ELAN

1st Workshop of ELAN

INFN-LNF, Frascati, 4-6 May 2004

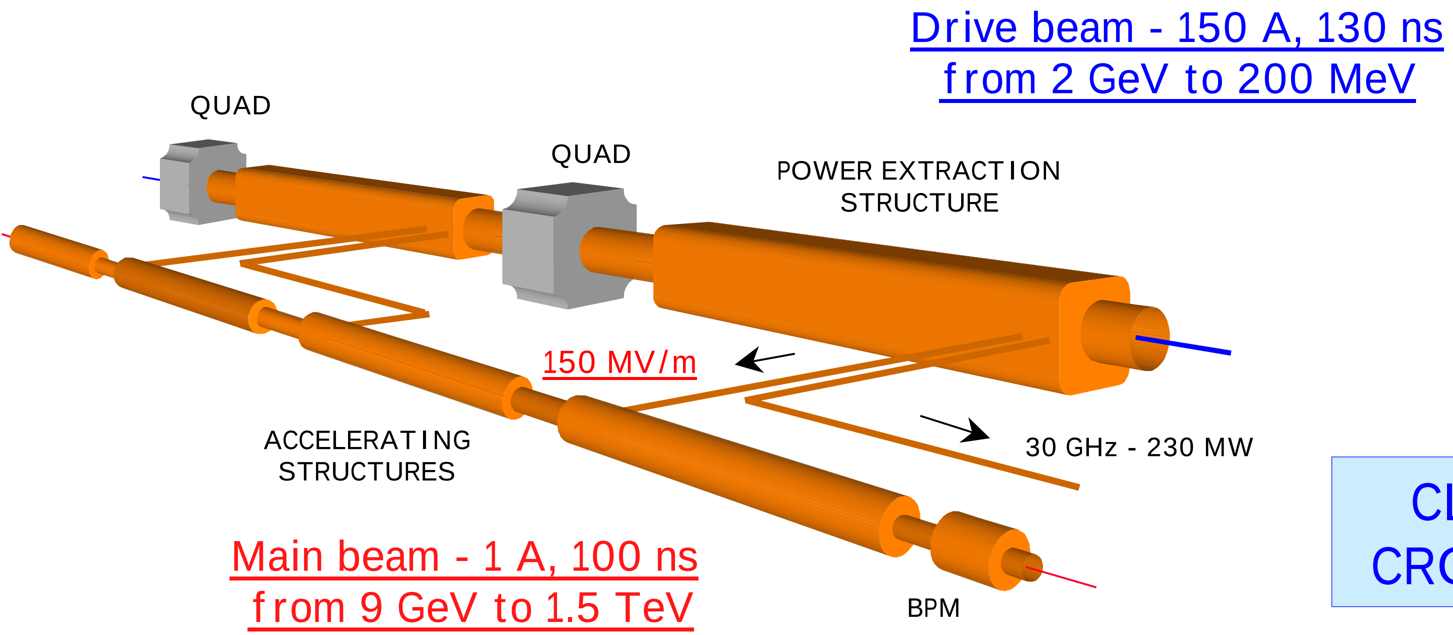
Operating experience on CTF3

R. Corsini

OUTLINE

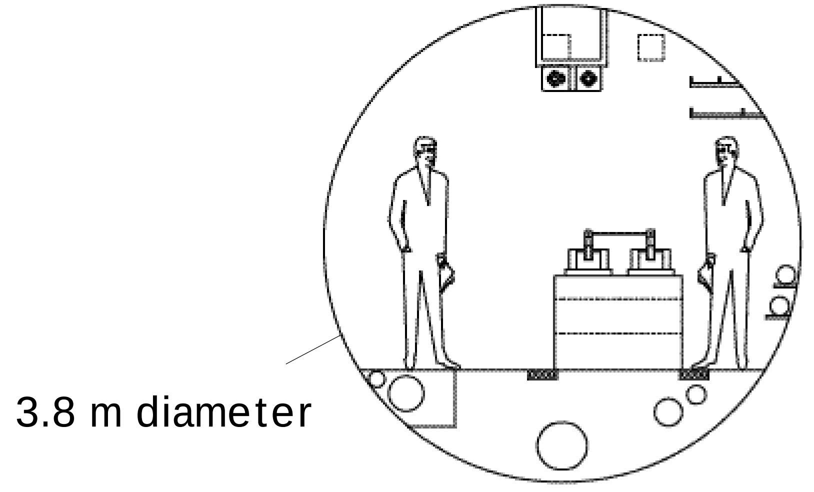
- CTF3: why, how & when
- The preliminary phase: description and results
- CTF3 injector and linac: commissioning experience

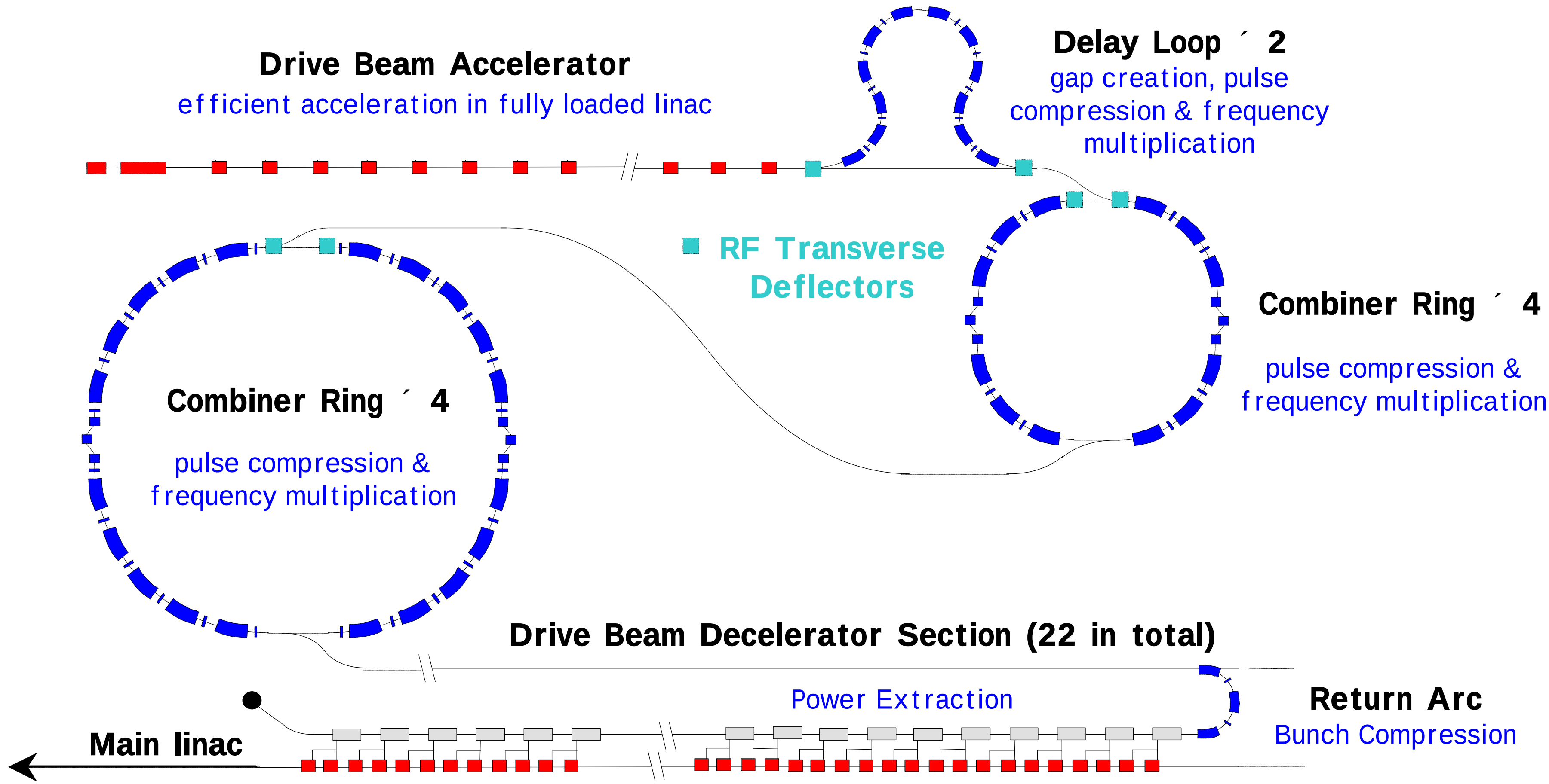
CLIC TWO-BEAM SCHEME



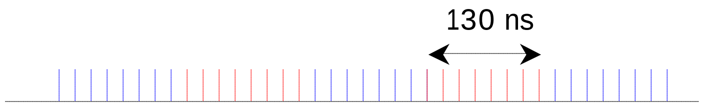
CLIC MODULE

CLIC TUNNEL CROSS-SECTION



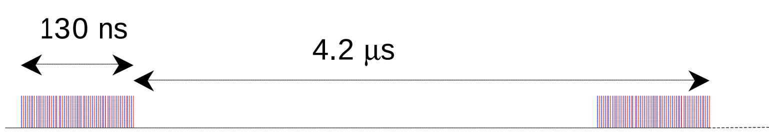


Drive beam time structure - initial



100 µs train length - 32 × 22 sub-pulses - 7.5 A
1.2 GeV - 64 cm between bunches

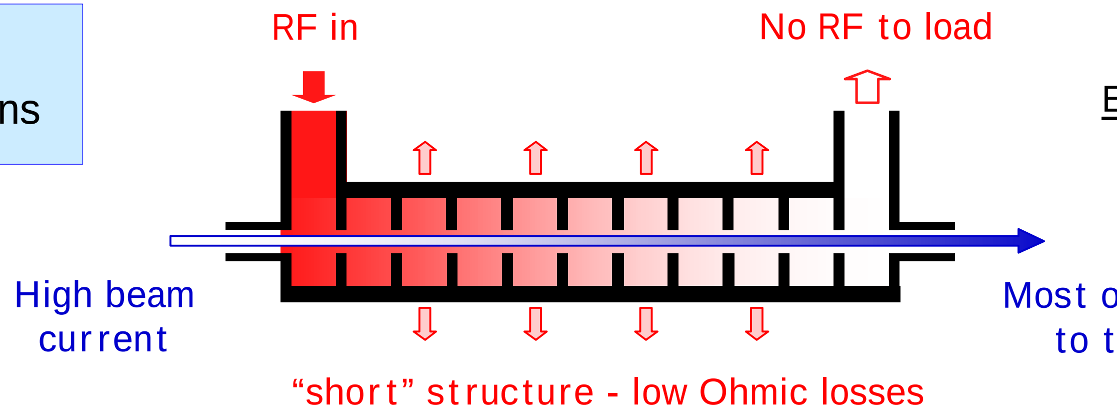
Drive beam time structure - final



22 pulses - 240 A - 2 cm between bunches

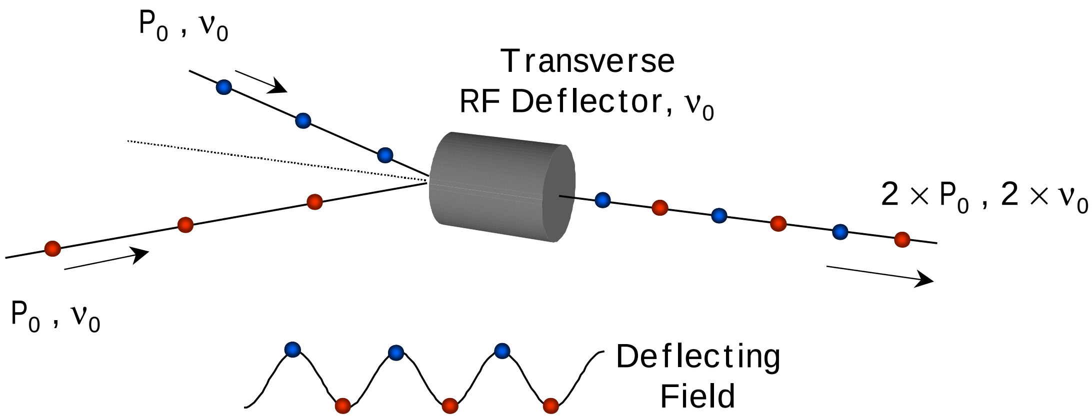
RF POWER SOURCE "BUILDING BLOCKS"

Full beam-loading acceleration in TW sections



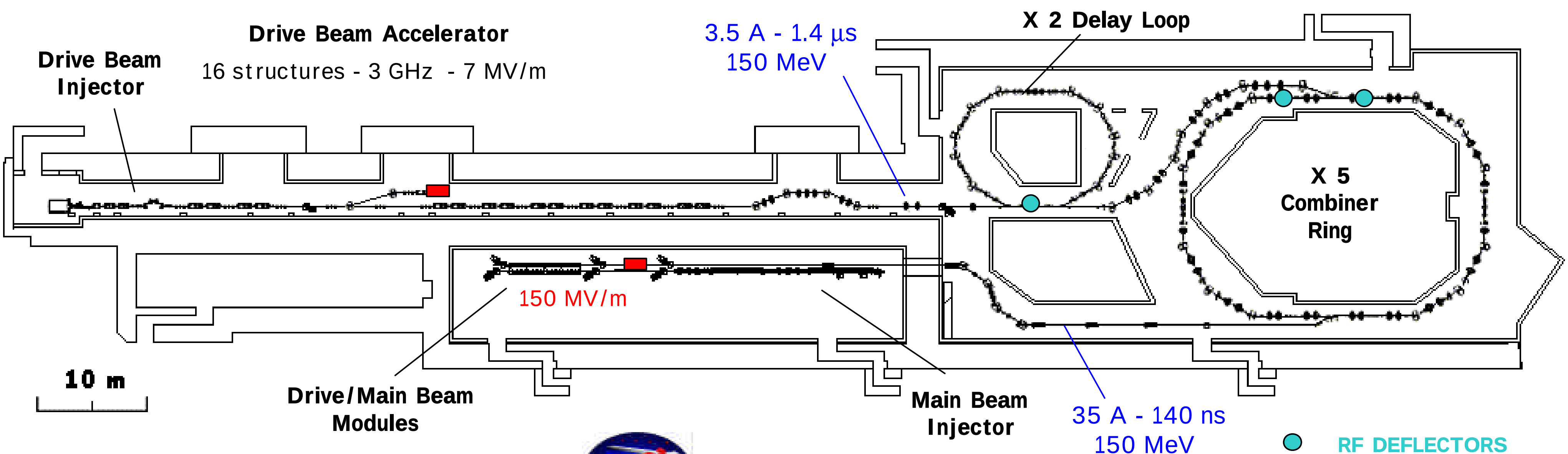
Efficiency > 95 %

Beam combination/separation by transverse RF deflectors



CTF3 NOMINAL PHASE

- Build a small-scale version of the CLIC RF power source, in order to demonstrate:
  - fully-loaded accelerator operation
  - electron beam pulse compression and frequency multiplication using RF deflectors
- Provide the 30 GHz RF power to test the CLIC accelerating structures and components at the nominal gradient and pulse length (150 MV/m for 130 ns) .

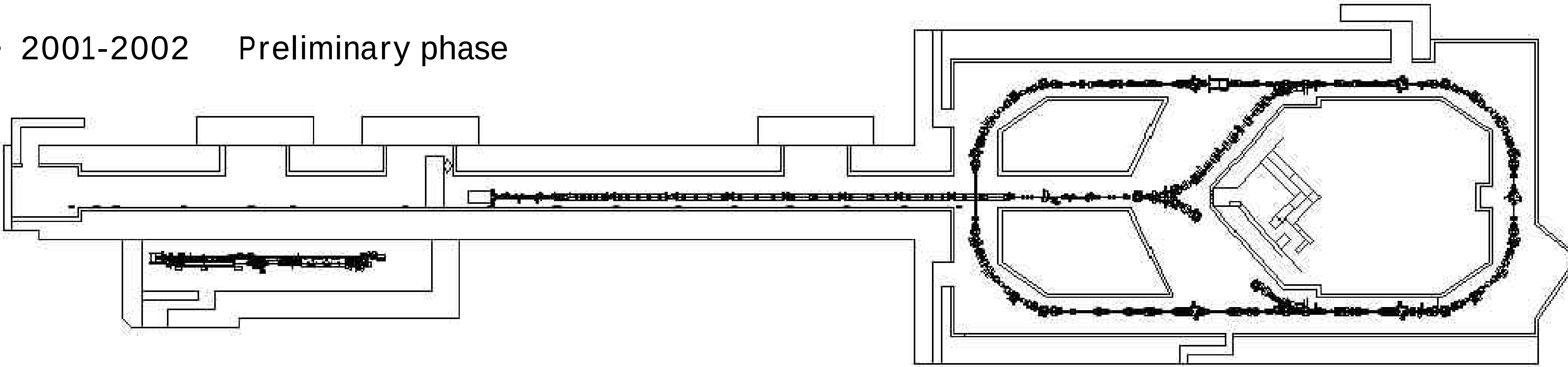


CTF3 COLLABORATION

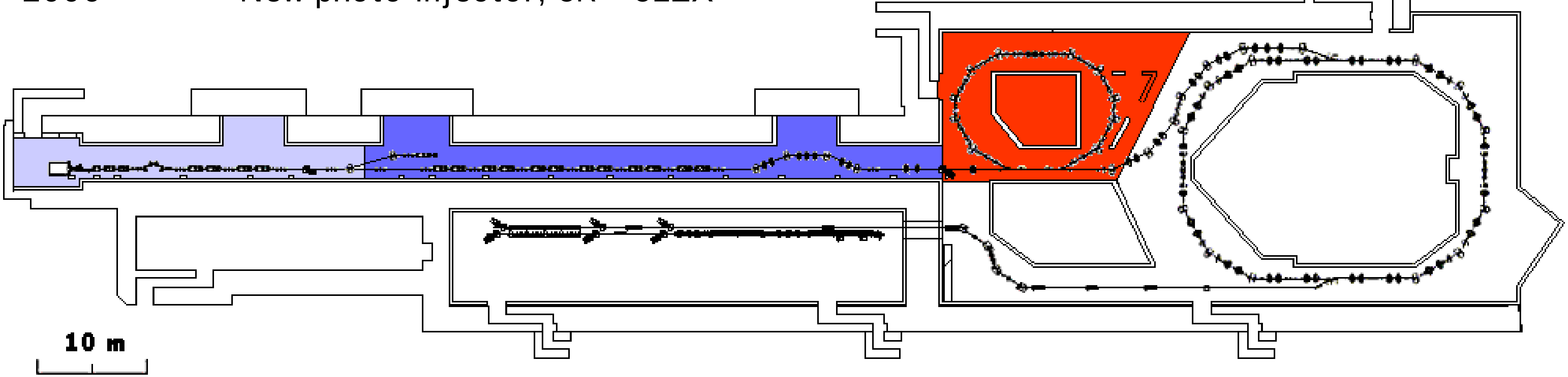
CERN, Geneva (Switzerland)	Northwestern University, (USA)
INFN , Frascati (Italy)	SLAC , San Francisco (USA)
LAL , Orsay (France)	Uppsala University , (Sweden)

CTF3 STAGES

- 2001-2002 Preliminary phase

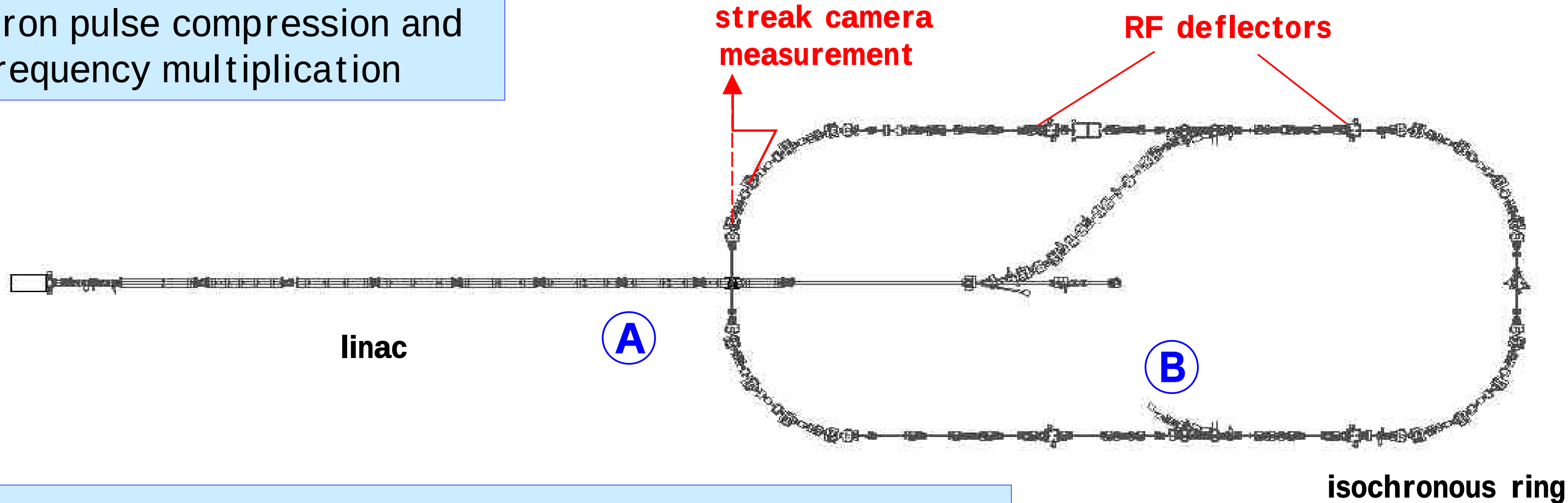


- 2003 Injector + part of linac
- 2004 Linac + 30 GHz high-power test stand
- 2005 Delay Loop + SHB
- 2006 + New photo-injector, CR + CLEX

