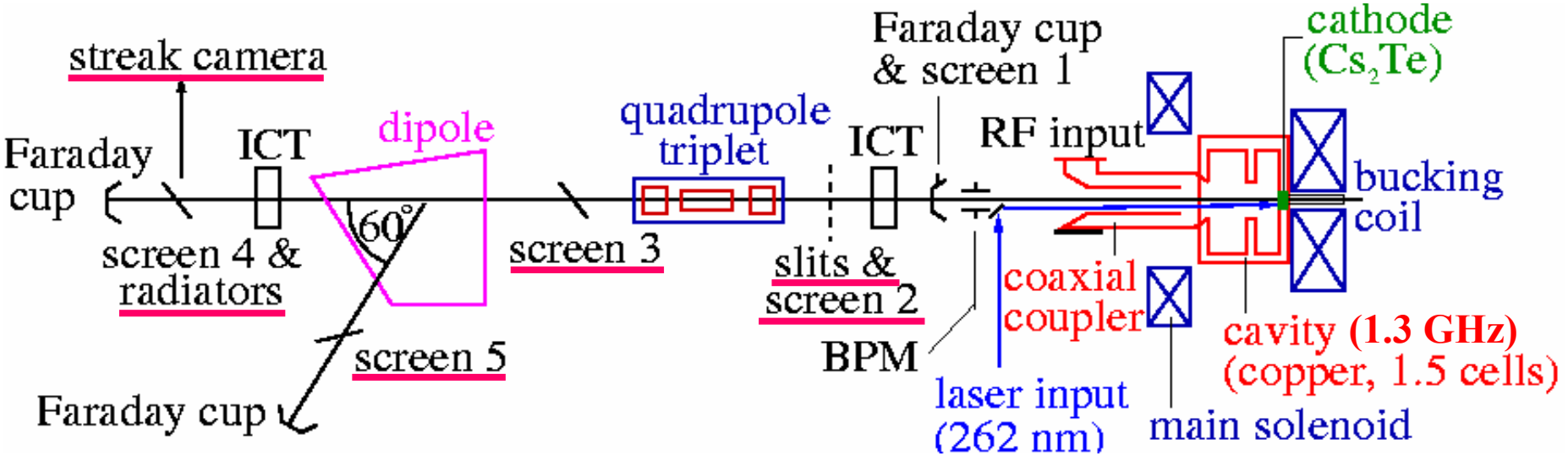
Recent Results and Perspectives of the Low Emittance Photo Injector at PITZ

- Introduction, Layout and Laser System
- Results for the VUV-FEL gun
  (gun prototype #2)
- Results from the next rf gun installed
  at PITZ (gun prototype #1)
- PITZ 2
- Summary

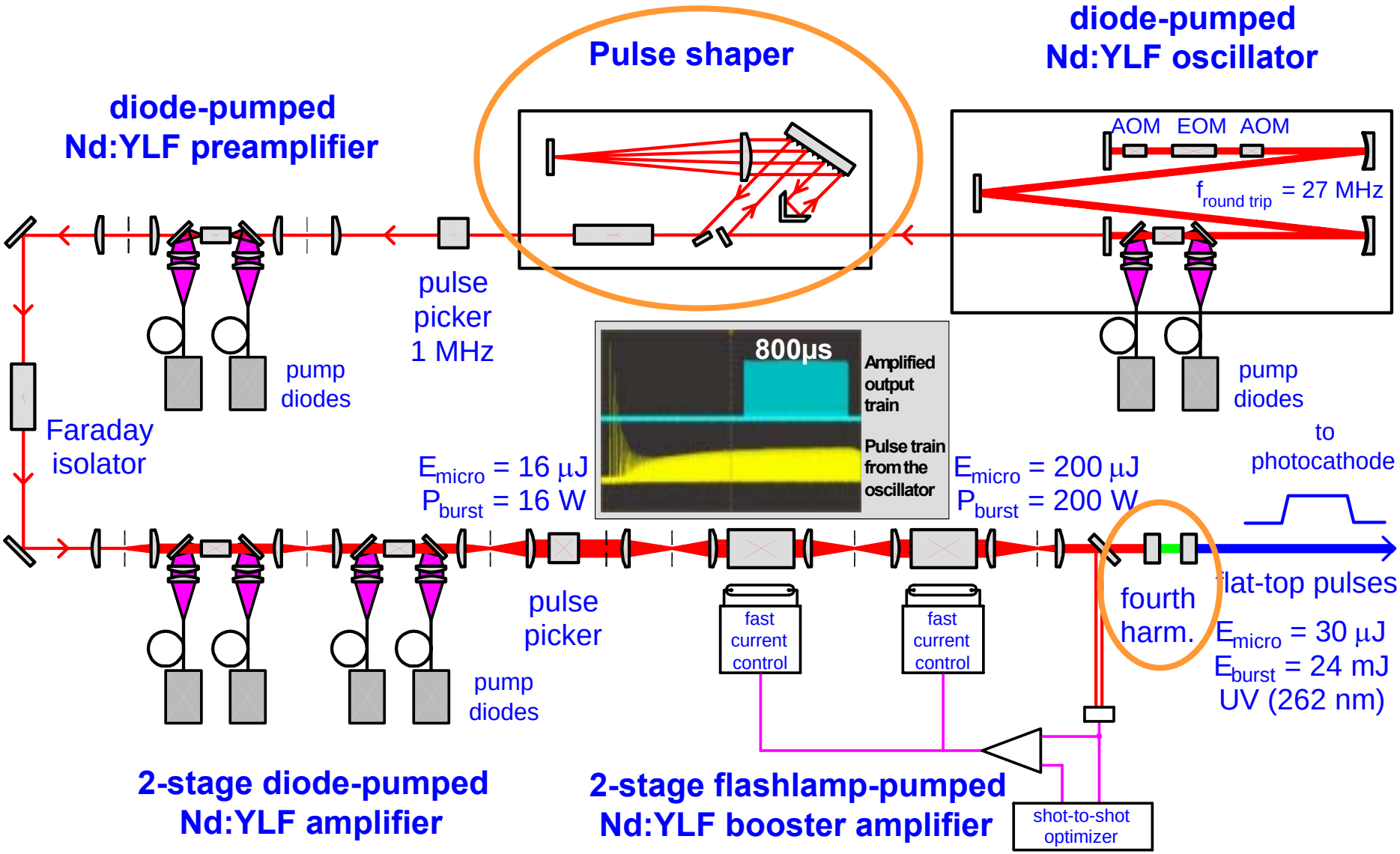
Collaboration and Layout

Collaborating Institutes:

BESSY Berlin, CCLRC Daresbury,
DESY (HH + Z), INFN Frascati,
INFN Milano, INR Troitsk,
INRNE Sofia, LAL Orsay,
MBI Berlin, TU Darmstadt,
U Hamburg, YERPHI Yerevan

