Commissioning of New Synchrotron Radiation Facilities

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Outline

- Overview of Synchrotron Radiation Facilities
- Commissioning of New SR Facilities
- Commissioning Approaches
- Summary and Conclusions

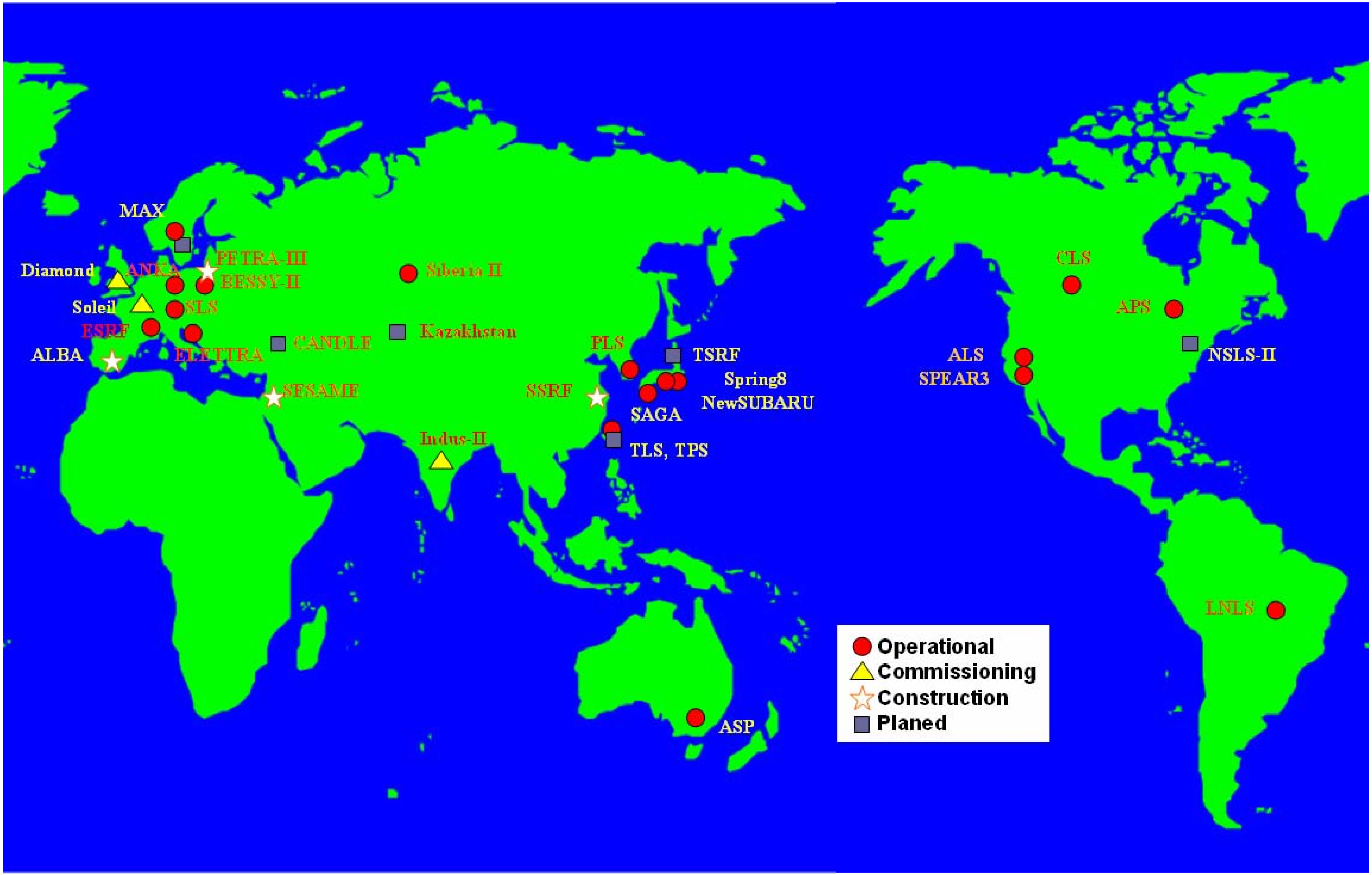
Acknowledgements

R. P. Walker and R. Bartolini of DLS, J. M. Filhol and A. Nadji of SOLEIL, G. LeBlanc and M. Spencer of ASP, M. Eriksson of MAX-Lab, S. Kotaiah of Indus-2 and Q. Qin of IHEP.

Synchrotron Radiation Facilities

- **Over the past 30 years, design and construction of dedicated SR facilities have been continuously carried out all around the world. Currently there are about 50 SR light sources in operation and about 20 of them are third generation light sources;**
- From the mid-1970s to the mid 1980s, second generation light sources were designed and constructed;
- From the mid-1980s, third generation light sources have been designed and constructed;
- Since the Mid-1990s, the construction of intermediate third generation light sources has been the focus of efforts worldwide;
- Meanwhile compact synchrotron radiation facilities have been designed and constructed.

Third Generation Light Sources around the world

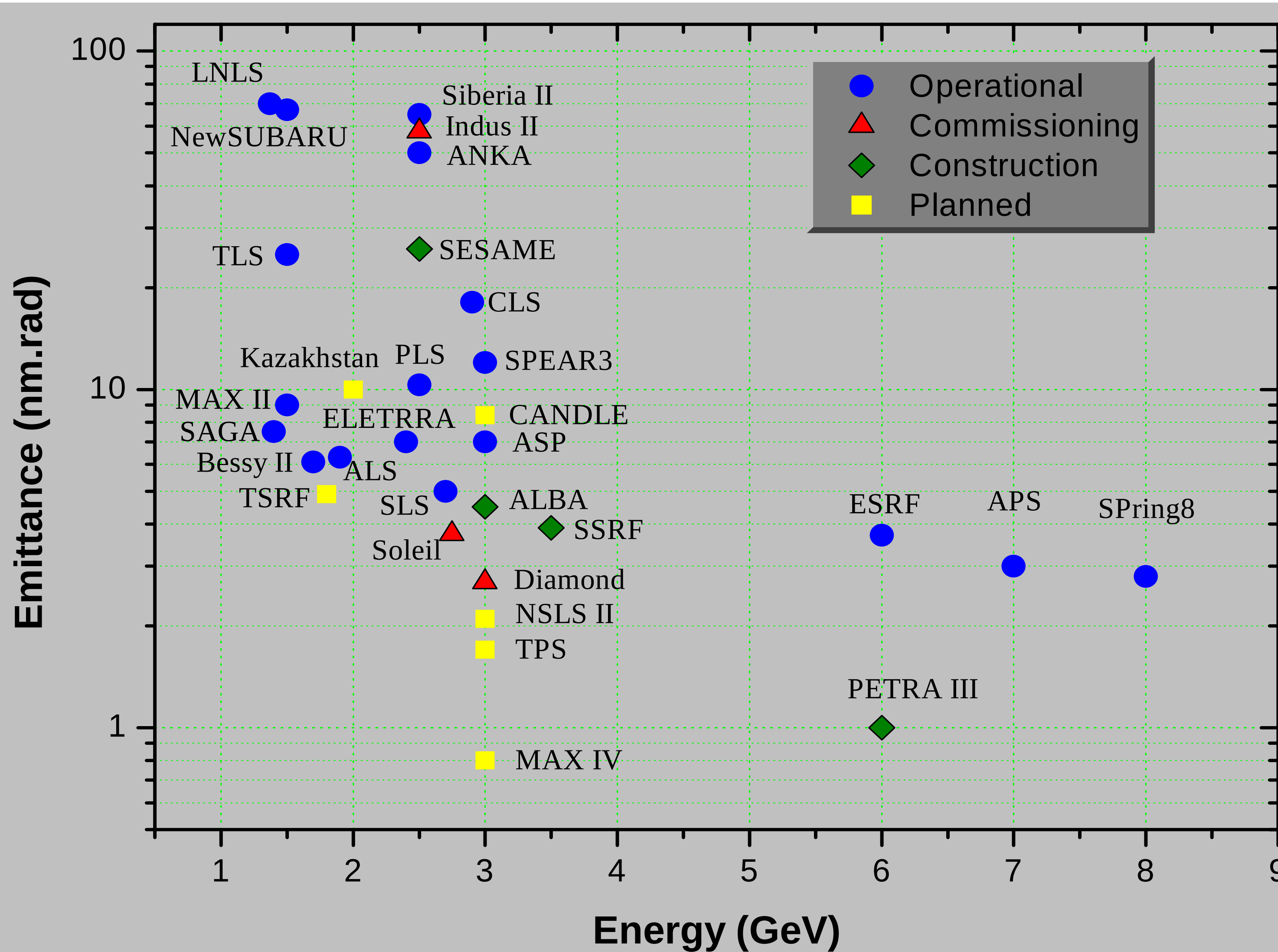


Third Generation Light Sources in Operation

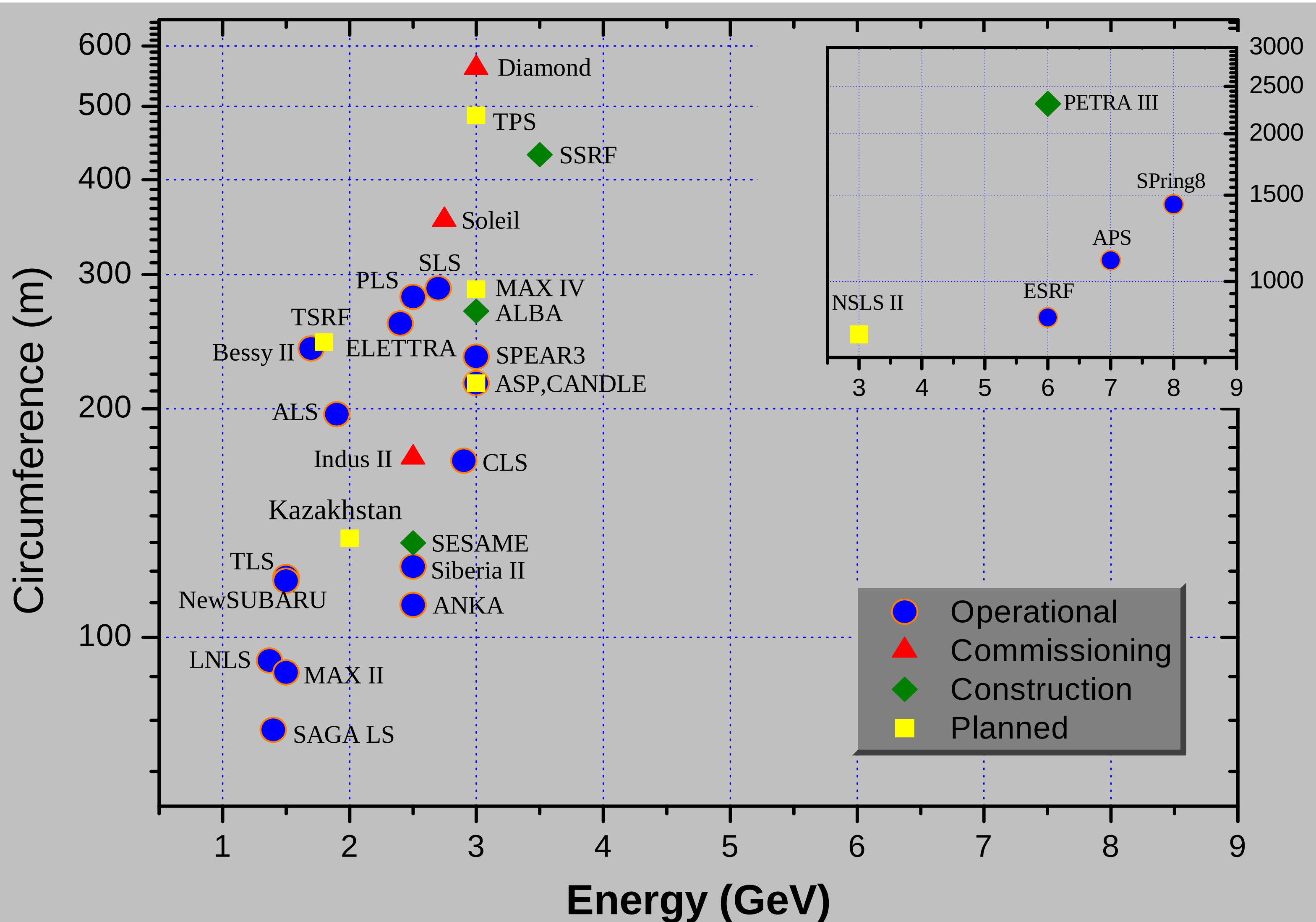
Light Source	Energy (GeV)	Circumference (m)	Emittance (nm.rad)	Current (mA)	Straight Section	Status
ESRF	6.0	844.4	3.7	200	32×6.3m	Operational(1993)
APS	7.0	1104	3.0	100	40×6.7m	Operational(1996)
SPring-8	8.0	1436	2.8	100	44×6.6m, 4×30m	Operational(1997)
ALS	1.9	196.8	6.3	400	12×6.7m	Operational(1993)
TLS	1.5	120	25	240	6×6m	Operational(1993)
ELETTRA	2.0/2.4	259	7	300	12×6.1m	Operational(1994)
PLS	2.5	280.56	10.3	200	12×6.8m	Operational(1995)
LNLS	1.37	93.2	70	250	6×3m	Operational(1997)
MAX-II	1.5	90	9.0	200	10×3.2m	Operational(1997)
BESSY-II	1.7	240	6.1	200	8×5.7m, 8×4.9m	Operational(1999)
Siberia-II	2.5	124	65	200	12×3m	Operational(1999)
NewSUBARU	1.5	118.7	38	500	2×14m, 4×4m	Operational(2000)
SLS	2.4-2.7	288	5	400	3×11.7m, 3×7m, 6×4m	Operational(2001)
ANKA	2.5	110.4	50	200	4×5.6m, 4×2.2m	Operational(2002)
CLS	2.9	170.88	18.1	500	12×5.2m	Operational(2003)
SPEAR-3	3.0	234	12	500	2×7.6m,4×4.8m,12×3.1m	Operational(2004)
SAGA-LS	1.4	75.6	7.5	300	8×2.93m	Operational(2005)

