SKB IR upgrade

K. Aoki, Y. Arimoto, H. Koiso, A. Morita, N. Ohuchi, M. Tobiyama, M. Masuzawa

IR upgrade is just one of many items, such as

- Injector upgrade
- Injection efficiency improvement
- Emittance blowup suppression in the BT
- New BT line
- Injection stability
- Higher stored beam currents (additional RF)
- etc.

New IR preliminary evaluation

Presented at 9/14/2023 UWG

Confirmation of characteristics of the new IR with anti-solenoid and QC1P with Nb_3Sn

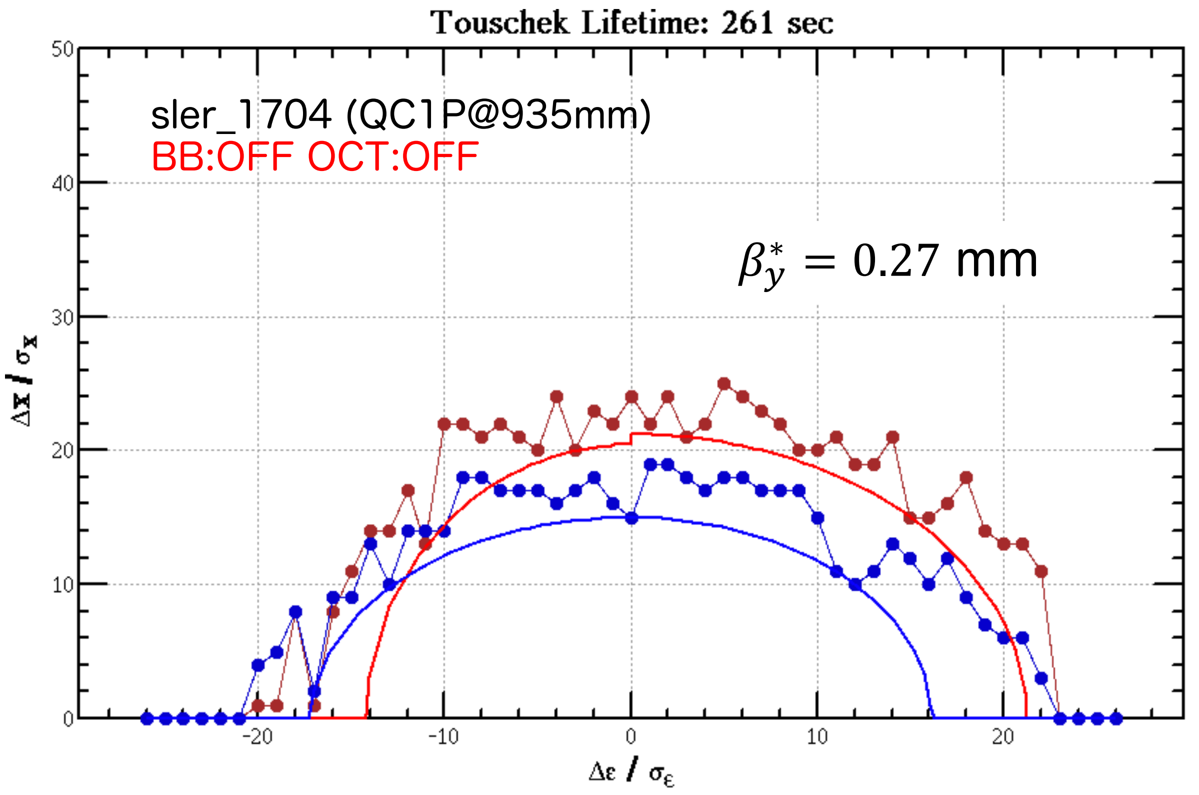
- Design concept
  - Separation of the solenoid field and QC1P
  - QC1P relocation, closer to the IP by ~100mm (from L*=935 mm to 835mm)

- Items to consider
  - Dynamic aperture, Touschek lifetime
  - Chromatic Coupling
  - Vertical emittance
  - Dispersion

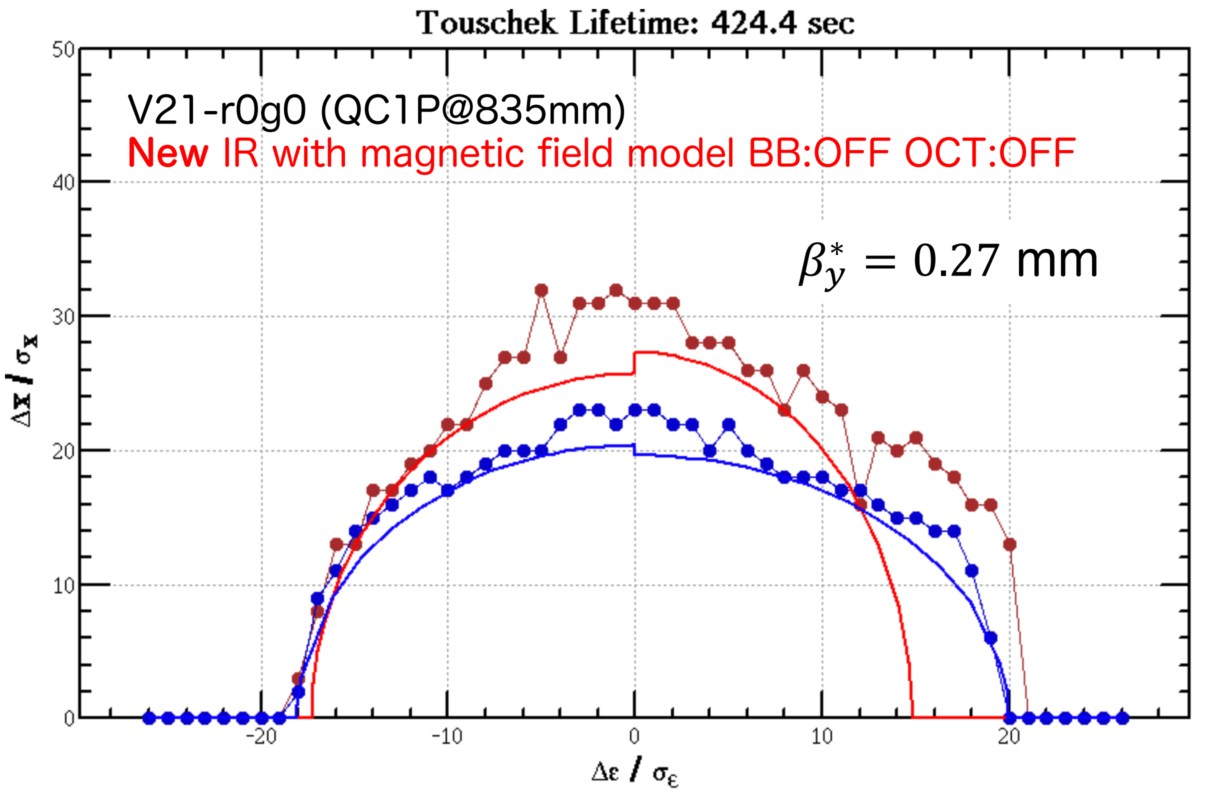
Can we make magnets with Nb_3Sn?

