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

F. Sakuma, RIKEN

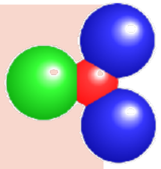
- Introduction
- K1.8BR Beam Line
- Apparatus →
  - Beam Line Spectrometer
  - Cryogenic Target System
  - Cylindrical Detector System
  - Trigger and DAQ System
- Summary

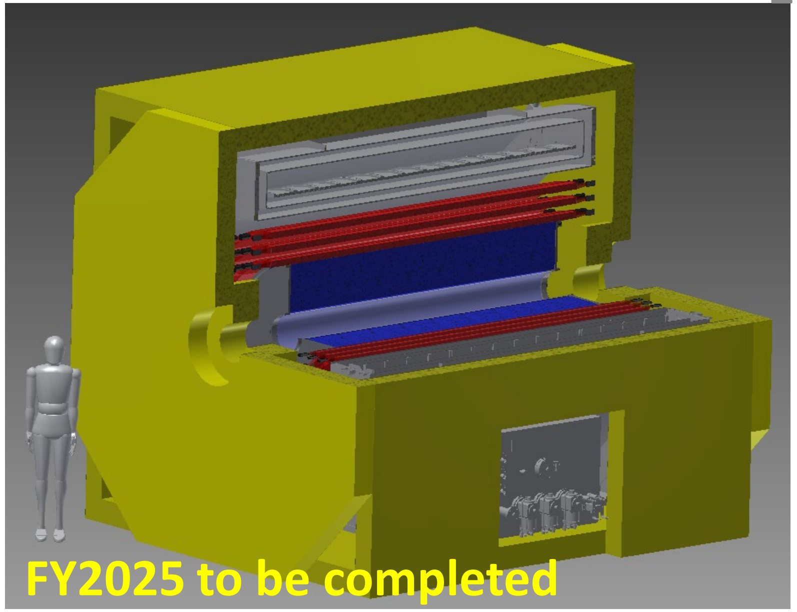
E80 Experiment (K^{bar}NNN search)

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

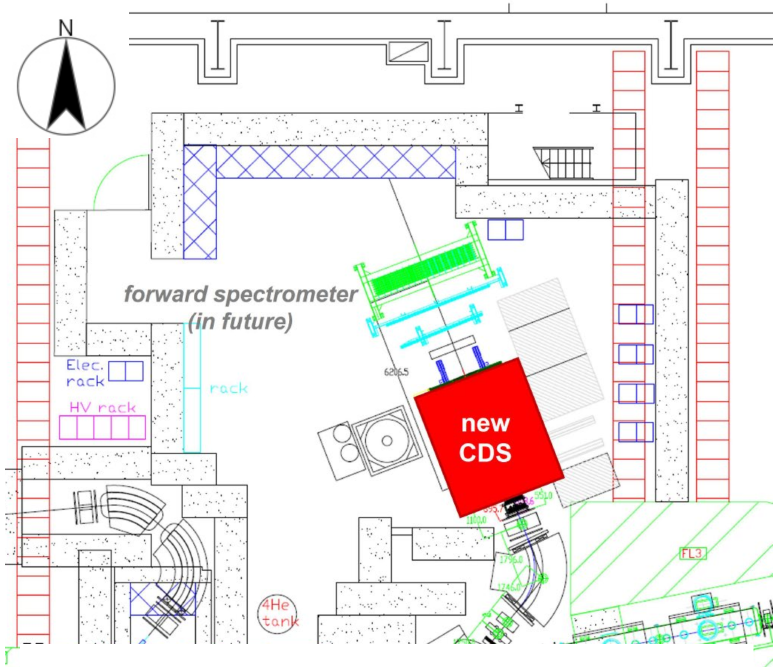
- **Construct a large solenoid spectrometer**
- **Improve kaon yield by modifying the K1.8BR**

E80 (L^{4}He)	
Expected result	**Establishment of K^{-}ppn (Λd/Λpn)**
Start date	**FY2025-26**
Beam intensity	**90kW**
Beam time	**1+1+3 weeks**





FY2025 to be completed



Hope to modify around FY2024

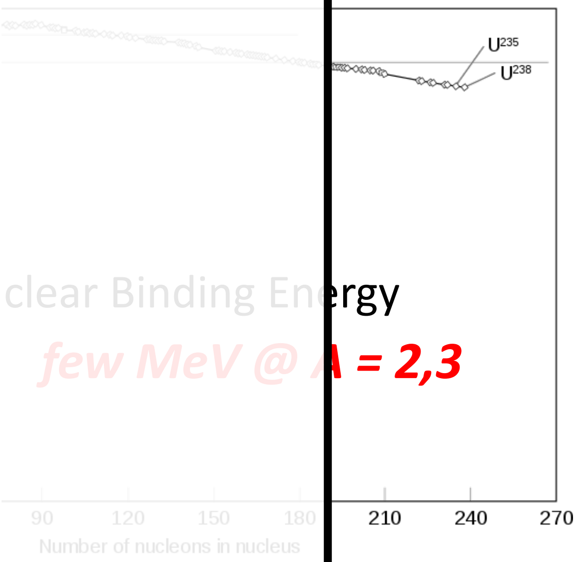
Introduction

Kaonic Nuclei

Predicted from ... action in I=0

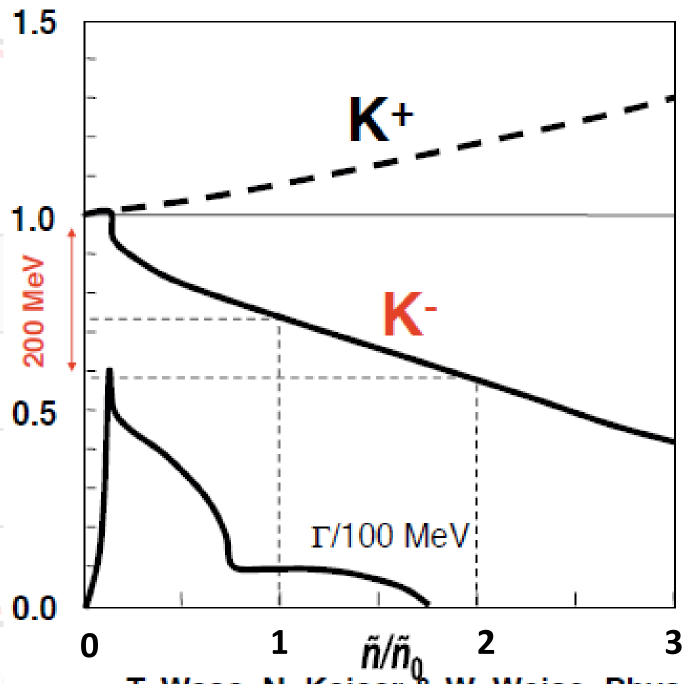
Kaonic Nuclei	Binding Energy [MeV]
$\Lambda(1405)$ = K^-p	27
K^-pp	48
K^-ppp	97
K^-ppn	118

...88., PRC65(2002)044005., etc.

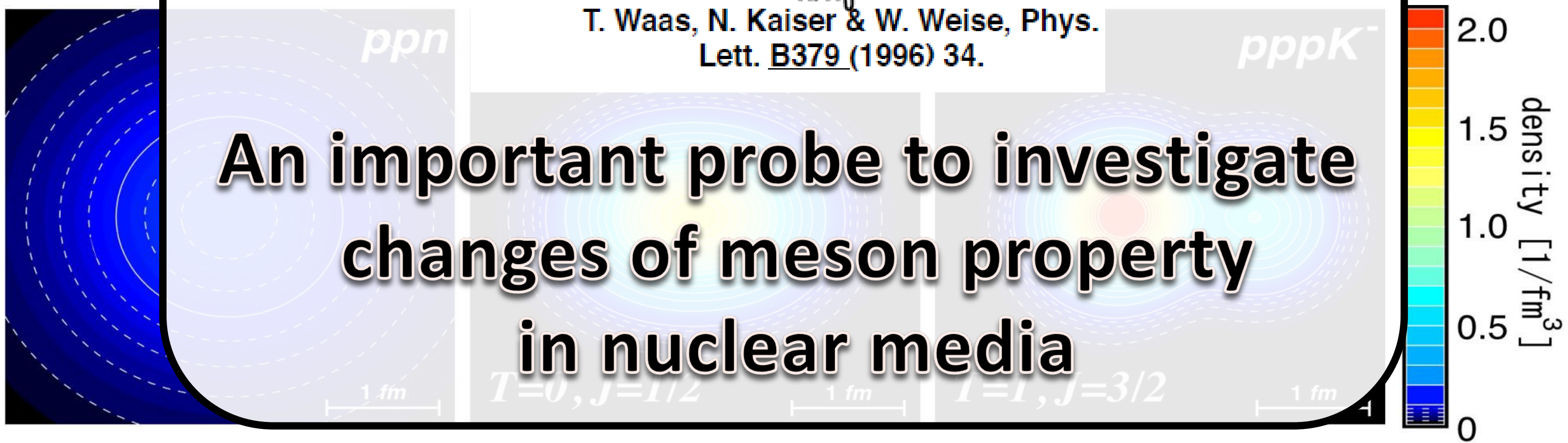


...clear Binding Energy

few MeV @ A = 2,3



T. Waas, N. Kaiser & W. Weise, Phys. Lett. B379 (1996) 34.

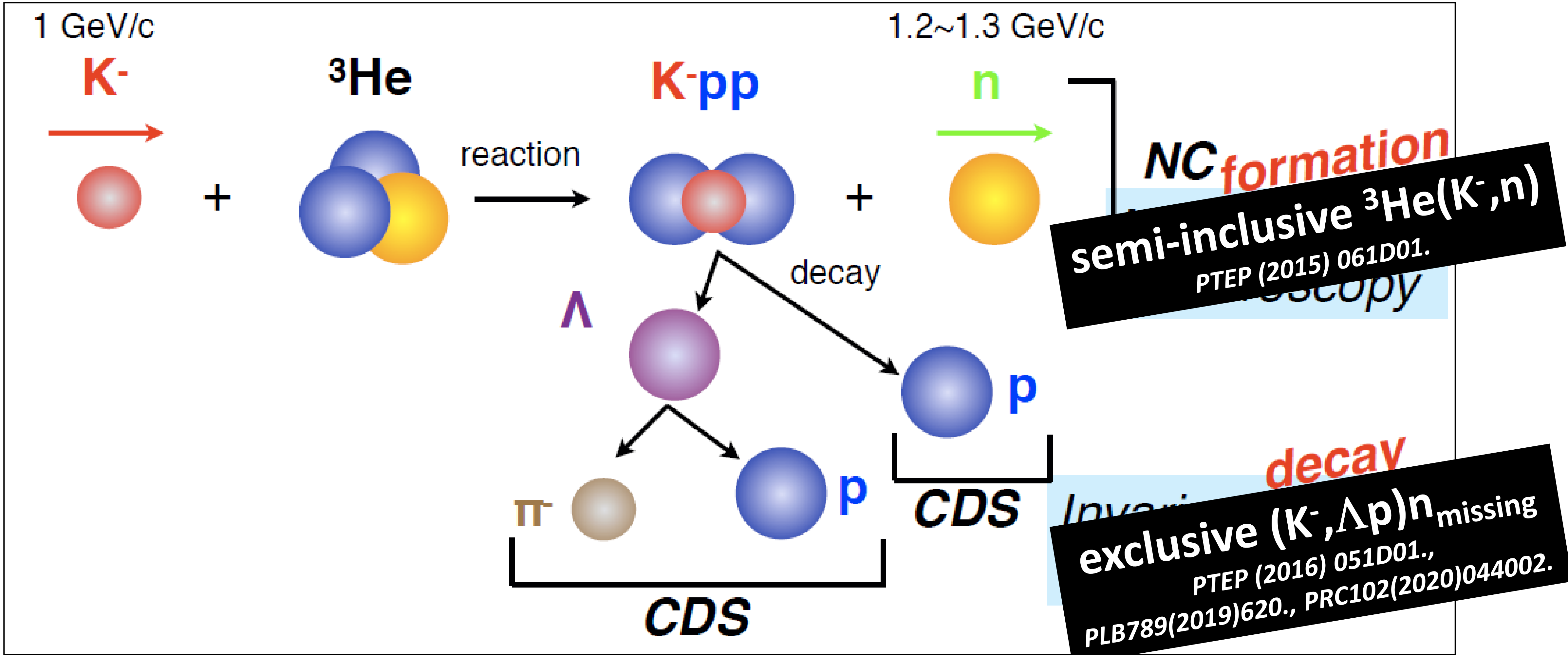


An important probe to investigate changes of meson property in nuclear media

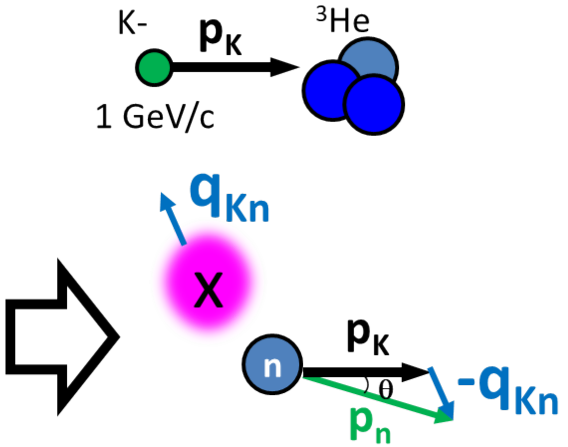
J-PARC E15 Experiment

^{3}He(*in-flight* K^{-},n) reaction @ 1.0 GeV/c

2NA and Y decays can be discriminated kinematically



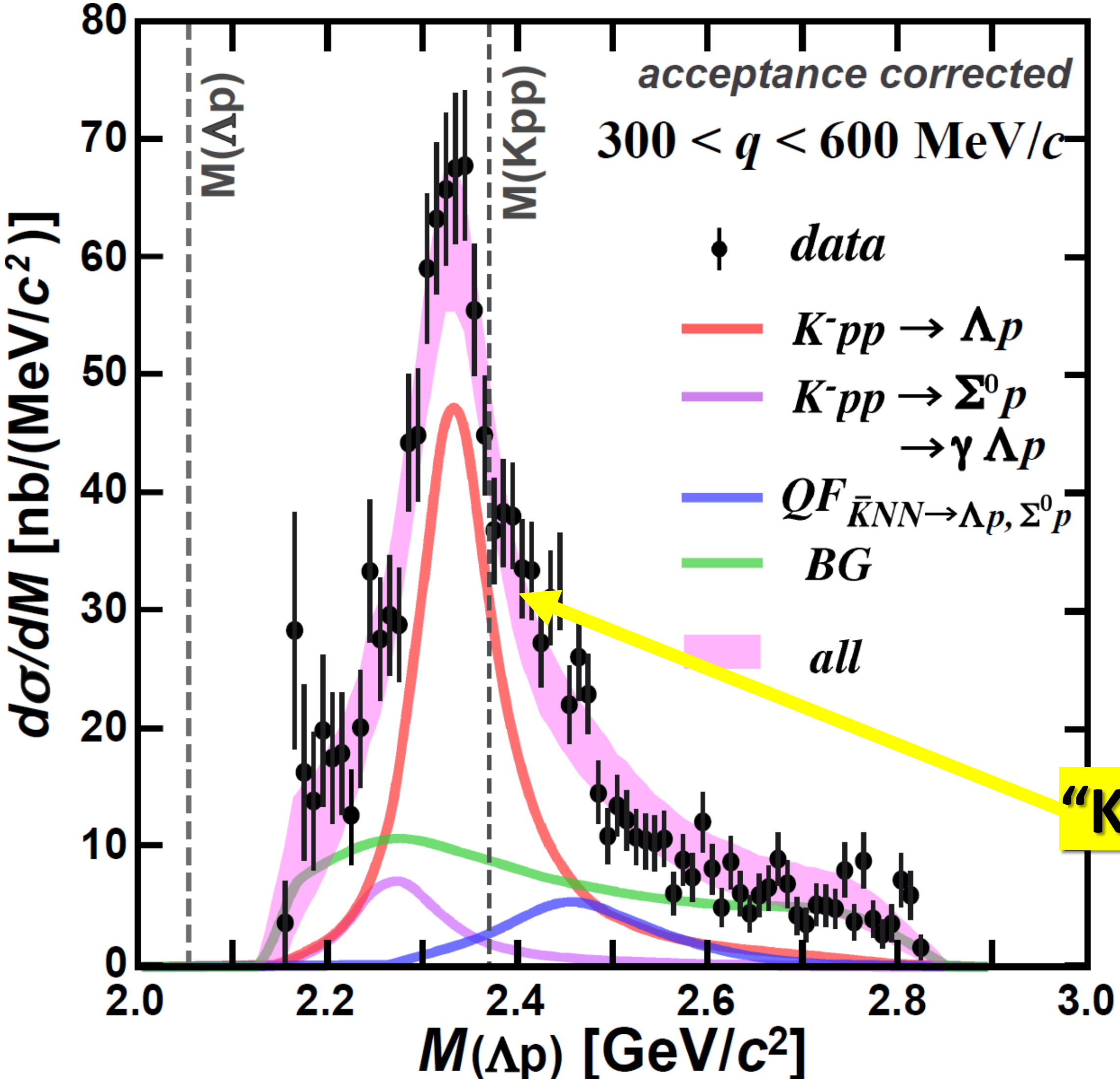
Exclusive $^3He(K^-,\Lambda p)n$

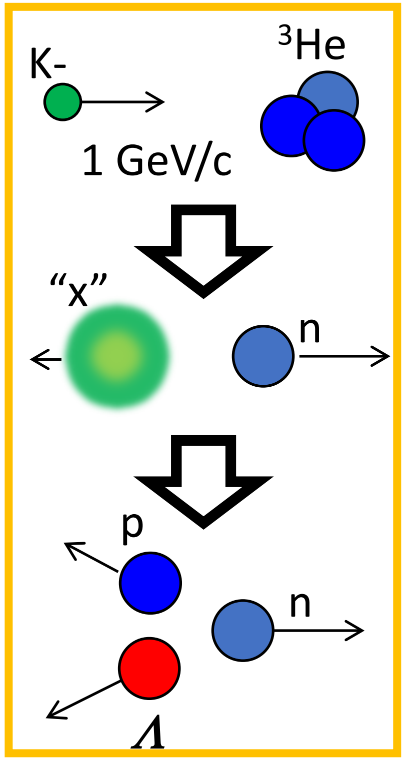


Momentum transfer analysis using the (K^-,n) reaction

- ✓ M(Λp) vs. q
- ✓ give a clear information on reaction processes

T.Yamaga et. al., PRC102(2020)044002.





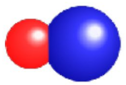
"K-pp" bound state exists

q-independent

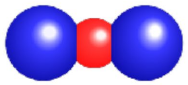
Need Further Investigations

to establish the kaonic nuclei

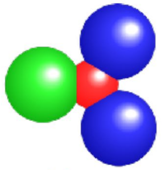
- **Λ(1405) state**
  - $\bar{K}N$ qusi-bound state as considered?
  - Relation between $\bar{K}N$ and $\bar{K}NN$?
- **Further details of the $\bar{K}NN$**
  - Spin and parity of the "K⁻pp"?
  - Really compact and dense system?
- **Heavier kaonic nuclei?**
  - Mass number dependence?
- **Double kaonic nuclei?**
  - Much compact and dense system?



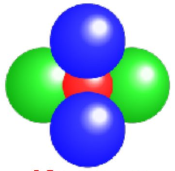
K^-p



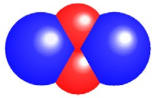
K^-pp



K^-ppn



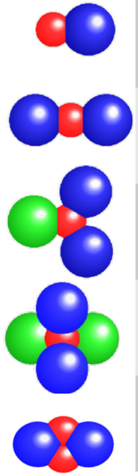
K^-ppnn



K^-K^-pp

Strategy of the New Project

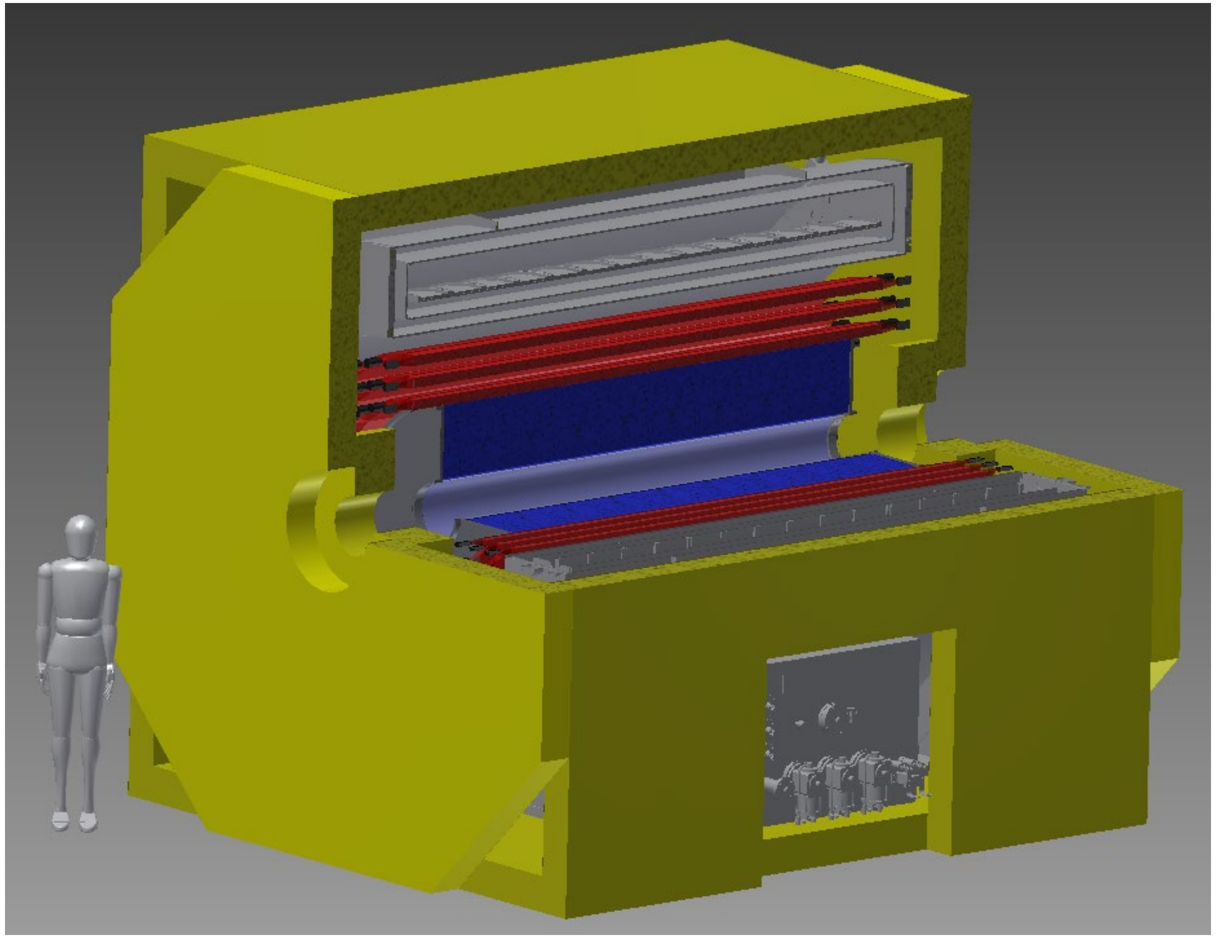
- for systematic study from the $\bar{K}N$ to $\bar{K}NNNN$ systems -

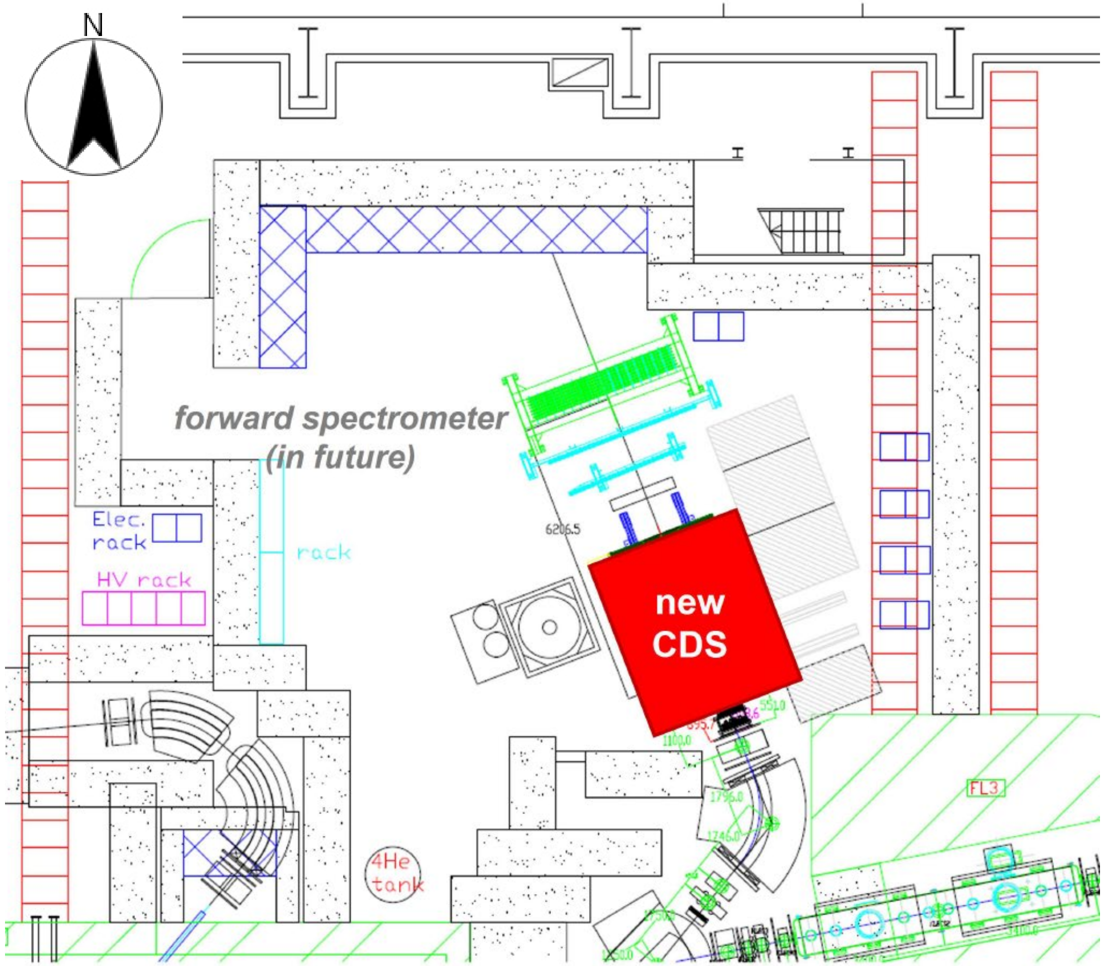


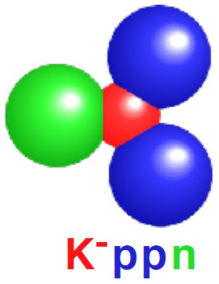
	Reaction	Decays	Key	Experiment
$\bar{K}N$	d(K$^-$,n)	$\pi^{\pm 0}\Sigma^{\mp 0}$	n/γ identification	Future
$\bar{K}NN$	^{3}He(K$^-$,N)	Λp/Λn	polarimeter	P89
$\bar{K}NNN$	^{4}He(K$^-$,N)	Λd/Λpn	large acceptance	E80 (P92) ← **A first step**
$\bar{K}NNNN$	*^{6}Li(K$^-$,d)*	*Λt/Λdn/Λpnn*	*many body decay*	*Future*
$\bar{K}\bar{K}NN$	*$\bar{p}$ + ^{3}He*	*$\Lambda\Lambda$*	*$\bar{p}$ beam yield*	*Future (LoI)*

- To realize the systematic measurements, we need
  - ☐ **a large acceptance spectrometer** **← new CDS**
    - detect/identify all particles to specify the reaction
  - ☐ **high-intensity kaon beam** **← improved K1.8BR**
    - more K$^-$ yield than the existing beamline
- *We take a **step-by-step** approach*

New CDS & Improved K1.8BR







A First Step: Search for $\bar{K}NNN$

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

Goals of the E80 experiment:

① **Observe the K$^-$ppn state via 2-body Λd decay**
- Establish the existence of the kaonic nuclei

② **Reconstruct the K$^-$ppn state via 3-body Λpn decay**
- As a feasibility study to access heavier system

- **Feasibility study of polarization measurement**
  - *e.g.*, by installing a prototype module of a polarimeter

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→Λd) ~ 1.2 x 10^4**
- **N(K^-ppn→Λpn) ~ 1.5 x 10^3**
  - c.f. 1.7 x 10^3 "K^-pp"→Λp accumulated in E15-2nd (40 G K^-)

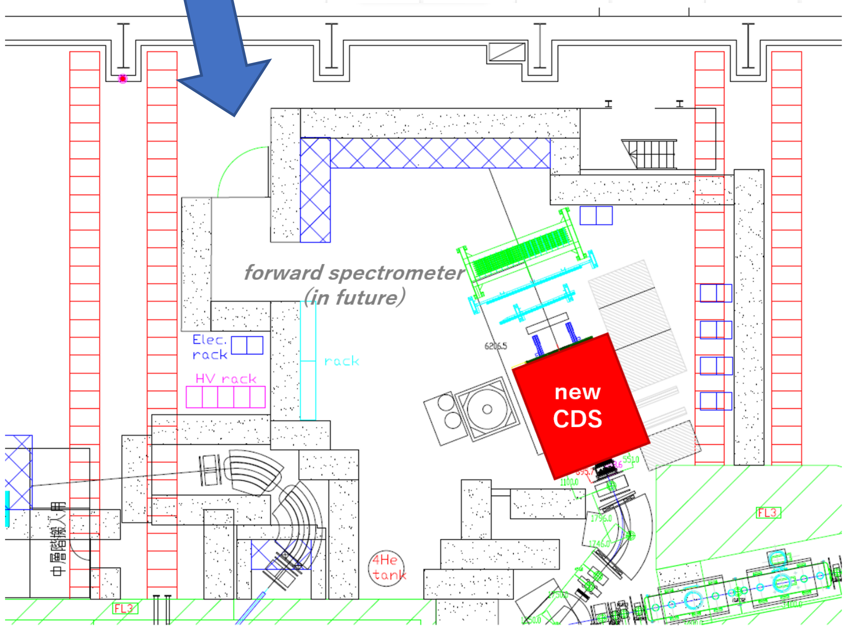
	Λd / Λpn
σ(K^-ppn)*Br	5 μb
N(K^- on target)	100 G
N(target)	2.56 x 10^{23}
ε(DAQ)	0.92
ε(trigger)	0.98
ε(beam)	0.72
Ω(CDC)	0.23 / 0.059
ε(CDC)	0.6 / 0.3
N(K^-ppn)	12 k / 1.5 k

Schedule

	FY2022				FY2023				FY2024				FY2025				2026~	
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4		
SC Solenoid	Design		Purchase (SC Wire)		Construction							Installation & Test			Integration	Commissioning	Physics Run	Analysis & Pblication
NC	Design		Purchase (Scinti.)		Assembly				Test & Commissioning									
CDC	Design				Construction				Test & Commissioning									
K1.8BR Beam Line	E73(CDC) -> E72(HypTPC) Experiments										Upgrade			E80 Experiment				

Aiming to complete detector construction in 4 years.

