Investigation Status of Emittance Blow up in Electron Beam Transport Line

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B2GM

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Luminosity limitation by injected beam

K. Oide

The luminosity can be written in terms of *specific luminosity* as:

$$\mathcal{L} = e^2 N_b N_+ N_- f_0^2 \mathcal{L}_{\mathrm{sp}} \ , \tag{1}$$

where $N_\pm$, N_b, f_0 are the particles/bunch, bunches/ring, and the revolution frequency, respectively. At the equilibrium, $N_\pm$ must balance with the injector currents $I_{\pm\mathrm{inj}}$ as:

$$e N_\pm N_b f_0 = I_{\pm\mathrm{inj}} \varepsilon_\pm \tau_\pm \ , \tag{2}$$

where $\tau_\pm$ and $\varepsilon_\pm$ are the lifetimes and the injection efficiencies of $e^\pm$ beams. Then the luminosity is expressed as

$$\mathcal{L} = I_{+\mathrm{inj}} \varepsilon_+ I_{-\mathrm{inj}} \varepsilon_- \frac{\tau_+ \tau_-}{N_b} \mathcal{L}_{\mathrm{sp}} \ . \tag{3}$$

Luminosity is directly depends on the quality of injection beam!

Low emittance injected beam increases injection efficiency.

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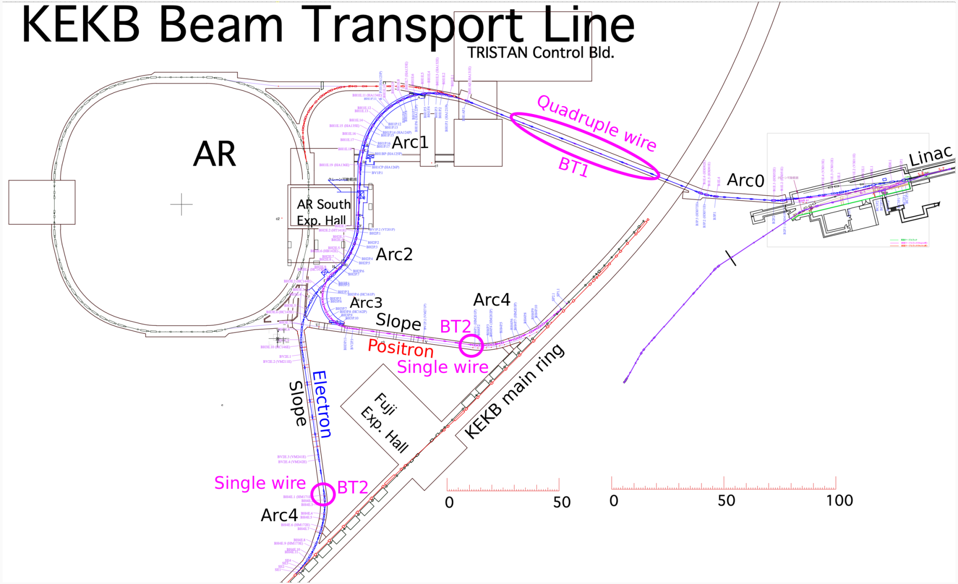
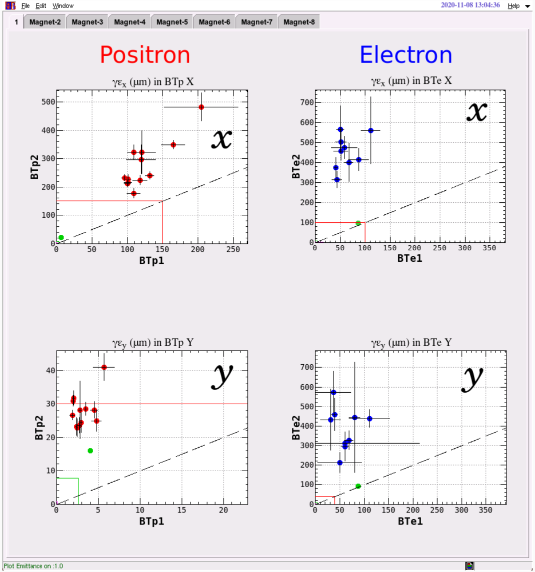
BT-line overview