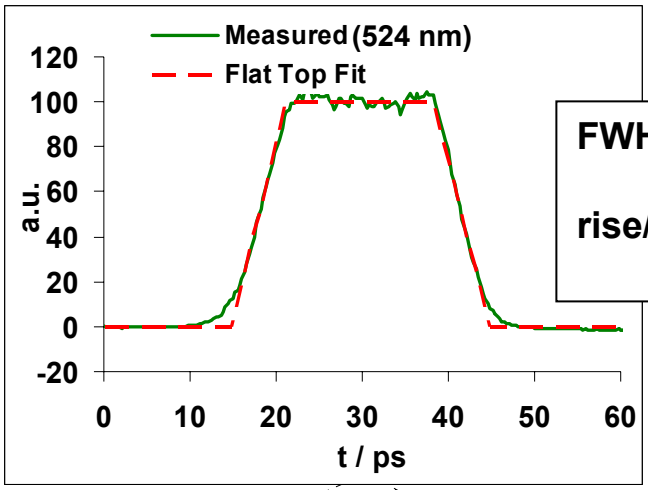


Laser system from the MBI in Berlin

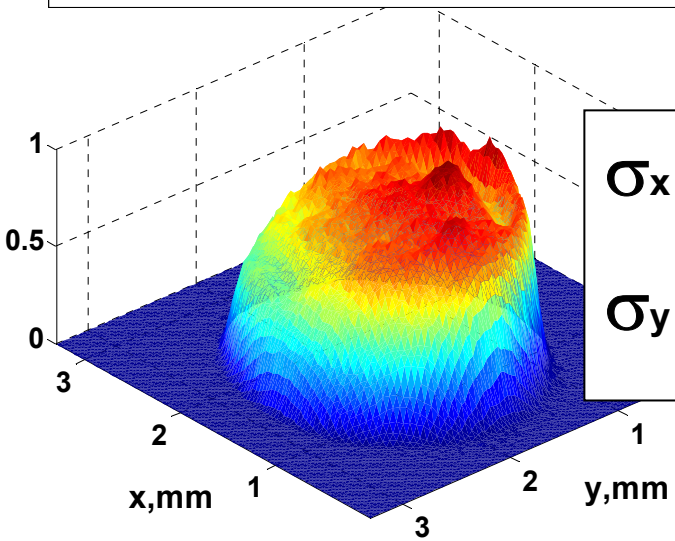


Temporal and Transverse Laser Profiles

in 2003 (VUV-FEL gun):



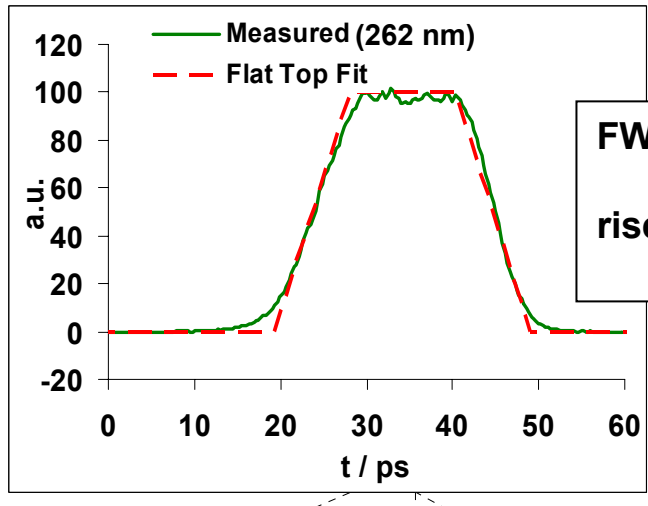
FWHM ≈ 18-23 ps
rise/fall ≈ 5-7 ps



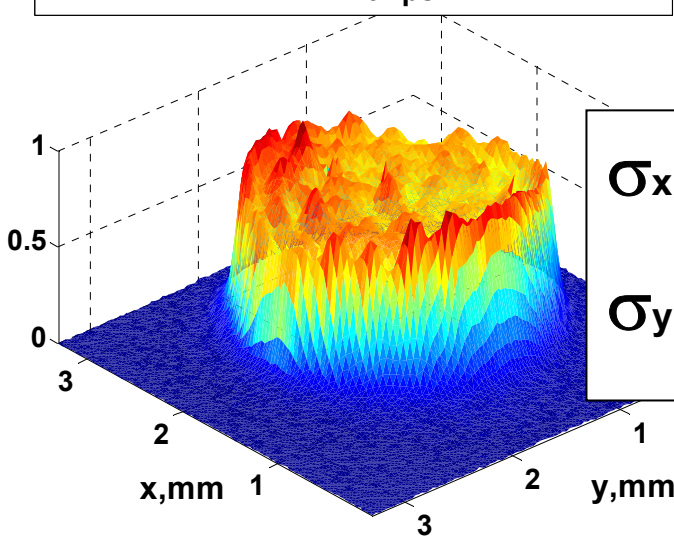
σ_x = 0.51 ± 0.02 mm

σ_y = 0.62 ± 0.02 mm

in 2004 (gun prototype #1):



