High intensity and low emittance gun

Paolo Michelato

INFN Milano - LASA

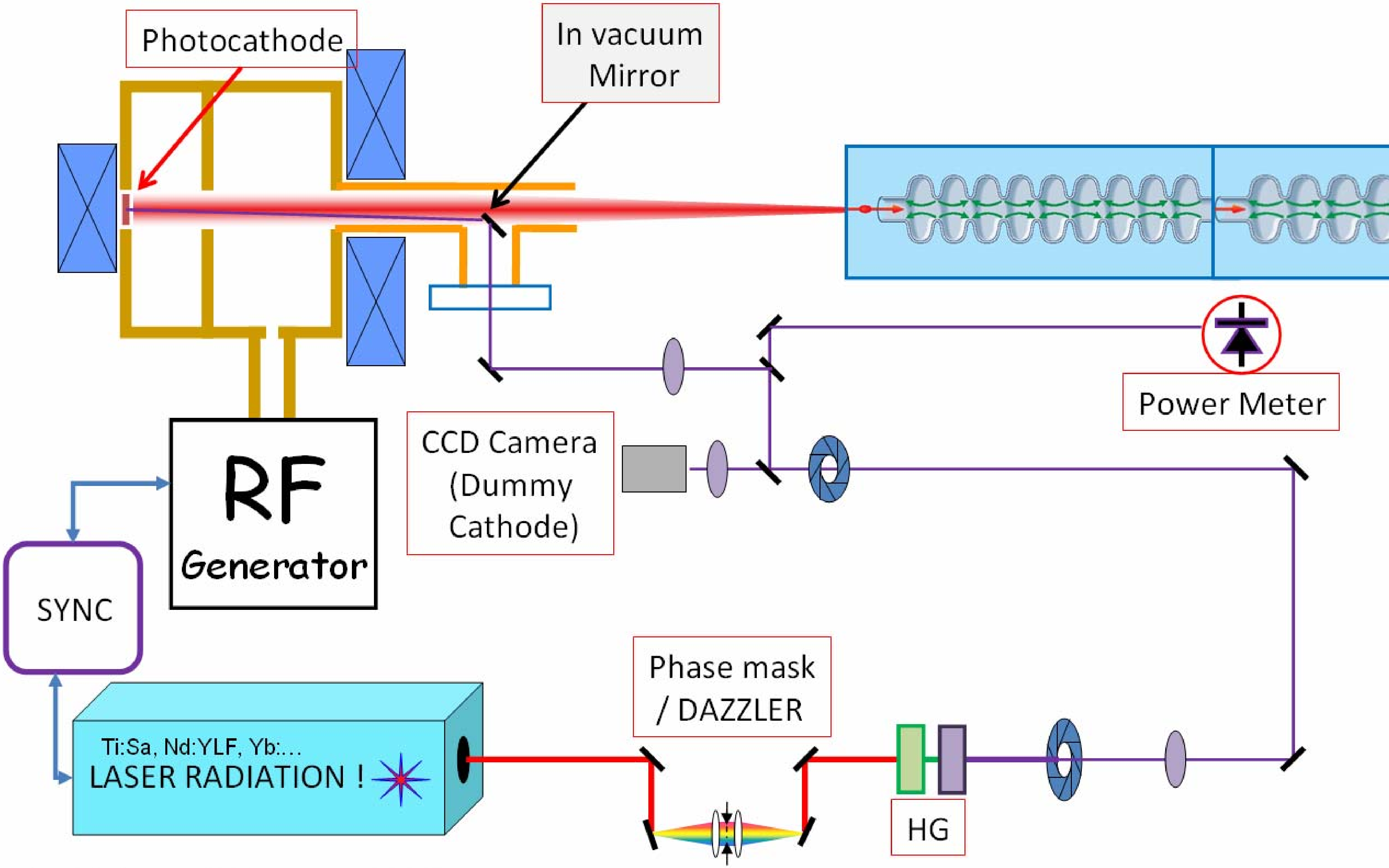
High brightness low emittance sources

- Many applications ask for high brightness

$$B \approx 10^{15}\ A/m^2$$

  - Energy Recovery Linac - ERL
    - High beam current (mean)
    - CW operation
    - Low emittance
  - FEL
    - Pulsed
      - Short, single pulse/long RF pulse, for multibunch
    - High peak current
    - Estreme low emittance ($\approx$ 1 mm·mrad or less)

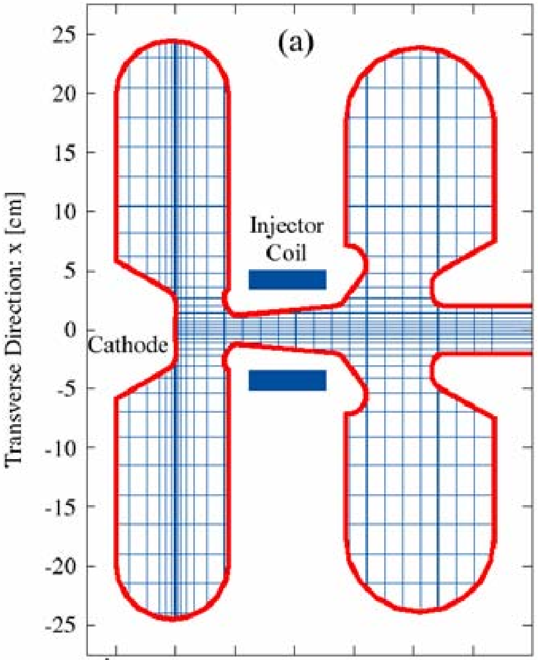
RF Photoinjector

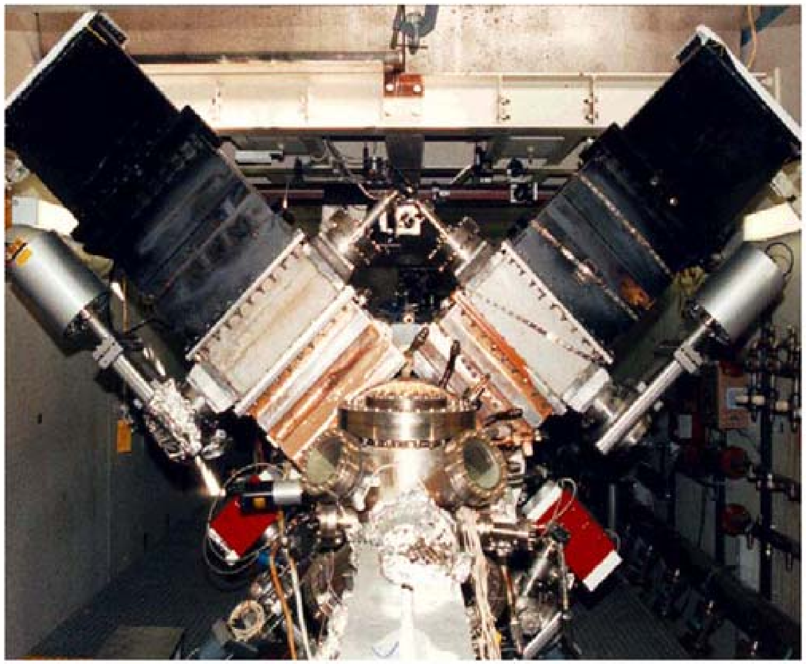


Normal Conducting RF GUN (photocathode embedded in the RF cavity)

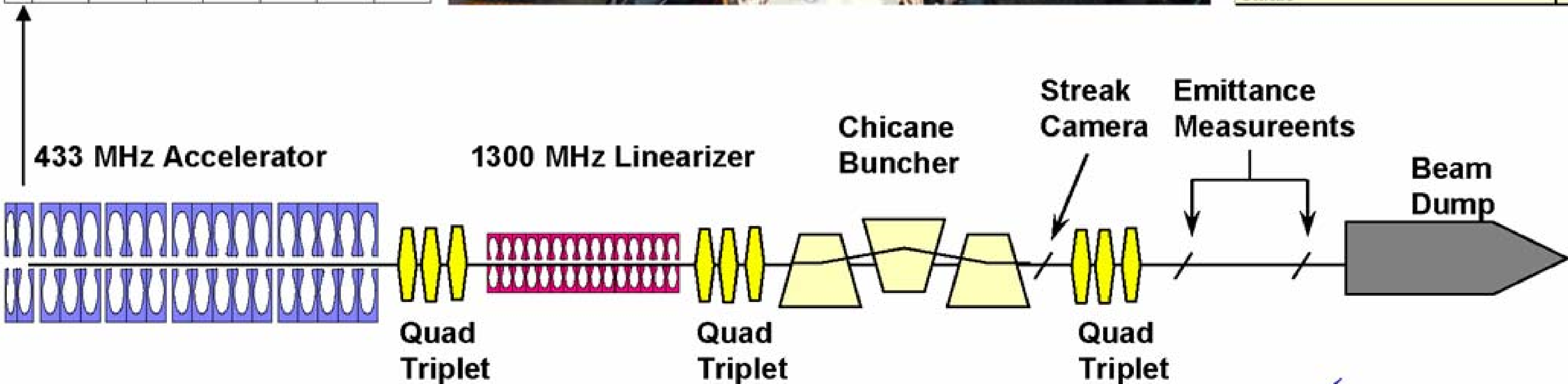
- "Low Frequency" RF gun with semiconductor cathode
  - **LANL (433 MHz), LANL/AES(700 MHz),** VHF (144 MHz)
- L-band with semiconductor cathode (Cs_2Te):
  - **FLASH, PITZ**, FNAL
- S-Band: BNL/UCLA/SLAC like, metal cathode
  - **LCLS, SPARC,** FERMI, and many others
- S-band with semiconductor cathode
  - KEK

The Boeing Gun: Still the Demonstrated State-of-the Art



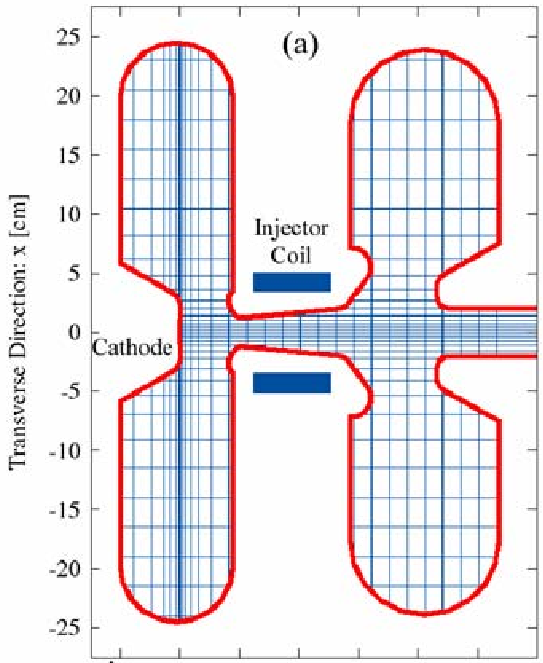


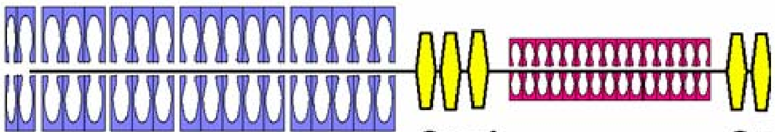
Gun Type	NCRF
Injector and ERL	
RF Frequency (MHz)	433
PRF (MHz)	27
Charge/Bunch (nC)	4.75
Current (mA)	32 (132 Peak)
Injector Energy (MeV)	5
Transverse RMS Normalized Emittance (	~ 7
Longitudinal RMS Emittance (keV-psec)	
RMS Bunch Length (psec)	
RMS Energy Spread (%)	~ 3
ERLP Energy (MeV)	N/A
ERL Energy Goal (MeV)	N/A
Electron Gun	
DC Gun Voltage (kV)	N/A
Gun Accelerating Field (MV/m)	
Cathode Material	CsKSb
Drive Laser FWHM Pulse Length (psec)	53
Laser Wavelength (nm)	527
Laser Power at 5% QE (W)	
Booster Accelerator	
Type	N/A
Geometry (Cavities x Cells)	1 x 1.5 + 1 x 3
Couplers per Cavity / Type	2 / WG
Coupler Power (kW)	
Status	Retired



Material Courtesy David Dowell and John Adamski

The Boeing Gun: Still the Demonstrated State-of-the Art





Material Courtesy Dav

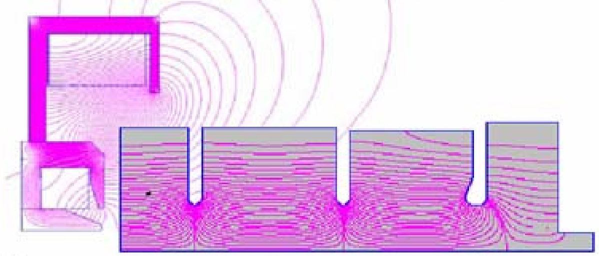
AMMT - ERL W/S - 03/05 - 7

Gun Type	NCRF
Injector and ERL	
RF Frequency (MHz)	433
PRF (MHz)	27
Charge/Bunch (nC)	4.75
Current (mA)	32 (132 Peak)
Injector Energy (MeV)	5
Transverse RMS Normalized Emittance (	~ 7
Longitudinal RMS Emittance (keV-psec)	
RMS Bunch Length (psec)	
RMS Energy Spread (%)	~ 3
ERLP Energy (MeV)	N/A
ERL Energy Goal (MeV)	N/A
Electron Gun	
DC Gun Voltage (kV)	N/A
Gun Accelerating Field (MV/m)	
Cathode Material	CsKSb
Drive Laser FWHM Pulse Length (psec)	53
Laser Wavelength (nm)	527
Laser Power at 5% QE (W)	
Booster Accelerator	
Type	N/A
Geometry (Cavities x Cells)	1 x 1.5 + 1 x 3
Couplers per Cavity / Type	2 / WG
Coupler Power (kW)	
Status	**Retired**

Paolo Michelato, EPAC08, Genoa, June 23, 2008.

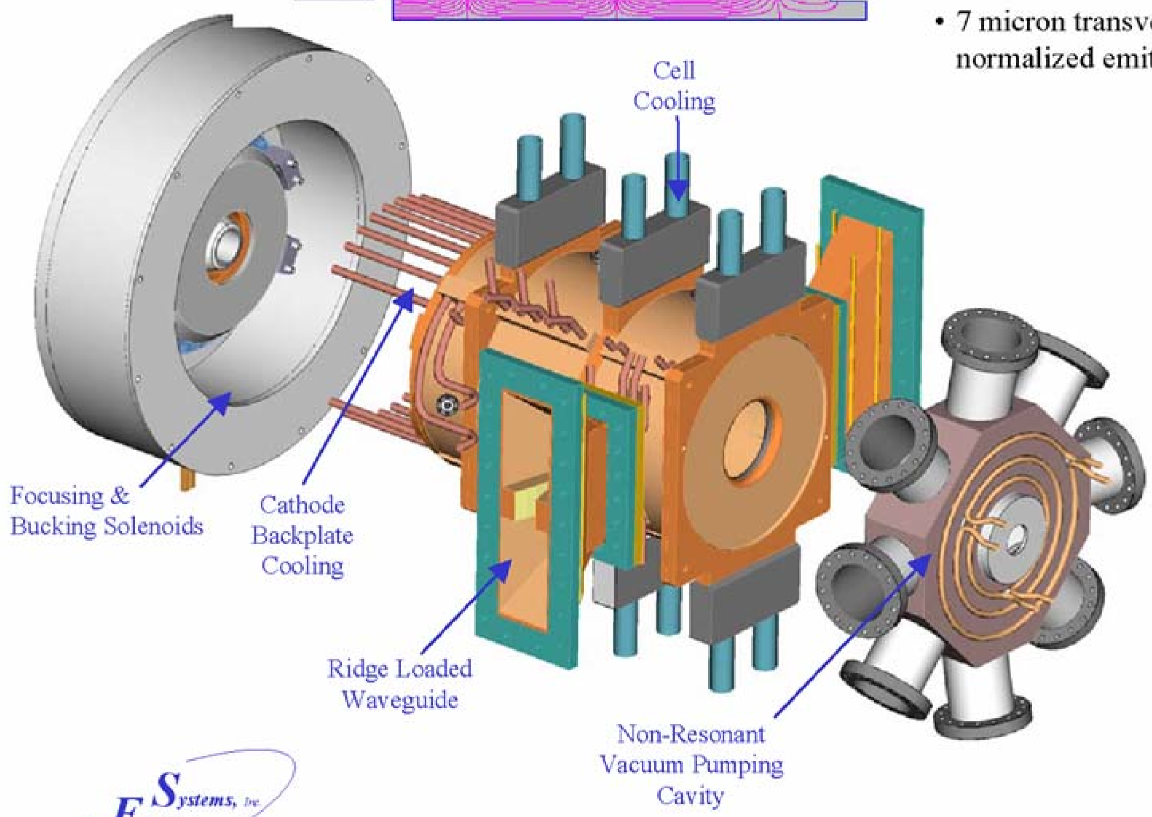
LANL-AES RF Gun Concept

2.5 Cell Injector & Solenoids
Showing Magnetic & Electric Fields

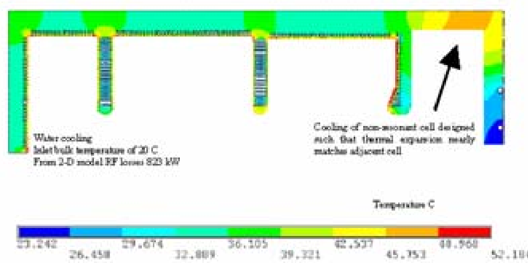


High-Power RF Injector Performance

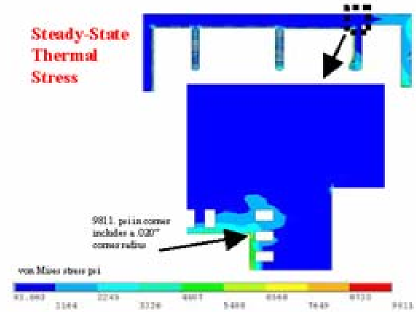
- 2.5 Cell Photoinjector Linac, 700 MHz, 7 MV/m, 2.7 MeV
- Following 4 Cell Booster Linac, 4.5 MV/m, 5.5 MeV
- 3.0 nC per bunch
  100 mA CW @ 33.3 MHz: 1.05 A CW @ 350 MHz
- 7 micron transverse, 200 keV-psec longitudinal rms normalized emittance, < 1% energy spread



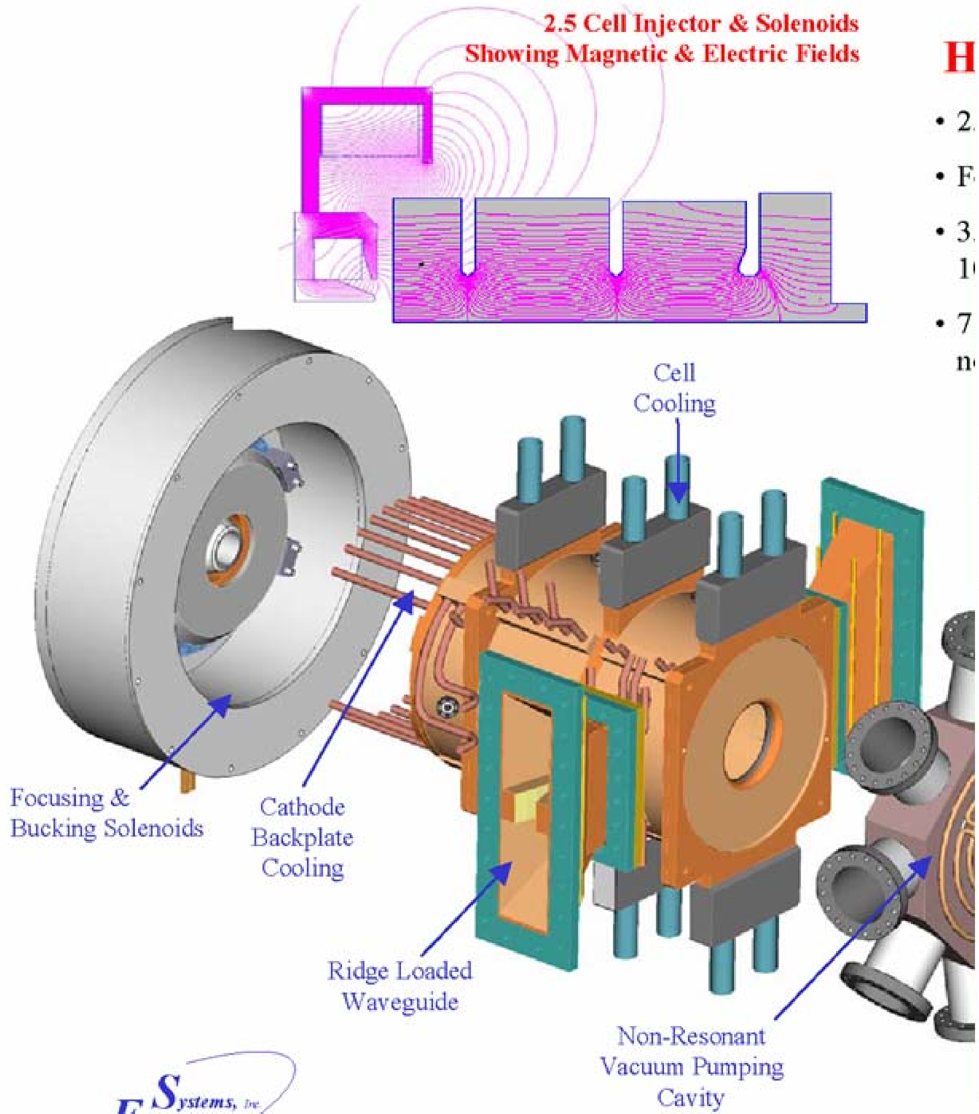
Steady-State Temperature Distribution



Steady-State Thermal Stress



LANL-AES RF Gun Concept



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Gun Type	RF
Injector and ERL	
RF Frequency (MHz)	700
PRF (MHz)	33.3 (350)
Charge/Bunch (nC)	3.0
Current (mA)	100 (1050)
Injector Energy (MeV)	2.5
Transverse RMS Normalized Emittance (	6
Longitudinal RMS Emittance (keV-psec)	145
RMS Bunch Length (psec)	
RMS Energy Spread (%)	0.5
ERLP Energy (MeV)	N/A
ERL Energy Goal (MeV)	N/A
Electron Gun	
DC Gun Voltage (kV)	N/A
Gun Accelerating Field (MV/m)	7 / 7 / 5
Cathode Material	Multi-Alkali
Drive Laser FWHM Pulse Length (psec)	16
Laser Wavelength (nm)	527
Laser Power at 5% QE (W)	5 (53)
Booster Accelerator	
Type	N/A
Geometry (Cavities x Cells)	1 x 2.5
Couplers per Cavity / Type	2 / WG
Coupler Power (kW)	500

Advanced Energy Systems, Inc

DESY Hamburg, Germany

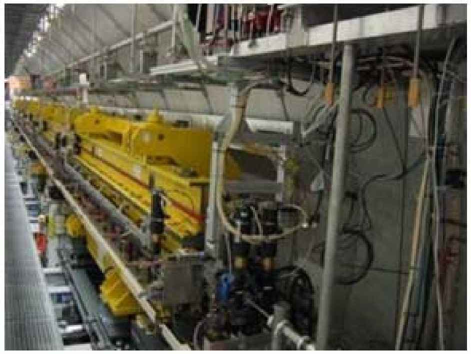
FLASH
Free-Electron Laser in Hamburg

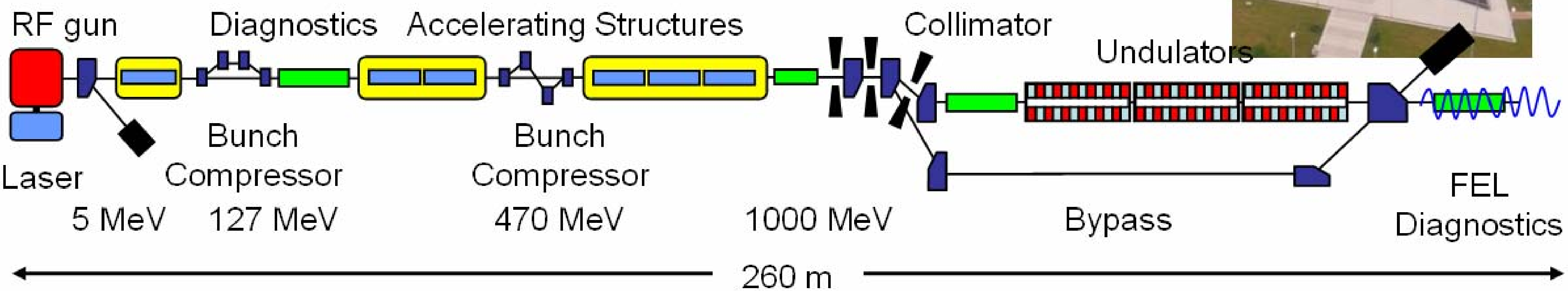
Courtesy S. Schreiber, DESY

FLASH Free-Electron Laser in Hamburg

FLASH Overview





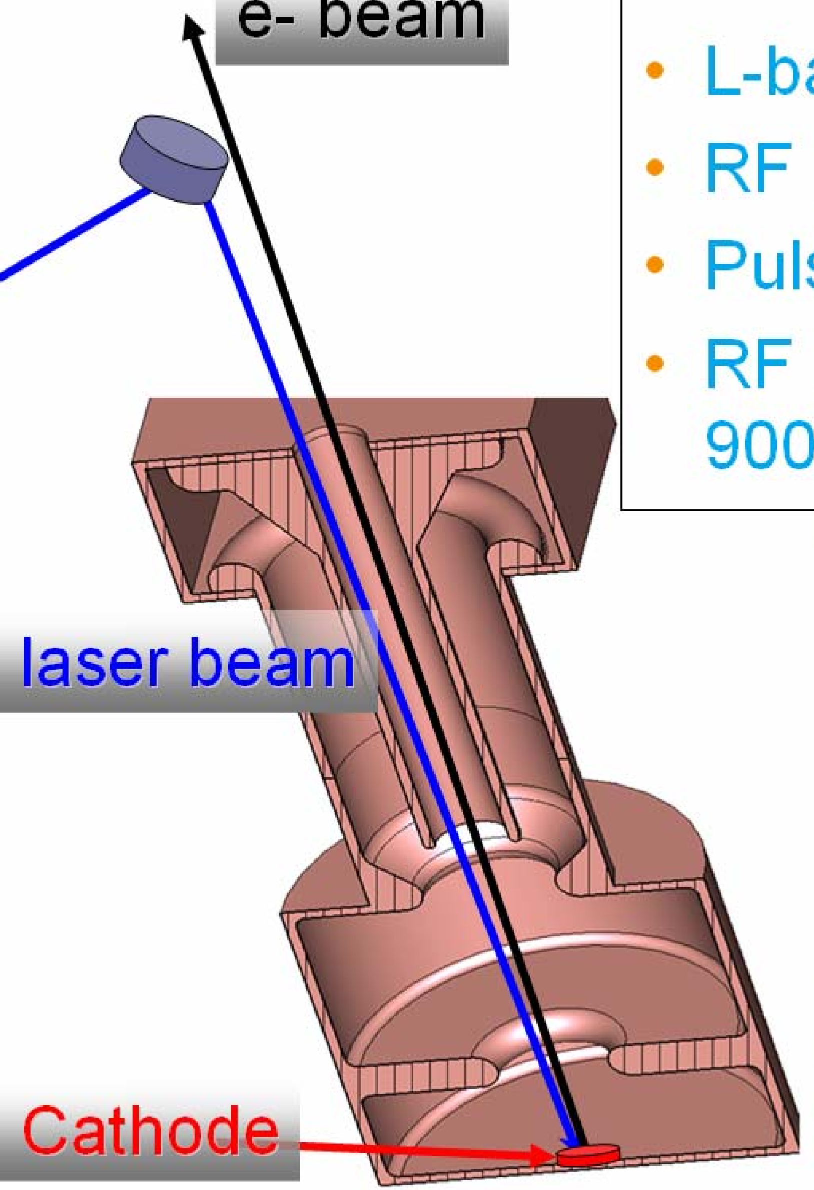



Courtesy S. Schreiber, DESY

FLASH
Free-Electron Laser in Hamburg

Photoinjector

- laser driven RF gun
- L-band 1.3 GHz
- RF power 3.5 MW
- Pulsed 5 or 10 Hz
- RF pulse length 100 to 900 µs

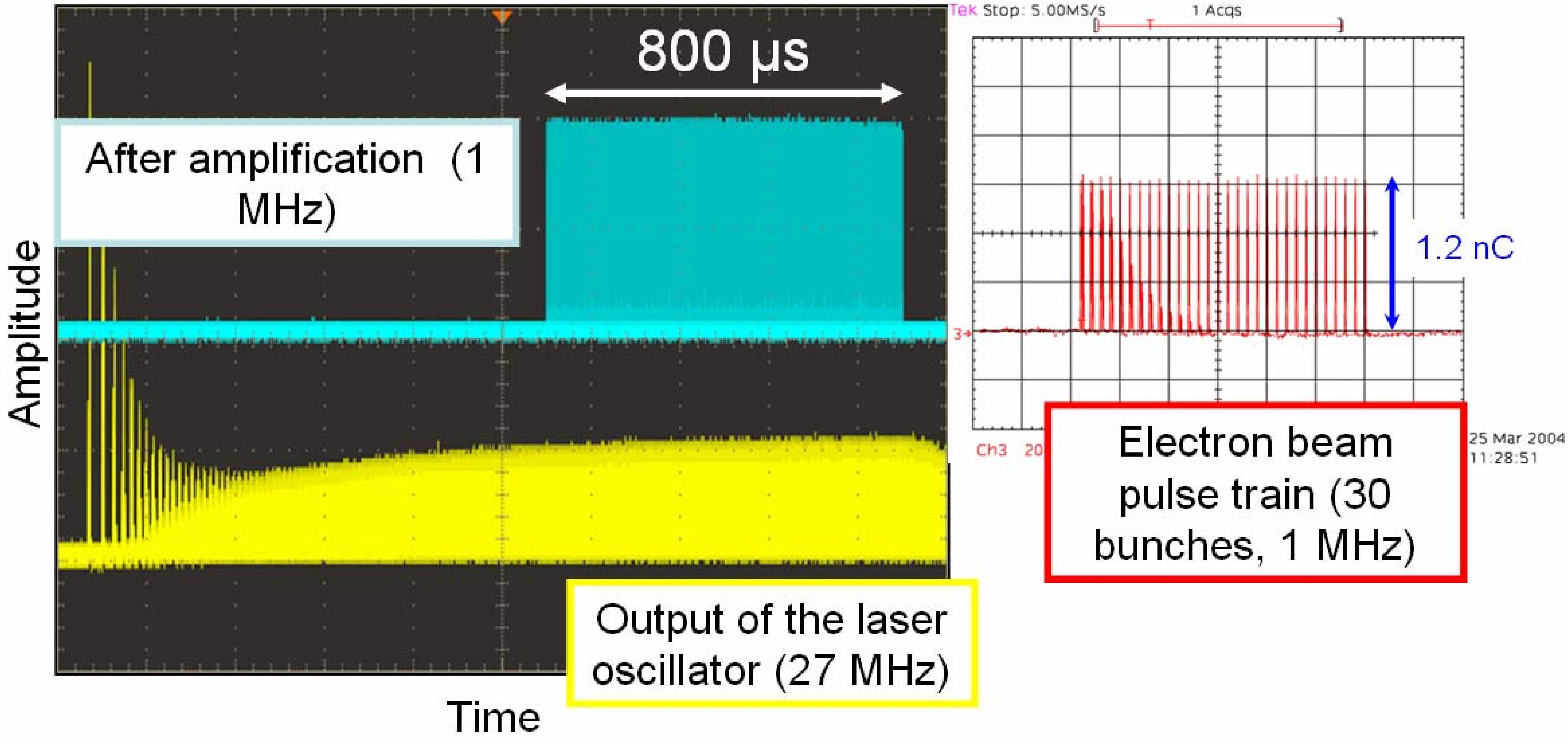


Paolo Michelato, EPAC08, Genoa, June 23, 2008.

