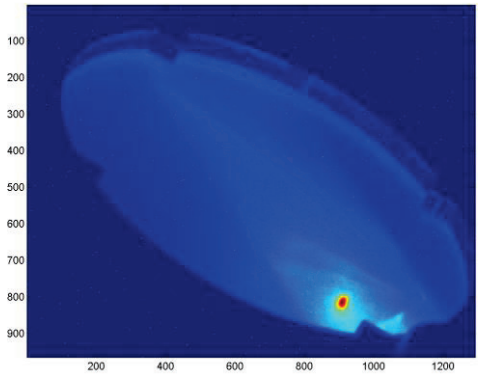
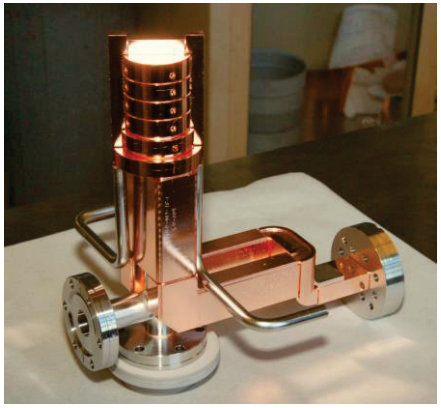


Initial Performance of SLAC X-Band Photoinjector

C.Limborg-Deprey



U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

X-Band photoinjector
A high brightness source

SLAC

- 20 years of development of X-Band technology at SLAC

  mature technology for high gradient field

  ~100MV/m for linac (25MV/m for S-Band)

  ~200MV/m for RF gun (120MV/m for S-Band)

- Success of LCLS and its RF photoinjector

  S-Band RF gun from SLAC/BNL/UCLA/APS

- X-Band photoinjector as a source for
  - Compact FELs (1)
  - Compact Inverse Compton scattering (ICS) source
  - Ultra-Fast Electron Diffraction

(1) PRST-AB ,**15, 030703 (2012) Y.Sun** et al.
180 m long, 2fs, 20GW, 6GeV based on 10pC, no linearizer

RF Gun Simulations

Peak brightness: 8x higher for X-Band than S-Band gun

SLAC

- **bunch length ⇨ shorter by 3-4**
  from high dE_z / dt
- **emittance ⇨ smaller by up to 2**
  from high $E_{RF,cathode}$
  beat surface field while at smaller r_{laser}
  smaller $\varepsilon_\perp \propto r_{laser}$

$$r_{laser} > \sqrt{\frac{Q\varepsilon_o}{\pi E_{RF,cathode}}}$$

	X-Band Test Acc. Simulations (*)				LCLS Simulations(*) and measurements		
Q [pC]	$\varepsilon_{x,95\%}$ [mm-mrad]	σ_l [mm]	$B_{peak}= Q/\sigma_l/\varepsilon^2$		$\varepsilon_{x,95\%}$ [mm-mrad]	σ_l [mm]	$B_{peak}= Q/\sigma_l/\varepsilon^2$
250	0.250	0.228	2.24				
250	0.280	0.184	2.21		0.40	0.620	0.32
20	0.075	0.109	4.16		0.15	0.220	0.52
10	0.076	0.055	4.02				
10	0.118	0.042	2.18				
1	0.016	0.080	6.2				
1	0.036	0.025	3.94				

(*) using Astra

X-Band Gun

A brief history

- Originally developed at SLAC for UC Davies (2001-2005) (1)
- Improved 5.5 cell version “Mark0”

  (racetrack coupling cell)
- Design revisited by SLAC/LLNL (2010)
- 5.6 cell version “Mark1” (2)

  (mode separation increased, elliptical irises, 5.6 cell)
- “Mark0” tested at XTA (2012 …)

