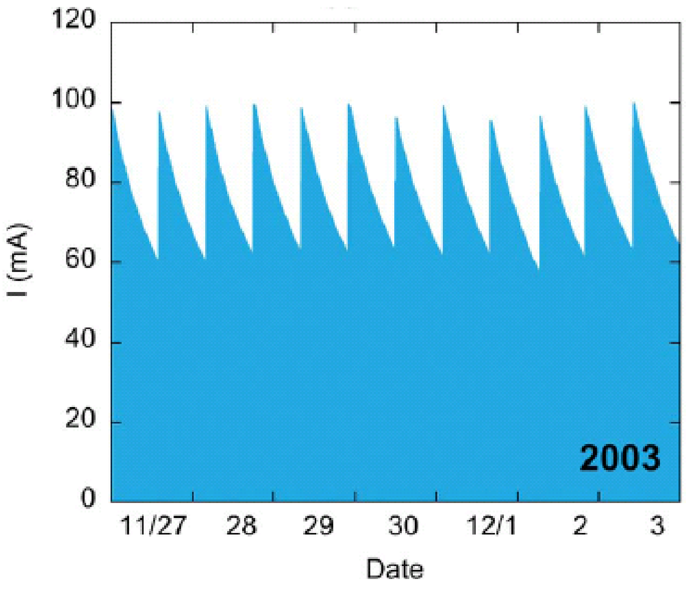
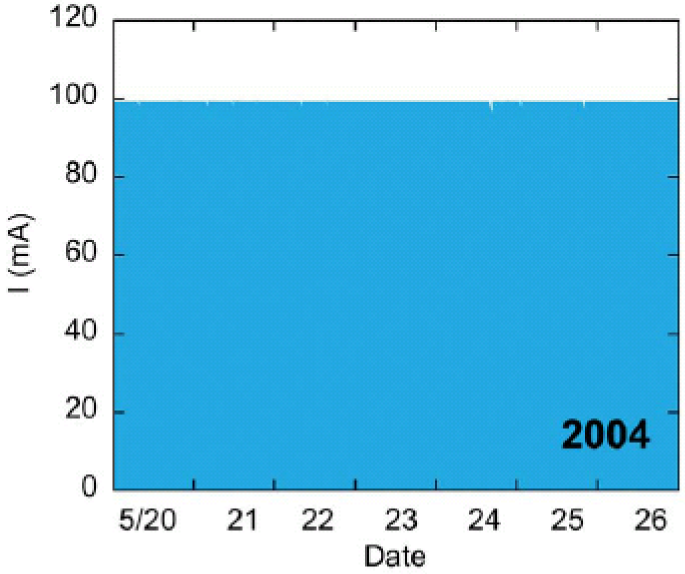
Top-Up Operation in Light Sources

H. Ohkuma, JASRI/SPring-8





EPAC08, Magazzini del cotone, Genoa, Italy / June 23, 2008

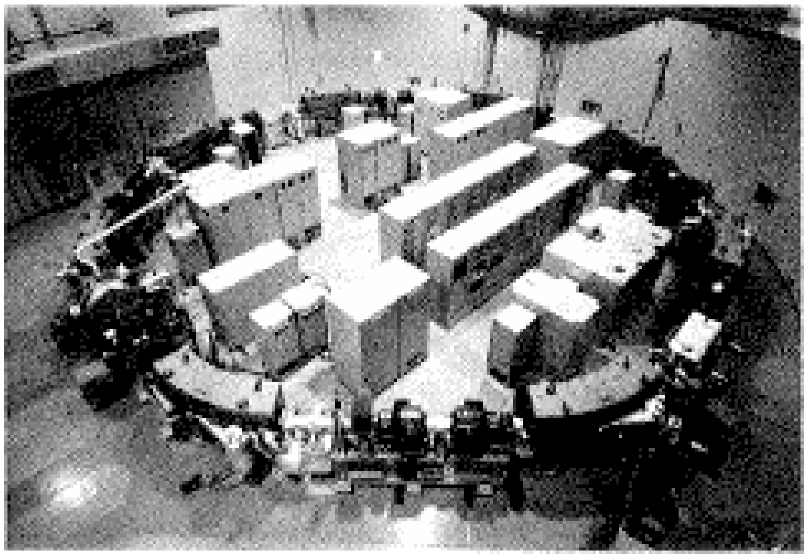
Merits of Top-up

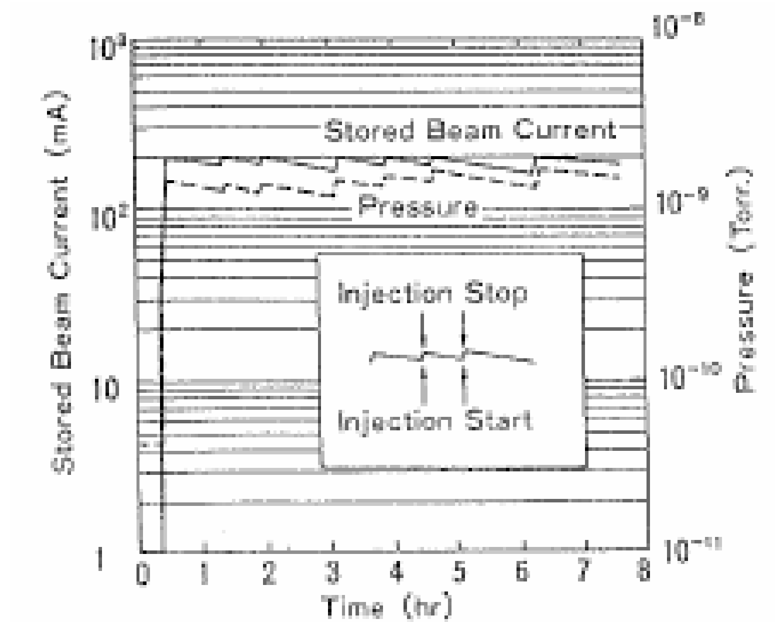
- **Short beam lifetime can be compensated.**
- **Variety of beam filling can be possible.**

  Especially, high current bunch in hybrid filling mode.
- **Photon source becomes effectively more brilliant.**
- **User experiments are not interrupted by beam refill.**
- **Photon beam becomes stable owing to constant heat load and thermal equilibrium of X-ray beam optics.**
- **Experimental data is free from normalization by current.**

History of Top-up operation

- **In 1990, demonstration of 1GeV SORTEC**





S. Nakamura et al., EPAC90, p.472

- **In 1996, TLS tested Top-up Operation in 194 -200 mA**

T. S. Ueng, et al., EPAC96, p.2477

History of Top-up operation (Con't)

Top-up in user time

- In 2001, APS started top-up.
- In 2001, SLS started top-up in beamline commissioning phase.
- In 2003, NewSUBARU started top-up, and in 2004, SPring-8 started.
- In 2005, TLS started top-up.

Successes at these facilities

↓

Top-up is standard operation mode in light sources.

Top-up Status at routinely operated sources

Facilty	Energy [GeV]	Current [mA]	Emittance [nm.mrad]	Injector	Injection Efficiency	Current Stability	Operatinal Status	Top-up Status
APS	7	102	3	7GeV Boost.	80 - 100%	±0.4%	Oper. (1996)	Oper. (2001)
SLS	2.4 (2.7)	400	5	2.7GeV Boost.	90 - 100%	0.3%	Oper. (2001)	Oper. (2001)
New SUBARU	1 (1.5)	220 (350)	67	1GeV Li.	~80%	0.6%	Oper. (2000)	Oper. (2003)
SPring-8	8	99.8	3.2	8GeV Boost.	>80%	0.03%	Oper. (1997)	Oper. (2004)
TLS	1.5	300 (360)	25	1.5GeV Boost.	>70%	±0.2%	Oper. (1993)	Oper. (2005)

Top-up at APS

Multi-bunch, 324 bunches (lifetime: 70 hours) : No Top-up

Top-up in two filling mode

24 bunches

- **Lifetime is 8 hours**
- **Injection interval : 2 min.**
- **Injection efficiency : ~100 %**

8 trains of 7 small bunches + one 16 mA bunch

- **Lifetime is 5.5 hours**
- **Injection interval: 1 min.**
- **Injection efficiency : 80 % (because of high chromaticicities)**

Current stability : ± 0.4mA at 100mA (±0.4%)

