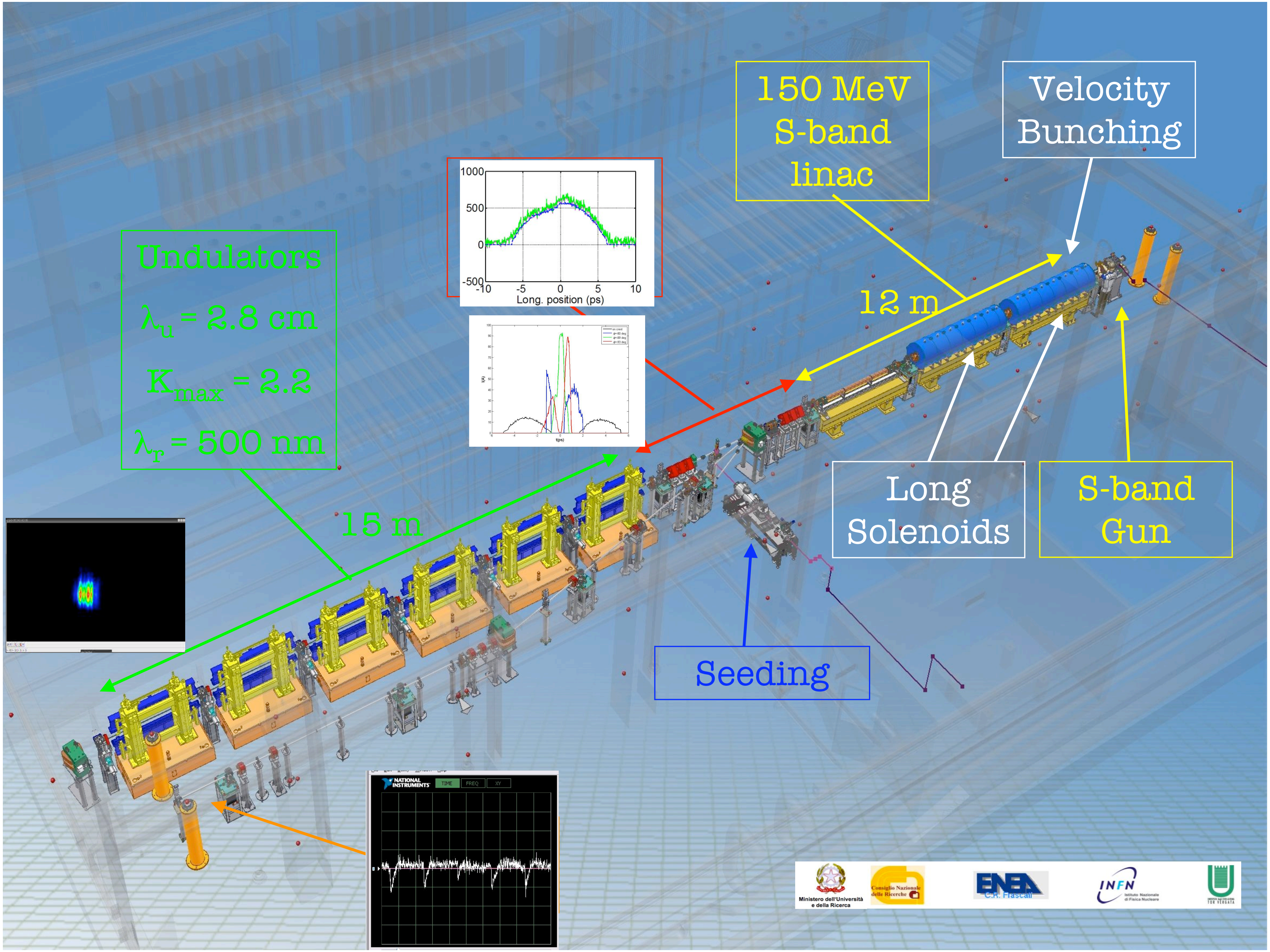
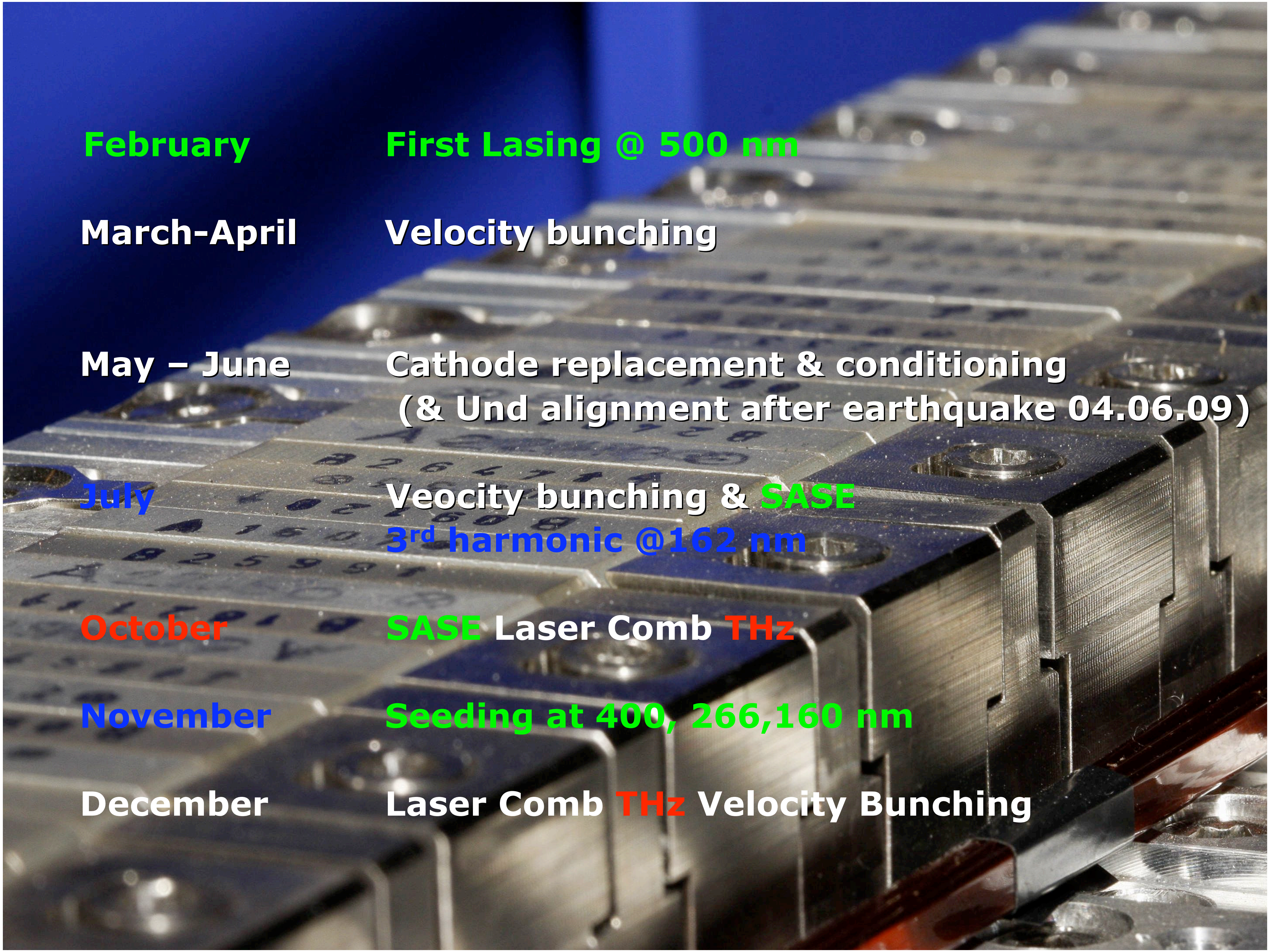
SPARC scientific activities and plans

Massimo Ferrario
on behalf of the SPARC team

39th LNF Scientific Committee Meeting - October 26, 2009



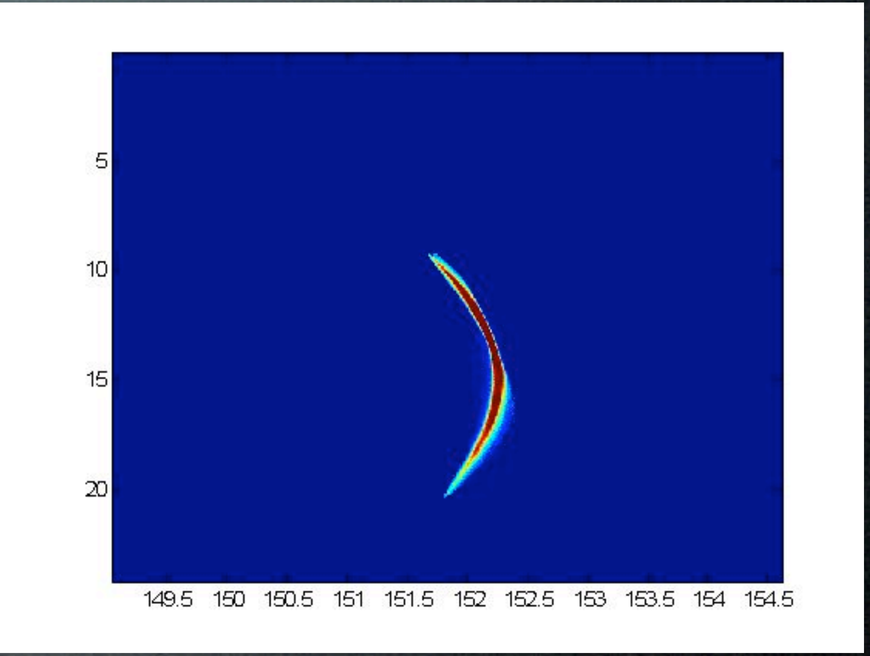
150 MeV S-band linac
Velocity Bunching
Undulators
λ_u = 2.8 cm
K_{max} = 2.2
λ_r = 500 nm
12 m
15 m
Long Solenoids
S-band Gun
Seeding
Long. position (ps)
NATIONAL INSTRUMENTS
TIME
FREQ
XY
Ministero dell'Università e della Ricerca
Consiglio Nazionale delle Ricerche
ENEA
C.R. Frascati
INFN
Istituto Nazionale di Fisica Nucleare

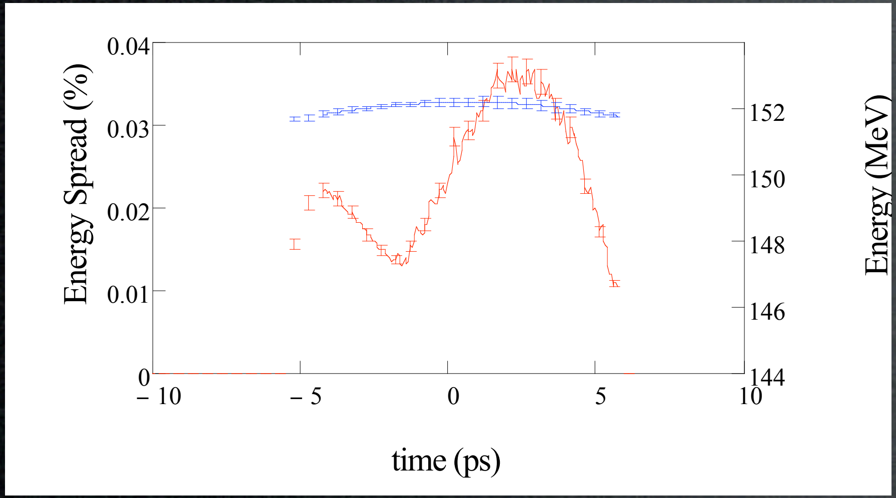

February First Lasing @ 500 nm
March-April Velocity bunching
May – June Cathode replacement & conditioning
(& Und alignment after earthquake 04.06.09)
July Veocity bunching & SASE
3rd harmonic @162 nm
October SASE Laser Comb THz
November Seeding at 400, 266,160 nm
December Laser Comb THz Velocity Bunching

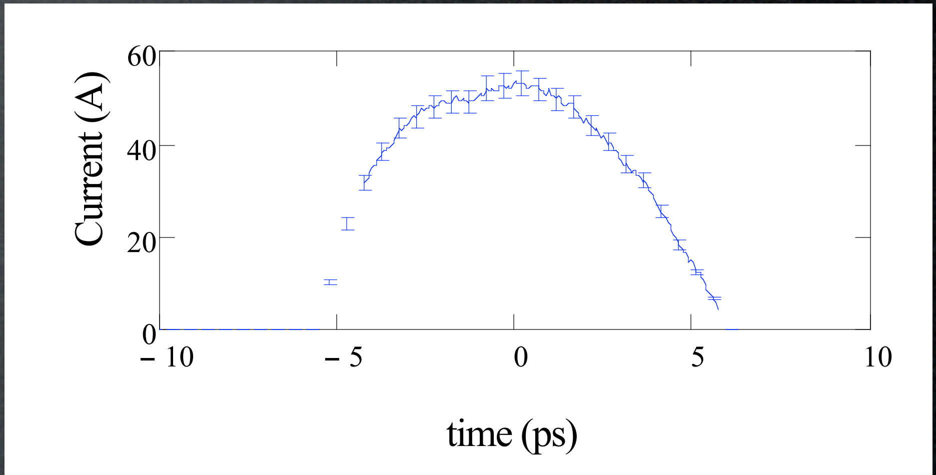
FEL experiments:
SASE at 500 nm

Shift of 24.07.09 (highest charge/current)

