

# Search for Pentaquark $\Theta^+$ in Hadronic Reaction at J-PARC

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at Jagiellonian Symposium, 8-12th June 2015, Krakow

# Outline

§ Introduction of J-PARC Hadron Facility

§ Recent Results

§ search for pentaquark  $\Theta^+$

§ Prospects of near future experiments

§ Summary

# J-PARC bird's-eye view

Tokai, Japan

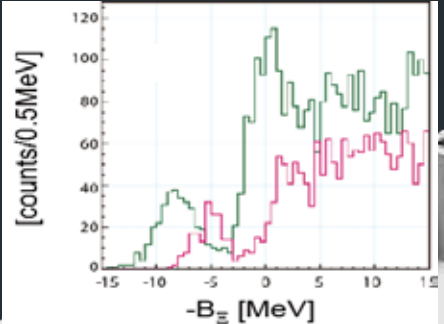




# Physic Program at J-PARC

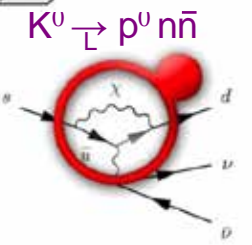
## Hypernuclear Physics

$\Xi$  hypernuclei in  $^{12}\text{C}(K^-, K^+)$  double- $\Lambda$



## Particle Physics

T-violation

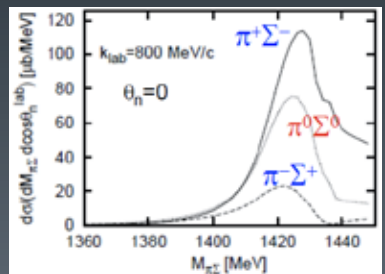


CP Violation

## Exotics

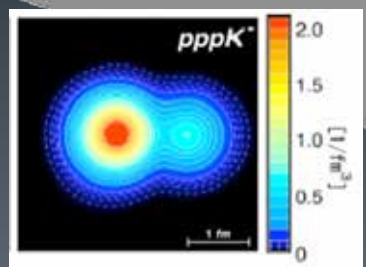


Pentaquark  $\Theta^+$



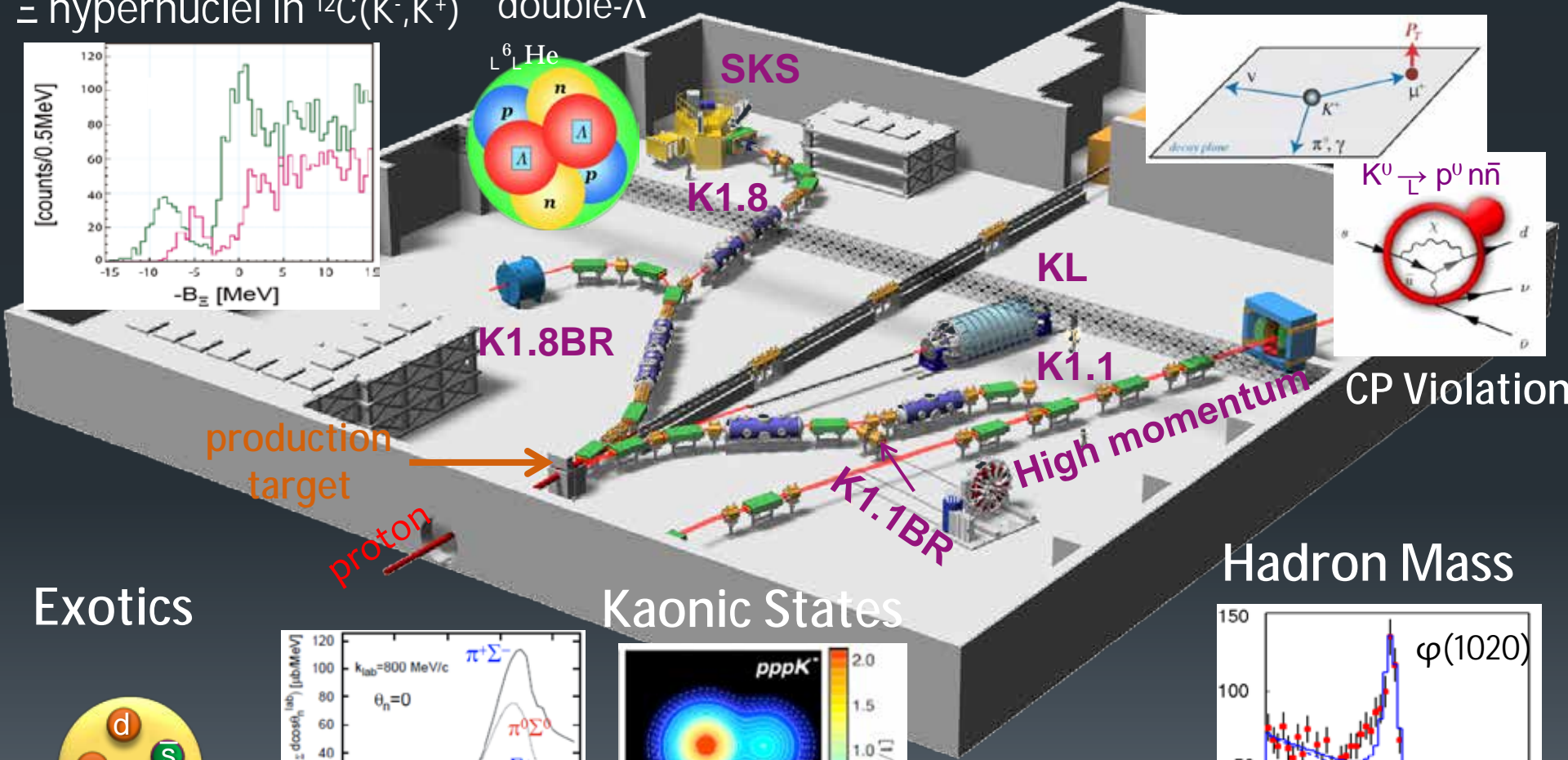
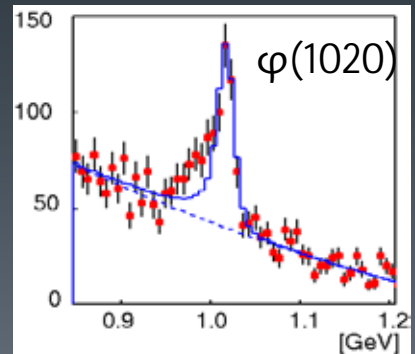
lineshape of  $\Lambda(1405)$

