High-Brightness Source R&Ds for a XFEL development in the Pohang Accelerator Laboratory (PAL)

S. J. Park, C. B. Kim, J. H. Park, Y. W. Park, J. Y. Huang, T. Y. Lee and I. S. Ko

Pohang Accelerator Laboratory/POSTECH

May 18, 2006

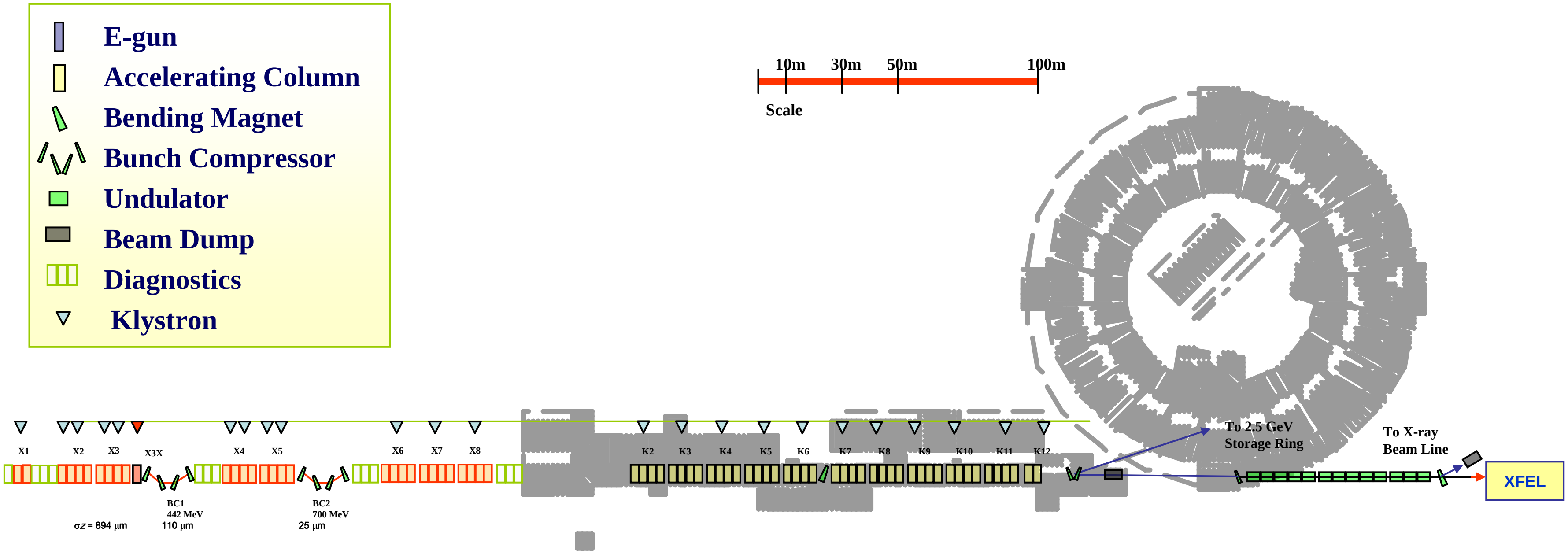
To be presented at the 37th ICFA Advanced Beam Dynamics Workshop on Future Light Sources

Pohang Light Source (PLS)

Beam energy (GeV)	2.5
Frequency (MHz)	2,856
Energy spread (%)	0.26
Bunch length (ps)	13
Beam current (A)	33
Normalized emittance (um)	150
Number of klystrons	12
Klystron power (MW)	80
SLED Gain	1.6
No. of accelerating columns	44
Total length (m)	160

	Designed Value	Achieved Value
Energy (GeV)	2(2.5)	2(2.5)
Stored current (mA)		
Multibunch	300(150)	305(182)
Single Bunch	10	26
Emittance (nm rad)	12.1(18.9)	≤11(13)
Lifetime(hr)		
100mA in 400 bunch		28(42)
10mA in single bunch		1
Bunch length (psec)	16.8	21.2
RF Voltage (MW)		1.6
Betatron Tunes		
Horizontal (V_x)	14.28	14.28(14.258)
Vertical (V_y)	8.18	8.187(8.147)
Synchrotron Tune	0.0109	0.0109

Layout of PAL XFEL



XFEL Linac

Eo=1.2 GeV

ε_n=1.0 um, I_P=3.0 kA, σ_E=0.03%

X1 (150 MeV), X2-3 (290 MeV)

X4-5 (260 MeV), X6-8 (500MeV)

PAL Linac

Eo=2.5 GeV

K2~K12

164MeV/module

XFEL

λ_x= 0.3 nm

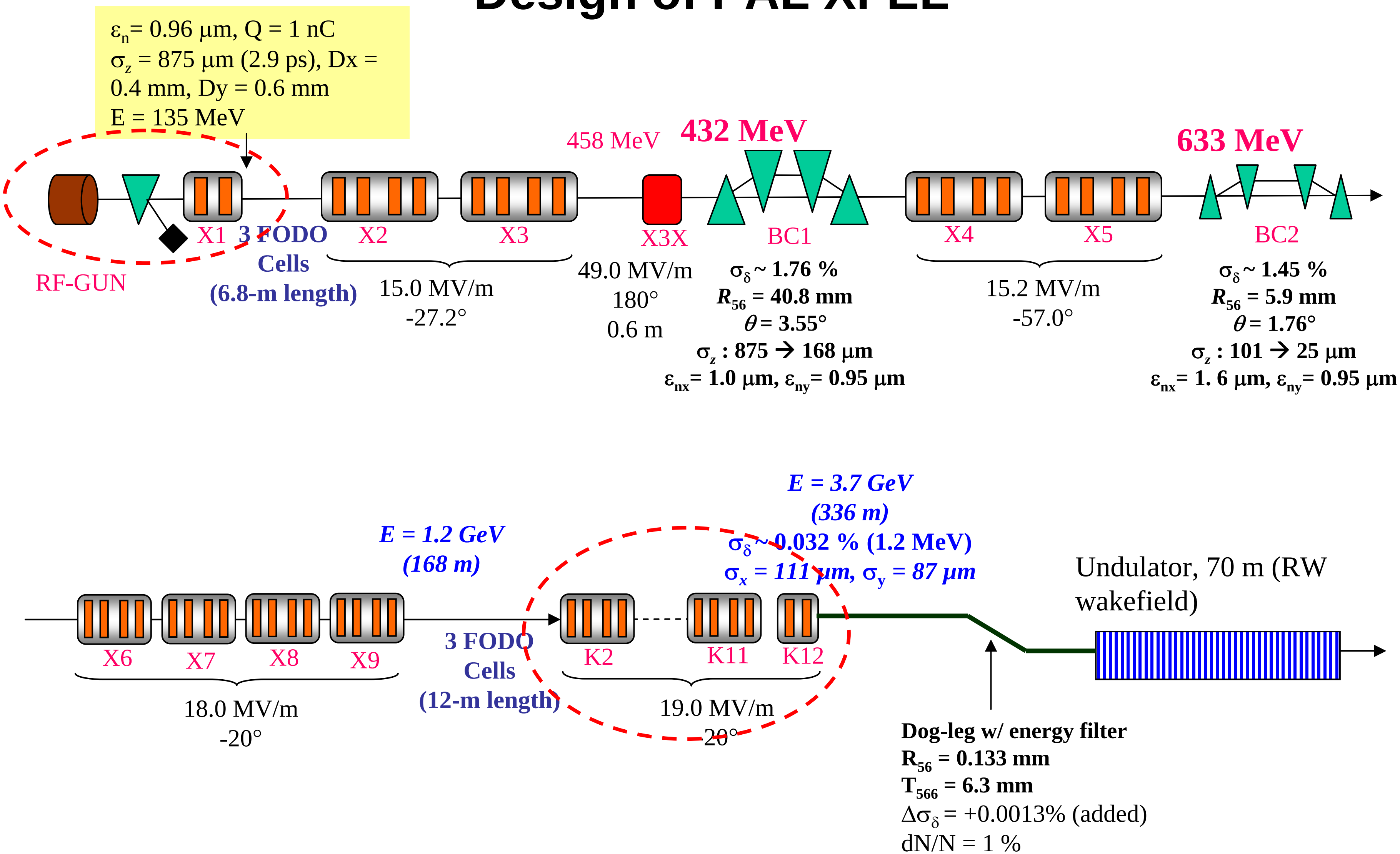
E_o= 3.7 GeV

λ_U = 1.5 cm

G = 4 mm

β = 10 m

Design of PAL XFEL



Requirements of Injector for the PAL XFEL

1. Beam Energy: > 130 MeV

2. Bunch Repetition Rate: 60 Hz max.

3. Bunch Charge: 1 nC nominal

4. Bunch Length: 10 ps nominal

5. Transverse (rms, normalized) Emittance (@ 1-nC beam charge)
   - Slice emittance @ undulator entrance: < 1 mm mrad
   - Slice emittance @ injector exit: < 0.8 mm mrad
   - Projected emittance @ injector exit: < 1.0 mm mrad

