Immanent risks and difficulties for ILC e-driven positron source

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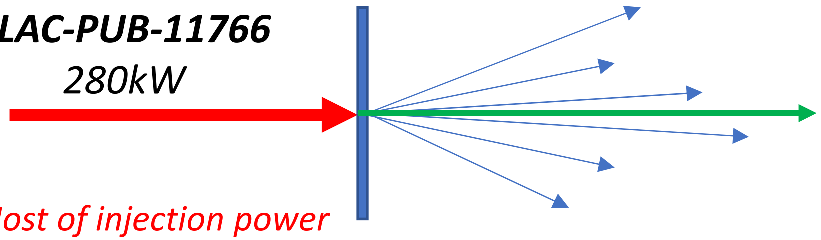
Energy Deposit by Radiation Dose

The power loss was evaluated at PAC'05 by V. Bharadwaj et al. (SLAC-PUB-11766).

Electron driven Scheme

SLAC-PUB-11766

280kW

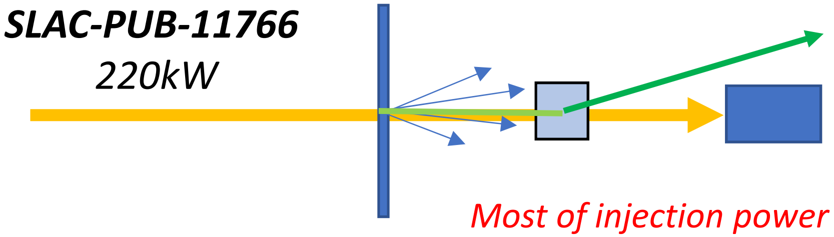


Most of injection power will be sprayed around target.

Undulator Scheme

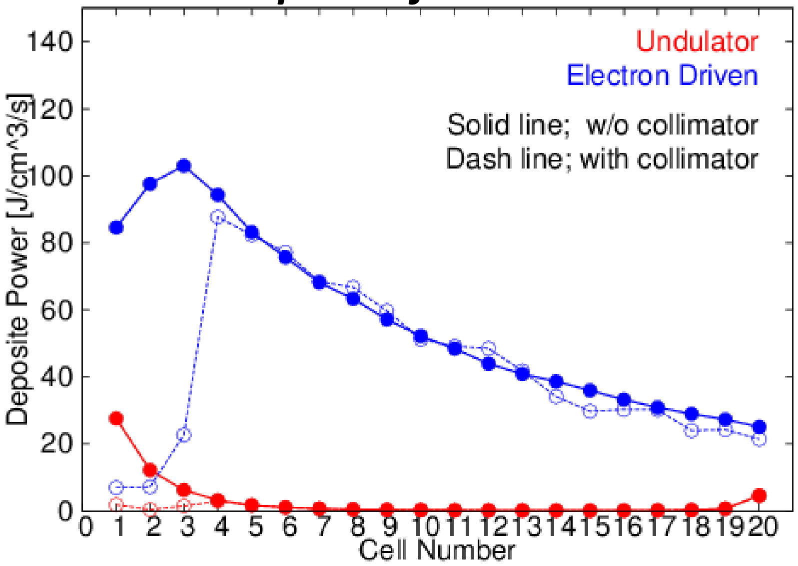
SLAC-PUB-11766

220kW



Most of injection power will be dumped to photon dump.

Power deposit of Innermost iris.



Injection beam power deposition

undulator scheme

6.1% in RF structure

1.5% in innermost iris for structures

Main radiation source is restricted around target.

Halo collimator between target and structure is effective.

electron driven scheme

53% in RF structure

22% in innermost iris for structures

Radiation source is distributed to wide area.

present ILC e-driven design : 47.3 kW drive beam power in 1312 bunch operation.

SuperKEKB operation : 500 W (2 order smaller than ILC e-driven)

Degradient was occurred (8MV/m now for 14MV/m design) in coupled year operation

presented by T.Okugi at LCWS2015
based on J. W. Wang, SLAC-PUB-12412

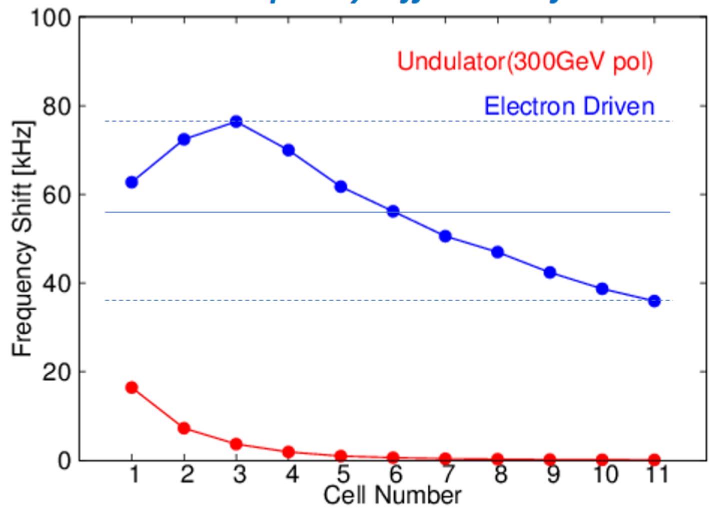
Scaled to present design

Since the parameters were changed from 2005, the power deposition was scaled to present parameter.

	e-driven	Undulator [300GeV]	
		unpolarized	polarized
Beam power to target	146kW *(6GeV & Nb=2.3e10)*	63.1kW	94.7kW
Acc. structure	77kW	3.8kW	5.8kW
Innermost iris only	32kW	0.9kW	1.4kW

Beam power for SLC positron source was < 40kW

Frequency difference of beam loss ON/OFF for e-driven scheme



Average frequency shift for beam loss ON/OFF
55kHz

We could store the RF in the cavity either the beam loss ON or OFF.

Frequency difference within 1 structure
40kHz

The frequency tolerance for RF structure
$\Delta f = f/Q = 43.8kHz$

greater than tolerance of RF cavity

Design was changed from LCWS2015.

1312 bunch
Beam energy : 6 GeV => 3 GeV
Bunch charge : 2.3e10 => 1.5e10
Beam power : 146kW => 47.3kW

(factor 3 reduction from LCWS2015 only by paper work)

2625 bunch
Beam energy : 4.8 GeV
Bunch charge : 1.5e10
Beam power : 151.4kW

Comparable to LCWS2015 design

Comparison of positron yield

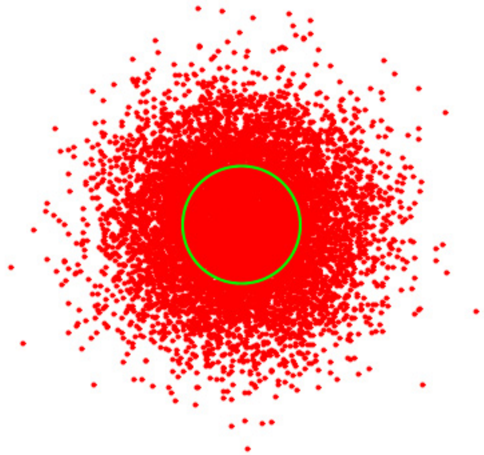
	SLC	SuperKEKB	ILC e-driven PS (design)	FCCee
Electron beam energy	33 GeV	3.0 GeV	3 GeV	4GeV
Beam size at target	0.6 mm	0.7 mm	2.0 mm	with hybrid
Aperture for 1st cavity	18 mm	30 mm	60 mm	
Gradient for 1st cavity	40 MV/m	8 MV/m (14MV/m in design)	8 MV/m (?)	
Positron yield at DR	1.1 e+/e- at DR (1.4 e+/e- at LTR)	**0.29 e+/e-** (0.4 e+/e- in design)	**2.0 e+/e-**	**0.5 e+/e**
Energy acceptance	+/-2.5%	+/-1.5%	+/-0.75 %	
Transverse acceptance	0.01 m	0.02 m	0.07 m	

Design of ILC e-driven PS is very large positron generation yield (2.0 e+/e-).
Otherwise, the radiation dose will be increased.
It affects
- *Radiation damage of RF structure after the target.*
- *RF frequency change by temperature rise by radiation.*

Requirement for ILC e-driven PS is 5 times larger than the design of SuperKEKB.
Design of a future project (FCCee) also same level to SuperKEKB.

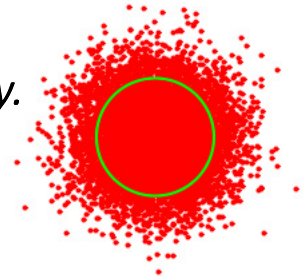
How to achieve such a huge positrons ?

SuperKEKB



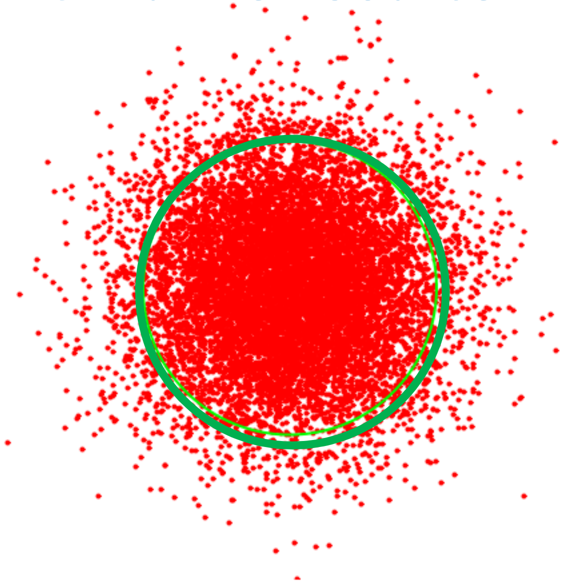
Capture efficiency will be improved
by increasing the positron beam quality.

ILC Undulator Source



Requirement of the accelerator
is comparable to the existing accelerators (SuperKEKB etc.)

ILC E-driven Source



In order to reduce the PEDD of the target,
the beam size at the target must be larger than SuperKEKB.
=> The beam quality is worse than SuperKEKB.

Present ILC e-driven design is assumed
to capture such a worse quality beam with huge capture rate.

The requirement of the capture beamline
is much difficult to existing accelerators (SuperKEKB etc.)

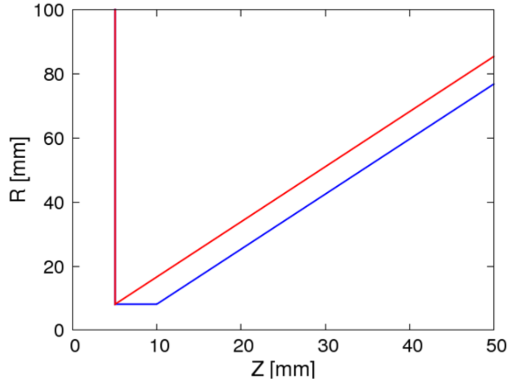
Requirement for Flux Concentrator

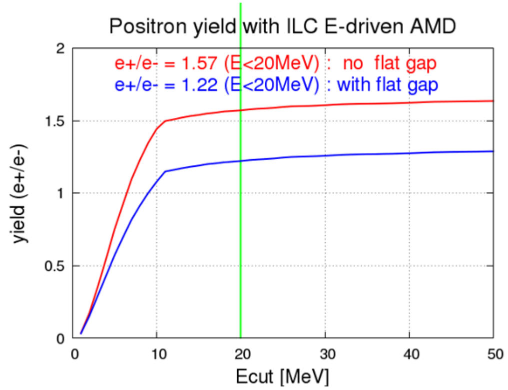
The large aperture AMD was assumed to be used for ILC e-driven (QWT for ILC undulator).

Requirement of modulator power

	SuperKEKB	ILC e-driven
B [T] (square)	3.5	5.0
Aperture (cubic)	7 mmϕ	15 mmϕ
Power [a.u.]	**1**	**20**

Distance between target to minimum aperture of FC is strongly affect to the capture yield for ILC e-driven PS.

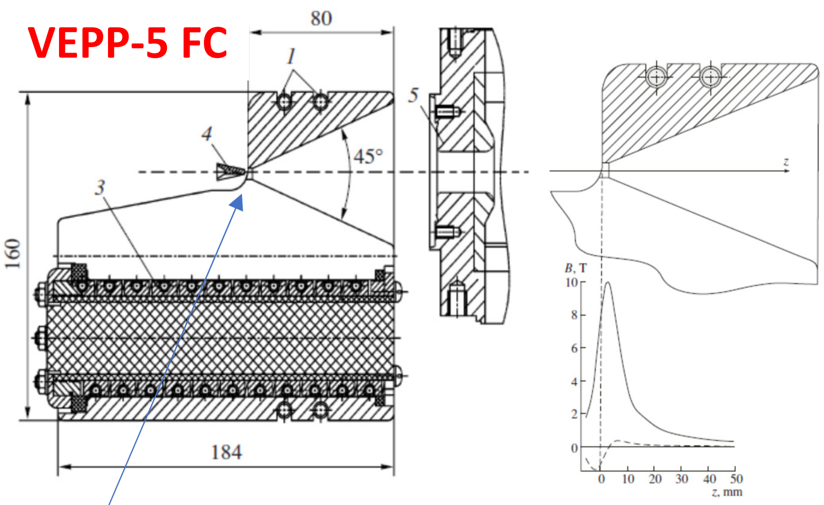




Large Aperture FCs in the world

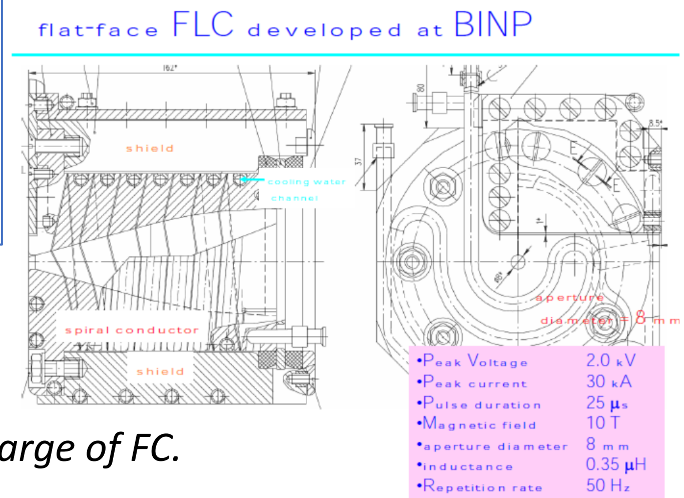
The minimum aperture of FCs with large aperture are not surface of FC.

VEPP-5 FC



Target was put inside of this hole, the longitudinal position of maximum field is no matter

BINP prototype for SuperKEKB



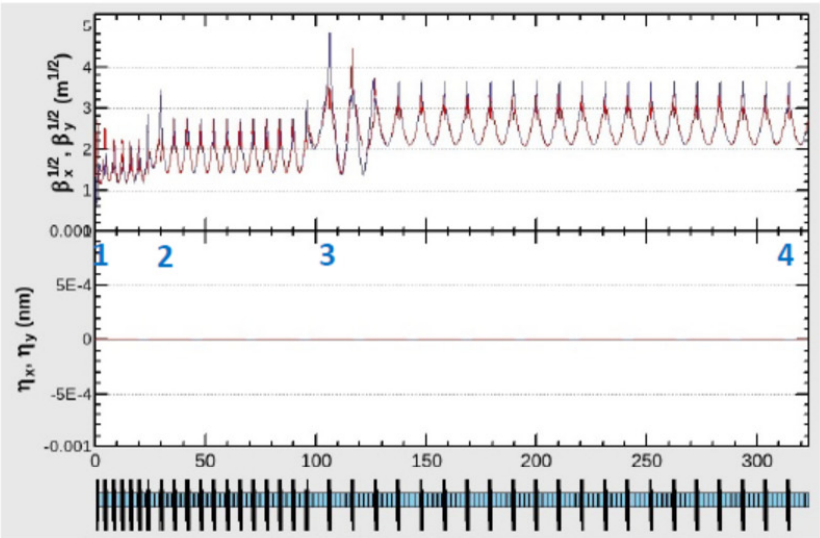
This was not adopted to SuperKEKB by discharge of FC.

Requiremet for booster Linac

In order to make the large acceptance by normal conducting RF with smaller aperture, 4 independent parameters should be matched every 2m at the entrance of booster linac. (4 quadrupoles were used every 2m for matching .)

No margin for transverse acceptance

T.Okugi LCWS13



From 250MeV to 5GeV

If we assumed to

Wx+Wy= 0.07/γ and βx = βy = 2.0 m,

sqrt (βx Wx + βx Wx) = 0.0189 m at 200MeV

sqrt (βx Wx + βx Wx) = 0.0169 m at 250MeV

sqrt (βx Wx + βx Wx) = 0.0154 m at 300MeV

Same acceptance to DR (twice for undulator PS)

RF System

L = 2m each

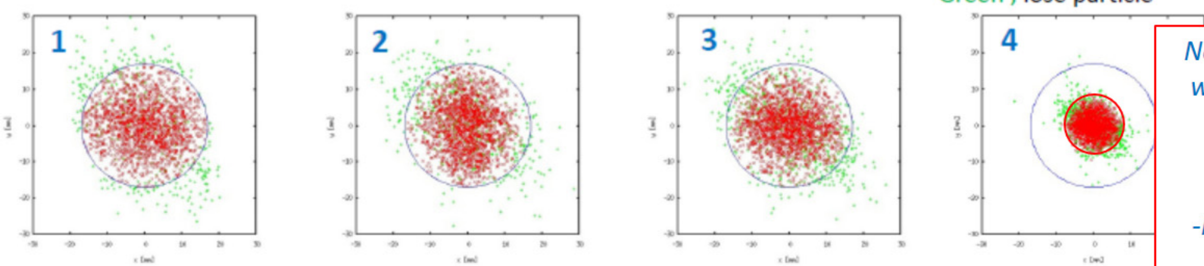
a = 0.017 m (minimum)

V = 35-45MV / structure

with Beam Loading Compensation (Beam Current) = 3.5e10/bunch

When we transport the beam to 2m long L-band structure without Solenoid field, the beam energy should be E>250MeV.

