J-PARC E16 has started

spectral change of vector mesons in nuclei

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Reimei Workshop
Hadrons in dense matter at J-PARC
Feb.21-23, 2022 online/KEK Tokai Campus

- J-PARC E16 Experiment
  - staging strategy
  - analysis strategy & expected signals
  - Hadron hall & High-p line
  - E16 spectrometer
- result from commissioning runs
- summary

J-PARC E16 Collaboration

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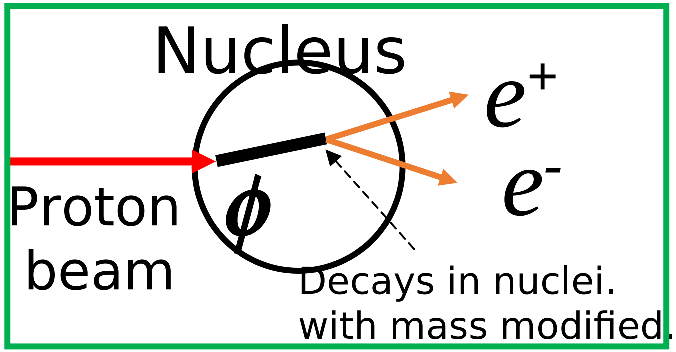
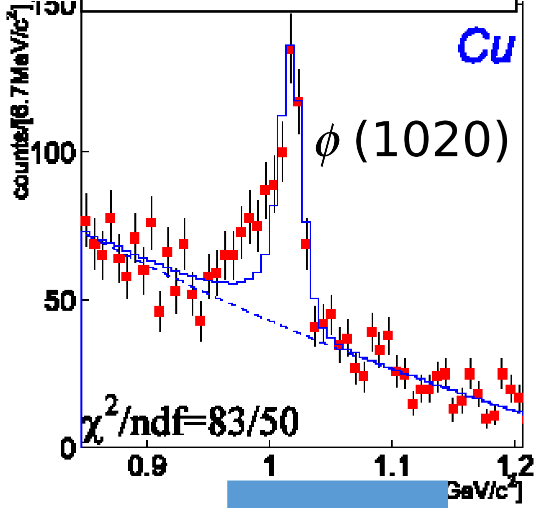
J-PARC E16 experiment

- E16 will measure the e^+e^- decay of $\rho/\omega/\phi$ produced in 30-GeV p+A (C, Cu, Pb, etc.) reactions.
- spectral change of mesons in nuclear matter theoretically predicted can be observed through the inside-nucleus decay of mesons.
- spectral change of vector mesons in the dilepton decay channel were already observed in several experiments in the world, including KEK-PS E325.
- Only E325 observed the change of ϕ meson in nuclear matter, which can be related to $\langle \bar{s}s \rangle_\rho$, 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.



KEK E325 results



[PRL 98 042501]

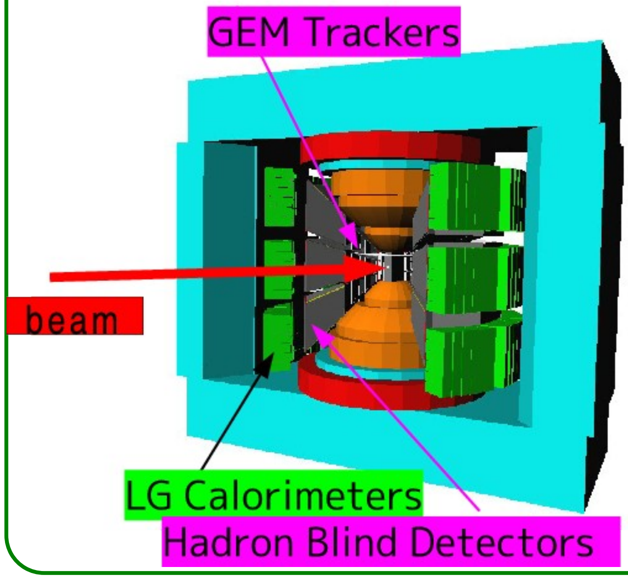
Higher stat.
Better res

J-PARC E16

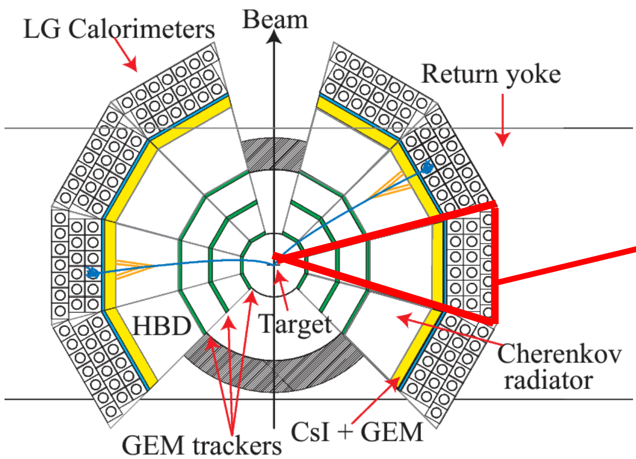
E16 Detectors

- ~10 MHz interaction at the targets with 1×10^{10} / 2 sec spill (5~6 sec cycle) of 30 GeV proton beam at the high-p line in the hadron hall, ~10 times as high as that of E325, in order to accumulate the higher statistics.
- Electron ID : Hadron Blind Detector(HBD) & lead glass EMC (LG)
- 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
- Trigger : two electron candidates: separated 60 degrees to suppress pairs from the dalitz & conversion
  - e-candidate = GTR*HBD (e-mode)*LG(>0.4GeV) position and timing matching.

Proposed Spectrometer

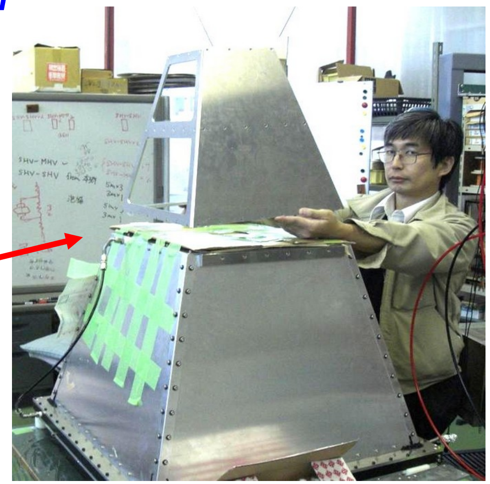


Plan View



26 detector modules

Prototype Module

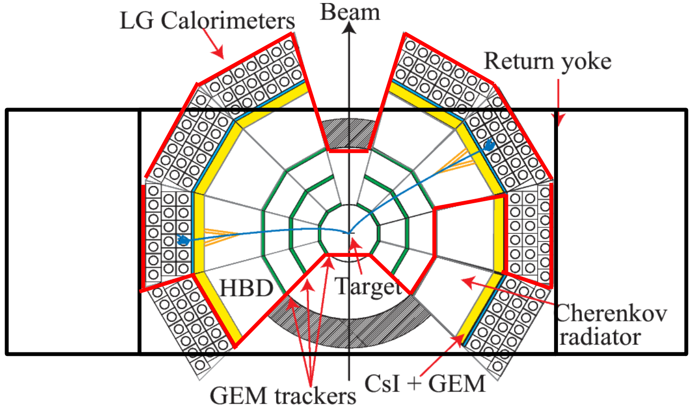


Staging strategy

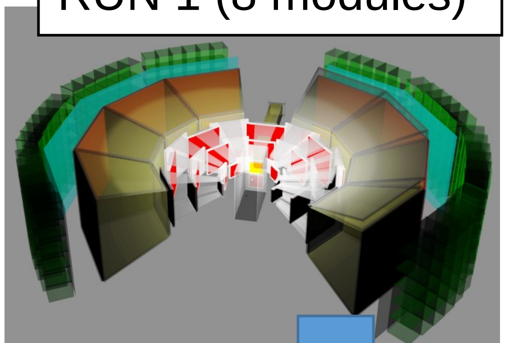
approved in PAC-24(2017)

- **RUN-0 -- 2020-21** -- 403 hours, C/Cu targets
  - Beam line / Detector commissioning were performed
    - Prove that the E16 spectrometer works under the huge bkg.
    - **6 (SSD) + 6 (GTR) + 2 (HBD) + 2 (LG) proposed in 2017**
    - **6 (SSD) + 8 (GTR) + 6 (HBD) + 6 (LG) were operated**
- **RUN-1 -- 2023:** -- 1280 hours, C/Cu targets
  - Physics run, not approved by PAC
  - **8 (SSD) + 8 (GTR) + 8 (HBD) + 8(LG)**
    - Physics data taking. 15k of phi mesons
- **RUN-2** -- 2560 hours, C/Cu/Pb targets
  - Physics run to accumulate more statistics to approach the slowest mesons, with various targets.
  - **26 (SSD) + 26 (GTR) + 26 (HBD) + 26 (LG)**

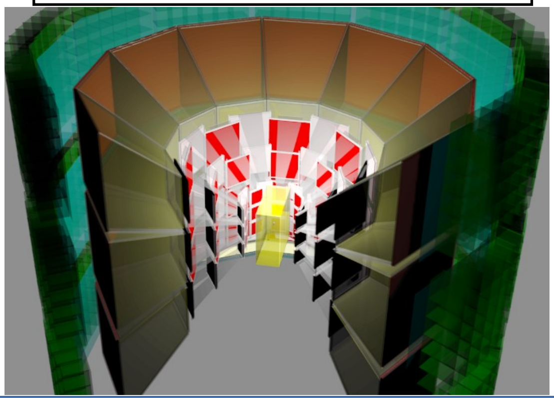
RUN 0 config. (2021)



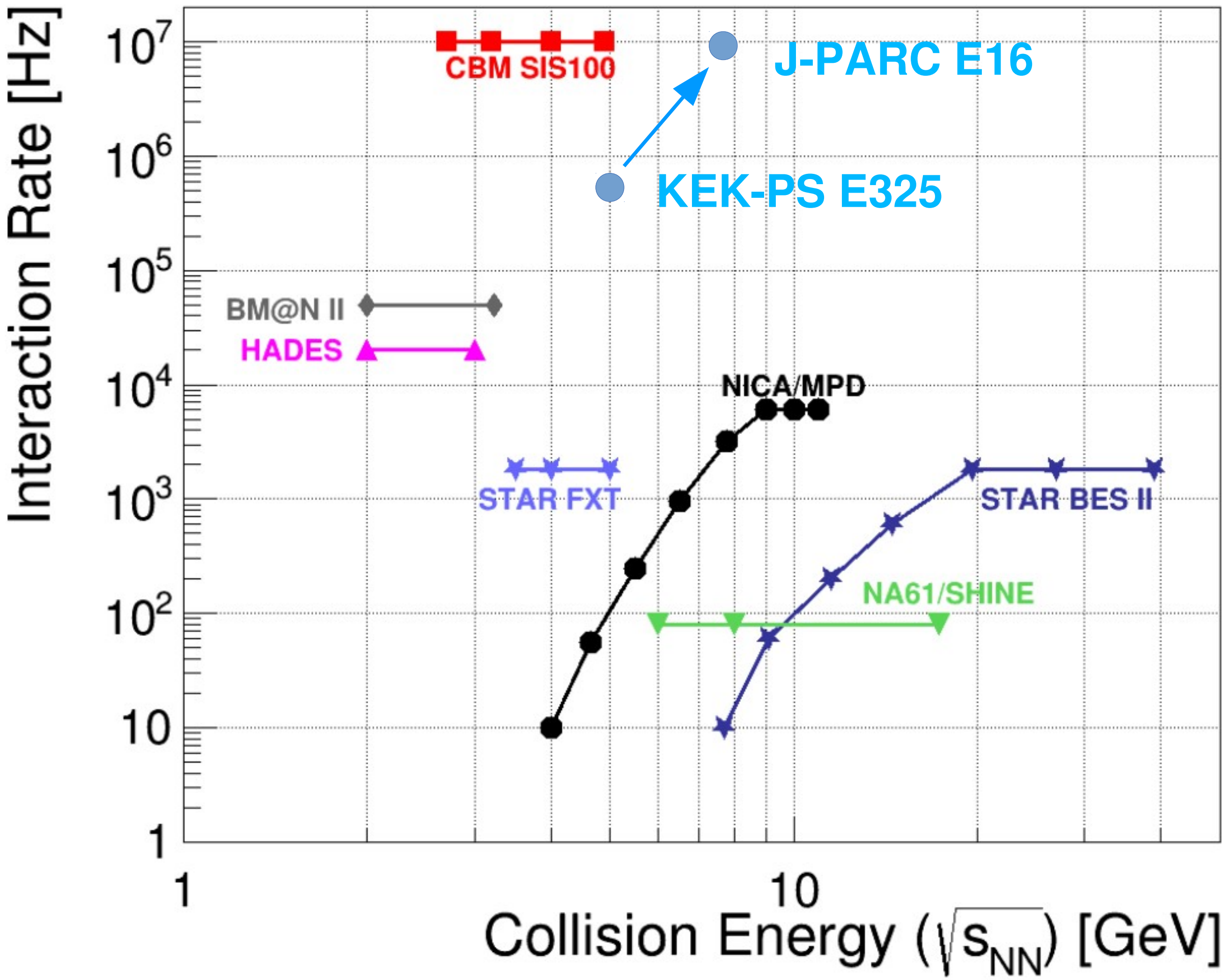
RUN 1 (8 modules)



RUN 2 (26 modules)



interaction rate at the targets



[taken from EPJA 53(2017)60]

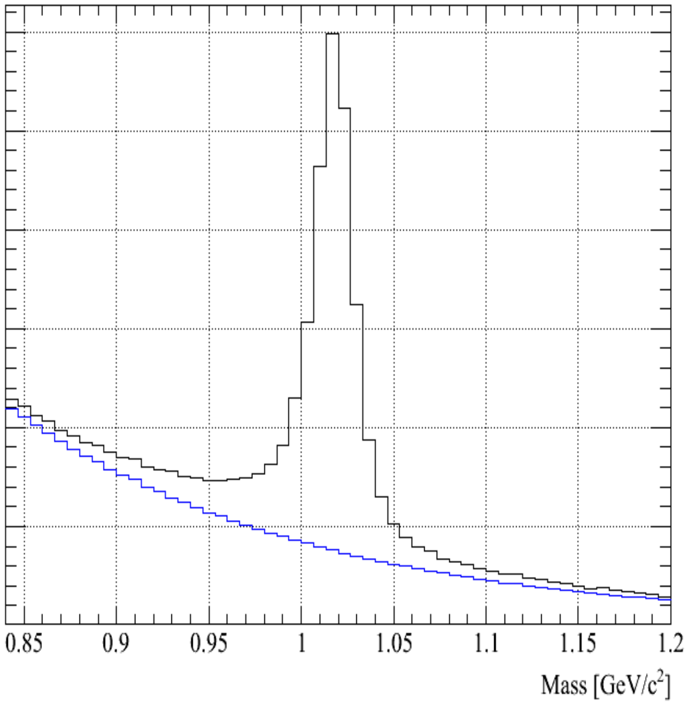
- E16 Run-0 and Run-1
  - 1x10^10 protons/spill
    - (2sec duration)
  - 0.2% int. length targets
    - 0.1% C+0.05% Cu x 2
  - 10MHz interaction

