THz Wiggler Applied for Measurements of Electron Bunch Longitudinal Structure

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Abstract

The infrared undulator constructed at JINR and installed at **FLASH** in 2007 is used for longitudinal bunch shape measurements in the range of several tenths µm.

An electromagnetic wiggler is applied for narrow-band THz radiation and measurements of electron bunch longitudinal structure. This is a planar electromagnetic device with 6 regular periods, each 30 cm long. The K parameter is varied in the range 0.5- 7.12 corresponding to a field range B=0.025- 0.356 T peak field on axis.

The **bunch compression** scheme allows the whole wavelength range to be covered by a super-radiant emission with a sufficient form factor. The wavelength range corresponds to 126 µm - 5.3 mm at electron momentum of 19.8 MeV/c. The 3D Opera simulations of THz wiggler are under discussion.

HELMHOLTZ
ASSOCIATION

PITZ
Photo Injector Test Facility
Zeuthen

DESY

JINR FAR INFRARED UNDULATOR AT FLASH

> FLASH far infrared undulator constructed by JINR:

- tunable over a K–parameter range from 11 to 44
- producing radiation up to 200 µm at 500 MeV and up to 50 µm at 1 GeV
- used for longitudinal electron bunch measurements

- undulator parameters:
  - undulator period corresponds to 40 cm
  - the number of periods is 9
  - the magnetic field is varied in range of 0.1-1.1 T
- output undulator radiation:
  - wavelength 5-200 µm
  - peak power 4 MW
  - micropulse energy 1 mJ
  - micropulse duration 0.5-6 ps

PULSE RADIATION ENERGY MEASHUREMENTS

- The energy radiated by the FIR undulator is defined by the number of electrons per bunch N and a form-factor F(λ):

$$\varepsilon_{coh} = \varepsilon_e \times \left[N + N(N-1)\left|\overline{F}(\lambda)\right|^2 \right]$$

ε_e is energy radiated by single electron.

Electron bunch current profile reconstructed from the form-factor of FIR radiation (FLASH, single shot measurements)

