Mitigation of RF Gun Breakdown by Removal of Tuning Rods in High Field Regions

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Tuner Breakdown

- Condition to > 7 MW

  Breakdowns occur, often catastrophic damage

  ⇨ New limit, much lower
- Examples:

  UCLA Neptune limit ~ 4.5 MW

  LLNL PLEIADES < 4 MW
- Lots of evidence in situ points to tuners…

The Solution

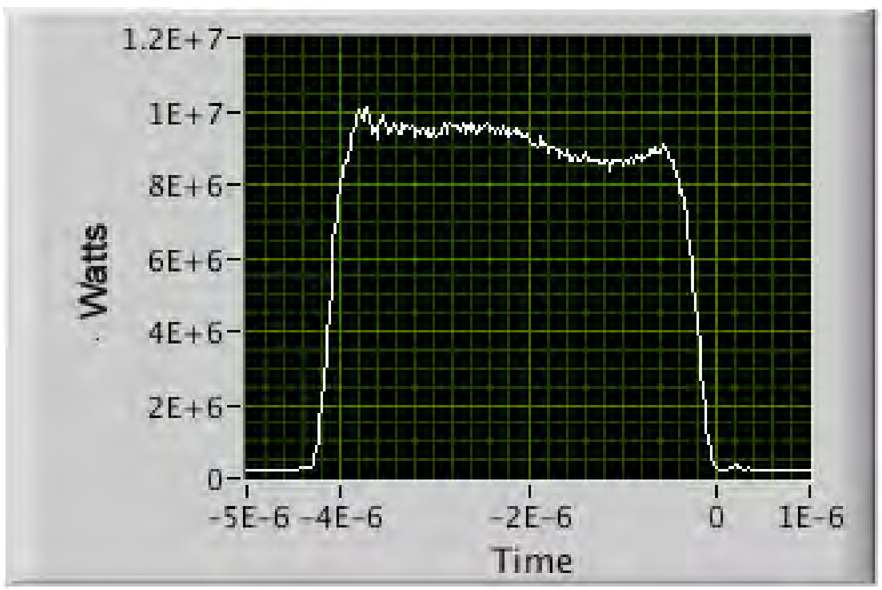
- Abandon inductive tuning with tuning rods
  - lose 2 MHz and a tuning knob!
- Cathode tuning not enough… requires lowering temperature too far
  - 44 KHz/deg → lower by ~ 45 deg

→ Stretch the full cell itself!!

High Power Conditioning

- Reached ~ 8.4 MW with unpolished Cu cathode
- Reached ~ 9 - 10 MW with polished Mg cathode
- Up from ~ 4.5 MW !!

Gun does work! Better!!!



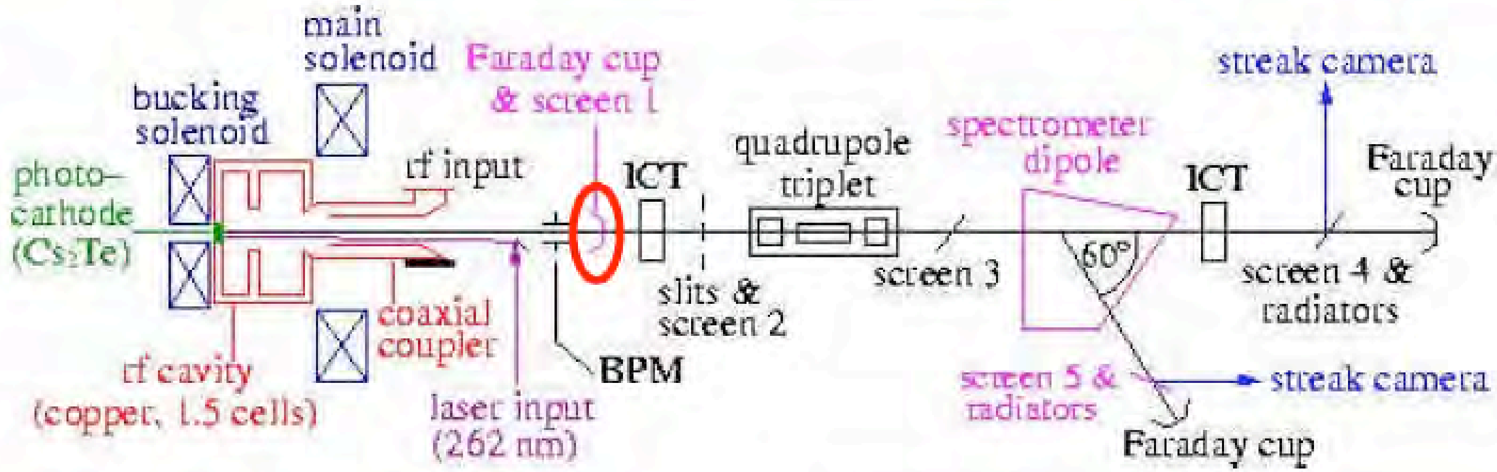
Multipacting at the photocathode in the rf gun cavity

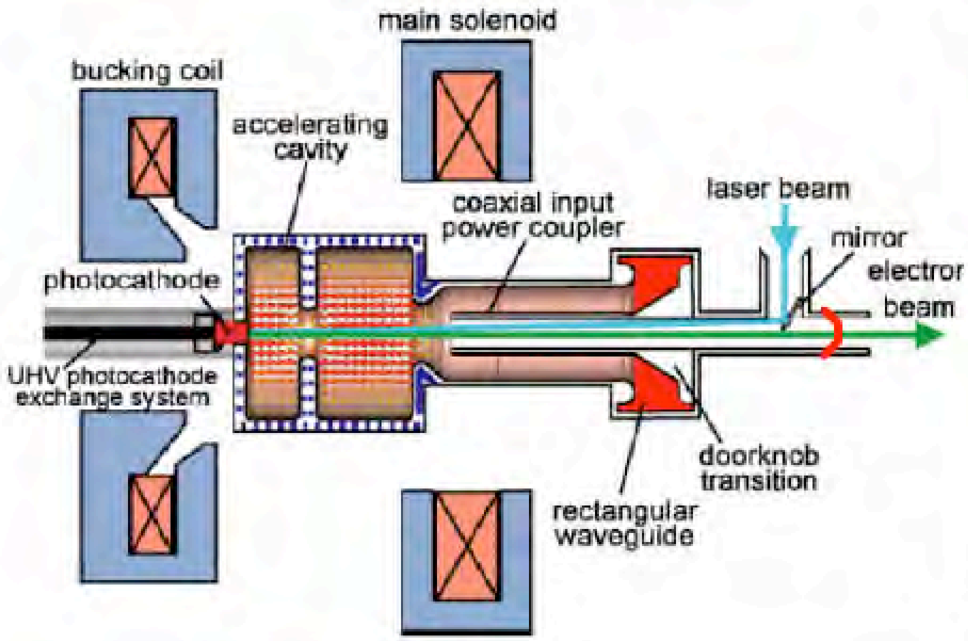
J. Han
DESY, PITZ
Erice, Italy, October 2005

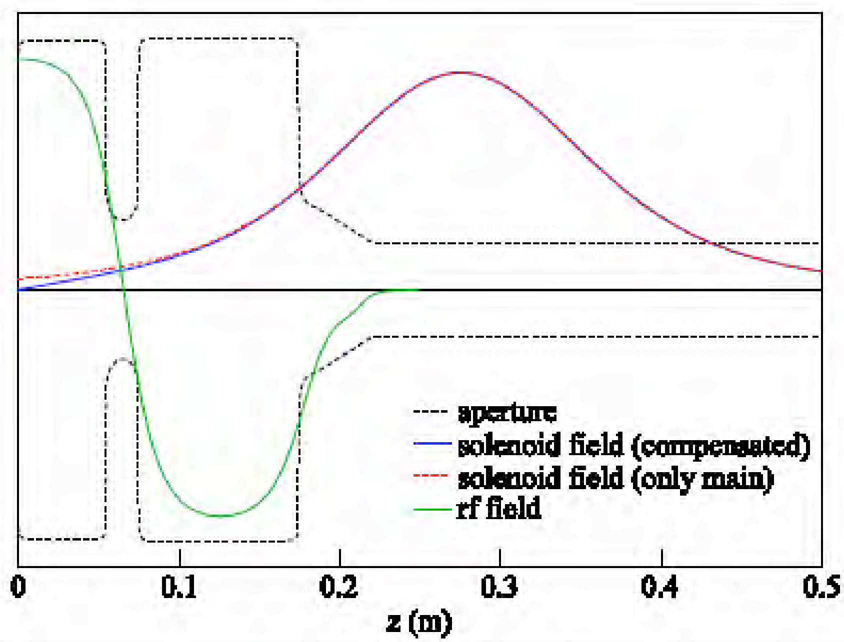
- Experimental observation
- Secondary emission model and test with beam dynamics
- Simulation of the electron multiplication process
- Summary

Measurement setup

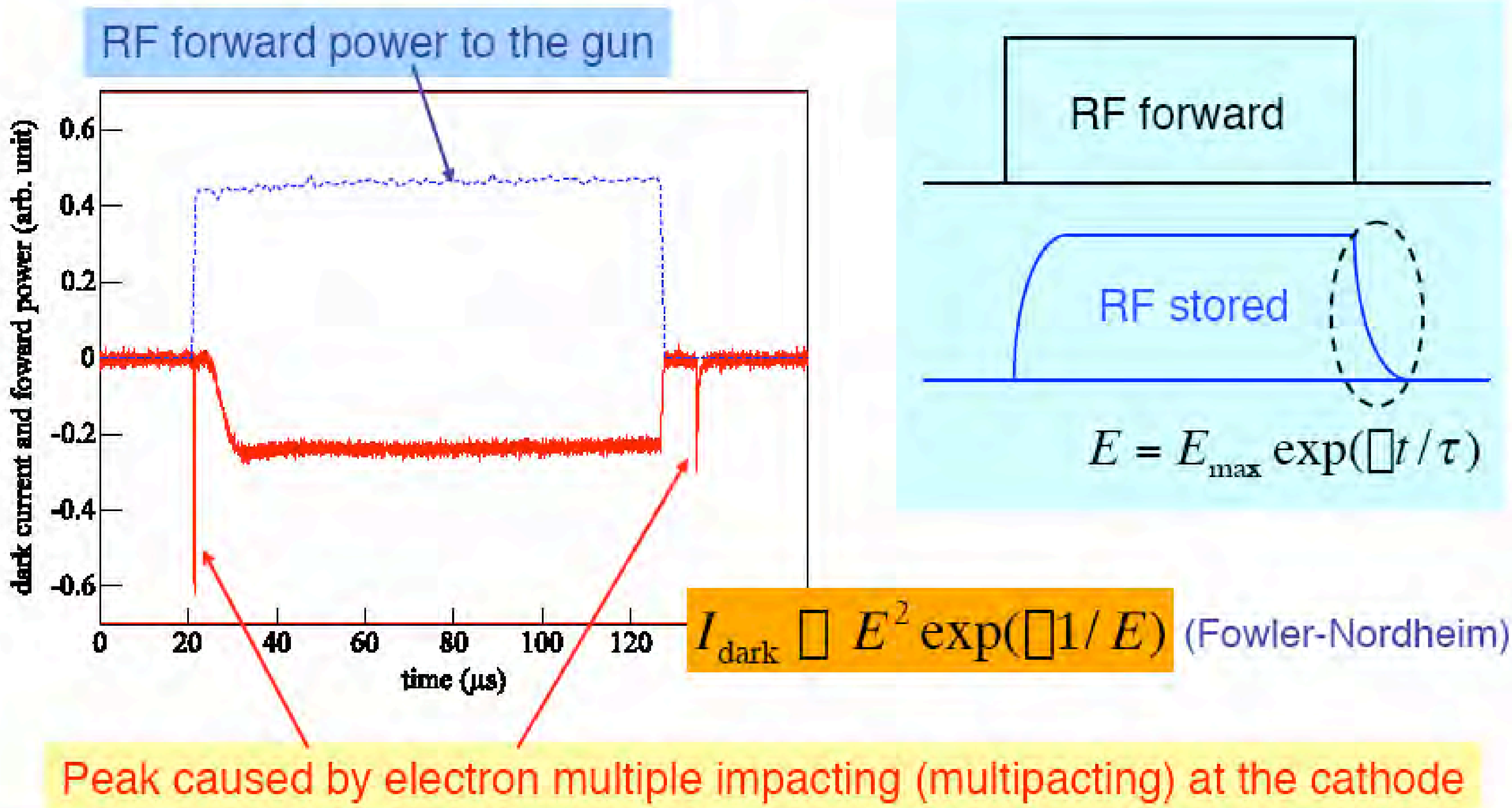
PITZ
Photo Injector Test Facility Zeuthen







Dark current measured with the Faraday cup 0.78 m from the cathode



Summary (I)

- Multipacting takes place at the Cs_2Te photocathode at a low rf gradient (~1MV/m) with a strong influence of the solenoid field configuration.

- Due to the high SEY of the photocathode (Cs_2Te), the multipacting cannot be pressed out.

- The position and the field configuration of the solenoids has to be determined in order to prohibit the multipacting as well as to keep the emittance small.

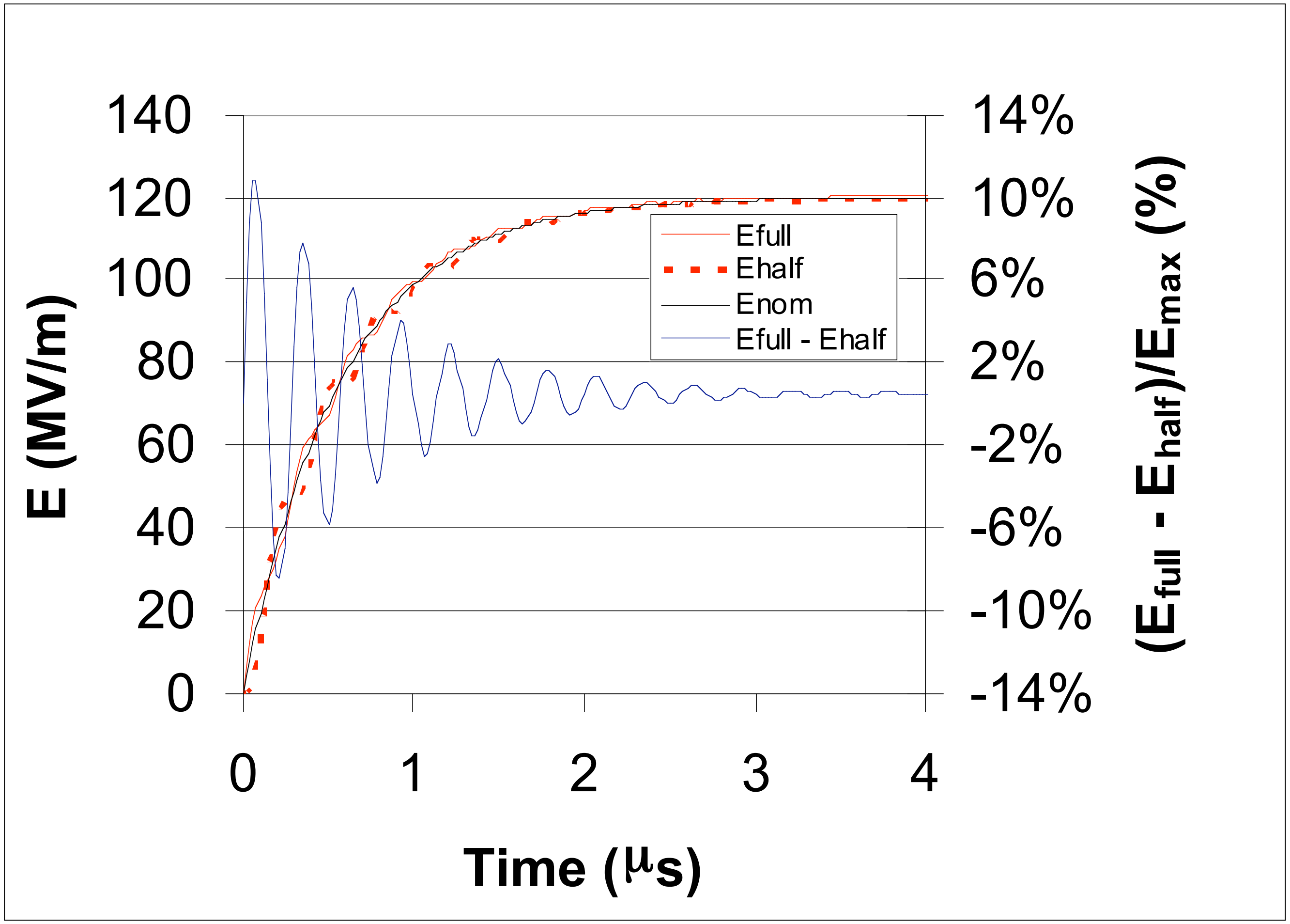
The 1.6 cell gun correlated energy spread dependence on π and 0 mode amplitude