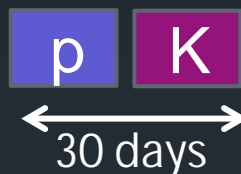
## Kaonic States



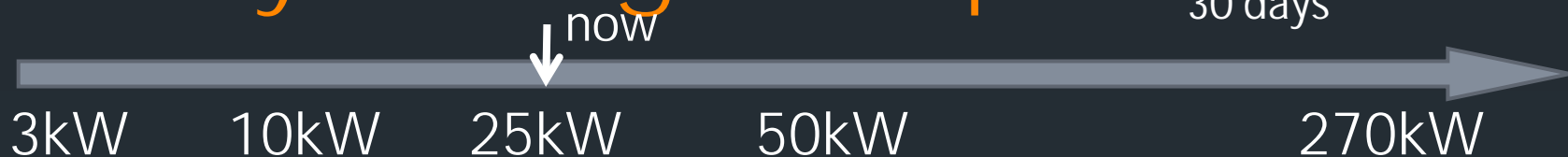
kaonic nuclei

## Hadron Mass

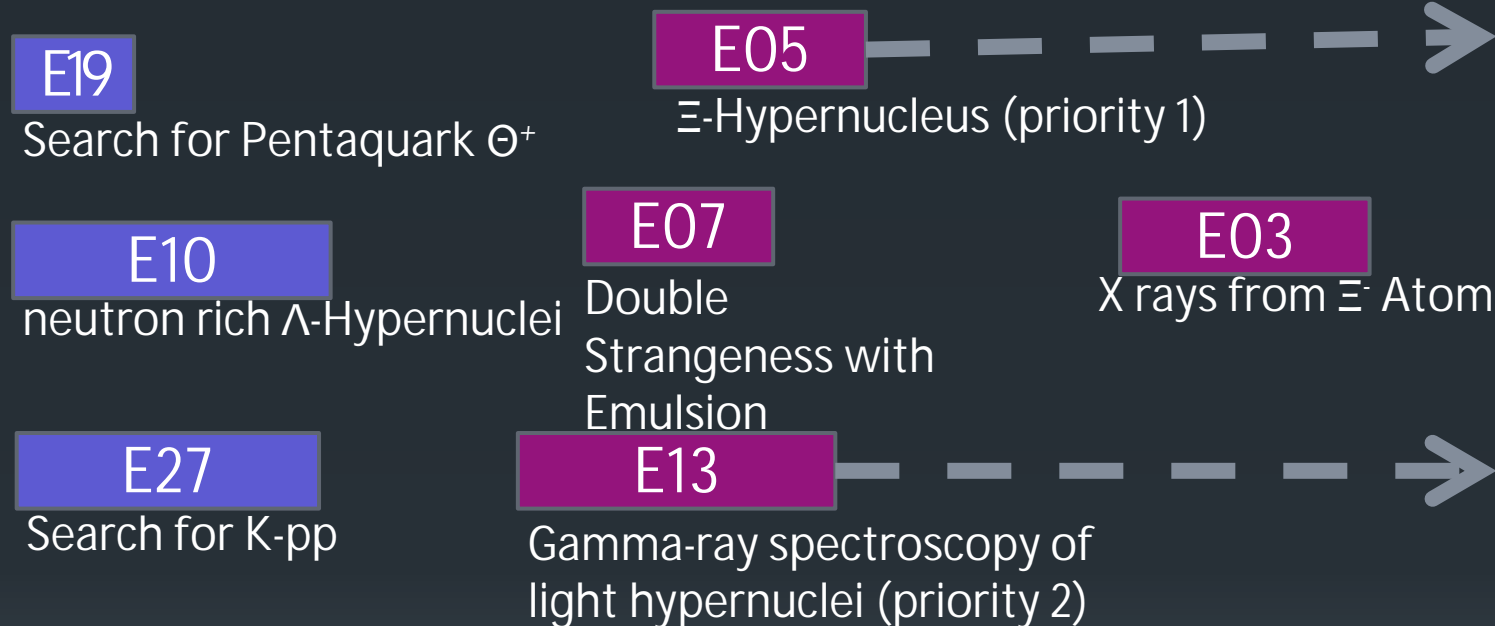




# Summary of Stage-2 Exp.

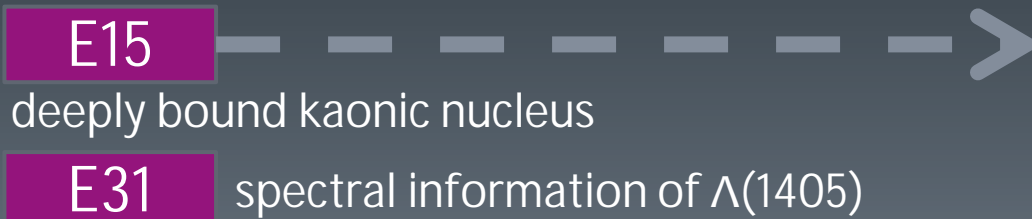


K1.8

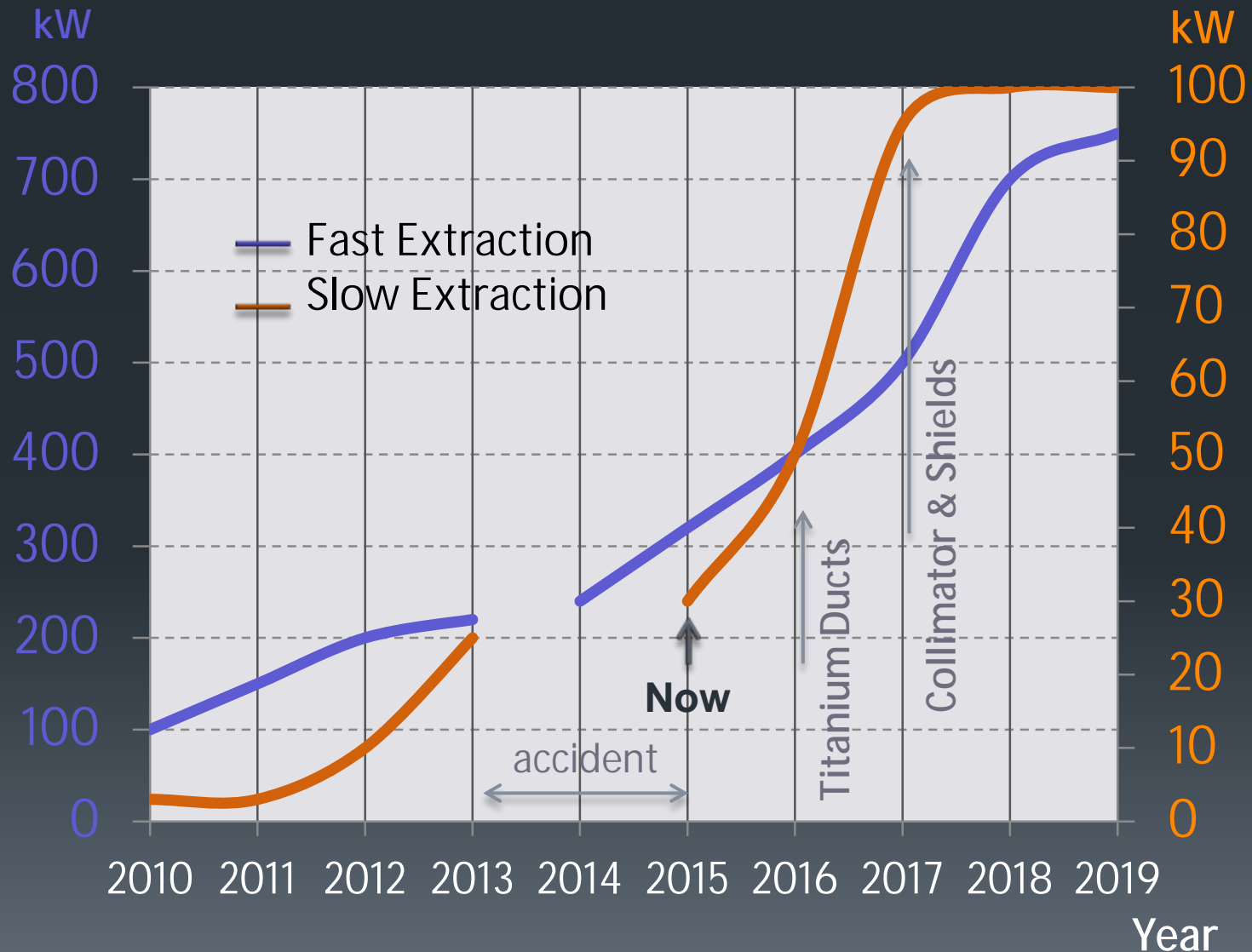


K1.8BR

**E17** Kaonic  $^3\text{He}$



# Power Upgrade Plan of 30GeV PS

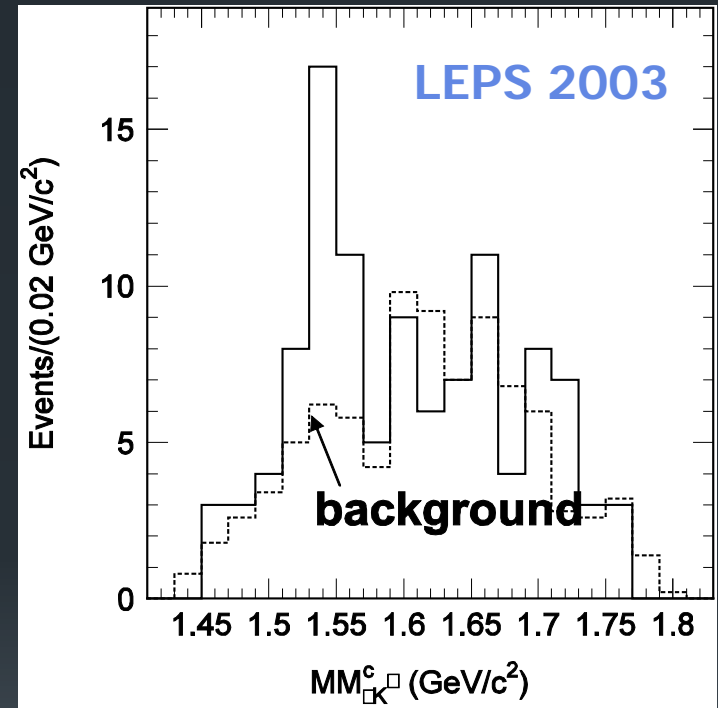


# Recent Results of hadron experiments

Search For Pentaquark  $\Theta^+$

# Search for pentaquark $\Theta^+$

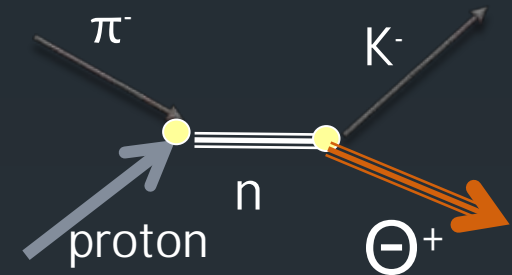
- §  $\Theta^+$  (uudd $\bar{s}$ ) : explicitly exotic 5-quark state
- § First discovery from LEPS
  - §  $\gamma n \rightarrow K^- + \rightarrow K^- K^+ n$
  - §  $M = 1.54 \pm 0.01 \text{ GeV}$
  - §  $\Gamma < 25 \text{ MeV}$
- § many positive & negative results
- § negative results from dedicated experiments
- § very narrow width
  - § internal structure





