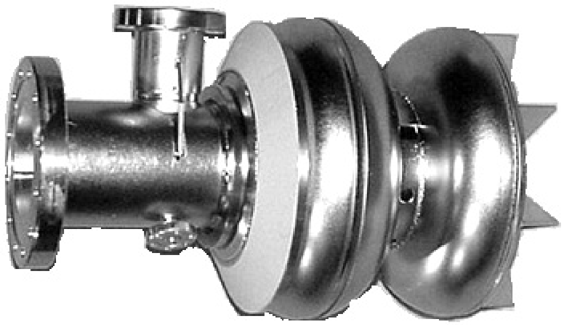


FIRST CHARACTERIZATION OF A FULLY SUPERCONDUCTING RF PHOTOINJECTOR CAVITY

HZB Helmholtz Zentrum Berlin

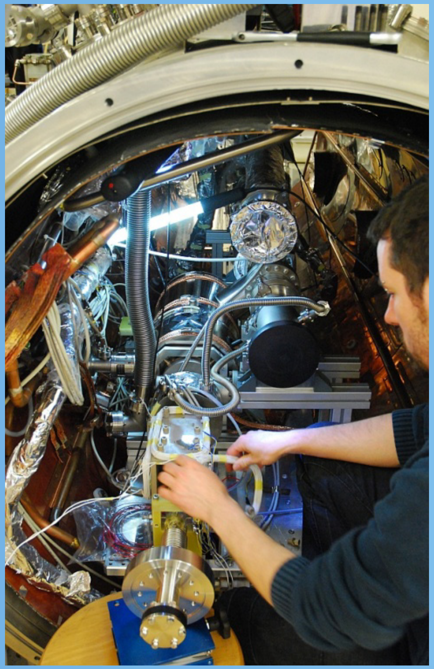
IPAC 2011 San Sebastián, Spain

A. Neumann

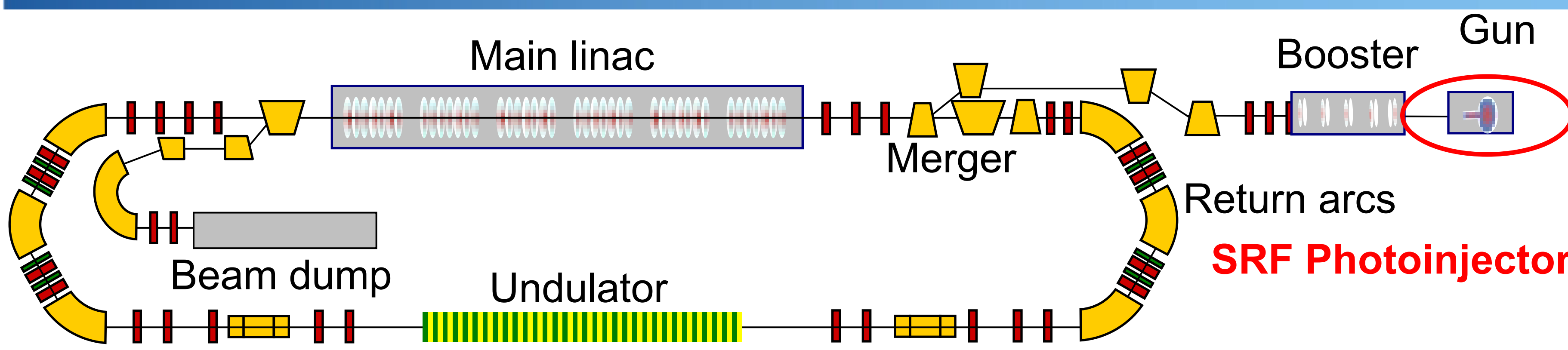
for a collaboration by

Jefferson Laboratory, DESY, A. Soltan Institute,

Brookhaven National Lab., MBI, BINP and HZB



Path towards a Photoinjector for B*ERL*inPro



Goals for ERL SRF injector

Beam energy	**≥ 1.5 MeV**
Max. current	**100 mA**
Nominal bunch charge	**77pc**
Max. rep. rate	**1.3GHz**
Normalized emittance	**< 1mm mrad**

Demanding goals!
3 stage approach

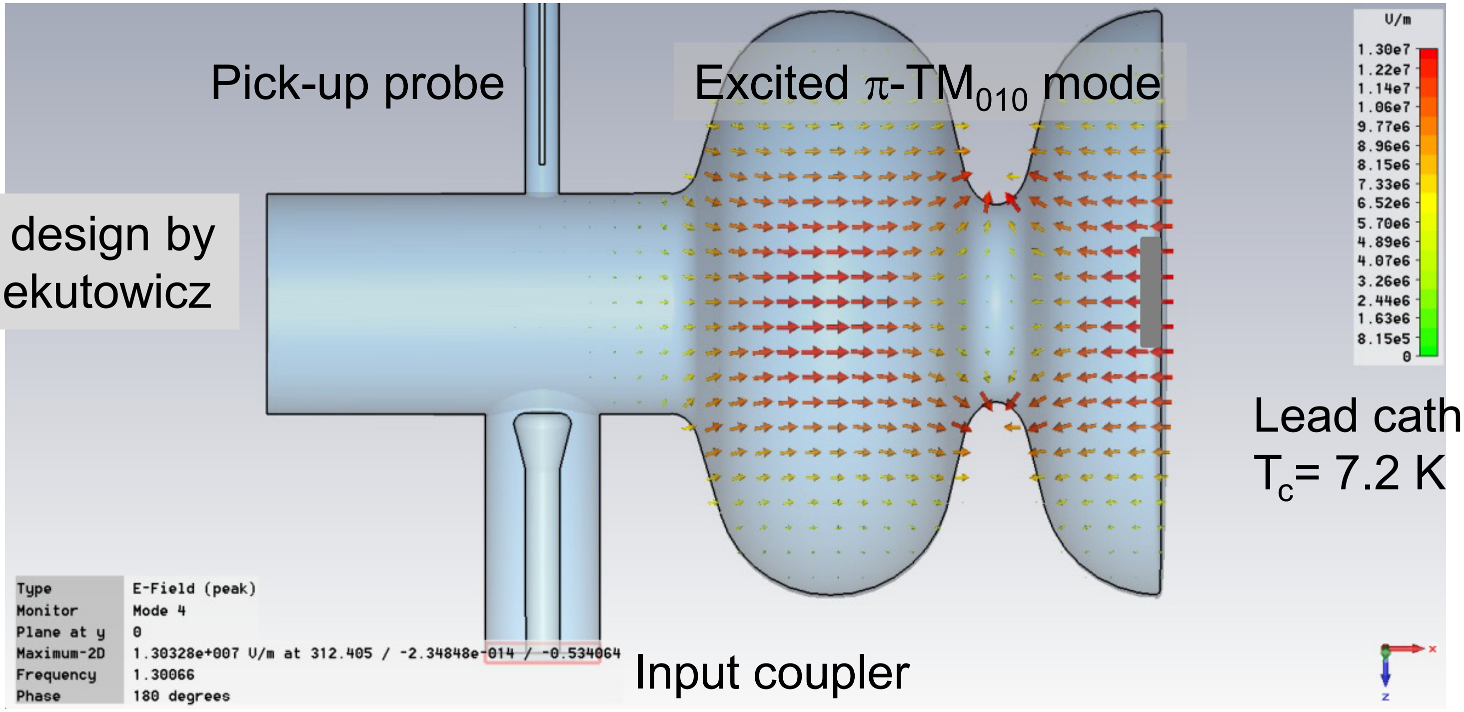
- Full SC injector for beam dynamics studies → ***This talk*** + THPC109
- Peak brightness injector, study NC cathode insert
- High average current injector

T. Kamps et al., Journal of Physics: Conference Series, 298

A. Jankowiak et al., Proc. Linac 2010

First step: SC RF Gun0

Original design by
Jacek Sekutowicz



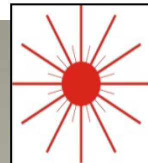
Frequency π-mode	1300 MHz
E_{peak}/E_{acc}	1.86
H_{peak}/E_{acc}	4.4 mT/(MV/m)
Geometry factor	212.2 Ω
R/Q (linac, β=1)	190 W

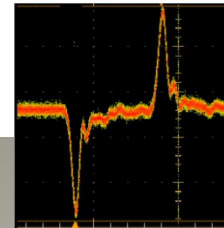
Sekutowicz et al., Proc. PAC 2009

- EM design: Highest fields at cathode region
- SC lead cathode on half-cell backwall: $QE_{Pb} \sim 10 \cdot QE_{Nb}$
- Study beam dynamics at short pulses, ERL parameter range