Tracking Simulation for radiation safety

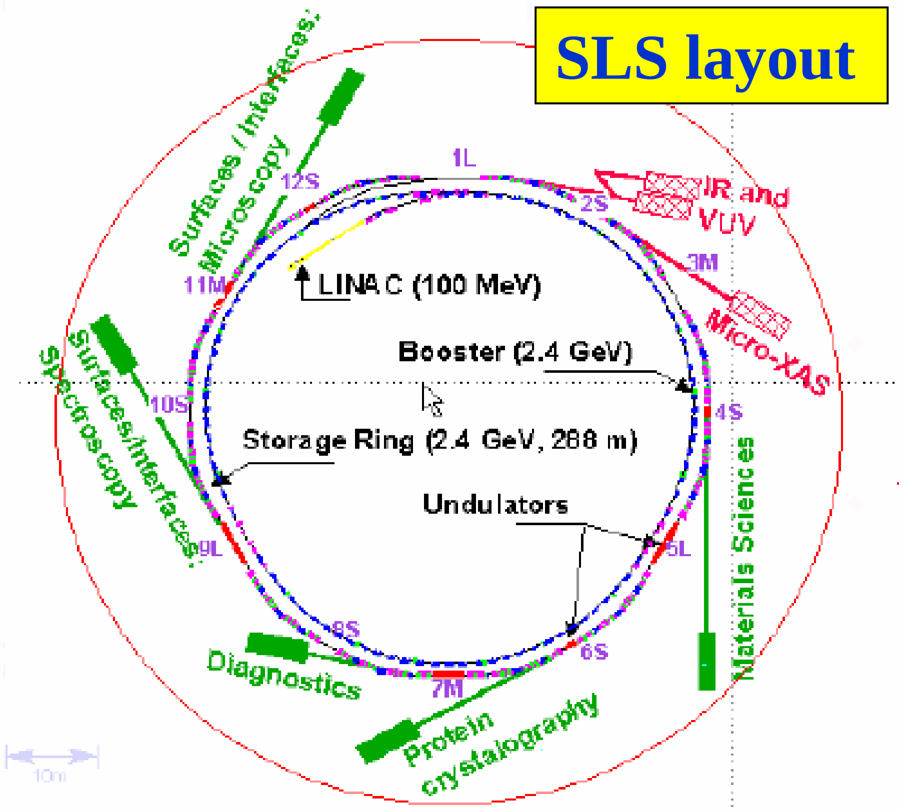
Interlocks:

- **injection with zero current stored**
- **energy mismatch between injector and storage ring.**

L. Emery and M. Borland, PAC99, p.2319

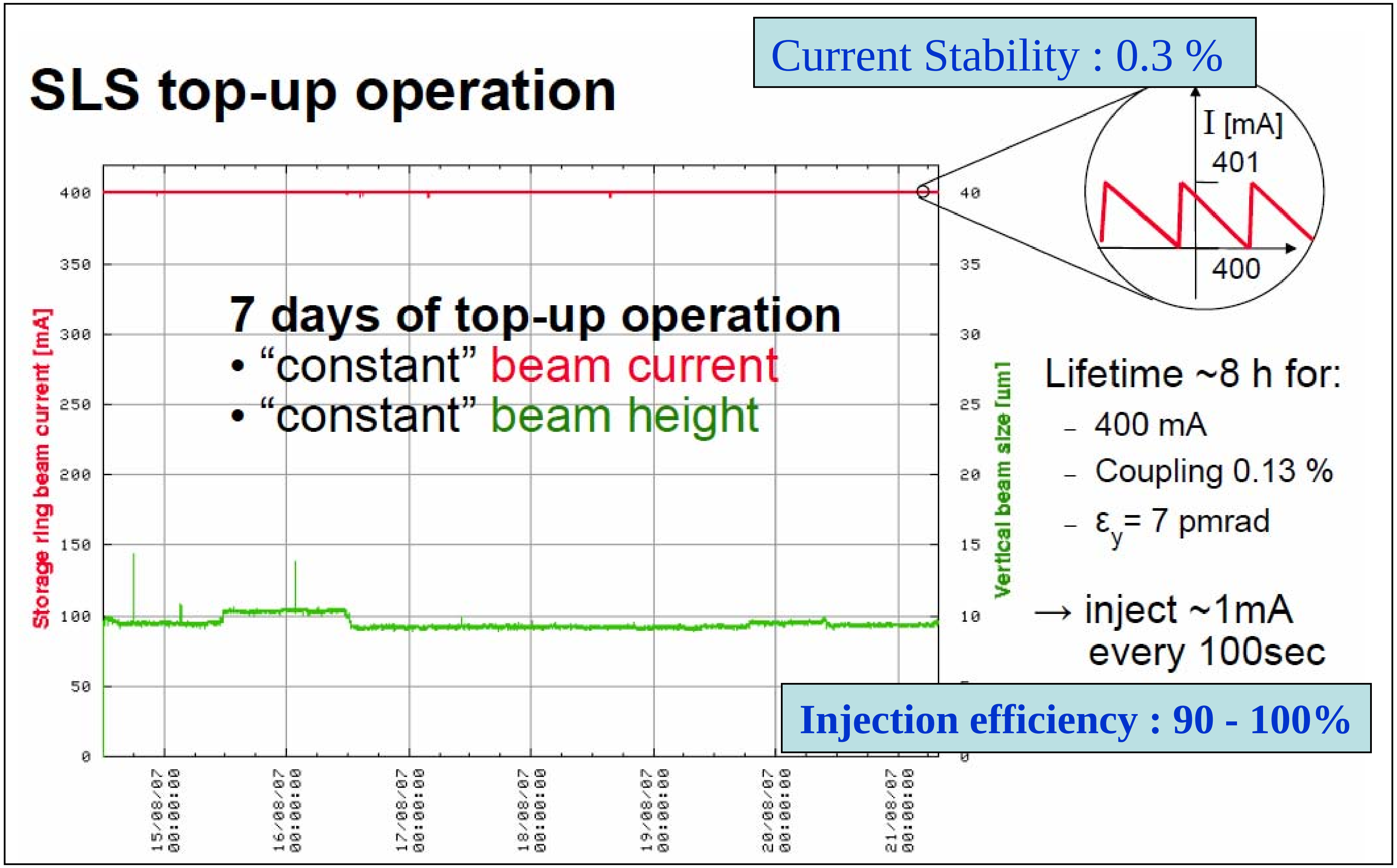
Top-up at SLS

- **Booster (in same tunnel of Storage Ring)**
  - **100 MeV to 2.7 GeV @ 3 Hz**
  - **Emittance : 9 nm.rad**
  - **Circumference : 270 m**
- **Injection section**
  - **11 m magnet free straight**
  - **Four Identical Bumps (Mirror Symmetry)**
- **Storage Ring**
  - **2.4 (2.7) GeV, 400 mA**
  - **Emittance : 5 nm.rad**
  - **Circumference : 288 m**



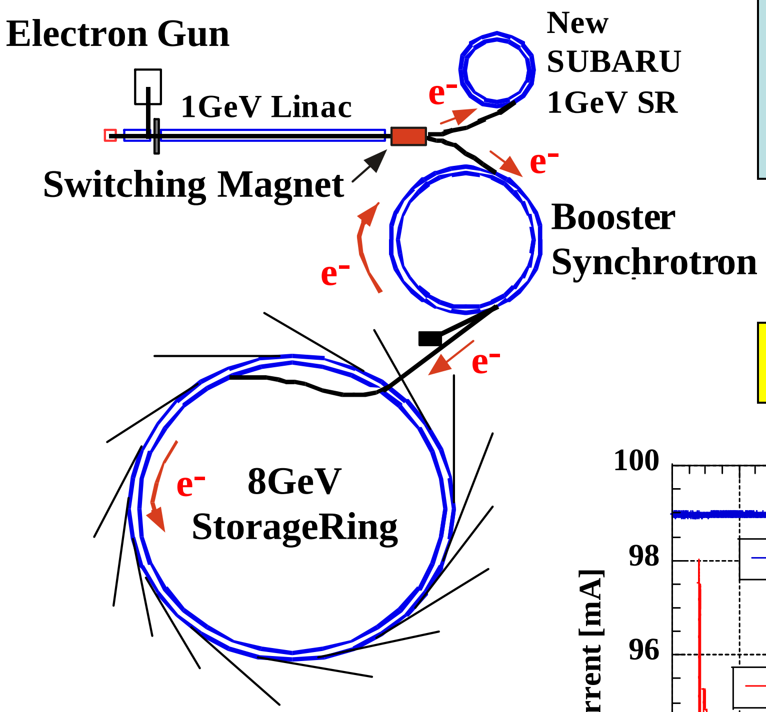
M. Böge, IWBS talk at SP8 (12/03/02)

Top-up at SLS (Con't)



