X-band activities at FERMI FEL project in Trieste

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Outline

- The FERMI@Elettra FEL project
- *X-band linearizer*
- *RF power source:*
  - *HV modulator*
  - *XL5 klystron*
  - *Accelerating structure and WG system*
- *Preliminary beam tests*
- *Outlook and conclusions*

Elettra Laboratory

FERMI@Elettra FEL project

Parameter	FEL1	FEL2
Wavelength (nm)	80-20	20-4
Electron beam energy (GeV)	1.2	1.5
Bunch charge (nC)	800	
Bunch length FWHM (fs)	500	
Peak current (A)	800	
Normalized emittance slice (μrad)	≤ 1.2	≤ 1.0
Energy spread slice (KeV)	≤ 250	≤ 150
Repetition rate (Hz)	10-50	

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

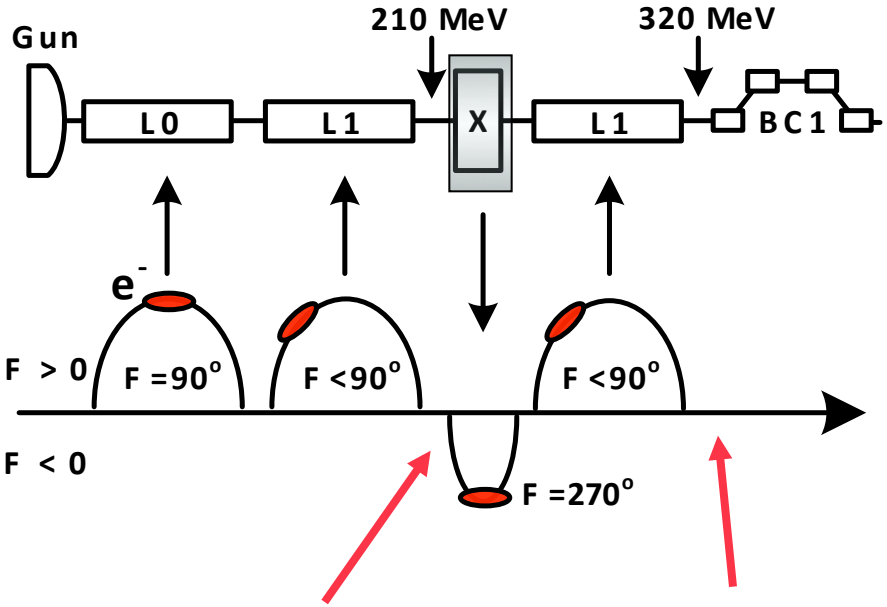
WR 90
(~ 20% losses)

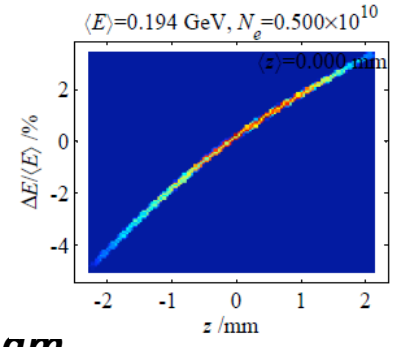
RF load

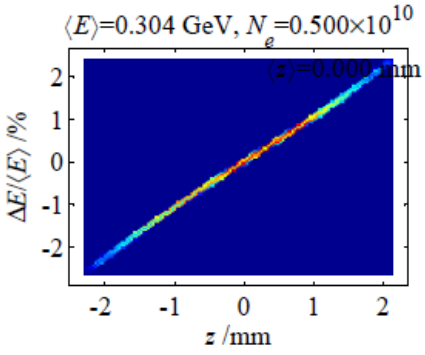
Accel Section
12 GHz, 0.75 m

e⁻ beam

27- 32 MV/m







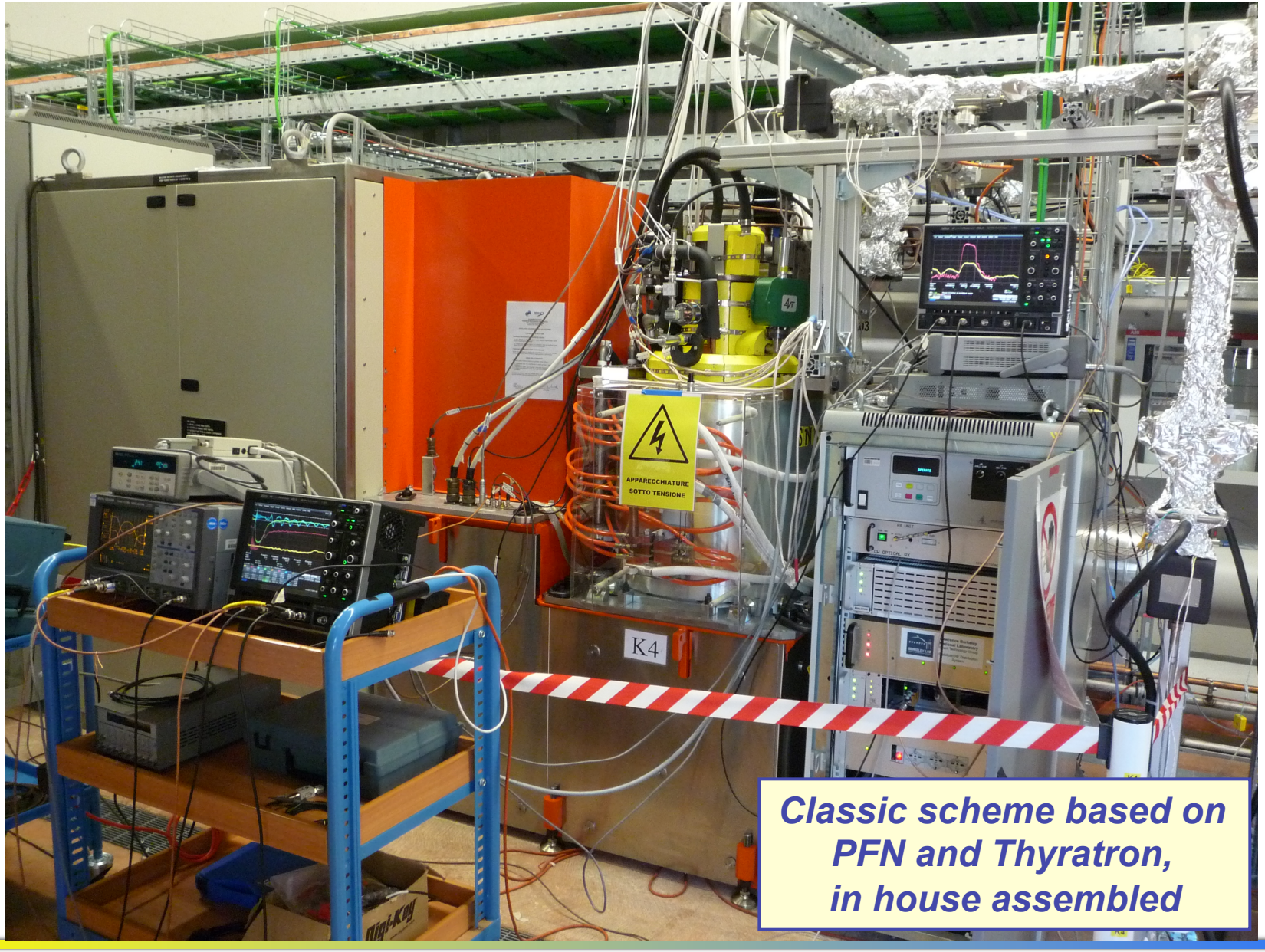
The X-band project

- *When the X-band program started, none of the components of the system were commercially available.*
- *For this reason a program for their development was activated and a three years grant from Regione Friuli Venezia Giulia was awarded (2009 – 2011, now extended up to 2013).*
- *To address the very challenging tasks, we decided to set up three important collaborations with external institutes:*
  - *On Feb. 19th 2009, together with CERN and PSI, a MoU with SLAC, for the construction of five X-band klystrons (scaled at European frequency of 11.992 GHz), was signed. Two klystrons for Elettra, two for PSI and one for CERN.*
  - *On Nov. 17th 2009, we have activated a collaboration with PSI for the construction of four X-band structures.*
  - *For the high power WG components and for the construction of the structures, we decided to join the CLIC Collaboration (Compact Linear Collider) at CERN (MoU signed on April 30th 2010).*
- *For the HV modulator we decided to adopt an internal solution based on the PFN technology.*

X-band system milestones

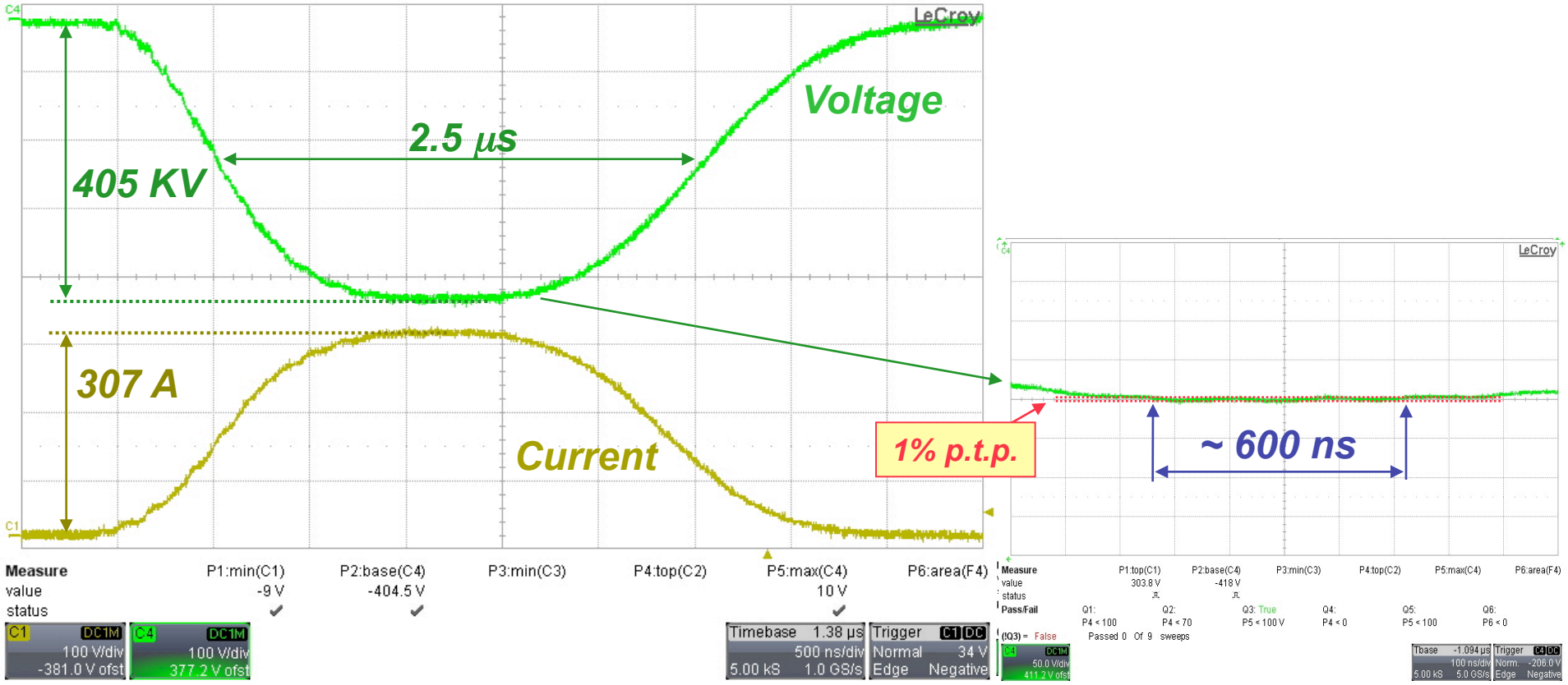
• Modulator completion and tests	July ’11
• First XL5 klystron at Elettra	August ‘11
• Klystron installation and tests (diode)	Sept. ‘11
• Accelerating structure and WG installations	Oct. ‘11
• XL5 activation and tests with RF	Nov.-Dec. ‘11
• XL5 gain curves verification (with SLAC)	Jan. ‘12
• RF power connection to accel. structure	Jan. ‘12
• RF conditioning (structure and WG system)	Febr. ‘12
• Preliminary beam tests	Febr.-March ’12
• LLRF improvements and second test phase	May ‘12

