



Tsinghua Thomson scattering X-ray source (TTX)

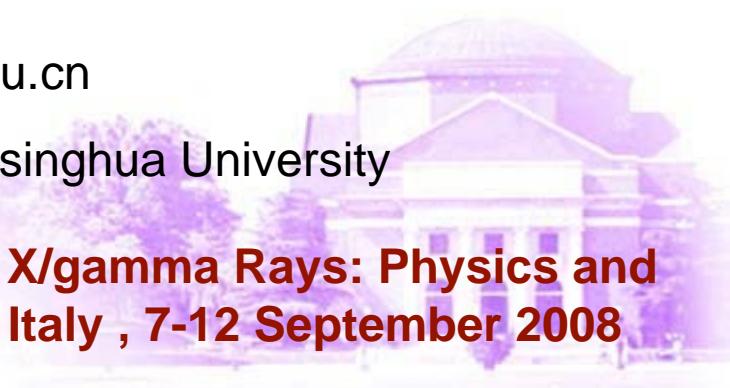
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W.H.Huang, H.B.Chen, Y.Ch.Du, Q.Du, T.B. Du, X.Zh.He,
R.K. Li , Y.Zh. Lin, Xiaohan Liu, Lee Ren, J.R. Shi, D.
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Applications, Porto Conte, Alghero (Sardinia) - Italy , 7-12 September 2008**



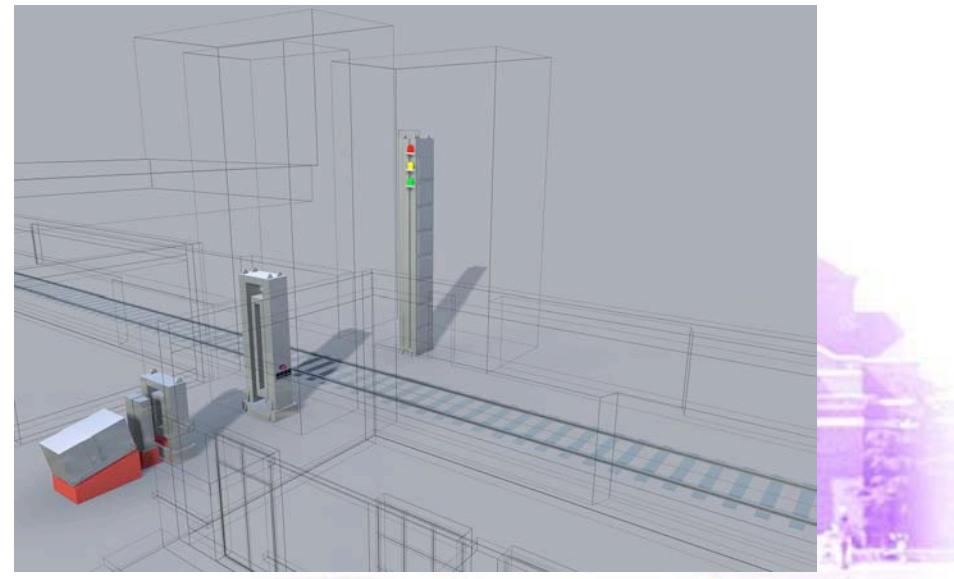


Content

- 1. Introduction
- 2. A Thomson Scattering Primary Experiment
- 3. Tsinghua Thomson Scattering X-ray Source
- 4. Photocathode RF Gun Studies
- 5. Summary



1 Some X-ray Imaging Systems Developed by THU and NUCTECH



Linacs for X-ray Imaging



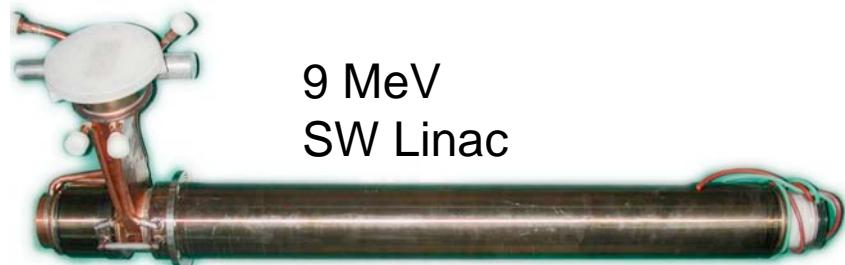
1.5 MeV
SW Linac



2 MeV
SW Linac



4 MeV
SW Linac



9 MeV
SW Linac



15 MeV
SW Linac



6 MeV
SW Linac

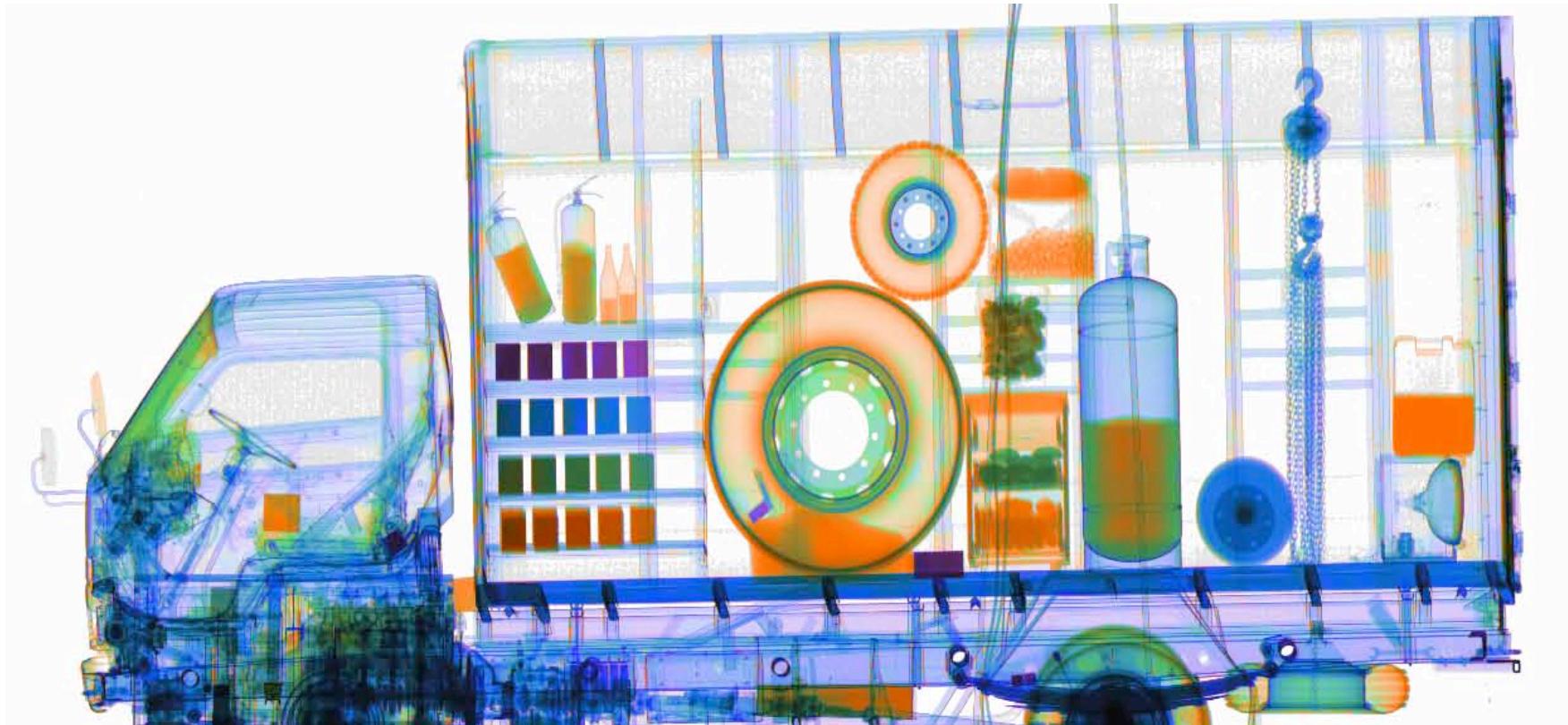




Image Example and Photo Grey Image of a Van with Different Tested Samples

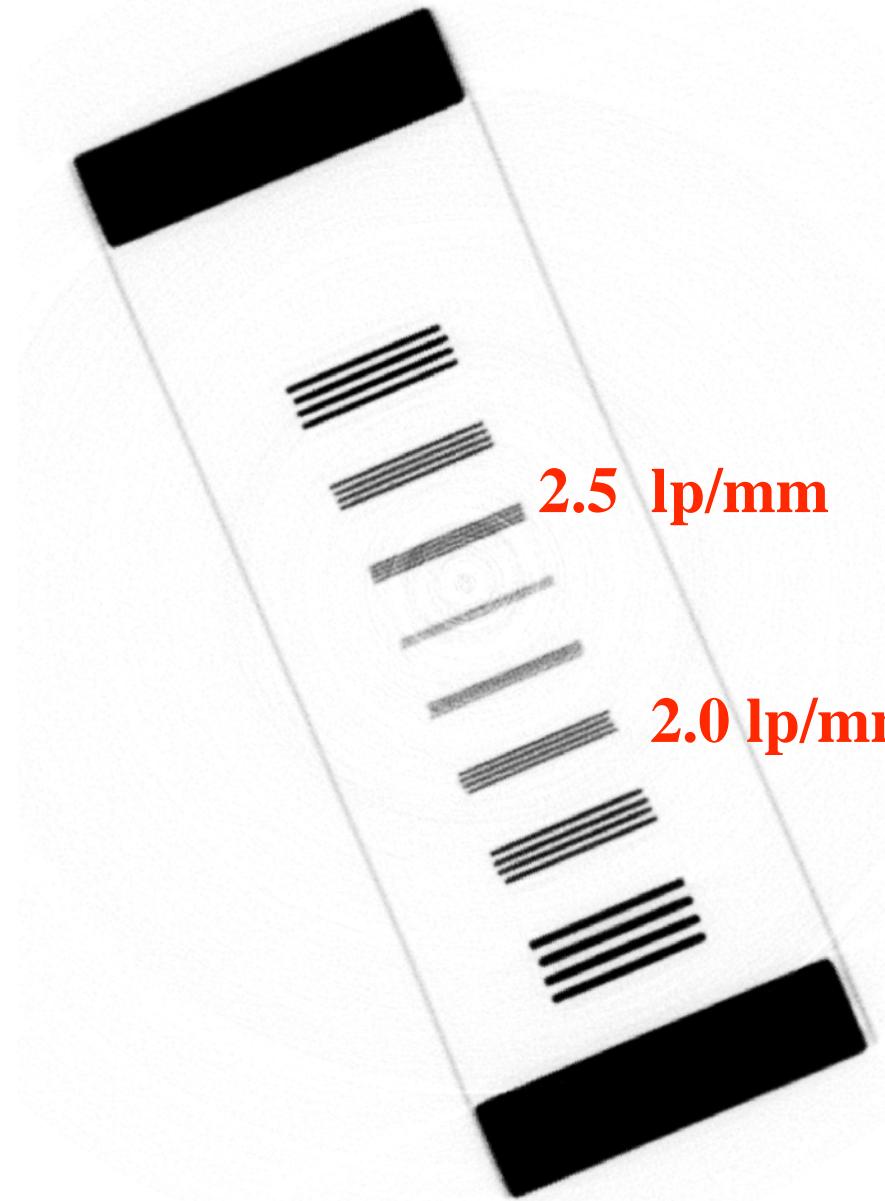


Image Example and Photo Dual-Energy Color Image of a Van with Different Tested Samples

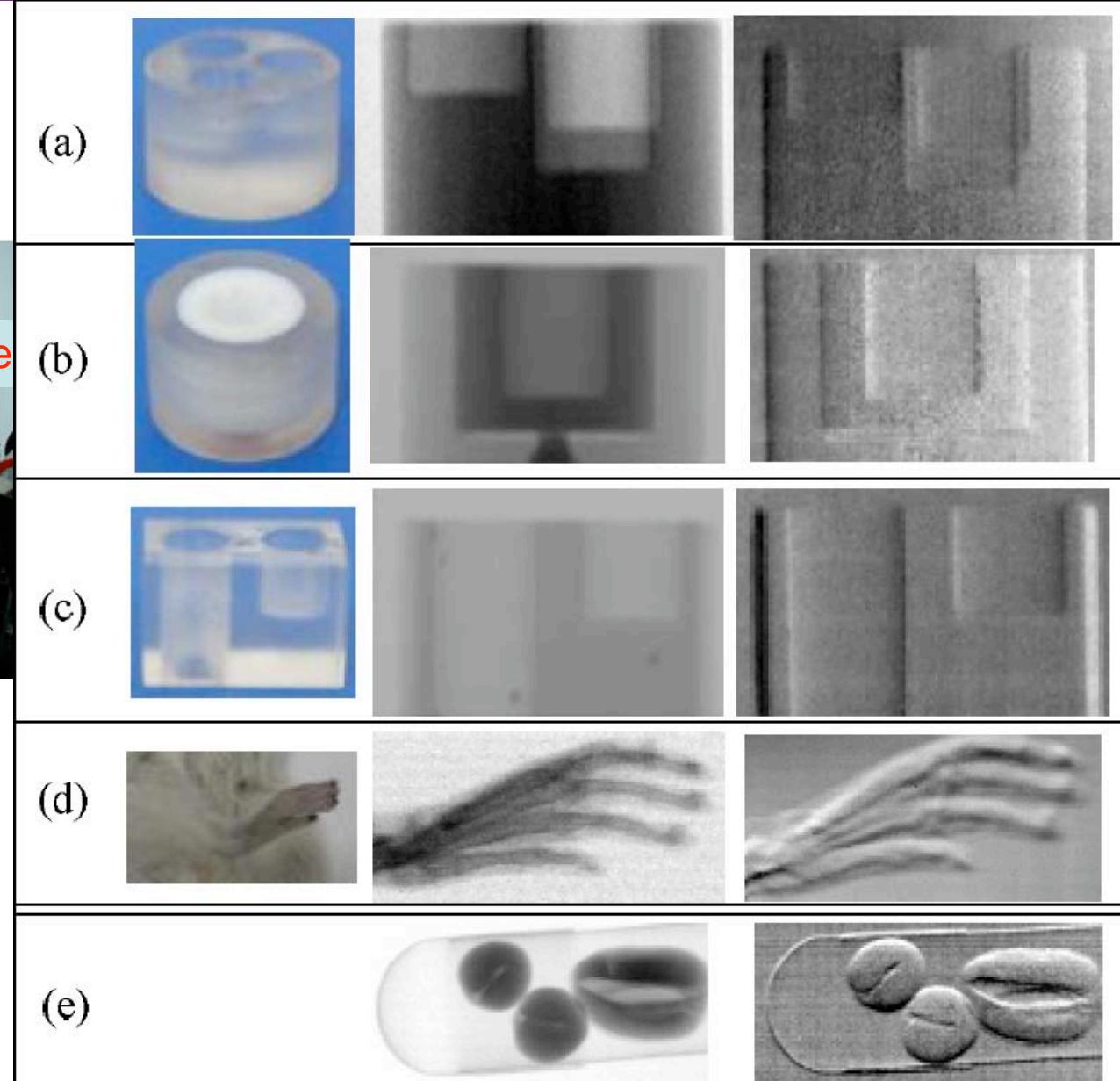
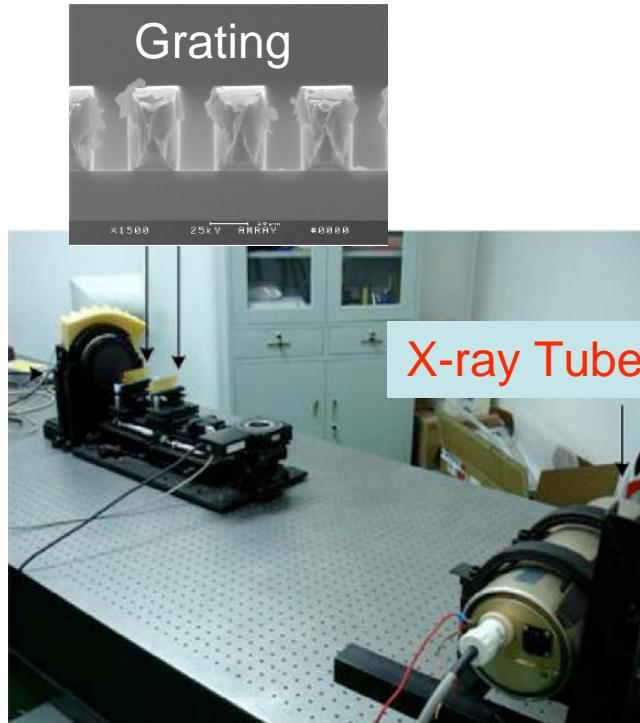


Dual-Energy Color Image: obtained by processing of dual-energy material discrimination algorithm according to effective atomic number

1 CT imaging with 9MeV Linacs in Tsinghua U.



1 PCI in Tsinghua U.



Courtesy of Zhifeng
Huang, "RESEARCH ON
GRATING-BASED PHASE-
CONTRAST IMAGING
UNDER INCOHERENT
CONDITION" 2008

Better Imaging needs better x-ray source. Thomson scattering x-ray is one of the candidates.

- Tunable Monochromatic X-rays
- Radiation in a small angle ($\sim 1/\gamma$)
- Ultra-short X-ray Pulse
- High Peak Brightness



1 Thomson Scattering X-ray Source

Number of photons for arbitrary scattering angle

$$n_x = C_{off} \frac{n_e n_l}{\sqrt{2\pi}} \Sigma \frac{1}{\sqrt{(\sigma_{ey}^2 + \sigma_{ly}^2)}[(1 - \cos\alpha)(\sigma_{ex}^2 + \sigma_{lx}^2) + (1 + \cos\alpha)(\sigma_{ez}^2 + \sigma_{lz}^2)]}$$

where C_{off} — a coefficient which shows the influences of the spatial and temporal differences of electron beam's and laser beam's position and timing on the photon yields. The Max. value of C_{off} is equal to 1.

