FEL 2007 Новосибирск

Direct Measurement of Phase Space Evolution in the SPARC High Brightness Photoinjector

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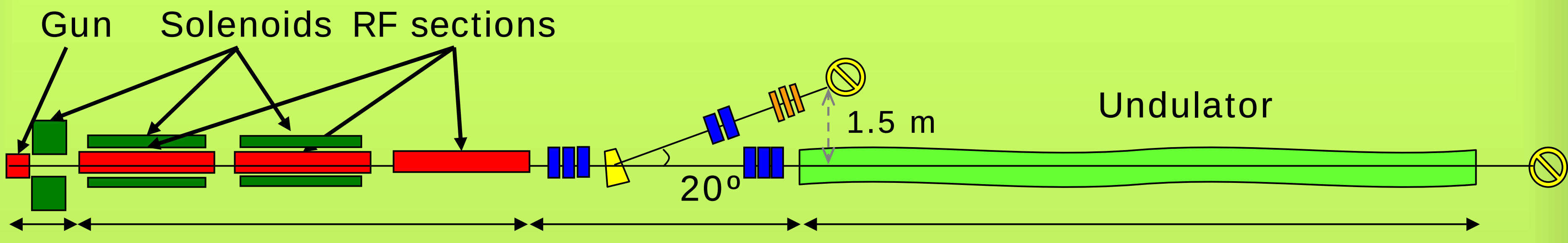
on behalf of the SPARC Collaboration

The SPARC Collaboration

System Description and Optimization

The SPARC Injector Project

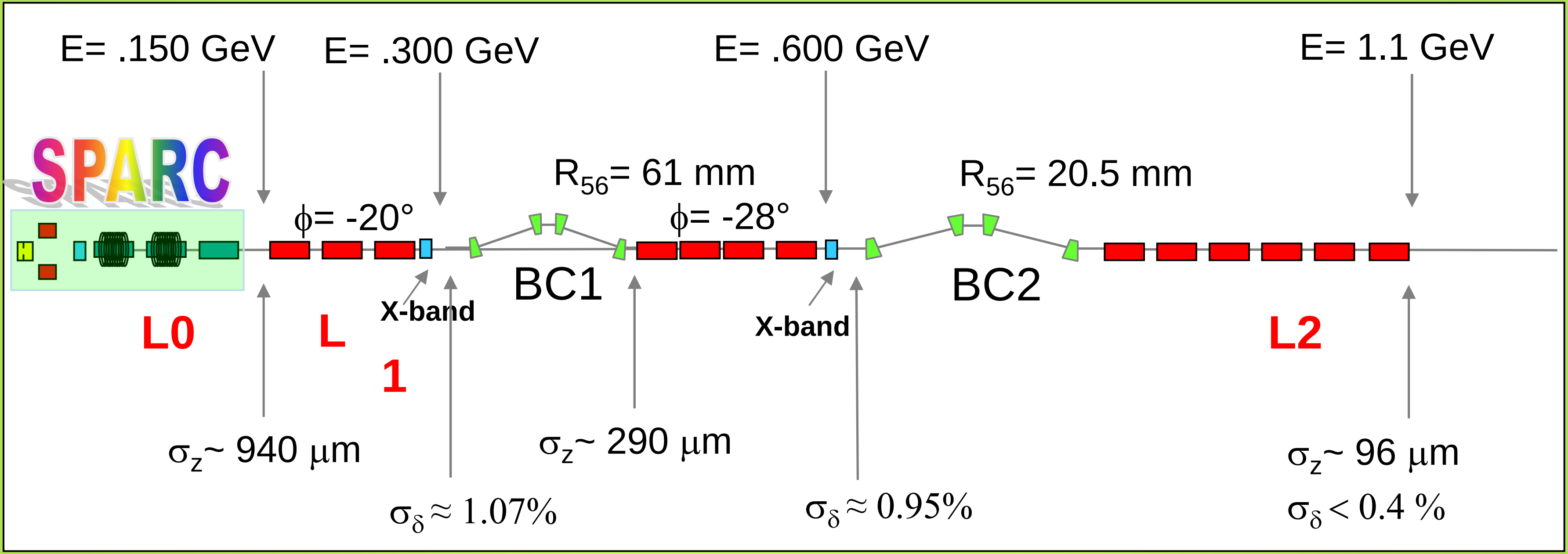
MAIN GOAL: the promotion of an R&D activity oriented to the development of a high brightness photoinjector to drive SASE FEL experiments



GUN PARAMETERS		LINAC PARAMETERS		FEL PARAMETERS
Frequency	2856 MHz	Frequency	2856 MHz	Wavelength 530 nm
Peak Field	120 MV/m	Accelerating Field	25 MV/m	Undulator period 2.8 cm
Beam Energy	5.6 MeV	Beam Energy	155 MeV	
Charge	1 nC	Energy Spread	10^{-3}	
Emittance	< 2 mm-mrad	Peak Current	100 A	
Laser	10 ps (Flat Top with <2 ps rise time)			

