Search for the Θ^+ pentaquark at J-PARC

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for the J-PARC E19 collaboration

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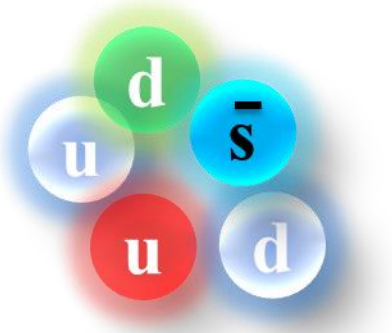
Pentaquark Θ^+



- made form five quarks ($qqqq\bar{q}$)
  - allowed combination by QCD.
- No convincing experimental evidence before 2002,
  - despite many searches in particle phys. exp.
- In 2003, SPring8/LEPS group first reported the evidence for Θ^+,
  - including $\bar{s}$. → At least 5-quark components.
- Dozen experimental groups published supporting evidence for the Θ^+,
- followed by a number of experiments with no evidence.

A Lot of Θ+ Searches

Group	Reaction	Mass (MeV)	Width (MeV)	Statistical significance (σ)
LEPS	$\gamma C \to K^+K^-(n)$	1540 ± 10	<25	4.6
LEPS	$\gamma C \to K^+K^-(n)$	1524 ± 2	<25	5.1
DIANA	$K^+Xe \to K^0_s pX$	1539 ± 2	<9	4.4
DIANA	$K^+Xe \to K^0_s pX$	1538 ± 2	0.39 ± 0.1	8
CLAS(d)	$\gamma d \to K^+K^-p(n)$	1542 ± 5	<21	(5.2)
CLAS(p)	$\gamma p \to \pi^+K^+K^-(n)$	1555 ± 10	<26	7.8
SAPHIR	$\gamma p \to K^+K^0_s nX$	1540 ± 6	<25	4.8
ITEP	$\nu A \to K^0_s pX$	1533 ± 5	<20	6.7
HERMES	$e^+d \to K^0_s pX$	1528 ± 3	12 ± 9	4.2
COSY-TOF	$pp \to K^0_s p\Sigma^+$	1530 ± 5	<18	4.7
ZEUS	$e^+p \to e^+K^0_s pX$	1522 ± 3	8 ± 4	4.6
NOMAD	$\nu A \to K^0_s pX$	1529 ± 3	$2 \sim 3$	4.3
SVD	$pA \to K^0_s pX$	1526 ± 5	<24	5.6
SVD	$pA \to K^0_s pX$	1523 ± 5	<14	8.0

Positive results

Negative results

Group	Reaction	Limit
BES	$e^+e^- \to J/\Psi \to \Theta\Theta$	$< 1.1 \times 10^{-5}$ B.R. (90% C.L.)
BES	$e^+e^- \to \Psi(2S) \to \bar{\Theta}\Theta$	$< 8.4 \times 10^{-6}$ B.R. (90% C.L.)
ALEPH	$e^+e^- \to Z \to pK^0_s X$	$< 6.2 \times 10^{-4}$ B.R. (95% C.L.)
BarBar	$e^+e^- \to \Upsilon(4S) \to pK^0_s X$	$< 1.0 \times 10^{-4}$ B.R. (90% C.L.)
BarBar	$eBe \to pK^0_s X$	not given
Belle	$e^+e^- \to B^0\bar{B}^0 \to p\bar{p}K^0_s X$	$< 2.3 \times 10^{-7}$ B.R. (90% C.L.)
Belle	$K^+n \to K^0_s pX$	$\Gamma < 0.64 MeV$ (90% C.L.)
CDF	$p\bar{p} \to K^0_s pX$	$< 0.03 \times \Lambda^*$ (90% C.L.)
SPHINX	$pC \to K^0_s pX$	$< 0.1 \times \Lambda^*$ (90% C.L.)
HERA-B	$pA \to K^0_s pX$	$< 2.7\% \times \Lambda^*$ (95% C.L.)
HyperCP	$pCu \to K^0_s pX$	$< 0.3\%$ $K^0_s p$
FOCUS	$\gamma BeO \to K^0_s pX$	$< 0.02 \times \Sigma^*$ (95% C.L.)
PHENIX	$dAu \to K^-\bar{n}X$	not given
WA89	$\Sigma^+A \to K^0_s pX$	$< 1.8 \mu$b/A (99% C.L.)
CLAS	$\gamma p \to \bar{K}^0_s K^+n$	< 0.8 nb (95% C.L.)
CLAS	$\gamma d \to K^-pK^+n$	$< 0.15 - 3$ nb (95% C.L.)
CLAS	$\gamma d \to K^+n\Lambda$	$< 5 - 25$ nb (95% C.L.)
COSY-TOF	$pp \to \Sigma^+pK^0_s$	$< 0.15 \mu$b/A (95% C.L.)
NOMAD	$\nu A \to K^0_s pX$	$< 2.13 \times 10^{-3} \nu$CC (90% C.L.)

