Superconducting insertion devices constructed by Budker INP

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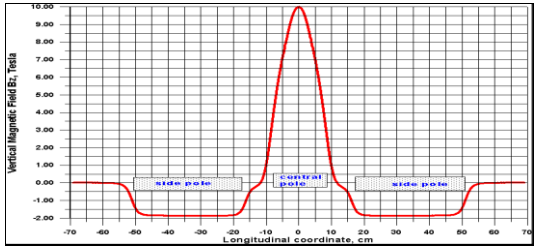
Budker INP

Outline

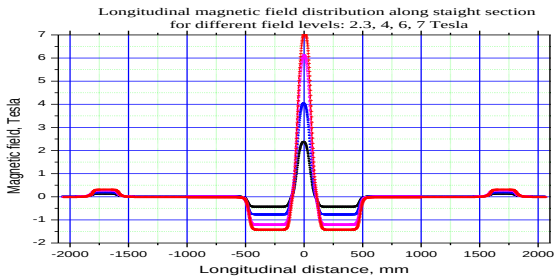
- **Introduction**
- **Superconducting insertion devices were already built**
- **Analysis of obtained data and application to SKIF**
- **Superconducting insertion devices for SKIF**
- **Other undulators based on the poles of the main undulator**
- **Resume**

Introduction

3-pole wiggler (shifter) –main objective is an increasing of radiation rigidity. It consists of three magnets, The central magnet is used as a radiation source. Two side magnets are used for compensation of orbit distortion.



Shifter with the fixed radiation point – The same objective as previous one. The central pole is used as a radiation source. The difference with the previous shifter is that two normally conducting magnets are added which form an orbit inside the shifter so that the position of the orbit in the central magnet lies on the axis of the straight section for any field level in central magnet.

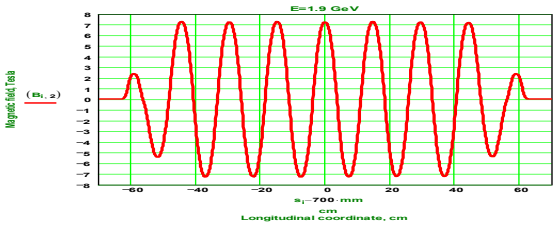


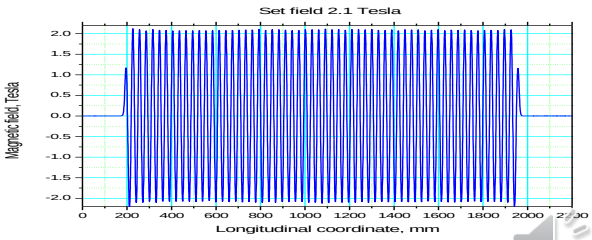
Superconducting multipole wiggler and undulator – contain many poles, which create sign alternating field. The main objective of a wiggler is generation of powerful <u>Synchrotron Radiation</u> (SR) with high photon flux density in the rigid X-ray range.

The difference between wiggler and undulator in deflection factor K:

$$K = 0.934 \cdot \lambda_0[\mathrm{cm}] B_0[\mathrm{T}]$$

K<3 - undulator. K>3 - wiggler



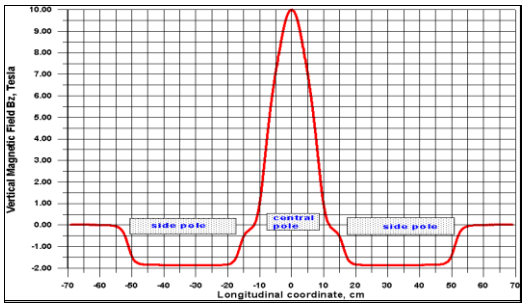


Superconducting undulator – a basic purpose is generation of spatially coherent <u>Undulator Radiation</u> (UR) of high brightness .

Superconducting insertion devices already were built

Standard shifters

3 pole shifter –The spectral characteristics of the synchrotron radiation from the magnet are determined by two parameters:
ε_c[keV]=$0.665E^2B$, E – electron energy [GeV], B- magnetic field [T]

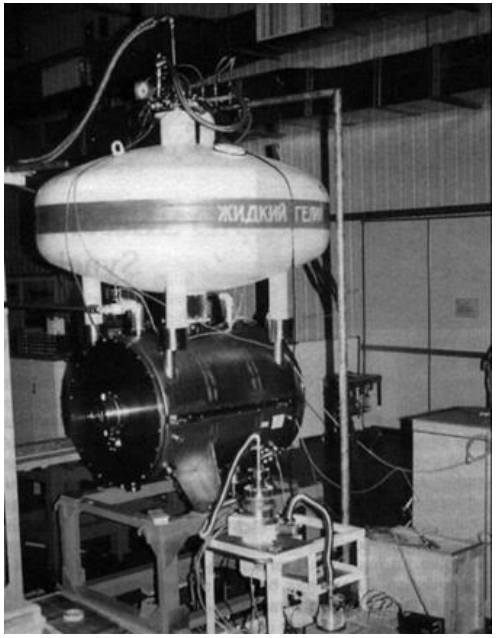


Longitudinal field distribution

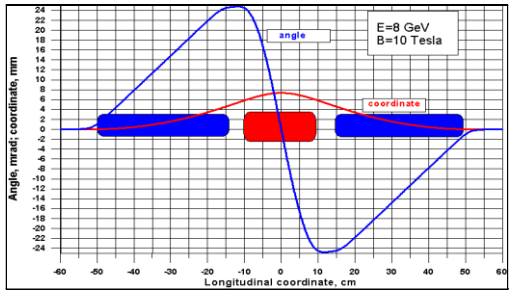
Two standard 3-pole shifters were fabricated.

1996 - 7.5 Tesla superconducting WLS for PLS, South Korea

2000 – 10 Tesla WLS for Spring-8, Japan



10 Tesla WLS for Spring-8 Slow Positron Source



Orbit inside the shifter

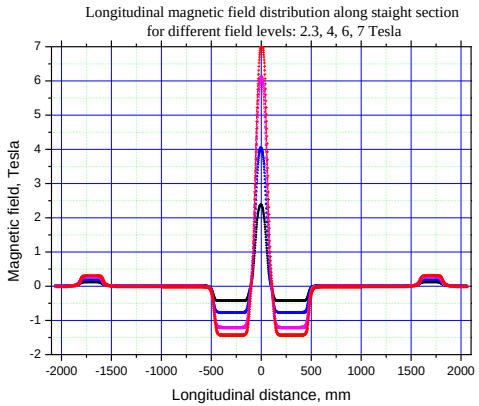
1996 PLS, South Korea

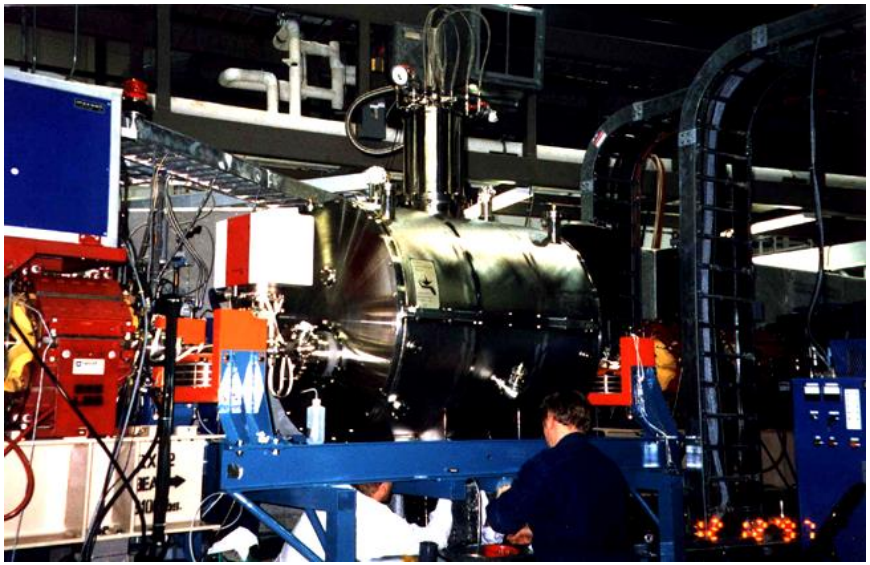
2000 Spring-8, Japan

Shifter with a fixed radiated point

Three superconducting WLS with field in central pole of 7 Tesla were built:

1997 - 7 T superconducting WLS with fixed radiation point for CAMD-LSU (USA)
2000 – 7 Tesla WLS with fixed radiation point for BESSY-2, Germany
2001 – 7 Tesla WLS with fixed radiation point for BESSY-2, Germany

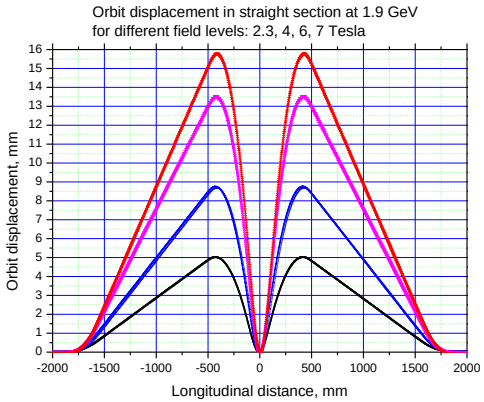


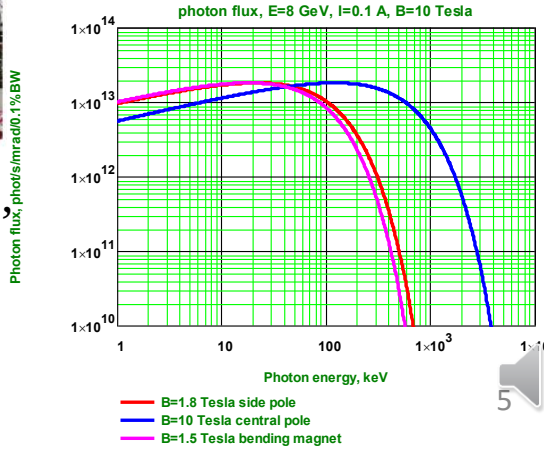


1997 CAMD-LSU, USA

Fig. 2-4 Photo of 7 Tesla WLS inserted into BESSY-2 straight section.