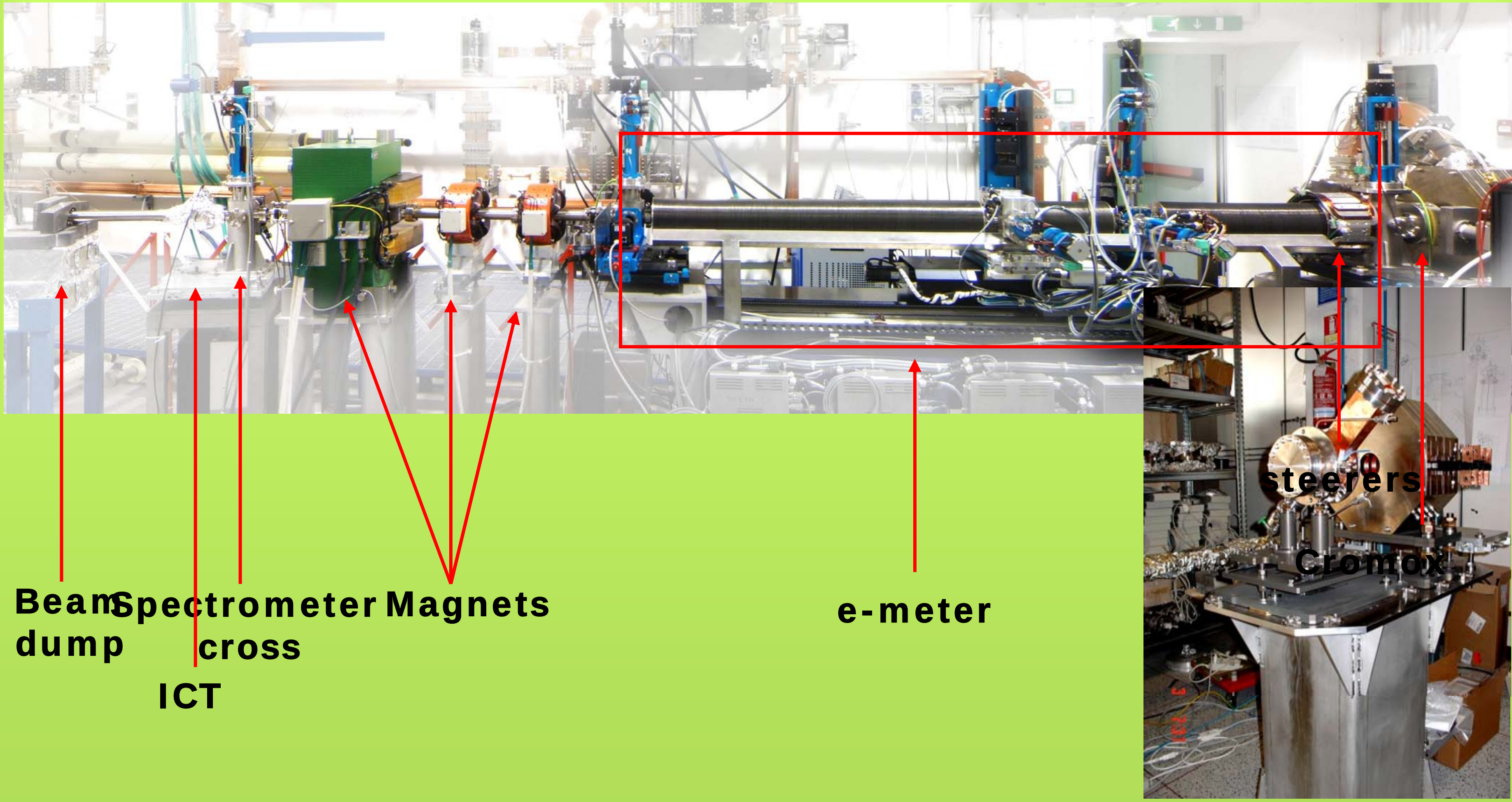
SPARX Project Recently Approved

1 - 2 GeV ➔ 10 - 1 nm FEL



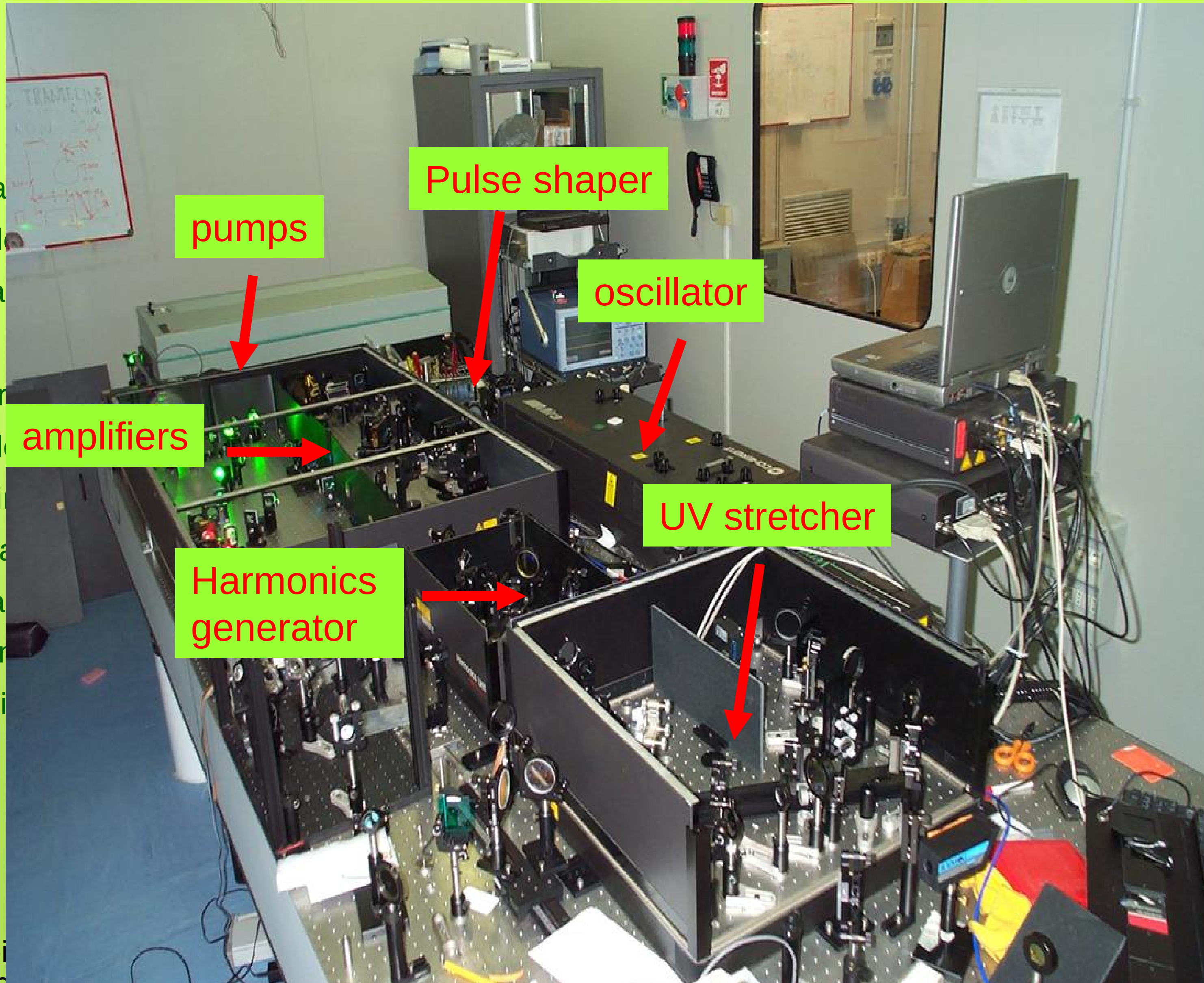
2007	TDR, Tunnel & buildings project
2008	Procurement of long term devices, Start tunnel construction
2009	Construction, Procurement, Installation
2010	Installation
2011	Installation & Commissioning
2012	Operation

SPARC Phase0 Layout

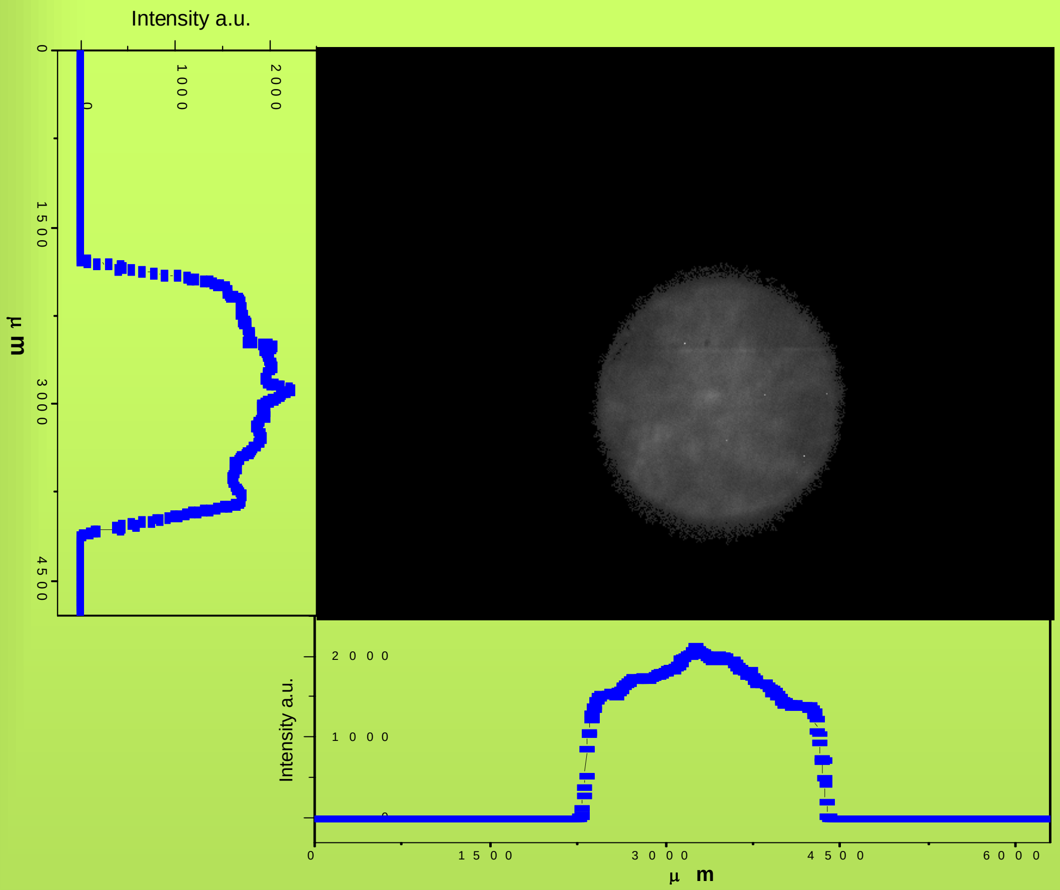


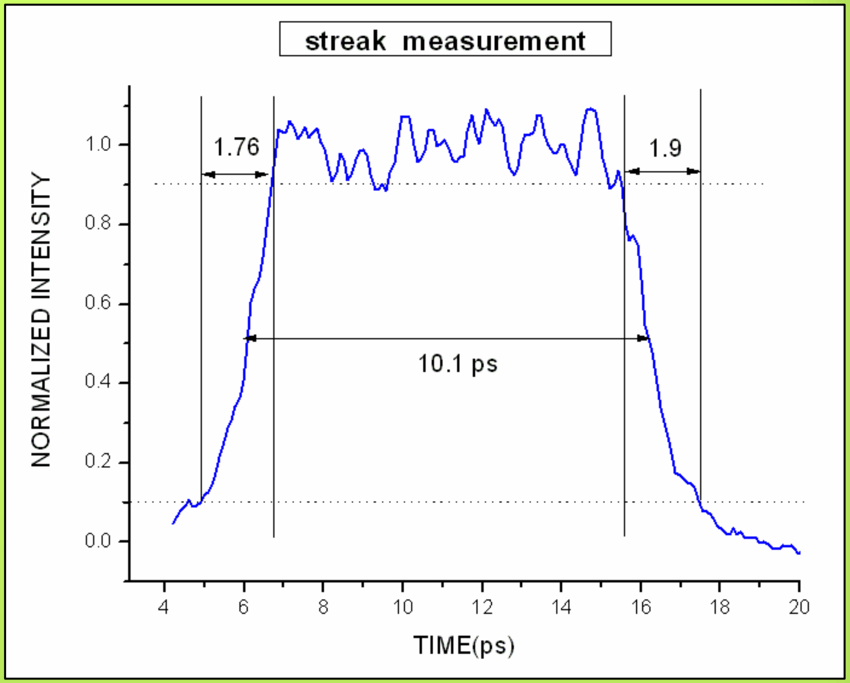
The SPARC Laser

Laser centra
Laser pulse l
Electron cha
RMS energy
Laser pulse r
Laser pulse l
Transverse i
Laser spot ra
RMS rf to la
Centroid poi
Spot ellipticí



