Performance of the TTF Photoinjector for FEL Operation

S. Schreiber, DESY
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- **Overview of the TESLA Test Facility**
  Injector and Linac for FEL operation
- **Performance of the injector**
  and properties of the beam delivered to the undulator
  -> transverse emittance
  -> bunch length
  -> energy spread
- **Conclusions**

The TESLA Collaboration

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FZK Karlsruhe
Rostock University
Wuppertal University

INFN Frascati
INFN Legnaro
INFN Milano
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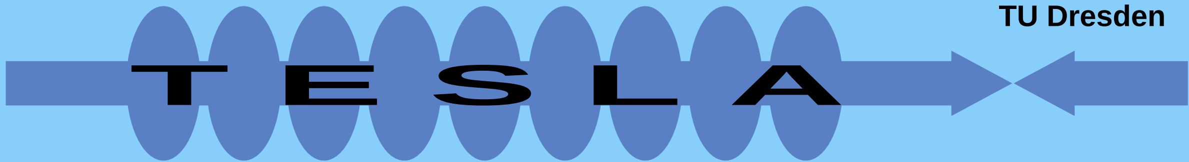

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BINP Protvino
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INR Troitsk

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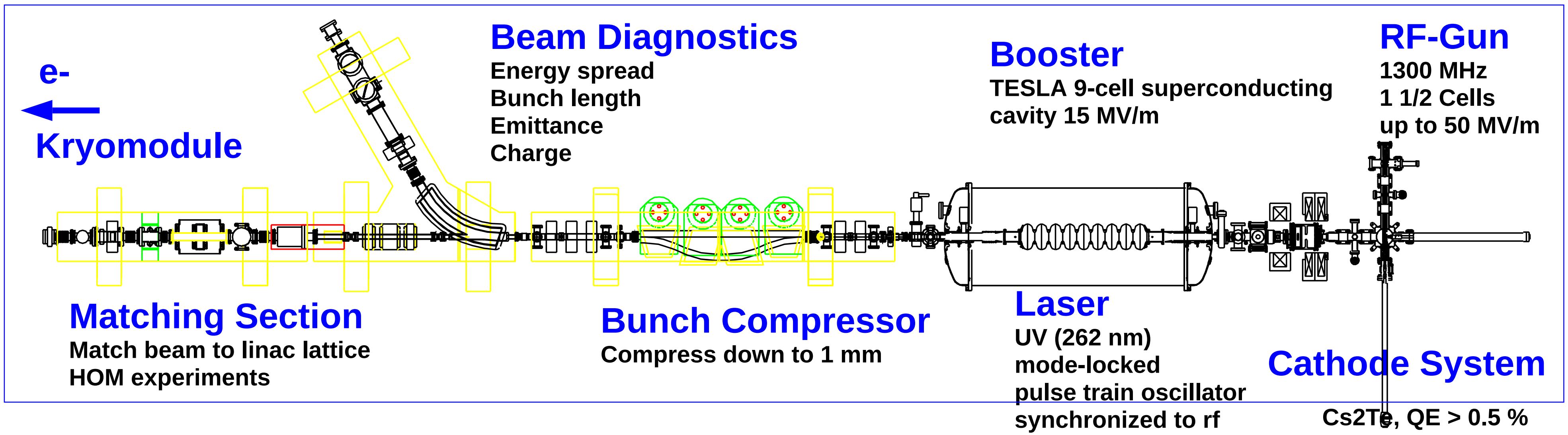
FNAL Batavia
Cornell University
TJNL Jefferson Lab.
UCLA Los Angeles

The TTF Photoinjector

Design Parameters	*TTFL(a)*	*TTFL(b)*	*TTF-FEL*
RF frequency of acc. structures	1.3 GHz		
Repetition rate	10 Hz		
Pulse train length	800 us		
Pulse train current	8 mA	9 mA	9 mA
Bunch frequency	1 MHz	2.25 MHz	9 MHz
Bunch charge	8 nC	4 nC	1 nC
Bunch length (rms)	1 mm	1 mm	0.8 mm
Emittance norm, x,y	20 um	10 um	2 um
Energy spread (rms)	0.1 %		
Injection energy	20 MeV		



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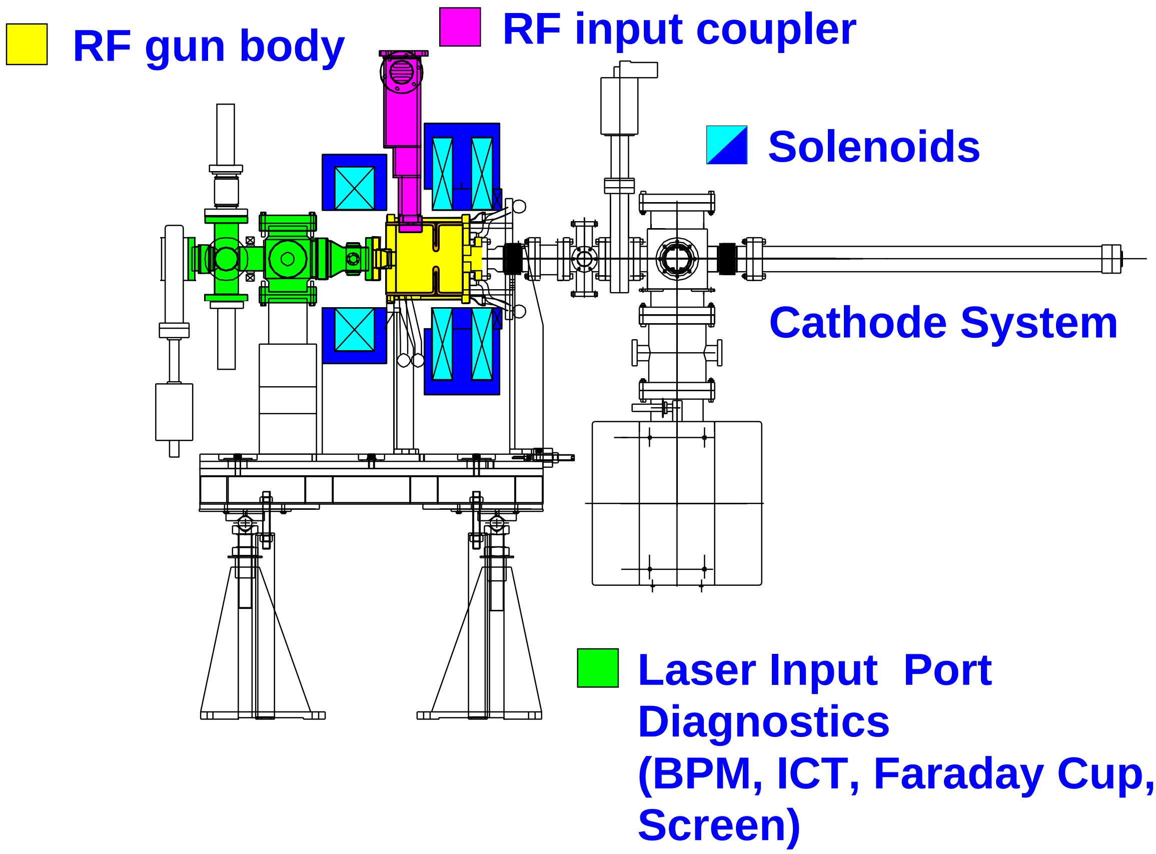
15 Jun 2001

