Experience with X-band at FERMI@Elettra FEL

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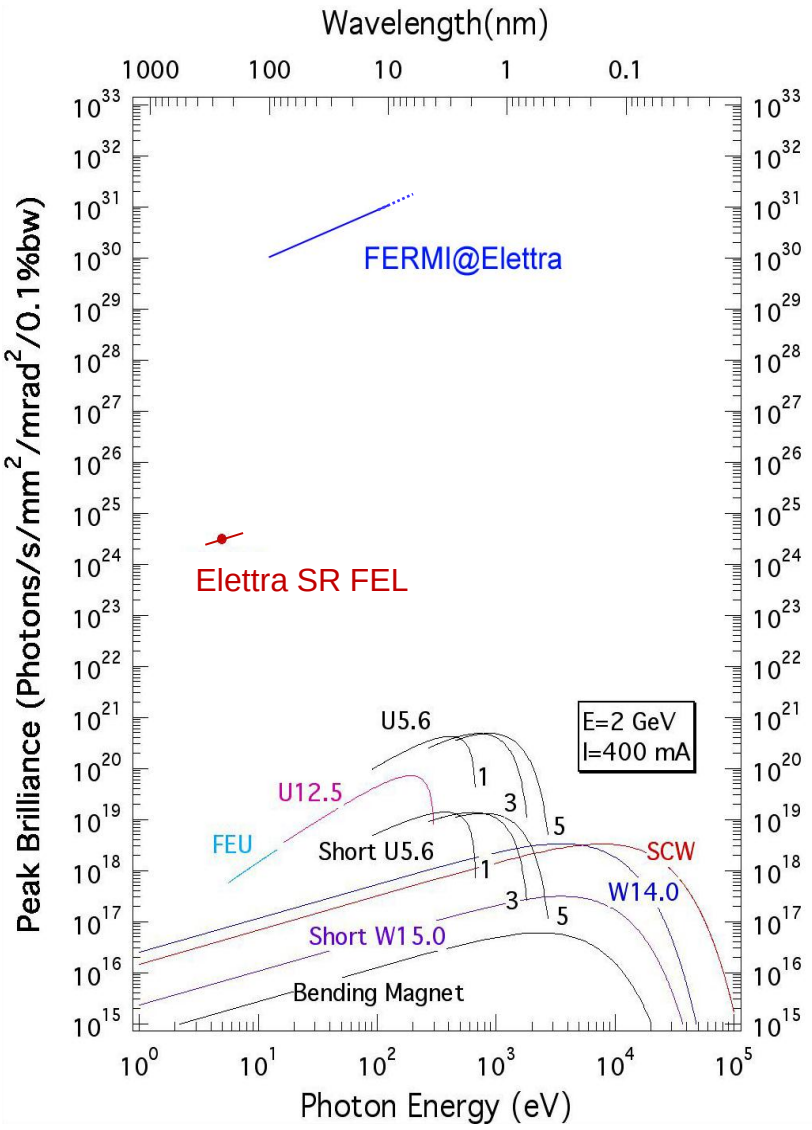
Outline

- **The FERMI@Elettra FEL project**
- ***X-band linearizer***
- ***RF power source:***
  - ***HV modulator***
  - ***XL5 klystron***
  - ***WG system***
- ***Preliminary beam tests***
- ***Future activities, opportunities and challenges***

Elettra Laboratory

FERMI@Elettra FEL project

FEL parameters	FEL 1	FEL 2
Output wavelength (nm, fundamental)	100-20	20-4
e-beam parameters	**FEL 1**	**FEL 2**
Energy (GeV)	1.2	1.5
Nominal charge (nC)	0.8	
Peak current (A)	900	
Bunch length, full width (fs)	700	
Slice normalized emittance (μmrad)	$\leq$ 1.0	
Projected normal. emittance (μmrad)	$\leq$ 2.0	
Uncorrelated energy spread, rms (keV)	150 KeV	
Total energy spread rms (%)	0.1	
Pulse to pulse energy stability rms (%)	0.1	
Timing jitter, rms (fs)	$\leq$ 150	
Undulator parameters	**FEL 1**	**FEL 2**
Period length (mm)	55	35
Minimum gap (mm)	10	
K param. @20 nm, 1.2 GeV	1.7	
K param. @10 nm, 1.2 GeV	1.0	
K param. @4 nm, 1.5 GeV		1.0



X-band linearizer

≥ 60 MW
~ 1 μs @ 50 Hz

HV modulator

LLRF

RF Driver

P < 1.0 KW
Δϕ ≤ 0.4°X
ΔV ≤ 0.5%

Klystron
SLAC XL5

12 GHz

WG system

P ≥ 30 MW, 200 ns

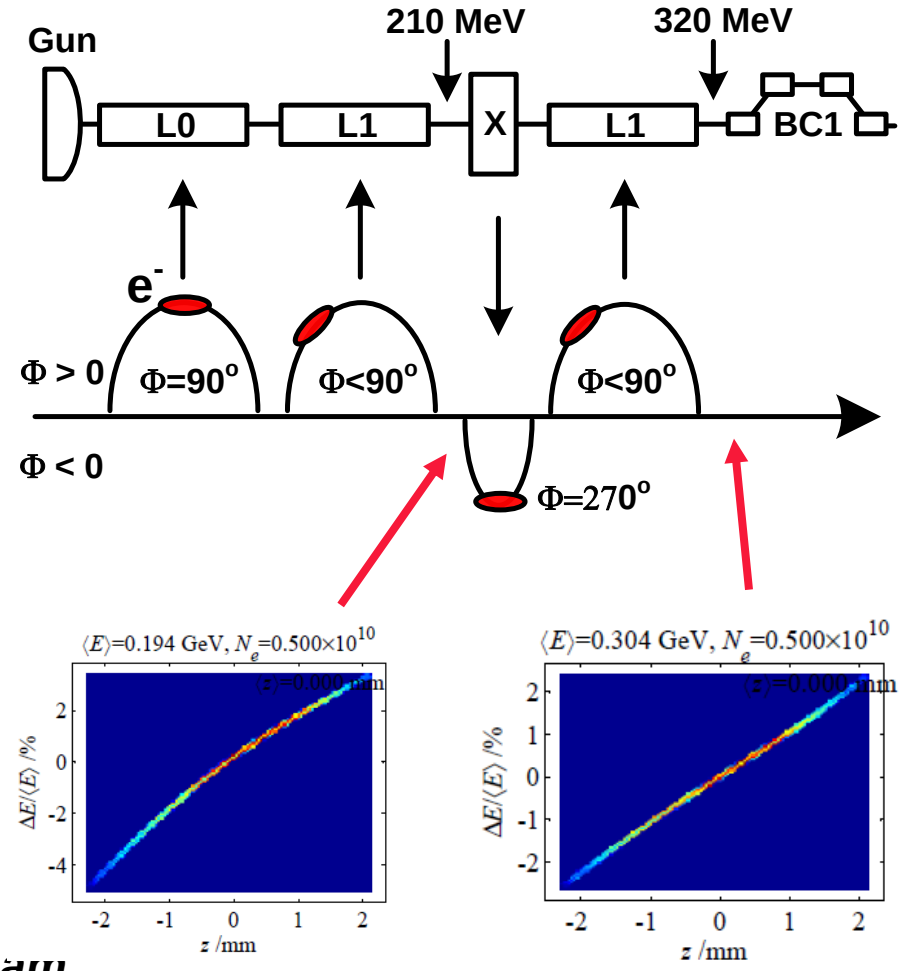
WR 90
(~ 20% losses)

