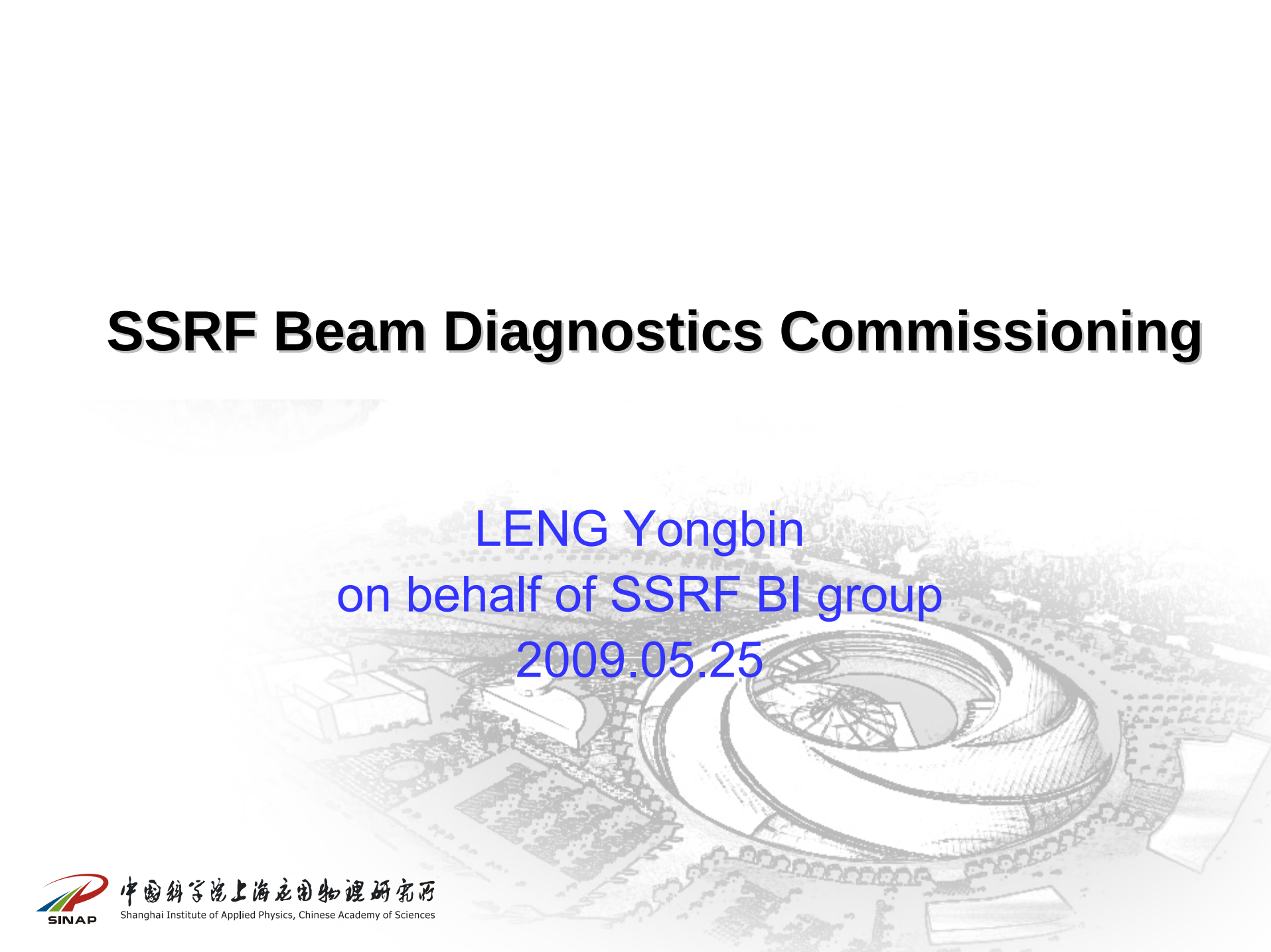
SSRF Beam Diagnostics Commissioning

LENG Yongbin
on behalf of SSRF BI group
2009.05.25



SINAP
中国科学院上海应用物理研究所
Shanghai Institute of Applied Physics, Chinese Academy of Sciences

Outline

- Instruction of SSRF
- Overview of SSRF BI system
- Subsystem
  - Beam position monitor
  - Tune monitor
  - Current & charge monitor
  - Diagnostics beam line
  - Transverse feedback
  - Status of other components
- Summary

Shanghai Synchrotron Radiation Facility

SSRF complex

Storage Ring
3.5GeV, C=432m

Booster
3.5GeV, C=180m

Electron Linac
150MeV

Ring Parameters

	DBA	Low-emittance mode	Normal Mode
Enenrgy	GeV	3.5	3.5
Circonference	m	432	432
Natural Emittance	nm· rad	3.9	11. 2
Current：Multi-bunch（Single）	mA	200~300(5)	200~300(5)
Number of Cells		20/4	20/4
Straights: Length×Number	m	12×4、6.5×16	12×4、6.5×16
$\beta_x/\beta_y/\eta_x$ in middle of 12m straight	m	10.0/6.0/0.15	10.0/6.0/0.0*
$\beta_x/\beta_y/\eta_x$ in middle of 6.5m straight	m	3.6/2.5/0.10	3.6/2.5/0.0*
Betatron Tune Q_x/Q_y		22.22/11.32	22.22/11.32
Chromaticity ξ_x/ξ_y		-56/-19	-56/-19
RF Voltage	MV	4.0~6.0	4.0~6.0
Energy Loss Per Turn (Dipole only)	MeV	1.448	1.448
Max beam power	kW	~600	~600

Beam lines in the first stage

- Macromolecular Crystallography (In-Vac Und.)
- High-Resolution Diffraction
- X-ray Absorption Fine Structure Spectroscopy (W)
- Hard X-ray Micro-focus and Application (In-Vac Und)
- X-ray Imaging and Biomedical Application (W)
- X-ray Scattering
- Soft X-ray Microscopy (Und.)
- X-ray Interference Lithography – (SINAP)

Construction schedule

- Dec. 2004 ~ Dce. 2006: Building construction
- Jun. 2005 ~ Jun. 2008: Accelerator equipment and components manufacture and assembly
- Dec. 2005 ~Dec. 2008: Beamline construction and assembly
- May. 2007 ~ Jul. 2007: Linac commissioning
- Oct. 2007 ~ Dec. 2007: Booster commissioning
- Dec. 2007 ~ Sept. 2008: Storage ring commissioning
- Jun. 2008 ~ Mar. 2009: Beamline commissioning
- Apr. 2009: The SSRF operation begins

Milestone for BI system

Time	Events
2001 ~ 2004	Preliminary research & design
2004.12.25	Project start
2005.04.12	Internal design review
2005.05.30	International design review (Bob, Guenther, JC, Sun Baogen, Cao Jianshe)
2007.05.15	Linac diagnostics ready in day one for Linac
2007.09.30	Booster diagnostics ready in day one for Booster
2007.12.21	BPM, DCCT, TM, parts of SRM ready in day one for Ring
2008.06.18	Interferometer online
2008.11.01	Streak camera & gated camera online
2008.12.19	Transverse feedback online
2009.03.31	System performance evaluation, targets achieved

Primary requirements

measurements	Ring	Booster	Linac&TL
Beam position	10um @ 694kHz 1um @ 10Hz	100um @ 1.67MHz	100um @ single pass
Tune	0.0001 @ 1Hz	0.001 @ 200Hz	
Current / Charge	10uA @ 1Hz	50uA @ 10kHz	2%
Profile / Size	10um	200um	200um
Bunch length	2ps		
Energy			0.1%
Other components			
Transverse feedback	1		
Slit/Scraper	1	3	
Fast orbit feedback	1		

System design

	LN	LTB	BS	BTS	SR	Purpose
Stripline BPM	3	3	50	5		Beam position, longitudinal distribution
Button BPM					152	Beam position, bunch charge, filling pattern
PCT			1		1	Average current, lifetime
WCM	5	2	1	3		Bunch charge, longitudinal distribution
ICT	1	1		1		Bunch charge
Faraday Cup	1					Bunch charge
Screen Monitor	5	3	4	4	2	Profile, energy, emmitance for Linac & TL
Tune Monitor			1		1	Tune measurement
Slit		2		1		Energy purity
Scraper					2	Machine study, collimator
Diagnostics BL					1	Profile, transverse beam size, bunch length
Transverse FB					1	Beam stability
Orbit FB					1	Orbit stability
Total	15	11	57	14	161	