Red ; trasmitted particle
Green ; lose particle



Now the aperture was smaller than LCWS2013 to use S-band

-Make tolerance small

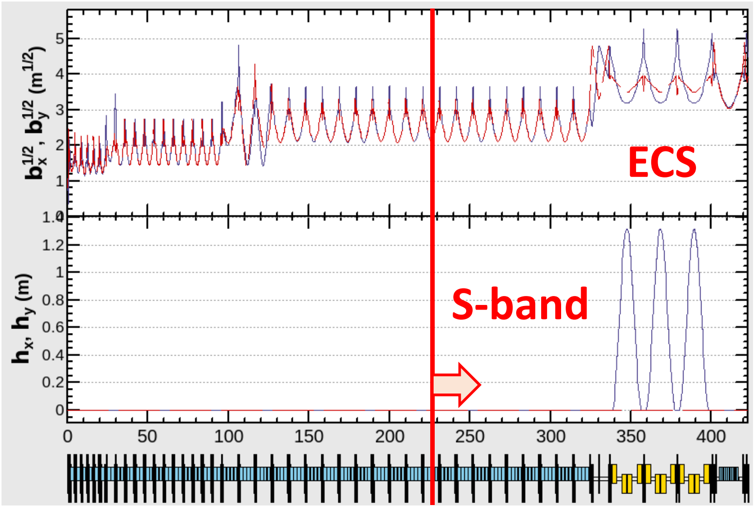
- Make transverse wake large !

Beam loss was generated by optics mismatch, misalignment, transverse wake etc.

Beam optics for both ILC positron source

E-driven positron source

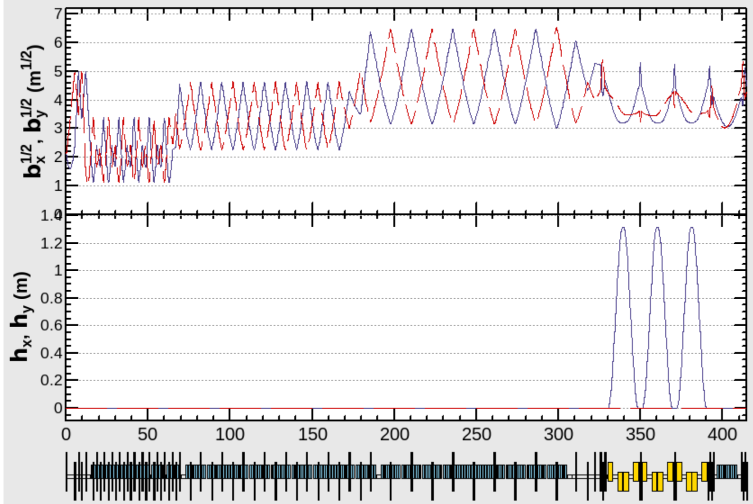
Injection energy is 250 MeV



Accelerating gradient for original design V=20.3 MV/m.
=> present design is roughly a half.
=> The beam line also is roughly twice as this optics.

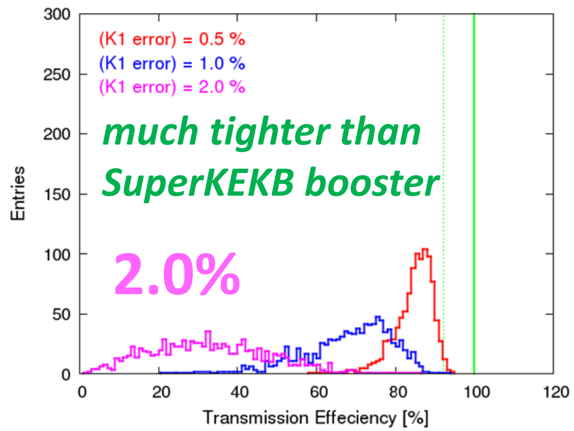
Undulator positron source

Injection energy is 400 MeV

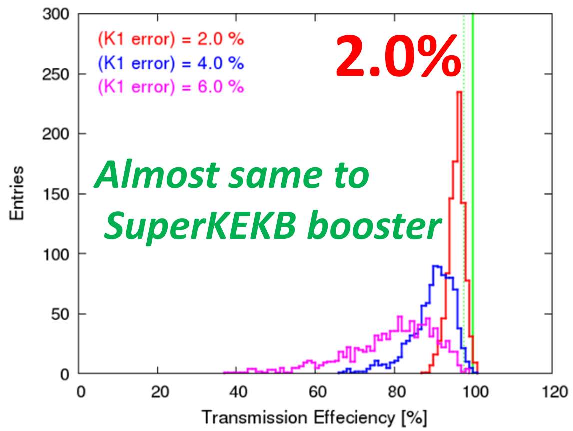


Present optics deck, based on FODO

Superconducting cavities was adopted as well as electron source.



Capture yield simulation with quadrupole strength error

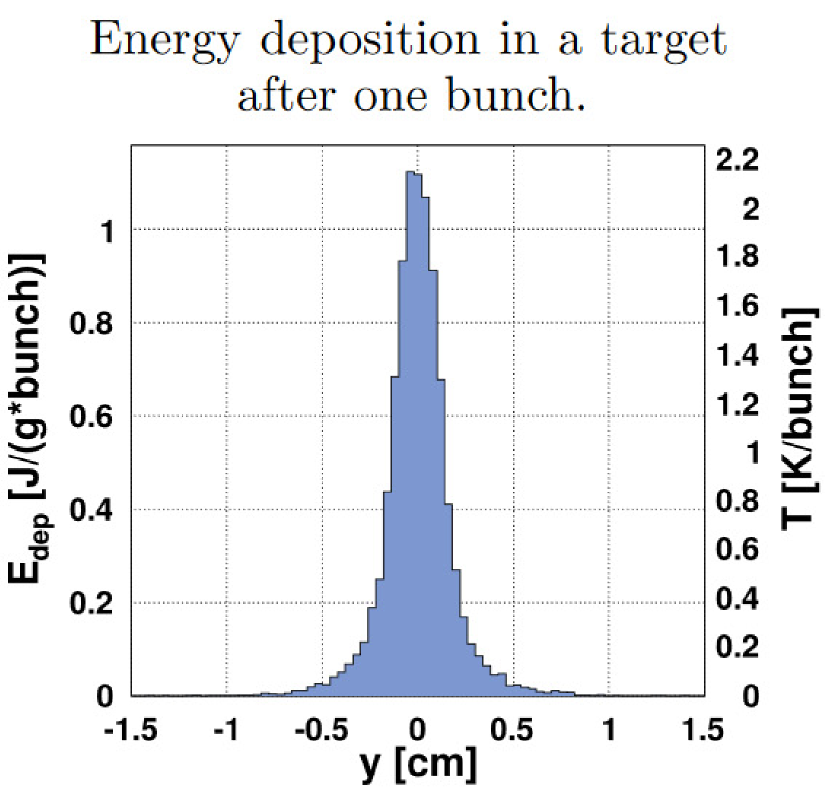


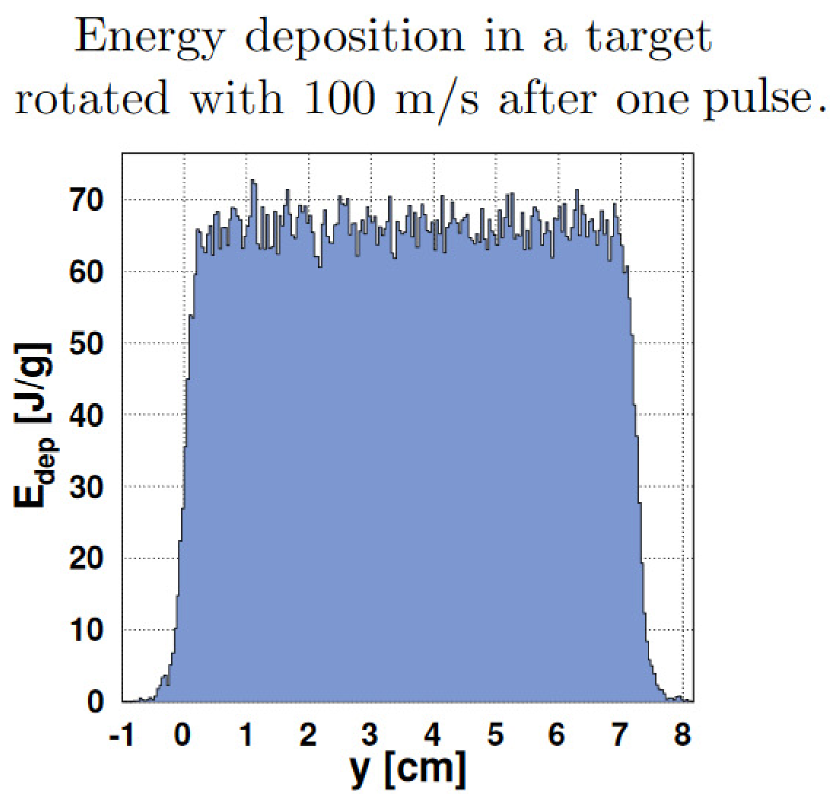
This type of too much challenging design has a risk to make the yield smaller than conservative design.

Multi-bunch positron capture under huge transient beam loading with multi-cell standing wave structure

Rotating Target for ILC undulator source

By using the rotating target (100m/s ; r=50cm, 200rpm),
the energy deposition is reduced to that for 1312 bunch => 59 bunches in pulse.





A. Ushakov, DESY-12-018

It was pointed out the high speed target is difficult to produce.

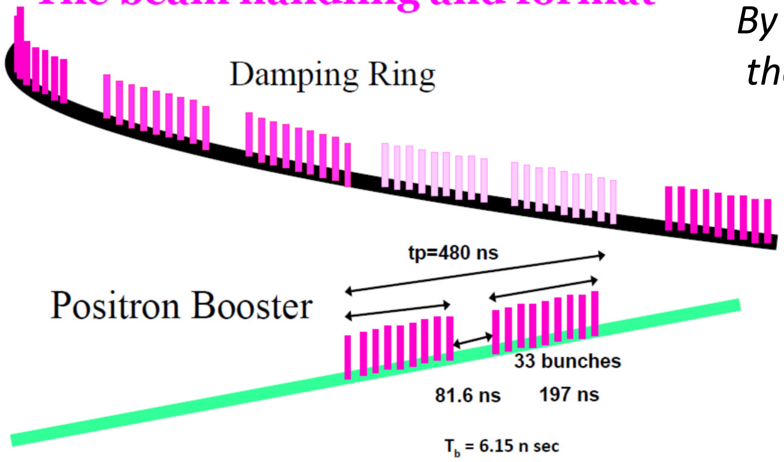
But, since it was found that we can use ***well-established magnetic bearing technique****,*
the speed of the rotating target is no matter at present.
(***no contamination, o (10000 rpm), o (Ton) bearings are used in many field*** *)*

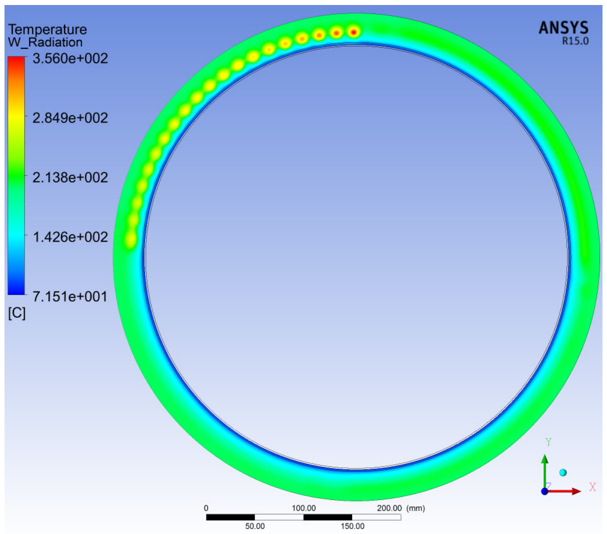
Idea of ILC e-driven source

Since the power deposit in target for ILC e-driven source is huge,
it is difficult to cool the target by the radiation cooling (***cannot use magnetic bearing*** *).*

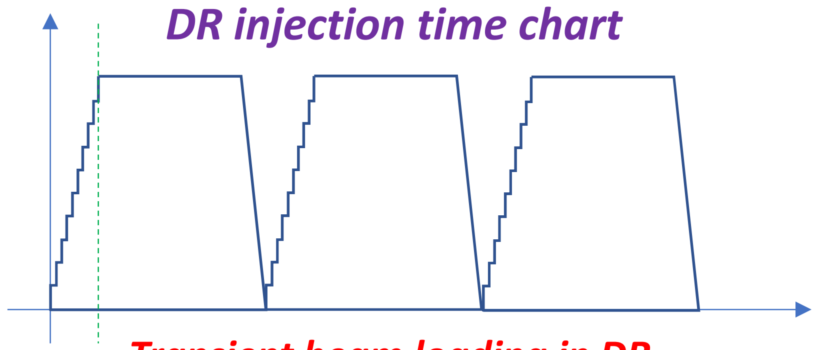
The ball bearing with ferromagnetic vacuum seal is used in present design to make a water path to target.
But, the technique have not ever used in accelerator with low vacuum pressure
(normal operation at $\sim 10^{-2}\ Pa$).

The beam handling and format





By injecting the positron beam with same bunch structure to DR,
*the energy deposition at the target can be 1312/39*2=67 bunches.*
(20 times Injection at 300Hz)



Transient beam loading in DR
should be also taken in account .

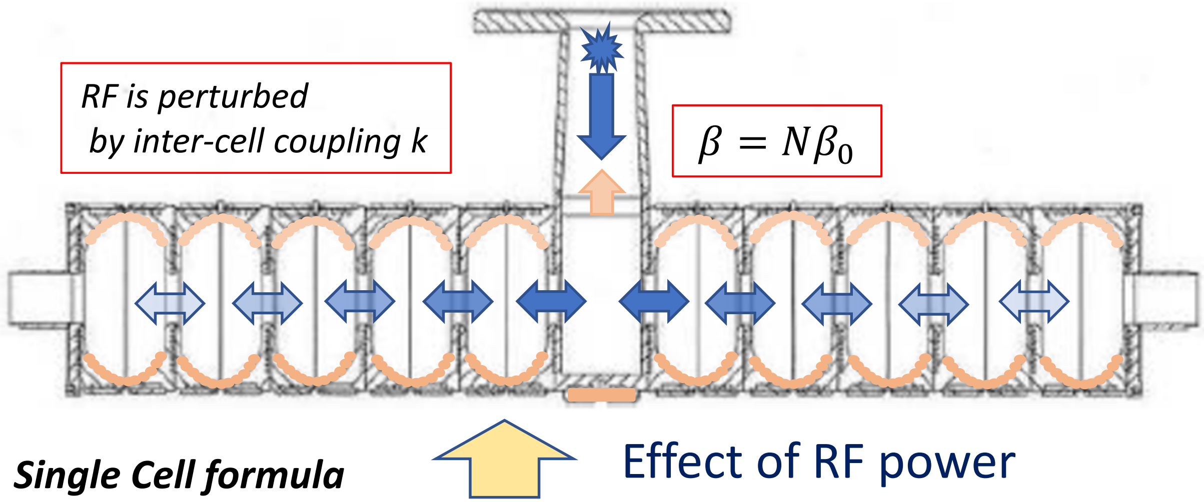
We can reduce the speed of rotation to 225rpm
by using the this scheme.

But, the beam loading current is increased by 2 order
of magnitude (Bunch separation ; 554ns => 6.15ns).

Beam loading compensation for huge beam current
is essential technique to use this scheme !

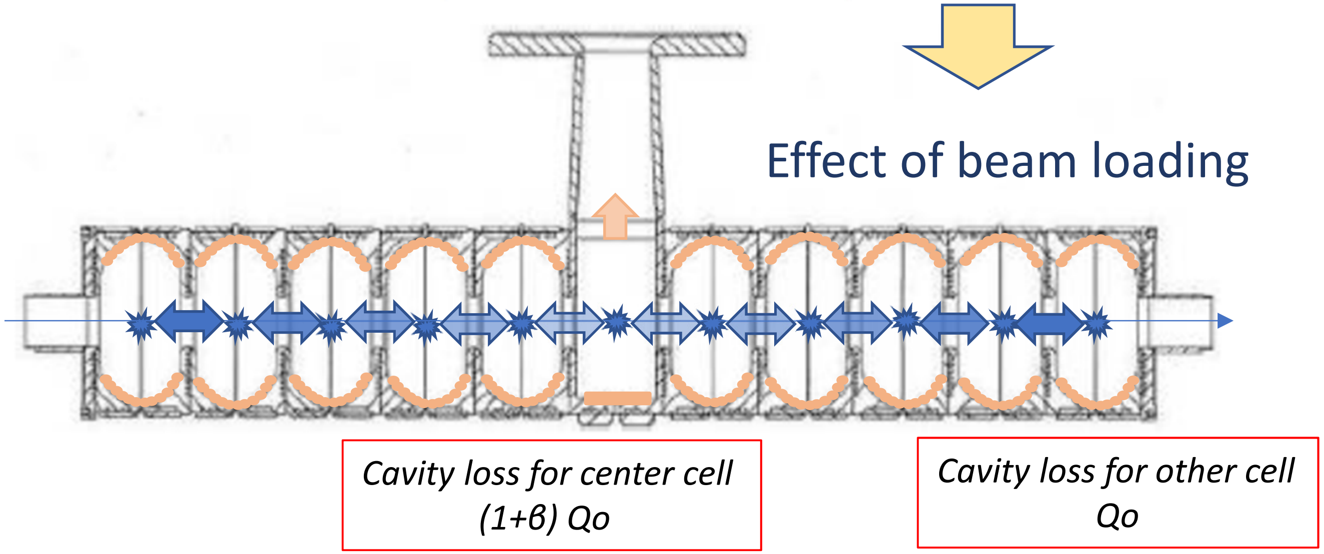
Multi-cell standing wave structure

In order to make ***large aperture of capture cavity****,*
ILC e-driven scheme also adopted to use the multi-cell standing wave structure.
Beam loading compensation for the structure is necessary for ILC e-driven.