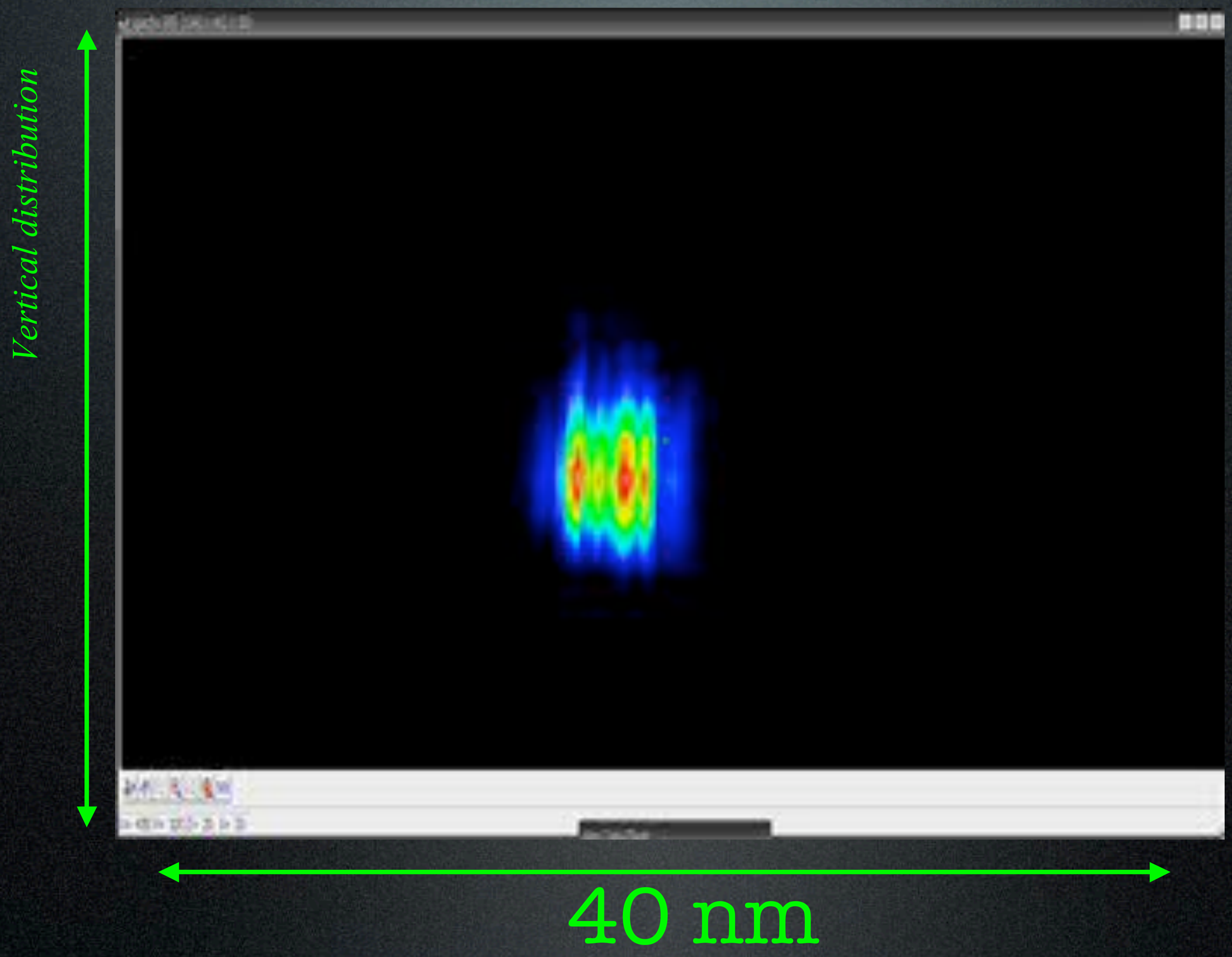
Energy	151.9 MeV
Charge	420 pC
I_{peak}	53 A
ϵ_x / ϵ_y	2.5/2.9 mm mrad
σ_z	2.65 ps

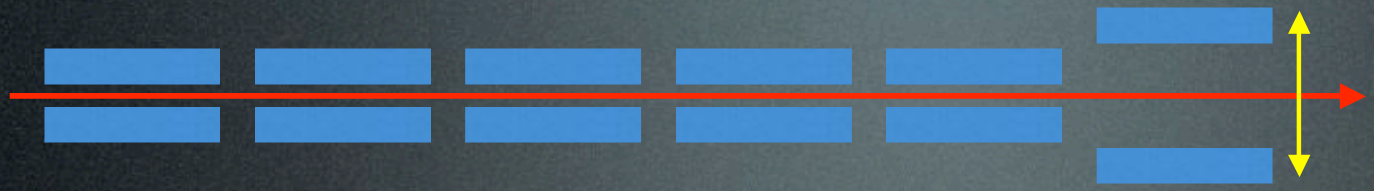


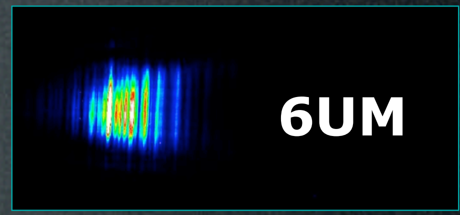




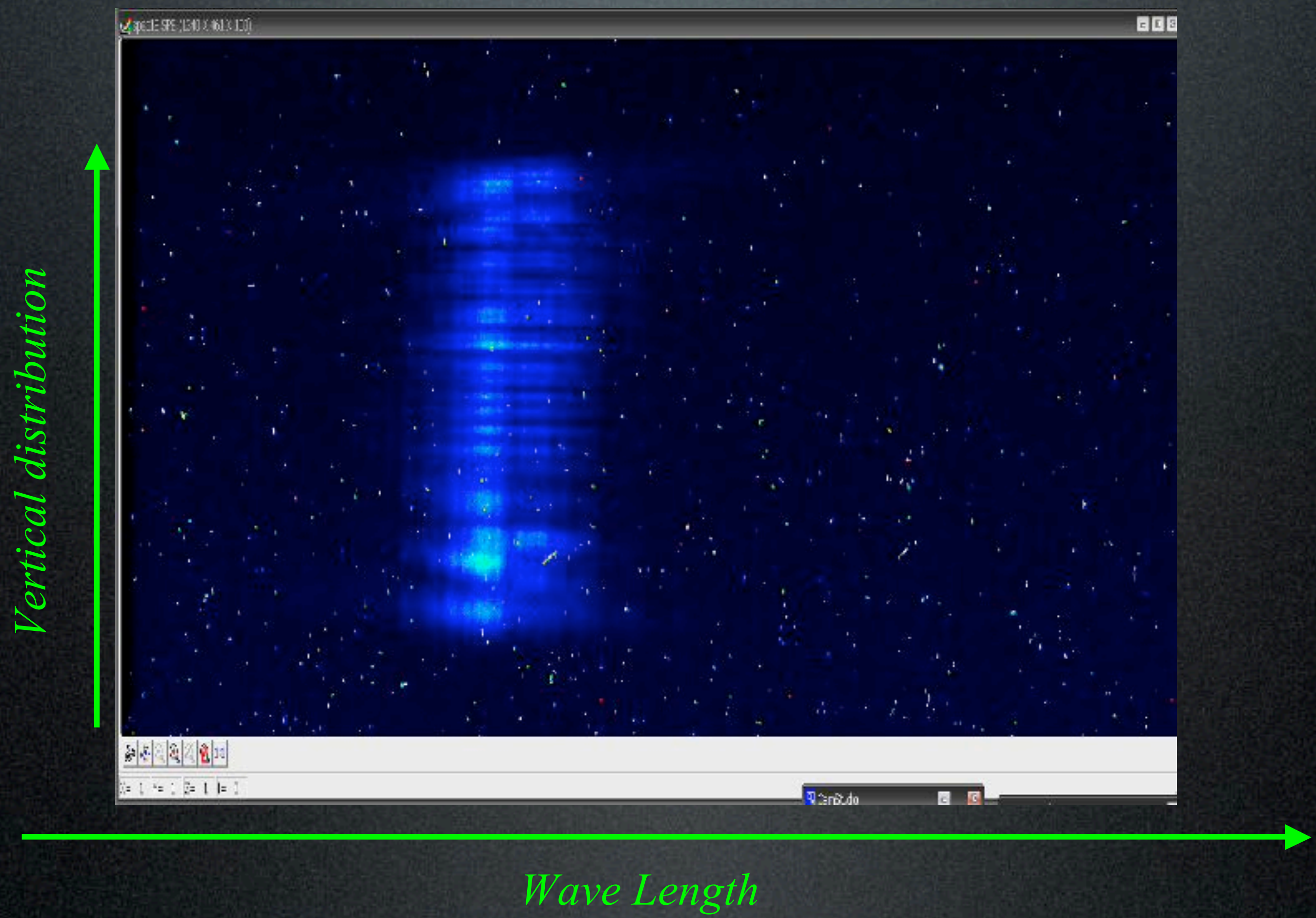
First experimental evidence of SASE at 500 nm on February 17th





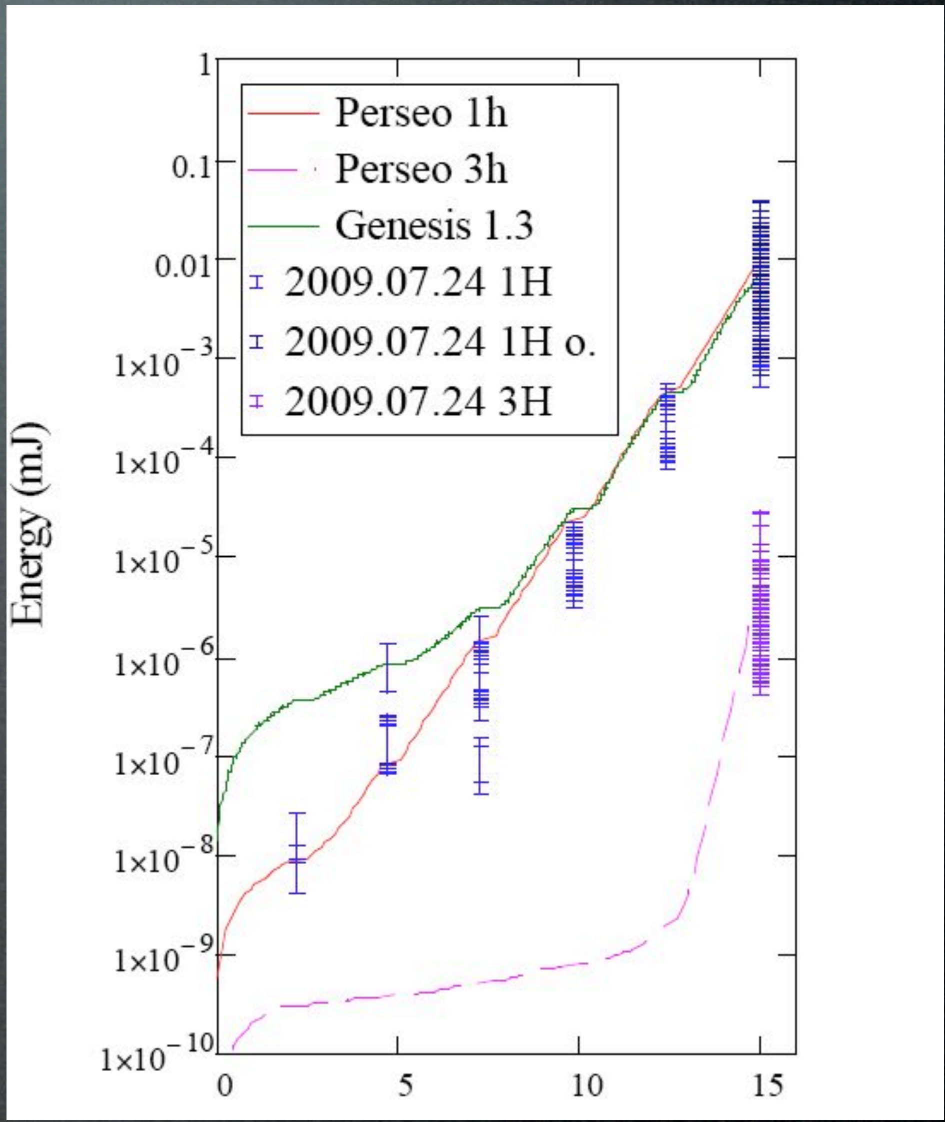


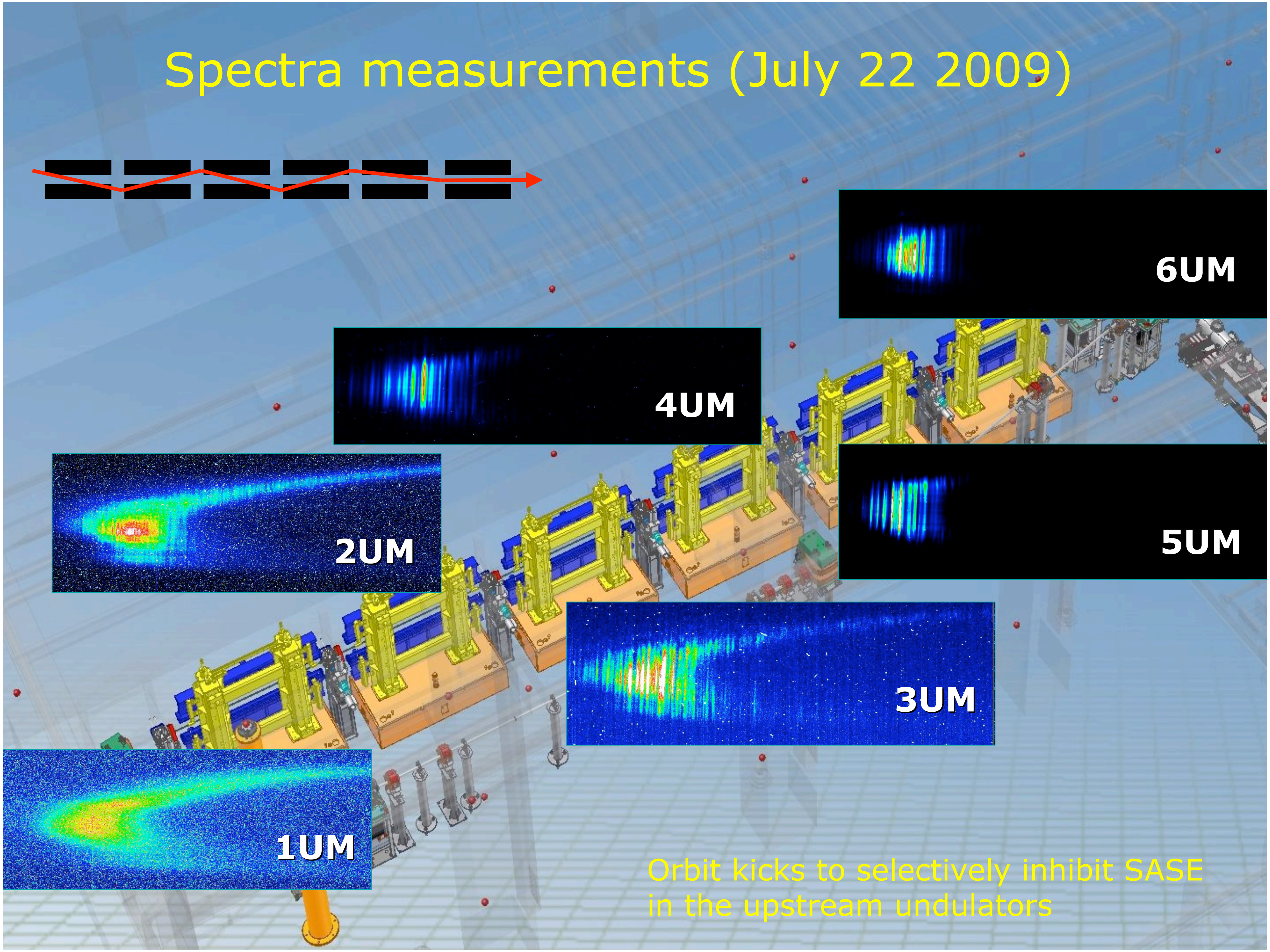
5 undulator sections set at resonance, the 6° section gap is slowly tuned over the resonance



