ビームロスシミュレーションについて

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コンパクトERLミニワークショップ第2部(1/19)
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場所：4号館2階輪講室1,2

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Introduction

- Some beam losses during the last operation of cERL in the spring 2014 were observed, when the beam current of 10 μA was reached.
- Most possible reasons:
  - Electron emission from the whole cathode plane due to the cathode lightning (明光)
  - Beam tail due to the cathode response (was studied by Miyajima-san in details)
- Other reasons:
  - Dark current from the main RF cavity

Motivation

Perform the beam loss simulation for the beam halo and beam tail accordingly the present value of the beam current (10 μA)

+

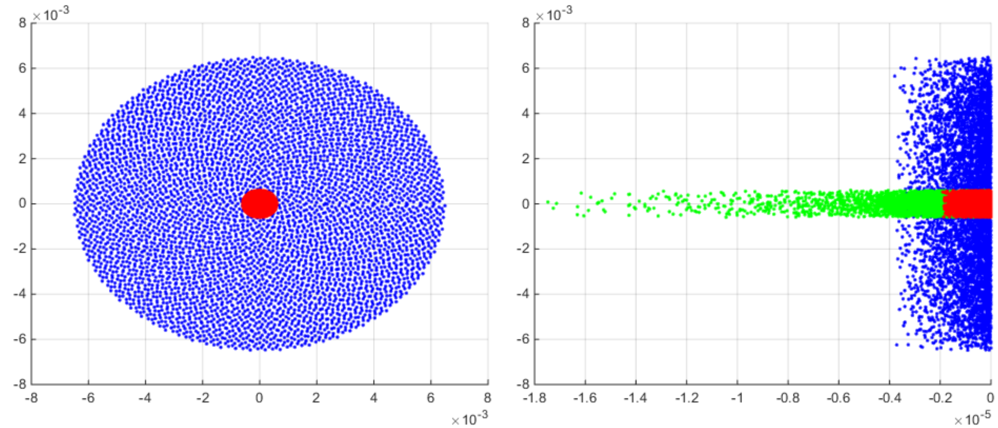
FE study for the two cavities case

Beam Halo and Beam Loss

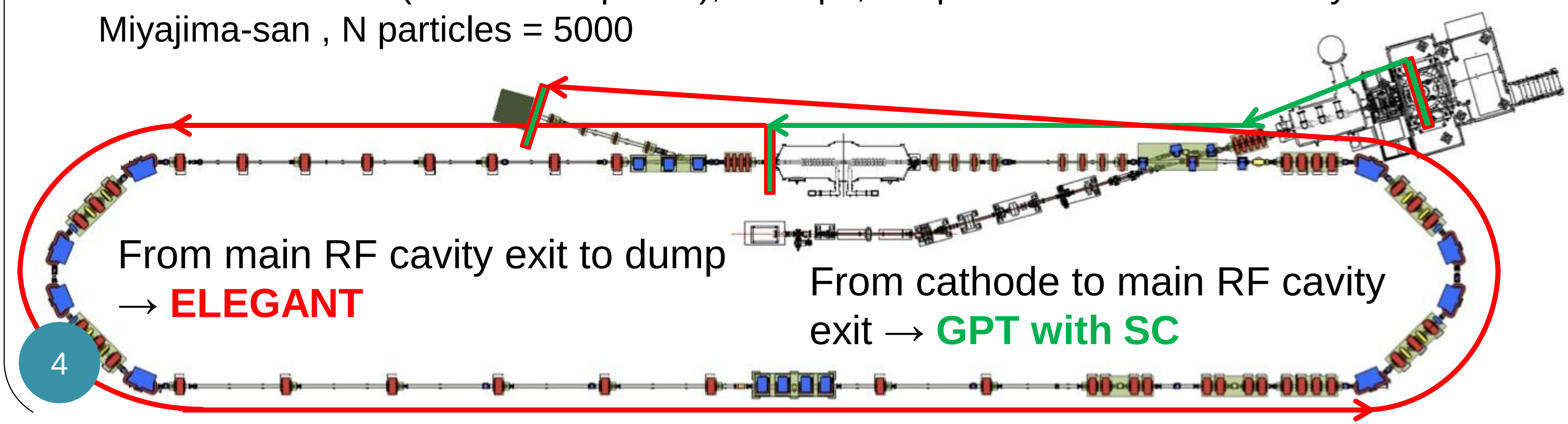
Simulation background

Beam parameters	
Beam energy	0.06 eV ~ 20 MeV
Total beam current	10 μA
Repetition	1.3 GHz
Charge per bunch	7.7 fC
Normalized beam emittance	1 mm·mrad
Rms Bunch length	3 ps

Initial particle distribution at cathode



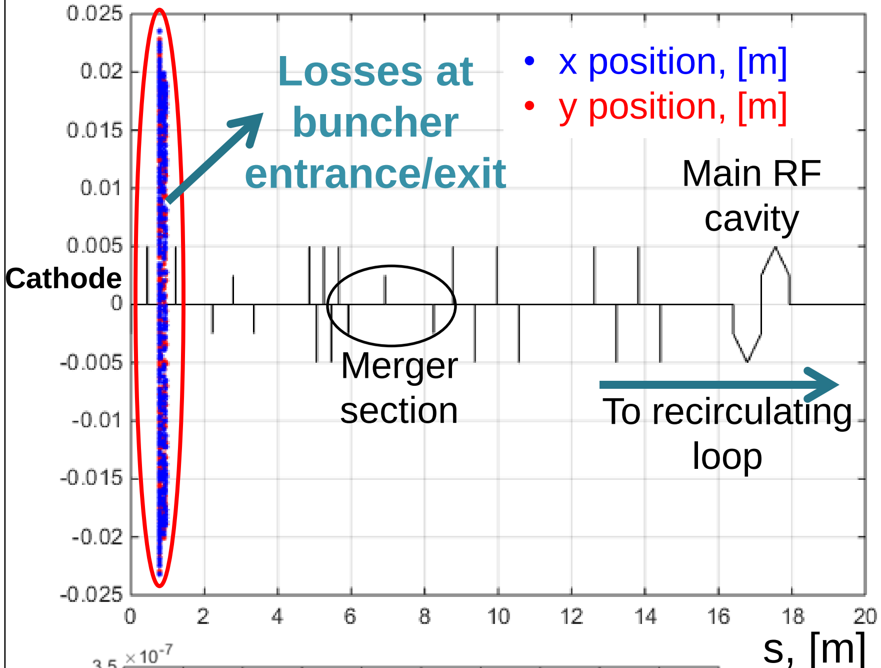
- **Red** – beam core, beer can distribution, N particles = 5000
- **Blue** – beam halo (明光), φ = 13 mm, beer can distribution, N particles = 5000
- **Green** – beam tail (cathode response), τ = 5 ps, temporal distribution courtesy of Miyajima-san , N particles = 5000

