Featuring the Characteristics of the Super Coherent Teraherz Photon Ring

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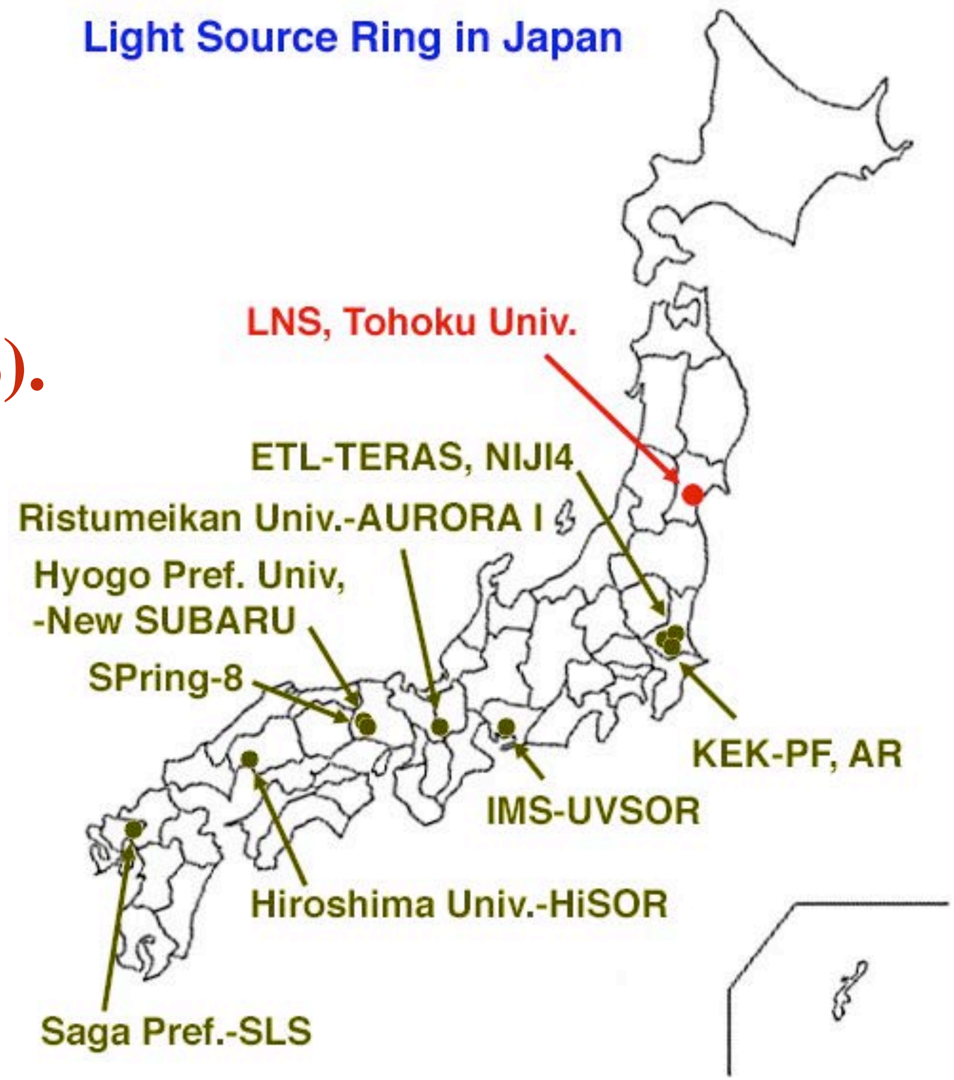
(JASRI) / SPring-8

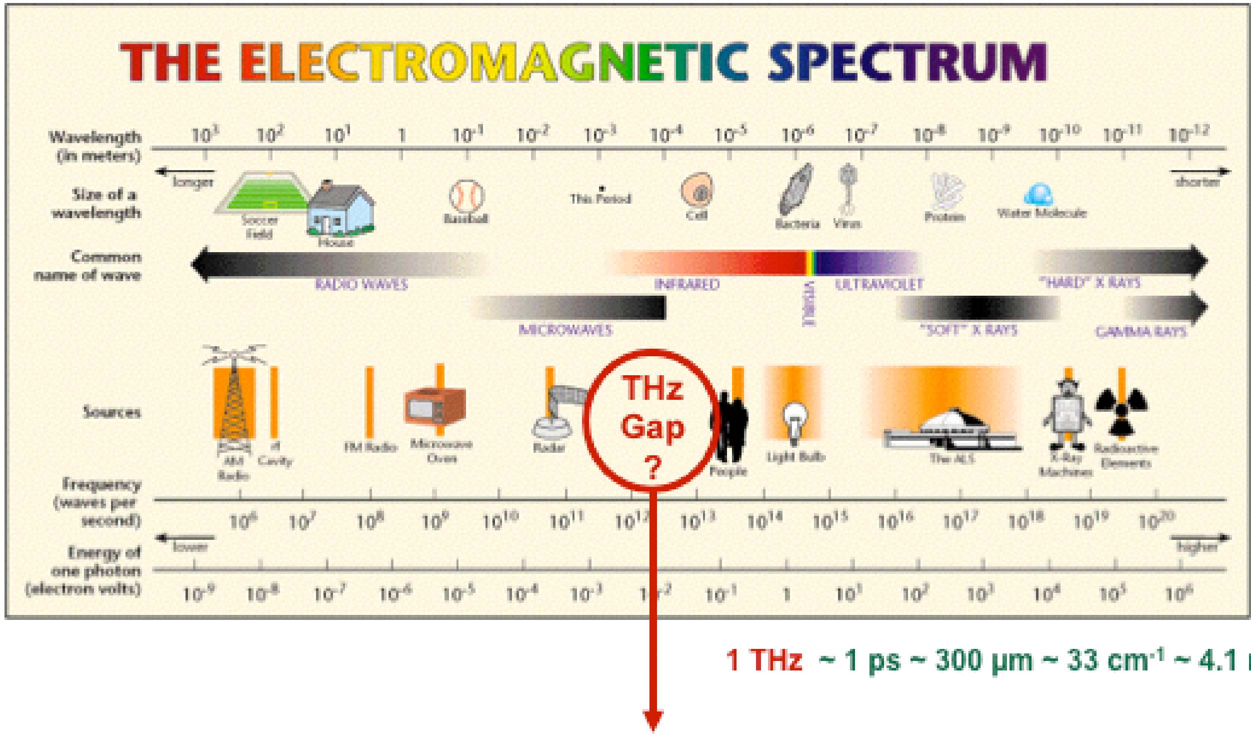
Coherent Synchrotron Radiation was firstly observed at LNS, Tohoku University (1988).