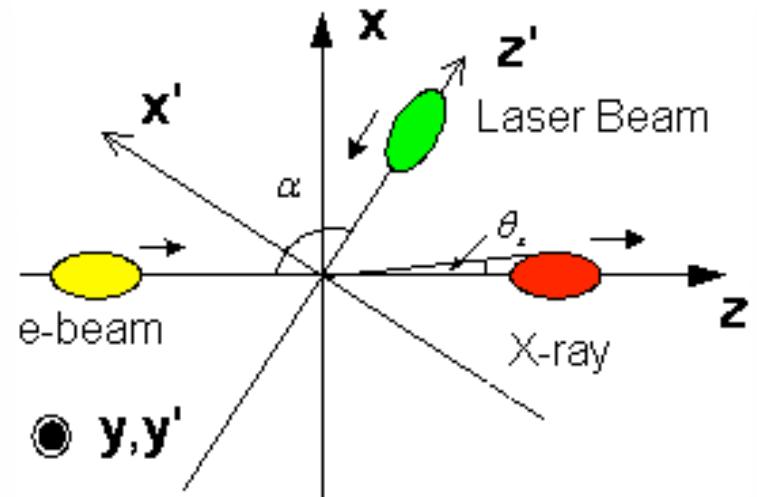
$\Sigma = 8\pi r_0^2 / 3$ — Thomson scattering section.

n_e — the total number of photon per pulse.

$\sigma_{ex}, \sigma_{ey}, \sigma_{ez}$ — the electron beam rms sizes and electron beam pulse rms length.

$\sigma_{lx}, \sigma_{ly}, \sigma_{lz}$ — the laser beam rms sizes and laser beam rms length.

α — Thomson scattering angle.



Thomson Scattering Configuration

1 Thomson Scattering X-ray Source

The above mentioned coefficient, C_{off} is as follows,

$$C_{off} = \exp\left(-\frac{(y_{e0} - y'_{l0})^2}{2(\sigma_{ey}^2 + \sigma_{ly}^2)} - \frac{[(z_{e0} + z'_{l0})\cos(\alpha/2) - (x_{e0} - x'_{l0})\sin(\alpha/2)]^2}{(1 - \cos\alpha)(\sigma_{ex}^2 + \sigma_{lx}^2) + (1 + \cos\alpha)(\sigma_{ez}^2 + \sigma_{lz}^2)}\right)$$

where $(y_{e0} - y'_{l0})$, $(x_{e0} - x'_{l0})$ represents the transverse differences between electron beam and laser beam spatial position respectively.

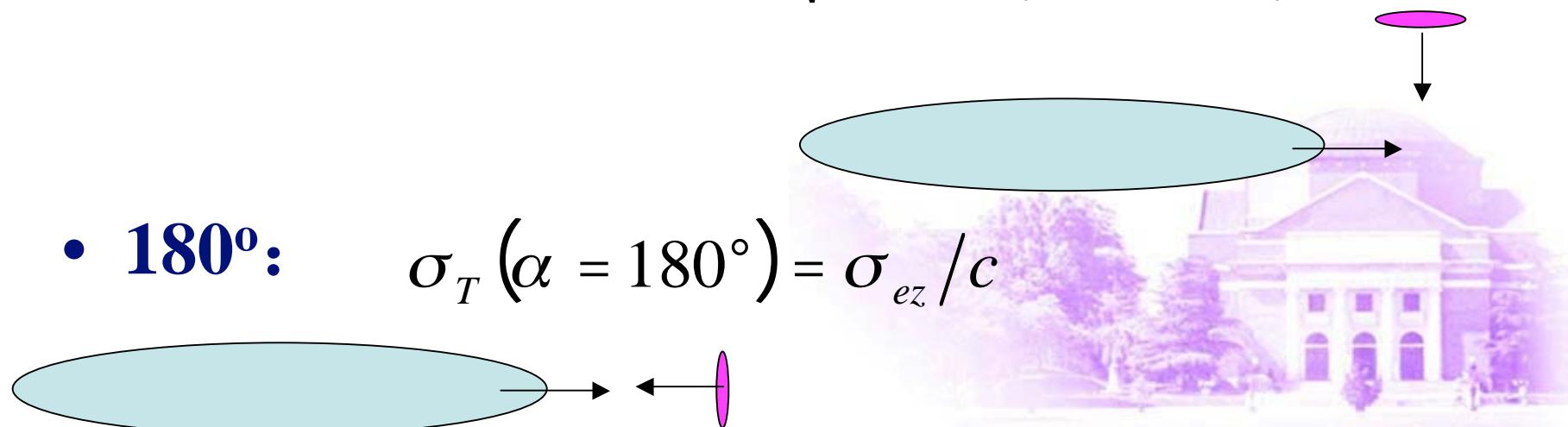
$(z_{e0} + z'_{l0})$ represents the longitudinal differences between electron beam and laser beam.

1 Thomson Scattering X-ray Source

The Pulse Length of The Scattering X-ray Pulse

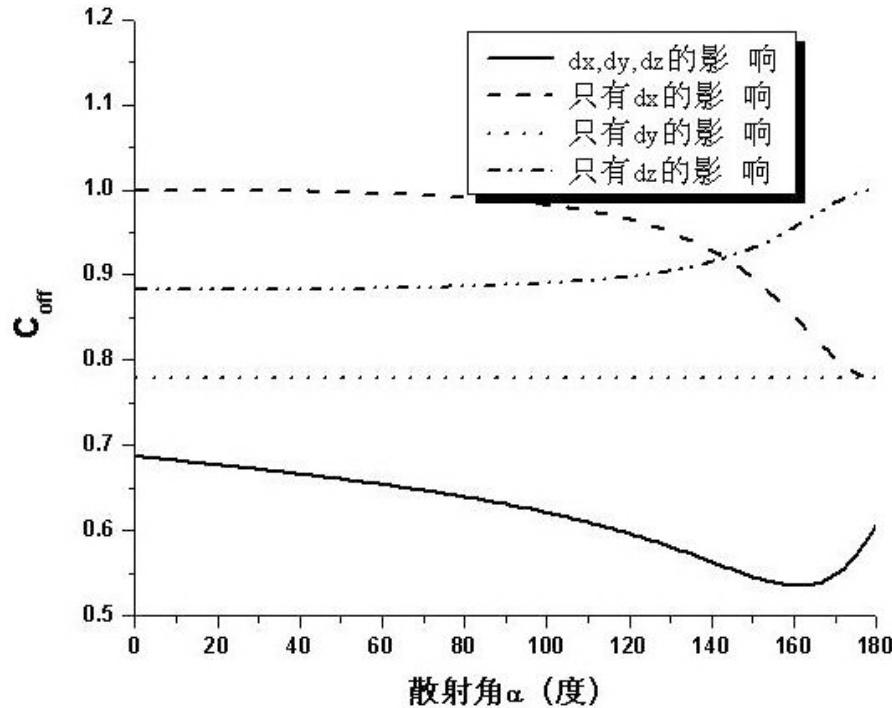
$$\sigma_T = \frac{\sigma_{ez} \sqrt{(1 - \cos\alpha)(\sigma_{ex}^2 + \sigma_{lx}^2) + (1 + \cos\alpha)\sigma_{lz}^2}}{c \sqrt{(1 - \cos\alpha)(\sigma_{ex}^2 + \sigma_{lx}^2) + (1 + \cos\alpha)(\sigma_{ez}^2 + \sigma_{lz}^2)}}$$

- **90°:** $\sigma_T (\alpha = 90^\circ) = \frac{\sigma_{ez} \sqrt{\sigma_{ex}^2 + \sigma_{lx}^2 + \sigma_{lz}^2}}{c \sqrt{\sigma_{ex}^2 + \sigma_{ez}^2 + \sigma_{lx}^2 + \sigma_{lz}^2}}$

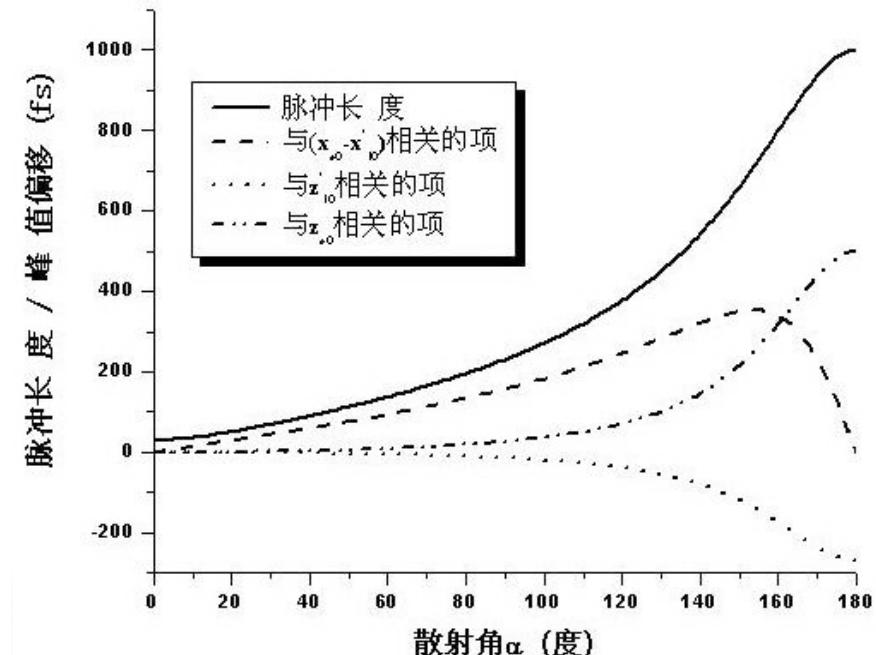


1 Thomson Scattering X-ray Source

- ◎ The influences of the non-ideal factors, such as the jitter of position and timing, emittance, energy spread etc. on the photon yields.

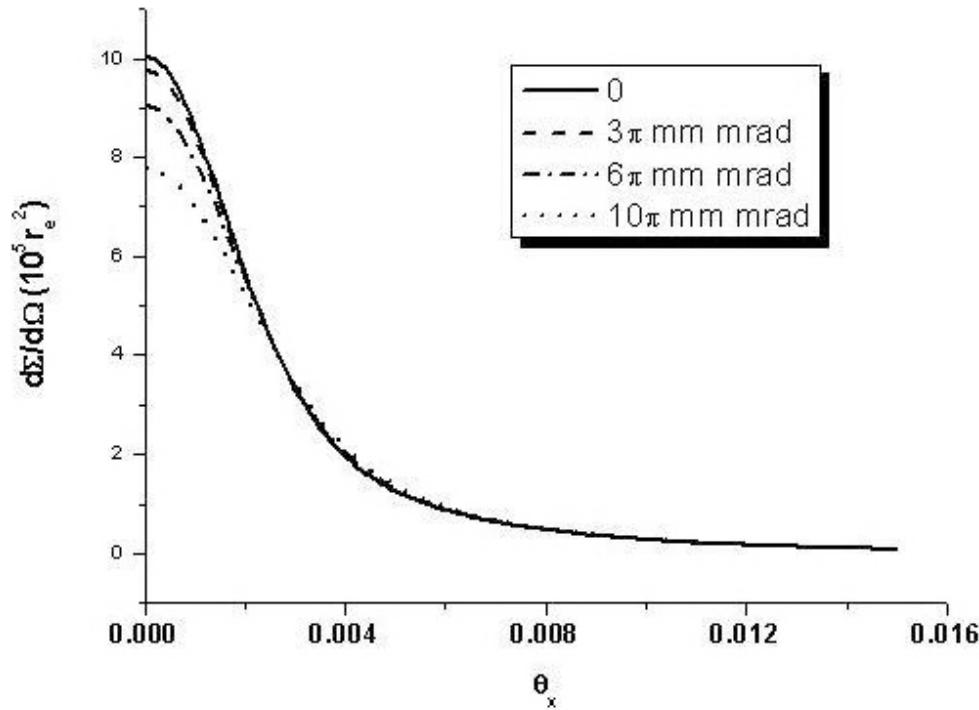


the influence of the jitter on the C_{off} coefficient VS. scattering angle.

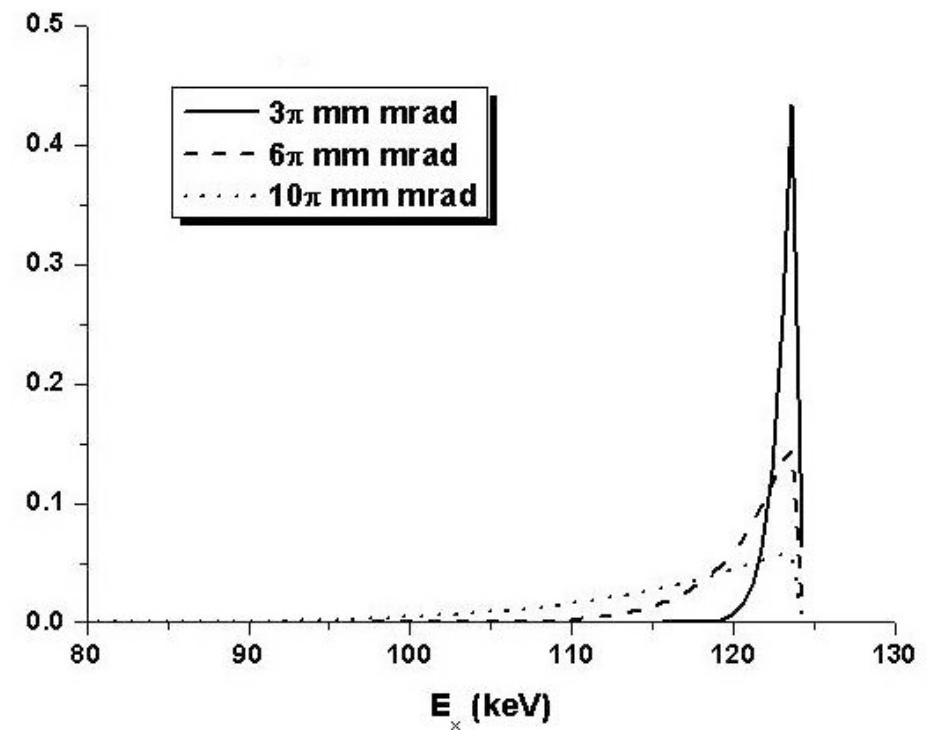


the influences of the jitter on the x-ray length VS. scattering angle.

1 Thomson Scattering X-ray Source

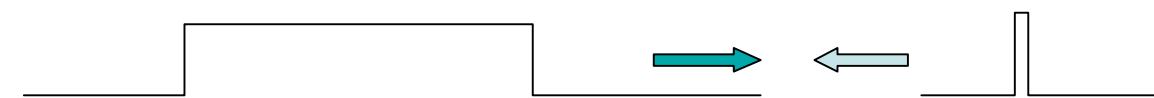
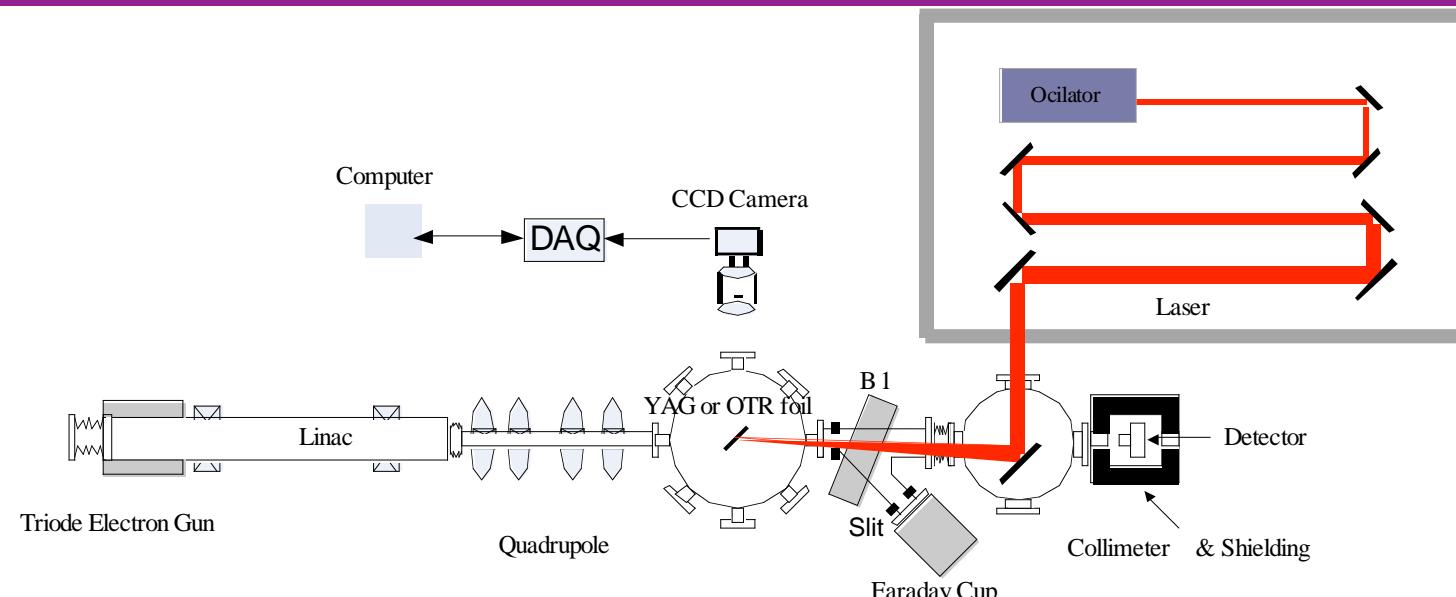


the influence of the emittance
on the X-ray angle distribution



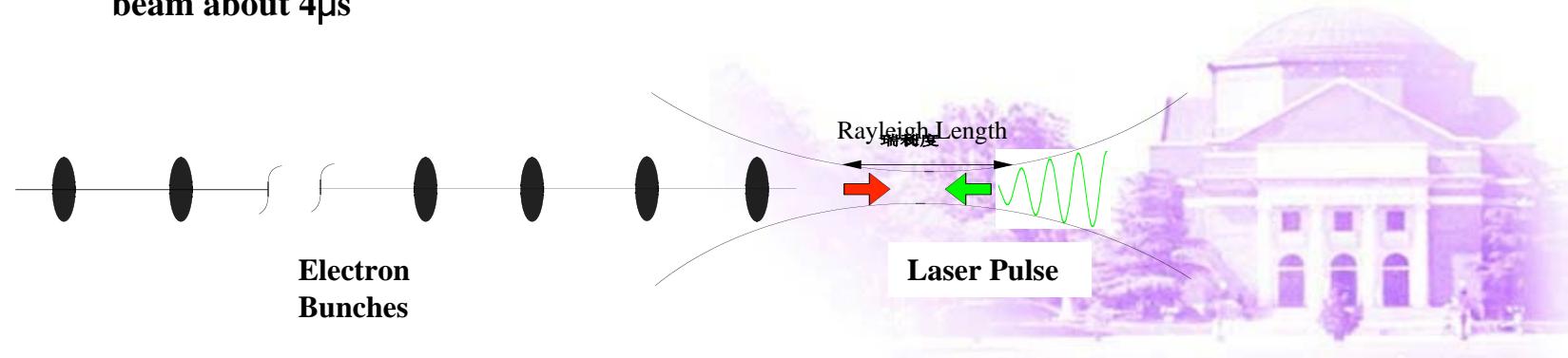
the influences of the emittance on
the X-ray energy spread.