# Search for $\Theta^+$ in $\pi^- p \rightarrow K^- X$ reaction

- § exclusive & only s-channel process contributes
- § background processes well studied
- § no strong angular dependence
- § cross section  $\Gamma_{\Theta}$



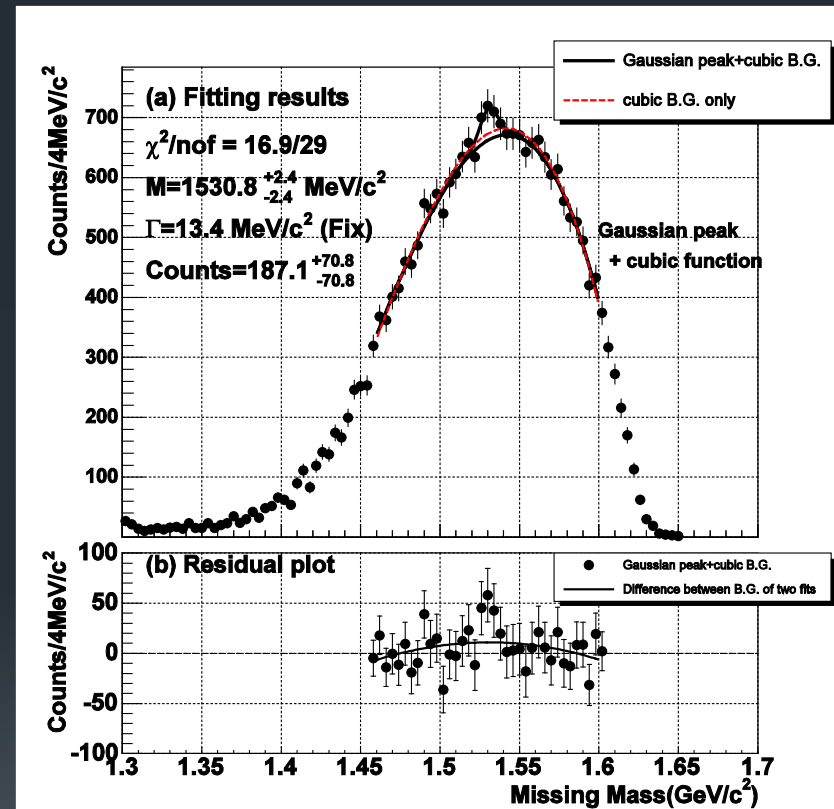
- ü examine the existence of the narrow pentaquark
  - with high statistics.
- ü determine the width
  - with high resolution of 2MeV

# KEK-PS E522 experiment

- $\Theta^+$  search via  $\pi^-p \rightarrow K^-X$  reaction
- $p_\pi = 1.87, 1.92 \text{ GeV}/c$
- target : polyethylene
- intensity :  $3.3 \times 10^5 \pi^- / \text{spill}$
- $\sim 7 \times 10^9 \pi^-$  on target
- $dM = 13.4 \text{ MeV}(\text{FWHM})$

a bump was observed  
 at  $M = 1530.8 \text{ MeV}/c^2$   
 at  $p_p = 1.92 \text{ GeV}/c$   
 but :  $S/N = 2.5\sigma$   
 upper limit :  $d\sigma/d\Omega < 2.9 \mu\text{b}/\text{sr}$

$$p_\pi = 1.92 \text{ GeV}/c$$



if exist,  $d\sigma/d\Omega = 1.9 \mu\text{b}/\text{sr}$

# J-PARC E19

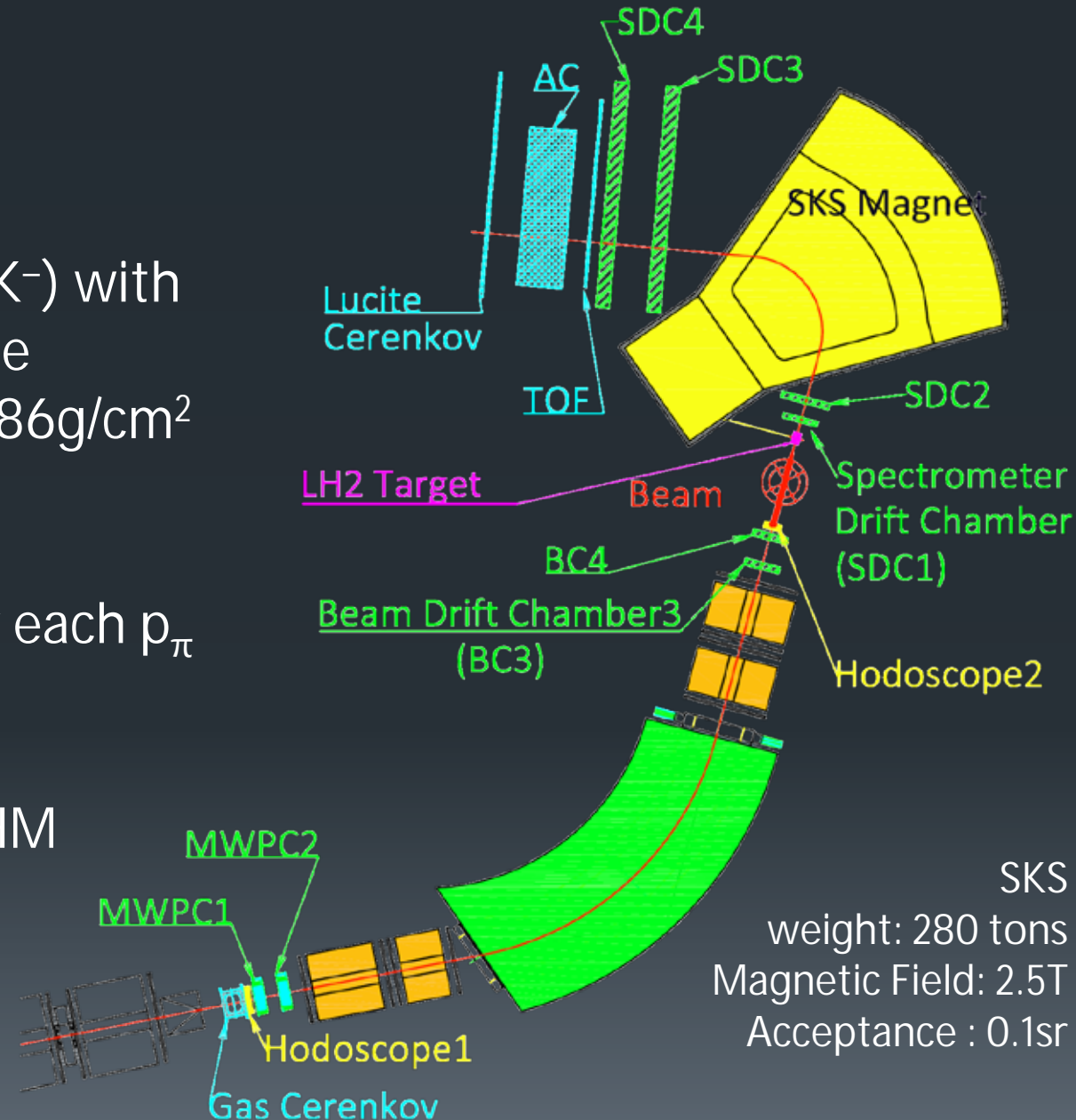
search for  $\Theta^+$  in  $p(\pi^-, K^-)$  with missing mass technique

target : liquid  $H_2$ ,  $\rho=0.86g/cm^2$

beam momentum :