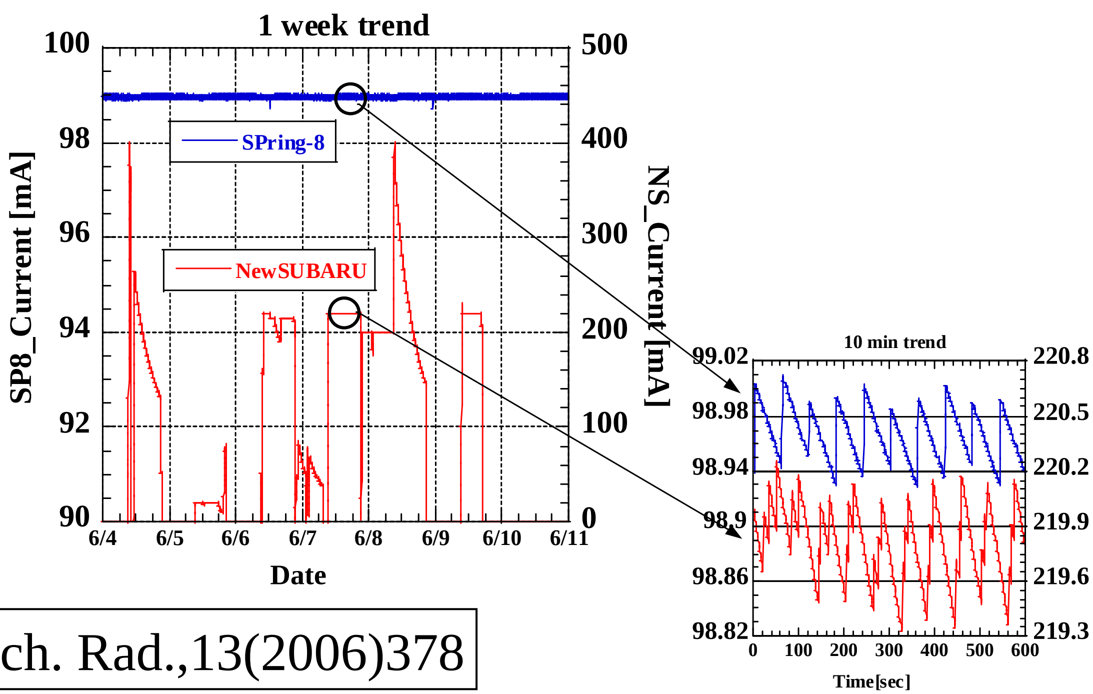
A. Lüdeke. at Diamond talk (22/11/07)

Top-up at SPring-8 and NewSUBARU



NewSUBARU
- 1.0 (1.5 GeV), 220 (350) mA
- ε_x = 67 nm.rad

Parallel top-up injections into two rings



SPring-8
- 8GeV, 100 mA
- ε_x = 3.2 nm.rad

H. Tanaka et al., J. Synch. Rad.,13(2006)378

Top-up at SPring-8

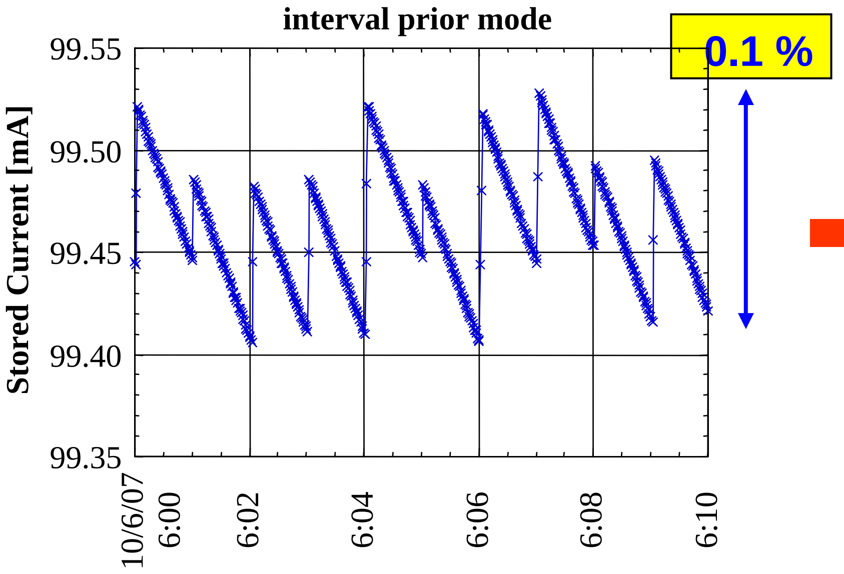
Filling Mode & Lifetime in 2007

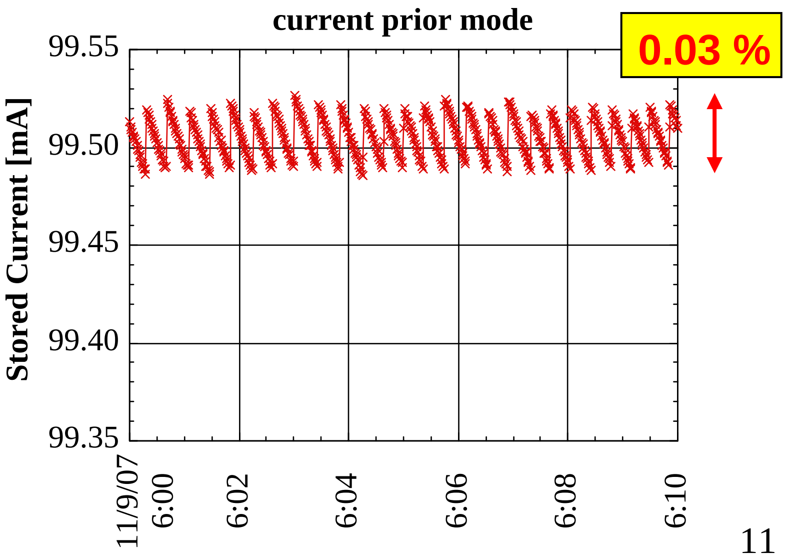
	bunch current	lifetime
Multi-bunch (160 bunch-train x 12)	0.05 mA	~ 200 hr
203 bunches	0.5 mA	25 ~ 30 hr
11 bunch-train x 29	0.3 mA	35 ~ 50 hr
1/7-filling + 5 single bunches	2.8 mA (single)	18 ~ 25 hr
1/14-filling + 12 single bunches	1.6 mA (single)	
2/29-filling + 26 single bunches	1.4 mA (single)	
4/58-filling + 53 single bunches	1.0 mA (single)	

Multi-bunch : 17.0 %, Several-bunch : 51.9%, Hybrid : 31.1%

Top-up at SPring-8
(Improvement of current stability)

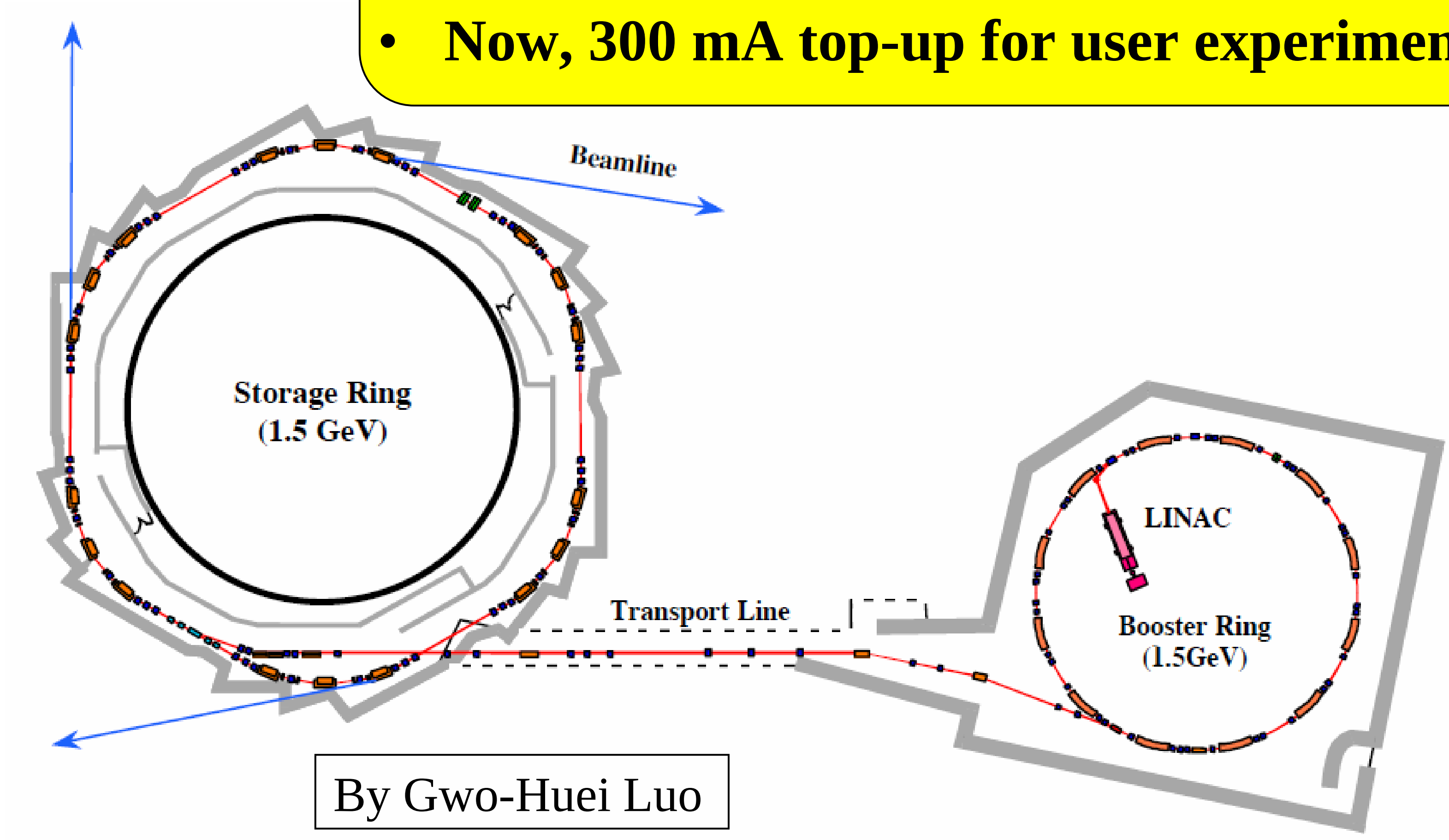
- **Fixed interval (~ Oct. 2007)**
  - **Interval 1 min (several, hybrid) or 5 min (multi-bunch)**
  - **Current stability 0.1 %**
- **Variable interval (Nov. 2007 ~)**
  - **Interval depending on lifetime 20 sec ~ 2 min.**
  - **Current stability 0.03 % (30 μA/one shot)**