2 A Primary Experiment at THU

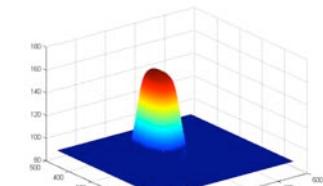
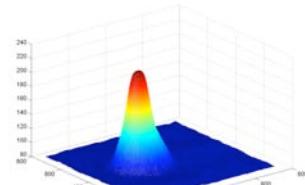


Macro-pulse of 16MeV electron beam about 4 μ s

Pulse of Laser beam about 10ns

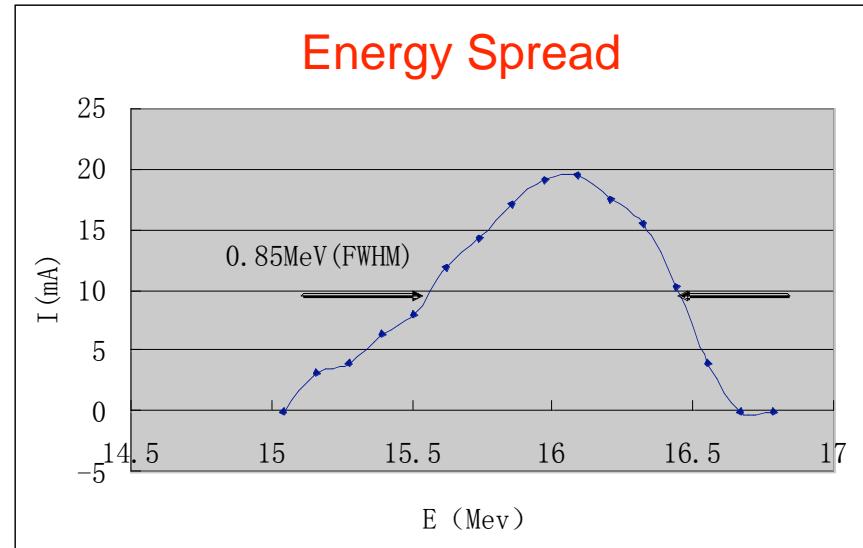


2 Experimental Setup

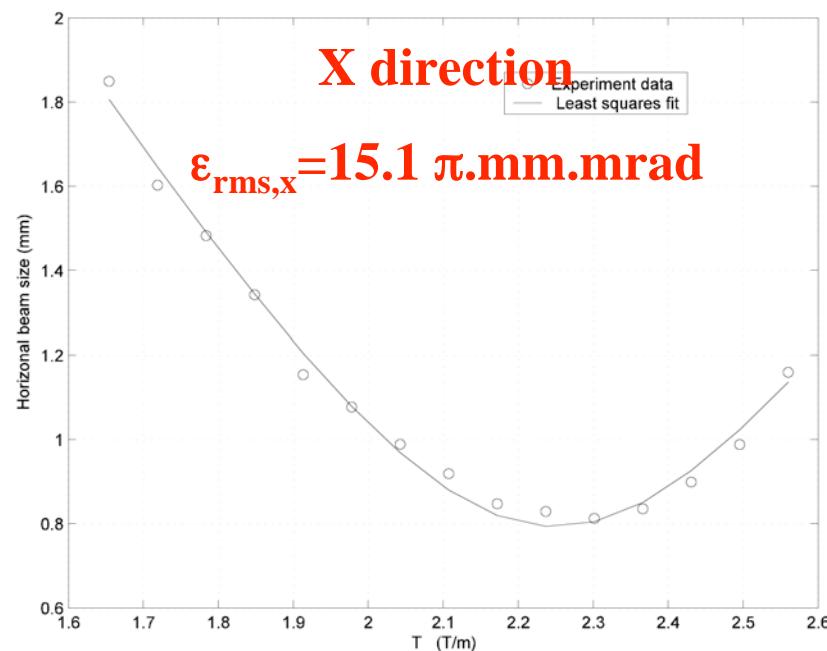


**CCD image of electron
and laser beam at interaction point
(up:electron, down:laser)**

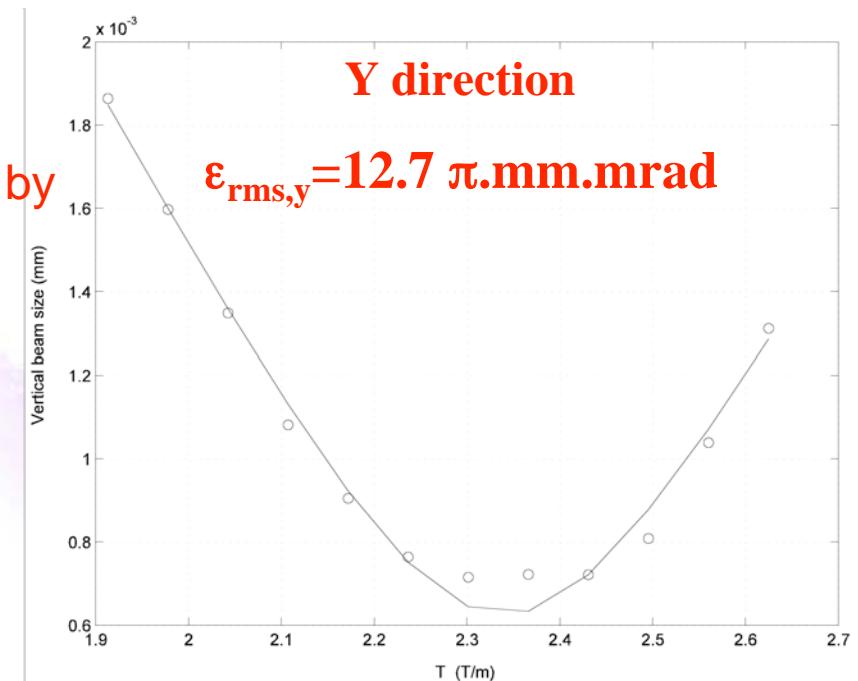
2 Beam Parameters



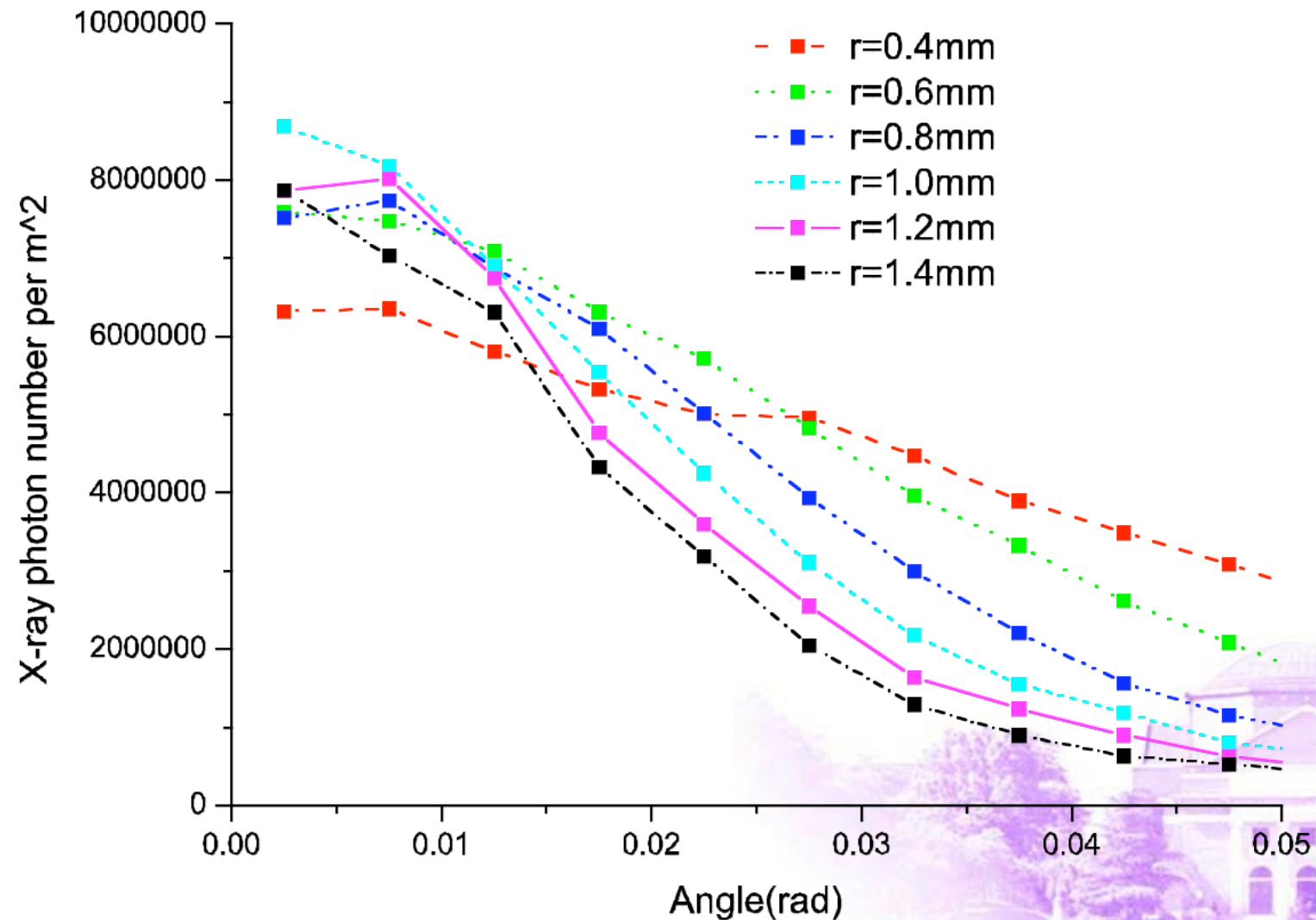
Pulse Current
105mA



Emittance
Measured by
Quad.

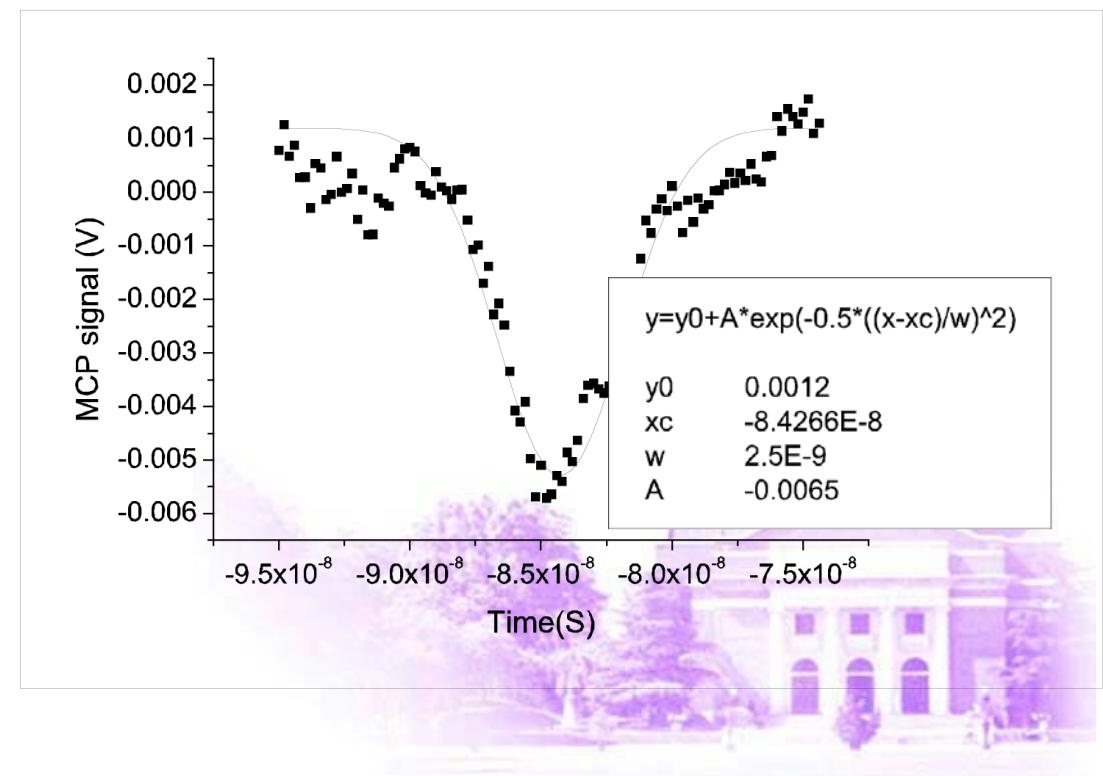
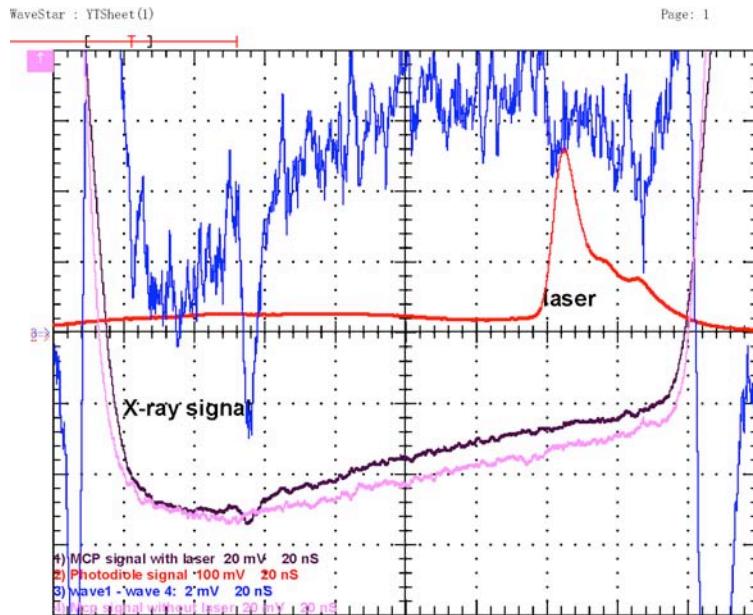


2 The scattering x-ray photon number simulation at the measure electron beam emittance

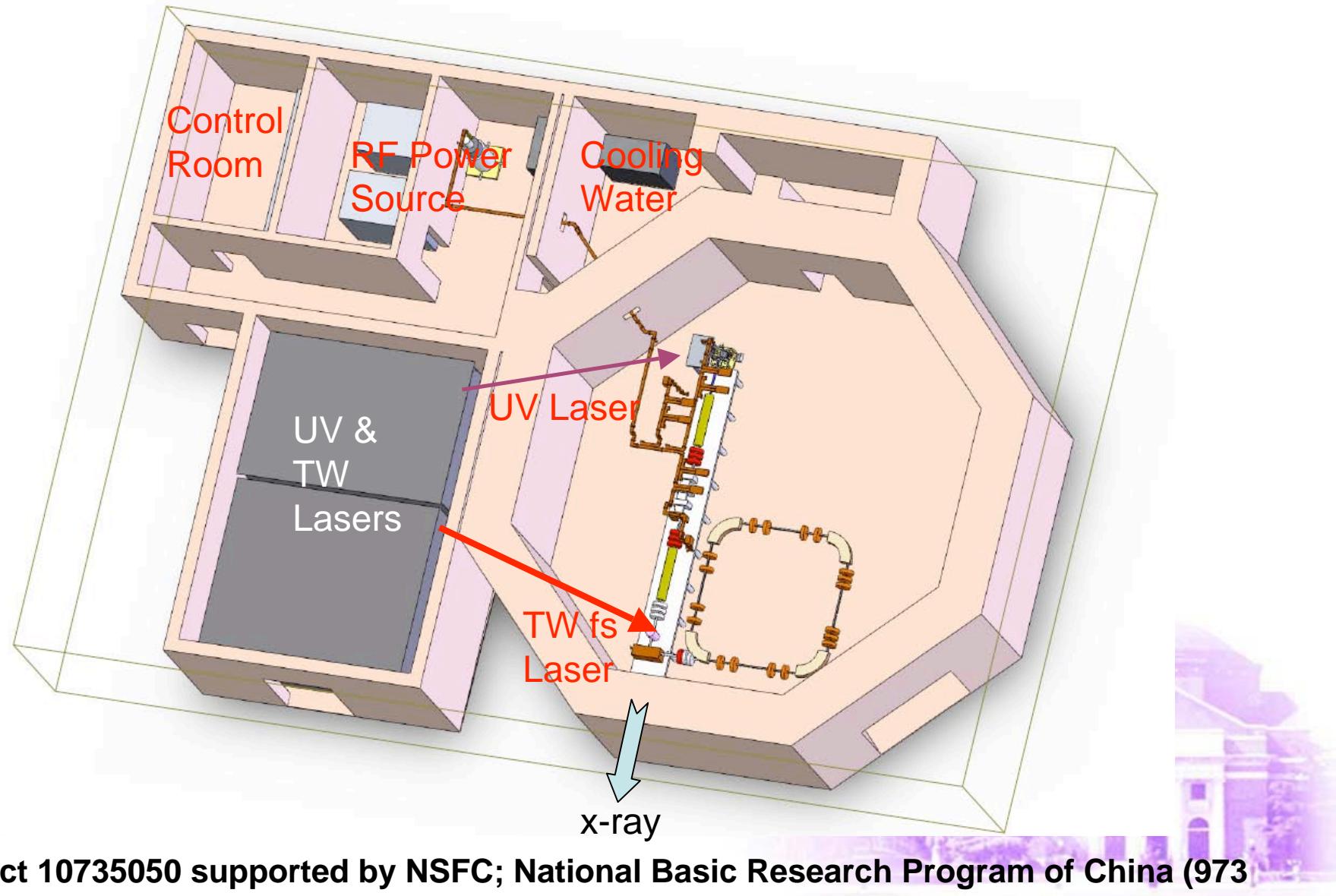


2 The Measured Scattering X-ray Signal

Pulse Width: 5.8 ns Amplitude: 6.5 mV
Efficiency of the Detector: ~5% Working Voltage: 1400 V
Amplified Factor: $\sim 2 \times 10^5$ Photon Number per Pulse: $\sim 1.7 \times 10^4$