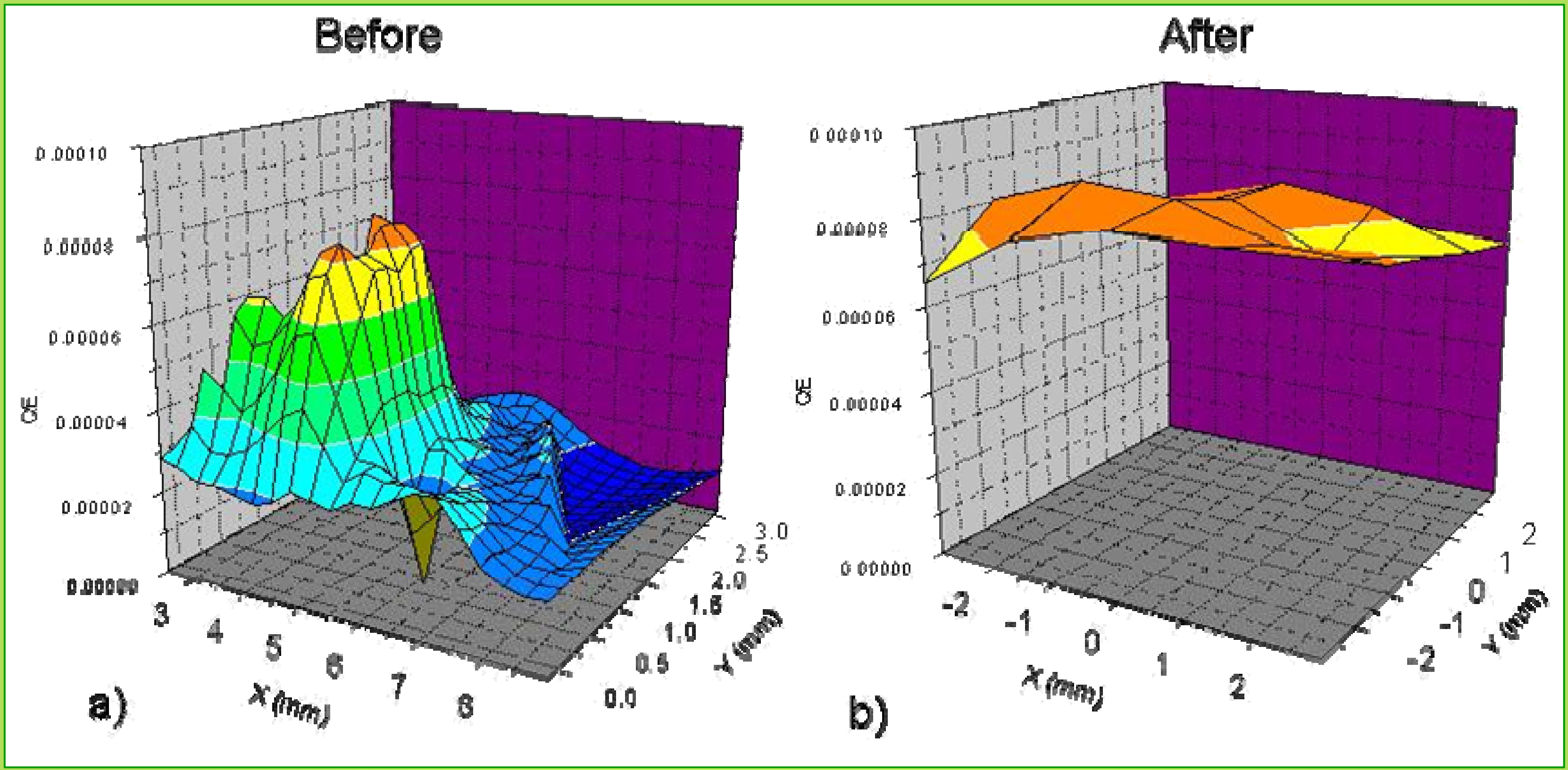
Transverse and Longitudinal Profiles





The beam transverse profile strongly influences the beam brightness

Quantum Efficiency Optimization



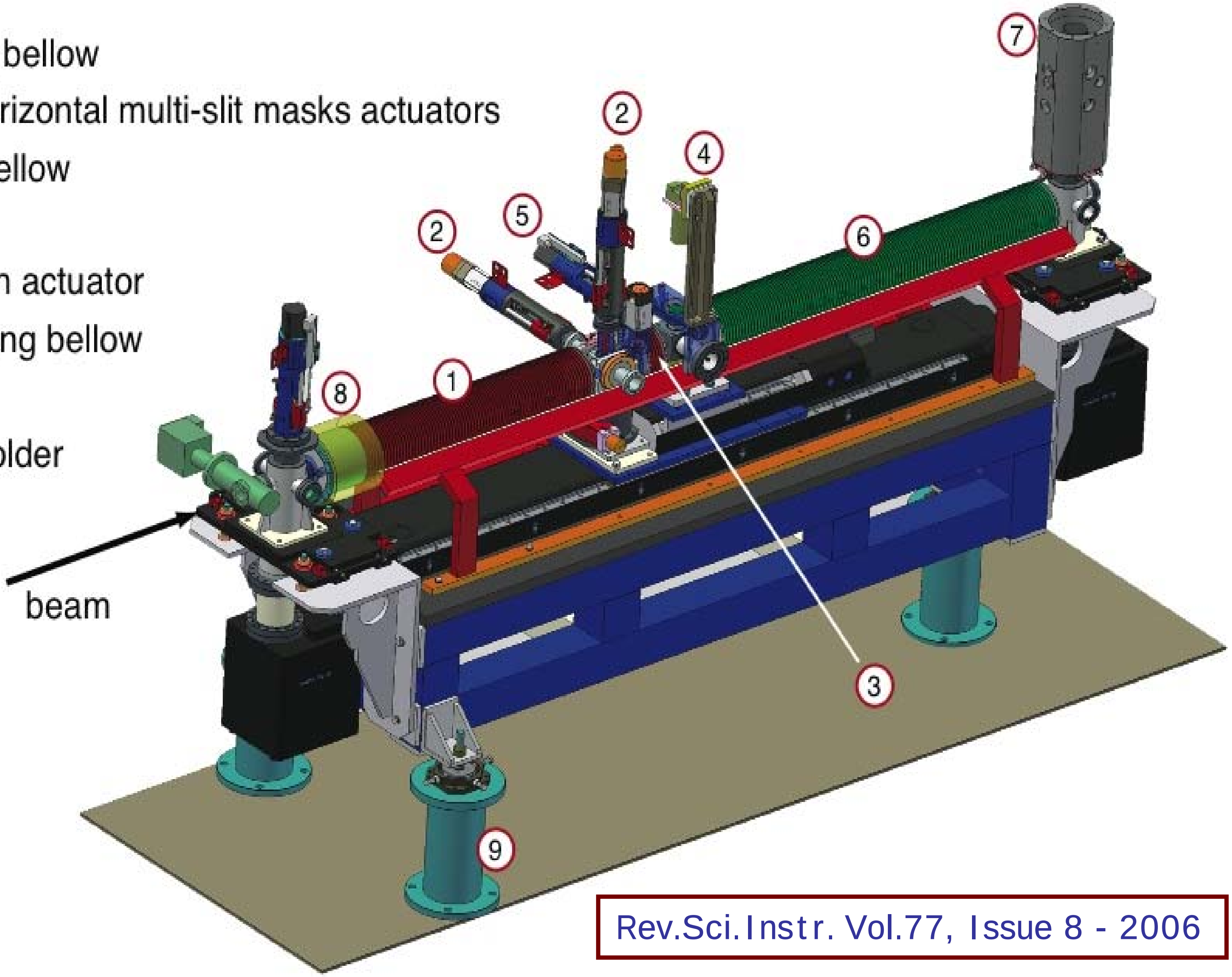
Laser cleaning with 10 μJ and 100 μm spot size diameter.

- *Mean QE increased from $2.3*10^{-5}$ to 10^{-4}*
- *<u>Improved uniformity</u> over a 4 mm square region*

1nC electron bunch with 50 μJ laser energy (~$6*10^{13}$ photons @ 266nm)

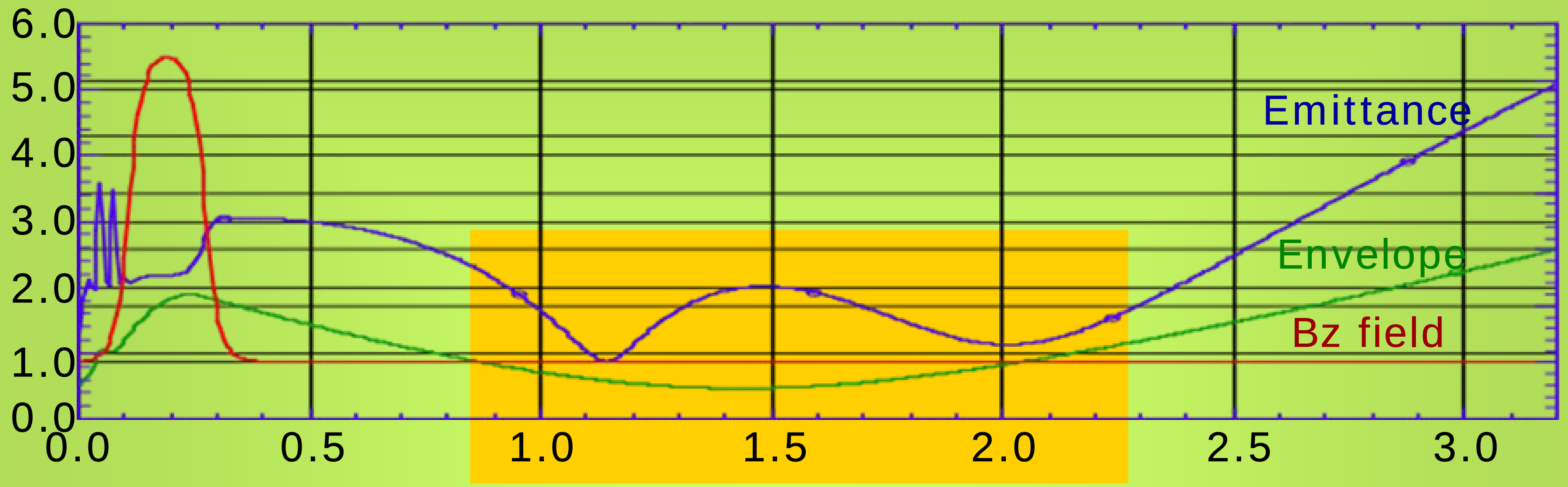
The Emittance-Meter

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.Sci.Instr. Vol.77, Issue 8 - 2006

