Pentaquark Θ^+ Search in Hadornic Reaction - complement to photo production -

M. Naruki, RIKEN

Contents:

- Introduction
- Past experiments: KEK-PS E522 & E559
- Future experiment: J-PARC E19

What is Pentaquark?

- Irreducible 5 quark state
  contain an anti-quark different in flavor than the 4 quarks

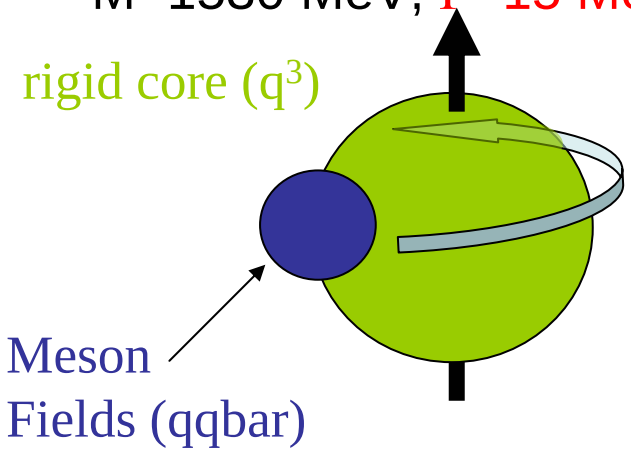
  The Θ^+ : uuddsbar

  Baryon number = 1/3 + 1/3 + 1/3 + 1/3 - 1/3 = 1

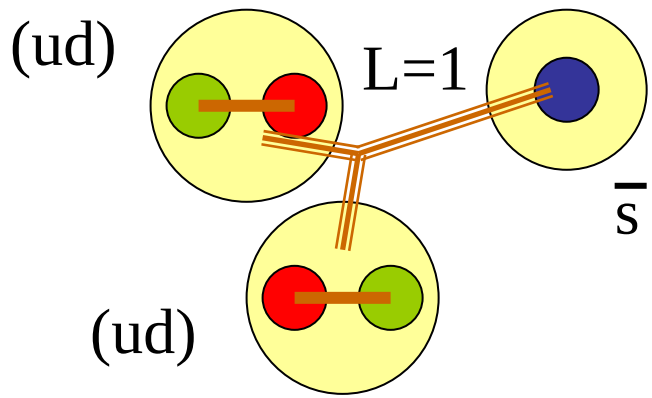
  Strangeness = 0 + 0 + 0 + 0 + 1 = +1

Chiral soliton model: Diakonov et al.

M=1530 MeV, Γ~15 MeV

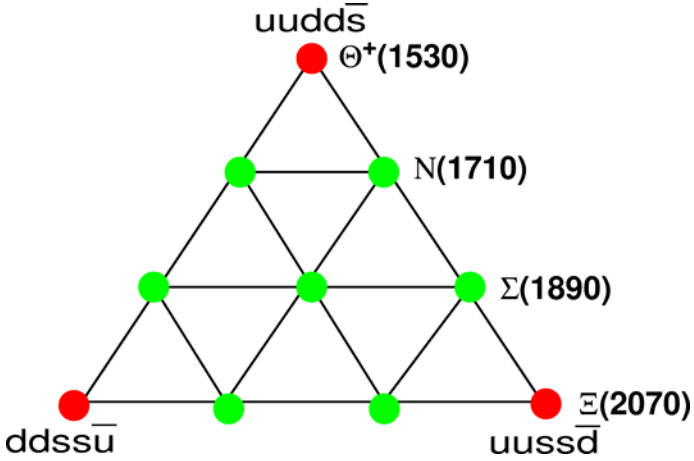


Quark description: Jaffe, Wilczek



Approach quark dynamics at low energy

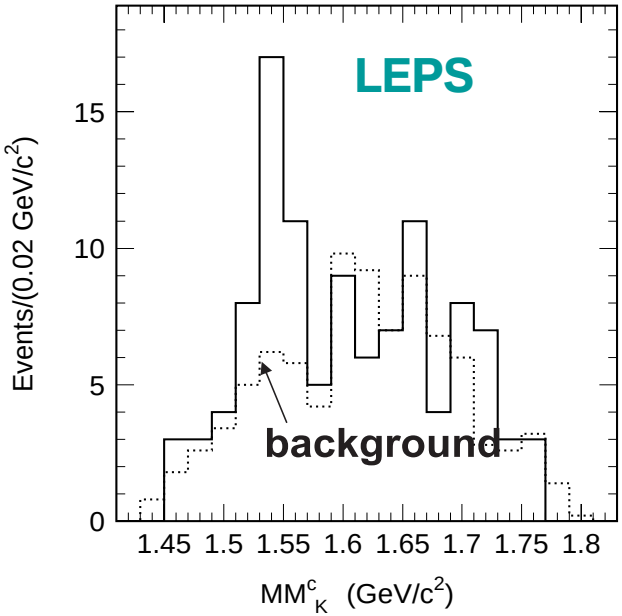
Discovery of Θ^+ baryon



Theoretical Prediction

Diakonov et al. Z. Phys. A359 ('97) 305

- Anti-decuplet in Chiral soliton model
- M=1530 MeV, Γ< 15MeV



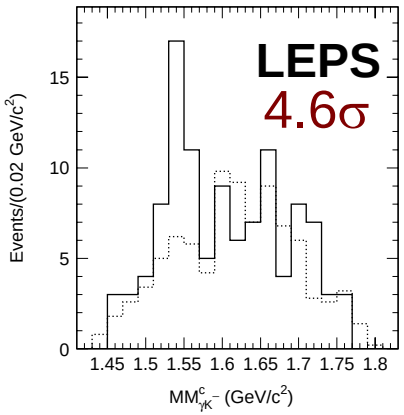
Experiment

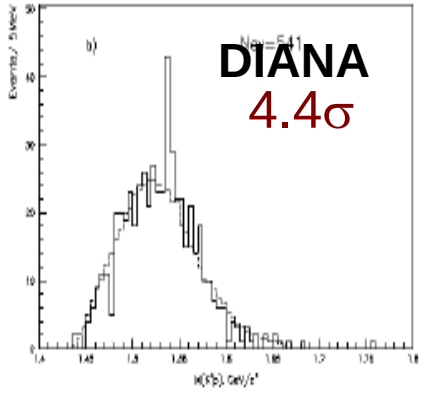
LEPS at Spring-8 ('03)

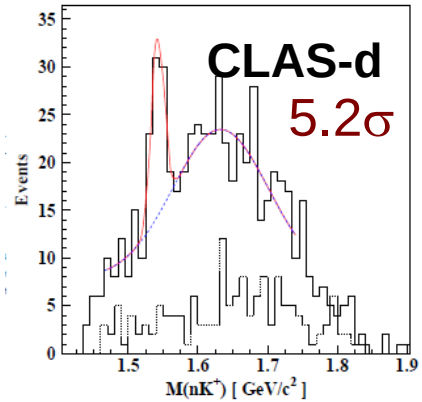
- $\gamma C \rightarrow K^- \Theta^+ X \rightarrow K^- K^+ n$
- M=1540±10 MeV
- Γ<25 MeV

