FLS2012電子源WG報告

原子力機構　西森信行

平成24年3月29日

第60回ERL検討会

電子源WG

- Carlos Hernandez-Garcia, JlabとThorsten Kamps, HZBがConvener
- 全部で20名位
- 最初の1,2時間は議論中心。
  「更なる高輝度化をいかにして実現するか」、
  「高ロバストネス、低コストをいかに実現するか」
- ６D位相空間（スライス、全体）ブライトネス、
  光カソードについての国際的なコラボレーション、
  電界放出電流（DC,NRF,SRF共通）

電子源関連の発表から

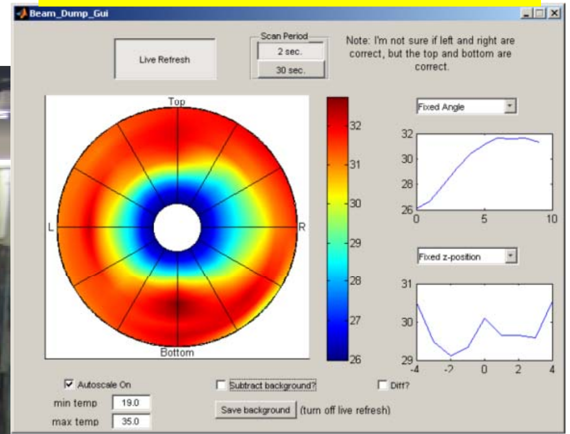
- "Overview of Photoinjectors for Future Light Sources" Ivan Bazarov, CLASSE
- "APEX description, status and plans" John Corlett, LBNL
- "Unwanted Beam Observations at ELBE" Jochen Teichert, HZDR
- "Ultra-bright Designer Photocathodes" Katherine Harkay, Argonne
- "Intense Super-Radiant X-rays from a Compact Source" Bill Graves, MIT

CLASSE

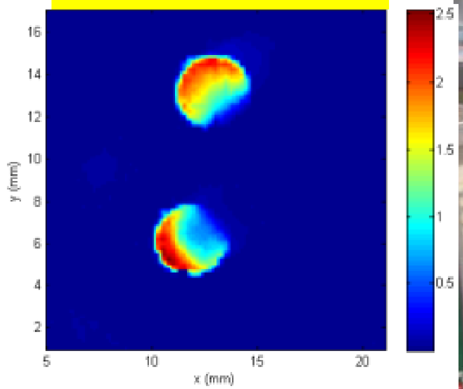
Overview of Photoinjectors for Future Light Sources

Ivan Bazarov

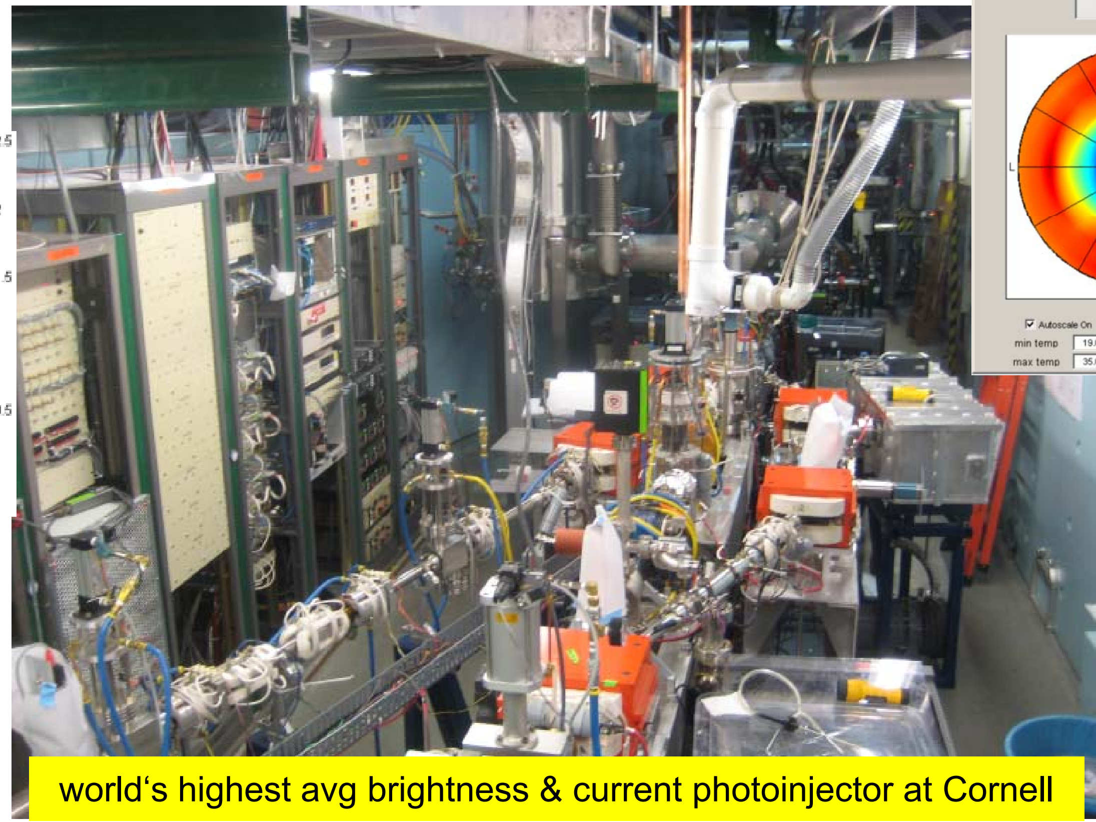
Cornell University



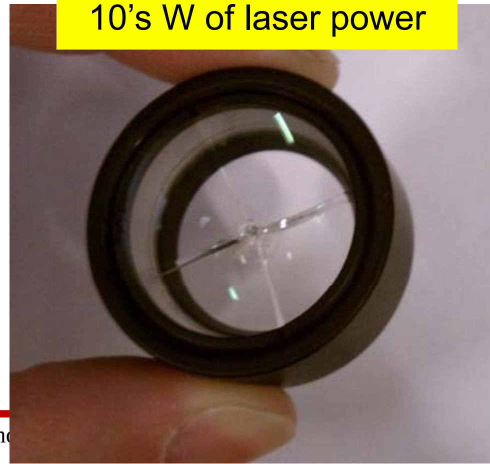
Main dump T-map during 35 mA high current running



GaAs QE(%) map after 50 mA run



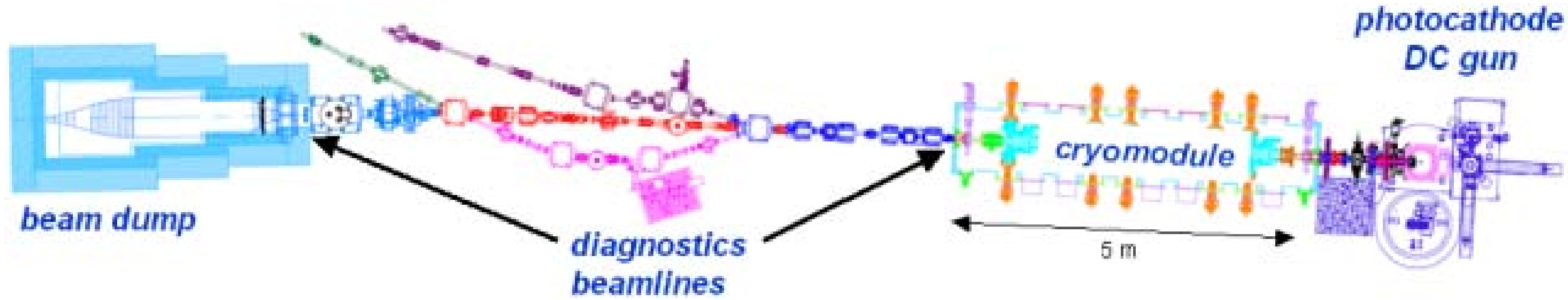
world's highest avg brightness & current photoinjector at Cornell