Expected signal and analysis strategy

analysis strategy

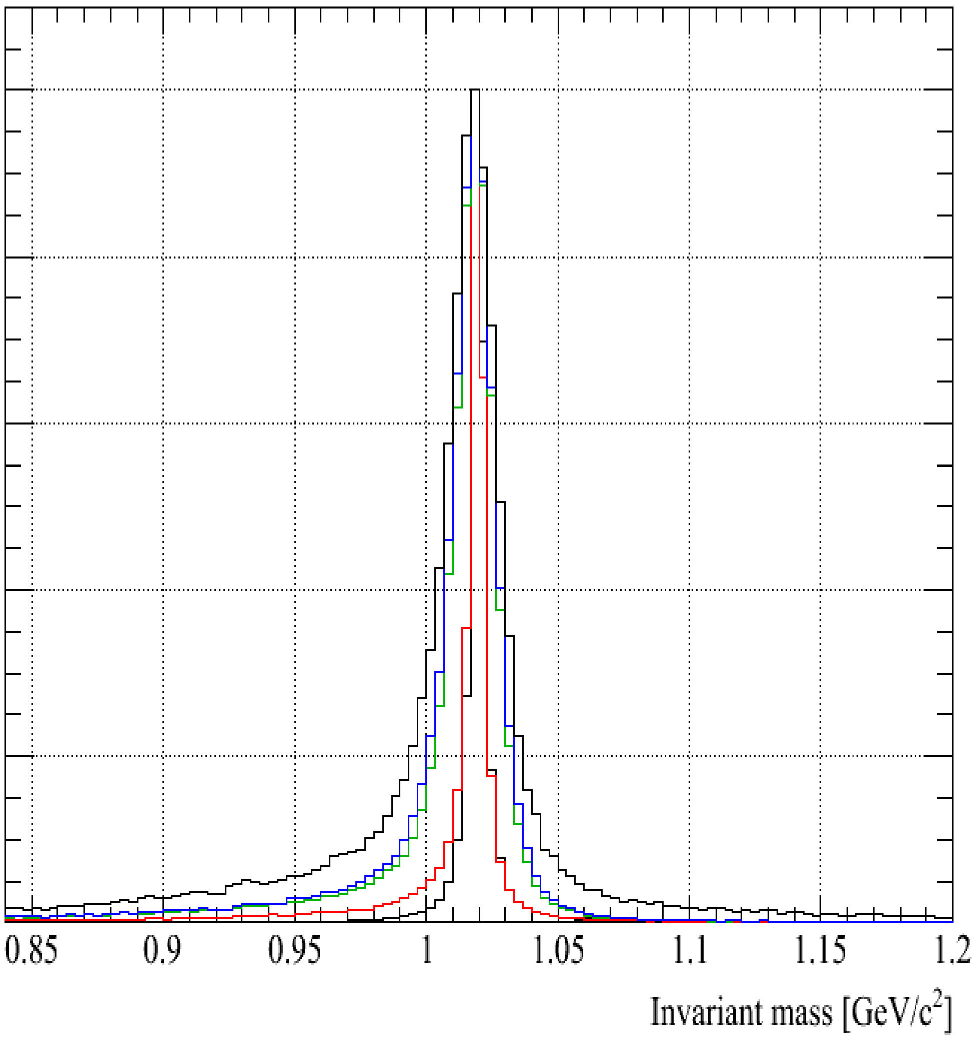
- model-independent analysis : prove the spectral change
  - compare the data with the vacuum shape (Breit-Wigner)
    - difference is significant or not
  - examin the $\beta\gamma$ dependence of difference
    - larger difference is expected in slower component
- model-dependent analysis
  - fit the data by theoretical spectral functions (cf. Gubler & Weise [NPA954(2016)125])
    - theoretical input is important
  - determine the modification parameter as E325 performed
    - deduce $<\bar{s}s>_\rho$
      - compare with, e.g., Gubler & Ohtani [PRD90(2014)090002]
    - momentum dependence will be deduced with higher stat.

expected ϕ in Run-1, for Cu, w/ bkg



- ~15000 ϕ for Cu target in 1280H (53 days)
  - 1×10^{10} protons/spill, 8 modules
- input to Geant4: Breit-Wigner for ϕ meson
  - momentum distribution from JAM
  - including internal radiative correction (QED vertex correction for ee decay)
- experimental effects as target & detector materials, misalignment, mistracking, etc. by G4 →next
  - approx. 8 MeV of mass resolution
  - for the “all (integrated) $\beta\gamma$” region
- combinatorial background : ee, eπ and $\pi\pi$ pairs (ratio ~13:7:1)
  - π^0 Dalitz decays, γ conversion to ee, 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 to next

Evaluation of internal radiative corrections and experimental effects

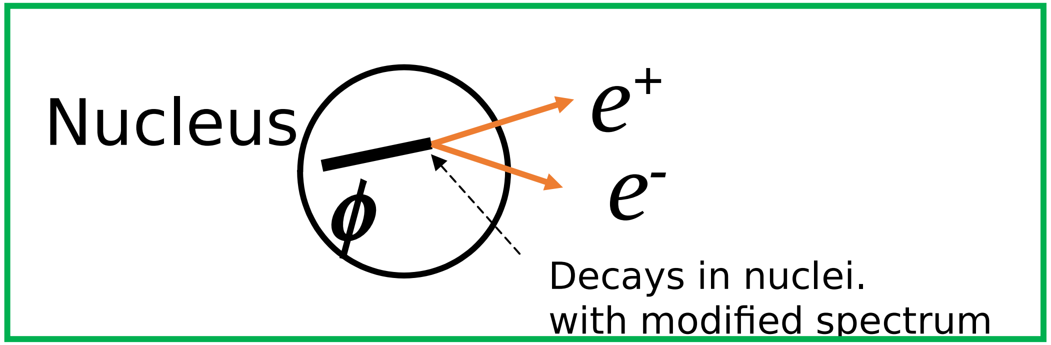


[normalized @ peak]

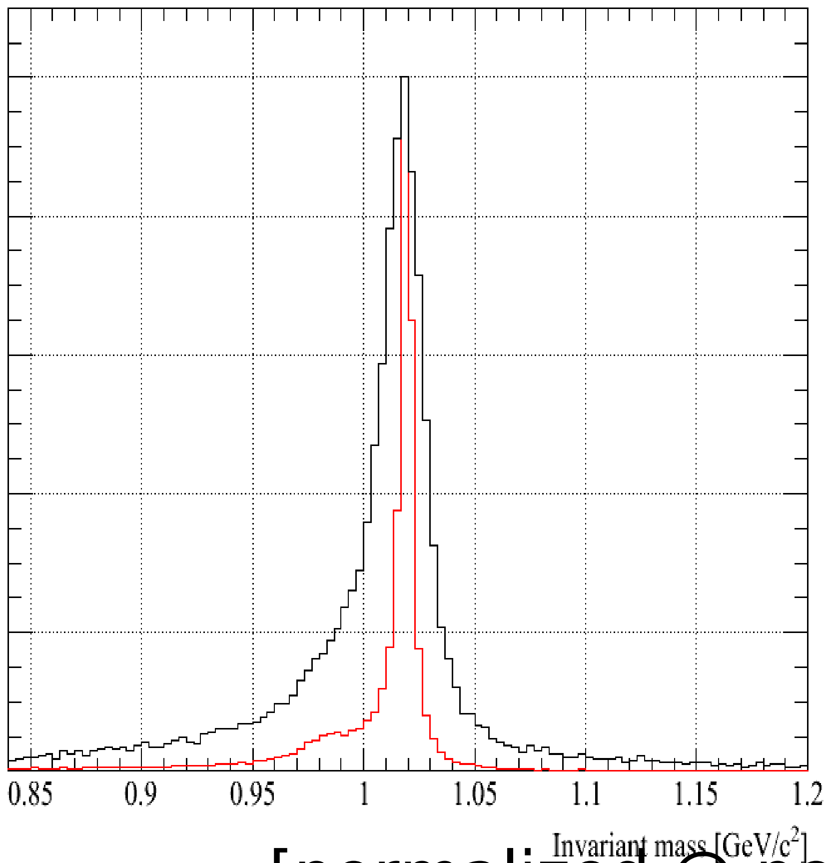
- for the Cu target (t=80μm)
- G4(material)+accidental BKG +Analysis
  - 7.92+-0.04MeV
    - right-side tail is significant
- G4(material)+Analysis
  - 6.13+-0.02MeV
- G4(material)+Analysis (w/o frame-hit)
  - 5.74+-0.02MeV
- BW+IRC
  - using the code PHOTOS
- BW shape

A model of modified spectral shape

- modified spectrum for the input to G4 : E325-type assumption:
  - BW , density-dependent change: mass Δ3.4% /3.6 x Γ @ρ_0
    - $m^* = m_0 \times (1- 0.034\rho/\rho_0)$
    - $\Gamma^* = \Gamma_0 \times (1+2.6\rho/\rho_0)$
  - generation point in nuclei is proportional to the Woods-Saxon type density distribution
  - momentum distribution by JAM
  - move and decay with modified mass and width, depend on the density

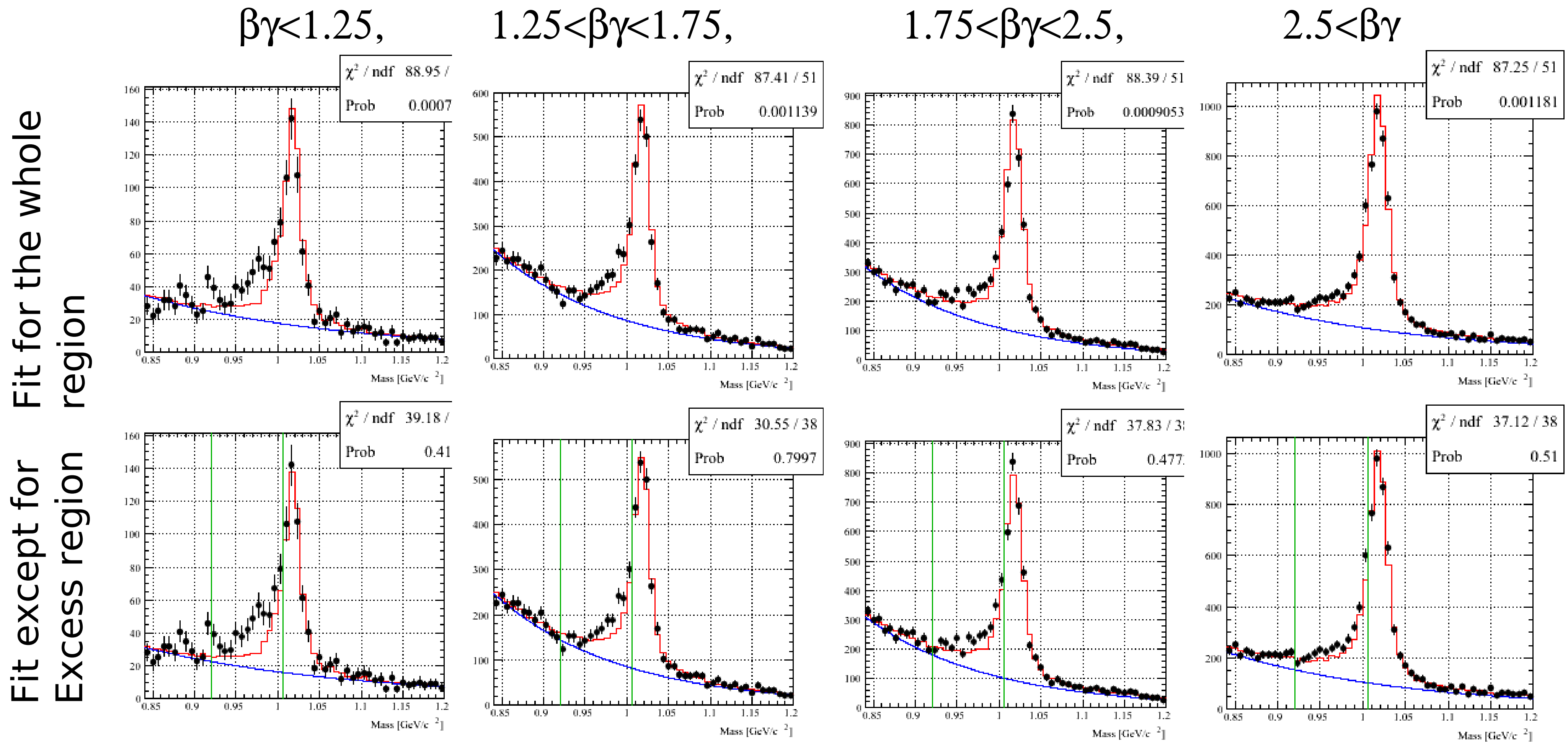


- for the Cu target (t=80μm)
  - G4(material)+accidental BKG +Analysis
  - modified+IRC



[normalized @ peak]

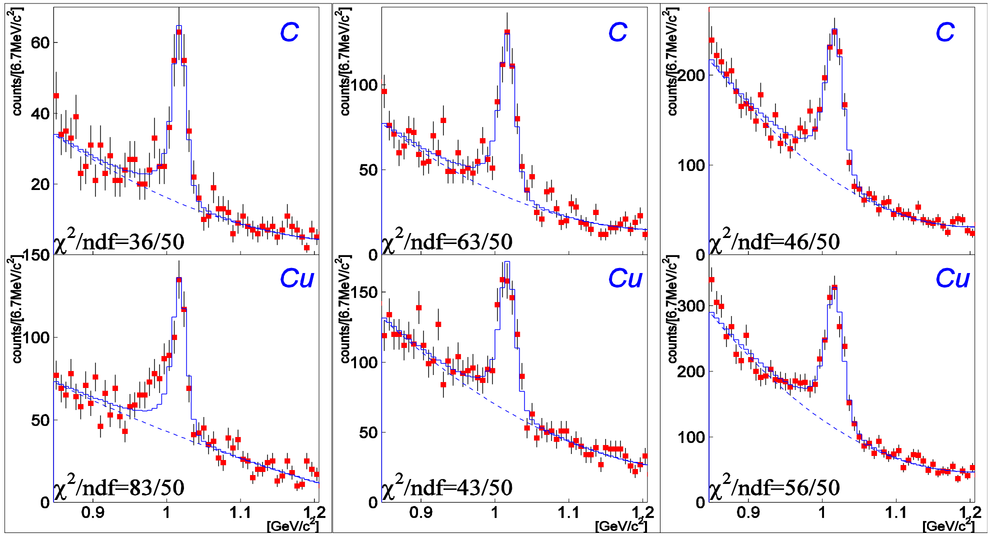
βγ dependence of spectral change [sim.]