Courtesy S. Schreiber, DESY

Pulse Trains

- 2 Pulse pickers, based on Pockels cells + polarizer → up to 1 MHz
- Pre-amplification (diodes) of 1.2 ms long train
- Power amplification with variable bunch pattern

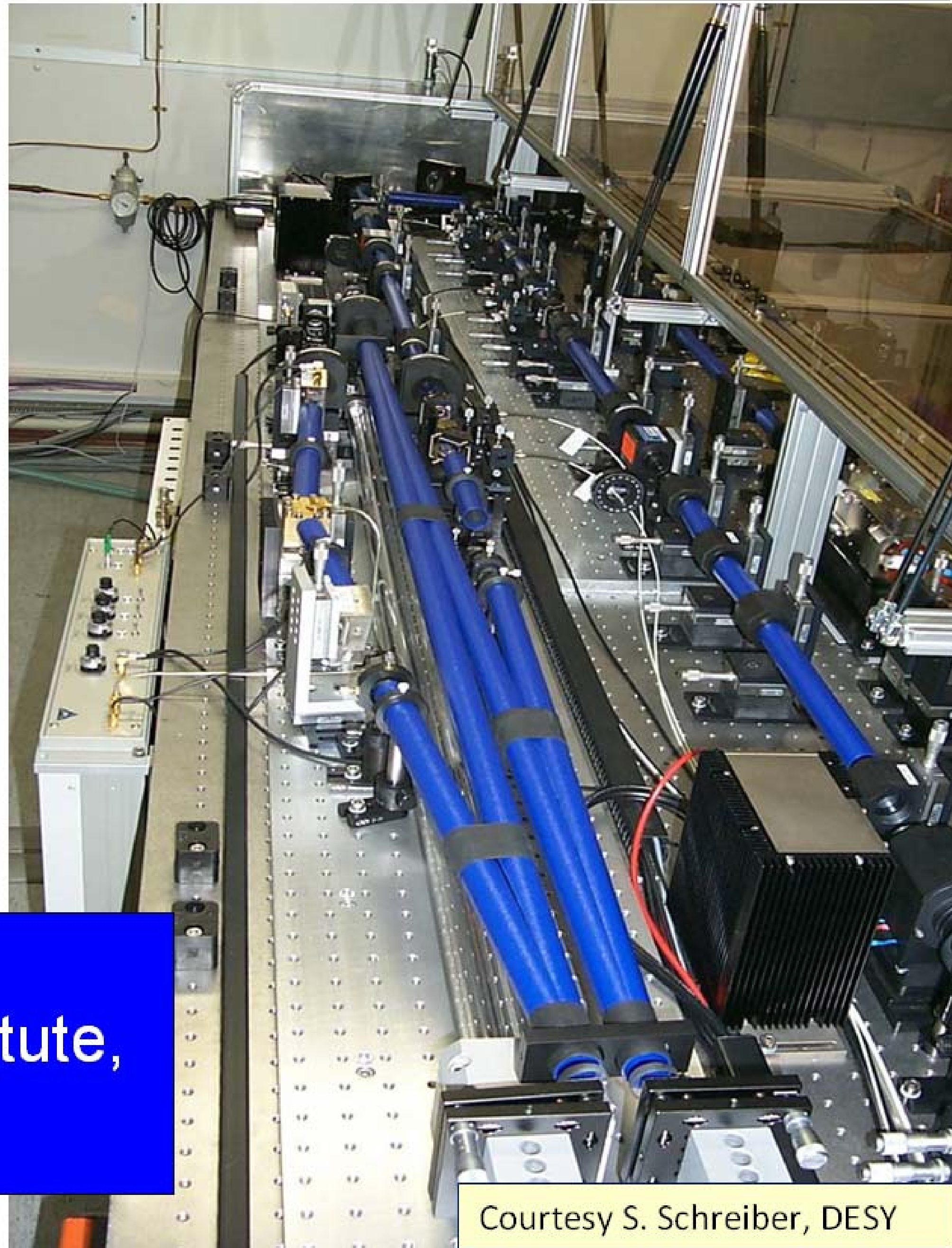


Courtesy S. Schreiber, DESY

Laser System

FLASH
Free-Electron Laser in Hamburg

- Nd:YLF based laser
- produces long pulse trains of up to 800 μs with up to 1 MHz
- laser system average power in the Watt range
- long trains require high QE cathodes (→ Cs_2Te)

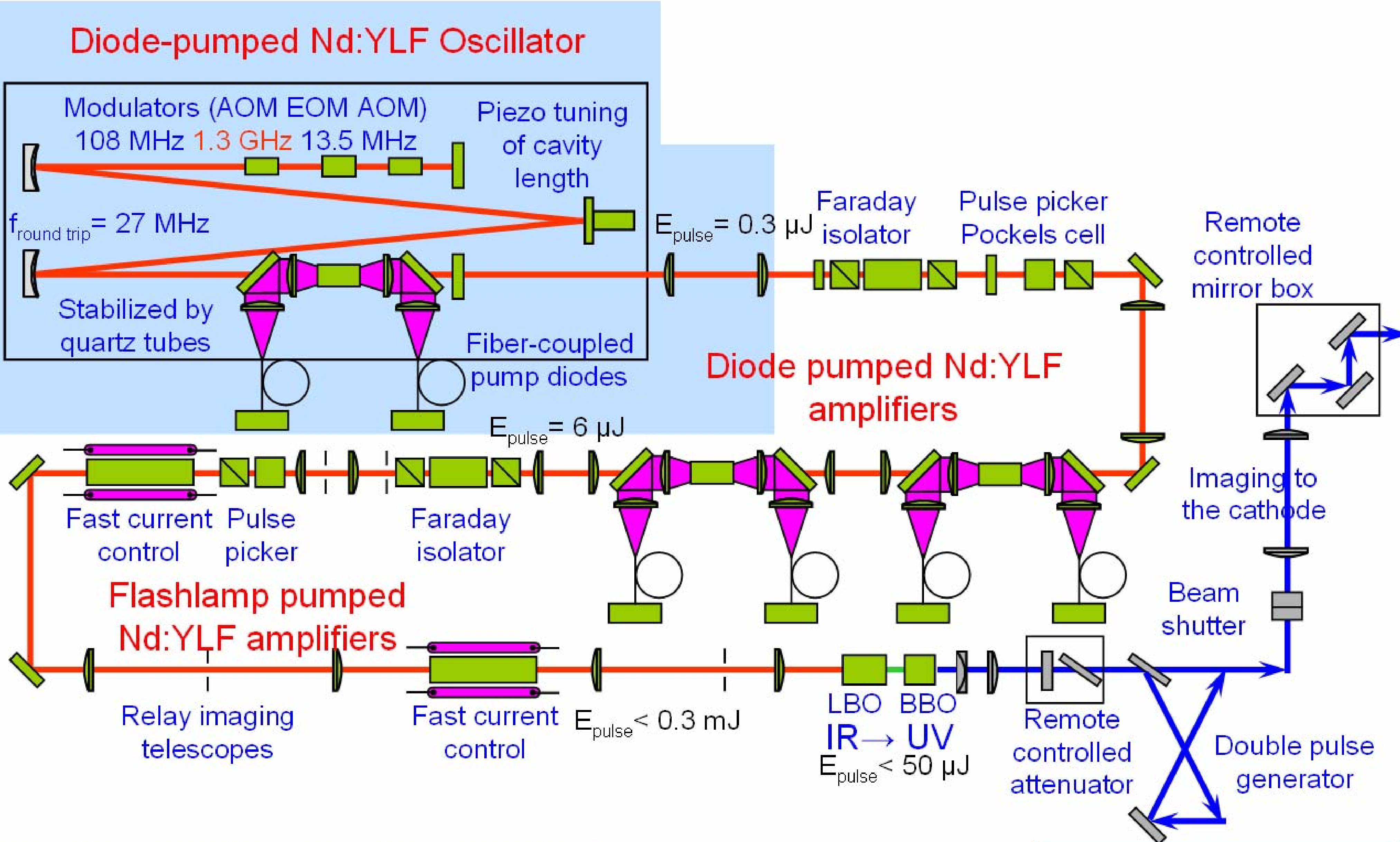


In cooperation
DESY / Max-Born Institute, Berlin

Courtesy S. Schreiber, DESY

Laser System Overview

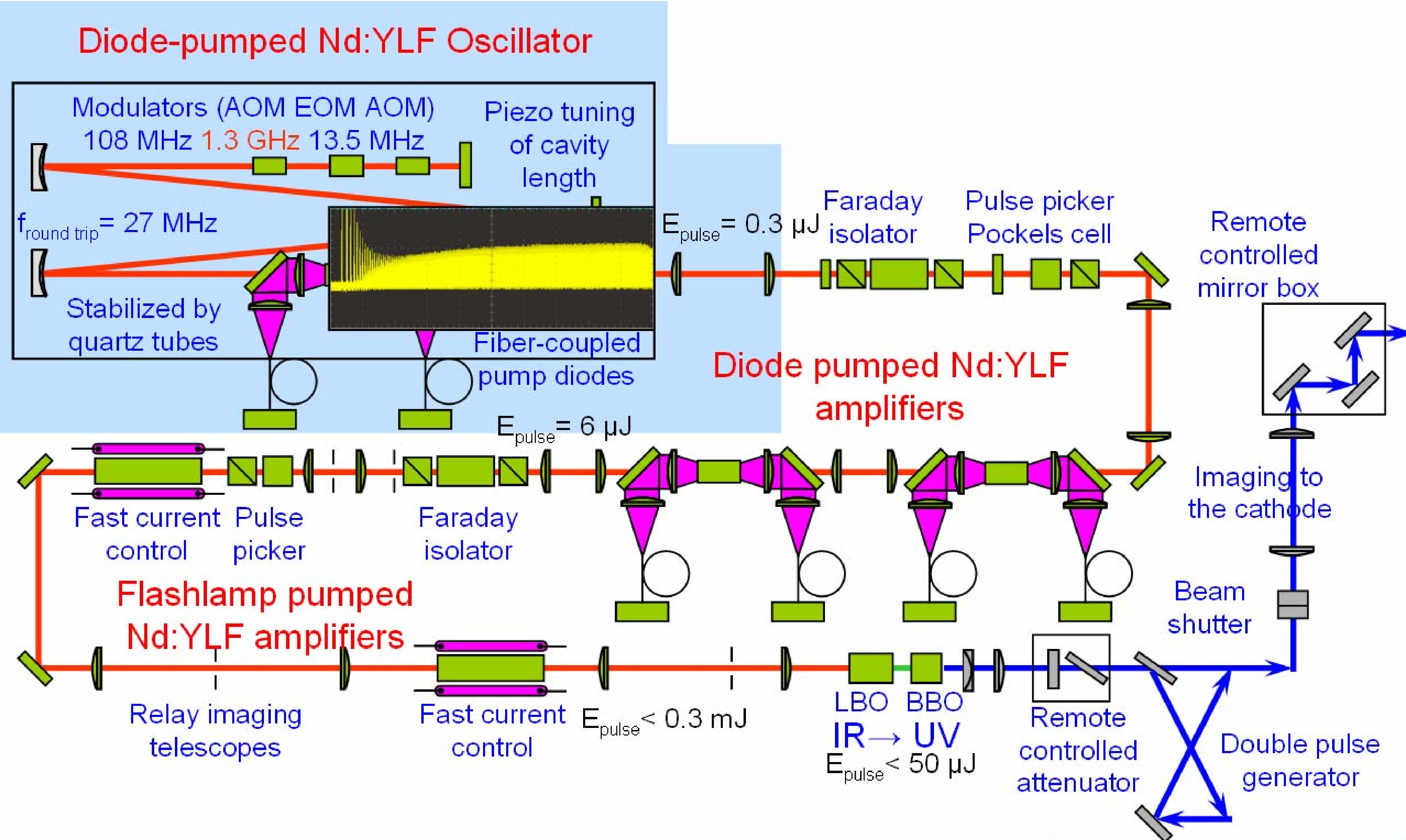
FLASH
Free-Electron Laser in Hamburg



Courtesy S. Schreiber, DESY

Laser System Overview

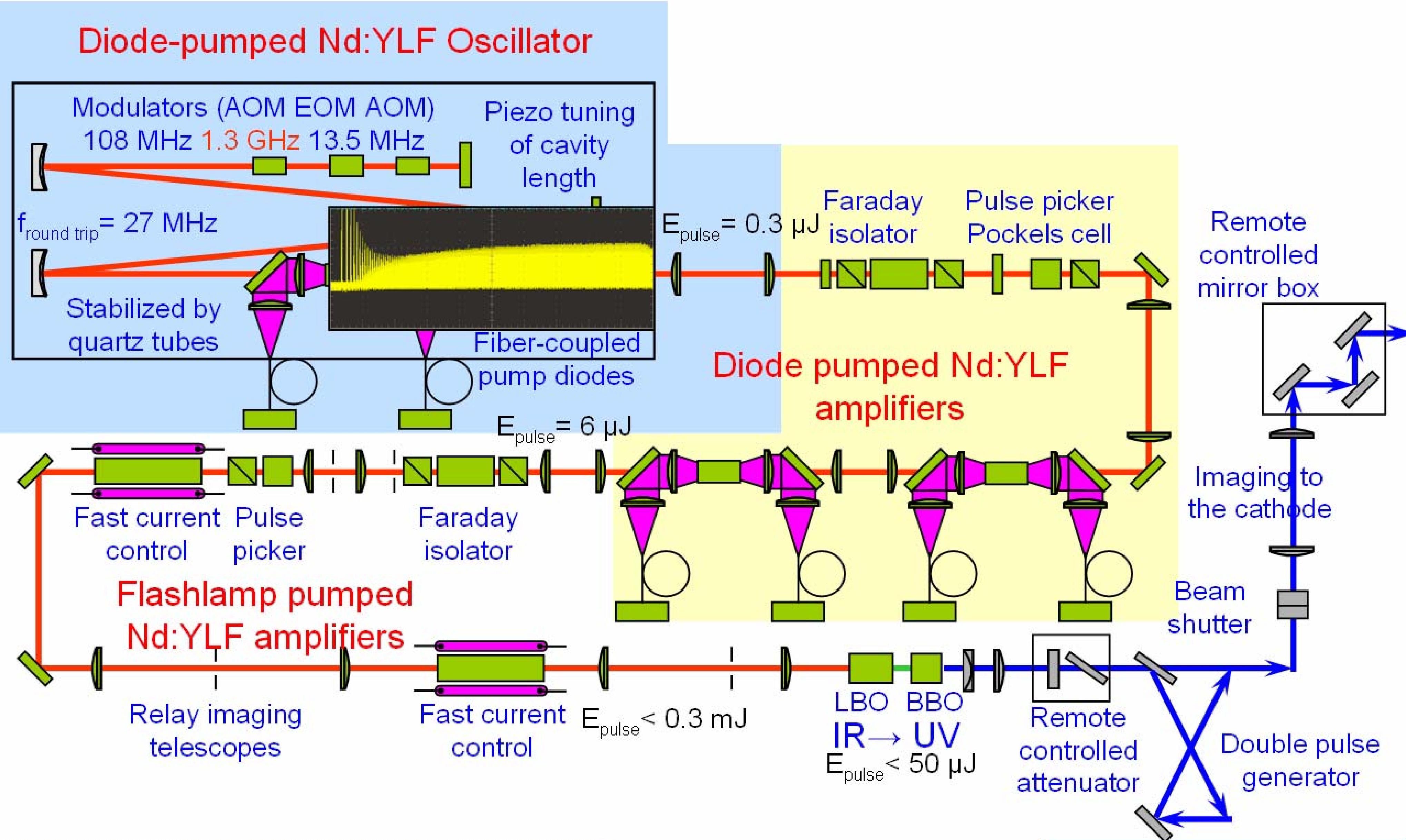
FLASH
Free-Electron Laser in Hamburg



Courtesy S. Schreiber, DESY

Laser System Overview

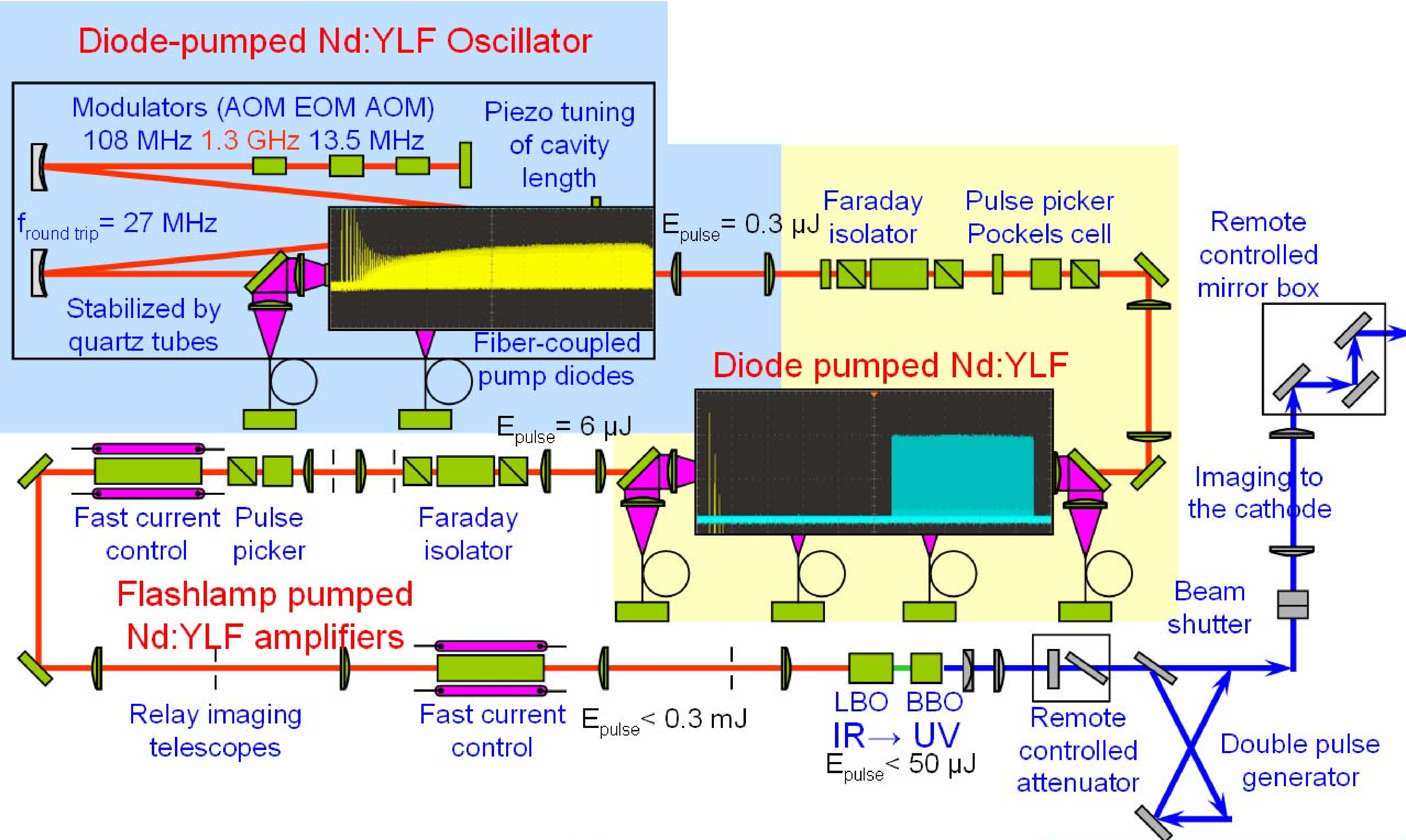
FLASH
Free-Electron Laser in Hamburg



Courtesy S. Schreiber, DESY

Laser System Overview

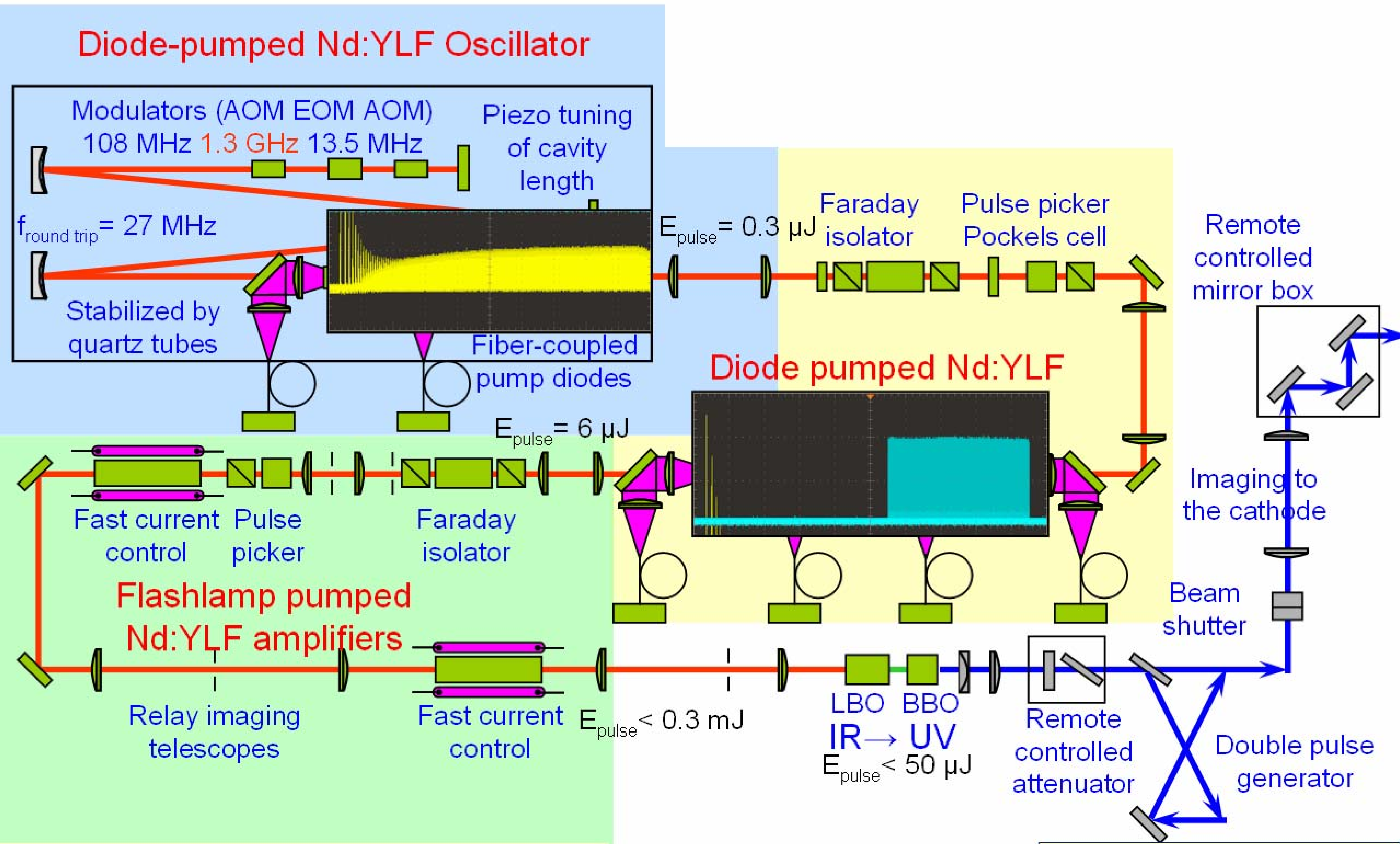
FLASH
Free-Electron Laser in Hamburg



Paolo Michelato, EPAC08, Genoa, June 23, 2008.

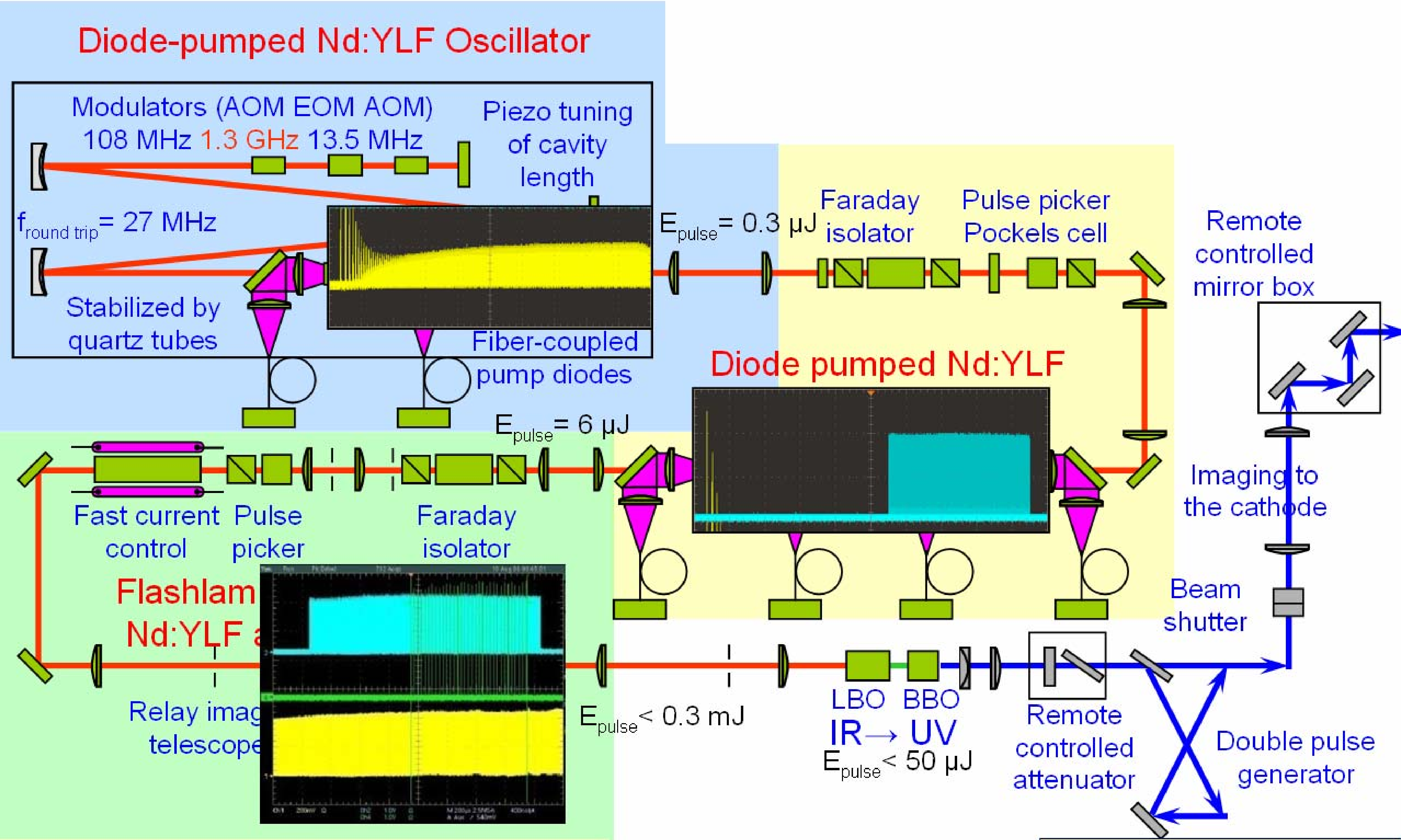
Courtesy S. Schreiber, DESY

Laser System Overview



Courtesy S. Schreiber, DESY

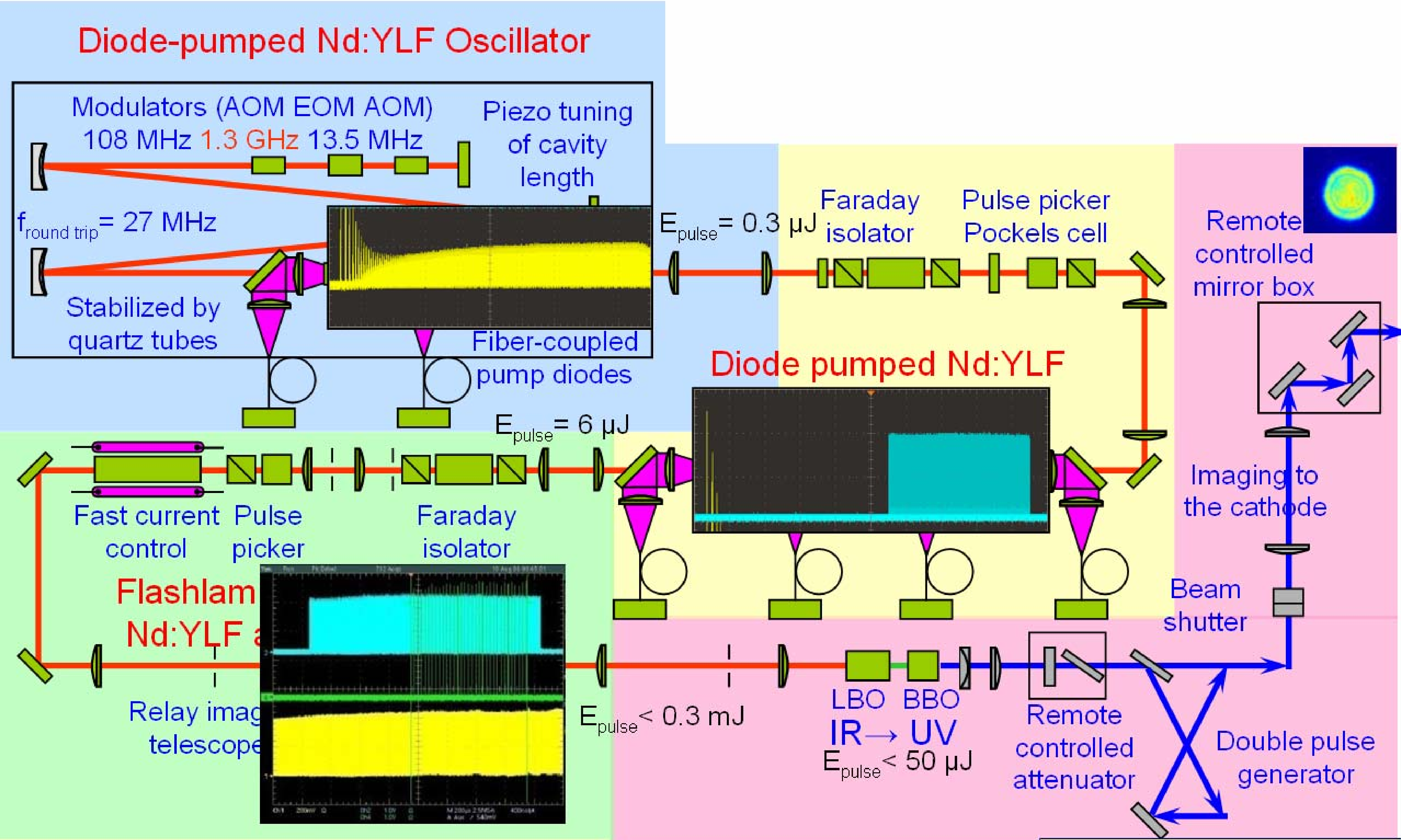
Laser System Overview



Paolo Michelato, EPAC08, Genoa, June 23, 2008.

