RECENT RESULTS FROM THE PENTAQUARK SEARCH EXPERIMENT AT J-PARC

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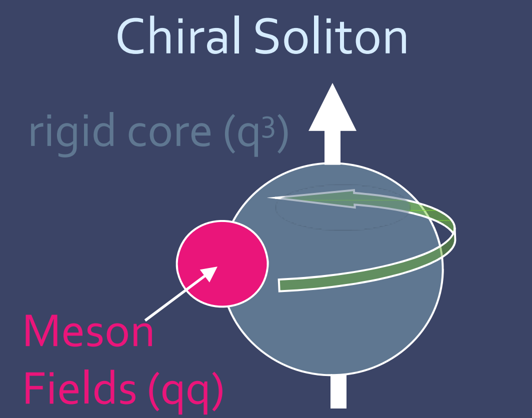
新ハドロン領域研究会

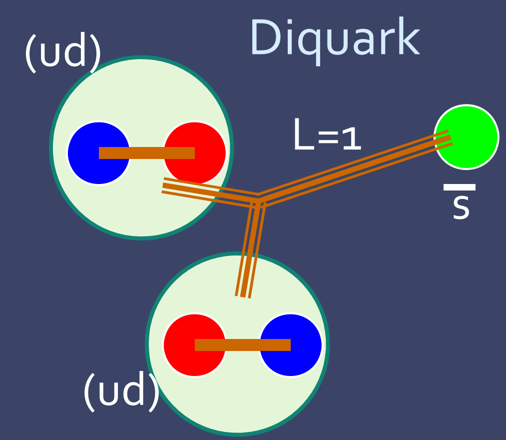
Outline

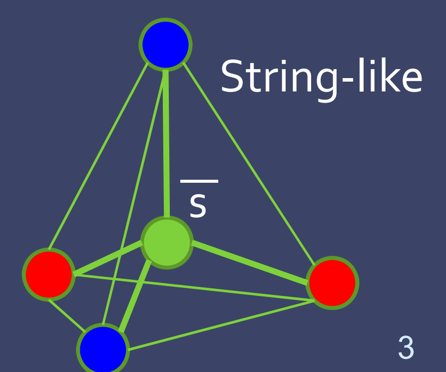
- Introduction
  - Physics Motivation
  - J-PARC hadron facility
  - J-PARC E19 experiment
- Recent Results from E19
  - Spectrometer performance
  - Sensitivity
- Summary

Physics Motivation
- Exotic hadron -

- we have already clues…
  - X(3872),Z(4430), Θ⁺ …← explicitly exotic
- What we have learned about Θ⁺
  - Pentaquark Θ⁺ : seems to be really "exotic"
    - extremely narrow width
      - suggests internal structure
    - production mechanism
      - negative results from high energy exp.
      - does not couple to K*N system.



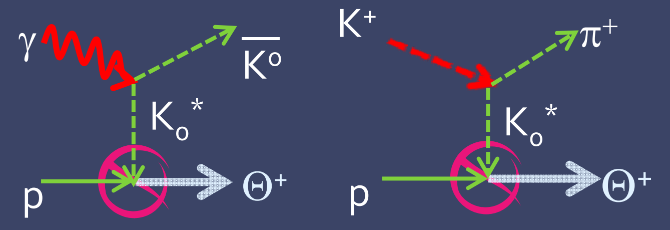




Possible production process

◉ coupling to K*N is very small.

CLAS-p	γp → K^0KN	U.L. 0.8nb
E559	K^+p → p^+X	U.L. 3.5 μb/sr



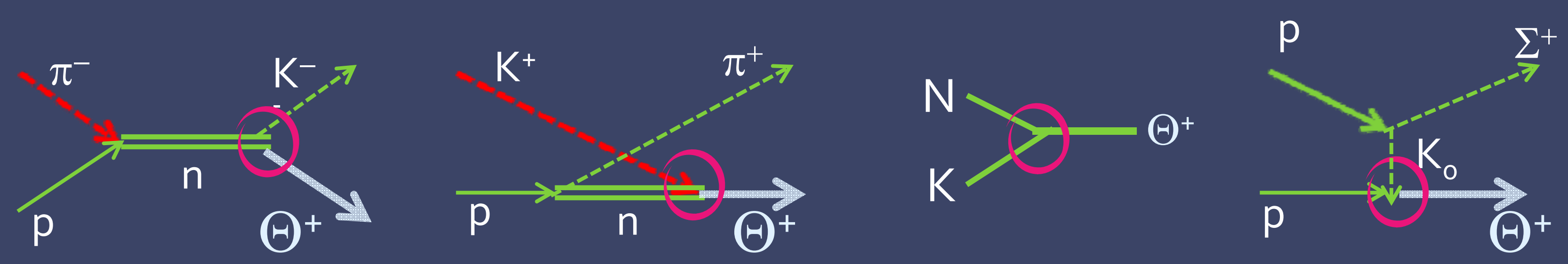
use coupling to KN system

❑ photo-production

LEPS	γC → K^-K^+(n)	4.6σ
CLAS-d	γd → pK^-K^+(n)	U.L. ~3nb for γn

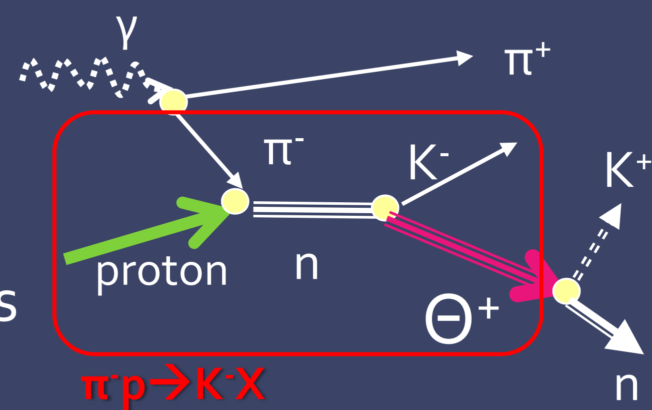
not inconsistent with each other.
strong angle/energy dependence.

❑ hadronic reaction



Search for Pentaquark Θ^+ in $\pi^- p \rightarrow K^- X$ reaction

- no angular dependence
- sizable cross section
  - $\sigma(\pi^- p \rightarrow K^- \Theta^+) \propto \Gamma_{\Theta^+}$
- strongly related to two positive results

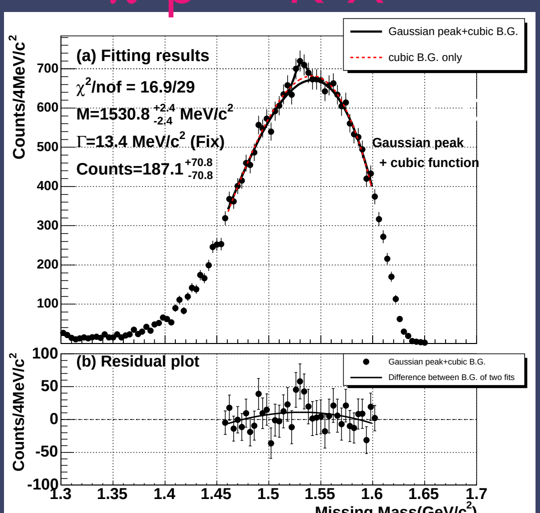


KEK-PS E522 experiment

Θ^+ search via $\pi^- p \rightarrow K^- X$

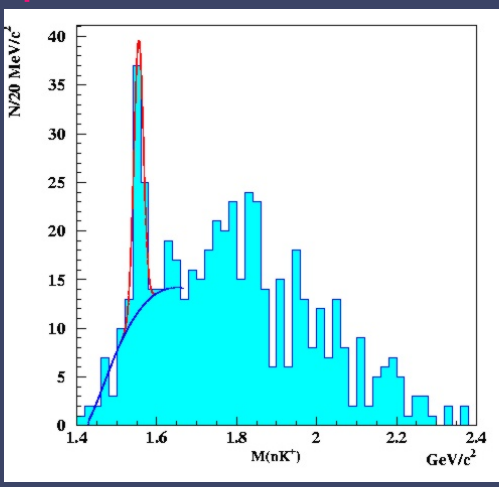
- K2 beamline + KURAMA
- p_{beam} : 1.87, 1.92 GeV/c
- ΔM = 13.4MeV(FWHM)
- peak structure was observed only at p_{beam} =1.92GeV/c