John Schmerge, SLAC

October 11, 2005

- Motivation
  - Measured Correlated Energy Spread
  - Measured Longitudinal Phase Space
- Gun Characterization
  - Frequency Domain
    - Network Analyzer Measurements
    - Bead Drop
  - Time Domain
  - Step Function Response
- 0 mode interaction with π mode
  - Total field in cells
  - Simulated Energy Spread vs Phase
  - Future experiments

Transient Response Including 0 Mode



GTF

$f = 2856.00$ MHz

$f_\pi = 2856.03$ MHz

$f_0 = 2852.53$ MHz

$Q_{0\,\pi} = 11856$

$Q_{0\,0} = 11823$

$\beta_\pi = 1.30$

$\beta_0 = 0.69$

$\tau_\pi = 576$ ns

$\tau_0 = 779$ ns

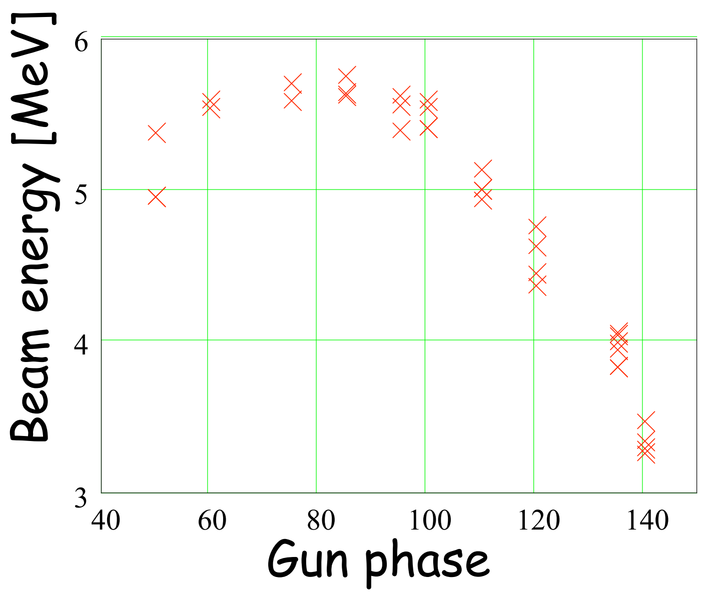
- 0 mode produces a measurable 3.5 MHz beating on the gun field
- Always a small steady state 0 mode term
  - Produces a small phase shift between cells in addition to 180° affects longitudinal phase space
  - 0 mode fields at cell to cell iris affect transverse phase space
  - Measured 0° phase (Schottky phase scan) determines phase with respect to total field not π mode field
- Simulations show 0 mode contributes to correlated energy spread
  - Best fit requires 10° phase shift of laser phase
  - Best fit requires 50% larger 0 mode amplitude

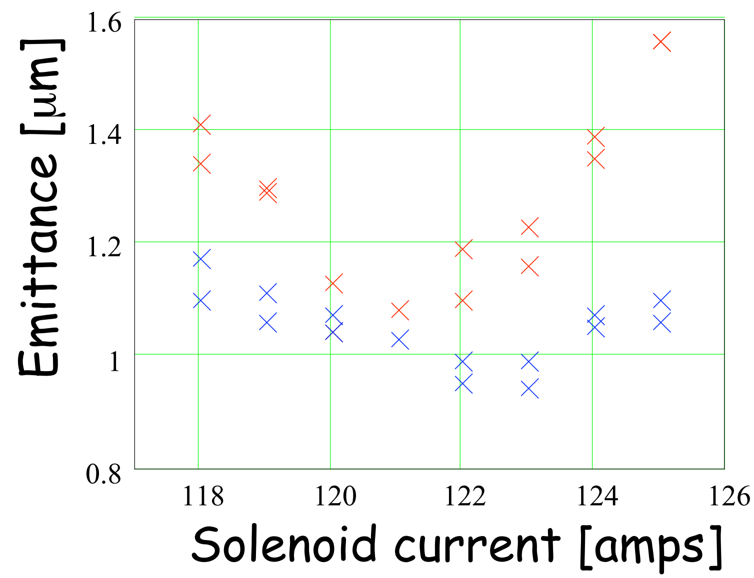
1.6 cell RF gun optimization for submicron emittance operation

Vitaly Yakimenko

October 11, 2005

Beam measurements





Beam charge 0.8 nC and 6.2 ps FWHM pulse length

Conclusion

- High gradient leads to better emittance
- Extremely high gradient shortens lifetime of the cathode?
- Use of tuners in the full cell may degrade gun performance
- Three important factors for submicron emittance:
  - laser profile uniformity;
  - alignment of the gun, solenoid and linac;
  - gradient in the gun

Emittance oscillation in the drift of split photoinjectors

Chun-xi Wang

Accelerator Physics Group/Advanced Photon Source

35th ICFA Workshop on the Physics and Applications of High Brightness Electron Beams
Erice, Sicily, Italy, October 9-14, 2005

“double-minimum” emittance oscillation

HOMDYN STUDY FOR THE LCLS RF PHOTO-INJECTOR[†]

M. Ferrario[1], J. E. Clendenin[2], D. T. Palmer[2], J. B. Rosenzweig[3], L. Serafini[4]

LNF-00/004 (P)
3 Marzo 2000

SLAC-PUB 8400

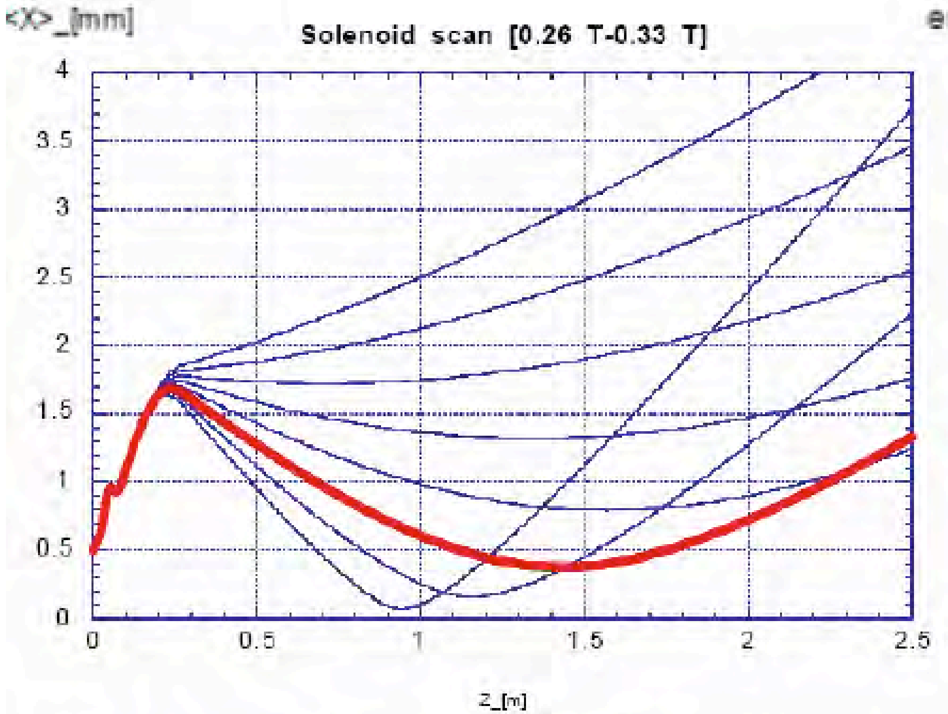


FIG. 10: Beam envelope versus z for different solenoid strengths.

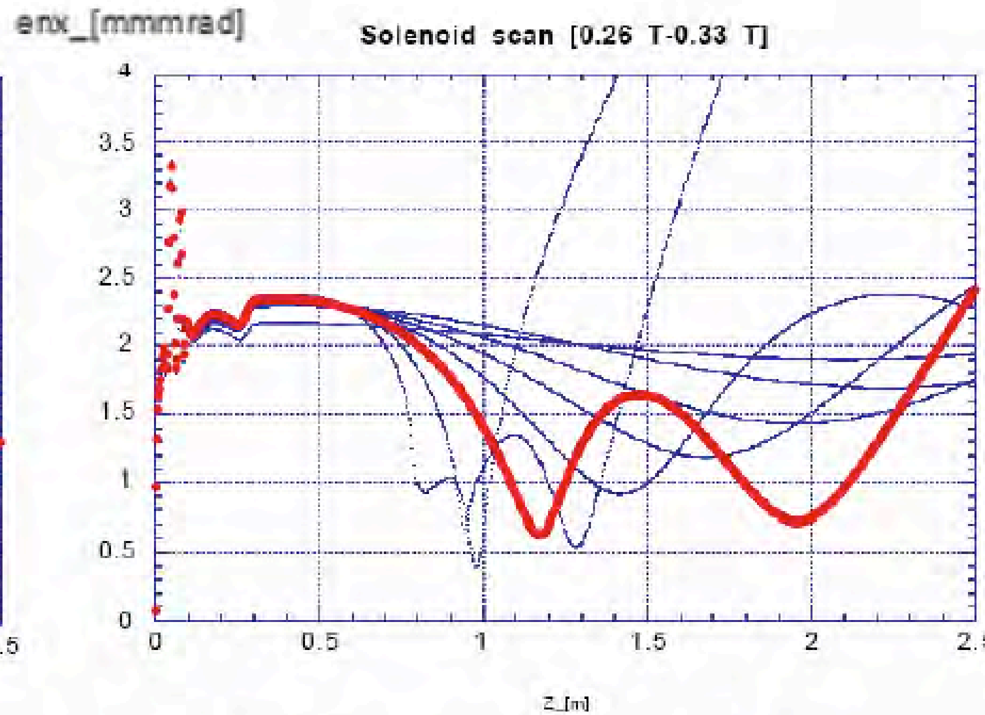
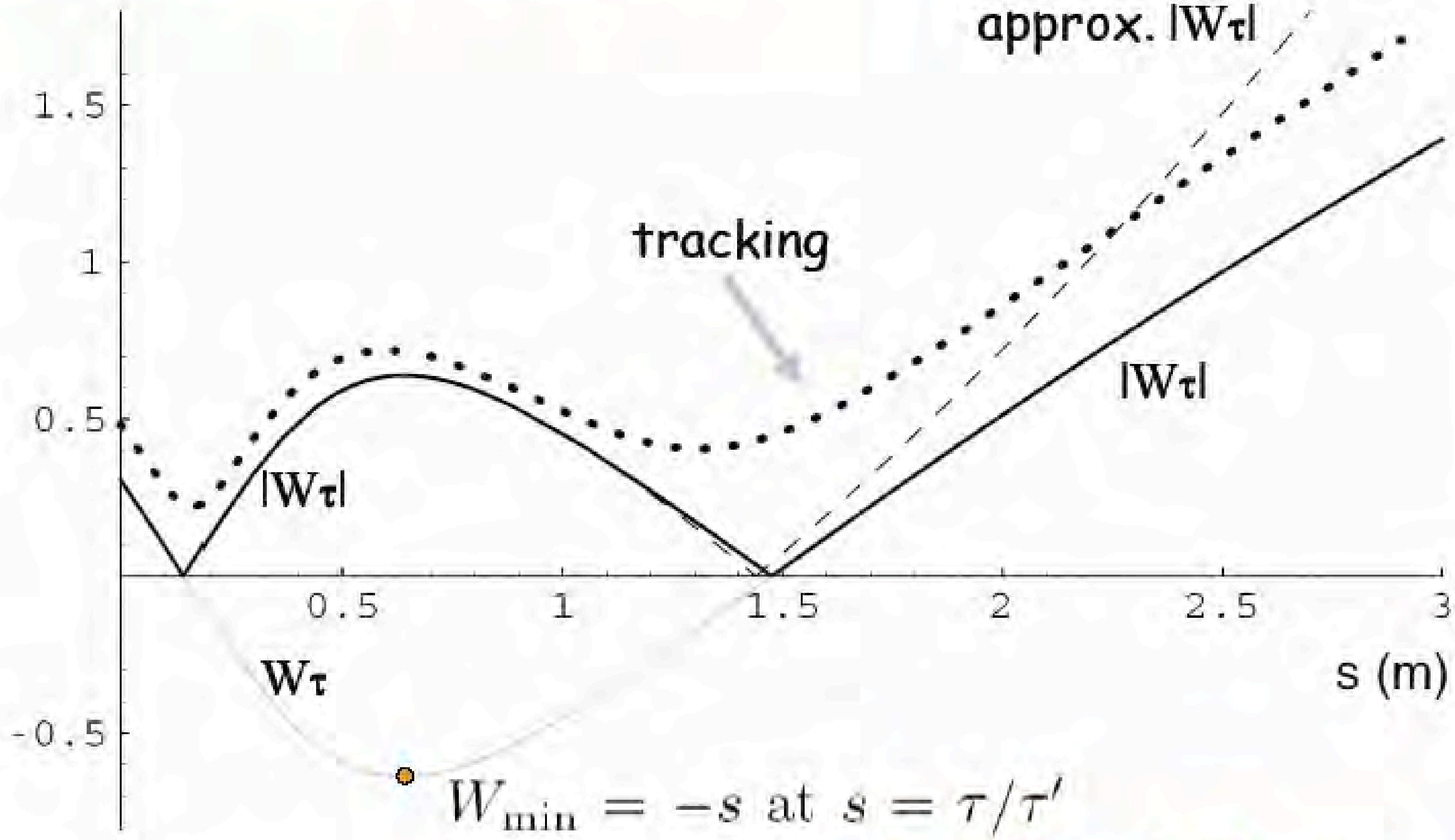


FIG. 11: Beam emittance versus z for different solenoid strengths.

Oscillations due to τ_0

$$\epsilon = |W_{\boldsymbol{\tau}}| \frac{(\Delta\tau_0)_{\rm rms}}{(\tau_0)_{\rm avg}} \;,\quad \mathbf{W}_{\boldsymbol{\tau}} = (\tau'^2 - 1)s - \tau\tau', \quad W'_{\boldsymbol{\tau}} = 2[(\tau'/\tau)s - 1] = 0$$

normalized emittance in τ-space



not at the waist location

The hybrid TW-SW photoinjector

David Alesini
for the hybrid gun study group*

(LNF-INFN, Frascati, Rome)

