

A.-S. Müller, I. Birkel, B. Gasharova, C.J. Hirschmugl<sup>\*\*</sup>, E. Huttel, R. Kubat, Y.-L. Mathis, D.A. Moss, F. Pérez<sup>\*</sup>, M. Pont<sup>\*</sup>, R. Rossmanith, P. Wesolowski

Institut für Synchrotronstrahlung, Forschungszentrum Karlsruhe

University of Wisconsin, Milwaukee, USA

\* now at ALBA Synchrotron Light Source, Spain



#### Overview



- Brief introduction to ANKA
- **A** low- $\alpha_c$  optics for ANKA
- Establishing the operation mode
- The ANKA-IR beamline
- Beam size and current
- The FIR spectrum
- Summary & Outlook



#### Research Centre Karlsruhe

#### Research & development in various fields:

- environmental analysis
- medicine/bio technology
- material science
- microsystem technology
- (astro) particle physics
- IT science
- nano technology



# The ÅNgström Source KArlsruhe



- Electron storage ring
  - ➔ injection energy 0.5 GeV
  - → special operation 1.3 GeV
  - → nominal energy 2.5 GeV
- Insertion Devices
  - → NC wiggler
  - → NC undulator
  - → SCU14 (demonstrator)
- Beamlines
  - → IR (1)
  - → Spectroscopy (4)
  - → Scattering/Imaging (4)
  - $\rightarrow$  LIGA (3)



# Bunch Length and Beam Energy

- Standard operation: two injections per day at 0.5 GeV, ramped to 2.5 GeV
- Special operation at 1.3 GeV e.g. for LIGA
- Measure bunch length as a function of the beam energy





- Measure by recording RF harmonics of bunch spectrum: FT is related to σ<sub>s</sub>
- Longitudinal instability due to one higher order cavity mode for E<sub>0</sub> < 1 GeV</p>
  - → Energy of choice for short bunch operation: 1.3 GeV



### The Low- $\alpha_c$ Optics



- Condition for CSR emission:  $\frac{2\pi\sigma_s}{\sqrt{\ln N}} \lesssim \lambda \lesssim 2h\sqrt{\frac{h}{\rho}}$ 
  - → for 100  $\mu$ A/bunch: 1.4  $\sigma_s \lesssim \lambda \lesssim$  4.9 mm
  - ➔ further bunch length reduction necessary
- A dedicated low- $\alpha_c$  optics with negative dispersion in the long and short straight sections has been put in operation following the pioneering work of e.g. BESSY II
- Observed momentum compaction factor range as extrapolated from Q<sub>s</sub> measurements:
  - → from  $7.2 \cdot 10^{-3}$
  - → to  $1.4 \cdot 10^{-4}$



#### **Optics Measurements**



Measured chromaticities for  $\alpha_c = 0.5 \cdot 10^{-3}$ 

→ 
$$Q'_x = 9.2 \pm 1.7$$

Calculated (MAD model) and measured horizontal dispersion for  $\alpha_c~=0.5\cdot 10^{-3}$ 





#### Measurements of $\alpha_c$ I

Measurement at 2.5 GeV with resonant depolarisation: true energy shift as a function of change in RF frequency



#### Measurements of $\alpha_c$ II



Derive momentum compaction factor in the low-α<sub>c</sub> mode using scans of f<sub>s</sub> measured with a strip line

$$\alpha_{c} = \alpha_{c0} + \alpha_{c1} \frac{\Delta p}{p_{0}} + \alpha_{c2} \left(\frac{\Delta p}{p_{0}}\right)$$





- Fit results:
  - →  $\alpha_{c0} = +(0.533 \pm 0.002) \cdot 10^{-3}$
  - →  $\alpha_{c1} = +(0.7 \pm 3.7) \cdot 10^{-3}$

→ 
$$\alpha_{c2} = -(185 \pm 5)$$

#### Operation in the Low- $\alpha_c$ Mode

- Energy ramp (regular optics)
  - → fill 1 train (34 bunches) at 0.5 GeV, ramp to 1.3 GeV
- Low-α<sub>c</sub> "squeeze"
  - → change quadrupoles & sextupoles in small steps
  - → orbit correction between steps



- RF frequency adjustment
  - → Beam energy:  $E \propto \oint BdL$
  - → contribution from correctors
  - $\rightarrow$  depends on  $\alpha_c$
  - → solution: correct simultaneously orbit and f<sub>RF</sub>

$$\frac{\Delta p}{p} = -\frac{1}{\alpha_c} \frac{(f_{RF} - f_{RF}^c)}{f_{RF}}$$





# Edge Radiation?



Advantage: more collimated than constant field radiation

Allows the observation of frequencies up to 30 GHz through a modest vertical aperture, which would not be possible with classical constant field emission due to the increasing beam divergence with decreasing frequency



# Edge Radiation!





in the visible



in the mid-IR (700-1400 cm<sup>-1</sup>)

- Detector used for CSER studies: liquid He cooled Si bolometer
- The Spectral dependence is recorded using a Bruker IFS66v/S spectrometer equipped with Mylar beam splitters with thicknesses between 6 and 125 µm depending on the application.

