2006. 1. 14

《ビームチャンネル　と　超伝導応用》

平林 洋美

1971年　KEK 設立
1973年　田無実験室→つくば移設終了

§ビームチャンネル部門
【久寿米朝男】★、美甘昭二、平林洋美、真木晶弘、黒川真一、高崎稔、田井野光彦、鈴木千尋、山本明、真庭　　、石井晴美、稲垣隆雄、(小野正明、【木代純逸】)

★：初代責任者 ( )：受託大学院生

1974～77年　ビームチャンネル部門
1977～87年　部門責任者
1978年　　　特別プロジェクト・チーム
「π１ビームにおける超伝導マグネット・システム」建設
⇒多くの若手人材

1983年　π１ビーム完成
1988年　低温センター長
　以後、超伝導マグネット関連プロジェクトを支援。

§　建設したビームチャンネル

１次ビーム・・・◇EP1、EP2
内部標的ビーム・◇π２
２次ビーム・・・◇K1(3⇔7GeV/c)⇒HBC,DCS有り
◇K2(1.5⇔3.0GeV/c)⇒同上
◇K3(0.5⇔1.5GeV/c)⇒同上
◆π1(4⇔7GeV/c)☆

☆One SC Septum & Two SC Dipoles
◇πμ(≒200MeV/c)
◎K means separated or enriched Kaon beam.

§　超伝導マグネット(SCM)

1960年代の中程より、銅安定化ニオブ・チタン(NbTi/Cu)線が開発され、最初にアルゴンヌ国立研究所(ANL)で水素泡箱の2Tソレノイドに適応された。

ラザーホード・ケーブル(超伝導線の成型撚線)の発達により、加速器マグネットなどへの応用が可能になった。
大型陽子加速器(例えばTevatron, LHCなど)および大型測定器では、超伝導マグネット・システムの採用は常識となった。

我が国の、実用的超伝導マグネットの活用は、1970年代の後半ビームチャンネルから始まった。すなわち先ず、電流シート型、方形断面を有するPanofsky Quadrupole Magnetが開発された。

　つづいて二基の大口径超伝導双極マグネット(SD430×2)と一基の超伝導セプタムおよび大型ヘリウム冷凍・液化機とからなるシステムが【π１ビームチャンネル】に投入され、高運動量の二次粒子であるpionの取り出しに成功し、長期間連続運転された。この開発には、所内に「特別プロジェクト・チーム」が編成され、ビームチャンネル部門以外からも、全所的に将来、超伝導マグネットの開発を目指す人材が多数参加して、腕を磨いた。

　この特別プロジェクト・チームの中から、超伝導双極、四極マグネットおよび大型ソレノイドと、それらのヘリウム冷凍・液化システムを担う多くの人材が輩出した。

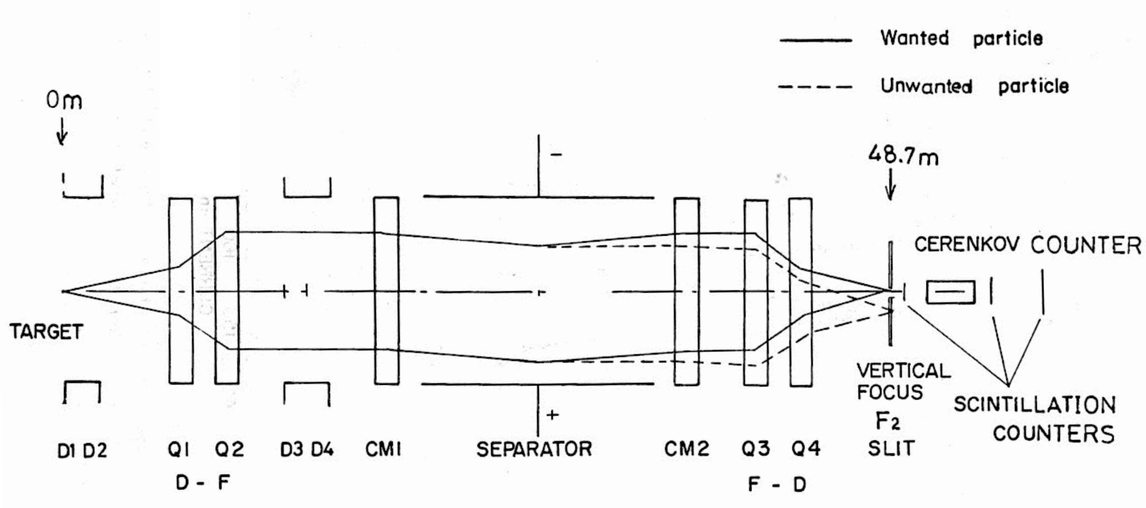


Fig. 6. The schematic beam envelopes of the beam K1 (vertical).

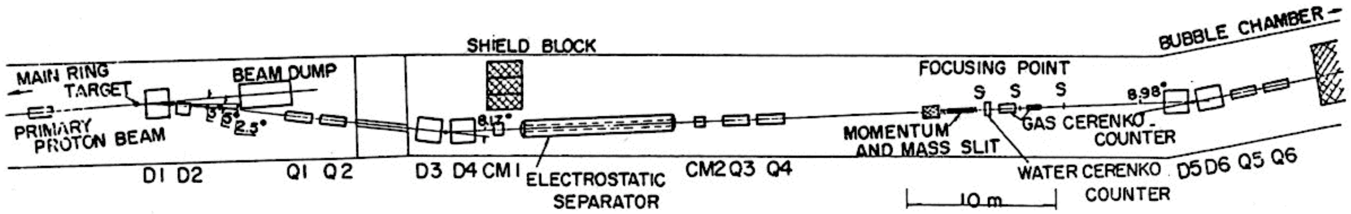
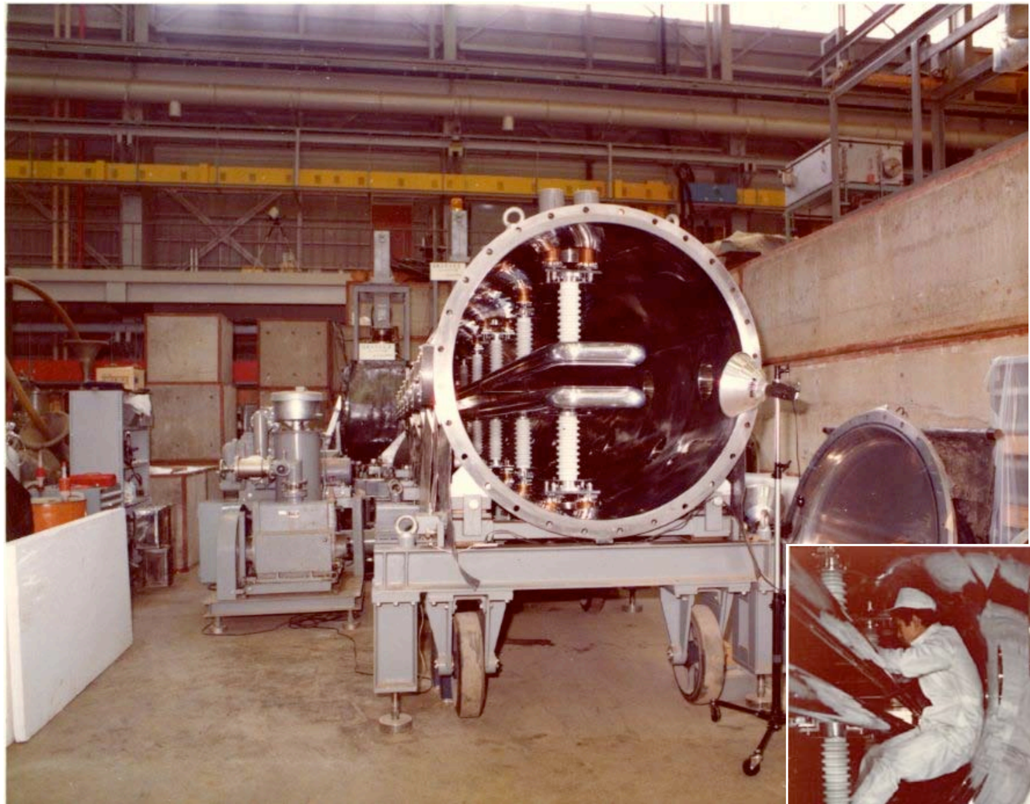


Fig. 5. Lay out of the beam K1.