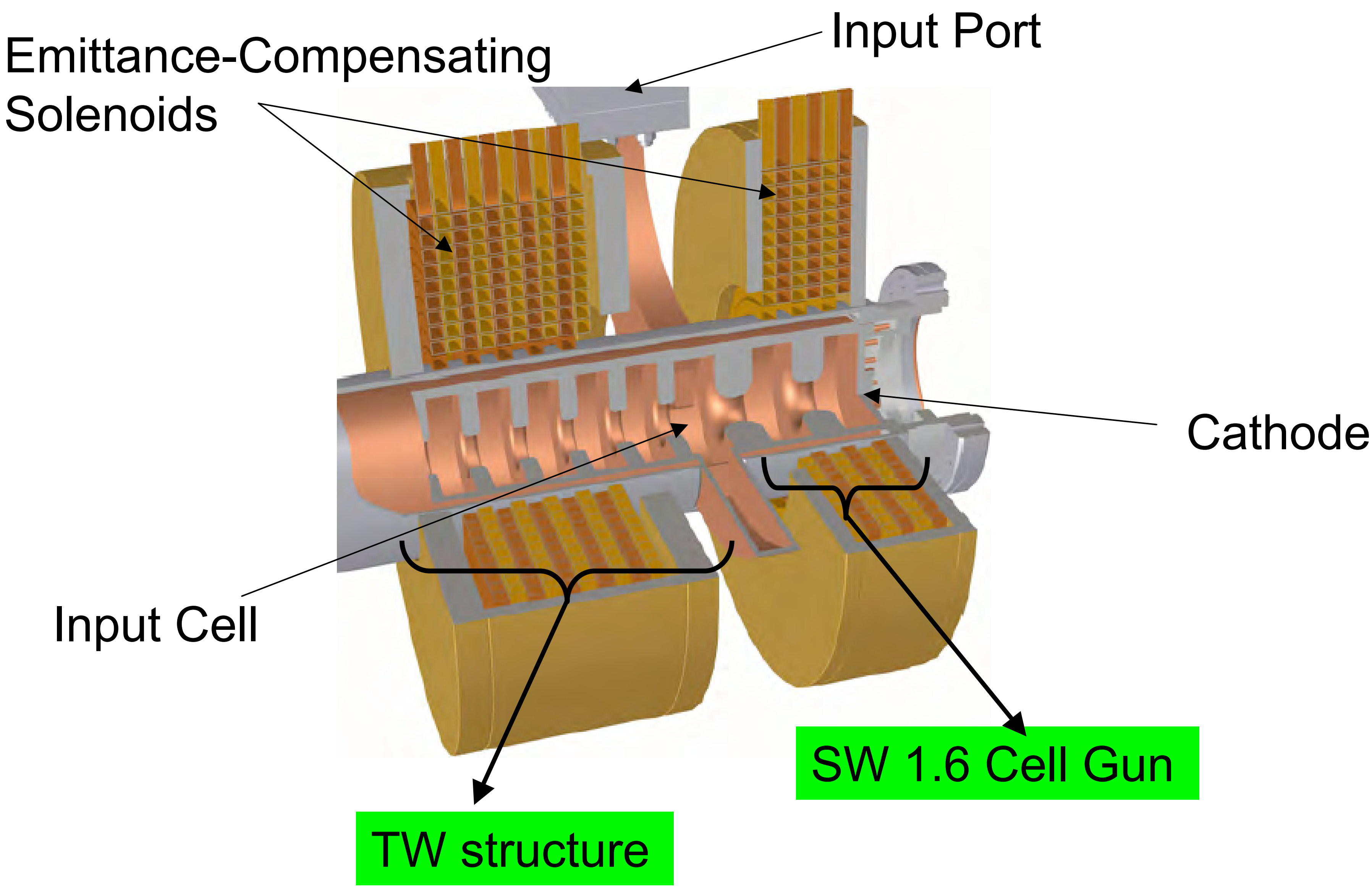
UCLA

INFN Istituto Nazionale di Fisica Nucleare

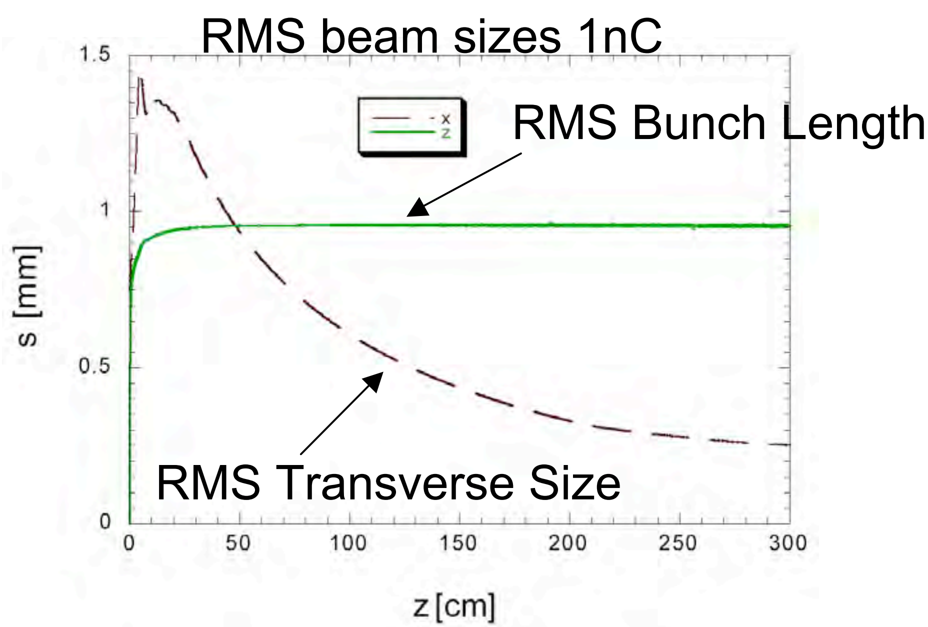
La Sapienza Università degli Studi di Roma

***J. Rosenzweig, B. O'Shea, L. Palumbo, A. Mostacci, B. Spataro, G. Caretti, A. Marinelli**

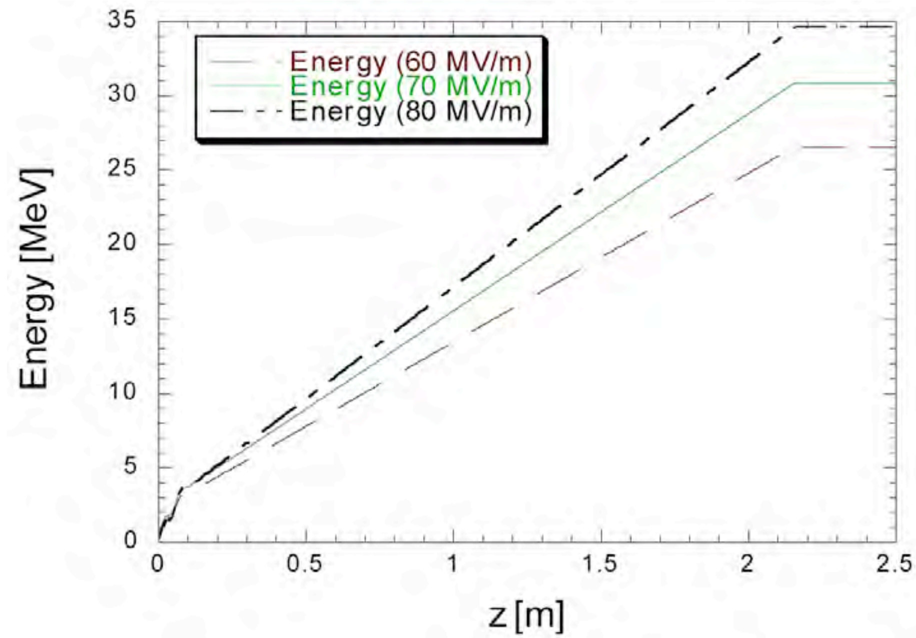
1) The Idea: sketch

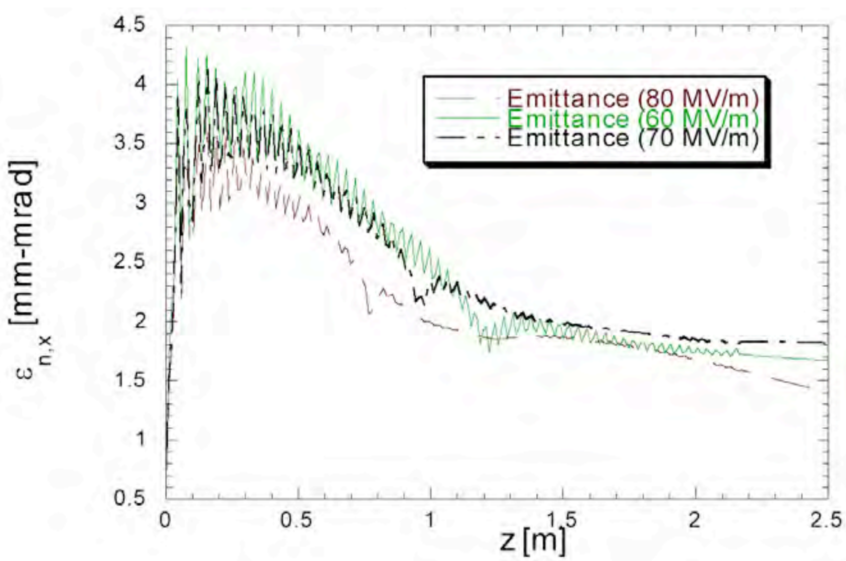


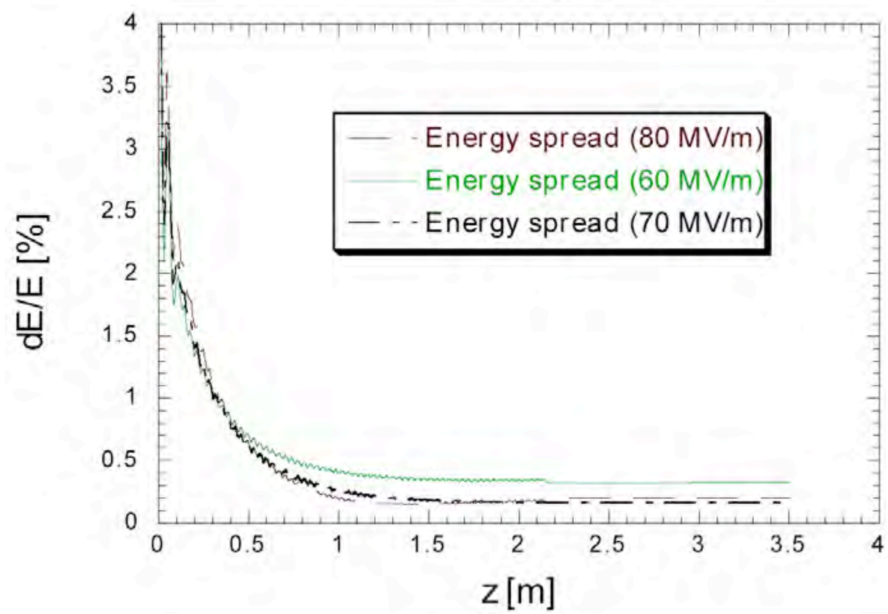
2) Beam dynamics simulation results



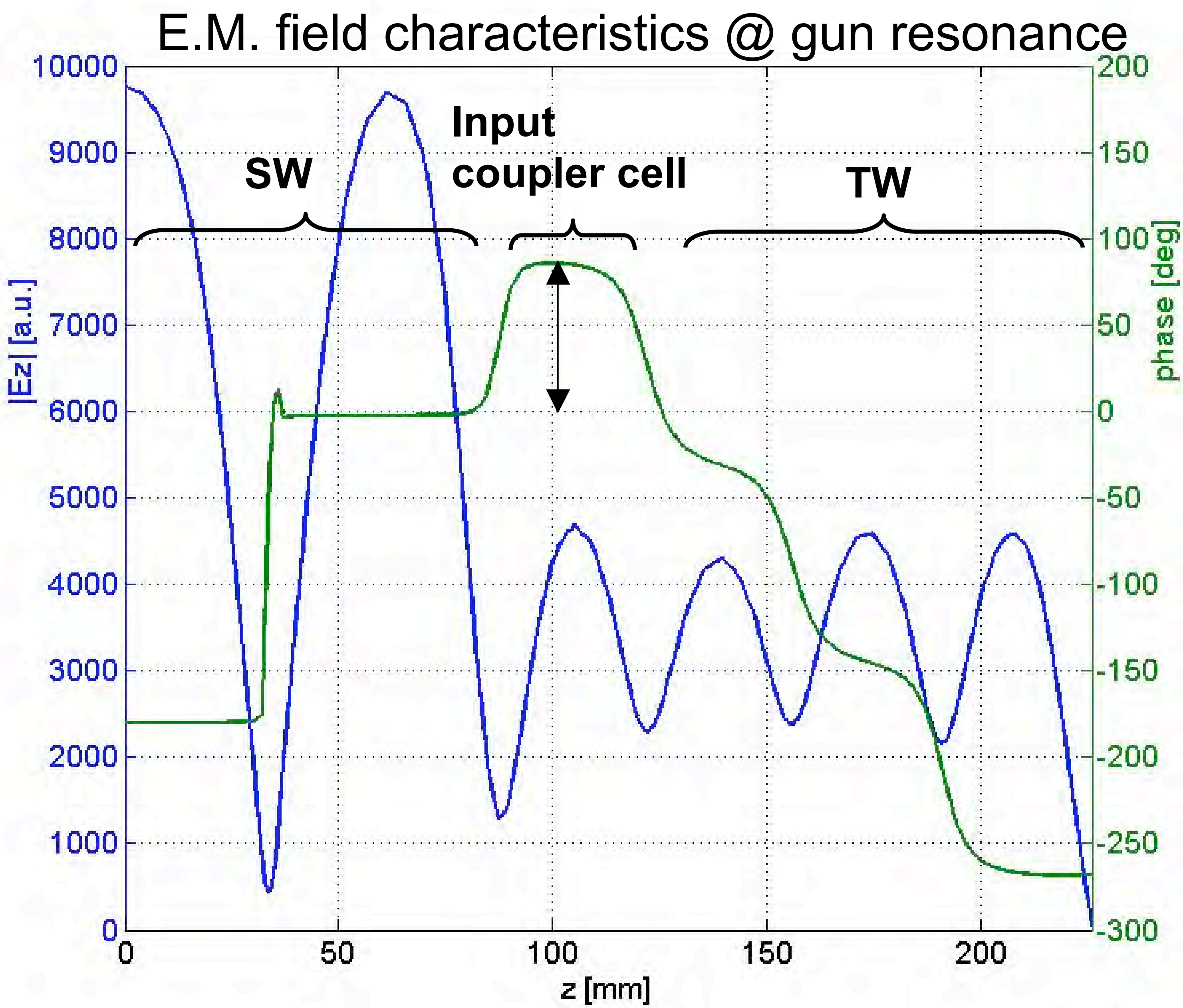
Energy Tunability







3) Electrom. design: adiabatic coupling SW –TW, coupling iris increase(3/3)



CONCLUSIONS

1) Hybrid SW-TW gun is a ***very promising device*** from the point of view of compactness simplicity, efficiency and beam dynamics;

2) ***RF design is not trivial*** but feasible: different ways to tune the gun have been investigated.

TO BE DONE

1) ***Final structure dimensions have to be found*** to perfectly matched the TW to the SW cavity from the point of view of E_z phase

2) Understand ***transient RF response*** (as well as steady state)

3) Different ***modes of operation*** have to be investigated from the beam dynamics point of view (SW cavity slightly detuned, temperature tuning,…)

4) Possible ***RF measurements*** on the device have to be analyzed

5) Beam dynamics optimization.

Design and RF Measurements of an X-band Accelerating Structure for the Sparc Project

INFN-LNF ; UNIVERSITY OF ROME LA SAPIENZA ; INFN - MI

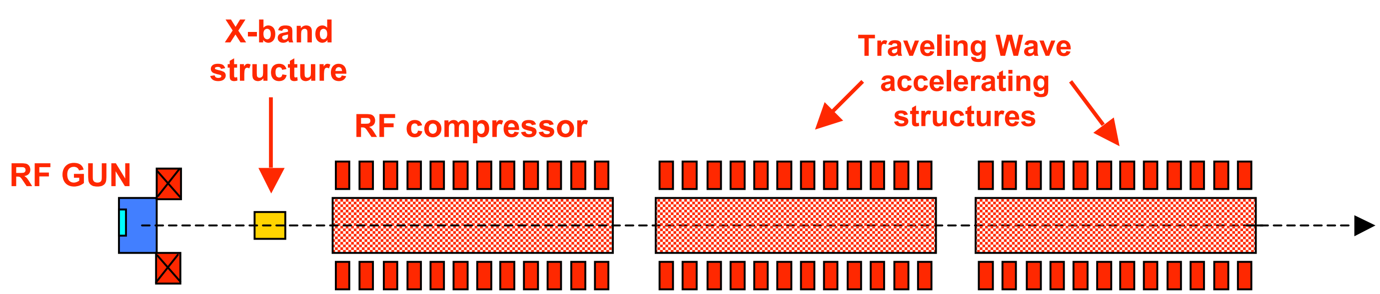
Presented by
BRUNO SPATARO

Erice, Sicily, October 9-14; 2005

SALAF (**S**trutture **A**cceleranti **L**ineari ad **A**lta **F**requenza)
is the INFN r&d programm on
" multicell resonating structures"
operating at X-band (10 ÷ 12 GHz).