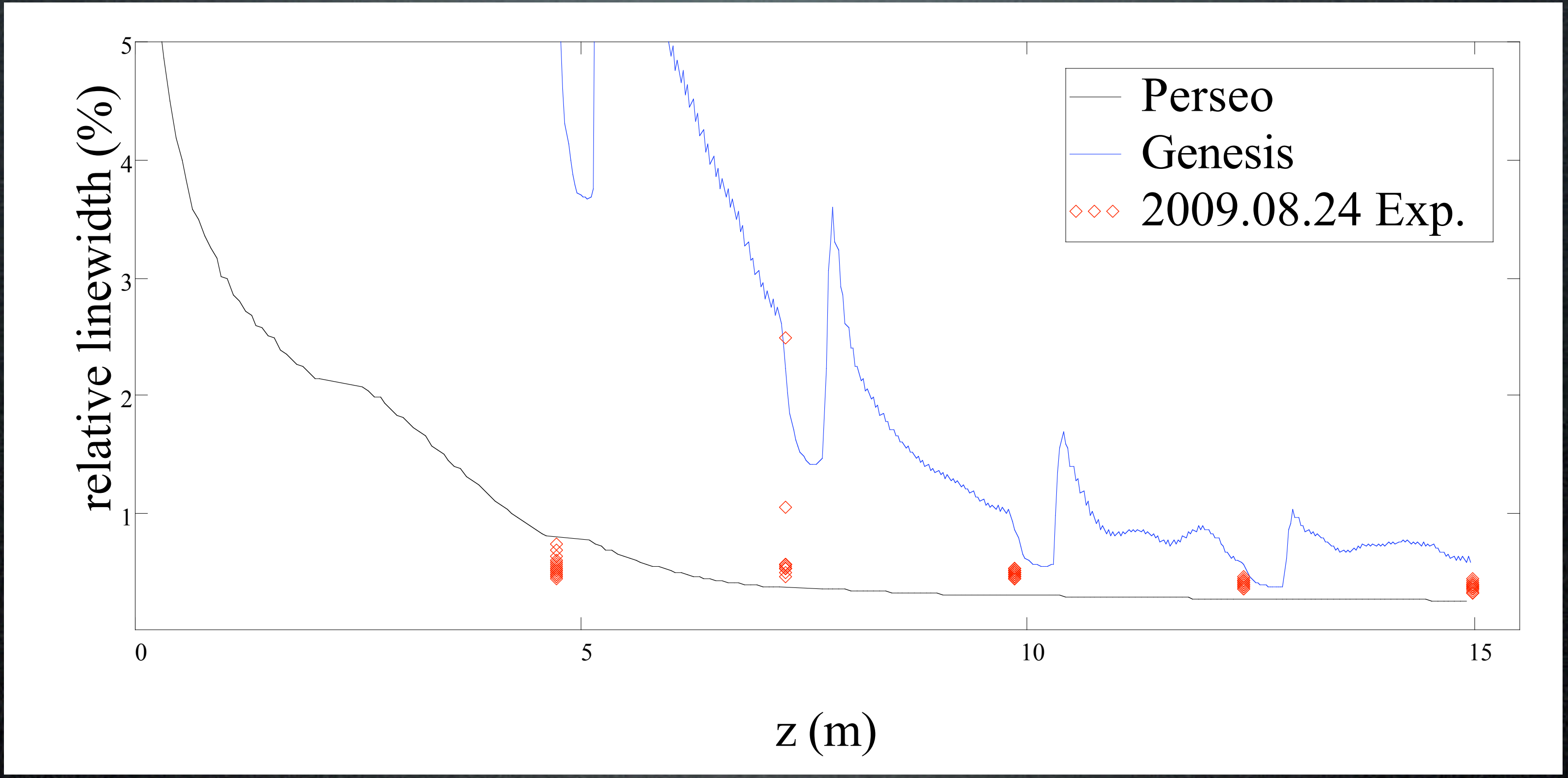
Comparison with simulations

- Third harmonic measured only with 6 undulators
- Perseo 1h & Perseo 3h represent 50 Perseo TD simulations
- Error bars represent 1 standard deviation




Spectra measurements (July 22 2009)
6UM
4UM
2UM
5UM
3UM
1UM
Orbit kicks to selectively inhibit SASE
in the upstream undulators

Spectral width vs z



Further Injector Improvements

Higher gradient 8 MW ==> 10 MW

Gun Vacuum 10^{-9} mbar ==> 10^{-10} mbar

New Gun

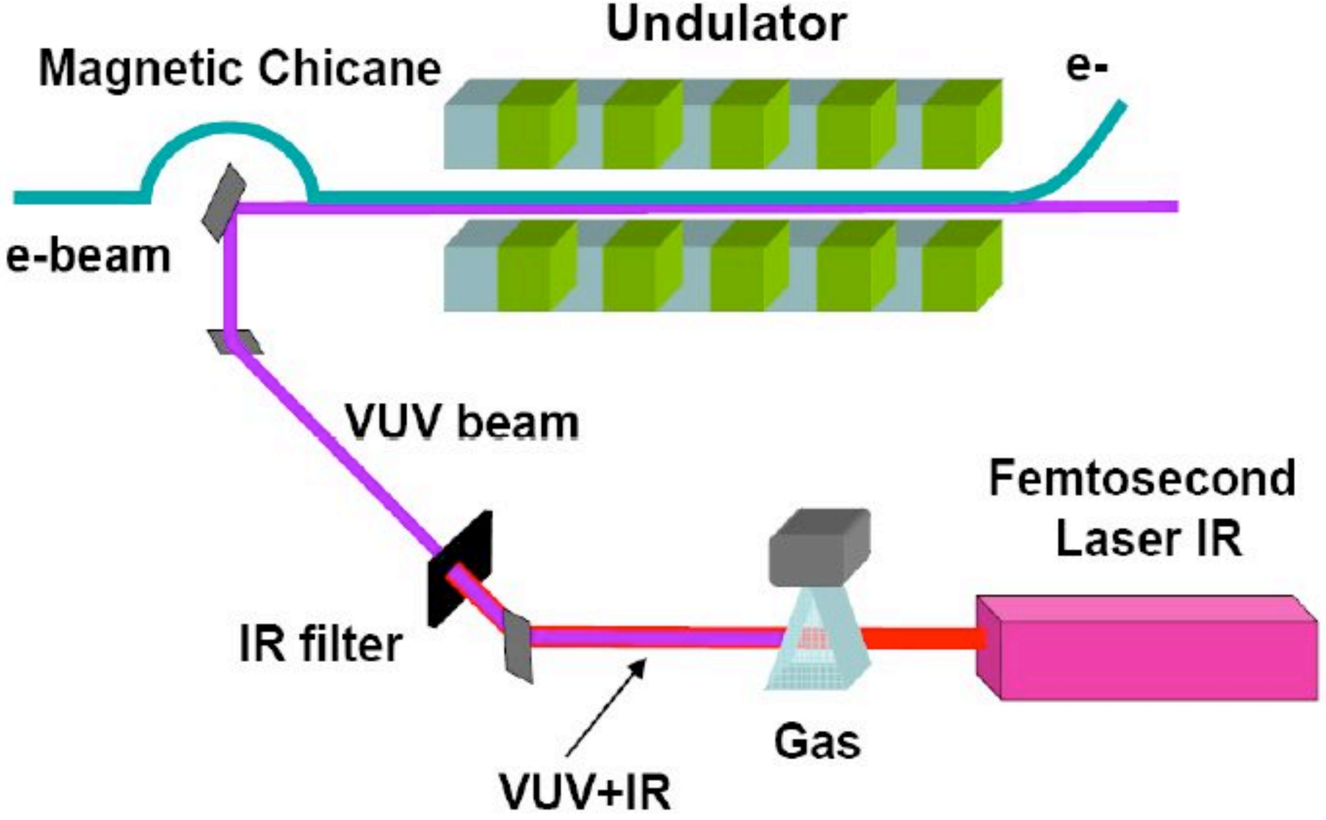
Higher charge ==> 1 nC

New Laser injection set up

Cathode QE

FEL experiments: seeding and synchronization

Optimization of the FEL process efficiency
Brillance maximization and Laser seeding



Schematics of a seeded FEL process in a dedicated facility.

Stability required ≈ few 100s fs (… challenging!)

Ti:Sa Regenerative amplifier
800 nm - 2.5 mJ – 1 kHz
+
High order harmonics
400 & 266 nm
+
High order armonics in gas:
266, 160, 114 nm
High Energy
Short duration
Spatial and temporal Coherence

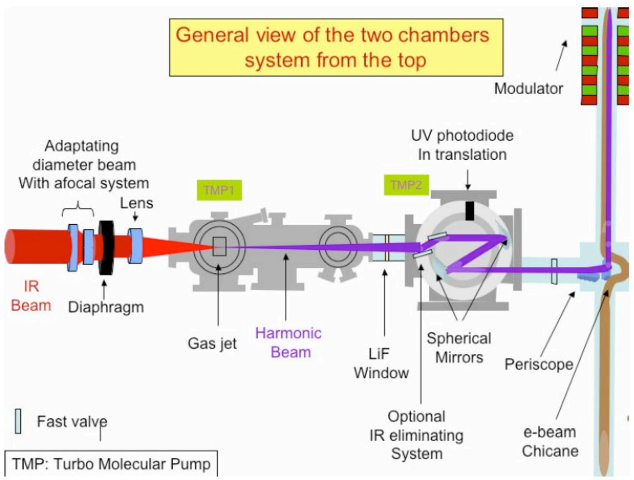
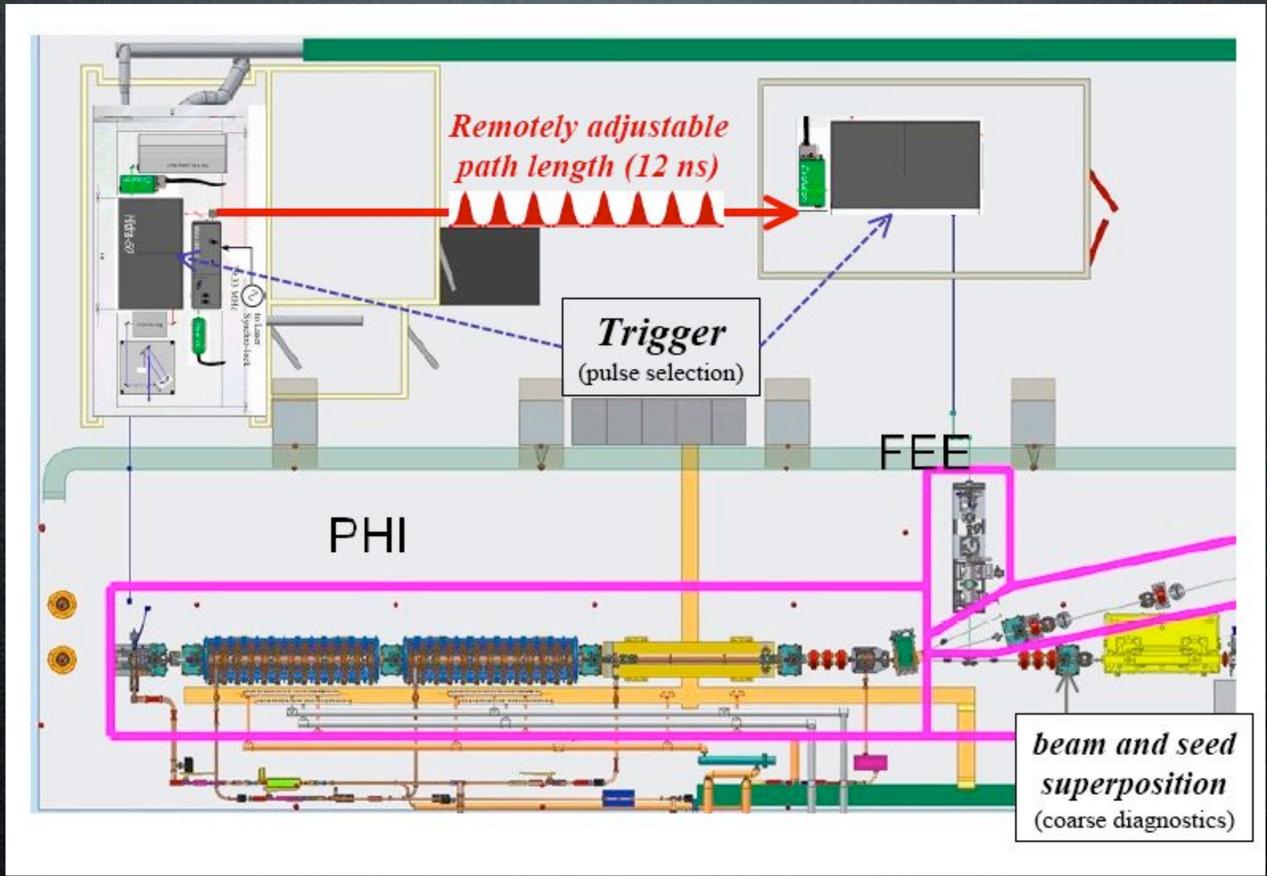


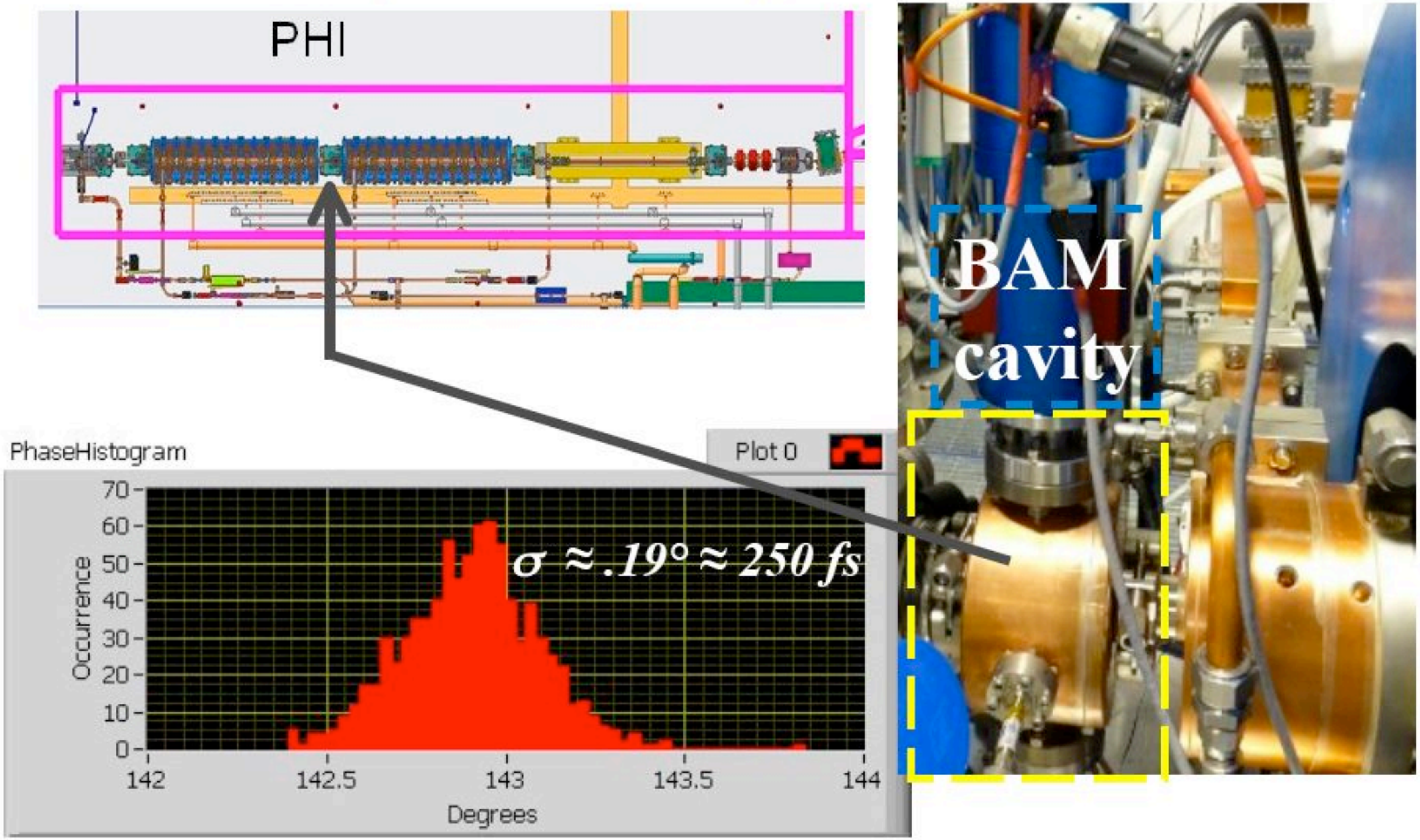
Fig. 31. *Lay-out of the harmonic chamber for the seeding experiment at SPARC. The first chamber is dedicated to the production of harmonics in gas. The second chamber is required for the opical mode adaptation.*

1) The seeding laser system is a regenerative amplifier, making use of a sample of the optical IR pulse train produced by the oscillator of the photocathode laser system. This makes the two lasers 100% time correlated.
2) The pulse of the laser oscillator are spaced by 12.6 ns (79.33 MHz). An optical delay line with a dynamic range > 12.6 ns allows shifting in time the 2 laser systems (and therefore the seed respect to the beam).