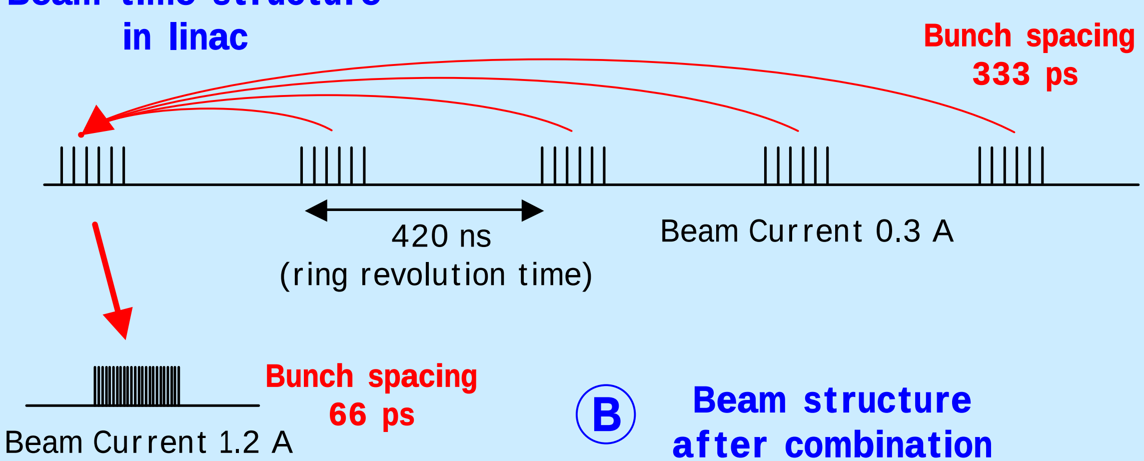


R. Corsini, A. Ferrari, L. Rinolfi, P. Royer, and F. Tecker, "Experimental results on electron beam combination and bunch frequency multiplication", Phys. Rev. ST Accel. Beams 7, 040101 (2004).

low-charge demonstration of the electron pulse compression and frequency multiplication



A Beam time structure in linac



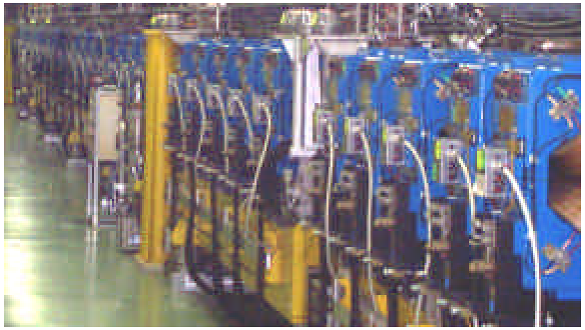
B Beam structure after combination

Beam parameters

Bunch charge	0.1 nC
Beam energy	350 MeV
$\gamma\varepsilon_{X,Y}$	25 π mm mrad
σ_t	< 7 ps
σ_E	~ 0.5 %

THE CTF3 PRELIMINARY PHASE (2001-2002)

Modifications to the LEP pre-injector complex

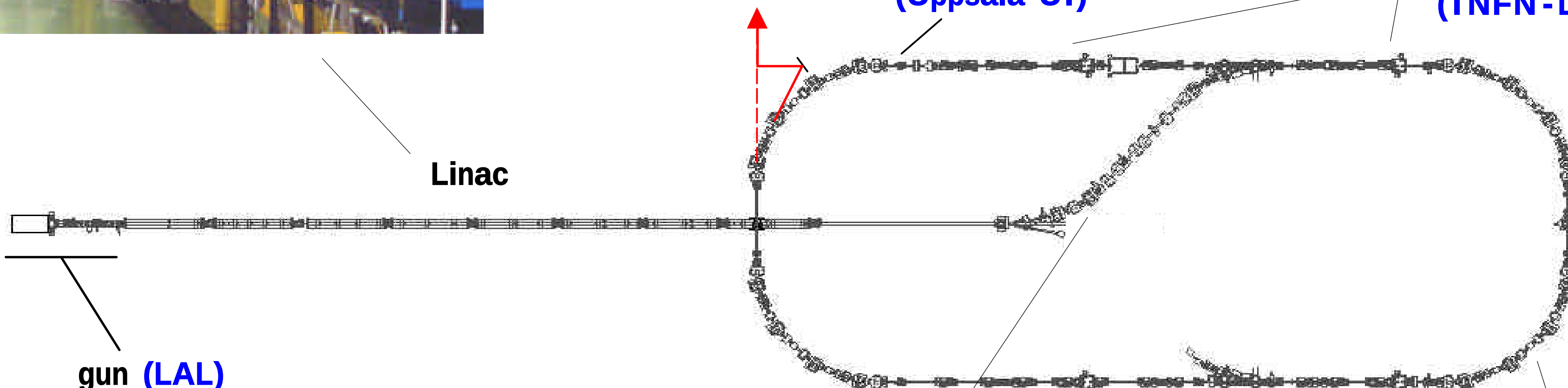


streak camera measurement

phase monitor (Uppsala U.)

RF deflectors (INFN-LNF)

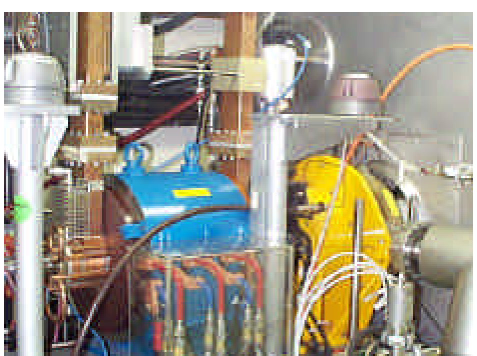
Linac

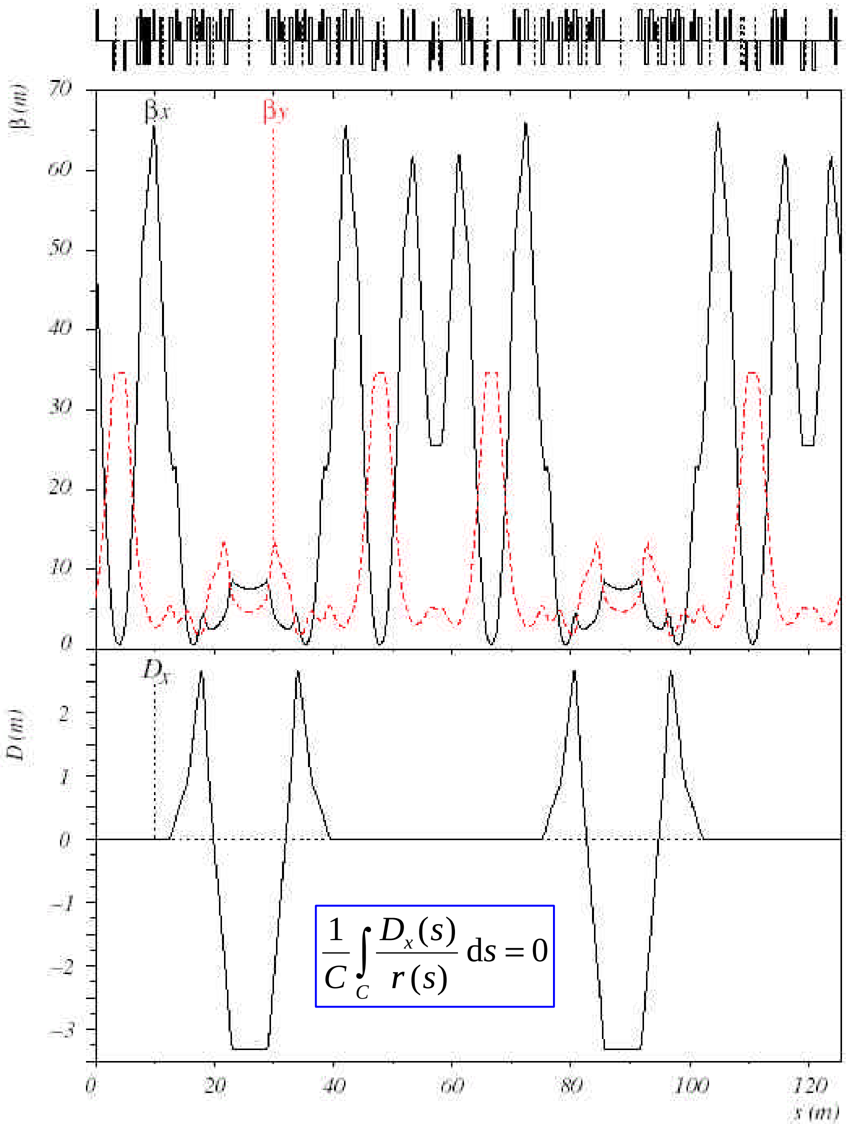


gun (LAL) & bunching system

isochronous injection line

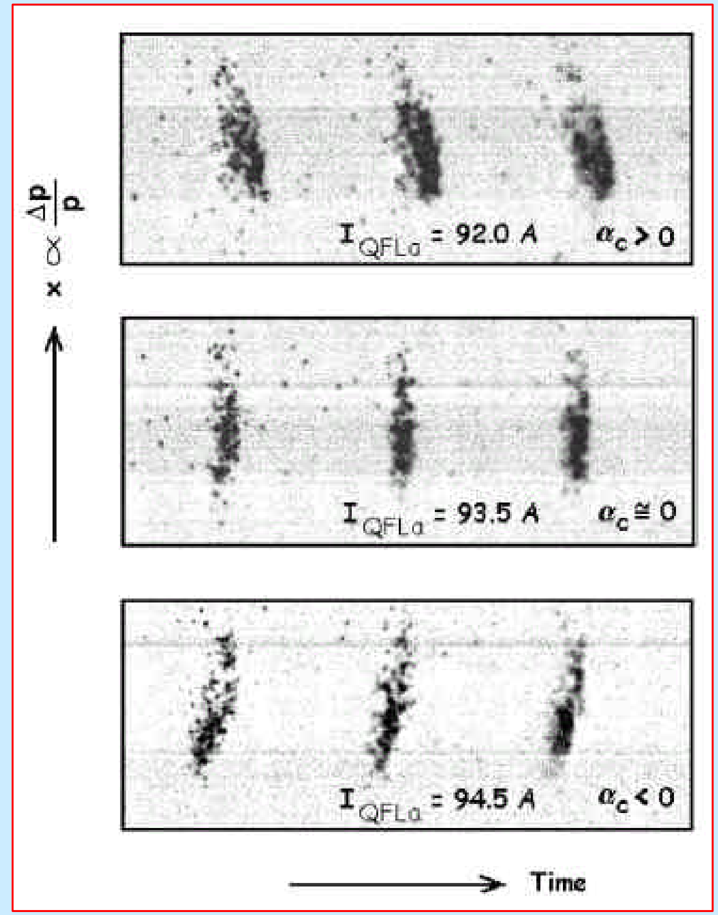
isochronous arcs





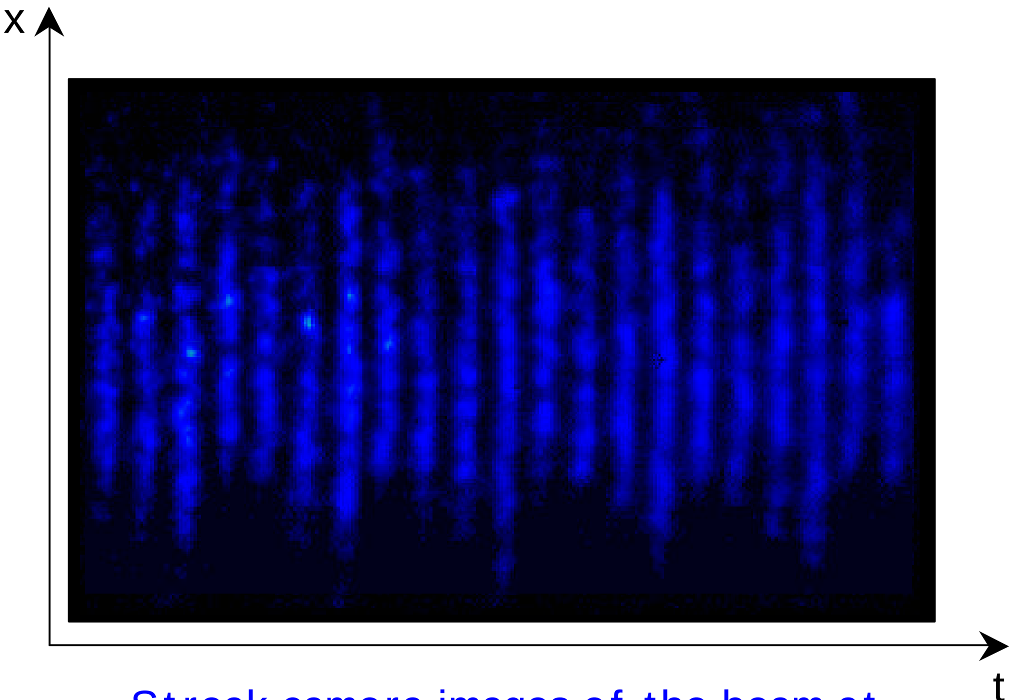
Design optics of the isochronous ring

Transition from **positive to negative** momentum compaction a_C seen on streak camera images for different settings of one quad family.



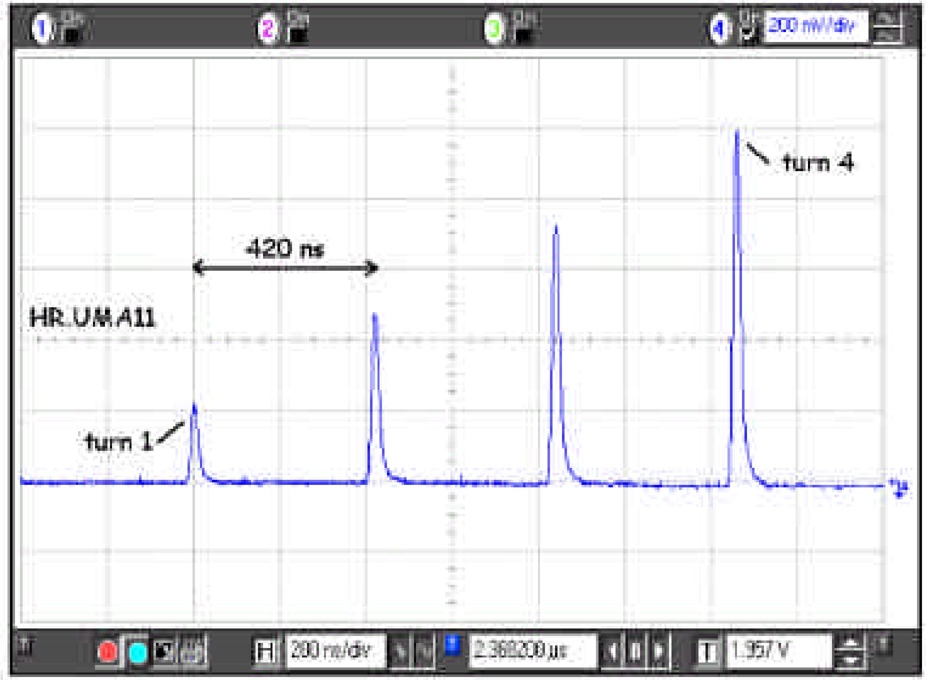
Images taken during the tenth turn at a location with nonzero dispersion. The horizontal position x is dependent on momentum, so the time-momentum correlation becomes apparent.

Combination factor 4



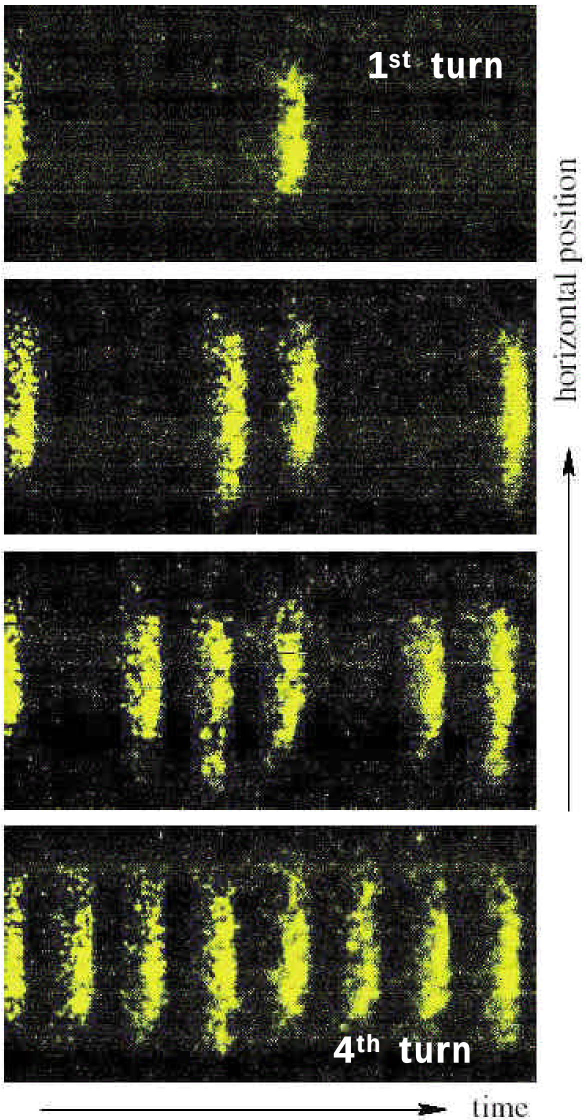
Streak camera images of the beam at different turns, illustrating the bunch combination process

(260 mm/ps scale)

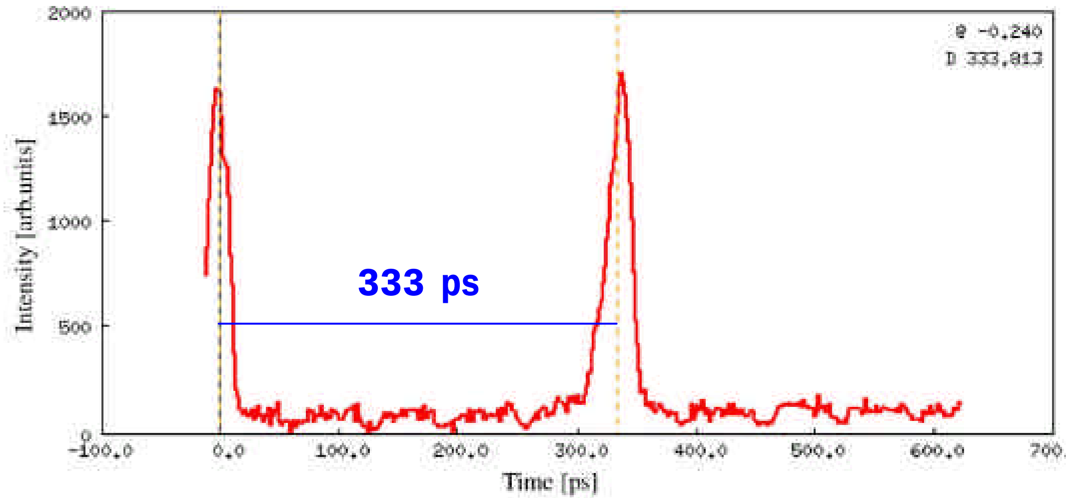


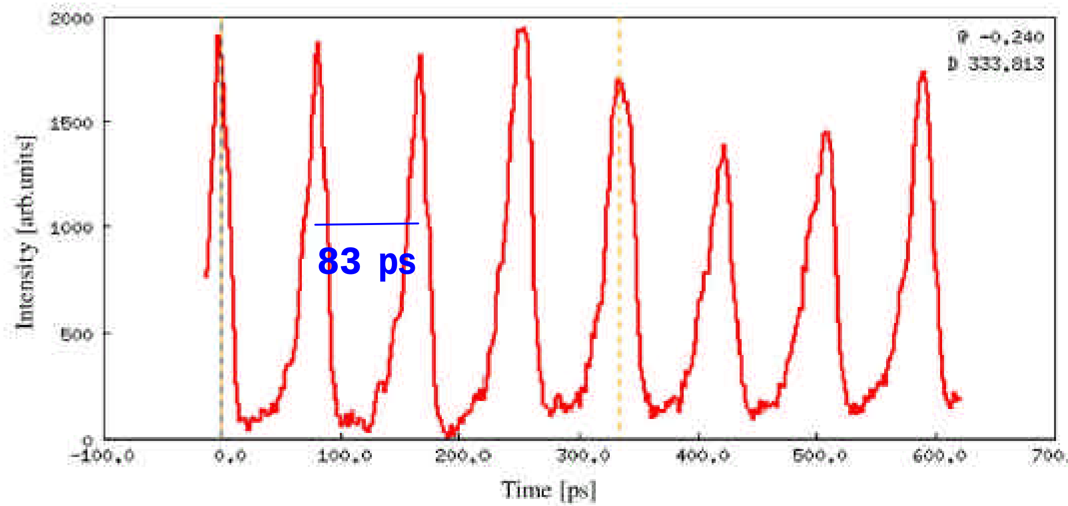
Beam current circulating in the ring measured during combination with a beam current monitor