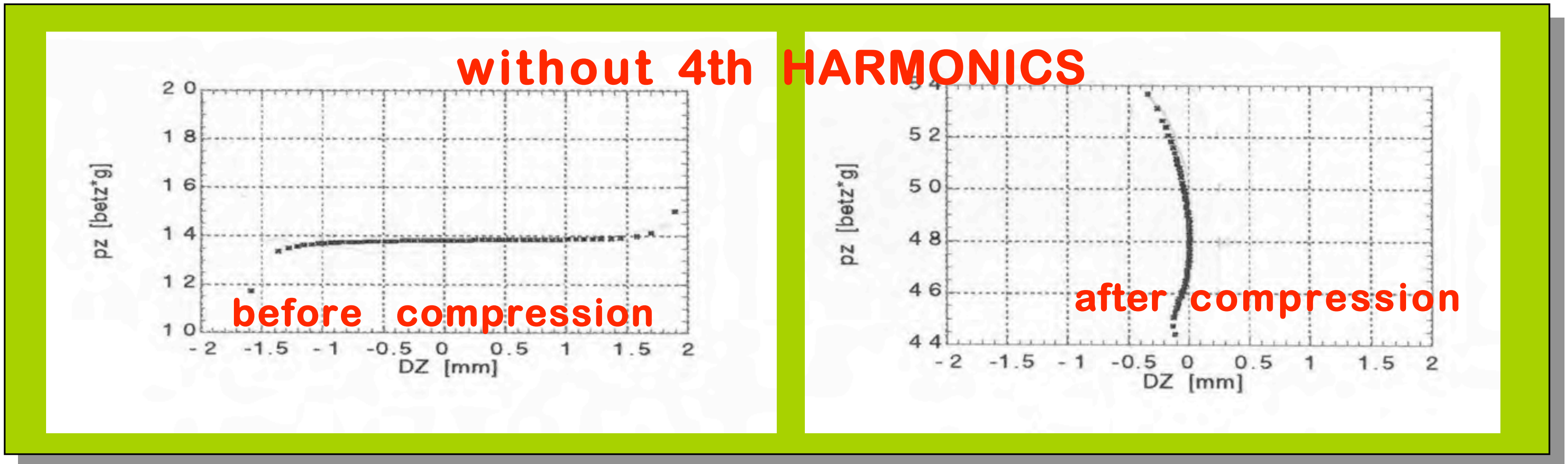
the MOTIVATION …….

- **To use in high brilliance photo-injectors *(SPARC-phase-2)* to compensate for the beam longitudinal phase-space distortion, enhanced by the bunch compression of the acceleration process**
- **To gain know-how in vacuum microwave technologies**

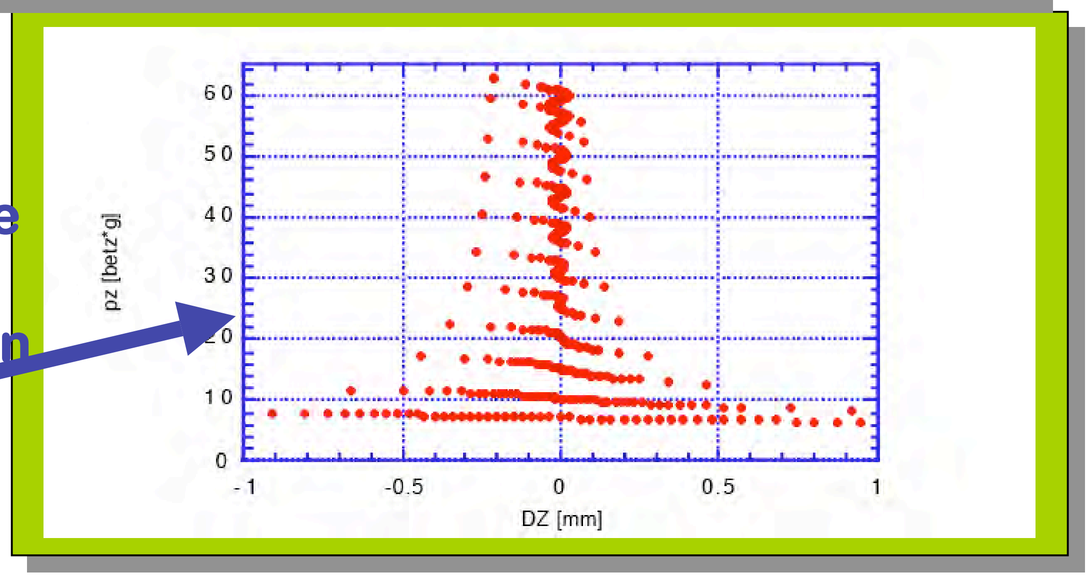


Correction of the Phase-Space distortion

- The 4th harmonic structure provides RF curvature local correction.
- Beam longitudinal emittance hold within limited values.
- Minimum bunch length achieved.

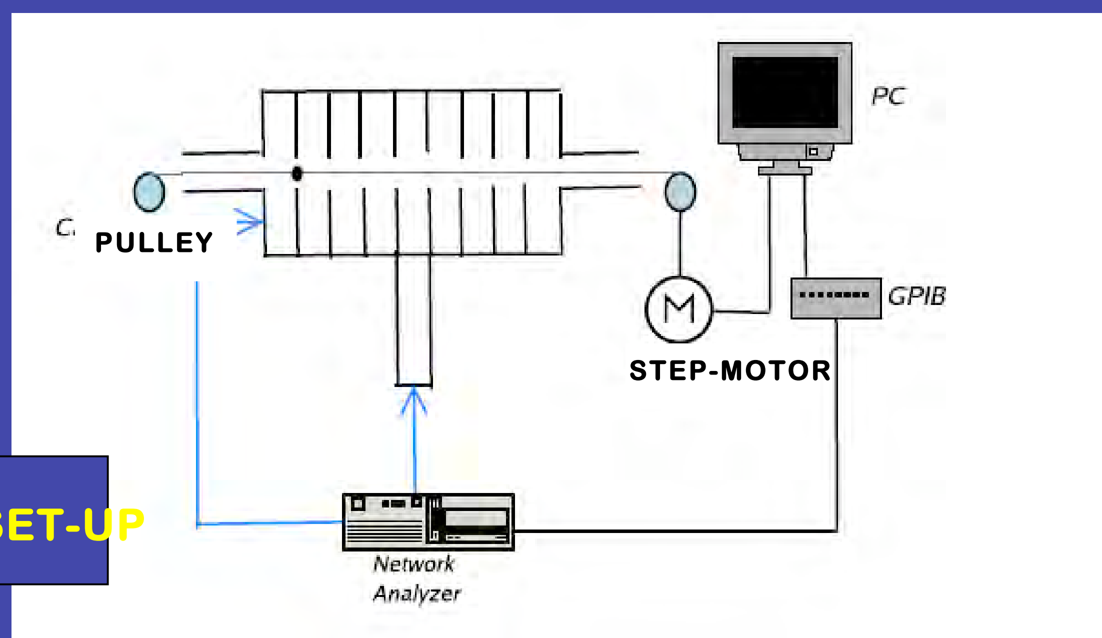


time evolution of the beam phase-space with RF compression + 4th Harmonics



CHARACTERIZATION OF THE X-BAND STANDING-WAVE COPPER MOD

RF MEASUREMENT SET-UP



BEAD-PULL MEASUREMENT SET-UP

-BAND COPPER PROTOTYPE MAIN PARAMETERS

π-mode frequency	11.424 GHz
Form factor r/Q	9400 Ω/m (*9165*)
Unloaded Q	7960 (*8413*)
External Q	8000
E-Field flatness	< 1 %
Number of cells	9
Structure length	110 mm

In red, the theoretical values

CONCLUSIONS

- FIRST R&D ACTIVITY on X-BAND STANDING WAVE DISK-LOADED STRUCT STARTED SUCCESSFULLY.
- IMPORTANT KNOW-HOW ASPECTS of the E.M DESIGN and FABRICATION of X-BAND ACCELERATING SECTIONS HAVE BEEN ACQUIRED
- FUTURE ACTIVITY : ⇨ CARRY OUT BRAZING PROCESS to VERIFY the VACUUM PERFORMANCES of a CAVITY

  ⇨ DEVELOPE a π/2-MODE STRUCTURE TO CH E.M. SENSITIVITY vs FABRICATION ERROR

Analysis of thermal emittance measurement at PITZ

Jang-Hui Han
DESY, PITZ
Erice, Italy, October 2005

- Measurement procedure
- Review of the Floettmann model
- Effective electron affinity due to the rf field
  → kinetic energy of emitted electron
- Analysis of the measurement
- Summary

Analysis of measurement (I)

PITZ
Photo Injector Test Facility Zeuthen

$$\varepsilon_{\text{meas}} = \sqrt{\left(\varepsilon_{\text{meas}}^{\text{therm}}\right)^2 + \left(\varepsilon^{\text{rf}}\right)^2 + \left(\varepsilon_{\text{slit.meas}}^{\text{sys.error}}\right)^2}$$

$$\varepsilon_{\text{meas}}^{\text{therm}} = \eta\, \varepsilon_{\text{theory}}^{\text{therm}}$$

$\varepsilon_{\text{meas}}^{\text{therm}}$: emittance from the real beam quality

η: discrepancy parameter between the measurement and the theory
might be from
imperfection of the model,
roughness and non-uniform QE of the cathode surface,
rf jitter (rf power, rf phase …), laser jitter (position, intensity)
measurement error of the laser spot size

$\varepsilon_{\text{theory}}^{\text{therm}}$: theoretical value expected by the Floettmann model

ε^{rf} : originated from the finite size of the beam under the rf field
← can be found with a simulation using the corresponding machine parameters

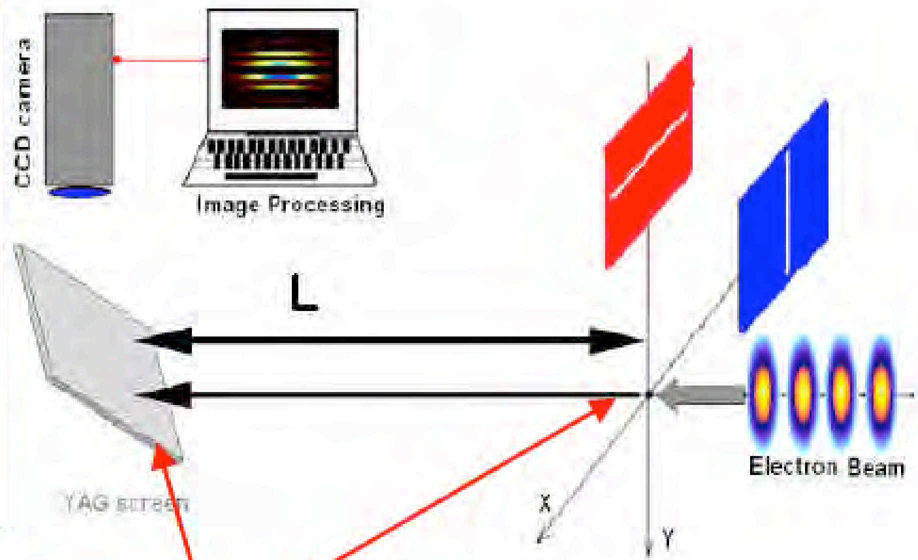
PITZ

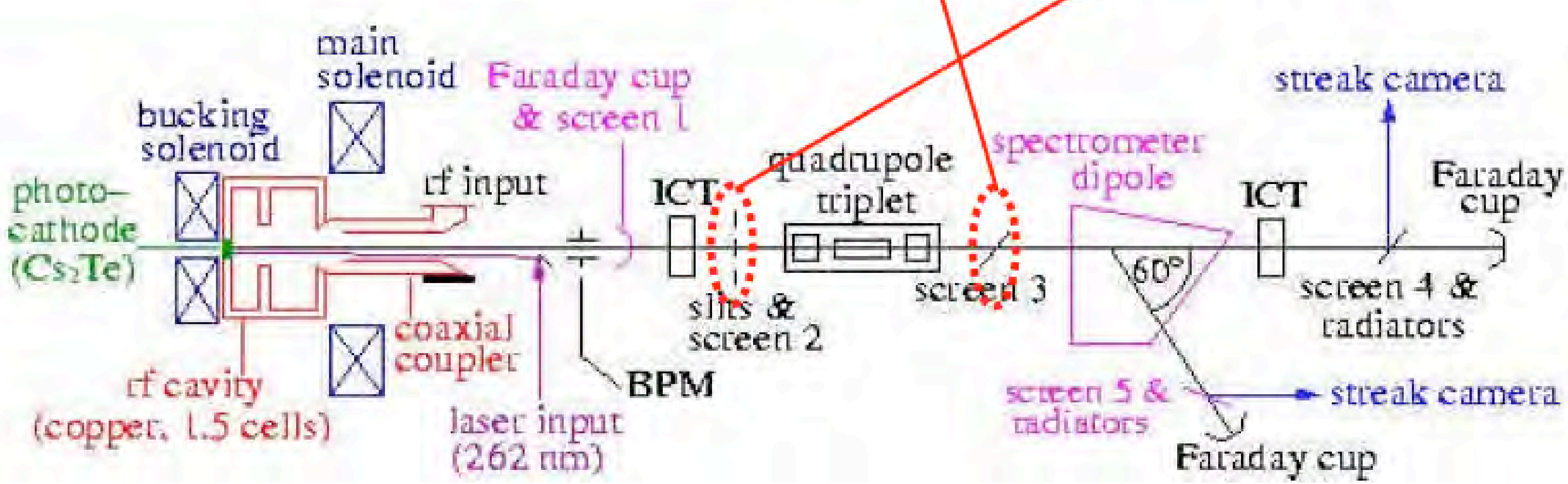
Test facility for electron source of FELs

- 1 mm mrad @ 1 nC with stable operation

Extensive R&D on photoinjectors in parallel with TTF operation

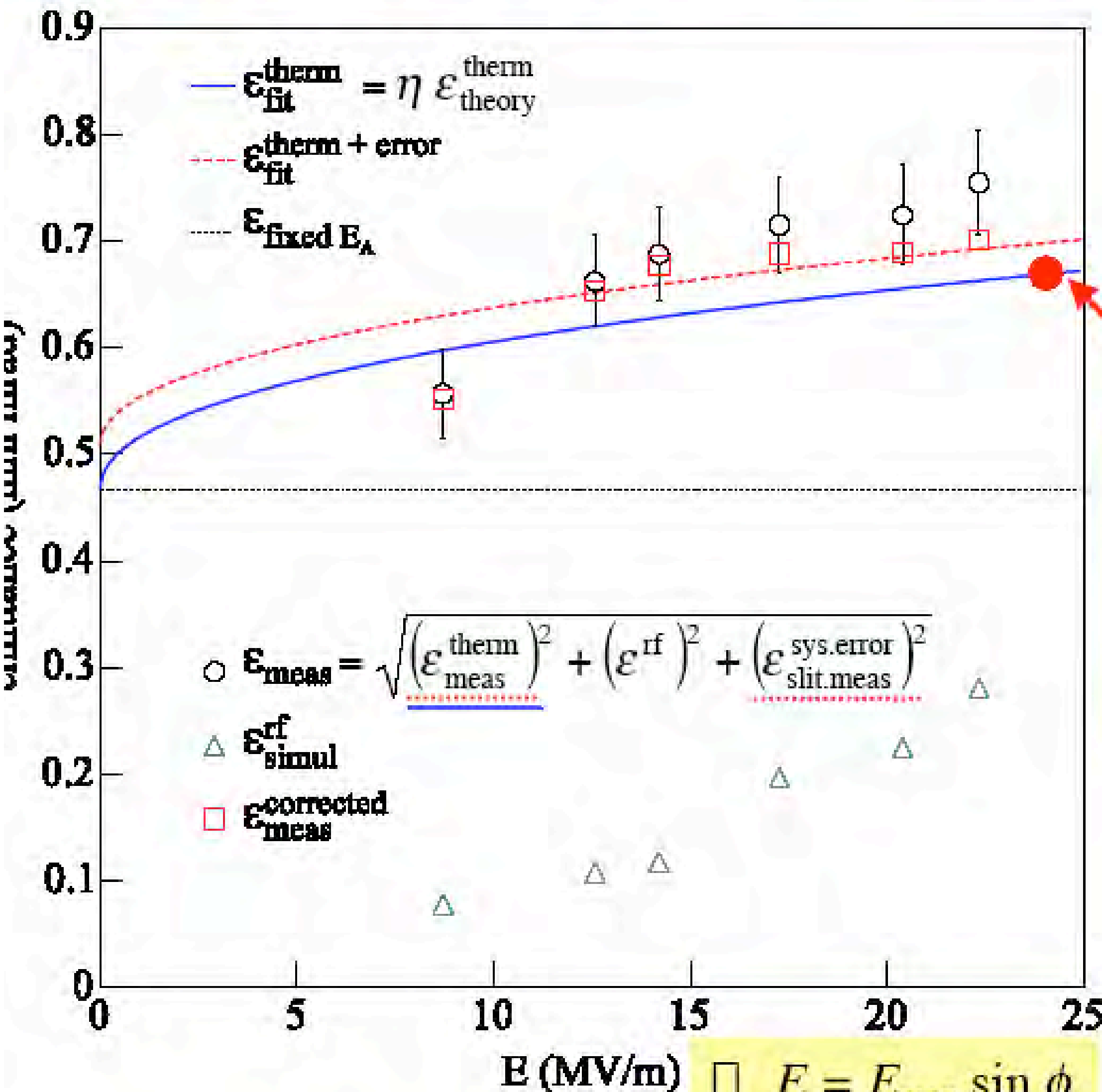
1.5 cell rf cavity operated with 1.3 GHz