LNS :founded in 1967

“Teraherz Gap” in the Electromagnetic Spectrum

http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html



1 THz ~ 1 ps ~ 300 µm ~ 33 cm^{-1} ~ 4.1 meV ~ 47.6 K

Broadband Techniques:

- Backward Wave Oscillators
- Time-domain Spectroscopy
- Coherent Synchrotron Radiation

Accelerator-Based THz Sources

The advantages of coherent synchrotron-based FIR include high brilliance, intrinsic polarization, wide spectrum, and broad temporal coherence, i.e. short pulses. Pulse shaping of the THz pulses has been achieved in storage rings by imprinting a shaped laser pulse profile as an energy modulation on the electron beam (laser slicing) .

R. W. Schoenlein et al., Science 287 2237-2240 (2000).

Storage Ring Based Source

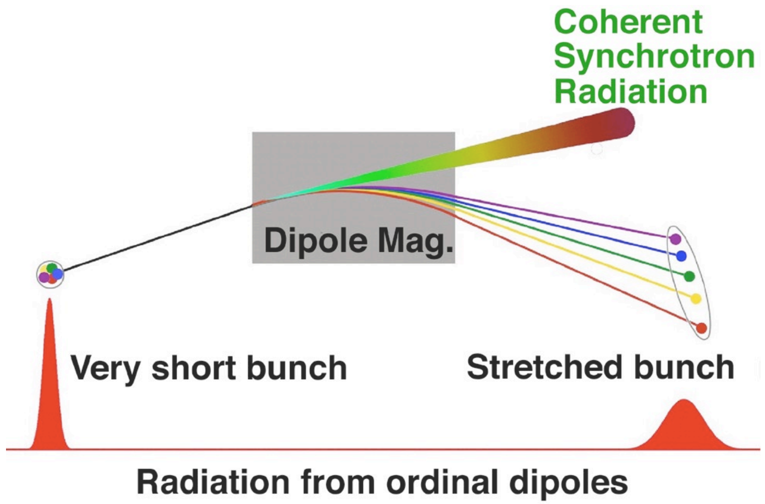
In recent years, significant progress has been made in understanding Coherent Synchrotron Radiation (CSR) in storage rings: stable CSR was produced in a storage ring and a theoretical model explaining the observation was developed, and experiments at LBNL demonstrated generation of intense terahertz CSR pulses from "laser-slicing", based on the energy modulation of a fraction of the electron beam by a femtosecond laser pulse.

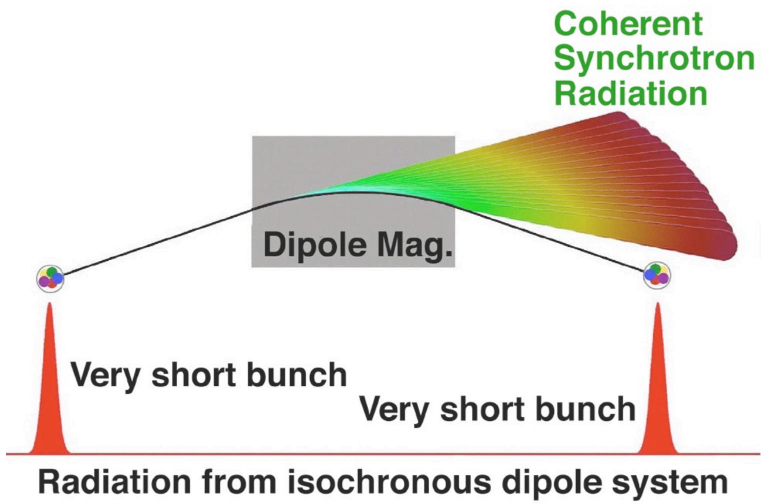
M. Abo-Bakr et al., Phys. Rev. Lett. 88, 254801 (2002) & Phys. Rev. Lett. 90, 094801 (2003).
F. Sannibale et al., Phys. Rev. Lett. 93 094801(2004).
J. M. Byrd et al., to be published.

Coherent Radiation from Isochronous System -I-

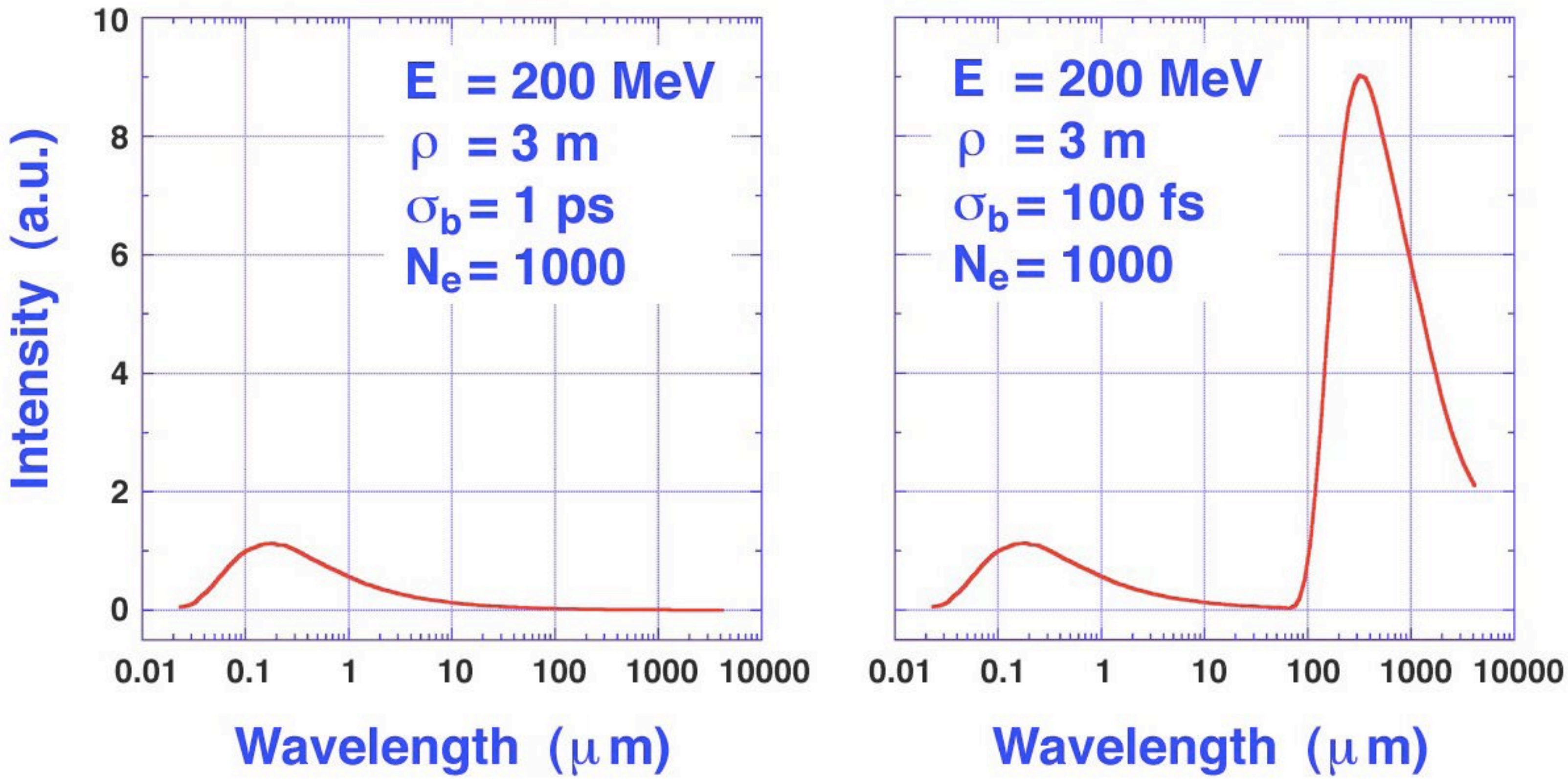
Short bunch beam can emit coherent synchrotron radiation, but its shape normally collapses.