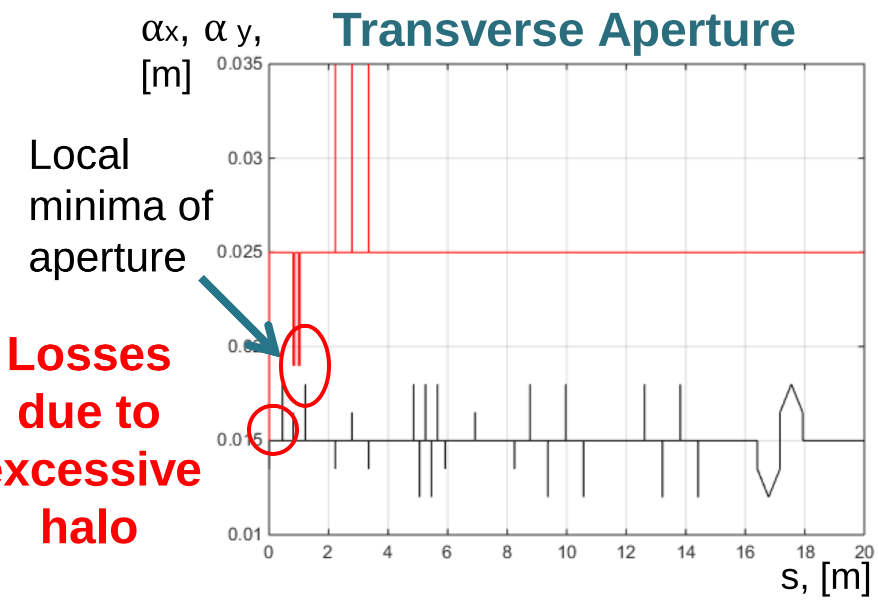


Beam Halo and Beam Loss

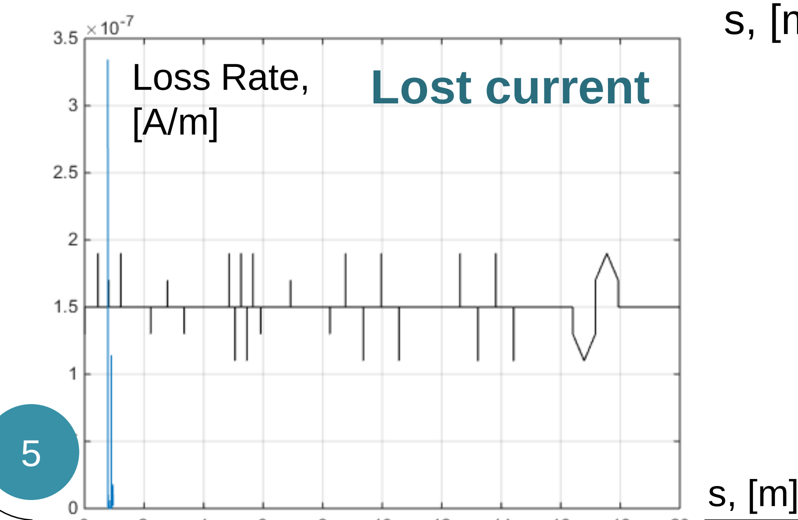
GPT with SC

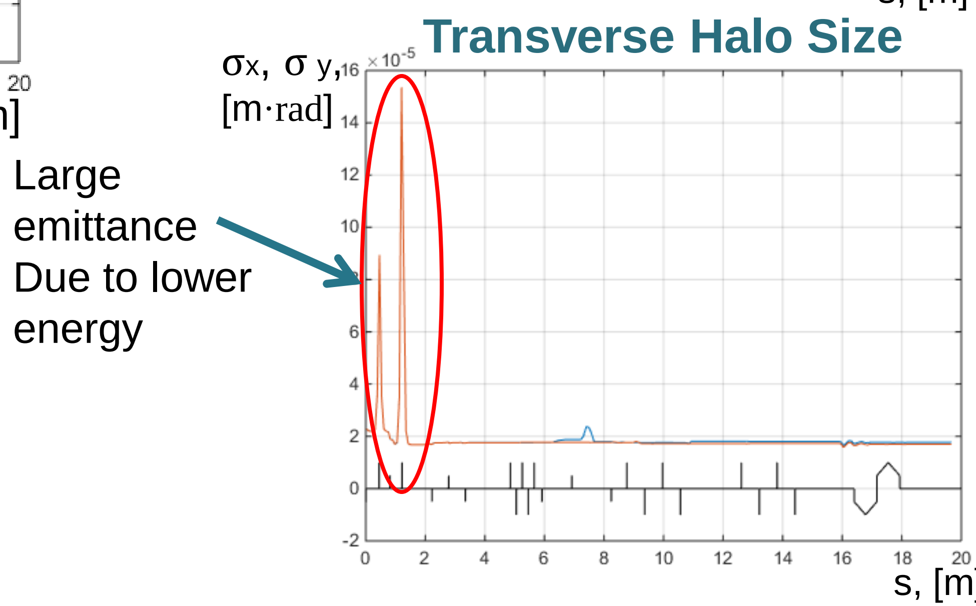
Injector line losses





Losses due to excessive halo

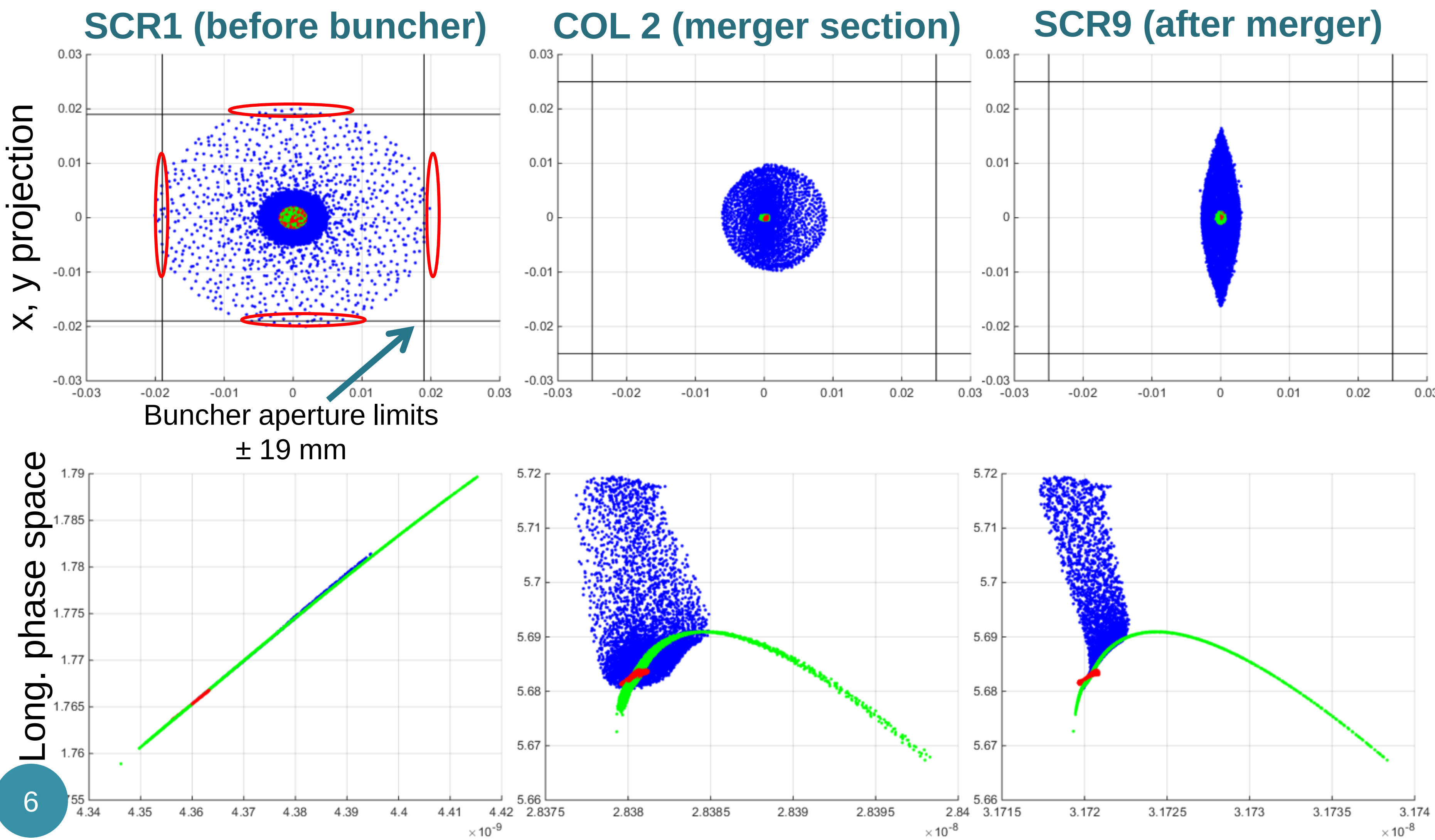




Beam Halo and Beam Loss

Injector line losses

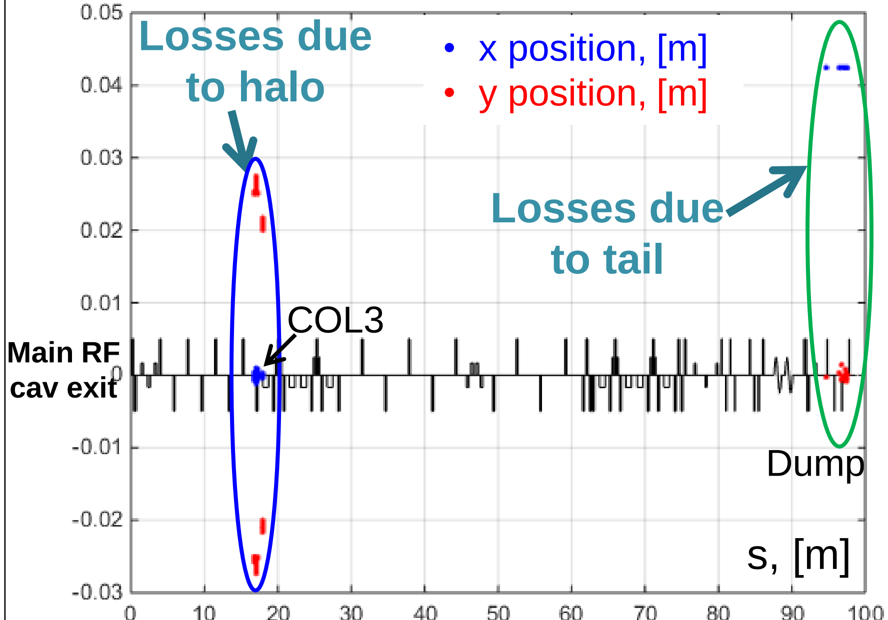
- **Red** – beam core
- **Blue** – beam halo
- **Green** – beam tail