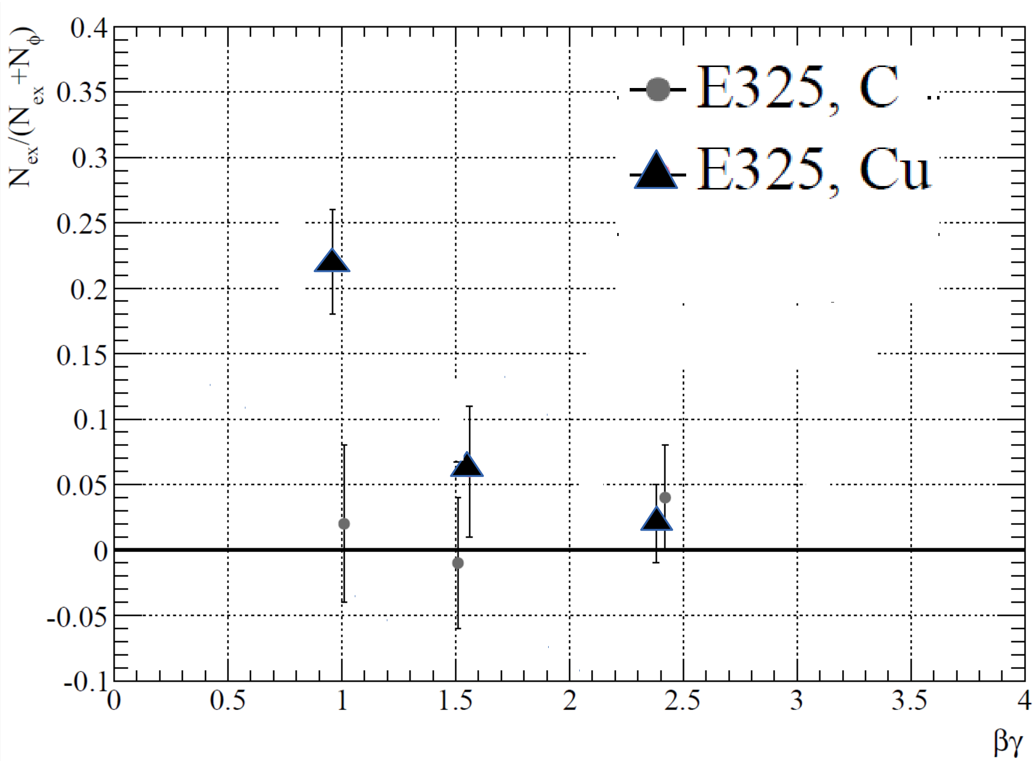


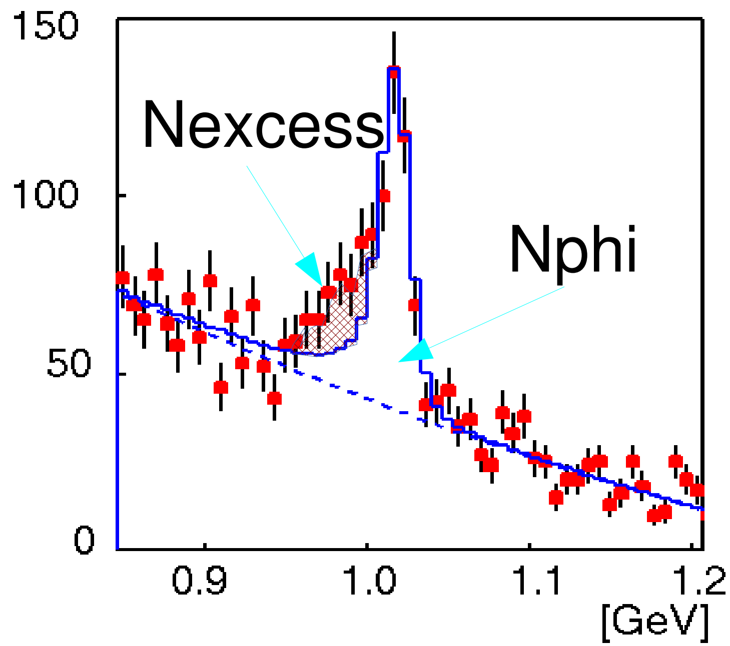
- spectral change measured E325 (mass Δ3.4% /3.6 x Γ) is assumed
- fit with the evaluated vacuum shape : excess is significant in all the panels
- βγ dependence of excesses is examined → next

excess ratio in E325

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

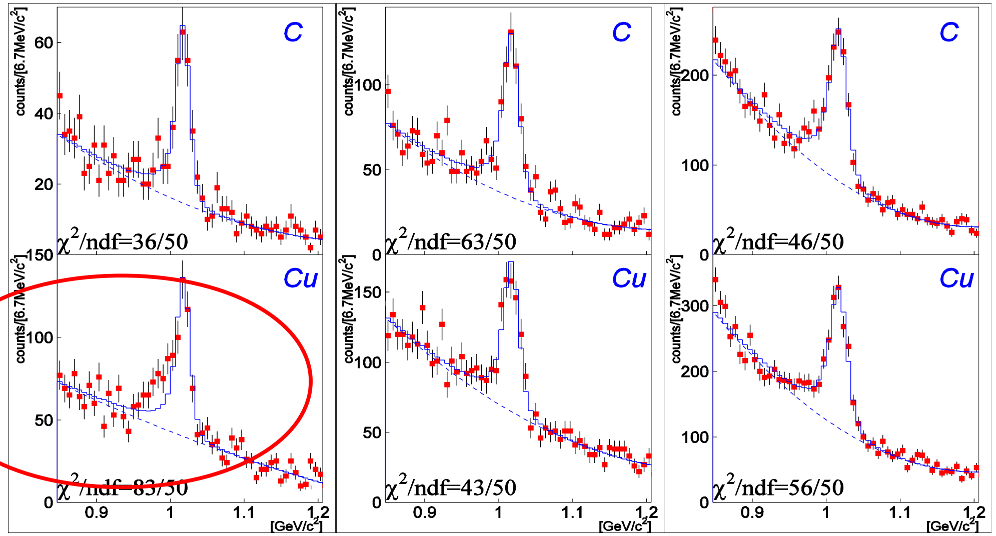


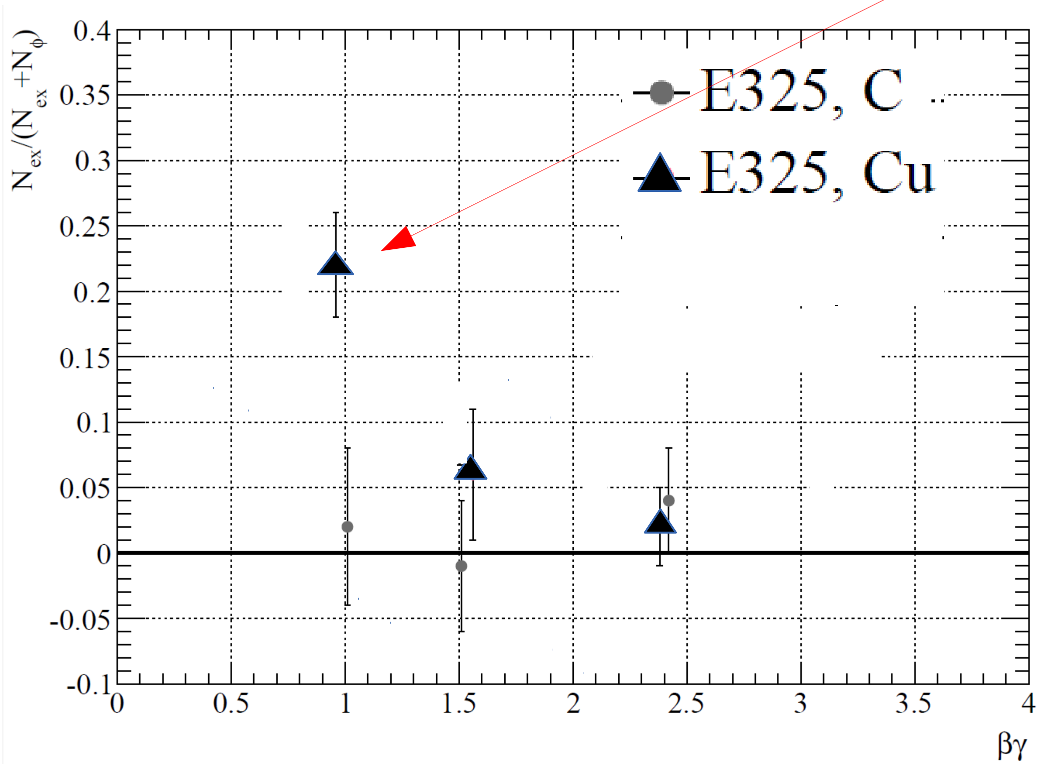




excess ratio in E325

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

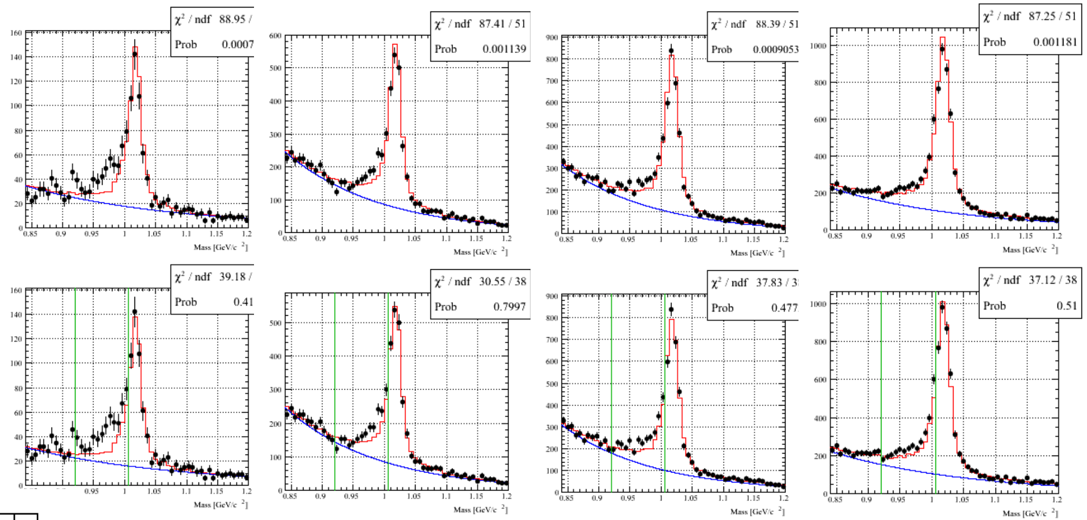


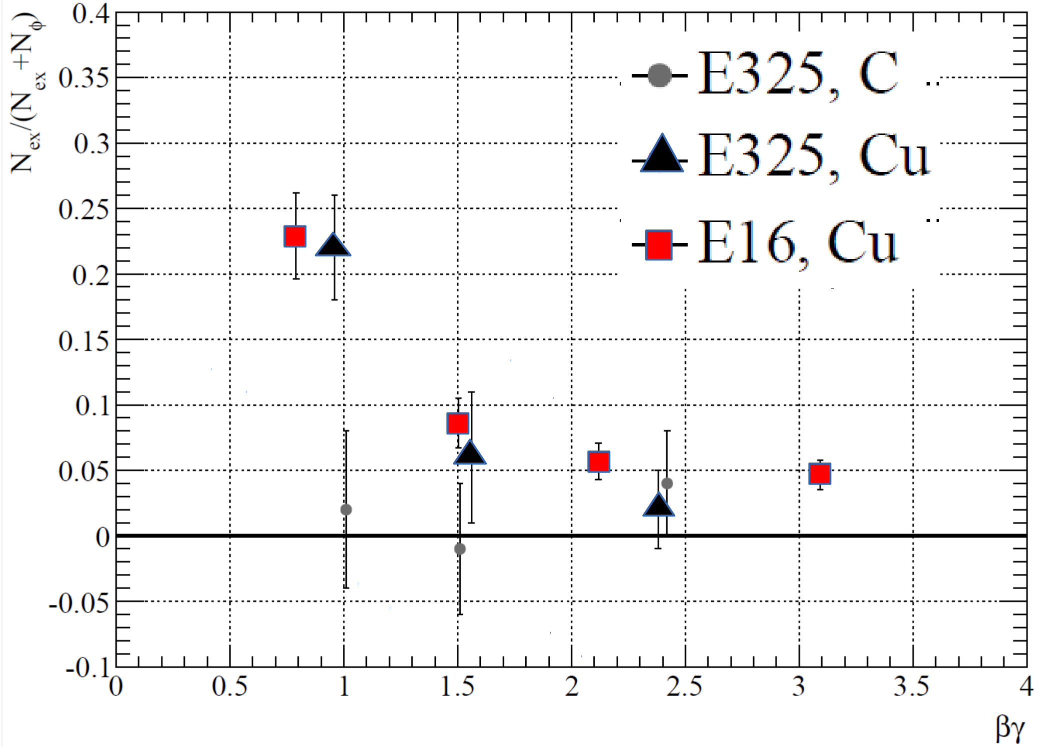


- larger excess in lower βγ (slower) bin : consistent with the modification in nuclei

excess ratio in E16 [sim.]

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





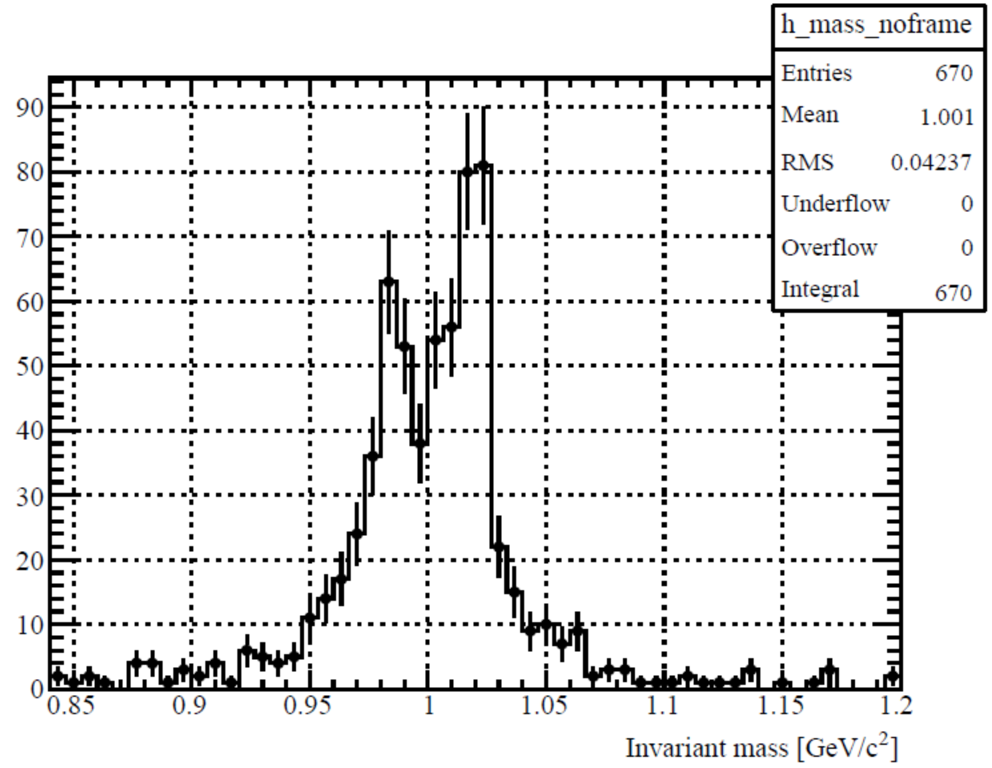
- larger excess in lower βγ (slower) bin :

  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 $\beta\gamma$<0.5 (very slow, only 1% of accepted)
-
- (combinatorial bkg is not shown)



- mass resolution 5.8+-0.1 MeV

(excluding frame-hit events)

analysis strategy

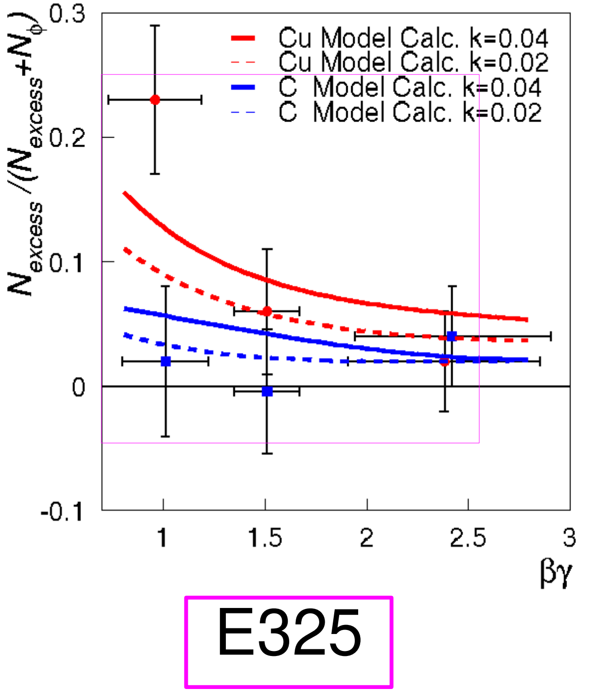
- model-independent analysis
  - compare the data with the vacuum shape (Breit-Wigner)
    - difference is significant or not
  - examin the $\beta\gamma$ dependence of difference
    - larger difference is expected in slower component
- model-dependent analysis : comparison w/ theoretical predictions
  - fit the data by theoretical spectral functions (cf. Gubler & Weise [NPA954(2016)125])
    - theoretical input is important
  - determine the modification parameter as E325 performed
    - deduce $\langle\bar{s}s\rangle_\rho$
      - compare with, e.g., Gubler & Ohtani [PRD90(2014)094002]
    - momentum dependence will be deduced with higher stat.