Gun with Diagnostic beamline at HZB

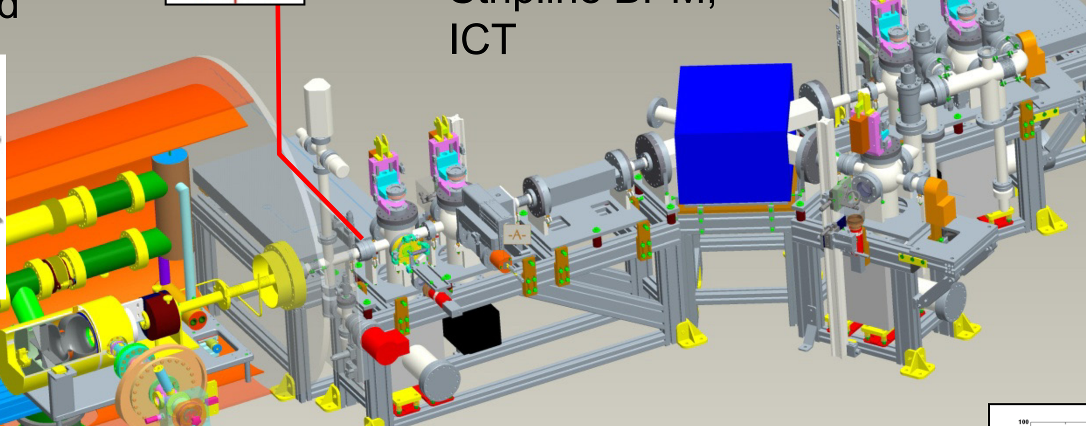
SC Solenoid





Stripline BPM, ICT

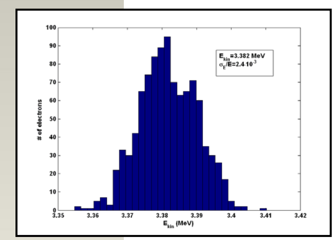
SC Cavity



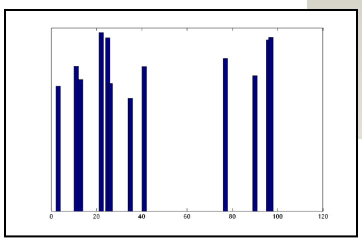
HoBiCaT cryostat

ΣQ

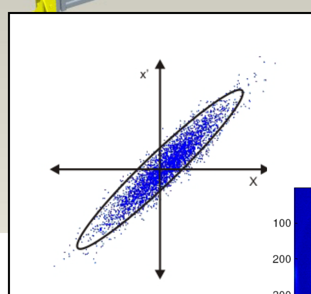
Faraday Cups

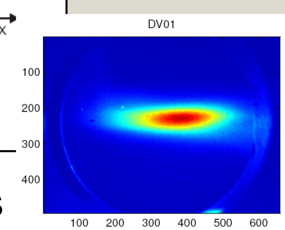


Dipole magnet



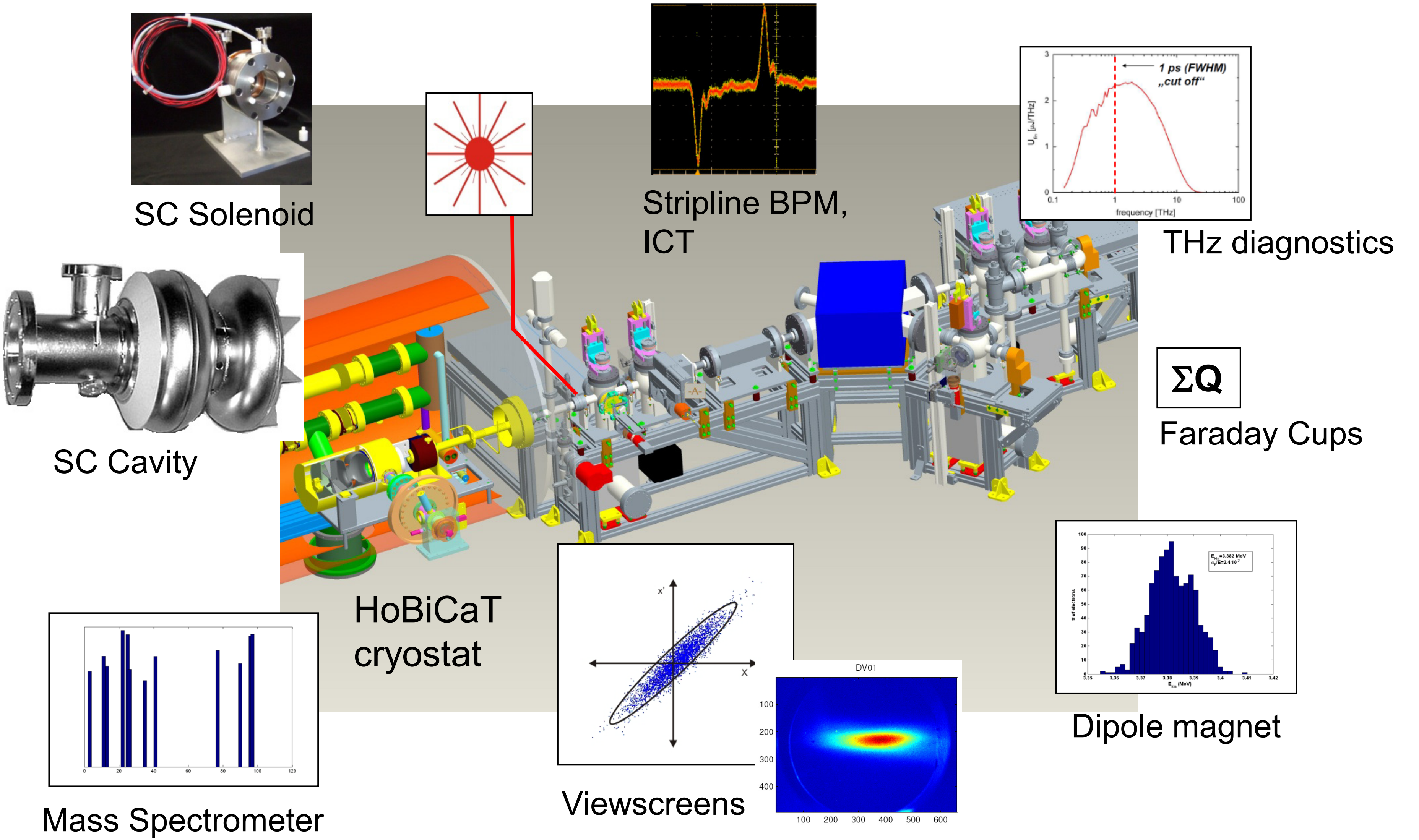
Mass Spectrometer





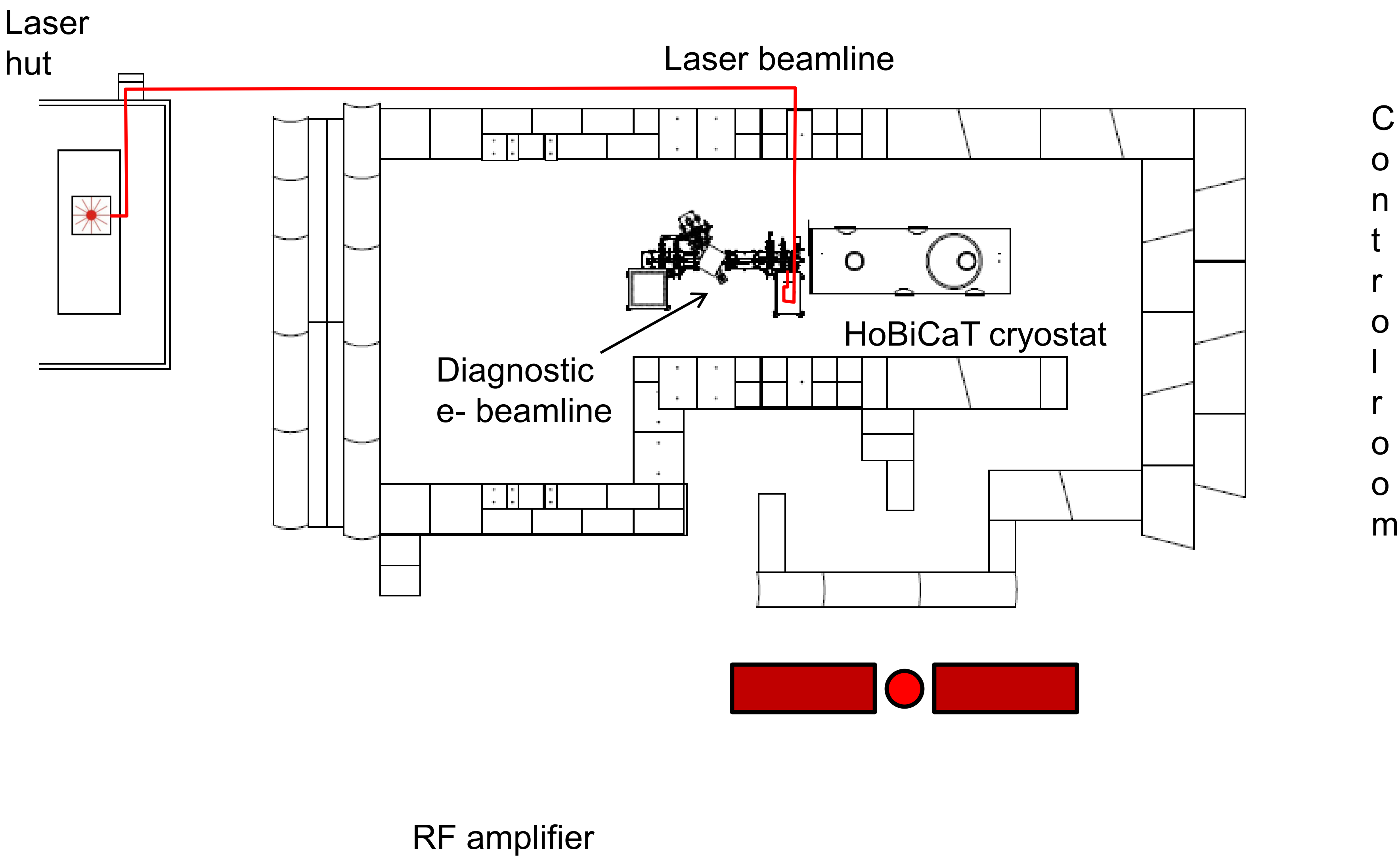
Viewscreens

Gun with Diagnostic beamline at HZB

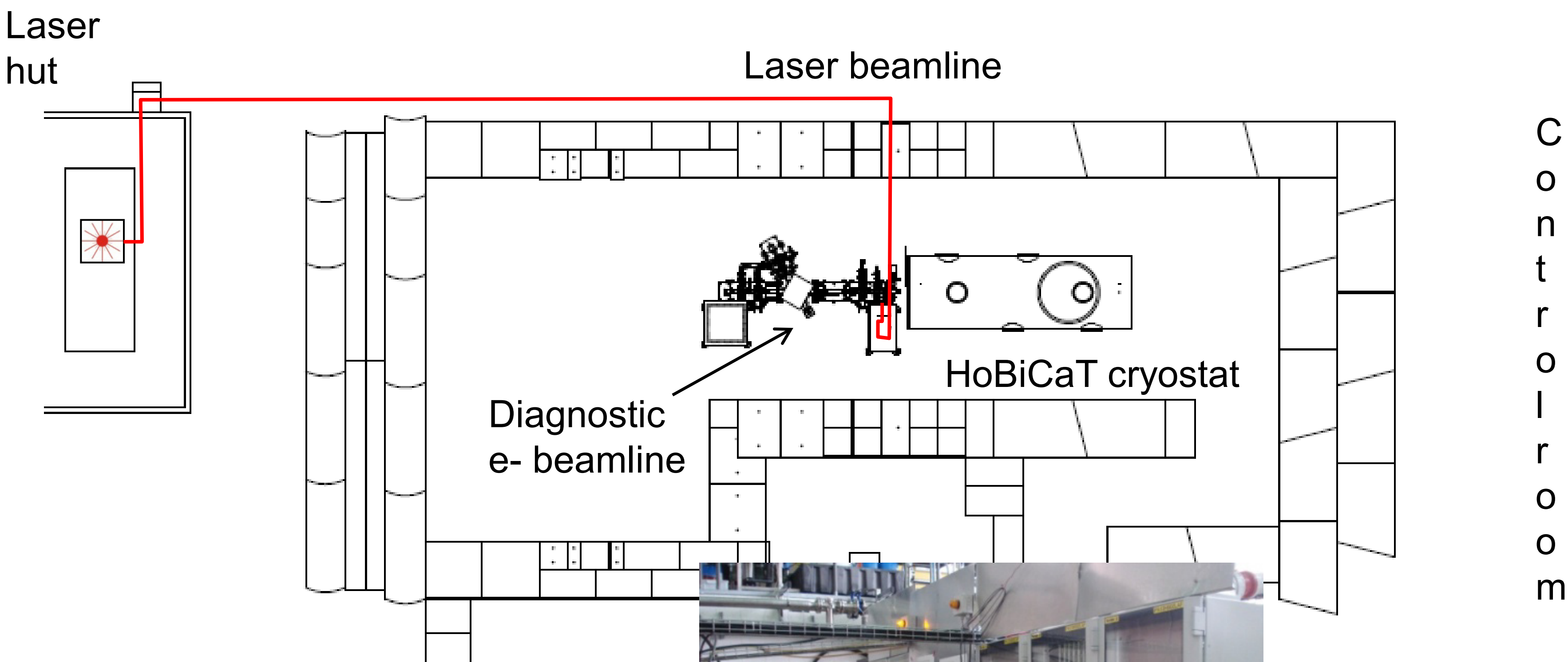


First time operated fully SC photoinjector ensemble (SC Cathode, Cavity, Solenoid)
Source/upgrade for CW low current machines (POLFEL, XFEL, FLASH)