Beam Halo and Beam Loss

Recirculating loop and dump line losses

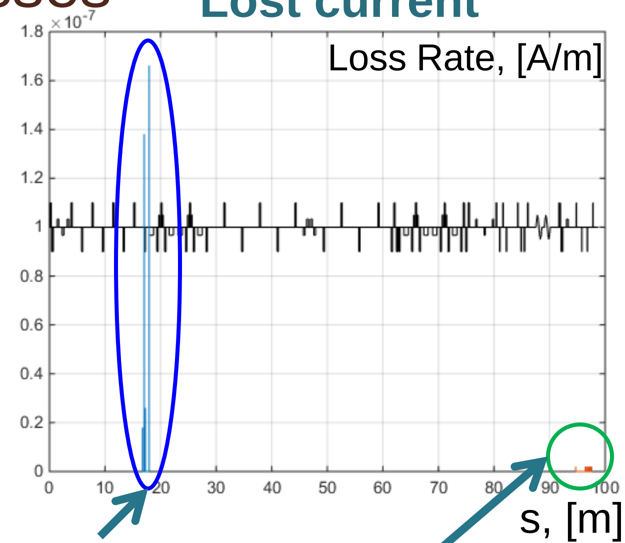
ELEGANT



No losses from core due to multiple apertures

Collimators in the lattice
+
Local minima of aperture

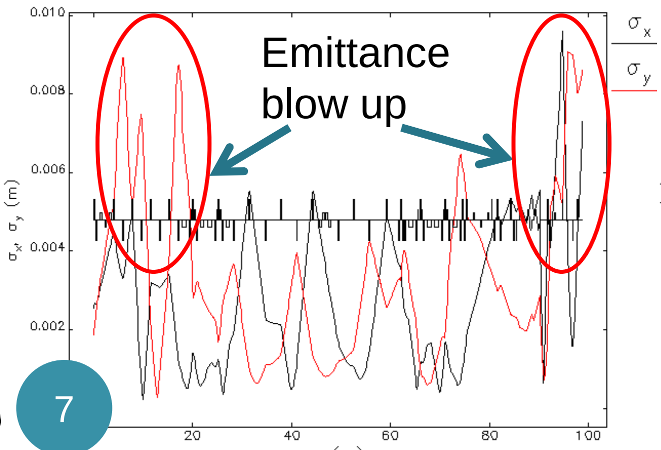
Lost current



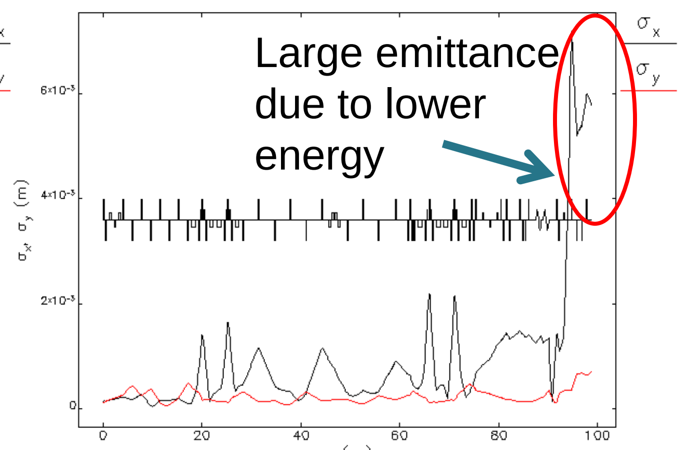
Lost current due to halo

Lost current due to tail

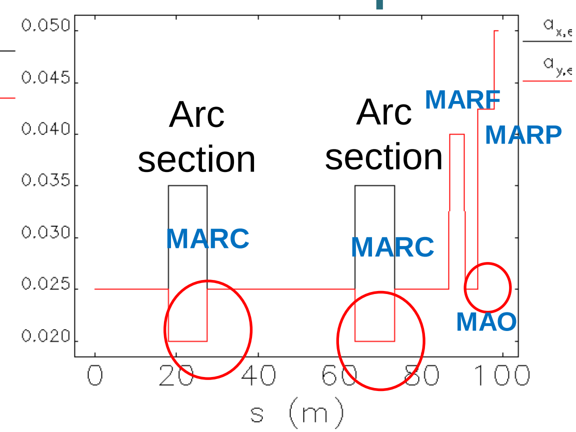
Transverse Halo Size



Transverse Tail Size



Transverse Aperture



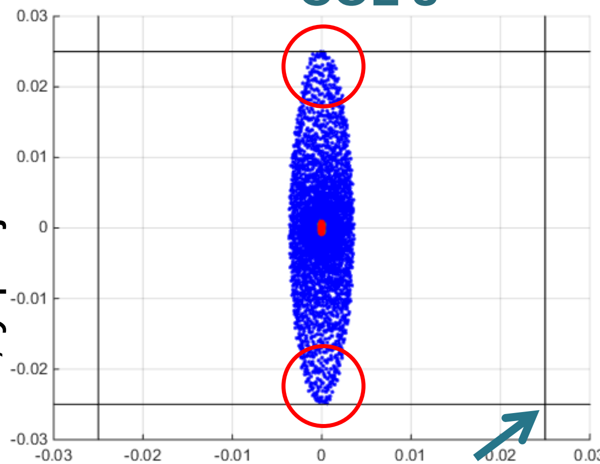
Beam Halo and Beam Loss

Recirculating loop and dump line losses

- **Red** – beam core
- **Blue** – beam halo
- **Green** – beam tail

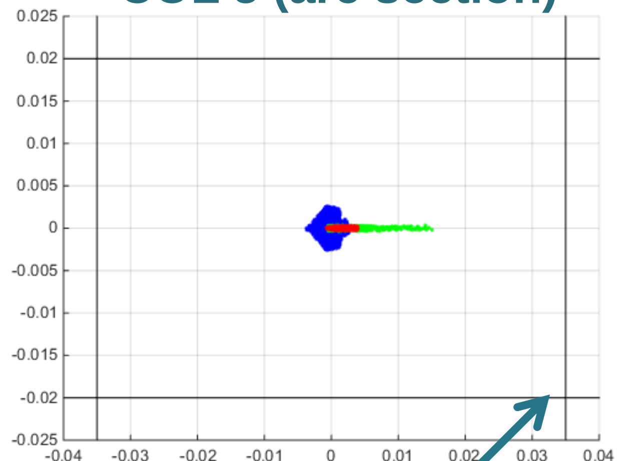
x, y projection

COL 3



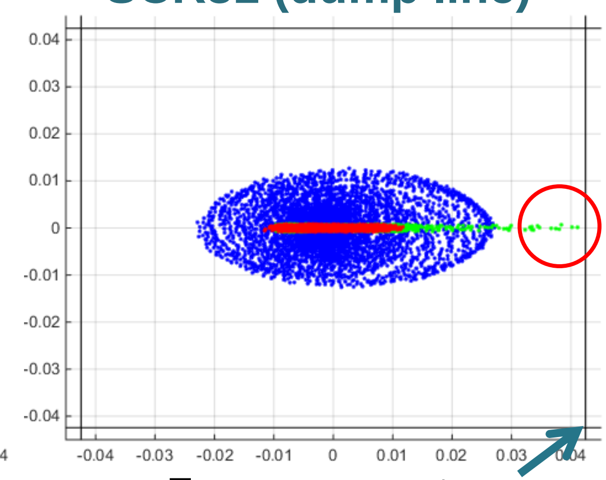
Transverse aperture limits ± 25 mm

COL 5 (arc section)



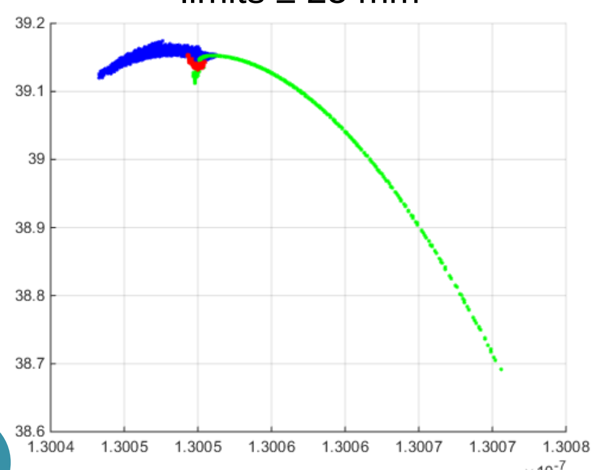
Transverse aperture limits x=± 35 mm, y=± 20 mm

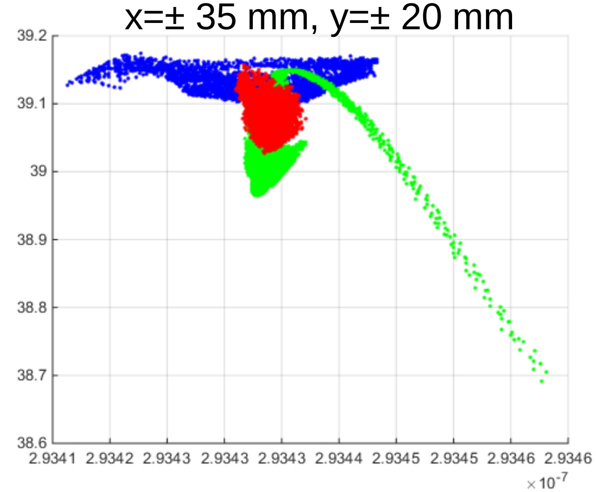
SCR31 (dump line)