Third Generation Light Sources in Operation

Third Generation Light Sources



Third Generation Light Sources



Intermediate Energy SR Facilities

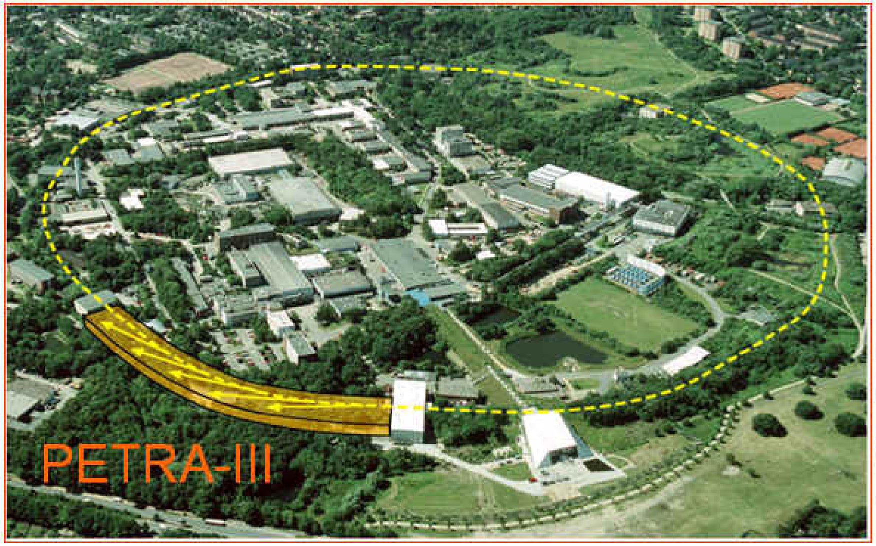
- **Since the beginning of 21st century, intermediate energy light sources have been being successively put into operation;**
- SLS in 2001, ANKA in 2002, CLS in 2003, SPEAR3 in 2004;
- Another four, Diamond, SOLEIL, ASP, Indus-2 are becoming operational this year;
- Three more will be operational in the coming years, SSRF in 2009, ALBA in 2010 and SESAME probably in 2011;
- NSLS-II, TPS and MAX-IV may start operation before 2015;
- **As a special case, a partially dedicated 2.5GeV synchrotron radiation facility, BSRF/BEPC-II, was put into operation in 2006.**
- **Other intermediate light source plans are under consideration or R&D in countries including Armenia (CANDLE), Poland and South Africa;**

New Third Generation Light Sources

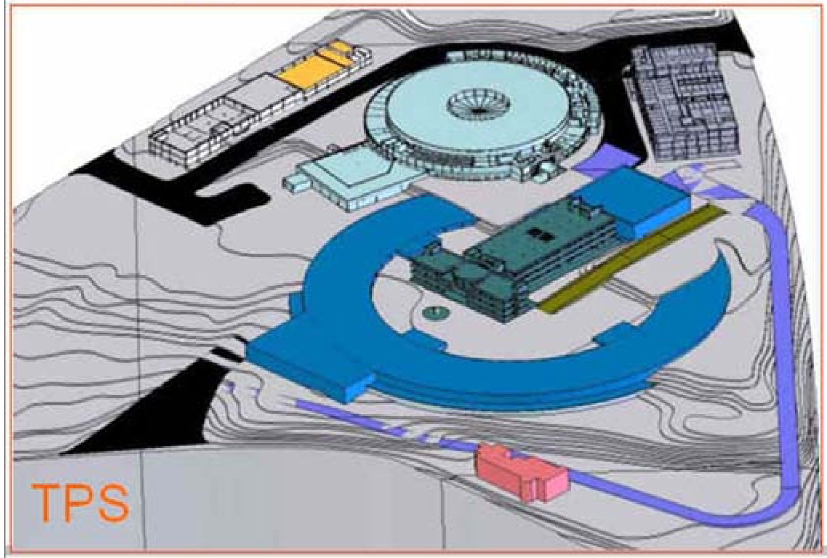
Light Source	Energy (GeV)	Circumference (m)	Emittance (nm.rad)	Current (mA)	Straight Section	Status
ASP	3.0	216	7-16	200	14×5.4m	Commis & Oper
Indus-2	2.5	172.5	58	300	8×4.5m	Commis & Oper
Diamond	3.0	561.6	2.7	300	6×8m, 18×5m	Commis & Oper
SOLEIL	2.75	354.1	3.74	500	4×12m, 12×7m, 8×3.8m	Commis & Oper
PETRA-III	6.0	2304	1.0	100	1×20m, 8×5m	Construction
SSRF	3.0	432	3.9	300	4×12m, 16×6.5m	Construction
ALBA	3.0	268.8	4.5	400	4×8m, 12×4.2m, 8×2.6m	Construction
SESAME	2.5	133.12	26	400	8×4.44m, 8×2.38m	Construction
CANDLE	3.0	216	8.4	350	16×4.8m	Planned
MAX IV	1.5/3.0	287.2	0.34/0.8	500	12×4.6m	Planned
NSLS-II	3.0	780	2.1	500	15×8m, 15×5m	Planned
TPS	3.0	486	1.7	400	6×11.7m, 18×7m	Planned

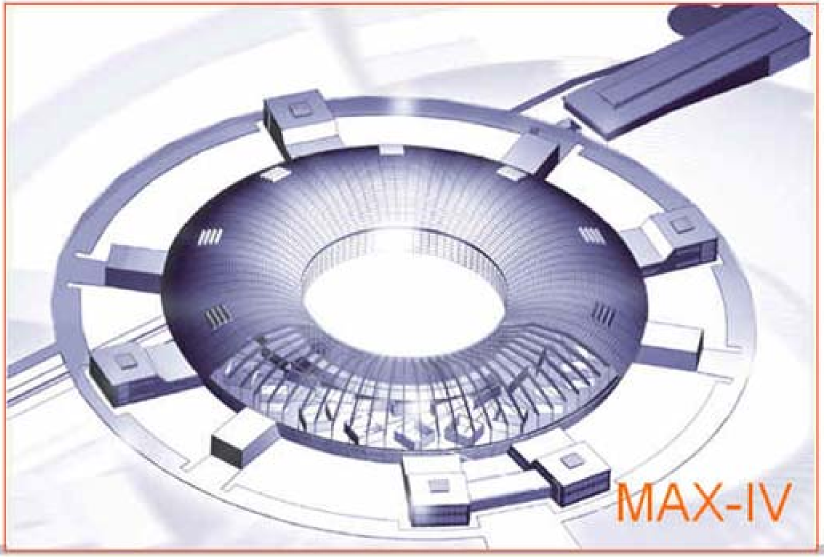
New Synchrotron Radiation Facilities

New Synchrotron Radiation Facilities



New Synchrotron Radiation Facilities





Low/High Energy and ultimate SR Facilities

- **Low energy light sources**
  - SAGA-LS operational in 2005, MAX-III has been just commissioned and MLS is under installation;
  - Many project plans in design and proposal stage, including 1.5GeV MAX-IV VUV source, proposals from INP in republic of Kazakhstan, Kayoto University and Tohoku University in Japan;
- **New high energy light sources: may be a practical option for future conversion of high energy machines, PETRA-III is a good model;**
- **Ultimate storage ring light sources: design studies to increase brilliance by two orders of magnitude have been performed at ESRF, APS and SPring-8. Top-up injection, feedbacks, damping wiggler scheme and probably longitudinal varying field dipole are the key technologies;**

Upgrades of SR Facilities

- High Brilliance by low emittance or high current;
- Micron to sub-micron beam orbit stability;
- Various polarizations of VUV and X-ray radiation;
- Higher photon energy based on superbend or higher harmonics of undulators;
- Short pulse (sub-ps) schemes;
- Top up injection operation;
- Coherent synchrotron radiation;
- Canted or double Undulator schemes;
- …

New Technologies for SR Facilities

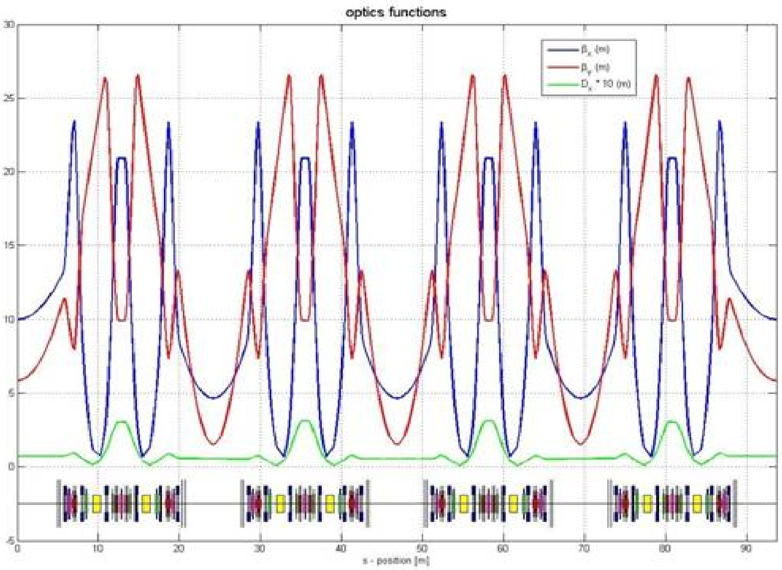
- Various novel insertion devices;
- Beam feedbacks and orbit feedbacks;
- Superconducting cavities;
- Superconducting magnets;
- Digital technologies: BPM system, power supply and LLRF system;
- …

New SR Facilities towards operation

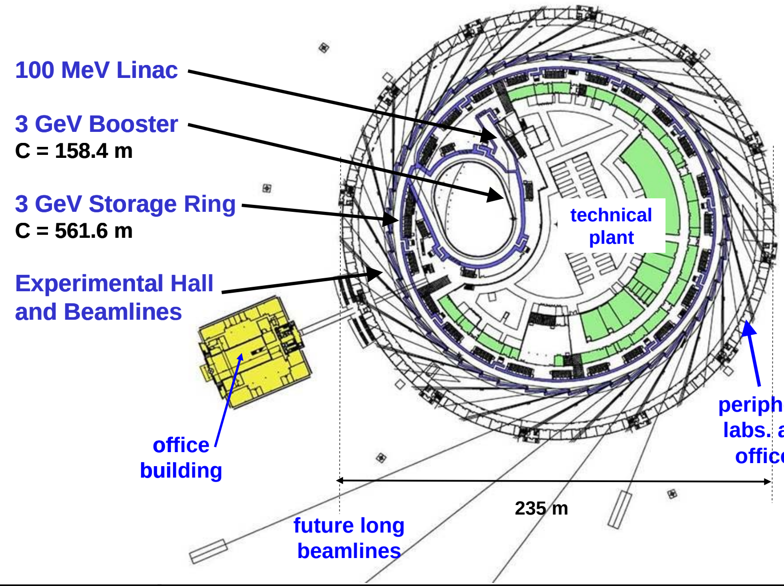
- Diamond: the New UK's light source;
- SOLEIL: the French light source;
- The Australian Synchrotron;
- Indus-2: the Indian light source;
- The MAX-III light source;
- BSRF/BEPC-II: the new partially dedicated light source;
- SSRF: the Shanghai light source;

The DIAMOND Light Source

Energy	3 GeV
Circumference	561.6 m
Straight Section	6x8m, 18x5m
Emittance	2.7nm.rad
Beam current	300 mA



Courtesy R. P. Walker, APAC07



Beamline	ID	Type	Max. rms phase error (°)
I02	U23	In-vacuum	3.9
I03	U21	In-vacuum	3.1
I04	U23	In-vacuum	2.8
I06	HU64	APPLE-II	5.5
I15	SCW	3.5 T Superconducting Multipole Wiggler	-
I16	U27	In-vacuum	2.3
I18	U27	In-vacuum	2.1
I22	U25	In-vacuum	2.1