RF load

Accel Section
12 GHz, 0.75 m

e⁻ beam

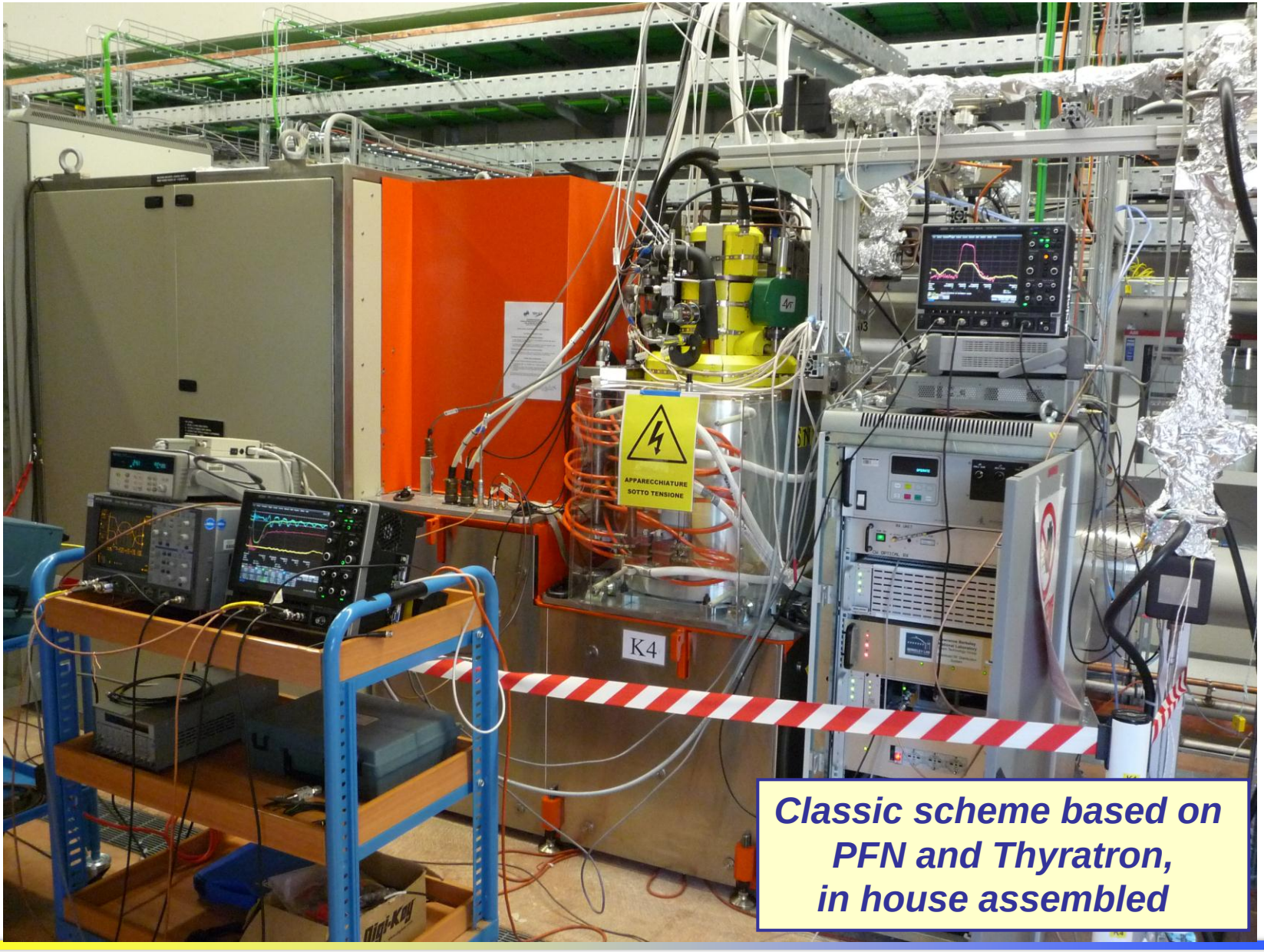
27- 32 MV/m



X-band system milestones

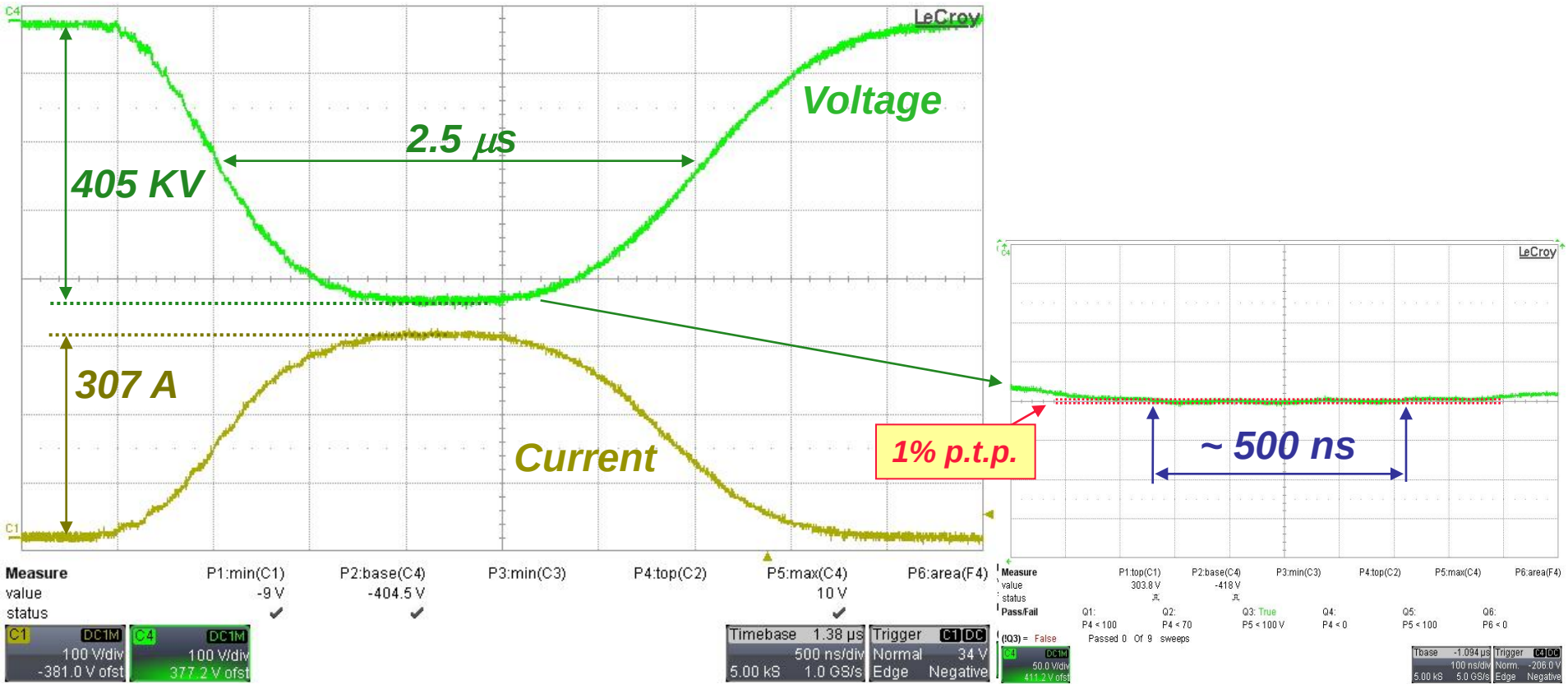
• Modulator completion and tests	July ‘11
• Klystron installation and tests (diode)	Sept. ‘11
• Accelerating structure and WG installations	Oct. ‘11
• XL5 activation and tests with RF	Nov.-Dec. ‘11
• XL5 gain curves verification (with SLAC)	Jan. ‘12
• RF power connection to accel. structure	Jan. ‘12
• RF conditioning (structure and WG system)	Febr. ‘12
• Preliminary beam tests	Febr.-March ‘12