Top-up at TLS

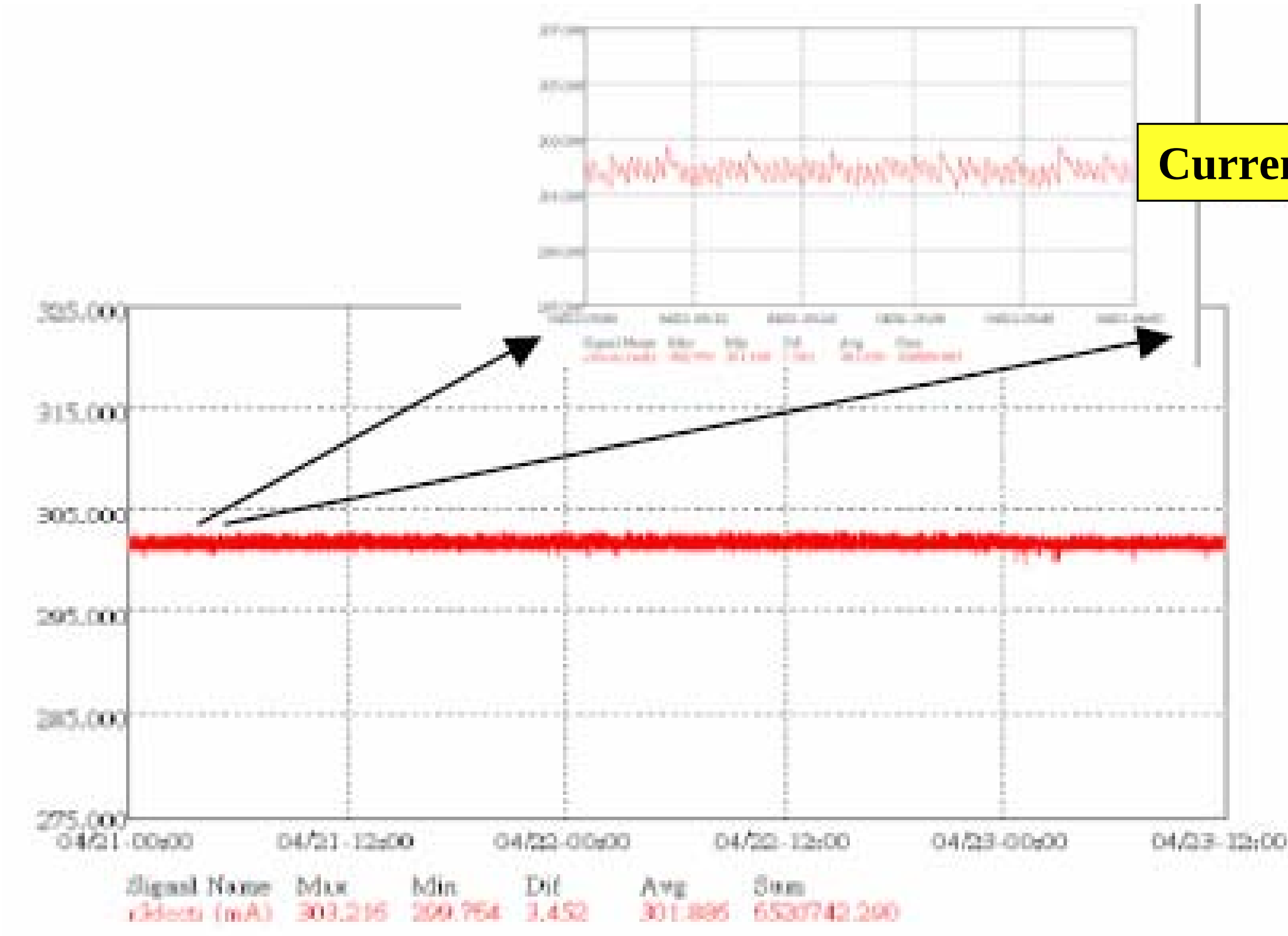
- Upgrade booster from 1.3GeV to 1.5 GeV for top-up operation in 2000.
- 200 mA top-up started in 2005.
- Now, 300 mA top-up for user experiments.



By Gwo-Huei Luo

Top-up at TLS (Con't)

- **Injection interval : 60 sec.**
- **Injection efficiency : 70 %**



Current stability : ± 0.2 %

Top-up Status (tested or planning)

Facilty	Energy [GeV]	Current [mA]	Emittance [nm.mrad]	Injector	Injection Efficiency	Current Stability	Operatinal Status	Top-up Status
UVSOR	0.75	350	27	0.75GeV Boost.	>80%	<0.6%	Oper. (1983)	Tested
PF	2.5	450	35	2.5GeV Li.	70 - 80%	±0.1%	Oper. (1983)	Tested
NSRL	0.8	300	160	200MeV Li.			Oper. (1991)	Planned
ESRF	6	200	3.7	6GeV Boost.	70%		Oper. (1993)	Tested
ALS	1~1.9	400	6.3	1.9GeV Boost.	>90%		Oper. (1993)	Planned
ELETTRA	2/2.4	330/150	7	2.5GeV Boost.	>95%	0.3%	Oper. (1994)	Tested
PLS	2.5	200	10.3	2.5GeV Li.	60%	<1%	Oper. (1995)	Planned (2010)
BESSY-II	1.72	300	6.1	1.72GeV Boost.	>90%	0.1%	Oper. (1999)	Tested
CLS	2.9	250	18	2.9GeV Boost.			Oper. (2003)	Tested
SPEAR-III	3	100 - 500	12	3GeV Boost	75 - 90%	1% - 0.1%	Oper. (2004)	Planned (2008)
Diamond	3	175 (300)	2.7	3GeV Boost.	90 - 95%	0.3%	Oper. (2007)	Tested
SOLEIL	2.75	250 (500)	3.74	2.75GeV Boost.	90 - 100%	0.1% - 1%	Oper. (2007)	Tested
ASP	3.0	200	7-16	3GeV Boost.	~ 90%		Oper. (2007)	Tested

Top-up Status (Con't)

Facilty	Energy [GeV]	Current [mA]	Emittance [nm.mrad]	Injector	Injection Efficiency	Current Stability	Operatinal Status	Top-up Status
SSRF	3.0	300	3.9	3GeV Boost.			Commis.	Tested
BEPC-II	2.5	250	76	1.89GeV Li.	50 - 60%		Commis.	Planned
PETRA-III	6	100 (200)	1.0	6GeV Boost.	>80%	0.1%	Constru.	Planned (2010)
ALBA	3	250 (400)	4.5	3GeV Boost.	>90%		Constru.	Planned (2010)
NSLS-II	3	500	2.1	3GeV Boost.	>90%	1%	Planned	Planned
TPS	3	400	1.7	3GeV Boost,	>90%	0.2%	Planned	Planned
CANDLE	3	350	8.4	3GeV Boost.			Planned	Planned

Top-up at Existing light sources

UVSOR-II : Booster Upgrade (650 MeV to 750MeV) .
Plan in 2008.

PF : Top-up at single bunch in 2007.

ESRF : Injection with Front-end open from 2003.

Elettra : New full energy booster was constructed.
Plan in 2008 or 2009.

ALS : Booster upgrade (1.5GeV to 1.95 GeV)

BESSY-II : Replacement of booster injector
(Microtron to Linac)

PLS : Plan in 2010.

SPEAR-III : plan in 2008.