Short bunch beam can emit coherent synchrotron radiation continuously in the isochronous beam transport system !!





Coherent Radiation from Isochronous System -II-



Simulated spectra from the bunched beam of N_e = 1000.

Scientific Approach

1. Electron Beam Source

☆**Thermionic RF Gun : ITC (Independently-Tunable Cells) RF Gun)**

2. S2Acc Simulation

☆**3-D FDTD (Finite Difference Time Domain) simulation in order to take "Wake-field" and "Space-charge" into account**

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3. Isochronous Optics

☆**Locally canceling out of** $\int \frac{\eta}{\rho} dl_{CELL}$ **to preserve the bunch length.**

☆**Locally canceling out of path length difference depending on the betatron amplitude.**

☆**Chromaticity cancellation for the energy acceptance.**

3. Estimation of Coherent Radiation

☆**Complete-vector-considered integration of Lienard-Wiechert 4-vector potential.**

$$\frac{d^2 I}{d\omega\, d\Omega} = \left\{ N\left[1 - f(\omega)\right] + N^2 f(\omega) \right\} \times \frac{e^2 \omega^2}{4\pi^2 c} \left| \int_{-\infty}^{+\infty} \vec{n} \times (\vec{\beta} \times \vec{n}) e^{i\omega\left(t - \frac{\vec{n} \cdot \vec{r}(t)}{c}\right)} \right|^2$$

$$f(\omega) = \left| \int_{-\infty}^{+\infty} e^{i\omega \vec{n} \cdot \vec{r} / c} S(\vec{r})\, d\vec{r} \right|^2$$ **form-factor (note! not ONE-dimensional)**

4. Combined Multipole Magnets (quoted Prof. Sato, RCNP, Osaka Univ.)

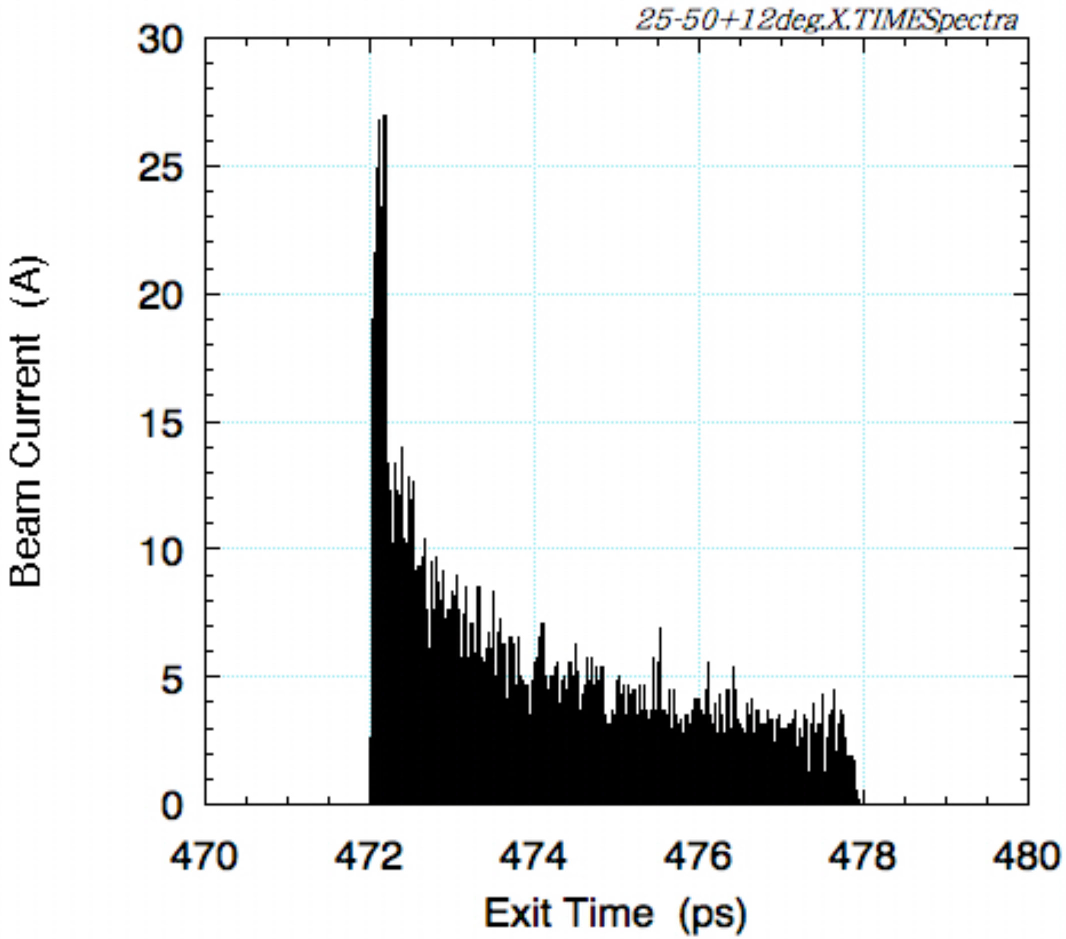
☆**Pole face => Mag. field vs. Mag. field => Pole face**

Maxwell's equaion $B = -\nabla \psi$

Laplace equation $\Delta \psi = 0$ **should be satisfied.**

Poisson, RADIA, Original 3D-Code.