$\pi^- p \rightarrow K^- X$



K. Miwa et al. PLB635,72(2006)

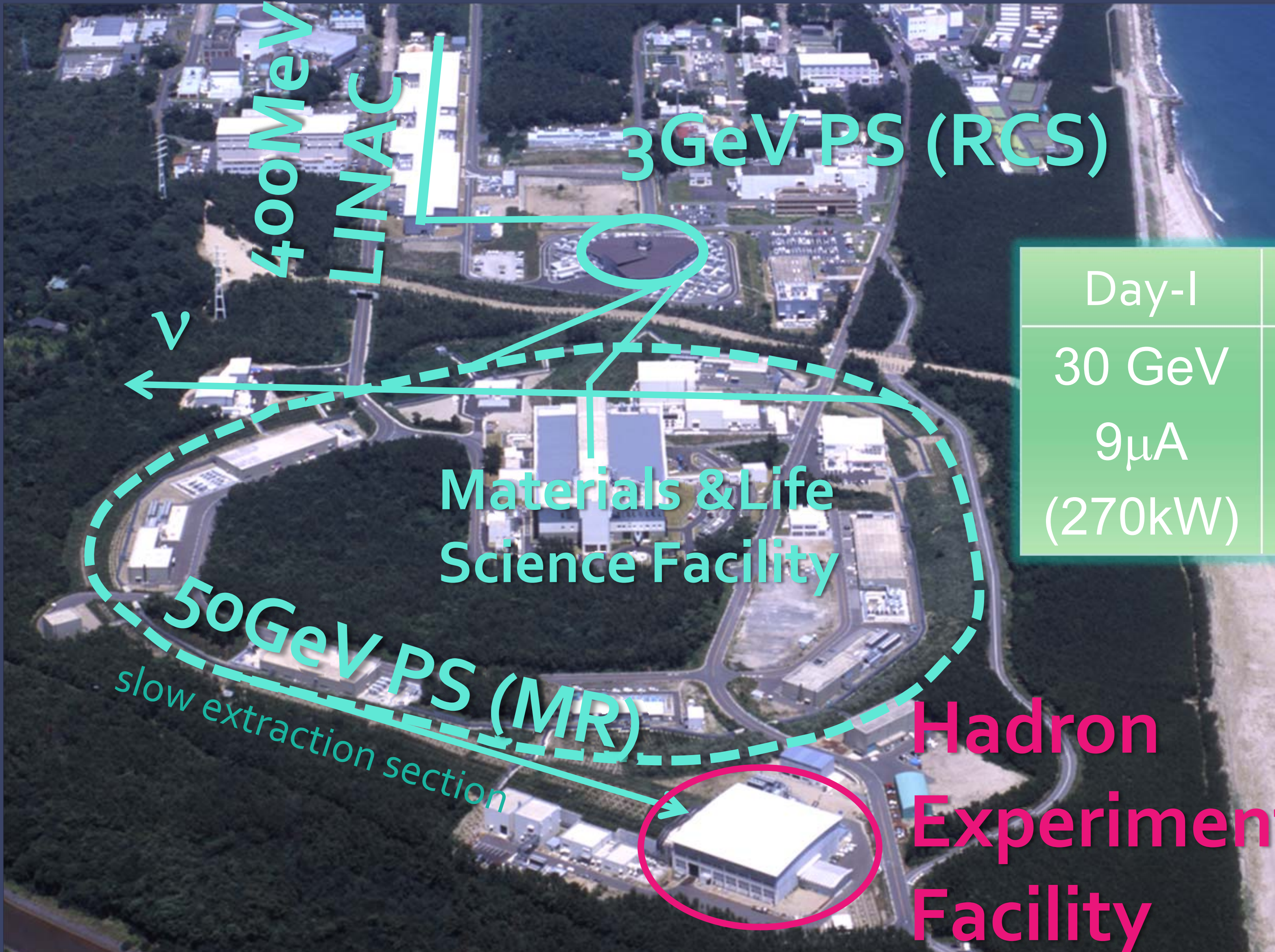
$\gamma p \rightarrow \pi^+ K^- K^+ (n)$



CLAS, PRL 92, 032001(2004)

J-PARC E19 experiment

J-PARC bird's-eye view



Day-I	Day-II
30 GeV	50 GeV
9μA	15μA
(270kW)	(750kW)

Hadron Experimental Facility

High Intensity Kaon Beams

K1.8
- p_{max} = 2.0 GeV/c
- $I_K \sim 10^6$ ppp
- Double-stage Electrostatic Separators

K1.8BR
- p_{max} = 1.1 GeV/c
- $I_K \sim 10^6$ ppp
- Large Exp. Area

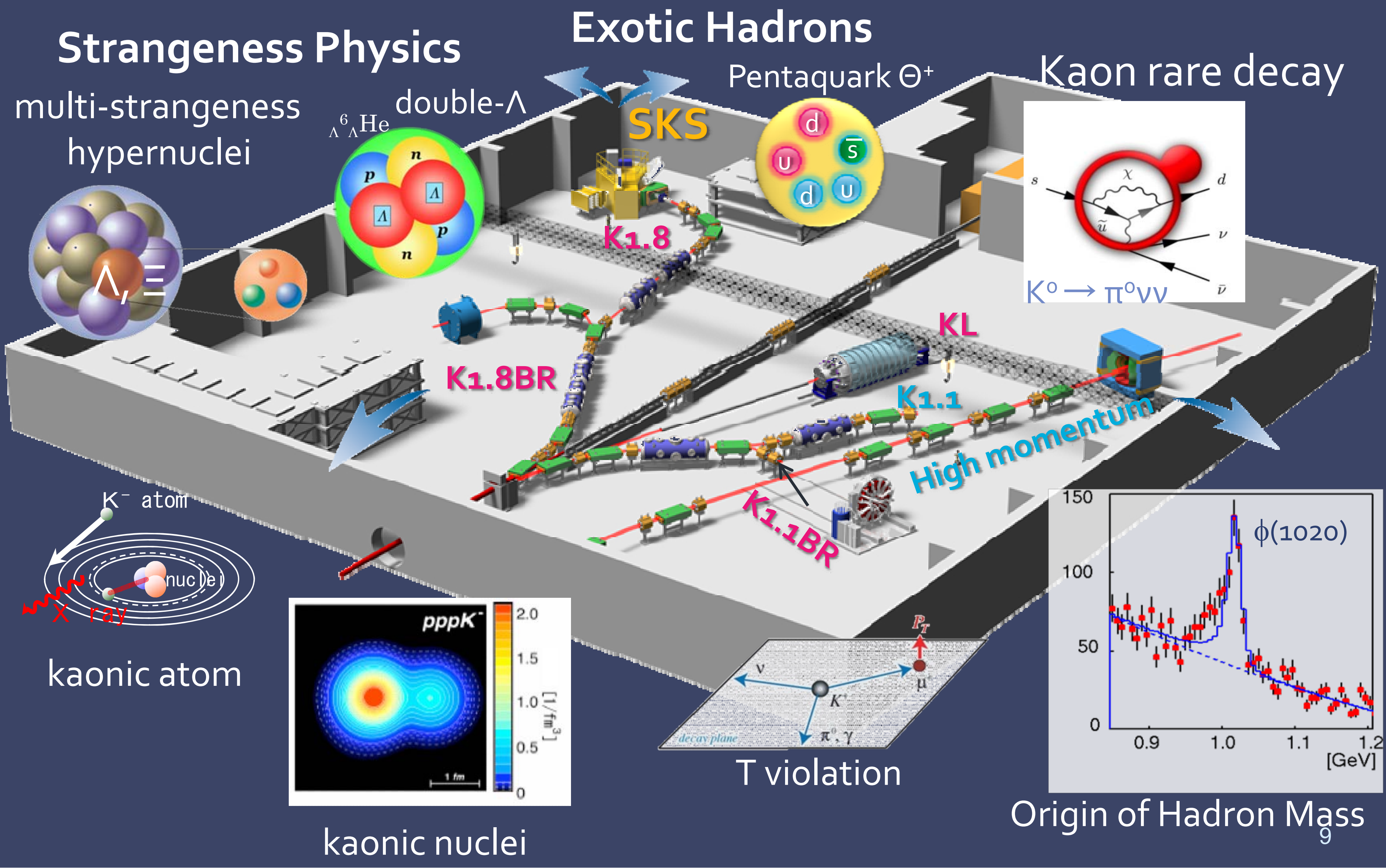
Production Target
Loss of 30%

K1.1BR
- p_{max} = 0.8 GeV/c
- $I_K \sim 10^6$ ppp
- suitable for stop-K experiment

