Systematic investigation of the light kaonic nuclei (E80@K1.8BR)

F. Sakuma, RIKEN

- Overview of the E80 Experiment
- Answers to the FIFC report
    - Superconducting solenoid magnet
    - Supporting structure of CDC and CNC
    - Other questions from referees
- Summary

FIFC @ KEK, 20240626

from FIFC REVIEW REPORT on July 29th, 2022

In conclusion, FIFC requests to submit an updated TDR which should include concrete design of the CDS based on the discussion at the FIFC meeting and this report. FIFC recognizes it is important to steadily construct the CDS with as better performance as possible. At present, our concerns and suggestions can be fed back to the actual design and fabrication. Thus, our concerns and suggestions are listed below.

Structural analysis in general

- Clarify definition of the analysis, allowable stress limits for materials, and criteria. Then results should be compared.

Overview of the E80 Experiment

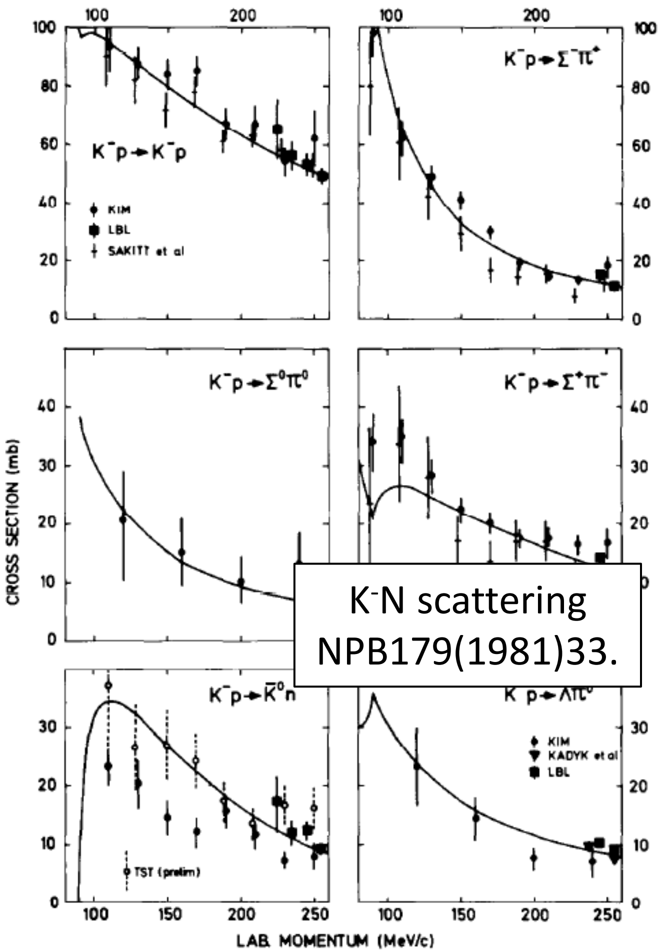
Physics Goal

Reveal the meson properties inside nuclei via **the $\bar{K}N$ interaction**

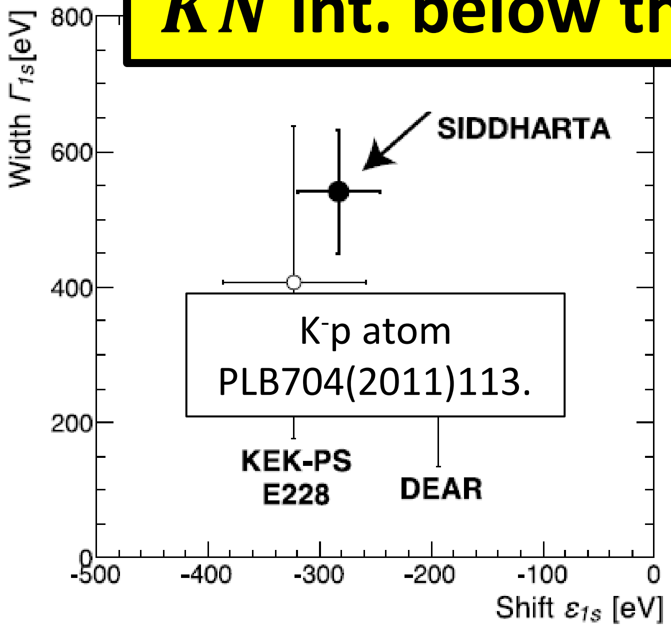
A powerful probe to understand low energy QCD

Strongly attractive in I=0 from extensive measurements

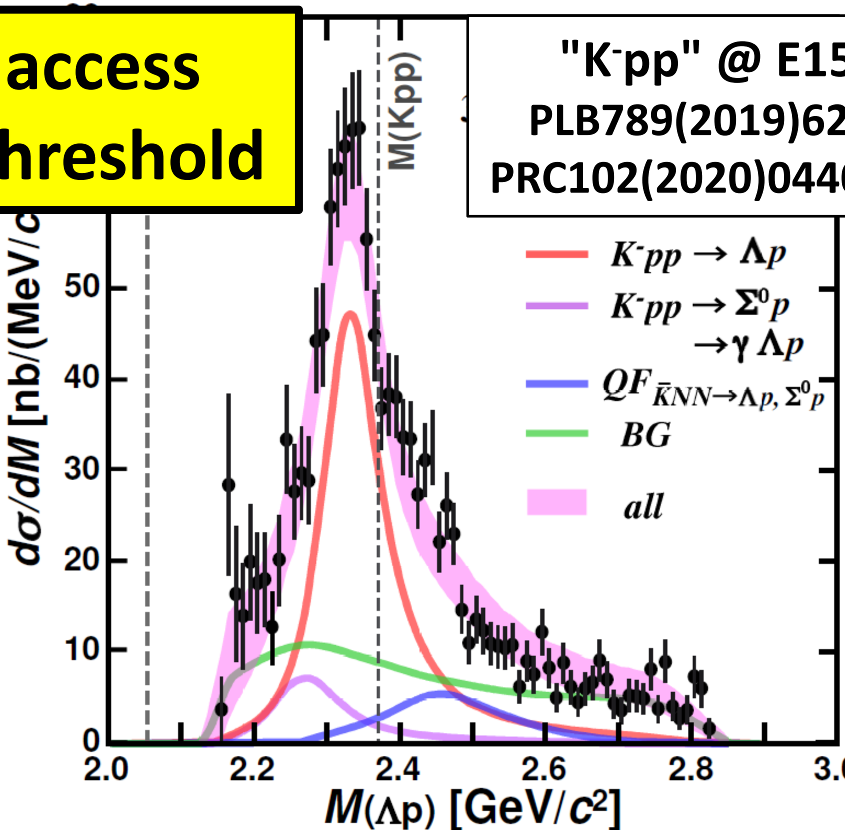
Kaonic nuclei can access $\bar{K}N$ int. below the threshold



K^-N scattering
NPB179(1981)33.



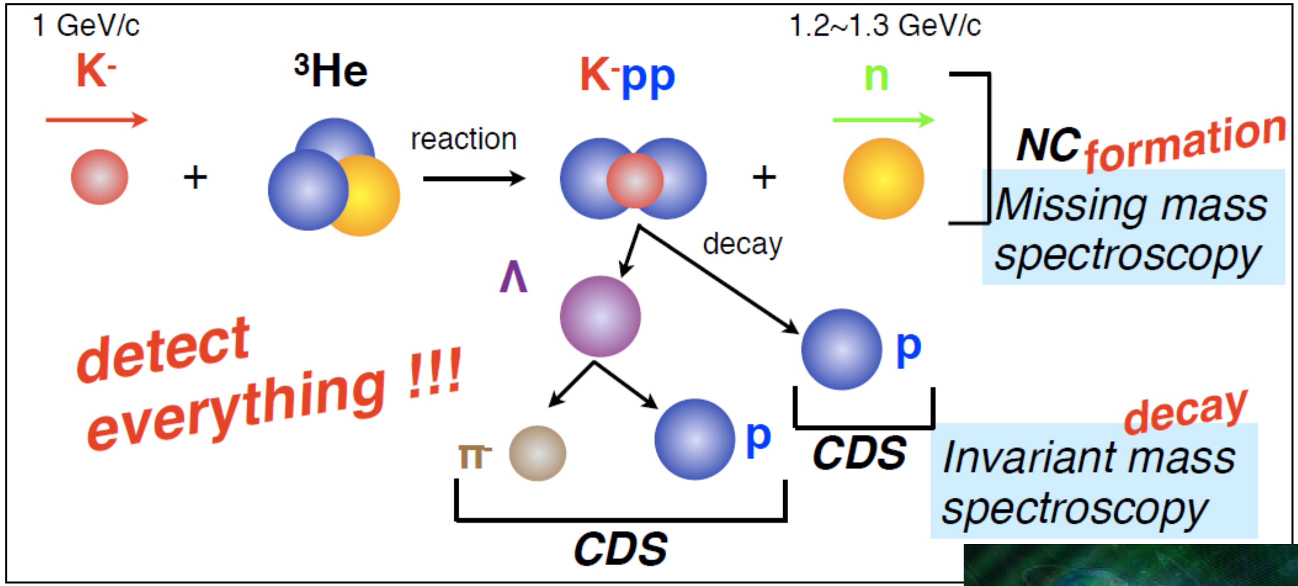
K^-p atom
PLB704(2011)113.

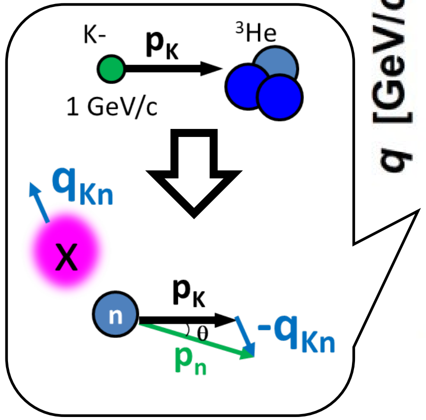


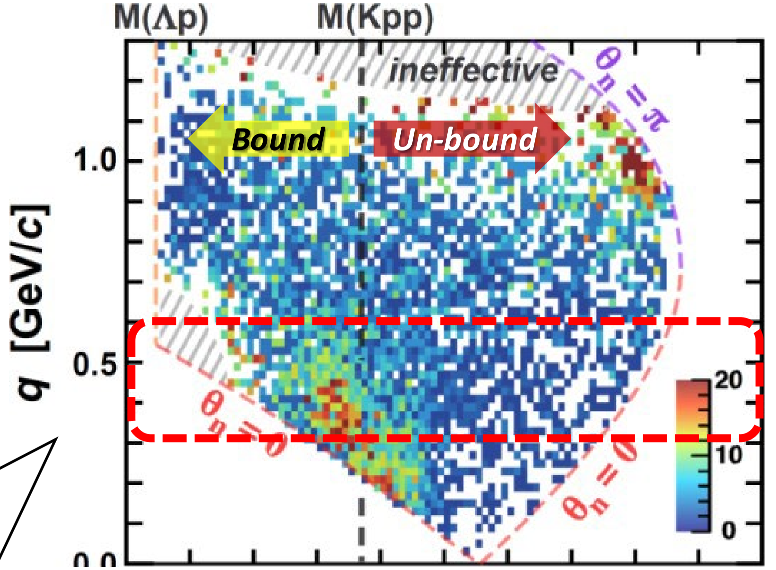
"K^-pp" @ E15
PLB789(2019)620.
PRC102(2020)044002.

J-PARC E15 Experiment

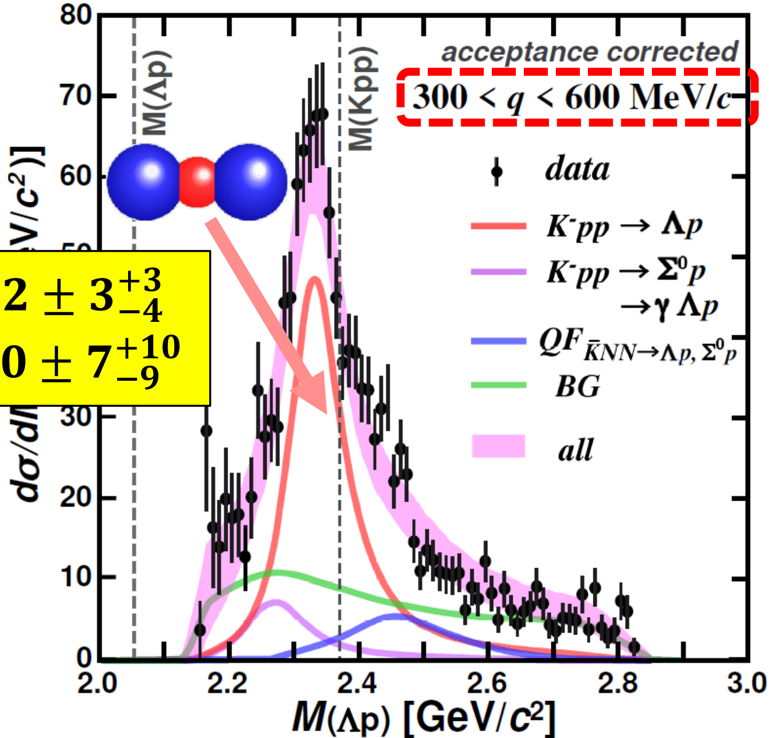
- "K⁻pp" bound state was observed in $^{3}He(K^{-},n)\Lambda p$



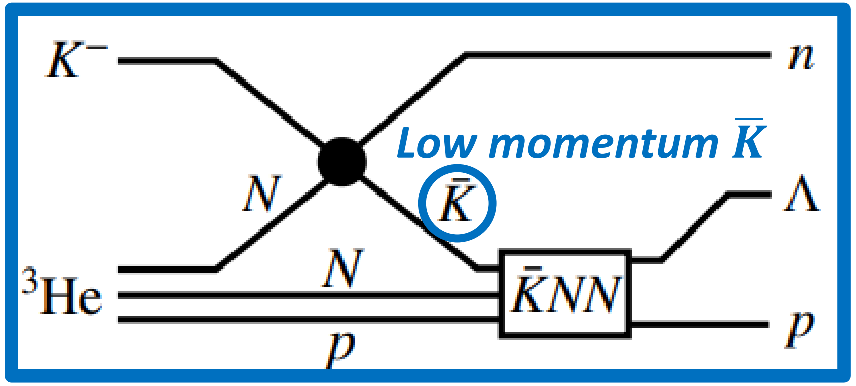


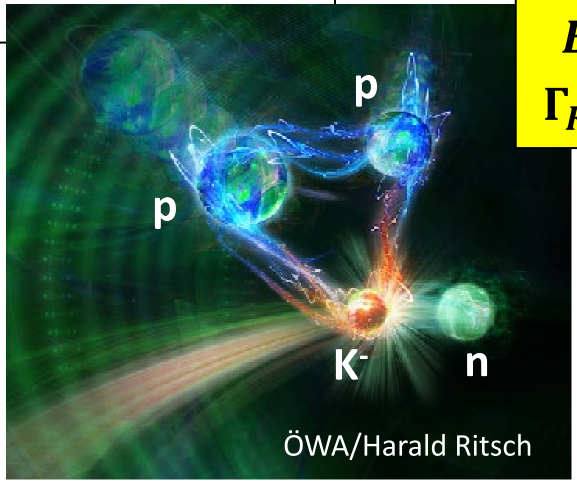


PLB789(2019)620., PRC102(2020)044002.



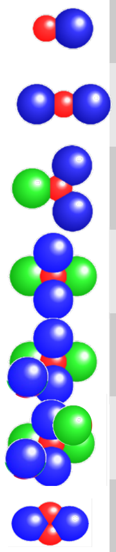
$$B_{Kpp} = 42 \pm 3^{+3}_{-4}$$
$$\Gamma_{Kpp} = 100 \pm 7^{+10}_{-9}$$



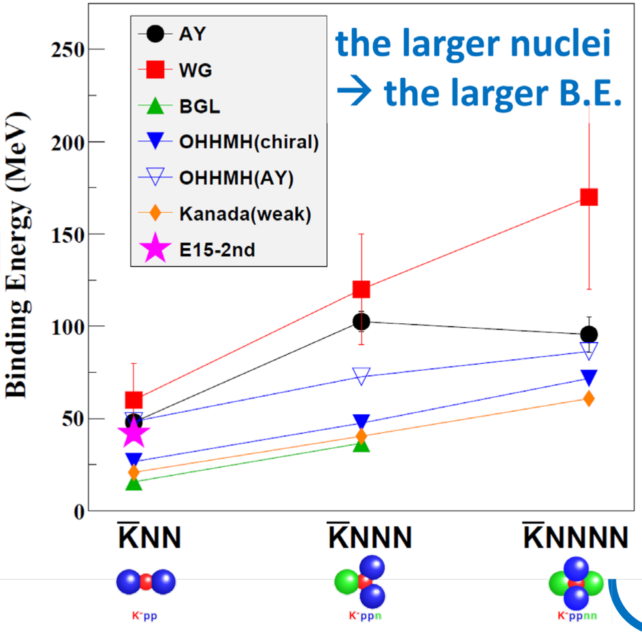


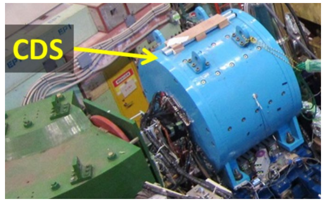
Systematic investigation of the light kaonic nuclei

- Systematic measurement of kaonic nuclei will be promoted starting from E80 ($\bar{K}NNN$)
  - Mass number dependence
    - Binding energy, Branching ratio, *q* dependence, ..
  - Spin/parity determination
  - Internal structure extracted with theoretical investigations

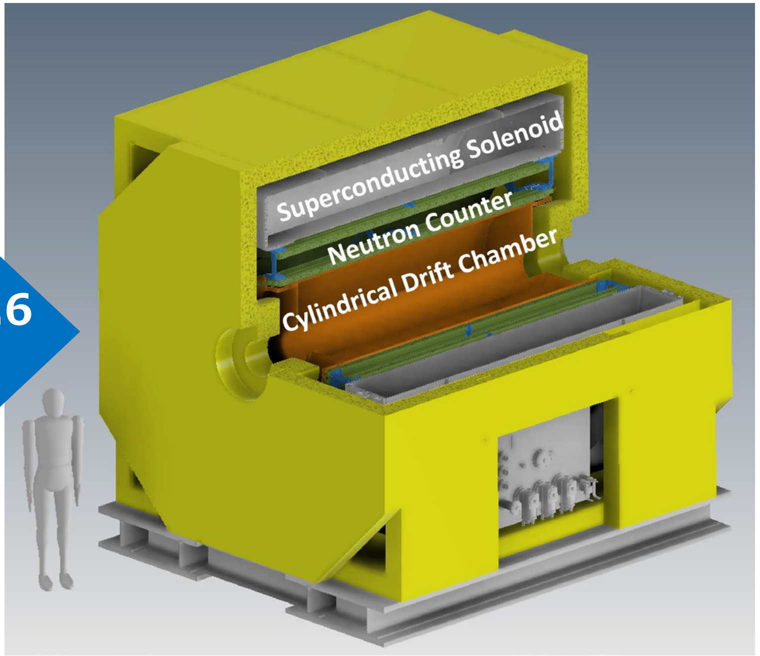


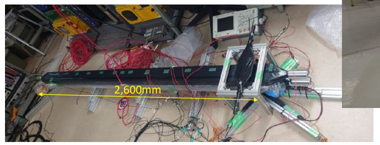
	Reaction	Decays
$\bar{K}N$	d(K⁻,n)	$\pi^{\pm 0}\Sigma^{\mp 0}$
$\bar{K}NN$	^{3}He(K⁻,N)	Λp/Λn
$\bar{K}NNN$	^{4}He(K⁻,N)	Λd/Λpn ← first step
$\bar{K}NNNN$	^{6}Li(K⁻,d)	Λt/Λdn
$\bar{K}NNNNN$	^{6}Li(K⁻,N)	Λα/Λdd/Λdpn
$\bar{K}NNNNNN$	^{7}Li(K⁻,N)	Λαn/Λddn
$\bar{K}\bar{K}NN$	*$\bar{p}$ + ^{3}He*	*ΛΛ*

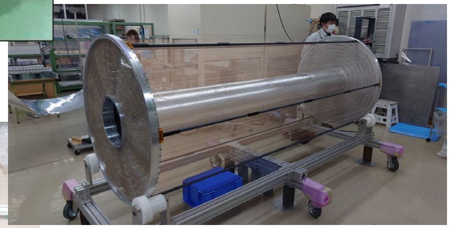




✓Solid angle: x1.6
✓Neutron eff.: x7







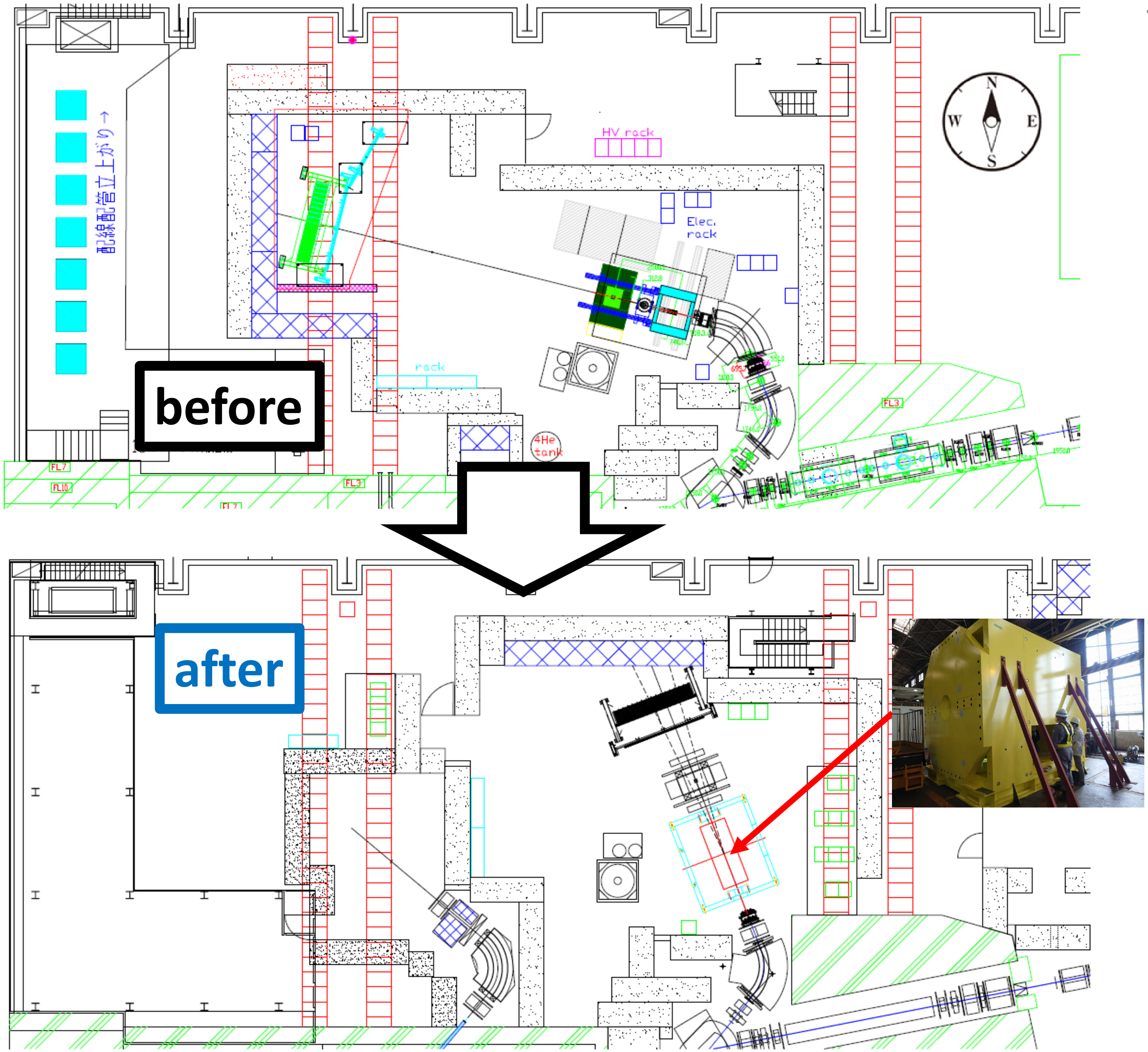
Will start in FY2026-27

K1.8BR Upgrade

- **We have proposed a new configuration of the beam line**
  - ➢ K- yield is expected to increase by **~ 1.4 times @ 1.0 GeV/c** with π/K ~ 2

Shorten the beamline (~2.5m) by removing the final D5 magnet

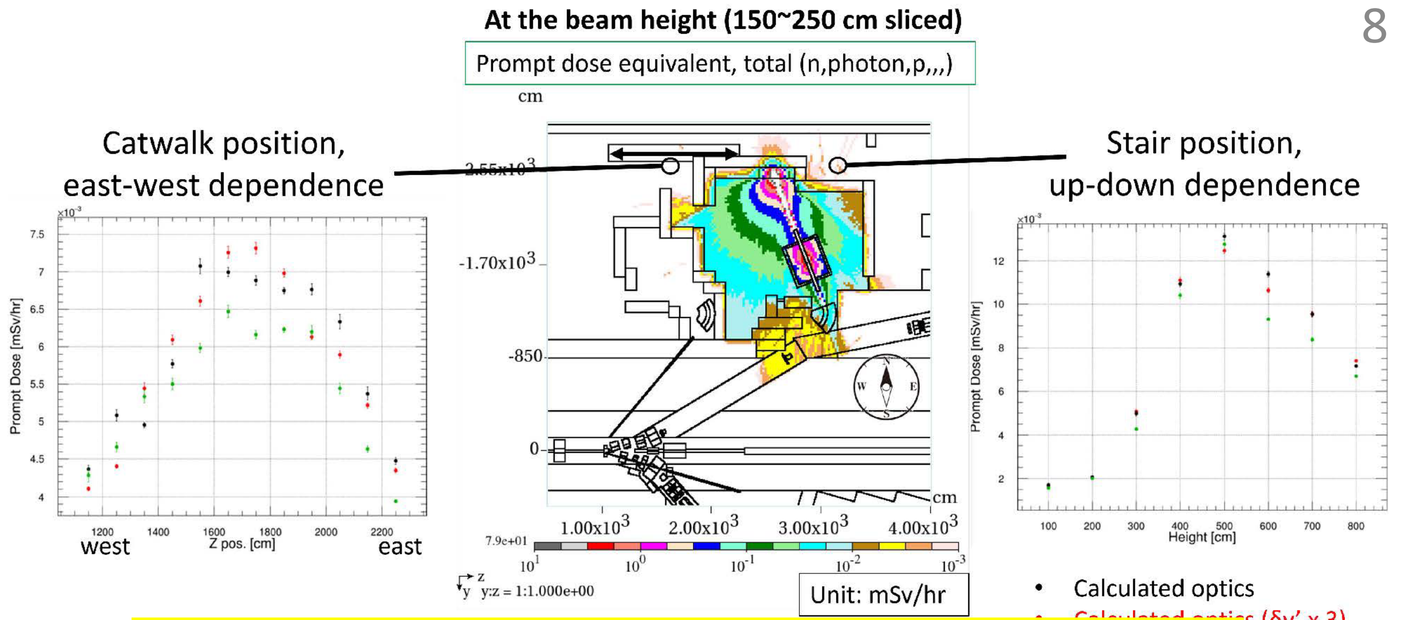
Relative beam-line length (beam yield)	D5	D4
Present CDS	0 (x1)	-3.7m (x1.6)
New CDS	+1.2m (x0.9)	**-2.5m (x1.4)**



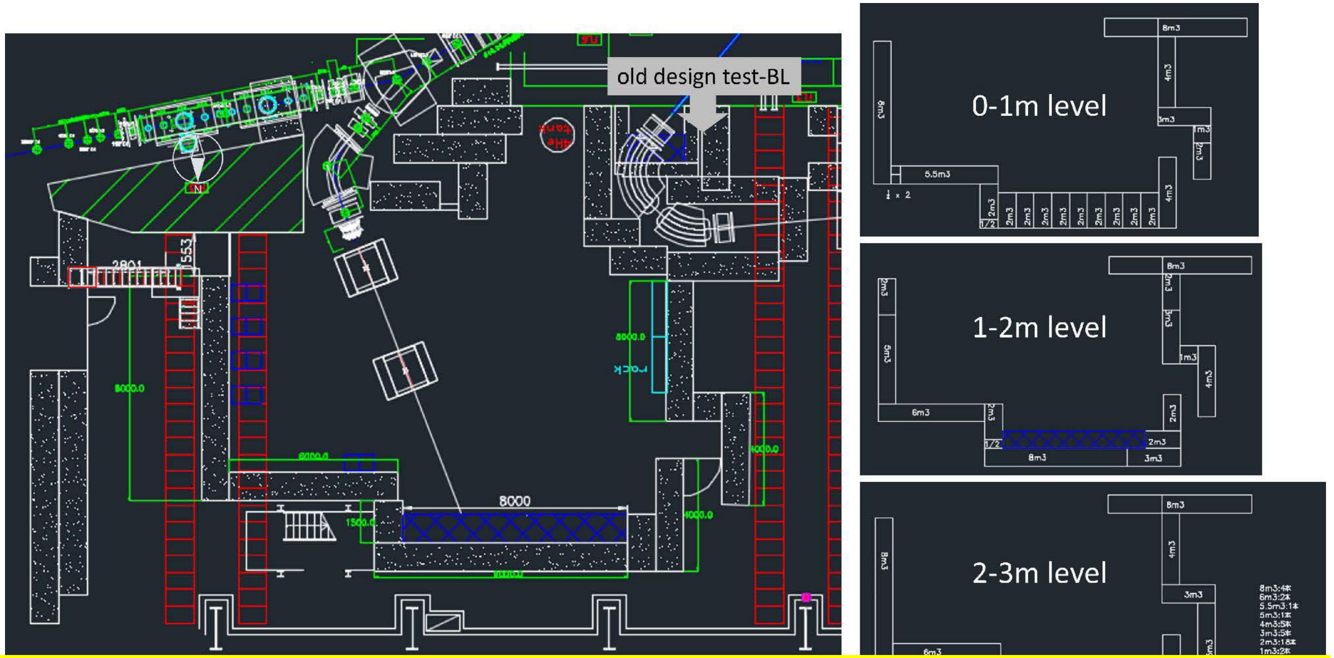
K1.8BR Upgrade

- Process
  1. D5 Removal
  2. Cable Removal
  3. Shield Rearrangement
  4. Cable Re-installation

  It will take ~6 months
- We have consulted with the HD-G and the Radiation Control Section
  - ➢radiation application is required
- **We hope to upgrade K1.8BR in late FY2025 or early FY2026**
  - ➢the application should be submitted in early FY2025



the radiation level is well below the 25 µSv/h limit



possible to rearrange the shields without purchasing new ones.