Single Cell formula

$$V(t) = \frac{2\sqrt{\beta P_0 r L}}{1+\beta}\left(1 - e^{-\frac{t}{T_0}}\right) - \frac{rIL}{1+\beta}\left(1 - e^{-\frac{t-t_b}{T_0}}\right)$$



Calculation of beam loading compensation in capture section

Equation of beam loading compensation for multicell standing wave structure for present e-driven team (based on the ILC positron report).

presentation at Japanese domestic positron meeting in 04/26/2018

11セルL-Band定在波加速管

11セルの微分方程式をまとめたものがこちら

$$
\frac{\mathrm{d}}{\mathrm{dt}}
\overset{\mathbf{V}}{\begin{pmatrix} V_{-5} \\ V_{-4} \\ V_{-3} \\ V_{-2} \\ V_{-1} \\ V_0 \\ V_1 \\ V_2 \\ V_3 \\ V_3 \\ V_4 \\ V_5 \end{pmatrix}}
=
\overset{\mathbf{A}}{\begin{pmatrix}
a_5 & \alpha & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\alpha & a & \alpha & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \alpha & a & \alpha & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \alpha & a & \alpha & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \alpha & a & \alpha & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \alpha & a_0 & \alpha & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \alpha & a & \alpha & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \alpha & a & \alpha & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha & a & \alpha & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha & a & \alpha \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha & a_5
\end{pmatrix}}
\overset{\mathbf{V}}{\begin{pmatrix} V_{-5} \\ V_{-4} \\ V_{-3} \\ V_{-2} \\ V_{-1} \\ V_0 \\ V_1 \\ V_2 \\ V_3 \\ V_3 \\ V_4 \\ V_5 \end{pmatrix}}
+
\overset{\mathbf{C_0}}{\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \frac{\omega\beta}{Q} V_{\mathrm{in}} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}}
-
\frac{\omega I R}{2Q}
\overset{\boldsymbol{C_{bl}}}{\begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}}
$$

$$
a_0 = -\left\{\frac{(1 + 11\beta)\omega}{2Q} + k\omega\right\} \qquad a = -\left\{\frac{\omega}{2Q} + k\omega\right\}
$$

$$
a_5 = -\left\{\frac{\omega}{2Q} + \frac{1}{2}k\omega\right\} \qquad \alpha = \frac{1}{2}k\omega
$$

Cell-to-cell coupling is assumed not via storage power, but via the voltage.

This equation means …

To simplify the problem, when we assumed to be $\beta = 0$,

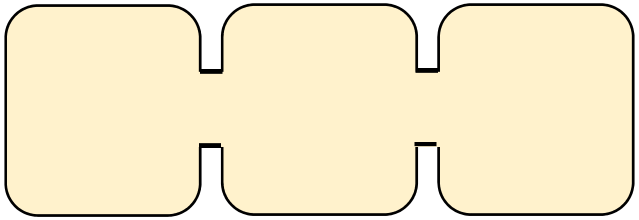
$$\frac{d}{dt}V = -\frac{\omega}{2Q}V \quad (V = V_{-5} + V_{-4} + \cdots + V_{+5})$$

The multicell standing wave cavity is treated as simple "single cell" cavity.
Therefore, the calculation was quite same to that for single cell cavity.

But, it is not correct actually.

By assuming the 3 cell cavity with $Q = \infty$,
the above equation shows ***the total voltage is constant in time.***

On the other hand, the actual total voltage change, even when the total power is constant.



The equation for multicell standing wave structure is not correct.

$$t = 0 \qquad 0\ (0) \quad + \quad P_0\ (V_0) \quad + \quad 0\ (0) \quad \rightarrow 1.00\ V_0$$

$$0.10\ P_0\ (0.32\ V_0) + 0.80\ P_0\ (0.89\ V_0) + 0.10\ P_0\ (0.32\ V_0) \rightarrow 1.53\ V_0$$

$$0.33\ P_0\ (0.58\ V_0) + 0.33\ P_0\ (0.58\ V_0) + 0.33\ P_0\ (0.58\ V_0) \rightarrow 1.73\ V_0$$

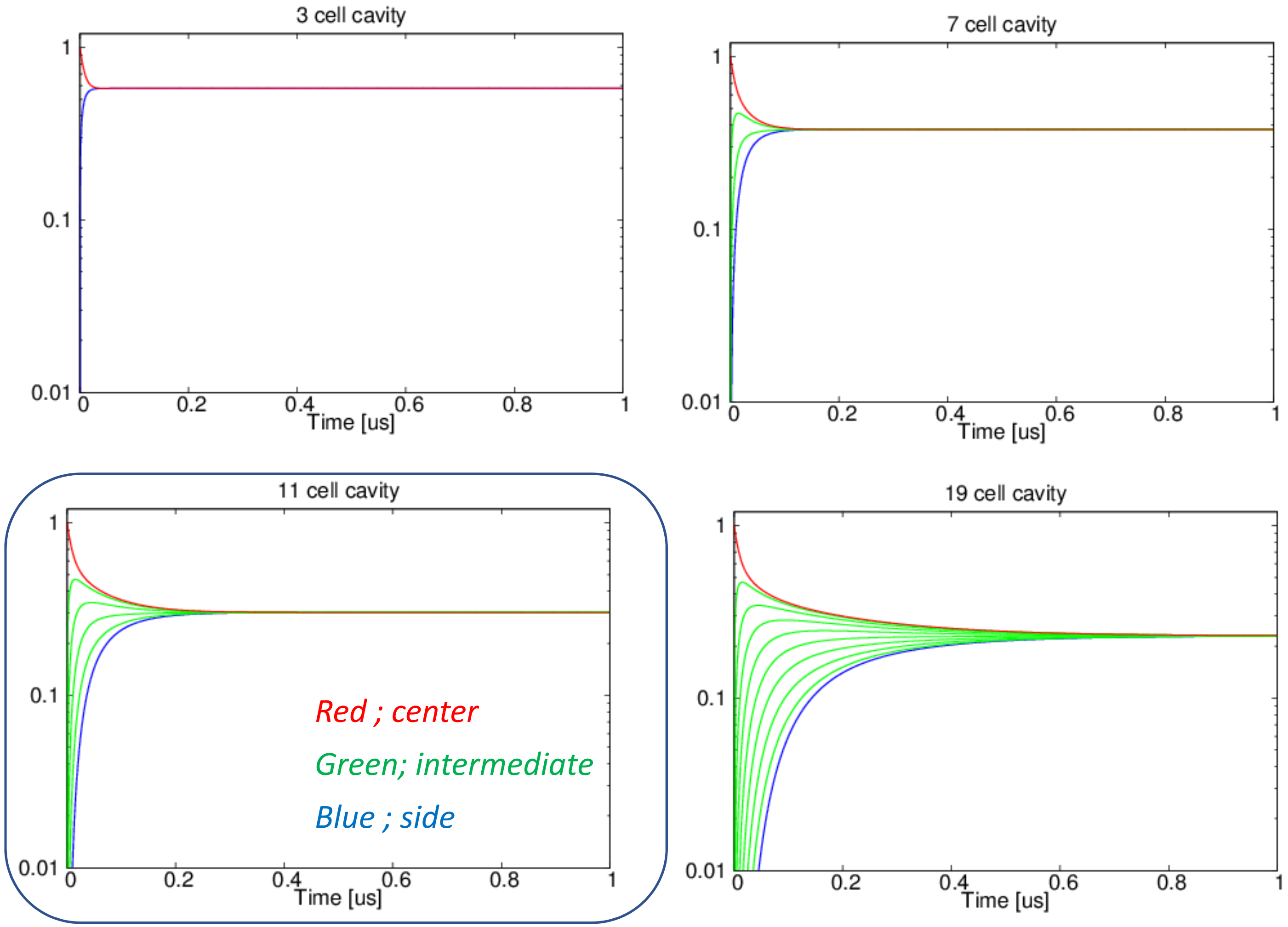
The report was written by using the incorrect equation !

RF perturbation in the multi-cell structure (time domain calculation)

presented by T.Okugi at LCWS2015

inter-cell coupling constant ;   k = 0.0125 (capture structure for undulator source)

$\beta = 0, \qquad Q = \infty$



- *RF power was stored only center-cell for t < 0.*
- *RF power will perturb for t > 0.*
- *No wall loss*

The total power is kept to be constant.

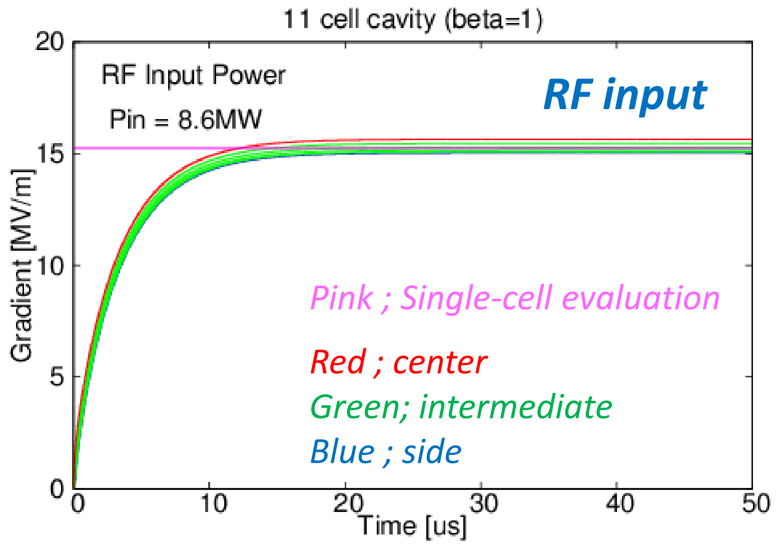
But, the total voltage is changing in time.

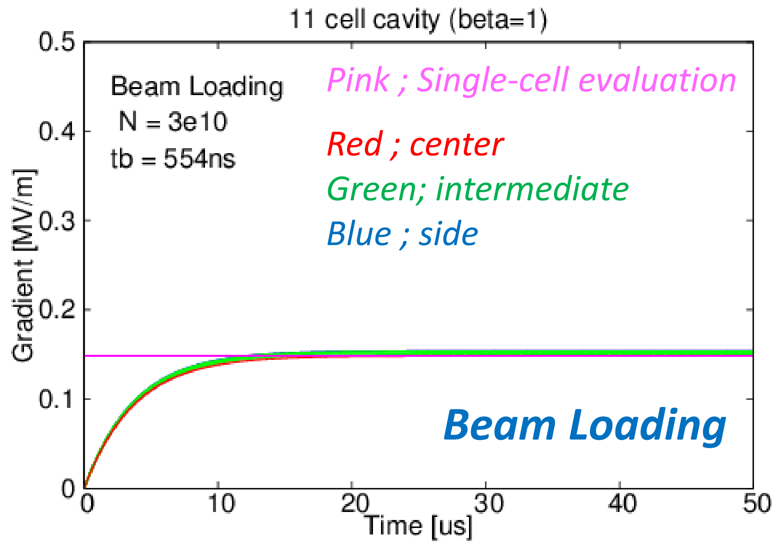
The time to be steady state is proportional to N^2.

For 11 cell cavity, the perturbation time is roughly O(0.1us).

Evaluation of steady state for normal conducting cavity

Capture cavity for Undulator positron source ($\beta = 1$)





The accelerating voltage and beam loading for steady state are same to the evaluation with single cell formula for undulator PS parameter.

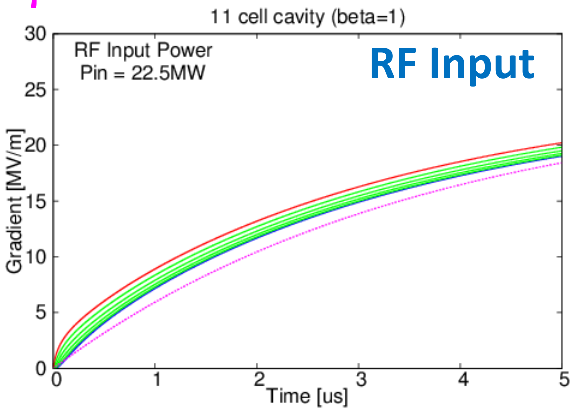
Since the beam current is very small for the capture cavity of undulation positron source, ***the effect of beam loading is only a couple % of accelerating voltage.***

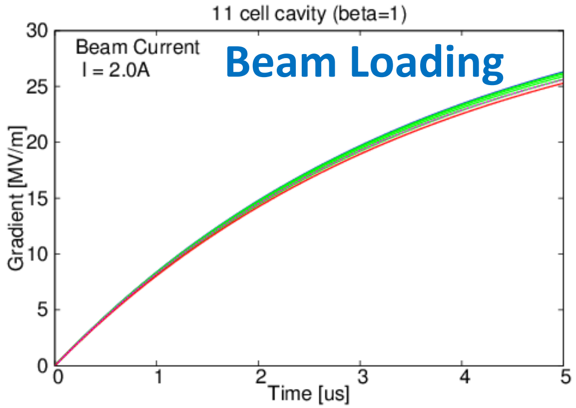
We can operate multi-bunch beam almost same as single bunch beam for ILC undulator positron source.

RF perturbation for normal conducting cavity

Transient beam loading with huge beam current

β=1





Pink ; Single-cell evaluation

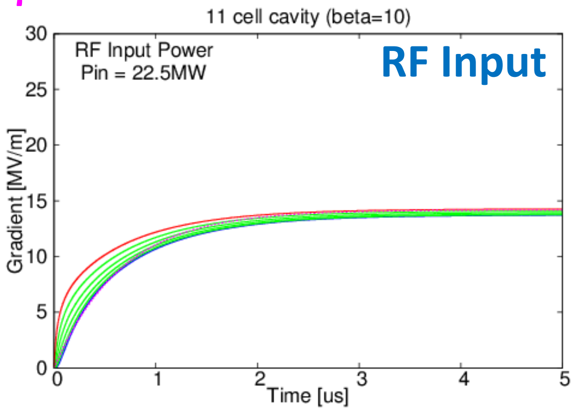
Red ; center

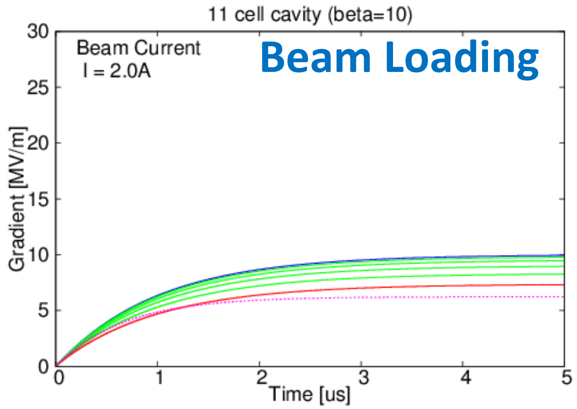
Green; intermediate

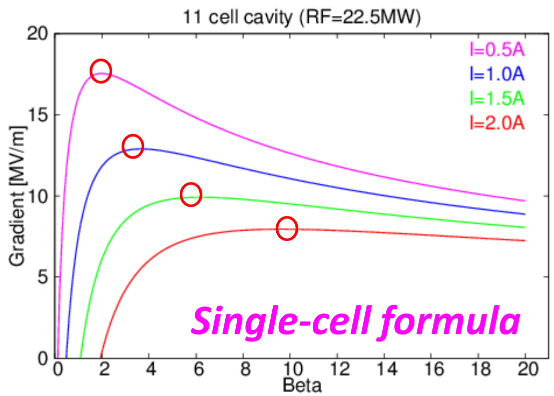
Blue ; side

Beam loading voltage is larger than that for RF input at β=1.

β=10







The time constant of input RF is different to single cell formula, especially for large beta.

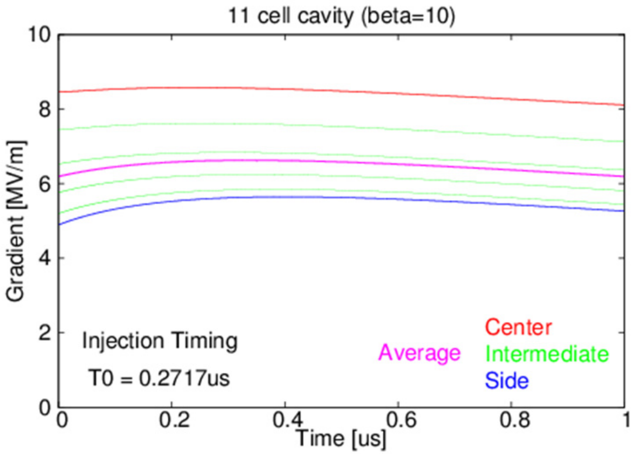
The time constant of input RF is not same to that for beam loading voltage.

Transient beam loading compensation with multi-cell model

Evaluation by time domain model

11cell and $\beta = 10$.

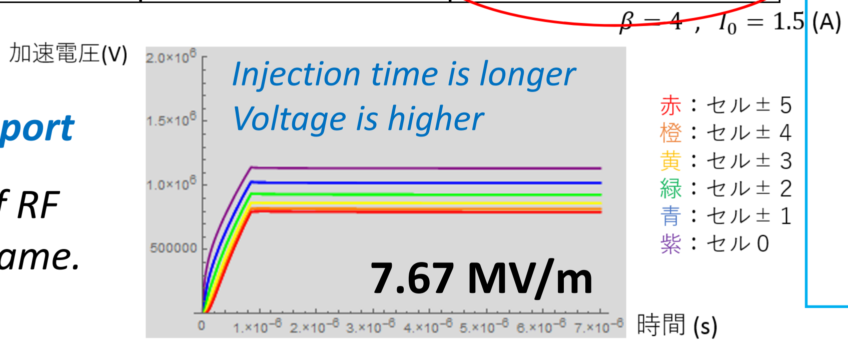
(Design at 2015/9/30 report is 11cell and $\beta = 10.3$)



	Single cell model	Multi-cell model
Average Gradient	8.0 MV/m	6.2 MV/m
Injection Timing	0.543us	0.272us
Field def. in train	0 %	7 % peak-to-peak
Cell-to-cell field def.	0 %	50% peak-to-peak

Evaluation by report

Time constant of RF and loading is same.

