Current Status of the Heavy Ion Acceleration Program at the J-PARC Accelerators

J-PARC Heavy-Ion Project 2024

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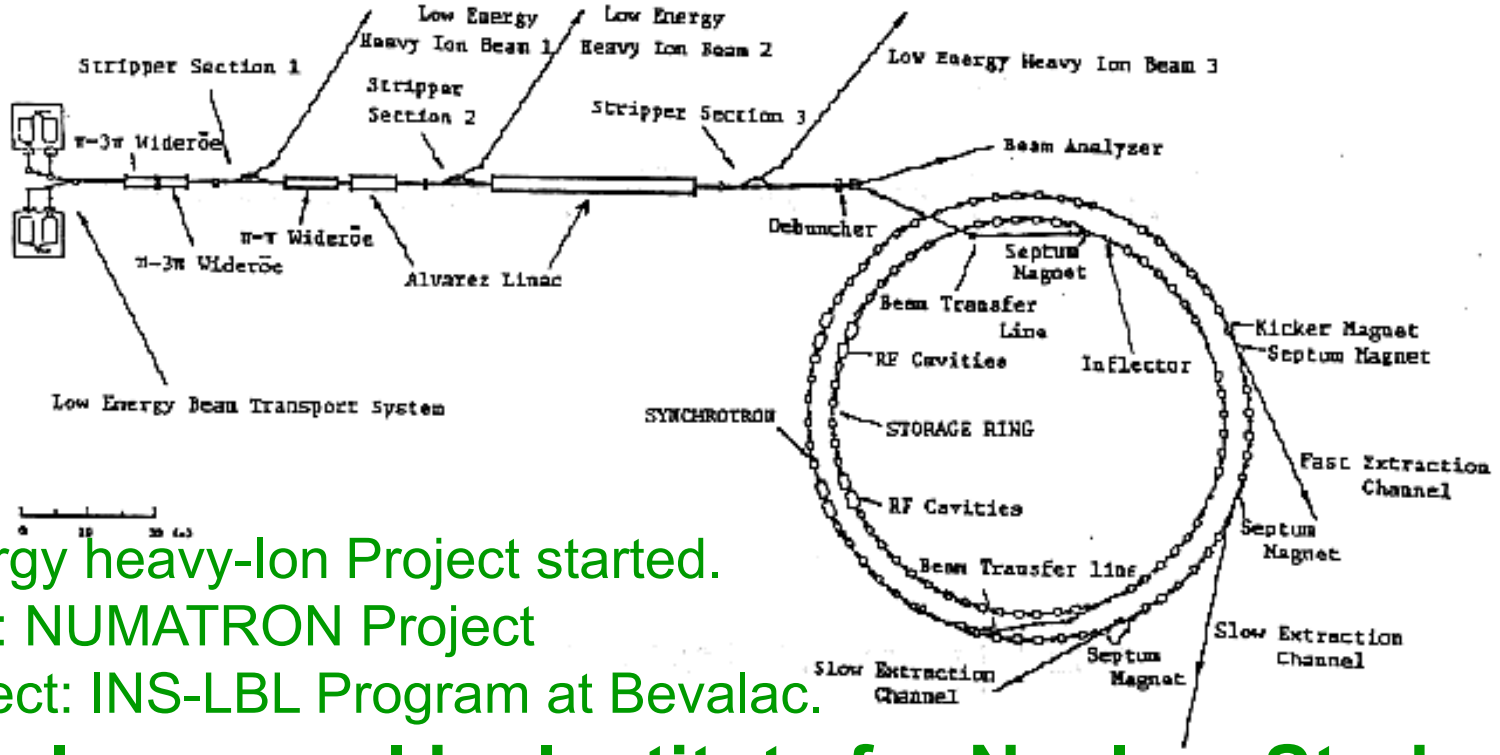
IPNS-KEK/ASRC-JAEA

Today's Talk

- Note No. 1: Story of Numatron
- Note No. 2: Adventure in the KEK 12GeV-PS
- Present Status at around J-PARC

The story began with Numatron

Heavy ion accelerator that can accelerate and utilize uranium up to 2 GeV per nucleon.

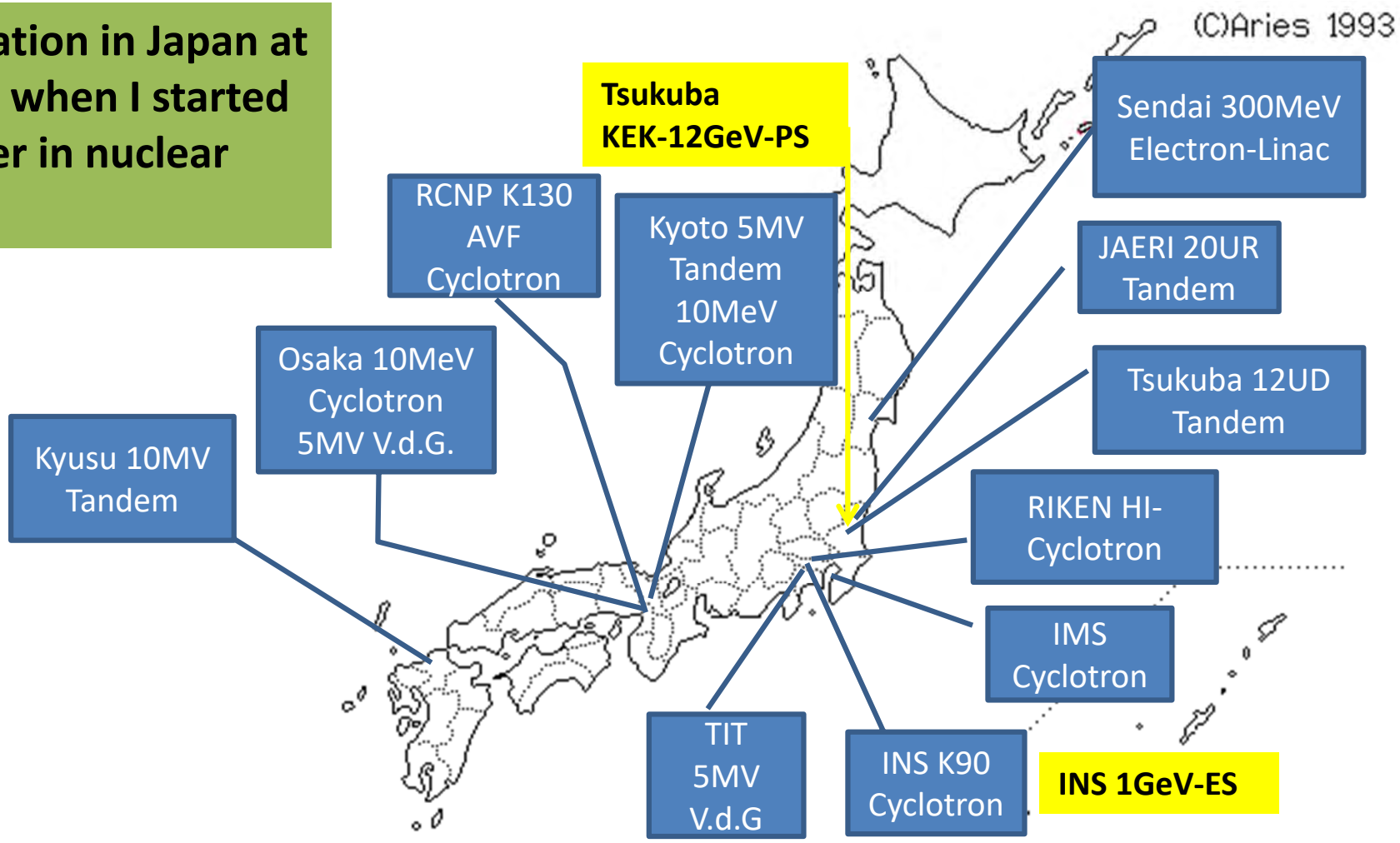


1974: High Energy heavy-Ion Project started.
Domestic: NUMATRON Project
Pilot Project: INS-LBL Program at Bevalac.

1976: Formal proposal by Institute for Nuclear Study, The University of Tokyo as Japan's First priority Project.

Japanese Accelerators for Nuclear Physics around 1975

The situation in Japan at the time when I started my career in nuclear physics!



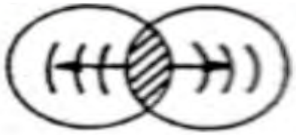
Physics of Numatron (Homework)

What happens when 2 Gev/u Uranium hits a Uranium target?

We asked our leading theoretical Physicists

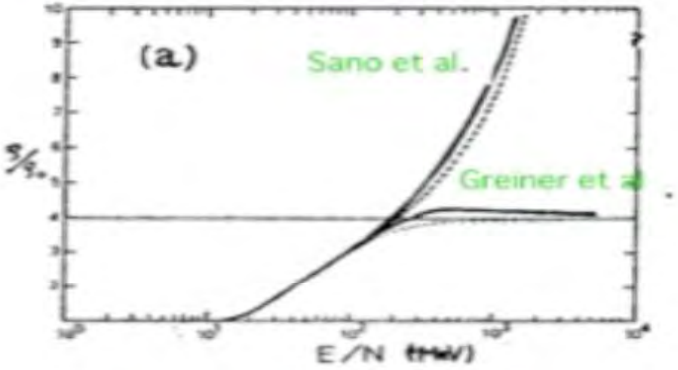
It has become a kind of homework

Jun'ichi Fujita: Nuclear Acoustics

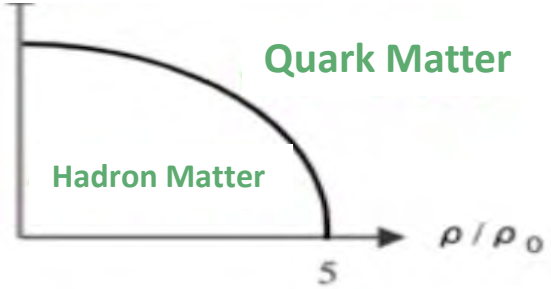


Sound Velocity in Nuclear Matter : Vs=(0.1~0.15)c
Vc < Vs incompressible fluid
Vc>Vs High-density nuclear matter

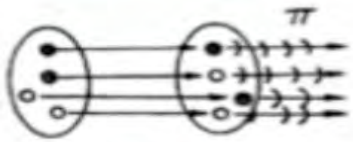
Mitsuo Muraoka: Formation of



Hironari Miyazawa: Quark Matter



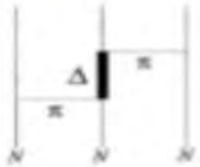
Hironari Miyazawa: Paser: Pion Laser



Katsumi Yamada:
New Isotope Production
Neutron Rich Nuclei
Superheavy Elwmwnts

Jun'ichi Fujita: Three (Many) Body Force

Multi-Δ states
Δ Matter

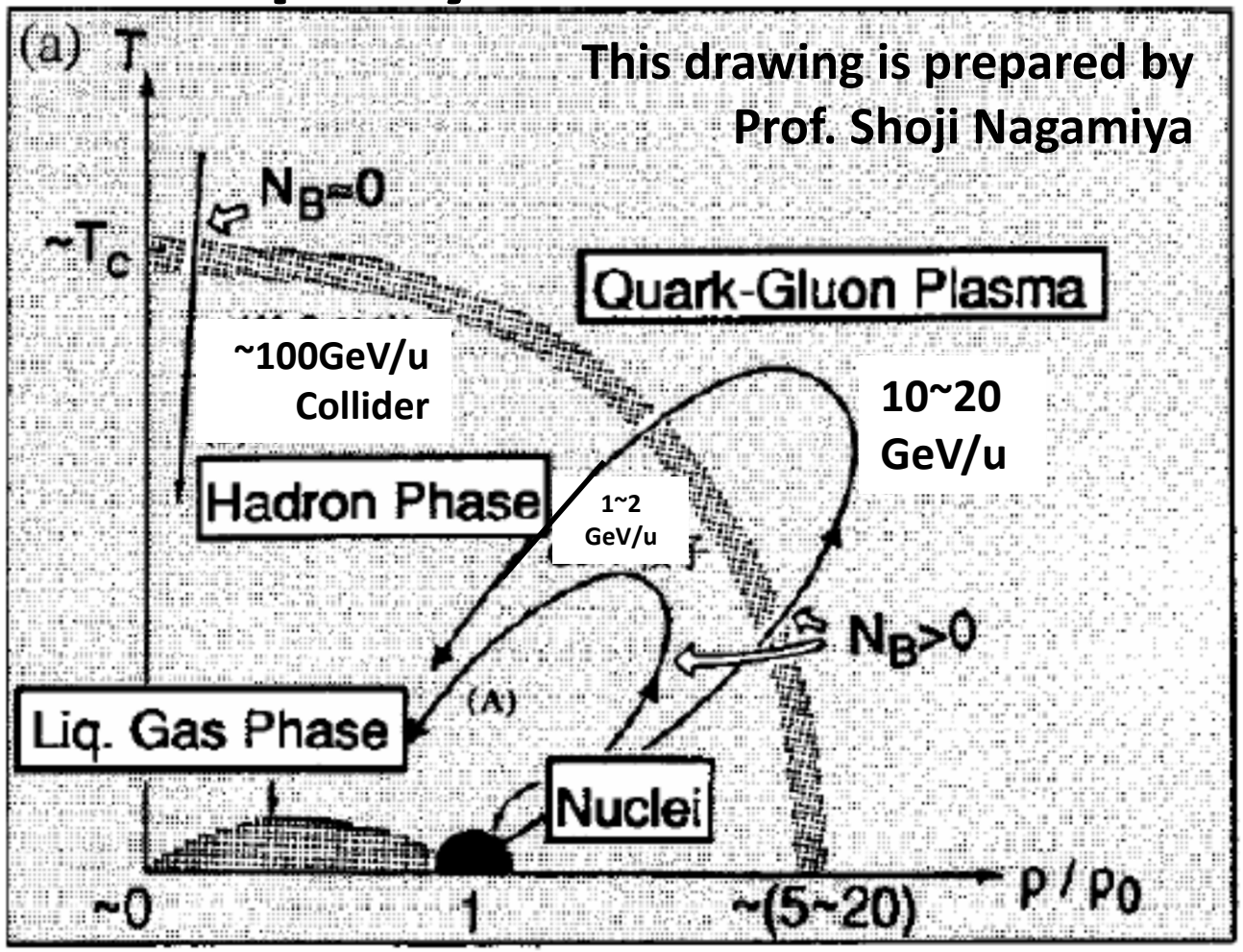


Physics of Numatron (Homework)

Hironari Miyazawa: Property of Nuclear Matter

A phase transition from nucleon many-body systems to **Quark Gluon Plazma** occurs at a density 4-20 times that of ordinary nuclear matter. The energy is around 10-20 GeV/u?

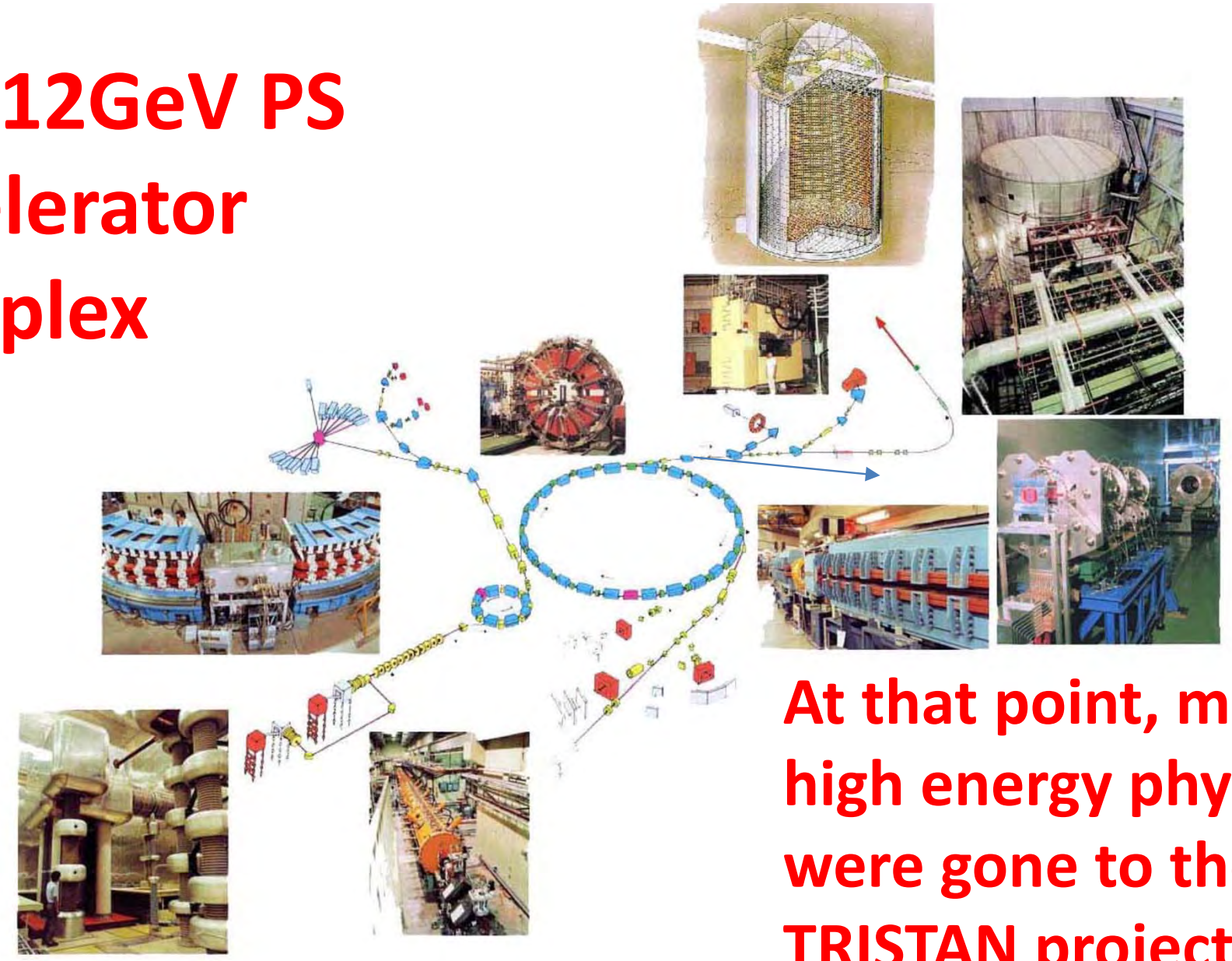
In highly excited nuclear matter, before QGP phase transition, the **'liquid to gas phase transition'** should occur. The energies are.<E0>/<A0> ~10 MeV or there around?



