Measurement of the spectral change of Vector mesons in nuclei

at the high-momentum beam line in J-PARC HEF

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- High-momentum (High-p) line
- Physics
- Experimental concept & spectrometer design
- Staging strategy
- Expected signal
- Preparation status
- Summary

J-PARC E16 Collaboration

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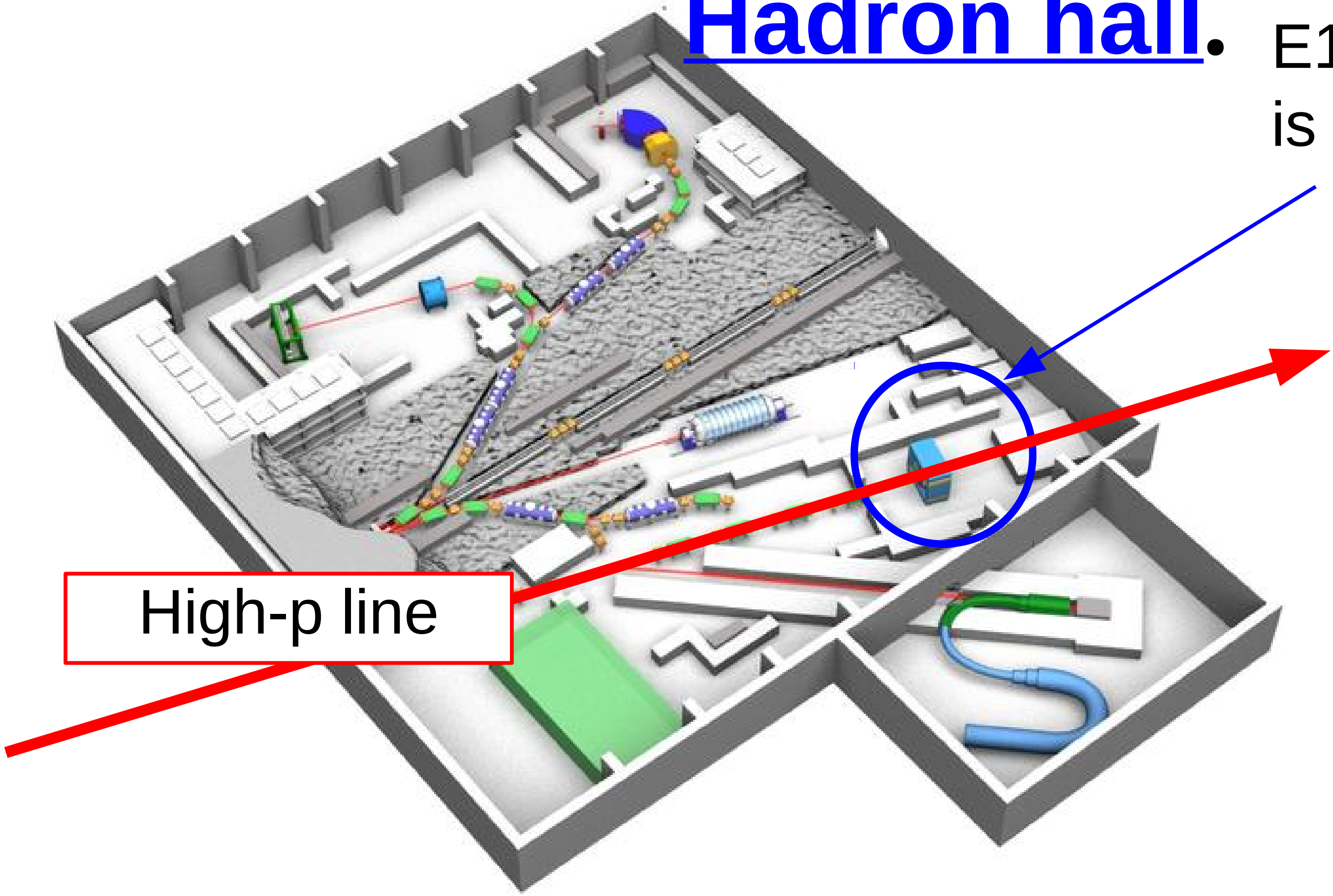
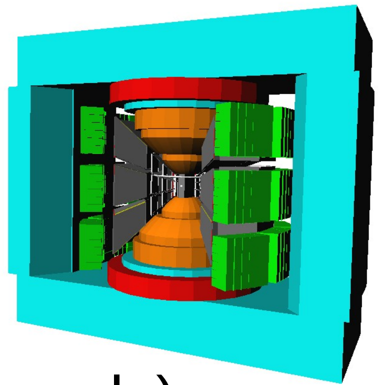
High-momentum beam line in J-PARC Hadron hall



- E16 spectrometer magnet is here



- 30 GeV primary protons of 1×10^{10} / 2 sec spill (5.52~6 sec cycle)
- secondary pions (unseparated) : ~2×10^{7} / spill @20 GeV/c (negative charge)
- can be operated simultaneously w/ other secondary beam lines
- First beam is planned in Feb. 2020

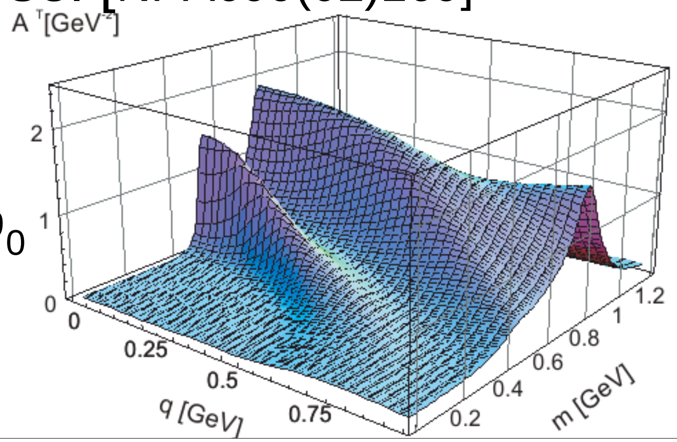
In-medium mass modification of hadrons

- hadron as the elementary excitation of QCD vacuum
  - elementary excitation on a ground state : changed when the ground state is changed
    - change of excitation reflects the vacuum nature : symmetry, phase
    - condensed matter: experimental examples, as the phonon softening in ferroelectric crystal around Tc
  - hadronic spectral function could be changed (mass, width and more complicated structure) in hot and/or dense matter, different vacuum on the QCD phase diagram
    - various theoretical calculations

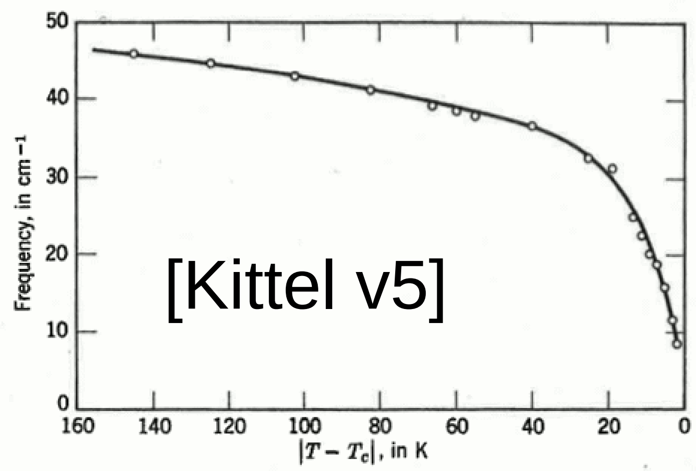
Post & Mosel [NPA699(02)169]

ρ-meson

density $\rho = \rho_0$



meson in nuclear matter, changing density, excited by incident photon/hadrons , dilepton decay to be measured



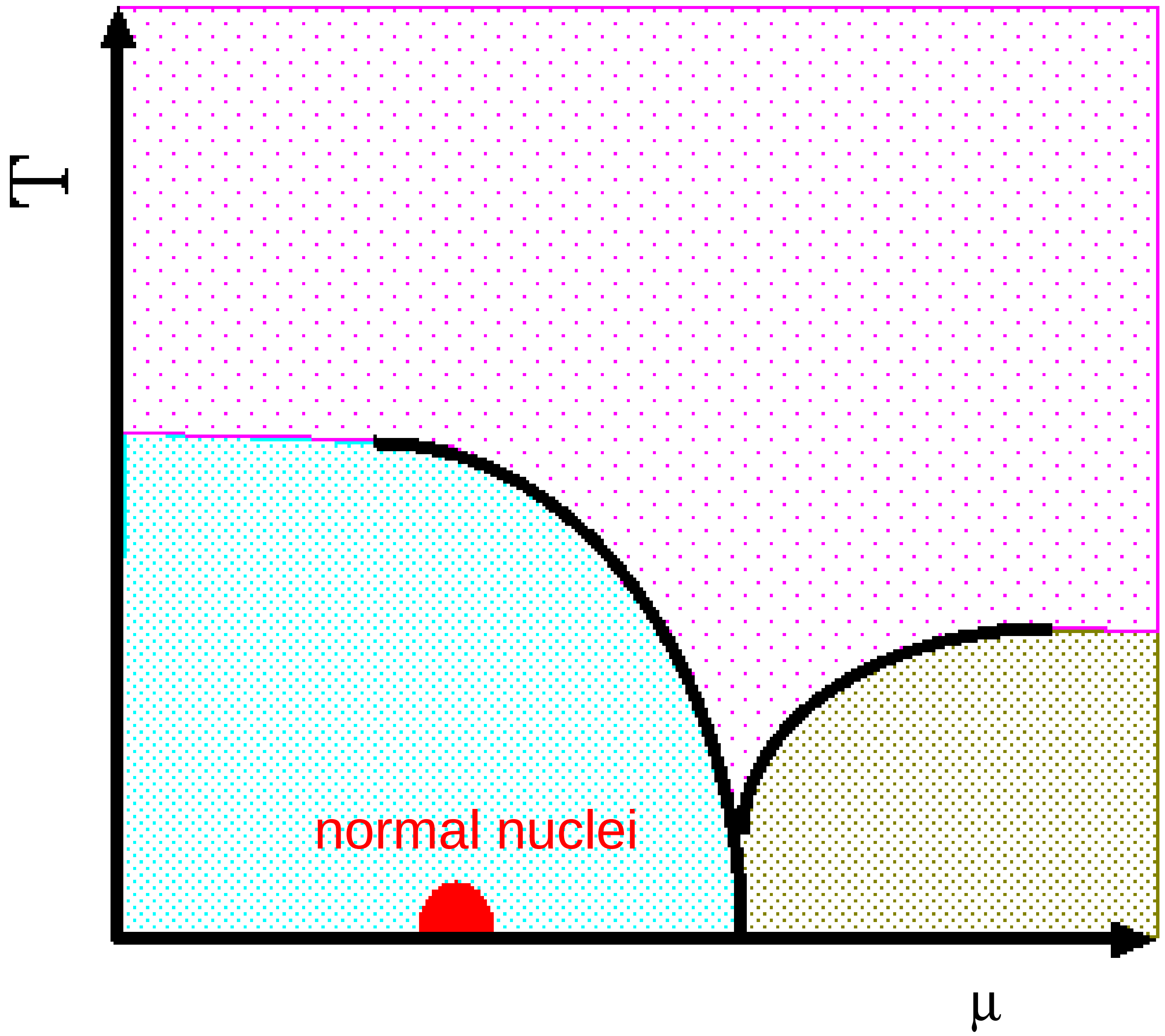
[Kittel v5]

phonon in SbSI crystal, changing T, excited by laser, scattered photon is measured (by Raman scattering)

In-medium mass modification of vector mesons

- vector meson ($\rho/\omega/\phi$) : dilepton decay
  - theoretically, spectral function probed by virtual photon
  - experimentally, smaller final-state interaction is expected
  - many dilepton measurements have been performed in the world
    - in hot matter : high-energy HI collision
    - in dense matter (nuclei) : γ+A, p+A reactions
- Particulary, ϕ meson,
  - experimentally: isolated and narrow resonance unlike the ρ and ω mesons case (ρ/ω interfere, etc)
  - theoretically (QCD sum rule): mean value of spectral function is related to the $\langle\bar{s}s\rangle_\rho$, a measure of (partial) restoration of chiral symmetry in dense matter.