Emittance measured with wire scanners (WS)

N. Iida



- Measured by WS
- Emittance due to Jitter
- Emittance due to BPM res.
- Emittance due to σ_δ (invisibly small)

Same emittance line of BT2 as BT1

Required emittance from LER/HER

- The horizontal orbit jitter in the e+ is negligibly small.
- The other jitter emittances at BT1 is comparable as measured emittance.
- But in BT2, all measured emittances are larger than the jitter emittances.

Investigation in this summer

Until now, we have done many kinds of effort, but still not been solved yet.

- Obstacle survey in the beam duct,
  - Remaining part: Arc3 - Slope
- Q-magnet check,
- Alignment,
- Simulation studies (on going).

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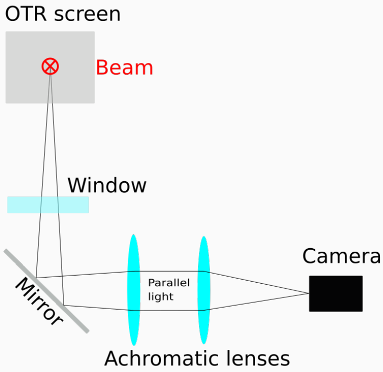
OTR monitor

- We have just started to measure the beam with OTR monitor as our next strategy.
- Precise beam size measurement can be accomplished.
- 5 of fluorescence screens are replaced by OTR screens.

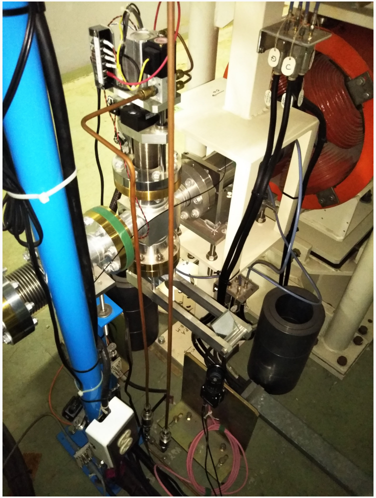
Experimental setup



Schematic view of setup.

-
- Light of OTR is detected by gated camera after passing through view port, mirrors, achromatic lenses and band-path filter.
- Gate width: $2\ \mathrm{ms}$ due to shutter timing jitter while OTR itself is within $\sim 20\ \mathrm{ps}$.
- Position resolution by CCD: $\sim 70\ \mu\mathrm{m}$. It should be updated by changing zoom factor for narrow beam.

Experimental setup

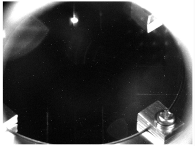


MSE.06

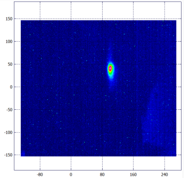
Images of OTR compared with fluorescent light

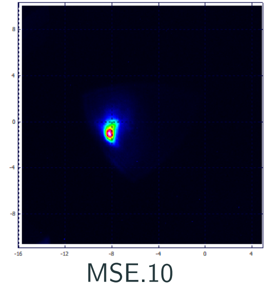
2019-04-02

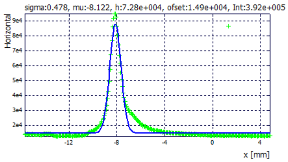
2020-10-27(OTR)