A Movable Diagnostic

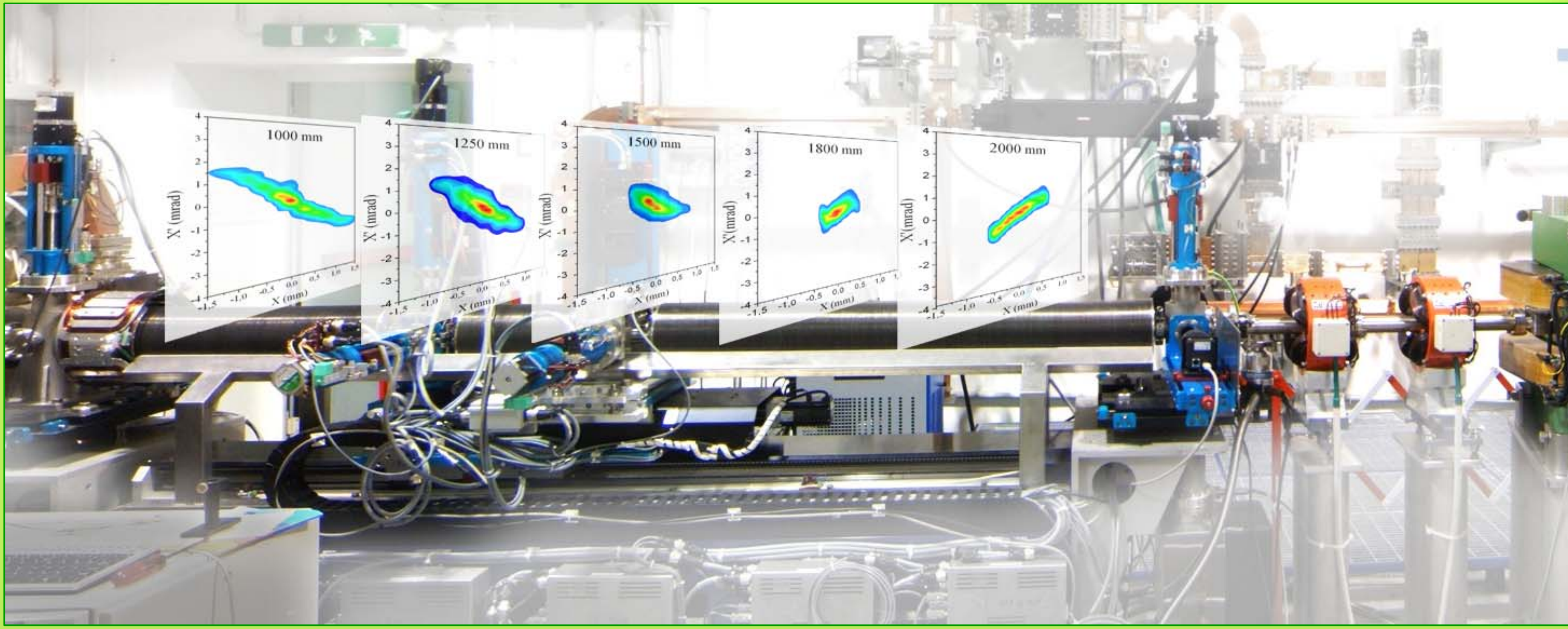


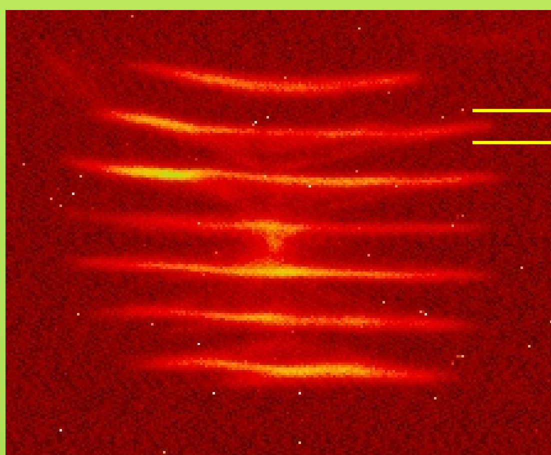
AUTOMATIC ENVELOPE AND EMITTANCE SCAN

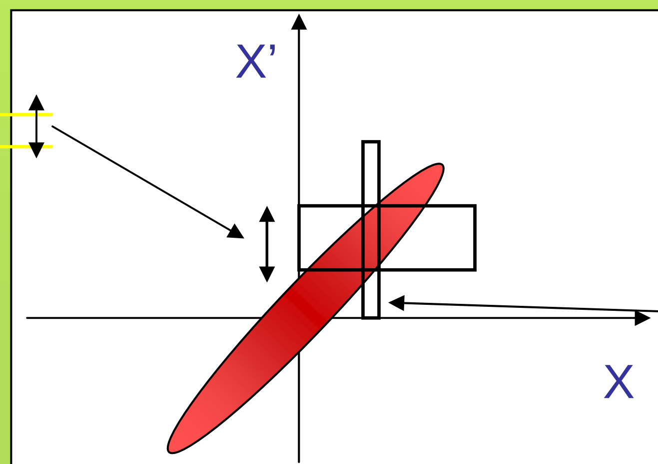
The emittance-meter moves and stops in several positions. Several images are collected at each point. An algorithm calculates beam centroids and RMS dimensions with corresponding error bars. Then an automatic emittance scan starts, making use of previously calculated parameters to center the slit and fix the slit step in different positions.

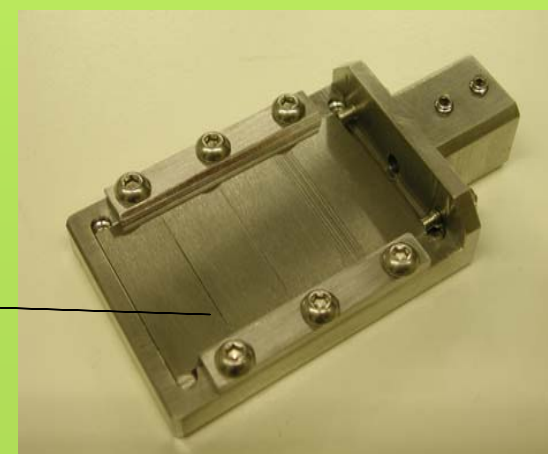
The possibility to move the measuring position along the beam line give the opportunity to study the emittance compensation process and define the beam parameters to match at 1.5 m the first linac section.

Phase Space Reconstruction

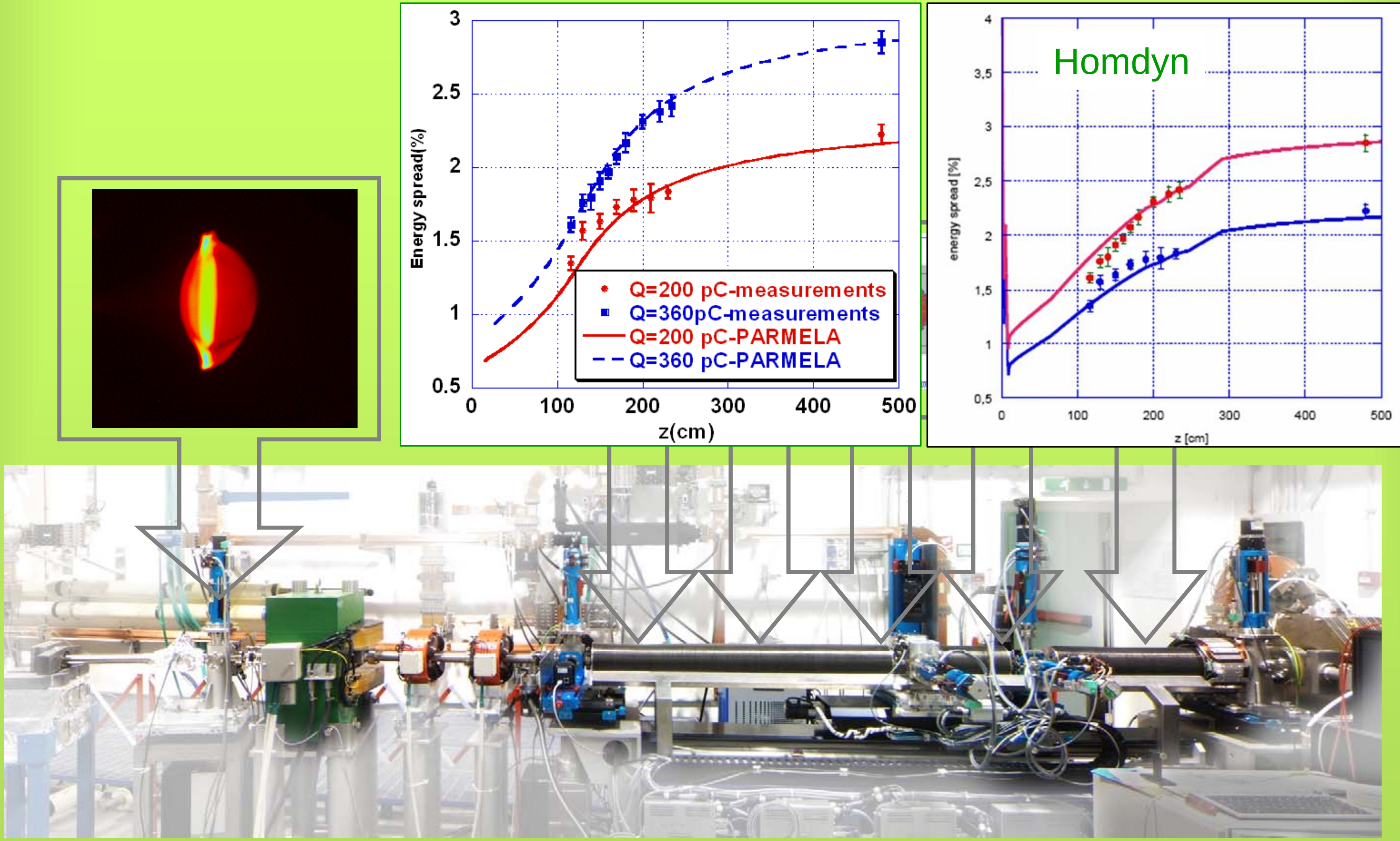








Longitudinal Diagnostics

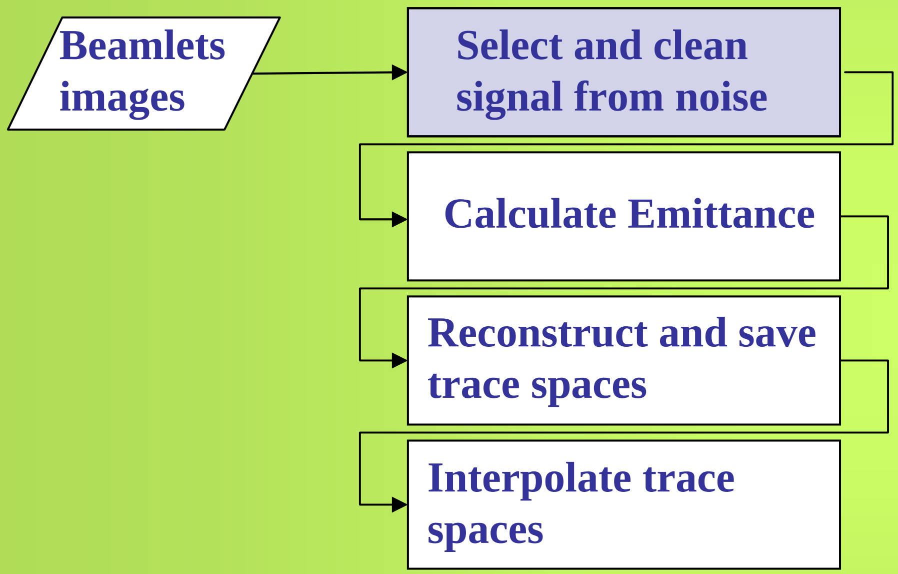


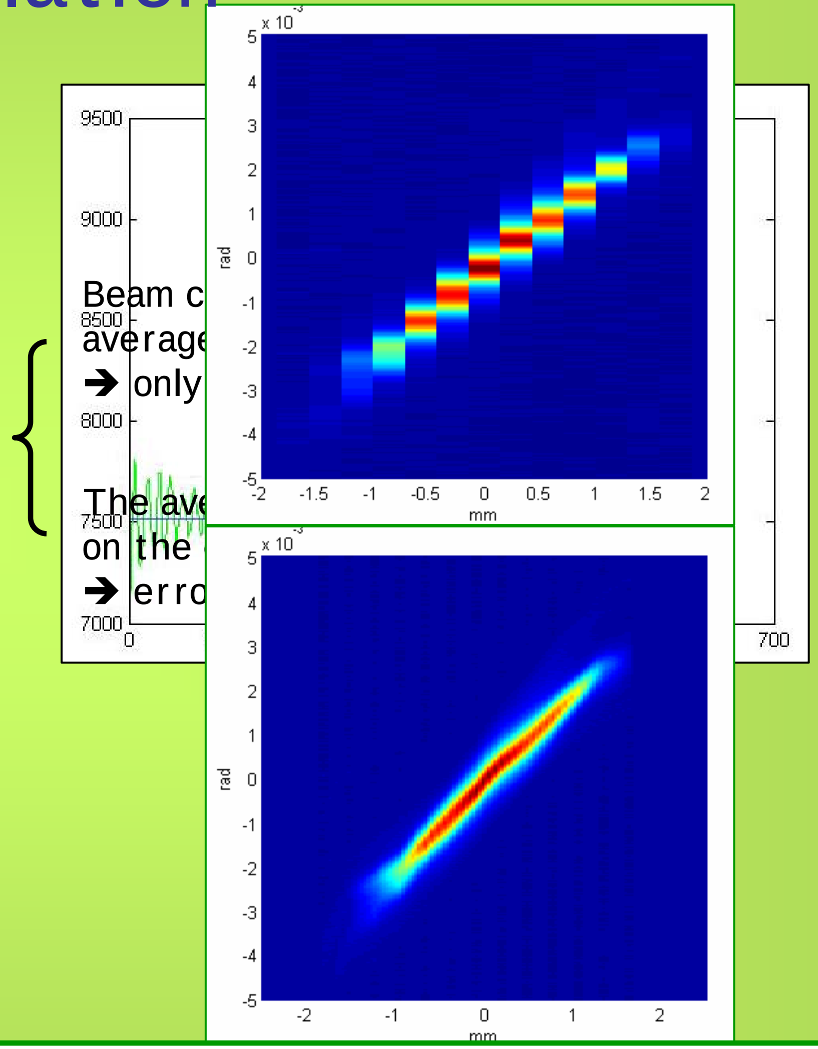
Data Analysis

- Need to know exactly the percent of charge used to calculate the emittance (**halos estimation**)
- **Same cut** for emittance measurement at different positions
- **High sensitivity** needed to measure small fluctuations