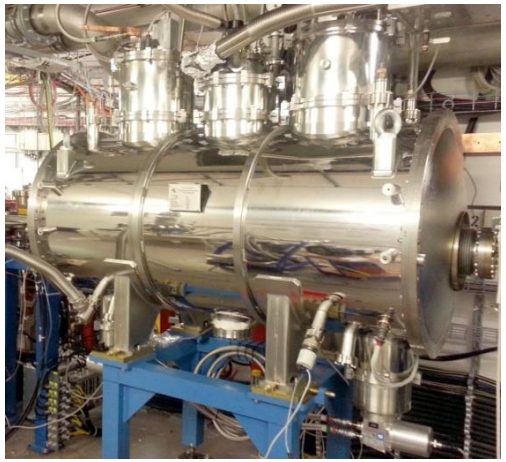
2000,2001 BESSY-2, Germany





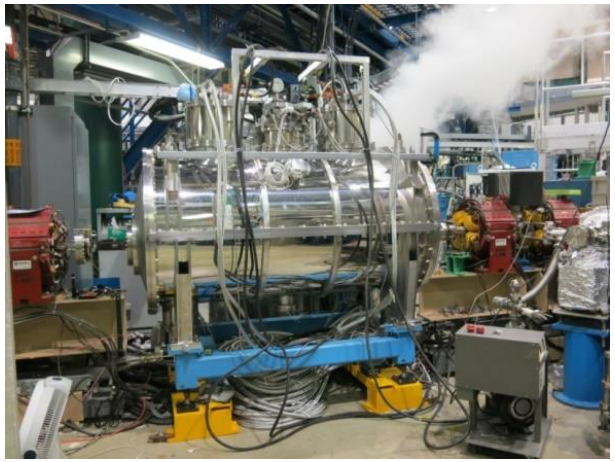
High field multipole wigglers

2002 – 7 Tesla 17 pole,	λ=148 mm, pole gap =19mm	SCW for BESSY-2	(E=1.7GeV),	Berlin, Germany
2006 – 7.5 Tesla 21 pole,	λ=164 mm, pole gap =16mm	SCW for Siberia-2	(E=2.5GeV),	Moscow
2013 - 7.5 Tesla 15 pole,	λ=200 mm, pole gap =25.2mm	SCW for LSU CAMD	(E=1.35GeV),	USA
2018 - 7 Tesla, 22 pole,	λ=128 mm, pole gap =16mm	SCW for DELTA	(E=1.5GeV) ,	Dortmund , Germany



BESSY, Berlin, 2002

KI, Moscow, 2006



CAMD, USA, 2013

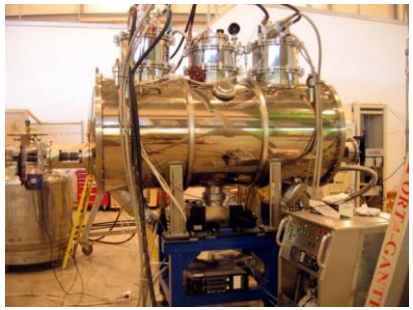
DELTA, Dortmund, 2018

½ magnet 7.5 Tesla

Medium field wigglers

2002 – 3.5 Tesla 49 pole,	λ=64 mm, pole gap=16.5mm	SCW for ELETTRA, Italy
2006 – 3.5 Tesla 49 pole ,	λ=60 mm, pole gap=16.5mm	DLS, England
2007 – 4.2 Tesla 27 pole ,	λ=48 mm, pole gap=13.4mm	SCW for CLS, Canada
2009 – 4.2 Tesla 49 pole ,	λ=48 mm, pole gap=14.4mm	SCW for DLS, England
2009 – 4.1 Tesla 35 pole ,	λ=60 mm, pole gap=14mm	SCW for LNLS, Brazil
2011 – 4.2 Tesla 63 pole,	λ=52 mm, pole gap=15.2mm	SCW for ANSTO, Australia
2012 – 2.5 Tesla 40 pole ,	λ=48 mm, pole gap=19mm	SCW for ANKA-CATACT, Germany
2016 - 3 Tesla 72 pole ,	λ=51 mm, pole gap=18mm	SCW for ANKA/CLIC, Germany/CERN
2019 – two 3 Tesla 54 pole ,	λ=48 mm, pole gap=14 mm	SCW for Kurchatov Institute, Moscow, Russia

ELETTRA, Italy



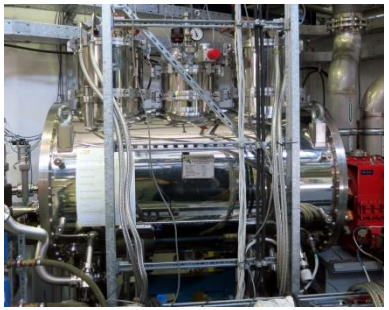
DLS, England

CLS, Canada

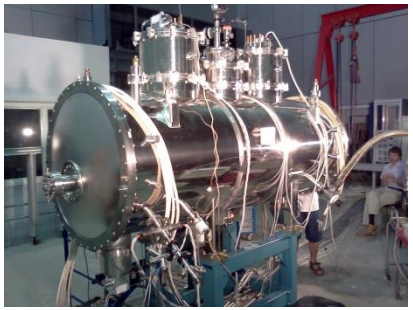
DLS, England

LNLS, Brazil

ANSTO, Australia



ANKA-CATACT, Germany



ANKA/CLIC, Germany/CERN

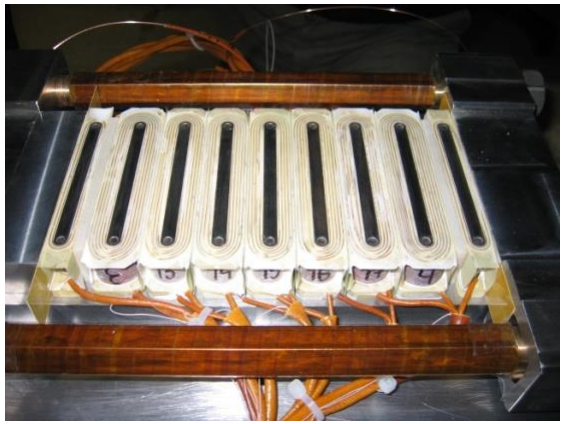
Kurchatov Institute, Moscow

Short period wigglers

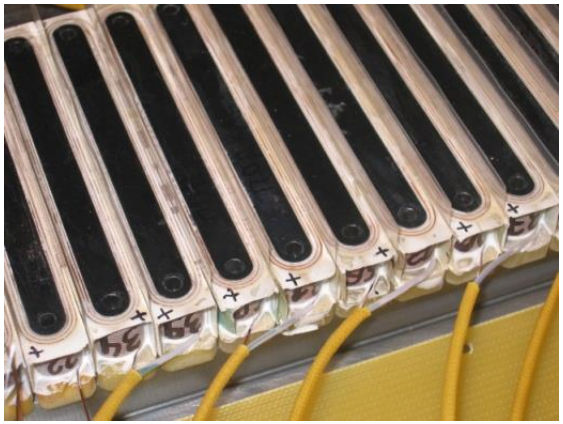
2005 – 2 Tesla 63 pole, λ=33 mm, pole gap=13.5 mm SCW for CLS, Canada
2010 - 2.1 Tesla 119 pole λ=30 mm, pole gap=12.4 mm SCW for ALBA, Spain