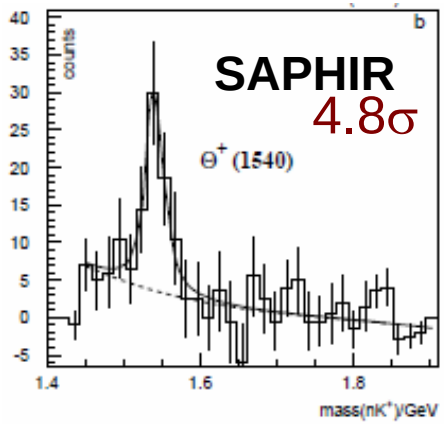
PRL 91(03)012002

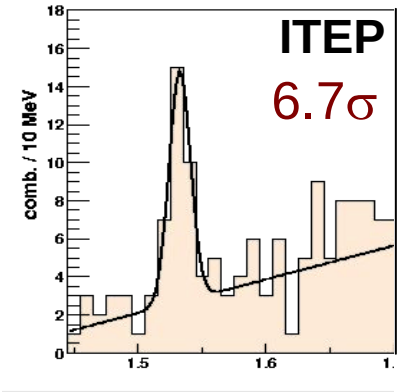
Positive Results

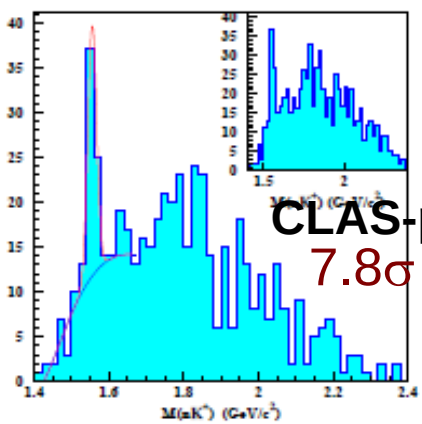


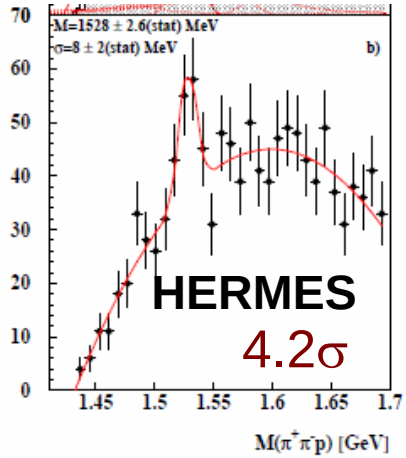


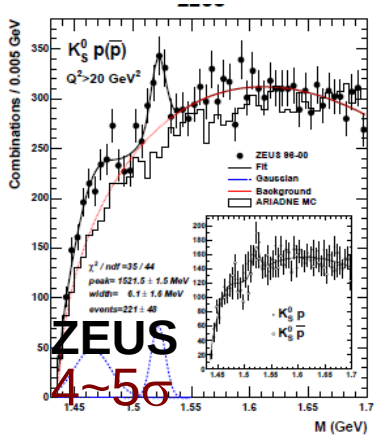


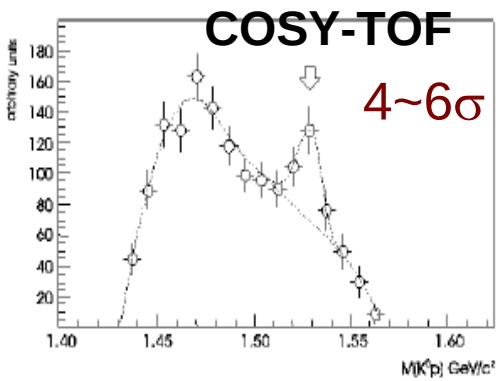


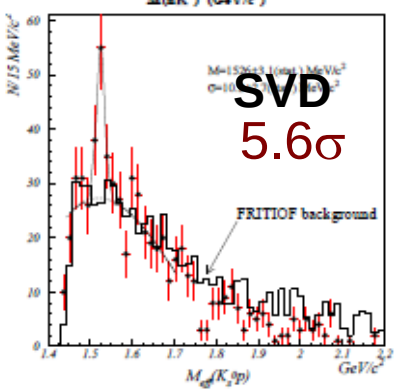










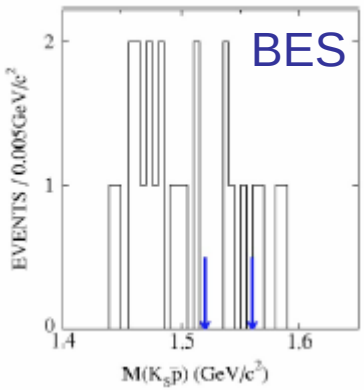


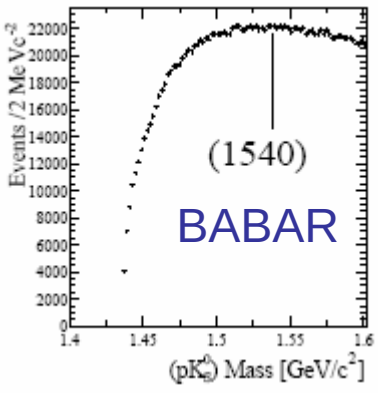
Experiments with positive evidence

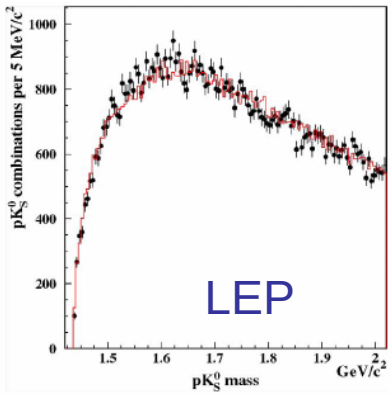
Better statistics is needed

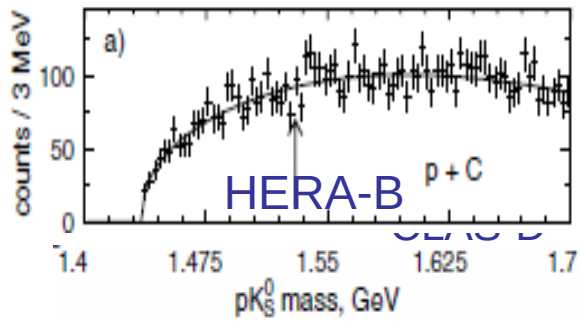
(significance ~ 5σ)