Electrostatic Separator



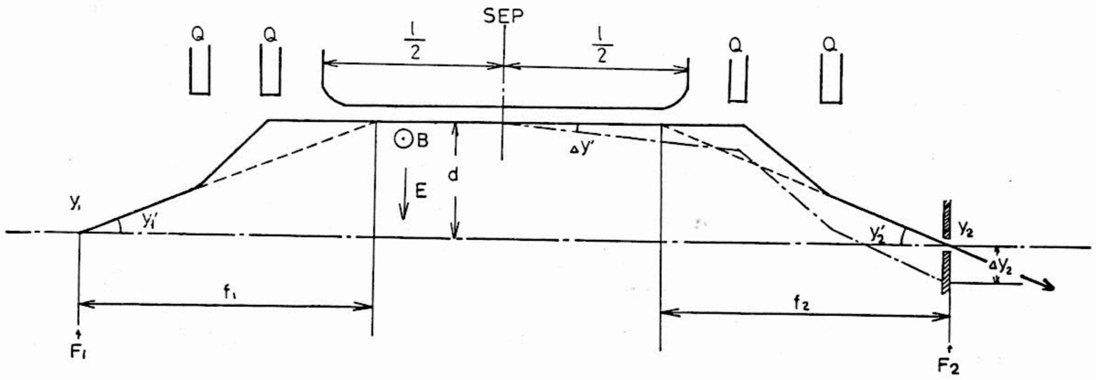


Fig. 4. Basic principle of the electrostatic mass separation.

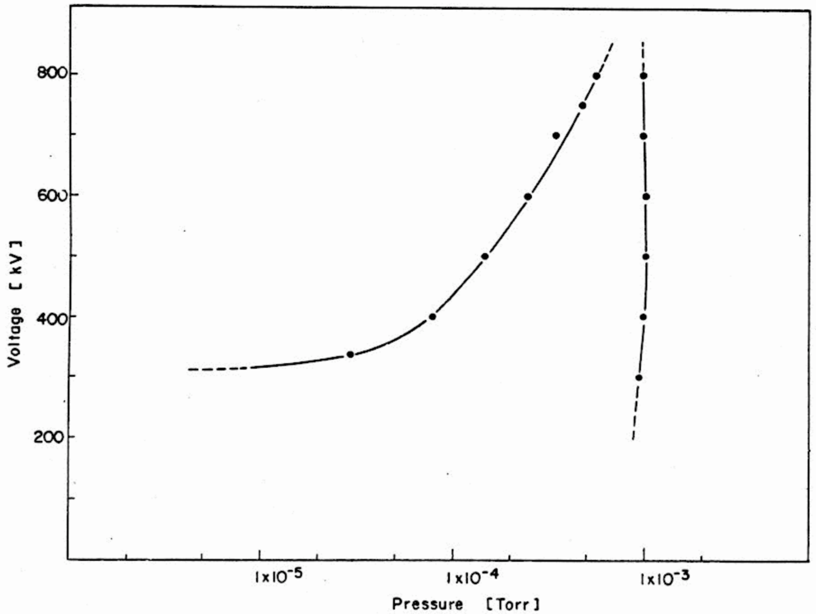


Fig. 3. Pressure-voltage curve of the 9 m electrostatic separator

KEK ELECTROSTATIC SEPARATOR

Type	Mark I
Length	9 m
Maximum field	80 kV/cm
Electrode spacing	10 cm
Maximum high-voltage	800 kV
Working field	70 kV/cm
Working high-voltage	700 kV
Spark rate	2 per day
Working time between conditionings	>500 h
Deconditioning rate	$\sim 1 \times 10^{-5}$ Torr per day
Pressure plateau	$\sim 5 \times 10^{-4}$ at 700 kV
Electrodes (anode)	Stainless steel
(cathode)	Anodised aluminium
Gas	Ne-He (65%-35%)

Table 1. Present performance of the 9 m electrostatic separator.

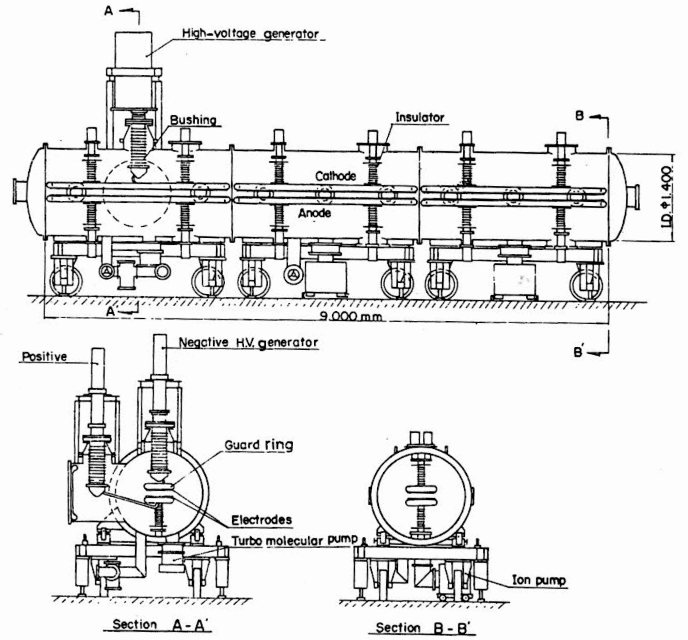


Fig. 2. The cross-sectional views of the 9 m electrostatic separator.

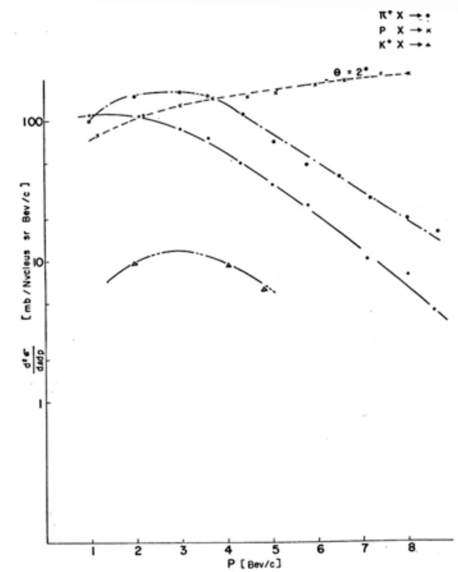


Fig. 1. The 2° secondary particle productions for 12.5 GeV incident protons.