$$p_\pi = (1.92, 2.00 GeV/c)$$

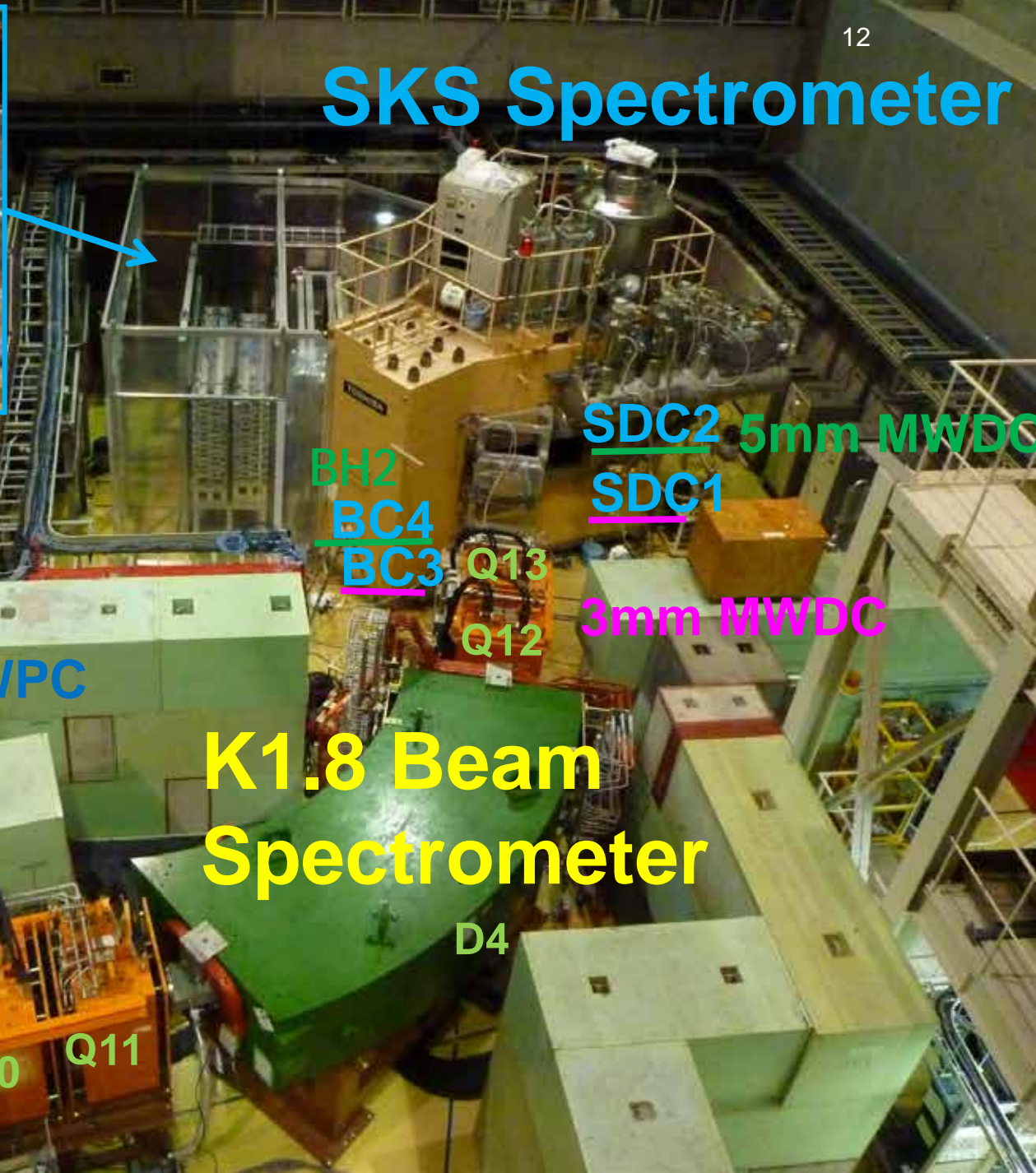
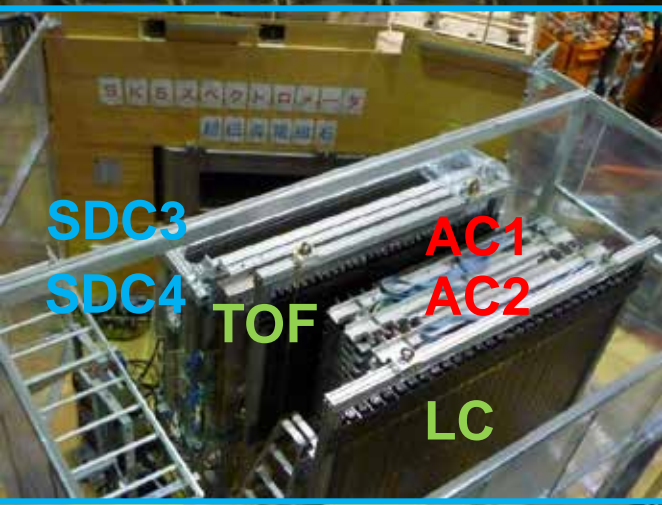
$8 \times 10^{10} \pi$  on target for each  $p_\pi$



Mass Resolution

$$SKS : \Delta M = 2MeV \text{ FWHM}$$

# SKS Spectrometer

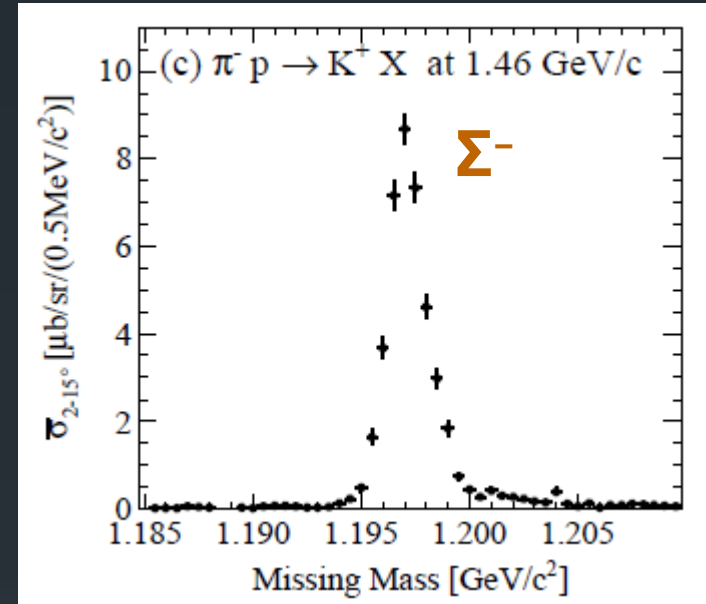


# K1.8 Beam Spectrometer

# Spectrometer Performance

Study of  $\Sigma^\pm$  production  
in  $\pi^\pm p \rightarrow K^+ X$  reaction

- $\Delta M_\Sigma = 2.21 \pm 0.05(\text{stat.}) \pm 0.1(\text{syst.})$   
(FWHM)  
 $\rightarrow \Delta M_{\Theta^+} = 2.13 \pm 0.15 \text{ MeV}/c^2$  (FWMH)
- absolute mass scale uncertainty :  
 $\pm 1.4 \text{ MeV}$  for  $\Theta^+$  region