Courtesy S. Schreiber, DESY

Laser System Overview



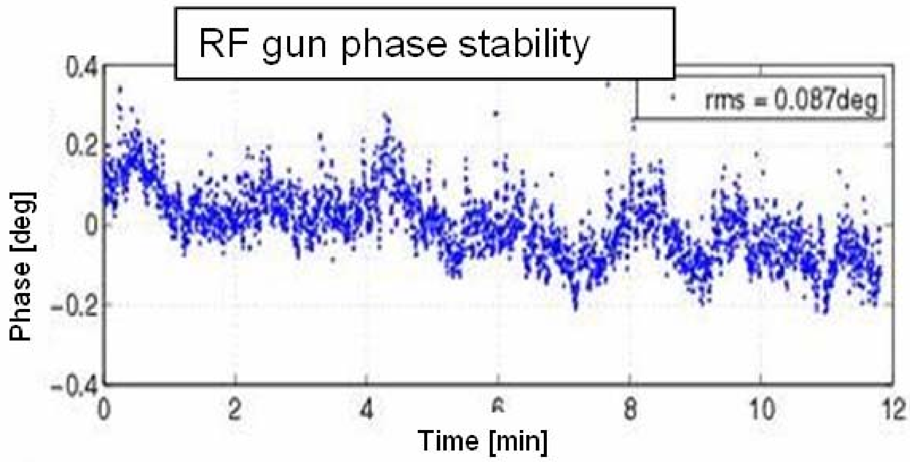
Paolo Michelato, EPAC08, Genoa, June 23, 2008.

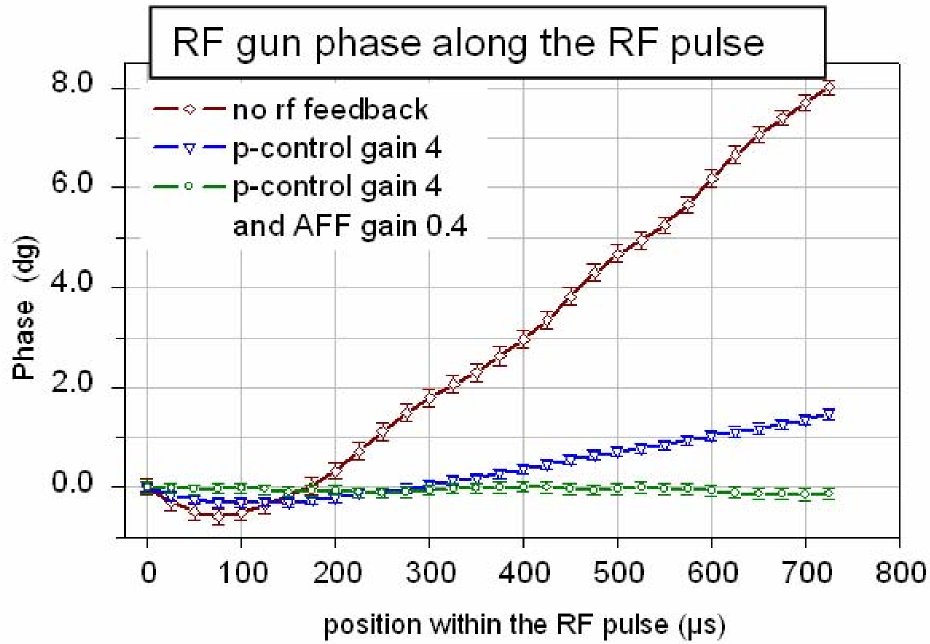
Courtesy S. Schreiber, DESY

RF-Gun Phase Stability

FLASH
Free-Electron Laser in Hamburg

- RF Gun has no probes → vector sum of forward and reflected power
- llrf system based on FPGA, p-control and adaptive feedforward, latency 150 ns
- RF gun phase stability: 0.1 deg (rms) @ 1.3 GHz
  - peak-to-peak stability: 0.4 deg, measured with beam at small phases

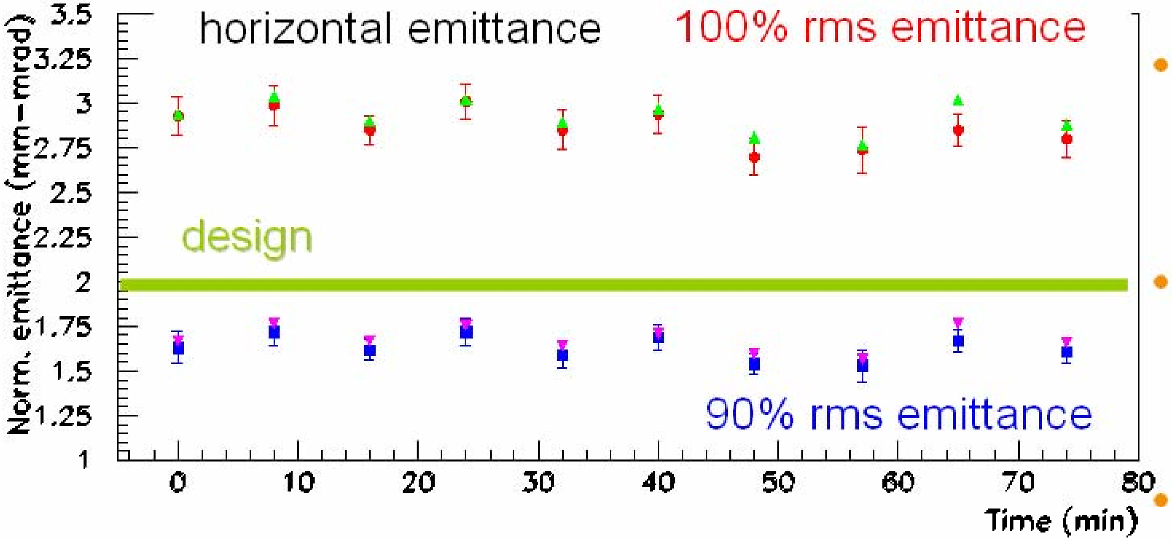


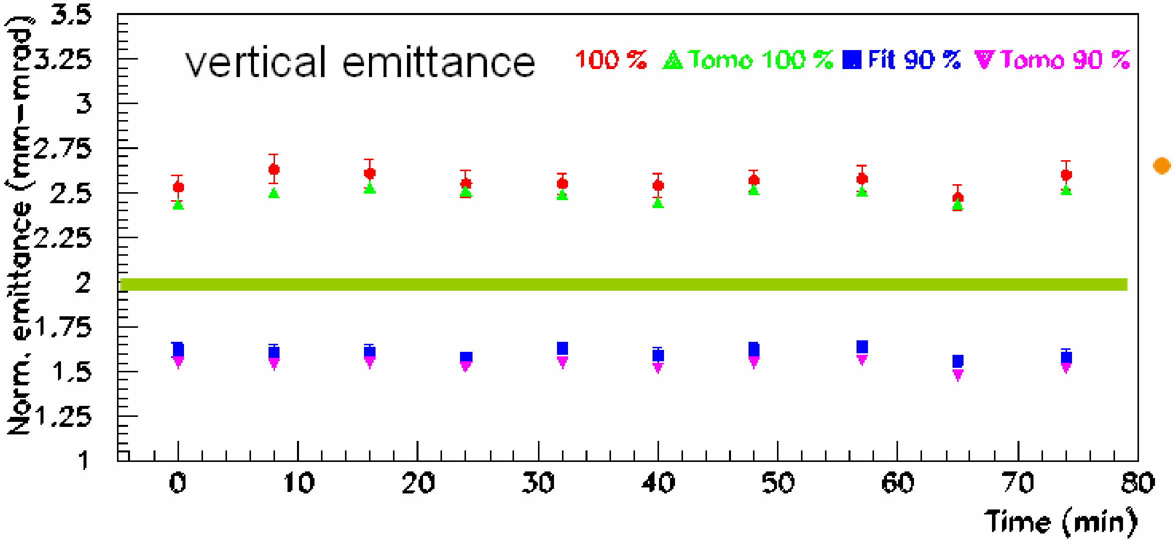


Courtesy S. Schreiber, DESY

Transverse Projected Emittance

FLASH
Free-Electron Laser in Hamburg





- Continuous measurements of the emittance during a period of ~1.5 hours (1 nC, 127 MeV)
- In this example, the projected normalized 90% rms emittance is 1.6 mm mrad
- Jitter 2 - 3 % (rms)

  → jitter agrees with the statistical error
- **lasing slice emittance in the undulator estimated to be 1 to 1.5 mm mrad**

Courtesy S. Schreiber, DESY

The PITZ collaboration

- DESY, Zeuthen and Hamburg
- BESSY, Berlin
- CCLRC, Daresbury
- INFN – LASA, Milano
- INFN – LNF, Frascati
- INR, Troitsk
- INRNE, Sofia
- LAL Orsay
- MBI, Berlin
- TU, Darmstadt
- Uni, Hamburg
- YERPHI, Yerevan

PITZ: Photo Injector Test Facility in DESY Zeuthen

PITZ layout (until August 2007)

This setup was used for the measurements in 2006 / 2007:

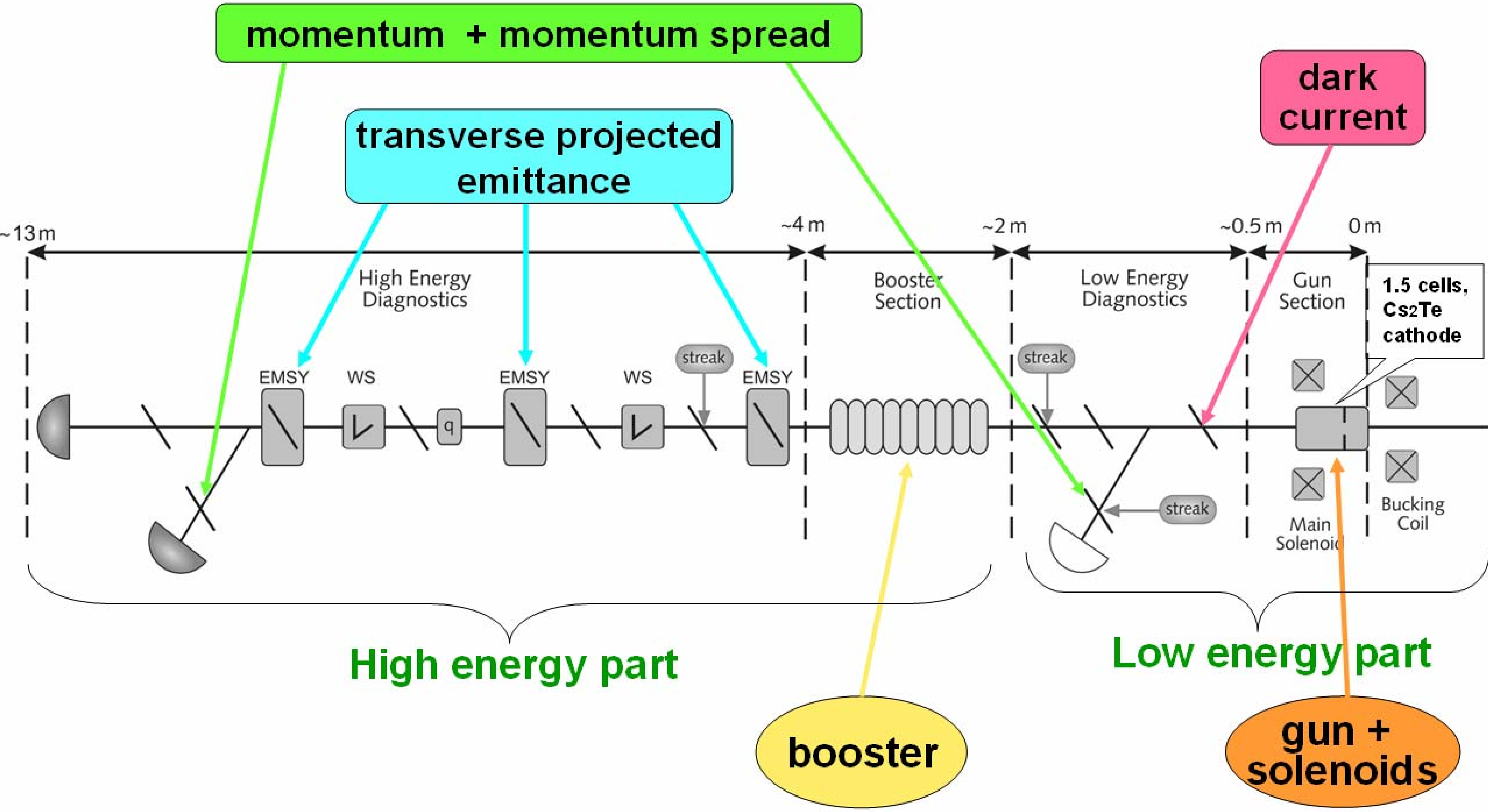
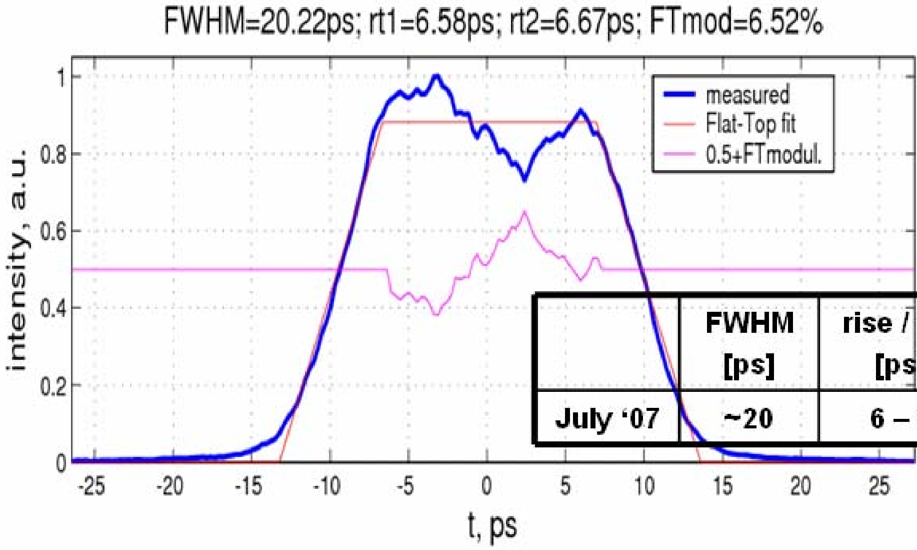


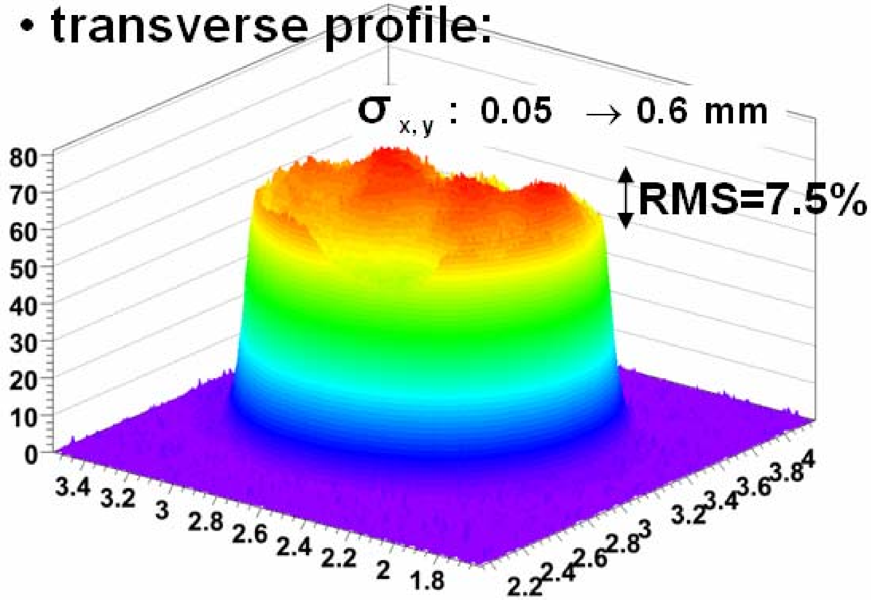
Photo cathode laser properties

• longitudinal profile:

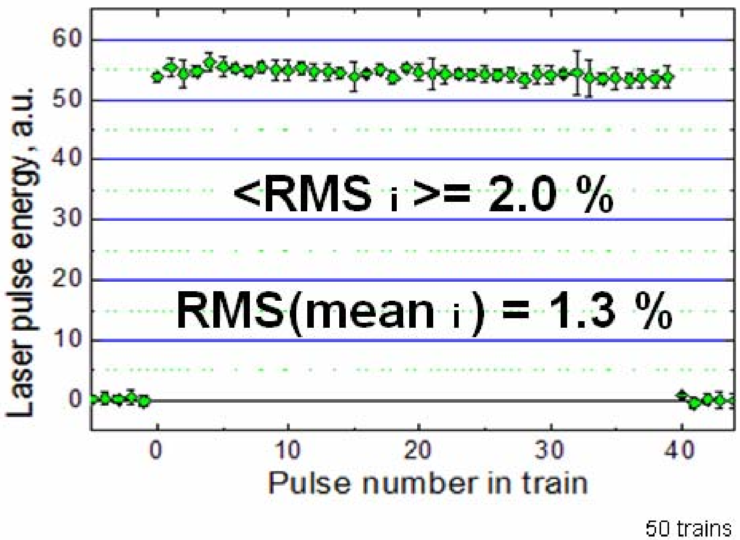


	FWHM [ps]	rise / fall [ps]	RMS [mm]
July '07	~20	6 – 8	~0.35

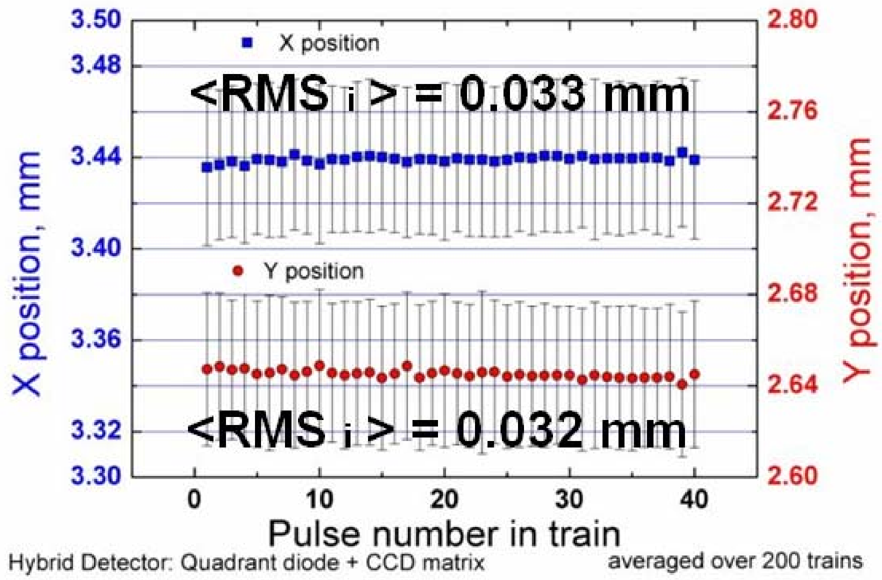
• transverse profile:



• energy stability:



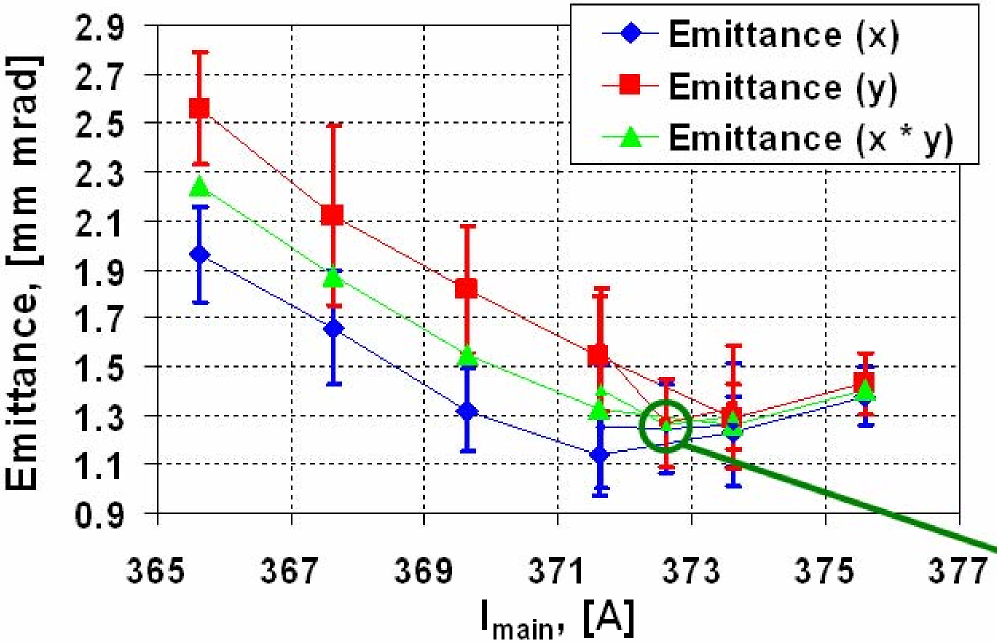
• pointing stability:



Courtesy F. Stephan, DESY PITZ

Emittance @1 nC, high gradient operation

(summer 2007)



→ in the minimum we obtained

$$\varepsilon_{x,n} = 1.25 \pm 0.19 \text{ mm mrad}$$

$$\varepsilon_{y,n} = 1.27 \pm 0.18 \text{ mm mrad}$$

@1nC

for 100 % RMS emittance !

→ ASTRA prediction:

$$\varepsilon_{x,y,n} = 1.28 \text{ mm mrad}$$

Cathode: # 90.1

Gun gradient: ~60 MV/m

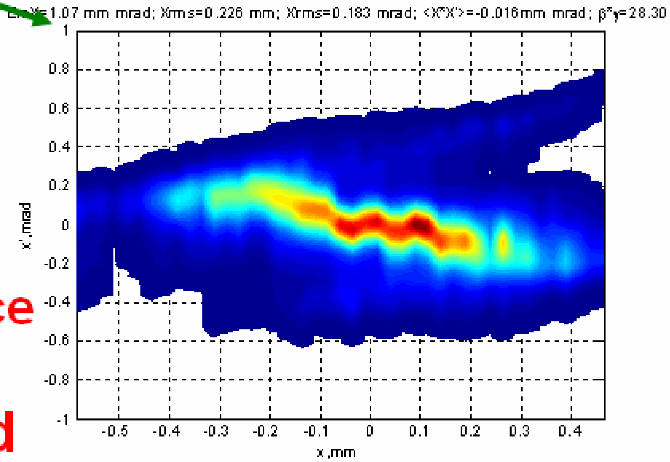
Gun phase: $\Phi^{gun} = \Phi^{gun}_{ref}$

Momentum from gun: ~6.44 MeV/c

Booster phase: $\Phi^{booster} = \Phi^{booster}_{ref}$

Total beam momentum: 14.5 MeV/c

x-x‘ phase space:



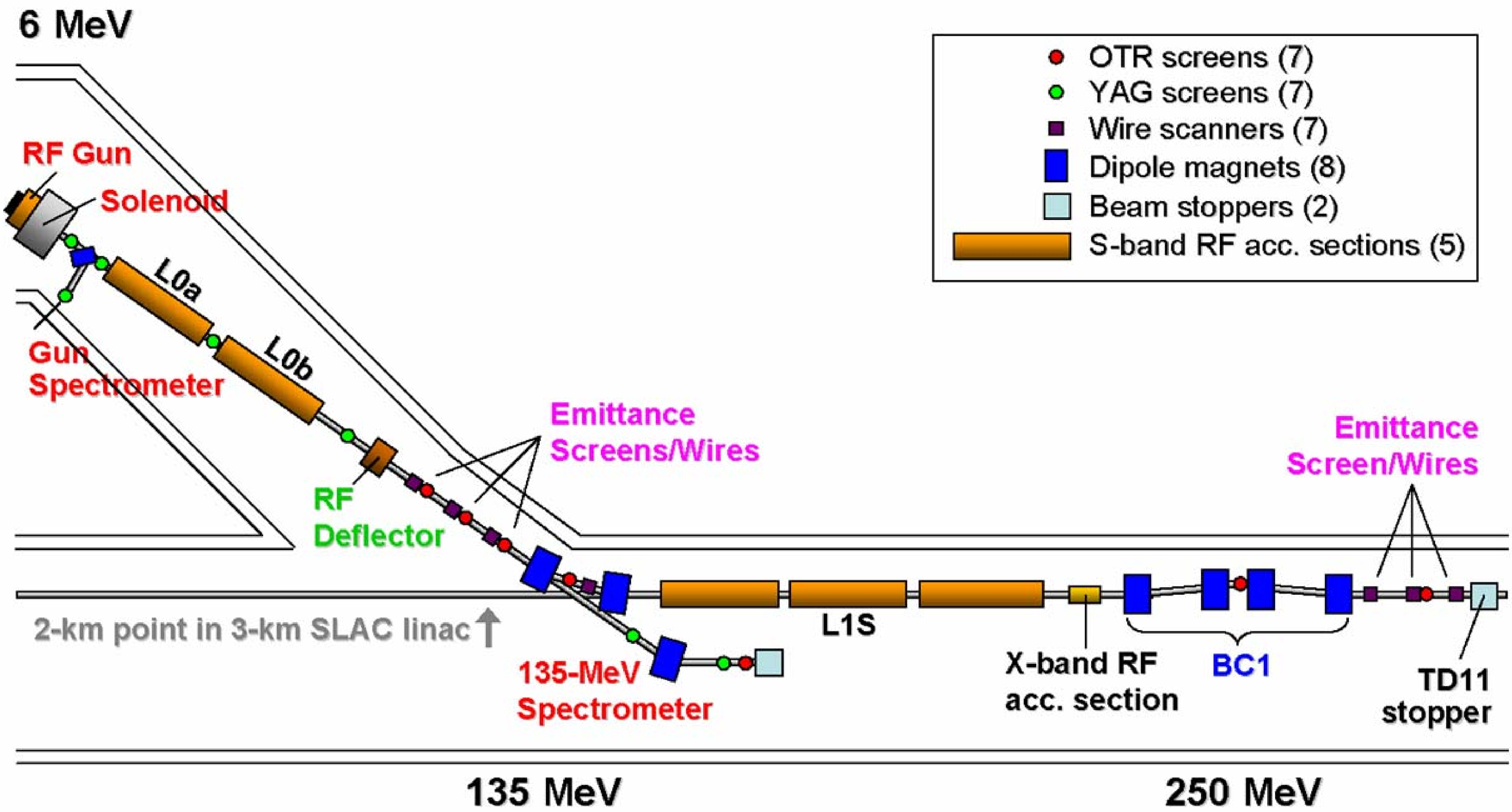
With a cut at 5% of maximum measured phase space density (remove non-lasing electrons)
→ normalized projected emittance = **~0.8 mm mrad**