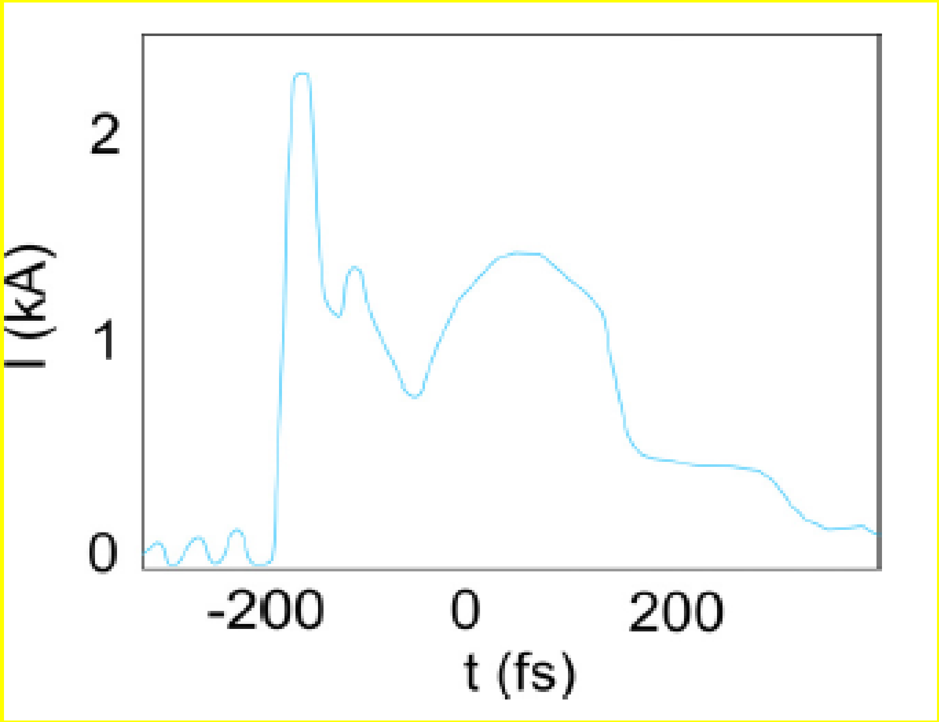


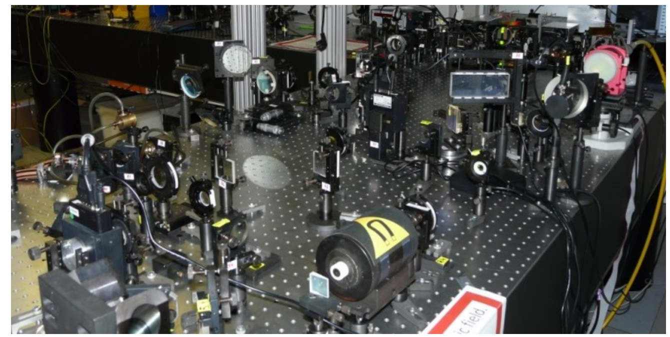
Photo cathode laser shaping → 3D ellipsoid (HRJRG-400 project)

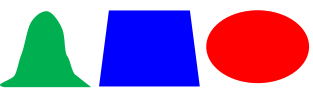
Goal – develop a photo cathode laser system with following parameters:

parameter	value	unit
wavelength	258	nm
micropulse energy	15	μJ
pulse train frequency	1	MHz
pulse train length	**0.3**	ms
pulse train rep.rate	10	Hz
micropulse rms duration	6±2	ps
transverse rms size	0.5±0.25	mm

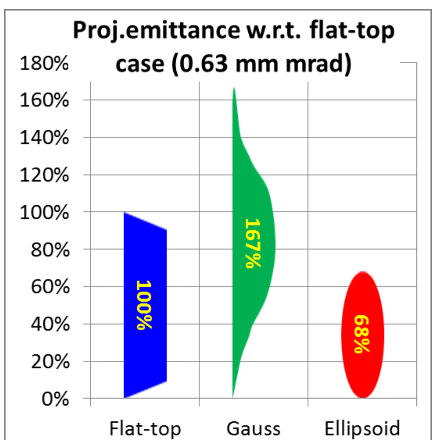
Collaboration:

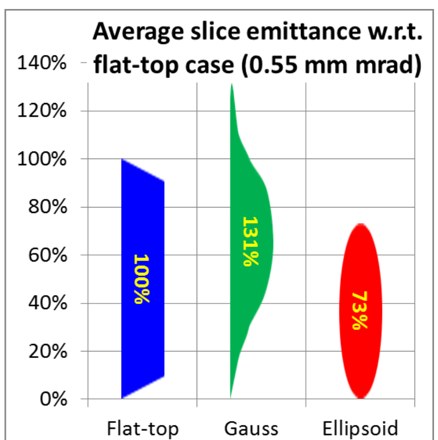
DESY (Zeuthen) – **IAP**(Nizhny Novgorod) – **JINR** (Dubna)





➔Various shapes of the photocathode laser pulse (Gaussian and Flattop temporal profiles vs. 3D-ellipsoid)





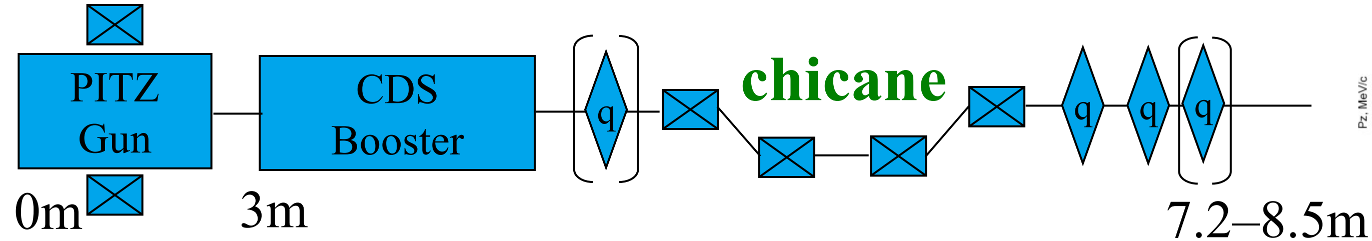
Benefits of using of 3D ellipsoidal pulses compared to conventional cylindrical ones:

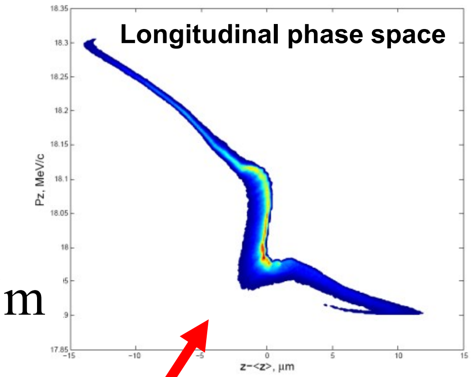
- ~no beam halo → better signal/noise, reduced **radiation damage**
- **~pure sinusoidal longitudinal phase space +3rd harm. →simplify/allow required compression**
- less sensitive to machine settings → higher **stability**

3D ellipsoidal cathode laser pulses ➔ Major improvements on electron beam performance

Short bunch generation: PITZ+BC (1pC preliminary simulations)

Setup:





Vary parameters and try different cathode laser shapes

Q=1pC	σ_t=1.2ps	FWHM=9.4ps	σ_t=4ps
σ_t	9.1 fs	9.6…8 fs	10.3 fs
I_{peak}	~60A	65...90A	**~200A**
σ_x	8.5 µm	5.4…13.4 µm	7.7 µm
σ_y	8.8 µm	9.9…4.7 µm	10.4 µm

~10fs

<10µm²

The installation of magnetic chicane in PITZ permits to reduce the bunch time duration down to (e.g.) 0.6 ps (200 um)