- Superconducting solenoid magnet
- CDC (cylindrical drift chamber)
- CNC (cylindrical neutron counter)
- K1.8BR area modification



Cost

- **Most of the construction cost will be covered by "Grant-In-Aid for Specially Promoted Research by MEXT (FY2022-26)".**

Superconducting solenoid magnet	~350M JPY
CDC (cylindrical drift chamber)	~50M JPY
CNC 1st-layer (cylindrical neutron counter)	~20M JPY

- The rest of the CNC will be built with budgets from other sources that we are currently trying to acquire.

CNC 2nd/3rd-layer (cylindrical neutron counter)	~50M JPY

Collaboration

Experiment

RIKEN
SC-Solenoid, Beam line, CDC, Data Analysis
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Y.Ma, K.Itahashi, H.Outa, Post.Doc., Students

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Data Analysis
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Osaka-U
RCNP
OSAKA UNIVERSITY
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TITECH
Tokyo Tech
Data Analysis
H.Fujioka, Students

Kyoto-U
Data Analysis
T.Nagae, Students

Theory

TITECH
Tokyo Tech
Structure
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Kyoto Pref. U
Reaction
T.Sekihara, Students

Osaka Elec. U
Reaction
T.Harada, Students

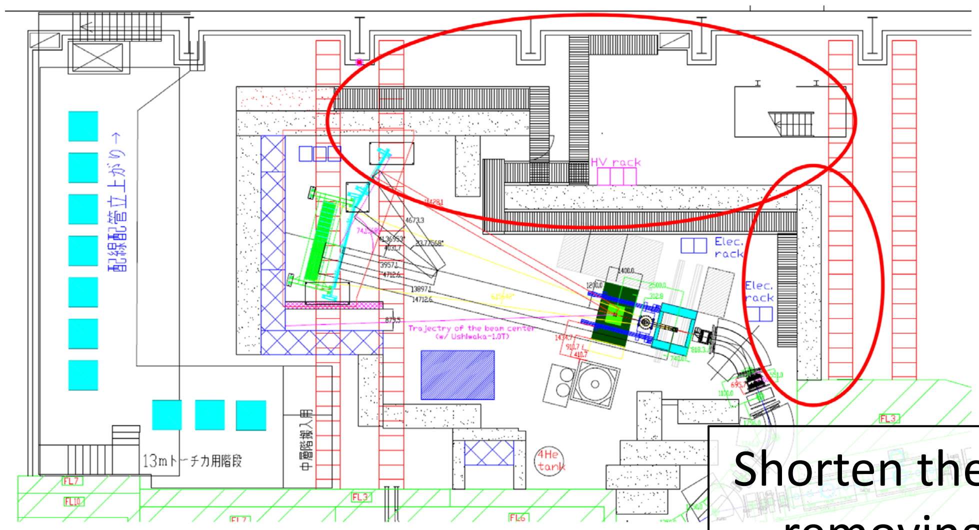
KEK
Structure
A.Dote, O.Morimatsu, Students

RIKEN
Lattice-QCD
T.Hatsuda, T.Doi, Students

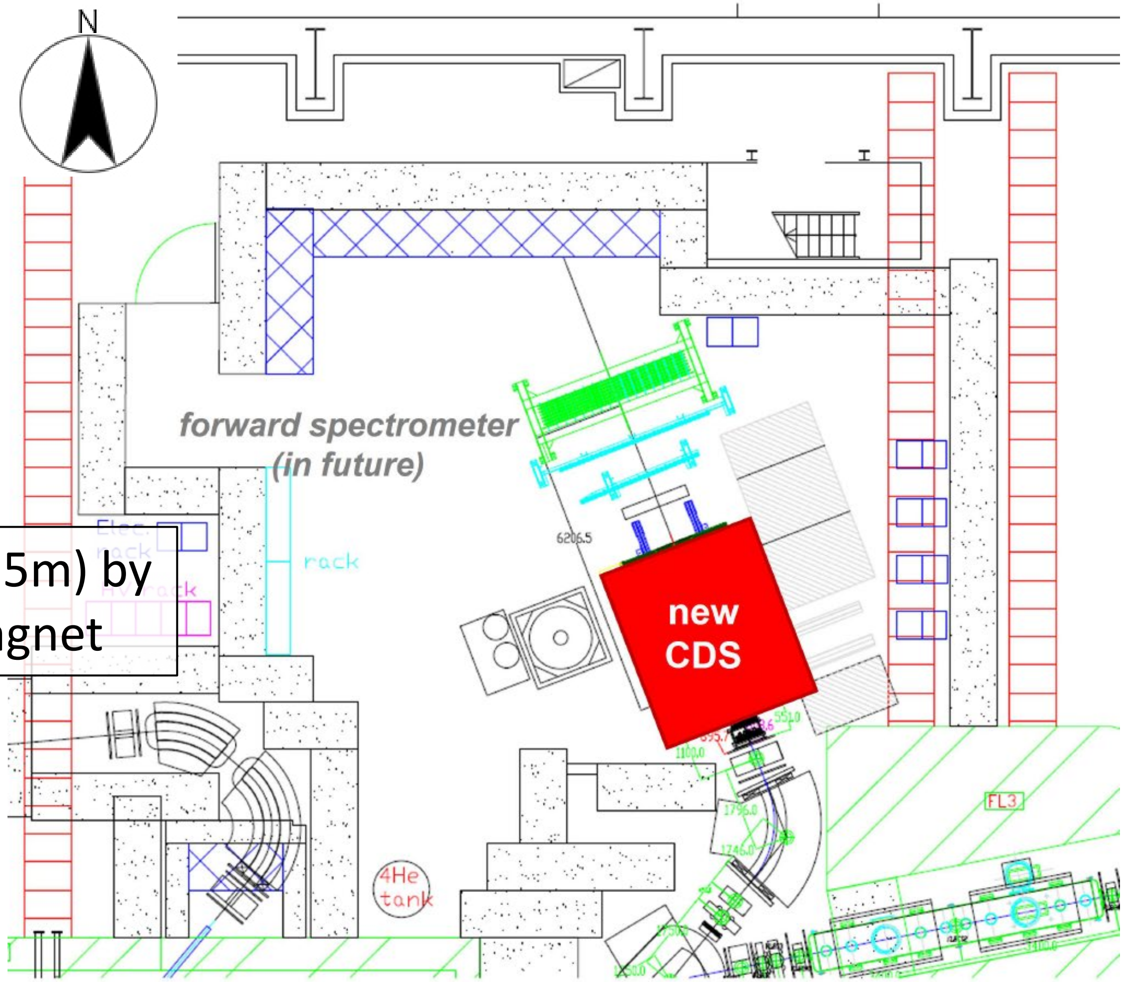
K1.8BR Beam Line

Overview

K1.8BR beamline



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

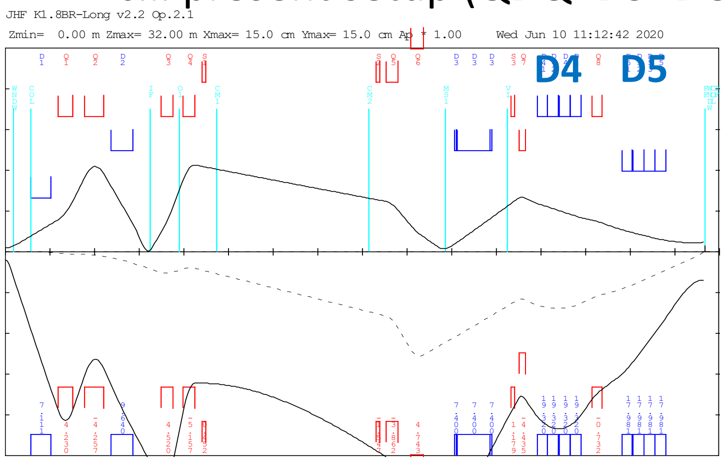


Relative beam-line length (m)	D5	D4
Present CDS	0	-3.7
New CDS	+1.2	**-2.5**

- **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

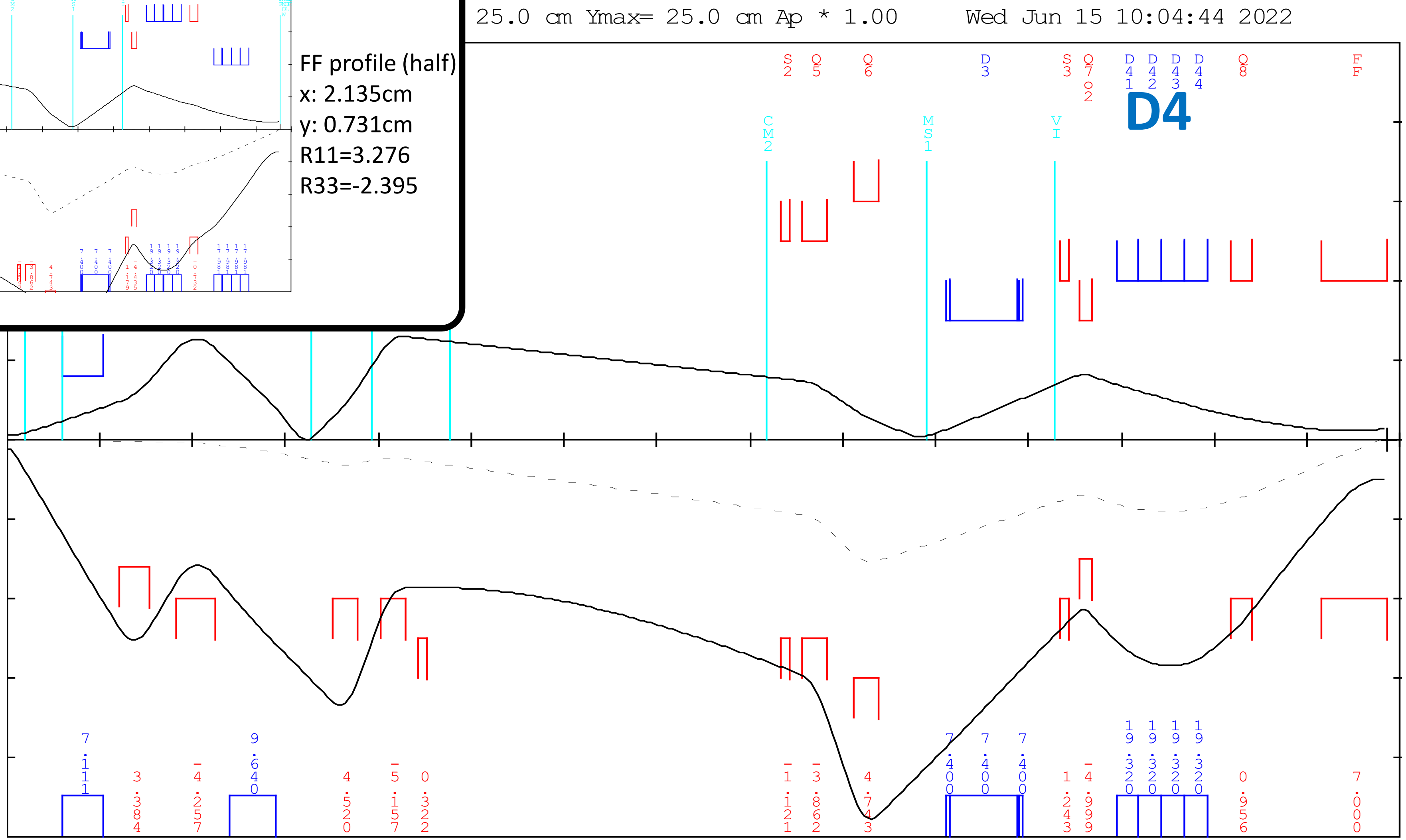
Beam Line Optics without D5

c.f. present setup (QDQ+D5+DORA)



FF profile (half)
x: 2.135cm
y: 0.731cm
R11=3.276
R33=-2.395

First Order Optics (QDQ+DORAMI)



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

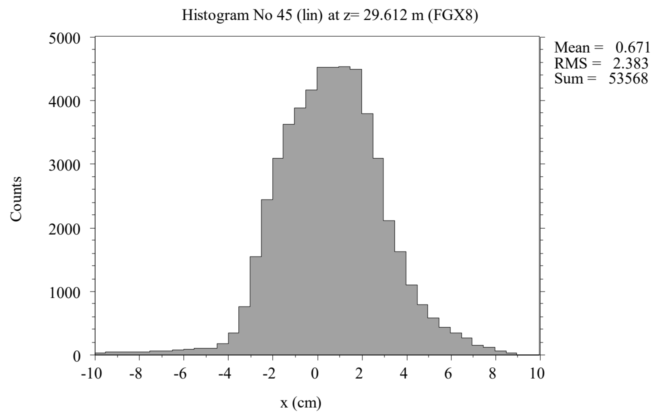
FF profile (half)
x: 2.574cm
y: 0.742cm
R11=4.150
R33=-2.139

br11220613ifm.dat by Noumi-san

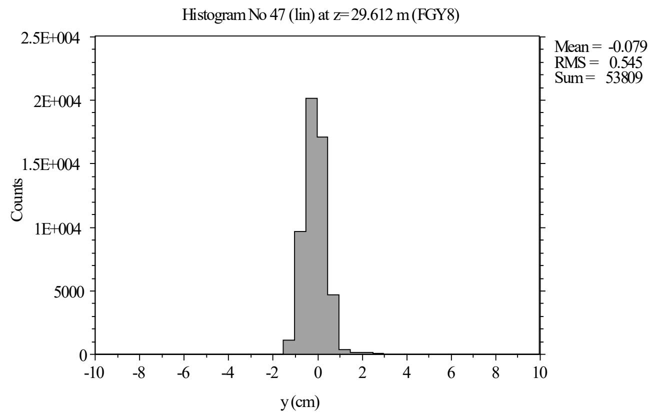
Beam Line Optics without D5

profile@FF(the Center of the DORAMI Solenoid) Turtle (3rd order)

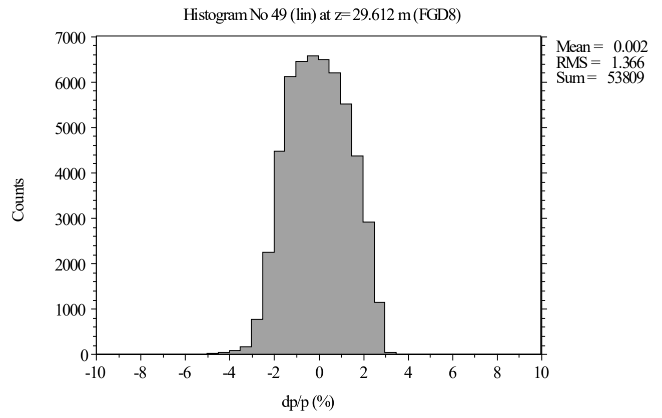
δx=2.4cm



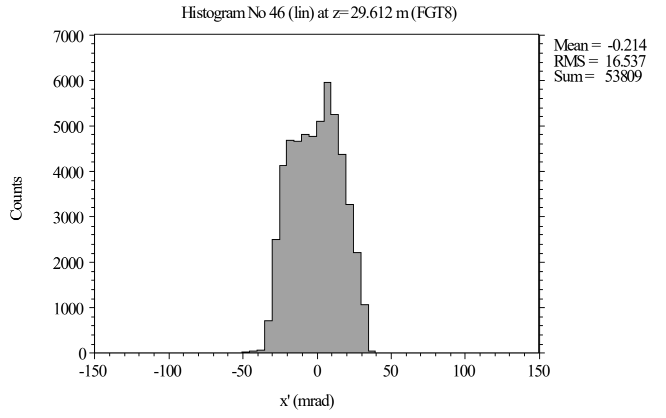
δy=0.55cm



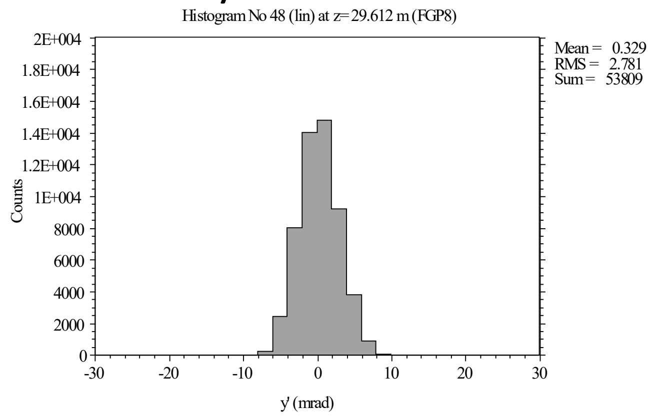
δ(dp/p)=1.4%

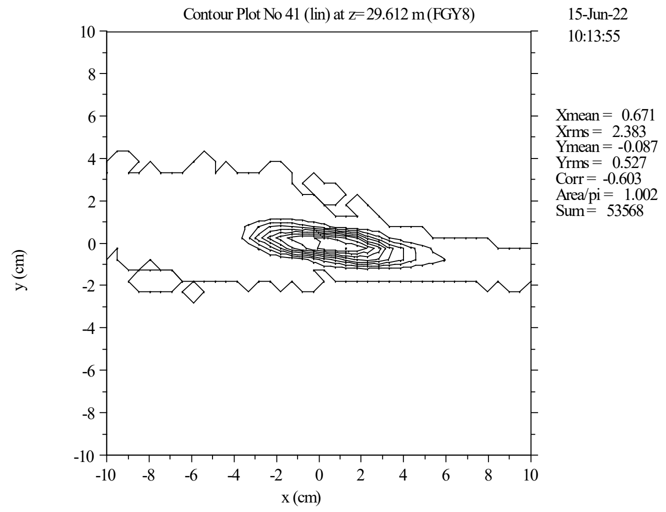


δx'=17mrad



δy'=2.8mrad

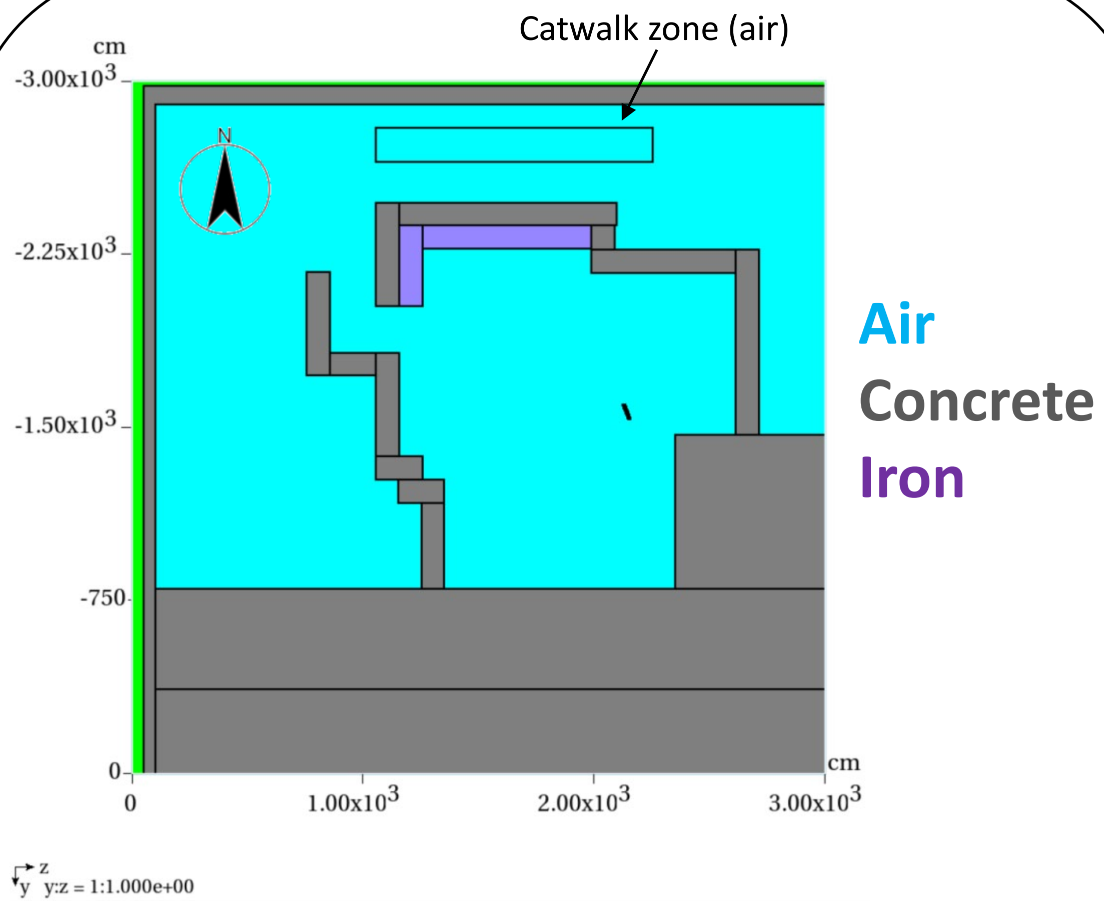




br11220613ifr2mkb2.dat by Noumi-san

Shielding Calculation using MARS

- mcnp mode (rmars-mcnp-linux)
- Energy thresholds:
  - ✓neutrons : 1e-12 GeV
  - ✓e and γ : 1e-4 GeV (default)
  - ✓muons, heavy ions, charged hadrons : 1e-3 GeV (default)
- Beam:
  - ✓**1.0 GeV/c pion**
  - ✓**calculated optics**
  - ✓beam height : 2.0 m
  - ✓from the center of the solenoid
  - ✓**intensity: $1.8\mathrm{x}10^{10}$/h → 30M/6s → 5 M/sec.**
- Experimental target:
  - ✓air or 2cm-Fe



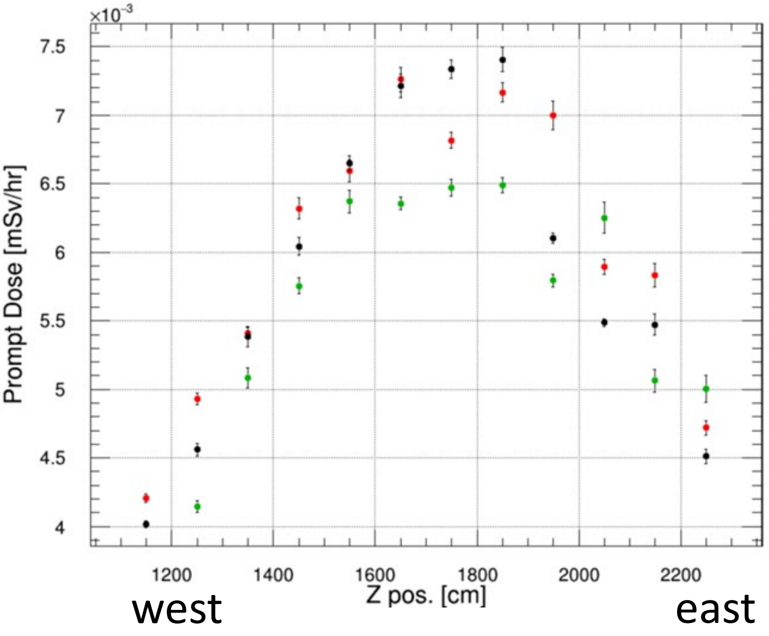
Height of shields and beam dump: 3.0 m
Thickness : 1.0 m

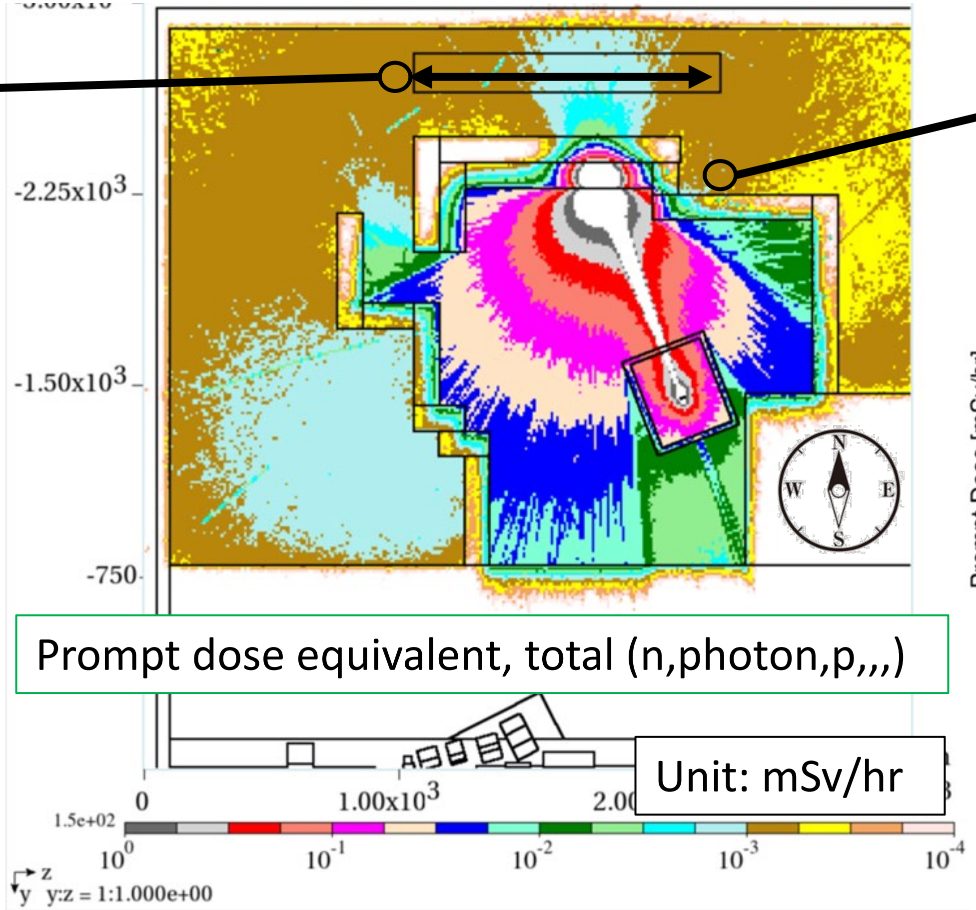
Shielding Calculation using MARS

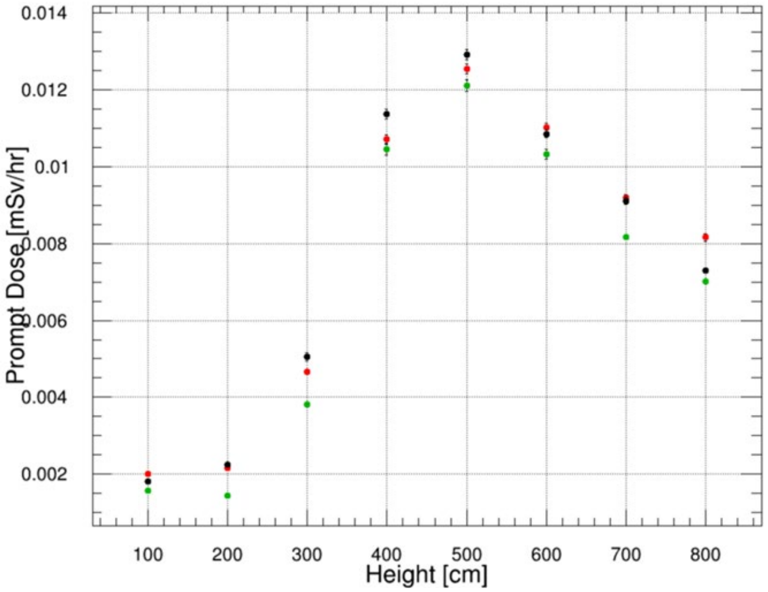
At the beam height :150~250 cm sliced

Catwalk position, east-west dependence

Stair position, up-down dependence







- Calculated optics
- Calculated optics (δy' x 3)
- pencil beam from D4

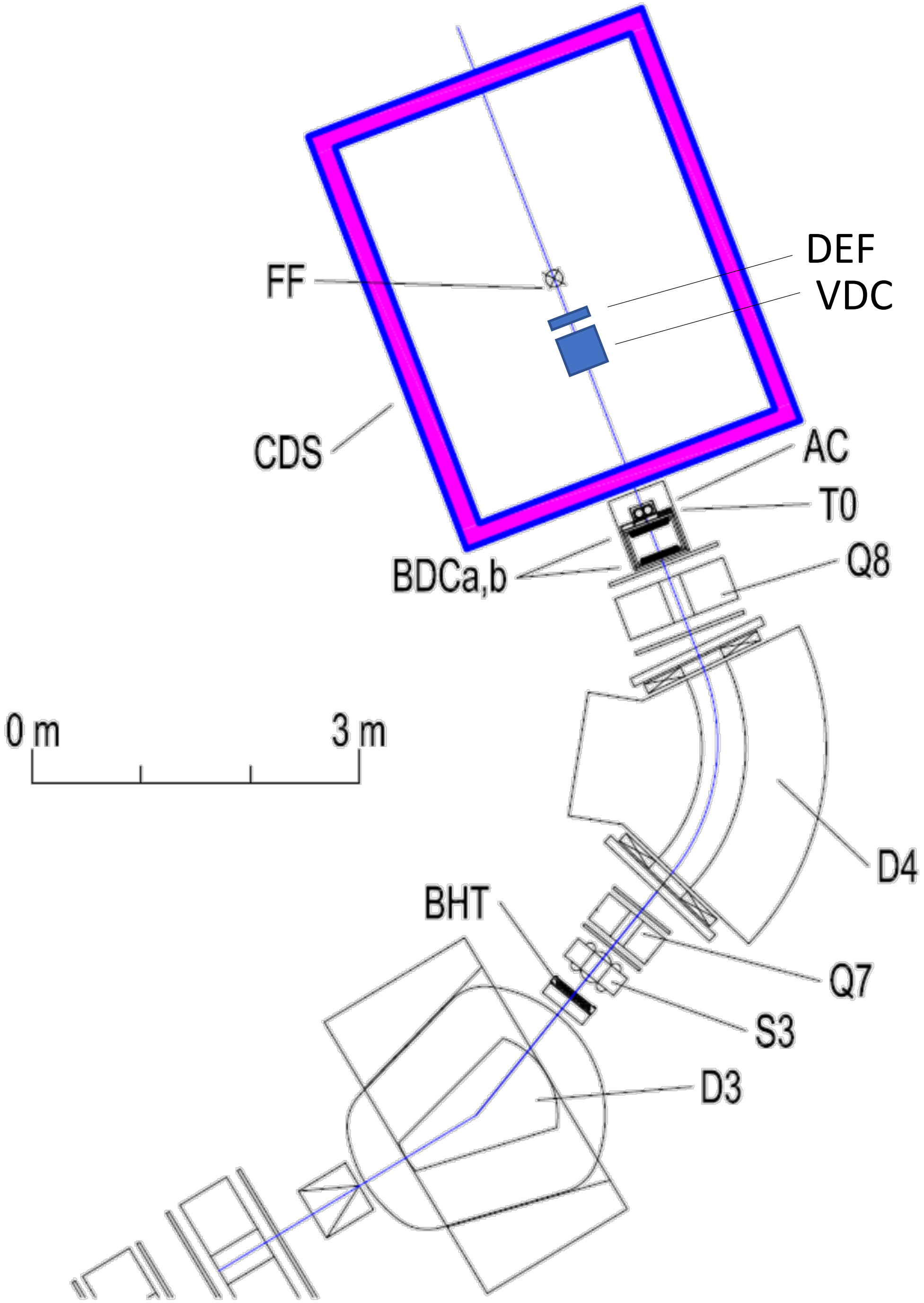
The results include safety factor of 4

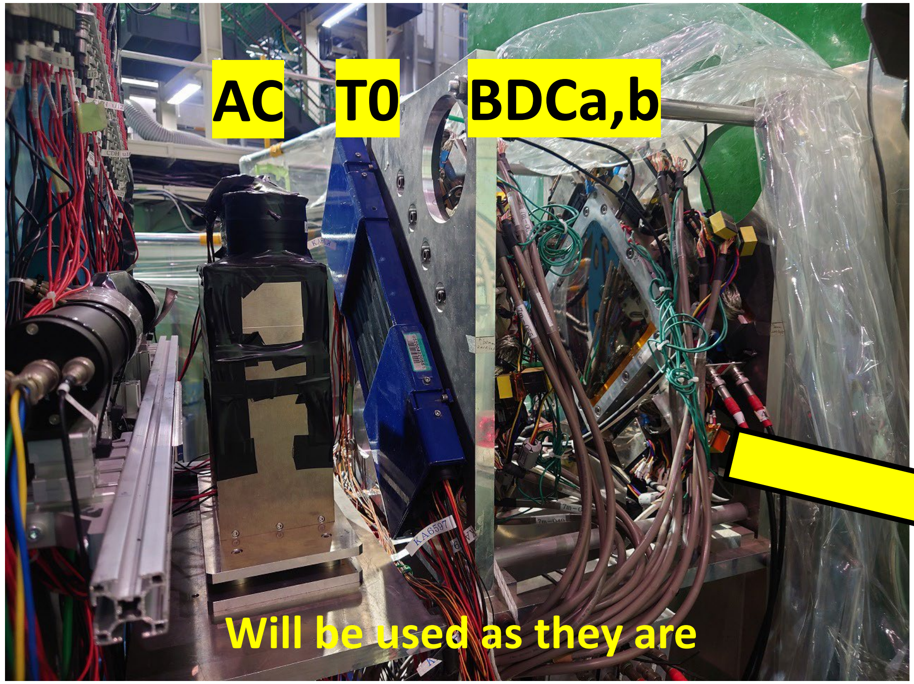
→ Radiation level is below the limit of 25 μSv/h outside of the area

