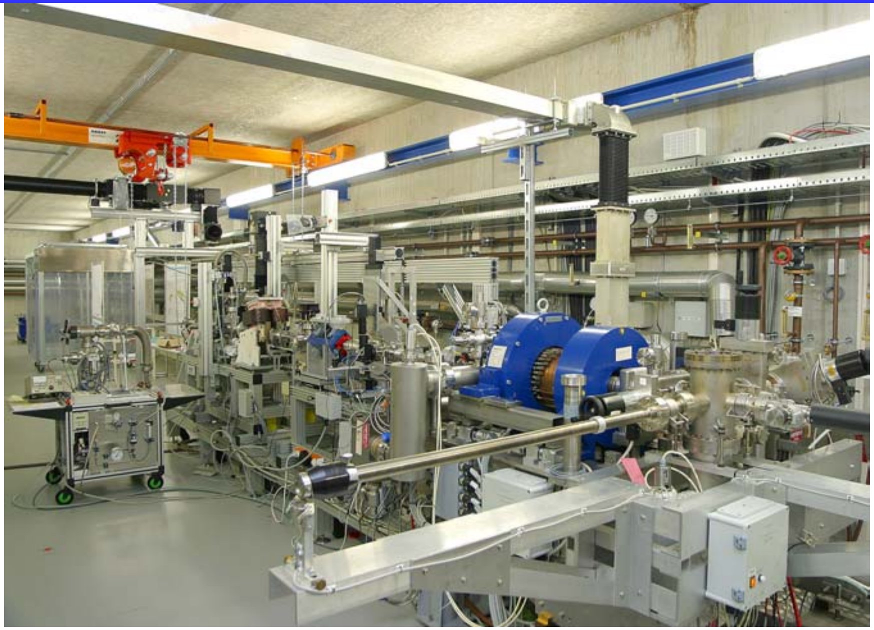
Recent Results and Perspectives of the Low Emittance Photo Injector at PITZ

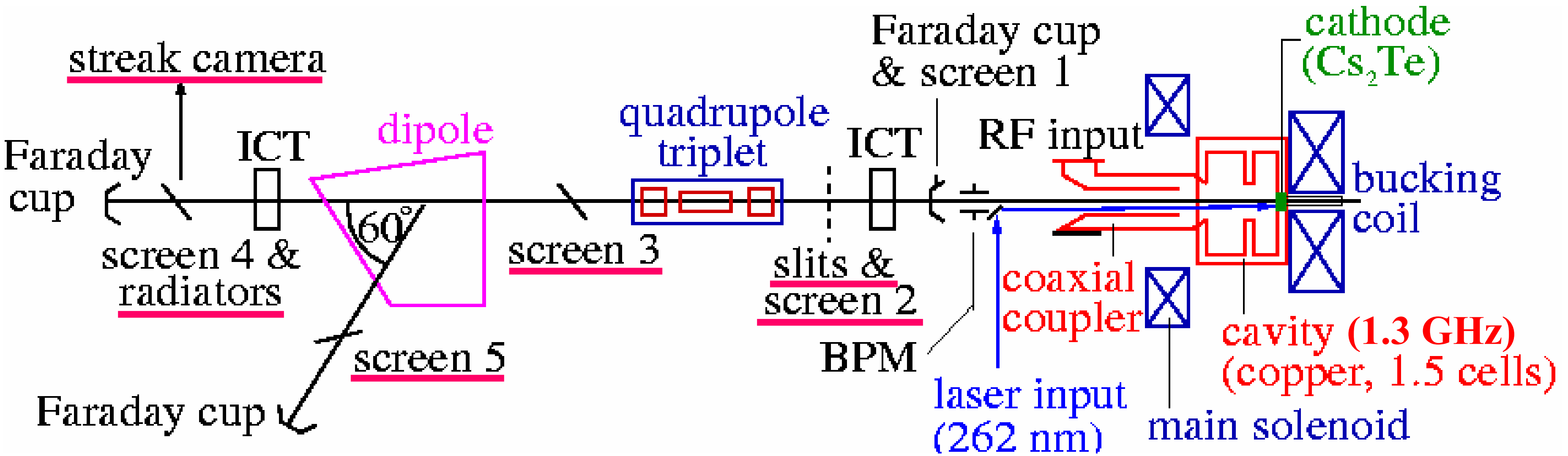
- Introduction, Layout and Laser System
- Results for the VUV-FEL gun
  (gun prototype #2)
- Results from the next rf gun installed
  at PITZ (gun prototype #1)
- PITZ 2
- Summary