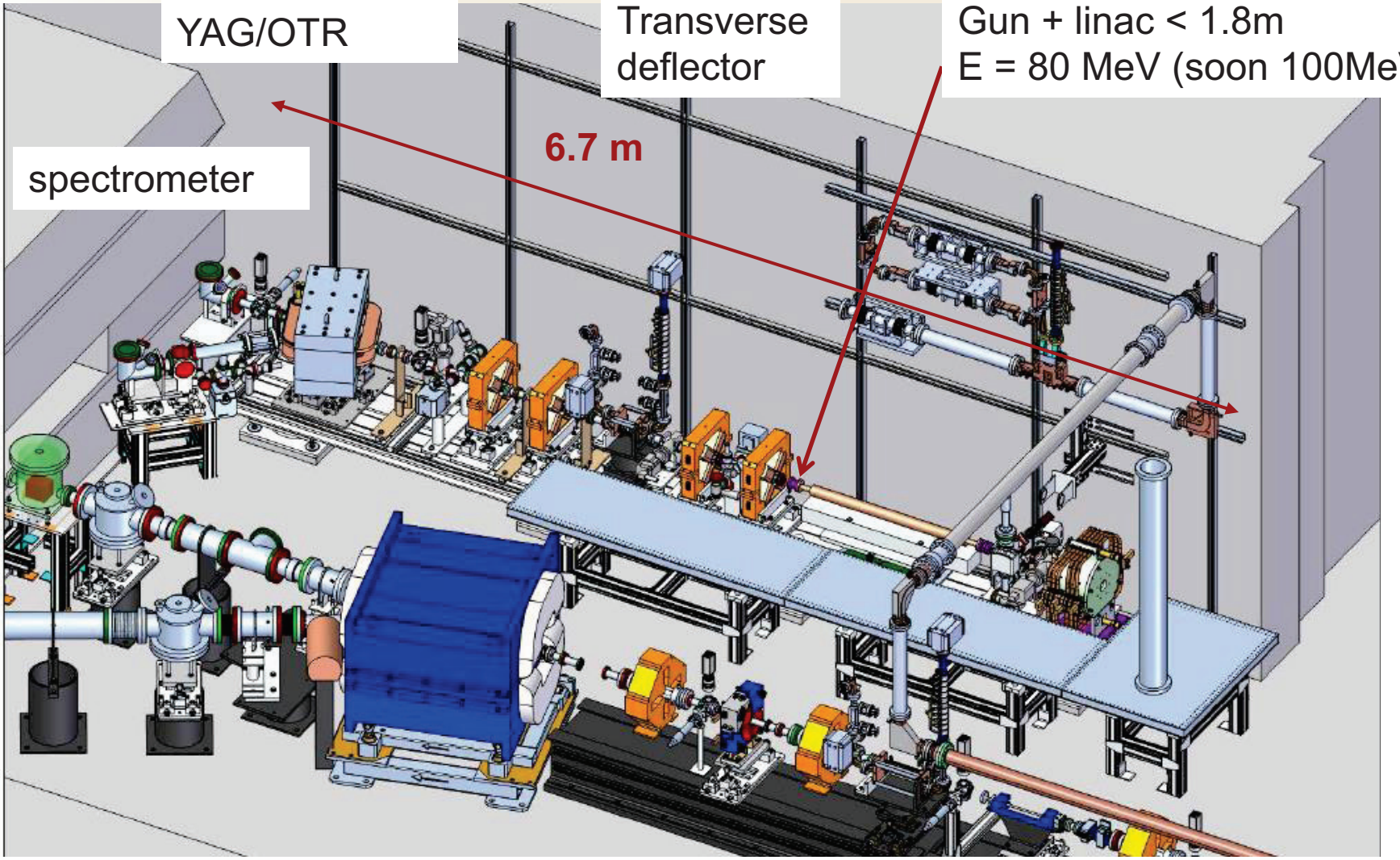
TABLE I. Mark 1 rf gun parameters.

Frequency	11.424 GHz
Unloaded quality factor	7055
First cell length	0.59 cell
Coupler type	Dual feed racetrack
Iris shape	Elliptical, 1.8 major/minor
Mode separation	25 MHz
Cathode material	Oxygen-free high conductance
Cathode peak field	200 MV/m
Final kinetic energy	7 MeV

(1) A.E. Vlieks, et al. “Recent measurements and plans for the SLAC Compton X-ray source”, SLAC-PUB-11689, 2006. 10pp. Published in AIP Conf.Proc.807:481-490,2006

