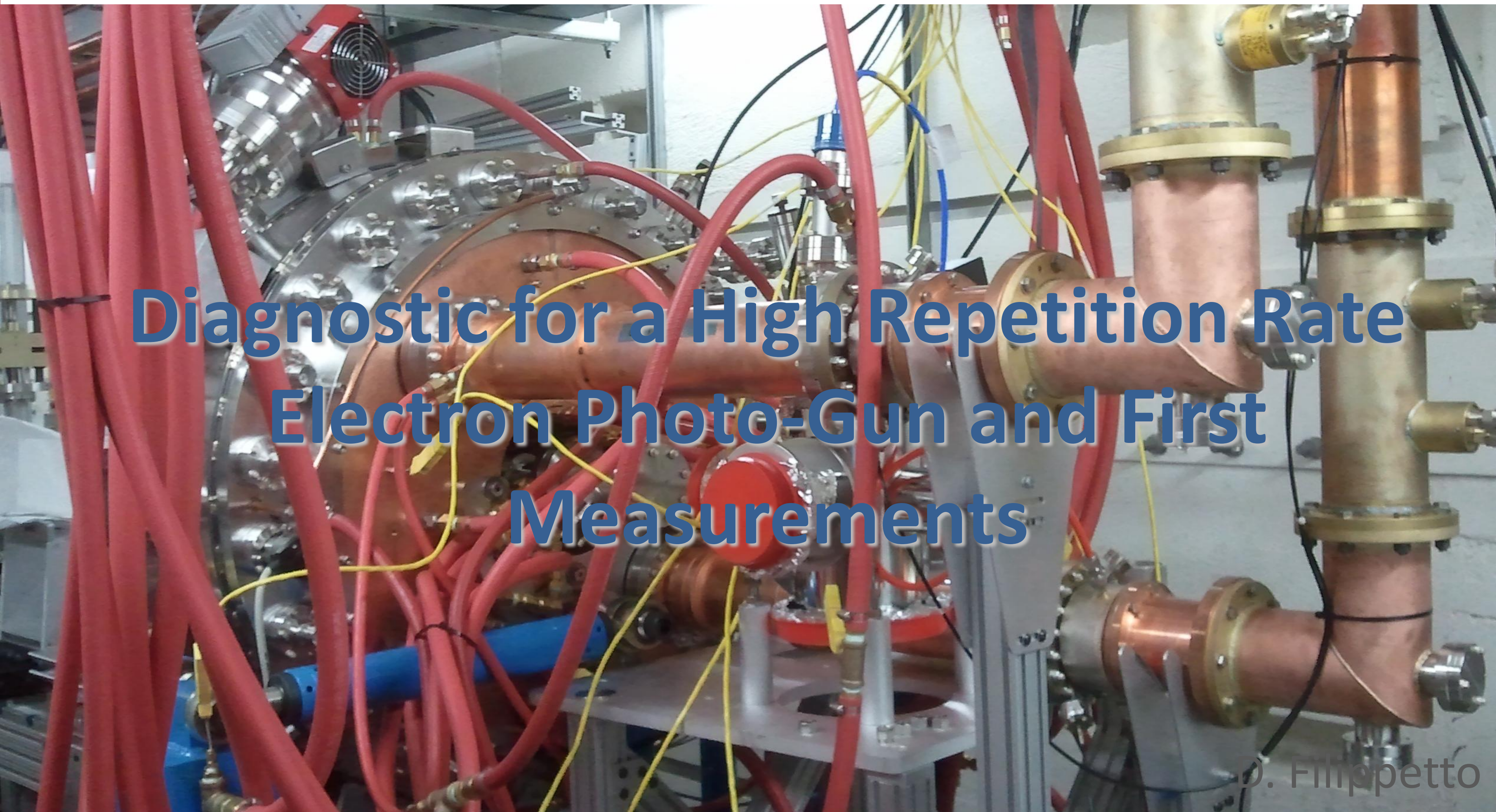
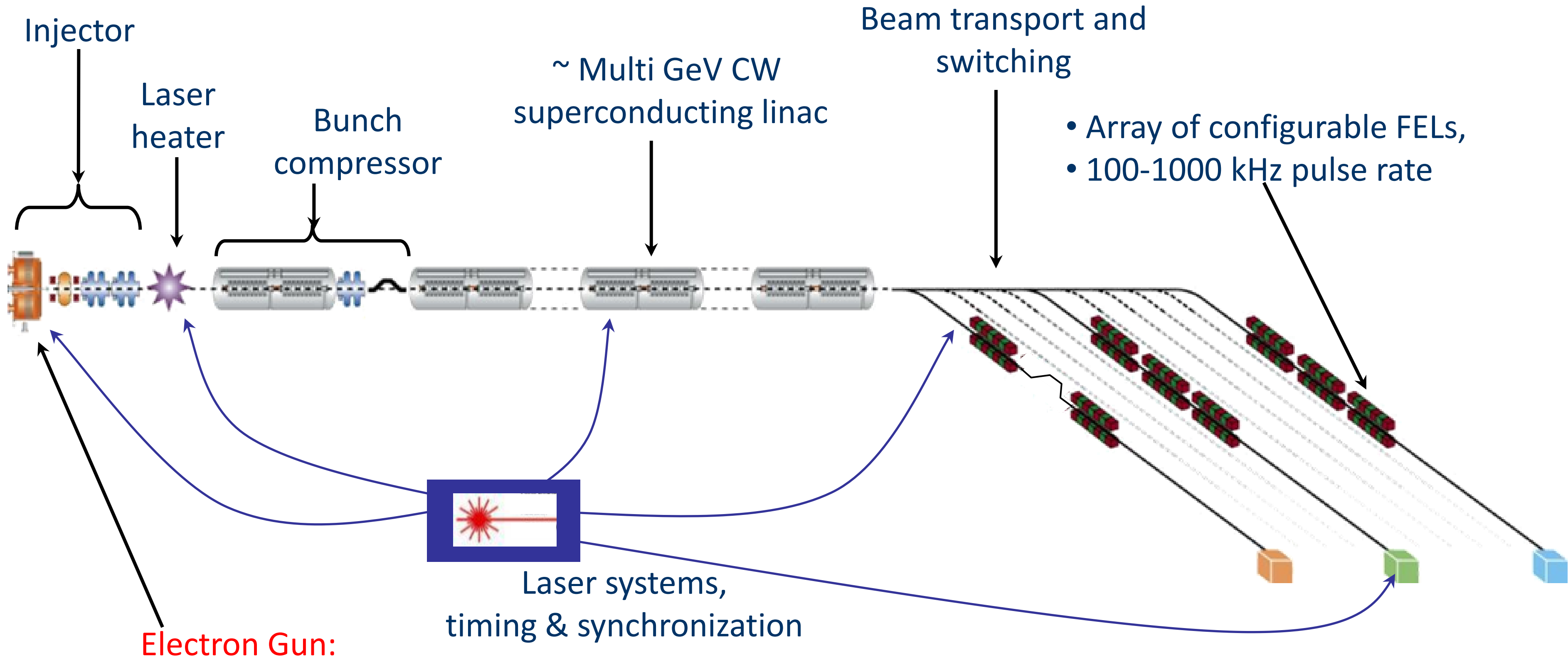
Diagnostic for a High Repetition Rate Electron Photo-Gun and First Measurements



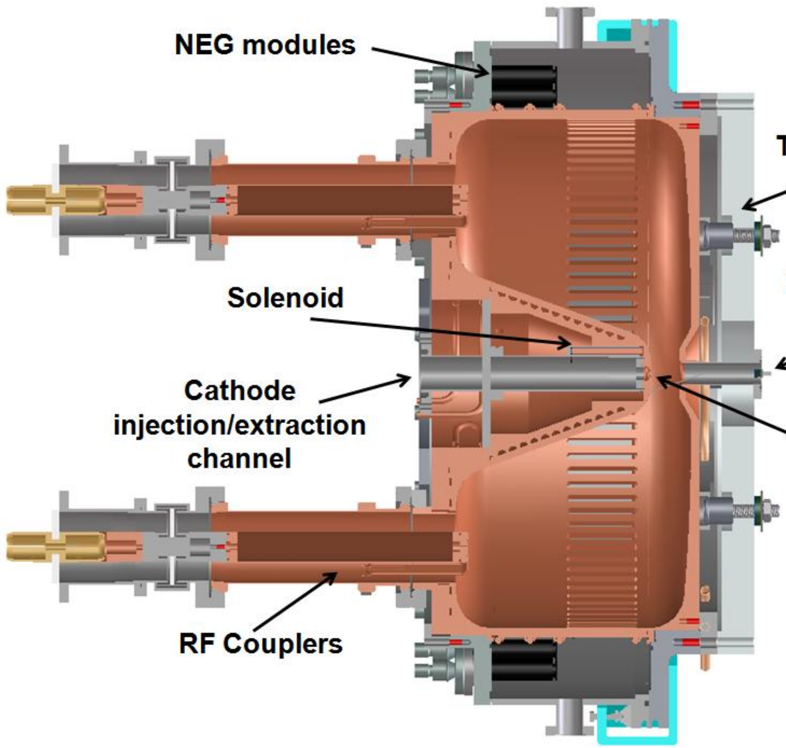
D. Filippetto

The LBNL idea of next generation light source



- MHz repetition rate
- electric field at the cathode > 10 MV/m (space charge limit)
- 10^{-9} - 10^{-11} Torr operation vacuum pressure (high QE photo-cathodes),
- "easy" installation and conditioning of different kind of cathodes,
- Reliability

The LBNL VHF Gun



K. Baptiste, et al, NIM A 599, 9 (2009)

Frequency	186 MHz
Operation mode	CW
Gap voltage	750 kV
Field at the cathode	19.47 MV/m
Q_0 (ideal copper)	30887
Shunt impedance	6.5 MΩ
RF Power	100 kW
Stored energy	2.3 J
Peak surface field	24.1 MV/m
Peak wall power density	25.0 W/cm^2
Accelerating gap	4 cm
Diameter/Length	69.4/35.0 cm
base pressure	~ 10^{-11} Torr

- At the **VHF frequency**, the cavity structure is large enough to withstand the heat load and **operate in CW mode** at the required gradients.
- Also, the **long λ_{RF}** allows for large apertures and thus for **high vacuum conductance**
- Based on **mature and reliable normal-conducting RF and mechanical technologies**.