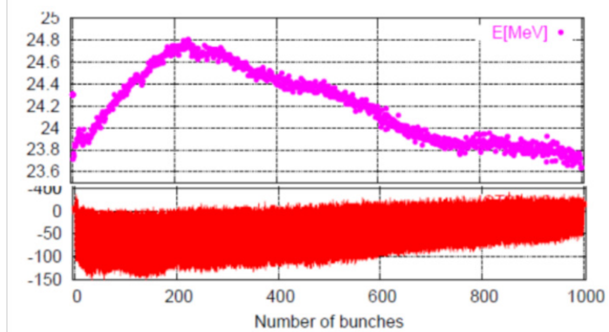


Example of Transient Beam Loading

S-band 12-cell standing wave structure

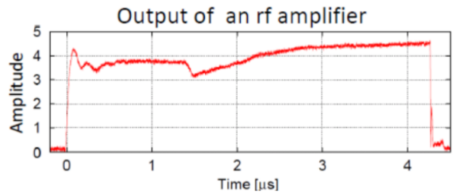
at LUCX, KEK (*0.2A, 2.8us,* β*=1.1* **)**

M.Fukuda, Proceedings of IPAC2015

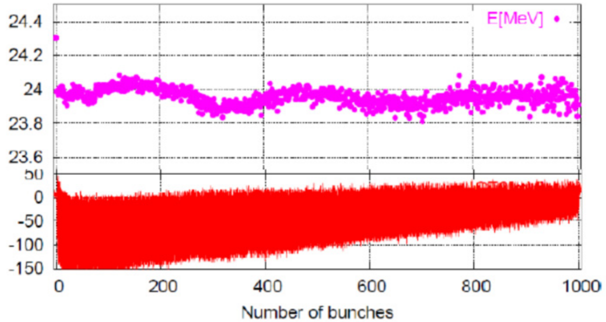


Observation of field def.

(no Amplitude modulation)



Amplitude modulation

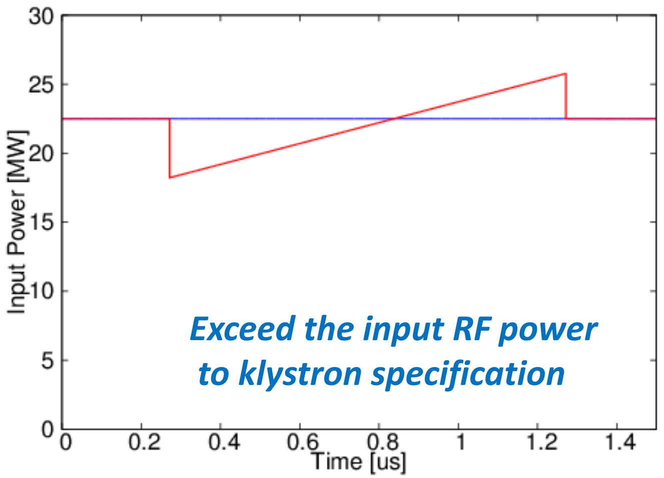


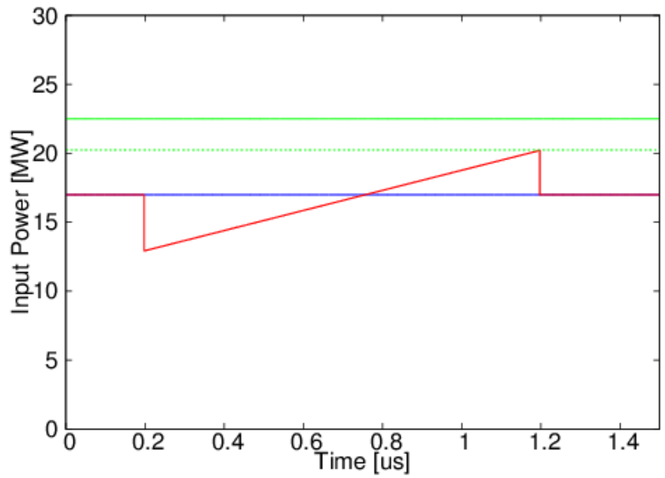
4% -> 1.3% peak to peak

Amplitude Modulation

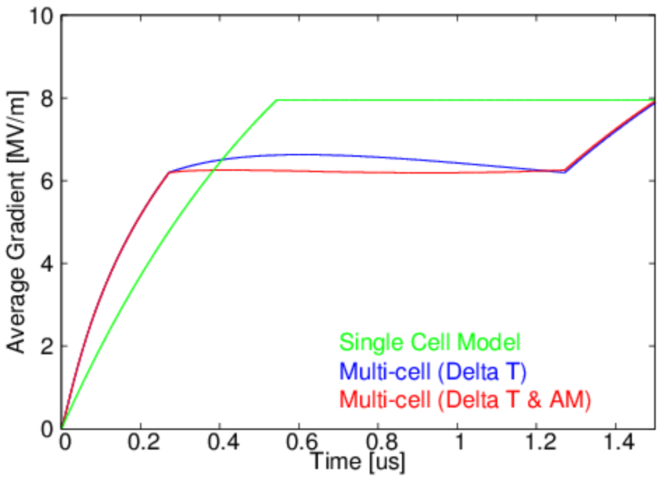
presented by T.Okugi at LCWS2015

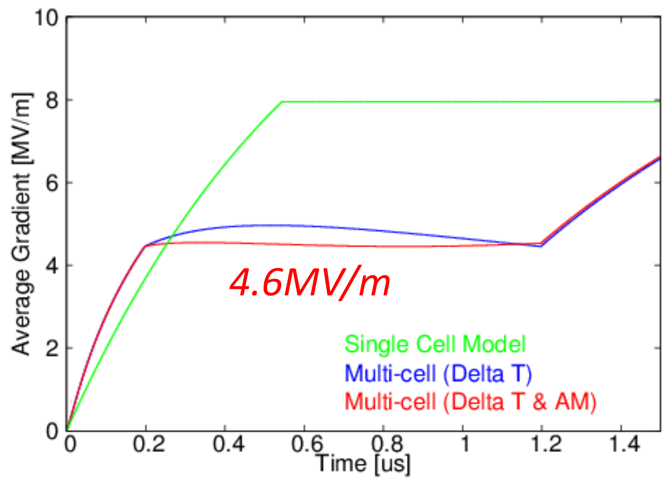
Since we will not operate the klystrons at saturation condition (to apply amplitude modulation), the input RF power should be reduced more (90% for ILC-ML RF).





90% of saturation level





50MW klystron to two 11cell cavities

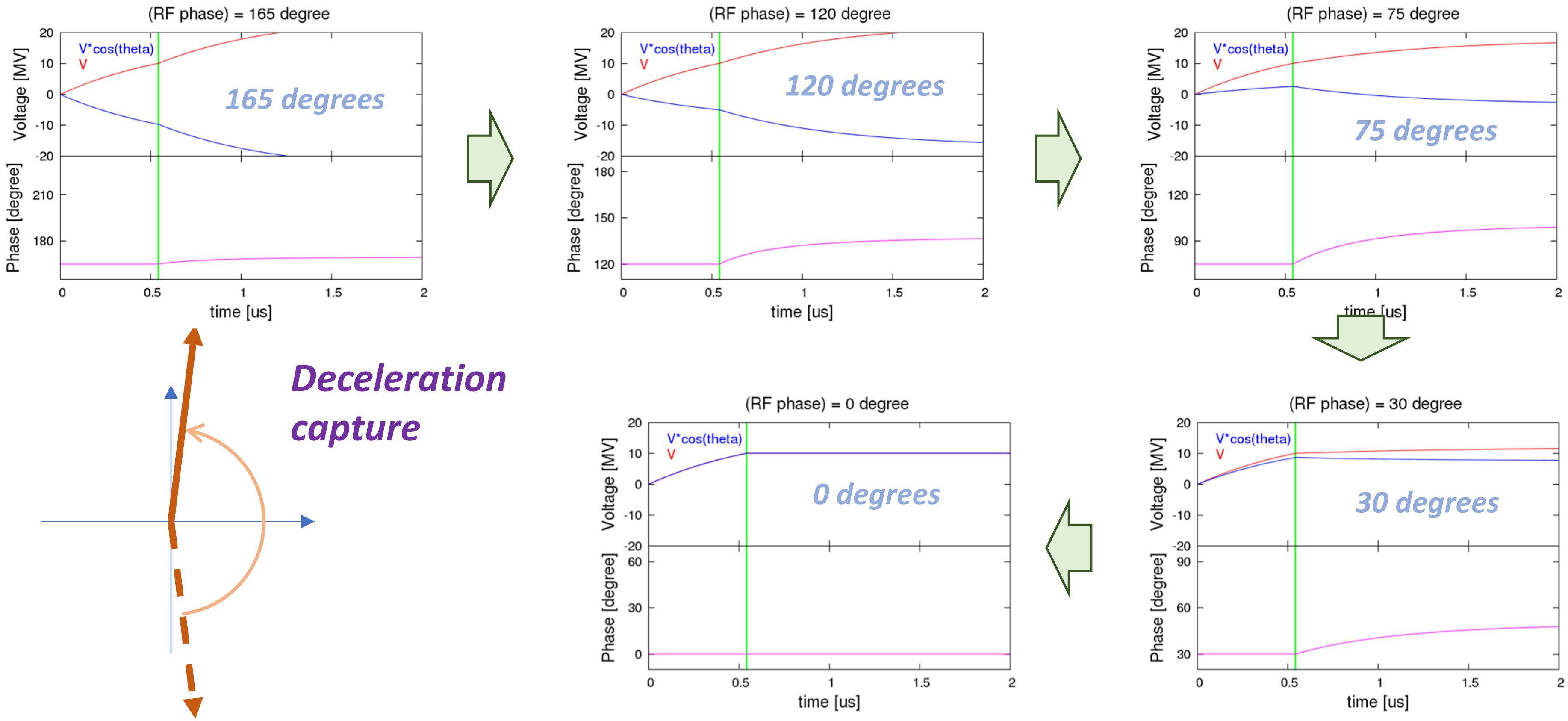
8.0MV/m Single-cell model

4.6MV/m Multi-cell model

Is the evaluation of the accelerating gradient correct ??
*=> **Are number of capture cavity, cost estimation correct ??***

Effect of beam loading for off-crest beam (Not yet applied)

Single cell cavity (beta = 10, I = 2A)

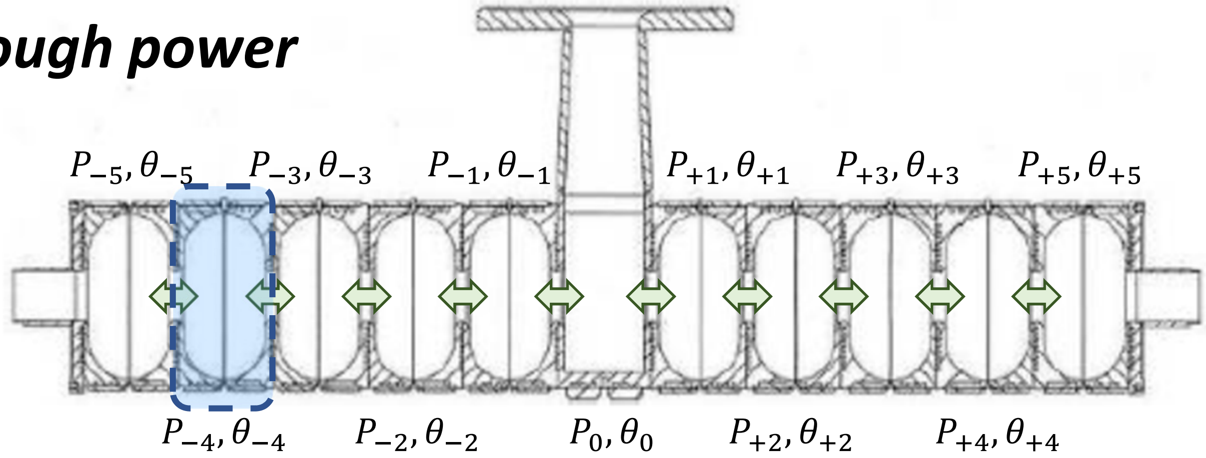


RF phase w.r.t. beam arriving timing is changing for deceleration capture scheme.

The RF voltage and beam loading voltage was summing up as vector sum.
The transient RF voltage and beam loading voltage are different bunch-to bunch.
Every bunch in multibunch beam is captured via different voltage and phase.

Time domain analysis for multicell standing wave structure

Coupling through power



Vector sum

$$(coupling\ via\ P_{-5}, \theta_{-5}) \Rightarrow E_{-4}\ (with\ wall\ loss) \Leftarrow (coupling\ via\ P_{-3}, \theta_{-3})$$

$$\Uparrow$$

$$(beam\ loading)\ P_l, \theta_l\ (via\ beam\ phase\ of\ each\ bunch)$$

depends on beam loading of all of upstream cavities

The proof-of-principle of huge current positron capture with multi-cell standing wave structure was not yet performed in the world.

Furthermore, the numerical evaluation also is not performed yet .

The capture efficiency for each bunch should be evaluated by assuming the appropriate voltage and phase for every cavities through all capture.

Why can we say no fundamental risk to be show stopper for this scheme ????

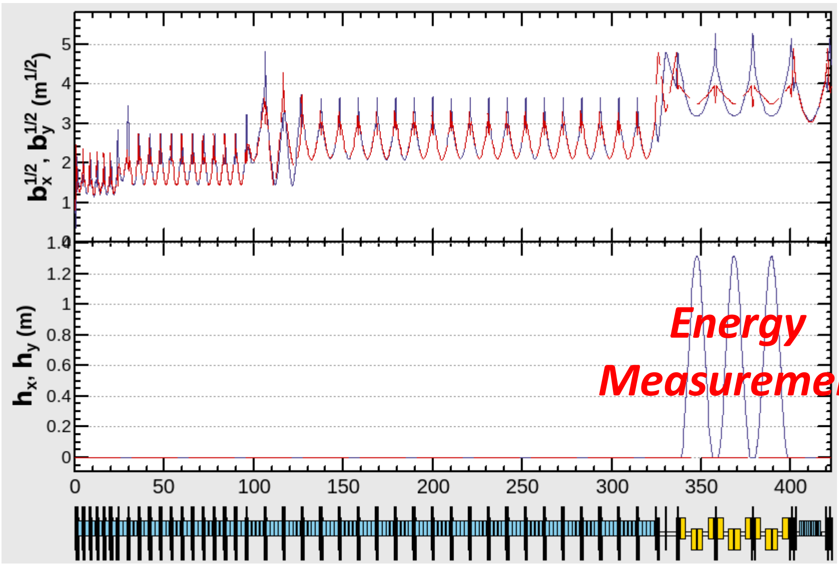
Booster linac beam tuning for beam loading compensation

Multi-bunch beam loading compensation

Energy measurement will be done after booster linac in present design.

E-driven positron source

Injection energy is 250 MeV



RF power

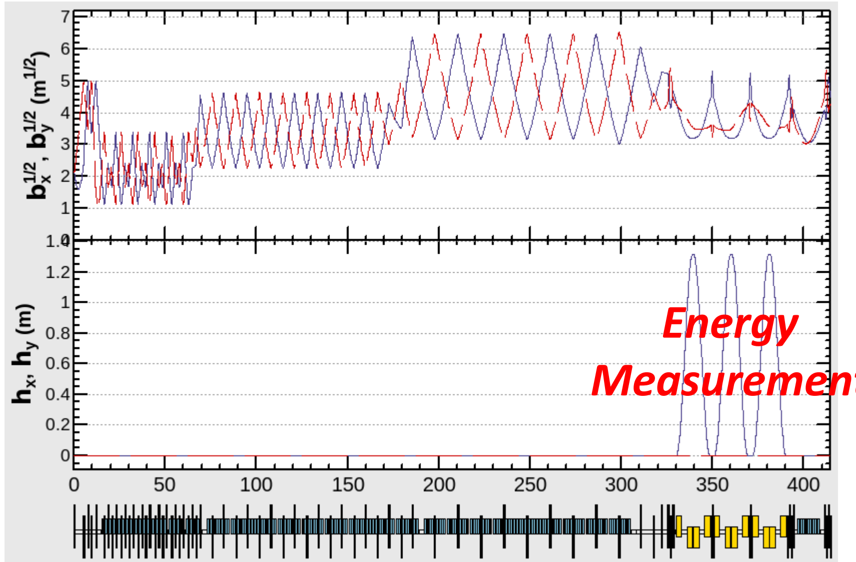
Beam Loading

We must tune multi-bunch beam loading compensation
by affecting the beam loading for all RF cavities.

I cannot image how to tune (?).

Undulator positron source

Injection energy is 400 MeV



RF power

detune | *tune* | ***detune RF cavities***

Beam Loading

We can apply quasi-local correction
by detuning unused RF cavities.
*- **same procedure to ILC e-source and ML.***

E-driven PS source (challenging)

Large Aperture AMD *(Transient)*

B_L (capture efficiency)
B_T (transverse kick)

Beam loading compensation
(Transient)

Kick by RF input coupler
(Transient)

Beam loading compensation
(Transient)

Orbit kick and aperture
(Small aperture and tolerance)

Beam Energy Monitor
(At the end of linac, with beam loading of all RF structures)

Small magnetic field tolerance

Intra-beam orbit tuning
(very fast feedback, not yet developed)

Capture Section	Booster Linac

QWT *(small transverse distribution)*
(Steady)

Beam loading compensation
(Small impact; no special treatment)

Kick by RF input coupler
(Steady)

Beam loading compensation
(Pk-Ql feedback, same as ML and E-source)

Orbit kick and aperture
(Large aperture and tolerance)

Beam Energy Monitor
(At the end of linac, but quasi-local by detuning the RF cavities)

Large magnetic field tolerance

Intra-beam orbit tuning
(FONT, tested at ATF extraction line)

Undulator PS source (conservative)

Summary

Large energy deposit on target

Water cooling is necessary.

=> cannot use the magnetic bearing technique (in vacuum, no contamination).

=> design is utilizing the ball bearing with ferromagnetic vacuum seal.

(Have not ever used in accelerator with low vacuum pressure ($\sim 10^{-6}$ *Pa*))

Acceleration with normal conducting cavity

=> Beam loading compensation for 100 times larger beam current to undulator .