RF power plant



Classic scheme based on PFN and Thyratron, in house assembled

Klystron driving pulses



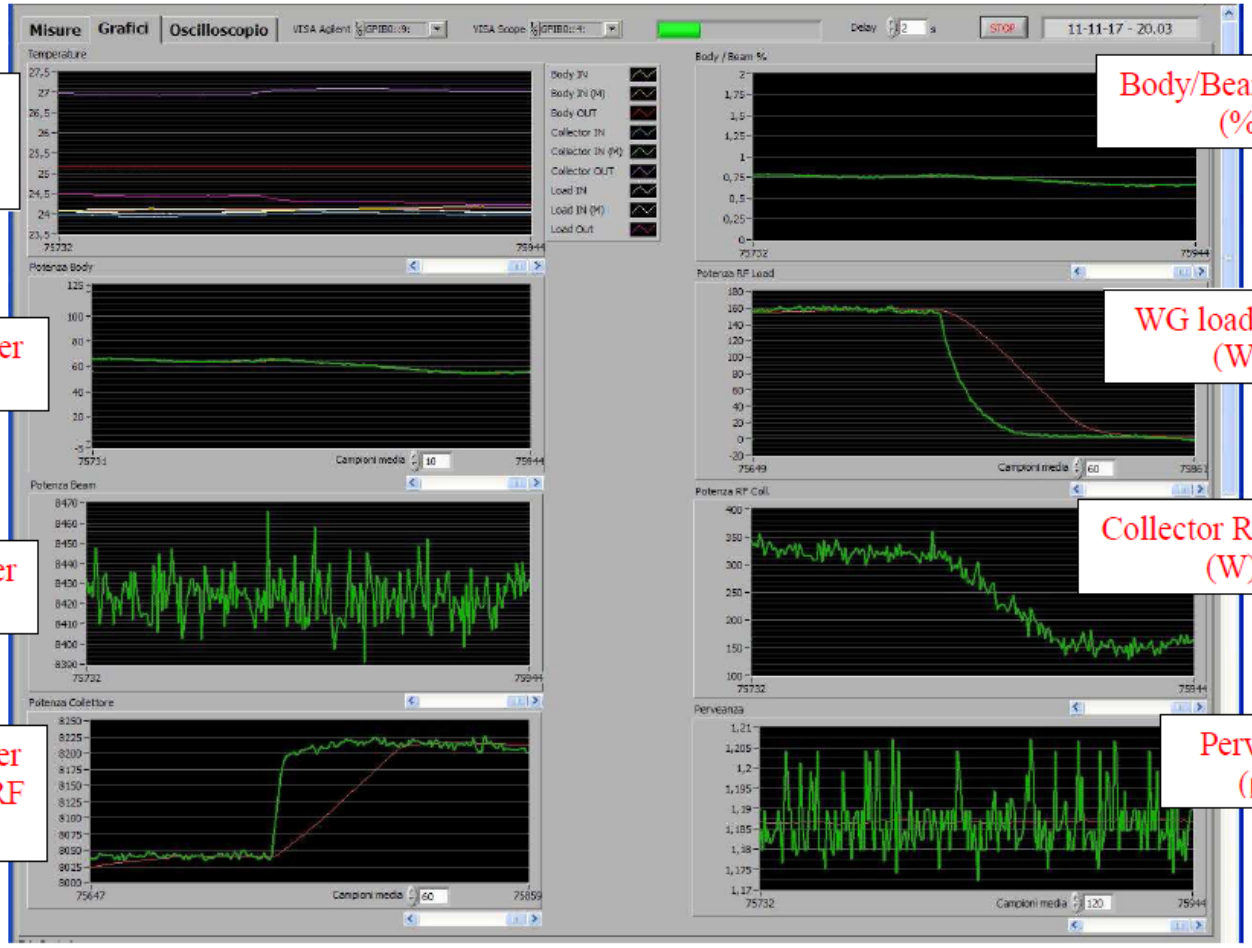
Klystron operation

XL5-1B Operation data

In diode mode at 50 Hz p.r.r.									With 300 nsec RF	
				Calorimetric measurements		V and I integrals				
Charging voltage	Anodic voltage	Anodic current	Micro perveance	Body power	Collector power	Collector power	Beam losses	Transm. effic.	Input RF power	Output RF power
V_{fug}(KV)	V_k(KV)	I_k(A)	(μP)	B_p(W)	C_p(KW)	C_p(KW)	B_L(%)	η(%)	RF_{in}(W)	RF_{out}(MW)
33.3	350	245	1.18	83	8.40	8.37	0.98	99.02	571	9.1
34.5	360	259	1.20	79	9.00	9.23	0.88	99.12	571	12.1
35.7	370	267	1.19	91	9.64	9.87	0.95	99.05	571	15.7
36.8	380	278	1.19	98	10.22	10.58	0.96	99.04	571	19.5
38.0	390	289	1.19	89	10.86	10.99	0.82	99.18	571	24.3
39.2	400	300	1.19	93	11.61	11.57	0.80	99.20	571	29.2
40.4	410	311	1.18	100	12.29	12.03	0.81	99.19	571	34.5

Filament hours (total)	2781
HV hours	1373
Diode	232
RF (WG loads)	678
RF (section and WG circuit)	463

Klystron activation



Water temperatures (°C)

Body power (W)

Beam power (W)

Collector power with and w/o RF (W)

Body/Beam power (%)

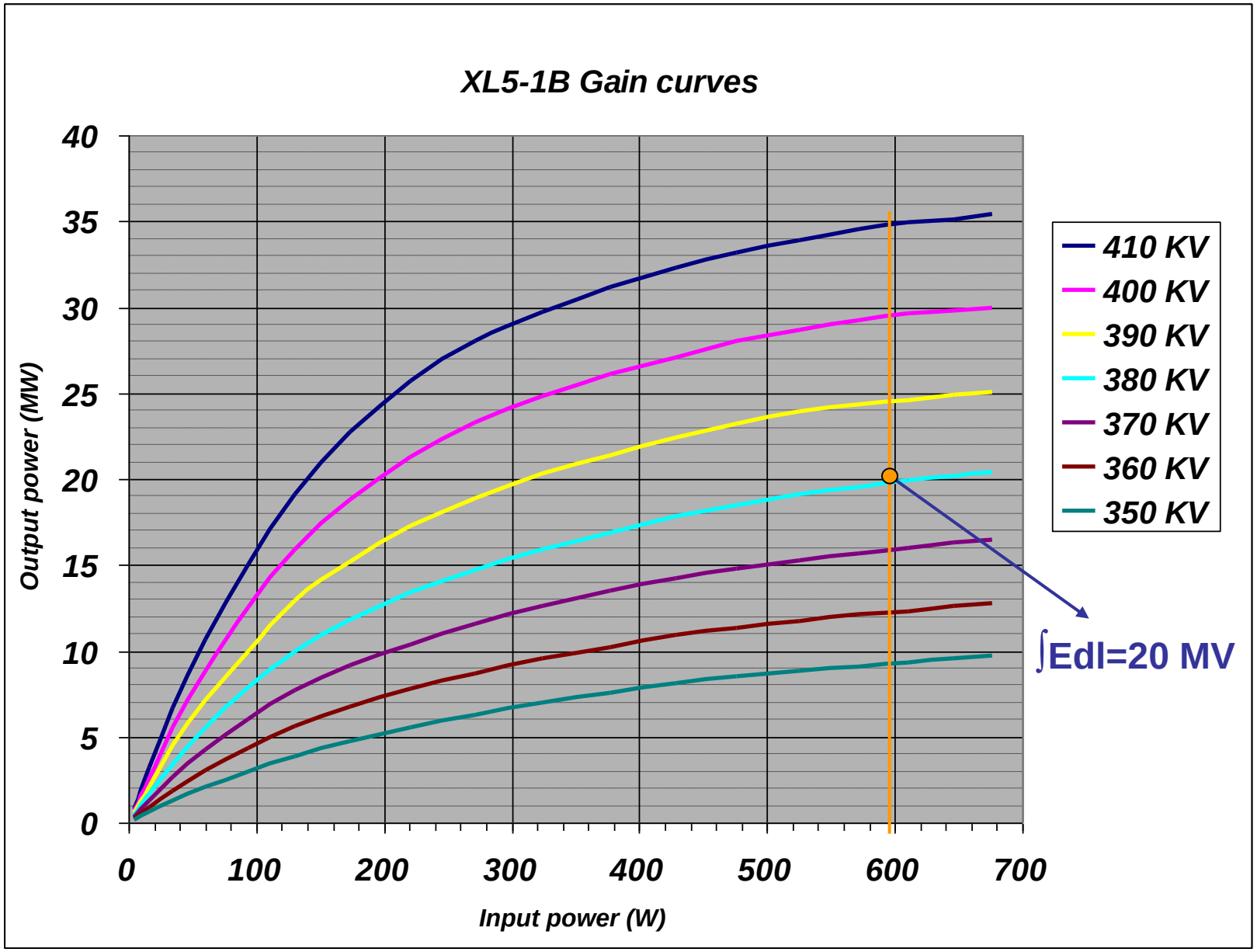
WG load power (W)

Collector RF power (W)

Perveance (µP)