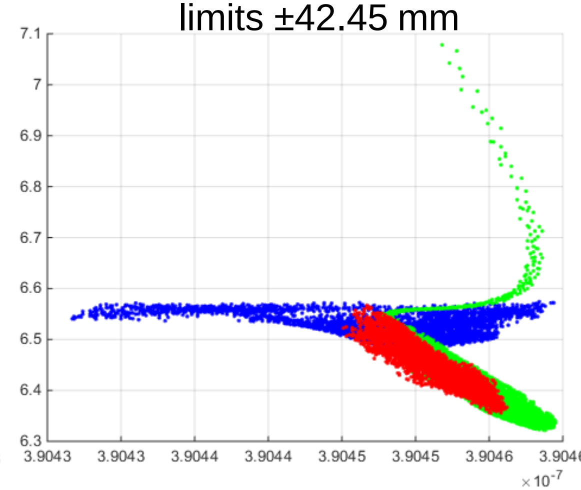


Transverse aperture limits ±42.45 mm

ong. phase space







Beam Halo and Beam Loss

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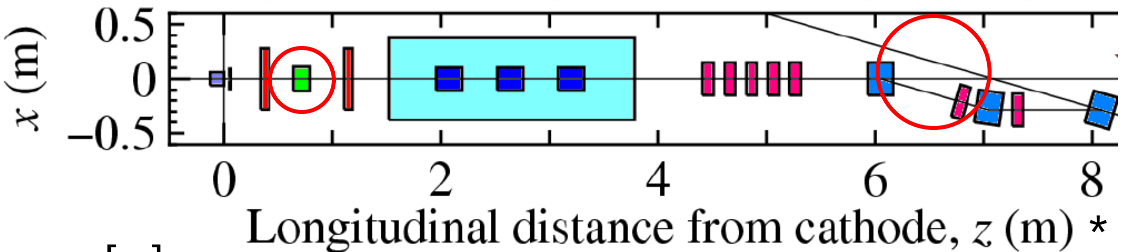
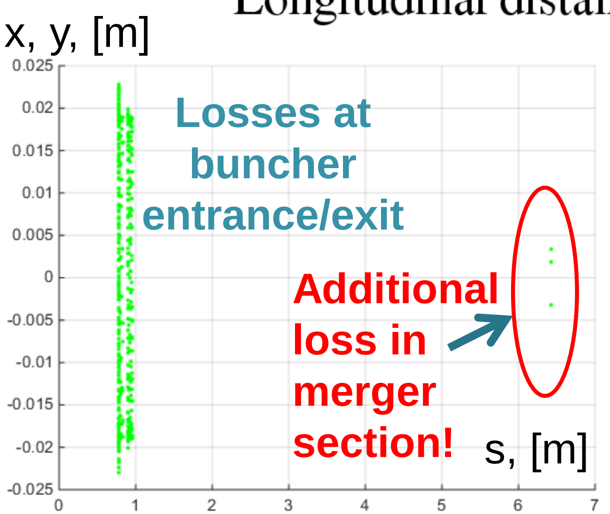
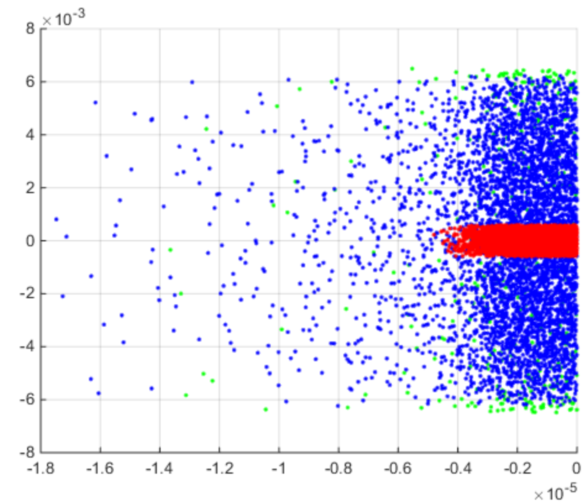
Worst scenario

Lost positions in injector line



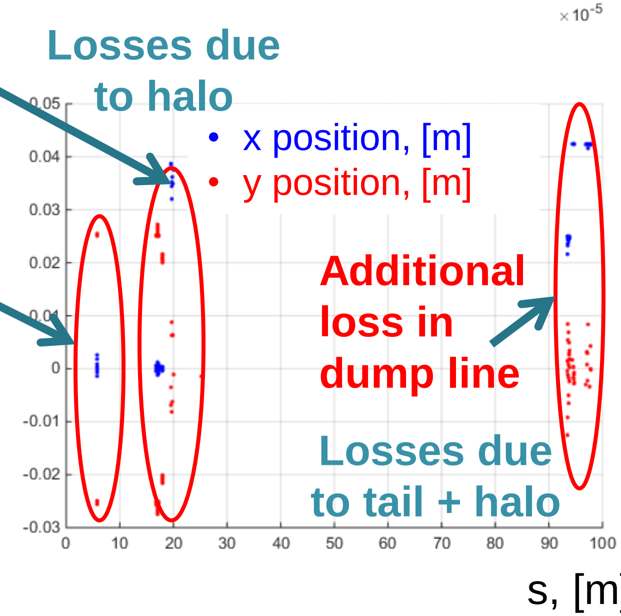


Distribution Z, Y at cathode

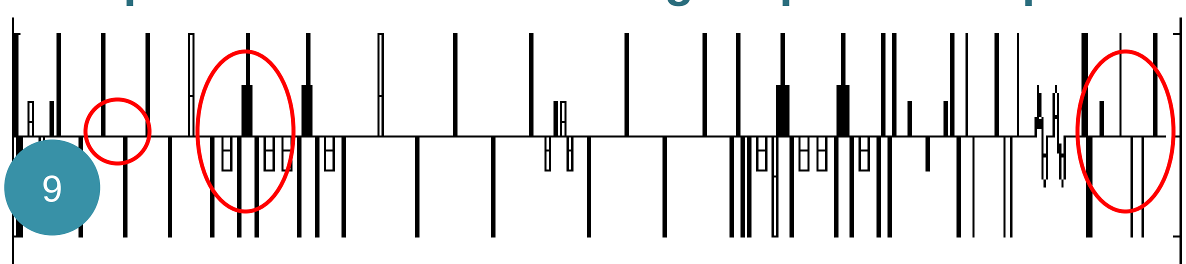


Additional loss due to dispersion and arc aperture

Additional loss due to emittance blow up



Lost positions in recirculating loop and dump line



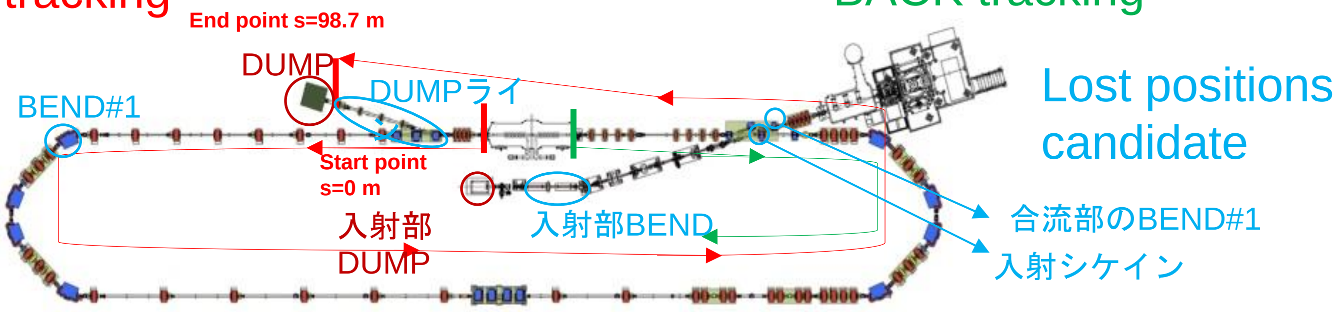
*Courtesy of Miyajima-san

Field emission issues

Simulation background

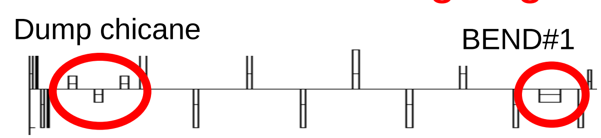
FORWARD tracking

BACK tracking

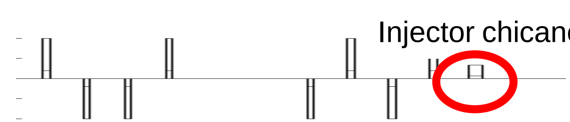


Beam parameters	Simulation	cERL目的（実際の状態）
Maximum energy	20 MeV	20 MeV
Total beam current	10 mA	10 – 100 mA (10mA)
Repetition	1.3 GHz	1.3 GHz
Charge per bunch	7.7 pC	7.7 – 77 pC (20fC~20pC)
Norm. beam emittance	1 mm·mrad	0.1 – 1.0 mm·mrad
Rms momentum spread	$1\cdot10^{-3}$	$< 3\cdot10^{-4}$
Bunch length	2 ps	1 – 3 ps