- Items to consider
  - Dynamic aperture, Touschek lifetime
  - Chromatic Coupling
  - Vertical emittance
  - Dispersion

Presented at 9/14/2023 UWG



a1: 14.2457 b1: 20.4588 a2: 21.2132 b2: 21.2132 (361.602 sec)
a1: 17.1532 b1: 15.0000 a2: 16.0997 b2: 15.0000 (204.130 sec)



a1: 17.3038 b1: 25.7583 a2: 14.7993 b2: 27.3386 (483.228 sec)
a1: 18.0871 b1: 20.4018 a2: 19.9531 b2: 19.6484 (378.334 sec)

- Items to consider
  - Dynamic aperture, Touschek lifetime
  - Chromatic Coupling
  - Vertical emittance
  - Dispersion

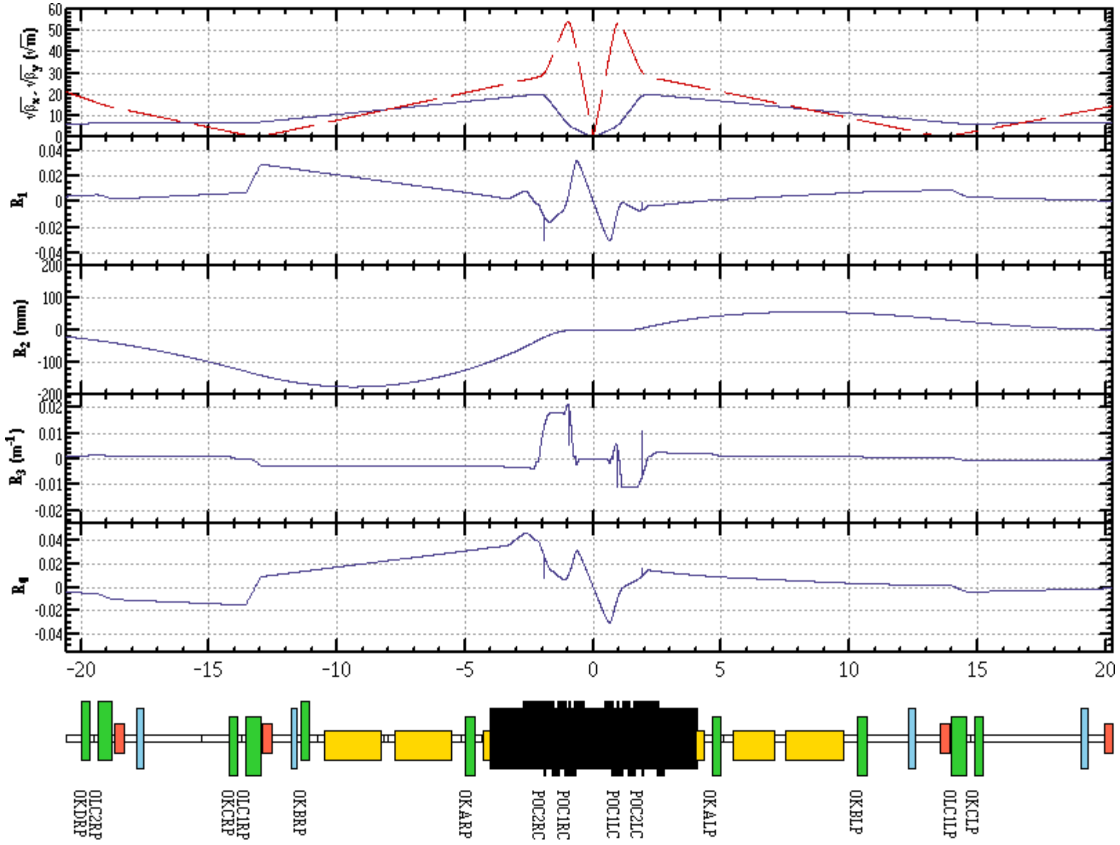
Presented at 9/14/2023 UWG

	Lattice	回転六極	∂R1/∂δ	∂R2/∂δ	∂R3/∂δ	∂R4/∂δ
935 mm	sler_1704	ON	-8.888×10^{-3}	$+4.012\times10^{-3}$	$-4.963\times10^{+1}$	+2.939
	sler_1704	OFF	-2.274	-1.011×10^{-2}	$-4.226\times10^{+2}$	$-6.058\times10^{+2}$
835 mm	V21-r0g0	ON	$+2.318\times10^{-5}$	-5.991×10^{-6}	-4.390×10^{-2}	$+5.509\times10^{-3}$
	V21-r0g0	OFF	$+1.059\times10^{-1}$	$+2.835\times10^{-4}$	+8.145	$+2.571\times10^{+1}$

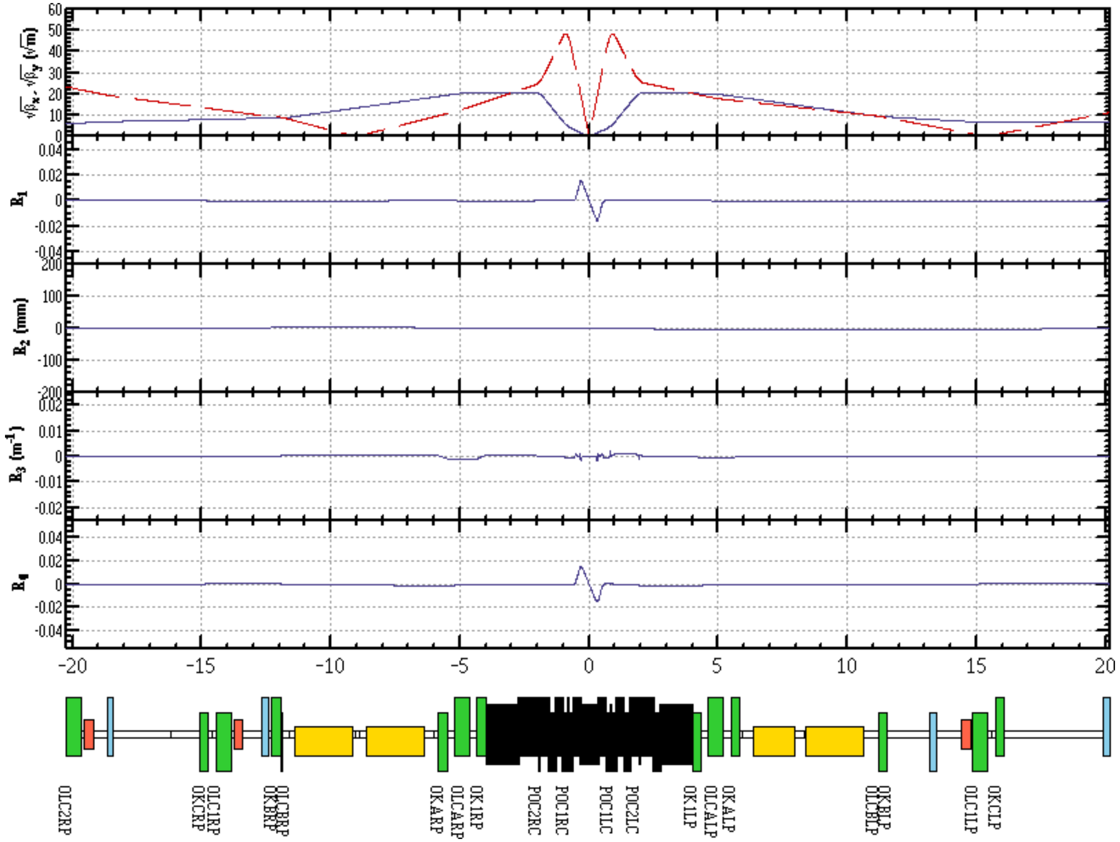
Chromatic coupling improves with new IR (QC1P@835mm)

- Items to consider
  - Dynamic aperture, Touschek lifetime
  - Chromatic Coupling
  - Vertical emittance
  - Dispersion

When set to the same scale



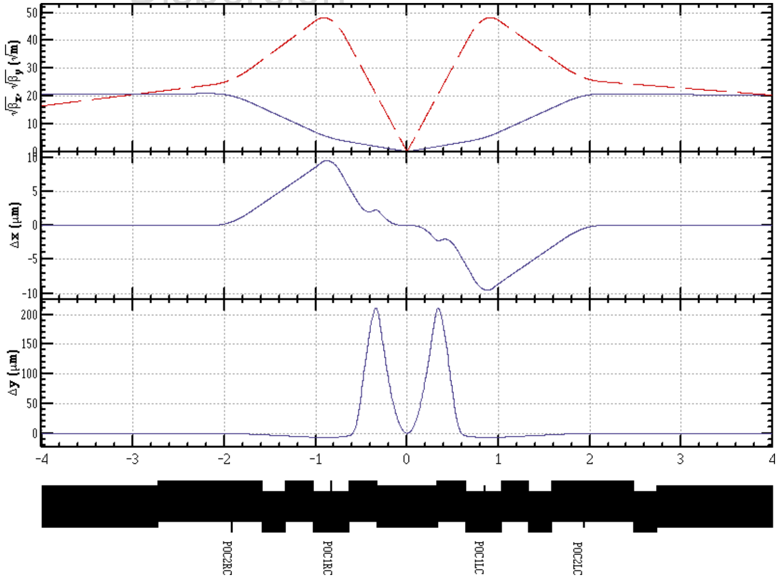
"sler_1704"
The current IR (design lattice)