Analysis of measurement (III)

PITZ
Photo Injector Test Facility Zeuthen



$E = E_{max} \sin \phi$

laser spot size ~ 0.55 mm
bunch charge ~ 3 pC
η = 1.34

~0.68 mm mrad (r_{rms} = 0.55 mm)
at PITZ1 & VUV-FEL (TTF2)
operating condition
E_{emit} ~ sin 35° x 42 (MV/m)
~ 24 MV/m

Summary

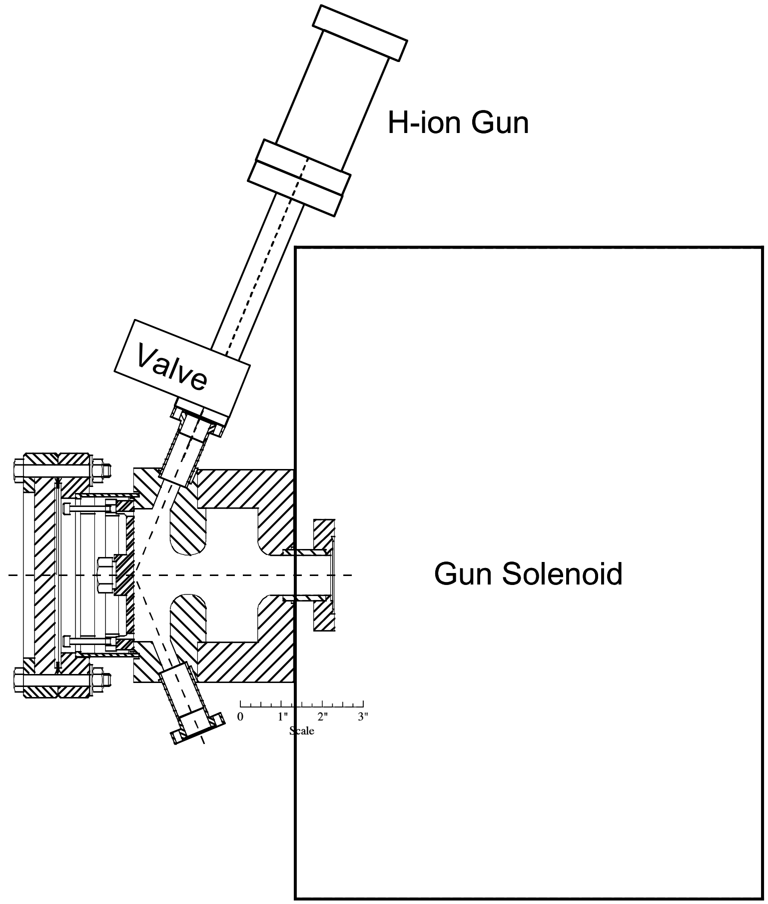
- The kinetic energy of emitted electron varies with the applied rf field strength at the cathode.
- The parameters in the Schottky effect have been found with bunch charge measurement vs. rf gradient.
- Between the measured and the theoretical thermal emittances, a discrepancy of 34% exists.
  This discrepancy must be understood.
- In parameter optimization for the electron beam of the XFEL, the electron affinity variation due to the rf field strength has to be considered.

H-Beam Cleaning of Metal Cathodes

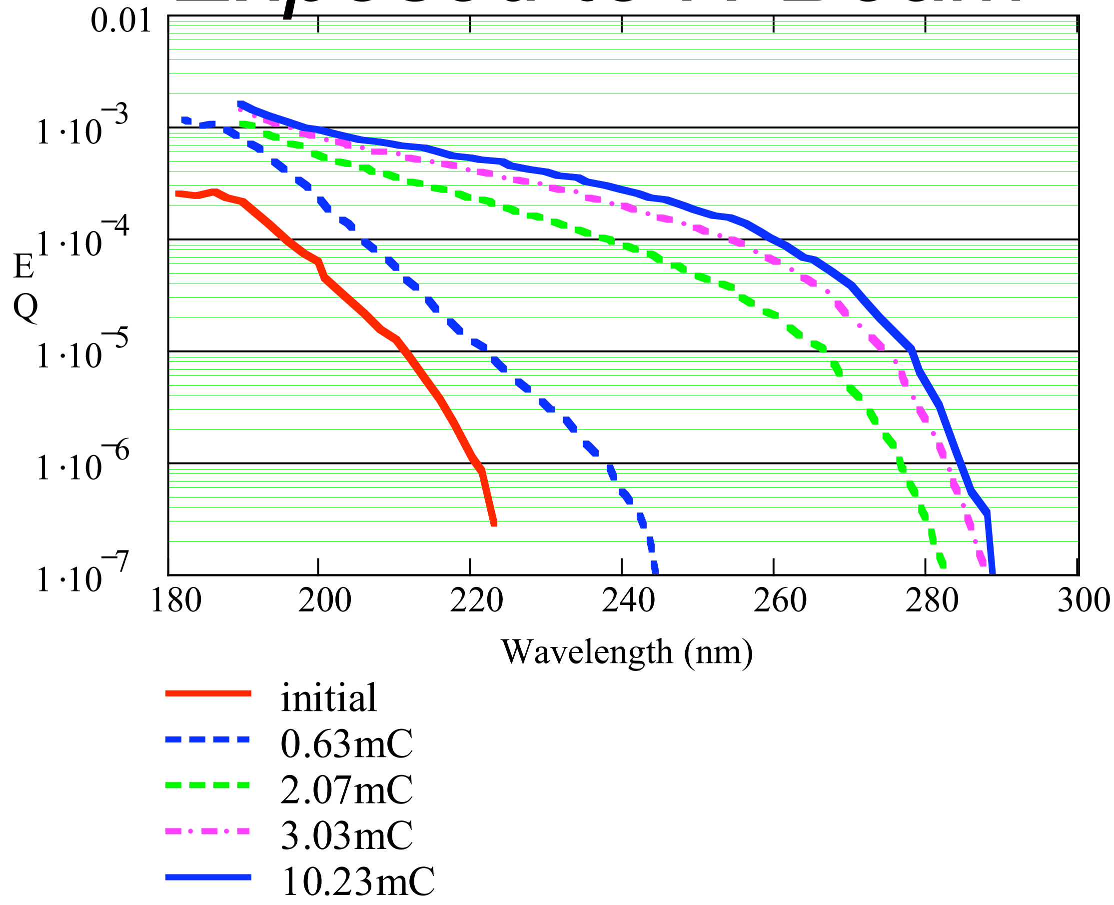
David H. Dowell
SLAC & LCLS

Introduction
Cleaning and Measurement of Metal Cathodes
Extraction of Work Functions
Comparison with Theory
Implementation into cathode processing and on gun

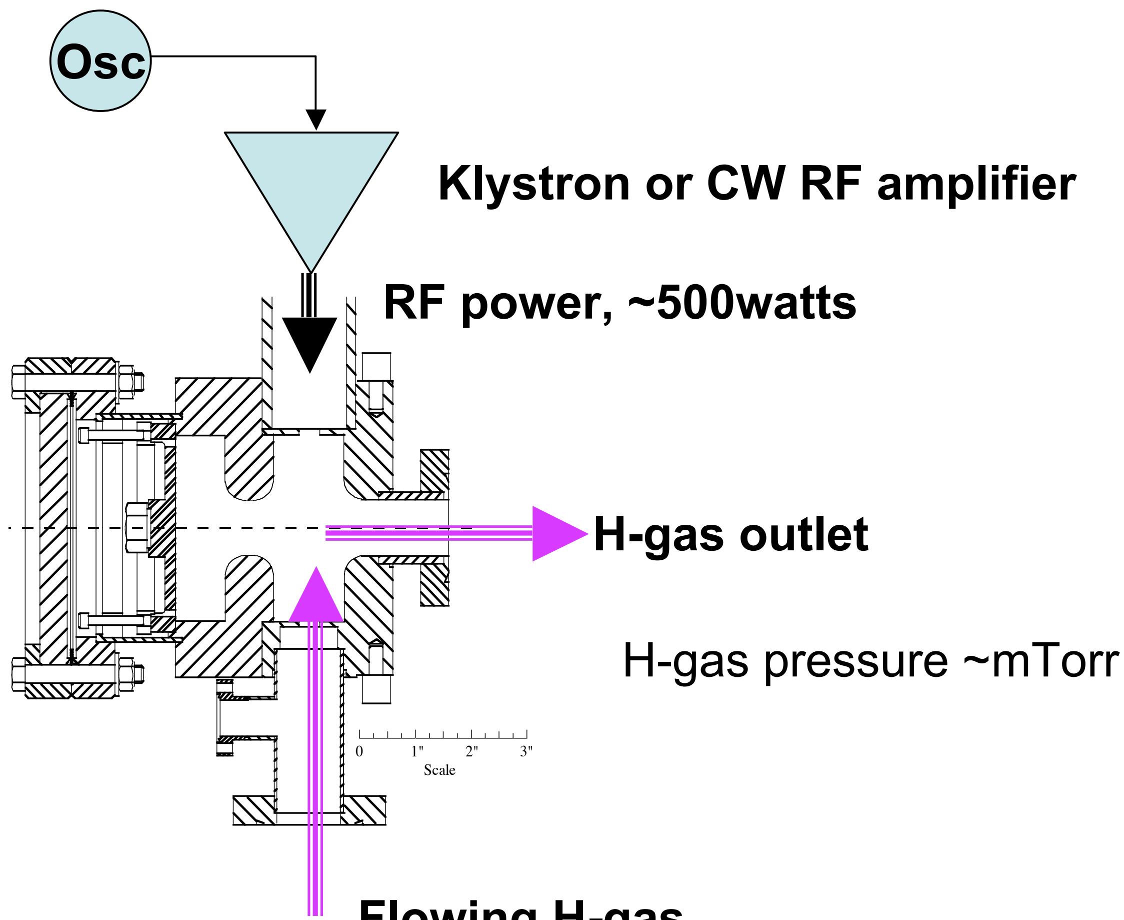
Possible Implementation on S-band Gun



QE vs. Wavelength with Increased Exposed to H-Beam



RF Plasma Cleaning of Gun & Cathode



Summary and Conclusions

H-beam and Plasma Cleaning is a promising technique for producing atomically clean surfaces

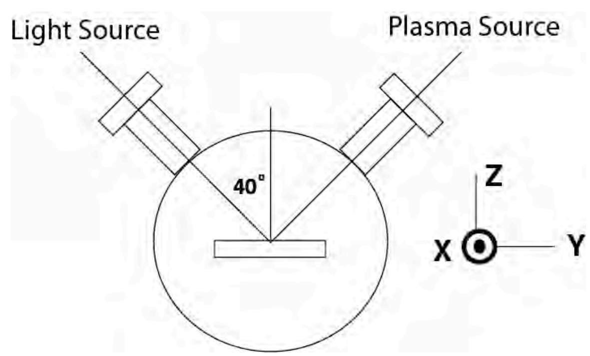
Excellent comparison of work function with theory

Plans for implementing on the RF gun is in progress

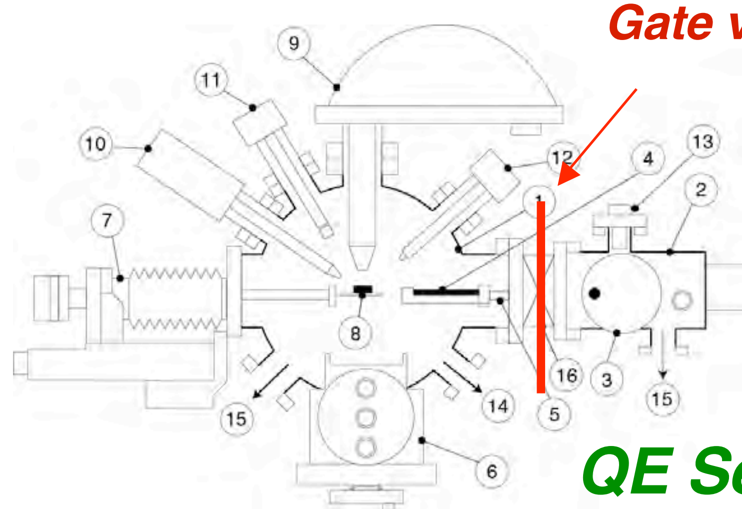
- *Cathode processing before installation*
- *In-situ processing*

XPS & QE Experiment Setup

Material Poly Cu

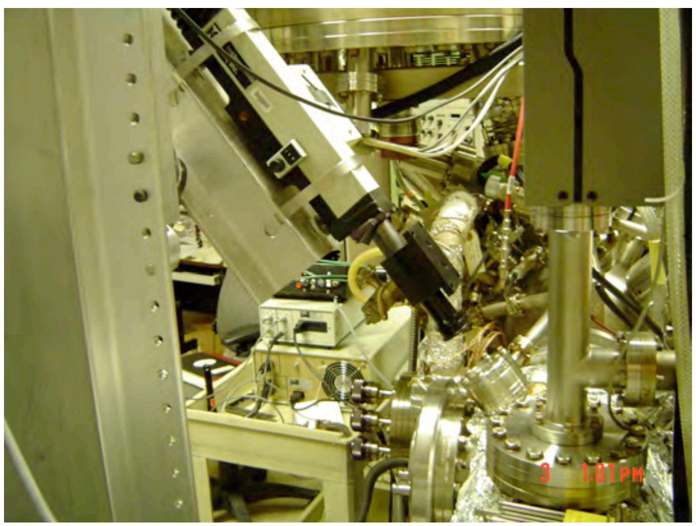


Gate valve



QE Setup

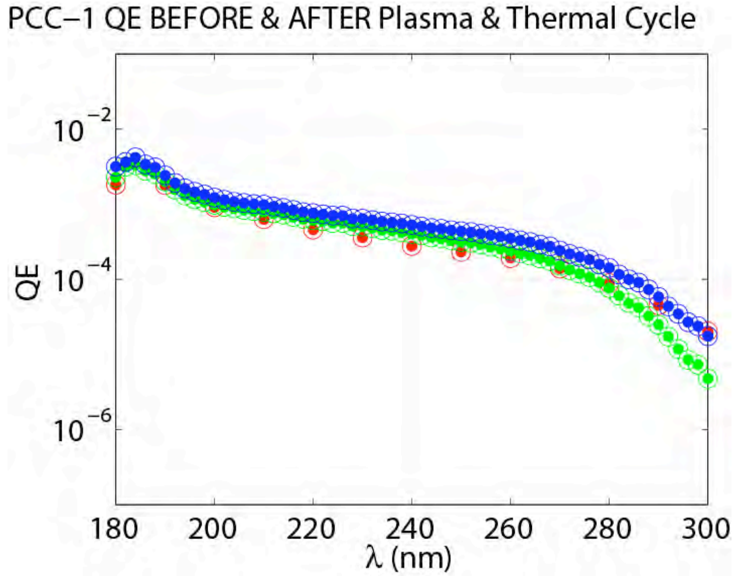
QE Setup

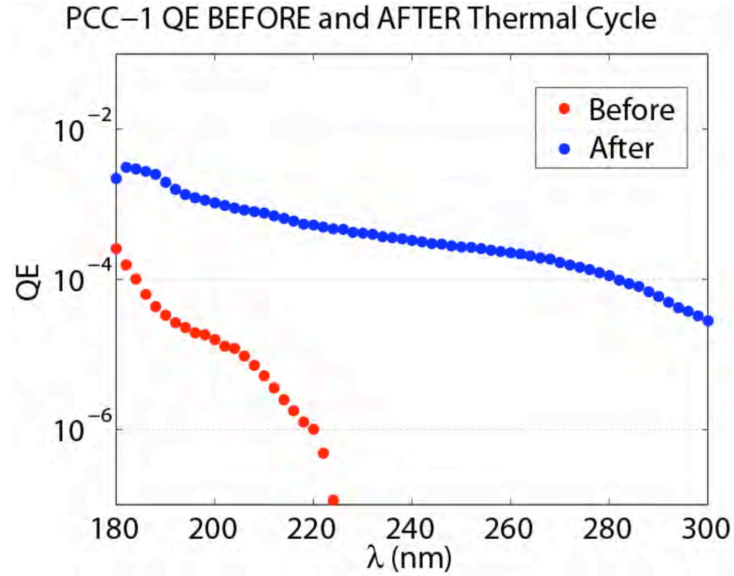


XPS Setup

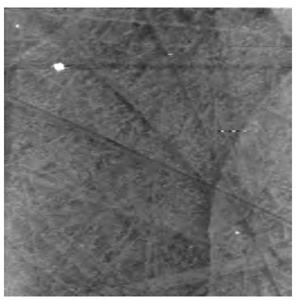
1. Analysis chamber	9. Electrostatic energy analyzer
2. Loadlock chamber	10. X-ray source
3. Sample plate entry	11. SEY/SEM electron gun
4. Sample transfer plate	12. Microfocus ion gun
5. Rack and pinion travel	13. Sputter ion gun / DUV window
6. Sample plate stage	14. To pressure gauges and RGA
7. XYZ Θ Omniax™	15. To vacuum pumps
8. Sample on XYZ Θ	16. Gate valve