FORWARD tracking alignment



BACK tracking alignment



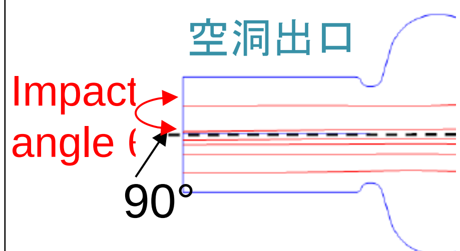
- Modify the lattice file to make use of the symplectic integration elements (ELEGANT code)

  EDRIFT drift space
  CSBEND bending magnet
  KQUAD quadruple magnet
  KSEXT sextuple magnet

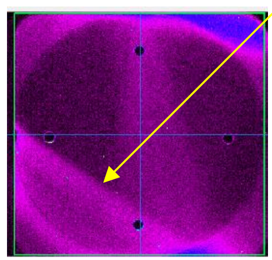
Field emission issues

Input distribution generation

- Output distribution file contains (x, y, xp, yp, t, p) rows
- Distribution is flat
- X, [m] data obtained from “Pos [cm]” row
- Y, [m] data obtained accordingly: Y = -0.36*X
- XP, YP [rad] data obtained from “Impact angle” row:
  XP = X/Z = tan(θ)*cos(ϕ); YP = Y/Z = tan(θ)*sin(ϕ)
- T is generated using random numbers (± 3ps interval)
- P=βγ data obtained from “Impact energy” row

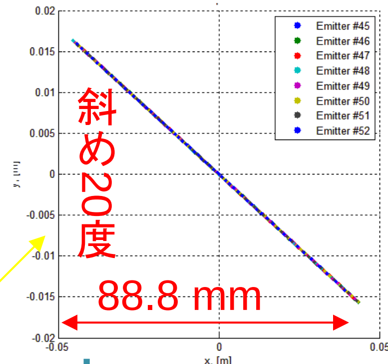


FEの写真、
cam11、
2014/05/27

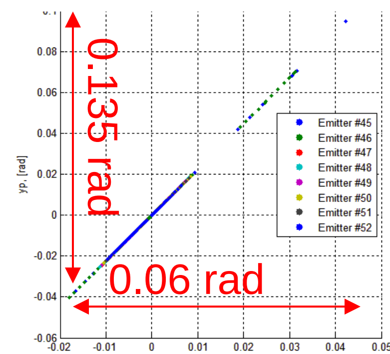


Cavity exit distribution,
Emitters ＃45～52

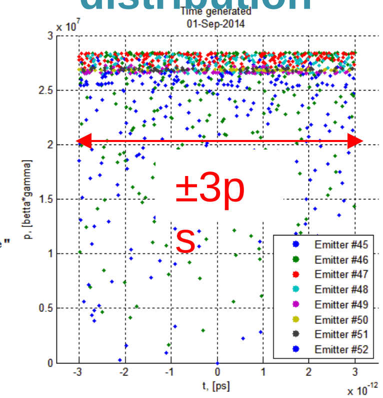
X,Y distribution



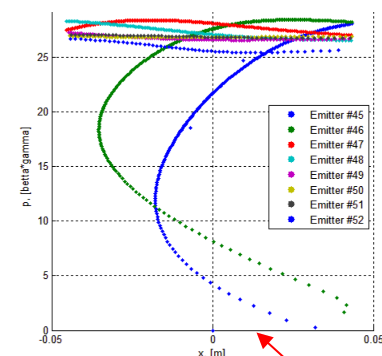
Angular distribution

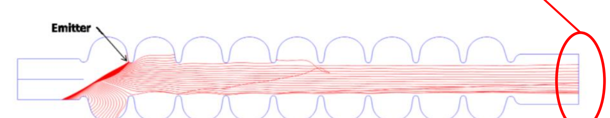


Long. distribution



Phase space distribution





Input data example

	A	B	C	D	E	F
1	Eacc [MV/m]	Pos [cm]	Energy [eV]	Impact angle	Emitter #	Current [A]
2	15	3.855774	14462376	88.68907397	45	9.36E-07
3	15	-0.67846	9458630.1	89.98662203	45	9.56E-07
4	15	0.965443	12602679	89.58966307	45	9.57E-07
5	15	3.191616	136568.26	84.07941156	45	9.45E-07
6	15	2.30708	460075.68	85.57512426	45	9.44E-07
7	15	1.787438	809623.77	85.72269598	45	9.43E-07
8	15	1.292157	1132710.3	86.15615441	45	9.41E-07
9	15	0.868967	1431180.6	86.60263099	45	9.40E-07
10	15	0.509513	1709340.4	87.00980081	45	9.38E-07
11	15	0.205506	1969520.1	87.36752111	45	9.37E-07
	15	-0.05453	2214373.6	87.68124989	45	9.36E-07

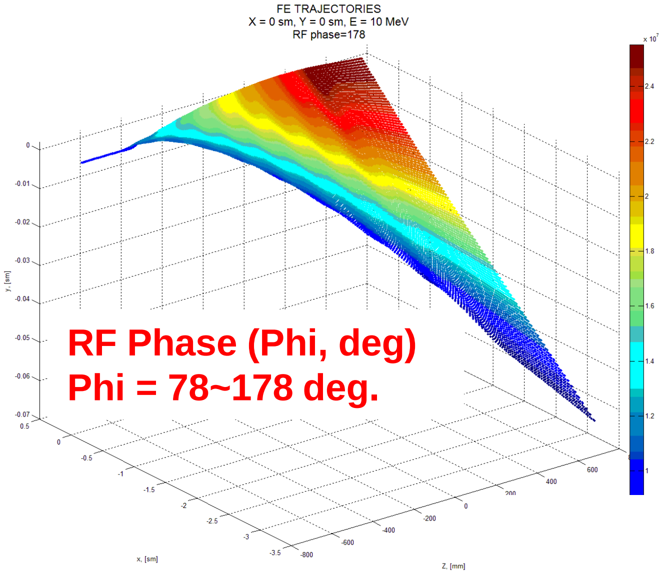
Output data example (*.bin file)

```
SDDS1
&description text="phase space", contents="phase space"
&column name=x, units=m, type=double,  &end
&column name=xp, symbol=x", type=double,  &end
&column name=y, units=m, type=double,  &end
&column name=yp, symbol=y", type=double,  &end
&column name=t, units=s, type=double,  &end
&column name=p, units="m$be$nc", type=double,  &end
&data
   mode=ascii
&end
1181
  0.038558  0.009339   -0.013881   -0.013881   2.407291e-12   2.830211e+07
-0.006785  -0.000095   0.002442   0.002442   -2.997806e-12   1.851004e+07
0.009654  0.002923   -0.003476   -0.003476   -1.003199e-13   2.466278e+07
0.031916  0.042319   -0.011490   -0.011490   -2.115152e-12   2.672569e+05
0.023071  0.031579   -0.008305   -0.008305   -1.110047e-12   9.003438e+05
```

Field emission issues

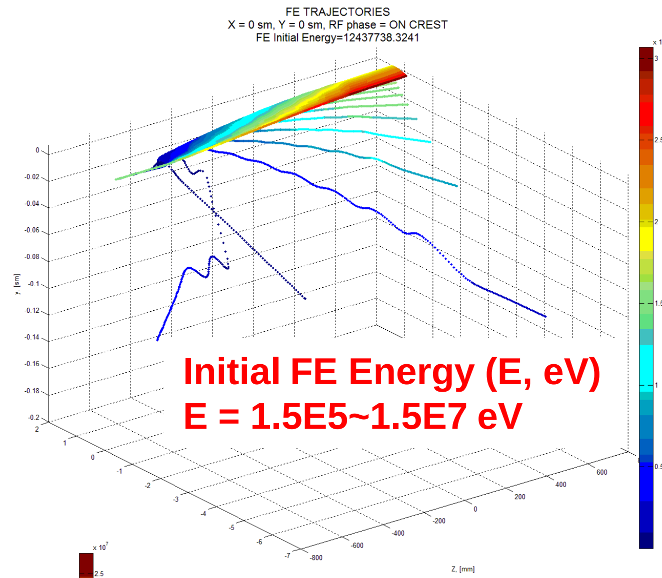
FE trajectories inside the cavity

- FE propagation inside the cavity depends on:



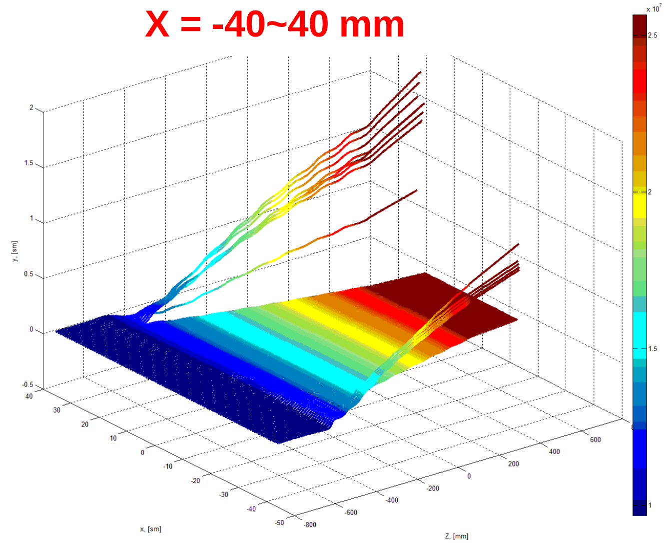
RF Phase (Phi, deg)
Phi = 78~178 deg.