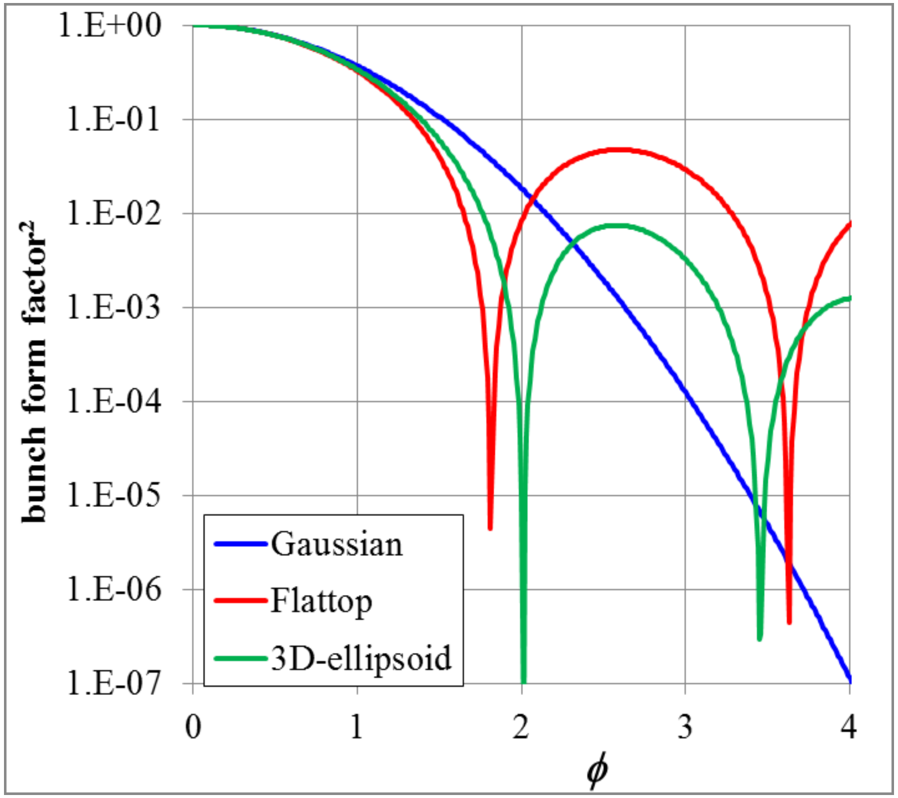
FORM FACTOR OF 3D ELLIPSOIDAL ELECTRON BUNCH

- Form factor F(ω) for 3D ellipsoidal bunch shape $(x^2+y^2)/5\sigma_x^2+(ct)^2/5\sigma_z^2\leq 1$

$F(\varphi)=3/(5\varphi^2)\times\{\sin(5^{1/2}\varphi)/(5^{1/2}\varphi)-\cos(5^{1/2}\varphi)\}$, where $\varphi=\omega\sigma_z/c$.

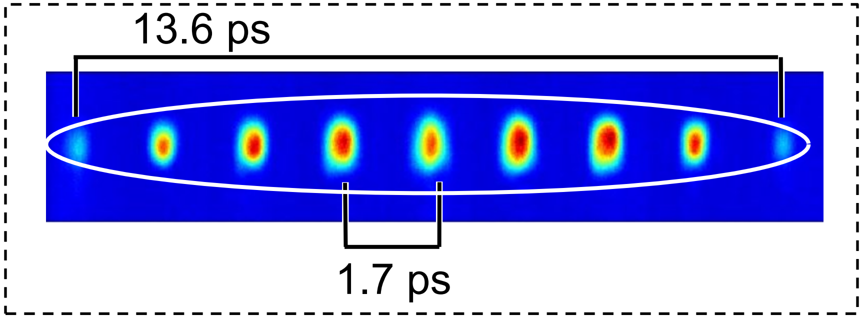
- Form factor of Gaussian beam:

$G(\varphi)=\exp(-\varphi^2/2)$.

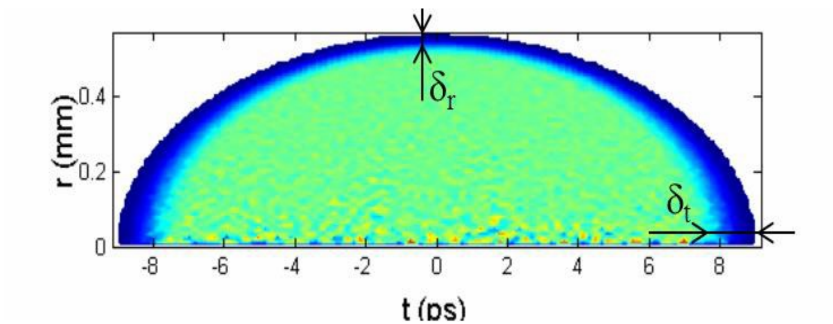


Dependence of square of form factor for ellipsoidal, flattop and Gaussian beams on $\varphi=\omega\sigma_z/c$