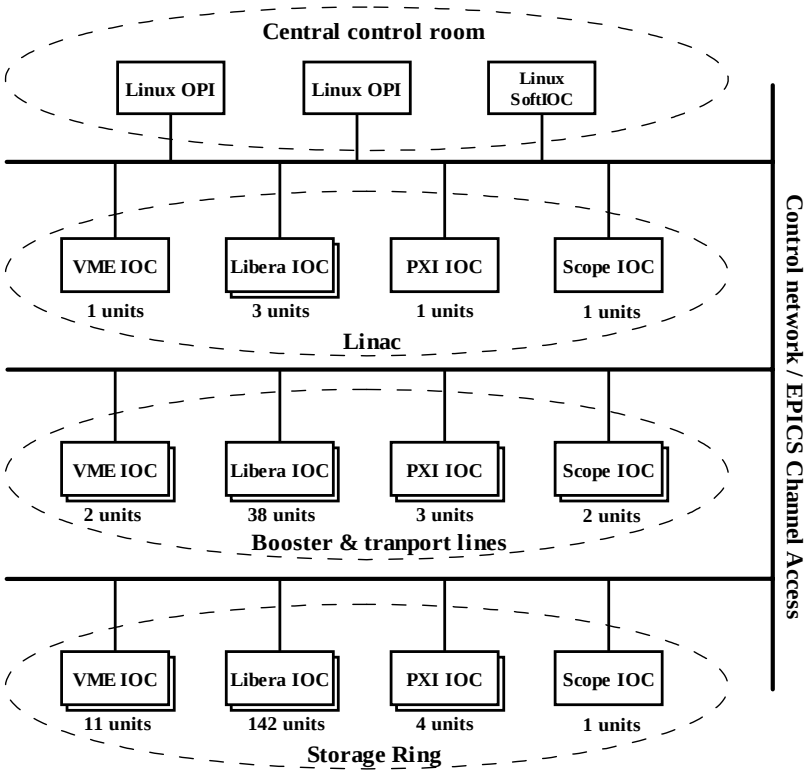
DAQ Hardware & software platform

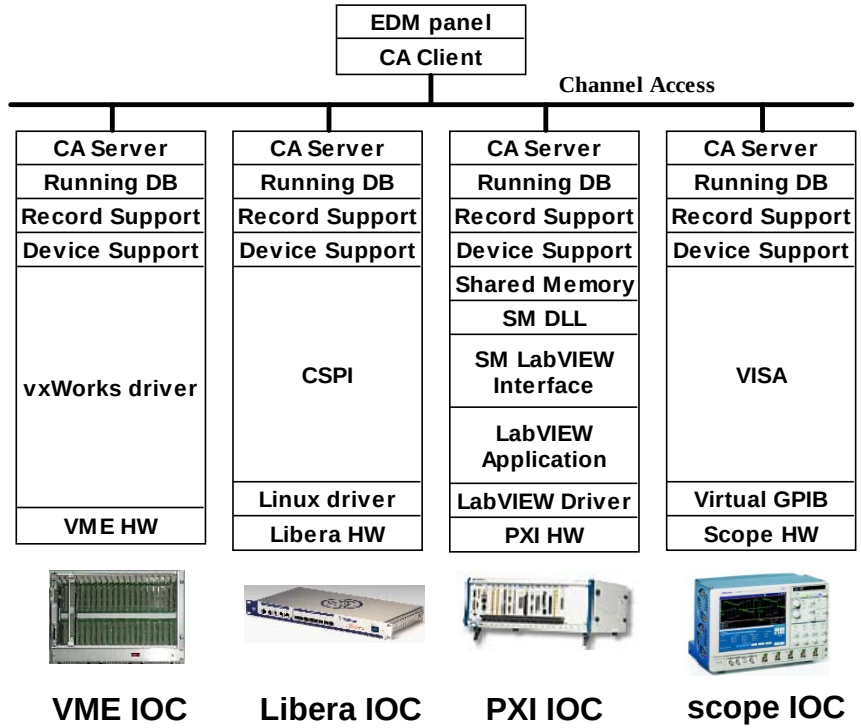
subsystem	Sensors	Electronics	DAQ/Control
Beam position	Button/stripline	Libera	Linux embedded IOC
Bunch charge	WCM/ICT/FC	Oscilloscope	Windows embedded IOC
Tune	Stripline kicker	Function generator	HTTP access
Trans profile	Phosphor / OTR	CCD	PXI IOC+ image grabber
Beam current	NPCT175	Bergoz	PXI IOC + DMM
Slit / Scrapper	Step motor	Motor driver	PXI IOC + Motion controller
Trans feedback	Stripline kicker	Spring-8 board	PXI IOC + DI/O
Filling pattern	Button	RF front-end	PXI IOC + waveform recorder
Beam size	SRM	Interferometer (CCD)	PXI IOC + image grabber
Beam length	SRM	Streak camera	**IPC + image grabber**
Timing		EVR	VME (VxWorks) IOC

PXI IOC talks to EPICS through Shared Memory IOCcore, which wins due to

- **We had experiences before**
- **Easy to learn and use for new players**
- **Easy to move from lab test system to field system**
- **Easy to modify and debug in the field**

DAQ System Architecture





- 13 BI stations + 1 SRM lab, total 212 IOCs
- Five kinds of IOCs used: VME, Libera, PXI, Scope, Soft

Beam Position Monitor

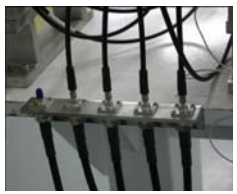
	Design goals	*Achievement*
Ring	1um @ 10Hz 10um @ 694kHz	< 200nm @ 10Hz < 3um @ 694kHz
Booster	100um @ 1.67MHz	< 50um @ 1.67MHz
Linac & TL	100um @ SP	< 33um @ SP

BPM System Architecture

BPM processors
Libera

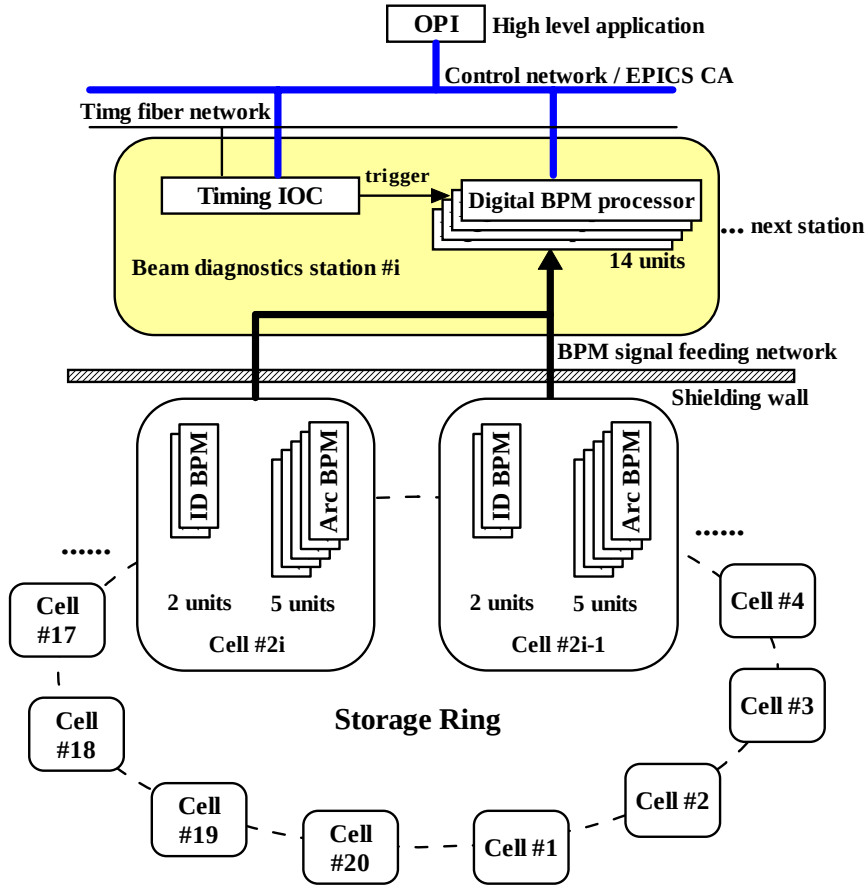


Cable panel
Cable tray




2 IDBPMs
& 5 ArcBPMs

Pickup assembly



BPM data & functions

Support by Diamond Light Source package

- ADC raw data @ 117MHz, 2048 points
- First turn data synchronized by injection trigger
- First 2048 samples of TBT data synchronized by injection trigger
- Up to 0.5M samples of TBT data on demand
- 10Hz SA data, orbit measurement
- Embedded position interlock logic
- User defined current scaling factor (beam current measurement)

Instrumentation Technologies delivered

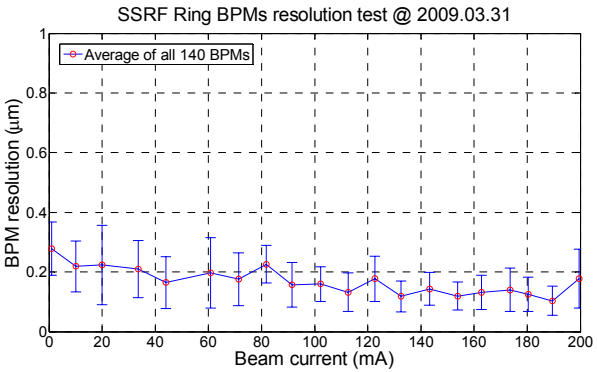
- 10kHz FA data @ SFP port

SSRF added some applications

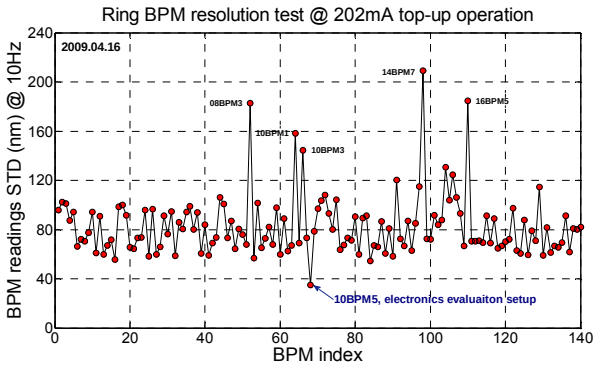
- 24 hours buffer for SA data @ EPICS DB level
- Auto Gain Control logic @ EPICS DB level
- Beam lifetime measurement @ EPICS DB level
- Phase advance measurement @ EPICS DB level