TTF RF Gun Operating Parameters

FNAL/INFN LASA/MBI/DESY

In operation since Dez. 1998
--> about 14 000 h and 5 E7 shots



Frequency	1.3 GHz
Number of cells	1 1/2
Half Cell length	5/4 λ/4
RF Coupling	transverse
Gradient on Cathode	35...42 MV/m
Repetition Rate	1 ... 5 Hz
RF Pulse Length	900 μs
Klystron Power	2.7 MW @ 39 MV/m
Av. Dissipated Power	12 kW @ 5 Hz
Cathode	Cs2Te or CsKTe

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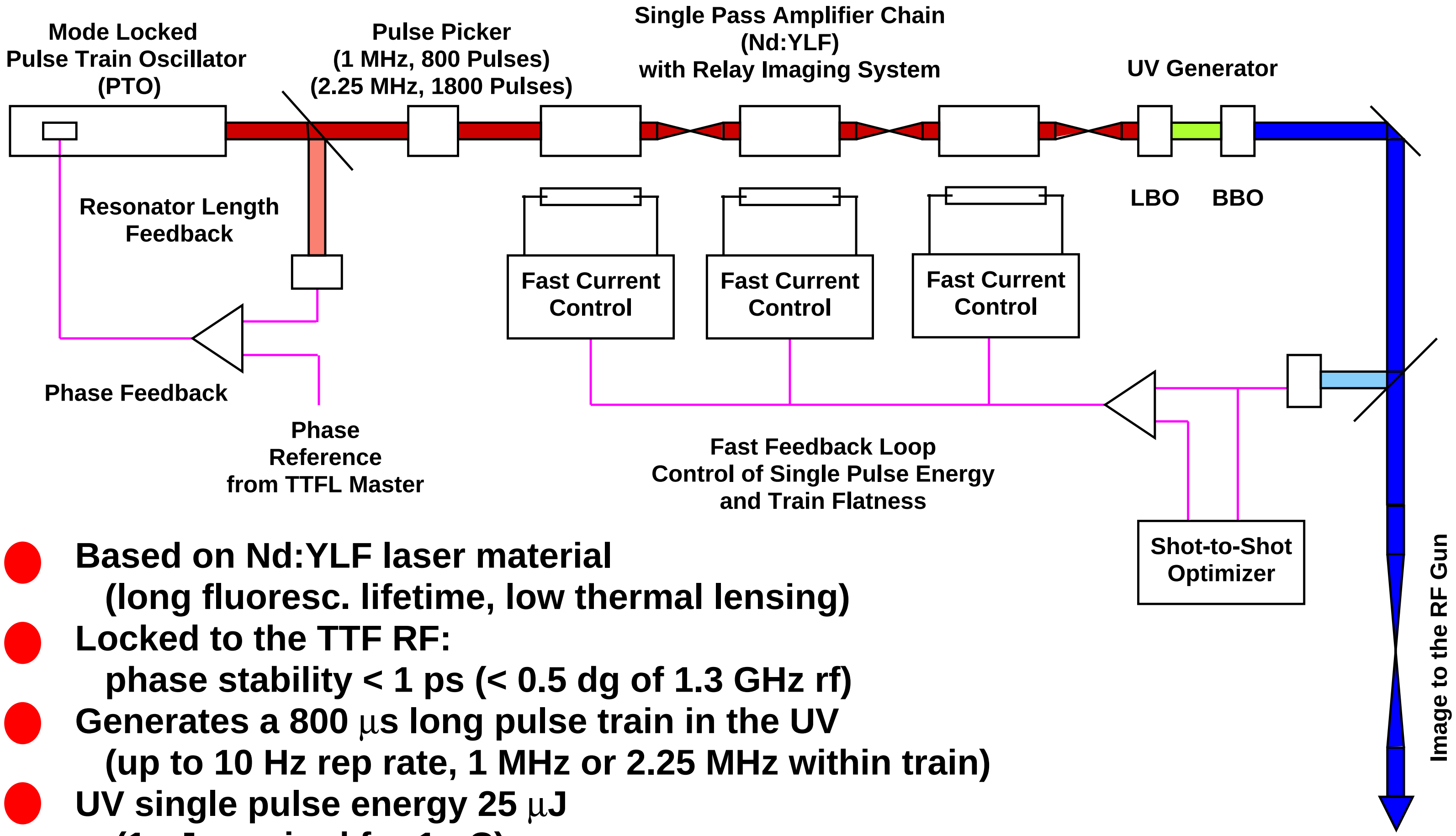
The Laser System for the TTF Photoinjector



- Based on Nd:YLF laser material
  (long fluoresc. lifetime, low thermal lensing)
- Locked to the TTF RF:
  phase stability < 1 ps (< 0.5 dg of 1.3 GHz rf)
- Generates a 800 μs long pulse train in the UV
  (up to 10 Hz rep rate, 1 MHz or 2.25 MHz within train)
- UV single pulse energy 25 μJ
  (1 μJ required for 1 nC)
- Energy stability < 5 % peak-peak within pulse train
  and < 10 % peak-peak from shot-to-shot
- Uses relay imaging to create a transverse flat-top profile
  and to enhance the pointing stability < 2 urad
- Pulse length in UV sigma = (7.1 $\pm$ 0.6) ps

