



# Hadron Physics at J-PARC

Shinya Sawada (KEK)

# Contents

- Overview of J-PARC and Hadron Experimental Facility (Hadron Hall)
- Experiments at Hadron Hall
- Earthquake and Recovery Plan
- Possibility of  $\pi N$  and  $KN$  reaction experiments at Hadron Hall

**J-PARC Facility  
(KEK/JAEA)**

South to North

Linac

3 GeV  
Synchrotron

Neutrino Beams  
(to Kamioka)

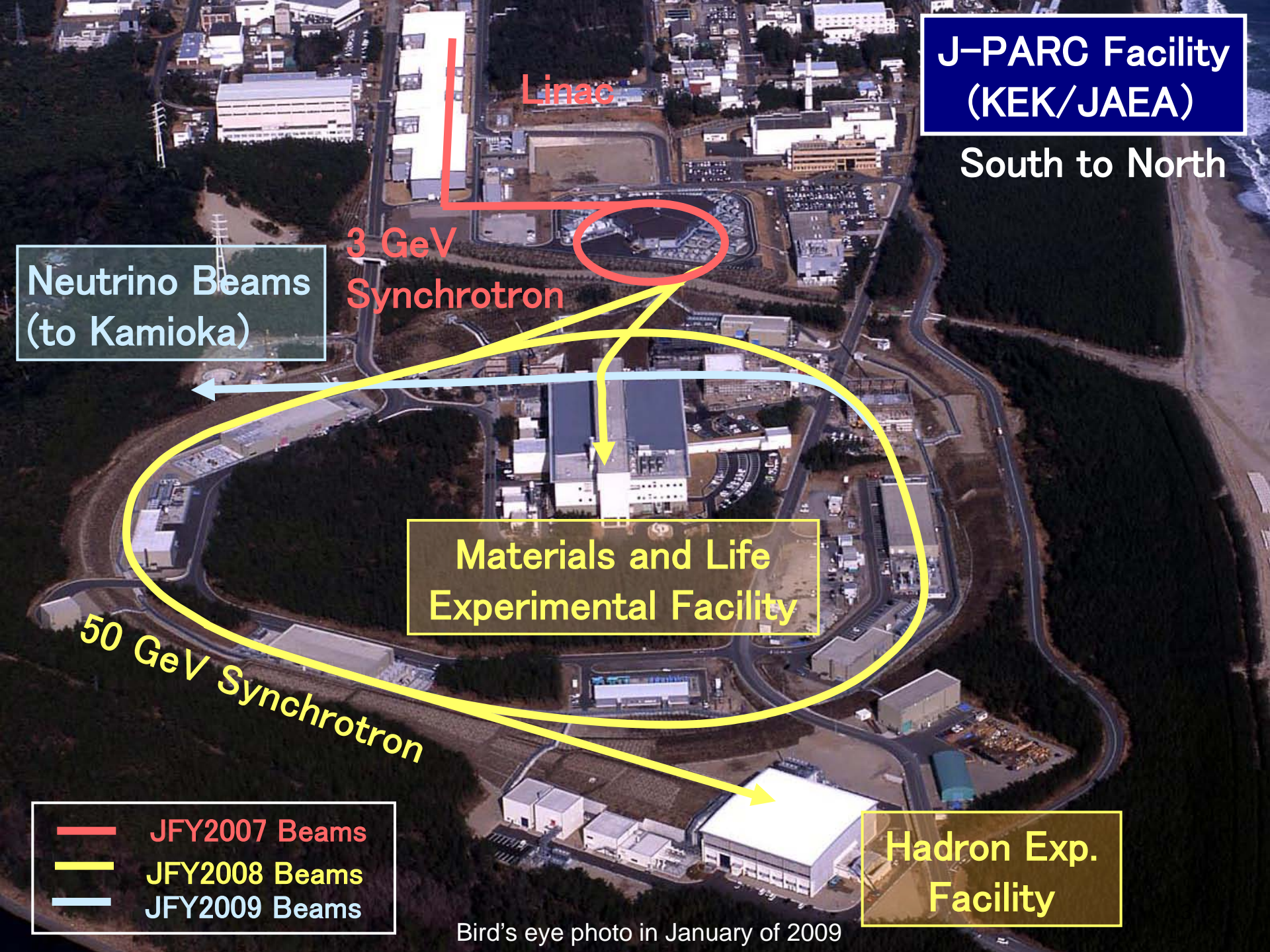
Materials and Life  
Experimental Facility