Collaboration and Layout

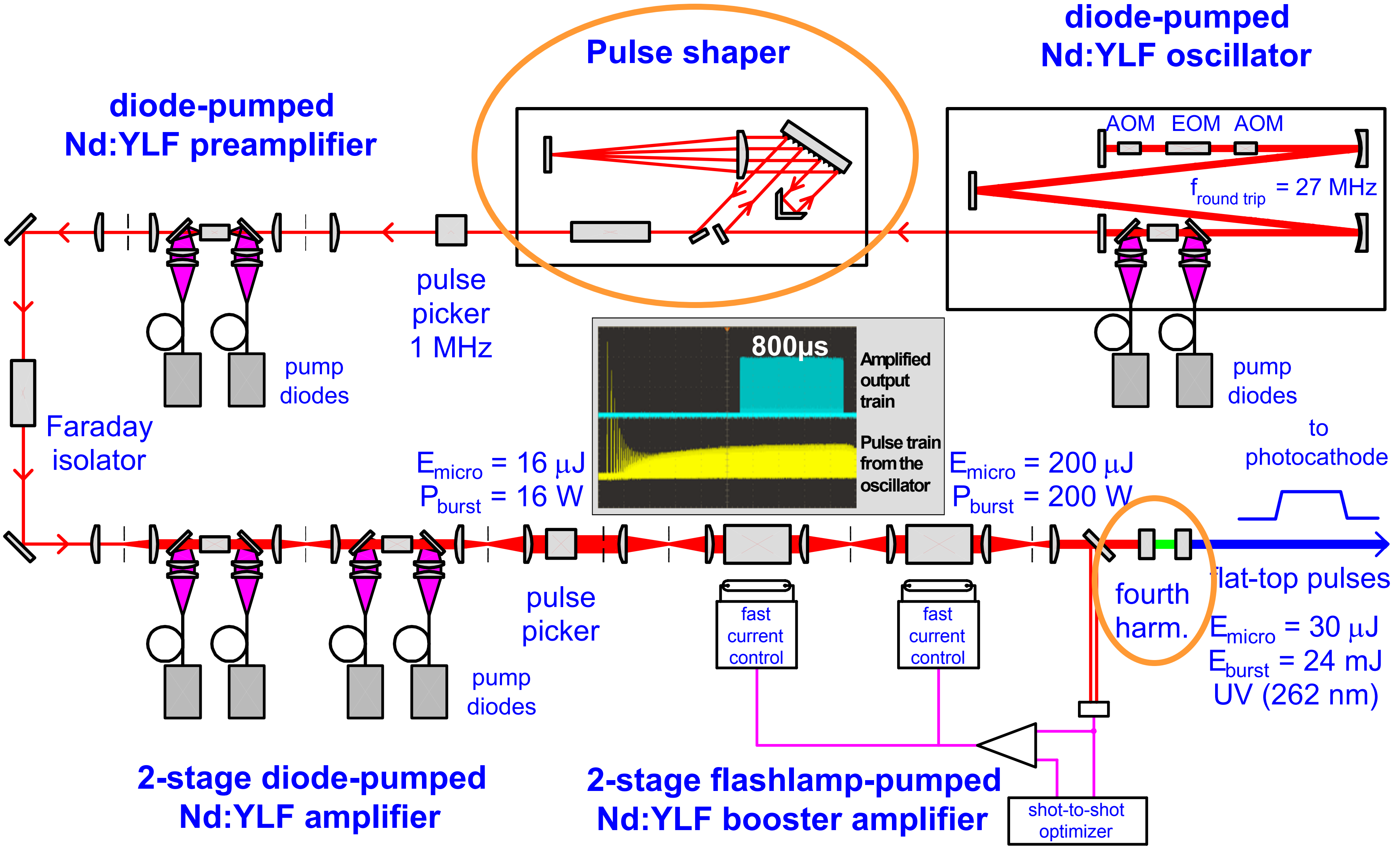
Collaborating Institutes:

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



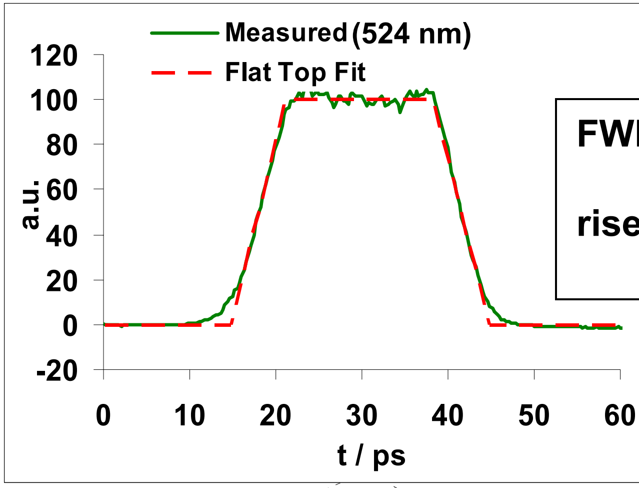


Laser system from the MBI in Berlin

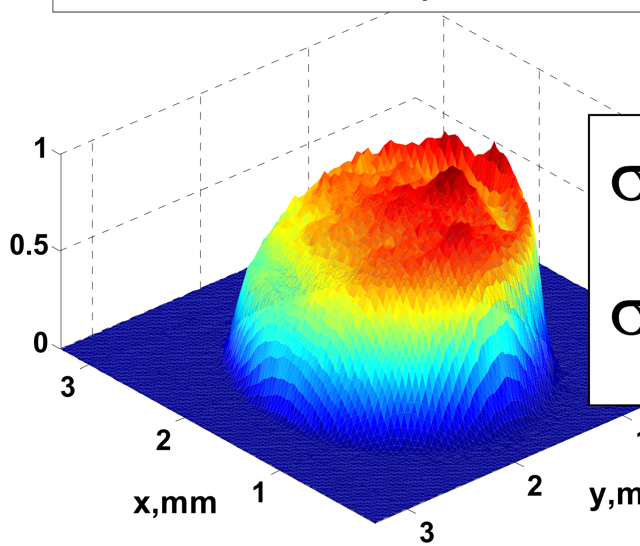


Temporal and Transverse Laser Profiles

in 2003 (VUV-FEL gun):



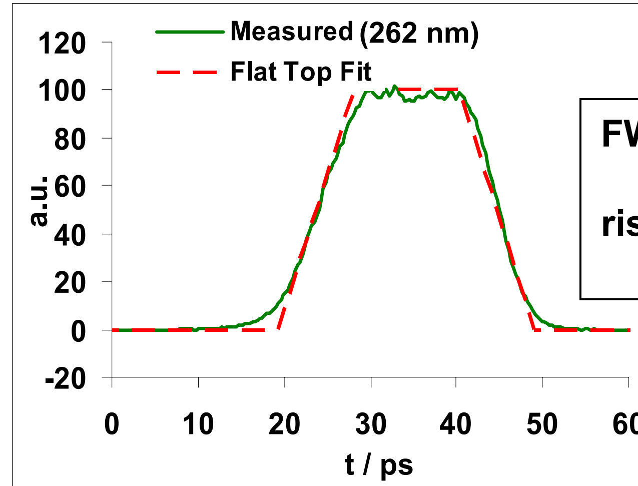
FWHM ≈ 18-23 ps
rise/fall ≈ 5-7 ps



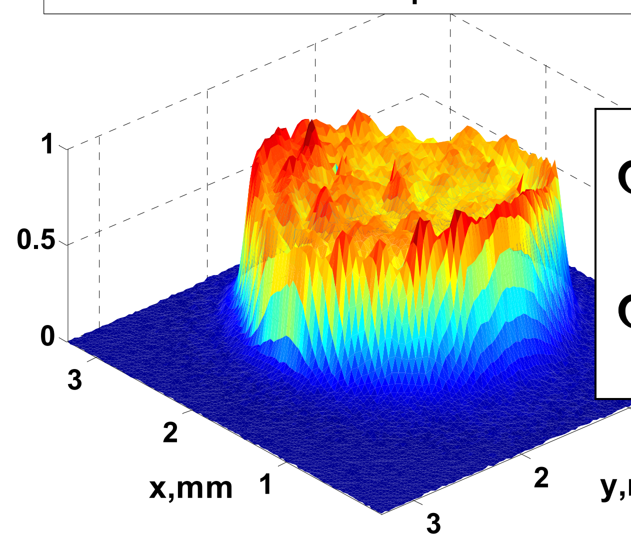
$\sigma_x = 0.51 \pm 0.02$ mm

$\sigma_y = 0.62 \pm 0.02$ mm

in 2004 (gun prototype #1):