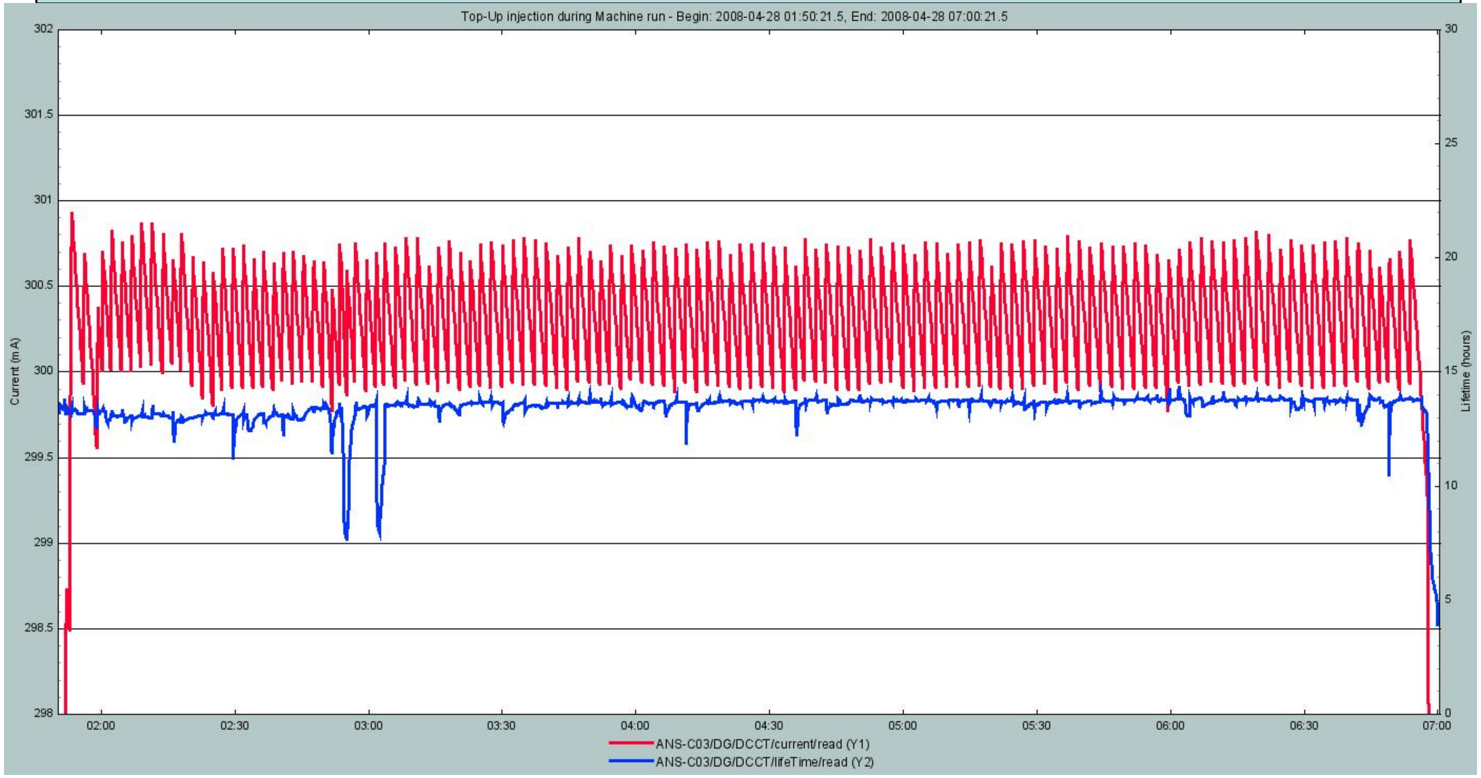
DELTA, BEPC-II, and CLS have plan of top-up.

Top-up at new light sources (SOLEIL)

Lifetime : 14 hours

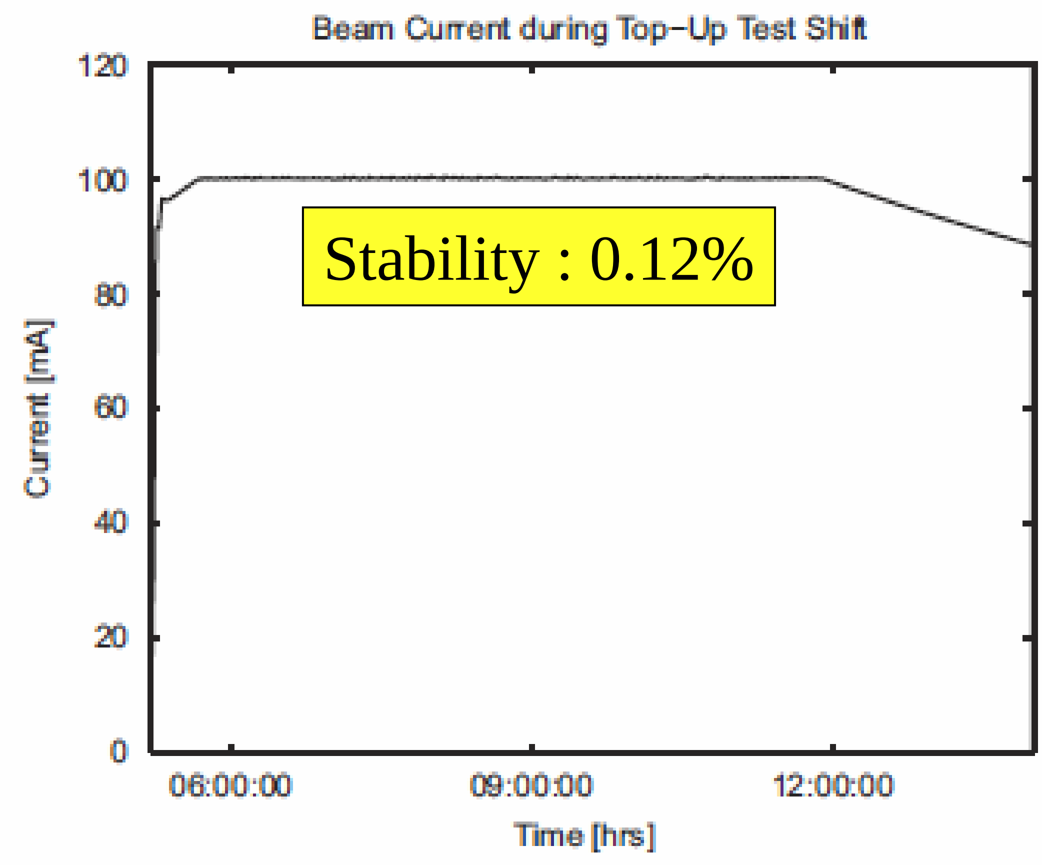
1 pulse of 0.8mA injected every 2min 20sec

I=300.3 mA ±0.5 mA ⟶ Current stability within 0.3%



by A. Naji

ASP:



D. J. Peake, et al, NIM A589(2008)143

SSRF : 100 mA ± 0.5 mA top-up operation daily.

Diamond: 175 mA top-up is tested. Stability is typically 0.3%.

Top-up : under construction , planning

PETRA-III : **plan in 2010.**

ALBA : **Booster emittance is 9 nm.rad.**

TPS : **Booster emittance is 4.29nm.rad.**

NSLS-II : **Booster emittance is 11.5 nm.rad (in same tunnel of storage ring) or 26.6 nm.rad (in separated building).**

CANDLE : **low-emittance booster.**

SAGA-LS, LNLS, NSRC (Siam), Indus-II, SESAME have no plan of top-up, because of no full energy injector.

Injection Efficiency

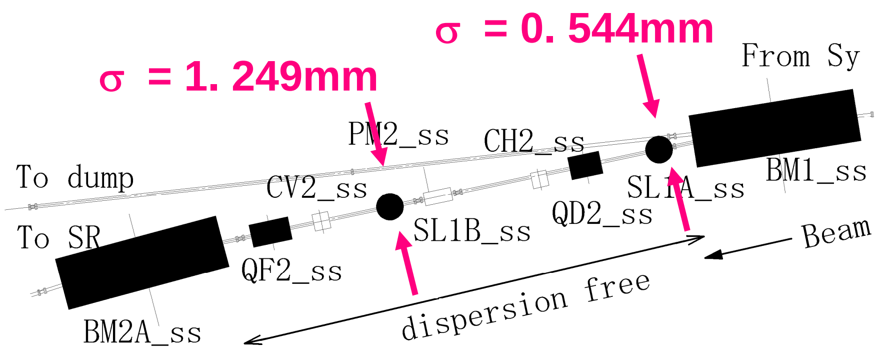
- **Injection efficiency is very important for radiation safety.**
- **Electrons lost at insertion devices will cause demagnetization of undulator magnets.**

- **Low-emittance injector to reduce the beam loss. (High injection efficiency)**
- **Conventional booster, ~100nm.rad : a beam collimation system in bean transport line is effective.**