Ring BPM resolution evaluation

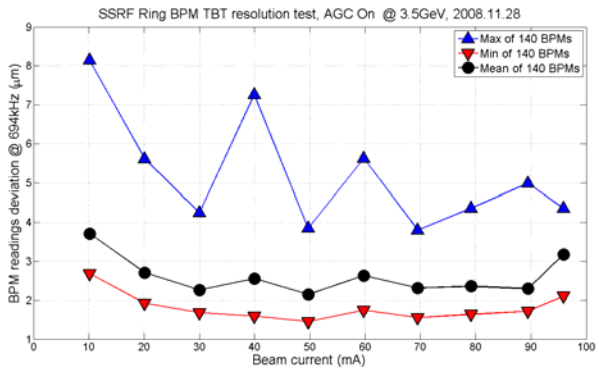
- COD resolution: typical <200nm, best <80nm, with ideal beam <40nm
- TBT resolution: typical 3um
- Uniformity of filling pattern is important for BPM performance



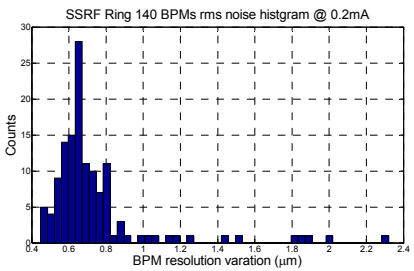
COD resolution, BW 2Hz



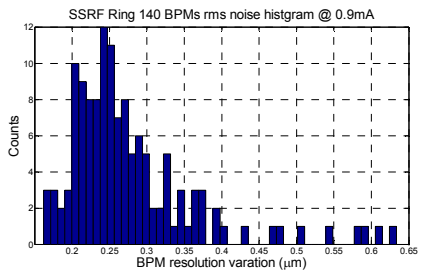
COD resolution @ topup operation



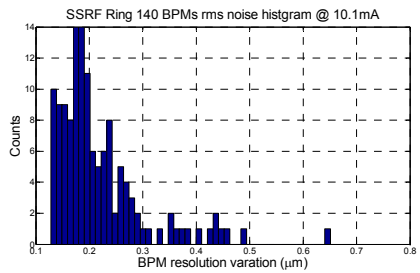
TBT resolution, BW 350kHz



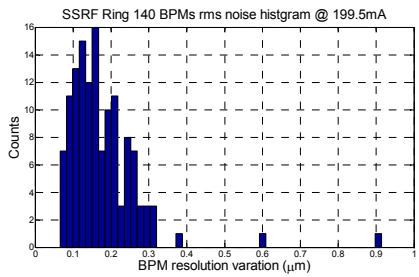
0.2mA



1mA



10mA

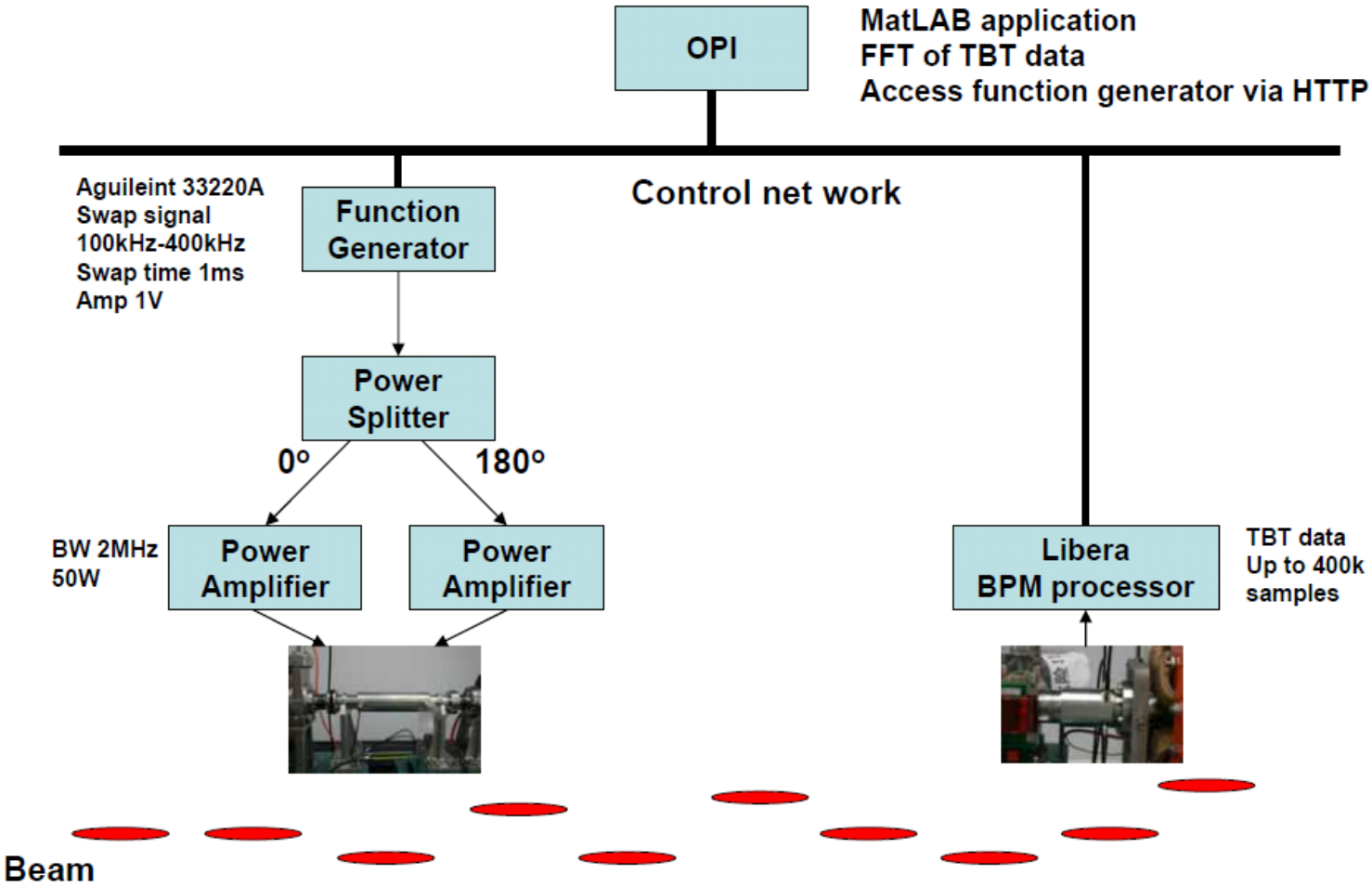


200mA

Tune Monitor

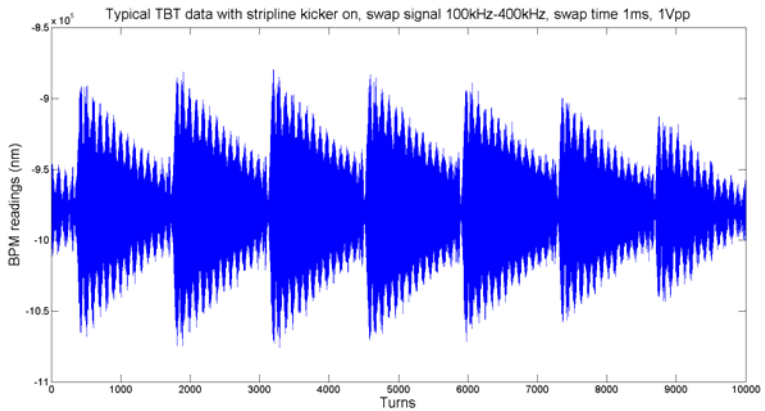
	Design goals	*Achievement*
Ring	0.001 @ 200Hz	0.001 @ 800Hz
Booster	0.0001 @ 1Hz	0.0001 @ 1Hz

