Overview of NC CW VHF gun developments at LBNL

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21.07.16 PPS

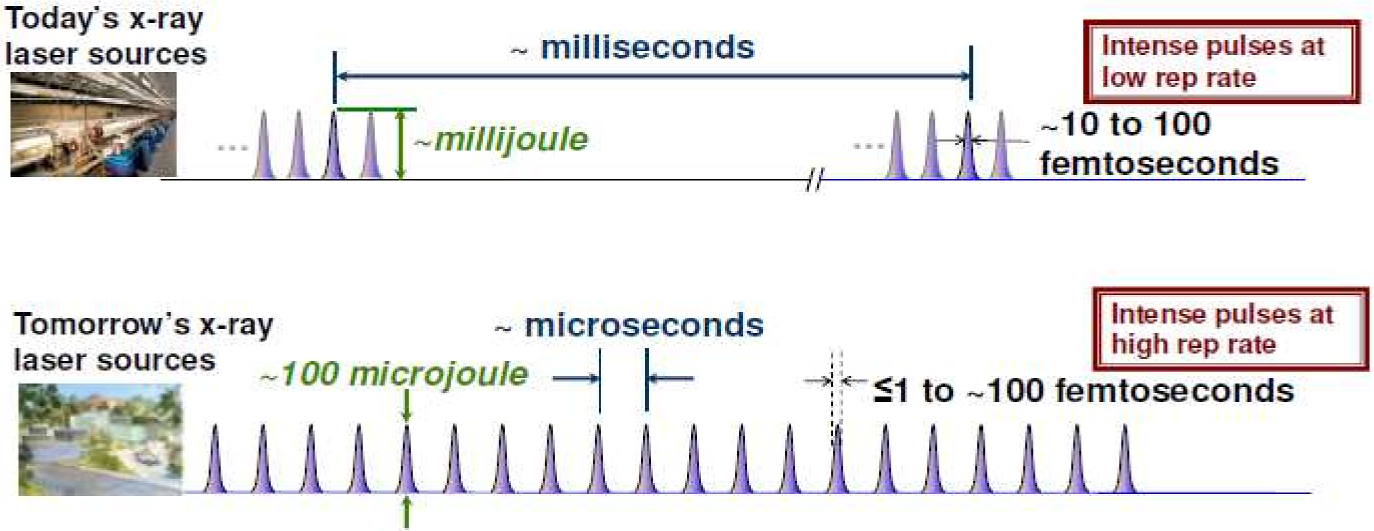
Outline

- Motivation
- VHF gun concept introduction
- APEX - **A**dvanced **P**hotoinjector **EX**periment

Motivations

- Next-gen XFEL facility: from 100 Hz to MHz
  - More coherent X-ray photon flux per sec
  - More stable machine with wider control BW
  - More FEL beamlines, more users

LCLS-1/SACLA/FLASH



~10^2-10^4 Hz

LCLS-2 (NGLS)

~1 MHz

Motivations

- Typical specs on electron source for MHz XFEL

Parameter	Value and Unit
Bunch Repetition rate	Up to 1 MHz
Charge per bunch	10 – 300 pC
Normalized emittance	0.2 – 0.6 mm
Beam energy at the gun exit	> 500 keV
Cathode electric field at photoemission	>10 MV/m
Bunch length and shape control	5 - 60 ps
Magnetic field at cathode	< 2 G
Dark current at nominal gun energy	< 400 nA
Operational vacuum pressure	$< 2\ 10^{-9}$ Torr
Loadlock cathode vacuum system	

LCLS-II electron injector spec

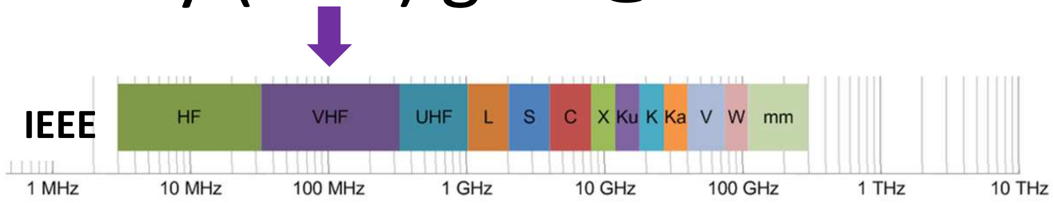
F. Sannibale, D. Filippetto, C. Papadopoulos, JMO **58**, 1419 (2011)

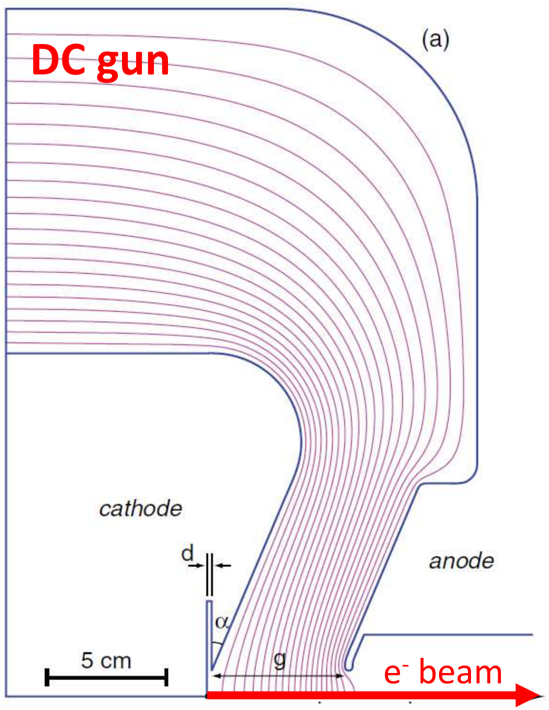
Motivations

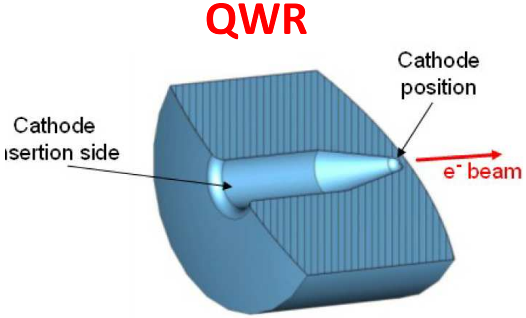
- CW Gun options
  - DC gun (<400 kV, E_{cath}<5 MV/m)
    - JLAB/Cornell/KEK
  - SRF gun (CW, high gradient, high QE cathode)
    - HZDR/DESY/HZB/BNL (L-band)
    - BNL/Wisconsin (VHF -band)
  - Scale GHz NC gun (thermal loading)
    - LCLS gun (S-band, 2 us x 10 Hz)
    - PITZ gun (L-band, 1 ms x 10 Hz)

VHF gun concept

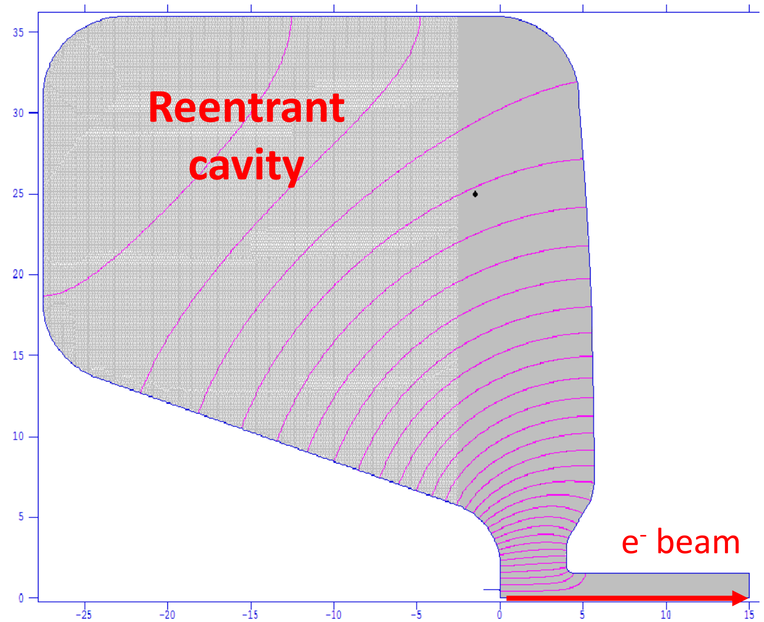
- NC Very High Frequency (VHF) gun @ LBNL