→ first demonstration of beam quality required for European XFEL

S-band gun

- Short RF pulse (μs)
- Rep. rate: up to hundreds of Hz
- High peak field (> 100 MV/m)
- Usually with metal cathode (Cu)

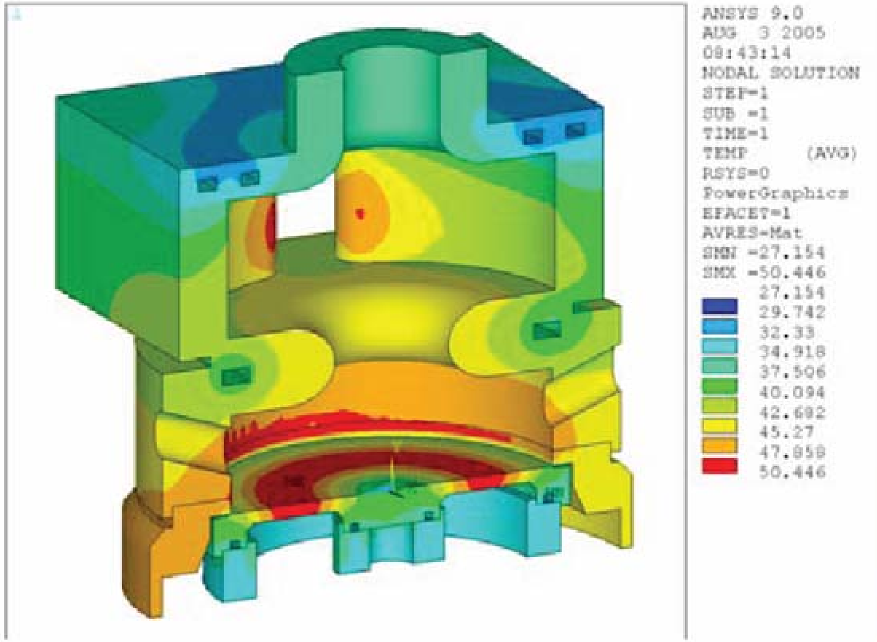
LCLS Injector Layout



Courtesy D. H. Dowell, SLAC

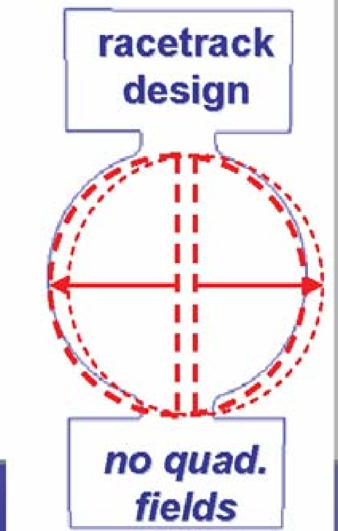
LCLS RF Photo-Cathode Gun

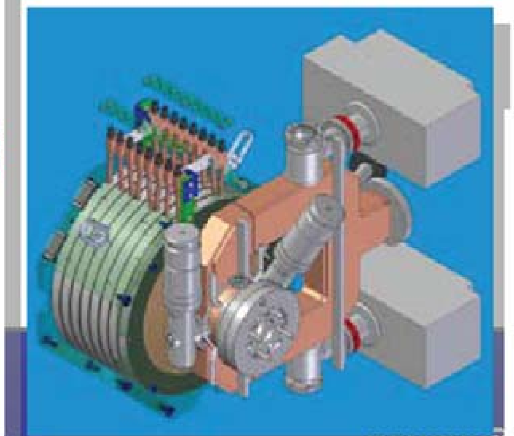
- 1.6-cell S-band (2856 MHz - *BNL/SLAC/UCLA*)
- Copper cathode
- 120-Hz repetition rate
- 140-MV/m cathode field (max)
- Axially symmetric RF fields
- 15 MHz 0-π mode separation
- Dual RF-feed
- Built at SLAC



ANSIS model of thermal profile

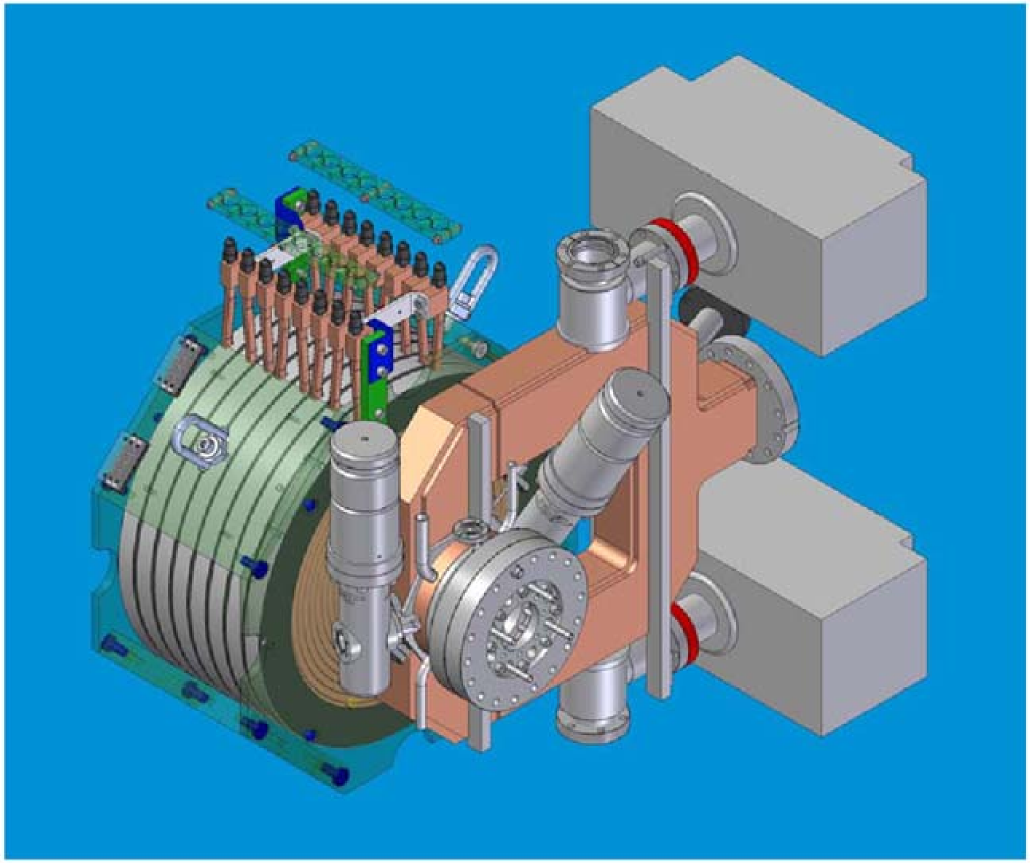
Courtesy D. H. Dowell, SLAC



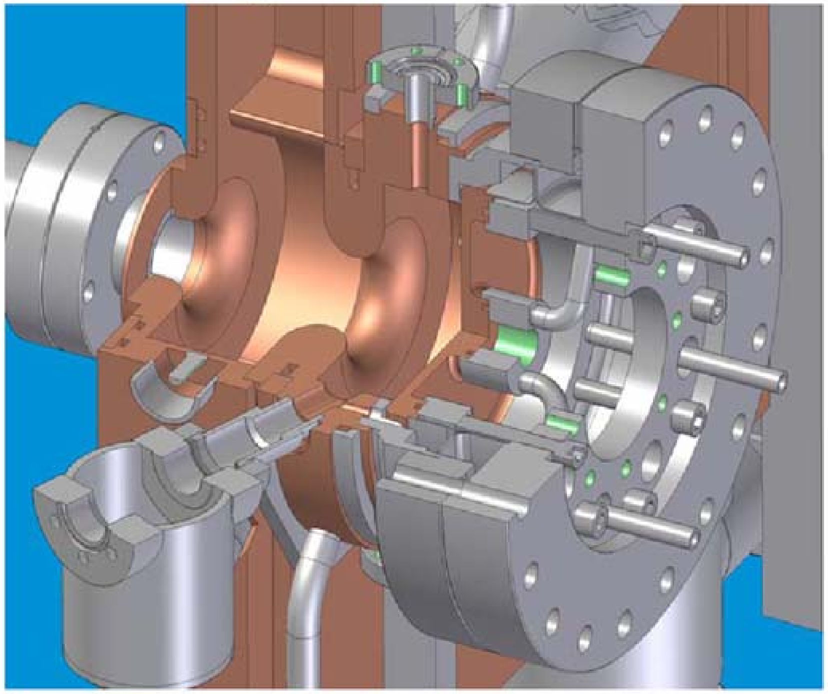


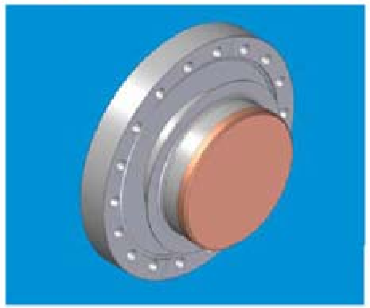
D. Dowell
V. Dolgashev
E. Jongewaard
B. Kirby
J. Lewandowsky
R.F. Boyce
C. Limborg
Z. Li
A. Vlieks
J. Schmerge
J. Wang
L. Xiao

Gun-Solenoid Assembly



Cut-away view of LCLS Gun



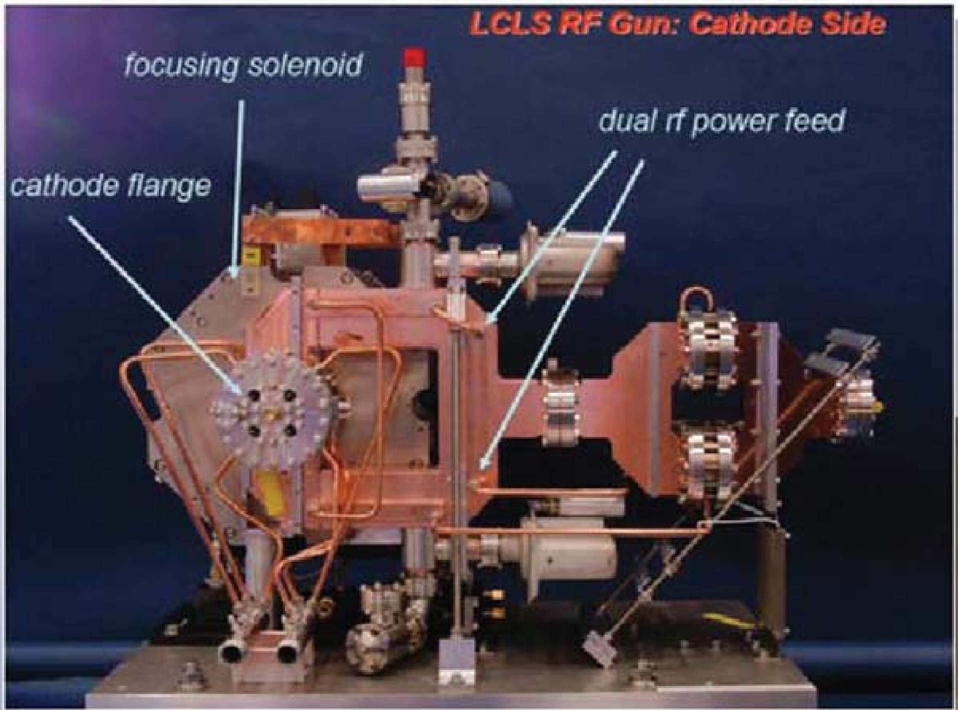


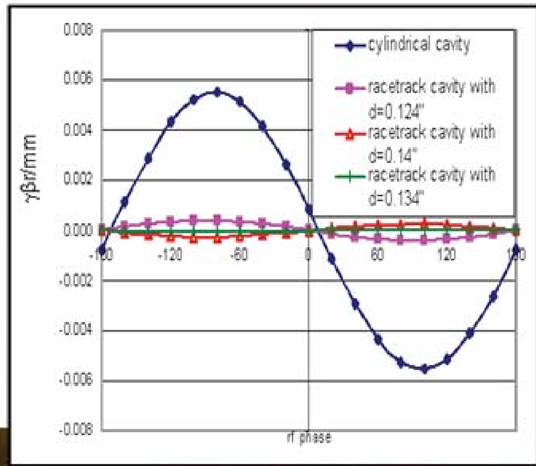
Cathode weld assembly

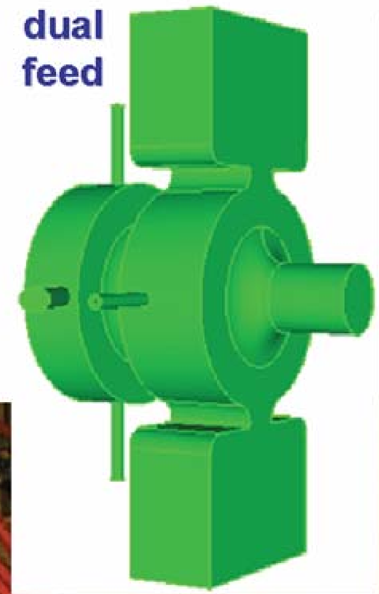
Compliments E. Jongewaard

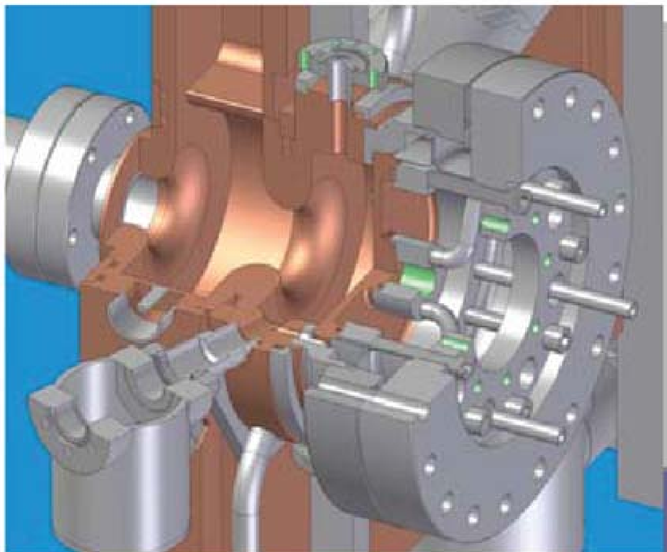
Courtesy D. H. Dowell, SLAC

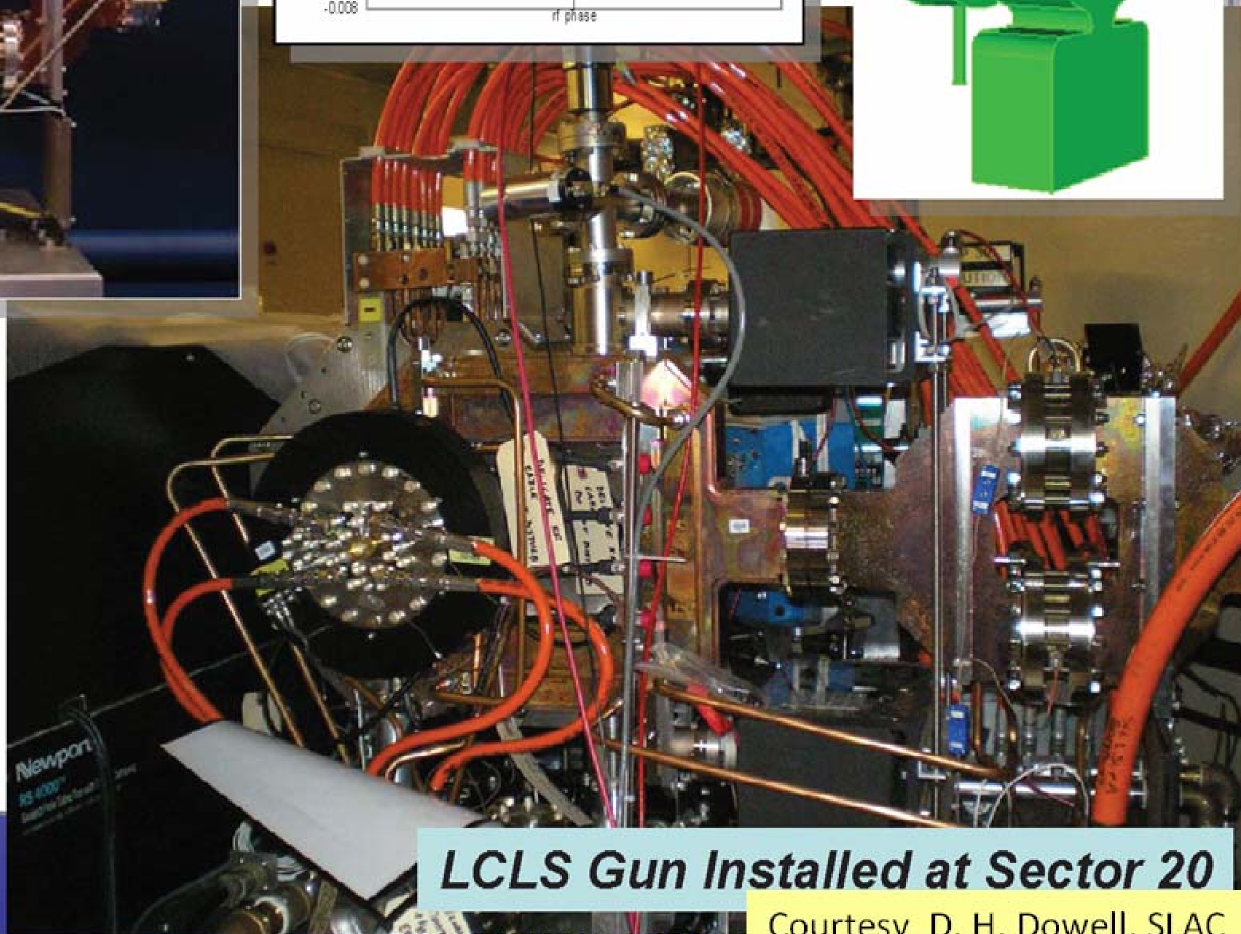
RF Gun1 Operating Since April 2007











Courtesy D. H. Dowell, SLAC

LCLS Gun Summary

- *Gun has operated reliably since April 2007*
- *Beam parameters meet the LCLS specifications*
  - *1.2 micron@1nC; 0.9micron@0.5nC*
- *Initial problem of low QE resolved with "active" and "passive" laser cleaning.*
  - *Produced non-uniform emission…acceptable for now*
- *Recent maintenance upgraded gun RF probes for 120 Hz operation*
- *Gun2 is completed and reserved as a spare.*

Courtesy D. H. Dowell, SLAC

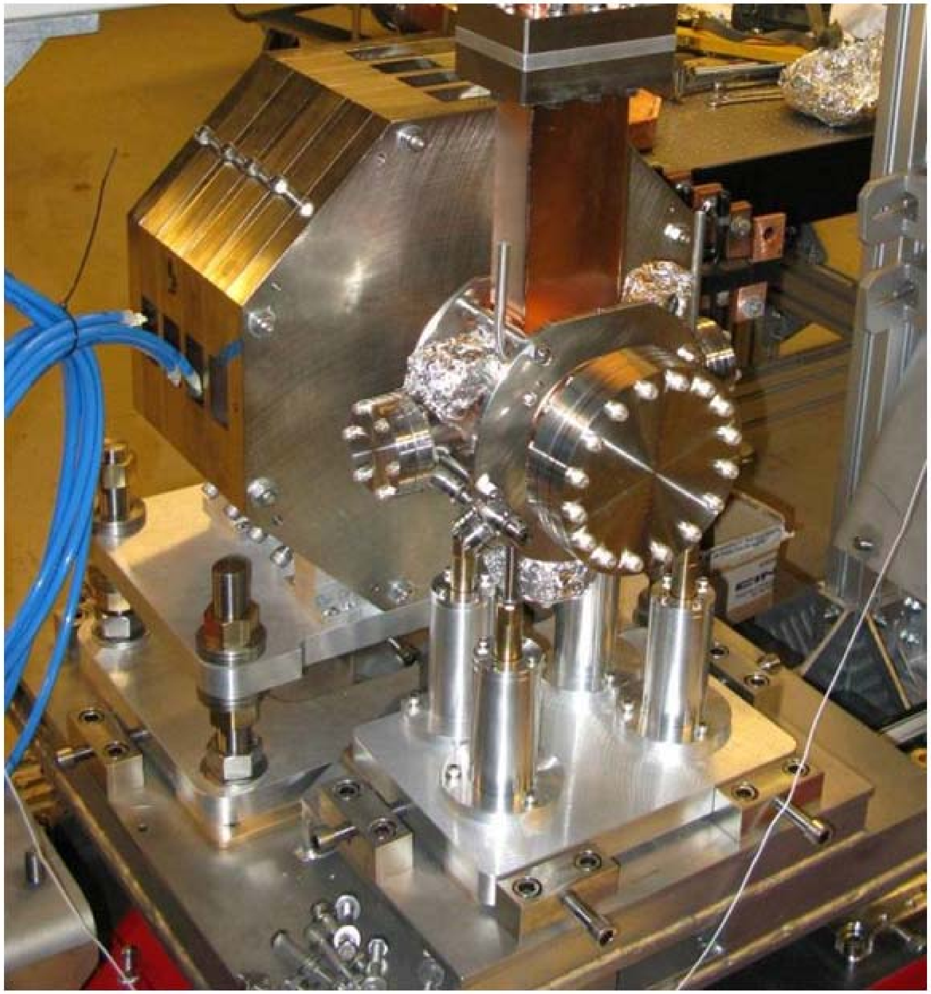
Design and Typical Measured Parameters

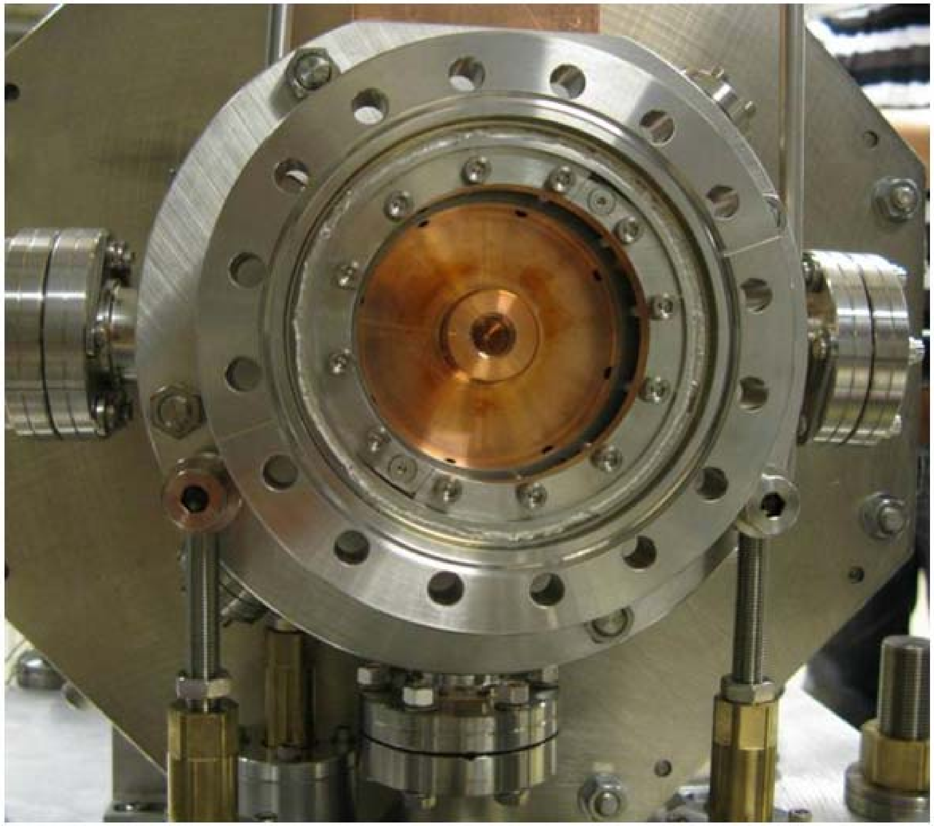
Parameter	sym	Design (1 nC)	measured (1.0 nC)	measured (0.25 nC)	unit
End of linac e^- energy	γmc^2	13.6	13.6	13.6	GeV
Init. bunch length (rms)	σ_{z0}	0.9	1.2	1.0	mm
Min. final bunch length (rms)	σ_{zf}	20	10	8	μm
Proj. norm. emittance* (inj.)	$\gamma\varepsilon_{x,y}$	1.2	1.2	1.0	μm
Proj. norm. emittance* (linac)	$\gamma\varepsilon^{L}{}_{x,y}$	1.5	2-6	1-2	μm
Slice norm. emittance* (inj.)	$\gamma\varepsilon^{s}{}_{x,y}$	1.0	0.9	0.8	μm
Slice energy spread (rms)	σ_E	<5	<10	<6	keV
Single bunch rep. rate	f	120	10-30	10-30	Hz
RF gun field at cathode	E_g	120	115	115	MV/m
Laser energy on cathode	u_l	250	300	70	μJ
Laser wavelength	λ_l	255	253	253	nm
Laser spot diam. on cathode	$2R$	2.0	1.6	1.2	mm
Cathode QE (pre Apr. '08)	QE	6	3.7	3.7	10^{-5}

Courtesy D. H. Dowell, SLAC

D. H. Dowell *et al.*
dowell@SLAC.Stanford.edu

Gun and cathode pictures

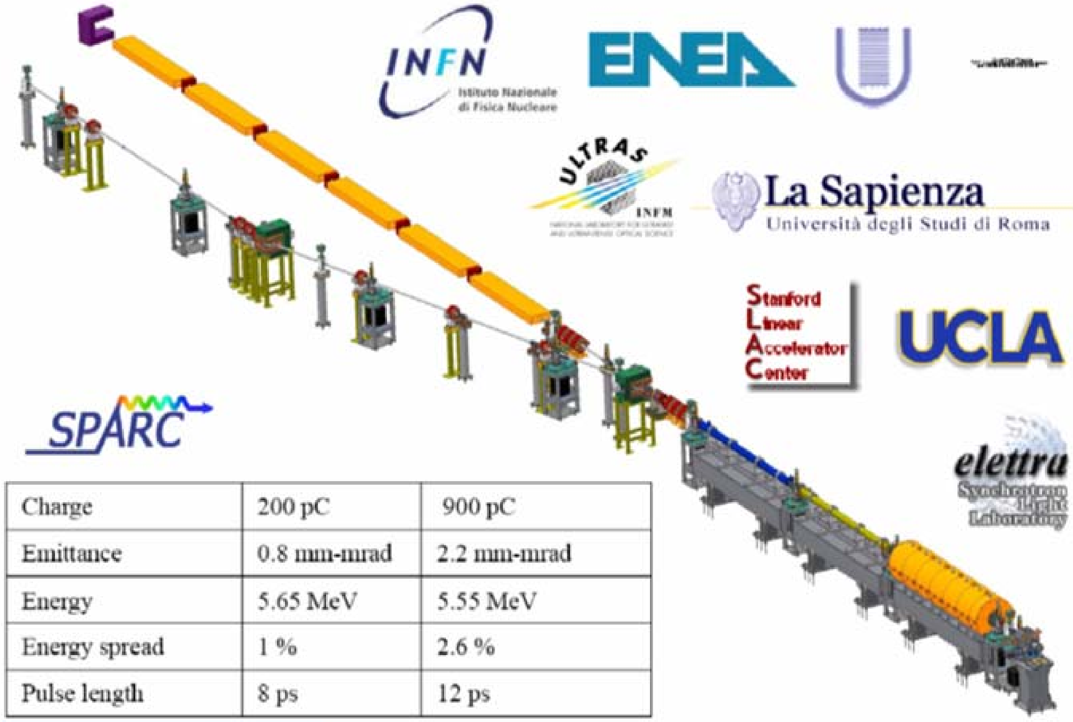




1.6 cell UCLA RF Gun

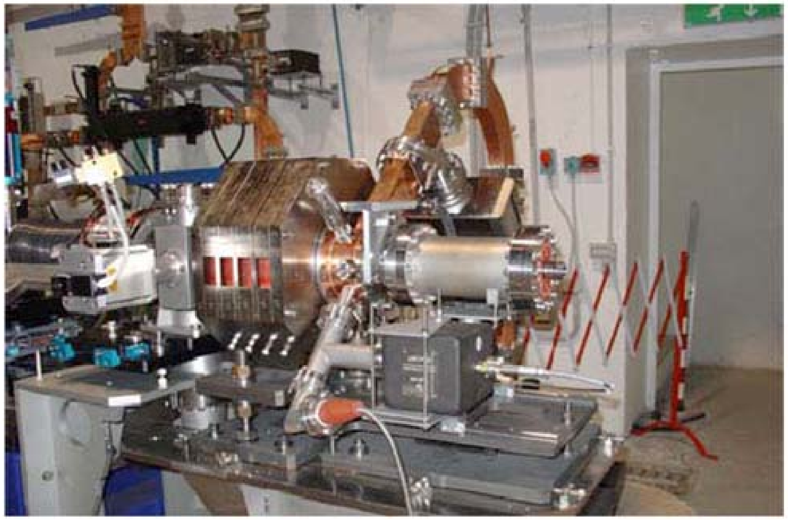
Courtesy G. Penco, FERMI Elettra

SPARC @ INFN - LNF

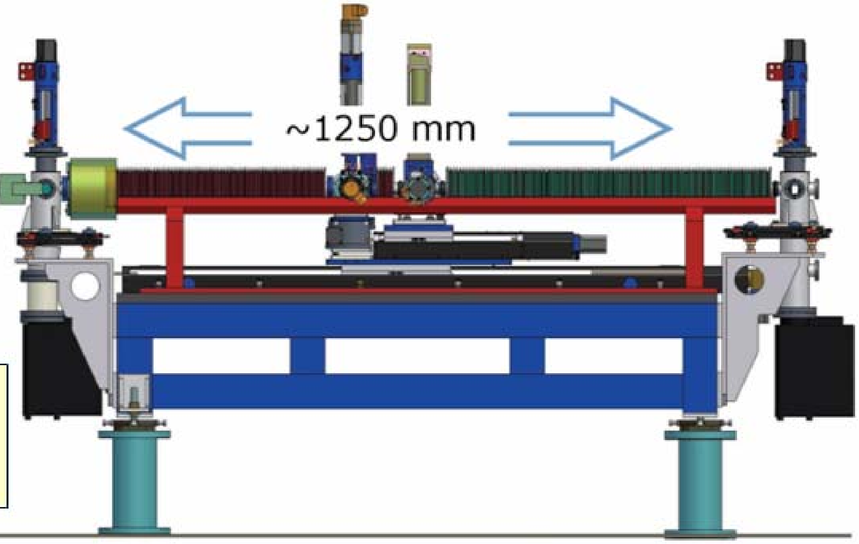


Charge	200 pC	900 pC
Emittance	0.8 mm-mrad	2.2 mm-mrad
Energy	5.65 MeV	5.55 MeV
Energy spread	1 %	2.6 %
Pulse length	8 ps	12 ps