FWHM ≈ 19-24 ps
rise/fall ≈ 7-9 ps



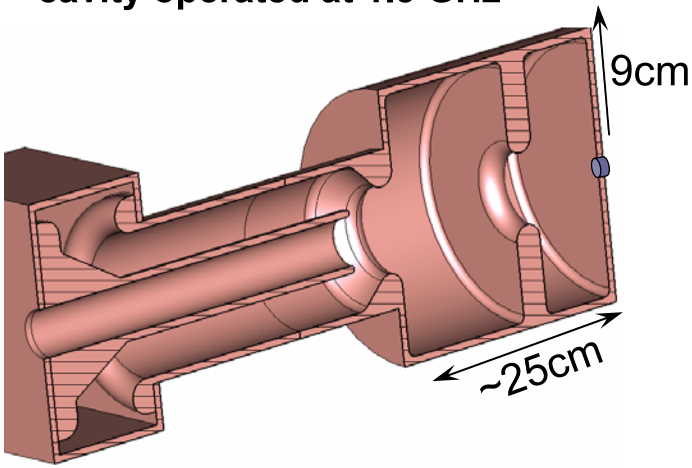
$\sigma_x = 0.57 \pm 0.02$ mm

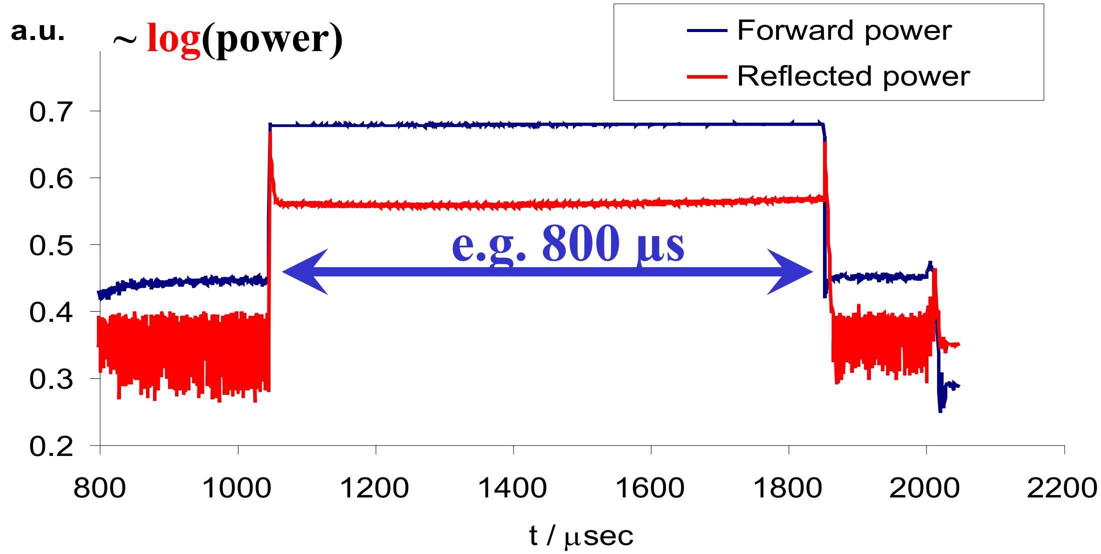
$\sigma_y = 0.58 \pm 0.02$ mm

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**

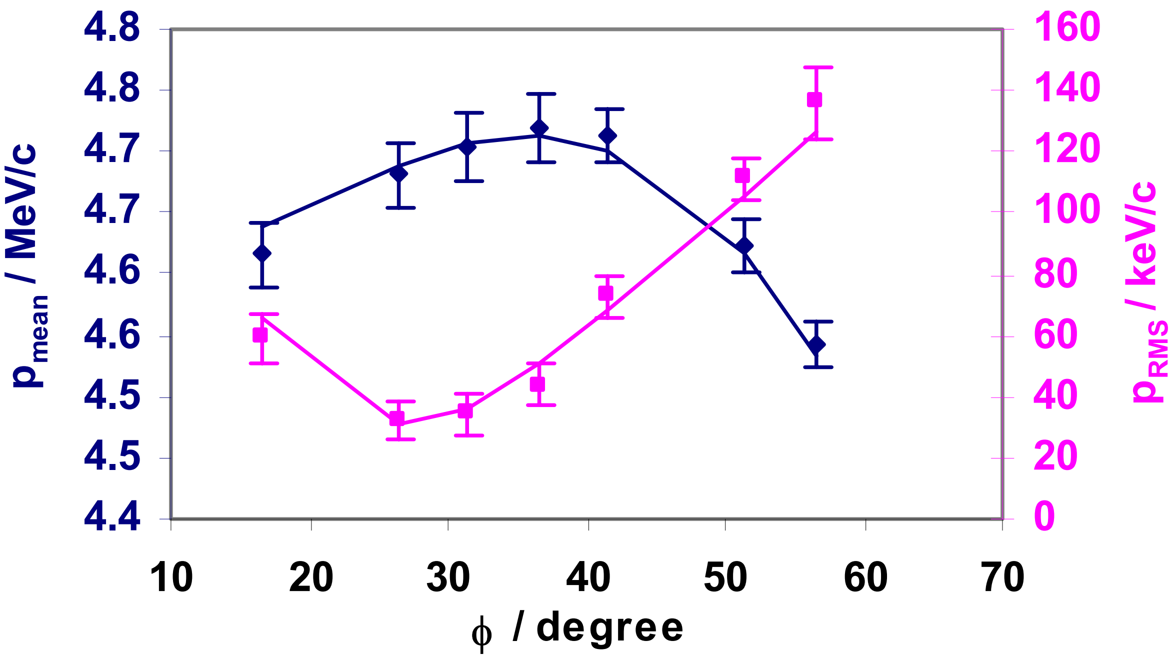
- gradient: **42 MV/m at the cathode** (~ 3 MW)