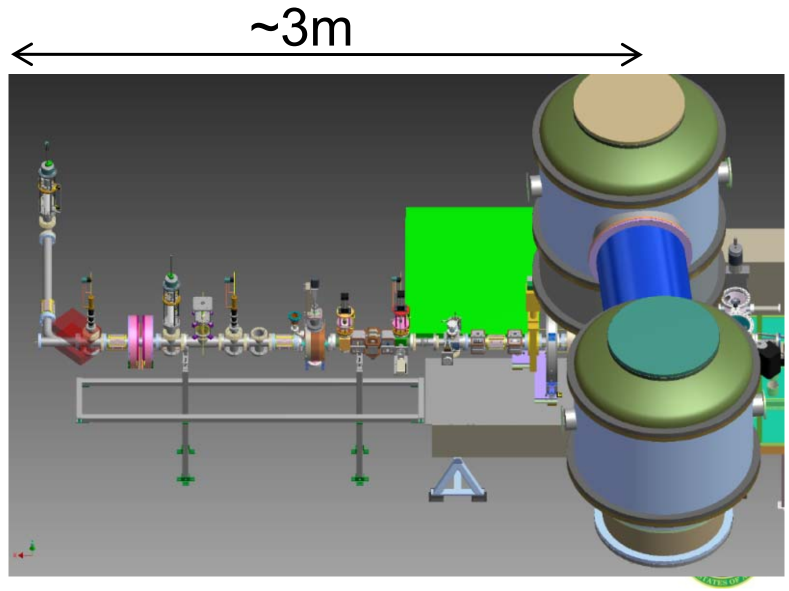
damaged optics after 10's W of laser power

Photoemission source development @ Cornell

- **Two accelerator facilities @Cornell to push photoinjector state-of-the-art: NSF supported 100mA 5-15 MeV photoinjector;**



- **New 500kV photoemission gun & diagnostics beamline (under construction): shoot to have HV by this summer**



Cornell ERL photoinjector highlights

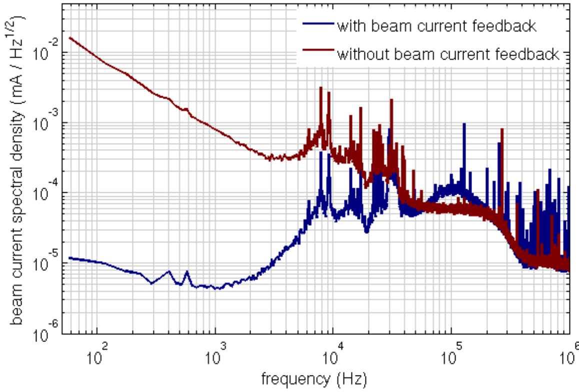
CLASSE

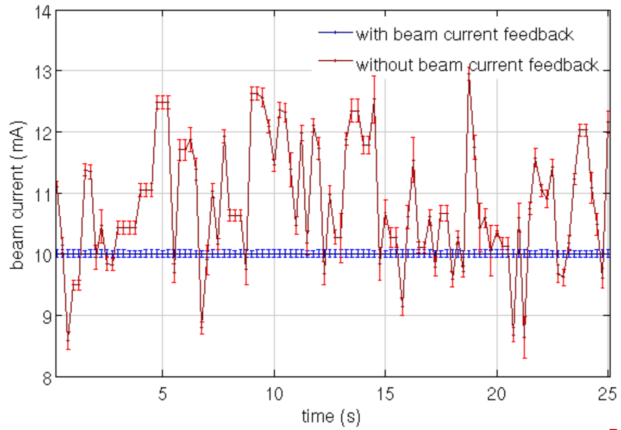
- Over the last year:
  - Maximum average current of 52 mA from a photoinjector demonstrated
  - Demonstrated feasibility of high current operation (~ kiloCoulomb extracted with no noticeable QE at the laser spot)
  - Original emittance spec achieved: now getting x1.8 the thermal emittance values, close to simulations (Sept 2011)

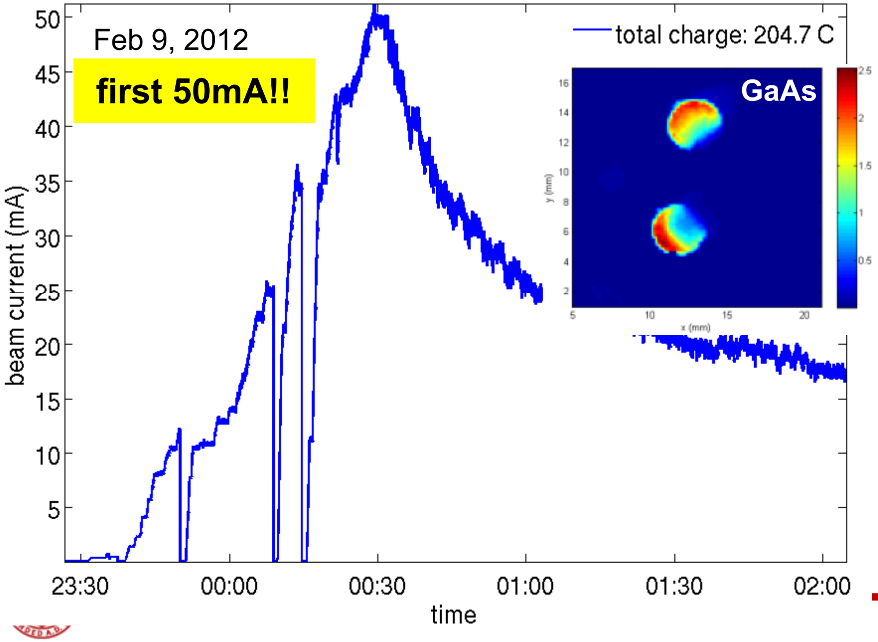
Pushing for high current

CLASSE

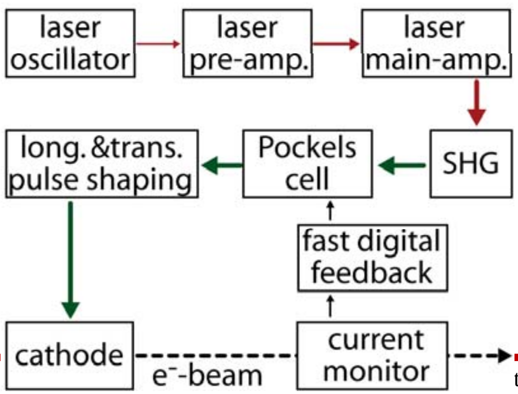
- **Key developments:**
  - **Expertise in several different photocathodes (both NEA and antimonides)**
  - **Improvements to the laser (higher power)**
  - **Feedback system on the laser**
  - **Minimization of RF trips (mainly couplers)**
  - **Minimizing radiation losses**