Short Bunch from a Thermionic RF Gun



(Quasi) Isochronous THz ring

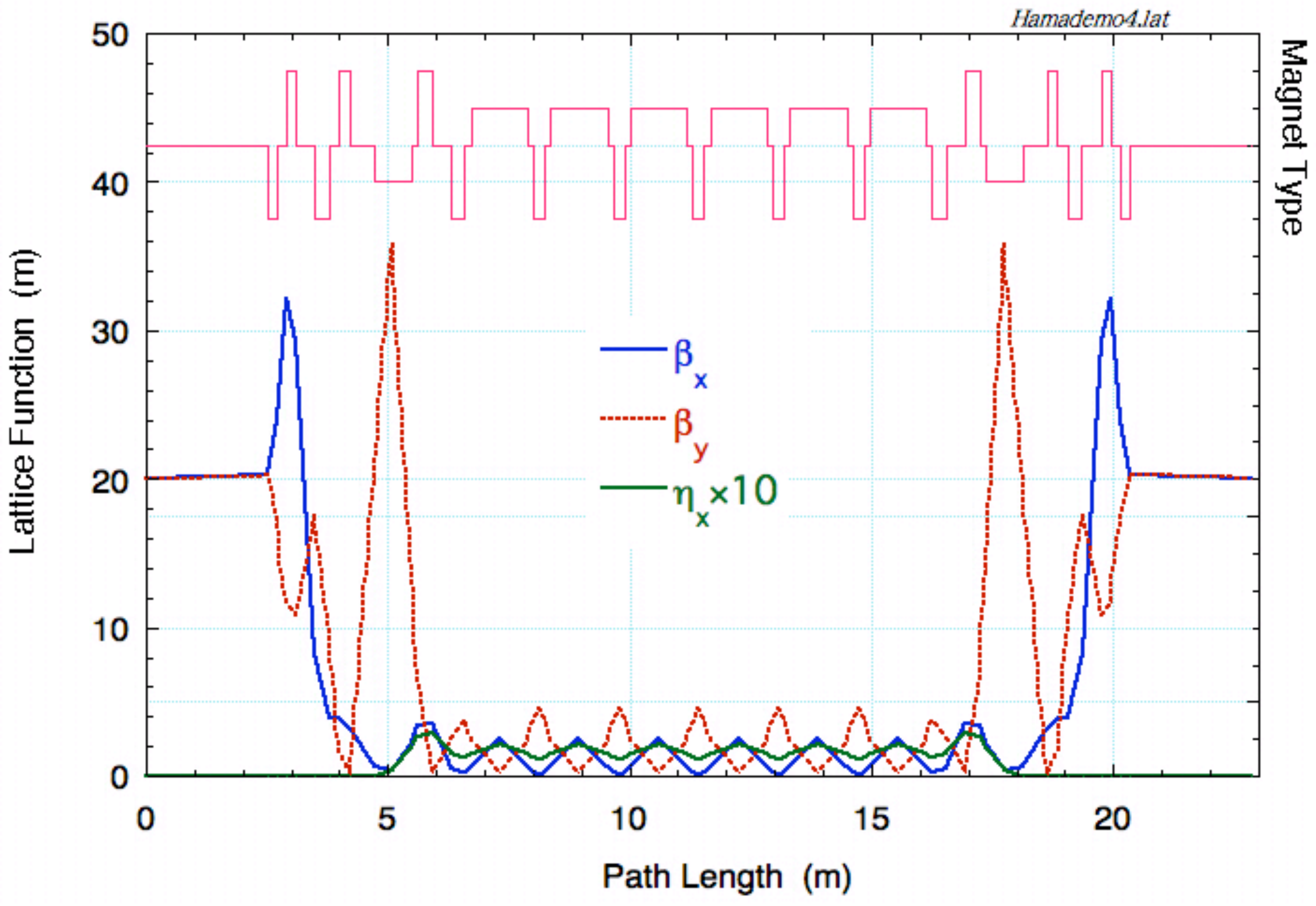
<u>Main term</u> of path-length deviation ΔL comes from bending sections. Drift space and Q-mag section are 2-nd order term.

Path Length Deviation
In the Bending Mag.