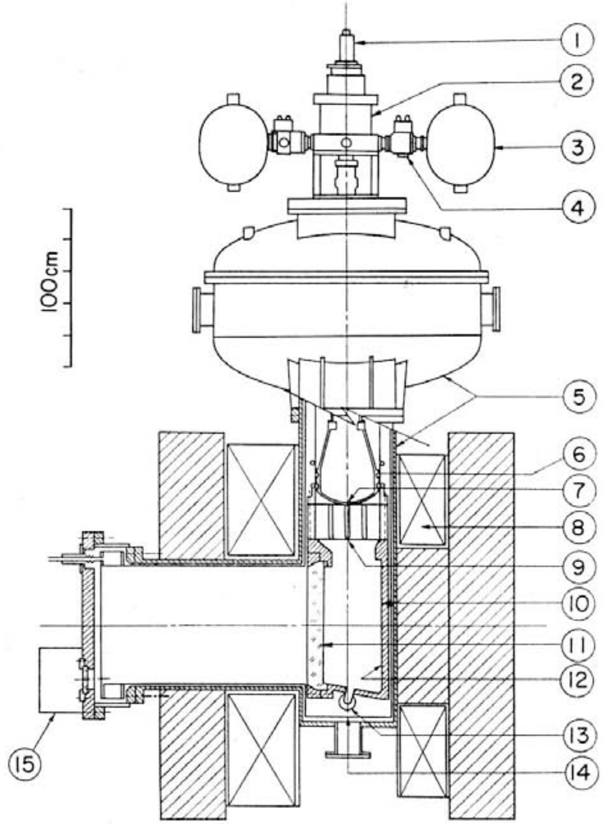


Fig. 1. Schematic cross section of the 75 cm hydrogen bubble chamber. 1. linear variable differential transformer. 2. piston actuator. 3. expansion (recompression) reservoir. 4. Boot valve. 5. vacuum tank. 6. piston cylinder. 7. cold piston. 8. magnet coil. 9. neck cooler. 10. body. 11. window glass. 12. Scotchlite. 13. cold valve. 14. super-insulator. 15. camera.

so simple and easy to fablicate, and the operation was proved to be quite satisfactory. The gasket material used was pure indium. In the typical operation of the chamber filled with liquid hydrogen, the helium pressure was ranged from 6 to 12 atm.

3.3 *Expansion system*

The idea of the expansion system of the 75 cm bubble chamber can be seen in Fig. 1 and in Table I. Many efforts were made to achieve the fast expansion and the reliability of the system. The most important parts of this system are the four Boot valves which are used to admit or exhaust the high pressure air under the driving piston. They were specially designed and tested extensivly. As will be described in the following section, this system showed very fast expansion and recompression of the bubble chamber liquid as compared with many other pneumatic expansion systems ever built, and was found to be quite useful to make the expansion ratio of the chamber liquid as small as posible and improve the quality of pictures.

3.4 *Heat insulator*

Thermal radiation from the warm vaccuum tank wall is interrupted by "super-insulator" which consists of many layers of crumpled

Table I

I. Body	
1. material:	manganese-rich stainless streel
2. liquid volume:	220 liters
3. visible volume:	140 liters
4. average inner diameter:	78 cm
5. inner depth:	35.2 cm
II. Window Glass	
1. material:	BK-7
2. diameter:	79.0 cm
3. thickness:	10.0 cm
4. flatness of the surfaces:	1.5×10^{-4}
5. distortion due to striae:	less than 1×10^{-4} or 0.3′
III. Expansion System	
1. cold piston diameter:	40.0 cm
2. maximum stroke:	4.0 cm
3. driving piston diameter:	30.0 cm
4. pneumatic valves:	four 5 cm Boot valves
5. air compressor:	IHI-JOY 35 kg/cm^2, 300 Nm^3/hr
IV. Refrigerator	
1. type:	Simple Linde
2. refrigerating power:	1000 (1500) watts at 25 K
3. liquid nitrogen temperature:	80 (65) K
4. liquid nitrogen consumption:	40 (50) liters/hr
5. inlet hydrogen gas pressure:	140 (140) kg/cm^2
6. flow rate of hydrogen gas:	320 (320) Nm^3/hr
V. Optics	
1. lenses	
focal length and opening:	75 mm/8
opening angle:	50°
distortion:	0.01% at 10°
magnification:	1/20
2. cameras	
3-eyed pulse-drive camera	
double exposures in 100 msec	
VI. Magnet	
1. weight of iron:	84.6 tons
2. weight of copper:	14.5 tons
3. coil gap:	70 cm wide × 104 cm × 84 cm
4. central maximum field:	17.8 kilogauss
5. power dissipation:	2.18 MW (6500 A × 335 V)
6. cooling water required:	140 liters/sec

aluminized mylar sheets. The inside of the vacuum tank was covered with about 50 layers of aluminized sheets on the average and the chamber was wrapped with about 60 layers. For maximum effectiveness of insulation at minimum cost and minimum space requirements, the density of stack of mylar sheets chosen was about 40 layers per cm.

From the measurement which was made when the chamber was warming up from the liquid hydrogen temperature in the vacuum tank, it was estimated that the radiant heat leak of the super-insulator from the vacuum tank wall to the cold chamber was 0.2×10^{-6}

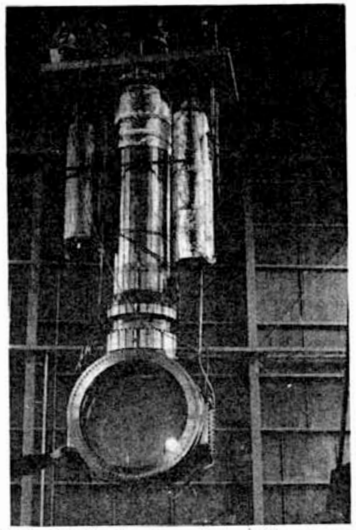


Fig. 2. Bubble chamber pulled out from the vacuum tank.