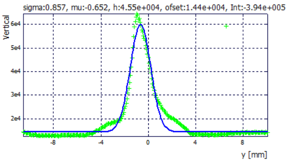


2019-05-22

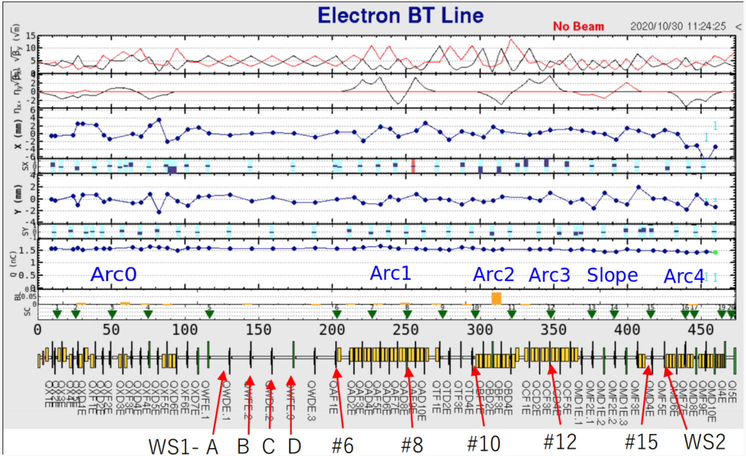








Installed location



Locations of wire scanners and OTR monitors.

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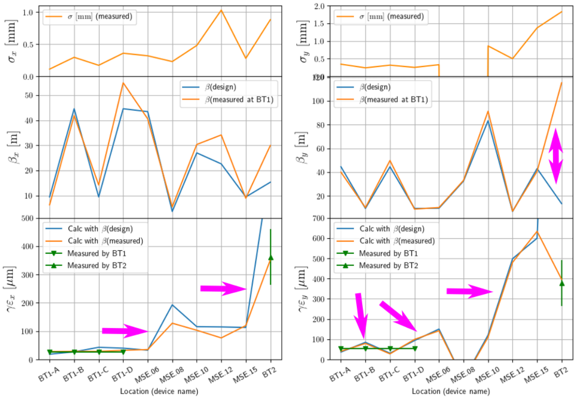
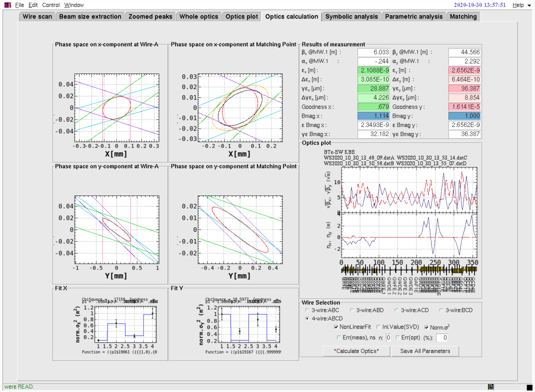


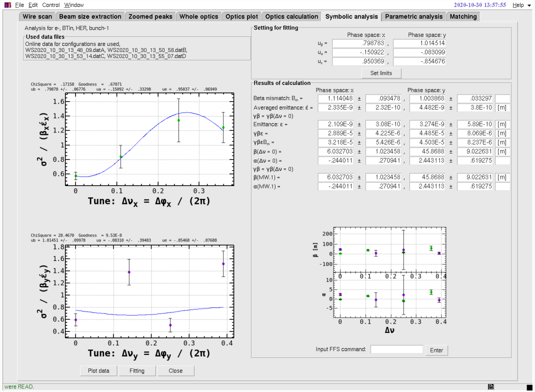
Summary of measurements and calculations.

Beam sizes measured after BT1 matching done, emittance on each location calculated.
Bunch charge: ~ 1.5 nC.
$B_{\text{mag}}(x) = 1.1, B_{\text{mag}}(y) = 1.0.$

1. Calc and measured in BT1 not matched,
2. Vertical emittance on BT1 and MSE.06 are not consistent,
3. Vertical emittance blow up seems to be seen between MSE.10 and MSE.12 (Arc2 - Arc3),
4. Calc and measured β not matched,
5. Horizontal emittance blow up seems to be seen between MSE. 06 and MSE.08 (Arc1),
6. Horizontal emittance between MSE.15 and BT2.