Calorimetric measurements

Klystron gain curves

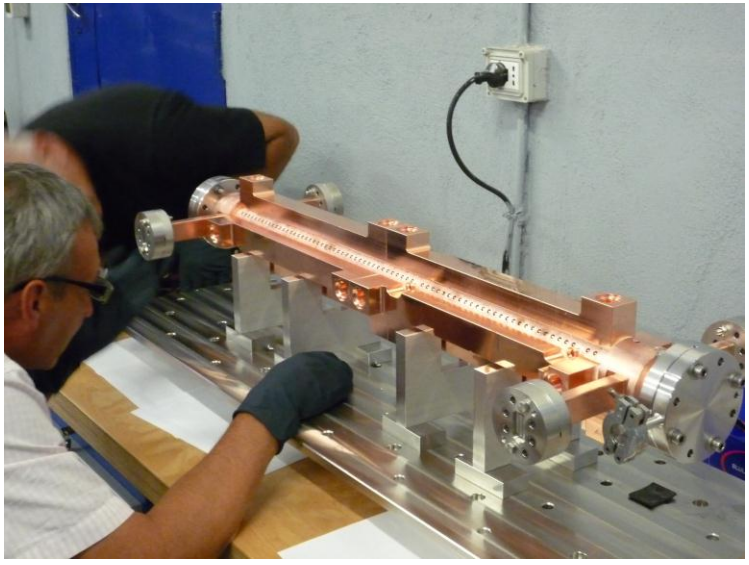


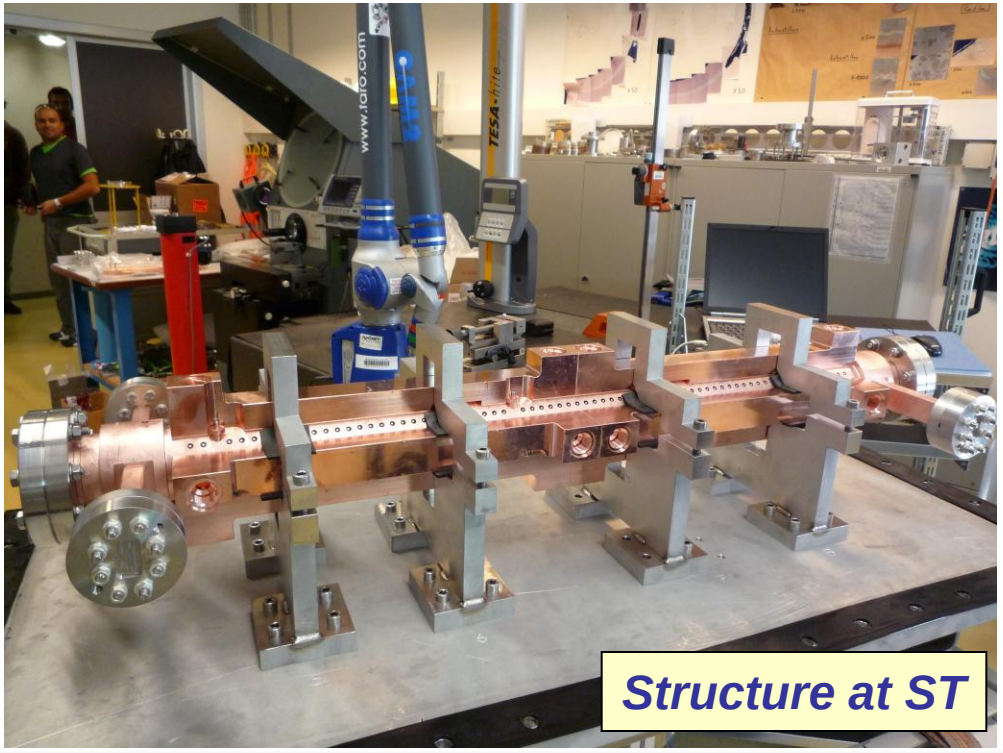
Structure vacuum baking

Structure vacuum bake-out at CO.ME.B. (Rome):

- ~ 350 hours
- oven pressure ≤ 10^{-8} torr
- T = 650 ^{o}C

Structure preparation

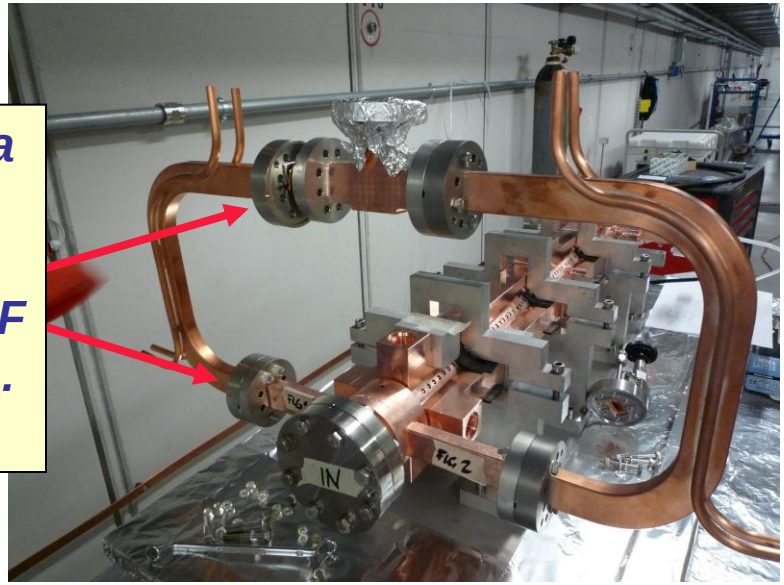


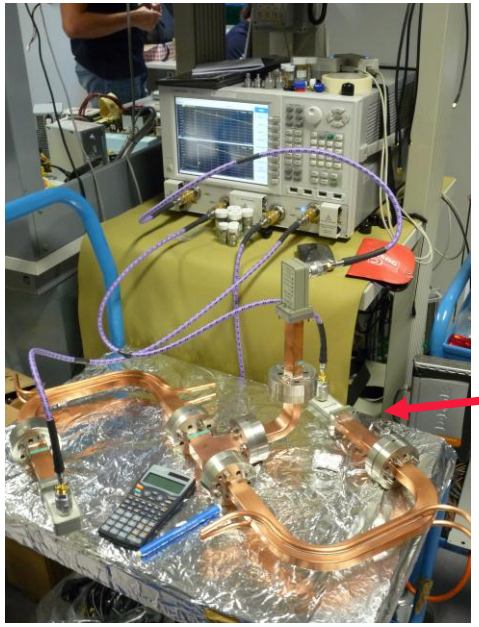


Structure at ST

Structure and WG installations

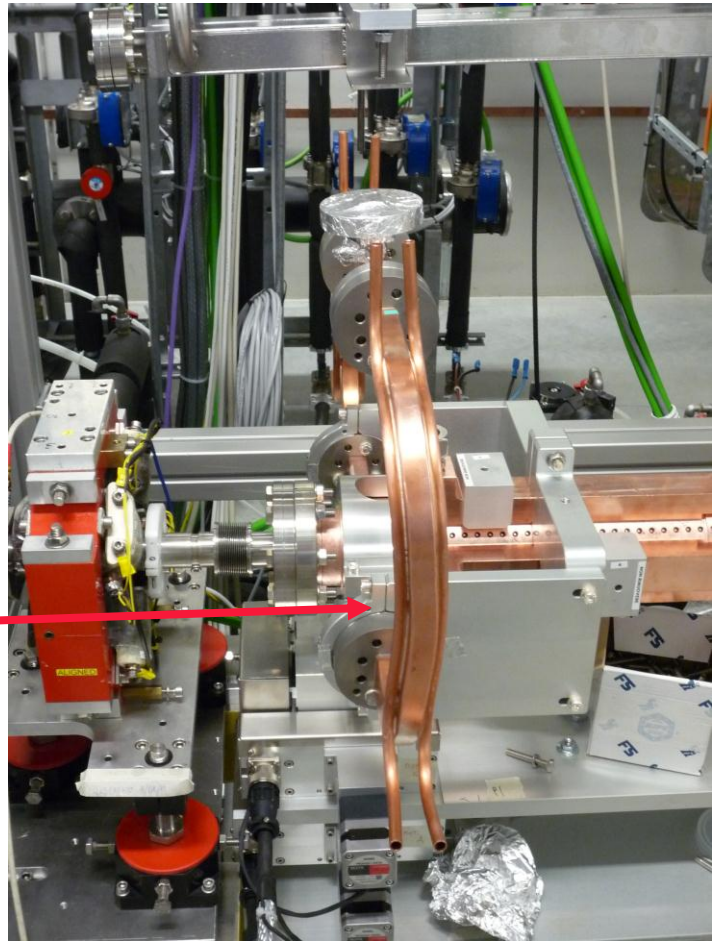
To recover a flange rotation of one of the RF input port …





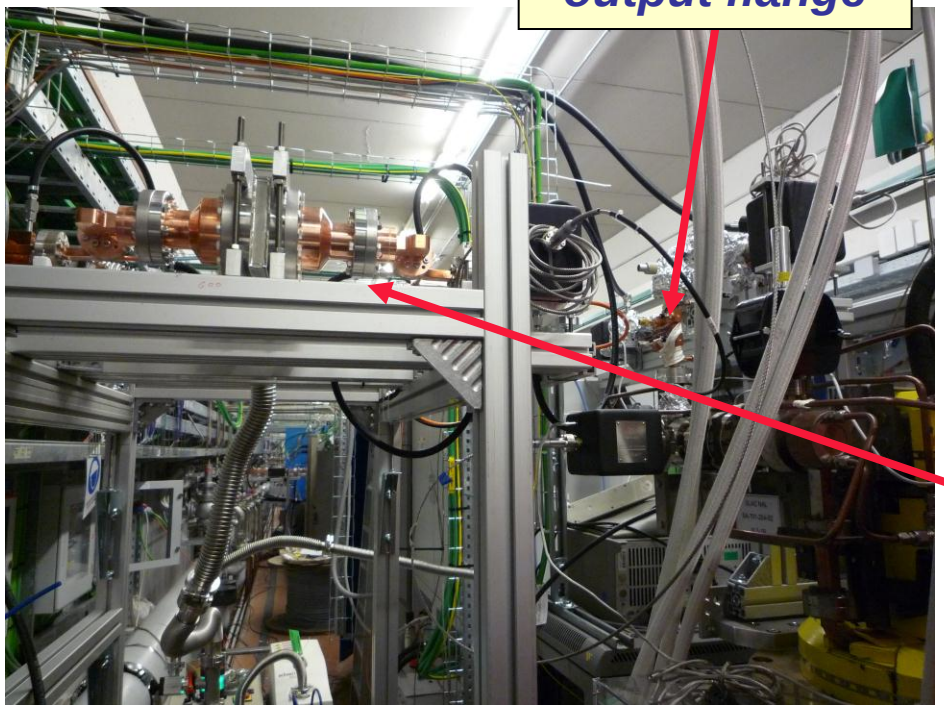
We were obliged to make a deformation on one of the RF "C" WG feedings.