Extension of the HoBiCaT Cavity Test Facility

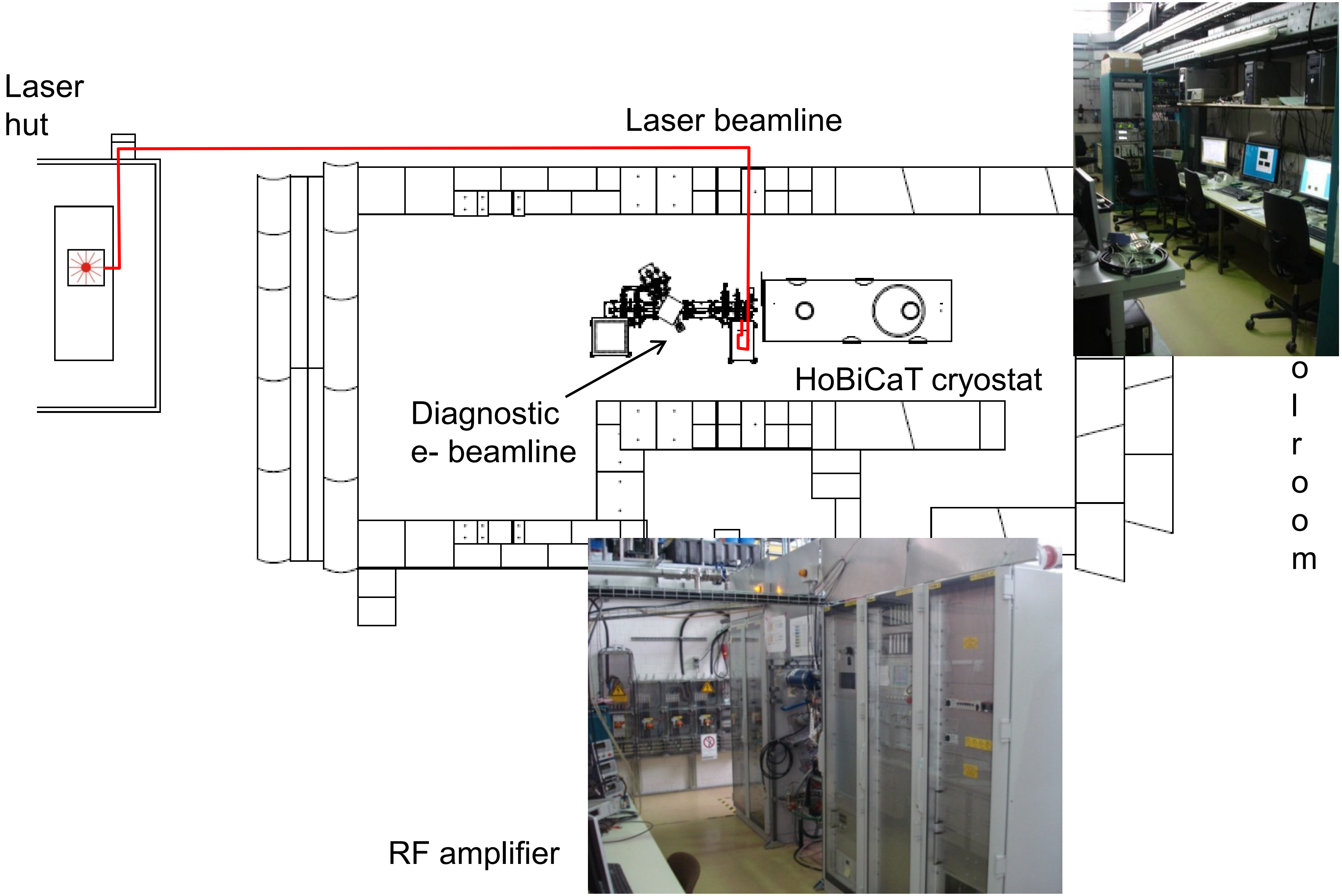


Extension of the HoBiCaT Cavity Test Facility

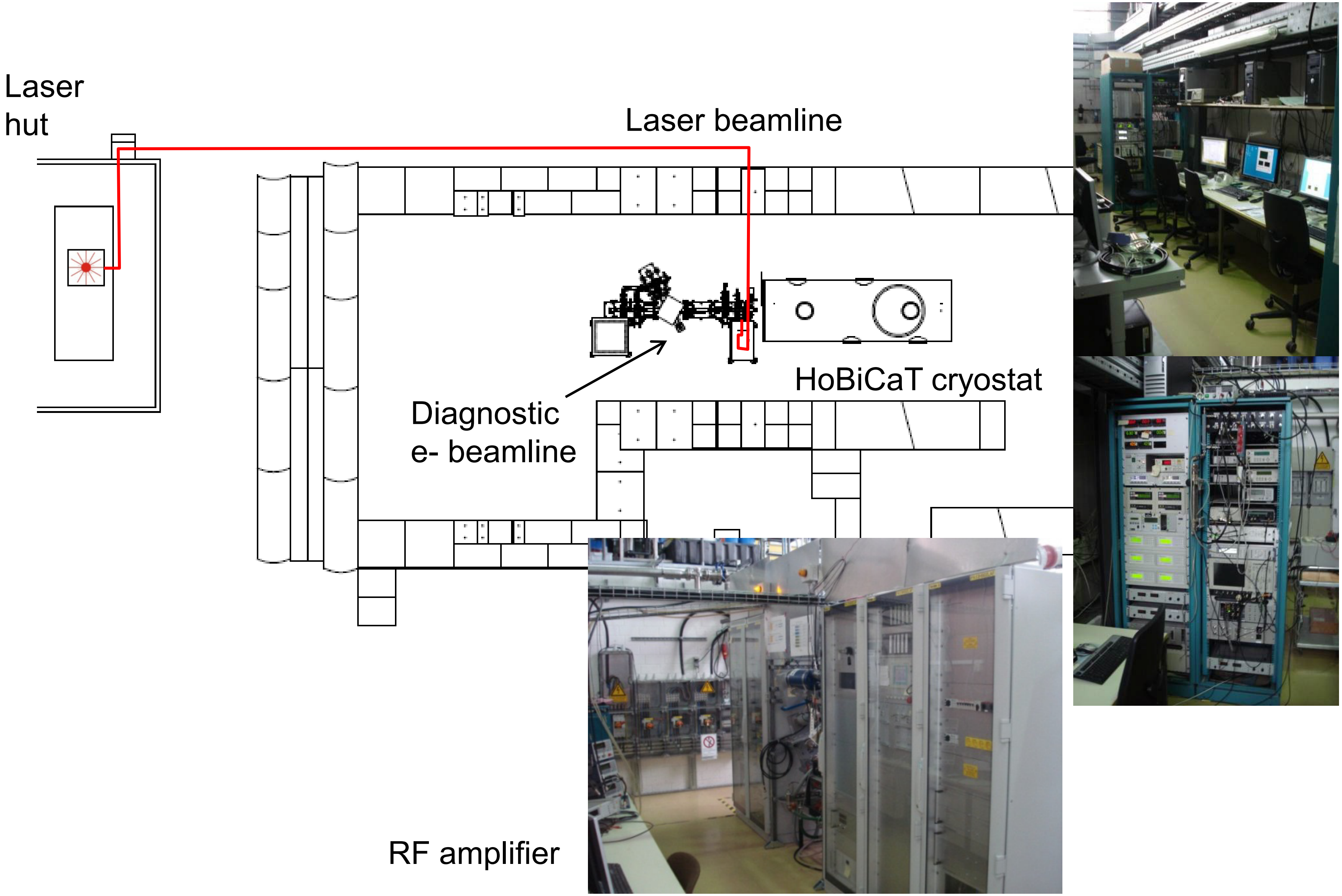


RF amplifier

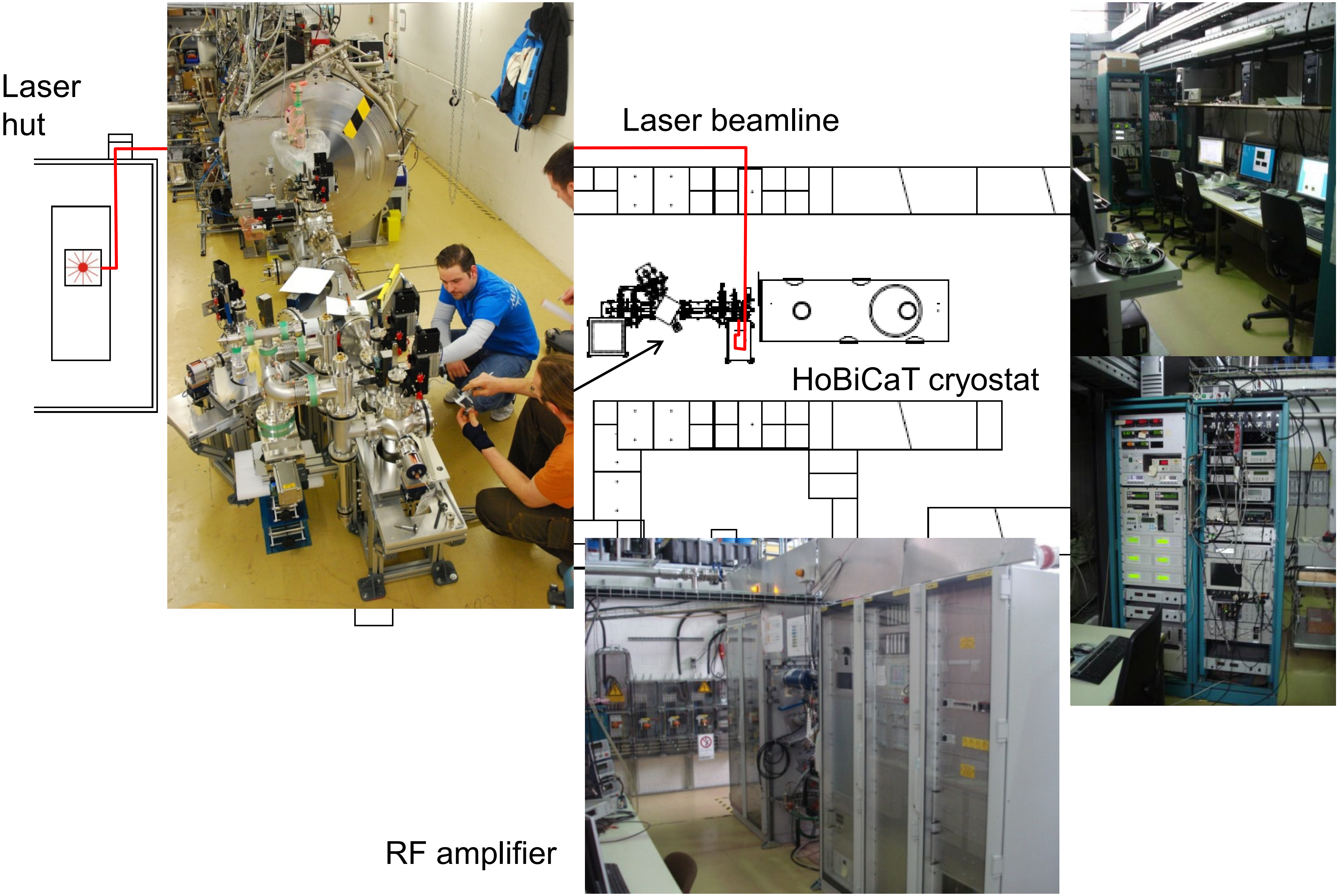
Extension of the HoBiCaT Cavity Test Facility



Extension of the HoBiCaT Cavity Test Facility



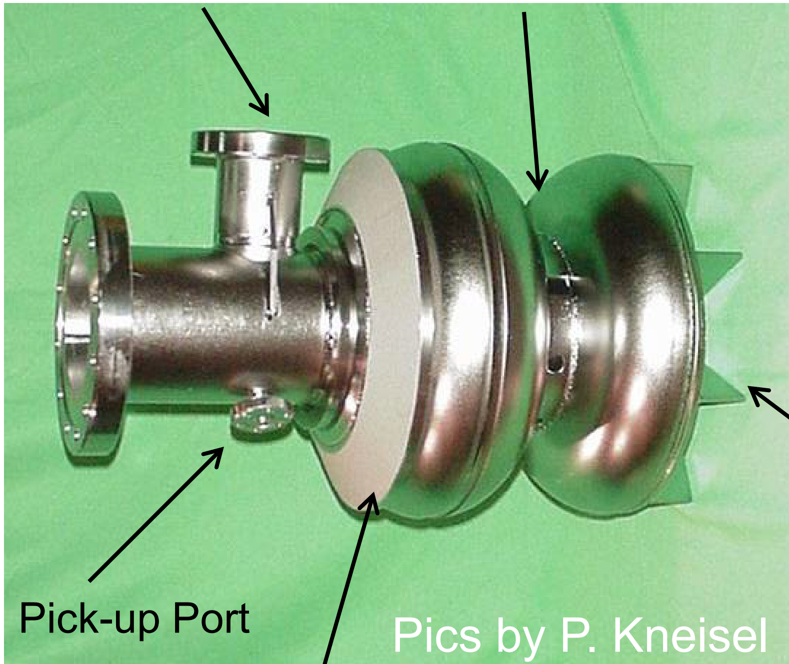
Extension of the HoBiCaT Cavity Test Facility



Cavity fabrication at Thomas Jefferson Lab (P. Kneisel, Proc. PAC 2011)

Fundamental power coupler port

Stiffening ring



Pick-up Port

Pics by P. Kneisel

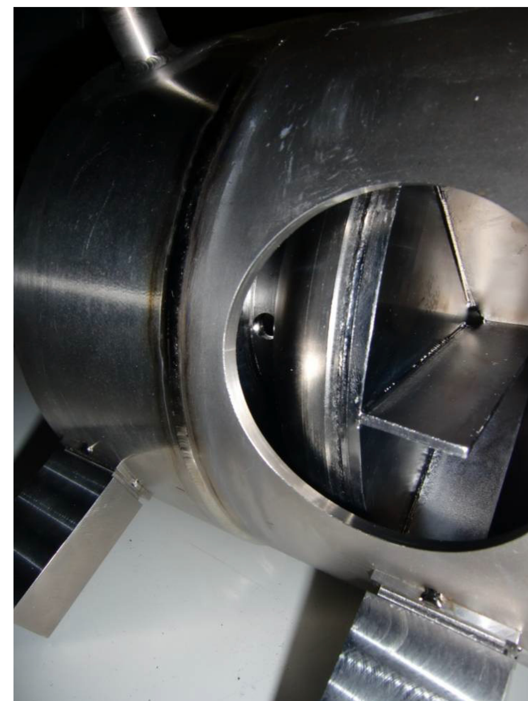
„Helium vessel endplate“

Passive stiffening System: “Spider“

TTF-III FPC: $Q_L = 1{\cdot}10^9$-$6{\cdot}10^6$ including 3-stub tuner

Large grain cavity backwall for cathode

Cavity half-cells

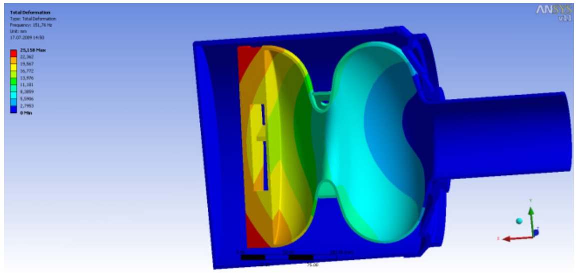


Cavity in helium vessel

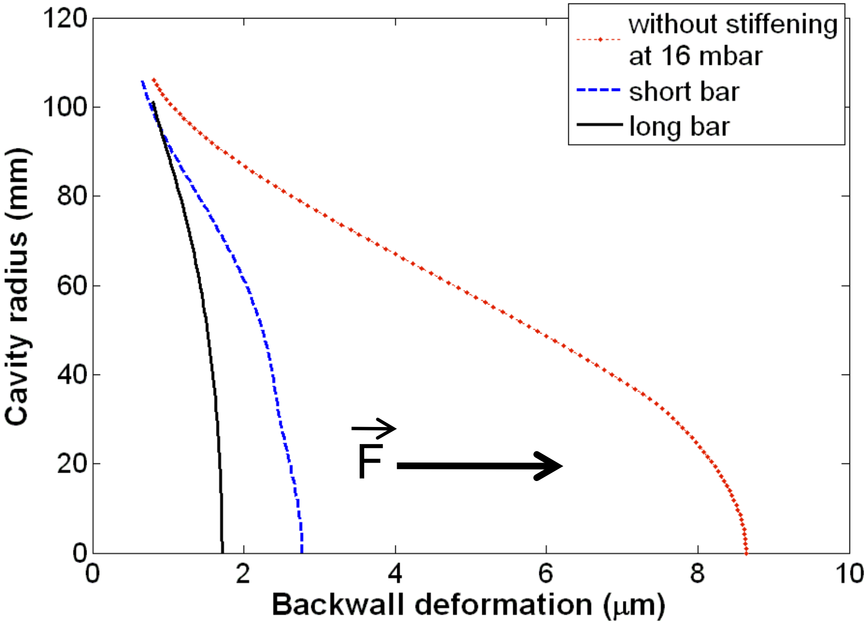
Mechanical design: Countermeasures to increase field stability

- Beam quality dominated by field stability
- Field stability in SC cavity: Avoid detuning (deformation) of the cavity

Combined FEM mechanical and
Electro-magnetic field simulations
→ low deformation (detuning) design




Backwall stiffening



Neumann et al., Proc. Linac 2010

Detuning in Hz/mbar

Type	SuperFish	CST MWS	Measured
Without	527	615	-
Short bar	200	-	474
Long bar	130	-	-
“Spider”	-	-	146