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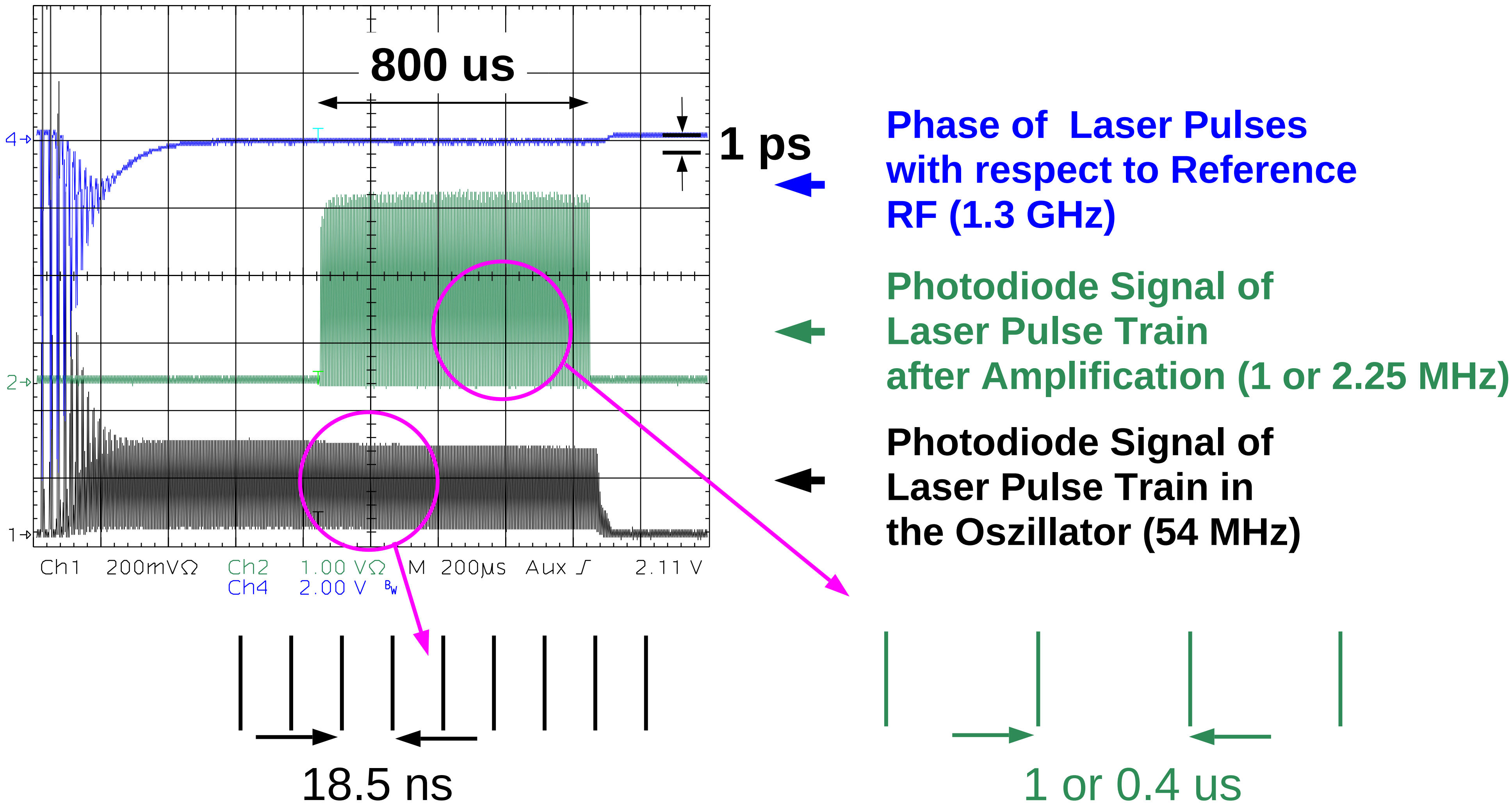
16-Oct-2000

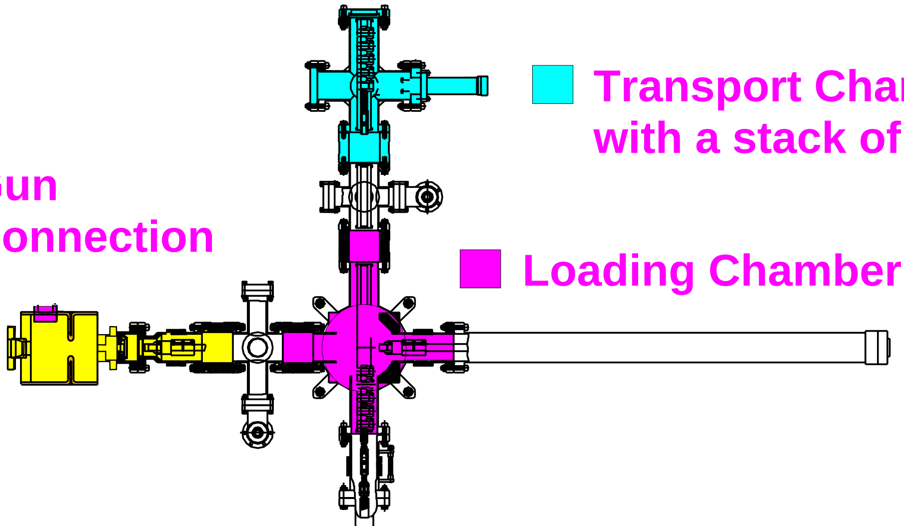
Scope Trace of the Laser Pulse Train



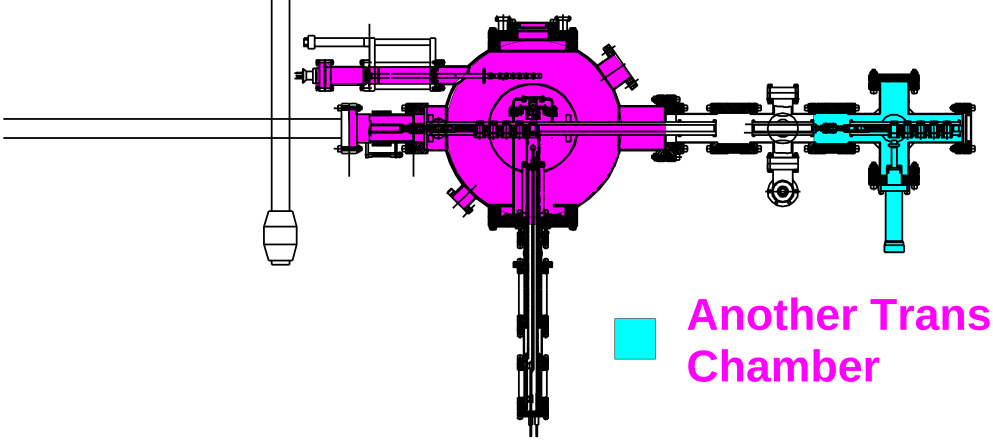
Cathode System

INFN Milano LASA
DESY

- Cs_2Te cathode: high quantum efficiency > 0.5 %
- A load lock system allows to change cathodes without breaking the UHV vacuum
  Vacuum better than 10^{-10}mbar required to maintain high quantum efficiency



- The cathodes are prepared off site in Milano and transported under UHV condition to DESY



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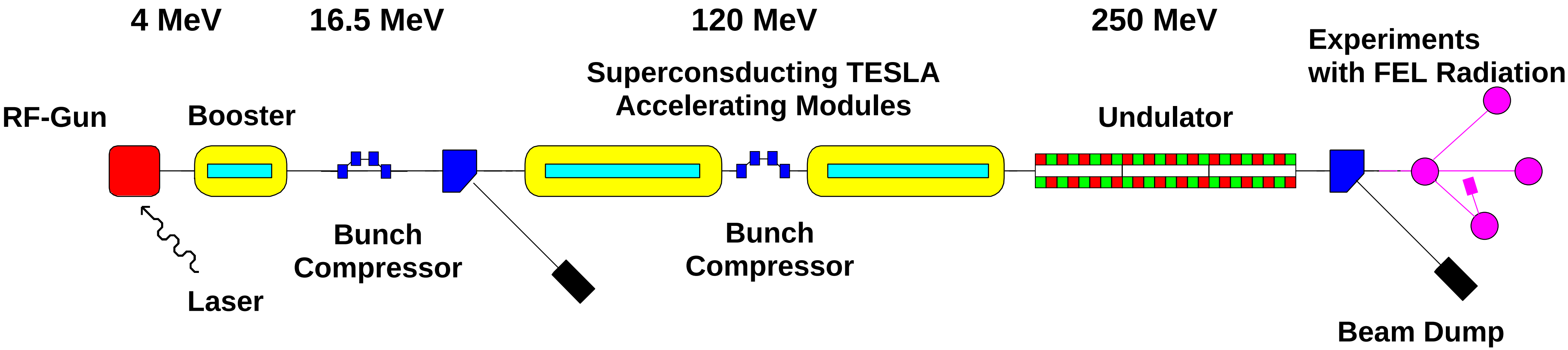
08-Apr-2001

