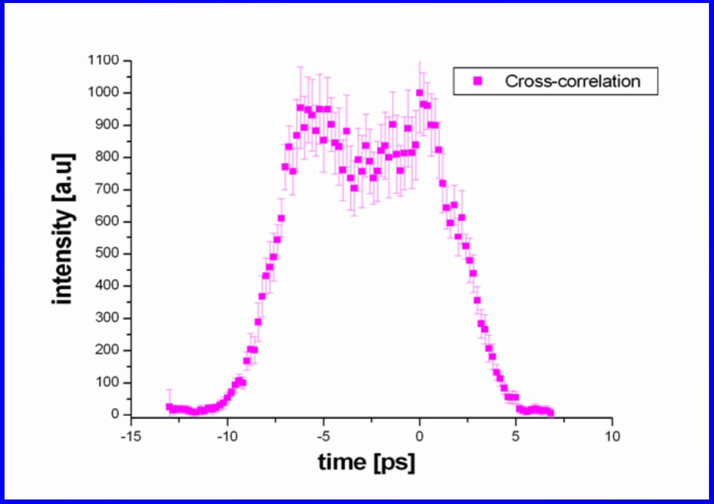
$w_0 = 2mm \rightarrow w = 70\,\mu m$

$\Delta\tau_{max} = 10\,ps$

IR shapers Features:

DAZZLER

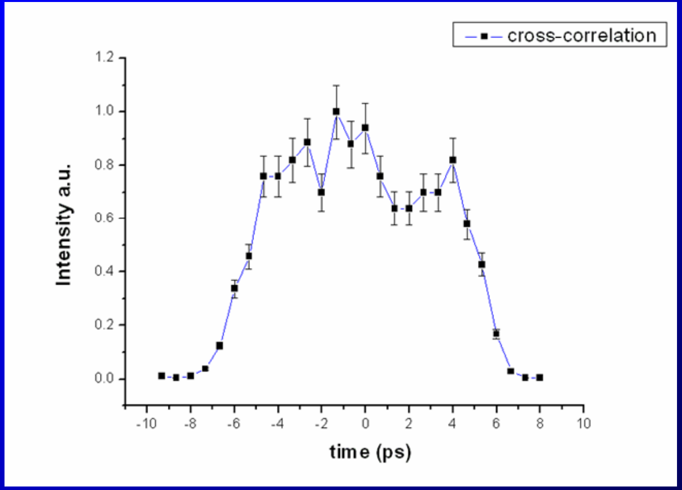
- Compact
- Easy alignment
- Simultaneously phase +amplitude modulation
- Losses within 50%
- Resolution = 0.3 nm
- Slow optimization



Rise and fall time ~ 2.6 ps

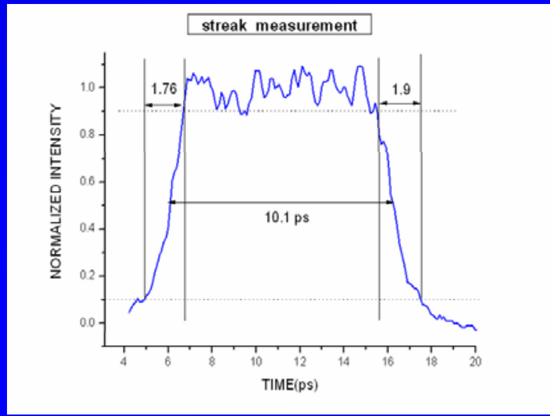
LC-SLM

- Not-compact
- Not easy alignment
- Phase only modulation
- Losses within 50%
- Resolution<0.1 nm
- Fast optimization