Unfortunately
Numatron Project was Rejected in 1981

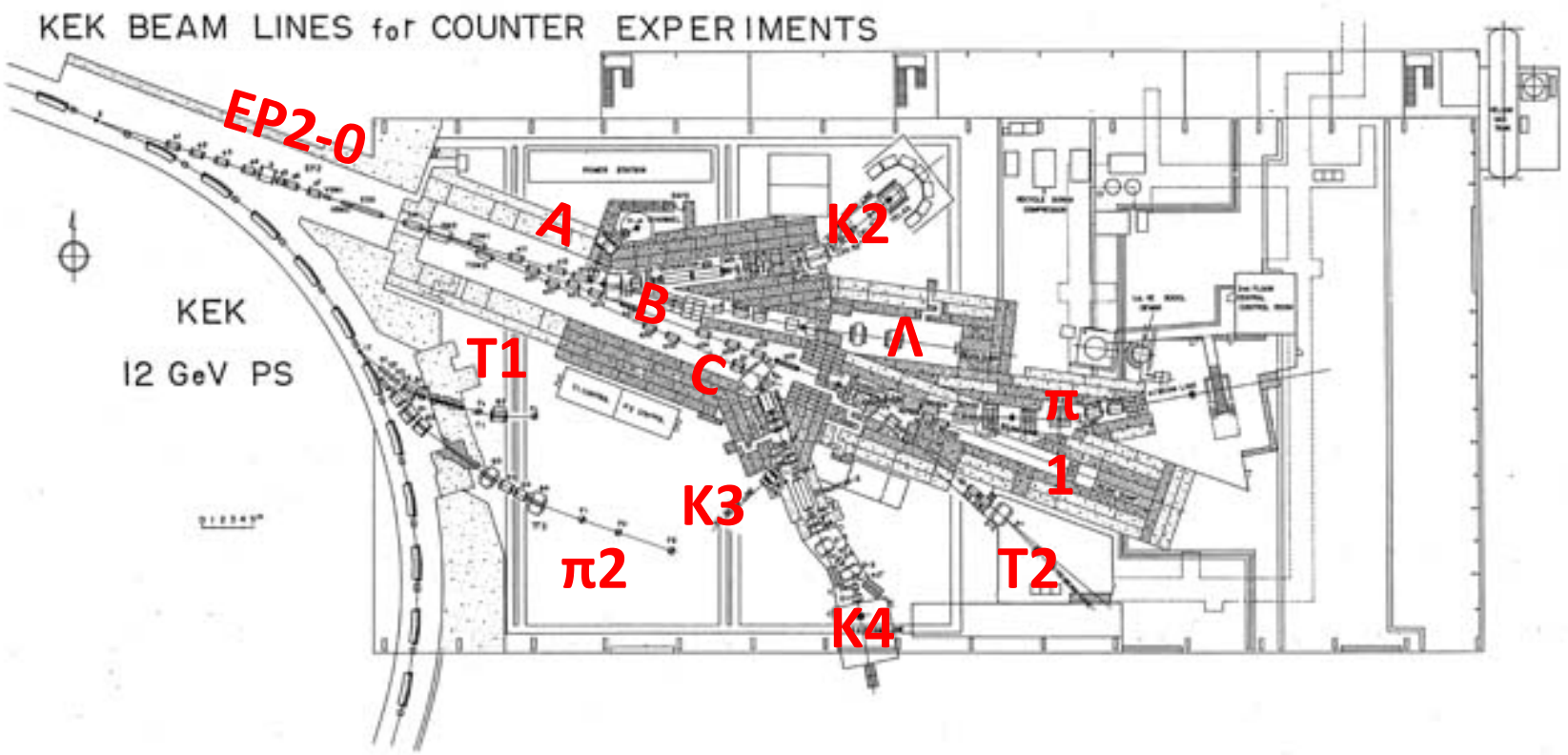
- A new Large Hadron Project centred on a high-intensity proton accelerator will be developed-> J-PARC.
- Research on unstable nuclei will be promoted at RIKEN's RIPS-> RIBF.
- Research on high-density nuclear matter will be promoted at overseas high-energy heavy-ion research facilities such as LBL, BNL and CERN.
- Maximum use of existing facilities (RCNP, ELPH, INS-SF and INS-ES).
- Nuclear physics using high-energy accelerators should be developed at KEK's **12GeV Proton Synchrotron** at the National Laboratory for High Energy Physics.

KEK-12GeV PS Accelerator Complex

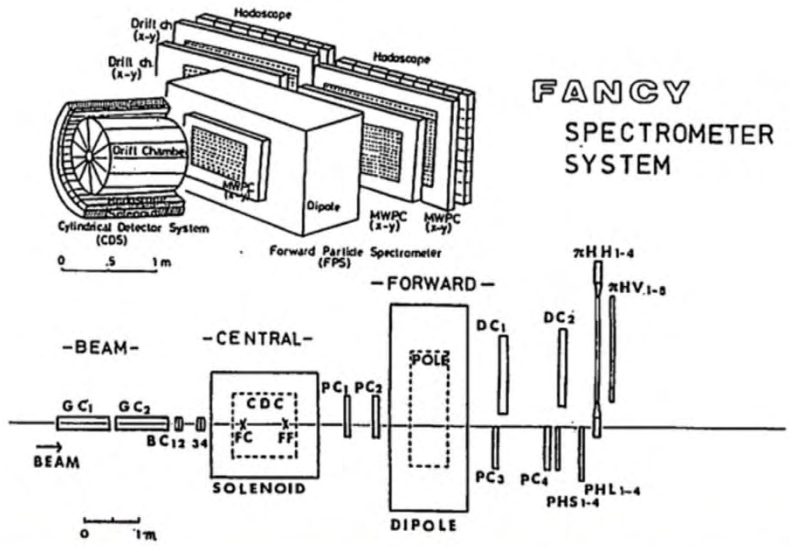


At that point, most high energy physicists were gone to the TRISTAN project

East Counter Hall in 1982



FANCY at π2

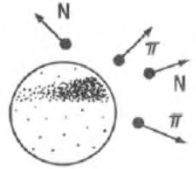


Stage 1

E_0^f = 120 ~ 140 MeV

β_s^f = 0.4 ~ 0.5

"Quasifree Emission"

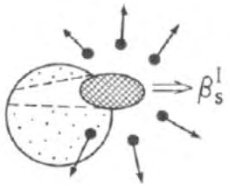


Stage 2

E_0^s = 60 ~ 70 MeV

β_s^s = 0.1 ~ 0.2

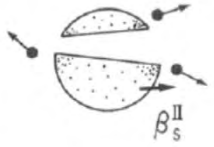
"Spectator Fireball"



Stage 3

E_0^p = 6 ~ 8 MeV

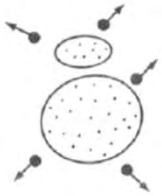
"Pre-equilibrium Emission"

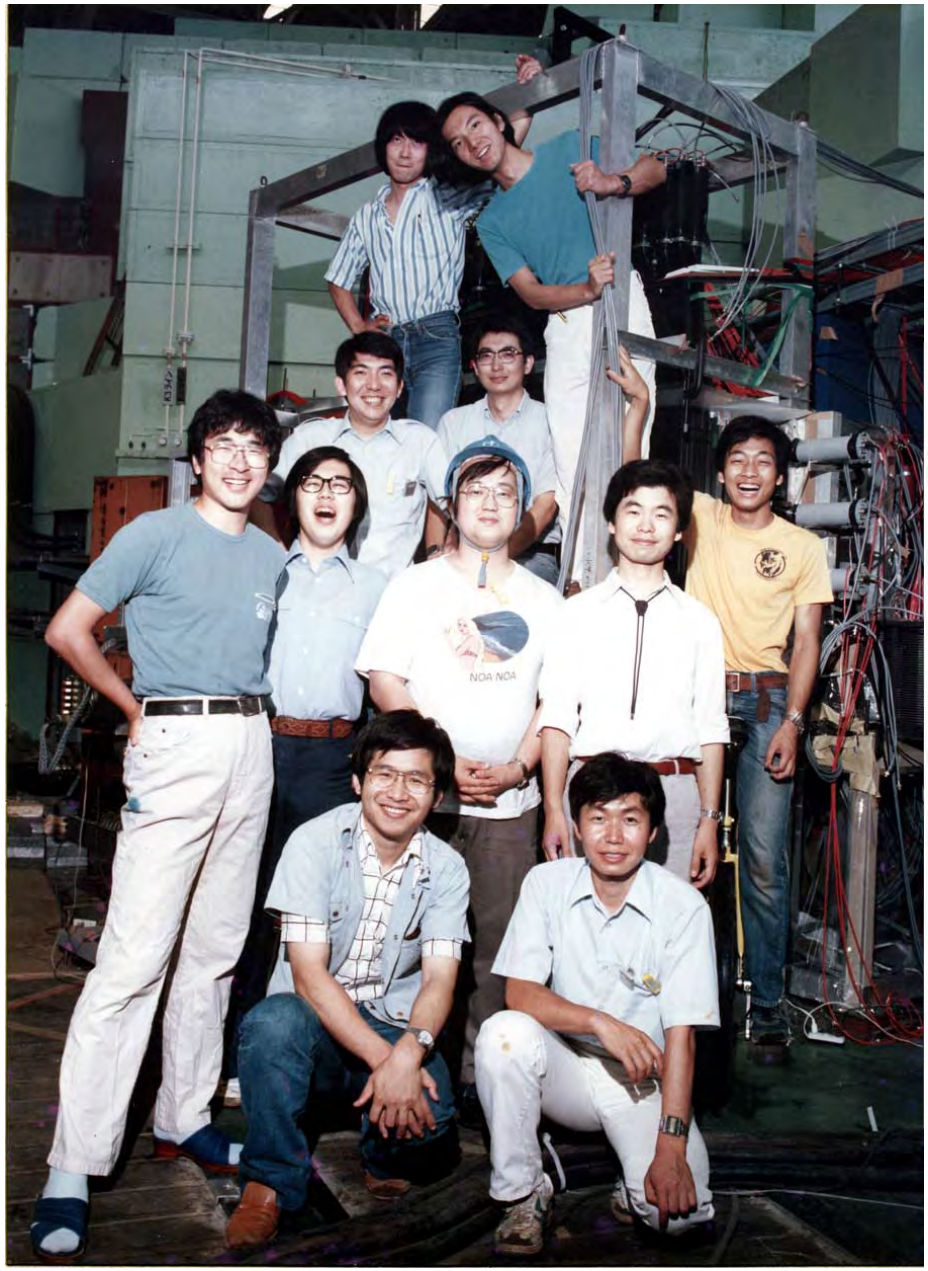


Stage 4

E_0^e = 1 ~ 2 MeV

"Evaporation"





Kμ at K3

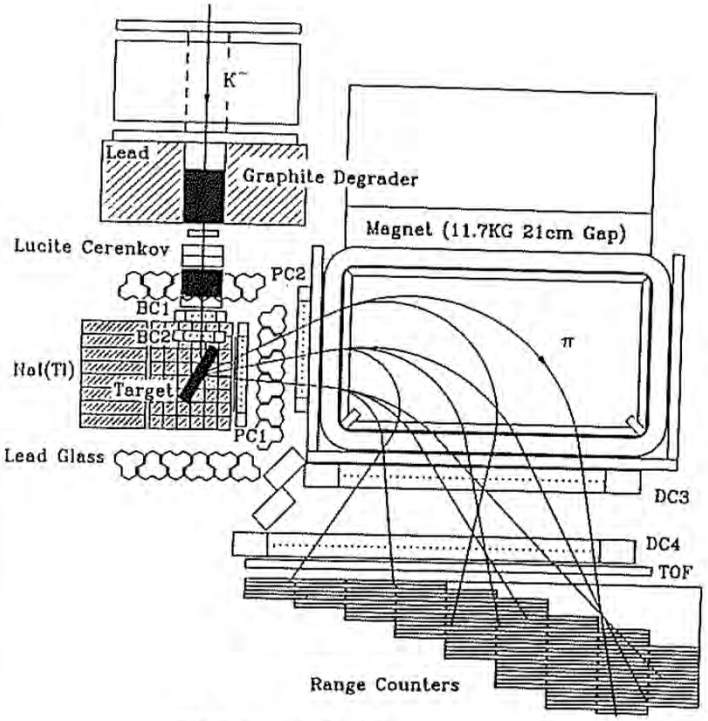
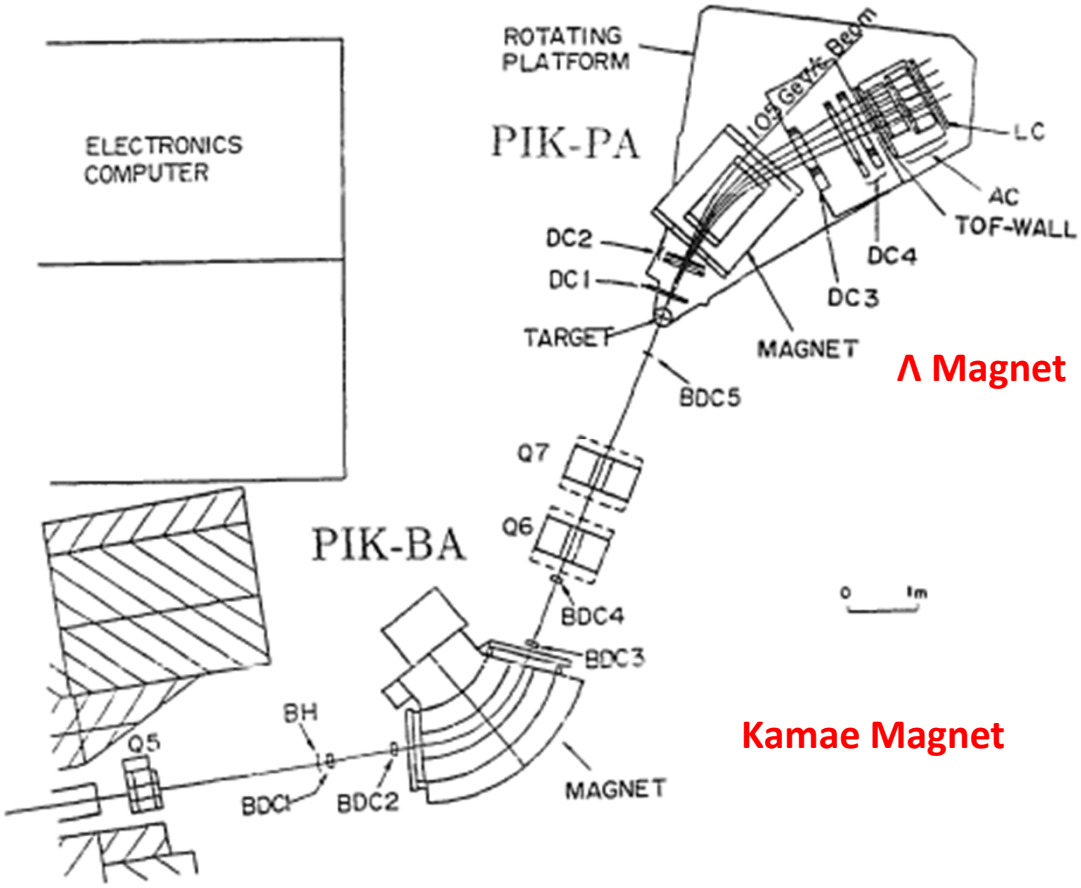


Fig. 4. Layout of the Kμ spectrometer.