RF power plant



Classic scheme based on PFN and Thyratron, in house assembled

Klystron driving pulses



Klystron operation

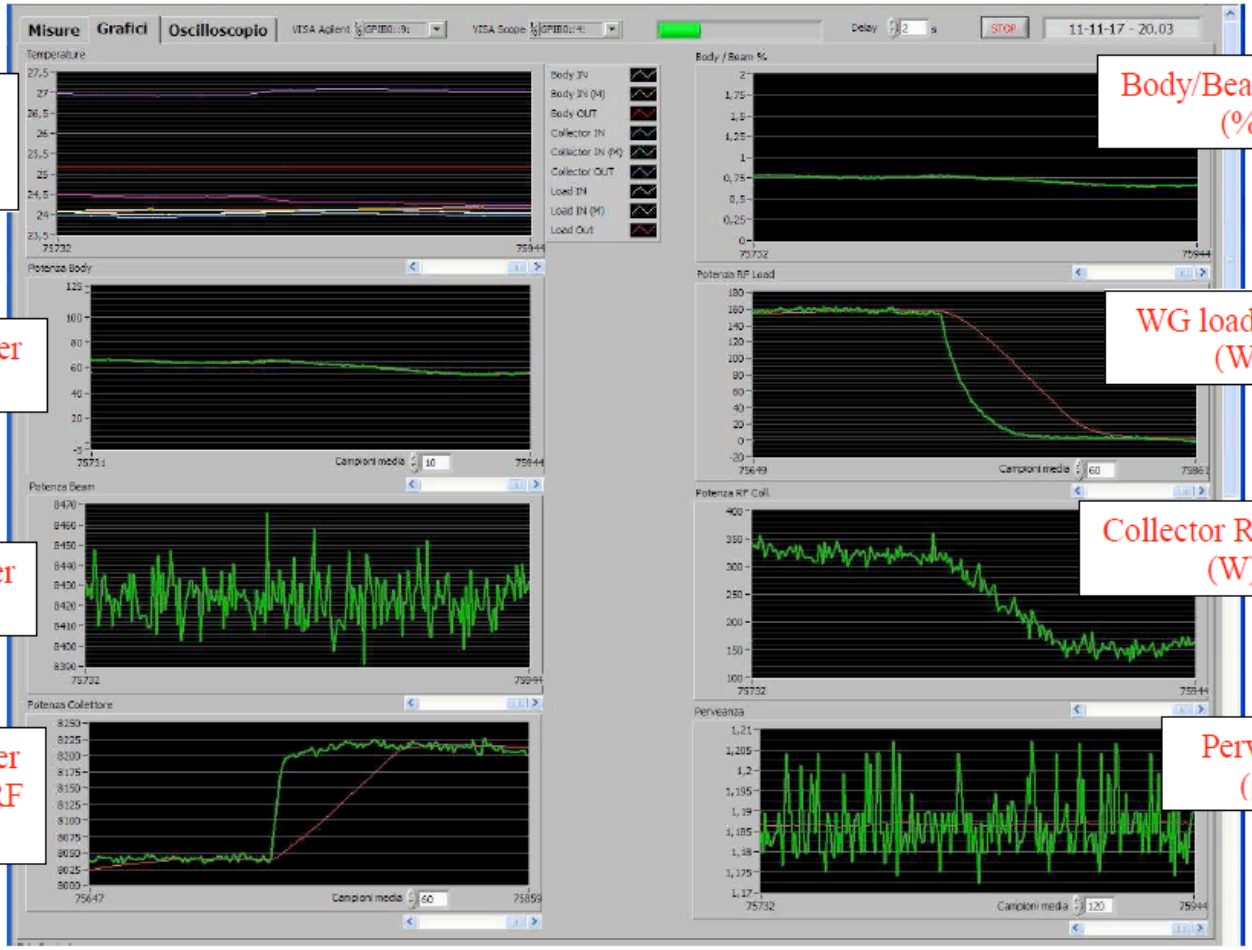
XL5-1B Operation data

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

← *Data up to April 2012*

Klystron activation



Water temperatures (°C)

Body power (W)

Beam power (W)

Collector power with and w/o RF (W)

Body/Beam power (%)

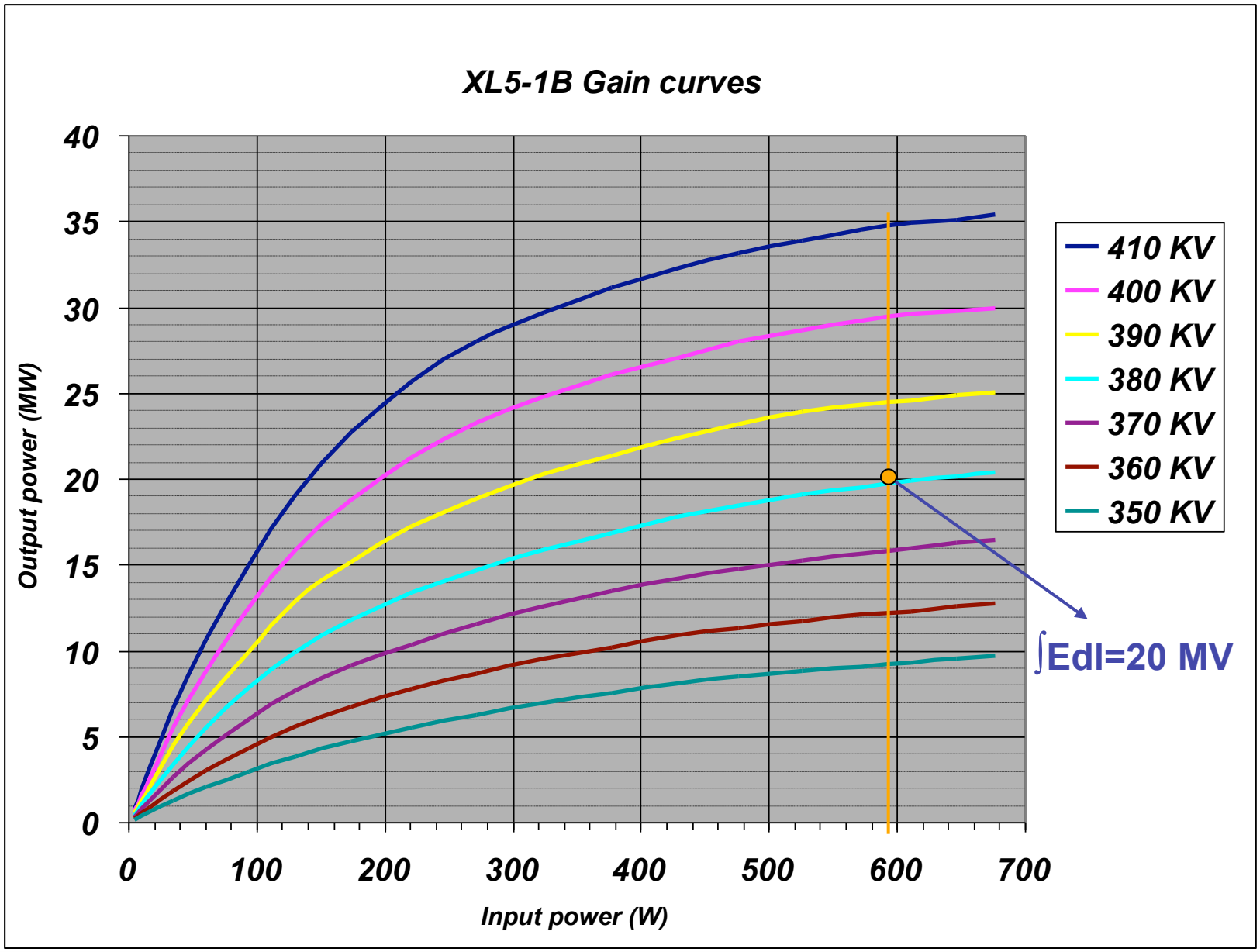
WG load power (W)

Collector RF power (W)

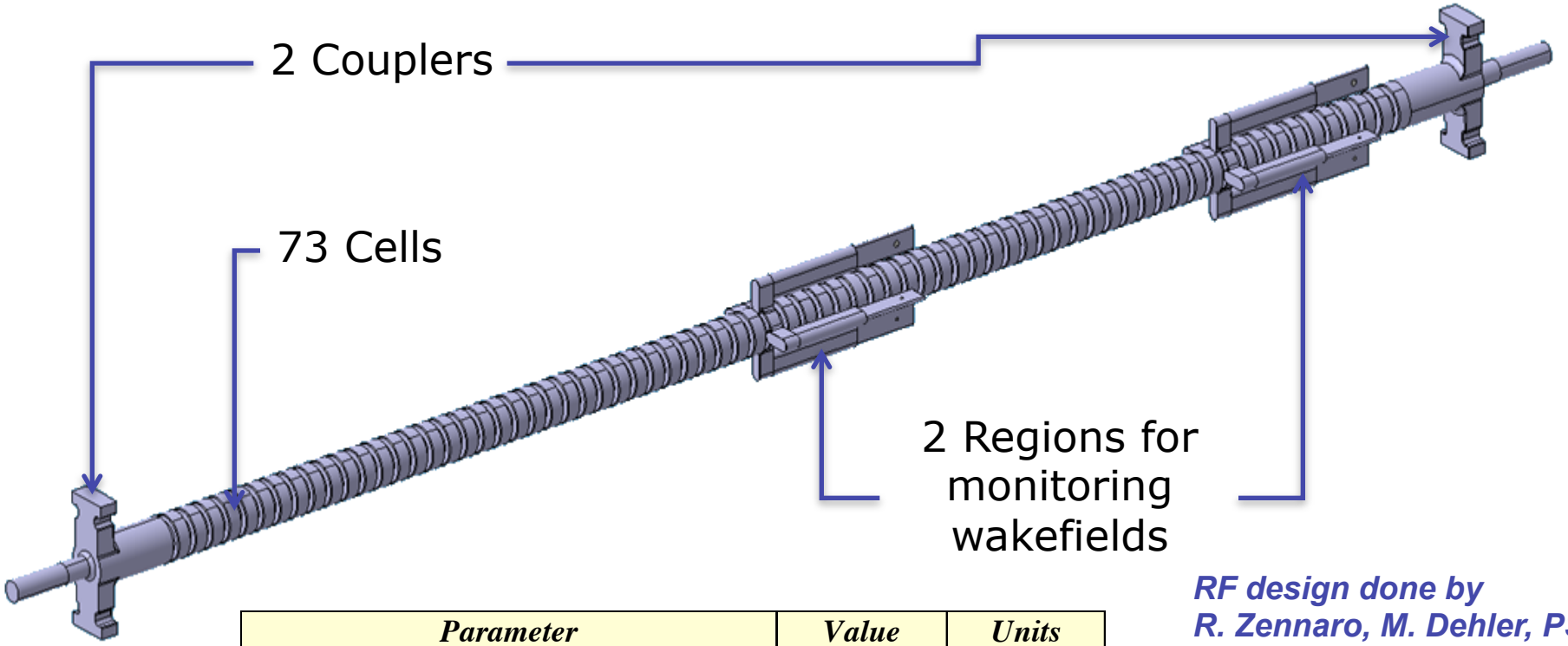
Perveance (µP)

Calorimetric measurements

Klystron gain curves



Accelerating structure

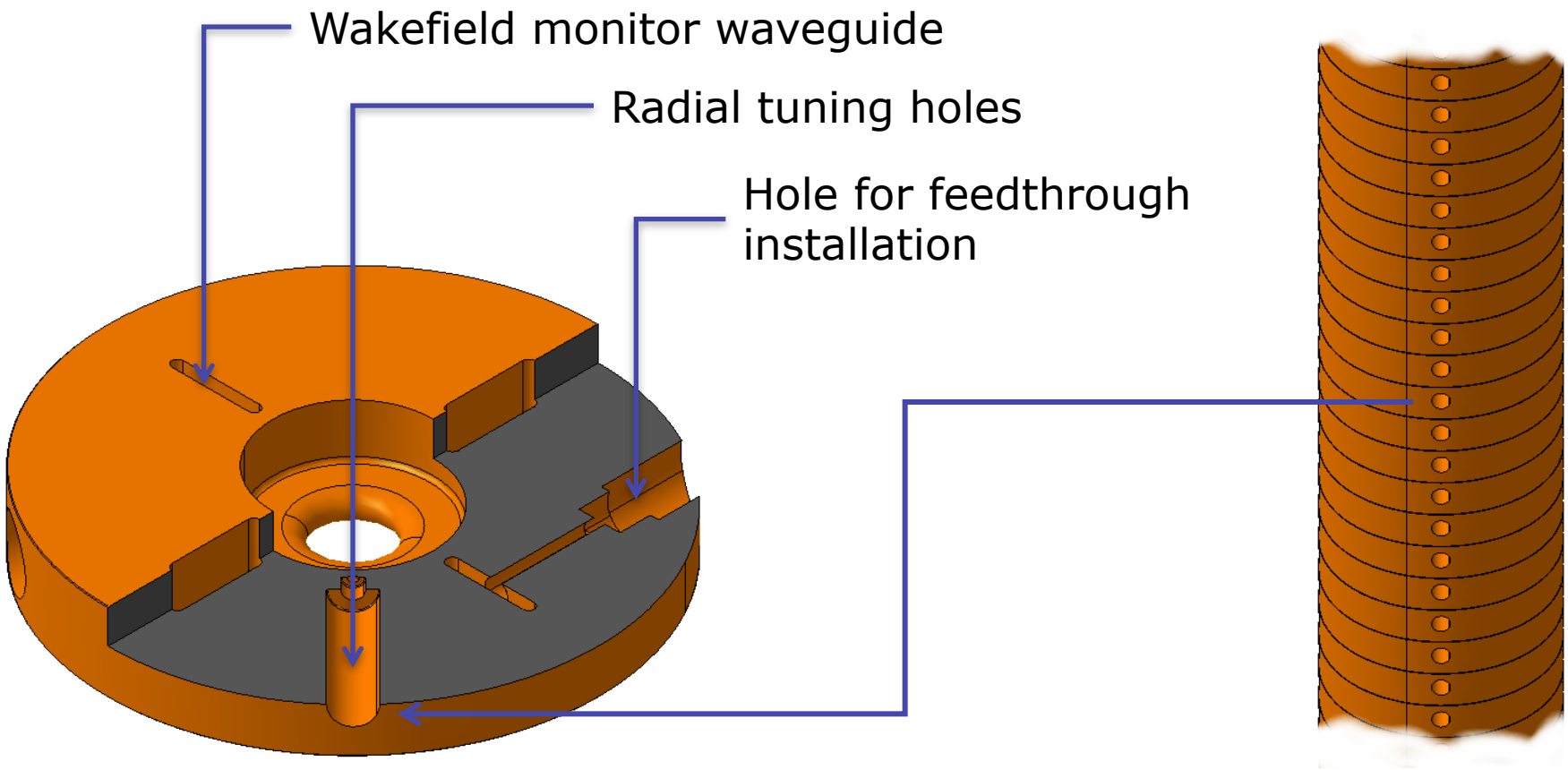


Parameter	*Value*	*Units*
Structure type	5/6 π, CG	
Working frequency	11.992	GHz
Overall length	0.965	m
Active length	0.750	m
Iris diameter (average)	9.1	mm
Filling time	100	ns
Pulse repetition rate	50	Hz
Max heat load @ operating gradient	300	W