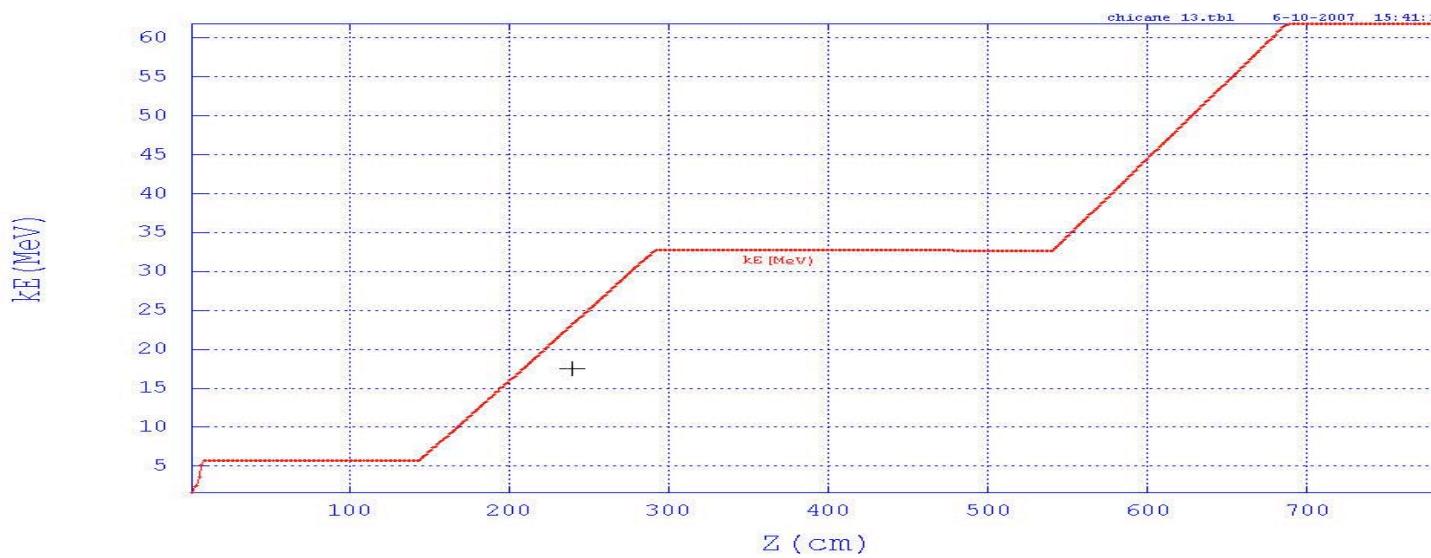
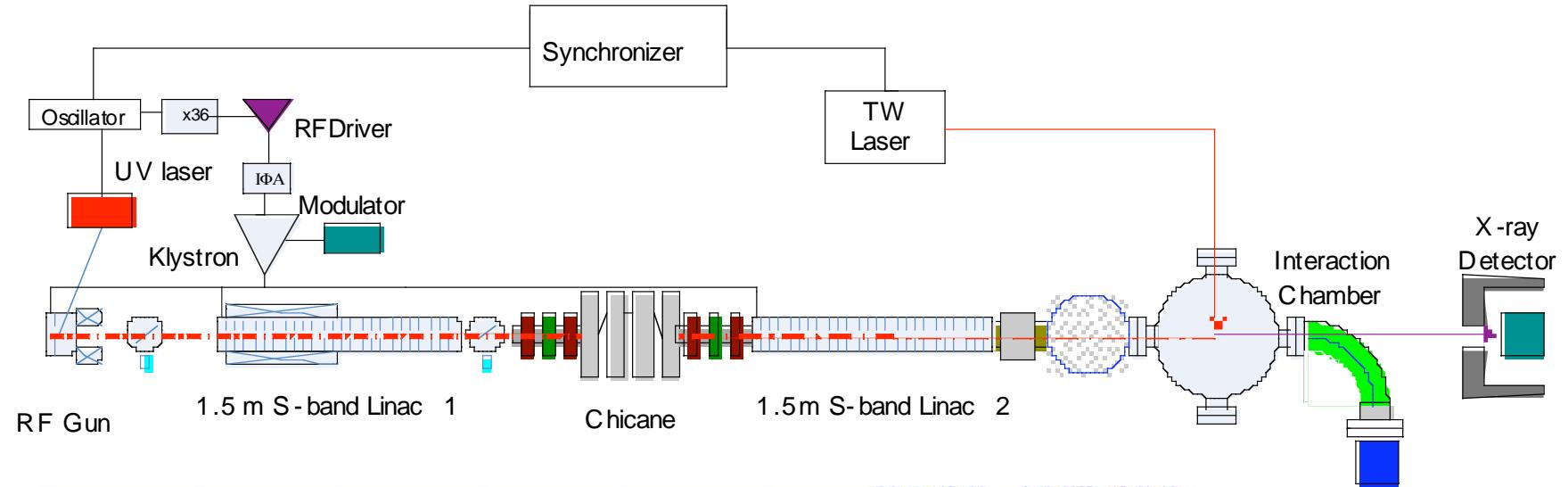


3 Tsinghua Thomson Scattering X-ray Source (TTX)



*Project 10735050 supported by NSFC; National Basic Research Program of China (973 Program) (Grant No. 2007CB815102)

3 TTX- One Design



Electron
Energy
simulated by
PARMELA

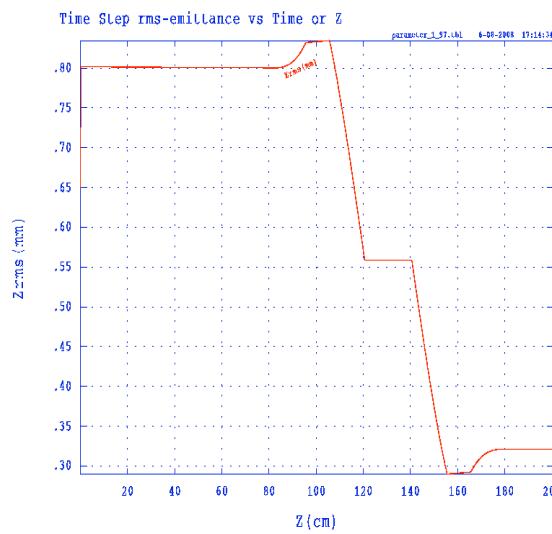
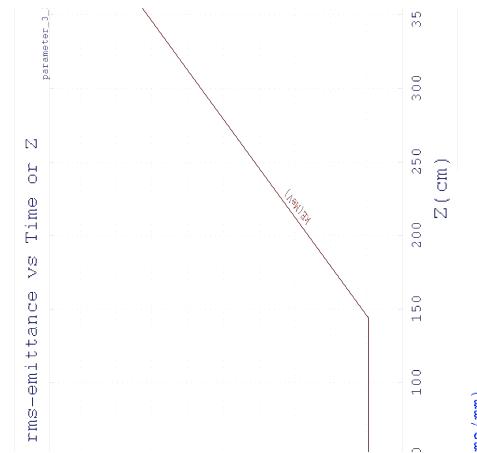
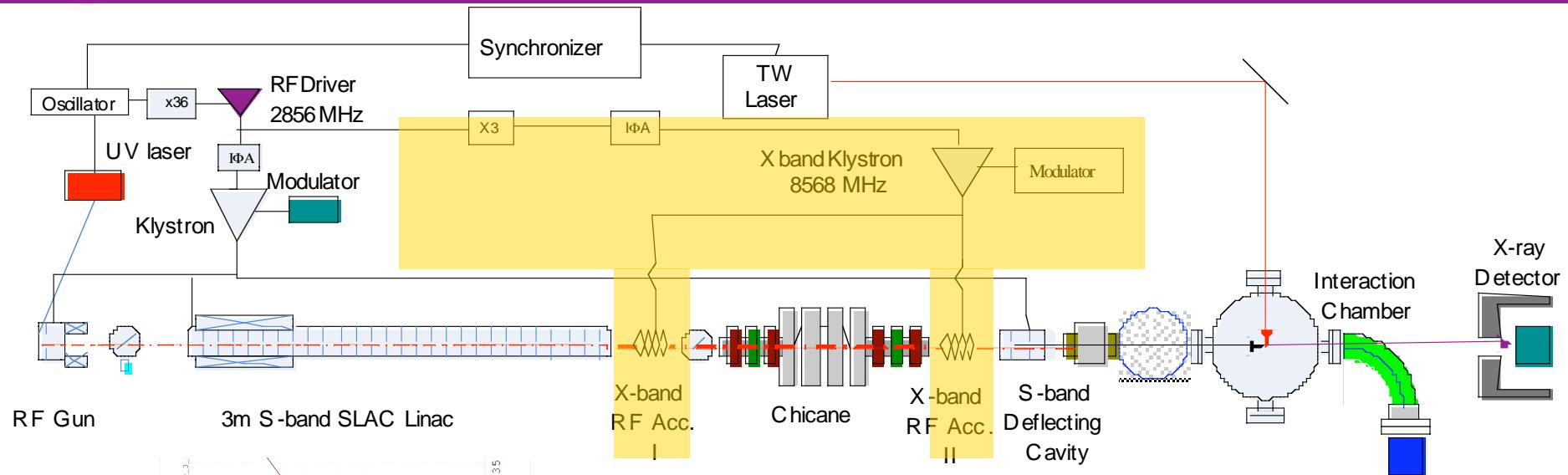
3 TTX-Simulated Bunch Length and Emittance



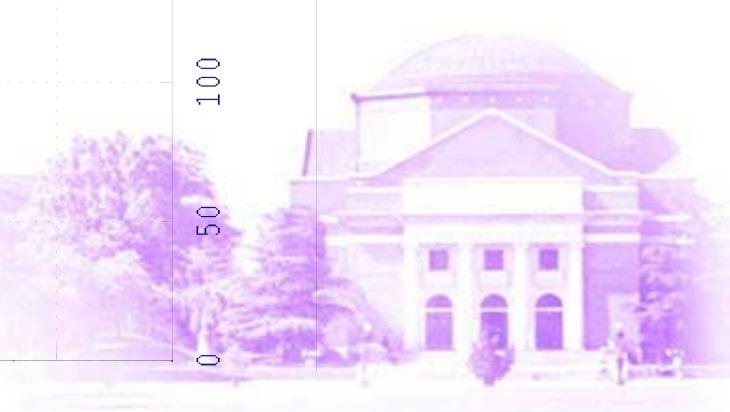
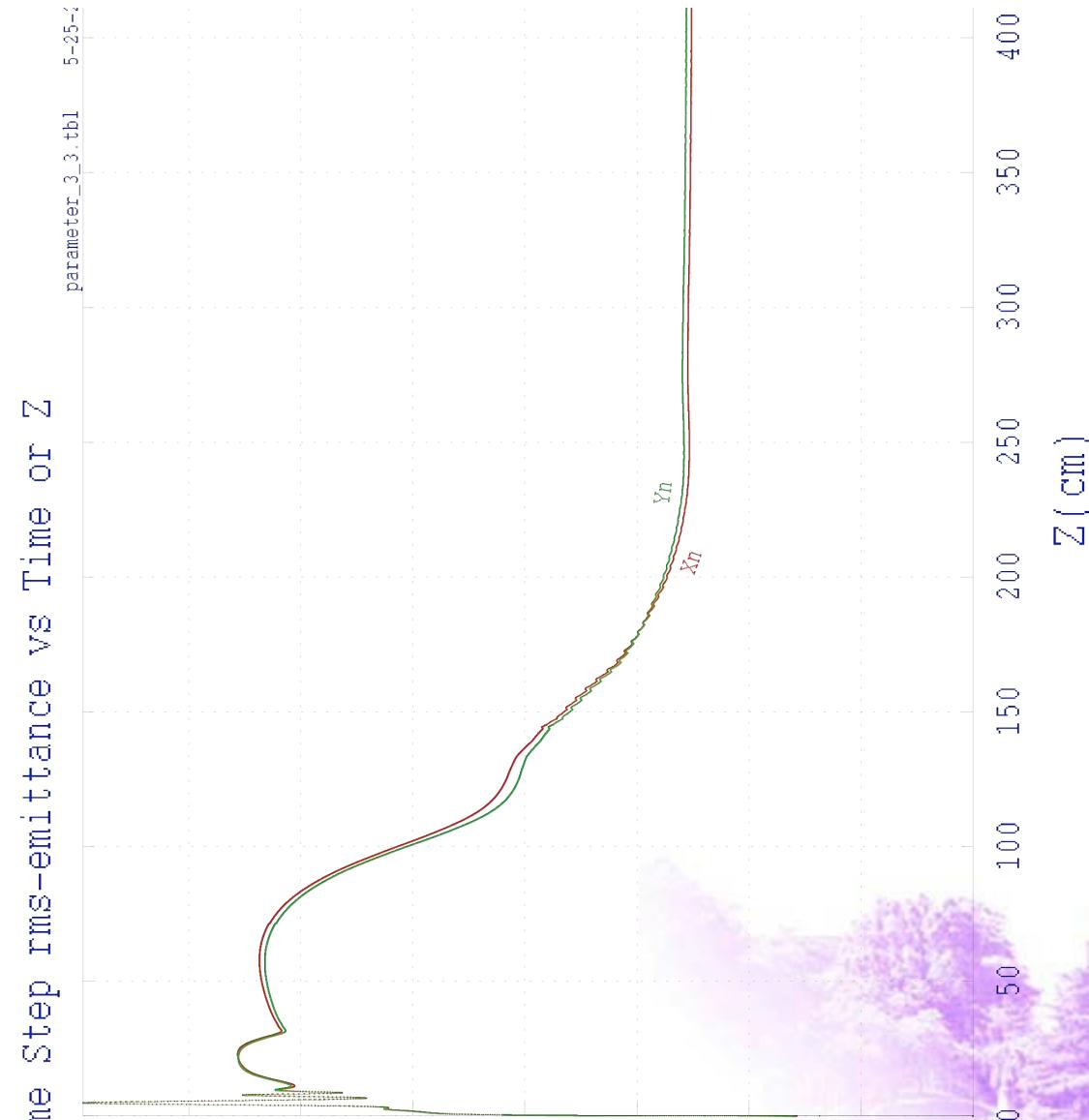
3 TTX-Simulated Parameters

Laser beam	
Wavelength	800 nm
Pulse Energy (Power)	600mJ (20TW)
Pulse duration	30 fs
Focal spot radius	~0.050 mm
Electron beam	
Energy	50 MeV
Bunch duration	1 ps
Charge/microbunch	1 nC
RMS Normal Emittance	$2 \pi \cdot \text{mm} \cdot \text{mrad}$
Beam radius	0.1 mm
x-ray pulse	
Photon energy	30(90deg)~59.5(180deg) keV
Pulse duration	350(90deg)~1000(180deg) fs
Number of photons	2.2X10 ⁶ (90deg)~1.3X10 ⁷ (180deg),