PIK Spectrometer at K2

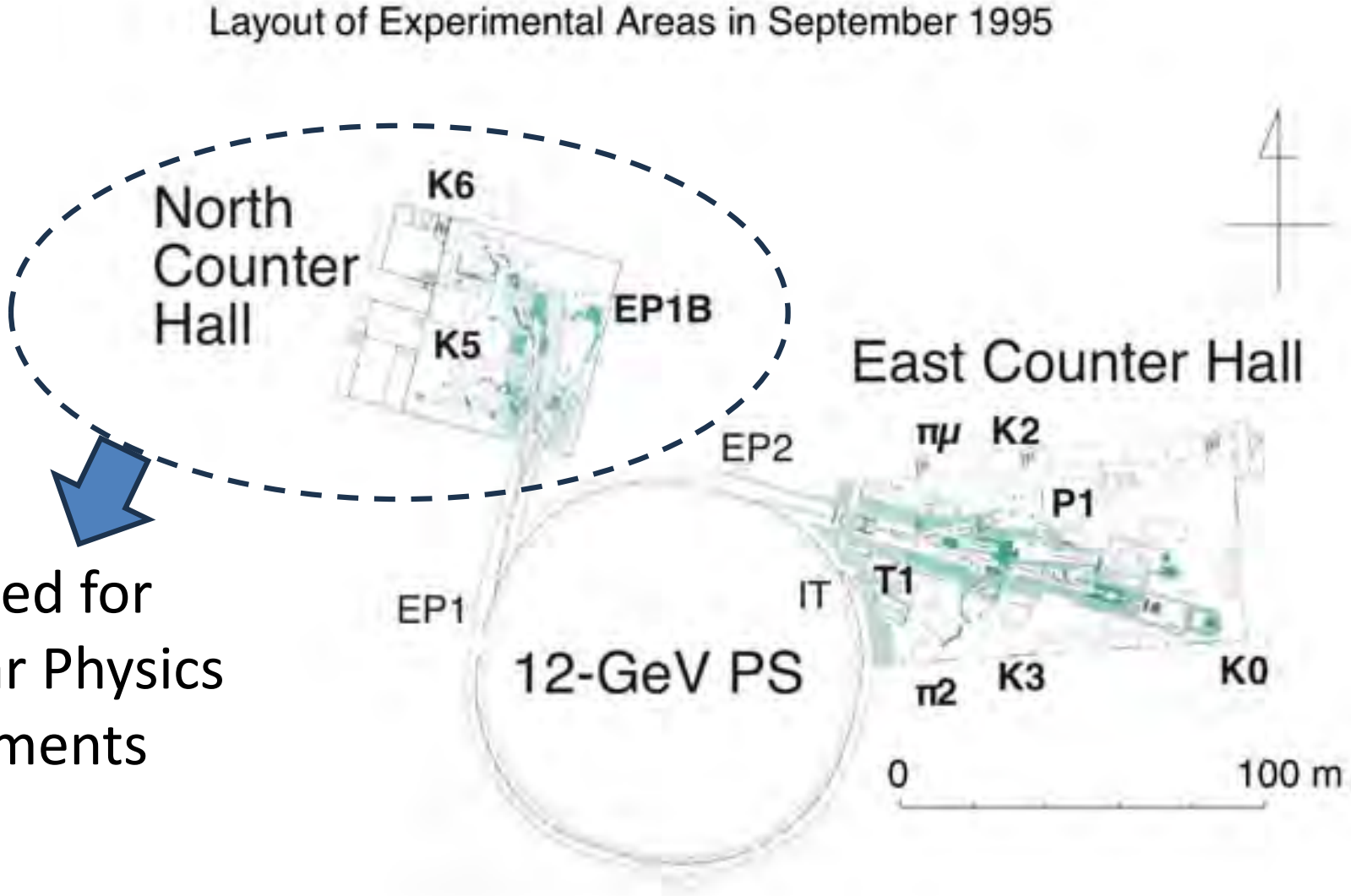


K2 ビームラインに設置された PIK スペクトロメーター
^{12}C 標的と ^{56}Fe 標的による(π^+,K^+)スペクトルの取得に成功

KANSAI UNION team
Prof. Imai (Kyoto)
Prof. Ejiri (Osaka)
Prof. Kishimoto (Osaka)
Prof. Nakazawa (Gifu+Nagoya)

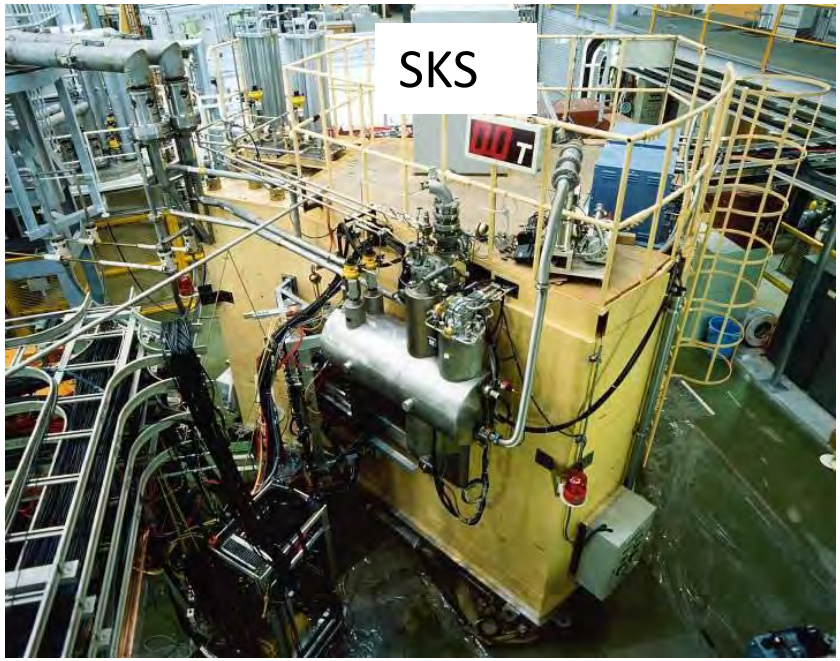
- S=-1 HN via (π, K) reactions
- Hyperon Scattering
- S=-2 HN via（K、K）reactions
- Hybrid Emulsion Exp.

Construction of New (North) Counter Hall

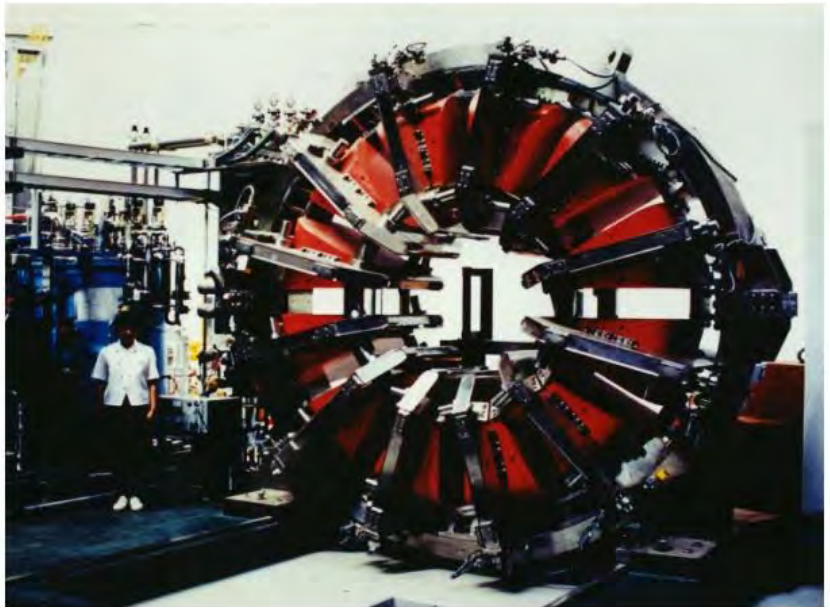


Designed for Nuclear Physics Experiments

Three Major Spectrometers in North Hall



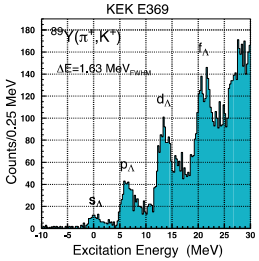
Superconducting toroidal magnet

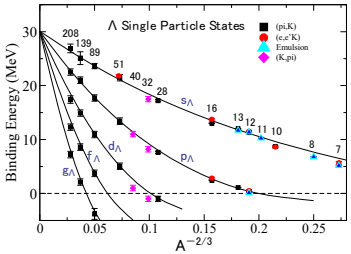


Strangenes Nuclear Physics in North Hall

—For Baryon–Baryon Interaction Physics and High Density Nuclear Matter Physics—

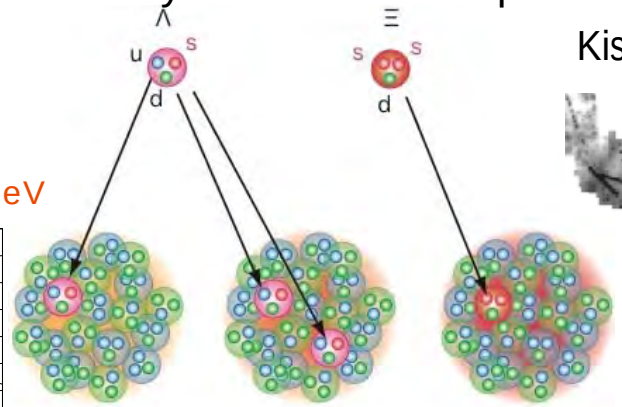
Heavy Hypernuclear spectroscopy via (π,K)reactions





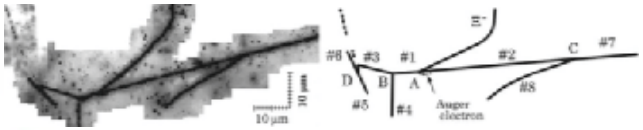
V_Λ= -30 MeV

Hybris emulsion Experiments



Λ、Σhypernuclei Double-Λhypernuclei Ξhypernuclei

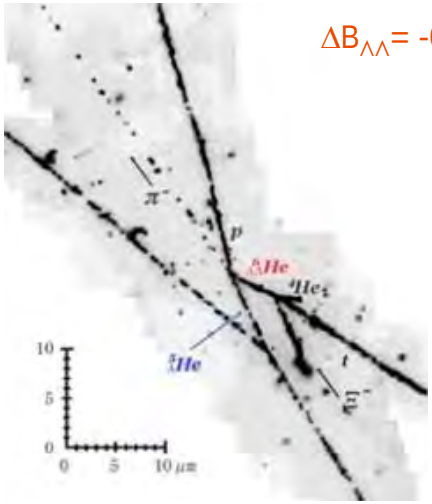
Kiso event (ΞNucleus)



B_{Ξ^-}= 1~4 MeV

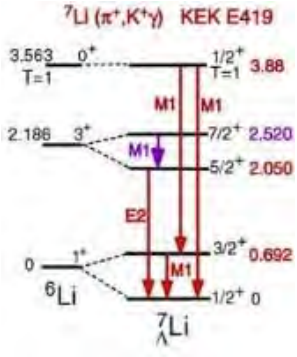
Nagara event (ΛΛNucleus)