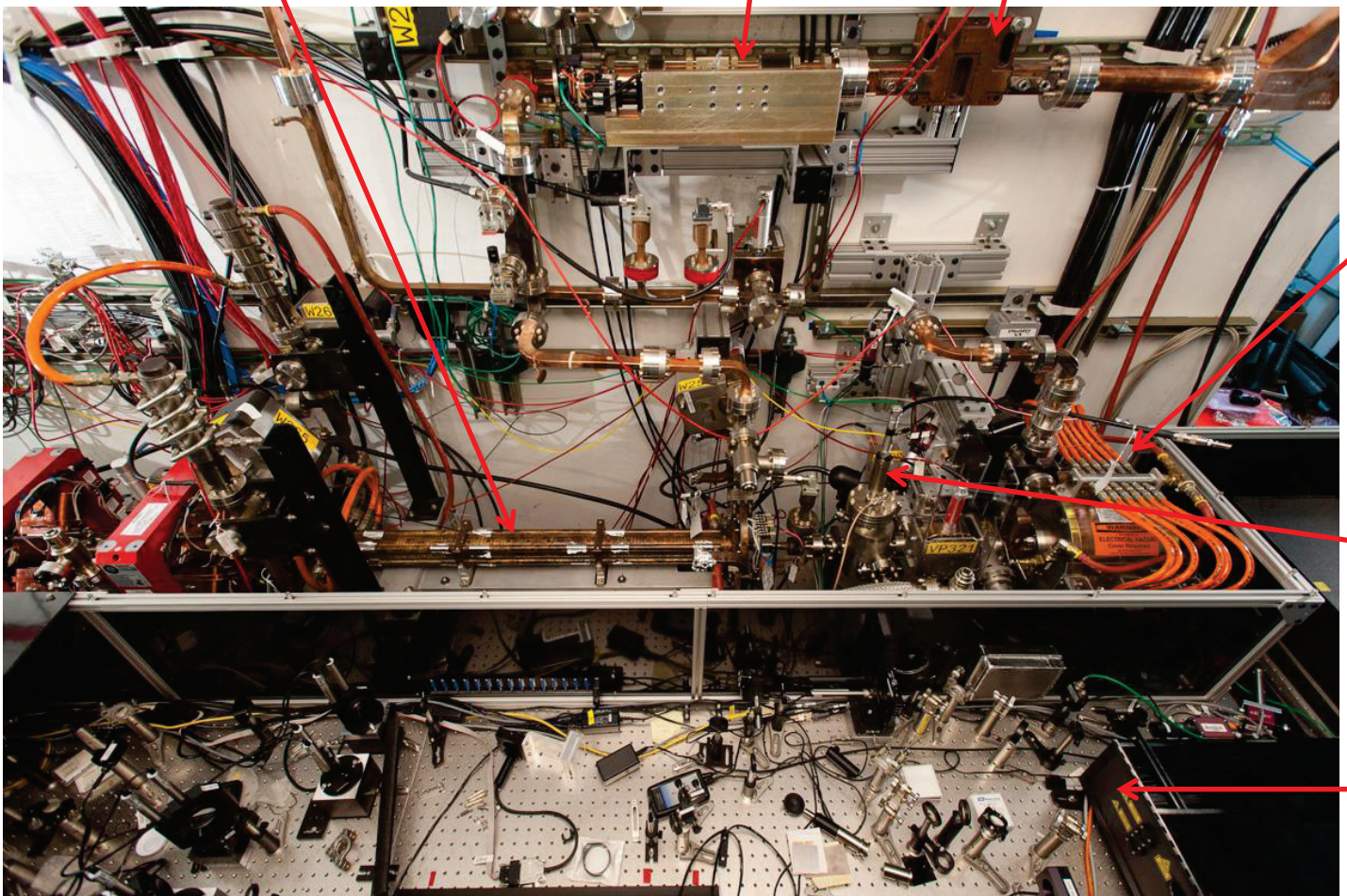
(2) R.Marsh et al. Phys. Rev. ST Accel. Beams 15, 102001 – Pub. 15 October 2012