3 TTX- The Latest Design



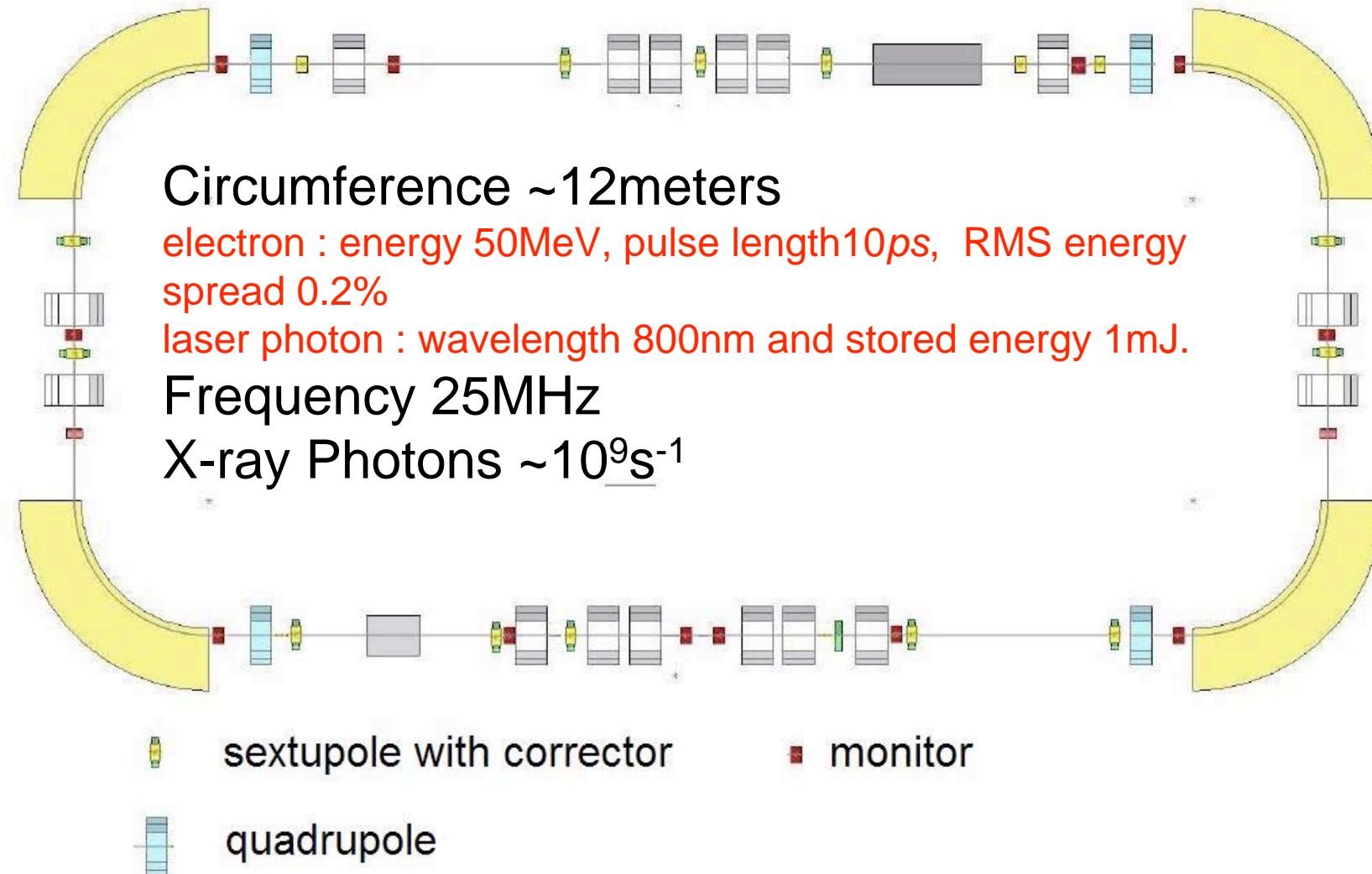
3 TTX- Emittance



3 TTX-Simulated Parameters

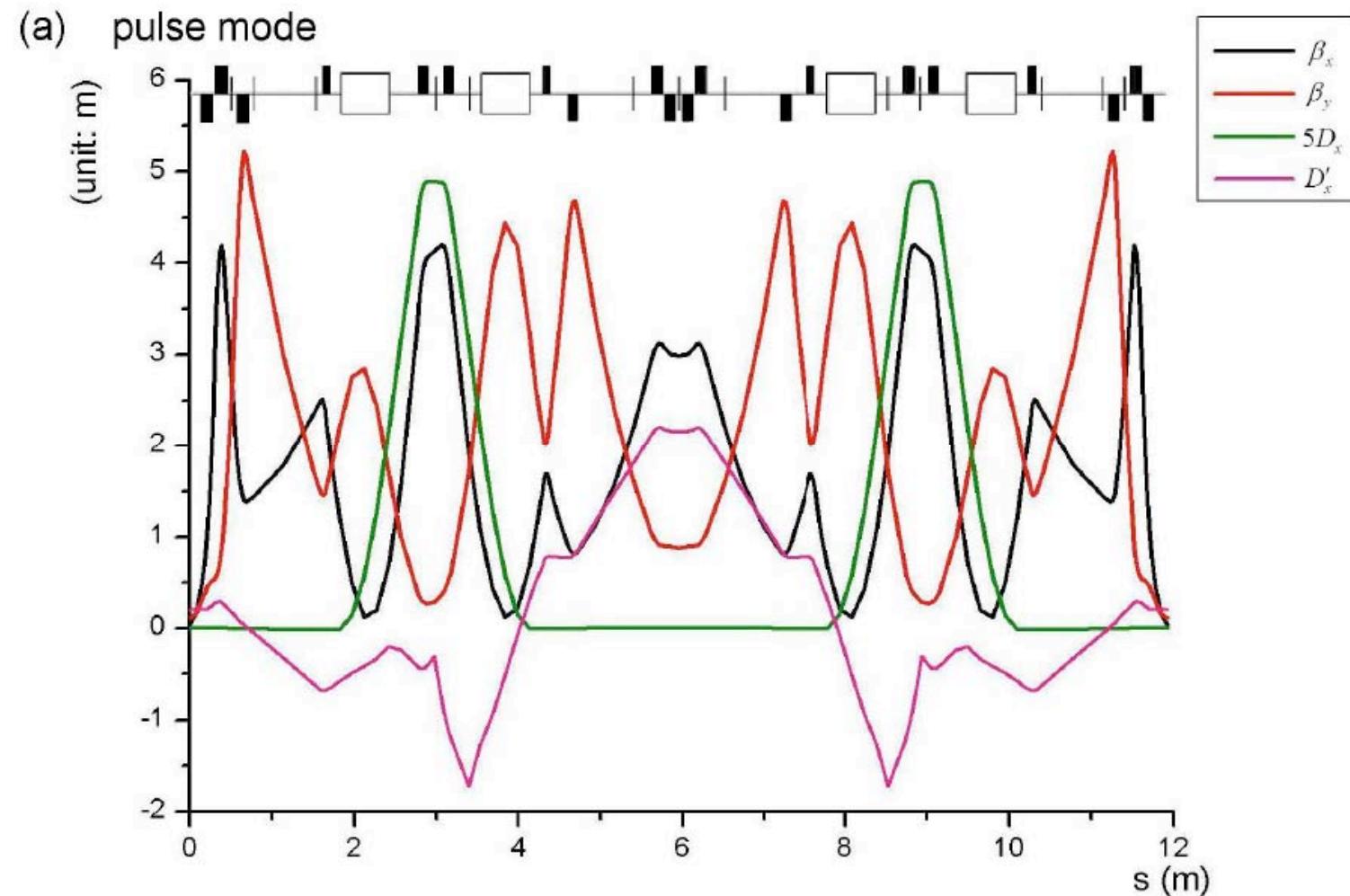
Laser beam	
Wavelength	800 nm
Pulse energy	500 mJ
Pulse duration	30 fs
Focal spot radius	~0.031 mm
Electron beam	
Energy	45 MeV
Bunch duration	1 ps
Charge/microbunch	0.7 nC
Energy spread	0.33%
Beam radius	0.03 mm(x),0.025mm(y)
x-ray pulse	
Photon energy	24(90deg)~48(180deg) keV
Pulse duration	160(90deg)~1000(180deg) fs
Number of photons	8.4X10 ⁶ (90deg)~5.5X10 ⁷ (180deg),

3 TTX- Mini SR



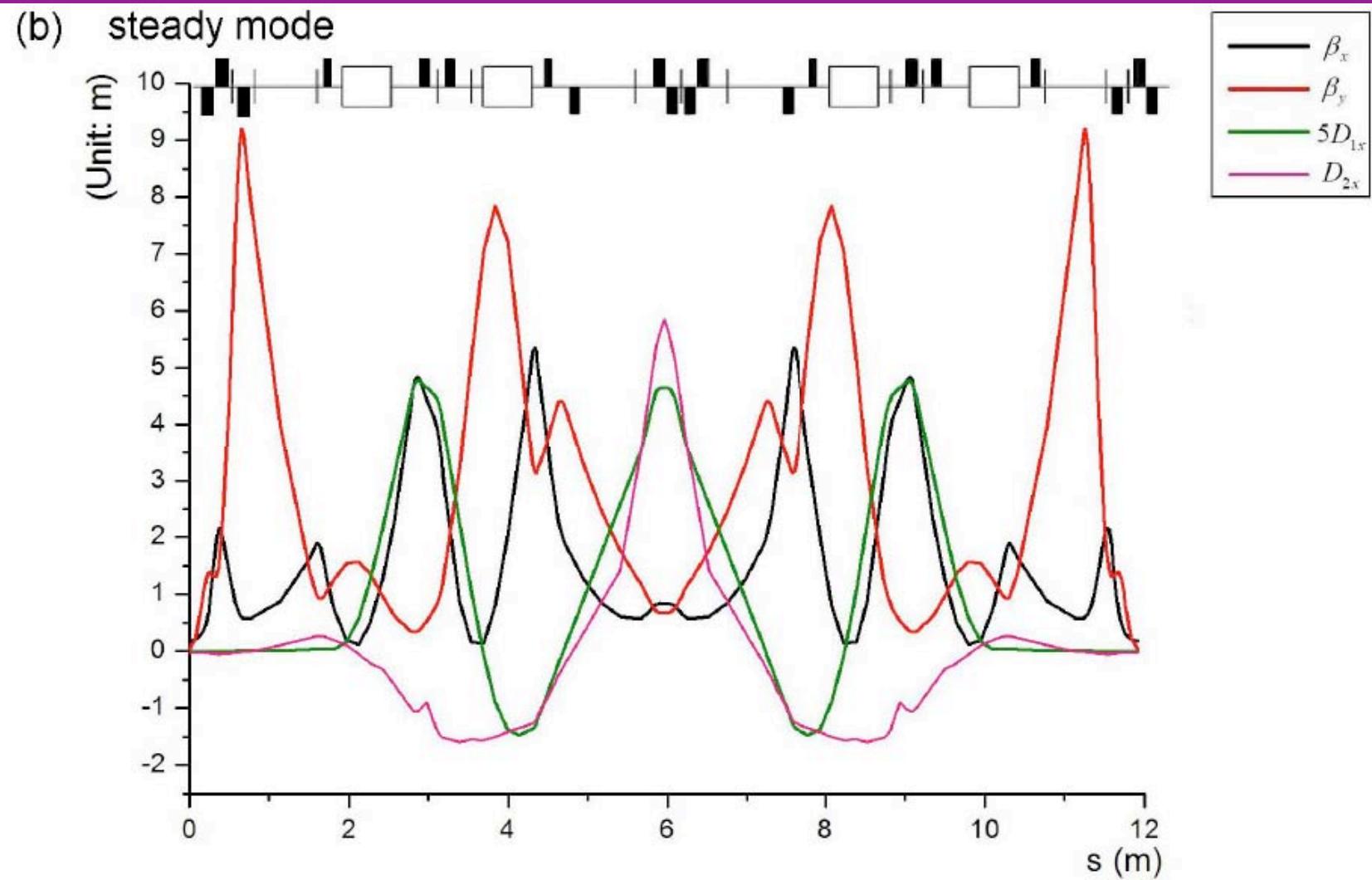
Courtesy from Peicheng Yu, et al, Optics for the lattice of a compact storage ring for Compton X-ray source, Chinese Physics C (HEP & NP) Vol 32, 2008

3 TTX- Mini SR



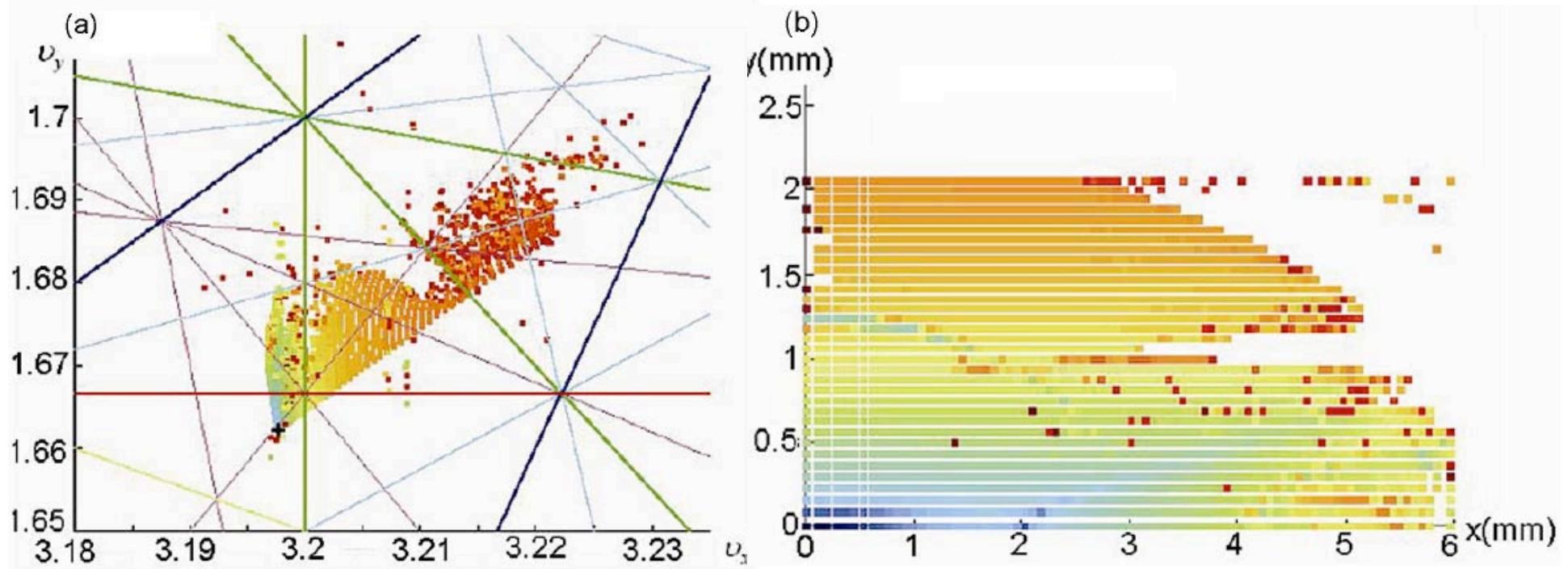
For the pulse mode, the transverse emittance right before the beam is dumped is $2.2 \times 10^{-7} \text{ m.rad}$, the energy spread is 0.3%.

3 TTX- Mini SR



As for the steady mode, the equilibrium transverse emittance is $1.2 \times 10^{-6} \text{ m.rad}$,
the equilibrium energy spread is 4.4%

3 TTX- Mini SR

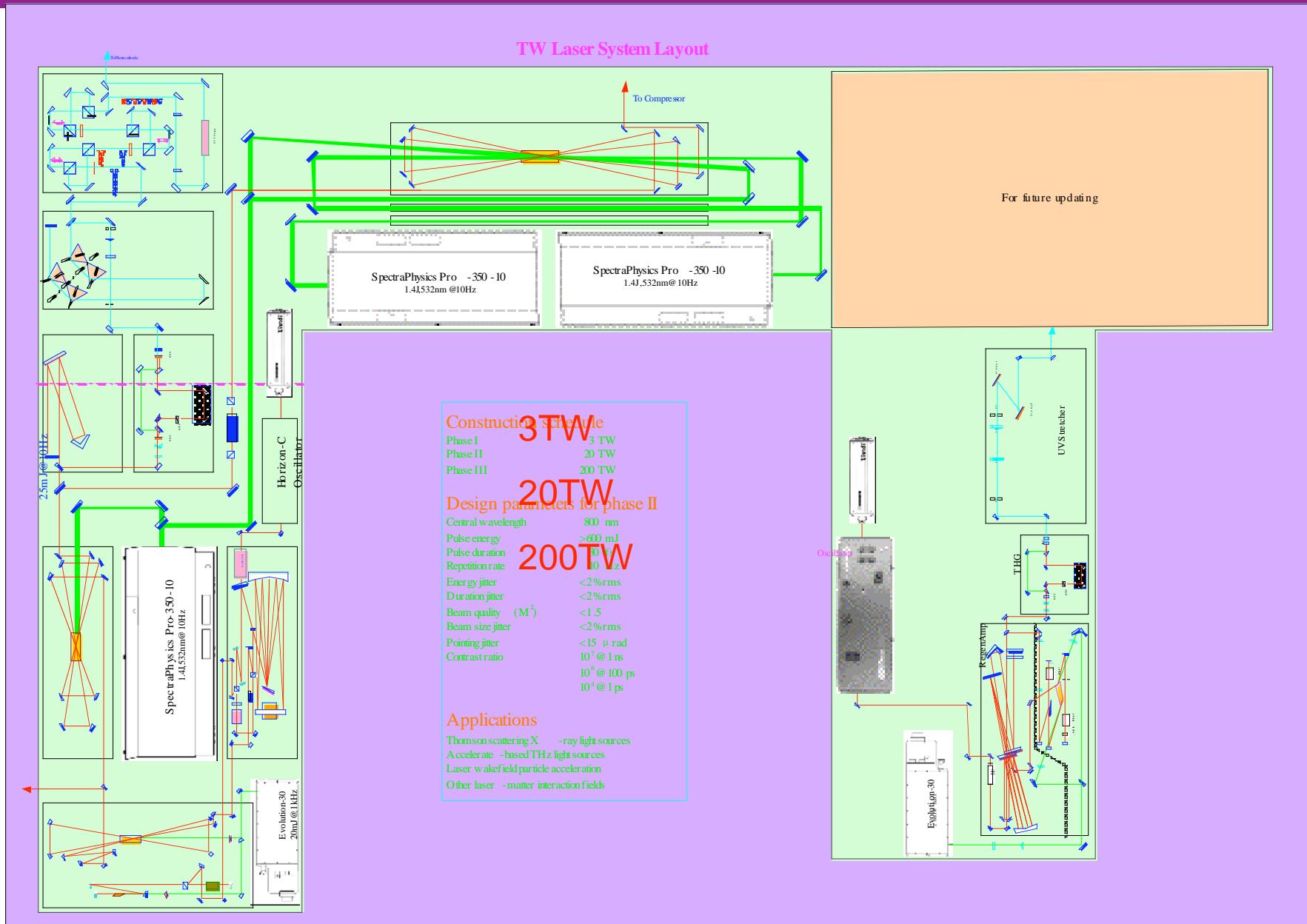


The working point of the steady mode is $(Q_x; Q_y) = (3:197; 1:662)$, which is close to the 5th order resonance. The dynamics is greatly influenced by the node $(3:211; 1:685)$, which limits the vertical DA. Moreover, the 5th order resonance may be further excited by the magnet errors. Nevertheless, the DA horizontal size is sufficient for the steady mode.

3 TTX- Optics Parameters of the LESR

Parameters	Pulse	Steady
Tunes		
Horizontal	2.87	3.197
Vertical	1.69	1.662
Beta function at IP		
Horizontal, <i>cm</i>	4.9	17.5
Vertical, <i>cm</i>	11.5	3.0
Momentum compaction factor	0.0789	0.007
Energy acceptance	3.4%	$\geq 8\%$
Horizontal beam size at IP		
With IBS (400,000 turns), <i>μm</i>	104	452
Natural chromaticity		
Horizontal	-6.06	-6.49
Vertical	-4.09	-6.14

3 TTX in Progress-Laser System



3 TTX in Progress-Laser System

800nm, 3TW, 30fs

266nm, 1mJ, 30fs



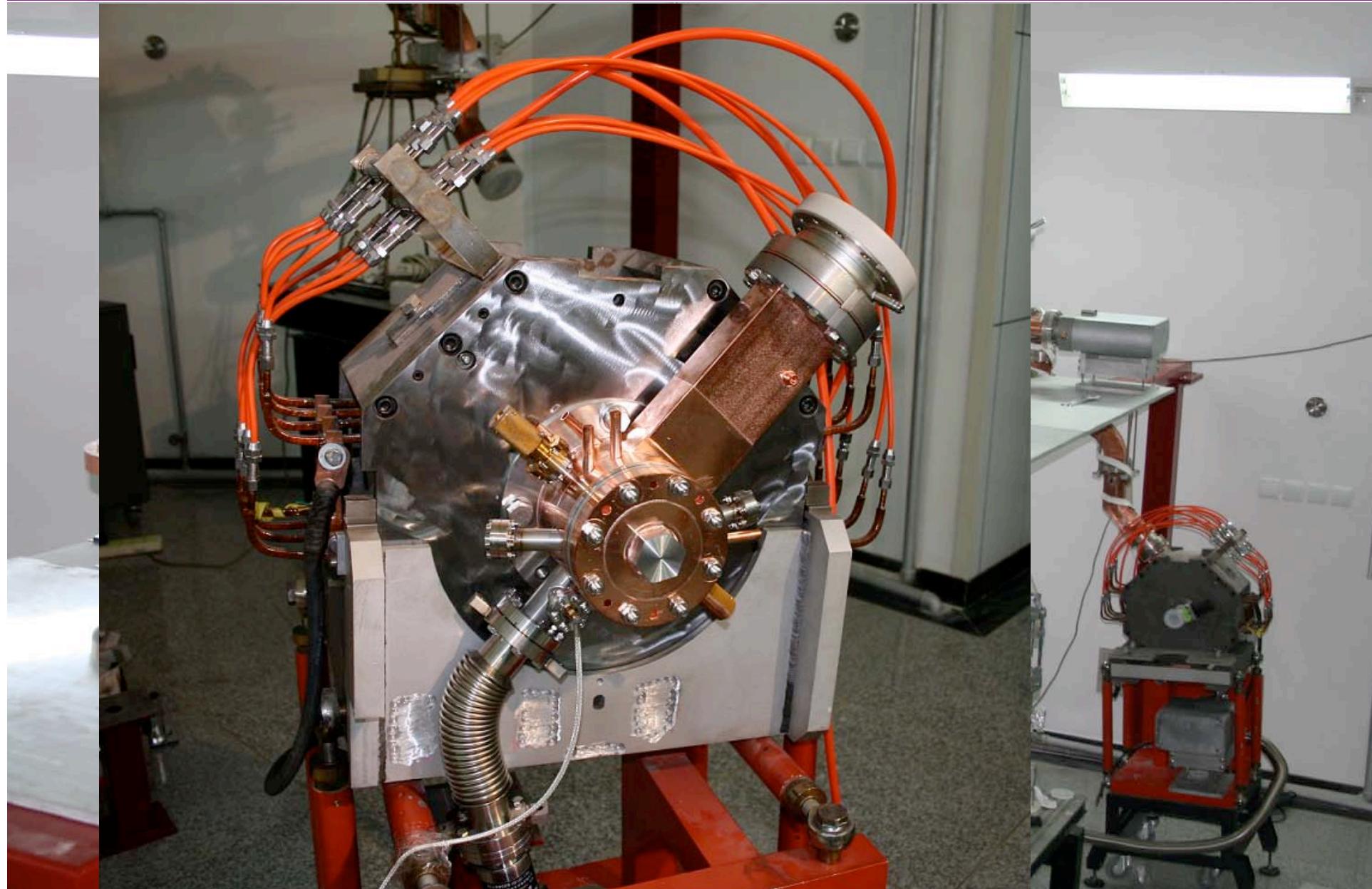
3 TTX in Progress-50MW RF Power Source



3 TTX in Progress-50MW RF Power Source



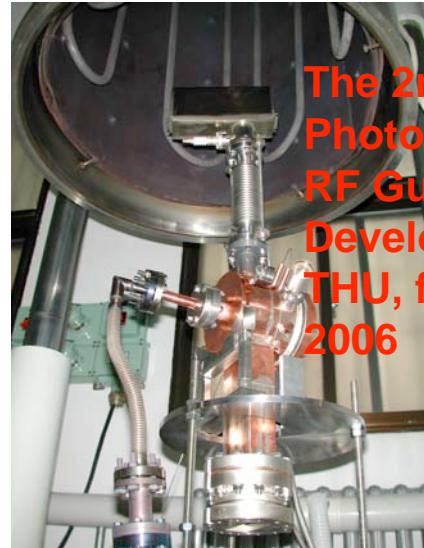
3 TTX in Progress-Installation of New RF Gun Finished