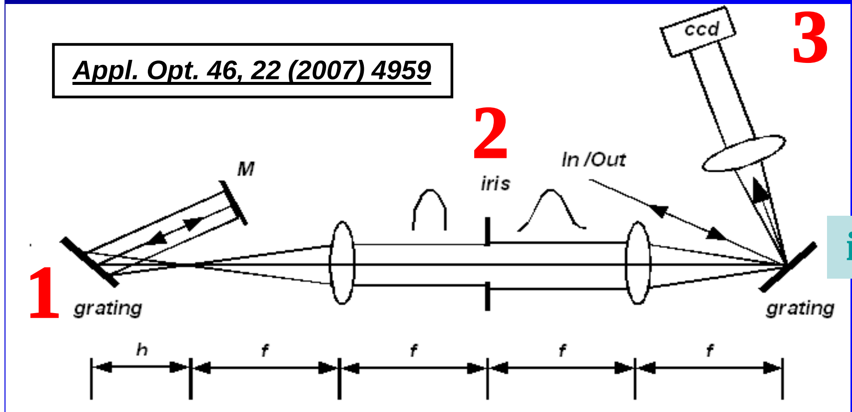
Rise and fall time ~ 2.1 ps

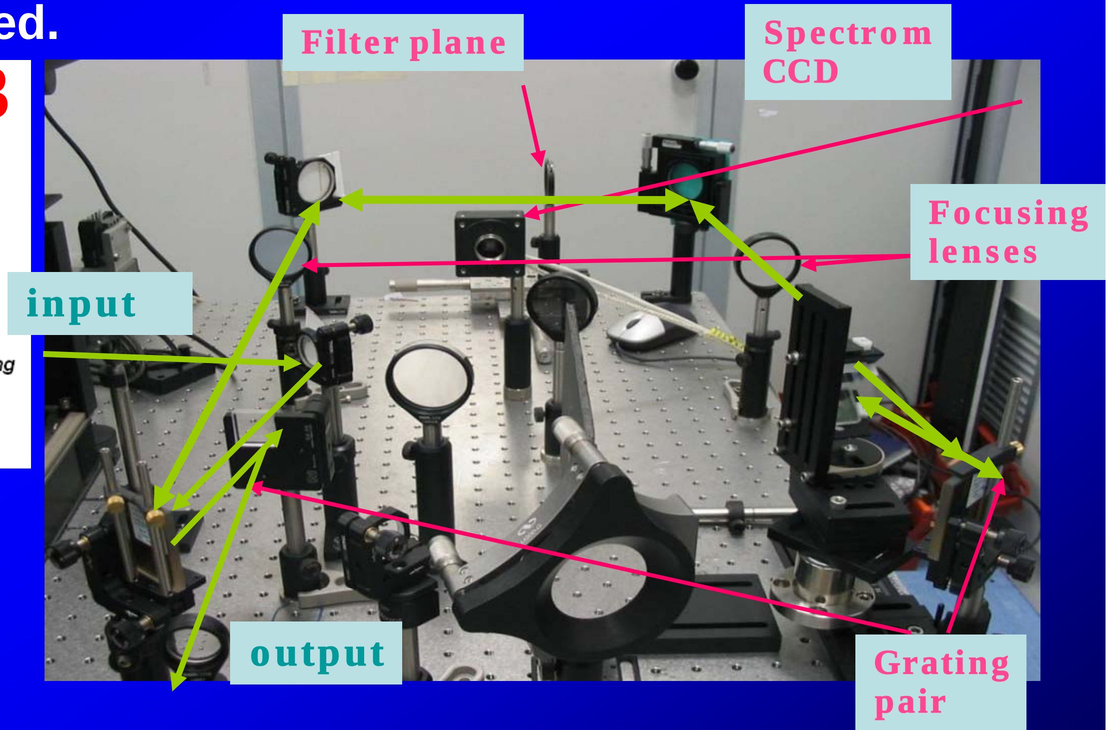
UV pulse shaper

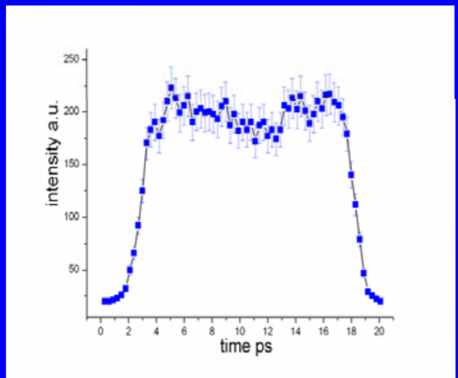


In the Fourier plane an amplitude filter, such as an iris, can be applied to cut the tails of an almost square spectrum produced by the DAZZLER or LC-SLM, the obtained spectrum profile is transferred into the time profile by the stretcher

A on-line spectrometer is integrated.