Discrepancy of vertical emittances on BT1 and MSE.06

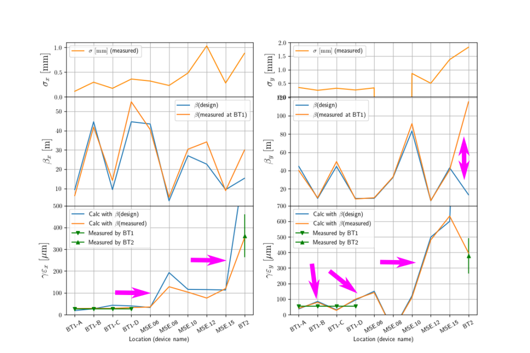




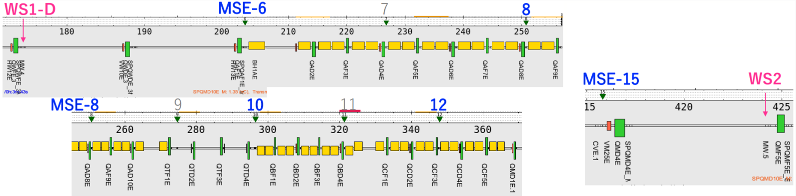
Fitting of the function of phase advance for y-component is not good.

Is this related with the emittance discrepancy between BT1 and MSE.06?

What can we do?



1. Replace screen MSE.11 with OTR screen,
2. Set zero current for QMD4E, compare MSE. 15 and BT2 measurements,
3. Q-magnet scan with OTR beam size measurement.



Summary

- Quality of injection beam is very important for luminosity, $\mathcal{L} = I_{+\mathrm{inj}}\varepsilon_{+}I_{-\mathrm{inj}}\varepsilon_{-}\frac{\tau_{+}\tau_{-}}{N_b}\mathcal{L}_{\mathrm{sp}}$,
- We have made an effort to solve the emittance blow up problem in BT-line, and still it is on going,
- As our next strategy, OTR monitors have been installed and emittances measured at each location,
- First result is obtained, we considered next plan.

Thank you for your attention.

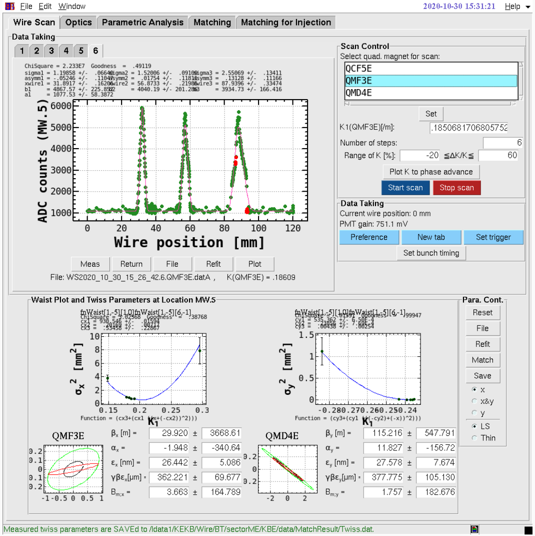
	WS1-A	WS1-B	WS1-C	WS1-D	MSE-06	MSE-8	MSE-10	MSE-12	MSE-15	WS2				WS2
sx [mm]	0.113	0.296	0.172	0.36	0.322	0.229	0.478	1.033	0.279	0.8766				0.8766
bx [m](design)	9.45	44.57	9.45	44.57	43.43	3.65	27	22.6	9.43	15.3				15.3
bx [m](measure)	6.3	41.87	14.2	54.9	40.55	5.5	30.34	34.13	8.91	11.3				29.92
ηx [mm](design)						116.6		3440						
σδ [%]						0.02723		0.02723						
gex [um] (design beta)	18.510	26.929	42.885	39.833	32.704	193.030	115.923	114.959	113.077	688.000				688.000
gex [um] (measured beta)	27.765	28.665	28.539	32.338	35.027	128.102	103.161	76.123	119.676	931.540				351.818
gex [um] (measured WS)	25.836±4.150													362.221±98.029
sy [mm]	0.344	0.242	0.317	0.254	0.325	1	0.857	0.501	1.372	1.8254				1.8254
by[[m] (design)	44.57	9.45	44.57	9.45	9.63	32.5	83.3	6.9	43	13.5				13.5
by [m](measure)	40	10.127	49.8	8.91	10.2	33.1	91.3	7.16	40.7	13.68				115.216
gey [um] (design beta)	36.371	84.894	30.885	93.522	150.251	421.496	120.780	498.314	599.676	3381.111				3381.111
gey [um] (measured beta)	40.526	79.219	27.642	99.190	141.855	413.856	110.197	480.219	633.565	3336.623				396.169
gey [um] (measured WS)	54.171±9.432													377.775±112.94