4 Photocathode RF Gun Studies in THU



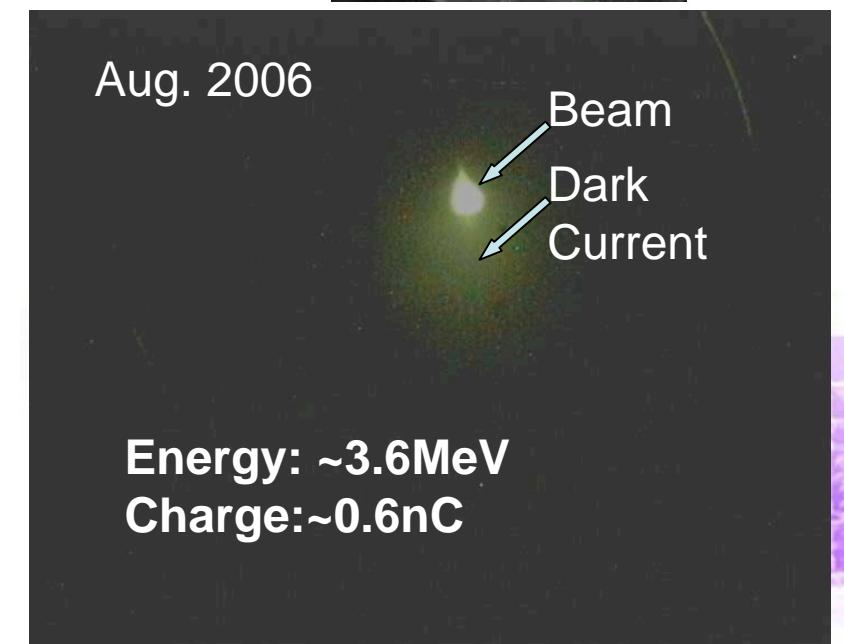
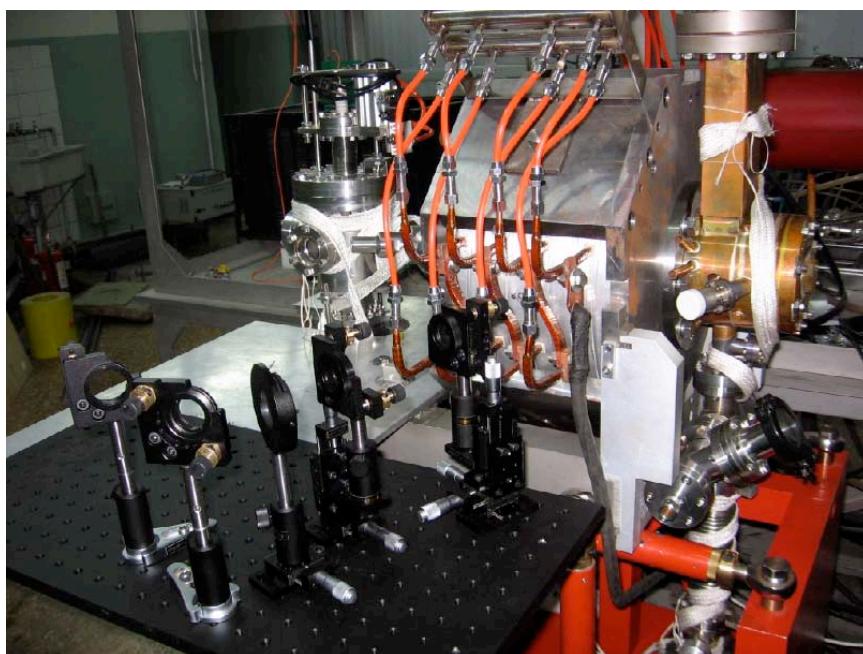
The 1st
Photocathode
RF Gun
Developed in
THU, 2006



The 2nd
Photocathode
RF Gun
Developed in
THU, for SSRF
2006

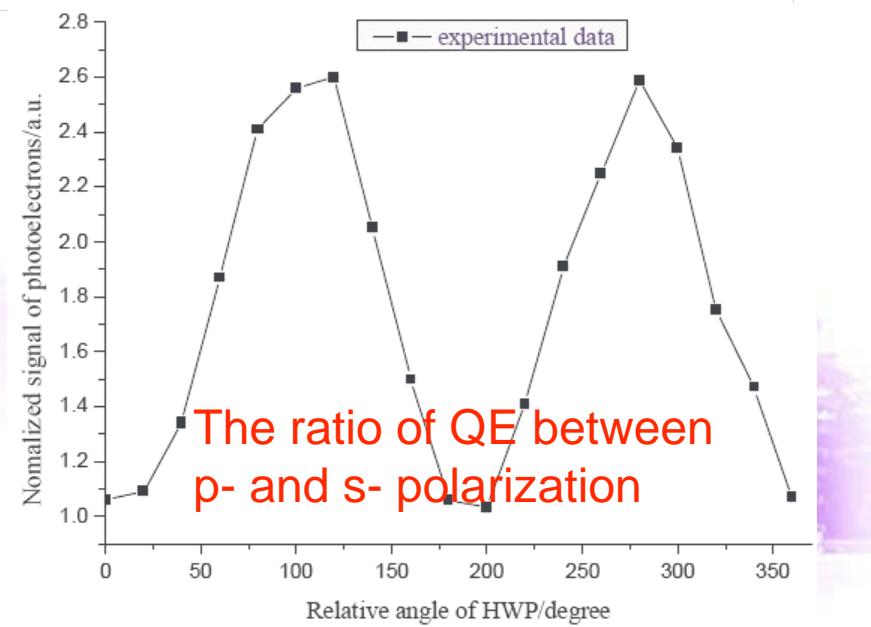
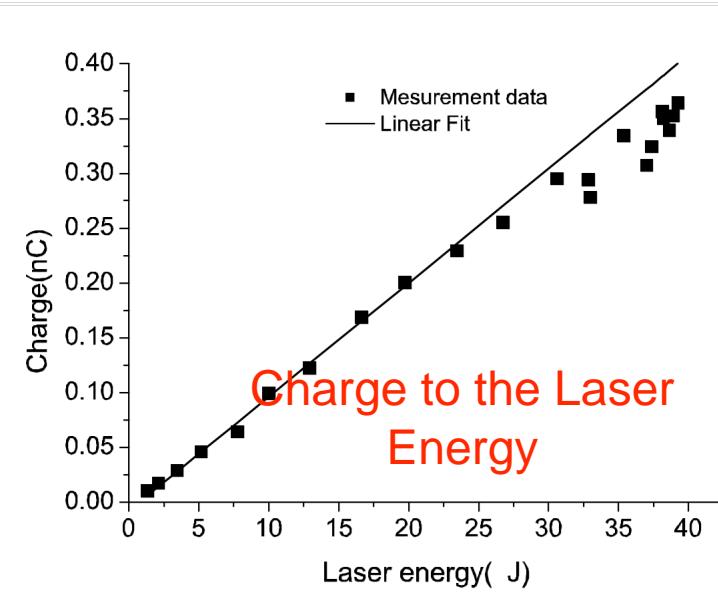
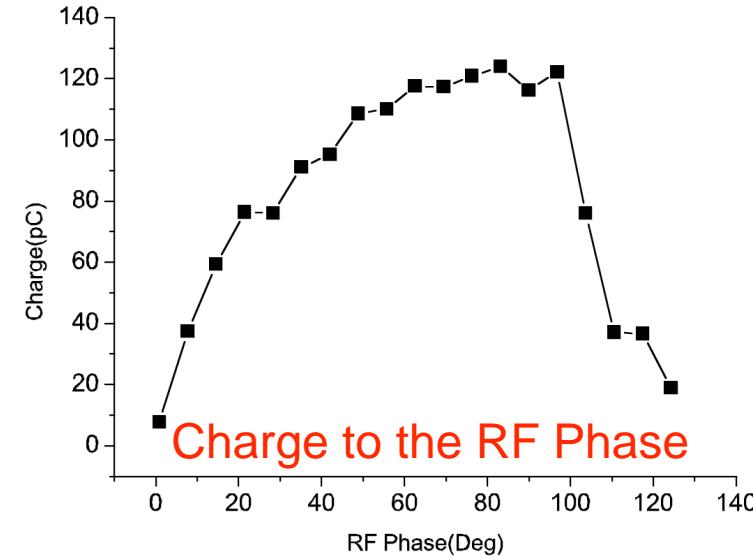
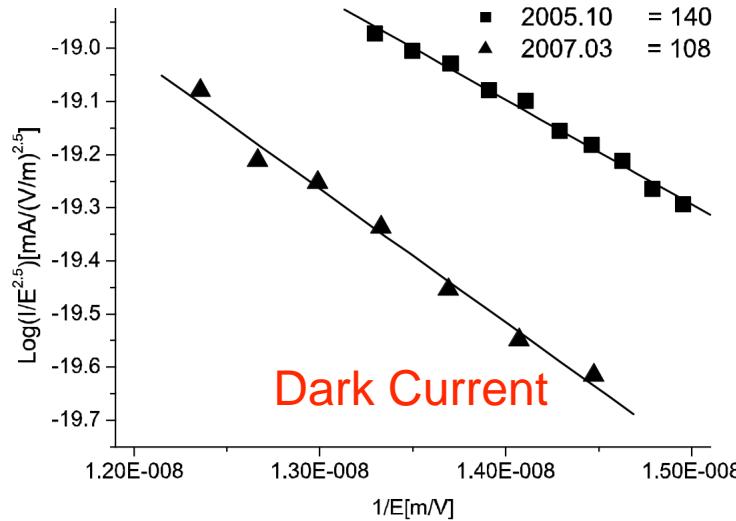


The 3rd
Photocathode
RF Gun
Developed in
THU, for BNL
2007



Energy: ~3.6MeV
Charge:~0.6nC

4 Photocathode RF Gun Experiments in THU



4 Laser Pulse Measurement

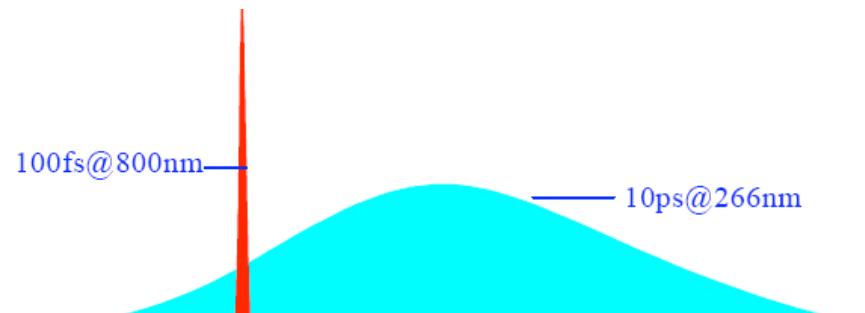


图 4.18 利用基频光对紫外光的采样扫描实现时间波形测量原理

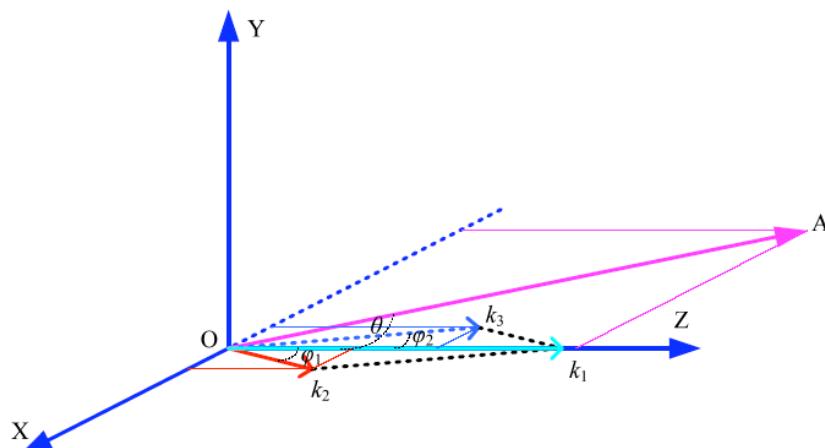


图 4.19 非共线差频产生相位匹配条件

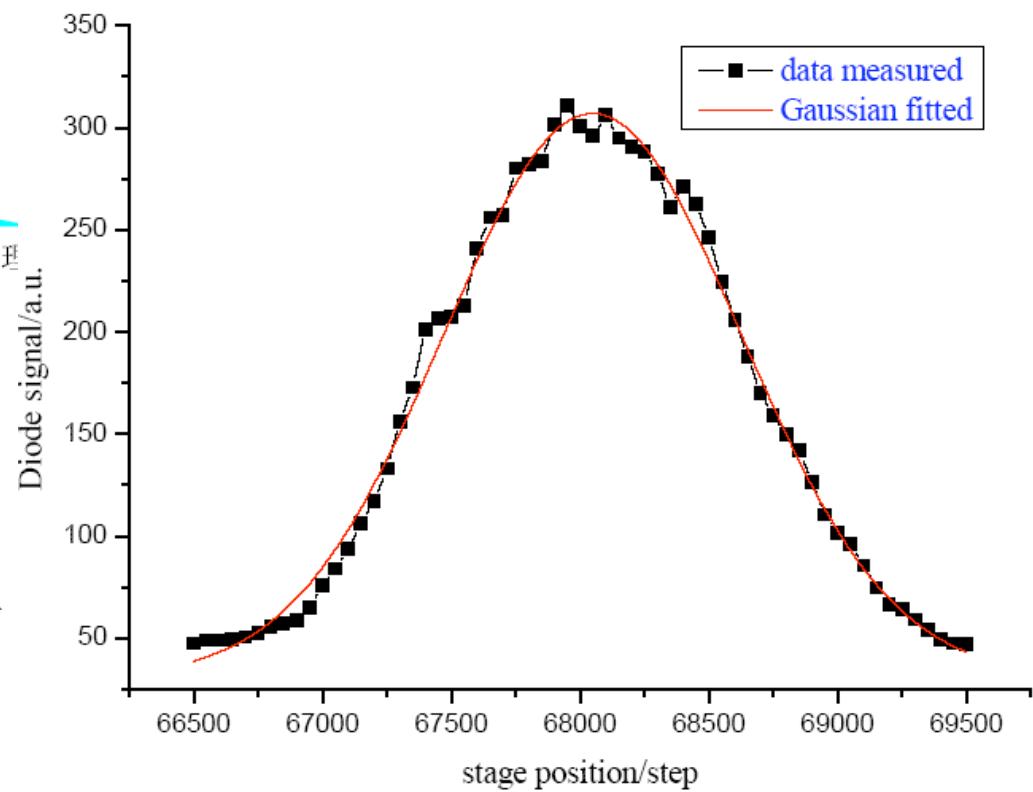
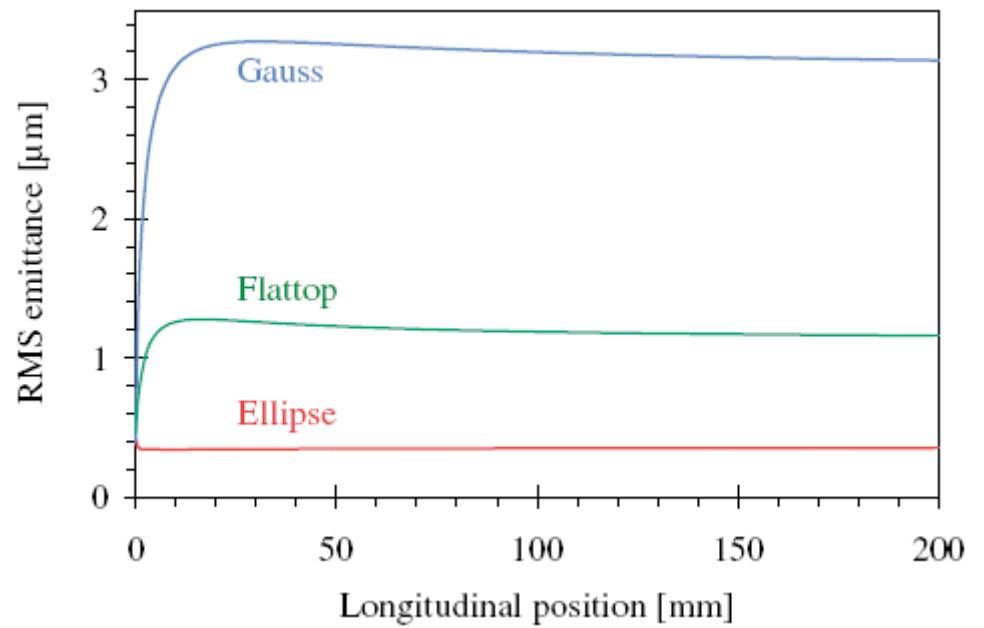
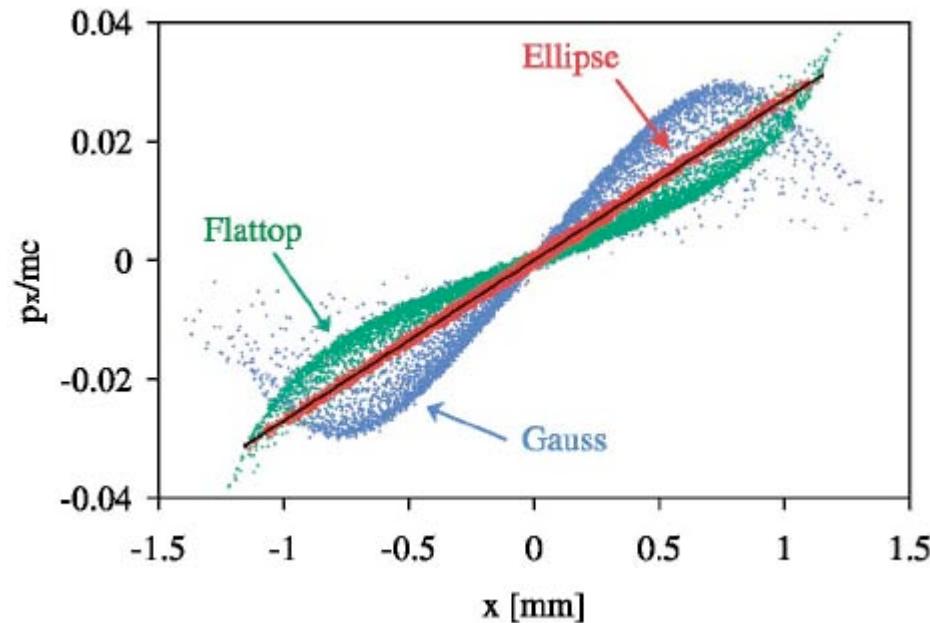