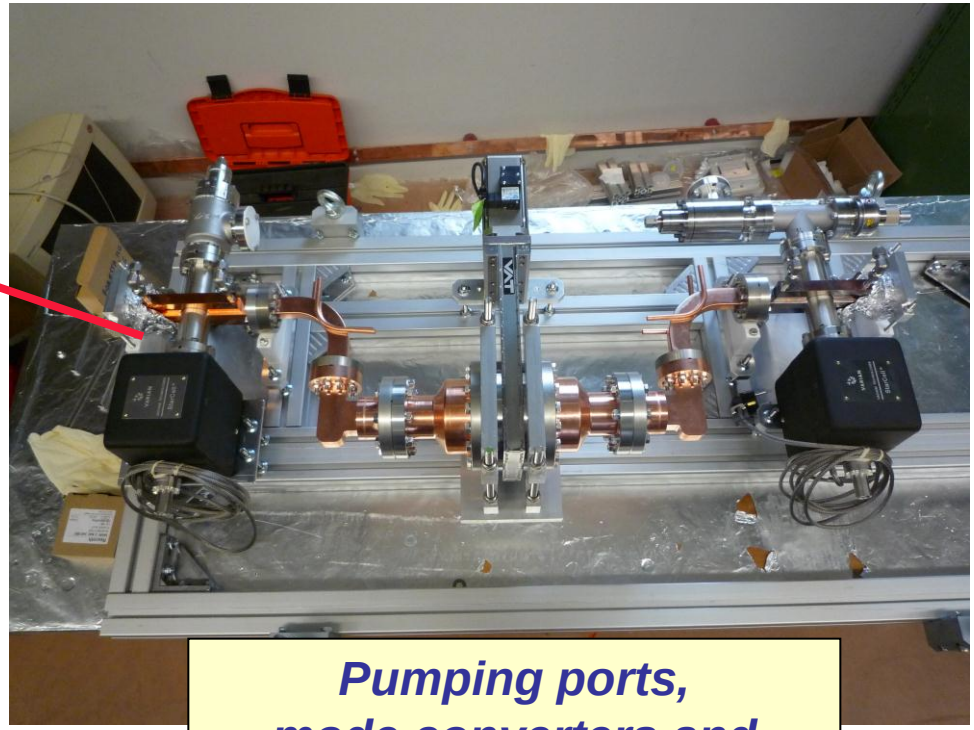
Both the "C" were re-calibrated after the deformation keeping ≤ 1°X phase unbalance