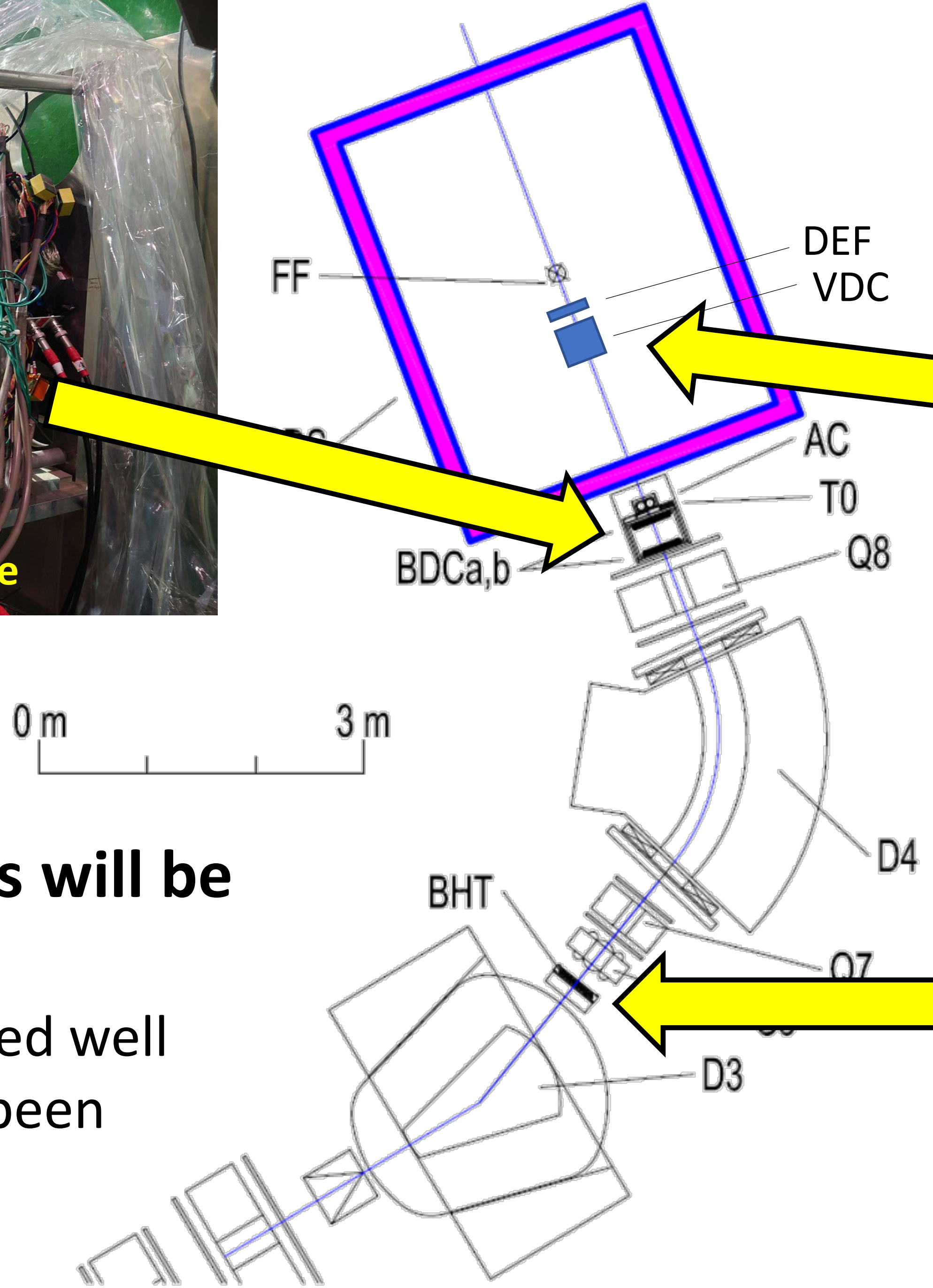
Apparatus:
Beam-Line Spectrometer

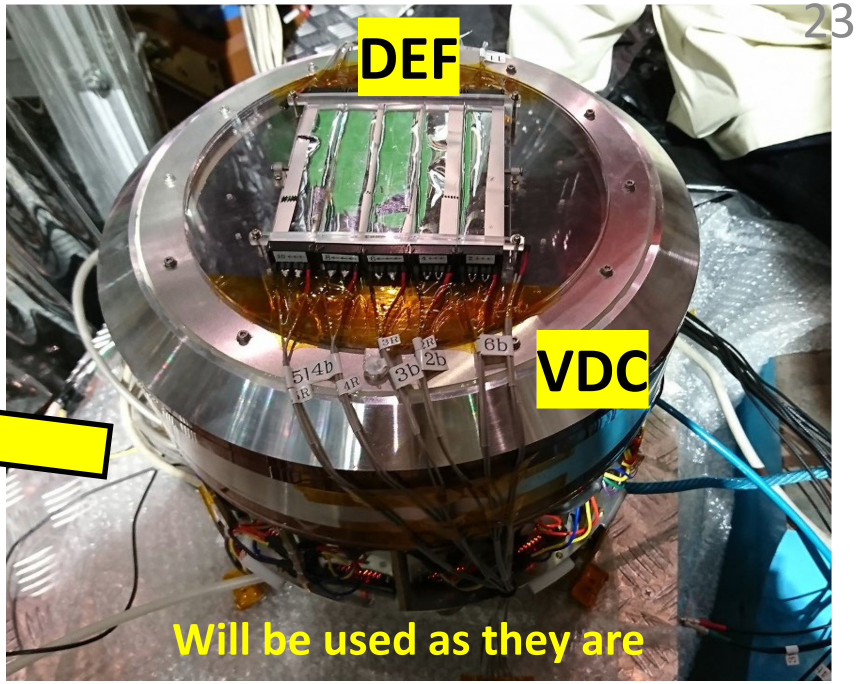
Overview

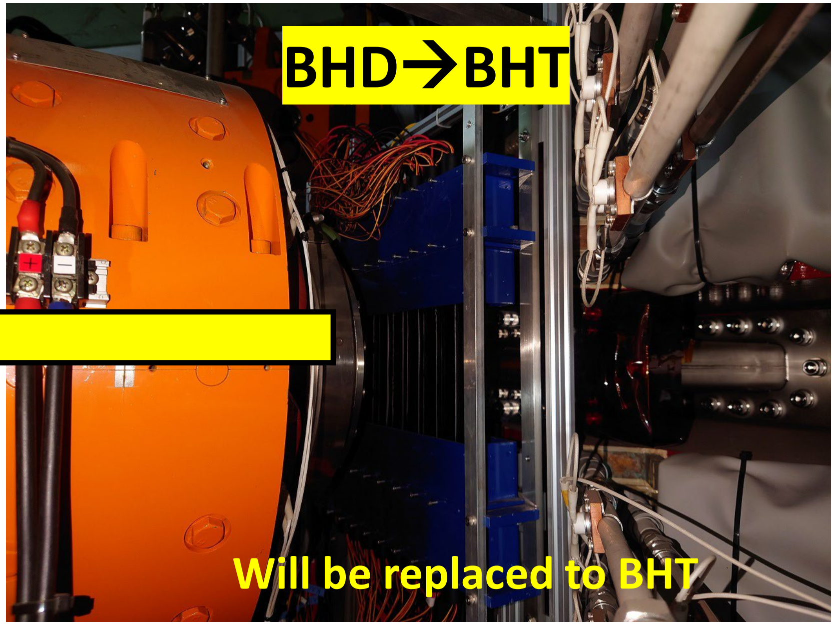
- **Beam intensity @ 90kW**
  - ~1M [2.0s/4.2s]
  - π/K ~ 1.5
- **Beam trigger by BHT, T0, and DEF**
  - TOF(BHT-T0) : 4.0m [$\delta t(\pi$-K) ~ 2.5ns]
  - $\delta_{TOF(BHT-T0)}$: σ ~ 160ps (expected)
- **Kaon ID by Cherenkov counter (AC)**
  - index : 1.05
  - π efficiency : >99%
  - miss-PID K→π : ~1%
- **Momentum measurement by D4**
  - 2 beam trackers : BHT and BDC
  - $\delta p/p$: σ ~ 0.2% (expected)











Almost all detectors will be used as they are

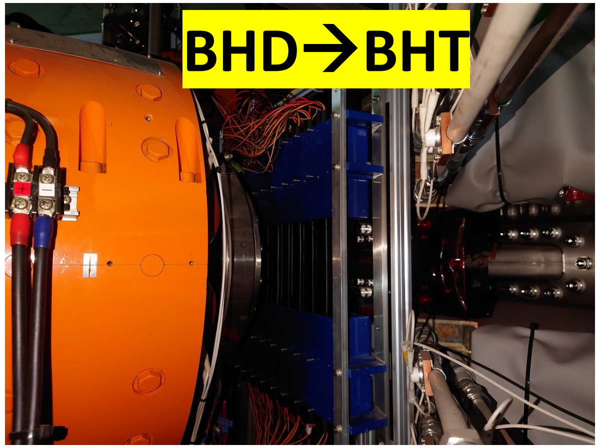
- detectors have worked well
- performances have been studied well

Trigger Counters

BHT (Beam Hodoscope Tracker)

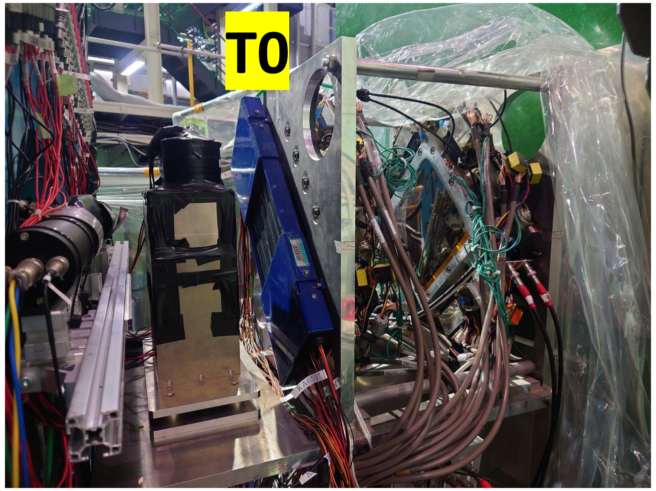
- Upstream (D3) plastic scintillator hodoscope
- Effective size 300 x 150 mm, 32 segments
- **will be installed in FY2022**

for E73 scheduled in FY2023



T0 (Time Zero Counter)

- Define time zero, downstream of Q8
- Effective size 160 x 160 mm, 5 segments
- **Already existing**

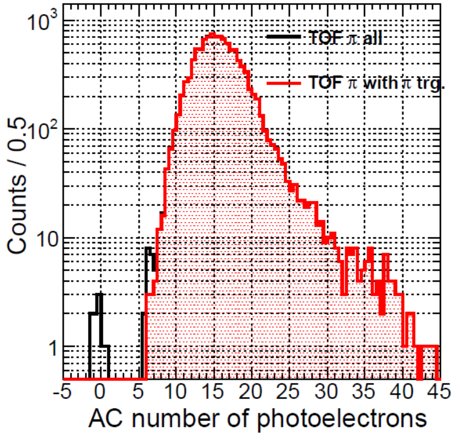


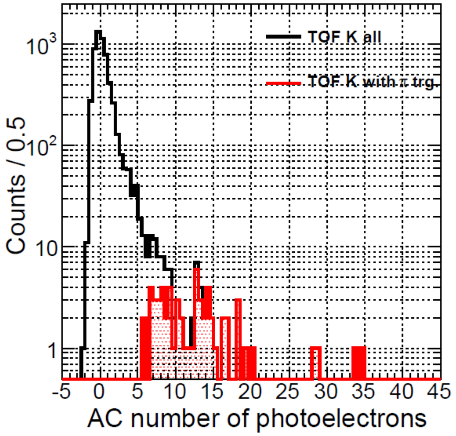
DEF (Beam Definition Counter)

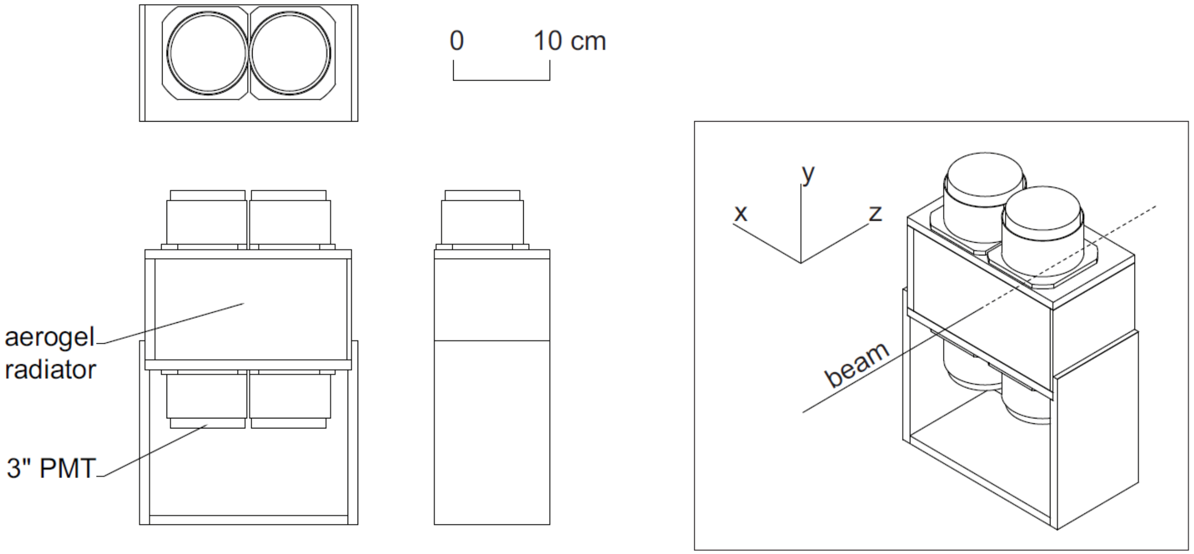
- Select beams that hits the target, upstream of target
- Effective size 100 x 100 mm, 5 segments
- **Already existing**

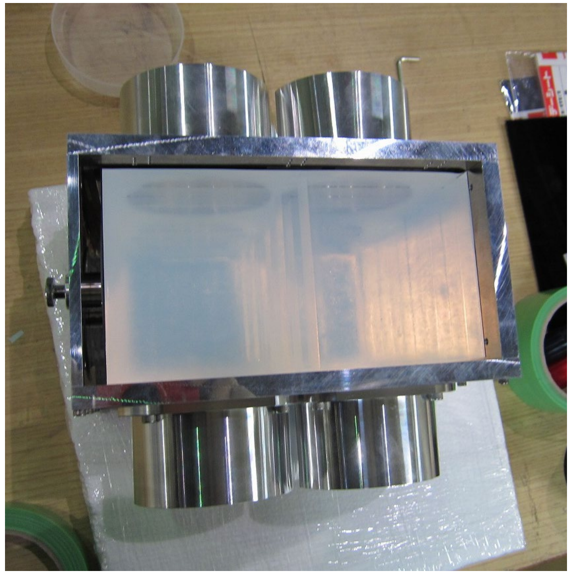
Kaon Identification Counter

- Aerogel Cherenkov counter with n=1.05
- downstream of T0
- size: 180 x 100 x 100 mm
- Average # of photons for pions: ~15
  - pion efficiency >99%
  - misidentification ratio of K as π ~1%
- **Already existing**





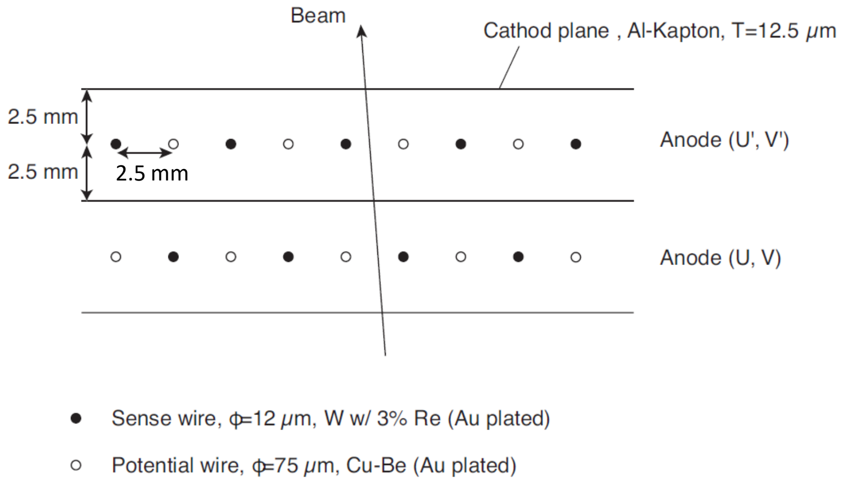


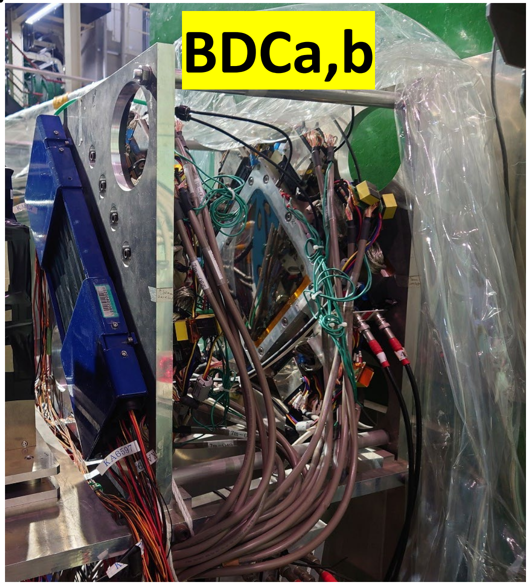


Beam Line Chambers

BDC (Beam Line Chamber)

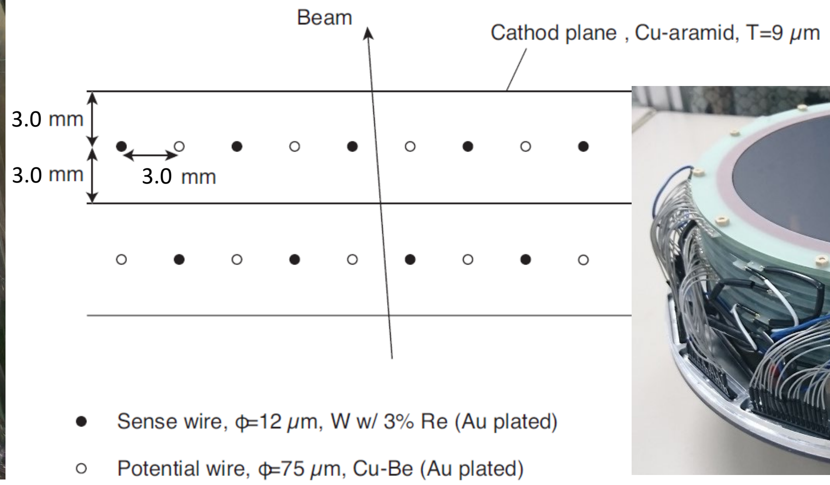
- upstream of T0
- 160 x 160 mm effective area
- 8 layers (UU’VV’UU’VV’) x2
- 32 sense wires, 2.5 mm drift length
- Typical resolution: ~150 μm
- **Already existing**

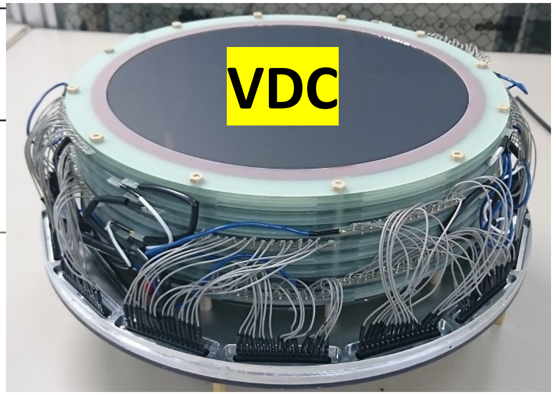




VDC (Beam Vertex Chamber)

- upstream of DEF
- ϕ197 mm effective area
- 8 layers (XX’YY’XX’YY’)
- 32 sense wires, 3.0 mm drift length
- Typical resolution: ~150 μm
- **Already existing**

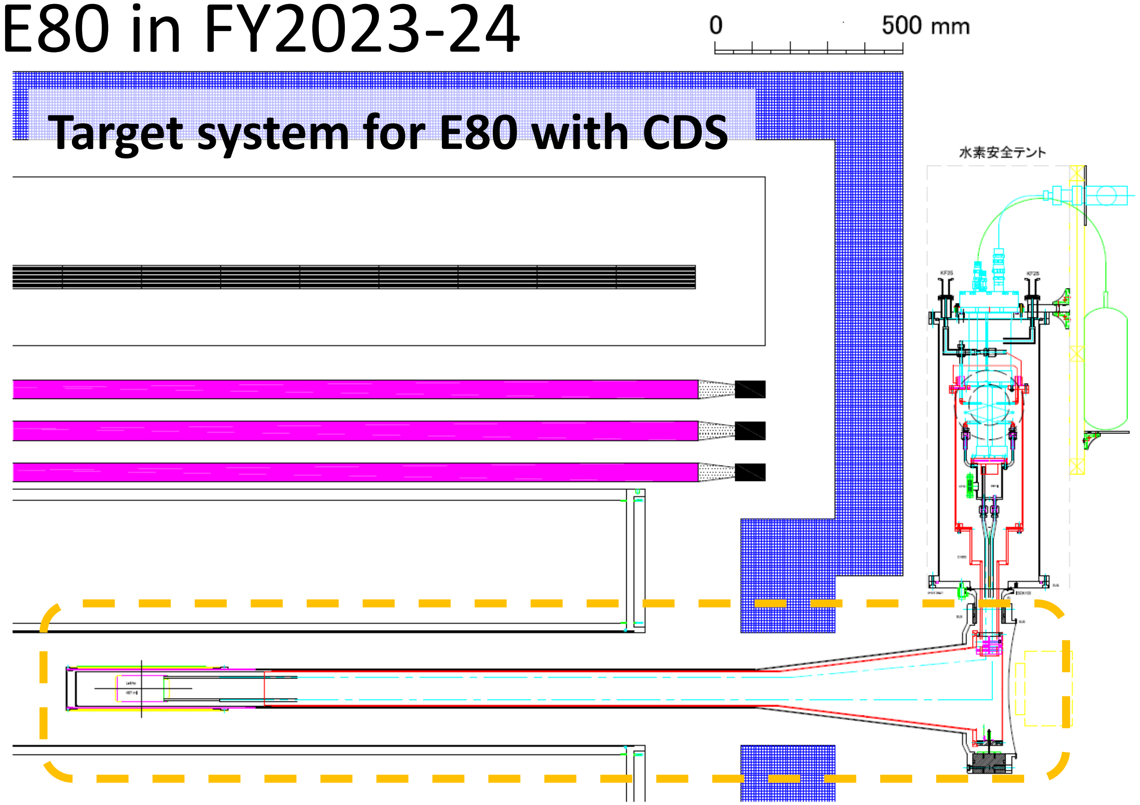




Apparatus:
Cryogenic Target System

Overview

- Cool down below 3K with pulse tube (Cryomech PT410), no cryogen required
- Capable to liquefy H_2/D_2/^3He/^4He gasses [Target replacement takes a few days]
- **The system has already worked well (T77/E73)**
- The horizontal part will be extended for E80 in FY2023-24



Target Cell

E73/E80
$^3He/^4He/H_2$ Target Cell

ID=68, L=150
Cylinder; Kapton 0.05 X 3

End Cap ϕ68
Mylar; t= 0.25

End Cap ϕ52
Mylar; t= 0.25

Max. working pressure:

- Hydrogen 0.15MPa
- He 0.1MPa

150% pressure test - OK

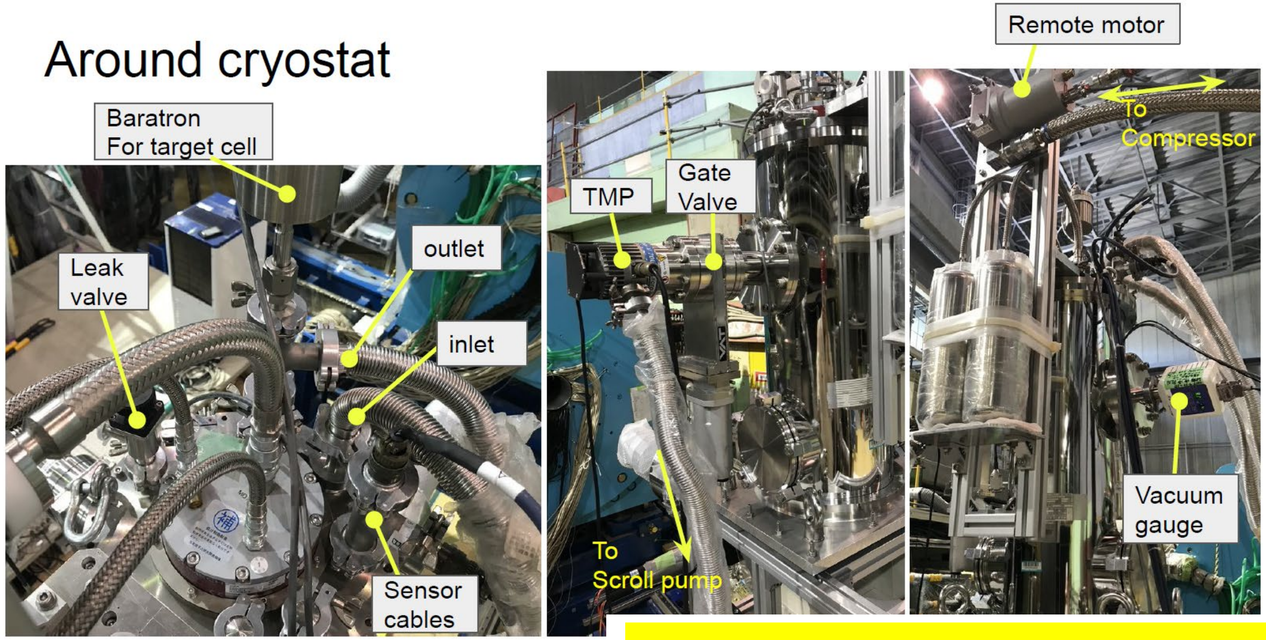
- differential pressure 0.22MPa @RT, LN2, 30min

Destructive test:

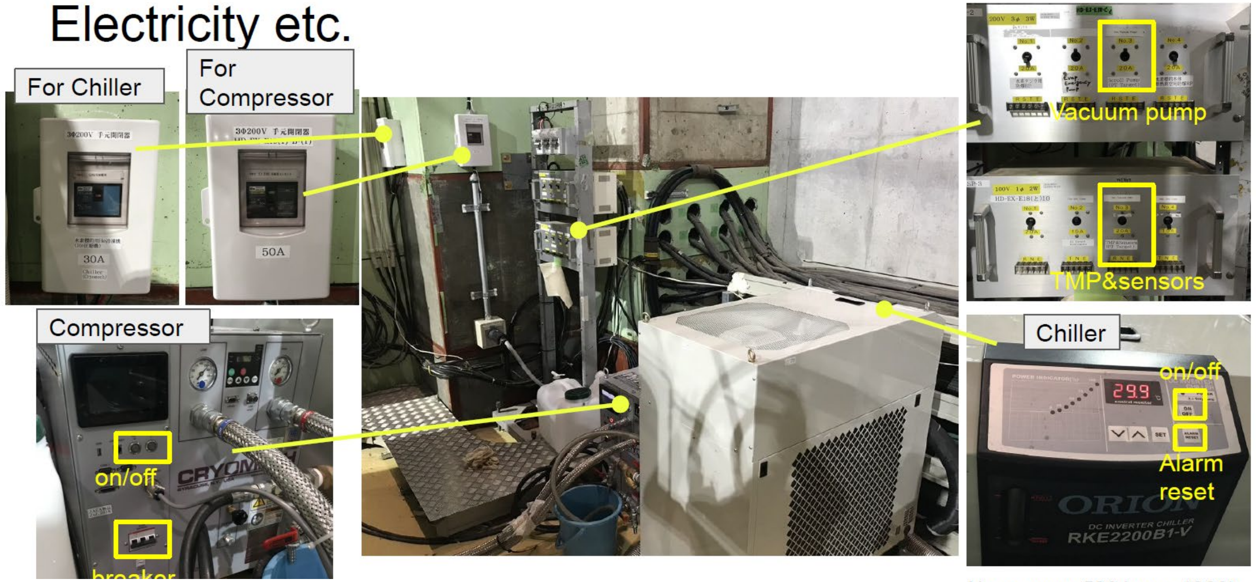
- Fractured at a differential pressure of 0.62 Mpa
  → safety factor >4

System has already been completed

Around cryostat

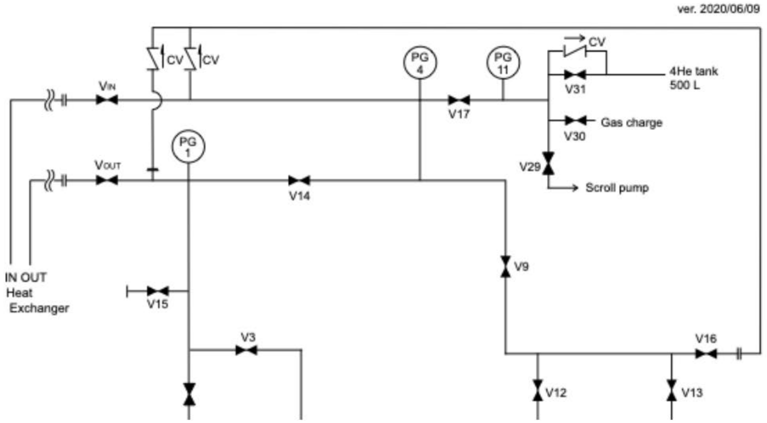


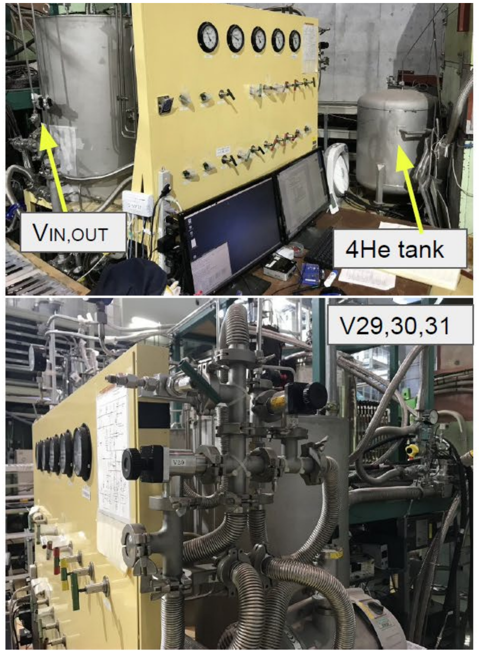
Electricity etc.