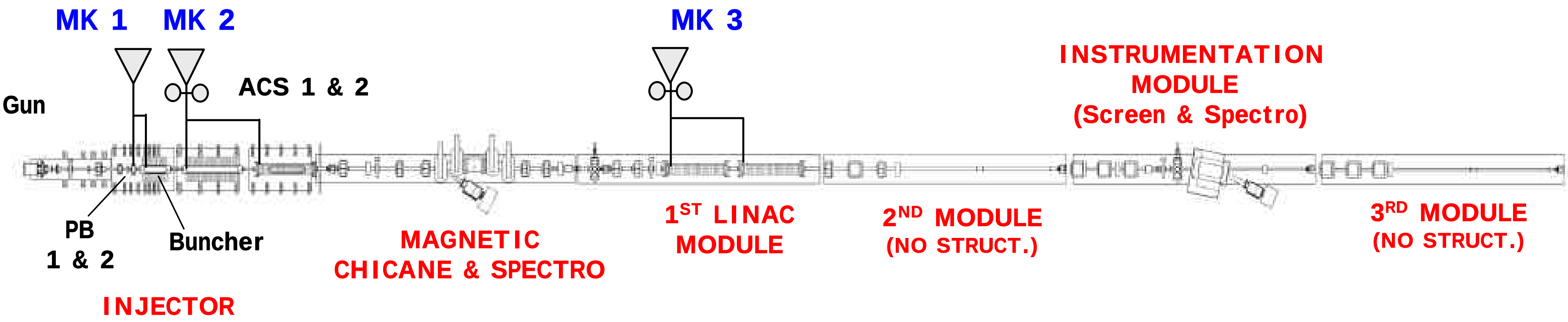
Streak camera image of beam time structure evolution

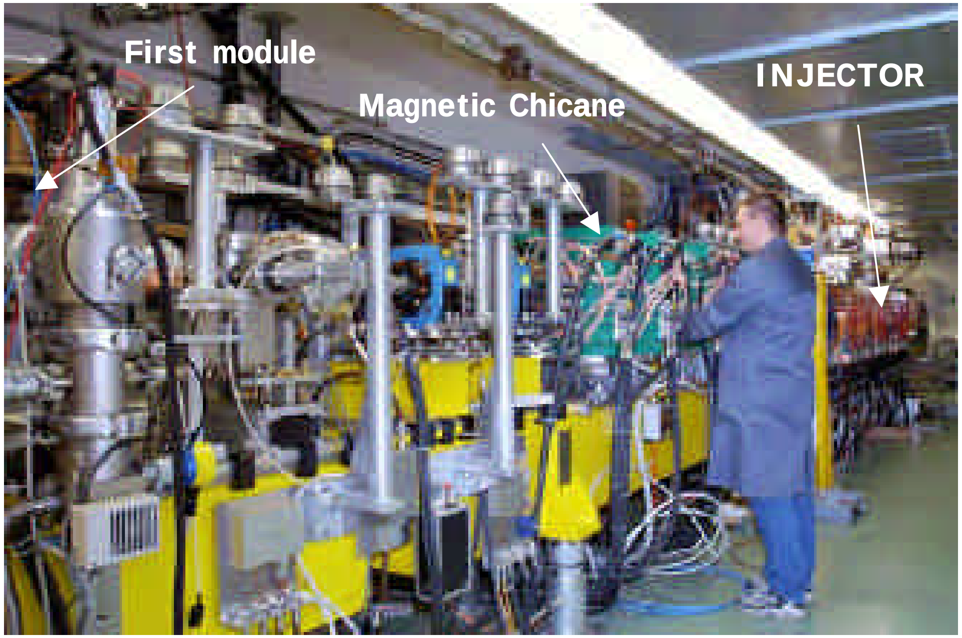


Intensity profile at 1st and 4th turn









CTF 3 during 2003 installation period

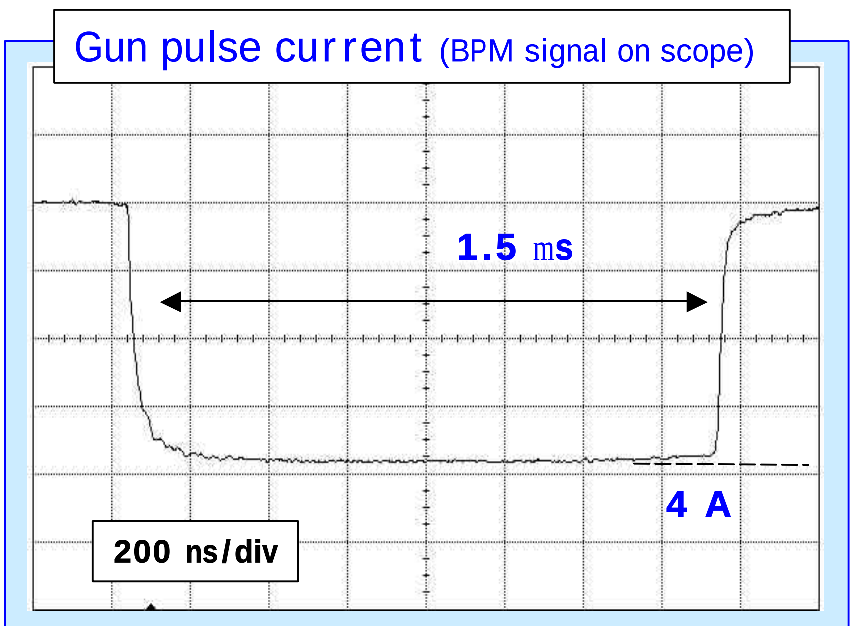
Main beam parameters

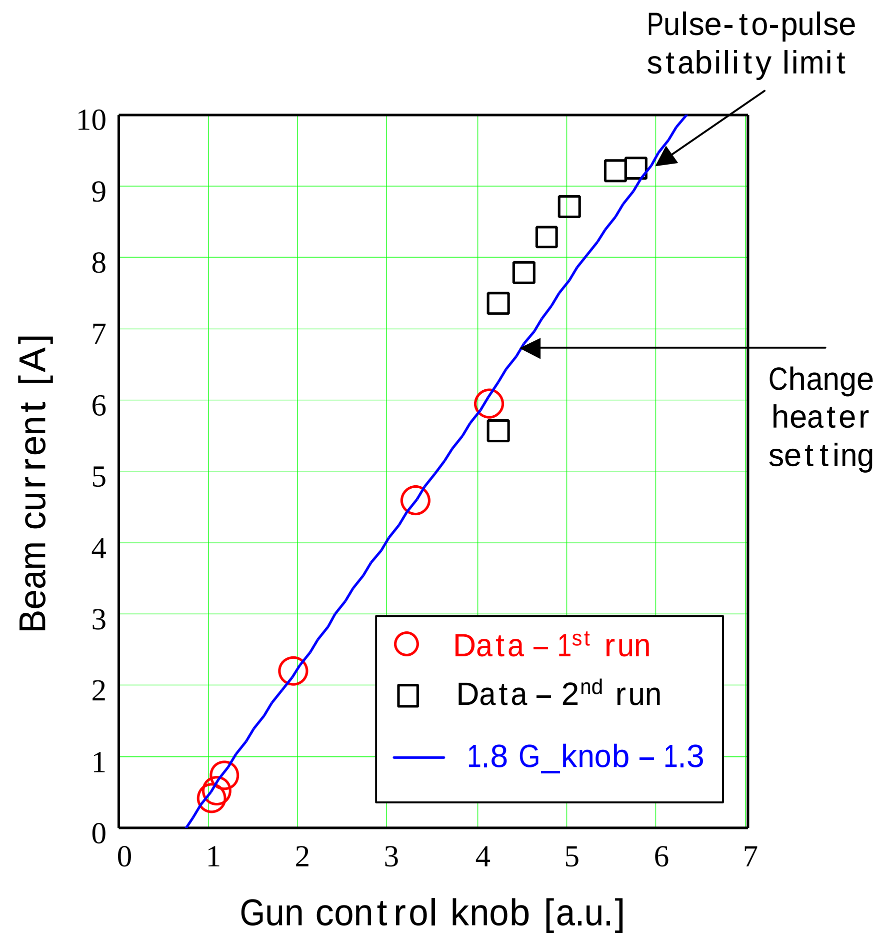
	Nominal	Achieved
I	3.5 A	5 A
τ_p	1.5 μs	1.5 μs
E	35 MeV	35 MeV
$\varepsilon_{n,rms}$	100 π mm mrad	~ 110 π mm mrad *
$\tau_{b,rms}$	5 ps	4 - 6.5 ps *

* Preliminary - for 3.5 A, 1.5 μs beam

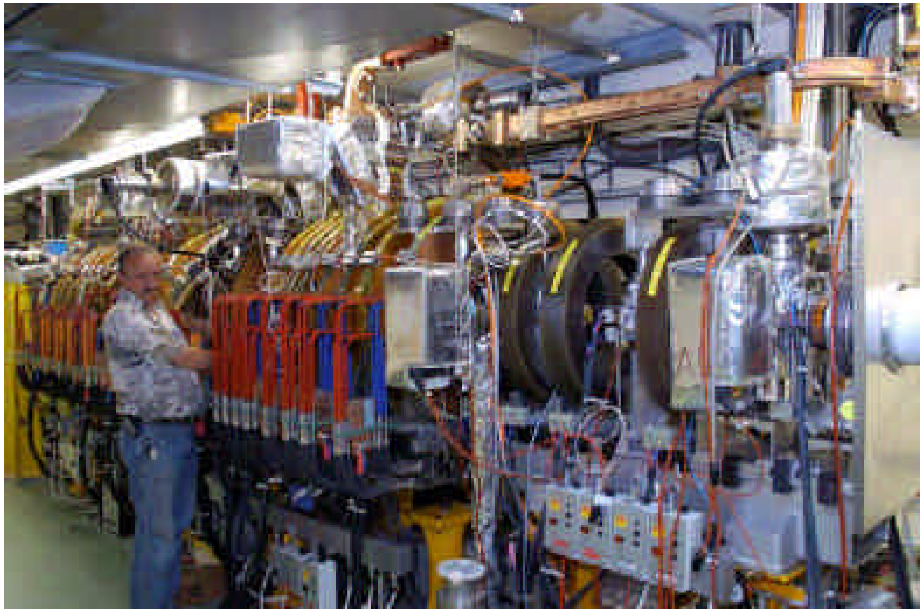
Max gun current 9 A
Max pulse length 1.5 μs

SLAC triode assembly
LAL HV deck, pulser, controls

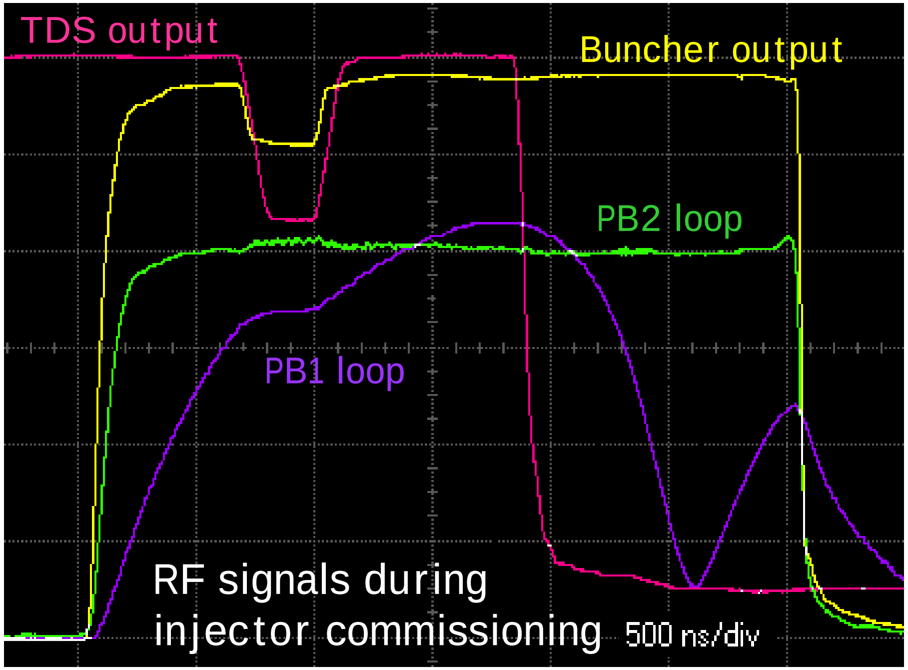


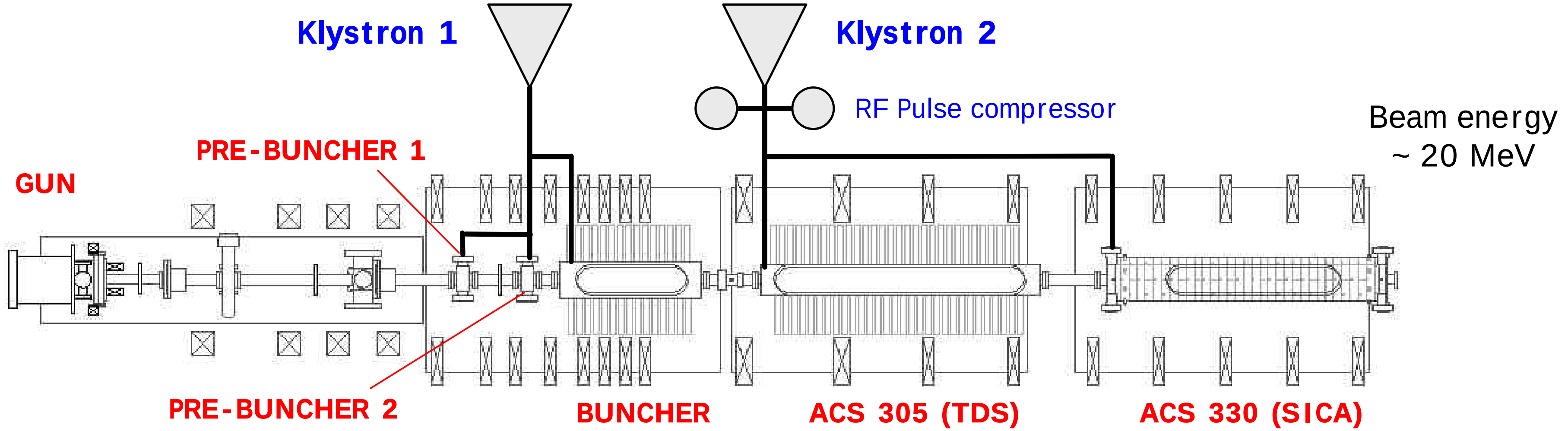


COMMISSIONING 2003 -THE CTF3 INJECTOR

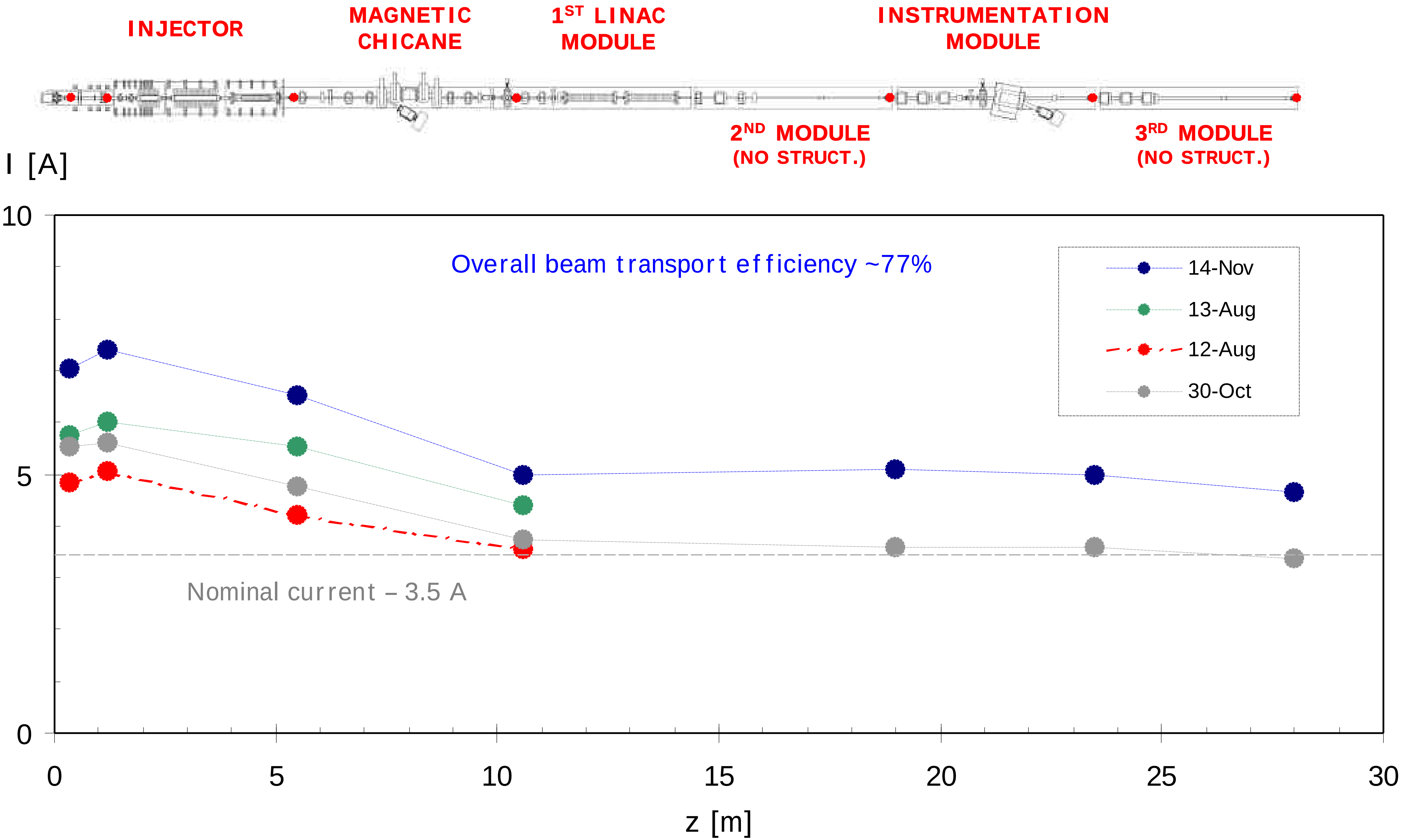


SLAC design, simulations, commiss. support
LAL PB1 & PB2, commiss. support
INFN/LNF commiss. support