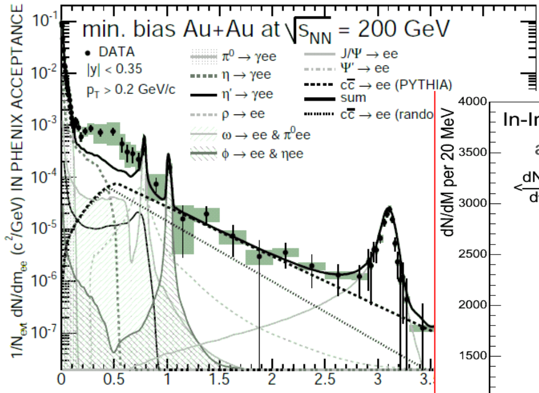
QCD phase diagram

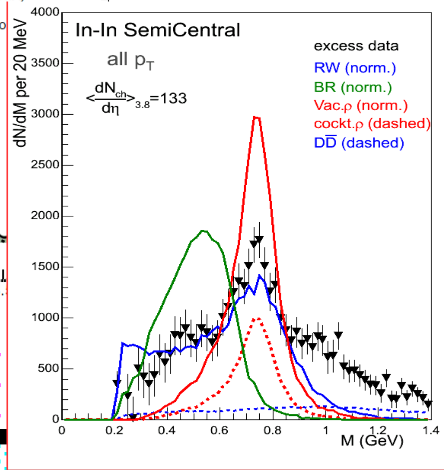


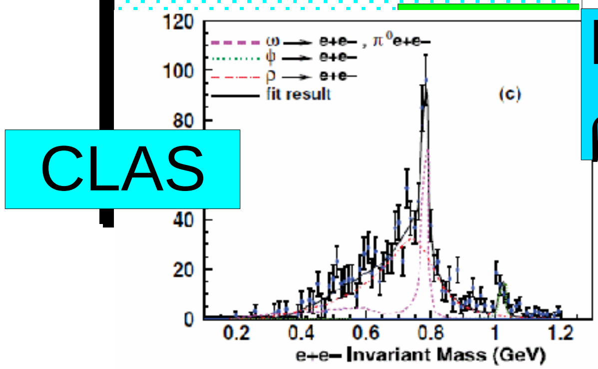
observed dilepton spectra in the world

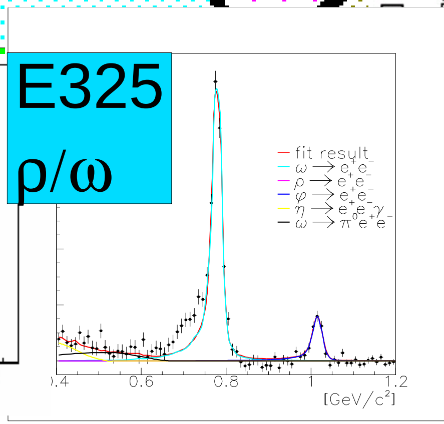
"low mass enhancement"
below the ω meson peak
in HI collisions
and HADES p+Nb

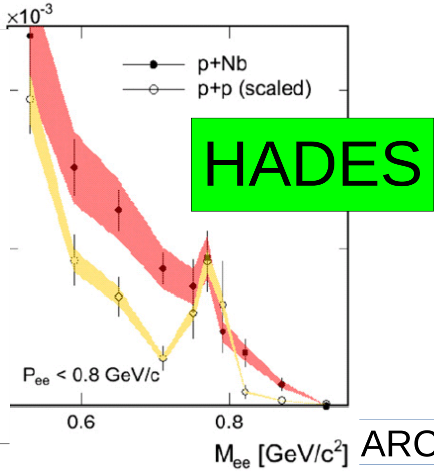
change of ϕ meson is
observed only by KEK-PS
E325 w/ good mass resolution
& high statistics

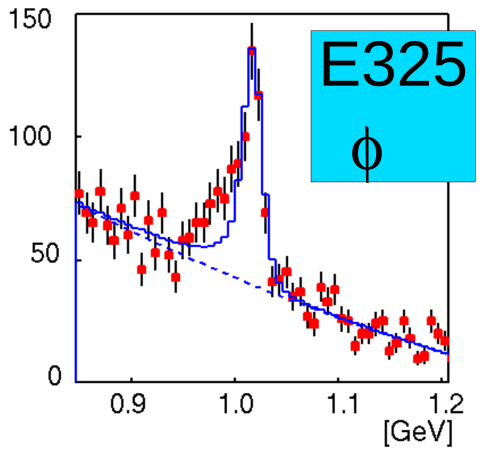






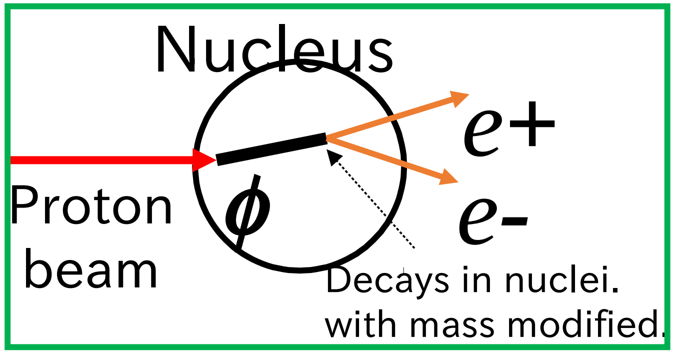


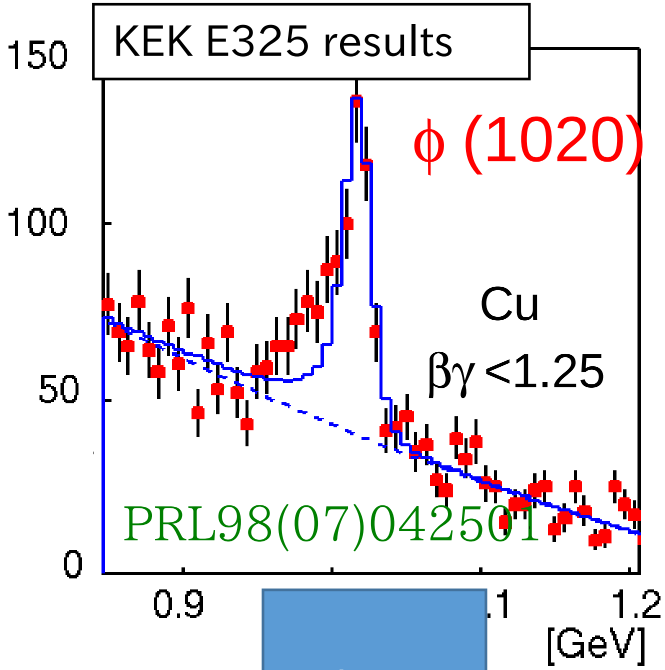


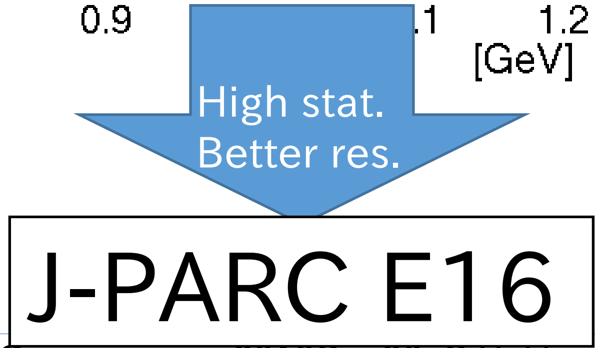


J-PARC E16 experiment

- E16 measure the e^+e^- decay of ρ/ω/φ produced in 30-GeV p+A (C, Cu, Pb, etc.) reactions.
- better S/N is expected in p+A reaction than that of high energy HI collisions
- In many experiments oberved the hadron modification, only E325 observed the change of φ meson in nuclear matter, which can be related $\langle\bar{s}s\rangle_\rho$, a measure of (partial) restoration of chiral symmetry in dense matter.
- Goal of E16 is to establish the spectral change of vector mesons, particularly φ meson, and obtain more precise information of spectra, e.g. the momentum dependence of change, through the systematic study with higher statistics (x10-100) from various nuclear targets, and with the improved mass resolution (11MeV-> 6-8 MeV) than that of E325.



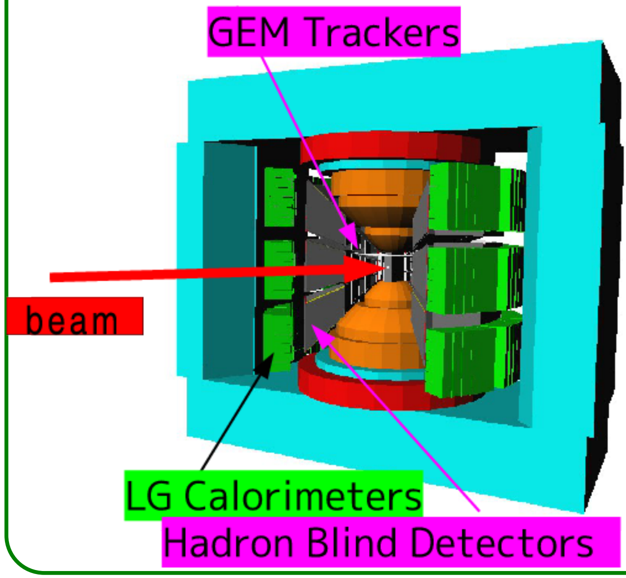




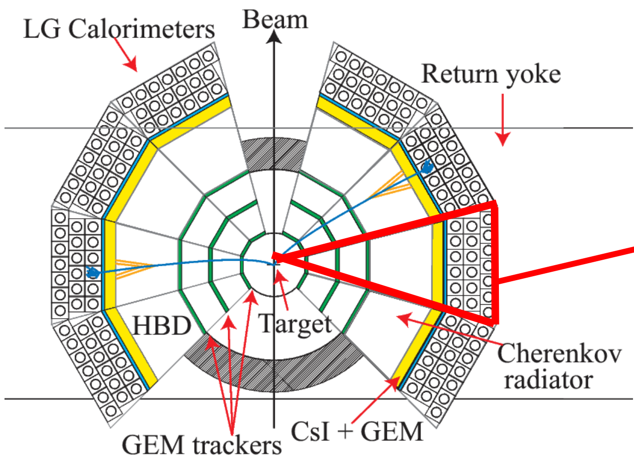
E16 Detectors

- ~10 MHz interaction at the targets with 1×10^{10} / 2 sec spill (5-6 sec cycle) of 30 GeV proton beam, ~10 times as high as that of E325, in order to accumlate the higher statistics.
- Electron ID : Hadron Blind Detector(HBD) & lead glass EMC (LG), used to trigger
- Tracking : GEM Tracker (3 layers of X&Y) / SSD (1layer of X, most inner)
  - 5 kHz/mm^2 at the most forward, 100μm resolution(x) for 5-6 MeV/c^2 mass resolution
  - to avoid mistracking due to the accidental hits, SSD is introduced