CLS, Canada

ALBA, Spain



½ medium period magnet

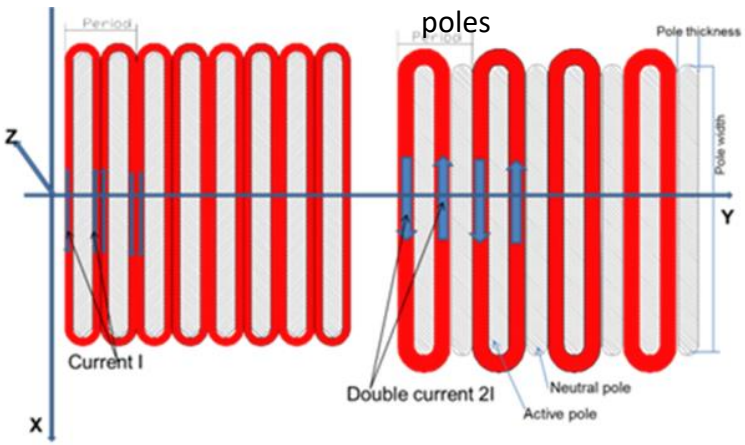


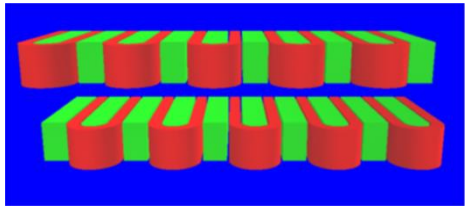
½ short period magnet

Superconducting undulator with neutral poles

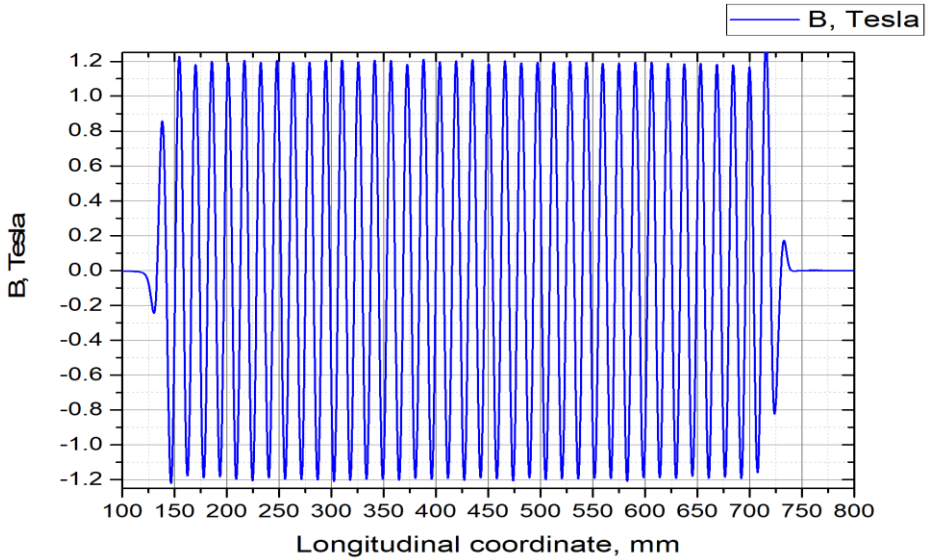
Standard solution- all poles are active

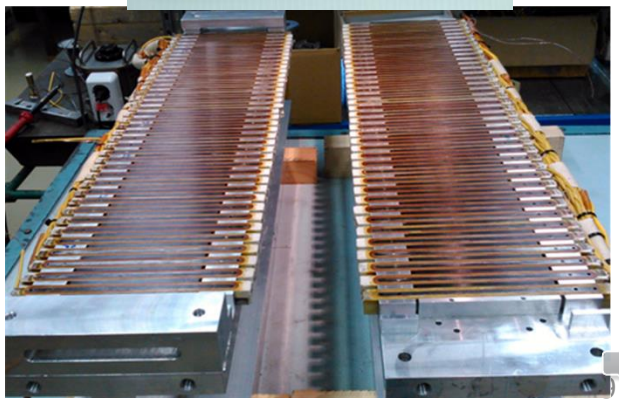
Solution with use of active and neutral poles



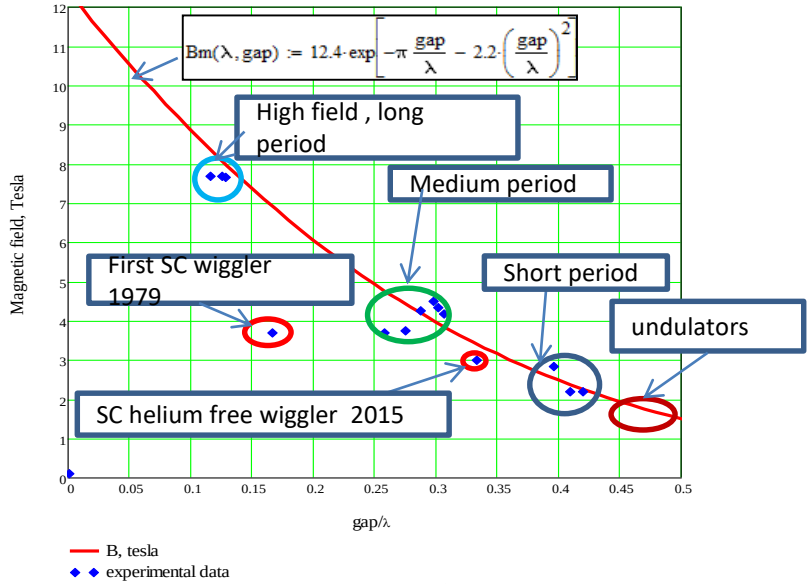


Period – 15.6 mm
Pole gap - 8 мм
Field - 1.2 Тесла
Wire NbTi/Cu – 0.5 мм

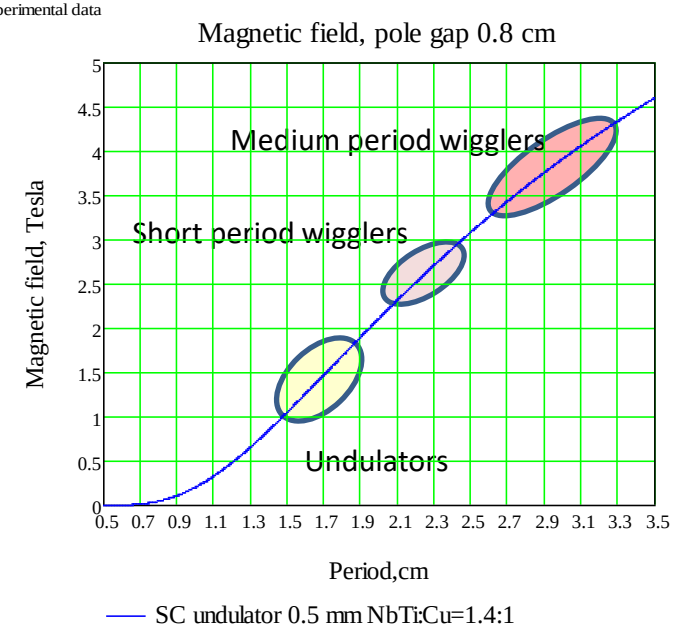




Analysis of obtained data and application to SKIF



With enough data from already manufactured multipole wigglers, it is possible to construct an empirical dependence of the maximum magnetic field on the ratio of the pole gap to the wiggler period. This empirical curve may predict the amplitude of the field if period of field change and the pole gap are fixed.



In fourth generation SR sources, the vertical aperture size for electron beam is allowed to be 6 mm or even less, respectively, the pole gap can be 8 mm or less for both wigglers and undulators.

Superconducting insertion devices for SKIF

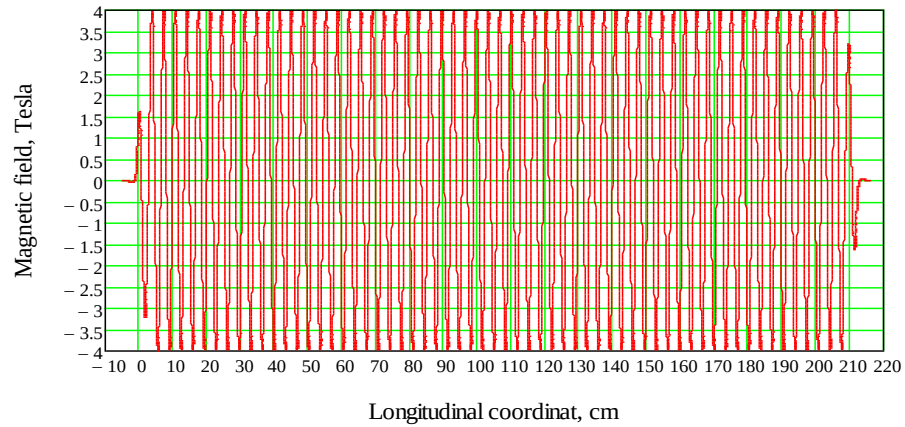
Superconducting Insertion device	Request for 1 milestone	Request for 2 milestone	Total
Wiggler (B=4Tesla, λ=33.7 mm)	2	2	4
Undulator (B=1.25 Tesla, λ-15.6 mm)	3	6	9
Special insertion devices		?	?