⇒ **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



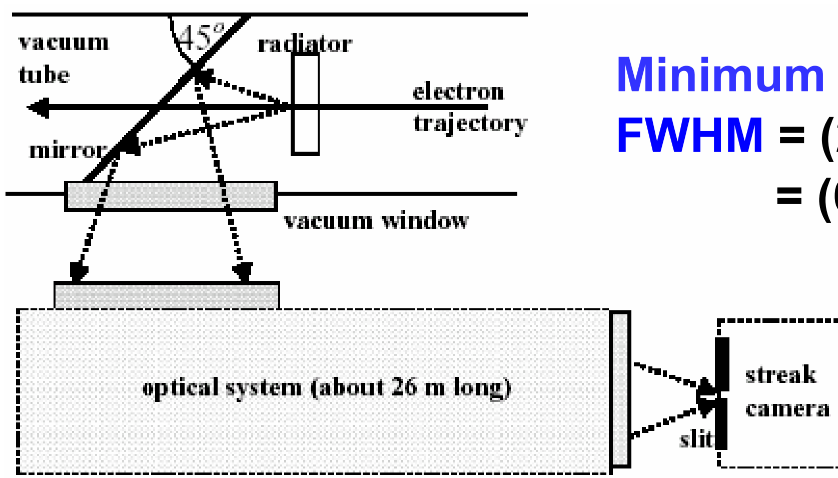
Q = 1 nC

max. mean momentum:
4.72 MeV/c

min. rms momentum spread:
33 keV/c

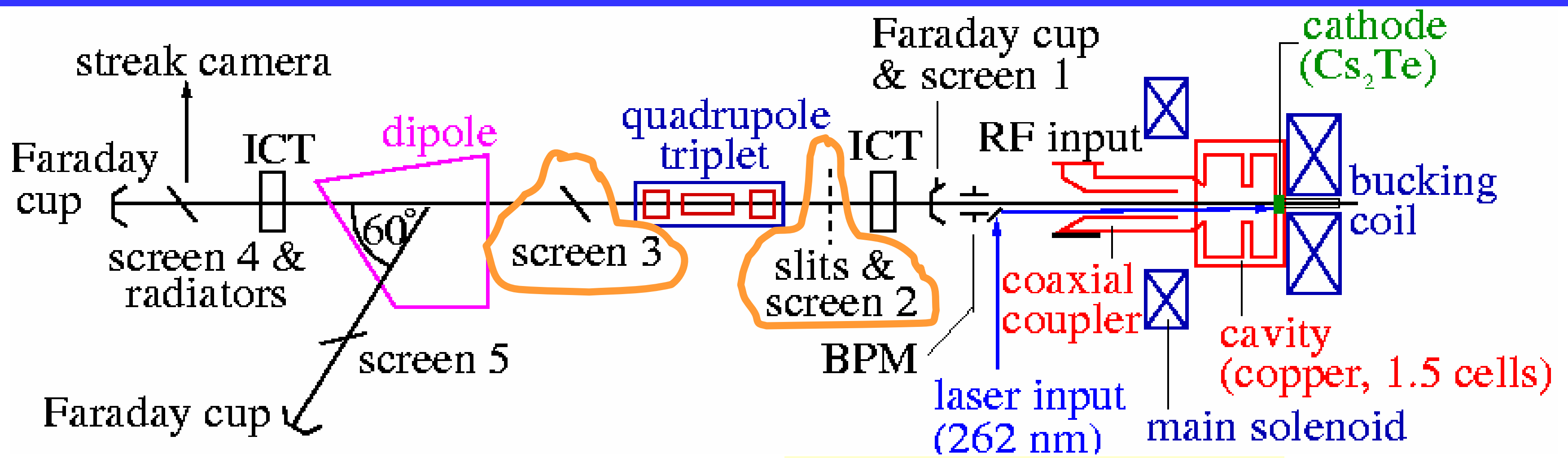
good agreement with simulations !

bunch length:



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

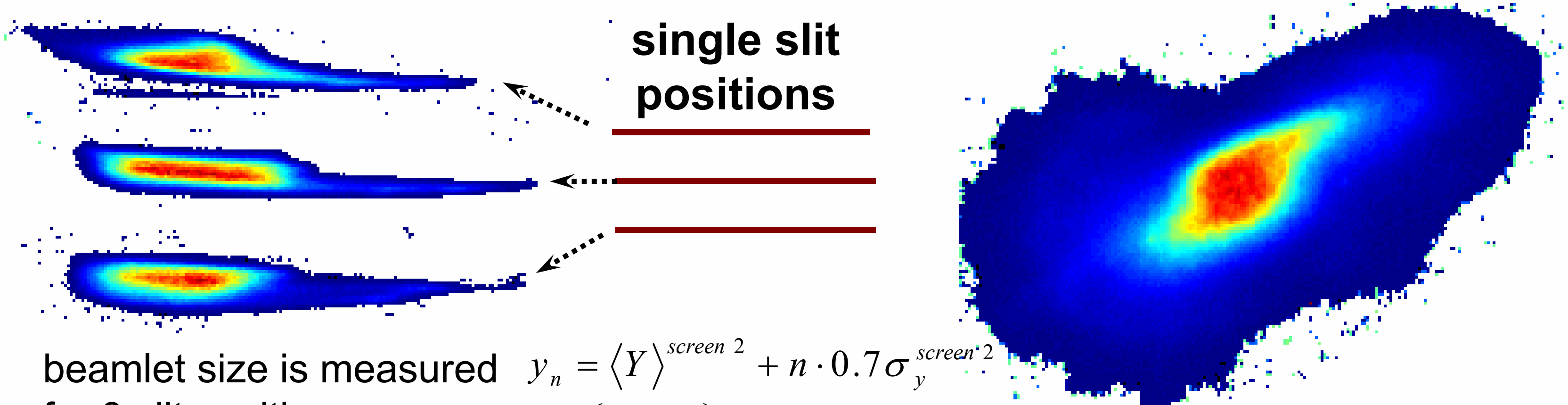
Transverse Emittance Measurements



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**

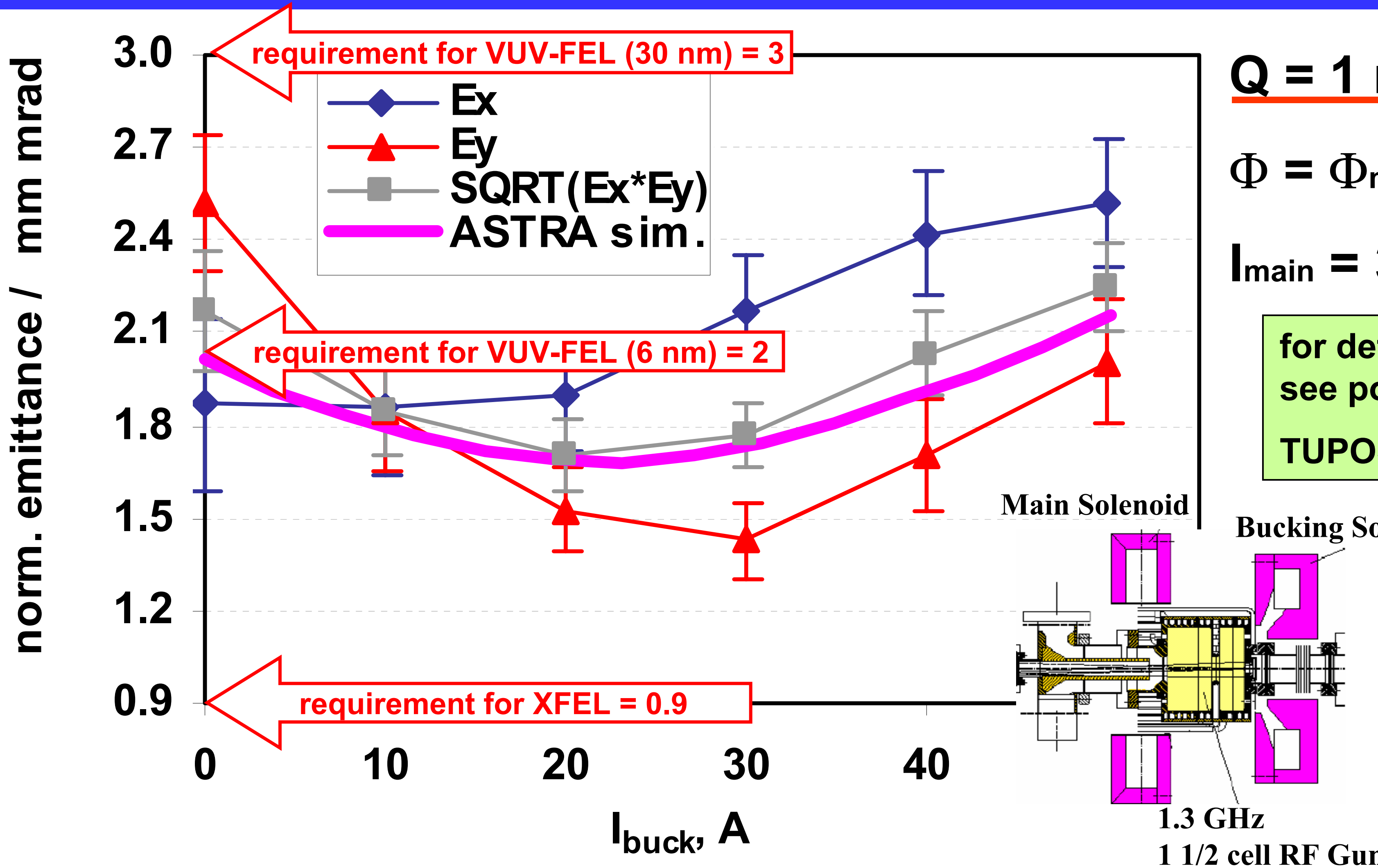


beamlet size is measured for 3 slit positions:

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

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

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 !