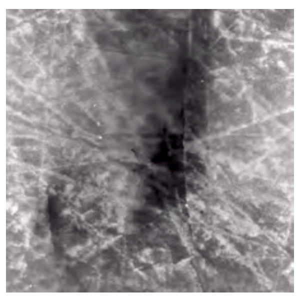
PCC-1

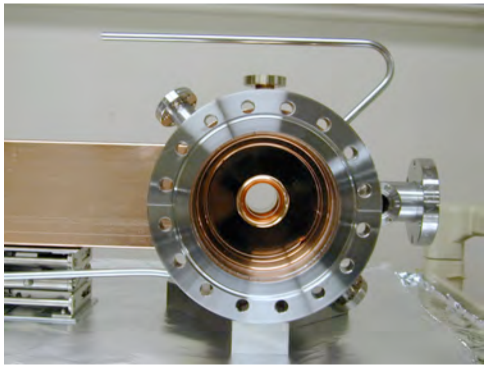


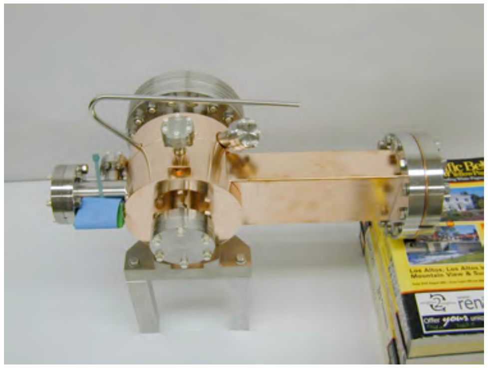


TOPOGRAPHY Results









Master_0   PCC-1

	Before		After	
	R_a (nm)	R_{pp} (nm)	R_a (nm)	R_{pp} (nm)
Master_0	12.3	17.2	15.8	20.1
PCC-1	14.0	17.9	20.7	25.8

Time Dependent Emission from Metal Cathodes

John Schmerge, SLAC

October 10, 2005

- Motivation
  - Schottky Scan
  - Charge vs Laser Energy
- Emission Model
  - Assumptions
  - Theoretical QE
  - Theoretical Thermal Emittance
- Difference between Laser and Electron Pulse Shape
  - Flat top laser
  - Flat top electron beam
  - Chirp
- Other Effects
  - Cathode response time
  - Surface roughness

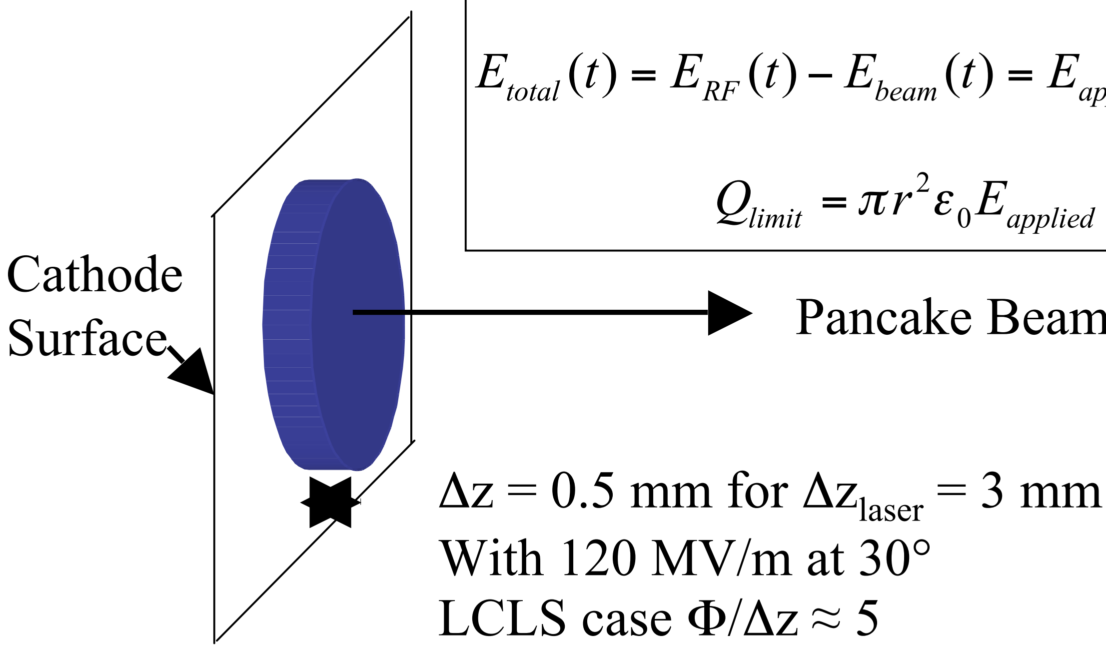
Schottky Effect

$$QE = \eta_0 \left[E_{photon} - E_{cathode} + E_{schottky}(t) \right]^2$$

$$E_{schottky}(t) = \sqrt{\left(\frac{eE_{total}(t)}{4\pi\varepsilon_0} \right)}$$

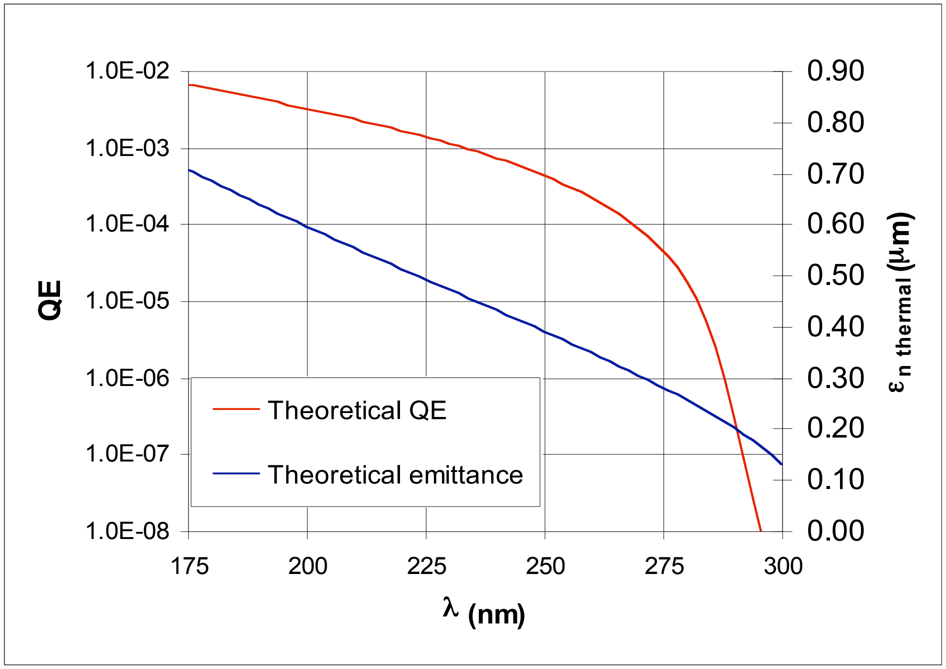
$$E_{total}(t) = E_{RF}(t) - E_{beam}(t) = E_{applied} \sin\left(\omega t + \theta_{applied}\right) - \frac{Q(t)}{\pi r^2 \varepsilon_0}$$

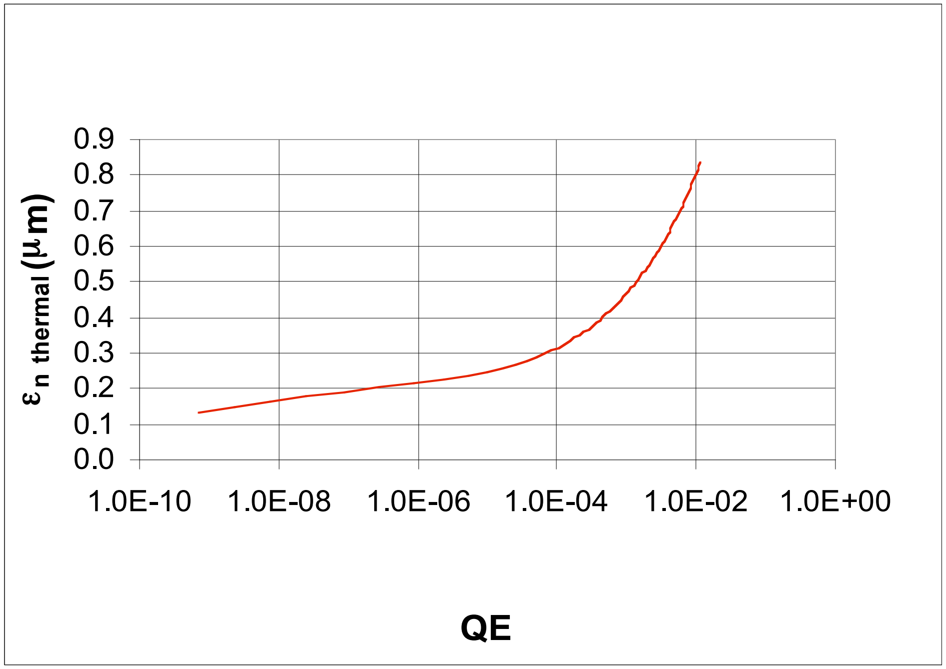
$$Q_{limit} = \pi r^2 \varepsilon_0 E_{applied} \sin\left(\omega t + \theta_{applied}\right)$$



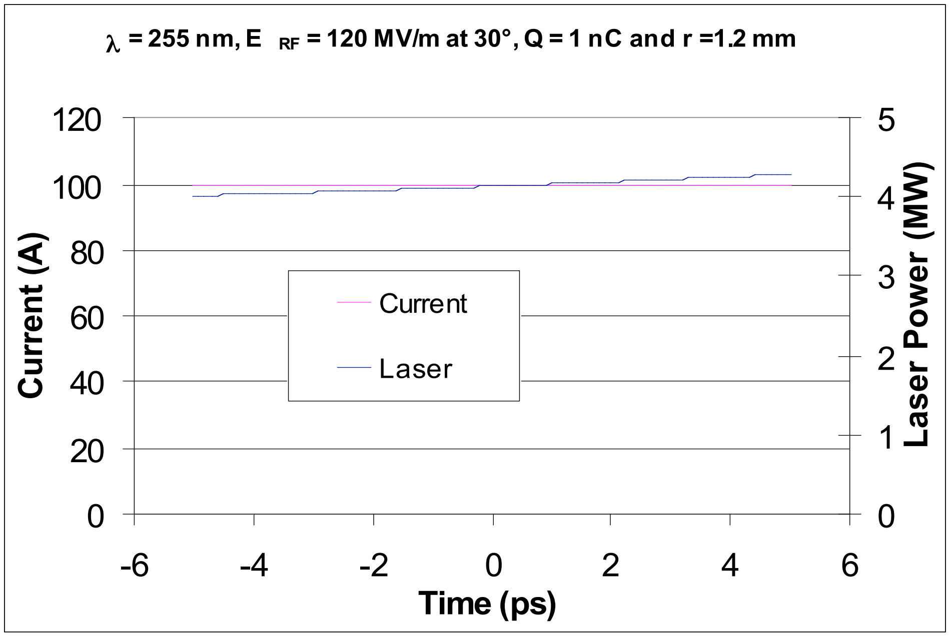
$\Delta z = 0.5$ mm for $\Delta z_{laser} = 3$ mm
With 120 MV/m at 30°
LCLS case $\Phi/\Delta z \approx 5$

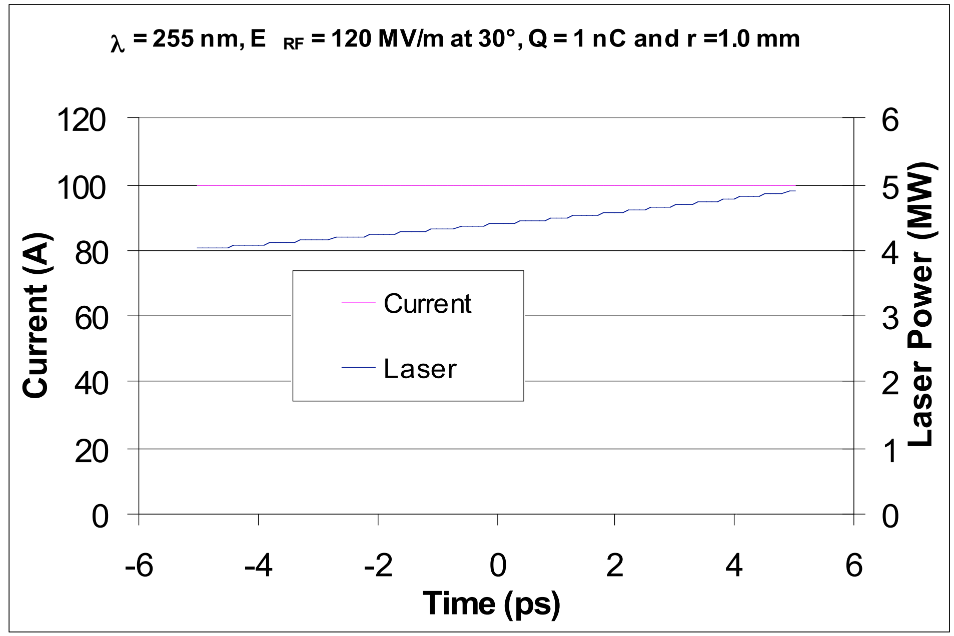
Thermal Emittance as a Function of QE





Laser Temporal Pulse with Flat Top Beam Current





Summary

- QE is time dependent in metal cathode due to strong Schottky effect
- Thermal emittance also time dependent since QE and thermal emittance are related
- Temporal shaping the laser pulse may be required to produce a flat top laser pulse
- Beam induced field can cancel the applied rf field variation in time
- Laser beam chirp also has strong effect
- Emission process not included in simulations

Ultra-Fast Effects in Metal Cathodes (effects we've been ignoring)

David H. Dowell
SLAC

- Introduction and what we assume about photoemission

- Optical properties and electron dynamics

- The role of bulk and surface resonances

- Summary and conclusions

In general the dielectric constant and the image charge should include damping

The damping parameter, γ, for copper is given by the Drude conductivity model:

$$\gamma = 4\times 10^{13}/s$$ or a 25fs damping time.