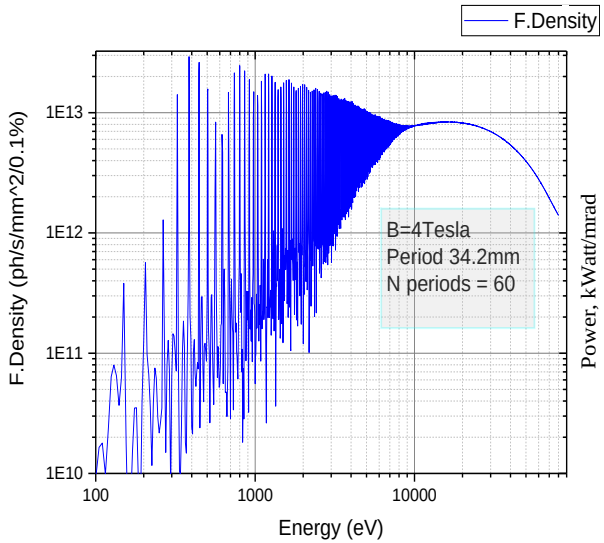
Superconducting insertion devices for SKIF

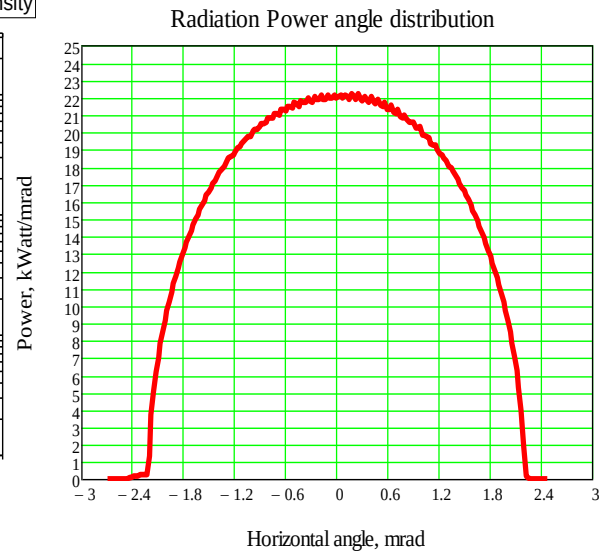
Superconducting wigglers with medium period

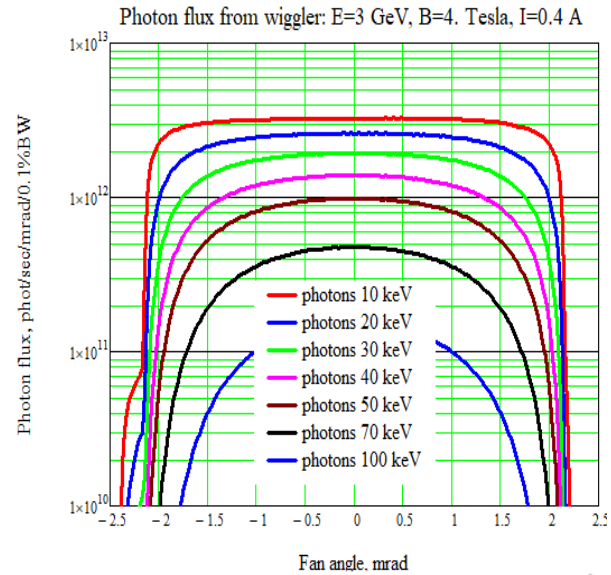
Nominal magnetic field, Tesla	4
Period, mm	33.7
Vertical/horizontal beam aperture, mm	6/60
Pole gap, mm	8
Period number	60
Magnet length, mm	~2120
Flange to flange distance, mm	~2840
Radiated power (B=4 Tesla, I=0.4 A, E=3 GeV), kW	75.9
Horizontal fan angle, mrad	± 2.2
Critical photon energy, keV	24

Magnetic field distribution









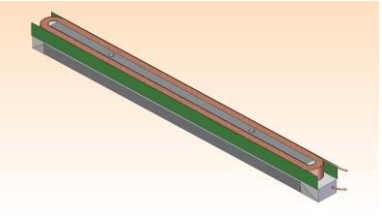
Spectrum at zero angle

Angle distribution of total power

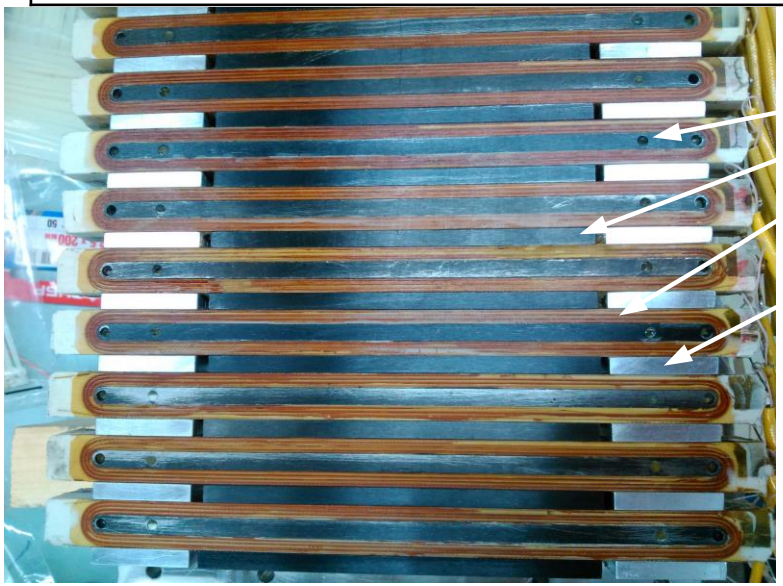
Angle-spectral distribution

Superconducting undulators

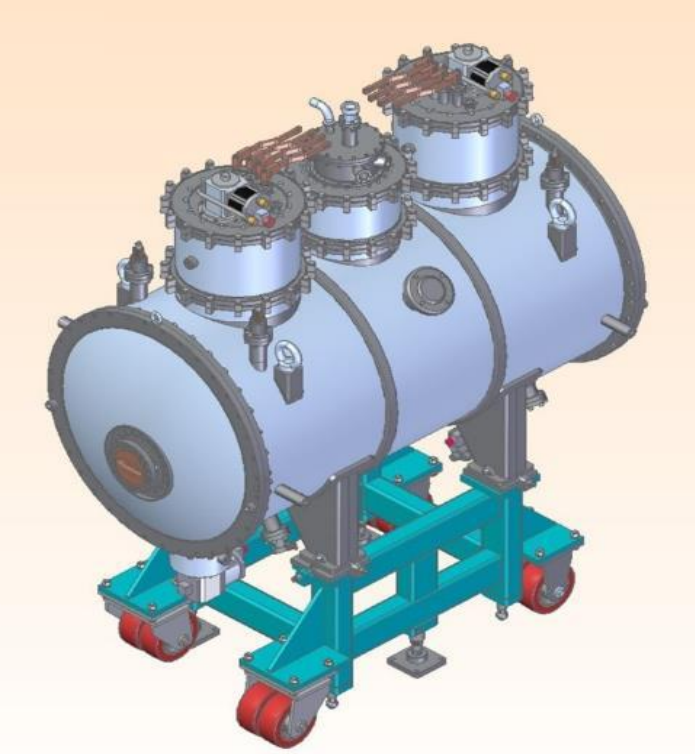
Nominal magnetic field, Tesla	1.2
Period, mm	15.6
Phase error, grad	<3
Vertical/horizontal beam aperture, mm	6/60
Pole gap, mm	8
Period number	128
Magnet length, mm	~2170
Flange to flange distance, mm	~2840
Radiated power (B=4 Tesla, I=0.4 A, E=3 GeV), kW	7.18
Horizontal fan angle, mrad	± 0.4