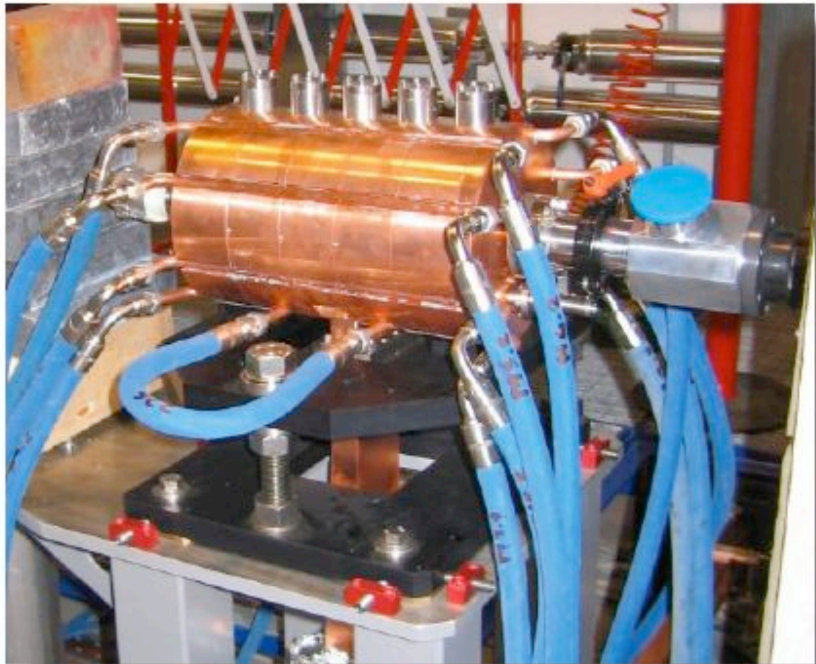


3) The trigger system allows to select the same pulse in the 2 laser systems for amplification .
4) A coarse (few ps) superposition of the beam and seed can be obtained by looking at the relative position of the pulses at the same target on a strek camera. SASE light (with seeding off) is the best candidate to identify the beam arrival time.
5) Fine tuning will be driven by observation and optimization of the seeding process.

SPARC Bunch Arrival Monitor (BAM) based on the resonant pulse stretching method

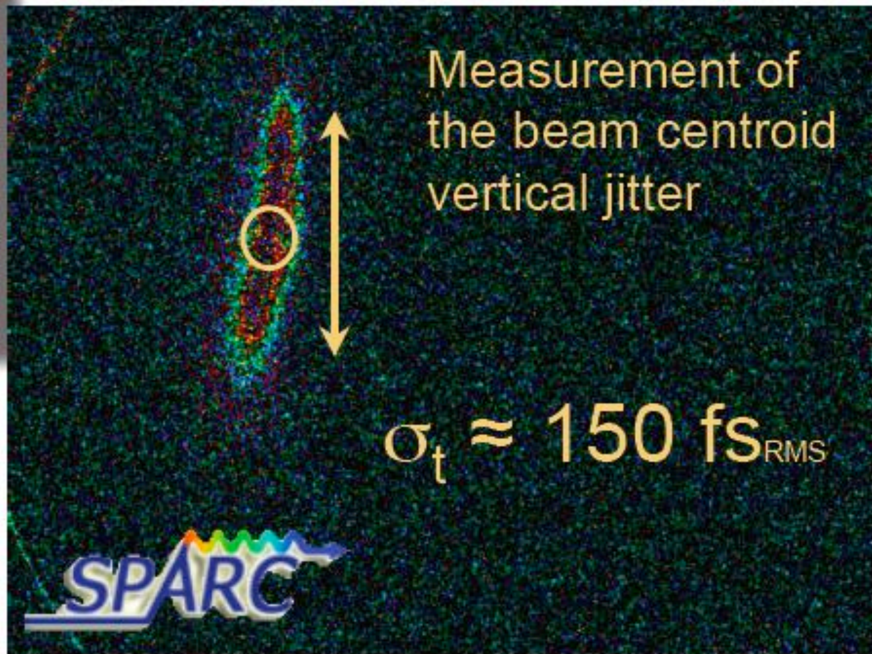


Bunch arrival jitter measured with the RF deflector

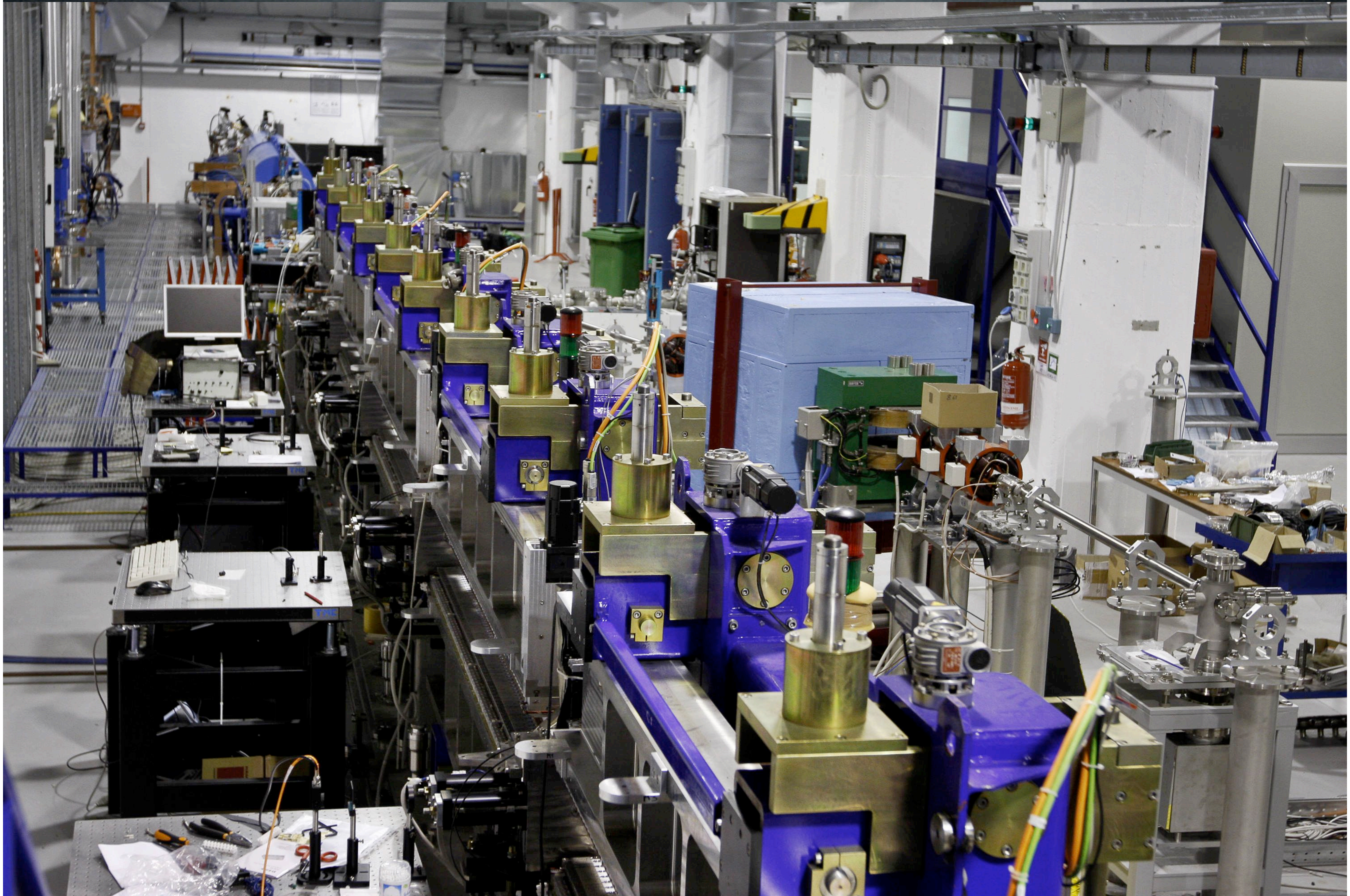


SPARC RF deflector

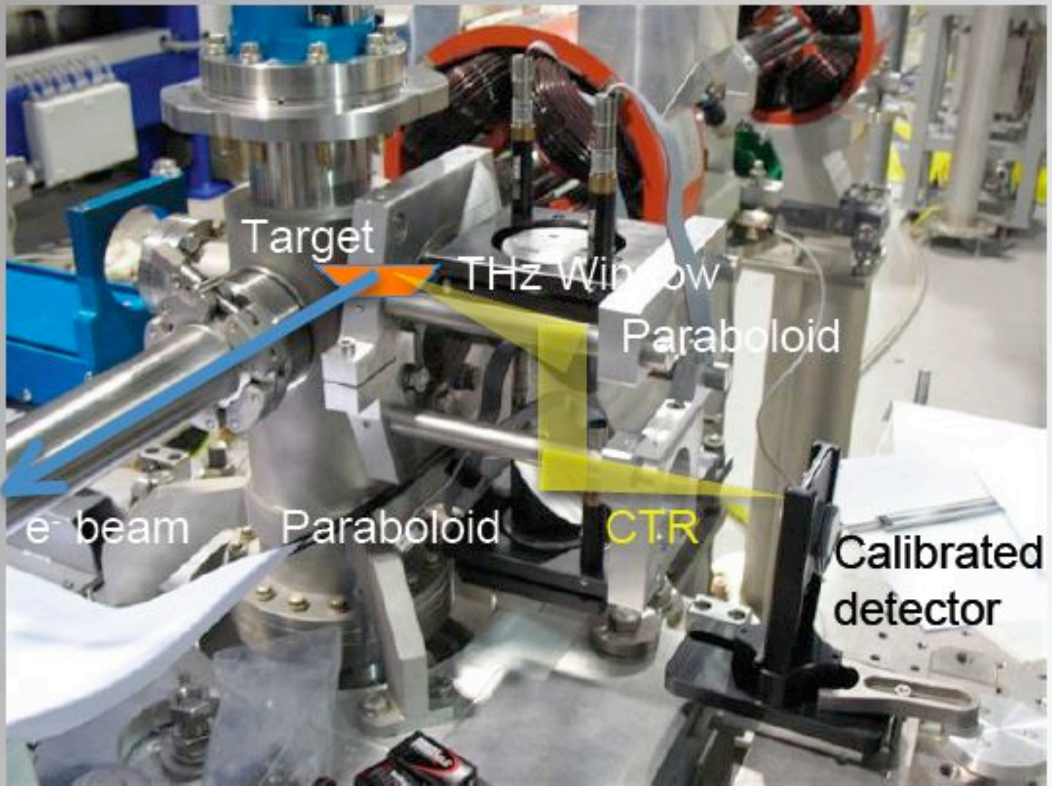
Image of a SPARC bunch vertically streaked on a target



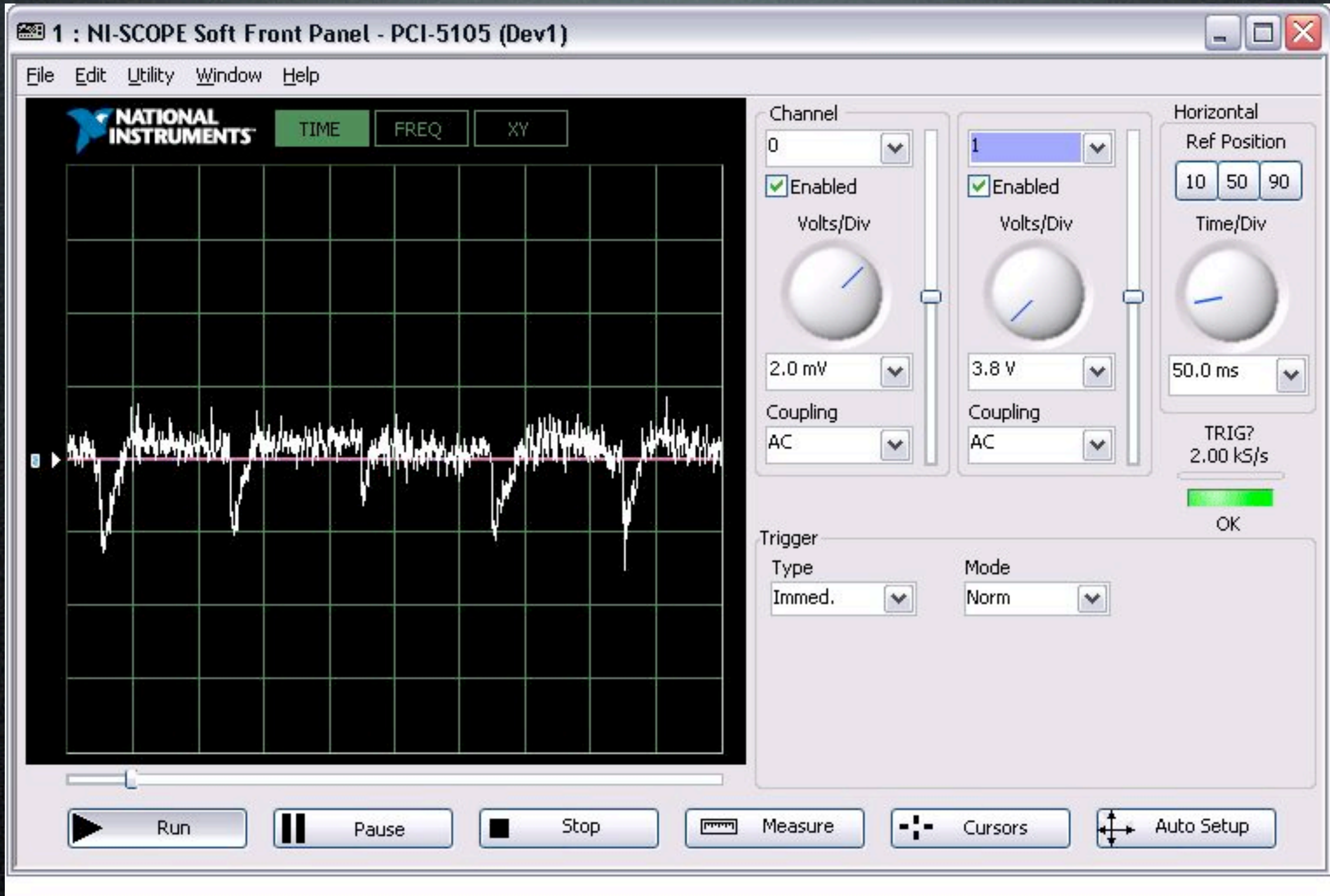
THz at SPARC



Optical setup for preliminary intensity measurements
(october 2009)