Summary table of measurements and calculations.

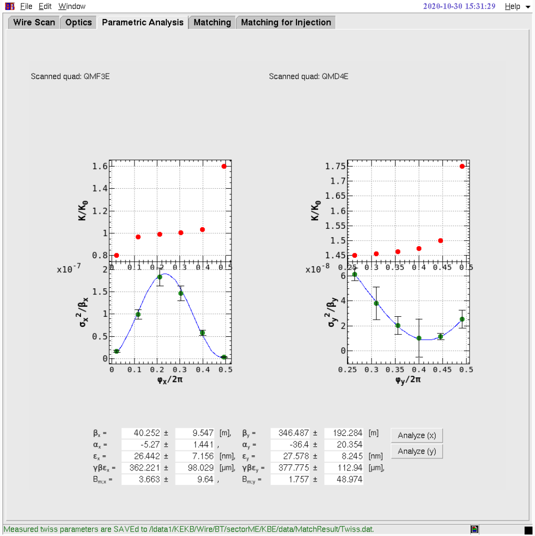
Beam sizes measured after BT1 matching done, emittance calculated on each location. $B_{\mathrm{mag}}(x) = 1.1, B_{\mathrm{mag}}(y) = 1.0$.

1. Vertical emittance on BT1 and MSE.06 are not consistent.
2. Horizontal emittance blow up seems to be seen between MSE.06 and MSE.08 where the location corresponds to Arc1.
3. Vertical emittance blow up seems to be seen between MSE.10 and MSE.11 where the location corresponds to Arc2 - Arc3.

BT2

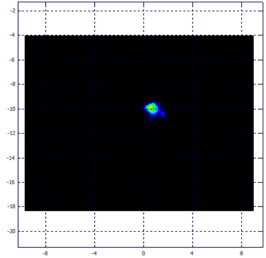


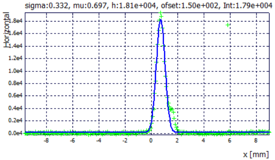
File Edit Window
2020-10-30 15:31:21
Help
Wire Scan
Optics
Parametric Analysis
Matching
Matching for Injection
Data Taking
Scan Control
Select quad. magnet for scan:
QCF5E
QMF3E
QMD4E
Set
K1(QMF3E)[/m]:
Number of steps:
Range of K [%]:
Plot K to phase advance
Start scan
Stop scan
Current wire position: 0 mm
PMT gain: 751.1 mV
Preference
New tab
Set trigger
Set bunch timing
ADC counts (MW.5)
Wire position [mm]
Meas
Return
File
Refit
Plot
File: WS2020_10_30_15_26_42.6.QMF3E.datA , K(QMF3E) = .18609
Waist Plot and Twiss Parameters at Location MW.5
Para. Cont.
Reset
File
Refit
Match
Save
QMF3E
QMD4E
Measured twiss parameters are SAVEd to /ldata1/KEKB/Wire/BT/sectorME/KBE/data/MatchResult/Twiss.dat.