A Lot of Θ⁺ Searches

Group	Reaction	Mass (MeV)	Width (MeV)	Statistical significance (σ)
LEPS	$\gamma C \to K^+K^-(n)$	1540 ± 10	<25	4.6
LEPS	$\gamma C \to K^+K^-(n)$	1524 ± 2	<25	5.1
DIANA	K^+Xe			
DIANA	K^+Xe			
CLAS(d)	$\gamma d \to K$			
CLAS(p)	$\gamma p \to \pi$			
SAPHIR	$\gamma p \to K$			
ITEP	$\nu A \to$			
HERMES	$e^+d \to$			
COSY-TOF	$pp \to K_s pZ$			
ZEUS	$e^+p \to e^+K^0_s pX$	1522 ± 3	8 ± 4	4.6
NOMAD	$\nu A \to K^0_s pX$	1529 ± 3	2~3	4.3
SVD	$pA \to K^0_s pX$	1526 ± 5	<24	5.6
SVD	$pA \to K^0_s pX$	1523 ± 5	<14	8.0

✓ ***Not well established in experiments***

➔ ***" Must confirm the existence/non-existence of Θ⁺ at first "***

ve results

Group	Reaction	Limit
BES	$e^+e^- \to J/\Psi \to \Theta\Theta$	$< 1.1 \times 10^{-5}$ B.R. (90% C.L.)
BES	$e^+e^- \to \Psi(2S) \to \bar{\Theta}\Theta$	$< 8.4 \times 10^{-6}$ B.R. (90% C.L.)
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		. (90% C.L.)
		0% C.L.)
		% C.L.)
		C.L.)
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WA89	$\Sigma^- A \to K^0_s pX$	$< 1.8\mu$b/A (99% C.L.)
CLAS	$\gamma p \to \bar{K}^0_s K^+ n$	< 0.8 nb (95% C.L.)
CLAS	$\gamma d \to K^- pK^+ n$	$< 0.15 - 3$ nb (95% C.L.)
CLAS	$\gamma d \to K^+ n\Lambda$	$< 5 - 25$ nb (95% C.L.)
COSY-TOF	$pp \to \Sigma^+ pK^0_s$	$< 0.15\mu$b/A (95% C.L.)
NOMAD	$\nu A \to K^0_s pX$	$< 2.13 \times 10^{-3} \nu$CC (90% C.L.)

Positive res

✓ **Low energy hadronic reaction (π or K beam)**

- **Few data**
- **Expect sizable production cross section.**
- **Complementary to the photo-production.**

Θ^+ search by high-resolution spectroscopy via $\pi^- + p \rightarrow K^- + \Theta^+$: J-PARC E19

Previous KEK-PS E522 experiment

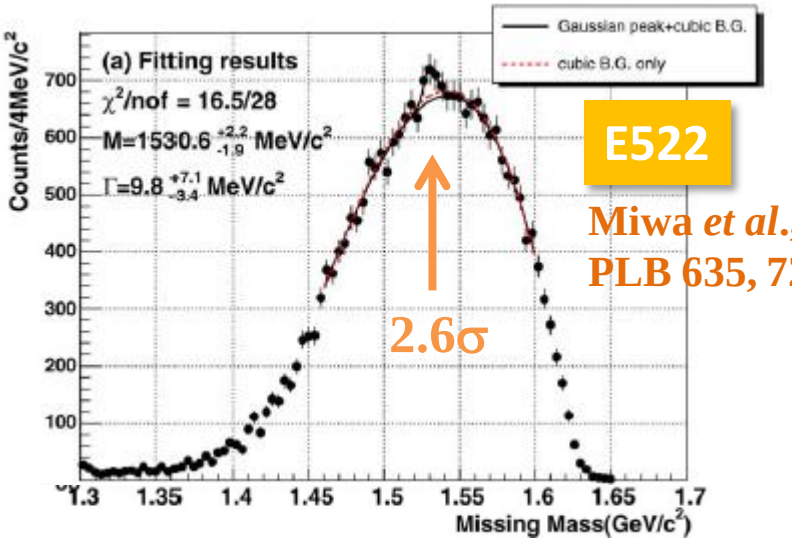
- Is this a sign of Θ^+ ?

➔ Not enough sensitivity

➔ They did not conclude the evidence of Θ^+.

- mass resolution

  $\Delta M \sim 13.4$ MeV (FWHM)



J-PARC E19 experiment

- same reaction as E522
- High resolution : SKS ➔ $\Delta M < 2$ MeV (FWHM)
- High statistics : High intensity beam at J-PARC

⇒ **Conclusive result by higher sensitivity.**

The first physics run at the J-PARC hadron facility !