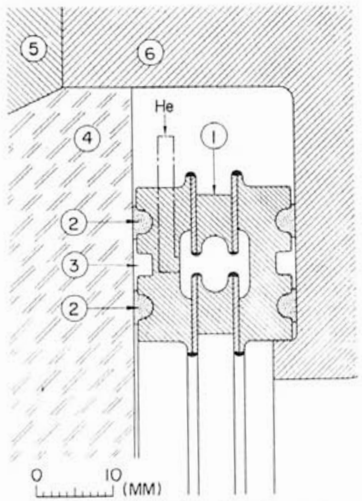
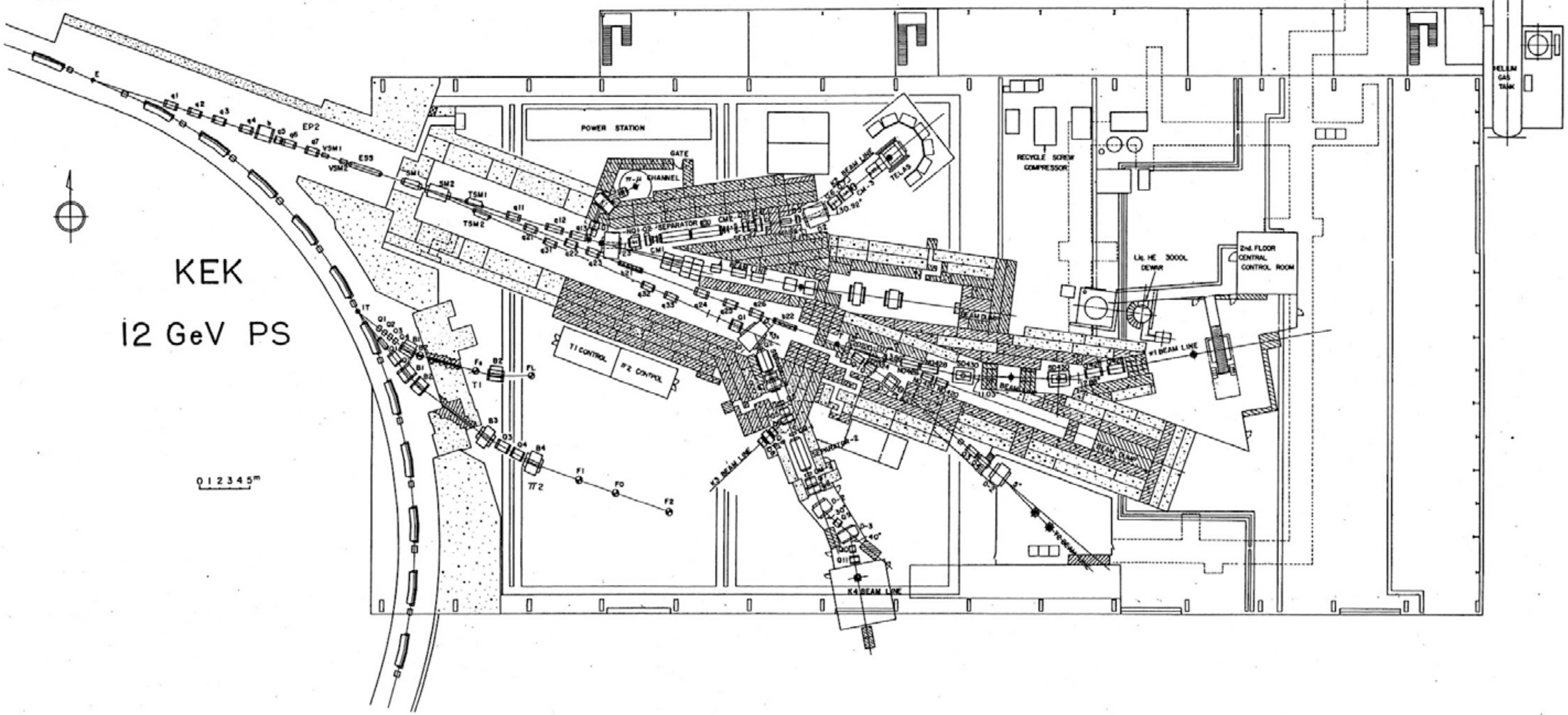
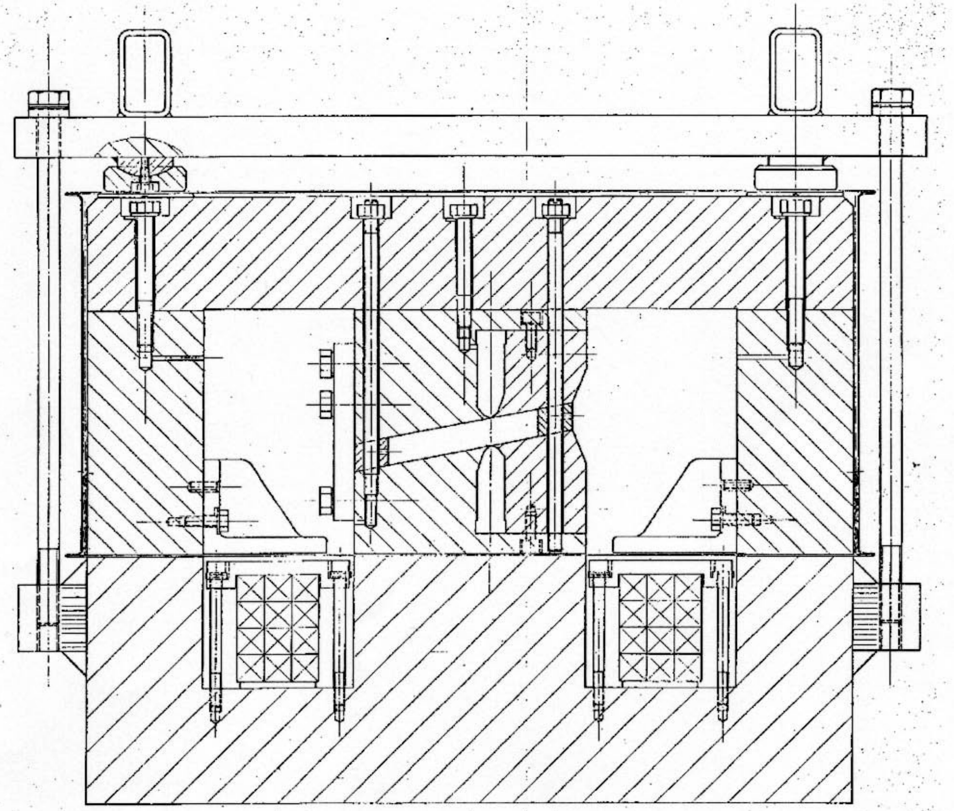


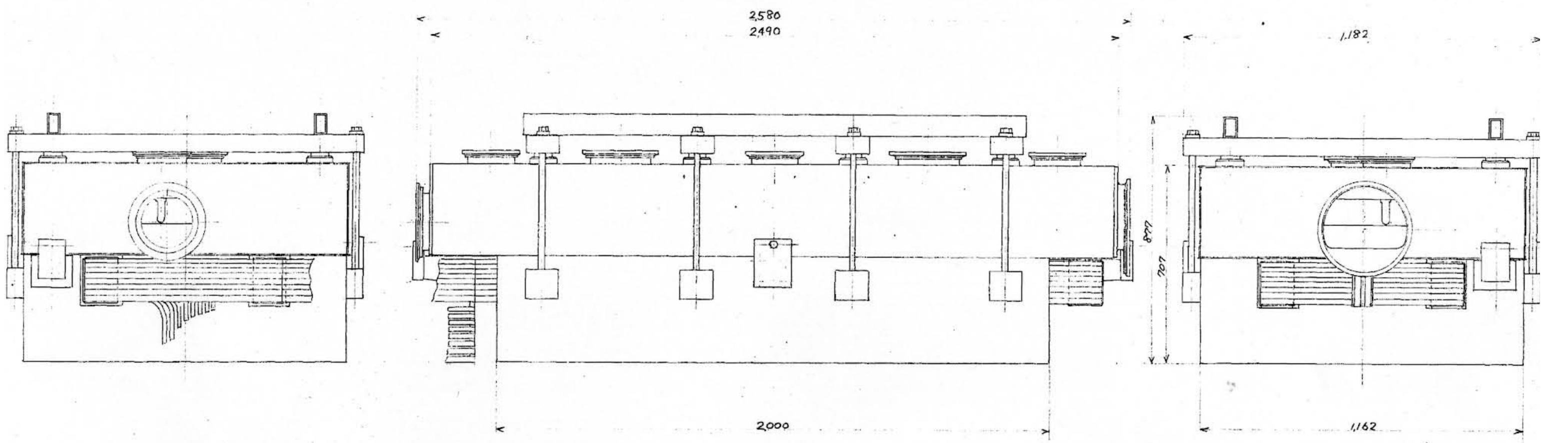
Fig. 3. Cross section of the inflatable gasket. 1. inflatable gasket. 2. indium gasket. 3. guard vacuum groove. 4. window glass. 5. window frame. 6. chamber body.