Superconducting Solenoid Magnet

- Same design as “the detector solenoid magnet” for COMET-I

being constructed in cooperation with the J-PARC Cryogenics Section

- 3.3m x 3.3m x 3.9m, ~108t in total
- Max. field of 1.0T @ center
  - 189A – 10V
- NbTi/Cu SC wire, 98km in total
- **Conduction-cooling with GM*3**
- Semi-active quench-back system
- **Will be completed in FY2024**

SHI FA-50 (air cooling)

RDE-418D4

Completed in FY2023

Completed in FY2023

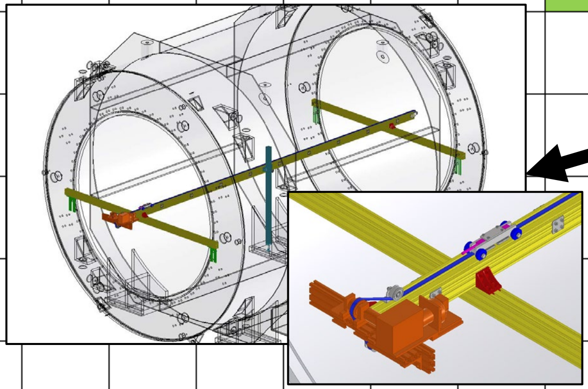
Completed in FY2022

Superconducting Solenoid Magnet

	FY2022				FY2023				FY2024				FY2025				FY2026			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
SC Wire	purchase																			
Return Yoke	Construction				stored at KEK															
GM Refrigerators	purchase																			
Cold Mass					Construction															
Power Supply w/ DAQ					Construction															
Vacuum Vessel									Construction											
Assembly																				
Cooling Tests																				
Excitation Tests w/o Return Yoke													stored at KEK							
On-site Assembly																				
Excitation Test																				
Magnetic Field Measurement																				

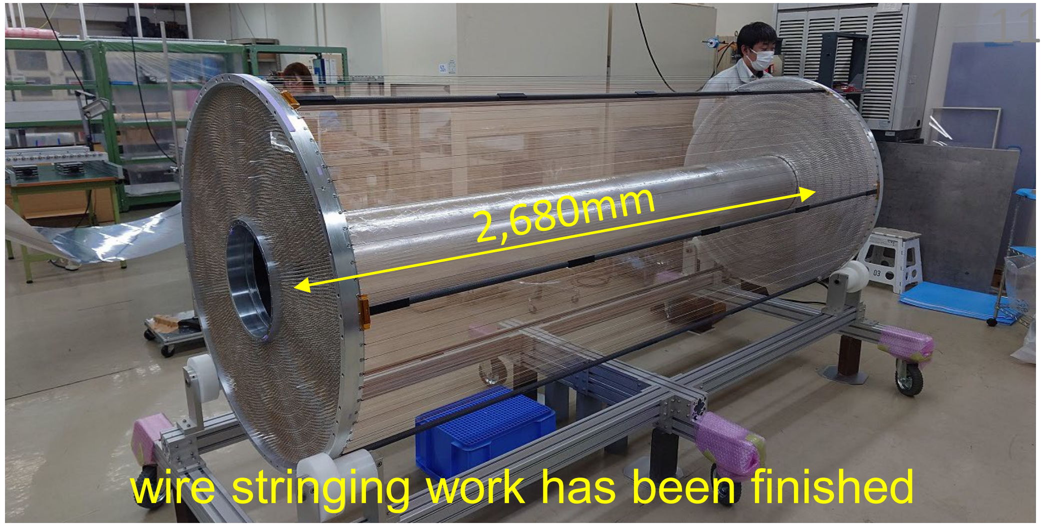
now

completion

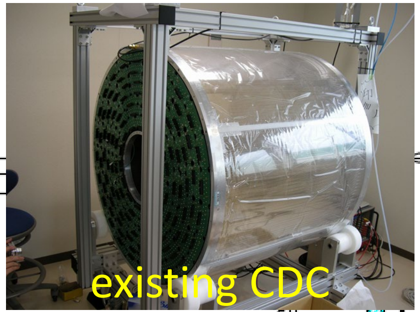


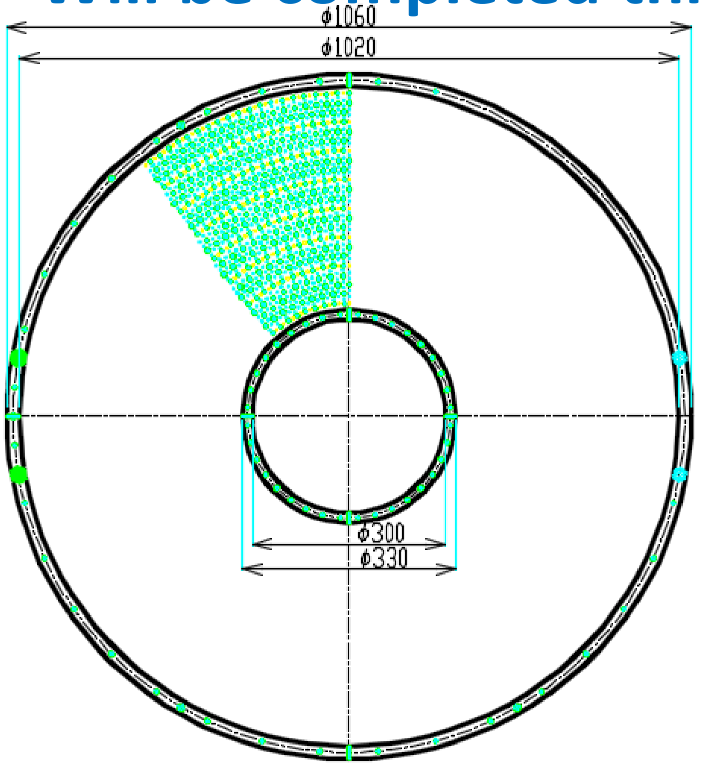
Cylindrical Drift Chamber

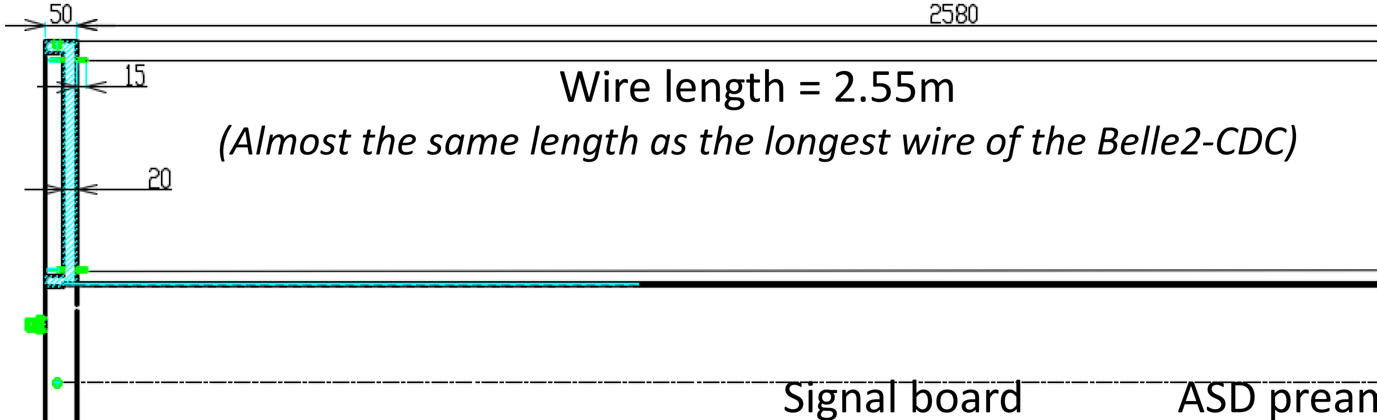
- 3 times the length of the existing CDC
  - Gas: Ar/CO_2=90/10
- The same design of the present end-cap
- Readout systems will be reused

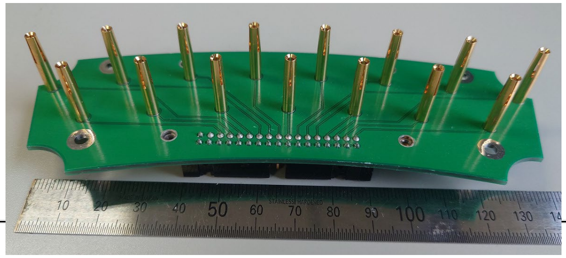


Will be completed this month, and commissioning starts @ J-PARC



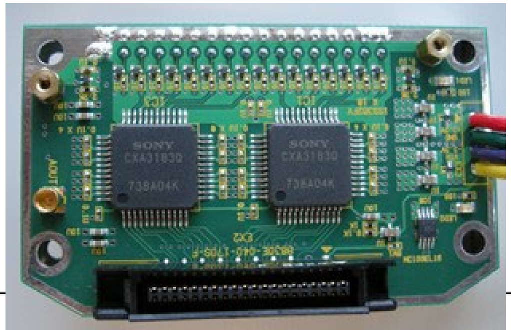






Signal board

ASD preamplifier board



Cylindrical Drift Chamber

- Wire stringing works in Jan-May 2024
- Pre-tension was applied
  - with 36 pre-tension bars
  - 1.67 tons loaded in total

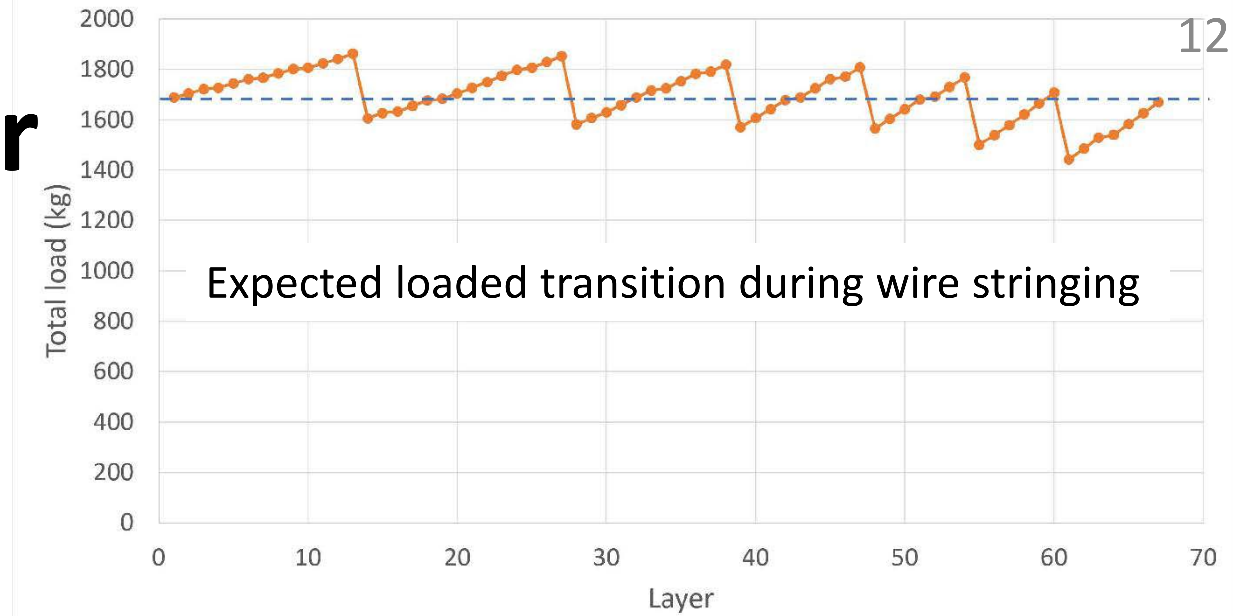
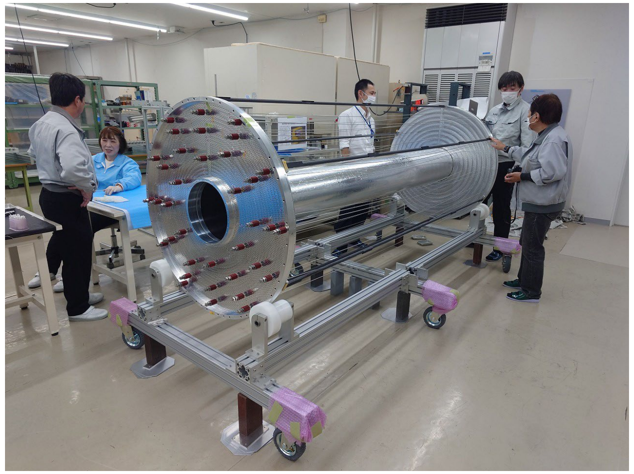
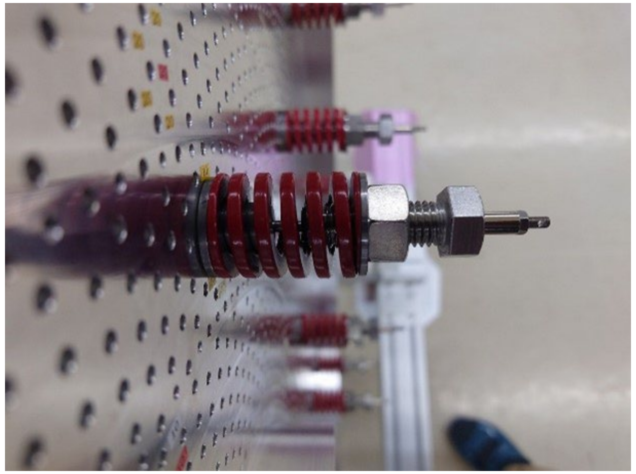
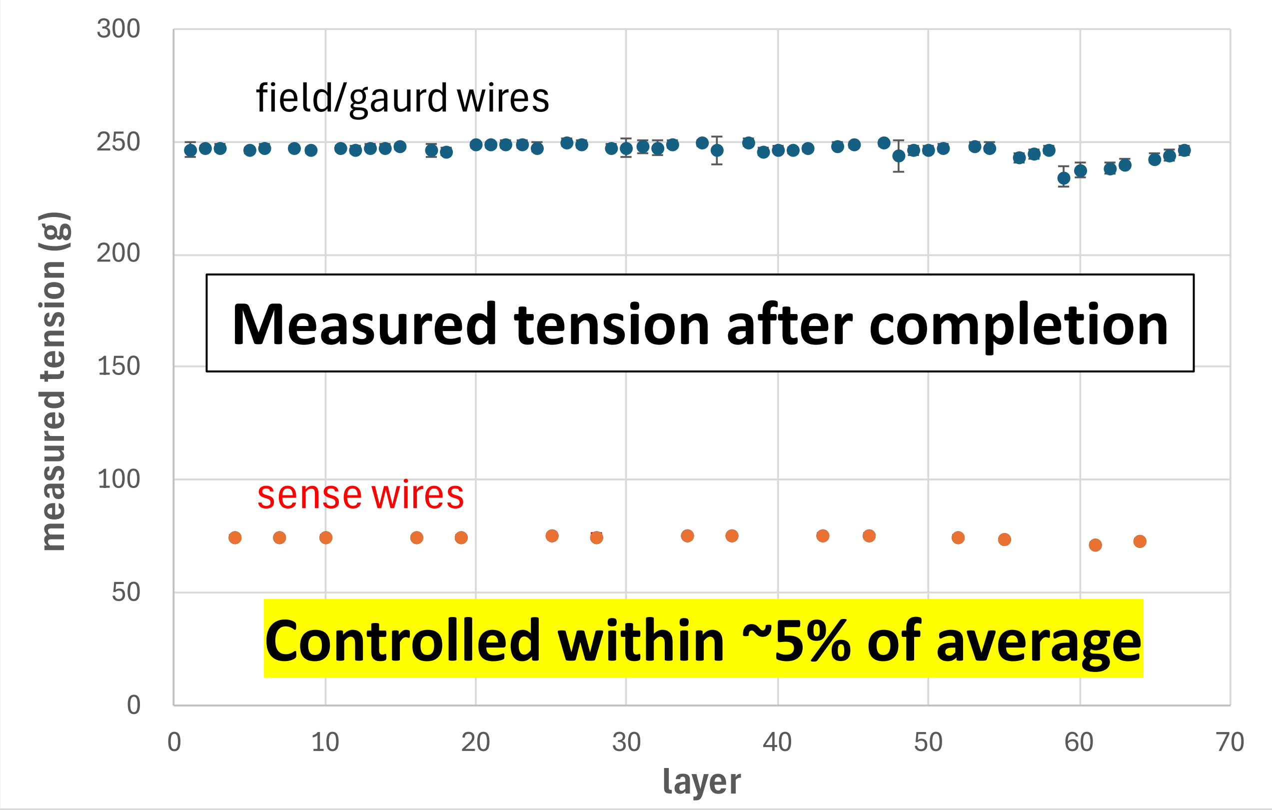


Table 13: Wire configuration of the CDC.

Wire type	Wire diameter	Wire material	Number of wires	Wire tension
Sense	$\phi 30\ \mu m$	Au-W	1,816	70 g
Filed	$\phi 80\ \mu m$	Be-Cu	5,376	240 g
Guard	$\phi 80\ \mu m$	Be-Cu	1,052	240 g
In total			8,244	1.67 tons

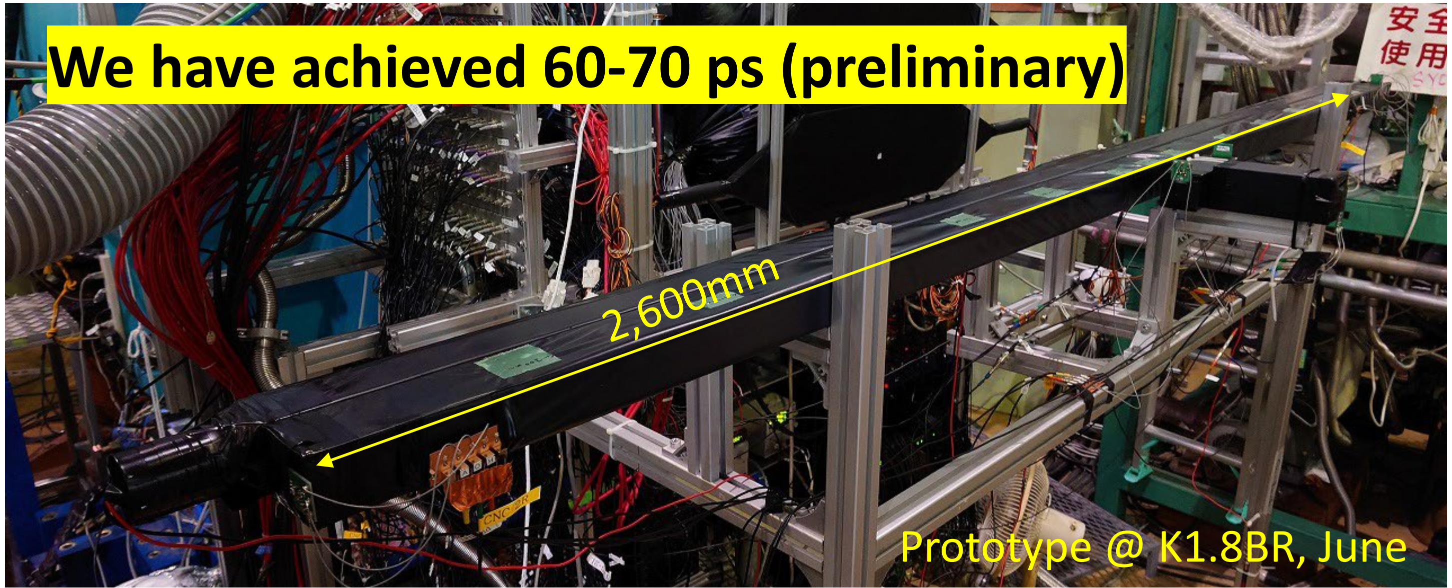


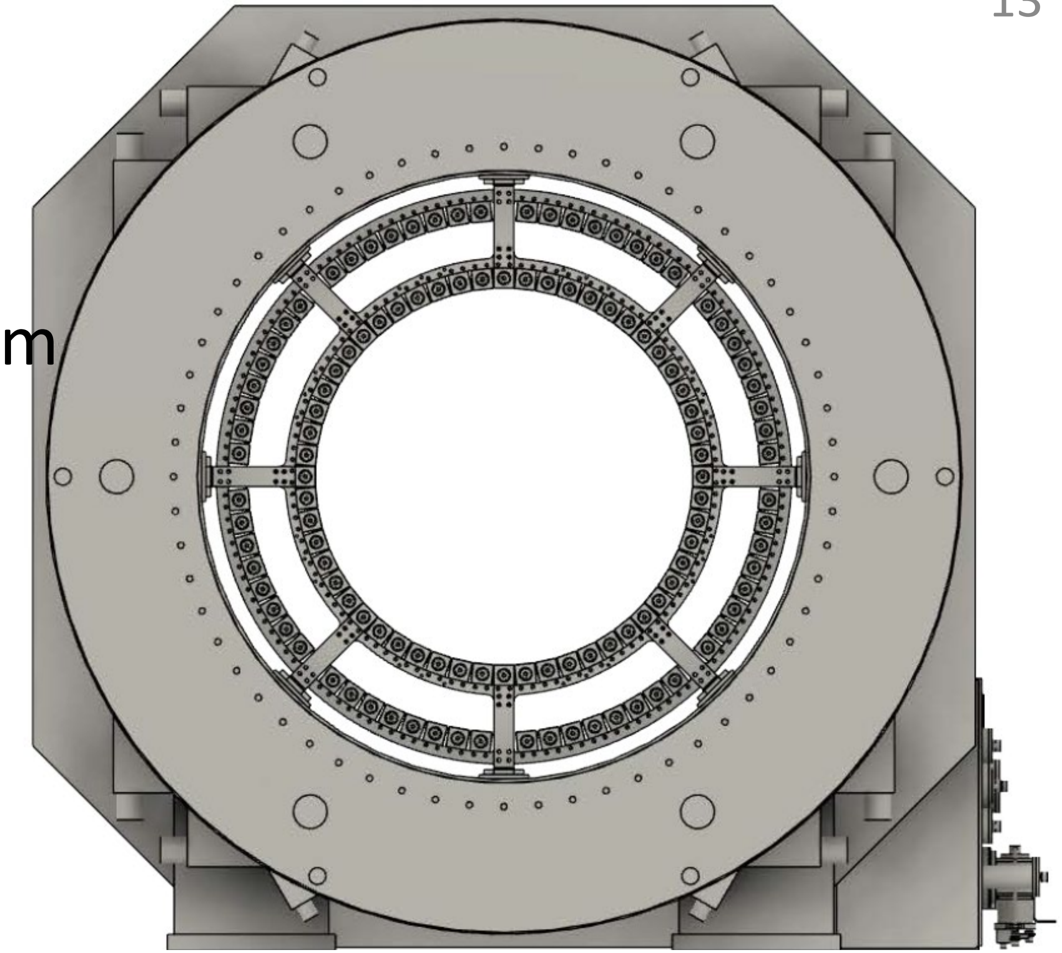




Neutron Counter

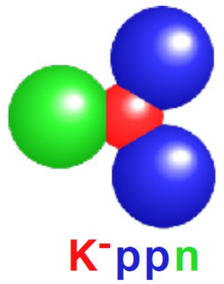
- scintillator array: 2 layers, 12cm thickness
- ELJEN EJ-200: (T)60mm, (W)60mm, (L)3,000mm
- 1.5-inch FM-PMT [H8409(R7761)]
  & MPPC array [S13361-6050AE-04]
- Neutron detection efficiency of 12~36%
- **Will be fabricated in FY2024**





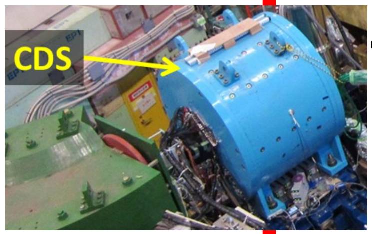
136 scintillators in total

- 56 segments @ r548~608mm
  - 112 FM-PMTs
- 80 segments @ r780~840mm
  - 160 MPPC-arrays



$\bar{K}NNN$ @ E80

via ^{4}He(1 GeV/c K^-, n) reaction



① **Establish the existence of $\bar{K}NNN$**

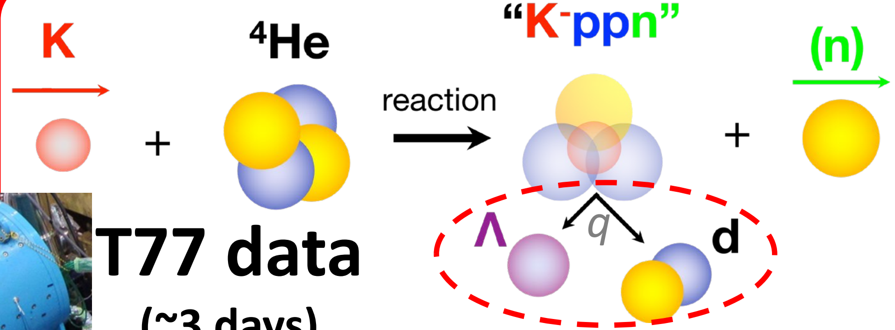
- "K^-ppn"→Λd 2-body decay

② **Study the multi-particle decay mode of $\bar{K}NNN$ toward understanding its internal structure**