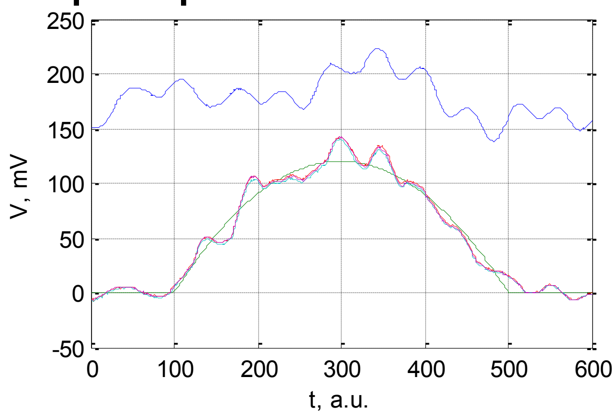
ACCURACY OF BUNCH LENGTH AND FORM FACTOR MEASUREMENTS



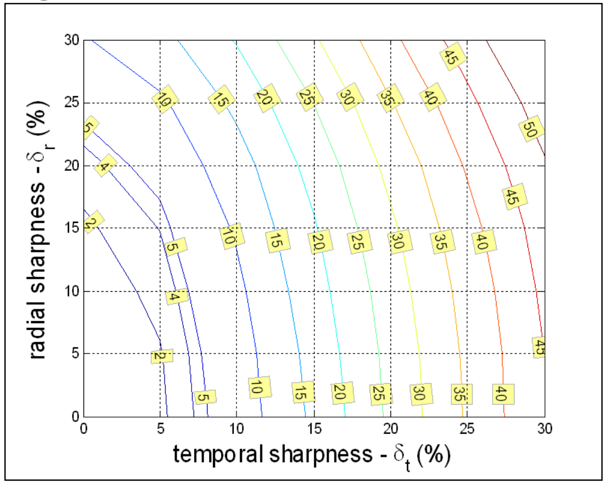
Cross-correlation measurement of pulse

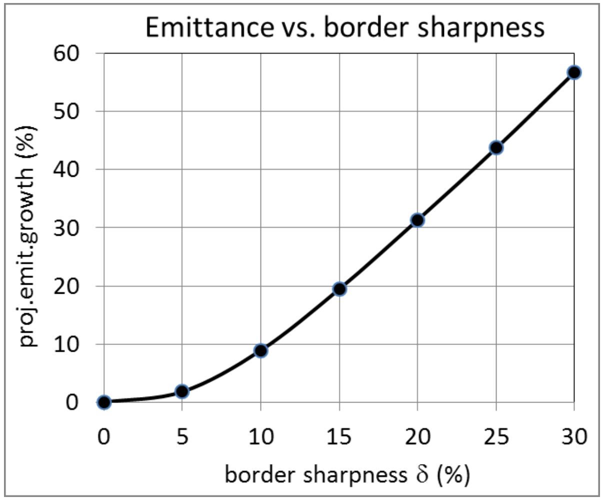


Laser pulse profile measured modulations



BD simulations: Emittance growth vs. border sharpness

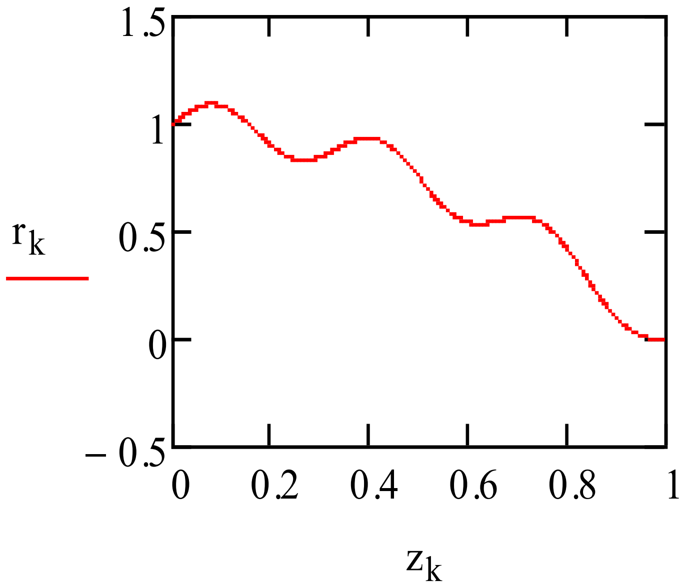




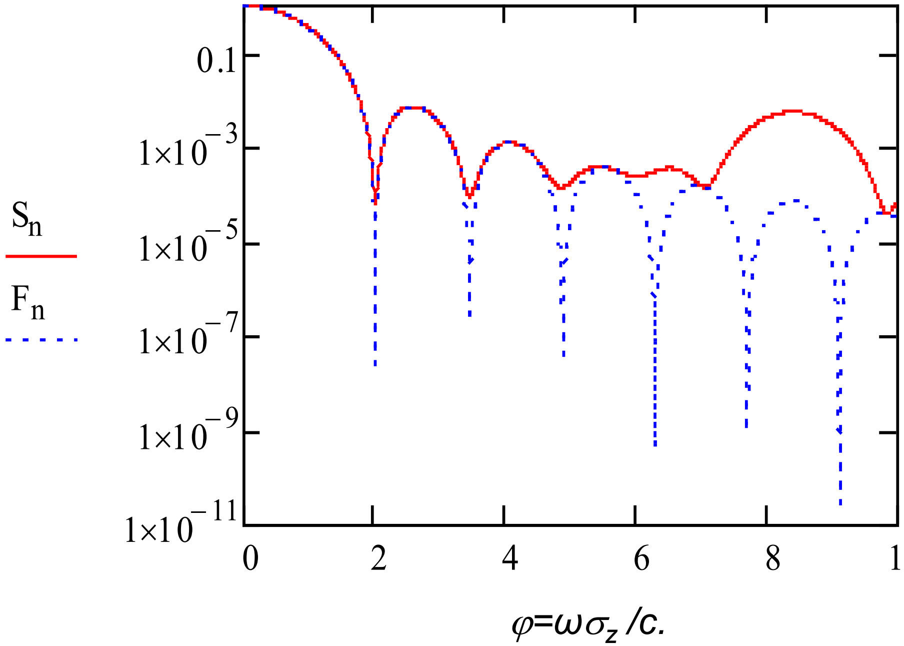
➔Relative accuracy of square of form factor and bunch length measurements → better than 10%

FORM FACTOR OF BEAM WITH IMPERFECTION OF ELLIPSOIDAL SHAPE

- Imperfection of bunch elliptical shape, $\delta \cong 0.1$ is relative amplitude of the border oscillations, m=3 is harmonic number.



Form factor (squared) of the ellipsoidal bunch



dashed line → perfect border

solid line →with border imperfections (δ=0.1 and m=3)