RF design done by
R. Zennaro, M. Dehler, PSI

Coutesy of D. Gudkov, CERN

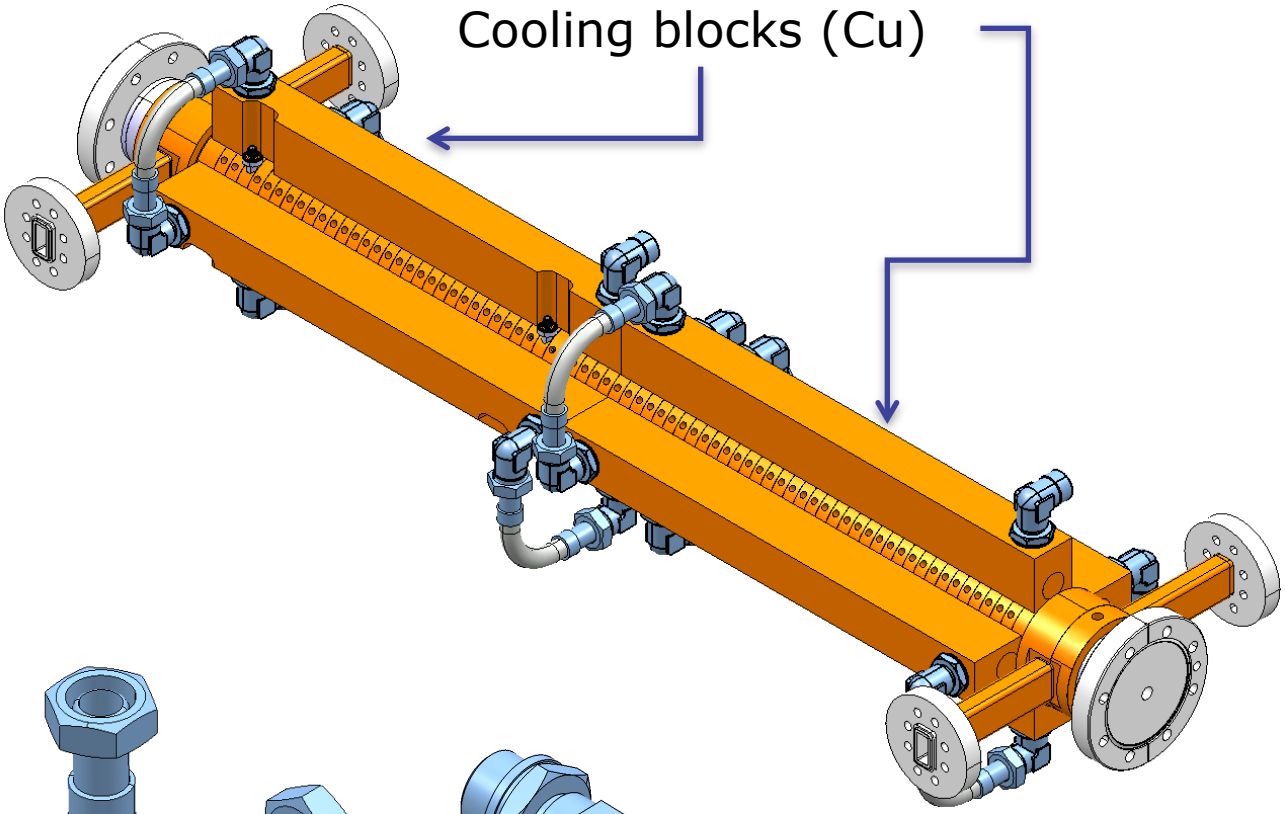
Copper disks



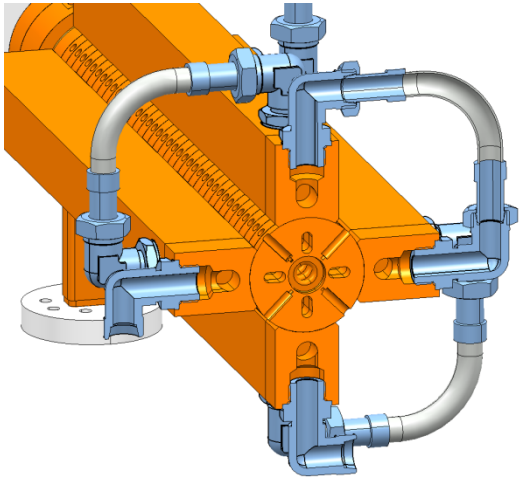
- The accelerating structure body consists of a stack of thick cylindrical copper disks, which are machined following the RF design of the cavity geometry.
- For the final RF frequency tuning, the disks are equipped with four radial holes.
- Each special wakefield monitor disk incorporates four coupling holes and is also equipped with tuning holes.

Coutesy of D. Gudkov, CERN

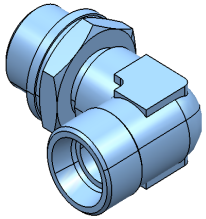
Cooling system



Fittings and hoses



Flexible hoses
WITZENMANN



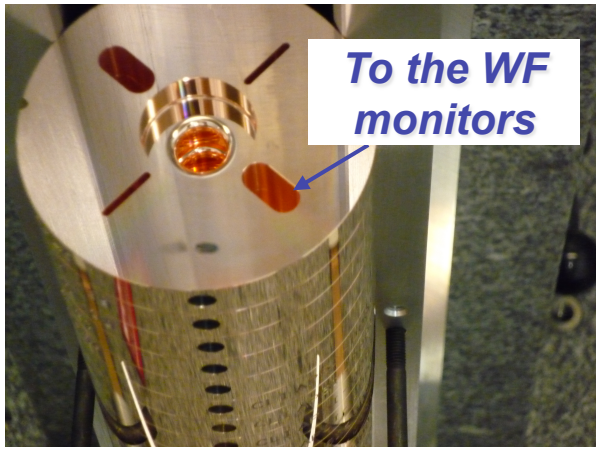
Standard fittings
LEGRIS

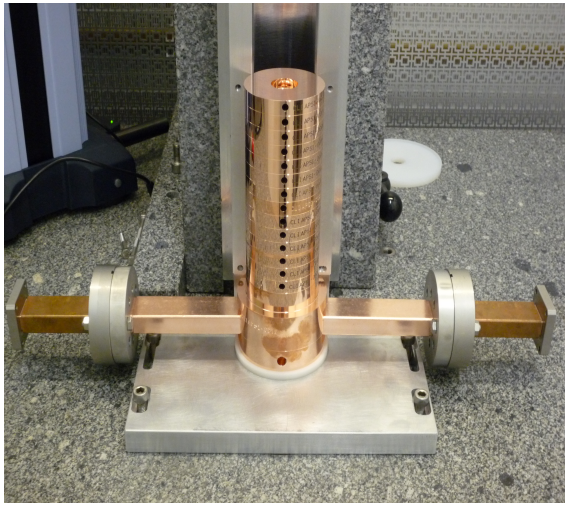
- Power dissipation in the structure of about 0.3 kW;
- Two parallel cooling circuits;
- 8 cooling blocks each of 394 mm long;
- Brazed directly onto the accelerating structure body;
- Standard water connectors.

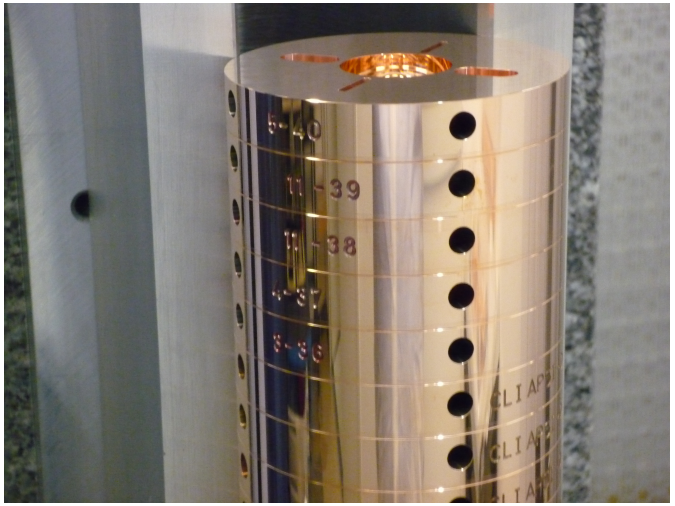
Coutesy of D. Gudkov, CERN

Preliminary RF measurements

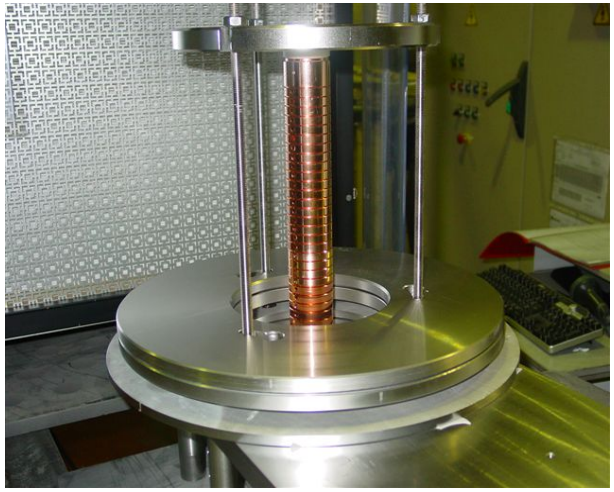
CERN preliminary RF tests structure Nº 2





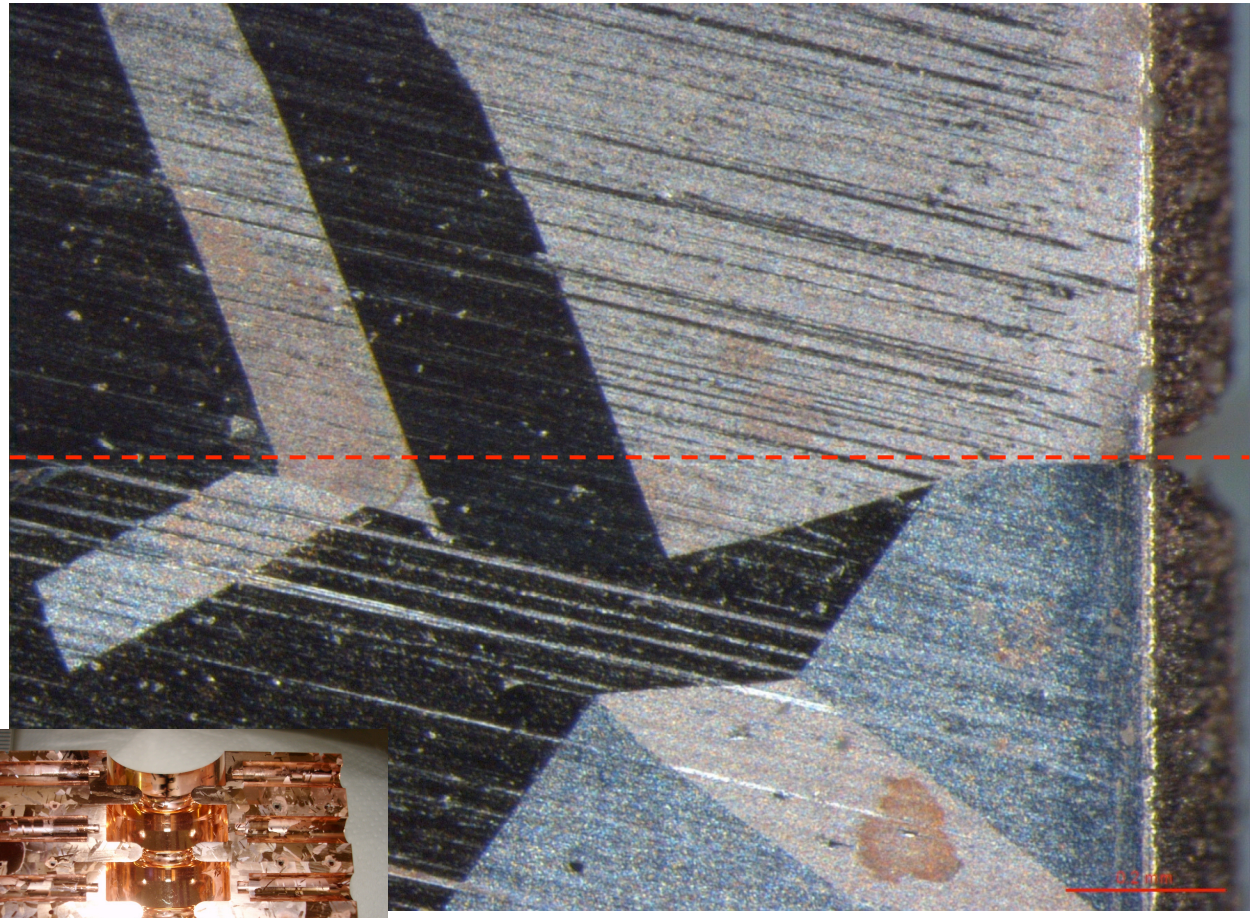


Bonding tests

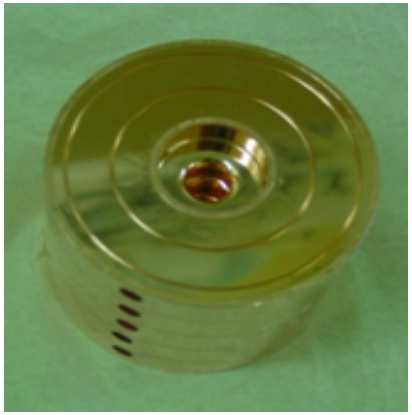


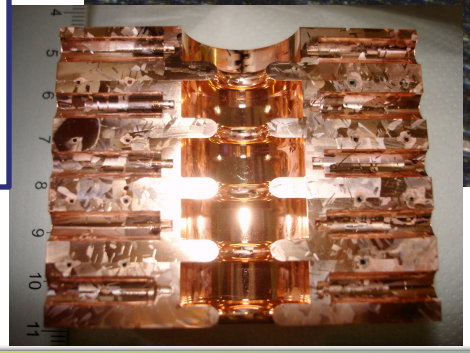
Metallographical observation..