- "K^-ppn"→Λpn 3-body decay

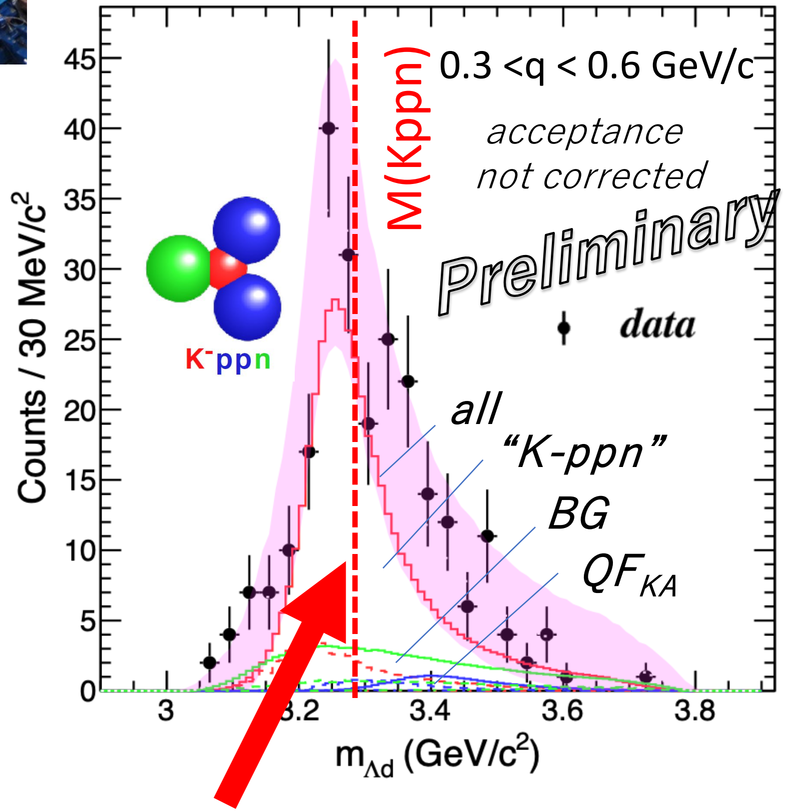
- Feasibility study of spin-spin correlation measurement for P89
  - *by* installing a prototype module of a polarimeter

Beam intensity	90kW
Beam time	1+1+3 weeks



T77 data

(~3 days)



the sign of the "K⁻ppn"

Expected Yield of $\bar{K}NNN$

$$N = \sigma \times N_{beam} \times N_{target} \times \epsilon,$$
$$\epsilon = \epsilon_{DAQ} \times \epsilon_{trigger} \times \epsilon_{beam} \times \epsilon_{fiducial} \times \Omega_{CDS} \times \epsilon_{CDS},$$

- N_{beam} = **100 G** K- on target
  - MR beam power of **90 kW**
  - **3 weeks** data taking (90% up-time)

$$\sigma(K^- ppn) \cdot Br(\Lambda d) \sim 5\ \mu b$$
$$\sigma(K^- ppn) \cdot Br(\Lambda pn) \sim 5\ \mu b$$

from the T77 preliminary result and an assumption

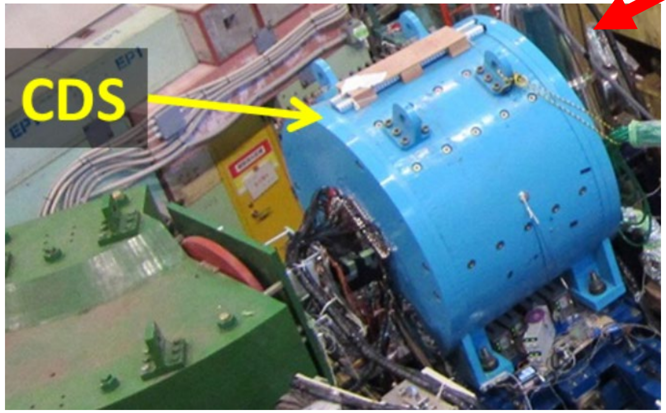
- **$N(K^- ppn \rightarrow \Lambda d)$ ~ 1.2 x 10^4**
- **$N(K^- ppn \rightarrow \Lambda pn)$ ~ 1.2 x 10^3**
  - c.f. 1.7 x 10^3 "$K^- pp$"$\rightarrow \Lambda p$ accumulated in E15-2nd (40 G K^-)

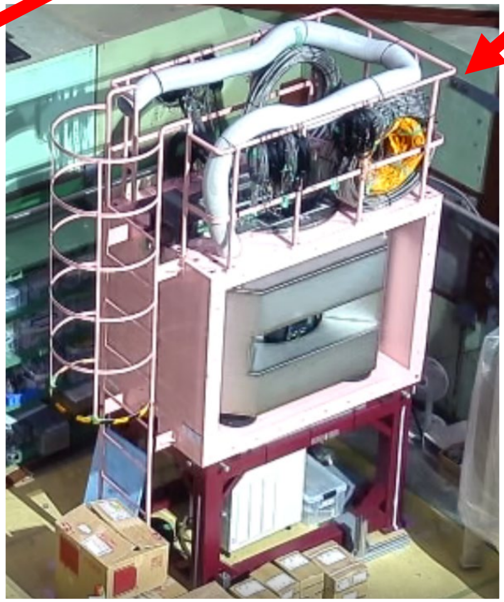
	Λd / Λpn
$\sigma(K^- ppn)$*Br	5 μb
N(K^- on target)	100 G
N(target)	2.56 x 10^{23}
ε(DAQ)	0.92
ε(trigger)	0.98
ε(beam)	0.72
Ω(CDC)	0.23 / 0.047
ε(CDC)	0.6 / 0.3
N(K^-ppn)	12 k / 1.5 k

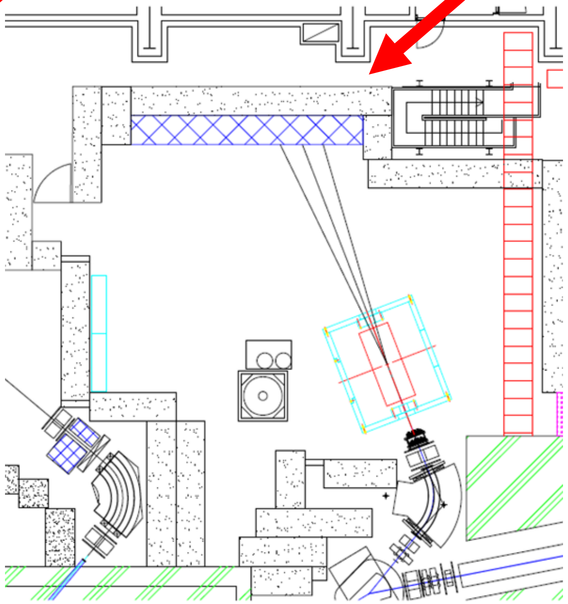
Schedule

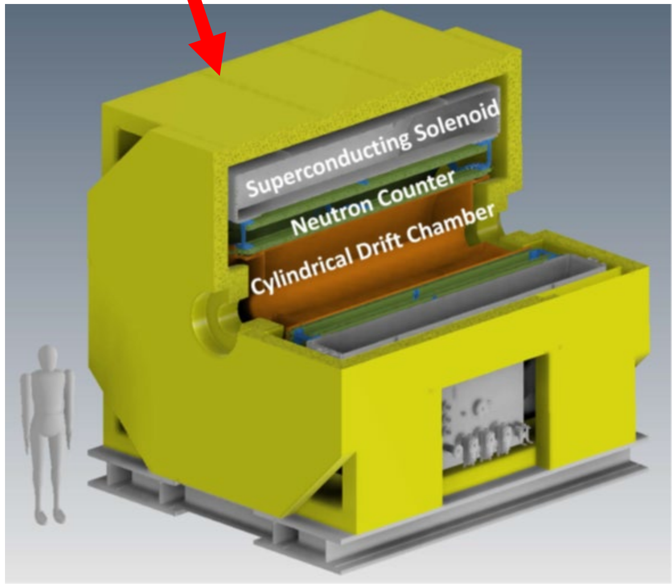
now

	FY2022				FY2023				FY2024				FY2025				FY2026				FY2027			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
SC Solenoid Magnet	Design		Purchase (SC Wire)		Construction								Stored at KEK				Installation	Integration, Test & Commissioning			Commissioning w/ Beam	Physics Run	Analysis & Pblication	
CDC	Design				Construction					Test & Commissioning														
NC	Design & R&D										Purchase (Scinti.)		Assembly	Test & Commissioning										
K1.8BR Beam Line	E73(CDS) -> E72(HypTPC) Experiments															Upgrade		E80 Experiment						









Cost

Already secured

- The magnet and CDC cost have been covered by **"Grant-In-Aid for Specially Promoted Research by JSPS (FY2022-26)"**.

Superconducting solenoid magnet	~370M JPY
CDC (cylindrical drift chamber)	~54M JPY

- The CNC will be built with a new budget, **"Grant-in-Aid for Scientific Research (S) by JSPS (FY2024-28)"**.

CNC (cylindrical neutron counter)	~80M JPY

- We hope that the cost of the K1.8BR upgrade will be covered by facility.

K1.8BR Upgrade [maximum estimate]	~38M JPY

Answers to the FIFC report

Superconducting solenoid magnet

- Compared with a similar-sized magnet, the cooling power of 5.4 W seems to be small. We would like to see the contents of heat loads in detail in order to confirm that the cooling power is sufficient. (Because of the low excitation current design of 200 A and the HTS current leads, heat generation at the current leads is low.)

- 4K section heat load: Total **4.2W**
  - ➢3.5W during steady operation
  - Refrigeration capability (4K): Total 5.4W

- Radiation shield heat load: Total **119W**
  - Refrigeration capability (50K): Total 126W

- **The refrigeration capacity exceeds the heat load and is sufficient to provide adequate cooling.**

4K section

4 K section heat load (Unit:W)

Item	Route	Heat load	Remarks
Thermal shield	Heat radiation	2.44	0.05 W/m^2
Supports	Heat transfer	0.75	
Current leads	Heat transfer + Ohmic heating	0.13	HTS lead
Residual gas	Heat transfer	0.10	
Pre-cooling tube etc.	Heat transfer	0.05	$\phi 12$
Measurement lines	Heat transfer	0.05	
Coil	AC loss	0.70	2h rise time
Radiation	Heat generation	-	
In total		4.2	

Refrigeration capacity (4 K)

Model	RDE-418D4	1.8	W @ 4.2 K
Number of units		3	
total capacity		5.4	

Radiation shield

Radiation shield heat load (Unit:W)

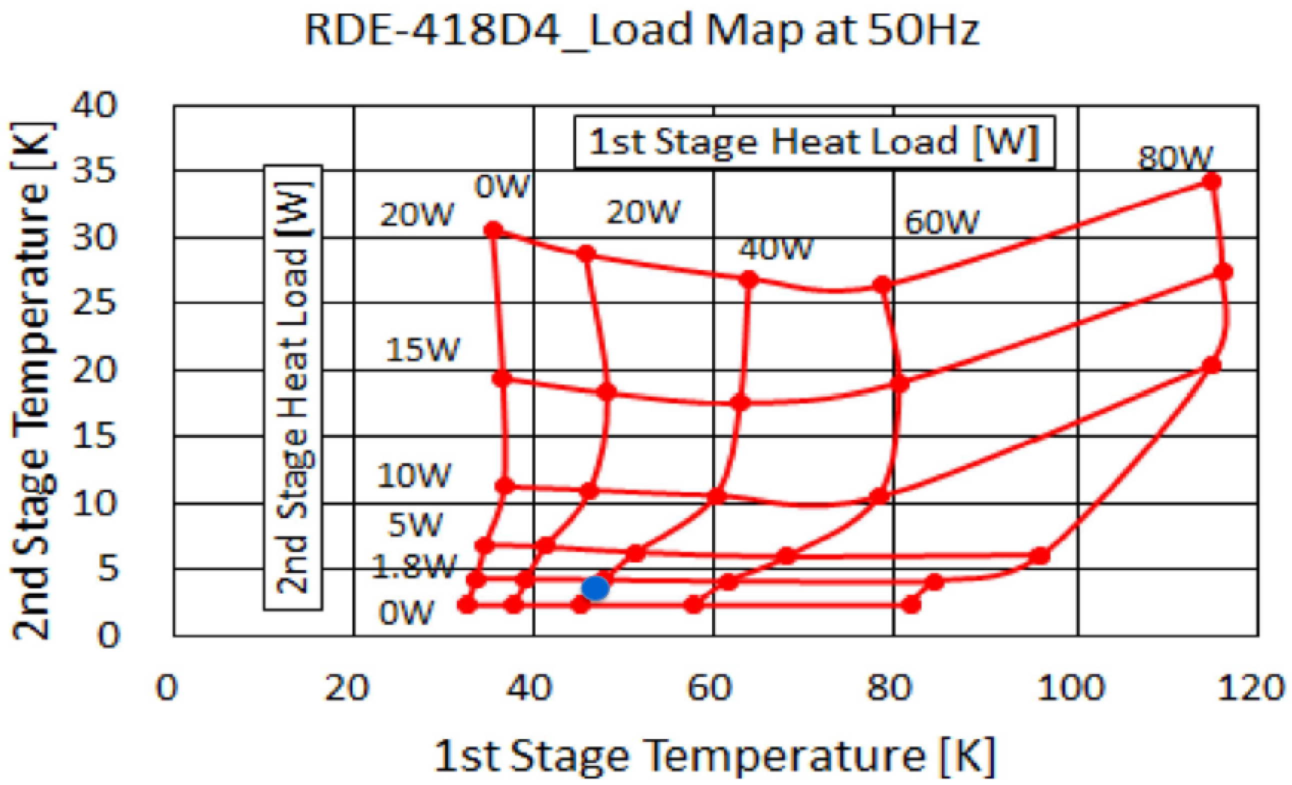
Item	Route	Heat load	Remarks
Thermal shield	Heat radiation	84.4	1.5 W/m^2
Supports	Heat transfer	5.1	
Current leads	Heat transfer + Ohmic heating	24.8	Cupper lead
Residual gas	Heat transfer	1.9	
Pre-cooling tube etc.	Heat transfer	2.4	$\phi 12$
Measurement lines	Heat transfer	0.3	
Coil	AC loss	-	
Radiation	Heat generation	-	
In total		119	

Refrigeration capacity (50 K)

Model	RDE-418D4	42	W @ 50 K
Number of units		3	
total capacity		126	

- Compared with a similar-sized magnet, the cooling power of 5.4 W seems to be small. We would like to see the contents of heat loads in detail in order to confirm that the cooling power is sufficient. (Because of the low excitation current design of 200 A and the HTS current leads, heat generation at the current leads is low.)

Expected operating point of refrigerator

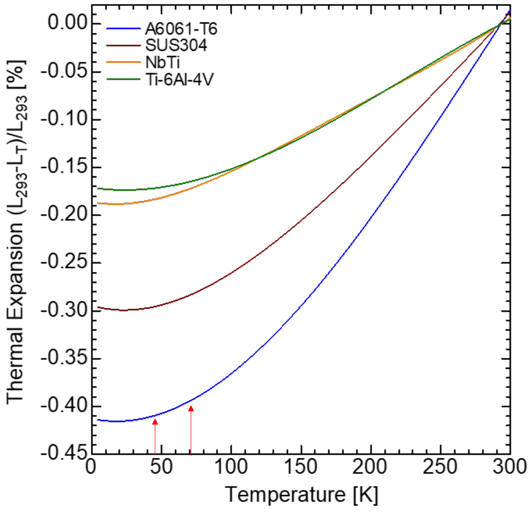


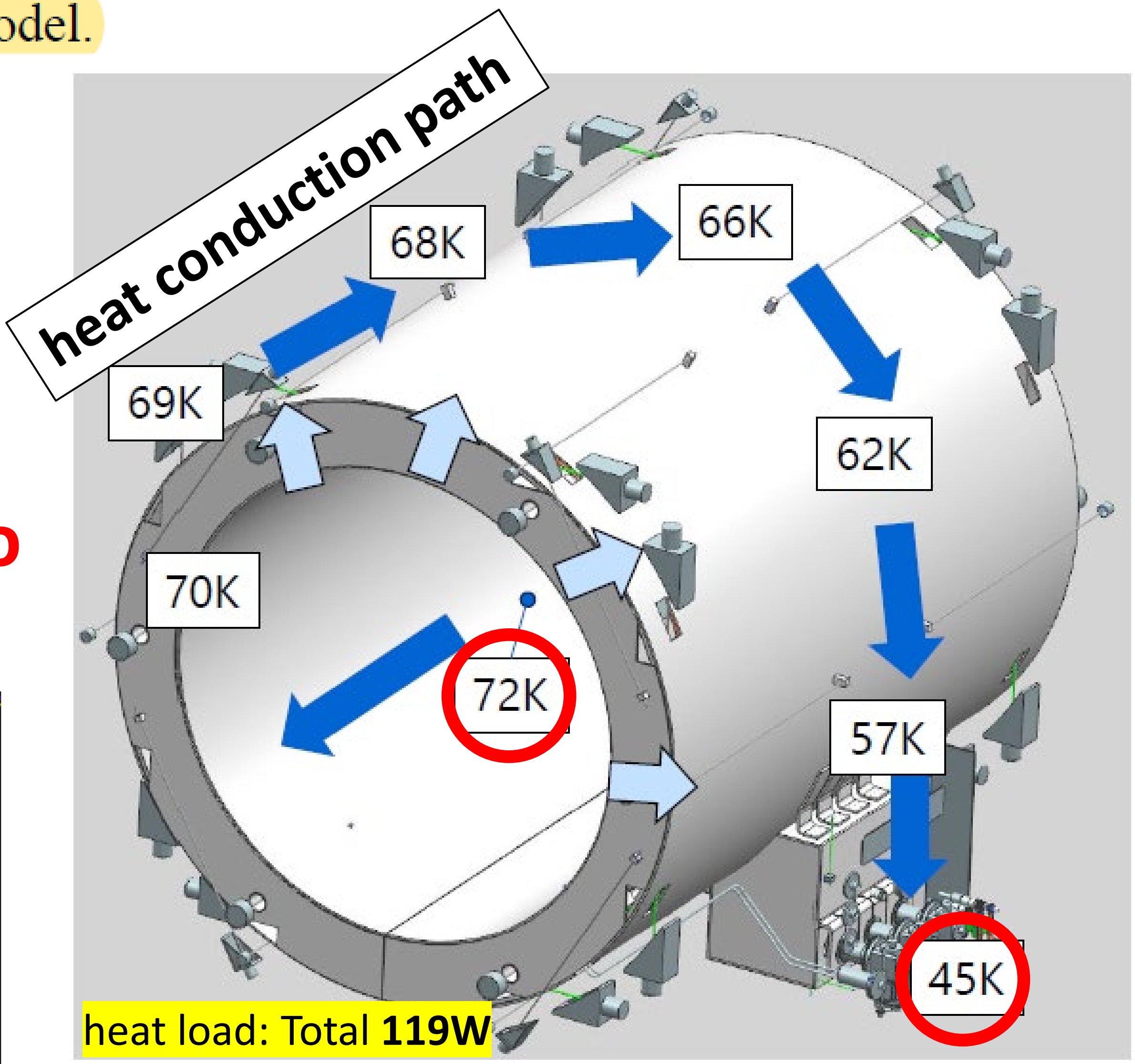
- 1st stage load: <u>119W</u> (40W/unit) → 1st stage temperature **<u>45K</u>**
- 2nd stage load: <u>4.2W</u> (1.4W/unit) → 2nd stage temperature **<u>4.2K</u>**

- Since heavy cold mass is cooled down from one side in the present design, a large temperature gradient is expected in the cooling process. It is better to confirm whether it is mechanically acceptable using 3D model.

- <u>Thermal shield temperature gradient</u> is estimated based on the thermal resistance of the heat conduction path.
- **Temperature difference of 27K (= 72K - 45K) from the refrigerators to the farthest point of the center of the inner cylinder**

➢ **Acceptable range**
  - Strain = 1.709E-04
  - Stress = 12 MPa
    - Young's modulus = 70 Gpa
    - Tensile stress > ~60 MPa



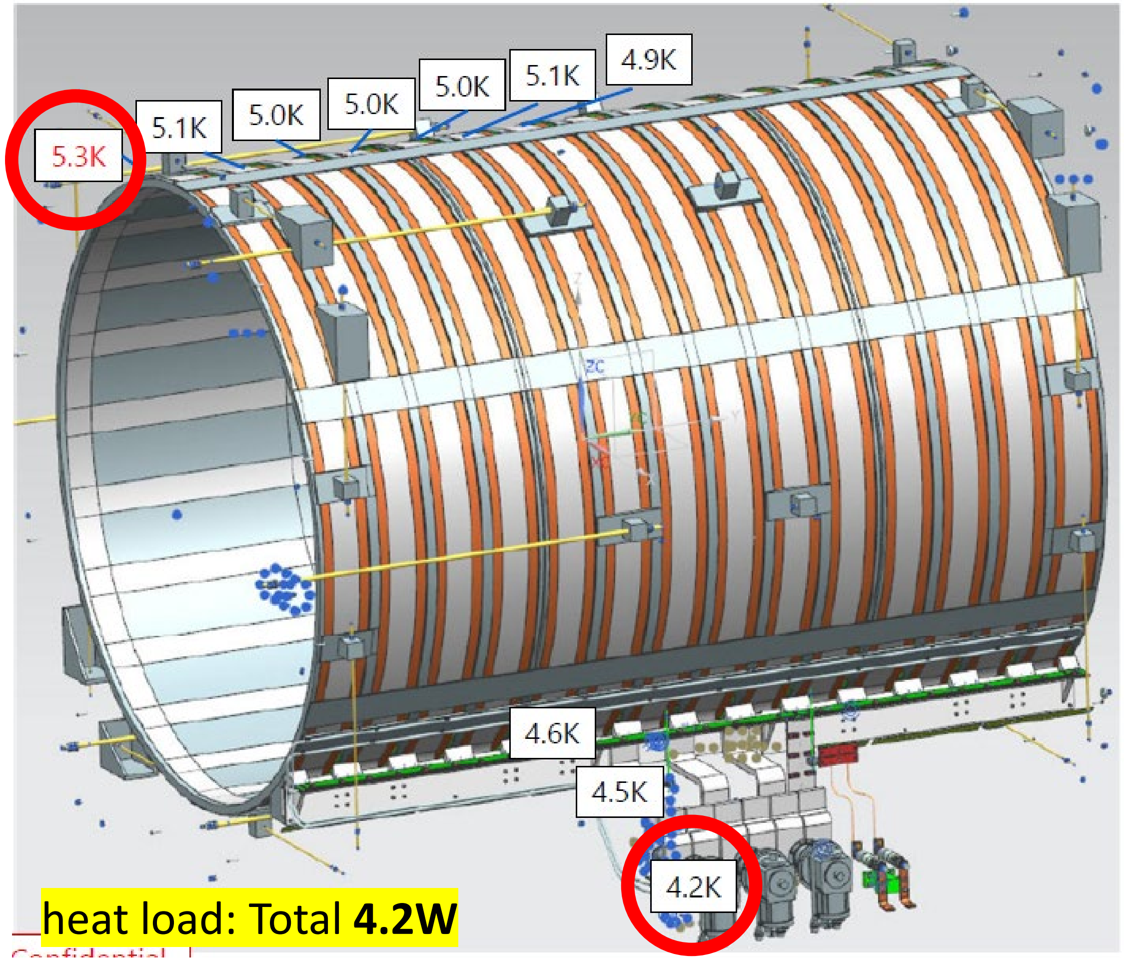


- Since heavy cold mass is cooled down from one side in the present design, a large temperature gradient is expected in the cooling process. It is better to confirm whether it is mechanically acceptable using 3D model.

- Temperature difference from the refrigerator to the farthest coil surface is calculated from the thermal resistance.
- **Temperature difference of 1.1K (= 5.3K - 4.2K) from the coil surface to the refrigerator.**

➢ **Sufficient temperature margin**
  - ✓ maximum temperature = 5.3 K
  - ✓ critical coil temperature = 8.0 K

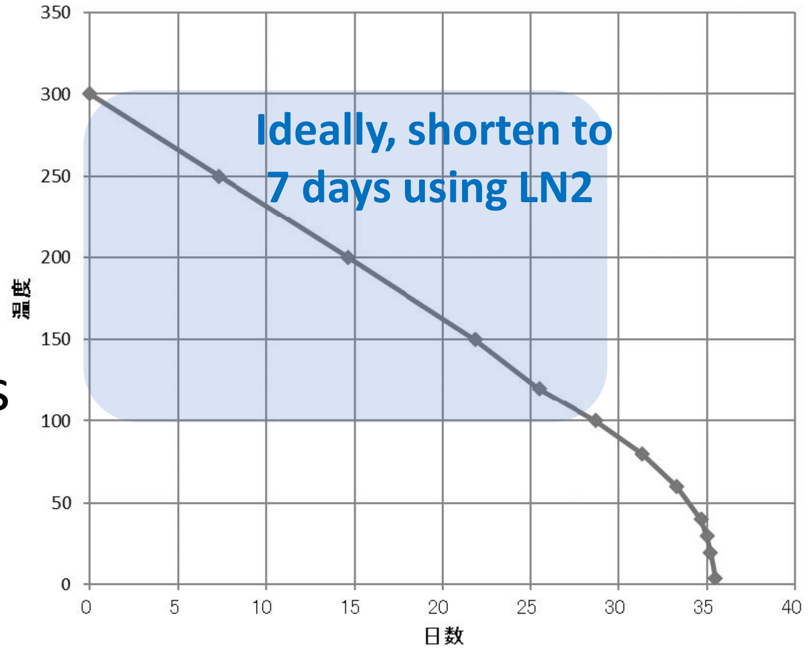
➢ **The cold mass is designed to come to the magnetic field design position after shrinkage at low temperatures.**
  - ✓ When cooled, the cold mass is lifted ~3mm to meet the design axis.



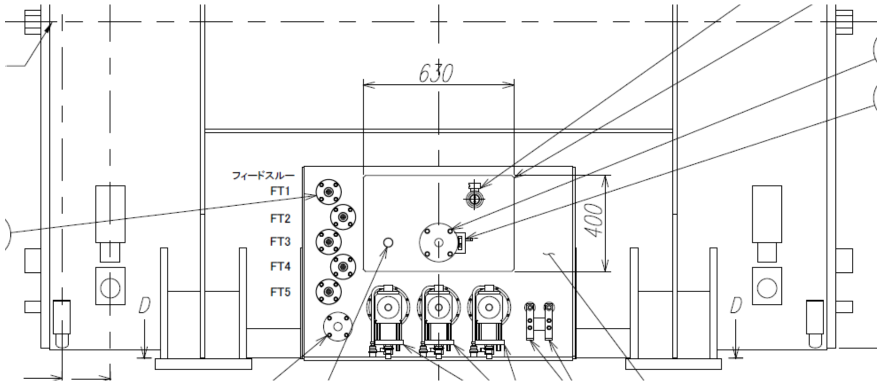
Each coil conduction cooling structure consists of cooling strips made of high purity aluminum with a thermal conductivity of approximately 4,000 W/m·K.