Huge radiation

RF cavity operation with huge radiation

(2 order larger drive beam power than SuperKEKB and ILC undulator)

Frequency shift by the temperature rise of radiation

(greater than the cavity tolerance especially for luminosity upgrade)

Huge capture efficiency is necessary (5 times larger than SuperKEKB, FCCee)

When we will not e able to achieve such a huge capture efficiency, the radiation dose will be increased more …

Worse beam quality

Huge aperture is required

- FC (20 times larger AMD power than SuperKEKB ; QWT for ILC undulator)
- Booster linac optics (5 times smaller field tolerance than ILC undulator)
- Capture section => Multicell standing wave structure

Present report is based on incorrect equation

Transient beam loading compensation (No proof-of- principle)

Backup

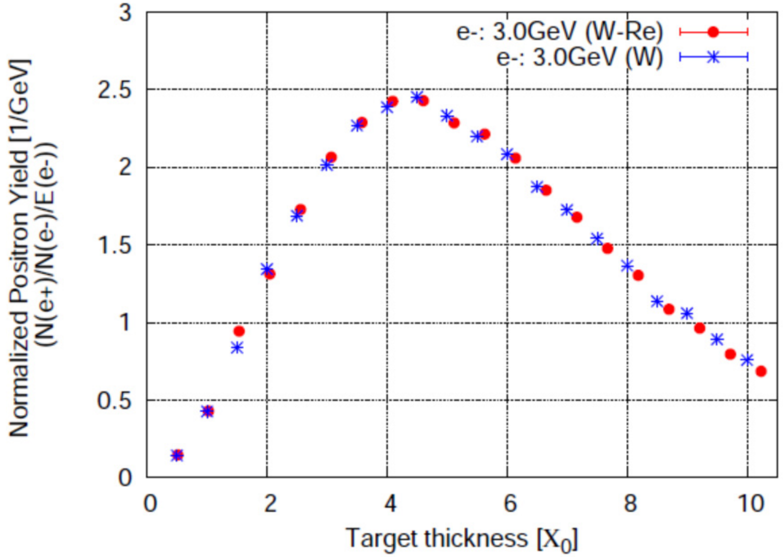
Positron distribution generation after the target

Positron distribution after target was simulated by M. Fukuda with EGS4 (Ek > 10keV).

SuperKEKB source

Input: Electron
Energy ; 3.3GeV
Beam size ; 0.7mm
NMP; 10000

Target:
W 14 mm



ILC e-driven source

Input: Electron
Energy ; 3.0GeV
Beam size ; 2.0mm
NMP; 10000

Target:
W-Re 16mm

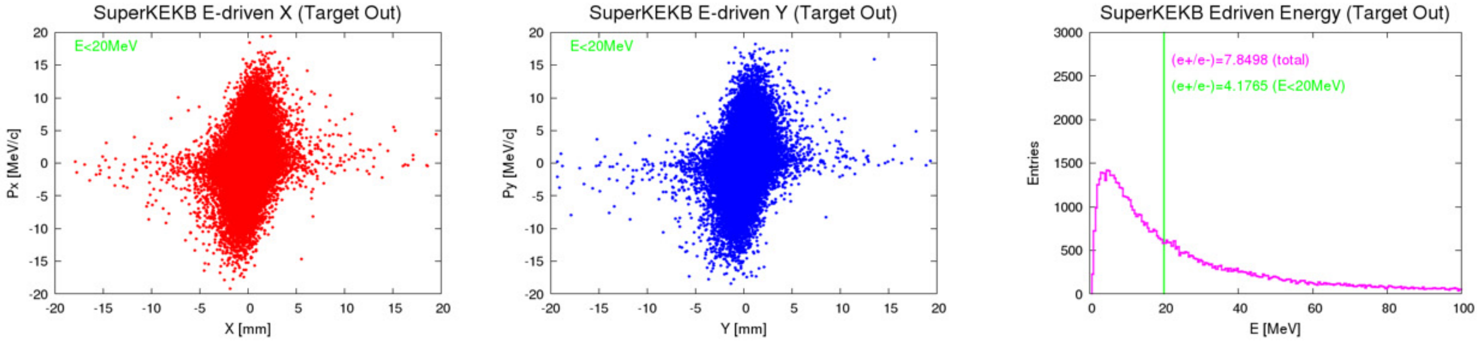
ILC undulator source

Input: Photon
Yokoya-san's calcultion
NMP: 1000 x 10

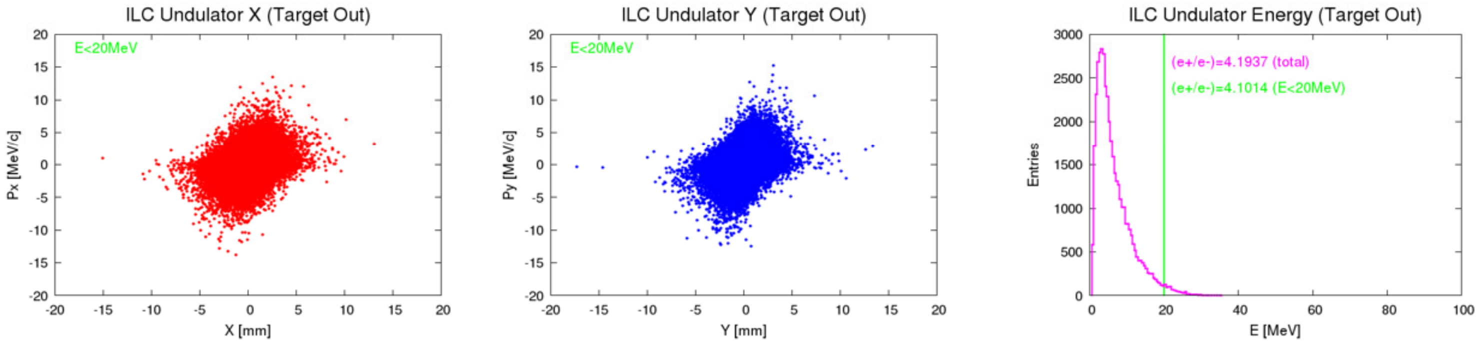
Target:
Ti 7mm

ターゲット後の陽電子の分布

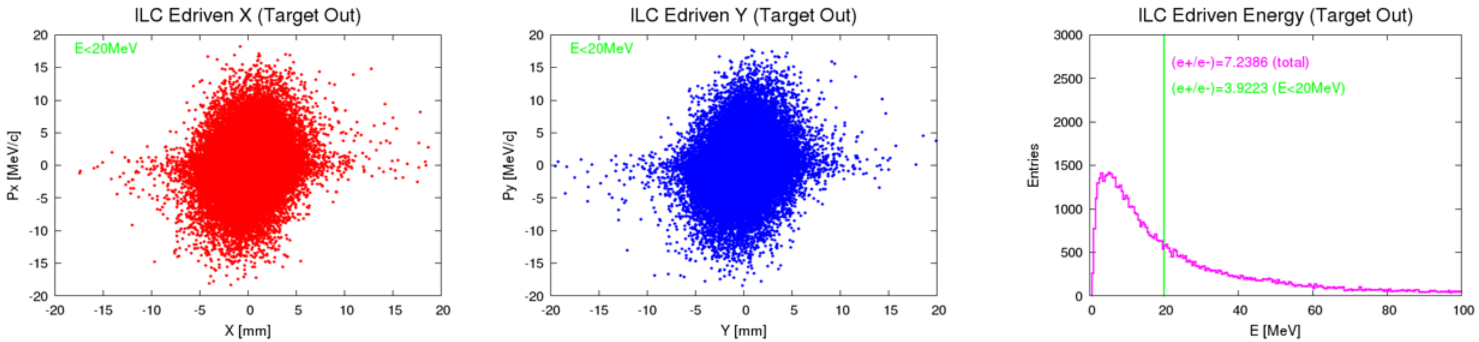
SuperKEKB



ILC undulator



ILC e-driven

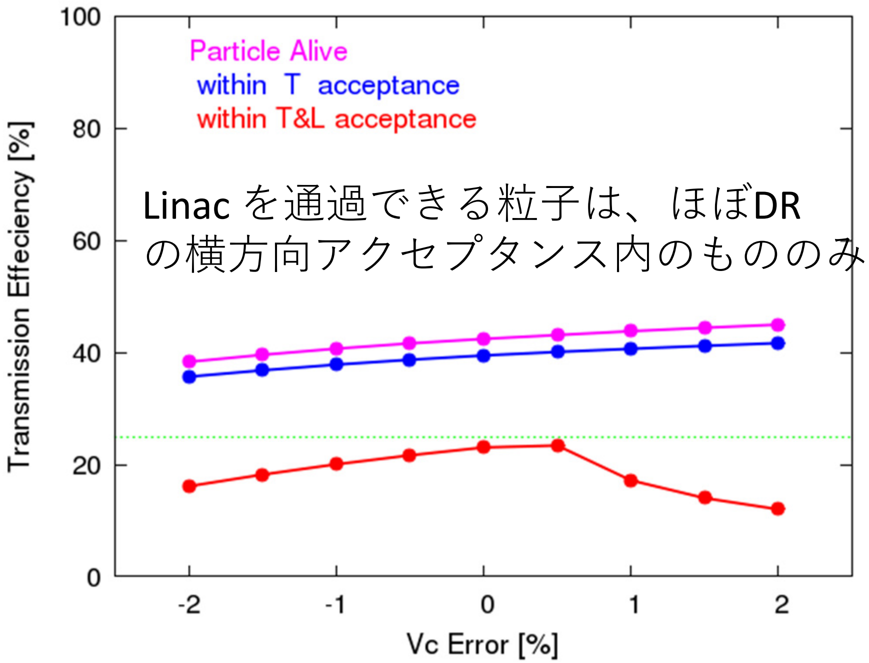


Booster Linac の輸送シミュレーションの結果

	Design	Simulation	(Simu.) / (Design)
E-driven	26008	23044	92.1%
Undulator	31993	31219	97.6%

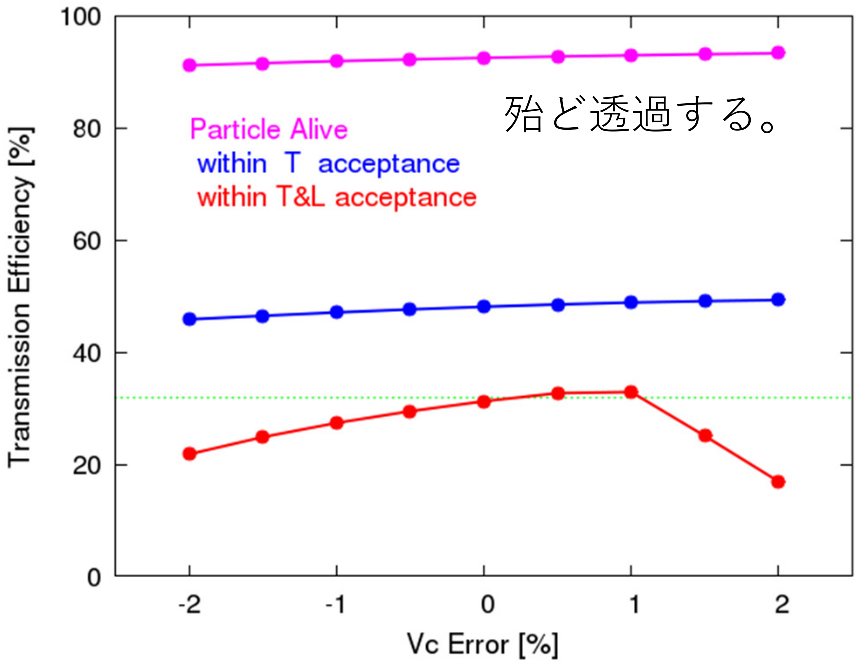
デザインの違いは、RF 周波数の違いによるビーム軸方向の許容値から来る。

E-driven PS



電磁石の磁場誤差や軌道誤差に弱い。

Undulator PS

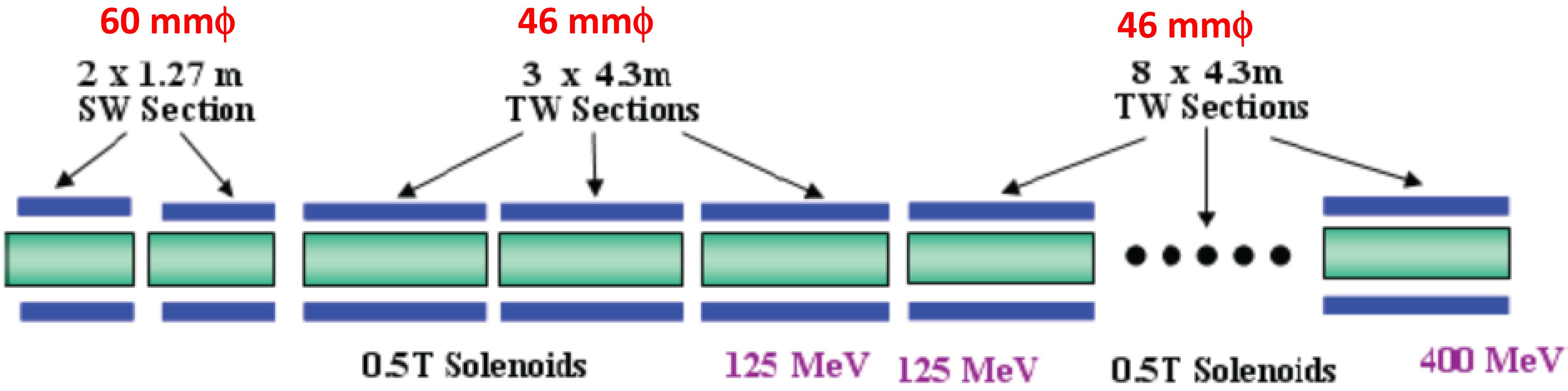


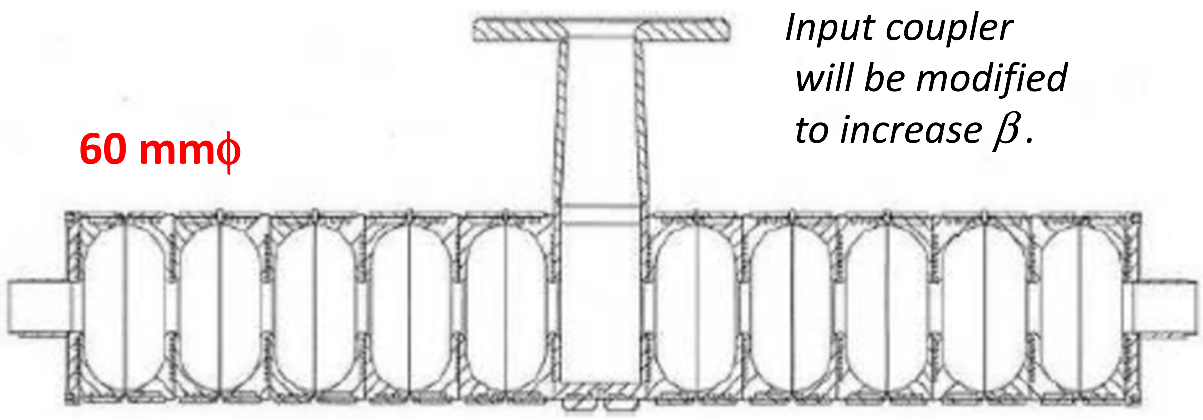
電磁石の磁場誤差や軌道誤差に強い。

加速管に当たらないように、
上流でコリメートする。

Requirement of Capture Section

Capture Section for ILC undulator PS





回転ターゲットの方法

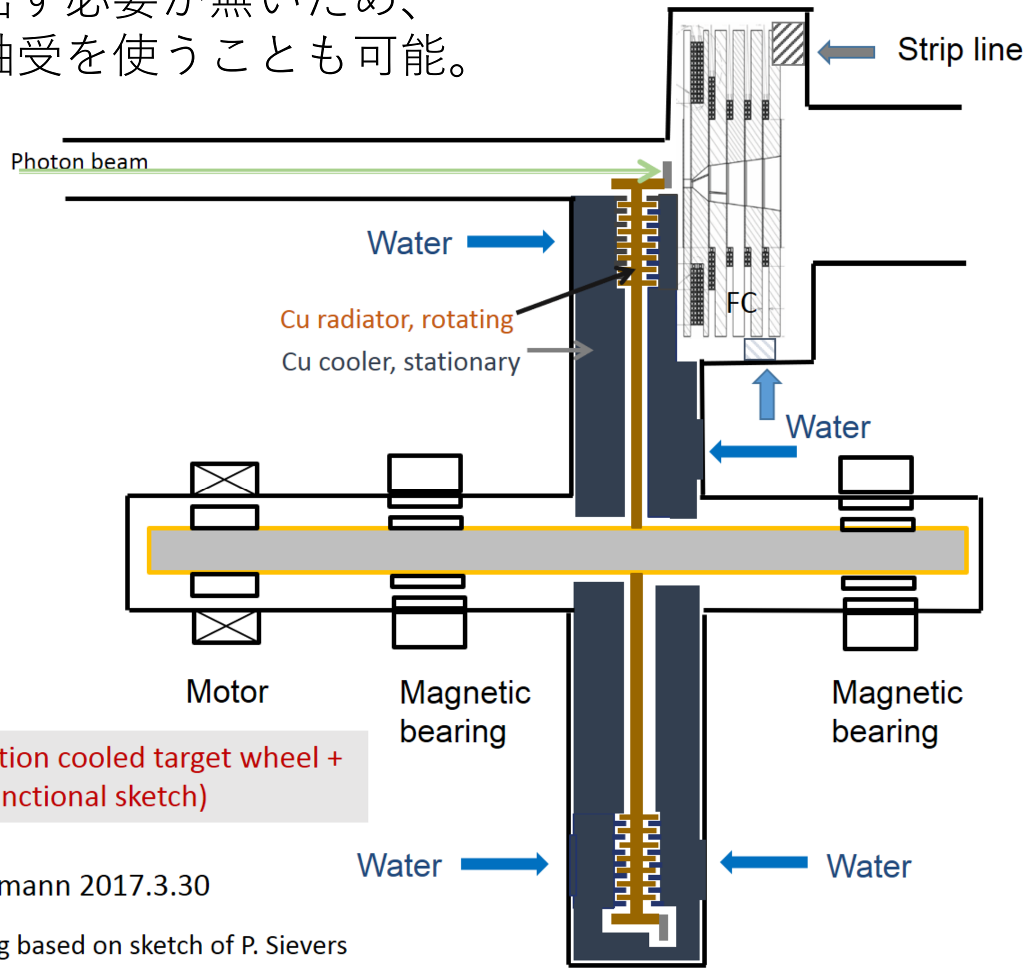
	アンジュレーター方式	電子駆動方式
ターゲットの材質	Ti6Al4V	W-Re
ターゲットの重量	25kg (7mm厚) 50kg (14mm厚)	100kg (中心部は Cu)
ターゲットの発熱量	**2-5kW**	**16-32kW**
ターゲットの回転数	2000rpm	200rpm
ターゲットの冷却方式	発熱量が少ないので、 放射冷却が可能	発熱量が多いので、 外部から冷却水を入れる必要有
	磁気浮上方式も可能。	**磁性流体シールを使う。**
	磁気浮上ベアリングでは 10000回転未満は低速	SLC では採用見送り LLNL の試験は不調