Active pole-Key element of the undulator

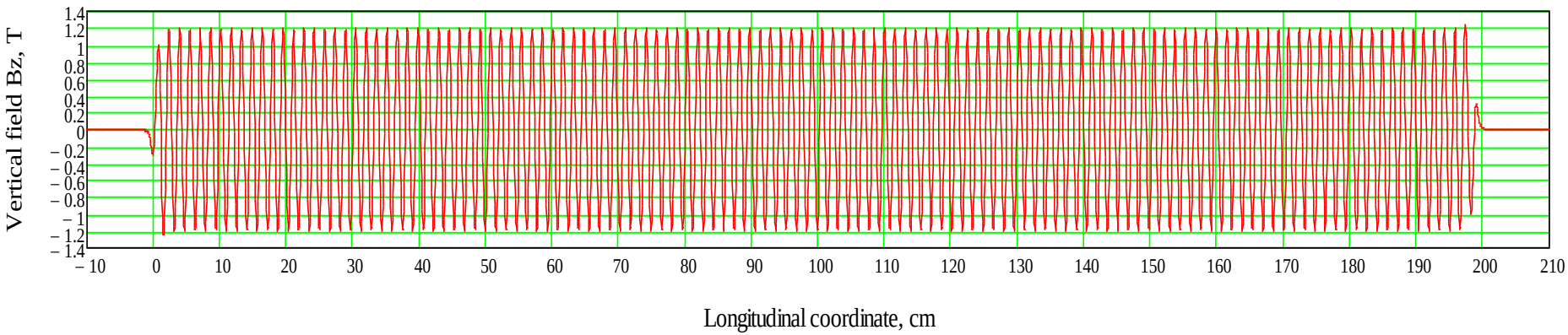


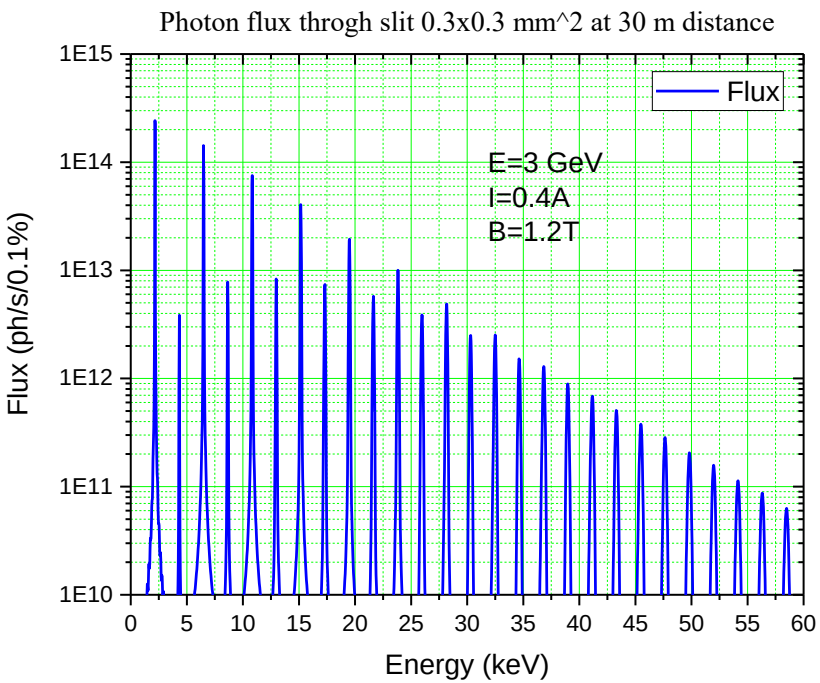
½ of undulator assembly



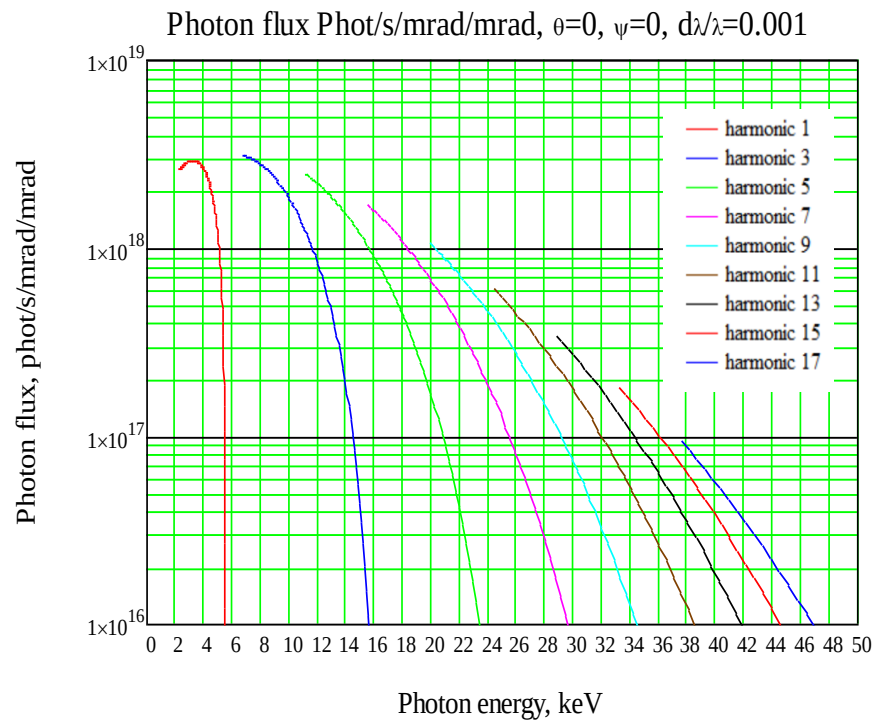
Cryostat for undulator

Superconducting undulators





Spectrum at zero angle and fixed field of 1.2 Tesla



Spectrum at zero angle for variable field

Other undulators based on the poles of the main undulator

Superconducting Undulator with tunable peak width (SCUTPW)

Changing the field in the longitudinal direction by means of shunt correction of current in groups of poles makes it possible to regulate the width of peaks in the radiation spectrum

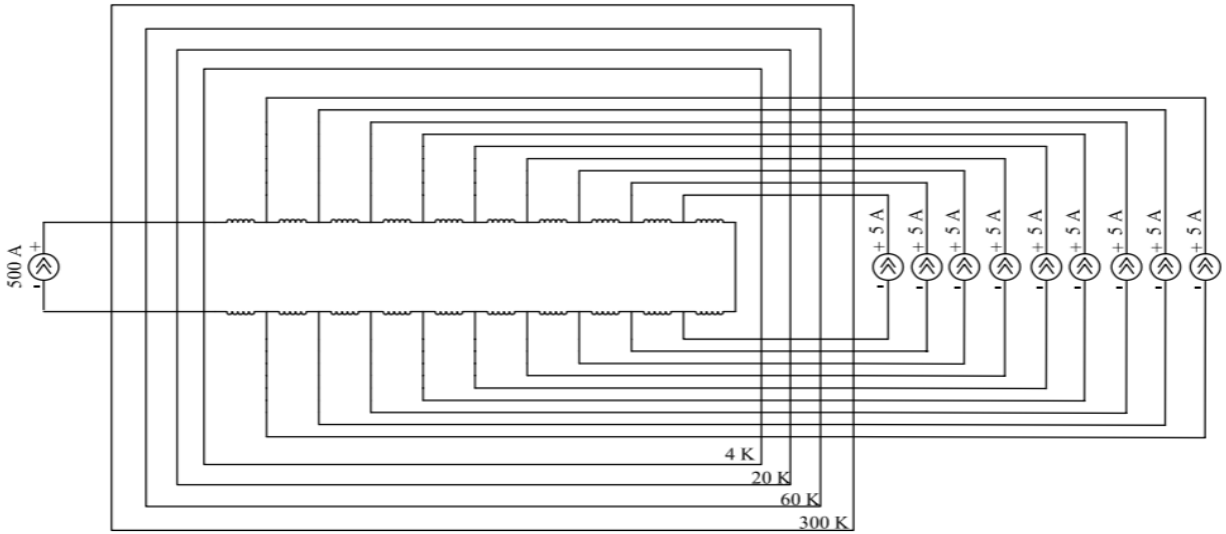
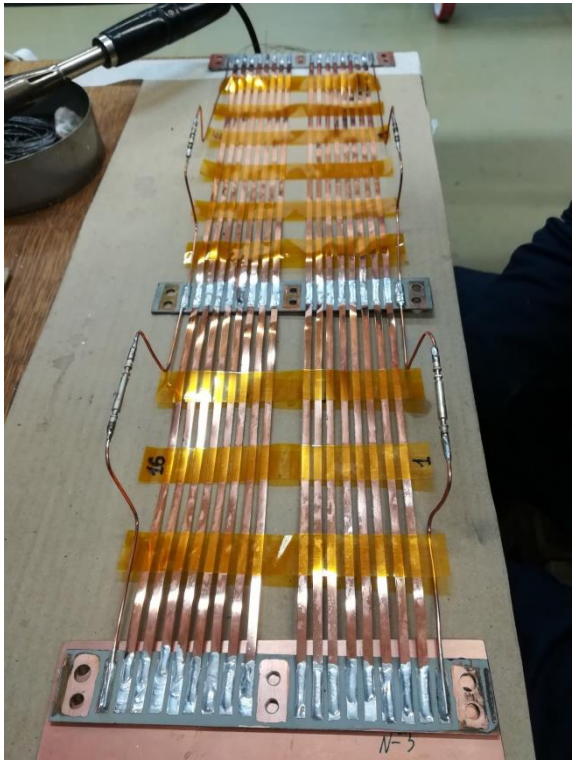
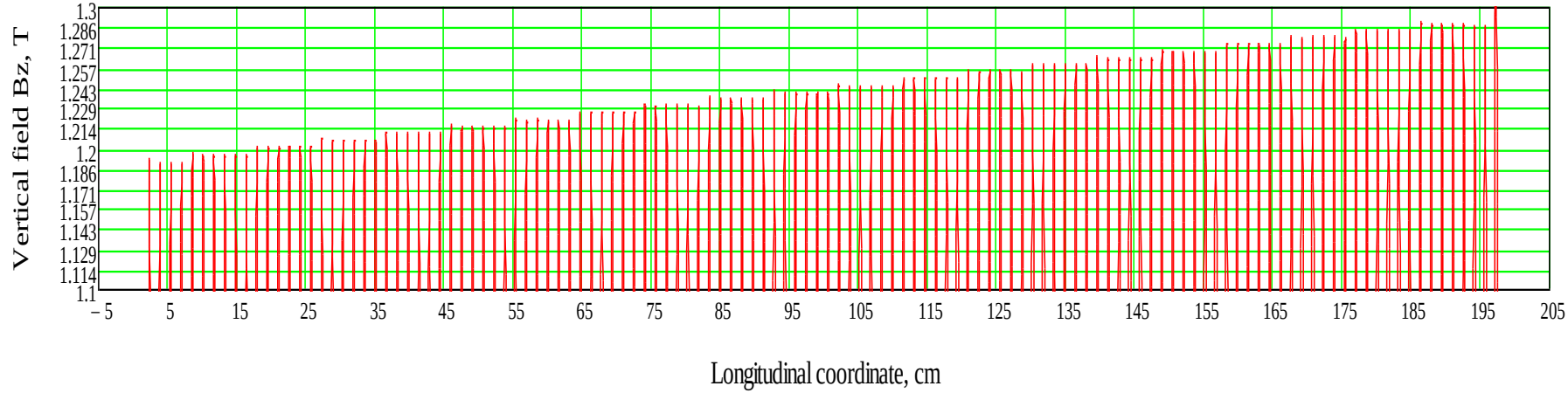