6. Energy Spread
   - Un-correlated (slice) energy spread : $\sim 10^{-5}$ rms
   - Integrated energy spread: 0.1 % rms

Strategy for PPI (PAL XFEL Photo-Injector) Development

GTS (Gun Test Stand)
BNL Gun-IV style PC RF Gun
Basic Gun Performance Test
High-Brightness Beam Physics R&D
FED (Femtosecond Electron Diffraction)

- - - → **FIR Facility @ TS Bldg**

↓

PTS (PPI Test Stand)
New RF Gun Cavity
Ti:Sa Laser with Pulse Shaping Capability
Ultra-stable RF Source
Beam Diagnostics from the GTS

→

PPI @ PAL XFEL Tunnel
PAL XFEL Injector
PC RF Gun
2 Acc. Structures
6D E-beam Instrumentation
Highly Reliable & Stable System

GTS (Gun Test Stand)

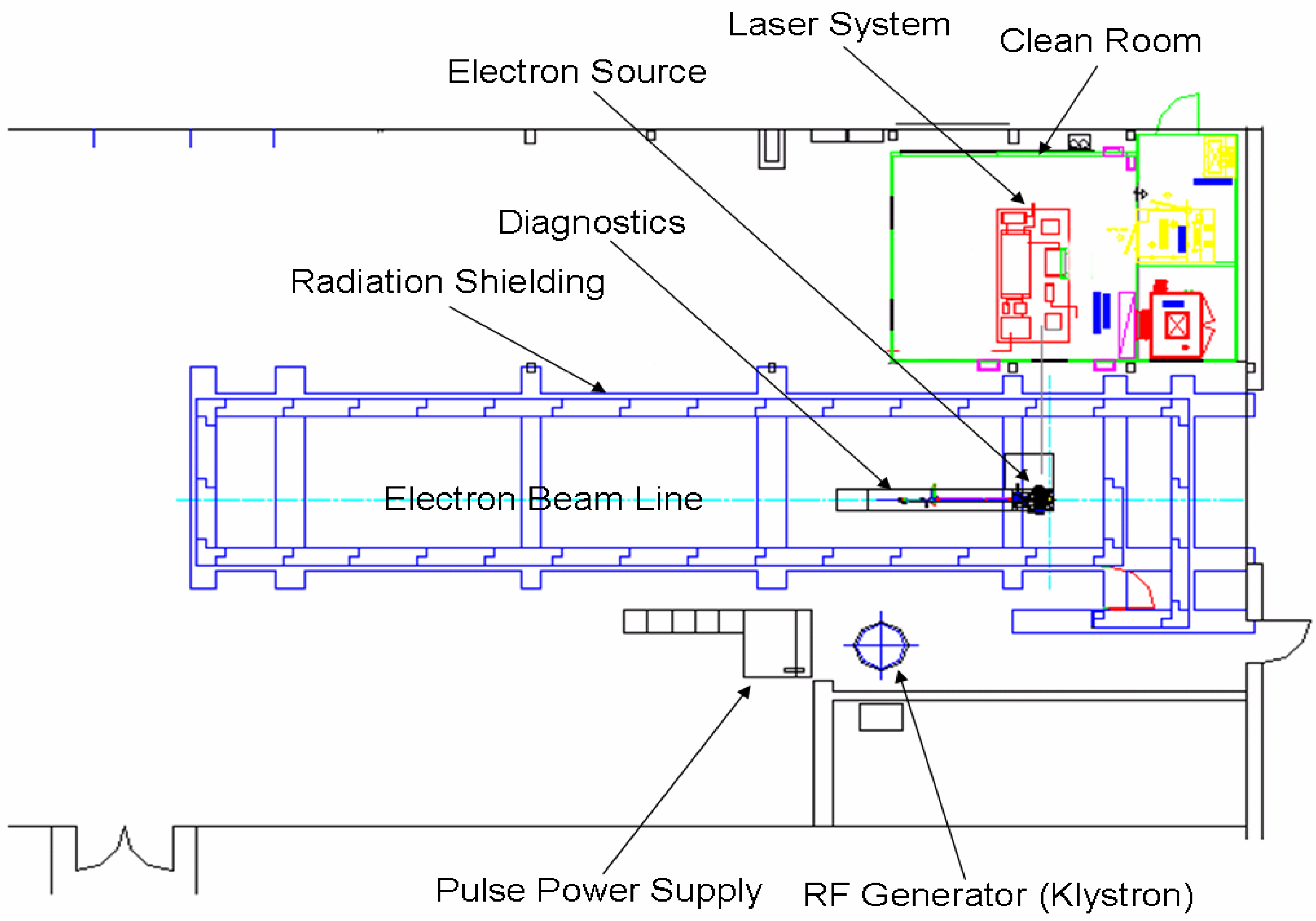
1. is a temporary facility for gun testing. It consist of a PC RF gun, a Ti:Sa laser, a RF source, and beam diagnostics.

2. is a high-brightness R&D resource at the PAL.
   - Diagnostics R&D.
   - Thermal Emittance (Cathode Intrinsic Emittance) R&D.

3. will be utilized for science applications including FED (Femtosecond Electron Diffraction).

4. will be converted to the electron source for a FIR facility.

GTS Layout


Laser System
Clean Room
Electron Source
Diagnostics
Radiation Shielding
Electron Beam Line
Pulse Power Supply
RF Generator (Klystron)

GTS Status

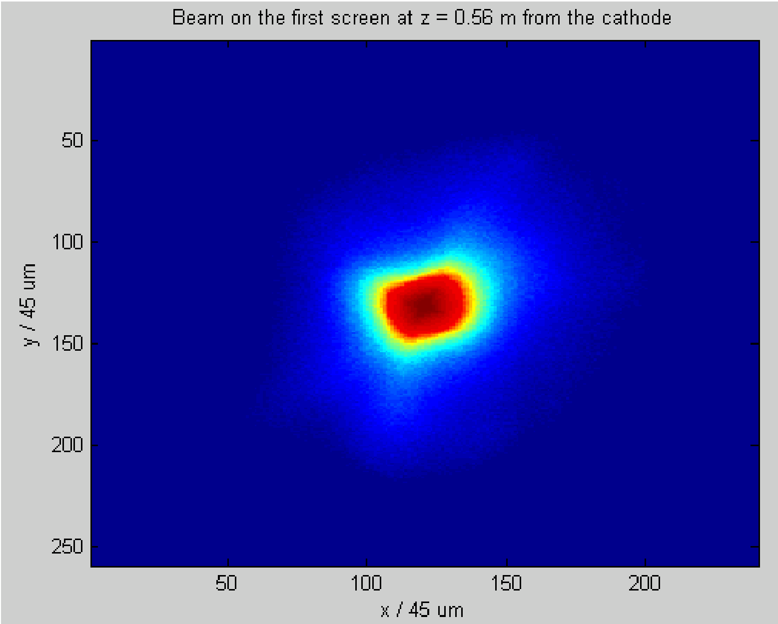
1. Construction started in December, 2004.