KL
- neutral kaon
- p = 2.1 GeV/c
- $I_K \sim 10^7$ ppp

High-p
- primary proton
- p_{max} = 51 GeV/c
- $I_p \sim 10^{9\sim12}$ ppp

Nuclear & Hadron Physics at J-PARC



Hadron Physics Programs

	Spokespersons	Title of the experiment	Approval status	Slow line priority		Beamline
				Day1?	Priority	
E15	M.Iwasaki, T.Nagae	A Search for deeply-bound kaonic nuclear states by in-flight 3He(K^-, n) reaction	Stage 2	Day1		K1.8BR
E17	R.Hayano, H.Outa	Precision spectroscopy of Kaonic 3He 3d->2p X-rays	Stage 2	Day1		K1.8BR
E31	H. Noumi	Spectroscopic study of hyperon resonances below KN threshold via the (K -,n) reaction on Deuteron	Stage1			K1.8BR
E03	K.Tanida	Measurement of X rays from Ξ^- Atom	Stage 2			K1.8
E05	T.Nagae	Spectroscopic Study of Ξ-Hypernucleus, 12 ΞBe, via the 12C(K^-, K^+) Reaction	Stage 2	Day1	1	K1.8
E07	K.Imai, Nakazawa, Tamura	Systematic Study of Double Strangeness System with an Emulsion-counter Hybrid Method	Stage 2			K1.8
E08	A.Krutenkova	Pion double charge exchange on oxygen at J-PARC	Stage 1			K1.8
E10	A. Sakaguchi, T. Fukuda	Production of Neutron-Rich Lambda-Hypernuclei with the Double Charge-Exchange Reaction (Revised from Initial P10)	Stage 2			K1.8
E13	T.Tamura	Gamma-ray spectroscopy of light hypernuclei	Stage 2	Day1	2	K1.8
E18	H.Bhang, H.Outa, H.Park	Coincidence Measurement of the Weak Decay of 12 $_{\Lambda}$C and the three-body weak interaction process	Stage 1			K1.8
E19	M.Naruki	High-resolution Search for Θ^+ Pentaquark in π^-p → K^-X Reactions	Stage 2	Day1		K1.8
E22	S. Ajimura, A.Sakaguchi	Exclusive Study on the Lambda-N Weak Interaction in A=4 Lambda-Hypernuclei	Stage 1			K1.8
E27	T. Nagae	Search for a nuclear Kbar bound state K-pp in the d(p^+,K^+) reaction	Stage 2			K1.8
E14	K.Ozawa	Search for ω-meson nuclear bound states in the π-+^{A}Z -> n+$^{(A-1)}{}_{\omega}$(Z-1) reaction, and for ω mass modification in the in-medium ω->$\pi^0\gamma$ decay.	Stage 1			K1.8
E06	H. Ohnishi	Search for ϕ-meson nuclear bound states in the pbar + ^{A}Z -> ϕ + $^{(A-1)}{}_{\phi}$(Z-1) reaction	Stage 1			K1.1
E16	S.Yokkaichi	Electron pair spectrometer at the J-PARC 50-GeV PS to explore the chiral symmetry in QCD	Stage 1			High pt

beam power vs stage-2 exp.

π K

30 days

3kW 10kW 30kW 50kW 270kW

K1.8

E19
Search for Pentaquark Θ^+

E05
Ξ-Hypernucleus (priority 1)

E07
Double Strangeness with Emulsion

E10
neutron rich Λ-Hypernuclei

E03
X rays from Ξ^- Atom

E13
Gamma-ray spectroscopy of light hypernuclei (priority 2)