For an isolated, damped resonance, the complex frequency-dependent dielectric constant and image charge are given by

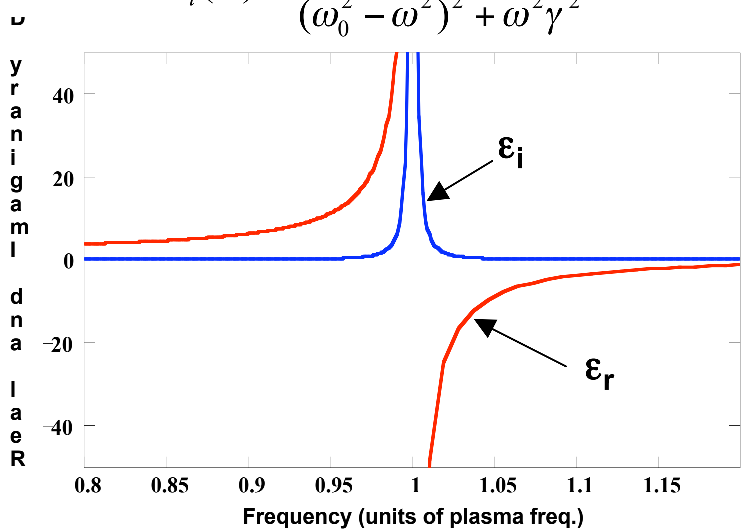
$$\varepsilon = \varepsilon_r + i\varepsilon_i$$

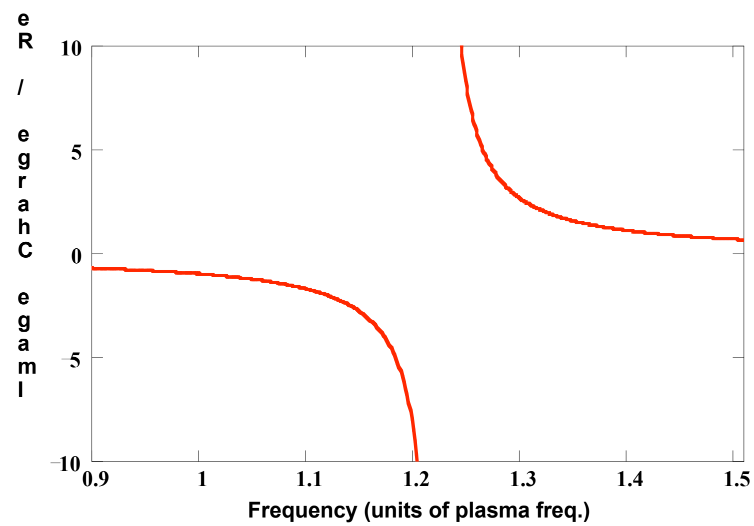
$$\varepsilon_r(\omega) = 1 + \frac{\omega_p^2(\omega_0^2 - \omega^2)}{(\omega_0^2 - \omega^2)^2 + \omega^2\gamma^2}$$

$$\varepsilon_i(\omega) = \frac{\omega_p \omega\gamma}{(\omega_0^2 - \omega^2)^2 + \omega^2\gamma^2}$$

$$\frac{q'}{q} = -\frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_2 + \varepsilon_1}$$

Image charge compute with only the real dielectric constant





Summary and Conclusions

- The optical characteristics determines the cathode's temporal response

- Bulk and surface plasmon excitations determine many of the optical properties

- The time-dependent dielectric constant affects the beam dynamics
  via. the image charge

- Beam-shearing is possible near plasmon resonance
  - Reversal of the image charge (q_{image}=>-q_{image})

- For smooth surfaces, the plasmon frequency effects are in the fs time domain

- Surface structures and imperfections can lower the surface plasmon frequency

- Surface states can have strong effects on fast electron emission

QUANTUM EFFICIENCY MEASUREMENTS OF Mg FILMS PRODUCED BY PULSED LASER ABLATION DEPOSITION FOR HIGH BRIGHTNESS ELECTRON SOURCES*

G.Gatti, L.Cultrera, F.Tazzioli, C.Vicario
INFN-LNF

A.Fiori
University of Rome "Tor Vergata", Chemical Science Department

A. Perrone,C. Ristoscu
University of Lecce, Physics Department and INFN

Work partially supported by the EU Commission in the sixth framework programme, contract no. 011935 EUROFEL

OUR GOALS ON Mg FILMS

SYNTHETIZE A Mg PC TO WORK IN A RF-GUN

FEATURES

- QE >10^{-4}
- SURFACE QUALITY (EMISSION DISTRIBUTION)
- LASER RADIATION RESISTANT
- HIGH FIELD RESISTANT (LOW DARK CURRENT)
- RUGGEDNESS (SUBSTRATE ADHERENCE)

ACTIVITIES

WORKING ON VARIOUS LINES

SPUTTERING

MEASUREMENTS TO EVALUATE THIS WELL KNOWN TECHNIQUE AS A REFERENCE POINT & MAKE IMPROVEMENTS (VACUUM ARC DEPOSITION)

-RESISTANT FILMS (POLLUTION & LASER)
-BEST QE RESULTS UP TO NOW (BNL)
-POOR ADHERENCE

PLAD

STUDYING & DEVELOPING NEW PC AND PROTECTIVE LAYERS BASED ON THIS PROMISING TECHNIQUE

- GOOD FILM QUALITY
- GOOD ADHERENCE
- MULTI LAYERS

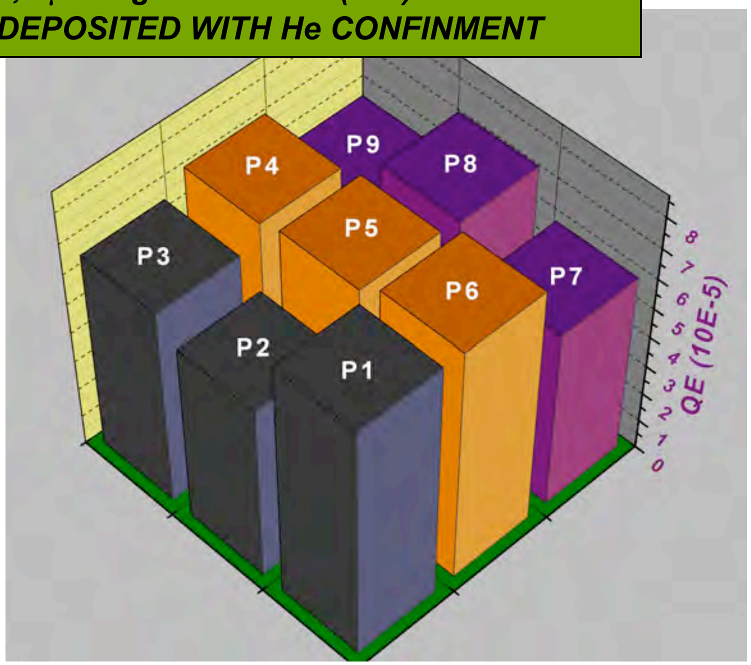
- DIFFICULT TO REACH BIG THICKNESS
- PRESENCE OF DROPLETS
- THICKNESS CONTROL

PLAD

SAMPLE 2

EMISSION UNIFORMITY
OVER SURFACE

2,5 μm Mg FILM ON Si (100) SUBSTRATE
DEPOSITED WITH He CONFINMENT



[9 SUB-AREAS OF 0,04 mm2]

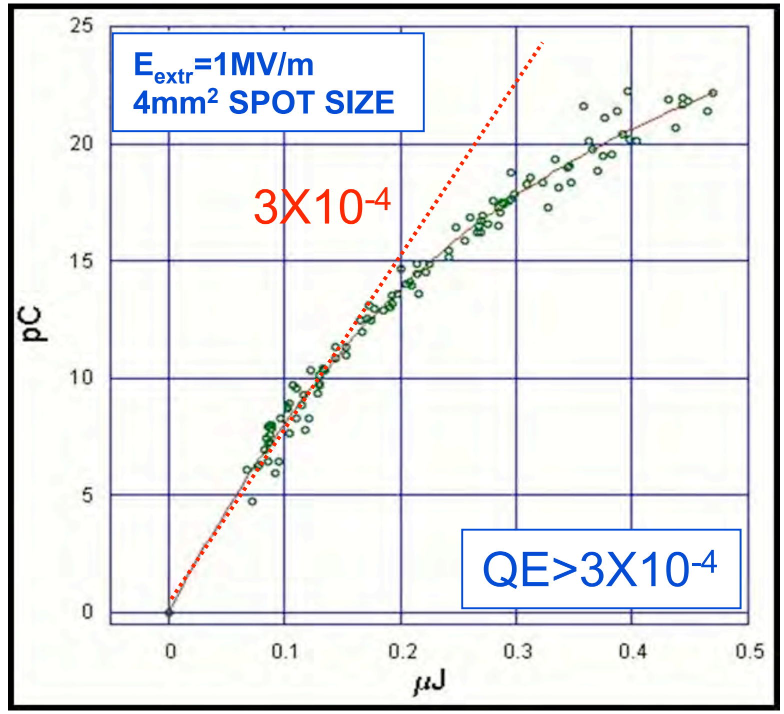
AVG . QE 6,94E-5
STD DEV 0,864 (12%)

MIN QE $5{,}76 \times 10^{-5}$
MAX QE $8{,}02 \times 10^{-5}$

SAMPLE 1

PLAD QE
& LAYER PROTECTION

1μm Mg FILM ON Cu SUBSTRATE
WITH C PROTECTIVE LAYER



-SAME QE AS SPUTTERING
-GOOD LAYER PROTECTION

-FIRST PROMISING RESULTS OF PLAD

-THICK FILMS FEASIBLE. IMPROVEMENT IN COURSE

-PROVEN QE = $3X10^{-4}$ IS SUFFICIENT BUT CAN BE IMPROVED

-PROTECTIVE LAYER WORKS BUT NOT NECESSARY WITH THICK FILMS

FUTURE PLANS

- TECHNIQUE IMPROVEMENT
- DEPOSITION ON RF-GUN FLANGE (TO TRY INSIDE A GUN)
- TRY OTHER MATERIALS & TECHNIQUES

Superconducting Photocathodes

BNL
J. Smedley
I. Ben-Zvi
A. Burrill
T. Rao

JLAB
P. Kneisel

DESY
J. Sekutowicz

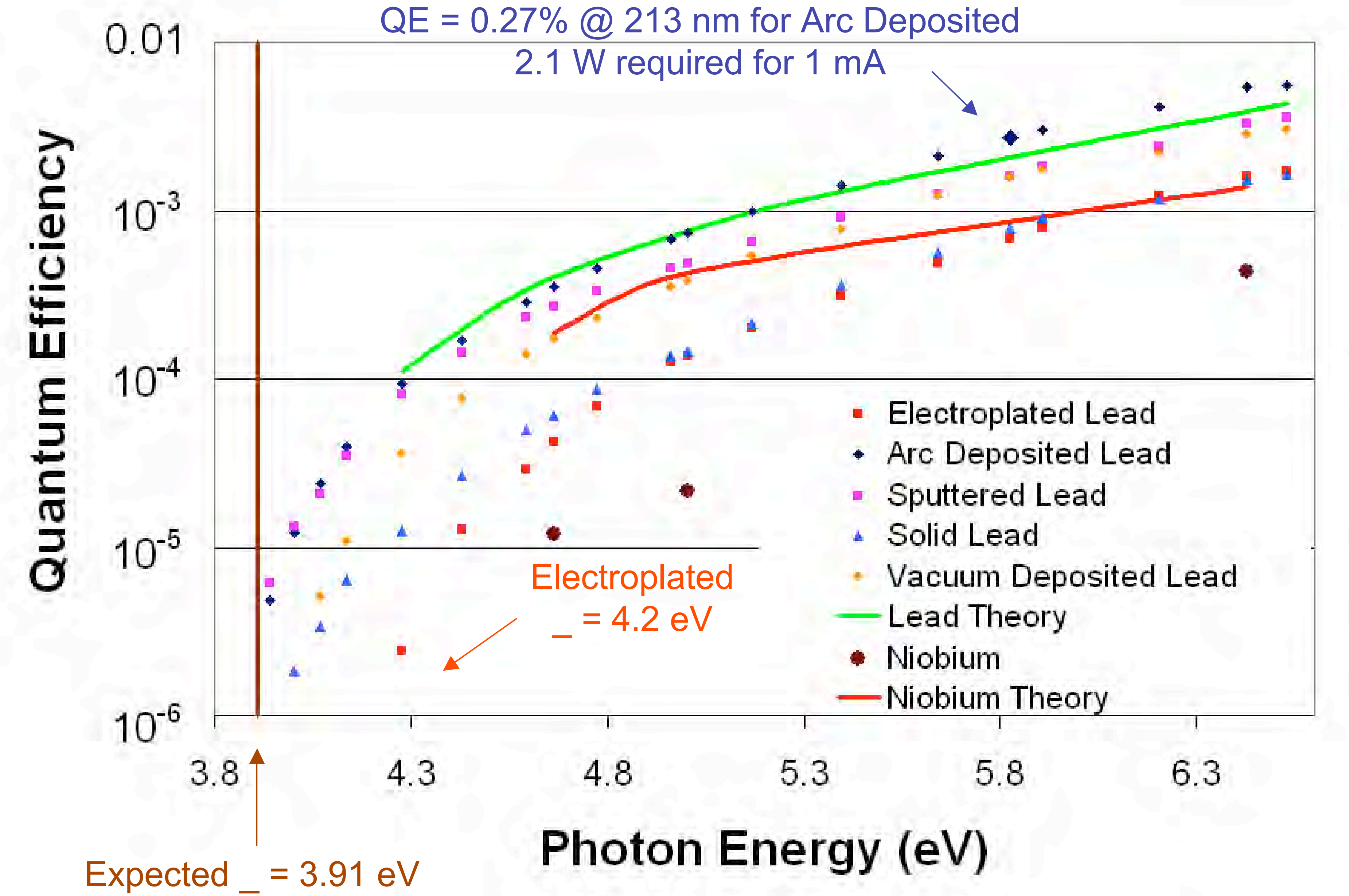
INFN
M. Ferrario

UNI-_ÓD_
K. Sza_owski

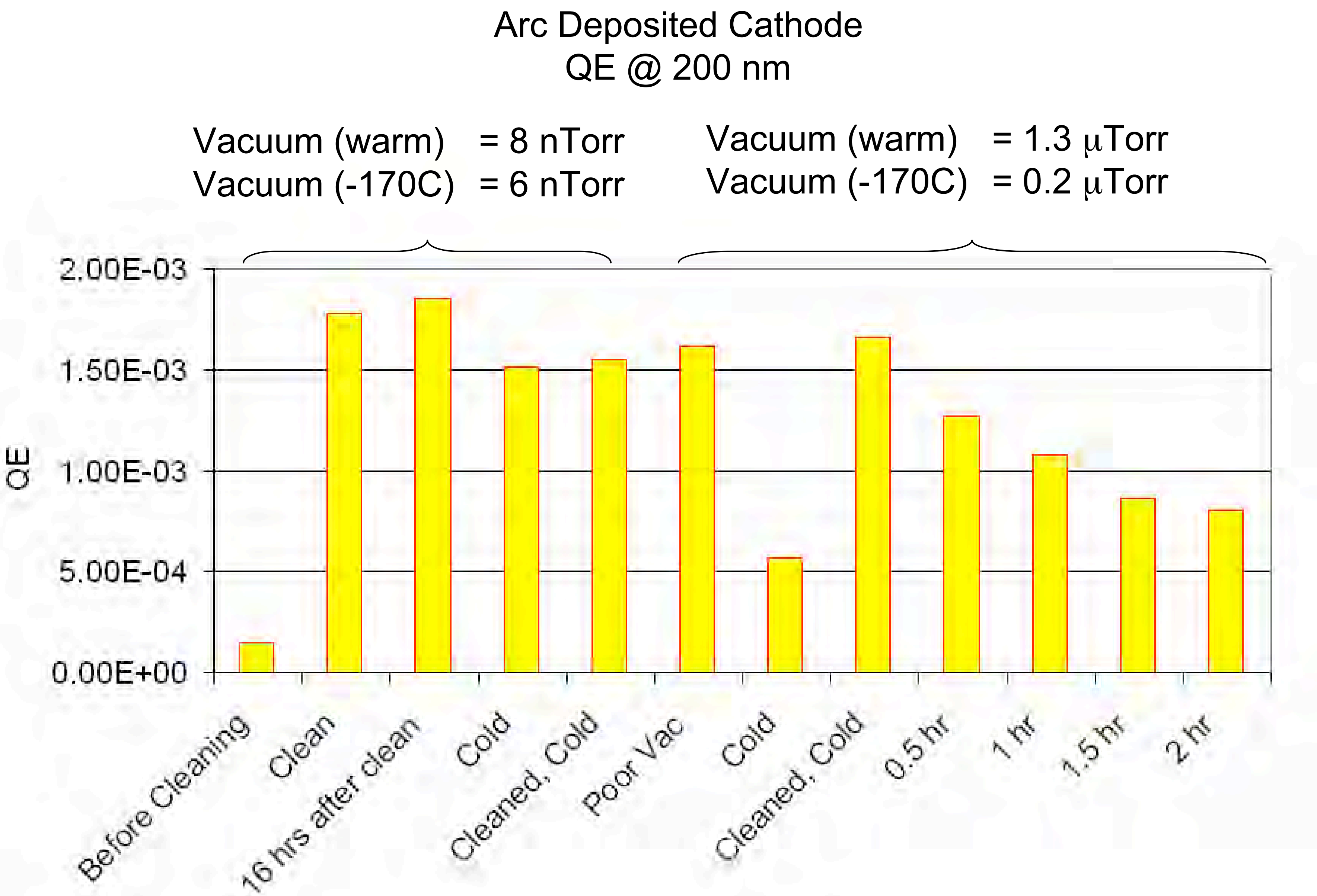
SBU
R. Lefferts
A. Lipski

INS-_wierk
J. Langner
P. Strzy_ewski

Photoemission Results



Effect of Temperature and Vacuum on QE



Summary

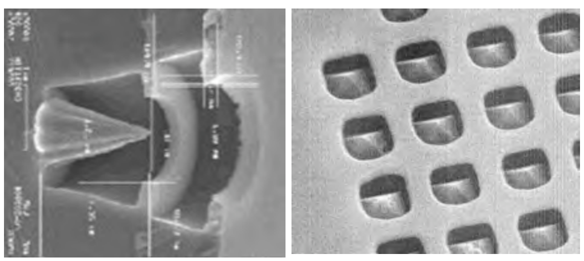
- Niobium, although a great superconductor, is a relatively poor photocathode
- The three-step model of photoemission well predicts the measured QE for lead, but not for niobium
- For moderate average currents, SC lead plating the cathode may be an attractive alternative to niobium
- Arc deposited lead has the best QE of the deposition methods tested, as well as good surface finish.
- QE_{266nm}=0.035%, QE_{213nm}=0.27%, QE_{190nm}=0.55%
- Cold temperature operation is not a problem, as long as vacuum is good
- For higher average currents, an RF choke assembly can be used to accommodate high-QE cathodes