X-Band Test Area (XTA) installed in NLCTA tunnel at SLAC



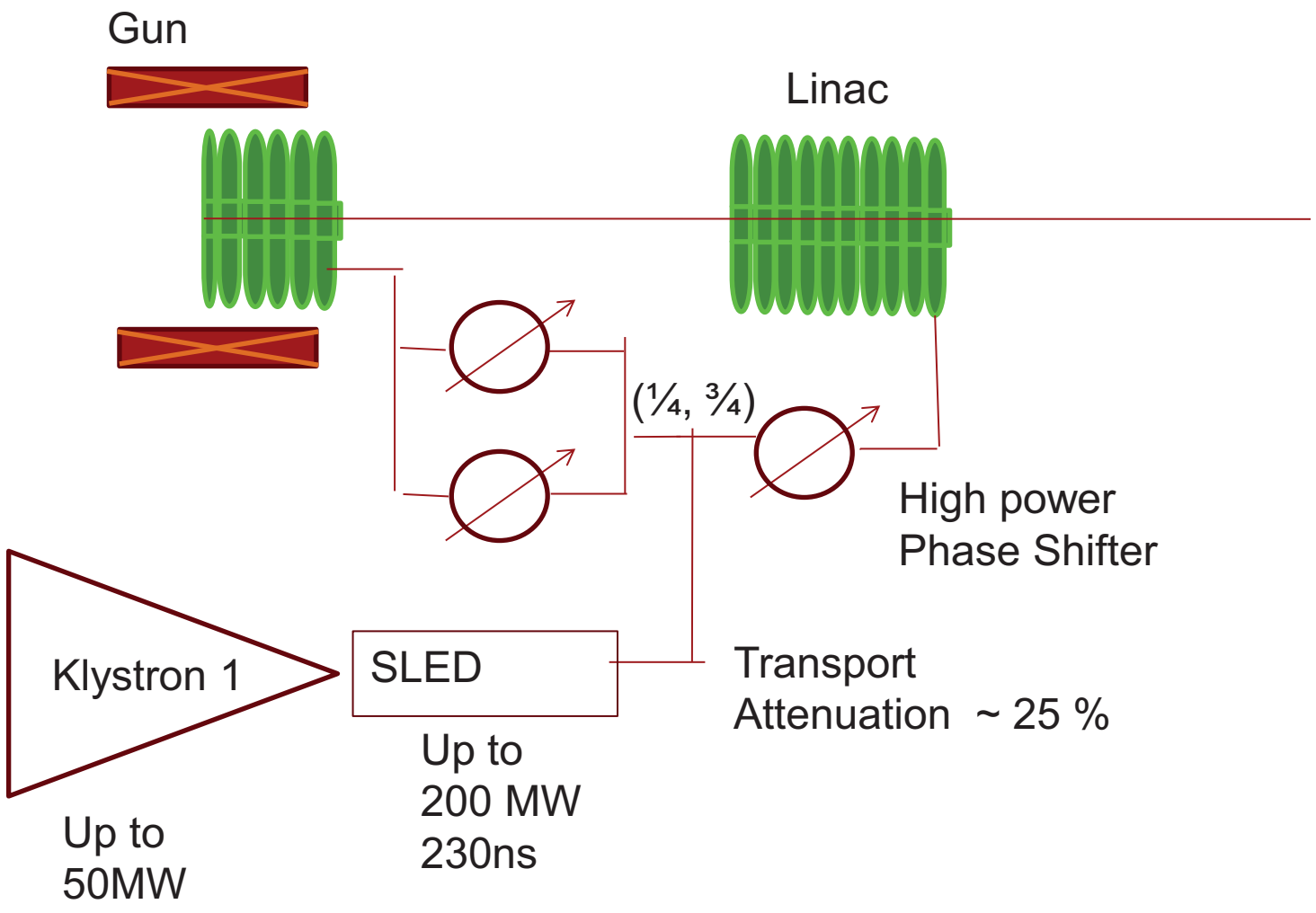
X-Band Test Area (XTA) operational since summer 2012

SLAC



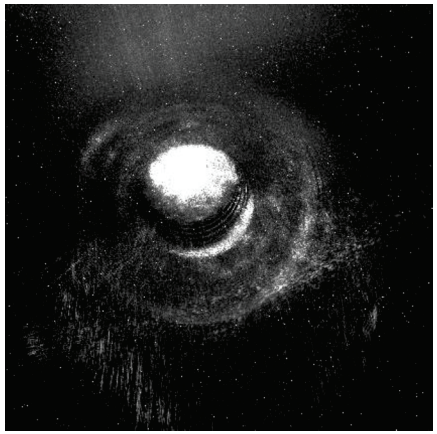
RF Distribution

Single RF source



XTA rapid turn-on

- 1st beam July 2012 ,18 months after project started
  - X-Band RF station and distribution available
  - NLCTA tunnel and infrastructure in place
  - Imported LCLS control system & applications



- During 1st year
  - Stabilization
    - Laser oscillator PLL: reduced noise from 500fs (2°) to 160 fs (0.64 °)
    - RF feedbacks (phase, amplitude, SLED)
  - Recent upgrades
    - 100MV/m linac
    - Cavity BPM