$$\Delta L = \int_0^C \frac{x}{\rho}\, ds + O\left(\Delta^2\right)$$

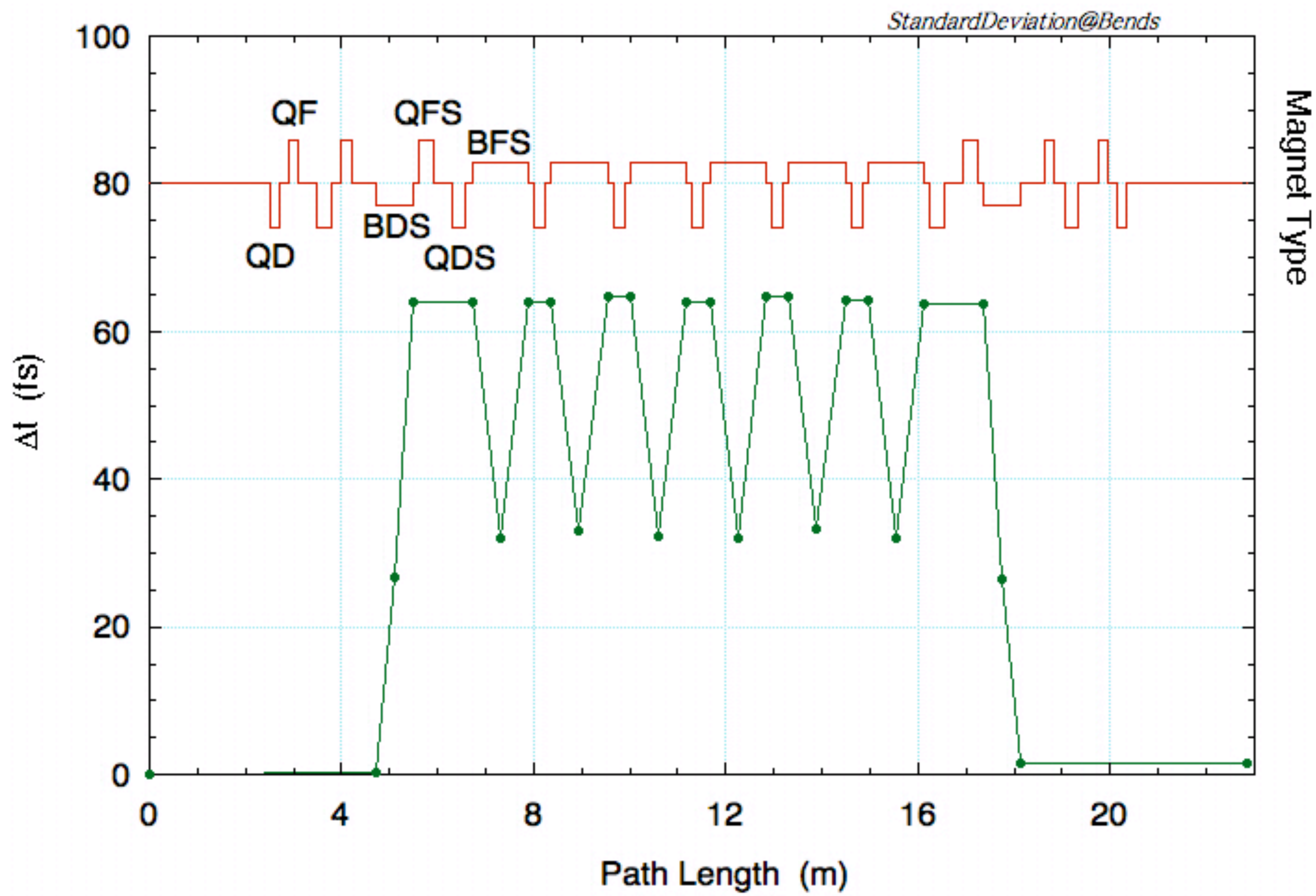
Betatron motion	$$x_\beta = \sqrt{\varepsilon_x \beta_x(s)}\ \cos\left(\psi(s) + \phi_0\right)$$
Path-length deviation	$$\Delta L \approx \int_0^C \frac{x}{\rho}\, ds = \int_0^C \frac{\sqrt{\varepsilon_x \beta_x(s)}\ \cos\left(\psi(s) + \phi_0\right)}{\rho}\, ds$$
Smooth approximation	$$\Delta L_\beta \sim \frac{\sqrt{\varepsilon_x}\left[\sin\left(\psi_2 + \phi_0\right) - \sin\left(\psi_1 + \phi_0\right)\right]}{\sqrt{\tilde{\beta}_x(s)}\ \rho}$$

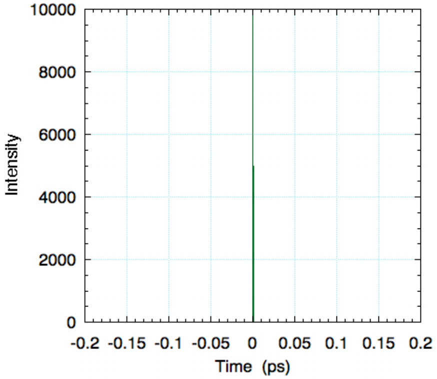
Lattice Example of a 180°-Arc



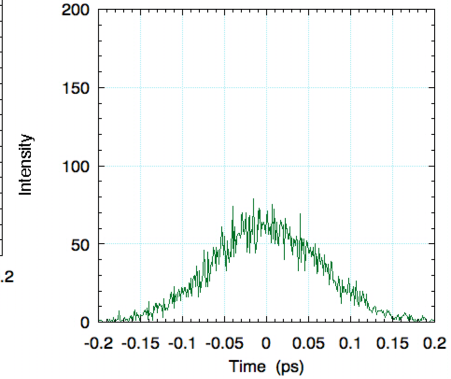
Isochronous Optics

(6 identical units + 2 dispersion suppressor for a 180°-arc)

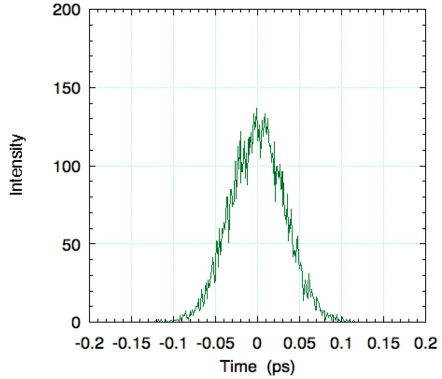




Initial

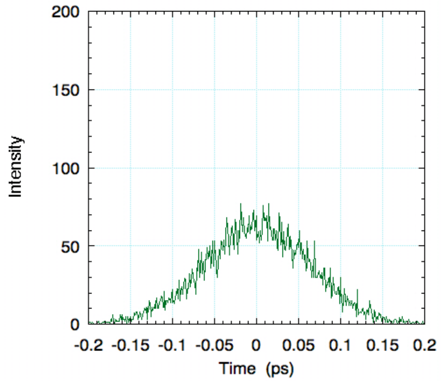


Entrance for B4

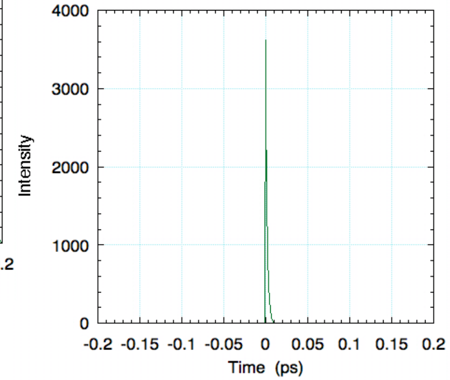


B4 Center

Exit for B4



Final



Bunchlength variation in a 180°-arc

Lattice Parameters as a "RING"

Circumference	C	45.691 m
Betatron Tune	(ν_x, ν_y)	(6.638, 7.945)
Momentum Compaction	α	0.02209
Natural Chromaticity	(ξ_x, ξ_y)	(-17.366, -53.585)
Damping Partition	(J_x, J_y)	(-1.260, 4.260)
RMS x Emittance*	ε_x	-0.001307 π mm-mrad
RMS Energy Spread*	ΔE	0.033 MeV
Synchrotron Radiation*	U_0	0.2688 keV/turn
Damping Times*	(τ_x, τ_y, τ_z)	(-0.2698, 0.3399, 0.0798) sec

*Normalized to $B\rho = 1$ ($E = 300$ MeV).