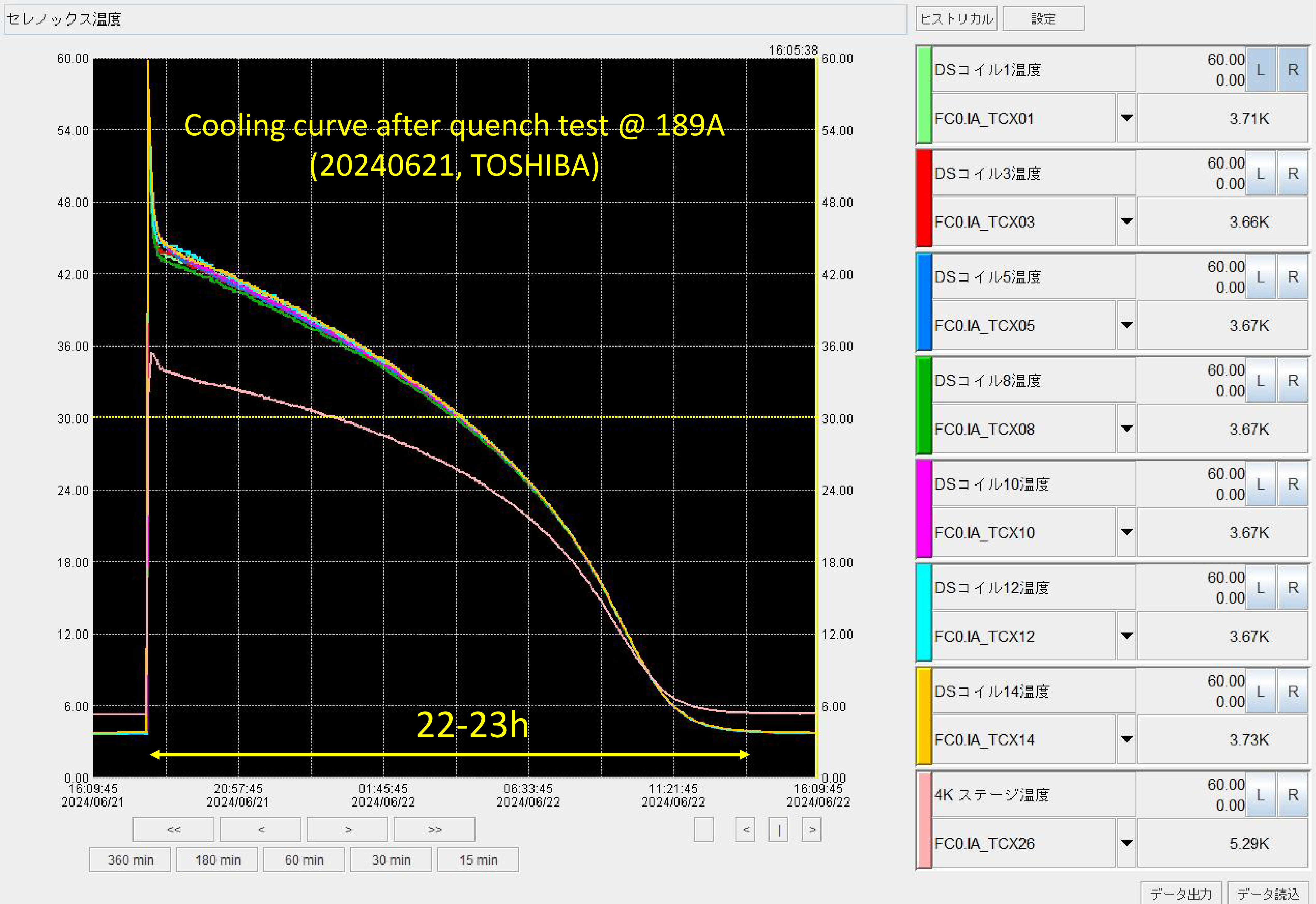
● It is recommended to add 1 GM refrigerator, if possible, to obtain sufficient cooling power against the trouble of one refrigerator and for shortening the cooling period and quench recovery time.

- The magnet can be cooled in realistic time with 3 GMs
  - COMET-DS was successfully cooled using 3 GMs with lower cooling capacity [RDK-415D(1.5W@4K)*3].
  - 36 days with only 3 GMs
  - 14 days by combining with pre-cooling using LN2 and 3 GMs
    - Full of pre-cooling (7 days) required 16,000l LN2 at TOSHIBA
  - In reality, it will take ~1 month by combining GM and the amount of LN2 we can handle



- About the design change (3→4 GMs)
  - Re-design work would take a long time which does not match our time scale
  - Cost of the system with a new design would be drastically increased in addition to cost inflation due to Covid-19 and Ukraine war




セレノックス温度
ヒストリカル
設定
16:05:38
Cooling curve after quench test @ 189A
(20240621, TOSHIBA)
22-23h
60.00
54.00
48.00
42.00
36.00
30.00
24.00
18.00
12.00
6.00
0.00
16:09:45 2024/06/21
20:57:45 2024/06/21
01:45:45 2024/06/22
06:33:45 2024/06/22
11:21:45 2024/06/22
16:09:45 2024/06/22
360 min
180 min
60 min
30 min
15 min
DSコイル1温度 60.00 0.00 L R
FC0.IA_TCX01 3.71K
DSコイル3温度 60.00 0.00 L R
FC0.IA_TCX03 3.66K
DSコイル5温度 60.00 0.00 L R
FC0.IA_TCX05 3.67K
DSコイル8温度 60.00 0.00 L R
FC0.IA_TCX08 3.67K
DSコイル10温度 60.00 0.00 L R
FC0.IA_TCX10 3.67K
DSコイル12温度 60.00 0.00 L R
FC0.IA_TCX12 3.67K
DSコイル14温度 60.00 0.00 L R
FC0.IA_TCX14 3.73K
4K ステージ温度 60.00 0.00 L R
FC0.IA_TCX26 5.29K
データ出力
データ読込

- In the contract of the SS400 yoke production, following items are recommended to be included; analysis of chemical components, measurement of B-H curve, and tensile strength test.

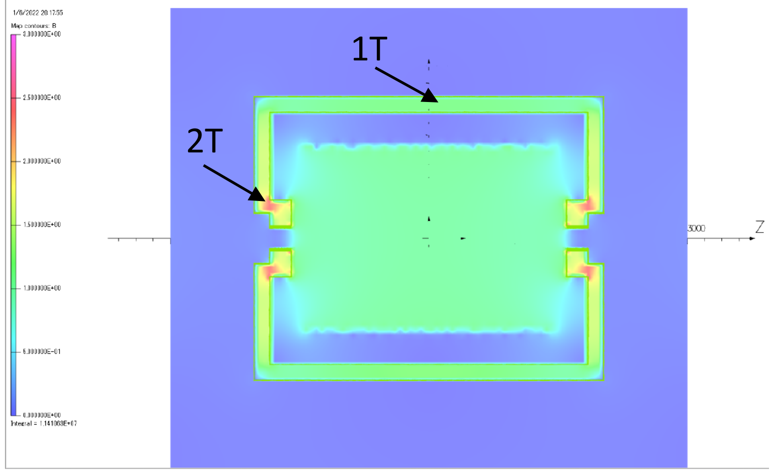
Inspection certificate (ミルシート) for the SS400 plates used for the return yoke

Inspection Certificate No.	Quantity	Plate No.	Manufacturer	Part Name	Tensile Test			Chemical Composition (%)				
					Yield Point, Yield Stress (N/mm2)	Tensile Strength (N/mm2)	Elongetion (%)	C (x1/100)	Si (x1/100)	Mn (x1/100)	P (x1/1000)	S (x1/1000)
P-01	1	809070661	Nippon Steel	bottom-1, bottom-3	253	428	36	15	18	94	11	4
P-02	1	809060301	Nippon Steel	bottom-2, side-6	253	428	33	15	18	94	11	4
P-03	1	809101341	Nippon Steel	side-1, side-3	238	427	37	16	17	95	9	3
	1	809101361			238	427	37	16	17	95	9	3
P-04	1	862302501	Nippon Steel	side-2, top-2	238	427	37	16	17	95	9	3
	1	809070641			253	428	36	15	18	94	11	4
P-05	1	809101341	Nippon Steel	side-4, side-5, top-1, top-2	238	427	37	16	17	95	9	3
	1	809101361			238	427	37	16	17	95	9	3
P-06	1	809070701	Nippon Steel	upstream-yokes, downstream-yokes	253	428	33	15	18	94	11	4
	1	809070801			253	428	33	15	18	94	11	4
P-07	2	437851001-02	Nippon Steel	base frame	292	460	36	17	21	88	18	4
P-08	2	640110409-10	Nippon Steel	base frame	274	428	34	18	16	49	17	4
	1	640110412			273	429	31	18	16	49	17	4
	5	640110412-16			254	421	32	18	17	48	16	5
P-09	4	838350401-04	Nippon Steel	base frame	259	426	34	18	16	46	17	6
P-10	6	437850303-08	Nippon Steel	base frame	267	431	33	18	10	50	20	5
	1	437850502			263	429	36	18	17	47	17	6
P-11	5	640110108-12	Nippon Steel	base frame	311	453	31	18	9	49	18	5
	2	640110215-16			287	428	31	17	9	48	21	6
P-12	1	1989841	Kobe Steel	donut yokes	235	445	30	21	13	75	17	8

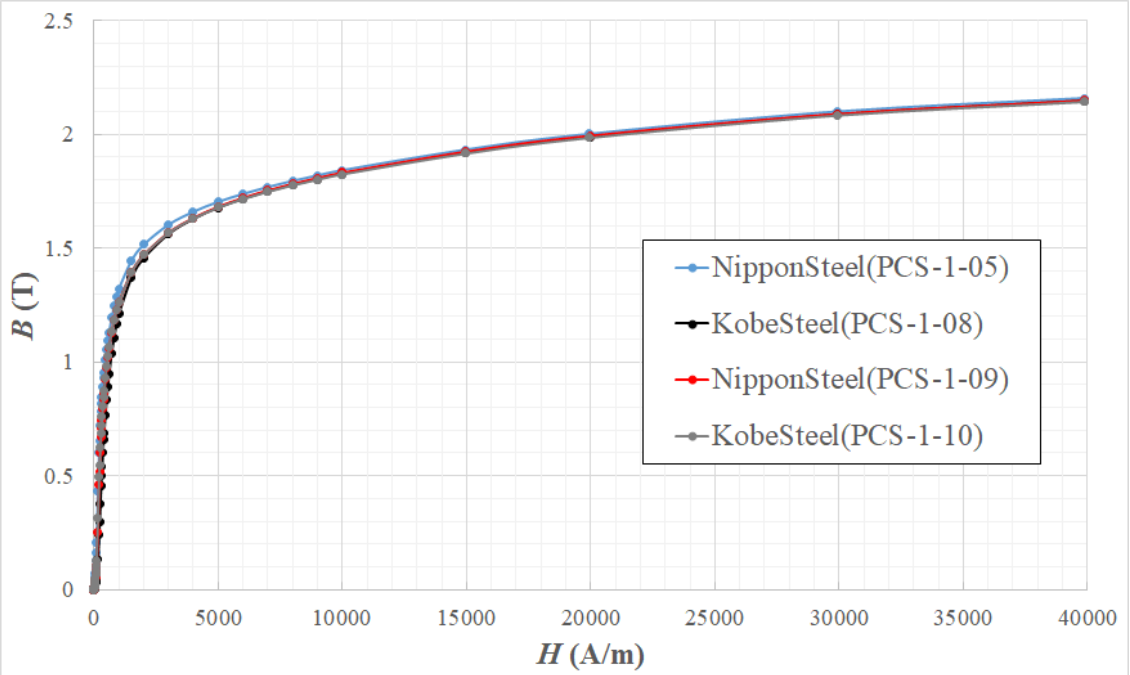
SS400: the lower limit tensile strength of 400 MPa

- In the contract of the SS400 yoke production, following items are recommended to be included; analysis of chemical components, measurement of B-H curve, and tensile strength test.

t=18cm (z,y) x=0 max:3T



- Basic Performance of SS400 was examined using several companies' SS400 test pieces for the COMET experiment in FY2021.
  - Many thanks to the COMET group
- The results on SS400 from "Nippon Steel" and "Kobe Steel" are summarized
  - SS400 plates we use are made by these companies.
- **There is no significant difference in the use of different SS400 at the level we are concerned with.**

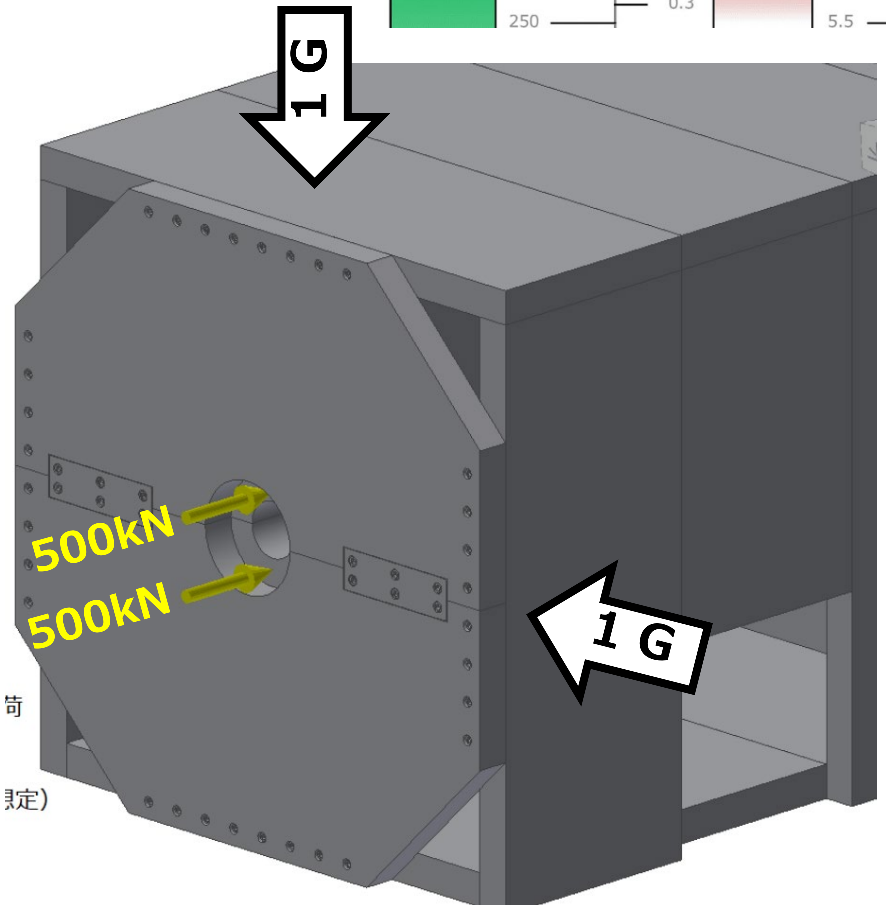


- In the structural analysis for the yoke structure by the electrical force, rotation degrees of freedom should be considered in the boundary condition. Larger displacements than the estimations due to the rotation will occur.

Analysis condition (end yoke)

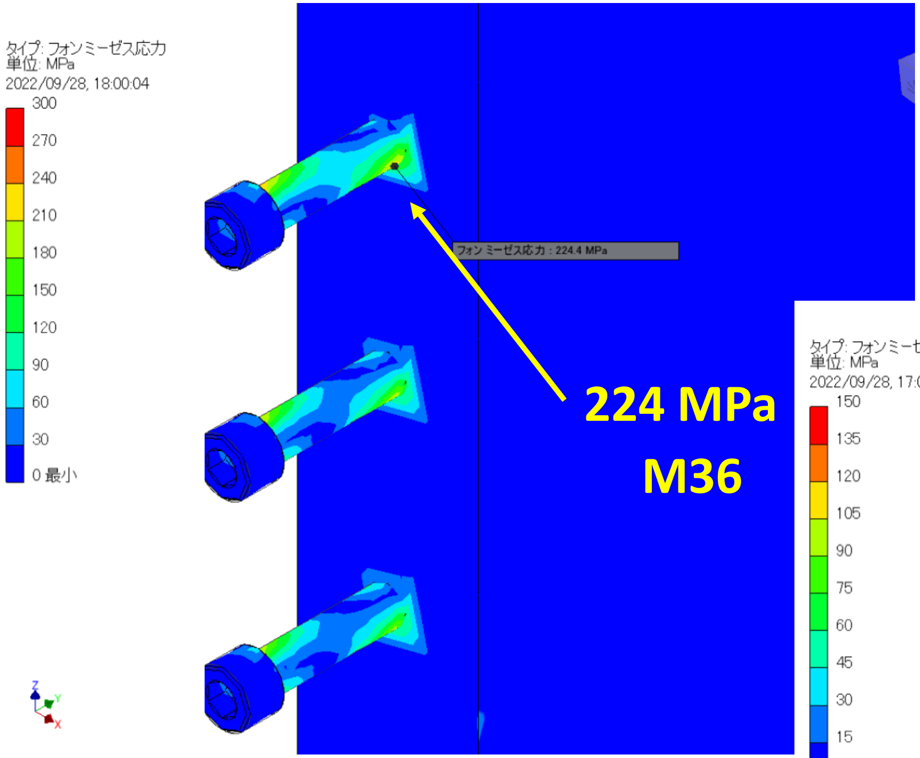
耐震コスト	設計用地震力		地震動レベル	気象庁	
	水平加速度（ガル）(cm/sec^2)	基準震度 K_G		計測震度	震度階級
高	1000	0.9			7
	400	**0.4**	大地震	6.5	6強
	250	0.3		5.5	6弱

- Study of the end-yoke fixing design using **Inventor 2020**
  - FEA (有限要素解析)
- Bolt: M36 x 32
- Connecting plates between top and bottom yokes using M36 x 12
- <u>Constraint condition: Bottom of yoke</u>
- Magnetic force evaluated with OPERA
  - 500kN at 2 points on the yoke center (maximum assumption)
- Gravity:
  - Vertical: 1.0 G
  - Horizontal: 1.0 G assuming earthquake

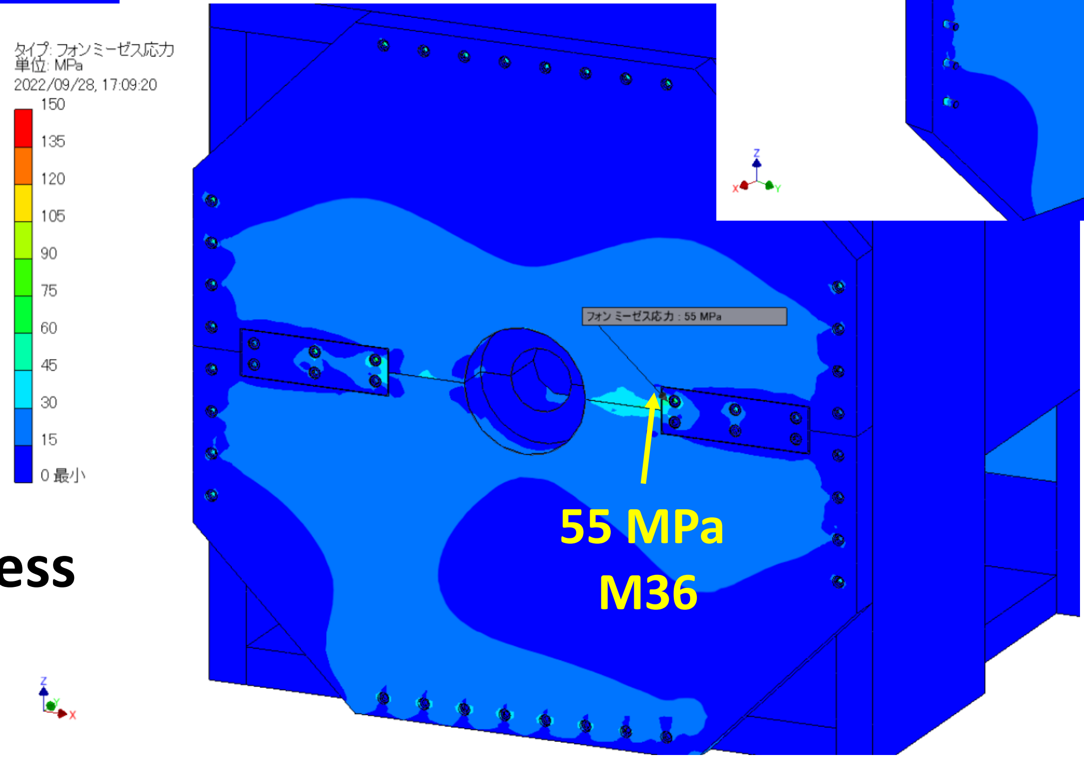


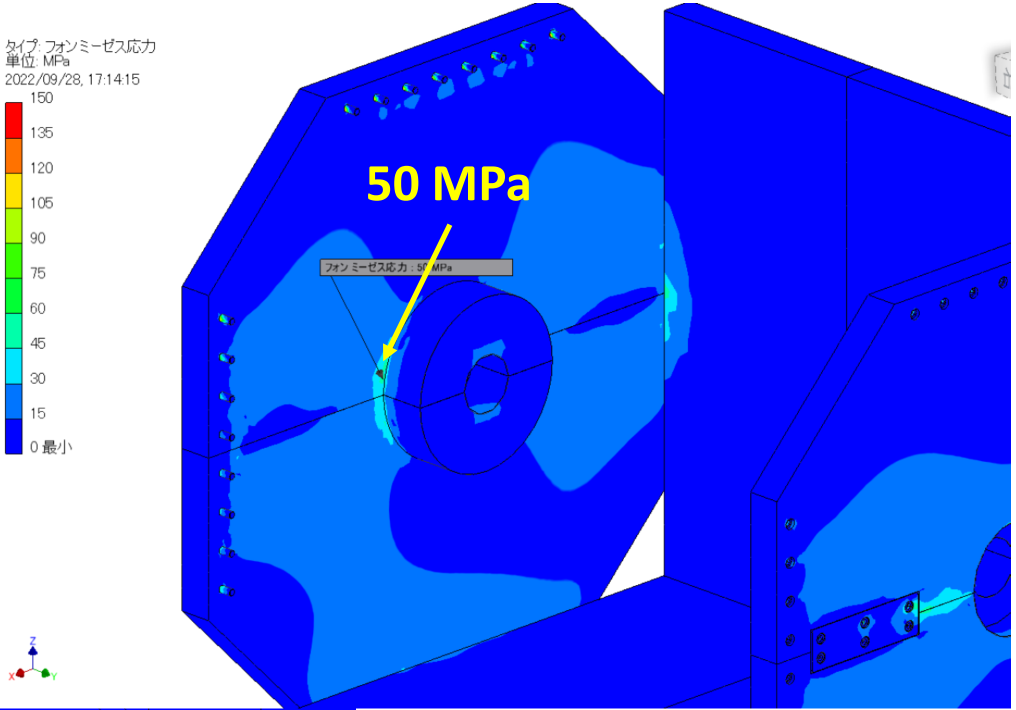
- In the structural analysis for the yoke structure by the electrical force, rotation degrees of freedom should be considered in the boundary condition. Larger displacements than the estimations due to the rotation will occur.

Stress



the maximum (tensile) stress on a bolt is 224 MPa





- In the structural analysis for the yoke structure by the electrical force, rotation degrees of freedom should be considered in the boundary condition. Larger displacements than the estimations due to the rotation will occur.

Source: AIJ Design Standard for Steel Structures - Based on Allowable Stress Concept – (社団法人 日本建築学会編 鋼構造設計基準 - 許容応力度設計法 -)

	Yield point		Allowable stress for temporary (seismic) loading			Allowable stress for sustained loading		
	SS400	**SCM435**		**SS400**	**SCM435**		**SS400**	**SCM435**
	F (N/mm^2)	F (N/mm^2)		(N/mm^2)	(N/mm^2)		(N/mm^2)	(N/mm^2)
Compressive/tensile stress (圧縮/引張応力)	245	930	F	245	930	F/1.5	163	620
Bending stress (曲げ応力)	245	930	F	245	930	F/1.5	163	620
Shear stress (せん断応力)	245	930	F/√3	141	537	F/(1.5*√3)	94	358

- Analysis condition (end-yoke bolt)

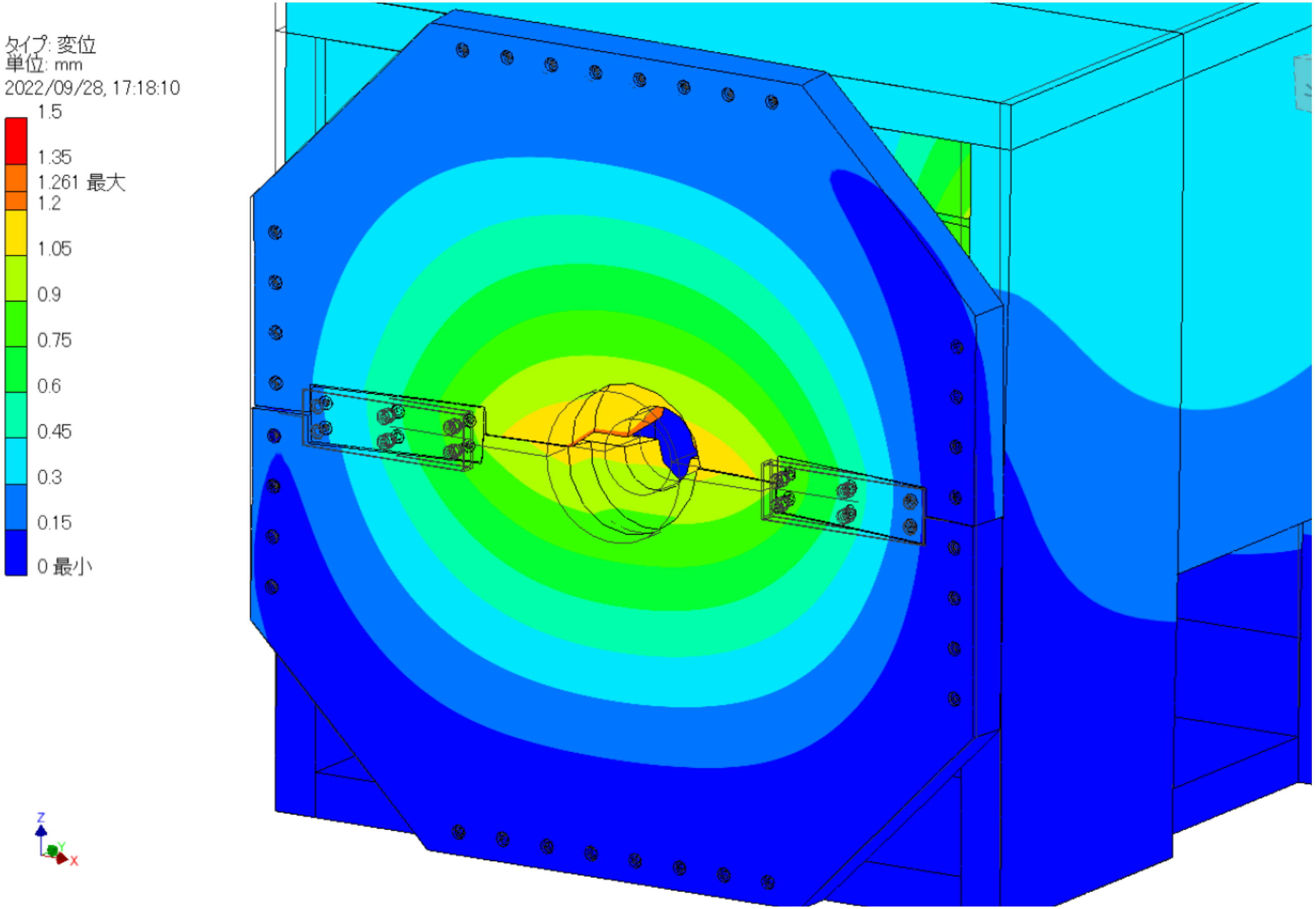
Tensile stress (Inventor analysis)	T	224	N/mm^2
Bolt size		M36	
Nominal diameter	ND	36	mm
Cross section to ND	A_{ND}	1018	mm^2
Effective thread length	L	29	mm
Material		**SCM435**	

- Results
  - Tensile stress → **Safety factor: 620/224=2.8**
  - Thread shear stress
    - Load per bolt: $F = T * A_{ND} = 228{,}004$ N
    - Area under force: $A = π * ND * L = 3279.8\ mm^2$
    - Thread shear stress: $S = F / A = 70$ N/mm2

    → **Safety factor: 358/70=5.1**

- In the structural analysis for the yoke structure by the electrical force, rotation degrees of freedom should be considered in the boundary condition. Larger displacements than the estimations due to the rotation will occur.

Displacement



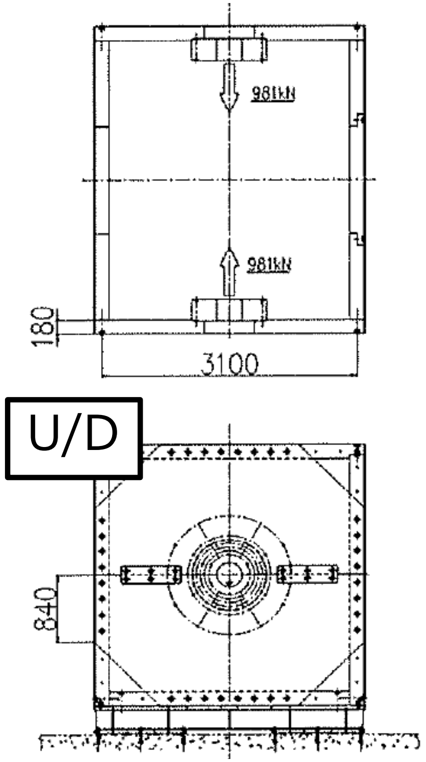
Maximum 1.26 mm

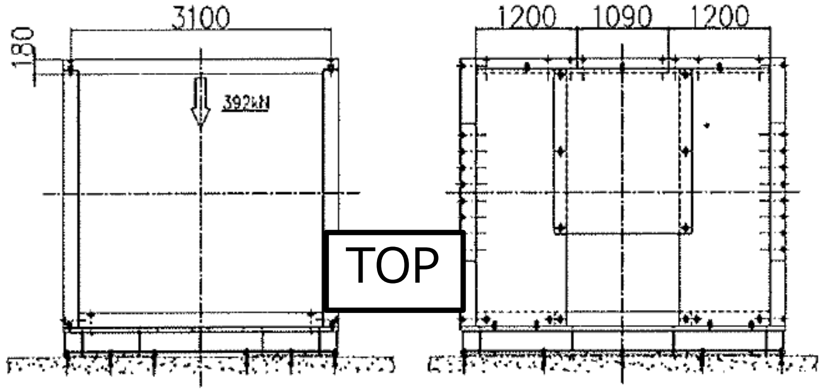
- In the structural analysis for the yoke structure by the electrical force, rotation degrees of freedom should be considered in the boundary condition. Larger displacements than the estimations due to the rotation will occur.