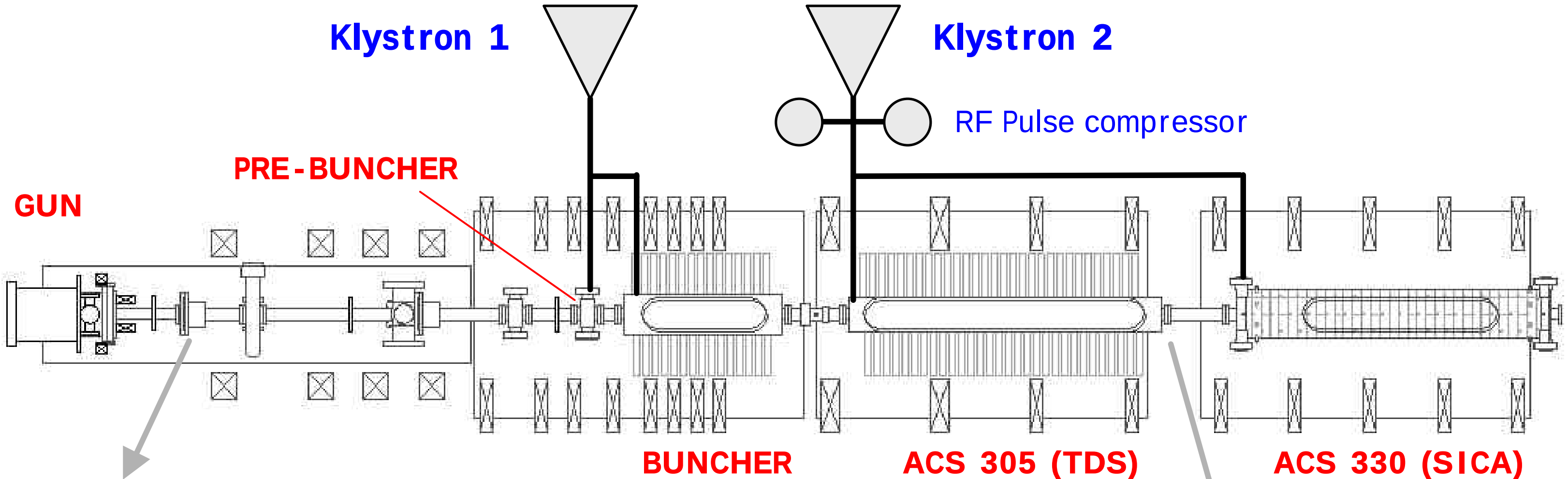


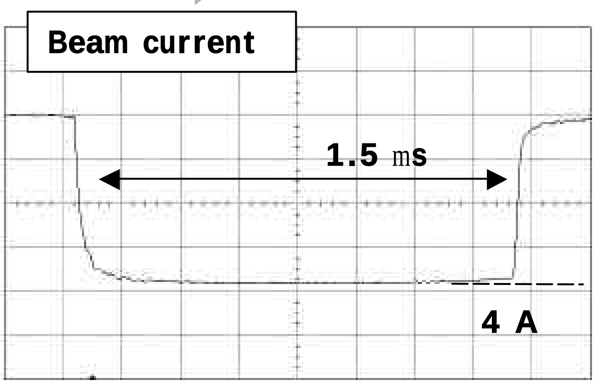


HIGH BEAM CURRENT OPERATION

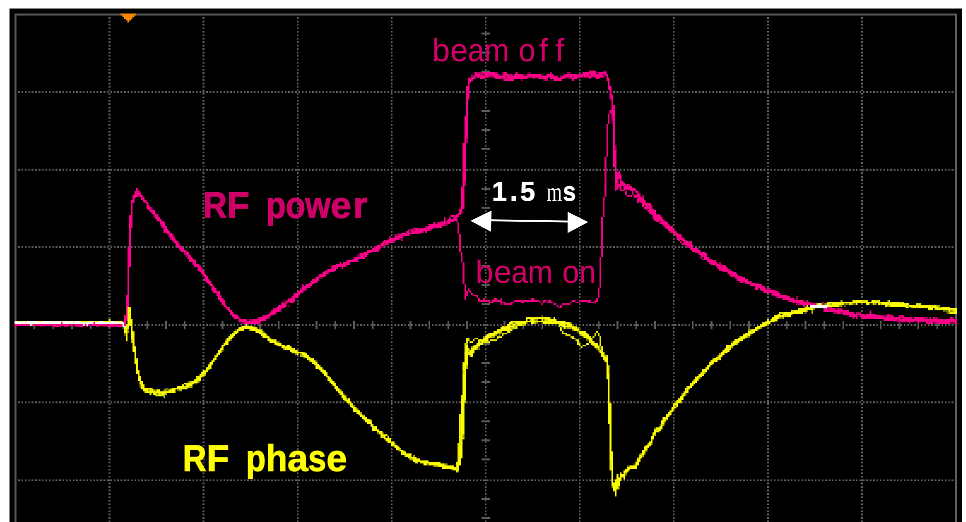


FIRST "FULL" BEAM LOADING OPERATION IN CTF3



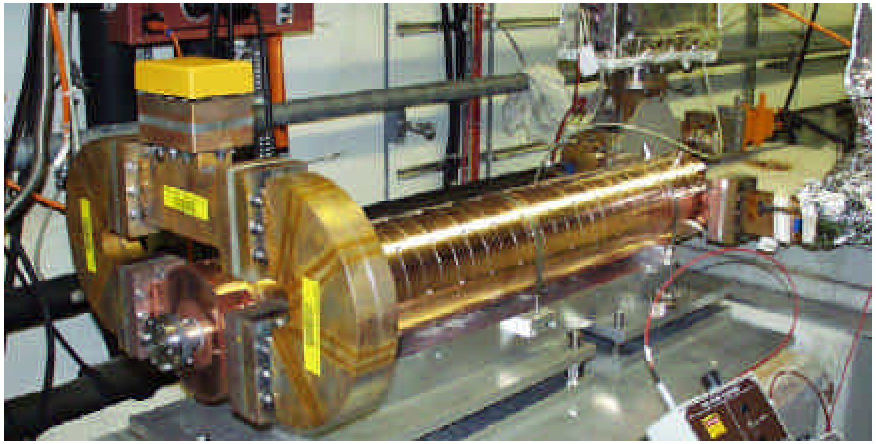


Beam current	4 A
Beam pulse lenght	1.5 μs
Power input/structure	35 MW
Ohmic losses (beam on)	1.6 MW
RF power to load (beam on)	0.4 MW
RF-to-beam efficiency	~ 94%
Phase variation along pulse	±4°

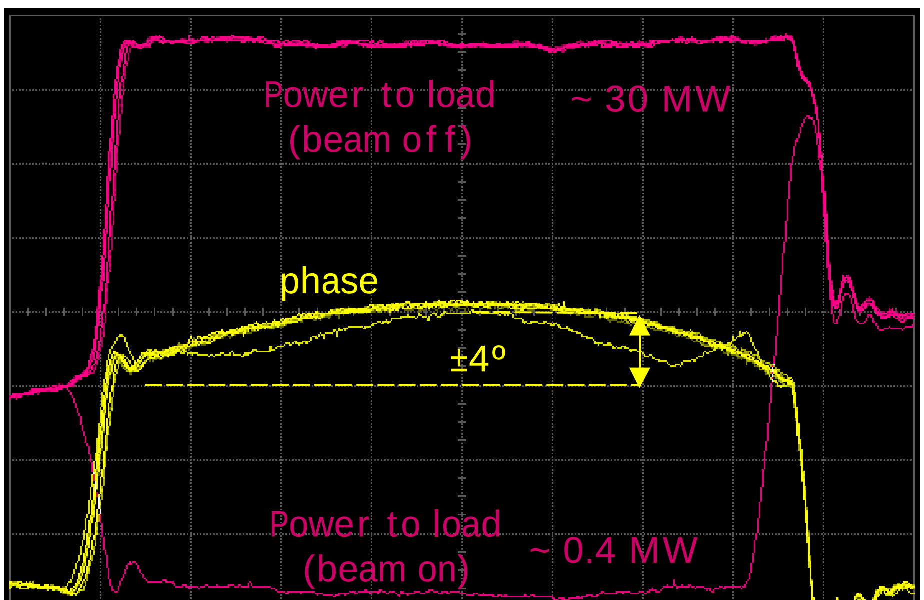


RF signals / output coupler of structure ACS305 (TDS)

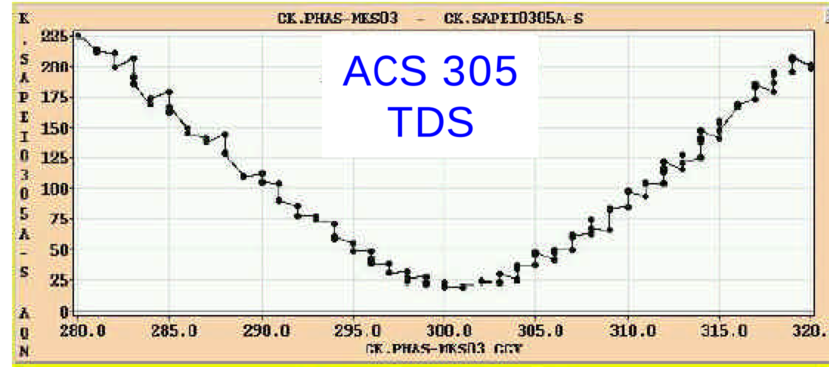
USING RF SIGNALS IN HIGH BEAM LOADING OPERATION



SICA Cavity during high power tests

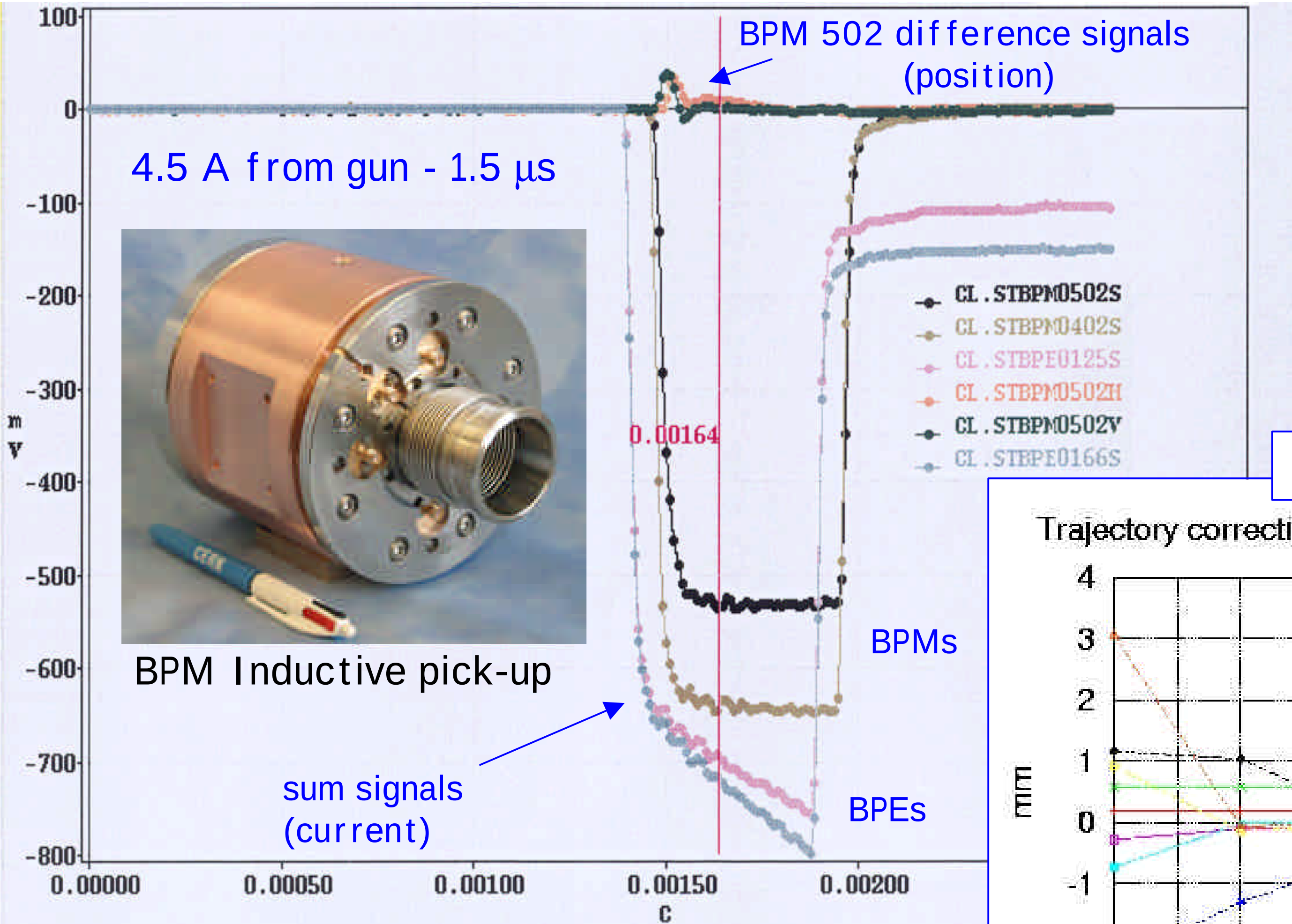


RF signals / output coupler of structure ACS305 (TDS)



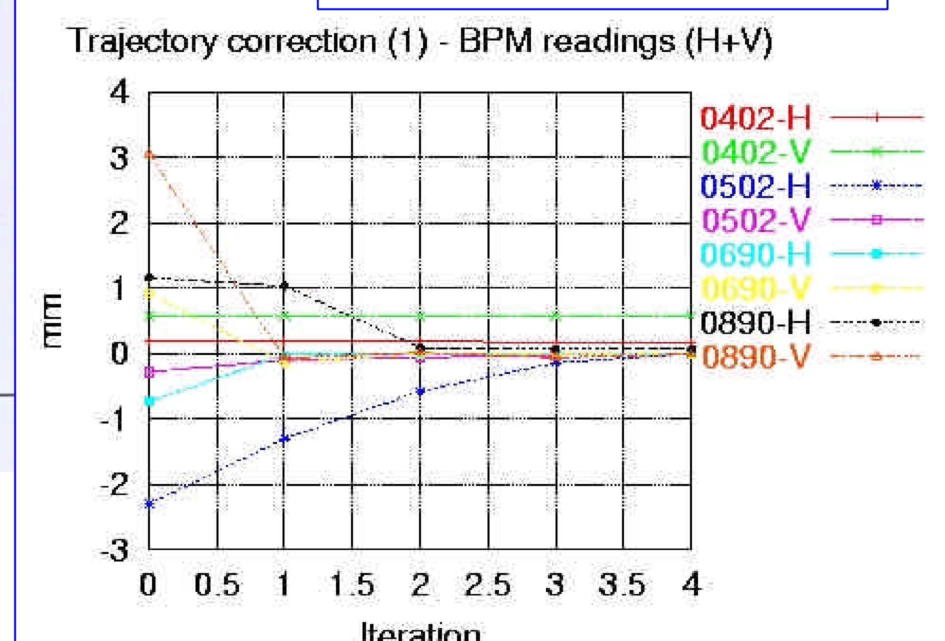
- Beam loading signal as a function of RF phase in two CTF3 structures
- Phase difference ACS305 - ACS330 (w.r.t. beam) ~ 1º

BEAM CURRENT & POSITION MEASUREMENTS



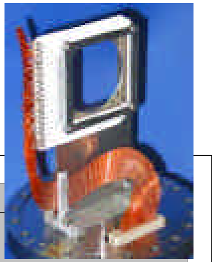
BPE Electrostatic pick-up

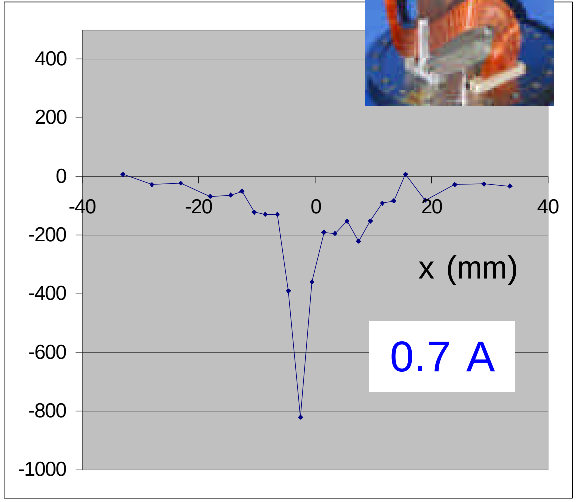
Automatic Beam Steering

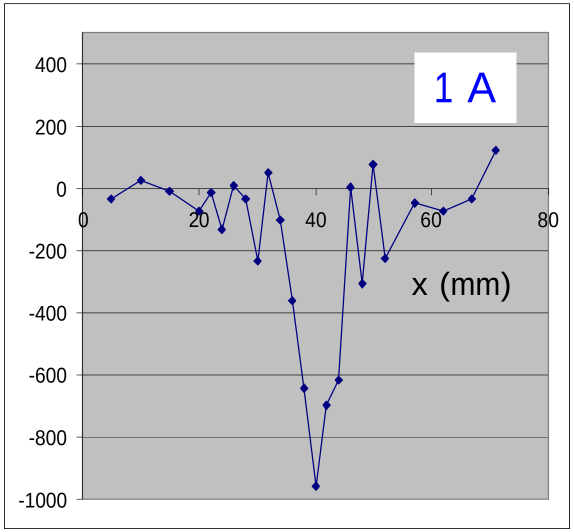


TIME-RESOLVED ENERGY SPECTRA

SEMgrid profiles

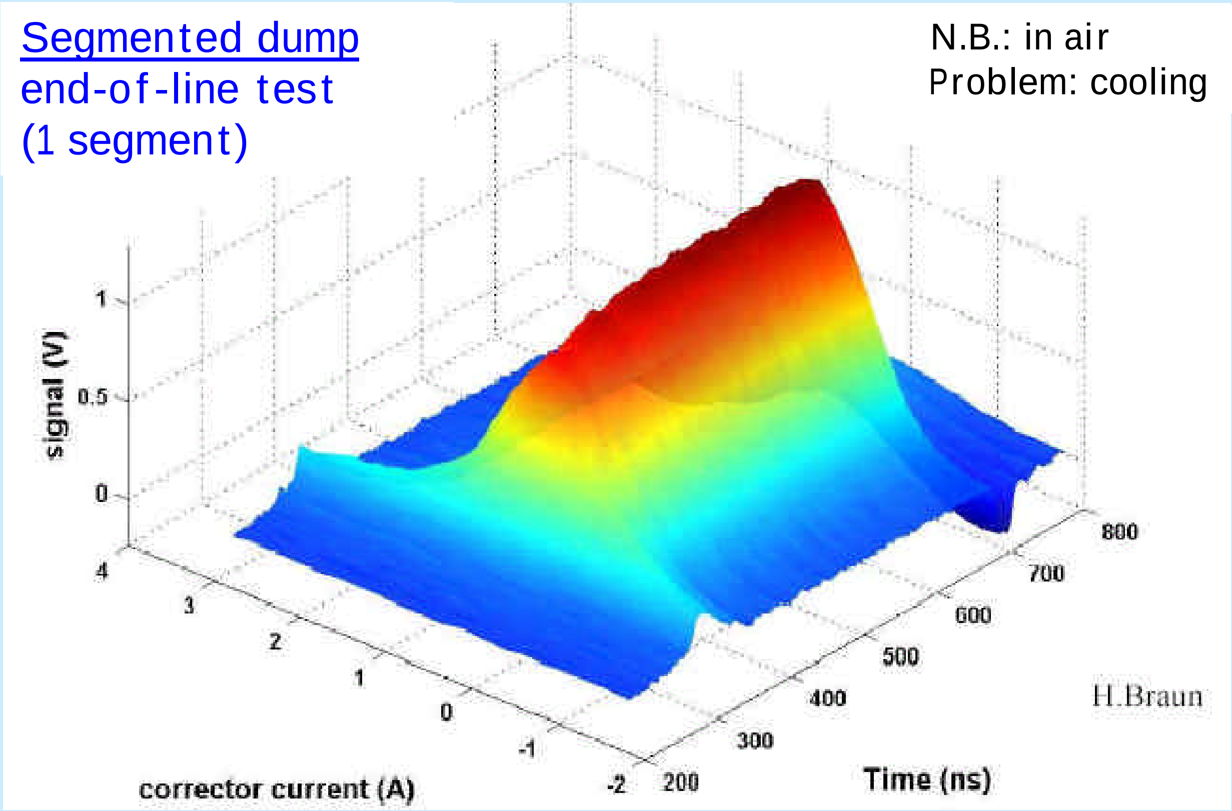




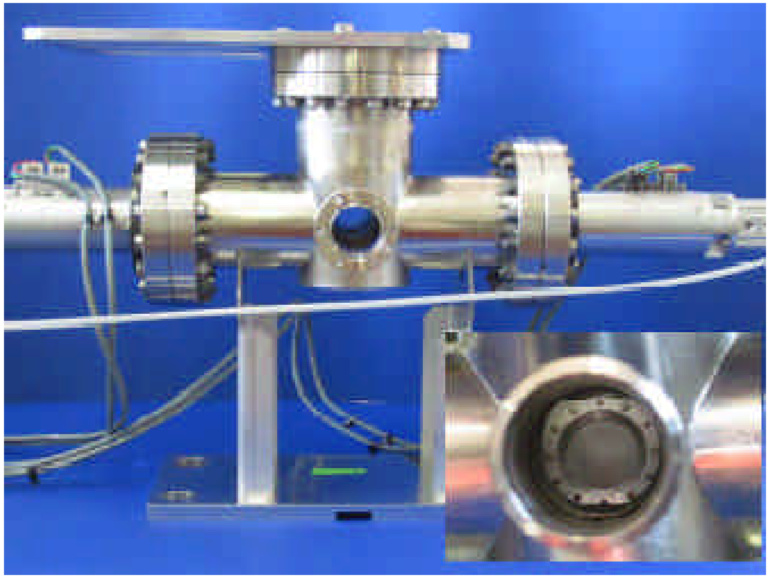


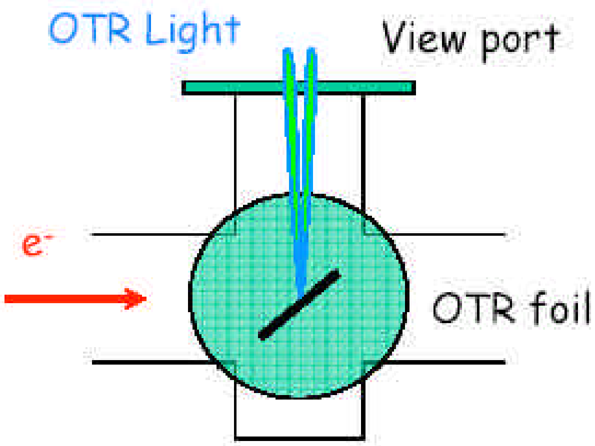
OK below 1 A - Problems at **high current**:

- parasitic em signals
- both negative and positive signals
- strange pulse shapes (in time)
- saturation problems