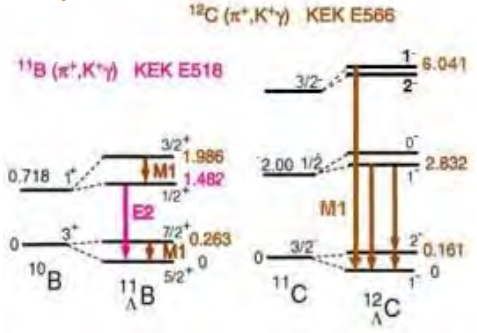
$\Delta B_{\Lambda\Lambda}$= -0.7 MeV

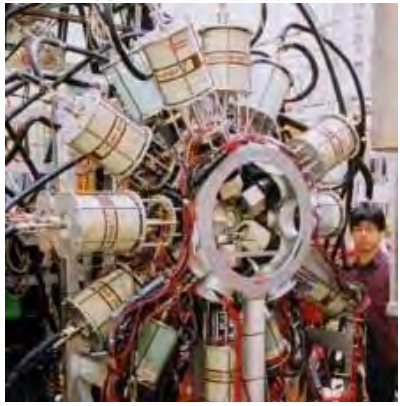


Gamma Ray Spectroscopy

Separation of fine structures

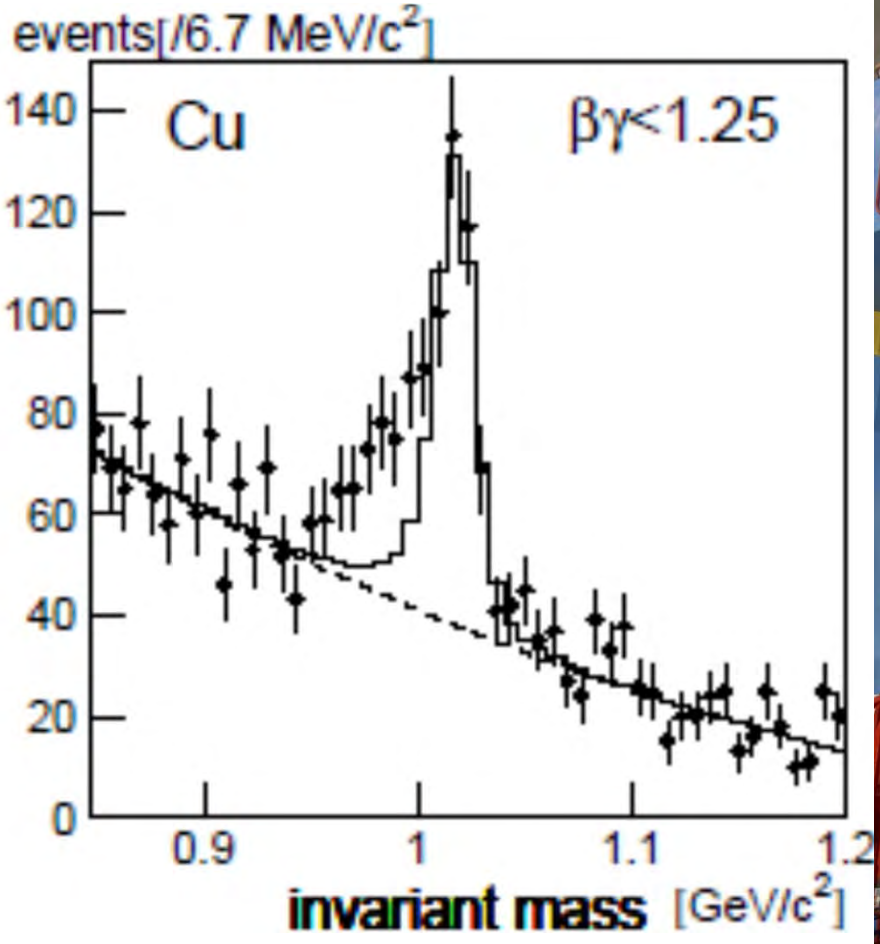






Hyper Ball

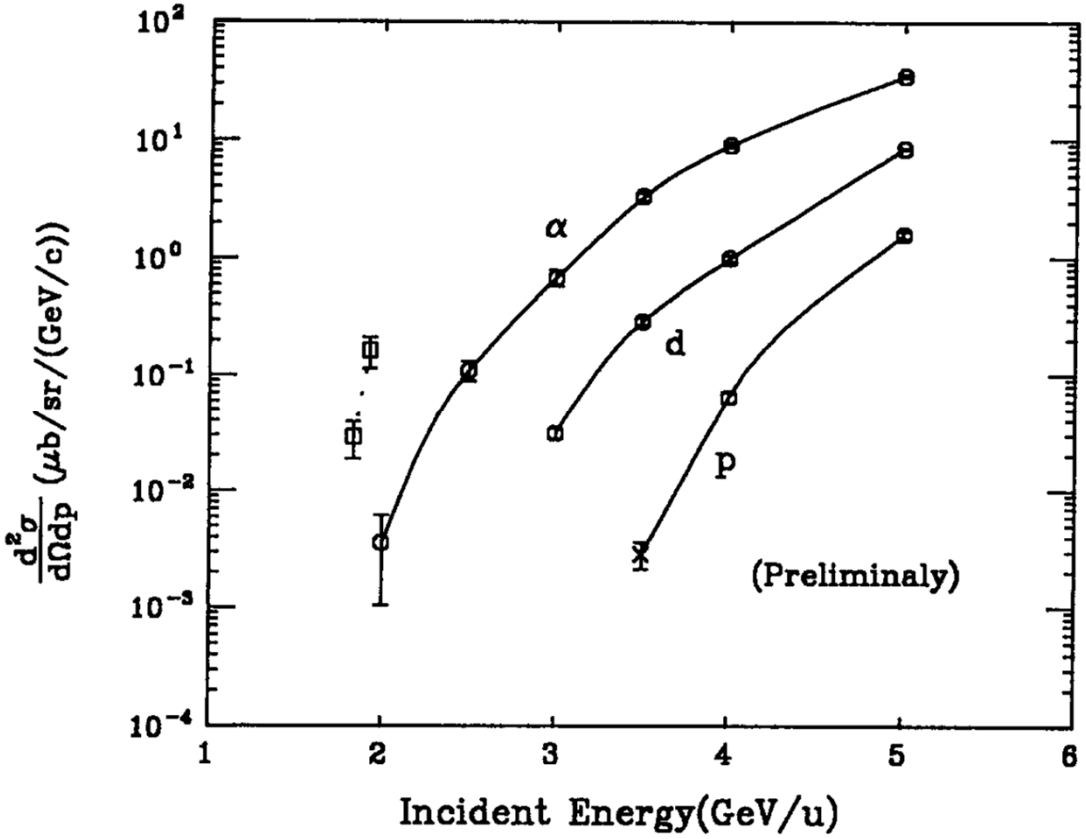
EP1B: The amount of the Excess
KEK－E325



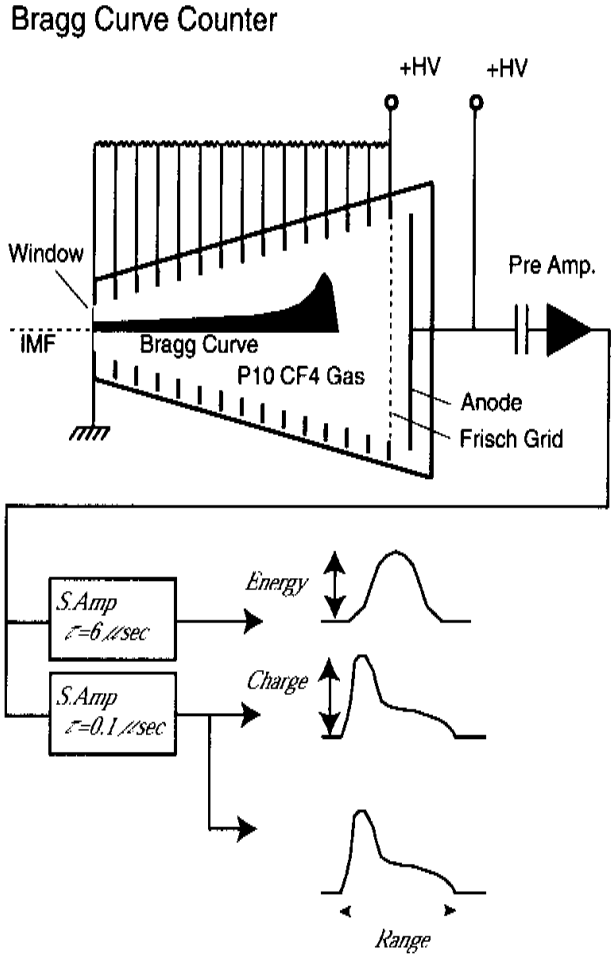
Heavy-Ion Beam Trial at the KEK-PS

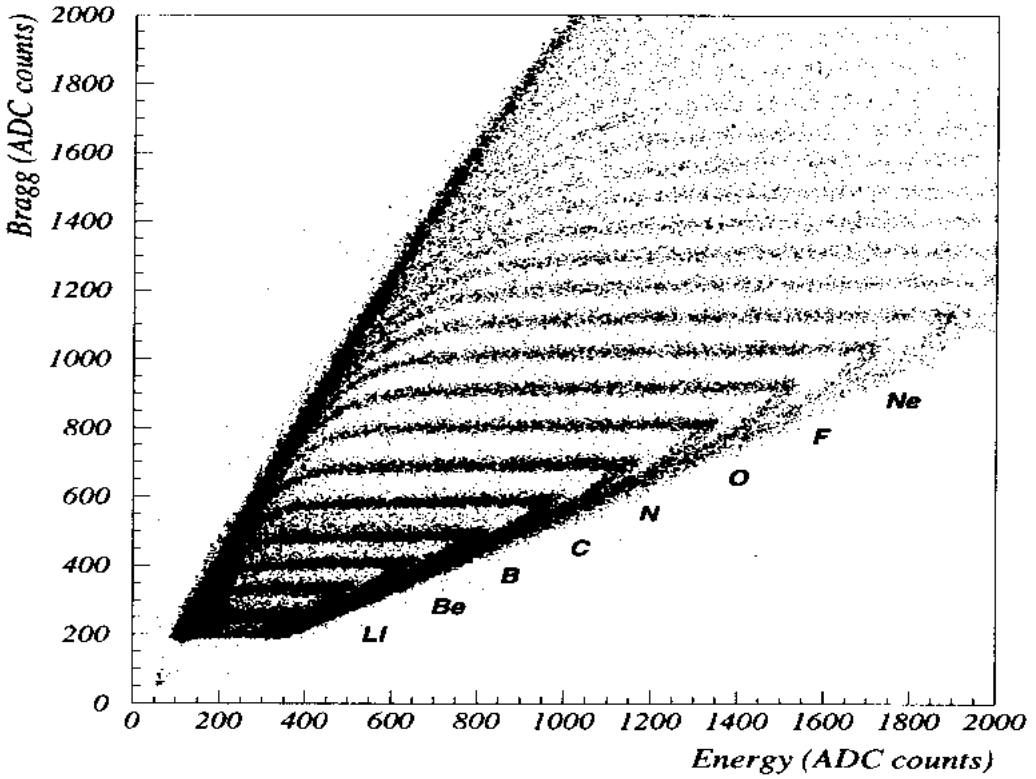
- Successful **deuteron acceleration** in linear accelerator.
- Development of septum with positive and negative switching injection.
  - Successful **alpha acceleration**
  - Coexistence with high-intensity proton acceleration and polarized beam acceleration
- **Experiments with heavy ion beams(trial)**
  - **Production of antiprotons below threshold (approved-done)**
  - **Multi-fragmentation (approved-done)**
  - **Experiments with high-energy neutrons (approved-done)**
  - **Heavy-ion version of Phi experiments (proposed)**
- **PS collider planning**

Doubly differential cross sections of antiproton productions at 1.5 GeV/c in p-, d- ~and α-Cu reactions are shown as a function of the incident energy.



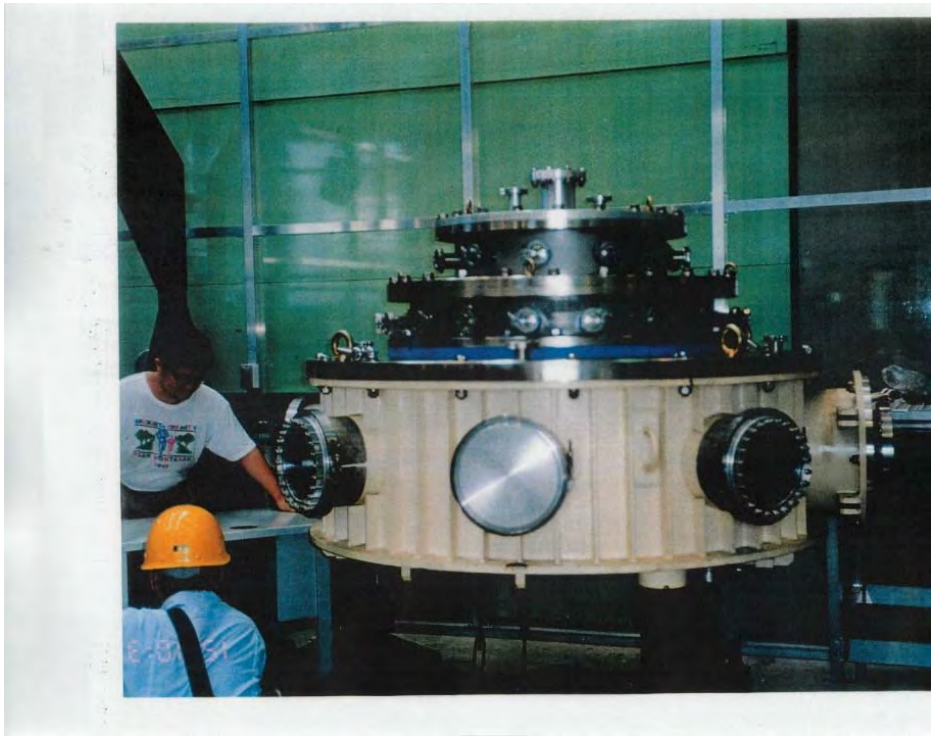
MULTI Experiment: Bragg Curve Counter



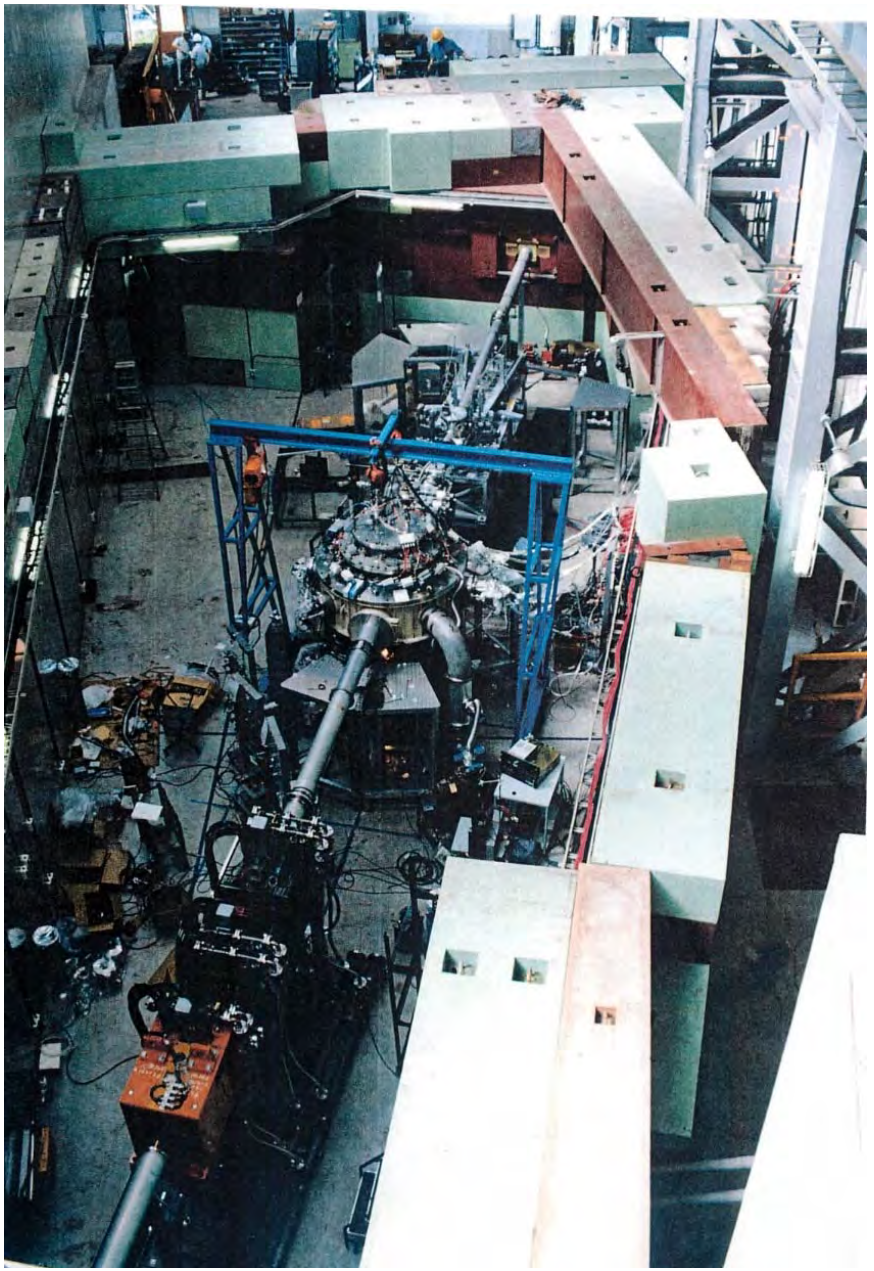


Energy-Charge Scatter Plot

MULTI experiments @EP1B

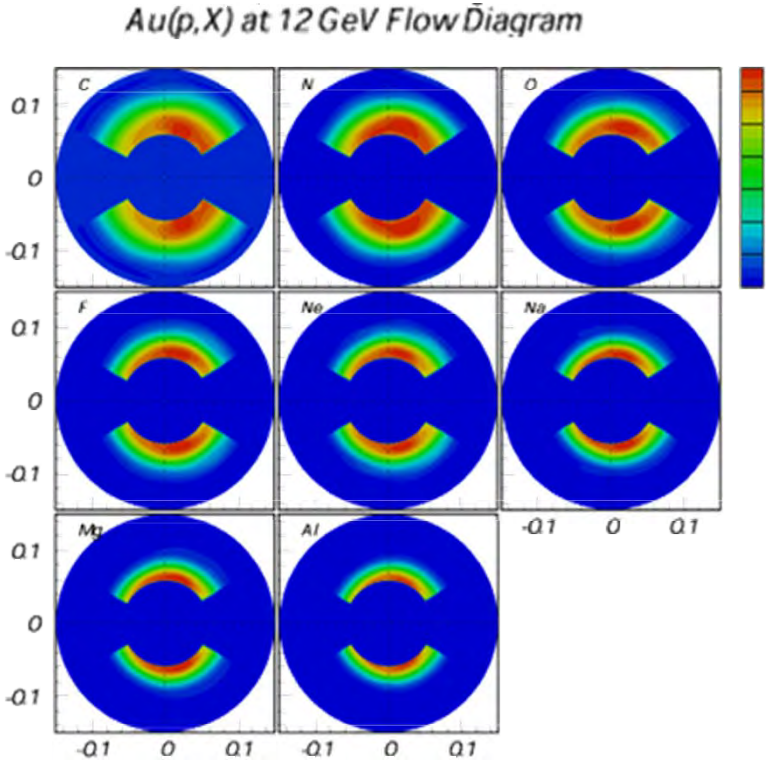


Apply techniques of low energy nuclear physics to high energy beams!