- Algorithm based on single image analysis and data extrapolation
- Algorithm based on trace space plot filtering
- Genetic Multi Slice Analyzer

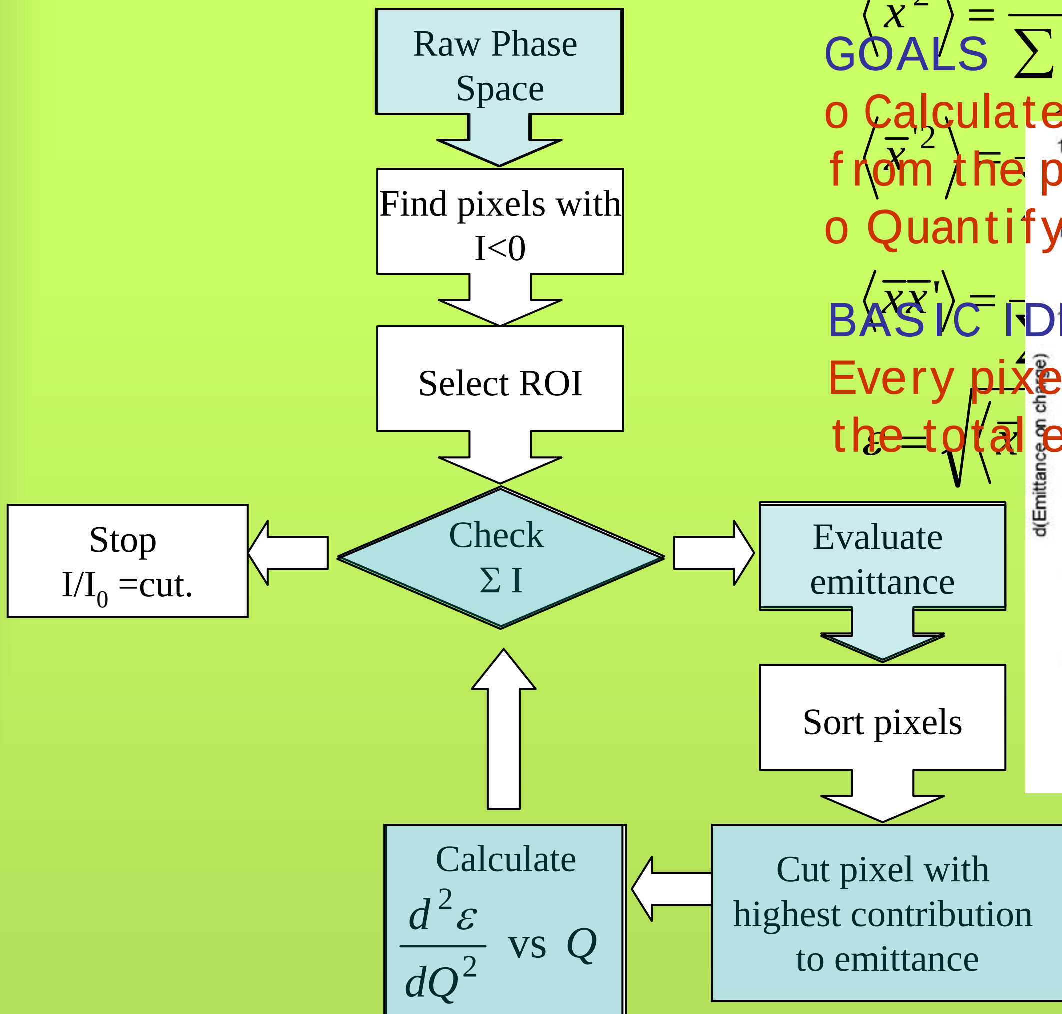
Single Image Analysis and Data Extrapolation





D. Filippetto,
“A robust algorithm for beam emittance and trace space evolution reconstruction”,
http://www.lnf.infn.it/acceleratori/sparc/technotes.html **SPARC/EBD-07/002**

Phase Space Filtering

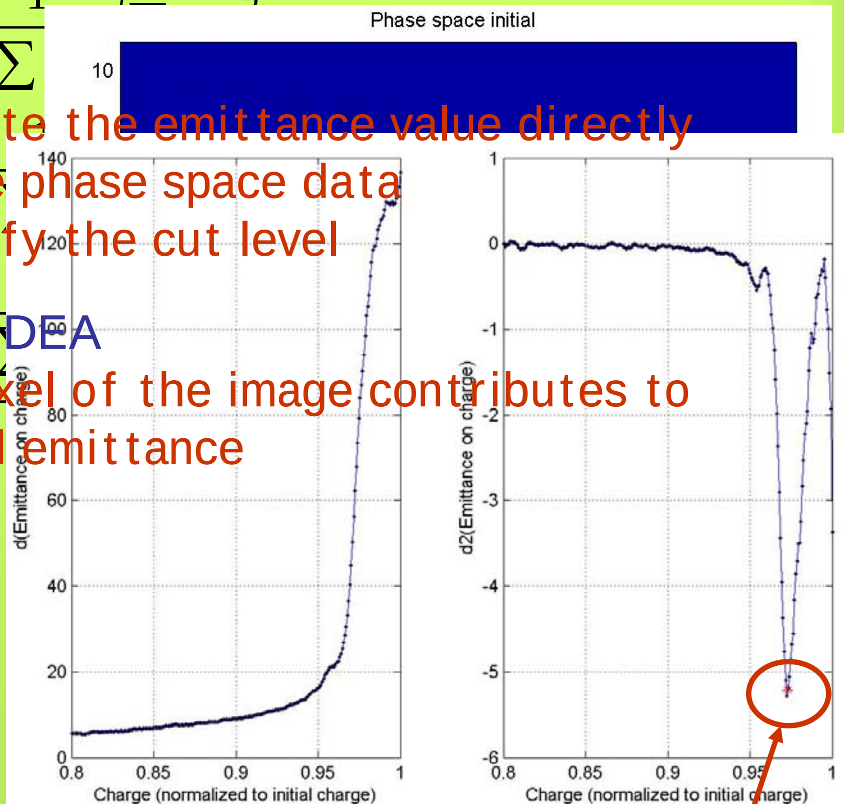


GOALS

- o Calculate the emittance value directly from the phase space data
- o Quantify the cut level

BASIC IDEA

Every pixel of the image contributes to the total emittance



I_0: corresponds to 100% of the real beam charge

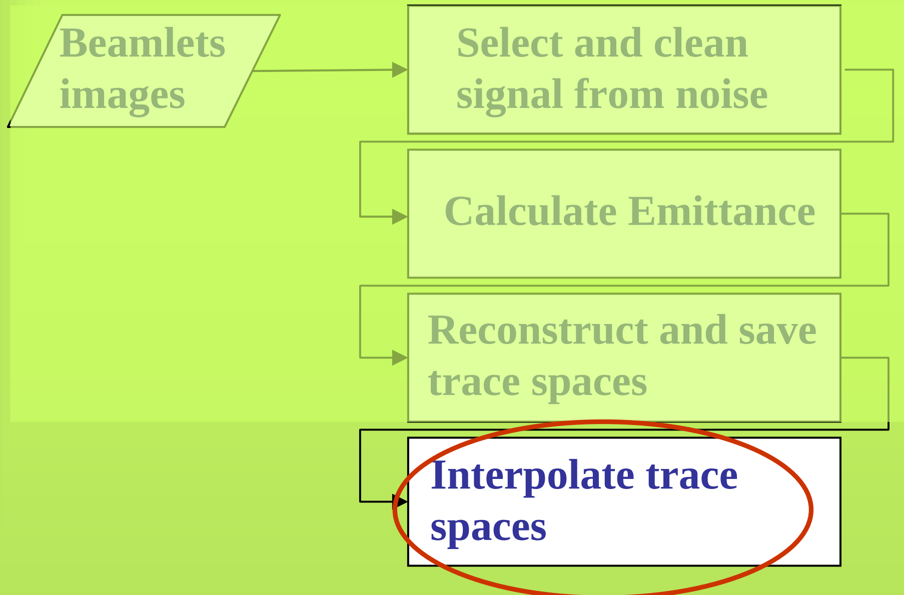
A. Cianchi et al.,
"Accurate emittance calculation from phase space analysis",
http://www.lnf.infn.it/acceleratori/sparc/technotes.html SPARC/EBD-07/003

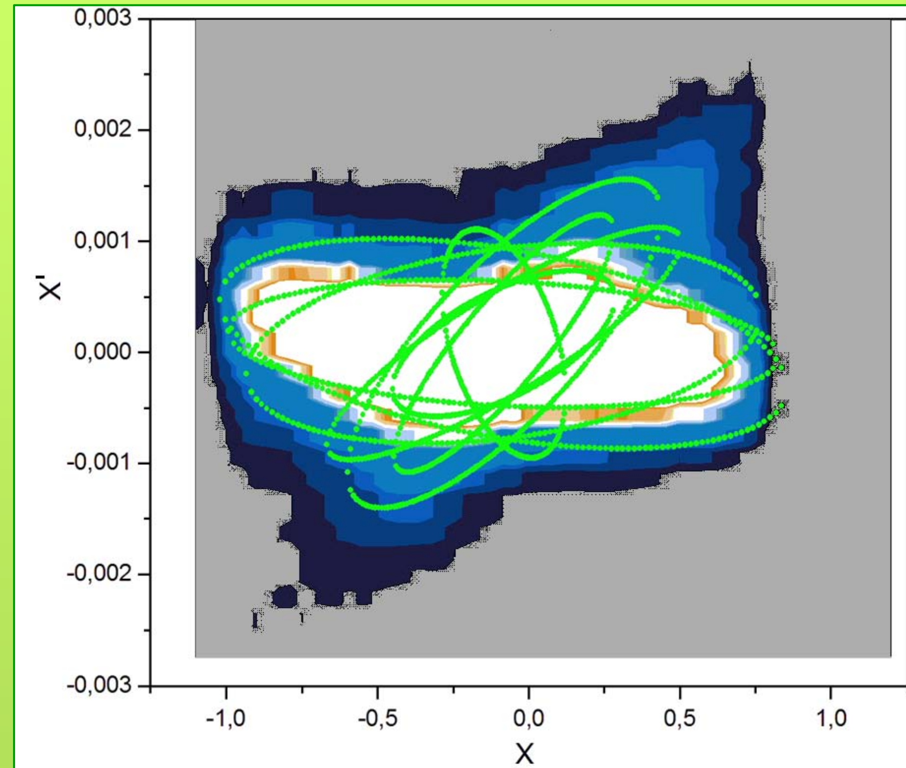
Genetic Multi Slice Analyzer

Basic Idea

Beam ⬄ ensemble of sub-beams of different density

➔ The real beam can be represented in the projected phase space by the union of N analytical ellipses with the same center