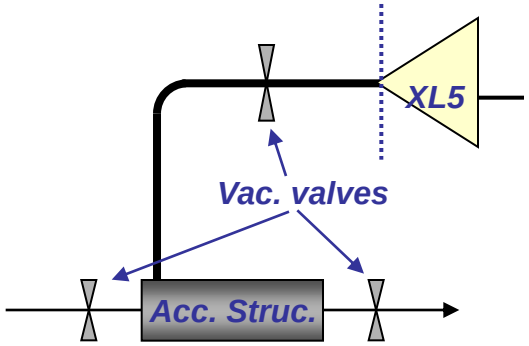
XL5 waveguide connection

Klystron output flange



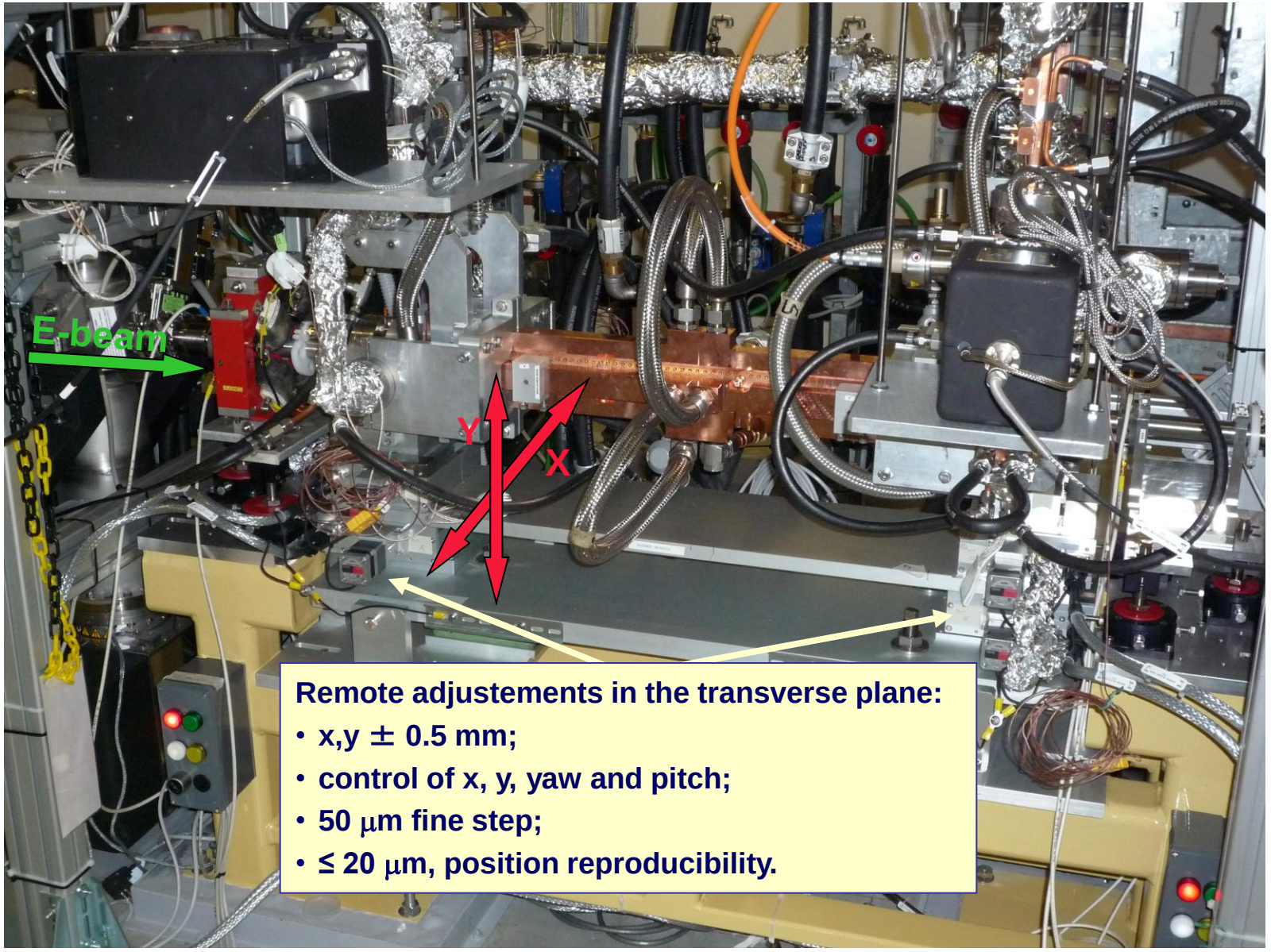


Pumping ports, mode converters and vacuum valve assembly



X-band plant with vacuum insulation

Structure installed

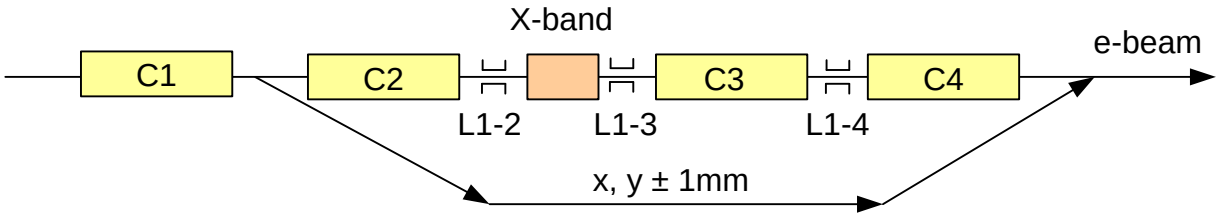


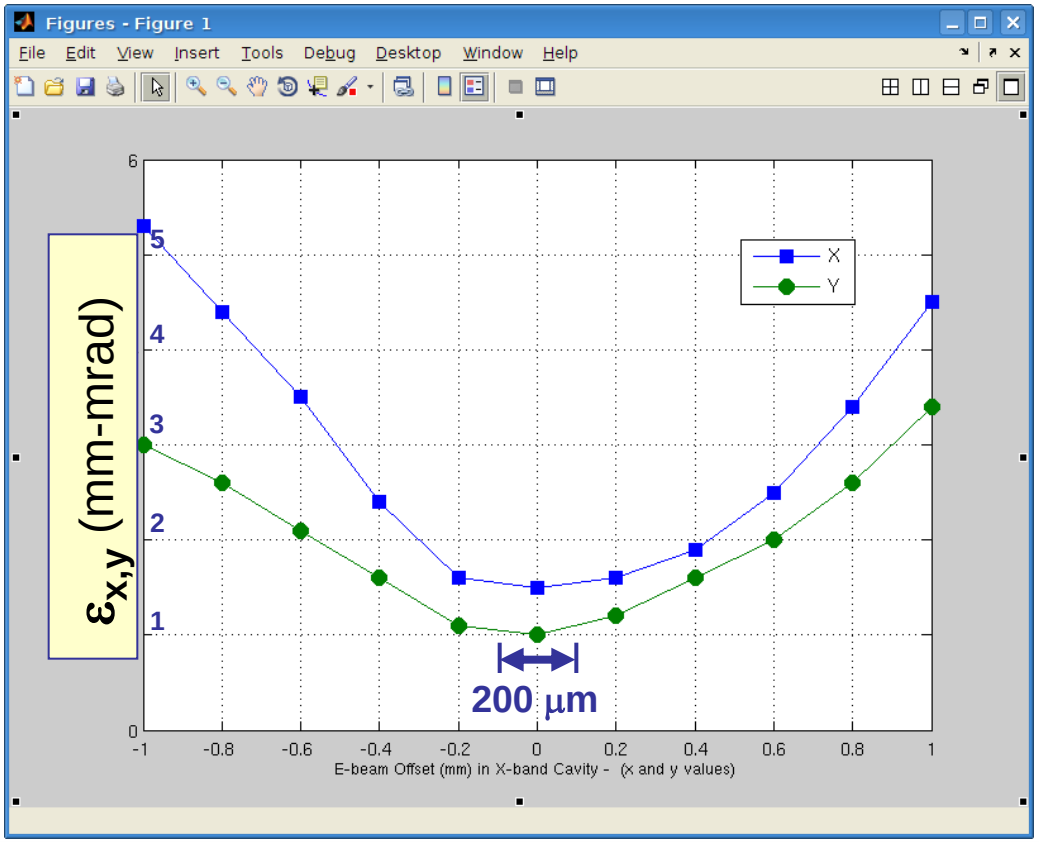
Remote adjustements in the transverse plane:

- **x,y ± 0.5 mm;**
- **control of x, y, yaw and pitch;**
- **50 μm fine step;**
- **≤ 20 μm, position reproducibility.**

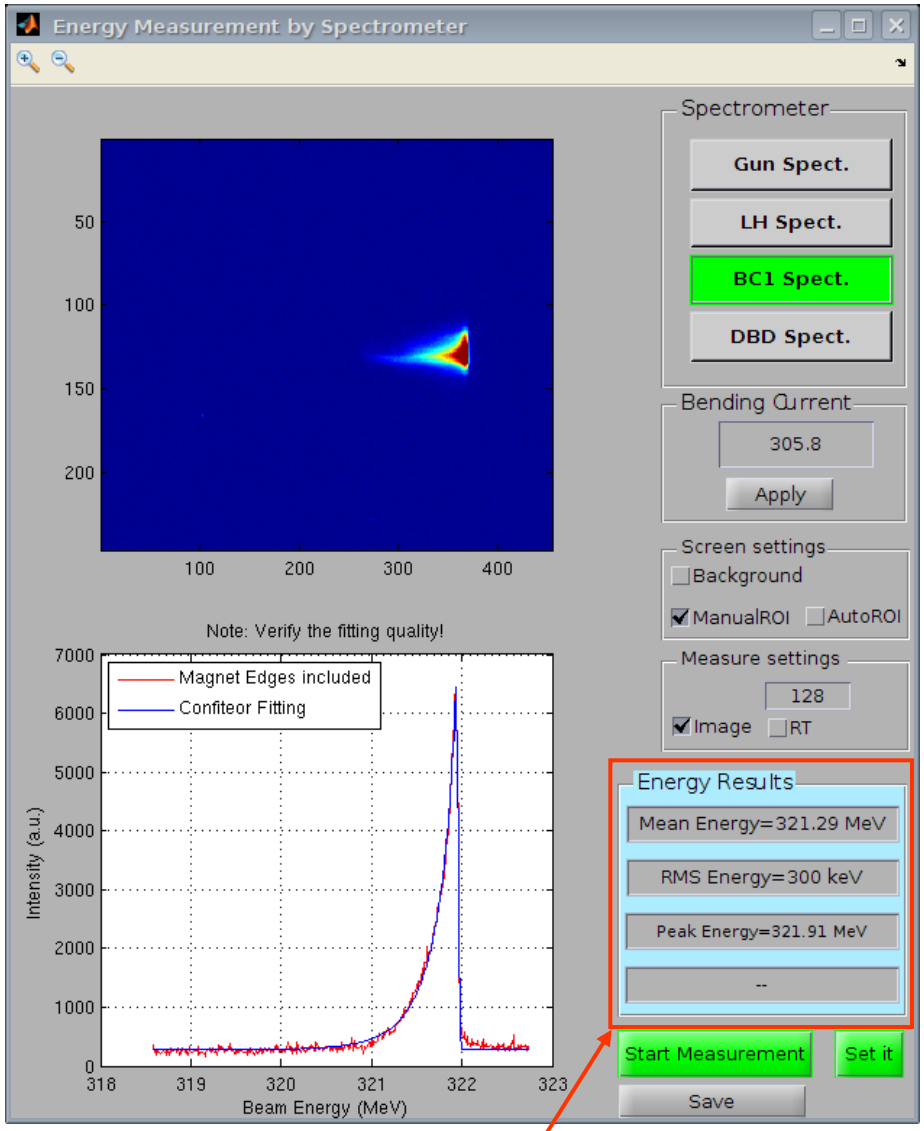
X-band beam effects

Measured ε_x and ε_y as we move the beam (6.5 ps_fwhm, 350 pC) along a line from ±1 mm in x-y, through the X-band structure (passive, no RF)