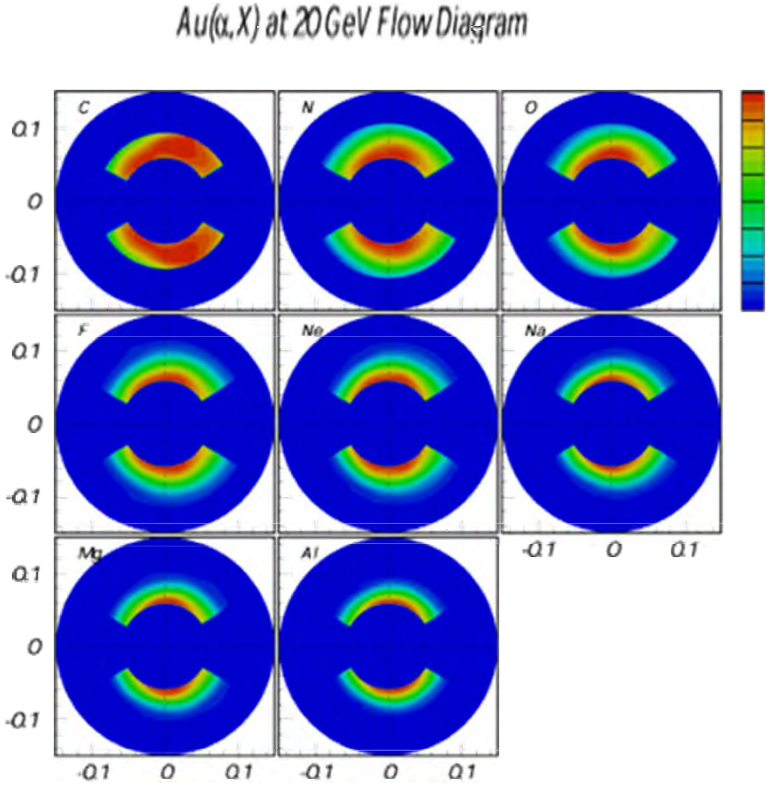


Inclusive Invariant Cross Section

p+Au（12 GeV）



α+Au（20 GeV）



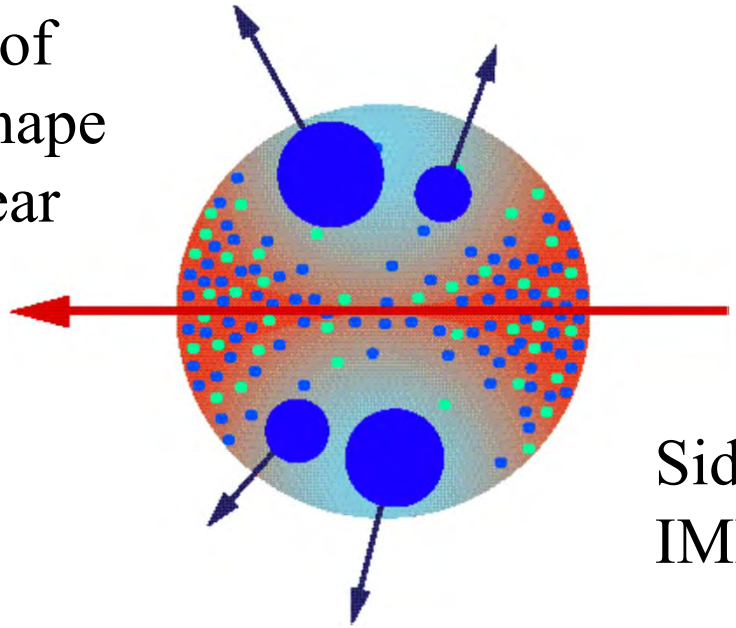
IMF Source Geometry

U-Shape Temperature & Nucleon Density
Sideward Peaking of IMFs

Sideward: Small Nucleon Density

→ *Missing Matter = Fragments ?*

Formation of Toroidal Shape Cold Nuclear Matter



Sideward Peaking of IMF Emission

PS-Collider

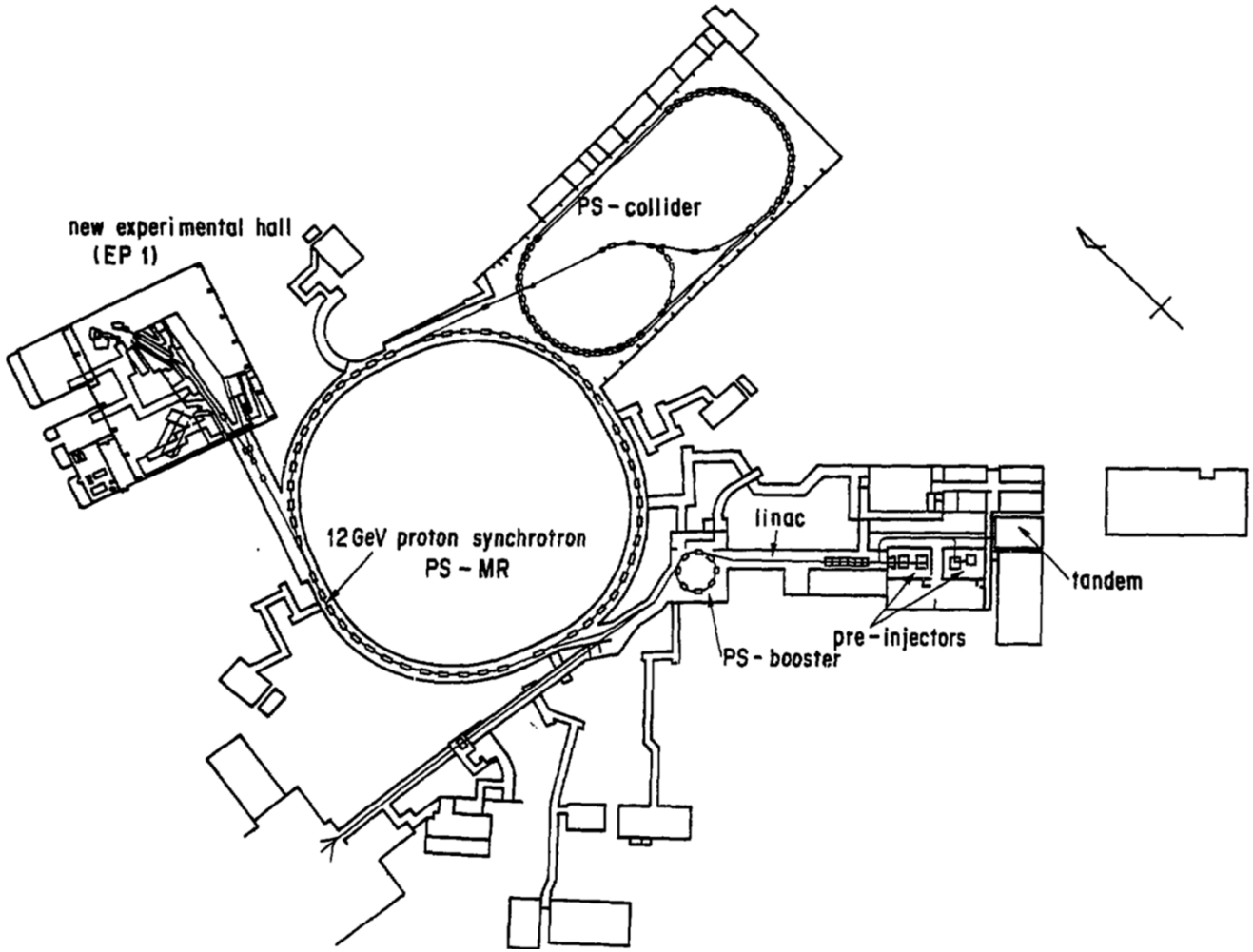


図1b PS—コライダーの配置図

PS Collider

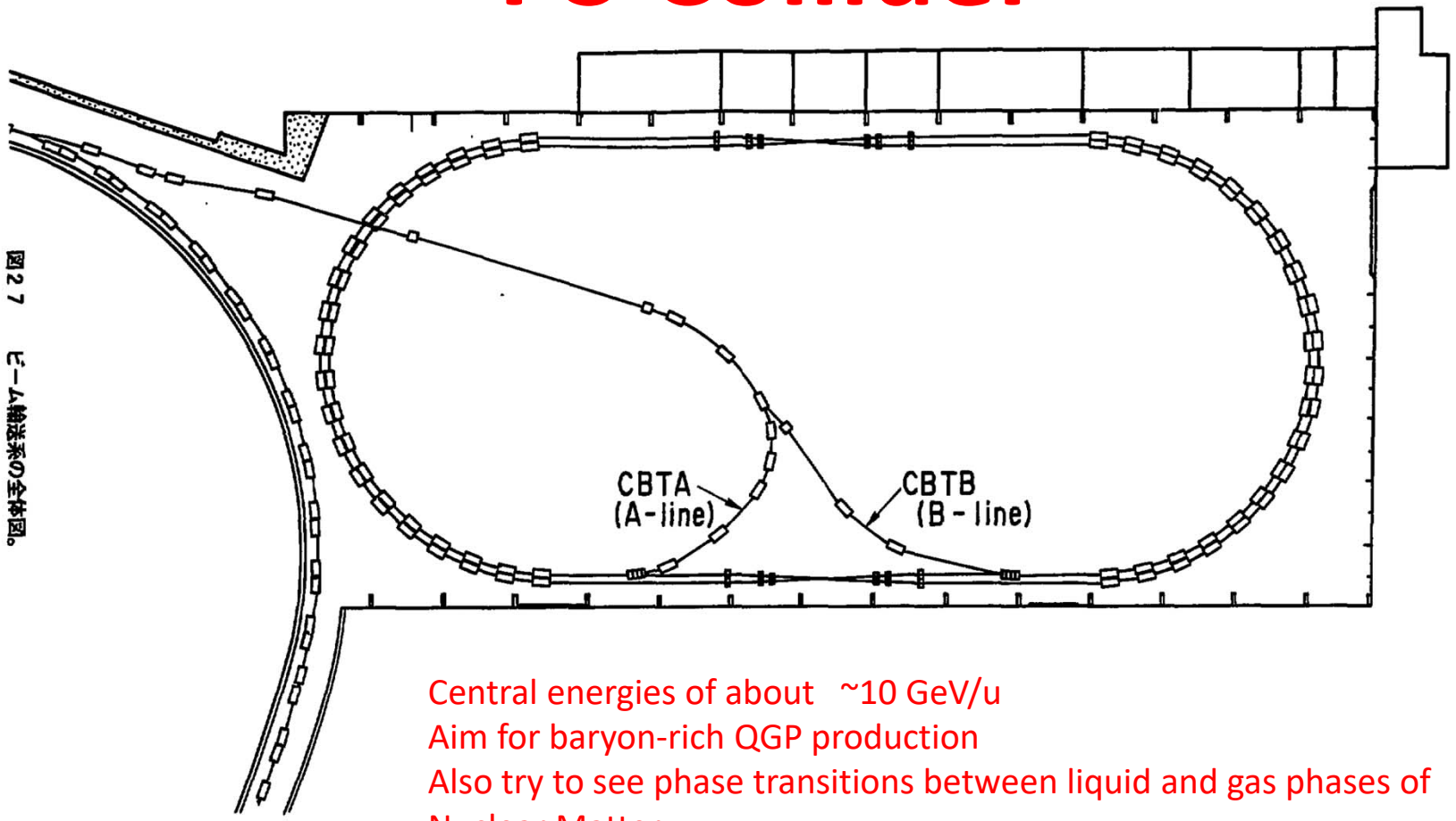
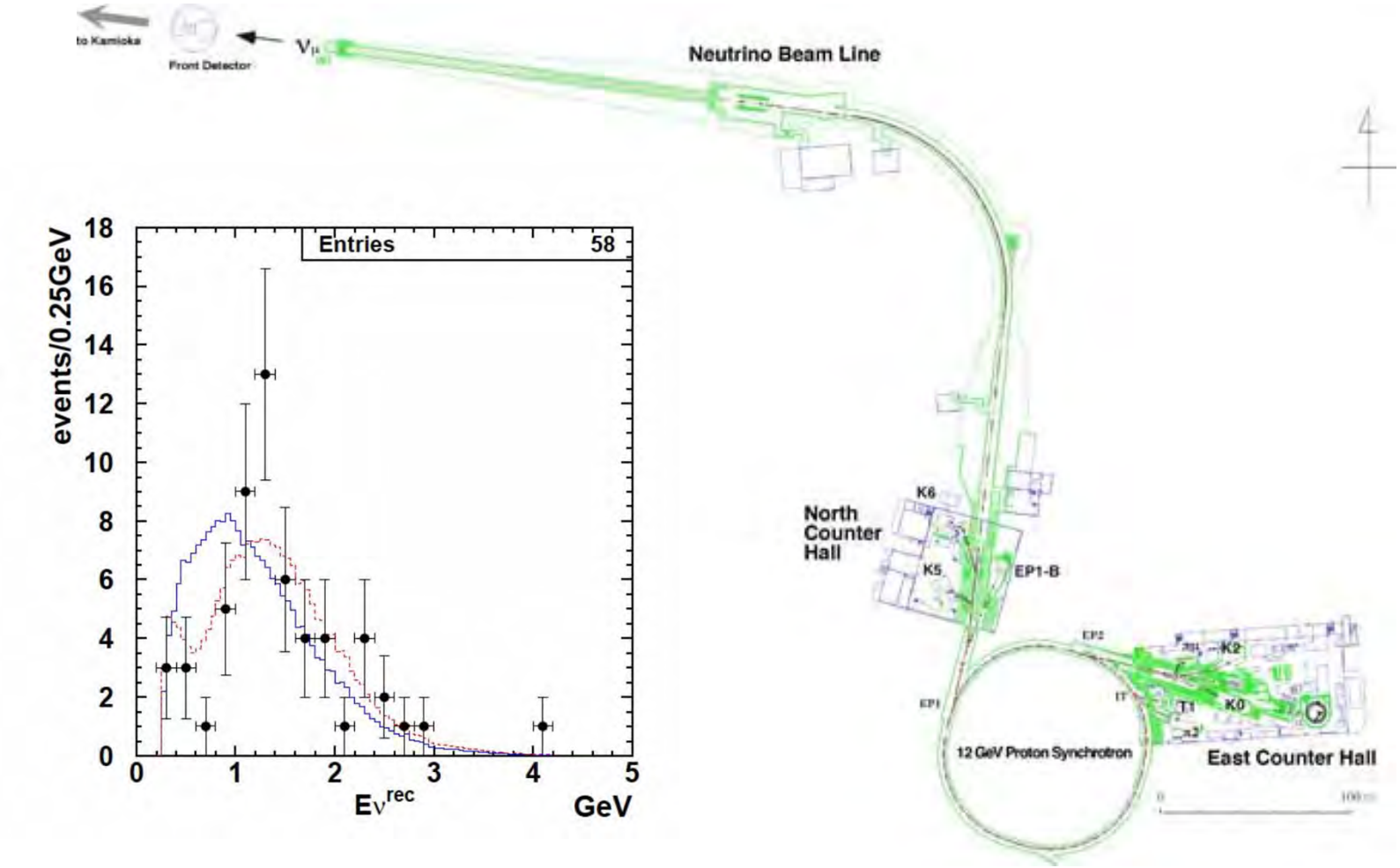
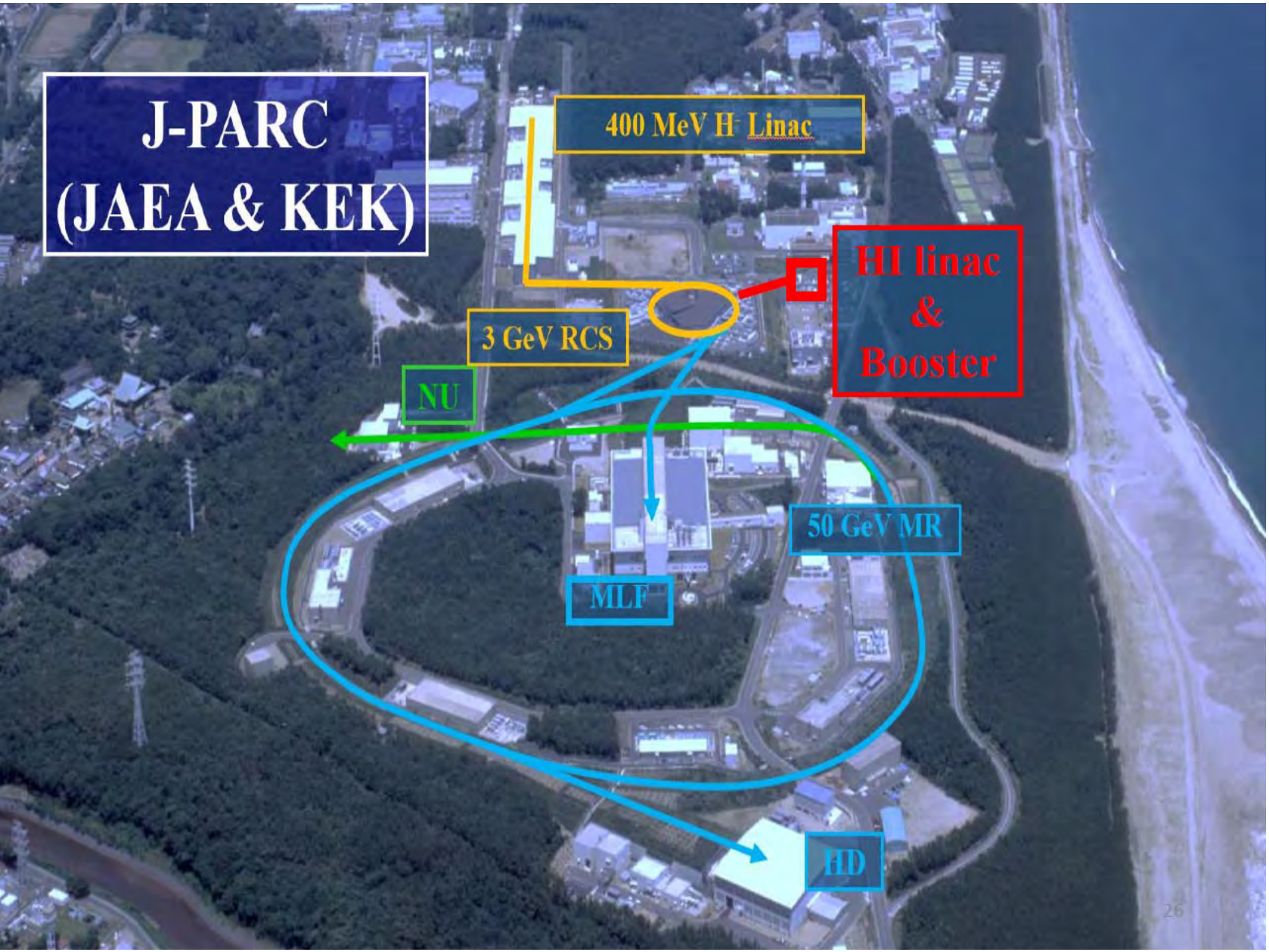


図２７　ビーム輸送系の全体図。

Central energies of about ~10 GeV/u
Aim for baryon-rich QGP production
Also try to see phase transitions between liquid and gas phases of Nuclear Matter
Likely to be realized recently at NICA (Dubna)Actually Numatron also realized at GSI as SIS18 ...

K2K（Neutrino) Beamline



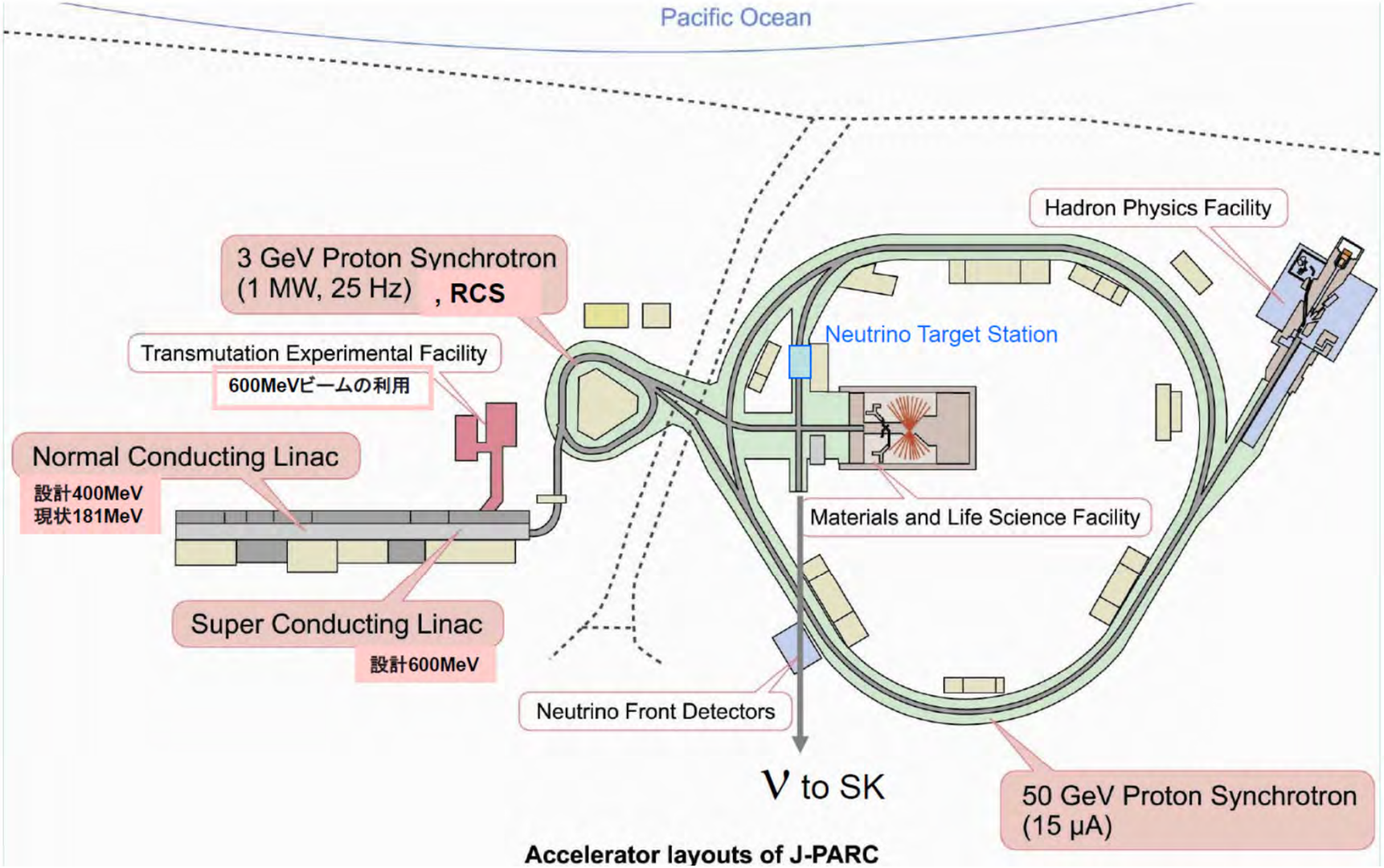


High Intensity Facility

30GeV

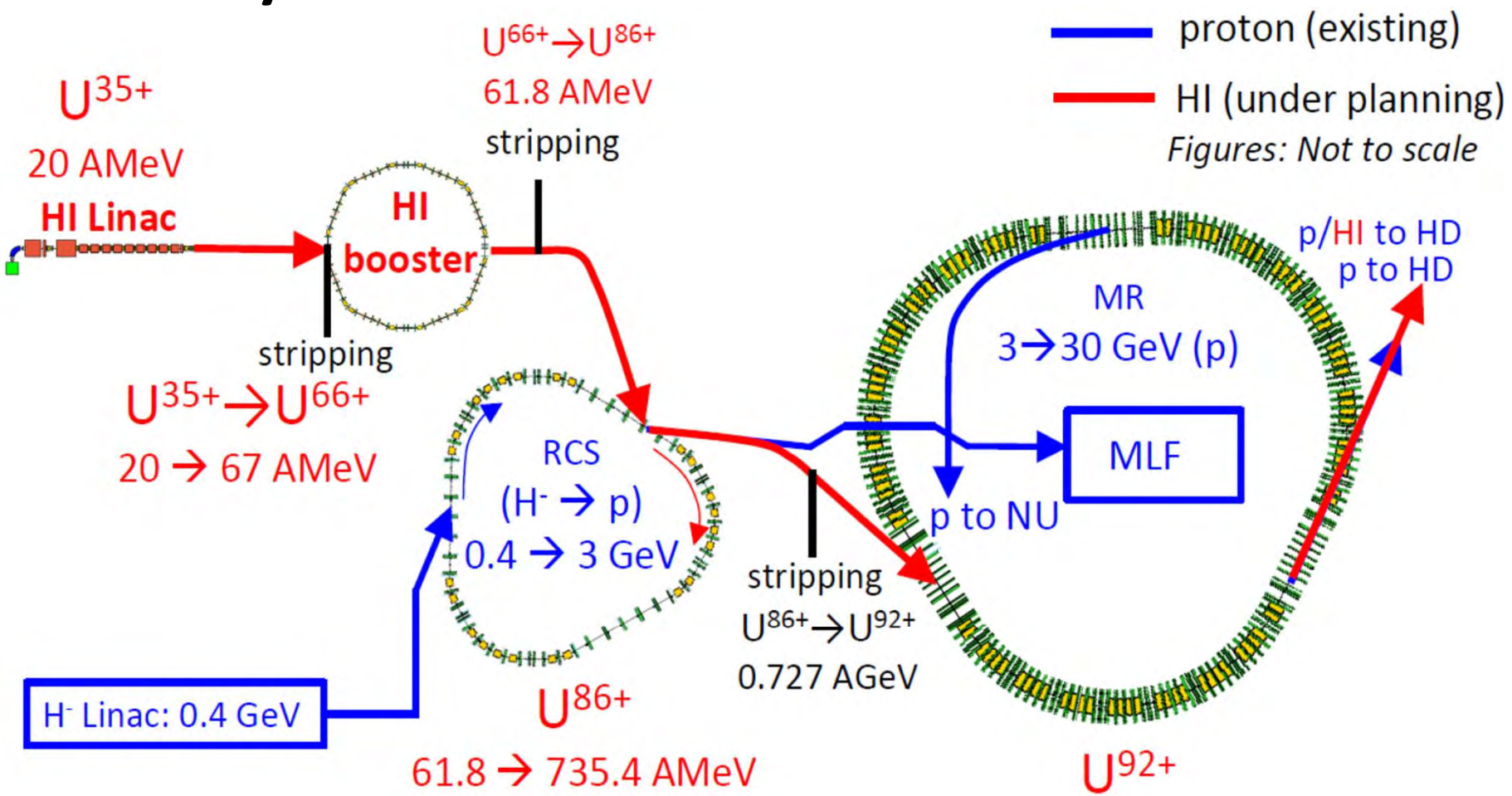
1.3MW for FE(ν), 150kW for SE.