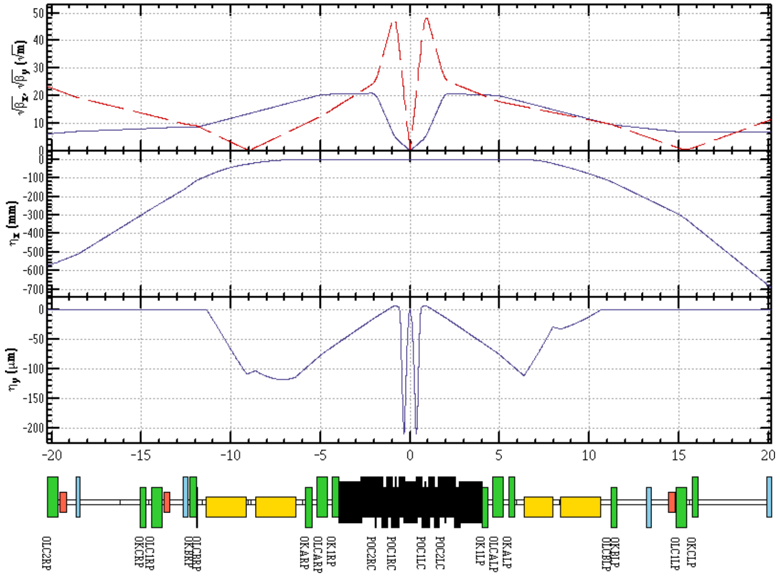


"V21-r0g0"
New IR

- Items to consider
  - Dynamic aperture, Touschek lifetime
  - Chromatic Coupling
  - Vertical emittance
  - Dispersion

Presented at 9/14/2023 UWG



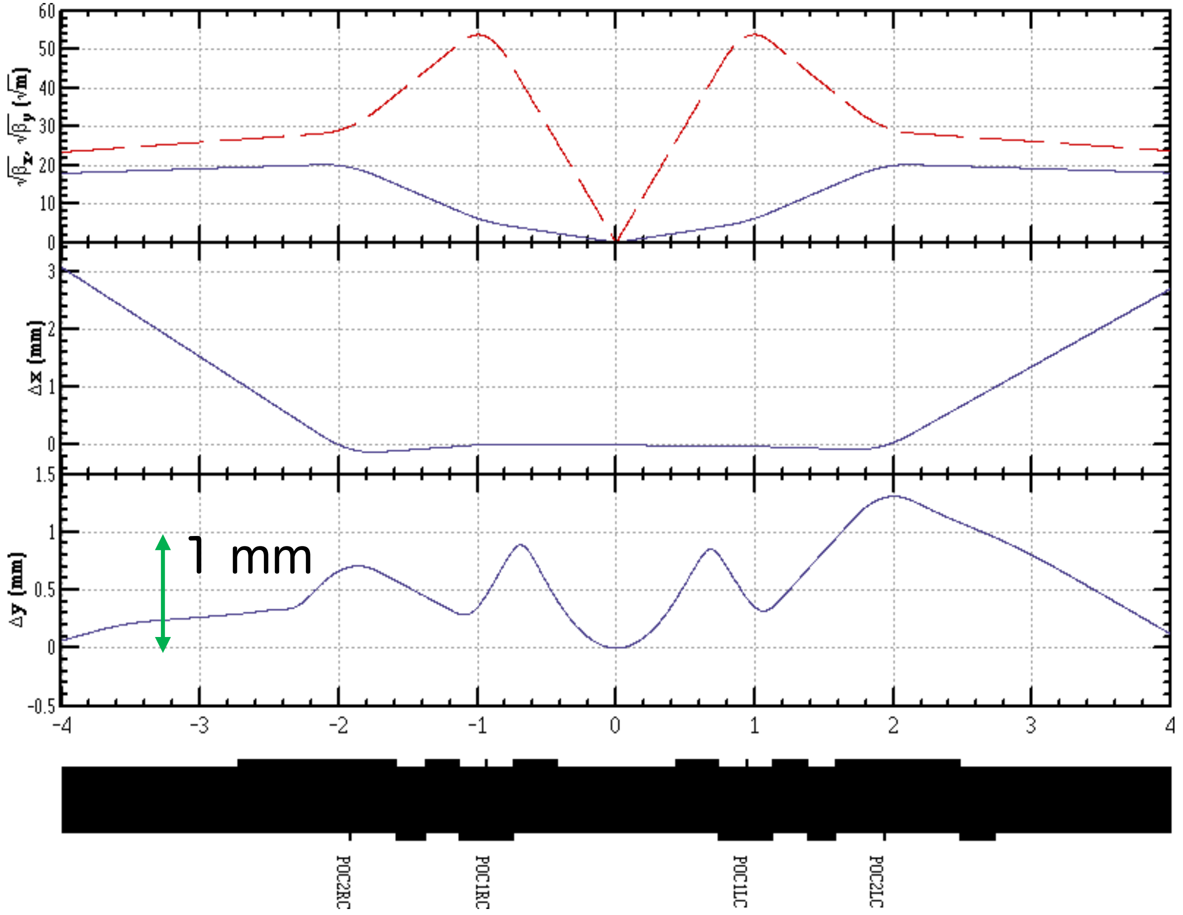


```
Design momentum       P0 = 4.0000000 GeV Revolution freq.      f0 = 99333.385 Hz
Energy loss per turn U0 = 1.7605072 MV  Effective voltage     Vc = 9.4123078 MV
Equilibrium position dz = 17.641387 mm  Momentum compact. alpha = 3.2061E-4
Orbit dilation          dl = 8.5922670 mm  Effective harmonic #  h = 5122.9481
Bucket height       dV/P0 =   .0256922

  Imag.tune: 0.0000000           0.0000000           0.0000000
  Real tune:-0.4669097          -0.4300851          -0.0245815

    Damping per one revolution:
        X : -2.200631E-04    Y : -2.200379E-04    Z : -4.399110E-04
    Damping time (sec):
        X :  4.574646E-02    Y :  4.575170E-02    Z :  2.288442E-02
    Tune shift due to radiation:
        X :  2.714858E-06    Y :  3.562791E-06    Z :  8.049892E-07
    Damping partition number:
        X :     1.0003       Y :     1.0002       Z :     1.9996

Emittance X          = 1.90575E-9 m   Emittance Y          = 1.1393E-14 m
Emittance Z          = 3.54412E-6 m   Energy spread        = 7.53011E-4
Bunch Length         = 4.70673080 mm  Beam tilt            = -4.8121E-9 rad
Beam size xi         =  .00780495 mm  Beam size eta        = 1.75297E-6 mm
```