Overview of the TESLA Test Facility Linac



Remark concerning the design

- The TTF injector has been designed
  for TESLA applications:
  -> design fulfills requirements for a
  TESLA type beam to test the
  superconducting accelerating structures

- To drive the TTF-FEL phase 1,
  demands are tighter:
  the FEL needs

  1. high peak current > 0.5 kA
  2. small energy spread < 0.1 %
  3. small transverse emittance < 6 um

- The rf gun source can do 2. and 3.,
  but not 1.
  -> the peak current is limited by
  space charge effects

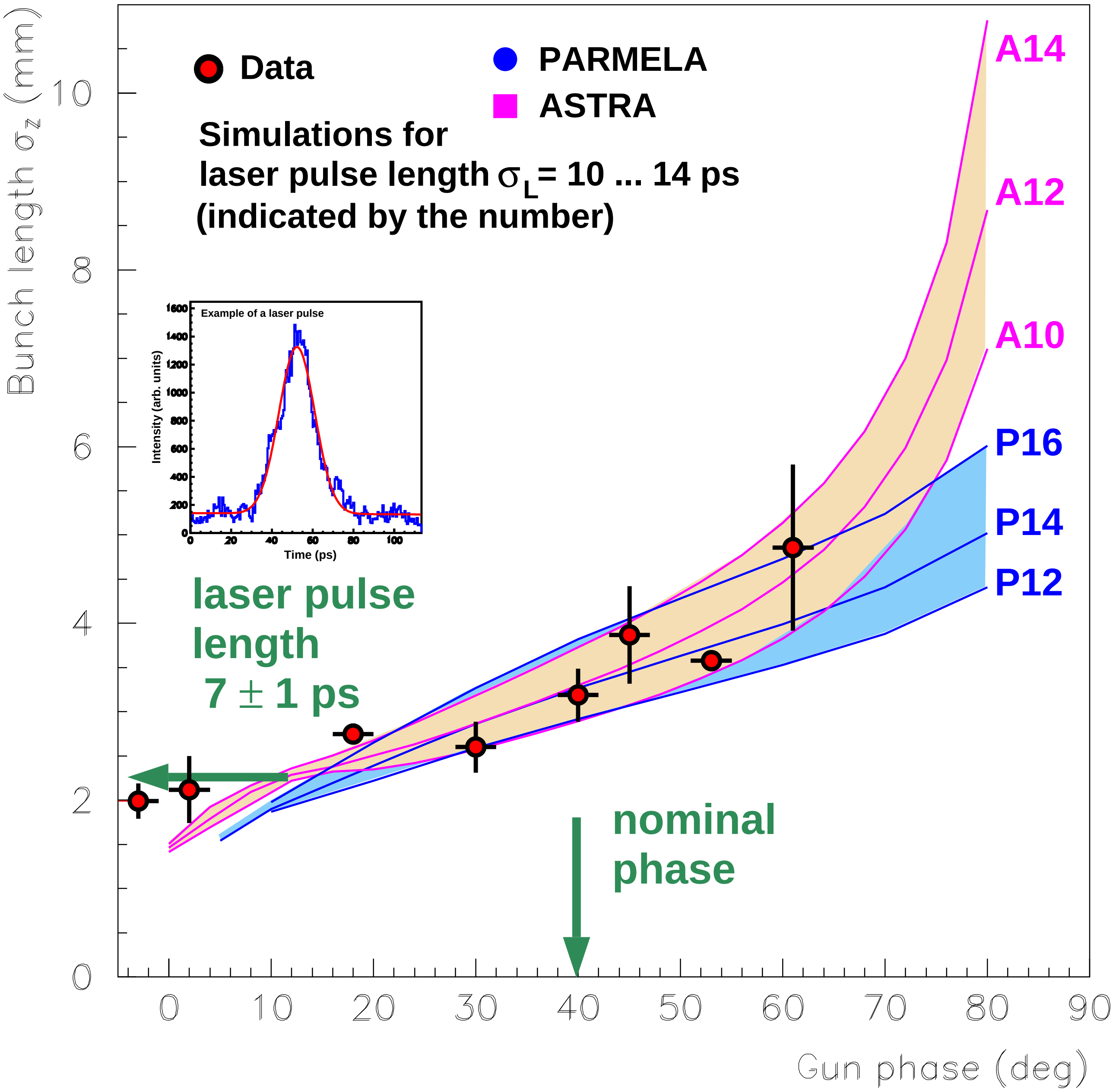
  That's why bunch compression
  after acceleration is required

- Do have the compression working correctly,
  the rf induced energy spread must be small
  -> short bunches of 0.8 mm length
  required before acceleration

- But this is shorter than the rf gun can do
  keeping at the same time the transverse
  emittance small

RMS Bunch Length after Booster

- measured as a function of rf gun phase with a streak camera (Photonetics) Charge: 1 nC, nominal rf gun settings



- Including measurements for larger bunch charges:
  1 nC -> 3.2 mm
  3 nC -> 4.3 mm