Tune monitor configuration

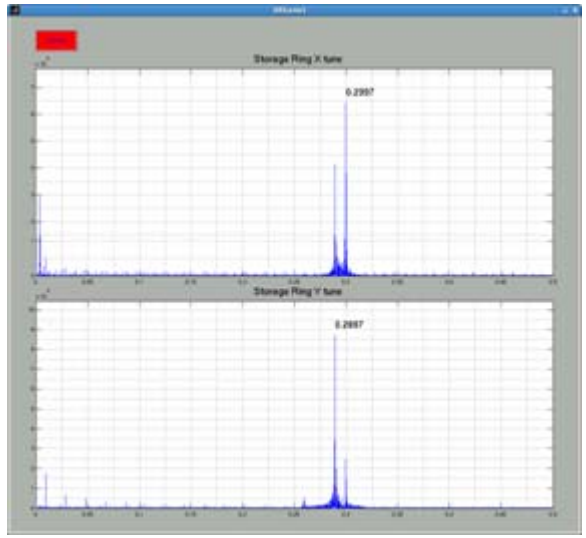


Configuration is the same for Booster and Ring

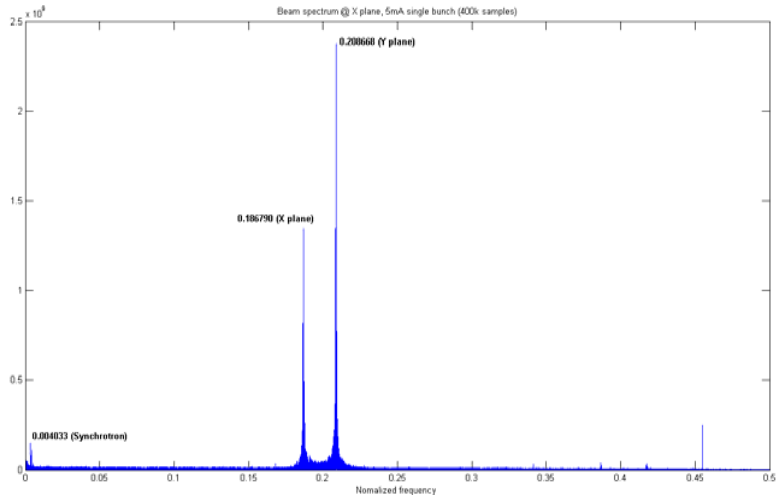
Tune monitor performance: Ring



Typical TBT data during tune measurement



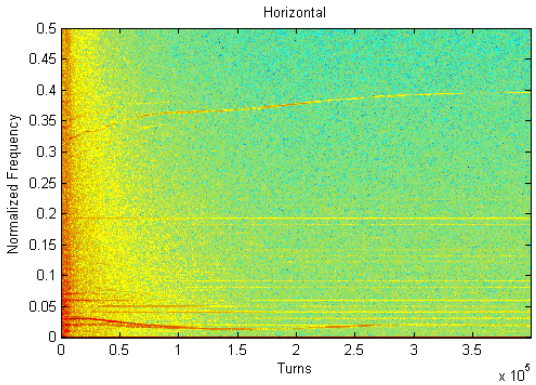
Daily operation panel



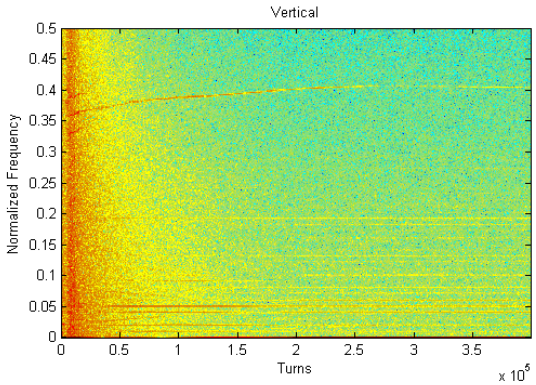
Precise tune measurement

Daily operation:
FFT of 10k TBT data, uncertainty < E-4

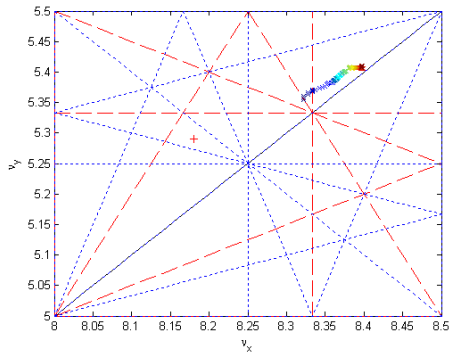
Tune monitor performance: Booster



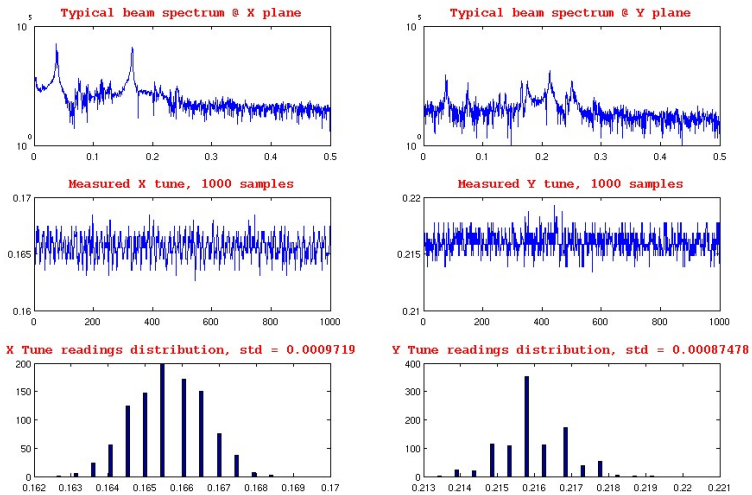
Horizontal ramping tune



Vertical ramping tune



Tune drift during ramping

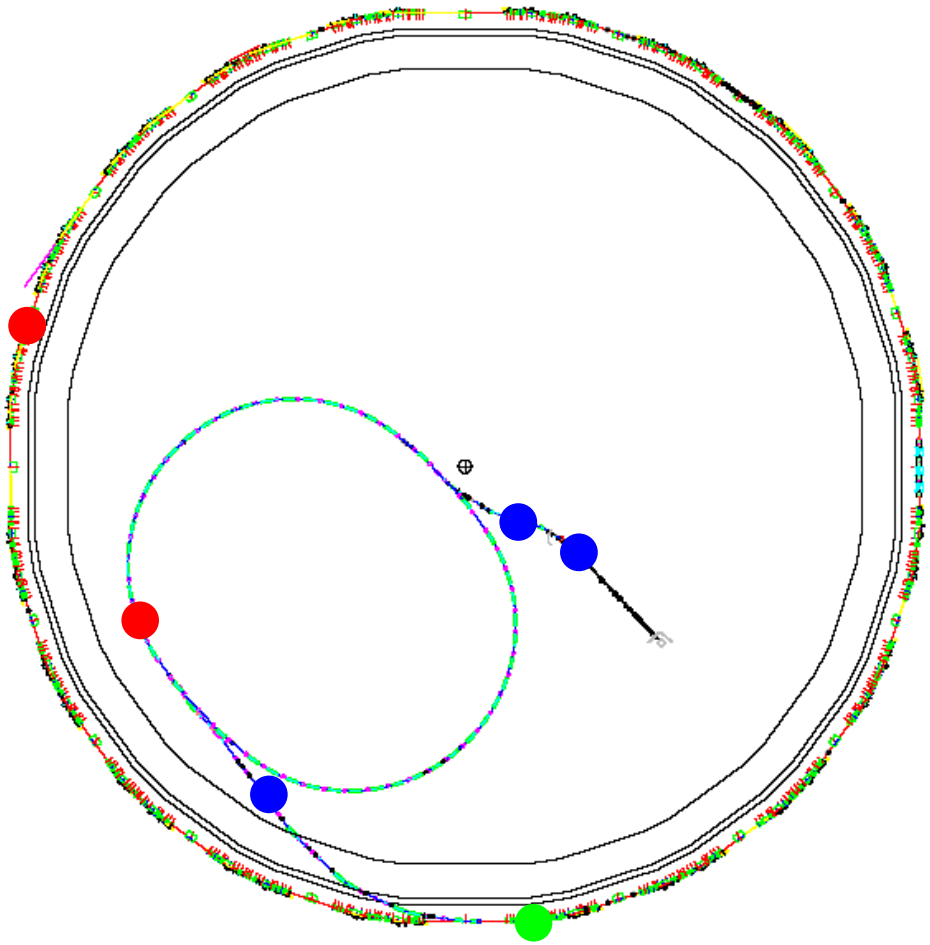


TBT data 400k samples, cover 240ms
FFT windows size 2048, 1/1.23us = 800Hz
Tune measurement uncertainty < E-3

Current & Charge measurement

	Design goals	*Achievement*
Ring DCCT	10uA @ 1Hz	2uA @ 1Hz
Booster DCCT	50uA @ 10kHz	30uA @ 10kHz 10uA @ 2Hz
ICT	2%	1% @ 2Hz