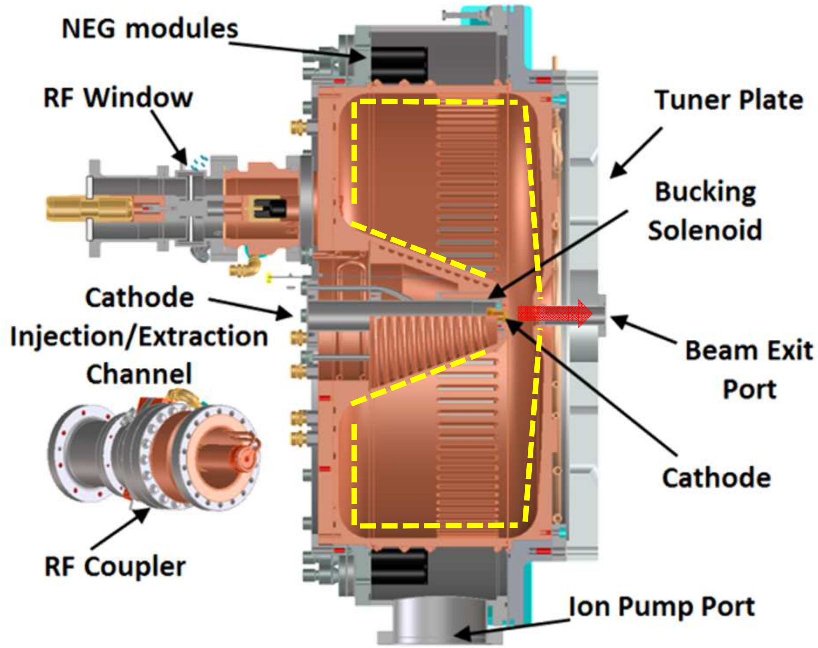
J. Staples, 2006



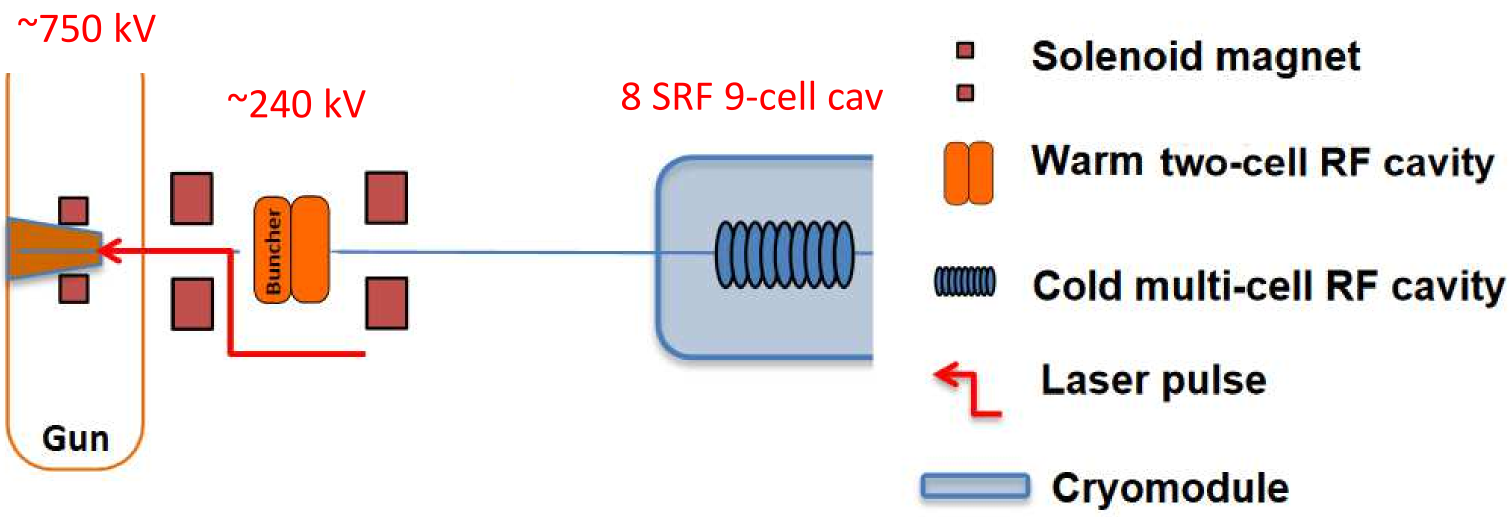
K. Baptiste, 2009, NIM A

VHF gun concept

- A DC gun with higher gradient & gun voltage
  - Frequency selection: 1300/7 (185.7)~ 1500/8 (187.5)
  - Quasi DC gun beam dynamics:
    - Wavelength: 1.6 m, 15 ps/deg
    - Phase slippage: ~ 6 deg
    - Beam bunch length: <4 deg
    - Beam transit time: ~14 deg
  - UHV
    - Lower thermal power density
      - 90 kW, < 30 W/cm^2 , < 50 deg C
    - Vacuum slots around cavity wall
      - 50% transparency, 10^6 L/s
  - Mature NC RF technology



MHz XFEL injector design based on VHF gun



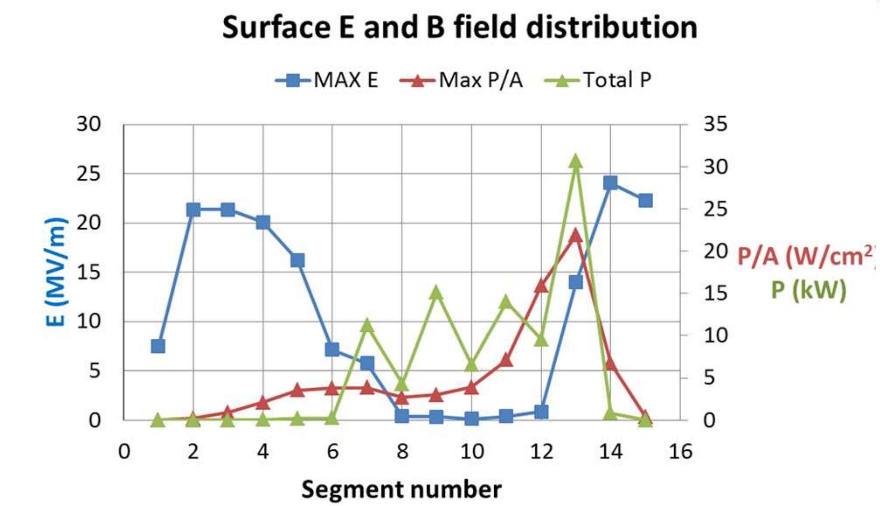
LCLS-II requirement*			VHF gun based simulations (ϵ_{th}~1 um/mm)
Charge [pC]	I_{peak} [A]	95% rms emittance [um]	100% rms emittance [um]
20	5	0.25	0.1
100	10	0.4	0.3
300	30	0.6	0.5