To determine the bunch length and extract the imperfection of the ellipsoidal bunch shape the phase range → 10>φ>0.3 → 124 um<λ<3.9 mm for the bunch length σ_z =200 um

THZ WIGGLER APPLIED FOR BUNCH SHAPE MEASHUREMENTS

Parameter of THz wiggler	value
period length, mm	300
number of full periods	7
number of poles including end-pieces	14+4
maximum wiggler parameter K_{rms}	7.12
peak field on axis, T	0.356
minimum field on axis,T	0.025
electron energy, MeV	19.8
maximum wave length, mm	5.1
minimum wave length, mm	0.12
clear gap, mm	100
position accuracy of magnetic axis, mm	0.5
angular precision of magnetic axis, mrad	0.5
field flatness at ±20 mm off-axis (horizontally), %	-0.1… +0.5
first field integral I1, G×cm	50
second field integral I2, G×cm^2	500
stability and reproducibility of magnetic axis, mm/μrad	±0.1/ ±50

WIGGLER DESIGN ISSUES

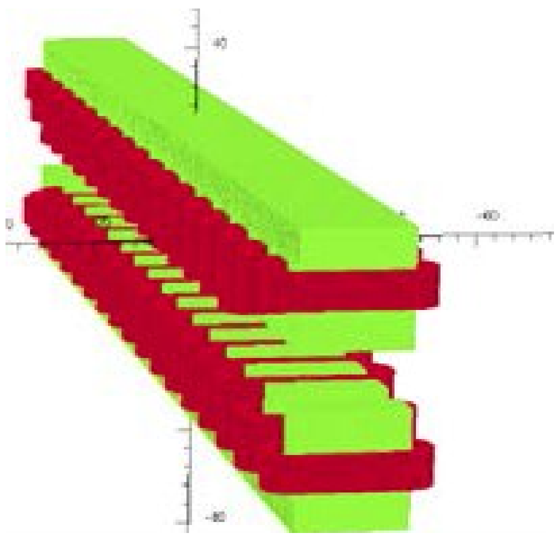
The peculiarity of wiggler → trim coils.