Diagram for connecting additional power sources to create a variable field in the undulator groups in the longitudinal direction

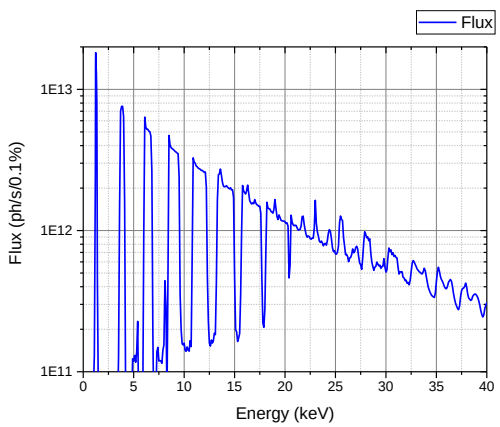


HTSC current leads for connecting additional current sources to the windings of the undulator

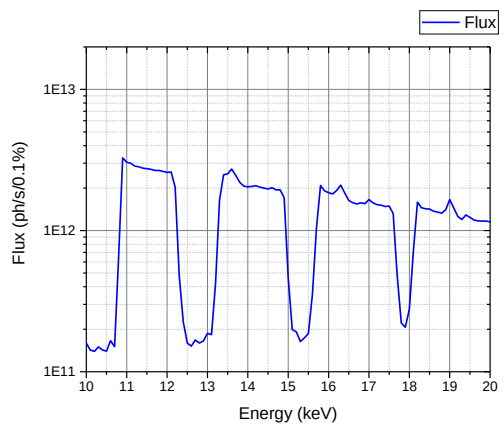
Superconducting Undulator with tunable peak width (SCUTPW)

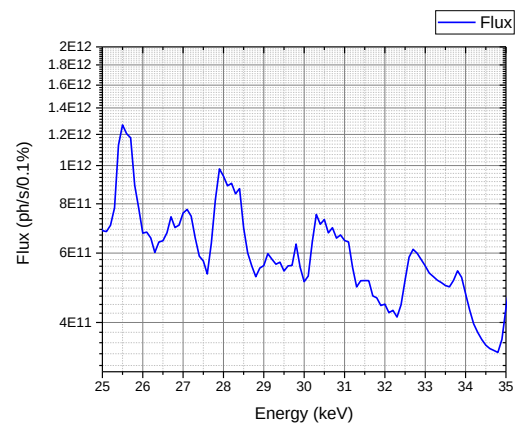


Magnetic field distribution in the undulator with shunt connection s of additional currents of 5 amperes in the mode of increasing currents in 8 poles groups.



Spectrum in region 0-40keV



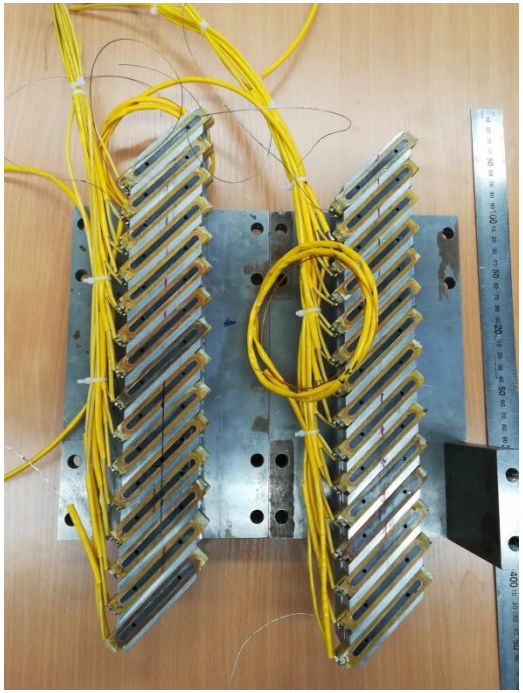


Spectrum in region 10-20keV

Spectrum in region 20-35keV

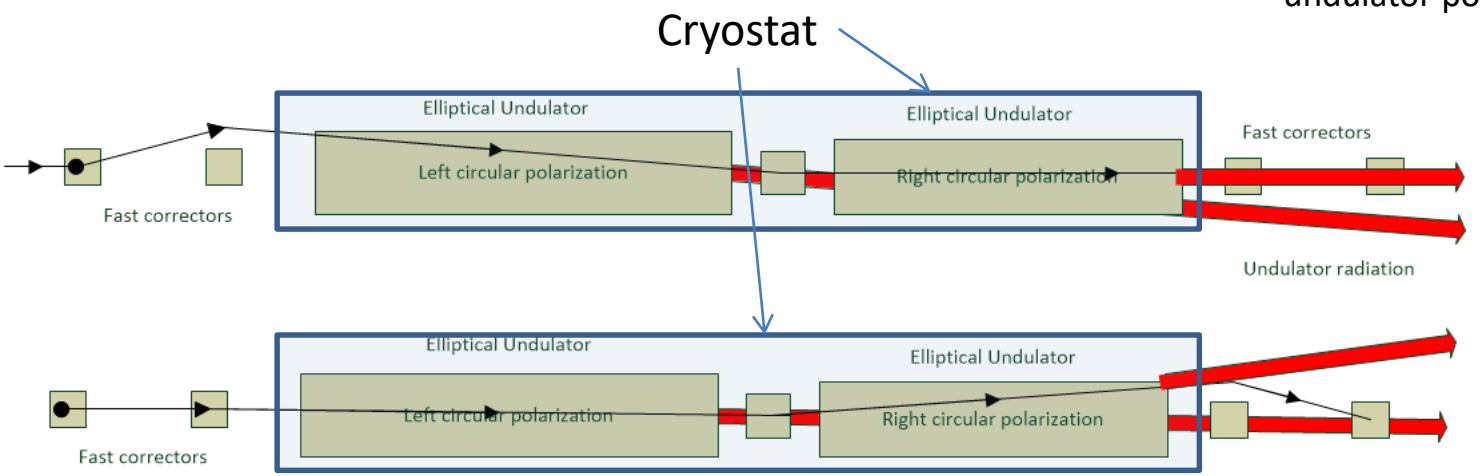
Superconducting Elliptical undulator (SCEU)

Nominal magnetic field Bz, Tesla	1.
Nominal magnetic field Bx, Tesla	0.7
Period, mm	~22
Phase error, grad	<3
Vertical/horizontal beam aperture, mm	6/60
Pole gap, mm	8
Period number	44
Magnet length, mm	~2200
Flange to flange distance, mm	~2840
Radiated power (B=4 Tesla, I=0.4 A, E=3 GeV), kW	~5