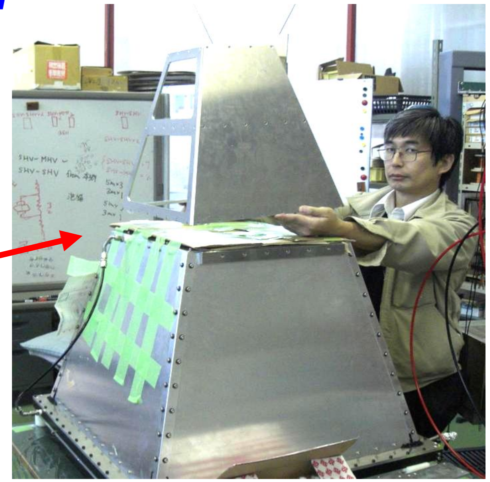
Proposed Spectrometer



Plan View



Prototype Module

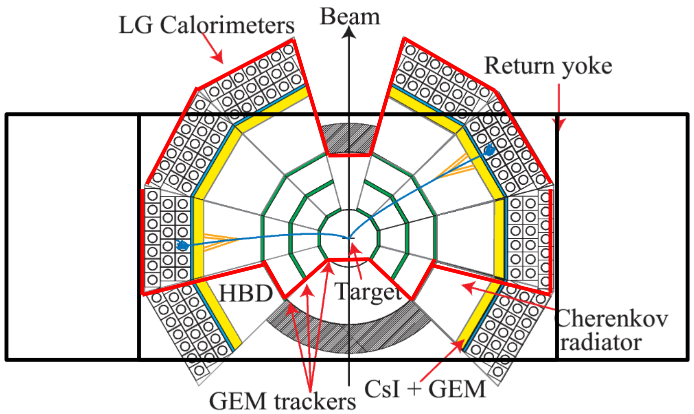


26 detector modules

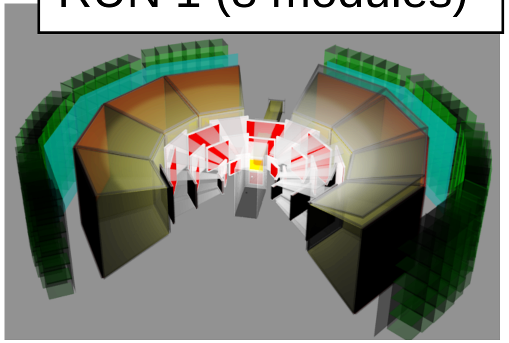
Staging strategy

- **RUN 0** -- 40 shifts, C/Cu targets Approved in 2017
  - Beamline / Detector commissioning + cross section
    - Prove that the E16 spectrometer works under the huge bkg.
    - limited detector configuration
    - **6 (SSD) + 8 (GTR) + 6 (HBD) + 6 (LG)**
- **RUN 1** -- 160 shifts, C/Cu targets Not approved yet
  - Physics run
    - review based on the Run0 results is required
  - **8 (SSD) + 8 (GTR) + 8 (HBD) + 8(LG)**
    - Physics data taking. 15k of phi mesons
  - **Secured only 6-8-6-6**
    - To obtain new SSD, collaboration w/ CBM has been started.
- **RUN 2** -- 320 shifts, C/Cu/Pb targets
  - Physics run to accumulate more statistcs to approach the slowest mesons, with various targets.
  - **26 (SSD) + 26 (GTR) + 26 (HBD) + 26 (LG)**
  - budget is not secured yet

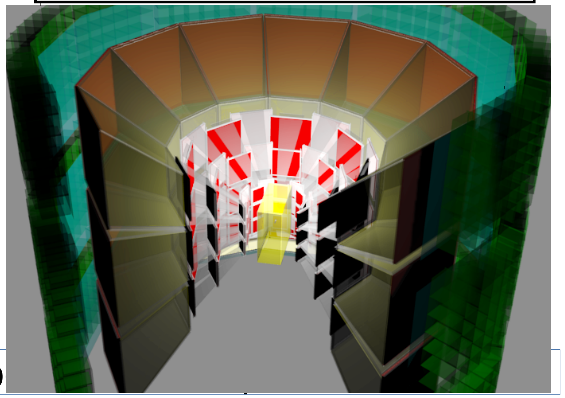
RUN 0 config.



RUN 1 (8 modules)



RUN 2 (26 modules)



beam time prospect

- KEK schedule on Hadron hall & E16 plan
  - JFY 2019 (Apr.- 2020 Mar.)
    - Feb.-Mar. 2020 : first beam at High-p line
      - E16 Run0-a (20 shifts=6.6 days), after 10-days commissioning of High-p line
  - JFY 2020 (Apr.- 2021 Mar.)
    - Autumn 2020 (not fixed) E16 Run0-b (20 shifts)
  - JFY 2021 (Apr.- 2022 Mar.) : no beam
      - No beam for the accelerator (Main Ring) upgrade
  - JFY 2022
    - E16 Run-1 (160 shifts=53.3 days) : review is still required for the approval by PAC

JFY	2019				2020				2021				2022			
	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3
		PAC		PAC		PAC		PAC		PAC		PAC		PAC		
		now		Rum0-a			Run0-b		No beam				Run-1			

Expected signal

Expected yield

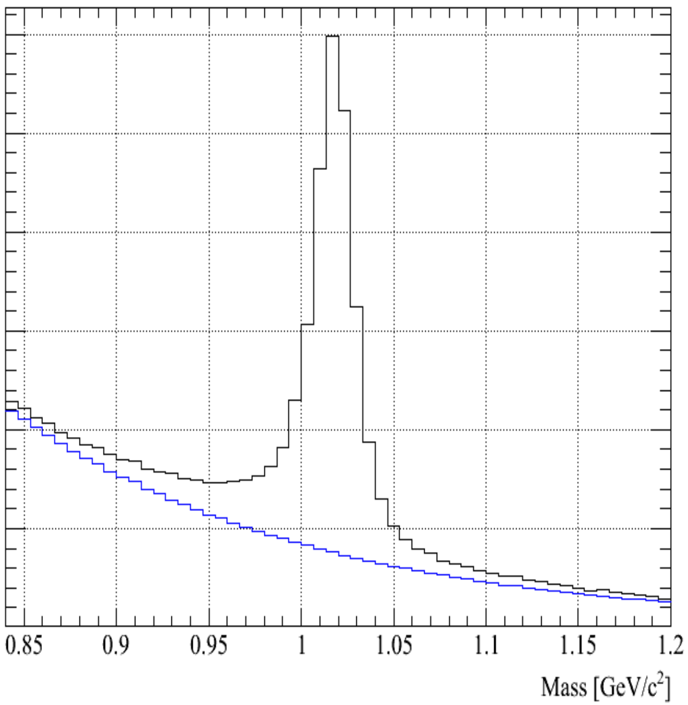
RUN	beam time	configuration	target	ϕ	ω
RUN 0	9 shifts	$6+6+2+2$	Cu	460	2400
RUN 0'	9 shifts	$8+8+8+8$	Cu	840	4400
RUN 1	160 shifts	$6+6+2+2$	Cu	8200	42000
RUN 1'	160 shifts	$8+8+8+8$	Cu	15000 (1700)	
RUN 1'	160 shifts	$8+8+8+8$	C	12000 (1500)	
RUN 2	320 shifts	$26+26+26+26$	Cu	69000 (12000)	
		KEK-PS E325	Cu	2400 (460)	3200

- In Run0 and Run1, C and Cu targets are used at the same time.
  - Cu 80 μm x2 & C 400 μm are located in-line w/ 20mm spacing, at the center of Spectrometer
  - → less than 0.5% radiation length for each, and 0.2% interaction length in total.
- The ρ, ω and J/psi are also measured simultaneously in e^+e^- spectra
  - modification of ρ/ω is also exmained.

analysis strategy

- model-independent analysis : prove the change
  - compare the data with the vacuum shape (Breit-Wigner)
    - difference is significant or not
  - examin the $\beta\gamma$ dependence of difference
    - larger difference is expected in slower component
- model-dependent analysis
  - fit the data by theoretical spectral functions (cf. Gubler & Weise [NPA954(2016)125])
    - theoretical input is important, particularly the momentum dependence of mass shape for ϕ meson
  - determine the modification parameter as E325 performed
    - deduce $\langle \bar{s}s \rangle_\rho$
    - momentum dependence will be deduced with higher stat.

expected ϕ in Run-1, for Cu, w/ bkg



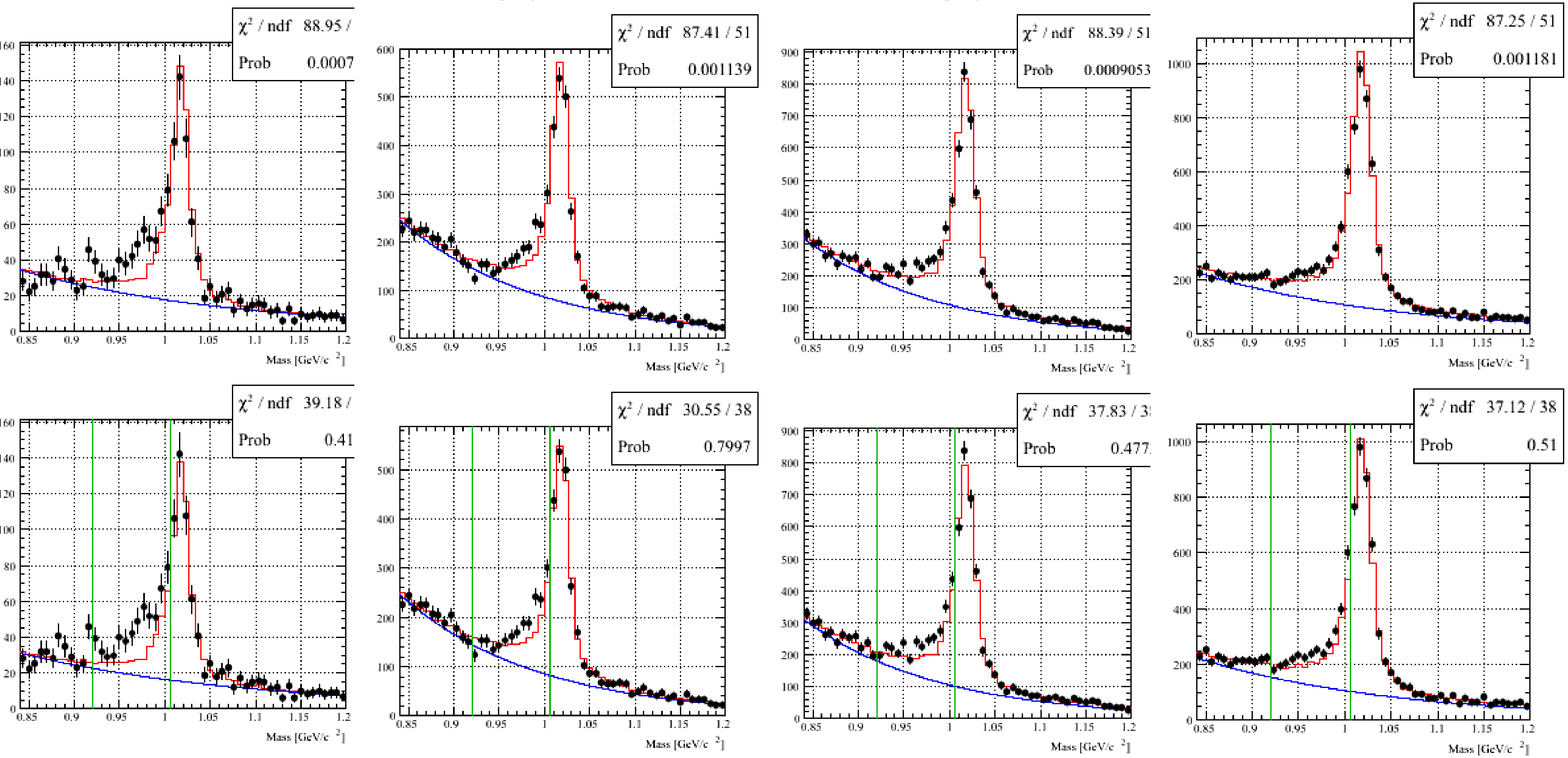
- ~15000 ϕ for Cu target in 160 shifts (53 days)
  - 1×10^{10} protons/spill, 8 modules
- input to Geant4: Breit-Wigner for ϕ meson
- approx. 8 MeV of mass resolution
  - for the "all (integrated) $\beta\gamma$" region
  - including internal radiative correction
  - including experimental effects as target & detector materials, misalignment, mistracking, etc.
- combinatorial background : ee, eπ and $\pi\pi$ pairs (ratio ~13:7:1)
  - π^0 Dalitz decays, γ conversion, and misidentified π
  - pions : evaluated by the cascade code JAM
- And, not only BW shape, but also the assumed modified shape is also evaluated by Geant4, and compared ->next

βγ dependence of spectral change [sim.]