..shows that grains are crossing the joining plane



Bonding of 5 test disks





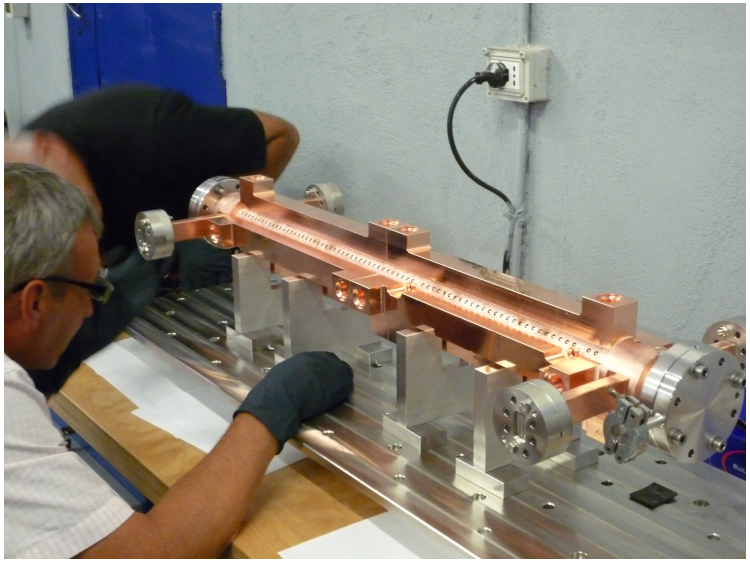
Coutesy of D. Gudkov, CERN

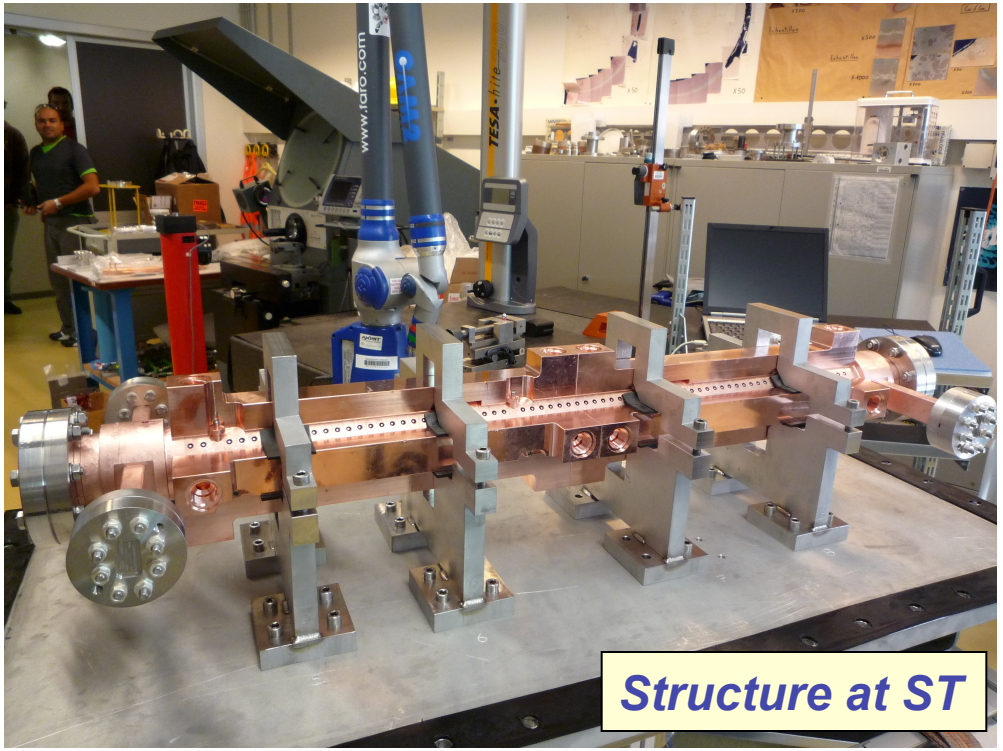
Structure vacuum baking

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

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

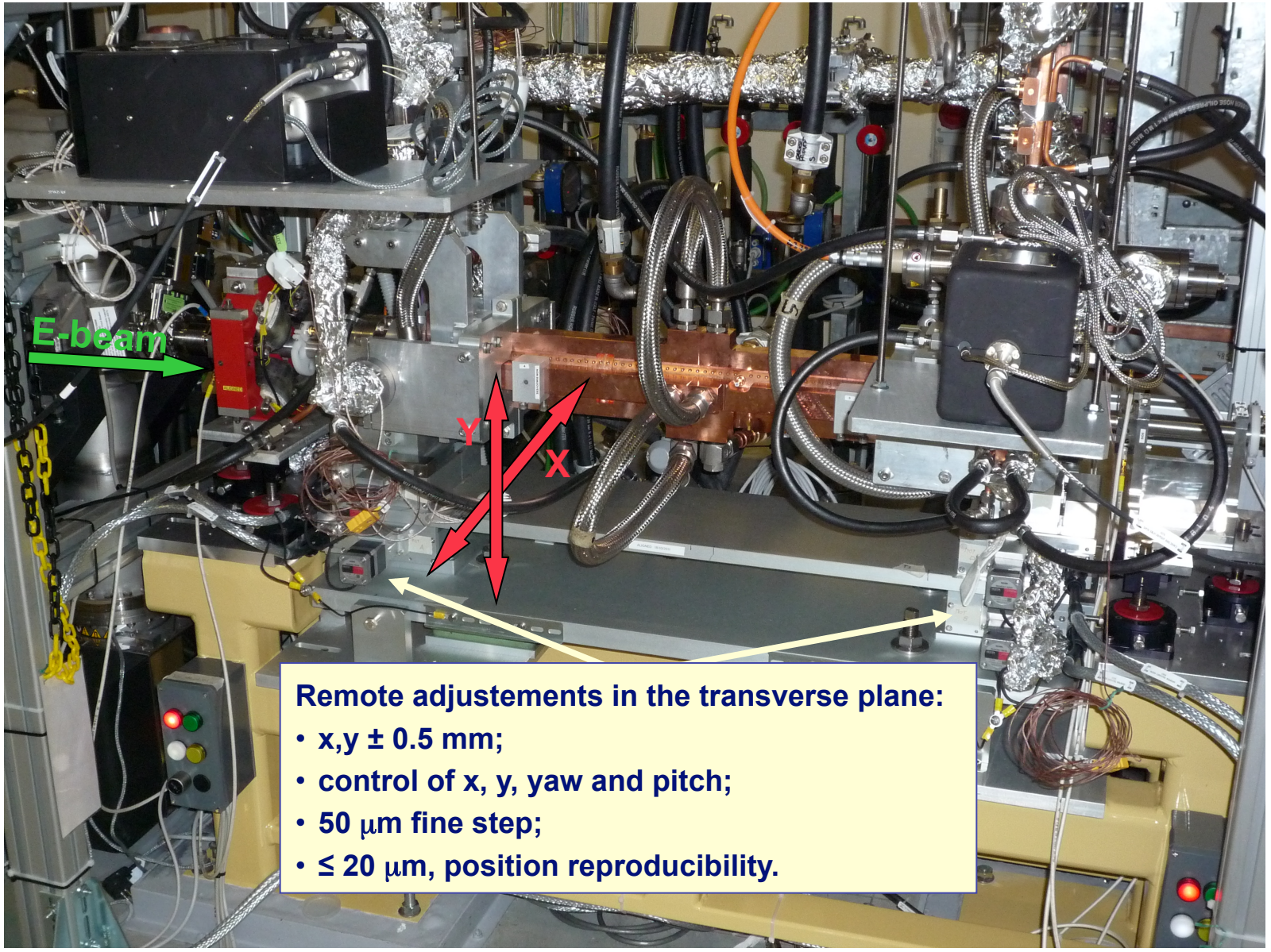
Structure preparation





Structure at ST

Structure installed

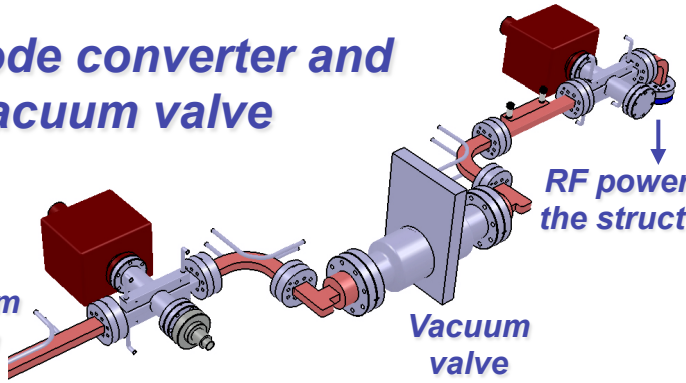


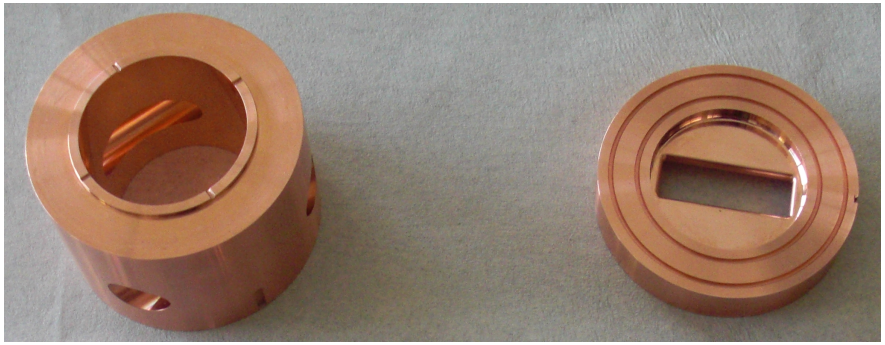
Remote adjustements in the transverse plane:

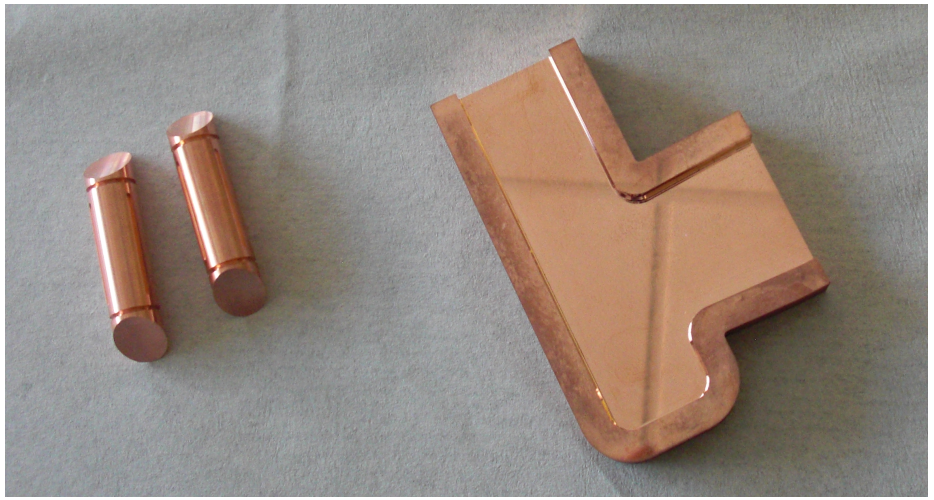
- **x,y ± 0.5 mm;**
- **control of x, y, yaw and pitch;**
- **50 μm fine step;**
- **≤ 20 μm, position reproducibility.**