First THz signal on the piroelectrict detector observed Saturday 24th

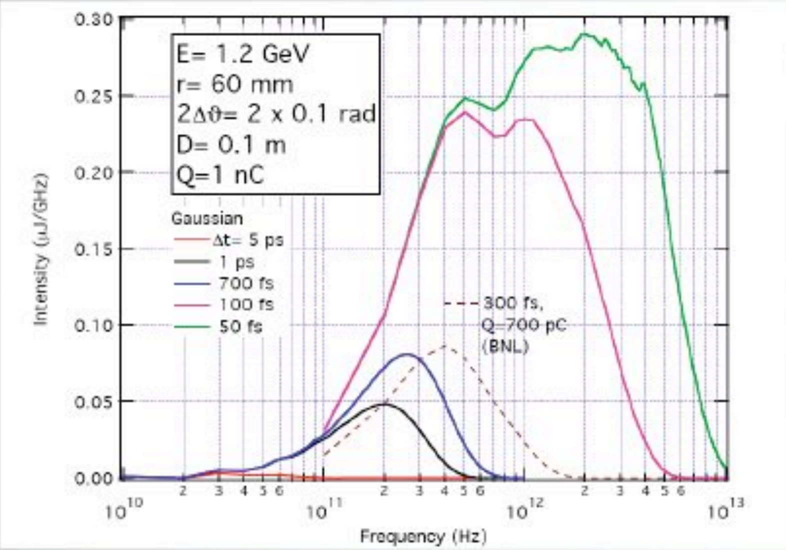


Task #1: SPARC beam diagnostics

Inverse Fourier transform of the CTR power spectrum provides
•the bunch length σ
•the bunch longitudinal form factor f_λ.

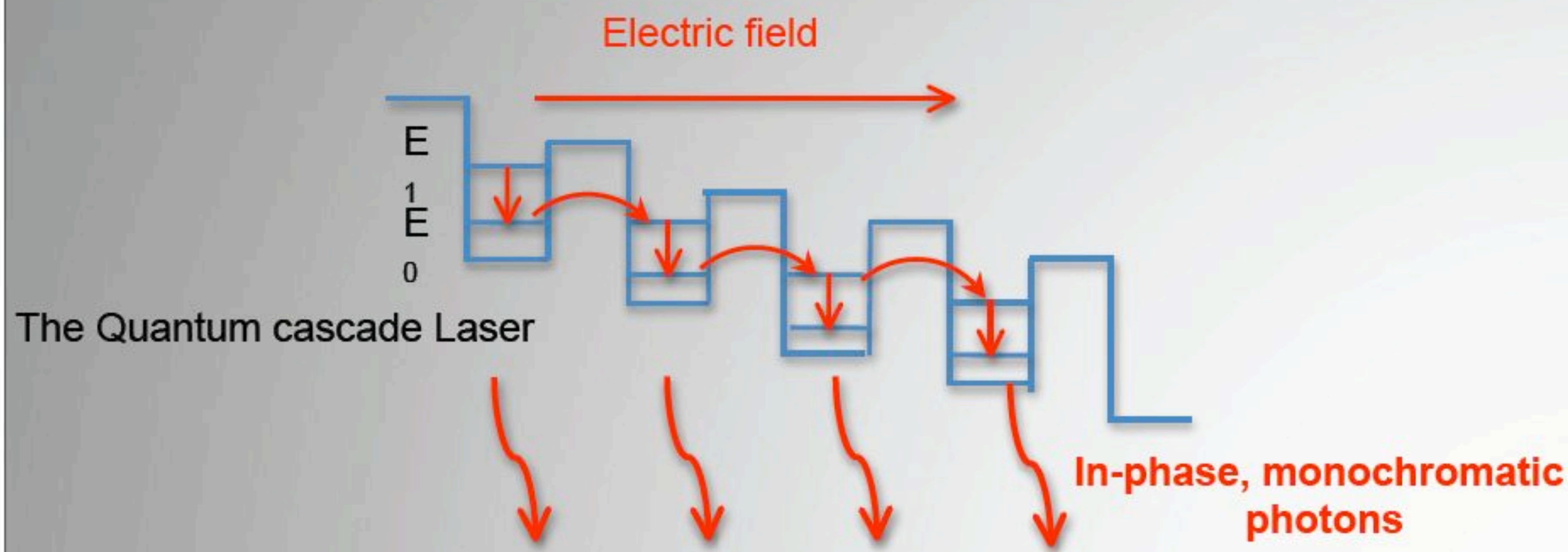
Example from Brookhaven:

Gaussian Bunch



Task #2: Experiments.

Lifetime of a QW excited state
(project of a Ge/Si-Ge Quantum-cascade Laser)

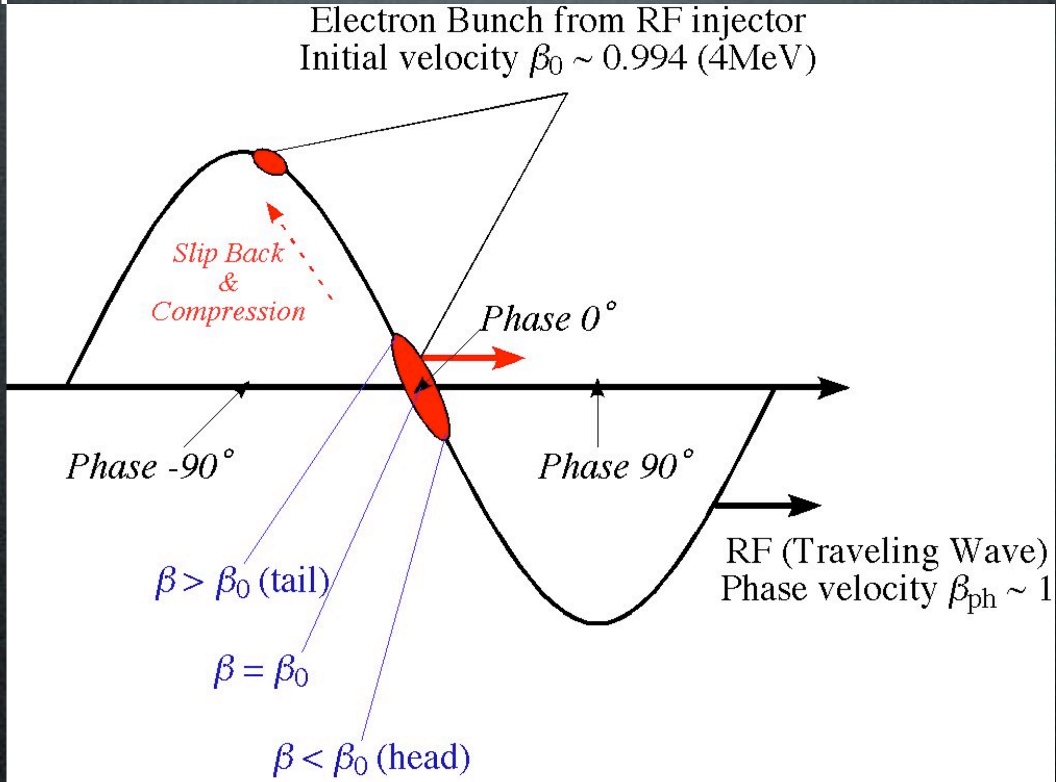


Basic Info: the lifetime of the E_1 state

High Brightness beam experiments: Velocity Bunching

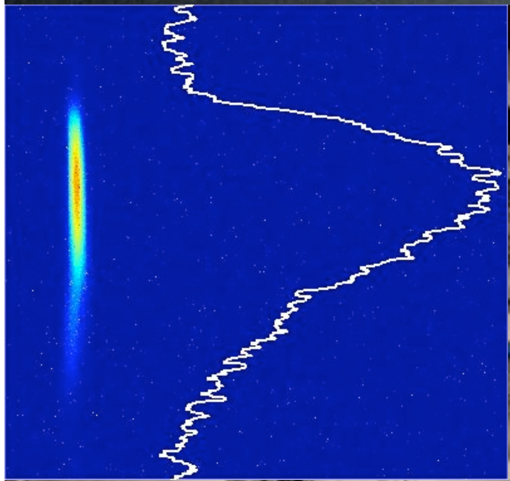
Velocity bunching concept

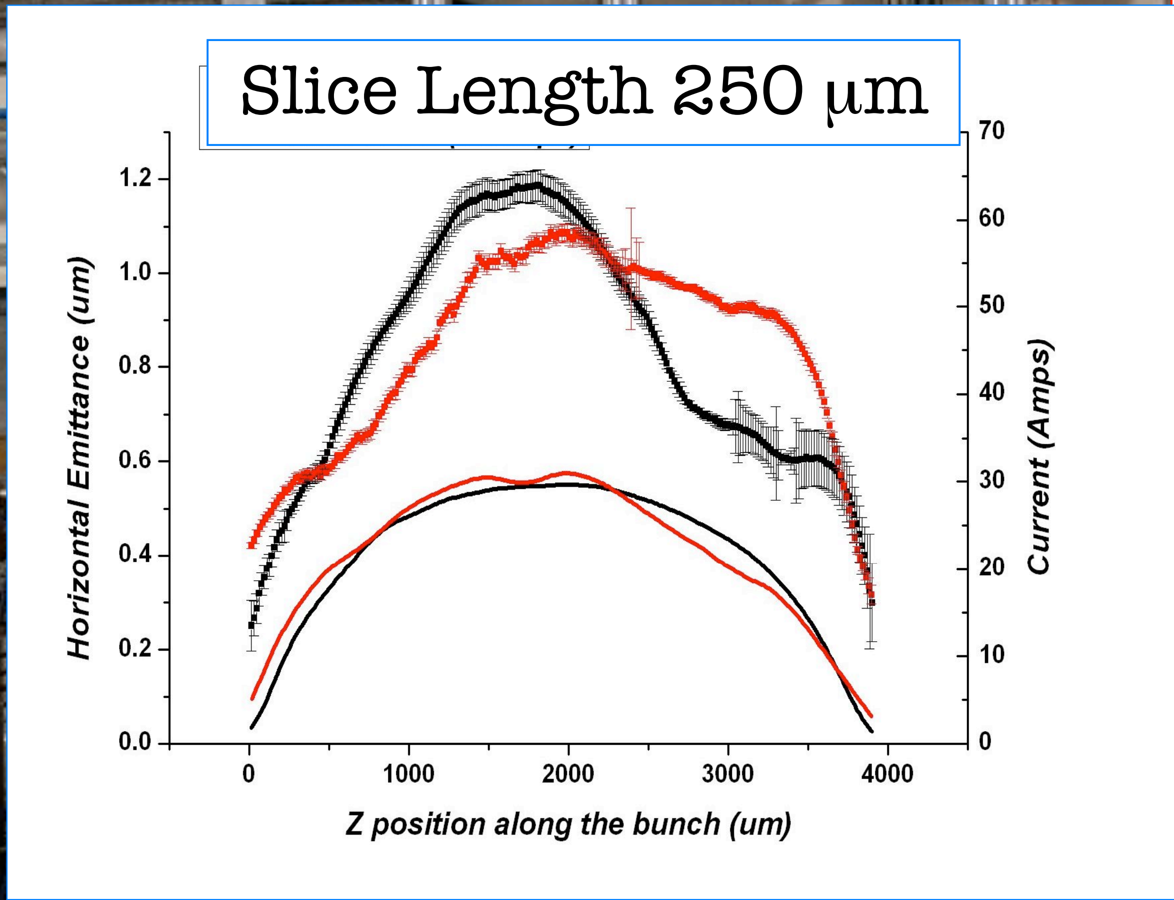
If the beam injected in a long accelerating structure at the crossing field phase and it is slightly slower than the phase velocity of the RF wave , it will slip back to phases where the field is accelerating, but at the same time it will be chirped and compressed.

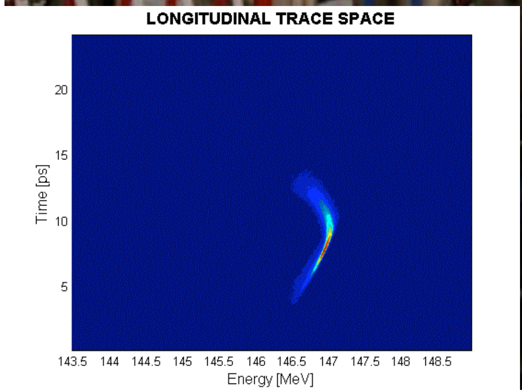


The key point is that compression and acceleration take place at the same time within the same linac section, actually the first section following the gun, that typically accelerates the beam, under these conditions, from a few MeV (> 4) up to 25-35 MeV.