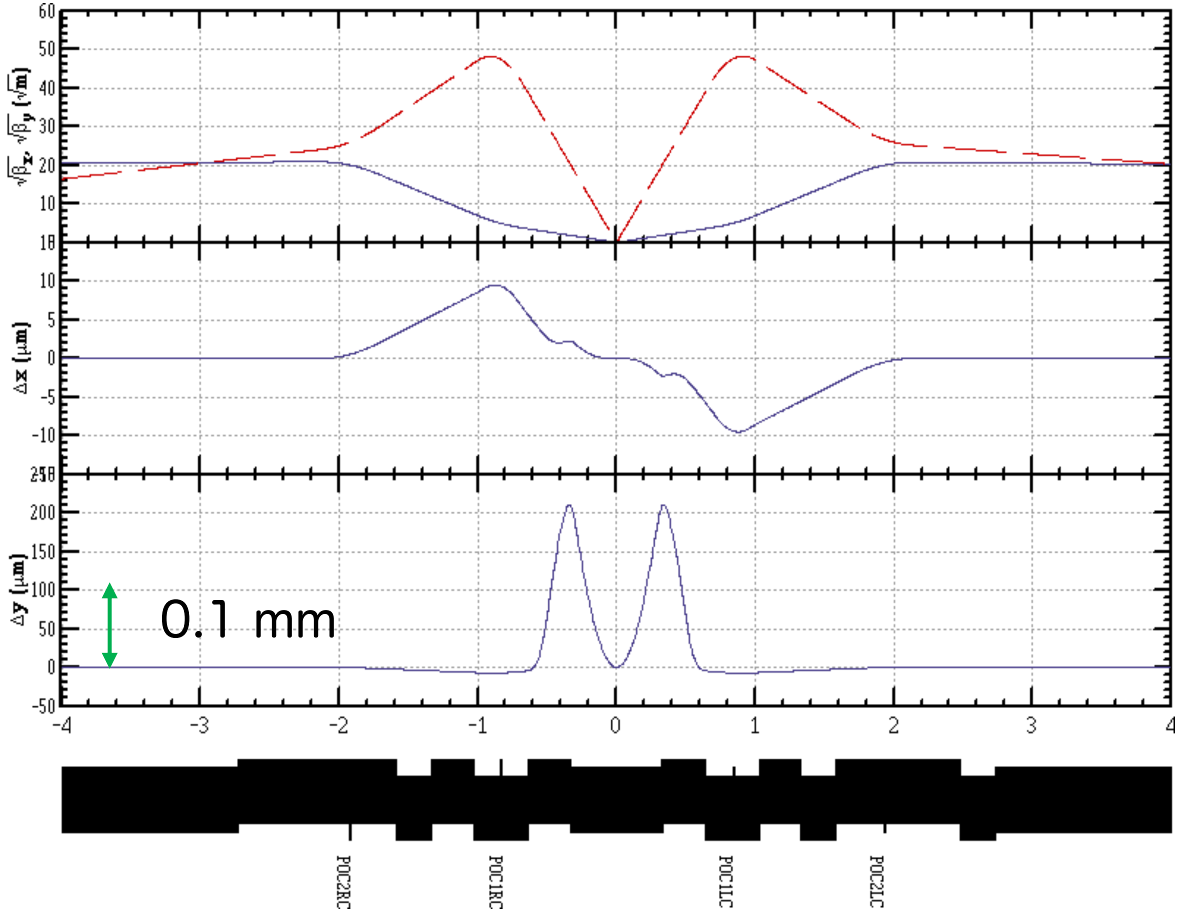
Contribution from
the new IR is several tens of femtometer

A. Morita

IR Orbit comparison



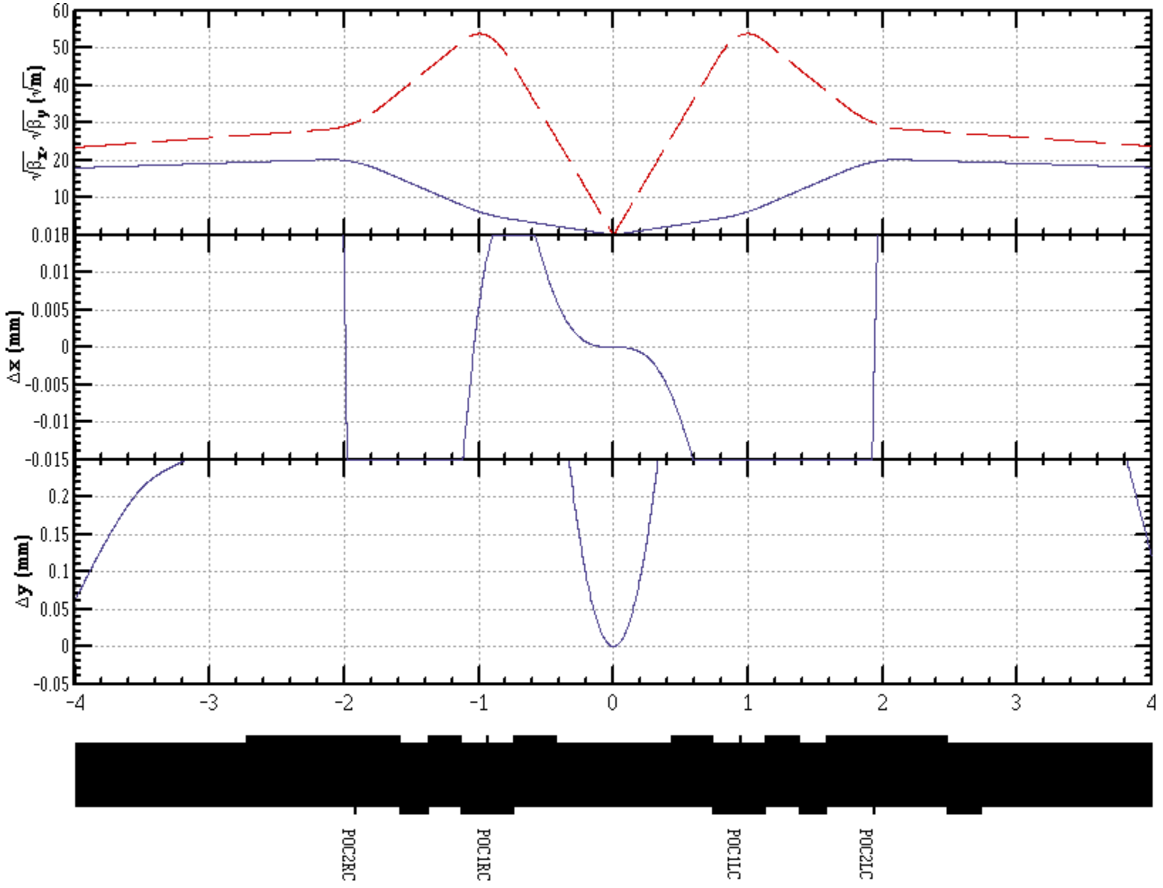
"sler_1704"
The current IR (design lattice)



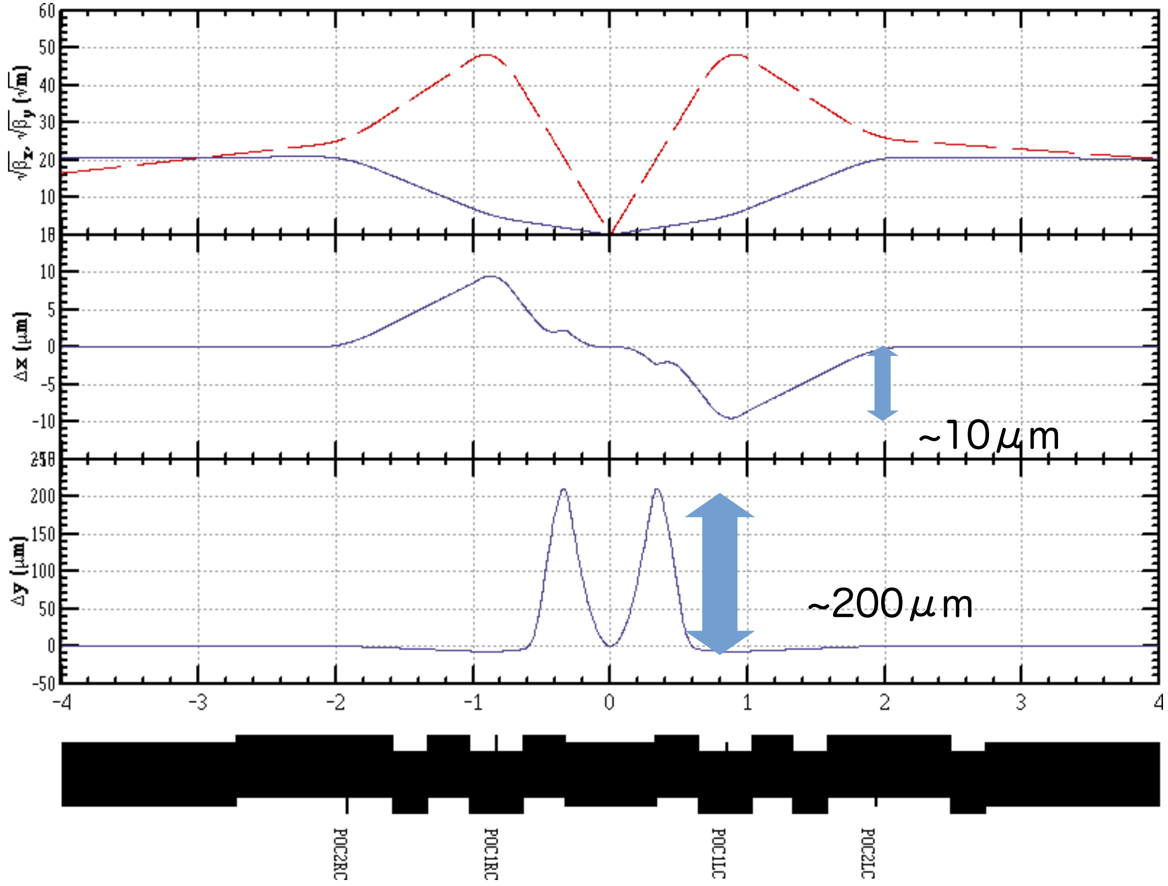
"V21-r0g0"
New IR

IR Orbit comparison

When set to the same scale



“sler_1704”
The current IR (design lattice)