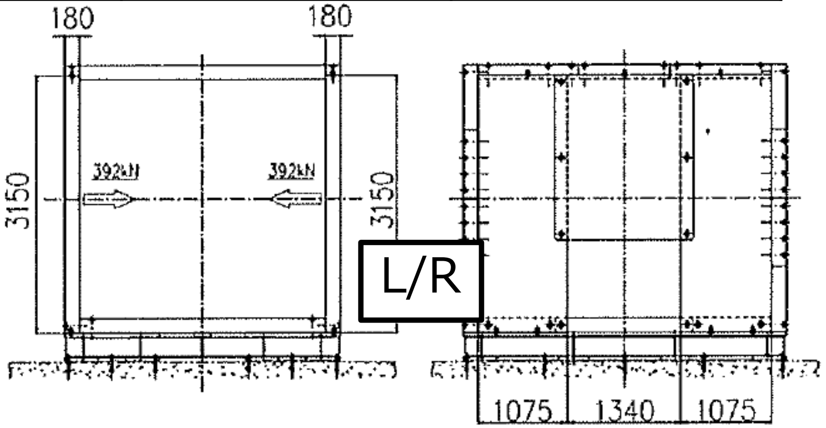
Analysis condition (yoke itself)

- worst-case conditions
- concentrated load in the center with maximum force evaluated with OPERA
- Constraint condition: both ends fixed

Material = **SS400**	Width [W] (mm)	Thickness [T] (mm)	Length [L] (m)	Magnetic force [F] (kN)
Top	1090	180	3100	392
Right	1075	180	3150	392
Left	1075	180	3150	392
Upstream	840	180	3100	981
Downstream	840	180	3100	981







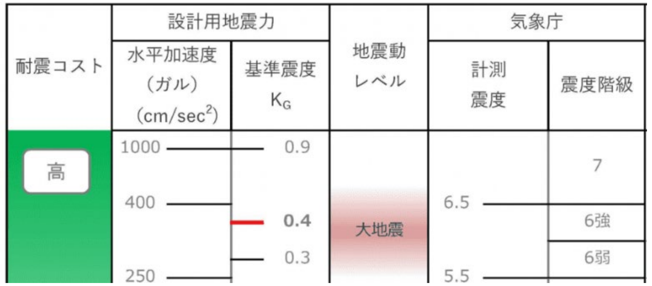
- In the structural analysis for the yoke structure by the electrical force, rotation degrees of freedom should be considered in the boundary condition. Larger displacements than the estimations due to the rotation will occur.

	Yield point		Allowable stress for temporary (seismic) loading			Allowable stress for sustained loading		
	SS400	**SCM435**		**SS400**	**SCM435**		**SS400**	**SCM435**
	F (N/mm²)	F (N/mm²)		(N/mm²)	(N/mm²)		(N/mm²)	(N/mm²)
Compressive/tensile stress (圧縮/引張応力)	245	930	F	245	930	F/1.5	163	620
Bending stress (曲げ応力)	245	930	F	245	930	F/1.5	163	620
Shear stress (せん断応力)	245	930	F/√3	141	537	F/(1.5*√3)	94	358

- Results
  - Moment: $M = 1/8 * L * F$
  - Section modulus: $Z = 1/6 * W * T^2$ (断面係数)
  - Bending stress: $S = M / Z$

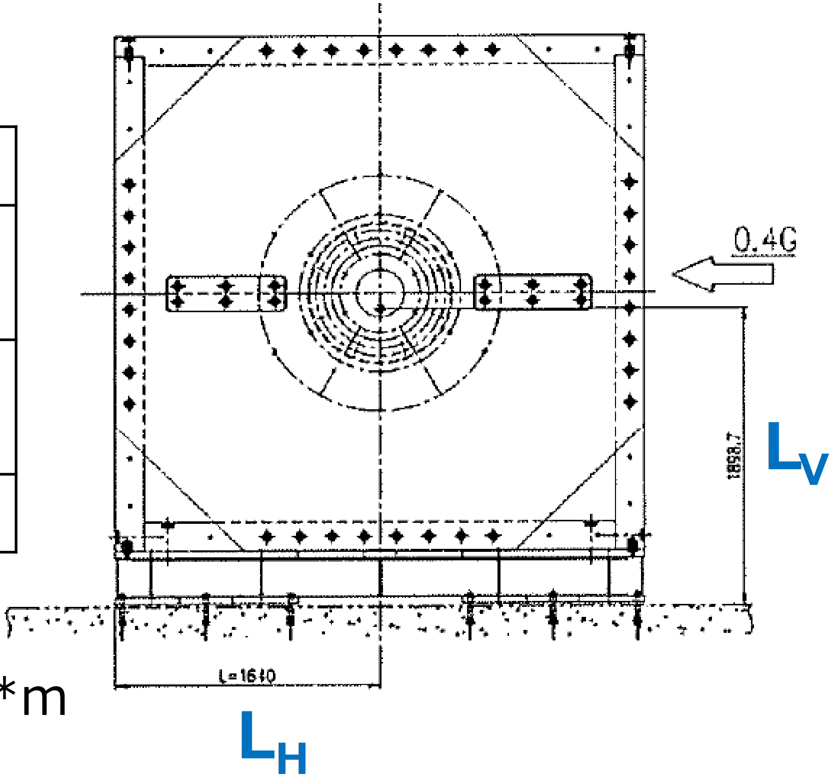
Material = **SS400**	Moment [M] (N mm)	Section modulus [Z] (mm³)	Bending stress [S] (N/mm²)	**Safety factor**
Top	151,900,000	5,886,000	25.8	**6.3**
Right	154,350,000	5,805,000	26.6	**6.1**
Left	154,350,000	5,805,000	26.6	**6.1**
Upstream	380,137,500	4,536,000	83.8	**1.9**
Downstream	380,137,500	4,536,000	83.8	**1.9**

(a) Earthquake resistance to overturning



- Evaluation of collapse due to earthquake <u>after completion</u>
  - Analysis condition and model

Weight (yoke+solenoid)	W	135,000	Kgf
Vertical distance between support and center of gravity	L_V	1898.7	mm
Horizontal distance between support and center of gravity	L_H	1640	mm
Horizontal acceleration		**0.4**	**G**



  - Results

    Overturning moment: $M_o = W * L_V * 0.4 = 102{,}528$ kgf*m

    Moment of resistance: $M_r = W * L_H = 221{,}400$ kgf*m

    → $M_o < M_r$, **the yoke does not collapse**

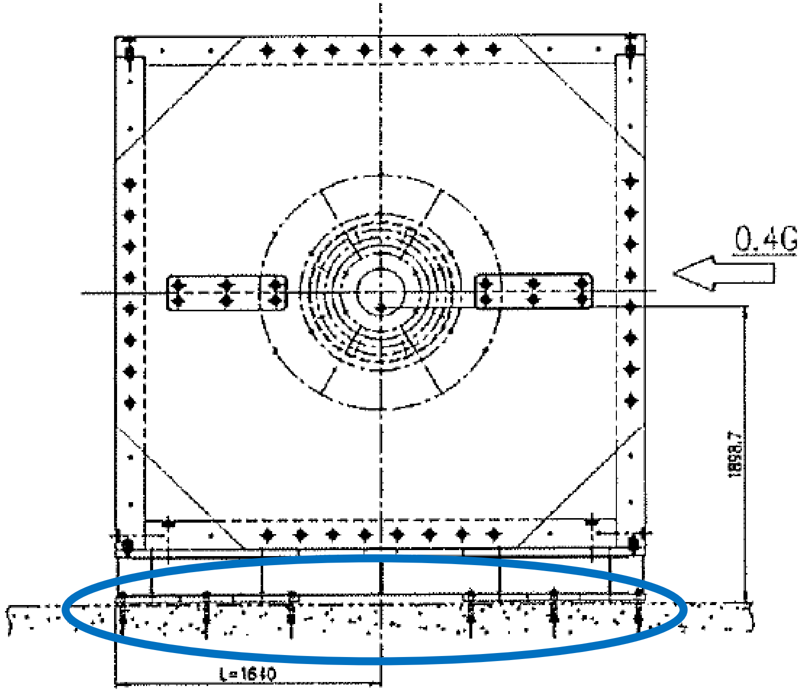
- Conduct seismic analysis to confirm safety.

(b) Earthquake resistance of anchor bolts

	Yield point		Allowable stress for temporary (seismic) loading			
	SS400	SCM435		SS400	SCM435	
	F (N/mm²)	F (N/mm²)		(N/mm²)	(N/mm²)	
Compressive/tensile stress (圧縮/引張応力)	245	930	F	245	930	F
Bending stress (曲げ応力)	245	930	F	245	930	F
Shear stress (せん断応力)	245	930	F/√3	141	537	F

- Evaluation of stresses on anchor bolts due to earthquake
  - Analysis condition and model

Weight (yoke+solenoid)	W	135,000	kgf
Horizontal acceleration		**0.4**	**G**
Bolt size		M24	
Effective diameter		22.051	mm
Cross section	A	381.9	mm2
Number of the bolt	N	24	
Material		**SS400**	



- Results

Shear stress: S = W * 0.4 / (A * N) = 57.8 N/mm2

→ **Safety factor: 141/57.8=2.4**

- Conduct seismic analysis to confirm safety.

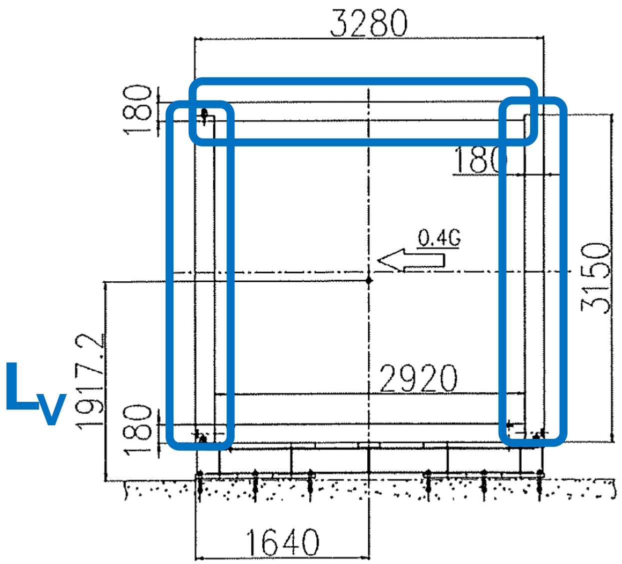
(c) Earthquake resistance to overturning during assembly

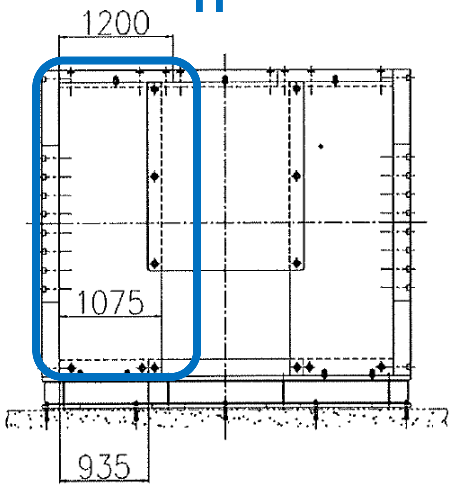
- Evaluation of collapse due to earthquake during construction
  - Analysis condition and model
    - using 1-section with a width of 1200mm

Weight (top+L+R)	W	15,131.1	kgf
Vertical distance between support and center of gravity	L_V	1917.2	mm
Horizontal distance between support and center of gravity	L_H	1640	mm
Horizontal acceleration		**0.4**	**G**

  - Results

Overturning moment: M_o = W * G * 0.4 = 11,604 kgf*m
Moment of resistance: M_r = W * L = 24,815 kgf*m
→ M_o < M_r, **the yoke does not collapse**



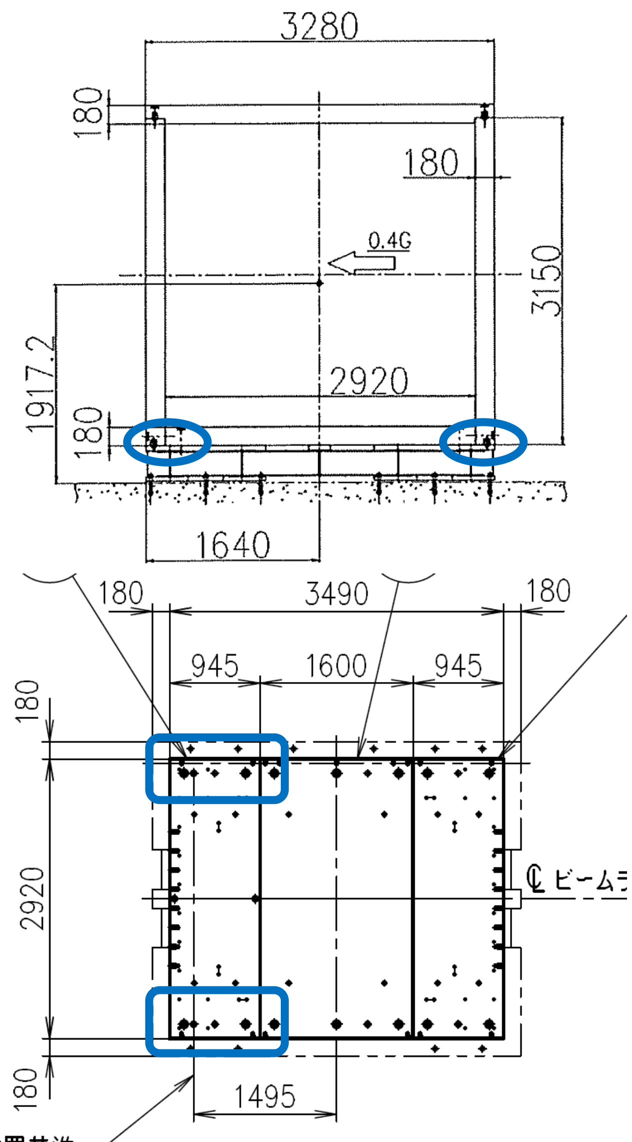


- Conduct seismic analysis to confirm safety.

(d) Earthquake resistance of securing bolts during assembly

- Evaluation of stresses on bottom yoke fixing bolts due to earthquake
  - Analysis condition and model
    - using 1-section with a width of 1200mm

Weight (top+L+R+bottom)	W	18,988.9	kgf
Horizontal acceleration		**0.4**	**G**
Bolt size		M30	
Effective diameter		27.727	mm
Cross section	A	603.8	mm2
Number of the bolt	N	4	
Material		**SS400**	

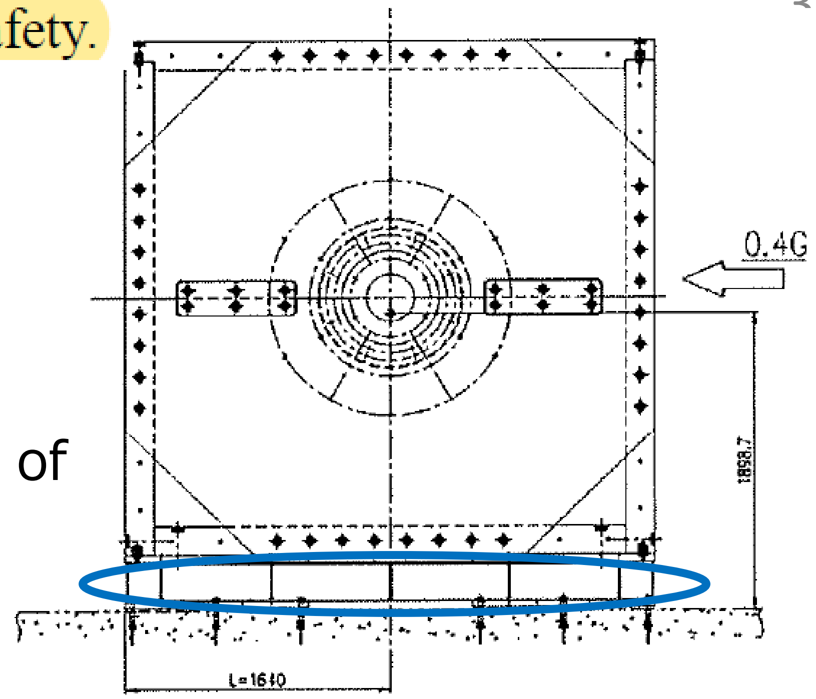


- Results

  Shear stress: S = W * 0.4 / (A * N) = 30.8 N/mm2

  → **Safety factor: 141/30.8=4.6**

● Conduct seismic analysis to confirm safety.



(e) Strength of the base frame

- Analysis Condition
  - Compressive stress is evaluated for the components of the base frame
  - Rib material is not considered (on the safe side)
  - Material = **SS400**

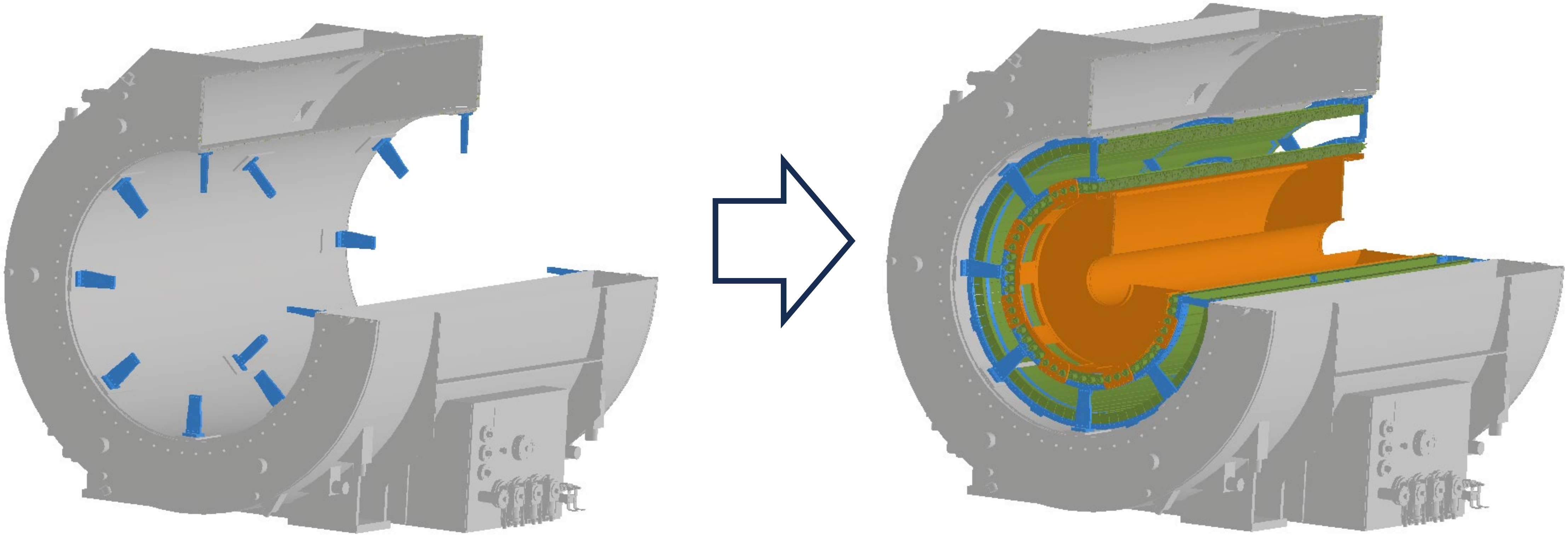
Cross section [S]	Quantity	Length (mm)	Thickness (mm)	Total (mm2)
	4	3,800	9	136,800
Weight [M]	Solenoid (kgf)	Yoke (kgf)	Upper part of the base frame (kgf)	Total (kgf)
	20,000	115,000	3,414	138,414

- Results:
  - Compressive stress: M / S = 9.9 N/mm2

→ **Safety factor: 163/9.9=16.5**

- In the fabrication of the coil vessel, the attachment structure should be made to fix the detector frame, LM guide rails, and the structure for the explosion-proof etc.

- Detector attachment method was changed from using a rail structure to **a pillar structure**
  - to simplify and robust the detector supporting structure
  - a support structure of the CNC and CDC is built directly into the inner wall of the magnet

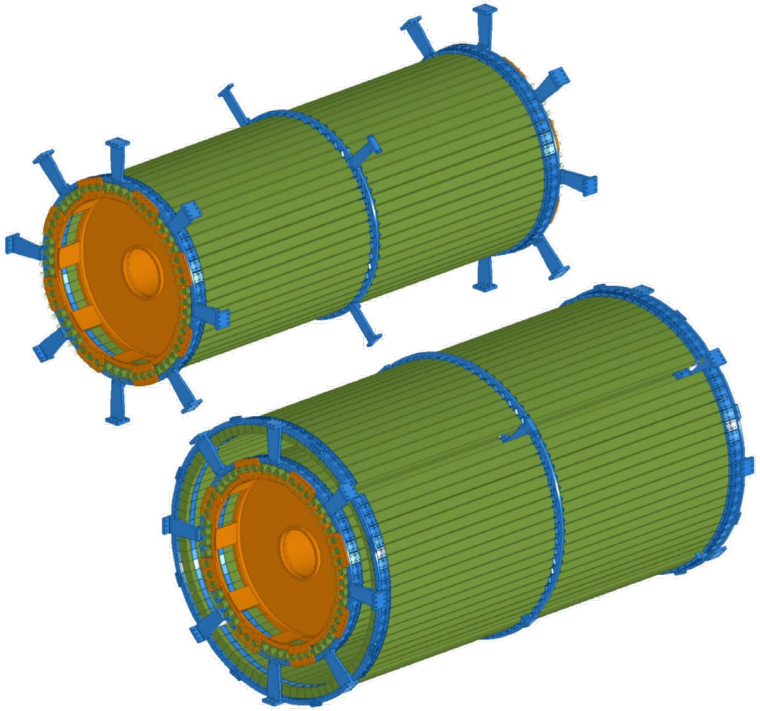


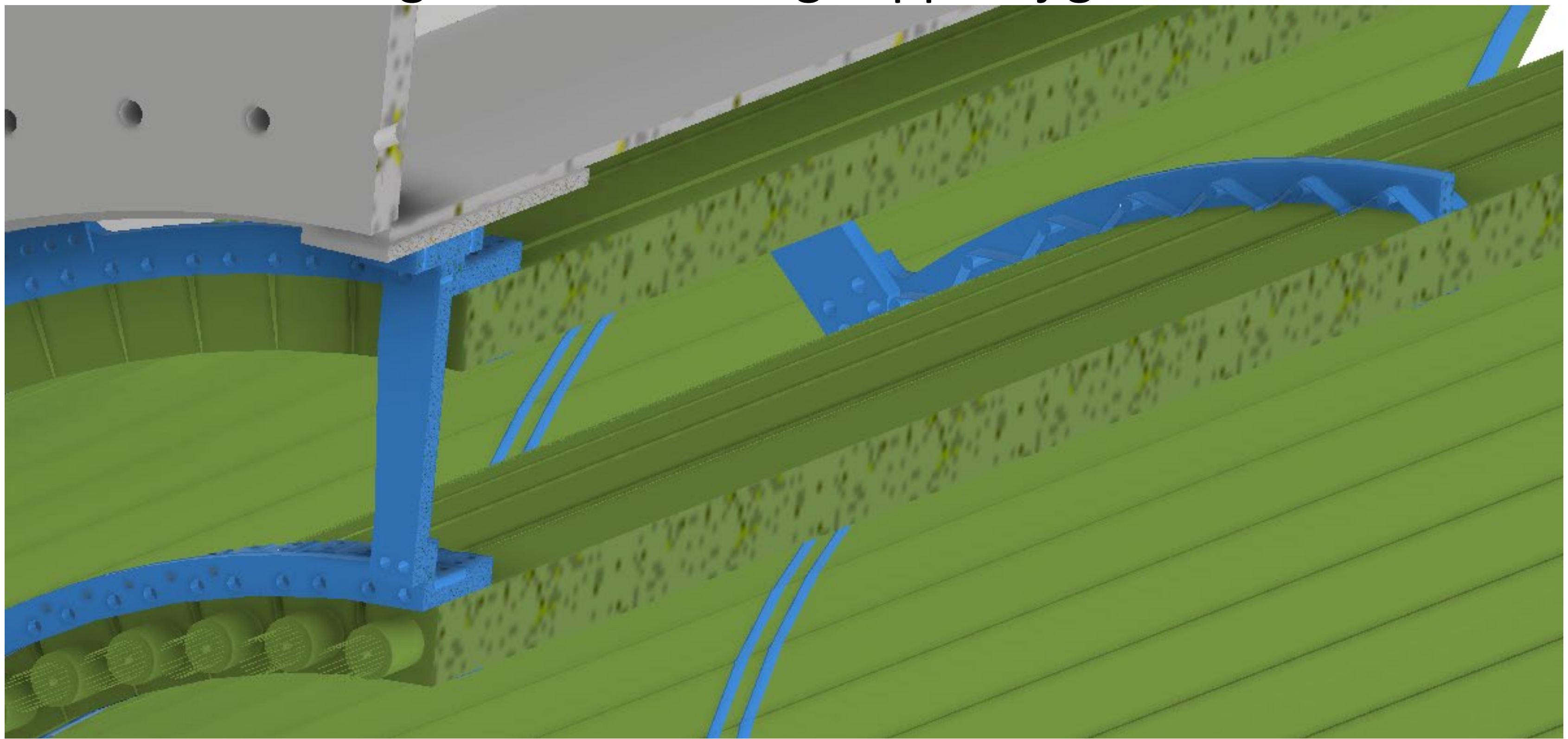
Answers to the FIFC report

Supporting structure of CDC and CNC

- Large sag is expected in the scintillators of 3 m length, rigid frame structure which is connected each other seems to be required to cover whole scintillators region, e.g., at upstream, downstream, and middle positions.

- Scintillators are supported at upstream, downstream and middle position using a ring support structure
  - ring structures are mounted on the pillars
  - each CNC module is mounted on the ring structures using support jigs and thin stainless-steel bands.