Mechanical design: Countermeasures to increase field stability

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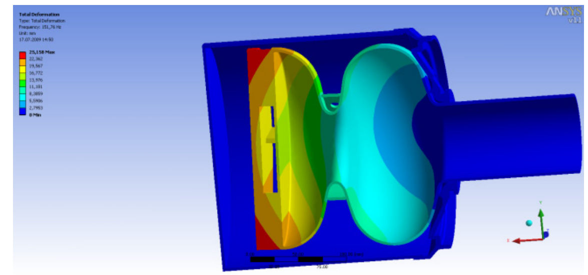
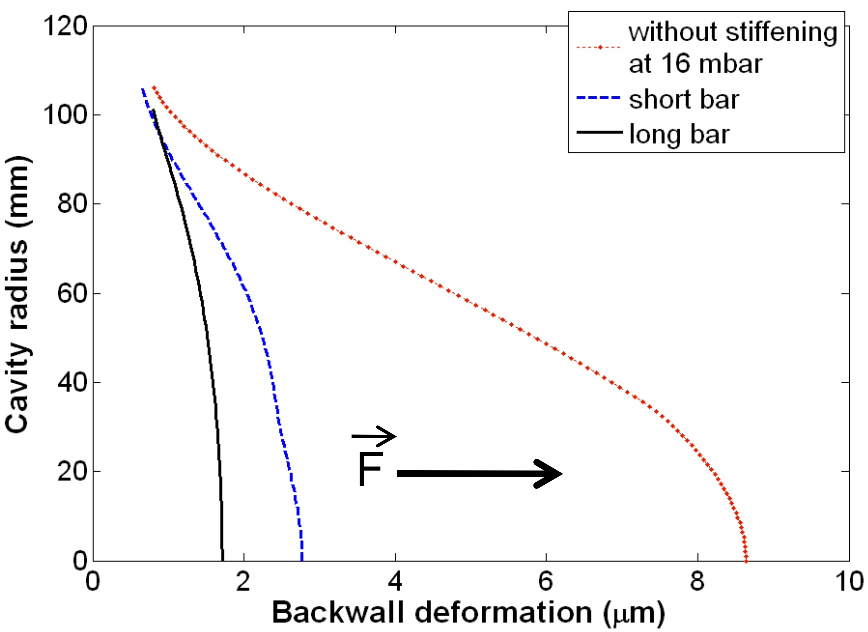
Electro-magnetic field simulations
→ low deformation (detuning) design





Neumann et al., Proc. Linac 2010

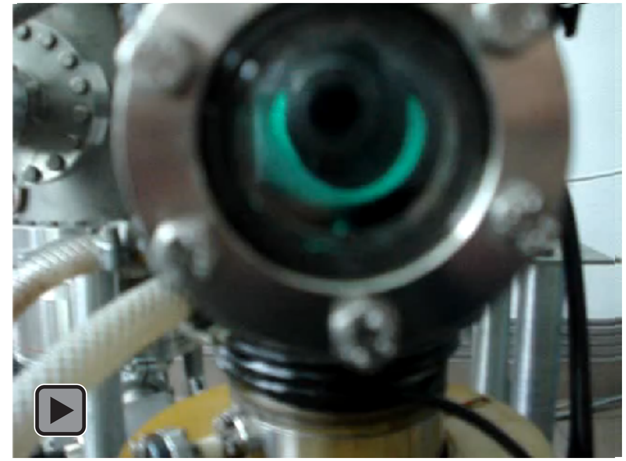
Detuning in Hz/mbar

Type	SuperFish	CST MWS	Measured
Without	527	615	-
Short bar	200	-	474
Long bar	130	-	-
“Spider”	-	-	114

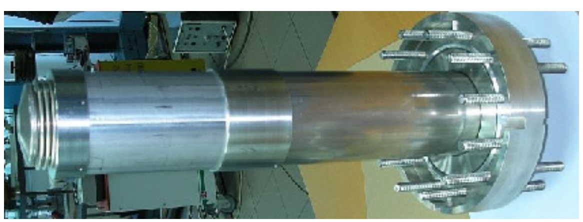
P. Strzyzewski et al.,
Phys. Scr. T123 (2006)

Cavity with helium vessel

Plasma arc
depositon setup
in 30° configuration



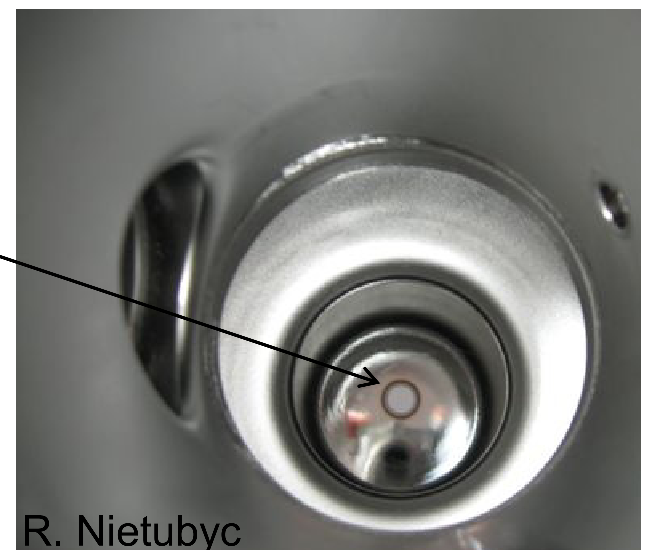
16 x 5min depositions result
in a few hundred nm thick
Pb cathode film



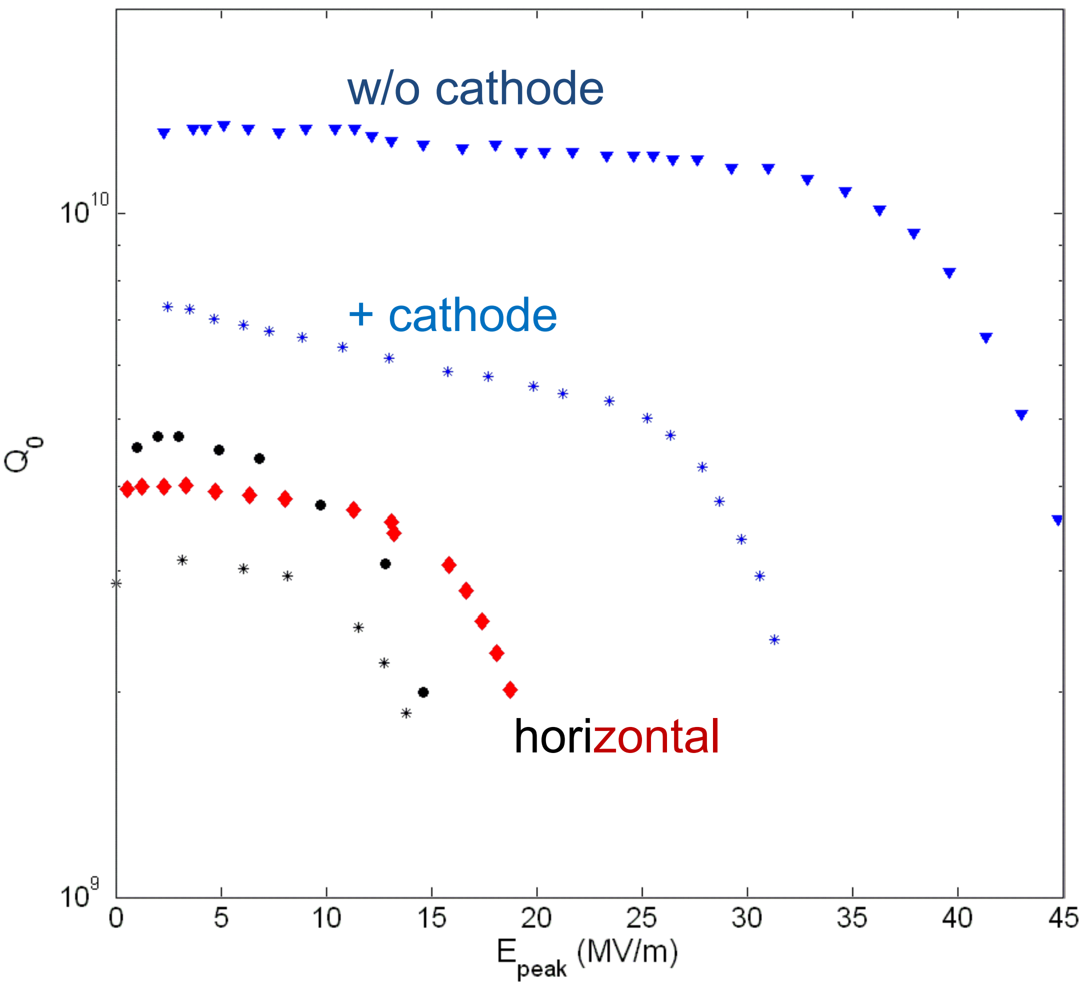
Mask to protect cavity

Pb cathode film

Final diameter
by BCP + special
mask: 5 mm



Quality factor measurements: Vertical and Horizontal tests (JLab and HZB)



Note: Horizontal RF tests at β_c~3-4, error bar!

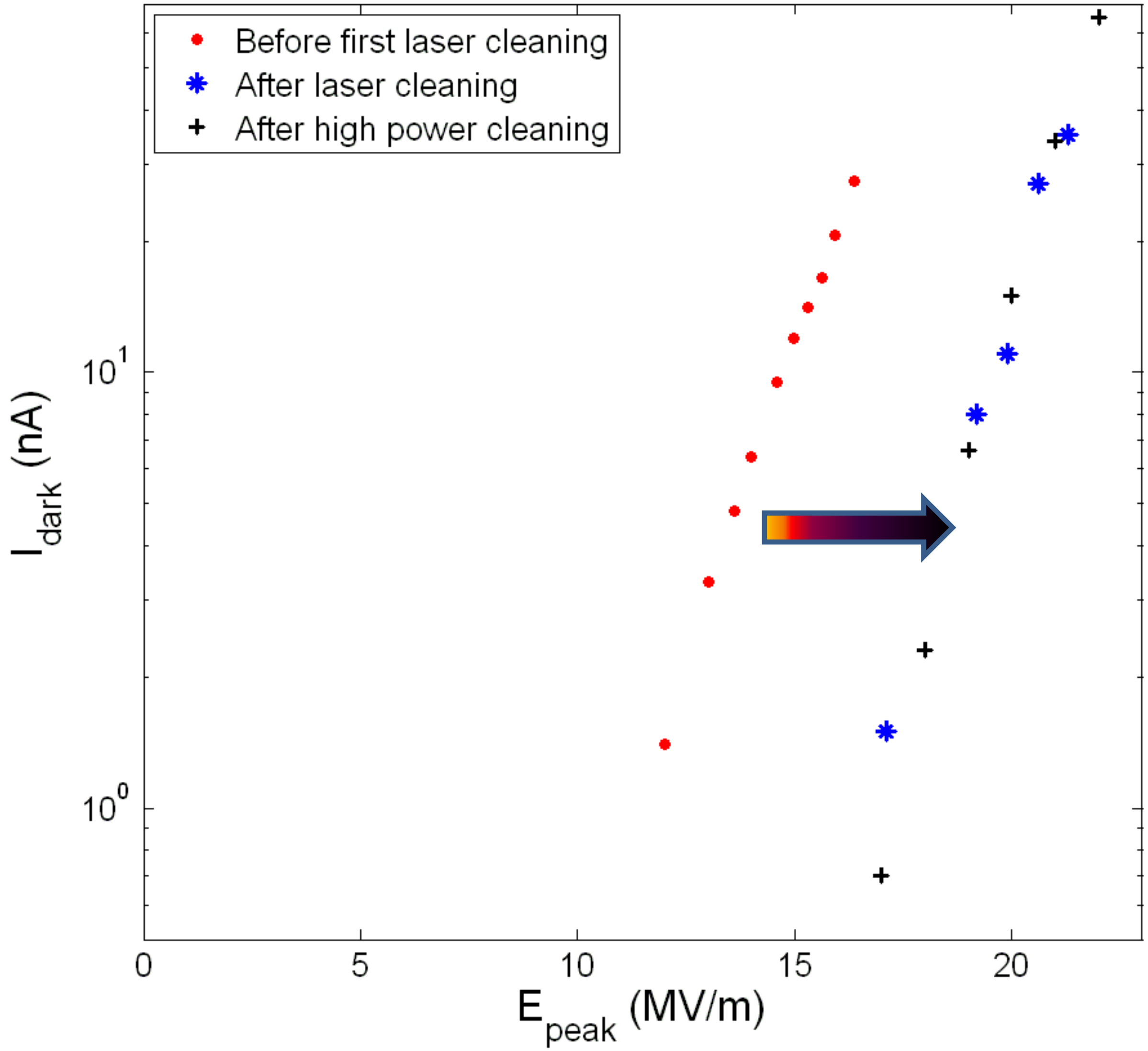
- Vertical test after fabrication, treatment and mounting $Q_0>1\cdot10^{10}$ for E_{peak}<35 MV/m
- After lead deposition Q drops significantly and field emission (FE) onset lowered
- Installation in HoBiCaT further Q degradation, FE onset 12 MV/m
- After additional cooldown cycle even worse, cavity collects residuals

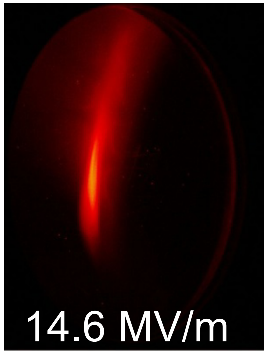
▪ Excimer Laser cleaning of lead cathode increased onset of FE to 15 MV/m

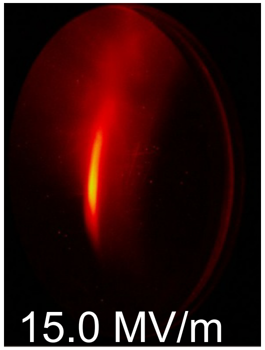
Operation of up to 20 MV/m, E_{acc} ~ 11 MV/m possible