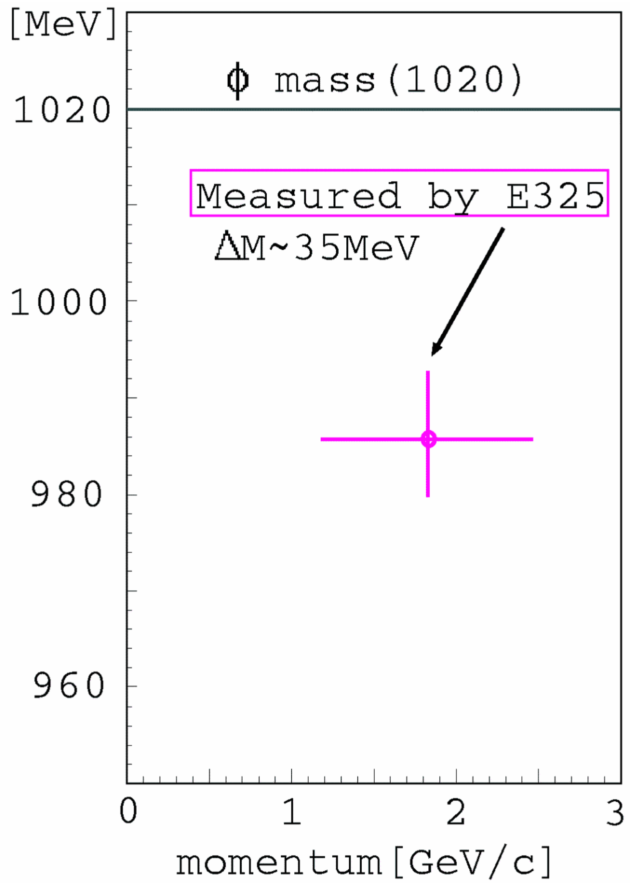
momentum dependence

- momentum dependence of mass
  - experimentally: extrapolation to p=0, to compare with theoretical predictions
  - theoretically: dispersion relation

momentum dependence and stat.

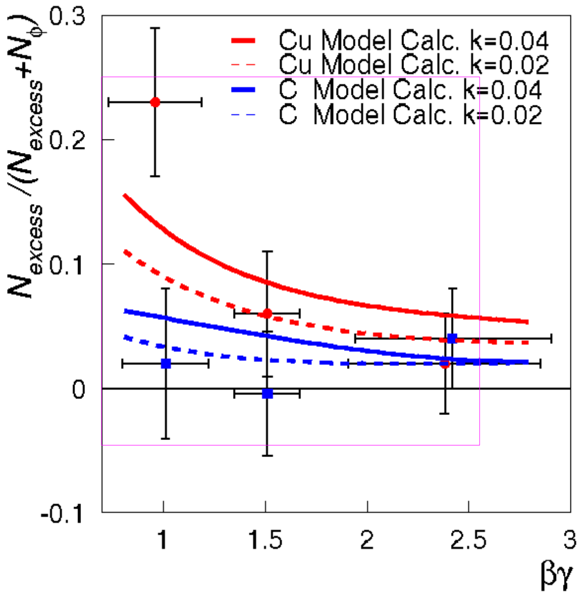
- momentum dependence of mass
  - experimentally: extrapolation to p=0, to compare with theoretical predictions
  - theoretically: dispersion relation



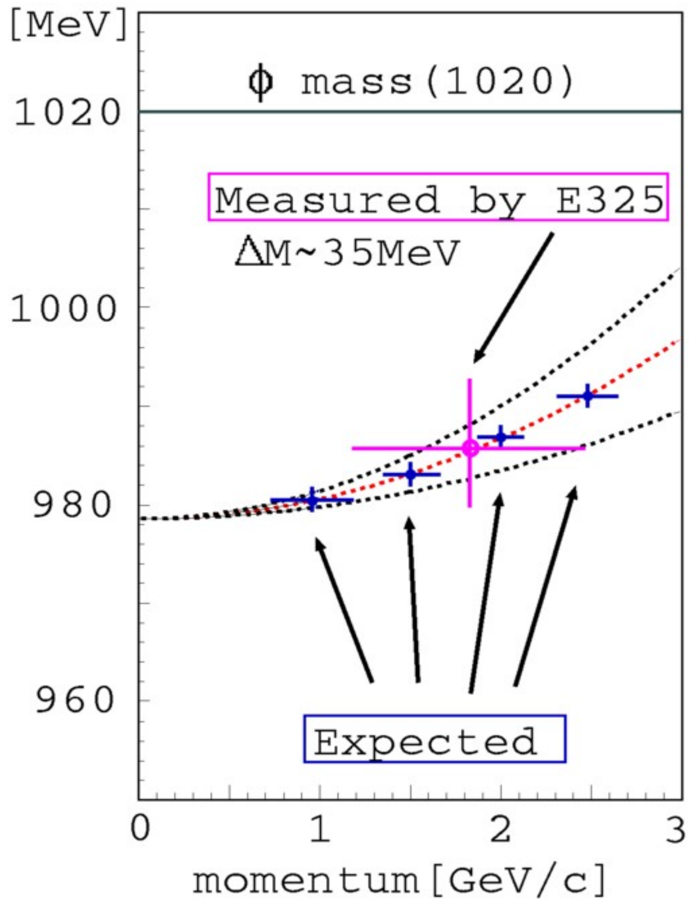


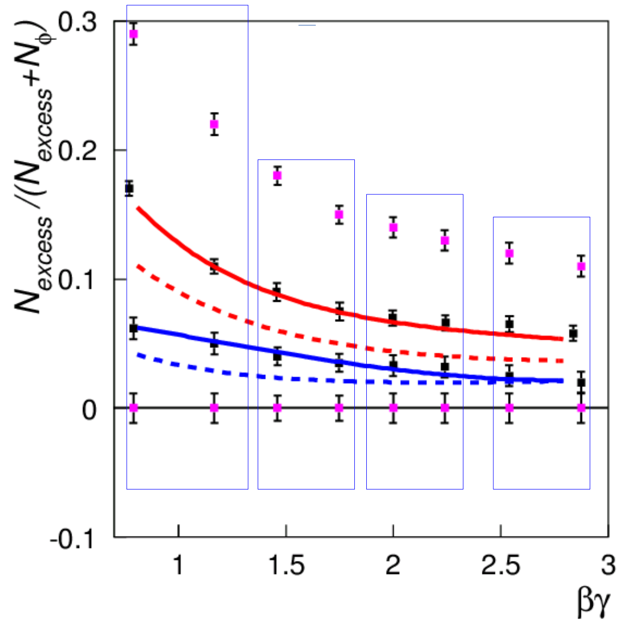
momentum dependence and stat.

- momentum dependence of mass
  - experimentally: extrapolation to p=0, to compare with theoretical predictions
  - theoretically: dispersion relation
- curve: Lee's prediction (PRC57(98)927, up to 1GeV/c)
- error bars in full statistics (E325 x100)



E325

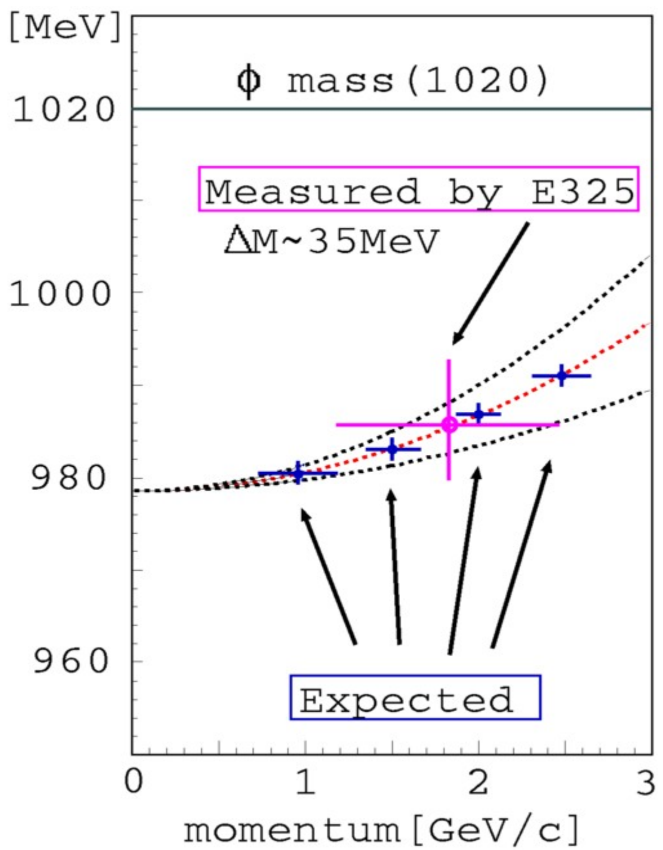


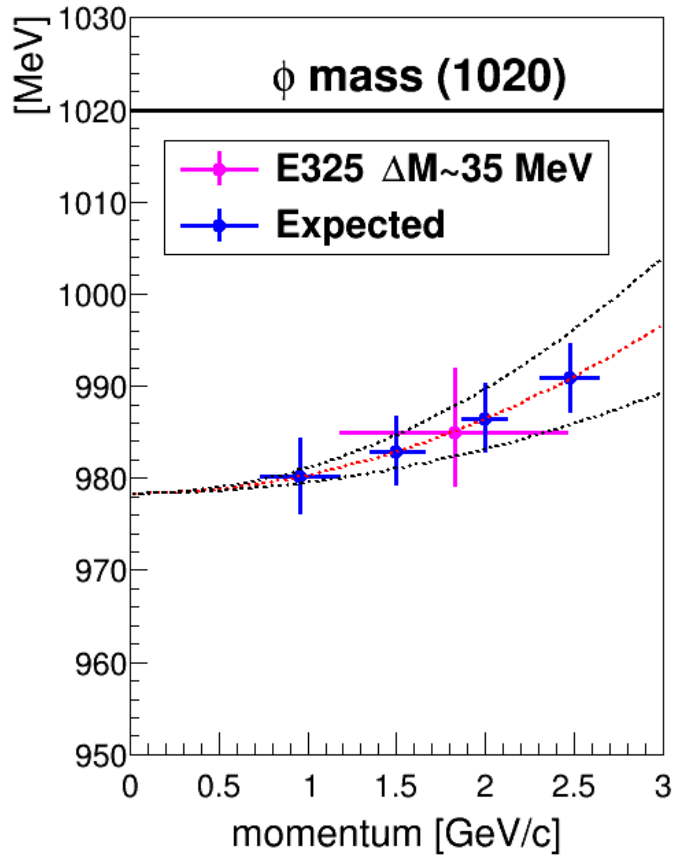


E16 full stat.

momentum dependence and stat.

- momentum dependence of mass
  - experimentally: extrapolation to p=0, to compare with theoretical predictions
  - theoretically: dispersion relation
- curve: Lee's prediction (PRC57(98)927, up to 1GeV/c)
- error bars in full statistics (E325 x100) and limited statistics (E325x10)