Alarm every 500 hours (C00)
Push "alarm reset" for a while

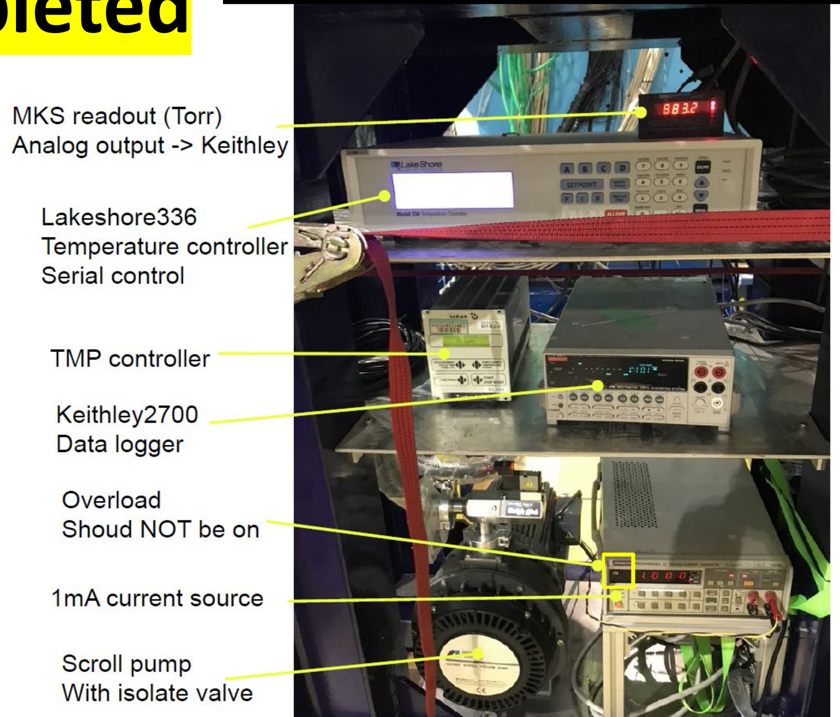
Gas system





V_in, V_out, V14, V17, V31, (V9, V16) open in normal operation
V_in, V14 close in closed operation
Others should be always closed

Readout system



Operation

from

Pulse Tube target manual

Ver. 20200609 For T77 (helium-4)

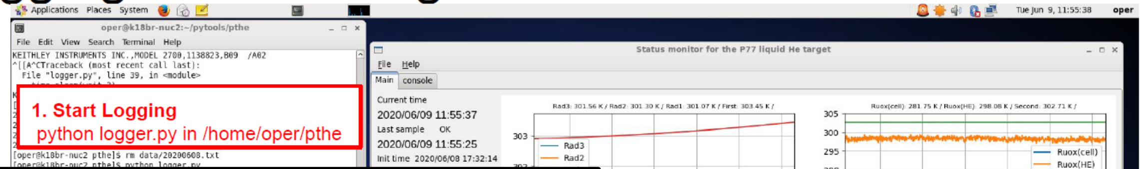
Operation procedure

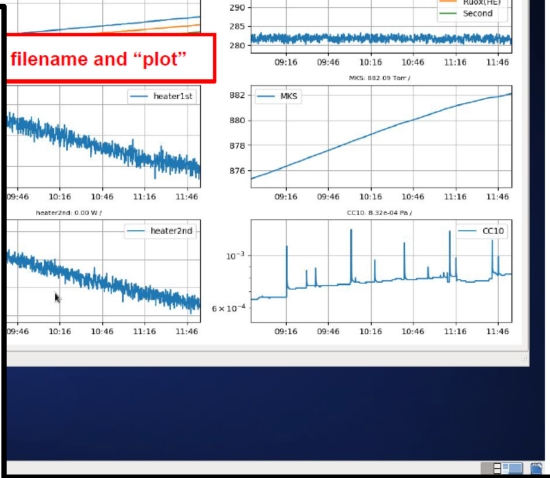
1. Start logging
2. Vacuuming
   a. Scroll pump < 1e2 Pa

…en the chamber

Logging & Monitering

Trend: http://k18br-nuc2.intra.j-parc.jp/
Sheet: http://k18br-nuc2.intra.j-parc.jp/fig/sheet.png
On ag: http://ag.riken.jp/lhe3/T77/





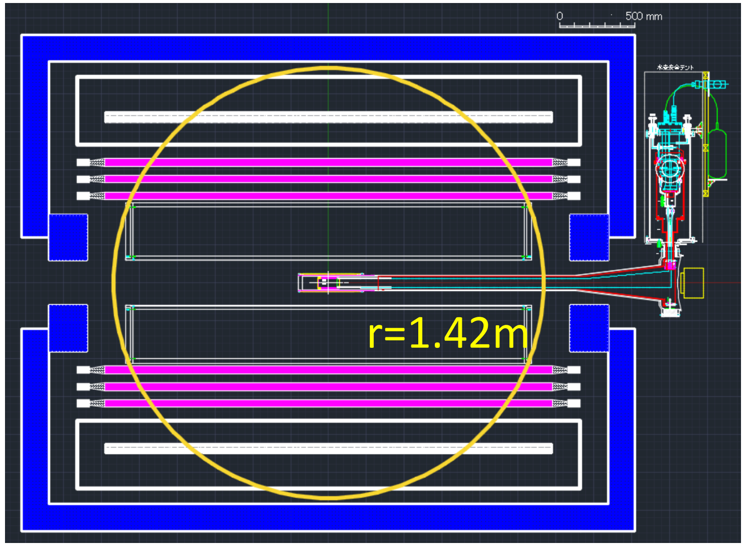
In case of troubles

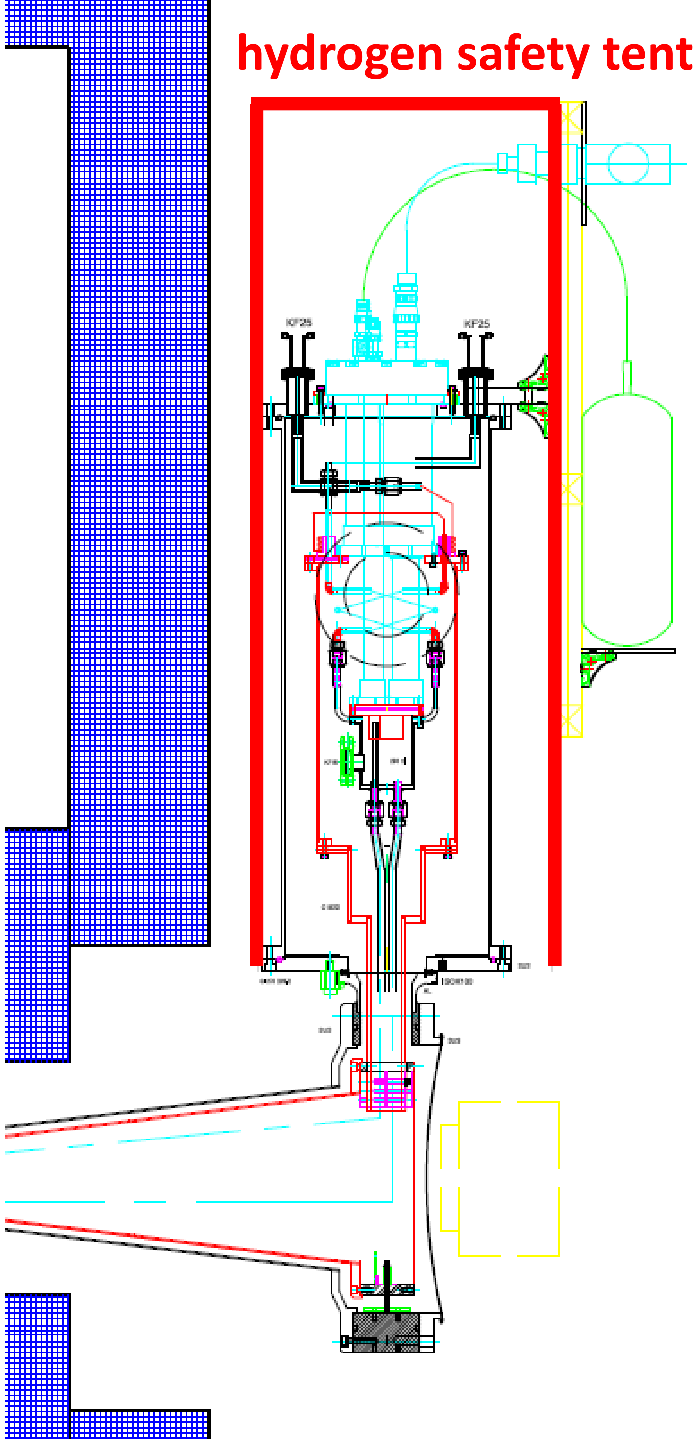
- Power failure
  - Compressor, Chiller stop, liquid will slowly evaporate and go back to the tank. Make sure the target cell and the gas tank is connected.
  - Vacuum pump stops, but isolate valve will keep vacuum. Close the gate valve if possible.
  - When the power recovers, restart logging first, vacuuming next, and then restart cooling.
- Vacuum problem
  - If the isolation vacuum level get worse, stop the compressor.
  - If vacuum became >1e0, stop TMP, if >1e3, close the gate valve
- Cell/Chamber damaged
  - Stop cooling and close the gate valve
- Experts: try to contact with them in any troubles
  - Tadashi Hashimoto 080-5221-6429
  - Shigeru Ishimoto
  - Shoji Suzuki

Operation procedure has been already established

Explosion-proof

- System is designed to be explosion-proof to liquify H_2/D_2 gasses
  - ✓Covered by “hydrogen safety tent”
  - ✓Safety measures prepared for the E31/E57 experiment will be used as is:
    - H_2/D_2 gas detector
    - H_2/D_2 exhaust system
    - Interlock system for detectors (critical radius of 1.42m)
- Will follow “the guideline for the usage of liquid hydrogen target at J-PARC”

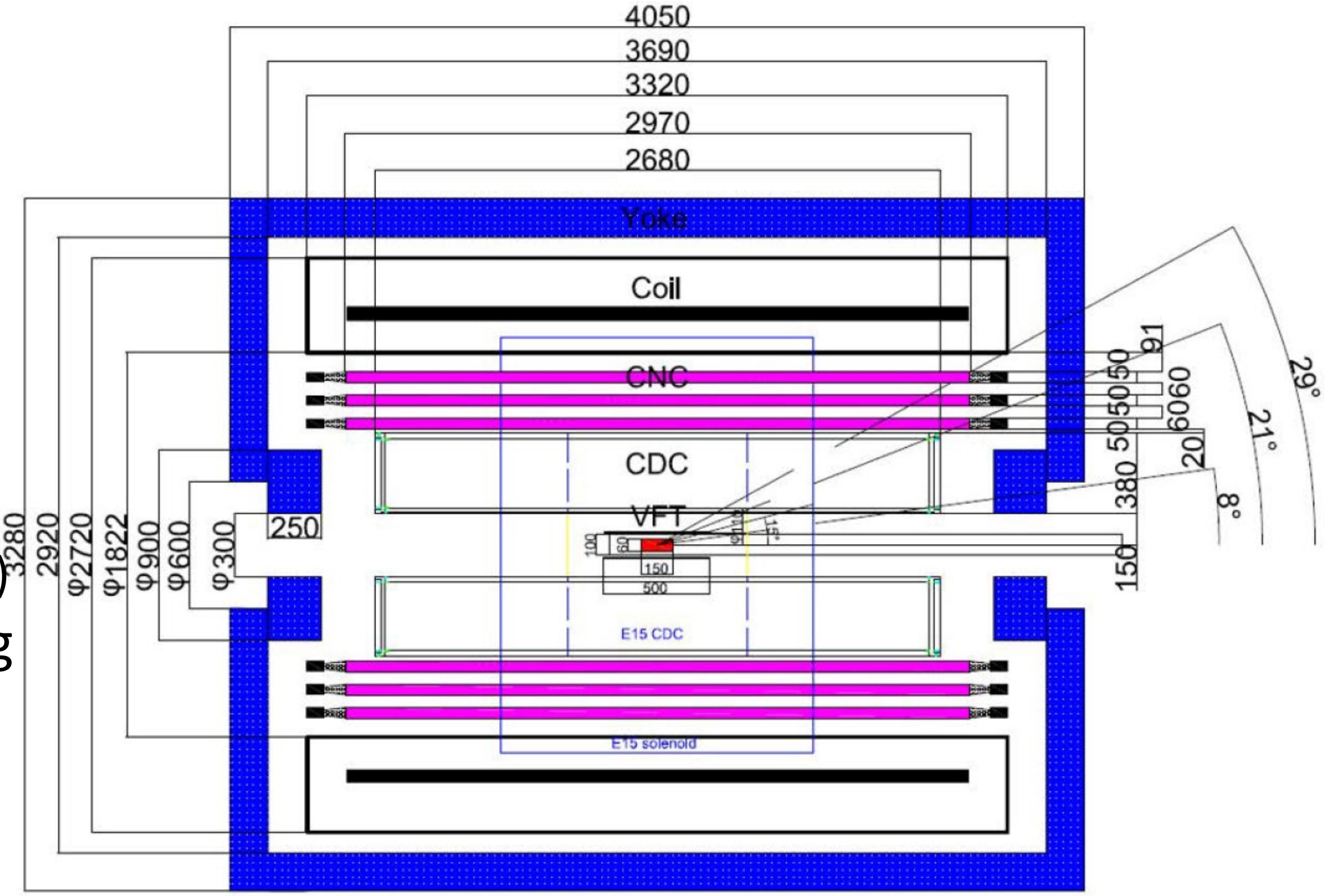




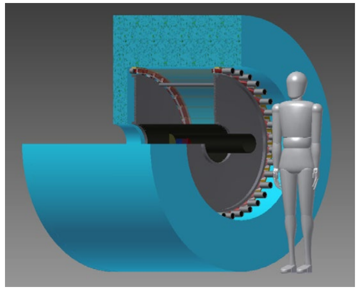
Apparatus:
Cylindrical Detector System

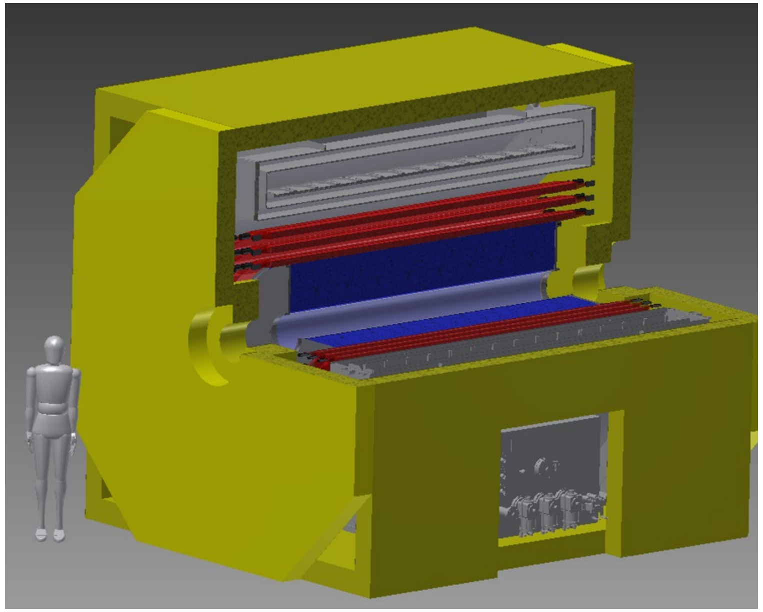
Overview

- Large acceptance solenoid spectrometer
  - ➢Superconducting solenoid magnet
  - ➢CDC (Cylindrical Drift Chamber)
  - ➢CNC (Cylindrical Neutron Counter)
  - ➢VFT (Vertex Fiber Tracker)
- Significantly improved performance compared to the existing CDS
  - ✓Solid angle: x1.6 (59% → 93%)
  - ✓Neutron eff.: x12 (3% → 15%x1.6)
- Resolution will retain the existing CDS performance
  - ✓$5.3\% p_T \oplus 0.5\%/\beta$
  - ✓σ[TOF(T0-CNC)] ~ 160ps

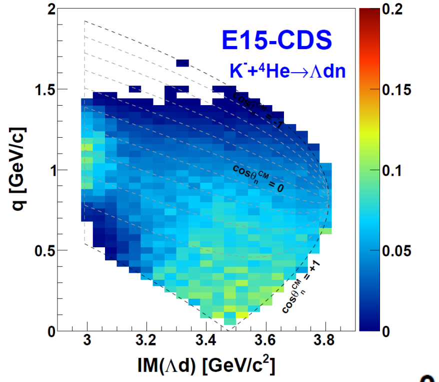


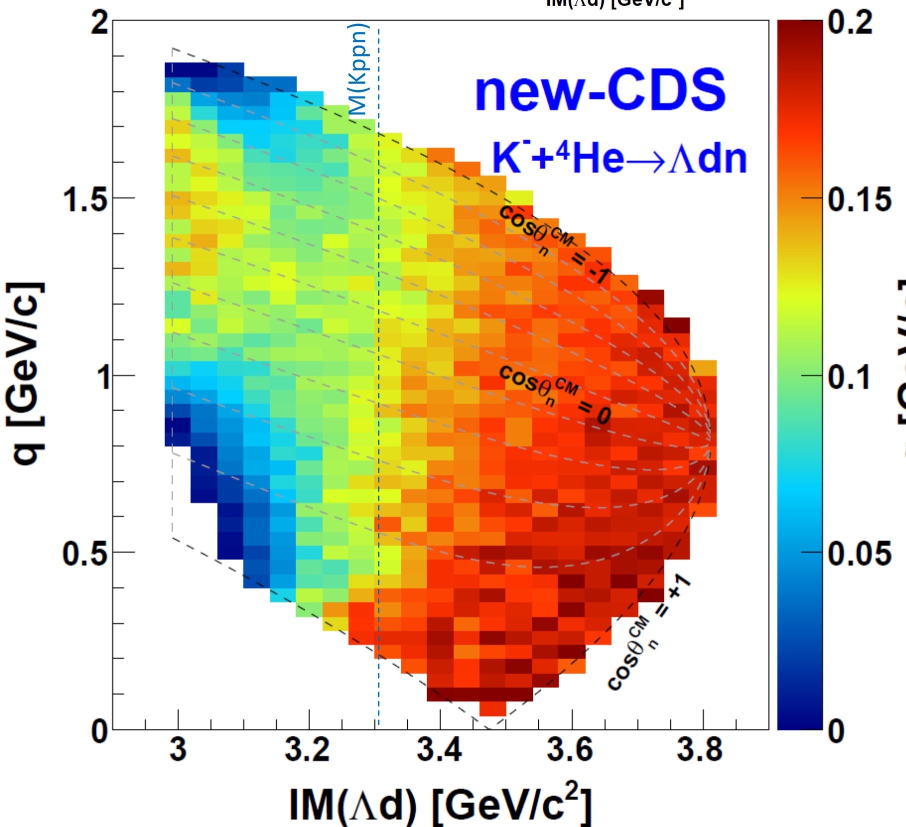
Acceptance for K^{-4}He reaction



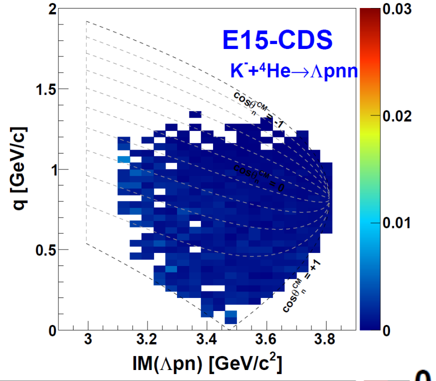


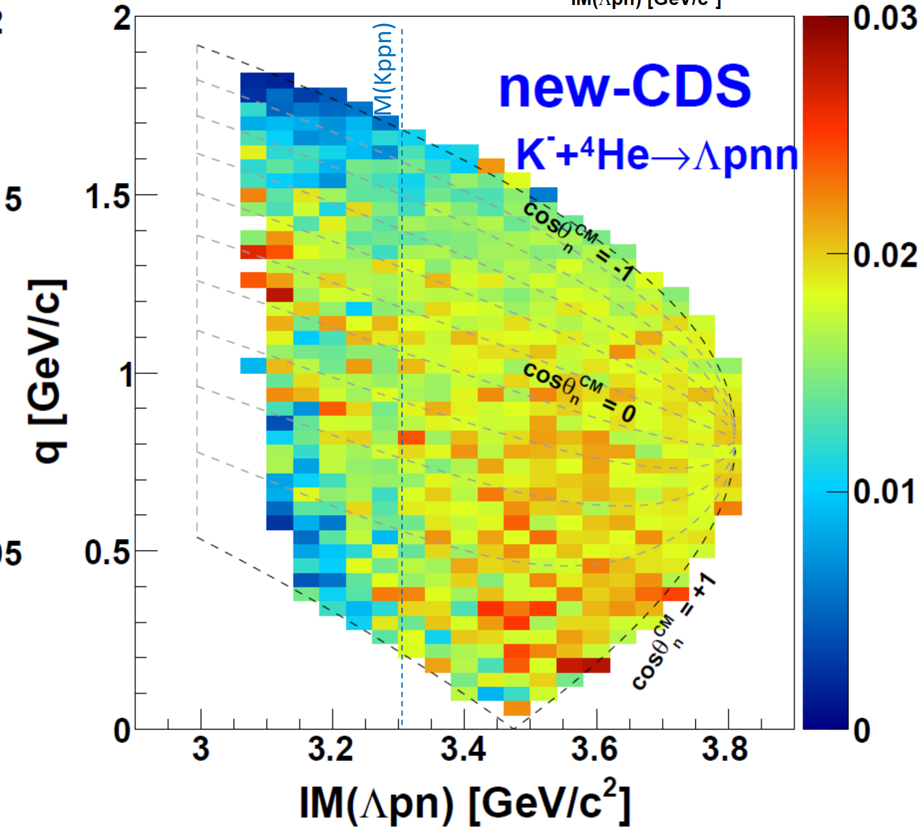
Λd in CDS





Λpn in CDS





CDS:
Superconducting Solenoid Magnet

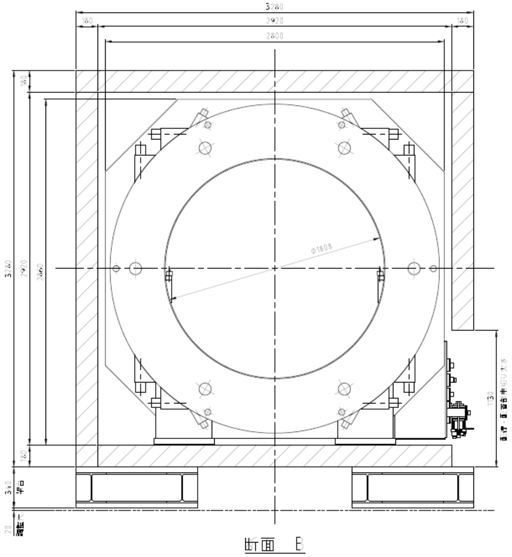
Overview

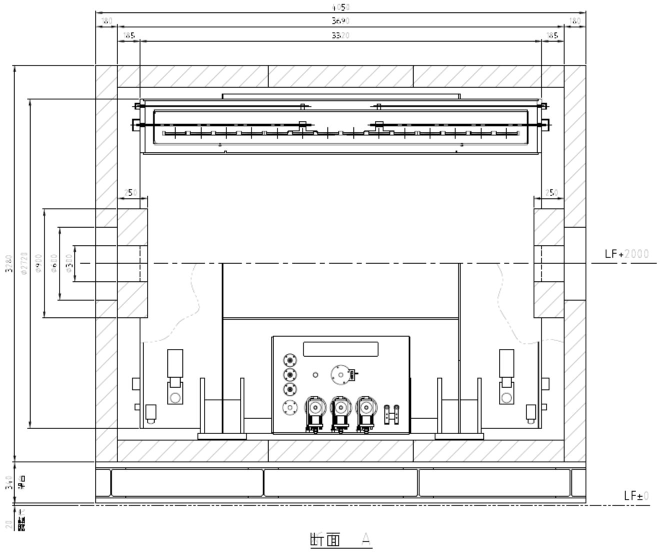
- Same design as “the detector solenoid magnet” for COMET-I
- 3.3m x 3.3m x 4.1m, ~125t in total
- Max. field of 1.0T @ center
  - 189A – 10V
- NbTi/Cu SC wire, 98km in total
- Conduction-cooling with GMx3
- Semi-active quench-back system
- **Will be completed in FY2024**

constructed in cooperation with the J-PARC Cryogenics Section

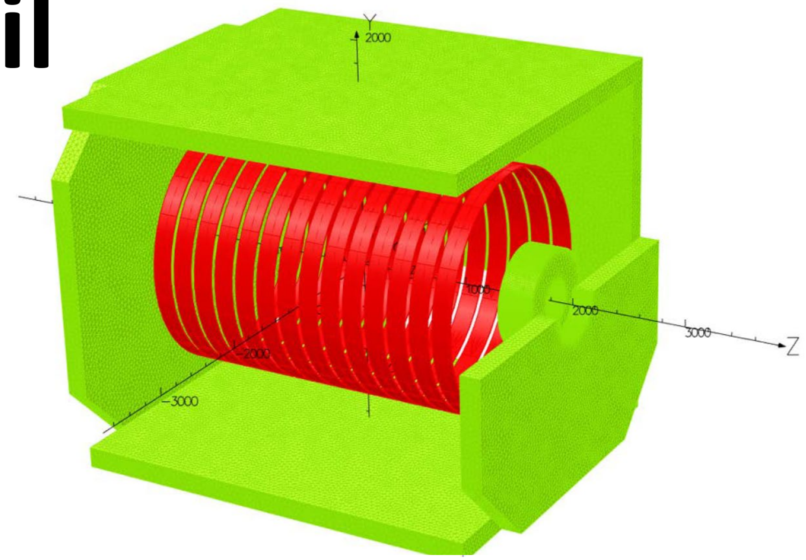
SHI FA-50
(air cooling)

SHI RDE-418D4





Superconducting Coil



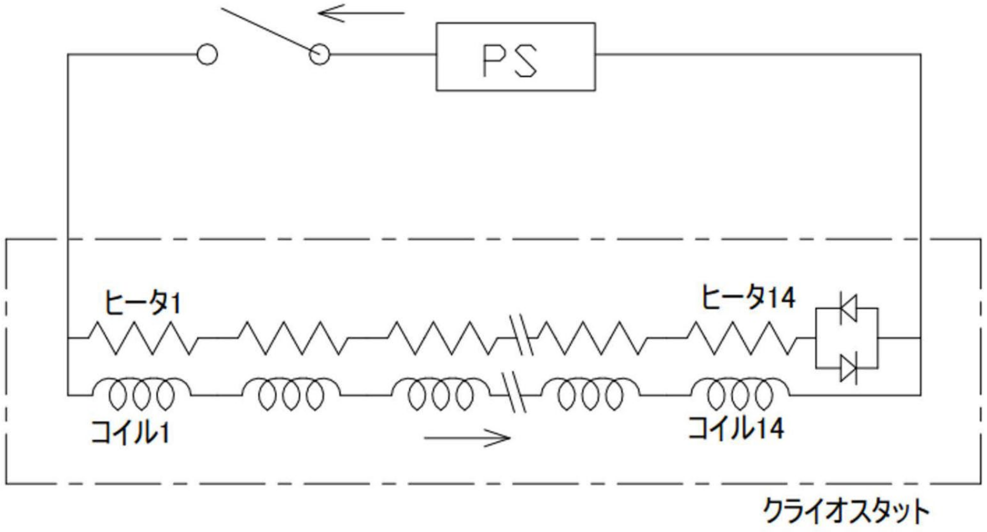
- 14 solenoid coils
- Copper wire is formed on each coils for the quench protection heater
- **SC wire will be purchased in FY2022**

Coil	Inner diameter	mm	2140
	Coil length	mm	171.7
	Coil thickness	mm	8
	Number of coils	pieces	14
	Total coil length	m	2.92
	Current desity	A/mm^2	131
	Number of turns per coil	turn	945
	Total number of turns	turn	13230
Superconducting wire	Conductor dimension	mm	1.2
	Copper ratio	Cu/NbTi	4.2
	Length per coil	km	7
	Total length	km	98

Quench Protection

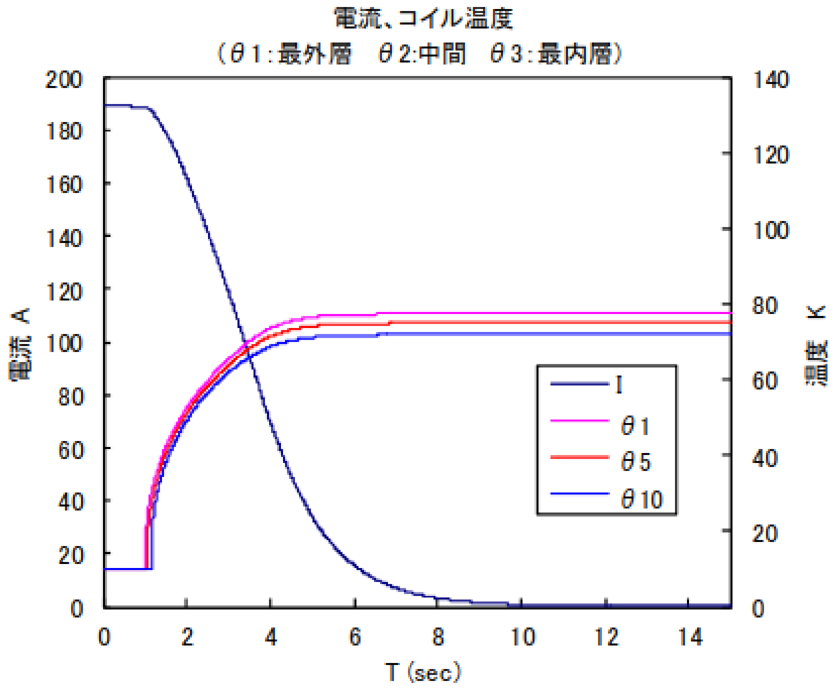
- Semi-active quench-back system similar to the MuSIC @ RCNP
  - ✓coils are connected in series
  - ✓copper quench-back heaters are connected in parallel to the coils via diodes