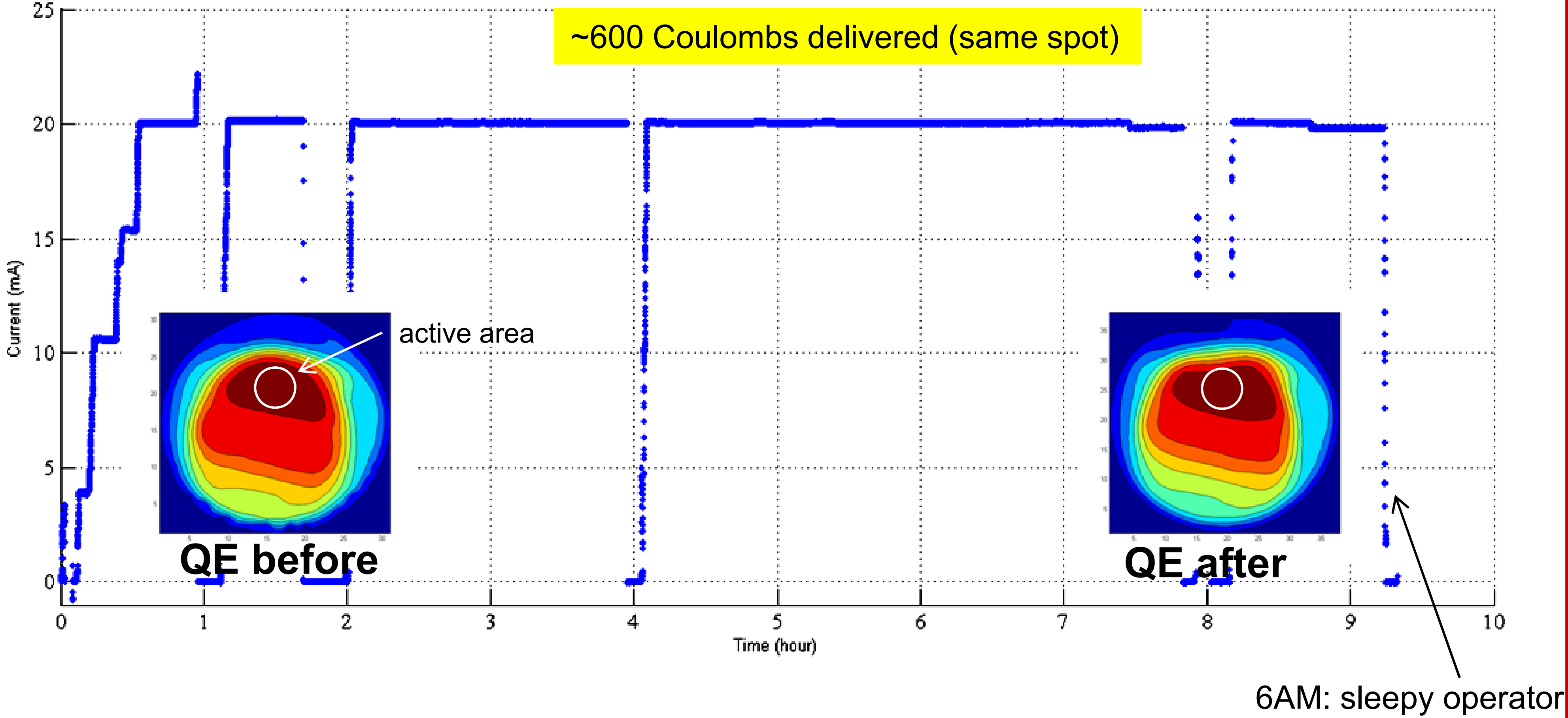




Laser intensity feedback system (developed by F. Loehl)



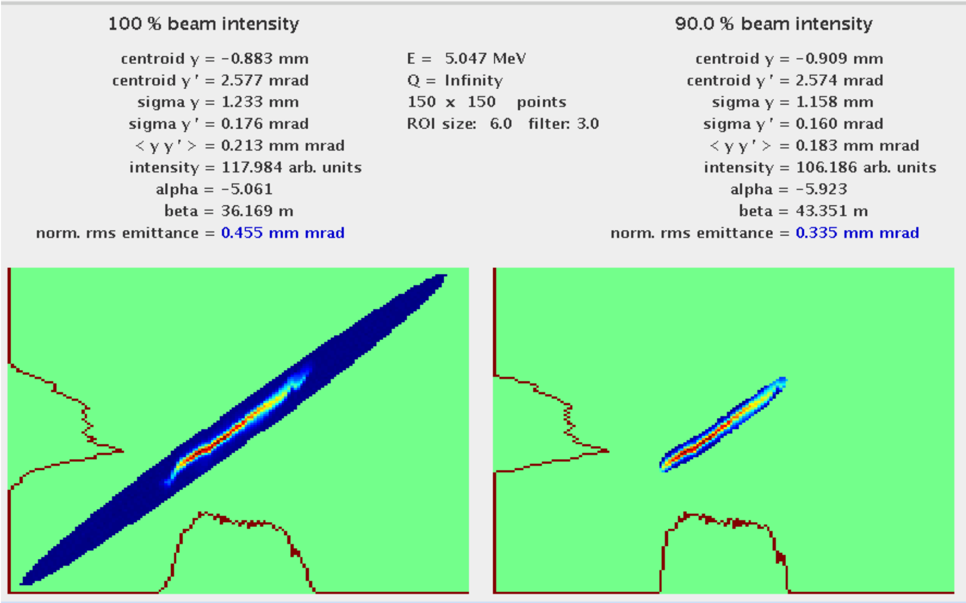
High current operation
(offset CsKSb gives excellent lifetime)



L. Cultrera, et al., PRST-AB 14 (2011) 120101

Laser off-center

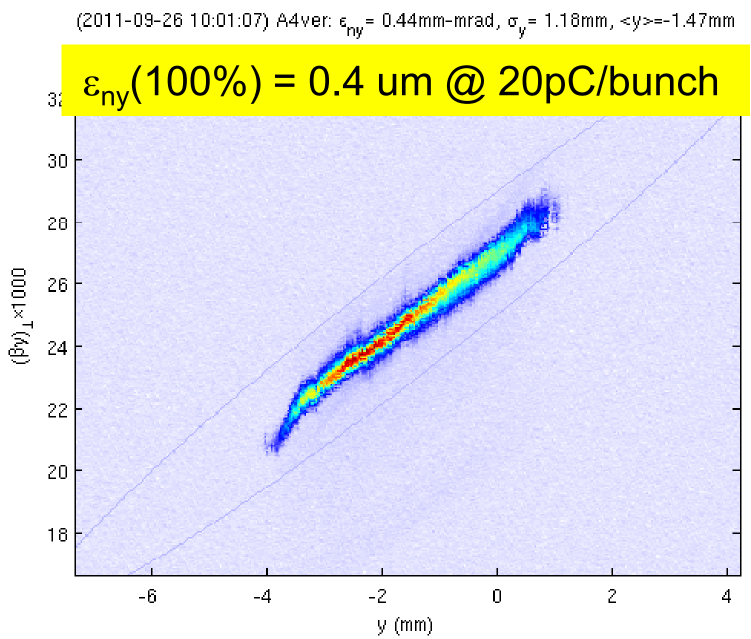
Good news: running 5 mm off-center on the photocathode gives the same emittance (20pC/bunch) due to intrinsically low geometric aberrations in the DC gun