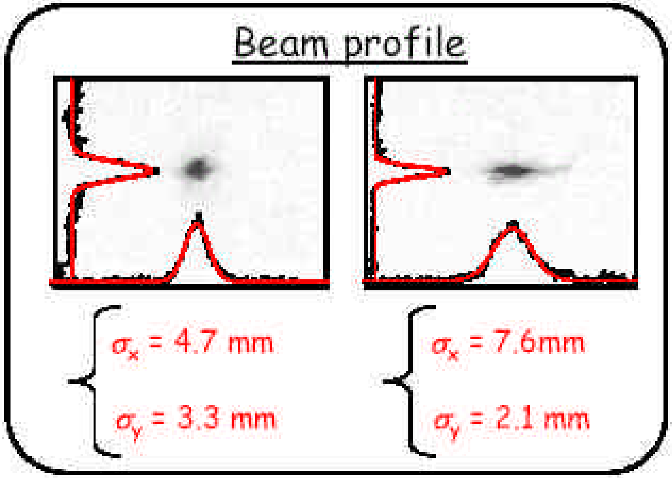


BEAM PROFILE MONITORS

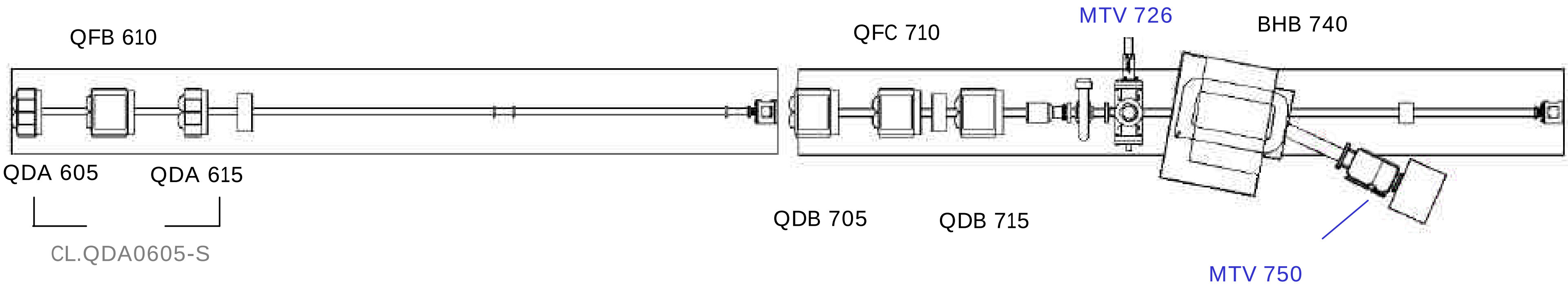




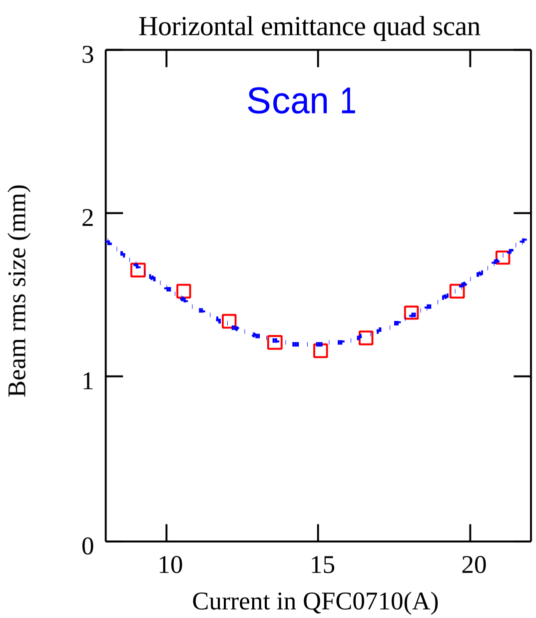
- Screens in spectrometers and along the linac
- OTR screens:
  100 μm thick aluminum or carbon foils
- Cameras:
  radiation hard (low sens.) or CCD (noise)
- Optical lines to streak camera
- Studies on OTR angular distribution, beam halo monitor …

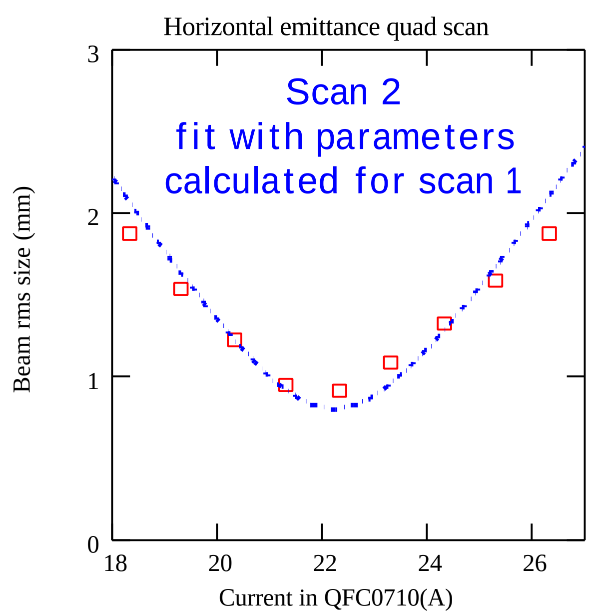


EMITTANCE MEASUREMENTS



- Several quadrupole scans made in different conditions
- Horizontal scans consistent - Not all vertical scans consistent (resolution limit in screens ?)





horizontal

$\beta = 16.23$

$\alpha = -2.44$

$\varepsilon \cdot \gamma = 1.12 \times 10^{-4}$

vertical

$\beta = 7.93$

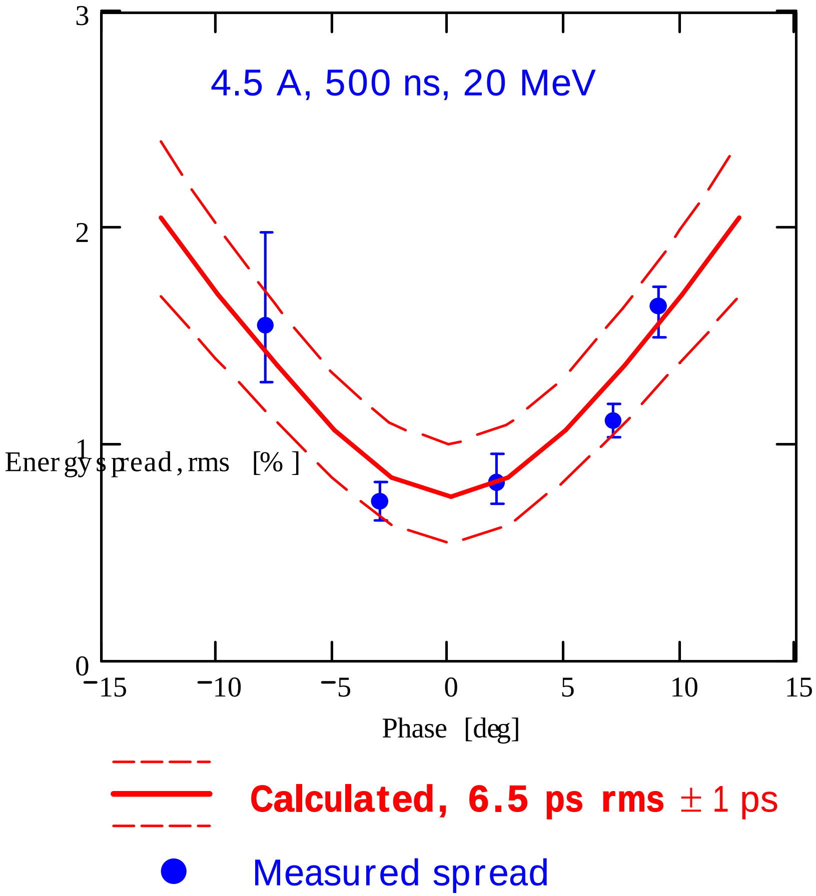
$\alpha = -1.41$

$\varepsilon \cdot \gamma = 1.03 \times 10^{-4}$

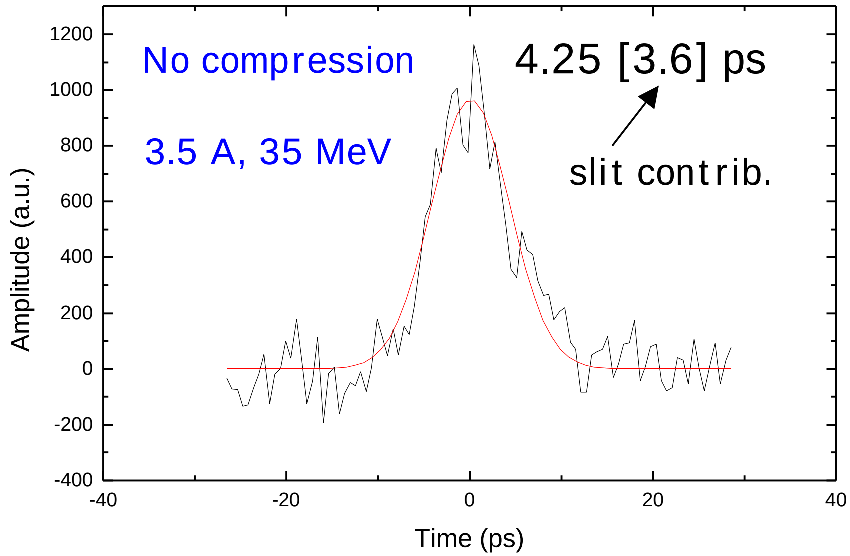
BUNCH LENGTH MEASUREMENTS

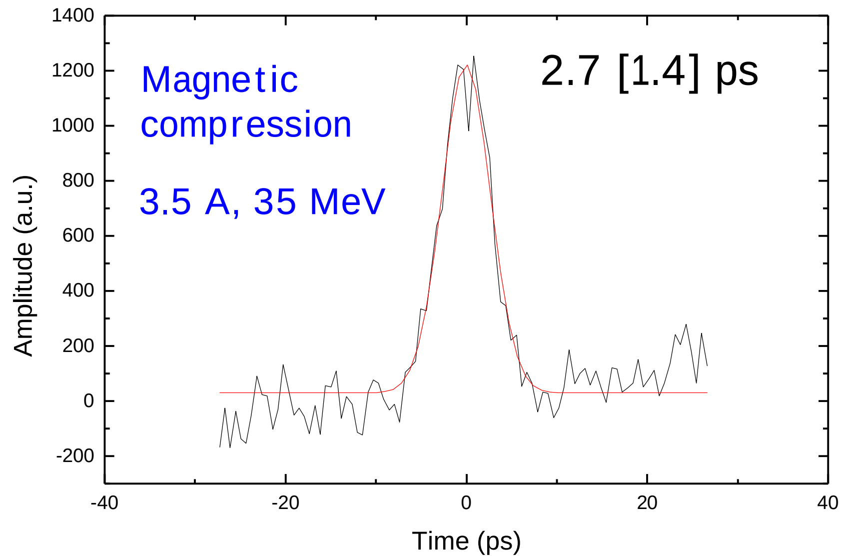
Phase scan method

Energy spread is measured for different RF accelerating phases, and compared with expected values for gaussian longitudinal profile bunches

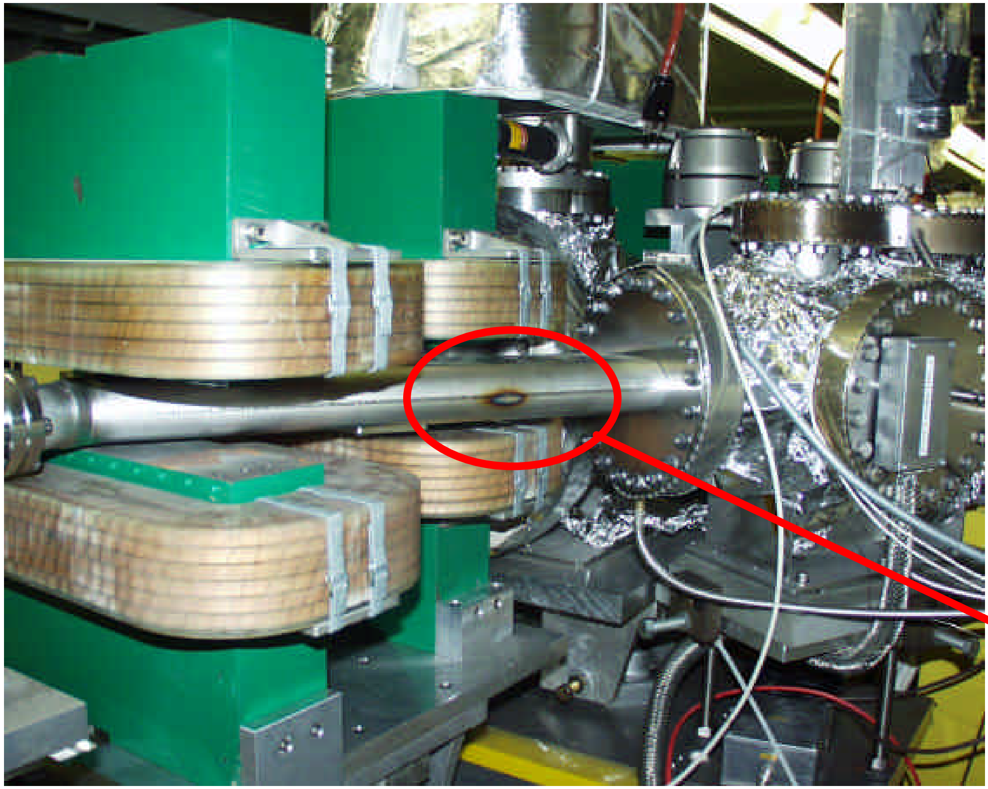


Streak camera, preliminary (accumulation of 3 images)

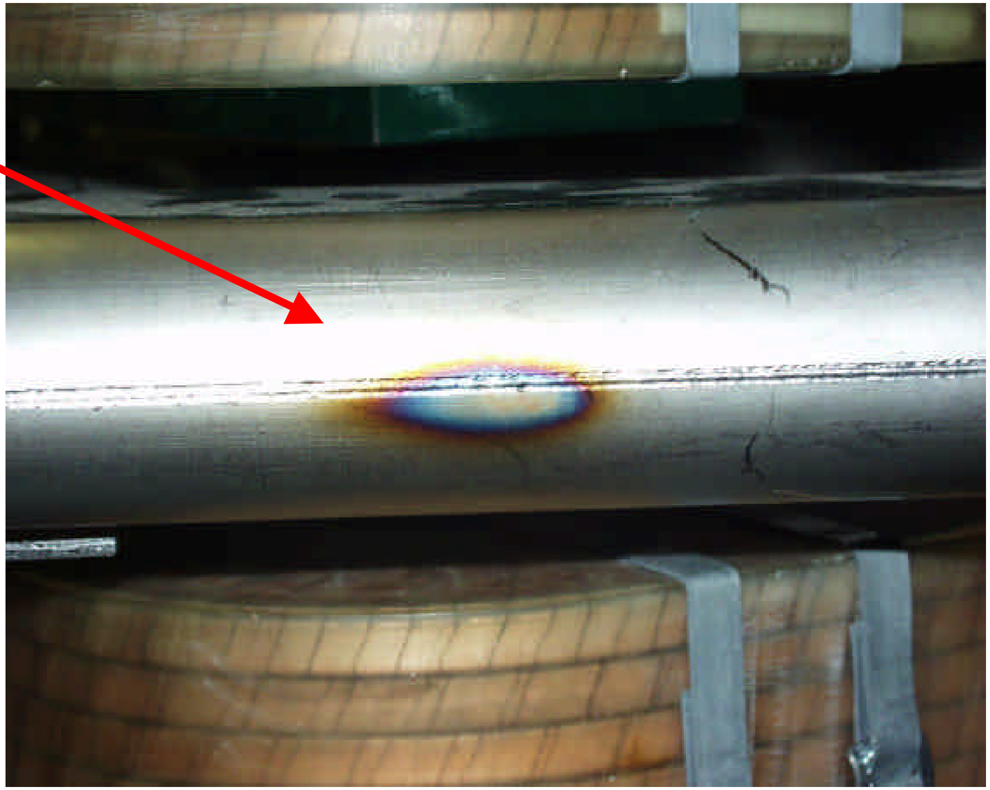




HIGH CURRENT OPERATION - BEAM DAMAGE 1

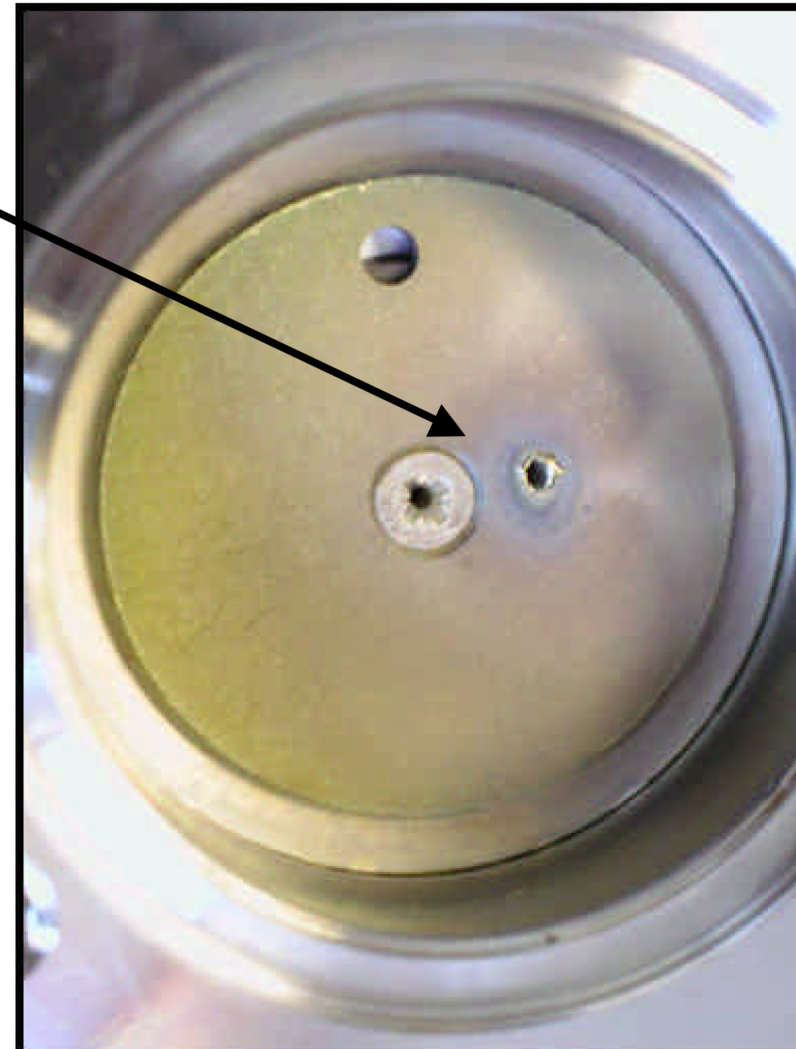


Sign of heating from beam in spectrometer vacuum chamber



HIGH CURRENT OPERATION - BEAM DAMAGE 2

Beam damage of vacuum valve



OUTLOOK – FUTURE CHALLENGES

Demonstration of drive beam generation

- Final drive beam parameters (35 A, 2.3 nC/bunch, 150 MeV, 140 ns, 1.4 μs initial pulse length)
- Down-scaled with respect to CLIC (150 A, 10 nC/bunch, 2 GeV, 130 ns, 100 μs initial pulse length) but **close enough to test relevant physical effects and benchmark simulation tools**
  N.B.: different scaling laws involved for different effects !

Need to demonstrate not only beam current and pulse length, but also:

Low losses along the complex, beam emittance preservation, efficiency, control of bunch length, current stability, energy stability, bunch phase stability

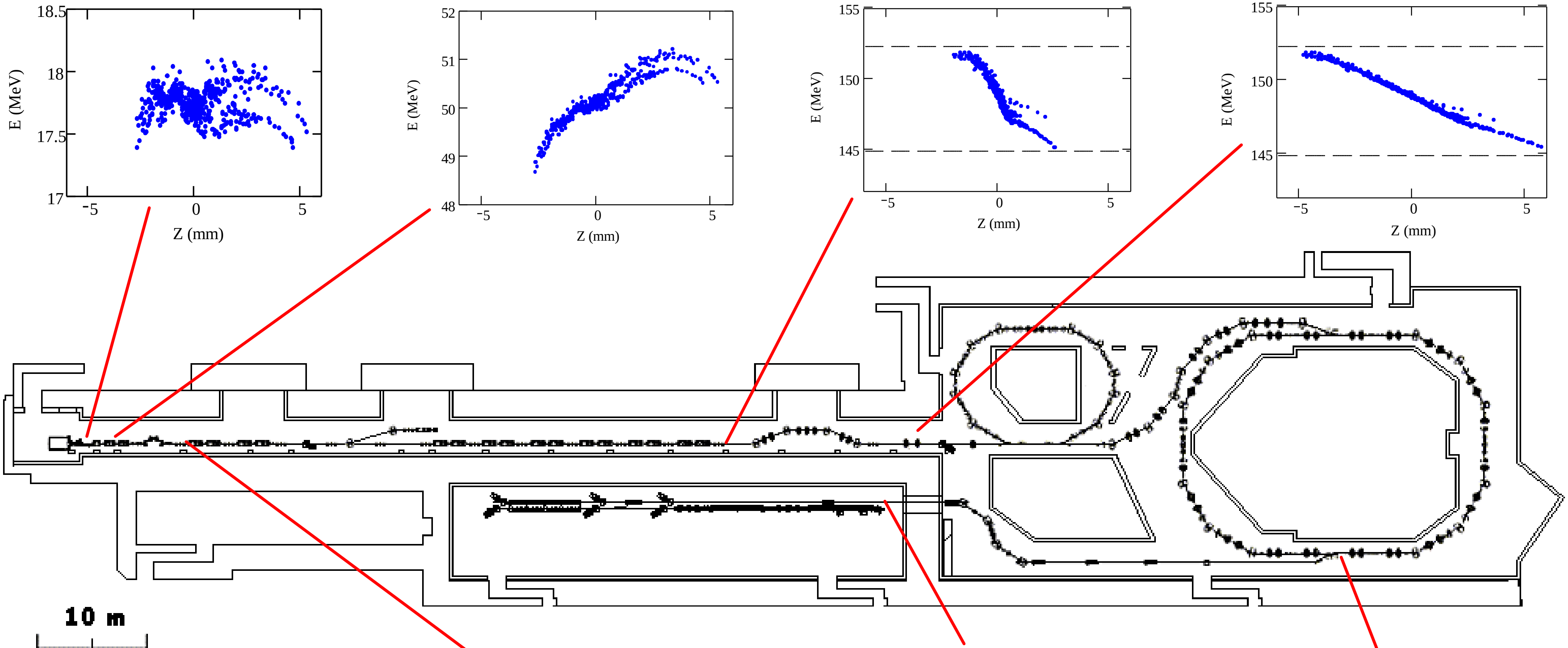
Generation of 30 GHz RF power with CLIC nominal parameters