FWHM ≈ 19-24 ps
rise/fall ≈ 7-9 ps



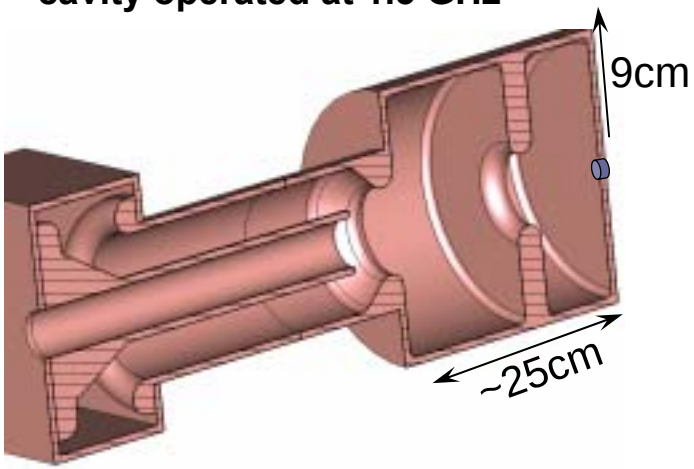
σ_x = 0.57 ± 0.02 mm

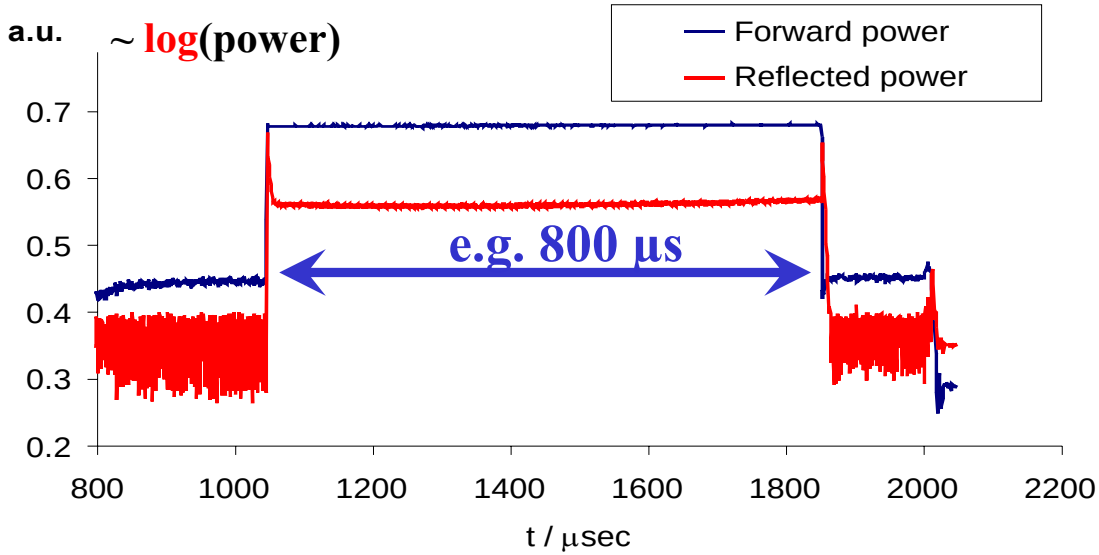
σ_y = 0.58 ± 0.02 mm

VUV-FEL Gun: RF Conditioning Results

RF Power source: 5 MW Klystron

RF Gun cavity: 1.5-cell copper cavity operated at 1.3 GHz





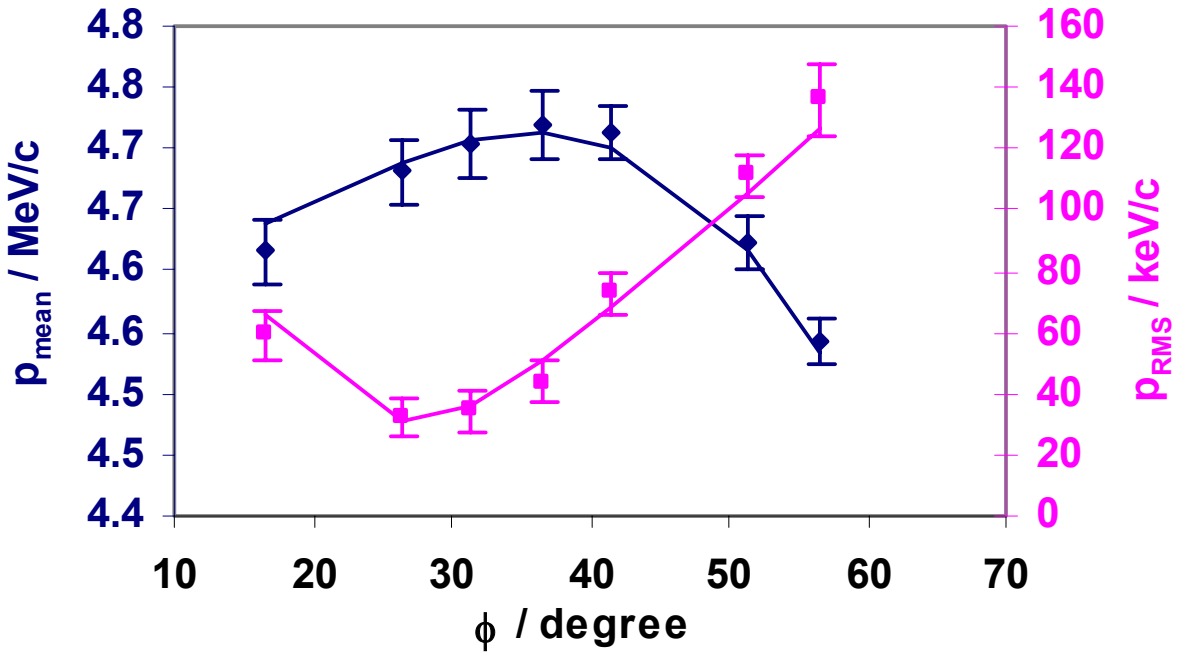
- rf pulse lenght: **900 µs ,** repetition rate: **10 Hz**
- gradient: **42 MV/m at the cathode** (~ 3 MW)

⇒ **duty cycle: 0.9 %, average rf power: 27 kW**

(results only limited by conditioning time)