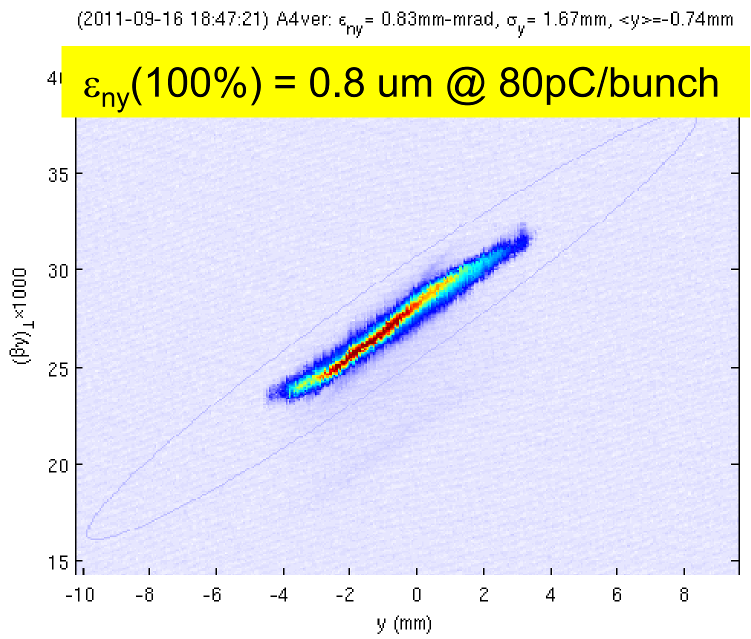


This is very important, as we know that we cannot run with the laser at the center of the cathode due to cathode damage issues.

Sept 2011: initial emittance spec achieved!

- **Keys to the result**
  - **Beam-based alignment (took us a couple of months)**
  - **Working diagnostics**
  - **Fight jitters in the injector**

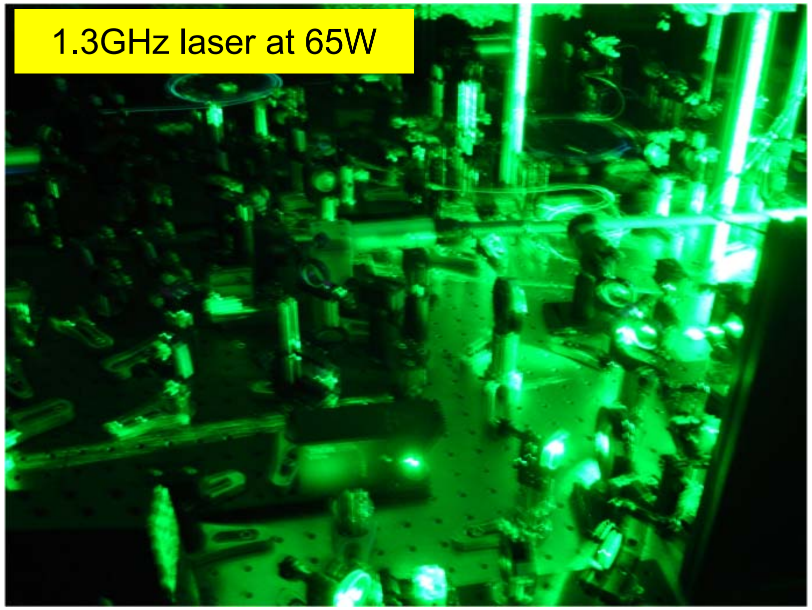




- **x1.8-2.0 thermal emittance! x1.4 simulated emittance**
- **correct scaling with bunch charge**

Lasers

Z. Zhou et al., Opt. Express 20 (2012) 4850



- Plenty of laser power when coupled with good cathodes
- Next steps:
  - better 3D shaping
  - engineering and integration into the machine via stabilization loops (all degrees of freedom)
- Practical shaping techniques
  - Temporal stacking (uniform)
  - Transverse clipping (truncated Gaussian)

  } better than “beer-can”; only ≤ 20% emittance increase compared to highly optimized shapes

  - Blowout regime if E_{cath} is high enough

Building collaboration on photocathodes for accelerators

- **Collaboration with**
  - ANL, BNL, JLAB
  - Cornell, SLAC
  - Berkeley, more…
- **Excitement and momentum in the community;**
- **Cathode workshops at BNL in 2010; in Europe 2011; coming up at Cornell in 2012**