- Needed to test RF components (accelerating structures demonstration, but not only…)
- Acquire experience in power production operation (switch on/off power from PETS, …)

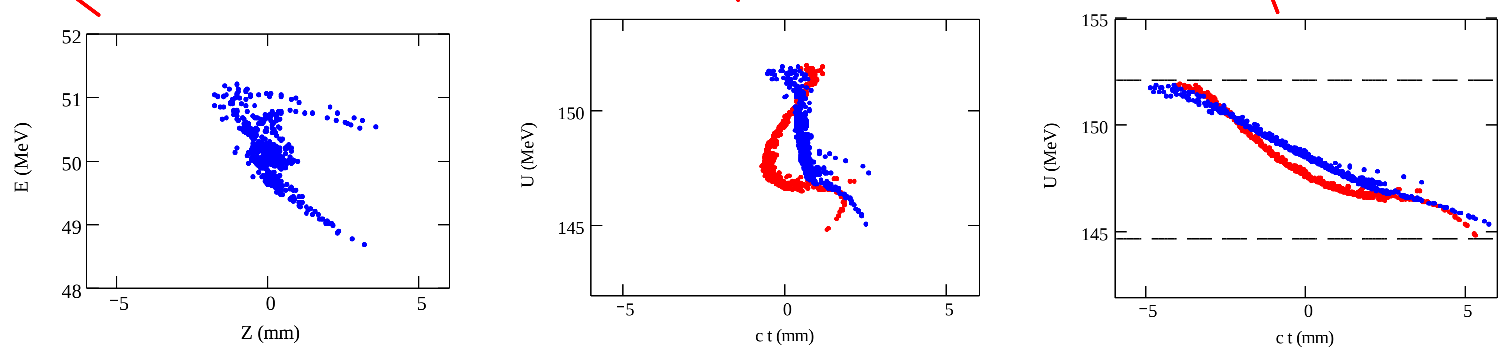
Proposed: Test Beam Line to assess transverse stability & beam control in DB Decelerator

- String of PETS (10-15), choose relevant drive beam parameters – need several betatron wavelength
- Measurement of wake-fields in decelerator (with probe beam ?)
- Study of halo production, machine protection…

CHALLENGES – LONGITUDINAL PHASE SPACE CONTROL

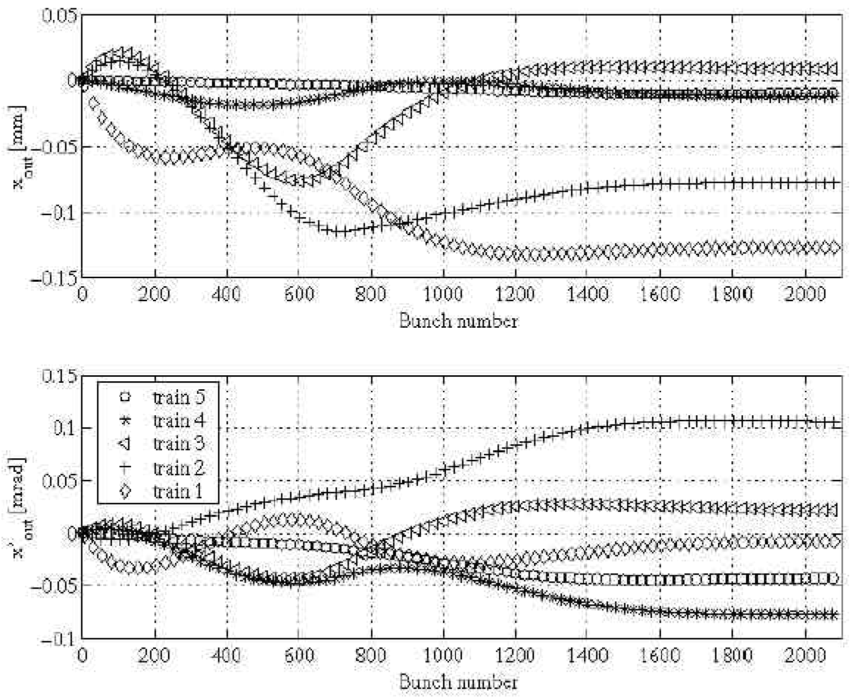


Bunch length control, longitudinal phase space gymnastics, CSR and impedance in DL and CR

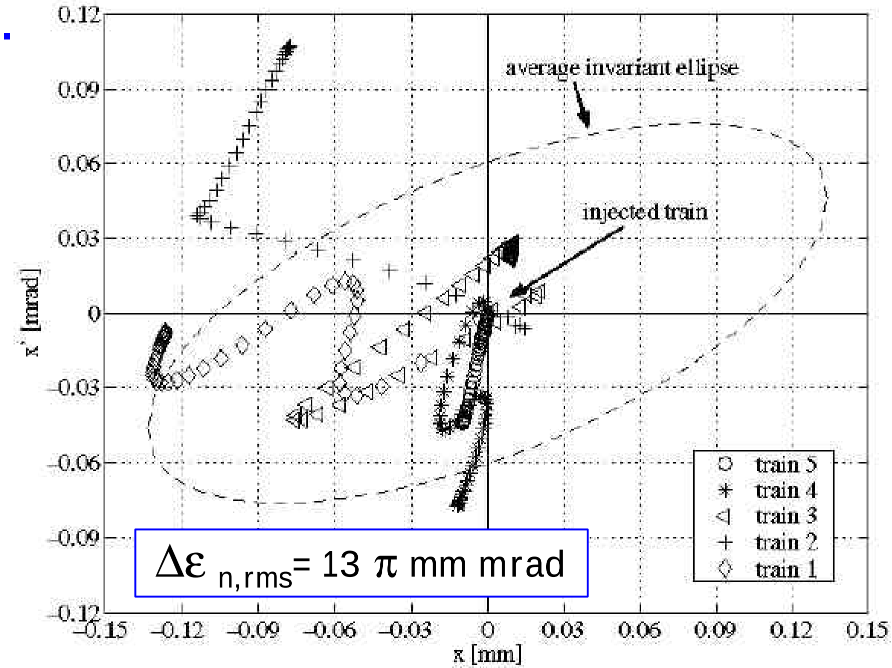


CHALLENGES – STABILITY IN TRANSVERSE DEFLECTORS

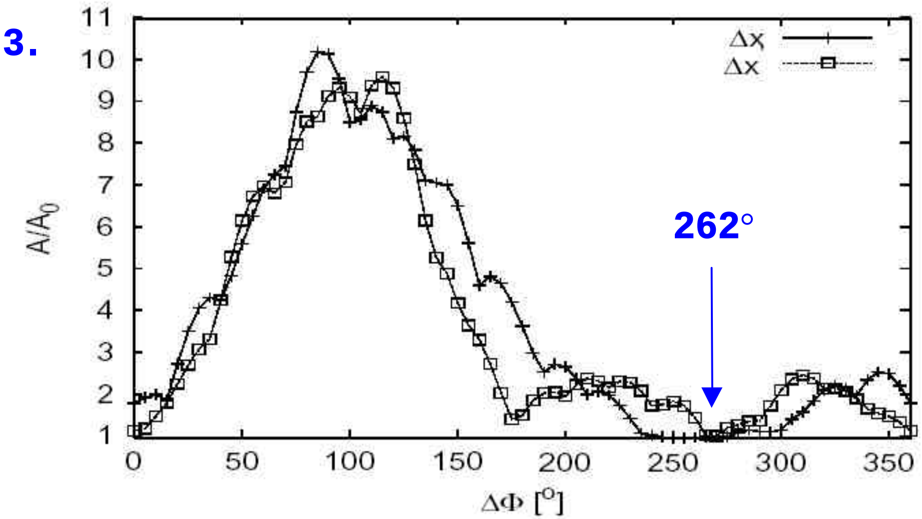
1.



2.



3.

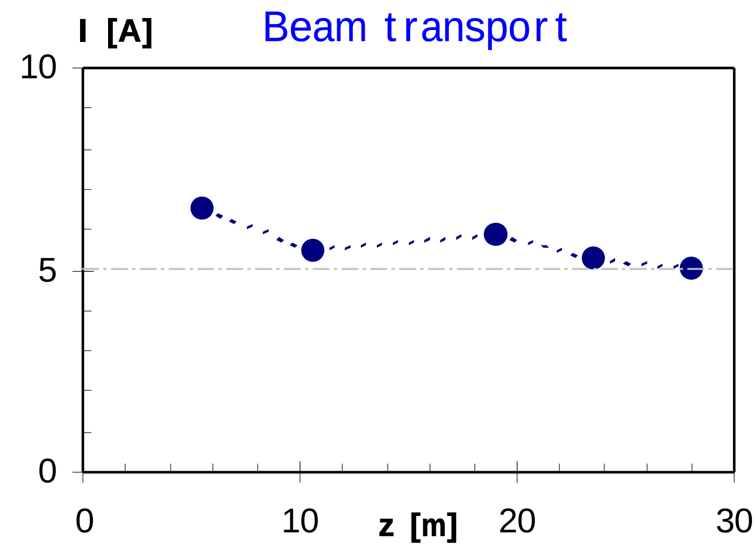


Transverse stability in combiner ring – effect of RF deflectors wake

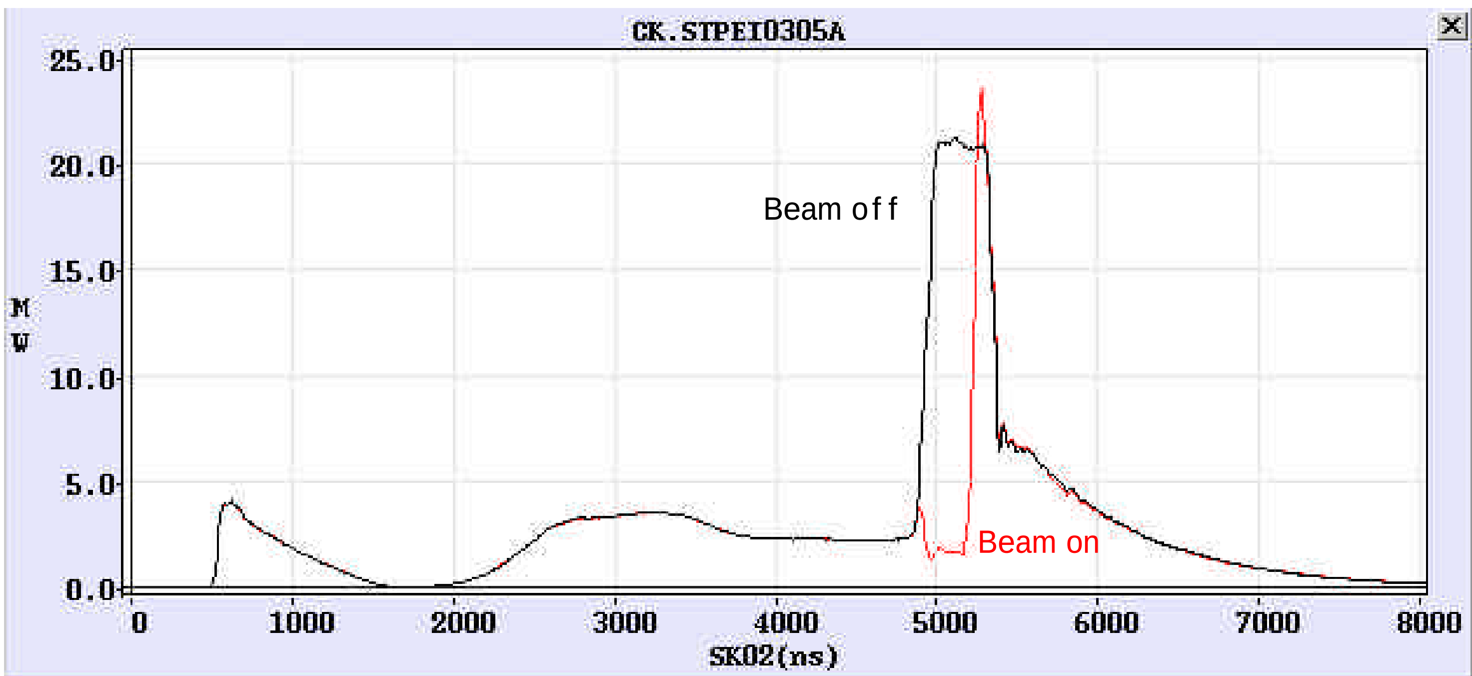
1. Final position and angle of bunches (systematic - no injection errors)
2. Phase space footprint of merged trains (systematic - no injection errors)
3. Tune dependence of the position and angle magnification of injection errors

Power mode test

P_{MKS03}	=	100 MW
P_{MKS05}	=	96 MW
T_{PULSE}	=	300 ns
E_{BEAM} (BHA 425)	=	19.5 MeV/c
E_{BEAM} (BHB 740)	=	32.9 MeV/c
I_{BEAM}	=	5 A

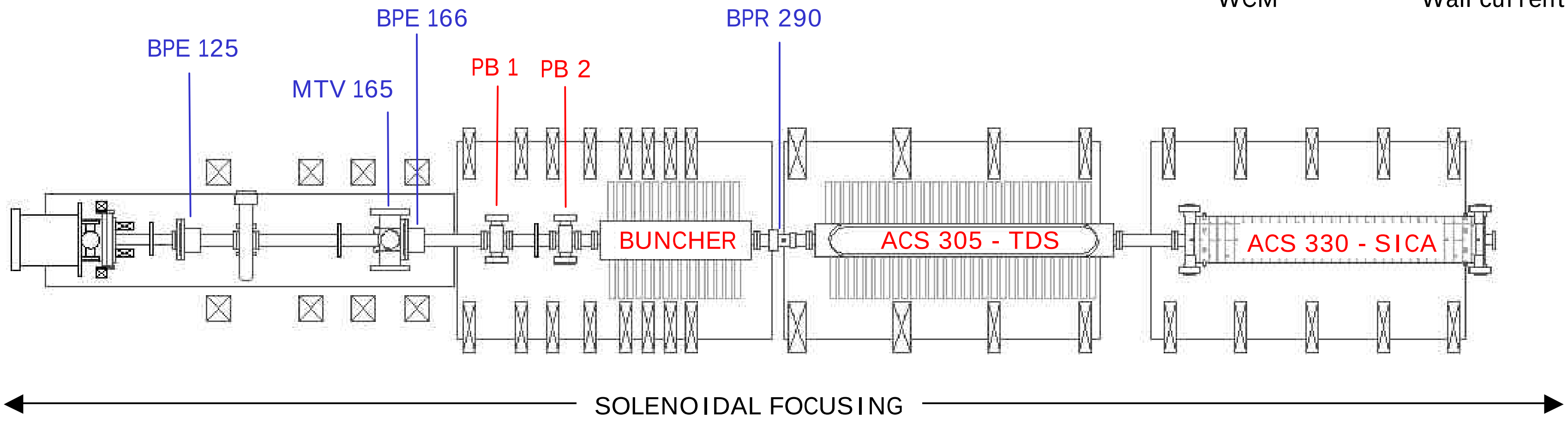


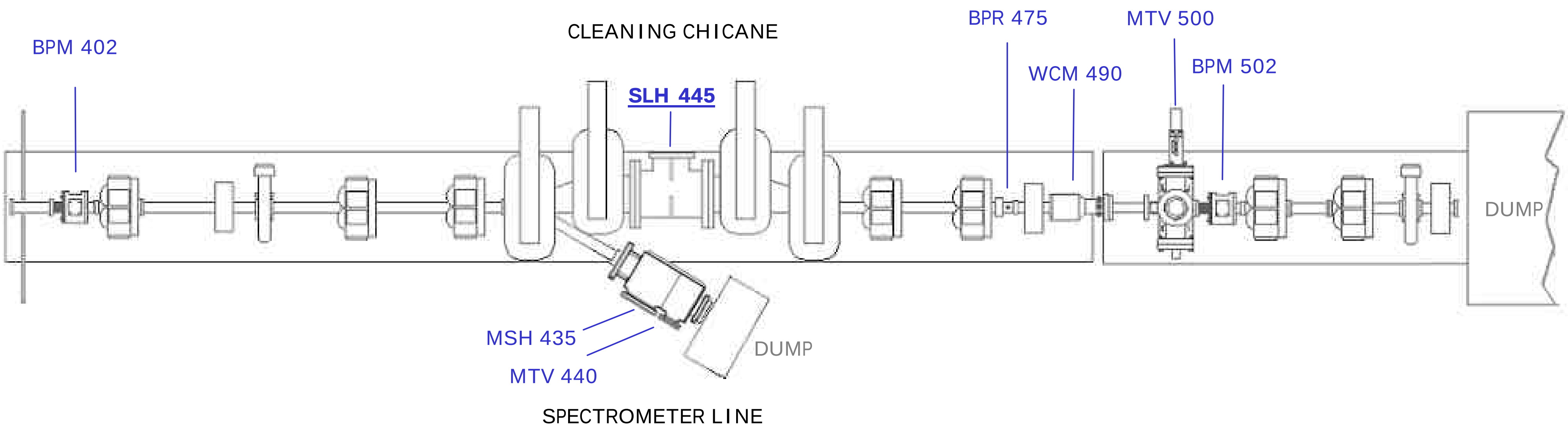
RF signals – output from ACS305 (TDS)



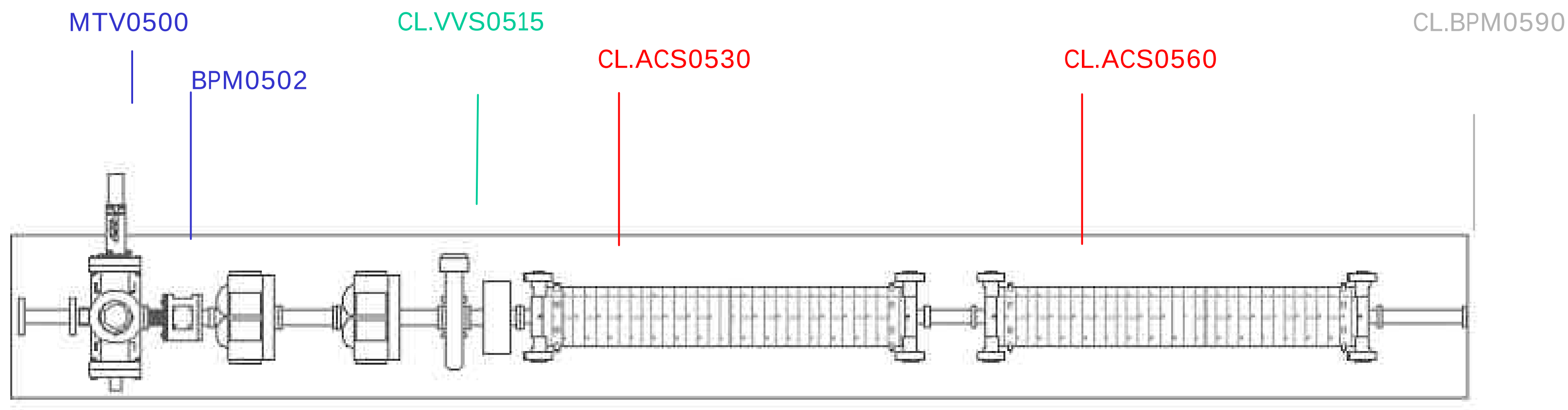
CTF3 layout (July-August 2003)

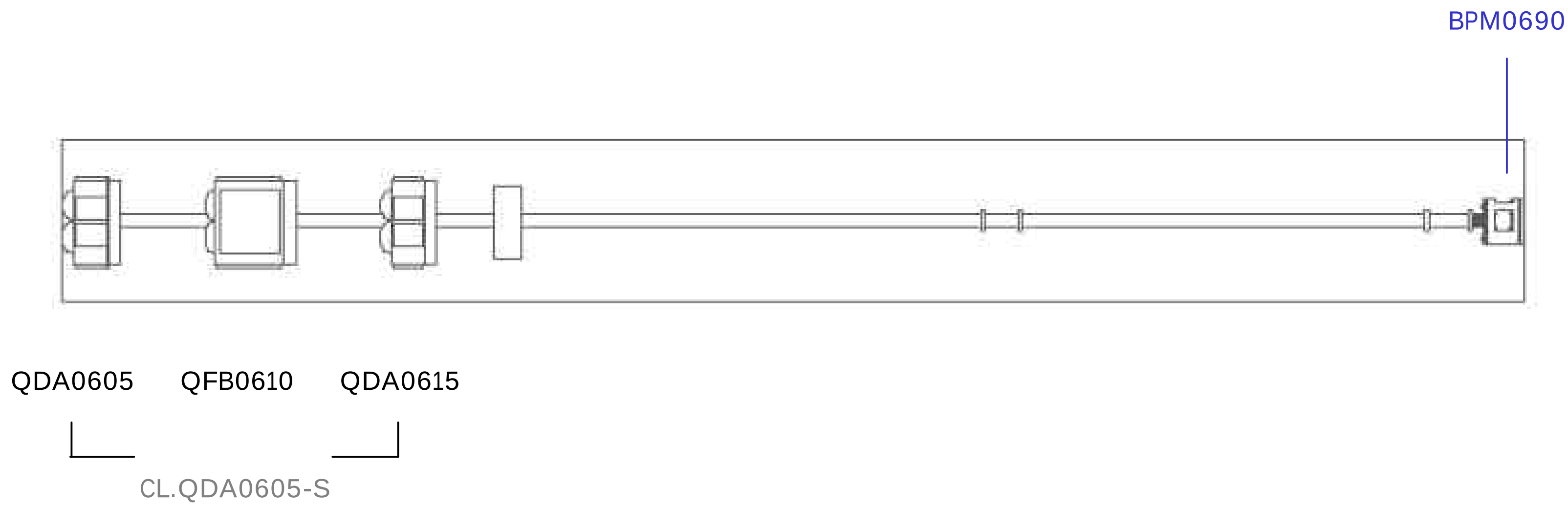
BPE, BPR, BPM	Beam position monitors
MTV	Screens
MSH	SEM-Grid
WCM	Wall current monitor