M. Ferrario, EPAC06



UCLA/BNL/SLAC type RF gun

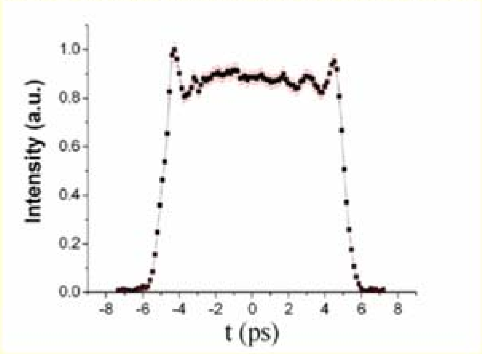


SPARC movable emittance meter

Ti:Sa system allows for impressive pulse shaping: Example: photocathode laser at SPARC

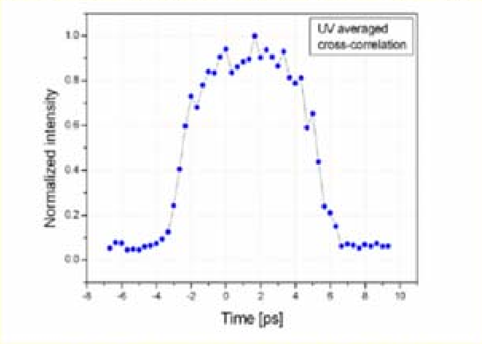
1. With a DAZZLER:

Time distribution at oscillator level



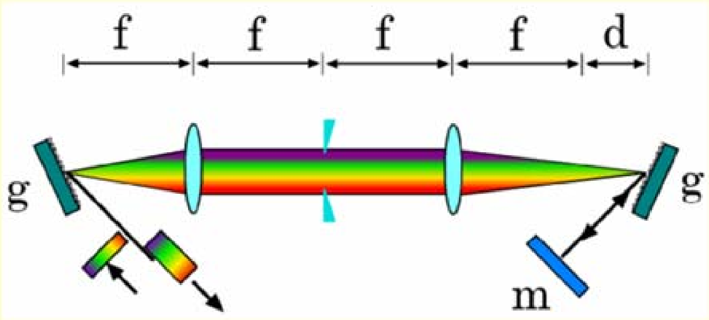
C. Vicario et al, EPAC04

Time distribution after the UV conversion

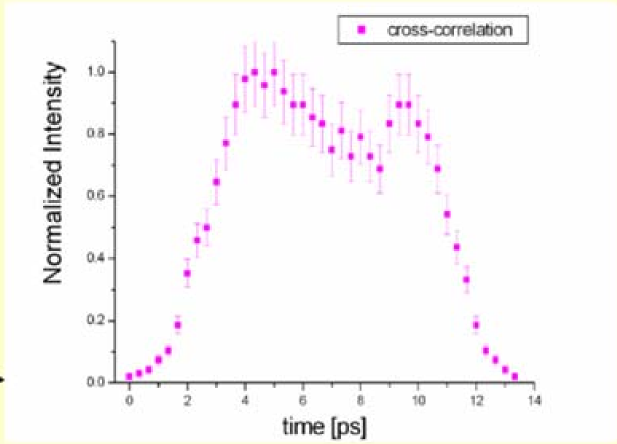


H. Loos et al, PAC05

2. With gratings:

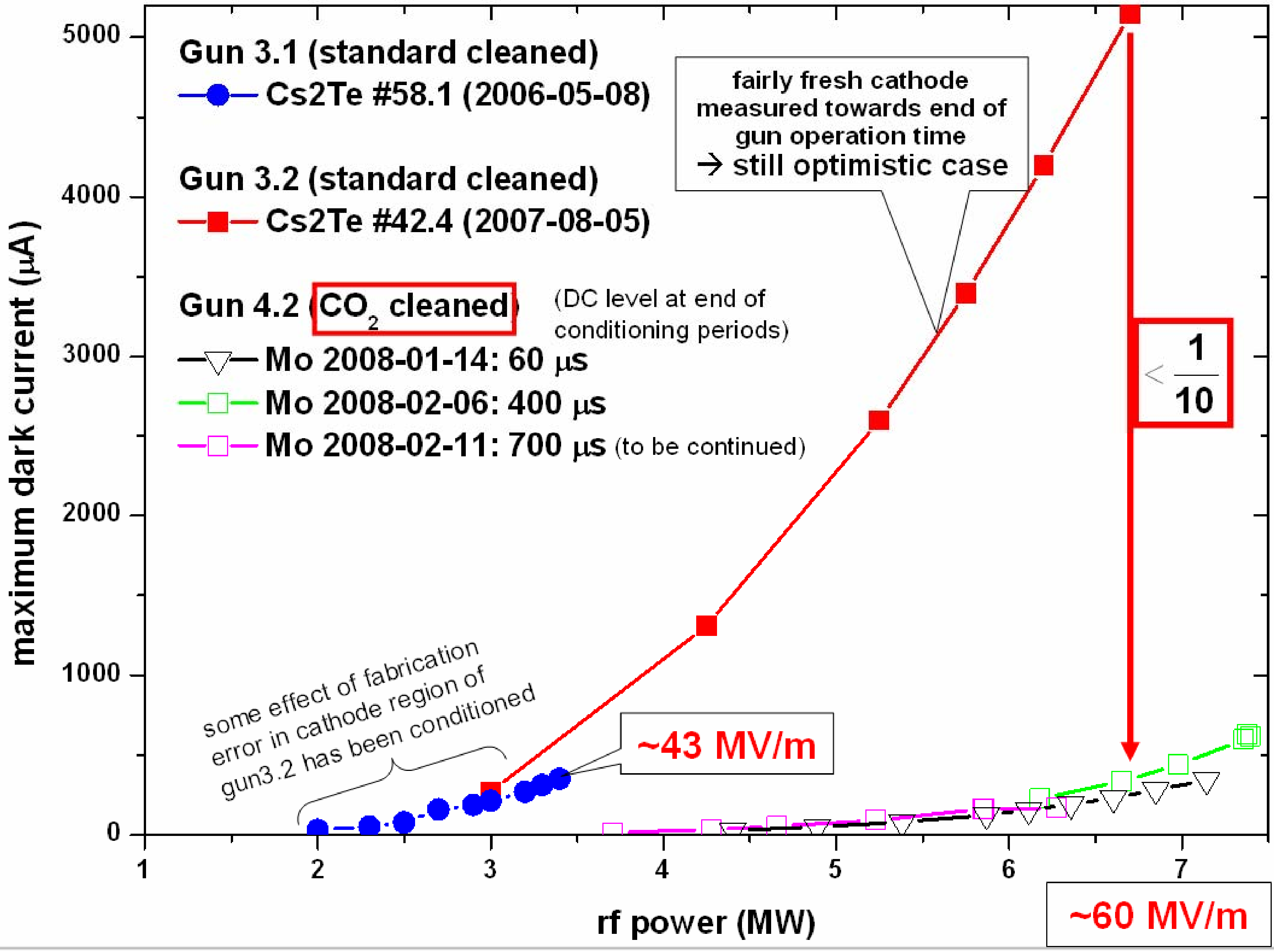


UV cross-correlation with 0.5 ps IR probe



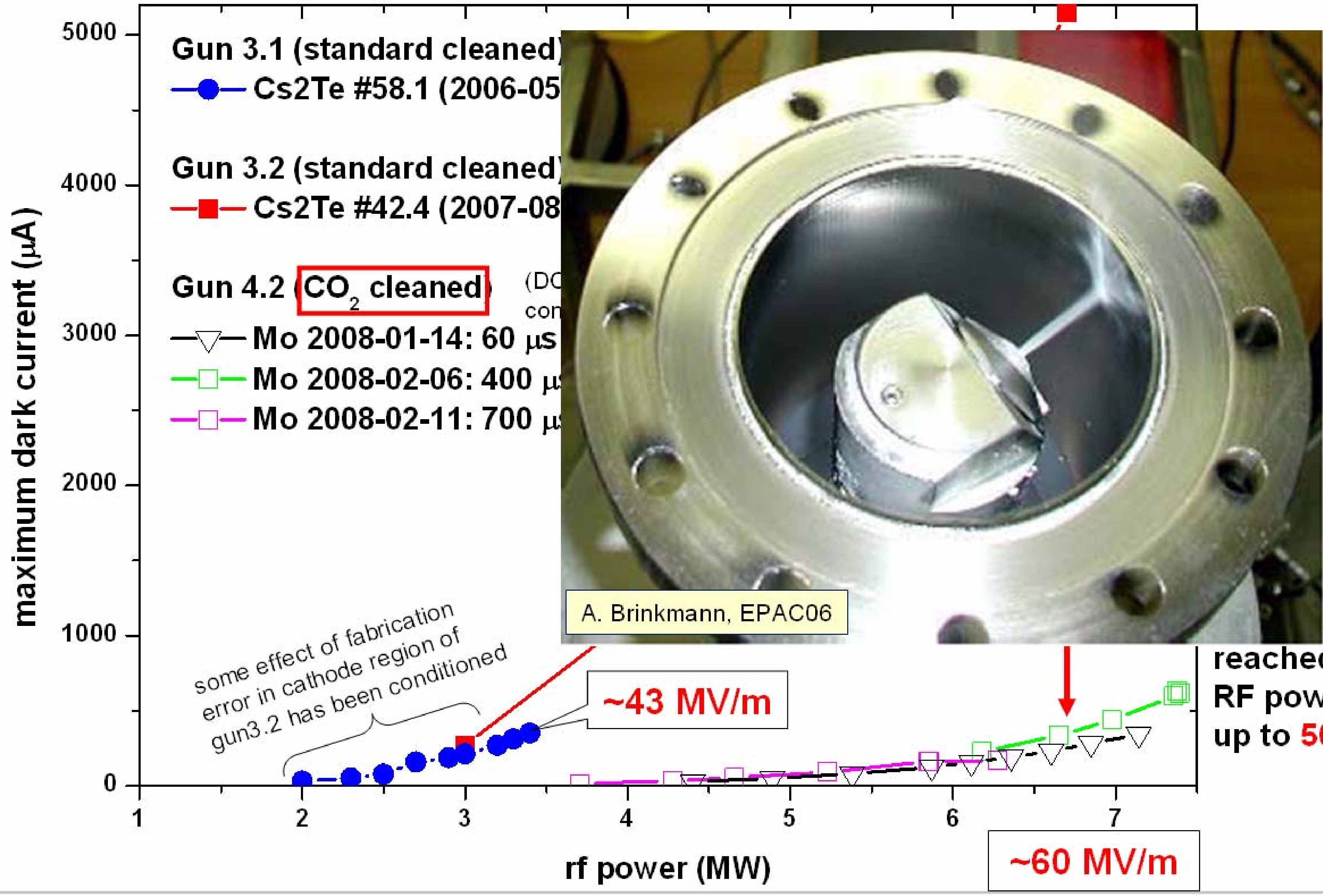
Taken from C.Vicario: Laser pulse shaping for high-brightness photoinjector CARE meeting, LNF, Nov15, 2006

L-band gun dark current



all operation at 10 Hz rep. rate
→ meawhile reached av. RF power up to 50 kW

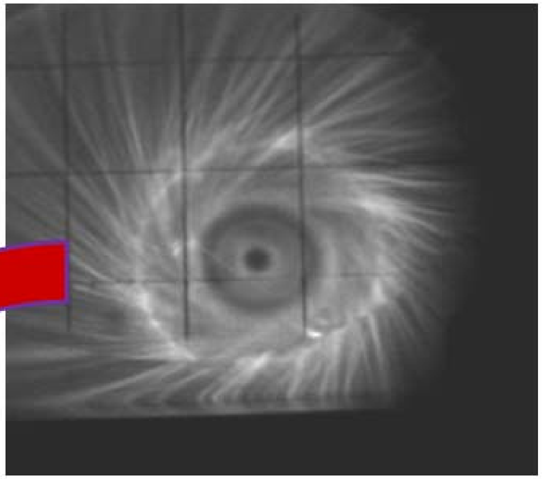
L-band gun dark current

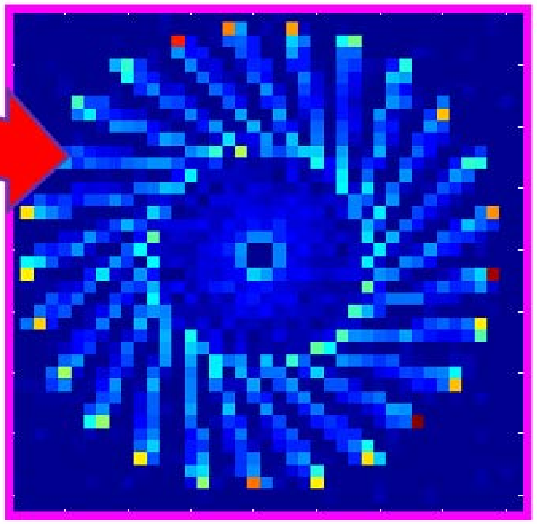


ration
z rep.

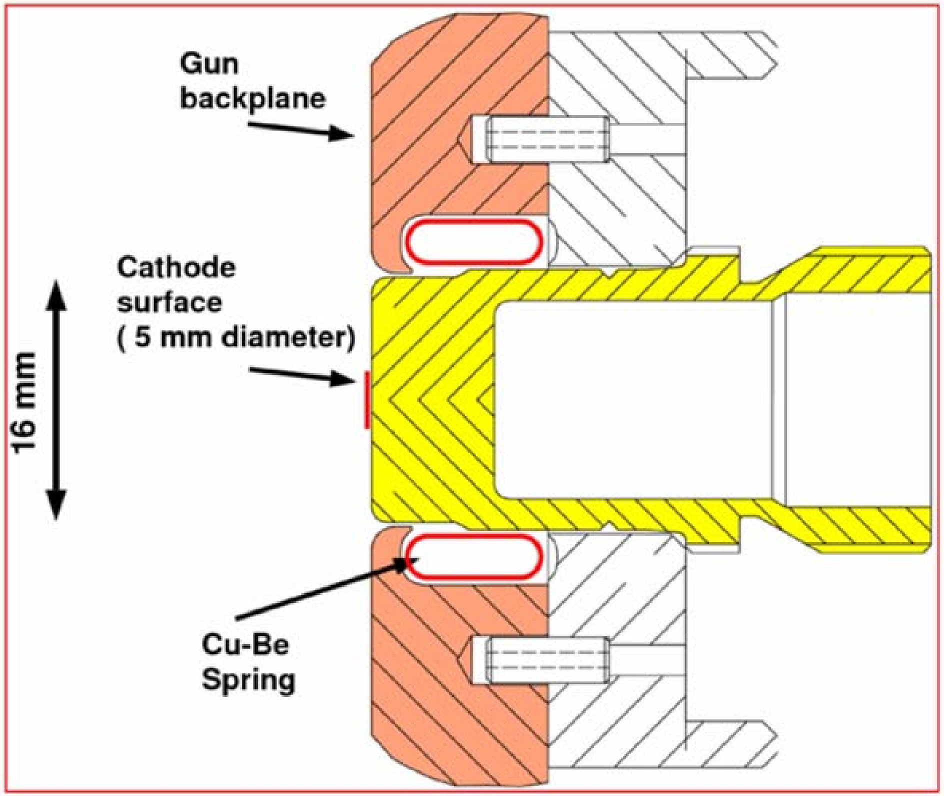
while
reached av.
RF power
up to 50 kW

FLASH/PITZ RF L-Band gun: dark current investigation





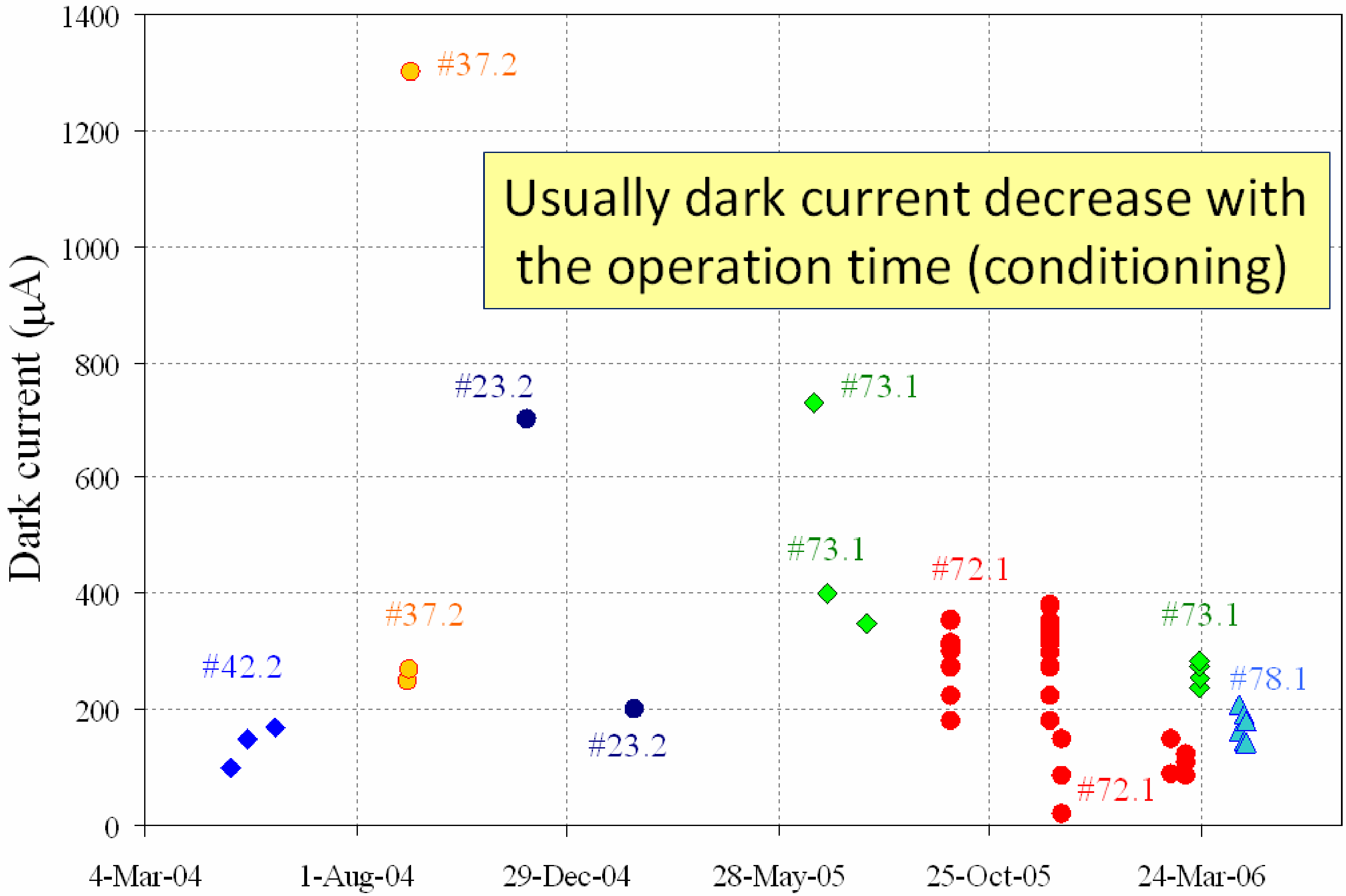
Simple model using ASTRA code



Gun backplane, cathode and RF Cu Be contact spring

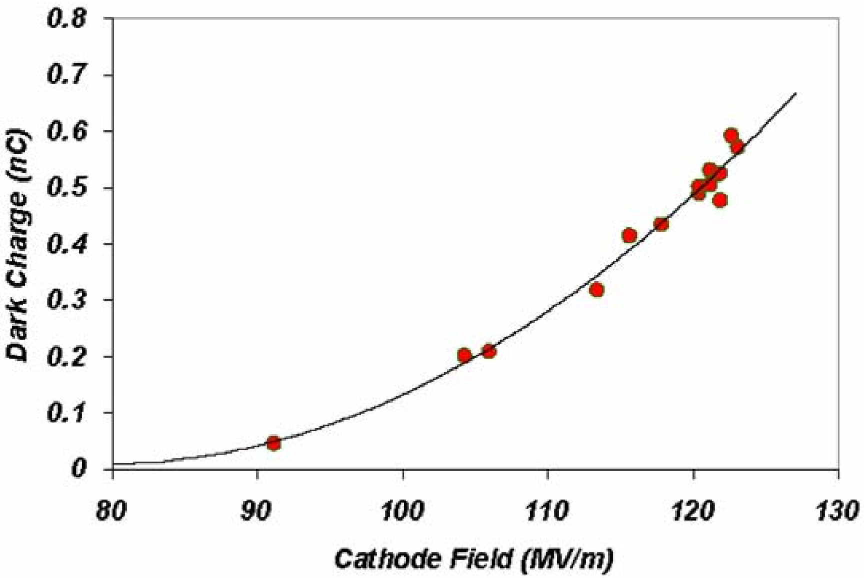
L. Monaco, EPAC06

FLASH/PITZ RF gun: dark current statistics

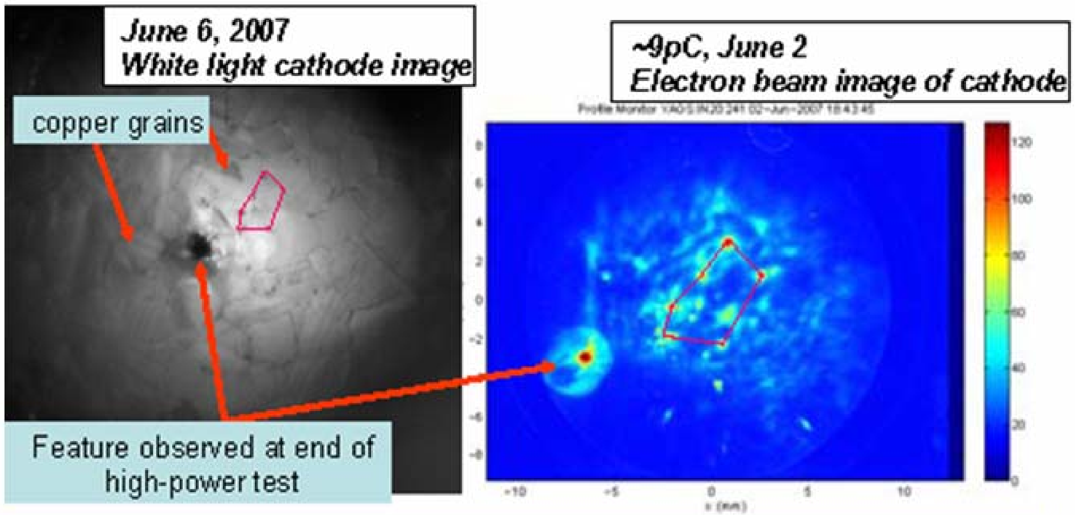


L. Monaco, EPAC06

NC S-band metal cathode gun
Dark charge @ LCLS

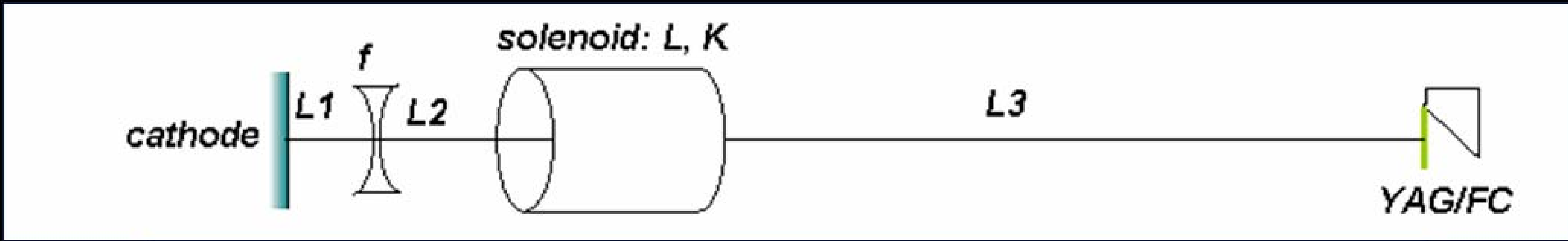


LCLS dark charge vs. cathode peak field



Images of the cathode taken using a white light source and a camera (left), and an electron emission image on a YAG screen (≈ 100 cm from the cathode). The gun solenoid is adjusted to image the cathode electrons on the 100 micron thick YAG screen.

Dark current investigation @ LCLS



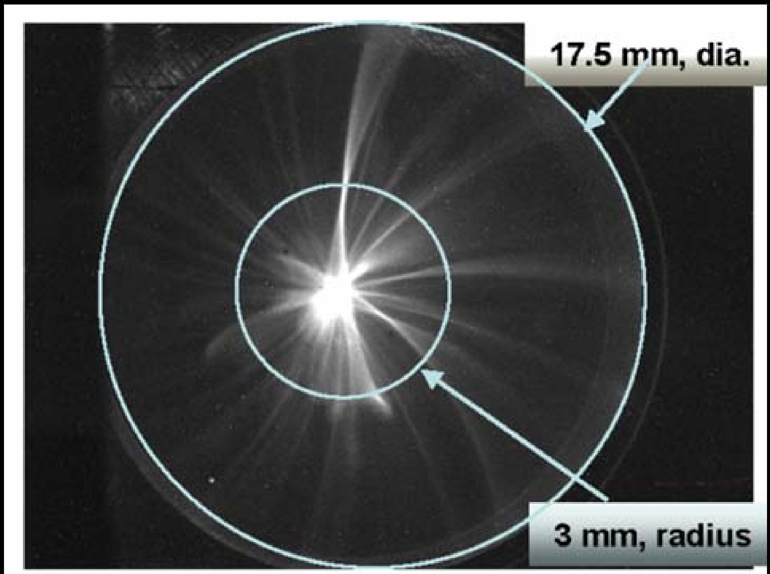
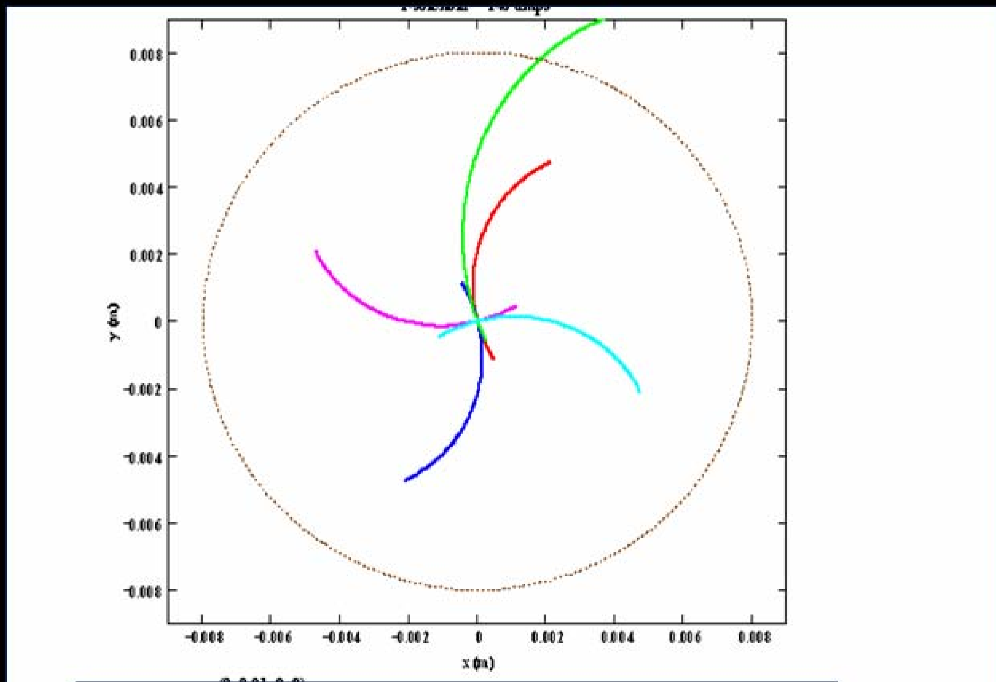


Image on the YAG

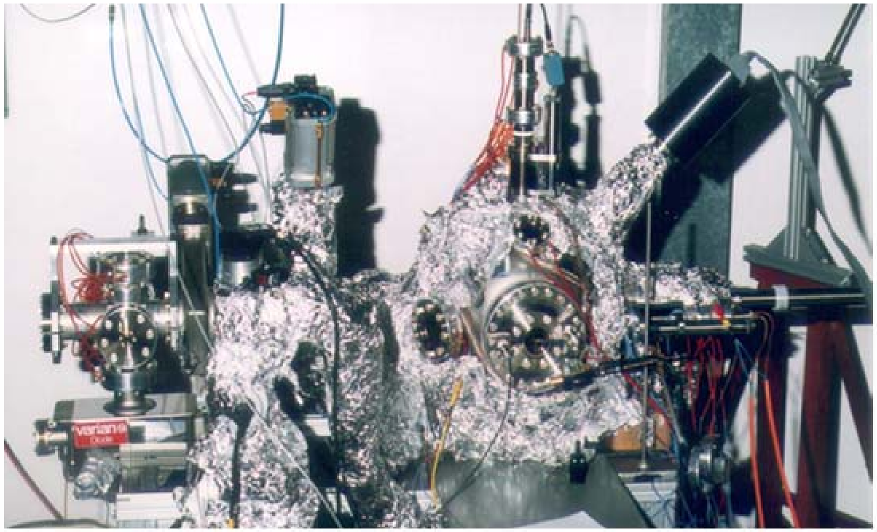


Electron trajectories computed using the linear model

Paolo Michelato, EPAC08, Genoa, June 23, 2008.