Sensors layout



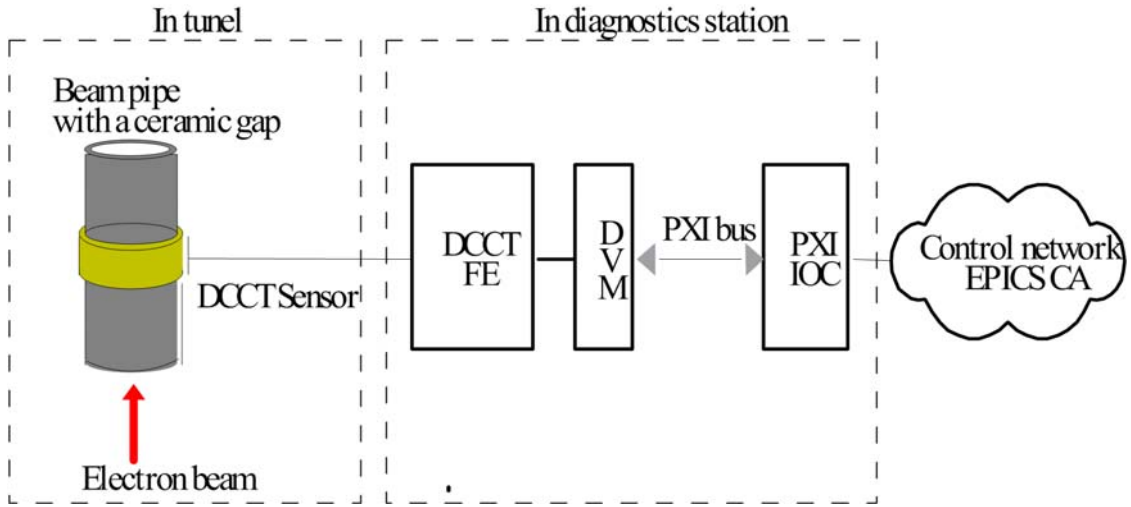
1 DCCT @ Booster
1 DCCT @ Ring

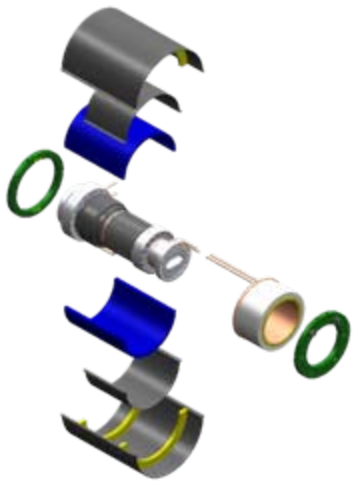
1 ICT @ Linac
1 ICT @ LTB transfer line
1 ICT @ BTS transfer line

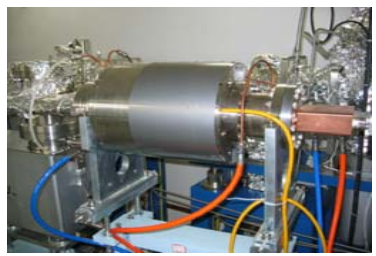
Transfer efficiency could be fully evaluated with this configuration