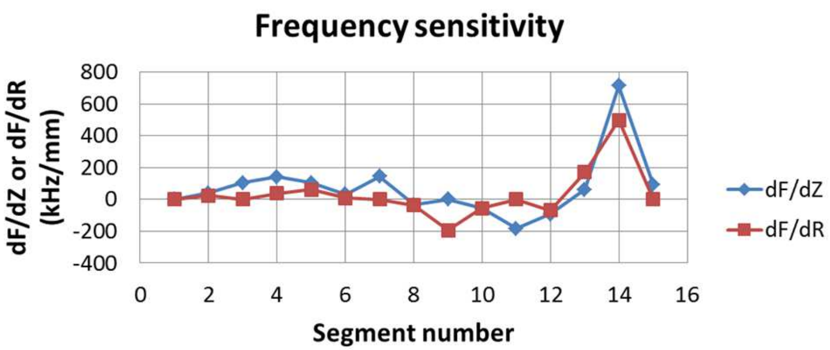
* H.O. δE < 15 keV

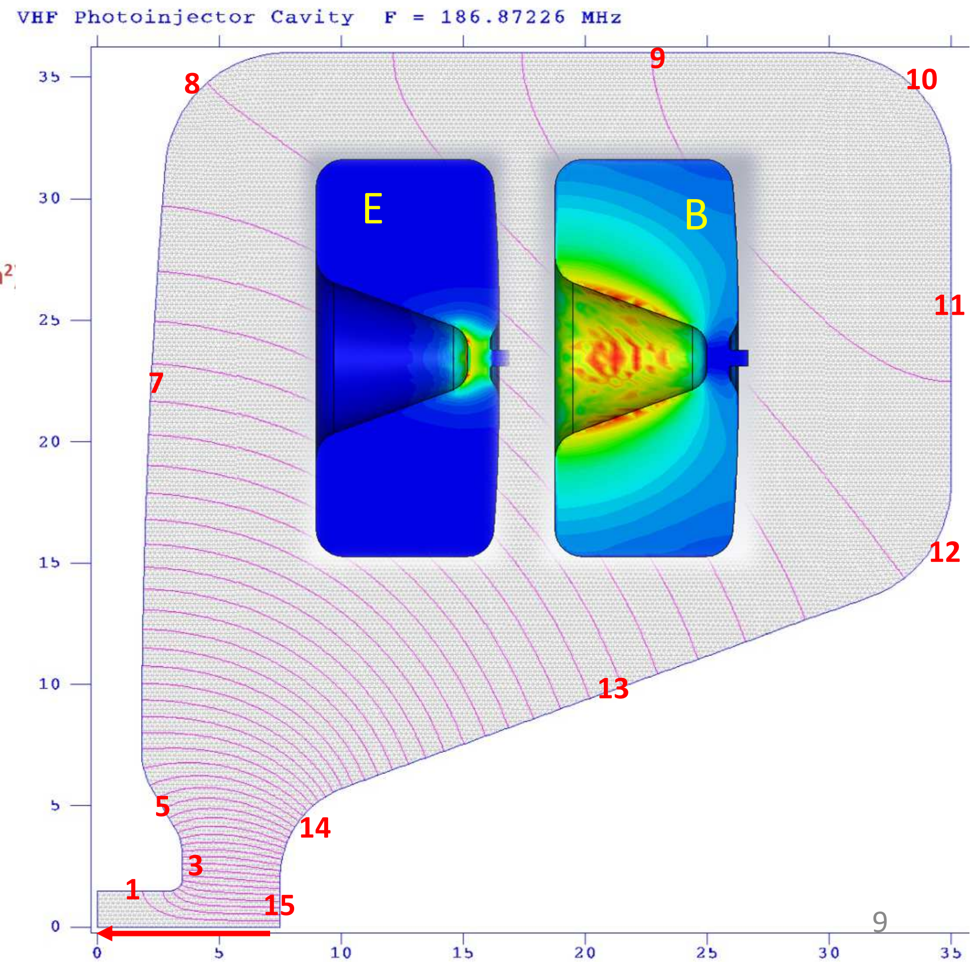
C. Mitchell, ipac 16

VHF gun cavity RF

- Gun profile and RF parameters

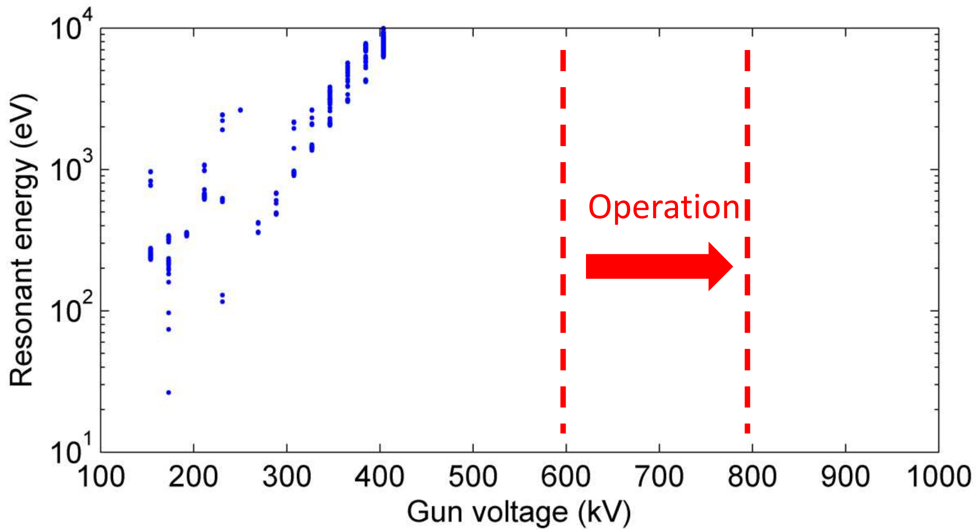


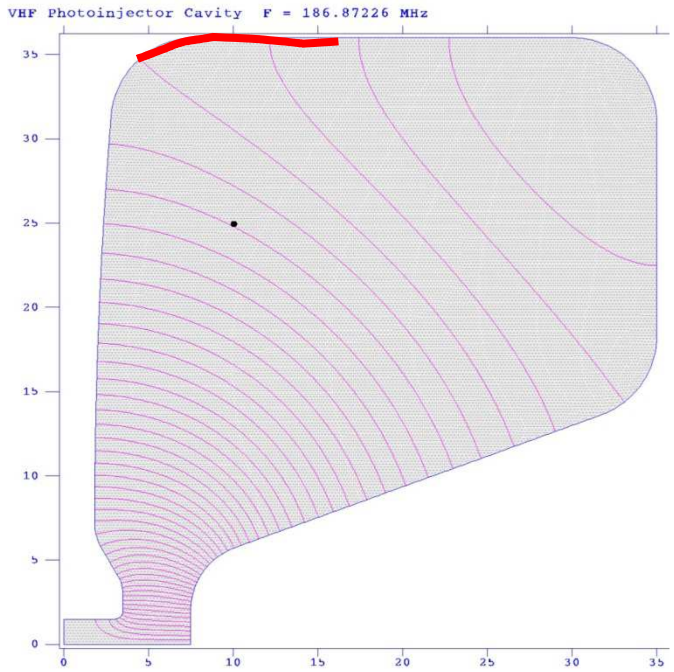




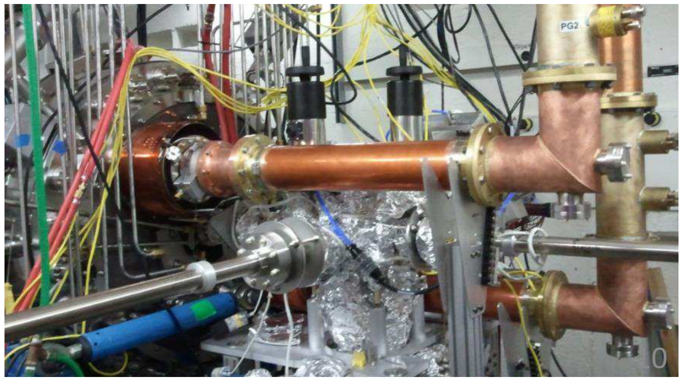
VHF gun multipacting

- Multipacting in the gun



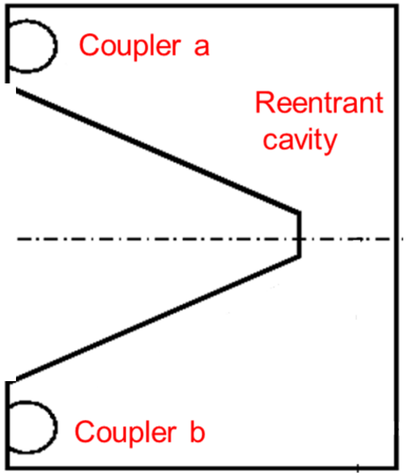


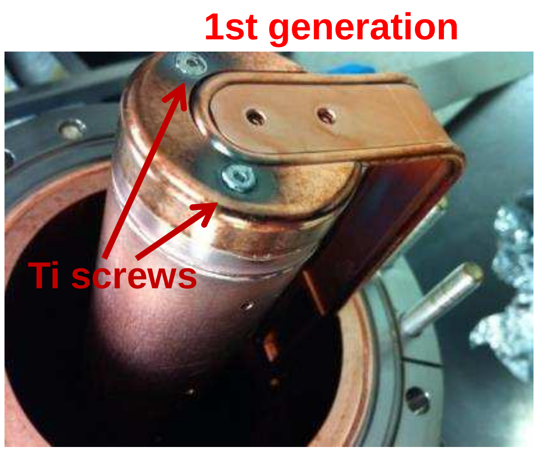
- Multipacting in waveguide
  - 28 – 52 kW per waveguide
  - 600 – 800 kV gun voltage

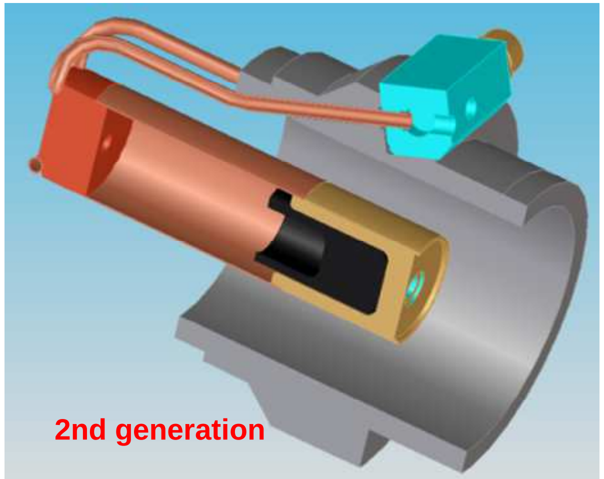


VHF gun power coupler

- Dual loop coupler







1st Generation RF couplers issues:

- **Multipacting in vacuum coaxial lines.**
- **Overheating of coupler tip (Ti screws)**

2nd Generation modifications:

- **TiN coating**
- **Shorter coupler/RF window distance.**
- **All copper brazing, no screws.**
- **Larger cooling**