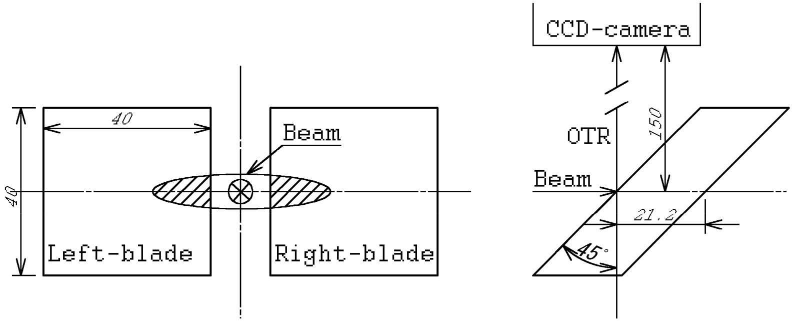
To keep high injection efficiency,

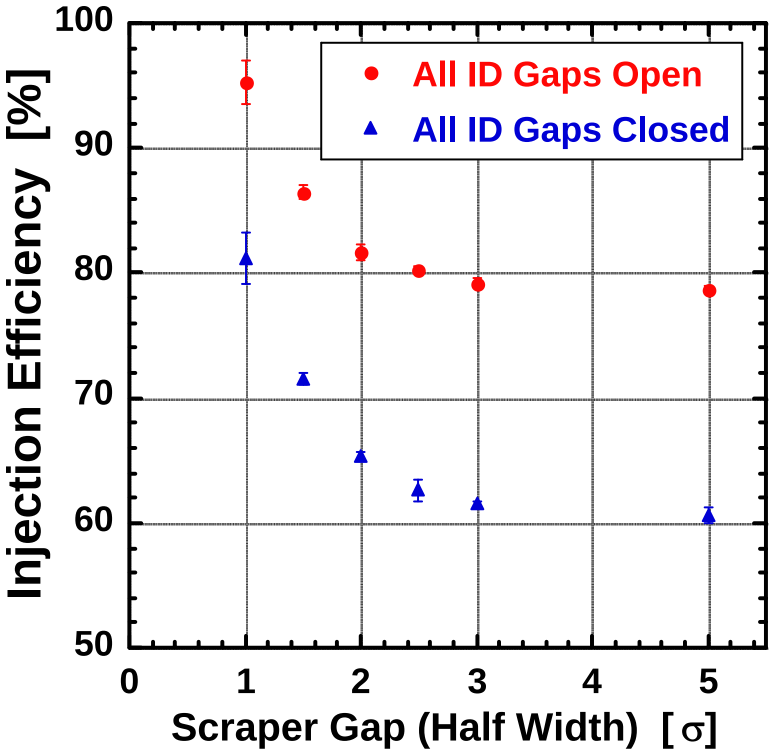
- **Beam Collimation in Transport Line**
- **Low Chromaticity Operation**
- **Beta-Distortion Correction**
- **Stability of Injection Orbit**

Beam Collimation in Transport Line at SPring-8



Phase difference : π/2



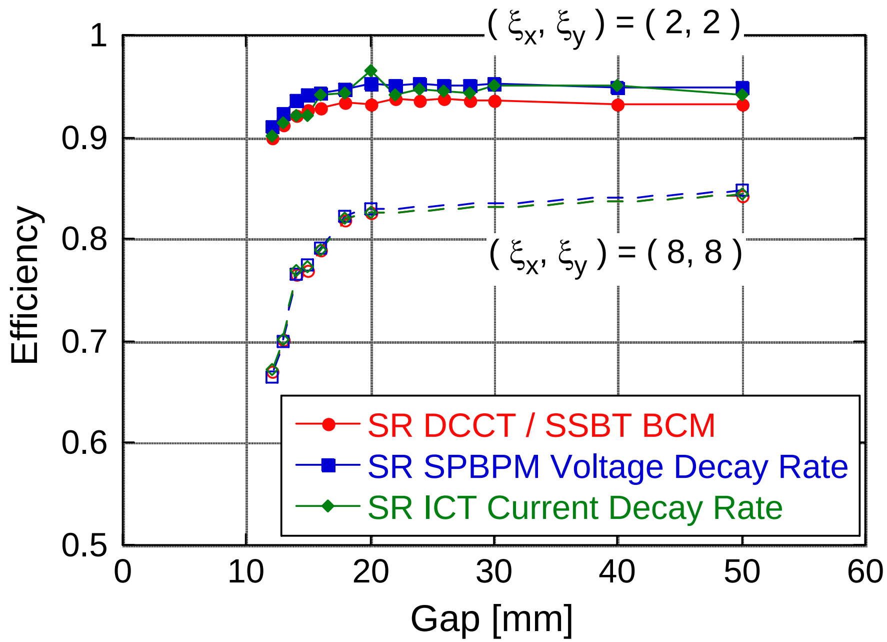


K. Fukami, et al., APAC04, p.103

- **In Top-Up Injection: ±1σ**
- **Injection beam position can become closer to storage ring.**

Reduction of Chromaticity

- **Low chromaticity-operation is effective for the reduction of the injection beam loss.**
- **Bunch-by-bunch feedback system assures the stable operation under the lower chromaticity.**
- **Combining the low chromaticity and the collimation system, the high injection efficiency could be achieved with all the gaps of IDs closed.**

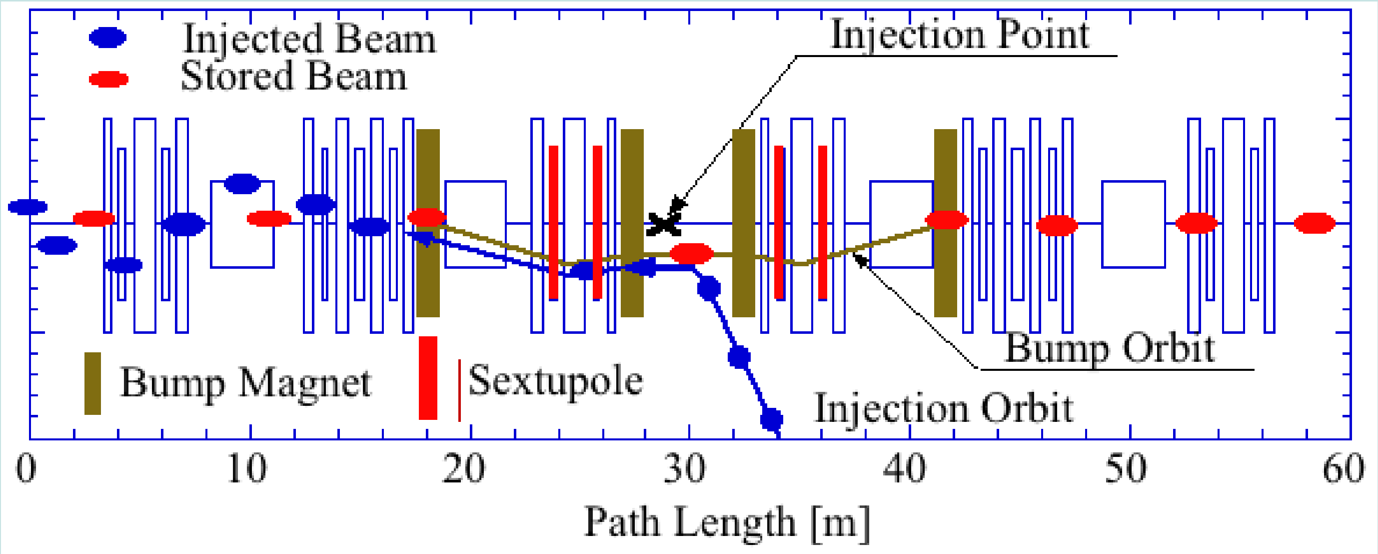


Suppression of Stored beam oscillation

Origins of stored beam oscillation.

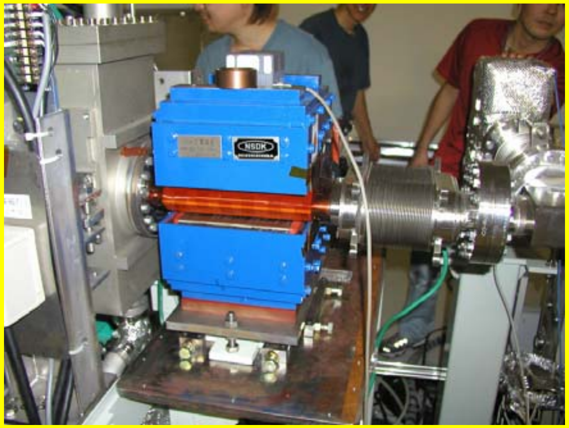
- **Injection bump magnet errors.**
- **Nonlinearity (sextupole) within an injection bump orbit.**

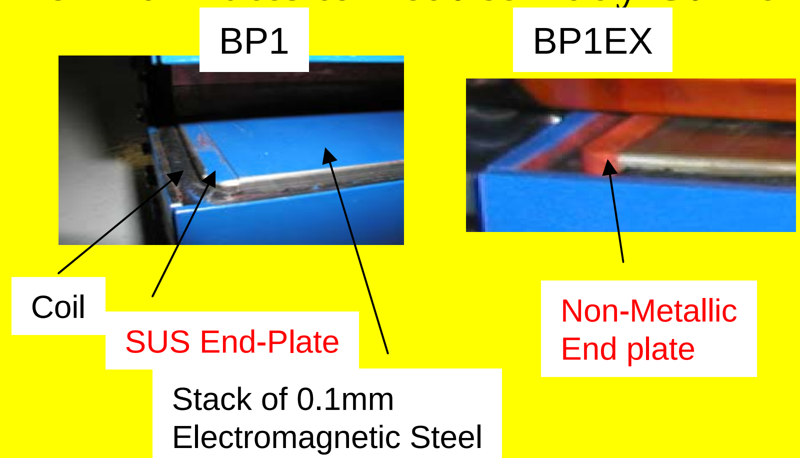
Magnet Arrangement of Injection Section at SPring-8