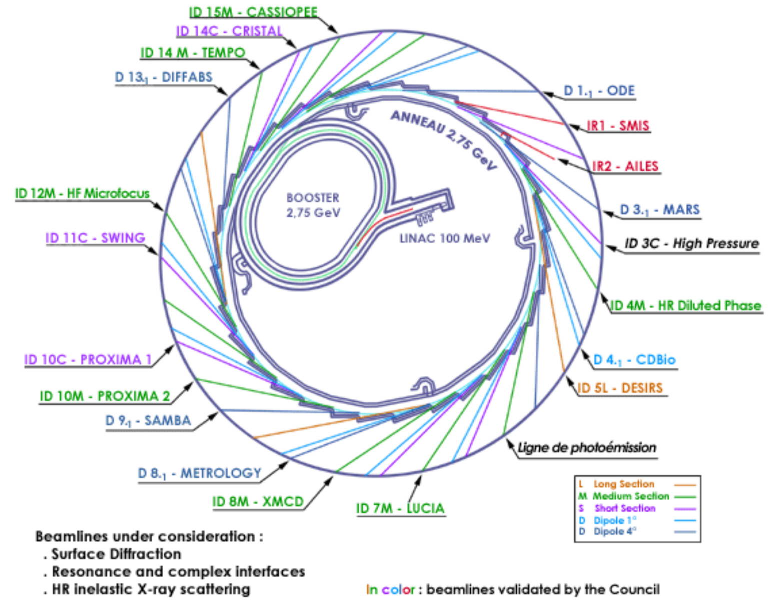
DIAMOND Commissioning Milestones

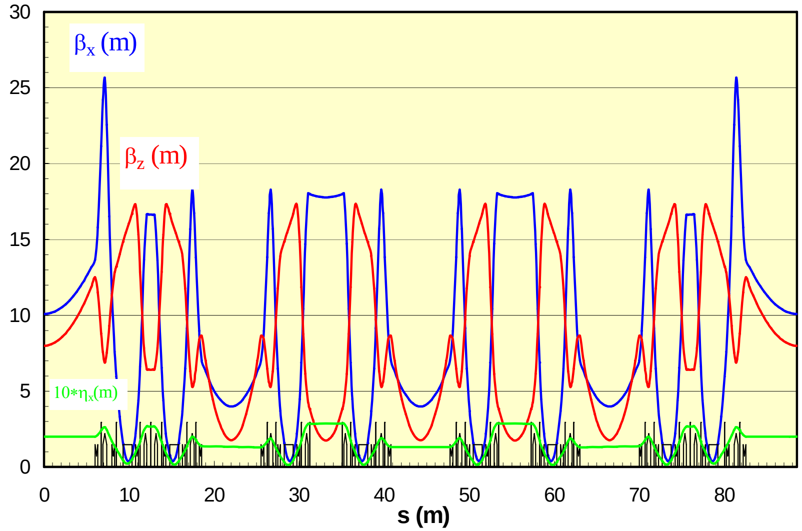
- May 2006, commissioned at 700MeV (lack of water cooling);
- Sept. 4 2006: first Injection at 3GeV;
- Sept. 6, 2 mA stored;
- Oct. 10, 90 mA stored;
- Oct. 12, start of beamline commissioning;
- Nov. 11, 100 mA achieved;
- Jan. 12, 2007, 150 mA achieved;
- 8 IDs have been installed and commissioned

Courtesy R. P. Walker, APAC07 and R. Bartolini, TUPMN085, PAC07

The SOLEIL Light Source

Energy	2.75 GeV
Circumference	354.1m
Straight Section	4×12m, 12×7m, 8×3.8m
Emittance	3.74 nm-rad
Beam current	500 mA





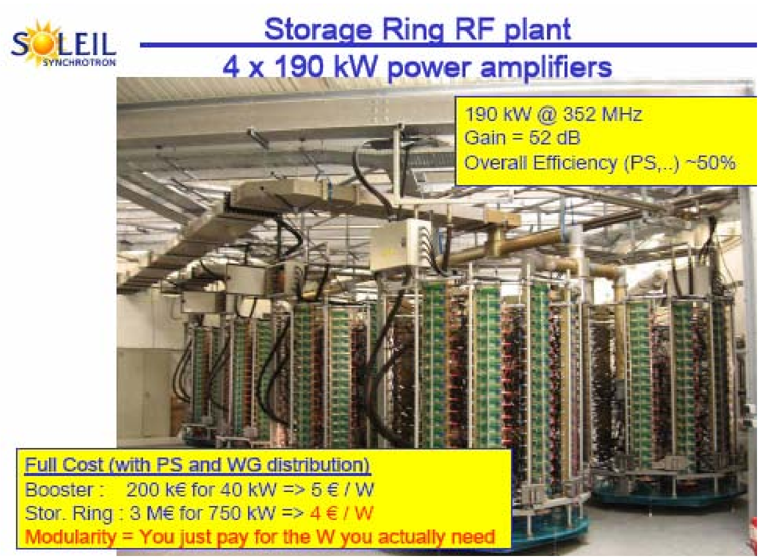
ID	Type	Spectral Range	Polarization
HU640	EM (AC/DC)	5eV-40eV	Elliptical
HU256x2	EM (DC)	10eV-300eV	Elliptical
HU80x2	PM (Apple-II)	35eV-2keV	Elliptical
U20x2	PM (hybrid)	4keV-15keV	Linear

Courtesy L. Nadolski, APAC07

Courtesy J. M. Fihol, et al, SRI06

SOLEIL Commissioning Milestones

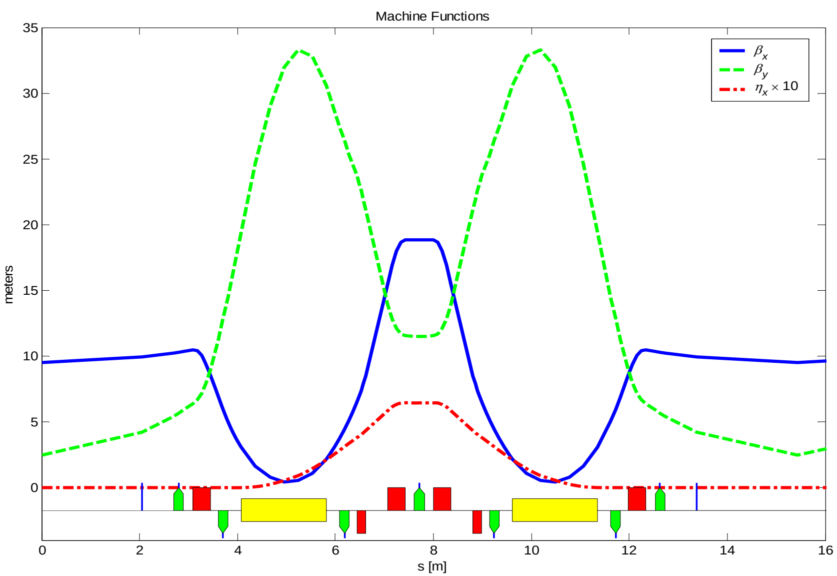
- May 14, 2006, First injection and turn;
- Jun.4, First stored beam and first beam accumulation of 8.35mA achieved;
- Jul. 4, current of 100mA achieved;
- Sept.16, 200mA obtained;
- Sept. 25 300mA achieved after 8 effective weeks of commissioning;
- Oct.15, 2006 beam lifetime of 8h with 100mA in 312 bunches achieved;
- 7 IDs installed and commissioned;



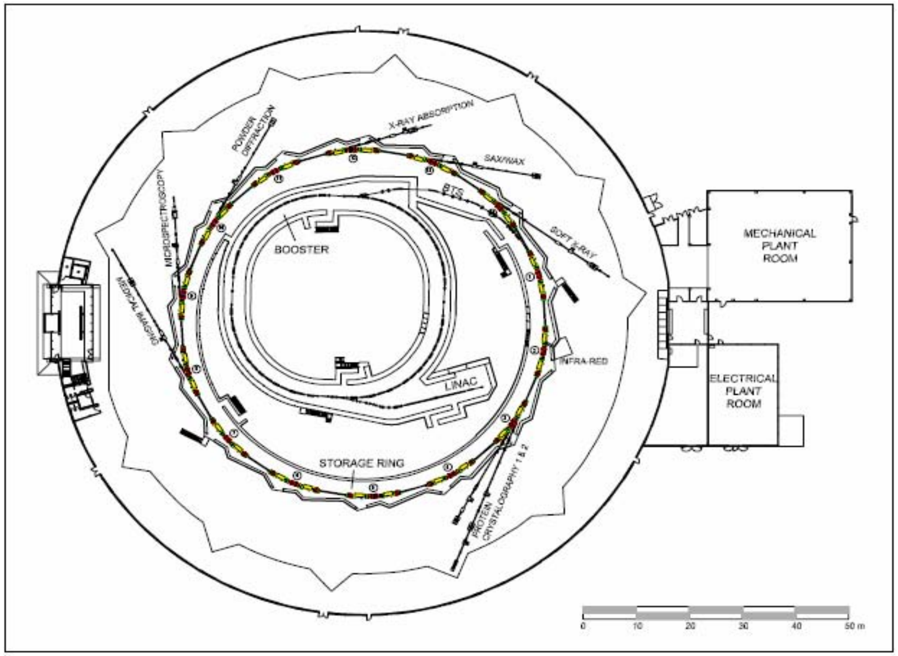
Courtesy A. Nadji, TUPMN009, PAC07

The Australian Synchrotron Project

Energy	3 GeV
Circumference	216m
Straight Section	14x5.4m
Emittance	7-16 nm-rad
Beam current	200 mA



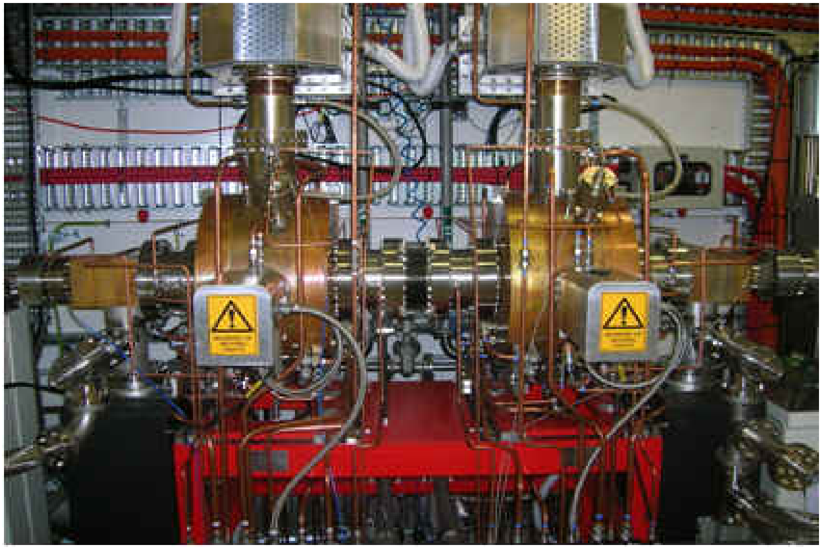
Courtesy G. LeBlanc, APAC07



3ID	Protein Crystallography 2	In-vacuum undulator
8ID	Imaging & Medical Therapy	Superconducting wiggler
9ID	Microspectroscopy	In-vacuum undulator
12ID	X-ray Absorption Spectroscopy	Wiggler
13ID	Small & Wide X-ray Scattering	In-vacuum undulator
14ID	Soft X-ray Spectroscopy	Apple-II undulator

ASP Commissioning Milestones

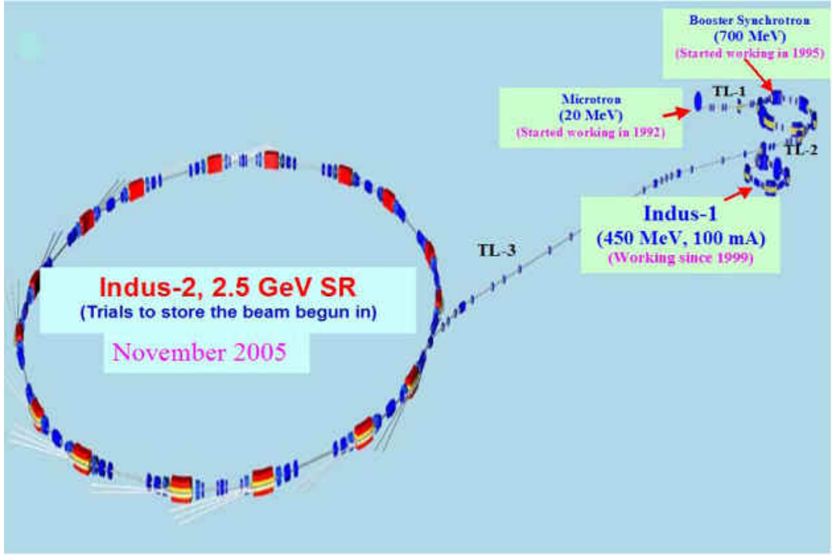
- Jun. 1, 2006, first beam in BTS;
- Jun. 8, first turn achieved;
- Jul. 14, First beam stored and stacked to 1mA;
- Jul. 21 10mA achieved;
- Mid-November, acceptance current of 100mA achieved;
- Dec. 15, 2006, 200mA obtained;
- Two IDs installed and commissioned;

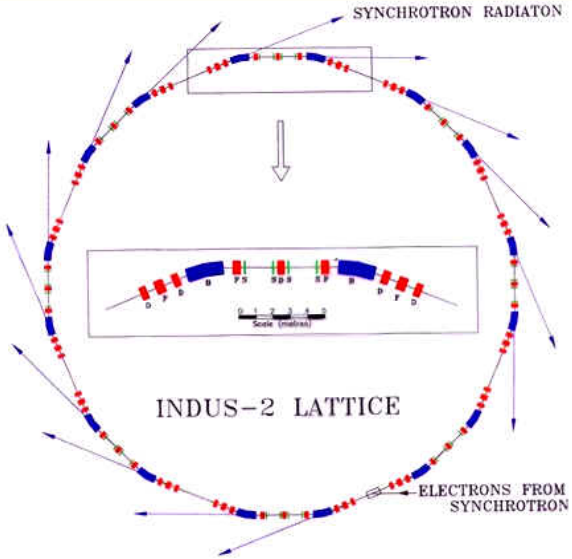


Courtesy Greg LeBlanc, APAC07
Alan Jackson, TUPMN001, PAC07

The Indus-2 Light Source

Energy	2.5 GeV
Circumference	172.5 m
Straight Section	8x4.5m
Emittance	58 nm-rad
Current	300 mA





Courtesy V.C. Sahni, APAC07

Indus-2 Commissioning Milestones

- Transfer line (TL-3) May 2005;
- First injection and four turns of beam circulations, Aug. 2005;
- First beam stored in Jan. 2006 and accumulated (few mA), in Feb. 2006;
- Successfully ramping from 450MeV to 2.4GeV, May-June ;
- First record of XRD, Sept. 2006
- 35mA@550MeV, 18mA@2GeV and 4.3mA@2.4GeV achieved;

Courtesy V.C. Sahni, APAC07
And S. Kotaiah

The MAX-III Light Source

- Compact ring, highly effective with ID partition of 54%, be a “prototype” for MAX-IV;
- Integrated Non-conventional Magnet, which makes its commissioning quite special and problem-free after the correction of magnet cells;
- Commissioning started in 2006, 350mA achieved with the help of 5th harmonic cavity;

Energy	0.7GeV
Circumference	36
Straight Section	8x2.45m
Emittance	13 nm-rad
Beam current	200mA

Courtesy M. Eriksson, EPAC06

The new BSRF

The new 2.5-GeV BSRF storage ring is comprised of two outer halves of the BEPC-II electron and positron rings, and it is operated as a partially dedicated SR source.