Experimental Results

SLAC

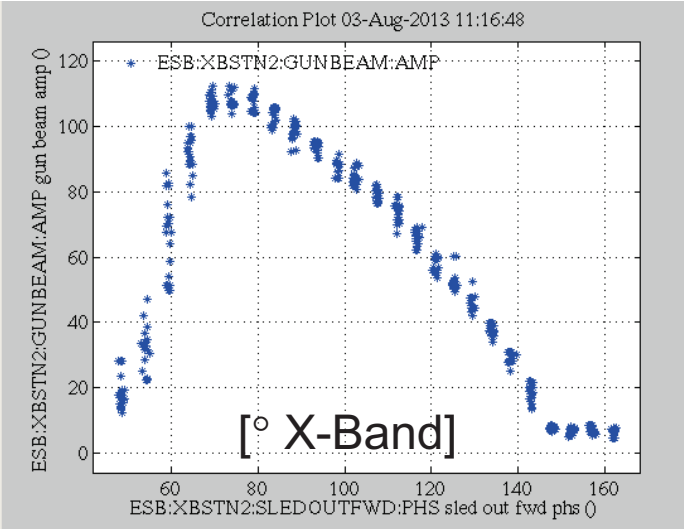
- e-beam energy out of gun ~ 7.5MeV ($V_{RF,peak}$~ 200MV/m)
- dark current acceptable
- e-beam at 80 MeV after 1m-linac
- charge of up to 100pC transmitted through linac
- QE in low 10^{-5}
- bunch length measured ~ 250 fs rms for 20pC
- energy spread rms 3.10^{-4} (15 pC) , 10^{-3} (60 pC)
- emittance ~ 1mm-mrad for 30 pC

Cathode peak field
200MV/m operated routinely

SLAC

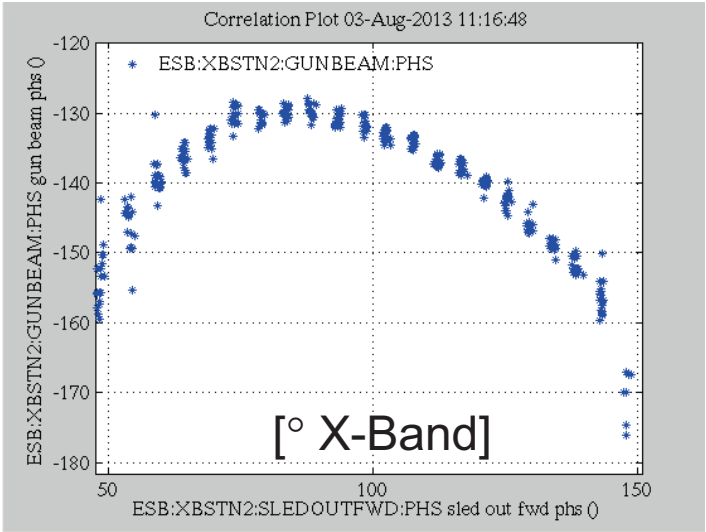
Schottky scan

Charge [a.u]

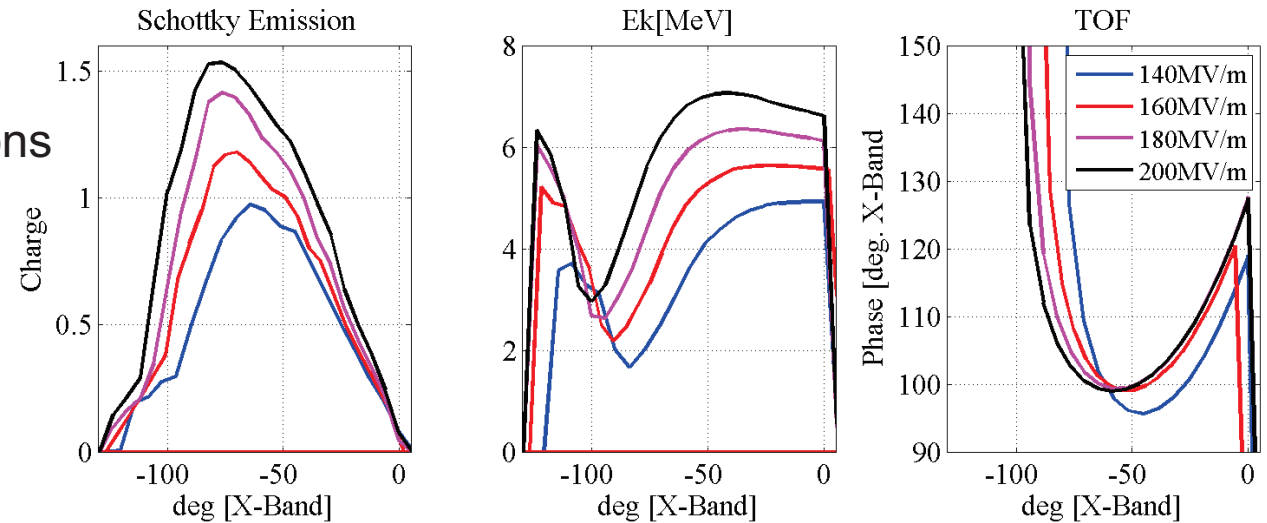


Time of Flight (TOF)

Arrival time [° X-Band]