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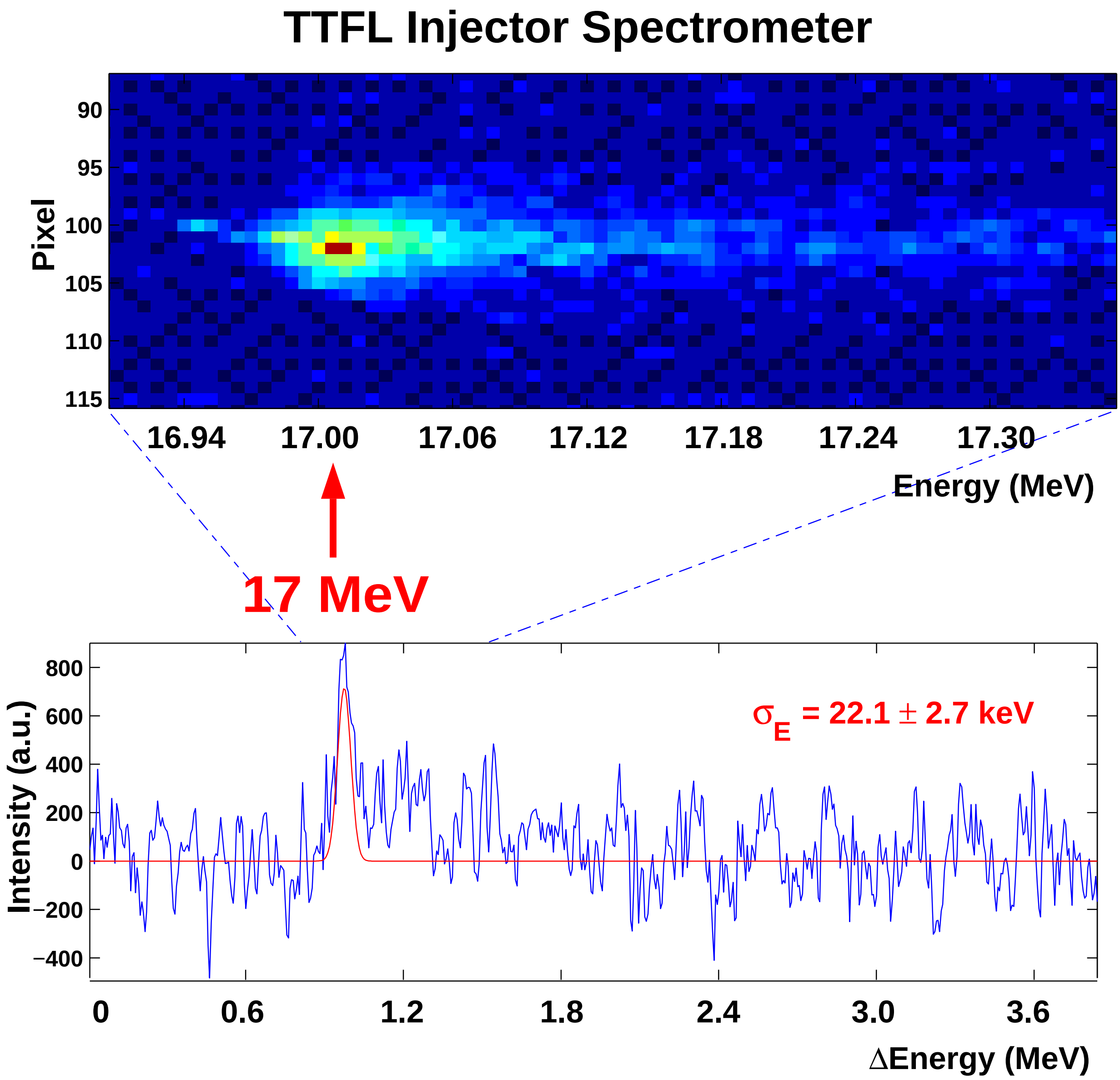
Energy Spread Measurement



- beam profile measured using optical transition radiation
- from a gaussian fit to the core:

$$\sigma_E = 22.1 \pm 2.7 \text{ keV}$$

$$\sigma_E / E = 0.13 \pm 0.02 \%$$

- tail: up to 50 keV

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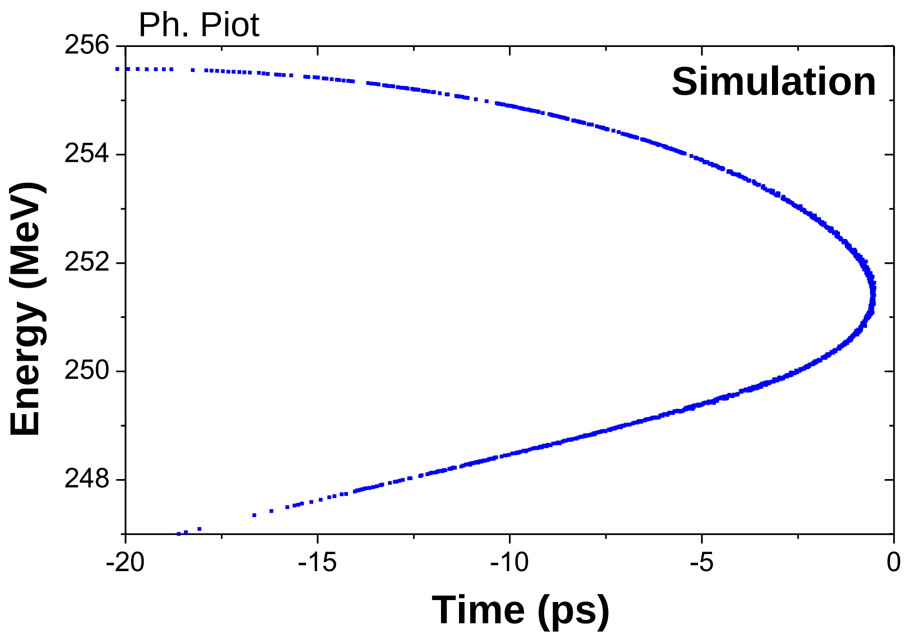
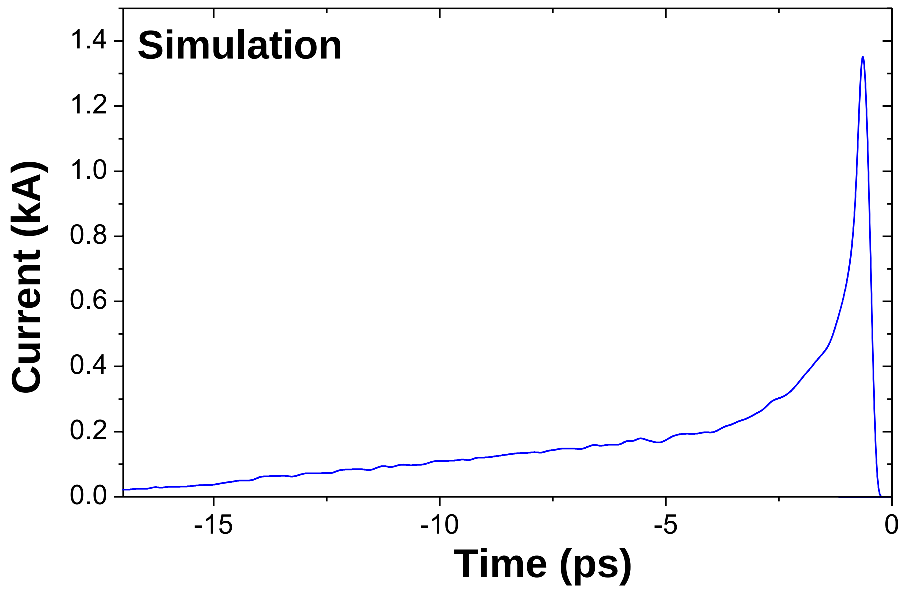
Expected longitudinal phase space at the undulator from simulation