Electron beam parameters at the linac exit







$E = 148\,MeV$

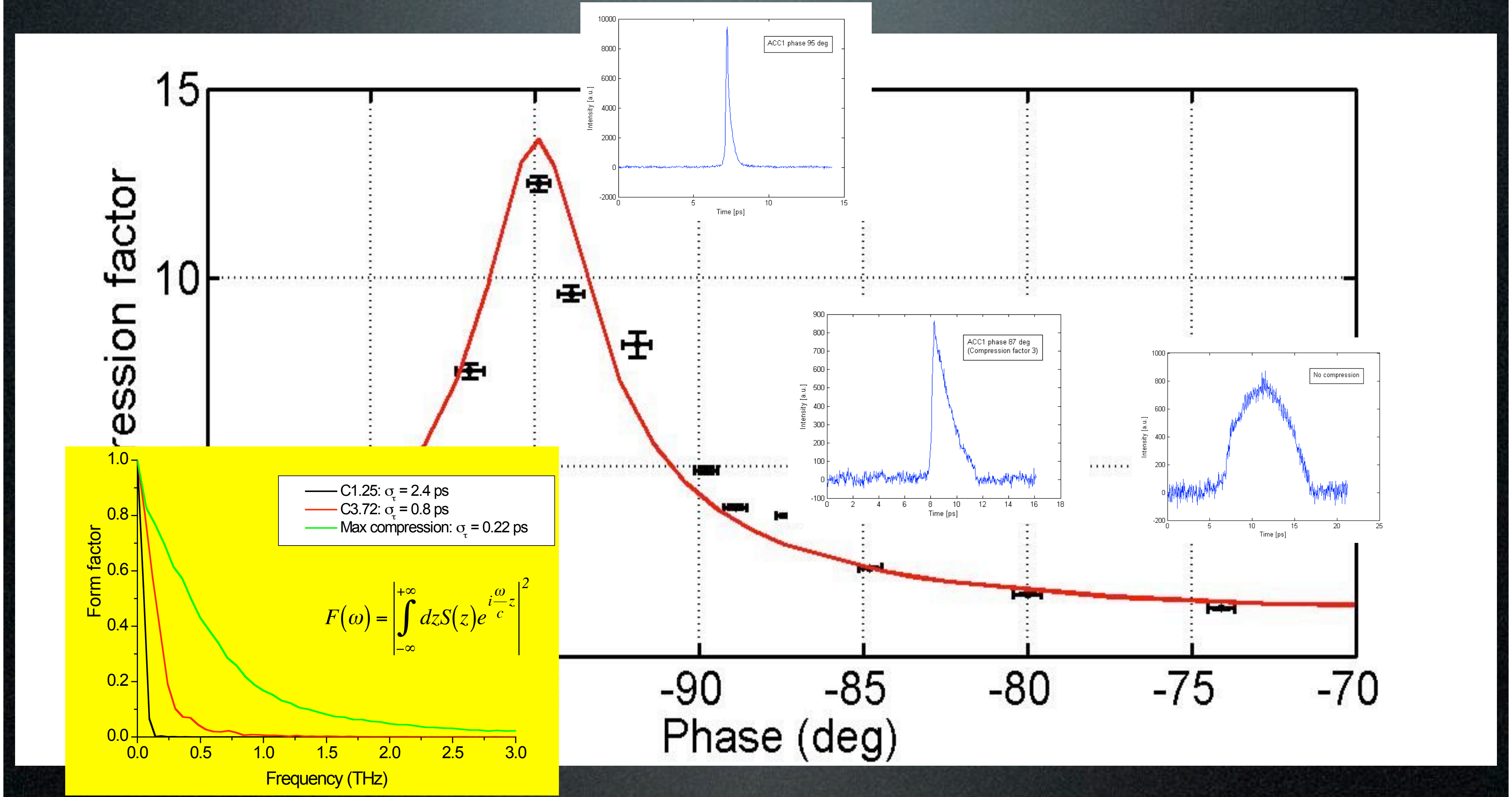
$\sigma_\gamma = 0.1\%$

$Q = 280\,pC$

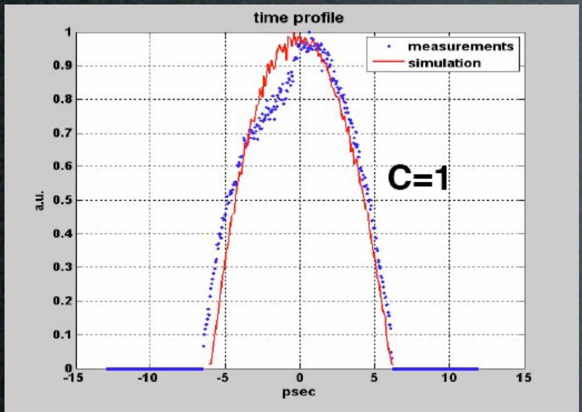
$\sigma_e = 3\,ps$

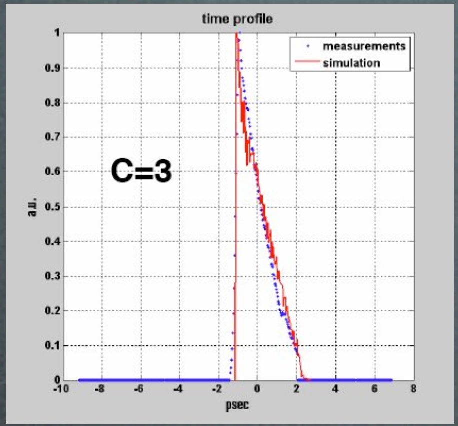
$\varepsilon_n = 1.8\,\mu m$

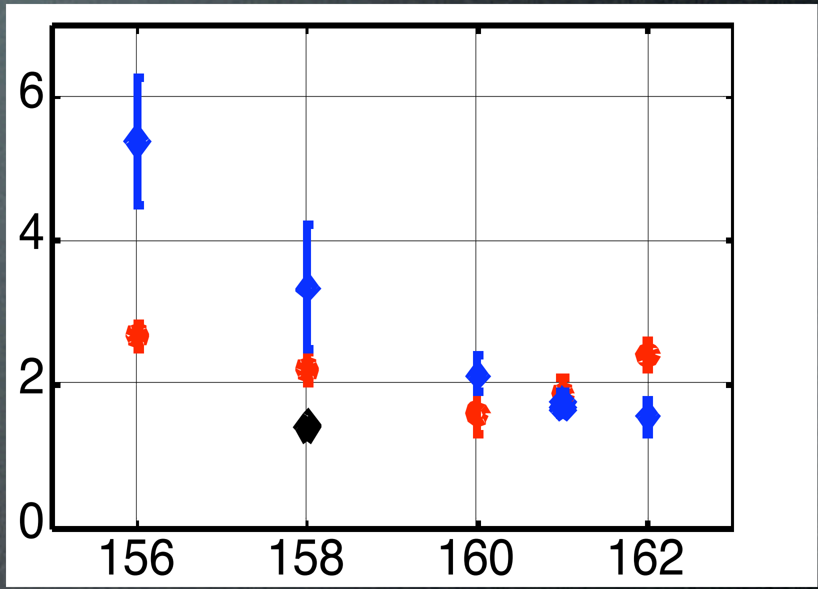
C-factor versus injection phase



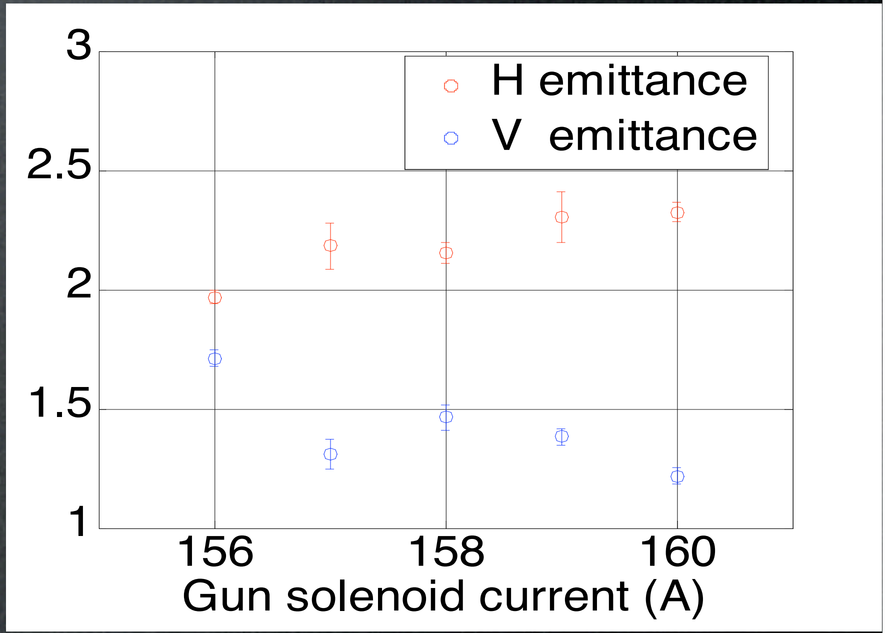
Measurement results with compression 3





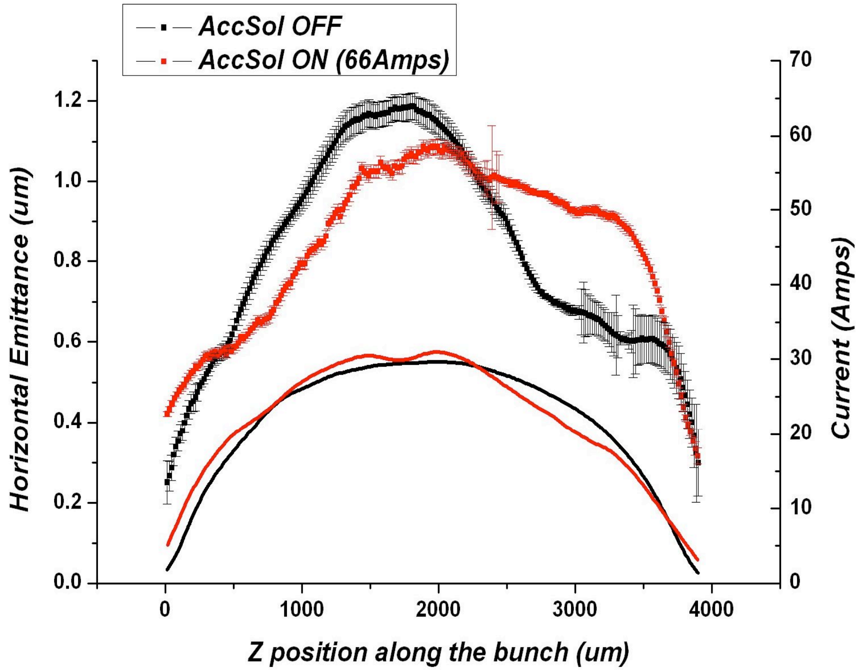


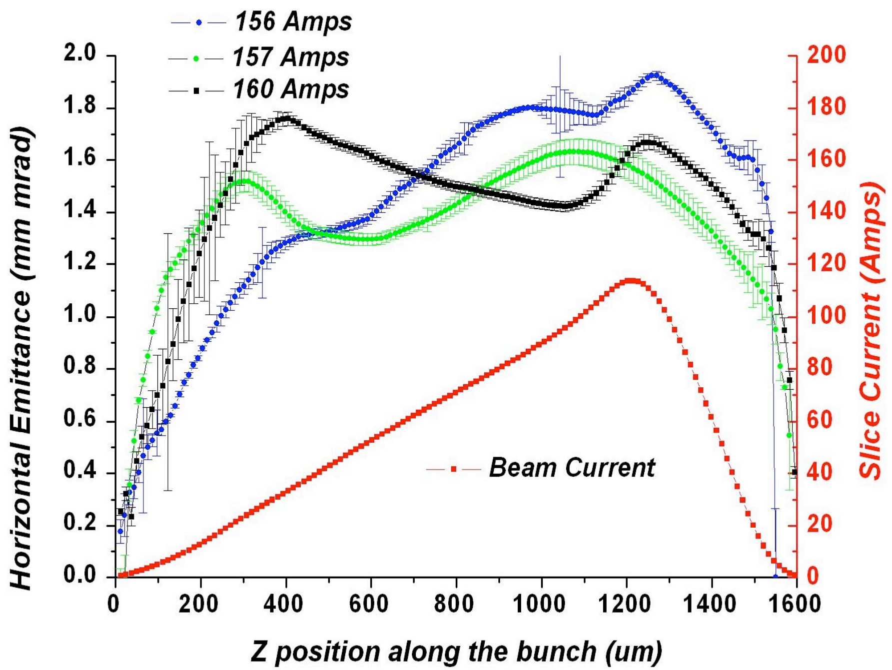
	No Compression	Compression 3
Bunch Charge	280 pC	280 pC
Injection phase	0 deg	-89 deg
Beam Energy	148 MeV	100 MeV
Total energy spread	0.1 %	1.0 %
Rms Bunch Length	3.1 ps	0.97 ps
Norm emittances x-plane	1.85 μm 1.4 μm solenoids off	2.12 μm 6.2 μm solenoids off
Norm emittances y-plane	1.65 μm 1.5 μm solenoids off	1.45 μm 4.0 μm solenoids off
Geometric mean $\sqrt{\varepsilon_{nx}\varepsilon_{ny}}$	1.75 μm	1.75 μm
Solenoid field	450 Gauss 0	450 Gauss 0