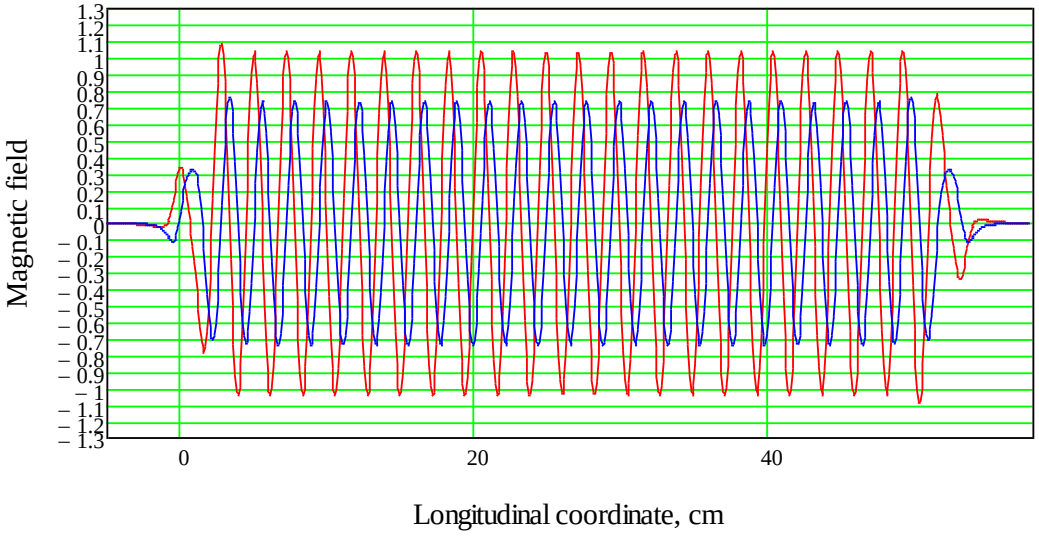


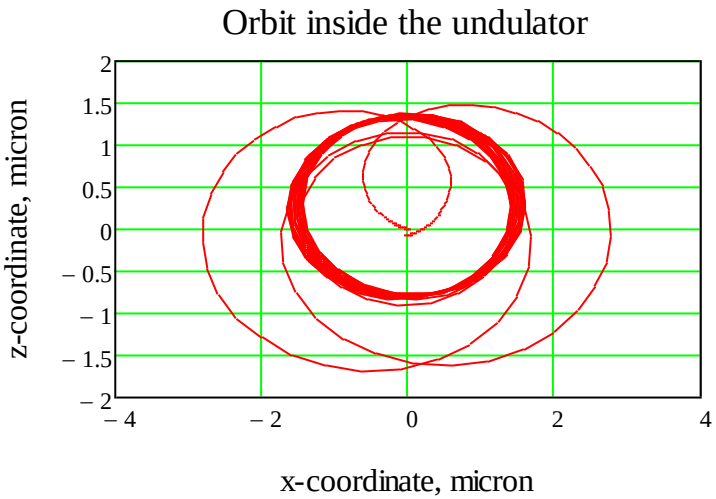
Two halves of elliptical undulator prototype assembled with standard undulator poles inclined on 45 degree

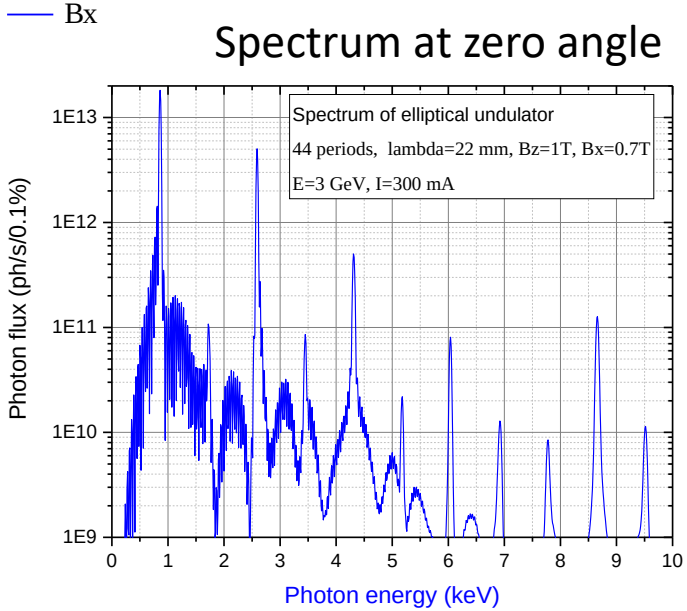
Scheme for fast switching of circular polarization

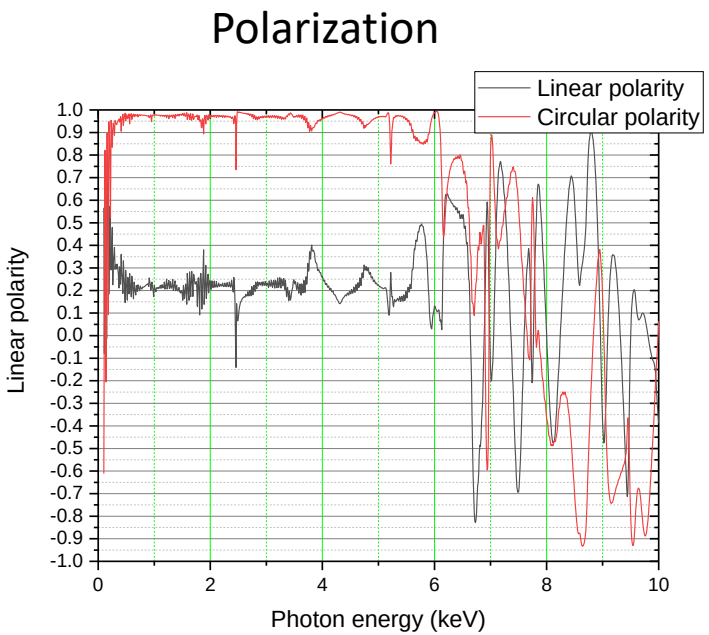


Superconducting Elliptical undulator (SCEU)



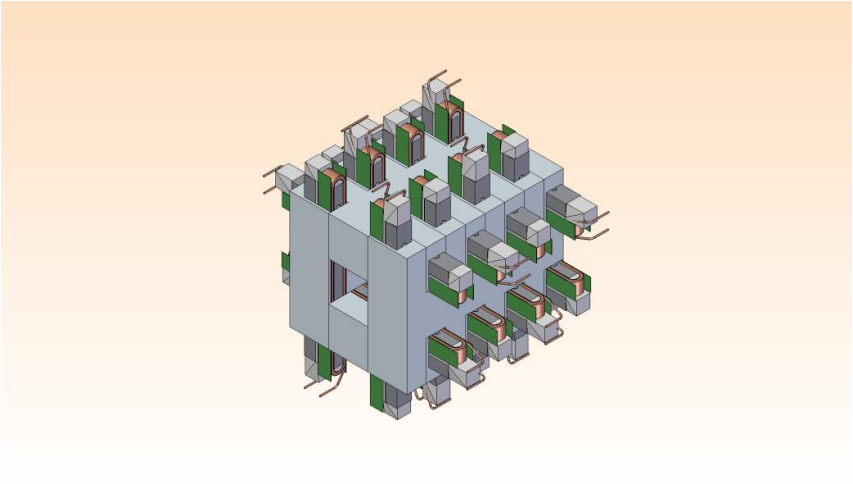






Superconducting Undulator with variable field configuration (SCUVFC)

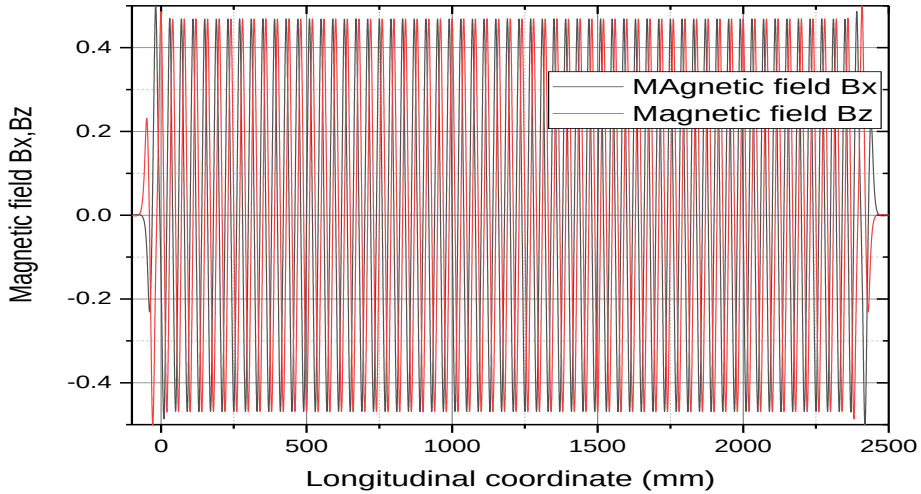
Nominal magnetic field Bz, Tesla	-0.5-- +0.5
Nominal magnetic field Bx, Tesla	-0.5-- +0.5
Period, mm	40-45
Phase error, grad	<3
Vertical/horizontal beam aperture, mm	16/16
Pole gap, mm	20
Period number	44
Magnet length, mm	~2200
Flange to flange distance, mm	~2840