Experimental setup

K1.8 beam line spectrometer & SKS
⇒Missing mass spectroscopy

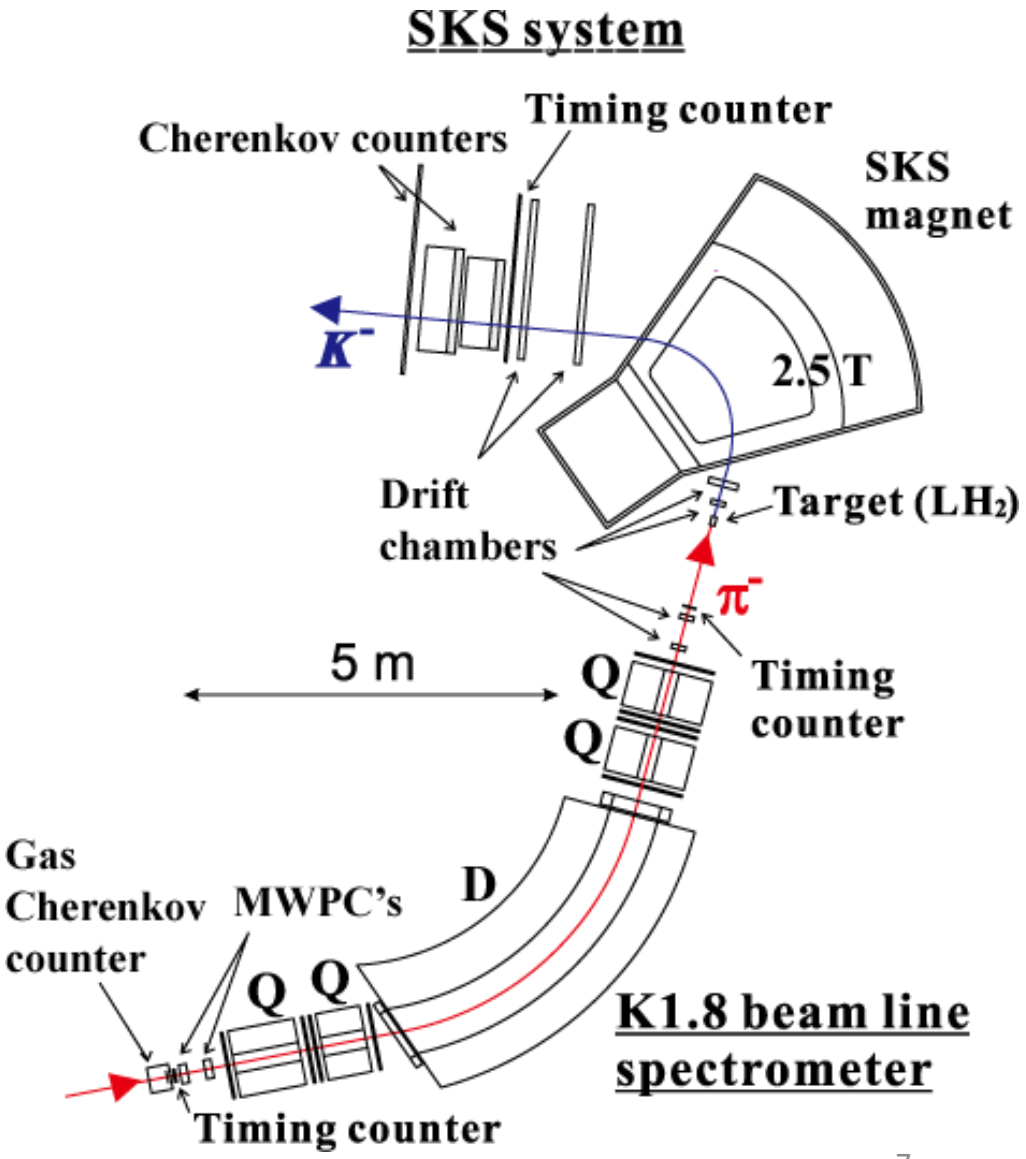
- **K1.8 beam line spectrometer : p_π**
  PID counters
  - Timing counters : TOF
  - Gas Cherenkov (π/e) : n=1.002

  Tracking
  - MWPCs : 1 mm pitch
  - MWDCs : 3 mm pitch

- **SKS system : p_K**
  PID counters
  - Timing counter
  - Aerogel Cherenkov (K/π) : n=1.05
  - Lucite Cherenkov (K/p) : n=1.49