J-PARC Accelerator Complex



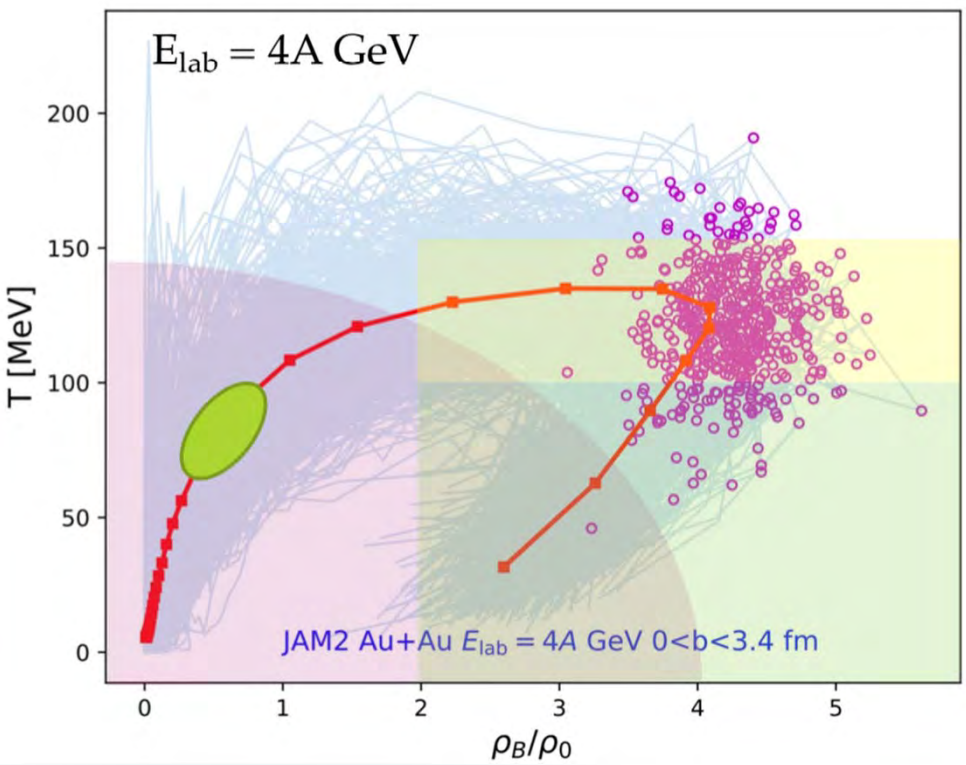
Accelerator layouts of J-PARC

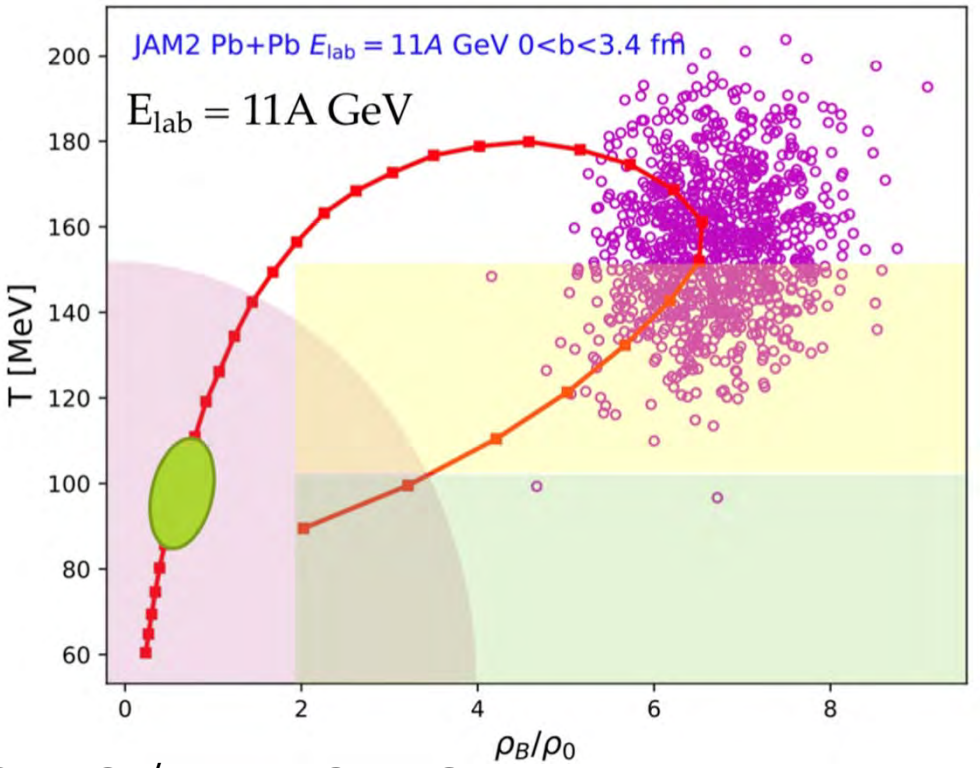
Heavy-ion Acceleration at J-PARC



In the RCS, more than 10^{11} U^{86+} ions can be achieved without any significant beam losses.

最高到達密度@J-PARC-HI

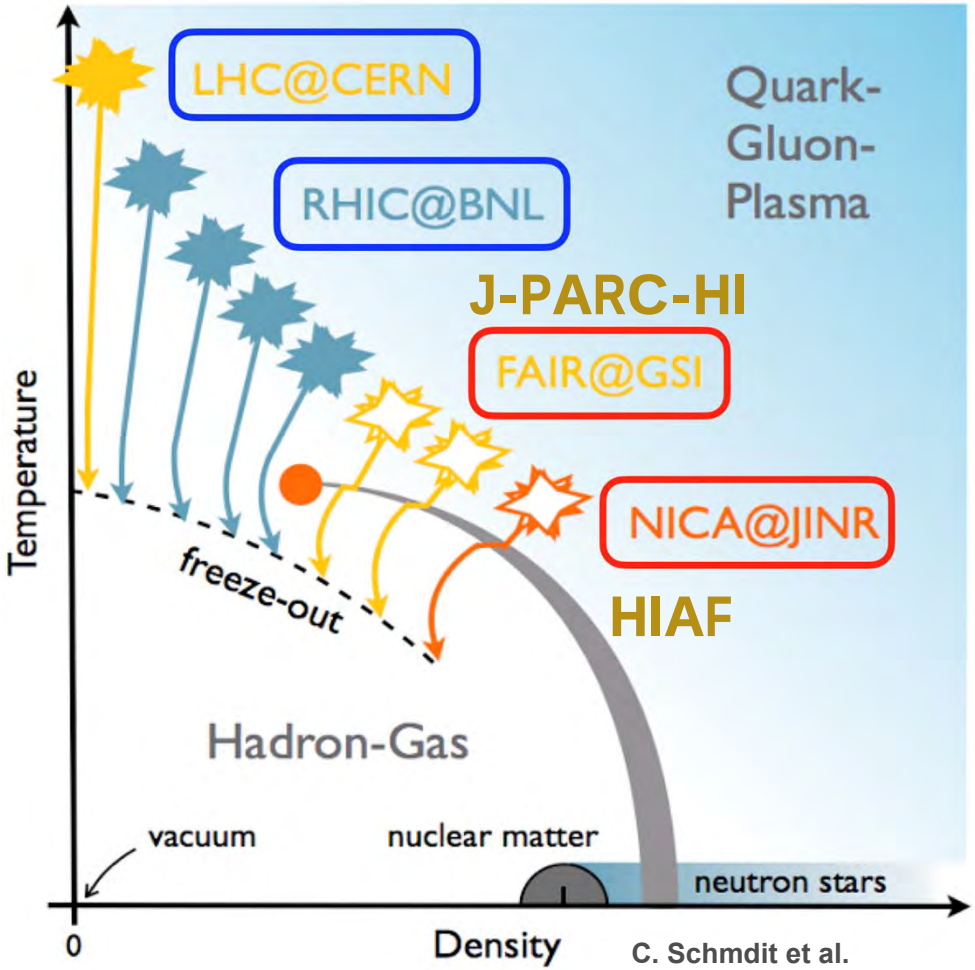




Maximum achievable density = 4-8ρ_0 @$\sqrt{s_{NN}}$ ~ 2-5 GeV
Rare event study with high intensity Beam (High density event, Lepton Pair Productions, Heavy Quark Production…)
Study of QCD-Phase Structure with High Statistics

High Energy Heavy-Ion Accelerators

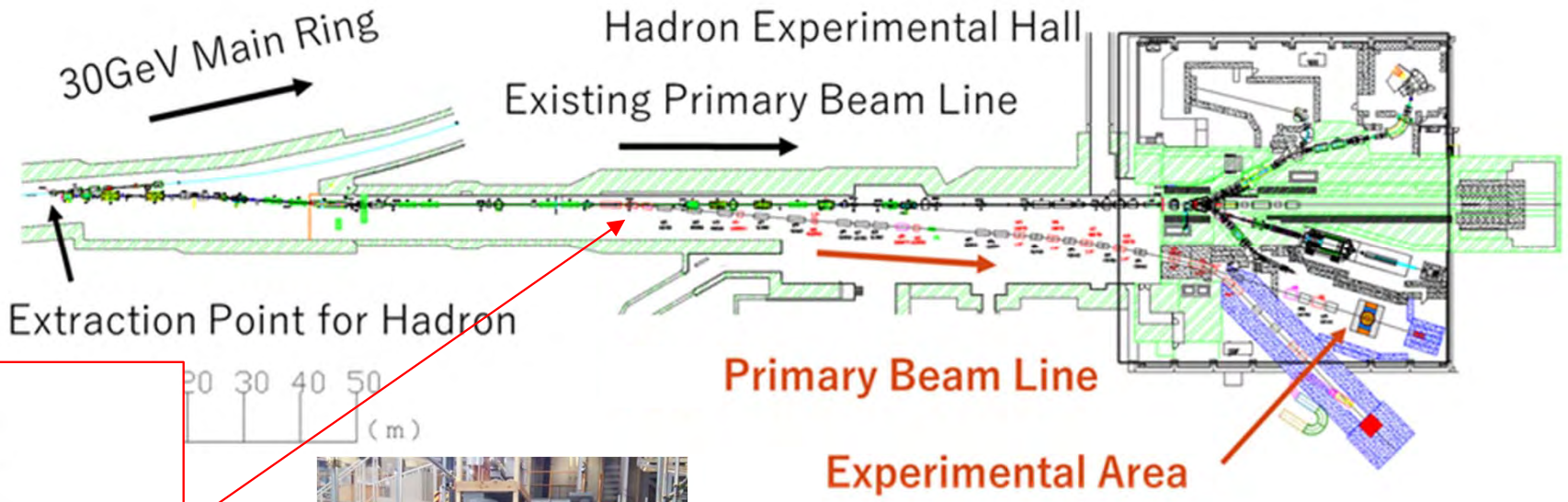
- **In Oparation**
  - RHIC@BNL (>2000, $\sqrt{s_{NN}}$=3 - 200 GeV)
  - LHC@CERN (>2009, $\sqrt{s_{NN}}$=2.76, 5.02 TeV)
  - SPS@CERN(固定標的, $\sqrt{s_{NN}}$ ~ 20 GeV)
  - SIS18@GSI(固定標的, $\sqrt{s_{NN}}$ ~ 2 GeV)
- **Under Construction**
  - FAIR-SIS 100 (固定標的, $\sqrt{s_{NN}}$ ~ 2-5 GeV)
  - NICA (衝突型, $\sqrt{s_{NN}}$ ~ 4-15 GeV)
  - HIAF
- **In Proposal**
  - FAIR-SIS300 ($\sqrt{s_{NN}}$ ~ 6-8-10 GeV)
  - FCC@CERN ($\sqrt{s_{NN}}$ ~ 39 TeV)
  - J-PARC-HI ($\sqrt{s_{NN}}$ ~ 2-5 GeV)

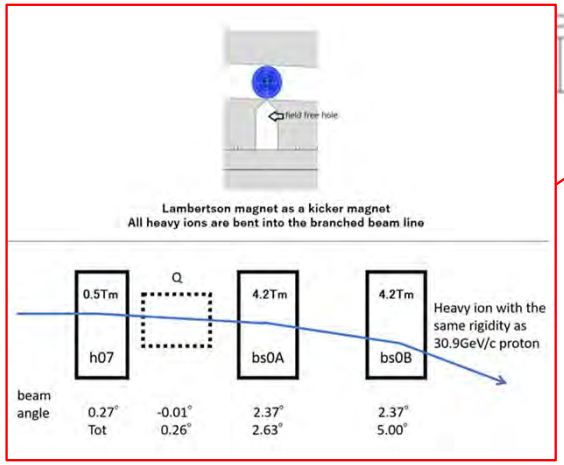


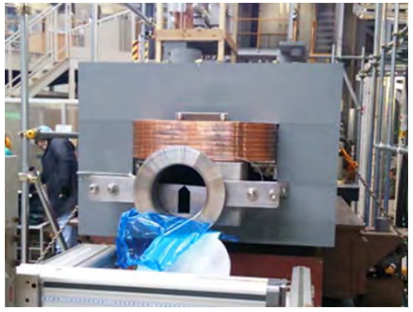
C. Schmdit et al.
J. Phys. G 44, (2017), 10, 104002

High-p line, HI transport line to the Hall

Heavy Ion beam is transported into the Hadron Experimental Hall with the existing primary beam line (high-p)
Beam rate : 10^8 Au ion / spill equivalent beam power to the proton 10^{10} / spill → No modification necessary in the beamline / beamdump / radiation shield.