βγ<1.25, 1.25<βγ<1.75, 1.75<βγ<2.5, 2.5<βγ

Fit for the whole region

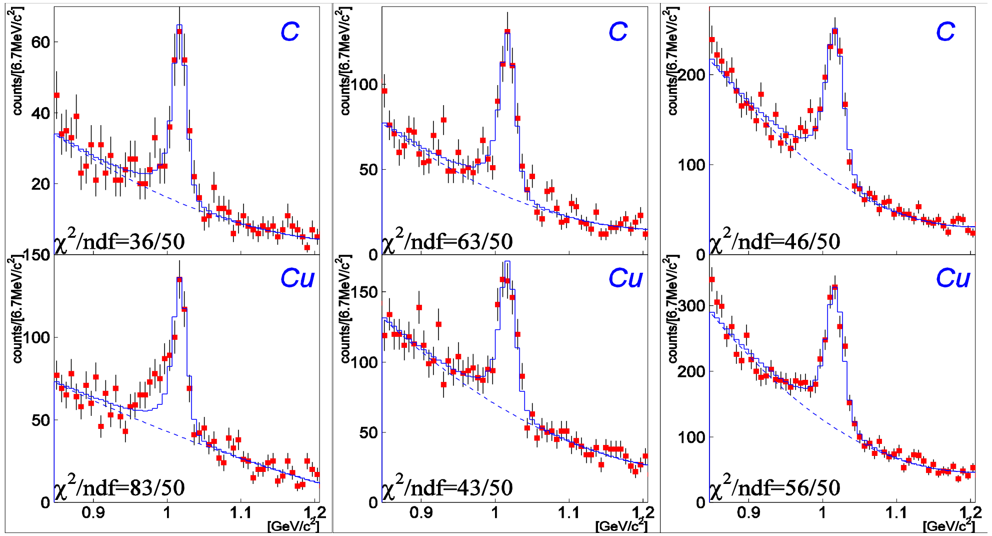
Fit except for Excess region

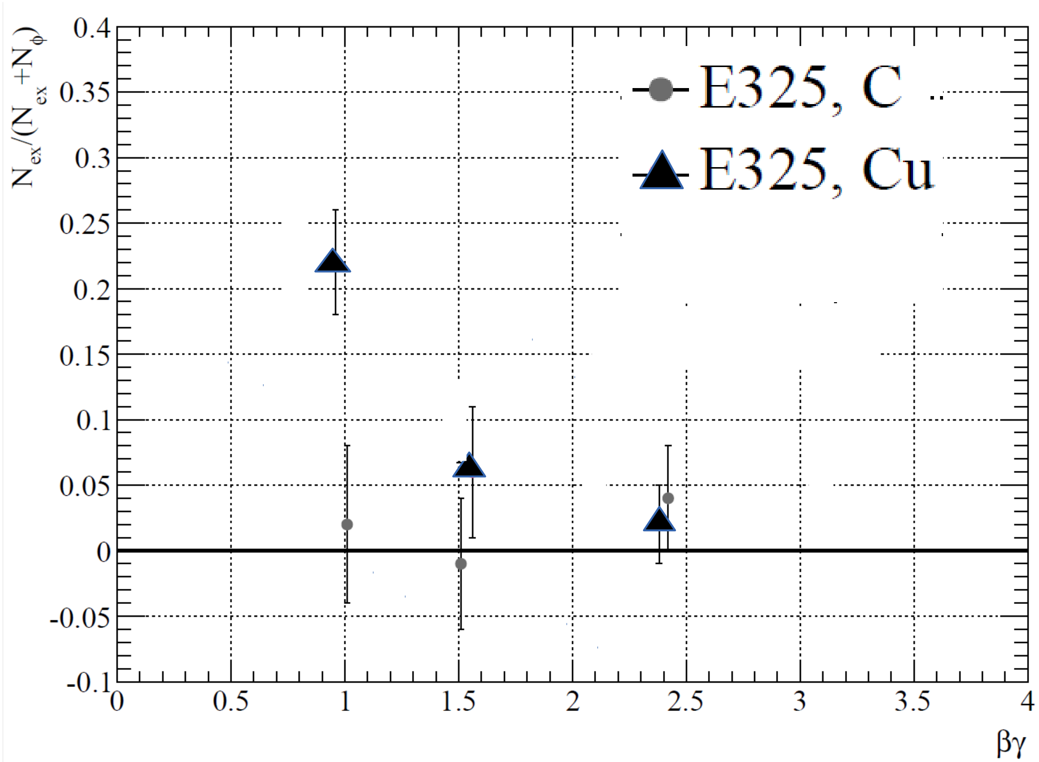


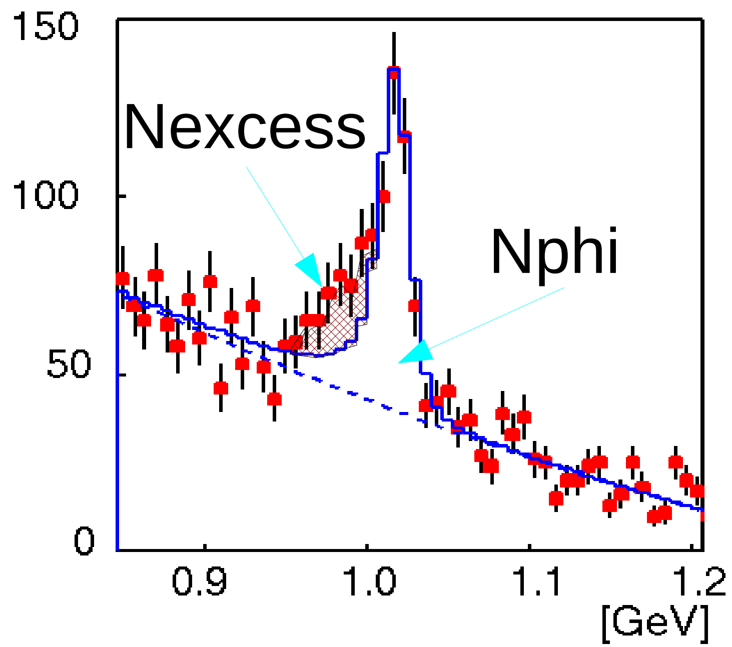
- spectal change measured E325 (mass Δ3.4% /3.6 x Γ) is assumed
- fit with the evaluated vacuum shape : excess is signigicant in all the panels
- βγ dependence of excesses is examined → next