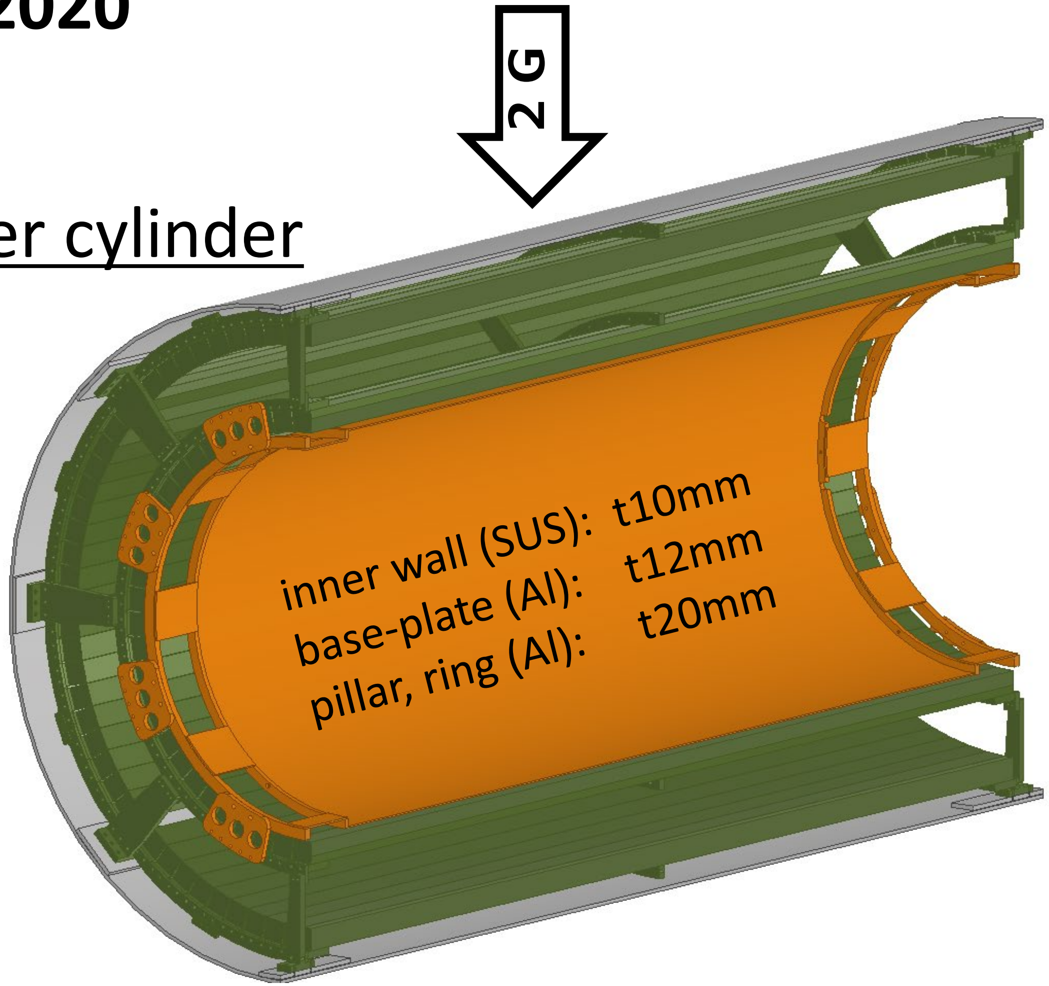




- Large sag is expected in the scintillators of 3 m length, rigid frame structure which is connected each other seems to be required to cover whole scintillators region, e.g., at upstream, downstream, and middle positions.

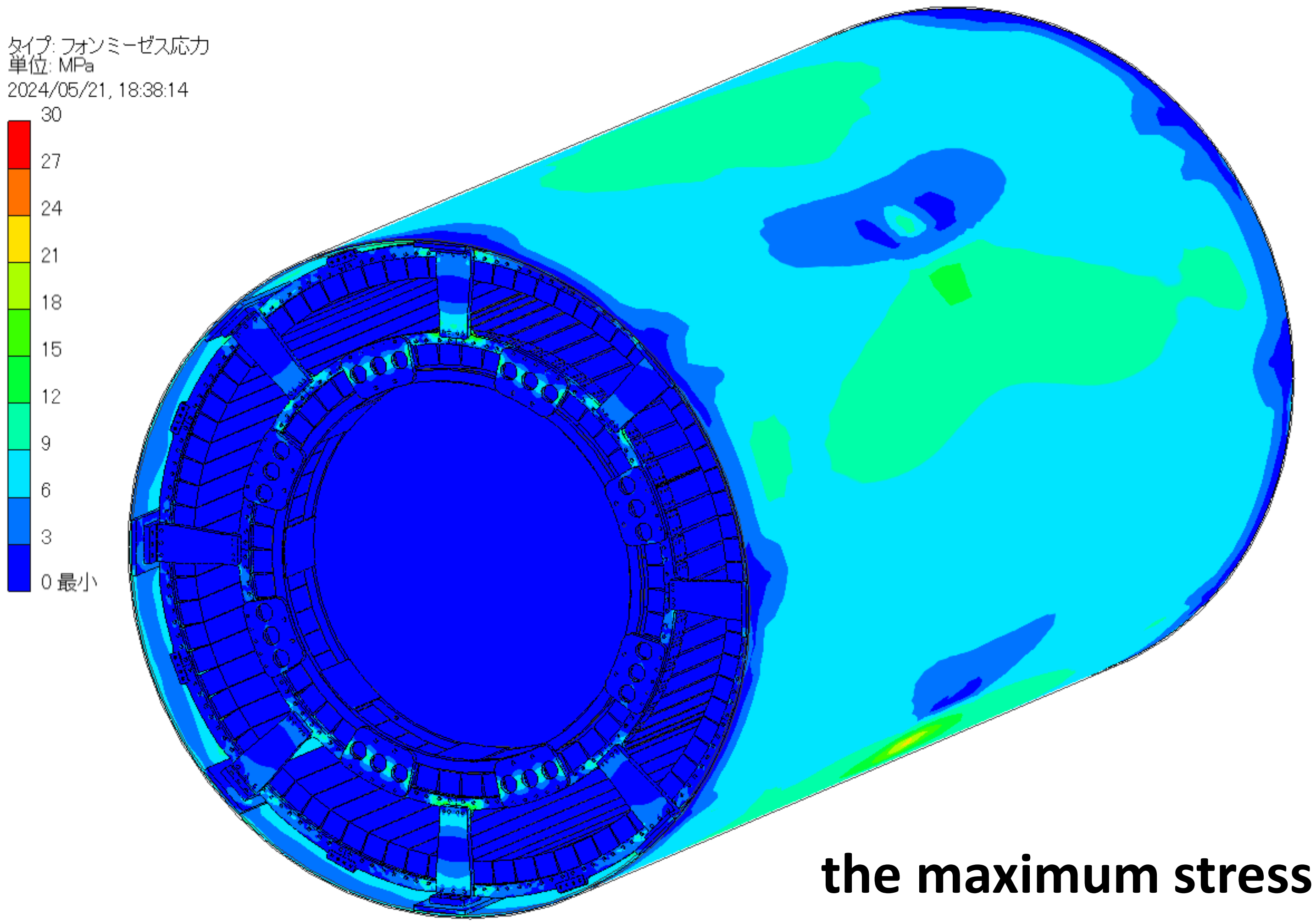
Analysis condition

- Realistic strength calculation using **Inventor 2020**
  - FEA (有限要素解析)
- Constraint condition: the end face of the inner cylinder
- Materials:
  - Inner wall of the vacuum vessel: SUS304
  - Supporting frame: A5083
  - Scintillator: PMMA (acrylic, 1.188g/cm3)
- Contact: the parts are bonded together
  - without friction
- Load: 2 G gravity in the vertical direction



- Large sag is expected in the scintillators of 3 m length, rigid frame structure which is connected each other seems to be required to cover whole scintillators region, e.g., at upstream, downstream, and middle positions.

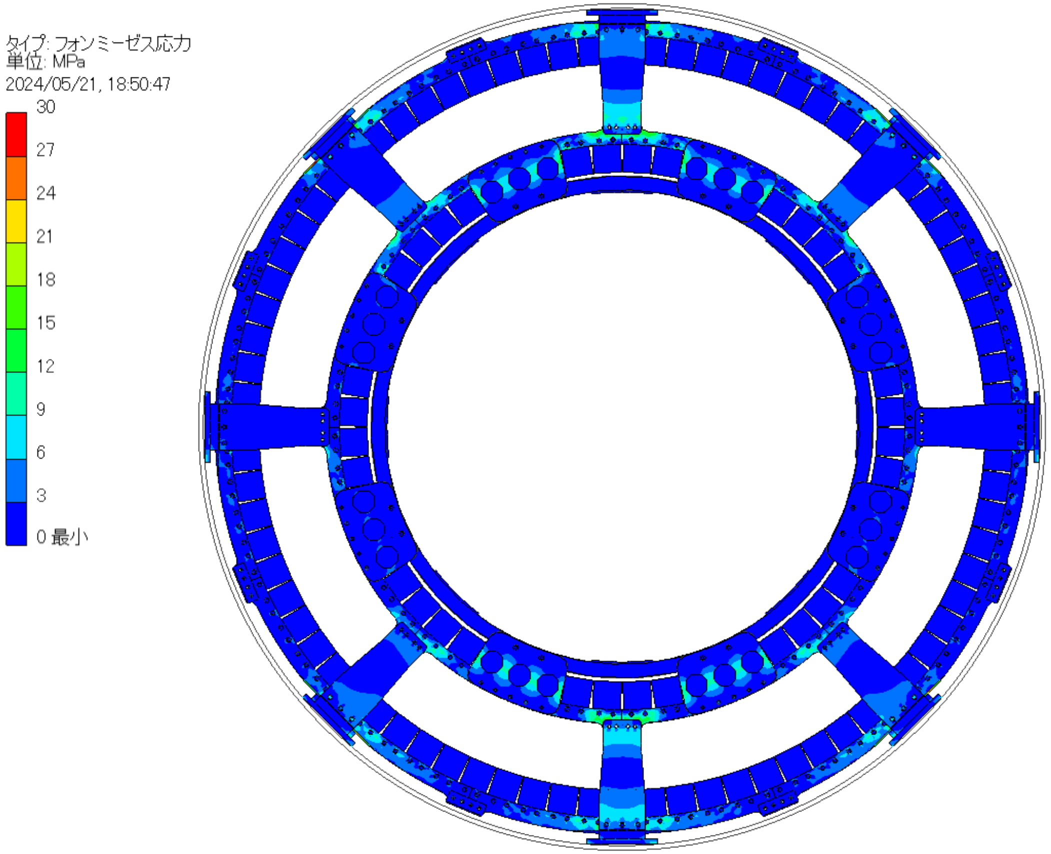
Stress (overall)

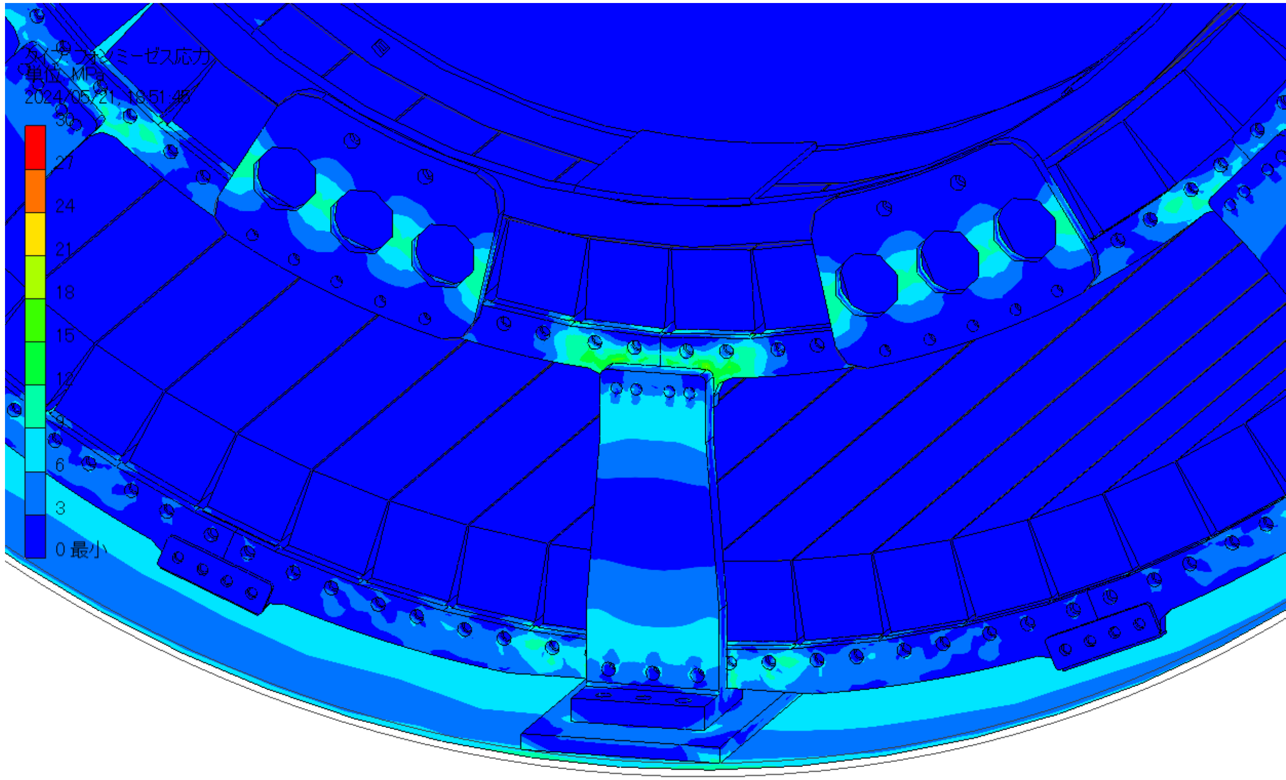


the maximum stress < 30 MPa

- Large sag is expected in the scintillators of 3 m length, rigid frame structure which is connected each other seems to be required to cover whole scintillators region, e.g., at upstream, downstream, and middle positions.

Stress (support frame, base part of the inner cylinder)

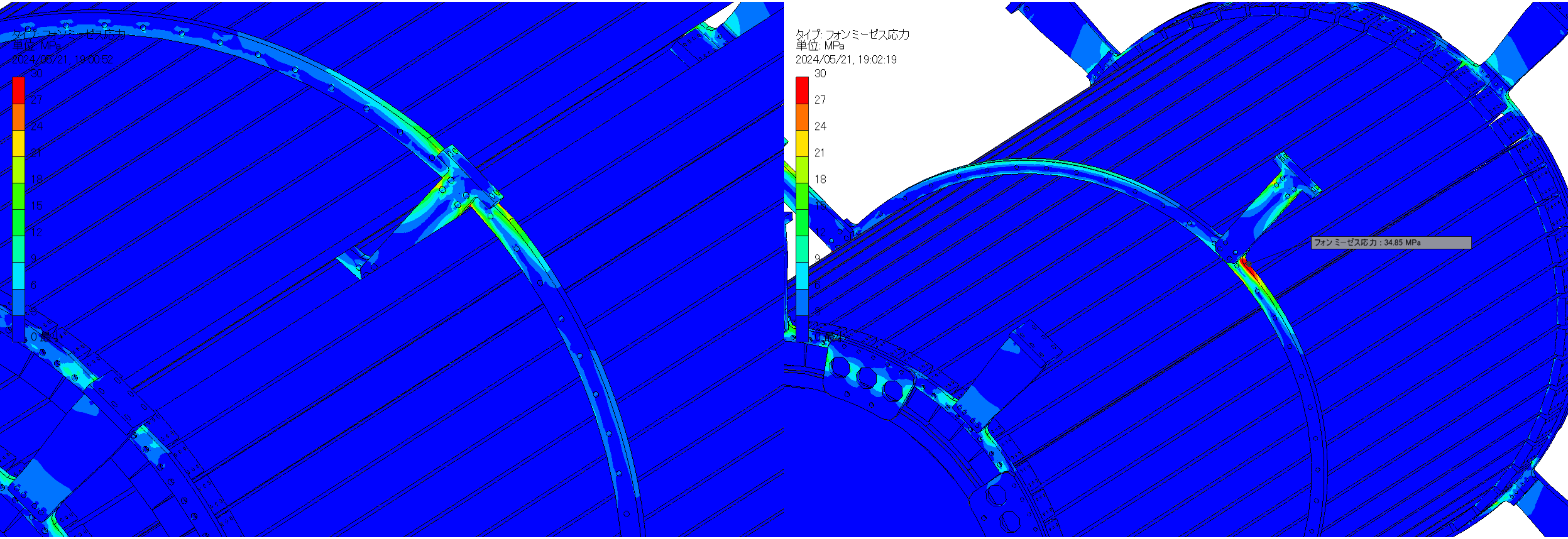




the maximum stress < 30 MPa

- Large sag is expected in the scintillators of 3 m length, rigid frame structure which is connected each other seems to be required to cover whole scintillators region, e.g., at upstream, downstream, and middle positions.

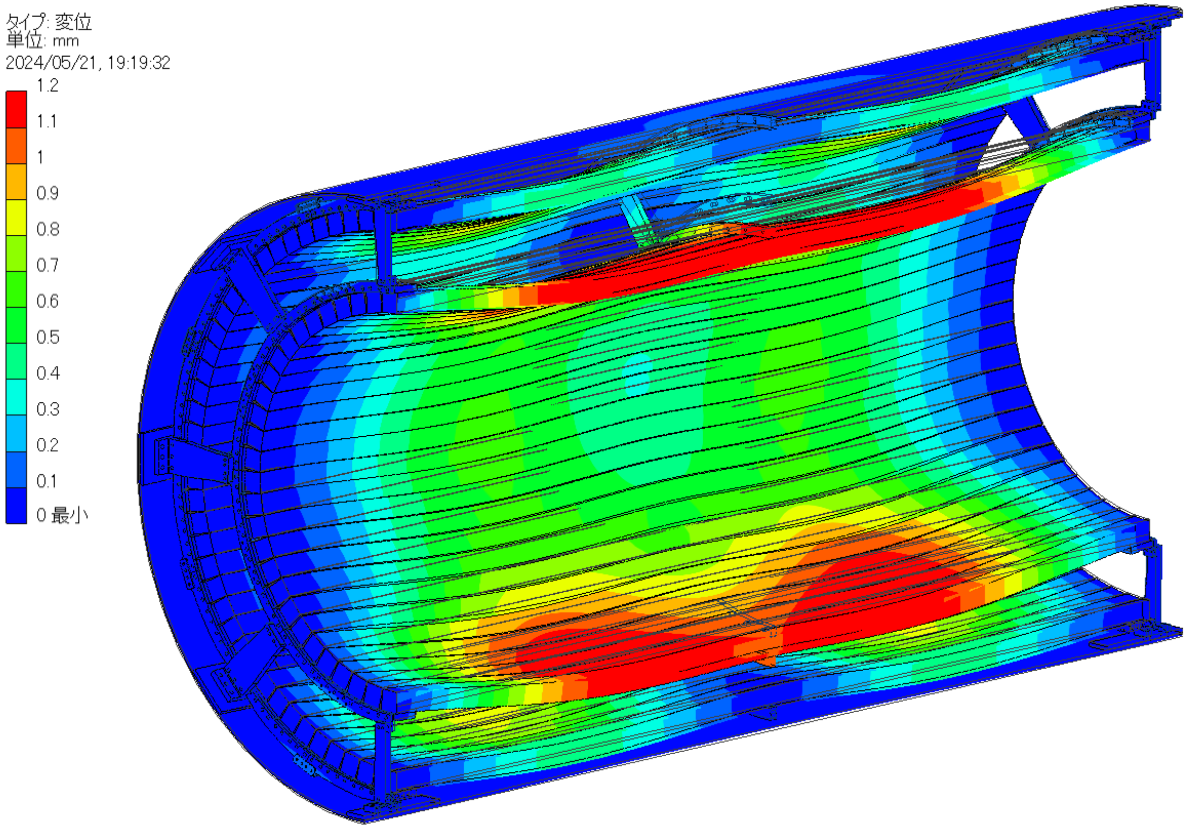
Stress (support frame at the CNC outer, inner layers at center of inner cylinder)

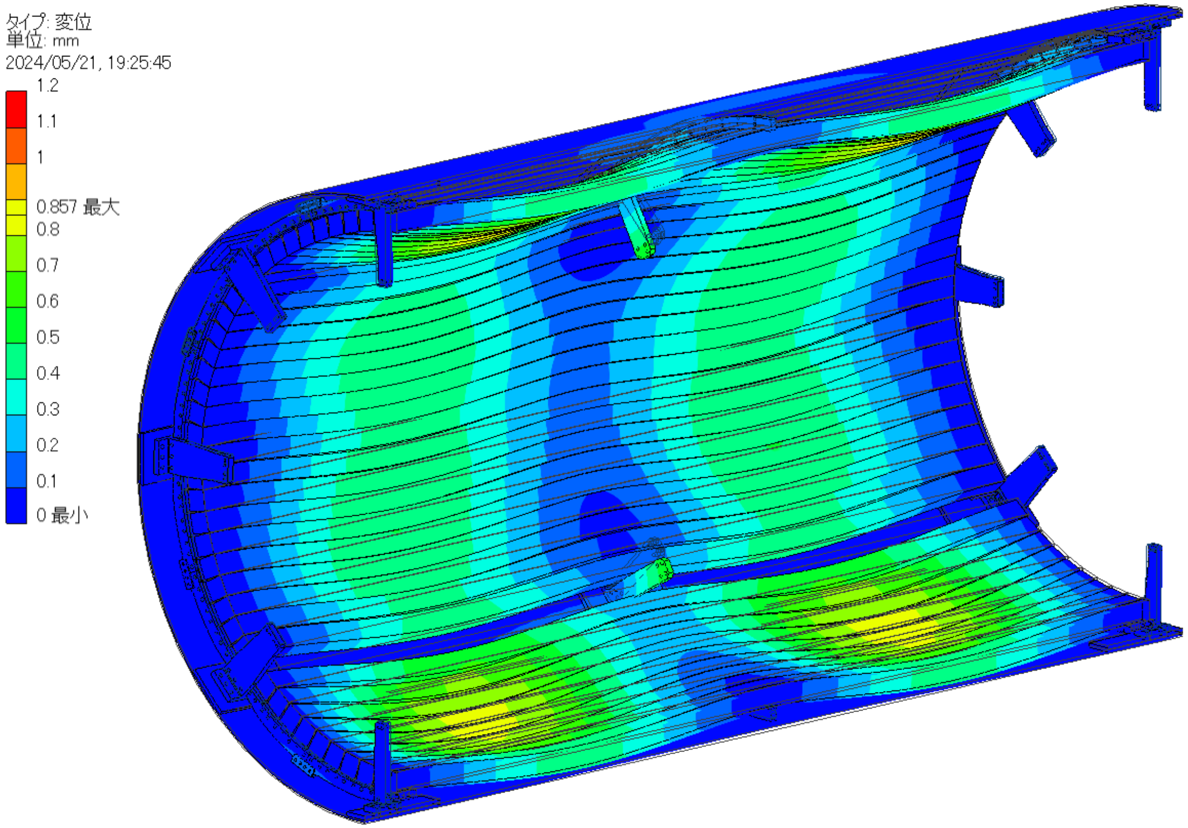


the maximum stress < 30 MPa

- Large sag is expected in the scintillators of 3 m length, rigid frame structure which is connected each other seems to be required to cover whole scintillators region, e.g., at upstream, downstream, and middle positions.

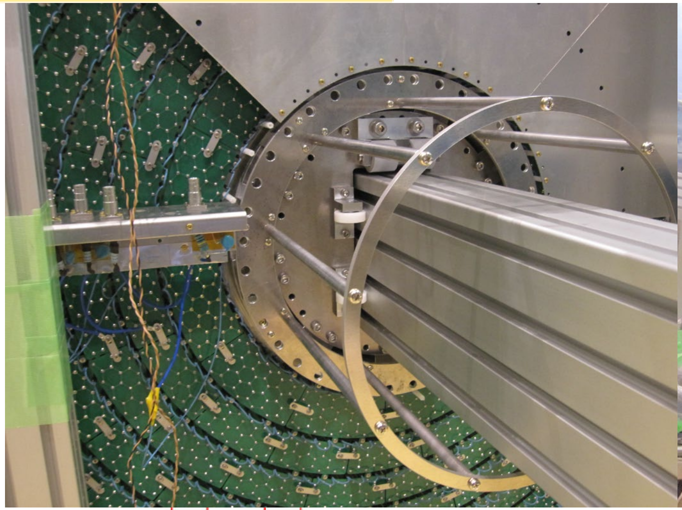
Displacements (the CNC inner layer, the outer layer)

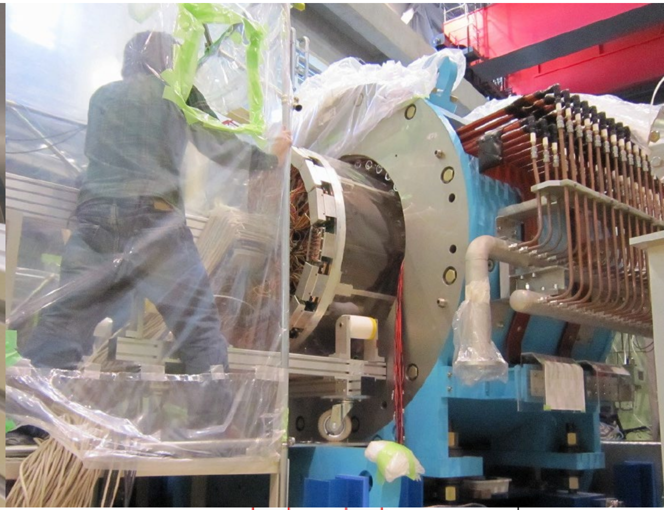




the sag of the scintillators ~ 1 mm

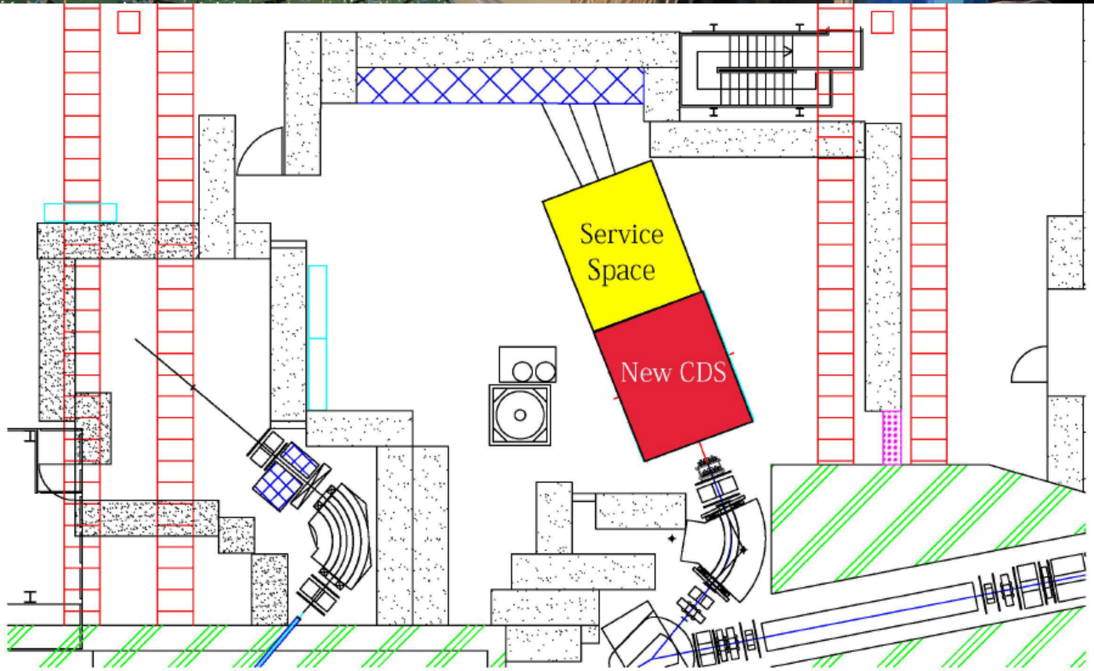
- Consider the cable supporting structure and their handling when the detector is rolled in/out. The method for rolling in/out and the required space for detector tests and maintenance may affect the design of the K1.8BR area.