图 4.21 紫外激光互相关测量结果曲线

4 Longitudinal distribution and the emittance



Courtesy of O. J. Luiten, et al. PRL, 93, 094802, 2004

4 Longitudinal shaping of the laser pulse

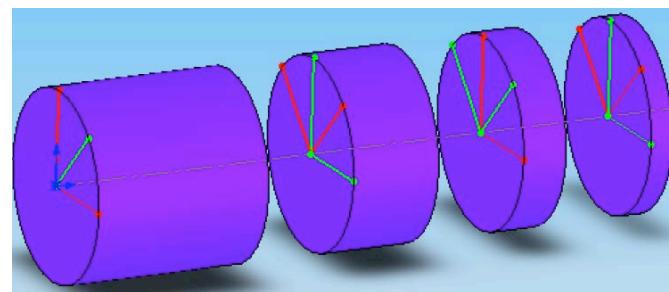
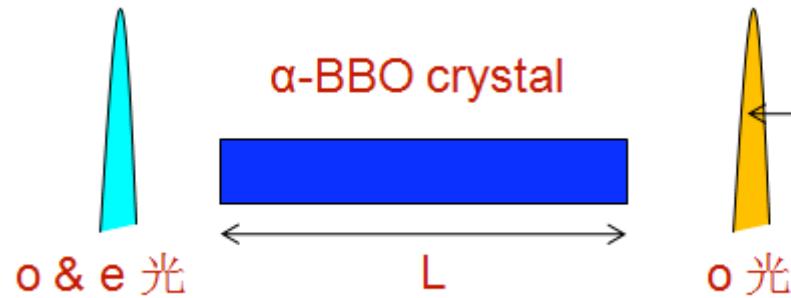


图 4.15 序列 α-BBO 晶体示意图

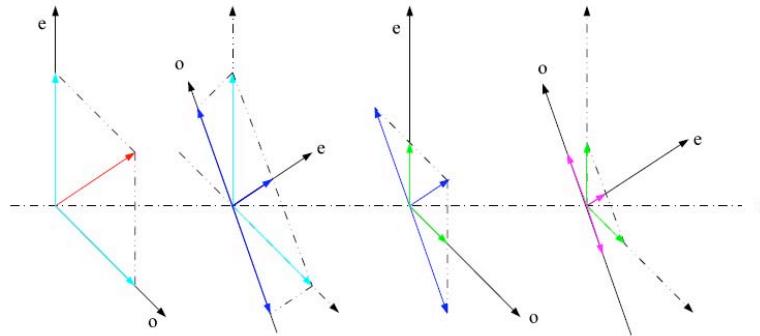


图 4.16 各级子脉冲偏振方向示意图

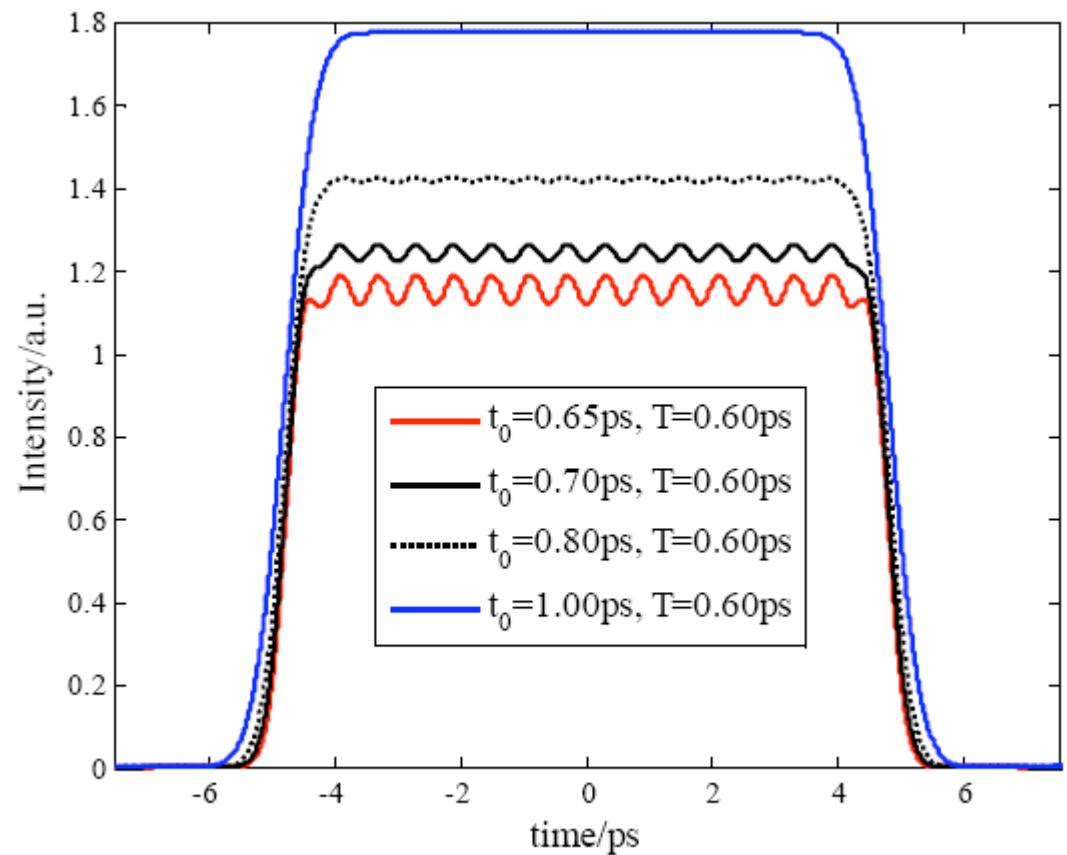


图 4.14 不同参数下 16 个高斯脉冲的堆积结果

4 Transverse shaping of the laser pulse

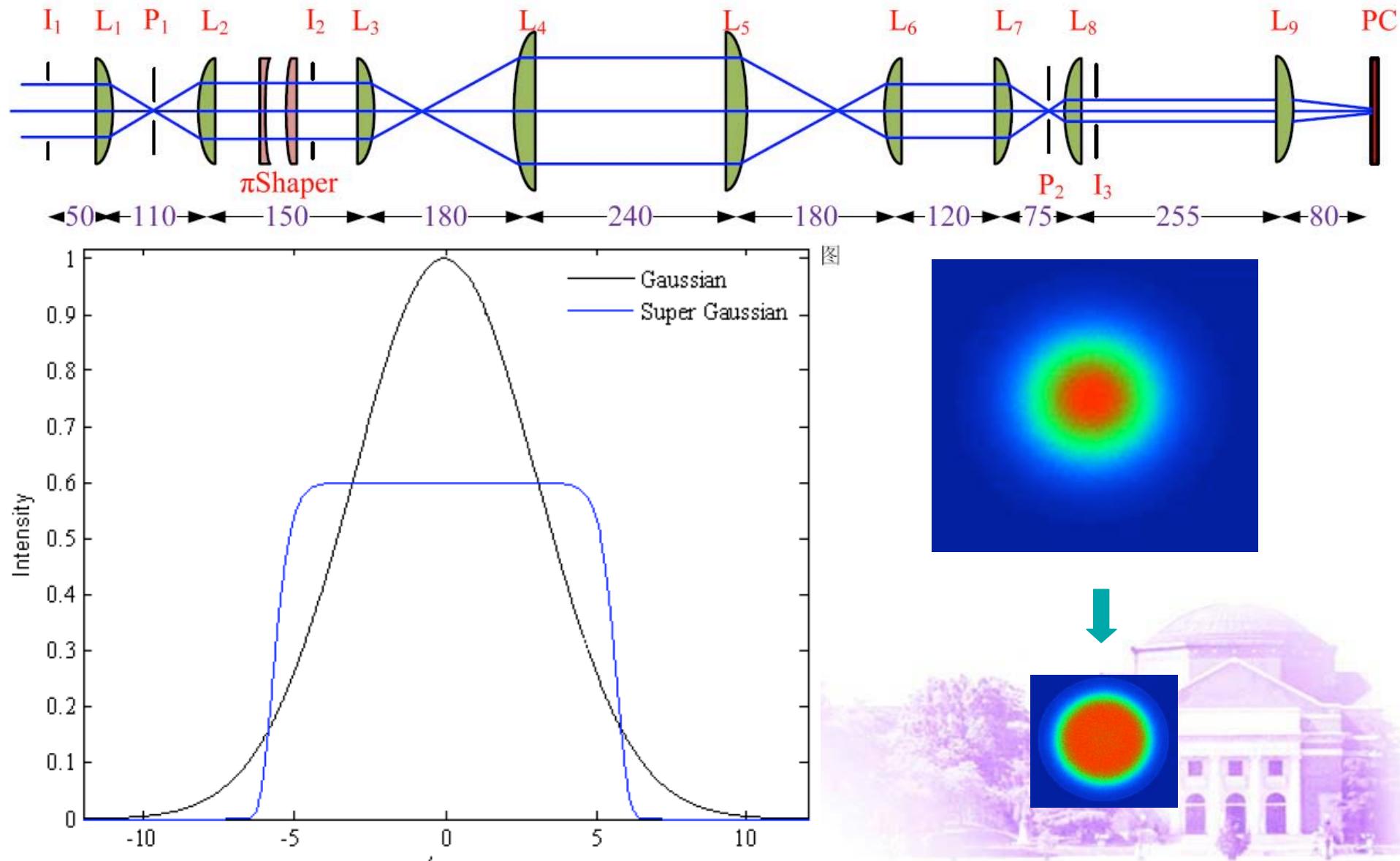
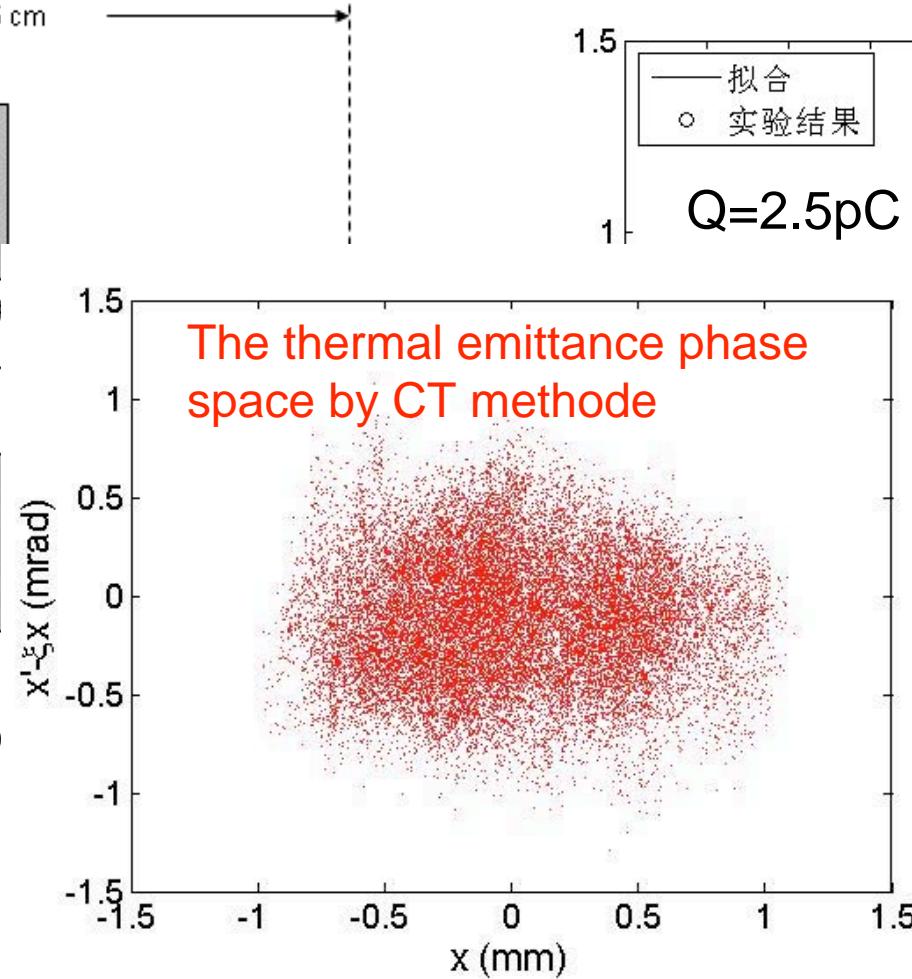
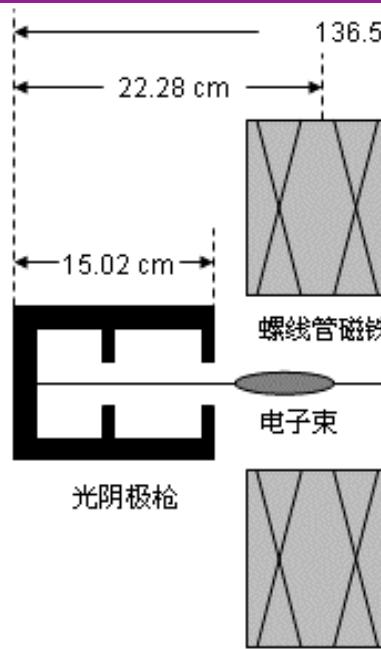


图 3.5 高斯光束整形为 16 阶超高斯分布

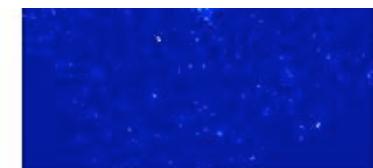
4 Thermal Emittance Measurement



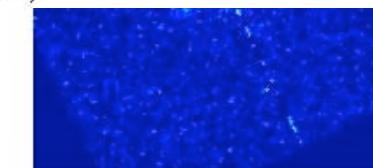
Beam Spot Size f



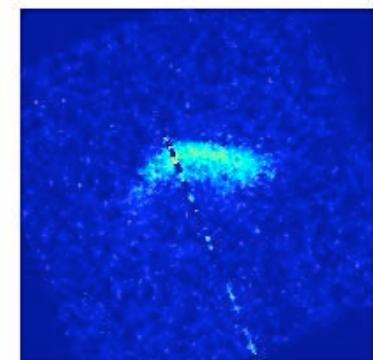
$I = 74 \text{ A}$



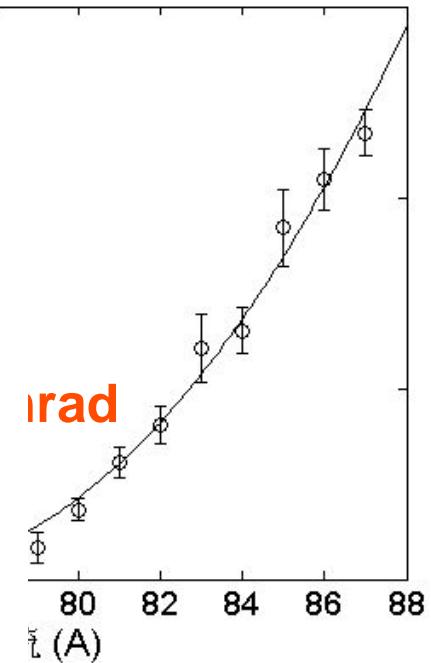
$I = 78 \text{ A}$



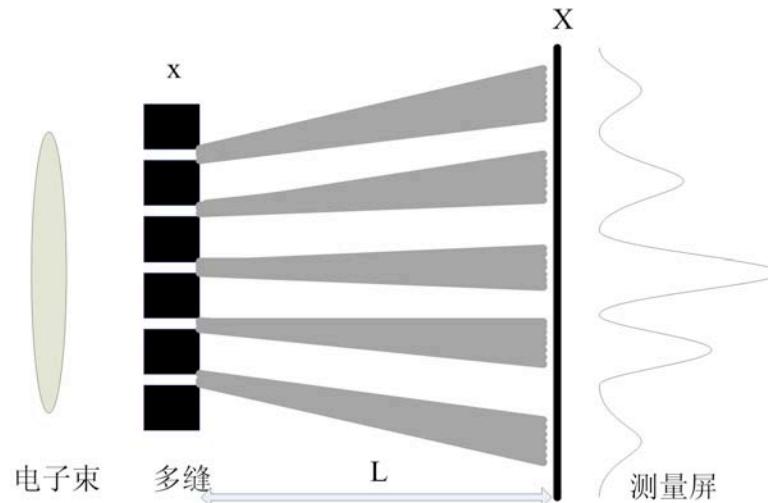
$I = 82 \text{ A}$



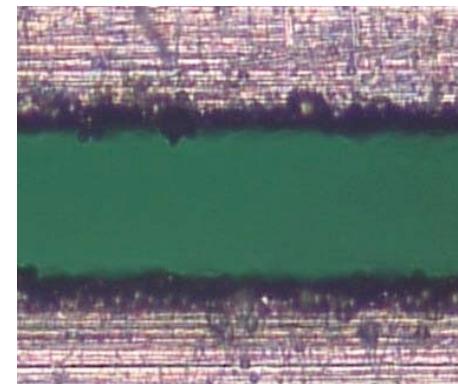
$I = 86 \text{ A}$



4 Emittance Measurement by Multi-slit



$$\sigma_x'' - \frac{\varepsilon_n^2}{\gamma^2 \sigma_x^3} - \frac{I}{\gamma^3 I_A (\sigma_x + \sigma_y)} = 0$$