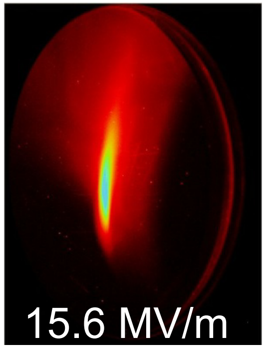
A. Neumann et al., SRF 2011

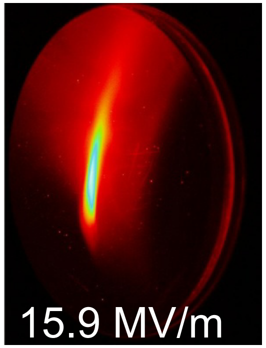
Dark current studies

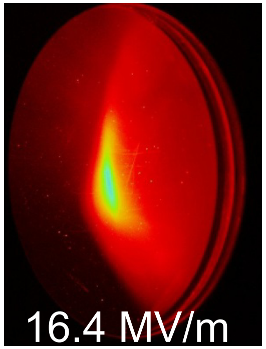








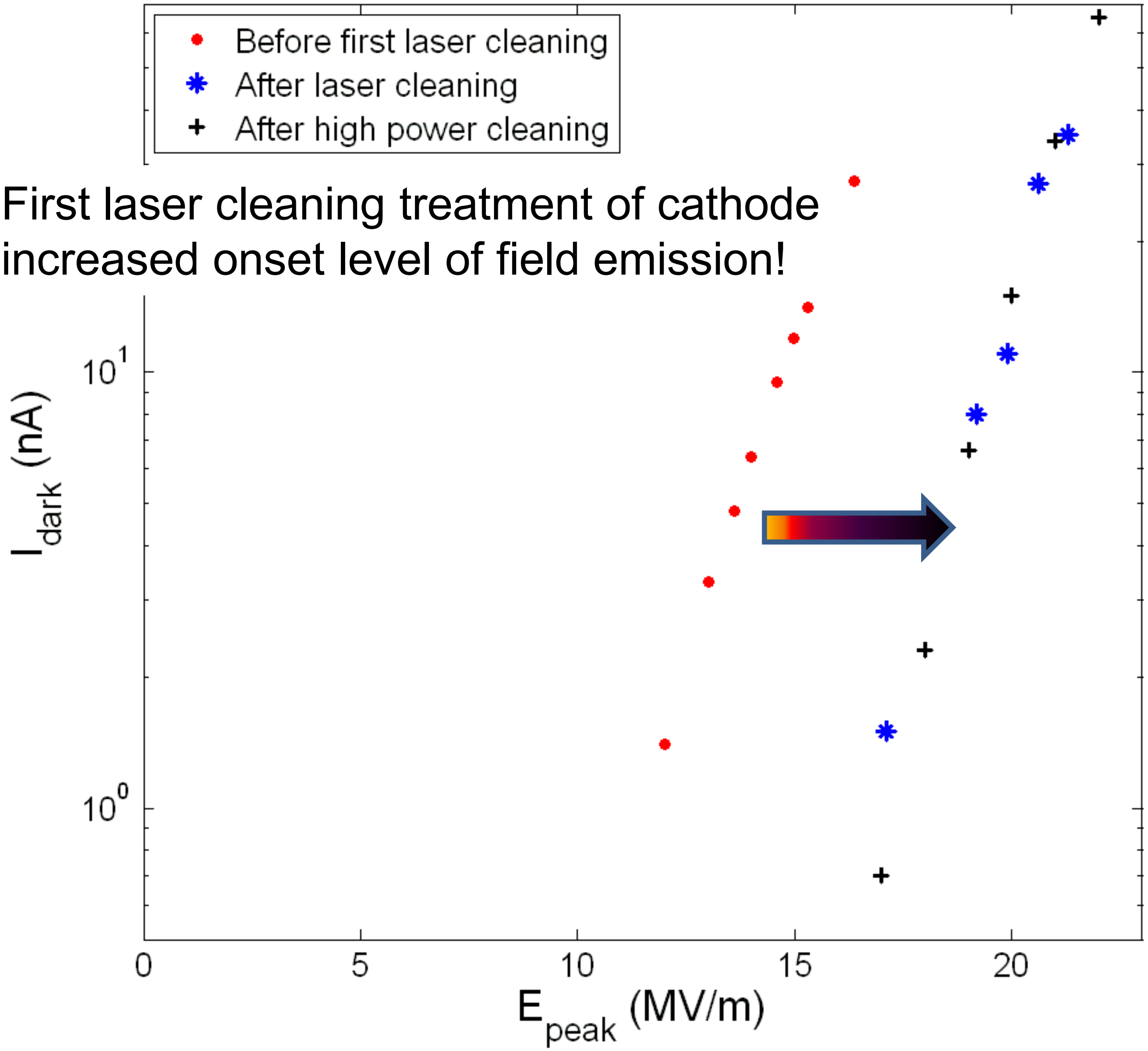




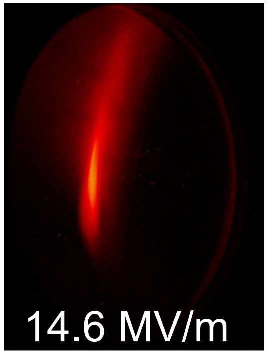
Dark current focussed by SC solenoid

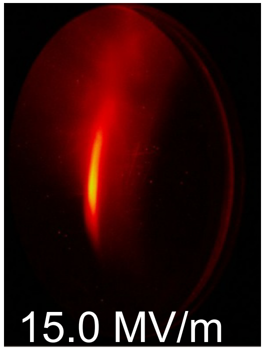
before laser cleaning

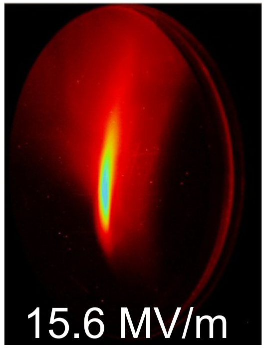
Dark current studies

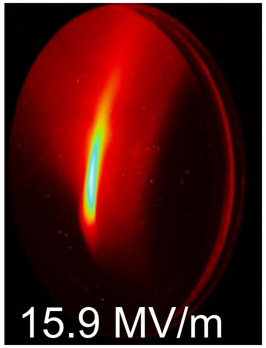


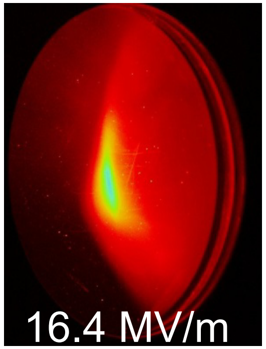
First laser cleaning treatment of cathode increased onset level of field emission!







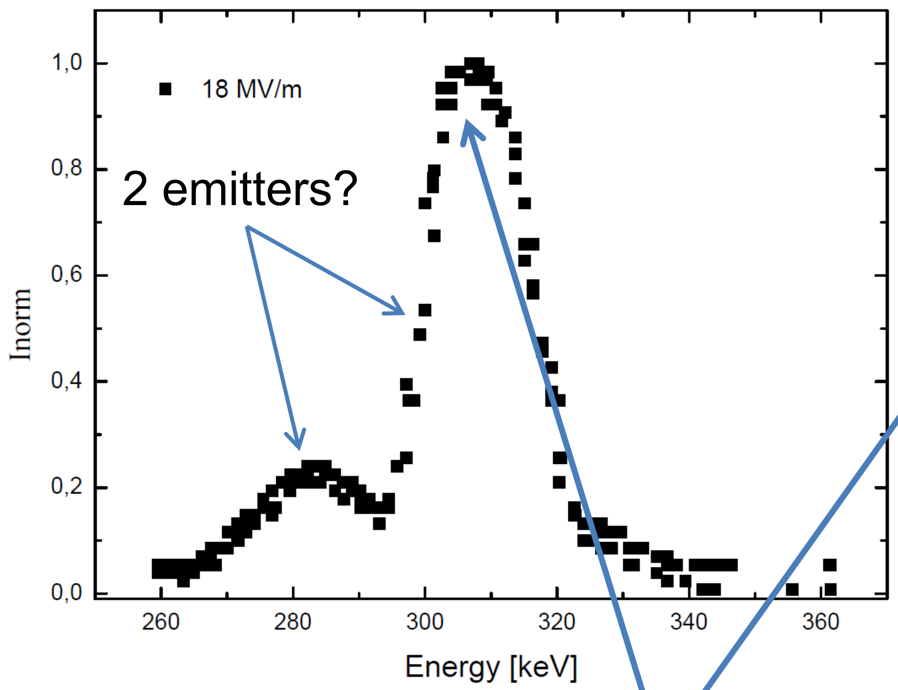


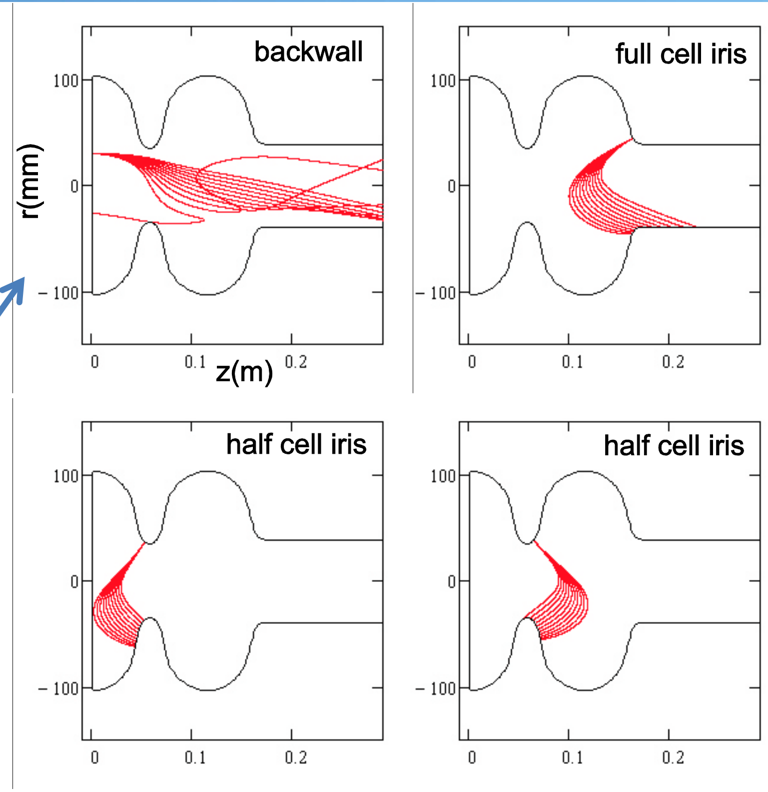


Dark current focussed by SC solenoid

before laser cleaning

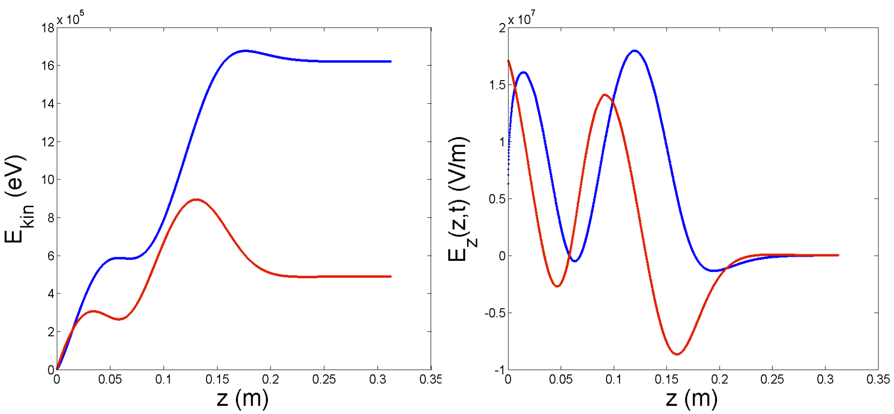
Dark current studies continued





Tracking studies suggest cathode region as field dark current source

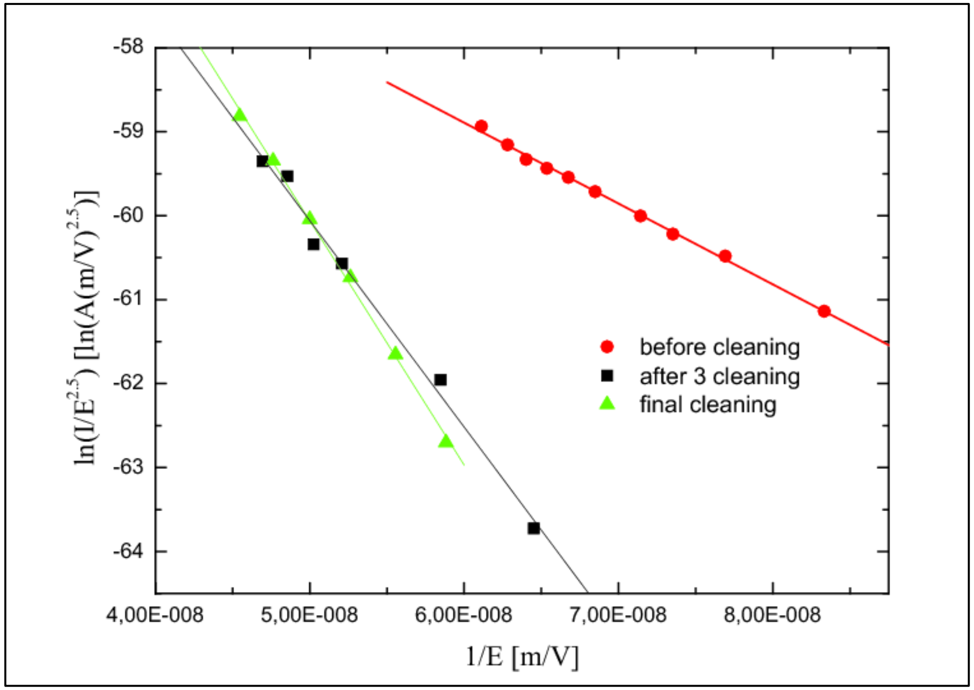
Measured dark current energy hints at 90 degree launch phase of field emission



V. Volkov, in preparation

R. Barday et al., Proc. Dipac 11

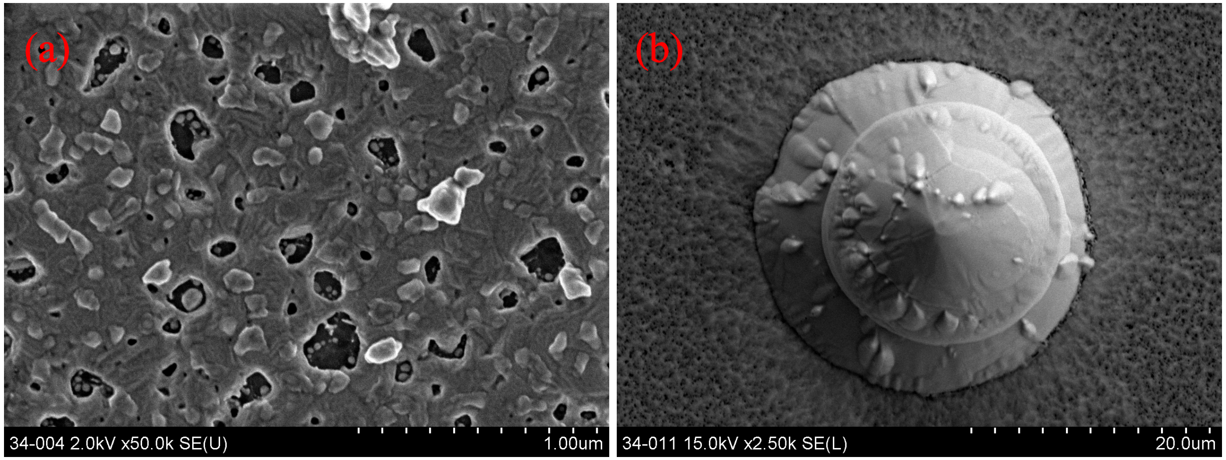
Dark current studies continued



Fowler-Nordheim fit of dark current/ field emission shows reduction of field enhancement factor β_{NF}.