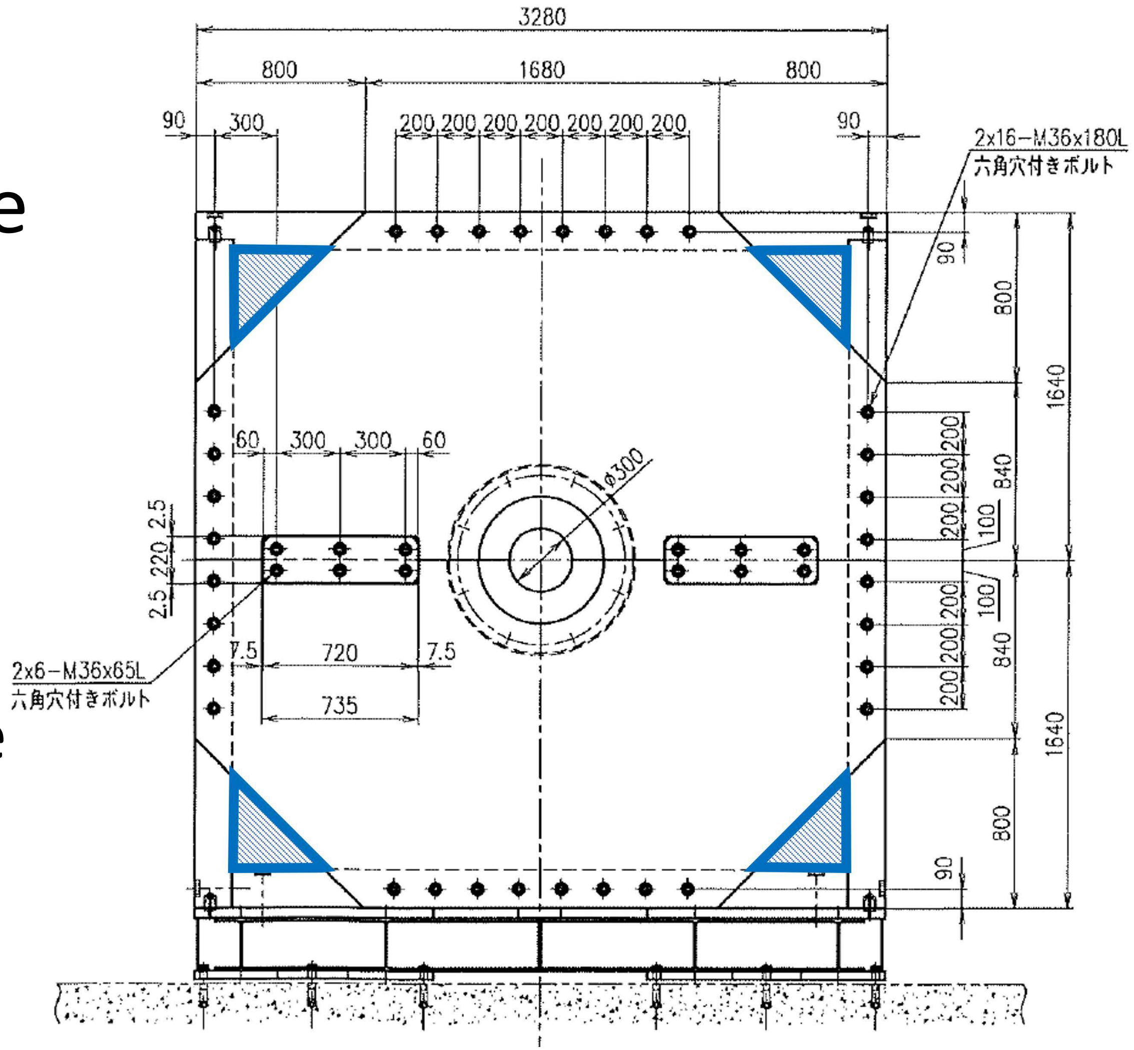
- CDC is installed by inserting a long frame bar into the center of the CDC and magnet
  - We plan to use a splittable bar twice the length of the solenoid.

- Service space equivalent to the installation area of the magnet is required downstream of the magnet
  - to prepare and install the CDC by rolling it in and out of the magnet



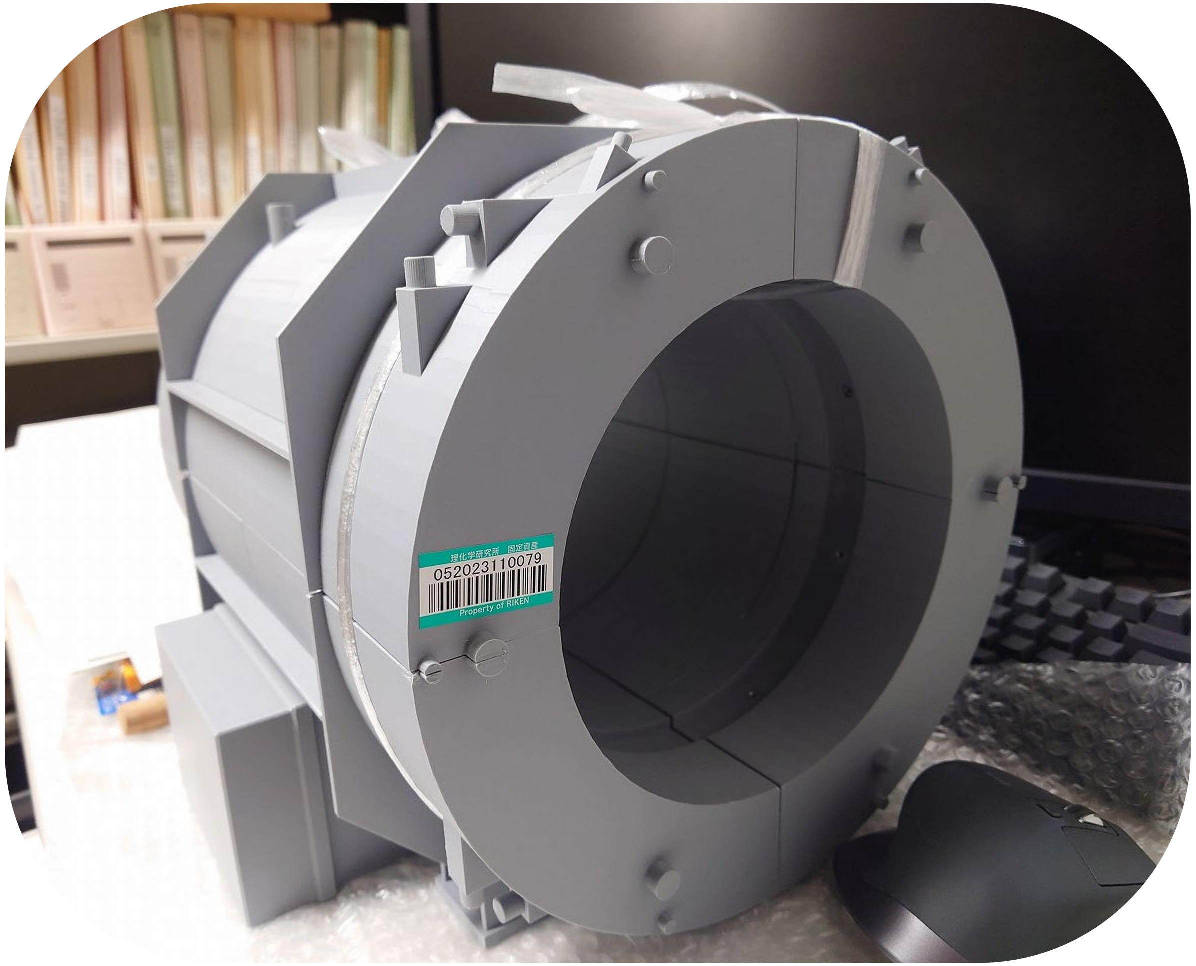
- Consider the cable supporting structure and their handling when the detector is rolled in/out. The method for rolling in/out and the required space for detector tests and maintenance may affect the design of the K1.8BR area.

- Cable support structure is built inside and outside the return yoke
  - cables for the CDC and CNC are fixed to the structure
  - cables are pulled out through the 4x2 holes of the return yoke
  - when rolling in/out of the CDC, cable handling can be done outside the return yoke



- Mock-up test is helpful in order to consider the mechanical structure and the detector maintenance scenario.

- Already made the 1/10 mock-up model
  - We will also make 1/10 detector models



Other questions from referees

K- beam

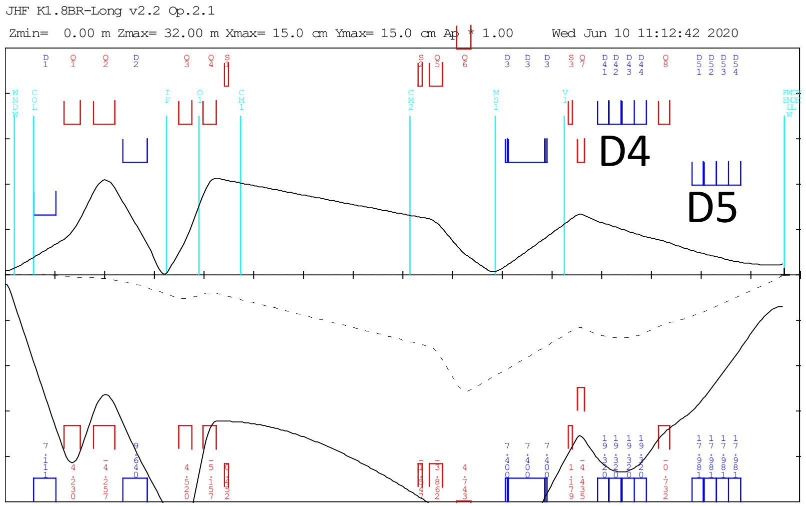
Q) Efficiency of the K- beam hitting the target with the current setup?

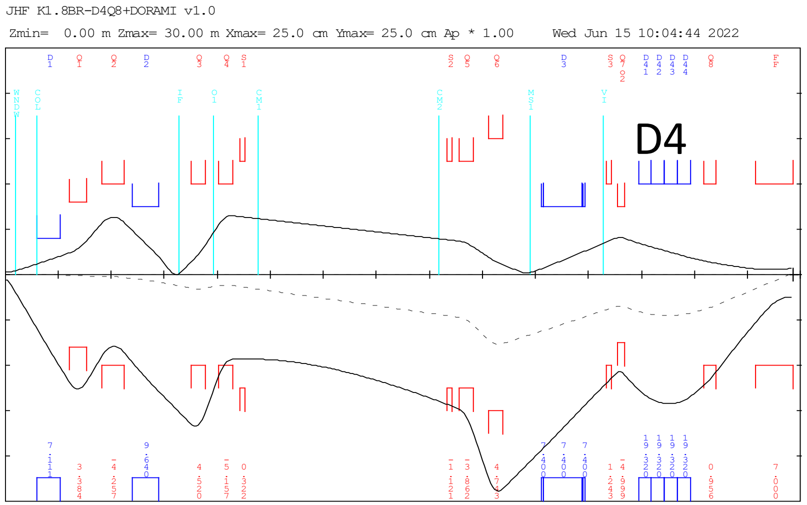
A) ~65% of K- beam detected by the DEF (beam definition counter)

Q) Will the efficiency change after removing D5?

A) No, the efficiency will be almost the same because the beam image at the FF is estimated to be almost unchanged from the TRANSPORT/TURTLE calculations

T1 profile (half)
x: 0.6 cm
dx: 50 mr
y: 0.3 cm
dy: 10 mr
dp: 3%





FF profile (half)
x: 2.135cm → 2.574cm
y: 0.731cm → 0.742cm
R11=3.276 → 4.150
R33=-2.395 → -2.139

K- beam

Q) Will the DEF be used on E80?

A) Yes, we will prepare the new DEF optimized for realistic beam profile

Q) How much does the magnification (R11) and dispersion (R16) from BHT to BLDC change after removing D5?

A) Magnification (R11) changes about twice as large, and dispersion(R16) about the same. Note that R12 becomes much smaller.

BLC1-D5-BLC2

	x[cm]	θ[mrad]	y[cm]	Φ[mrad]	l[cm]	δ[%]
x'[cm]	0.19678	0.20554	0	0	0	-1.33079
θ'[mrad]	-4.6338	0.24164	0	0	0	-7.67738
y'[cm]	0	0	1.23585	0.32661	0	0
Φ'[mrad]	0	0	1.55747	1.22077	0	0
l'[cm]	0.76774	0.12565	0	0	1	-0.28727
δ'[%]	0	0	0	0	0	1

jps2012aki by T. Hashimoto

VI(BHT)-S3-Q7-D4-Q8-FF(Q8out+0.9m)

1st order Transfer Matrix

-0.34812	0.00001	0.00000	0.00000	0.00000	1.04183
-15.54516	-2.87220	0.00000	0.00000	0.00000	-4.46785
0.00000	0.00000	-2.48598	0.64159	0.00000	0.00000
0.00000	0.00000	-14.40805	3.31624	0.00000	0.00000
-1.77508	-0.29923	0.00000	0.00000	1.00000	-0.34394
0.00000	0.00000	0.00000	0.00000	0.00000	1.00000

Oct_30_2006_BS.pdf by M. IIo

K- beam

Q) Is the π/K separation sufficient after shortening TOF length of BHT-T0?

A) Yes, a time resolution of σ_{TOF} ~ 0.2 ns, which has already been achieved, is sufficient for the π/K separation.

- ✓The difference in time of flight between K and π at 1 GeV/c is 2.7ns at 7.7m and 1.4ns at 4.0m.
- ✓At 1 GeV/c +/- 50 MeV/c, the spread of π is σ ~ 7.5 ps and that of K is σ ~ 84 ps.

Q) Why is the BLDC tilted 45 degrees?

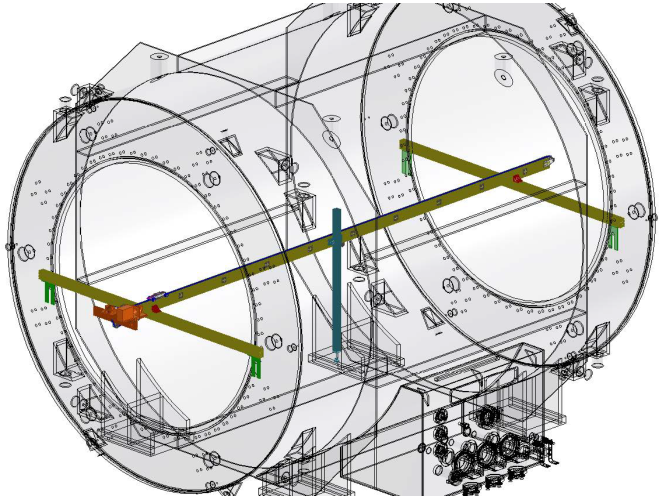
A) Due to the narrow beam distribution in the y-direction compared to that in the x-direction

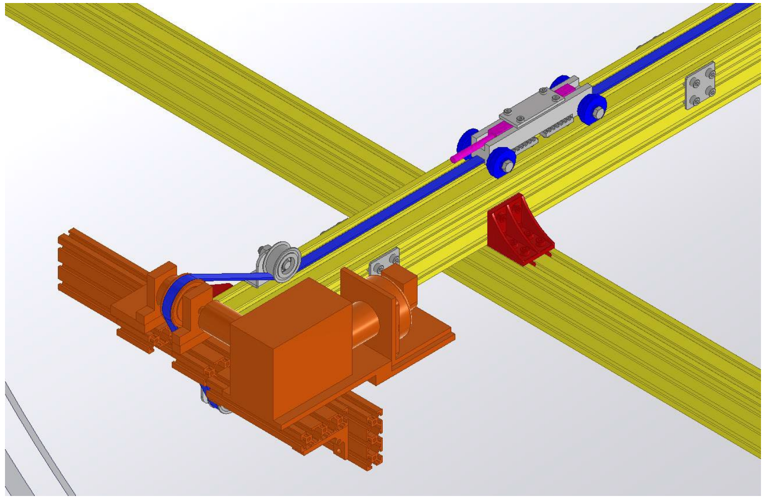
Solenoid magnet

C) Especially for the test at K1.8BR, you need to consider the work schedule (cooling -> current tests -> measurement -> detector installation work).

Q) What level of magnetic field measurements do you plan to perform at the factory (w/o yoke) and at K1.8BR (w/ yoke)?

A) At the factory, the beam axis will be scanned in a few days using a 3D Hall probe prepared for the COMET and E80 magnets. At K1.8BR, we plan to do three-dimensional scanning by remote control using a modified system by remote control over several weeks.



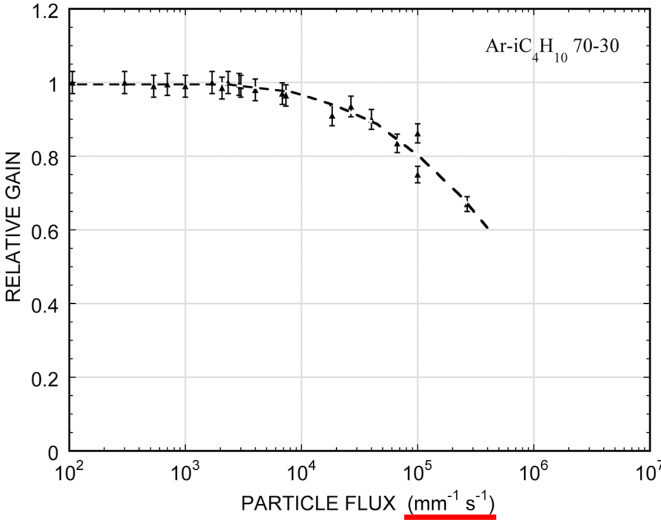


Solenoid magnet

Q) How much LN2 will be used for 7 days of pre-cooling? Is it realistic to transport LN2 frequently and safely vent N2 gas?

A) In a factory cooling test, the COMET-DS reached 100K in one week using 16,000 liters of LN2. At J-PARC, a maximum of ~1,000 liters of LN2 can be used per week, so the cooling time will be only slightly less than with GM alone.

CDC



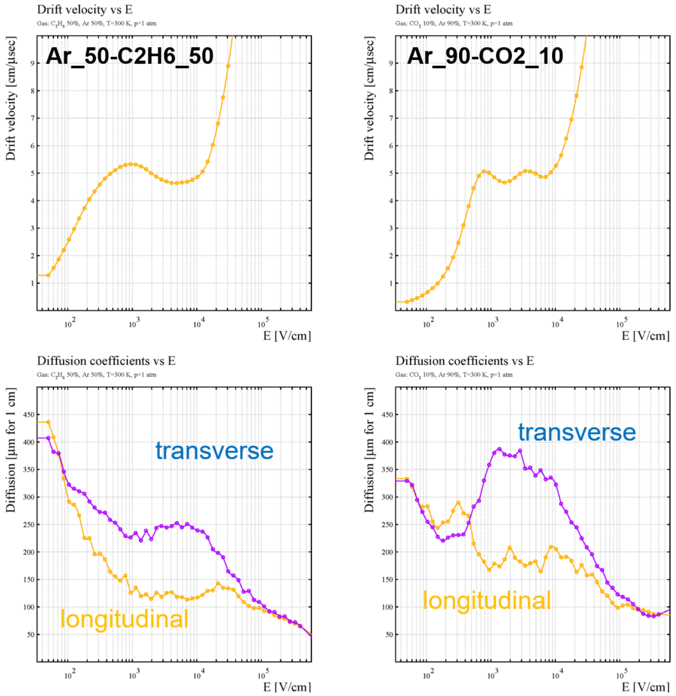
Q) Why change Ar(50)-C2H6(50) to Ar(90)-CO2(10)?

A) Three reasons: safe, inexpensive, and proven. Ar(90)-CO2(10) gas has been widely used for wire chambers at many facilities, such as JLab, GSI, and CERN.

Q) Is there a rate resistance problem?

A) No. Based on the E73 results, the particle rate in E80 will be several 10^5/spill at most corresponding to several 10^3 particles/cell/spill where the gain can be kept high enough.

- ✓ Ar(90)-CO2(10) gas has been used for the GEM detectors which operate at higher rates than wire chambers.



c.f. The maximum collision rate of K-/π- (1M) + LHe4 (~3%) will be ~3x10^4/spill with 1M/spill beam. In reality, most contributions come from sources other than the target.

DAQ

Q) Are there any plans to further improve the DAQ performance or optimize the trigger?

A1) With the current system, we can accumulate 12k/spill events with over 90% efficiency.

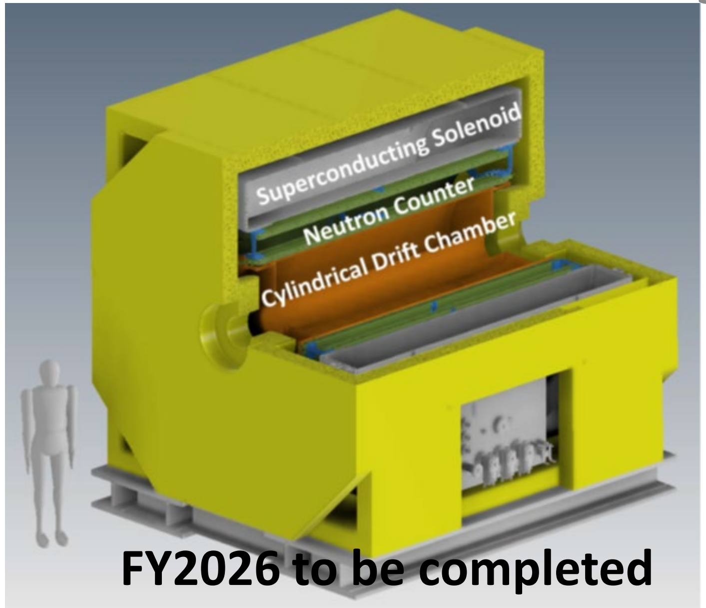
A2) By using the optimized DEF, we expect to reduce the trigger rate. In addition, in the future, we plan to gradually replace the current DAQ system with an advanced system, such as triggerless DAQ.

Summary

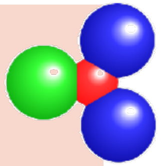
E80 Experiment ($K^{bar}NNN$ search)

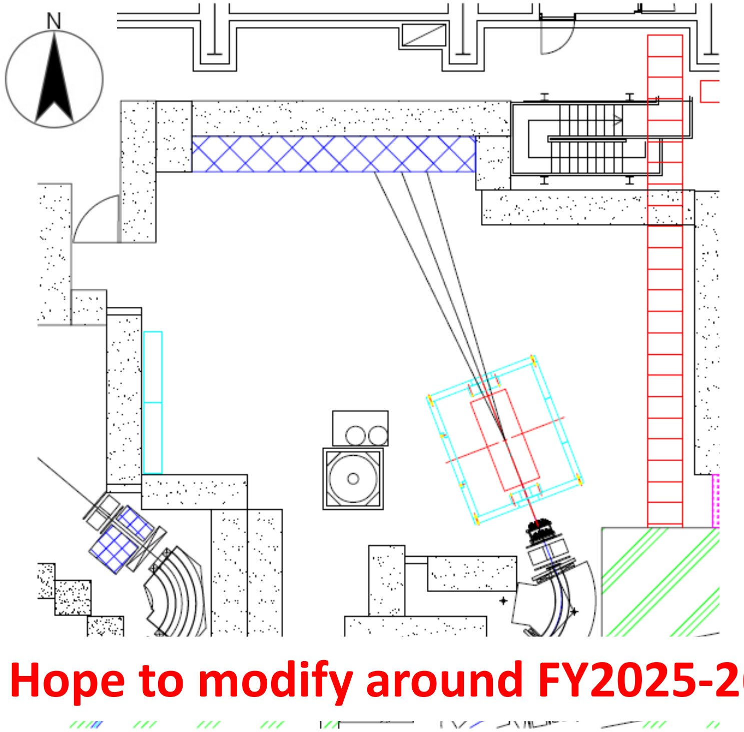
E80 investigates the **K^-ppn** bound state, toward the systematic study of the kaonic nuclei

- **Construct a large solenoid spectrometer**
- **Improve kaon yield by modifying the K1.8BR**



E80 (L^4He)	
Expected result	Establishment of K^-ppn ($\Lambda d/\Lambda pn$)
Start date	FY2026-27
Beam intensity	90kW
Beam time	1+1+3 weeks



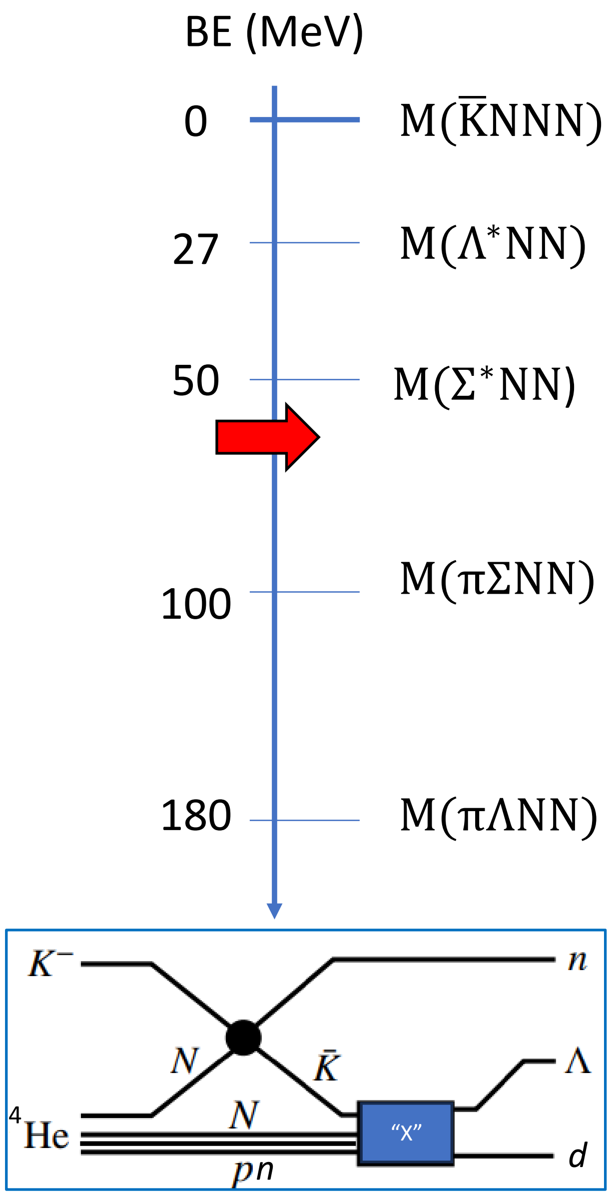


Hope to modify around FY2025-26

$K^{-4}He \rightarrow \Lambda dn$ Analysis with the T77 Data

What is the observed structure? [Discussion]

1. "X"→Λd decay mode is unique evidence of **$I_{"X"} = 0$**
   - I(J^P) : Λ = 0(1/2⁺), d = 0(1⁺), K^- = 1/2(0⁻), ^{3}He = 1/2(1/2⁺) , ^{4}He = 0(0⁺)
2. **"X"="K^-ppn" with $J_{"X"}$ = 1/2** would be likely, considering the isospin and spin combination in S-wave interaction
   - **$J_{"X"}$ = 1/2:** ^{4}He initial state is I(J) = 0(0) and low-momentum intermediate $\bar{K}$ would react with remaining NNN [I(J) = 1/2(1/2)] in S-wave
   - **Exclusion of Y*(I=1)NN**: probability of "X"→Λd decay would be suppressed because spin/isospin flip is needed to reconfigure NN [I(J) = 1(0)] into deuteron [I(J) = 0(1)]
     - ➢ Λpn decay would be dominant



** 俊行さんからのメール **
Subject: E80 TDR
Date: Wed, 19 Jun 2024 15:50:51 +0900
From: toshiyuki.takahashi@kek.jp
Reply-To: toshiyuki.takahashi@kek.jp
To: 佐久間 <sakuma@ribf.riken.jp>, tadashi.hashimoto@a.riken.jp, Takumi Yamaga <takumi.yamaga@gmail.com>
CC: toshiyuki.takahashi@kek.jp, Mifuyu Ukai <mifukai@post.kek.jp>, shinya.sawada@kek.jp

佐久間さん、
他皆様、

TDR読みました。
審査とは関係ないことも含めて、質問です。

１）ビーム
現在のセットアップで、K-ビームが標的にあたっている効率は
どの程度（Efiducial=0.65でしょうか？あるいはこの一部）
エリアアップグレードしてもこの程度は変わらない？
（サイズはそれほど変化がなく、これでのGainはないようですが）
E80でのDEFカウンターは使用するのですよね？

分解能はそれほど重要ではないですが、D5を取りのぞいて、
BHT->BDCでのdispersion(R16)や倍率（B11）はどの程度変わりますか？

BHT（？）-＞T0の距離が短くなっても1.0GeV/cなら、pi/Kの分離は充分でしょうか？

（定量的に評価されていないので、気になりました。）

BDCを45度傾けている（UV)のは、ビームのYサイズが小さいためでしょうか？

２）ドラミ
磁場測定を工場（No Yoke）及びK1.8BRで行うとのことですが、
その程度の測定を計画しているのでしょうか？
（測定器は？　今すぐ使えるものがあるなら、K1.8の問題で使えるなら使わせてほしい）

とくに K1.8BRでの測定は、冷却・通電試験と検出器のインストール作業の間に
行う必要があるので、現実的に可能かなど検討が必要

LN2でPreCooolingすれは冷凍機による冷却時間を７＋７日に減らせるので
現実的には必要ですが、７日間のPre-coolingで使用するLN2（または発生するガス）
の量はどの位でしょうか？
LN2の運搬頻度や安全な gN2排気は現実的に実施てきるものでしょうか？

３）CDC
Ar(50)+C2H6(50)をAr(90)＋CO2(10) に変更する理由（本音）は？
（可燃性ガスでないので安全上はよいですが、、）
位置分解能は、問題ないとの確認はされていますが、
レート耐性などは問題ないでしょうか？
（Ar＋C02の特性は忘れました、その辺がどうだったか.,,,?）