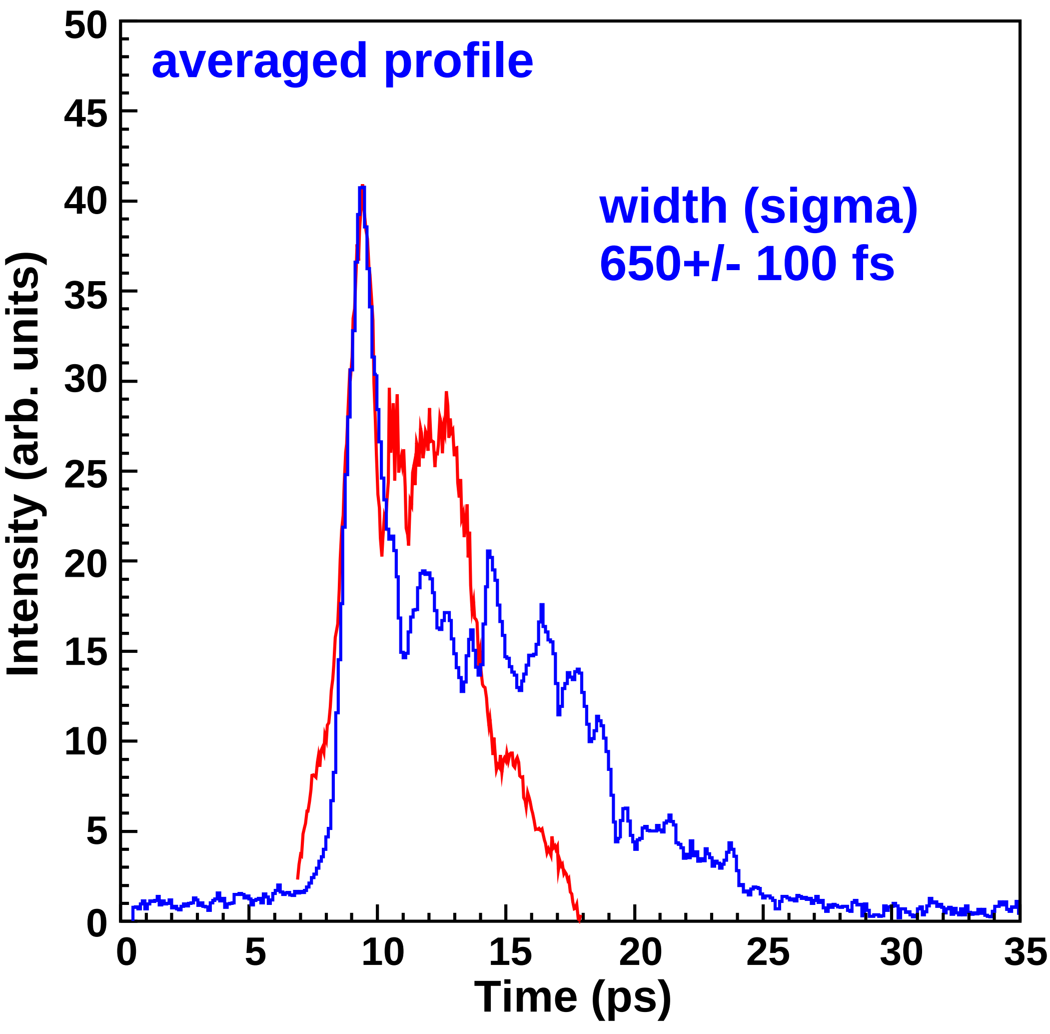




- We expect a sharp peak and a long tail
- The peak sharpness reflects the uncorrelated energy spread from the injector of ~20 keV

Bunchlength measurement with a streak camera

- syncrotron light from the last dipole has been measured with a fast streak camera (FESCA 200 Hamamatsu)



- for comparison: profile obtained with tomographic method (M. Hüning)

- Estimated peak current: 0.6 kA
  30 % of the charge of 3 nC is in the peak

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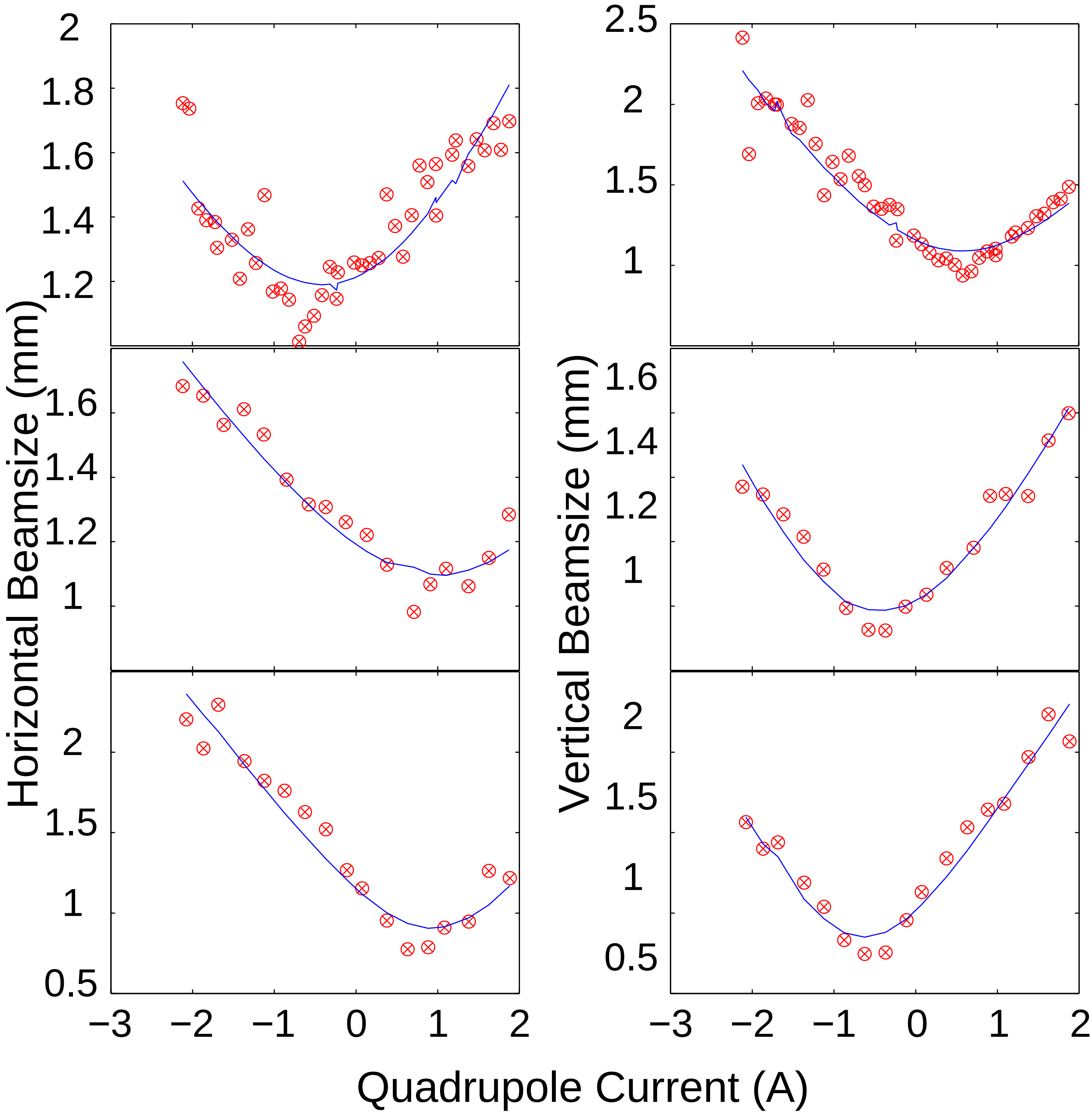
Quadscan for Different Solenoid Fields