APEX PHASES:

Phase 0 scope:
- Demonstration of the RF performance at full repetition rate.
- Vacuum performance demonstration.
- Dark current characterization.
- High QE cathode physics (QE, lifetime, intrinsic emittance)

Phase I scope:
(Phase 0 + extended diagnostics)
- High current emittance
- Diagnostics systems tests
- Low energy beam characterization

currently being installed

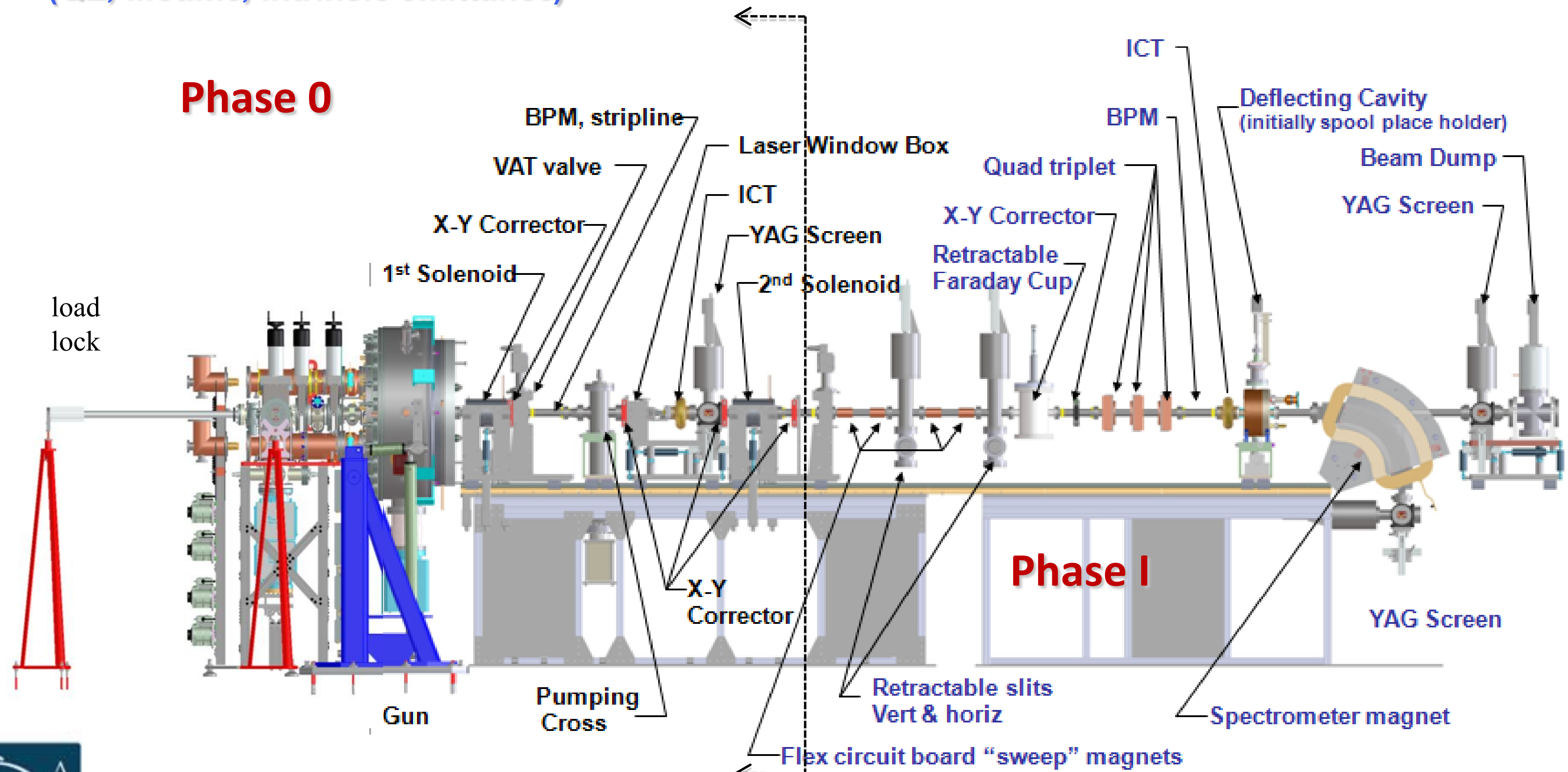
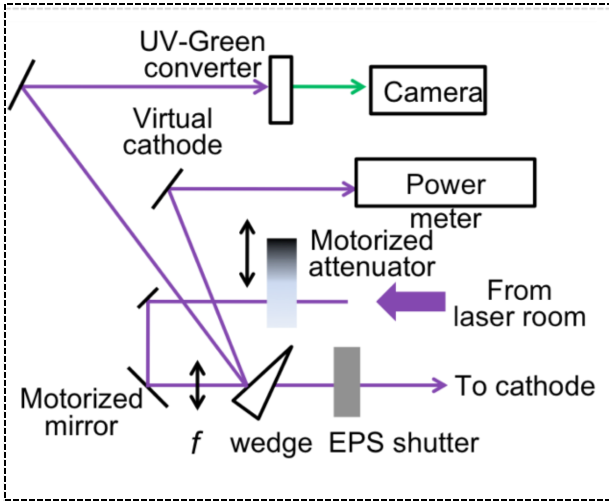
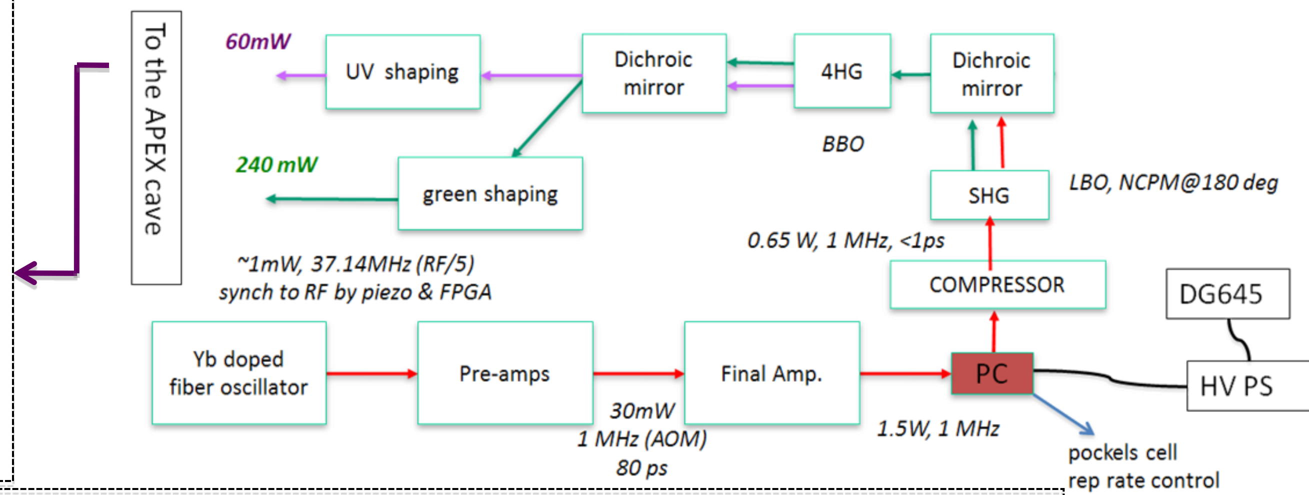
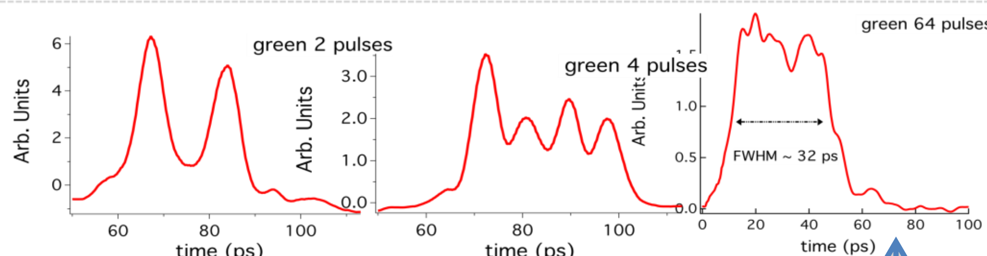
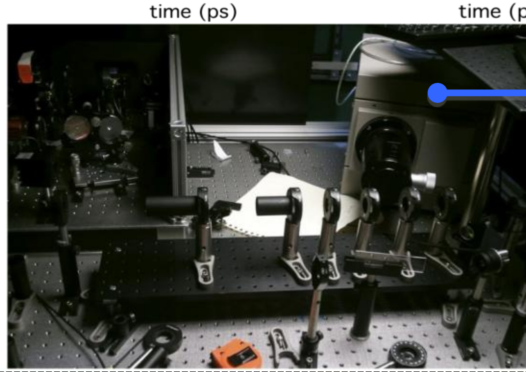


Photo-Cathode Laser system







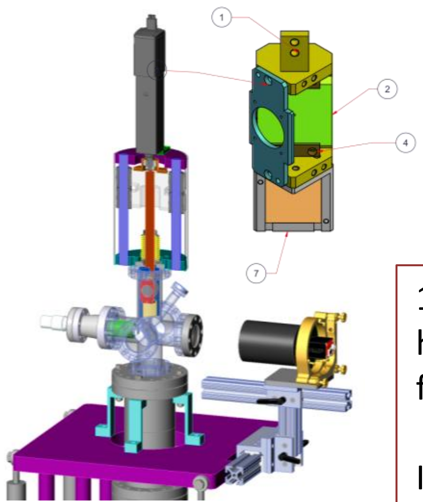


streak camera in synchroscan mode

APEX Phase 1 Beam Diagnostics

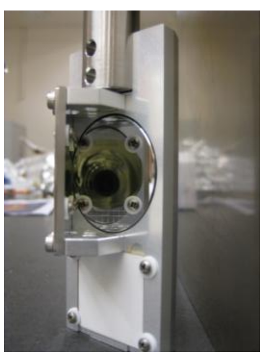
- Full 6D phase space characterization
- Cathode physics

- Measure charges from fC to nC
- Accurate measurements of time and energy

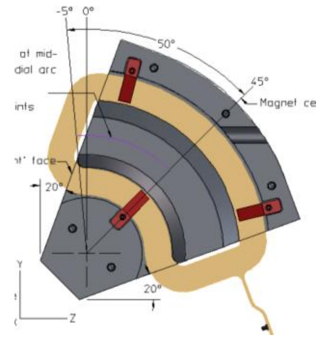


12bit CCD (Ethernet)
high quality macro lenses for imaging (M=1/2)

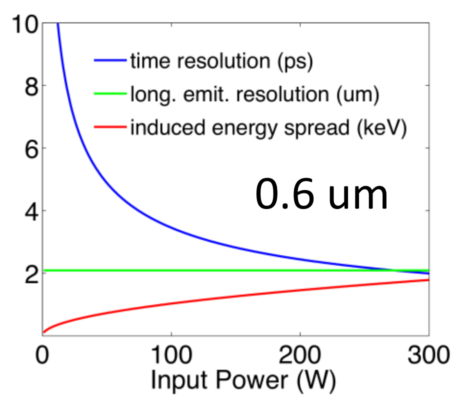
Imaging screens:
- Yag:Ce (100 µm)
- BeO (higher saturation)