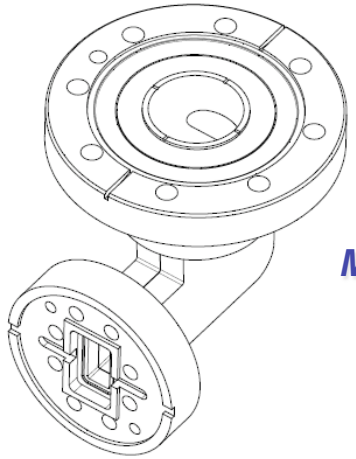
Waveguide components

WG mode converter and vacuum valve

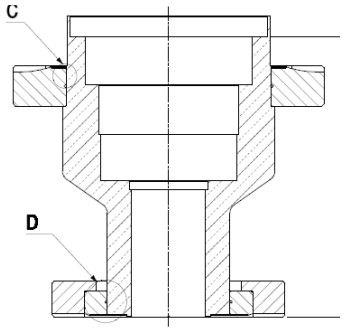




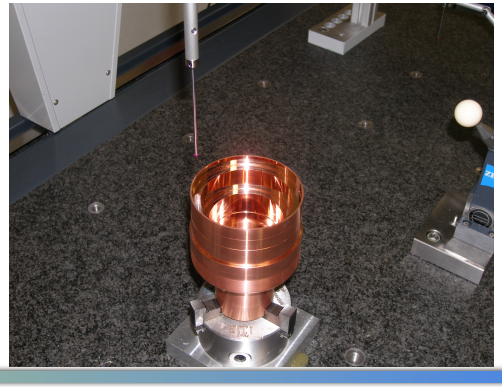




Mode converter



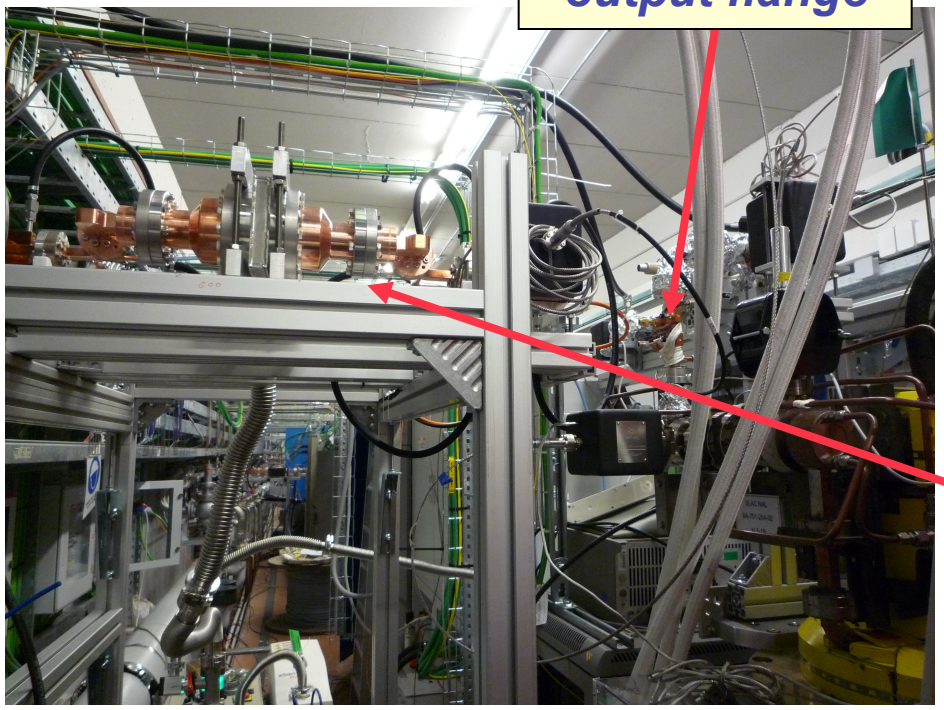
Vacuum valve adapter

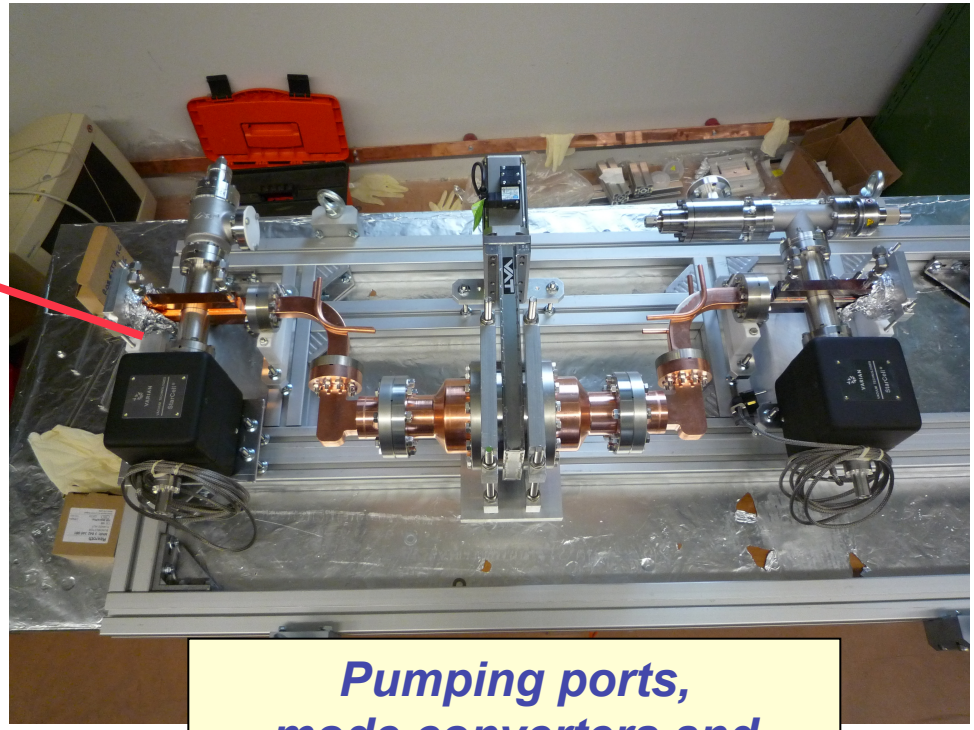


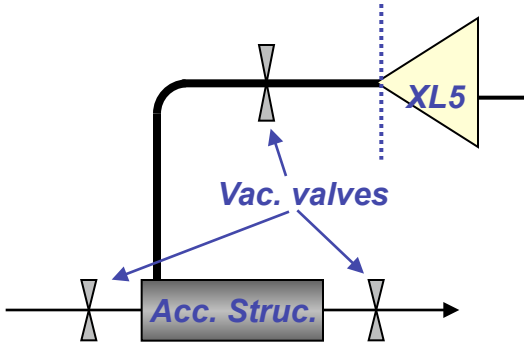
Courtesy of F. Peauger

XL5 waveguide connection

Klystron output flange





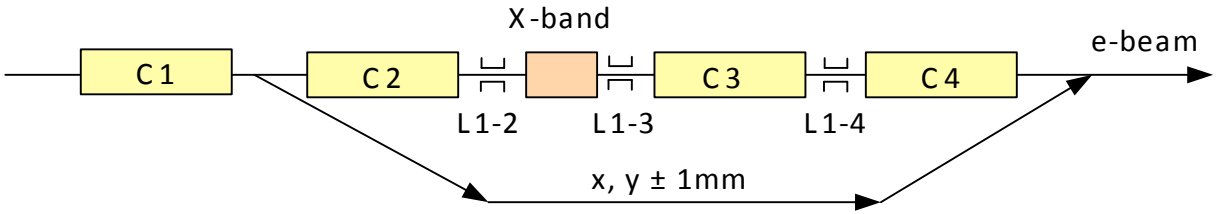


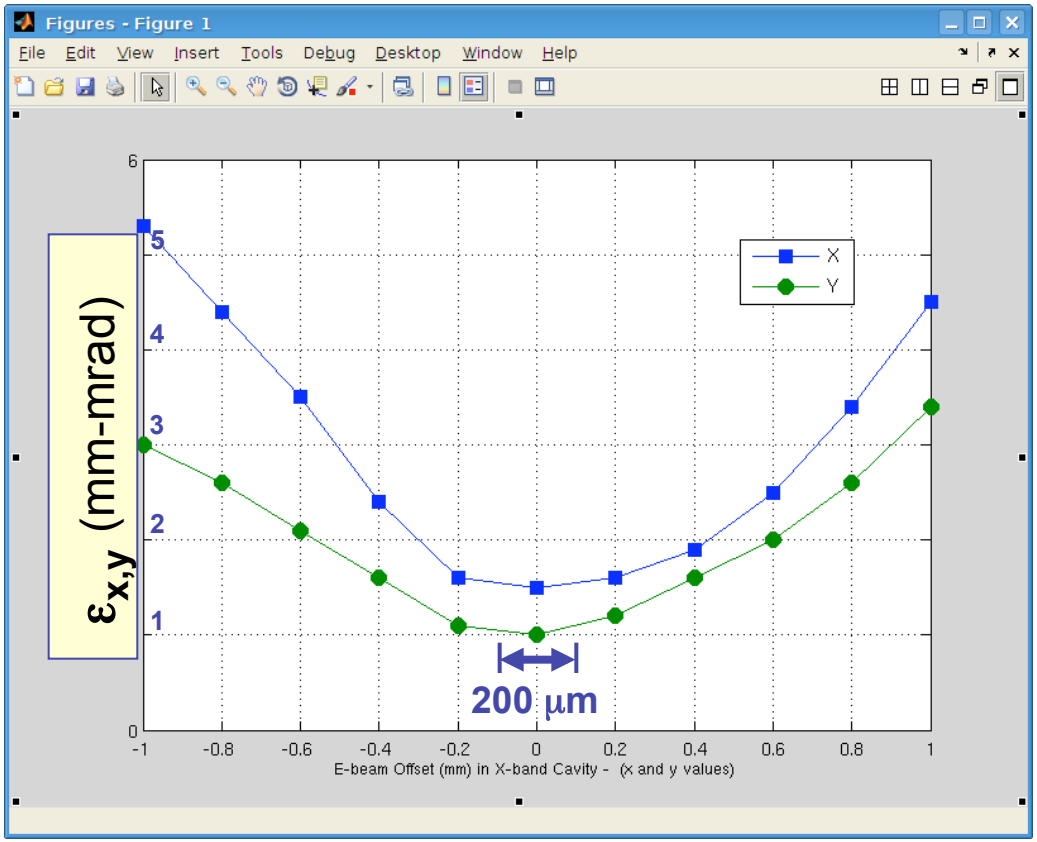
X-band plant with vacuum insulation

Pumping ports, mode converters and vacuum valve assembly

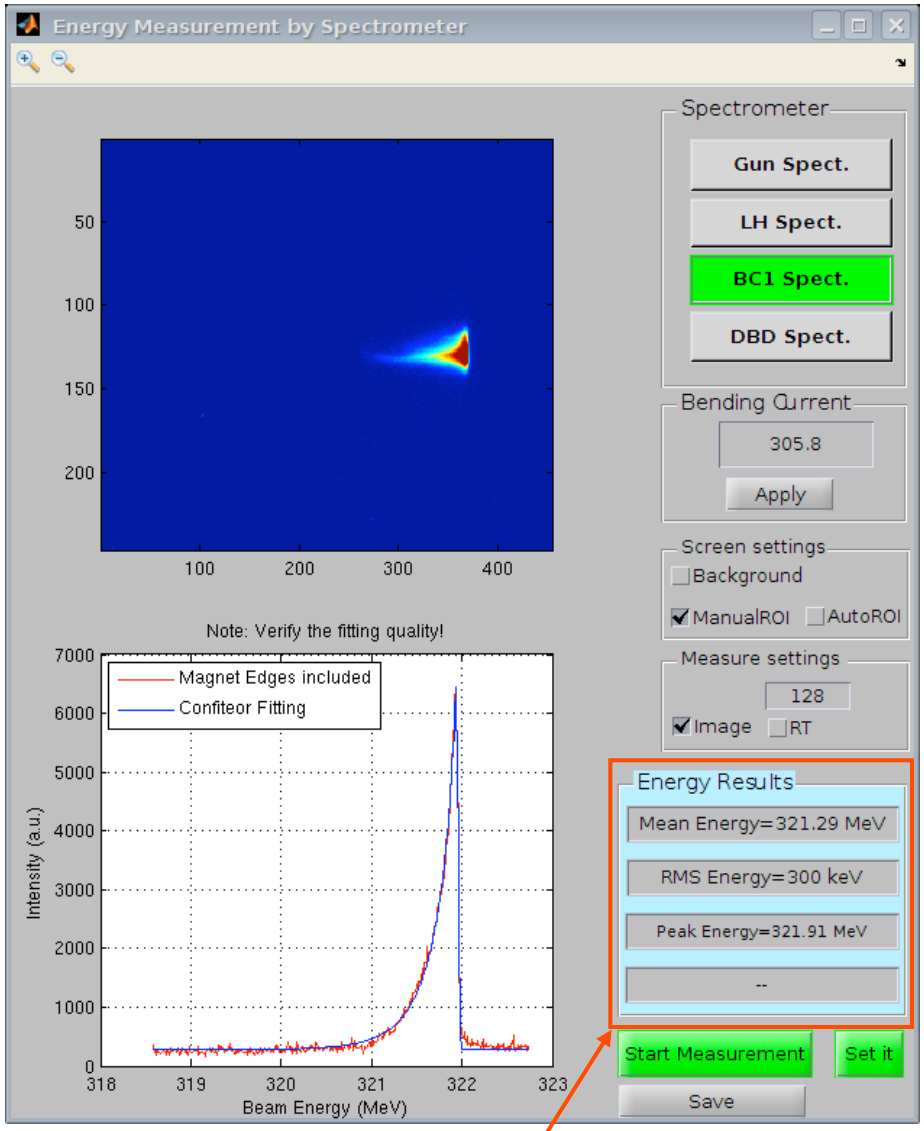
X-band beam effects

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)