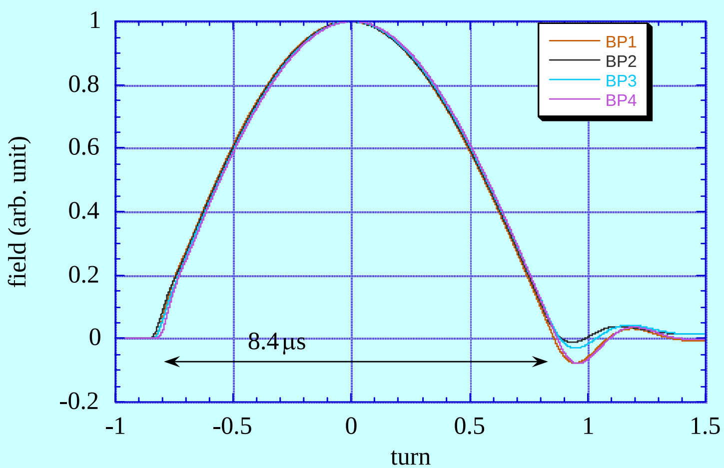


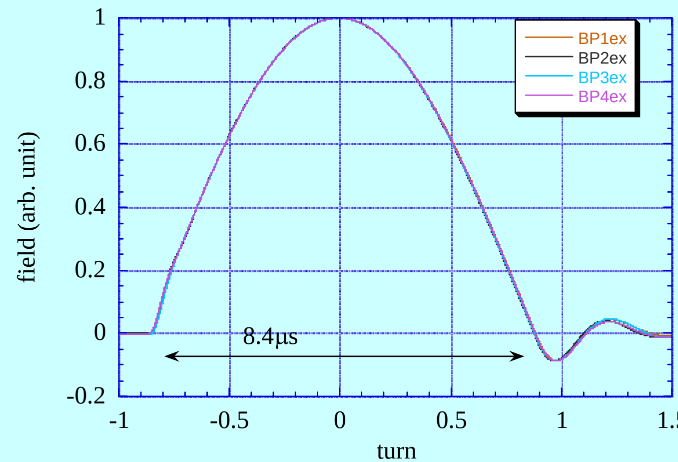
Suppression of Stored beam at SPring-8

- Non-Similarity of Magnetic Field of Bump Magnets
- New Magnets with Non-Metallic End-Plates to Reduce Eddy Current



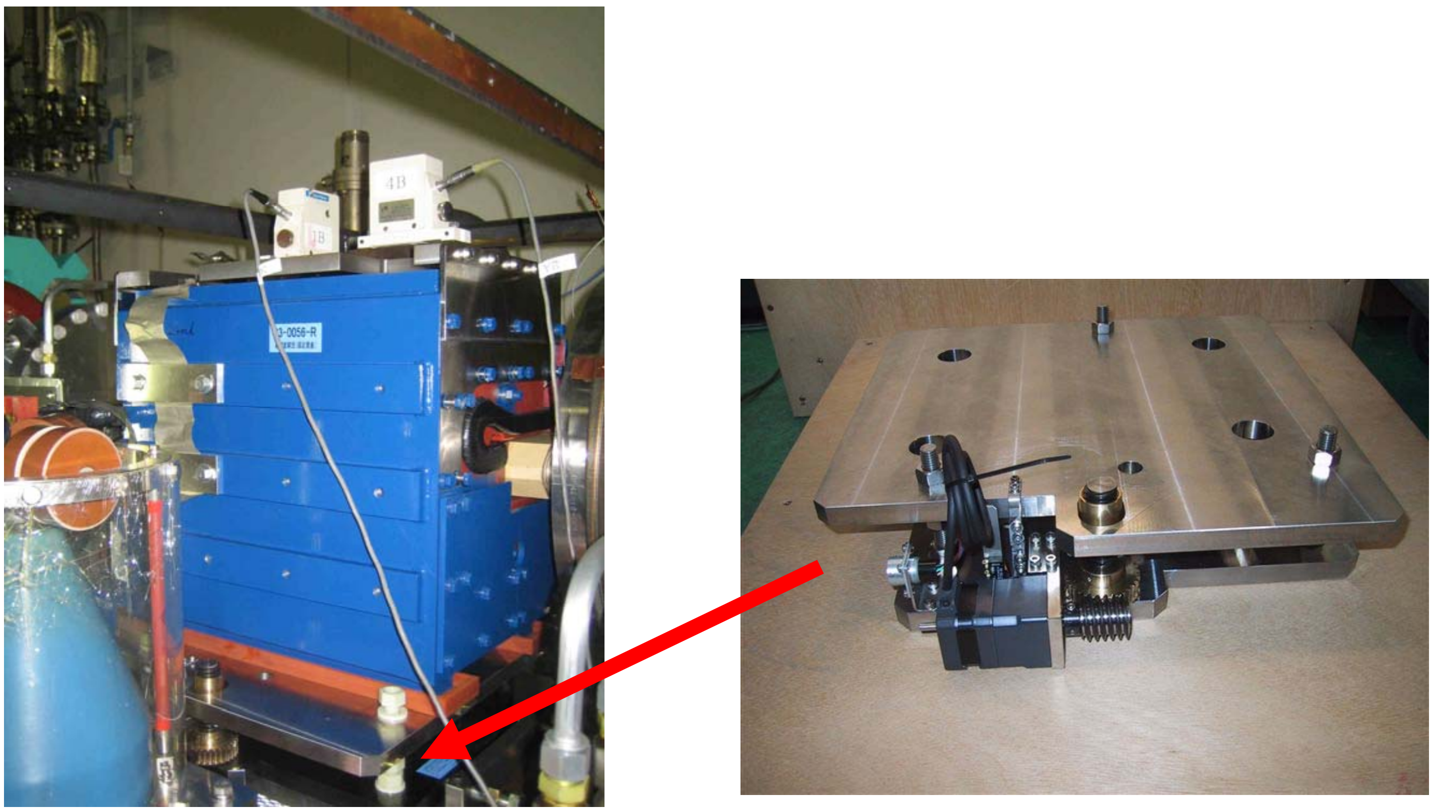






Suppressing Oscillation of Stored Beam at Top-up injection

Remote Tilt-Control of Bump Magnets for Suppressing Vertical Oscillation.

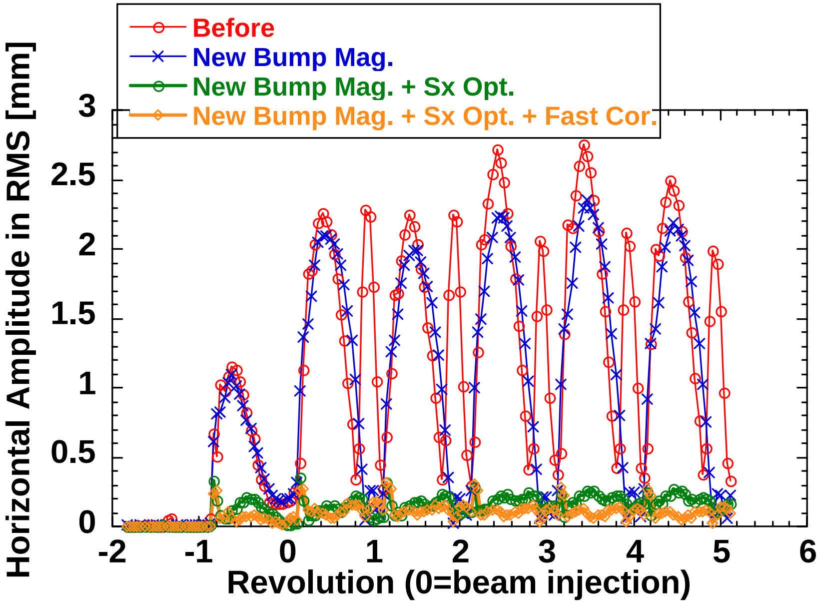


Result of Suppressing Oscillation

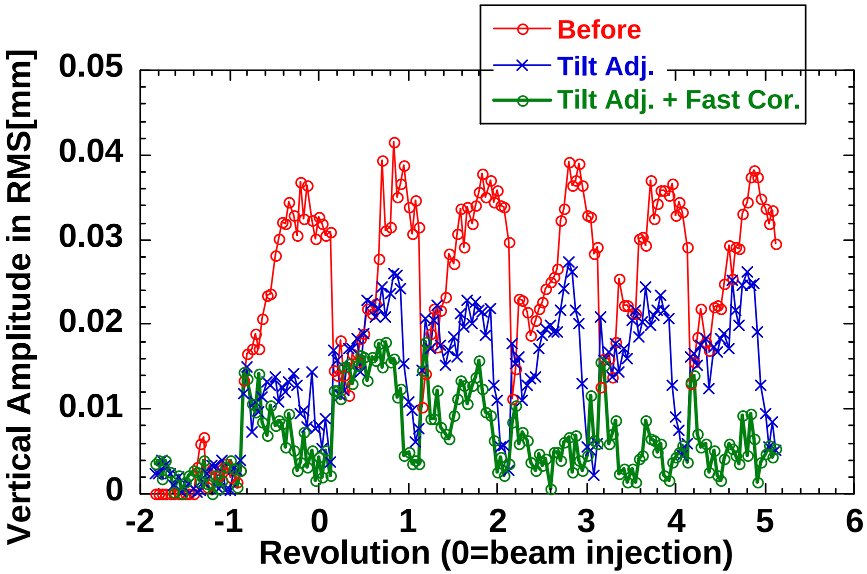
Correction of Residual Oscillation

- **Feedforward Correction with Pulsed Corrector Magnets (Arbitrary Waveform Generator + Amplifier)**