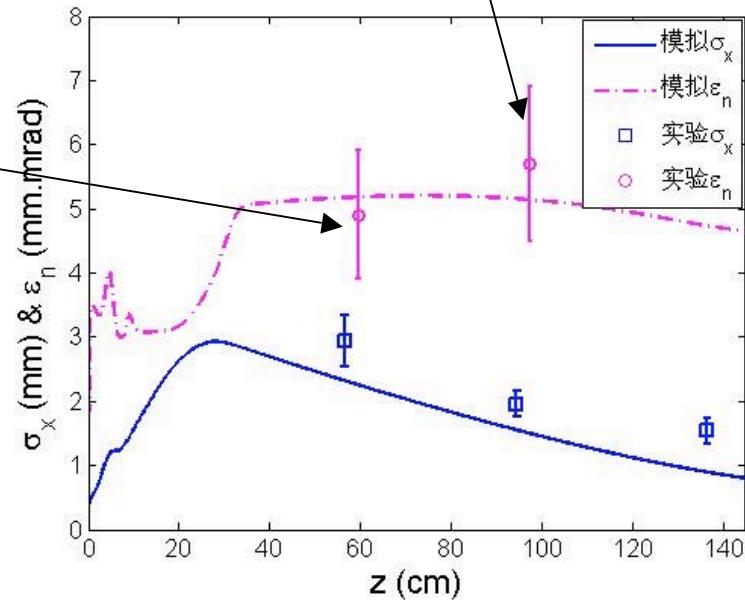
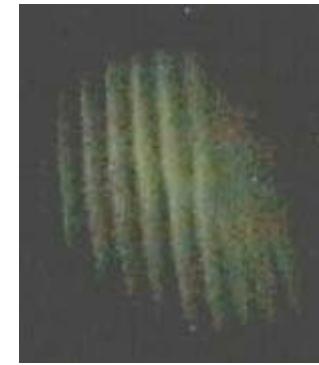
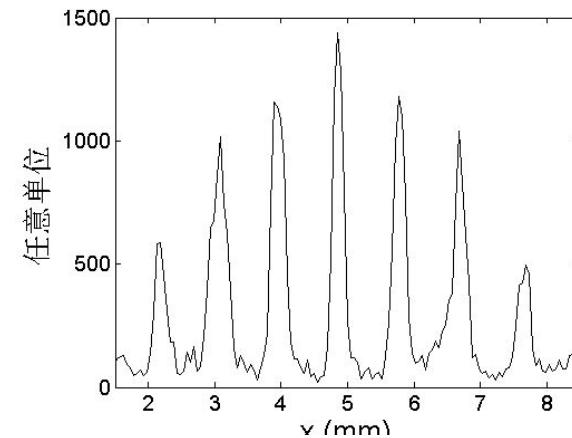
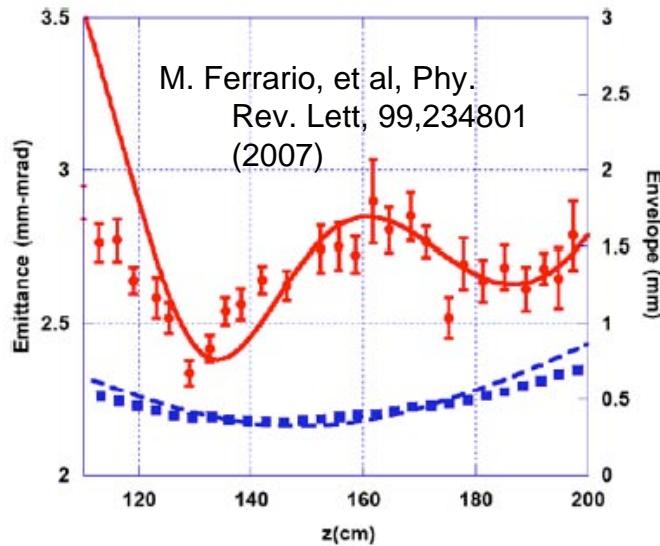


- 缝宽 80 μm
- 缝厚 2 mm
- 漂移距离 30~40cm
- 缝间距 0.8~1mm
- 测量屏 Ce:YAG



4 Emittance Measurement by Multi-slit

- $Q = 200 \text{ pC}$
- Bunch Length 5 ps (FWHM)
- $\varphi = 30^\circ$
- $E = 2.6 \text{ MeV}$

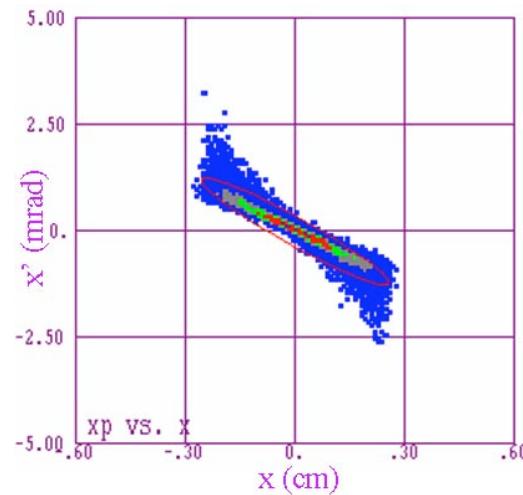


4 Emittance Measurement by Multi-slit

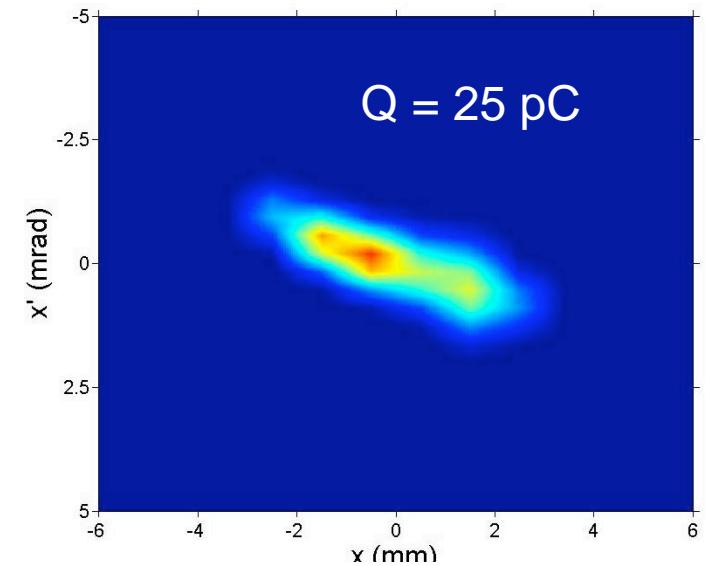
- Space Charge Effect



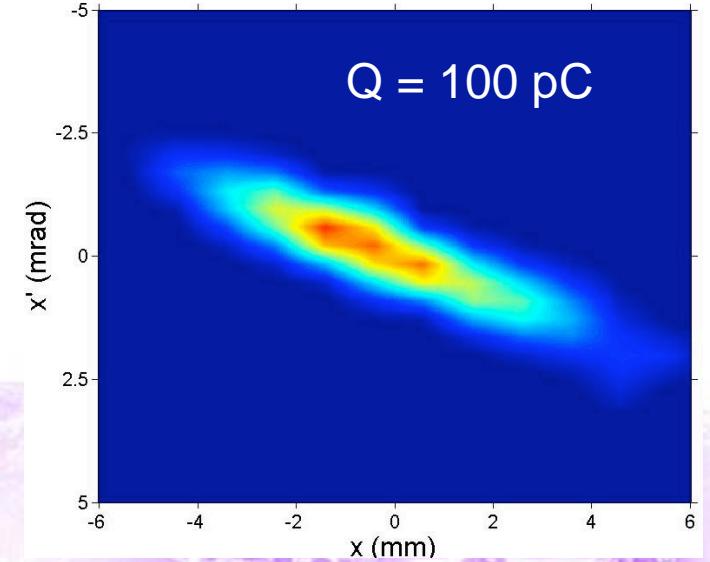
Original Images



Parmela



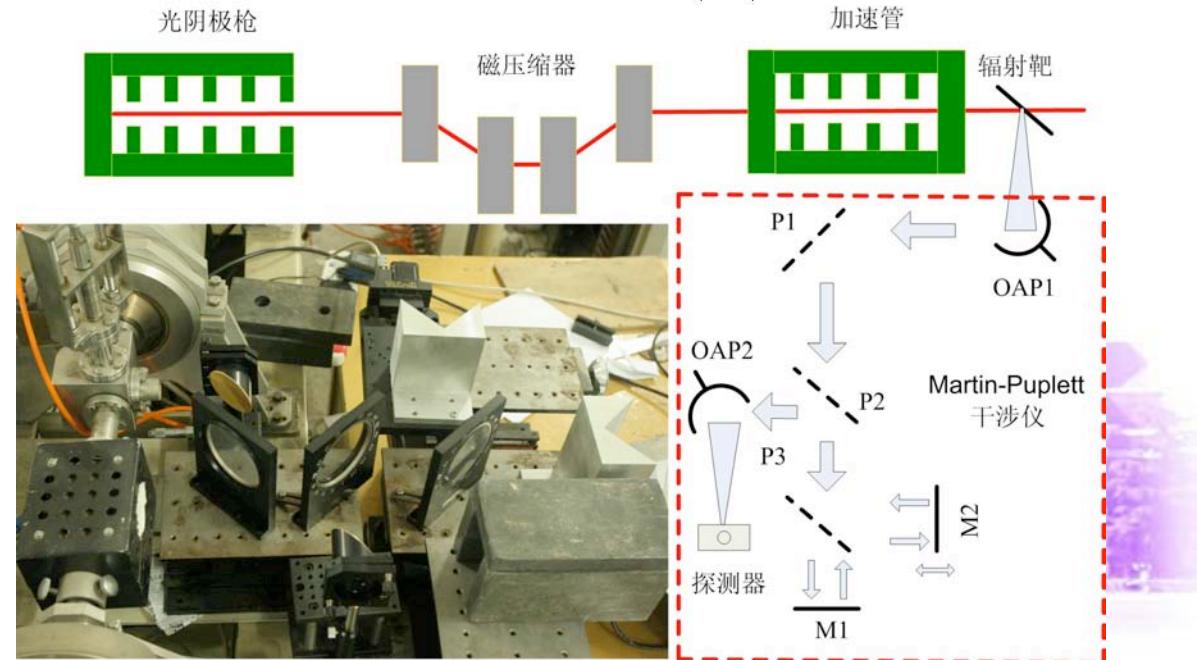
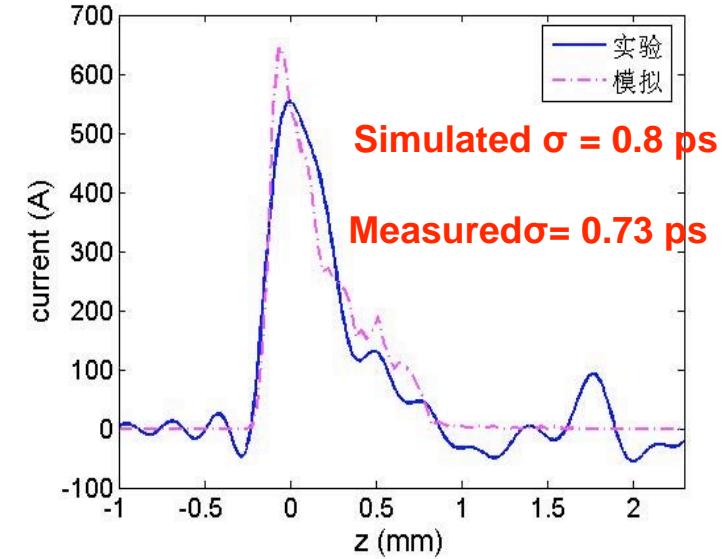
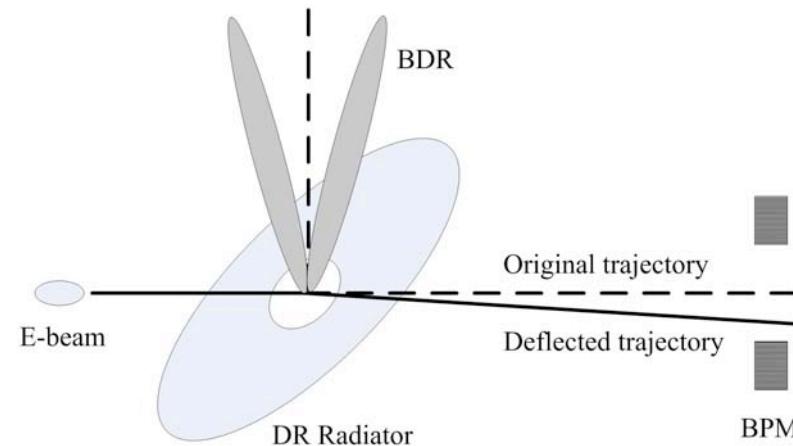
$Q = 25 \text{ pC}$



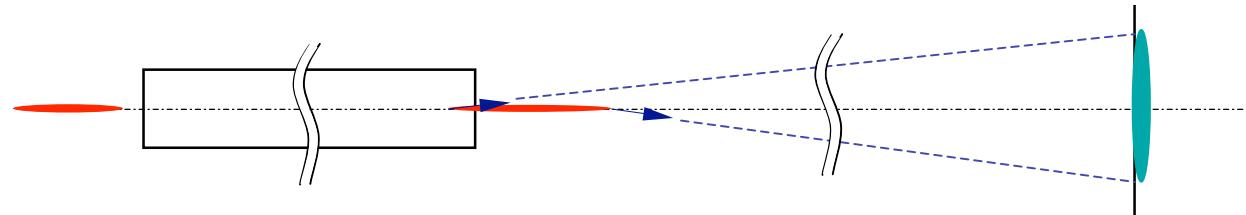
$Q = 100 \text{ pC}$

Experimental Results

4 Bunch Length Measurement by CDR



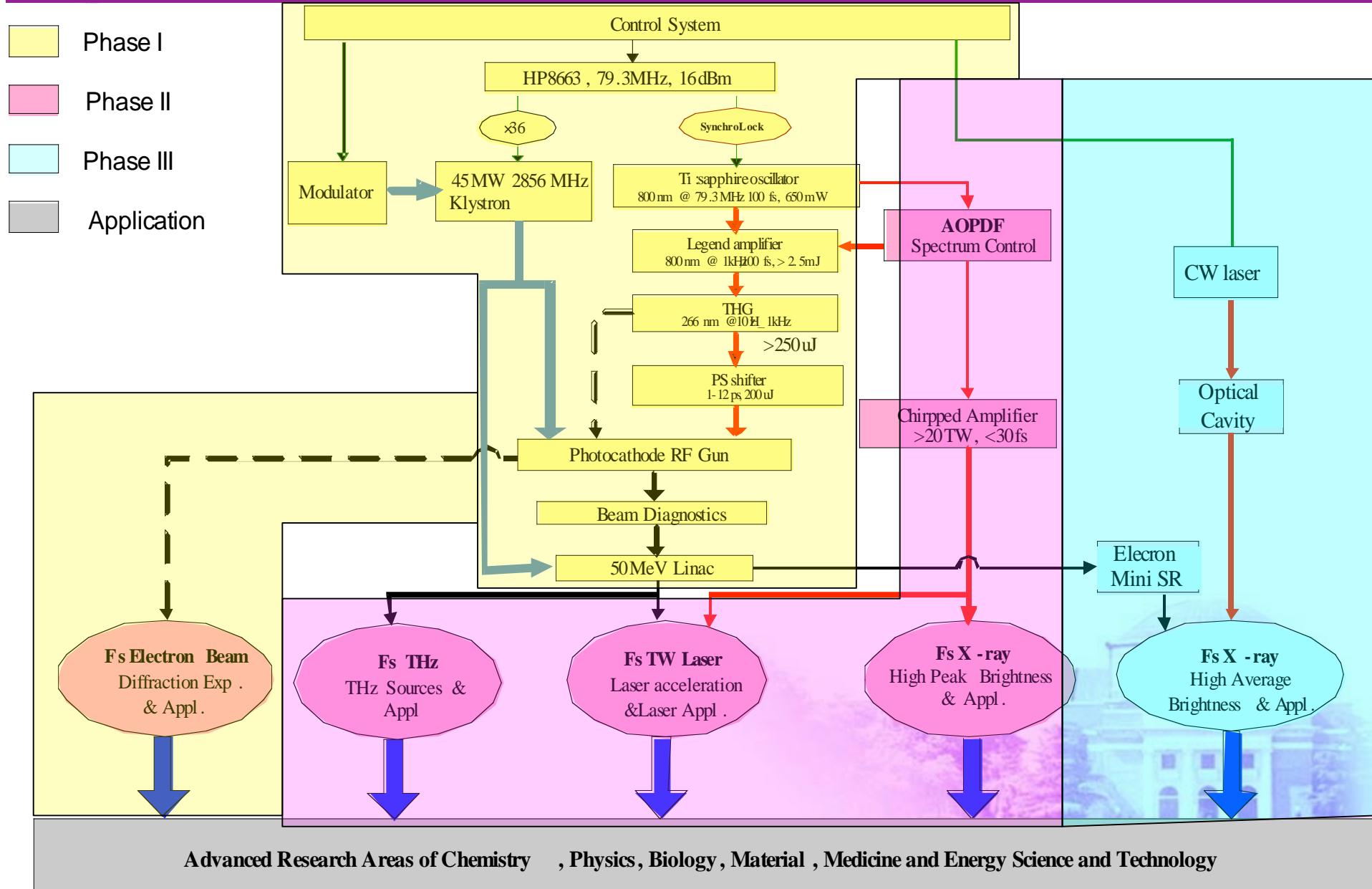
4 Bunch Length Measurement by Deflecting Cavity



Deflecting-cavity under cold test



4 Summary- An Electron and Photon Multidisciplinary Research Lab. In Future





清华大学
Tsinghua University

Thanks for Your Attention !