BPM + combiner @ Ring
Bunch charge & filling pattern

Average current measurement: DCCT







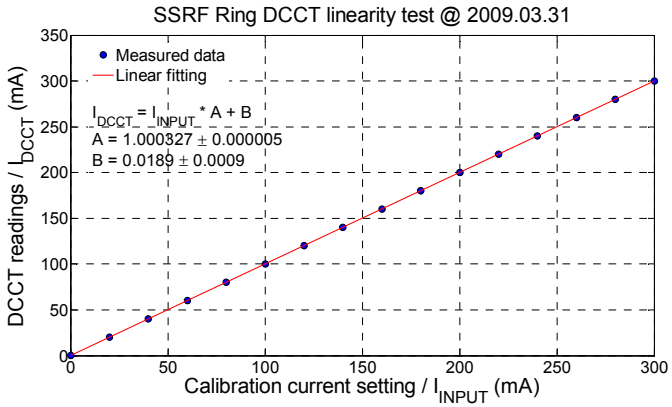
Shield design borrowed from SPEAR3

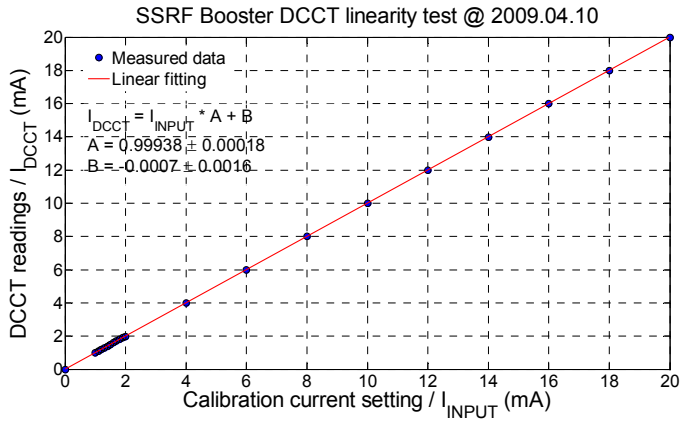
Bergoz NPCT175

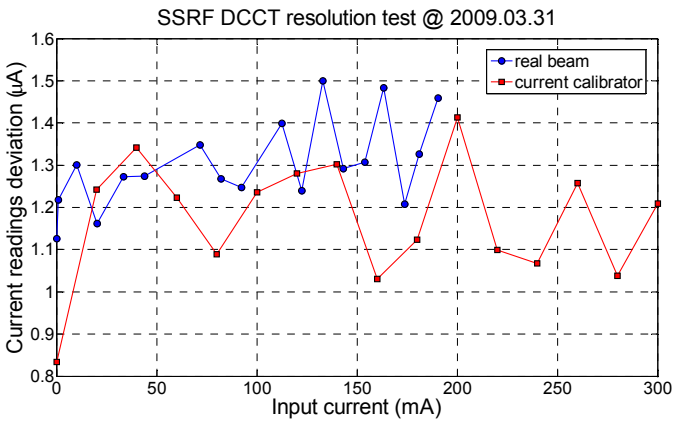
NI 4070
DVM

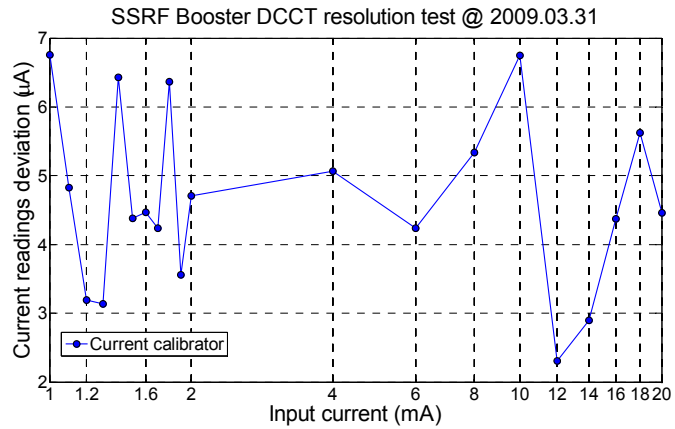
NI 8187
PXI controller

DCCT performance evaluation









Ring

Resolution < 2uA @ 1Hz

Nonlinearity < 0.03% @ 0 ~ 300mA

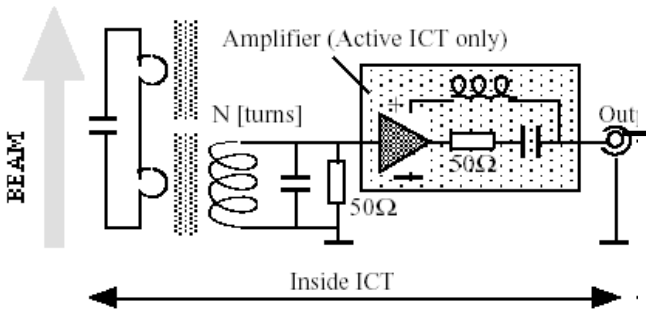
Booster

Resolution < 30uA @ 10kHz,

< 10uA @ 2Hz

Nonlinearity < 0.07% @ 0 ~ 20mA

Bunch charge measurement: ICT

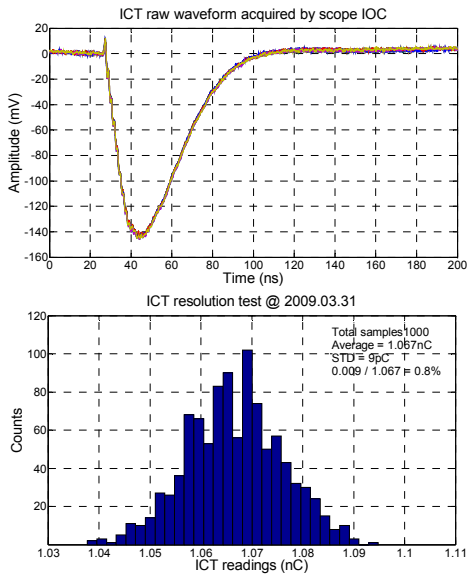


Scope embedded IOC

TEK DPO7054

BW 500MHz

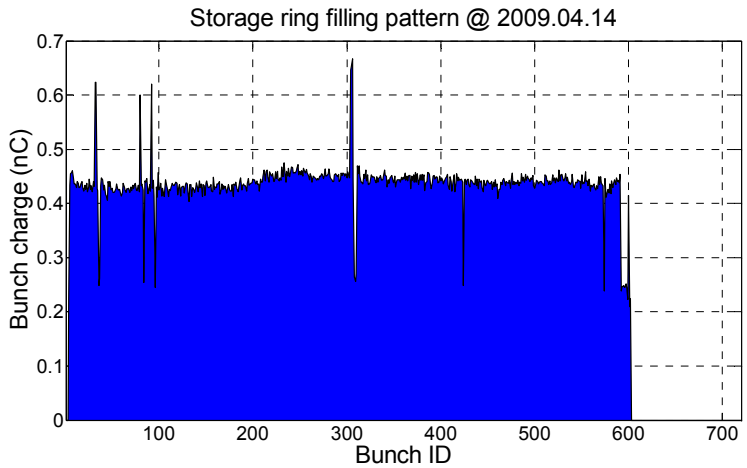
Bergoz ICT

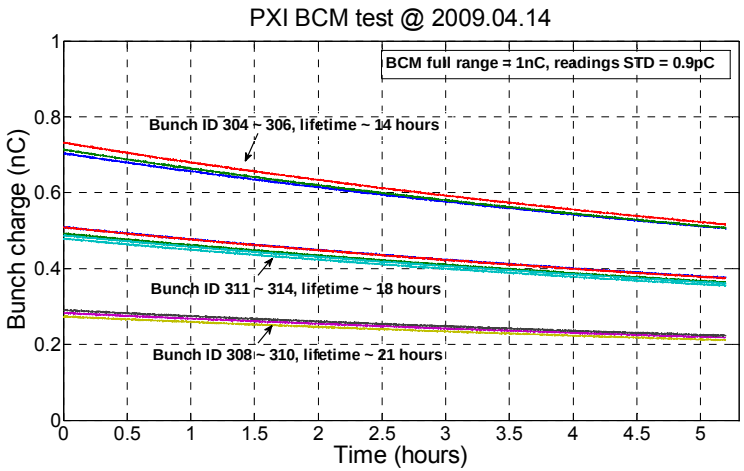


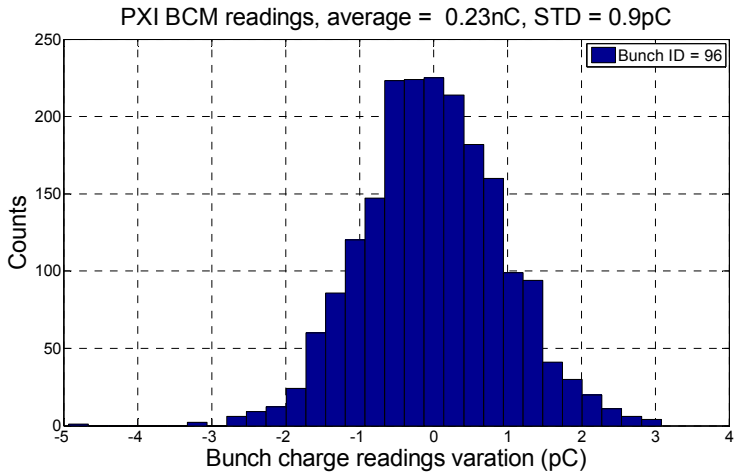
1000 samples **RMS: 0.009/1.067nC = 0.8%** **P-P: 0.06/1.067 = 5%**

Bunch charge measurement: BPM

Acquiris DC252, BW 2GHz
Sampling rate 8GHz





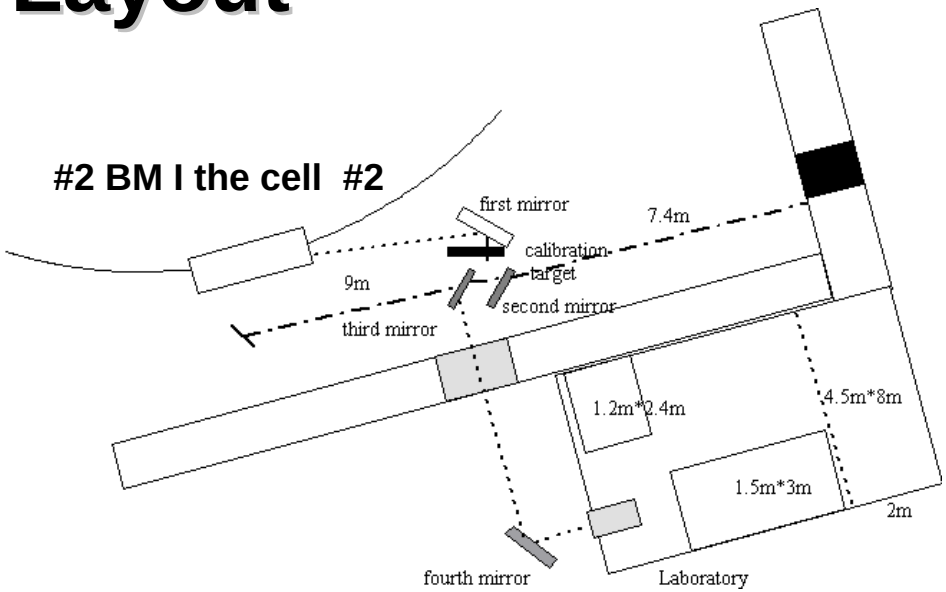


2000 samples **RMS: 0.9pC/1.0nC = 0.1%**

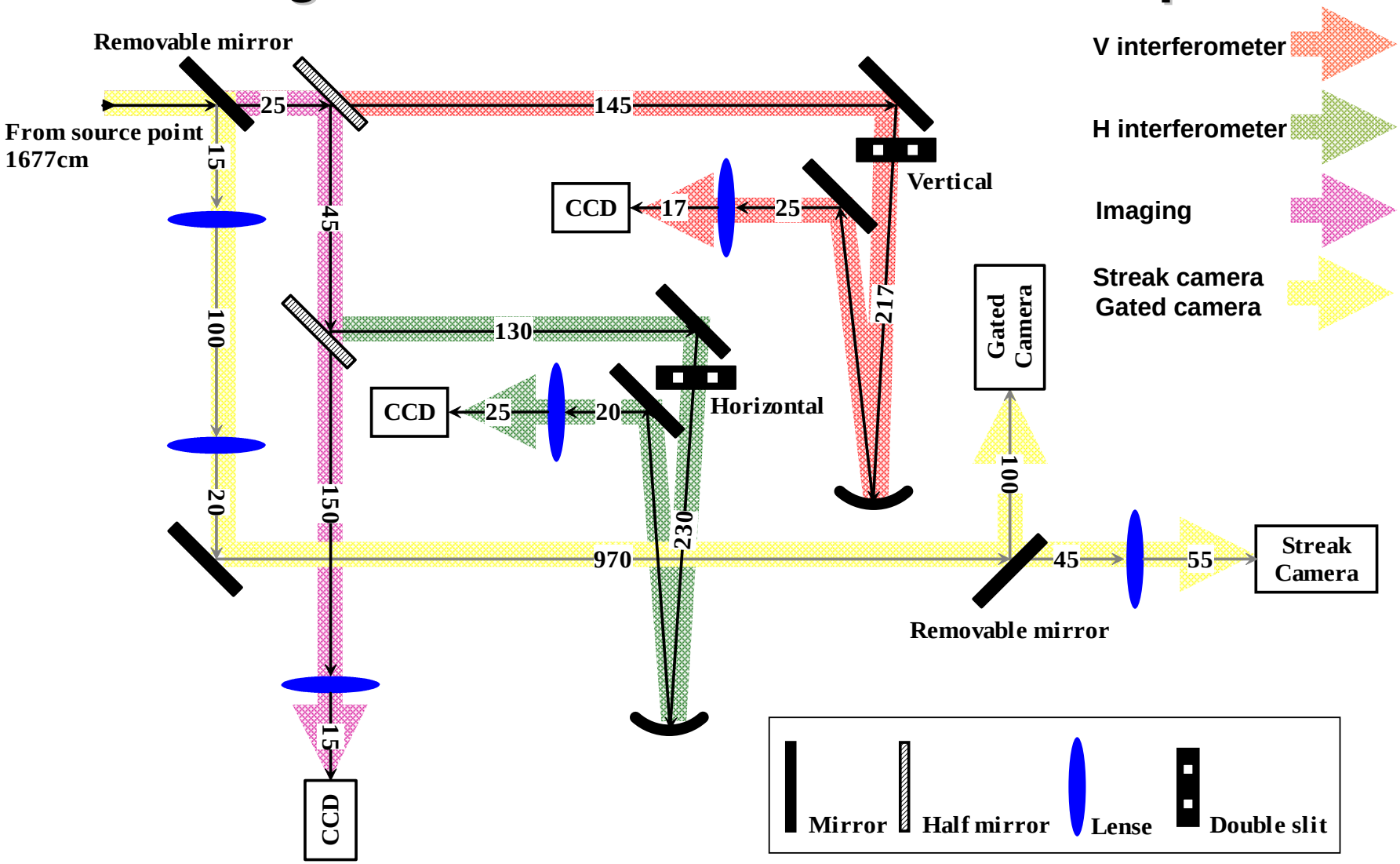
Diagnostics Beam Line

	Design goals	*Achievement*
Beam size	10um	10um
Beam length	2ps	2ps

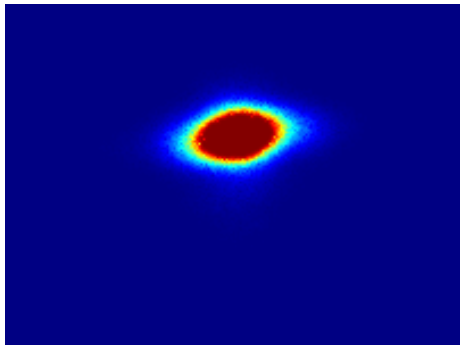
Layout


#2 BM I the cell #2
first mirror
7.4m
calibration target
9m
second mirror
third mirror
1.2m*2.4m
4.5m*8m
1.5m*3m
2m
fourth mirror
Laboratory