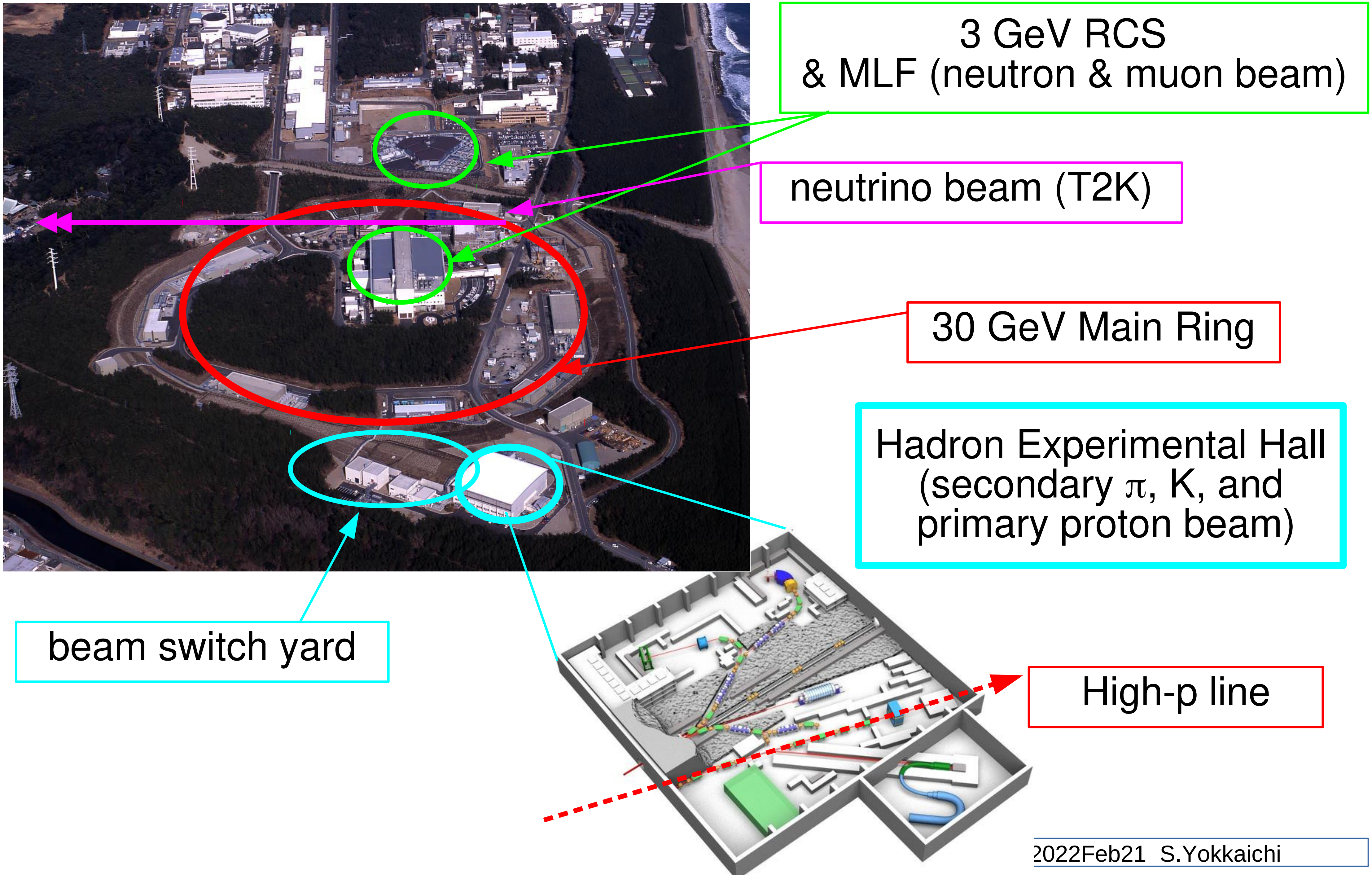




Beam line

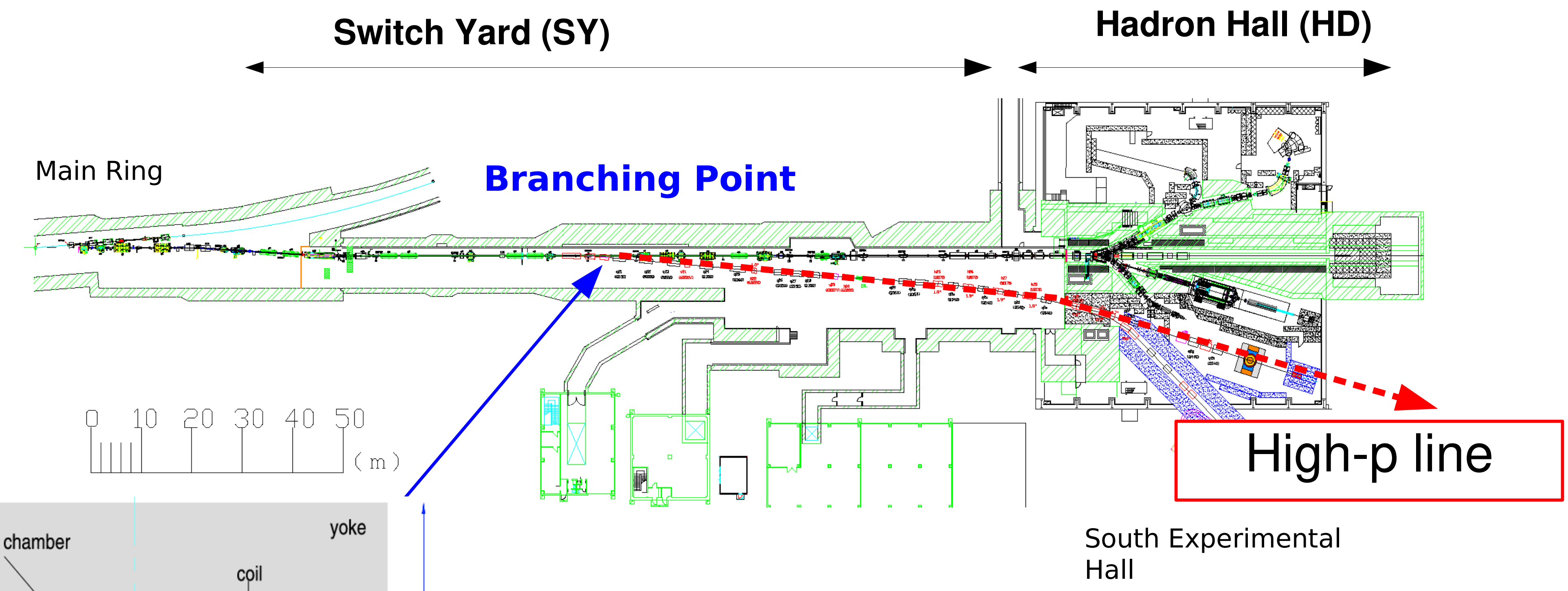
J-PARC MR & Hadron experimental hall

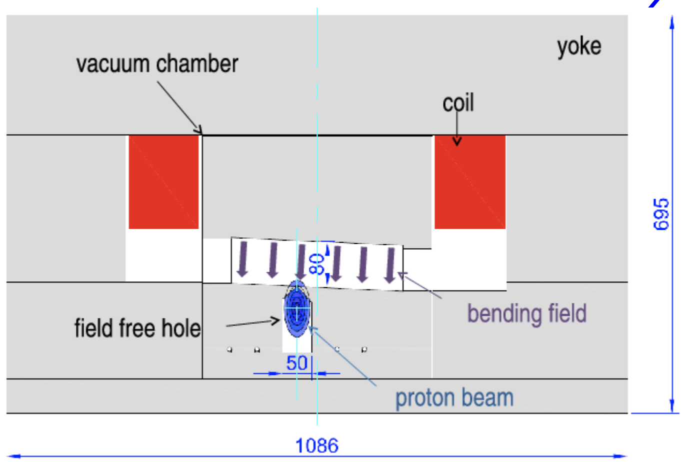
J-PARC MR & Hadron experimental hall



High momentum beam line in Hadron hall

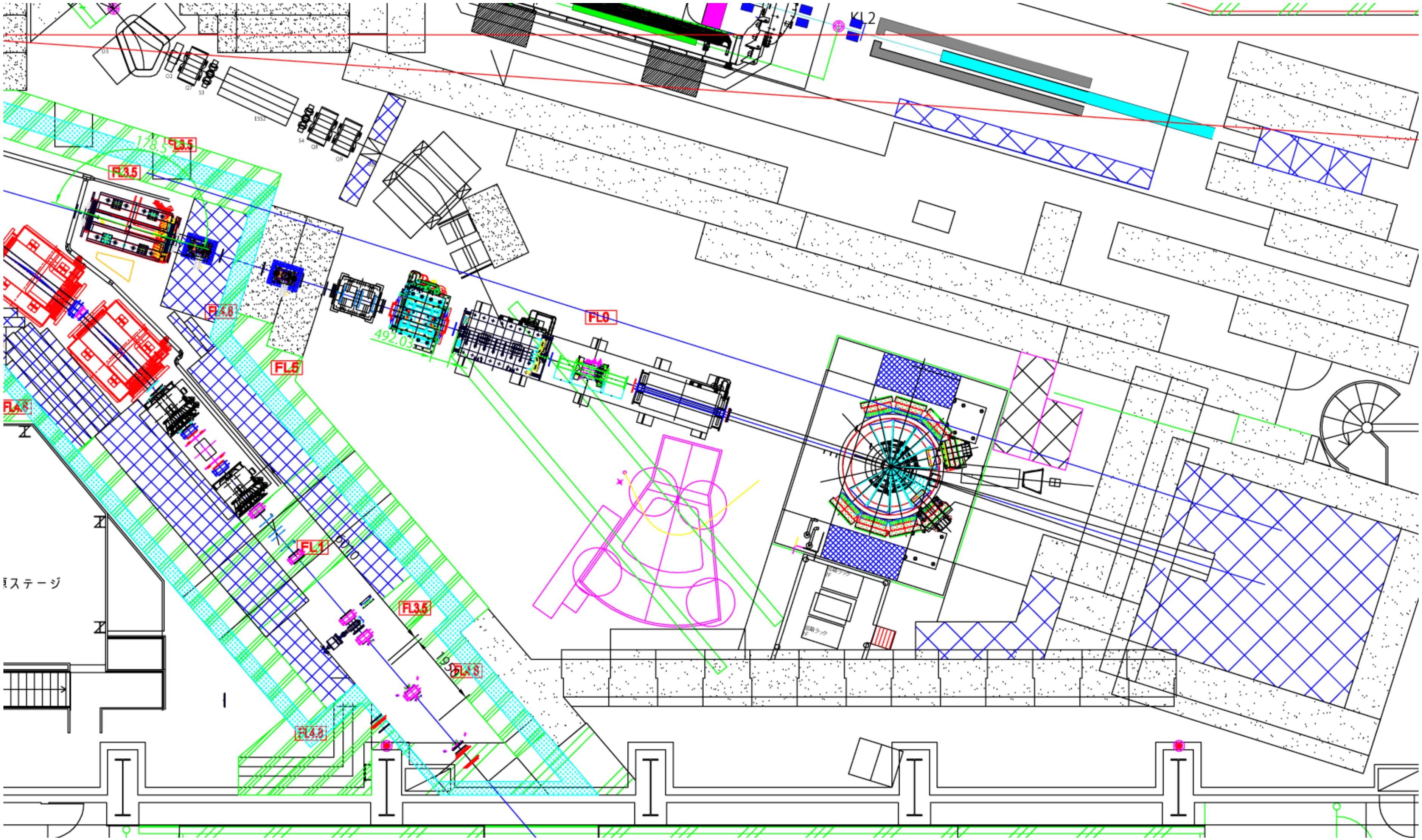
- High momentum beam (High-p) line is completed in June, 2020
  - 30 GeV primary protons: 1x10^10 per spill (2-sec duration/5.2-sec cycle)
  - secondary beam will be available : ~2x10^6 pions @ 20GeV/c



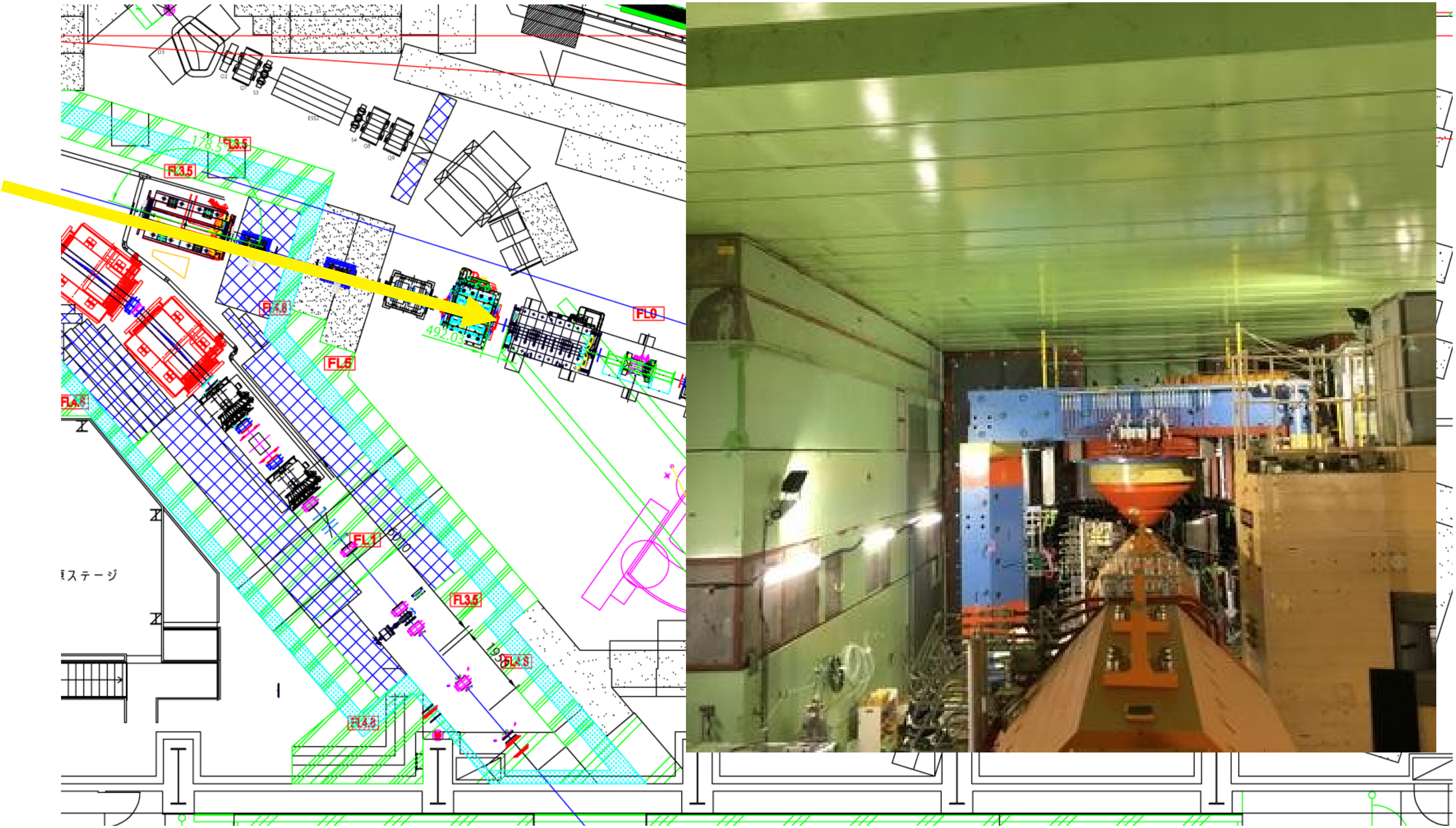


Lambertson magnet
to branch the ~0.1% of primary proton beam from MR

experimental area

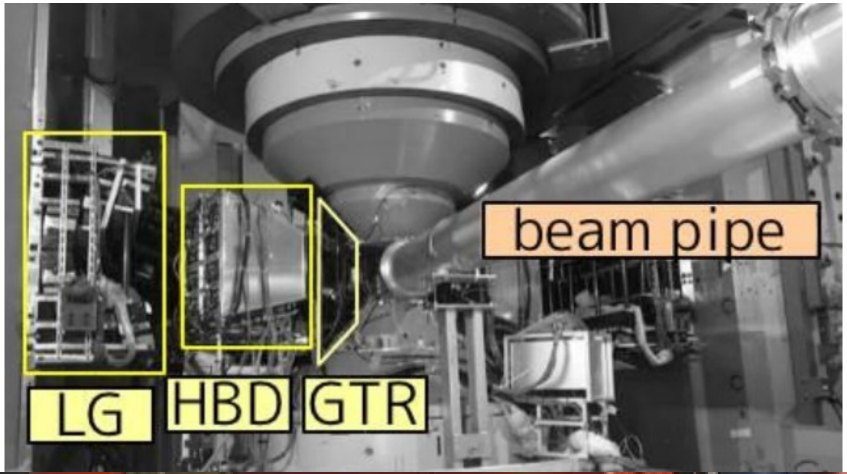


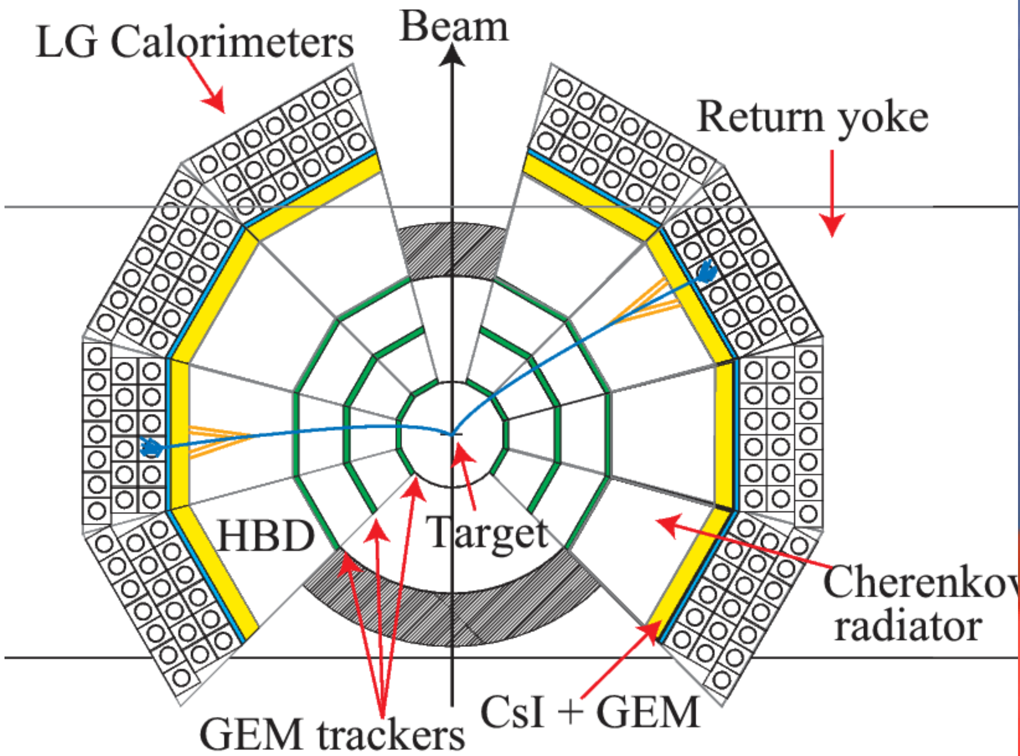
experimental area



Ceiling shield of the experimental area is closed when the beam is used.