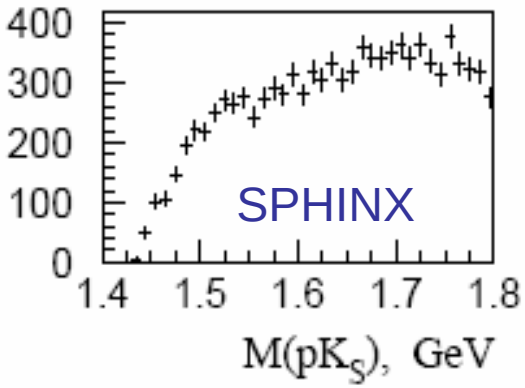
Negative Results

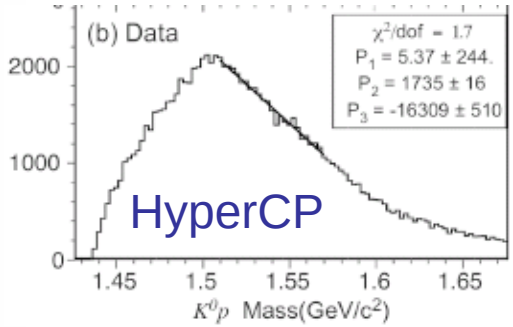


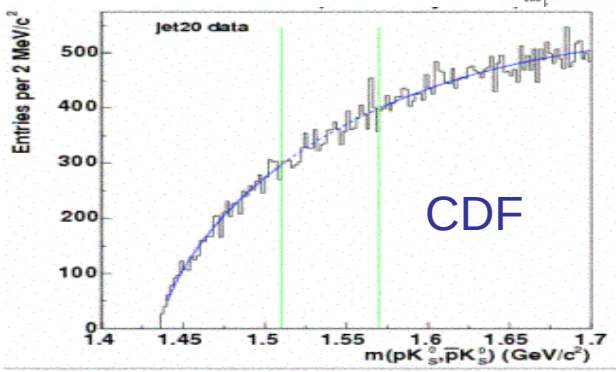


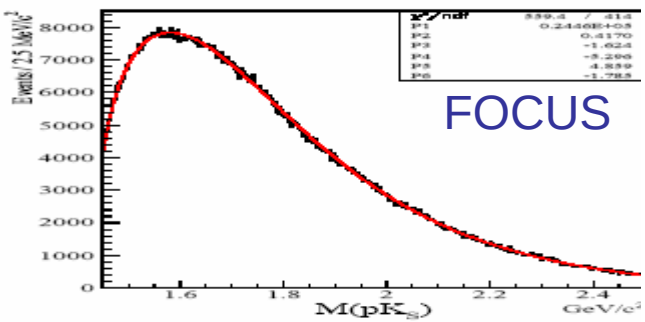


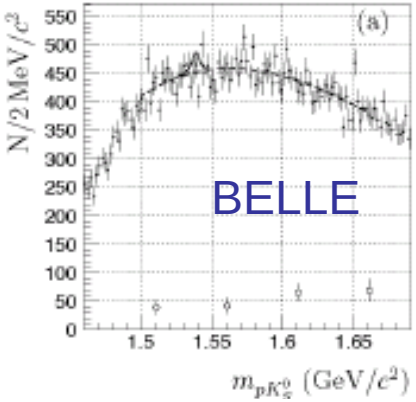


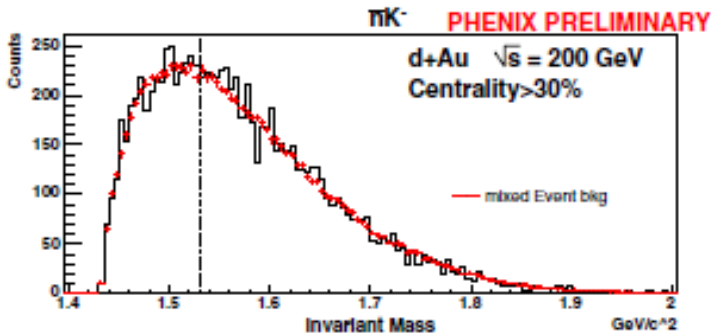








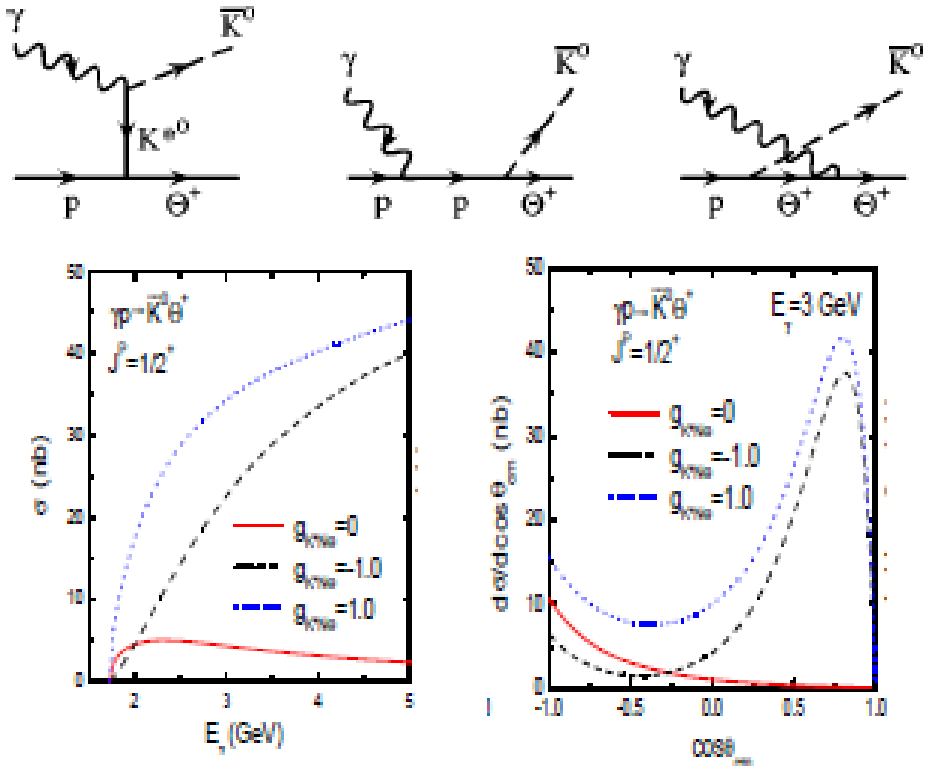




Negative Results

Exp.	$\sqrt{s}(E_{beam})$	Reaction	Upper Limit
BES	3.7GeV	$e^+e^- \rightarrow J/\psi \rightarrow \Theta\Theta$	$< 1.1 \times 10^{-5}$ B.R.
BaBar	10.58GeV	$e^+e^- \rightarrow \Upsilon(4S) \rightarrow pK^0X$	$< 1.0 \times 10^{-4}$ B.R.
Belle	11GeV	$e^+e^- \rightarrow BB \rightarrow ppK^0X$	$< 2.3 \times 10^{-7}$ B.R.
LEP	198GeV	$e^+e^- \rightarrow Z \rightarrow pK^0X$	$< 6.2 \times 10^{-4}$ B.R.
HERA-B	41.6GeV	$pA \rightarrow K^0pX$	$< 0.02 \times \Lambda^*$
SPHINX	11.5GeV	$pC \rightarrow K^0\Theta^+X$	$< 0.1 \times \Lambda^*$
HyperCP	(800GeV)	$pCu \rightarrow K^0pX$	< 0.3% K^0p
CDF	1.96TeV	$pp \rightarrow K^0pX$	$< 0.03 \times \Lambda^*$
FOCUS	~300GeV	$\gamma BeO \rightarrow K^0pX$	$< 0.02 \times \Sigma^*$
Belle	(~0.6GeV)	$K^+A \rightarrow pK^0_s$	$\Gamma < 0.64$ MeV
PHENIX	200GeV	$Au + Au \rightarrow K^-nX$	-
BaBar	9.4GeV	$eBe \rightarrow K^0pX$	-
CLAS-d	0.8-3.6GeV	$\gamma d \rightarrow pK^-K^+(n)$	3nb for γn
CLAS-p	<3.8GeV	$\gamma p \rightarrow K^oKN$	0.8nb

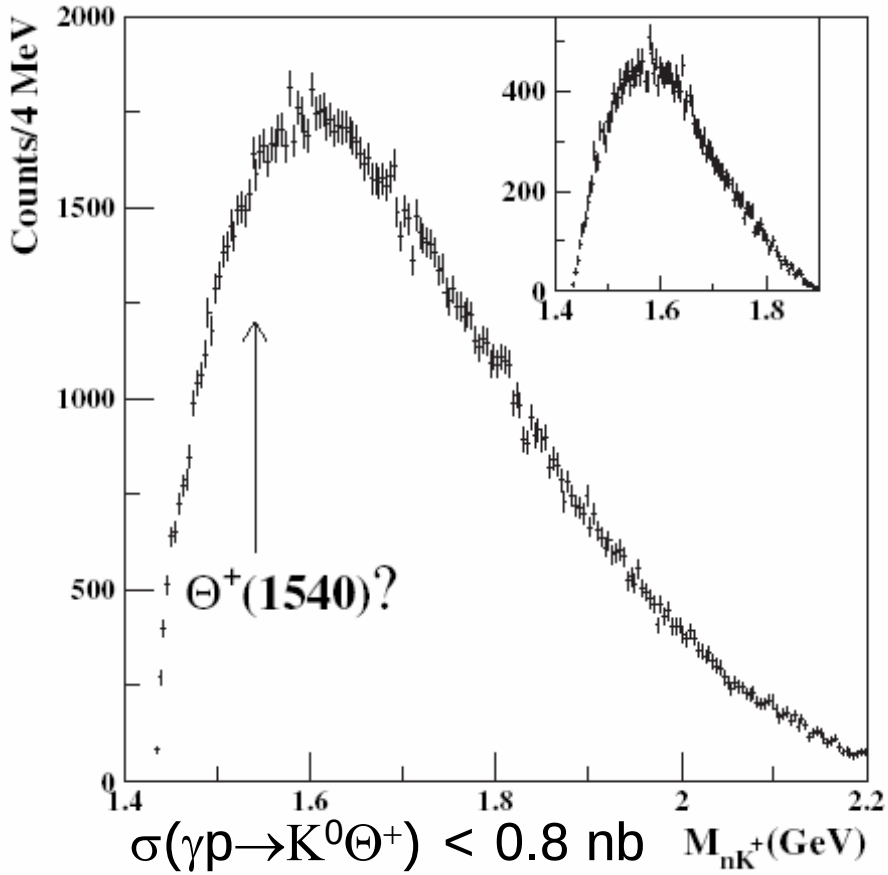
New Negative Results : $\gamma p \to K^0 \Theta^+$



C. M. Ko and W. Liu, nucl-th/0410068

Γ ~ 1MeV

PRL 96, 042001 (2006)



$\sigma(\gamma p \to K^0 \Theta^+) < 0.8$ nb

The result puts a very stringent limit on a possible production mechanism of the Θ^+; it implies a very small coupling to K*.

$g_{NK^*\Theta^+} \sim 0$

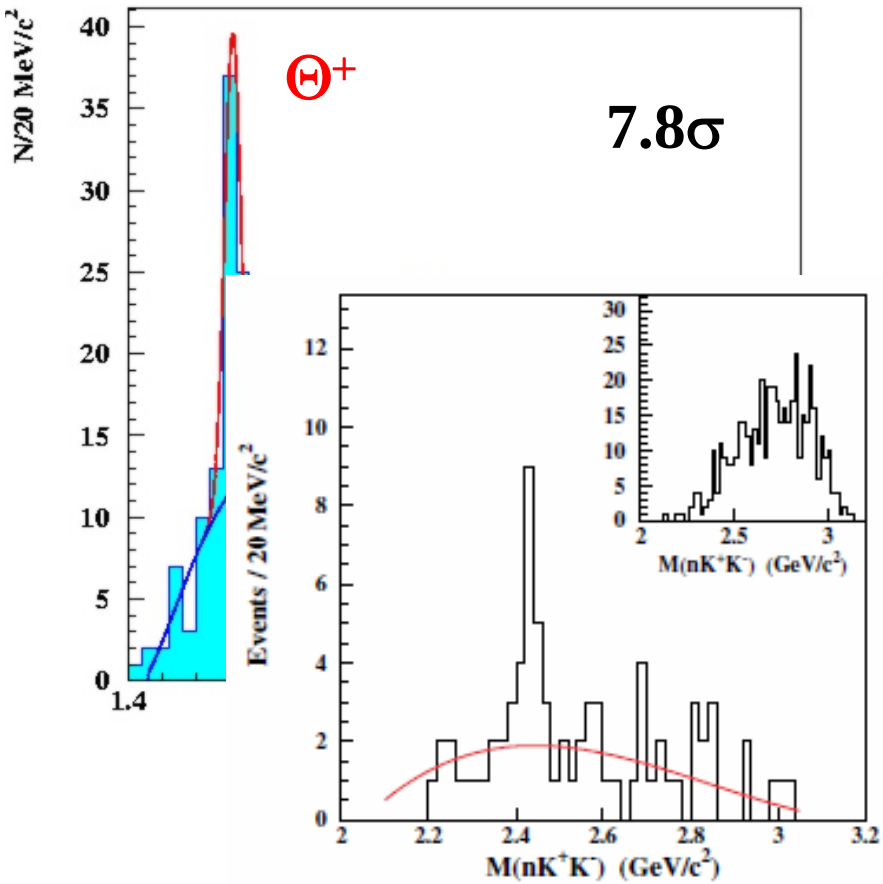
Positive Results

Exp.	Energy($\sqrt{s}$)	Reaction	Mass	Width	σ	
LEPS	≤2.4GeV	$\gamma C \rightarrow K^- K^+ (n)$	1540 ± 10	< 25	4.6	*
DIANA	≤750MeV/c	$K^+ Xe \rightarrow K^0 pX$	1539 ± 2	< 9	4.4	*Belle
~~CLAS-d~~	~~1.58-3.8GeV~~	~~$\gamma d \rightarrow p K^- K^+ (n)$~~	~~1542 ± 5~~	~~< 21~~	~~5.2~~	
~~SAPHIR~~	~~≤2.8GeV~~	~~$\gamma p \rightarrow K^0 K^+ (n)$~~	~~1540 ± 6~~	~~< 25~~	~~4.8~~	
ITEP	40GeV	$\nu A \rightarrow K^0 pX$	1533 ± 5	< 20	6.7	
CLAS-p	3-5.47GeV	$\gamma p \rightarrow \pi^+ K^- K^+ (n)$	1555 ± 10	< 26	7.8	
HERMES	27.6GeV	$e^+ d \rightarrow K^0 pX$	1528 ± 3	13 ± 9	4.2	?
ZEUS	(300,318GeV)	$e^+ p \rightarrow e' K^0 pX$	1522 ± 3	8 ± 4	4~5	?
COSY	2.95GeV/c	$pp \rightarrow K^0 p \Sigma^+$	1530 ± 5	< 18	4-6	
SVD	70GeV/c	$pA \rightarrow K^0 pX$	1526 ± 5	< 24	5.6	*

BaBar	(10.58GeV)	$eBe \rightarrow K^0 pX$
CLAS-d	0.8-3.6GeV	$\gamma d \rightarrow p K^- K^+ (n)$
CLAS-p	<3.8GeV	$\gamma p \rightarrow K^o KN$

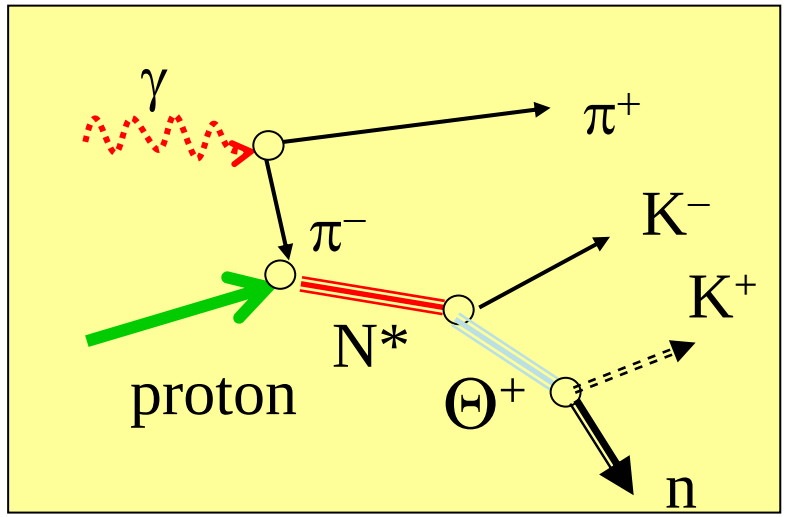
negative results challenging the above positive results.