excess ratio in E325

- Nexcess/(Nexcess+Nphi)
  - index of the modification

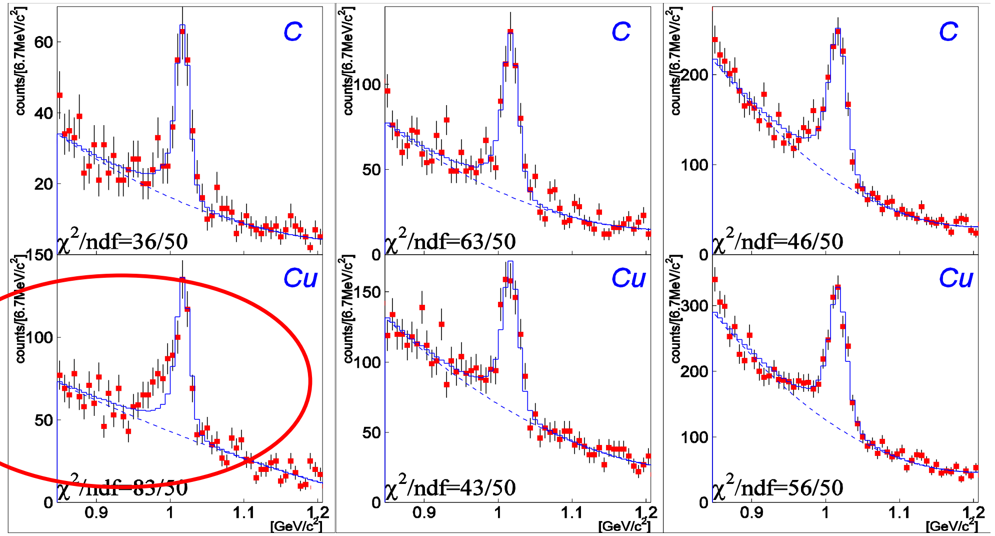


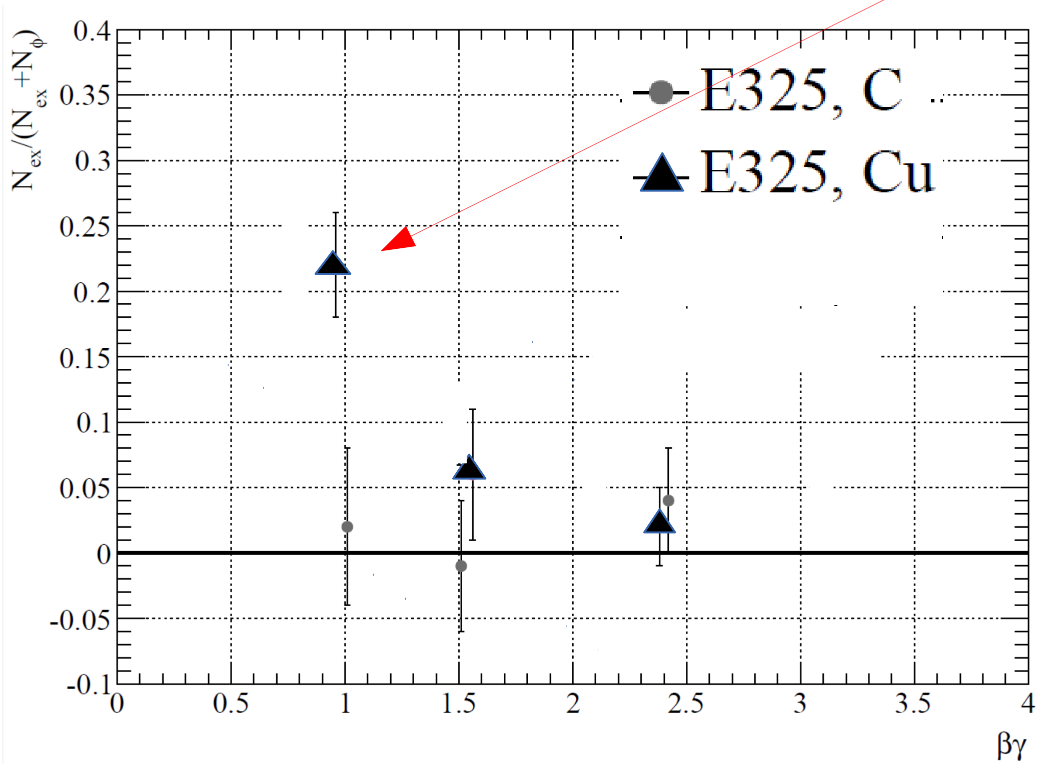




excess ratio in E325

- Nexcess/(Nexcess+Nphi)
  - only slow Cu is significant in E325

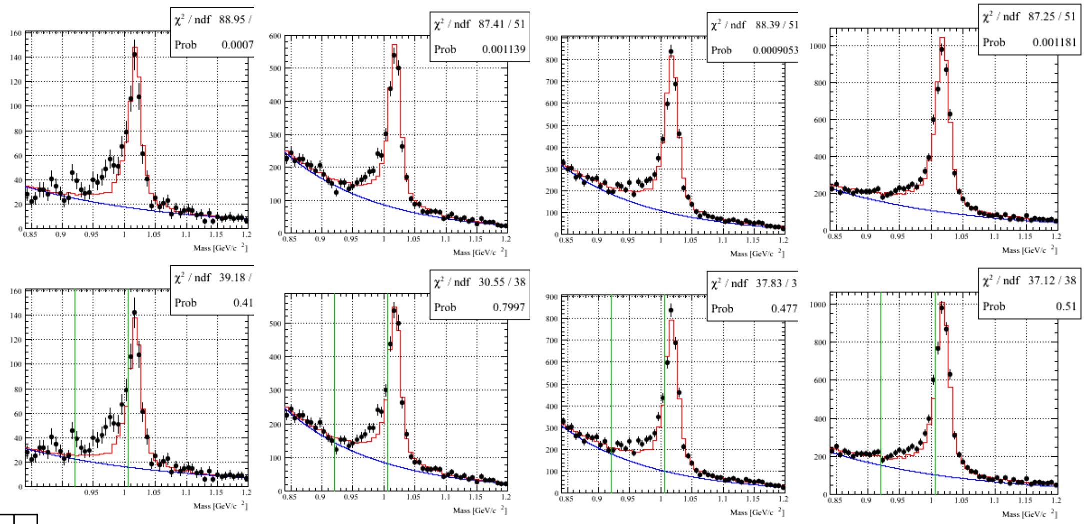


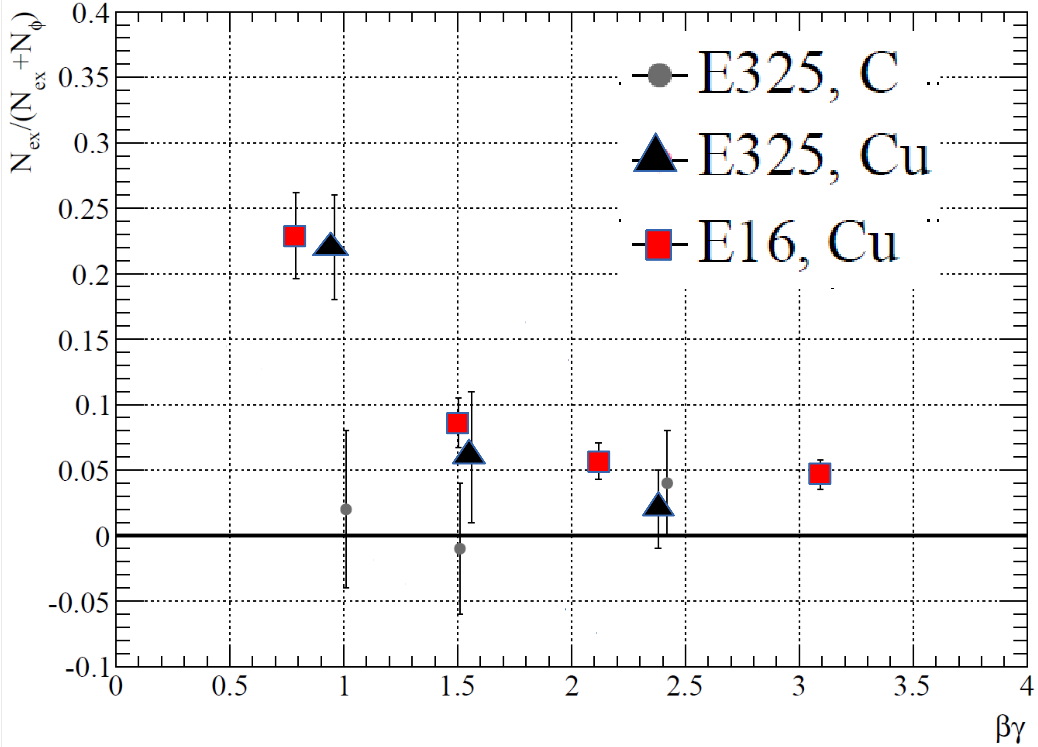


- larger excess in lower βγ (slower) bin : consistent with the modification in nuclei

excess ratio in E16 [sim.]

- Nexcess/(Nexcess+Nphi)
  - all bins for Cu are significant in E16





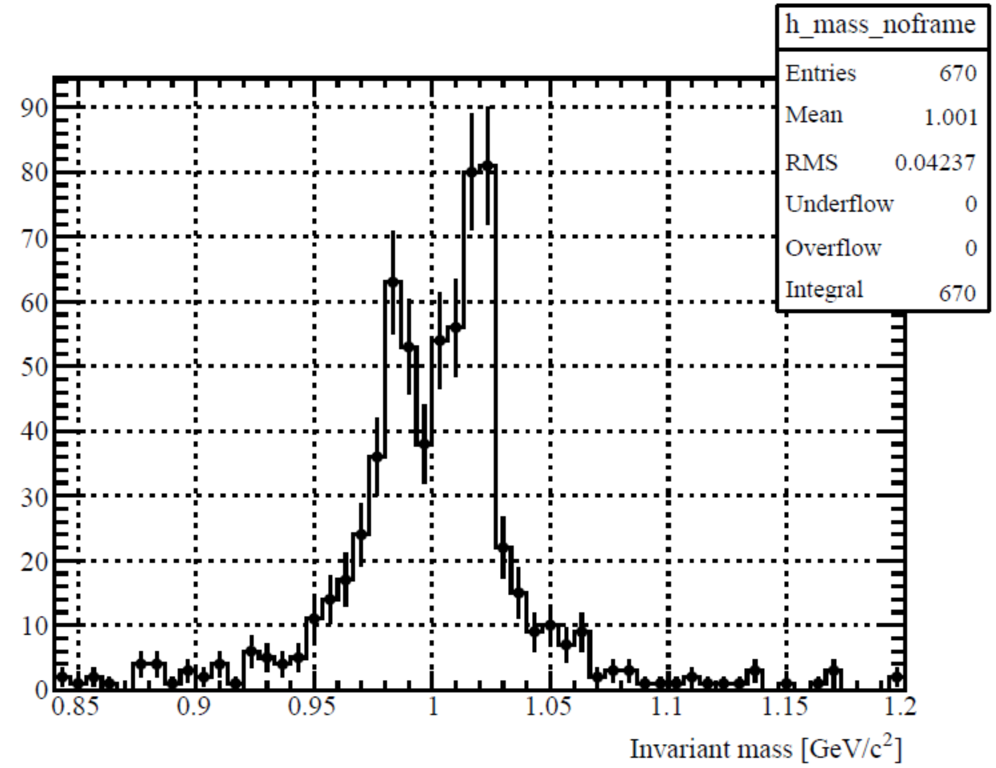
- larger excess in lower βγ (slower) bin :

  the tendency become more clear and significant

  than that of E325.

E16 Run-2 prospect [sim.]

- Pb targets (30um x 3)
- full (26) modules x 106 days
- modified BW (k_1=0.034 & k_2=2.6)
- selecting only βγ<0.5 (very slow)
-
- (combinatorial bkg is not shown)



- mass resolution 5.8+-0.1 MeV

  (excluding frame-hit events)

analysis strategy

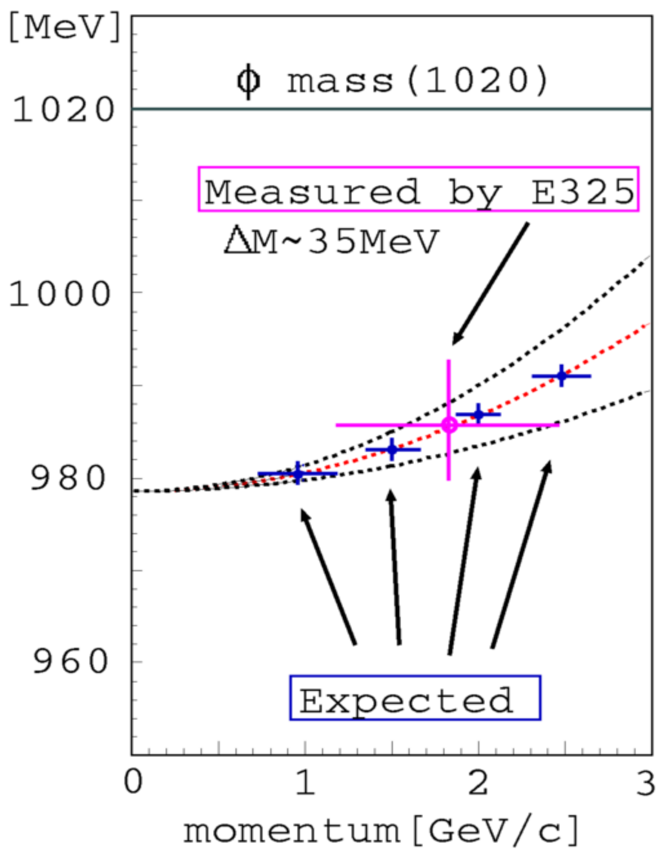
- model-independent analysis
  - compare the data with the vacuum shape (Breit-Wigner)
    - difference is significant or not
  - examin the $\beta\gamma$ dependence of difference
    - larger difference is expected in slower component
- model-dependent analysis : comparison w/ predictions
  - fit the data by theoretical spectral functions (cf. Gubler & Weise [NPA954(2016)125])
    - theoretical input is important, particularly the momentum dependence of mass shape for ϕ meson
  - determine the modification parameter as E325 performed
    - deduce $\langle \bar{s}s \rangle_\rho$
    - momentum dependence will be deduced with higher stat.

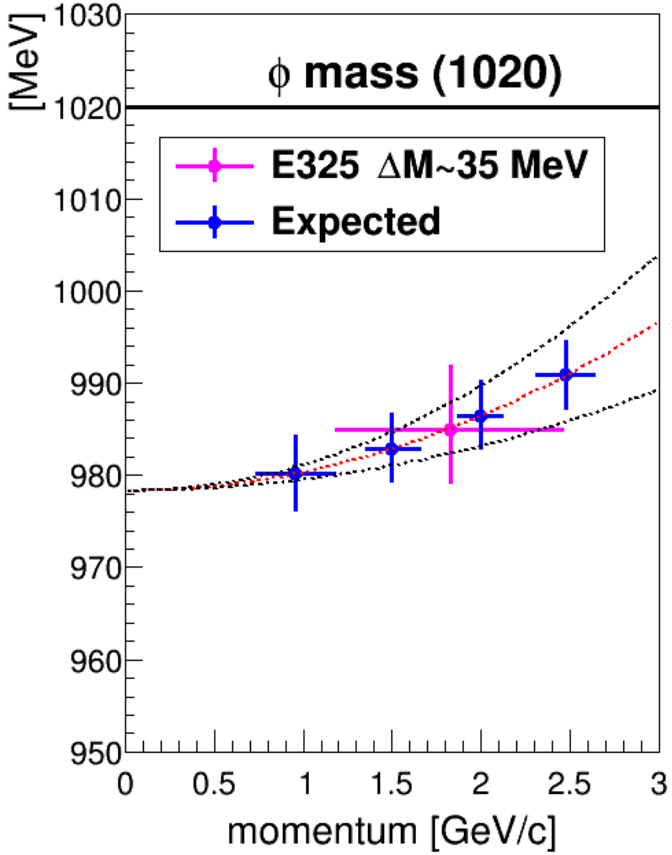
momentum dependence

- momentum dependence of mass
  - experimentally: extraporation to p=0
  - theoretically: dispersion relation of the elementary excitation, 1st measurement in QCD
- curve: Lee's prediction (PRC57(98)927, up to 1GeV/c)

momentum dependence and stat.