fulfills VUV-FEL RF parameter requirements

VUV-FEL Gun: Longit. Phase Space



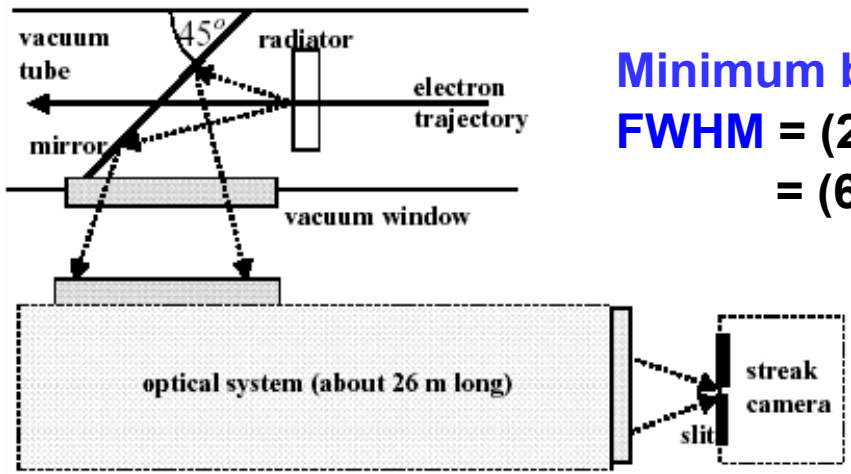
Q = 1 nC

max. mean momentum:
4.72 MeV/c

min. rms momentum spread:
33 keV/c

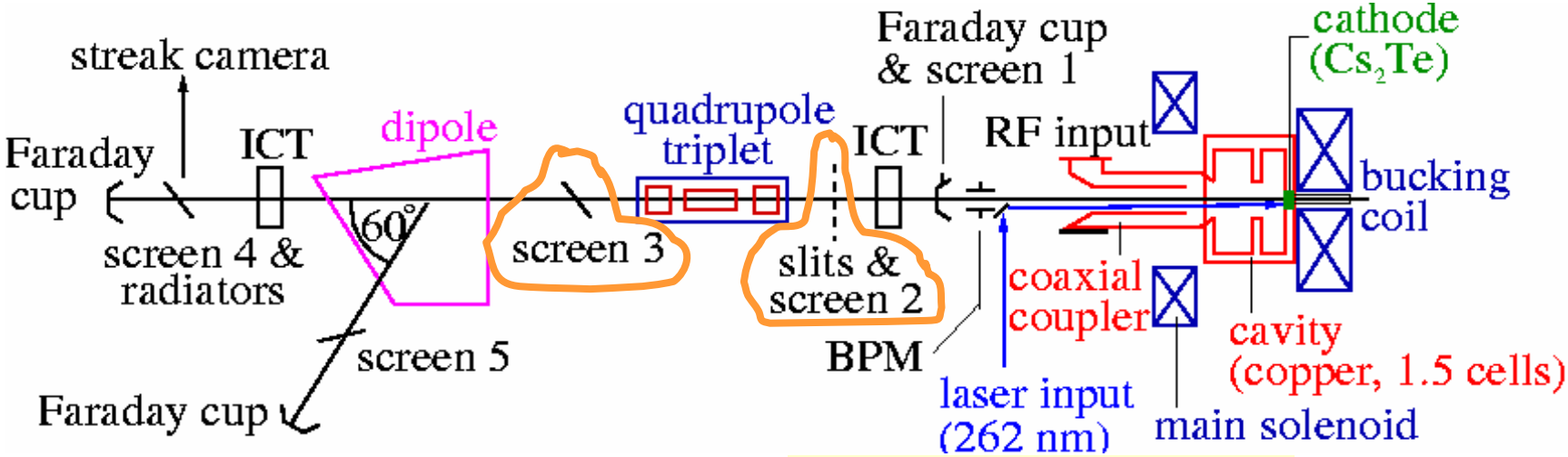
good agreement with simulations !

bunch length:



Minimum bunch length:
FWHM = (21.04 ± 0.45stat ± 4.14syst) ps
= (6.31 ± 0.14stat ± 1.24syst) mm

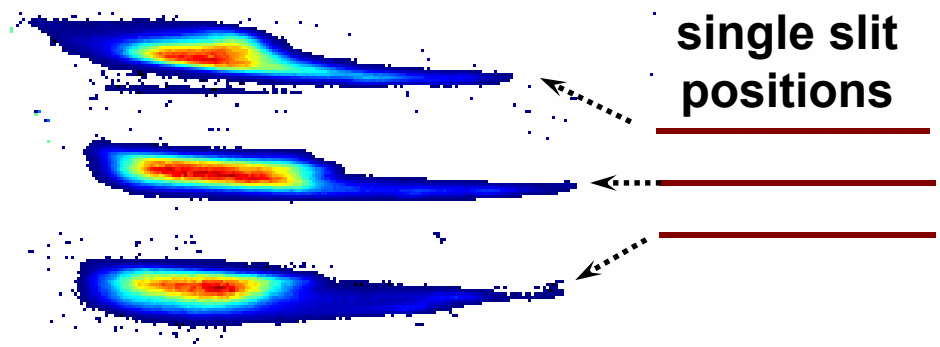
Transverse Emittance Measurements



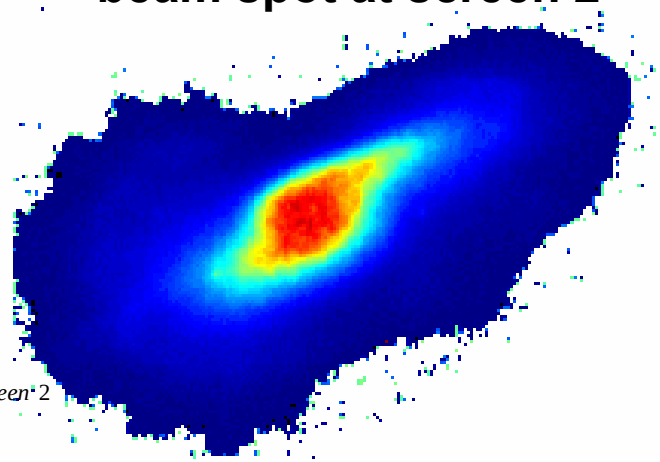
Single Slit Scan Technique

$$\varepsilon_{nx} = \beta\gamma\sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$

beamlets at screen 3



beam spot at screen 2

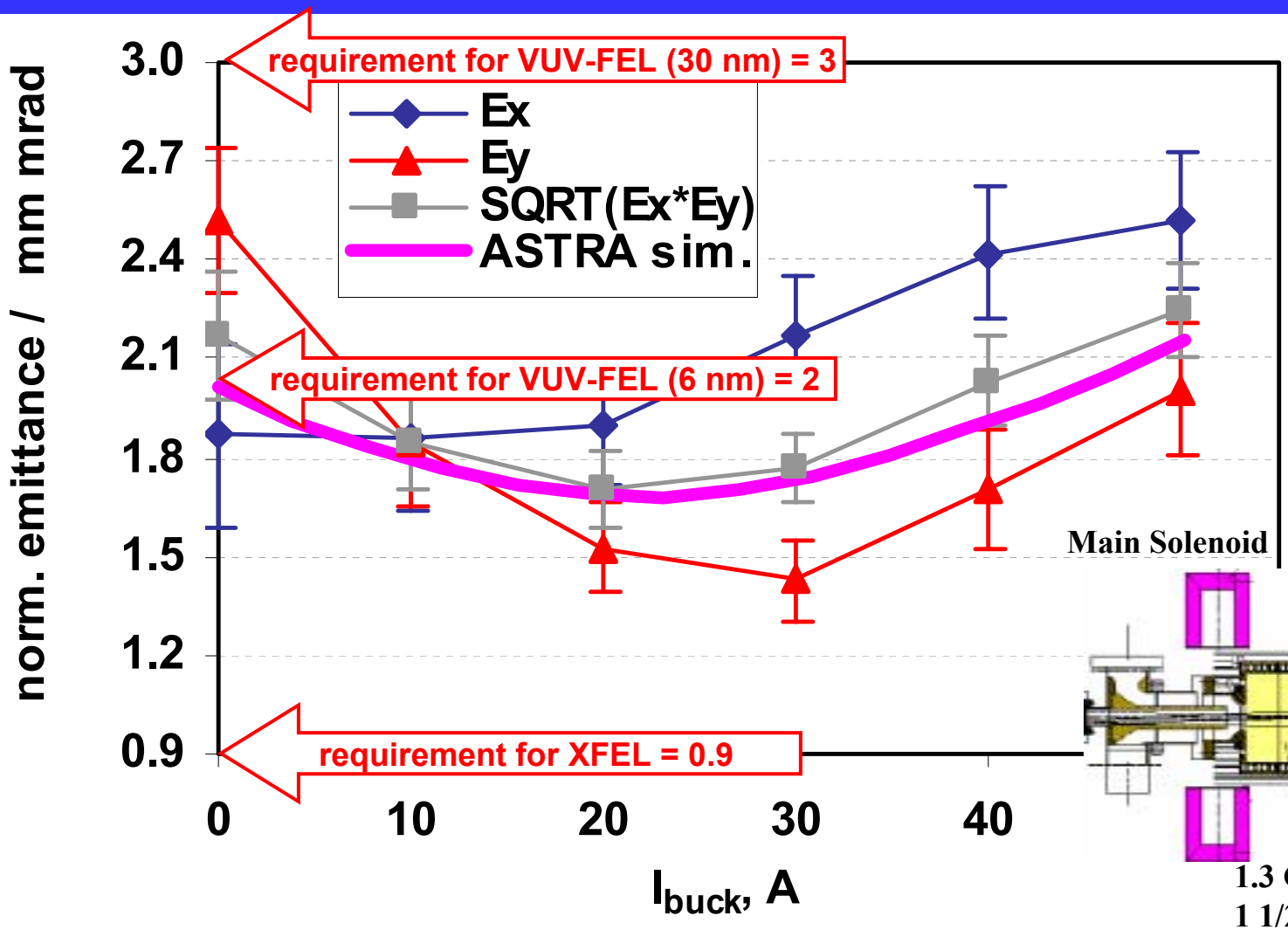


beamlet size is measured for 3 slit positions:

$$y_n = \langle Y\rangle^{screen\ 2} + n \cdot 0.7\sigma_y^{screen\ 2}$$

$$n \in \{-1,0,1\}$$

VUV-FEL Gun: Transverse Emittance



Q = 1 nC,

$\Phi = \Phi_m - 5°$

I_{main} = 305 A

for details see poster TUPOS09

Start-up requirement of TTF2 is clearly fulfilled !

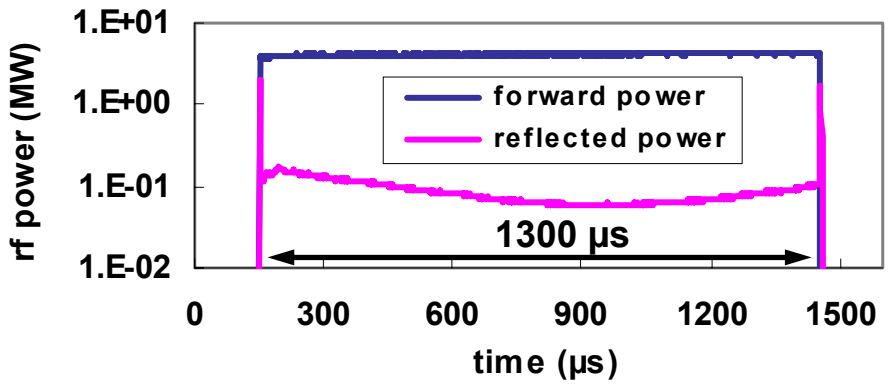
Prototype #1: RF Conditioning Results

goals for the XFEL: ~ 6.5 MW, ≤ 650 μs, 10 Hz

conditioning results obtained in 2004:

limited by 5 MW klystron and water cooling system !!

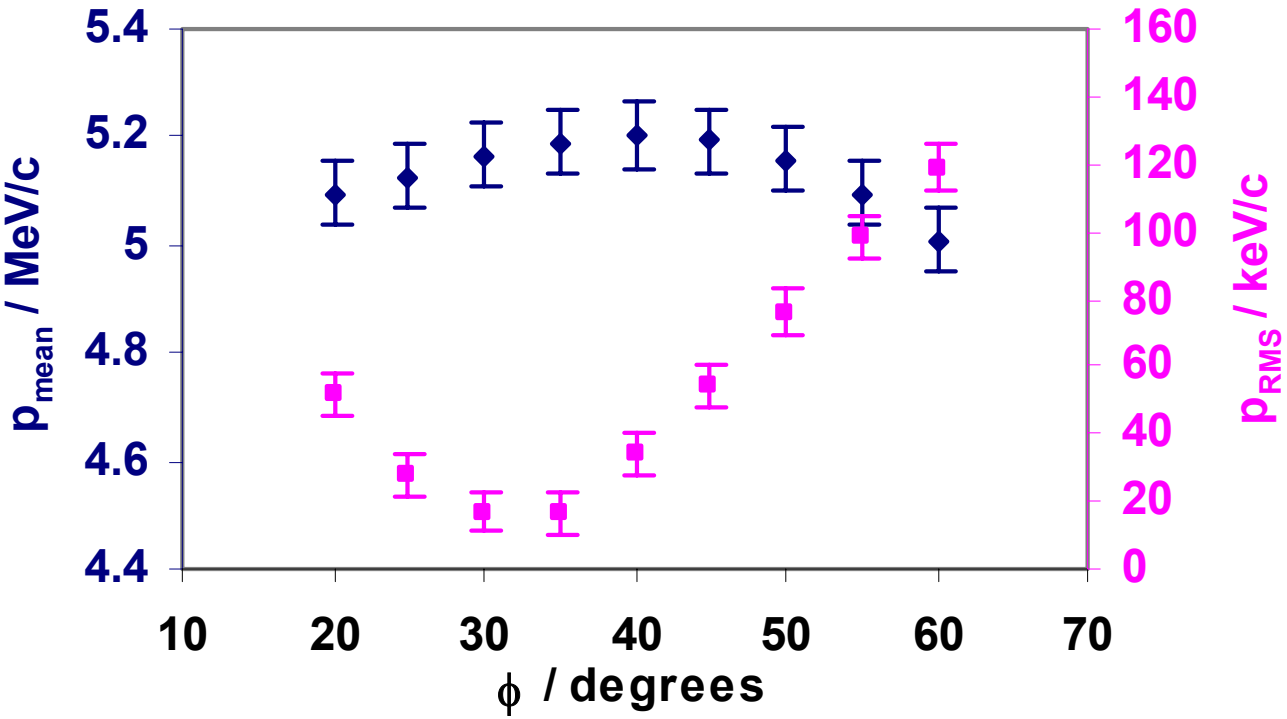
→ upgrade Dec'04 – Feb'05



repetition rate	10 Hz	5 Hz	10 Hz
rf pulse length	0.5 ms	1.3 ms	1.0 ms
peak power at gun	4 MW	4 MW	3 MW
mean power	20 kW	26 kW	30 kW
duty cycle	0.5 %	0.65 %	1.0 %

for details see poster TUPOS03

Prototype #1: Longit. Phase Space



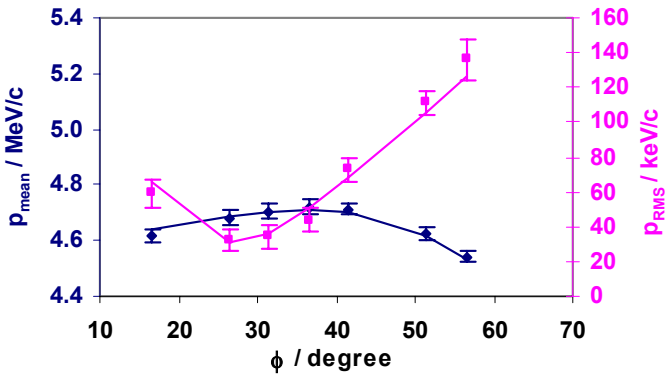
Q = 1 nC

max. mean momentum:
5.20 MeV/c
(+ 10%)

min. rms momentum spread:
16 keV/c
(- 50 %)