Default parameters:
X = 0 mm
E = 10 MeV
Phi = on crest



Initial FE Energy (E, eV)
E = 1.5E5~1.5E7 eV

FE Entry point (X, mm)
X = -40~40 mm



*see attached movie

*see attached movie

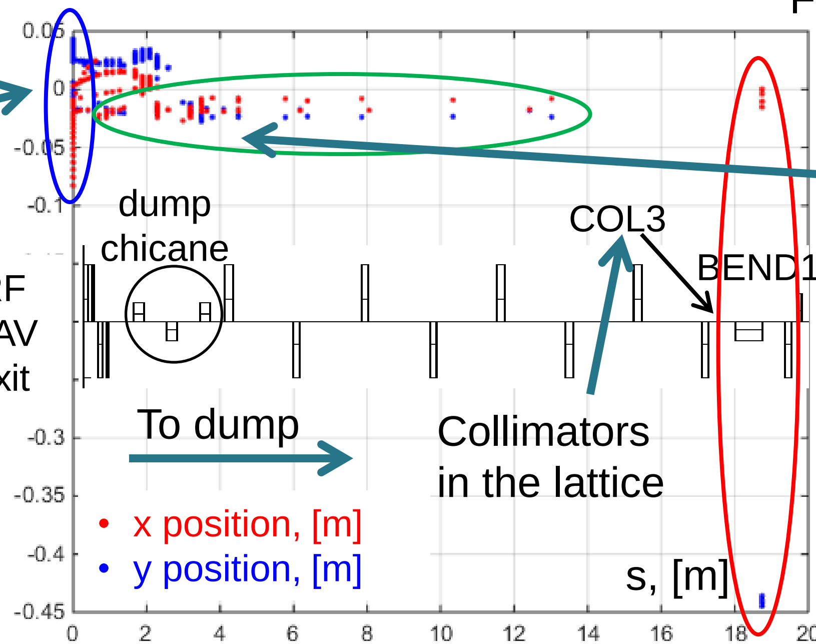
Field emission issues

Field emitted electron losses

FORWARD

*FEE = Field Emitted Electrons

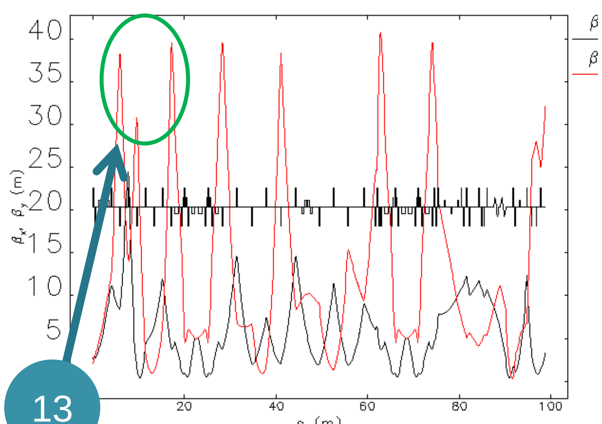
Local peak due to difference in cavity pipe and beam pipe apertures (40 mm and 25 mm correspondingly)



Then FEE are lost at dump chicane

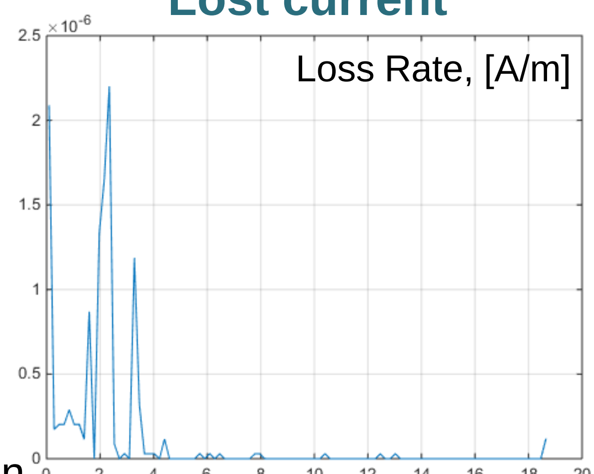
FEE reach the arc section

Beta - function



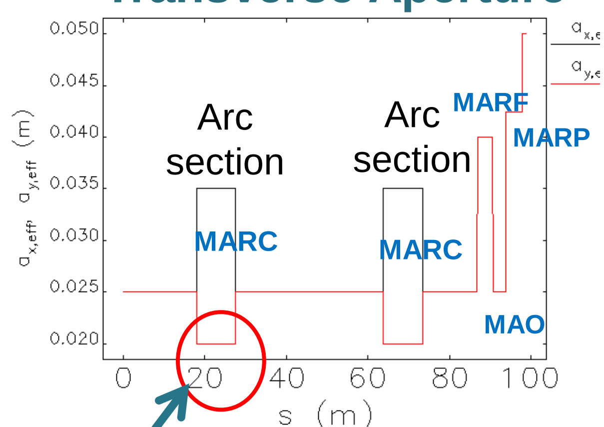
Local maxima of beta-function

Lost current



s, [m]

Transverse Aperture



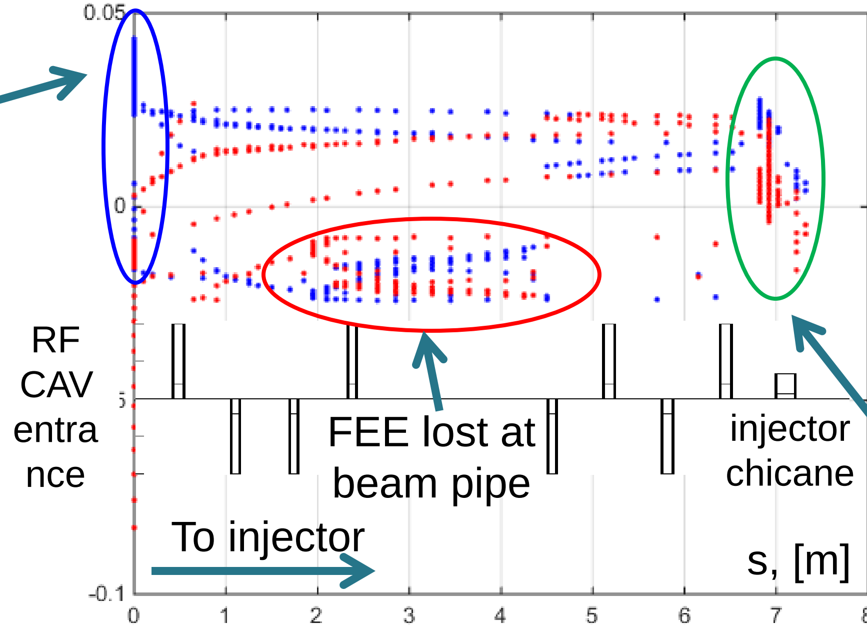
Local minima of aperture

Field emission issues

BACK

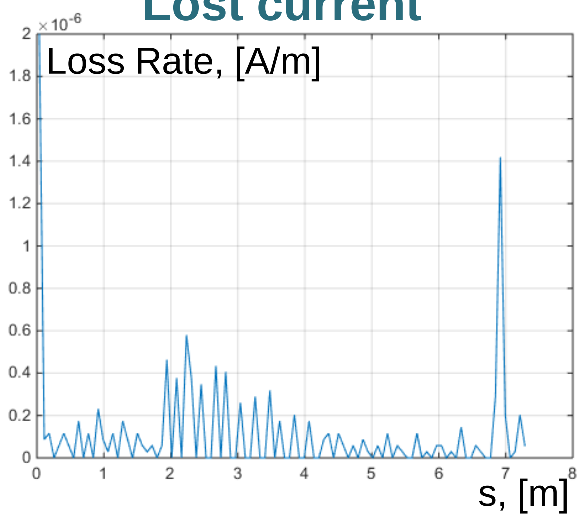
Field emitted electron losses

Local peak due to difference in cavity pipe and beam pipe apertures (40 mm and 25 mm correspondingly)