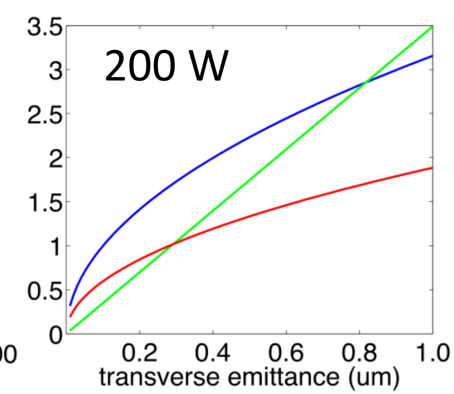


based on Cornell design



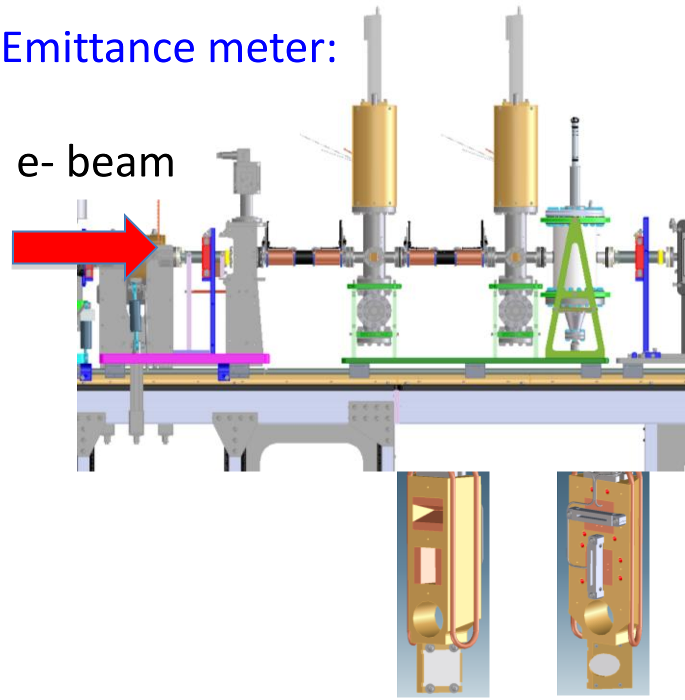
- 90 deg, 110 G at 750 keV
- 10^{-4} Energy resolution
- 500 eV δE resolution



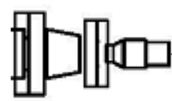


APEX Phase 1 Beam Diagnostics

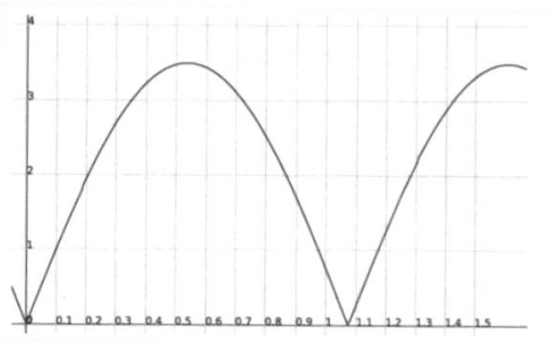
Emittance meter:



Electronics for the faraday cup:



Beam position monitors:



15 cm shorted stripline BPM

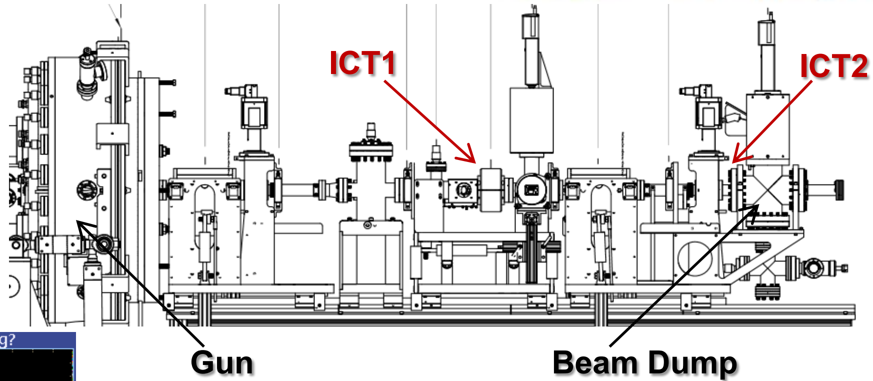
BPF @ 260MHz sampled at 100MHz

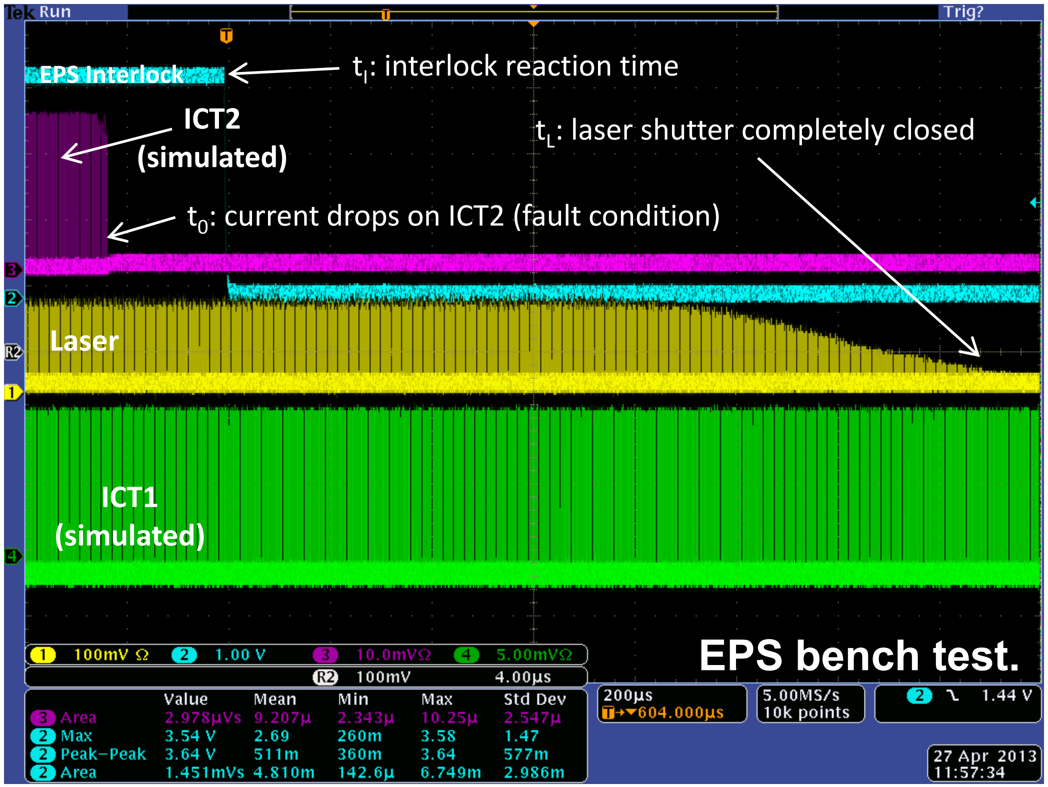
~3mV for good reading

S. De Santis, MOPC24

The Fast Equipment Protection System

Operation @ 1 MHz ~ 300 pC/bunch requires an EPS system for protecting the chamber from accidental misteering of the beam





IF (|ICT2-ICT1| > $I_{threshold}$) THEN Close Laser Shutter

$$t_I - t_0 \sim 0.240 \text{ ms}$$

$$t_L - t_I \sim 1.5 \text{ ms}$$

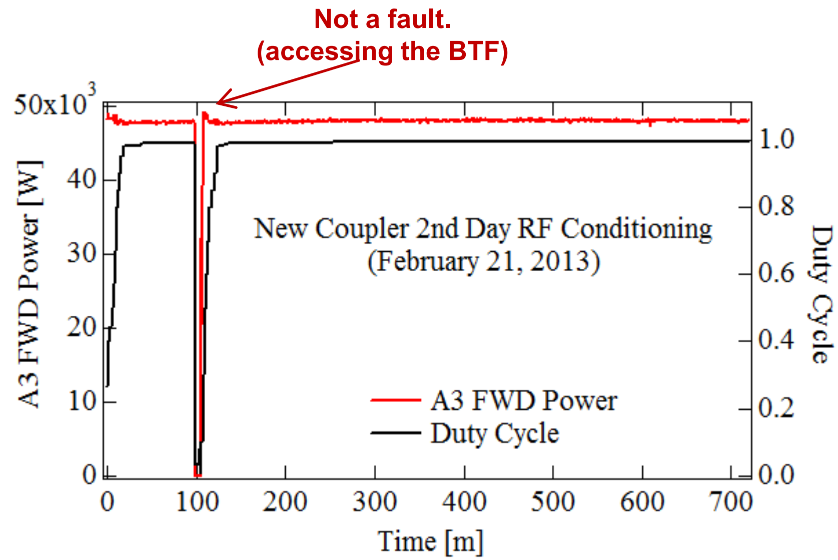
Total response time: ~1.75 ms (estimated 2 ms required)

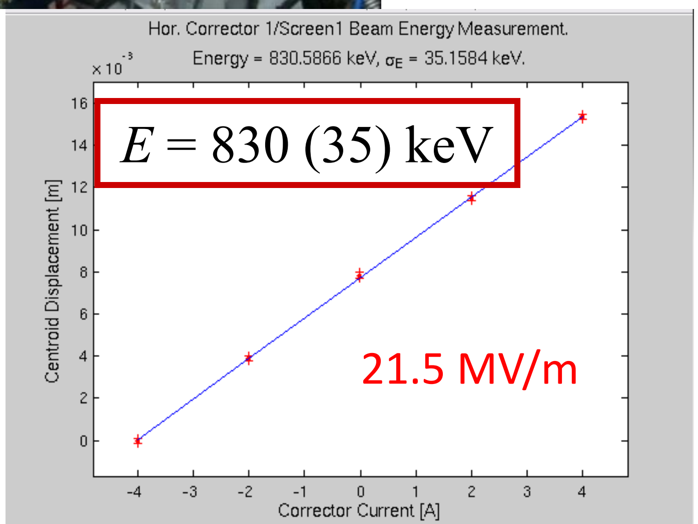
LLRF-FPGA based (Eric Norum)

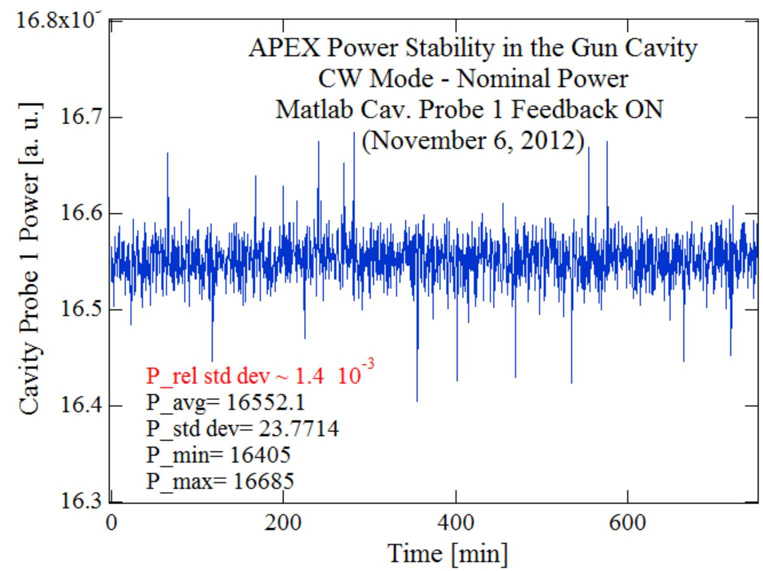
Ready for MHz repetition rate tests!