磁気浮上ベアリングを使う際にはターゲットの回転速度は問題では無い。

現在のターゲット設計

ターゲットの軸に冷却水を通すため、軸を真空の外に出す必要により
磁性流体シール軸受を想定していたが、アンジュレーター式では、
発熱量が 1-5kW と低いので、放射冷却でのターゲット冷却が可能。

放射冷却を利用すれば、
軸受を真空外に出す必要が無いため、
軸受は磁気浮上軸受を使うことも可能。



Radiation cooled target wheel + FC (functional sketch)

S.Riemann 2017.3.30

Drawing based on sketch of P. Sievers

磁気浮上軸受の実例

Magnetic bearing feature

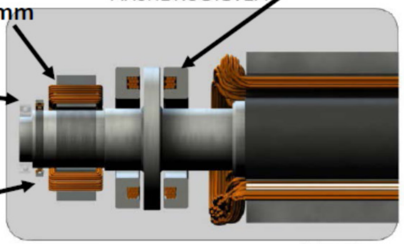
- Payload capacity
  - **Magnetic bearings can support a heavy rotor.**
  - Ex. 9 MW gas turbine
    - Speed: 6090 r/min
    - **Total rotor weight: 10 tons**
    - Total rotor length: 10 m
- Vacuum
  - **Oil free:** No lube oil system
  - **Vacuum sealing is simple.** Magnetic bearings and a motor can be hermetically sealed.
- High rotation speed
  - ex. Fermi chopper： Up to 600Hz.

The magnetic bearing is made of electromagnets which is attached to the rotor.
The bearing is contactless with a radial clearance of 0.5 to 1mm.

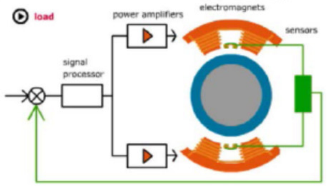
<u>Radial bearing</u>
- At least two bearings are needed.
- **Radial clearance: 0.5 – 1.0mm**

<u>Thrust bearing</u>

<u>Touch down bearing</u>
- Oil-free ball bearing
- **The clearance is a half of that of the radial bearing to prevent the rotor touching sensors or magnets**



<u>Position sensor</u>
- The rotor position is measured and controlled by position sensors.
- **At least five sensors are needed to measure the position and the slope of the rotor.**
  (Two radial position(H,V) in two place, the axial position)



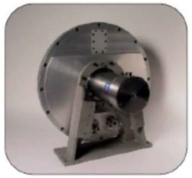
M. Fukuda, LCWS17

Magnetic bearing applications

The neutron choppers are used in various laboratories.
It is the most similar application to the positron rotating target.

Neutron chopper
- Payload capacity of 45 kg
- Operation up to 300 Hz (18,000 rpm)

g5 Systems
Disk Choppers (0-300Hz): 10
Spare Controllers: 16



g3 Systems
Disk Choppers (0-300Hz): 62

SKF global installations bring experience

100+ neutron choppers delivered and operational

S2M magnetic bearings are used in Neutron choppers of J-Parc.

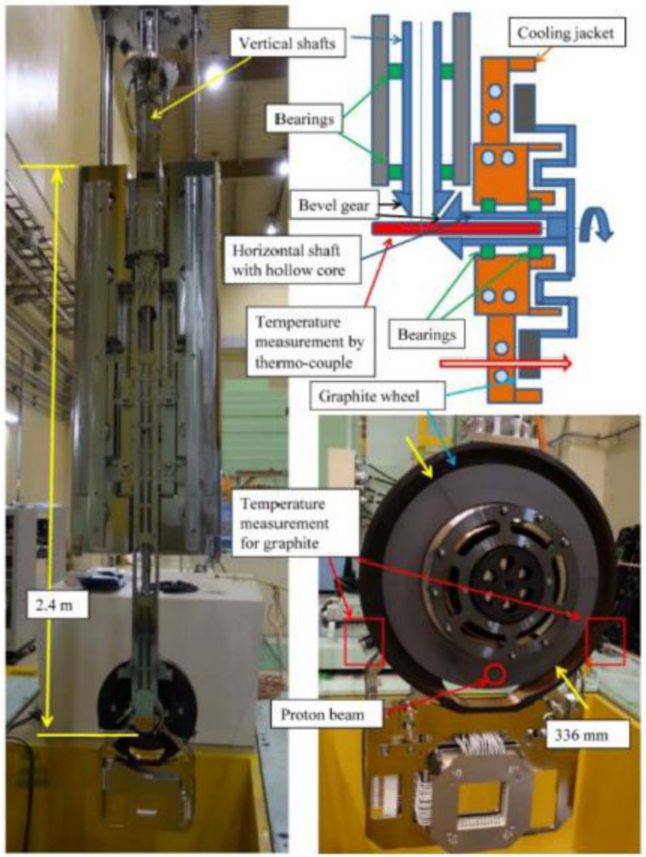
軸浮上軸受を使った製品を多数出荷している日本SKFと、打ち合わせをおこなった結果、仕様に問題ないとの見解を貰った。

実際に、タイプは違うが、磁気浮上軸受の中性子チョッパーを使っているJ-PARCのビームライン担当者と話した結果、ノーメンテで長期間放射線環境下での使用に耐えているとのこと。

Y. Morikawa, LCWS17

放射冷却の実例

J-PARC ミューオンターゲット
（ターゲット物質：カーボングラファイト）



- S Makimura et.al., J Radioanal Nucl Chem (2015) 305:811–815
- KEK proceeding 2014-5

- Heat load: **4kW**@1MW proton beam
  ⇒**Max temperature of graphite:620℃**@1MW
- Material: Isotopic Graphite(IG-430U:toyo-tanso)
- Disk Size: ϕ330mm × t20mm
- Proton beam : 16mm(2σ)

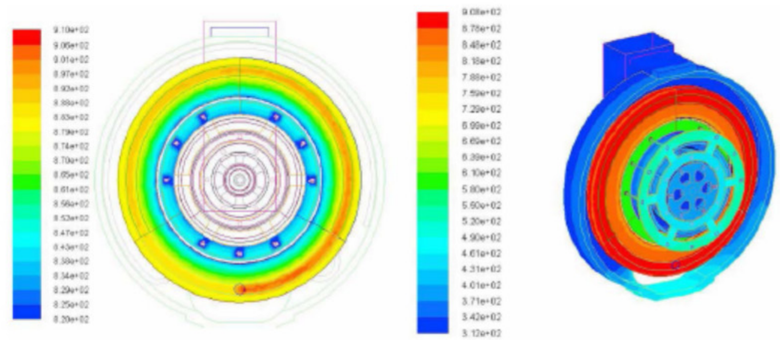


Fig. 2 The temperature distributions of the equilibrium condition obtained by the FEM

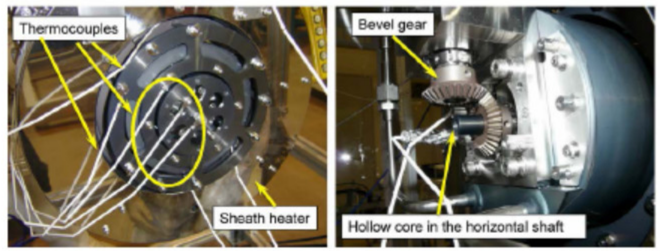
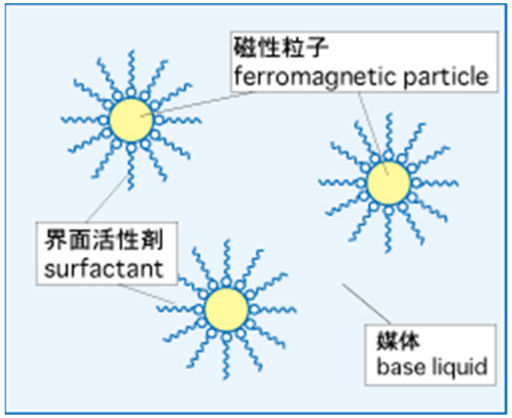


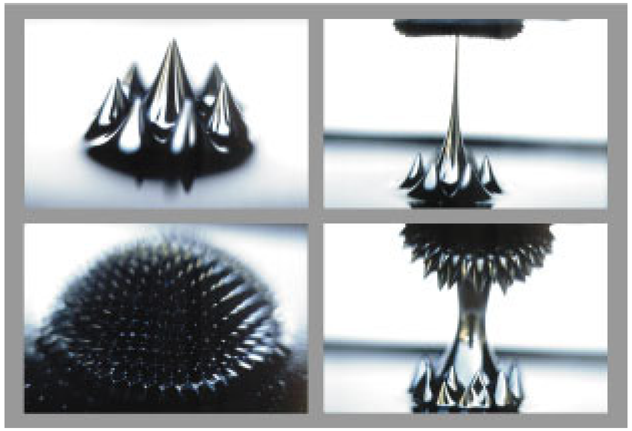
Fig. 3 Pictures of the mock-up. On the *left*, the picture of the heater, and several thermocouples attached to the rotating body. On the *right*, the picture of the bevel gears and the horizontal shaft with a hollow core for the thermocouples

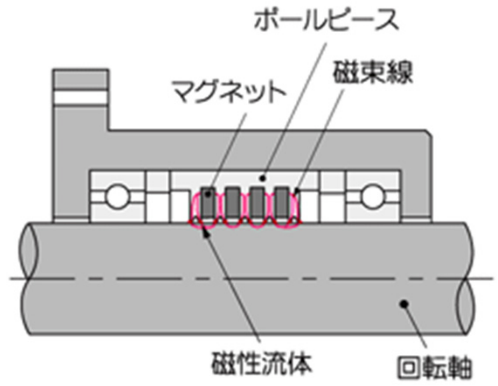
S Makimura et.al., J Radioanal Nucl Chem (2015) 305:811–815

J-PARCの標的の専門家と何度か議論したが、冷却できる能力としては1-5kW は問題が無いとのこと、ターゲット物質の違いの影響などは工夫次第で解決でき、本質的な問題になるようなものでは無いとの見解だった。

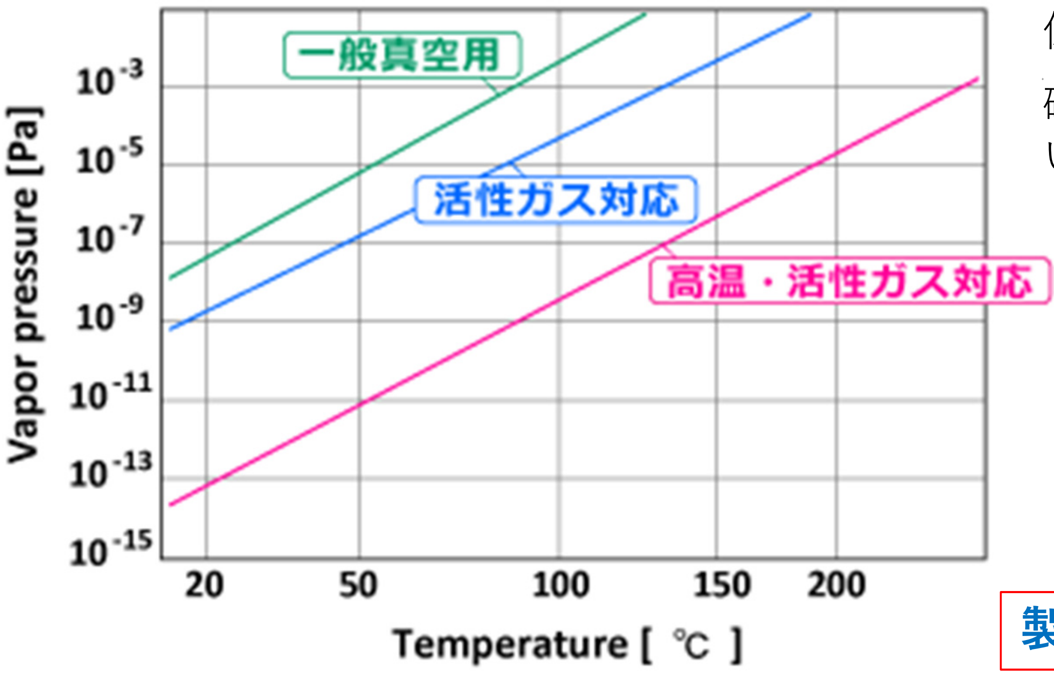
磁性流体シールとは







磁性流体はマグ ネタイトや複合フェライトなどの強磁性超微粒子、界面活性剤、水や油などのベース液の3つの成分から構成されています。（理学HPより）



蒸気圧曲線は磁気シールの動作や寿命を保証するものではありません。

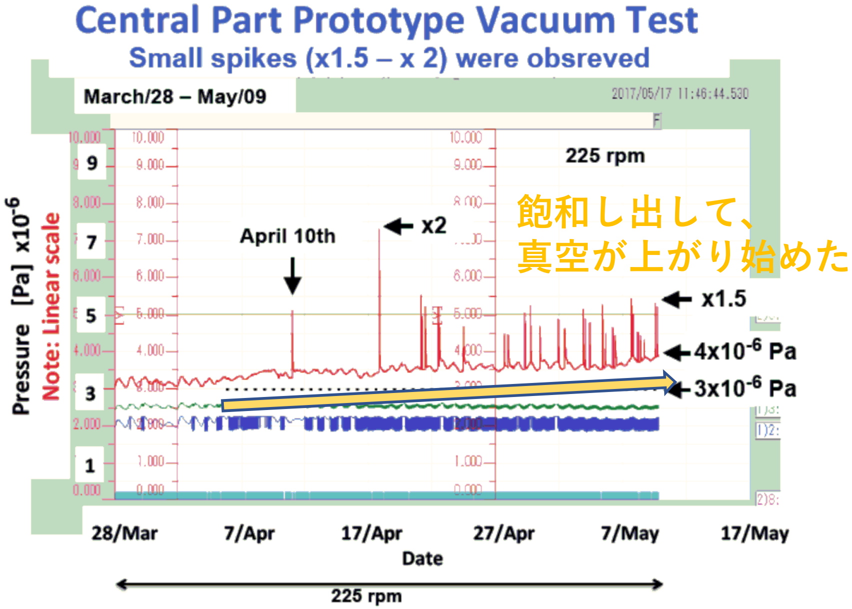
磁性流体の飽和蒸気圧よりも2桁程度高い圧力でのご使用を推奨します。
（理学HPより）

アルキルナフタレン系シールの理学推奨の使用限界真空度

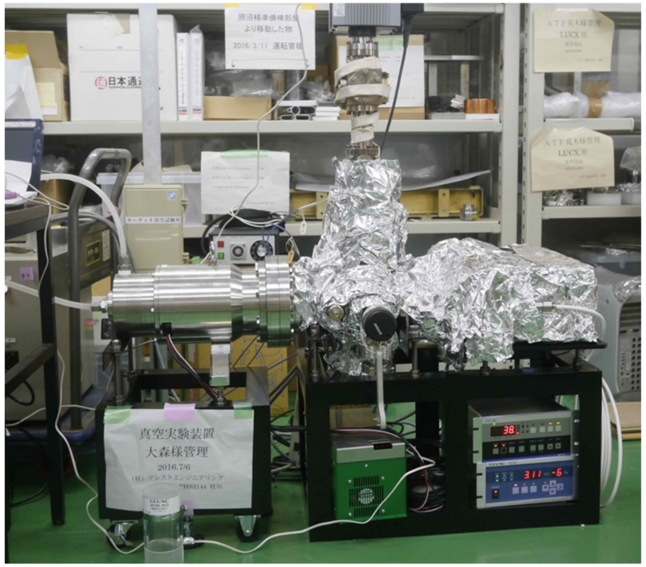
20℃：2×10^{-7} Pa
50℃：1×10^{-5} Pa
100℃：3×10^{-3} Pa