1st workshop

2nd workshop

Photocathode Physics for Photoinjectors 2012

Cornell University, 8-10 October 2012

http://www.bnl.gov/pppworkshop/

http://photocathodes2011.eurofel.eu

http://www.lepp.cornell.edu/Events/Photocathode2012

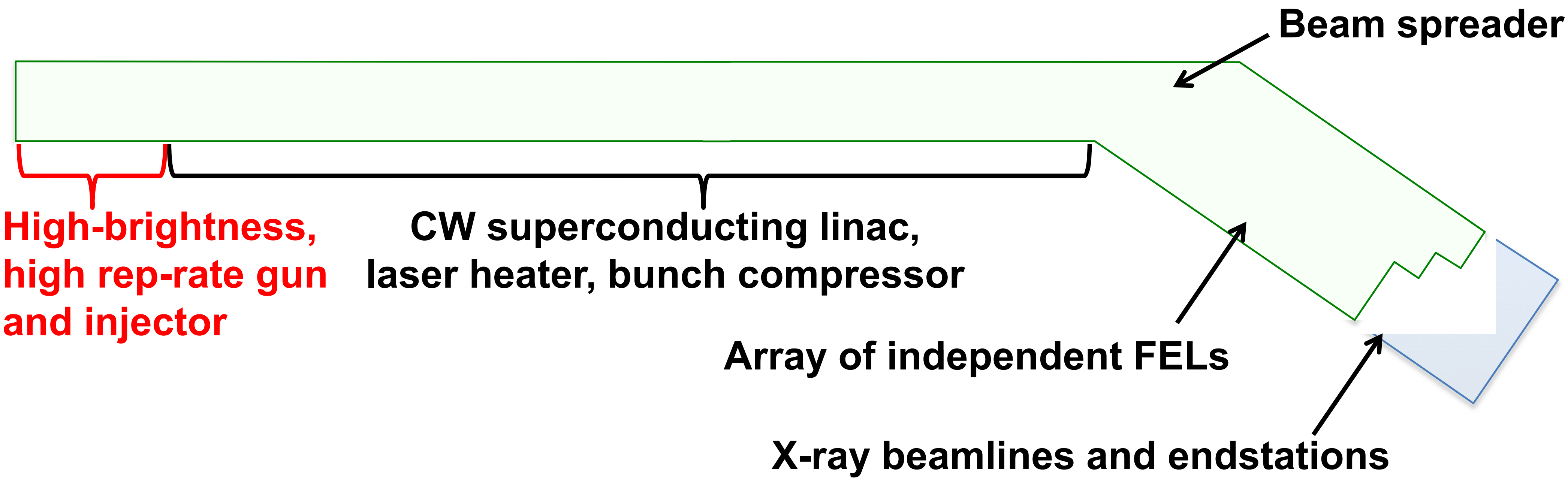
APEX
description, status and plans

John Corlett for the APEX team

Lawrence Berkeley National Laboratory

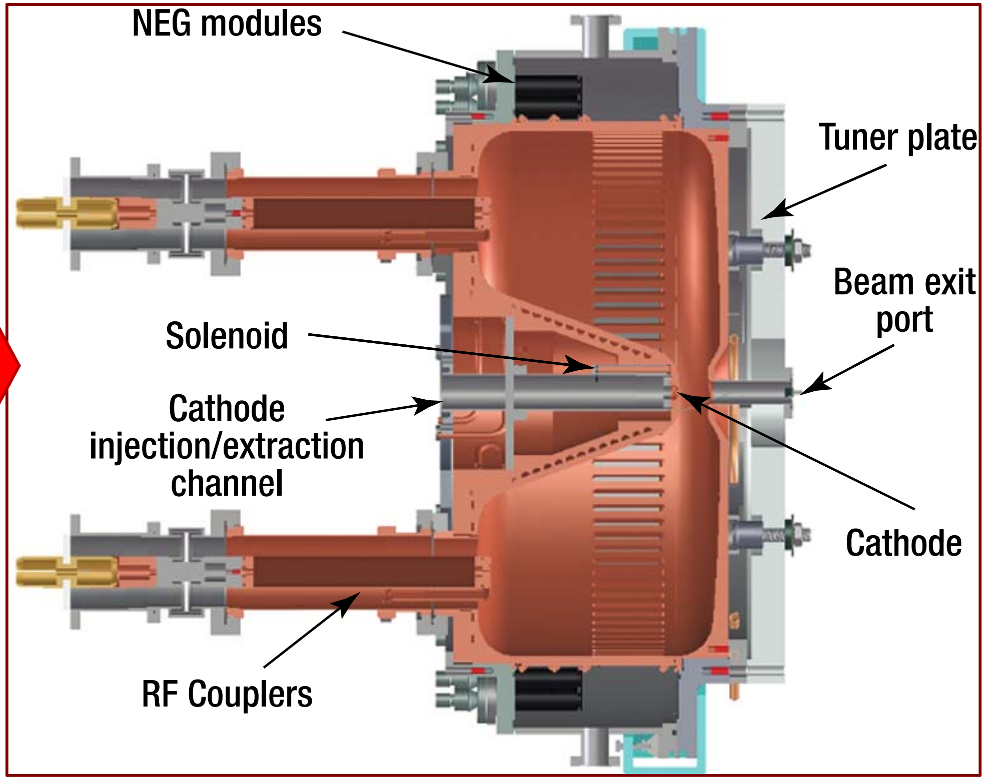
Approach

High average power electron beam distributed to an array of FELs from high rep-rate injector and CW SCRF linac



Injector design goals – APEX gun

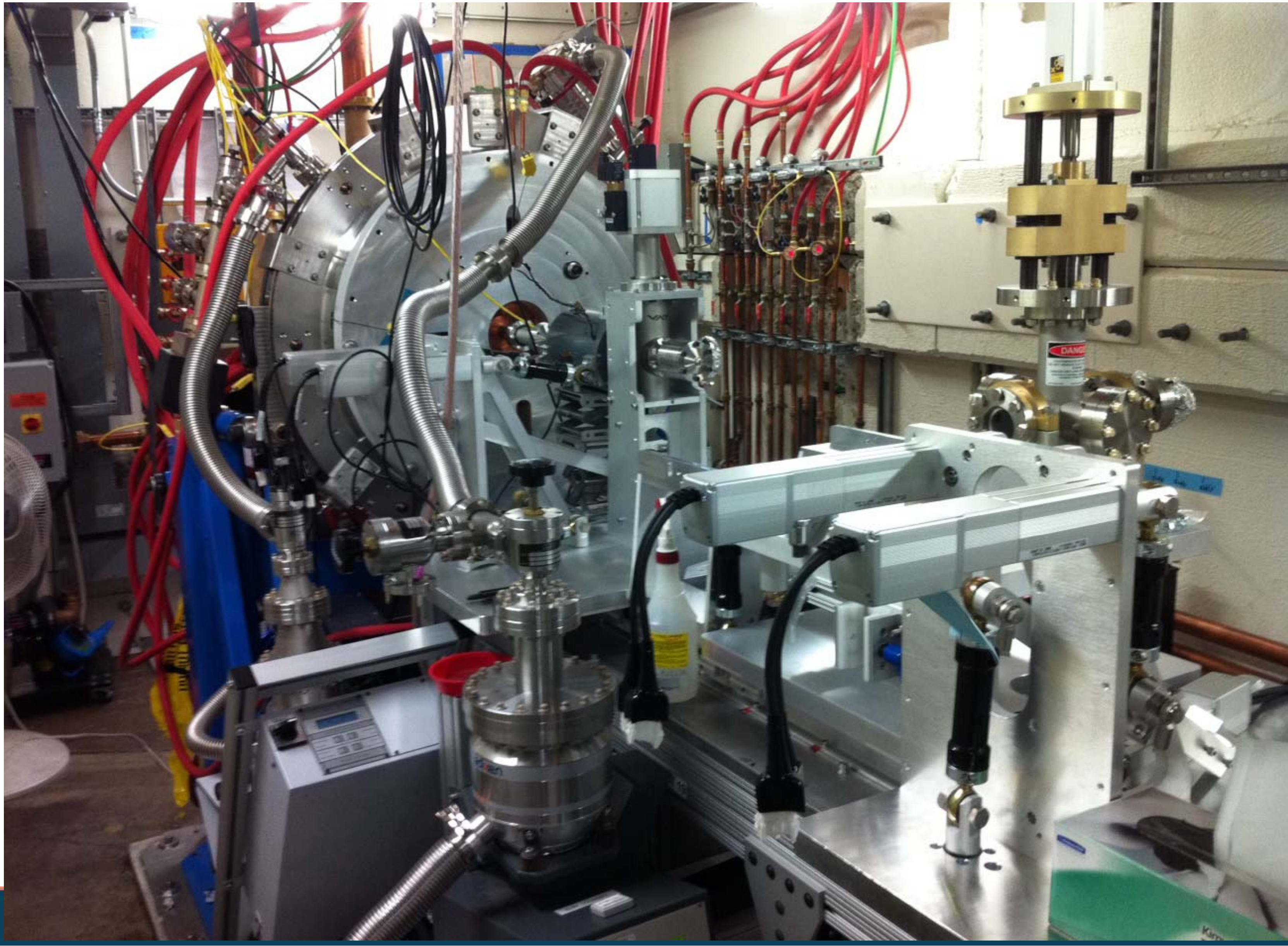
- Repetition rate 1 MHz
- Charge per bunch from ~10 pC to ~1 nC
- Emittance <10^{-6} mm-mrad (normalized)
- Electric field at the cathode ≥~10 MV/m (space charge emission limit)
- Beam energy at the gun exit ≥~500 keV (space charge control)
- Bunch length ~100 fs to ~10 ps for handling space charge effects, and for allowing different modes of operation
- Compatible with magnetic field control within the gun (emittance exchange and compensation)
- 10^{-11} Torr vacuum capability (cathode lifetime)
- Accommodates a variety of cathode materials
- High reliability for user operations