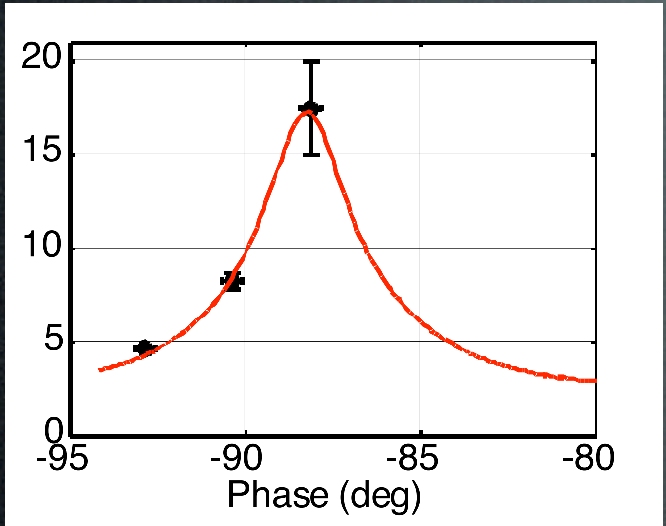
Slice Emittance

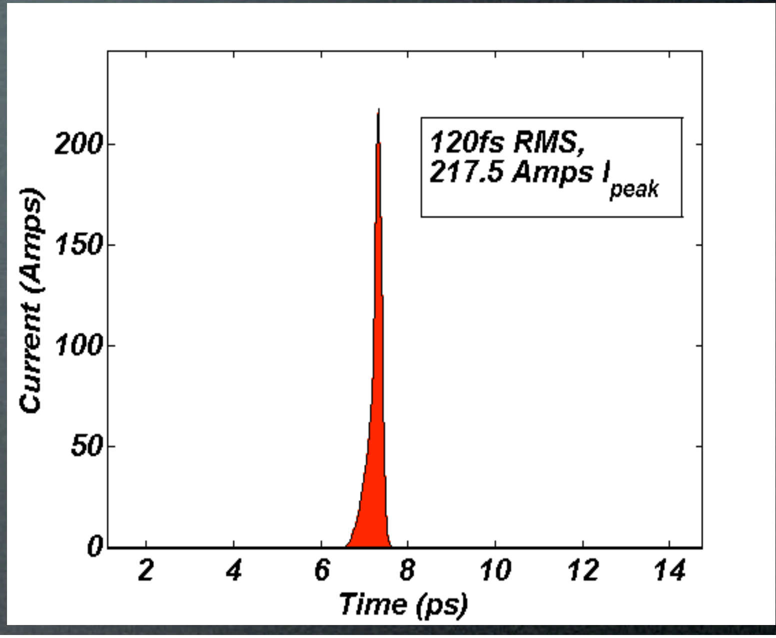
No Compression ------ Compression



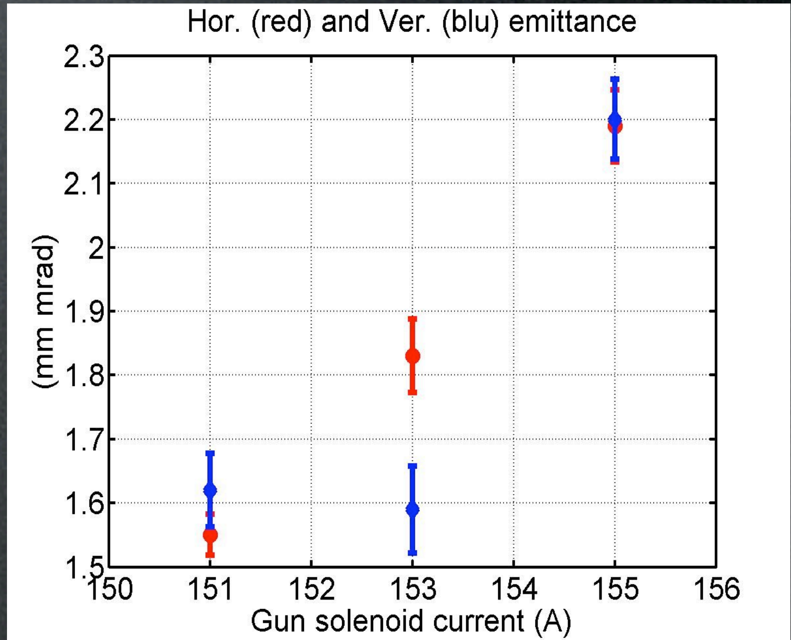


Low charge - extreme compression 17





	No Compression	Compression 17
Bunch Charge	60 pC	60 pC
Injection phase	0 deg	-88 deg
Beam Energy	148 MeV	98 MeV
Total energy spread	0.1 %	1.0 %
Rms Bunch Length	1.95 ps	0.12 ps
Norm emittances x-plane	0.55 µm solenoids off	1.52 µm 4.1 µm solenoids off
Norm emittances y-plane	0.56 µm solenoids off	1.62 µm 3.4 µm solenoids off
Solenoid field	0	450 Gauss 0



Laser Comb

Laser Comb: a train of THz bunches

M. Boscolo et al. / Nuclear Instruments and Methods in Physics Research A 593 (2008) 106–110 107

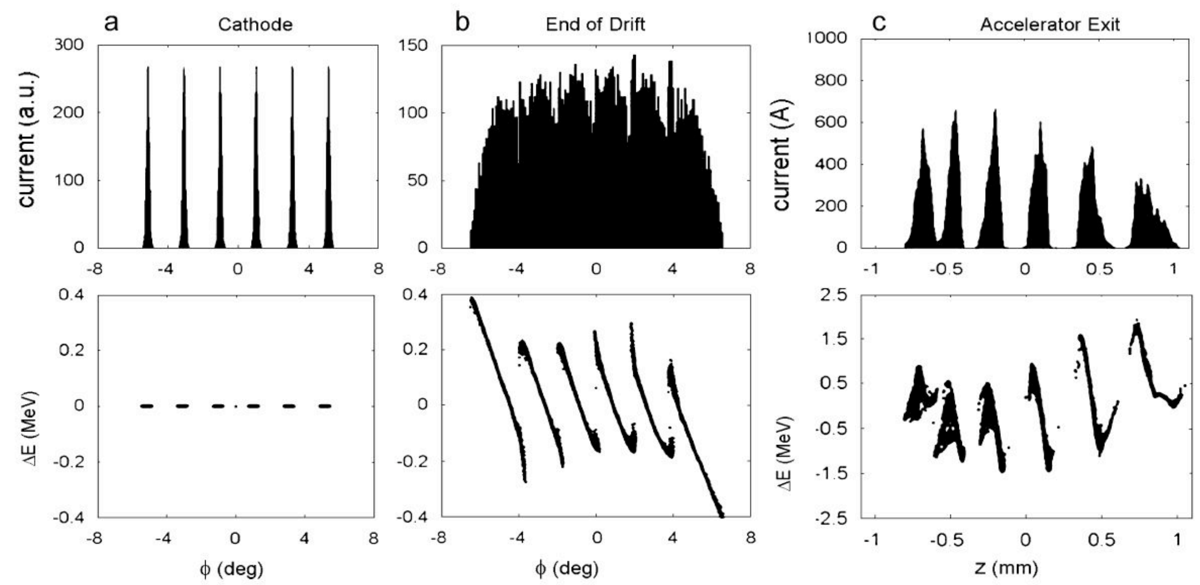
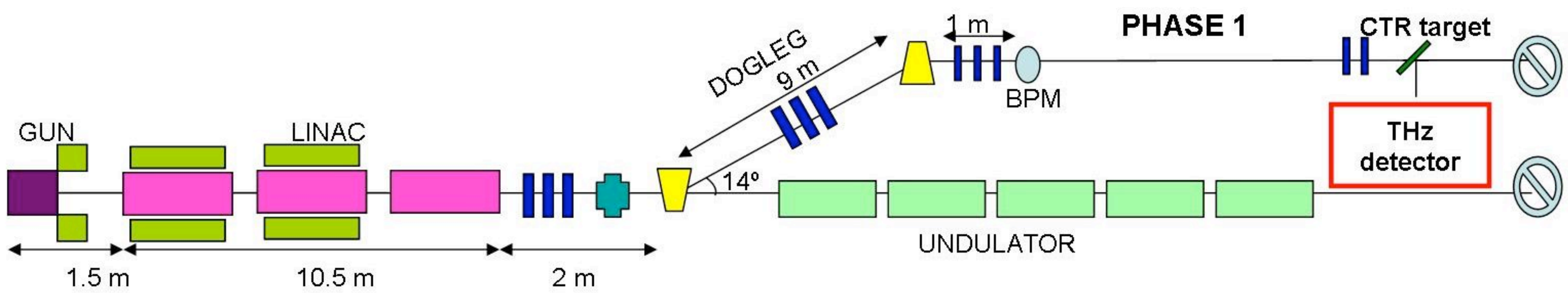
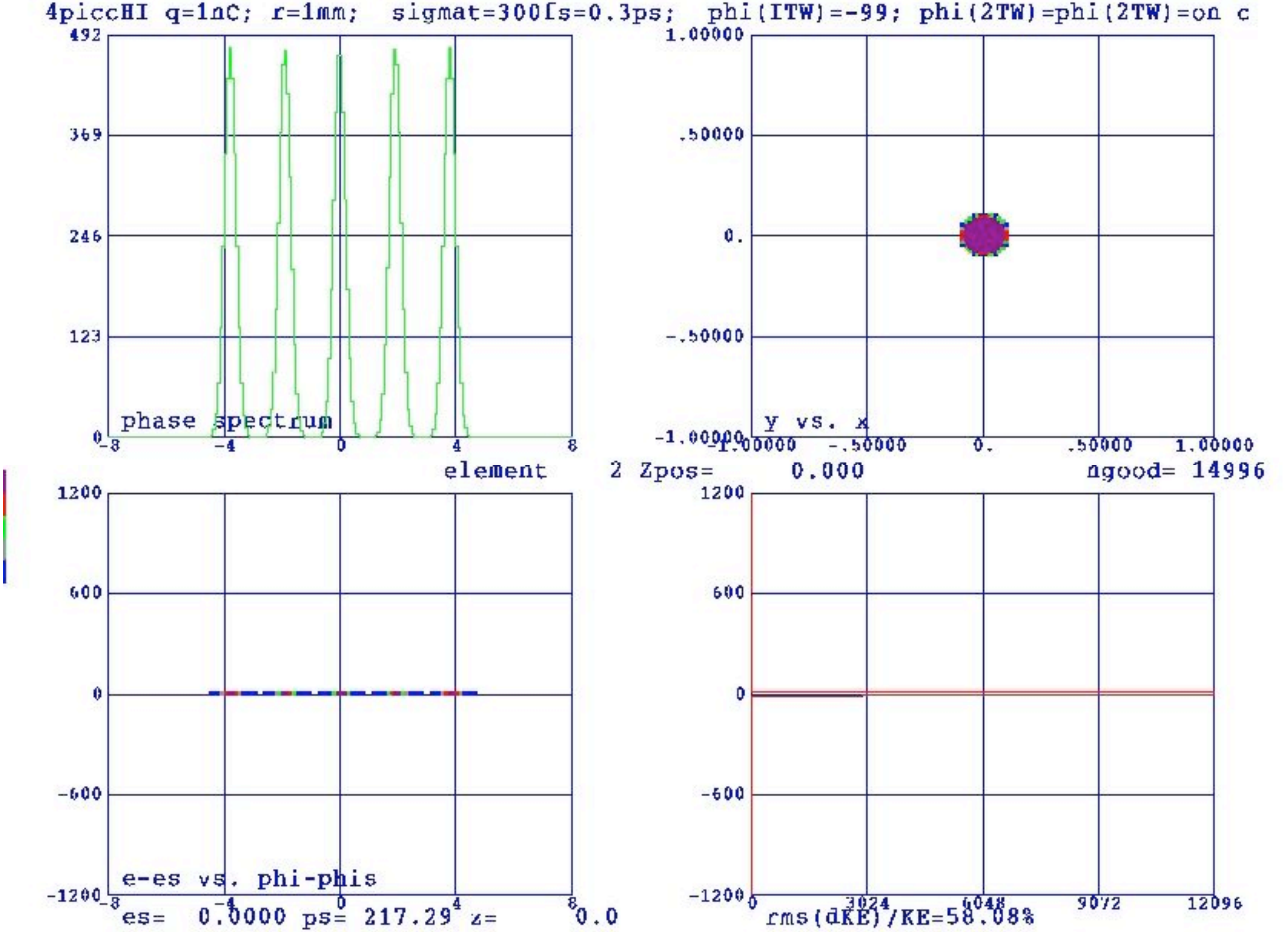
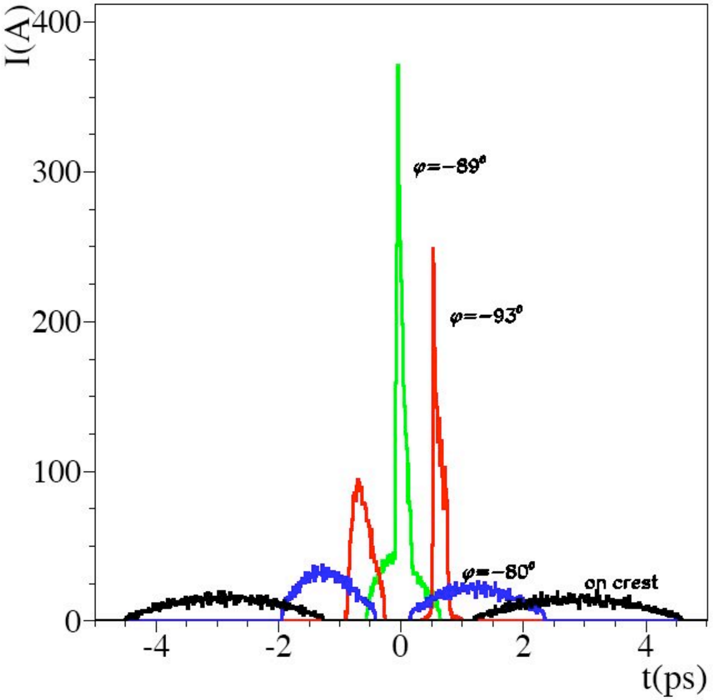


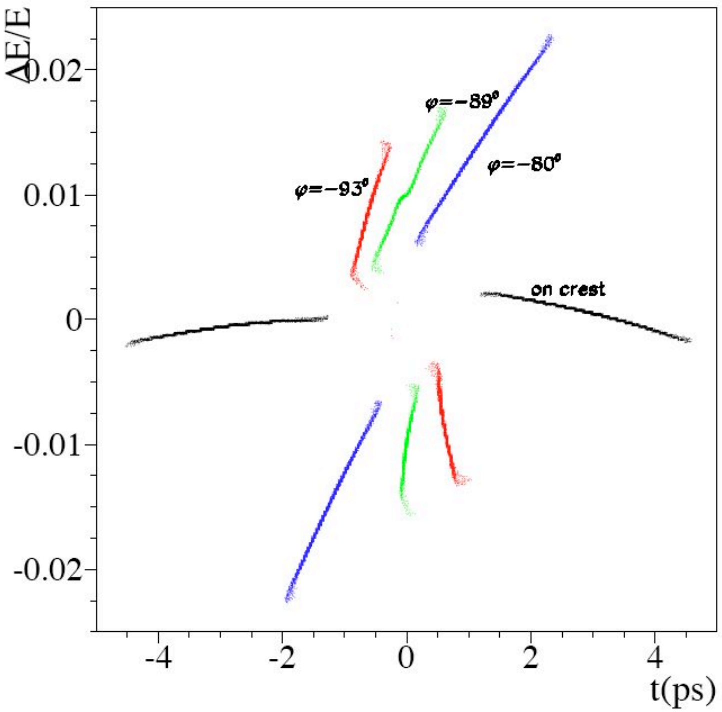
Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation ΔE (MeV).