50 GeV Synchrotron

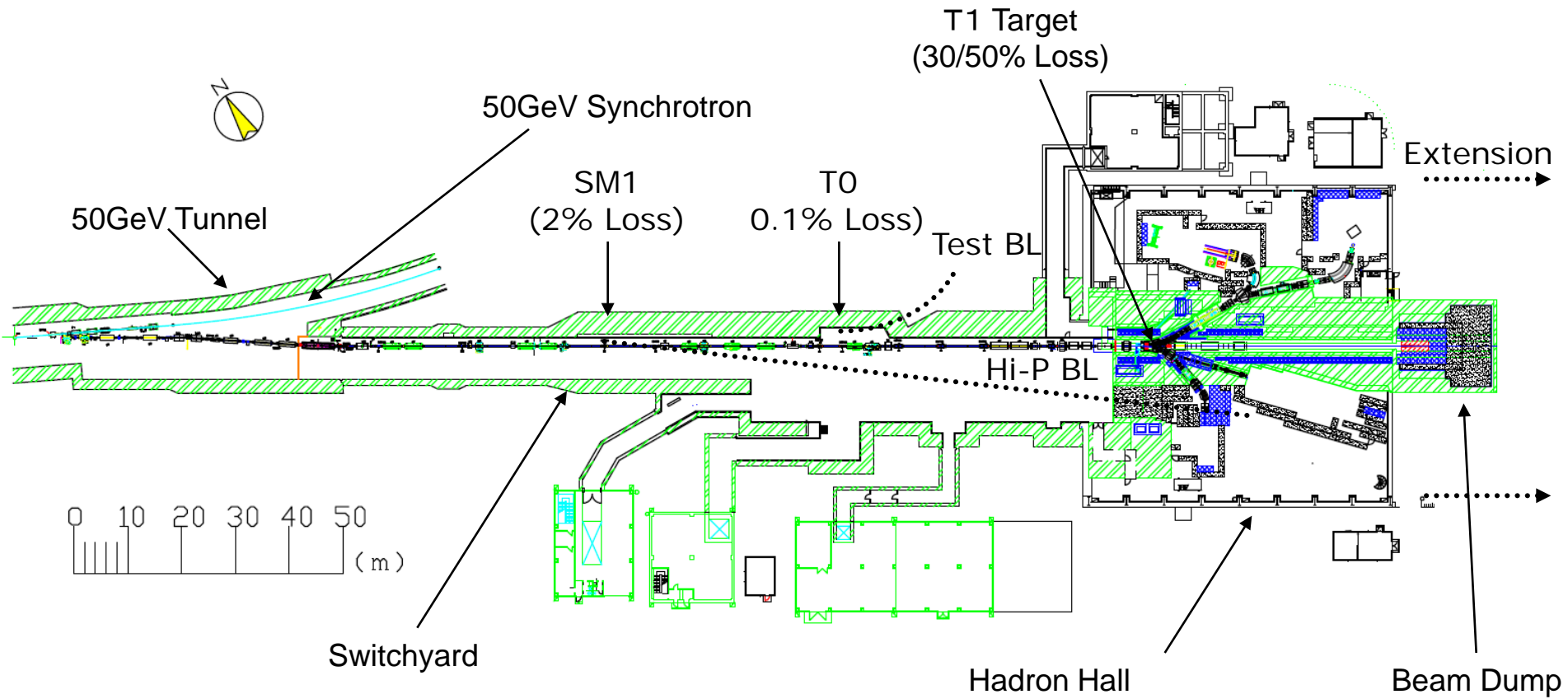
Hadron Exp.  
Facility

- JFY2007 Beams
- JFY2008 Beams
- JFY2009 Beams

Bird's eye photo in January of 2009



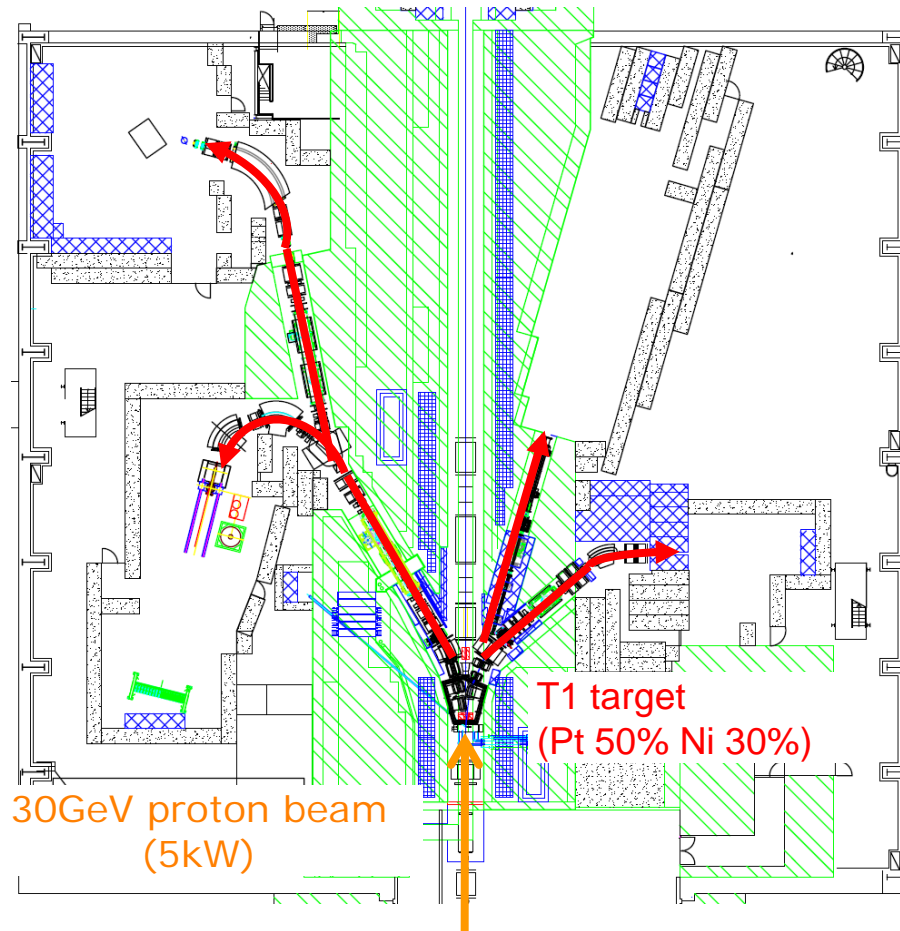
# Hadron Experimental Facility (Current Layout)



# Hadron Hall

K1.8 Beamline  
(2009.10-)

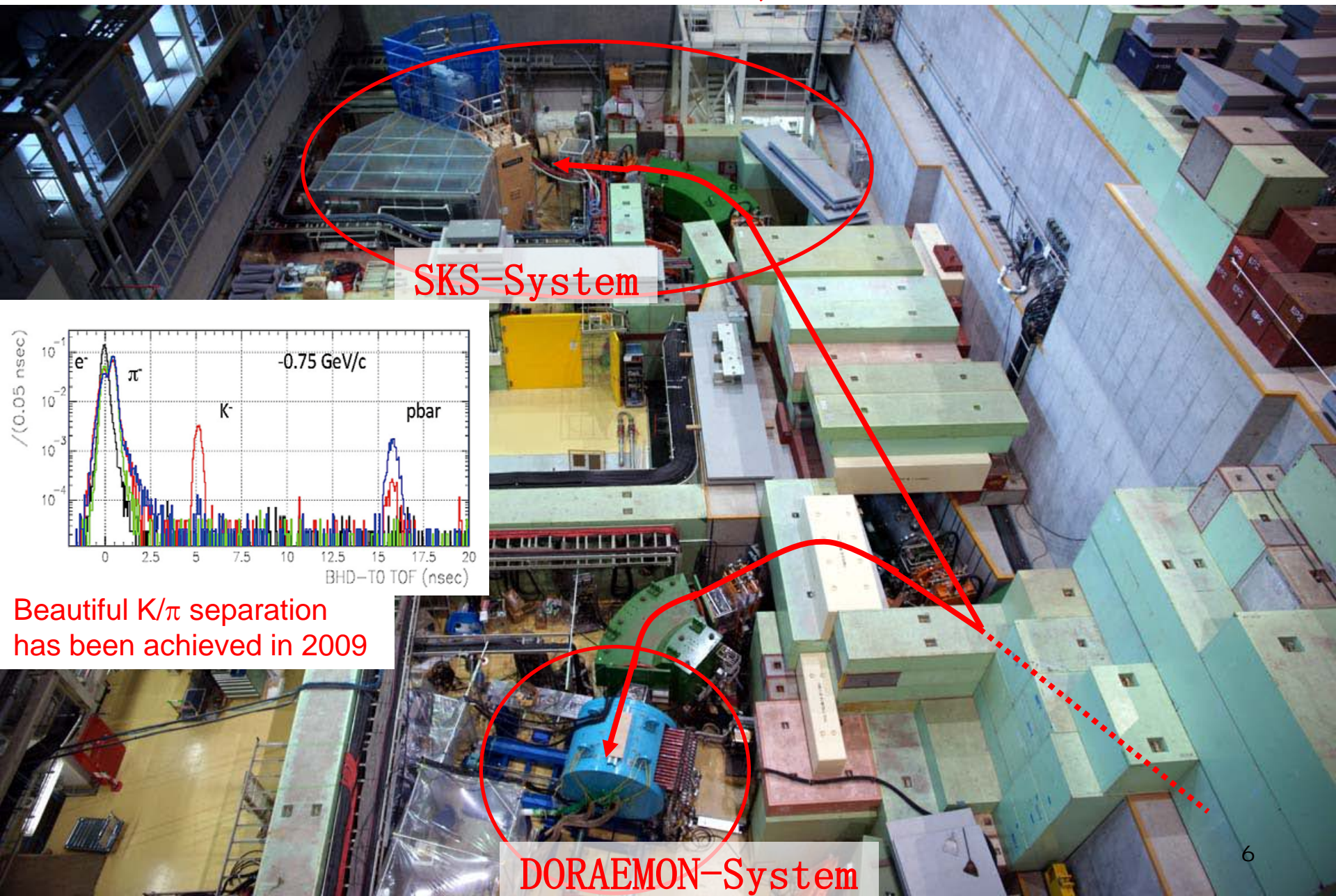
K1.8BR Beamline  
(2009.1-)



KL Beamline  
(2009.10-)

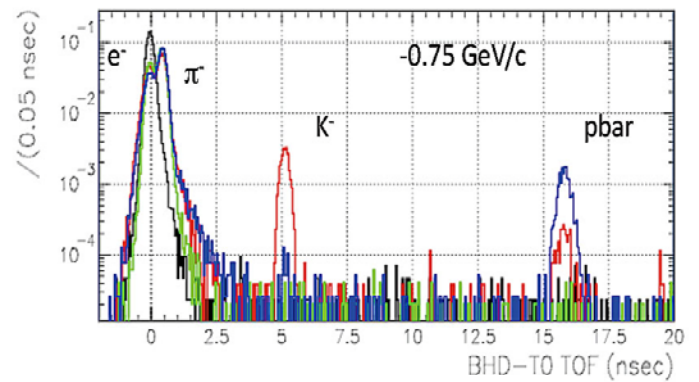
K1.1BR Beamline  
(2010.10-)