Energy	2.5 GeV
Circumference	241.13 m
Emittance	120 nm-rad
Current	250 mA

Courtesy C. Zhang and Q. Qin, APAC07

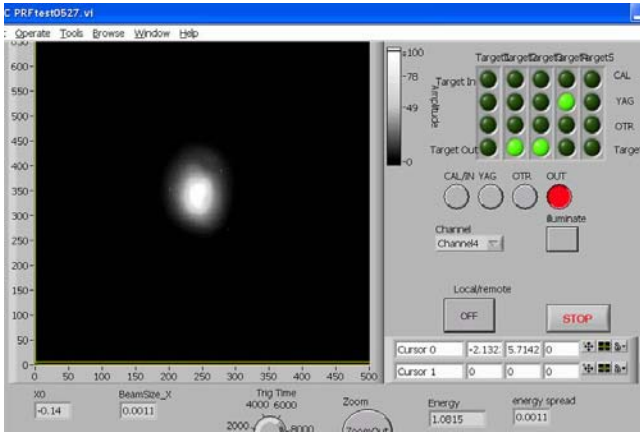
Commissioning Milestones

- Nov. 13, 2006, Injection at 1.89GeV;
- Nov. 13, First turn achieved;
- Nov. 18, First beam obtained;
- Dec. 25, 100mA at 2.5 GeV;
- 5 wigglers instal& commissioned;
- Operating at 2.5GeV/180mA now;

The Shanghai Synchrotron Radiation Facility

Energy	3.5 GeV
Circumference	432m
Straight Section	4x12m, 16x6.5m
Emittance	3.9 nm-rad
Beam current	300 mA

	Type	N	Min.Gap mm	Peak Field
EPU100	PPM	42	32	0.6(By) 0.33(Bx)
IVU25-1	Hybrid	80	6	0.94
IVU25-2	Hybrid	80	6	0.94
W79	Hybrid	19	14	1.2
W140	Hybrid	8	14	1.94



The SSRF linac beam

Commissioning of New SR Facilities

A summary of Commissioning Milestones of New SR Light Sources					
Light Source	Start	First Turn	Beam Accumulation	100mA	Open to Users
Indus-II	May ’05	Aug.27, ’05	Jan. ’06	Not yet	Not yet
Diamond **(0.7/3GeV)**	May 4th, ’06 **Sept. 4th ’06**	May 5th, ’06 **Sept.5th, ’06**	May 30th, ’06 **Sept 7th, ’06**	**Nov. 11th ’06**	**End Jan. ’07**
SOLEIL	May ’06	May14th, ’06	Jun. 4th, ’06	Jul.4th, ’06	Spring, ’07
ASP	June ’06	June 8, ’06	July 14th, ’06	Mid-Nov. ’06	April, ’07

Commissioning Approaches

- Injection and Accumulation
- Closed Orbit Minimization and Stabilization
- Optics and Machine Characterization
- Beam Current, beam lifetime and Instabilities
- Insertion Device Commissioning
- Top-up Operation Studies and Commissioning

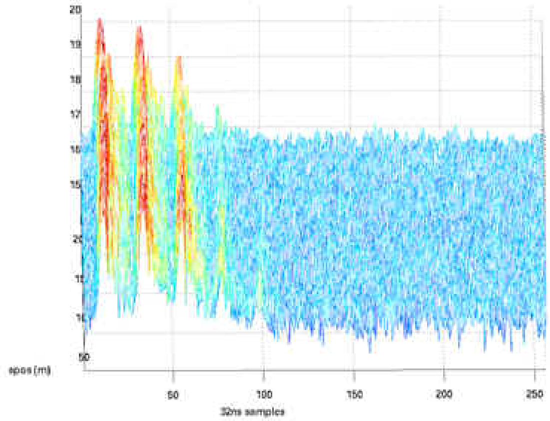
❑Injection and Accumulation

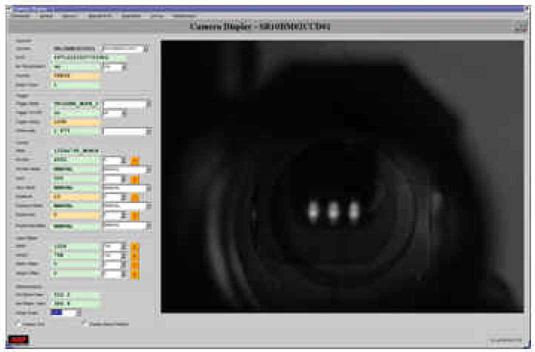
- Beam injection, storage and accumulation are the first approaches of the storage ring commissioning;
- Beam tests of alignment and field measurement quality of magnets as well as the performance of injection system, RF system, power supplies, control system and beam diagnostics;
- First play with injection system, and then play with sextupoles, correctors and RF;
- On axis injection can be deliberately used for correcting the first turn beam orbit and confirming the injection energy (SOLEIL);
- First turn and turn by turn BPM capabilities are valuable;
- First turn trajectory correction is the base of further commissioning;

Injection and Accumulation Cases

Courtesy G. LeBlanc, APAC07

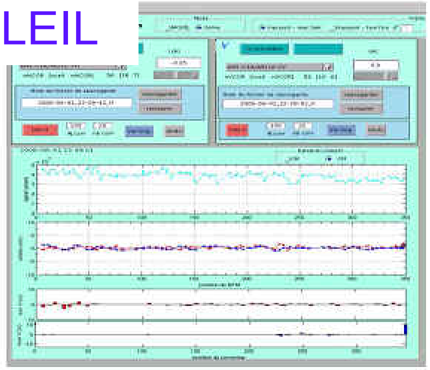
ASP

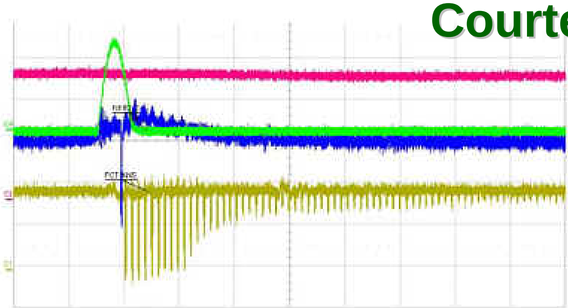


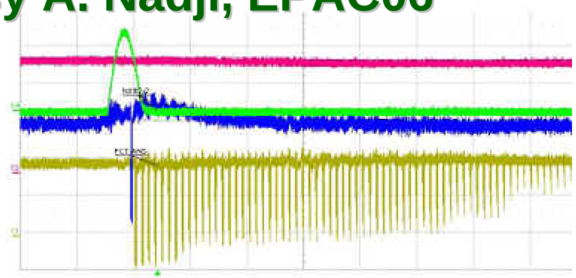


Courtesy A. Nadji, EPAC06

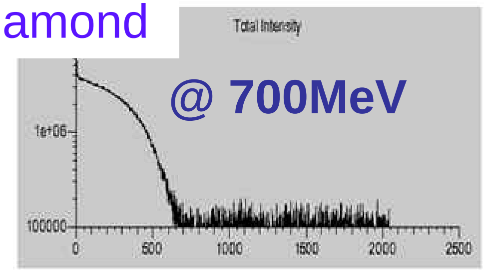
SOLEIL



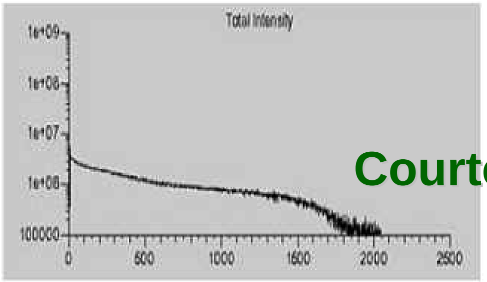


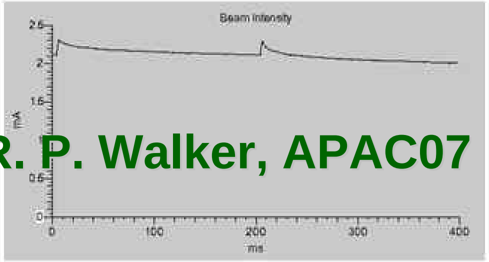


Diamond



@ 700MeV





Courtesy R. P. Walker, APAC07

❑Closed Orbit Minimization and Stabilization

- rms closed orbit of bare lattice is on the level of mm, thanks to the advanced alignment and field measurement of magnets;
- Use BBA to determine the offset of BPM-Quadrupole magnetic center: quadcenter (MML);
- Make SVD based closed orbit correction
- With the former 2 techniques, rms closed orbit can be corrected to the level of ten micrometers
- Study orbit motion correlations with thermal, mechanical and electrical factors, and use PSD analysis to identify vibration sources;
- Use SOFB to stabilize the orbit to micron or sub-micron level, which depends on the noise source situation

Closed Orbit Corrections

in rms value

	Bare Orbit (corrector off)	SVD based correction	Closed Orbit After BBA (corrector on)	Orbit Stability (with SOFB)
Diamond	4.8mm (H) 3.1mm (V)	0.7mm (H & V)	< 60 µm (H) <40 µm (V)	3~4 µm (H) 0.8 µm (V) (0~1kHz)
SOLEIL	3.1mm(H) 0.41mm (V)		42µm (H) 78 µm (V)	<2 µm (H, V) (0~100Hz)
ASP			~16 µm	

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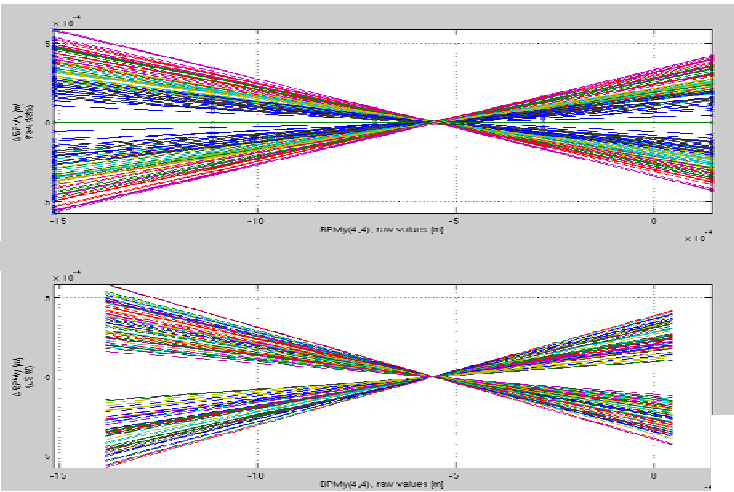
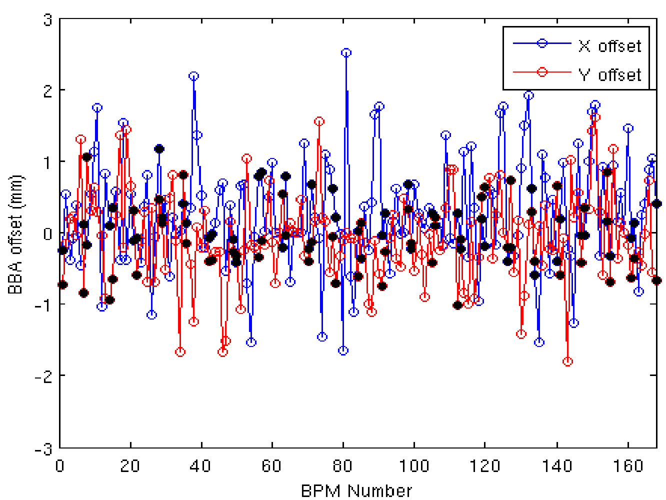
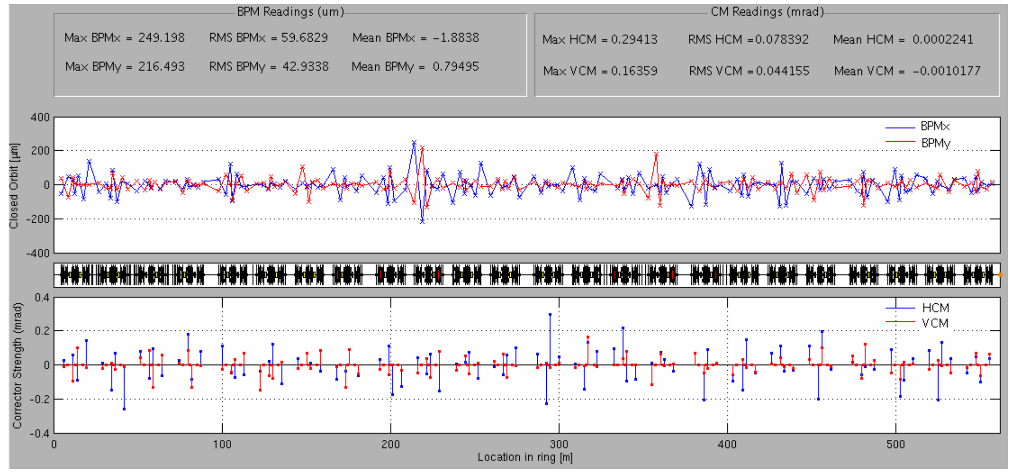
Diamond BBA, close orbit correction and orbit PSD