- momentum dependence of mass
  - experimentally: extraporation to p=0
  - theoretically: dispersion relation of the elementary excitation, 1st measurement in QCD
- curve: Lee's prediction (PRC57(98)927, up to 1GeV/c)
- full statistics (E325 x100) & limited stat. (E325 x 10)





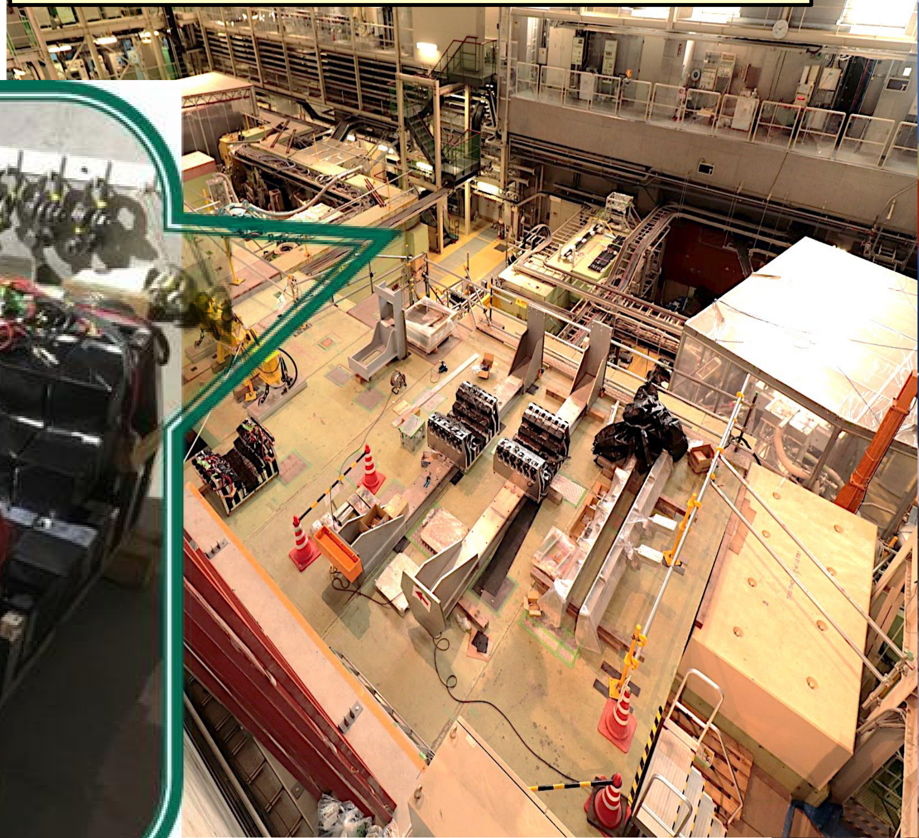
preparation status

LG

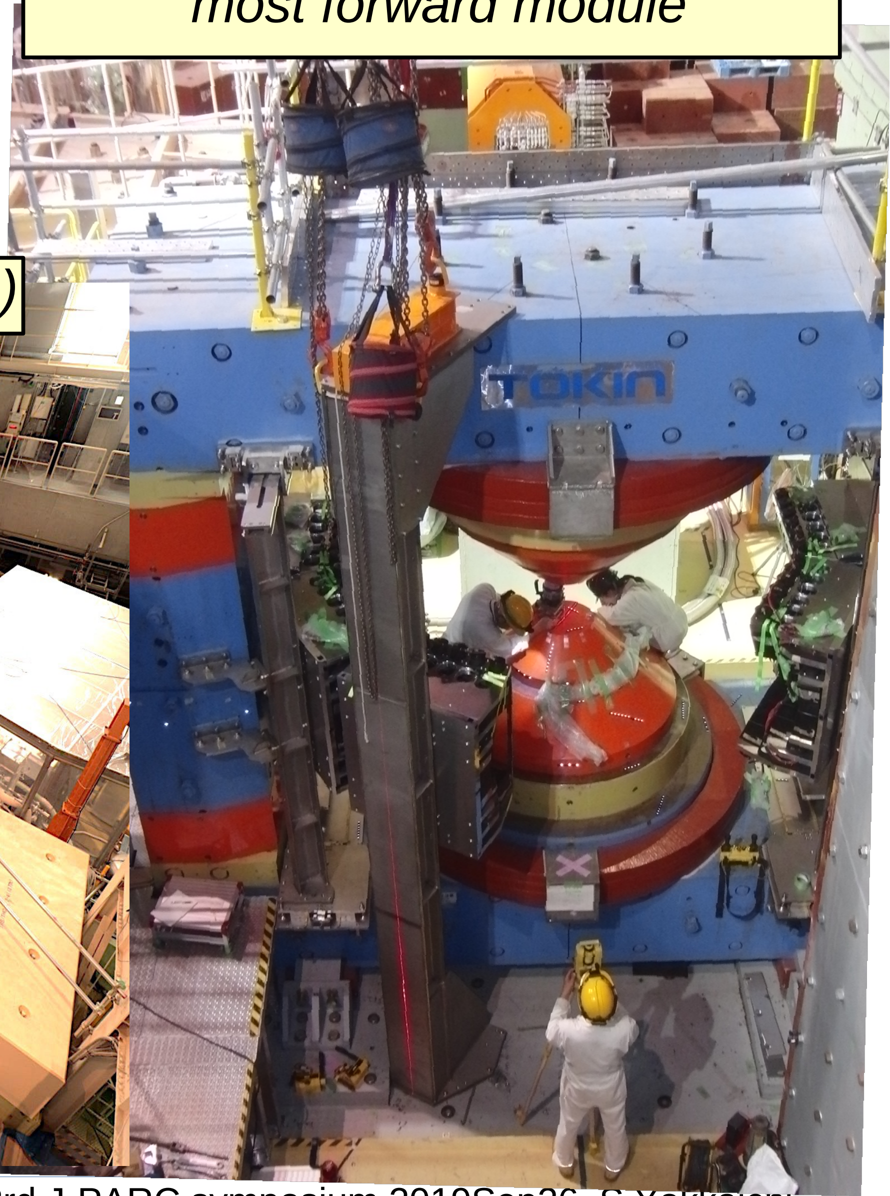
- Assembly of 6 modules was done.
- Installation of 6 modules was perfomed in Aug., took 3 weeks.

a LG module

LG modules on pillers (most fwd.)



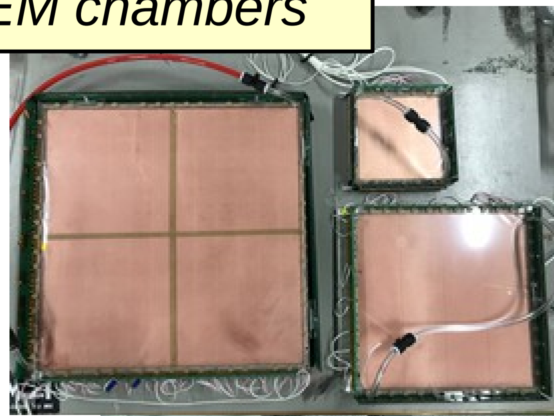
installation of a LG-module at most forward module



Tracking devices

- GTR (6 modules Installation in Oct.)
  - Check of GEMs were done. Chemical/Plasma cleaning of bad GEMs was completed in Jul.
  - Assembly of 18 chambers (for 6 modules) will be done in Sep. at KEK.
  - Support stage and CFRP frame in the magnet was delivered at J-PARC.
  - Mounting the chambers and wiring of preamps on the CFRP frames in Oct. at J-PARC.
- SSD (6 modules Installation in Dec.)
  - 6 SSDs borrowed from E03 group, including R/O curcuits(APVDAQ)
  - support structure on the target chamber will be delivered by Dec.
-

GEM chambers



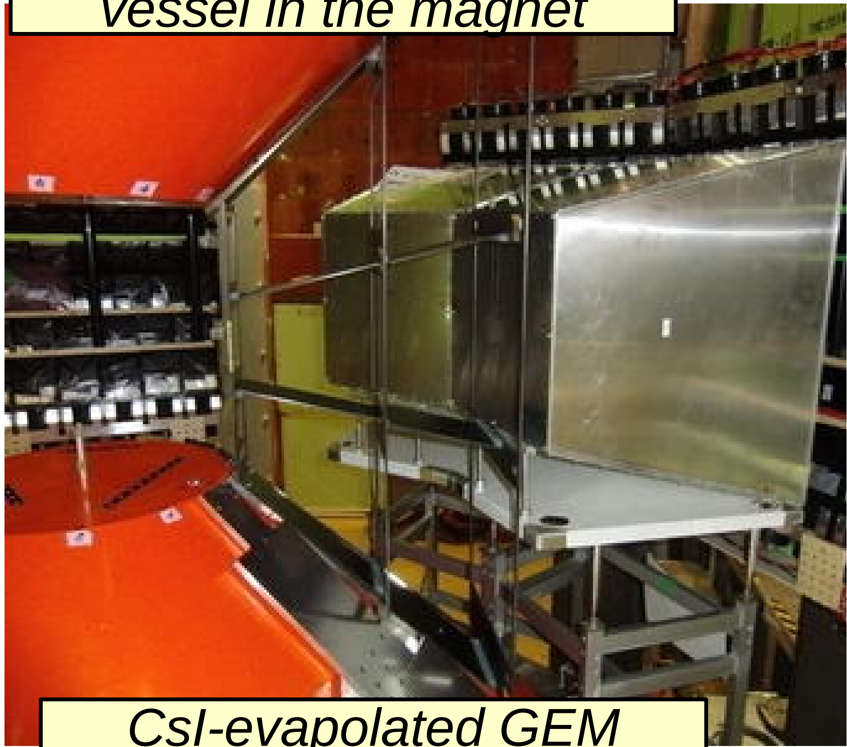
CFRP frame of GTR

support of GTR

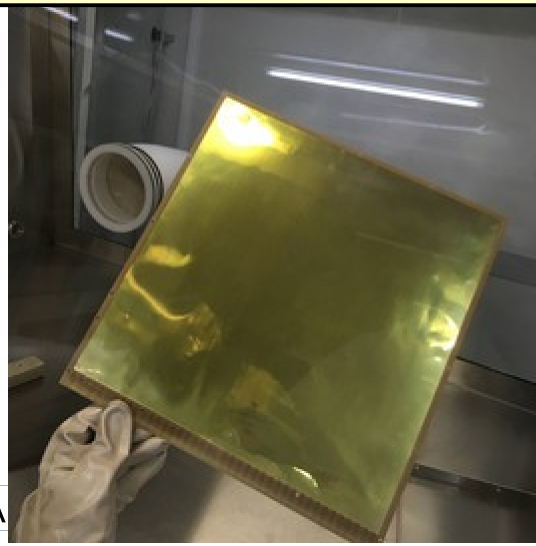
HBD

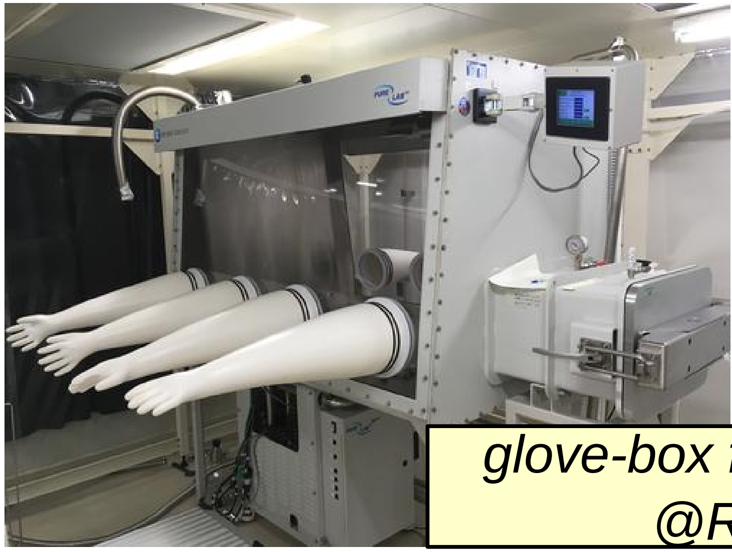
- HBD (4 modules Installation in Dec.)
  - Supports for 4 modules in the magnet were aleady delivered. Test installation of gas-vessel in the magnet was performed in Sep.
  - CsI evaporation by Hamamatsu started in Mar. and continue until Sep.
  - Assemble work in the glove-box at RIKEN, in Sep-Nov.
  -
-

test installation of the gas vessel in the magnet



CsI-evapolated GEM delivered from Hamamatsu





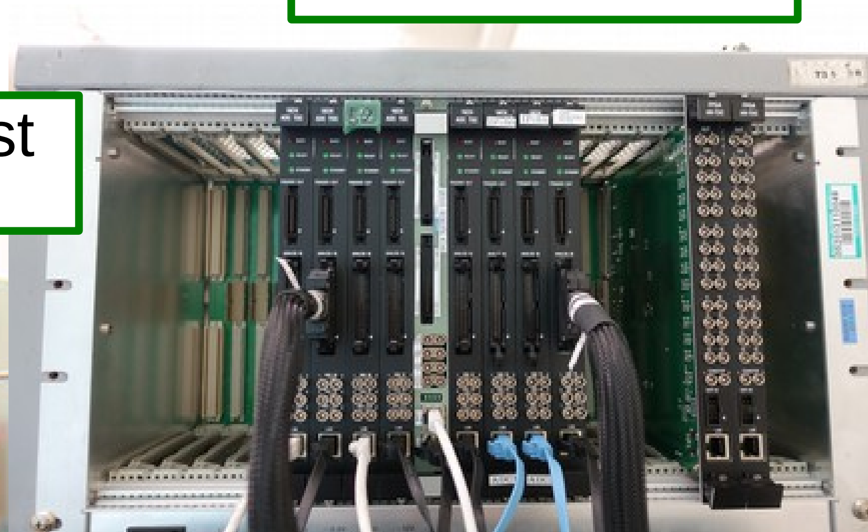
glove-box for CsI-GEM @RIKEN

Electronics

- FEM for 8 GTR/HBD (SRS-ATCA) and 6 LG (DRS4) were delivered.
- GTR & HBD trigger ASD board v2 (production) were delivered.
- Trigger logic modules were delivered. Firmware development is in progress. BelleII trigger protocol (B2TT) is modified and used.
- Trigger circuit /DAQ integrated test with LG-FEMs was done in May(see next page). Next test is planned in Oct. with GTR/HBD FEMs.
    - signal flow of “FEM → MRG → UT3” and “UT3→ FTSW → FEMs” worked well.