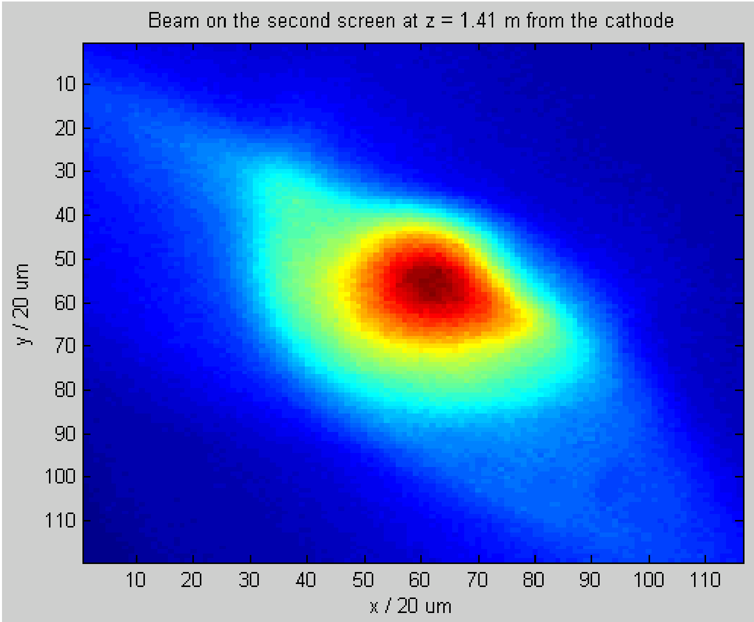
2. First beam was achieved on November 1, 2005.

3. Best beam achieved as of May 10, 2006:
   - Energy ~ 2 MeV (not exactly measured yet)
   - Initial phase = 30^{o}
   - Q = 320 pC (maximum ~500 pC at higher initial phase)
   - Laser pulse length = 5 ps (FWHM)
   - Peak current = 64 A
   - Beam size at 1.46 m from cathode = 500 μm rms
   - Laser spot diameter at the cathode = 3 mm (hard edge)
   - Normalized rms emittance ~ 4 mm mrad

4. Things to be done
   - Energy measurement
   - Time slew compensation (need normal incidence ?)
   - Tests at higher energies (with a new cavity ?)

Beam Images on Phosphor Screens

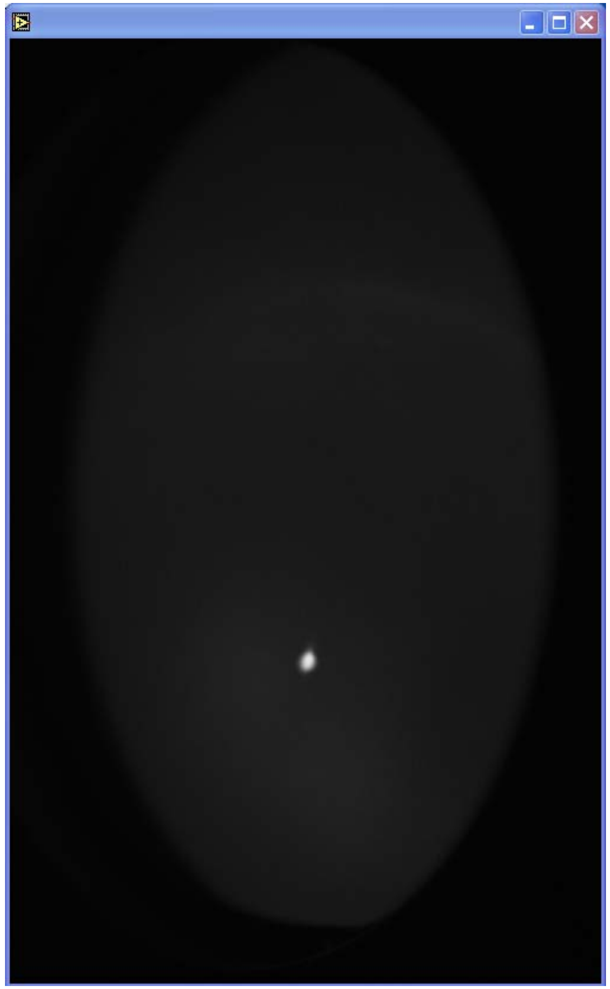




- Beam energy ~ 2 MeV
- Initial phase = 30^o
- Charge = 320 pC
- Laser Spot Diameter (hard edge) = 3 mm, obliquely incident
- Laser Pulse Length (FWHM) = 6 ps
- Normalized rms emittance ~ 4 mm mrad