#### FIR Spectrum





- Individual spectral regions show different current dependence
  - → change of effective bunch length/instability regime?

#### Beam Size from IR Interferogram



- Measure bunch length as a function of beam current
  - → fast reduction of bunch length at a threshold current of about 50 µA/bunch

Bunch length can be derived from FWHM of IR-interferogram

ANKA

Systematic effects arise e.g. from beam splitter thickness



#### Bursting and Steady State Emission



I Time domain signals of the bolometer show transition from bursting emission via an intermediate regime to steady state emission



# Summary & Outlook

- Bunch lengths < 1 ps can be stored in the ANKA storage ring
- **Reproducible procedure for low-** $\alpha_c$  **operation**
- Steady state CSR has been observed
- Thorough investigation of longitudinal instabilities and FIR spectra in progress
- First user experiments have already done with this mode – more are scheduled

# Acknowledgements



Sincere thanks to all who have contributed to the results presented here. Especially we would like to thank K. Holldack, P. Kuske and G. Wüstefeld for interesting and instructive discussions and R. Stricker and M. Süpfle for technical support.

# **Orbit Correction**



- 36 beam position monitors
- 28 horizontal correctors
- 16 vertical correctors
- SVD based orbit correction
- choice between measured or model response matrix
- RF frequency as a free parameter in the correction