Best Positive Evidence



Super-g Eγ ~ 3.8 – 5.7 GeV planned for 2006

- $\gamma p \rightarrow \pi^+ K^- K^+ (n)$
- CLAS: V. Kubarovsky *et al.* PRL 92 032001 (2004)
- Combined analysis of all CLAS data on protons for Eγ <5.2 GeV
- Cuts: forward π^+, backward K^+
- indications of production from heavy N*(2420)



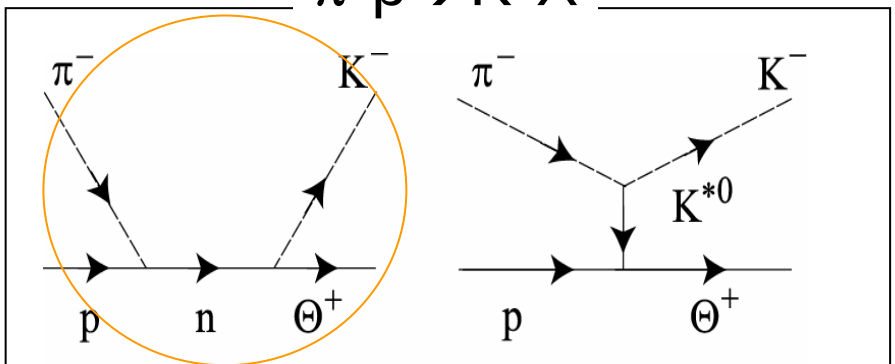
Θ^+ Search in meson-induced reactions

- ✓ Can the "positive" low energy results be reproduced?
  - – better statistics is needed.
- ✓ How far can we restrict the width to?
  - • the width appears to be very narrow. ~ 1MeV.
- ✓ Spin and Parity → width

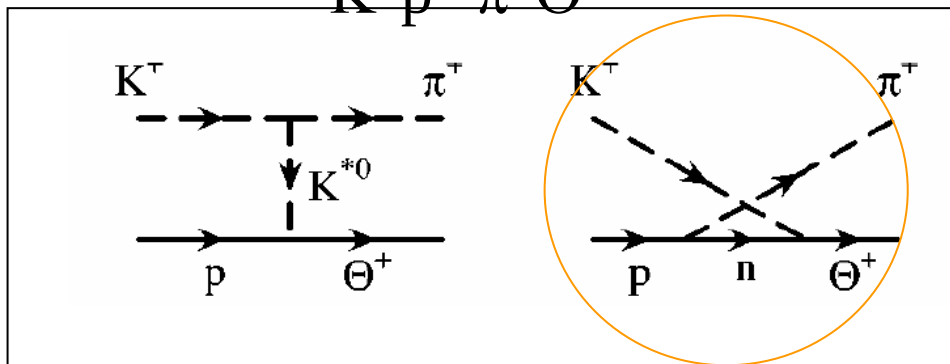
hadronic reaction

Since we already know that the K* coupling is small, the possible production mechanism will be clarified in the following meson induced reactions.

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



$K^+ p \rightarrow \pi^+ \Theta^+$



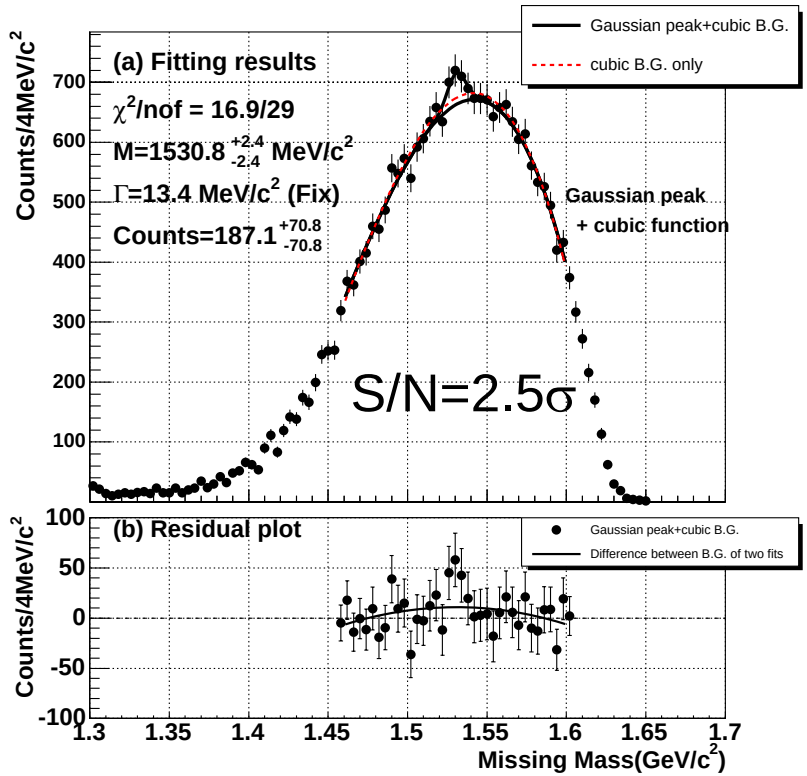
KEK-PS E522 : $\pi^- p \rightarrow K^- X$

- Θ^+ search via $\pi^- p \rightarrow K^- X$ reaction
- beam momentum : 1.87, 1.92 GeV/c
- target : Polyethylene
- intensity : 3.3 X 10^5 π^- /spill
- net beam time : 32 hours for each momentum → ~ 7 X 10^9 π^-

a bump was observed
at M =1530.8MeV/c2
at p_π=1.92 GeV/c
but : S/N = 2.5σ
upper limit : σ_{tot} = 3.9μb

if exist

p_π=1.92 GeV/c

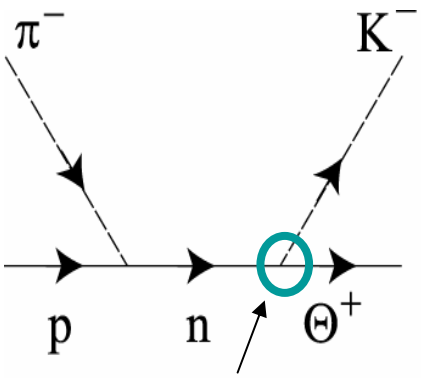


$d\sigma/d\Omega$ = 1.9 μb/sr
→ σ_{tot} = 2.9 μb

$\sigma(\pi^- p \to K^- \Theta^+)$: KEK-PS E522

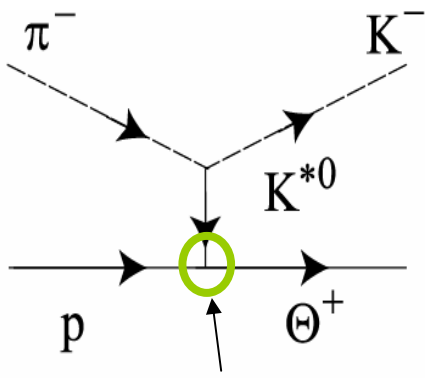
- Theoretical calculation with effective Lagrangian