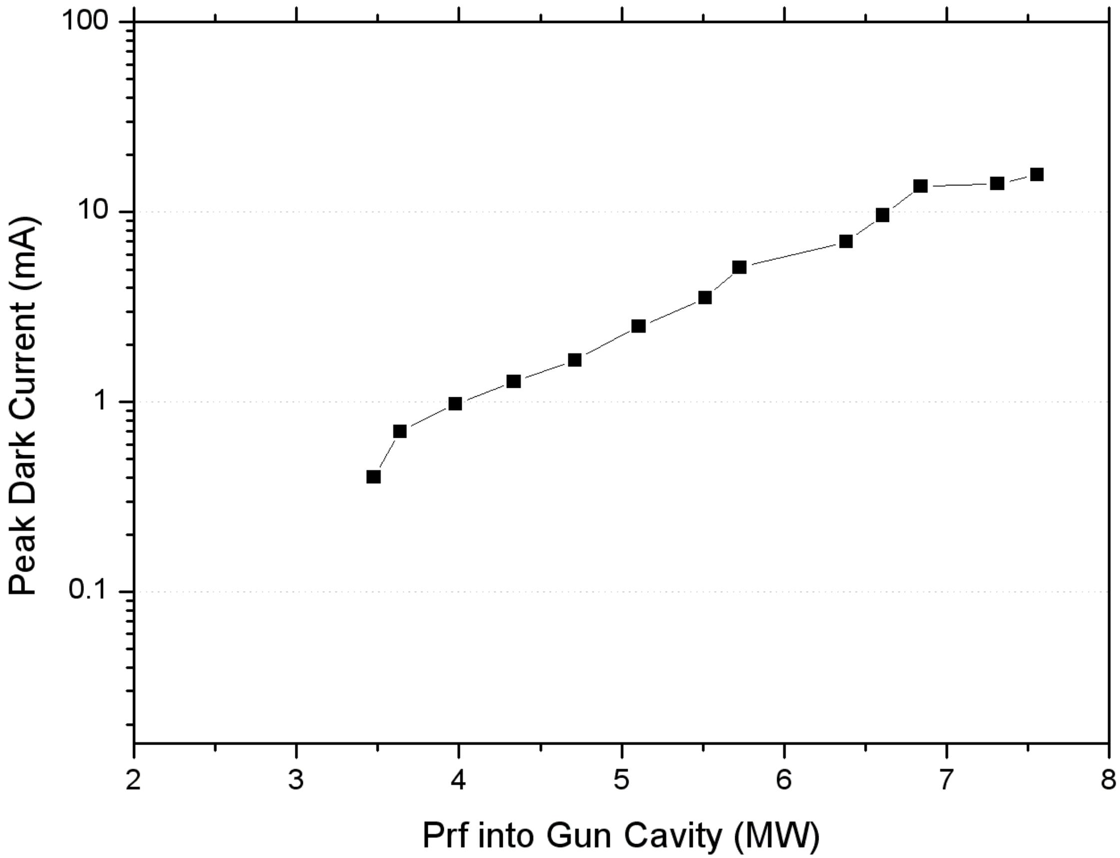
Beam Position Stability

- Beam on S1 at z = 0.56 m from the cathode -

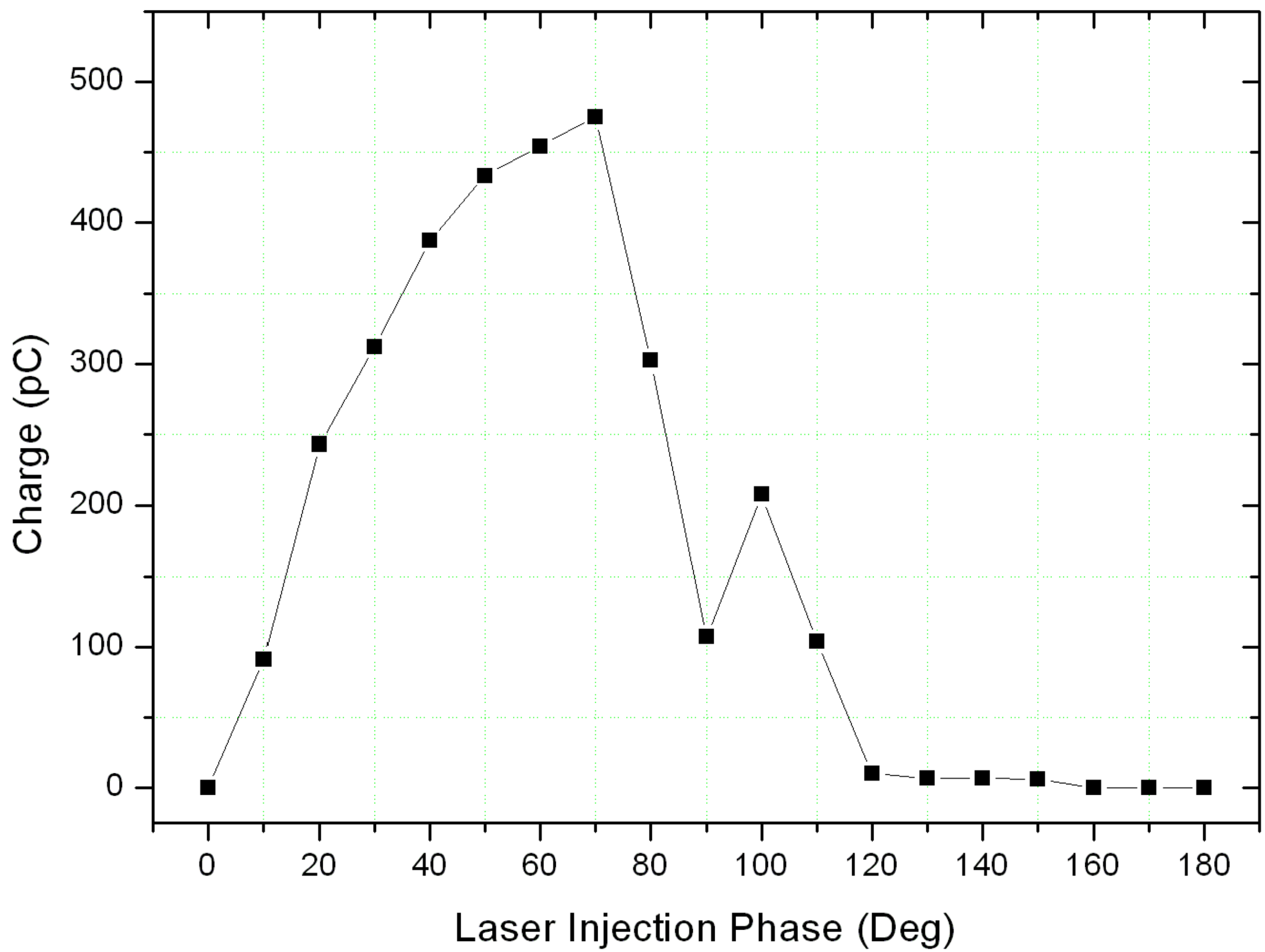


E ~ 2.5 MeV
Q ~ 2 pC
σ_x ~ 100 μm
ϕ_o ~ 30^o
f_{rep} = 5 Hz

Dark Current vs. RF Power Input

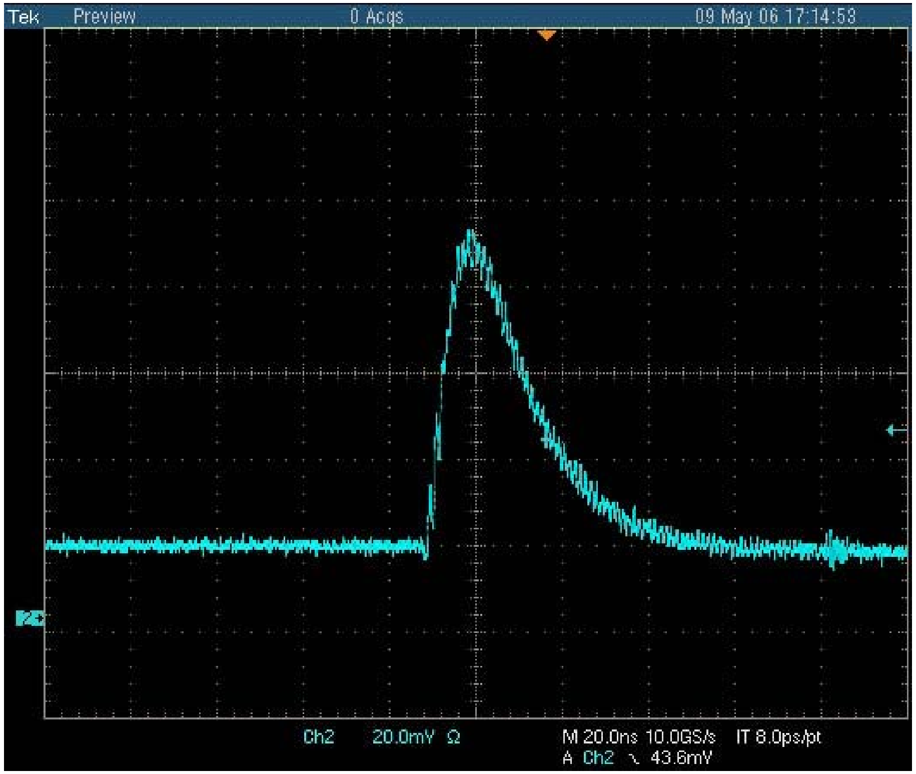


Measurements of Charge vs. Initial Phase



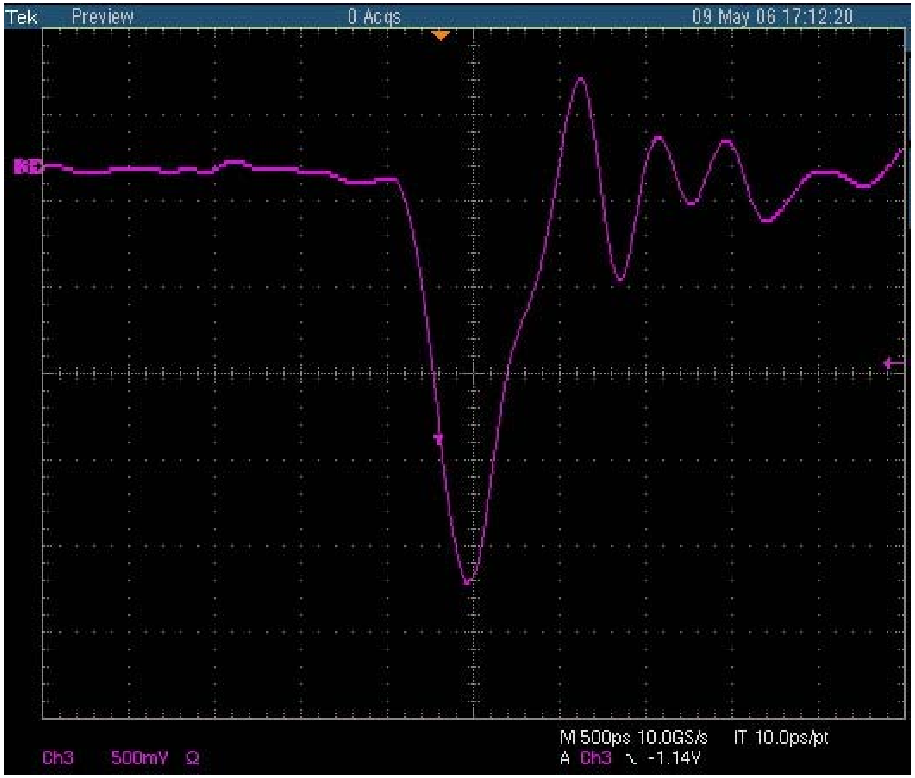