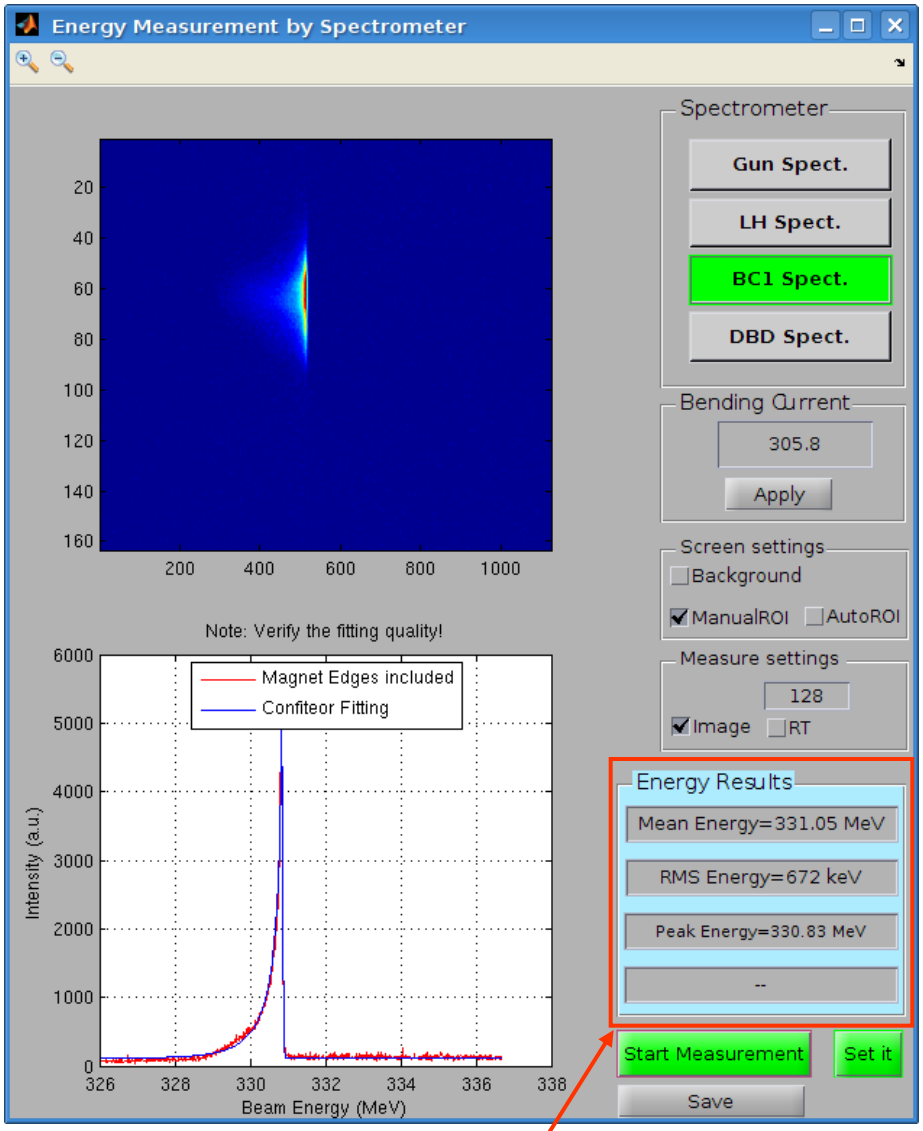




First beam tests with RF_27-02-12



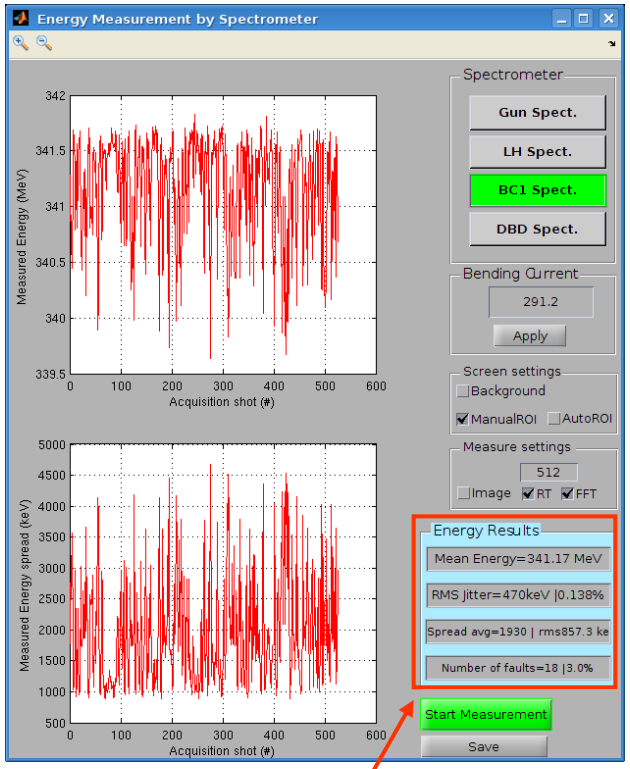
X-band OFF



X-band gain ~10 MeV

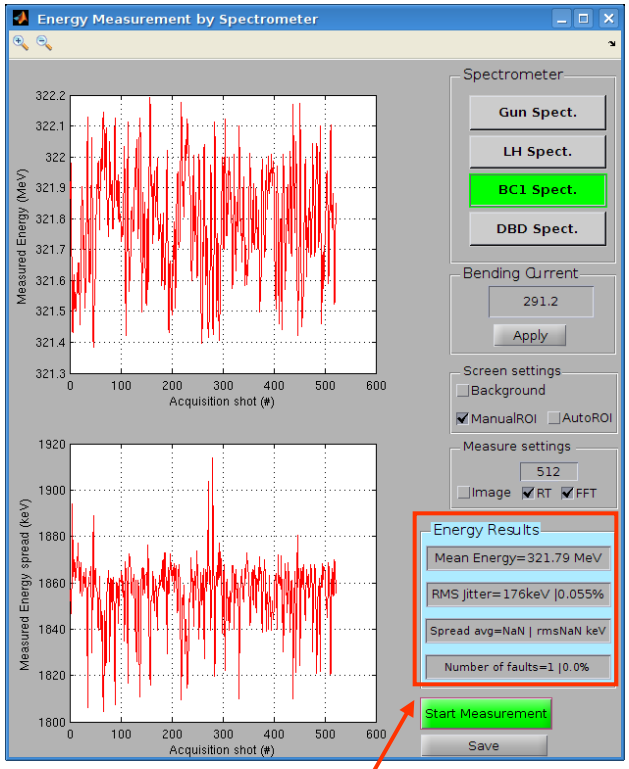
Beam energy jitter

Beam energy 341.2 MeV



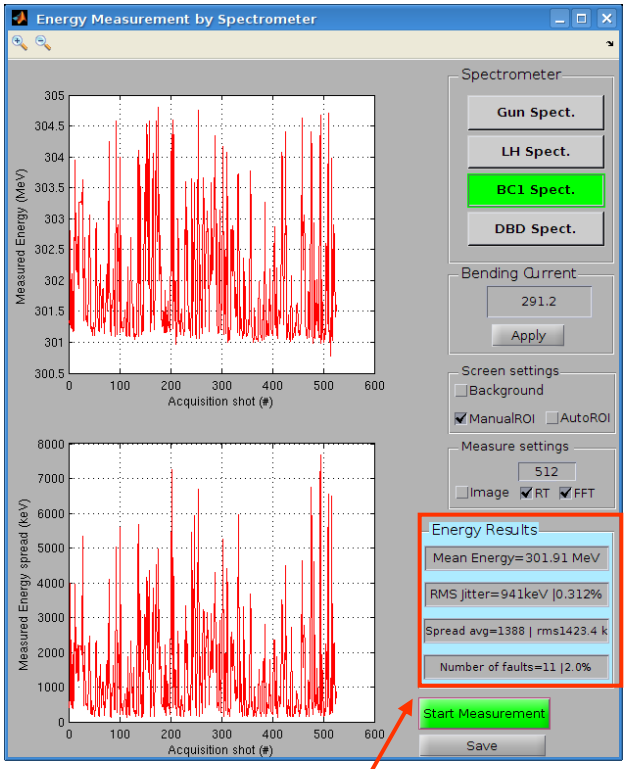
X-band set +20 MeV,
on crest (acceleration)
energy jitter ~500 keV (rms)

Beam energy 321.8 MeV



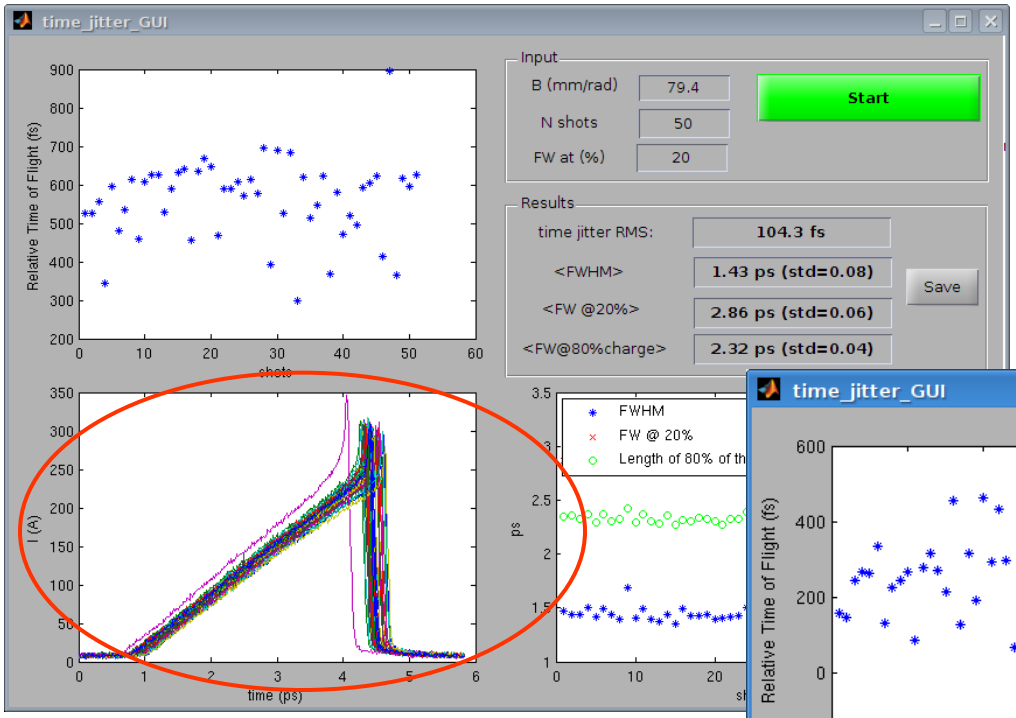
X-band at zero crossing,
no energy gain
energy jitter ~200 keV (rms)