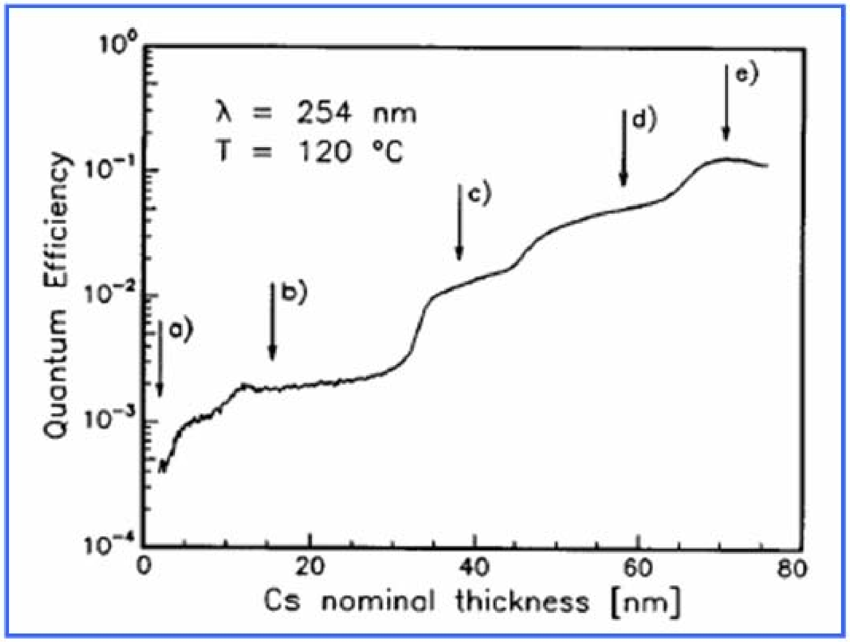
D. H. Dowell, PAC07

FLASH RF gun: Cs_2Te cathode QE & lifetime 1/2



Cathode preparation in Milano
and transportation to DESY

Cathode I.D.	CW QE (%) @ 254 nm	Operation (days)	Charge (C)
#42.2	8.0	123	1.1
#23.2	9.6	195	1.7
#72.1	9.2	180	1.6
#73.1	7.9	114	1.0
#78.1	7.8	62	0.5

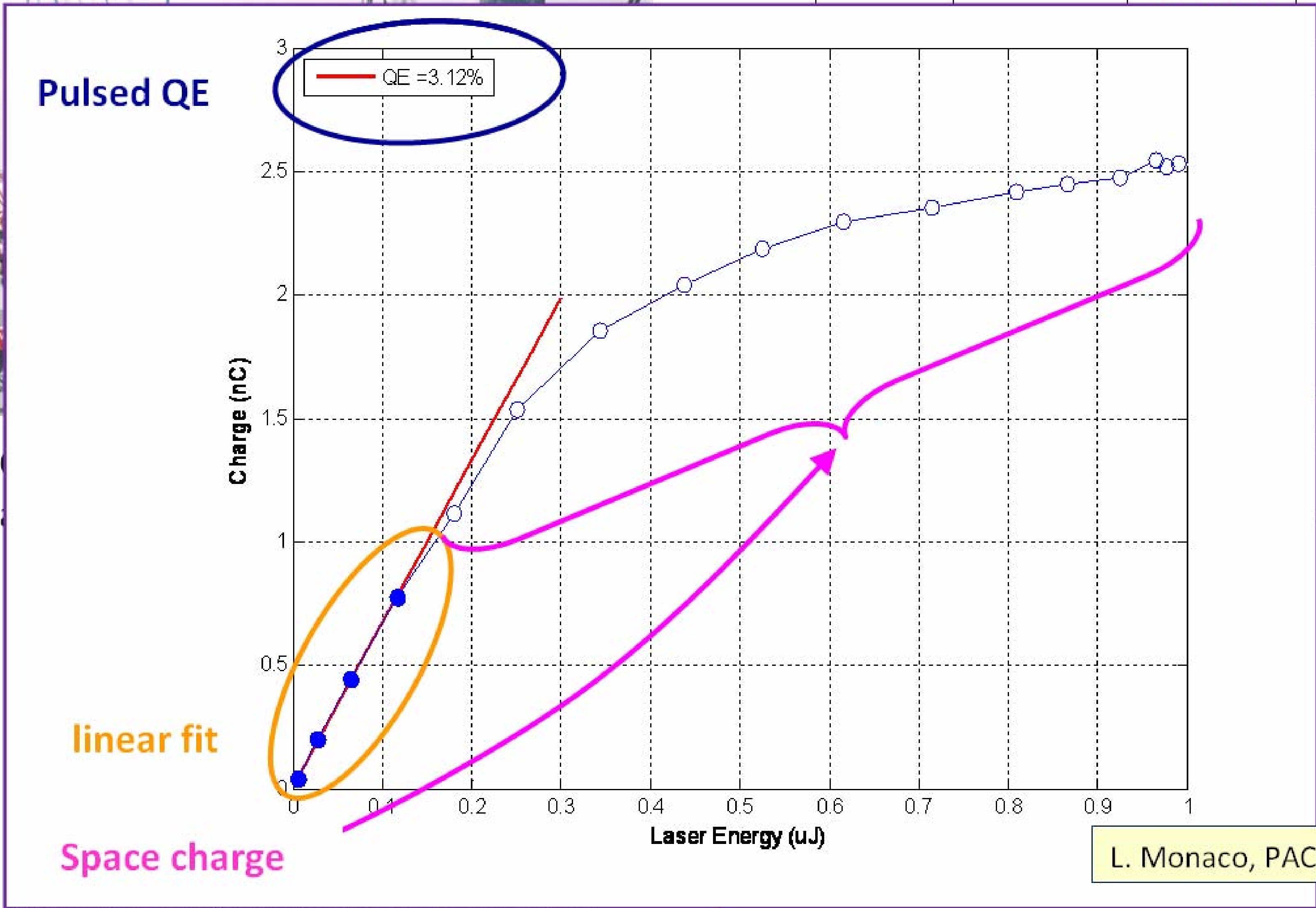


Cathode growing recipe

Paolo Michelato, EPAC08, Genoa, June 23, 2008.

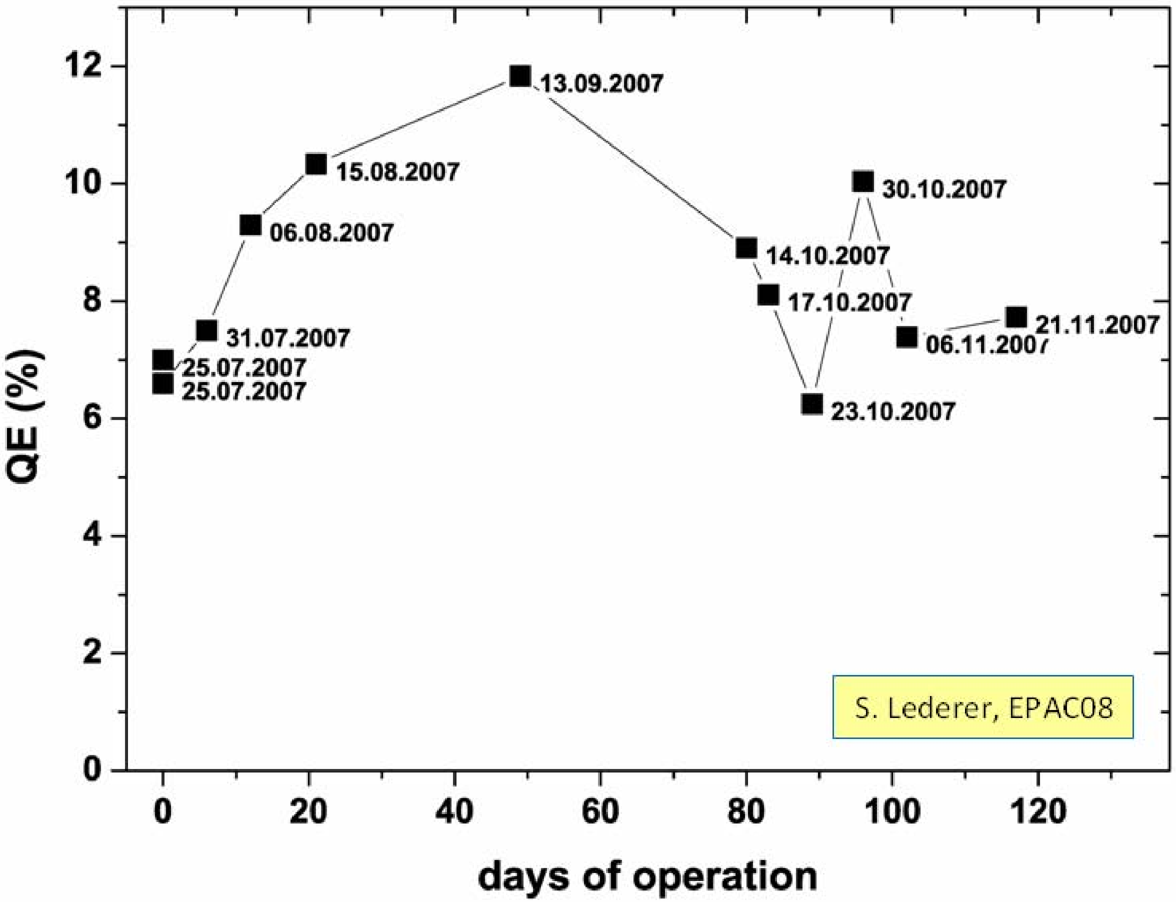
FLASH RF gun: Cs_2Te cathode QE & lifetime 1/2

Cathode	CW QE (%)	Operation	Charge (C)
			1.1
			1.7
			1.6
			1.0
			0.5

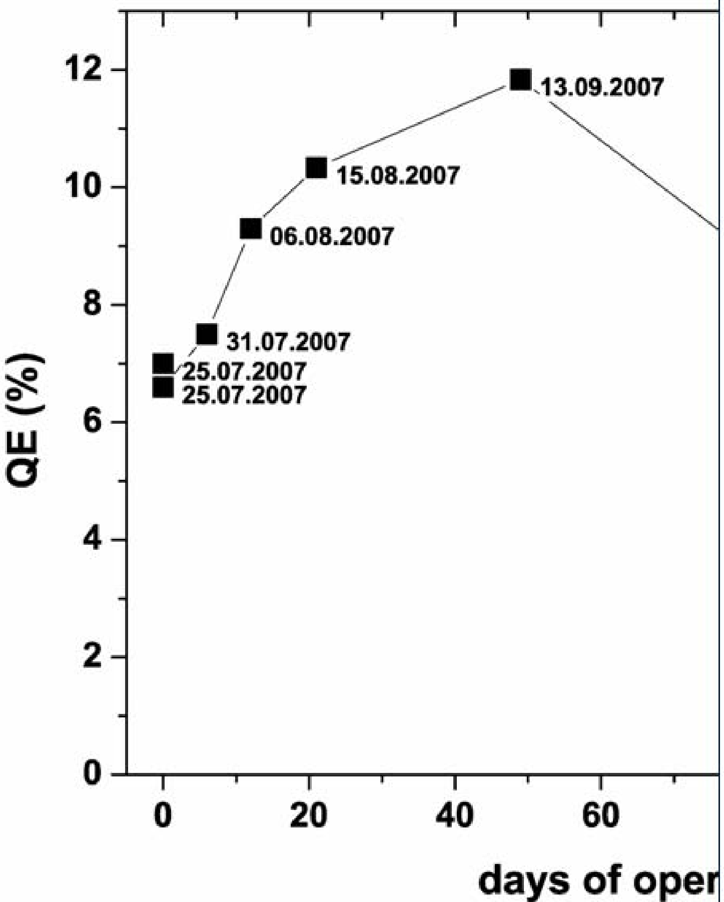


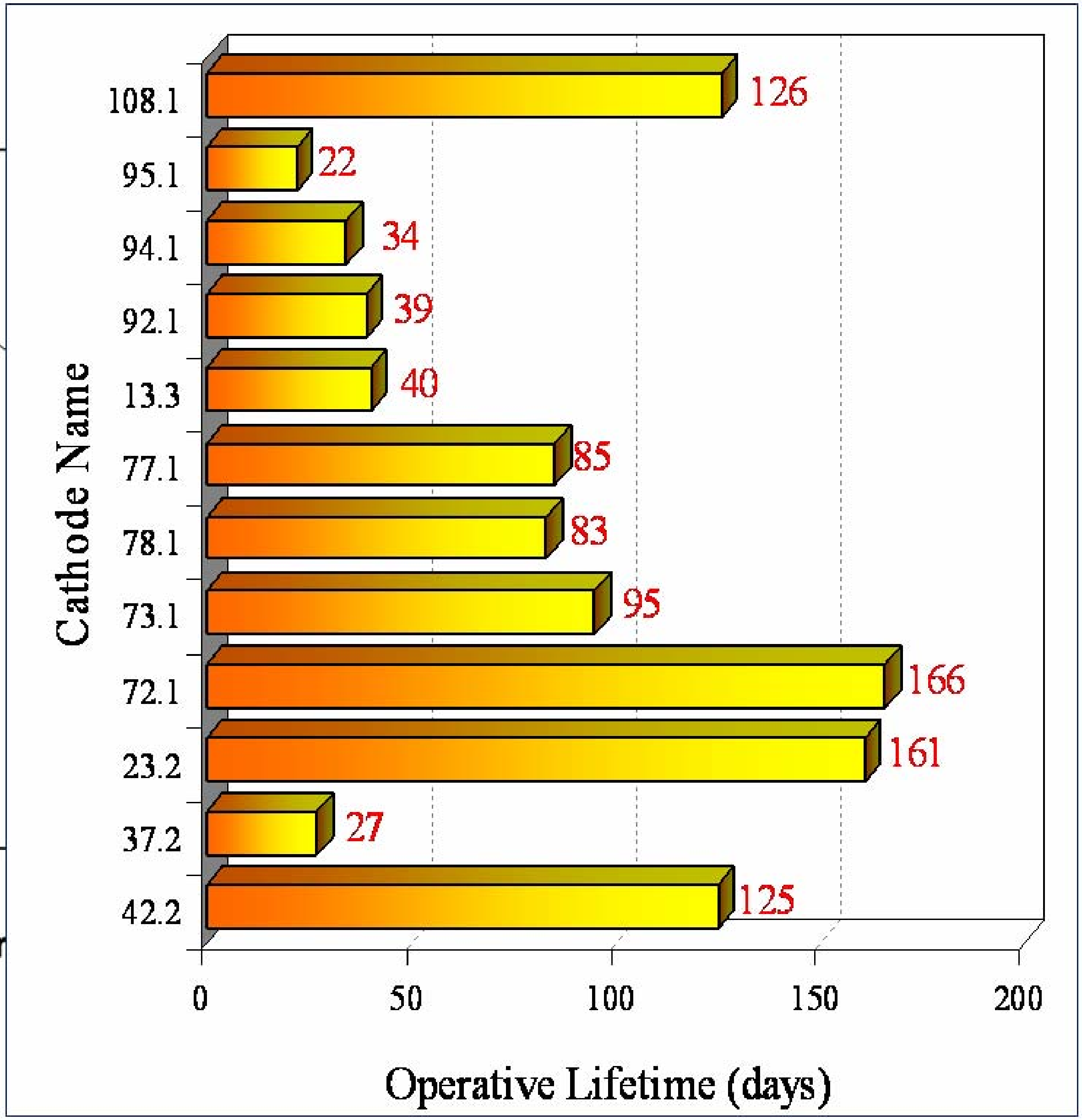
Cathode growing recipe

FLASH RF gun: cathode QE & lifetime 2/2



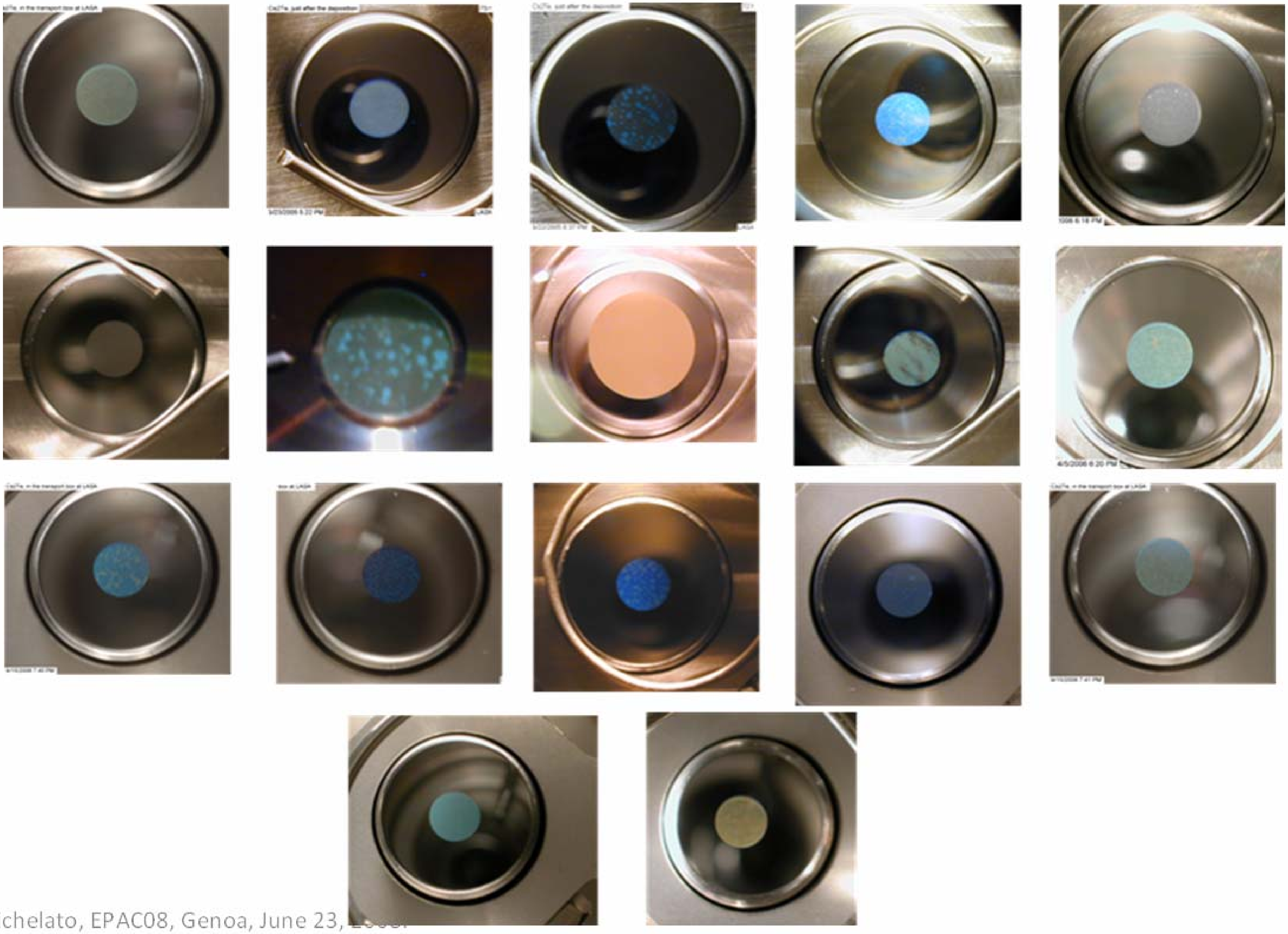
FLASH RF gun: cathode QE & lifetime 2/2





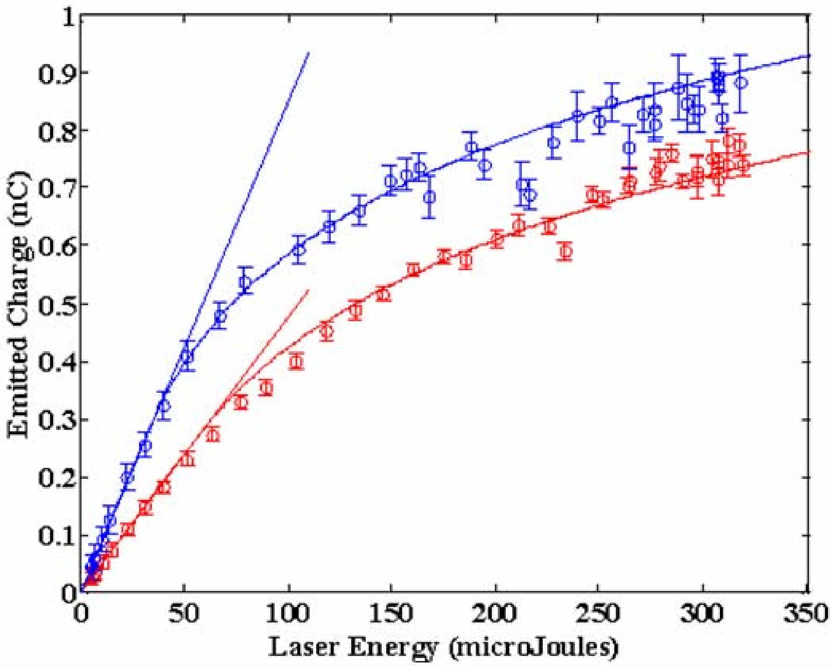
Paolo Michelato, EPAC08, Genoa, June 23, 2008.

FLASH/PITZ/FNAL: cathode “color” ? A Puzzle!

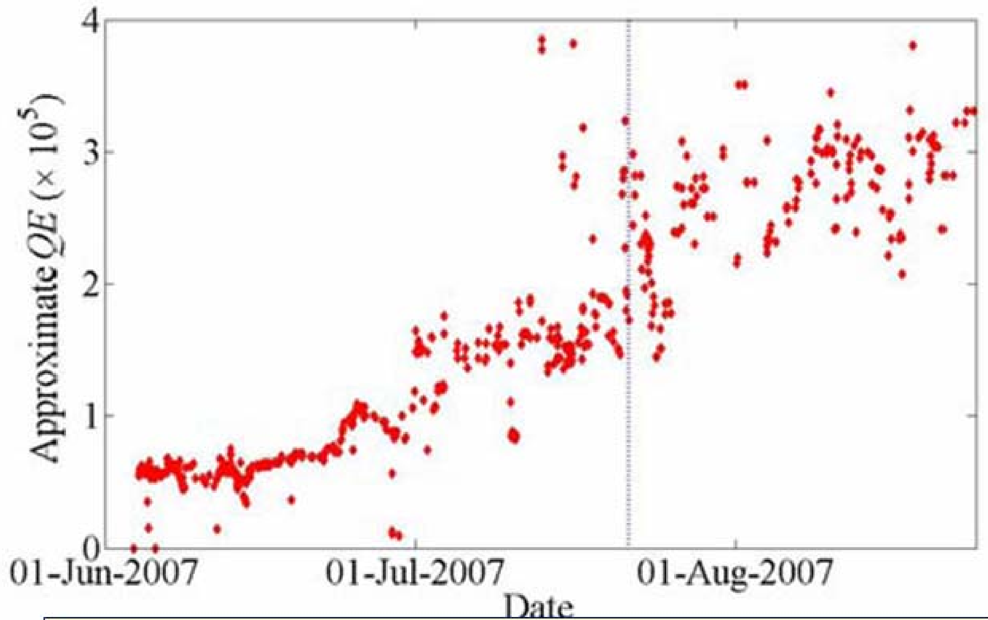


NC S-band metal cathode gun: QE @ LCLS

- QE of copper was at the early beginning about 1 order of magnitude lower then the foreseen
- After laser cleaning reach about $4x10^{-5}$ @253 nm



The measured charge vs. laser energy before (red) and after (blue) laser cleaning. The initial *QE was* 2.3×10−5 and after mild laser cleaning it was 4.1×10−5.



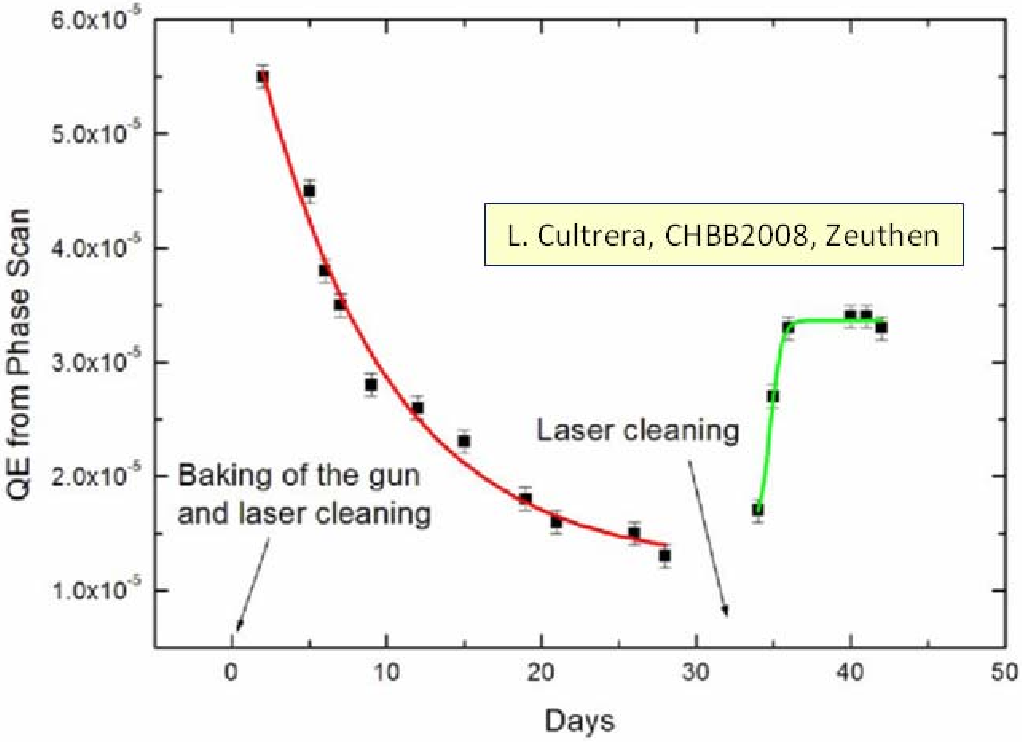
The approximate quantum efficiency (*QE)* during the last three months of commissioning. The vertical line indicates July 21 when the cathode was lightly cleaned with the drive laser at a higher fluence.

Paolo Michelato, EPAC08, Genoa, June 23, 2008.

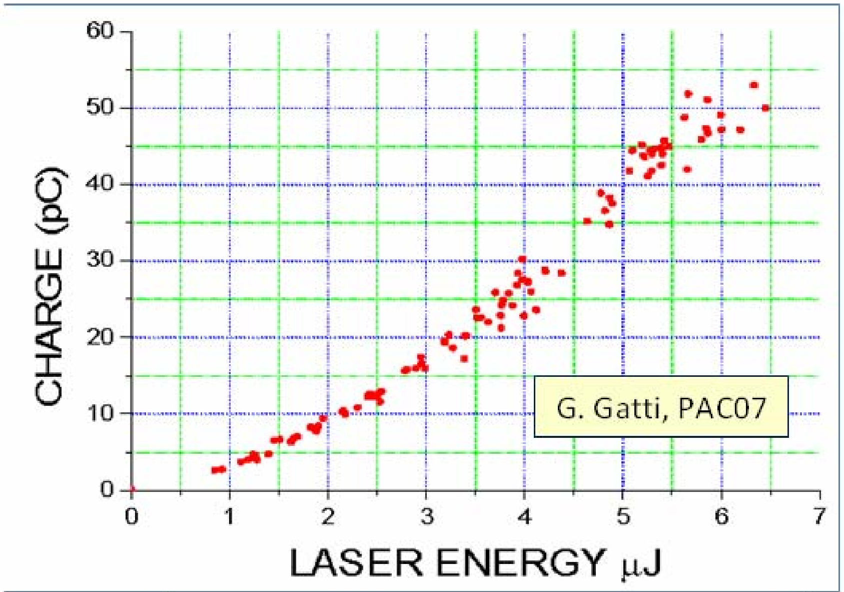
D. H. Dowell, SLAC PUB 13014

NC S-band metal cathode gun: QE @ SPARC

- QE of **copper** decrease with time, laser cleaning for rejuvenation.
- Investigation under way on **Mg** deposited by **PLD** (Pulsed Laser Deposition). QE @ 266 nm : 3×10^{-5} but quadratic behavior of charge vs. laser energy (multi photon?)



Cu cathode QE in the gun. Before a gun venting (linac installation) QE was 7×10^{-5}. After the venting QE decrease of a factor 10. After laser cleaning QE recovered.



Mg PLD film QE in the RF gun. QE about 3×10^{-5} @ 266 nm.