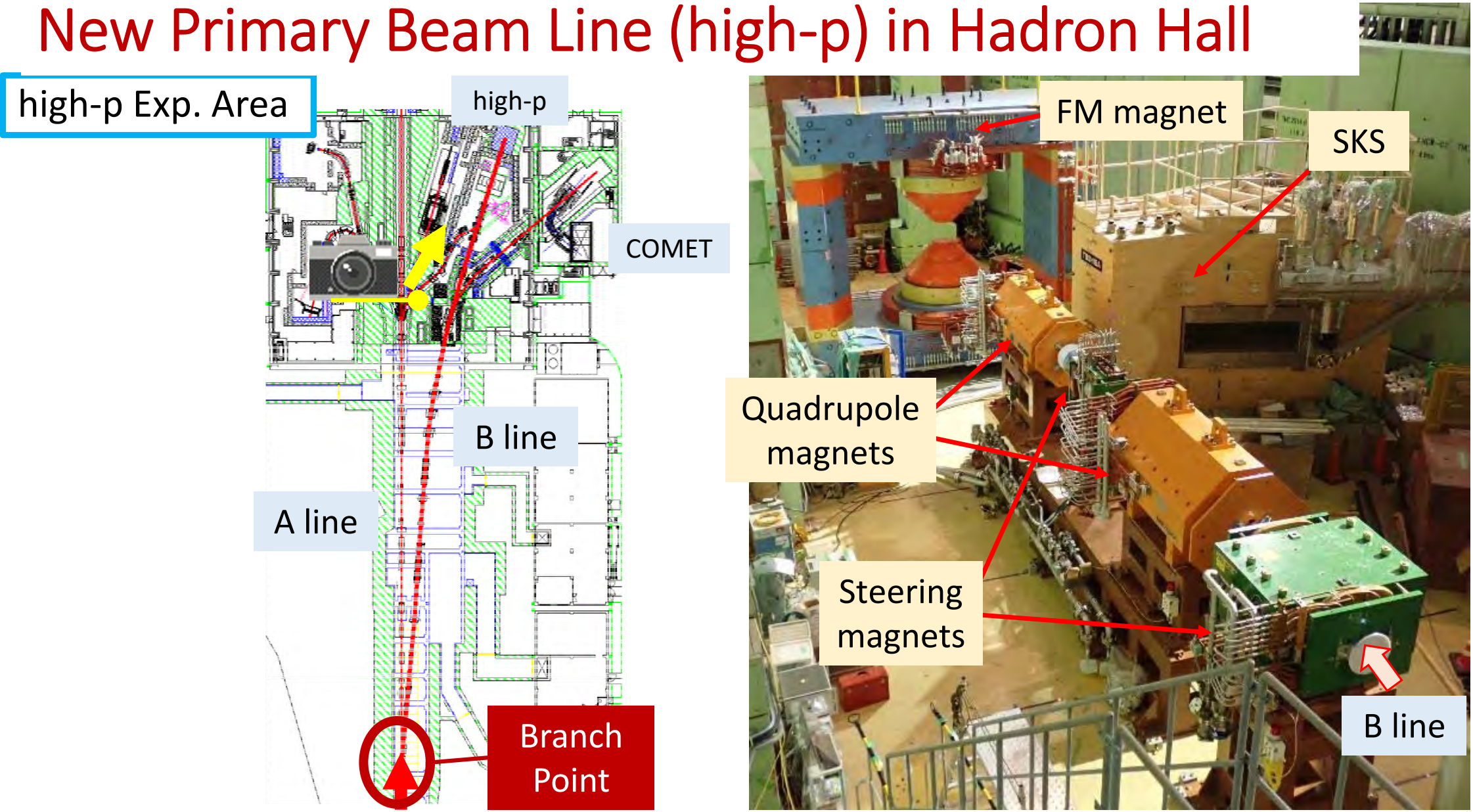






Branching Point and Magnet

New Primary Beam Line (high-p) in Hadron Hall



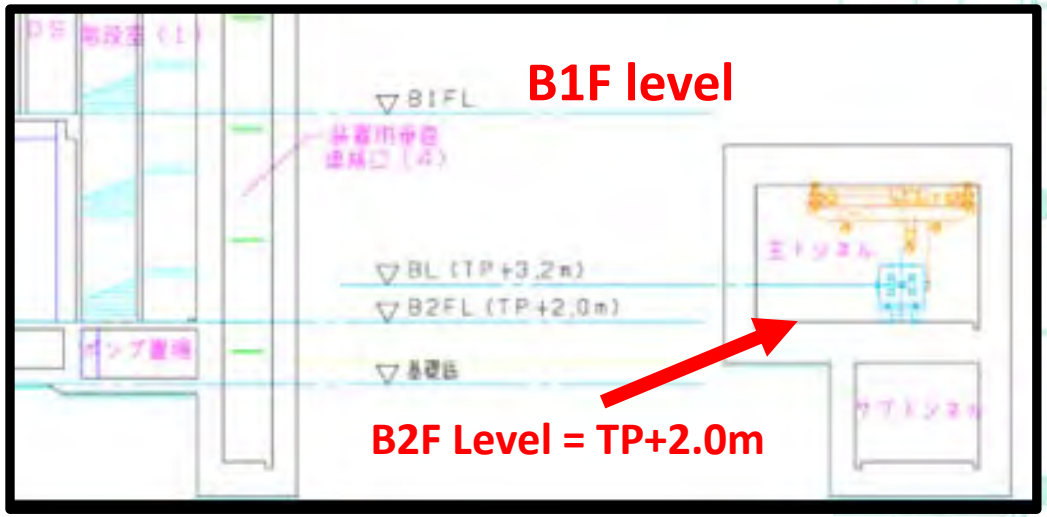
Old plan in 2022

New plan in 2023

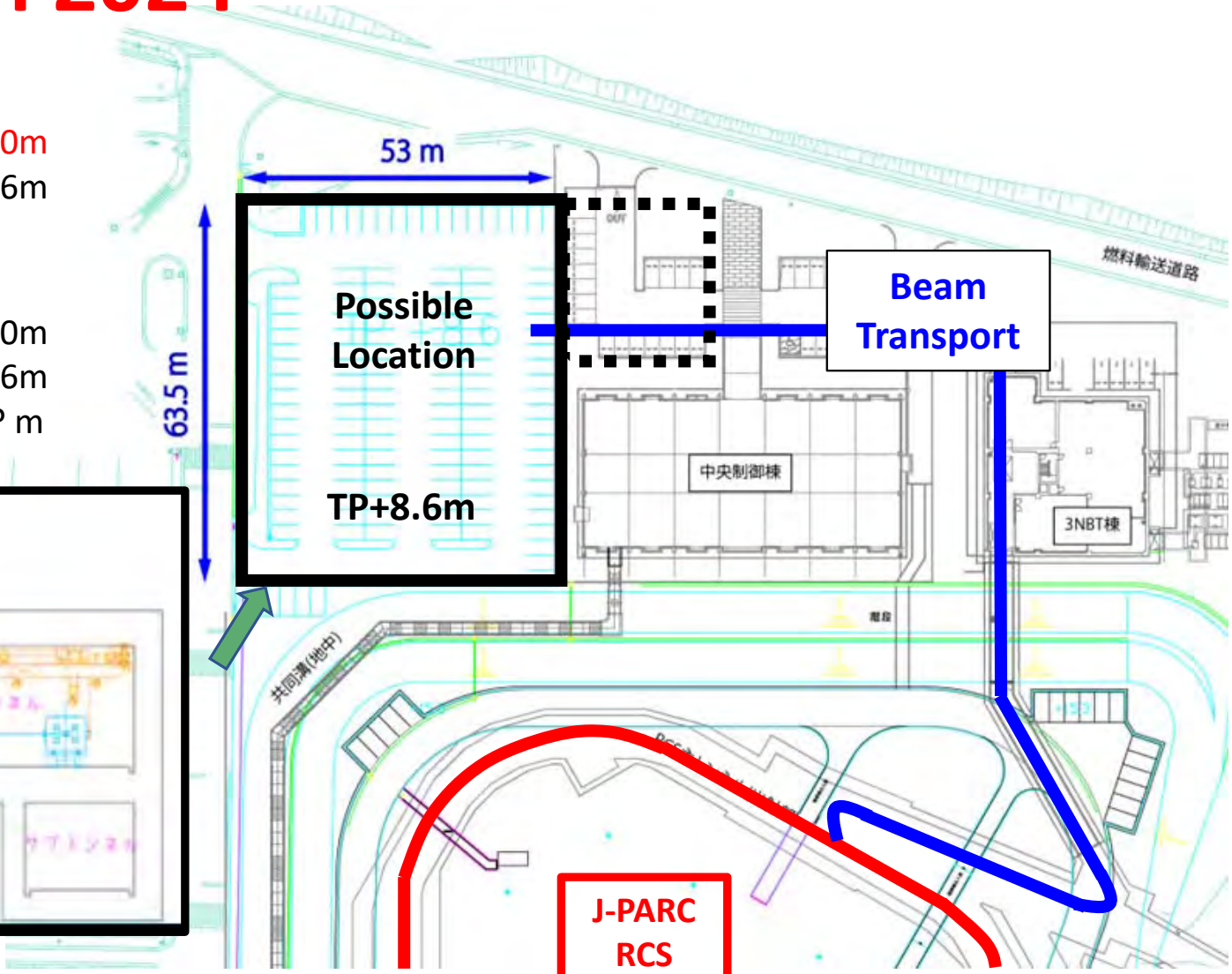
Location and Plan in 2024

Floor Level of J-PARC RCS（B2F） : TP+2.0m
Present Parking Lot（New Proposal） : TP+8.6m

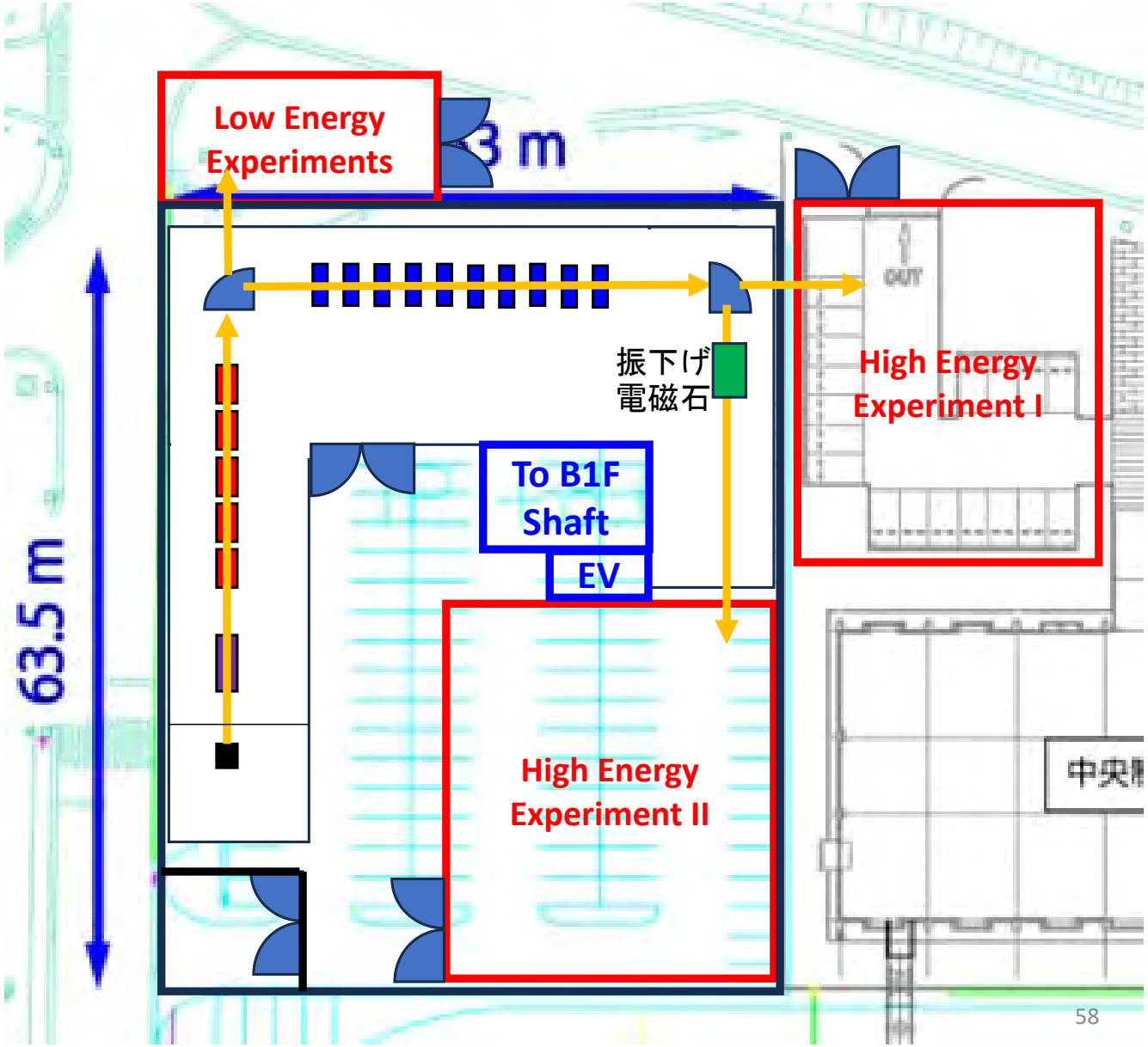
Heavy-Ion Frontier Facility
Ring＋BT＋α（B1F） : TP+2.0m
Linac＋Experimental Facility（1F） : TP+8.6m
CNTL＋Water＋Electricity（2F） : TP+?? m



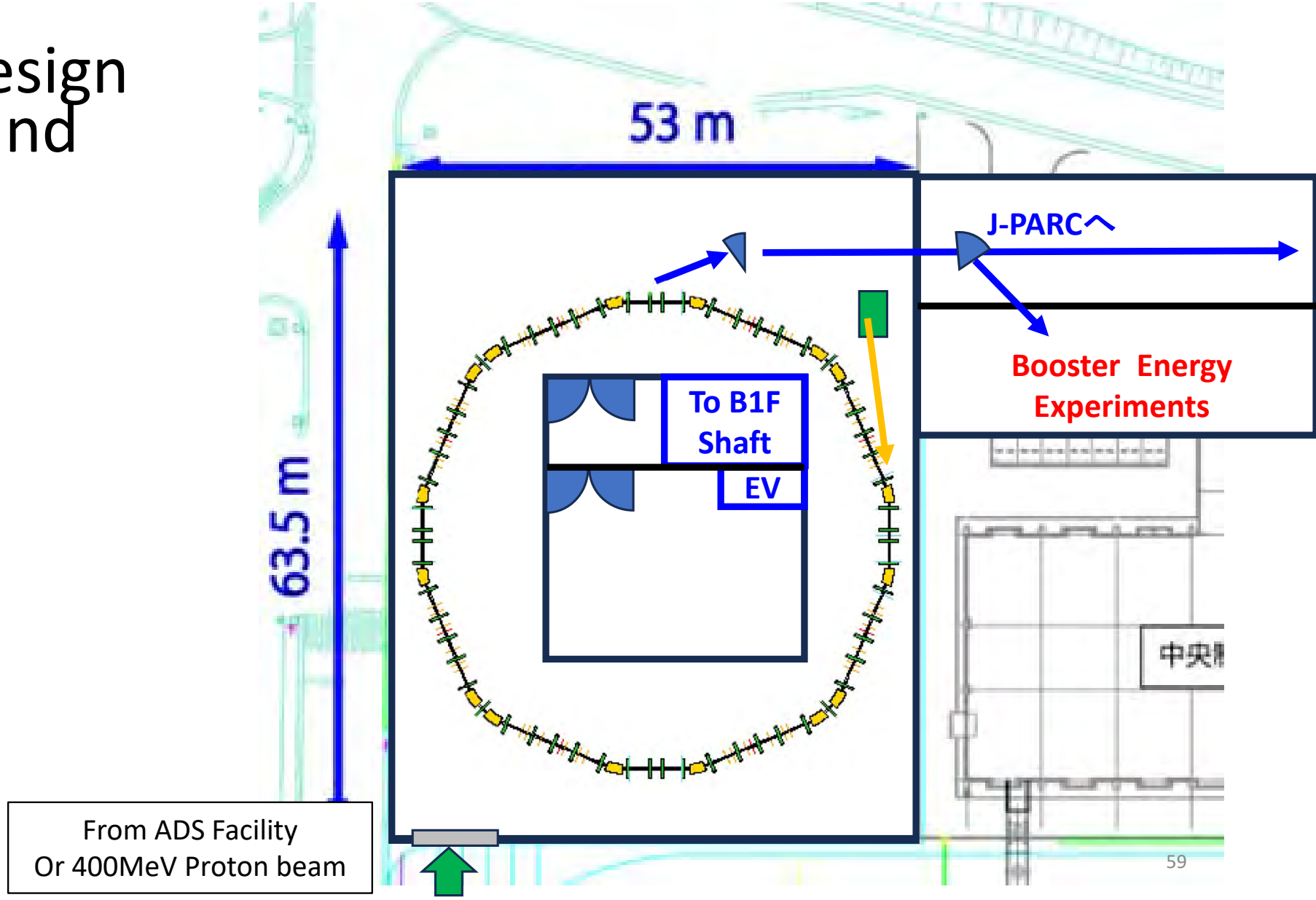
J-PARC RCSの断面



Building Design
B1F level



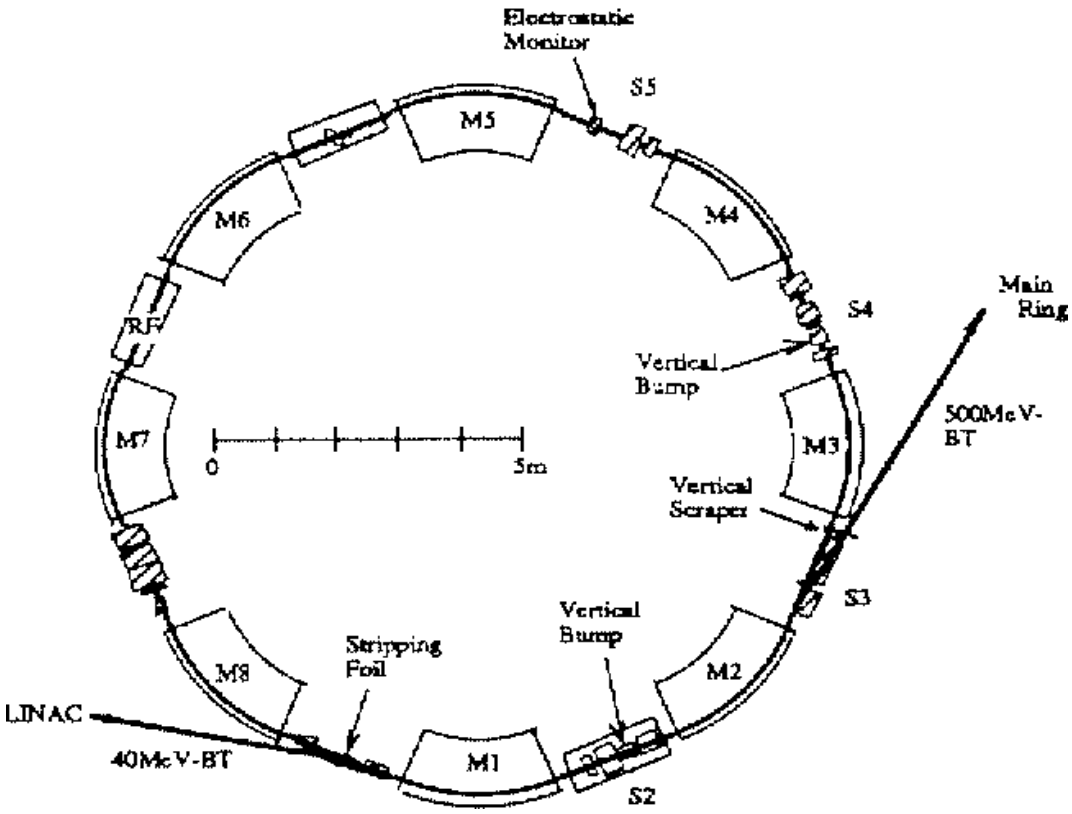
Building design Underground B2F Level （Phase-II）