Gun performances

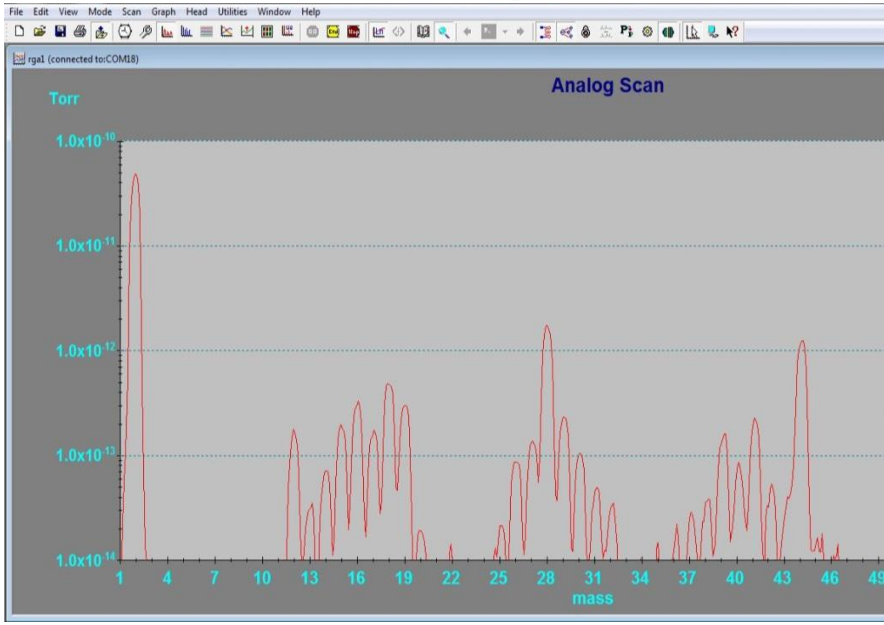
The gun was conditioned in less than 120 hours





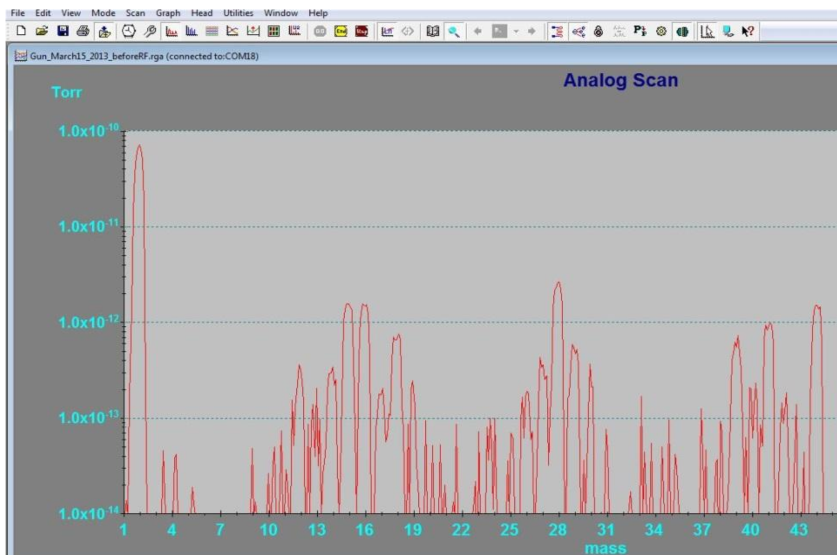


APEX Gun RGAs (RF OFF vs. RF ON)



Argon	0.1%
Carbon dioxide	2.8%
Carbon monoxide	2.6%
Helium	0.0%
Hydrogen	91.2%
Methane	0.6%
MP Oil	0.7%
NO	0.2%
Neon	0.0%
Nitrogen	0.6%
Oxygen	0.0%
Water	1.2%

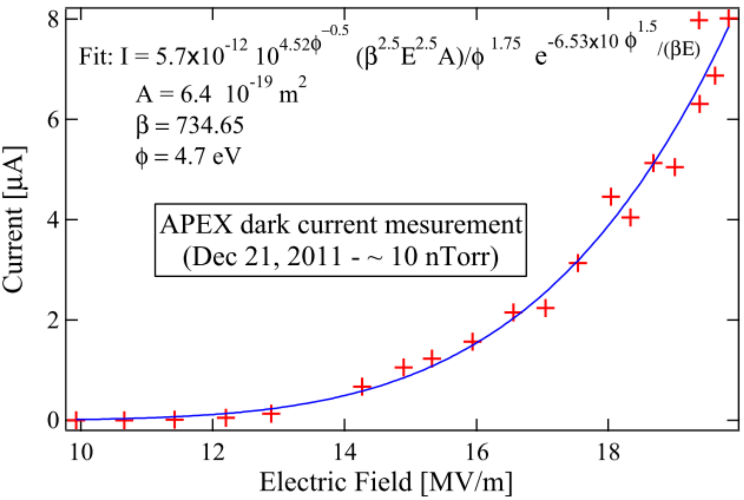
RF OFF:
P_{TOT} ~ 3 10^{-11} Torr.
Largely H_2 and H_2O, CO and CO_2 at percent level

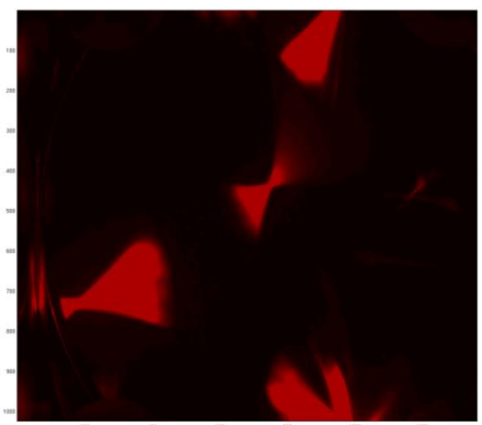


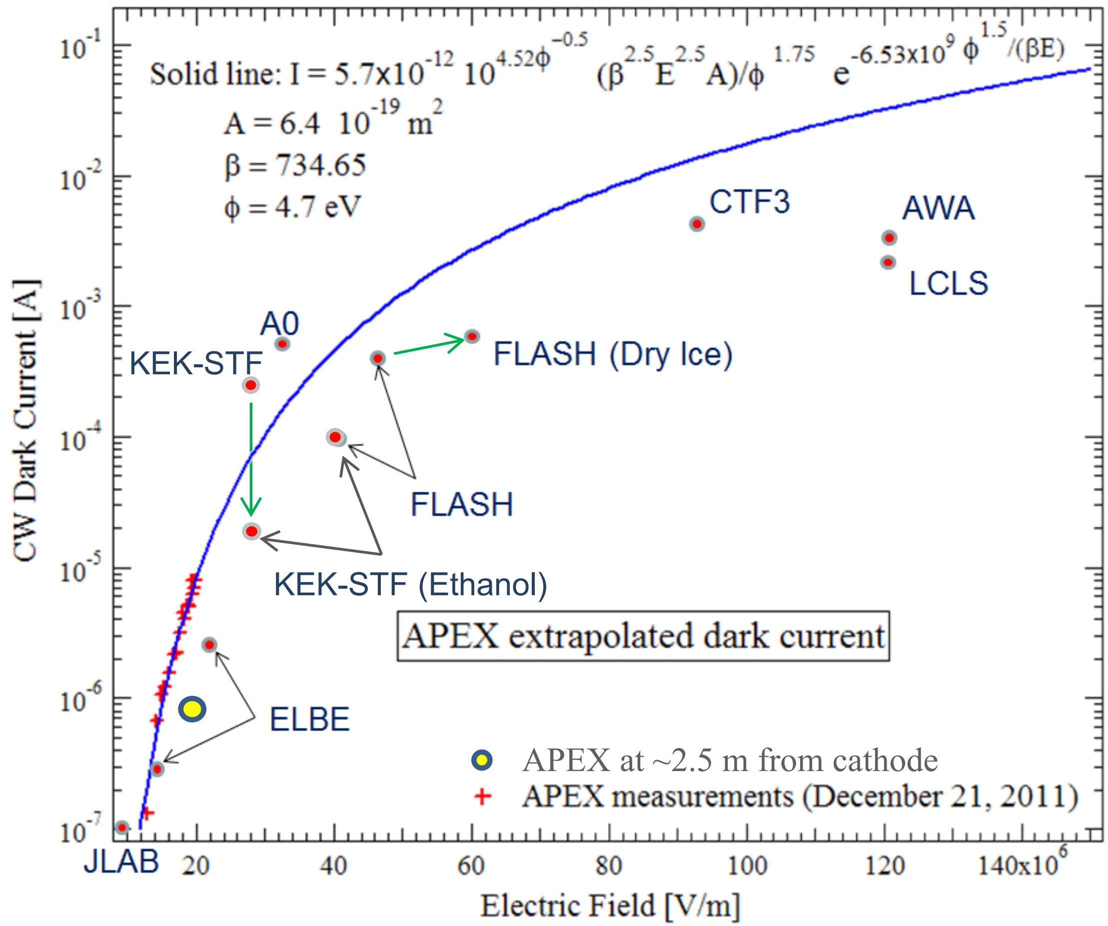
Argon	0.6%
Carbon dioxide	2.2%
Carbon monoxide	1.9%
Helium	0.1%
Hydrogen	85.2%
Methane	3.8%
MP Oil	2.4%
NO	0.5%
Neon	0.1%
Nitrogen	1.2%
Oxygen	0.2%
Water	1.7%

RF ON:
(nom. power 98% duty Cycle)
P_{TOT} ~ 9 10^{-10} Torr
H_2O, CO and CO_2 still at percent level.