E16 spectrometer



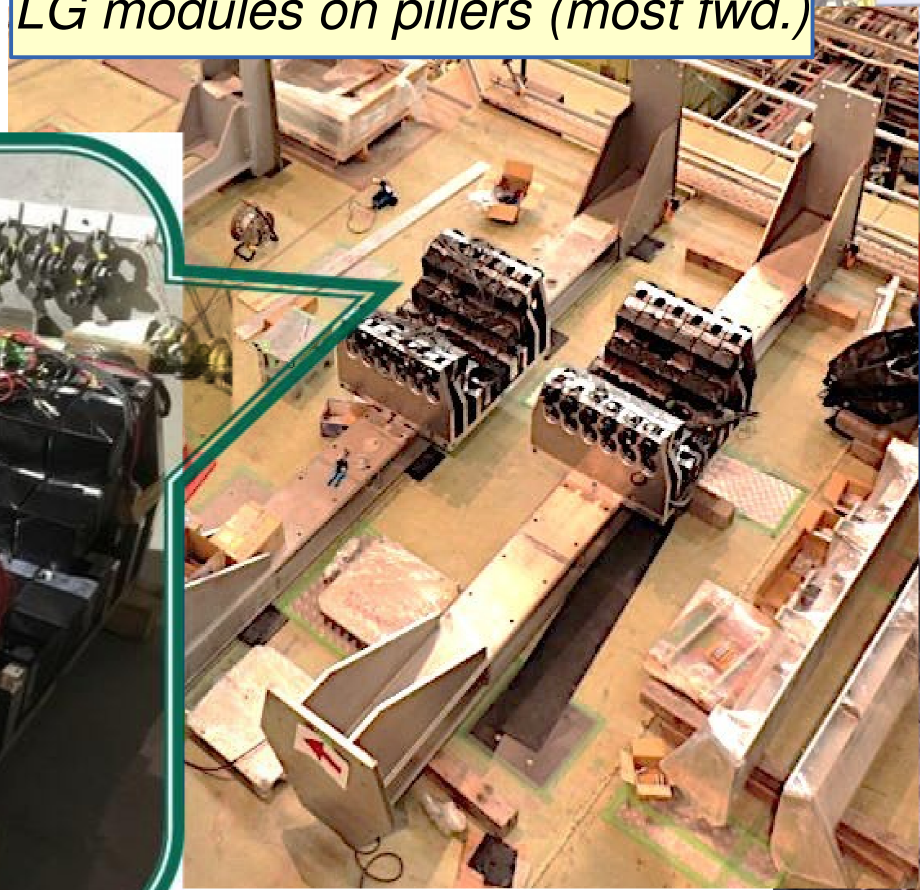


LG

installation of a LG-module at most forward module

LG modules on pillers (most fwd.)