  Tracking
  - MWDCs : 3 mm pitch
  - DCs : 10 mm pitch, 2m × 1m size

- **Target: Liquid hydrogen**
  - ~0.86 g/cm²
  - Free from Fermi motion effect



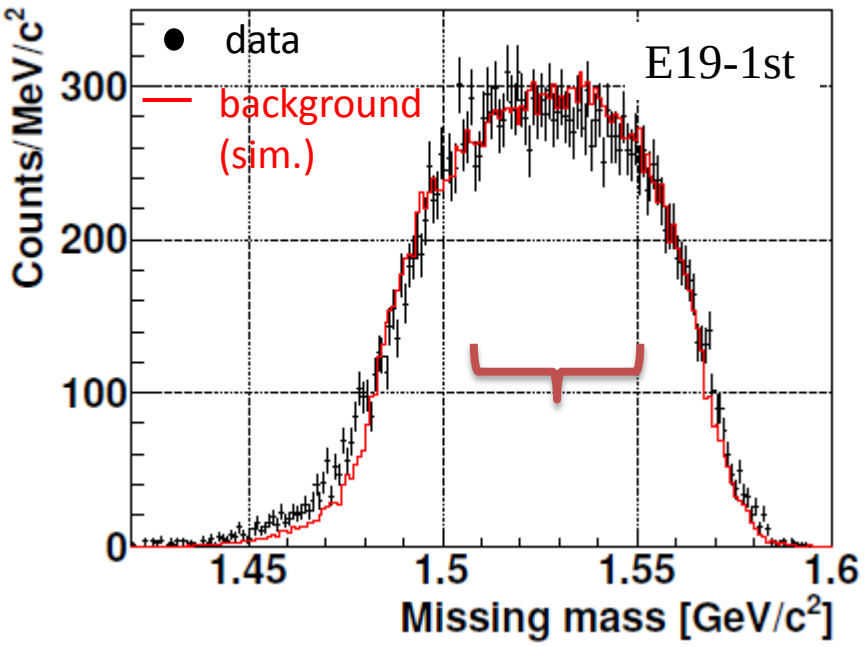
History of E19

	Comment	Beam Momentum	Beam intensity	π's on Target
2009/10 ~	K1.8 beam line & detector commissioning start			
2010/10-11 1st RUN	**examine the 2.6σ bump structure observed in E522**	**1.92 GeV/c**	**1.0 M /spill**	**7.8 x 10^{10}**
2012/02 2nd RUN	**new data at the highest beam momentum at K1.8**	**2.0 GeV/c**	**1.7 M /spill**	**8.7 x 10^{10}**

Successful completion of both 1st and 2nd run

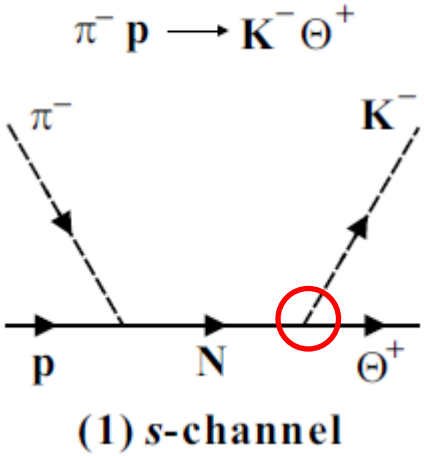
1st run result of E19

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



- **No prominent peak structure**
- Upper limit: **< 0.26 μb/sr**
  @ 1.51–1.55 GeV/c²

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



- ✓ s-channel dominance
- ✓ $\Gamma_\Theta \propto g^2_{KN\Theta} \propto \sigma_{tot}$

➔Upper limit of decay width

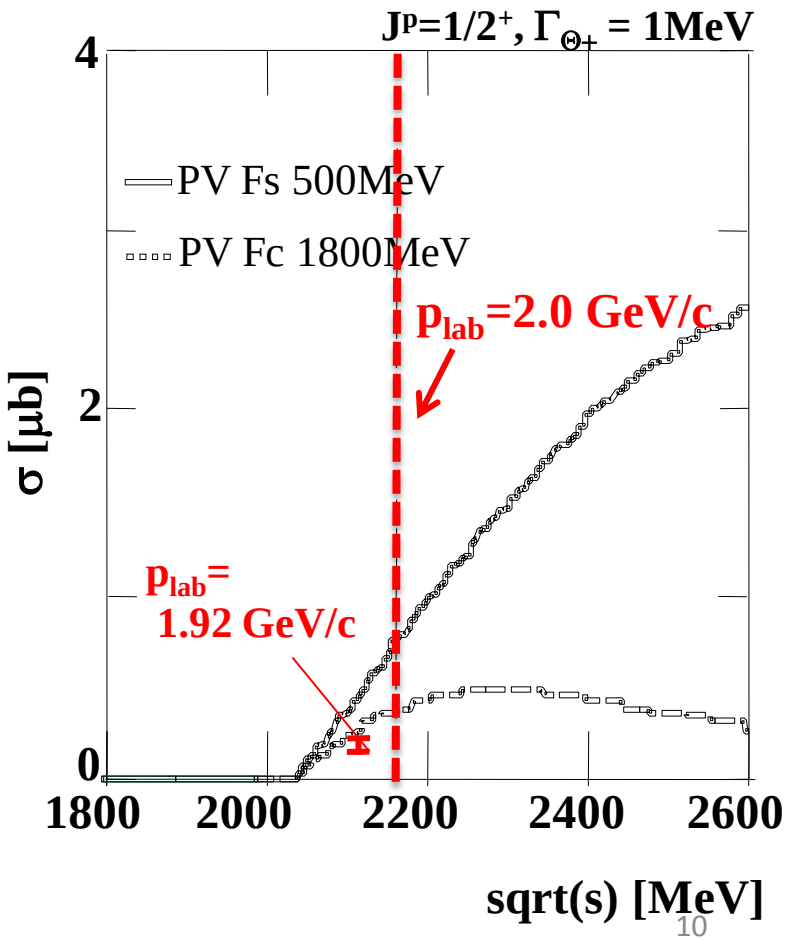
- 0.72 MeV for ½+
- 3.1 MeV for ½-

2nd run of E19

- Beam time: 2012/Feb
- Higher beam momentum
  2.0 GeV/c (= Max. of K1.8 B.L.)
- Expecting increased cross section
  ➔ higher sensitivity

➔ Stringent restriction
on the Θ^+ decay width.