SRS-ATCA

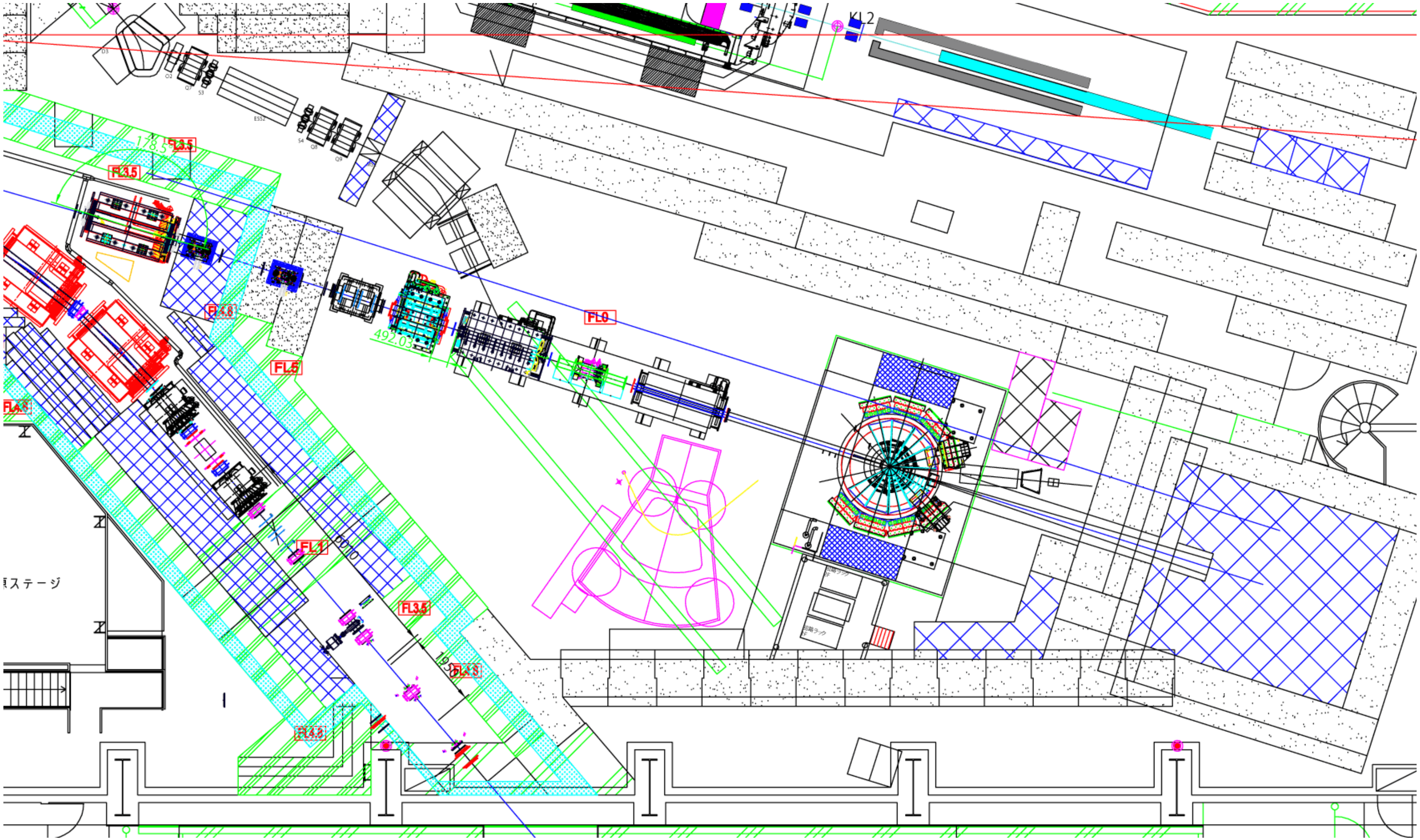
DRS4



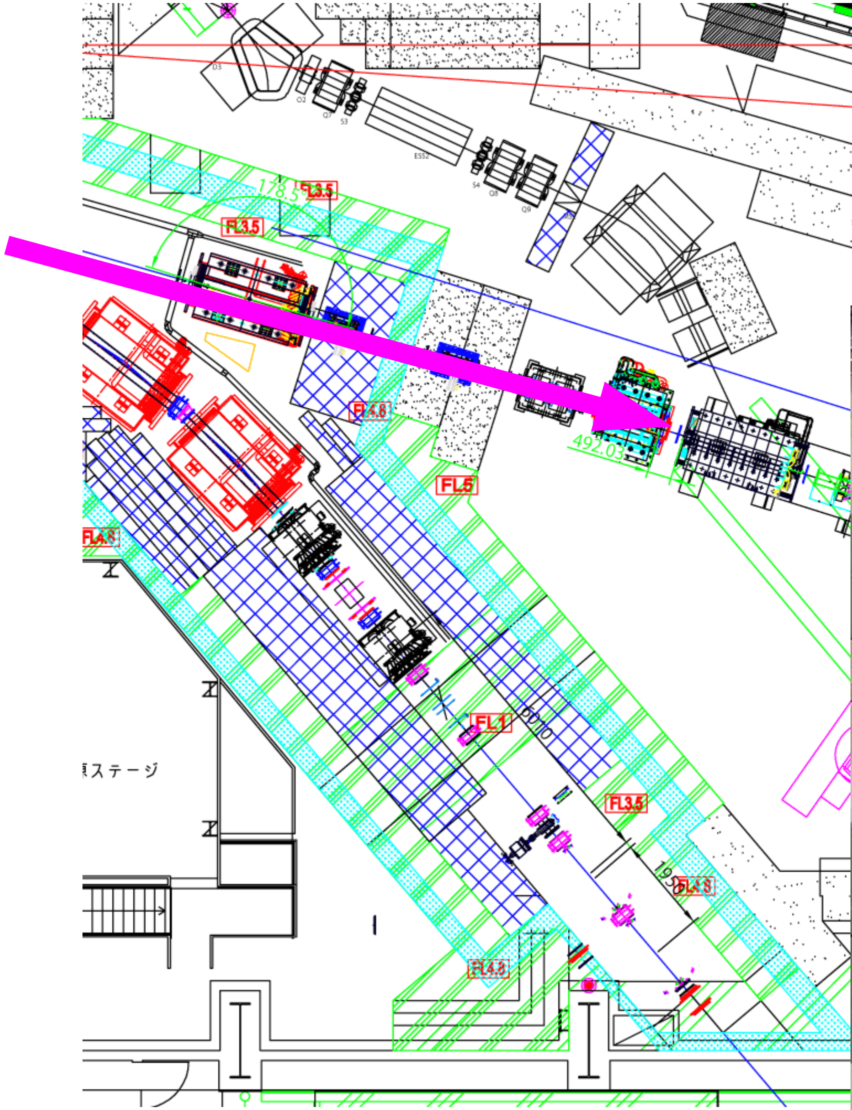
GTR-ASD in the test

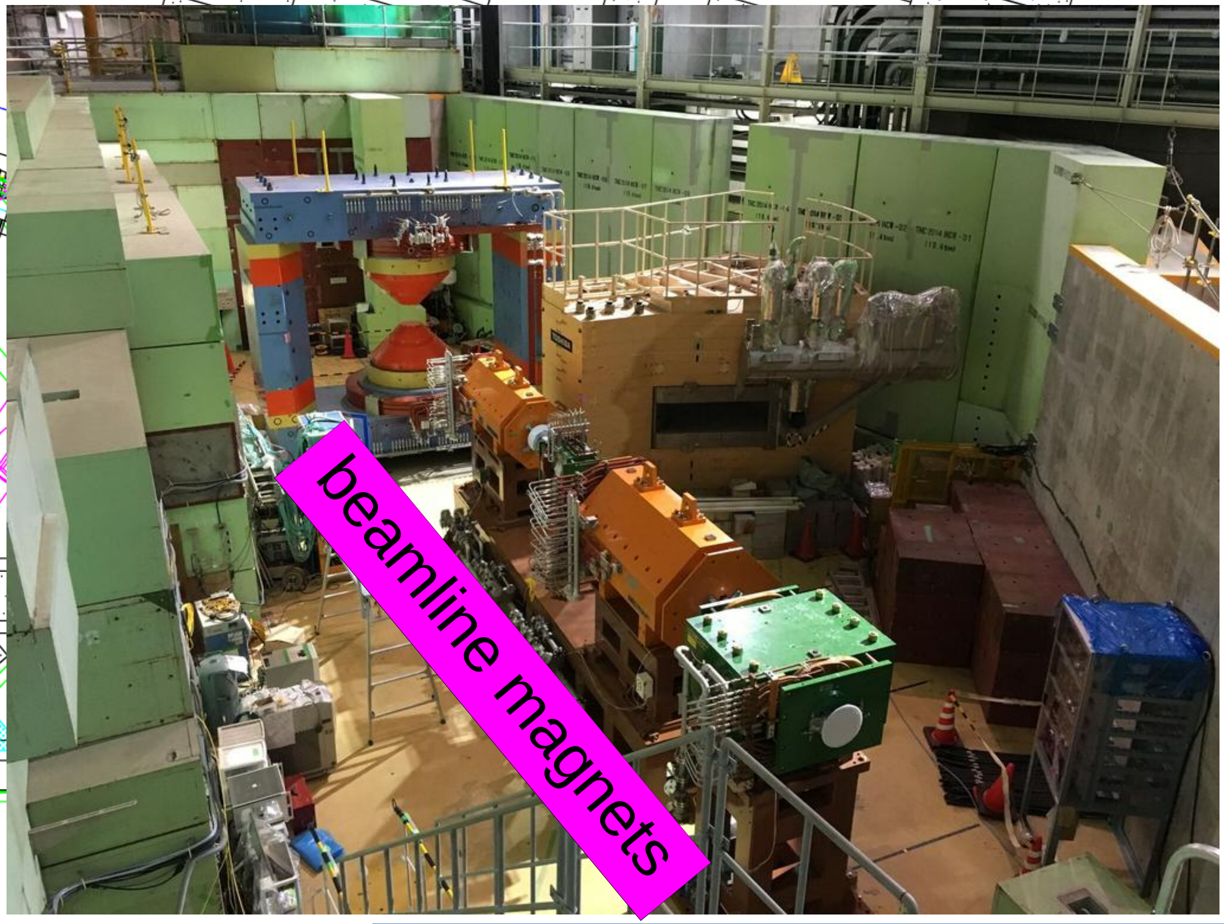
TRG-signal flow test

experimental area

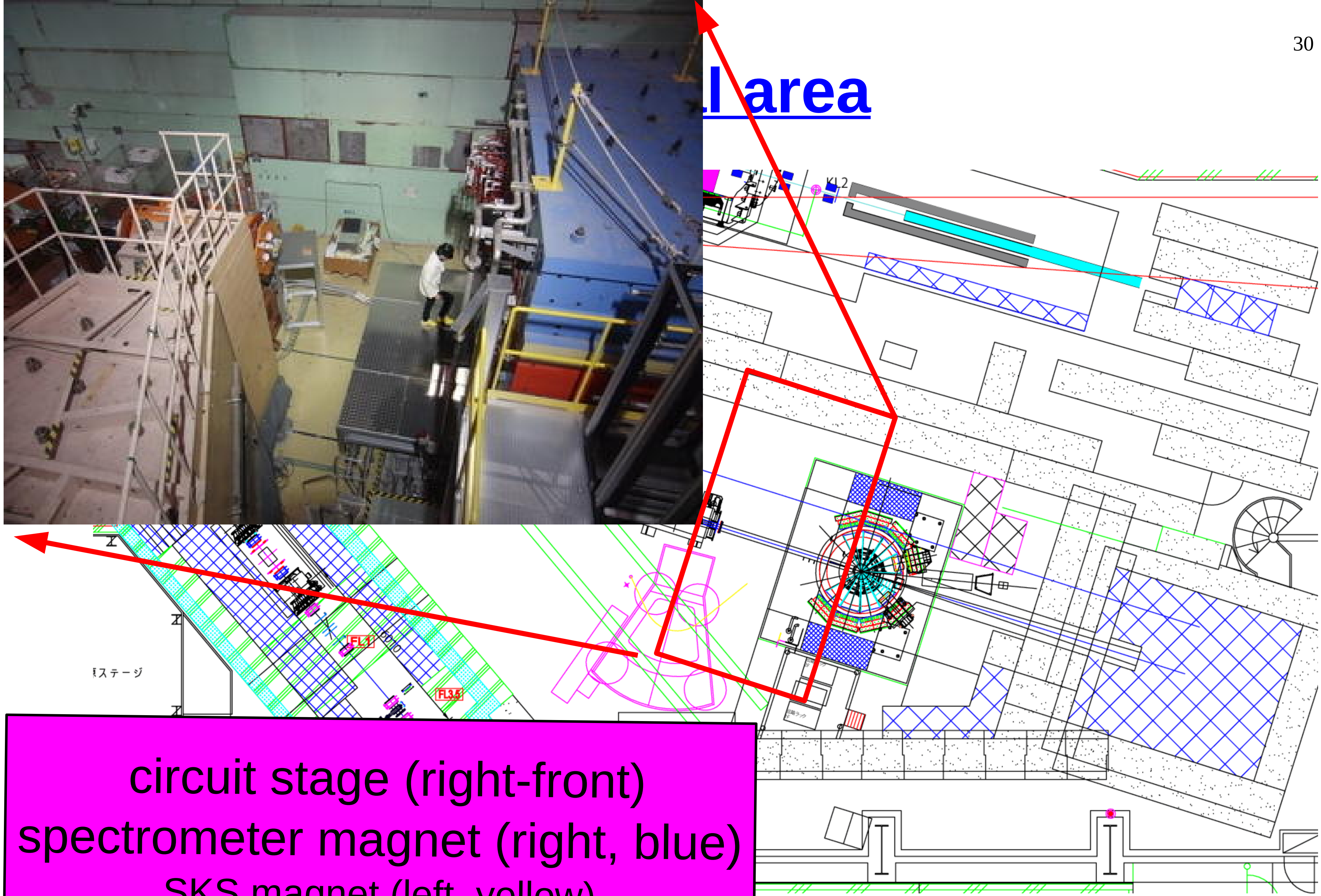


experimental area



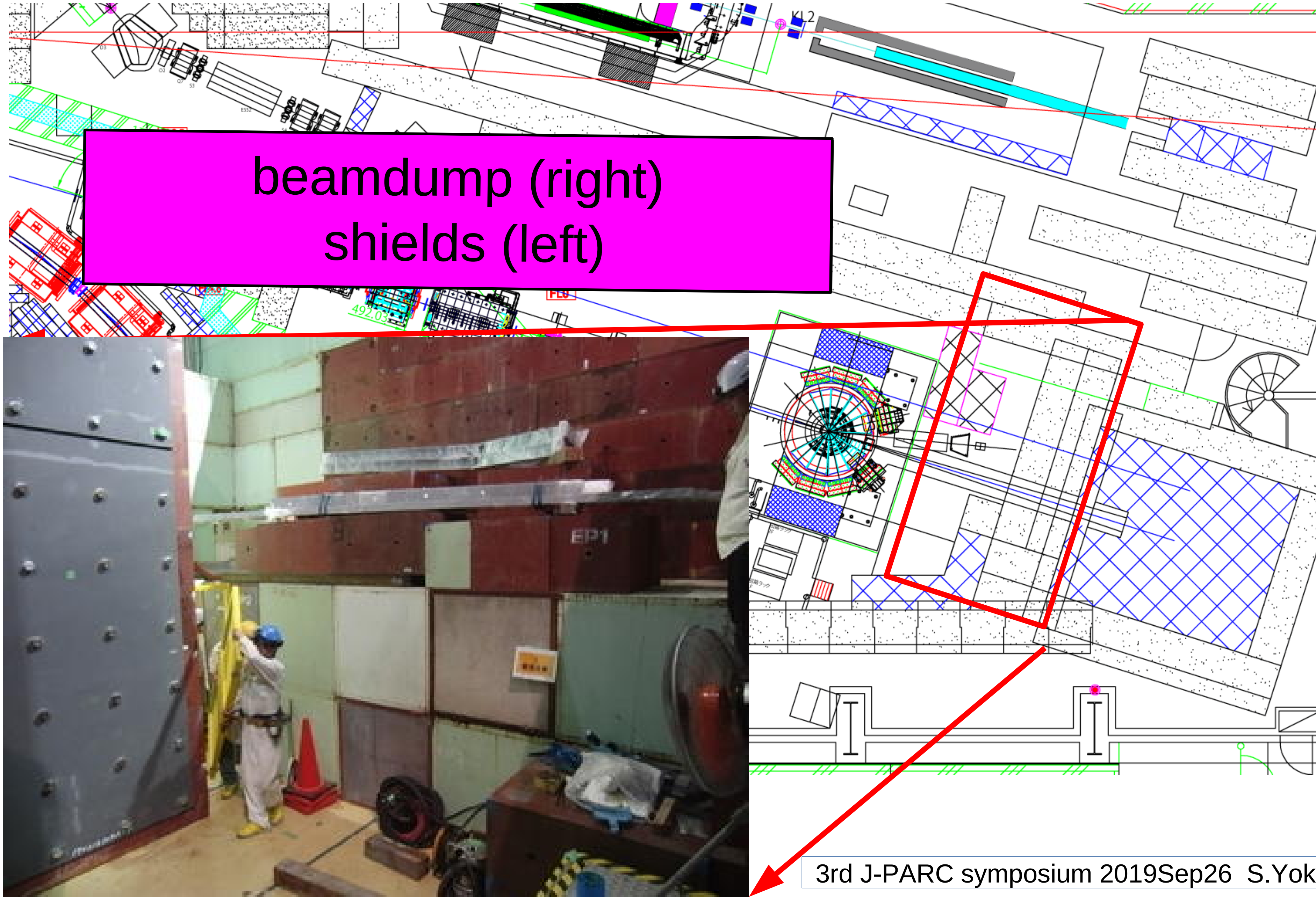


l area

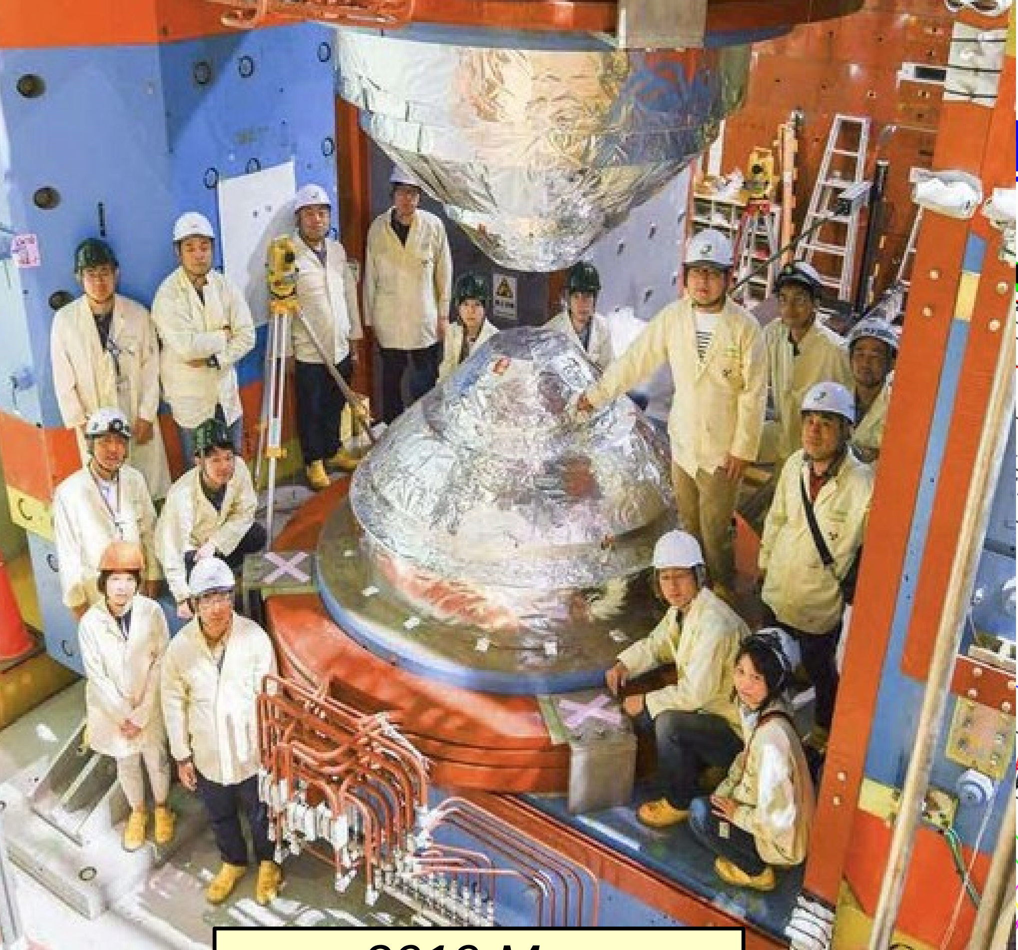


circuit stage (right-front)
spectrometer magnet (right, blue)
SKS magnet (left, yellow)

experimental area



ntal area



magnet &
field-measurement machine

2019 May

field mapping was performed in June-July, in shift work by E16 collaborators,
with the support of the hadron group

Summary

- J-PARC E16 will measure the spectral change of vector mesons in nuclei with the ee decay channel, using 30-GeV primary proton beam in newly-built High-p line.
  - confirm the observation by E325 and obtain more precise information of the spectral change of vector mesons in dense nuclear matter.
- Toward the Run-0 (beamline and detector commissioning), planned in early 2020, preparation of detectors and electronics is on-going.
  - With the granted budget (KAKENHI-S), 8 GTR, 6 HBD and 6 LG modules are secured.
    - 6 SSD + 6 GTR + 4 HBD + 6 LG will be ready by Jan. 2020.
    - Secured 6-8-6-6 will be ready in autumn 2020.
  - prove the spectrometer works well, even under the huge background.
- Beam time prospect : can be performed simultaneously with other hadron experiments
  - 40 shifts in 2020 for the commissioning run (Run-0), based on the stage-2 approval at PAC-24. First 20 shifts (Run0a)in Feb-Mar. and another 20 shifts(Run0b) in autumn 2020.
  - 160 shifts for the physics run (Run-1) will be requested in the PAC based on the Run-0 result.

Backup slides...

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Data collection and trigger data flow