Yes, it cannot be a storage ring !

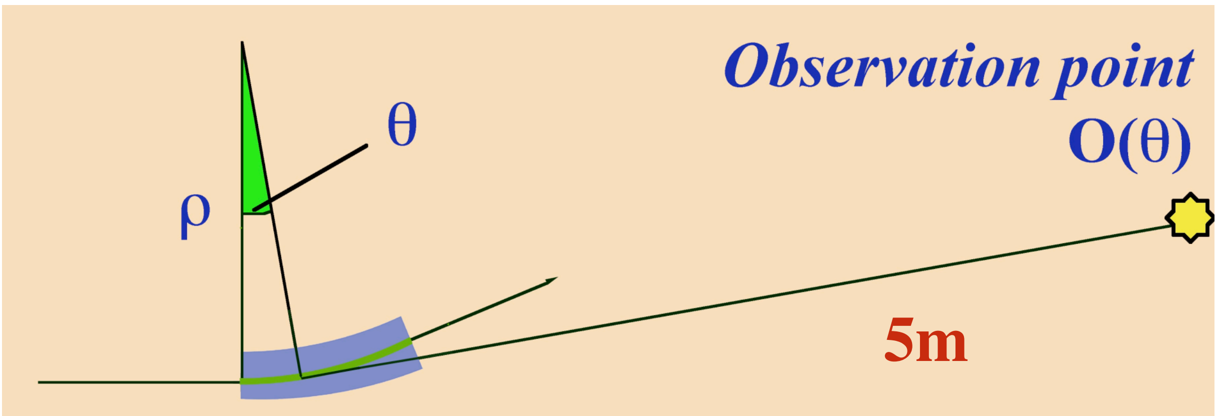
Simulation of Coherent THz Synchrotron Radiation

Lienard-Wiechert 4-vector potential

$$\phi\left(\vec{r}, t\right) = \frac{1}{4\pi\varepsilon_0}\int_V \frac{\rho\left(\vec{r}, t - r/c\right)}{r}\,dV \qquad \vec{A}\left(\vec{r}, t\right) = \frac{\mu_0}{4\pi}\int_V \frac{\vec{J}\left(\vec{r}, t - r/c\right)}{r}\,dV$$

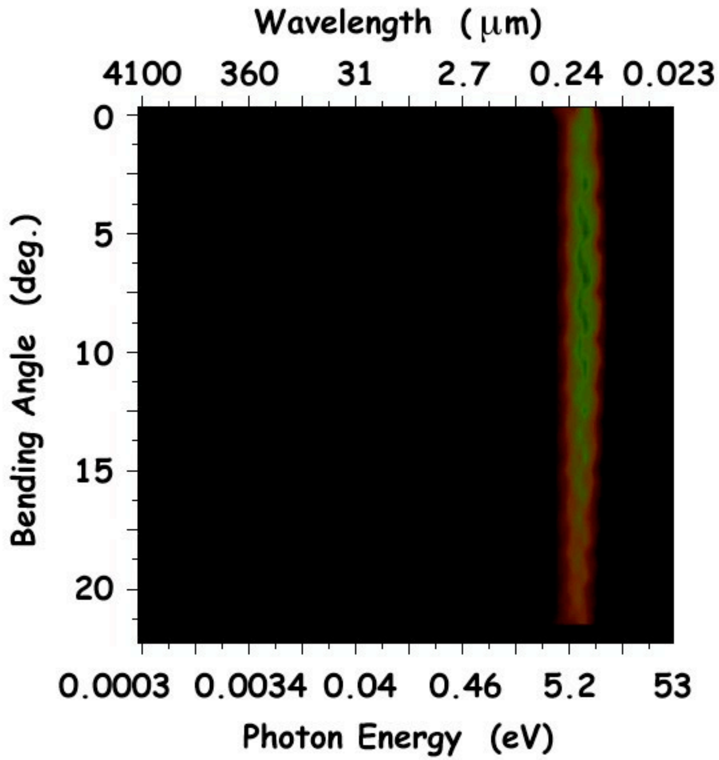
Power spectrum per unit solid angle

$$\frac{d^2 I}{d\omega\, d\Omega} = \frac{e^2}{4\pi^2 c}\left|\int_{-\infty}^{\infty} e^{i\omega\left[t' + R(t')/c\right]}\,\frac{\boldsymbol{n}\times\left[(\boldsymbol{n}-\boldsymbol{\beta})\times\dot{\boldsymbol{\beta}}\right]}{(1-\boldsymbol{\beta}\cdot\boldsymbol{n})^2}\,dt'\right|^2$$