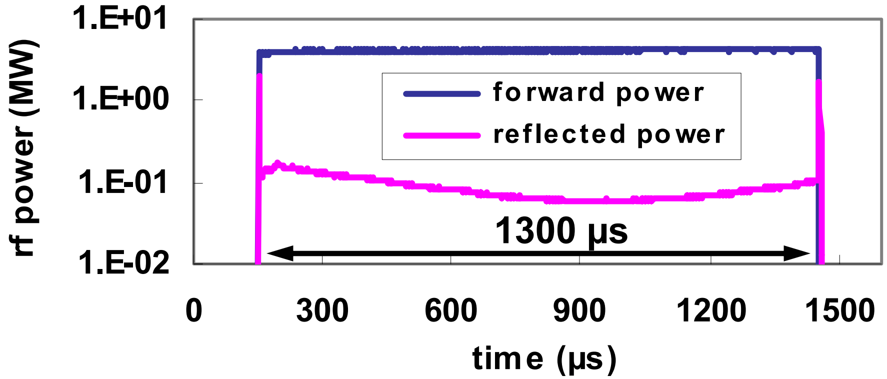
Prototype #1: RF Conditioning Results

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

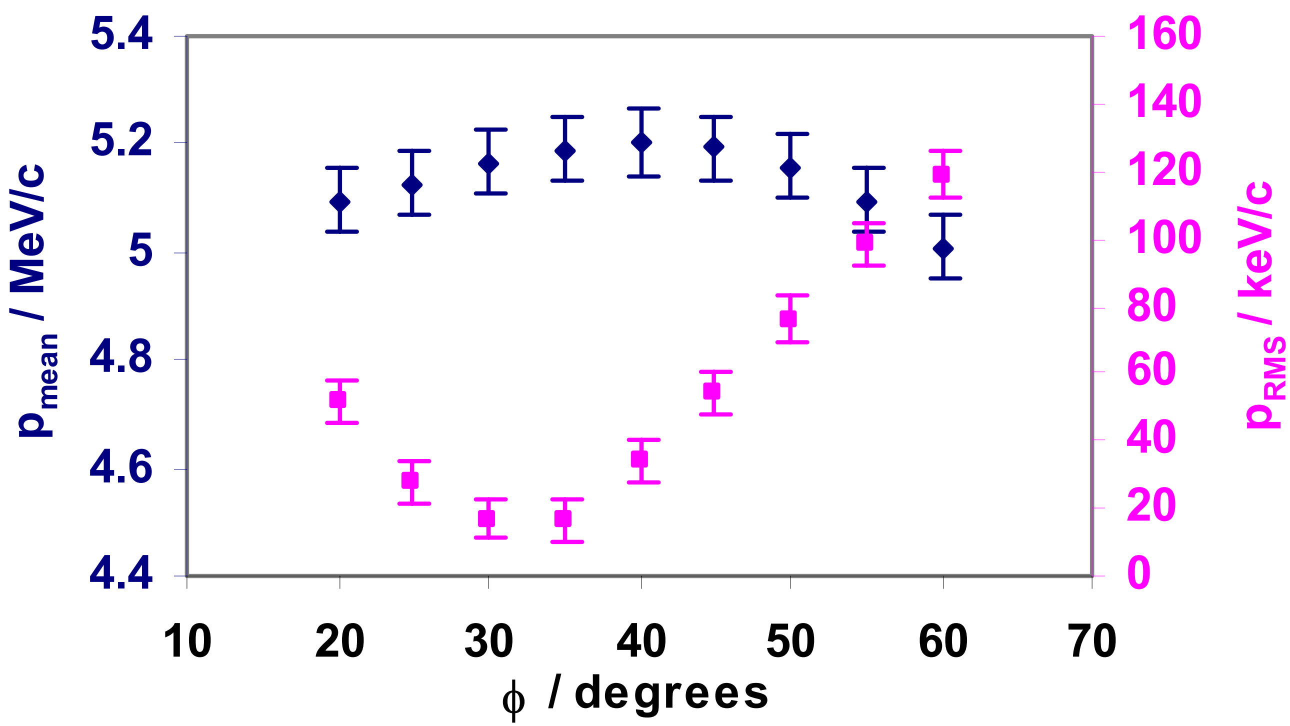


repetition rate	10 Hz	5 Hz	10 Hz
rf pulse length	0.5 ms	1.3 ms	1.0 ms
peak power at gun	4 MW	4 MW	3 MW
mean power	20 kW	26 kW	30 kW
duty cycle	0.5 %	0.65 %	1.0 %

for details see poster

TUPOS03

Prototype #1: Longit. Phase Space



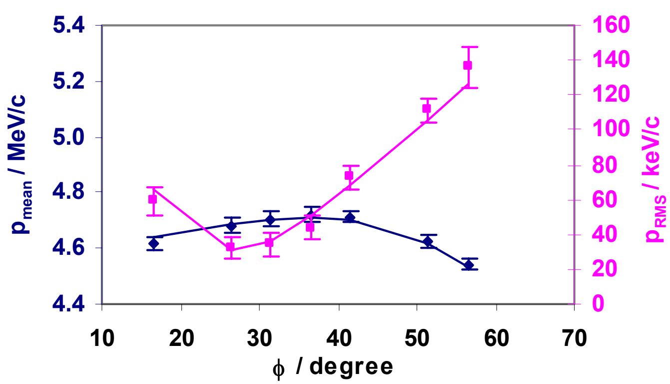
Q = 1 nC

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

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

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

old data from VUV-FEL gun:

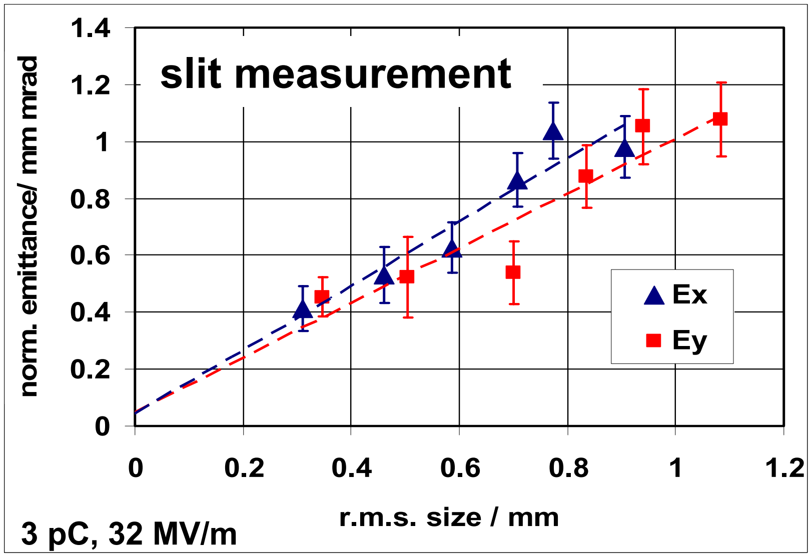


Prototype #1: Thermal Emittance

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

for details see poster

TUPOS09

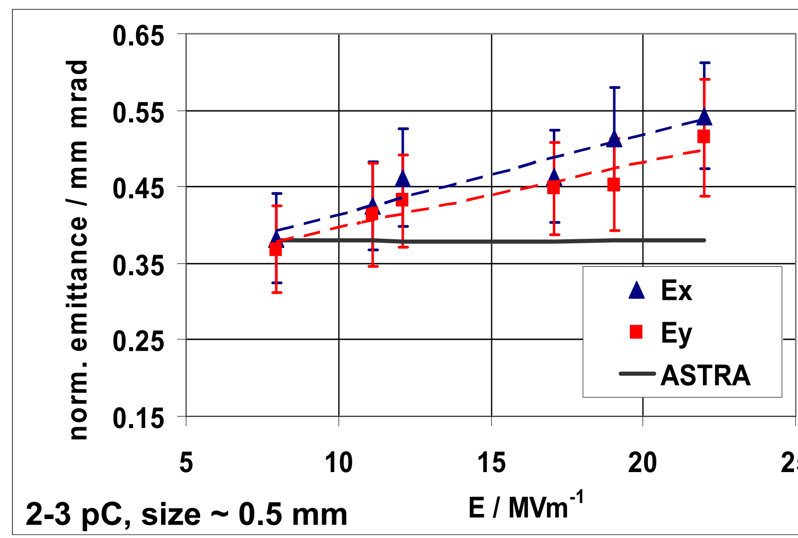


cross check with solenoid scan yielded same result: $E_k = 0.8 \pm 0.1\,\mathrm{eV}$