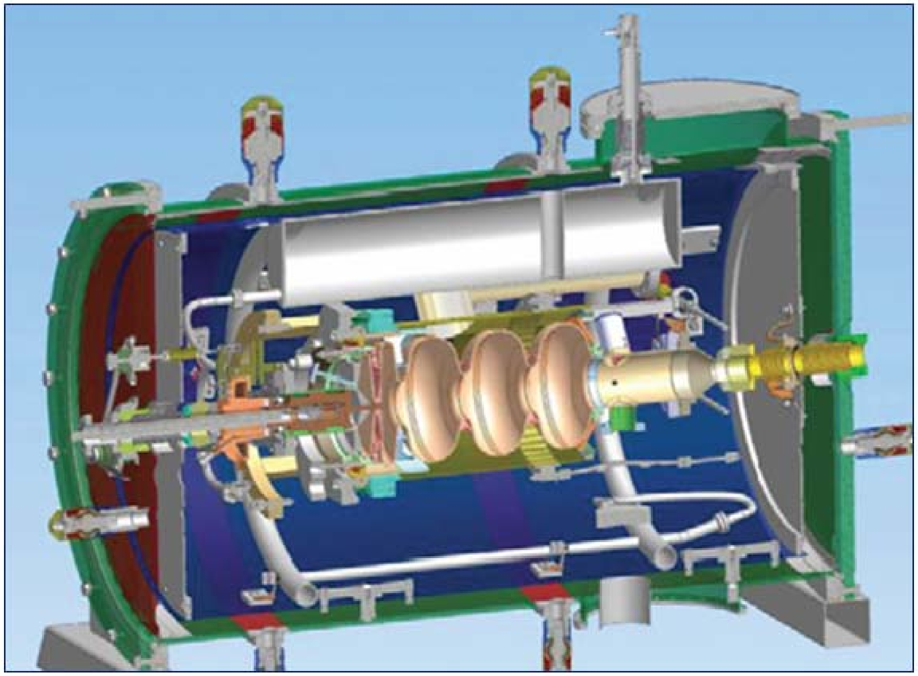
NC RF GUN challenges summary

- Dark current/dark charge
  - From cathode
  - From the contact between cathode and gun
- Cathode QE and vacuum (also for metallic cathodes!)
- Cooling and temperature stabilization
  - Main issue for CW (ERL or long pulse)
- Laser system
  - Transversal uniformity
  - Flat top
  - Jitter stabilization
  - …

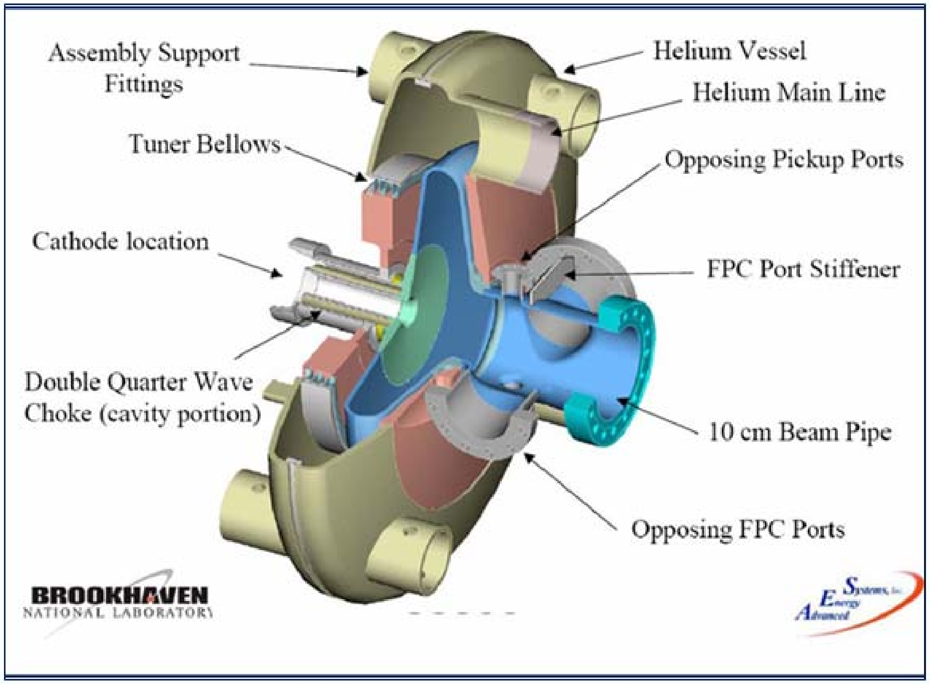
SC RF gun (embedded cathode)

- Quite attractive choice
  - Low power dissipation, high conversion efficiency from the plug to the beam.
    - CW operation possible!
- Projects
  - FZD/ELBE photoinjector (1.3 GHz), with Cs_2Te cathode
  - BNL/AES (703 MHz), with alkali (K_2CsSb) or diamond electron multiplier
  - Collaboration BNL/DESY/ JLAB for an "all metal all superconductive" RF gun (Nb or Nb + Pb)

SCRF gun cathode embedded



FZD/ELBE



BNL/AES

BNL/JLAB/DESY

SC RF gun (cathode embedded) cont.

- Photocathode choice
  - Semiconductor photocathode (alkali metal telluride, UV) or antimonide (green light)
    - Proof of principle: OK
    - One injector under conditioning: FZD/ELBE
    - Still to be proved for long time operation
  - Metal cathode
    - Cavity back wall (Nb)
    - Pb film deposited on the Nb SC cavity back wall
  - Diamond photocathode amplifier

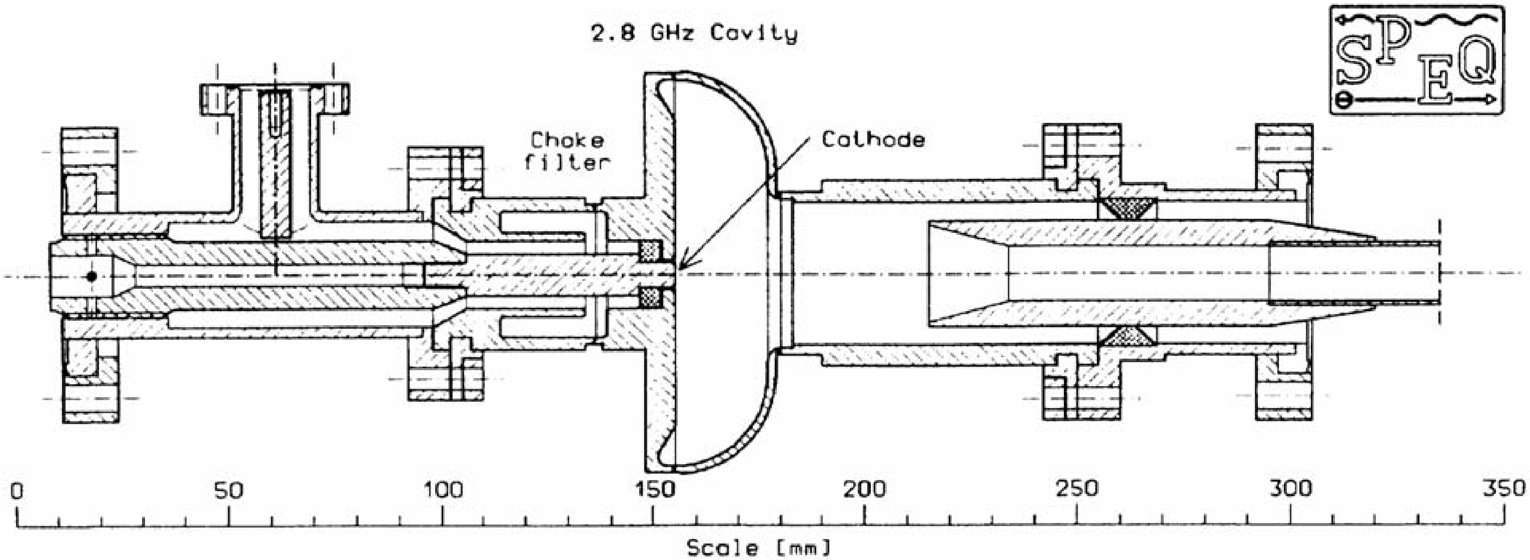
SC RF gun - cesiated cathode: ELBE & BNL

Problems and open questions

- Cavity contamination (sputtered "particles" from cathode)
- Cathode operation at cryogenic temperature
- High field on the cathode: cathode have to be moved in and out the SC cavity
  - Cathode cooling
  - Cathode RF contact/choke filter joint
- Emittance compensation: not possible like in NC RF gun (solenoid).

SC gun: the first proof of principle

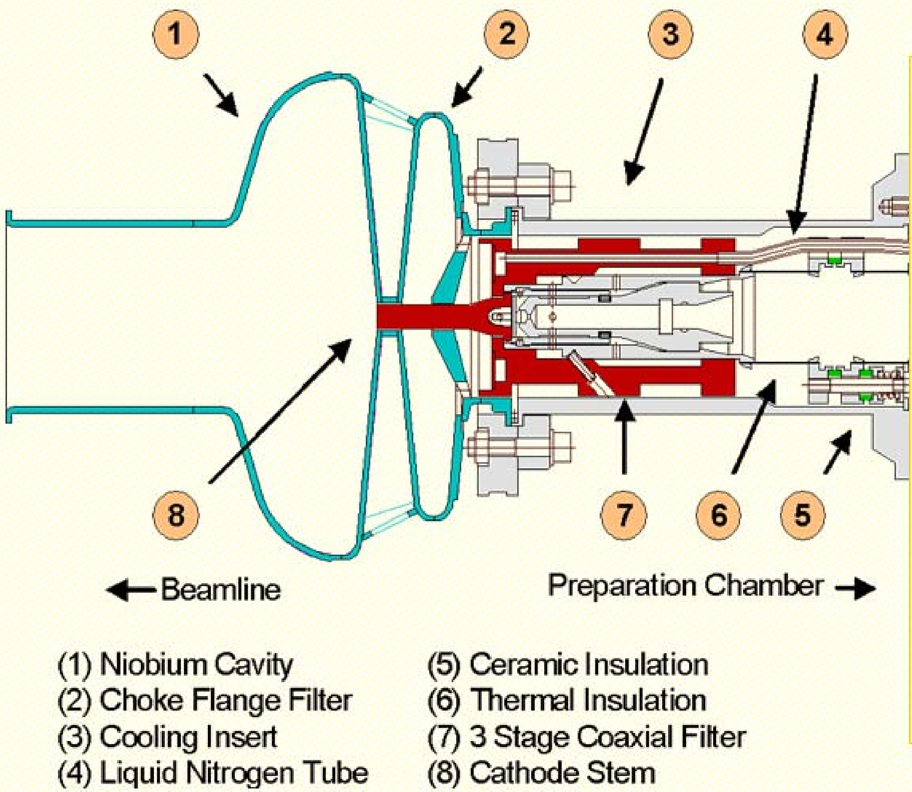
- Wuppertal experiment (1992)
  - SC cavity & Cs_3Sb cathode on Nb plug
  - Cathode stem insulated (thermally and electrically) by sapphire ring
  - Choke filter joint



A. Michalke, EPAC1992

Photo Cathode – NC Cathode in SC Cavity

successful Rossendorf ½ - cell gun with NC cathode
D. Janssen et al., NIM-A, Vol. 507(2003)314



- Heat input:

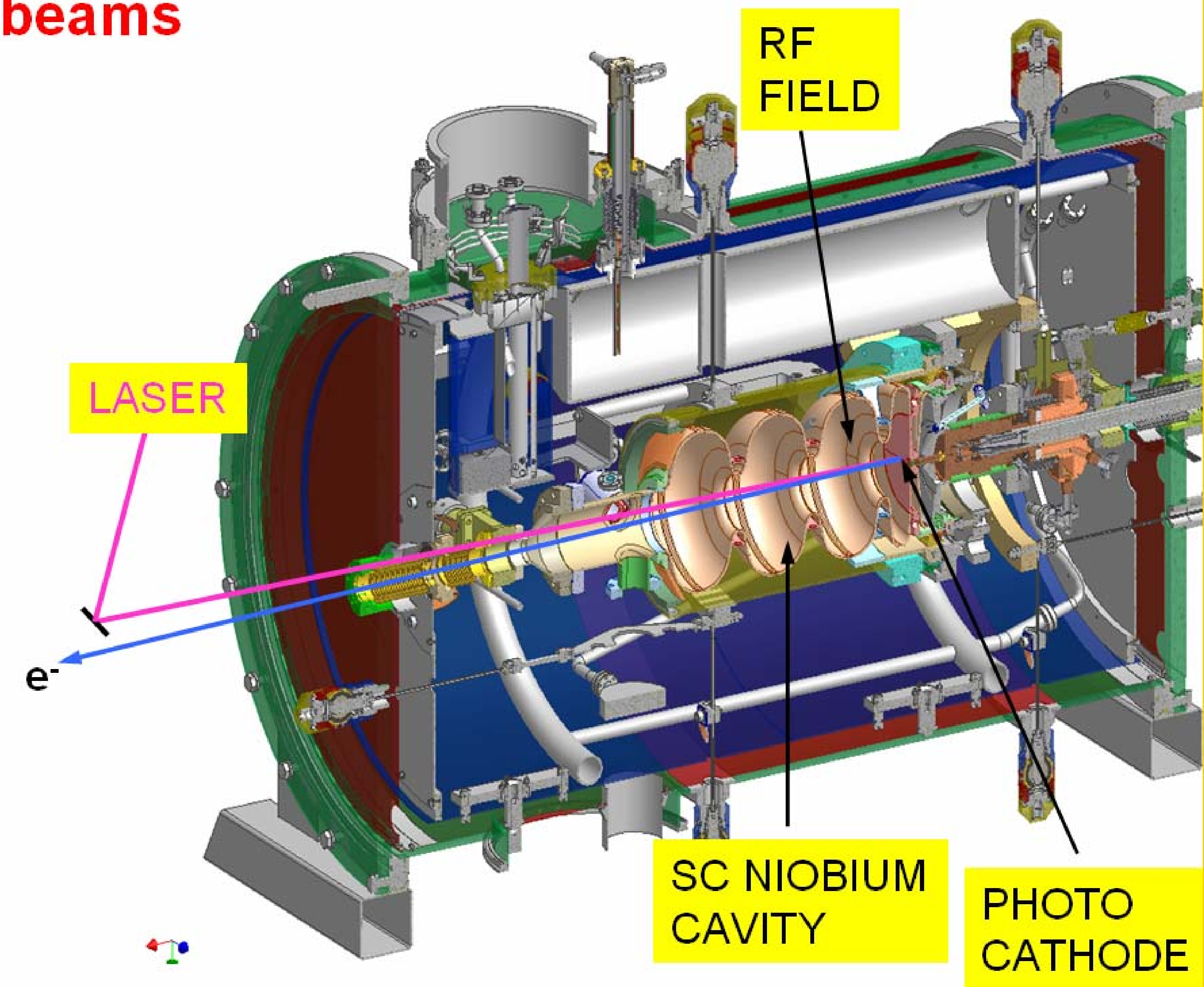
$$P_{diss} = R_{surf} \int_{cathode} \frac{H_{\varphi}^2}{2} dA \approx 5\ \mathrm{W}$$

dielectric loss ≈ 15 W
laser power = 1 W

- isolated from Nb cavity
- liquid N2 cooling
- SC Nb choke filter prevents rf flow

Courtesy J. Teichert, FZD

Generation of high brightness electron beams



1. direct production of short pulses:

laser & photo cathode

2. high acceleration field at cathode:

radio frequency field

3. CW operation for high average current:

superconducting cavity

ELBE SRF PHOTO INJECTOR

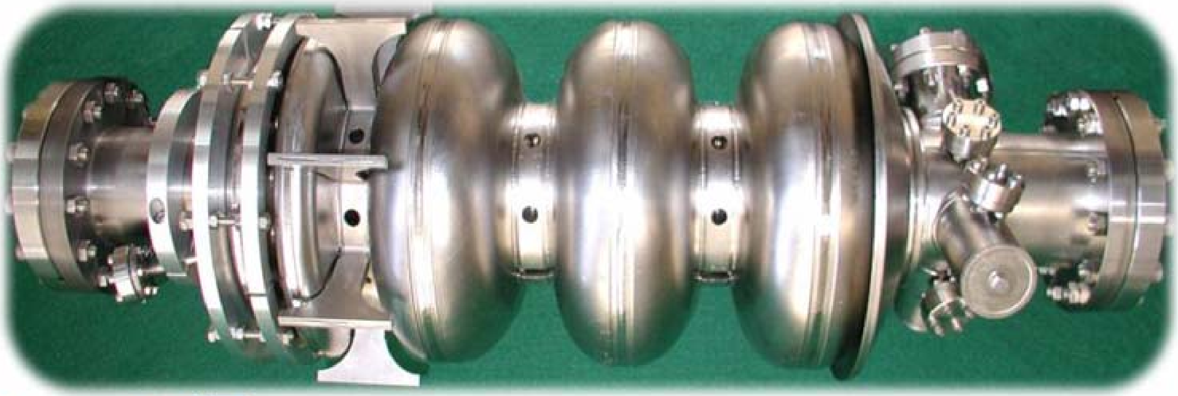
Courtesy J. Teichert, FZD

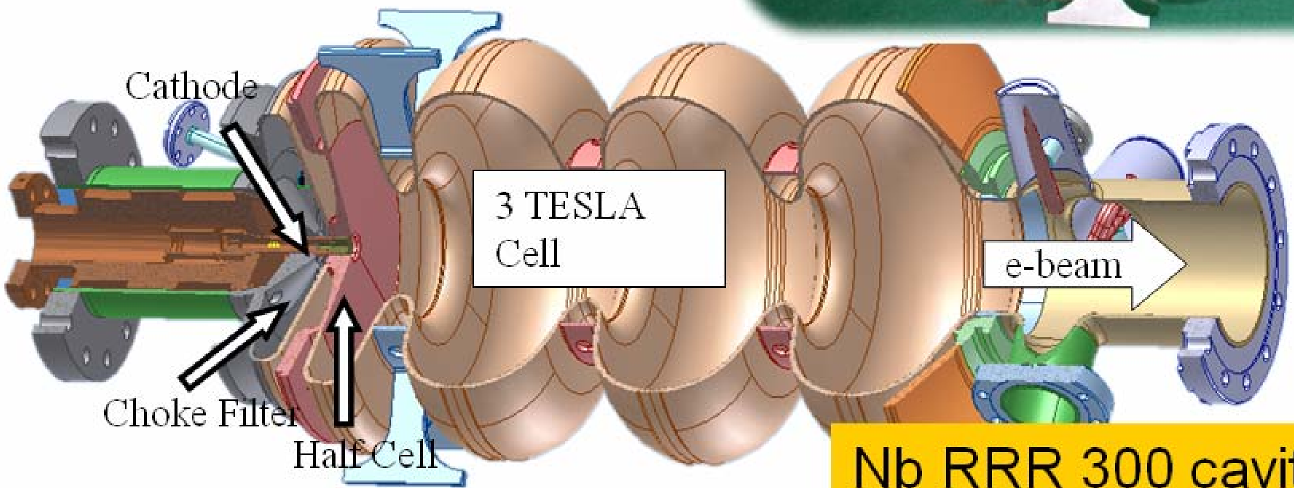
FZD / ELBE SRF Gun Parameters

Mode	ELBE	High Charge	BESSY-FEL
final electron energy	≤ 9.5 MeV		
RF frequency	1.3 GHz		
RF power	10 kW		
operation mode	CW		
drive laser	262 nm		
photo cathode	Cs_2Te		
quantum efficiency	≥ 1 %		≥ 2.5 %
bunch charge	77 pC	1 nC	2.5 nC
repetition rate	13 MHz	500 kHz	1 kHz
laser pulse (FWHM)	4 ps	15 ps	50 ps
transverse rms emittance	1 mm mrad	2.5 mm mrad	3 mm mrad
average current	1 mA	0.5 mA	2.5 µA

Courtesy J. Teichert, FZD

Niobium Cavity





Nb RRR 300 cavity

E_{acc}= 25 MV/m in TESLA cells, Q_0=1x10^{10} (TESLA 500 specification)

110 mT maximum magnetic surface field

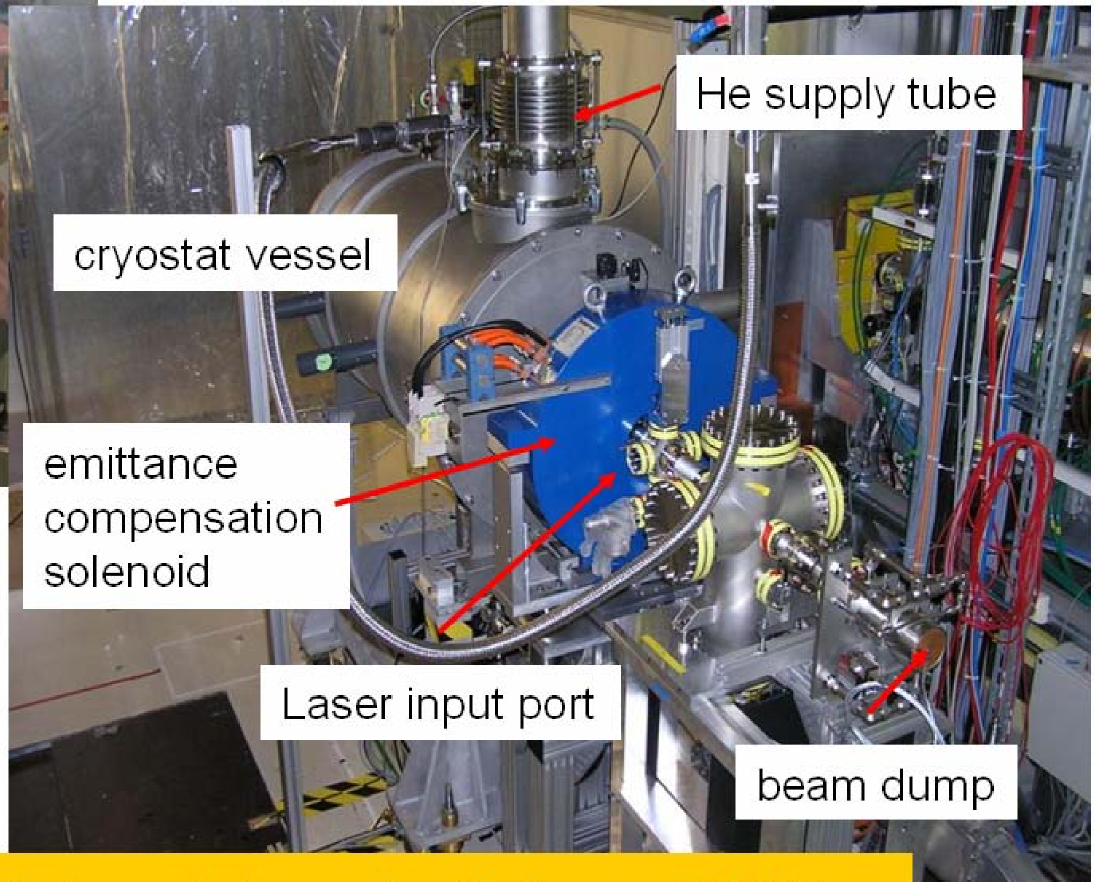
E_{peak} (TESLA cells) = 50 MV/m

E_{peak} (half-cell) = 30 MV/m

$E_{cathode}$ = 20 MV/m (retreated cathode)

Courtesy J. Teichert, FZD

Installation of the SRF gun Cryostat in the shut-down June/July 2007



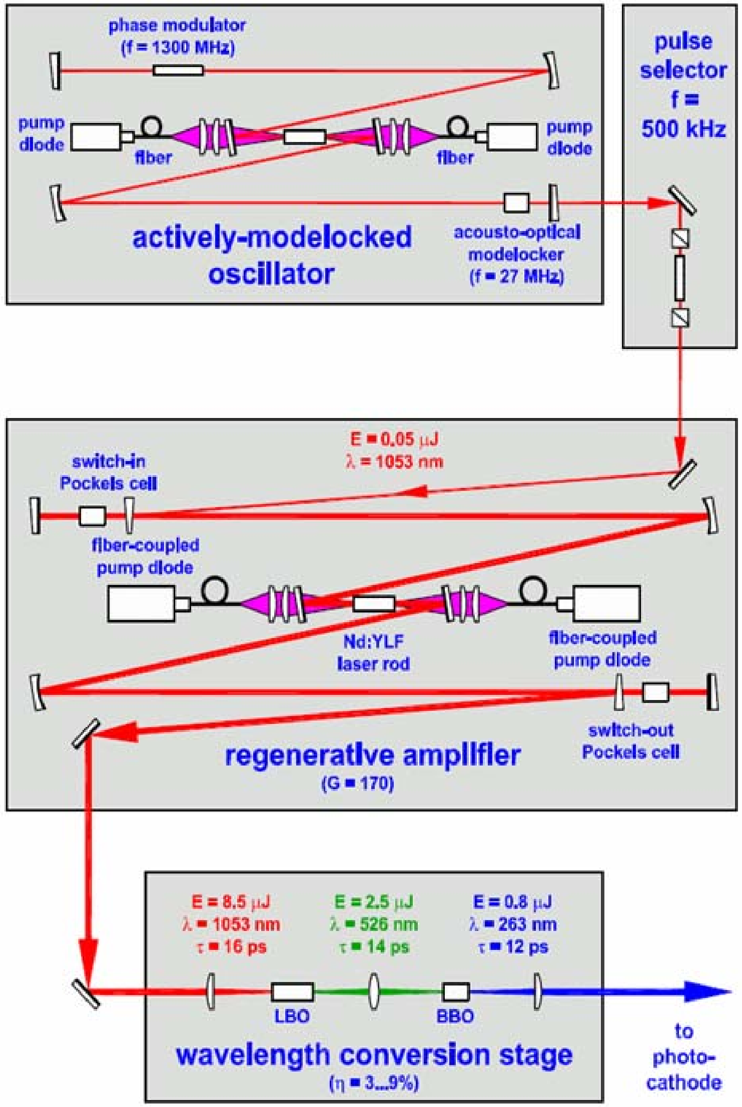
first cool-down 1 – 2 August 2007

Courtesy J. Teichert, FZD

500 kHz laser for High-charge mode:

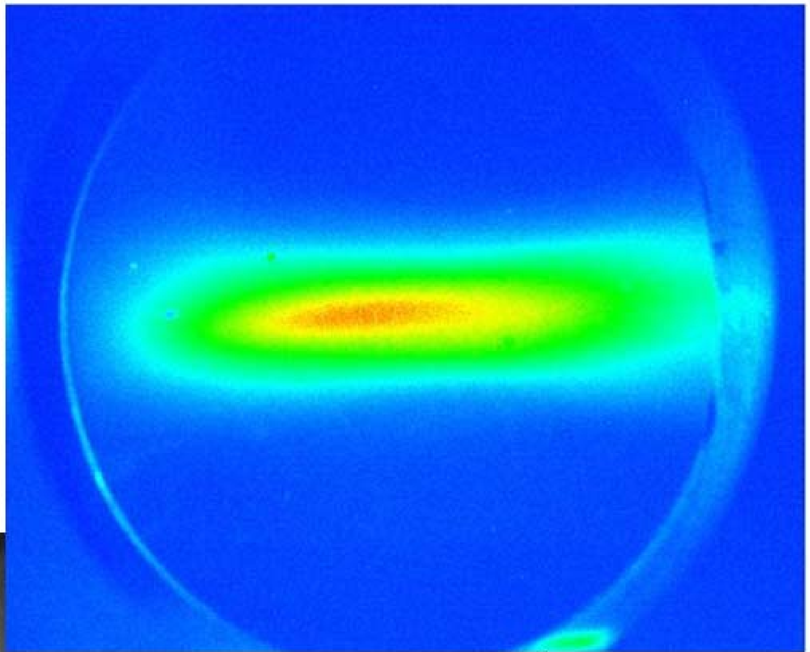
- Max. frequency: 0.5 MHz
- Lower frequencies for alignment
- Pulse duration: 12…15 ps
- Laser material: Nd:YLF, pumped by 8 fiber-coupled diodes

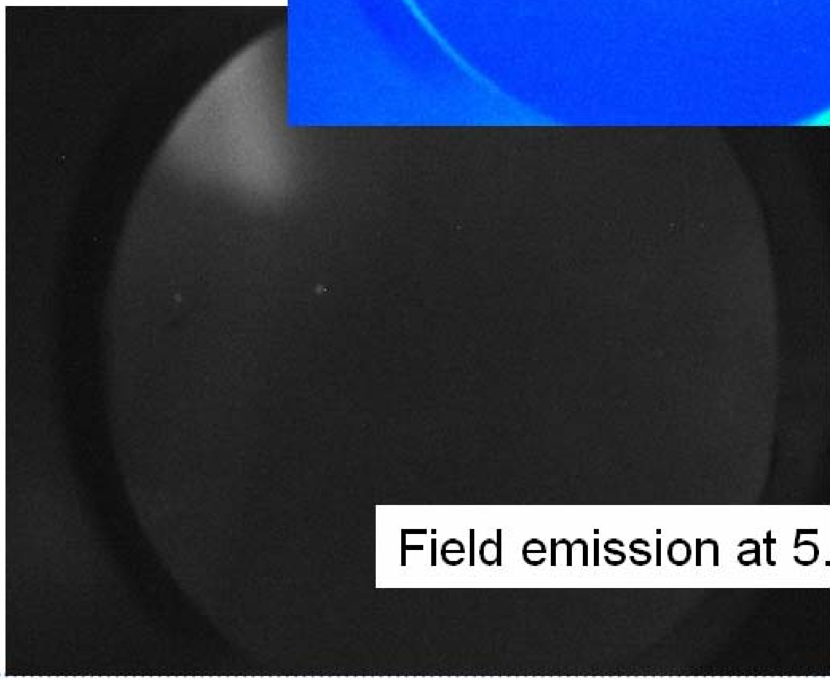
developed by Max-Born-Institut, Berlin



Courtesy J. Teichert, FZD

November 19th, 2007





Field emission at 5.5 MV/m

RF:

E_{acc} = 5 MV/m

f = 1300. 38327 MHz

150 Hz bandwidth

P_{diss} = 6 W

Laser:

263 nm, 100 kHz reprate

0.4 W power (4 µJ)

15 ps FWHM Gaussian

Δx = 4 mm Δy = 6mm, Gaussian

Cathode: Cu

Q.E. ≈ 10^{-6}

Electron beam:

11 mm x 2 mm (FWHM) size on screen

50 nA average current

0.5 pC bunch charge

2.0 MV energy (estimated)

Courtesy J. Teichert, FZD

FZD/ELBE SC RF gun

Test with Cs_2Te cathode are under way

Next future:

- Cathode QE
- Dark current
- Reliable compatibility with SC cavity
- Gun reliability
- Cathode lifetime
- …

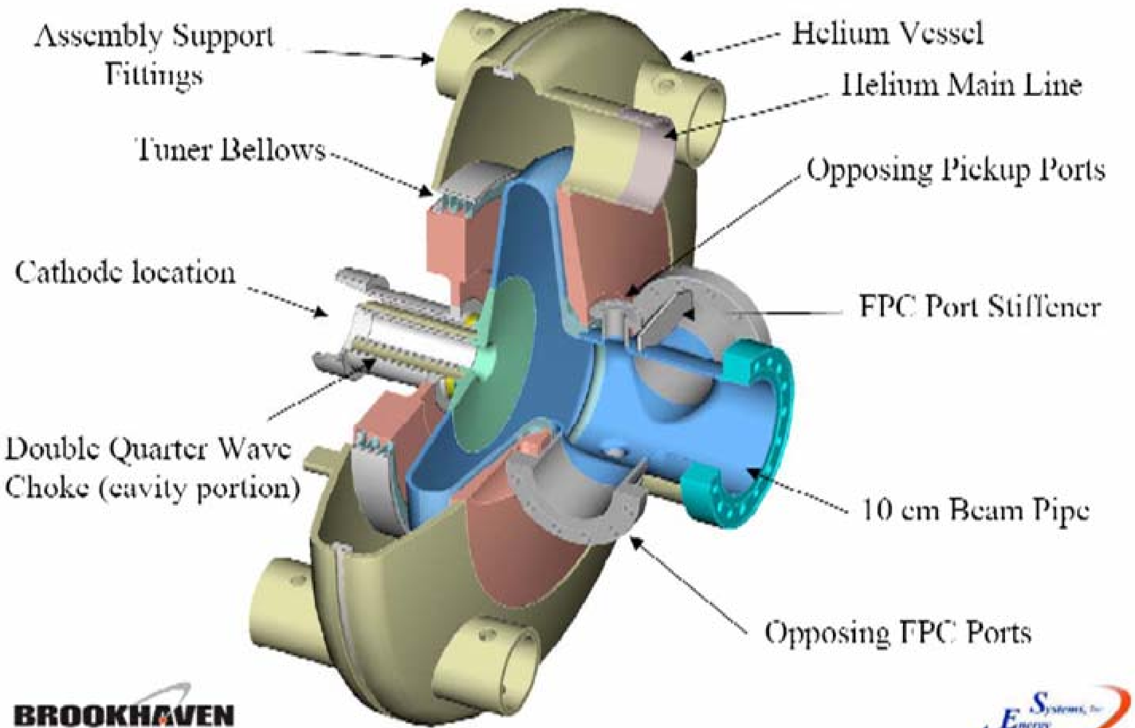
BNL 703 MHz ERL SRF Photoinjector

Overview

- ERL operating at 703 MHz using SRF photoinjector and accelerating cavity
- Photoinjector designed to deliver 2 MeV beam, 5 nC/bunch at 9.38 MHz.
- Laser system designed to ramp up in power and rep rate, so various diagnostics will be possible
- Ideally operate in multiple modes
  - 93 MHz, 1.4 nC/bunch (130 mA) scale to 0.5A with 351 MHz laser
  - 9.38 MHz, 5 nC/bunch (50 mA) for RHIC II
  - Start-up mode 1 Hz and up, low bunch charge

BNL 703 MHz SRF Photoinjector, cont

Gun Design



BROOKHAVEN NATIONAL LABORATORY

Andrew Burrill ERL Workshop 2007

Office of Science U.S. DEPARTMENT OF ENERGY

BNL 703 MHz SRF Photoinjector, cont.