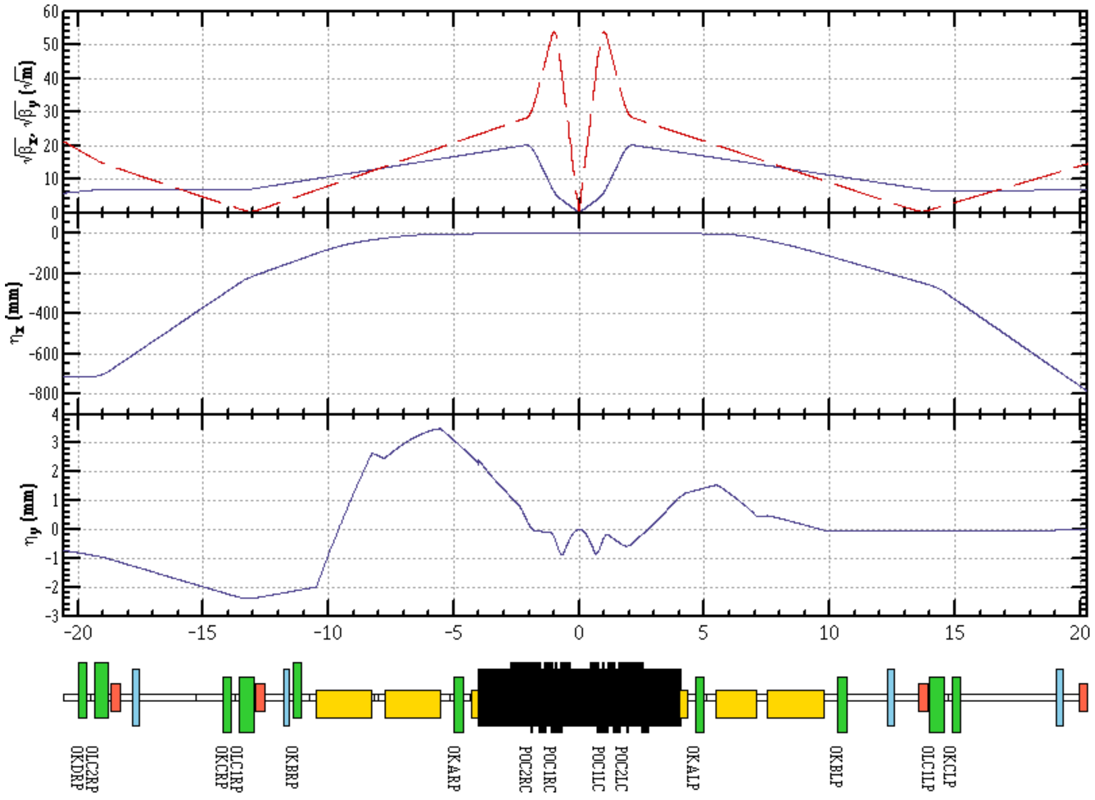


“V21-r0g0”
New IR

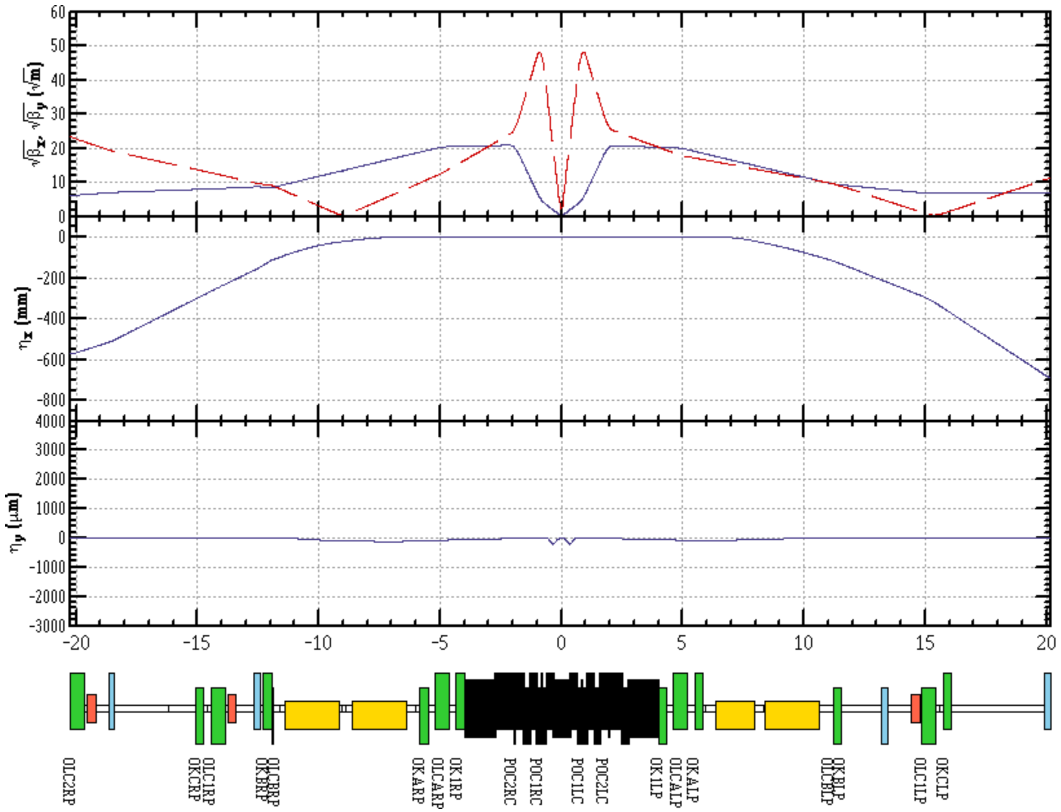
- Items to consider
  - Dynamic aperture, Touschek lifetime
  - Chromatic Coupling
  - Vertical emittance
  - Dispersion

IR dispersion comparison

When set to the same scale



“sler_1704”
The current IR (design lattice)



“V21-r0g0”
New IR

A. Morita

New IR preliminary evaluation

Confirmation of characteristics of the new IR with anti-solenoid and QC1P with Nb_3Sn

- Design concept
  - Separation of the solenoid field and QC1P
  - QC1P relocation, closer to the IP by ~100mm (from L*=935 mm to 835mm)

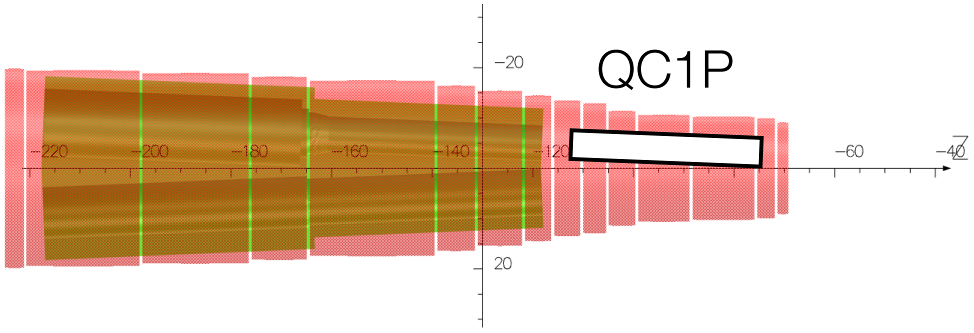
- Items to consider
  - Dynamic aperture, Touschek lifetime →improves
  - Chromatic Coupling →improves
  - Vertical emittance → becomes smaller
  - Dispersion becomes smaller

The obstacles/difficulties with luminosity tuning will be removed.