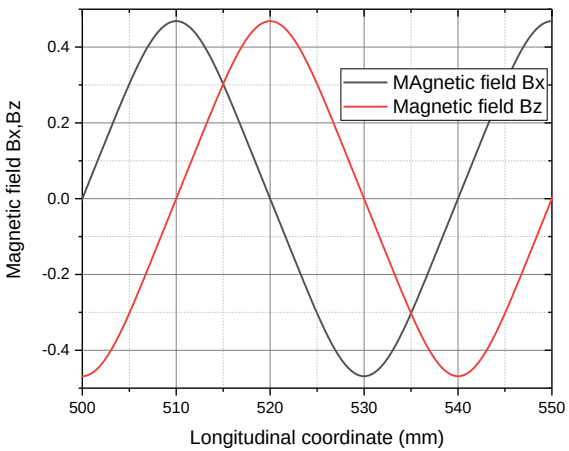


Modes of operation:

- Planar undulator with vertical field up to 0.5T
- Planar undulator with horizontal field up to 0.5T
- Spiral undulator with changeable helicity
- Any intermedium state

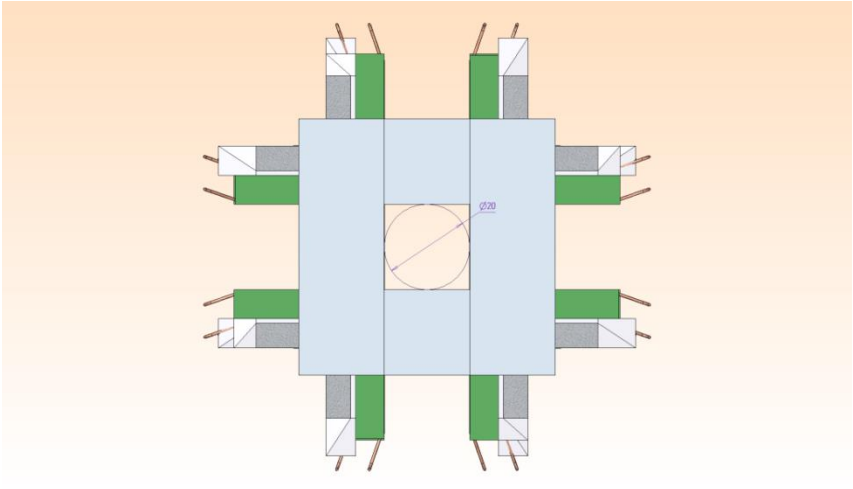
Superconducting Undulator with variable field configuration (SCUVFC)

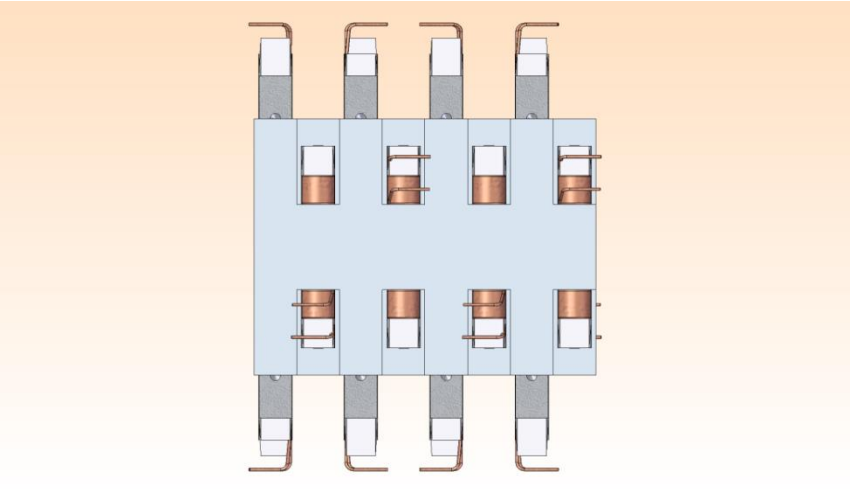




The longitudinal distribution of the field components Bx, Bz

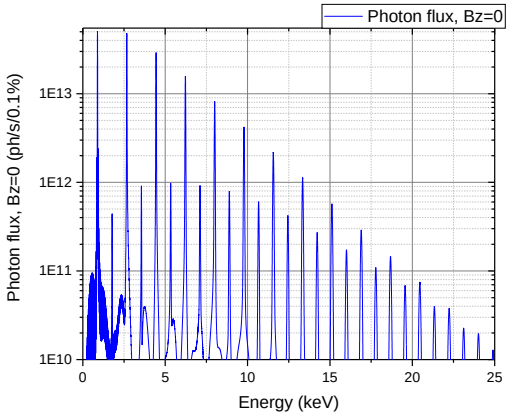
Fragment of the distribution of the field components Bx,Bz



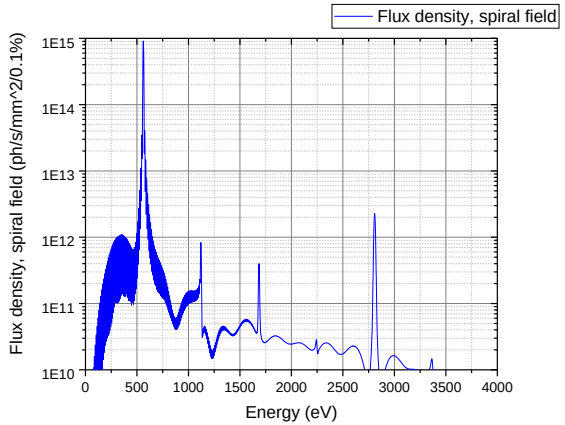


Superconducting Undulator with variable field configuration (SCUVFC)

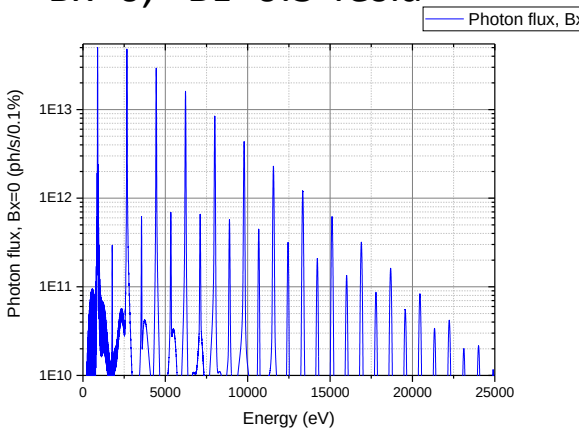
Undulator with vertical
Linear polarization
Bx=0.5 Tesla, Bz=0



Spiral undulator with
changeable helicity
Bx=0.5 Tesla, Bz=0.5Tesla



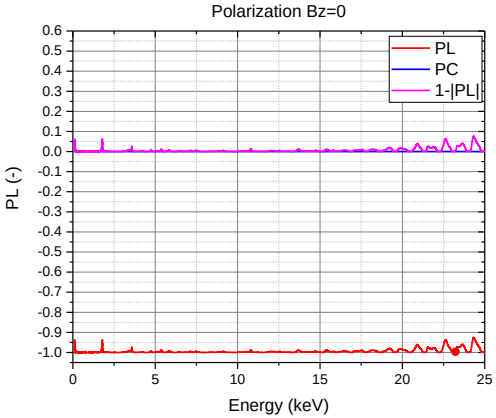
Undulator with horizontal
Linear polarization
Bx=0, Bz=0.5 Tesla

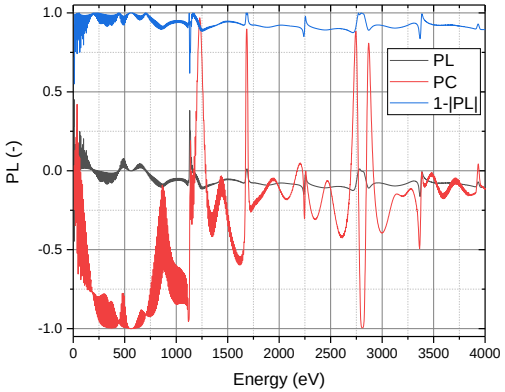


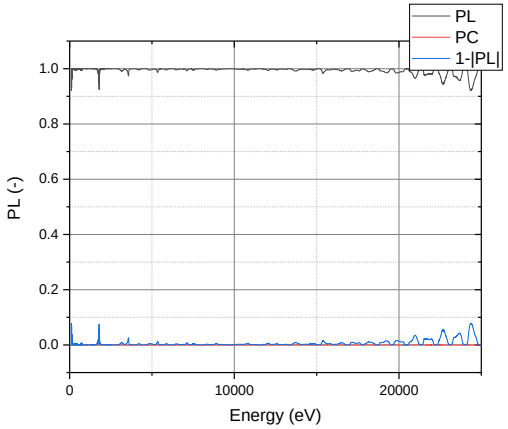
Spectrum at zero angle

Spectrum at zero angle

Spectrum at zero angle







Polarization

Resume

- The experience gained over the past 40 years will be used in the production of wigglers magnetic structures and cryostats.
- Over the past 2 years a model of a superconducting undulator with a horizontal racetrack and short period with a phase error of less than 3 degrees has been developed and successfully tested.
- Cryostats for superconducting magnets with indirect cooling using cryocoolers down to 3K temperature have been developed and implemented.
- We are open to discussing any insertion device that use superconducting magnets.

Thanks for attention