VHF gun main RF parameters

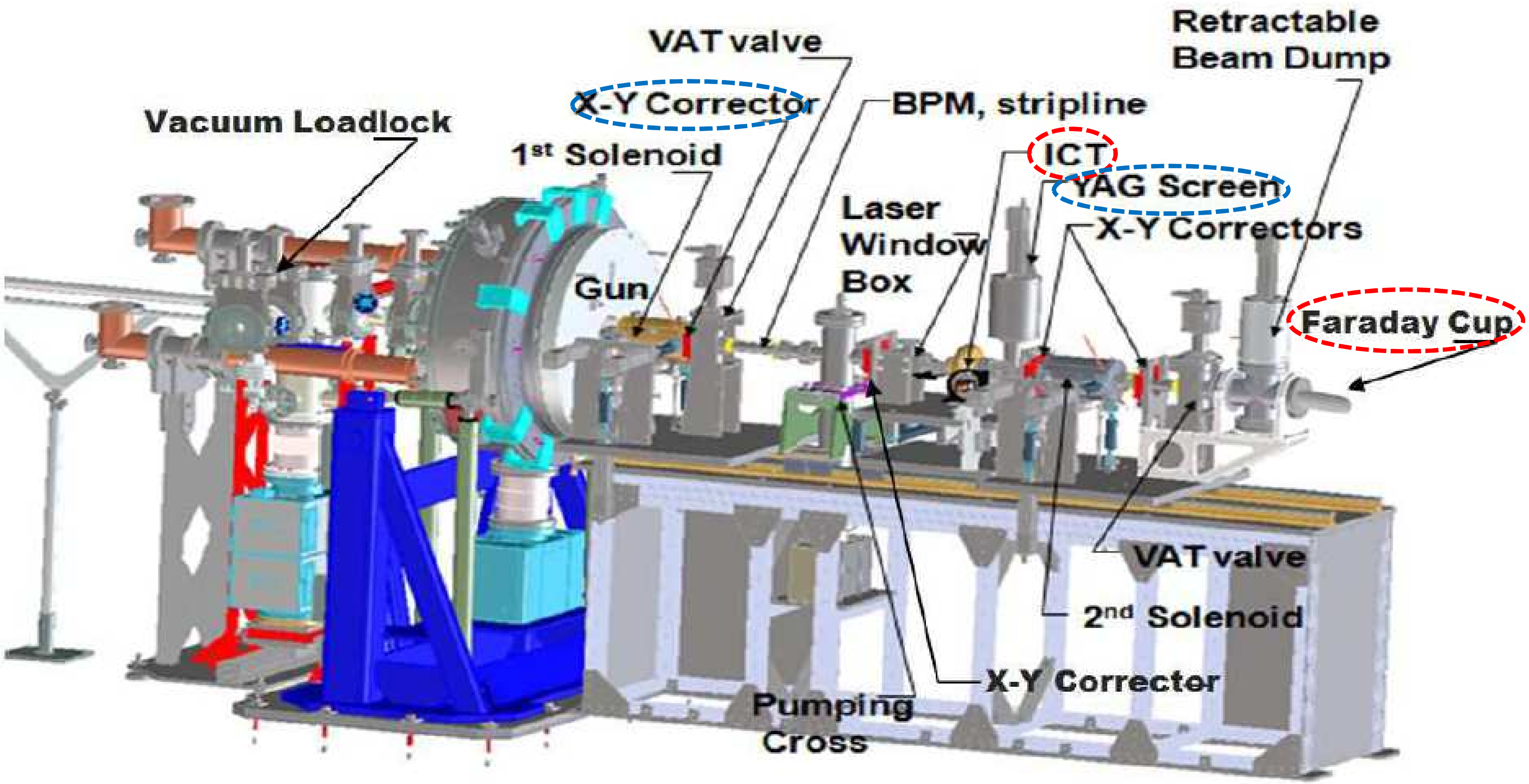
Frequency	186 MHz
Operation mode	CW
Nominal Gap voltage	750 kV
Field at the cathode	19.8 MV/m
Q0 (measured at R.T.)	30050
Shunt impedance	6.25 MΩ
RF Power @ 45 C	90 kW
Stored energy	2.4 J
Peak surface field	24.1 MV/m
Peak wall power density	27.2 W/cm^2
Accelerating gap	4 cm
Diameter/Length	69.4/35.0 cm
Operating pressure	~ 10^{-10}-10^{-9} Torr
Transported dark current	~350 nA

F. Sannibale, et al., PRST-AB 15, 103501 (2012)

NC VHF gun demonstration

- Advanced Photoinjector Experiment (APEX)
  - Phase 0
    - Demonstration of CW RF performance
    - Demonstration of UHV vacuum
    - Dark current characterization
  - Phase I
    - High QE cathode (QE, life time, thermal emittance…)
    - Beam 6D phase space diagnostics at gun energy
  - Phase II
    - Demonstration of the brightness performance at ~ 30 MeV

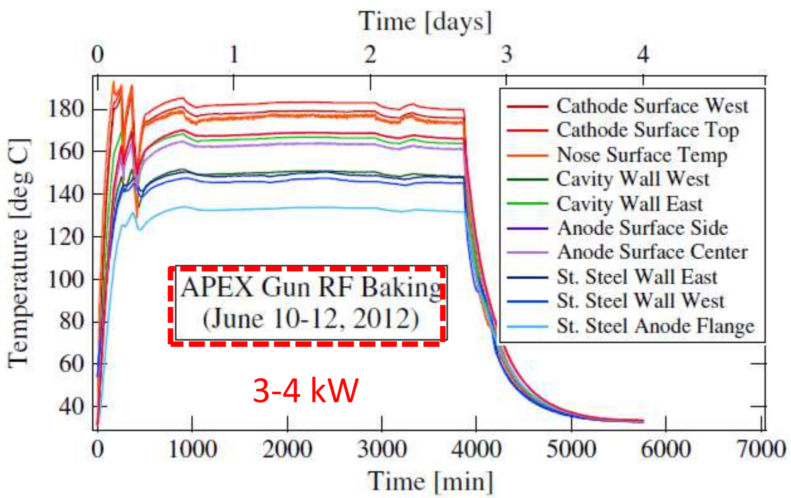
APEX Phase 0

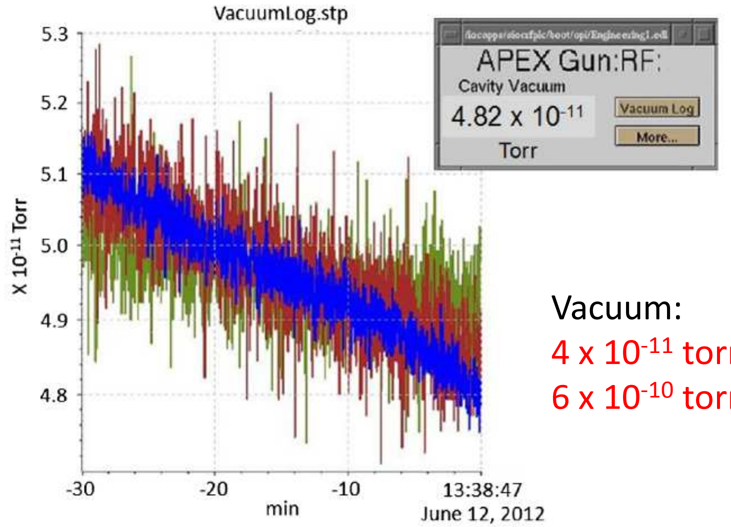


F. Sannibale, et al., PRST-AB 15, 103501 (2012)

UHV Vacuum

- RF baking

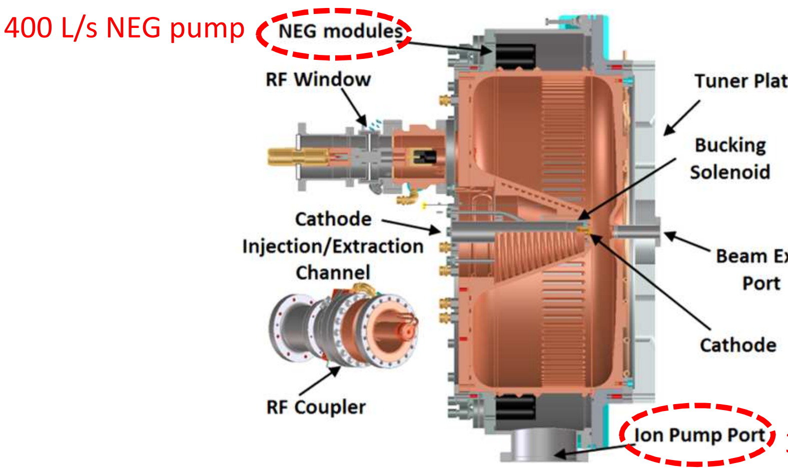




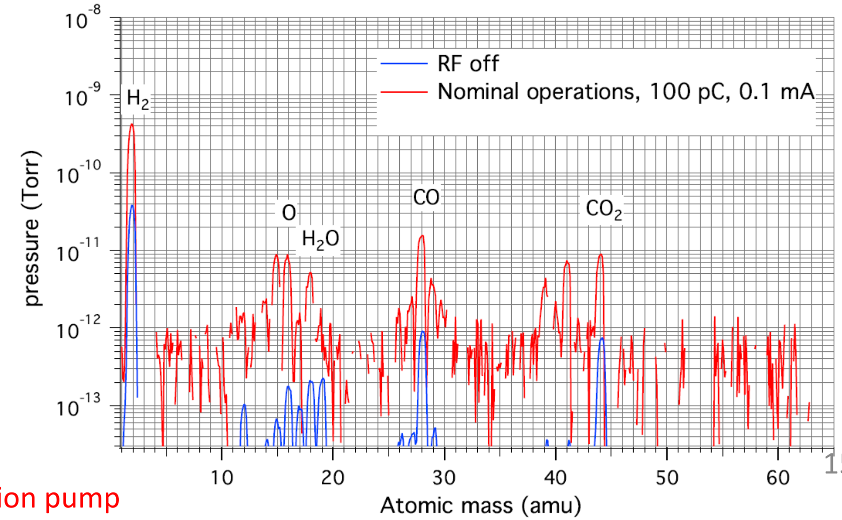
Vacuum:

4 x 10^{-11} torr (RF off)

6 x 10^{-10} torr (RF on)