# North Side: K1.8, K1.8BR



SKS-System

DORAEMON-System



Beautiful K/ $\pi$  separation  
has been achieved in 2009

# SKS Spectrometer

K1.8 & SKS

Q13

Q12

K1.8 Beam Spectrometer

D4

Q10

Q11

# South part of Hadron Hall (during construction)



**K1.8/K1.8BR  
Beamline**

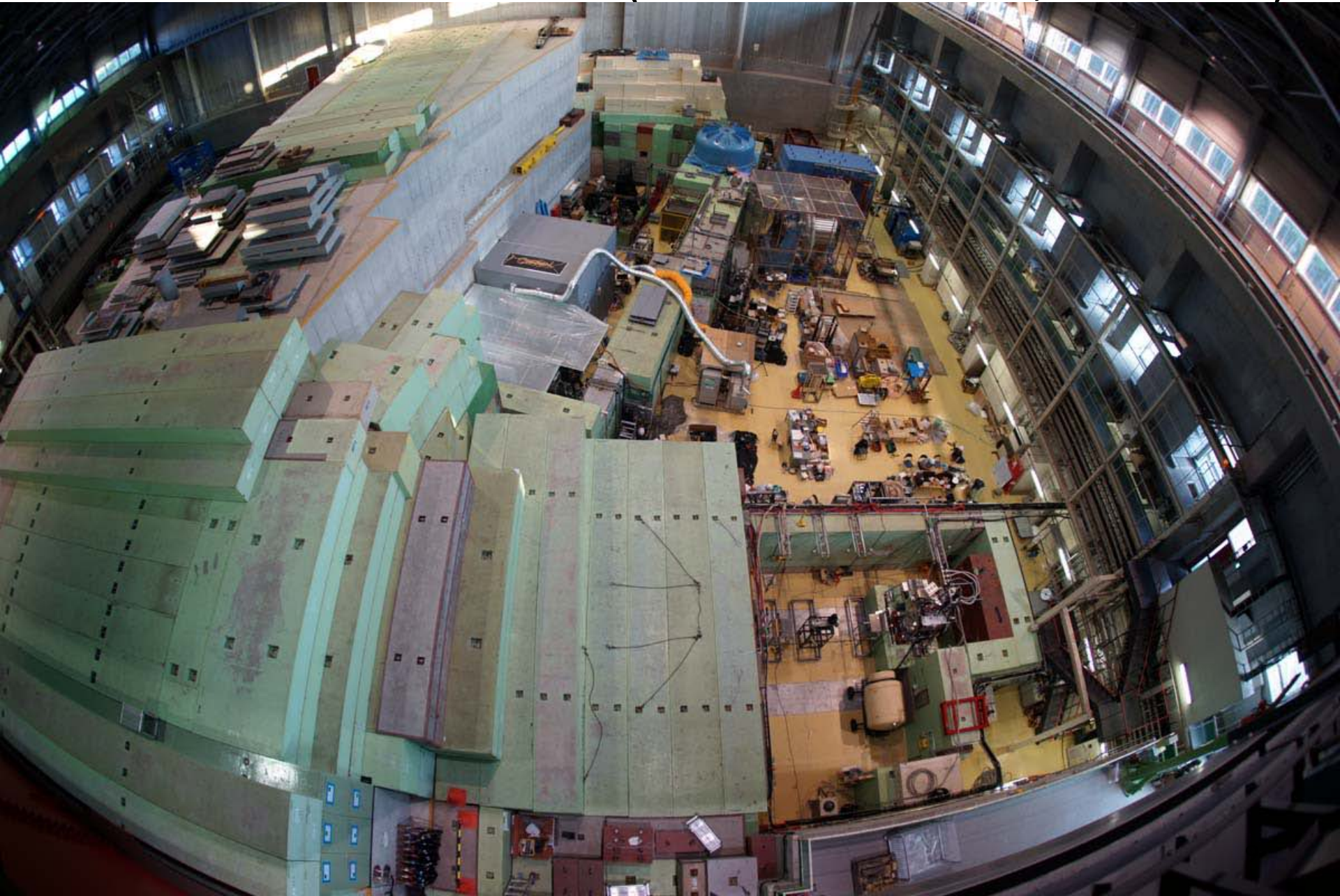
**Primary B  
eamline**

**KL Area**

**K1.1BR  
Area**

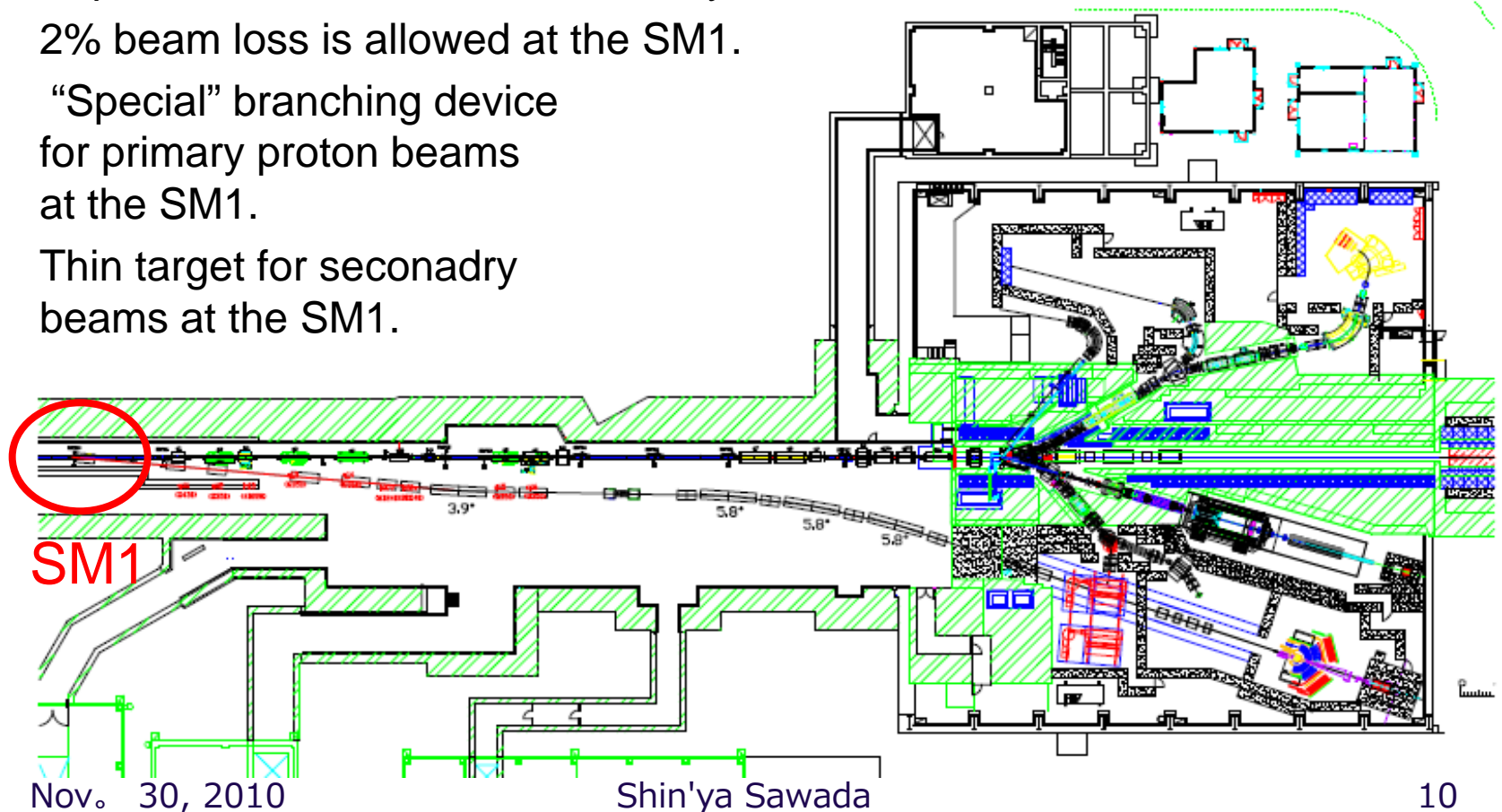


# South Part of Hadron Hall (after construction, Oct. 2010)



# High-Momentum Beam Line

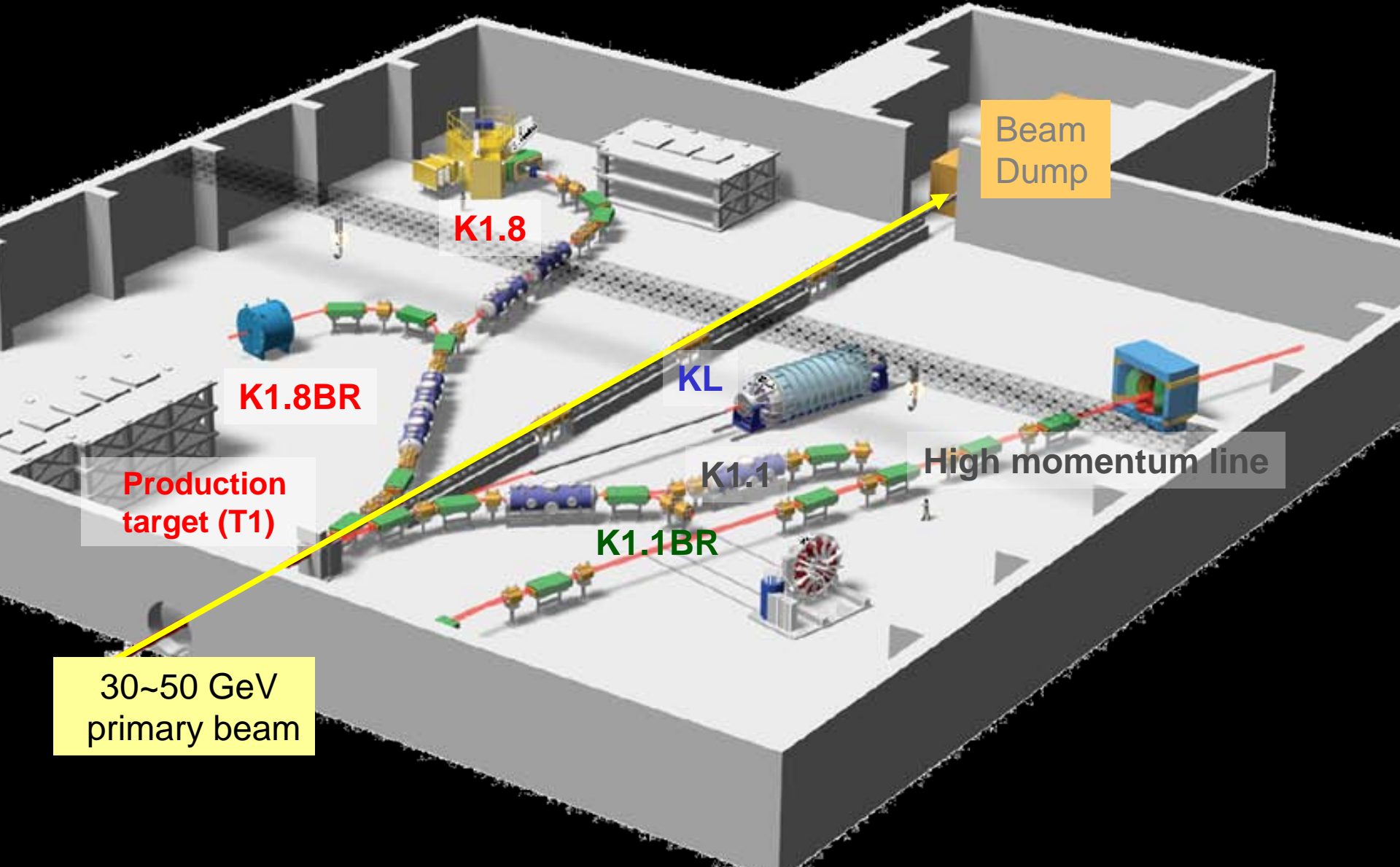
- For  $10^{10}$  protons/s (E16, vector meson mass),  $10^{12}$  protons/s (P04, nucleon structure), and unseparated  $\pi/K$ .
- Yet to be funded!
- Separated at the SM1 in the switchyard.
- 2% beam loss is allowed at the SM1.
- “Special” branching device for primary proton beams at the SM1.
- Thin target for secondary beams at the SM1.



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- Effects of the Earthquake and Recovery Plan
- Possibility of  $\pi N$  and  $KN$  reaction experiments at Hadron Hall

# experiments in Hadron Hall



Beam  
Dump

K1.8

K1.8BR

Production  
target (T1)

KL

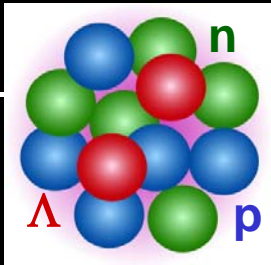
K1.1

High momentum line

K1.1BR

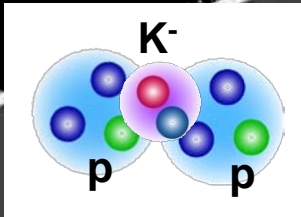
30~50 GeV  
primary beam

# Hall



$\Xi$  hypernuclei  
 $\Lambda\Lambda$  hypernuclei  
 $\Xi$ -atomic X-rays  
 $\Lambda$  hypernuclear  $\gamma$  rays  
Neutron-rich  $\Lambda$  hypern.  
Pentaquark  $\Theta^+$  search  
 $K^-pp$  bound state

Hyp. weak decay ( $A=4$ )  
Hyp. weak decay ( $A=12$ )  