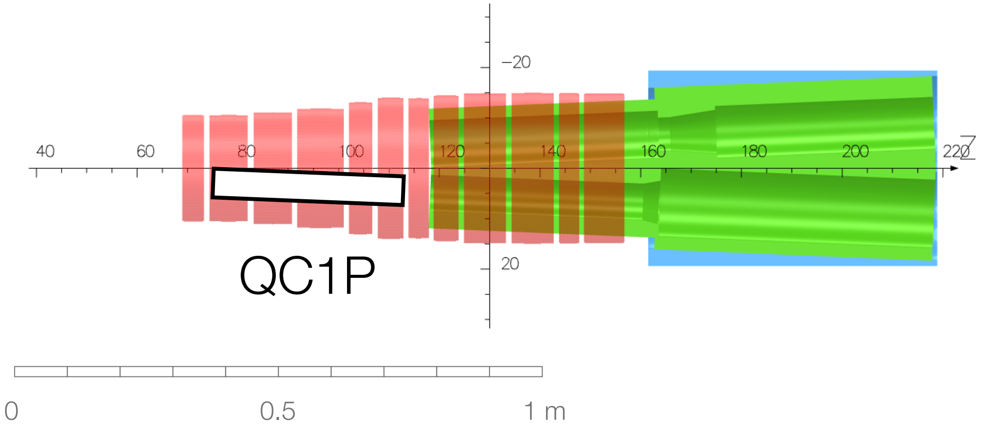
Can we make magnets so small/thin?
Hardware feasibility evaluation

Current ver.

Forward

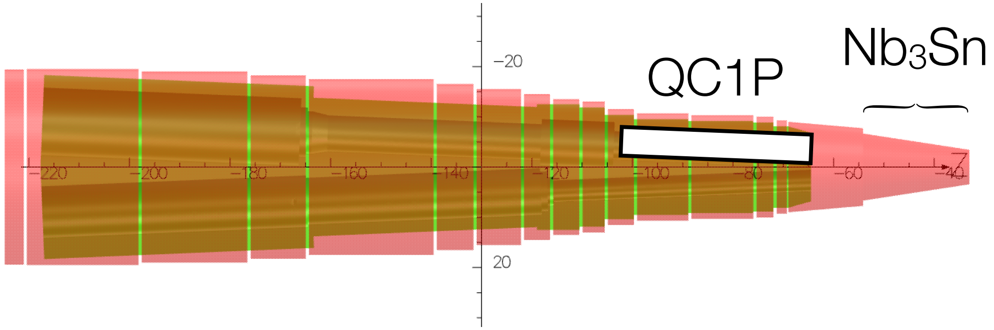


Backward

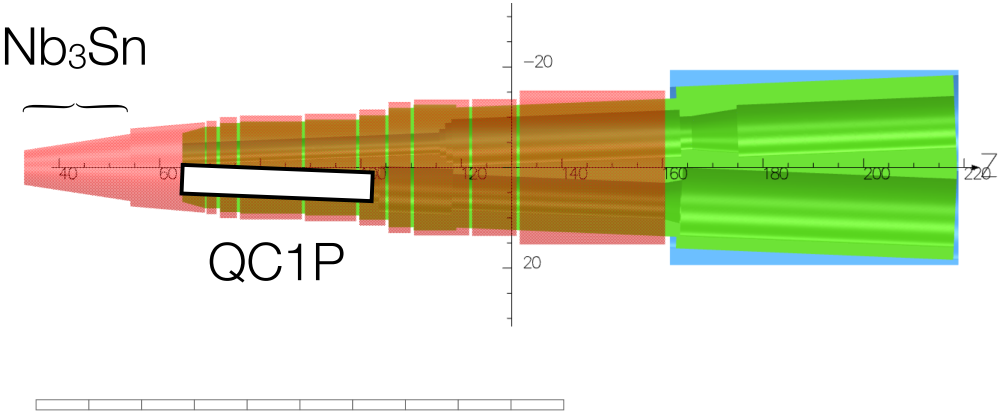


Upgraded ver.