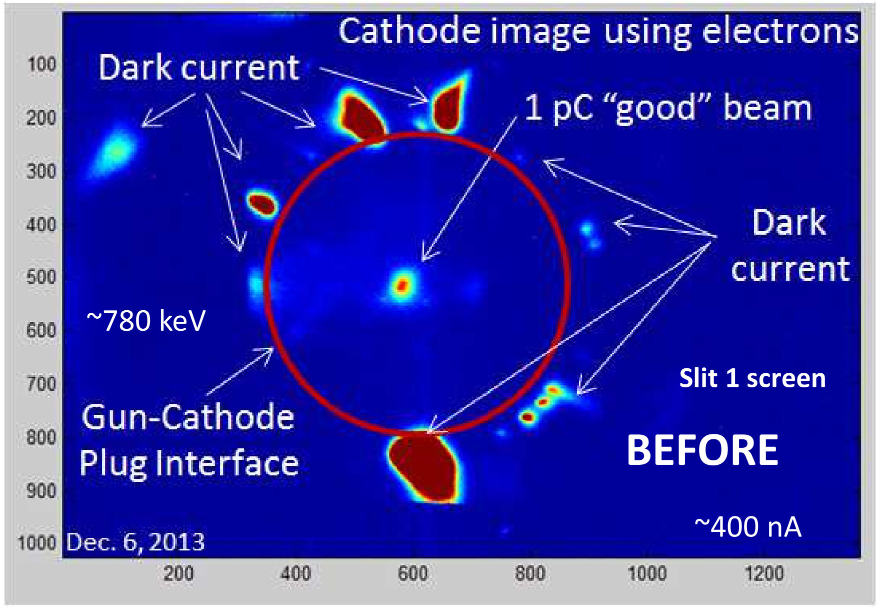


300 L/s ion pump

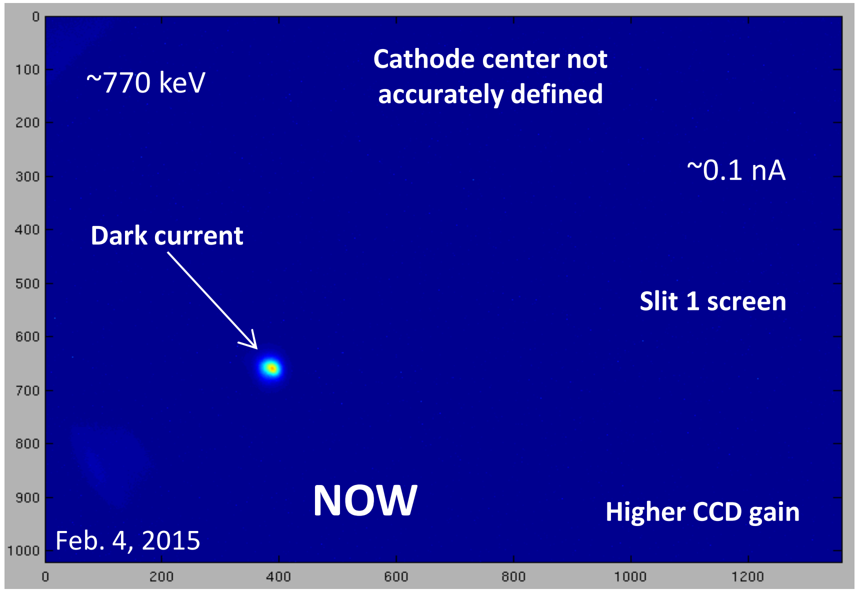


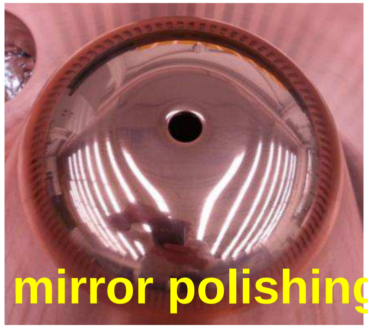
Dark current imaging

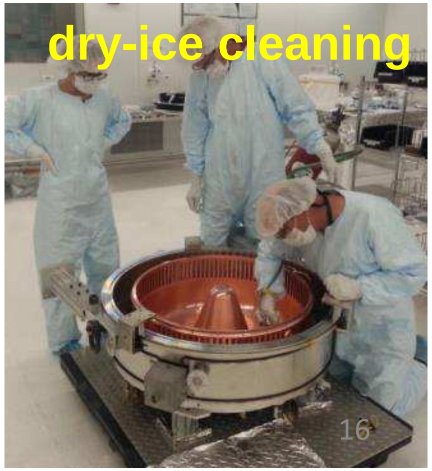
~ 350 nA @ 780 kV



~ 0.1 nA @ 770 kV

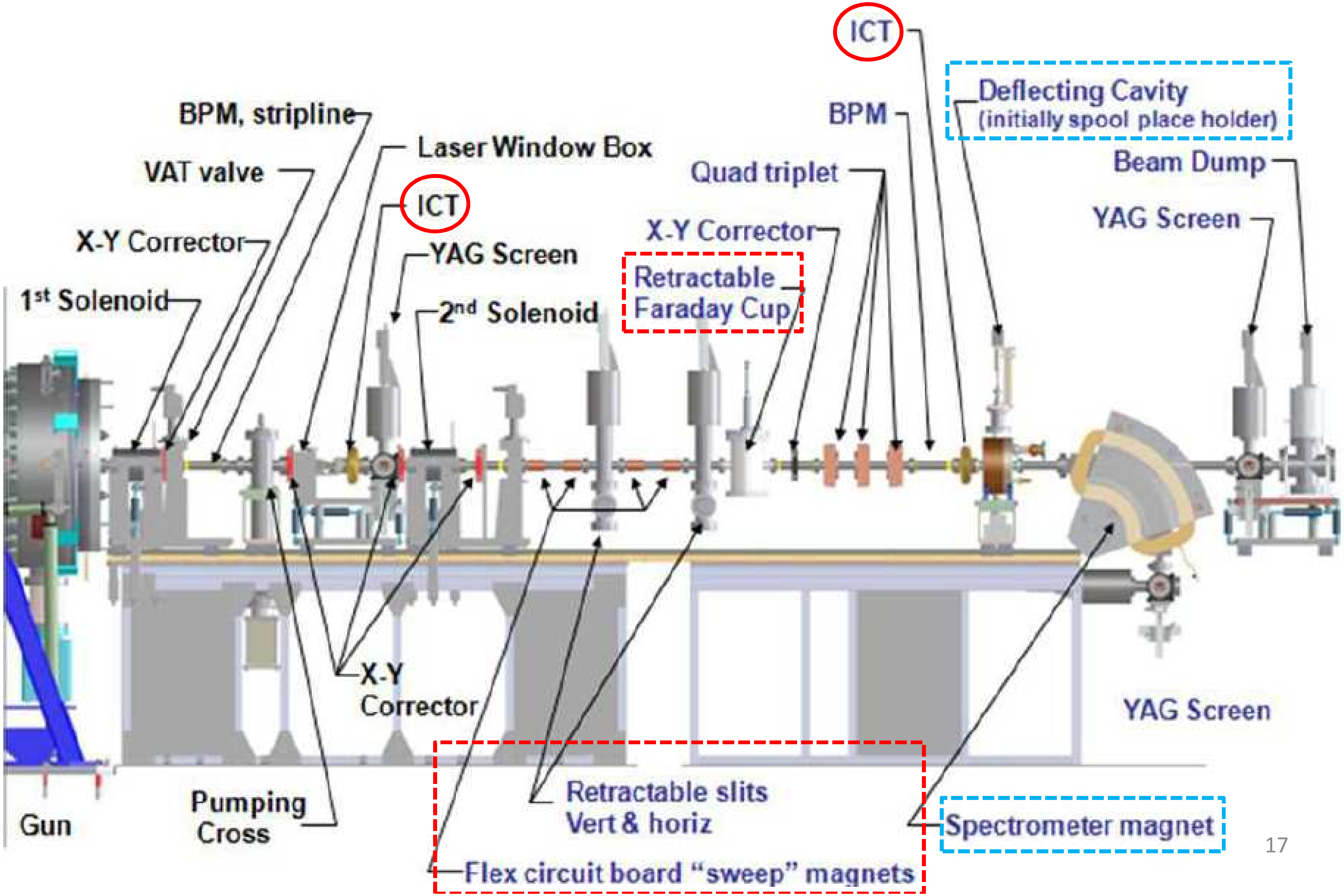






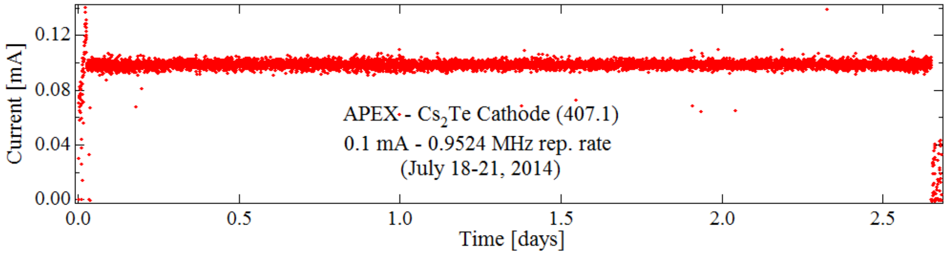
R. Huang, et al., PRST-AB 18, 013401 (2015)

APEX Phase I

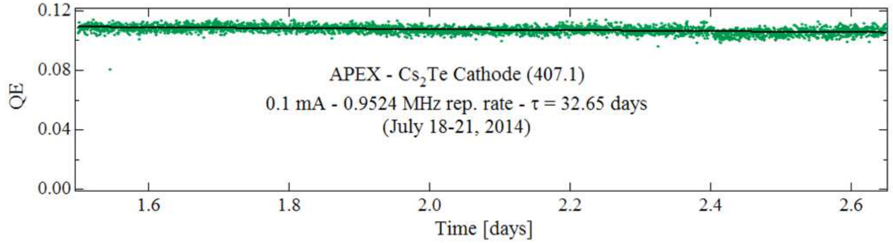

ICT
Deflecting Cavity
(initially spool place holder)
BPM, stripline
BPM
Laser Window Box
Beam Dump
VAT valve
Quad triplet
ICT
YAG Screen
X-Y Corrector
X-Y Corrector
YAG Screen
Retractable
Faraday Cup
1st Solenoid
2nd Solenoid
X-Y
Corrector
YAG Screen
Retractable slits
Vert & horiz
Pumping
Cross
Gun
Spectrometer magnet
Flex circuit board "sweep" magnets