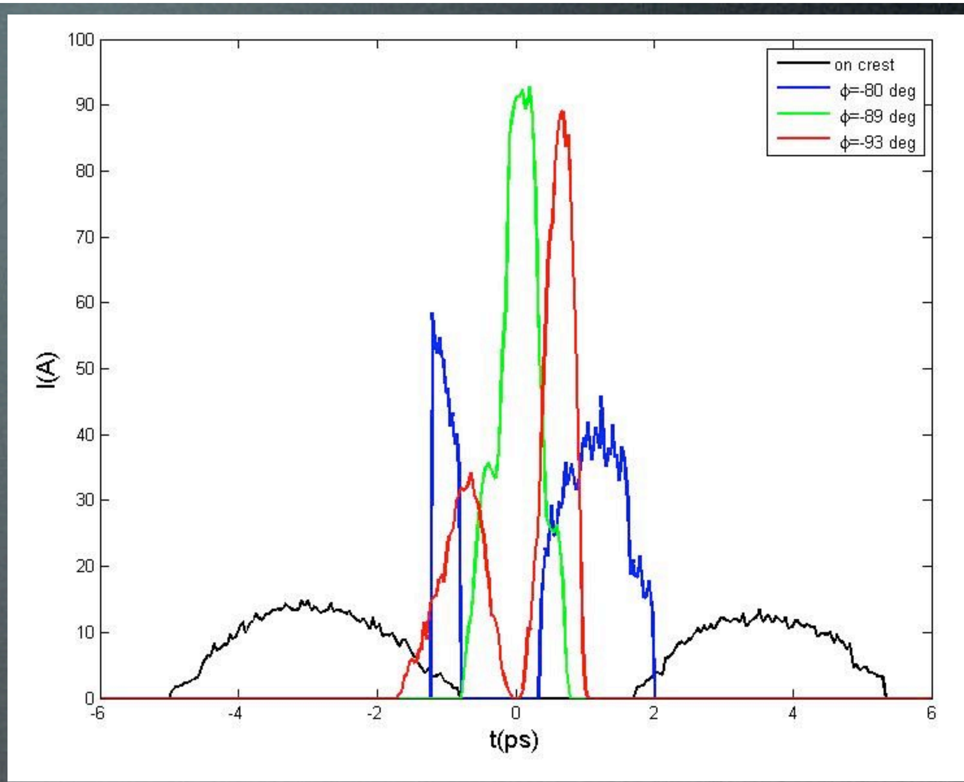


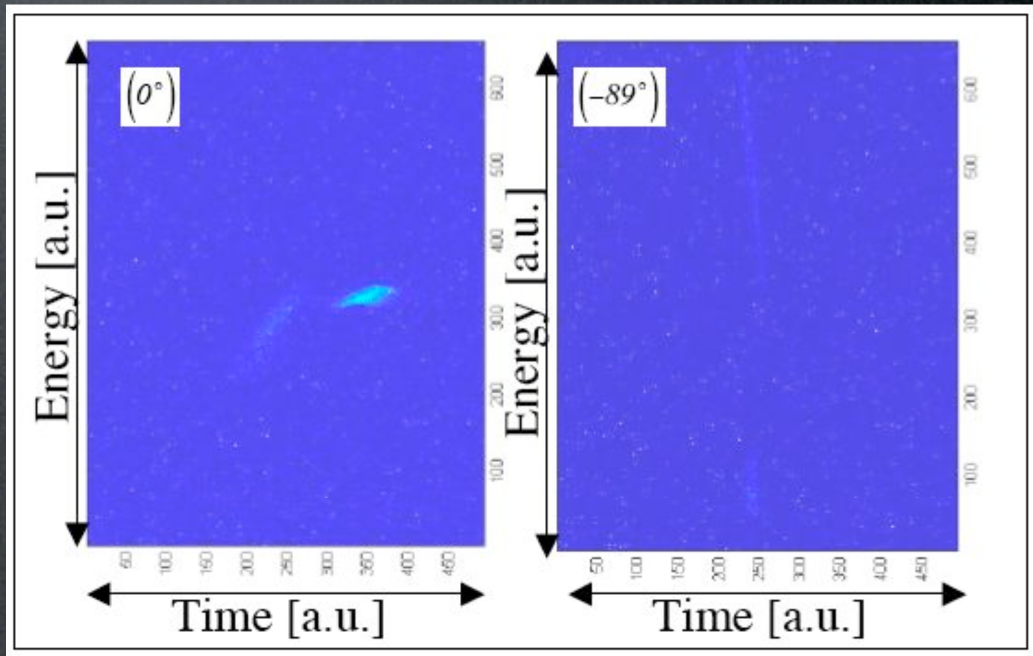
- P.O.Shea et al., Proc. of 2001 IEEE PAC, Chicago, USA (2001) p.704.
- M. Ferrario. M. Boscolo et al., Int. J. of Mod. Phys. B, 2006 (Taipei 05 Workshop)


4piccHI q=1nC; r=1mm; sigmat=300fs=0.3ps; phi(1TW)=-99; phi(2TW)=phi(2TW)=on c
phase spectrum
y vs. x
element 2 Zpos= 0.000
ngood= 14996
e-es vs. phi-phis
es= 0.0000 ps= 217.29 z= 0.0
rms(dKE)/KE=58.08%


I(A)
t(ps)
φ=−89°
φ=−93°
φ=−80°
on crest

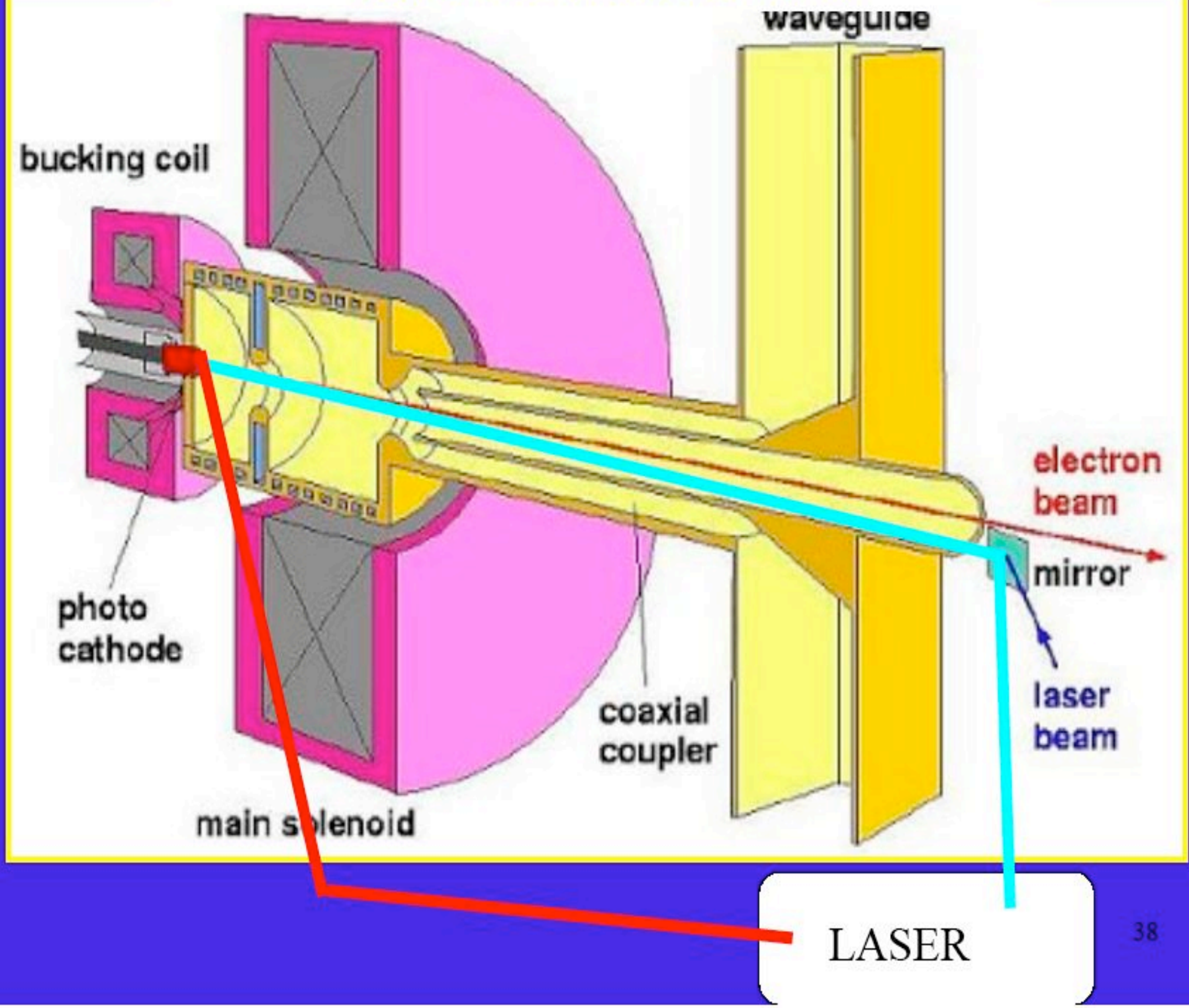

ΔE/E
t(ps)
φ=−89°
φ=−93°
φ=−80°
on crest

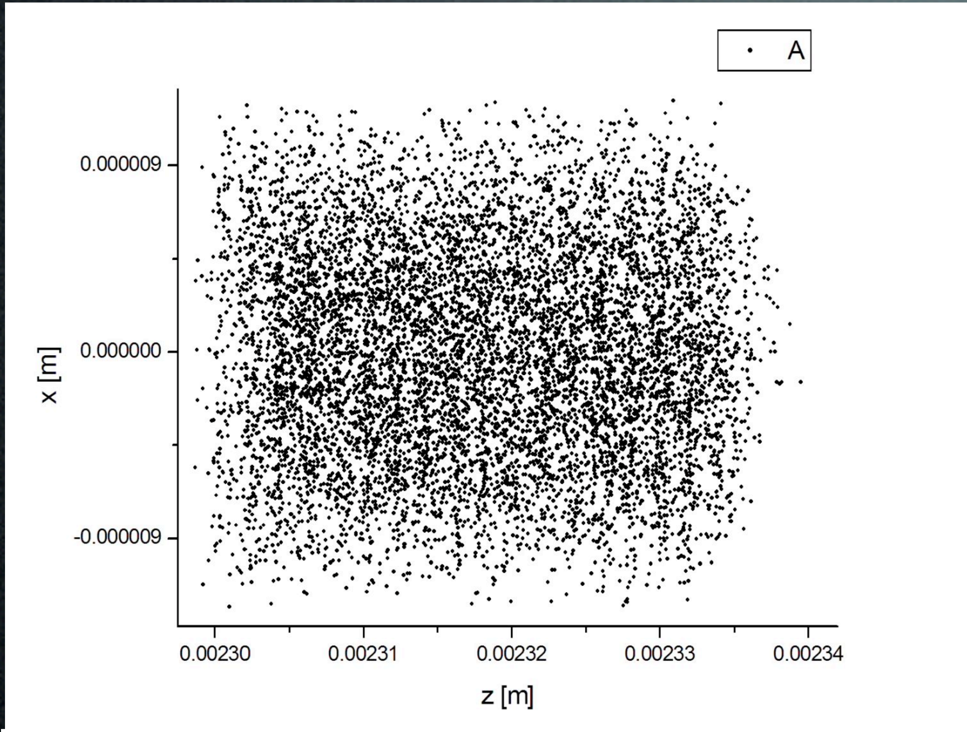

I(A)
t(ps)
on crest
φ=-80 deg
φ=-89 deg
φ=-93 deg

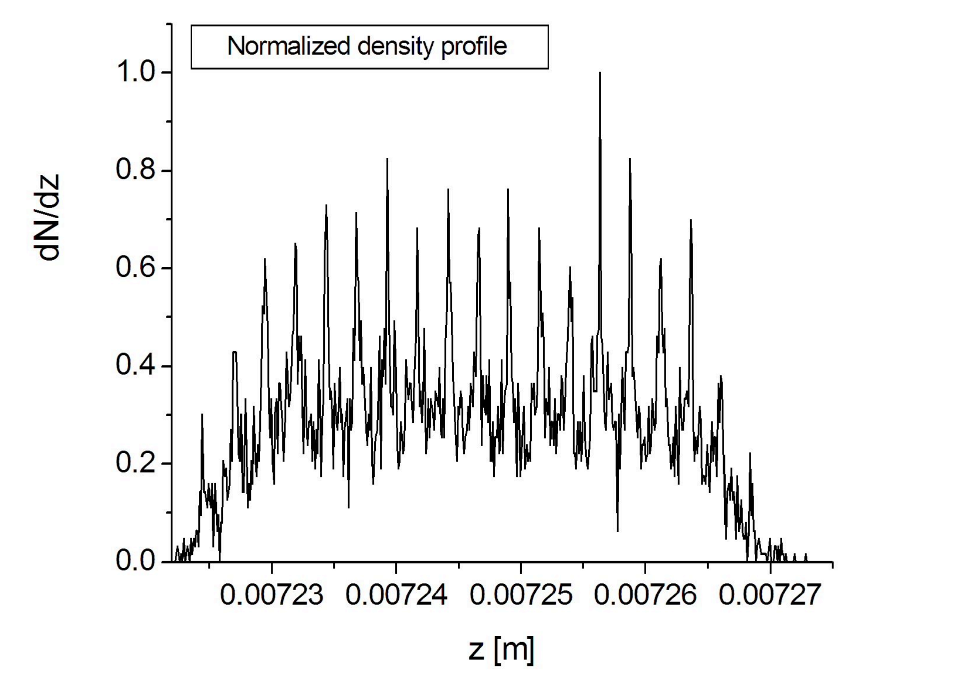

(0°)
(−89°)
Energy [a.u.]
Energy [a.u.]
Time [a.u.]
Time [a.u.]

IR laser beam induced modulation

LASER CONDITIONING





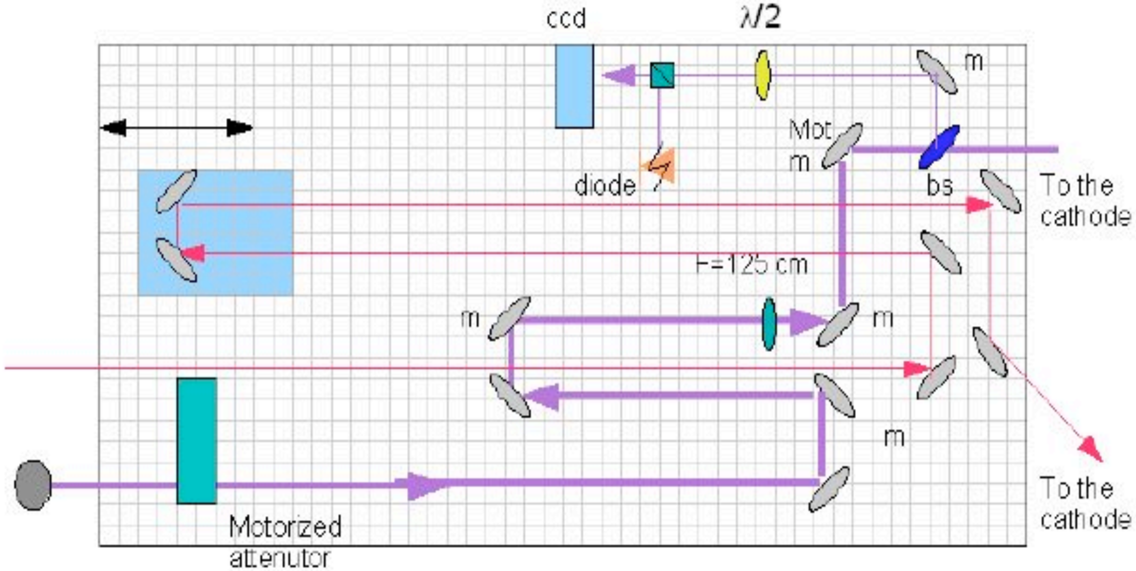


A. Bacci - RETAR

Laser IR 0.8 micron
E0 = 500 MV/m @ 72 Deg
Bunch radius = 5 micron
Laser pulse length = 2 ps
Injection phase= 29.1 Deg

Gun table

IR optical transfer line



m = hr mirror 45 deg 266 nm

bs = thin beam splitter


@!!&^%$
$$#???@
GRRRR
PAUL SCHERRER INSTITUT
PSI

SPARC next runs

- Seeding
- Velocity Bunching => SASE Single Spike
- THz radiation
- Laser Comb
- Laser IR beam induced modulation

Thank you