E27
Search for K-pp

K1.8BR

E17
Kaonic 3He

E15
deeply bound kaonic nucleus

KL

E14

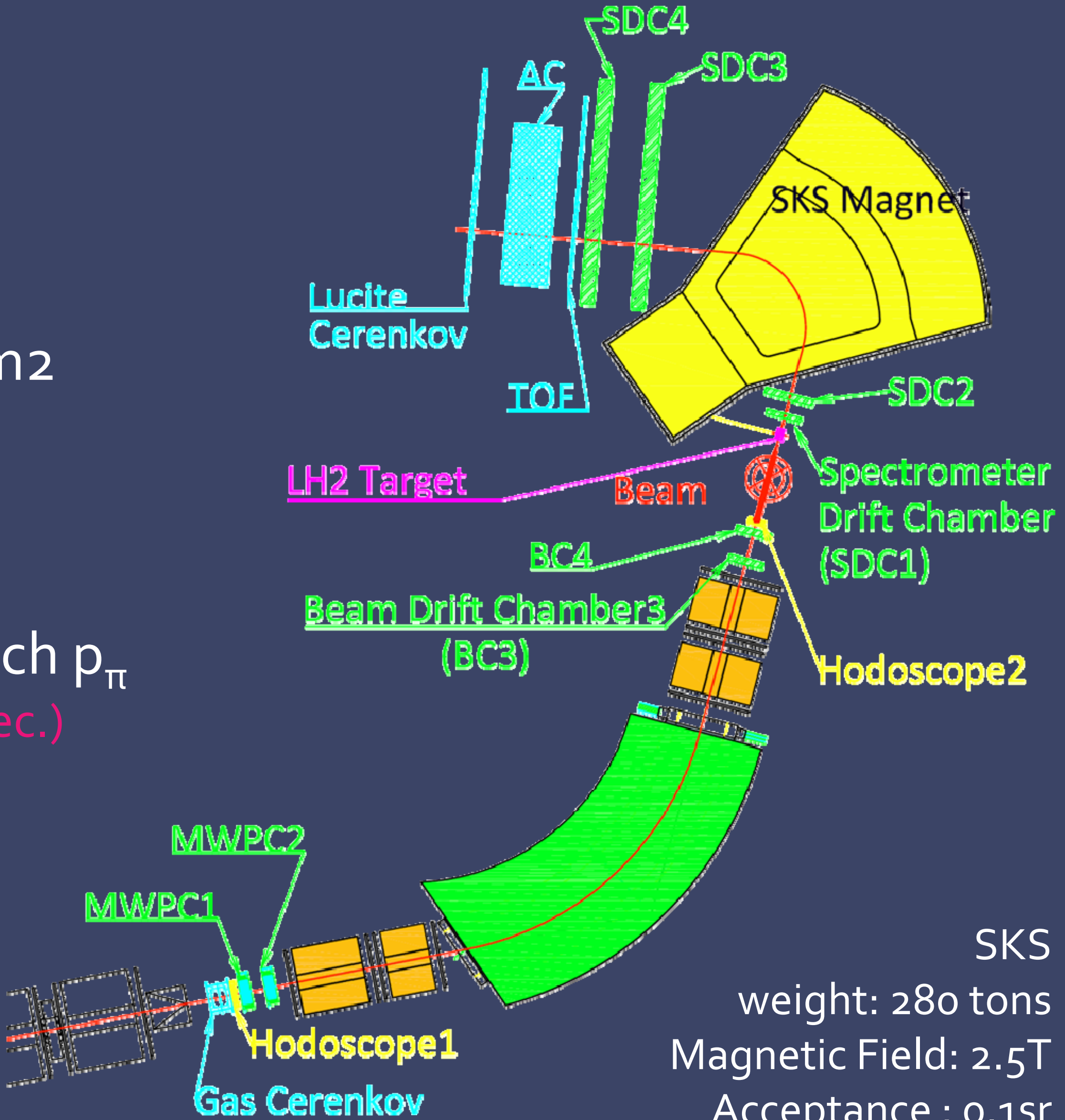
E14

E14
Kaon Rare Decay

J-PARC E19

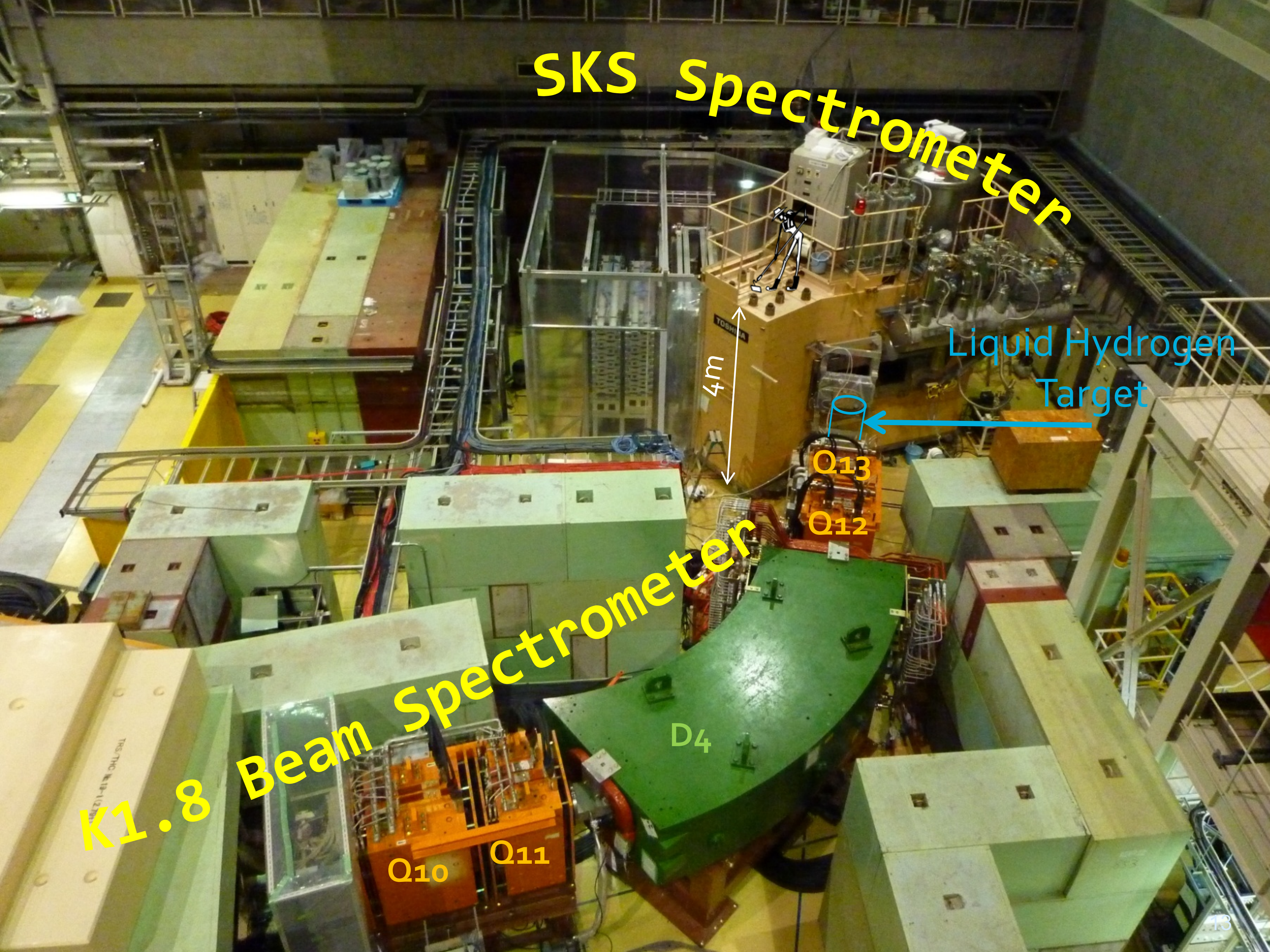
- search for Θ^+ in $p(\pi^-, K^-)$
- target : liquid H2, 0.86g/cm2
- at K1.8 beamline + SKS
- beam momentum :
  p_π=(1.87,1.92,2.00GeV/c)
- 4.8 x 10^{11} π on target for each p_π
  - beam intensity : 10^7/spill(2sec.)
  - beam time : 160 hours

SKS : ideal for Θ^+ detection
large acceptance : 0.1sr
ΔM = 2.5MeV FWHM



SKS
weight: 280 tons
Magnetic Field: 2.5T
Acceptance : 0.1sr

Yield : 10^4 events for each momentum
Sensitivity : 75nb/sr
→ confirm the existence of Θ^+


SKS Spectrometer
Liquid Hydrogen Target
4m
Q13
Q12
K1.8 Beam Spectrometer
D4
Q10
Q11

Short-term goal – 2010 autumn

- as Step1 (FY2010)
  - confirm Θ^+ with 10σ for 6days(=144 hrs) data taking.
  - cf. KEK-PS E522 : bump measured at p_π=1.92GeV/c, σ_Θ = 1.9μb/sr.
- beamtime : 272 hrs=11.3days (incl. 10% downtime)

Menu	hrs	#π on target
Commissioning & Control Run	116	
Production Run 1.92GeV/c $\pi^- p \to K^- X$	156	7.8×10^{10}

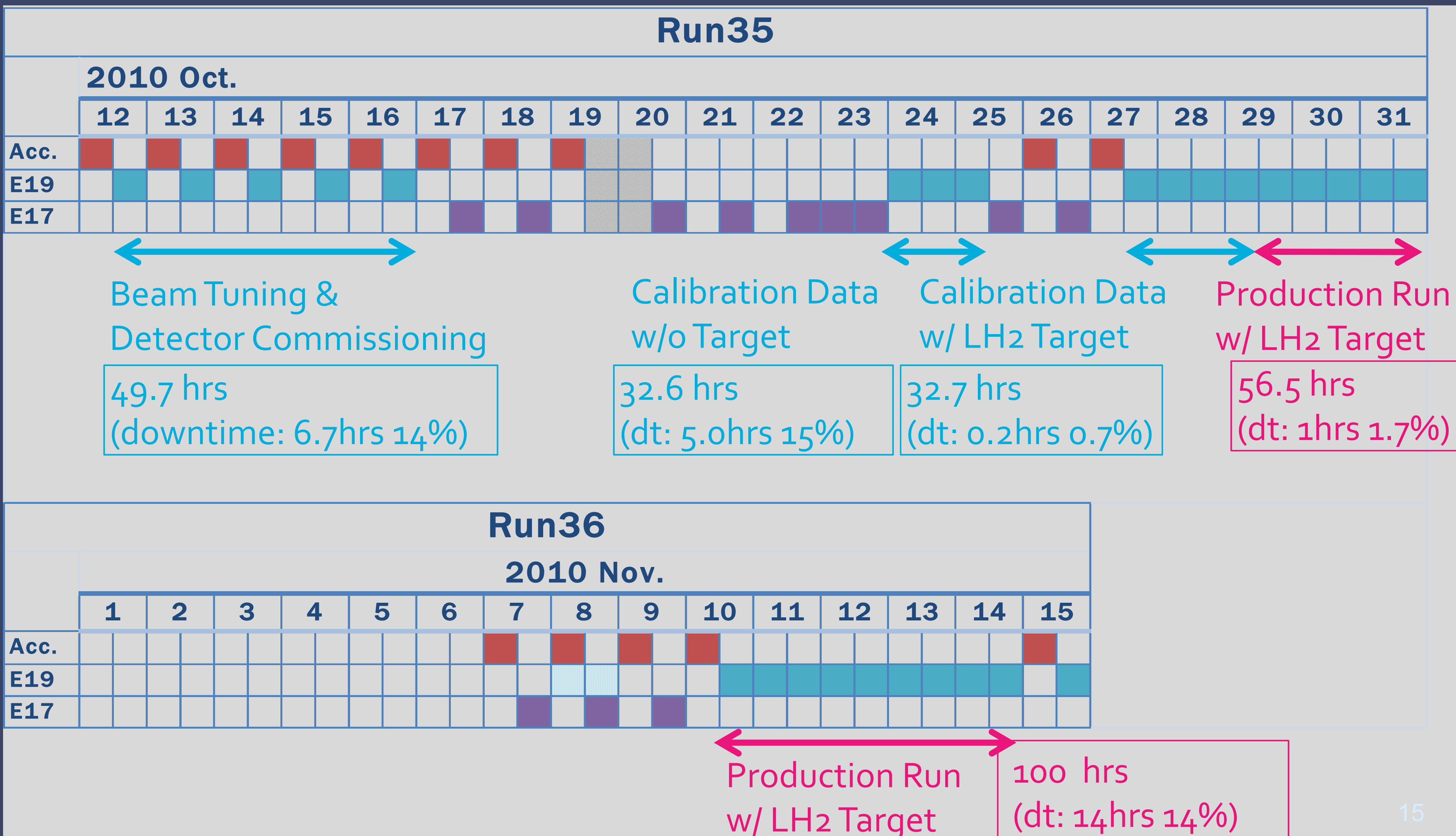
~16% of the final goal

  - successfully accumulate the intended statistics.
- Duty factor
  - improved. to 16% (measured w/ K1.8 counter)
  - acceptable beam rate is 1.1M π/spill with duty of 16%.

Beam time : 2010 Autumn

for Hadron : 18 days (12% downtime)

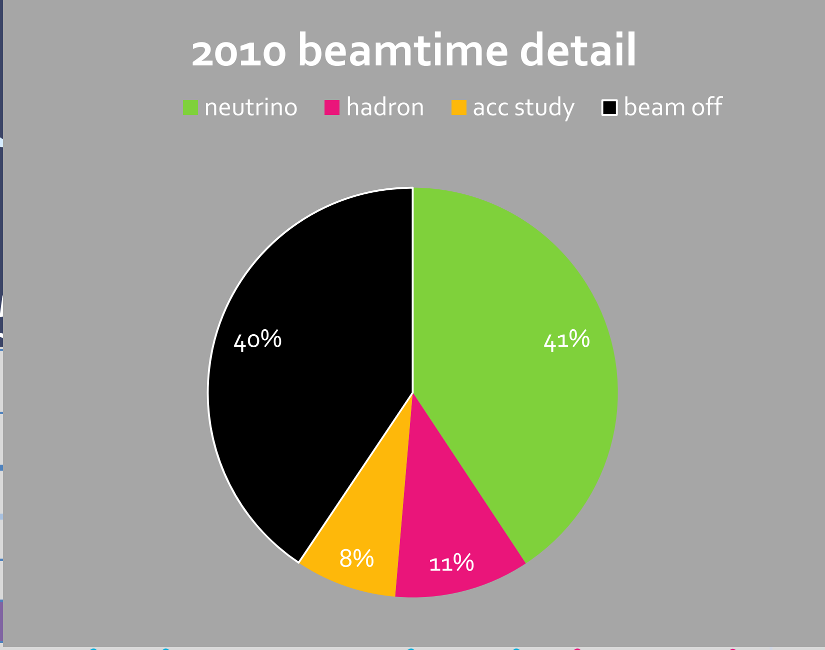
for E19 : 12 days for E19 & 6 days for E15/E17