４）DAQ
Kaon （fCNC_3)のtrigger rateが12k/spillで致命的ではないが
結構シビアになってくると思いますが、さらにDAQ性能向上や
Triggerの最適化の計画はありますか？

取りいそぎ、

ハドロンの受入側としては、やはり、冷却や磁場測定が
気になりますね。

（永江さんの所属はRCNPだよ）

高橋俊行

HDDAQ

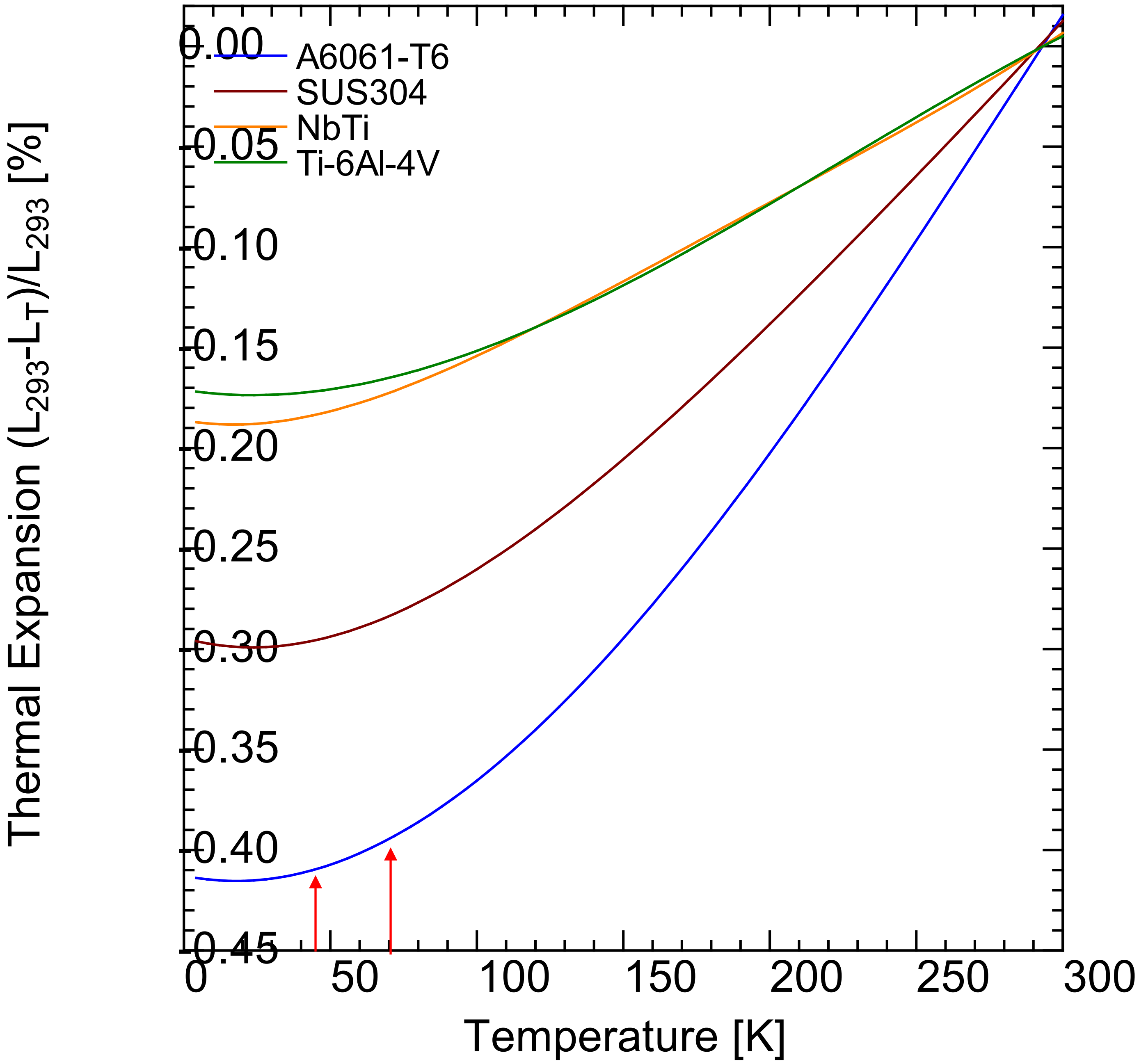
run_number 248 start_time 2024-04-21 01:08:12 comment Helium-4 production

81kW, E73 log vol7, p.86

Run#248: averaged for 10 spills; raw data (TM normalized) ; last spill at 2024/04/21 Sun 01:09:20

FT	1	(10)	KaonxCDH2	6,238	(63,804)
TM	97,770	(1,000,000)	KaonxCDH3	1,969	(20,139)
SYIM	9,039	(92,460)	KaonxCDH1xg	398	(4,072)
BHT	9,260,007	(94,711,472)	PionxCDH1	24,850	(254,166)
T0	1,645,126	(16,826,374)	Calori_cosmic	1,251,588	(12,801,267)
AC	1,251,199	(12,797,285)	SpillStart	0	(0)
T1	1,459,296	(14,925,704)	SpillEnd	1	(10)
DEF	964,221	(9,862,072)	BeamPrescaled	136	(1,399)
Veto	1,474,622	(15,082,459)	PionPrescaled	65,268	(667,567)
Calori	1,413,578	(14,458,101)	Kaon2Prescaled	9,705	(99,265)
BTC	970,121	(9,922,410)	Kaon3Prescaled	260	(2,660)
CDH1	211,047	(2,158,592)	KaonxCDH1_trig	1,793	(18,344)
CDH2	47,312	(483,910)	KaonxCDH2_trig	3,072	(31,424)
CDH3	11,832	(121,018)	KaonxCDH3_trig	1,969	(20,139)
NC	80,327	(821,588)	KaonxCDH1xg_trig	391	(4,002)
CVC	220,270	(2,252,928)	Kaonxgamma_trig	3,564	(36,453)
BeamAsBHTxT0	1,574,141	(16,100,334)	PionxCDH_trig	1,332	(13,626)
BeamAsT0xT1	1,348,741	(13,794,944)	PionxPbF2_trig	317	(3,248)
BeamAsT1xDEF	909,896	(9,306,429)	ElectronPrescaled	500,652	(5,120,684)
Kaon1	499,050	(5,104,293)	CDH_cosmic	0	(0)
Kaon2	320,218	(3,275,200)	ProtonPrescaled	0	(0)
Kaon3	259,842	(2,657,674)	Request	7,758	(79,354)
pion1	1,087,398	(11,121,930)	Accept	7,067	(72,282)
pion2	652,686	(6,675,684)	RealTime	14,587	(149,200)
proton	136,155	(1,392,595)	DeadTime	832	(8,513)
electron	0	(0)	Clock10kHz	745	(7,619)
KaonxCDH1	18,279	(186,967)	tmp54	0	(0)

slayer-1	216	cell		1.60E-19	C/electron									
	10	uA		3.00E+04	amplification factor		http://ag.riken.jp/J-PARC/tsukada/Matome/Tsukada_090403x.pdf							
	0.046296296	uA/cell		80	# of initial electron		http://ag.riken.jp/J-PARC/sakuma/weekly_meeting/CDSstudy24/CDSstudy24.pdf							
	4.62963E-08	C/cell												
	2.89E+11	electron/cell after amplificaiton												
	9.65E+06	electron/cell before amplificaiton												
	1.21E+05	track/cell ?												
	8.68E+06	track ?												
					liquid helium4		https://pdg.lbl.gov/2020/AtomicNuclearProperties/HTML/liquid_helium.html							
	1.00E+06	maximum beam / spill		0.1249	density (g cm-3)									
	3.42E+04	collision rate / spill		51.8	Nuclear collision length (g cm-2)				2.00E+05	CDH1/spill＠81kW-He4			10倍異なる	
				415.1	Nuclear collision length (cm)									
	10	assumed multiplicity		14.2	target length (cm)									
	3.42E+05	# of tracks / spill		0.034209	Nuclear collision length									
	4.75E+03	# of tracks / cell / spill							1.97E-01	uA			50倍異なる。。	
	1.42E+02	# of tracks / mm / s												



A6061-T6
SUS304
NbTi
Ti-6Al-4V
Thermal Expansion (L293-LT)/L293 [%]
Temperature [K]
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
-0.40
-0.45
0
50
100
150
200
250
300

beamline spectrometer

BLC1-D5-BLC2

	x[cm]	θ[mrad]	y[cm]	Φ[mrad]	l[cm]	δ[%]
x′[cm]	0.19678	0.20554	0	0	0	-1.33079
θ′[mrad]	-4.6338	0.24164	0	0	0	-7.67738
y′[cm]	0	0	1.23585	0.32661	0	0
Φ′[mrad]	0	0	1.55747	1.22077	0	0
l′[cm]	0.76774	0.12565	0	0	1	-0.28727
δ′[%]	0	0	0	0	0	1

jps2012aki by T. Hashimoto

VI(BHT)-S3-Q7-D4-Q8-FF(Q8out+0.9m)

Momentum resolution

Estimation by TRANSPORT Framework

R11 = -0.34812, R12 = 0, R16 = 1.0483 cm/%

(Resolution of tracking device : dx = 0.02 cm)

dp/p = SQRT(1+R11^2)*dx/R16

= 0.0203 %

1st order Transfer Matrix

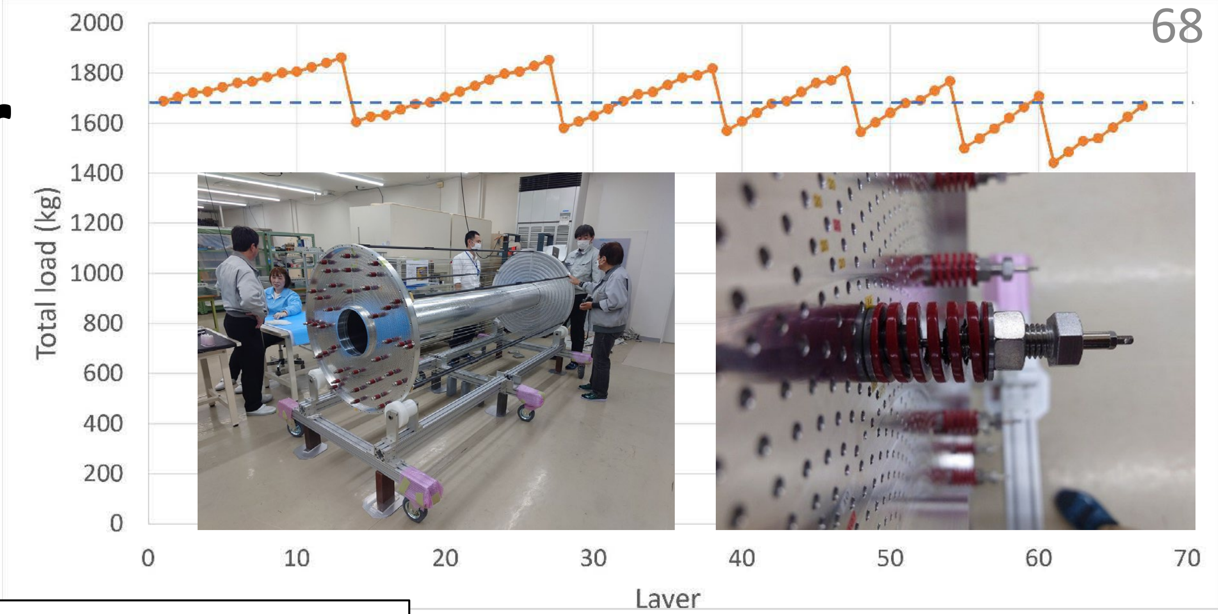
-0.34812	0.00001	0.00000	0.00000	0.00000	1.04183
-15.54516	-2.87220	0.00000	0.00000	0.00000	-4.46785
0.00000	0.00000	-2.48598	0.64159	0.00000	0.00000
0.00000	0.00000	-14.40805	3.31624	0.00000	0.00000
-1.77508	-0.29923	0.00000	0.00000	1.00000	-0.34394
0.00000	0.00000	0.00000	0.00000	0.00000	1.00000

Oct_30_2006_BS.pdf by M. IIo

R11~2倍ぐらい、Dispersion(R16)同じぐらい。
R12を小さくできるのが重要

Cylindrical Drift Chamber

- Wire stringing works: Jan-May 2024
- Pre-tension was applied
  - with 36 pre-tension bars
  - 1.67 tons in total



Measured tension during stringing

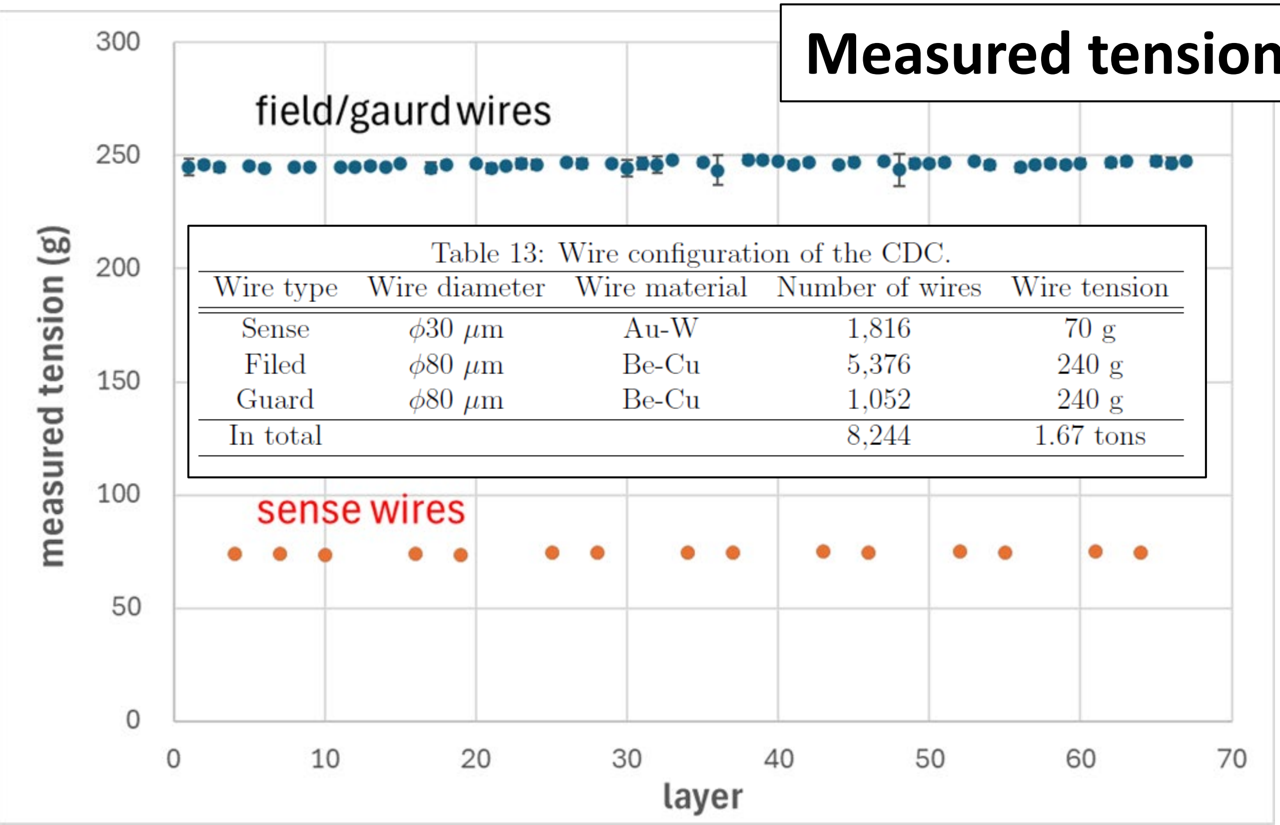
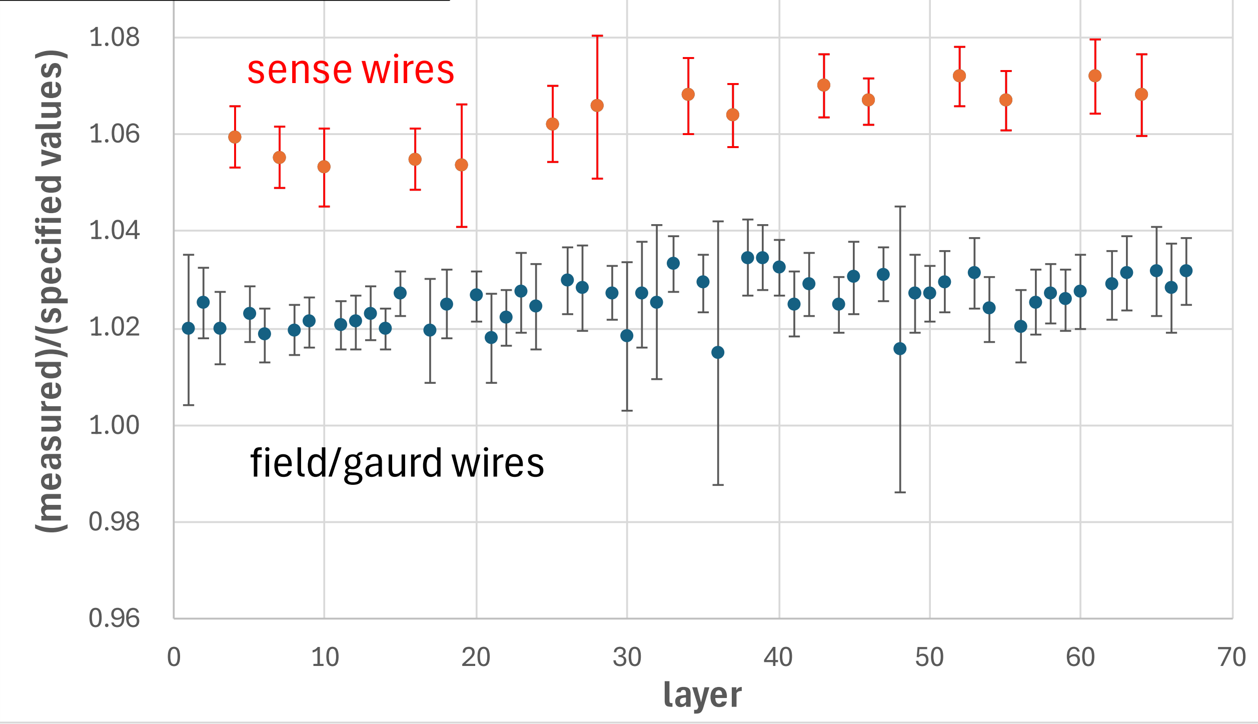


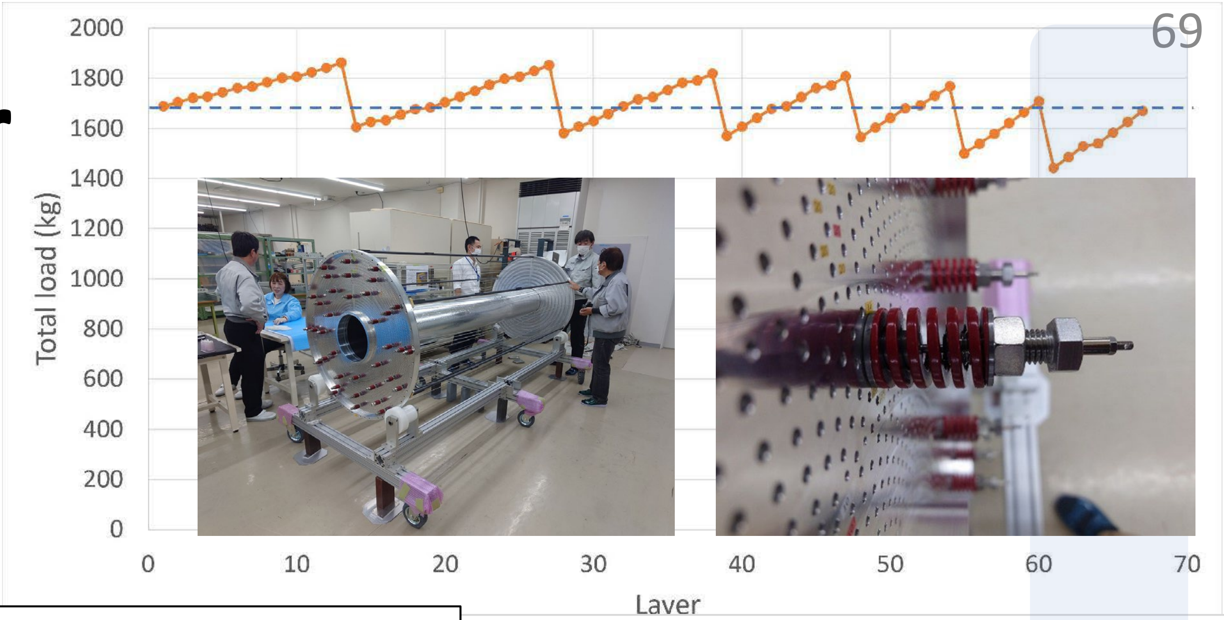
Table 13: Wire configuration of the CDC.

Wire type	Wire diameter	Wire material	Number of wires	Wire tension
Sense	$\phi 30\ \mu m$	Au-W	1,816	70 g
Filed	$\phi 80\ \mu m$	Be-Cu	5,376	240 g
Guard	$\phi 80\ \mu m$	Be-Cu	1,052	240 g
In total			8,244	1.67 tons



Cylindrical Drift Chamber

- Wire stringing works: Jan-May 2024
- Pre-tension was applied
  - with 36 pre-tension bars
  - 1.67 tons in total



Re-measured tension after completion

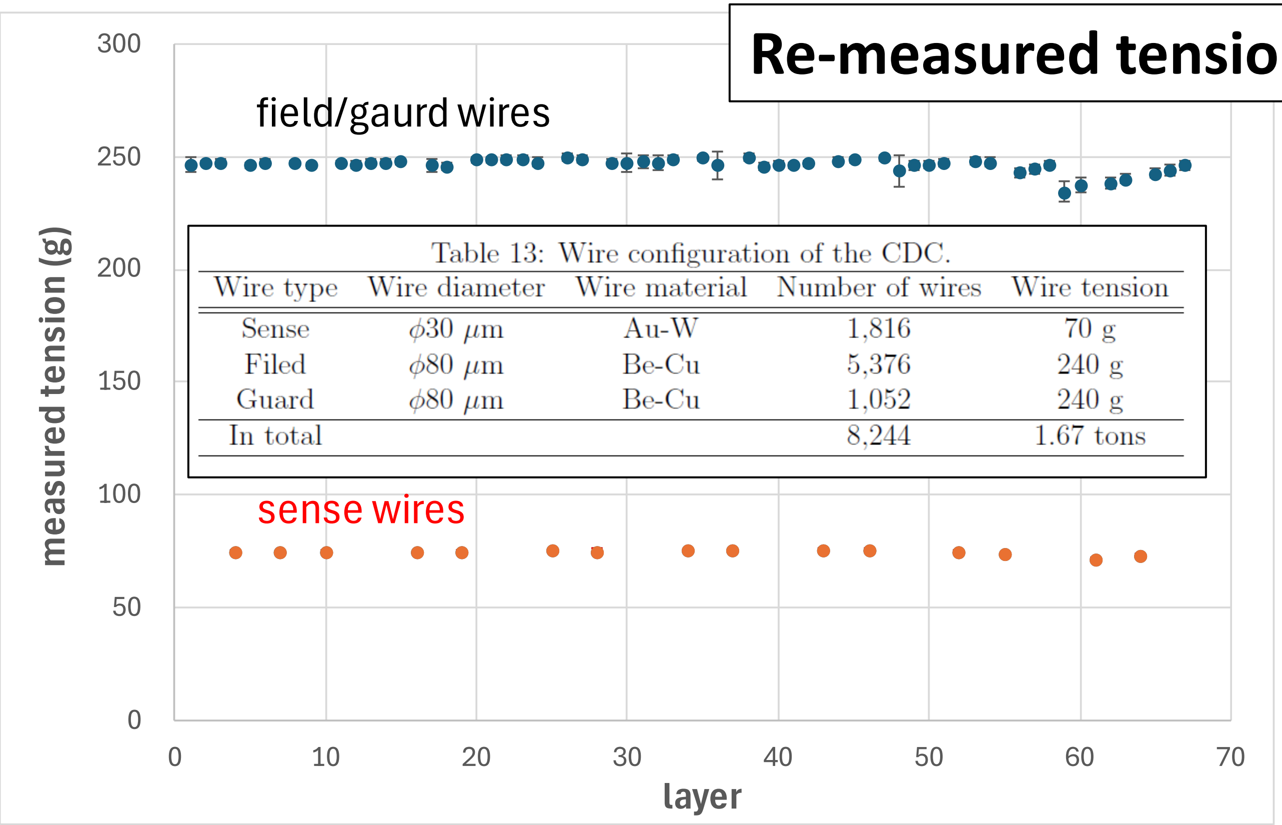
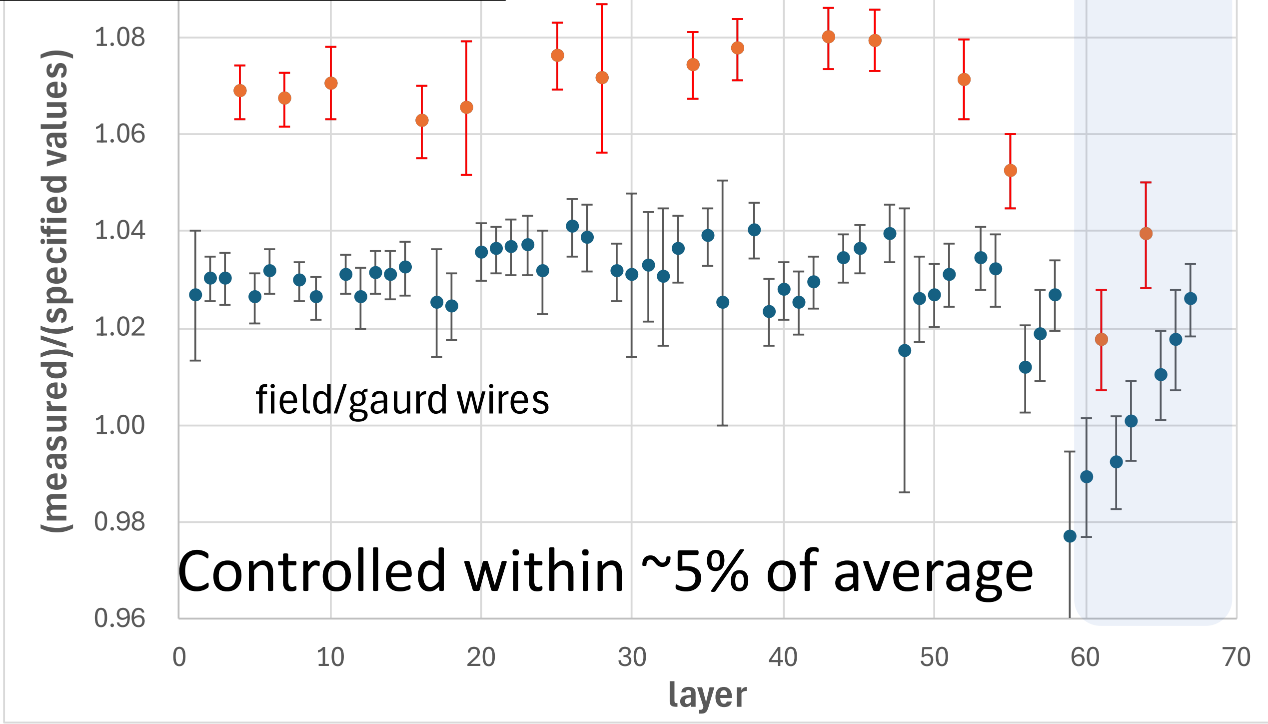


Table 13: Wire configuration of the CDC.

Wire type	Wire diameter	Wire material	Number of wires	Wire tension
Sense	$\phi 30\ \mu m$	Au-W	1,816	70 g
Filed	$\phi 80\ \mu m$	Be-Cu	5,376	240 g
Guard	$\phi 80\ \mu m$	Be-Cu	1,052	240 g
In total			8,244	1.67 tons



Controlled within ~5% of average