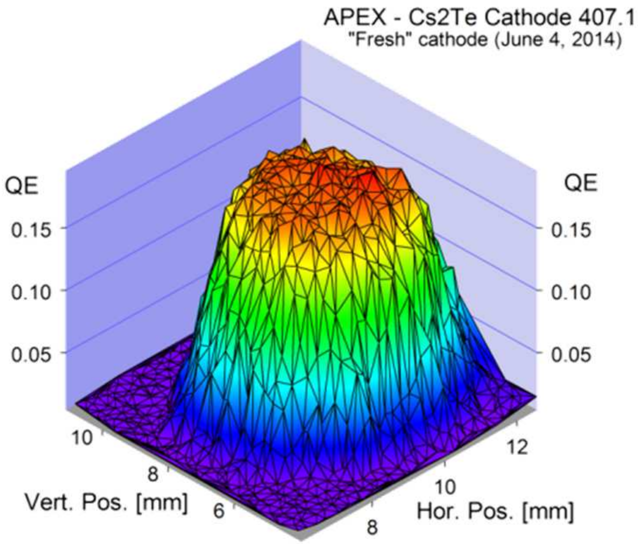
MHz beam from Cs_2Te

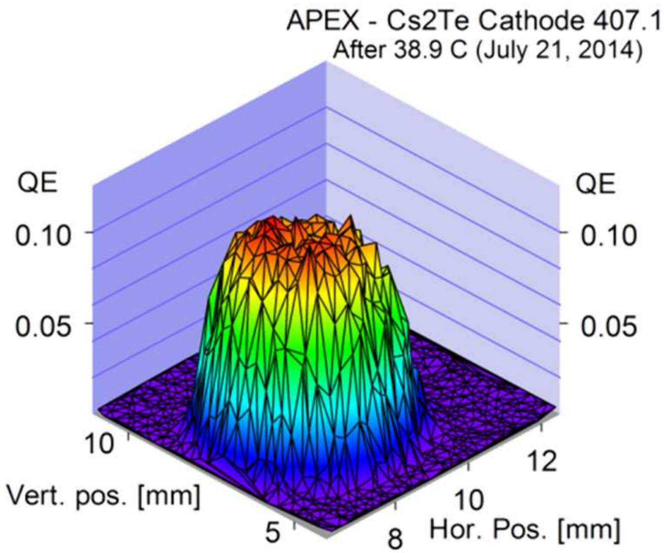
100 pC @ 1 MHz



QE





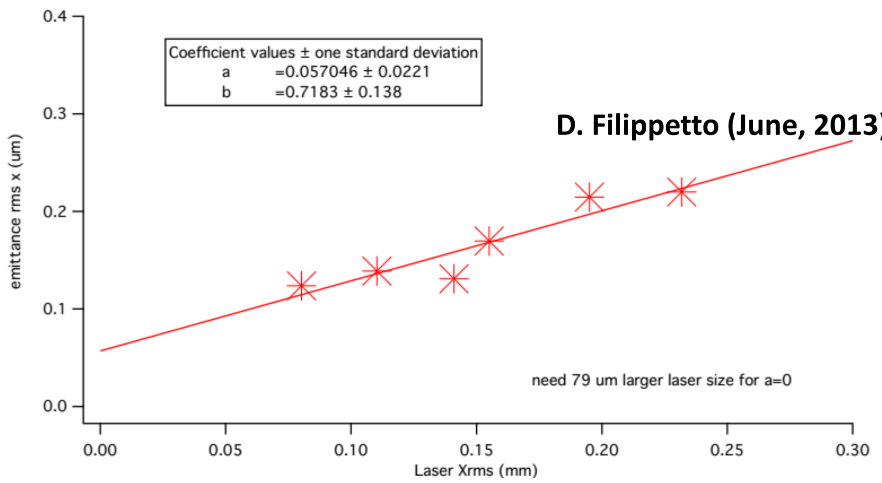


2014.06.04 – 2014.07.21, after 38.9 C the QE degraded from ~16% vs. ~10.5%

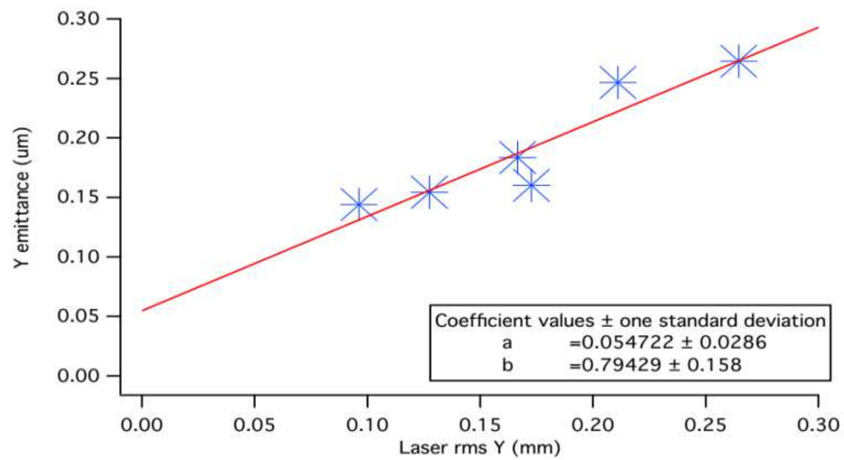
D. Filippetto, Appl. Phys. Letters 107, 042104 (2015).