 $\pi$  Double charge exch.  
 $\omega$  mesonic nuclei  
 $\Sigma p$  scattering



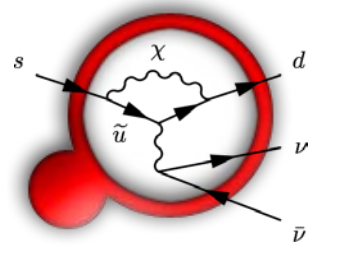
K1.8

$K^0_L$  rare decays

Hadron mass in nuclei  
Nucleon quark structure



K1.8BR



KL

K1.1

Not funded

K1.1BR



High momentum line

$K^-pp$  bound states  
 $K^-$  atomic X rays  
 $\eta$  mesonic nuclei

T violation in  $K^+$  decay  
Universality in  $K^+$  decay  
 $\Theta^+$  study by  $K^+n$  scattering

$\Phi$  mesonic nuclei  
 $\Lambda$  hypernuclear  $\gamma$  rays  
 $\Sigma$ -nuclear systems  
YN scattering  
 $\Theta^+$  hypernuclei

30~50 GeV  
primary beam

Approved (stage-2) / (stage-1) / proposed, LOI

$\mu$ -e conversion searches

# Beam Time in Fall, 2010

## ■ Run 35:

□ Oct. 12 – Nov. 1

Includes first physics data acquisition at the Hadron Hall!

Beam Line	Exp.	Beam Time (hr)	Down Time (hr)	Down Time (%)	Net Beam Time (hr)
K1.8	E19	179.8	13.1	7	166.6
K1.8BR	E17	105.3	15.8	15	89.5
KL	E14	281.1	24.1	9	257.7
K1.1BR	T25	12.0	0.0	0	12.0
	E06	140.0	12.0	9	128.0
	T32	162	15	9	147.0

## ■ Run 36:

□ Nov. 7 – 16

K1.8	E19	110.3	19.0	17	91.4
K1.8BR	E17	31.5	2.0	6	29.5
KL	E14	144.0	16.2	11	127.8
K1.1BR	E06	31.5	2.0	6	29.5
	T38	68.0	13.0	19	55.0

# First Results from E19

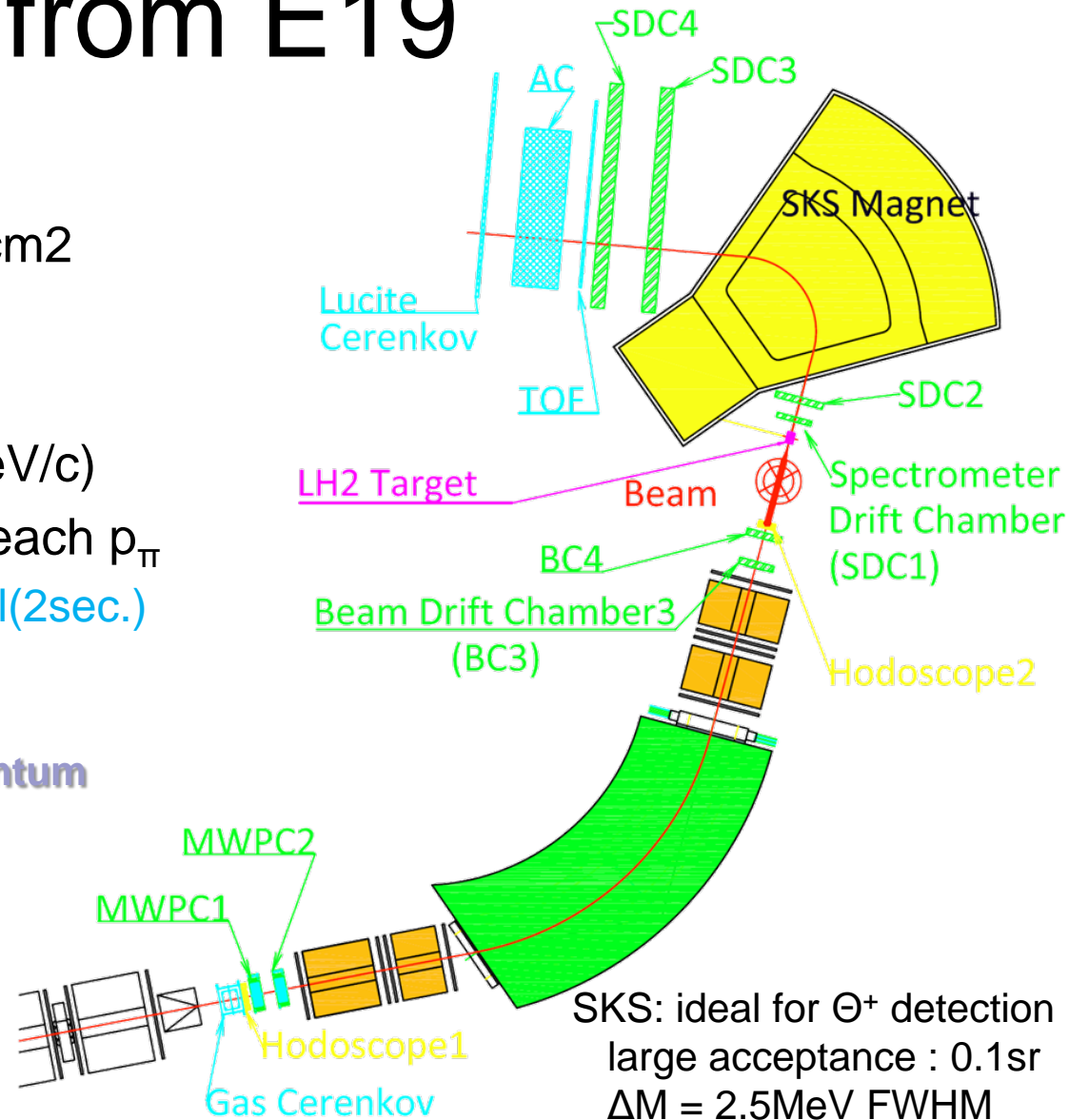
- search for  $\Theta^+$  in  $p(\pi^-, K^-)$
- target : liquid H<sub>2</sub>, 0.86g/cm<sup>2</sup>
- at K1.8 beamline + SKS
- beam momentum :
  - $p_\pi = (1.87, 1.92, 2.00 \text{ GeV}/c)$
- $4.8 \times 10^{11} \pi$  on target for each  $p_\pi$ 
  - beam intensity :  $10^7/\text{spill}(2\text{sec.})$
  - beam time : 160 hours