Astra simulations

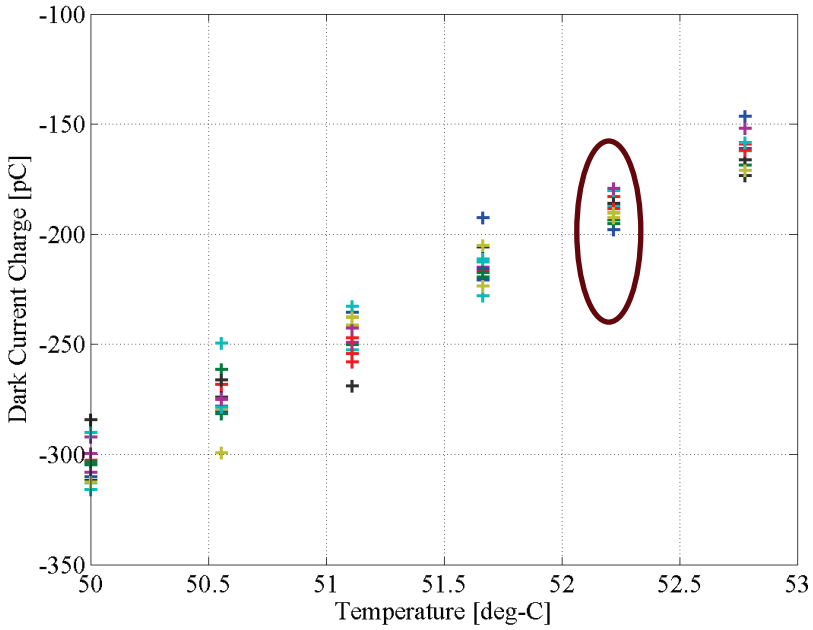


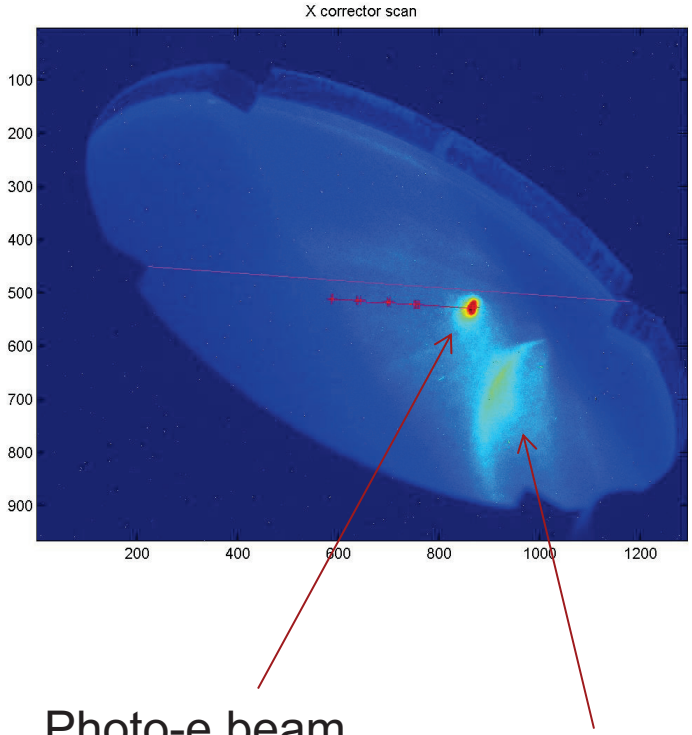
200MV/m also confirmed by steering measurement

Dark Current level acceptable

17.5 MW in gun ~ 209 MV/m

Dark Current ~ 180pC (for 160ns long RF pulse)