Thermal emittance of Cs_2Te

- By solenoid scan

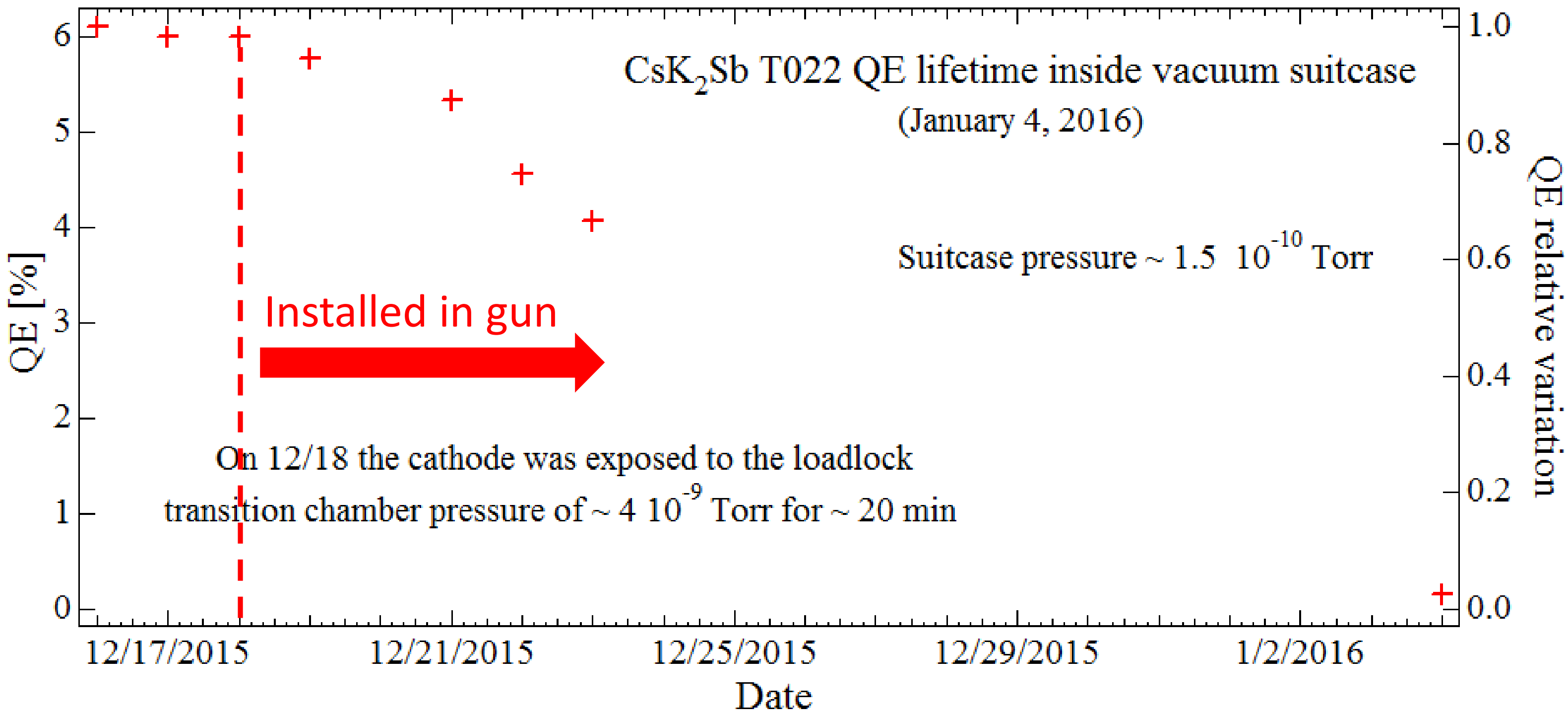


D. Filippetto (June, 2013)



<u>Fixed charge</u>: 0.5 pC bunch charge, 56 ps
780 keV beam energy

Initial test of Cs_2KSb



~ 2 weeks, ~ 18% duty cycle, 650 kV, 10 Hz beam

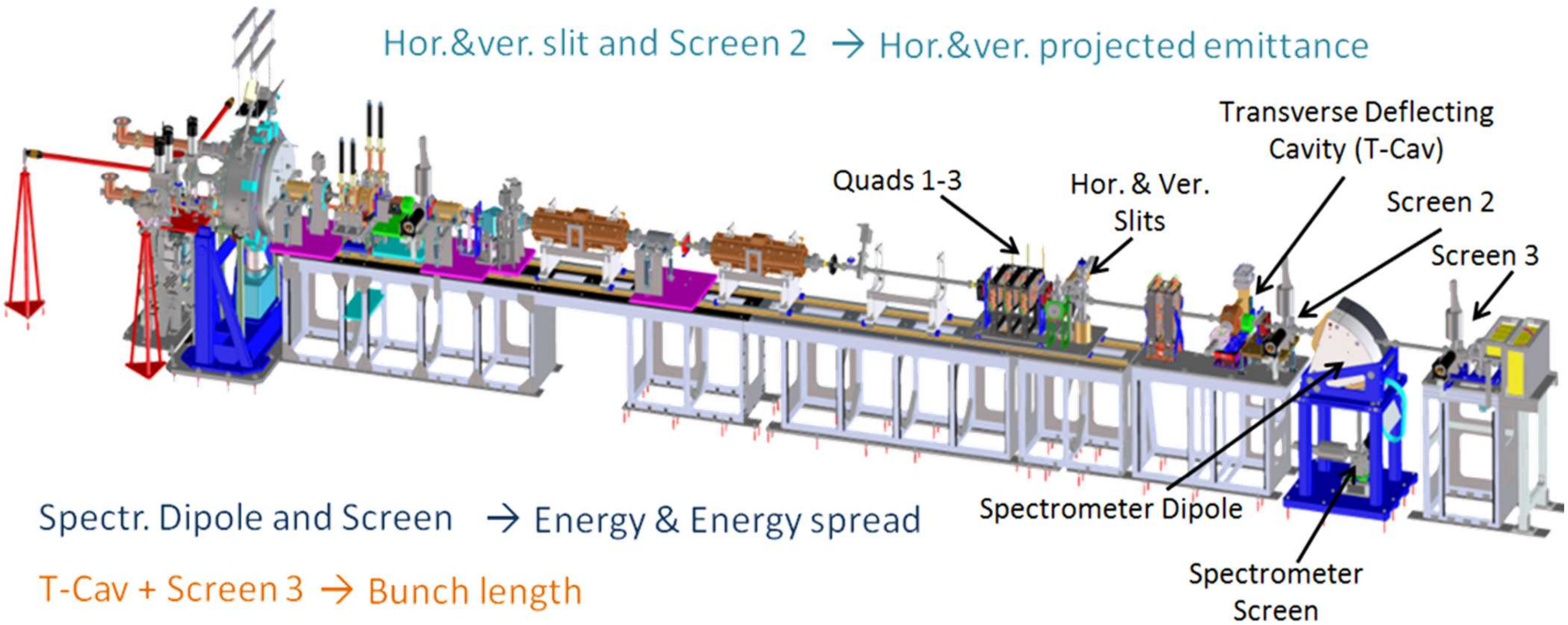
Initial results, not conclusive, further testing on going now

Not published, do not distribute

APEX phase III

Quad 3 + Screen 3
Quad 1 + Quad 3 + Screen 3 } Hor.&ver. projected emittance

Hor.&ver. slit and Screen 2 → Hor.&ver. projected emittance



Spectr. Dipole and Screen → Energy & Energy spread

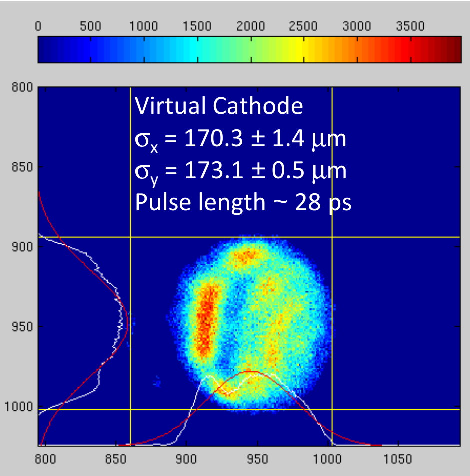
T-Cav + Screen 3 → Bunch length

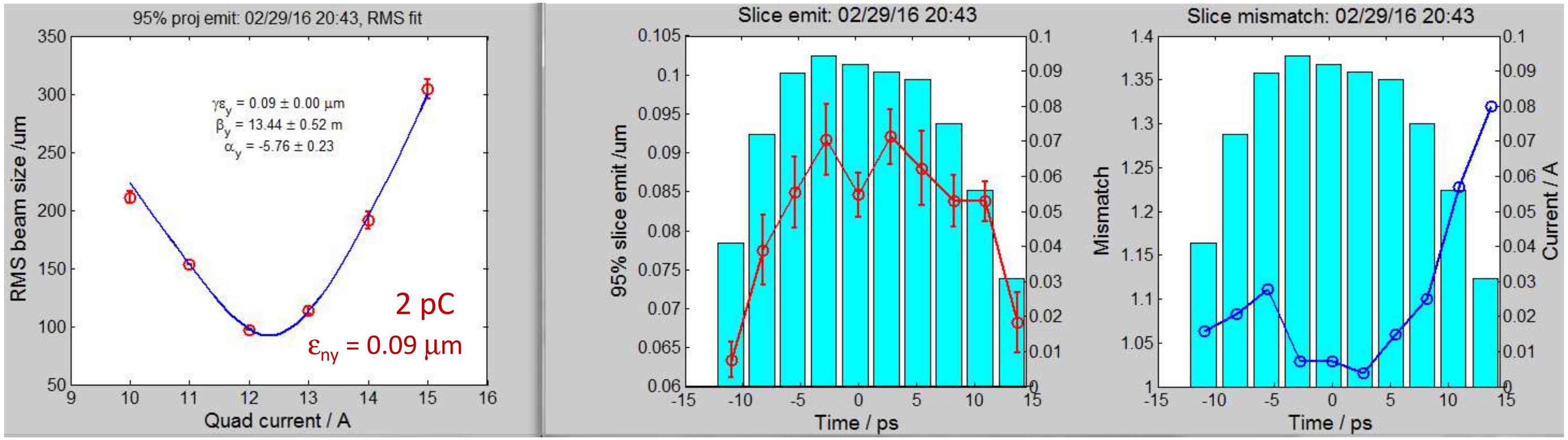
Quad 1 and 3 + T-Cav + Screen 3 → Slice emittance

T-Cav + Spectr. Dipole + Spectr. Screen → Longitudinal phase space
Slice energy spread

Initial 20 pC beam tuning results (2015.12 – 2016.02)

- Gun: 650 kV, 18 ms x 10 Hz
- Linac: 15 MV, 10 us x 10 Hz
- Cathode: Cs_2KSb
  - 0.5-0.6 um/mm





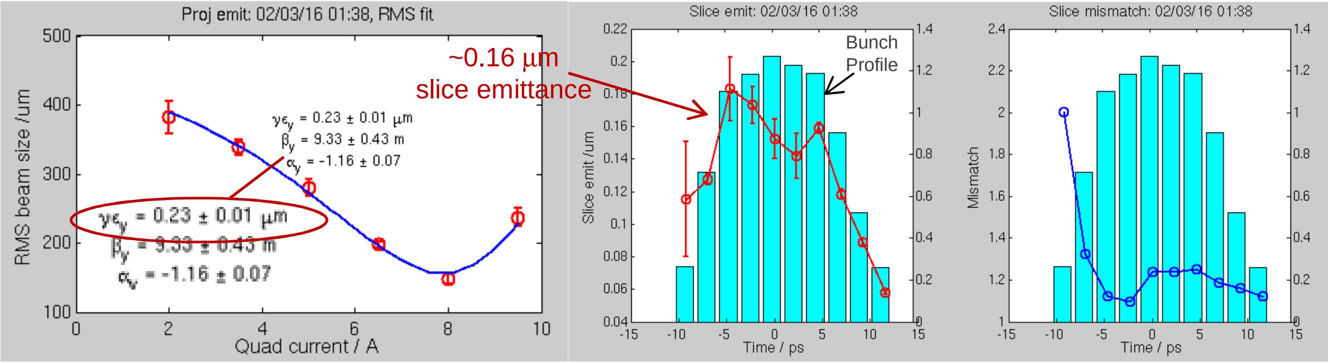
Not published, do not distribute

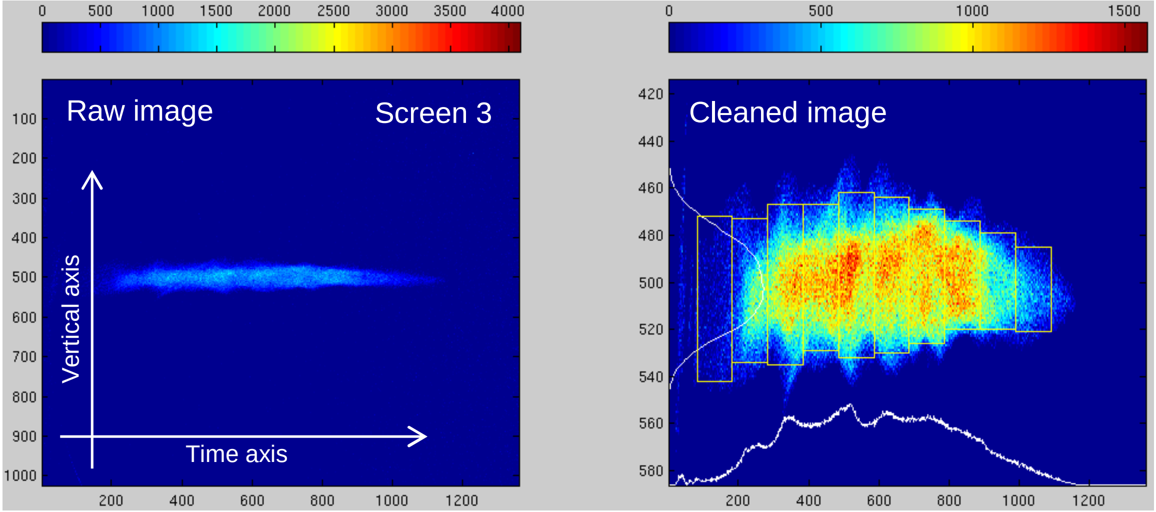
Initial 20 pC beam tuning results (2015.12 – 2016.02)