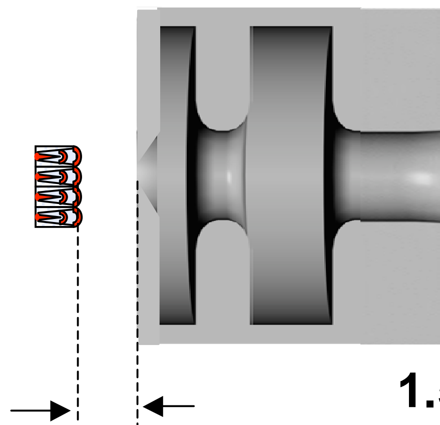
Low Emittance Gun Concept
R. Ganter

Goal: 5.10 $^{-8}$ m.rad ; 5 A; 30ps ; 3.5 MeV

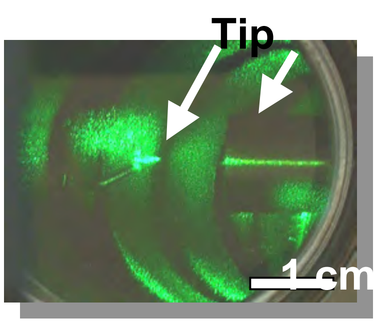
Field Emission Source

1. **Field Emitter Arrays**





2. **Single Needle + Laser**



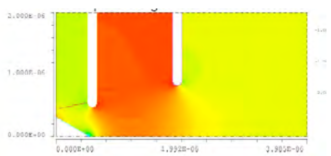
Pulsed Diode Acceleration
1 – 4 mm
250 – 1000 MV/m

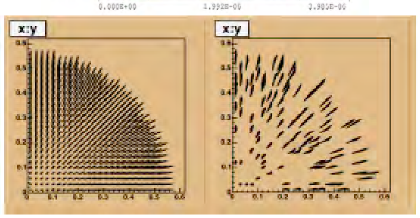
1.5 Cell RF cavity
Two Frequency Cavity

http://leg.web.psi.ch/

Results

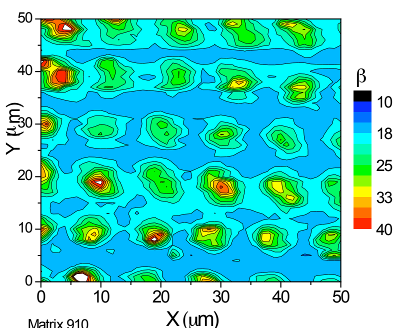
Field Emitter Arrays



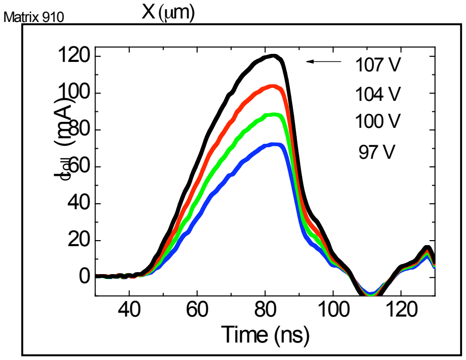


Simulations :

10^{-10} m.rad / Tip
5.10^{-8} m.rad / Array

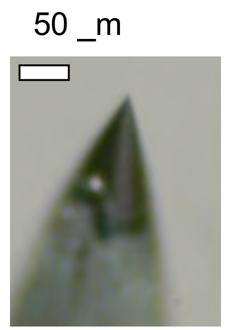


Exp. Tests :
- Mapping of _
- Conditioning
- Peak Current:

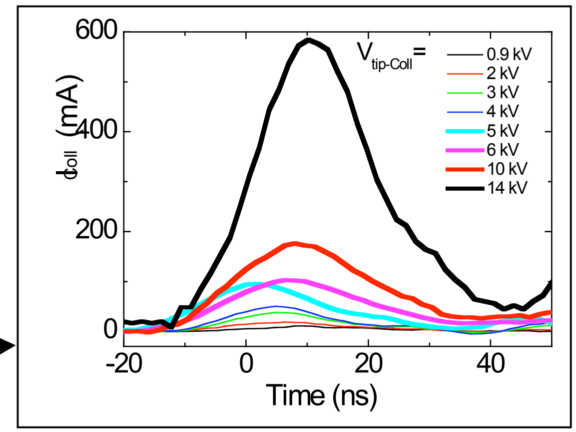


Reached: 100 mA Goal: 5 A

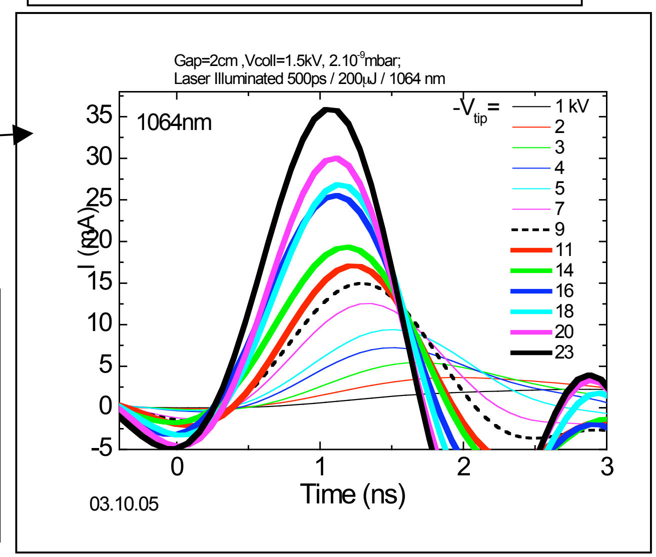
Laser illuminated Needle



With 532 nm Laser Pulses



With 1064nm Laser Pulses

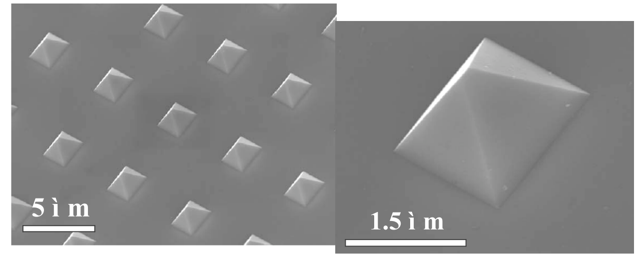


Reached: 500 mA Goal: 5 A

Other Activities at PSI

Field Emitter Fabrication

Goal: Double Gated FEA production



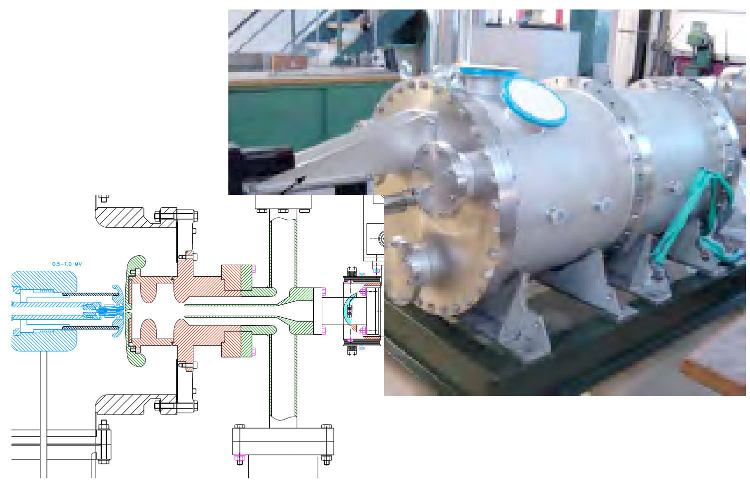
100 keV Gun Test Stand

Goal: Emittance Measurements

High Voltage Pulser Construction

500 kV - 250 ns - 10 Hz

Goal: 250 MV/m Diode Accel.



POST ACCELERATION CONCEPT FOR THE

LEG LOW EMITTANCE GUN PROJECT

- The PSI X-Ray FEL concept behind LEG

(if LEG works what shall we do?)

- "RF-gun" structure for post acceleration

(compensation of the RF contribution to the emittance dilution)

J.-Y. Raguin, R.J. Bakker, K. Li, R. Ganter, M. Pedrozzi

Leg.web.psi.ch

The Physics and Applications of High Brightness Electron Beams, Erice, Italy, October 9-14, 2005

Conclusions

•Emittance dilution due to time dependent RF forces can be compensated over a large range of input phase (zero current case)

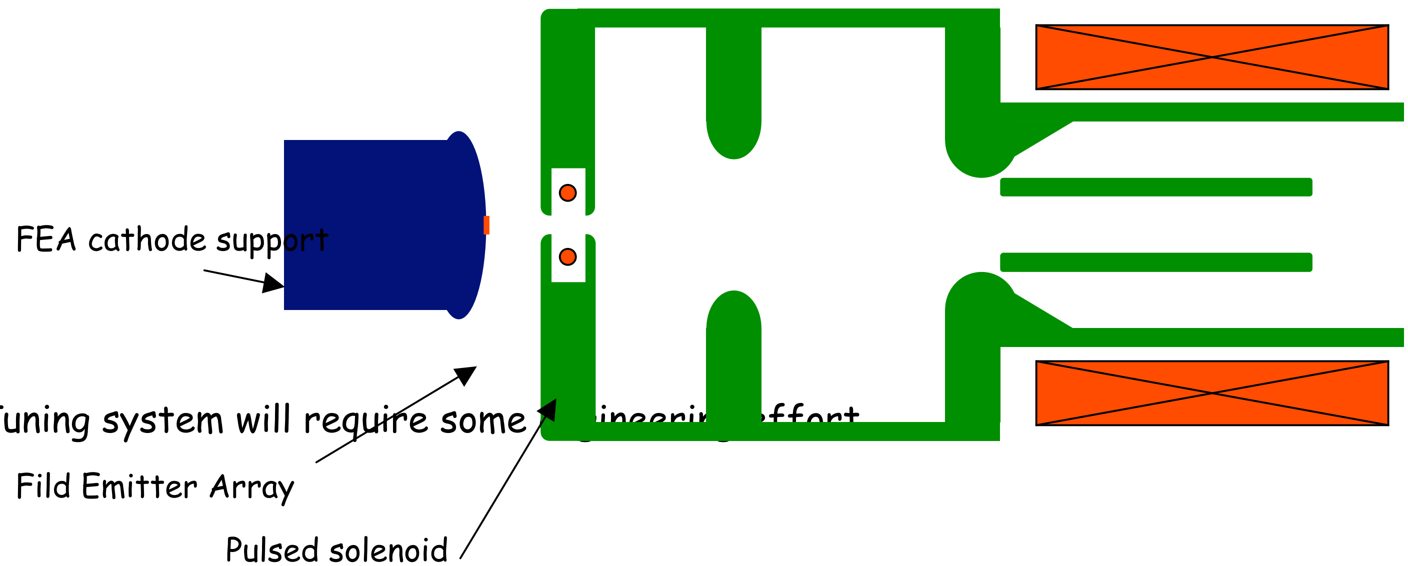
• More flexibility with a two frequency scheme (better for bunching)

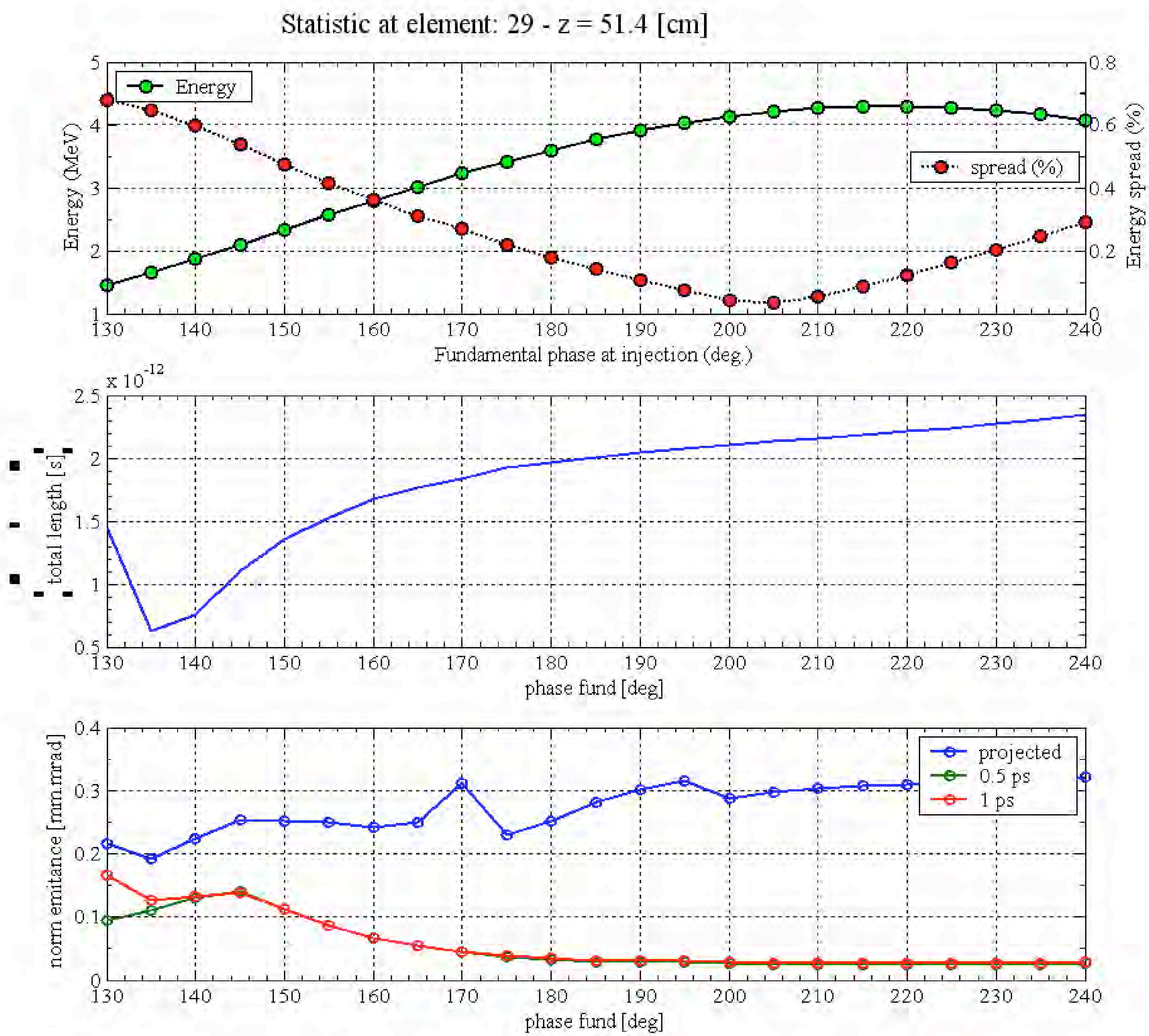
• First simulations with space charge are promising. Optimisation with third harmonic and space charge compensation scheme must be introduced.

• Cavity with 1.6 up to 2 cell will be designed to study the benefit of the RF focusing in the first cell.

• Presently investigated the possibility to implement a pulsed solenoid in the input iris.

• Tuning system will require some engineering effort





Statistic at element: 29 - z = 51.4 [cm]
Energy
spread (%)
Energy (MeV)
Energy spread (%)
Fundamental phase at injection (deg.)
x 10^-12
total length [s]
phase fund [deg]
projected
0.5 ps
1 ps
norm emitance [mm.mrad]
phase fund [deg]