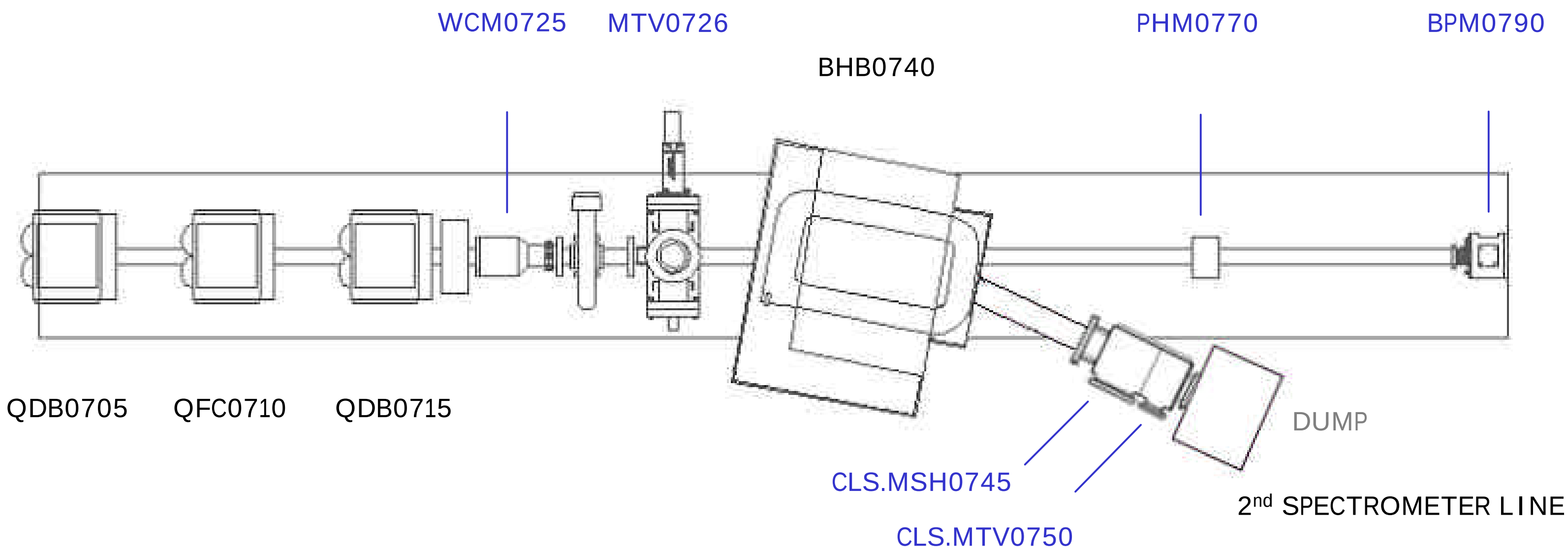


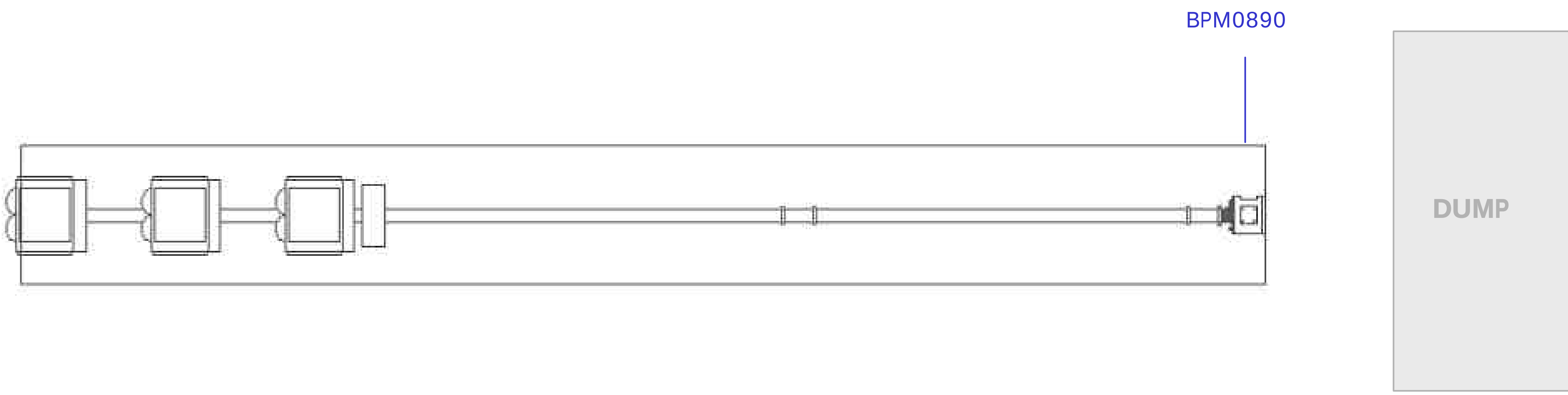
CTF3 layout


MTV0500
BPM0502
CL.VVS0515
CL.ACS0530
CL.ACS0560
CL.BPM0590

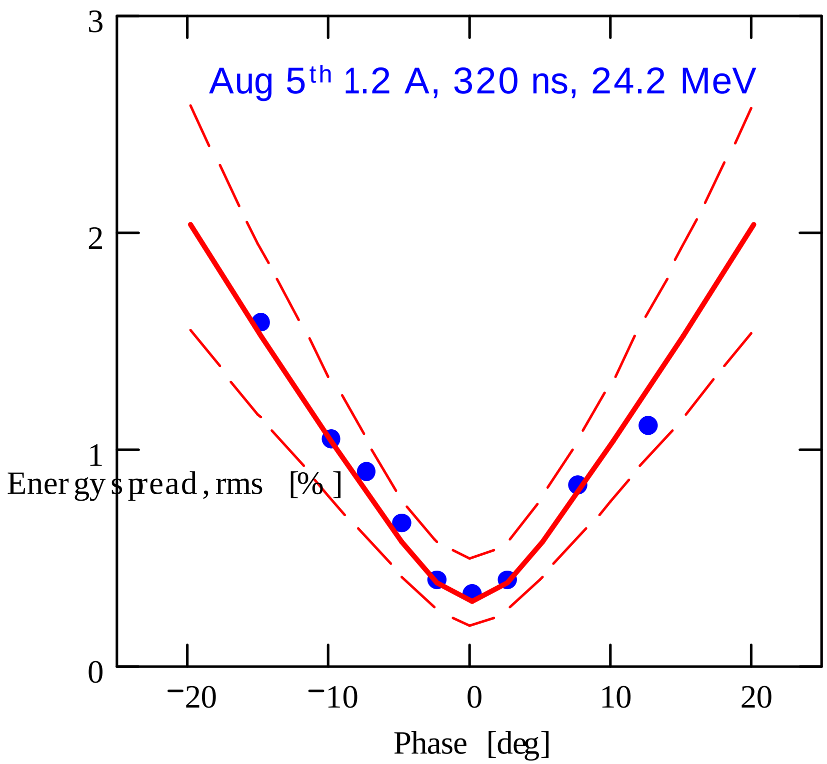

BPM0690
QDA0605
QFB0610
QDA0615
CL.QDA0605-S

CTF3 layout


WCM0725
MTV0726
PHM0770
BPM0790
BHB0740
QDB0705
QFC0710
QDB0715
DUMP
CLS.MSH0745
CLS.MTV0750
2nd SPECTROMETER LINE

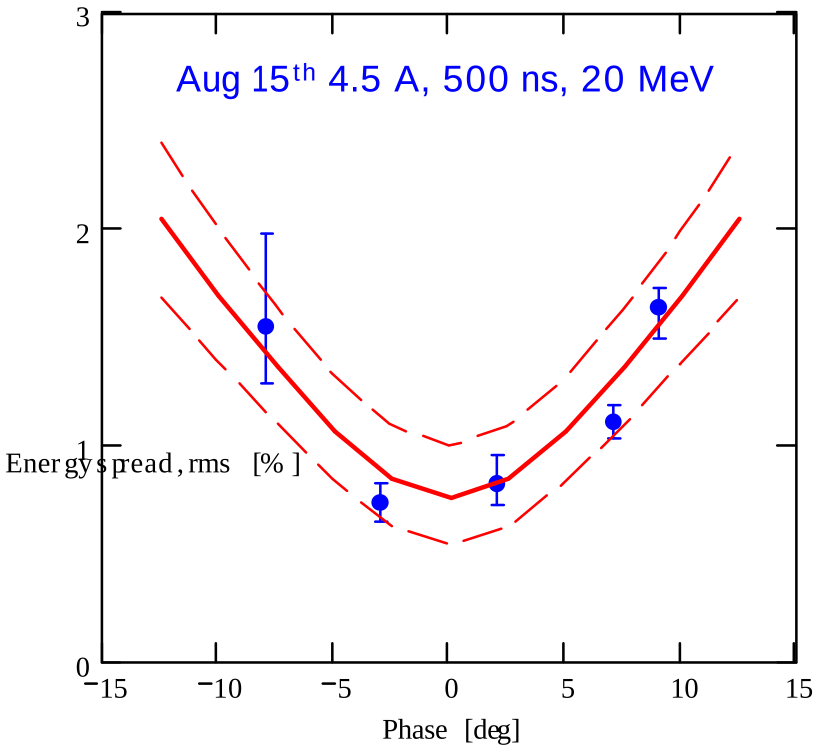

BPM0890
DUMP

Bunch length – phase scan method



Calculated, 4 ps rms ± 1 ps

Measured spread

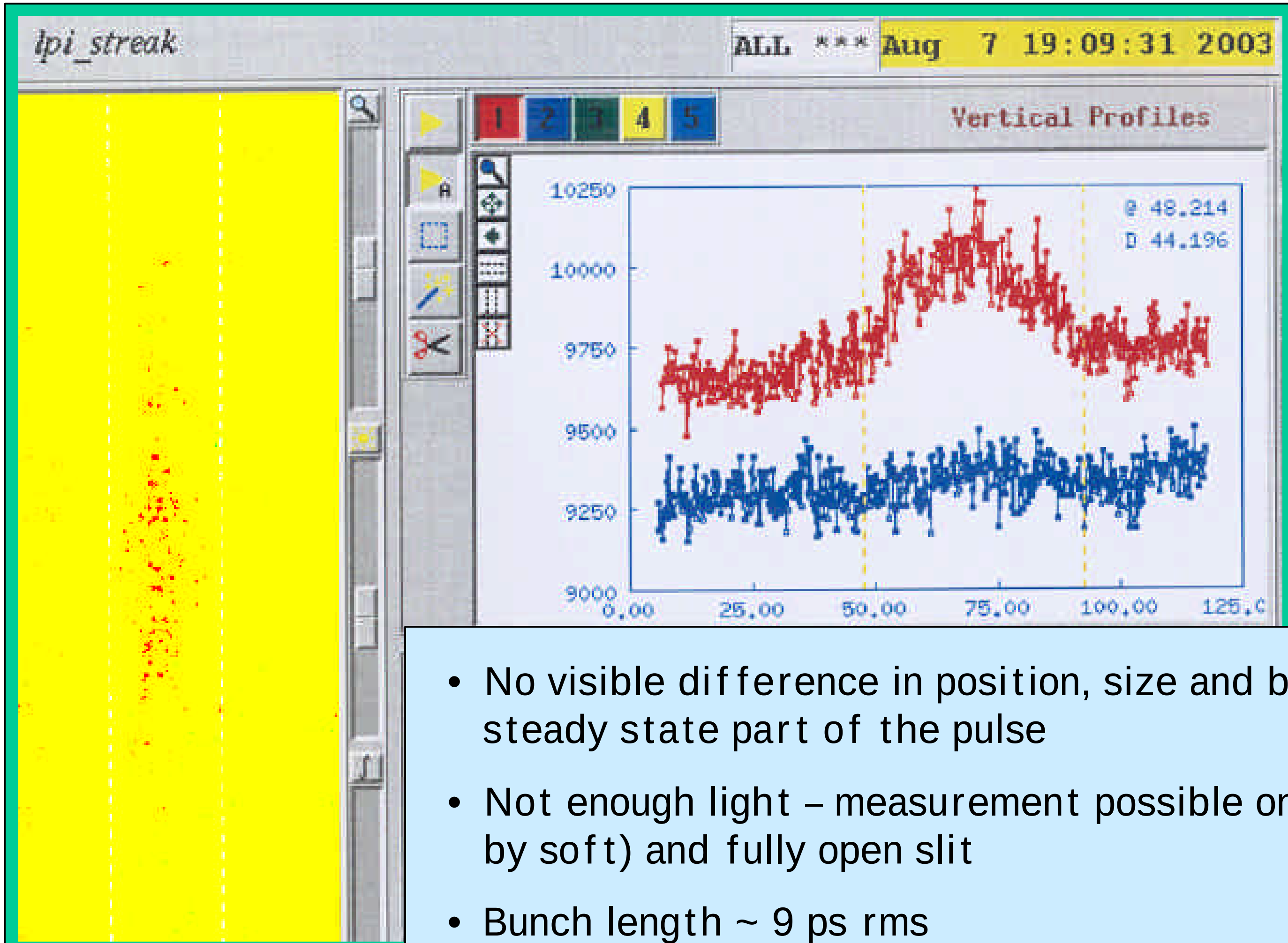


Calculated, 6.5 ps rms ± 1 ps

Measured spread

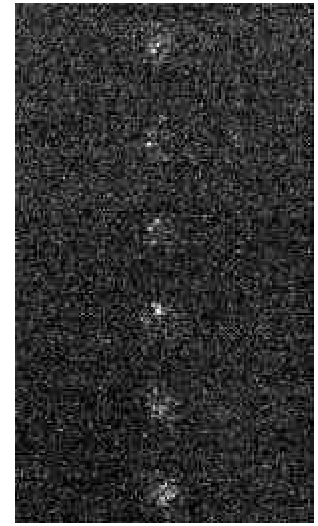
Two phase scans were performed measuring the beam energy spread with MTV440 in different conditions on August 5th (vidicom), and 15th (CCD camera).
The minimum values of the measured energy spread were respectively 0.56 % and 0.87 %.
The best fit to the calculated curves is obtained correcting these values with an “uncorrelated spread” of 0.45 % and 0.3 %, yielding respectively 0.33 % and 0.74 % for the corrected values.

Bunch length – streak camera



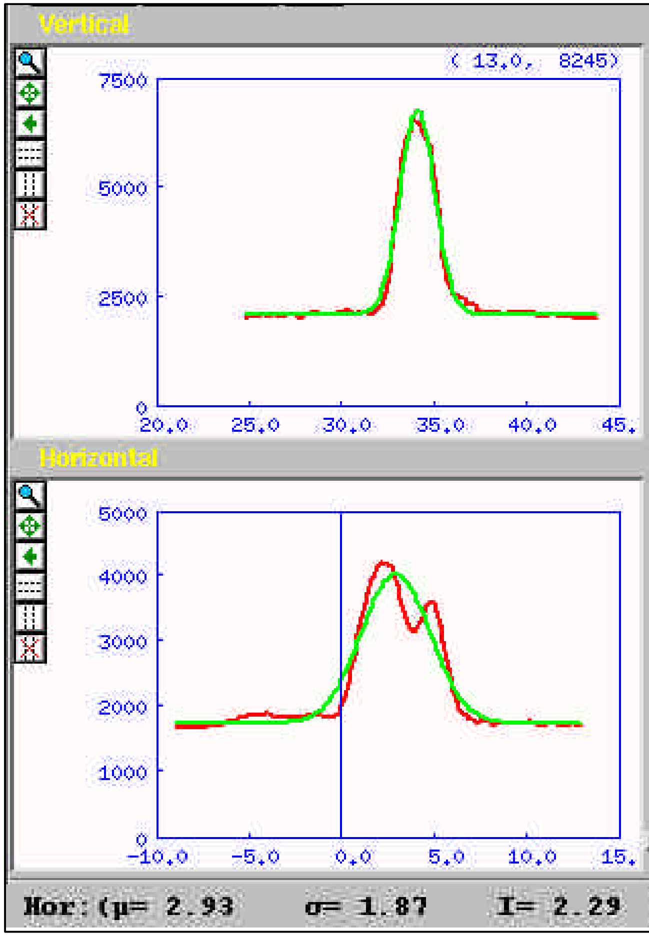
MTV500 carbon screen
2 A, 20 MeV
fast time scale, accum.

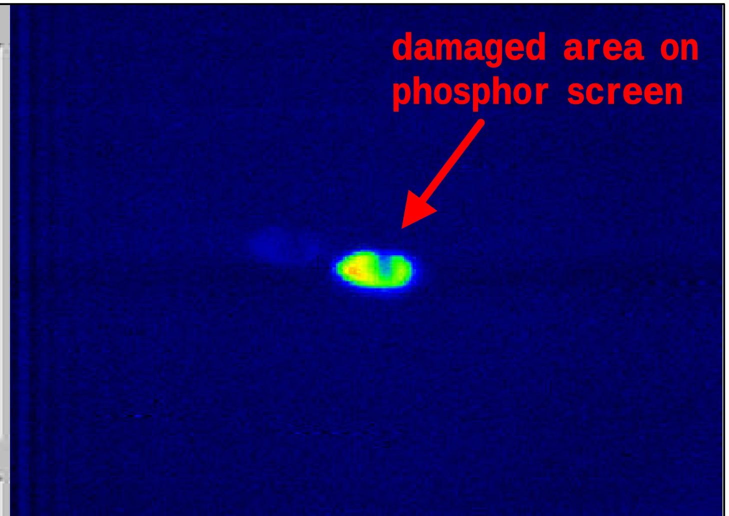
MTV500 carbon screen
3.5 A, 20 MeV
slow time scale, no accum



- No visible difference in position, size and bunch length within the steady state part of the pulse
- Not enough light – measurement possible only with accumulation (limited by soft) and fully open slit
- Bunch length ~ 9 ps rms
- Assuming 3 ps time jitter, 3 ps intrinsic resolution and 3 ps slit contribution, the estimated bunch length would be ~ 6 ps

Diagnostics: screens



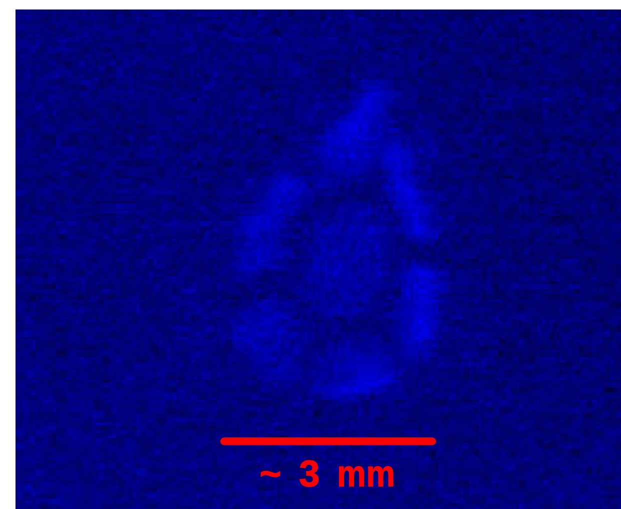


MTV 165 – Vidicom - phosphor screen

August 5th

MTV 165 – Vidicom phosphor screen

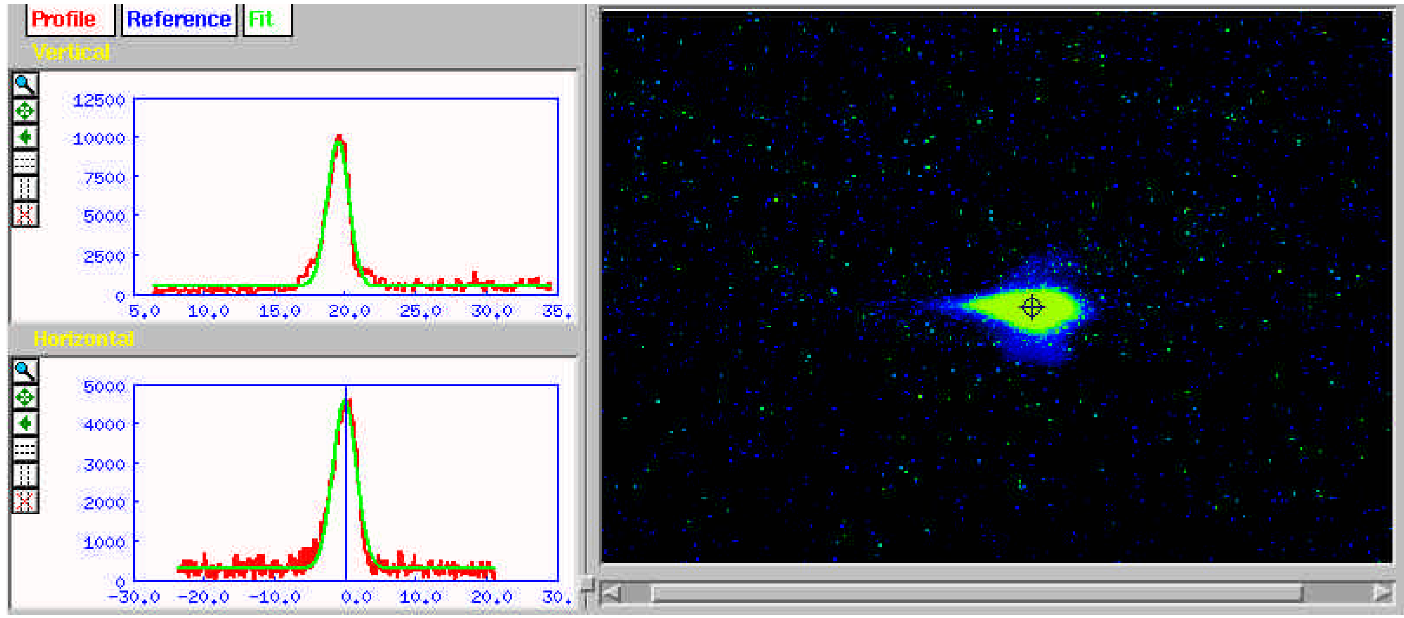
Dark current (pulsing off)