Beam Charge Measurements

ICT from Bergoz Instrumentation



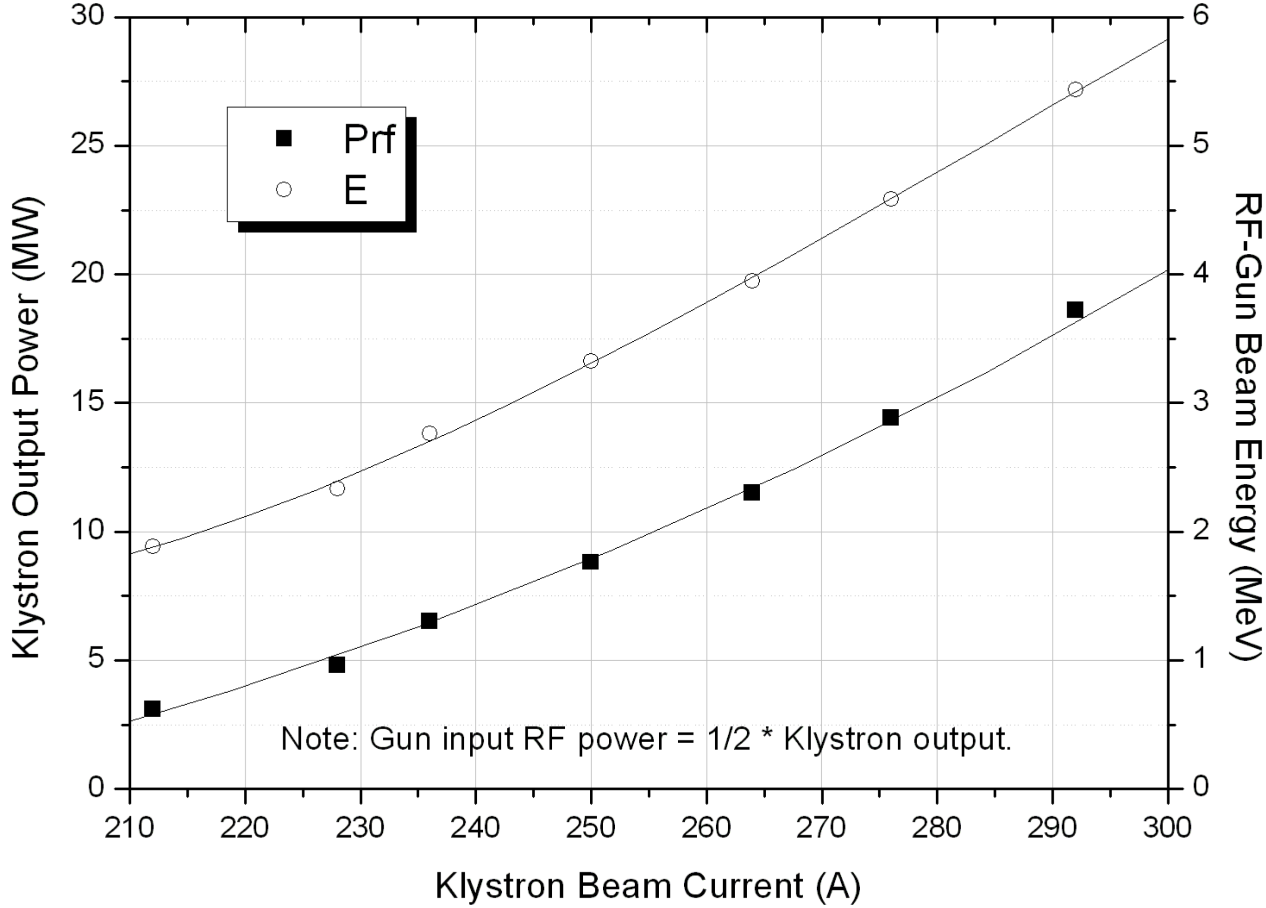
- ICT sensitivity = 5 Vs/C
- Output pulse length = 20 ns

Coaxial Faraday cup, home-made

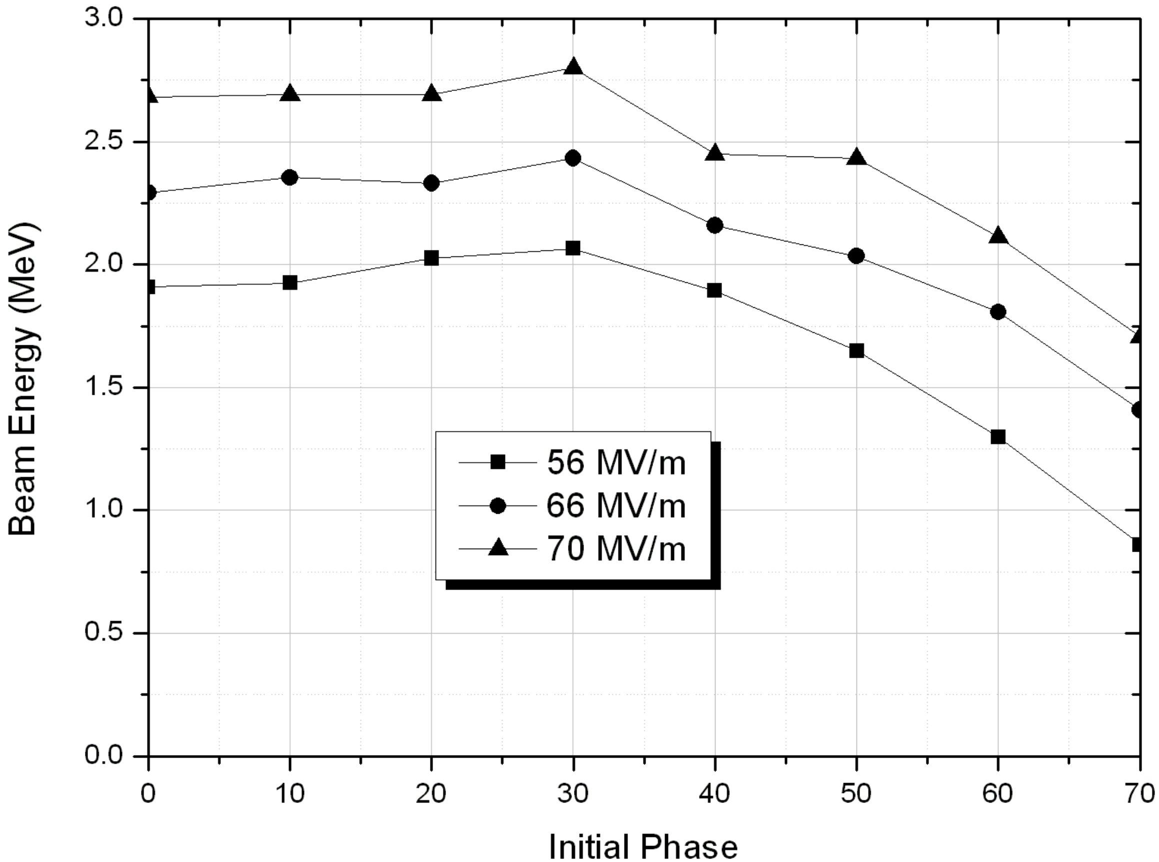


- A cone-shape button (~15-mm dia.) is attached to a N-type connector
- Capacitance of the button is several pF