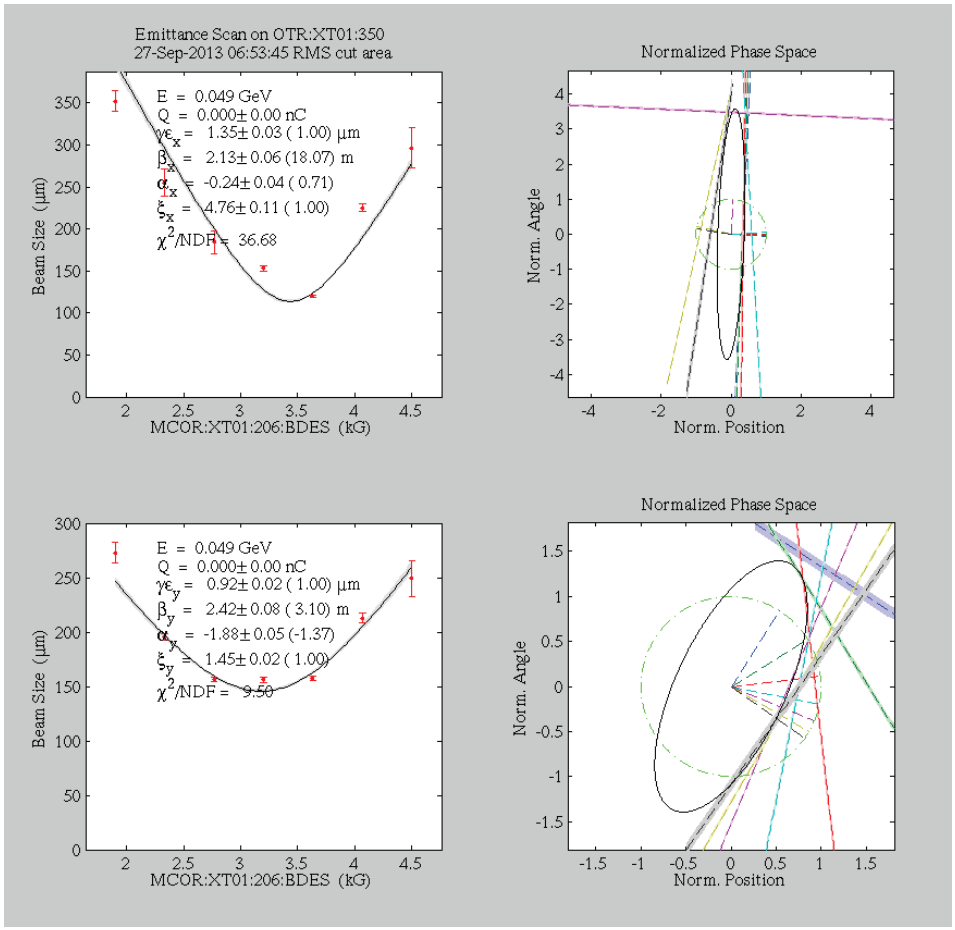




13% Dark Current fluctuations <->
Power fluctuations at ~1% level

Preliminary emittance numbers

30pC , $\varepsilon_x/\varepsilon_y$ ~ 1.3/0.9 mm-mrad



- Combination of all systems operating at spec. has only been met recently
- No laser pulse optimization yet
- Measurements done despite large energy spread

⇨ Quite promising

Simulations for perfect “everything” :
$\varepsilon_{x/y}$=0.26/0.26 for 250pC
becomes 1.0/1.7 if
Laser pulse not shaped, too long,
r =1.2mm, offset 0.5 mm,
solenoid z-offset 1mm

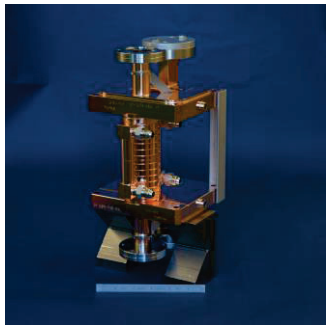
At X-Band
Tolerances 4X tighter than S-Band

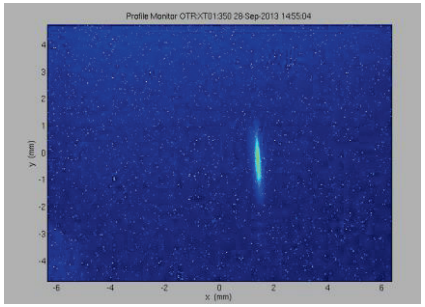
Bunch length measurements – 250 fs rms at 20pC

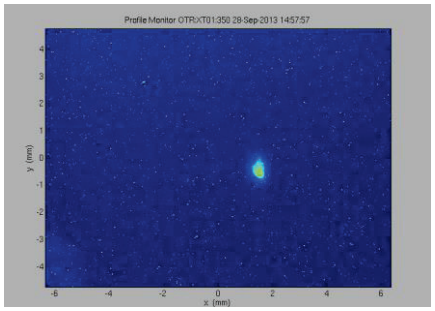
SLAC

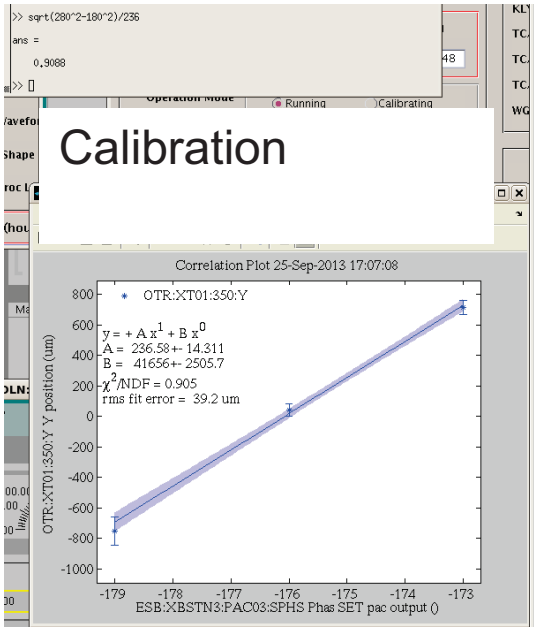
X-Band transverse deflector (TCAV)