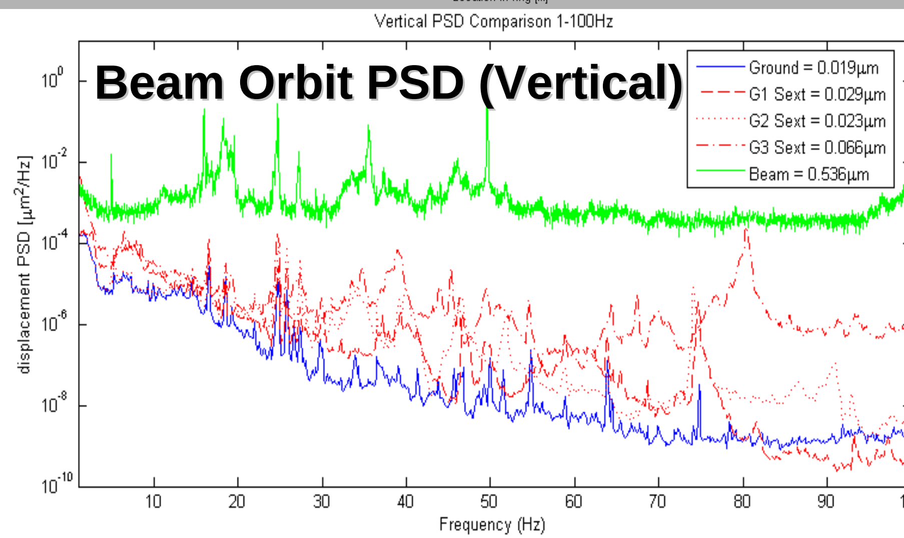
Beam Based Alignment





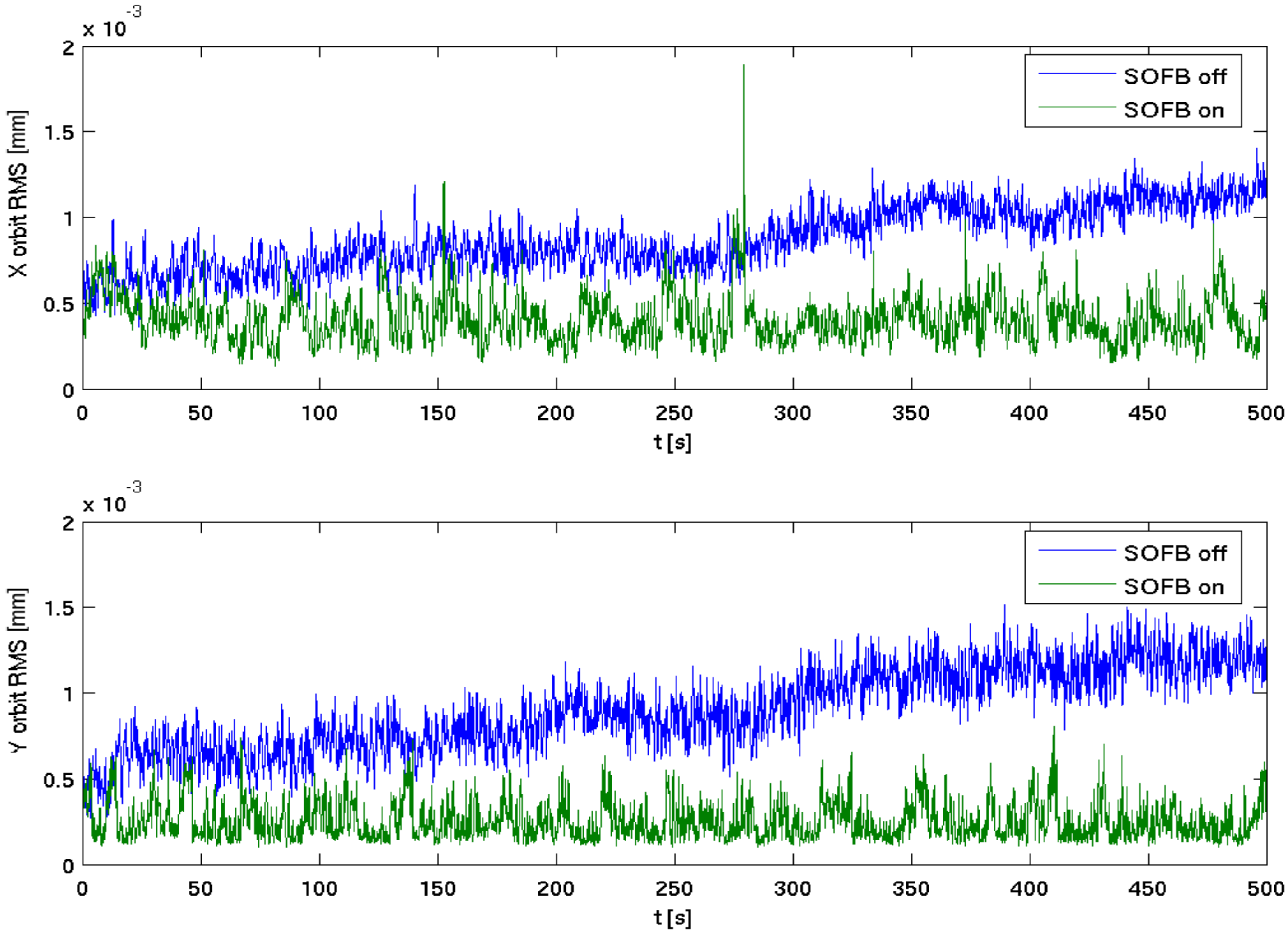
Closed Orbit GUI





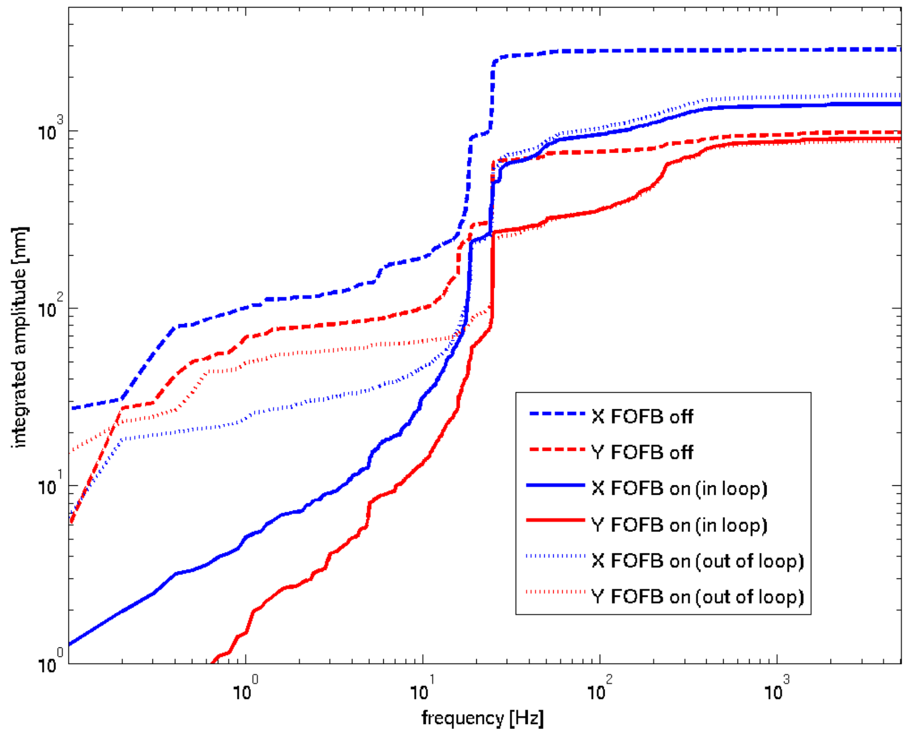
Courtesy R. P. Walker, APAC07

The Diamond SOFB (0.2Hz) Performance



The Diamond FOFB Performance

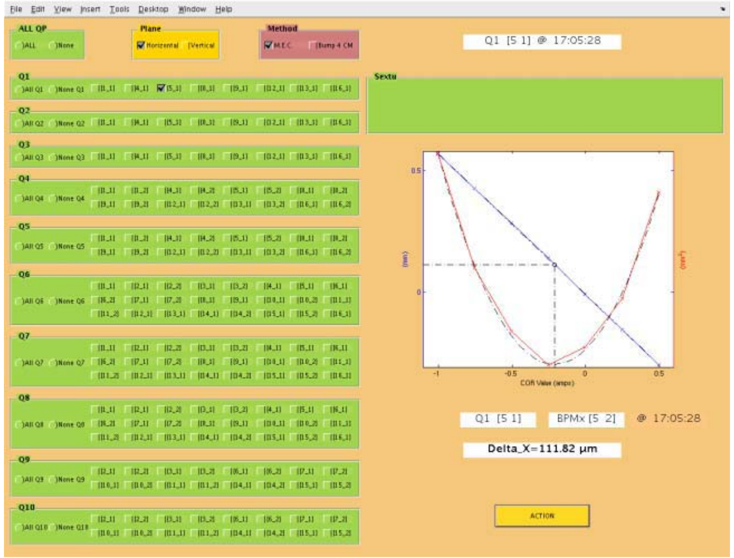
- 168 eBPMs and 168 dipolar correctors
- 10kHz sampling rate
- 24 CPUs
- 4um→1um(H)
- 1um→0.4um(V)