Theoretical calculations :
Hyodo, Hosaka, PRC 72, 055202 (2005).

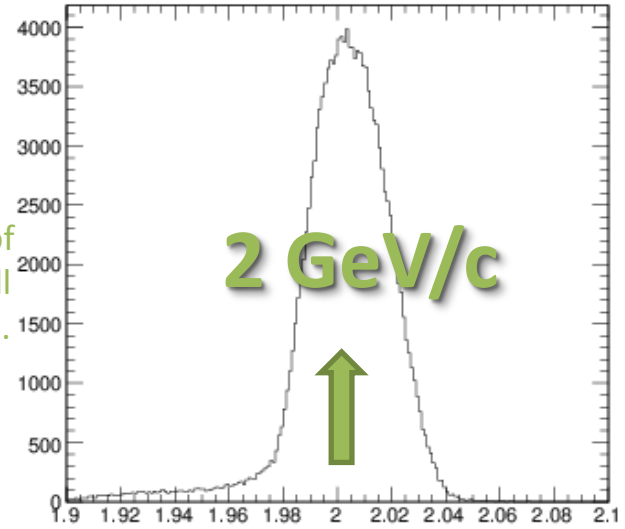


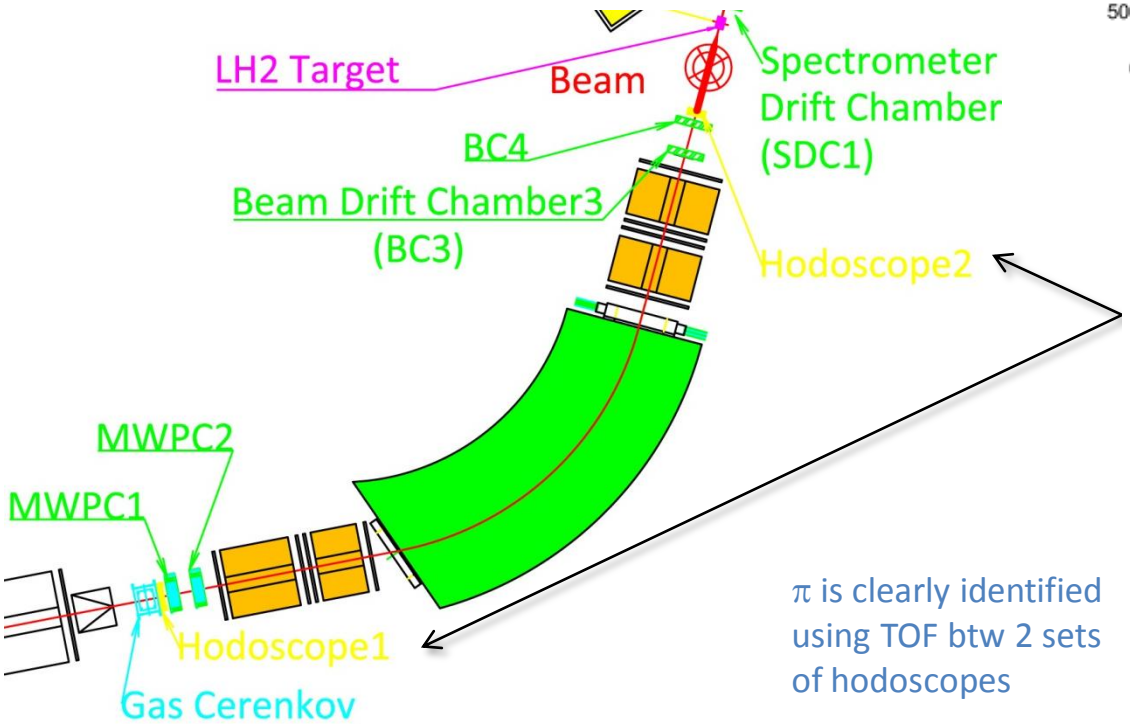
K1.8 Beam spectrometer

Beam Momentum

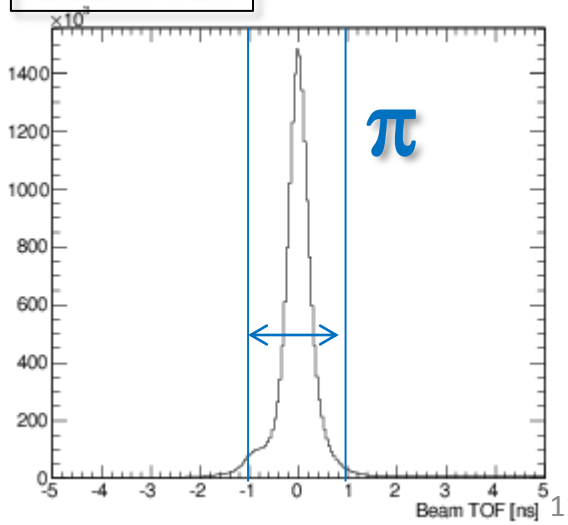
- **K1.8 beam line spectrometer : p_π**
  - PID counters
    - Timing counters : TOF
    - Gas Cherenkov (π/e) : n=1.002
  - Tracking
    - MWPCs : 1 mm pitch
    - MWDCs : 3 mm pitch

Beam mom. of 2 GeV/c is well reconstructed.