Klystron Output Power and Expected Beam Energy vs. Klystron Beam Current



Beam Energy vs. Initial Phase for different Field Gradient at Cathode



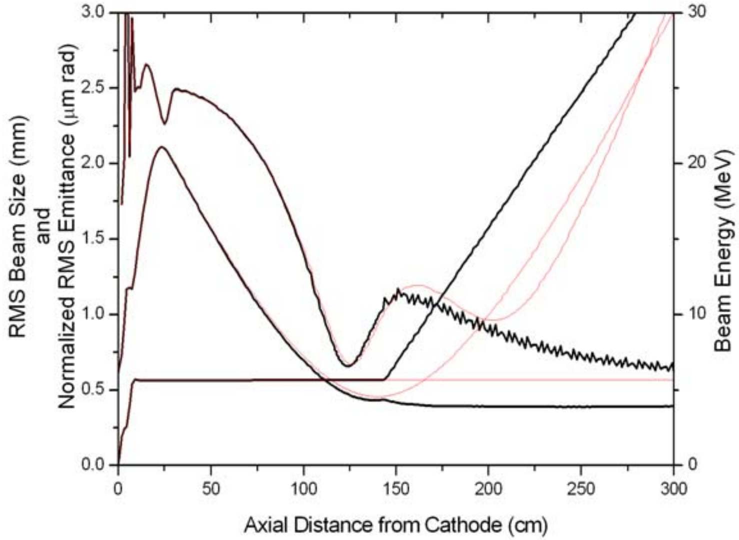
Emittance Compensation by Generalized Brillouin Flow (Invariant Envelope)

Evolution of rms beam envelope through accelerating and focusing channel is given by the following equation of motion,

$$\sigma'' + \sigma'\left(\frac{\gamma'}{\beta^2\gamma}\right) + K_r\sigma - \frac{\kappa_s}{\sigma\beta^3\gamma^3} - \frac{\varepsilon_n^2}{\sigma^3\beta^2\gamma^2} = 0$$

,which applied to the LCLS-type injector configuration, yields the matching condition at the entrance of the booster accelerator:

$$\sigma' = 0 \qquad \text{and} \qquad \gamma = \sqrt{\frac{2}{3}}\frac{\hat{I}}{I_0\varepsilon_{th}\gamma'}$$

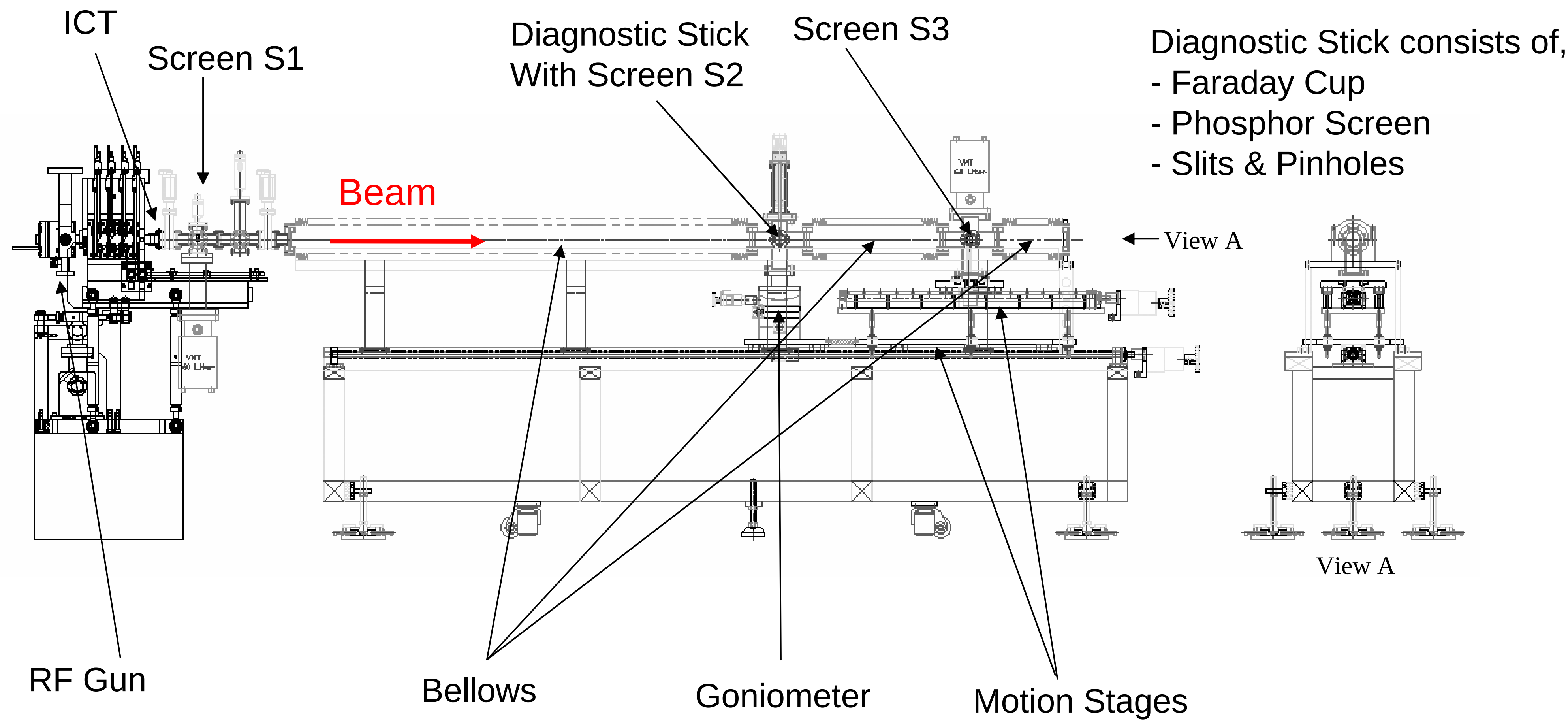


PARMELA Simulation with Modified LCLS Injector Layout

(R. Serafini & J. Rosenzweig, PRE55, p7565)

Measurement of Emittance Oscillation (1/3)

- Experimental Setup -*

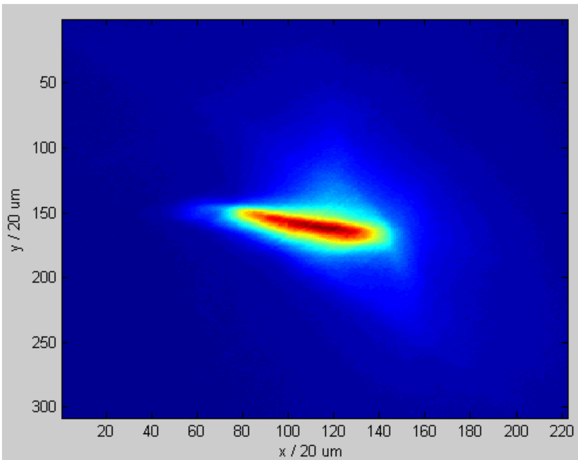


* The SPARC/INFN work on the emittance meter inspired us.

Measurement of Emittance Oscillation (2/3)