Beam time : 2010 Au

for Hadron : 18 days (12% downtime)

for E19 : 12 days for E19 & 6 days for E1



Run35

	2010 Oct.										
	12	13	14	15	16	17	18	19	20	21	22
Acc.											
E19											
E17											

Beam Tuning & Detector Commissioning
49.7 hrs (downtime: 6.7hrs 14%)

Calibration Data w/o Target
32.6 hrs (dt: 5.0hrs 15%)

Calibration Data w/ LH2 Target
32.7 hrs (dt: 0.2hrs 0.7%)

Production Run w/ LH2 Target
56.5 hrs (dt: 1hrs 1.7%)

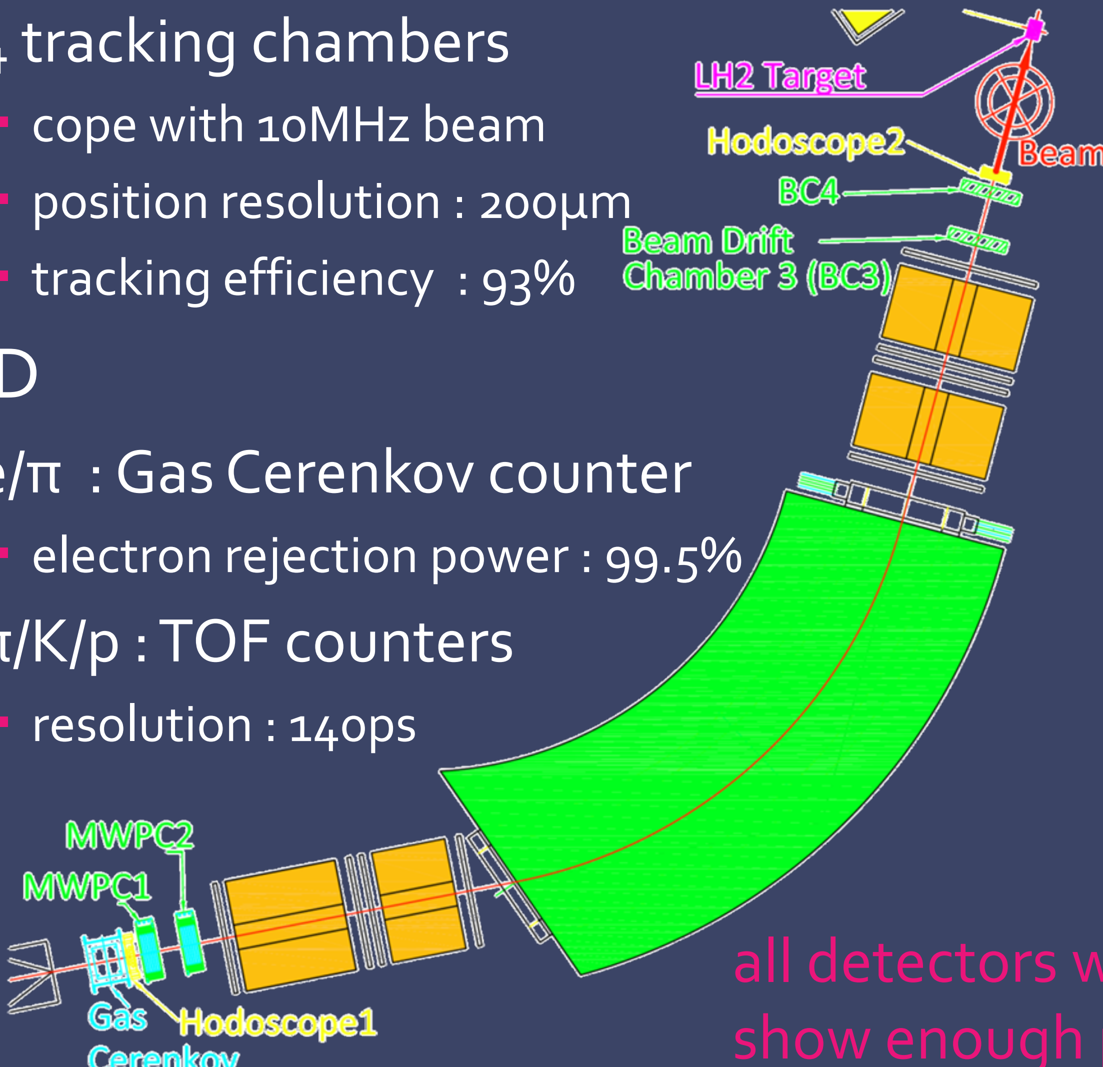
Run36

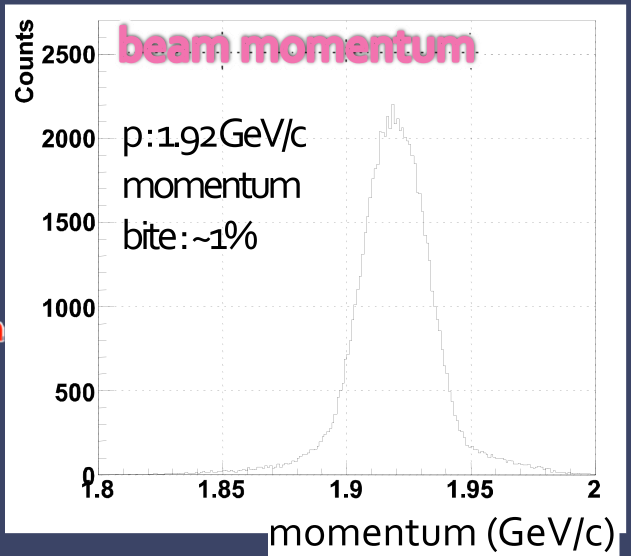
	2010 Nov.														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Acc.															
E19															
E17															

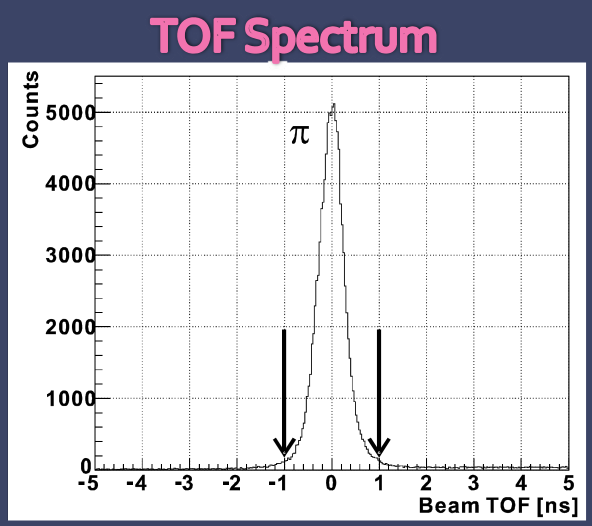
Production Run w/ LH2 Target
100 hrs (dt: 14hrs 14%)

K1.8 Beamline Spectrometer

- momentum analysis
  - 4 tracking chambers
    - cope with 10MHz beam
    - position resolution : 200μm
    - tracking efficiency : 93%
- PID
  - e/π : Gas Cerenkov counter
    - electron rejection power : 99.5%
  - π/K/p : TOF counters
    - resolution : 140ps





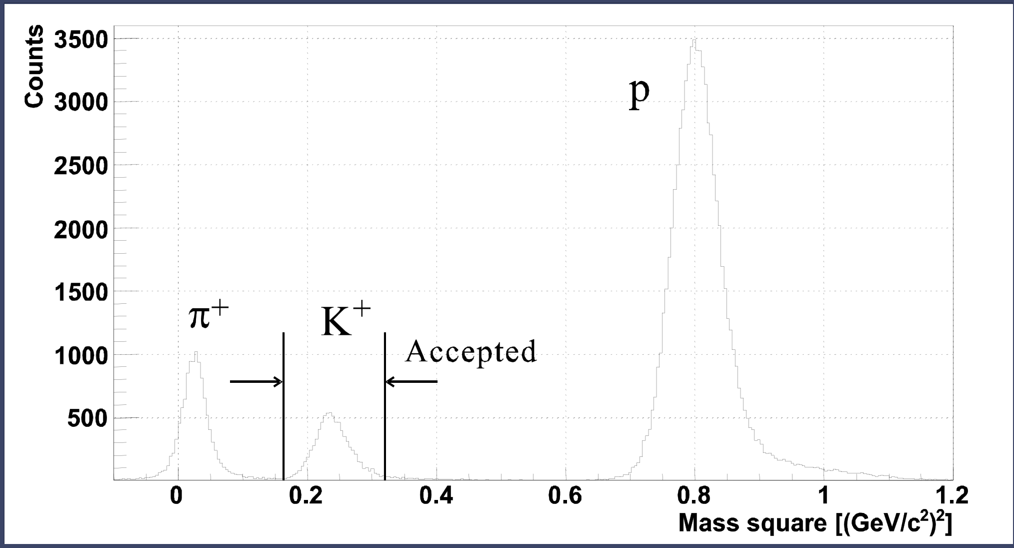


all detectors worked well & show enough performance.