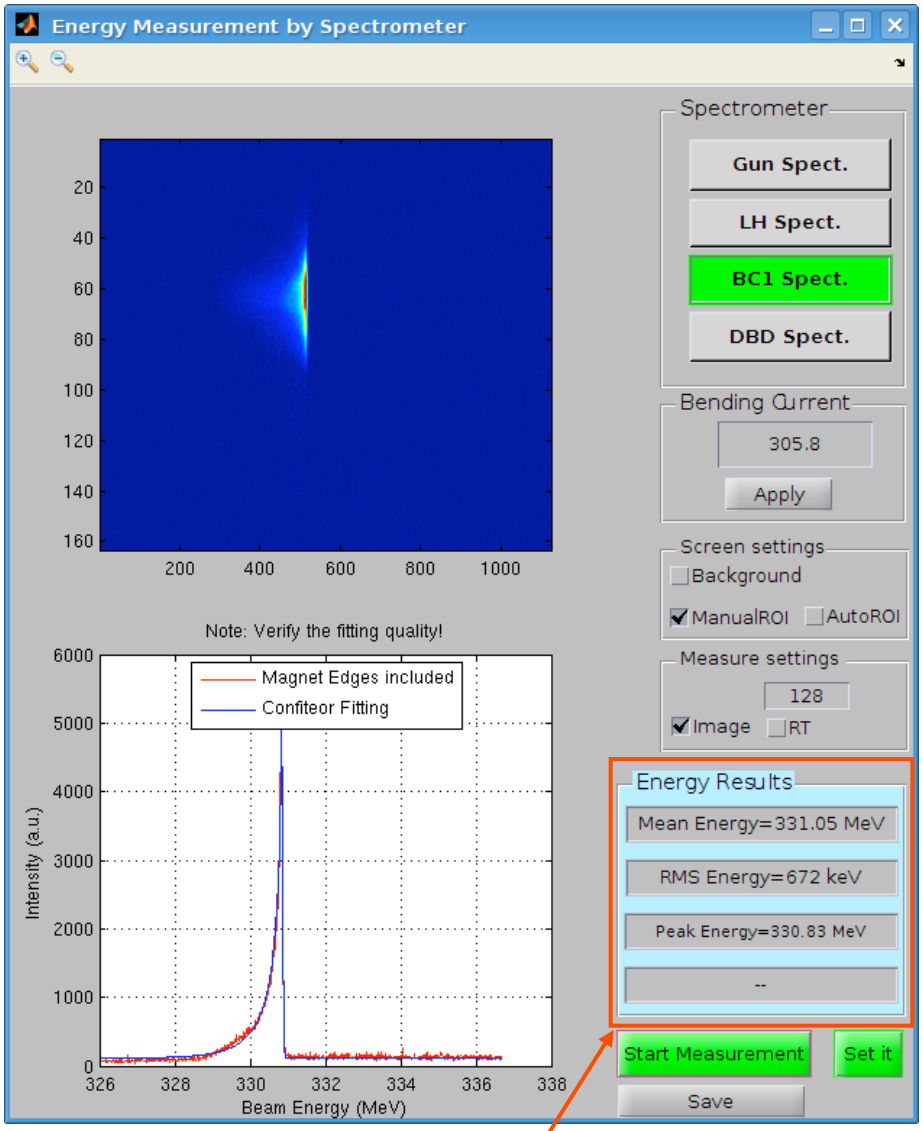




First beam tests with RF_27-02-12

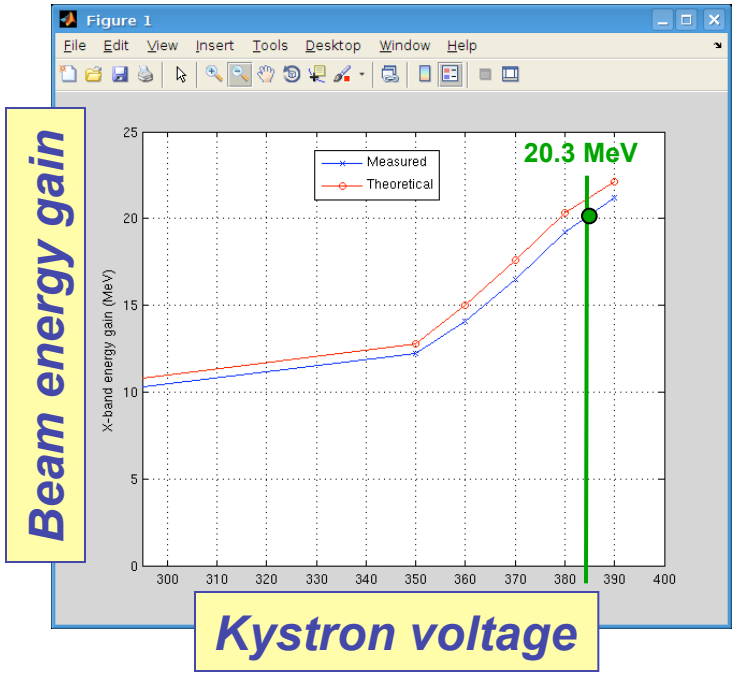


X-band OFF

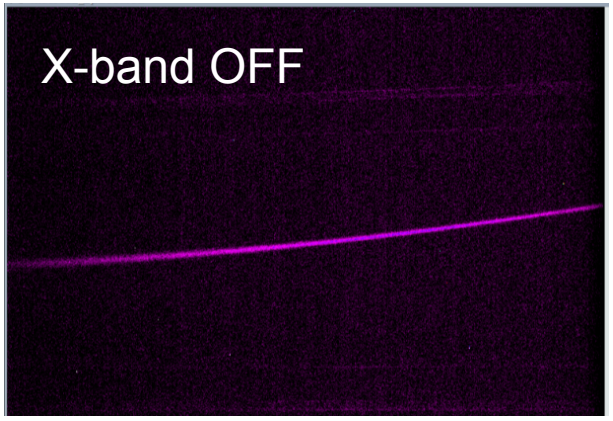


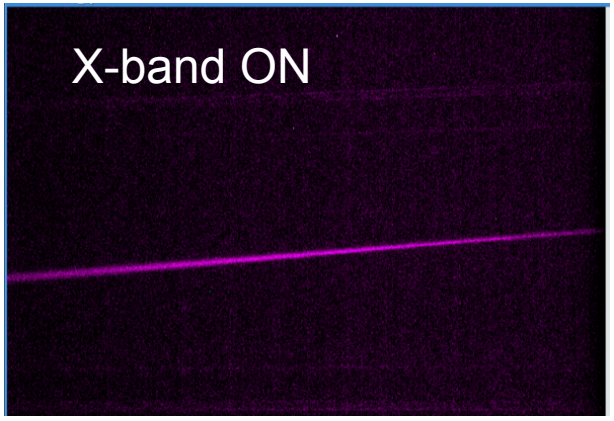
X-band gain ~10 MeV

Structure gradient



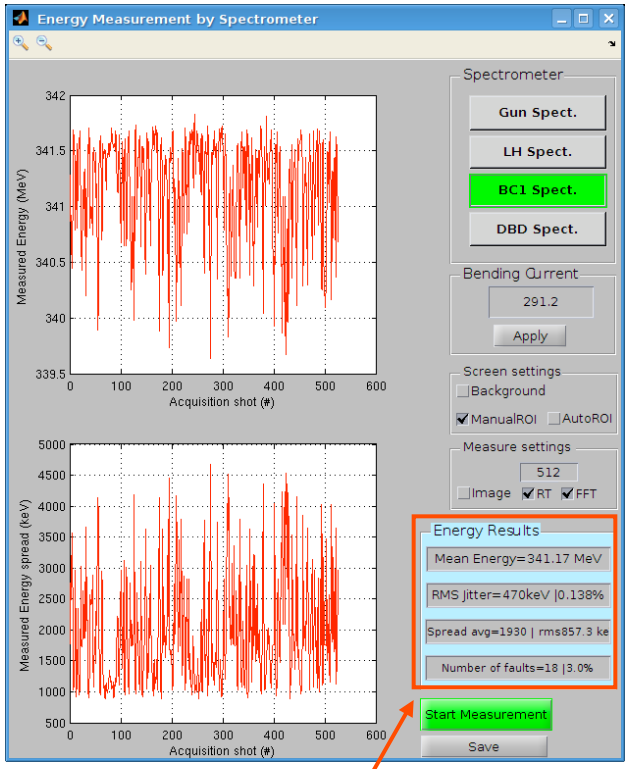
We set V_k = 385 kV, corresponding to X-band energy gain=20.3 MeV





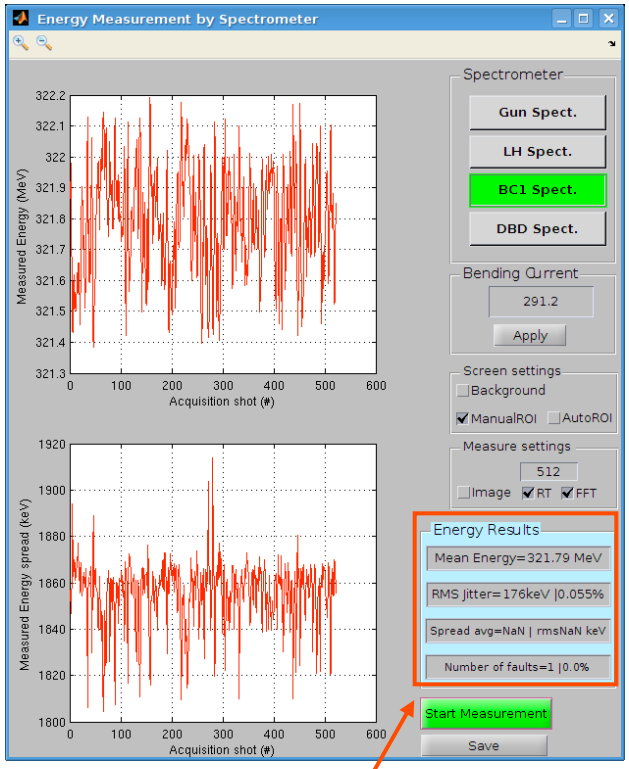
Beam energy jitter

Beam energy 341.2 MeV



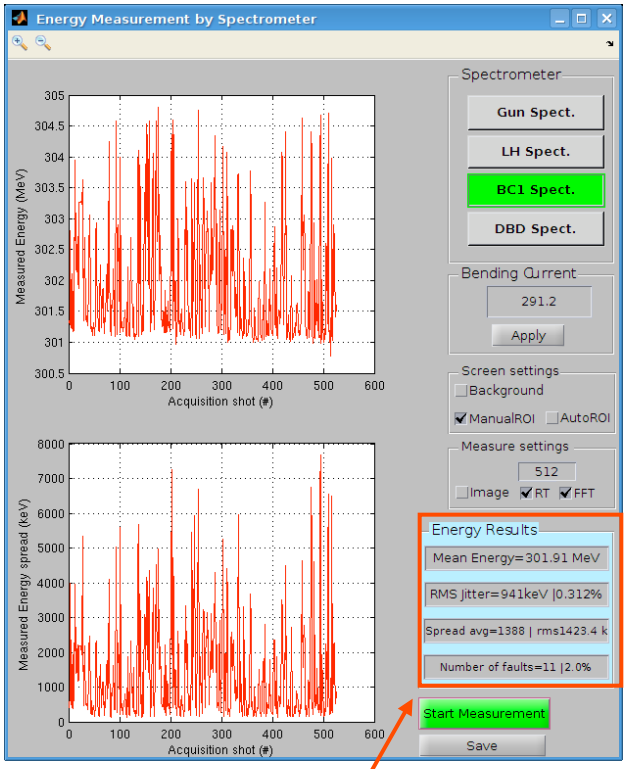
X-band set +20 MeV,
on crest (acceleration)
energy jitter ~500 keV (rms)

Beam energy 321.8 MeV



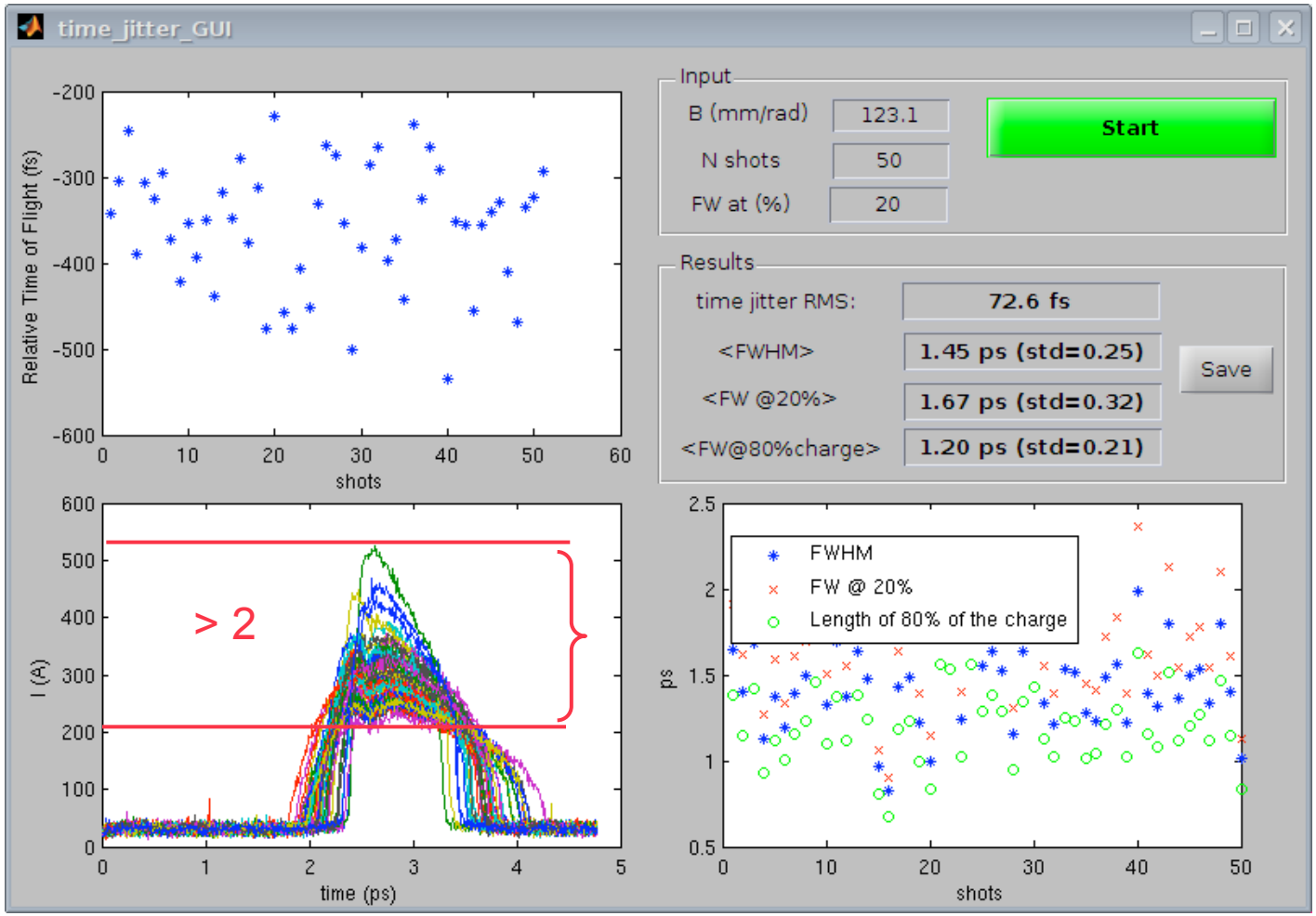
X-band at zero crossing,
no energy gain
energy jitter ~200 keV (rms)