KEK BEAM LINES for COUNTER EXPERIMENTS





アイアンスプリッター　I



アイアンスプリッター　Ⅱ

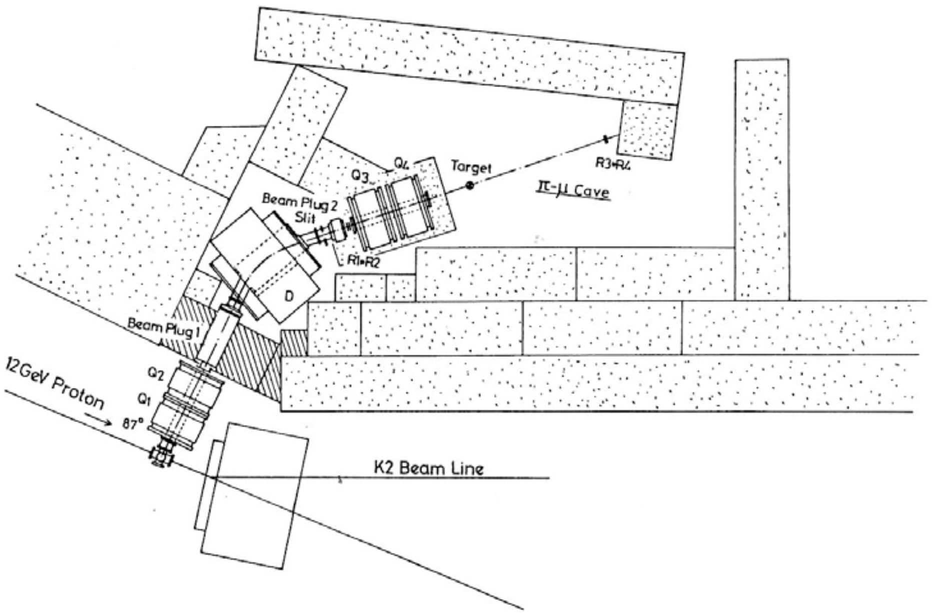


Fig. 1. The layout of $\pi-\mu$ channel. R1–R4 are the plastic scintillation counters used for channel performance test.

beam lines, K2, in the counter-experiment hall for the slow-extraction beam. Pions from a production target inserted in the primary beam line just before the K2 production target are transported via five magnets (Q_1, Q_2, D, Q_3, Q_4) to the $\pi-\mu$ cave. The maximum momentum of available beam is 300 MeV/c. The length of the line from the production target to the secondary target is 8.7 m. The "cloud" and "Arizona" muons (see Sect. 2.3) can also be transported from the production target or its vicinity. In order to use low-energy beams, particularly the Arizona muons, the beam line is evacuated. The $\pi-\mu$ cave is shielded from the primary beam lines with 3 m thick dense concrete walls and three-fold walls along the beam line. A beam plug is provided between Q_2 and D.

2.1. Beam optics

Due to the limitation of space we designed the channel with the simplest configuration, Q–Q–D–Q–Q, with 45° bending. The inner diameter of the quadrupole magnets is 20 cm, and the gap of the dipole magnet is 15 cm. Two types of channel operation modes were designed and tested, which are called "ordinary mode" and "dispersive mode". Calculated beam envelopes [1] of the two modes are shown in fig. 2. The "ordinary mode" is to maximize the pion intensity on the secondary target. In this mode the pion beam is vertically focussed by Q_1 and Q_2 at the center of dipole magnet D to avoid loss of beam by hitting the pole pieces of the dipole magnet. The

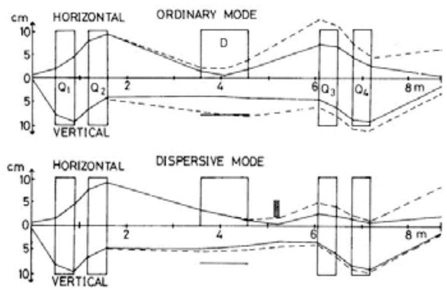
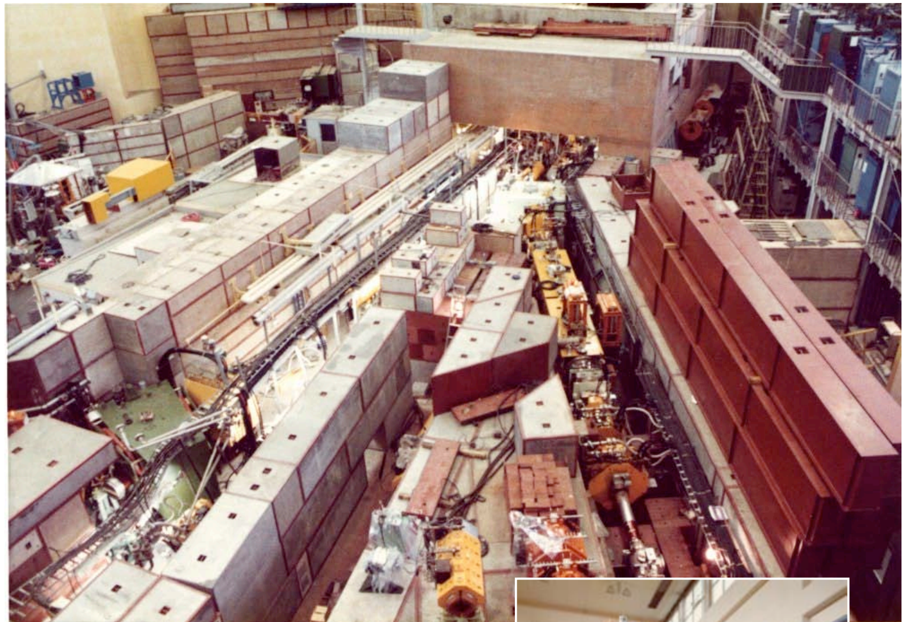
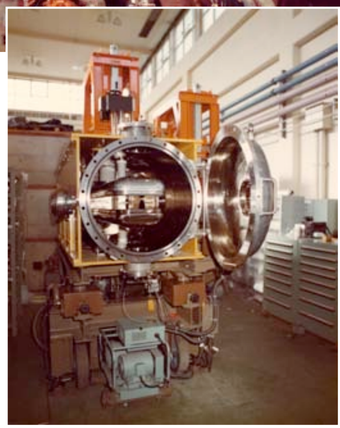
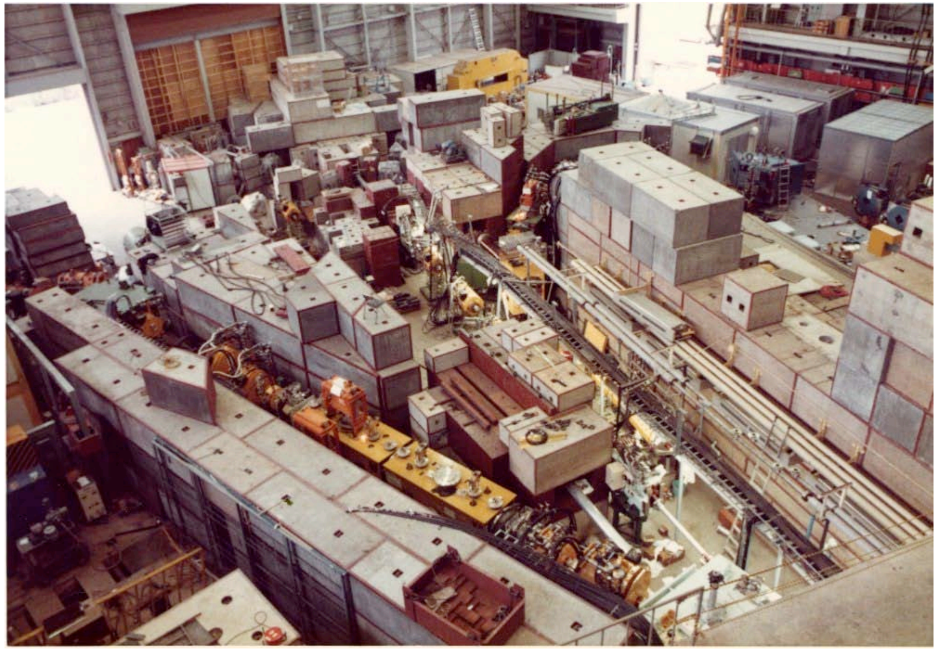