phase difference between p^{max}_{mean} and p^{min}_{RMS} only ~5 degrees

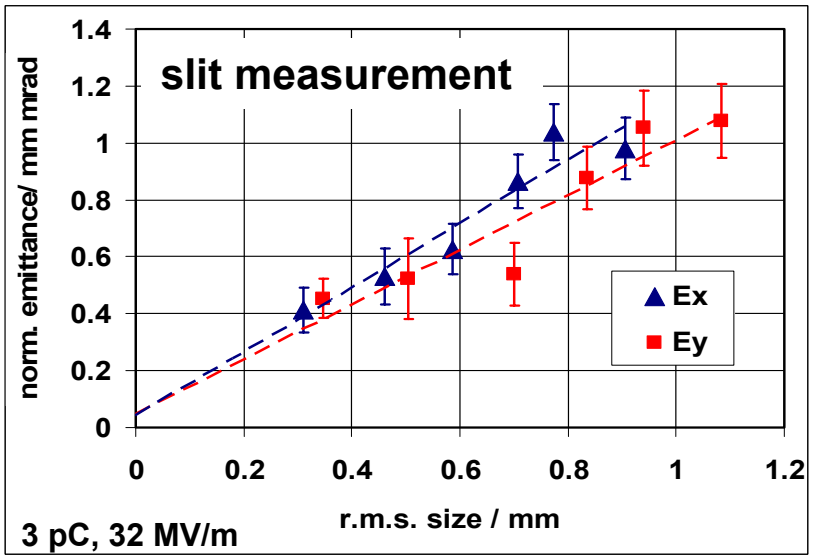
old data from VUV-FEL gun:



Prototype #1: Thermal Emittance

methode: $\varepsilon_{th} = \sigma\sqrt{\frac{2E_k}{3m_0c^2}} \quad \longleftrightarrow \quad E_k = 1.5\, m_0c^2\left(\frac{d\varepsilon_{th}}{d\sigma}\right)^2$

for details see poster TUPOS09



cross check with solenoid scan yielded same result:

$$E_k = 0.8 \pm 0.1\,\text{eV}$$

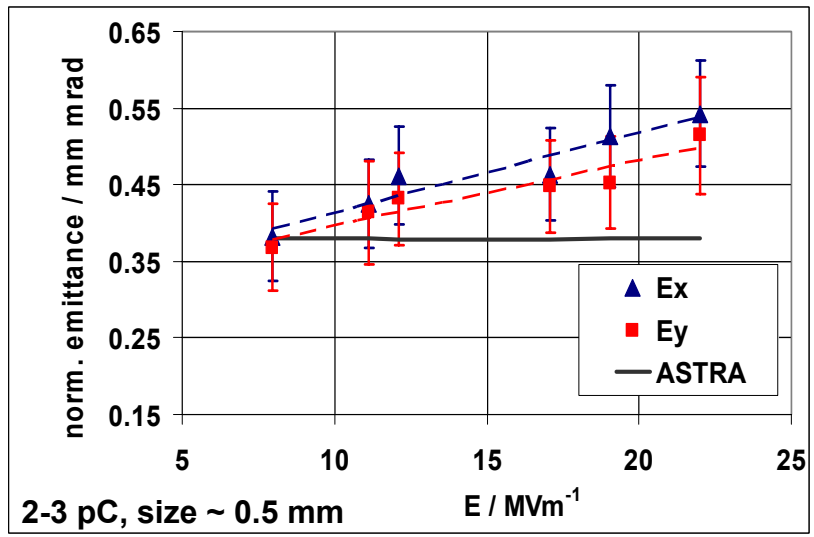
for laser r.m.s. size = 0.58 mm

$$\varepsilon_{th} \approx 0.6\,\text{mm mrad}$$

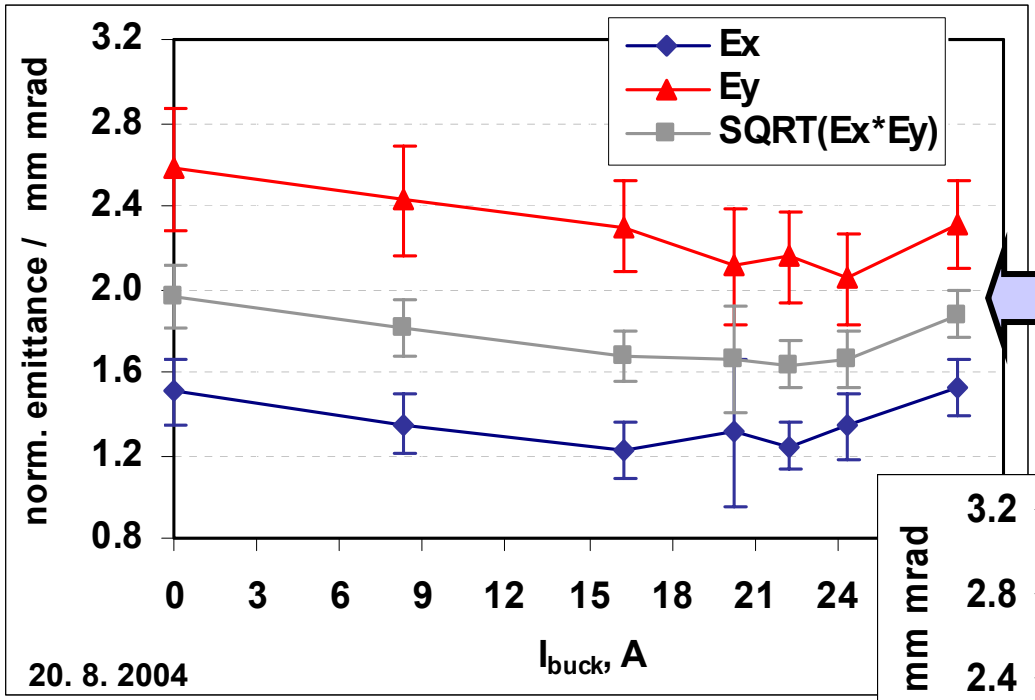
ε_{th} vs. accelerating gradient:

- ASTRA does not scale kin. energy of the emitted electrons

→ modified Schottky effect



Prototype #1: Transverse Emittance



optimization ongoing

→ preliminary results !