$$\frac{\Delta p}{p} = -\frac{1}{\alpha_c} \frac{(f_{RF} - f_{RF}^c)}{f_{RF}}$$

I.0         I.0 <thi.0< th=""> <thi.0< th=""> <thi.0< th=""></thi.0<></thi.0<></thi.0<>	AVG -0.119 -0.002 0.000 bit Correct V S. [m] V 4.5 V 6.4 V 15.5 V 15.6 V 15.6 V 15.6 V 15.6 V 15.6 V 20.9 V 20.9	66.00 RMS 0.553 0.053 0.000 Ion Ion BBPM DBPM DBPM DBPM DBPM DBPM	PM ST.01 S1.01 S1.02 S1.03 S1.04 S1.05 S1.06	70 D 0 140 1 153 0 100 0 0054 -0.122 -0.053 -0.054 -0.228 0.447 -0.228	88.80 MAX 1.375 1.124 0.000 0.053 -0.119 -0.053 -0.119 -0.445 -0.228	99.90 Save O	rbit delta avg
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raged         -0.011         0.191         0.190         0.445         averaged. saved av           ed av.         0.000         0.000         0.000         0.000         averaged. saved av           PRIZONTAL Correction         VERTICAL Correction         Automatic Orb           PRIZONTAL CORRECTION         Frequency OC           s[m]         Corrector         angle         correct         after           1.6         MCH_S1.01         0.01870         0.09551         0.27727         •           6.7         MCH_S1.02         0.01080         0.23445         0.24317         •           8.5         MCH_S1.03         -0.01253         0.22917         0.21653         •           13.3         MCH_S1.04         -0.07105         0.29428         0.22431         •           18.9         MCH_S1.08         -0.06351         -0.14741         -0.20844         •           29.3         MCH_S2.01         0.32269         0.15099         0.47267         •           34.3         MCH_S2.02         0.18284         -0.08813         0.09503         •           36.1         MCH_S2.03         0.02487         -0.18096         -0.15473	-0.002 0.000 bit Correct v 3.5 v 6.4 v 1.5 v 15.6 v 15.6 v 18.5 v 23.6 v 23.6	0.053 0.000 ion BPM_ DBPM_ DBPM_ DBPM_ DBPM_ DBPM_ DBPM_	PM S1.01 S1.02 S1.03 S1.04 S1.05 S1.06	pos 0.054 -0.122 -0.053 0.447 -0.228 0.245	avg pos 0.053 -0.119 -0.052 0.445 -0.228	Saved p	delta avg
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6.7         MCH_S1.02         0.01080         0.23445         0.24317           8.5         MCH_S1.03         -0.01253         0.22917         0.21653           13.3         MCH_S1.04         -0.07105         0.29428         0.22431           18.9         MCH_S1.04         -0.07105         0.29428         0.22431           18.9         MCH_S1.06         0.17218         0.21596         0.38958           20.7         MCH_S1.07         0.13903         0.13019         0.27150           25.0         MCH_S2.01         0.32269         0.15099         0.47267           34.3         MCH_S2.02         0.18284         -0.08913         0.09503           36.1         MCH_S2.03         0.02487         -0.18906         -0.15473	<ul> <li>✓ 6.4</li> <li>✓ 8.8</li> <li>✓ 11.5</li> <li>✓ 15.6</li> <li>✓ 18.5</li> <li>✓ 20.9</li> <li>✓ 23.6</li> </ul>	DBPM_ DBPM_ DBPM_ DBPM_ DBPM_	S1.02 S1.03 S1.04 S1.05 S1.05	-0.122 -0.053 0.447 -0.228	-0.119 -0.052 0.445 -0.228		
8.5         MCH_S1.03         -0.01253         0.22917         0.21653           13.3         MCH_S1.04         -0.07105         0.29428         0.22431           18.9         MCH_S1.04         -0.07105         0.29428         0.22431           18.9         MCH_S1.06         0.17218         0.21596         0.38958           20.7         MCH_S1.07         0.13903         0.13019         0.27150           25.0         MCH_S1.08         -0.06351         -0.14741         -0.20844           29.3         MCH_S2.01         0.32269         0.15099         0.47267           34.3         MCH_S2.02         0.12284         -0.08813         0.09503           36.1         MCH_S2.03         0.02487         -0.18096         -0.15473	<ul> <li>✓ 8.8</li> <li>✓ 11.5</li> <li>✓ 15.6</li> <li>✓ 18.5</li> <li>✓ 20.9</li> <li>✓ 23.6</li> </ul>	DBPM_ DBPM_ DBPM_ DBPM_	S1.03 S1.04 S1.05 S1.06	-0.053 0.447 -0.228	-0.052 0.445 -0.228		
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NCH_S100         0.17218         0.21390         0.38358           20.7         MCH_S107         0.13903         0.13019         0.27150           25.0         MCH_S108         -0.06351         -0.14741         -0.20844           29.3         MCH_S201         0.32269         0.15099         0.47267           34.3         MCH_S2.02         0.18284         -0.08813         0.09503           36.1         MCH_S2.03         0.02487         -0.18096         -0.15473	× 18.5 × 20.9 × 23.6	DBPM_	S1.05	0.220	-0.220		
25.0         MCH_S1.08         -0.06351         -0.14741         -0.20844           29.3         MCH_S2.01         0.32269         0.15099         0.47267           34.3         MCH_S2.02         0.18284         -0.08813         0.09503           36.1         MCH_S2.03         0.02487         -0.18096         -0.15473	20.9	DODM		-11 / 13	-11 /10		1
29.3         MCH_S2.01         0.32269         0.15099         0.47267           34.3         MCH_S2.02         0.18284         -0.08813         0.09503           36.1         MCH_S2.03         0.02487         -0.18096         -0.15473	23.6	DBPM	S1.07	0.345	0.345		-
34.3         MCH_62.02         0.18284         -0.08813         0.09503           36.1         MCH_52.03         0.02487         -0.18096         -0.15473		DBPM	S1.08	-0.162	-0.162		1
36.1 MCH_82.03 0.02487 -0.18096 -0.15473	₩ 31.1	DBPM_	S2.01	0.097	0.096		
	₩ 34.0	DBPM_	S2.02	-0.252	-0.251		
40.4 MCH_52.04 0.32529 0.01613 0.34323	₩ 36.4	DBPM_	S2.03	0.166	0.166		
PE Generator fraguency correct after	₩ 43.2	DBPM_	S2.05	-0.047	-0.046		-
SG D 01 499 67470 -0.00337 499 67133	₩ 46.1	DBPM_	S2.06	0.026	0.026		
	11/1485	DRPM S	S7 II7	I-n n77	-0.071	1.	4.
fset 0.0 The mm Beam AVG 0.00000 mm	[ Con	ector 50	rengan	reduction		-	
Model Takes Average for Off	Eigenva	alues:	min. all	owed:	0 💌	used:	1 28
nervalues: min allowed: 10 Tused: 20 (29	Moinht		RMS	and the state	Current	Chan	ge [%]
	vveign		Correct	tors (m	0.000	0.000	-
RE Frequency Correction	1.0		Beam	ineur	0.000	0.000	
amplification: 0.0 💌 %							
Test Correctors Scale All [%] 100.0 💌 Apply Correct	ction						
Invis Last		Abort					
	st ]						
alculations invalidated: field changed							