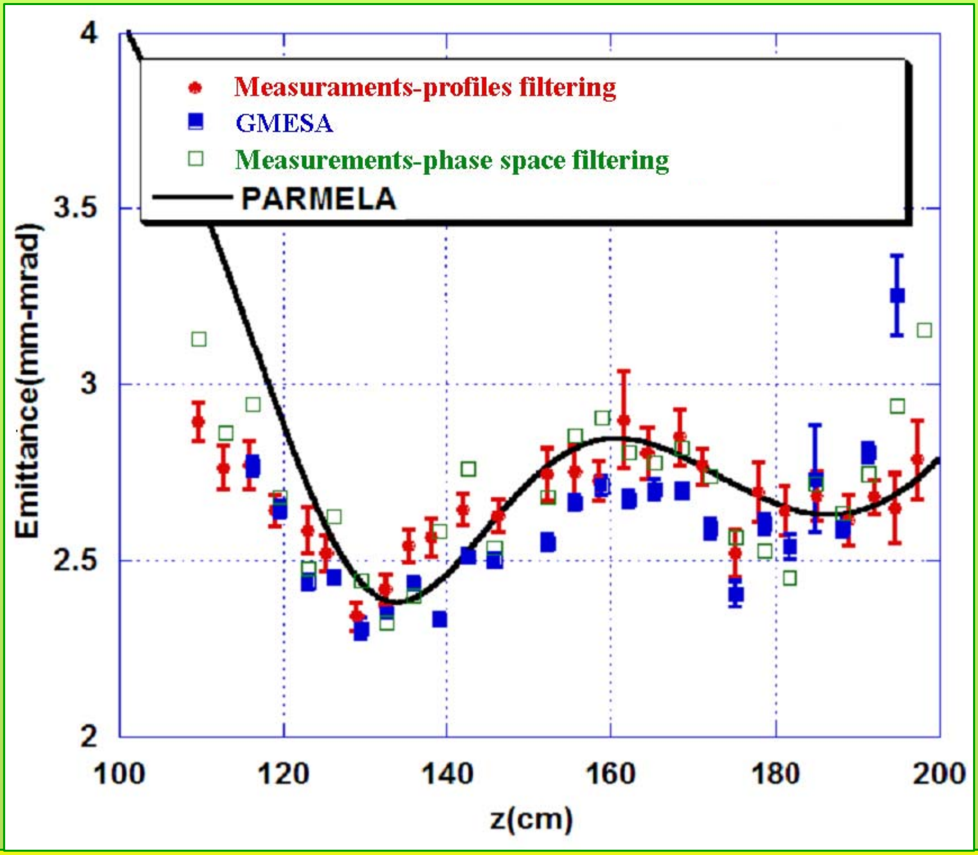
A. Bacci,

"A Genetic Code able to compute the emittance value of a real beam by a Multiple Ellipse Slice Analysis of the transversal phase space image",

http://www.lnf.infn.it/acceleratori/sparc/technotes.html SPARC/EBD-07/004

Comparison

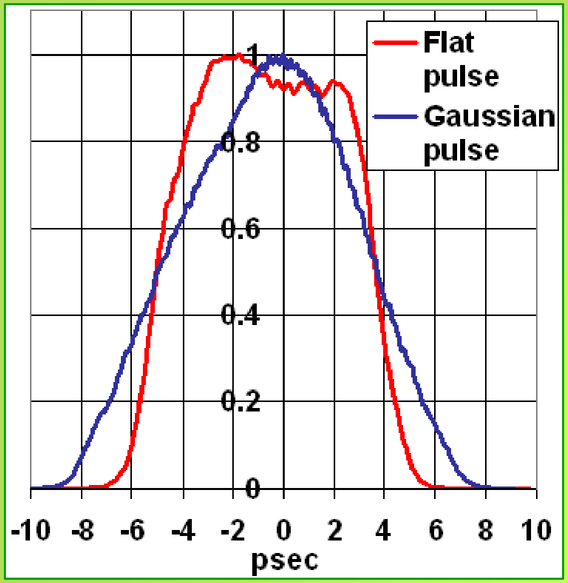
One of the most significant emittance curve has been chosen to compare all the codes, being the small amplitude of the double minimum oscillation an excellent candidate to check that every method is able to resolve it.



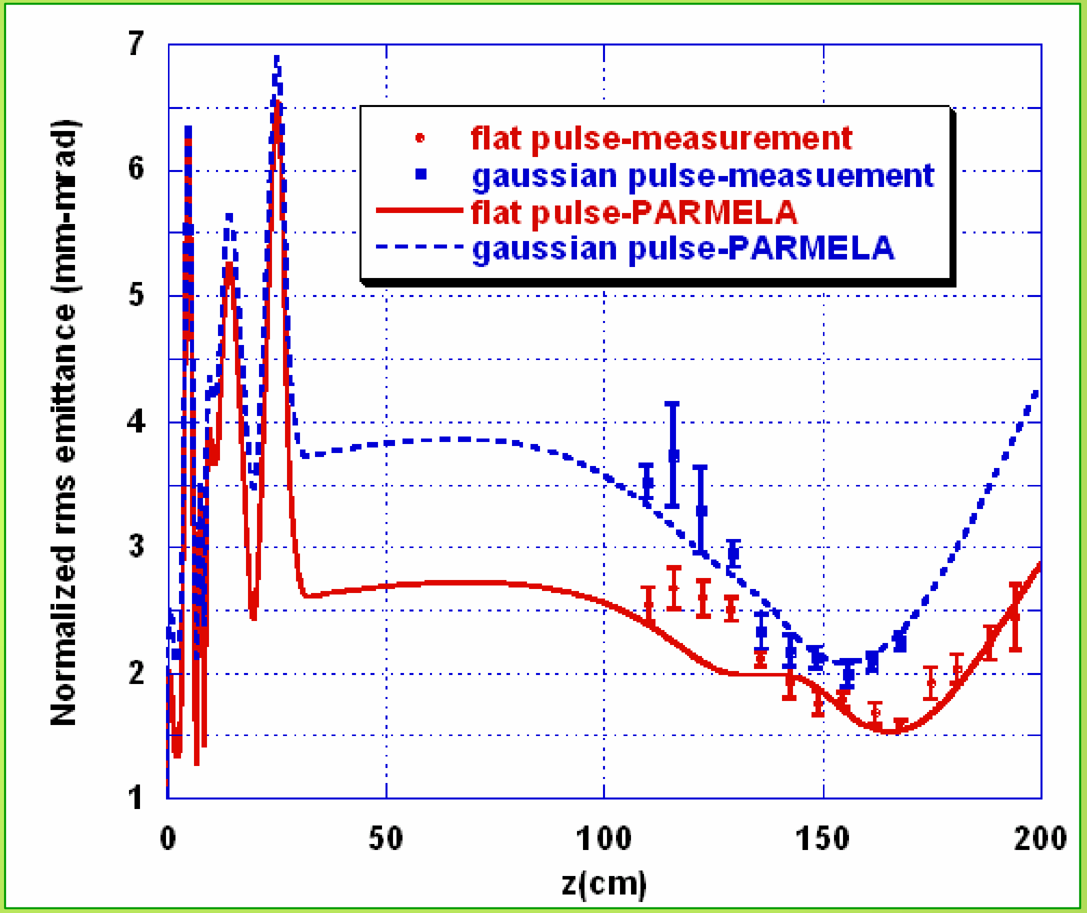
very good agreement with PARMELA simulation

Result Highlights

Flat-Top VS Gaussian Pulse

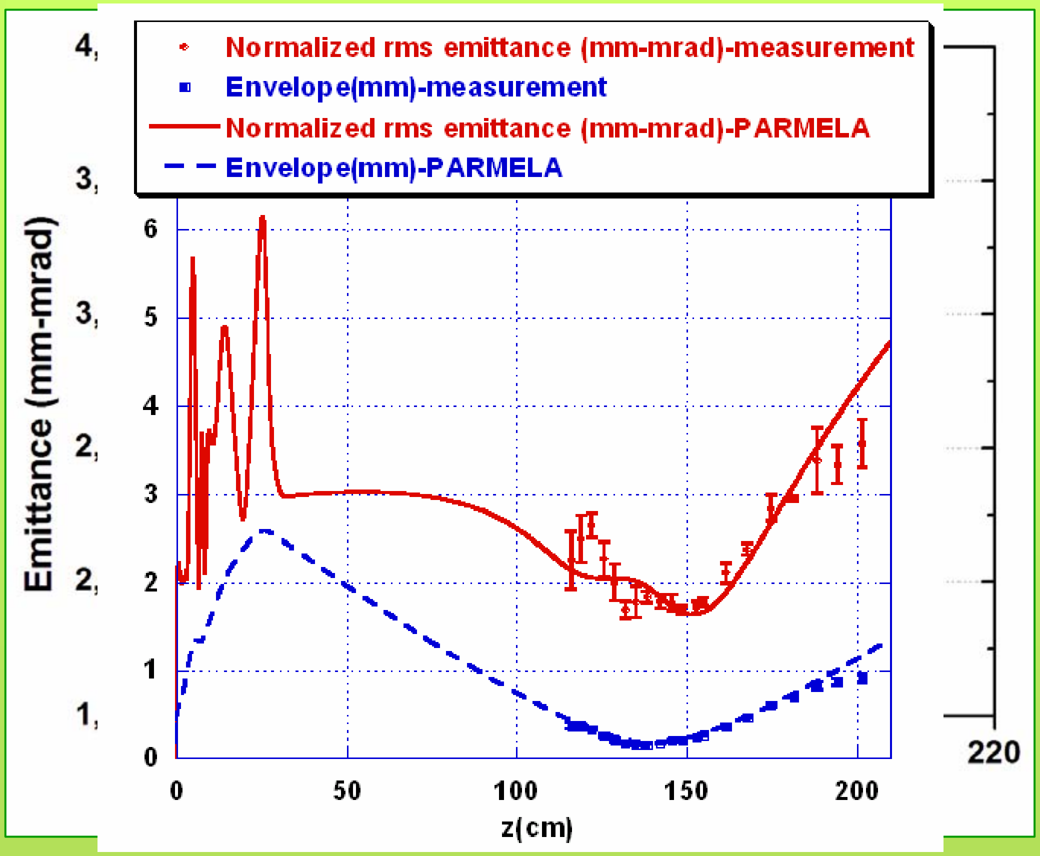


Energy	5.4 MeV
charge	0.74 nC
pulse length (FWHM)	8.7 ps
rise time	≈ 2.5 ps
rms spot size	0.31 mm