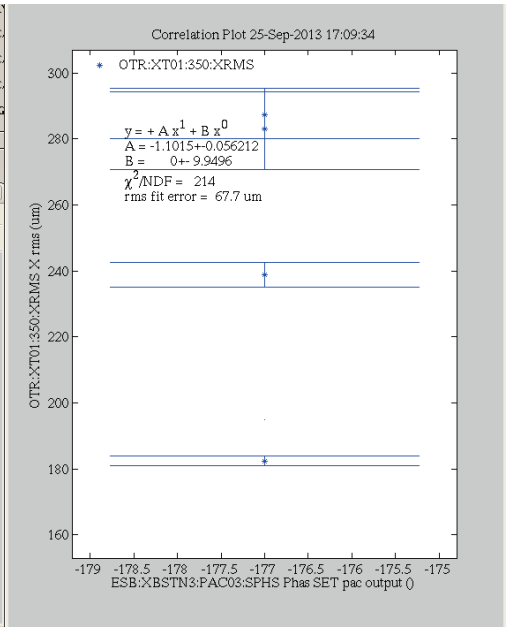
Needs ~ 1MW











Measured compression at low Q

475+/-70 fs rms at 50° (15pC)
250+/-70 fs rms at 30° (10pC)
125+/-30 fs rms at 15° (5pC)

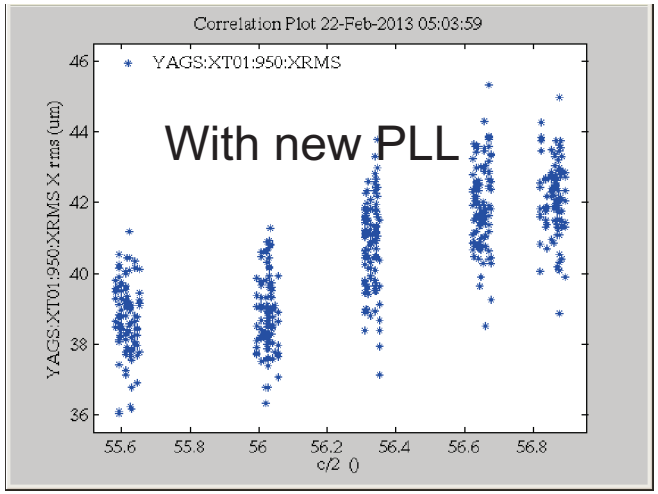
Measured 250fs earlier for 20pC

As expected from simulations

Energy spread and energy jitter

1° X-band = 250 fs

- Laser : Oscillator Phase Lock Loop (PLL)
  - Replaced internal loop (80MHz) by external PID control of piezo (at 2856MHz)
  - Noise rms reduced from 500fs (2°) to 160 fs (0.6 °)
- RF contributions :
  - Modulator HV: measured 124 ppm so should have $d\Phi \sim 0.2°$, $dV/V \sim 10^{-4}$
  - RF fed to gun/linac : measure $d\Phi \sim 0.4°$, $dV/V \sim 10^{-3}$



rms energy spread
~15 keV ~ 3.10^{-4} at very low charge
~10^{-3} for charges up to 70 pC

Energy jitter from 3.10^{-4} to 10^{-3}

Horizontal Beam size at spectrometer

Summary

SLAC

- Compact X-Band photoinjector in operation
- 80 MeV reached at 1.8m
- 200MV/m cathode field with tolerable dark current
- 250 fs rms , 20 pC bunch
- QE ~ 10^{-5} at low field (120MV/m)
- ε ~ 1mm-mrad , 30 pC, (with coarse optimization only)
- Energy spread 2.10^{-3} to 3.10^{-4}
- Energy jitter of same order
- Tolerances/alignment challenging but within reach

Acknowledgments

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- NLCTA Team: C.Hast, D.Mc.Cormick , K.Jobe, M.Dunning , E.Hemsing, S.Weathersby, F.Fu
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- Mechanical: D.Walz, R.Rogers …
- Alignment: G.Gassner, H.Imfeld …
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