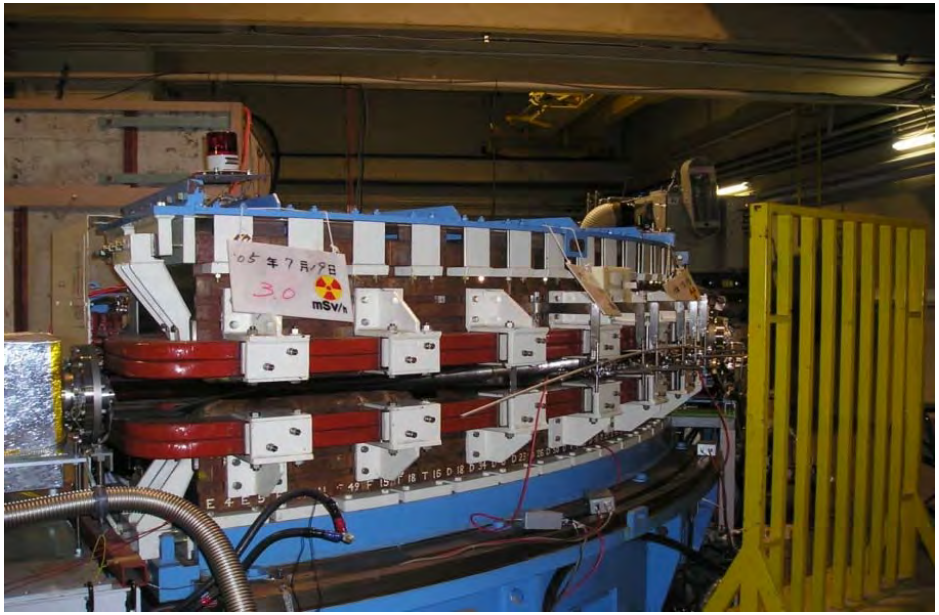


Old KEK-12GeV PS Accelerator Complex

Already shut down

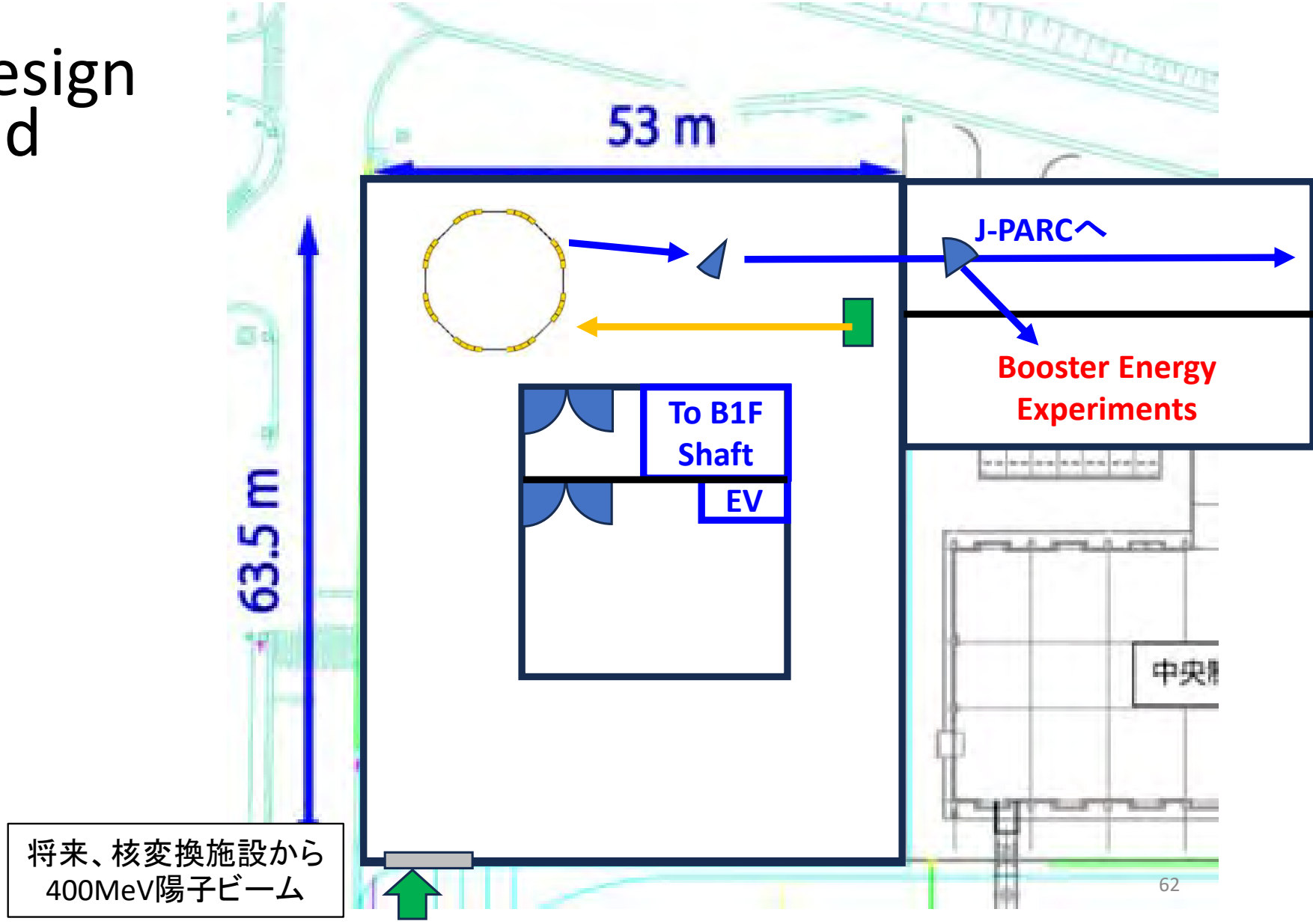
KEK-PS Booster





- **Real Radius ~6m.**
- **Circumstance 37.7m.**
- **Max. B 0.84T.**
- **Repetition Rate 10Hz.**
- **Betatron Frequency is $2.17_H/2.30_V$**
- **Max Energy (proton) 500MeV**

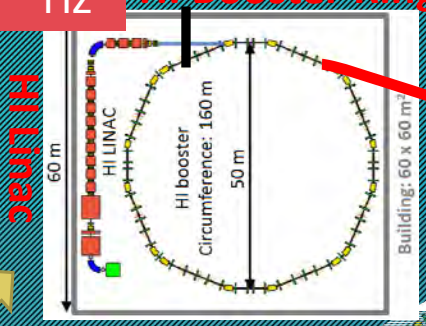
Buildding Design Underground B2F Level （Phase-I）



Staging Plan

Full Spec : 10^{11} Hz

Phase I : 10^8 Hz



Au^{51+}
→ 32.2 AMeV

stripping

3 GeV RCS
(p)
0.4 → 3 GeV

Au^{56+}
→ 500 AMeV

H⁻ Linac: 0.4 GeV

stripping

MR
3→30 GeV (p)

MLF

p/HI

Hadron Facility

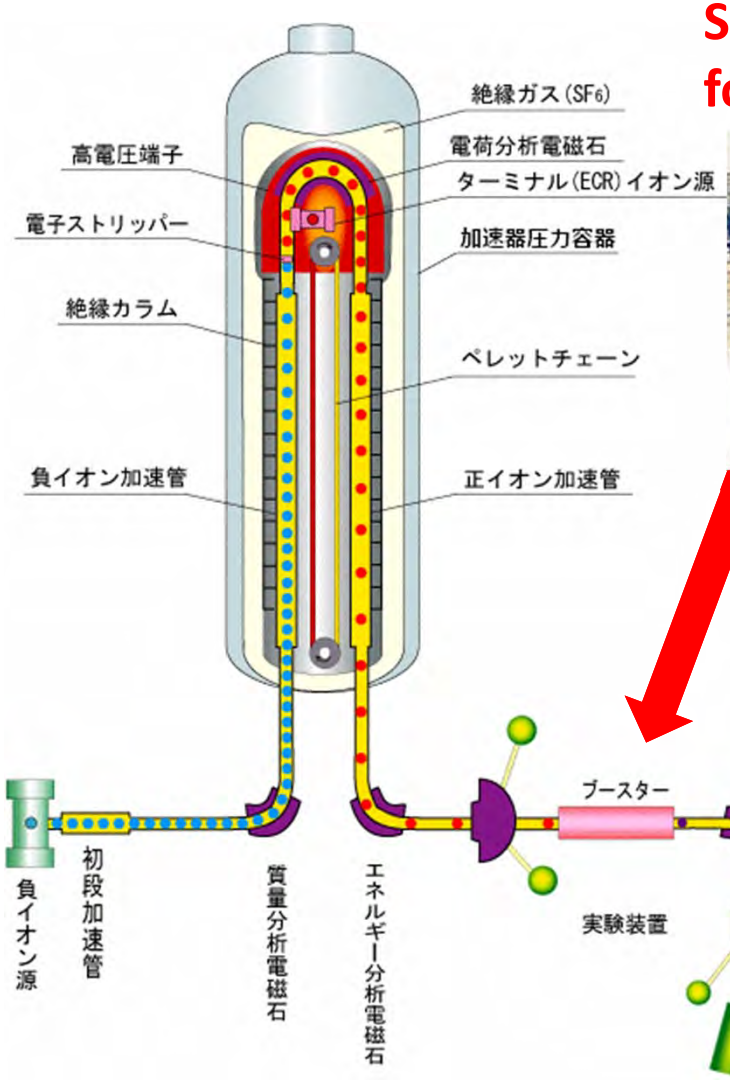
Au^{79+}
→ 11.5 AGeV

proton

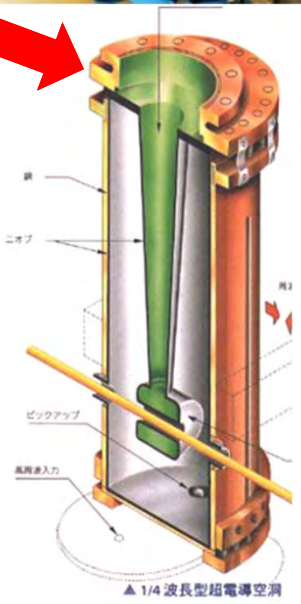
HI

E_{lab} (Au) = 1–12 AGeV → $\sqrt{s_{NN}}$ (Au) = 1.9–4.9 GeV

Existing SC Cavity at old 20UR Tandem VdG



Superconducting Booster LINAC for 20UR Tandem VdG is existing!

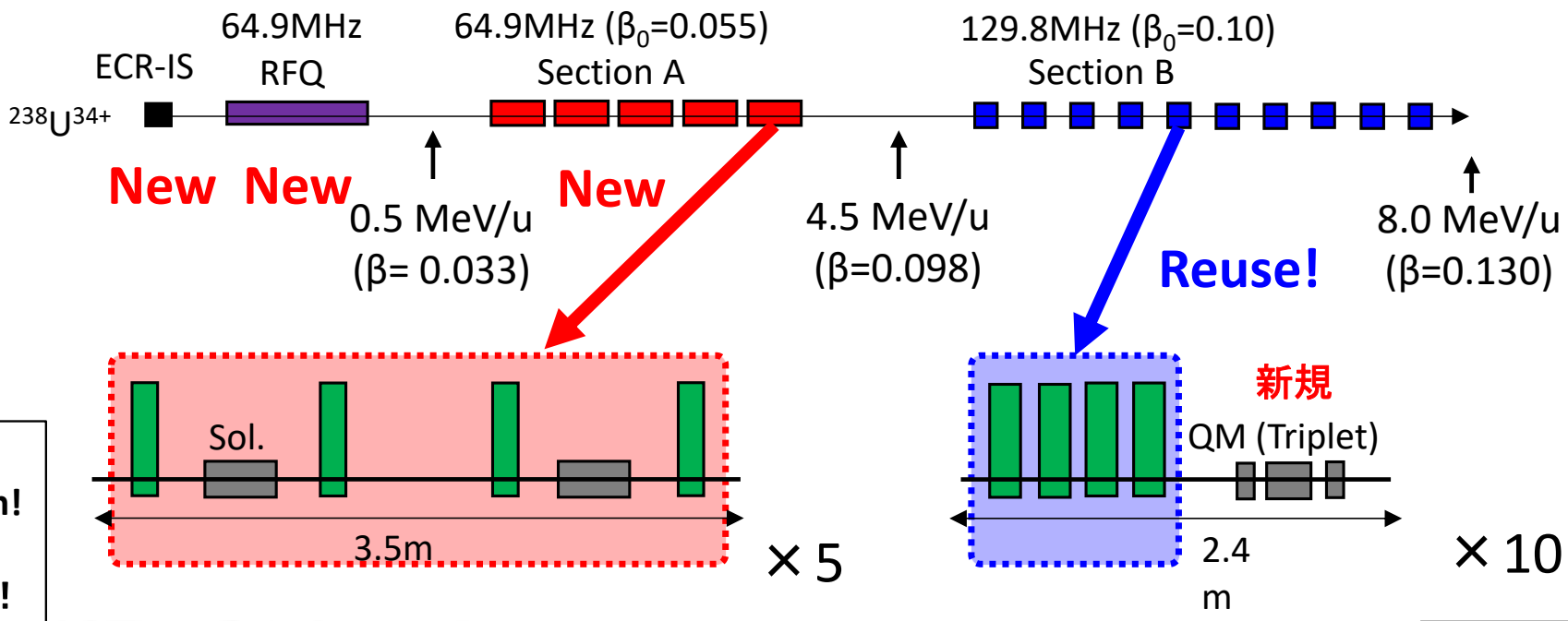


Typical Acceleration Energy =

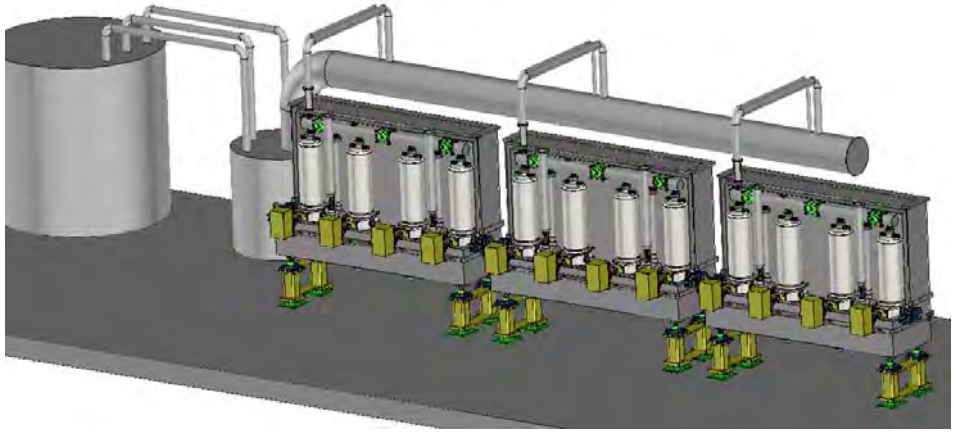
A ～100 region: 10 MeV/u

A ～50 region: 20 MeV/u

New H-I Linac Construction using Old SC Cavity



SC Cavity New System! Design Completed !



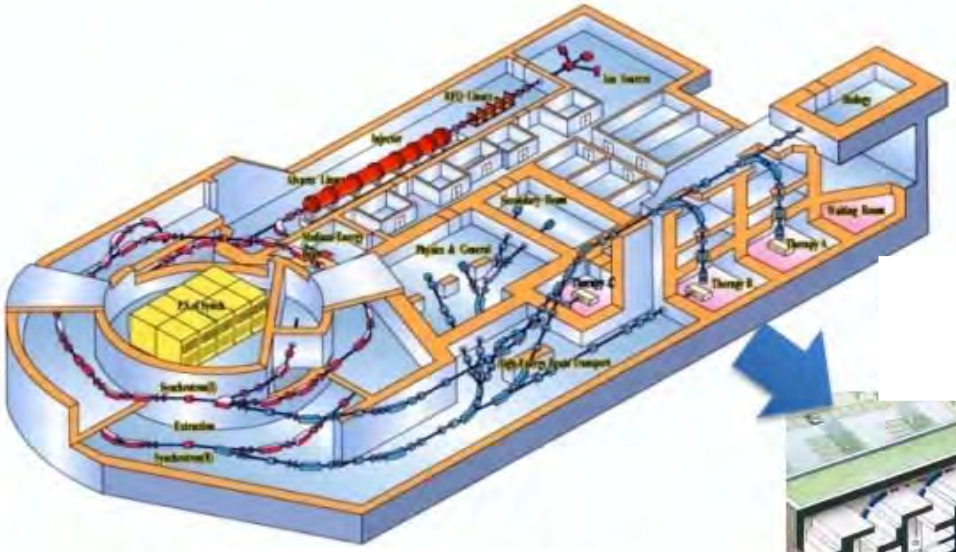
40 Existing SC Cavity

Summary

- J-PARC-HI project is the third chance to realize high-energy Heavy-ion accelerator in Japan.
- By adding 400 MeV-proton-equivalent-momentum heavy ion beam injector, J-PARC Accelerator Complex can accelerate heavy ions up to its full energy!
- We already have an experimental area for primary beam experiments in Hadron Hall.
- Using old but existing **KEK-PS 500-MeV Booster ring** and **JAEA Tandem Booster linac**, we can save construction money and construction time of this Heavy-Ion injector.

Future Future-Plans : Unstable Ion beams from ADS

Recycle of old medical accelerators



1994: **NIRS HIMAC**

120 x 65m

Medical Accelerators becoming smaller and smaller!
Existing ones are “too big” and can be reused as a heavy-ion injector?

2010: **Gumma Univ.**

60x45m (1/3)

Quantum Mess
20x10m (1/40)