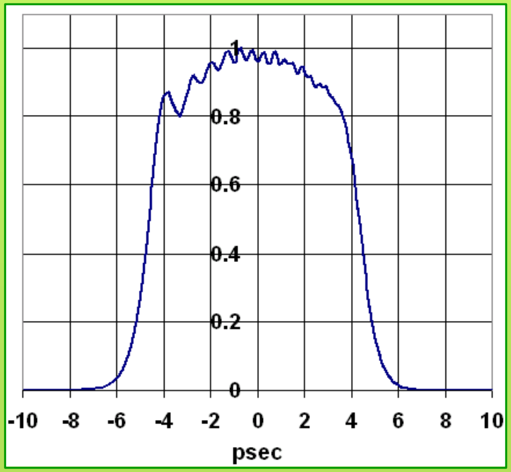


High Brightness Beam

$E = 5.6\ MeV,\ I = 92\ A,\ \varepsilon_n = 1.6\ \mu m \rightarrow B = 7\times10^{13}\ A/m^2$

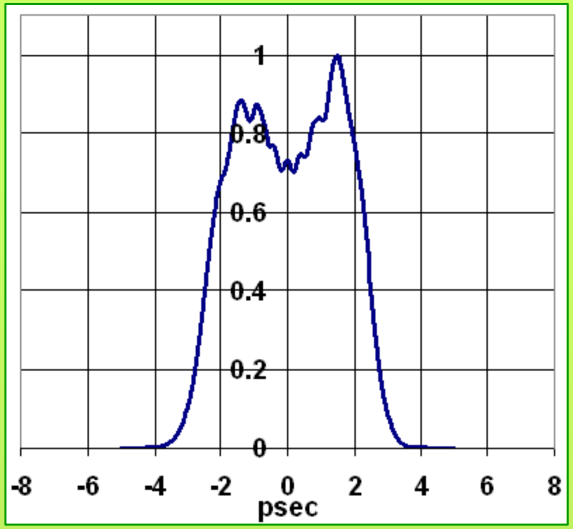


charge	0.83 nC
pulse length (FWHM)	8.9 ps
rise time	2.6 ps
rms spot size	0.36 mm
RF phase ($\varphi-\varphi_{max}$)	-8°

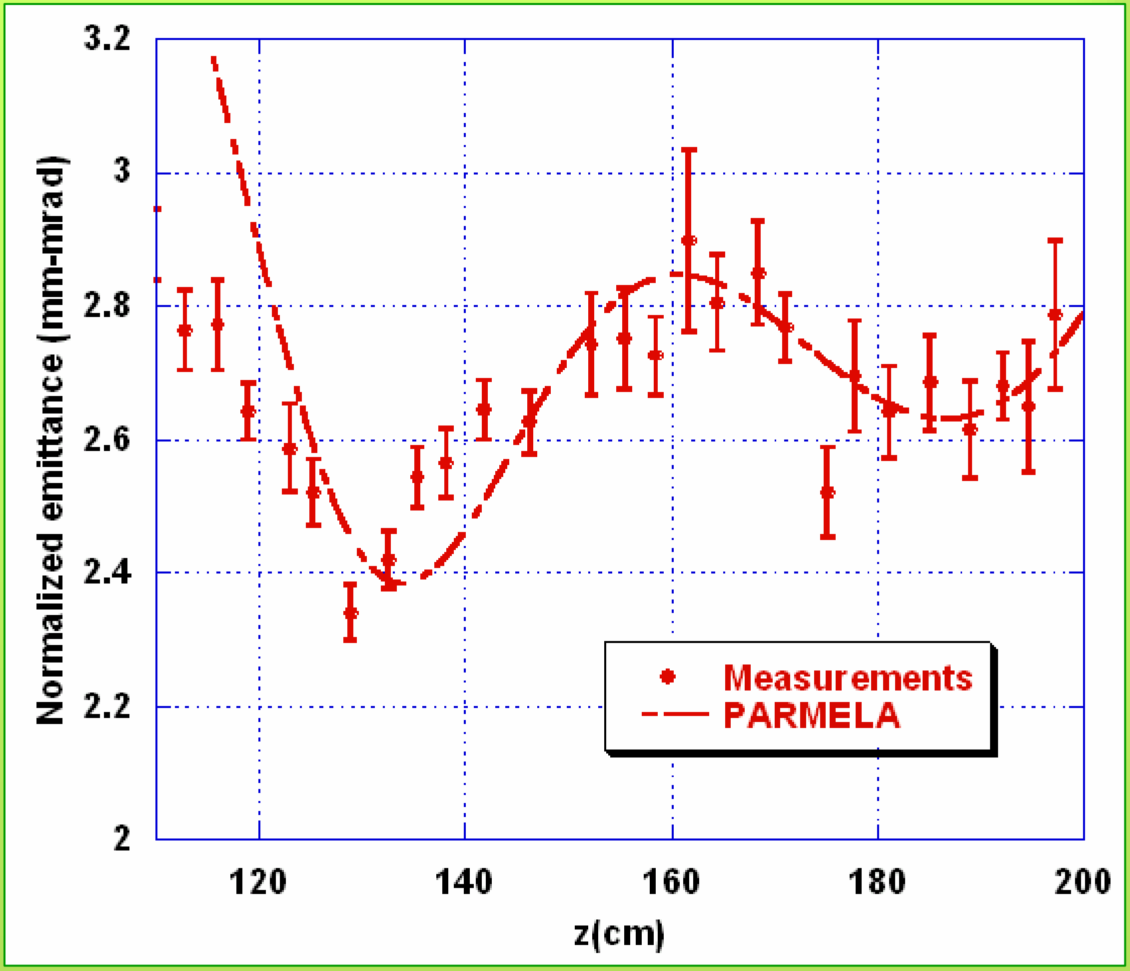


A. Cianchi et al.,
"High brightness electron beam emittance evolution measurements in SPARC RF photoinjector",
submitted to Phys. Rev., Special Topics AB

Double Minimum Signature



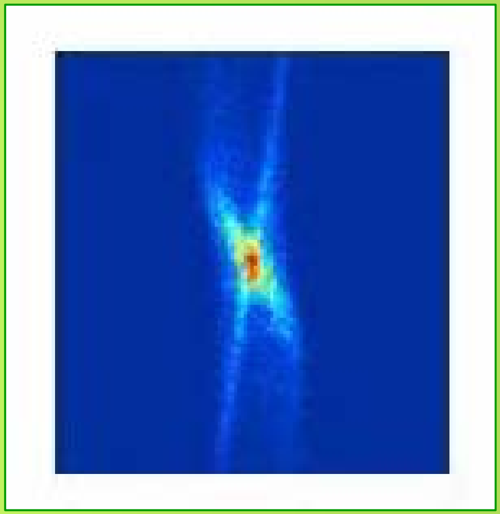
charge	0.5 nC
pulse length (FWHM)	5 ps
rise time	1.5 ps
rms spot size	0.45 mm
RF phase (φ-φ_{max})	+12°



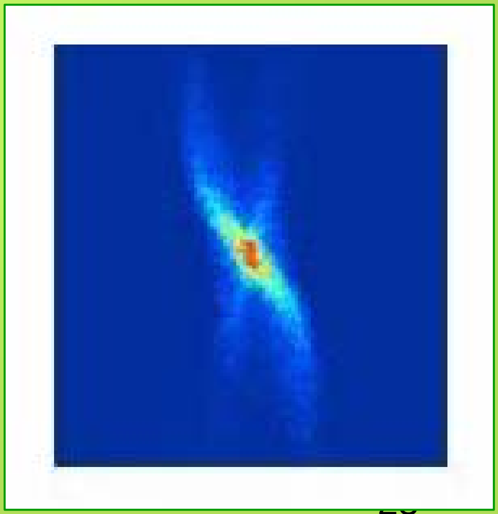
M. Ferrario et al.,
***"Direct measurement of double emittance minimum in the SPARC high brightness photoinjector"*,**
submitted to Physical Review Letters