Effectively emitting A_e area increases

Discuss at THPC109

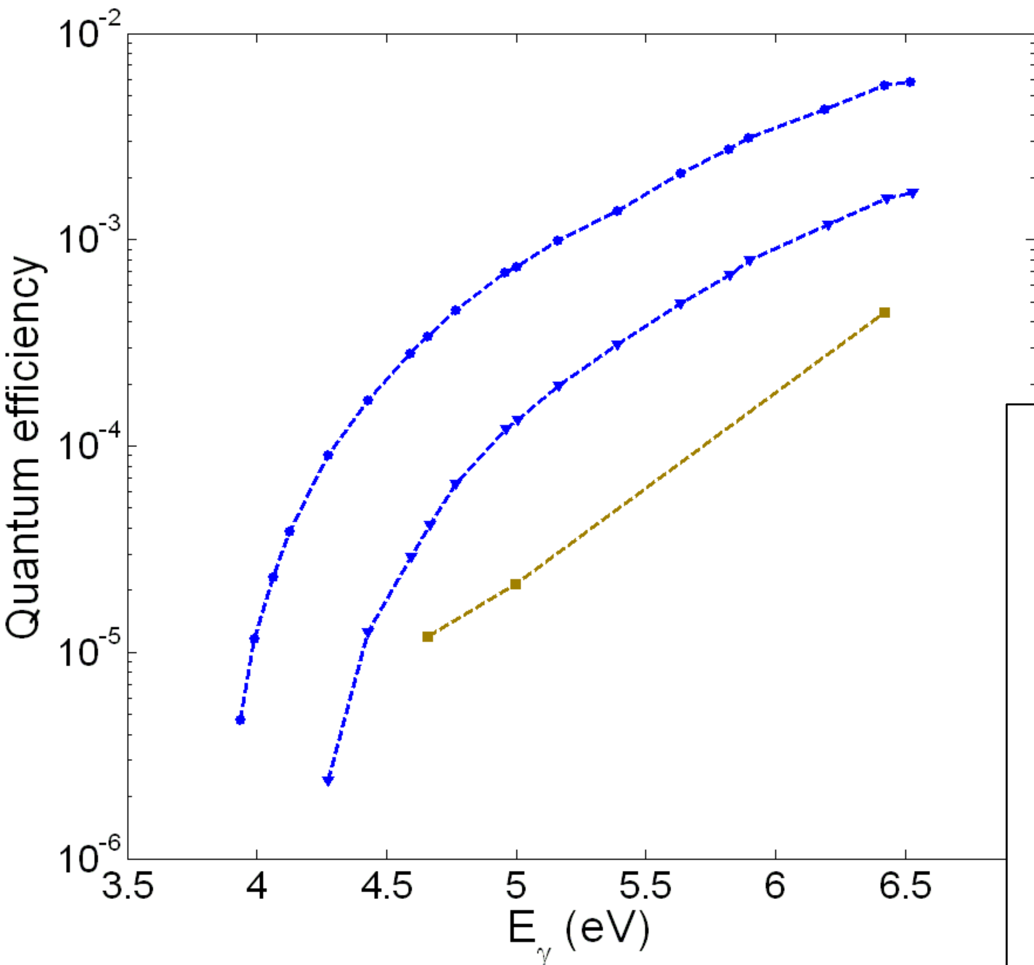


SEM images of comparable samples show droplets and tip on tip like structures

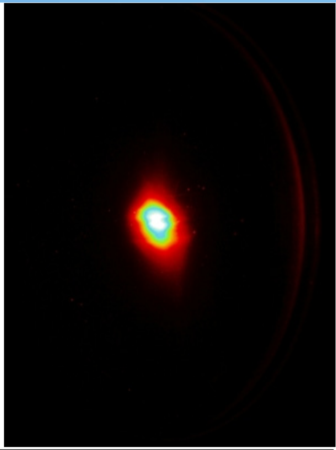
Laser cleaning levels small defects? (λ=248 nm, 0.1 mJ/mm²)
Tests with Niobium are planned

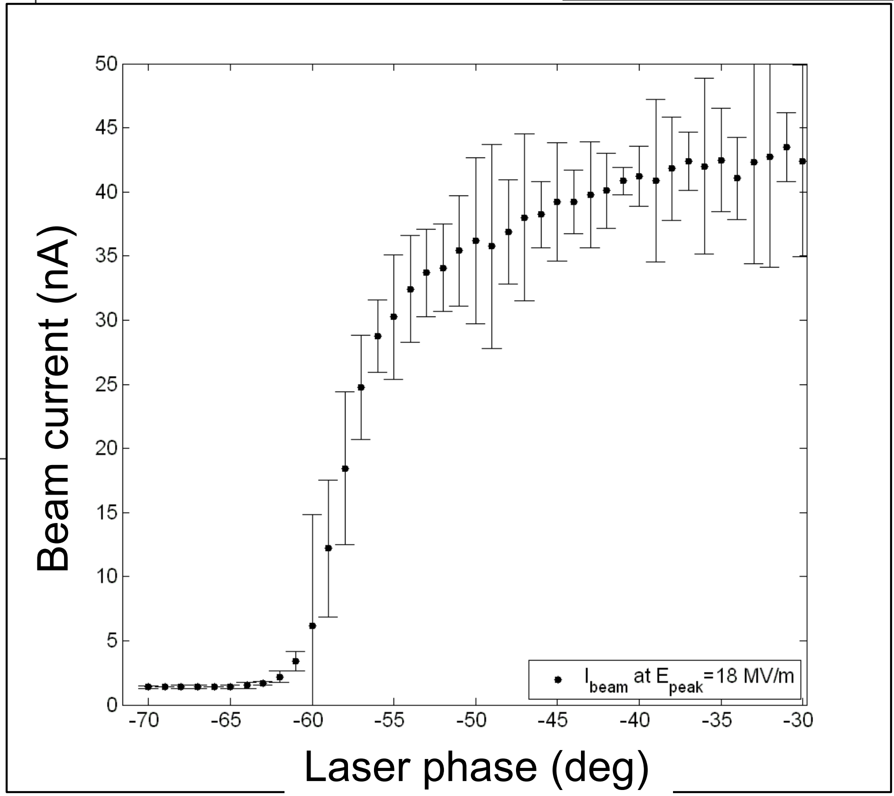
Arc deposited lead samples sem image S. Schubert et al., in preparation

J. Smedley, T. Kamps, T. Quast, A. Neumann, R. Barday



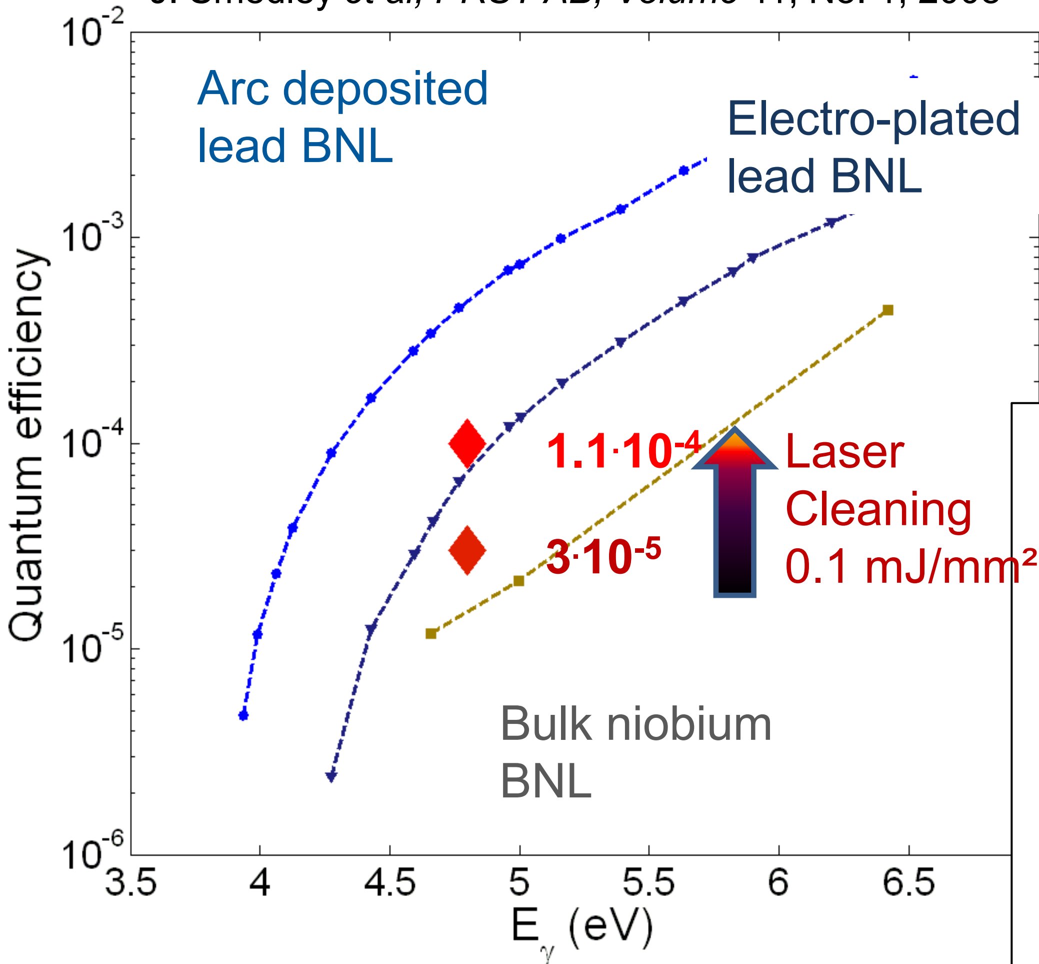
First beam
21st of April 2011
on YAG viewscreen