Beam energy 301.9 MeV

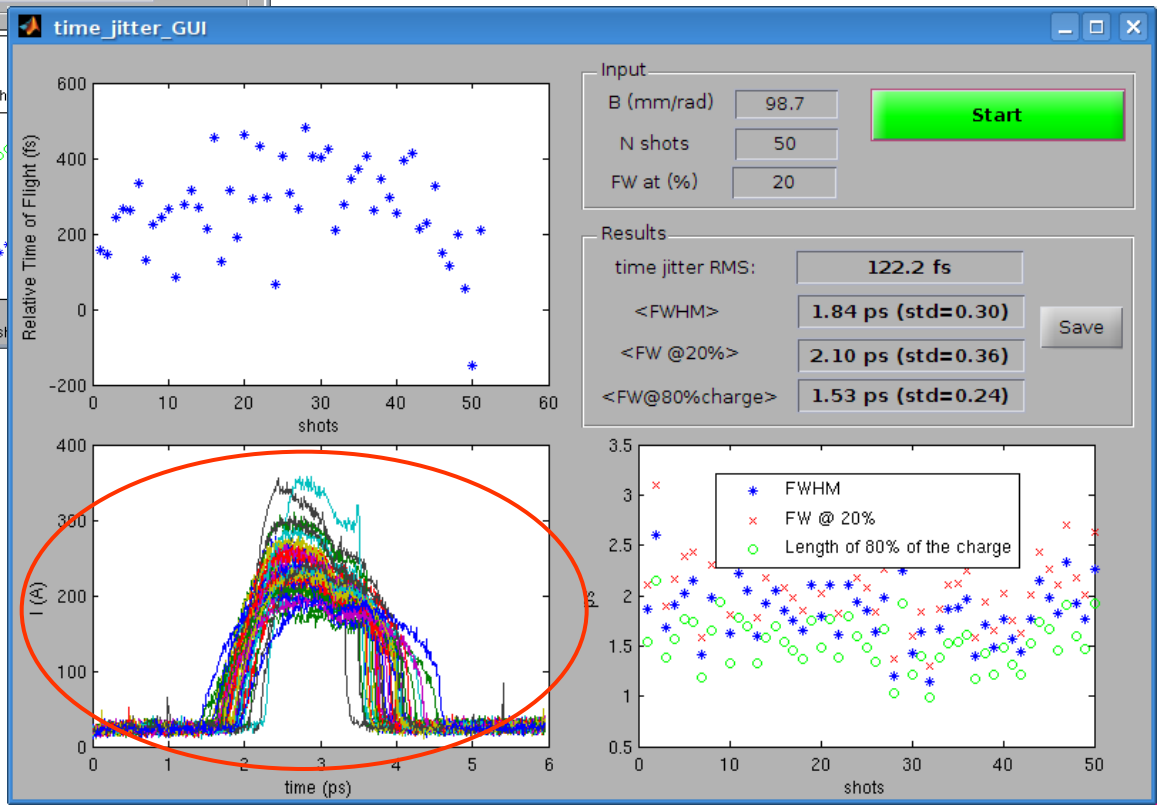


X-band set –20 MeV,
@180 deg (deceleration)
energy jitter ~900 keV (rms)

Beam compression



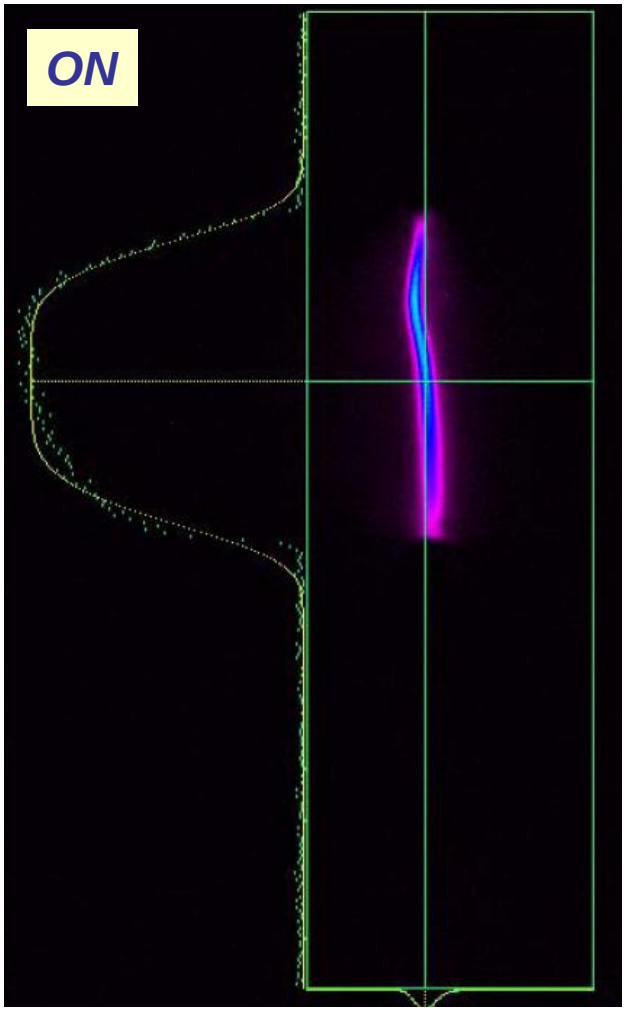
Without X-band



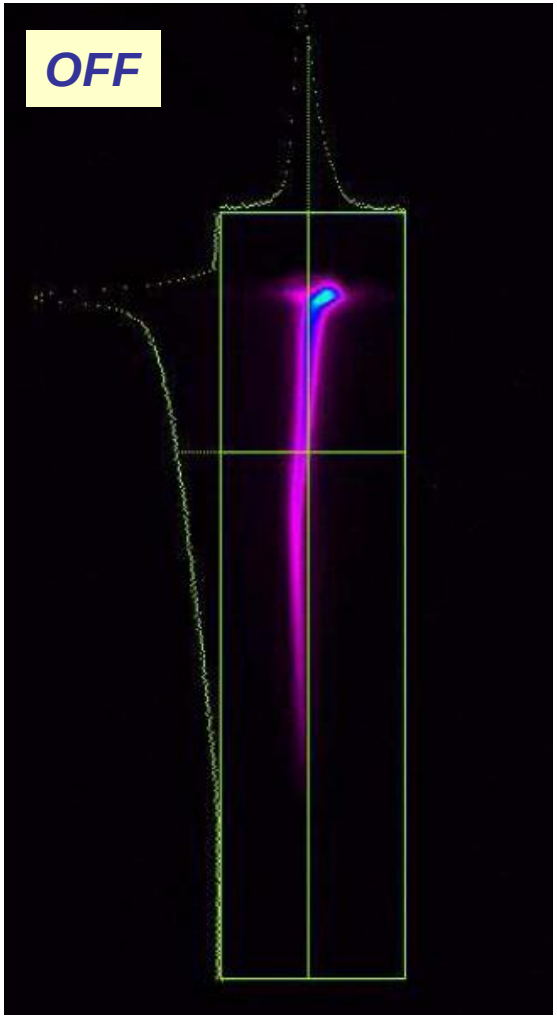
With X-band at -17.5 MeV

Charge distribution analysis with deflecting cavities

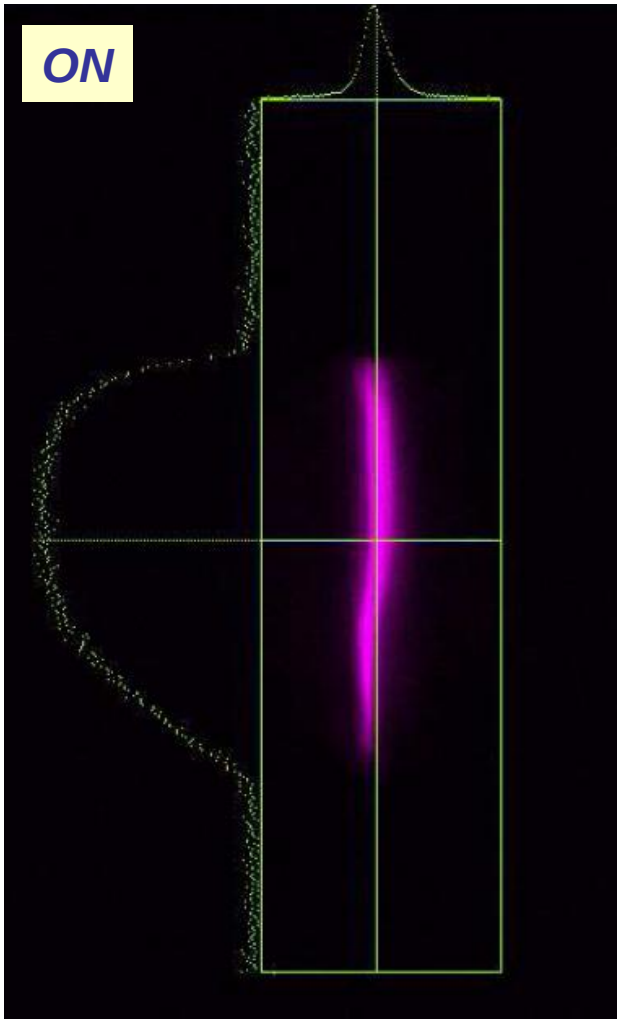
X-band @-19 MeV



mscrccd_bc01.03
@ 300 MeV



mscrccd_tls.03
@ 1.2 GeV



mscrccd_tls.03
@ 1.2 GeV

Future activities and challenges

Short term program on the linearizer

- Full structure characterization with the beam:
  - improve the RF field stability and the beam energy jitter
  - find the best operating point checking the compression factor, R_{56}…
  - measure the beam kick due to the RF couplers
  - verify the wake fields effects
- Activation of the wake field monitors

Future opportunities and challenges

- Assembly of a second RF station
- Acceleration tests of very short bunch at energy > 1 GeV and beam quality measurements

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