Beam TOF



π is clearly identified using TOF btw 2 sets of hodoscopes

SKS spectrometer

- **SKS system : p_K**

  PID counters
  - Timing counter
  - Aerogel Cherenkov (K/π) : n=1.05
  - Lucite Cherenkov (K/p) : n=1.49

  Tracking
  - MWDCs : 3 mm pitch
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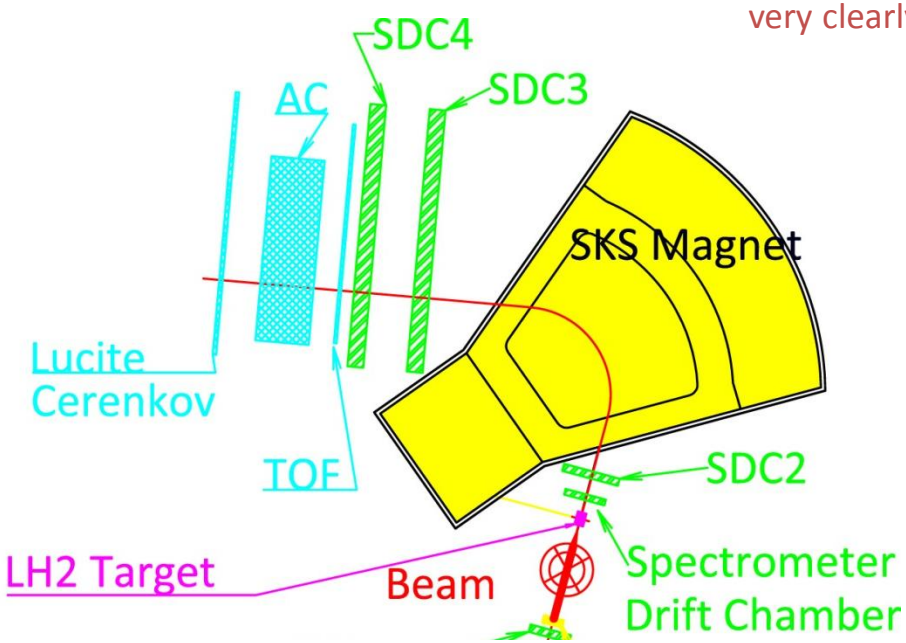
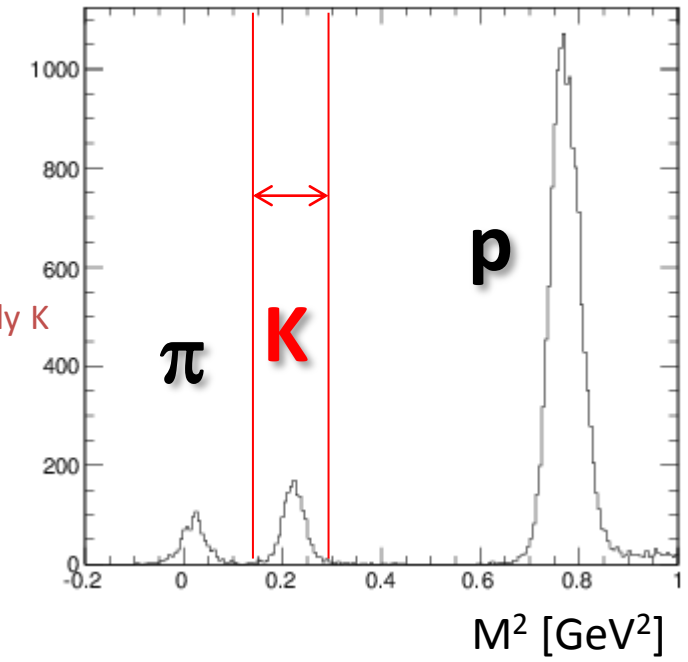


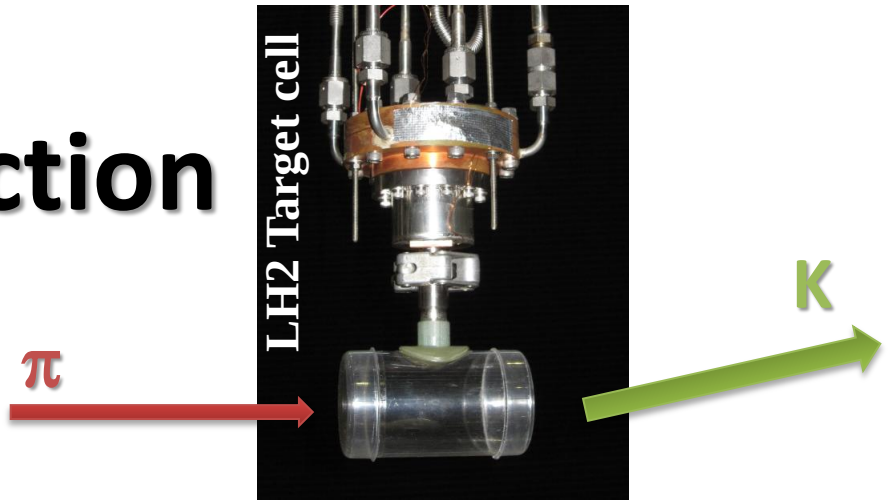
We can separate only K very clearly.