s-channel



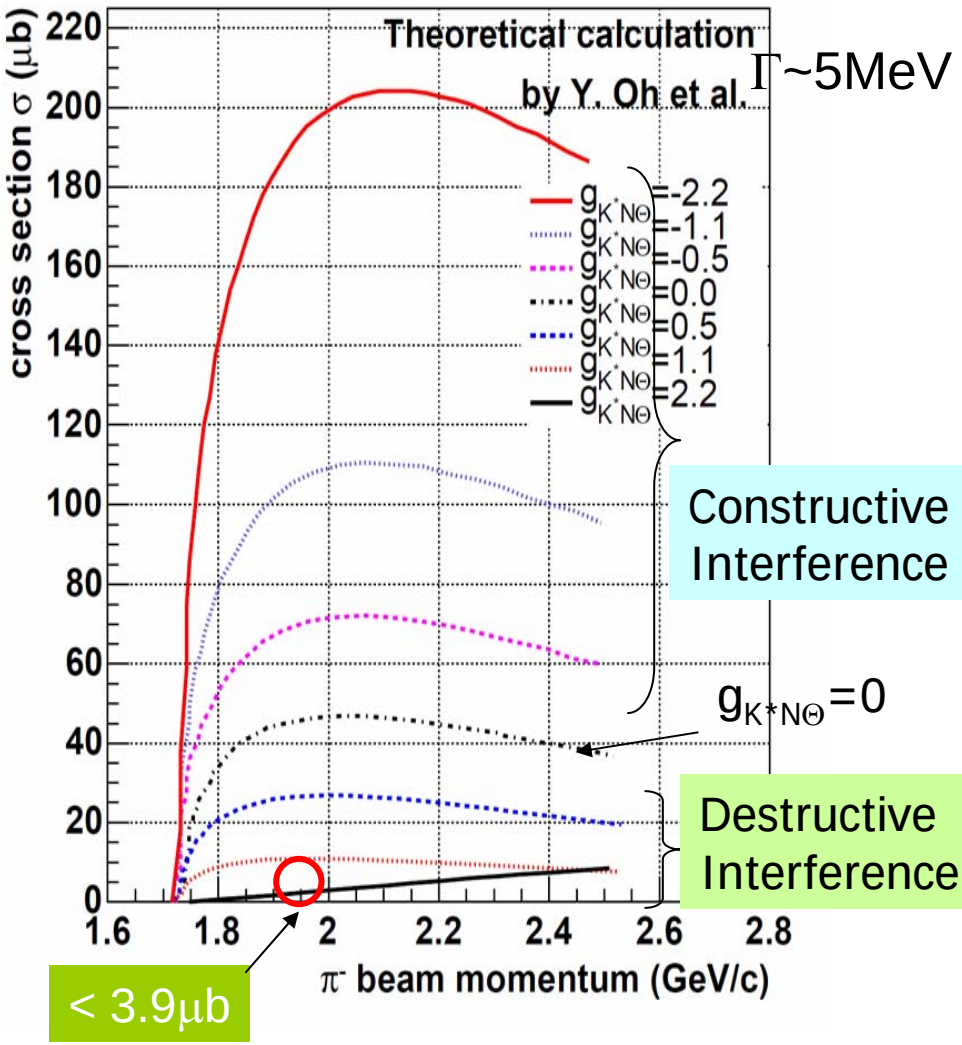
$g_{KN\Theta} \propto \Gamma_\Theta$

t-channel



$g_{K^*N\Theta}$

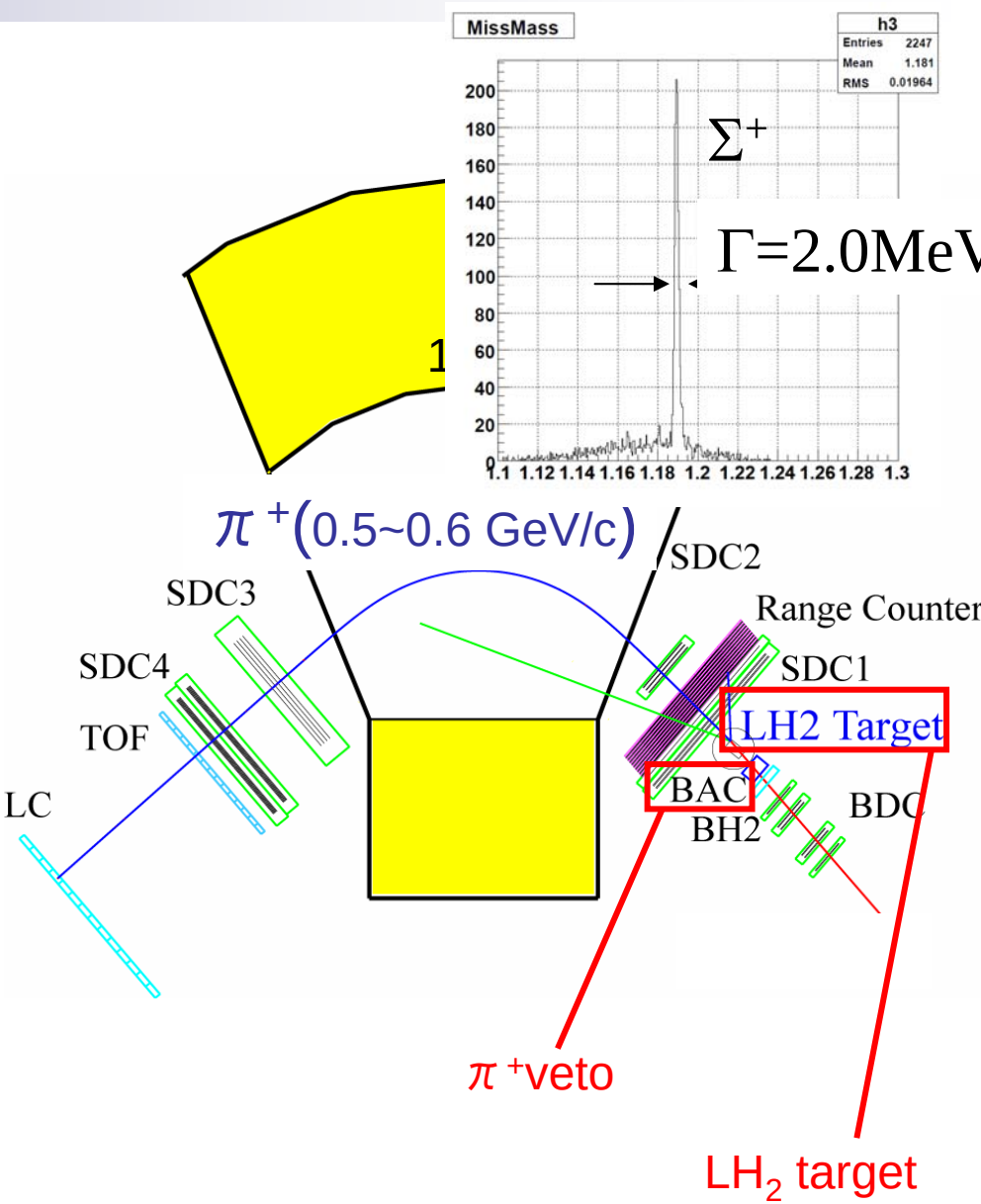
unknown



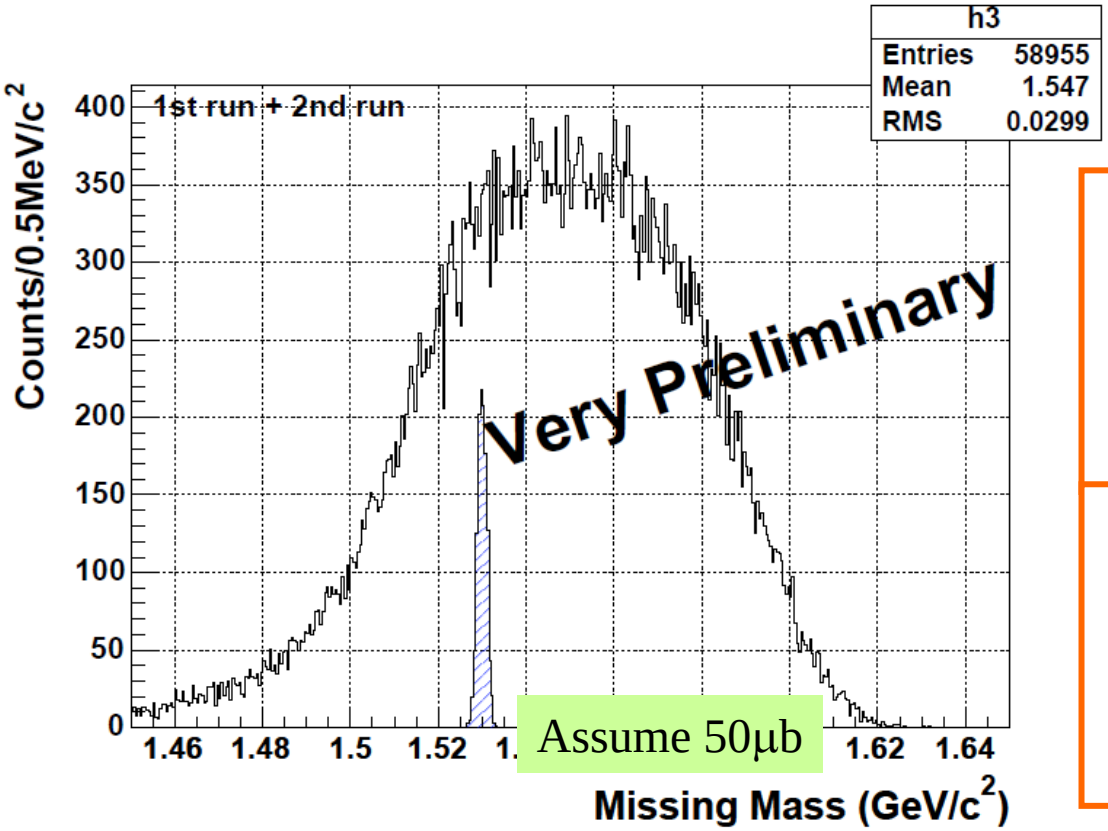
- Form factor determined from $\pi N \to K\Lambda$ reaction

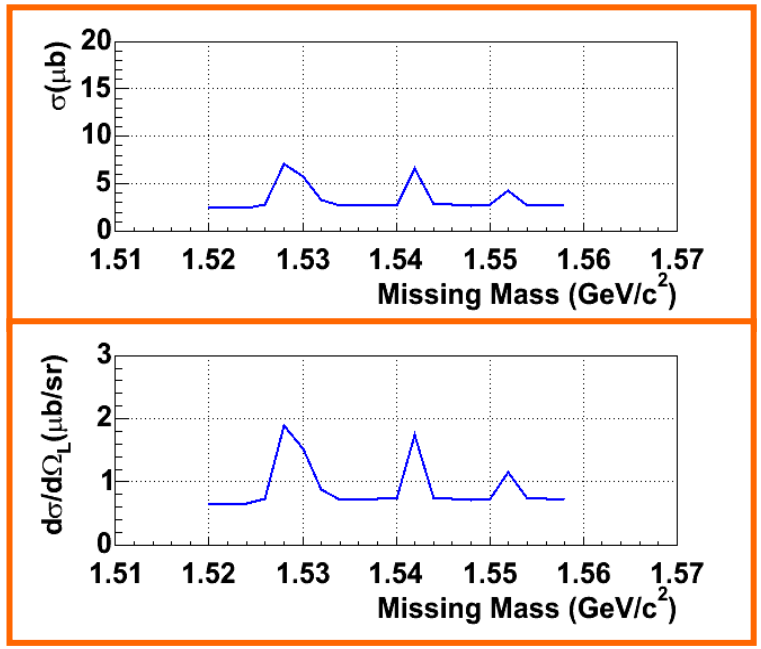
KEK-PS E559 : $K^+p \rightarrow \pi^+\Theta^+$

- Θ^+ search via $K^+p \rightarrow \pi^+X$ reaction
  - K6 beam line + SKS spectrometer
- Excellent missing mass resolution
  - 2.4MeV (FWHM) expected
  - Checked by $\pi^+p \rightarrow K^+\Sigma^+$
- Decay event suppression
  - Rejection of 3 body decay of K^+ is crucial
  - Large acceptance chamber
  - Range Counter



Missing Mass spectrum $(K^+p \rightarrow \pi^+X)$

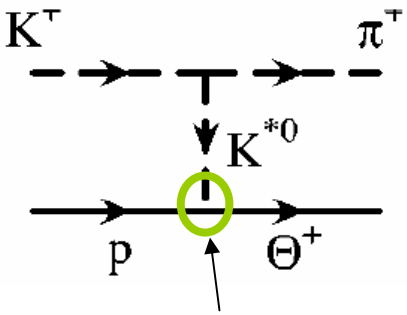


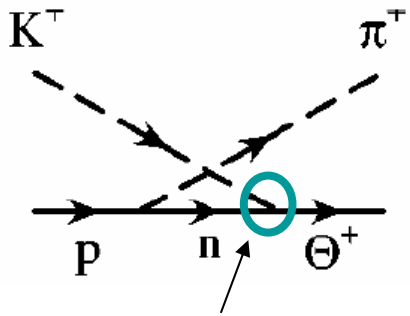


No significant peak is observed.
upper limit of cross section at 90% C.L.