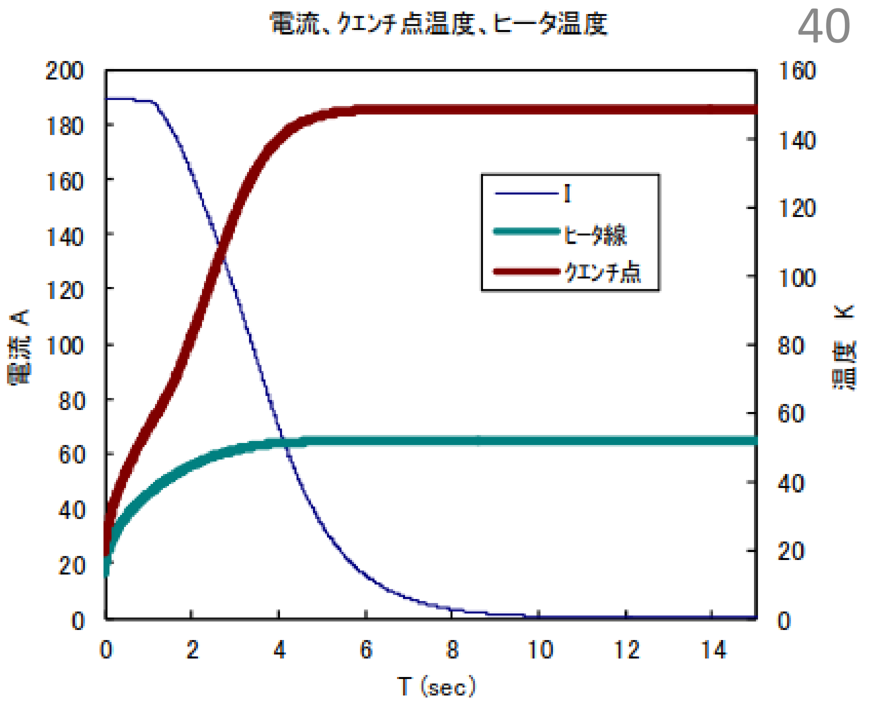
- If the quench is detected,
  - ① the power supply is immediately shutdown
  - ② the current in the coils is bypassed into the heater path
  - ③ almost all the energy stored in the magnet (4.2MJ) is dumped in the cold mass

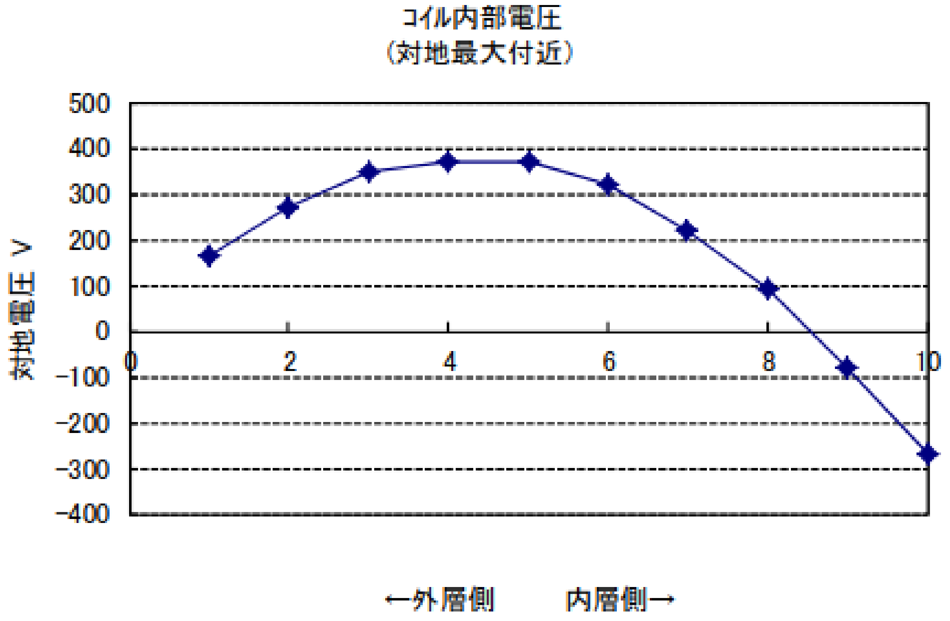


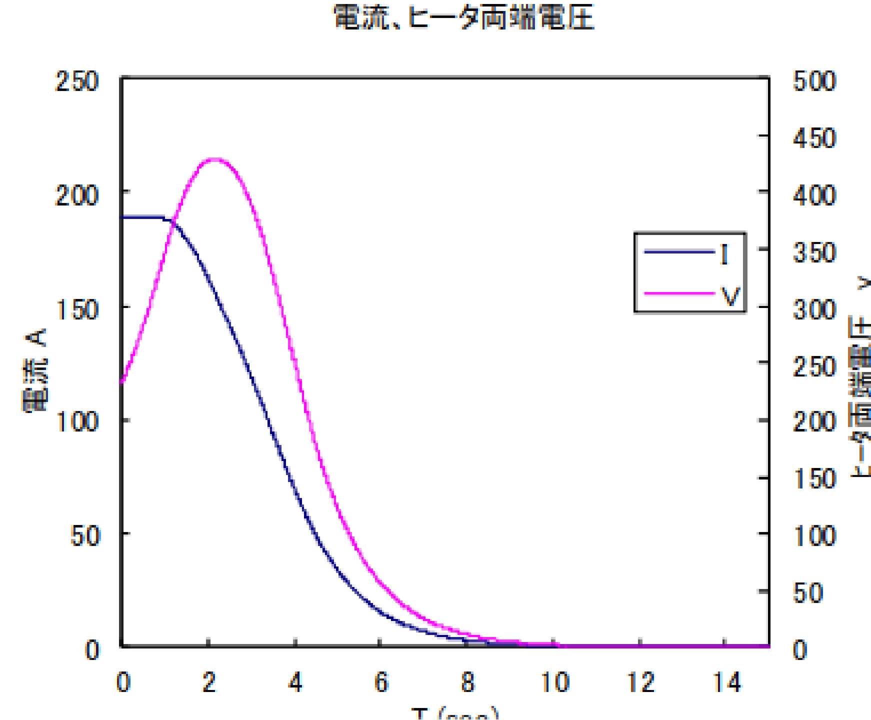
Quench Protection

- Current decay time ~ 10s
- Max. heater voltage at both ends ~ 450V
- Max. quench spot temperature ~ 150K
- **safely and reversibly protected**









Fast Control

From Iio-san's slides

RA3100

合 計(税込) ¥1, 837, 660– 消費税 (¥167, 060) 税抜 (¥1, 670, 600)

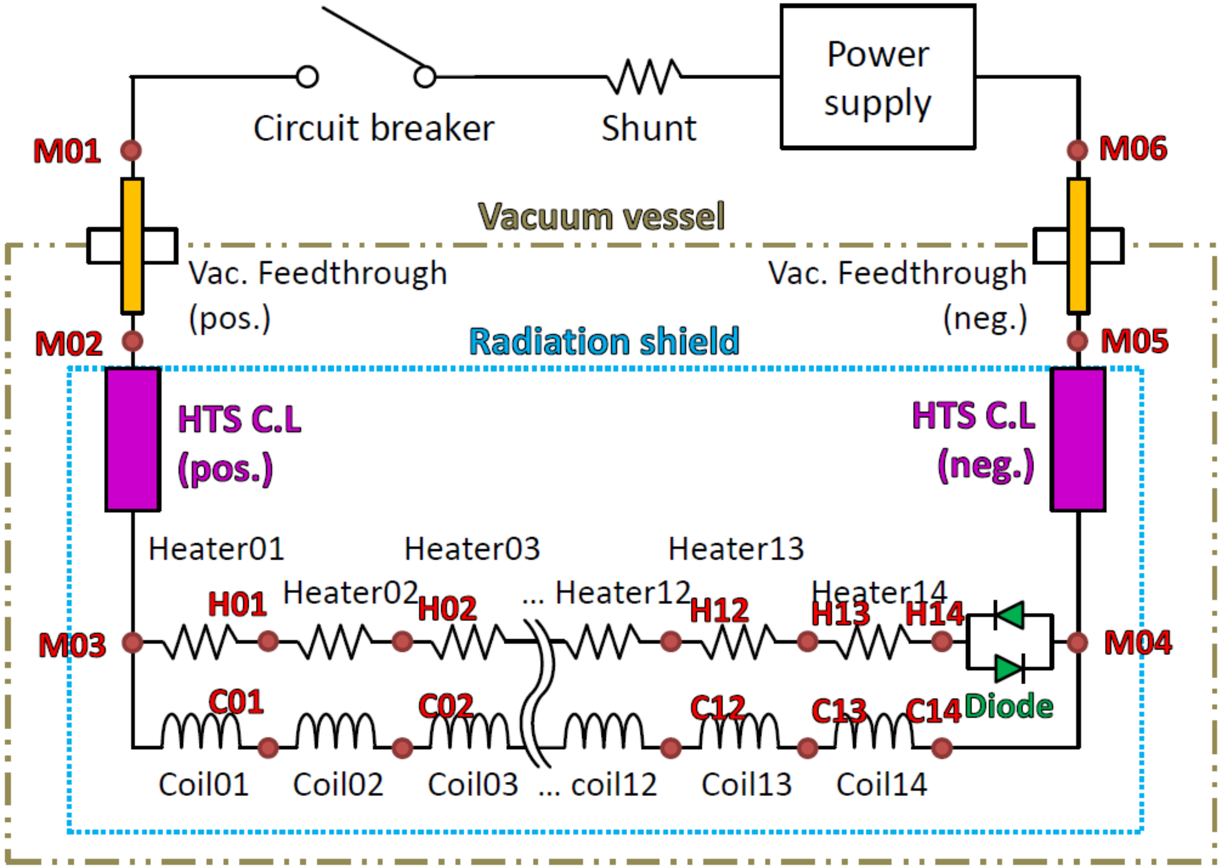
品 名／型 名	数 量	単 価
オムニエース RA3100 AVRA3100	1	882, 000
校正証明書／検査成績書(本体用) AZ-KENSA-RA	1	7, 000
4ch電圧モジュール RA30-101 AVRA30-102	4	135, 000
校正証明書／検査成績書(モジュール用) AZ-KENSA-RA	4	7, 000
AV トレーサビリティ 体系図(本体、モジュール共通) AZ-TRB-AV	1	12, 000
	16	12, 600

	標準価格(税抜)
0V、アンチエリアシングフィルタ付	¥100,000
±200V	¥150,000
±500V	¥90,000
	¥80,000
測温抵抗体対応、温度	¥120,000

3

V-tap位置

Main	Heater	Coil
M01	H01	C01
M01	H02	C02
M03	H03	C03
M04	H04	C04
M05	H05	C05
M06	H06	C06
	H07	C07
	H08	C08
	H09	C09
	H10	C10
	H11	C11
	H12	C12
	H13	C13
	H14	C14
6	14	14
	Total:	34



2

- **PS/DAQ will be purchased in FY2022**
  - ➢200A – 10V
  - ➢AC200V
  - ➢air cooling

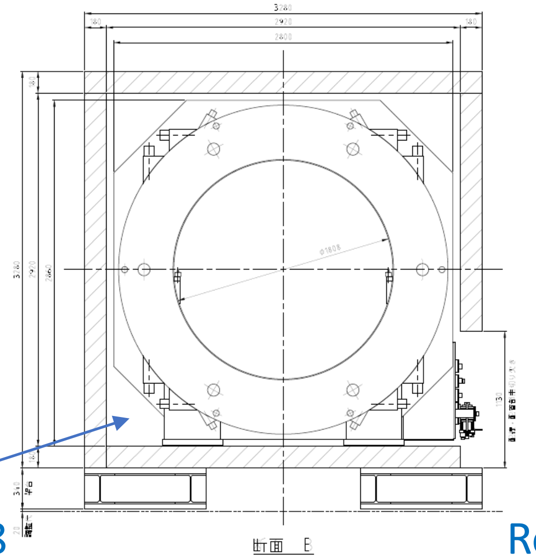
Vacuum Vessel and Return Yoke

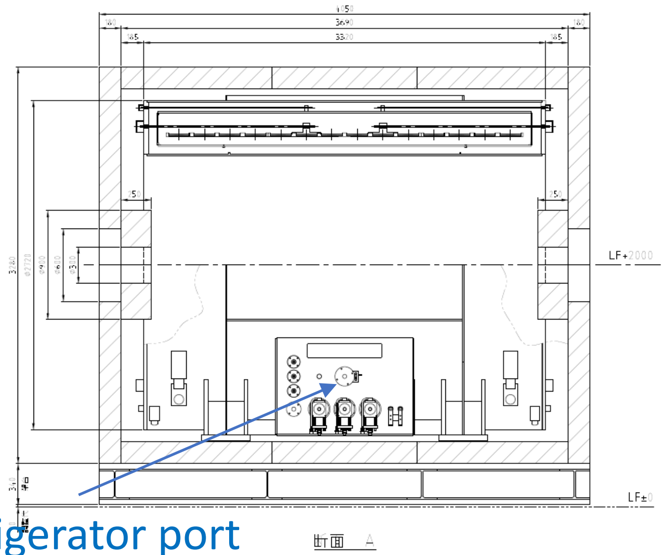
Vacuum Vessel

- Bore dia. = ϕ1.8m, length = 3.3m
- Outer dia. = ϕ2.7m
- Weight = 5.9t
- **Will be constructed in FY2023-24**

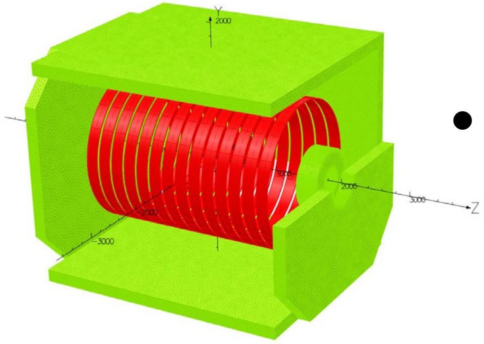
Return Yoke

- Square shaped
- 3.3m x 3.3m x 4.1m
- ~115t
- **Will be constructed in FY2022**

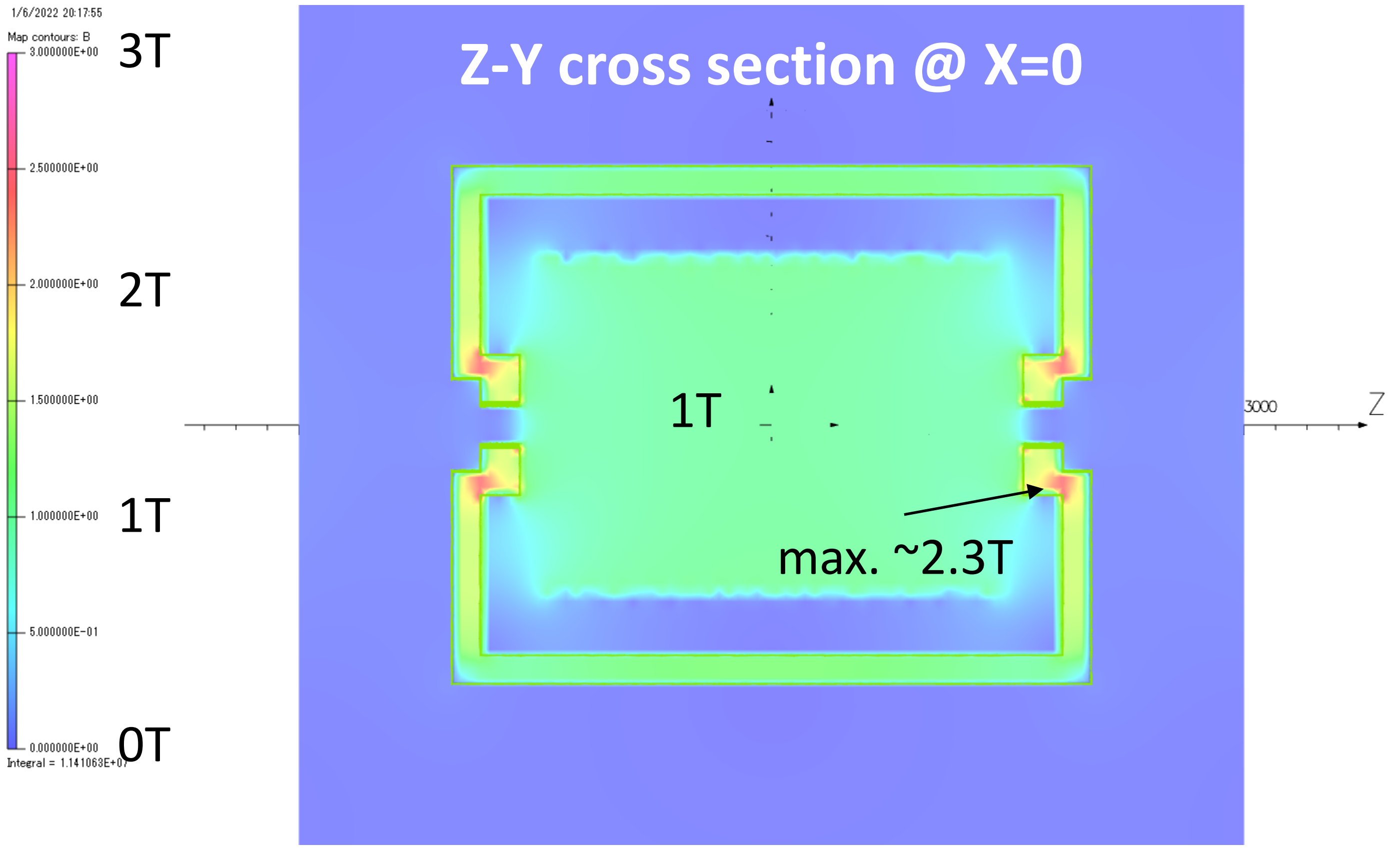


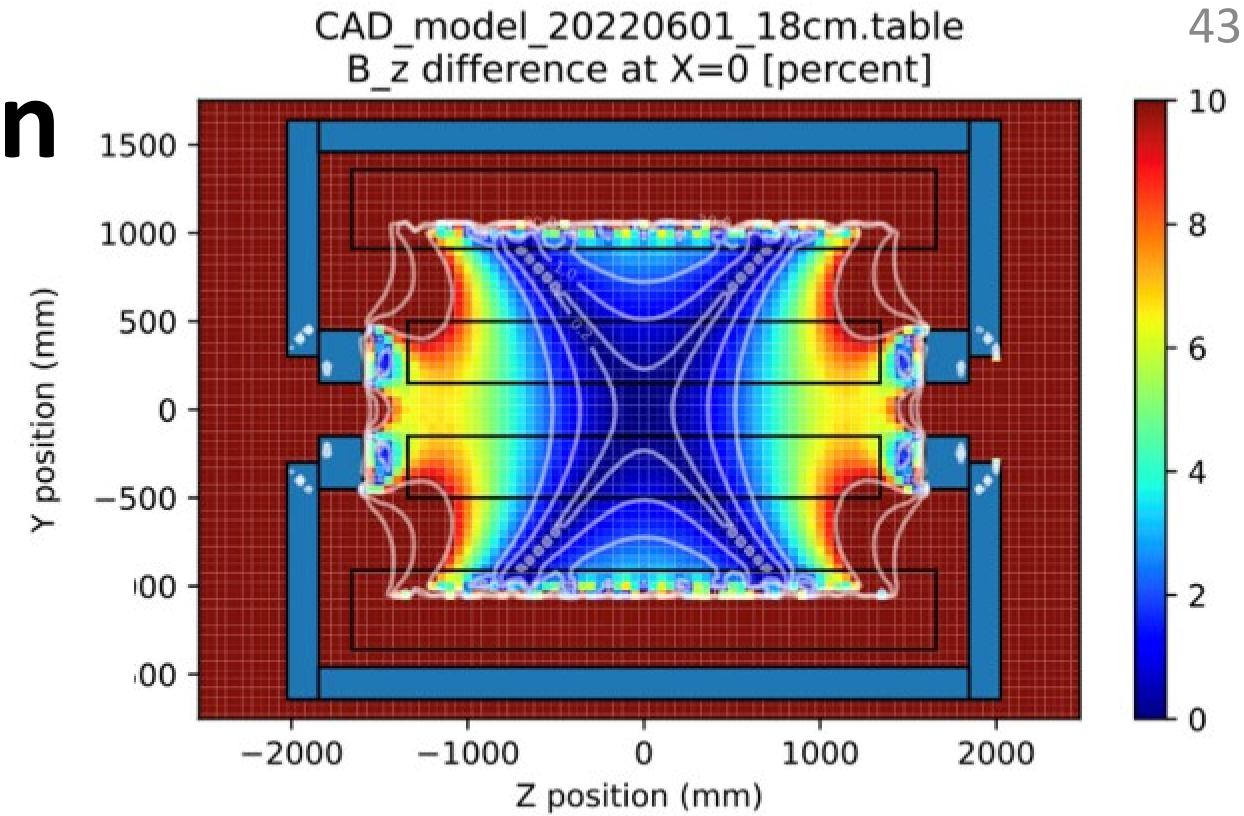


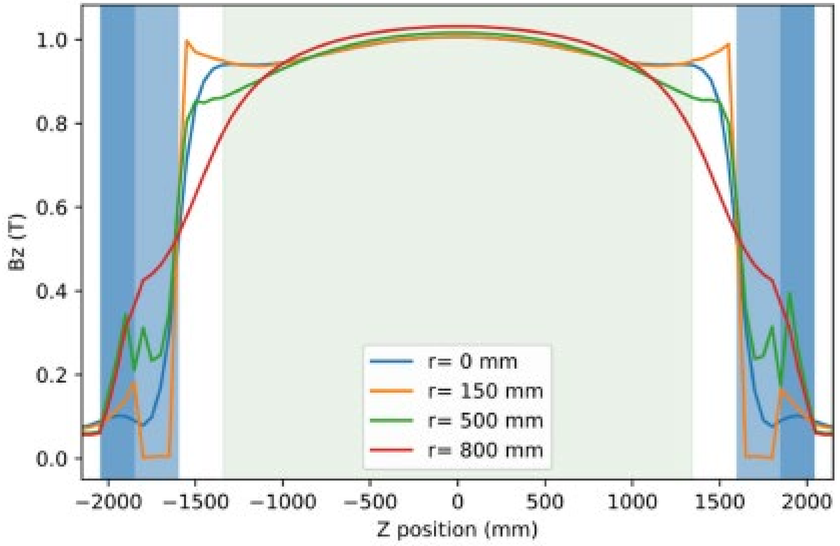
Magnetic Field Calculation



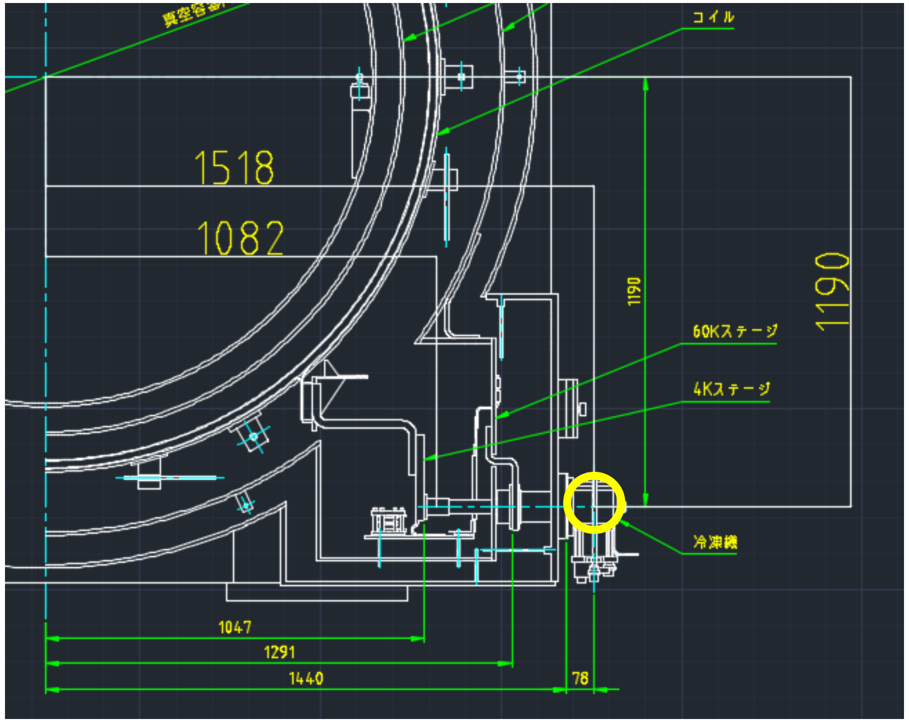
- Full 3D-model simulation using OPERA-3D



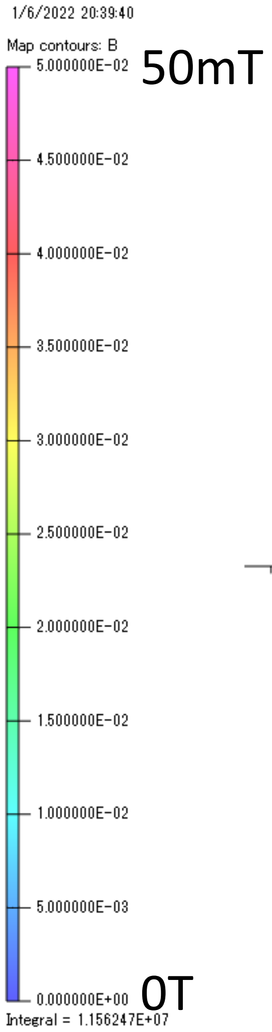


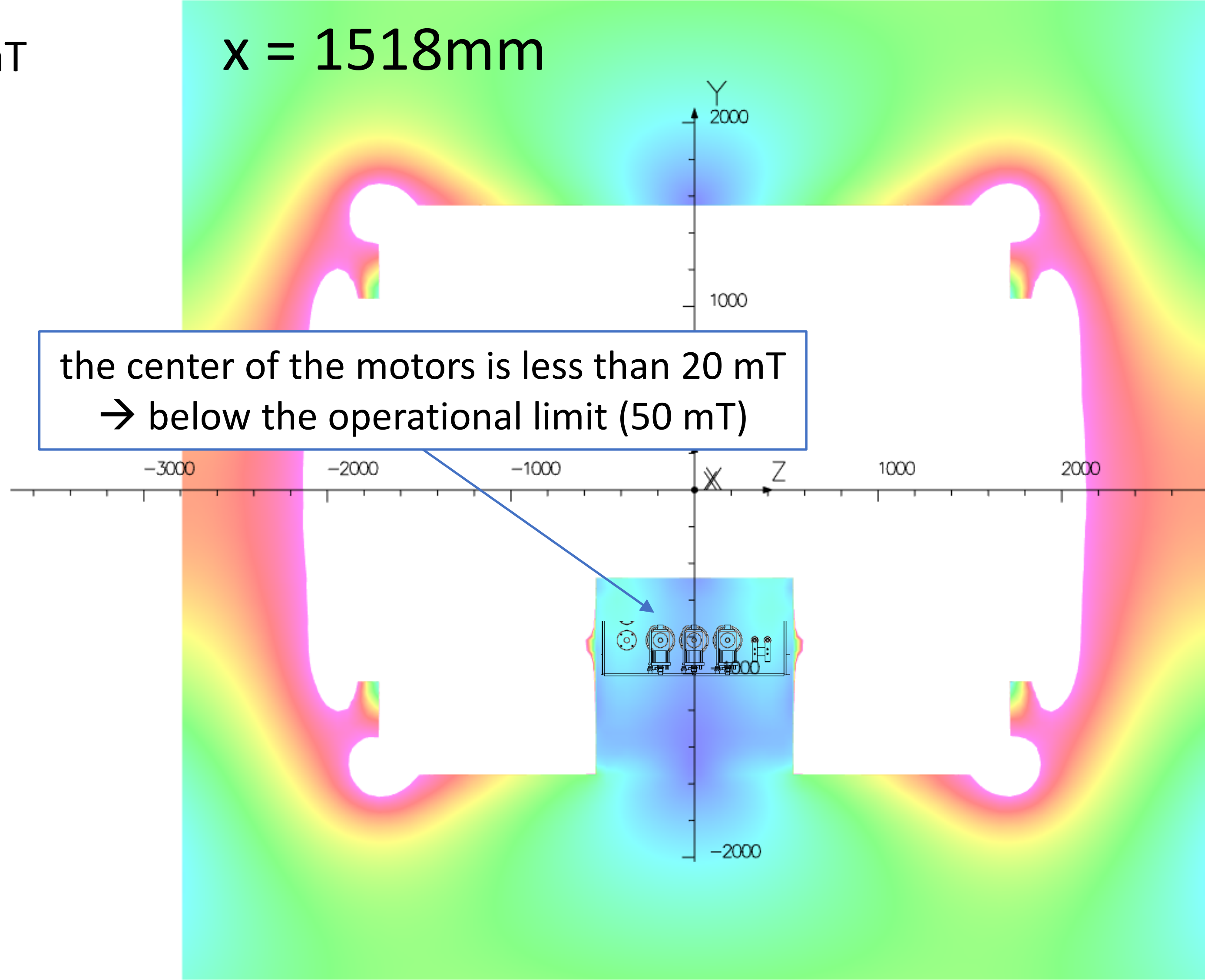


Magnetic Field around GM-port



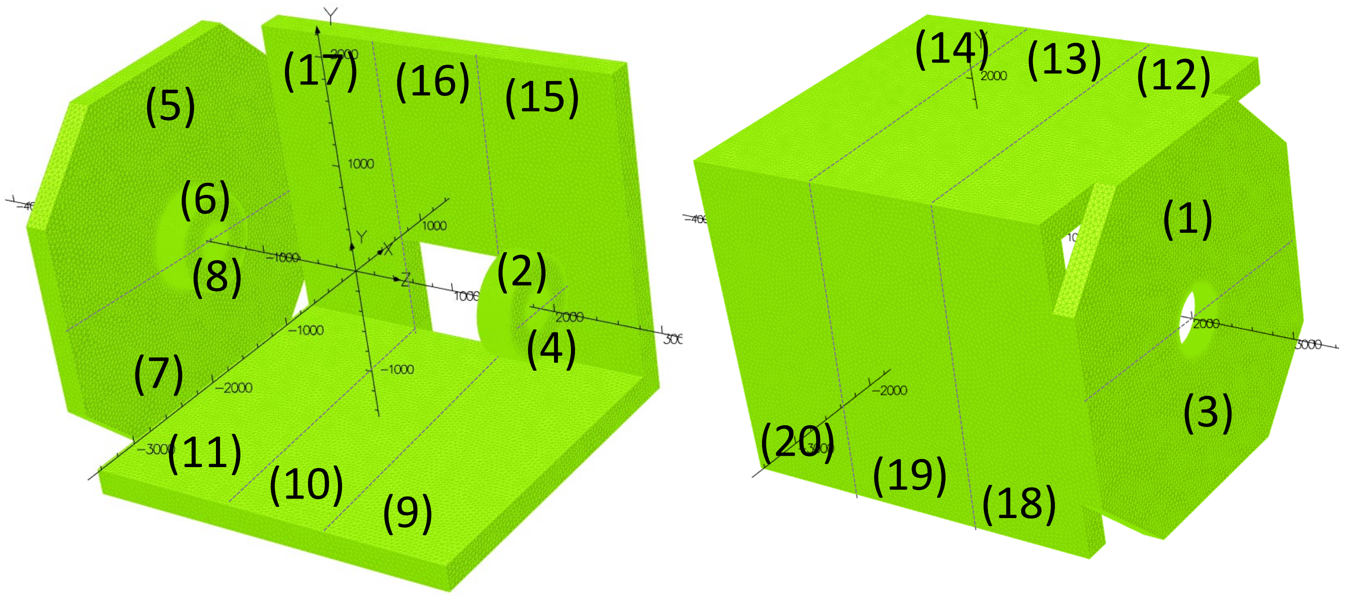
X=1518, Y=-1190: motor head





the center of the motors is less than 20 mT
→ below the operational limit (50 mT)