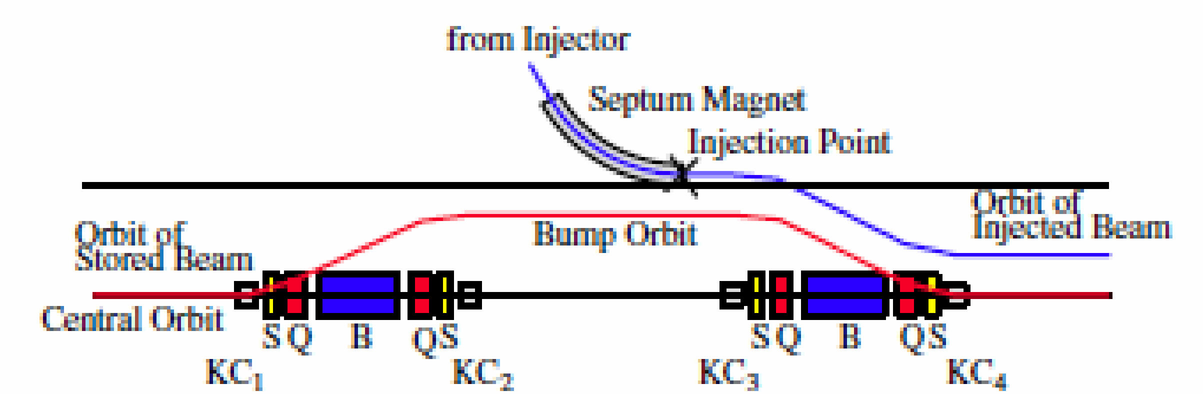
Horizontal



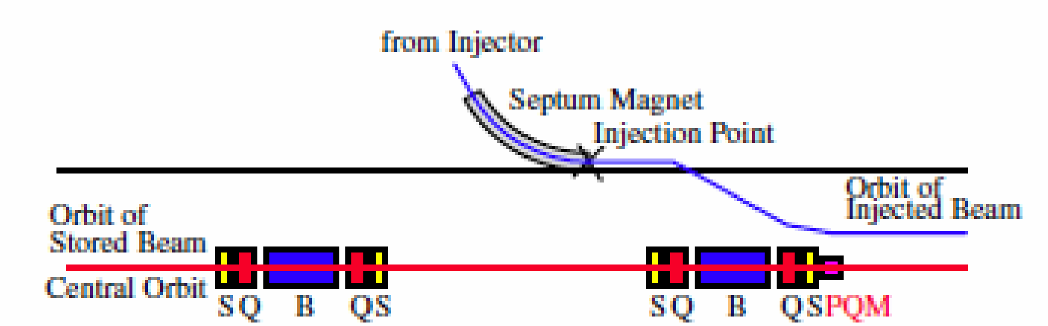
Vertical



New scheme for beam injection (proposed and tested at PF-KEK)



Conventional injection scheme using four septum.



New injection scheme using a pulsed Q-mag.

- **Center field is zero, and nonzero elsewhere.**
- **Stored beam is not kicked, but injected beam is kicked.**

K. Harada et al., PRST-AB, 10(2007)123501

Impact on user experiments

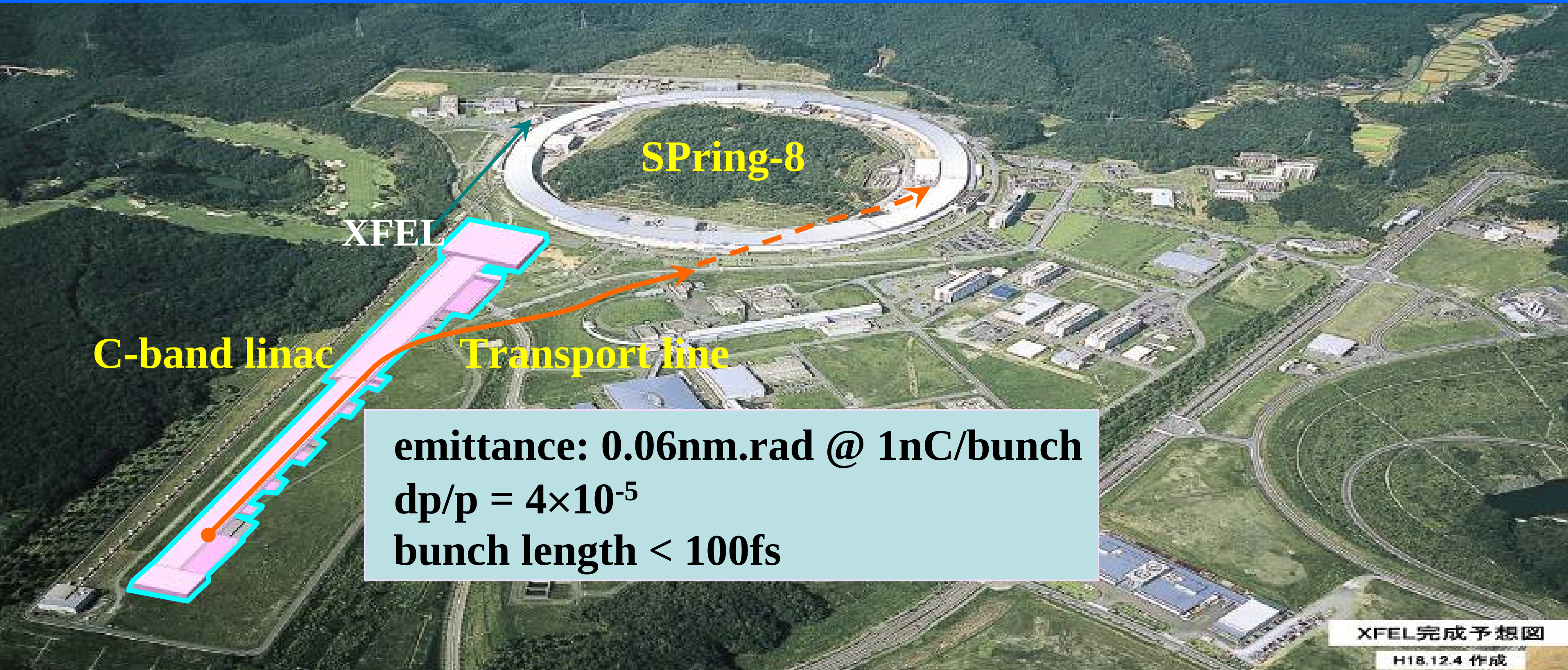
- **Increase in time averaged photon flux: which leads to a high counting statistic measurement due to constantly high beam intensity. Especially for the single bunch experiment a few times higher intensity were provided, because a various beam filling for the use of a single bunch has electrons with shorter lifetime. In addition, a continuous operation without shut down for beam refill excluded not only a time loss for experiment but also a time loss for the warm-up of optics.**
- **Current stability: The minimized current fluctuation of a stored beam leads to a constant heat load for optics including monochromators, which enables the achievement of a virtually absolute measurement with intensity monitor free. The constant flux improved the accuracy and reliability in spectroscopy experiments.**
- **No interruption by beam refilling : The operation without shut down for electron refilling allows us planning of long time stable measurement.**

Future of Top-up

- **Future of storage ring-based light sources go toward an ultra low-emittance and a short bunch.**
- **In these light sources, a lifetime of stored electron beam will be extremely short.**
- **Top-up operation will become increasingly important.**
- **It will be necessary to use a stable, high charged, and very low-emittance injection beam.**

• **From this point of view, a beam transport line from the C-band linac for the XFEL has been constructed for beam injection to the storage ring at SPring-8.**

Beam Transport line to Storage Ring from C-band linac of XFEL/SPring-8



emittance: 0.06nm.rad @ 1nC/bunch
$dp/p = 4\times10^{-5}$
bunch length < 100fs

Summary

- Five facilities is routinely operated with top-up operation for user experiment.
- At many existing and new facilities, the top-up operation is tested and planned.
- Current stability is realized within 10^{-3} ~10^{-4} .
- High Injection efficiency is very important for demagnetization of ID's magnets and radiation safety.
- Suppression of stored beam oscillation is very important for stable user experiments without injection-timing signal for data masking.
- There are many impact on user experiments by the stable top-up operation.

Thanks to

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P. Kuske (BESSY-II), R. Hettel (SPEAR-III),
Koda (SAGA), G. Singh (Indus-II),
P. Klysubun (NSRC), R. Bartolini (Diamond),
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Thank you for your attention.