Dark current



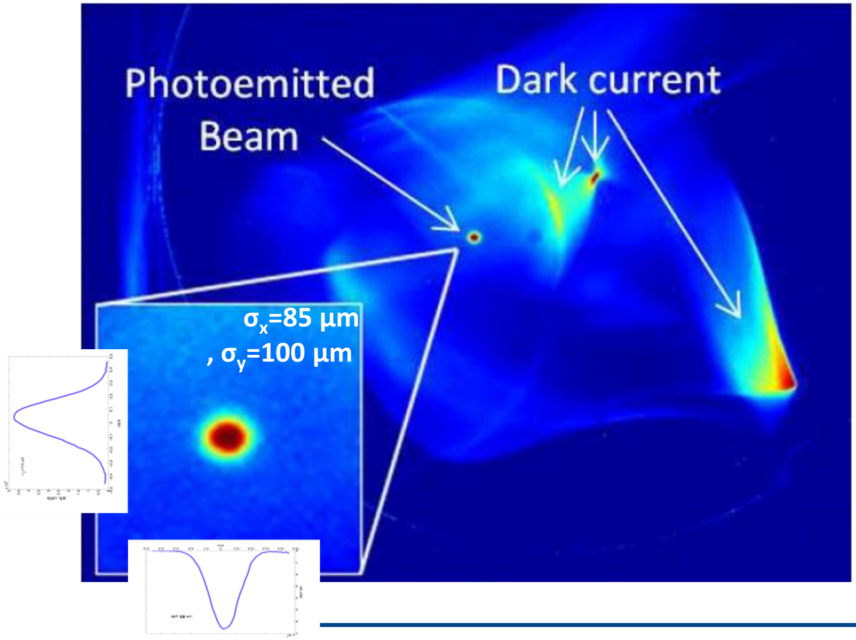


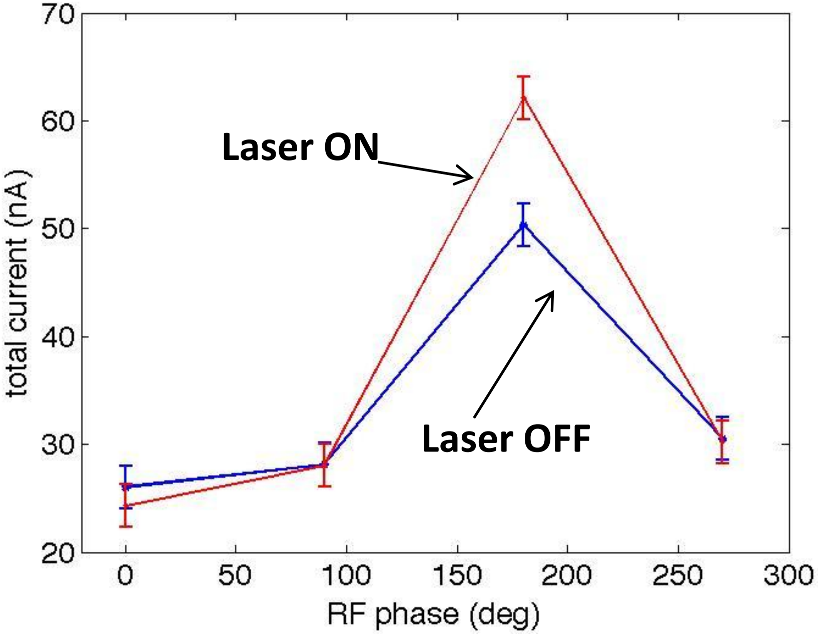


REMARK: **APEX data collected right downstream the gun (~ 25 cm from cathode). Most of other data were collected few meters downstream the beamlines.**

(Very) low charge measurements

Photoemitted average current measured by a lock-in amplifier with the MHz laser trigger as reference and the Faraday cup signal in input.

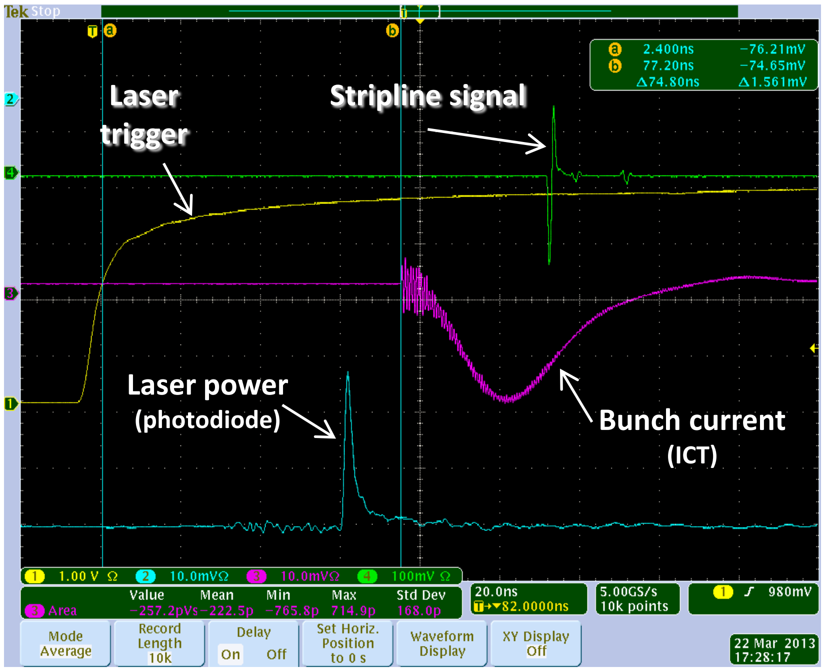


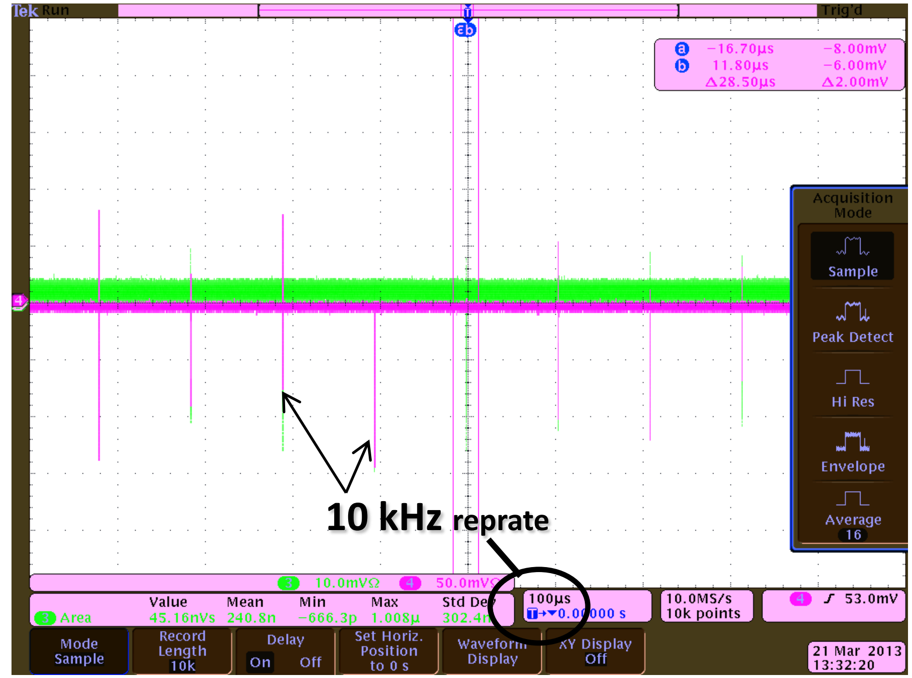


Laser average power at the cathode: ~ 30 mW at ~ 266 nm.
Cathode: Molybdenum plug, QE ~ 10^{-6}
Expected charge per bunch : ~ 6 fC
Expected average current at 1 MHz: ~ 6 nA (dark current ~ 50 nA)

Measured ~ 10 nA, consistently with expectations!

Beam Operation with Cs_2Te



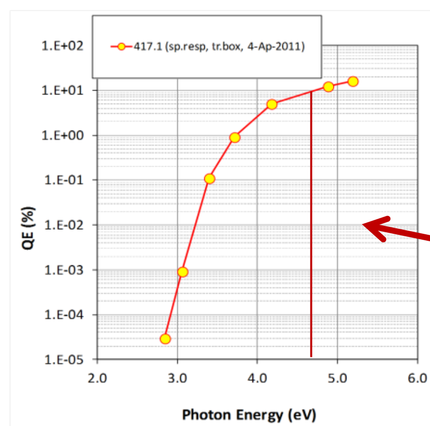


Example of QE measurement:

~ 450 pC/bunch

~ 18.7 nJ/pulse
@ 266 nm (4.7 eV)