4 trim coils with individual power supply should be installed in the wiggler:

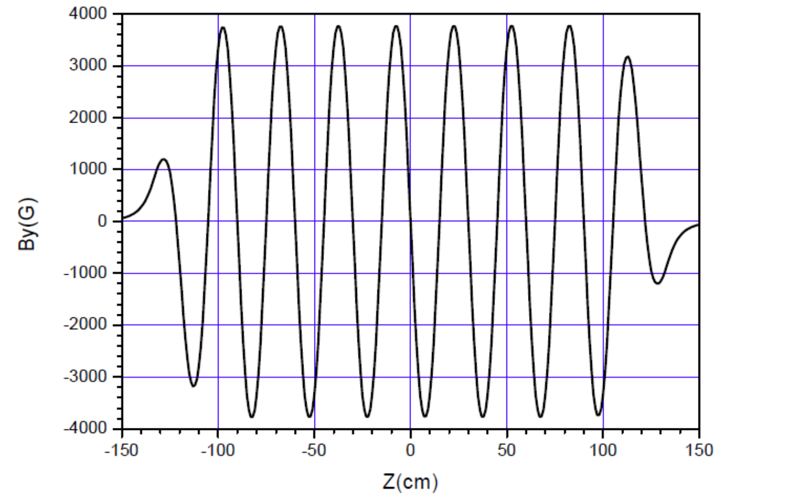
- to compensate the first (< 50 G×cm) and second (500 G×cm^2) integrals for the full wiggler length
- for this → an additional correction coil in each regular coil. They should compensate imperfection of wiggler mechanical construction and errors in coil position.
- in parallel to each individual correction coil a variable resistance divider will be installed (only 1 power supply for all 7 pairs of correction coils)

WIGGLER MAGNETIC FIELD SIMMULATIONS

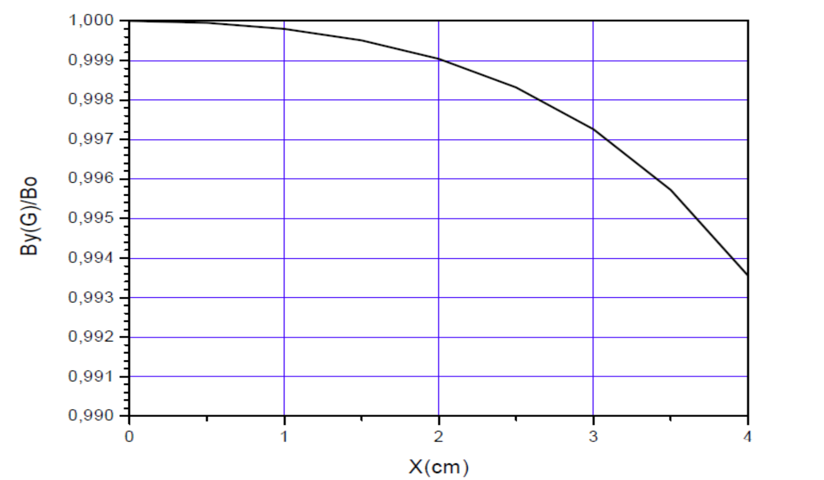
- The 3D wiggler simulations at its full scale were performed by TOSCA code.



Wiggler magnetic field distribution along wiggler axis



Dependence of normalized wiggler magnetic field at Iw=21.5 kA×turns on transverse coordinate.



- The maximum available magnetic field corresponds to 0.356 T at number of Ampere×turns of IW=1.85·103.

Conclusions and Outlook

- THz radiation can be used to characterize the shape of the radiating electron bunch
- JINR has rich experience in the design and production of the IR/THz undulator (FLASH 2007)
- A THz wiggler has been proposed to be used for parameters close to PITZ (+bunch compression → 200um) in order to characterize electron bunch:
  - Bunch length measurements
  - Bunch shape characterization (e.g. 3D ellipsoidal shape, including imperfections)