Scattered particle M^2



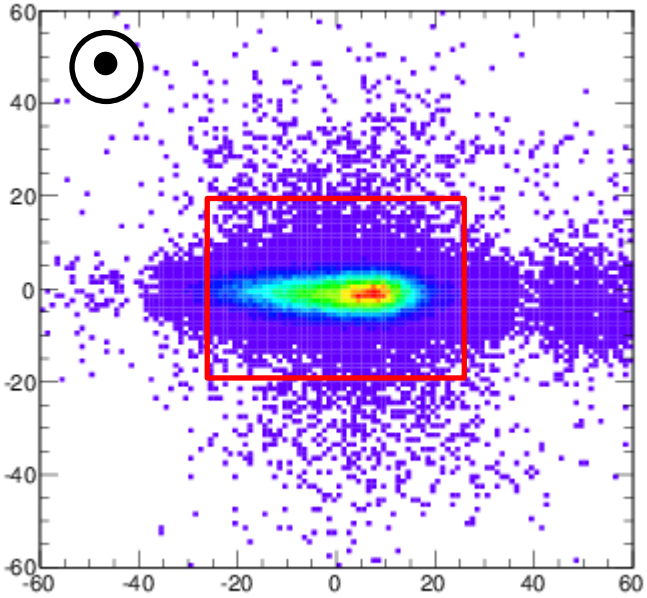
Good momentum reconstruction and PID !!

Vertex Reconstruction



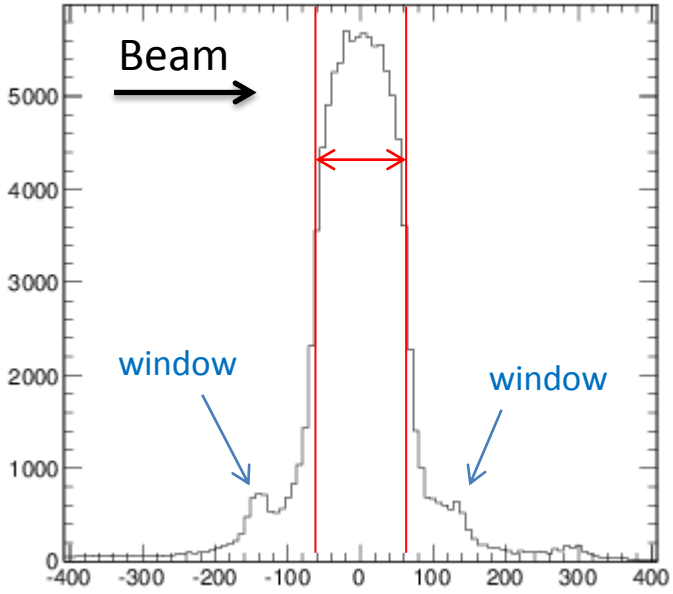
$\phi 67.8 \times 120$ mm

Vertex-(X vs Y)



Consistent with horizontally oblate beam shape.

Vertex-Z



Target cell is clearly identified !!

Performance of the spectrometers

Calibration

- $\pi^+ + p \rightarrow K^+ + \Sigma^+$ @ 1.37 GeV/c
- Missing mass resolution:

  ΔM_Σ = 2.0 MeV (FWHM)

  Equivalent to the 1st run !!