SKS Spectrometer Performance

- SKS magnet
  - successfully operated up to 2.5 T at 400 A.
- Tracking Chambers
  - resolution ~ 250μm
  - tracking efficiencies : 96%
- Particle Identification
  - LC efficiency : 98.6%
  - AC over killing rate : 6.3%
  - KID efficiency : 83%

M^2 spectrum of scattered particles

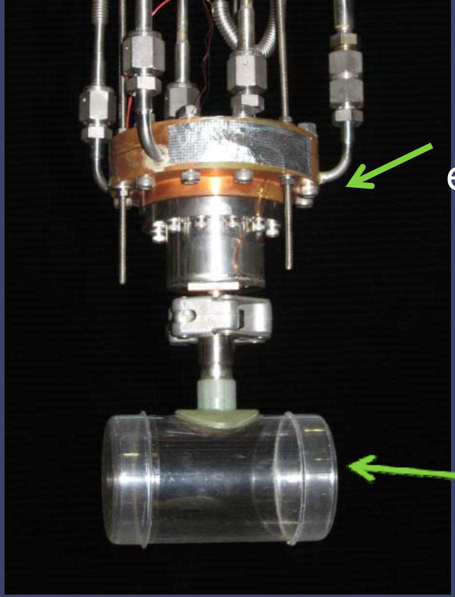


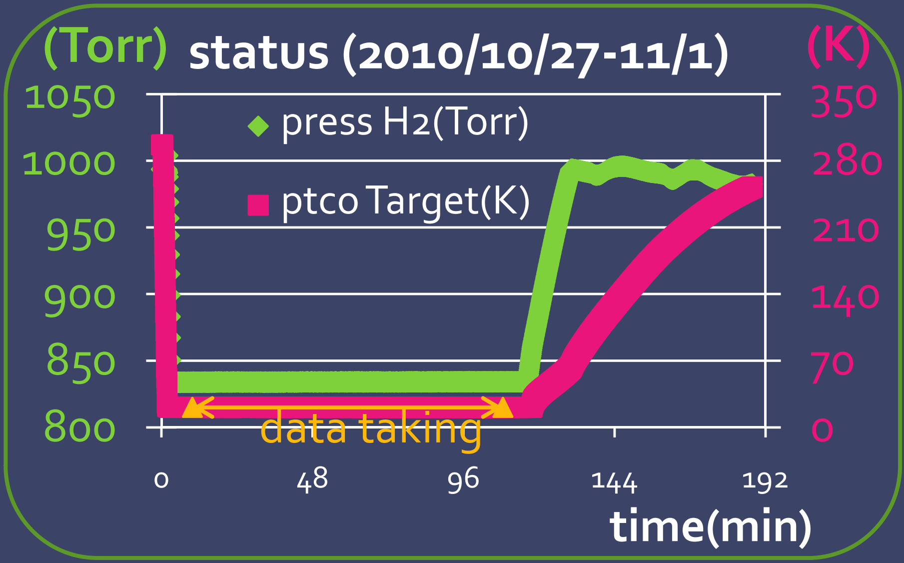
Mass square [$(GeV/c^2)^2$]

Enough performance has been achieved.

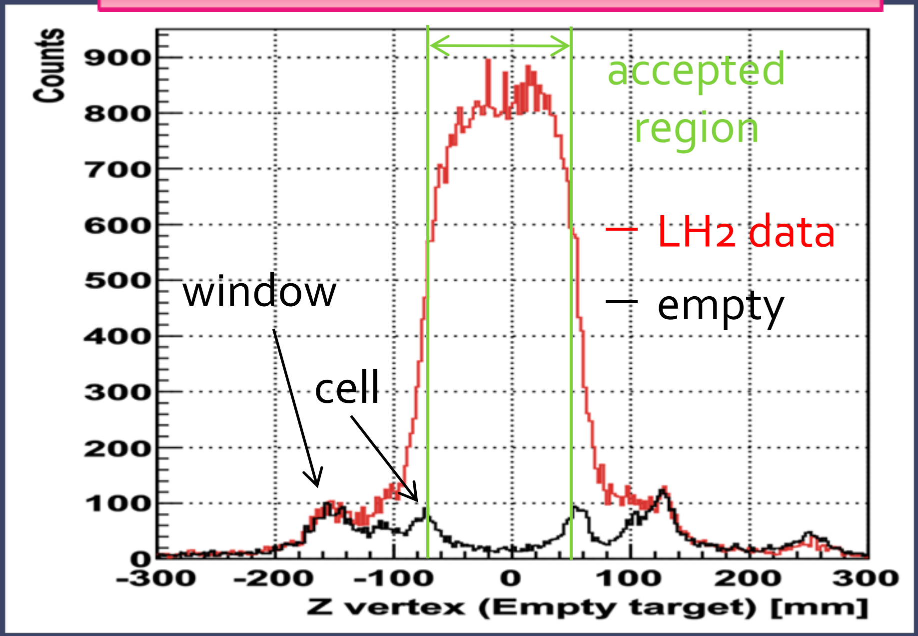
LH2 Target

- continuous-flow Liquid Helium Cryostat
- key to suppress background & free from Fermi motion effect
- thickness : 0.86g/cm²
- safely operated during data taking
  - $d\rho/\rho \leq 10^{-5}$





Vertex Distribution



vertex cut efficiency = 75%, background contamination < 3%

Spectrometer Performance

- Σ^- & Σ^+ production have been studied
  - in (π^-,K^+) / (π^+,K^+) reactions
  - Target : Liquid Hydrogen
  - p_{beam} : -+1.37 GeV/c.

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

→ Θ^+ missing mass resolution : 1.5 MeV/c^2 (FWMH)

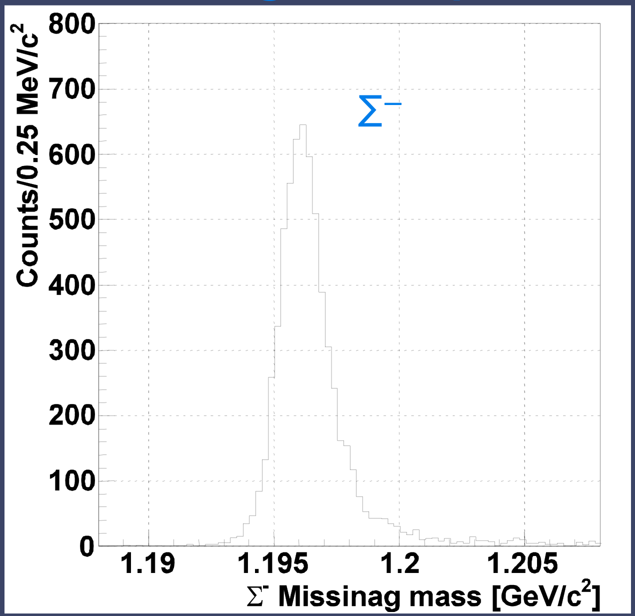
overall efficiency is examined with $\sigma(\Sigma^+)$.

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

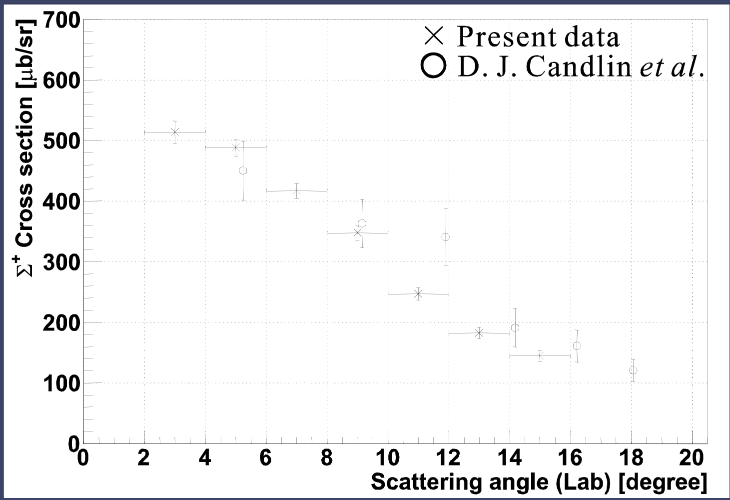
Achieved enough good resolution.

Yield is consistent with the estimation.