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

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

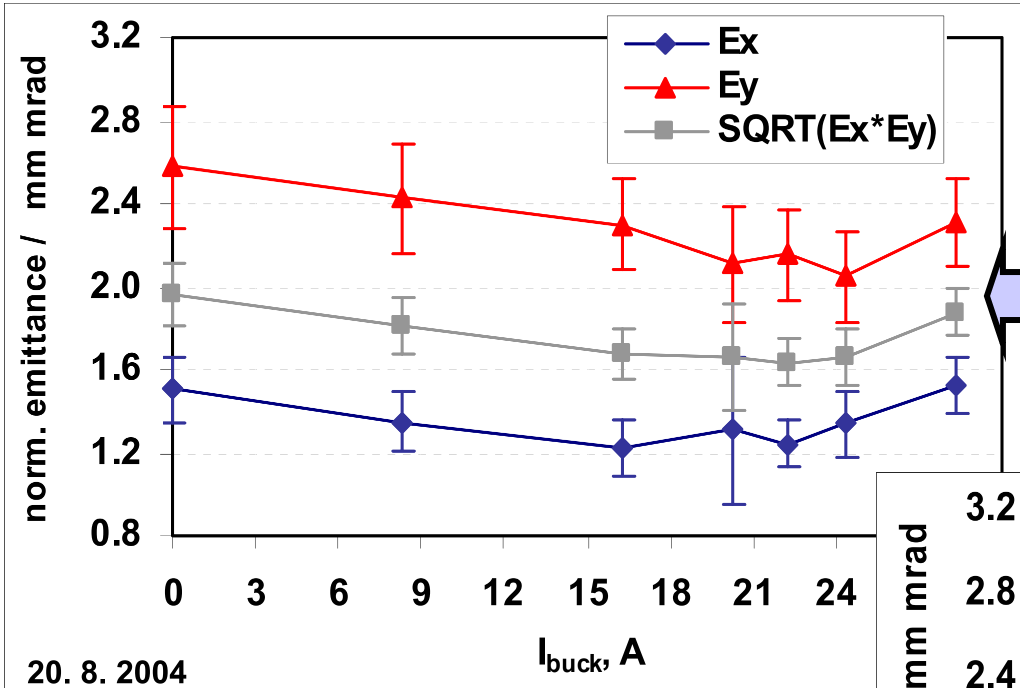
ε_{th} vs. accelerating gradient:



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

→ modified Schottky effect

Prototype #1: Transverse Emittance



optimization ongoing

→ preliminary results !

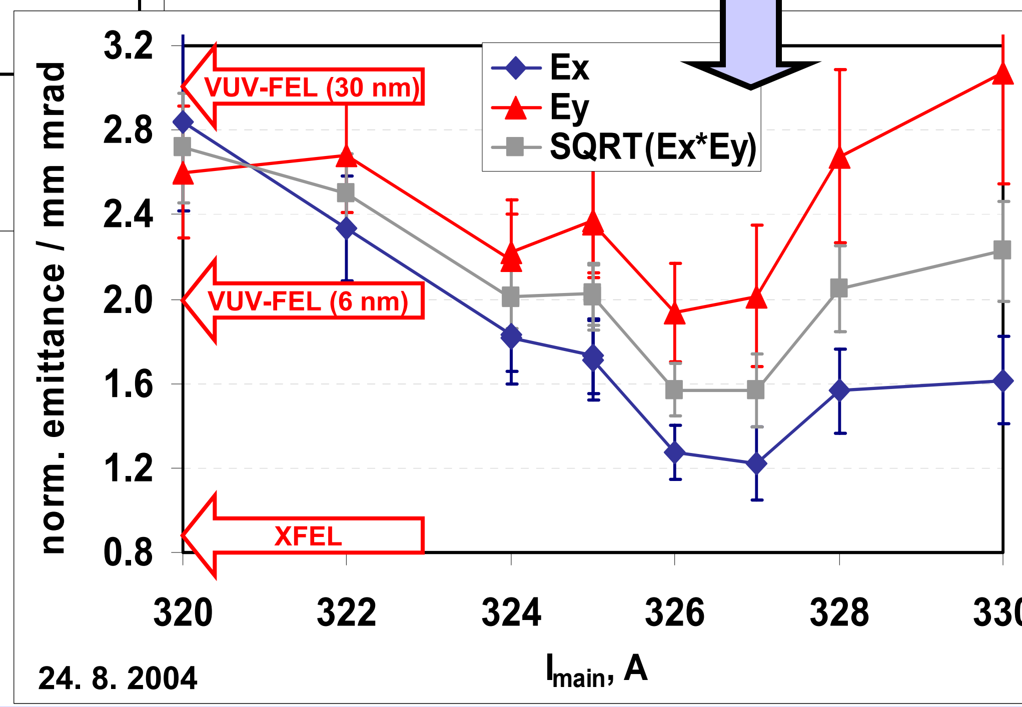
all for Q = 1 nC

$\Phi = \Phi_m - 5°$

$I_{main} = 326$ 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)