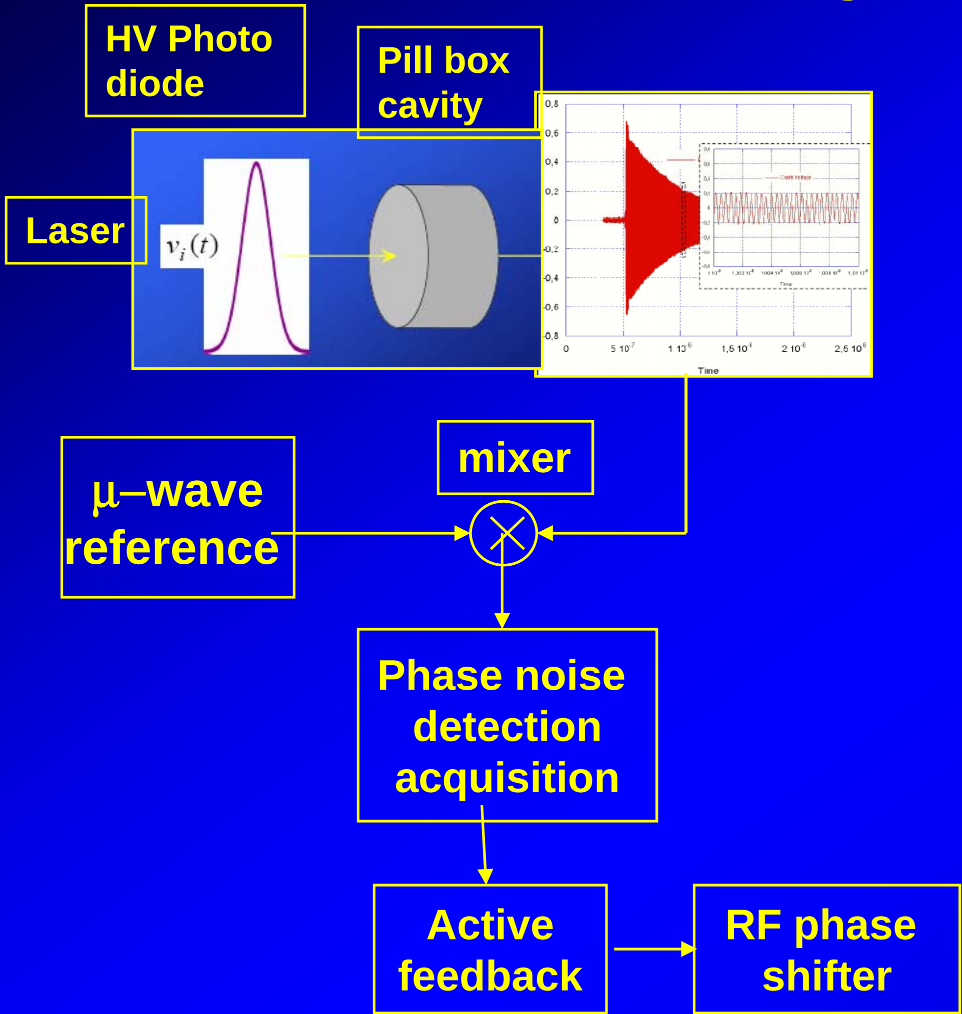


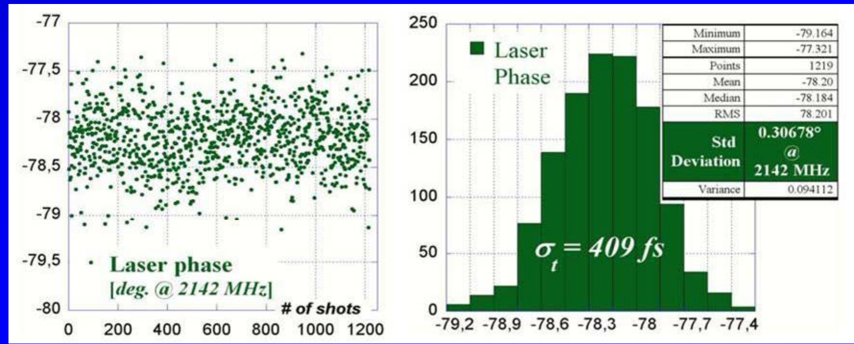


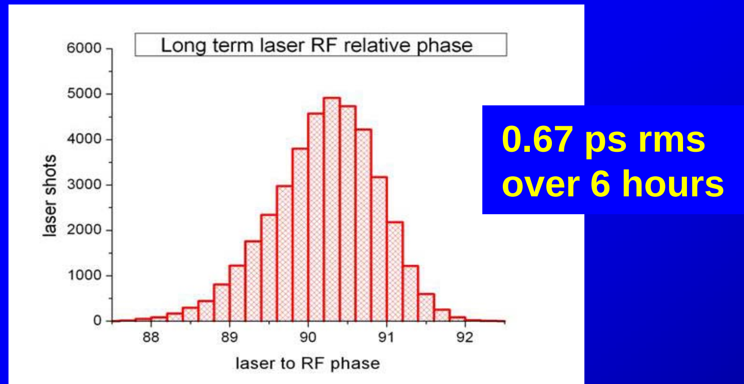


FWHM 15 ps rise time 1.5 ps