Missing mass spectrum

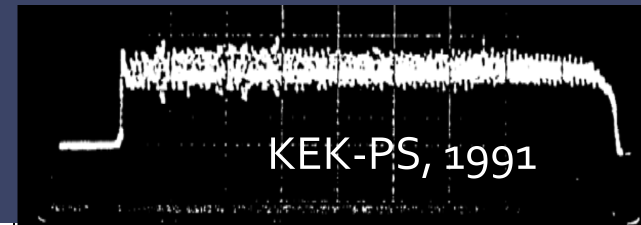


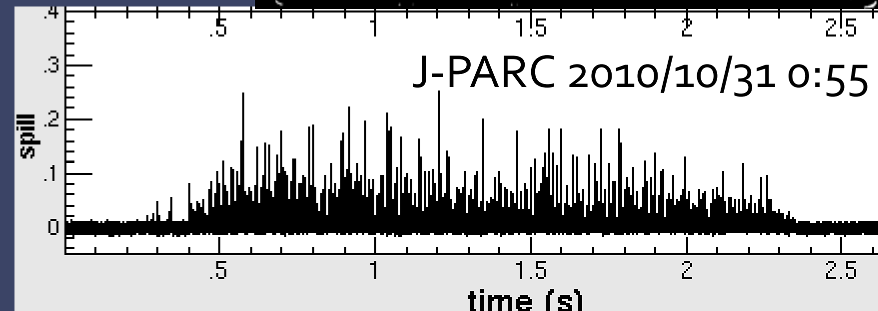
Production cross section of Σ^+



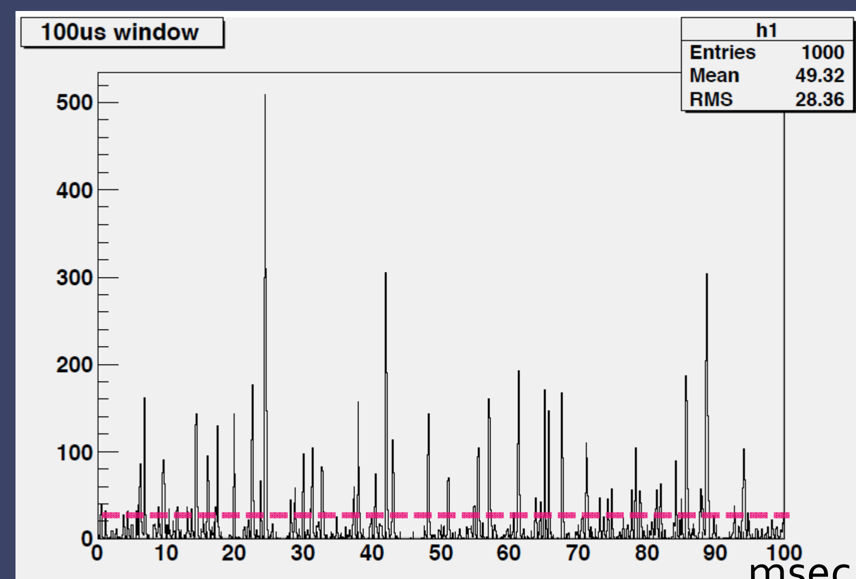
Spill Structure – it's bothering us

- duty factor （D.F）
  - acceptable intensity ∝ D.F.
  - → needs 1/D.F times beamtime
- spill structure has been improved.
  - Feb. 2010 : 8%
  - Oct. 2010 : 12%
  - Nov. 2010 : 16%
- duty has been very stable during the data taking. ~ 16%.
- acceptable beam rate is ~1.1M π/spill with duty of 16%.

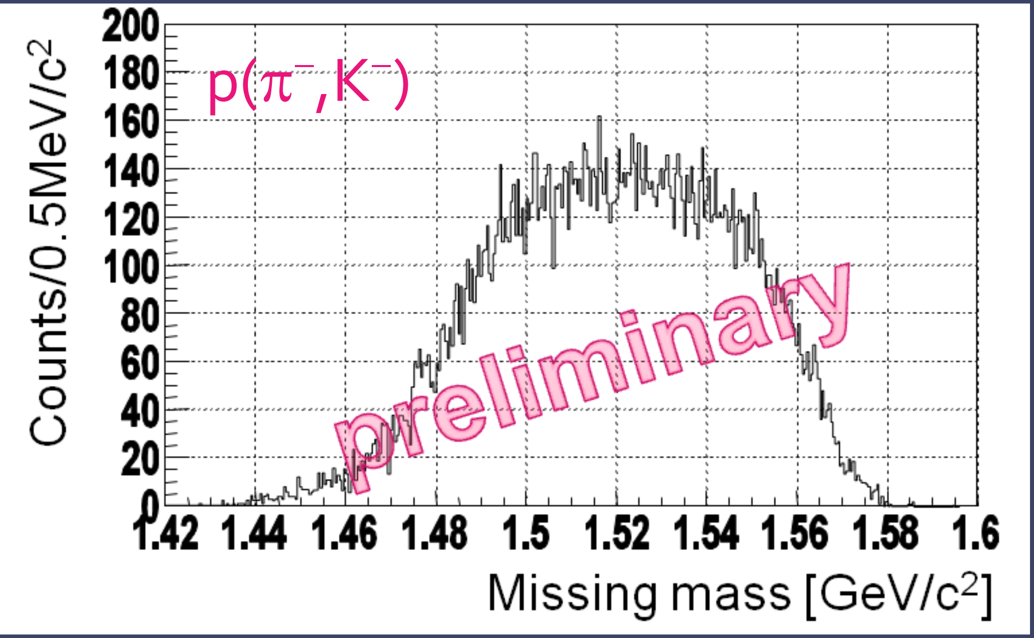




cf. duty factor ~ 80% at KEK-PS



Missing Mass Spectrum



- #beam 7.8×10^{10}
- #target 5.3×10^{23} /cm²
- 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 ~ 0.4μb (90%C.L.) (very preliminary) cf. 3.9μb (KEK-PS E522)

energy dependence of σ_{tot}

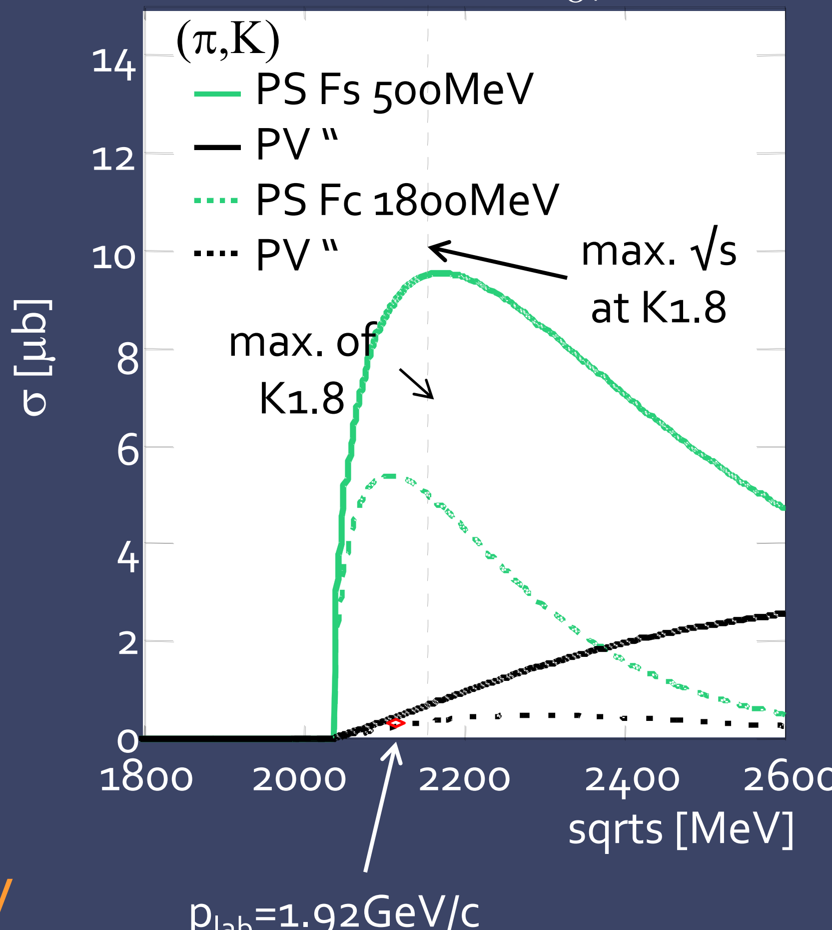
Theoretical calculations :
PS: Oh et al., PRD69(04)014009
Ko, Lee & Park, PLB611(05)87
PV: T. Hyodo, PRC72(05)055202.

the cross section is expected to increase with energy.