Structural Calculation (EM force)



component name	Fx [N]	Fy [N]	Fz [N]
(9) bottom down	-36	22,811	-153,692
(10) bottom middle	160	622	-250
(11) bottom up	-28	22,564	153,750
(12) top down	6	-13,595	-110,830
(13) top middle	17	-876	-17
(14) top up	4	-13,672	110,961

component name	Fx [N]	Fy [N]	Fz [N]
(15) left down	-7,508	-9,926	-64,584
(16) left middle	-525	39	-166
(17) left up	-7,512	-9,660	63,407
(18) right down	7,603	692	-79,596
(19) right middle	619	22	13
(20) right up	7,602	730	79,782

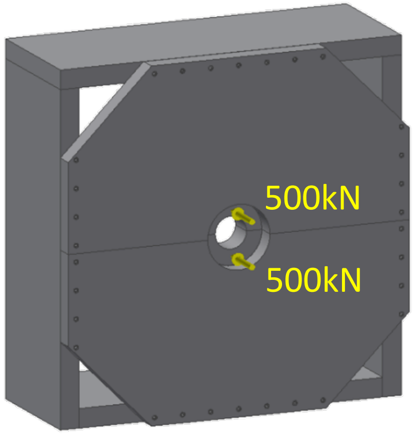
component name	Fx [N]	Fy [N]	Fz [N]
(1) cap down bottom	2	25,452	-759,143
(2) donut down bottom	107	19	206,973
(3) cap down up	29	-25,644	-776,760
(4) donut down up	107	19	206,973
(5) cap up bottom	22	25,536	757,753
(6) donut up bottom	131	-356	-206,821
(7) cap up up	116	-25,293	777,720
(8) donut up up	131	-356	-206,821

force that pulls the end-caps inward is about 100t

component name	Fx [N]	Fy [N]	Fz [N]
all coils (Lorentz force)	-390	226	-103

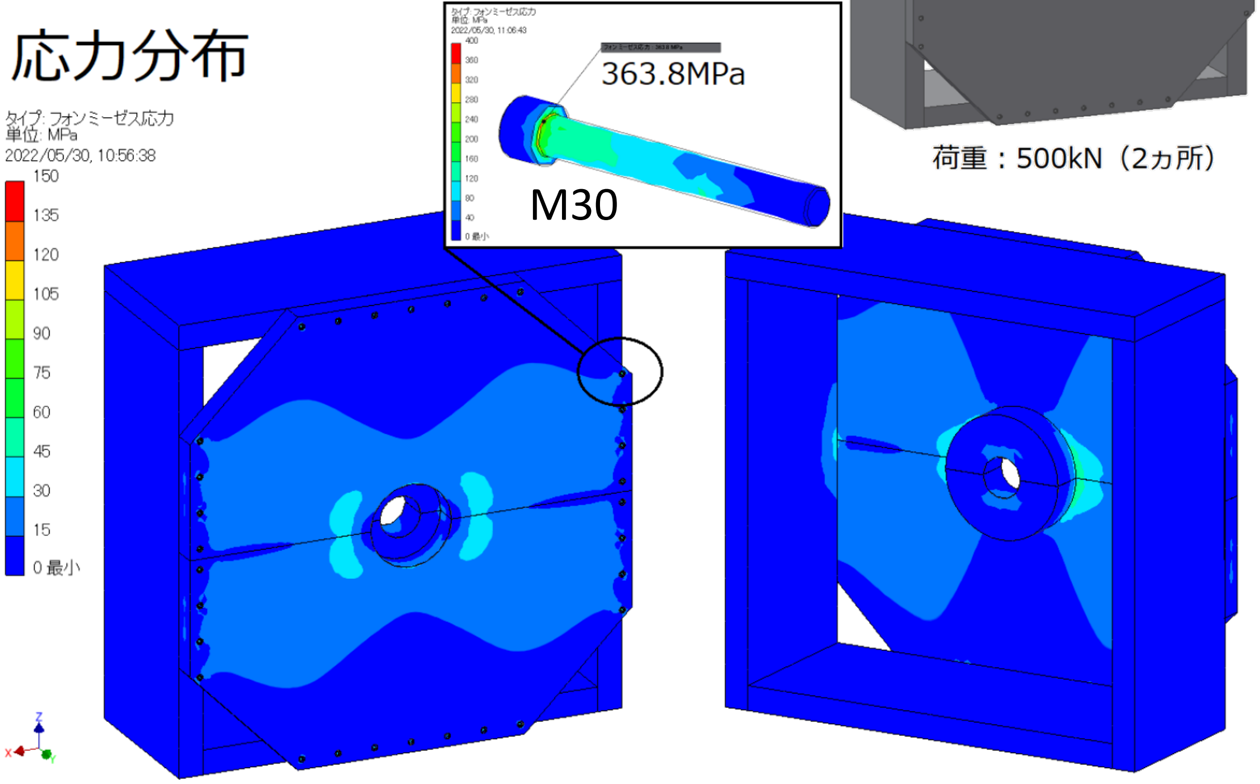
Structural Calculation (Stress & Displacement)

analysis was performed by applying a force of 500kN per the upper and lower end-cap to a single point near the center



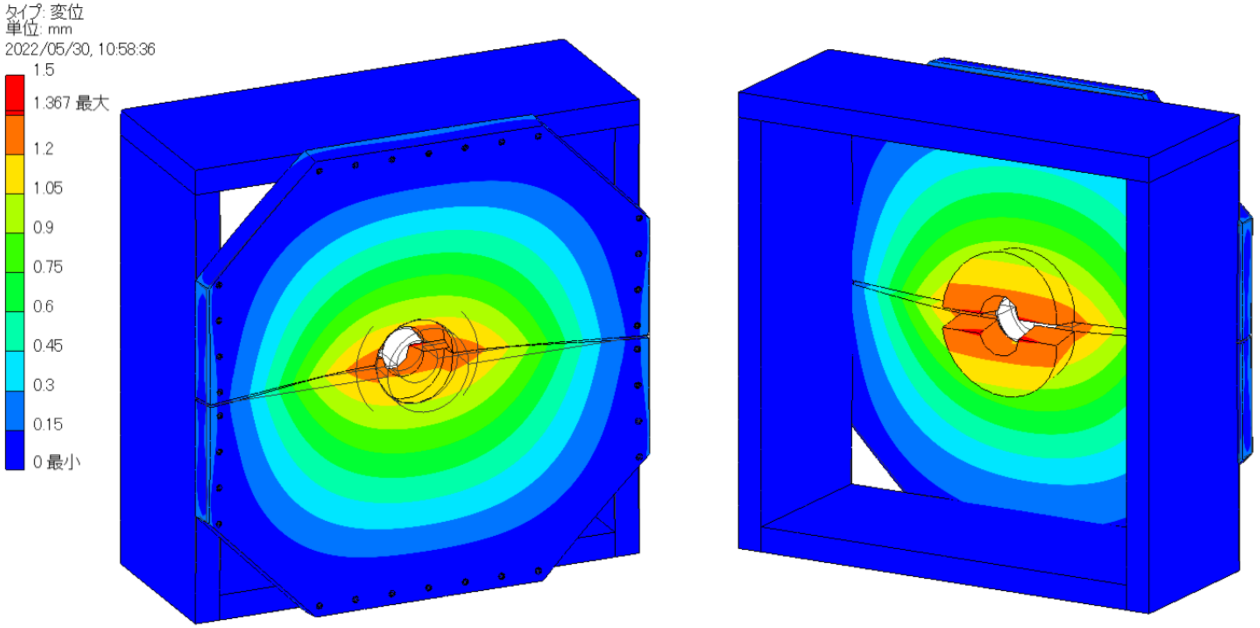
荷重：500kN（2カ所）

応力分布



Max. stress on a bolt is about 300Mpa
→ covered by using such as SCM435 M36 bolts

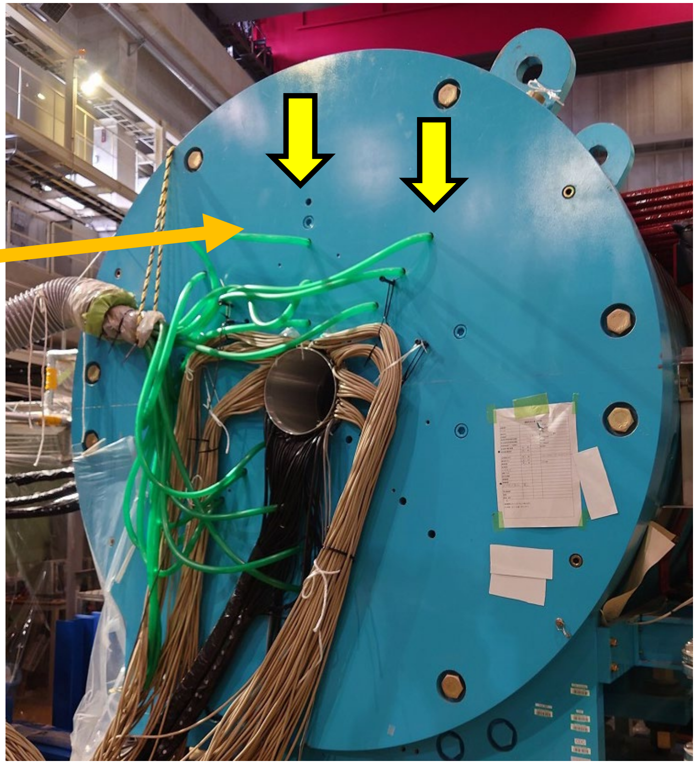
変位



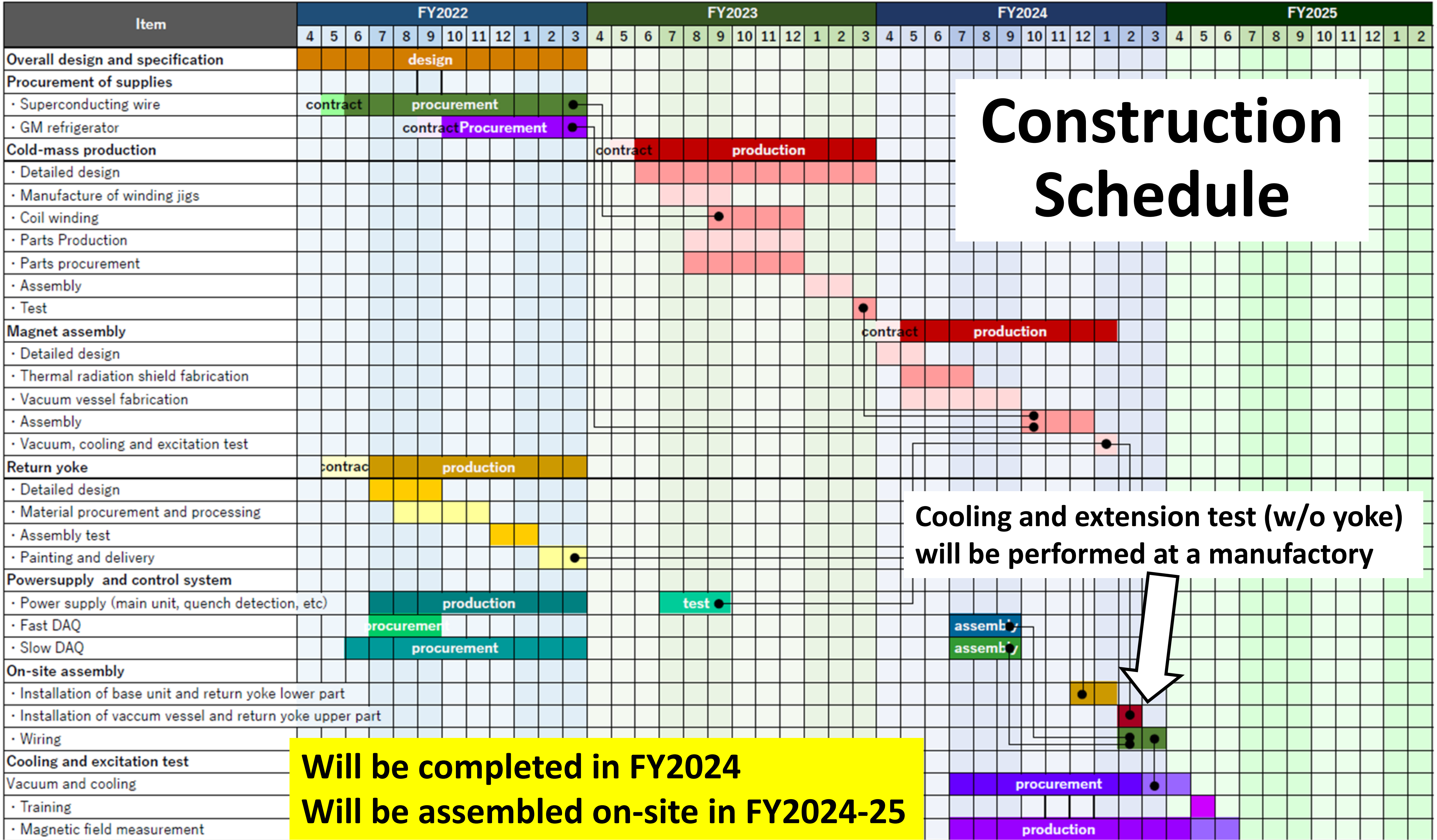
Max. displacement is about 1 mm near the center

Test, Magnetic Field Measurement, etc.

- Cooling and extension test will be performed without the return yoke at a manufactory
- We will negotiate with a company that quench test (= power cutoff test) can be performed at manufactory
- Magnetic field measurement will be performed by passing a 3D Hall probe from the outside through small holes provided in the end-caps
  - magnetic field scan with respect to the beam-axis direction at several positions in the (x,y) plane
  - compared with the calculated values



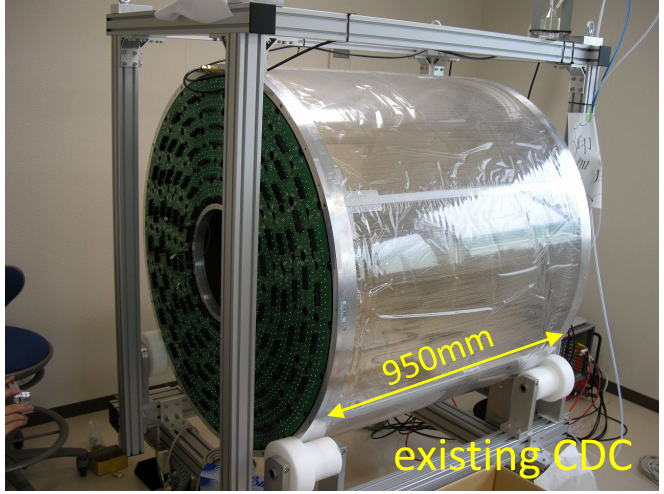
Construction Schedule



Cooling and extension test (w/o yoke) will be performed at a manufactory

Will be completed in FY2024
Will be assembled on-site in FY2024-25

CDS:
Cylindrical Drift Chamber

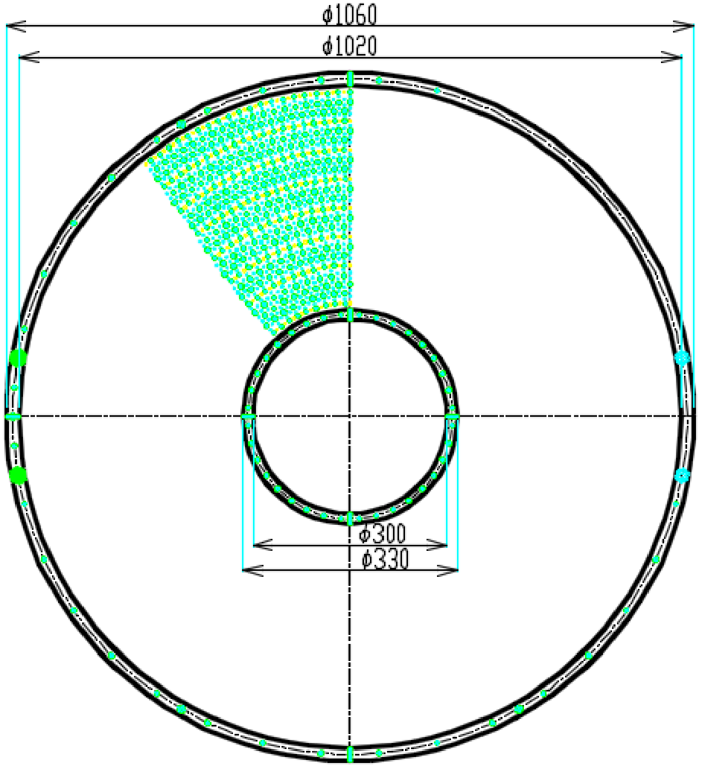


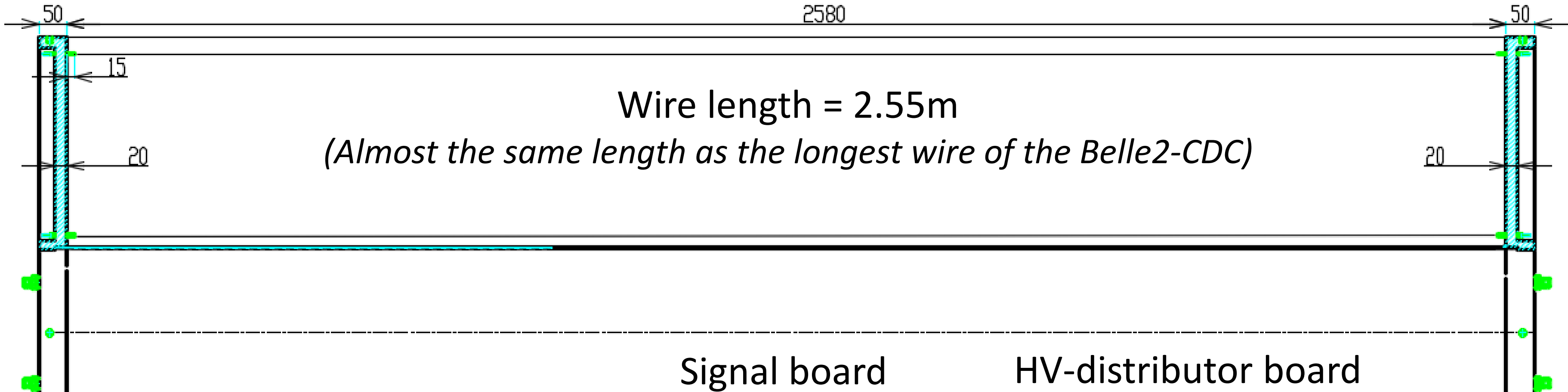
New CDC = 3 * existing CDC

Design

- The same design of the present end-cap will be adopted
    - To reuse the existing Signal/HV-distributor boards
    - New CDC is 3 times the length of the existing CDC as it is

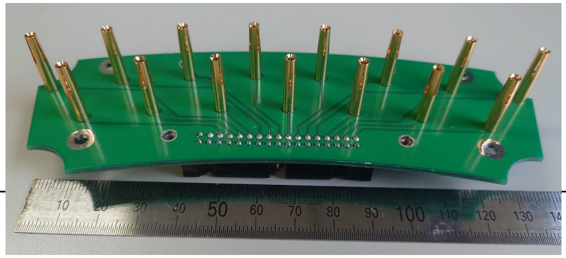
Will be completed in FY2023





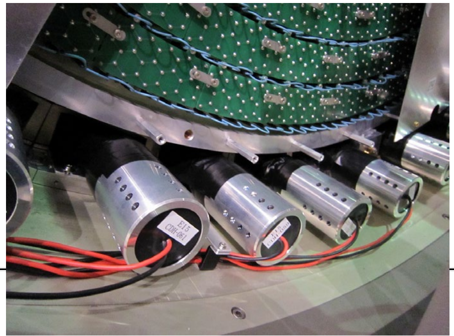
Wire length = 2.55m

(Almost the same length as the longest wire of the Belle2-CDC)



Signal board

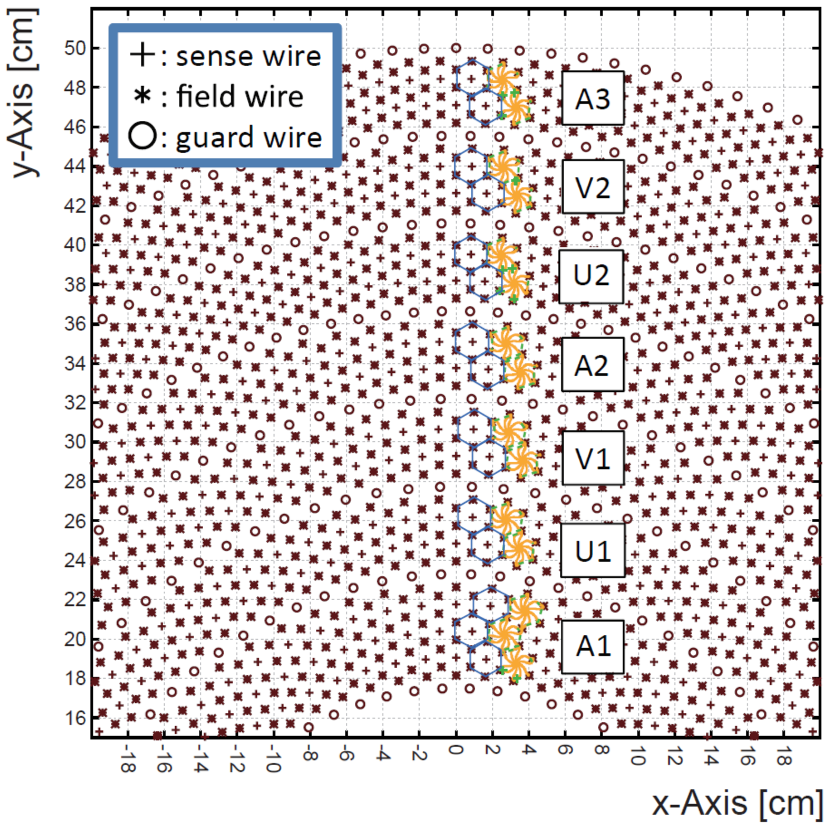
HV-distributor board



Structure

- 7 super layers (AUVAUVA) and 15 layers
- 1,816 ch with hexagonal cells
- 8,064 wires are supported by feedthroughs

Resolution will retain the existing CDC performance
✓$5.3\% p_T \oplus 0.5\% / \beta$

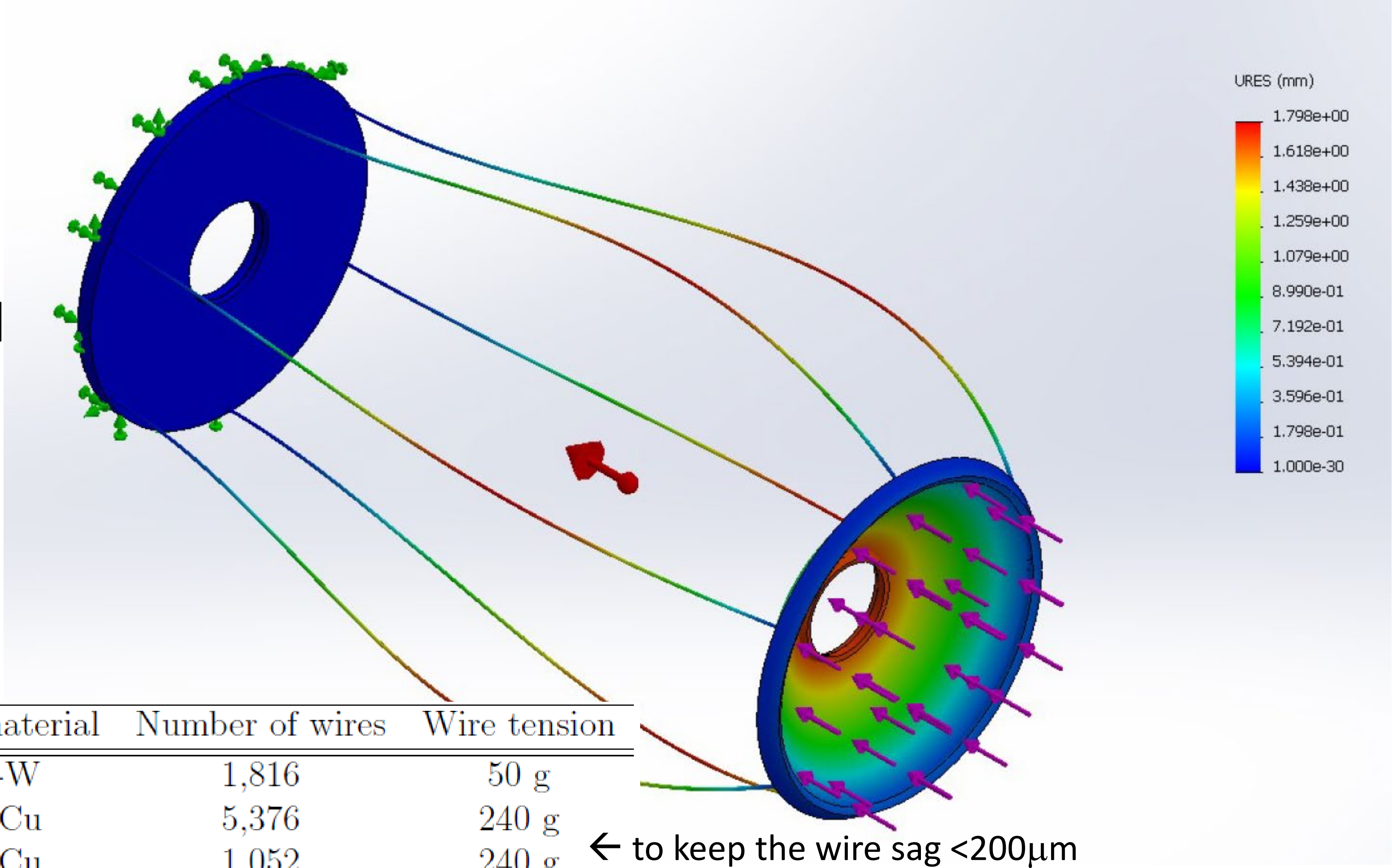


Super-layer	layer	Wire direction	Radius (mm)	Cell width (degree)	Cell width (mm)	Stereo angle (degree)	Signal channels per layer
A1	1	X	190.5	5.00	16.7	0	72
	2	X'	204.0		17.8	0	
	3	X	217.5		19.0	0	
U1	4	U	248.5	4.00	17.3	-2.27	90
	5	U'	262.0		18.3	-2.39	
V1	6	V	293.0	3.60	18.4	2.42	100
	7	V'	306.5		19.3	2.53	
A2	8	X	337.5	3.00	17.7	0	120
	9	X'	351.0		18.4	0	
U2	10	U	382.0	2.40	16.0	-2.82	150
	11	U'	395.5		16.6	-2.92	
V2	12	V	426.5	2.25	16.7	2.96	160
	13	V'	440.0		17.3	3.05	
A3	14	X	471.0	2.00	16.4	0	180
	15	X'	484.5		16.9	0	

c.f. ~3.5 deg. @ existing CDC

Structural Analysis

- Six pipes support wire tension of ~1.6t
  - Need pre-tension for 2mm deformation
- Inner tube: Al-mylar-Al
  - Al: ~3mm
  - mylar: ~0.3mm
- Outer tube: Al
  - Al: ~2mm

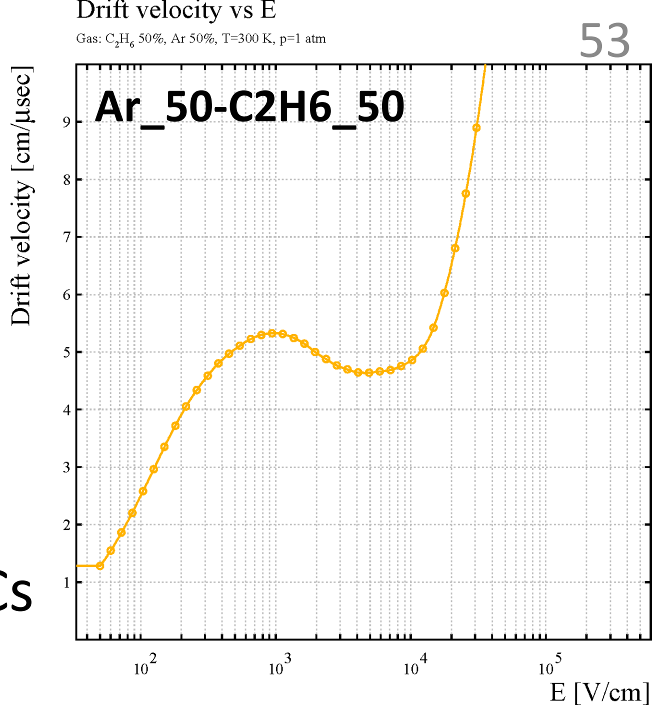


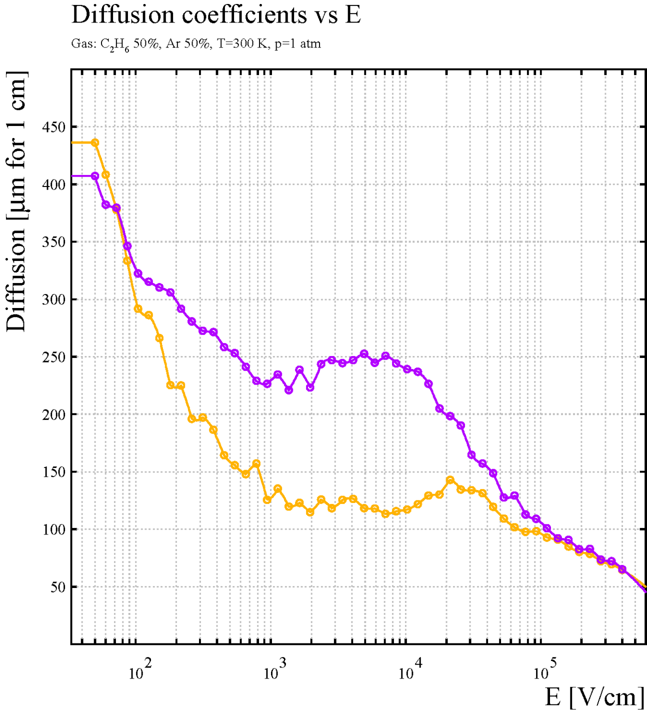
Wire type	Wire diameter	Wire material	Number of wires	Wire tension
sense	$\phi 30\ \mu m$	Au-W	1,816	50 g
filed	$\phi 80\ \mu m$	Be-Cu	5,376	240 g
guard	$\phi 80\ \mu m$	Be-Cu	1,052	240 g