J. Smedley, T. Kamps, T. Quast, A. Neumann, R. Barday

J. Smedley *et al, PRST-AB, Volume* 11, No. 1, 2008



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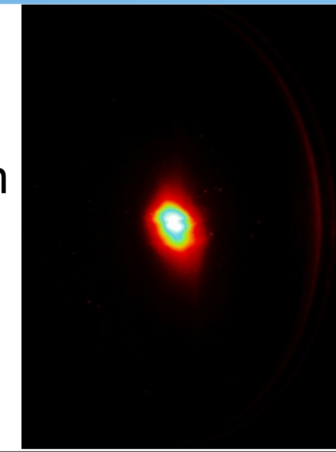
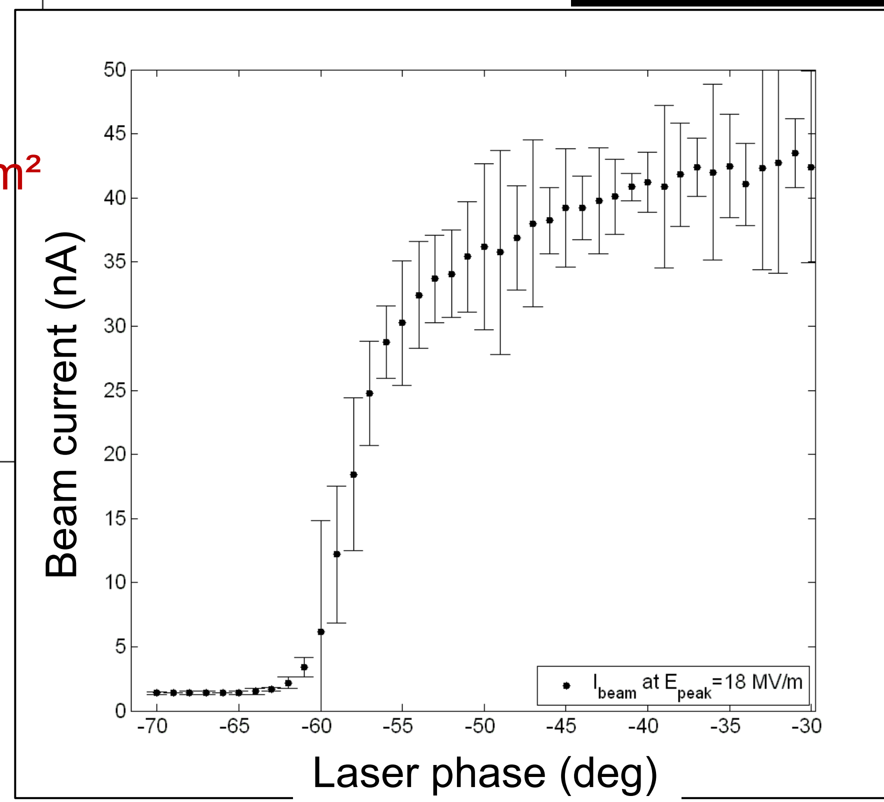
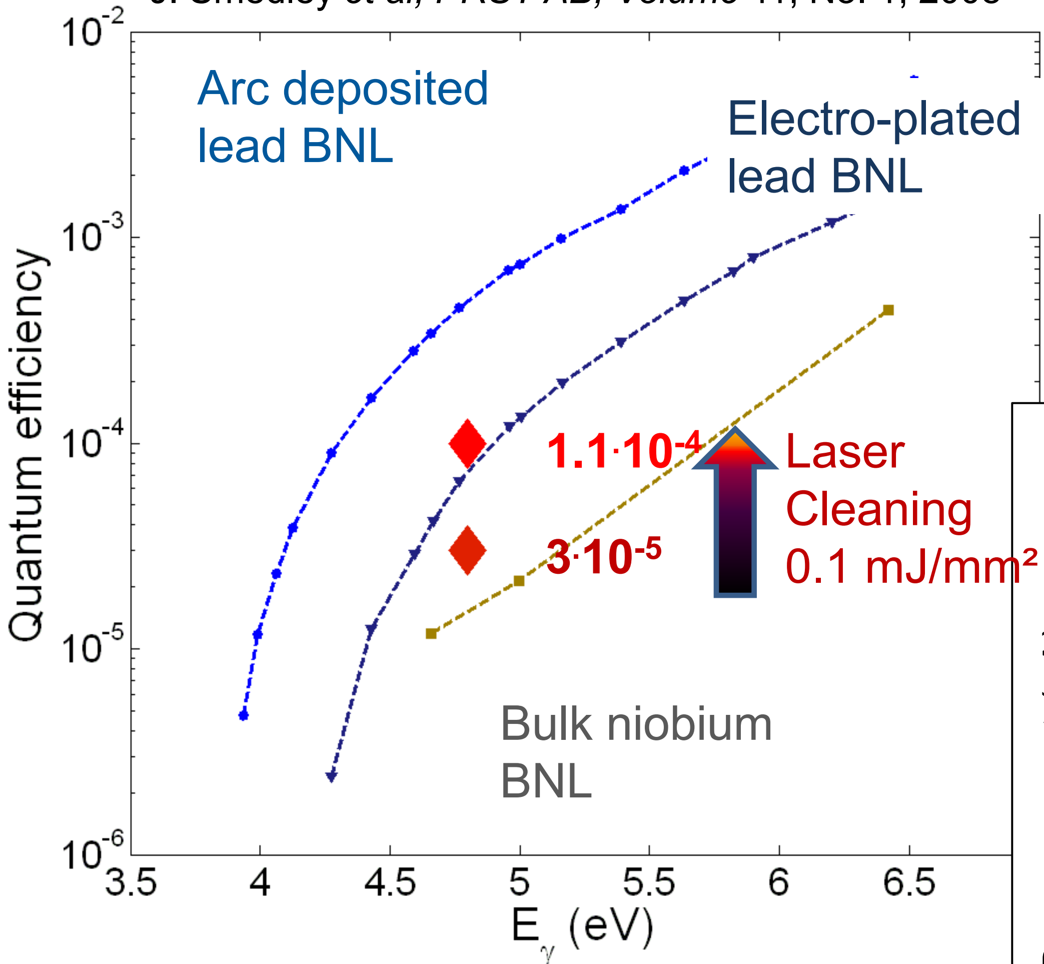
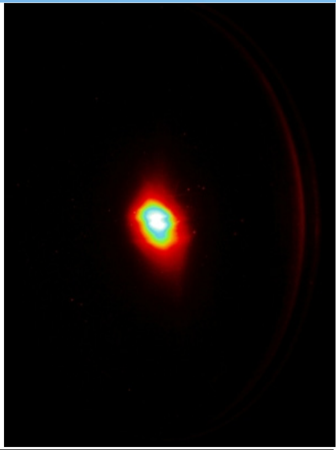




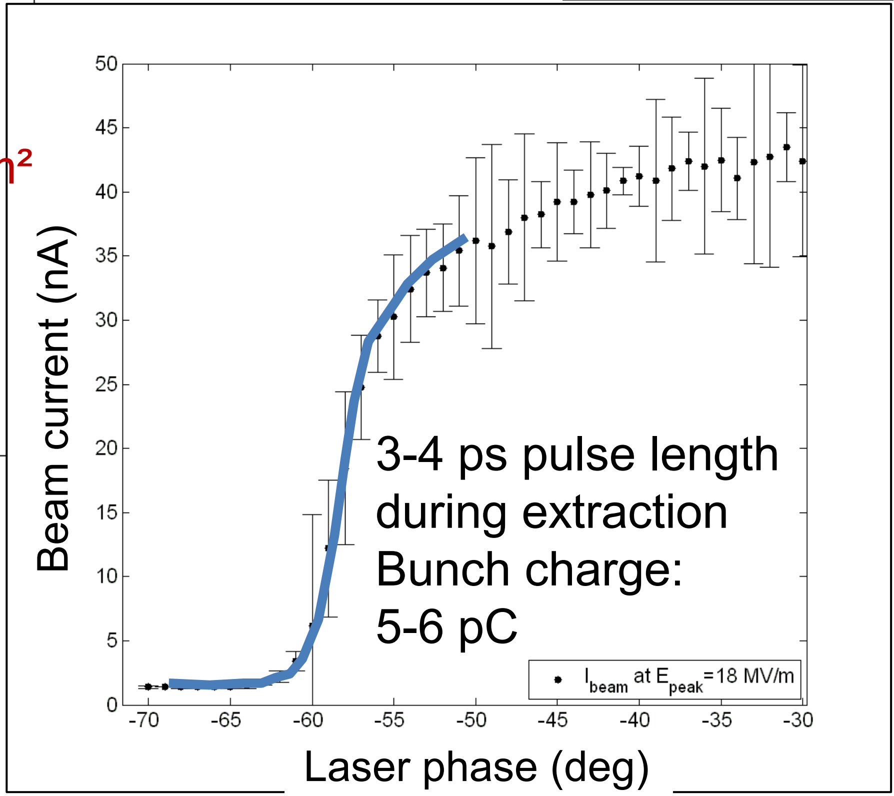
J. Smedley *et al, PRST-AB, Volume* 11, No. 1, 2008



First beam
21st of April 2011
on YAG viewscreen

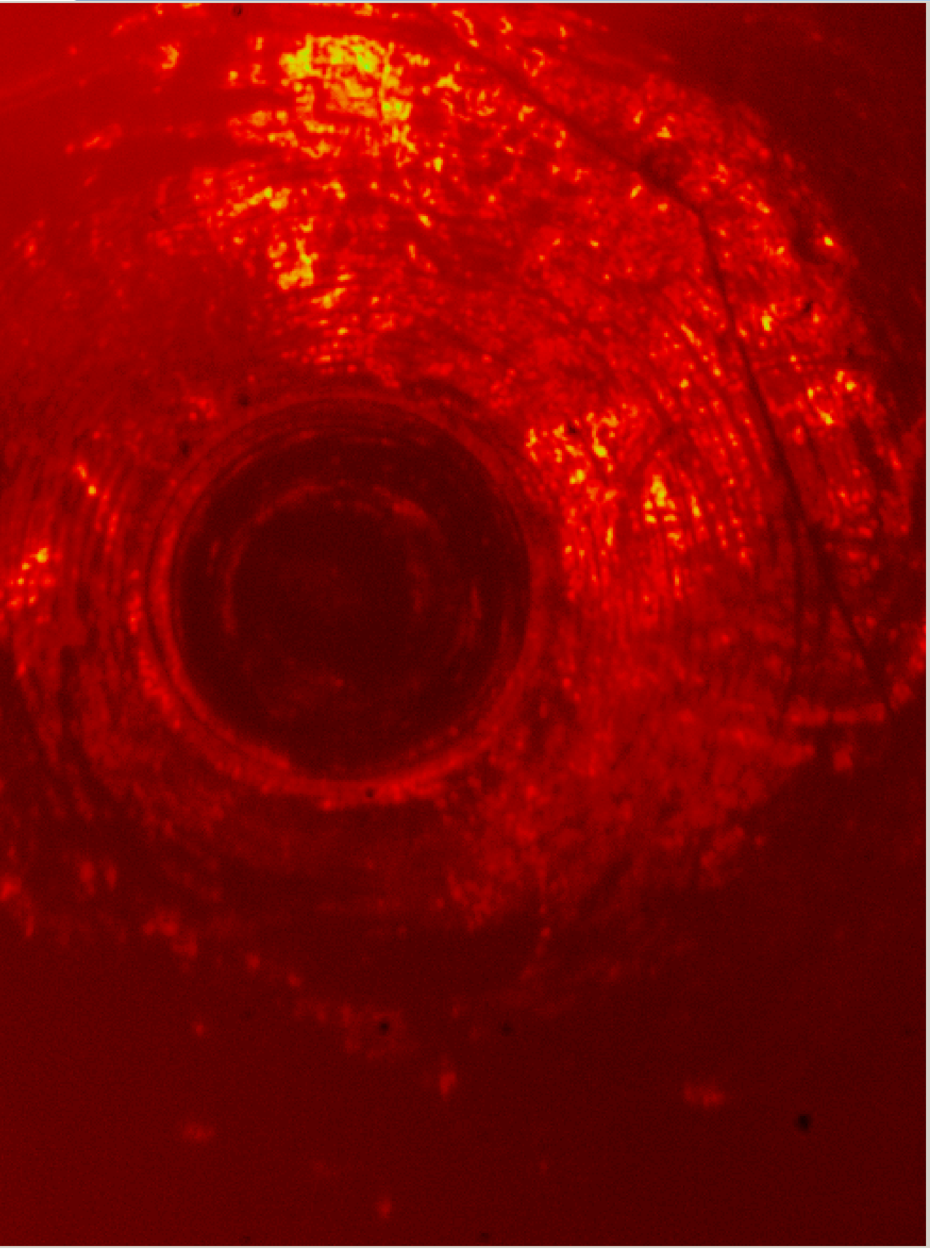


Visit T. Kamps at THPC109 for Beam results!



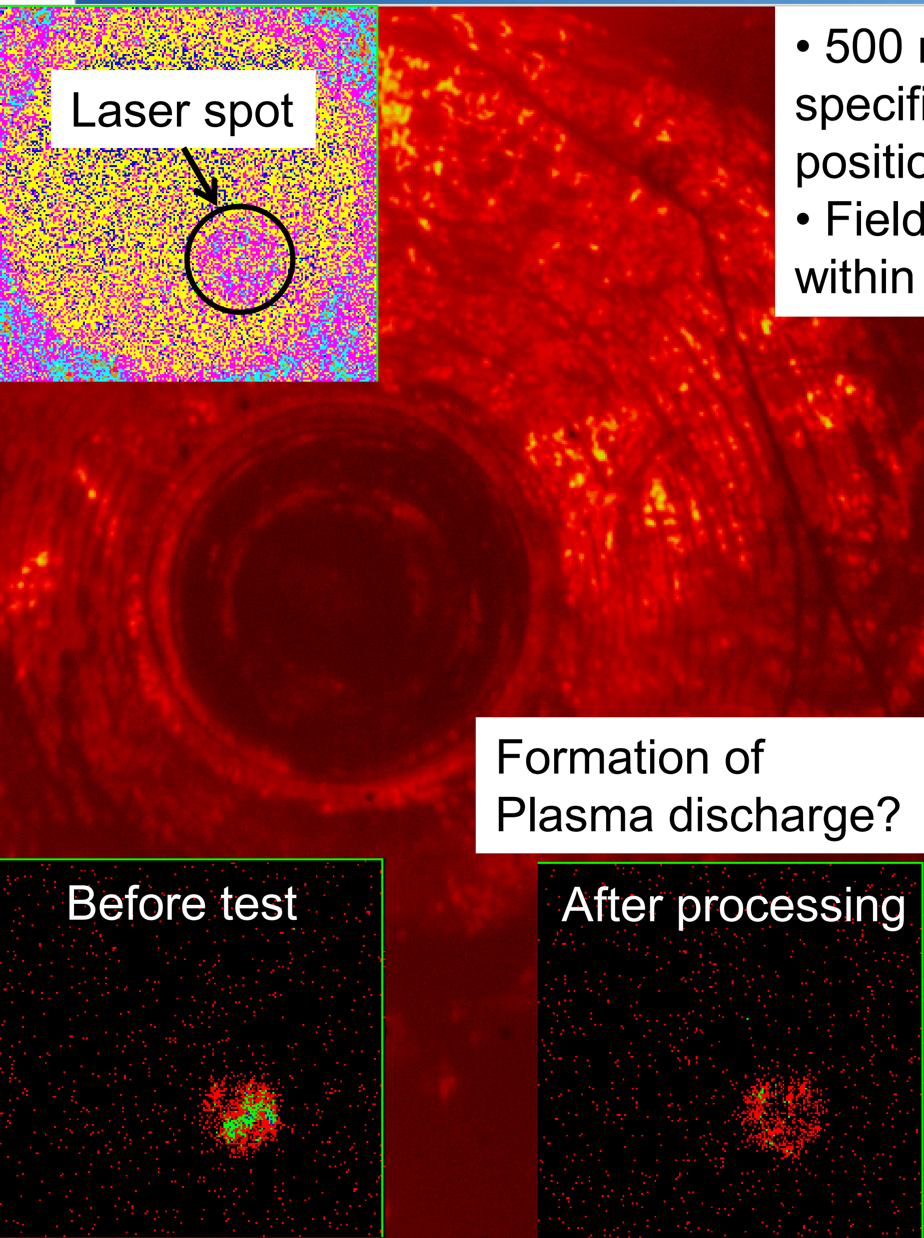
I_{beam}=50 nA at E_{cath}=20 MV/m
at 8 kHz Laser rep. Rate, λ=258 nm