- Total cross section < 7.1μb
- Differential cross section <

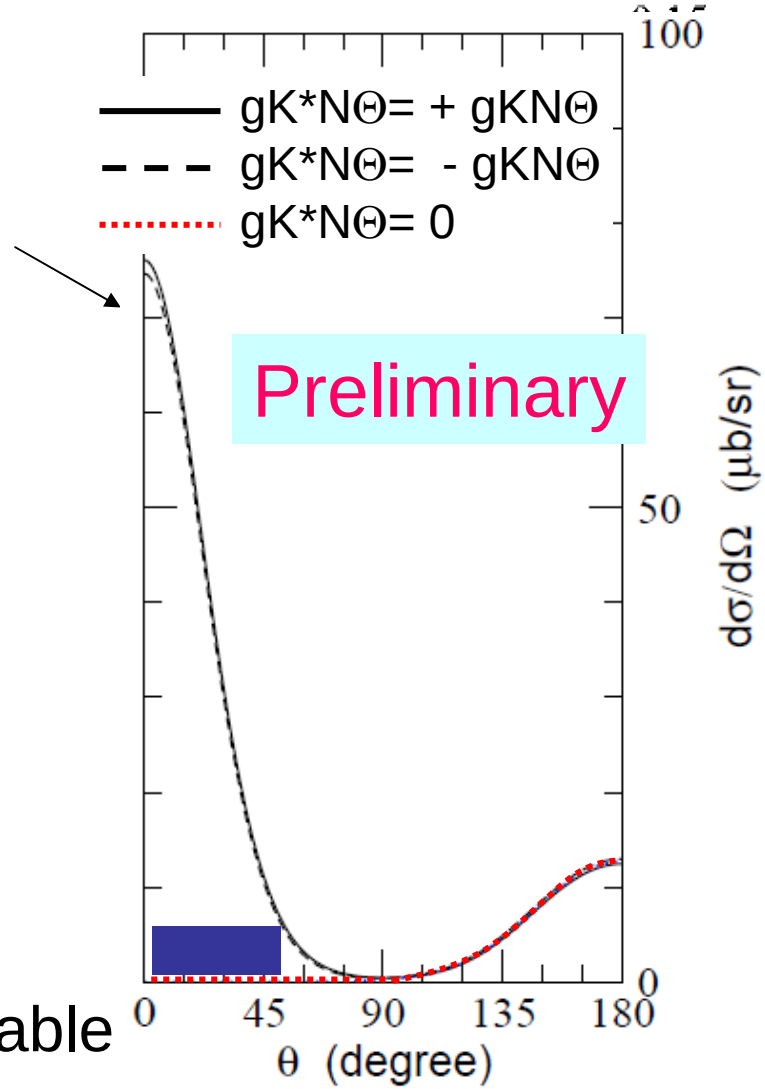
Impact on Θ^+ production mechanism





$g_{K^*N\Theta}$

$g_{KN\Theta} \propto \Gamma_\Theta$



- Calculation with effective Lagrangian
- if $g_{K^*N\Theta} \sim 0$,
  - (K^+,π^+) reaction → u-channel backward peaking
  - (π^-,K^-) reaction → s-channel : sizable

Y. Oh et al. PRD 69, 074016

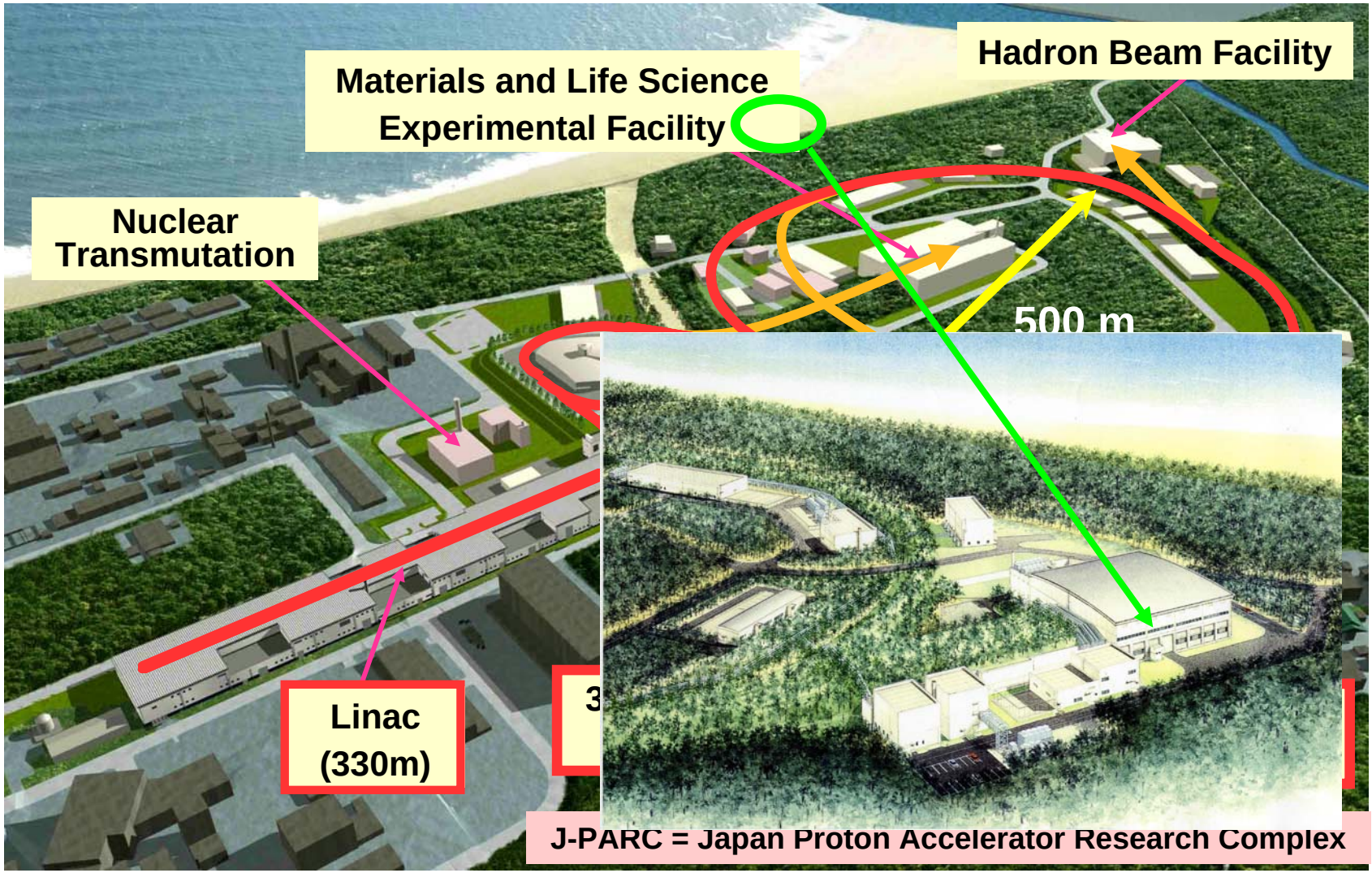
J-PARC E19 experiment

- natural expansion of E522 (πp→KX@K2)
- ~5 times better resolution : ~ 2.5MeV FWHM with SKS
  - 10 times better S/N
- 100 times larger yield : 1.2 X 10^4 Θ^+ with 20 shifts