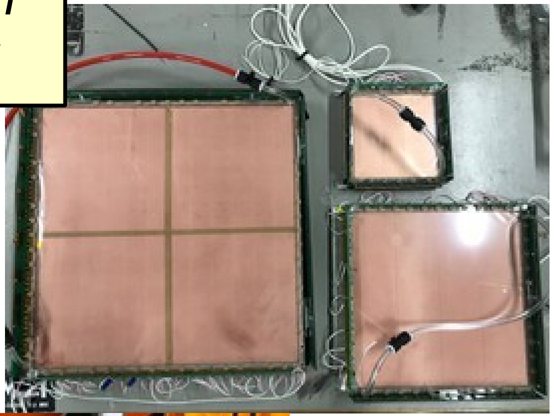
a LG module



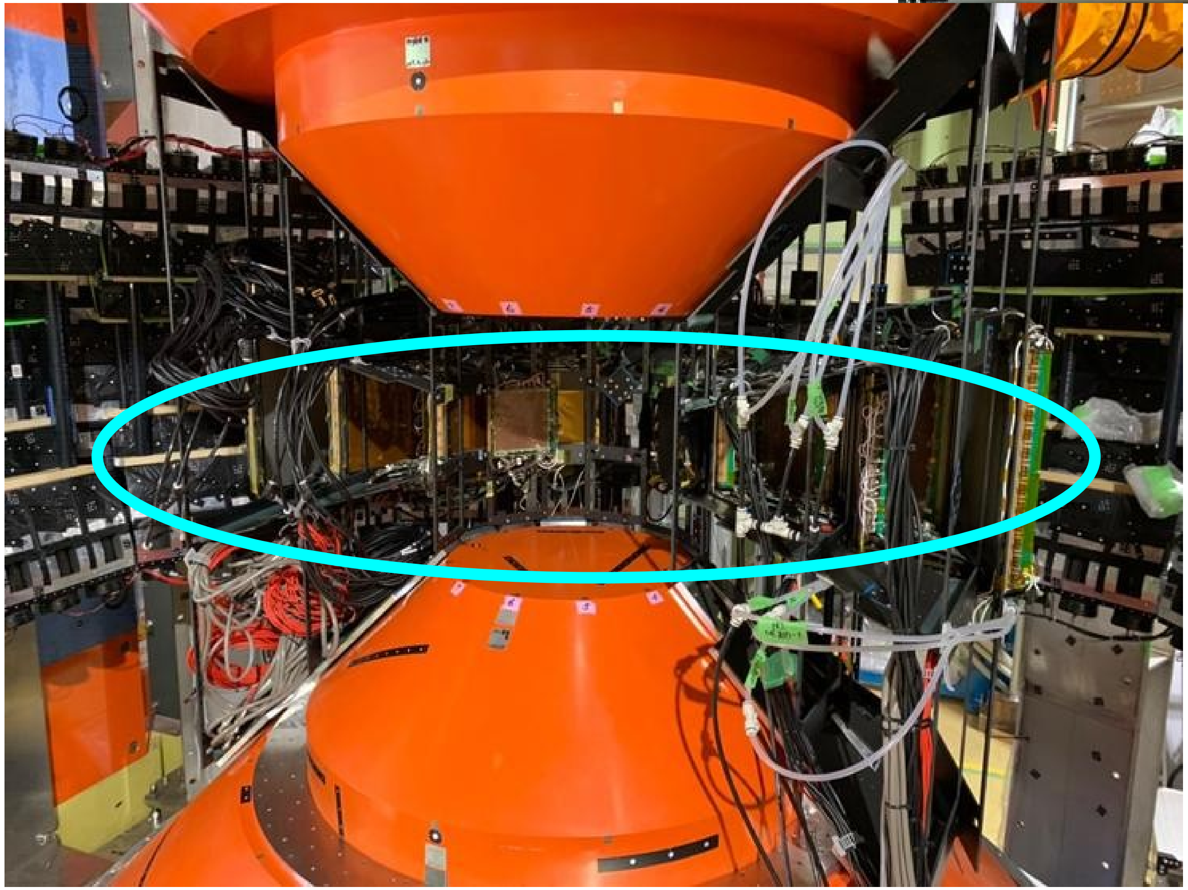
GEM tracker

Assembly of GEM chambers

100,200, 300mm GEM chambers

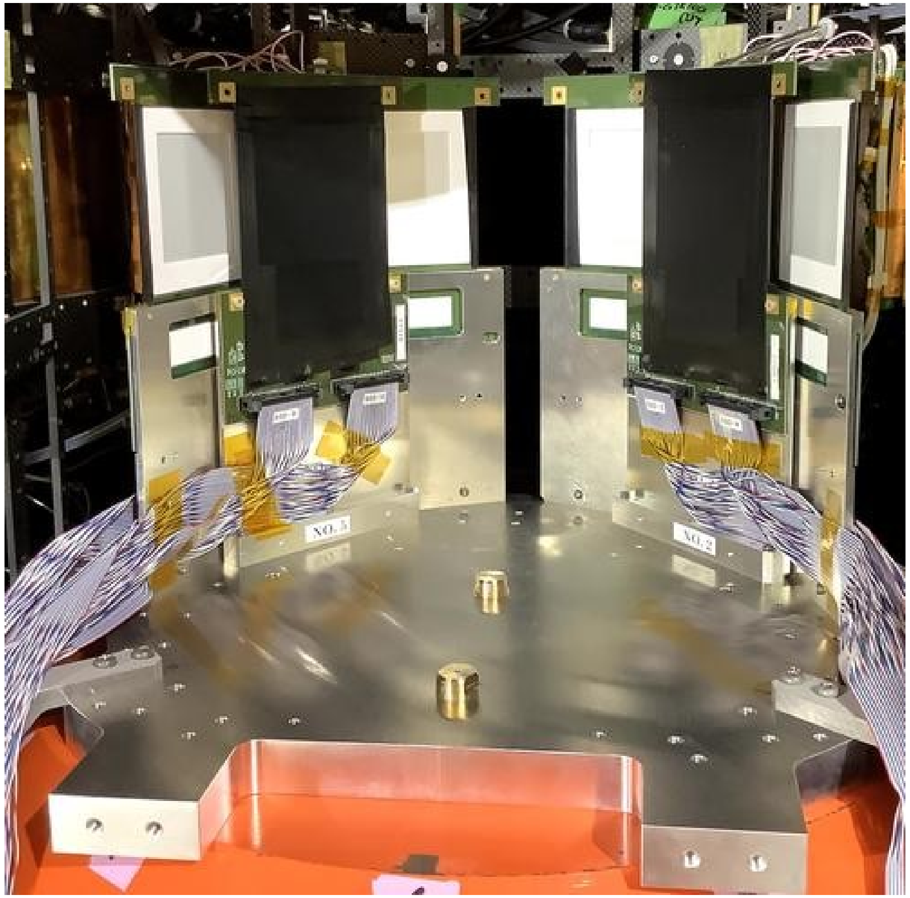


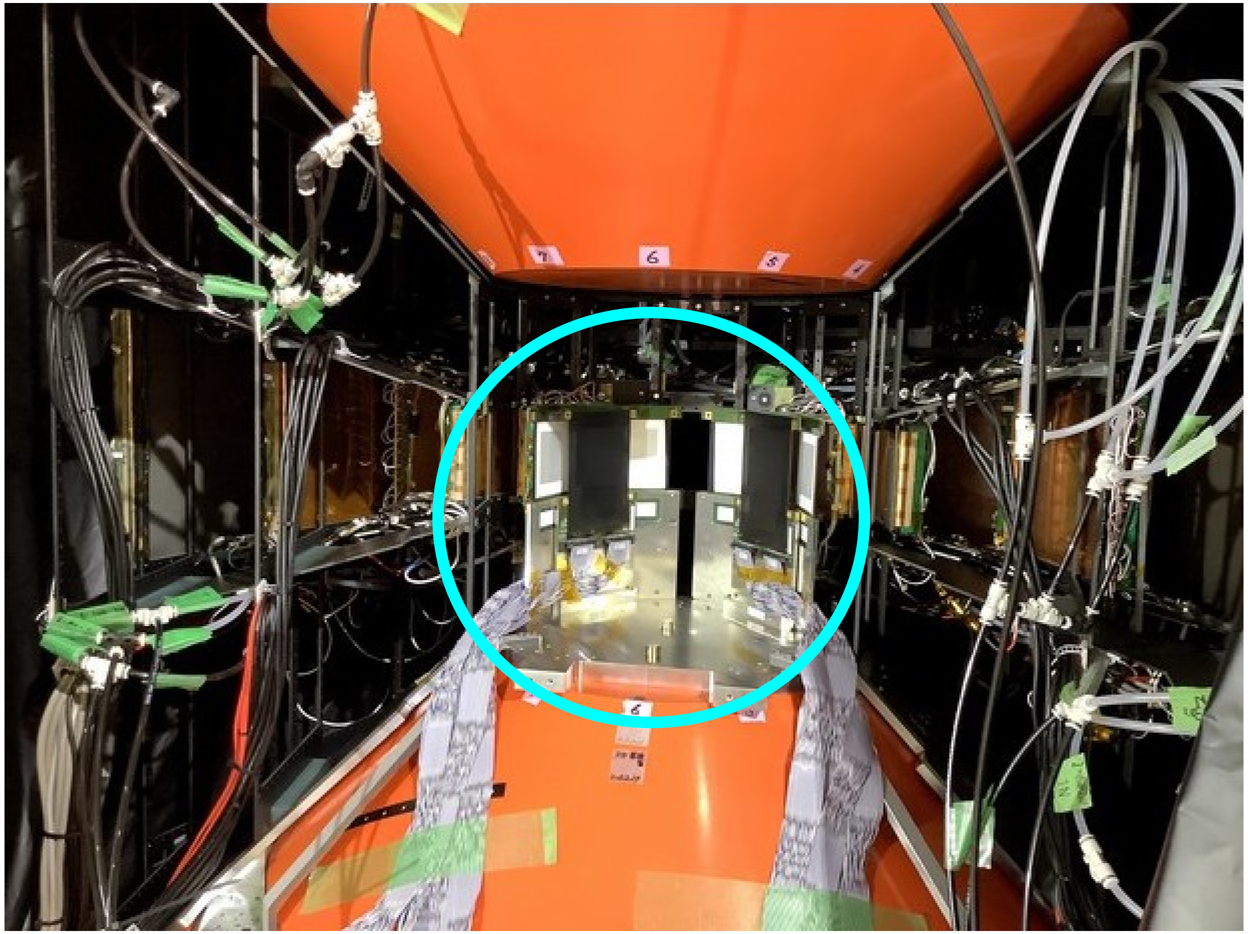
GEM chambers on the CFRP frame



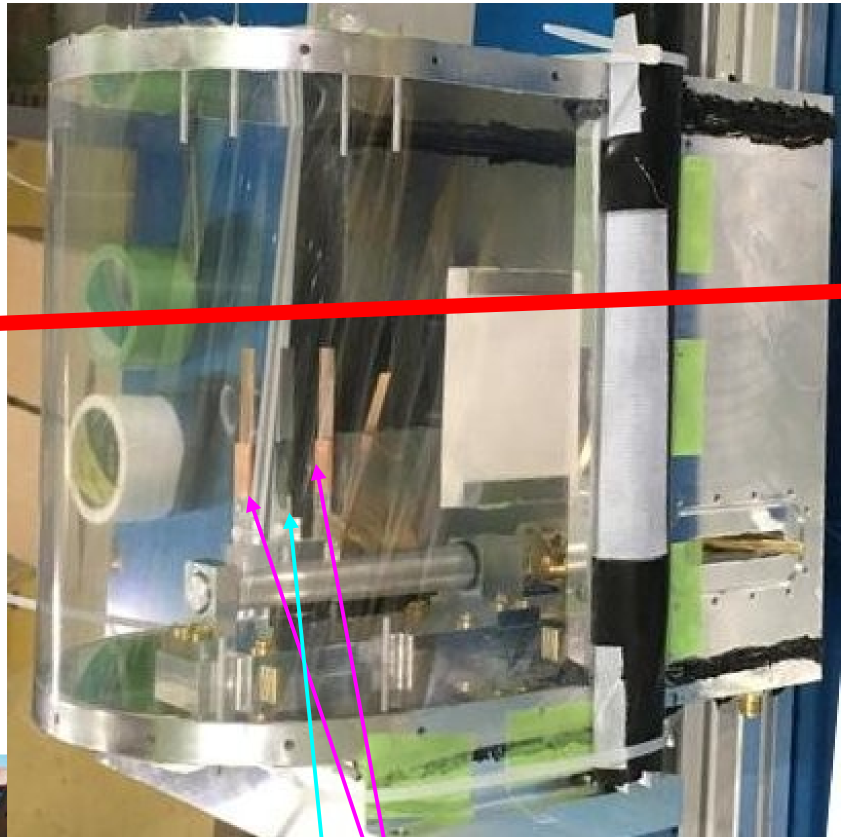
SSD

- Assembly and installation of 6 SSDs inside the GTR





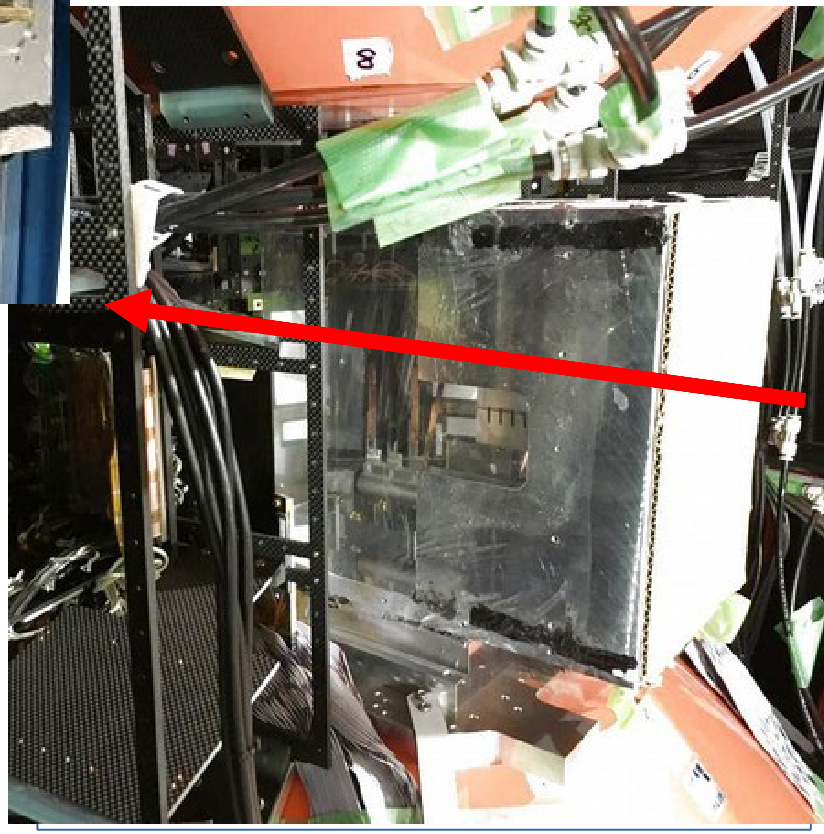
target chamber



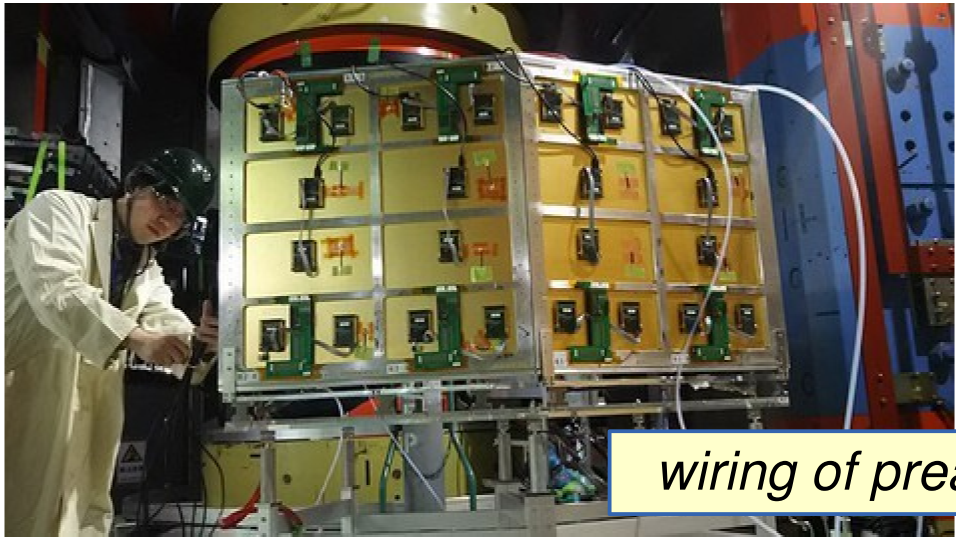
beam direction

Copper
80um x2

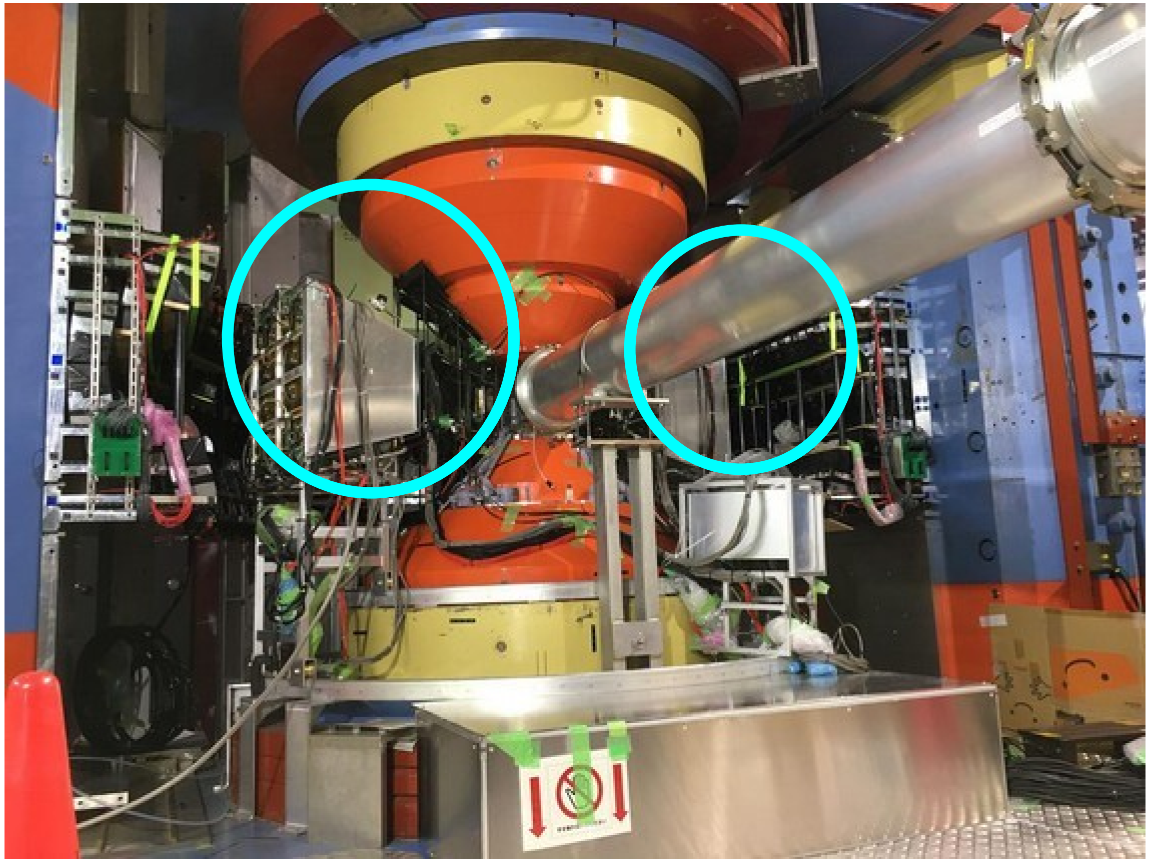
Carbon
400um

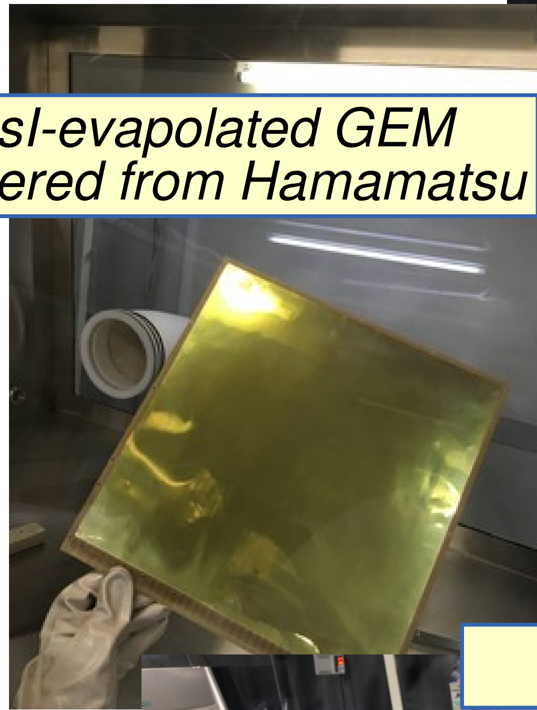


HBD



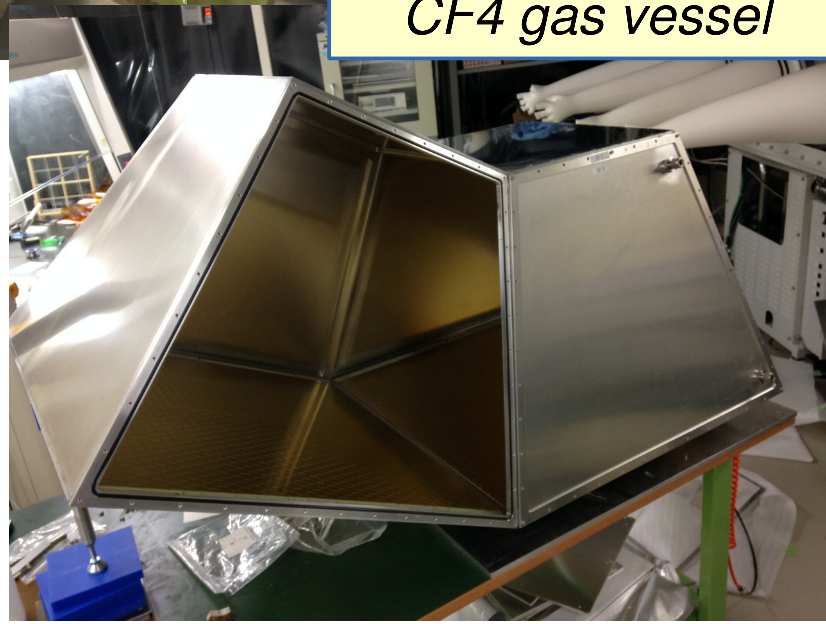
wiring of preamps





CsI-evapolated GEM
delivered from Hamamatsu

glove-box for
CsI-GEM
@RIKEN

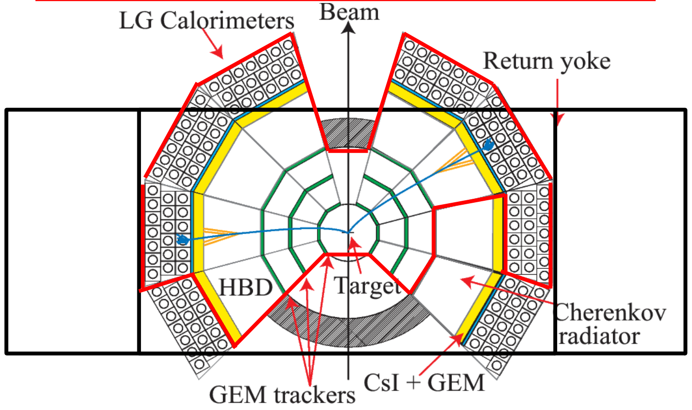


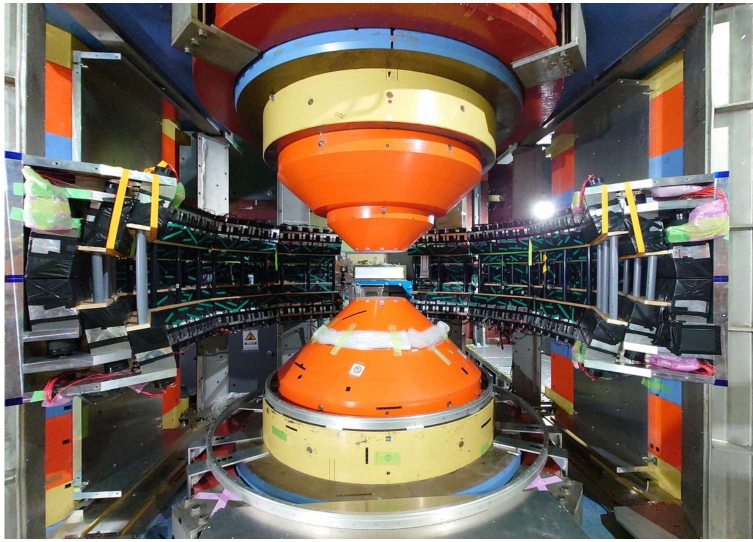
CF4 gas vessel

Commissioning runs and after

- Run-0a in 2020/Jun.4-20
  - With 6(SSD)-6(GTR)-4(HBD)-6(LG)
  - beam intensity raised from 5x10^8 to 1x10^10 step-by-step
- Run-0b: 2021/Feb.
  - 2-GTR & 2-HBD are additionally installed.
  - suspended by malfunction of MR-ESS
- Run-0c: 2021/Jun.
  - ee-trigger run was performed
  - micro beam structures is found, which deteriorate the DAQ live time
- 2021/Nov.: new 2-LG modules were installed, after the un-installation of HBD/GTR/SSD for the maintenance.
- New 8-SSD w/ CBM group is under construction
- 2022: 8-GTR(Aug.), SSD and HBD (Nov.) will be re-installed
  - full 8-module will be ready in the end of Nov.
- 2023: beam study to suppress the micro structure, and Run-1 (not fixed yet)

RUN-0b/c (2nd-half) config.