Photocathode choice and challenges

- CsK_2Sb is cathode of choice, with a diamond amplified photocathode as the next generation cathode
- Lots of experience with CsK_2Sb photocathode deposition, extensive R&D on diamond amplified photocathode

Challenges	Solutions
Cathode lifetime	No vacuum degradation
Thermal isolation	Actively cooled cathode stalk
Particulate and interface to gun	Proper engineering and design

“All superconducting” RF GUN

Collaboration BNL, JLAB, DESY, Pekin Univ. FZR,…

Challenges:

- Superconducting RF structure
  - Pb coating compatibility
- Superconducting photocathode:
  - Nb back wall of the cavity
    - low QE, High laser power required
    - 5^{th} harmonic (λ < 250 nm)
  - Deposited Pb on the back wall of the cavity
    - Cavity processing (HPR)
    - Cathode refurbishment
  - Moveable stem with Pb coating
    - Choke joint

Assumption:

a superconducting metal cathode with theoretically “infinity” long life time should simplify the design.

The first approach:

photoemission from the cavity wall, so called “all niobium RF-gun”, proposed at BNL

The simplest way, but very low QE < 10^{-5} @ λ = 266 nm

The second approach:

Bulk niobium cavity with the emitting spot of Pb, which is a commonly used sc (Tc=7.2 K)

Courtesy J. Sekutowicz

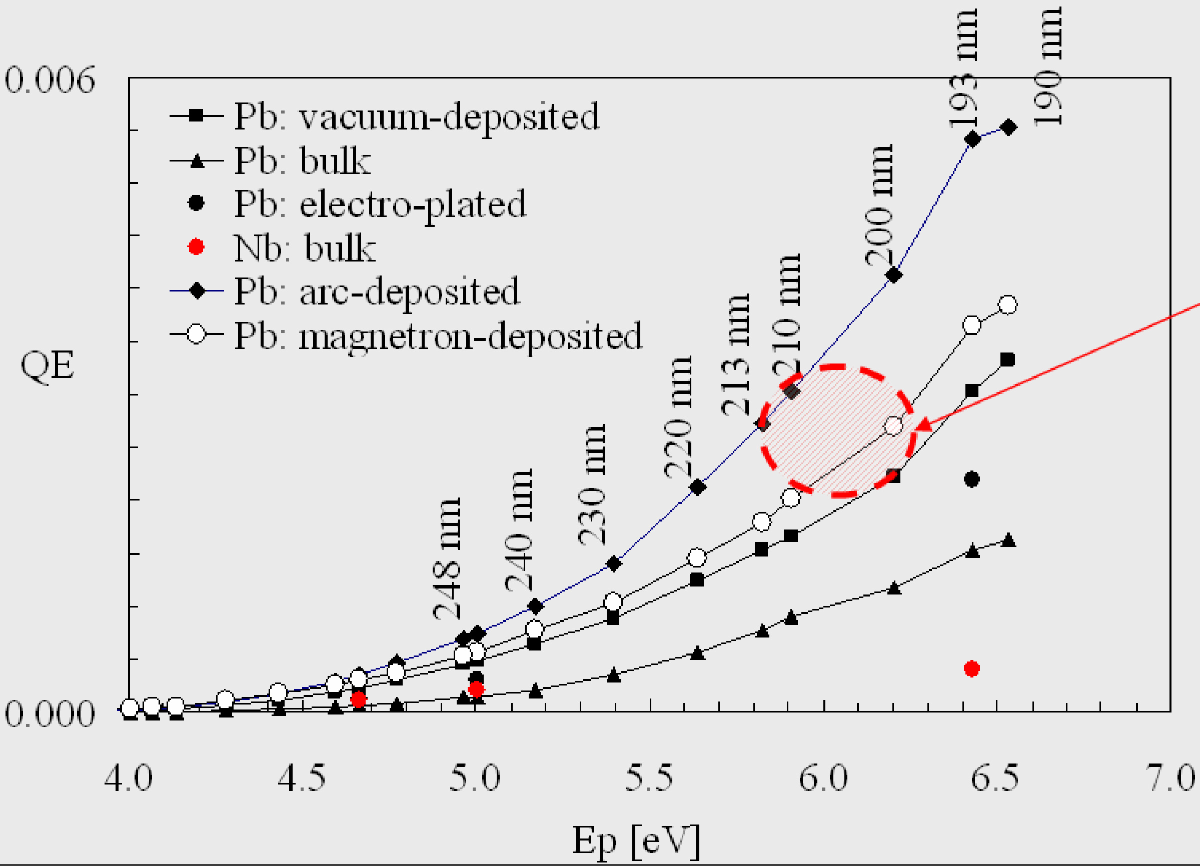
III. SC cathode + SRF cavity

Measured QE at 300 K

Irradiating light sources:

ArF- laser: 193 nm, KrF-laser: 248 nm, 4-th harmonic Nd: YAG laser : 266 nm

Deuterium light source with monochromator (2 nm bandwidth): 190-315 nm



QE sufficient to generate
~0.5 nC at rep. rate ≤100 kHz

Courtesy J. Sekutowicz


Jlab Half-Cell

Cavity Tests
Pb/Nb ½ Cells
RF performance


DESY Half-Cell

Fabrication Options:

Deposition of **lead** directly onto "cathode area" of cavity back wall via arc deposition (DESY cavity)

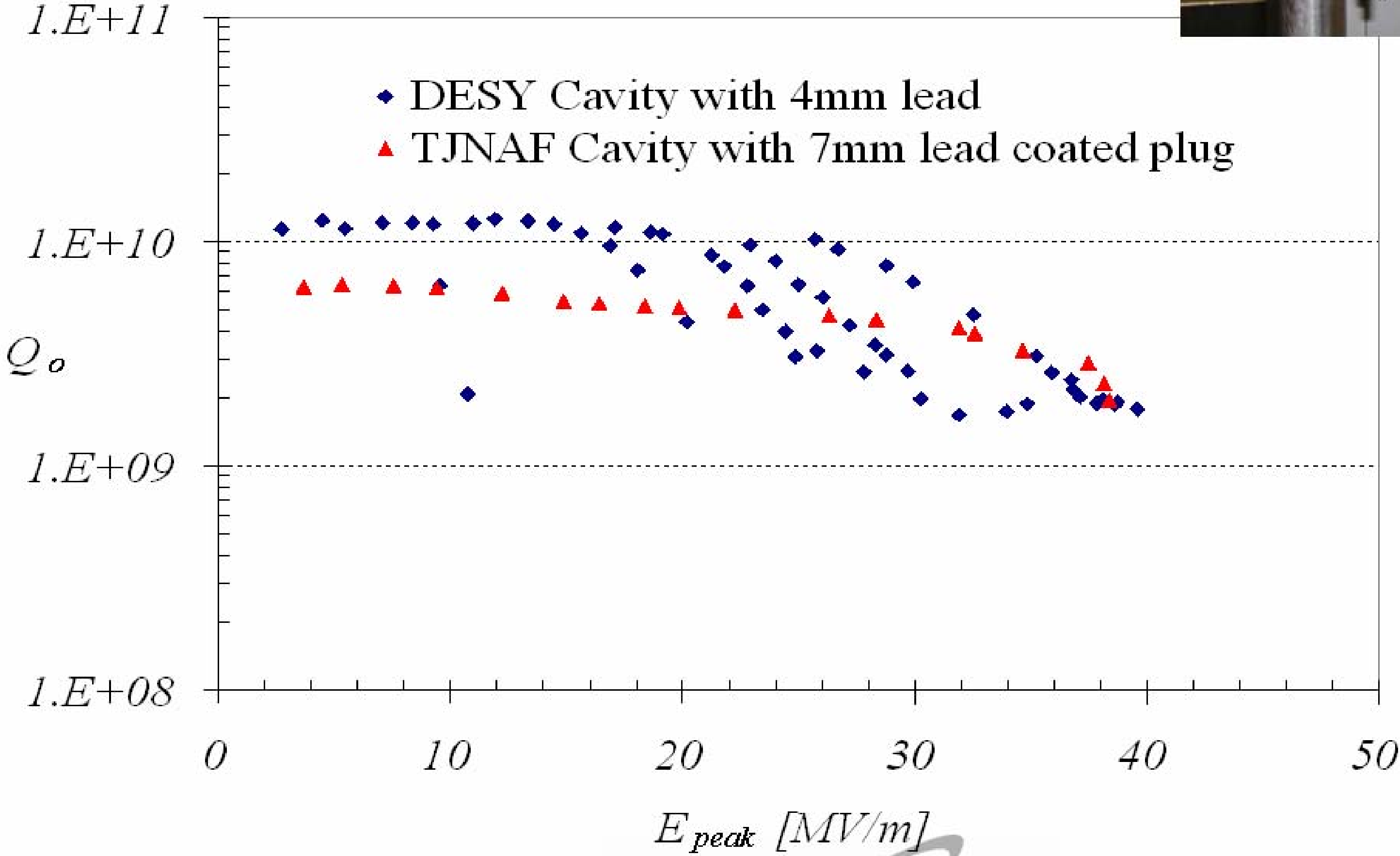
or

Use cavity with **removable** portion of the back wall (plug), which can be coated independently of cavity cleaning (Jlab cavity)

In both cases, cavities **reached 40 MV/m** with lead cathodes. The Q of both cavities was unchanged by the presence of lead.

Courtesy J. Smedley

Cavity Tests
Pb/Nb ½ Cells
RF performance



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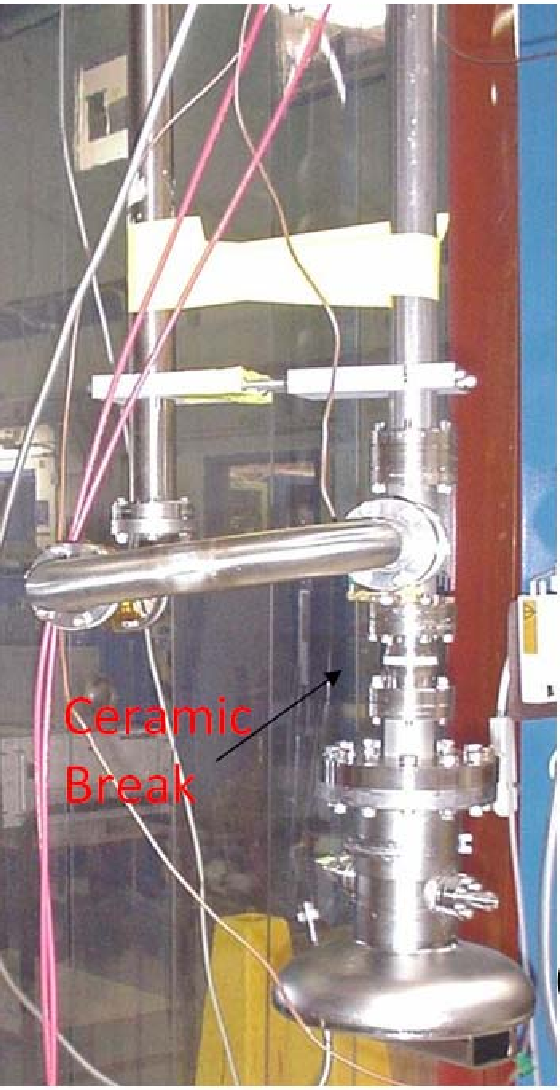
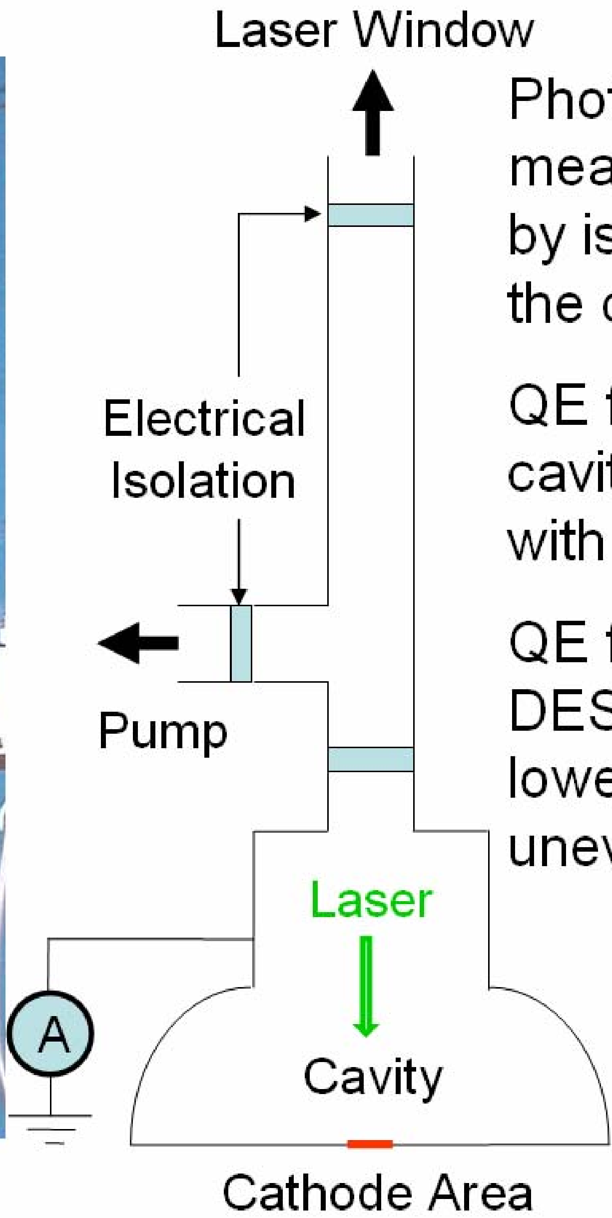
Courtesy J. Smedley

DESY

Charge Measurement





Photocurrent for both cavities measured in Jlab Vertical Test Area, by isolating the cavity and monitoring the current leaving

QE for electroplated lead plug in Jlab cavity was **1.6×10^{-4}** (@248nm), in line with expected performance

QE for Arc deposited lead cathode in DESY cavity was **1.4×10^{-4}** (@248nm), lower than expected, possibly due to uneven lead coating

Courtesy J. Smedley

“All superconducting” RF GUN Summary

- Hybrid Pb/Nb cavities have been fabricated using two designs
  - Direct plating of Pb on cavity back wall via masked arc deposition
    - Avoids need for joints or seams
    - **Challenging to do, cavity cleaning post deposition is challenging, may harm Pb**
  - Use cavity with removable plug in back wall, that is coated separately
    - Easy to coat with lead, using a variety of techniques, easy to clean cavity
    - **Requires a joint, which may limit electric field on cathode**
- RF performance good for both designs, unchanged by presence of lead spot
- For plug gun, QE is 1.6×10^{-4} (@248nm) in line with expected value for electroplated lead. The arc deposited spot on the DESY cavity has a QE of 1.4×10^{-4} (@248nm).
- We were unable to cause a quench in the cavity, with 0.7W (>0.5 MW peak) of laser power delivered (the Q dropped by 20% in this case)

Courtesy J. Smedley

Conclusions

- NC RF gun are a mature technology , they can provide the beam quality for FEL, in terms of current, emittance, etc.
- NC RF gun for ERL: still critical for RF power dissipation.
- SC RF gun are close to demonstrate to be a reliable choice for ERL and FEL with semiconductor photocathodes (ELBE, BNL).
- SC RF gun “all superconductive” is a promising approach also in terms of reliability (no RF joint, no choke)

BUT…

High brightness low emittance with thermionic gun !

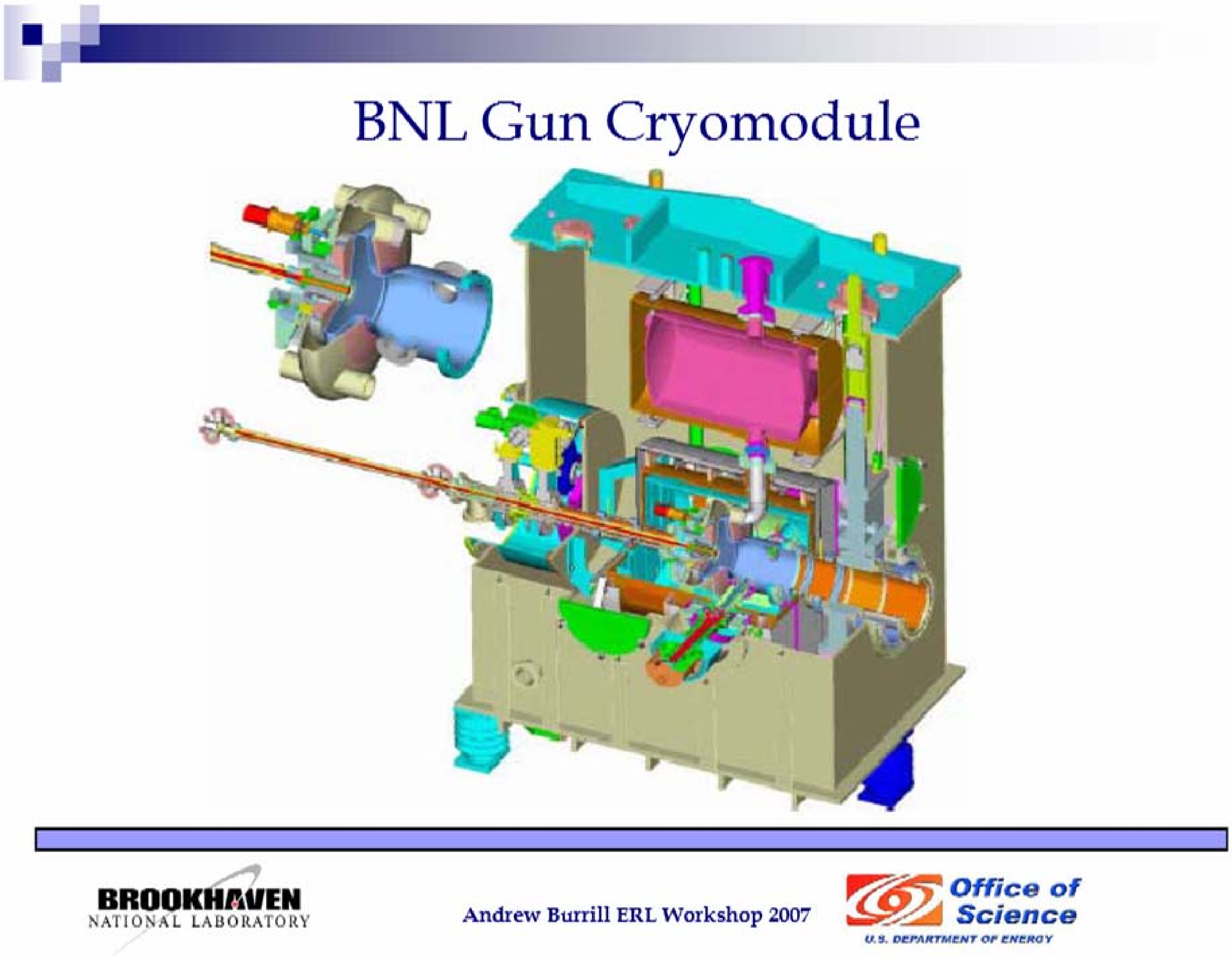
- **Results obtained at RIKEN Spring-8 by T. Shintake**
- **CeB_6 thermionic cathode**
- **Beam peak current 300 A, emittance: 1 mm · mrad**

Thanks

- I first would thanks you for your attention and patience…
- I would apologize for having not included all the people and the projects around the world
- I would thanks all the people that have contributed in the collection of the information relative to the RF guns

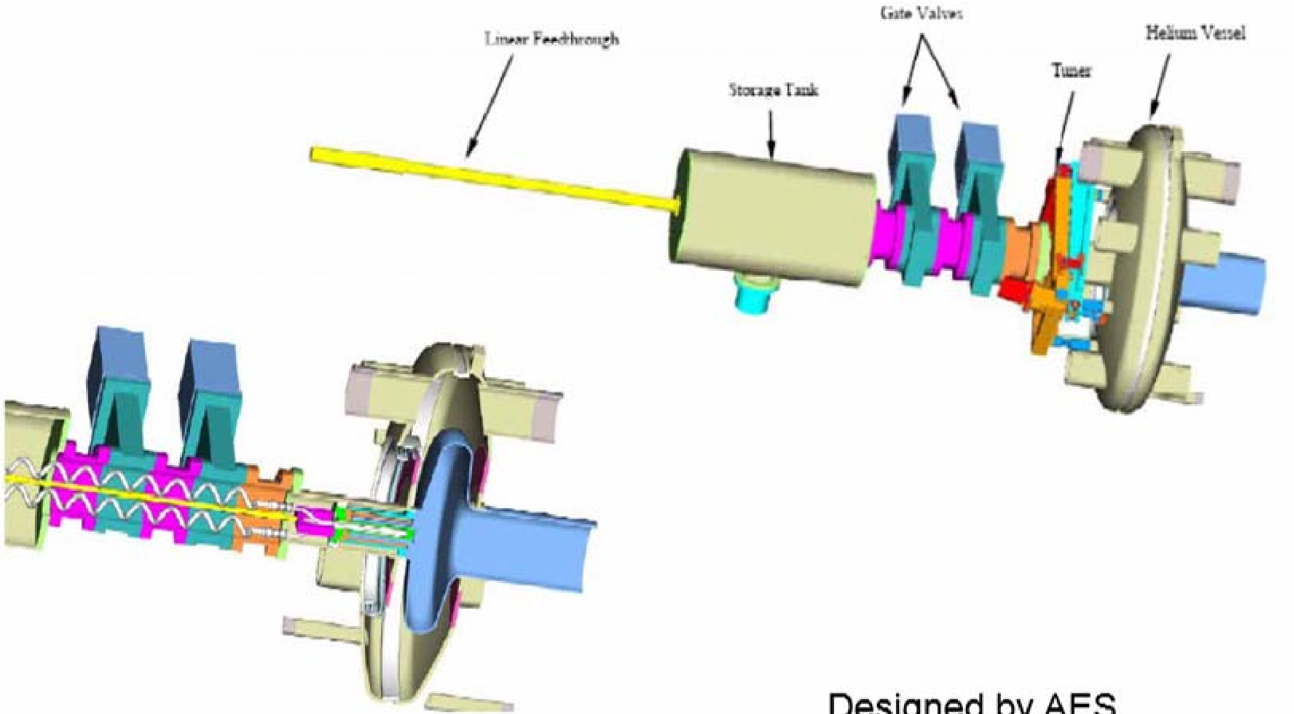
The end

BNL 703 MHz SRF Photoinjector, cont.



BNL 703 MHz SRF Photoinjector, cont.

Cathode insertion mechanism



Designed by AES

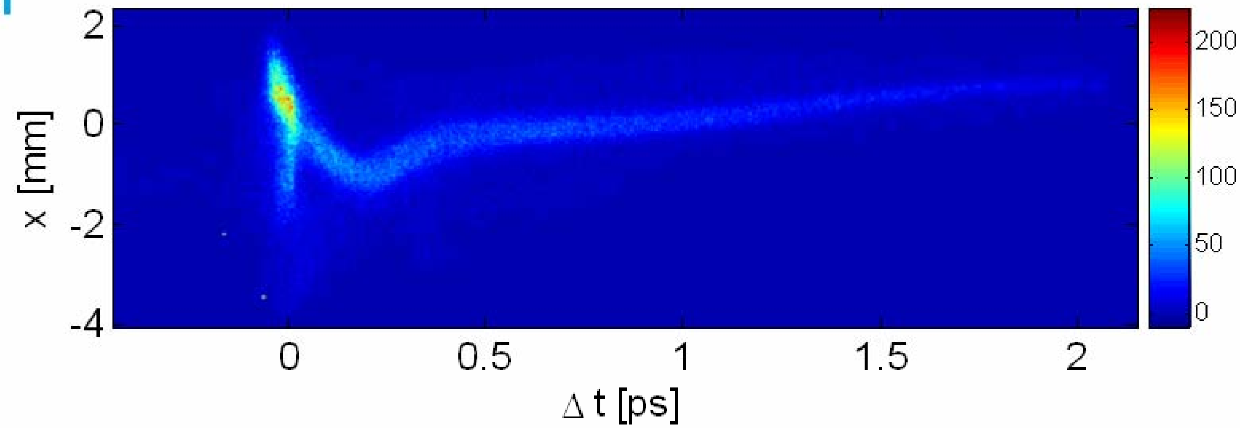
BROOKHAVEN NATIONAL LABORATORY

Andrew Burrill ERL Workshop 2007

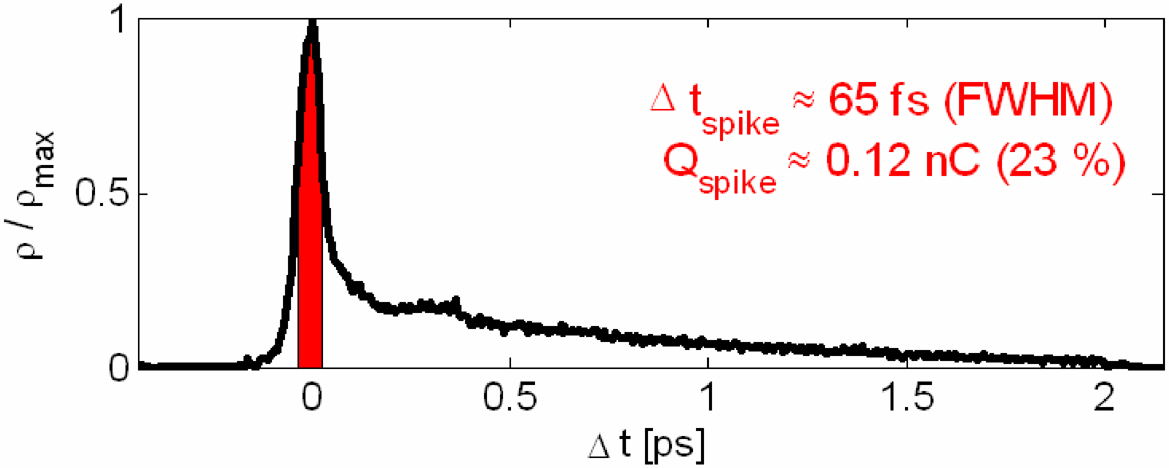
Office of Science U.S. DEPARTMENT OF ENERGY

Longitudinal Bunch Shape

- Measured with LOLA – S-band deflecting cavity
- resolution 10 to 50 µm



- Development of spike(s) observed as predicted
- It's the spike which carries the high peak current ~2 kA and is actually lasing



Courtesy S. Schreiber, DESY