Yield :  $10^4$  events for each momentum

Sensitivity : 75nb/sr

→ confirm the existence of  $\Theta^+$

E19 took the first physics data with  $p = 1.92 \text{ GeV}/c$  in Oct/Nov, 2010.



# Spectrometer Performance

- $\Sigma^-$  &  $\Sigma^+$  production have been studied
  - in  $(\pi^-, K^+) / (\pi^+, K^+)$  reactions
  - Target : Liquid Hydrogen
  - $p_{\text{beam}} : \pm 1.37 \text{ GeV}/c$ .

$$\Delta M = 1.9 \pm 0.1 \text{ MeV}/c^2 (\text{FWHM})$$

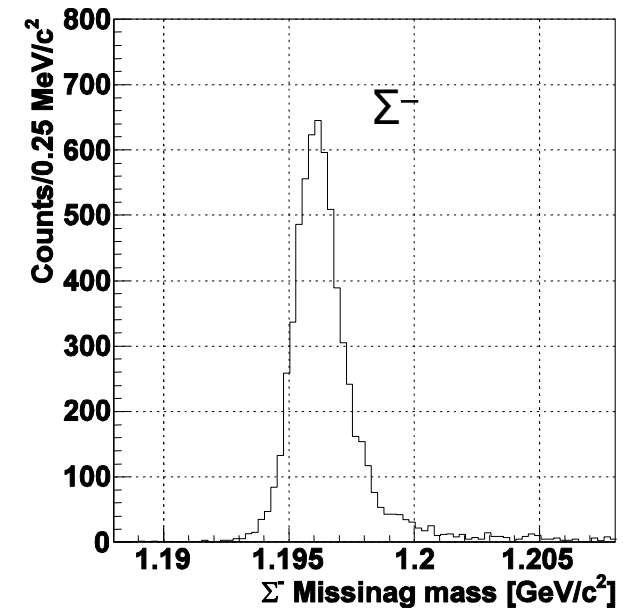
→  $\Theta^+$  missing mass resolution : 1.5  $\text{MeV}/c^2$  (FWMH)

overall efficiency is examined with  $\sigma(\Sigma^+)$ .

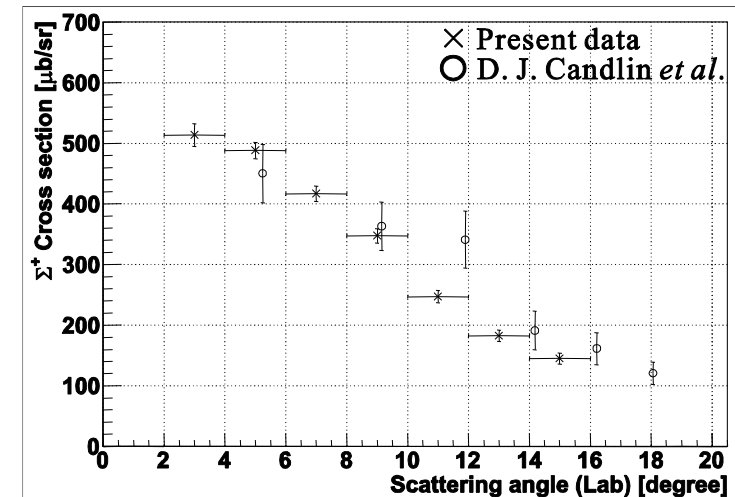
tracking & counter efficiency, acceptance,  
decay rate of Kaon  $\rightarrow \varepsilon_{\text{all}} = 0.10$

Achieved enough good resolution.  
Yield is consistent with the estimation.

## Missing mass spectrum

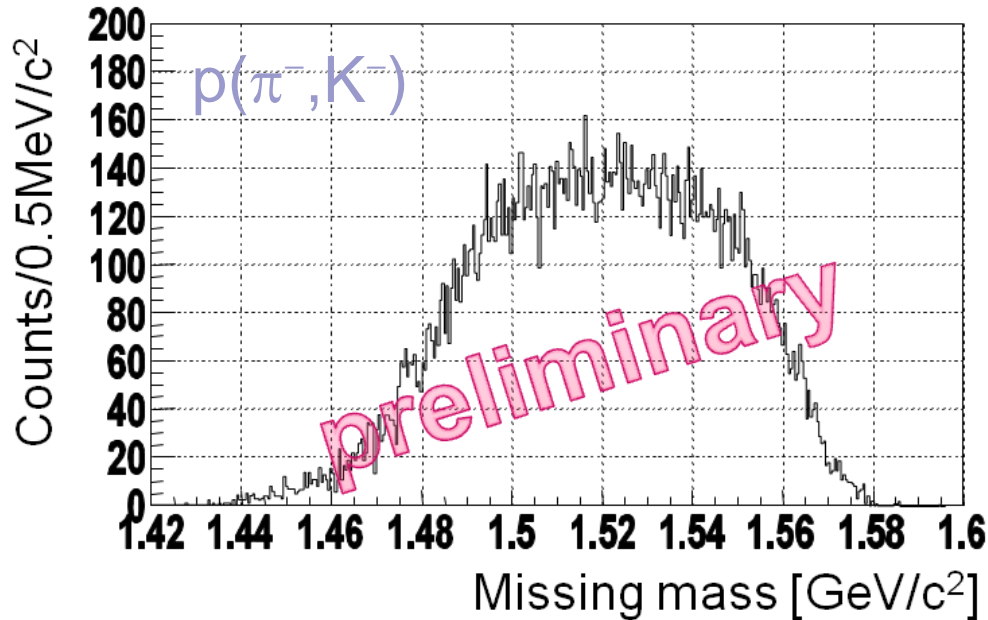


## Production cross section of $\Sigma^+$





# Missing Mass Spectrum



- #beam  $7.8 \times 10^{10}$
- #target  $5.3 \times 10^{23} / \text{cm}^2$
- acceptance 0.1sr
- efficiency 0.10
  - worse than 0.25 (at proposal)  
← vertex cut & multi-track
- mass resolution 1.5MeV(FWHM)
  - better than 2.5MeV (at proposal)

$\sqrt{(1.5/2.5)} / \sqrt{(0.1/0.25)} \sim 1.2$   
→ can keep the sensitivity under the current spectrometer performance.