Fig. 2. Calculated beam envelopes of (a) the "ordinary mode" with central momentum p_0 (solid curve) and $p_0 \times (1 \pm 0.06)$ (dashed curve) and (b) the "dispersive mode" with p_0 (solid curve) and $p_0 \times (1 \pm 0.025)$ (dashed curve).

Slow Extracted Proton Beam and Kaon Beam Lines







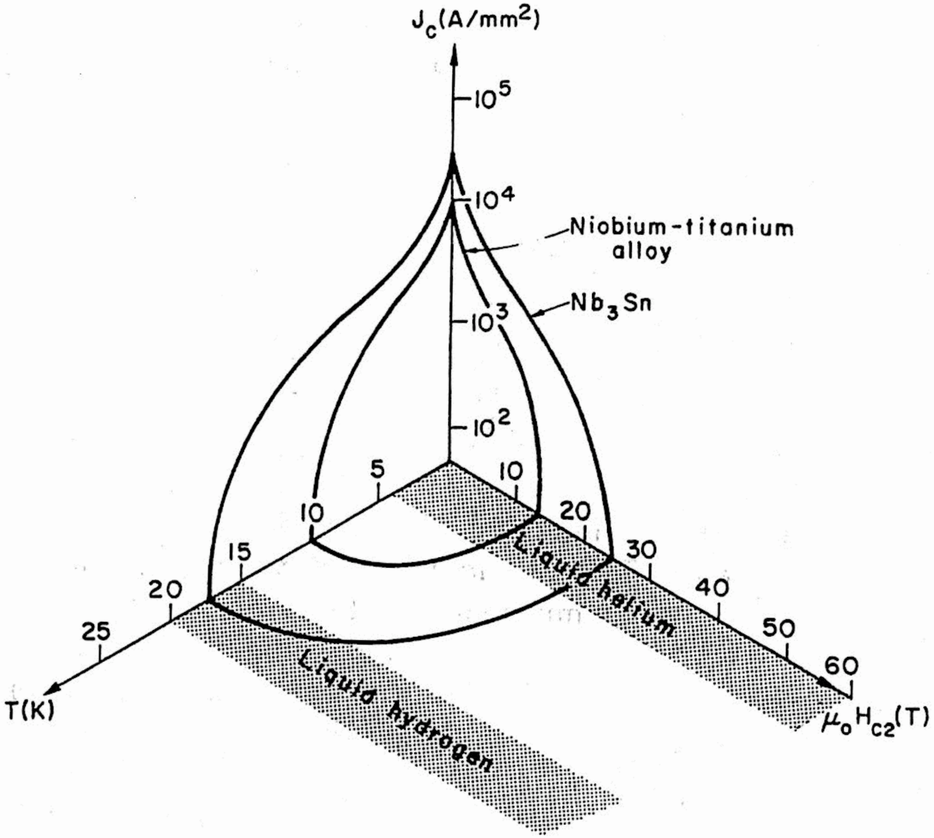
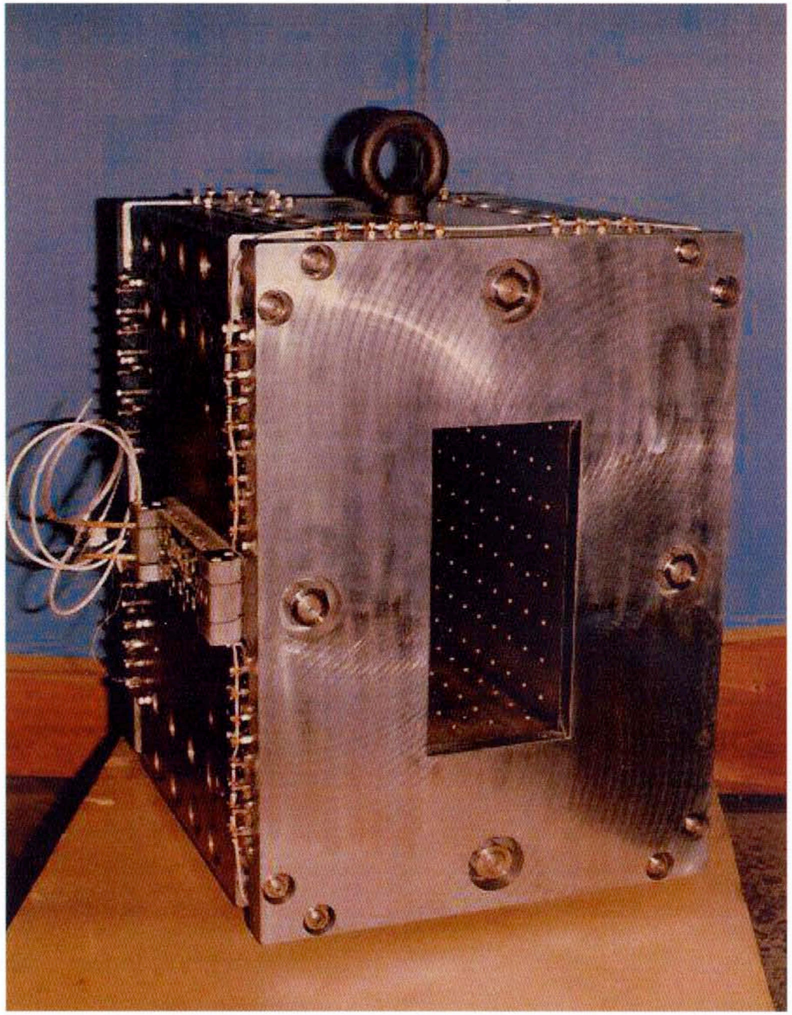
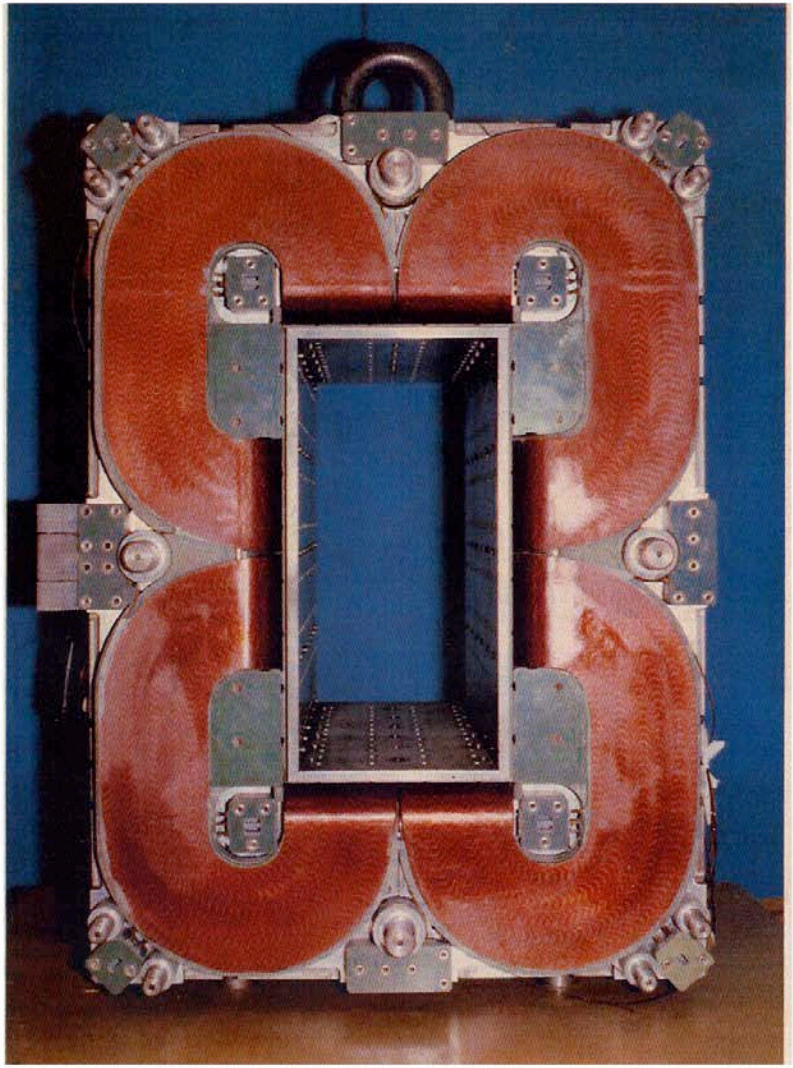