← to keep the wire sag <200μm

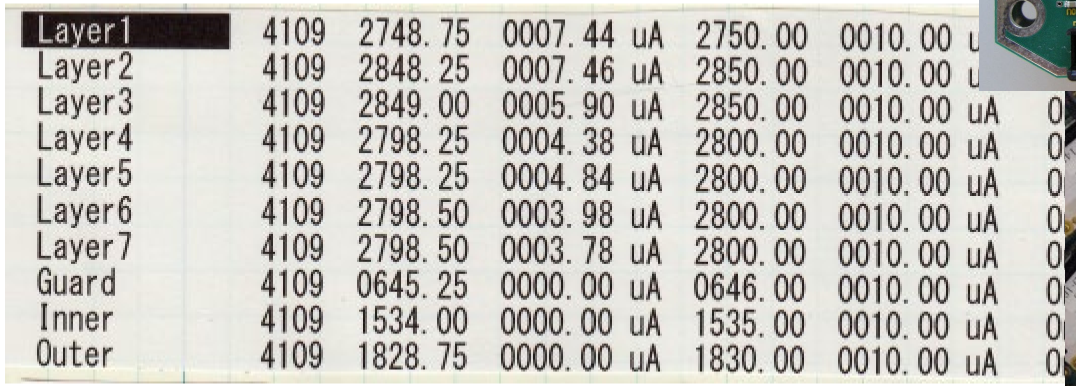
Gas, Readout, HV

- Basically, same as the existing CDC
  - <u>Gas:</u> Ar(50%)-C_2H_6(50%) at 1 atm
  - <u>Readout:</u> ASDs (SONY-CXA3183Q, τ = 16 ns) and HUL multi-hit TDCs
  - <u>HV:</u> almost the same settings we have been studied so far

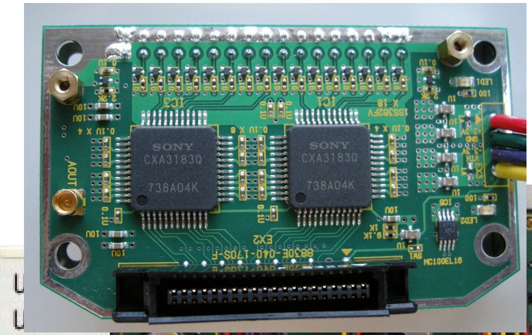


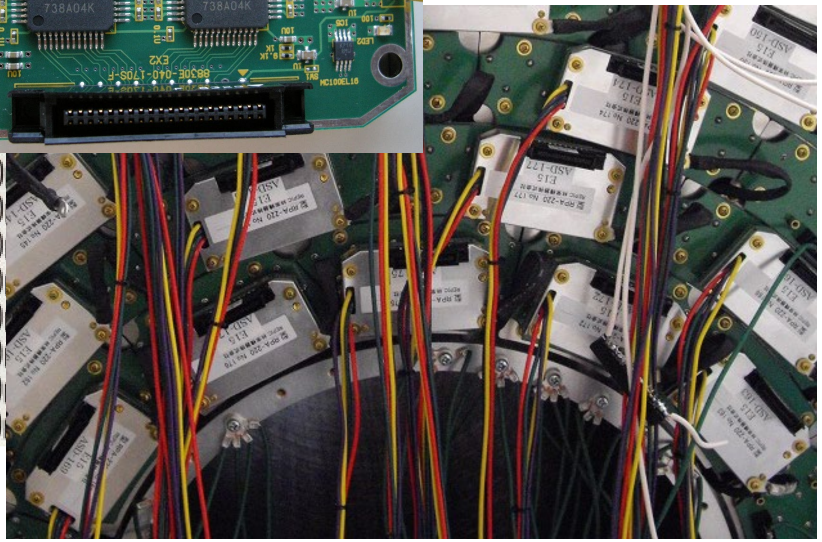


@E73, 64kW(5.2s), 2021.5



Layer1	4109	2748.75	0007.44 uA	2750.00	0010.00 u
Layer2	4109	2848.25	0007.46 uA	2850.00	0010.00 u
Layer3	4109	2849.00	0005.90 uA	2850.00	0010.00 uA
Layer4	4109	2798.25	0004.38 uA	2800.00	0010.00 uA
Layer5	4109	2798.25	0004.84 uA	2800.00	0010.00 uA
Layer6	4109	2798.50	0003.98 uA	2800.00	0010.00 uA
Layer7	4109	2798.50	0003.78 uA	2800.00	0010.00 uA
Guard	4109	0645.25	0000.00 uA	0646.00	0010.00 uA
Inner	4109	1534.00	0000.00 uA	1535.00	0010.00 uA
Outer	4109	1828.75	0000.00 uA	1830.00	0010.00 uA

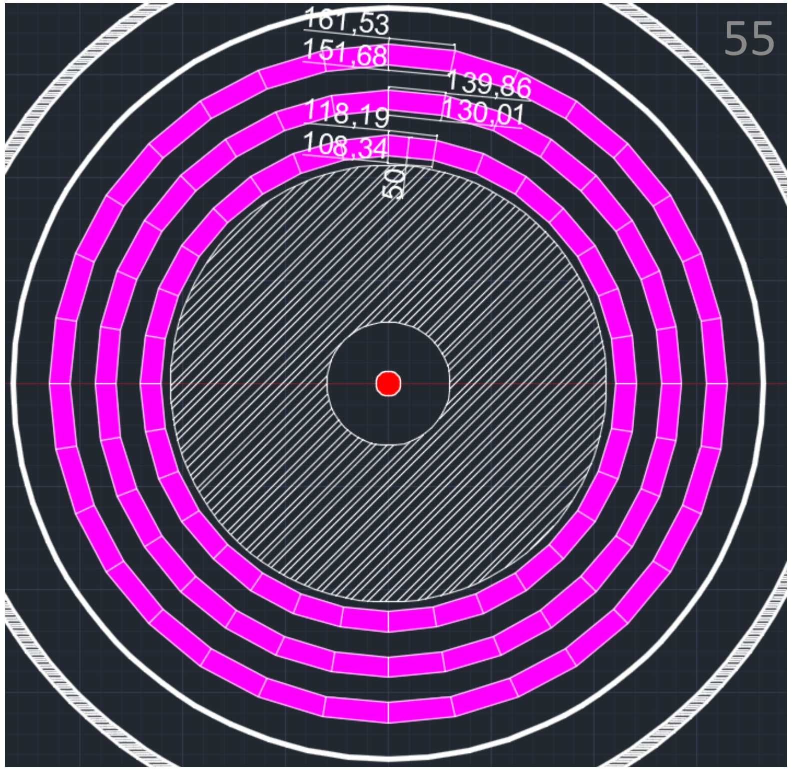


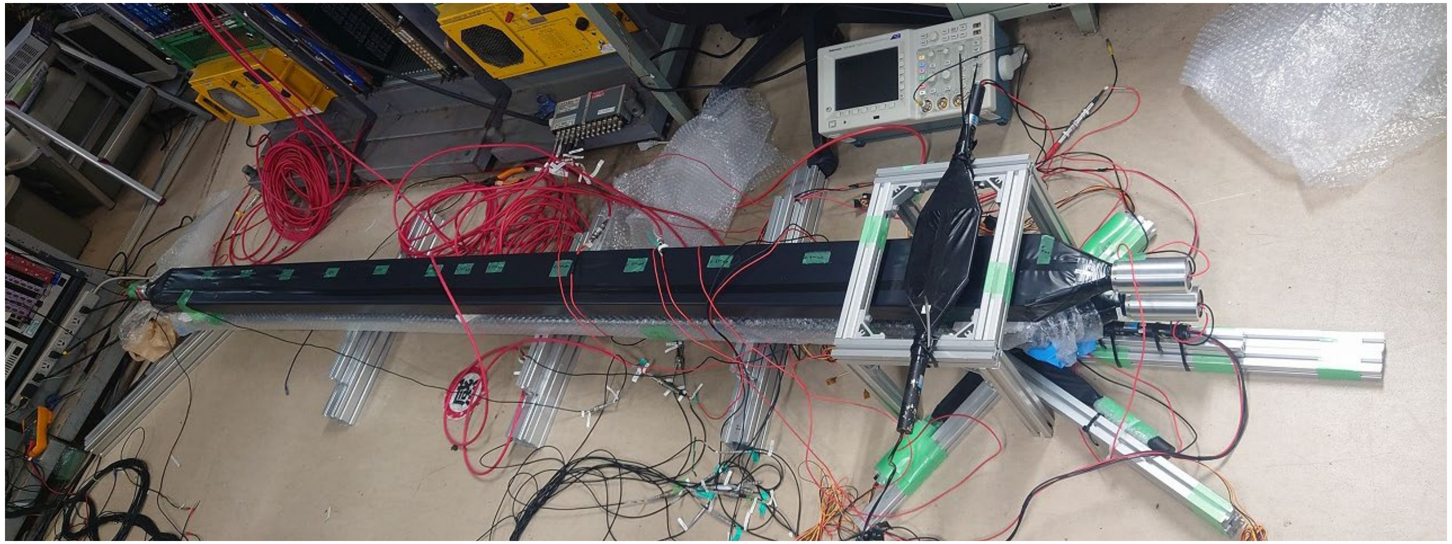


CDS:
Cylindrical Neutron Counter

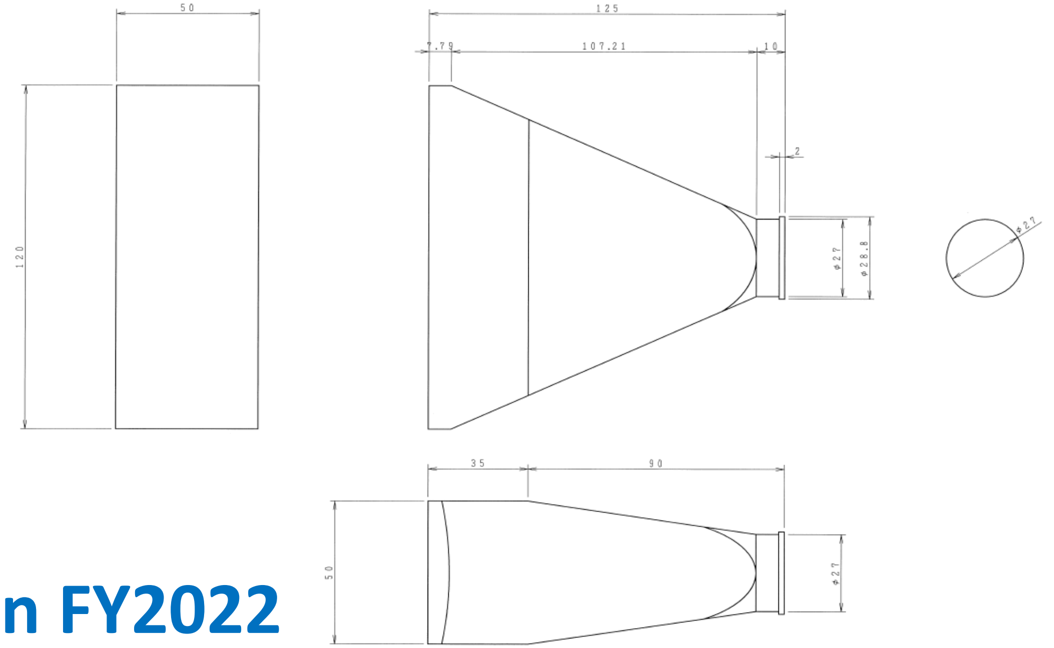
Design

- scintillator array: 3 layers, 32 segments
- ELJEN EJ-200: (T)50mm, (W)~130mm, (L)~3,000mm
- 1.5-inch FM-PMT [H8409(R7761)]
- Neutron detection efficiency of ~15%
- **First layer will be constructed with current budget**





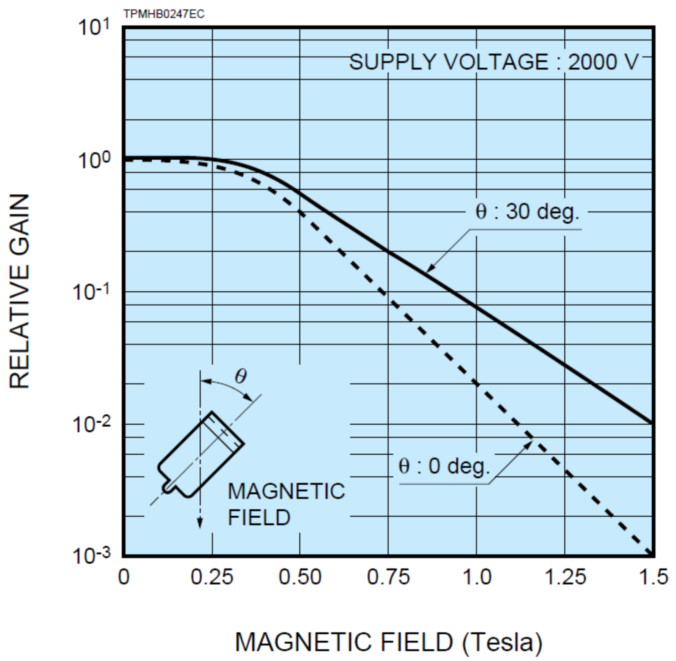
prototype@J-PARC, being in test



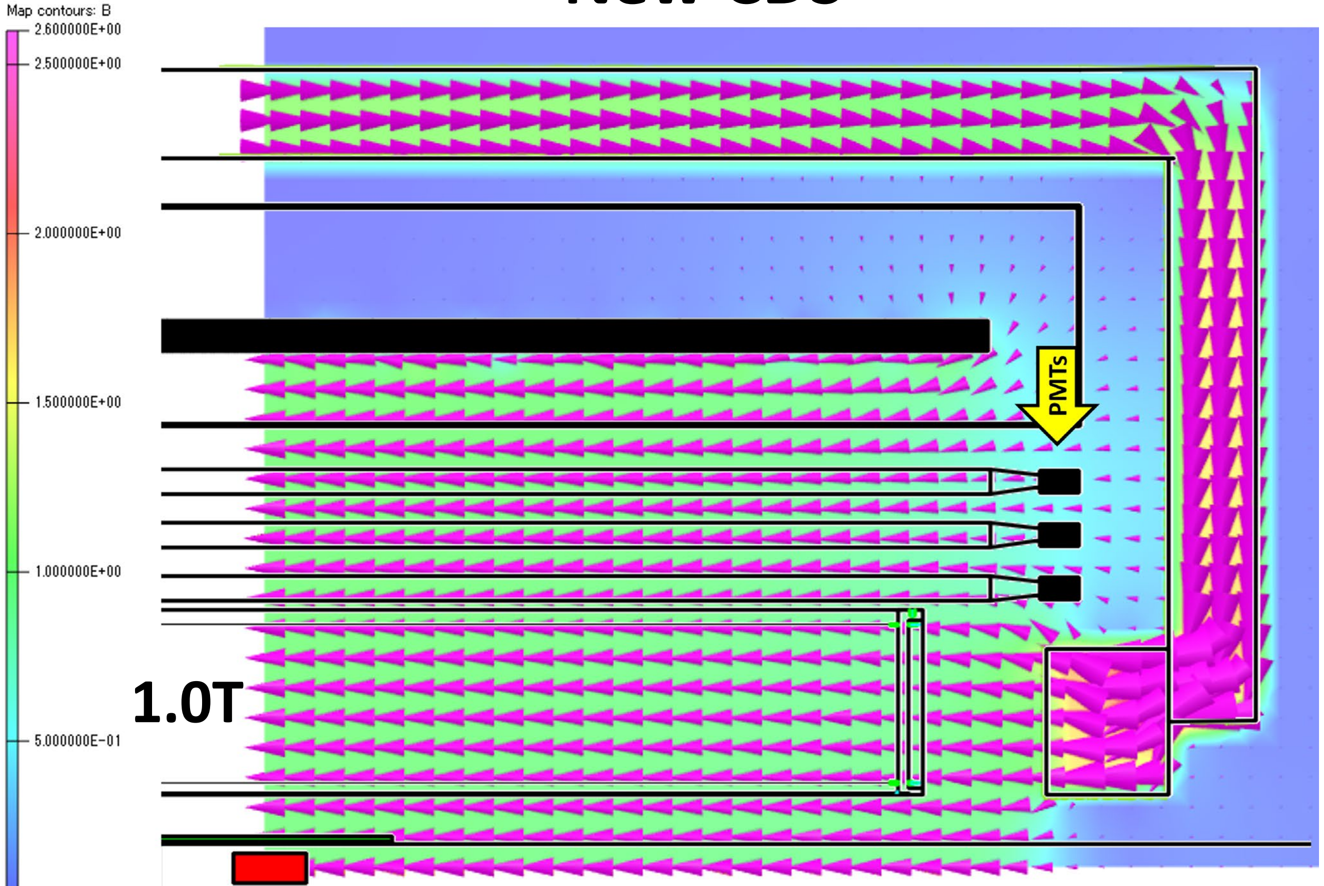
Will be delivered in FY2022

Operation in Magnetic Field

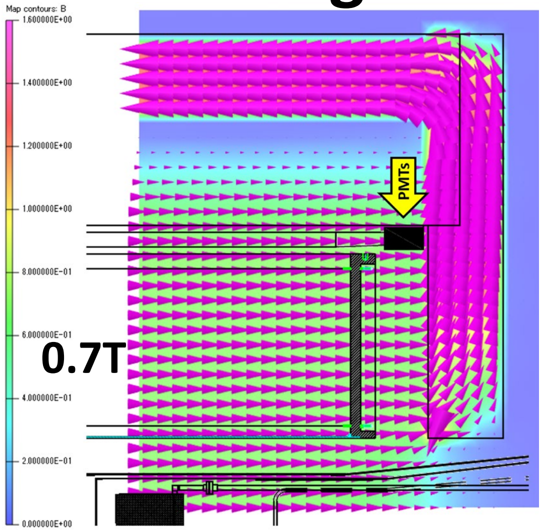
- The magnetic-field direction at the location of the FM-PMT is approximately parallel to the photomultiplier axis
  ← **the same situation as the existing CDS, no problem**



New CDS



Existing CDS



Neutron ID

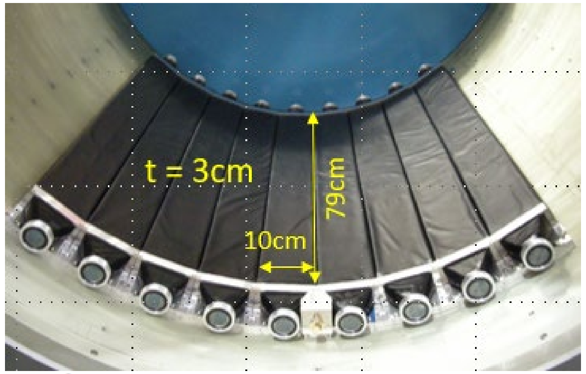
- Neutron will be identified using absence of CDC tracks in front of the neutron hit

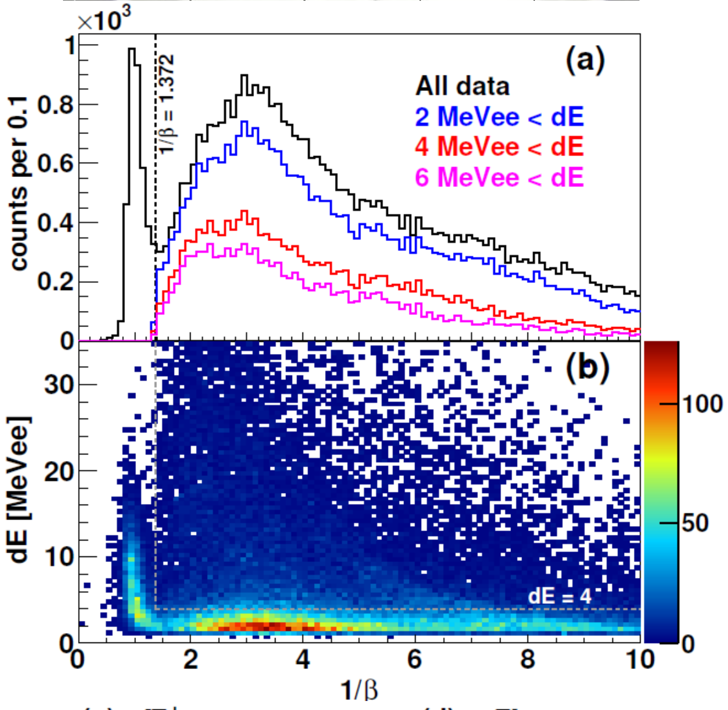
- At E15, we successfully identified neutron from Σ decay using 3cm thickness scintillator (CDH)
- δt ~100ps → δz ~2cm (CDH result)

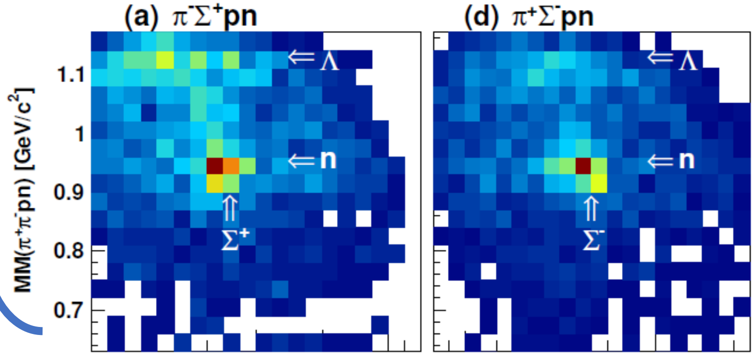
Light velocity of CDH: ~15cm/ns

- We need δt ~100ps for the CNC
  - Being in performance test using cosmic rays

Resolution will retain the existing CDS performance
✓σ[TOF(T0-CNC)] ~ 160ps



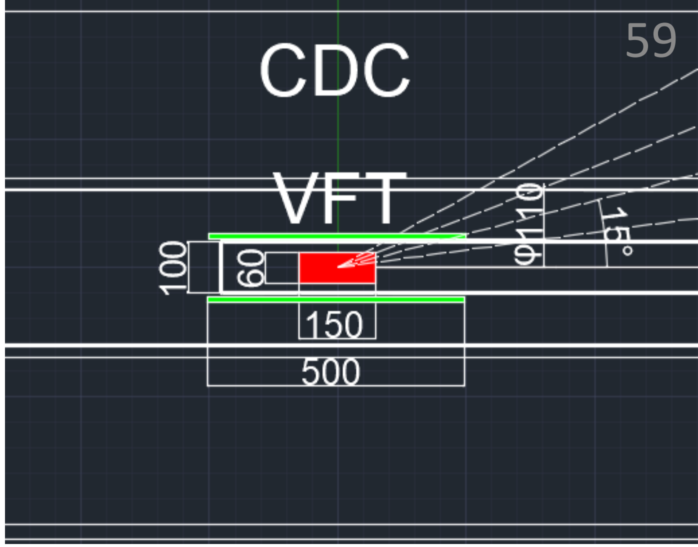




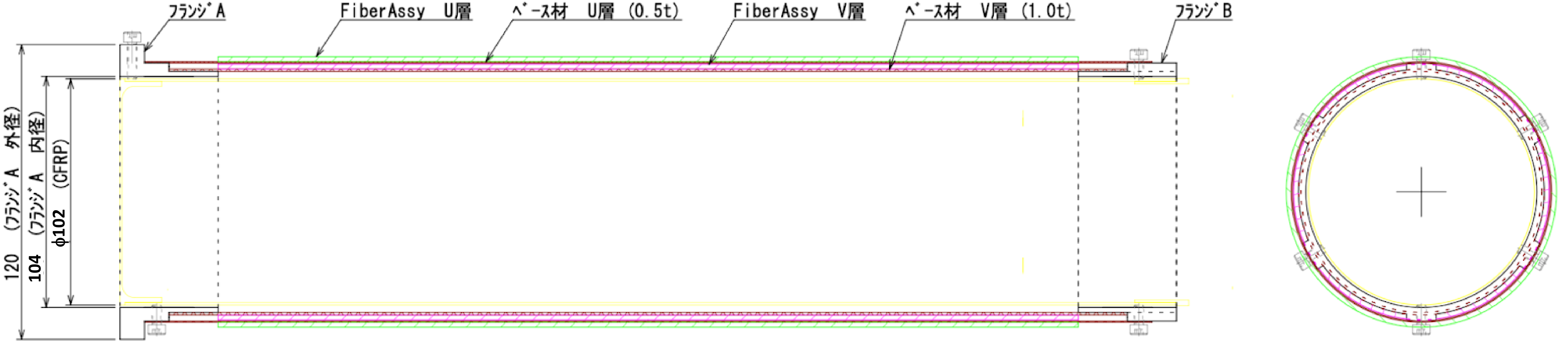
CDS:
Vertex Fiber Tracker

Design

- Located on the outer wall of the target chamber (r~55 mm)
- 4 layers of ϕ1mm scintillating fibers – UU'VV'
- 896 (= 224x4) channels
- MPPC + VME EASIROC



Will be constructed in FY2022, and will be used for E73 at first



Improvement by the VFT

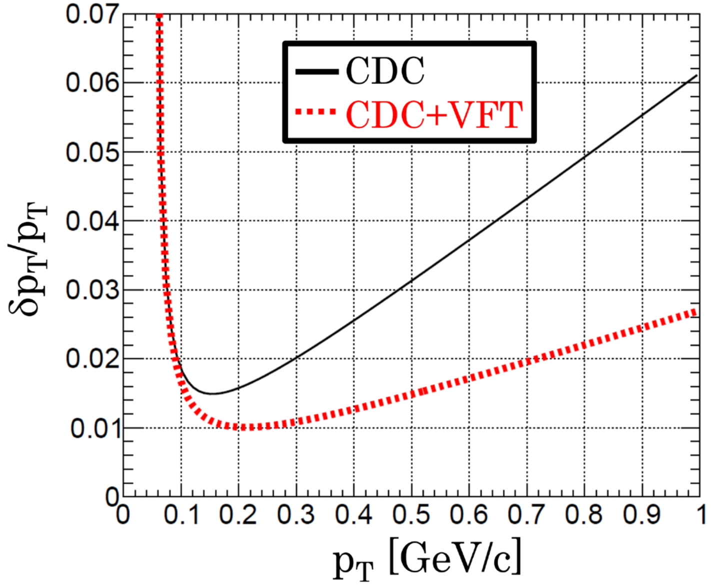
- Vertex resolution of the beam direction
  ~1cm (CDC only) → ~1mm (CDC+VTF)
  ➢ will enable us to discriminate between the signals and backgrounds with event topology such as distance of closest approach method

Particle	cτ (cm)
Λ	7.89
Σ+	2.404
Σ−	4.434

- Solid angle covering the target region
  97% of 4π (15°-165°)
  ➢ will enable us to efficiently reduce backgrounds from multi-π productions

- Momentum/mass resolution
  L=~30cm (CDC only) → ~43cm (CDC+VFT)

$$\left(\frac{\delta P_T}{P_T}\right)_m = \frac{P_T \sigma_{r\phi}}{0.3 L^2 B}\sqrt{A_N}$$

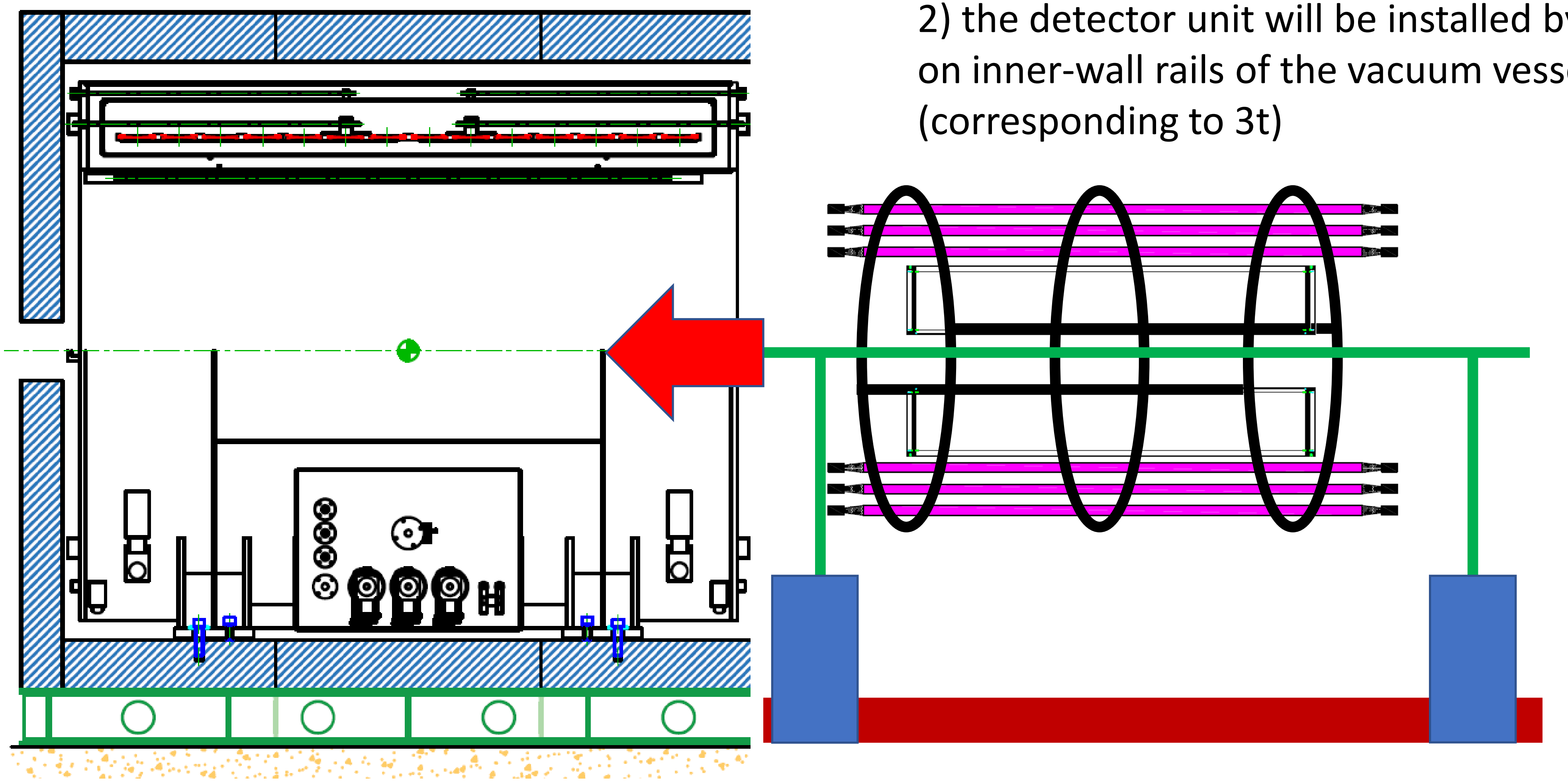


CDS:
Support Structure

How to install detectors 1

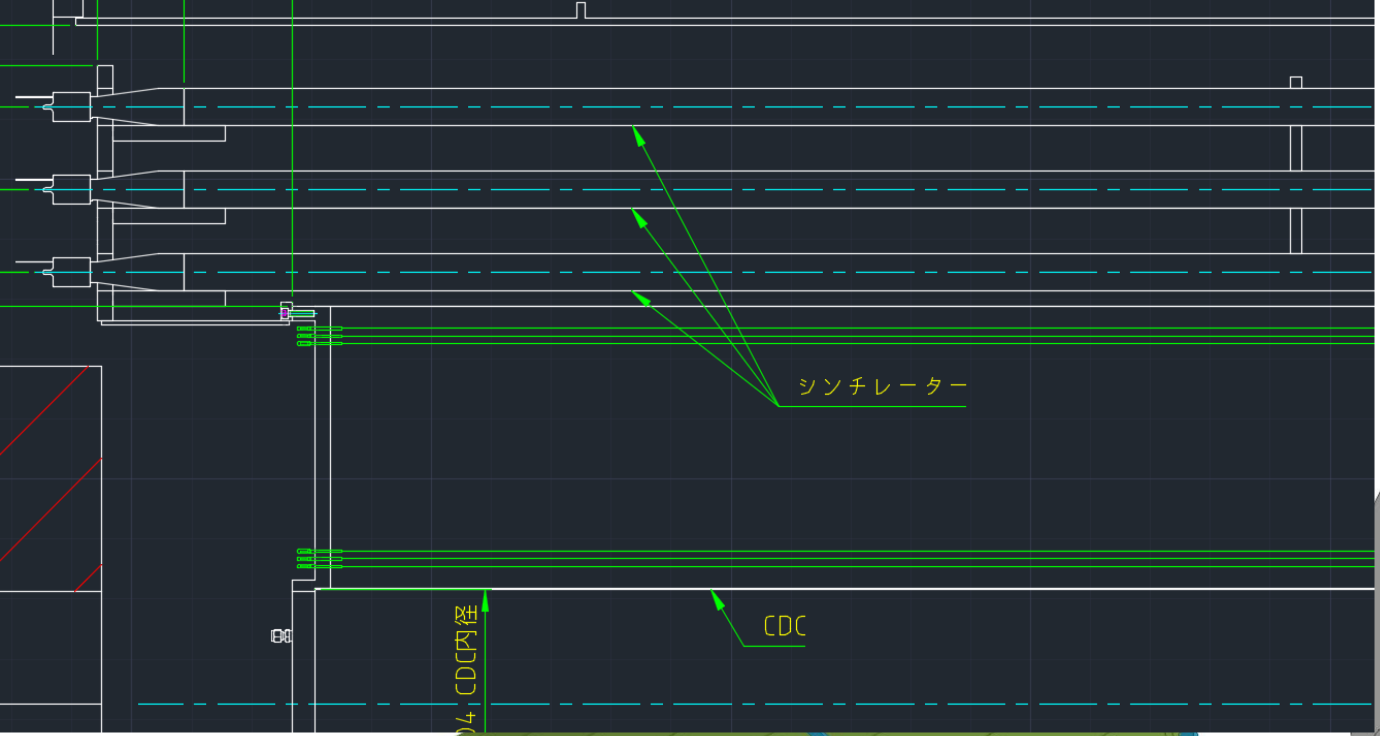
1) a structure supporting the CNC will be built stand-alone or built into the end-cap of the CDC, and the CDC and CNC will be assembled as one unit