- no significant structure has been observed.
- upper limit with current statistics :  $0.3 \sim 0.4 \mu\text{b}$  (90%C.L.) (very preliminary) cf.  $3.9 \mu\text{b}$  (KEK-PS E522)

# Strategy

## ■ Original plan

- approved beamtime :  $4.8 \times 10^{11} \pi$  on target for 3 momenta (160 hours x intensity :  $10^7 \pi/4\text{sec}$ )
- sensitivity :  $75\text{nb/sr} \leftrightarrow \Gamma < \mathbf{0.2\text{MeV}}$

## ■ Oct. – Nov. 2010

- collect  $7.8 \times 10^{10} \pi$  on target (156 hours x  $1\text{M} \pi/6\text{sec}$ )
- to confirm  $\Theta^+$  with  $10\sigma$  assuming  $1.9\mu\text{b/sr}$  at  $p_{\text{beam}} = 1.92\text{GeV}/c$

## ■ Spring 2011 (assuming 16% duty factor) → **Spring 2012?**

- request 6 days to take data at  $p_{\text{beam}} = 2\text{GeV}/c$ 
  - identify  $\Theta^+$  with  $5\sigma$ , if exist.
  - reach the sensitivity of  $\sim 0.3\mu\text{b}$ . ( $< 0.5\mu\text{b}$  : theoretical prediction)

## ■ Autumn 2011 - (assuming 30% duty factor) → **Autumn 2012??**

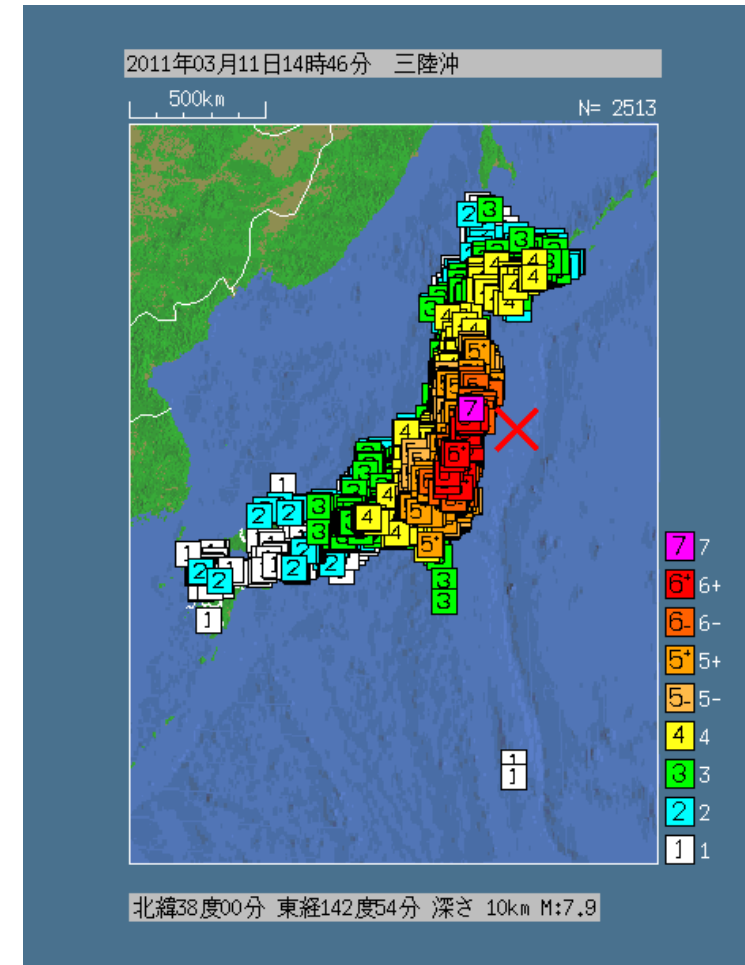
- Sensitivity : to reach  $75\text{nb/sr}$  18 days for each momentum.
- momentum dependence of  $\sigma_{\text{tot}}$

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# Earthquake

- Largest earthquake (M=9.0) at 2:46pm, March 11, 2011 and a lot of smaller (but large enough) aftershocks followed.
- Intensity at Tsukuba and Tokai was 6- (collapse of buildings and landslips occur) on the Japanese seven-stage seismic scale.
- No injuries at J-PARC.
- No Tsunami damage to J-PARC.



# Damage to Linac

## Entrance for Linac



2011.3.17.

About 1.5 m drop was seen over a wide area. Electric wires and water pipes were all damaged.

## Inside Linac Tunnel



2011.3.17.

Concerning the central area of Linac, no serious damages were seen by looking from outside. There were water leaks to the tunnel.

# Damage to 3-GeV RCS

## Condenser Bank for 3 GeV



2011.3.17.

Condenser bank was waded.  
Cables were distorted  
with heavy weight on them.

## RCS Tunnel



2011.3.29.

No obvious damages were observed.

# Damage to 50-GeV Main ring

50-GeV Tunnel

Neutrino Beam Line



2011.3.17.

No obvious damage to the magnets. Water leaks were observed. Precise survey is being done to judge what extent the realignment should be necessary.



Superconducting primary beam line for Neutrino looks healthy. Investigation of the components is underway.

# Hadron Beam Line



Beam line from switch yard to Hadron Hall.  
Magnets themselves seem healthy. Detailed survey is on going.  
Several mm level of displacement (between different sections of  
the buildings) has been observed.



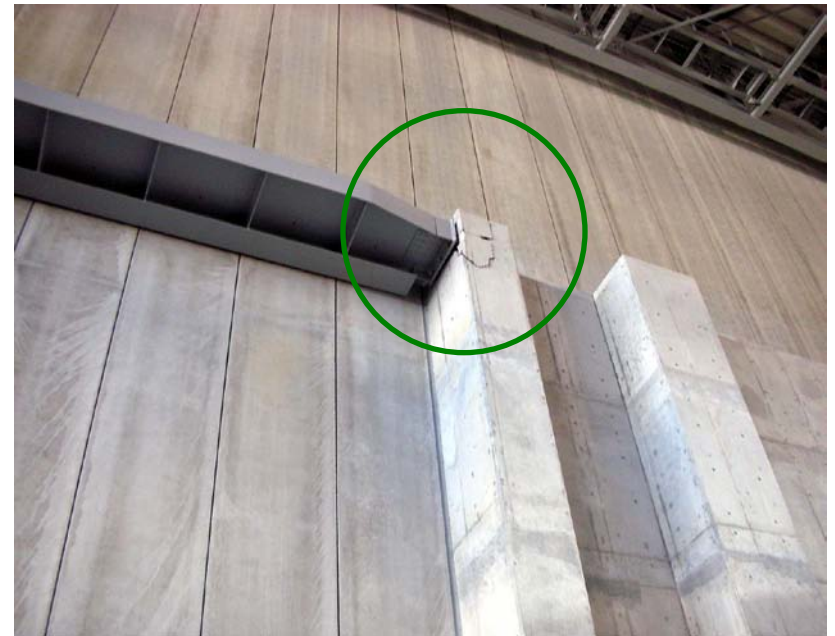
# Hadron Hall Building

- Cave-ins occurred around the building, which is secured by the piles.



Entrance of the loading deck.  
Already repaired.

- Beams supporting the beams of the east wall were damaged.



Pieces of concrete fell down to the floor. Emergent repair was completed.

- Cooling water has significant problem.



← North entrance for the Hall. About 1 m drop.



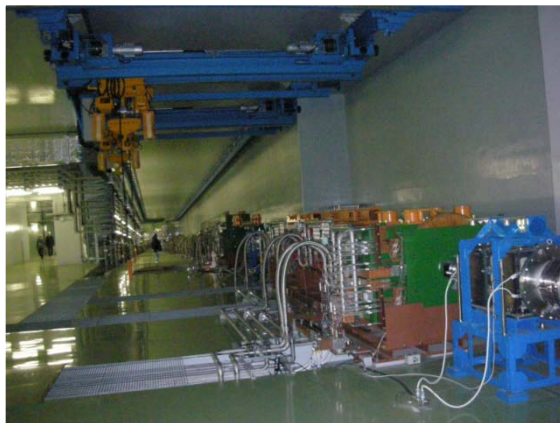
↑ Disconnected pipes



↑ Distortion of bellows

- Experimental Hall are reasonably OK.

- No serious damage for vacuum.

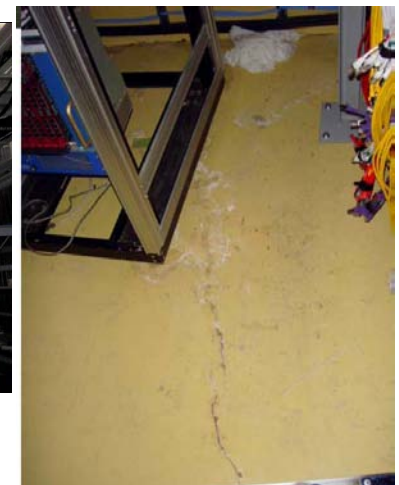


Beam dump area.

← Switch Yard



Slight displacement is observed for experimental apparatus.