		P_{lab}= 1.92GeV/c	P_{lab}= 2GeV/c
PS	Fs 500MeV	9.3 μb	9.8 μb
	Fc 1800MeV	5.4 μb	4.9 μb
PV	Fs 500MeV	0.51 μb	0.75 μb
	Fc 1800MeV	0.30 μb	0.50 μb

as the next step,
take data & accumulate statistics at maximum momentum.

J^p=1/2$^+$, $\Gamma_{\Theta+}$ = 1MeV



sensitivity = 75nb/sr (lab)
corresponds to an stringent limit to the decay width of Θ^+.

1 MeV * **75 nb/sr** / 0.4 μb/sr = 0.2MeV

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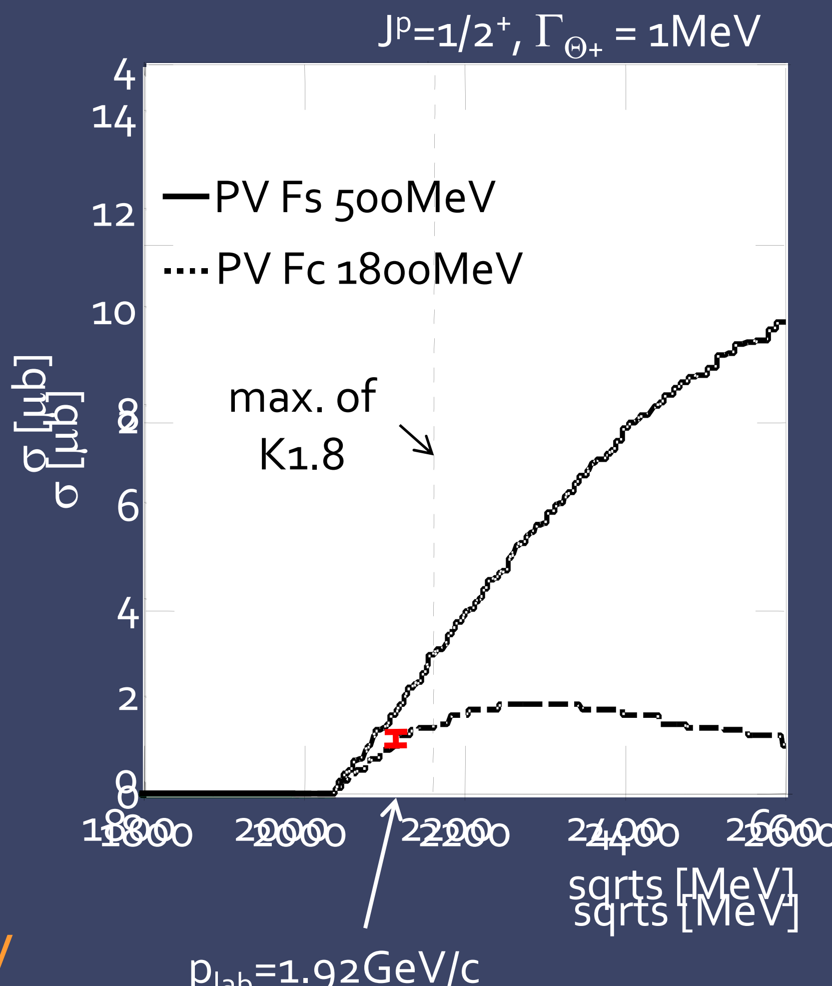
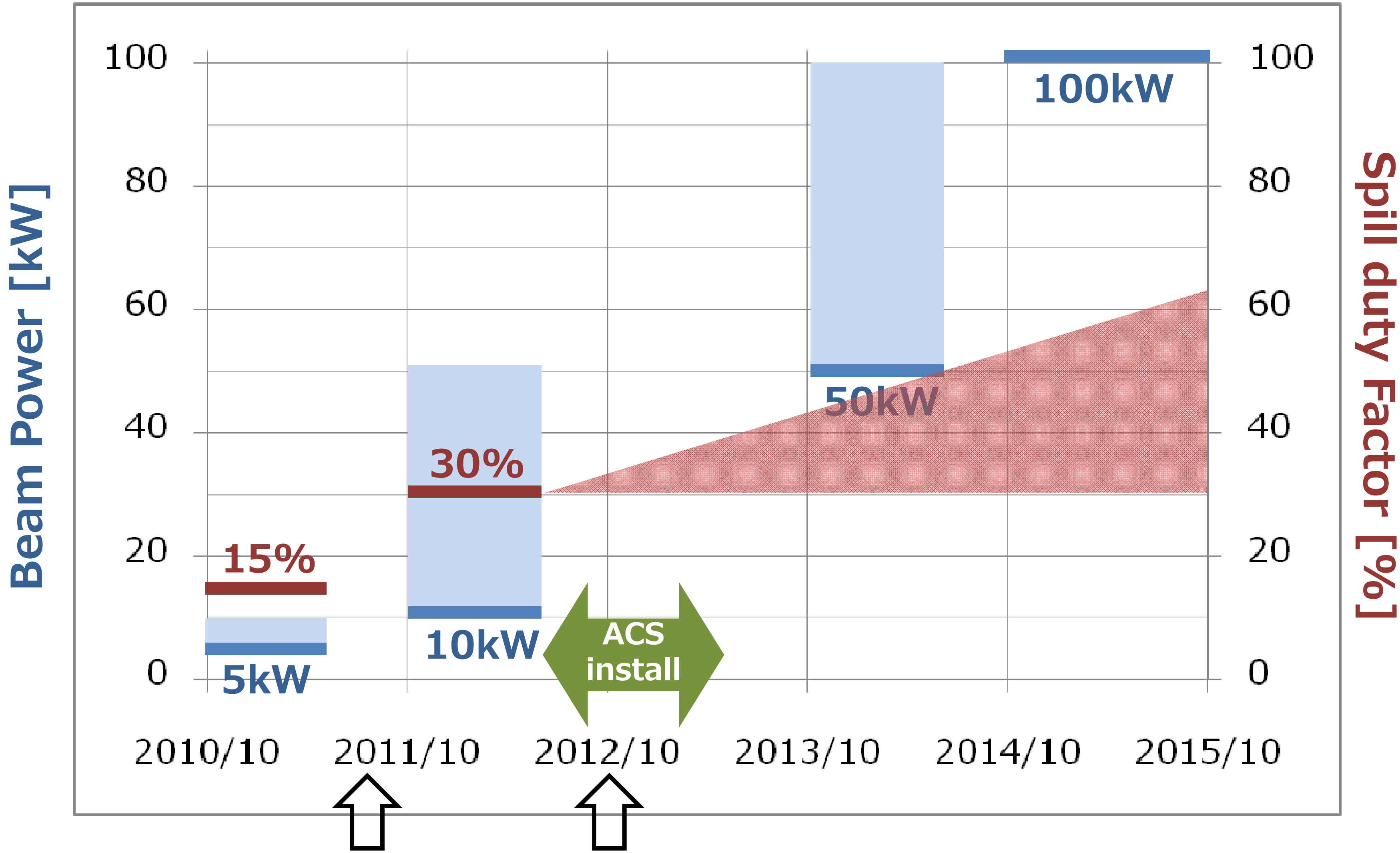


Strategy

- **Original plan**
  - approved beamtime : 4.8×10^{11} π on target for 3 momenta (160 hours x intensity : 10^7 π/4sec)
  - sensitivity : 75nb/sr $\leftrightarrow$ Γ < **0.2MeV**
- **Oct. – Nov. 2010**
  - collect 7.8×10^{10} π on target (156 hours x 1M π/6sec)
  - to confirm Θ^+ with 10σ assuming 1.9μb/sr at p_{beam} = 1.92GeV/c
- **Spring 2011 (assuming 16% duty factor)**
  - request 6 days to take data at p_{beam} = 2GeV/c
    - identify Θ^+ with 5σ, if exist.
    - reach the sensitivity of ~0.3μb. (< 0.5μb : theoretical prediction)
- **Autumn 2011 - (assuming 30% duty factor)**
  - Sensitivity : to reach 75nb/sr 18 days for each momentum.
  - momentum dependence of σ_{tot}

どのくらいのBeam Powerが期待できるのか?



SX Collimator
T-RF Power Up
Ripple canceller 等の調整

Ti chamber
maintenance strategyの確立
FBQPS Power Up

Summary

- J-PARC E19 searches for Θ^+ in $\pi^- p \rightarrow K^- \Theta^+$ reaction
  - K1.8 beamline + SKS is ideal for Θ^+
  - significance ~60σ, sensitivity ~75nb/sr
  - with mass resolution of 2.5MeV(FWHM)
- The first physics run was successfully done.
  - accumulate 16% of the full statistics.
  - spectrometer performance is OK.
  - no significant structure has been observed.
- We plan to study the energy dependence of the production cross section at the next beamtime.

~40 people
From KEK, Kyoto U., Tohoko U., U.Tokyo, Nara WU, Osaka U., JAEA, UNM(USA), INFN(Italy), Seol N. U., ITEP, JINR