Courtesy R. Bartolini

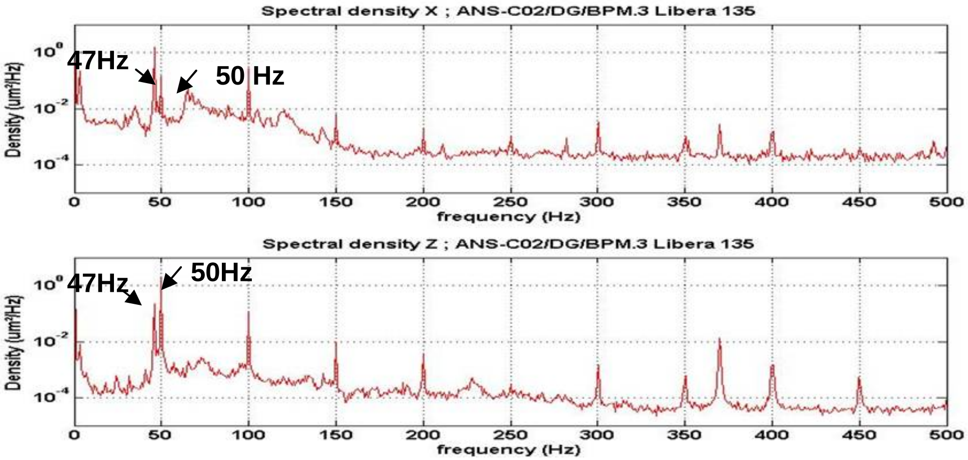
The SOLEIL BBA and its beam orbit PSD

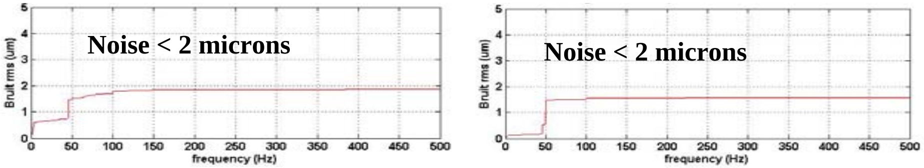
Beam Based Alignment



Courtesy A. Madur, EPAC06

Beam Orbit PSD

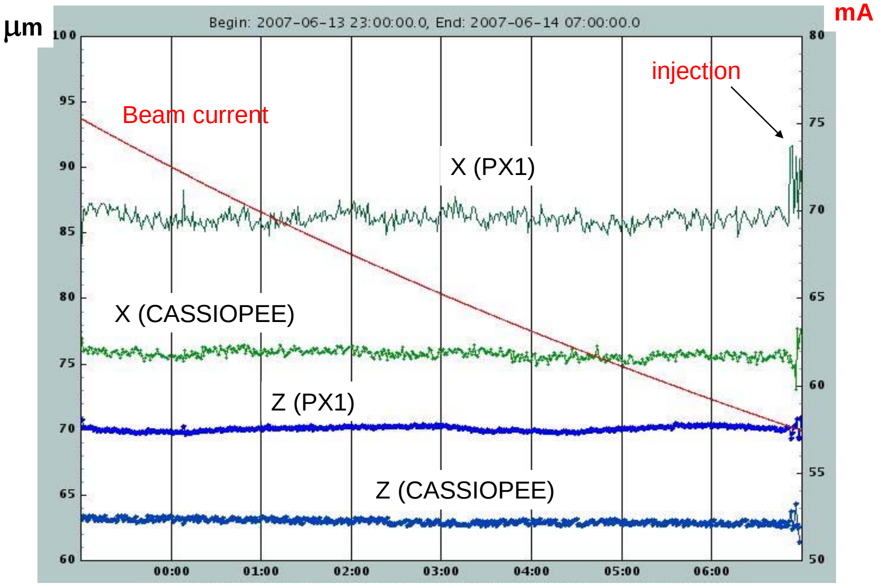




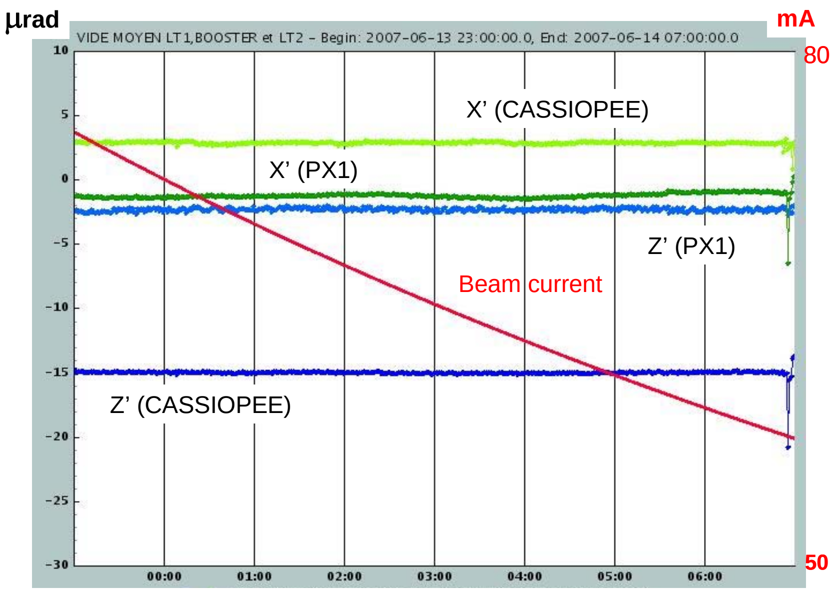
Courtesy L. Nadolski, APAC07

The SOLEIL SOFB Performance

Position Stability in 8 hours @ Light sources points



Divergence Stability in 8 hours @ Light sources points



Courtesy A. Nadji

❑Optics Calibration and Machine Characterization

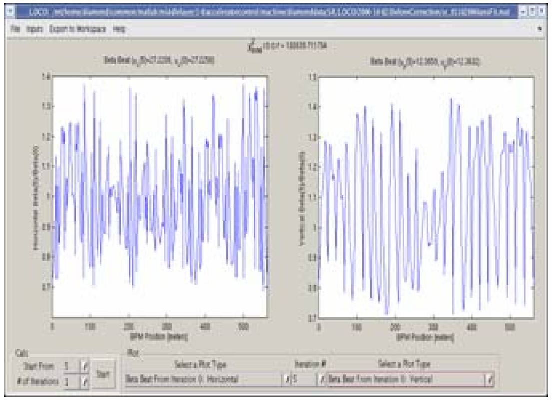
- LOCO: Quadrupole gradients finding, beta beat reduction and dispersion correction, coupling correction and etc.;
- Beam and synchrotron radiation based measurement verification;
- Beam optics measurement: traditional or turn by turn data (MIA) approach;
- Beam size, emittance, energy spread measurement: pinhole camera;
- Coupling measurement: closest tune approach

James Safranek, Nucl. Inst. And Meth, A 388, 27 (1997)

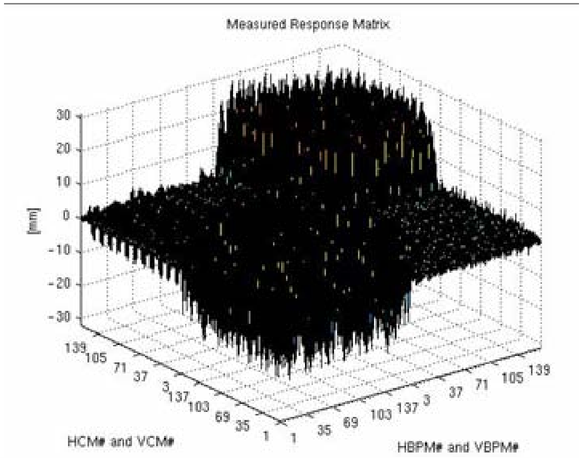
James Safranek et al, MATLAB Based LOCO, EPAC02

Diamond machine calibrations and measurements

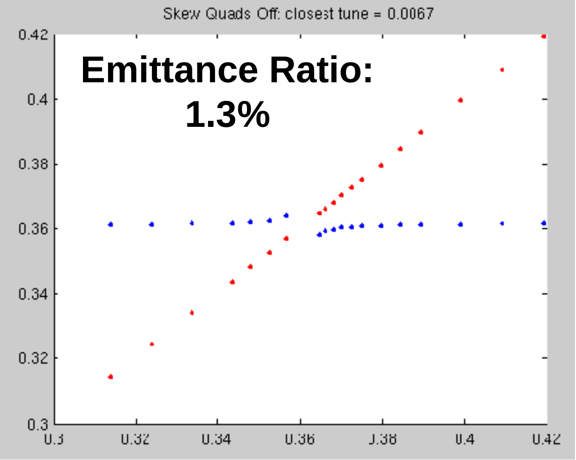
Beta Beat: +/- 40%



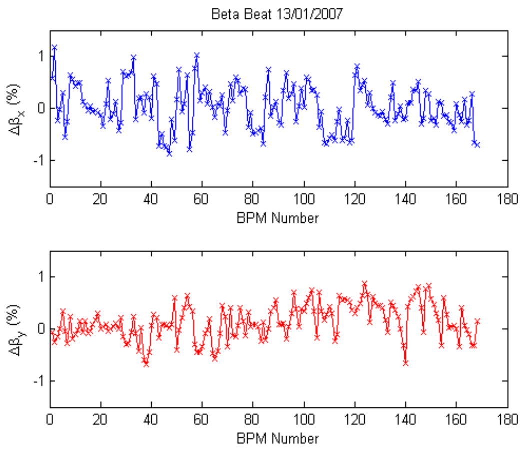
Response Matrix

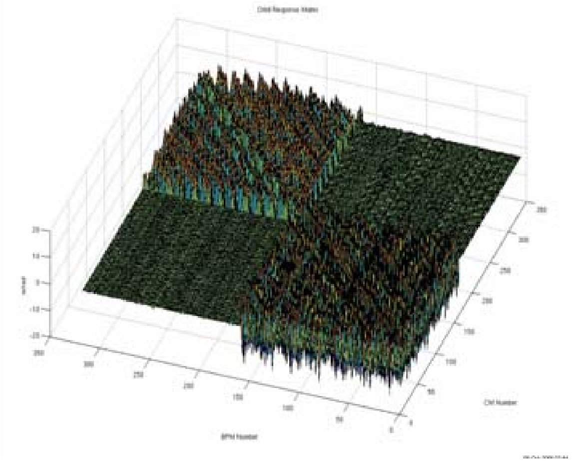


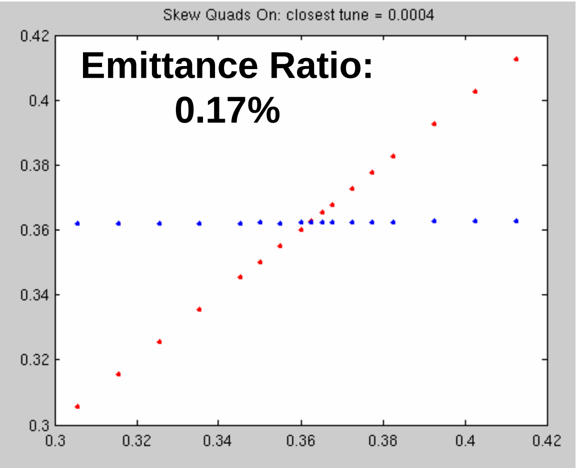
Coupling



Beta Beat: +/-1%

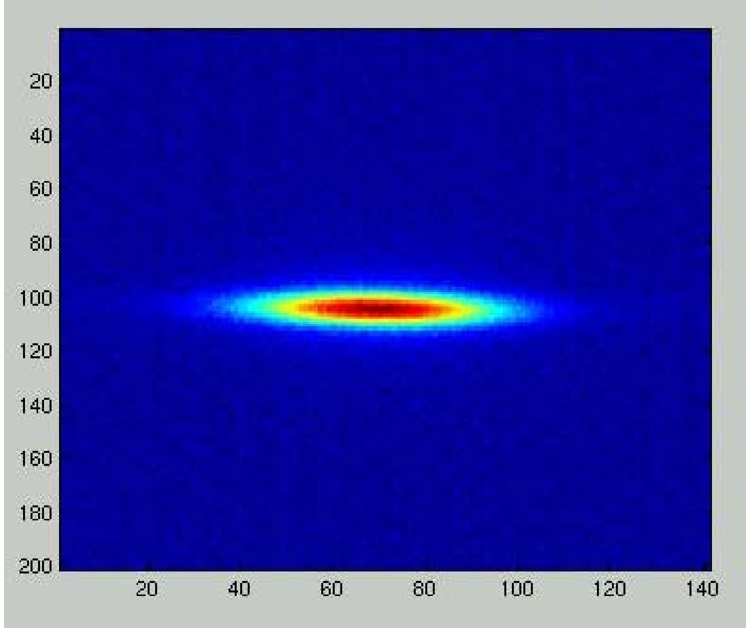


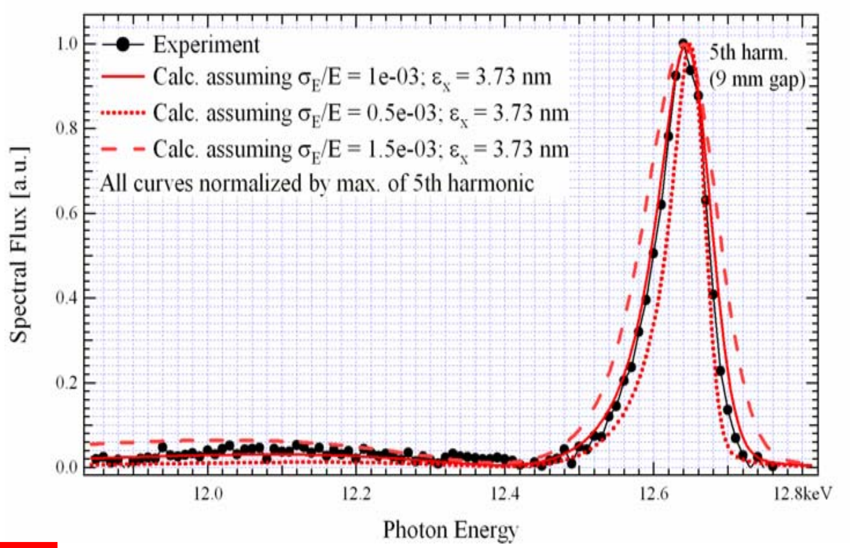




Courtesy R. P. Walker, APAC07

SOLEIL machine calibrations and measurements





$\varepsilon_x \cong 3.7$ nm.rad

$\varepsilon^*_z < 5$ pm.rad ($\kappa < 0.13$ %)

σ_z =9 µm (including 5 µm instrument resolution)

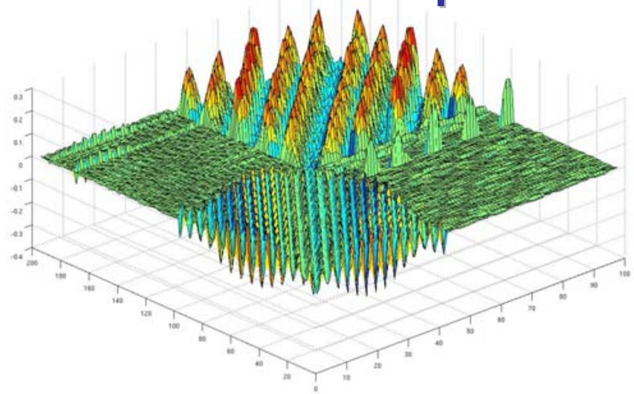
Horizontal emittance and energy spread deduced from the measured spectrum of U20 PROXIMA1

Courtesy A. Nadji

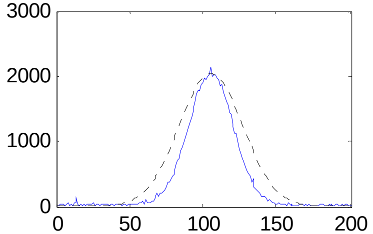
***: after correction. Before correction κ is around 0.3%.**

Australian synchrotron calibrations and measurements

First Measured Response Matrix



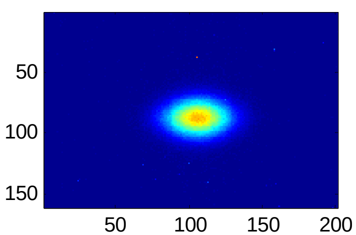
horizontal sigma = 108.32 um
position = 105.48