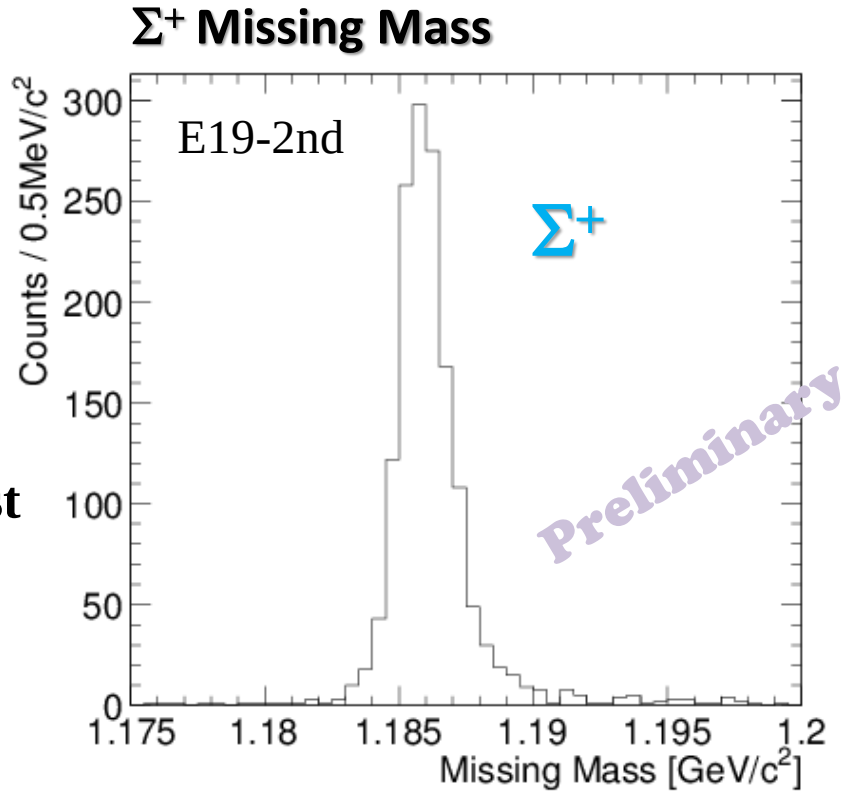
  Cf.) ΔM_Σ = 1.9±0.1 MeV @ E19-1st

⇒ estimate Θ^+ case:

ΔM_Θ = 1.75 MeV (FWHM)

- Yield estimation (rough):

  Almost Consistent with the 1st run !!

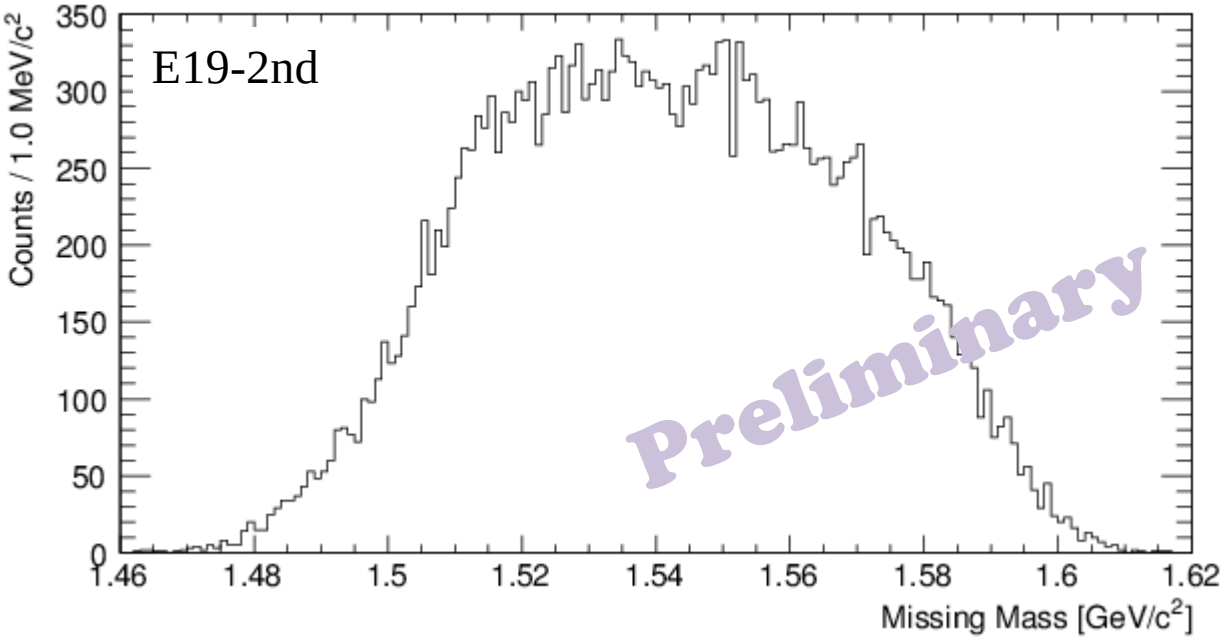


Γ = 2.02±0.06

Enough performance !!

Preliminary result of E19-2nd run

Missing Mass : p (π^-, K^-) *X* @ p_π = 2.0 GeV/c



- Analysis parameters were not finally tuned yet.
- No clear peak structure was observed.
- Efficiency evaluation is on-going.
- Tentative expected sensitivity ~ 0.3 μb/sr.

Summary

- **J-PARC E19 : High-resolution search via $\pi^- p \rightarrow K^- \Theta^+$ reaction**
  - **The first physics experiment at the J-PARC hadron facility !**
  - **1st run result was published in PRL. (@ 1.92GeV/c beam)**
    - **More than 10 times higher sensitivity than E522.**
    - **No clear Θ^+ peak → < 0.26 μb/sr**
    - **Strong constraint : Γ < ~1 MeV**

- **2nd run was successfully carried out. (@ 2 GeV/c beam)**
  - **Good performance of both K1.8BS and SKS.**
  - **No clear Θ^+ peak (preliminary)**
  - **Efficiency evaluation etc. are in progress.**