Forward



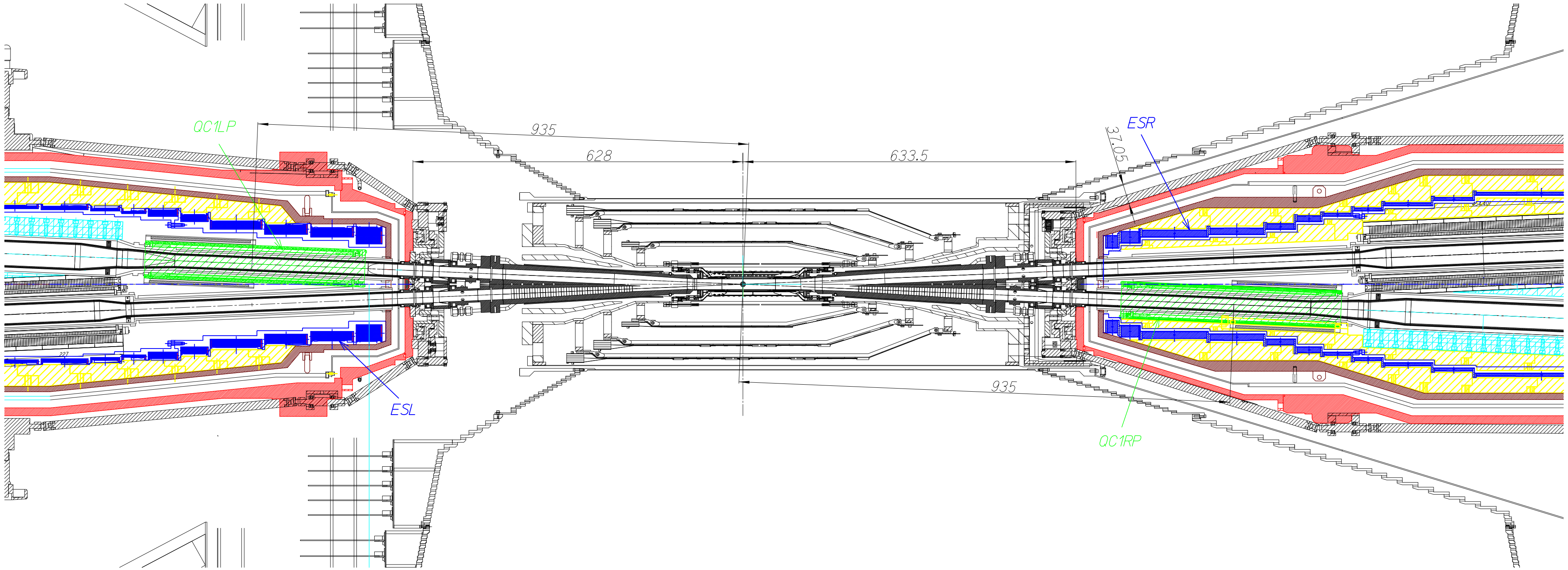
Backward



0 0.5 1 m

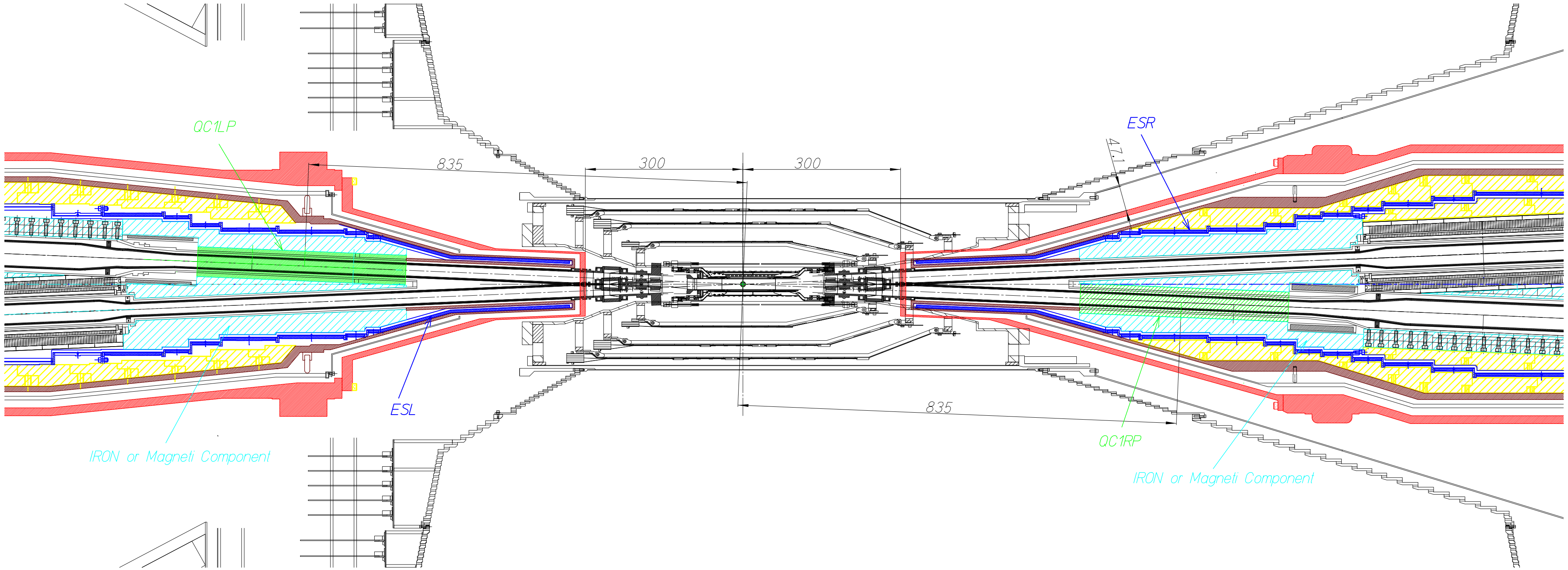
Y. Arimoto

Current Cryostat



K. Aoki/N. Ohuchi

New Cryostat



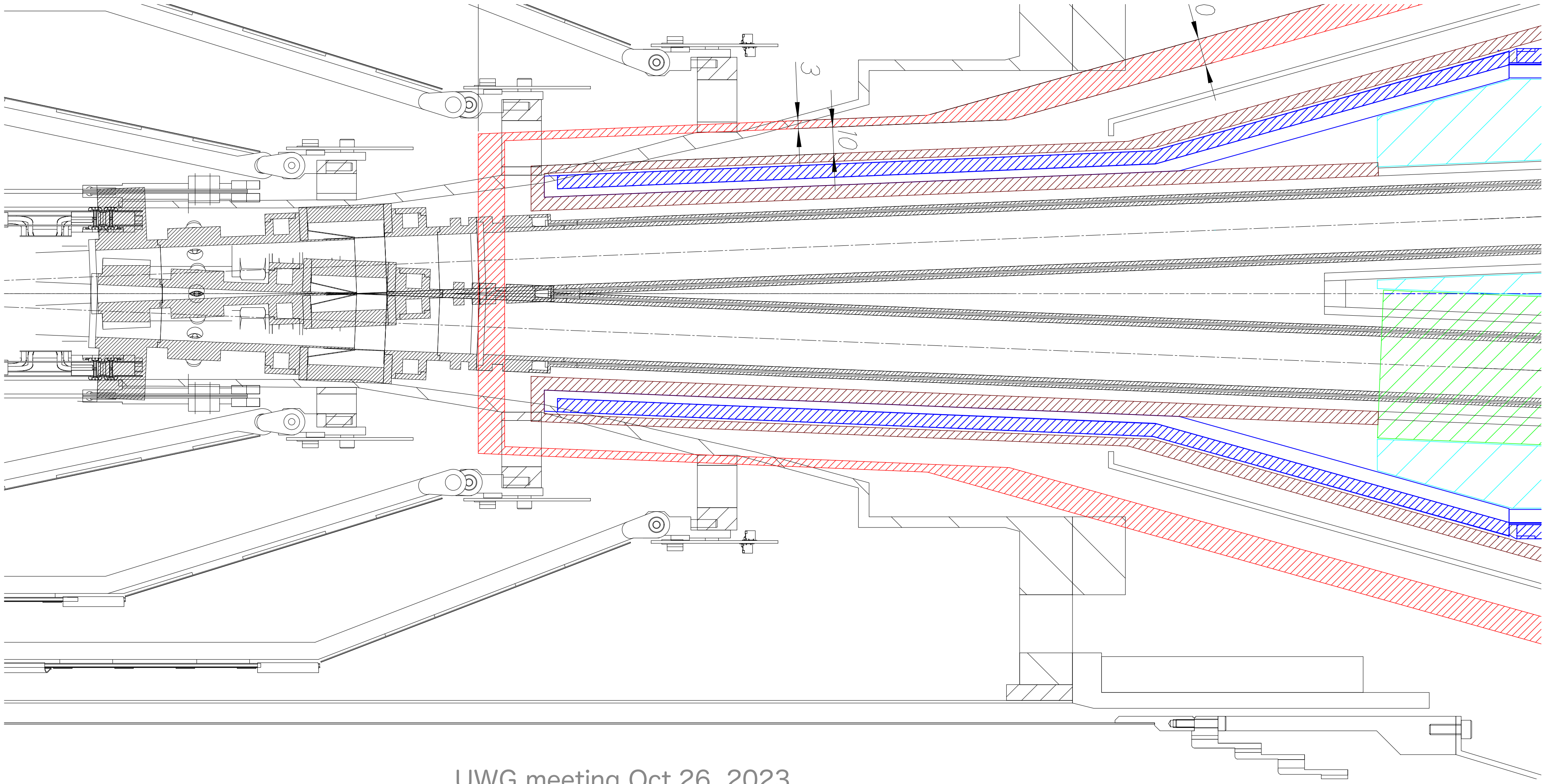
K. Aoki/N. Ohuchi

New Cryostat

3 mm thickness :Just enough for withstanding vacuum pressure

We should evaluate the minimum thickness needed, including beam pipe etc.

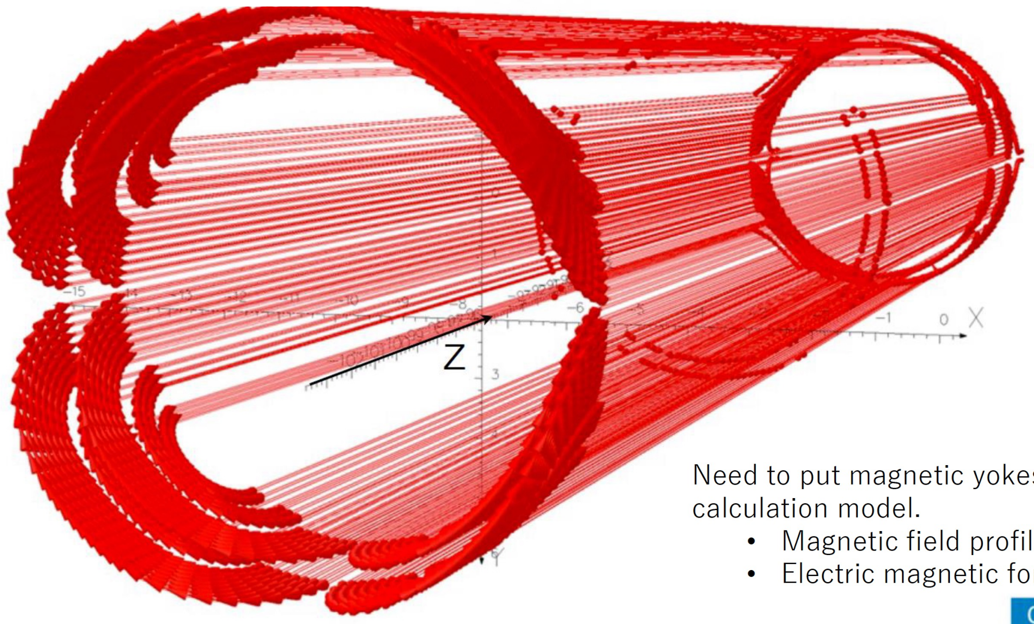
Note: The whole thing depends on how compact the anti-solenoids and QC1P can be made.



K. Aoki/N. Ohuchi

Can we realize such an IR configuration?

QC1RP line current model



Need to put magnetic yokes in the calculation model.

- Magnetic field profile
- Electric magnetic force on the coil

Opera

Smaller, thinner magnet with Nb_3Sn cables is the key
R&D work is a must

Funding sources for

- R&D of the Nb_3Sn wire (cable)
  - filament size
  - Rutherford cable/flat wire
- fabrication of a test coil
- fabrication of a test magnet
- evaluation of the magnetic force on the coil, design of the coil support, etc.

are needed.

Hardware R&D

Collaboration with FNAL on Nb_3Sn, with BNL on NbTi corrector magnets

2. Works on Nb_3Sn cable in KEK

Transfer process of Nb_3Sn sample wire from KEK to FNAL

- We have gotten the document for the export control from the Furukawa Electric Co., Ltd, which produced the Nb_3Sn wire.
- Now, all documents for exporting the wire are sent to the KEK administration office and we are waiting the export permission by the office.