製品仕様がILCの使用環境ギリギリ。

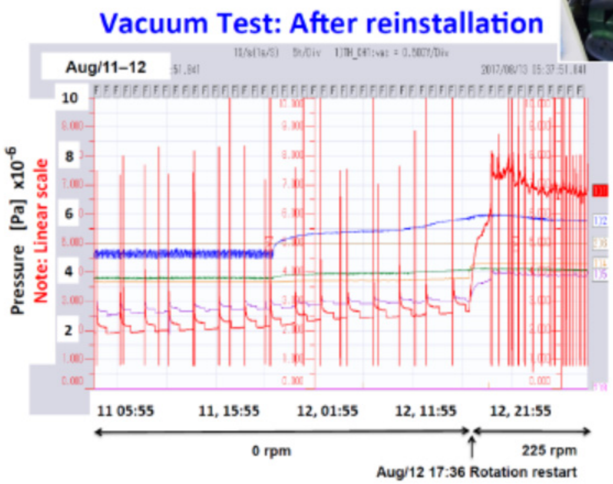
軸受の真空試験の結果



既製品の軸のみで真空が達するか試験した



その後、
シール材を入れ替えて再試験



実際の使用環境は軸に荷重がかかり、
軸中に冷却水が入るので、
それに伴う振動、温度上昇が予想される。

飽和蒸気圧の温度依存性は激しいので、
実際は、この試験よりも更に厳しい
環境で使用することになる。
（必要条件であるが、充分条件では無い）

ターゲット回転方式のまとめ

磁気浮上ベアリング方式を使う場合

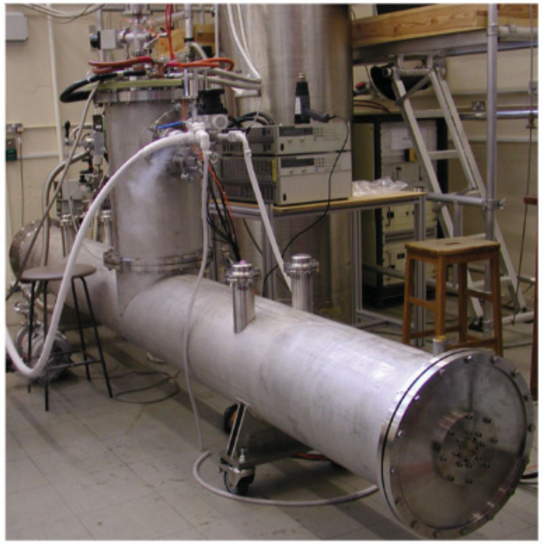
アンジュレーター方式の陽電子源
この方式では回転数は問題にならない。
不純物フリーの環境で使用できる。
放射線環境や高温環境150度以下の環境での実績も豊富。

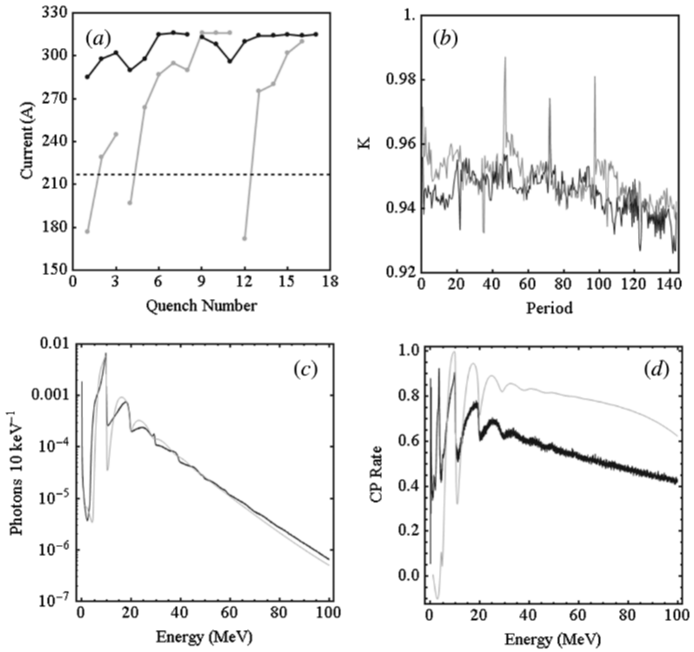
磁性流体シールで真空を封鎖する場合

電子駆動式の陽電子源
高真空用のフッ素系のシールがあるが放射線劣化が激しい。
CH系のシールは放射線劣化に強いが、飽和蒸気圧が低く、超高真空に向かない。
回転数が上がる影響は摩擦による軸の温度上昇で、飽和蒸気圧に伴う2次的なもの。
試験の結果、真空度の上昇が度重なり観測された。
蒸気圧の影響は真空度だけでなく、CH系の潤滑材(油)が揮発する可能性がある。
陽電子捕獲空洞への影響が無いかは trivial ではない。

Data of Daresbury SC Helical Undulator

PHYSICAL REVIEW LETTERS **107** (2011) 174803





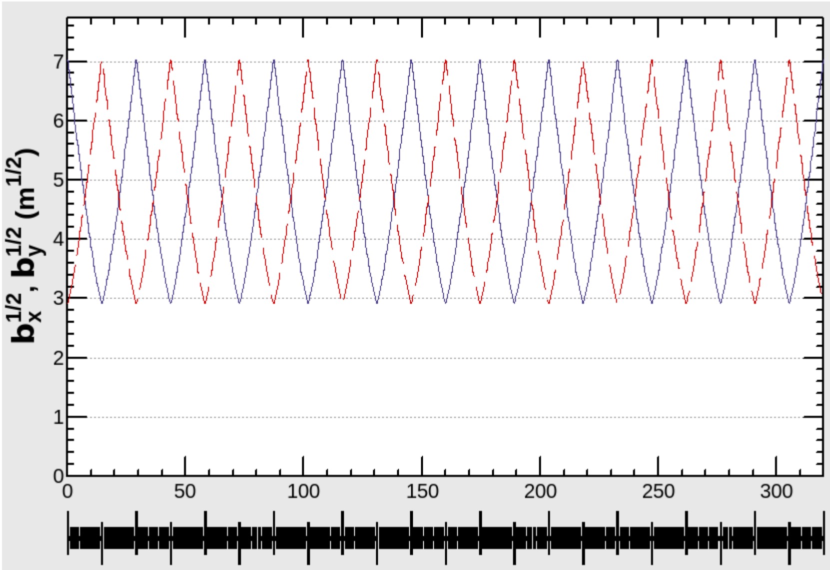
Integrated field error

Parameter	I_x	I_y	J_x	J_y
M1, H1	-0.49 ± 0.32	-2.19 ± 0.47	-1777 ± 390	-1392 ± 440
M1, H2	-0.73 ± 0.27	-2.13 ± 0.14	-1950 ± 290	-1218 ± 260
M2, H1	0.01 ± 0.11	0.13 ± 0.02	297 ± 11	-1399 ± 90
M2, H2	-0.02 ± 0.07	-0.05 ± 0.13	22 ± 110	-1380 ± 74

For 125 GeV Electron Beam, the beam angle and position was changed by $5\ \mu\text{rad}$, $5\ \mu\text{m}$.

- *Both of 2 undulator were reached to K=0.92 (one of them is K > 1.15) .*
- *Number of photon, generated by the undulator was almost same to the ideal.*
- *Circular polarization was smaller than the ideal.*
- *Integrated field error for 1 undulator was large, it generate 5urad orbit kick for E=125GeV.*

Effect of the undulator field error



The orbit kicks of all undulators is assumed to be same level of the worse undulator.

Undulator field error

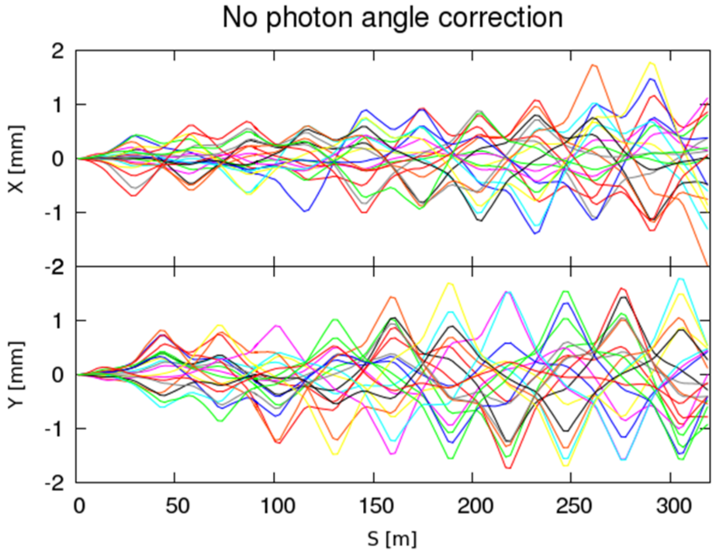
$$\sigma_{K_0} = 5\ \mu\text{rad}$$

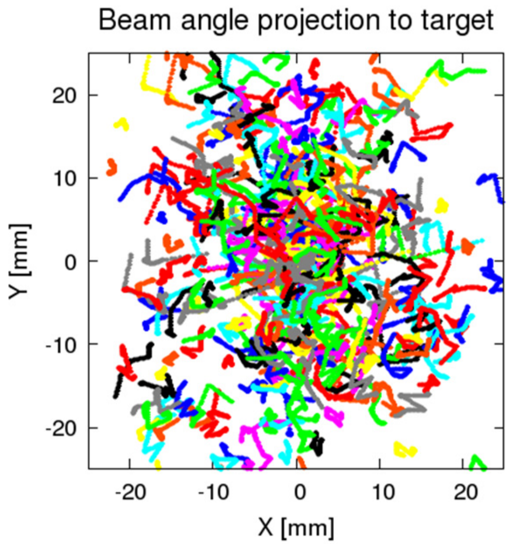
Random kick angle

put to all 132 undulators

No correction

Electron beam orbit and photon target position distribution (No correction, 20 random seed)





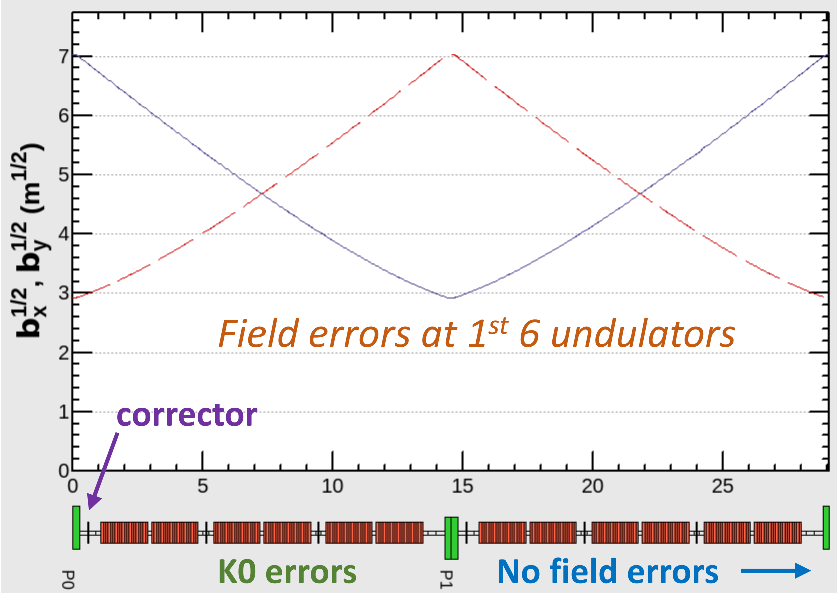
Procedure of undulator photon angle correction

Electron angle in undulator to target was corrected by centering the photon position at positron target.

The steering magnet was located each quadrupole (upstream of every 6 undulator).

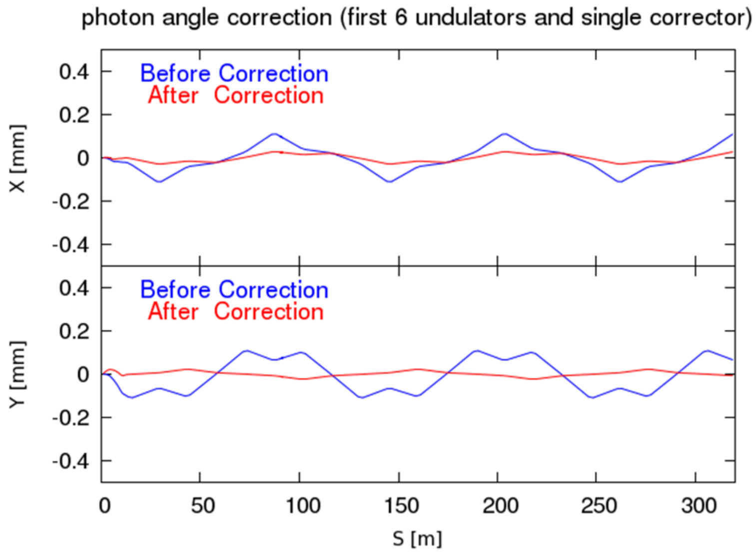
The procedure was applied every section of (undulators and corrector) set independently.
=> Then, applied to magnetic fields for all undulators.
The corrector fields will be applied appropriate strengths.

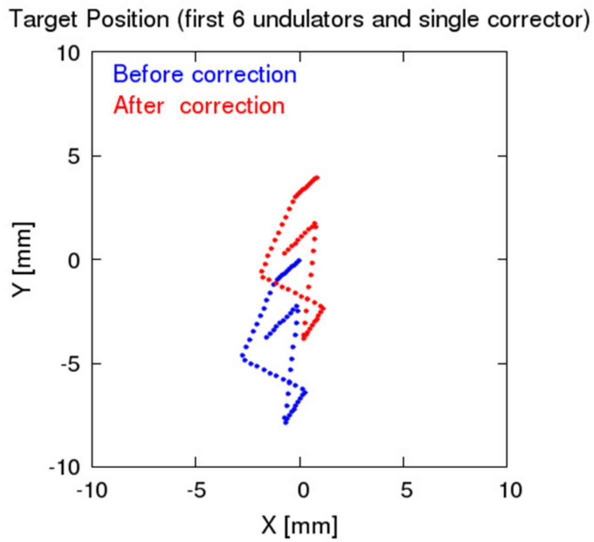
Normal tuning procedures for SR and FEL sources.



Example of 1-by-1 photon angle correction

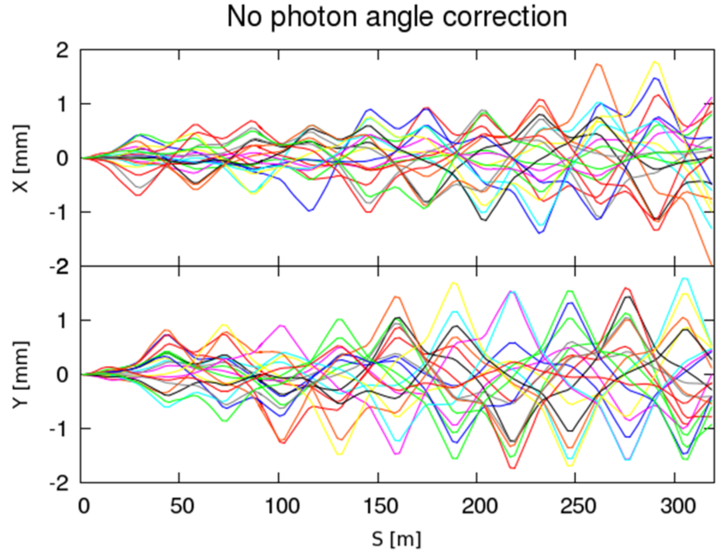
The kick angle error was only put first 6 undulator, and corrected by using single corrector.
When the photon target position was corrected, the beam orbit also reduced to be small.

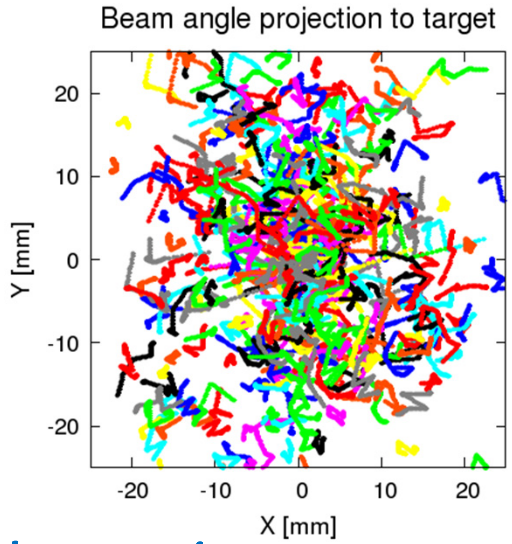




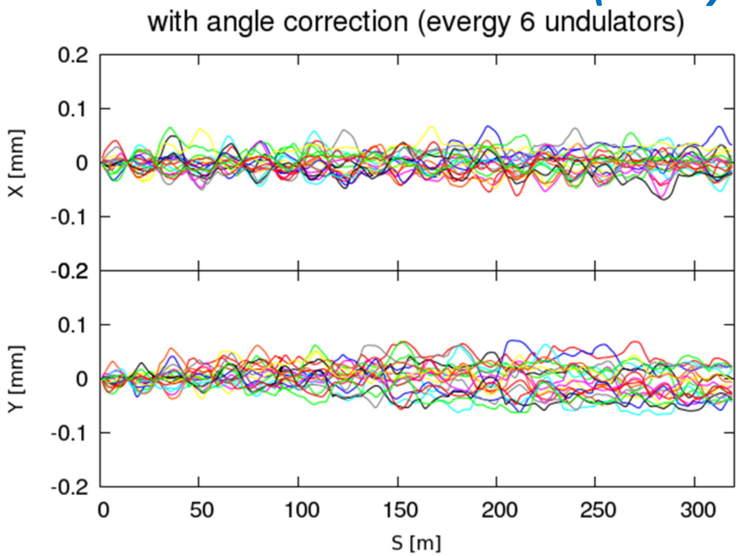
Apply the field errors to all undulators, and correction

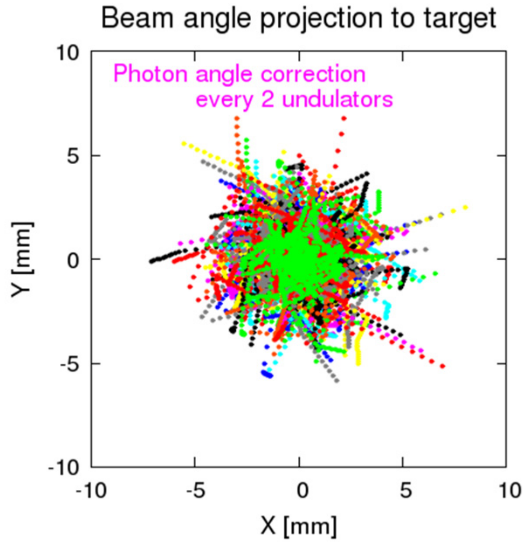
Not apply any correction





Results of the photon angle correction (every 6 undulators)