- Beam Images at and after a slit -

S2 & Slit

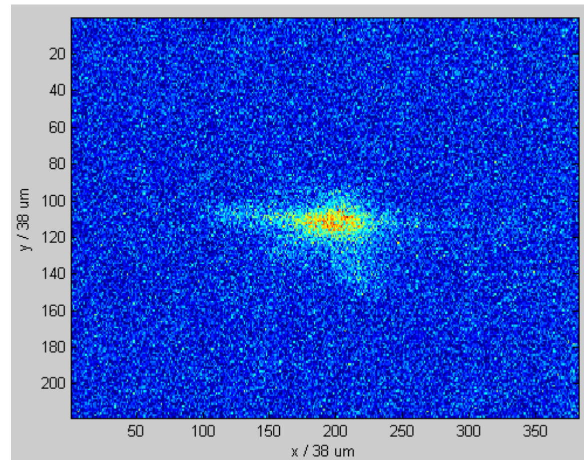


710 mm

$$\varepsilon_{rms} = \sigma\sigma' = \sum_j I_j \frac{\sigma_s}{L}$$

$$\varepsilon_{n,rms} = \gamma\varepsilon_{rms}$$

S3

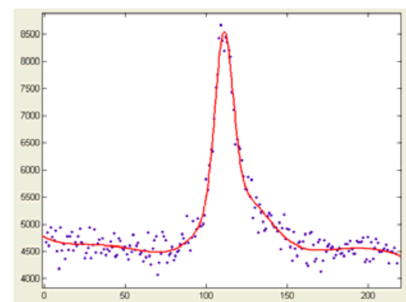


σ_{rms} = 0.459 mm

σ_y = 207.6 μm
σ_y' = 0.29 mrad

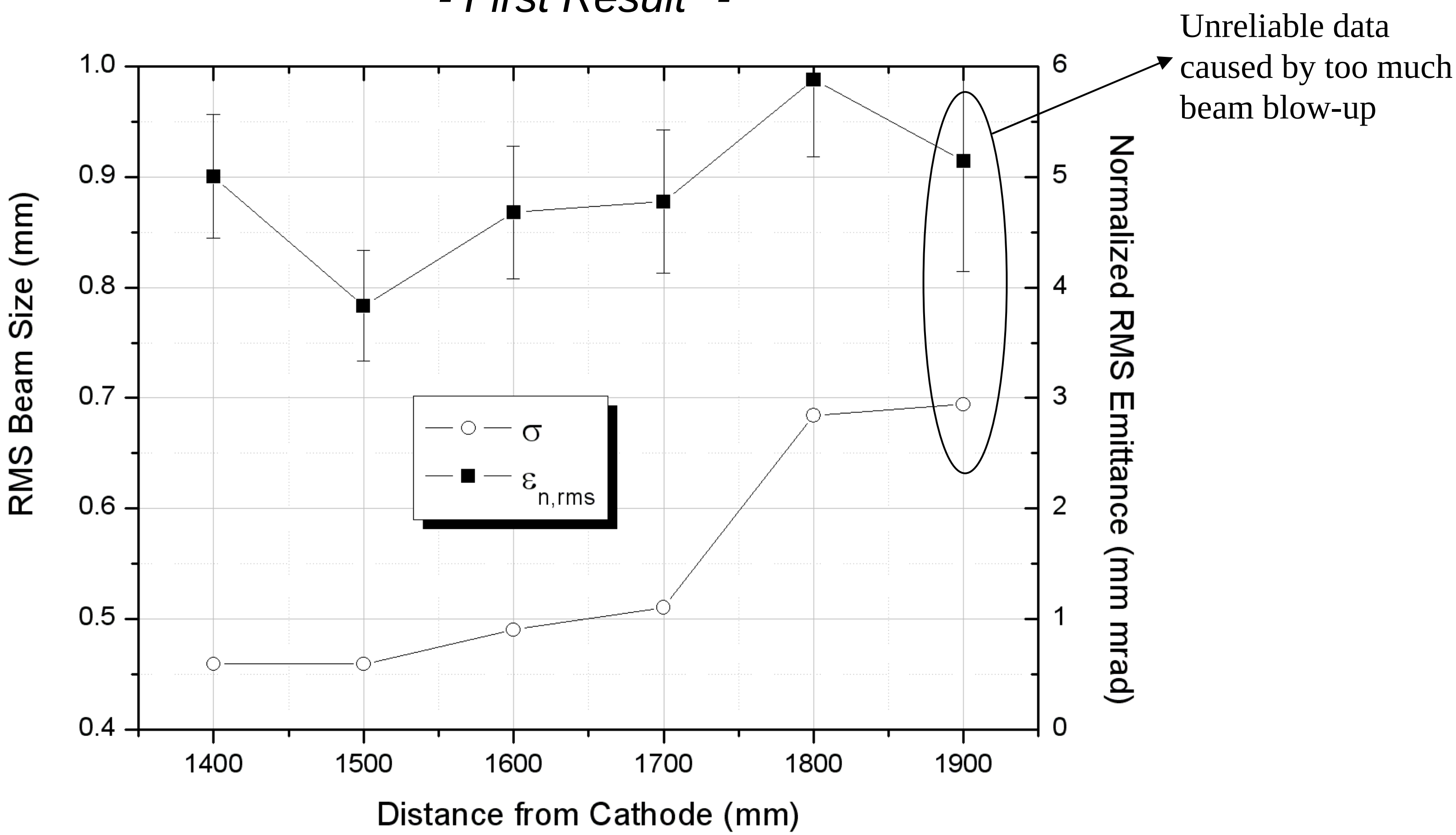
Horizontal slit with 30-μm width, made of 0.5-mm thick Tungsten plate

Phosphor screen



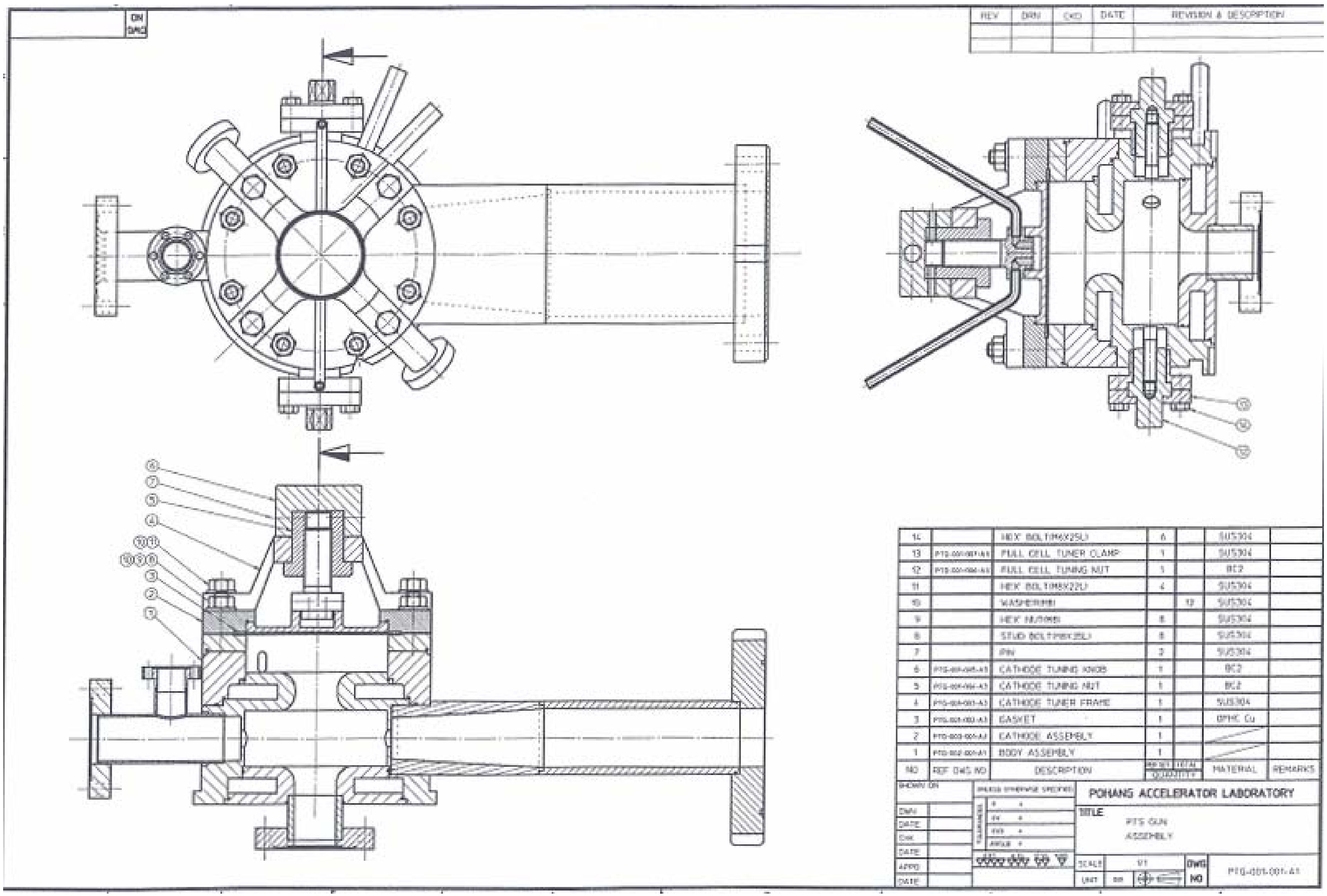
Measurement of Emittance Oscillation (3/3)