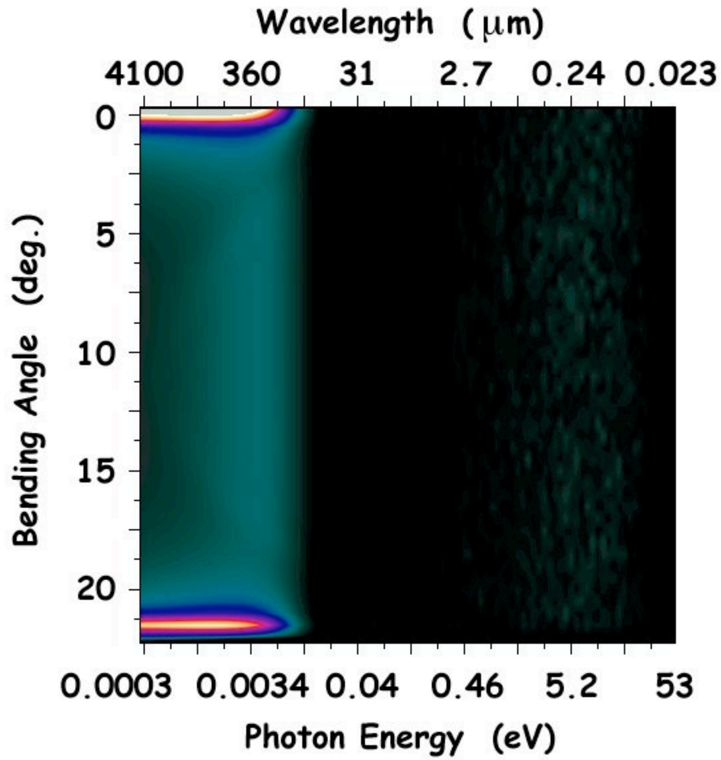


Coherent THz Radiation

$E = 200$ MeV, $\rho = 3$ m, $u_C = 5.92$ eV, $\lambda_C = 0.21$ μm

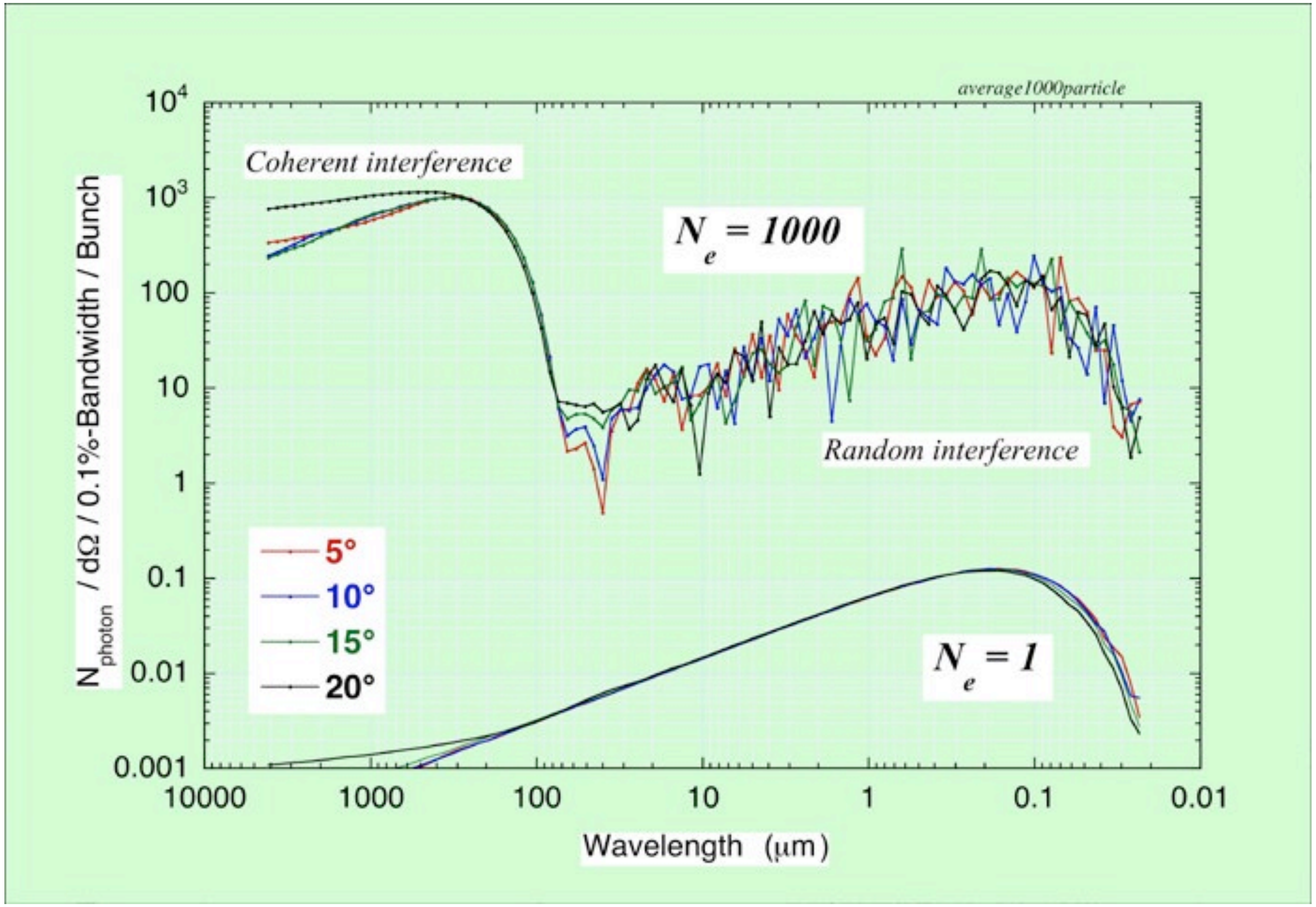


Ne = 1



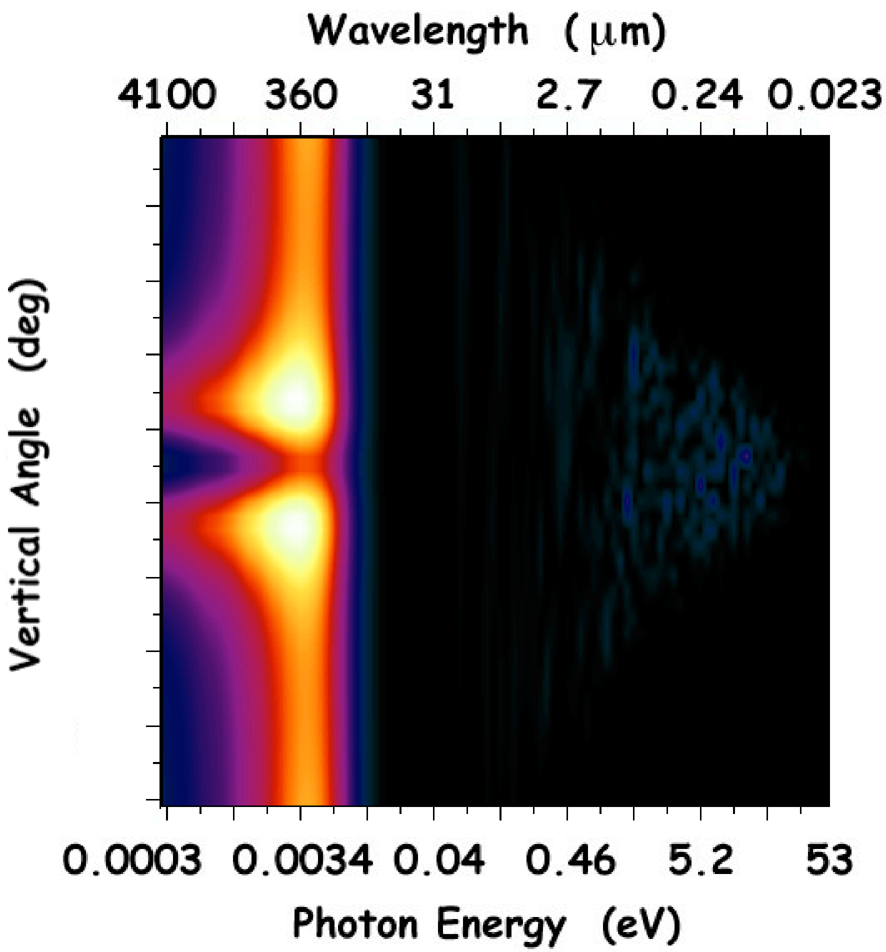
$N_e = 1000$

Spectra



average1000particle
Coherent interference
$N_e = 1000$
Random interference
$N_e = 1$
5°
10°
15°
20°
N_{photon} / dΩ / 0.1%-Bandwidth / Bunch
10^4
10^3
100
10
1
0.1
0.01
0.001
10000
1000
100
10
1
0.1
0.01
Wavelength (μm)

Vertical Angular Distribution !!!



Summary & Prospect

1. This is a ring type light source but "not" storage ring.
2. Complete isochronous should be realized by taking both the energy dispersion and the betatron oscillation into account.