The gun is the most challenging component
LBNL approach uses a CW VHF cavity

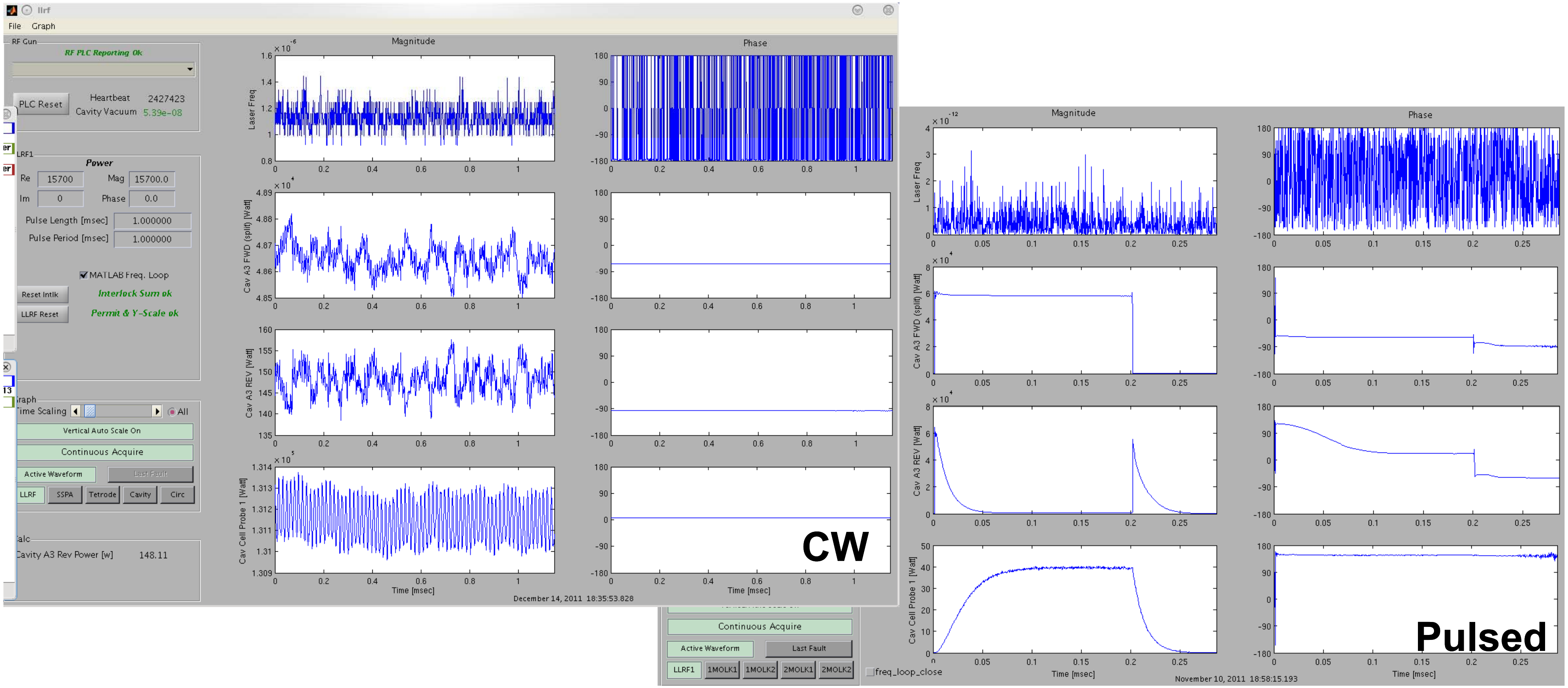
APEX gun: high-brightness MHz electron source

- **APEX cavity is successfully RF conditioned**



RF conditioning completed

Gun RF conditioning started on November 7, 2011



At Dec. 15, 2011 integrated < 120 hours of conditioning.

December 15: CW mode at nominal power ran for 12,5 hours without faults

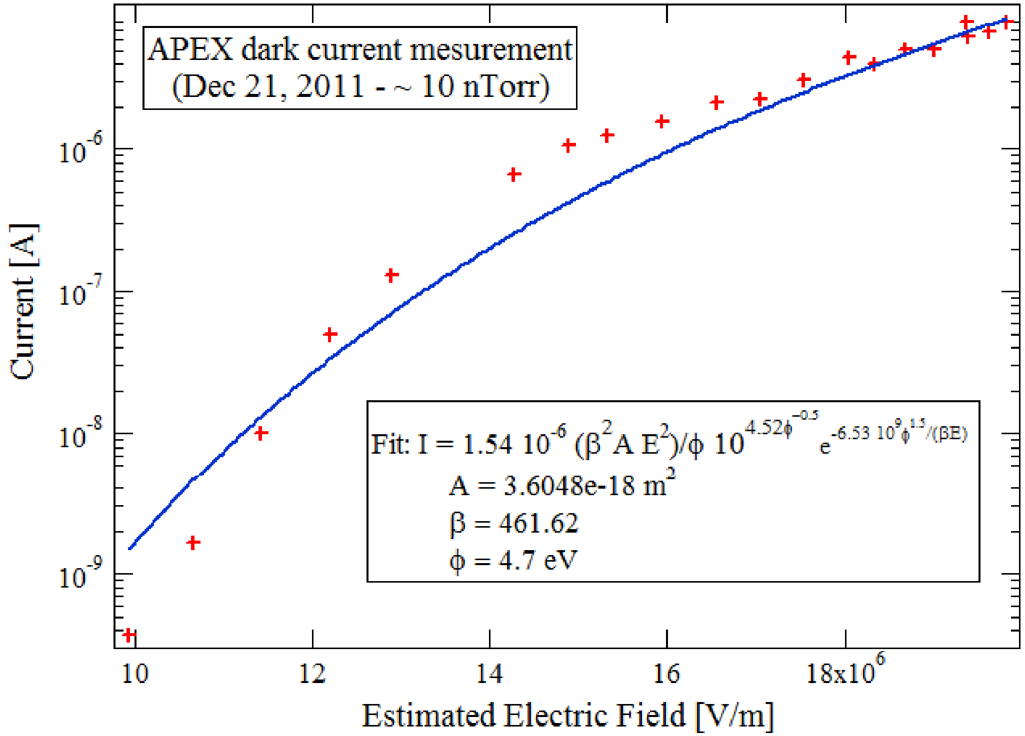
Results reconfirmed the day after (> 24 hours no fault)

Power stability ~2x10^{-3}

Dark current

NGLS next generation light source

Measurements performed in CW mode on a coaxial Faraday cup right downstream the beam pipe exit