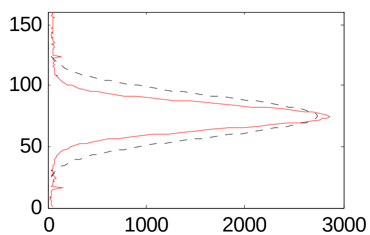
σ_x = 108.32 um
σ_y = 84.28 um

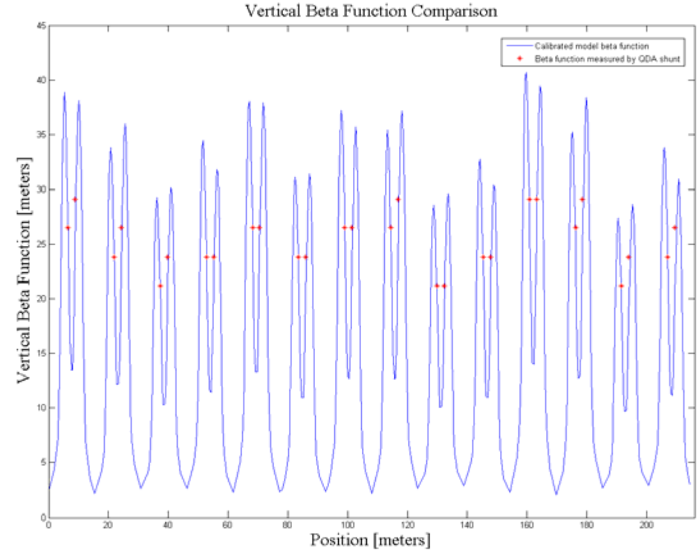
ε_x = 17.52 nm
ε_y = 0.22 nm

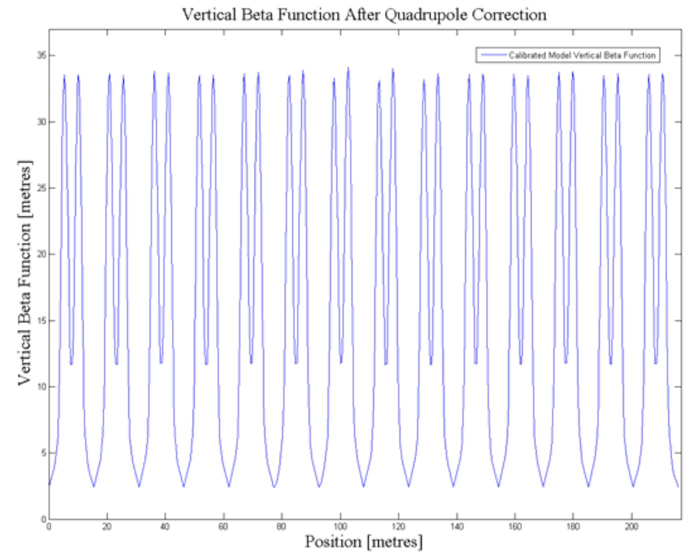
ccd image



vertical sigma = 84.28 um
position = 87.00







Courtesy G. LeBlanc, APAC07

Emittance and Energy Spread Measurements

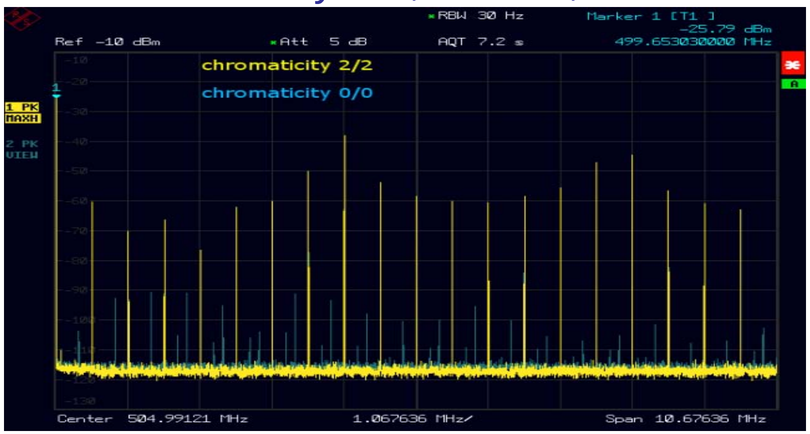
	Emittance Design(nm-rad) (Coupling)	Emittance Measurement (nm-rad)	Emittace Ratio Before→After Correction	Energy Spread Design (Measure)
Diamond	2.7 (1%)	2.85	1.3%→0.17% 0.1~10% (controllable)	0.11% (0.096%)
SOLEIL	3.74 (1%)	3.73±0.2	0.3%→0.1%	0.1016% (?)
ASP	7-16 (1%)	17.52	1.26%→0.5%	0.1% (?)

❑Beam Current, Beam lifetime and Instabilities

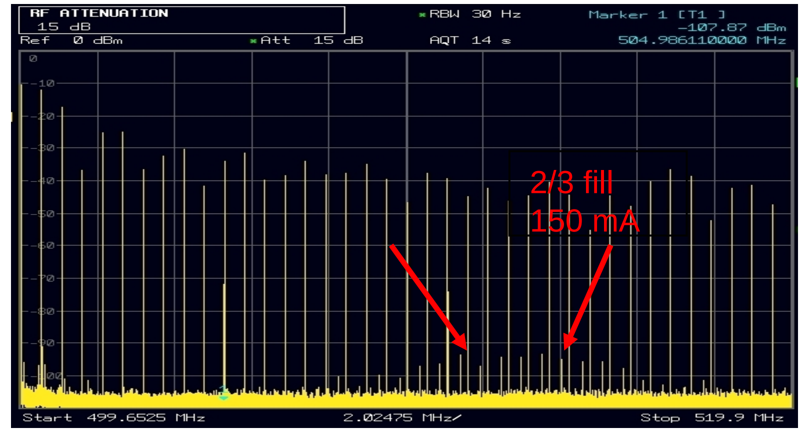
- Beam lifetime improved by increasing integrated beam current, the beam lifetime of Diamond, SOLEIL and Australian synchrotron have exceeded 20 hours at 100mA;
- Injection efficiency increased to above 90% at Diamond and SOLEIL;
- Experimental nonlinear beam dynamics studies;
- Observations and analyses of beam Instabilities, studies and cures (Chromaticity, resistive wall impedance, ion trapping, etc);
- Bunch filling pattern study for high beam current;
- Transverse beam feedback system (TBF);

Beam Instabilities in DIAMOND

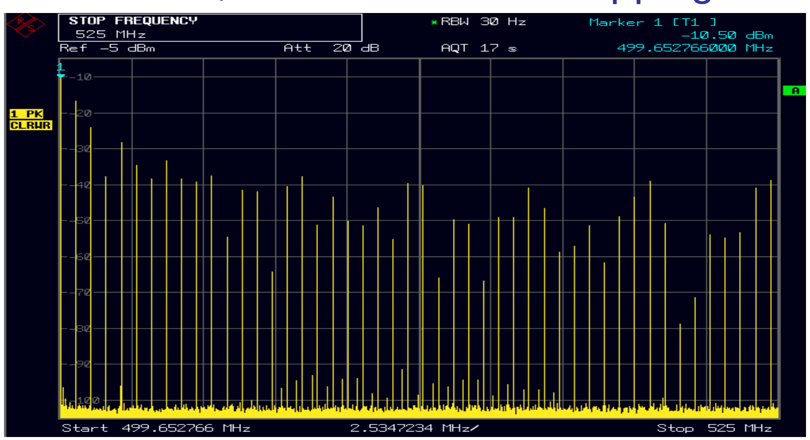
Chromaticity=0, Vertical instability: 17mA (<40mA, RW)
Chromaticity=+2, 110mA, Stable



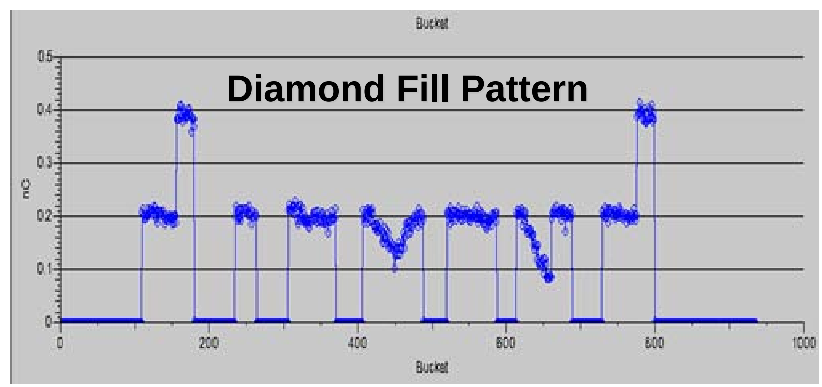
2/3 Fill, Ion related instability still exists
→TBF needed