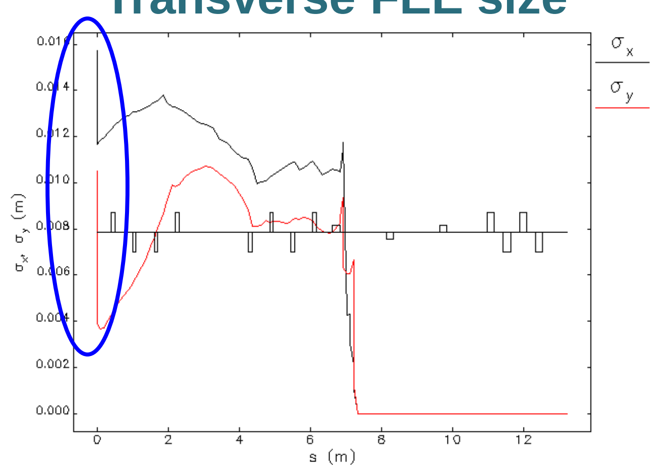


FEE lost at injector chicane

Lost current



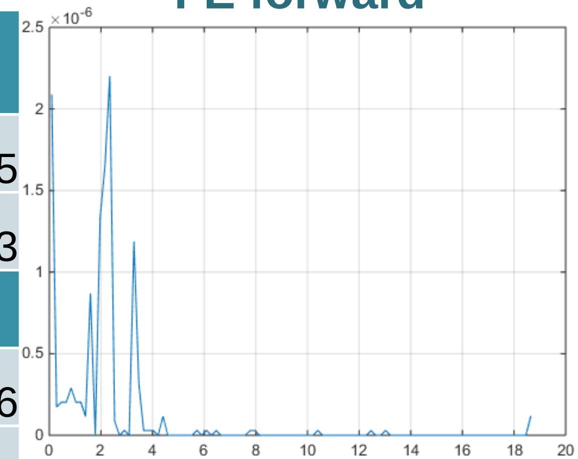
Transverse FEE size



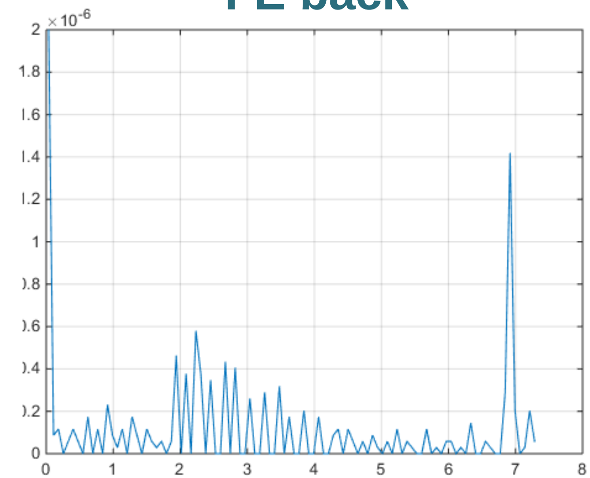
Lost current summary

		Injector	Recirculating loop
Beam Halo & Tail	Peak, pA/m	3.50E+05	1.70E+05
	Average, pA/m	6.08E+03	2.61E+03
Field Emission		**Forward**	**Back**
	Peak, pA/m	2.25E+06	1.42E+06
	Average, pA/m	5.89E+05	1.33E+05

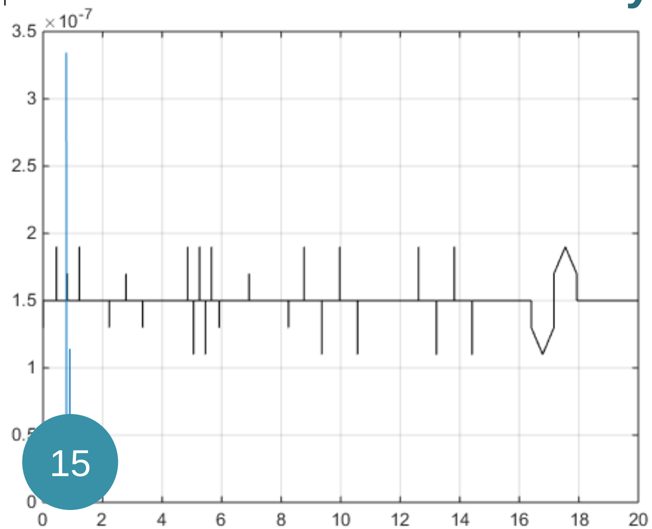
FE forward



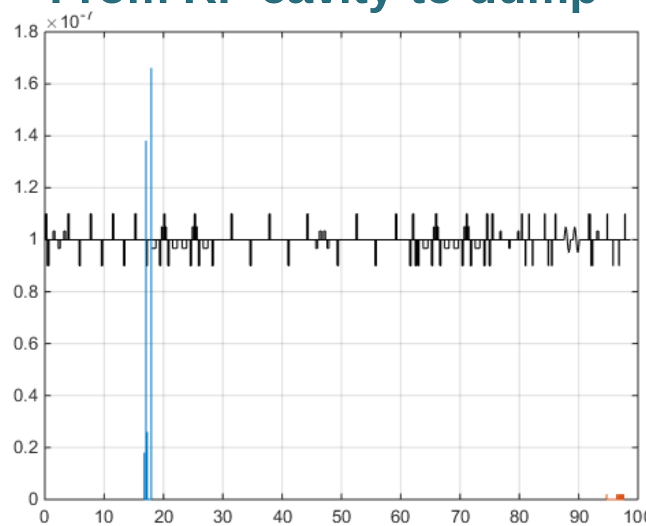
FE back



From cathode to RF cavity



From RF cavity to dump



Summary and Prospect

- Beam loss simulation for the beam halo and beam tail accordingly the present value of the beam current (10 μA) was performed. Loss positions and lost current values in the injector line, the recirculating loop and the dump line were found.
  - Beam halo from the whole cathode plane is lost at the buncher entrance/exit in injector line, and at the COL3 of the recirculating line.
  - Beam tail is lost at the transverse aperture of the dump line.
- As the continuation to the FE study, 2 cavities cases was treated. FE trajectories inside the second cavity with respect to the entry position, RF cavity phase, and initial FE energy were simulated. Current, lost forward and backward along the beam line was calculated.
  - FE electrons, emitted along the beam motion direction, are lost at the beam pipe aperture, dump chicane, and the BEND#1 of the arc section
  - FE electrons, emitted backward, are lost at the beam pipe aperture, and injector chicane.

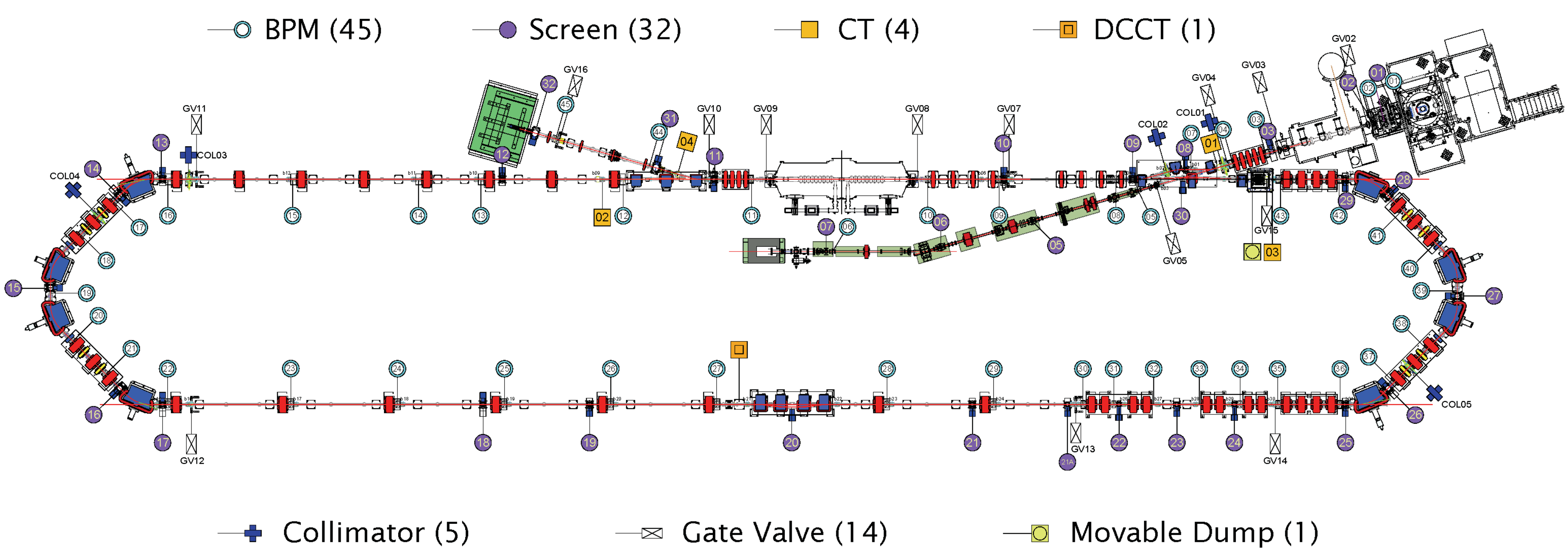
➢ All the beam loss results should be updated with respect to the higher beam current (100 μA)

Thank you for your attention!