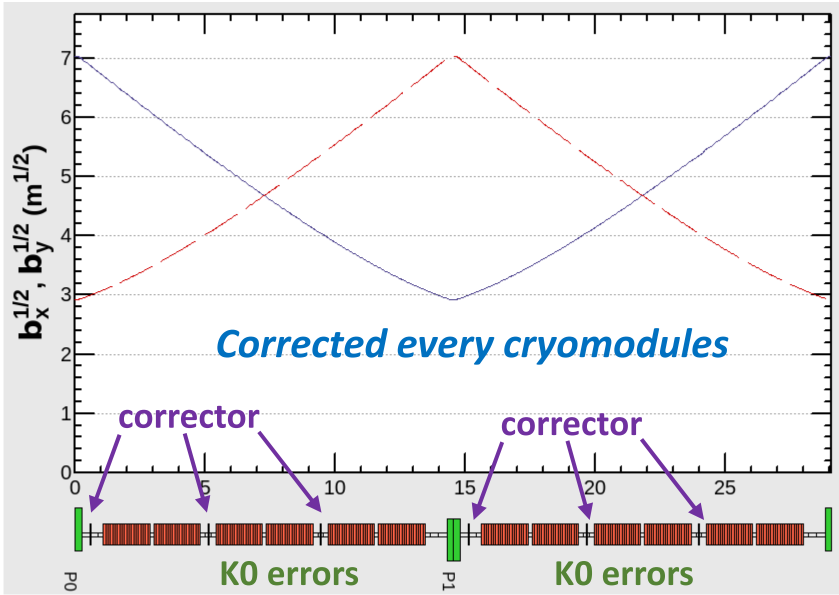


Application to each cryomodules (every 2 undulators)

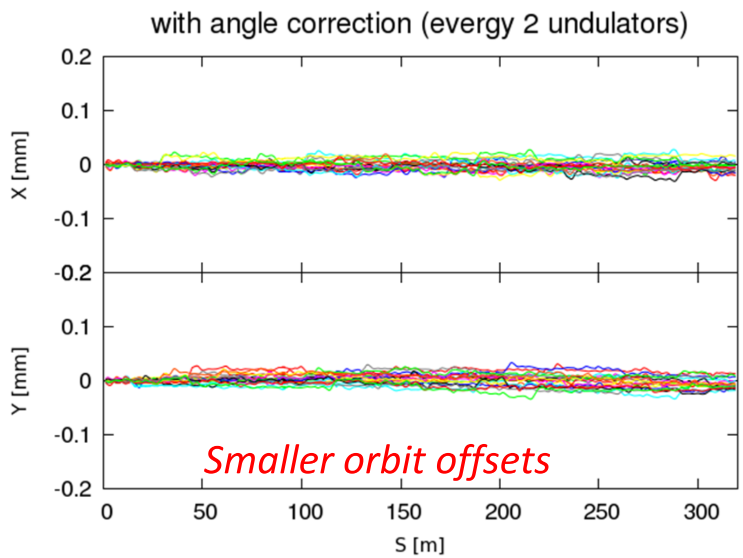
More precise correction can be applied by putting the steerings to every cryomodule.

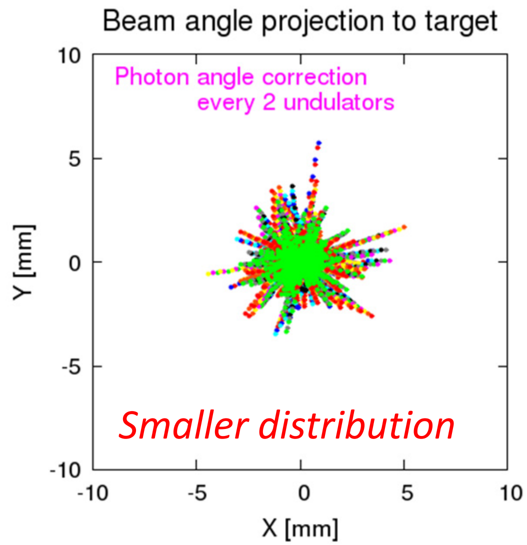
The distance between cryomodule is 20 cm. The required magnetic field for correctors is less than 100 gauss · m.

The strength is comparable to 6cm–long ATF air-cooling steering magnets.



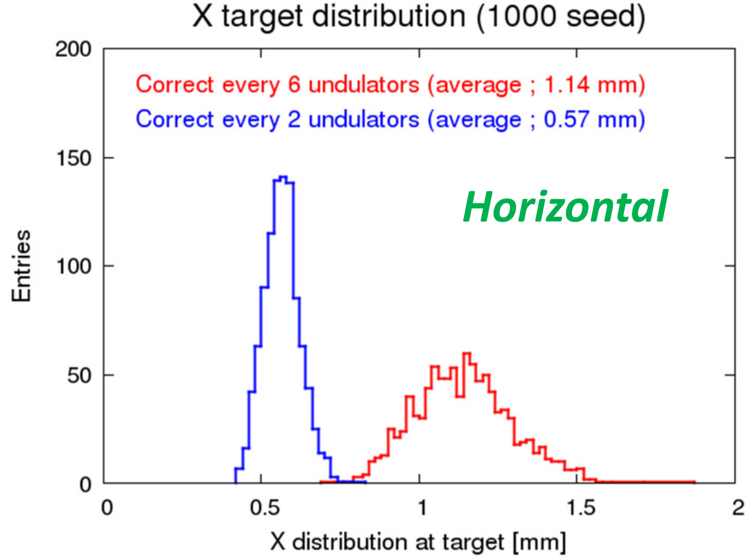
Results of the photon angle correction (every 2 undulators)

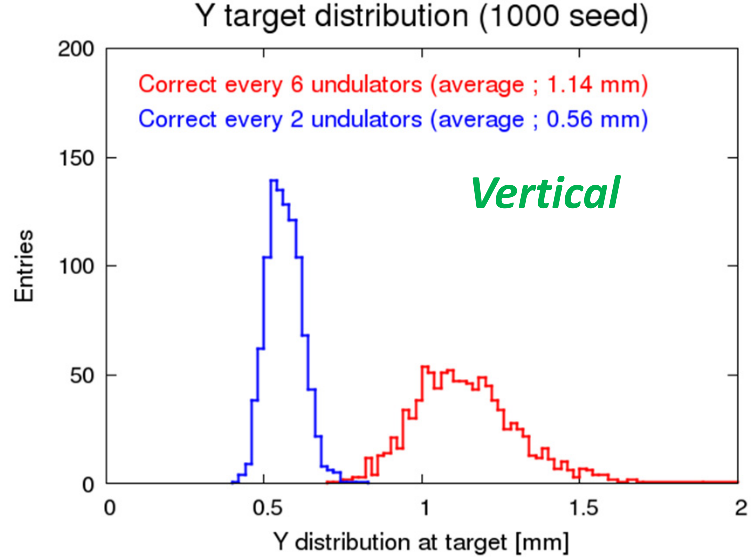




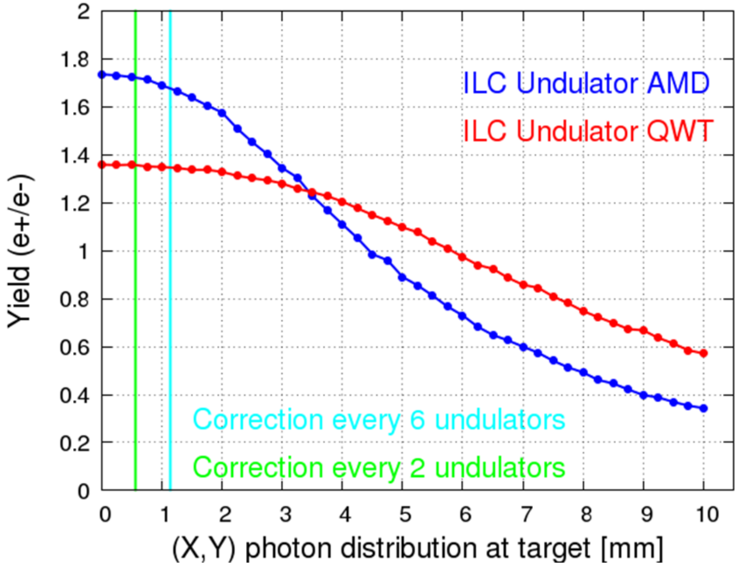
Effect of the positron generation yield

Electron angle at undulator to be extrapolated to target position
(10 source points in single undulator)





Photon deviation and positron yield



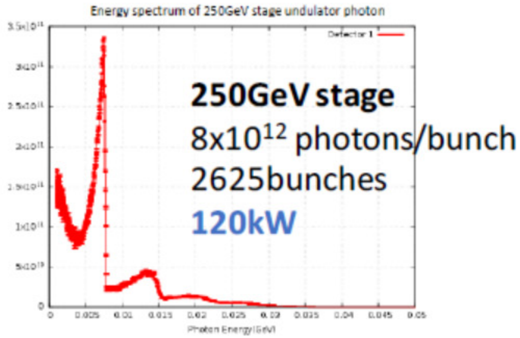
Tolerance of photon deviation at target is increased by changing from AMD to QWT.

By using normal 1-by-1 photon angle correction at every 6 undulator (each quadrupole), the positron yield is small effect even for the worse field error of Daresbury SC helical undulator.

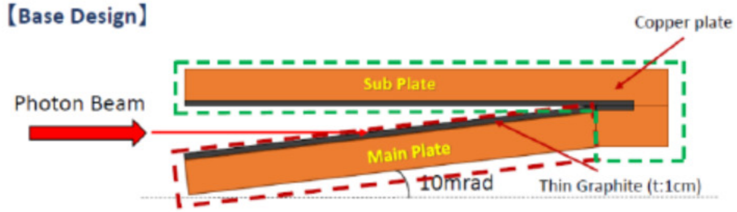
By applying the 1-by-1 photon angle correction at every 2 undulator (each cryomodule), The photon angle can be corrected higher precision.

グラファイトを使ったフォトンダンプ

LCWS2017, T. Morikawa



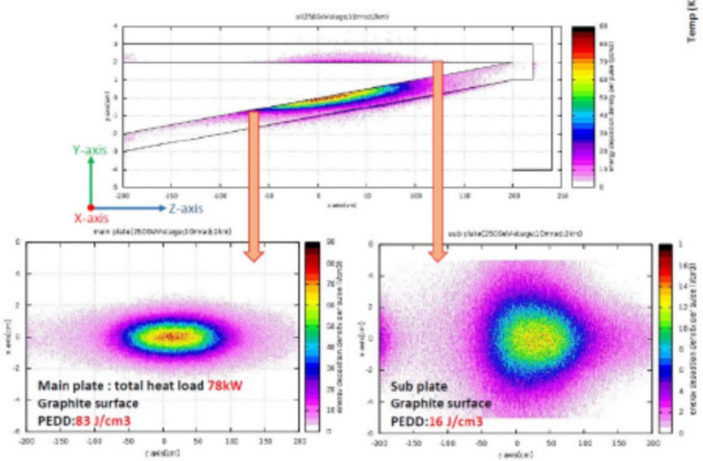
【Base Design】

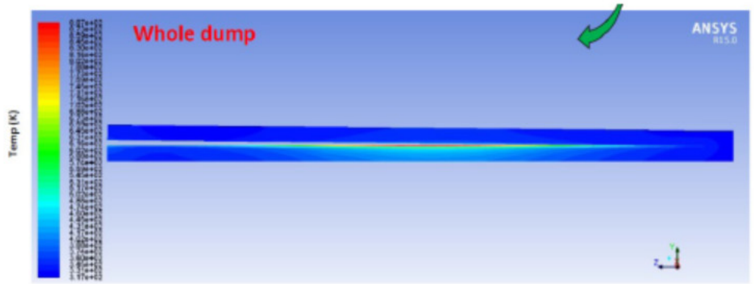


Main Plate : 78kW deposited (65% of total) ⇒ Primary Beam
Sub Plate : 42kW deposited (35% of total) ⇒ Secondary (scattered) Beam

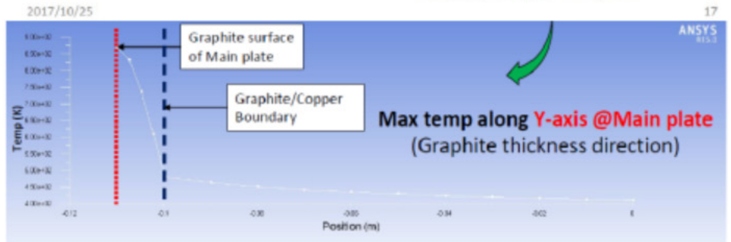
Cooling mechanism : Only cooling water in copper
No cooling, protection gas : No need to introducing the beam window

PEDD, ΔT





・Max temp for 250GeV-High lumi stage : 614℃(887K) @ Main plate
143℃(416K) @ Sub plate

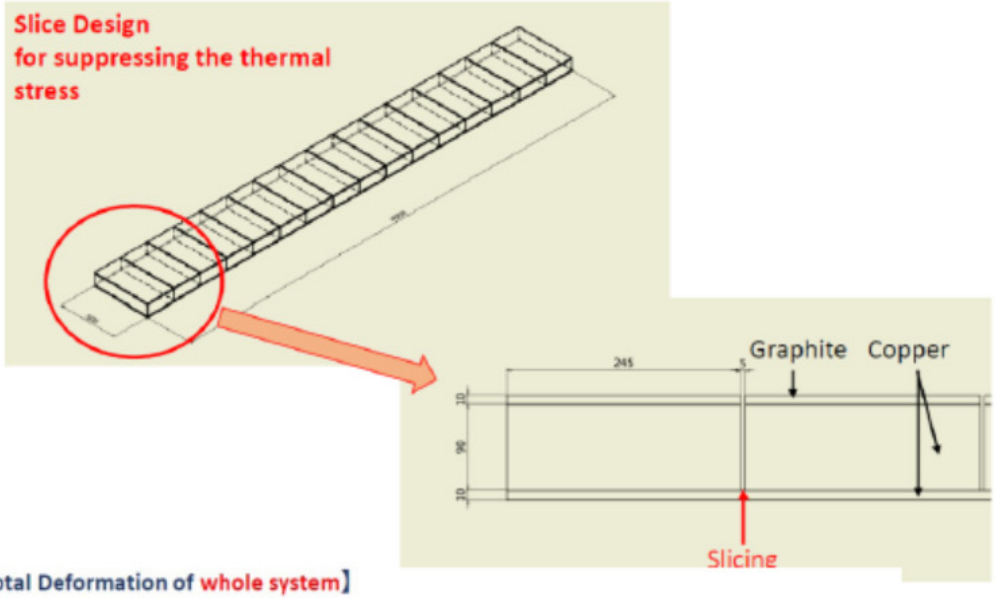


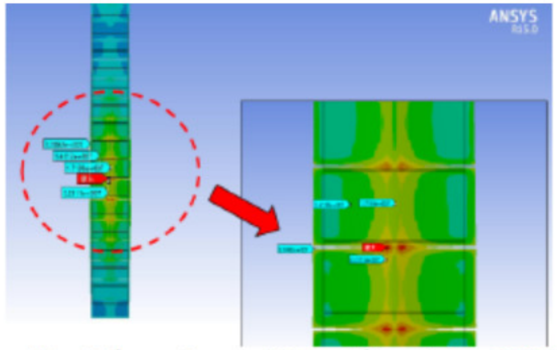
・The temp gradient in graphite is very high,
⇒Max temp strongly depends on graphite thermal conductivity.

（PEDD） 83J/(cm3/pulse) ⇒ ΔT=70℃/pulse
（DPA） 3.5E-9/pulse ⇒ 0.315@5000h operation
（Max Temp） 614℃ @ Graphite thermal conductivity : 20W/(Km)
1027℃ @ Graphite thermal conductivity : 10W/(Km) ⇒ back up slide

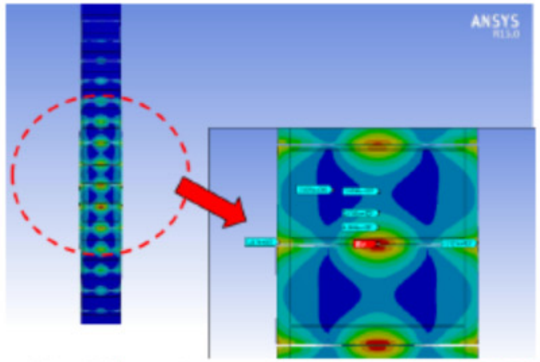
更なる最適化

LCWS2017, T. Morikawa





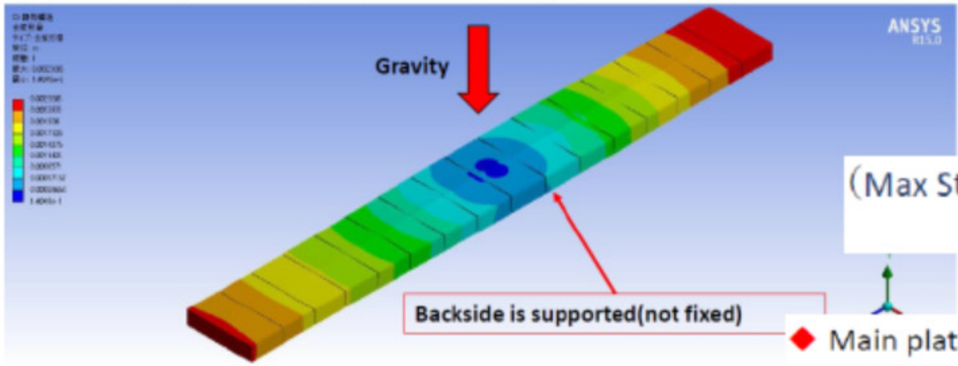
Max Von Mises stress of Graphite-plate : 30MPa



Max Von Mises stress of Copper-plate : 103MPa

【Total Deformation of whole system】

Deformation by thermal expansion. Include self weight



Main plate is expanded 2.5mm in longitudinal direction.

(Max Stress) Base design : Graphite : 25MPa , Copper : 148MPa
Slice design : Graphite : 30MPa , Copper : 103MPa

- Main plate expand 2.5mm and there is problem of thermal stress.
  ⇒ Next issue is to consider a structure that suppress the thermal stress.

グラファイト表面や冷却のための銅との界面での熱応力が限界に近い。
更なる最適化に向けて検討中（J-PARC 標的グループに相談に乗ってもらっている）