3. Bunch length of 100 fs is required, if Gaussian, to obtain the coherent THz radiation.
4. The beam power may be recovered by additional decelerating structures.

Toward (nearly) Complete Isochronous

1. **Pathlength deviation due to betatron amplitude may be Ok.**

2. **Mometum compaction (or R_{56}) has to be compensated.**

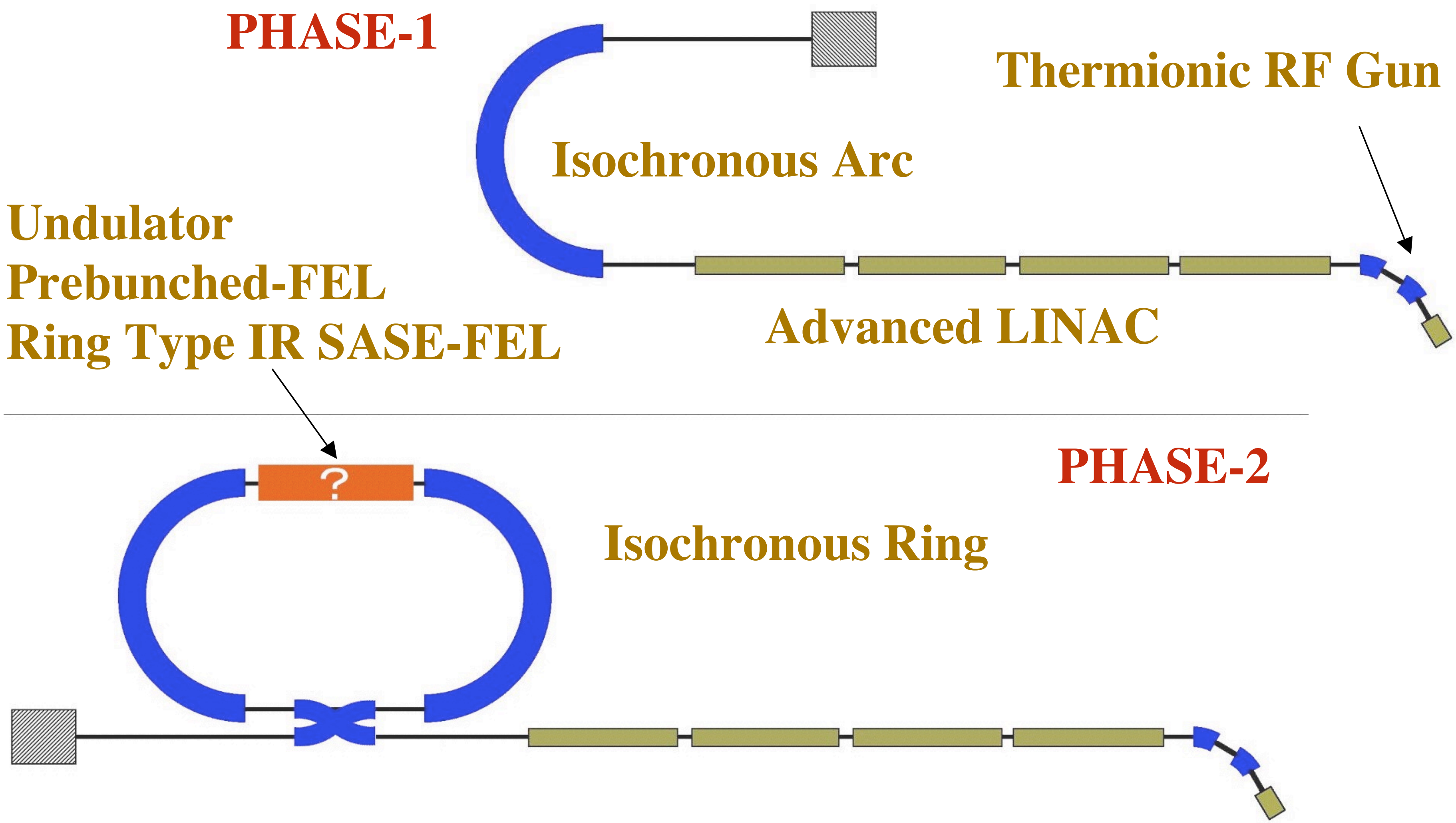
   => Maybe "inverted bends" are inserted into the dispersion suppressor.

Designing work is continued.

THz Powers

Source	Peakpower (Micropulse)	Averagepower (Macropulse)	Averagepower
p-Ge laser	1 W (10 us)	-	100 uW
YAG+NOE	300 mW (4 ns)	-	60 nW
FEL	10 kW (1 ps)	100 W (10 us)	10 mW
SCTR(phase-1)	100 kW (250 fs)	70 W (100 ns)	3.5 mW
SCTR(phase-2)	1 MW (250 fs)	700 W (10 us)	350 mW

Project Goal



Time Schedule