Fig. 2.11. Upper ciritcal field, temperature, and current density for commercial superconducting materials NbTi and Nb_3Sn (from Schwartz and Foner[27]).

Curitical parameters of superconductors



Panofsky Quadrupole I



Panofsky Quadrupole Ⅱ

International Collaborations in Applied Superconductivities - High Energy Accelerators and Detectors -

H. Hirabayashi, KEK

May 2002

1. CDF magnet construction ······· US - Japan (Fermilab)

   1985 ~ 1990

2. Muon Storage Ring Construction ······· US – Japan (BNL)

   1986 ~ 1996

3. LHC Quads Construction ······· CERN – KEK (CERN)

   1998 ~

4. LHC/ATLAS Solenoid construction ······· CERN – KEK (CERN) 1998 ~

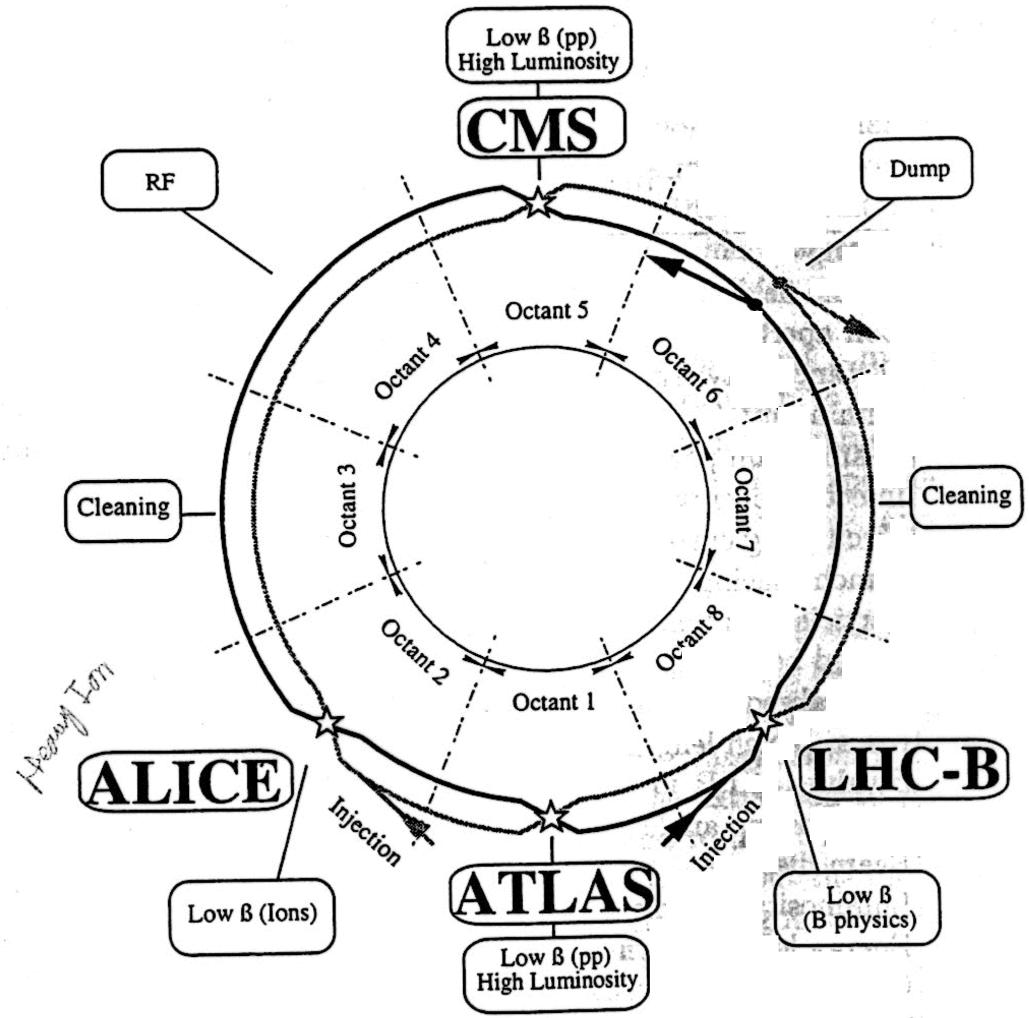


Figure 1: Schematic layout of the LHC

§　結び

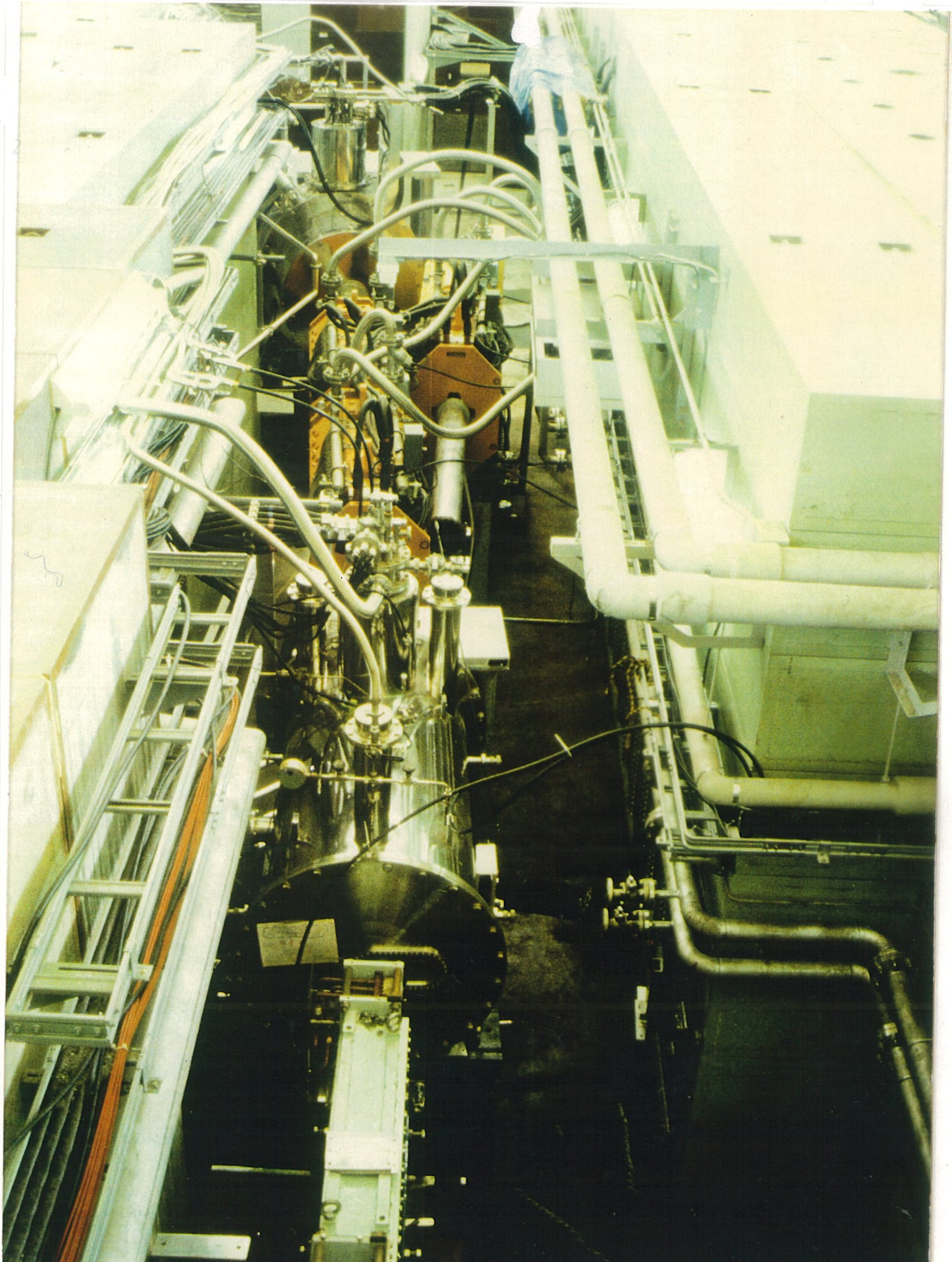
Ⅰ. 12Gev PSの一次、二次ビームチャンネルを建設した。
即ち、EP1、EP2(-A,-B,-C)と、内部標的ビームチャンネル、π2、外部標的ビームチャンネル K1、K2、K3、π1およびπ-μ チャンネルである。

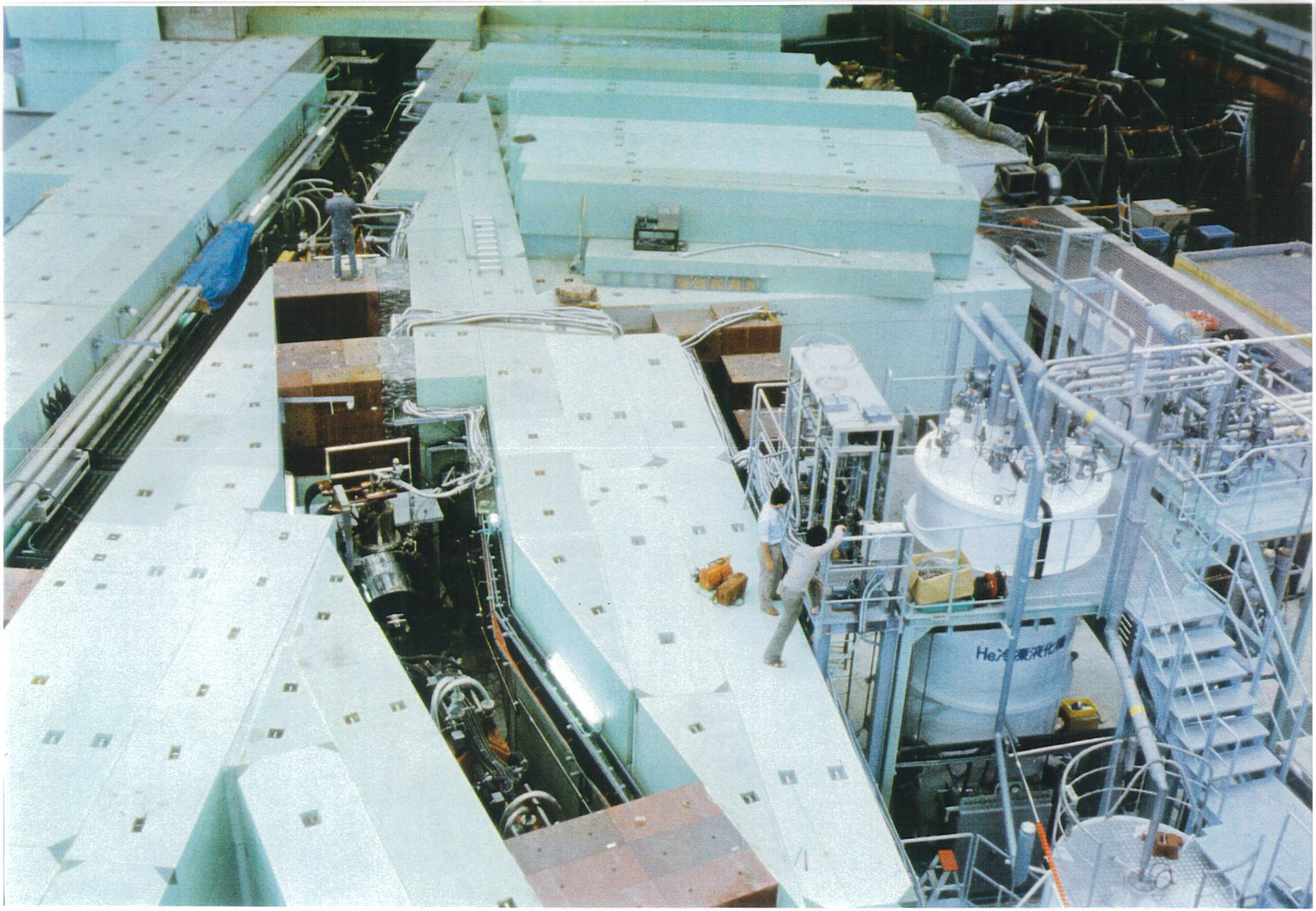
Ⅱ. 超伝導マグネットの開発を推進し、技術的には、世界第一級となった。
即ち、NbTi/Cuラザーホード・ケーブルを実用化し、超伝導Panofskyマグネット、ソレノイド、IOT双極ダイポールを開発し、π１ビームチャンネルにおいて、三基の超伝導マグネット・システムを採用し、長期間運転した。
→ヘリウム冷凍・液化機の長期間運転を経験し、超伝導応用の基礎となった。

Ⅲ．謝辞

技術的に高度かつ多岐にわたる開発と建設に加勢して頂いた各位に感謝している。PSと初期の物理実験をとりもつことができた。放射線管理を含めて、特段の事故もなく、幸運に恵まれた。

以上




He