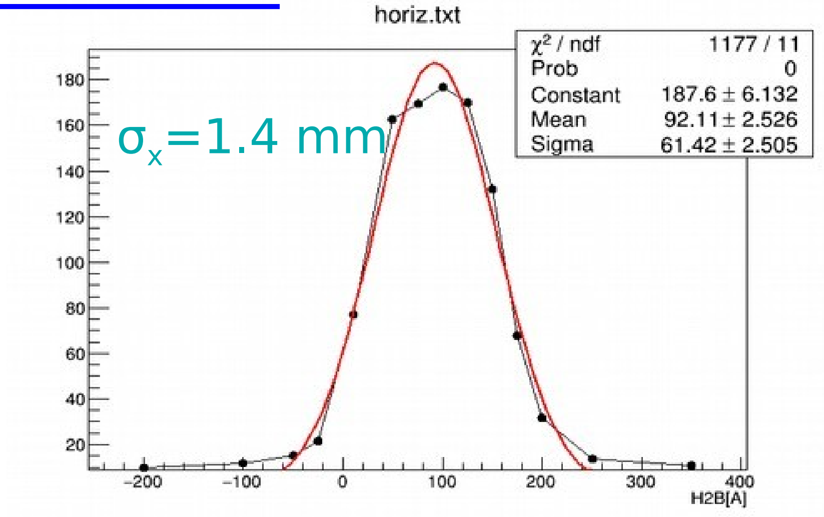




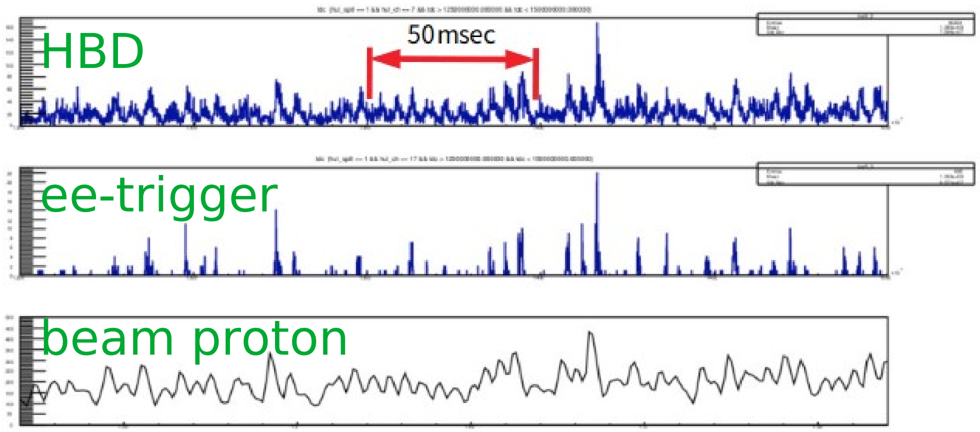
Results from commissioning runs

-

Beamline performance in Run-0



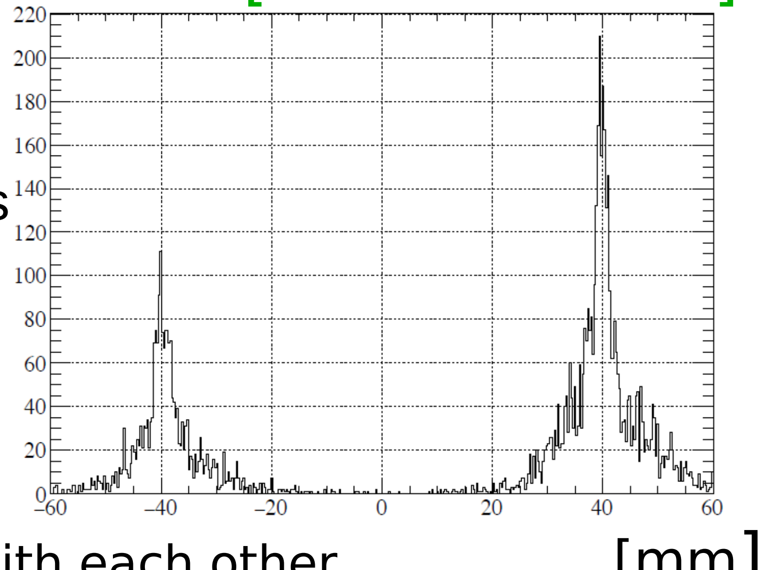
- Beam profile was enough small
  - Measured by a scattering method at the target point
  - Beam width is smaller than the design value
- Single rate was higher than the expectation
  - Single rates of detectors located near the beam position show two times as high as our estimate based on KEK-PS results.
    - e.g., 1.0 MHz for LG, where the estimate is 0.5 MHz at 1×10^{10} /spill.
    - A factor of 2 is within our margin of design. Thus we can use the designed value 1×10^{10} protons per spill.
- Micro structures deteriorate the DAQ performance
  – 5.2 μs and 5 ms cycles
  – ee-trigger is localized in time
  – Countermeasures will be applied in 2023
    - in cooperation with beam line and & accelerator groups



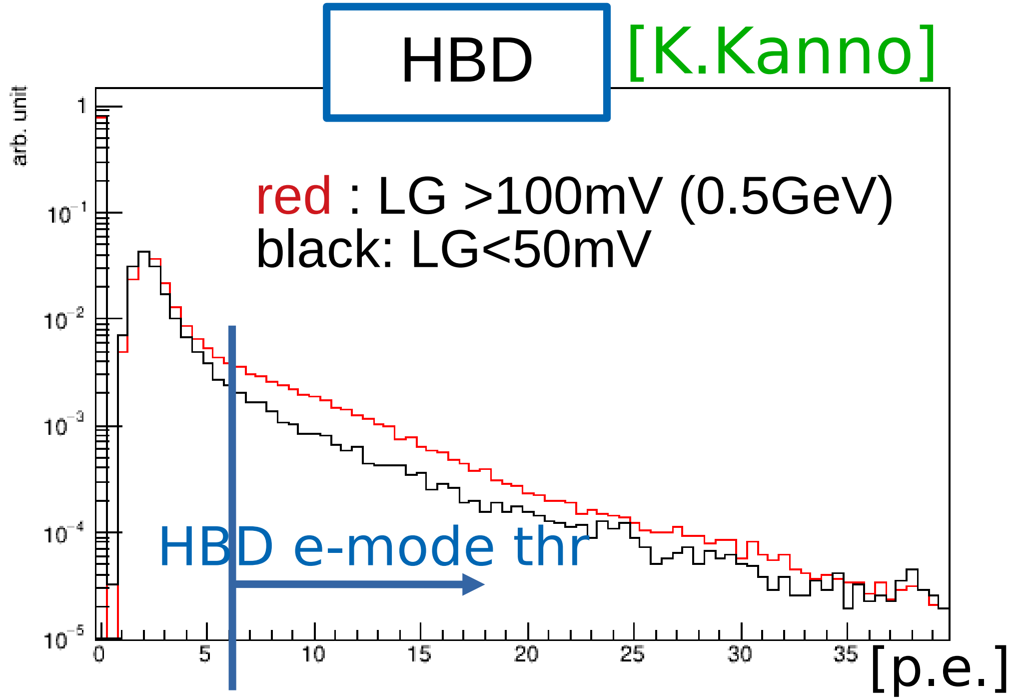
detector performance: online

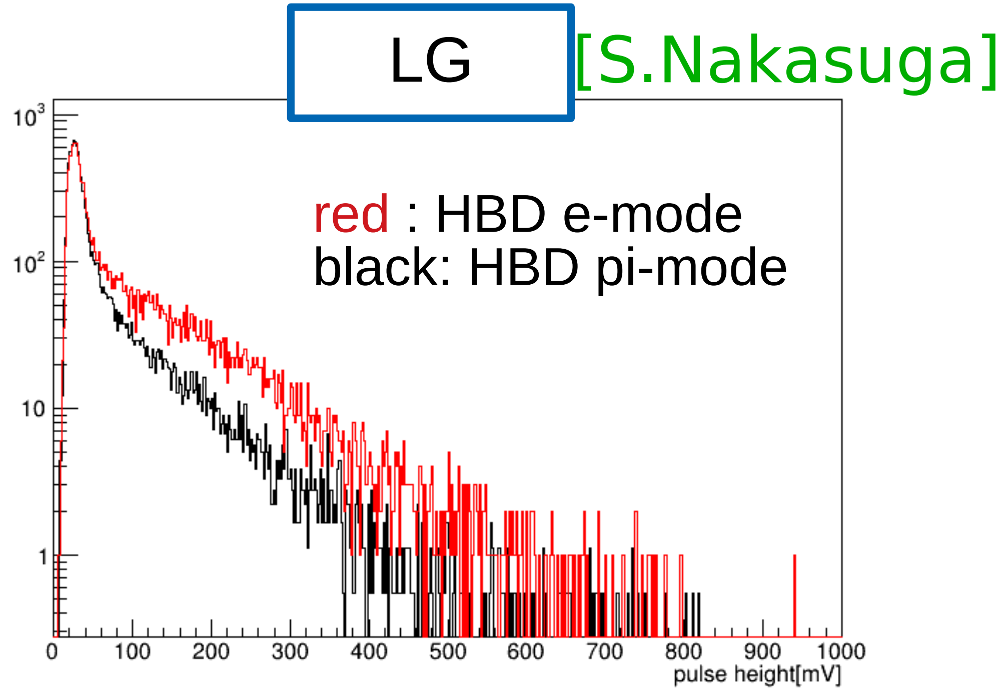
[T.N.Murakami]

- Tracking in wire-target Run for tracker alignment
  - ~5x10^9 protons/spill
  - cross point of two straight tracks w/ SSD & 3-GTRs
  - two wires separated 80 mm are seen



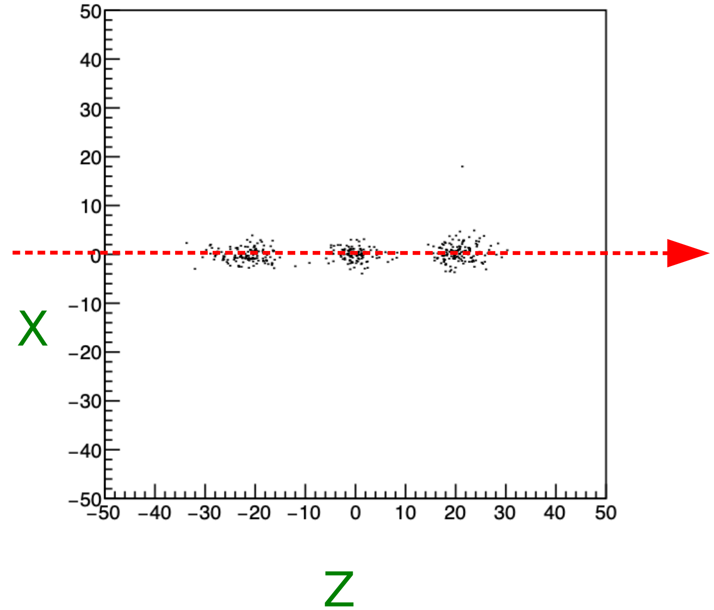
- electron ID
  - calibration runs in ~5x10^9 protons/spill
  - enhancement is seen by selecting e-candidates with each other

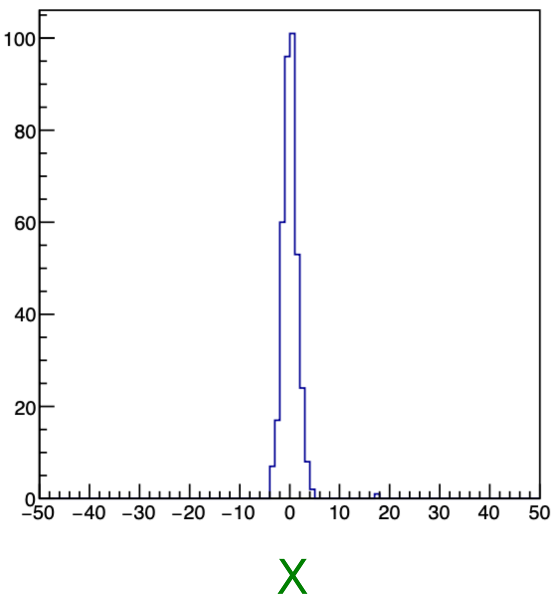




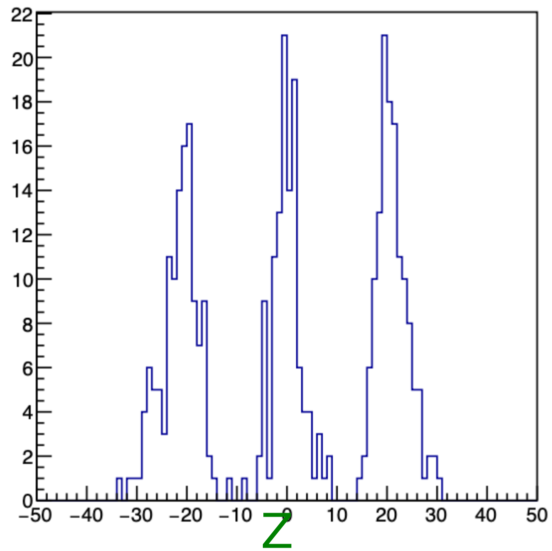
Vertex distribution in offline analysis

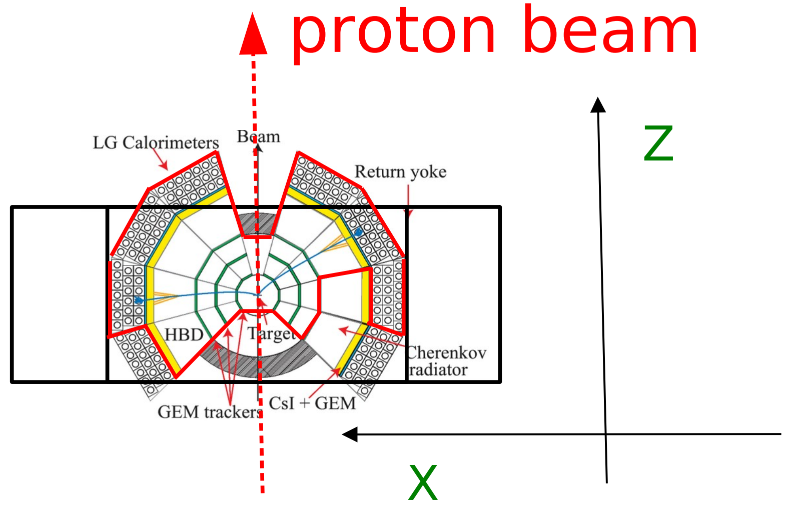
- three experimental targets are clearly seen
- most closest point of two tracks, triggered by two modules in each arm, w/ magnetic field





[M.Ichikawa]





Persons working for each subsystem & shift clue

- GTR : Ozawa, Murakami (Tokyo), Nakai (RIKEN), Kondo (Hiroshima)
- HBD : Aoki (KEK), Kanno (RIKEN)
- LG: Naruki, Ashikaga, Nakasuga (Kyoto/JAEA)
- SSD: Ozawa, Aoki (KEK), Takaura, Arimizu (Kyoto)
- Beam/halo monitor: Komatsu, Morino (KEK), Arimizu
- Target Chamber : Ozawa, Muto, Komatsu, Hirose (KEK)
- Trigger/DAQ/Software : Takahashi, Nakai (RIKEN), Ichikawa (Kyoto/RIKEN), Honda(KEK), Kajikawa (Tohoku), Chang, Lin, Wang (Academia Sinica)
- Sako/Sato (JAEA), Kyan, Asamizu, Nonaka K.Tsukui(U-Tsukuba), R. Tatsumi, Y.Kimura, Shirotori, Noumi (Osaka/RCNP), K.Ebata, K.Yahiro,Yamaguchi, Suzuki(Kyoto), M.Sekimoto(KEK/RIKEN), S.Kobayashi (Tokyo) participated in construction works and data taking.

At the end of E16 Run-0a
2020/June/22

Counting room E16 Run-0c
2021/June

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.
  - confirm the observation by E325 and obtain more precise information of the spectral change of vector mesons in dense nuclear matter.
- High-p line at J-PARC is completed in June 2020. Commissioning run (Run-0) of E16 spectrometer was performed in June 2020, Feb and June 2021.
  - 6 SSD + 8 GTR + 6 HBD + 6 LG were operated.
  - In total, 403 hours (Run-0a 159 + 0b 110 + 0c 134 hours) executed.
      - » Detectors worked well.
  - data were taken with the ee-trigger in the full beam intensity (1x10^10 protons/spill) in Run-0c
    - – beam micro structures deteriorated the DAQ performance
      - » countermeasures in beam line and DAQ will be applied in 2023 beam time
    - – efficiency evaluation is on-going in the offline analysis
- Run-1 (physics run) will start in 2023, after the long shutdown for MR upgrade
  - with full 8-module configuration
  - PAC approval is required for the beam time allocation of Run-1
  - It will be requested in the PAC held in 2022 July., with updated TDR.