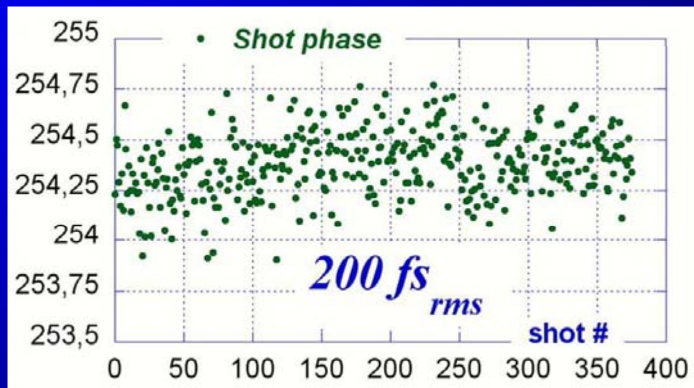
UV time jitter: measure at 10 Hz







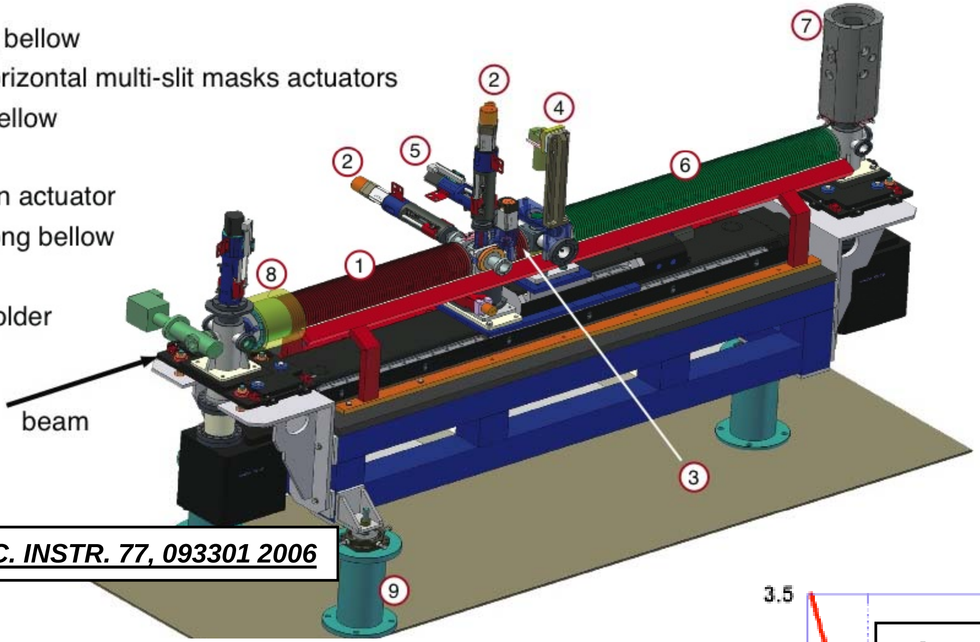
Time of arrival jitter estimated with the RF deflector is 390 fs