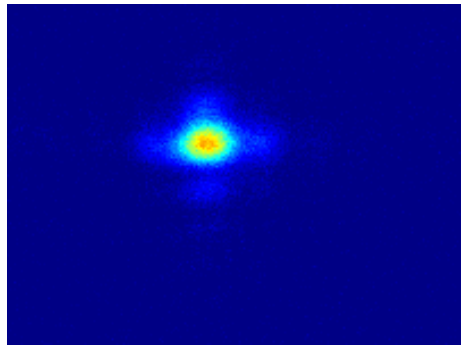
Diagnostics beam line: bench setup



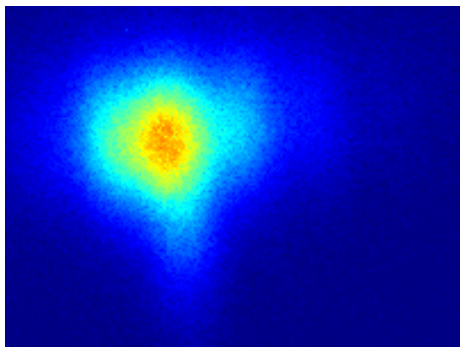
Diagnostics beam line: image system



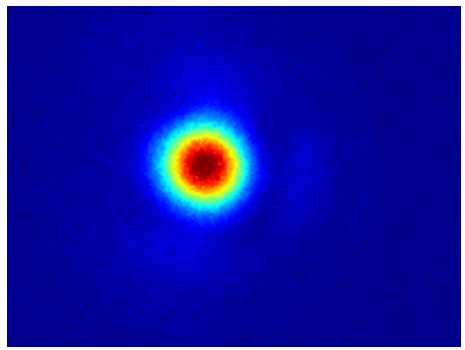
2008.01.03
80mA, no COD correction
copper cavity



2008.04.10
100mA, COD um level
copper cavity

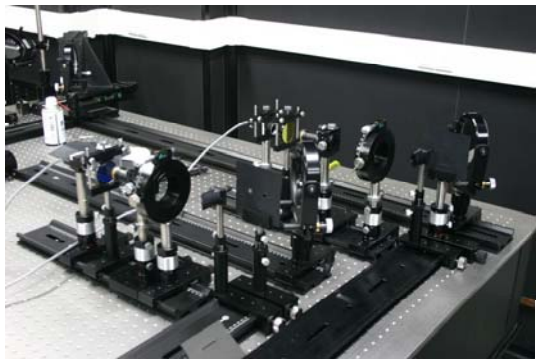


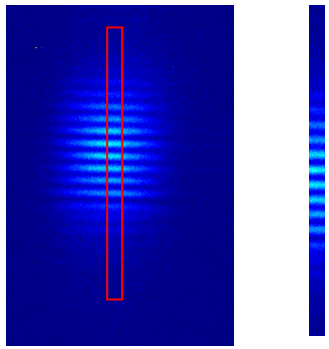
2008.10.01
150mA
SC cavity, noisy PS

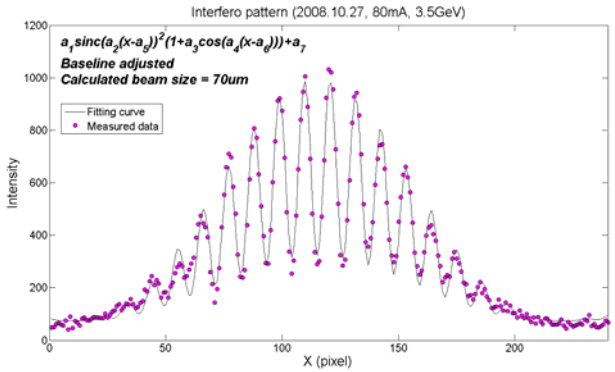


2008.10.27
86mA
SC cavity, noisy PS fixed

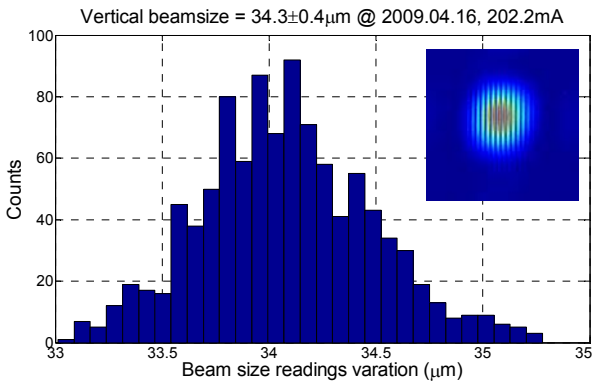
Diagnostics beam line: Interferometer

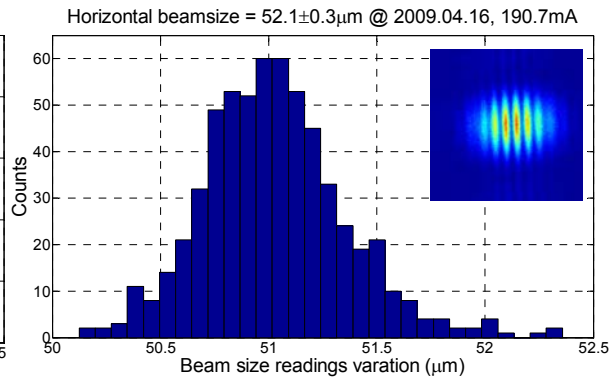


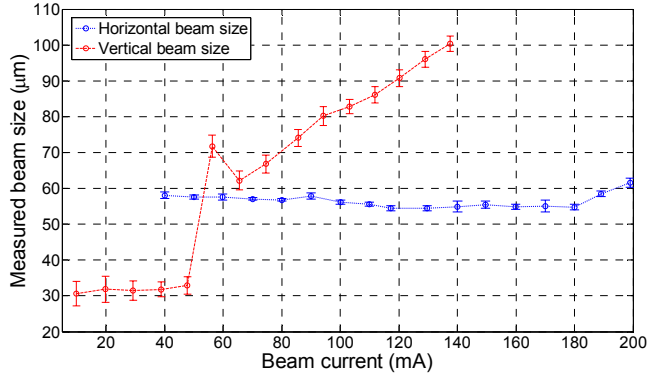




$$I(y_1) = I_0[\sin c(\frac{2\pi a}{\lambda R_1} y_1)]^2 \cdot [1 + |\gamma(\nu)| \cos(\frac{2\pi D}{\lambda R_1} y_1 + \varphi)]$$





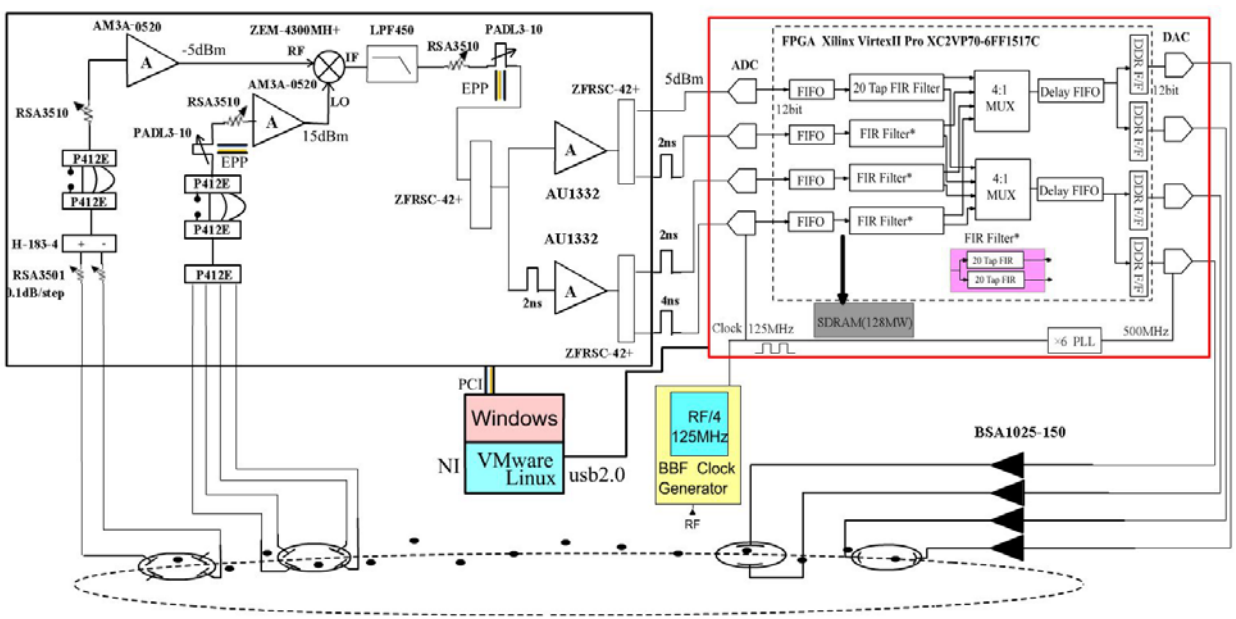


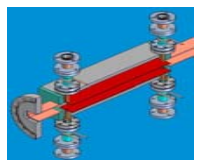
Measurement uncertainty um level, system resolution better than 10um