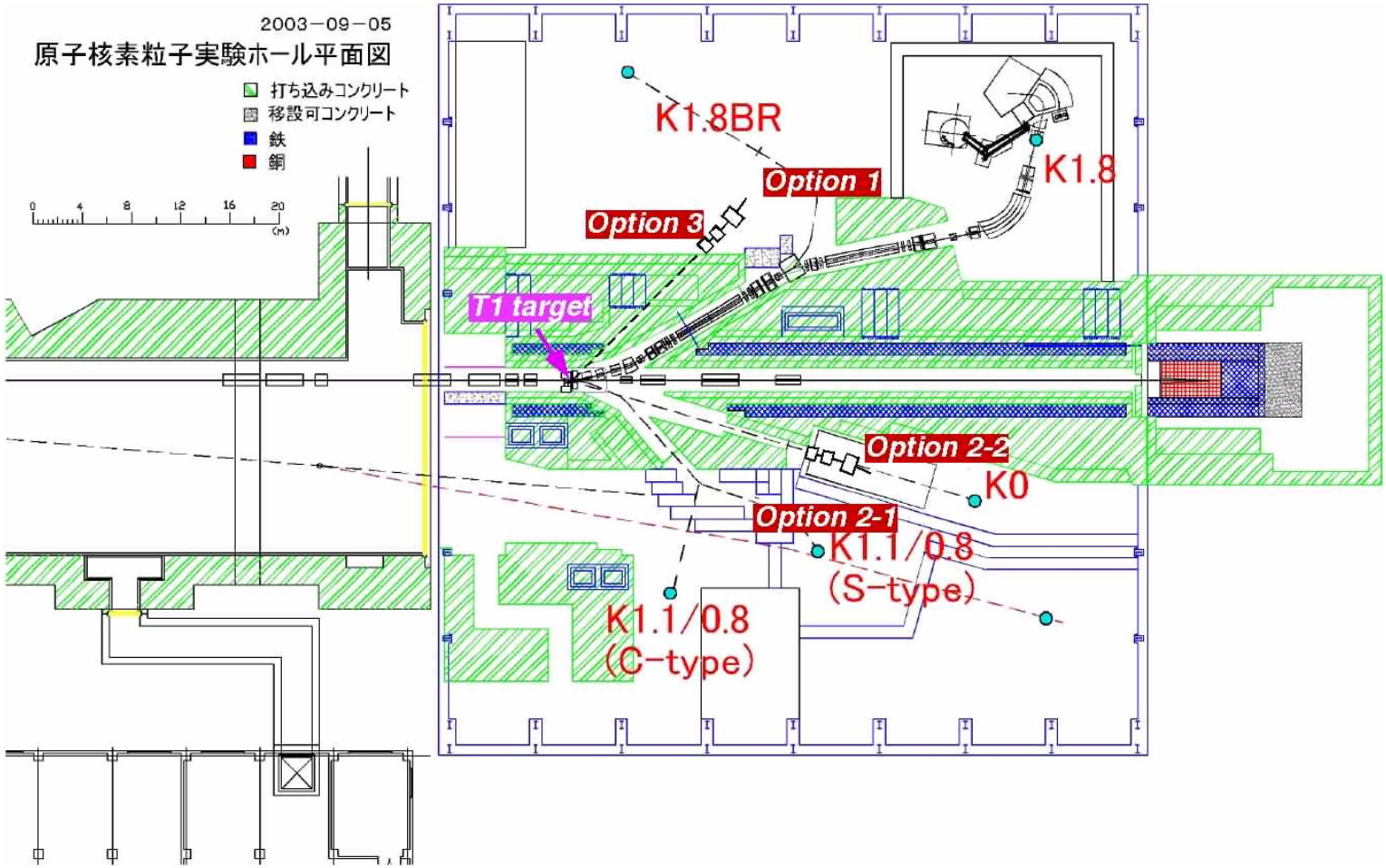
- expected sensitivity (lab) 75nb/sr Γ < 2 MeV → σ_{tot} ~112nb
  150nb/sr Γ = 10 MeV
- momentum dependence of cross section : p_π=(1.87,1.92,1.97GeV/c)

- Goal -
confirm Θ^+ existence with high statistics

J-PARC Facility



Hadron Beam Facility



J-PARC E19 Collaboration

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Tohoku Univ.	H. Tamura
Univ. of Tokyo	H. Fujioka, D. Nakajima and T.N. Takahashi

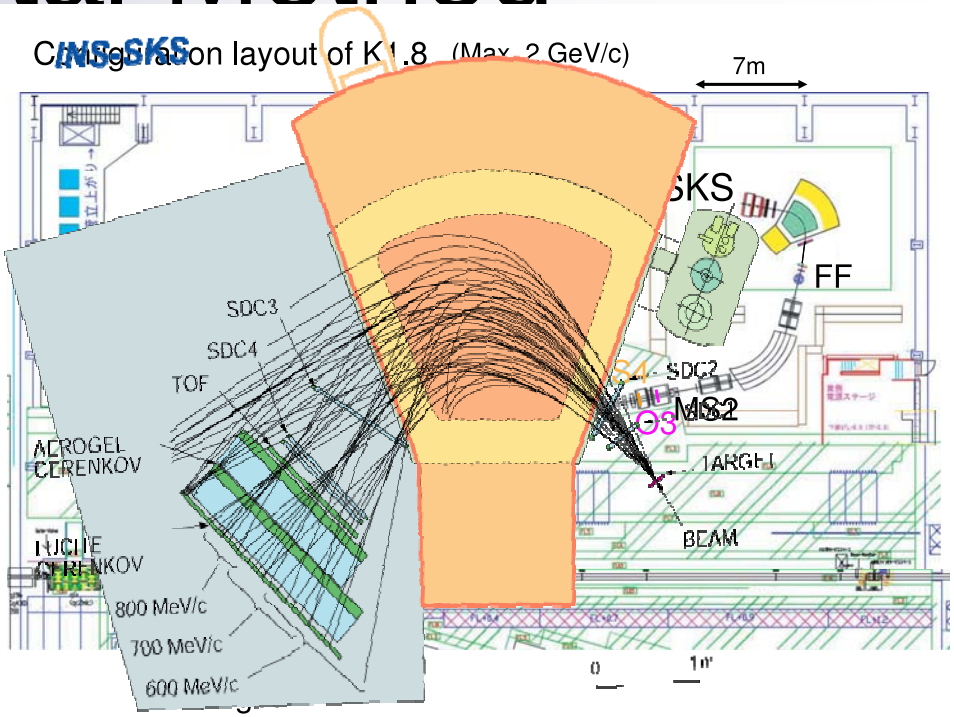
Experimental Method

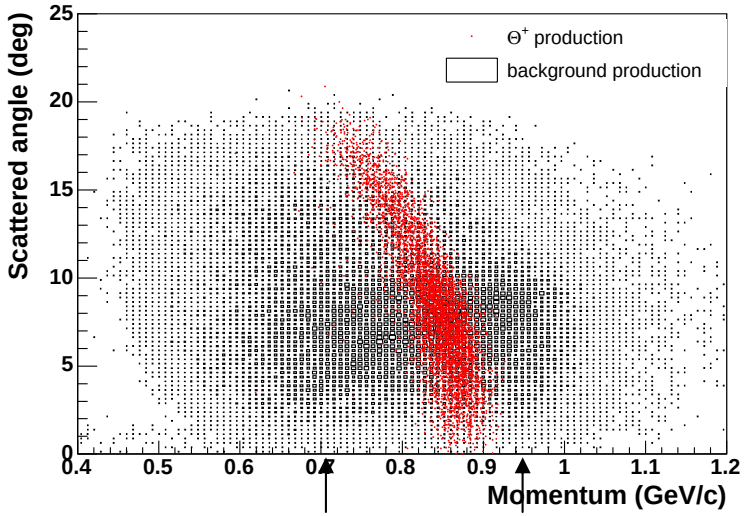
K1.8 beam line + SKS

2GeV/c $\pi^- + p \rightarrow K^- + \Theta^+$
target : liquid H_2, reuse E559's

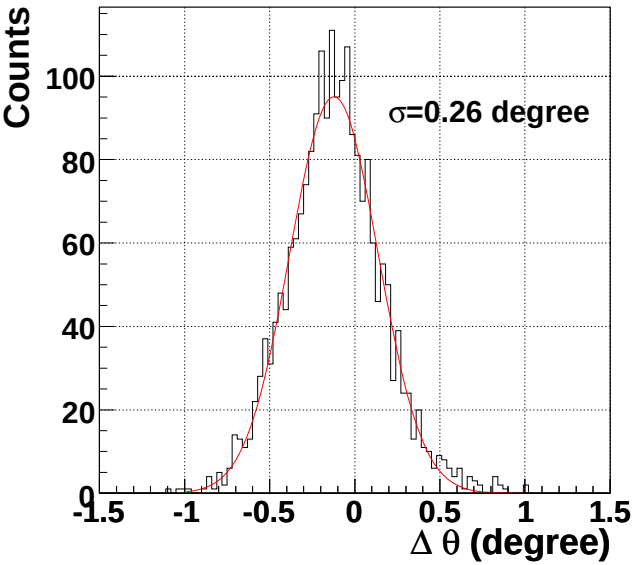
K^- : scattered angle ≤ 40°
momentum up to 0.9 GeV/c

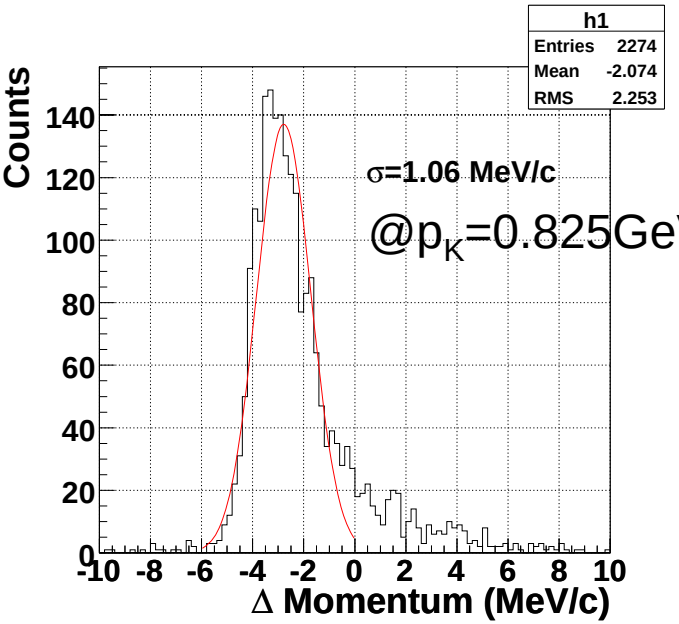
SKS : momentum coverage : 0.7-0.95GeV/c
angle coverage ≤ 20°
$p_{scattered}$ up to ~ 1.1 GeV/c
dp/p ~ 0.2% @ 1GeV/c
(~10 times better than KURAMA)
ideal for Θ^+ detection