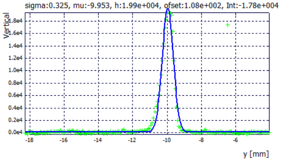
File Edit Window
2020-10-30 15:31:29
Help
Wire Scan
Optics
Parametric Analysis
Matching
Matching for Injection
Scanned quad: QMF3E
Scanned quad: QMD4E
Analyze (x)
Analyze (y)
Measured twiss parameters are SAVEd to /ldata1/KEKB/Wire/BT/sectorME/KBE/data/MatchResult/Twiss.dat.

MSE.06



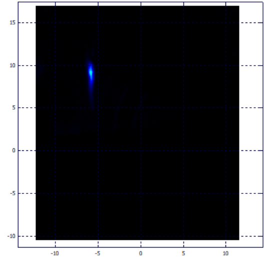


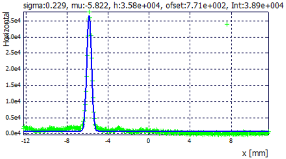
sigma:0.332, mu:0.697, h:1.81e+004, ofset:1.50e+002, Int:1.79e+004
Horizontal
x [mm]



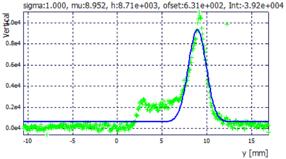
sigma:0.325, mu:-9.953, h:1.99e+004, ofset:1.08e+002, Int:-1.78e+004
Vertical
y [mm]

MSE.08





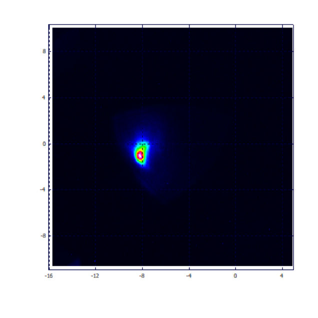
sigma:0.229, mu:-5.822, h:3.58e+004, ofset:7.71e+002, Int:3.89e+004
Horizontal
x [mm]

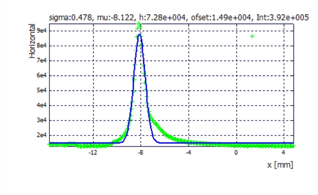


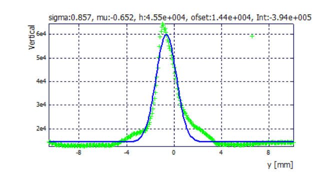
sigma:1.000, mu:8.952, h:8.71e+003, ofset:6.31e+002, Int:-3.92e+004
Vertical
y [mm]

MSE.10

Band path filter: 550 ± 40 [nm]

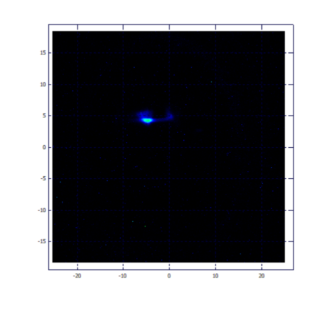


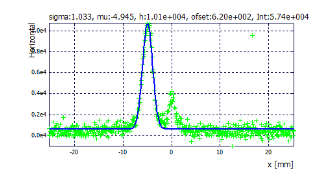


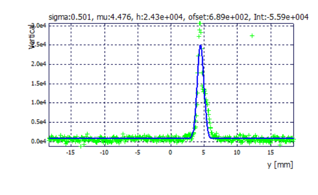


MSE.12

Short pass filter: 700 nm

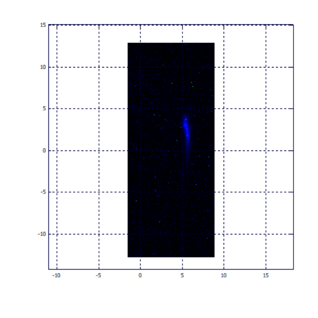


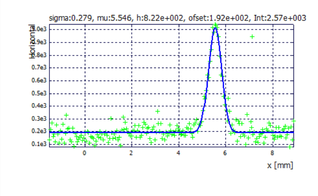


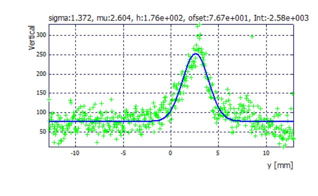


MSE.15

ROI: 8-bit (this camera only, 12-bit for others)