- **To reduce the time jitter we can synthesize the RF frequency from a photodiode excited by the oscillator pulses.**

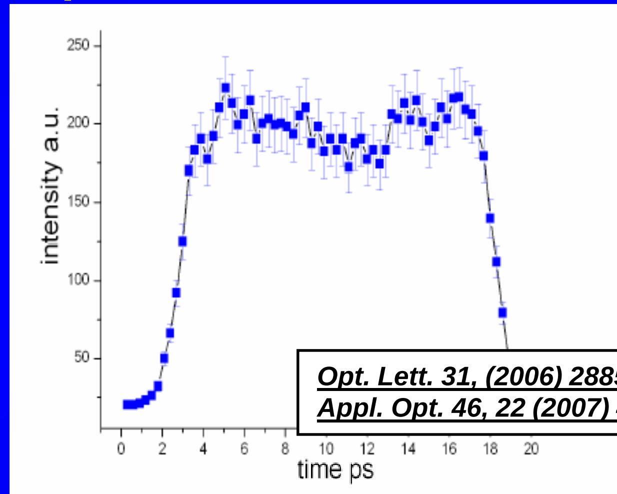
SPARC emittance measurements

1 - upstream long bellow
2 - vertical and horizontal multi-slit masks actuators
3 - intermediate bellow
4 - CCD camera
5 - Ce:YAG screen actuator
6 - downstream long bellow
7 - alignment tool
8 - steering coil holder
9 - leg extender