Beam energy 301.9 MeV



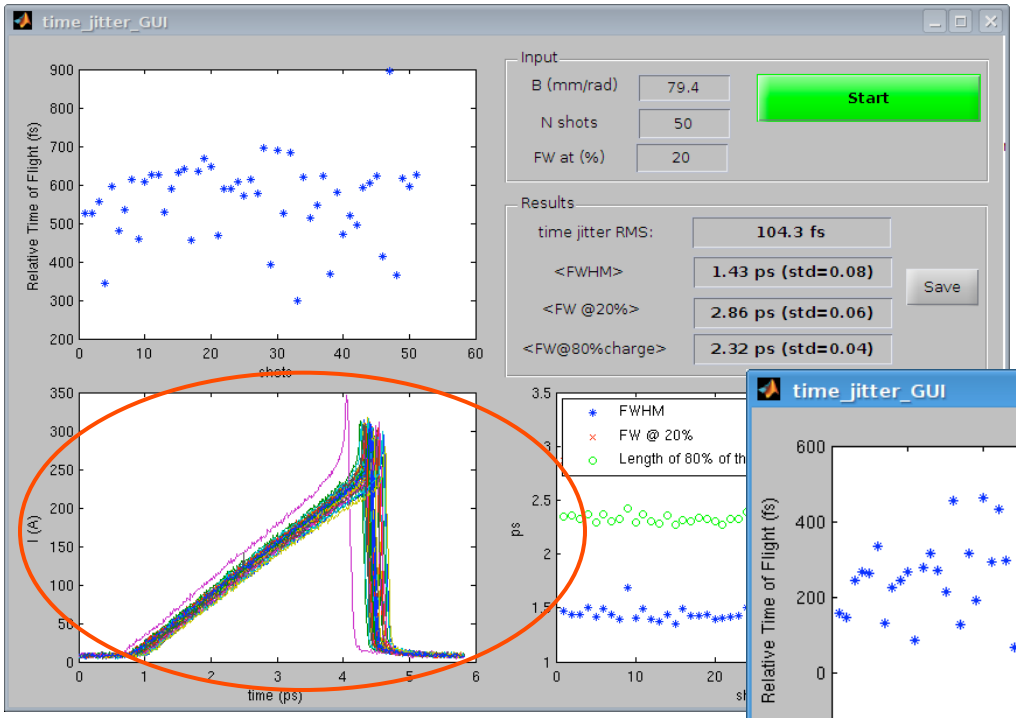
X-band set –20 MeV,
@180 deg (deceleration)
energy jitter ~900 keV (rms)

First tests on beam compr. March '12

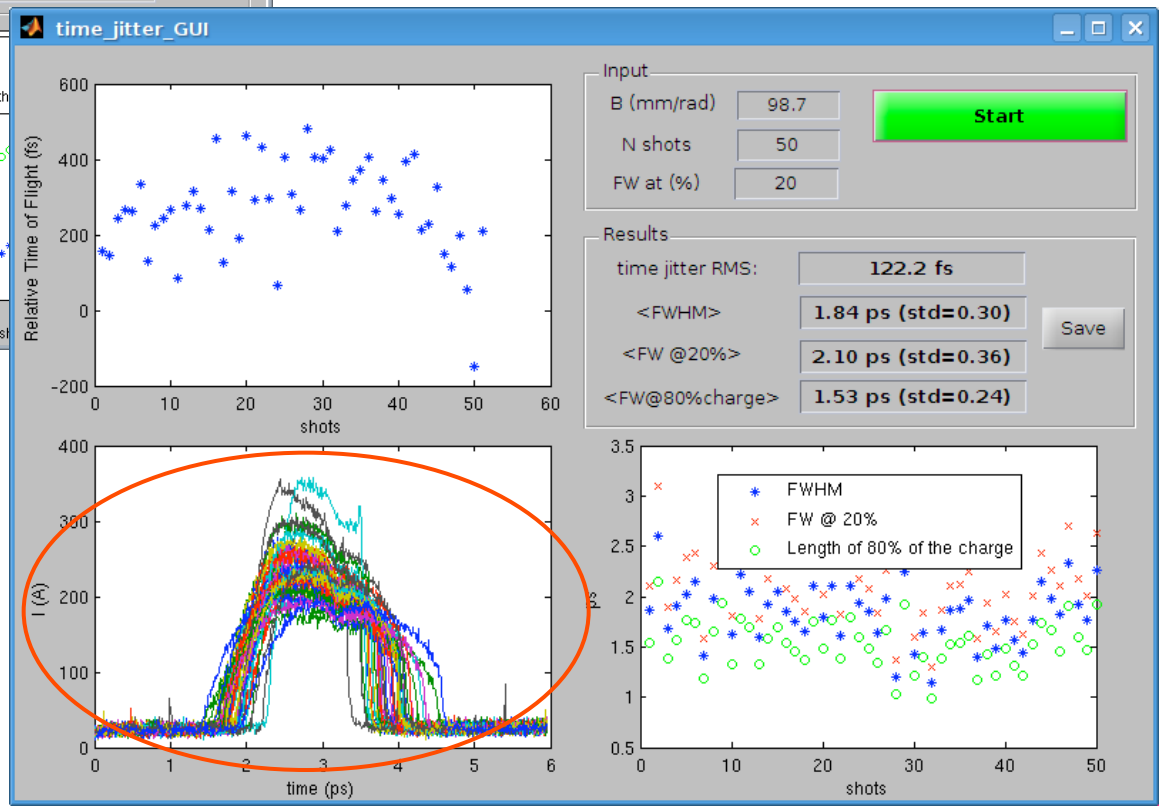


X-band at -19.2 MeV (@180 deg)