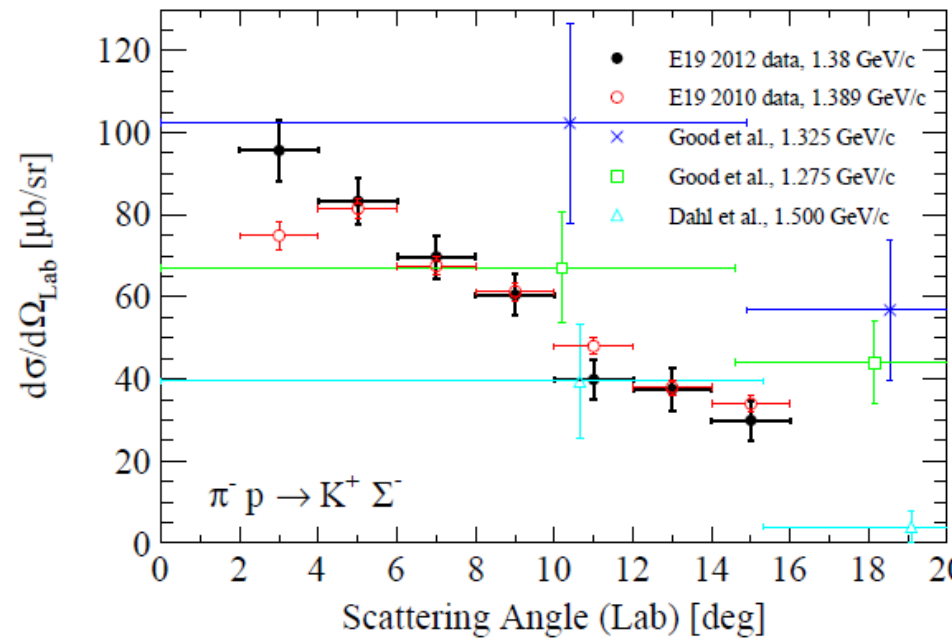
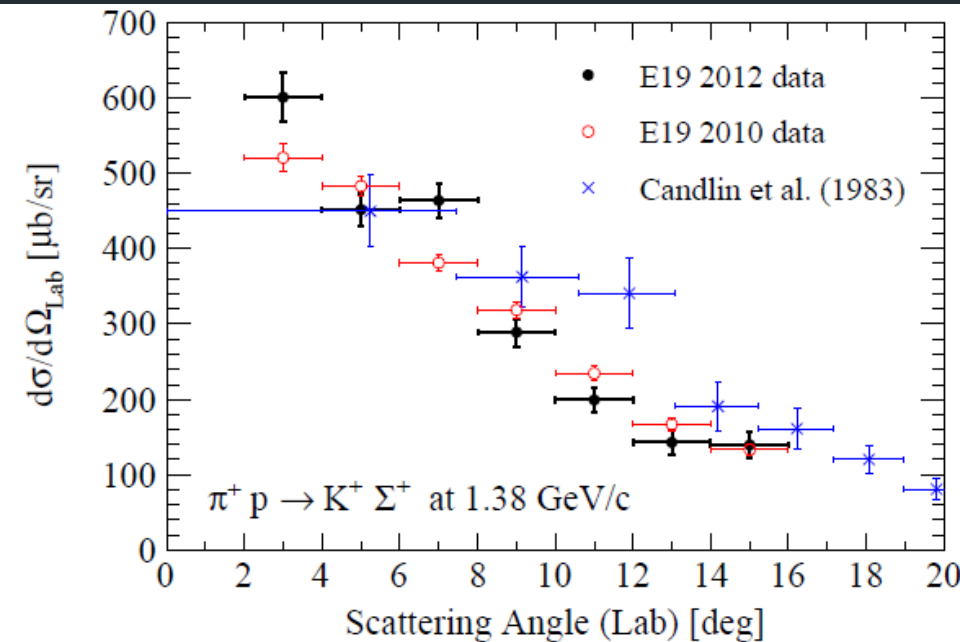


Achieved enough good resolution.

# $\Sigma$ production cross section

$\pi^+ + p$      $K^+ + \Sigma^+$  @ 1.38 GeV/c

$\pi^- + p$      $K^+ + \Sigma^-$  @ 1.38 GeV/c

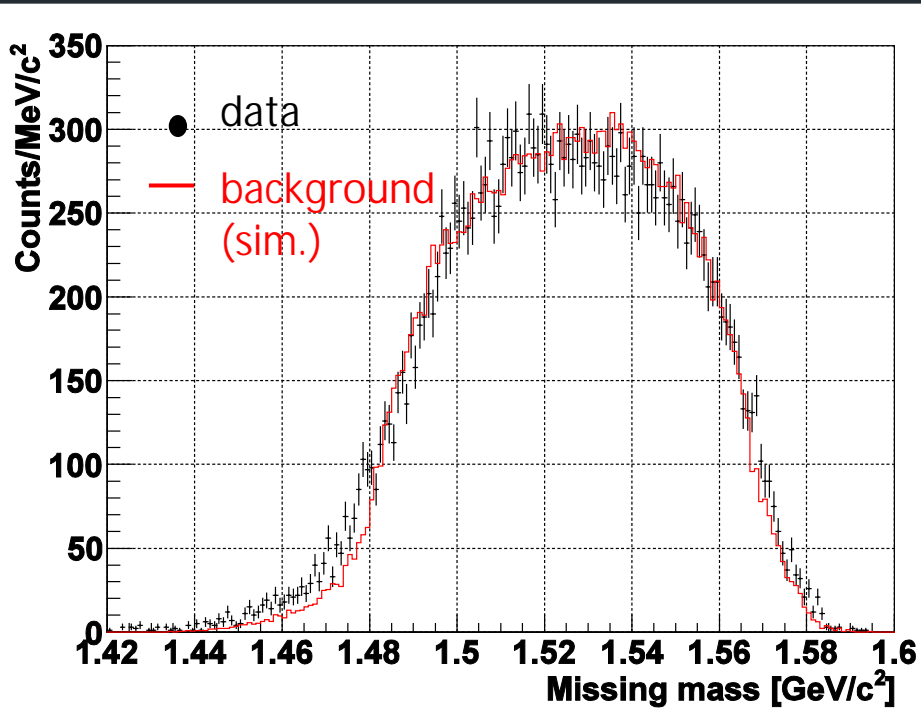


- ü Good agreement with previous data
- ü Most precise measurement from E19

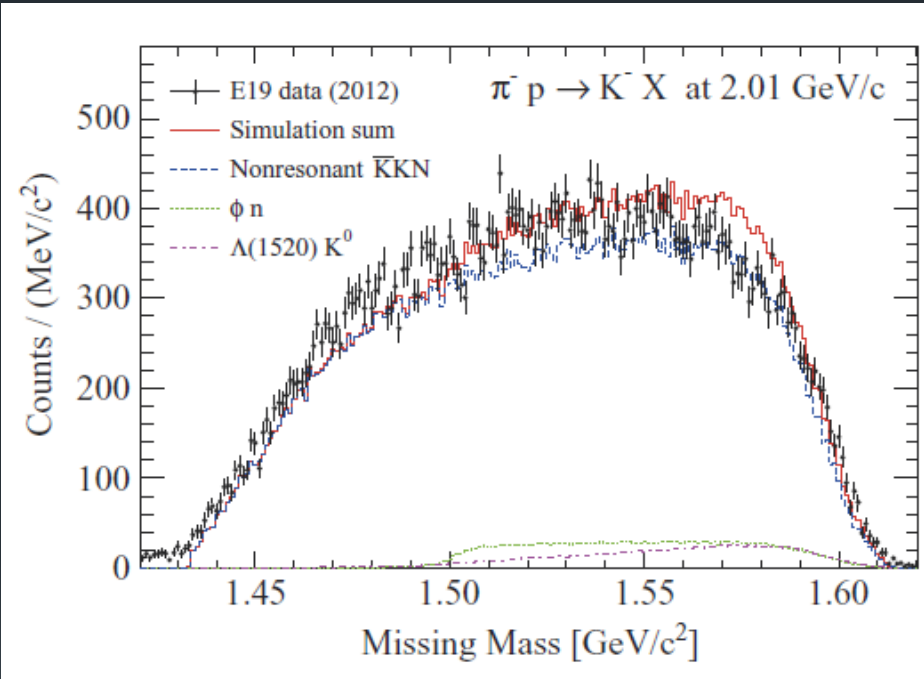
# Missing Mass Spectrum

1.92 GeV/c  $\pi^- p \rightarrow K^- X$

2.01 GeV/c  $\pi^- p \rightarrow K^- X$



K. Shirotori *et al.*, PRL 109 (2012) 132002



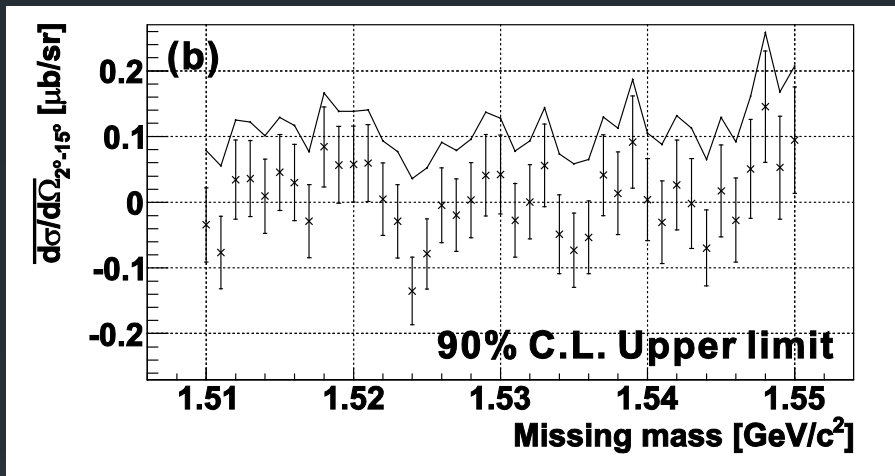
M. Moritsu *et al.*, PRC90 (2014) 035205

§ no significant structure was observed.