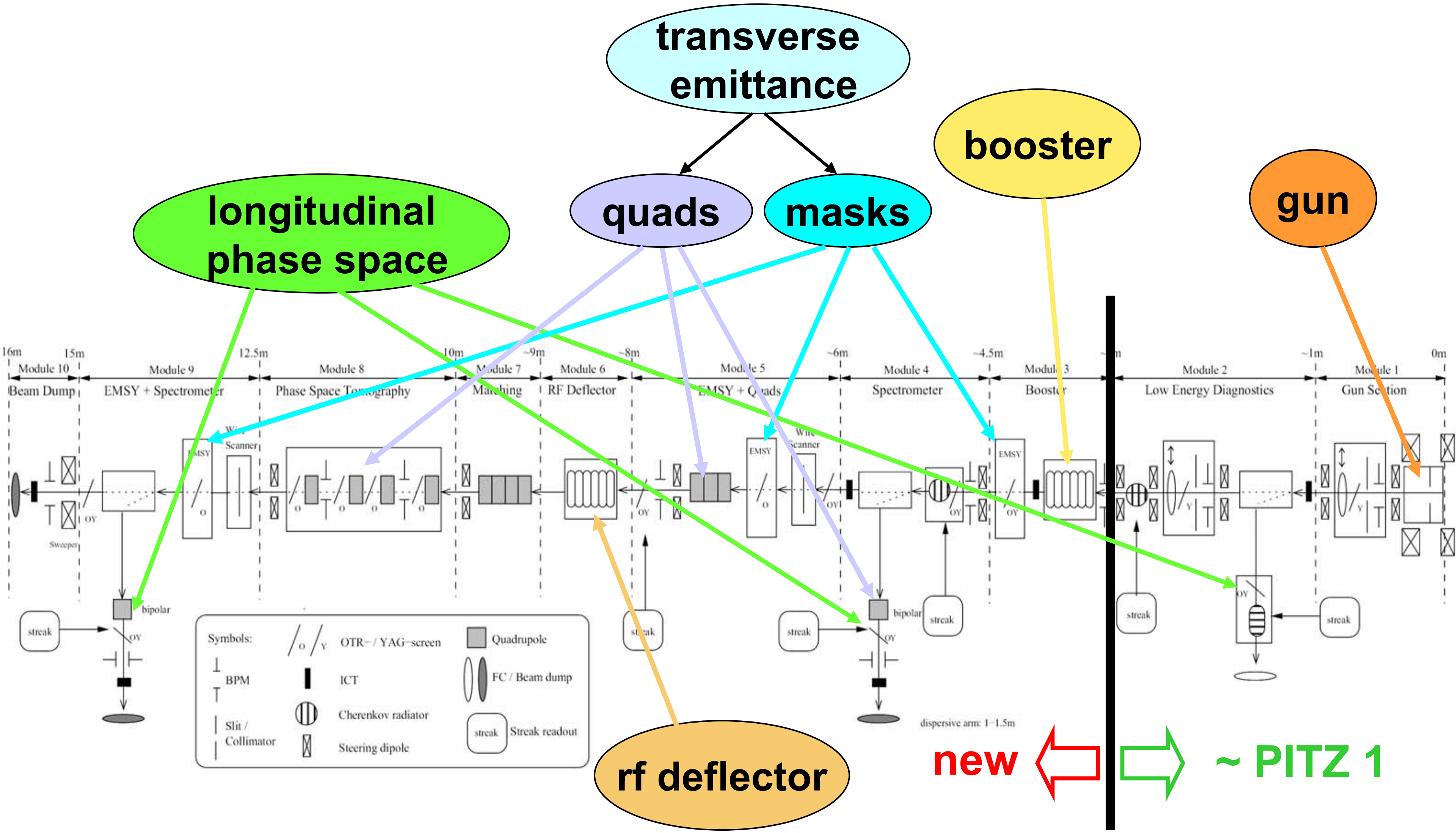
- **study XFEL parameter space:**

  (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

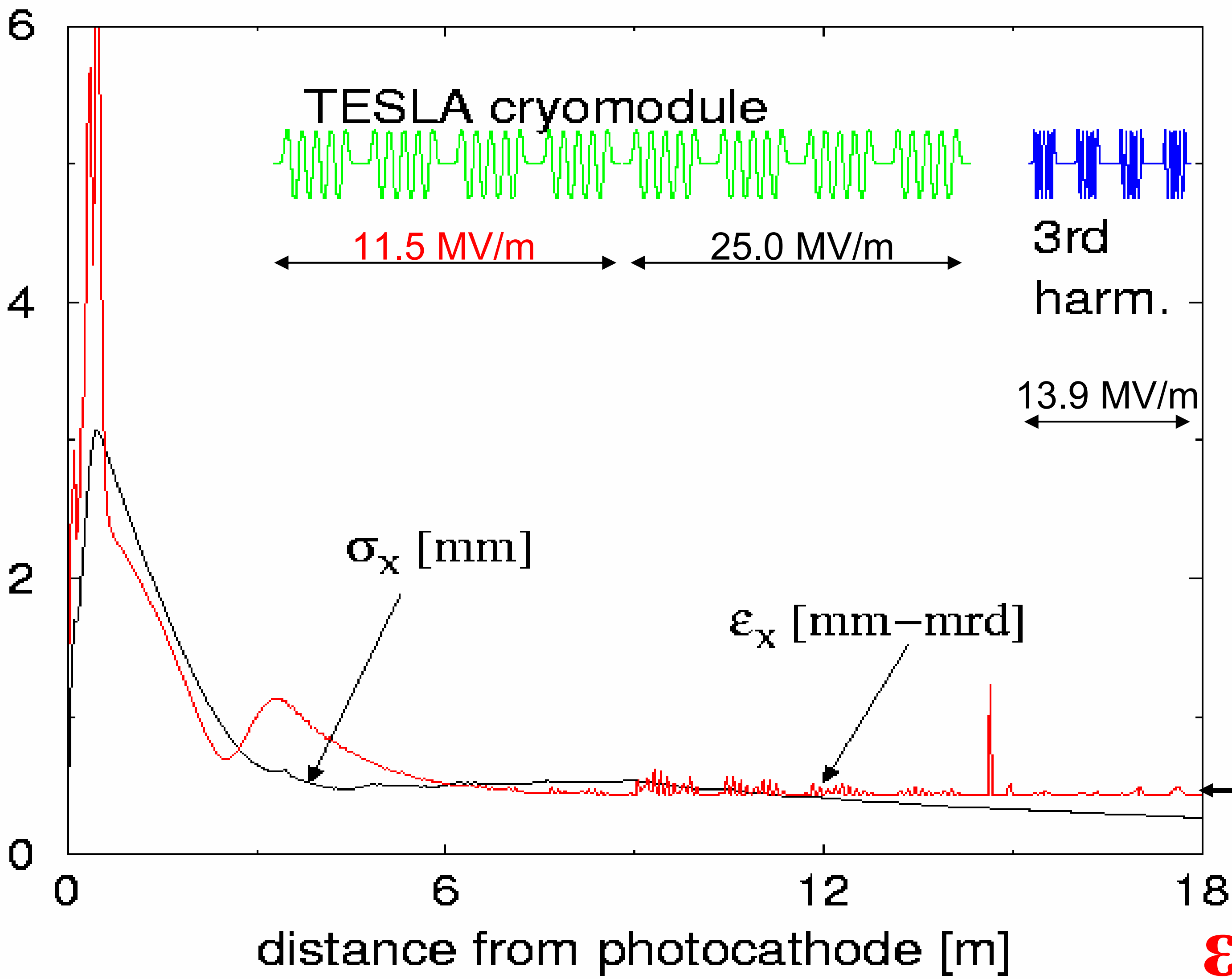
    ⇒ ε_n ~ 1.5 mm mrad @ 1 nC
  - improved longitudinal laser profile (20 ps FWHM, 2 ps rise/fall time):

    use a broadband laser medium, solve problem of high average power, conserve stability

    ⇒ ε_n ~ 1.2 mm mrad @ 1 nC
- **in addition, with 60 MV/m at the cathode:**

  ⇒ ε_n ~ 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