First tests on beam compr. March '12



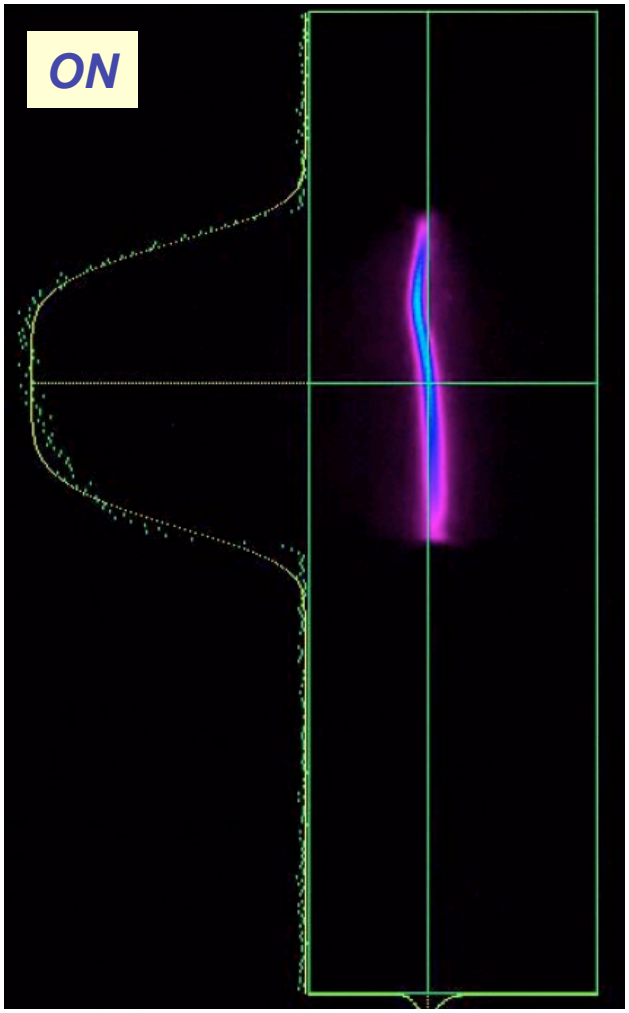
Without X-band



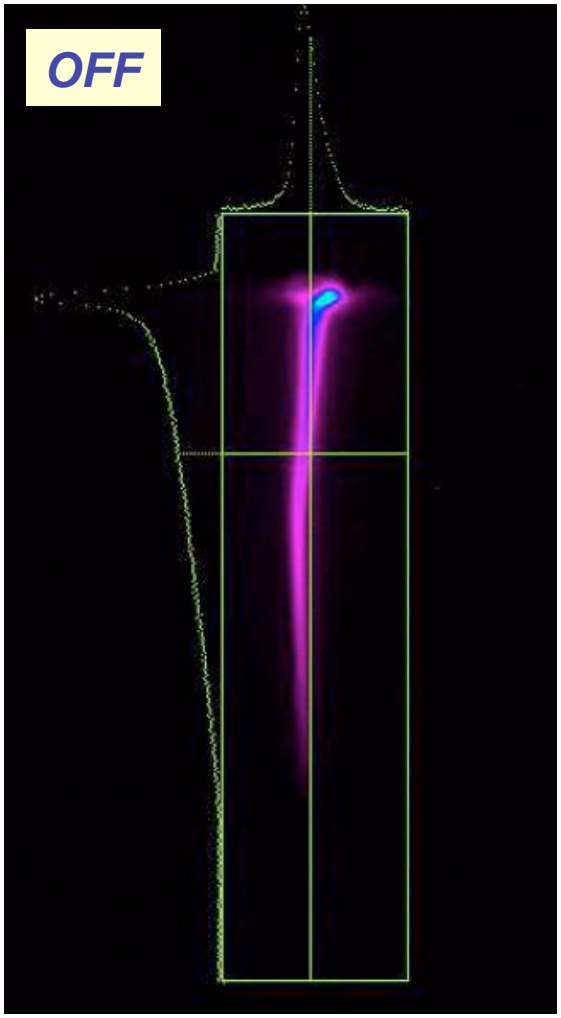
With X-band

Charge distribution analysis with deflecting cavities

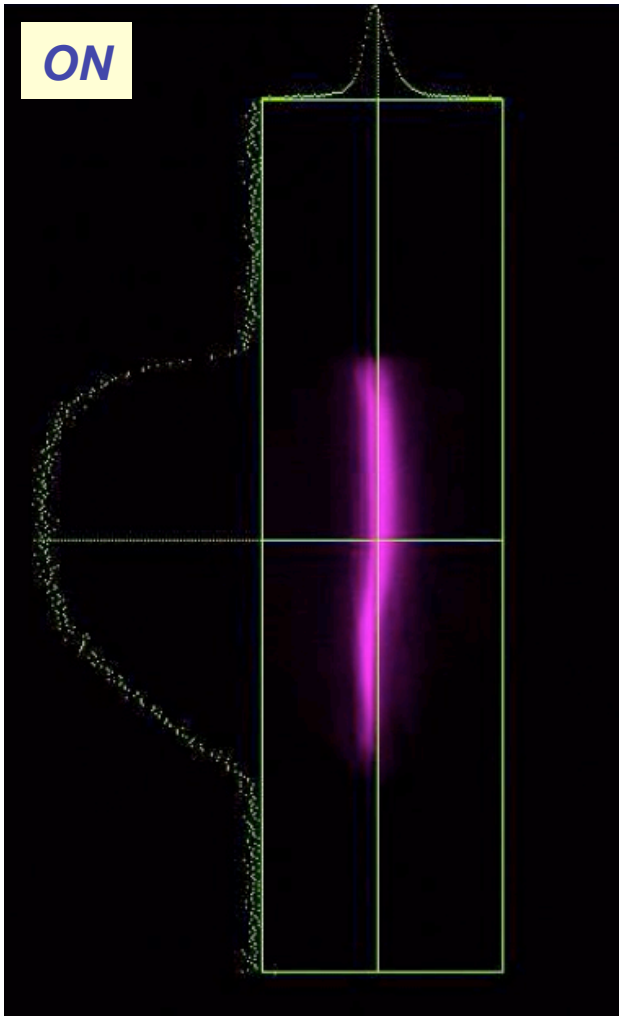
X-band @-19 MeV



mscrccd_bc01.03
@ 300 MeV



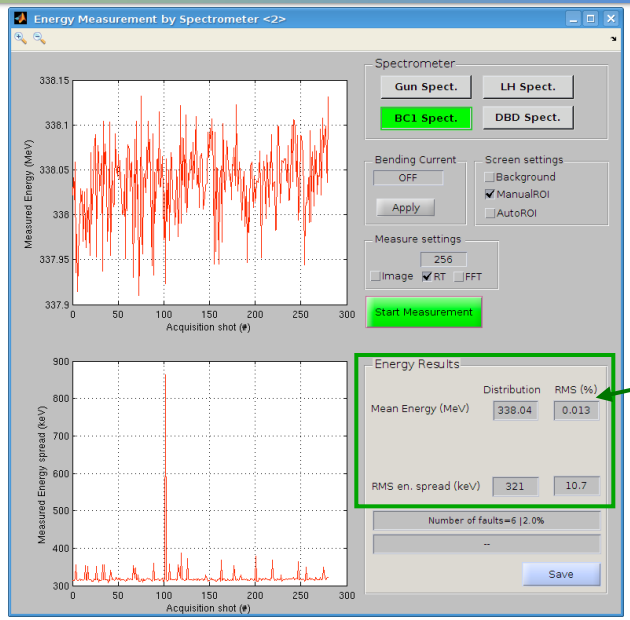
mscrccd_tls.03
@ 1.2 GeV



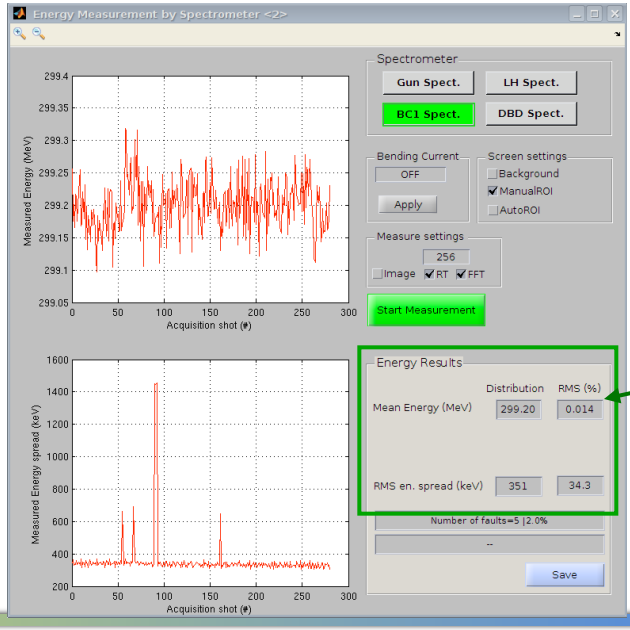
mscrccd_tls.03
@ 1.2 GeV

Last results_May '12

X-band at 19.4 MeV beam energy 320 MeV

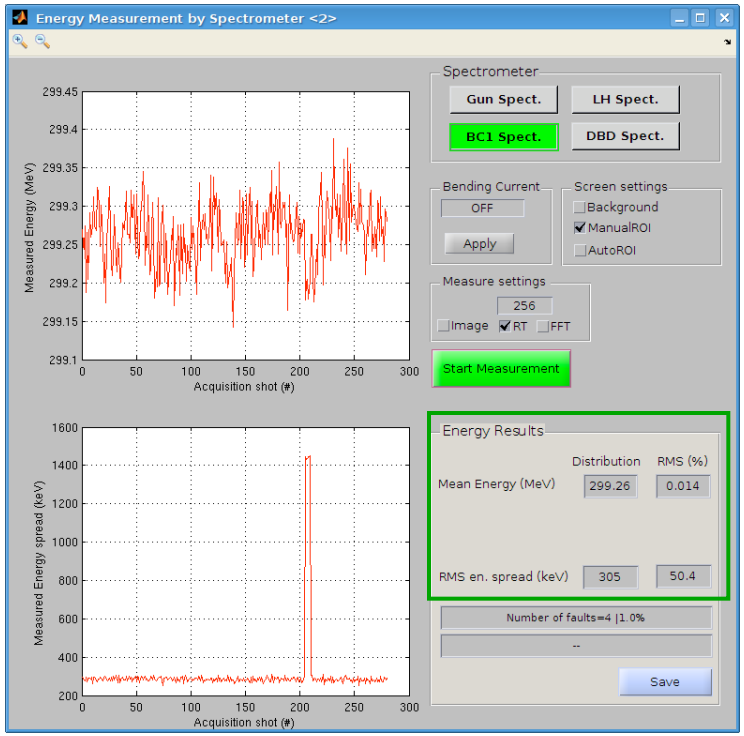


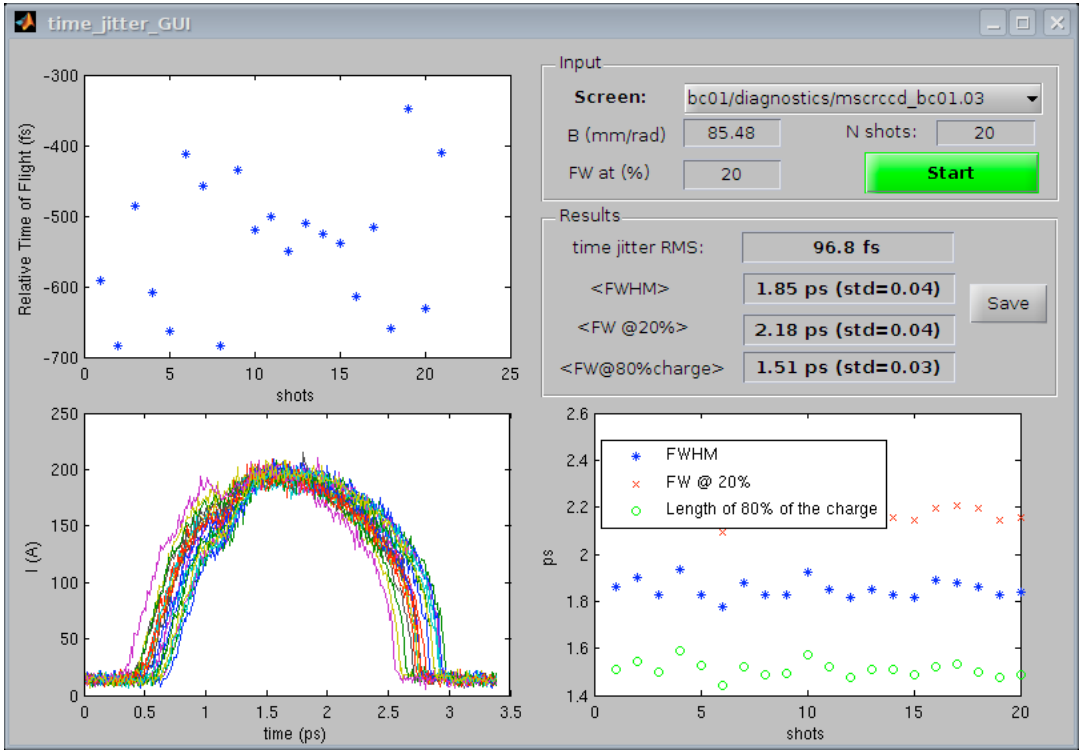
X-band in acceleration energy jitter ~ 0.1%



X-band in acceleration energy jitter ~ 0.1%

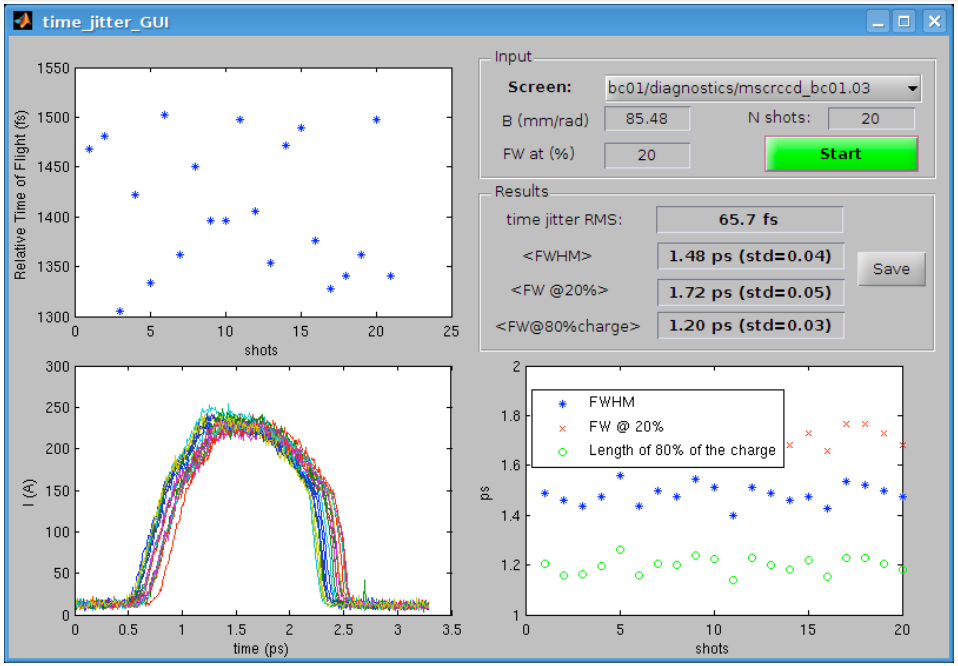
Compression May ‘12



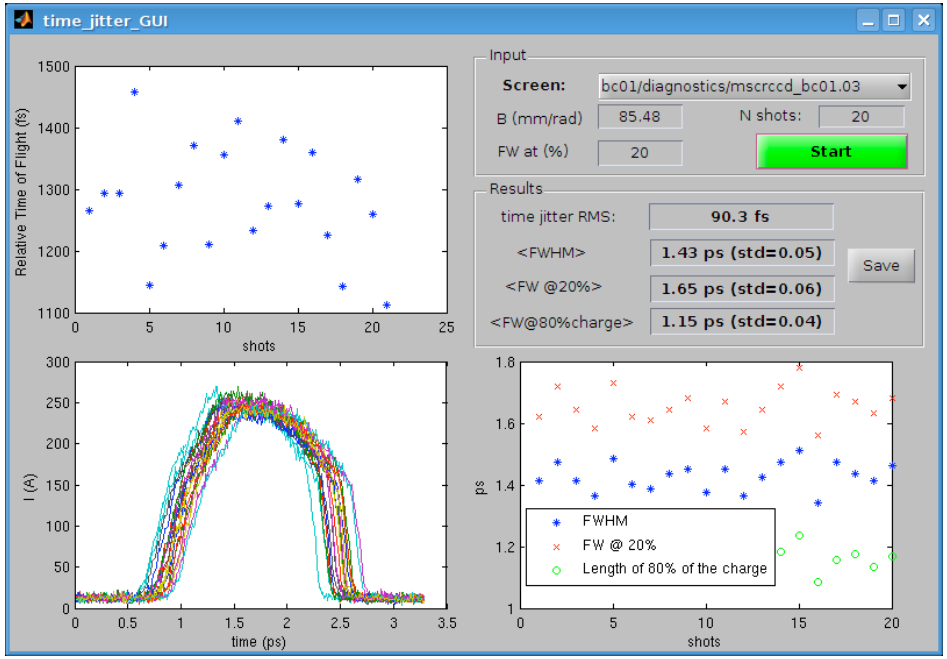


X-band at 19.4 MeV
-180°

Compression May ‘12

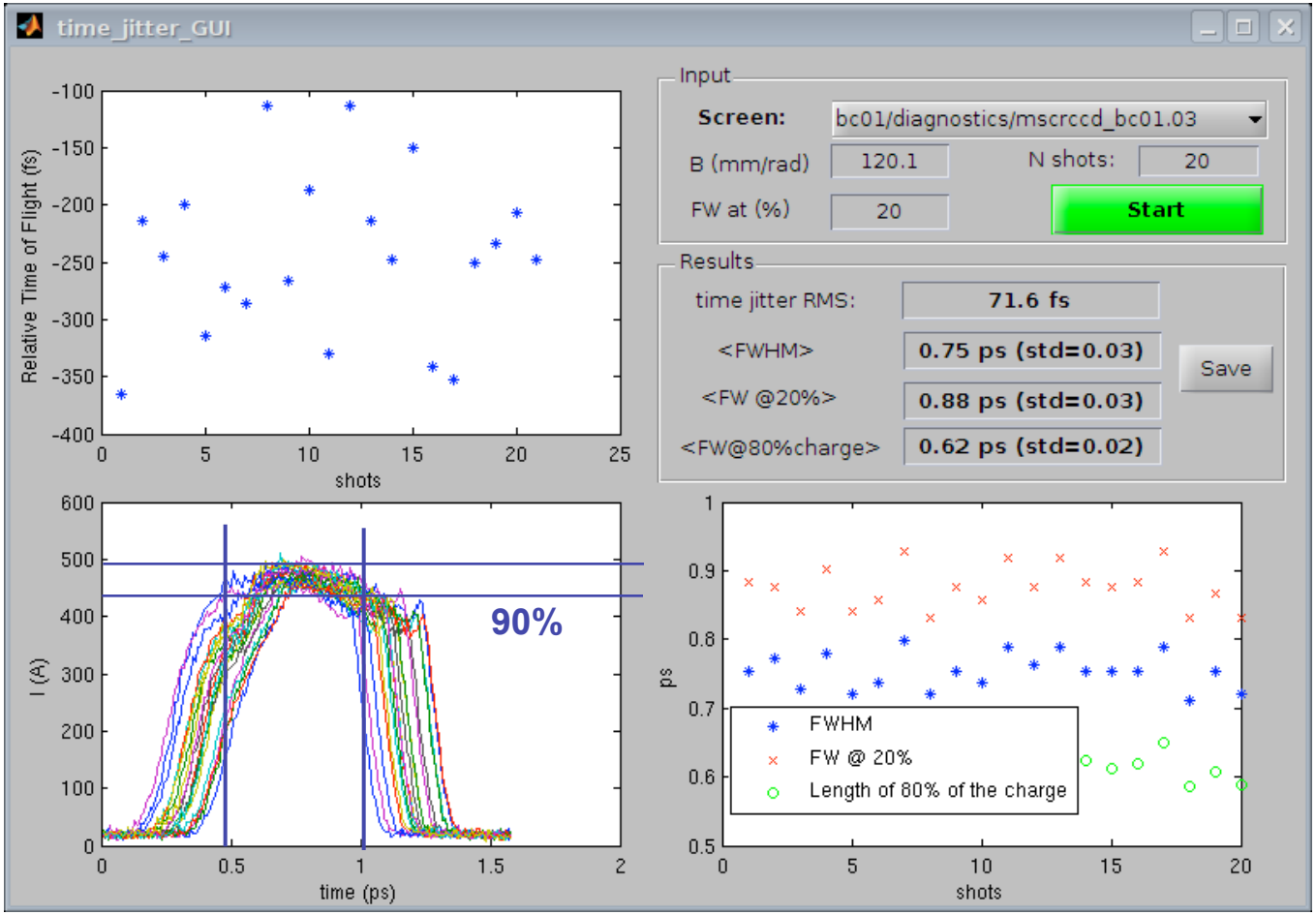


X-band at 19.4 MeV
-178°



X-band at 19.4 MeV
-175°

Compression May ‘12



X-band at 19.0 MeV
-180°

From :	William Fawley <wmfawley@lbl.gov>
Subject:	grazie! Re: READ this --- from FERMI CR --- do you have the calibration table for K4 voltage
Date:	Wed, 13 Jun 2012 21:10:51 +0200
To:	Gerardo D'Auria <gerardo.dauria@elettra.trieste.it>

grazie -- *we are having pretty good success -- making ostensibly nice pulses with 700-800 A peak currents with reasonable semi-flat portions* ; we have K4 at 37 kV

enjoy the California sun (until the fog comes in!)

cheers -- Bill & Simone

Conclusions

Short term program

- **Full structure characterization with the beam:**
  - find the best operating point;
  - more dedicated studies on the beam kick due to the RF couplers,
  - verify wake fields effects, etc.

Long term program

- **Activation of the wake field monitors**

Acknowledgements

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The members of linac group and Fermi commissioning team, Sincrotrone Trieste.

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F. Peauger, CEA.

J. Eichner, A. Haase, D. Sprehn, A. Vlieks, SLAC.