Backup slides

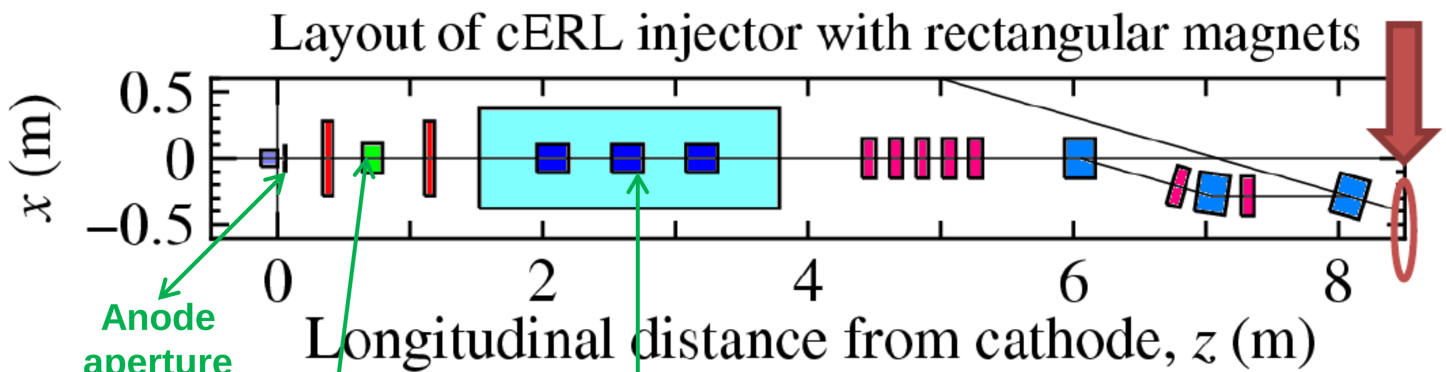
Backup slides

cERL monitor layout



Backup slides

Injector line layout



Beam line aperture ϕ 50 mm

Anode aperture ϕ 30 mm

Buncher aperture ϕ 38 mm

Cavity aperture ϕ 70 mm

Injector

screen3	ZPMGA01	0.448791
buncher	ZCBGA01	0.809291
screen4	ZMSGA01	1.020741
solenoid	ZSLGA02	1.127702
screen5	ZPMGA02	1.219791
cavity	ZCSGB01	2.221252
cavity	ZCSGB02	2.781252
cavity	ZCSGB03	3.341252
screen6	ZpointB	4.754474
QUAD#1	ZQMGC01mgc	4.854474
QUAD#2	ZQMGC02mgc	5.054474
[illegible]3	ZQMGC03mgc	5.254474
[illegible]4	ZQMGC04mgc	5.454474
QUAD#5	ZQMGC05mgc	5.654474

Merger

screen7	ZPMGC02	6.044474
COL1P1	ZCOL11	6.054474
screen8	ZSCOL11	6.071474
COL1P2	ZCOL12	6.074474
screen9	ZSCOL12	6.075474
BEND#1	ZBMAG01	
BEND#2	ZBMAG02	**ccs2, m**
screen10	ZSCOL21	0.350976
COL2P1	ZCOL21	0.351976
screen11	ZSCOL22	0.368976
COL2P2	ZCOL22	0.371976
screen12	ZSCOL23	0.372976

Recirculating loop

BEND#3	ZBMAG03	0
screen13	ZSCM03	0.181023
QUAD#6	ZQMAG01mgc	0.52
QUAD#7	ZQMAG02mgc	1.12
QUAD#8	ZQMAG03mgc	1.72
QUAD#9	ZQMAG04mgc	2.32
screen14	ZSCM04	4.045
QUAD#10	ZQMAG05mgc	4.37
QUAD#11	ZQMAG06mgc	4.97
QUAD#12	ZQMAG07mgc	5.57
QUAD#13	ZQMAG08mgc	6.17
screen15	ZpointD	6.47
cav#1	ZCSAC01	8.158664
cav#2	ZCSAC02	9.684466
screen16	ZpointA	11.755001
screen17	ZSCM05	12.755001

Backup slides

Lost current calculation

- First transform the N_{lost} distribution into the probability of particle loss / m $P_{lost}(s)$
  - Change the bin size to 1 m
  - Divide each numbers per bin by N=5000
- Number of beam particles per second

$$\frac{dN_{beam}}{dt} = \frac{Q_{tot}f}{qe}$$

- Number of lost particles per second

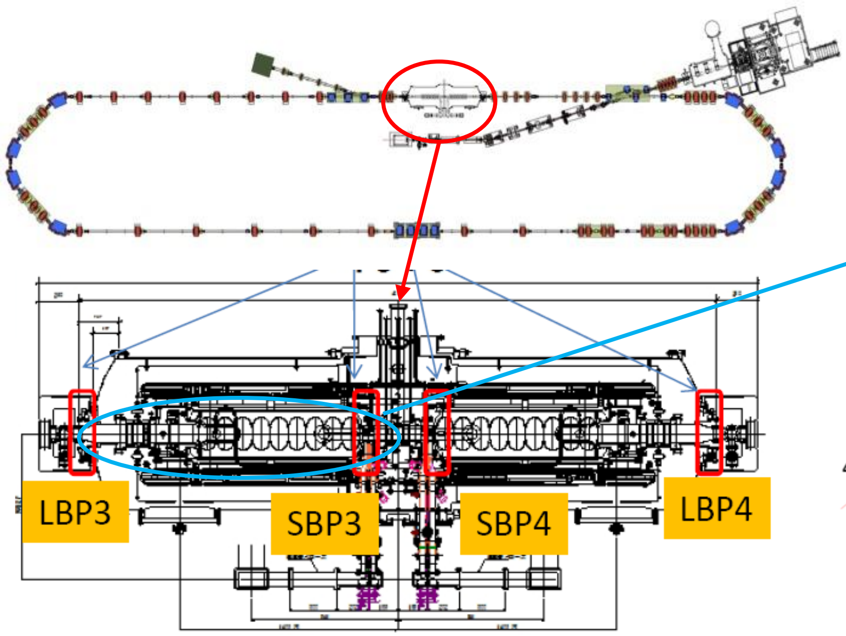
$$\frac{dN_{lost}}{ds} = \frac{dN_{beam}}{ds} p_{lost}(s) = \frac{Q_{tot}f}{qe} p_{lost}(s)$$

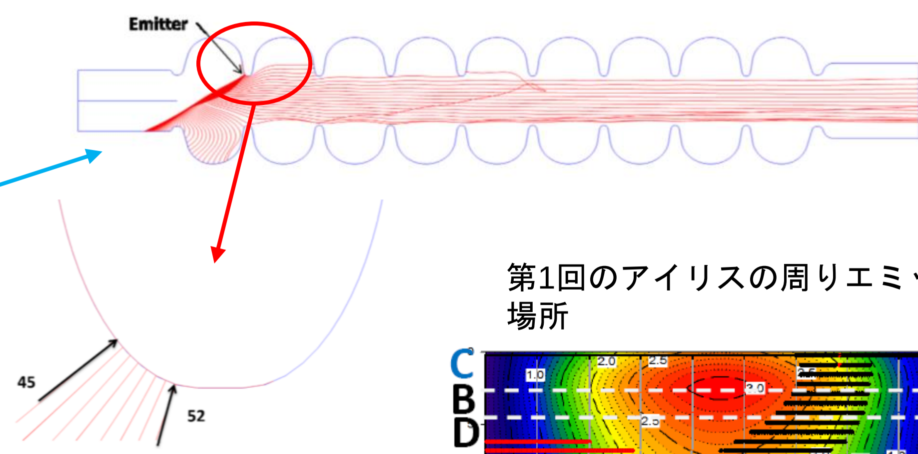
- Current of lost particles per m

$$\frac{dI_{lost}}{ds} = \frac{dN_{beam}}{ds} qe = Q_{tot} f p_{lost}(s) = J p_{lost}(s) \text{ (A)}$$

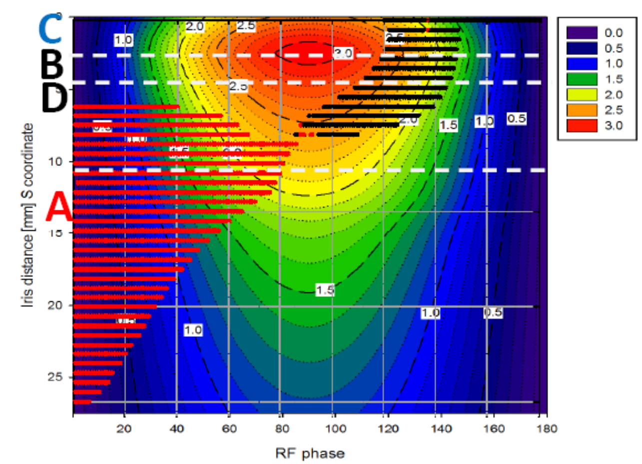
II Field emission issues*

*Cenniさんの計算方法





第1回のアイリスの周りエミッタの場所



Black dots are trajectories that reach cavity right end (LBP)
Red dots are trajectories that reach cavity left end (SBP)

Field emission parameters	
Acceleration field	15 MV/m
Surface field peak	45 MV/m
Aperture	40 mm
Enhancement parameter	100
Emission area size	$8 \cdot 10^{-13}$ m^2
Emitted electron energy	0.27~28.41 MeV
Emitted current	0.56~957.04 nA
Time interval	±3 ps
Number of emitters	8
Number of electrons	1181
Beam momentum	39.14

頂いたInput dataはフィールド・エミッションが空洞の右側（LBP）まで飛んでいます

E. Cenni, KEK, 2012