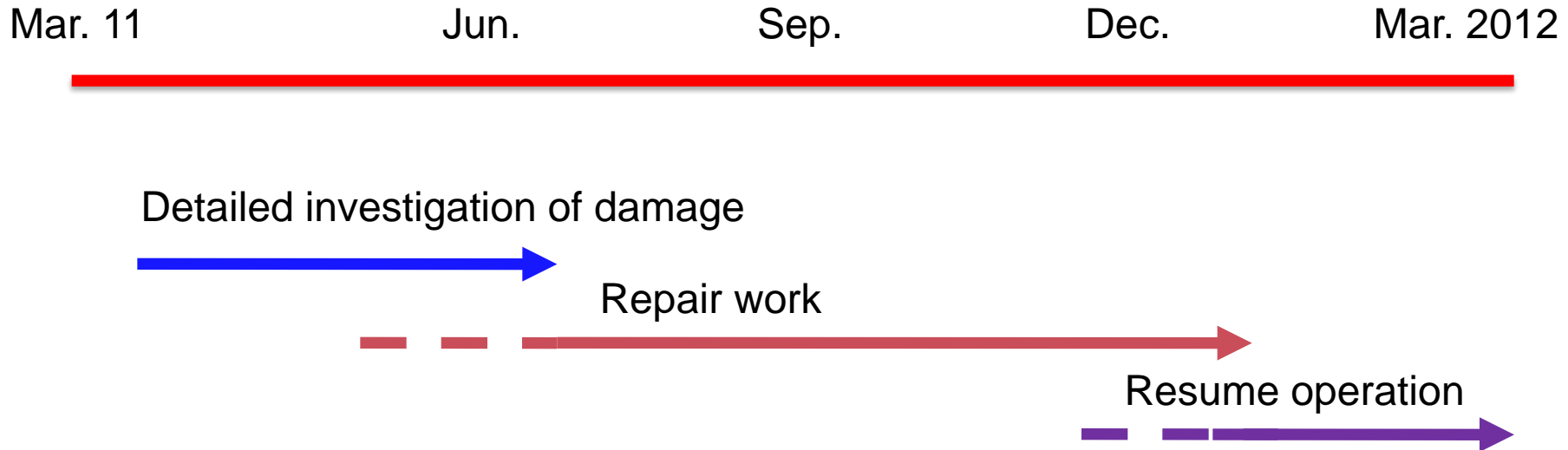


Crack observed on the floor. Water leakage is observed.

# Summary of Damage to Hadron

- Buildings
  - Damages to Hadron Hall building have been or are being repaired.
  - Some cave-ins will be repaired later, but not a significant problem.
- Cooling water is still under repair. Currently only one, out of five, cooling water line is available.
- Magnets, vacuum, ...
  - Magnets themselves seem healthy. A few supports were broken at the experimental areas.
  - Need **realignment**. Several mm displacement (and sinking) have already been observed. This is due to the displacement (and sinking) of the buildings.
  - Vacuum needs replacements of some elements.
  - Major problem has not been observed for the beam dump.
  - **Reconstruction/relocation of shielding** with blocks need much time.
- We try to recover the primary beam line by this fall, and ready to accept the beam by the end of the year.

# Recovery Plan of J-PARC

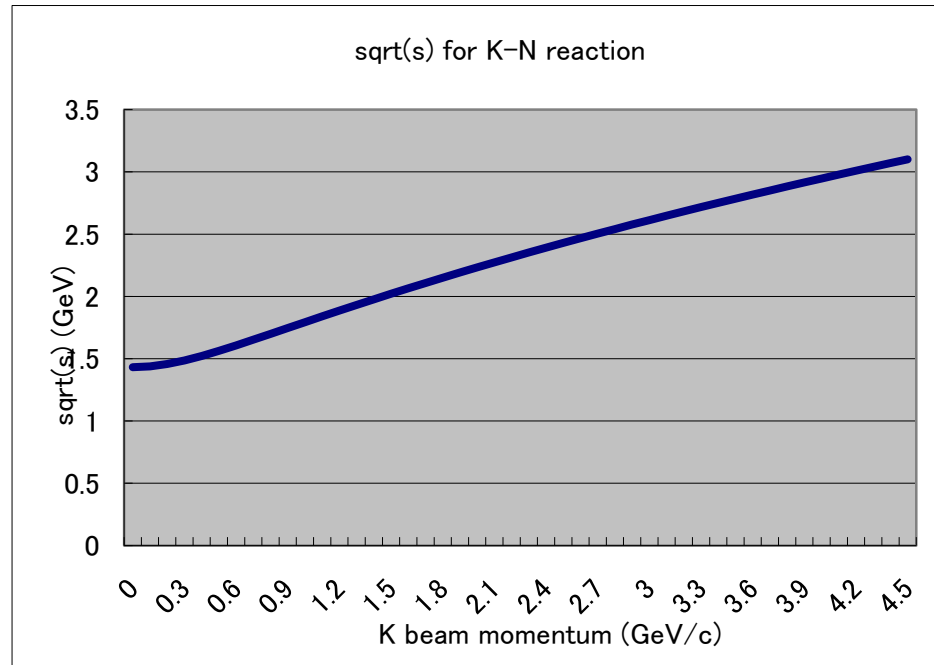


- Tentative goal is to have a beam to all accelerator within this year, and we try to run up to two months to users within this fiscal year until March 2012.

# Contents

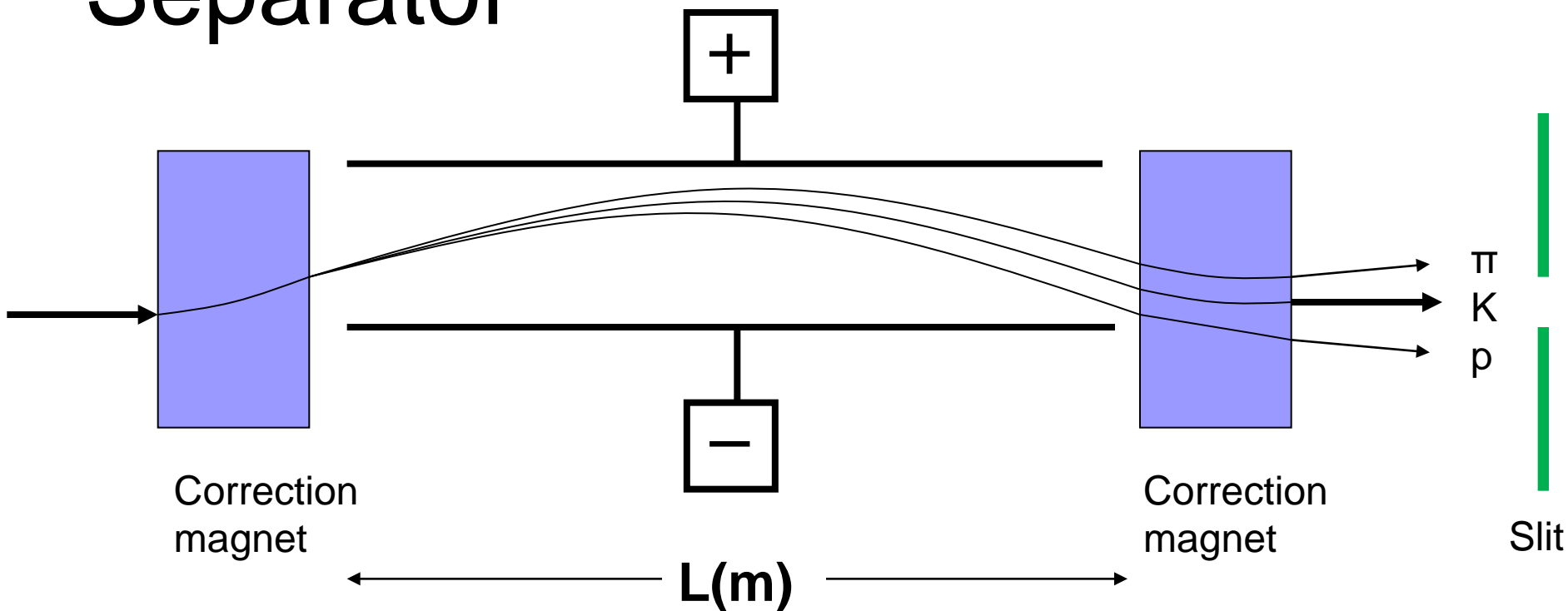
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# $\pi/K$ beam for excited baryons



- For  $\sim 3$  GeV,  $\sim 4.5$  GeV/c  $\pi/K$  beams are necessary, while current max. is 2 GeV/c.
- Unseparated beams (mainly  $\pi$ 's) will be available at the high-momentum beam line.

# Principle of Electrostatic Separator



Displacement at exit:  $\xi = eEL^2 / 2pc\beta$

Angle change at exit:  $\Delta\theta = 2\xi / L$

# Electrostatic Separator

- Sample calculation with  $L=6\text{m}$  and  $E=600\text{kV}/10\text{cm}$

Momentum GeV/c	Particle	$\xi$ (m)	$\Delta\theta$ (rad)	$\Delta$ at 3m (m)	$\Delta(K) - \Delta(\pi)$ at 3m
1	$\pi$	0.109	0.0362	0.218	23 mm
	K	0.120	0.0402	0.241	
	$\rho$	0.148	0.0494	0.296	
2	$\pi$	0.0541	0.0180	0.108	3 mm
	K	0.0556	0.0185	0.111	
	$\rho$	0.0596	0.0199	0.119	
3	$\pi$	0.0360	0.0120	0.0720	1.1 mm
	K	0.0365	0.0122	0.0731	
	$\rho$	0.0377	0.0126	0.0755	
4	$\pi$	0.0270	0.00901	0.0540	0.4 mm
	K	0.0272	0.00907	0.0544	
	$\rho$	0.0277	0.00924	0.0554	

- Need huge ES separator ( $\sim 30\text{m}$  for  $6\text{ GeV}/c$ ) or RF separator!