Table 1. Nb_3Sn cable parameter

Item	Number
Wire diameter	0.83 ± 0.01 mm
Cu ratio	1.0 ± 0.1
No. of filaments	17,300
Filament diameter	2.3 μm
Twist pitch	15 ± 0.2
Twist direction	Z
I_c at 4.2 K at 5 T	about 850 A
RRR	> 100

10 m long wire

2023/7/7 FNAL-KEK Research Collaboration Meeting 3

N. Ohuchi

Funding status affects the process and schedule.

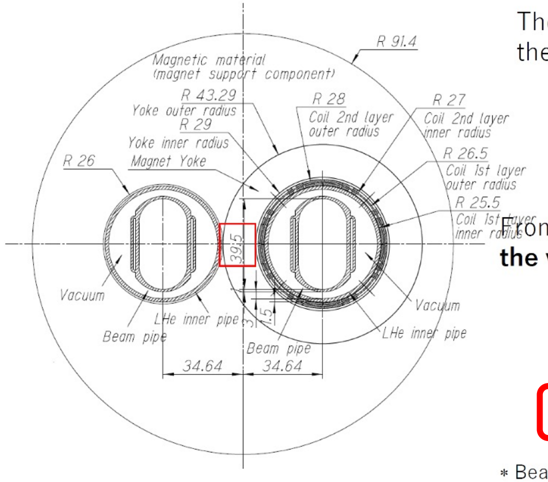
Collaboration with Fermilab

Revised yoke and aperture dimensions

N. Ohuchi etc.

Beam pipe in the magnet bore

Preliminary evaluation of the beam pipe diameter in the cryostat by the optics group



The present magnet-cryostat cross section,
the vertical diameter of the beam pipe = ϕ 39.5 mm

- **Inner radius of the SC coil = 25.5 mm**
- Thickness of the inner vessel = 1.5 mm
- Vertical gap between the beam pipe and the inner vessel = 3mm
- Moving the SC corrector magnets to the back of QC1P

From the beam operation,
the vertical diameter of the beam pipe = ϕ 32 mm

- Magnet, cryostat and beam pipe assembly error with respect to beam = 0.5 mm
- Thickness of the pipe = 1 mm
- Vertical gap between the beam pipe and the inner vessel = 3.5 mm
- ~~Thickness of the inner vessel = 1.5 mm~~
- **Inner radius of the SC coil = 22.5 mm**

* Beam pipe= ϕ 32 mm : the positron beam of 40 σ_y(L*) circulates 1000 turns without radiation dumping under 2 % x-y coupling.

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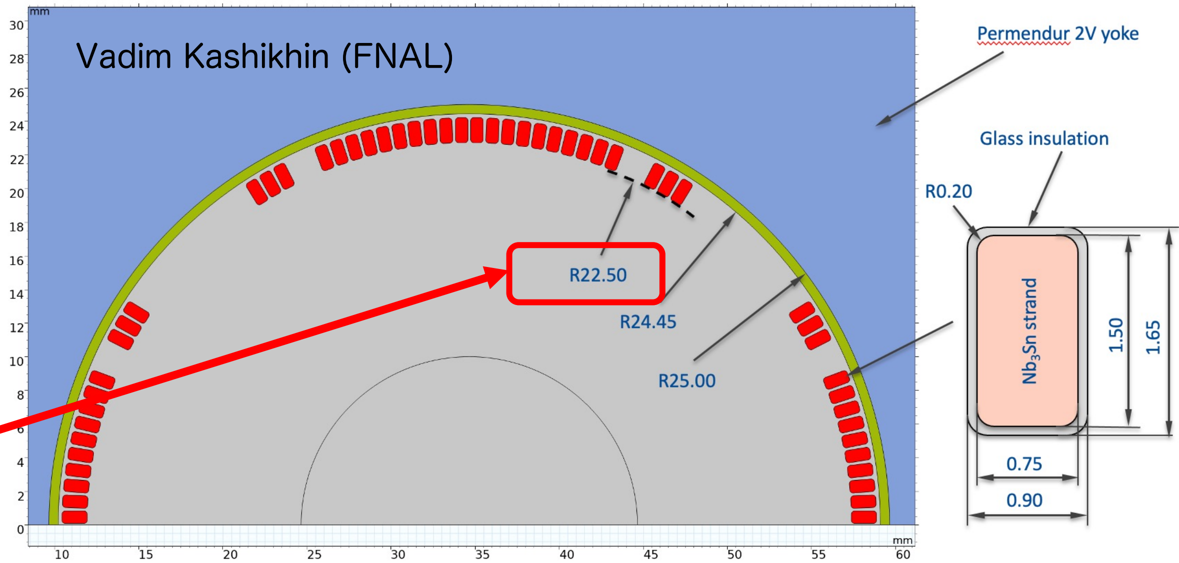
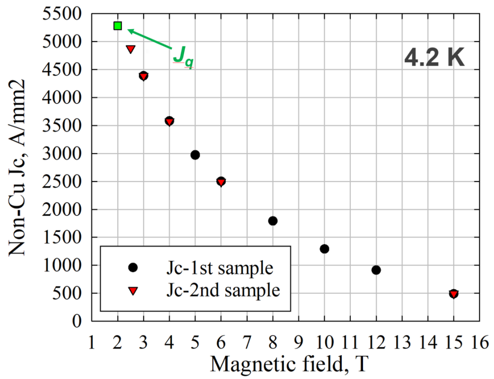
New



Nb_3Sn strand measurements at FNAL (by Xingchen)

J_c-B results of the first wire (0.83mm dia.):



Parameter	Value
Wire diameter	0.83 ± 0.01 mm
Wire diameter with glass braid	0.98 ± 0.025 mm
Cu ratio	0.91
No. of filaments	17,347
Filament diameter	**2.3 μm**
Twist pitch	17
Twist direction	Z
I_c at 4.2 K at 5 T	815 A
RRR	349
Heat treatment	575°C 100H +650°C 125H

- Added analytical temperature dependence from

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 19, NO. 3, JUNE 2009

$J_C(B, T, \varepsilon)$ Parameterization for the ITER Nb_3Sn Production

Luca Bottura and Bernardo Bordini

- ITER-2008 fit was used
- h(t) = $(1-t^{1.52})(1-t^2)$
  $t = T/T_C^*(0, \varepsilon)$
- T_c = 18 K

Fermilab

Collaboration with Fermilab

Requirements for the Nb_3Sn QC1P magnet

Parameters	
Integral magnetic field	26.7 T
Effective magnetic length	0.3336 m
Field gradient	80 T/m
Transport magnet current	< 1500 A
Magnetic yoke material	Iron or Permendur
Coil shape	Cos2θ, 2 layer-coil
Innermost layer coil radius	R=25.5 mm
Outermost layer coil radius	R=28.0 mm
Yoke inner radius	R=29.0 mm
Magnet physical length	397 mm
Cable material	Nb_3Sn
Cable parameters	To be studied in the work
Magnet operation temperature	4.7 K
Temperature margin to T_{cs}	4 K
Higher order field components	< 2 units at R_{ref}=10 mm
Quadrupole field decay for 8 hours from an hour later after exciting to the operation current	< 2 units

ollaboration Meeting

Findings by FNAL

- The magnet requirements can be met with 1 layer of 0.75-mm x 1.5-mm Nb_3Sn
- Both field and temperature margins are adequate
- The conductors with > 0.75 mm thickness will have operating current >1500 A

Evaluation continues

R&D Funding sources

human resources

backup

Design Tuneの力学口径(1)

- 原型(QC1P 935mm) sler_1704 Touschek寿命評価(design tune)
  - 425.9秒 OCTUPOLE補正有り
  - 261.0秒 OCTUPOLE補正キャンセル時
  - Fuji BV* Chicane OFF → 影響無し
- 誘導したSolid QUAD Toy Model (QC1P 835mm)
  - BC1P off、QK*PをNormal QUAD化してMatching自由度を稼ぐ
  - Zero chromaticity matchingのみの状態で、400秒オーダー
- IR挿入Model (QC1P 835mm)
  - BC1P撤去、BLC前方へNormal/Skew QUAD各1台追加、ZDS{12}PをNormal QUAD化
  - TPSAによるLifetime最適化にて、424秒