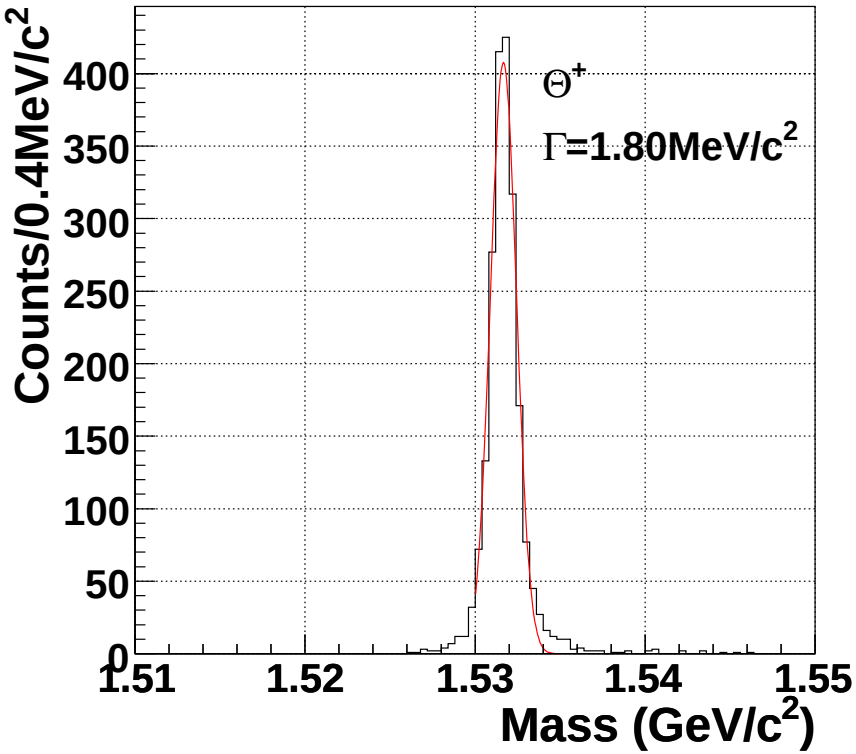


Missing Mass Resolution





@p_K=0.825GeV/c



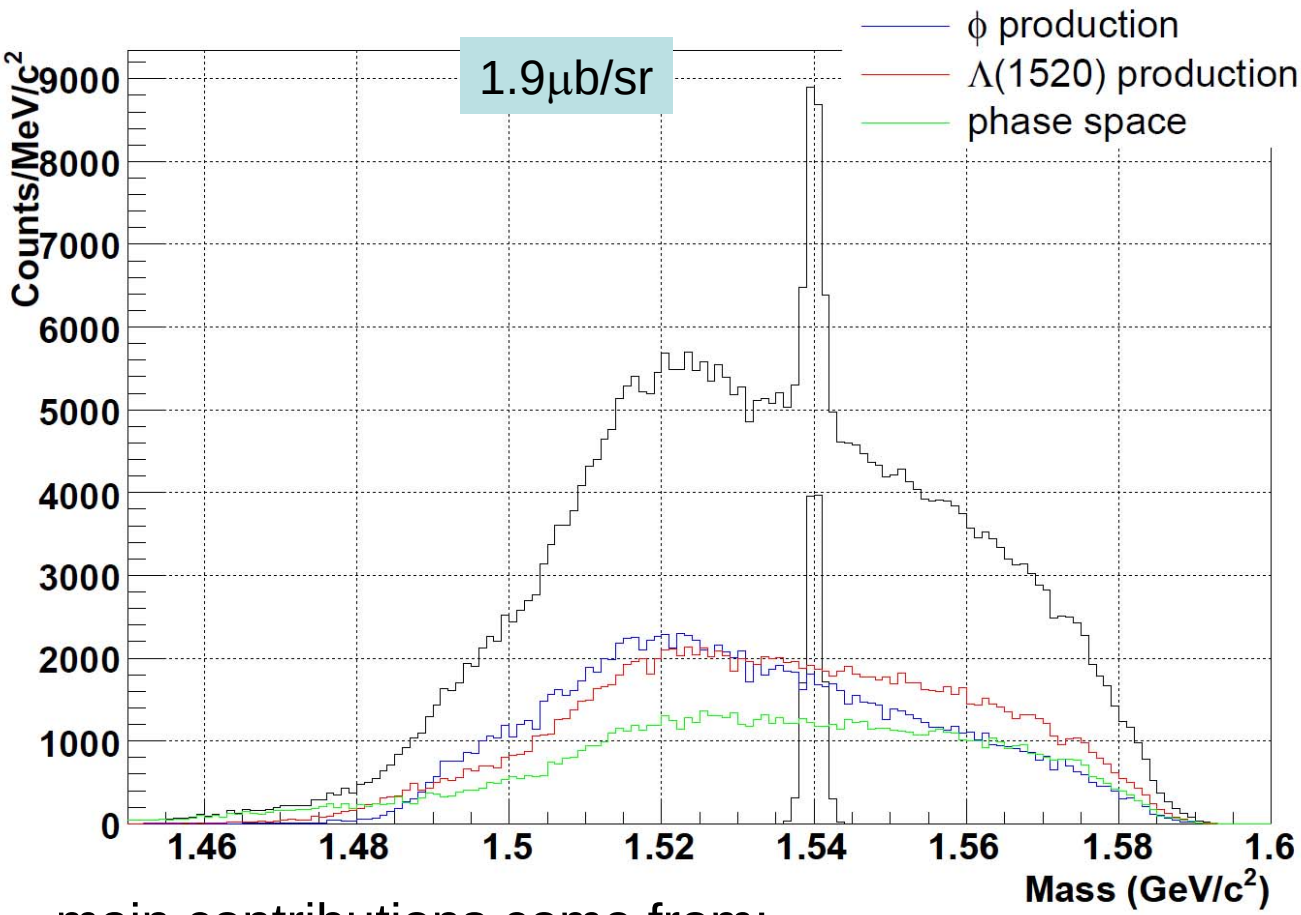
ΔM = 1.8 MeV (FWHM sim.)

$\sigma_\theta = 0.26^\circ$

$dp_K/p_K = 0.096 \times p\% + 0.092\%$

$dp_{beam}/p_{beam} = 1.4 \times 10^{-4}$ @ 1 GeV/c

Expected Missing Mass Spectrum



significance : 62σ
assuming
Γ < 2MeV
σ = 1.9μb

main contributions come from;

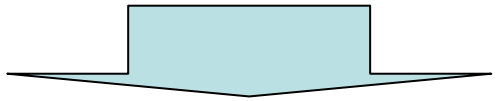
φ :	$\phi n \rightarrow K^+K^-n$	30.0±8.0 μb
Λ :	$\Lambda(1520)K^0 \rightarrow K^-K^0p$	20.8±5.0 μb
phase space :	K^-KN	26 μb

Expected Yield & Sensitivity

- yield
  - beam pions :160 hours beam time → 4.8 X 10^{11} π for each p_π
  - SKS acceptance : 0.1 sr
  - analysis efficiency : 50%
  - K decay : 50% ← TOF 4.7m
  - 1.9μb/sr @ p_π=1.92GeV/c ← E522

    → 1.2 X 10^4 events
- background
  - 0.8 μb/sr/MeV @ 1.530MeV for proton target ← E522
  - momentum flat

    → 5.0 X 10^3 counts/MeV



statistics	sensitivity
62σ Γ < 2 MeV	75nb/sr Γ < 2 MeV
48σ Γ = 10 MeV	150nb/sr Γ = 10 MeV

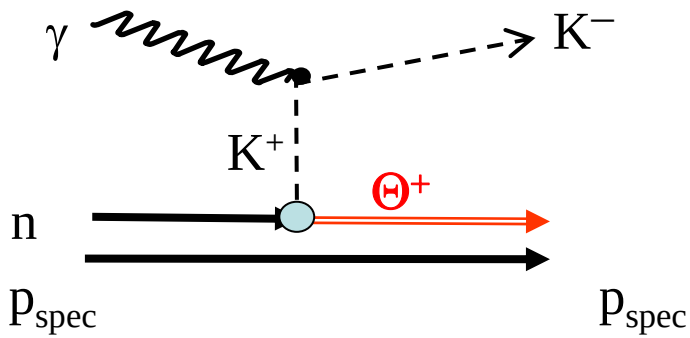
Summary

- E559 experiment searched for Θ^+ in (K^+,π^+) reaction but observed no peak structure.
  - we set an upper limit of 7.1μb and 1.9μb/sr at 90% C.L.
- E522 experiment searched for Θ^+ in (π^-, K^-) reaction and observed bump structure around 1.53GeV with statistical significance of 2.5σ.
- J-PARC E19 experiment was approved to search for Θ^+ in (π^-, K^-).
  - K1.8 beam line + SKS is ideal for Θ^+ production
  - s-channel production at low energy
  - hadronic reaction → high statistics
  - with high mass resolution; 2.5MeV(FWHM)

strategy to read the conclusion

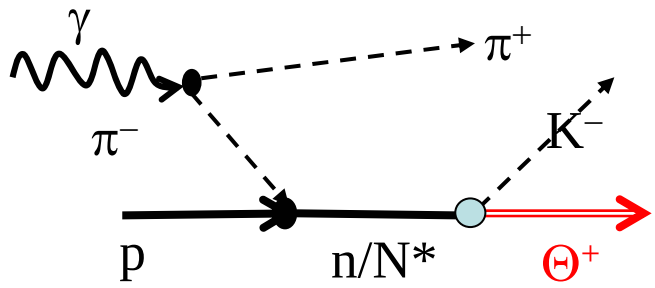
- photo-production
  - $\gamma n \rightarrow K^- \Theta^+$
  - $\gamma p \rightarrow \pi^+ K^- K^+ (n)$

  Spring-8/J-Lab



- meson induced reaction
  - $\pi^- p \rightarrow K^- \Theta^+$

  J-PARC



- pp collision
  - $pp \rightarrow \Sigma^+ \Theta^+$

    COSY
  - baryon fragmentation?

- formation process
  - $Kn \rightarrow K_s^0 p$

    J-PARC