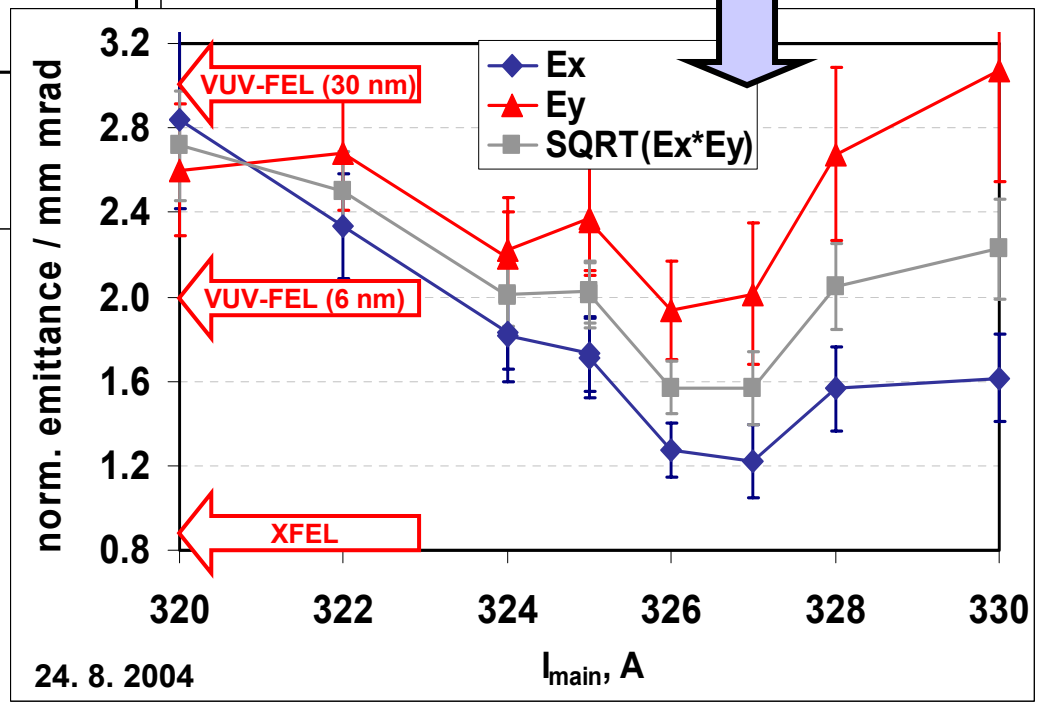
all for Q = 1 nC

$\Phi = \Phi_m - 5°$

$I_{main} = 326$ A

$\Phi = \Phi_m$

$I_{buck} = I_{main} * 0.075$



- **min. emittance improved**
- **geom. average improved**
- **still long way to go for XFEL requirements !**

PITZ 2

→ large extension of the facility and its research program

- **study emittance conservation principle:**

  (booster cavity + new diagnostics beam line + beam dynamics)

- **reach XFEL requirements: 0.9 mm mrad @ 1 nC:**

  (increased RF field on photo-cathode + improved laser system + improved photo-cathodes)

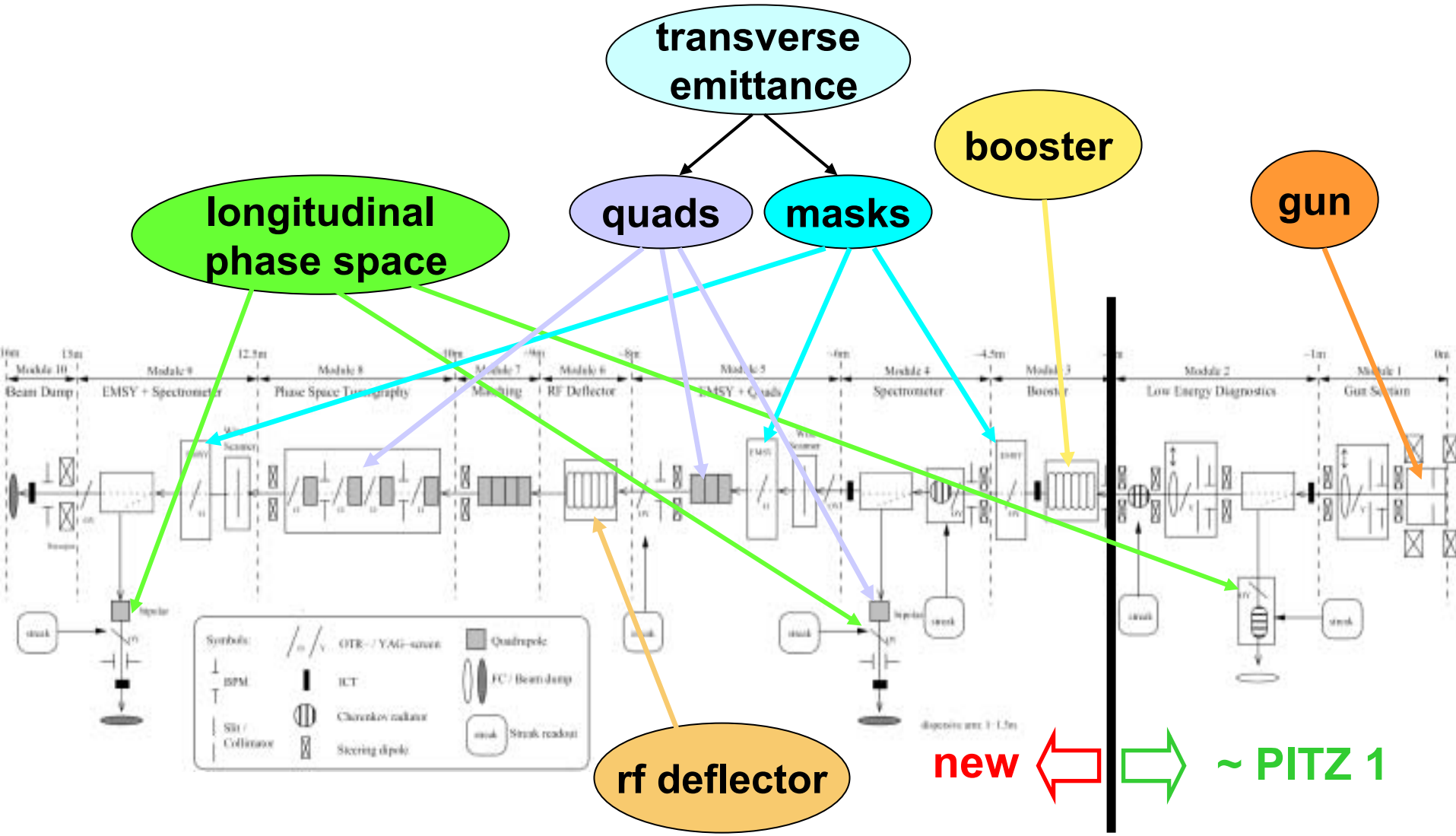
- **study XFEL parameter space:**

  (low charge and short bunches + vice versa)

- **operate at higher repetition rates:**

  (more cooling + new RF system + new gun cavity + diagnostics)

Preliminary Layout of PITZ2



How to reach the beam quality required for the XFEL

Goal: 0.9 π mm mrad from the injector for 10 Hz, 650 μs !!