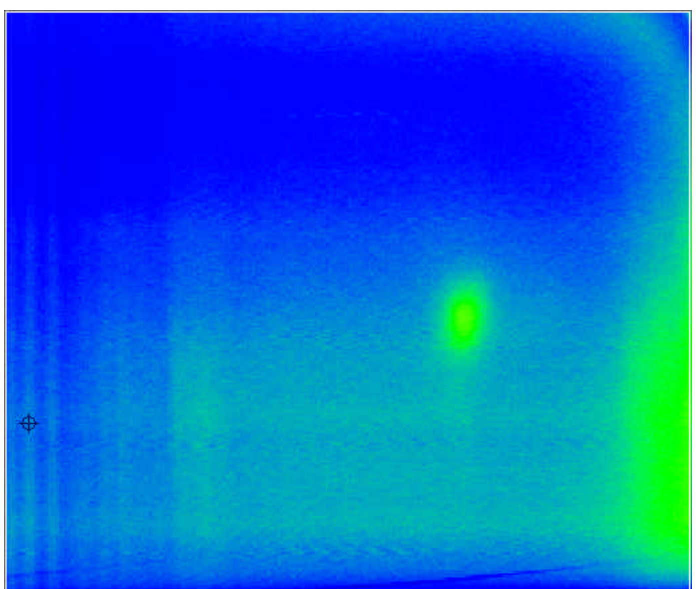


Diagnostics: screens

MTV 500 – CCD camera carbon screen

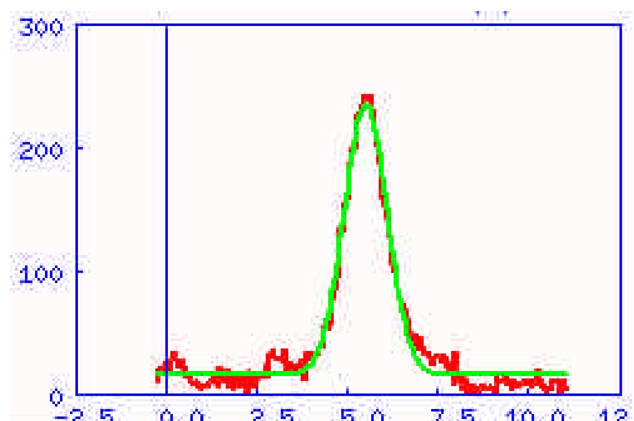
quad scan of August 13th





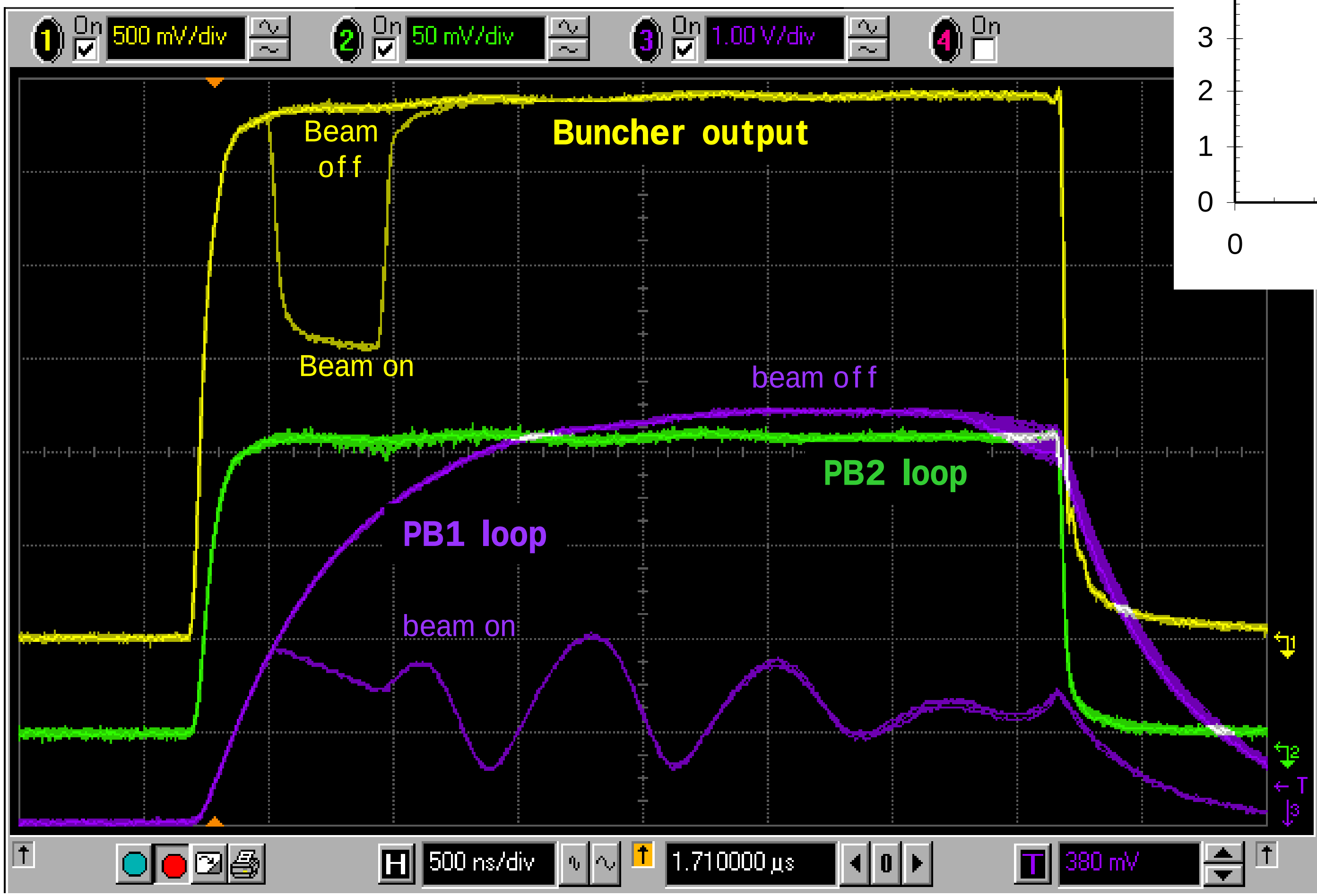
MTV 440 – Vidicom - aluminum screen

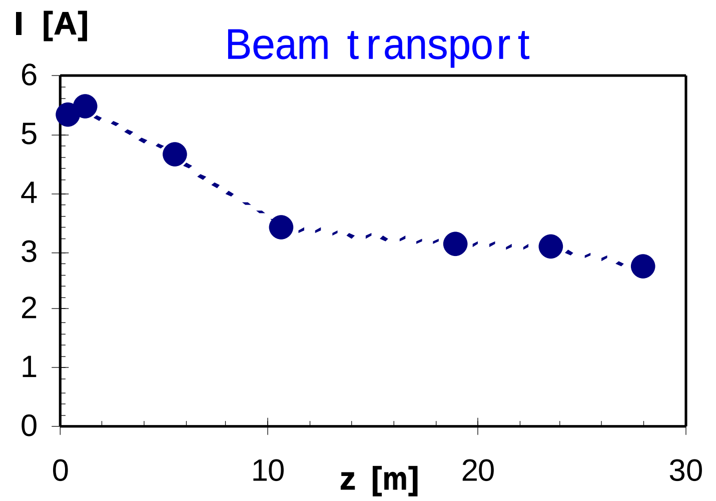
phase scan of August 5th



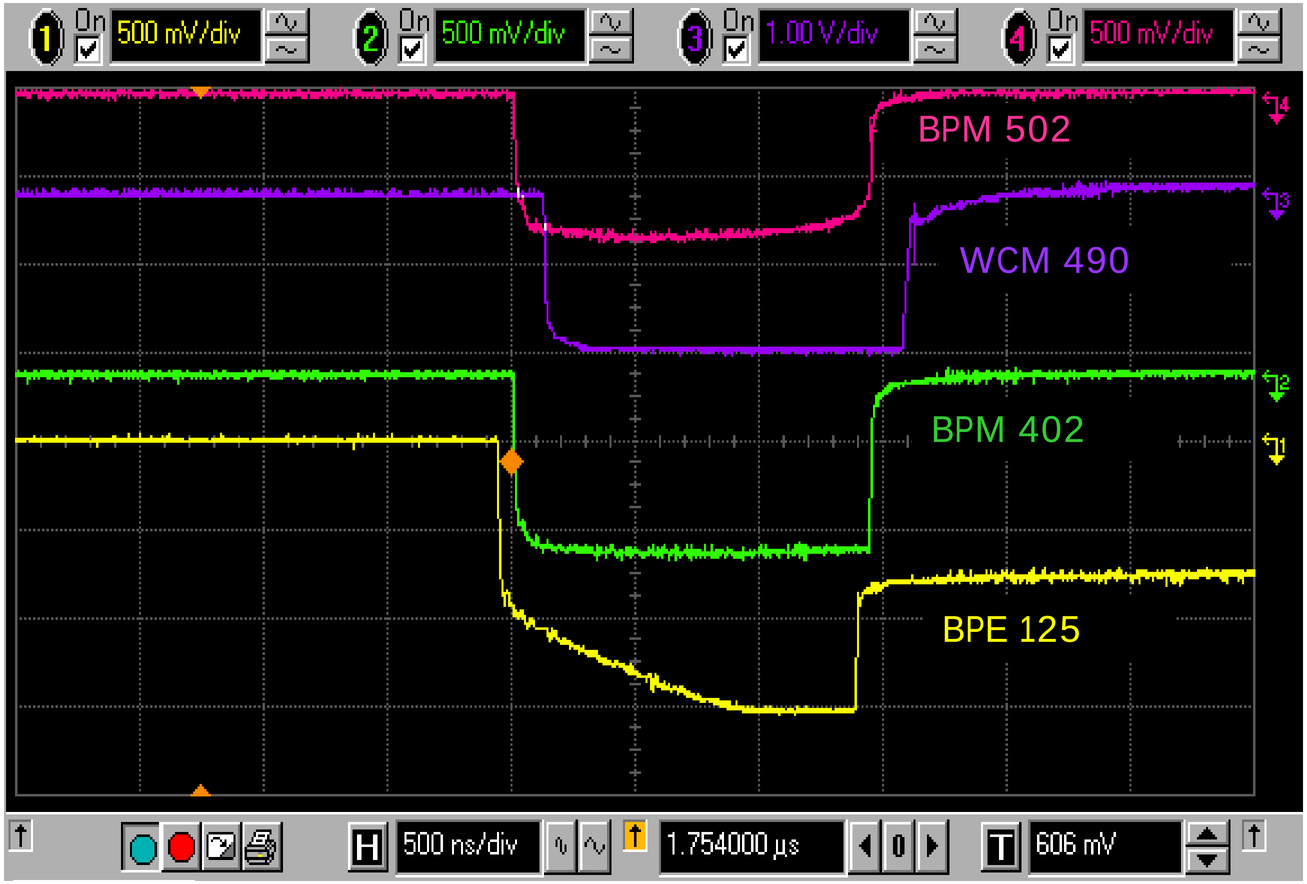
Operational limit with PB1

RF signals





Beam current measurements

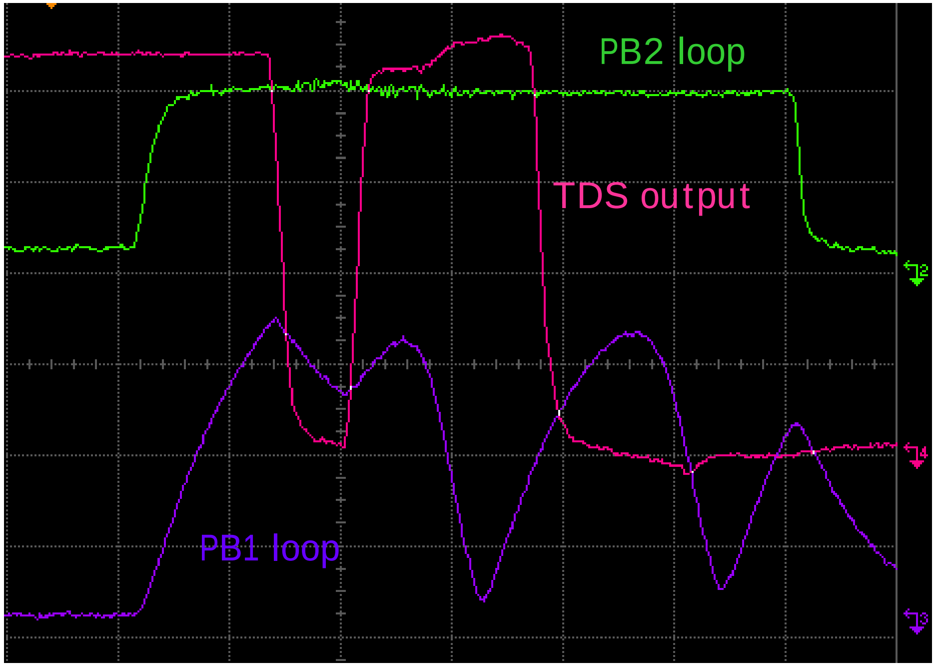


August 13th

6 A from gun
1.5 µs

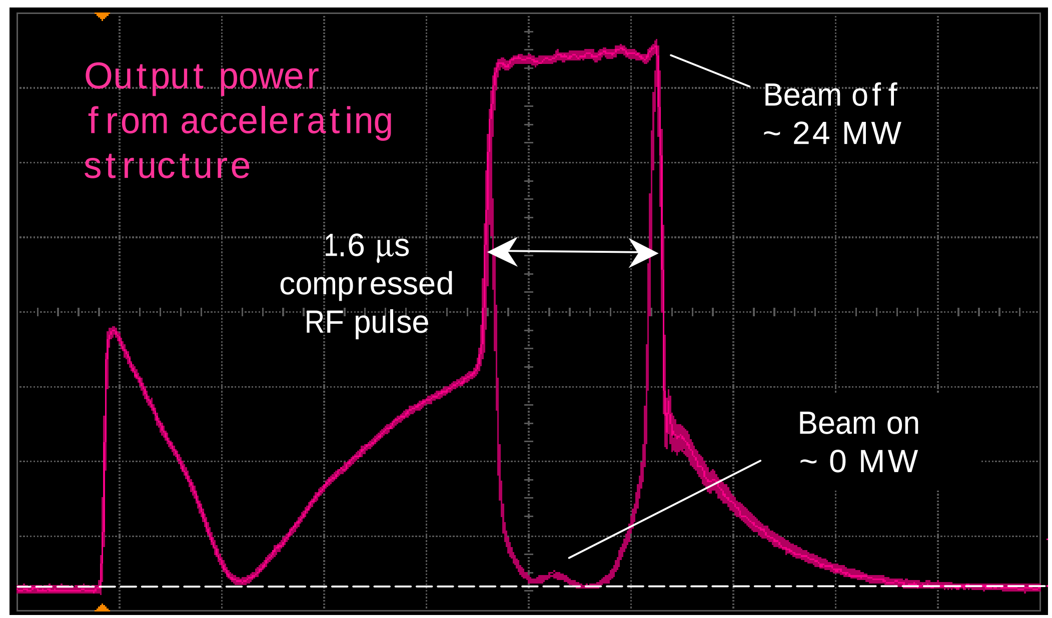
Analog signals from scope read-out

Beam loading I



First CTF3 fully loaded operation – no RF compression

August 5th (~ 3 A)



Full beam loading – compressed RF pulse

August 12th (3.5 A)

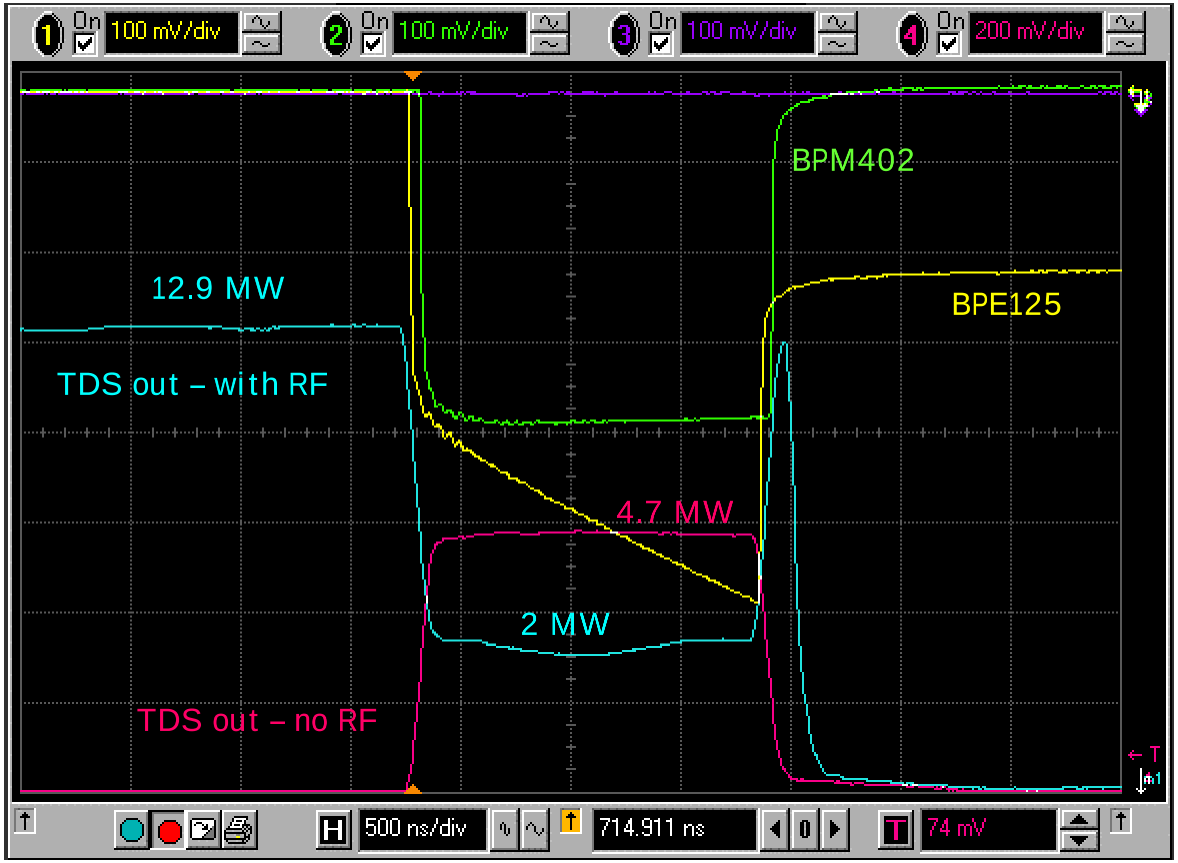
Beam loading II

Beam Loading experiment

- P_MKS03 = 31 MW – no pulse compression

- E = 20 MeV
- I_BPE125 = 2.2 A
- I_BPM402 = 2.06 A
- I_BPM502 = 1.73 A

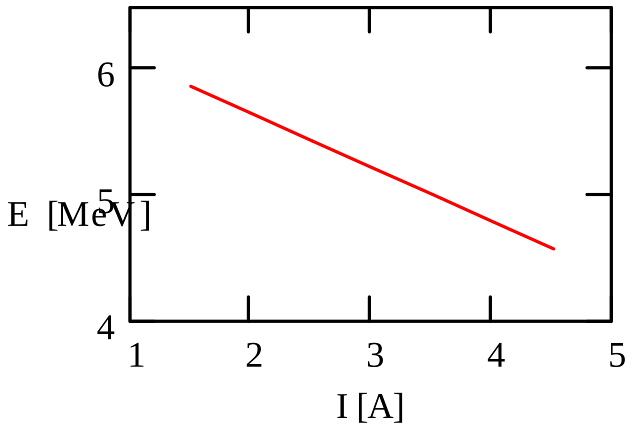
- Evaluate RF power out of TDS structure with and without RF, using output signals, peak power measurements at MKS03 output. Assumed 5% losses in waveguides plus attenuation in structure calculated with Erk's spreadsheet.



- Compare with calculations from Erk's spreadsheet:
  - With RF P_{out} = 2 MW for I = 1.8 A (ΔE = 13.26 MV)
  - Without RF P_{out} = 4.7 MW for I = 1.8 A (ΔE = -5.56 MV)

Beam Loading & Energy gain

- Assume energy gain in buncher as a function of beam current



- Calculate energy gain needed in ACS305 and ACS330 in order to reach 20 MeV (taking into account 5% losses in waveguides)
- Calculate (Erk's spreadsheet) power needed in each structure
- Compare with experimental data