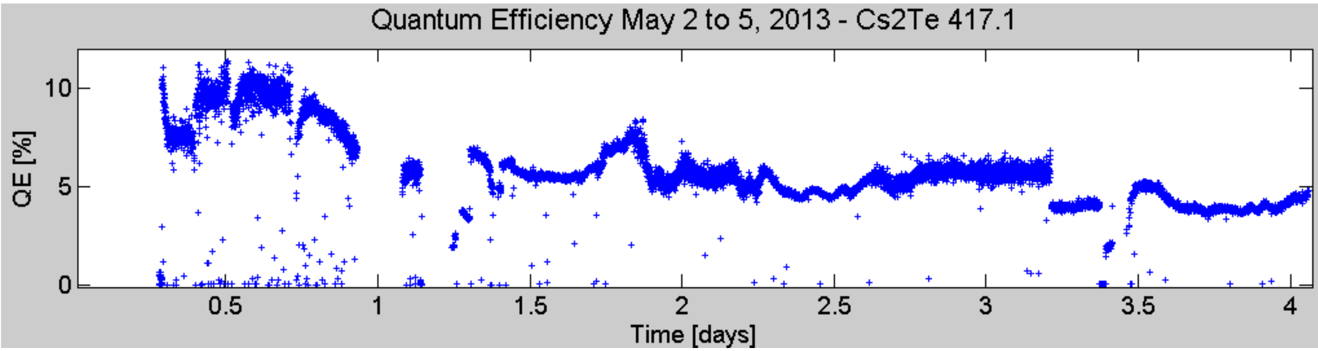
QE ~ 11%

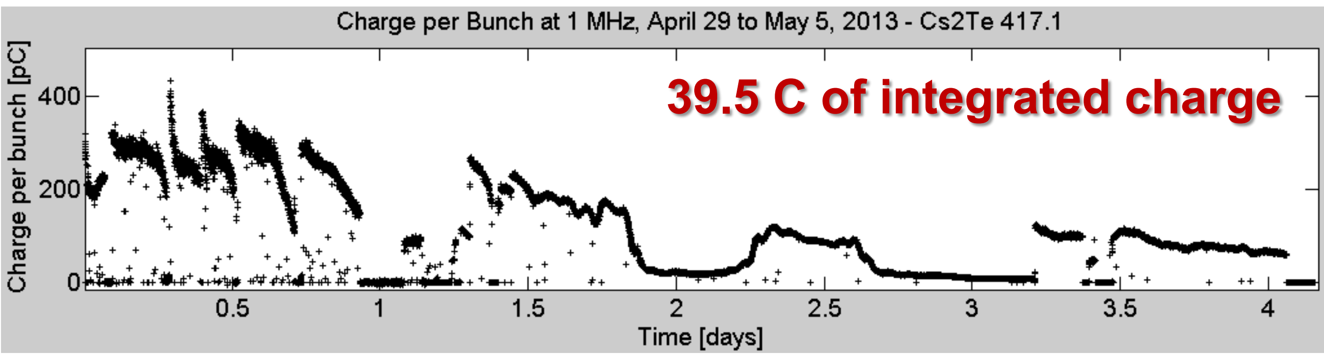


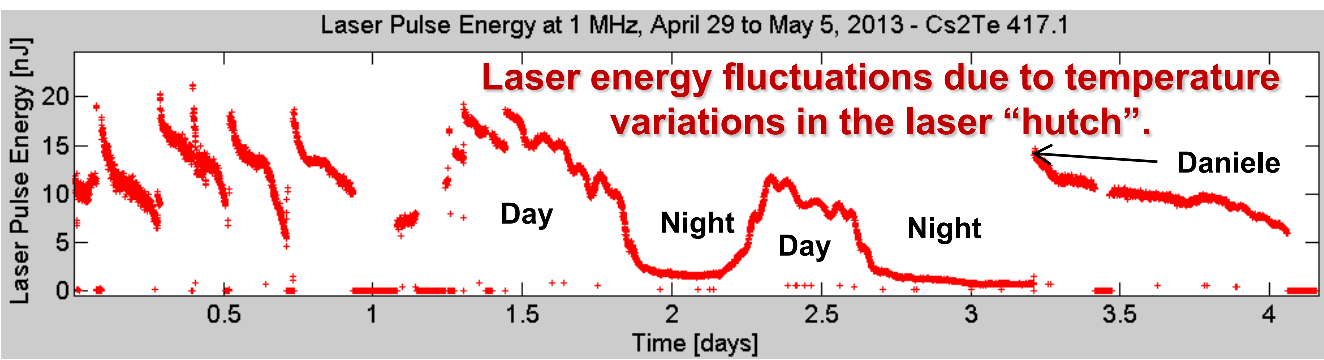
Cathode 417.1: Cs_2Te
(deposited at INFN-LASA on 3/30/2011)

10 % QE measured at INFN-LASA in March 2011

Summary Results after 4 Days of MHz Tests.







Laser action items:

- feedbacks (pointing & energy).
- laser area temperature control.
- replace present laser by a commercial more stable & powerful unit

39.5 C equivalent to ~ 3 months of FLASH operation.

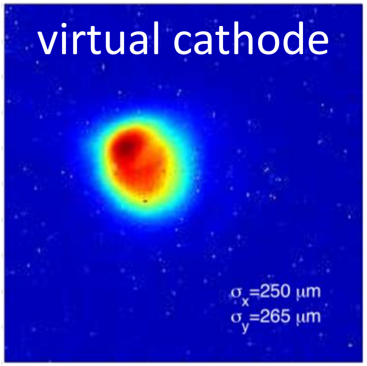
QE dropped from ~ 10 to ~ 4 %

Best FLASH cathode QE dropped from 10 to 1% in 6 months.

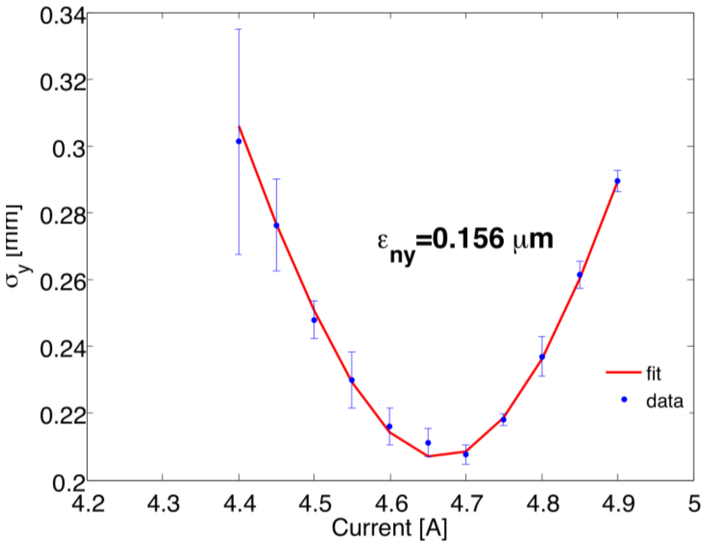
Thermal emittance of Cs_2Te (Sept. 9,2013)

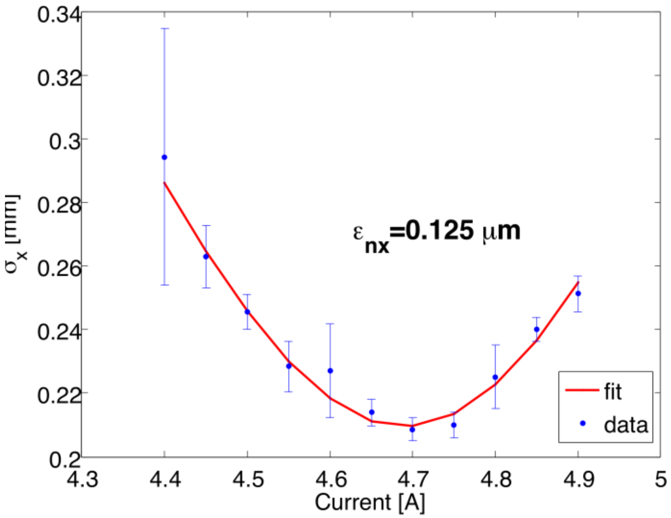
APeX @ Berkeley Lab

parameter	Value
Q (fC)	900
τ_{laser}, FWHM (ps)	58, flat top
$\sigma_{Xlaser}/\sigma_{Ylaser}$, RMS (µm)	250/265
T_{el}, (keV)	830



0.5 µm/mm RMS

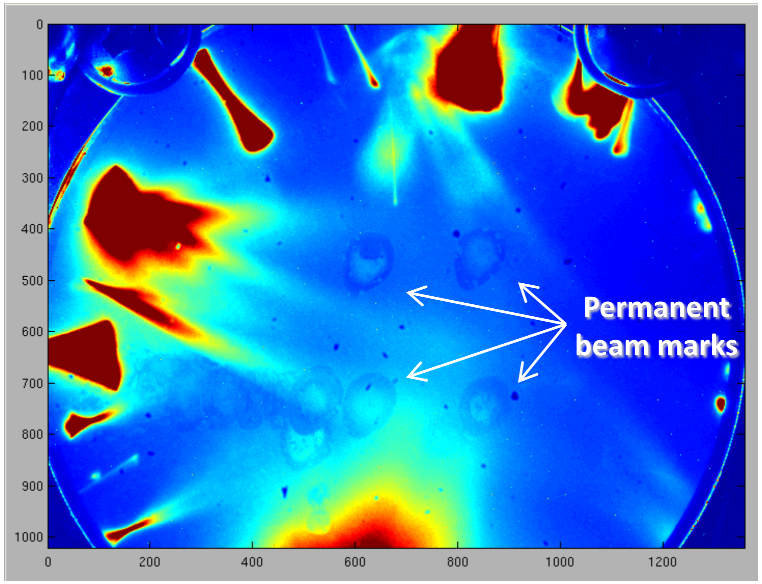


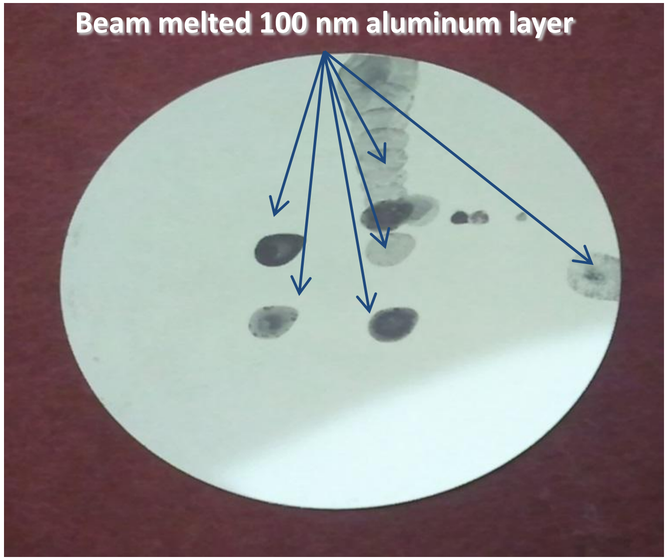


Transport matrix from cathode calculated by solving eq. of motion in steps (in canonical variables)

Lesson Learned:

~ several hundreds of pC at 1 kHz repetition rate + Focused on few hundred microns rms spot on a YAG screen





~45 mW/mm^2 peak average power density deposited

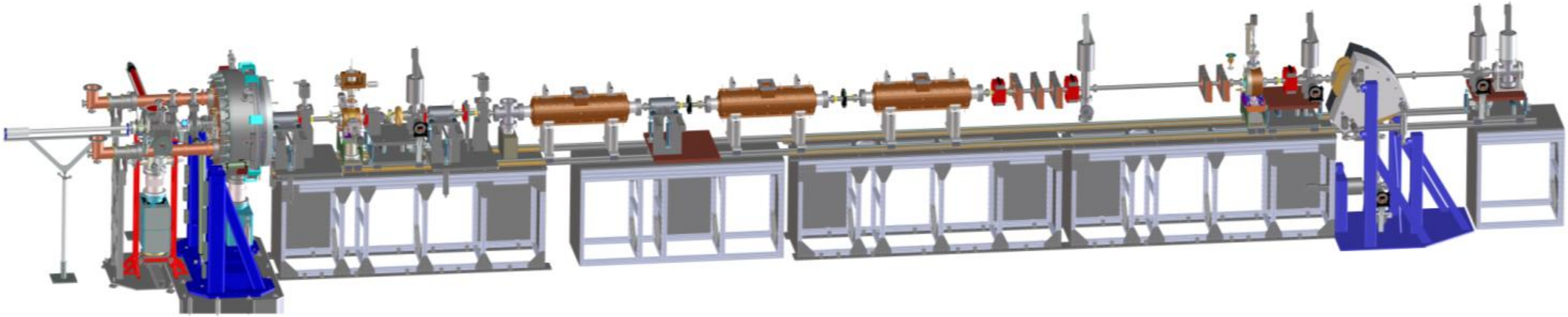
~0.5 fC/μm^2 peak charge density

March 21, 2013.