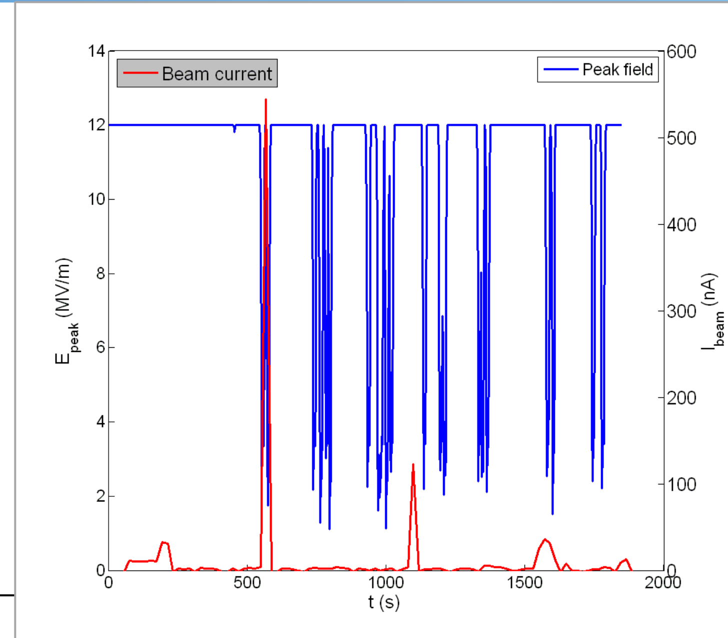
Cavity field trips

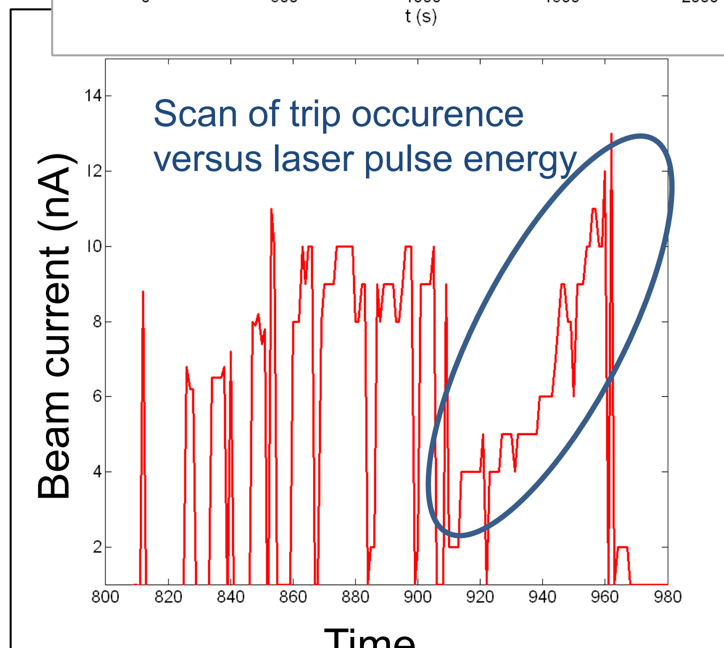


Cavity field trips

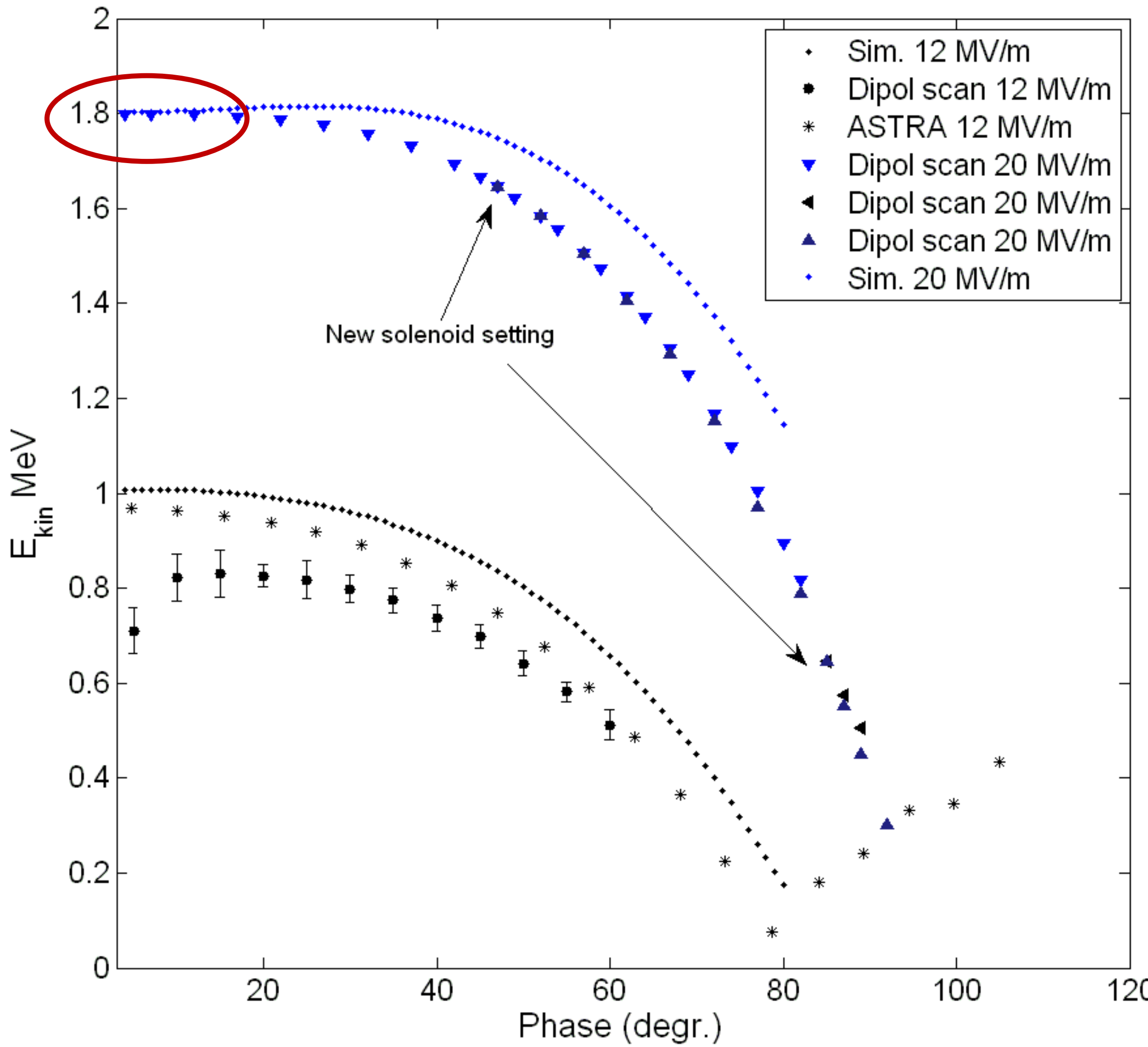
- 500 nA at specific cathode positions!
- Field decays within <1 μs





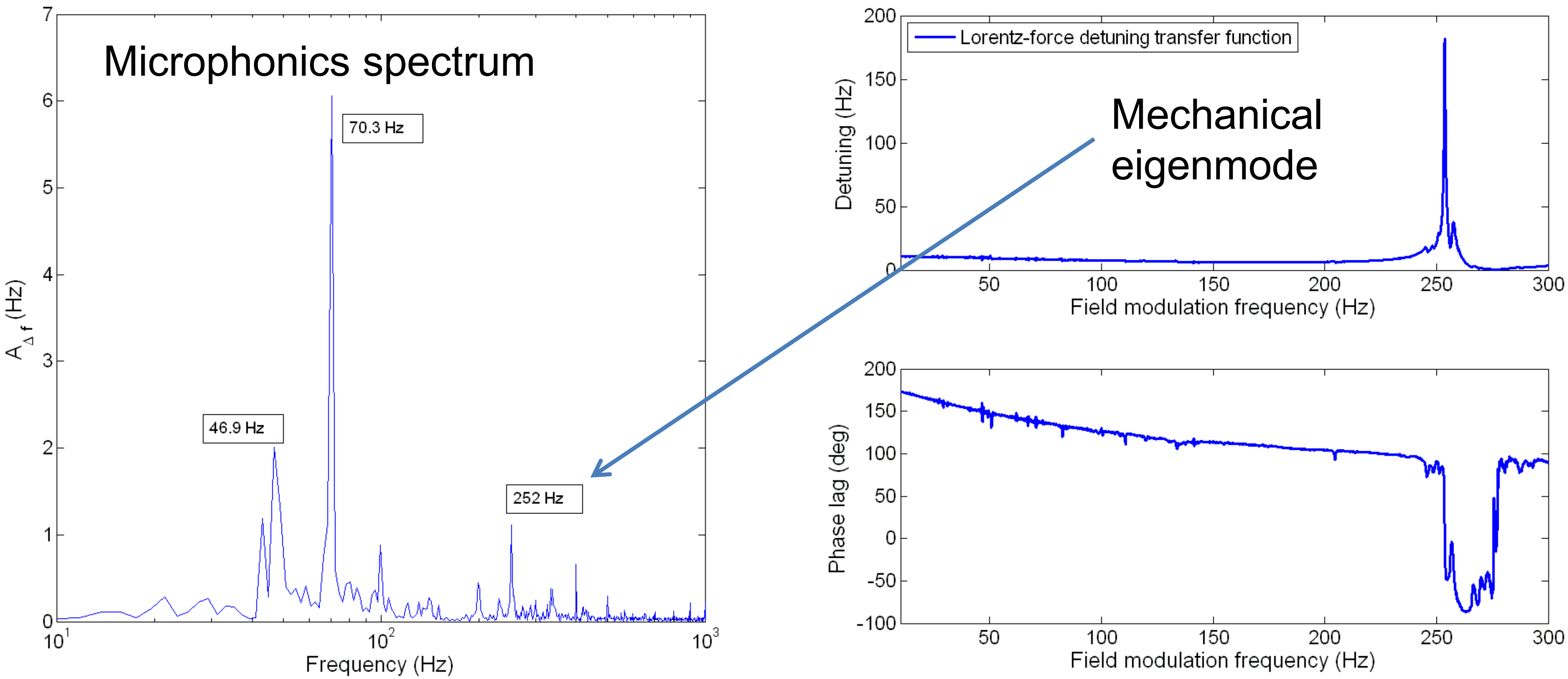


Beam energy



- Phase calibration
- Orbit errors by steering of solenoid
- Systematic errors due dipole and cavity field calibration
- Need to optimize setup for next run

Field stability



Q_L	E_{peak}	σ_f	σ_Φ	σ_A/A
$6.6 \cdot 10^6$	20 MV/m	7.0 Hz	0.017 deg	$1 \cdot 2.10^{-4}$
$1.4 \cdot 10^7$	12 MV/m	5.0 Hz	0.02 deg	$1 \cdot 5.10^{-4}$

Using Cornell LLRF system+ slow PLL loop

Outlook: Near future

- Measurements of beam emittance and thermal emittance of lead are in progress, please visit T. Kamps on Thursday **THPC109**

- More detailed studies about laser cleaning,
  QE measurements, also XPS analysis
  will be published in the near future (S. Schubert, R. Barday in prep.)

- Further studies about the cavity trips
  will be done, improvement of Q_0
  by helium processing is planned for

- J. Sekutowicz and P. Kneisel are working on an improved version of the 1.6 cell cavity, this time with tuning system
  R. Nietubycz *et al.* are building a new improved cathode deposition set up

- New cavity will be installed early 2012 in HoBiCaT

Thanks for your attention!
Gracias por su atención!
Eskerrik asko zure arretagatik!

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The three stage approach

Parameter	HoBiCaT Stage A	Gun lab Stage B	BERLinPro Stage C
Goal	Beam Demonstrator	Brightness R&D gun	Current Production gun
Electron energy	$\geq$ 1.5 MeV		
RF frequency	1.3 GHz		
Design peak field	$\leq$ 50 MV/m		
Operation launch field	$\geq$ 10 MV/m		
Bunch charge	$\leq$ 77 pC		
Repetition rate	30 kHz	54 MHz	1.3 GHz
Cathode material	Pb	Cu, CsK_2Sb	CsK_2Sb
Laser wavelength	258 nm	355, 526 nm	526 nm
Laser pulse energy	0.15 µJ	$\leq$ 1 µJ	4 nJ
Laser pulse shape	Gaussian	Gaussian, Flat-top	Flat-top
Laser pulse length	2.5 ps FWHM	$\leq$ 15 ps	15 ps
Average current	0.5 µA	$\leq$ 10 mA	100 mA

Stage A (Beam dynamics):

- Study beam dynamics of SC RF photoinjector:
  - Emittance
  - Field levels
  - Stability
- Fully SC design
- Starting point for design and operation of SRF gun

Stage B (Peak Brightness):

- Study + develop cathode insert into SC injector:
- Lifetime and QE of cathode materials
- Reliable cathode replacement scheme

Stage C (High avg. Current):

- SC design for ERL design current
- High power operation
- HOM damping
- Cathode lifetime

Started here