Chromaticity=+2
170mA, Evidence of Ion Trapping

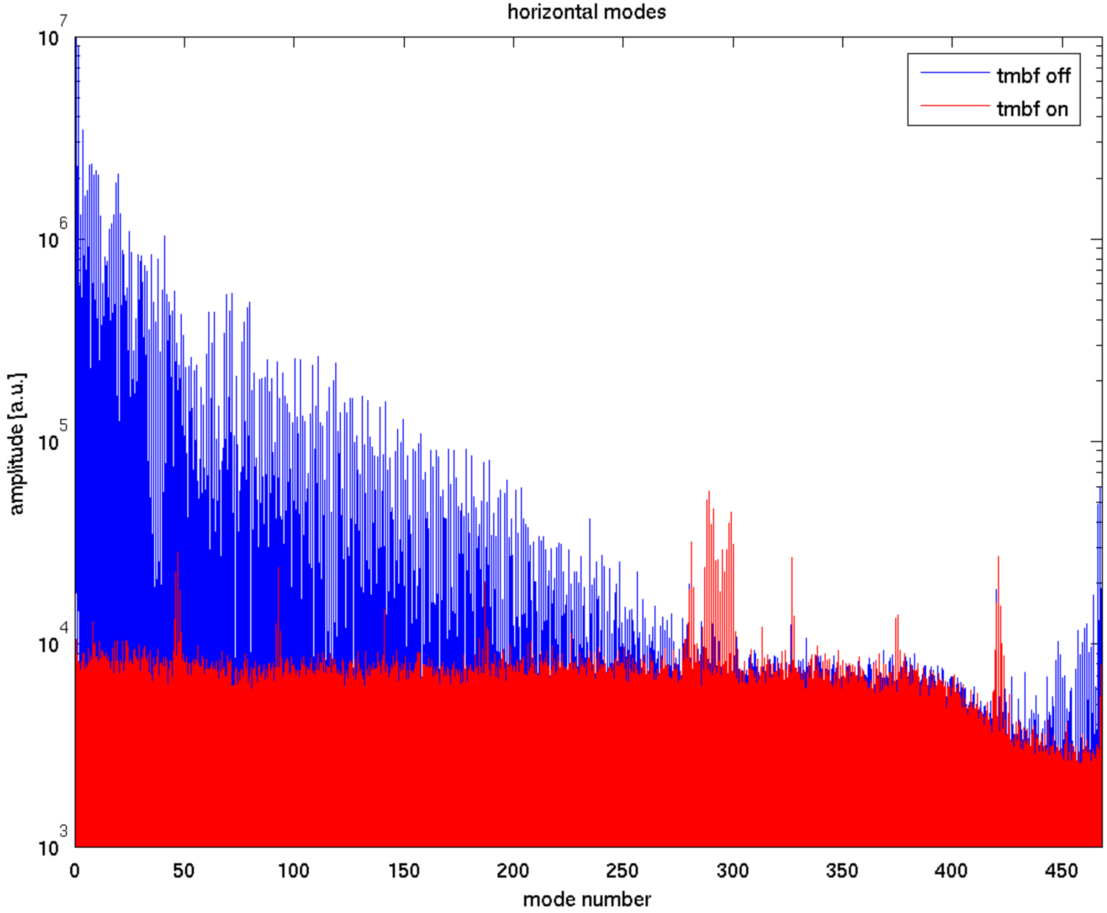


Courtesy R. Bartolini



Courtesy R. P. Walker, APAC07

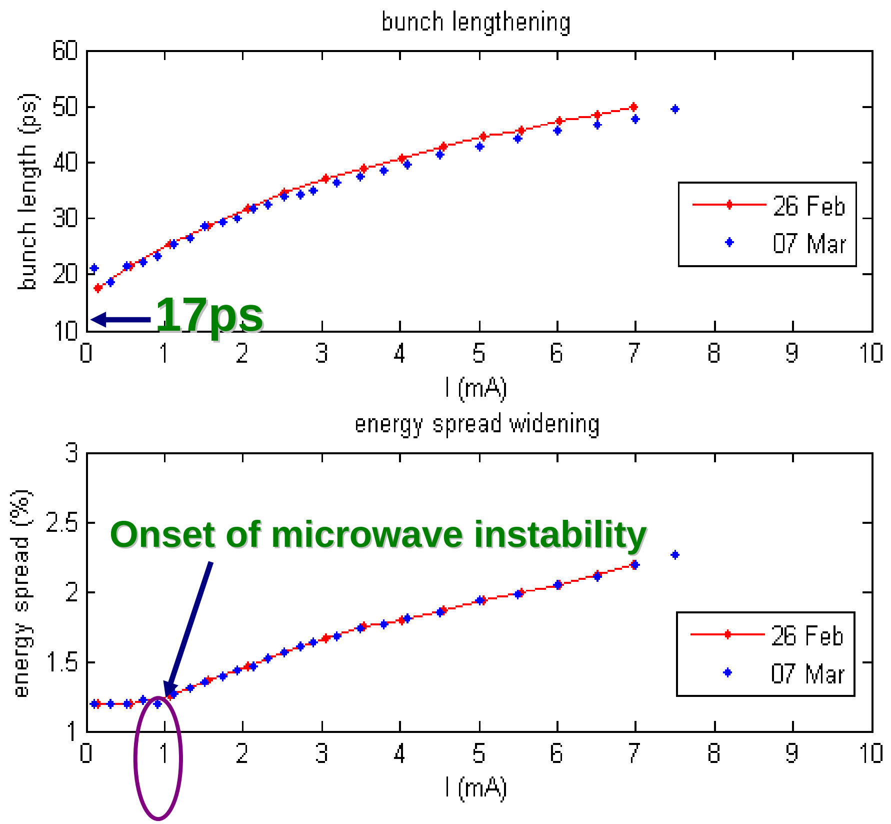
The DIAMOND TBF Performance



Courtesy, R. P. Walker

Bunch Lengthening and Energy Widening in Diamond

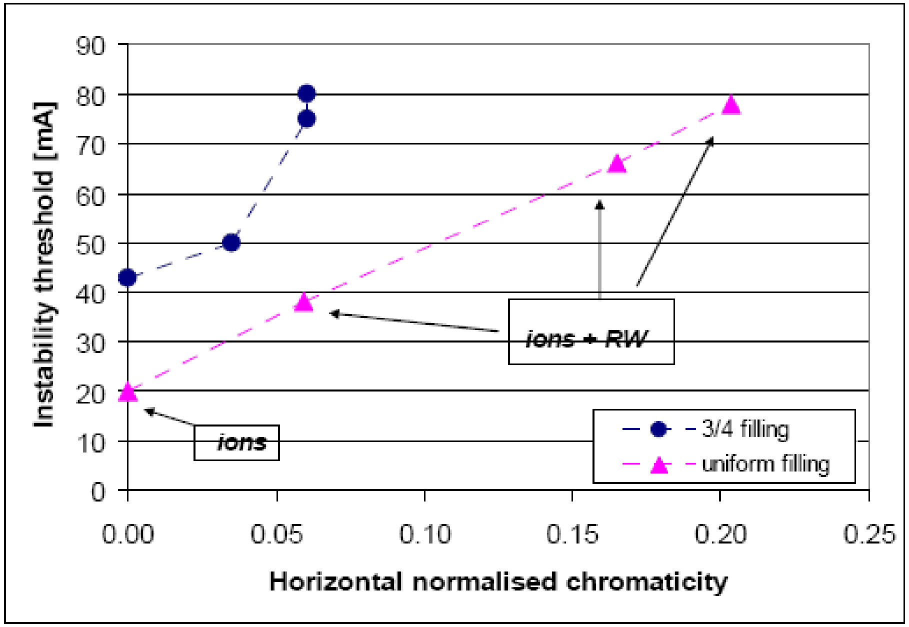
- Single bunch operation
- 10mA per bunch achieved
- Streak camera for bunch length measurement
- X-ray pinhole camera for energy spread measurement
- With one cavity (1.8MV)

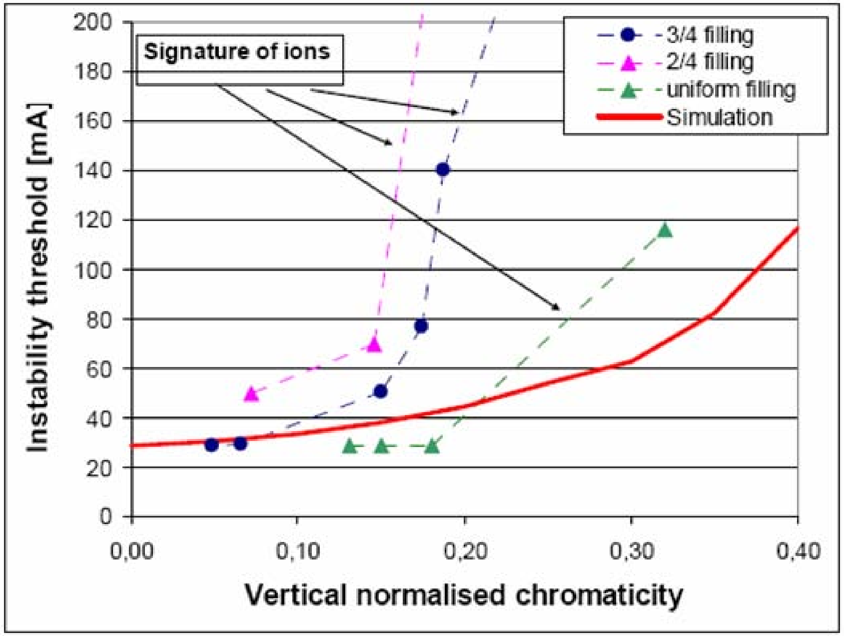


Courtesy, R. Bartolini

Beam instabilities in SOLEIL

Observed transverse multi-bunch instability threshold
Vs. Normalized chromaticity



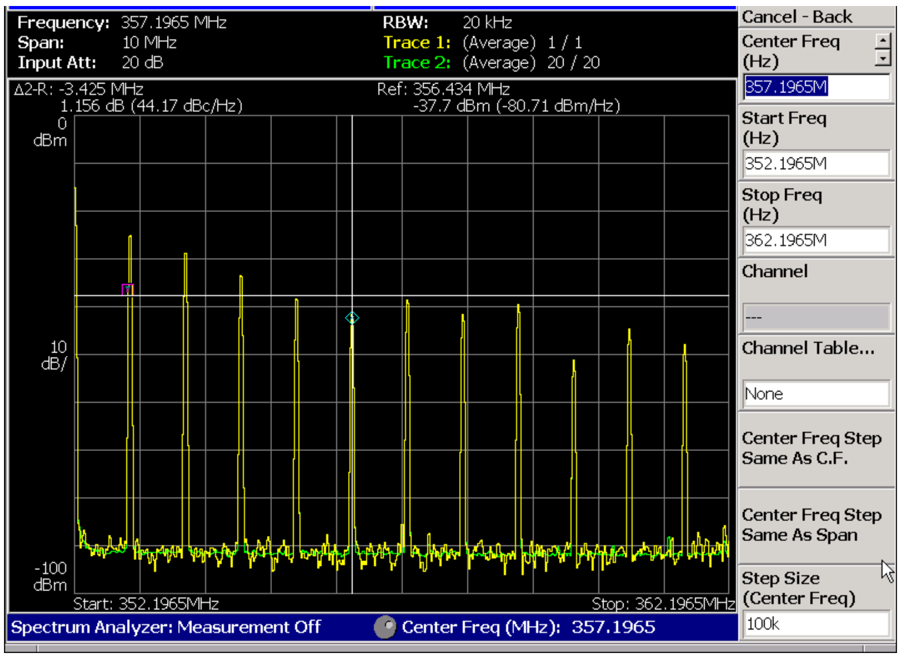


Courtesy L. Nadolski, APAC07

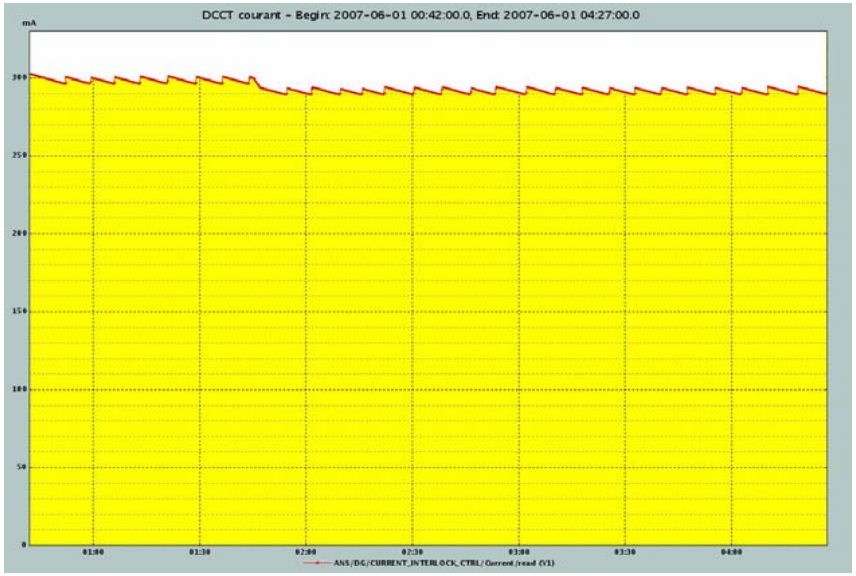
The SOLEIL TBF Performance and Its Current Status

<u>System commissioned in Dec'06</u>
(~6 months after the TBF project started)

With a single chain, the beam stabilized up to 300mA at zero chromaticity, in both horizontal and vertical planes.



The maximum beam current of 300mA with frequent injection



The installation of the second cryomodule is foreseen in the beginning of 2008.
This will enable to reach 500mA.

⇨Suppress also ion related instabilities (fast and slow)

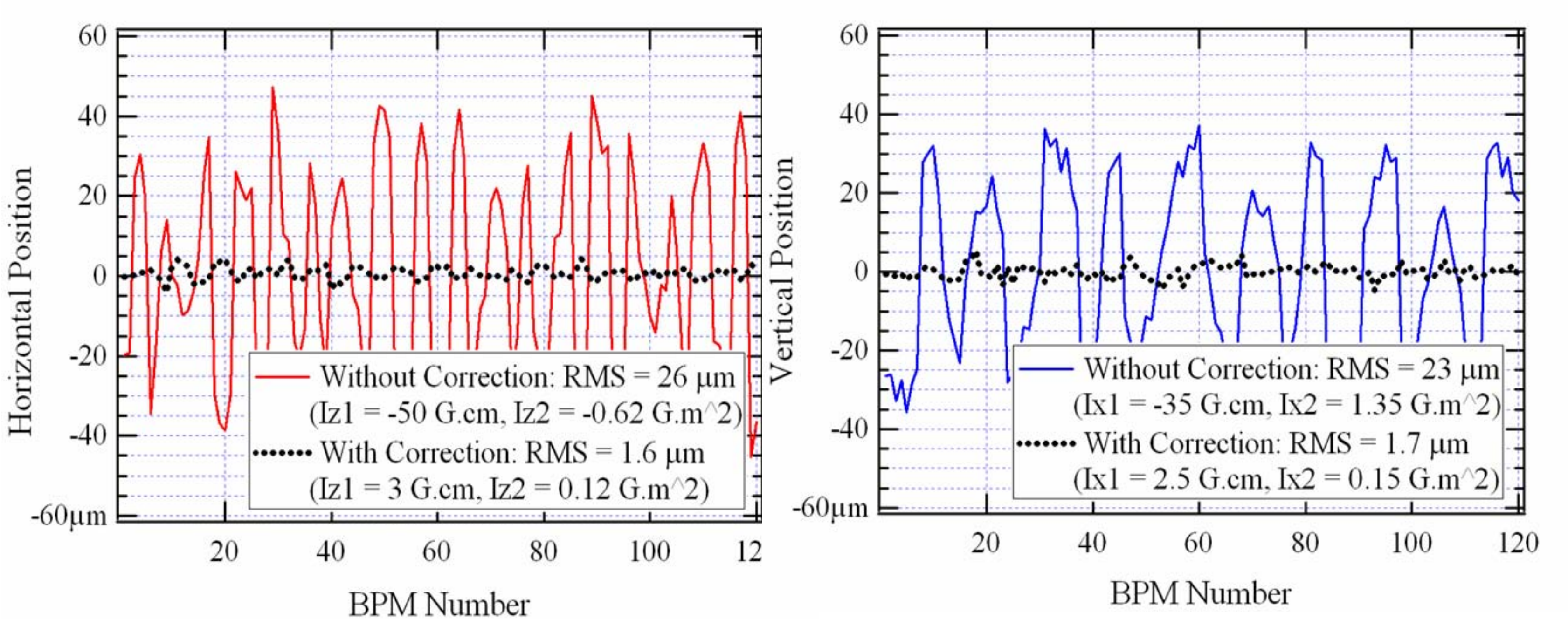
Courtesy A. Nadji

❑Insertion Device Commissioning

- Closed Orbit Distortion
- Tune Shift (Typically Negligible)
- ID Compensation with LOCO (Beta Beat)
- Feed-forward for gap changes
- Lifetime reduction as gap changes
- Nonlinear effects: dynamic aperture reduction and thus injection efficiency degradation

Insertion device compensation

SOLEIL ID Feed-forward correction



Courtesy A. Nadji

❑ Top-up Injection Studies and Commissioning

- Top-up operation is very attractive due to the constant heat loads on storage ring and beamline components, and it has been proven to be very helpful in improving photon beam stability;
- For most new light sources, top-up operation has been considered from their design stages. Once the basic commissioning with IDs is achieved, commissioning of top-up operation is chosen as the next task of high priority;
- Diamond, SOLEIL and the Australian synchrotron have conducted top-up preparations and machine studies, and preliminary results have been achieved, their top-up operations are expected to start either by end of this year or next year;

R. Bartolini, TUPMN085, PAC07,
A. Nadji, TUPMN009, PAC07,
M. J. Boland, FRPMN002,PAC07,

Summary and Conclusions

- The development of storage ring-based synchrotron radiation facilities is still active and growing. There will be more than 10 new light sources operational before 2015.
- The commissioning of recent facilities, Diamond, SOLEIL, ASP and Indus-2, has been successful and valuable experience has been gained that will benefit facilities now in construction and planning.
- Commissioning techniques and application software are mature and efficient, and particularly worldwide collaboration and sharing of experience are very effective.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