Transition radiation with normal incidence

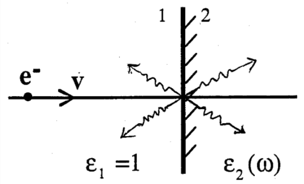
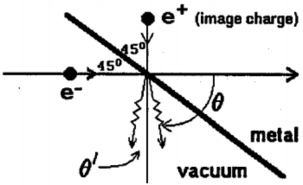


Figure 1: Figure in ref. [2].

Transition radiation is the radiation occurs when a charged particle with relativistic velocity passes through the boundary of two materials have different permittivity. It is derived from Maxwell equation with boundary condition.[1]。

$$\frac{\mathrm{d}^2 I_1(\theta,\omega)}{\mathrm{d}\omega\mathrm{d}\Omega} = \frac{e^2\beta^2\sqrt{\varepsilon_1}\sin^2\theta_1\cos^2\theta_1}{\pi^2 c} \times \left| \frac{(\varepsilon_2-\varepsilon_1)\left(1-\beta^2\varepsilon_1+\beta\sqrt{\varepsilon_2-\varepsilon_1\sin^2\theta_1}\right)}{(1-\beta^2\varepsilon_1\cos^2\theta_1)\left(1+\beta\sqrt{\varepsilon_2-\varepsilon_1\sin^2\theta_1}\right)\left(\varepsilon_2\cos\theta_1+\sqrt{\varepsilon_2\varepsilon_1-\varepsilon_1^2\sin^2\theta_1}\right)} \right|^2 \tag{1}$$

Optical transition radiation with 45° incidence



Though the calculation becomes complexed for 45° incident, will be simplified in the case of visible light region and metal medium.[2]。

$$\frac{\mathrm{d}^2 I}{\mathrm{d}\omega \mathrm{d}\Omega} = \frac{1}{4\pi^2 c}\left|\frac{-e\sin\theta}{1-\beta\cos\theta} + \frac{e\sin\theta'}{1-\beta\cos\theta'}\right|^2 \tag{2}$$

Angular distribution

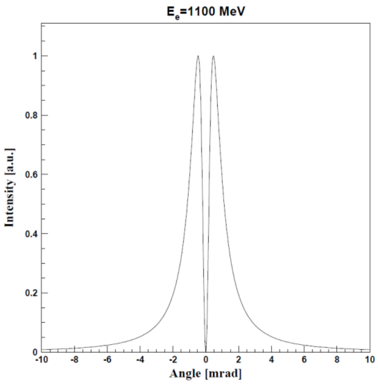


Figure 2: OTR angular distribution for $E = 1.1\ [\mathrm{GeV}]$. It has a peak at $\theta \approx 1/\gamma$.

Number of photons

Equation (3) is obtained by the integration of Equation (2) about whole solid angle and ω, and the division by $\hbar\omega$.

$$N = \frac{\alpha}{\pi}\left[2\ln\gamma - 1\right] \times \ln\left(\frac{\omega_2}{\omega_1}\right) \tag{3}$$

$$\alpha = \frac{e^2}{\hbar c} \qquad \text{(CGS Gauss unit system)} \tag{4}$$

Number of positrons for $2\ \mathrm{nC}$ bunch: 1.25×10^{10}
Number of generated photons per bunch: 1.2×10^{9}

References i

[1] V. L. Ginzburg and V. N. Tsytovich, "SEVERAL PROBLEMS OF THE THEORY OF TRANSITION RADIATION AND TRANSITION SCATTERING", Physics Reports (Review Section of Physics Letters) 49, No. 1 (1979) 1-89.

[2] B. Gitter, CAA-TECH-NOTE-internal-#24.