Conclusions

- Reliable operation at full CW power (>20MV/m)
- Vacuum levels on the 10^{-11} Torr level achieved
- Dark current measurements within the expectations
- Measured 1MHz photo-beam current and thermal emittance

Next future (18-24 months)



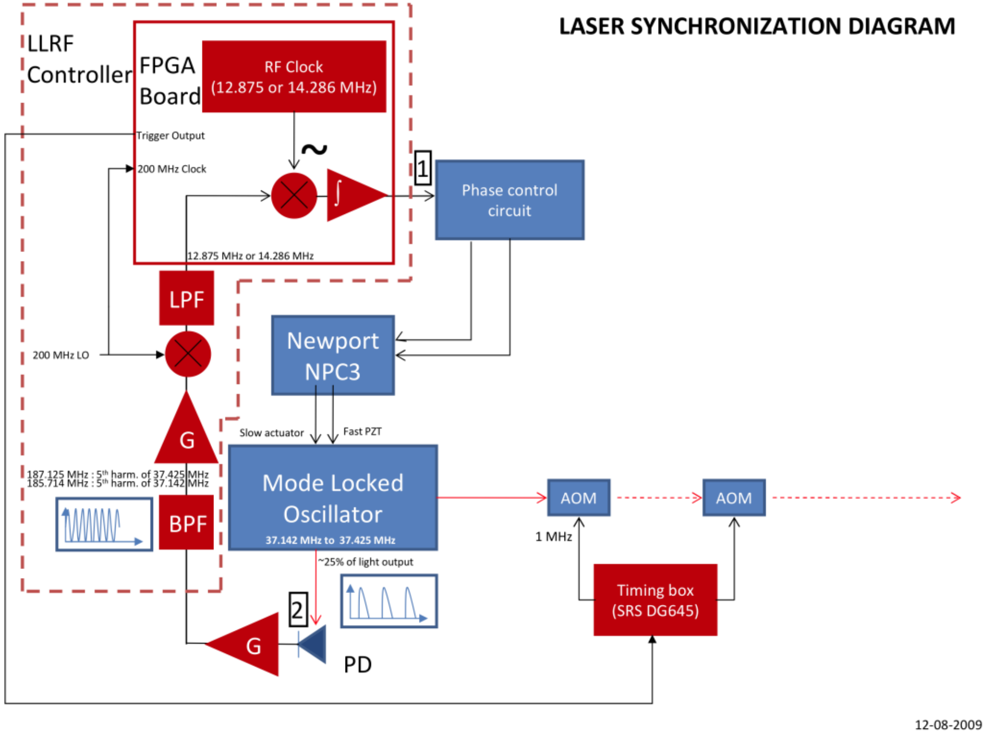
The Team:

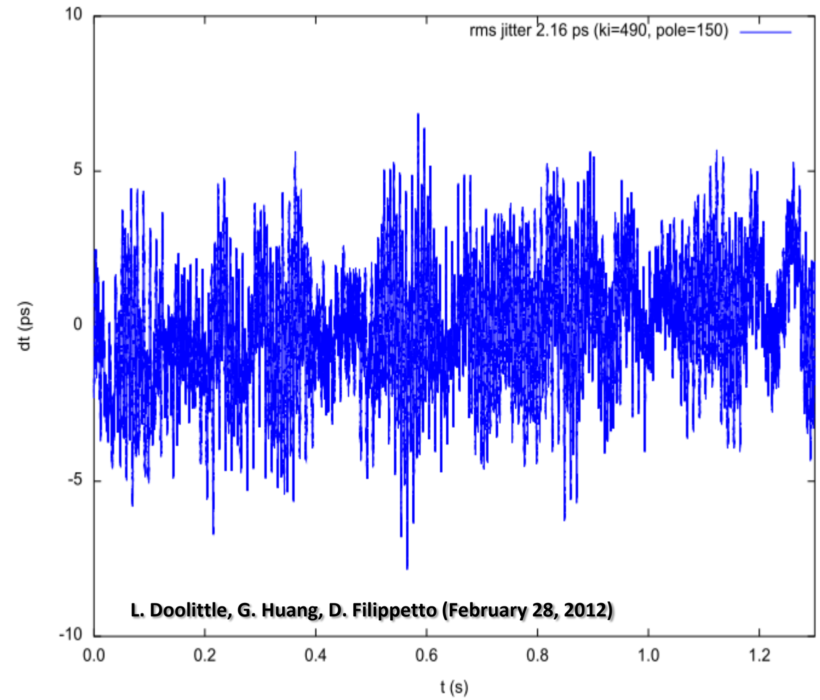
K. Baptiste, M. Chin, J. Corlett, C. Cork, S. De Santis, L. Doolittle, J. Doyle, D.Filippetto, G. Harris, G. Huang, H. Huang, T. Kramasz, S. Kwiatkowski, T. Luo, V.Moroz, W. E. Norum, H. Padmore, C. Papadopoulos, G. Portmann, H. Qian, F. Sannibale, J. Staples, M. Vinco, W. Wan, R. Wells, M. Zolotorev, … .

BACK UP SLIDES

LASER-RF SYNCHRONIZATION

The LLRF system controls the synchronization between the laser oscillator frequency and the VHF gun RF.





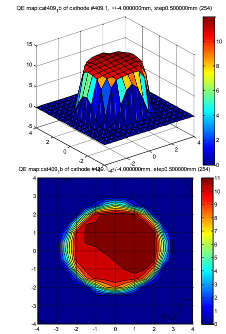
Jitter ~ 2 ps rms (~ 0.15 RF deg @ 186 MHz).
More than enough for present APEX operation.
To be improved by upgrading the piezo/picomotor mirror actuator.

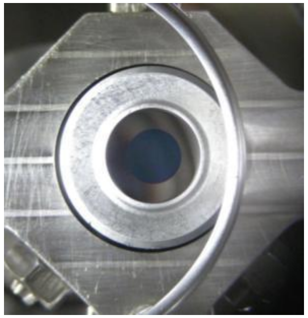
PHOTO-CATHODES FOR APEX

APeX @ Berkeley Lab

PEA Semiconductor: Cesium Telluride Cs_2Te (In collaboration with INFN-LASA)

- <~ps pulse capability
- relatively robust and un-reactive (operates at ~ 10^{-9} Torr)
- successfully tested in NC RF and SRF guns
- high QE > 1%
- photo-emits in the UV (~260 nm) (4^{th} harm. conversion from IR)
- for 1 MHz reprate, 1 nC, ~ tents of W 1060nm required

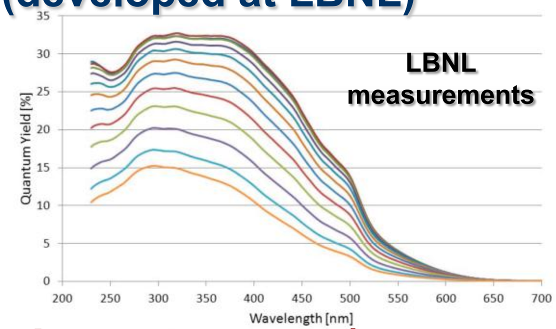




First 3 cathodes successfully developed at INFN/LASA and delivered to LBNL.

PEA Semiconductor: Alkali Antimonides CsK_2Sb, (developed at LBNL)

- <~ps pulse capability
- reactive; requires ~ 10^{-10} Torr pressure
- high QE > 1%
- requires green/blue light (eg. 2^{nd} harm. Nd:YVO4 = 532nm)
- for nC, 1 MHz reprate, ~ few W of IR required



Cathodes under development at LBNL (H. Padmore's group).
Promising lifetime and intrinsic emittance results (Cornell and LBNL).
Transfer chamber from preparation chamber to VHF gun in fabrication.

Try other cathode materials (diamond amplifier,…)

March 2013 Vacuum Base Pressure Tests

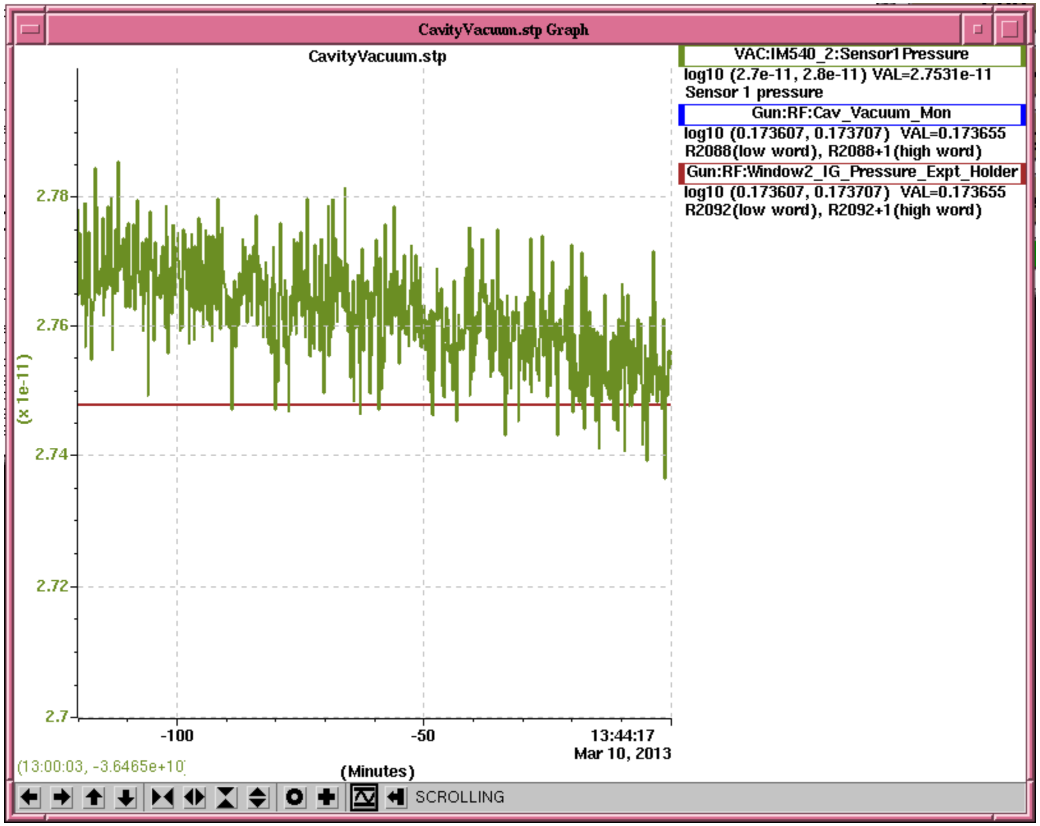
APeX @ Berkeley Lab

- All 20 NEG pumps activated
- 2.5 days of RF baking at ~ 180-200 °C

Pressures at the 3 gun gauges:

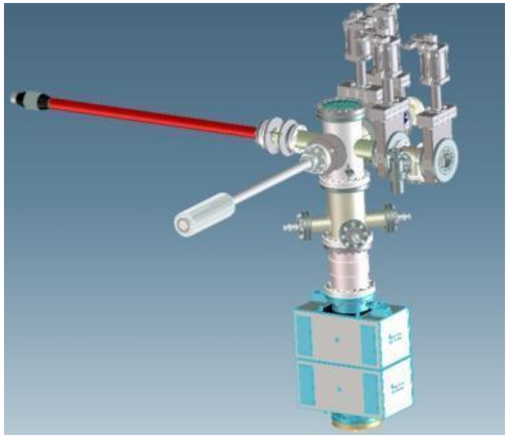
•Bottom IG: 1.4 10^{-12} Torr (beyond gauge sensitvity)
•Side IG: 1.4 10^{-12} Torr (beyond gauge sensitvity)
•Extractor gauge: **2 10^{-11} Torr** (2.7 10^{-11} mBar) (this gauge has the proper sensitivity)

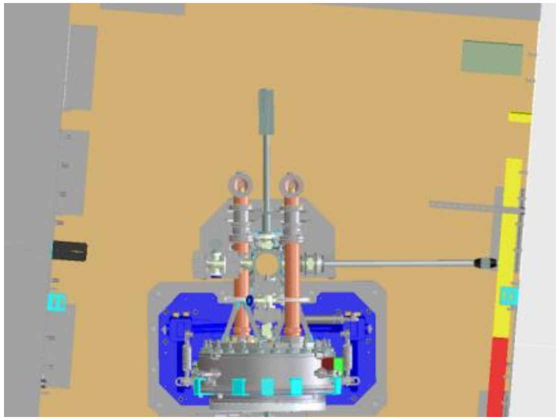
RGA measurement indicated partial pressures of H_2O, CO, CO_2 two-orders of magnitude smaller.



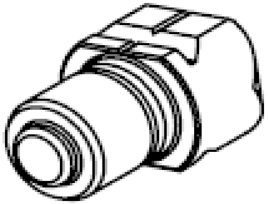
Pressure in the loadlock ~ 2 10^{-10} Torr, with ~ 10^{-12} Torr of H_2O, CO and CO_2.

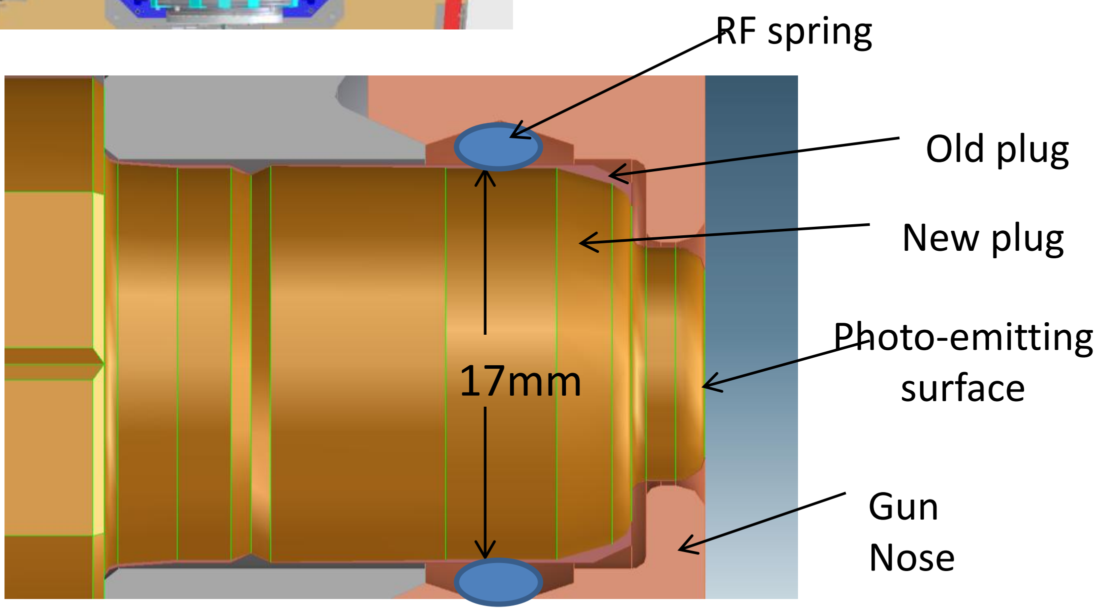
VACUUM LOAD LOCK SYSTEM





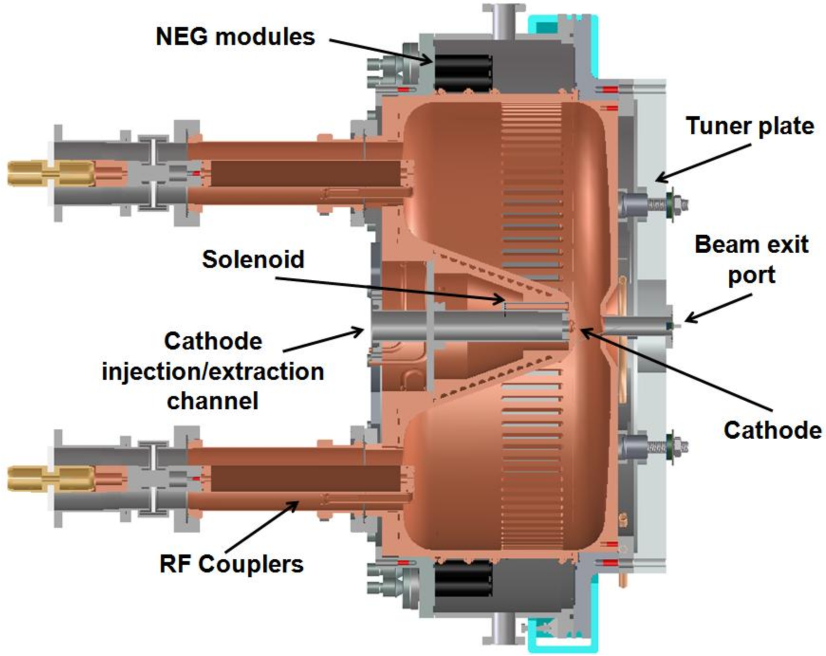
Adapted version of the INFN/PITZ/DESY load-lock system

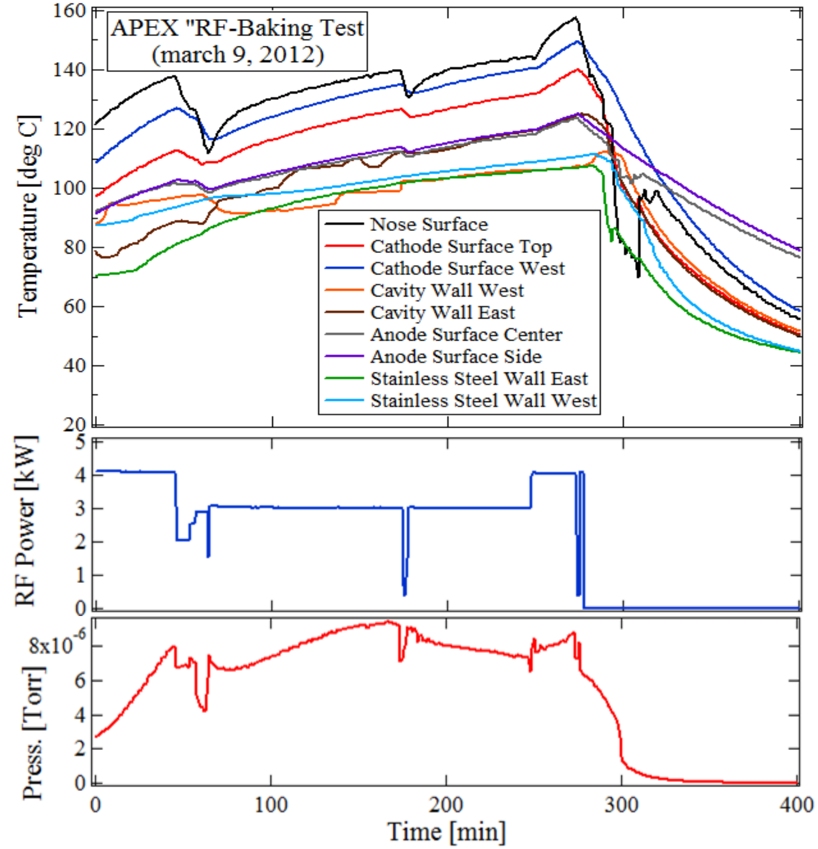




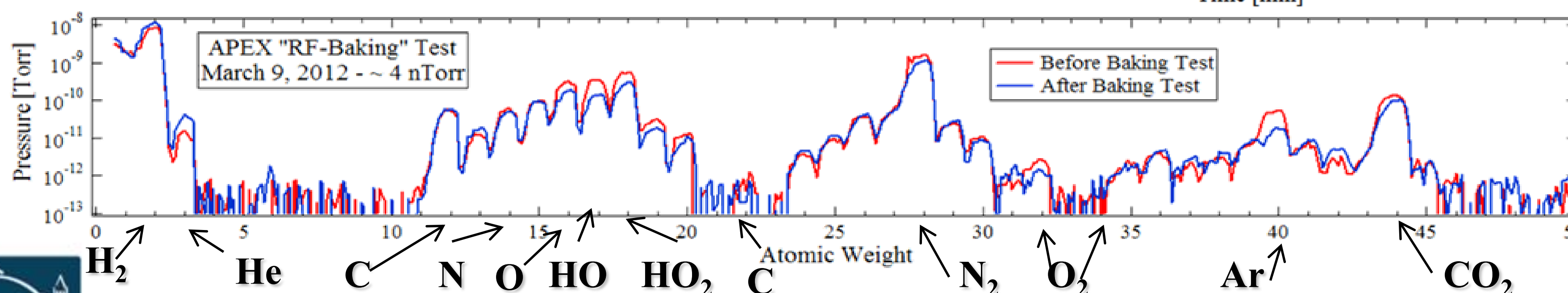
Any photocathode deposited on a same geometry plug can be potentially tested at the VHF gun

"RF BAKING"





Baking the gun with no water cooling (!) and 2-4 kW average RF power.



RGA MEASUREMENTS – RF ON and OFF

APEX @ Berkeley Lab

Measurements performed with a Dycor 2000 RGA system.
1 NEG pump activated, 1 ion pump, 2 turbo pumps. No gun baking.