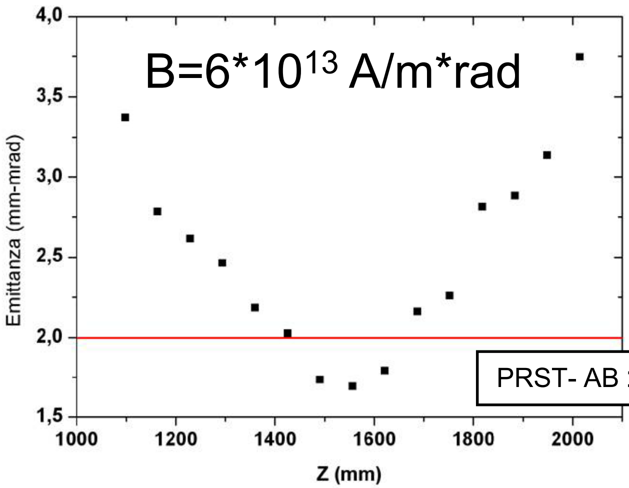


REV. SC. INSTR. 77, 093301 2006

Square laser at the cathode

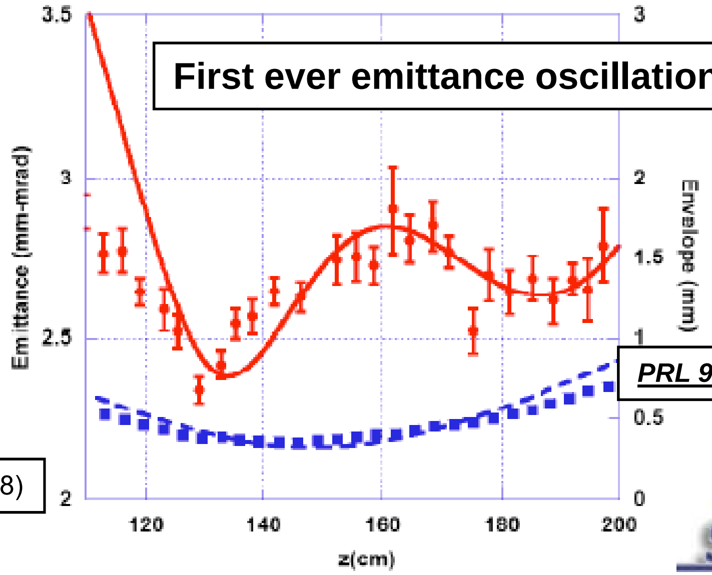


Opt. Lett. 31, (2006) 2885
Appl. Opt. 46, 22 (2007) 4959



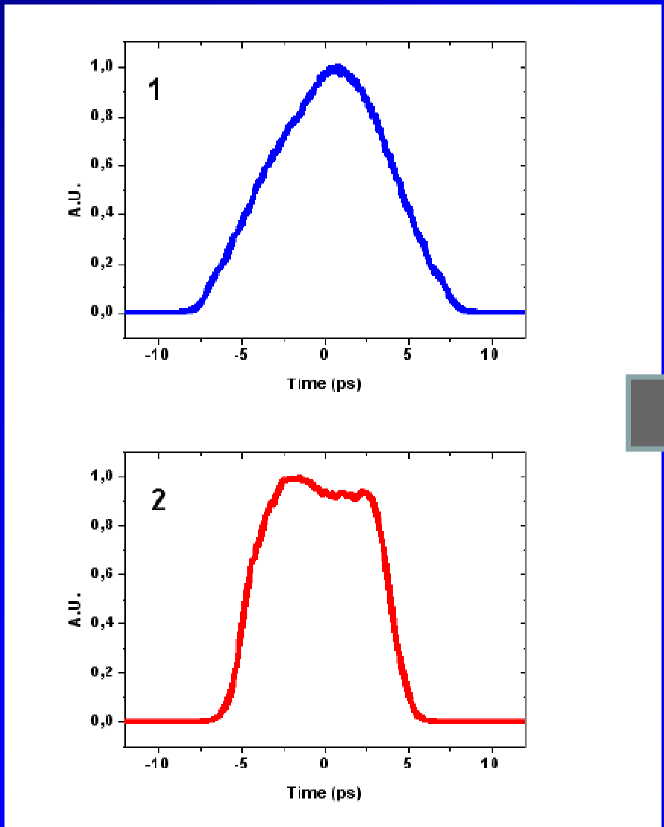
PRST- AB **11**, 032801 (2008)

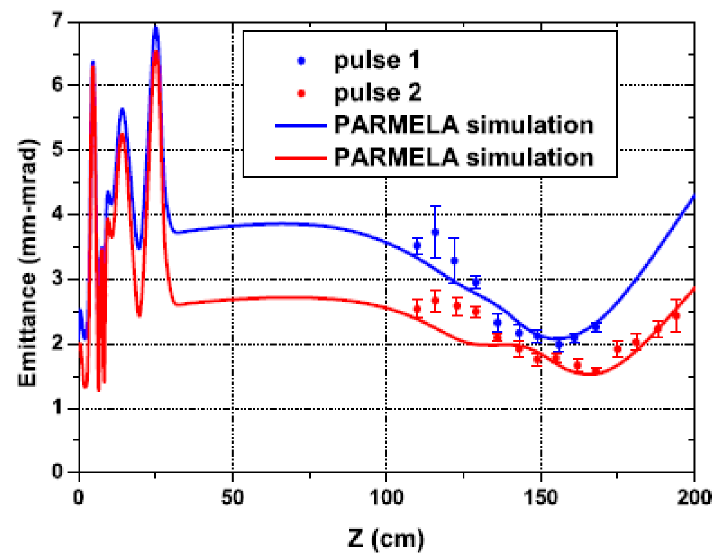
First ever emittance oscillation



PRL 99, 234801 (2007)

Gaussian vs flat beam:comparison





PHIN collaboration produced 115 papers

	PUBL	CONF	NOTES	REPORT	THESIS
2004	2	6	2	1	
2005	5	2	1	6	1
2006	13	11	1	5	1
2007	3	11		8	
2008	6	13	9	8	
TOT	29	43	13	28	2

Conclusions

- We achieved the results foreseen in the PHIN project
- We accumulated delay in the construction of components but all deliverables will be completed before the end of the year
- The experience in PHIN Joint Research Activities is a great success in terms of new photoinjectors realization and in scientific and technological achievements.
- All the work has been realized in collaborative and friendly atmosphere with real international scientific exchange
- Thanks to CARE – ESGARD and welcome EuCARD