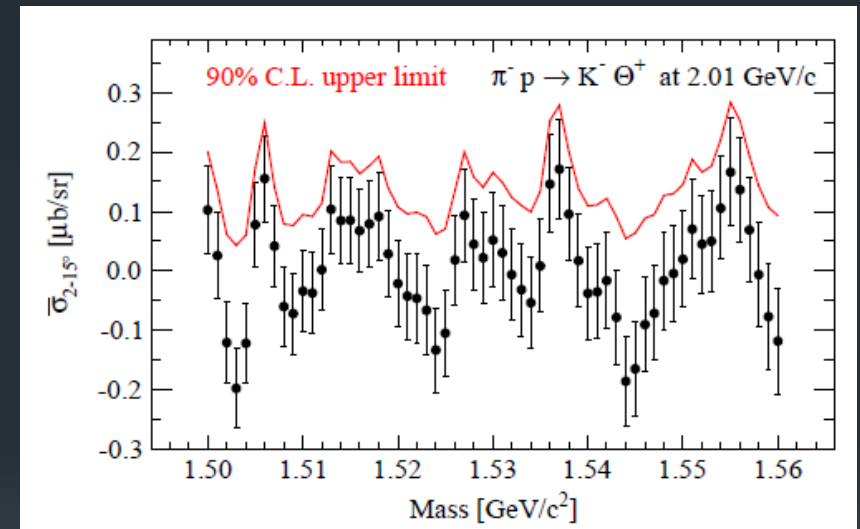
# Upper Limits

90% C.L. upper limit of cross section

1.92 GeV/c  $\pi^- p \rightarrow K^- X$



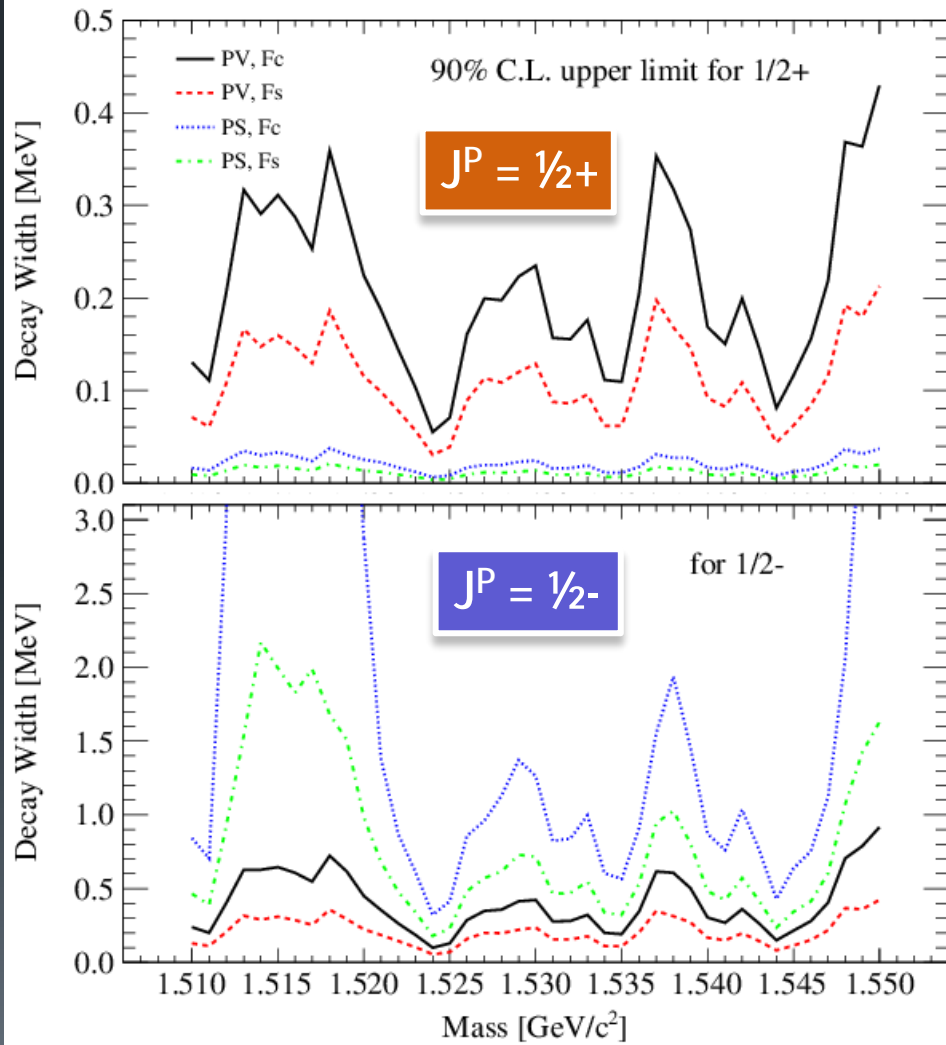
2.01 GeV/c  $\pi^- p \rightarrow K^- X$



§ upper limit of the differential cross section is  $0.28 \mu\text{b/sr}$  (90% C.L.)



# Upper limit on decay width



Upper limit of decay width can be obtained in model dependent analyses.

$$\sigma \quad \Gamma$$

Hyodo, Hosaka & Oka, PTEP 128, 523 (2012)

With combined analysis, we obtain

$$\Gamma < 0.36 \text{ MeV for } 1/2+$$

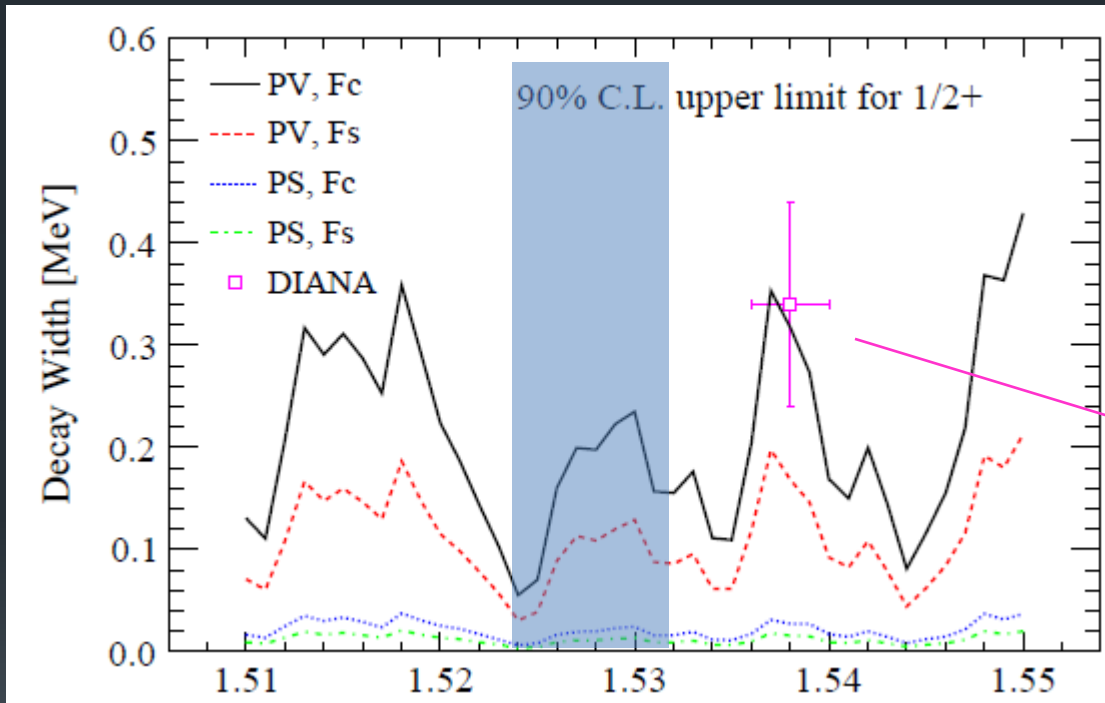
$$\Gamma < 1.9 \text{ MeV for } 1/2-$$

$1/2+$  : P-wave resonance

$1/2-$  : S-wave resonance

# comparison with other experiment

ü We give the best upper Limit among negative results  
cf. Belle ( $\Gamma_{\Theta} < 0.64 \text{ MeV}$ ) R.Mizuk *et al.*, PLB 632, 173 (2006)



finite width reported from  
DIANA estimated from  $\sigma$

**DIANA:**  
 $M = 1538 \pm 2 \text{ MeV}$   
 $\Gamma = 0.34 \pm 0.10 \text{ MeV}$   
 PRC 89, 045204 (2014)

**LEPS:**  
 $M = 1524 \pm 2 + 3 \text{ MeV}$   
 PRC 79, 025210 (2009).

For LEPS region,  $\Gamma < 0.22 \text{ MeV}$ .