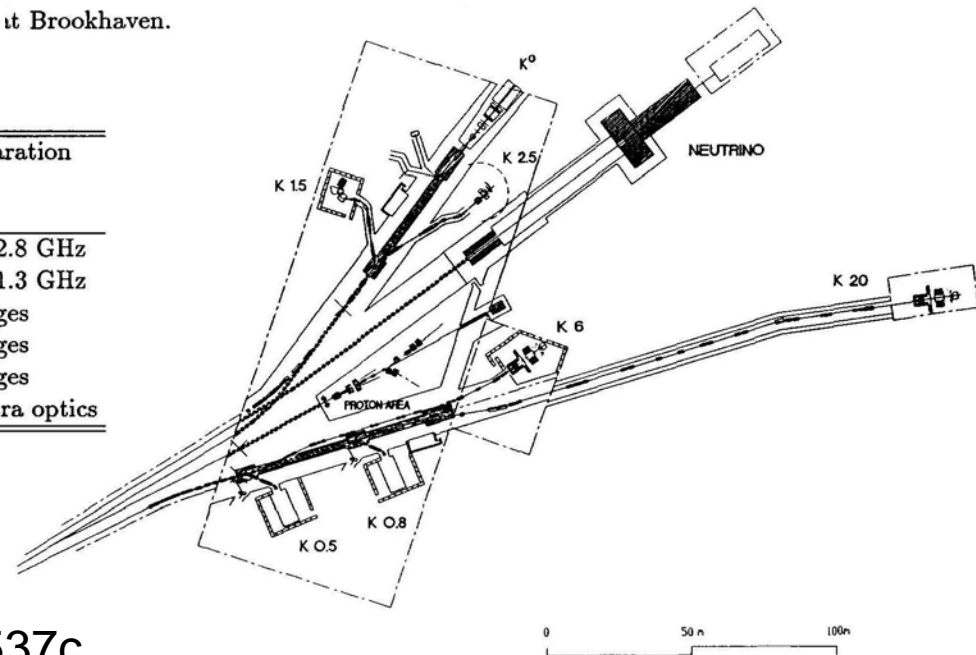


# K6 Beam Line at KAON Factory (TRIUMF)

at Brookhaven.

Properties of Separated Beams at KAON.

Channel	Momentum GeV/c	Solid Angle msr $\Delta p/p$ in %	Momentum Acceptance	Length m	Type of Separation
K20	20 - 6	0.1	1	160	rf, 3 cavities, 2.8 GHz
K6	6 - 2.5	0.08 - 0.30	3	110	rf, 3 cavities, 1.3 GHz
K2.5	2.5 - 1.25	0.5 - 2.0	4	54	dc, 2 stages
K1.5	1.5 - 0.75	2.0	4	30	dc, 2 stages
K0.80	0.80 - 0.55	6.0	5	18	dc, 2 stages
K0.55	0.55 - 0.40	8.0	6	14	dc, 1 stage, extra optics

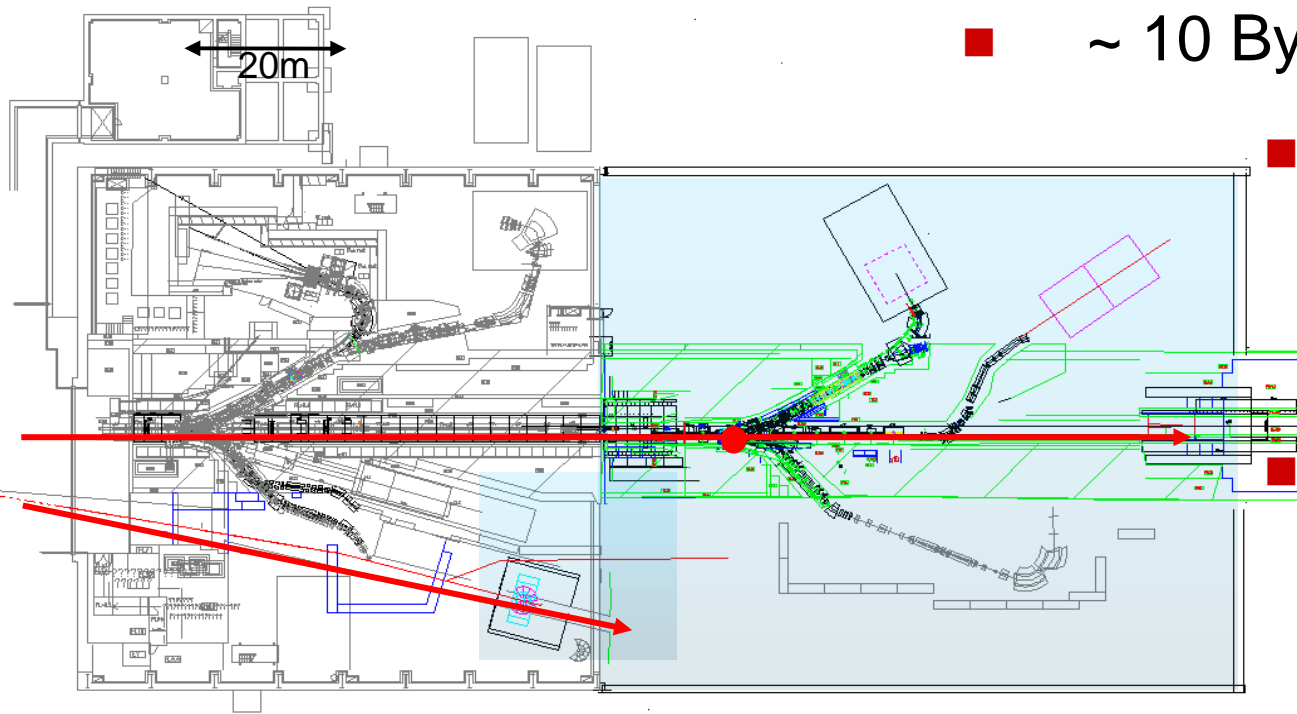


E. Vogt, Nucl. Phys. A558 (1993) 537c.

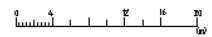
- RF separator needs ~100m length.
- Separated high-momentum beam needs Extension of Hadron Hall.

# Extension of Hadron Hall

- Extend Hadron Hall
- Install the 2<sup>nd</sup> production target
- Install several beam lines
- Install spectrometers for hadron physics
- ~ 10 Byen (~ \$80M)



- Concrete plan of the beam lines and detectors is to be discussed.
- Good physics cases needed to realize high-mom separated beams.



RIKEN is now interested in contributing to the extension.

# Summary

- Hadron Experimental Facility of J-PARC started its physics run in the fall of 2010.
- E19 (pentaquark with  $\pi p \rightarrow K\Theta$ ) obtained its first physics data with 1.92 GeV/c.
- The huge earthquake assaulted J-PARC also, but there were no injuries and building collapses at J-PARC.
- Detailed investigation including precise survey is being done. A goal is to resume the proton beam around the end of this year.
- Higher momentum separated beams ( $> 2$  GeV/c) need a longer space. We welcome good physics cases for such a beam line at the extended Hadron Hall.



# BACKUPS



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# ひばり



写真提供:共同通信社

地震の後、渦を巻く大洗港付近の海



Above: Tsunami at the nearest creek  
Max height ~ 6m. Below: after Tsunami





Guest house of JAEA



村松海岸 (4/7)



H23/4/7



警備用  
道路

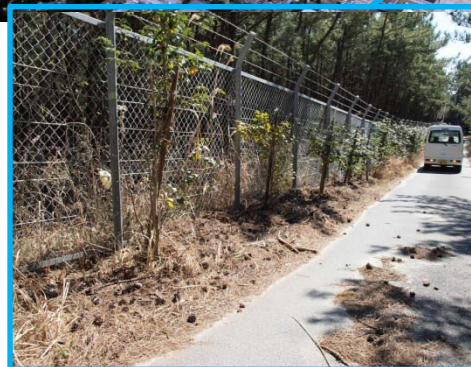


Debris on a fence



H23/3/11 17:43

Nearest creak.



新川河口 (写真奥が原科研側)

Tsunami reached the fence next to Hadron. Pine trees knocked down by Tsunami.