Dark current follows Fowler-Nordheim dependence on the E field

At the nominal field (19.5 MV/m) the present value is ~ 8 μA

Expected to decrease when the beamline is installed and vacuum bake completed

J. Teichert, A. Arnold, U. Lehnert, P. Michel, P. Murcek, R. Xiang (HZDR)
R. Barday, T. Kamps, S. Schubert (HZB)

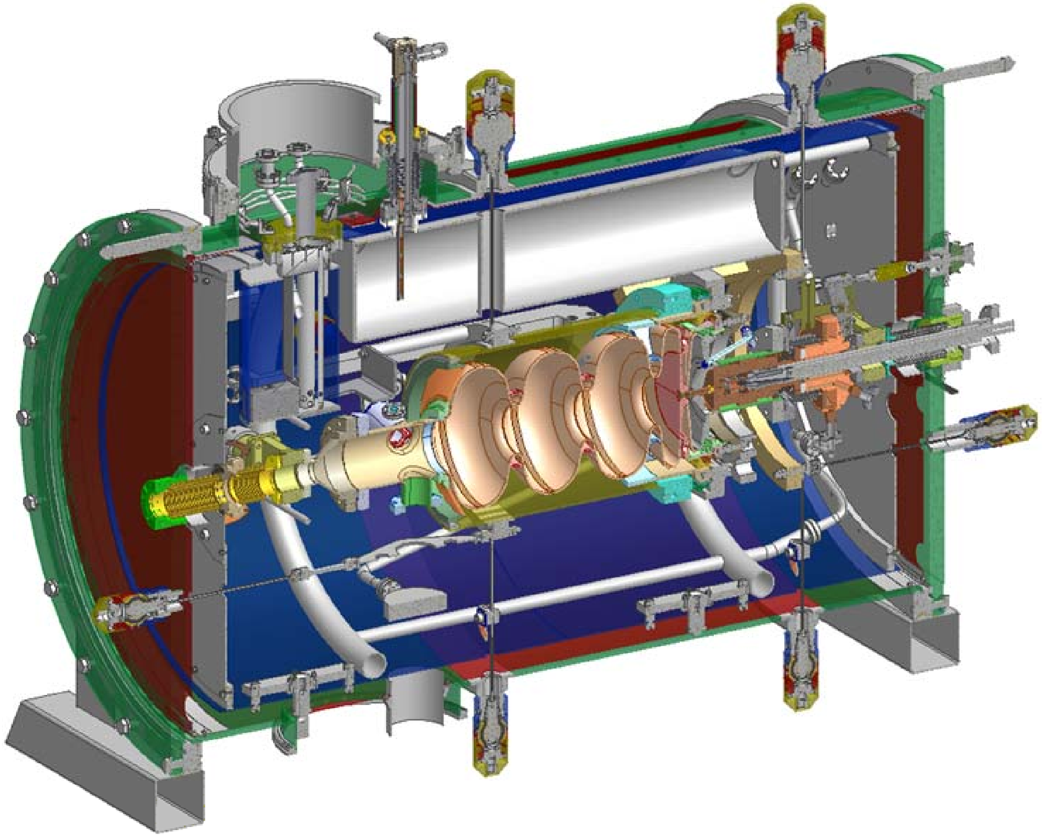
Unwanted Beam Observations at ELBE

FLS2012 ICFA Workshop on Future Light Sources
March 5-9, 2012, Thomas Jefferson Lab, Newport News, VA

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Application

- high peak current operation for CW-IR-FELs with 13 MHz, 80 pC
- high bunch charge (1 nC), low rep-rate (<1 MHz) for pulsed neutron and positron beam production (ToF experiments)
- low emittance, medium charge (100 pC) with short pulses for THz-radiation and x-rays by inverse Compton backscattering

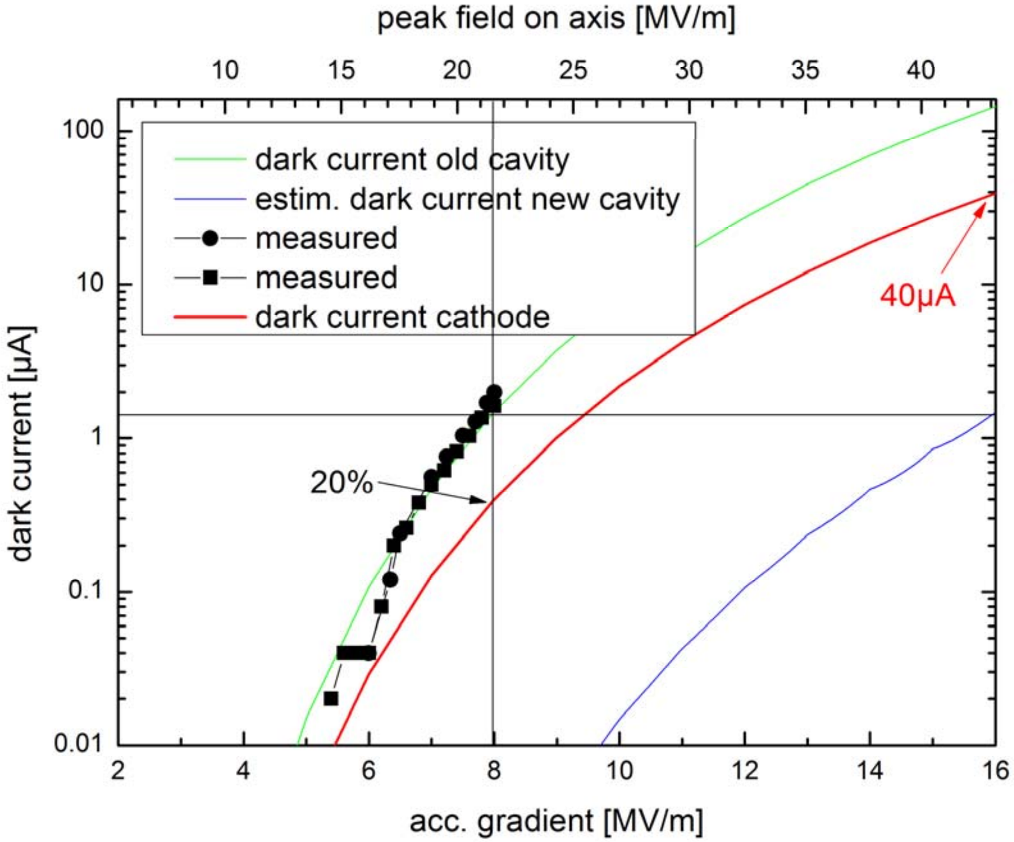


Design

medium average current:
1 - 2 mA (< 10 mA)
high rep-rate:
500 kHz, 13 MHz and higher
low and high bunch charge:
80 pC - 1 nC
low transverse emittance:
1 - 3 mm mrad
high energy:
≤ 9 MeV, 3½ cells (stand alone)
highly compatible with ELBE cryomodule (LLRF, high power RF, RF couplers, etc.)
LN2-cooled, exchangeable high-QE photo cathode

Extrapolation of Fowler Nordheim results for new cavity:

- New cavity will be operated at the high-field limit of 16 MV/m. Here we expect the same field emission level as for 8 MV/m for the old cavity (blue curve) -> smaller field enhancement factor ($\kappa = 591$)
- FN fit for 20 % of current emitted from cathode ($\phi = 4.3$ eV for Cs_2Te, 40% peak field) and extrapolation to 16 MV/m (read curve) gives 40 μA cathode dark current



Kathy Harky (ANL)
Ultra-bright Designer Photocathodes

- Ultra-bright photocathodes are a key technology for the development of future light sources.
- Two approaches are applicable, depending on time-frame:
  - **Near-term**: Optimize the synthesis and performance of long-known photocathodes such as Cs_2Te, CsKSb, GaAs (ANL, ASTeC, BNL, HFZD, INFN, JLab, LBNL, PITZ, et al.)
  - **Mid-to-far-term**: Explore novel crystal systems numerically and optimize ("design") their properties, or nano-engineer surfaces, or other novel idea (**ANL**, ASTeC, BNL, Eindhoven, Jlab, LBNL, SLAC, UCLA, Vanderbilt, et al.).
- Properties to design or tune include:
  - Intrinisic emittance
  - Workfunction
  - QE
  - Reliability, robustness (vacuum, E-field, field emission)

Intense Super-radiant X-rays from a Compact Source

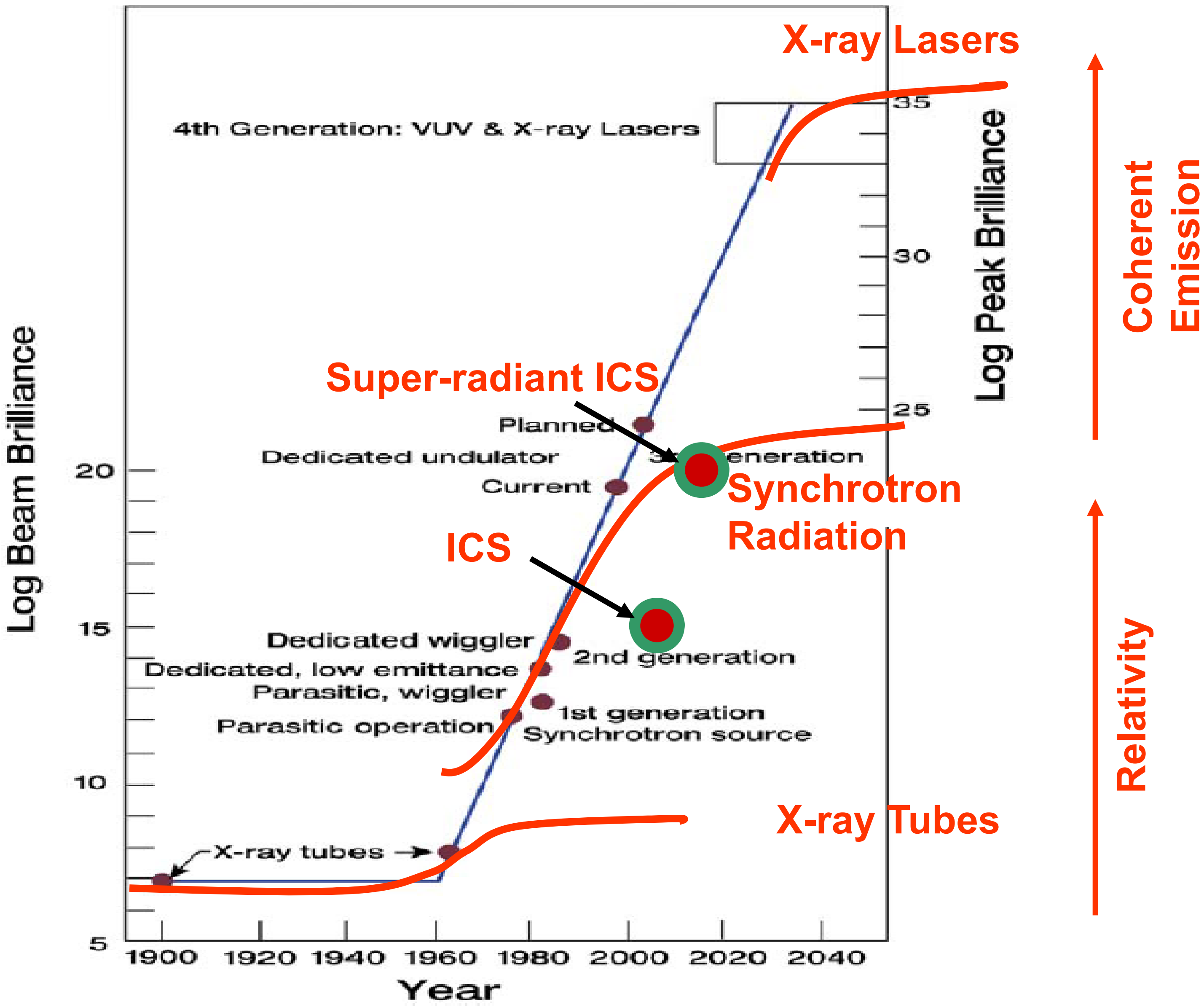
W.S. Graves

MIT

March, 2012

Presented at the ICFA Future Light Sources Workshop

Generations of Hard X-ray Sources

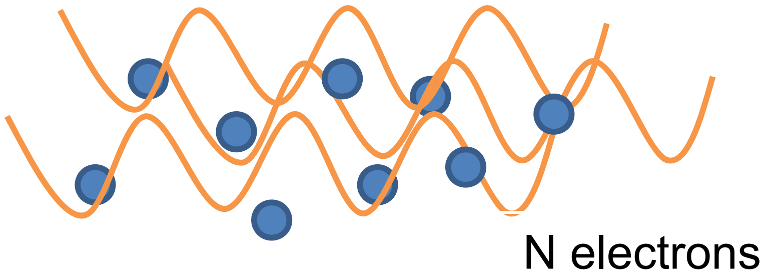


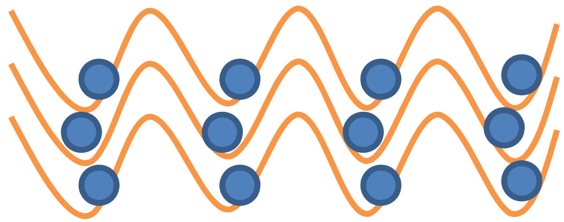
W.S. Graves (MIT) FLS Workshop 3/2012

Super-radiant X-rays via ICS

ICS (or undulator) emission is not a coherent process, scales as N

Super-radiant emission is in-phase spontaneous emission, scales as N^2





Steps

1. Emit array of electron beamlets from cathode 2D array of nanotips.
2. Accelerate and focus beamlet array.
3. Perform emittance exchange (EEX) to swap *transverse* beamlet spacing into *longitudinal* dimension. Arrange dynamics to give desired period.
4. Modulated electron beam backscatters laser to emit ICS x-rays in phase.

"Intense Super-radiant X-rays from a Compact Source using a Nanocathode Array and Emittance Exchange"
W.S. Graves, F.X. Kaertner, D.E. Moncton, P. Piot
submitted to PRL, published on arXiv:1202.0318v2

Super-radiant ICS Example at 13 nm

FEA ⇨ gun ⇨ focus & matching ⇨ emittance-exchange ⇨ ICS