For DIANA region,  
 Our U.L. is comparable to their width, but  
 does not completely contradict the DIANA result.

# Comparison with LEPS

- § LEPS :  $\sigma = 12\text{nb/sr}$  (lab.)
- §  $\sigma$  is translated into  $\Gamma^\circ$  through calculations based on the effective Lagrangian.

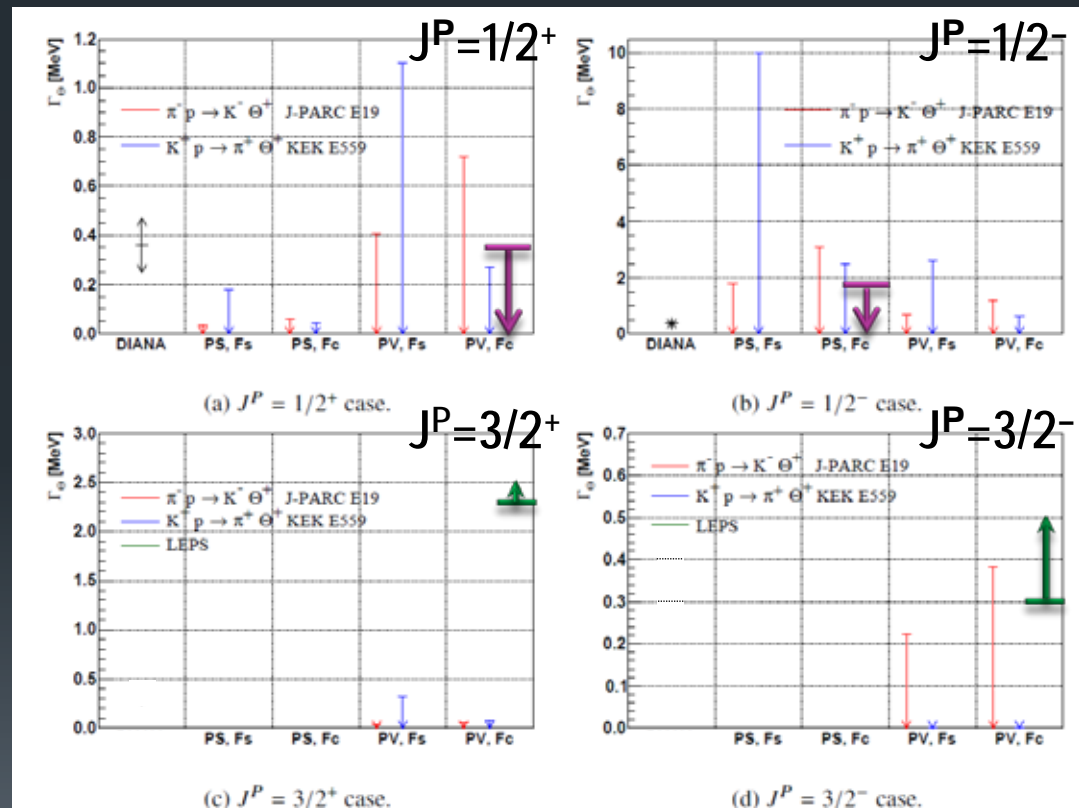
Nam *et al.*, PLB 579 43 (2004)

- § the allowed regions are shown by red/blue arrows, obtained from  $\pi/K$ -induced reactions, respectively.

- § the  $\Gamma_{\text{LEPS}}$  is shown by green arrows.

- § seems no model to reproduce  $\sigma_{\text{LEPS}}$  within upper limits from meson induced reactions.

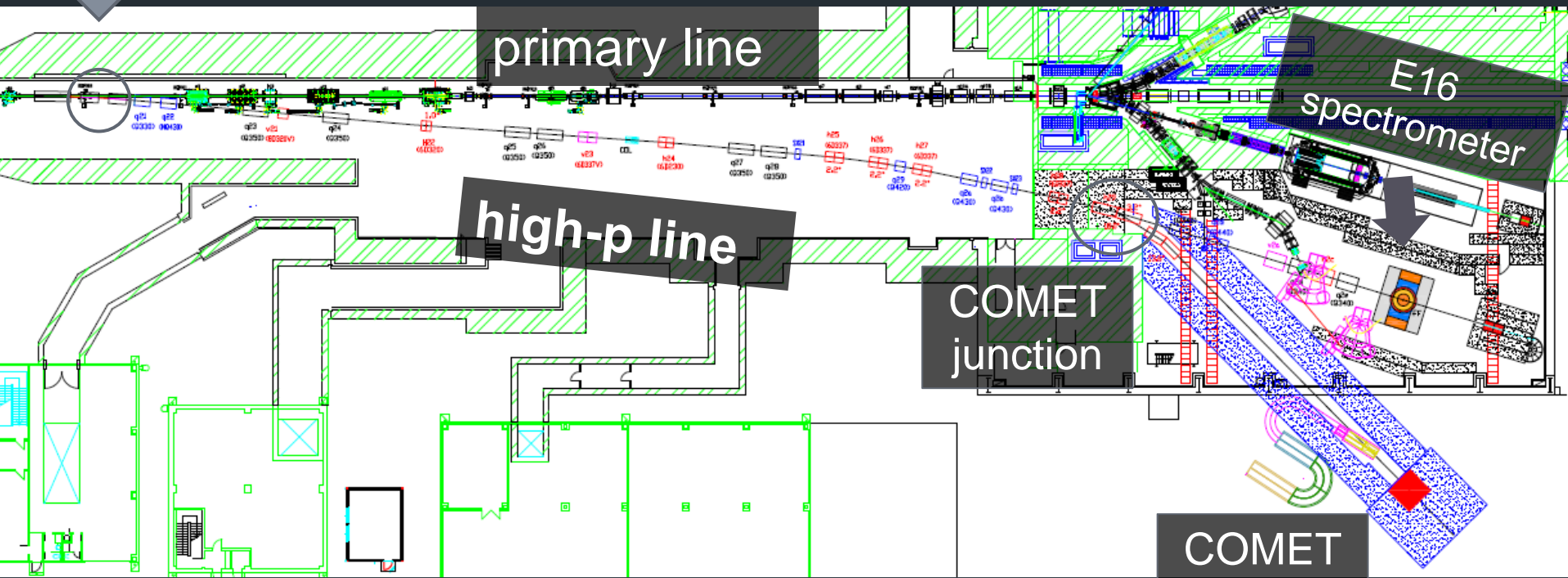
allowed regions of  $\Gamma$



# High-momentum beam line

SM1

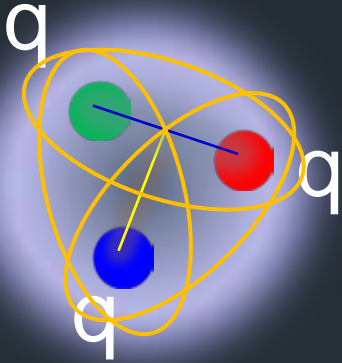
branch angle :  $5^\circ$



at SM1 high-p beam branches off from the primary line

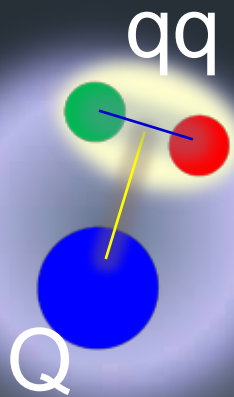
- 30 GeV primary proton ( $10^{10}/s$ ,  $10^{12}/s$ )
- 8 GeV primary proton for COMET
- secondary particles ( $\sim 20$  GeV/c)