Charge 1 nC, Energy 17.2 MeV, exit booster

Sol. 1/2	emit. x	emit. y (mm mrad)
200/104 A	4.19 +- 0.13	4.58 +- 0.15
220/104 A	3.02 +- 0.17	3.47+- 0.12
	beta (m) = 0.39+-0.03 / 0.51 +- 0.02	
	alpha = 0.78 +- 0.06 / 0.6 +- 0.04	
240/104 A	4.08 +- 0.57	4.52 +- 0.47



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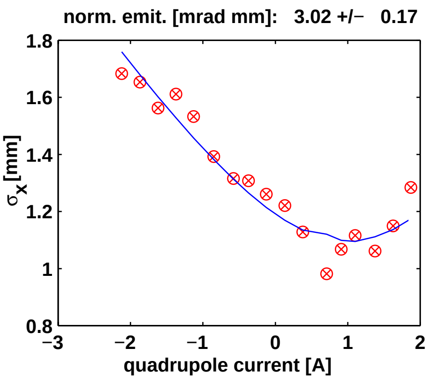
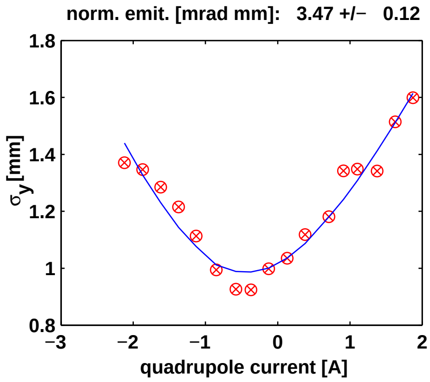
Development of the emittance along the linac

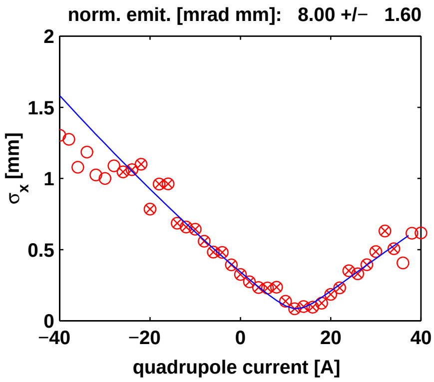
rf gun parameters:

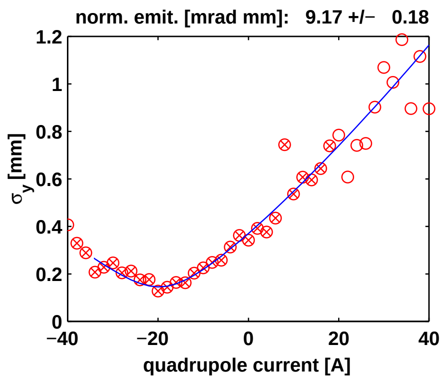
1 nC, 40 MV/m, spot size r=1.5 mm,phase 40 dg,
Solenoids 0.105/0.088 T, booster 12 MV/m



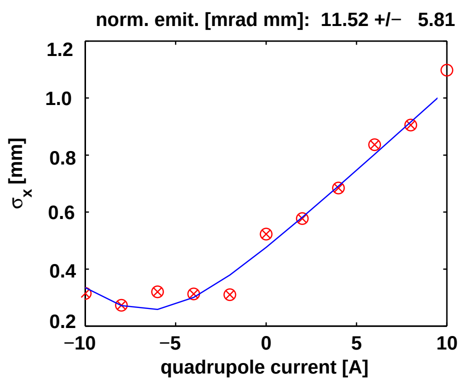


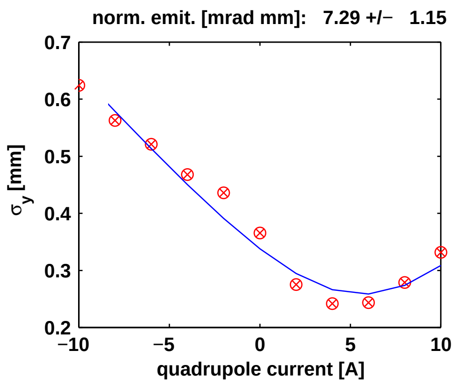
After the booster:
3.0 (3.2) +- 0.5 mm mrad hor. (vert)





After acceleration to 137 MeV:
8 (9) +- 2 mm mrad hor. (vert)

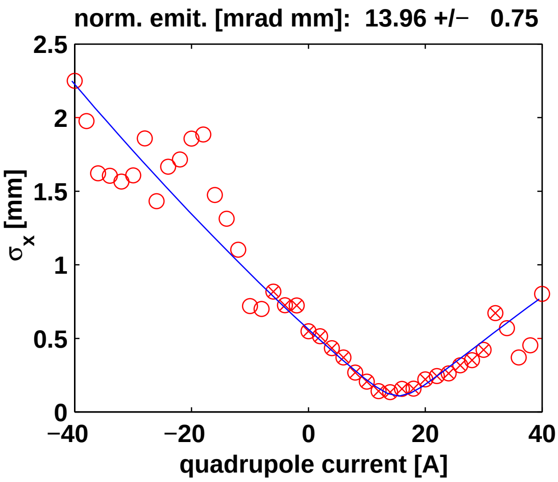


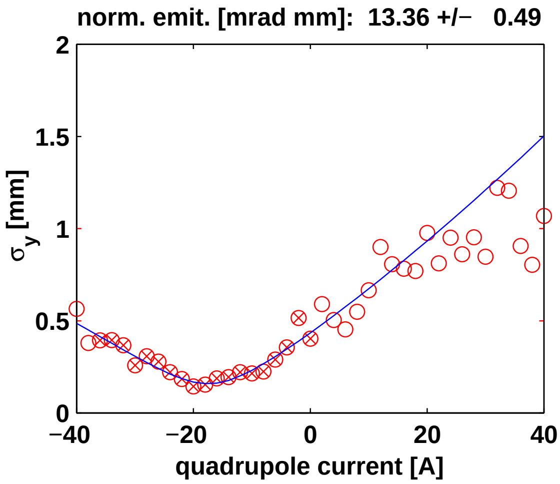


After acceleration to 246 MeV:
11 +- 6 (7 +- 2) mm mrad hor. (vert)

Emittance after Compression
higher charges

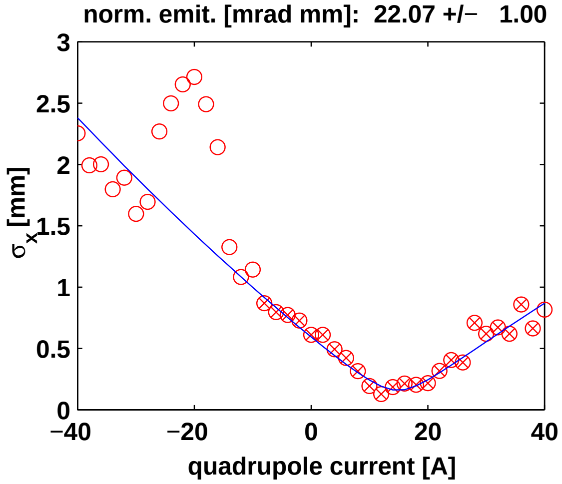
Quadrupole scan after second bunch compressor