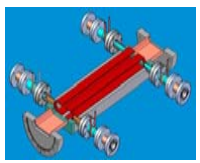
Transverse Feedback

	Design goals	*Achievement*
Bandwidth	250Mhz	250Mhz
System gain		> 40dB

Transverse feedback

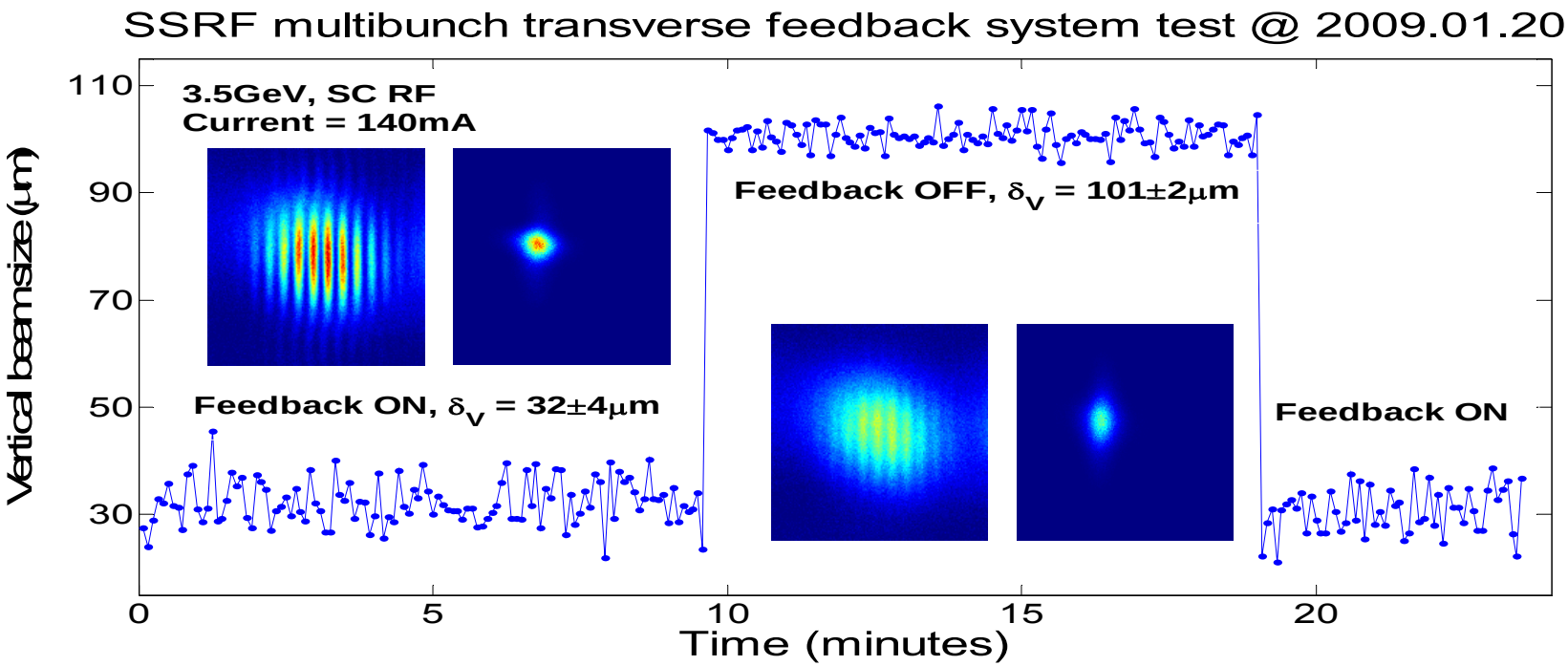


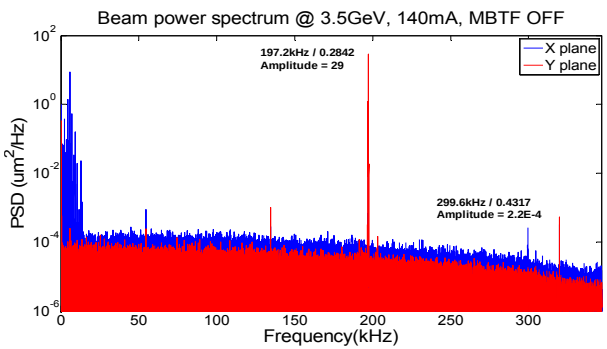


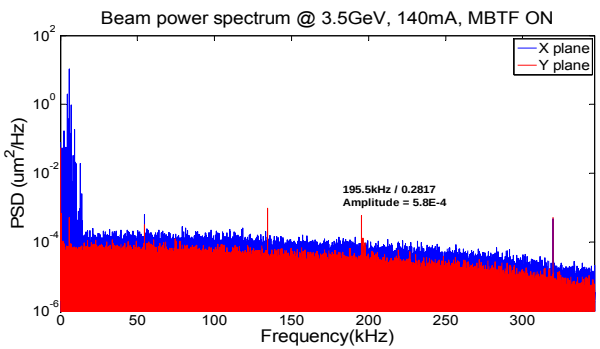


- Stripline kicker @ injection section, BPM pickups @ #2 straight section
- Spring8 designed digital feedback processor
- In-house made separate stripline kicker
- in-house made RF front-end
- Betatron oscillation attenuation > 40dB

Transverse feedback performance







System gain
29/7E-4 > 40dB

Status of the other components

- **Screen monitor is daily operation toolkits for Linac & TL**
  important in day one commissioning for both booster & ring

- **Slit is rarely used now**
  used few times during booster commissioning

- **Scraper is very useful for machine study**
  used as collimator to protect IDs in daily operation

- **WCM is rarely used now**
  good tools for operator in commissioning stage

- **Fast orbit feedback is under commissioning**

Summary (1)

	Measurement	Specification	Achievement
LINAC LTB BTS	Beam position	Resolution 100μm@2Hz	**< 33um @ SP**
	Beam profile	Resolution 200μm@2Hz	200um @ 2Hz
	Bunch charge	Relative accuracy 2%	1%
	Energy	Relative accuracy 0.1%	0.1%
	Emmitance	Relative accuracy 10%	10%
BS	Beam position	Resolution 100μm@1.67MHz	**< 50um@1.67MHz**
	Beam profile	Resolution 200μm@2Hz	200um @ 2Hz
	DC current	Resolution 50μA@10kHz	**30uA@10kHz** **10uA@2Hz**
	Tune	Resolution 0.001@200Hz	0.001@800Hz
SR	Beam position	Resolution 10μm@694kHz Resolution 1μm@10Hz	**3um @ 694kHz** **200nm @ 10Hz**
	Beam profile	Resolution 10μm	10um
	Beam length	Resolution 2ps	2ps
	DC current	Resolution 10μA@1Hz	**2uA @ 1Hz**
	Tune	Resolution 0.0001@1Hz	0.0001@1Hz
	MBTF	BW 250MHz	**BW 250MHz, -40dB gain**

Summary (2)

- **Beam diagnostics meets all physical requirements**
- **All necessary diagnostics tools ready in day one for commissioning**
- **Adopting new technologies and methods accelerates system development and implementation**
- **All design goals achieved except fast orbit feedback**
- **Fast orbit feedback could be online this year**
- **We need keep working on stability & reliability issues**

Acknowledgments

The development of SSRF beam diagnostics is a successful story of international collaboration. Without comments, suggestions from accelerator community we could not make it.

In particularly many thanks to

- *Guenther Rehm* and *Michael Abbott* from Diamond Light Source
- *Bob Hettel*, *Jim Sebek*, *James Safranek*, *Jeff Corbett* from SLAC
- *Tadayoshi Misuhashi* from KEK
- *Takeshi Nakamura* from Sring8
- *Jean-Claude Denard* from Soleil Light Source
- *Hsu Kuo-Tung* from Taiwai Light Source
- *Cao Jian-She* and *Ma Li* from IHEP
- *Sun Bao-Geng* from NSRL

We hope we can do more contribution to this community in the future.

Thanks

SINAP
中国科学院上海应用物理研究所
Shanghai Institute of Applied Physics, Chinese Academy of Sciences