- First Result -*

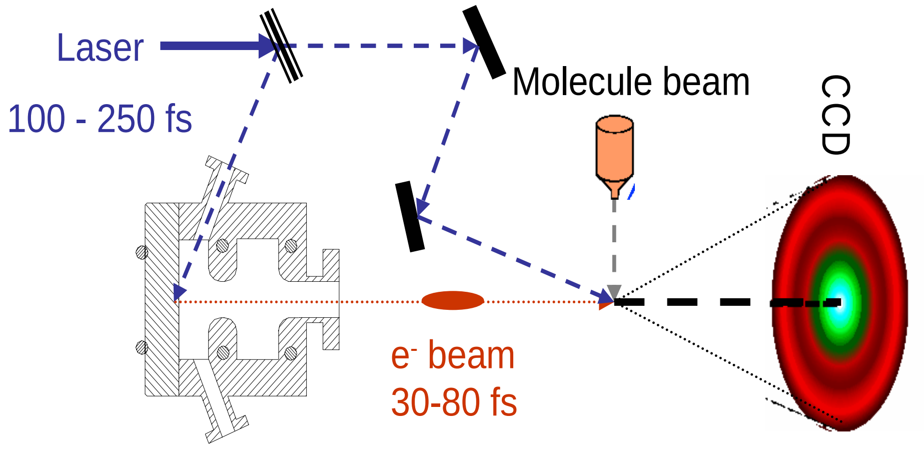


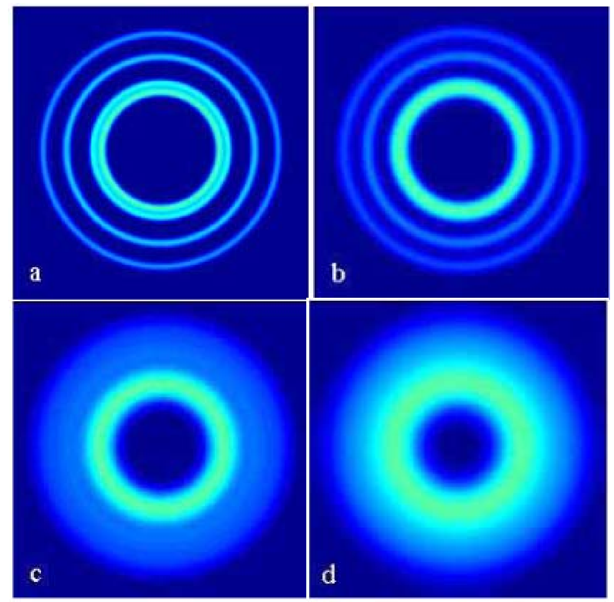
* For better result, we need (1) to improve data analysis methodology, and (2) to automate data acquisition processes.

Fabrication of a new Gun Cavity



Possibility of Measuring Very Small Beam Divergence Using Electron Diffraction





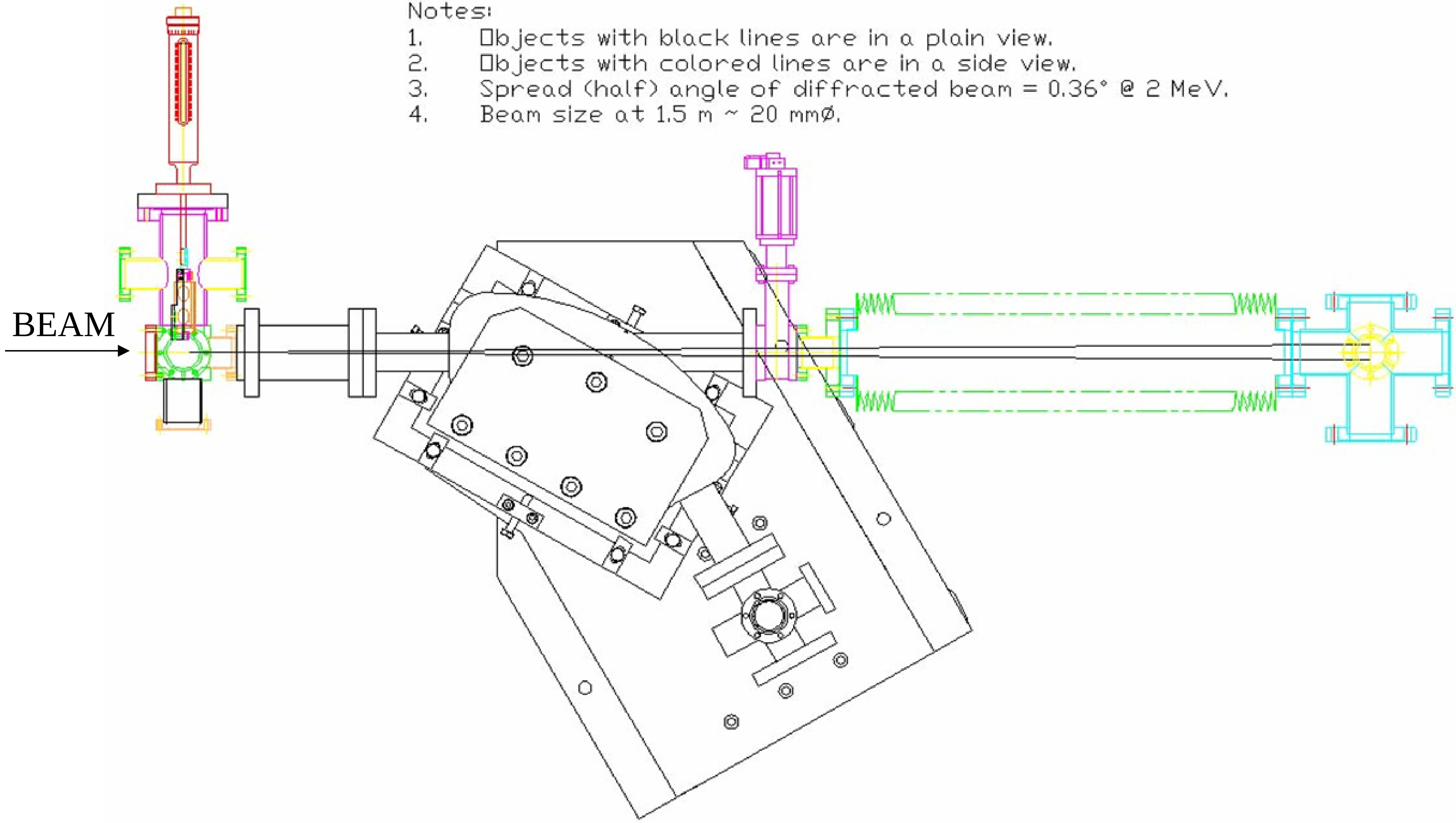
Simulated aluminum-foil diffraction patterns from beams with divergences of (a) 0.05, (b) 0.1, (c) 0.2, and (d) 0.3 mrad

Experimental Setup for Femtosecond Electron Diffraction

(S. Park, April 13, 2006)

Notes:

1. Objects with black lines are in a plain view.
2. Objects with colored lines are in a side view.
3. Spread (half) angle of diffracted beam = 0.36° @ 2 MeV.
4. Beam size at 1.5 m ~ 20 mmø.



Conclusion

1. A photo-injector test facility was established and high-brightness R&Ds are under way.

2. A demonstration experiment for the FED (Femto-second Eectron Diffraction) will be performed in this year. Measurement of bunch length for FED beams (low charge, fs bunch length) is challenging.

3. A new photo-injector facility will be constructed.
   - An ultra-stable RF source (modulator stability < 0.05 %).
   - A Ti:Sa Laser with pulse-shaping capability.
   - A new gun cavity.
   - An accelerating structure.
   - 6D beam diagnostics.