- 20 pC, buncher off, 1.2 A, 0.16 um slice emit

20 pC, 15.4 MeV, 95% Projected emittance

95% Slice emittance & mismatch parameter

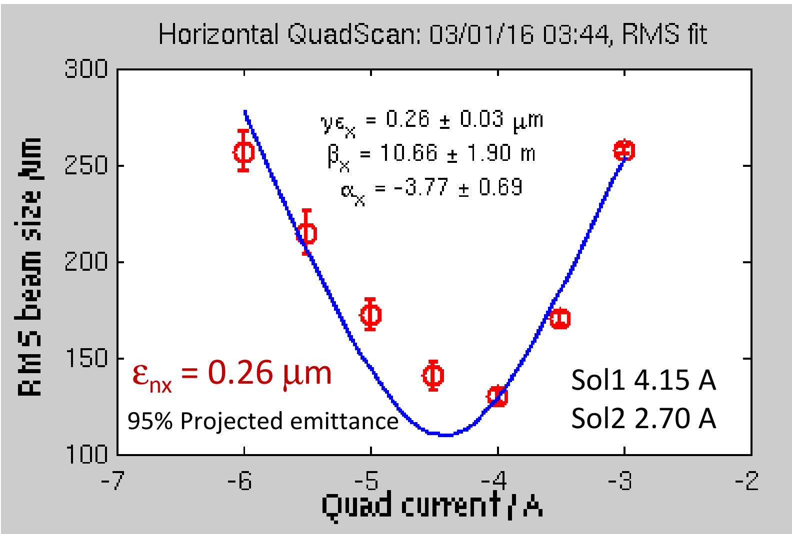


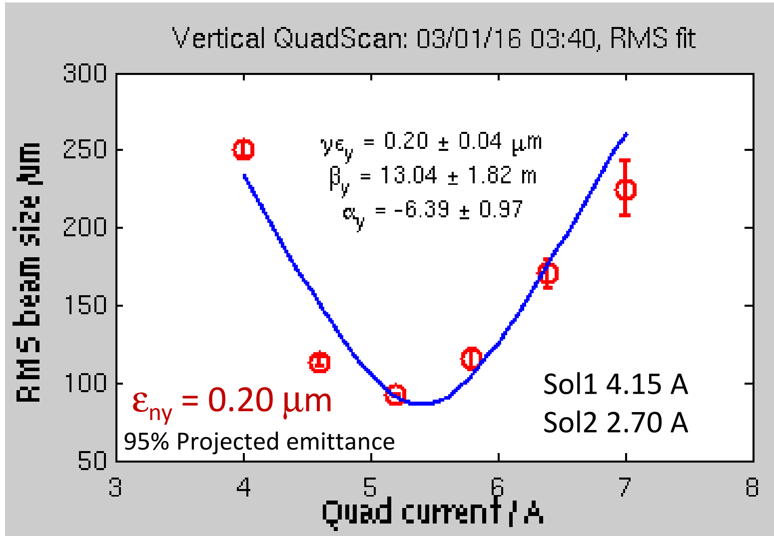


Not published, do not distribute

Initial 20 pC beam tuning results (2015.12 – 2016.02)

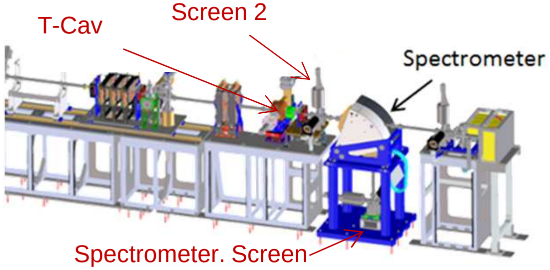
- 20 pC, buncher on
  - Projected emittance
  - ~7 A, <0.25 um (over estimation due to spch)





F. Sannibale, IPAC 16

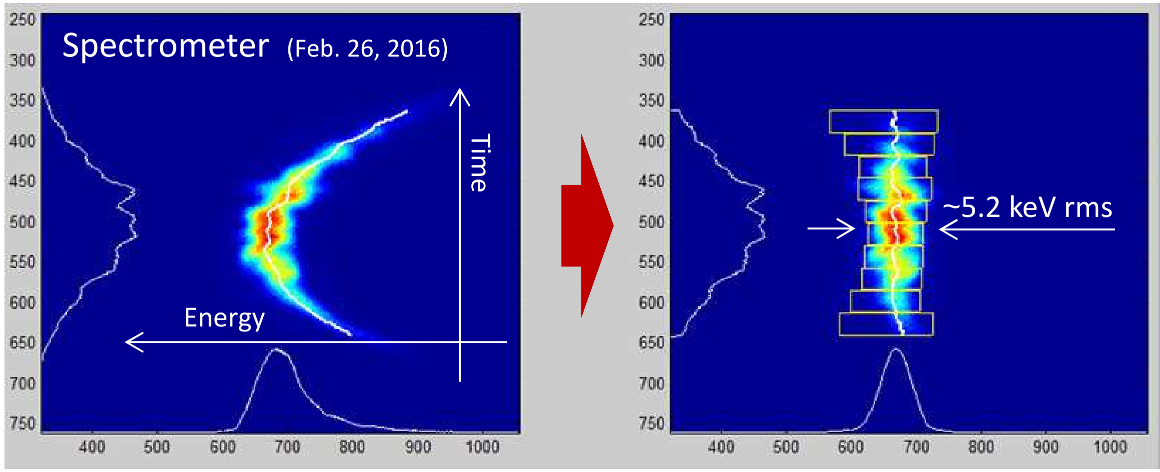
Initial 20 pC beam tuning results (2015.12 – 2016.02)



T-Cav induced energy spread
(2.2 keV/100 μm σ_x)
~ 3.6 keV rms

22 pC, 15.7 MeV

~3.2 A peak current



H.O. energy spread < $(5.2^2 - 3.6^2)^{1/2}$ keV < 3.7 keV rms

(space charge affected)
(spectrometer resolution not deconvolved)

The APEX Team!

K. Baptiste, C. Cork, J. Corlett, M. Decool, S. De Santis, M. Dickinson, L. Doolittle, J. Doyle, J. Feng, D. Filippetto, D. Gibson, S. Giermann, G. Harris, G. Huang, M. Johnson, M. Kirkpatrick, T. Kramasz, S. Kwiatkowski, D. Leitner, R. Lellinger, R. Li, T. Luo, C. Mitchell, V. Moroz, J. Nasiatka, W. E. Norum, H. Padmore, G. Portmann, H. Qian, F. Sannibale, J. Schmerge, J. Staples, D. Syversrud, T. Vecchione, M. Vinco, S. Virostek, R. Wells, F. Zhou, M. Zolotorev.

Large part of people was part time on APEX

Backup slides

Incomplete publications

- J. Staples, F. Sannibale, S. Virostek, "VHF-band Photoinjector", CBP Tech Note 366, October 2006
- S. Lidia, et. al., ”Development of a High Brightness VHF Electron Source at LBNL”, Proceedings of the 41st Advanced ICFA Beam Dynamics Workshop on Energy Recovery Linacs, Daresbury Laboratory, UK, May 21-25, 2007.
- J. W. Staples, et al., "Design of a VHF-band RF Photoinjector with MegaHertz Beam Repetition Rate". 2007 Particle Accelerator Conference, Albuquerque, New exico, June 2007.
- K. Baptiste, et al., "The LBNL normal-Conducting RF gun for free electron laser and energy recovery linac applications", NIM A 599, 9 (2009).
- K. Baptiste, et al., Status of the LBNL normal-conducting CW VHF photo-injector, Proceedings of the 2009 Particle Accelerator Conference, Vancouver, Canada, May 2009.
- F. Sannibale, D. Filippetto, C. Papadopoulos, JMO 58, 1419 (2011)
- F. Sannibale, et al., PRST-AB 15, 103501 (2012)
- R. Huang, et al., PRST-AB 18, 013401 (2015)
- D. Filippetto, H. Qian, F. Sannibale, Appl. Phys. Letters 107, 042104 (2015).