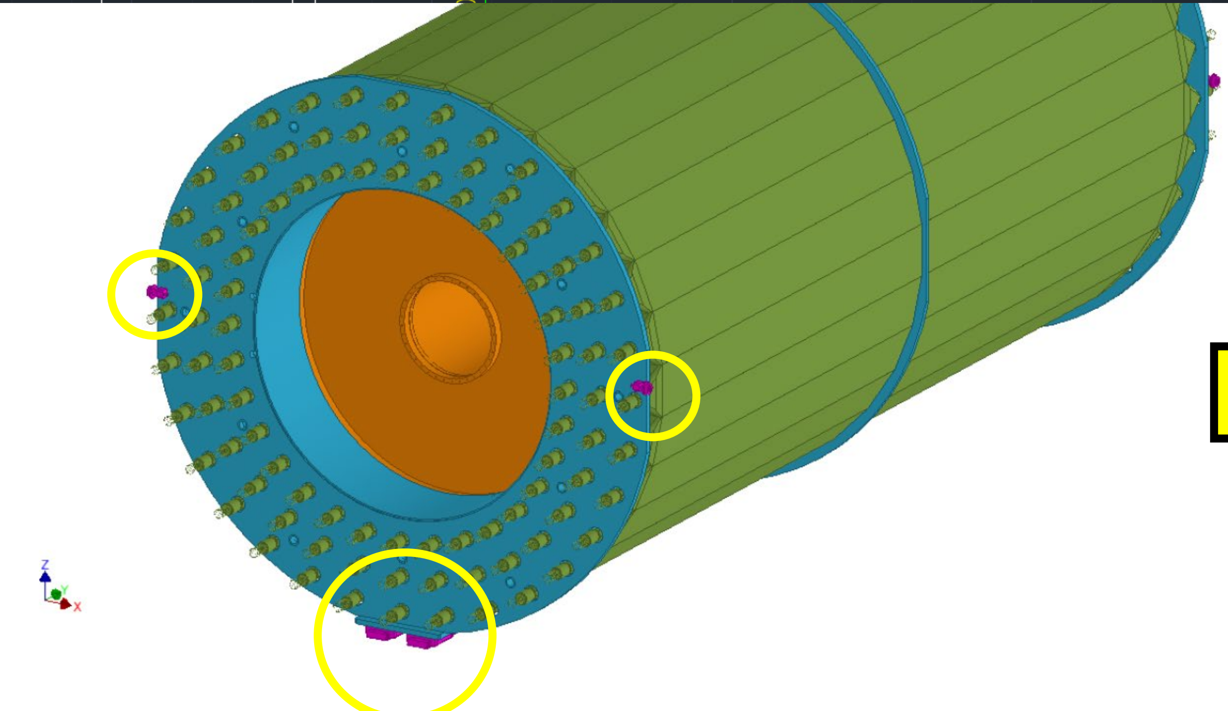
2) the detector unit will be installed by sliding it on inner-wall rails of the vacuum vessel (corresponding to 3t)

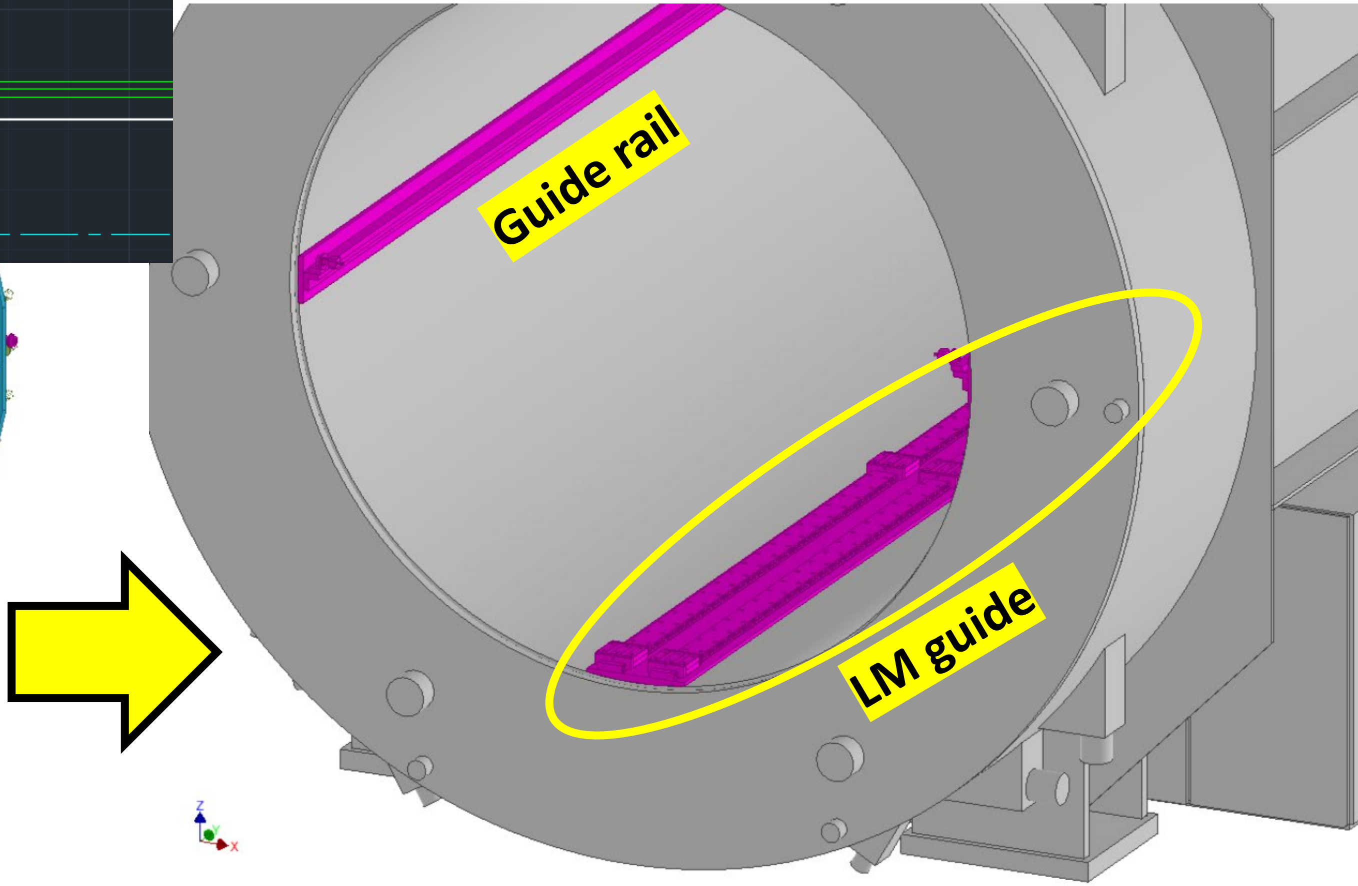


→ **The detailed design of the support structure is being done by a design firm.**

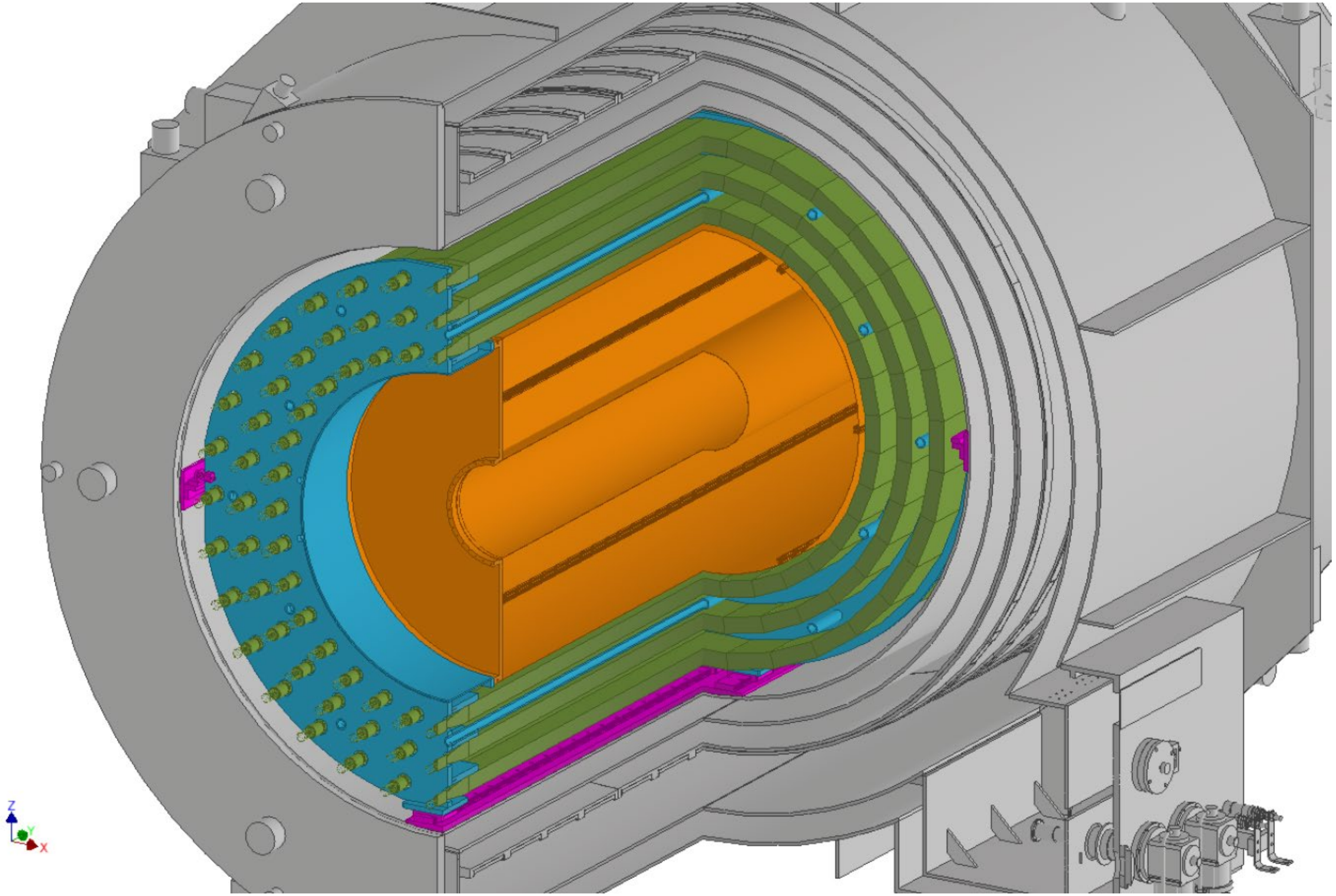
Idea of the support structure (preliminary)

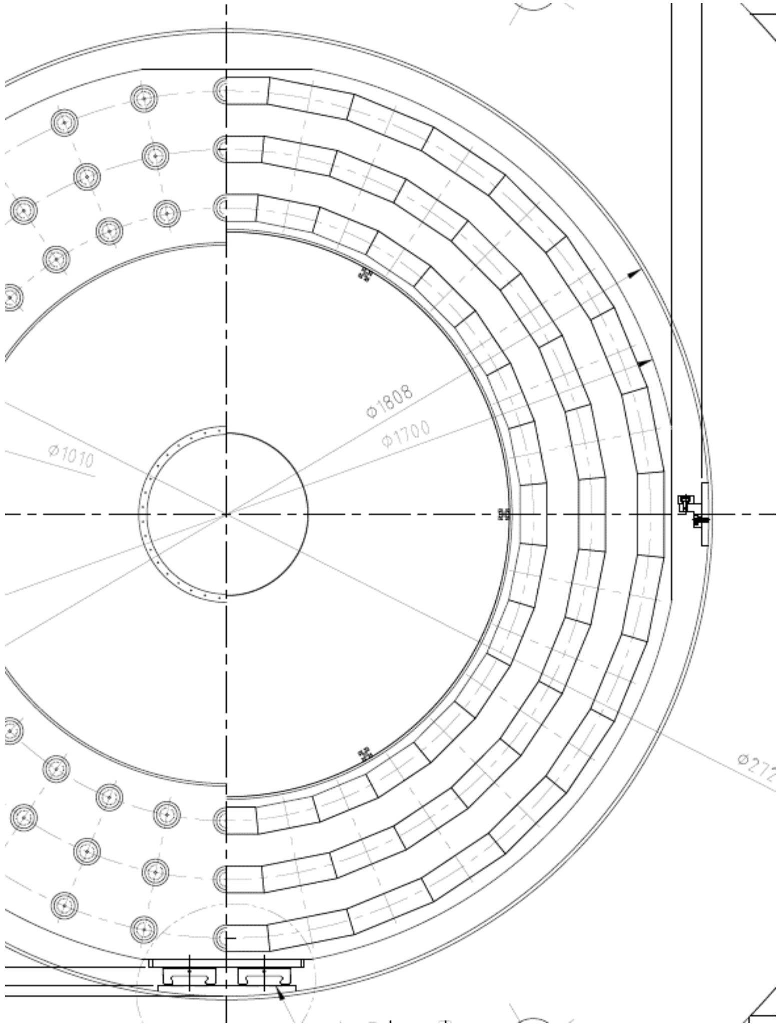






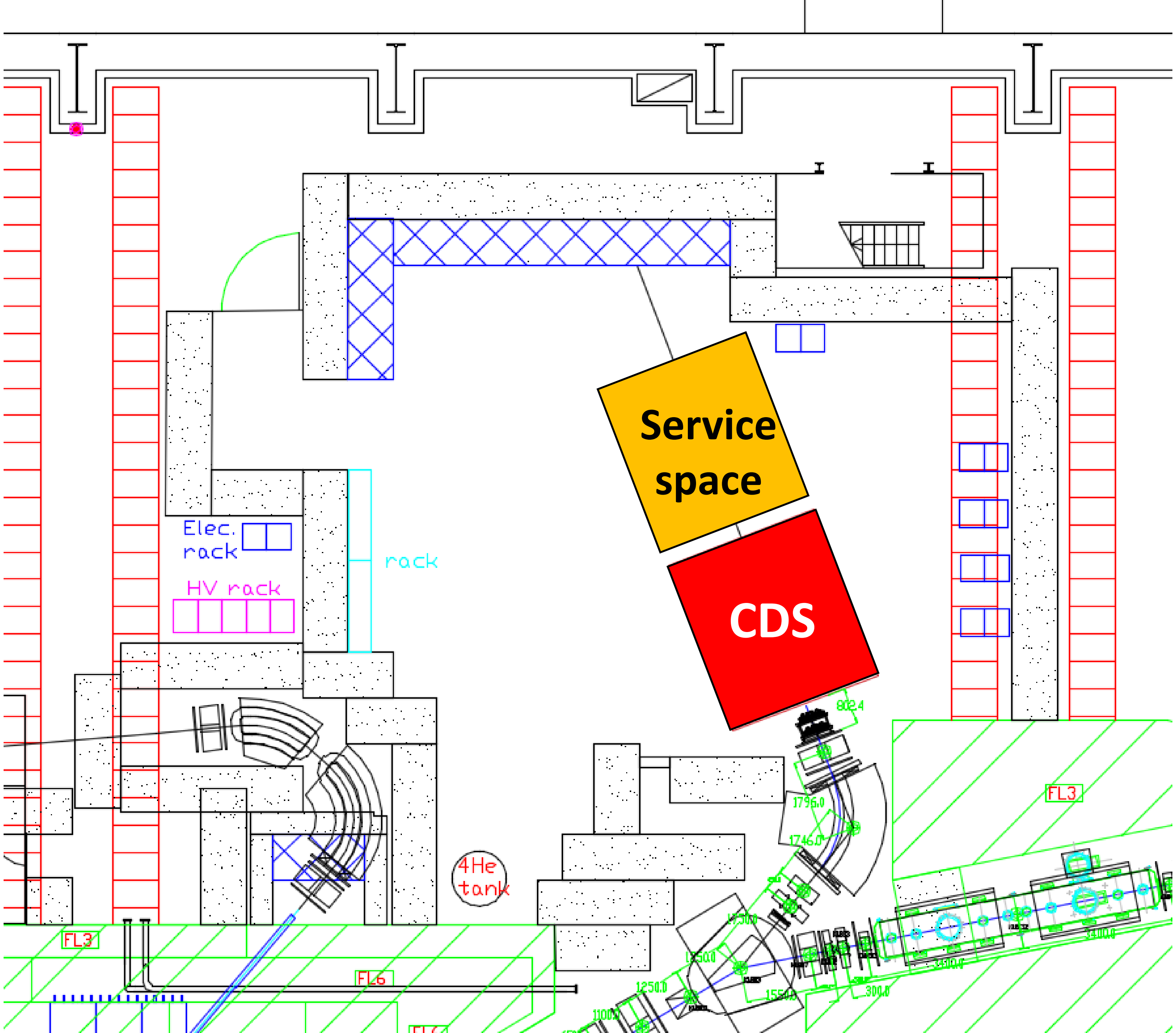
Idea of the support structure (preliminary)





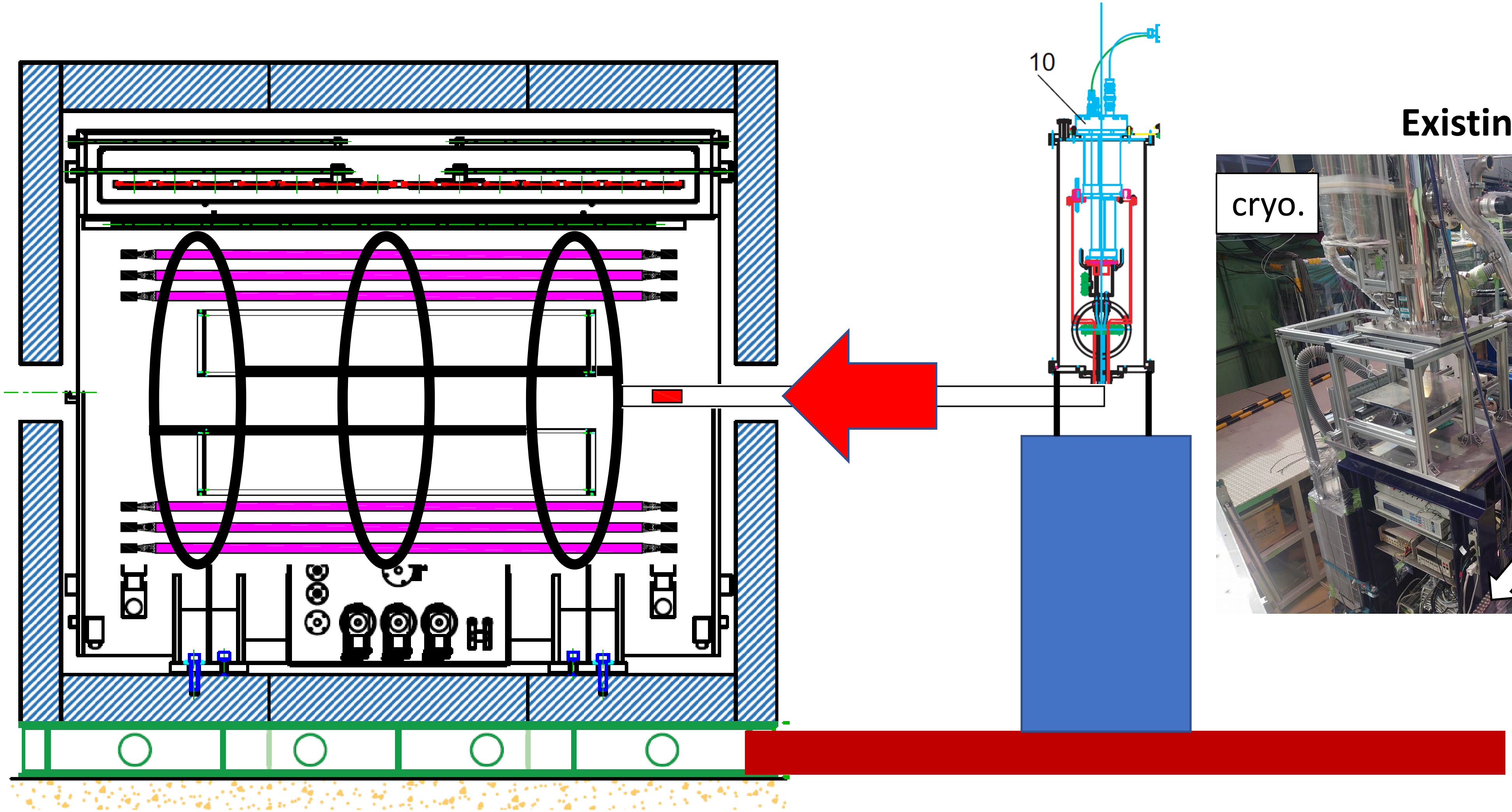
Detector Service Space

We need the same area space as the CDS for the detector service space

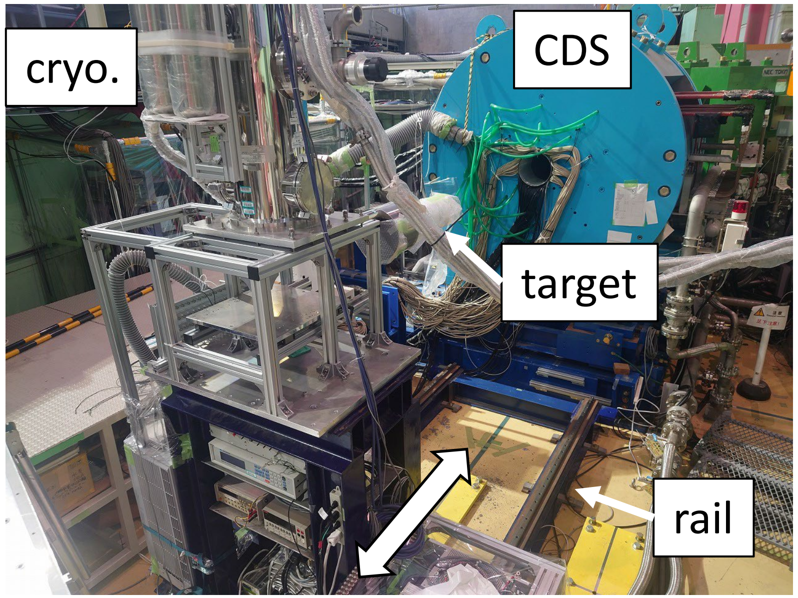


How to install detectors 2

3) Cover with the end-cap
4) Install the target

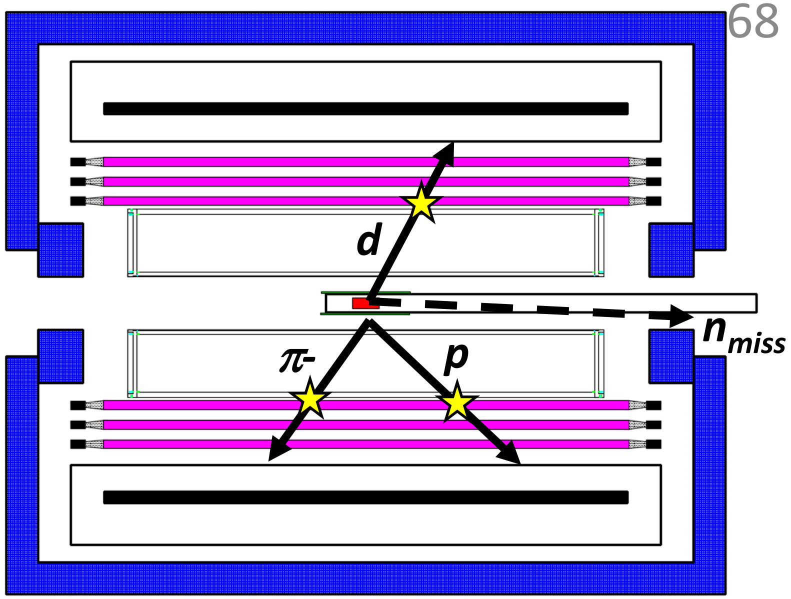


Existing system



Apparatus:
Trigger and DAQ System

Trigger



- Simplest charged-multiplicity trigger
  - Multiplicity trigger of the first layer of the CNC (fCNC)
  - 3≥ hits of the fCNC (fCNC3) is the main trigger for E80

$$K^- \ {}^4\mathrm{He} \rightarrow \text{“}K^-ppn\text{”}\ n \rightarrow \Lambda dn \rightarrow \underline{\pi^- pd}n$$
$$K^- \ {}^4\mathrm{He} \rightarrow \text{“}K^-ppn\text{”}\ n \rightarrow \Lambda pnn \rightarrow \underline{\pi^- pp}nn$$

- Trigger rate is estimated based on T77 [^{4}He, 51kW(5.2s)~63kW(4.2s)]
  - Simply scaled by increased beam power(63kW→90kW), K-intensity(x1.4), and solid angle(59%→93%)

T77 [51kW(5.2s), Run85]		E80 [90kW(4.2s)]	
Beam (BHD*T0*DEF)	640k	Beam (BHT*T0*DEF)	1,000k
Pion (Beam*AC)	430k	Pion (Beam*AC)	620k
Kaon (Beam*ACbar)	210k	Kaon (Beam*ACbar)	420k
Pion*CDH1	10k	Pion*fCNC1	22k
Kaon*CDH1	13k	Kaon*fCNC1	41k
Kaon*CDH2	4k	Kaon*fCNC2	12k
Kaon*CDH3	**1.3k**	**Kaon*fCNC3**	**4.0k**

DAQ

- Will use the existing HDDAQ framework @ K1.8BR
- Max. accumulation rate has been confirmed to reach to ~10 k events per spill with more than 90% DAQ efficiency
  - Trigger rate of main trigger (fCNC_3) will be ~4k → **well controllable**
    - Other triggers will be sampled and accumulated keeping the DAQ efficiency high

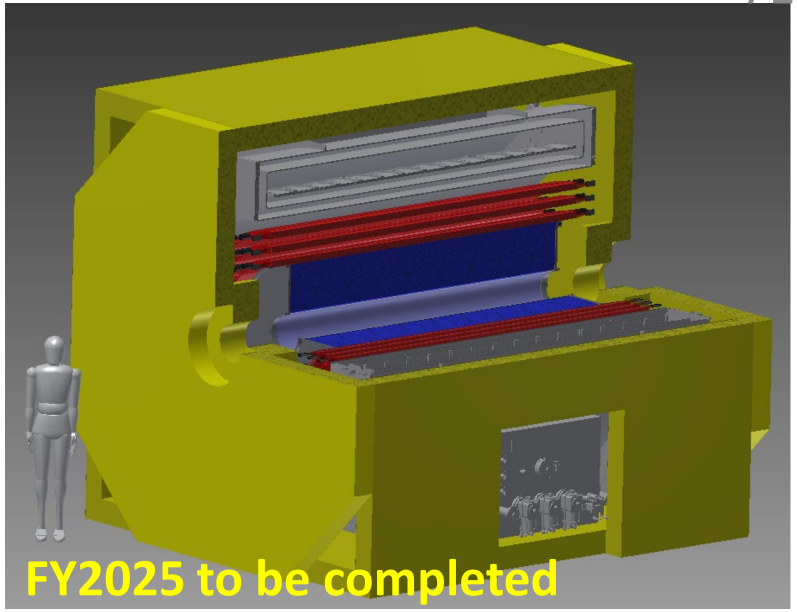
Detector	# of channels	Sub-type	# of nodes	memo
BDC, VDC	512+256	HUL MH-TDC	6	
CDC	1816	HUL MH-TDC	15	
BHT	128	HUL HR-TDC	2	
T0,DEF,AC	20+α	HUL HR-TDC	1	
		VME QDC	1	CAEN V792
CNC	192	HUL HR-TDC	3	
		VME QDC	1	CAEN V792
VFT	896	VME EASIROC	14	or CIRASAME
Scaler	128	HUL Scaler	1	
			44	

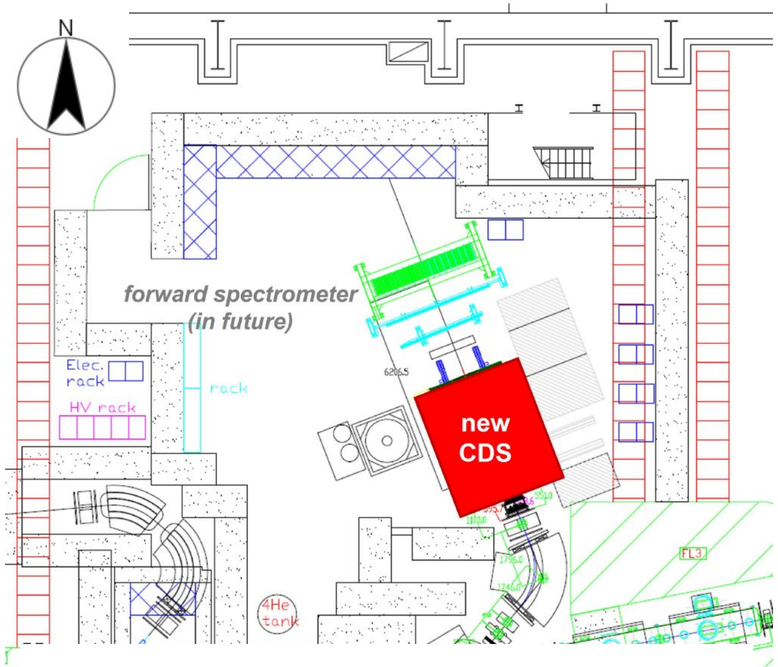
Summary

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**





Hope to modify around FY2024

E80 (L^4He)	
Expected result	**Establishment of K^-ppn (Λd/Λpn)**
Start date	**FY2025-26**
Beam intensity	**90kW**
Beam time	**1+1+3 weeks**