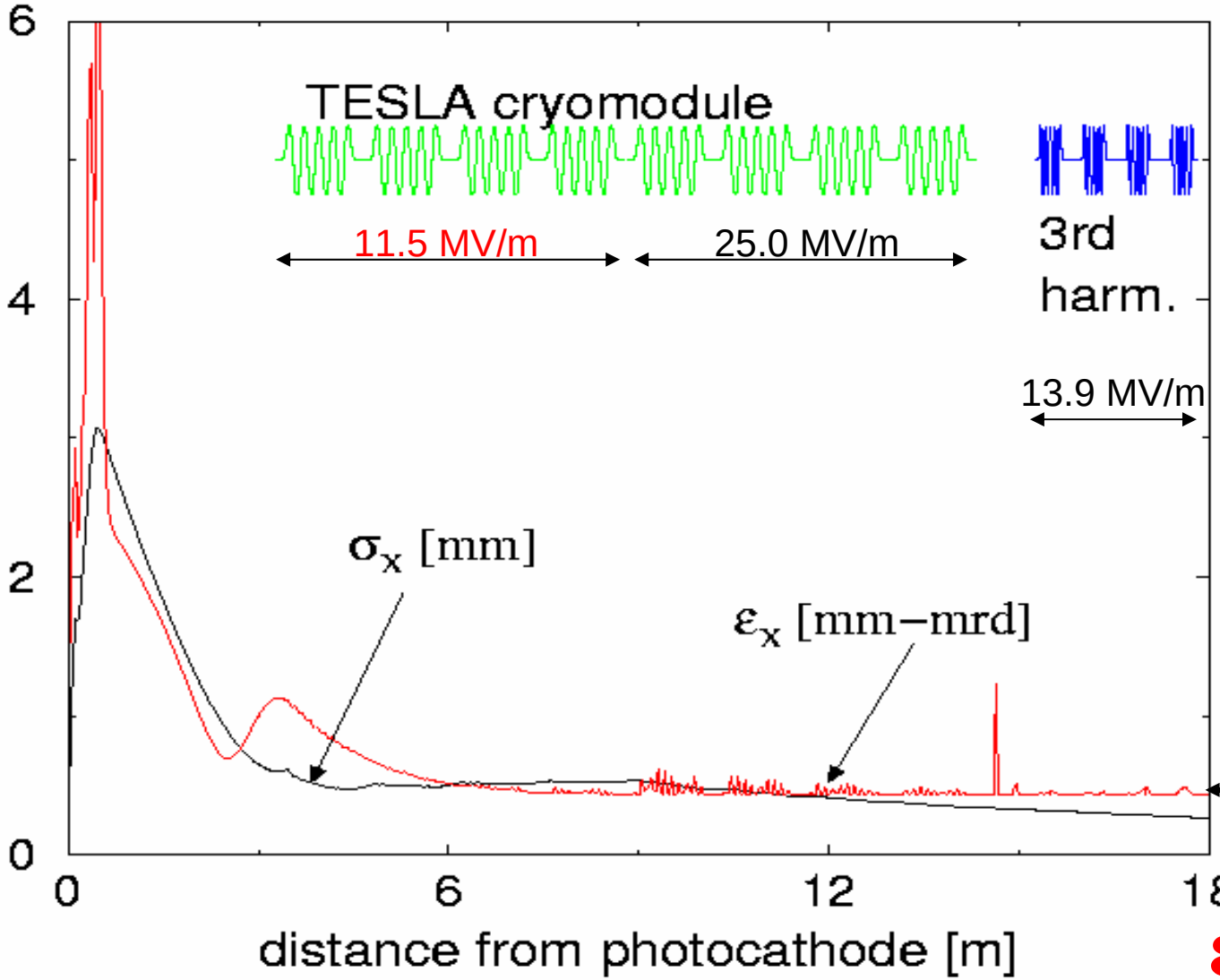
- **upgrades with ~ 40 MV/m at the cathode:**
  - improved homegenous transverse laser profile:
    remote controllable diaphragm close to the cathode

    $\Rightarrow \varepsilon_n \sim 1.5$ mm mrad @ 1 nC
  - improved longitudinal laser profile (20 ps FWHM, 2 ps rise/fall time):
    use a broadband laser medium, solve problem of high average power, conserve stability

    $\Rightarrow \varepsilon_n \sim 1.2$ mm mrad @ 1 nC
- **in addition, with 60 MV/m at the cathode:**

  $\Rightarrow \varepsilon_n \sim 0.9$ mm mrad @ 1 nC

Transverse Beam Parameters for the XFEL Injector



gun param.:

rms laser spot	0.75 mm, uniform
assumed therm. emittance	0.74 mrad mm
laser pulse length	20 ps, uniform
gun acc. gradient	**60 MV/m**
injecting phase	44°

proj. emittance
≈ 0.5 mrad mm
(no th. emittance)

ε_n = 0.9 mrad mm

(including th. emittance)

Courtesy of Ph. Piot, FNAL

Summary

- **VUV-FEL gun:**
  - **minimum normalized emittance (one plane): 1.5 mm mrad**
  - **minimum geometrical average (both planes): 1.7 mm mrad**
  - **good agreement with simulations**

- **next gun installed at PITZ:**
  - **increased rf power: <P> = 30 kW, 1 % duty cycle, P_{peak} = 4 MW, rf pulse lenght = 1.3 ms**
  - **beam characterization ongoing:**
    transverse emittance already improved (~1.3 / ~1.6 mm mrad)

- **PITZ 2 will start operation in spring 2005:**
  - **further improve emittance from gun**
  - **study the conservation of small emittance to higher beam energy**

Job Announcement

Deutsches Elektronen-Synchrotron
Accelerator physics

DESY

DESY is world-wide one of the leading accelerator centres exploring the structure of matter. The main research areas range from elementary particle physics over various applications of synchrotron radiation to the construction and use of X-ray lasers.

For the running of Free-Electron Lasers like the VUV-FEL and XFEL electron sources with excellent beam quality are needed. For the development of such electron guns a test facility for rf photo injectors is running and will be substantially upgraded at DESY Zeuthen. The development of photo injectors is based on detailed measurements, corresponding simulations and further development of theoretical models. The laboratory in Zeuthen (near Berlin) is searching for a

Postdoc(m/f)

for participating in the photo injector project. You should have a Ph.D. in physics and be under 33 years of age. You have substantial knowledge and professional experience in one or more of the following fields: accelerator physics, beam dynamics, laser, software development for data acquisition systems, hardware development of accelerator subsystems and beam diagnostics (optical or electronical). You are ready to take responsibility for sub-projects and will contribute significantly to the experiments, the upgrade and optimization of the electron source. You like to work in a motivated team of physicists and engineers and have a good knowledge of the English language. In the framework of the position shift work may be necessary at times.

Contact to project group: Dr. F. Stephan
Phone: +49-(0)33762-77338
e-mail: frank.stephan@desy.de

The position is limited to 2 years at the beginning.

Salary and benefits are commensurate with public service organisations. DESY operates flexible work schemes, such as flexitime or part-time work. DESY is an equal opportunity, affirmative action employer and encourages applications from women.

Deutsches Elektronen-Synchrotron DESY
member of the Helmholtz Association
· Platanenallee 6 · D-15738 Zeuthen · Germany

We are looking for
2 postdocs and
1 PhD student
to join our team.

Please contact me.

The End