From theory

Under laminar condition, in a space charge dominated regime

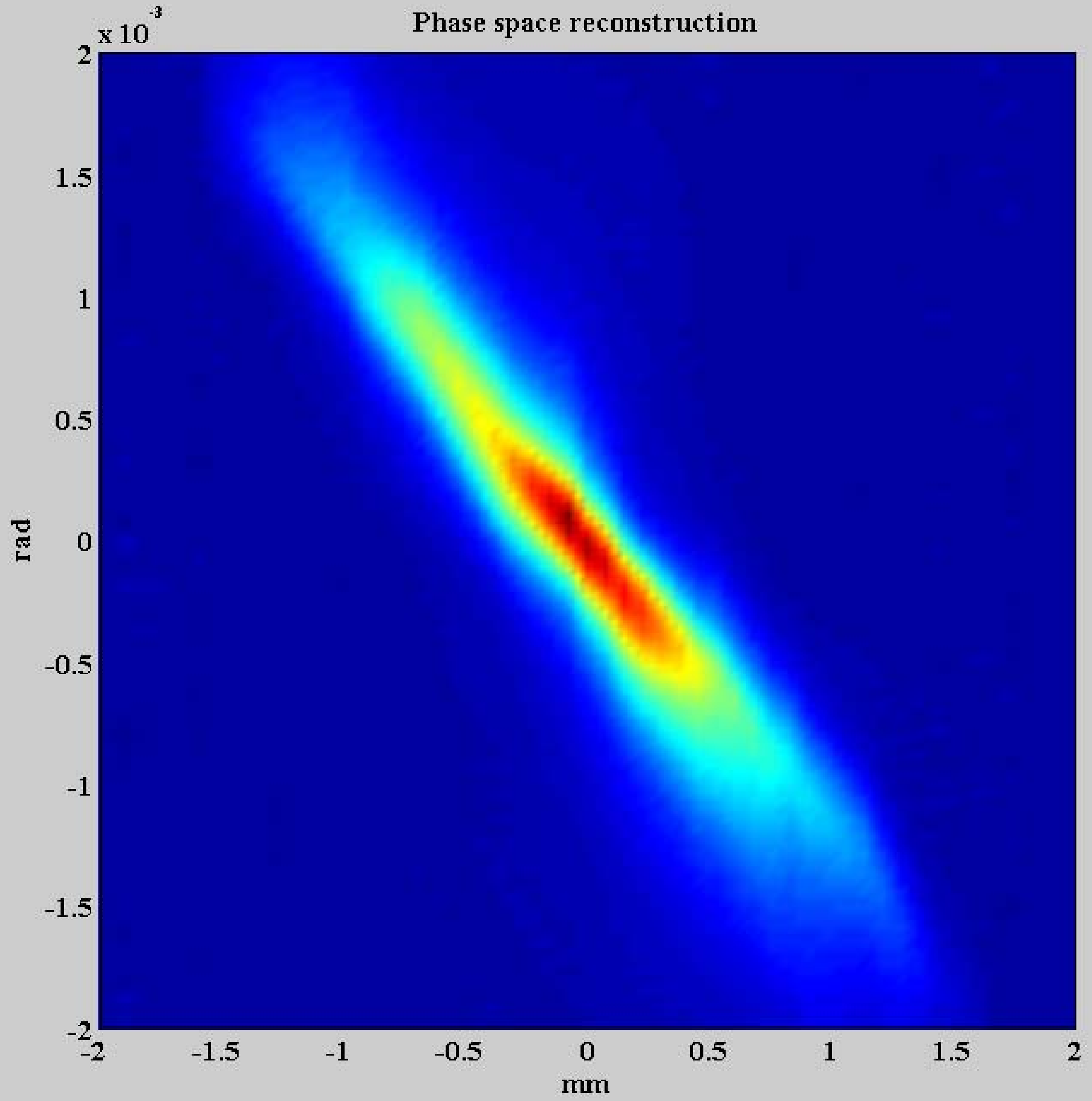


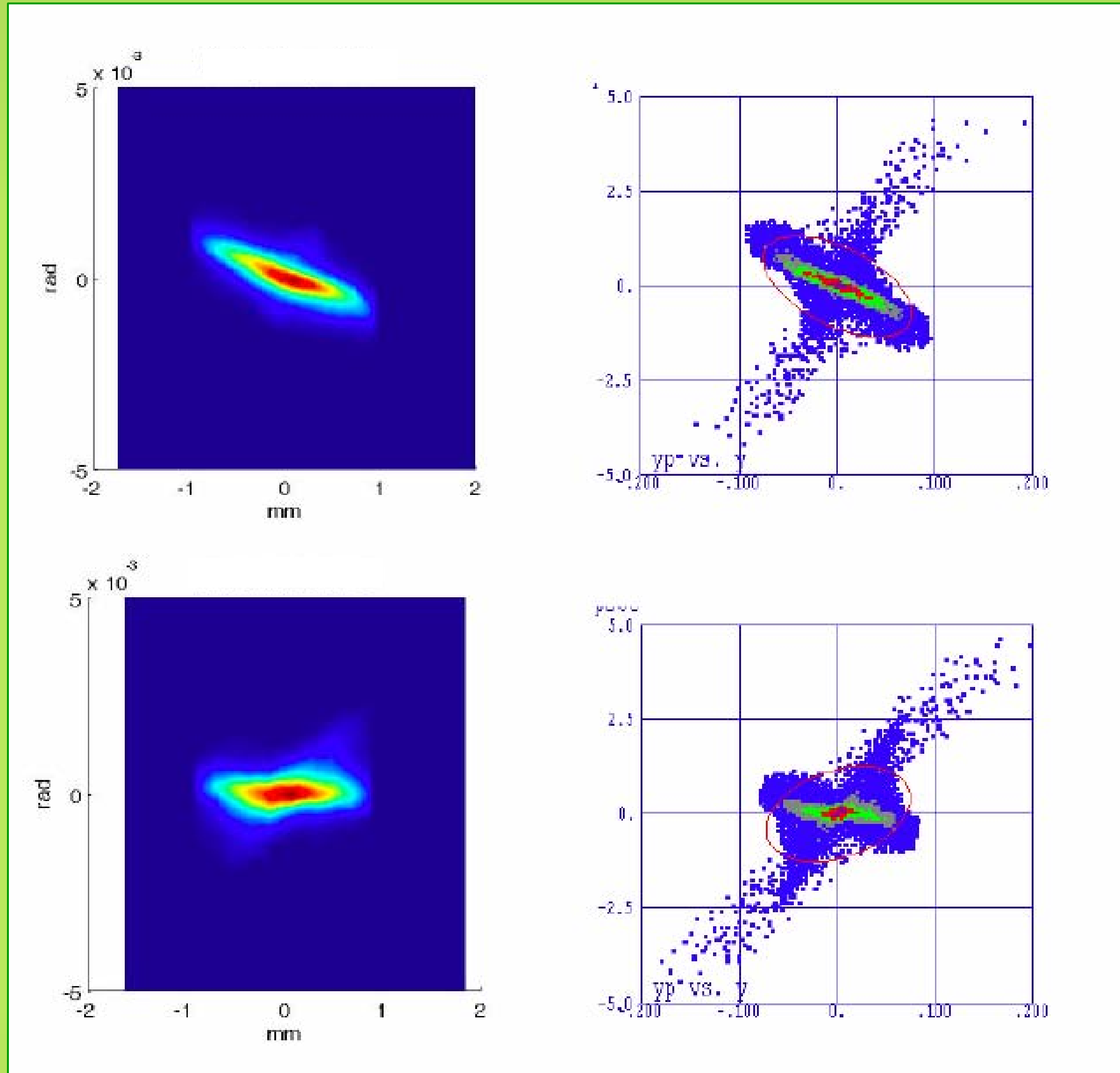
flat top distribution
the waist is reached at different positions by the head and the tail of the bunch
➔ cross shape in the transverse phase space



Gaussian distribution
the "ends" of the bunch gives a lower contribution due to the smaller current
➔ the cross shape is not visible or weaker

Flat Top: Double Minimum Oscillation





C. Ronsivalle et al.,
"*Comparison between SPARC E-Meter Measurements and Simulations*",
Proceedings of PAC07, Albuquerque, New Mexico, USA

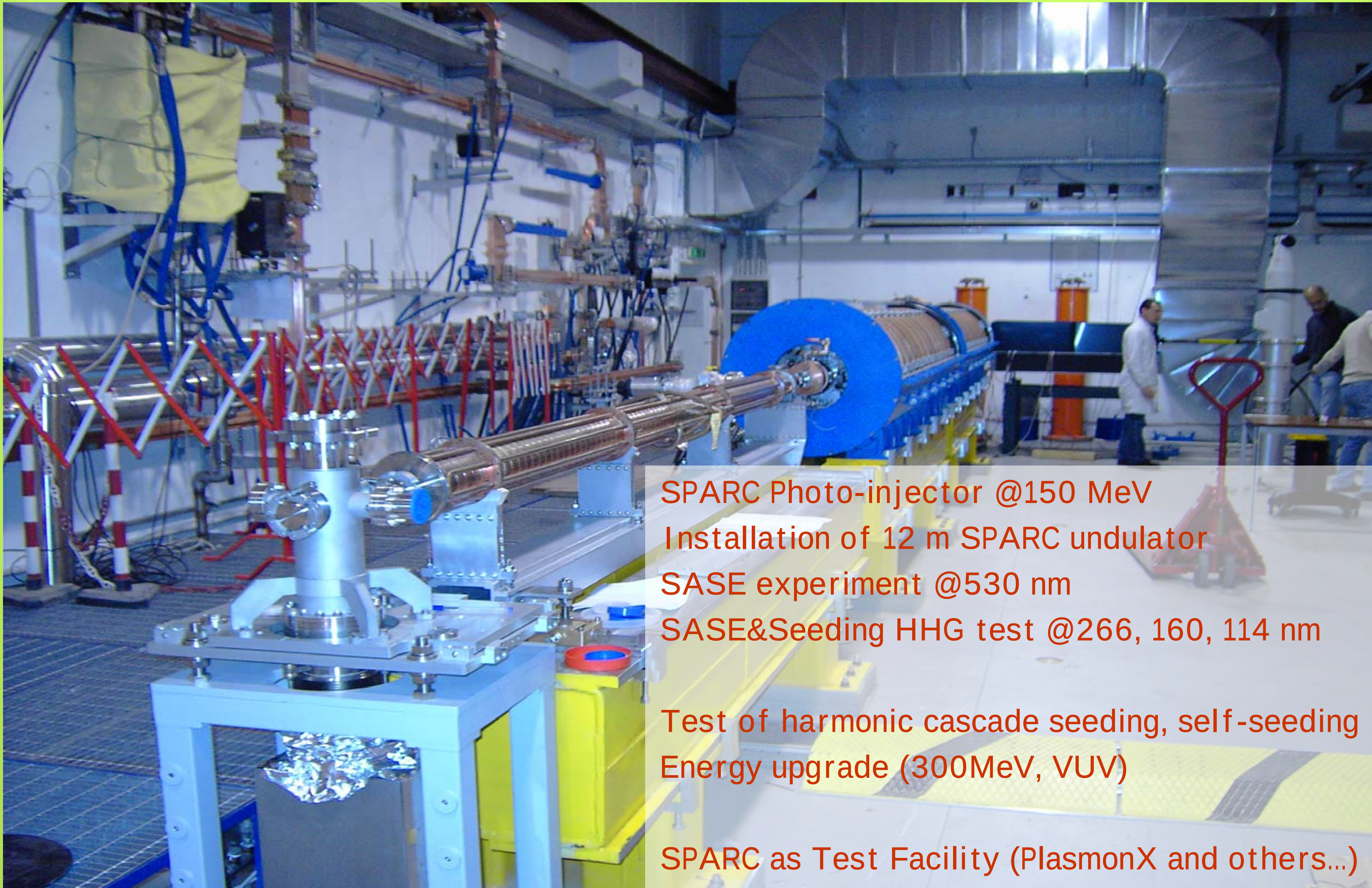
Conclusions...

- Commissioning of the SPARC phase 0 system
- Generation of Flat-Top UV pulses
- Achievement of nominal beam parameters
- Very Good agreement with simulations
- Phase space evolution
- Energy spread evolution
- Comparison between Flat-Top and Gaussian pulses
- **First experimental observation of emittance oscillation**

More than a conventional emittance diagnostics device, the e-meter defines a new strategy for characterizing photo-injectors and thus allowing an easier matching to the linac sections.

☞ It will travel to other Labs.....

…& Developments



SPARC Photo-injector @150 MeV

Installation of 12 m SPARC undulator

SASE experiment @530 nm

SASE&Seeding HHG test @266, 160, 114 nm

Test of harmonic cascade seeding, self-seeding

Energy upgrade (300MeV, VUV)

SPARC as Test Facility (PlasmonX and others…)

Thank you
for your attention!