# Physics Programs at High-p



§ Medium modification of mass of light vector mesons

§ dilepton measurement



§ Baryon Spectroscopy

§ Strangeness to Charm :  $\Xi \rightarrow \Lambda_c$

§ close up diquark correlation inside baryon

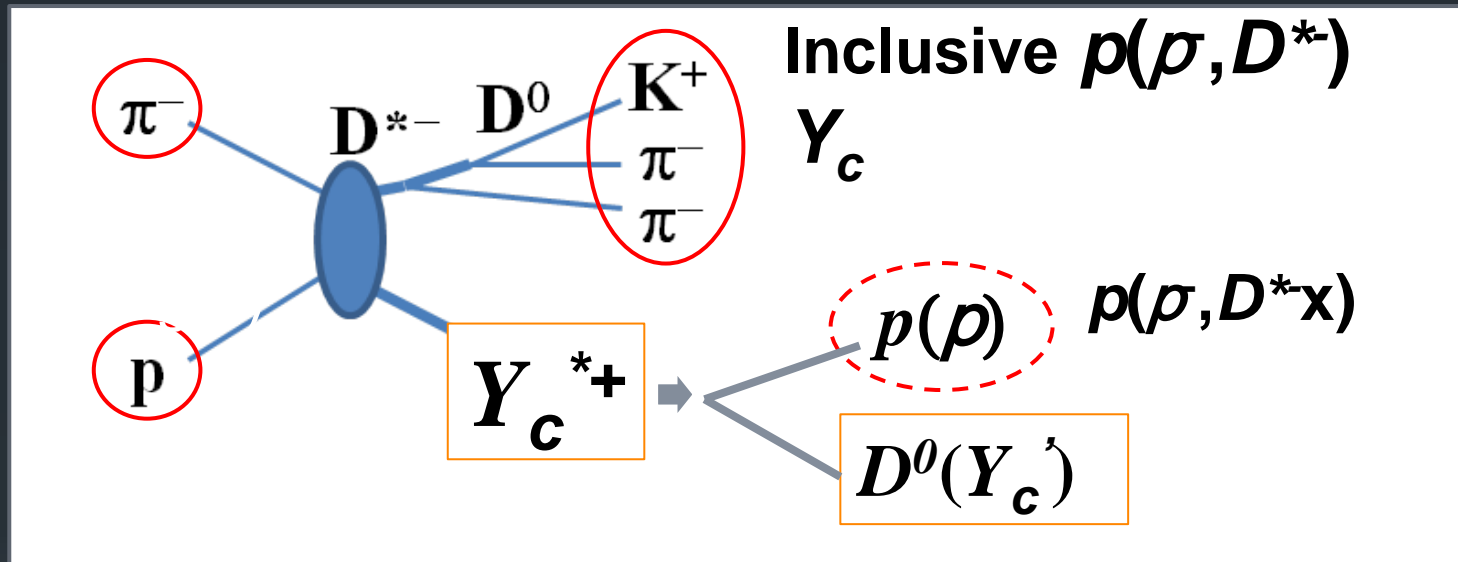
§ Exotics

§  $\Xi(1690)$  : K- $\Sigma$  molecular states?

§  $q$  (udss)

§  $\Xi^{--}$ ?

# Charmed Baryon Spectroscopy

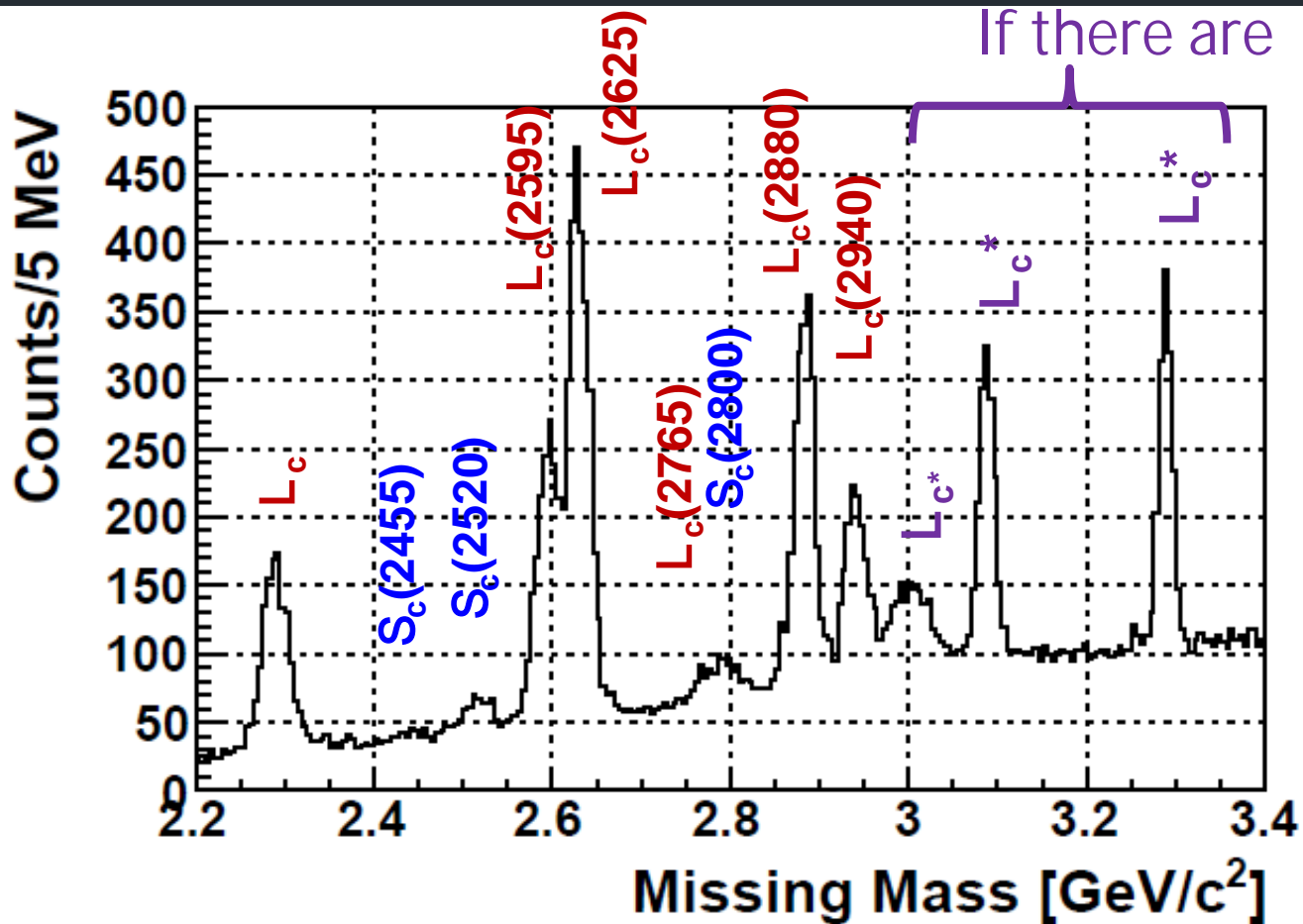


- \* Decay measurement in coincidence w/  $p(\pi^-, D^{*-})$  assists the missing mass spectroscopy.
- \* Decay Branches:  
 diquark correlation affects  $\Gamma(\Lambda_c^{*-} \rightarrow pD) / \Gamma(\Lambda_c^{*-} \rightarrow \Sigma_c \pi)$ .
- \* Angular Distribution: spin, parity

# Expected spectra: $\sigma_{GS} = 1 \text{ nb}$

$N(\text{Yc}^*) \sim 1000$  events/1nb/100 days

Sensitivity:  $\sim 0.1 \text{ nb}$  ( $3\sigma$ ,  $\Gamma \sim 100 \text{ MeV}$ )



# Summary

§ The first physics programs was successfully done.

§ upper limit of  $\pi p \rightarrow K \Theta$  production

§ observation Kpp-like structure in  $d(\pi^+, K^+)$  reaction

Y. Ichikawa *et al.*, PTEP 2015 (2015) 2, 021D01

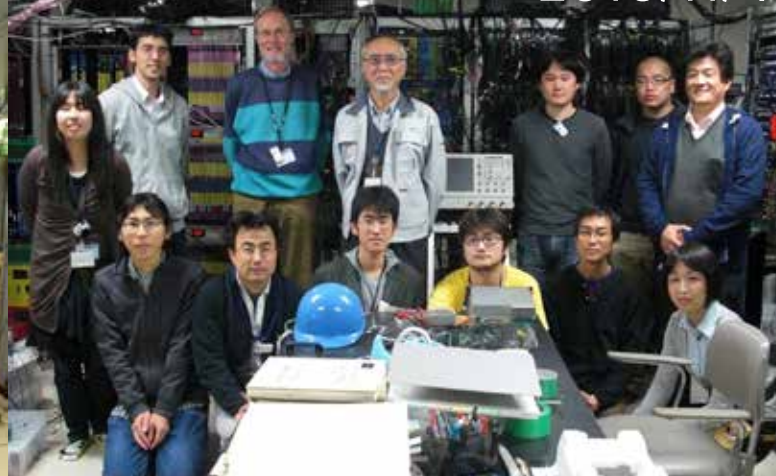
§ New high-momentum beamline will provide us an opportunity to study a variety of hadron physics programs.



2009/10/23



2010/11/4



25

# K1.8 Exp. Group

Nov. 2010



19th, Feb. 2012



~70 people

From KEK, Kyoto U., Tohoku U., U. Tokyo, Nara WU, Osaka U., JAEA, UNM(USA), INFN(Italy), Seoul N. U., ITEP, JINR