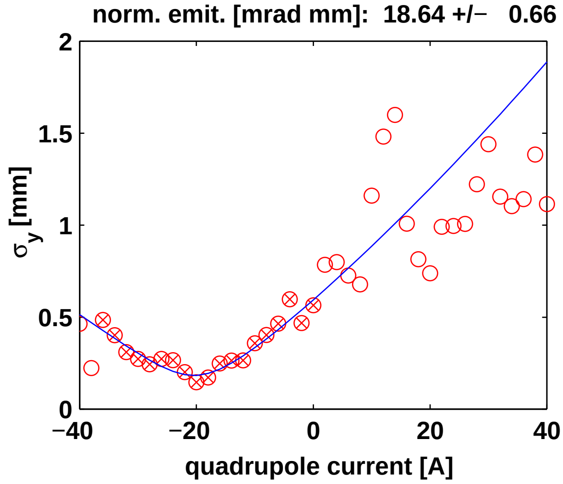




1 nC with compression:

14 (13) +- 2 mm mrad hor. (vert.)





2 nC with compression:

22 (19) +- 2 mm mrad hor. (vert.)

The projected emittance grows with compression and higher charges

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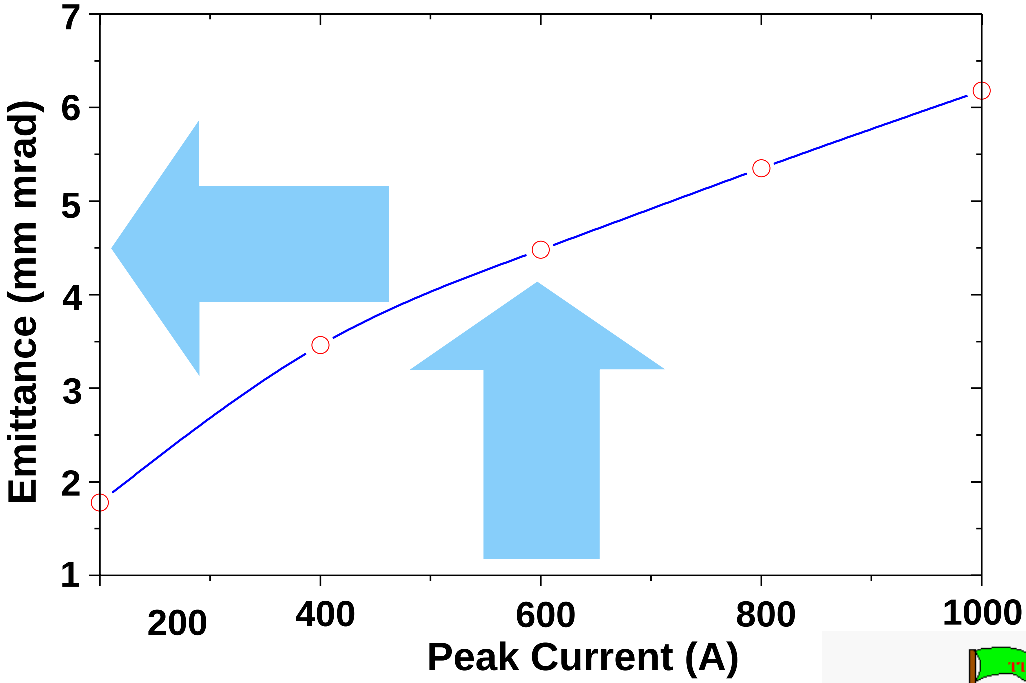
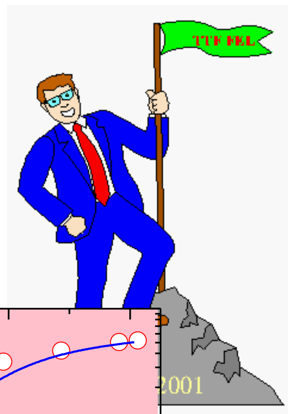
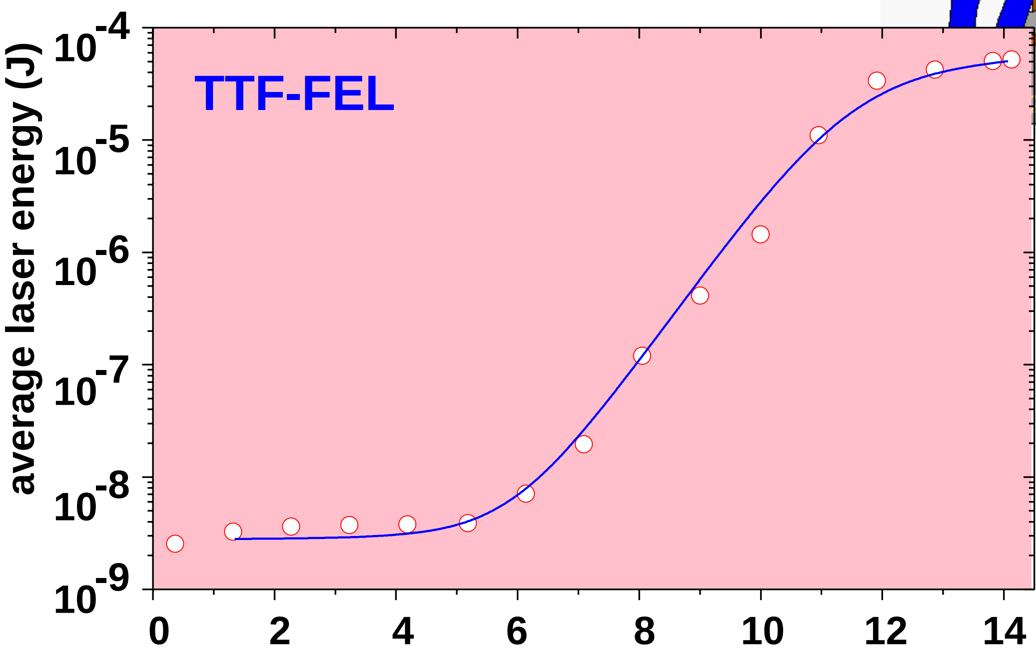
Expected Slice Emittance from FEL Radiation Properties

Problem: we measure only the projected emittance



Estimated slice emittance
from FEL radiation properties
and the gain length (67±5 cm)





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Conclusion

- The TTF photoinjector is in operation
since Dec. 1998
(14 000 h with beam or 5 E7 shots)

- It has been originally designed for
TESLA beam parameters
and is used to drive the TTF-FEL as well.

- The effect of rf curvature when accelerating
long bunches produces
--> a sharp peak in the longitudinal profile
after compression

- This peak fulfills the requirement for the
--> peak current 0.6 kA
(from streak camera data)
--> slice emittance 4.5 mm mrad
(from FEL properties)

- In this way,
saturation of the TTF SASE-FEL at 95 - 105 nm
has been achieved (10-Sep-2001).

- --> To drive a SASE FEL,
an electron source design has to include
the whole linac
in order to evaluate the performance of the
beam entering the undulator