Pentaquark Θ^+ search experiment using pion beam at J-PARC

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for the J-PARC E19 collaboration

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1. Introduction
2. J-PARC E19 experiment
3. 1st run result
4. 2nd run analysis status and preliminary result
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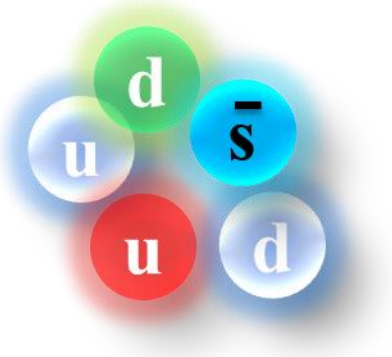
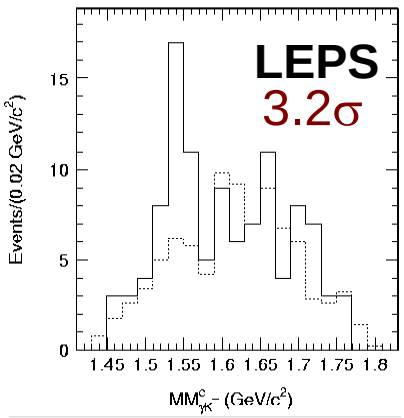
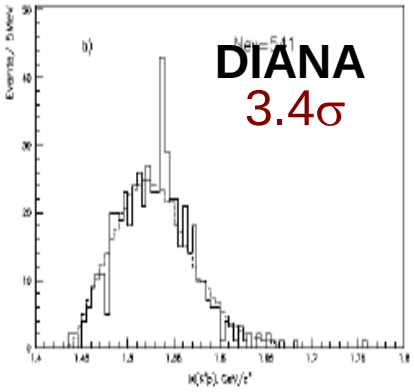
Pentaquark Θ^+

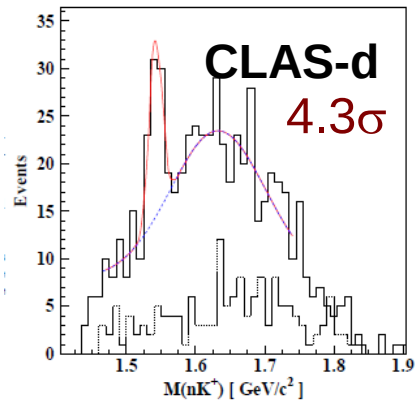


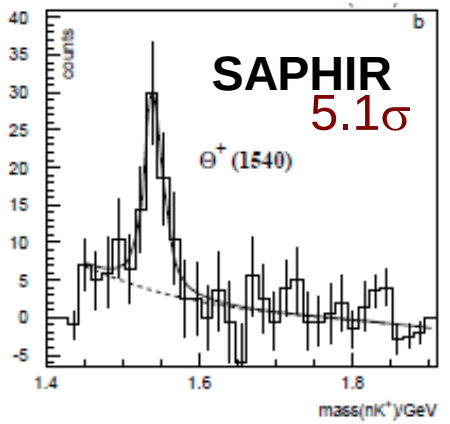
- made form five quarks ($qqqq\bar{q}$)
  - allowed combination by QCD.
- No convincing experimental evidence before 2002,
  - despite many searches in particle phys. exp.
- In 2003, SPring8/LEPS group first reported the evidence for Θ^+,
  - including $\bar{s}$. → At least 5-quark components.
- Dozen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

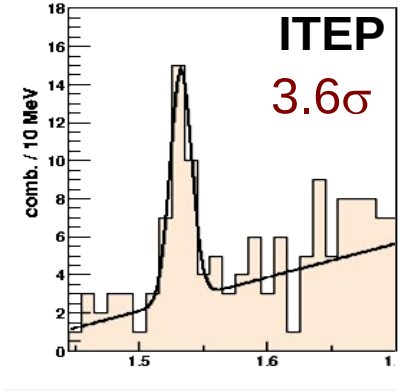
Positive Results (~2005)

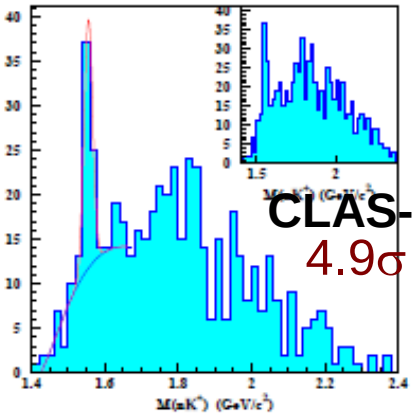


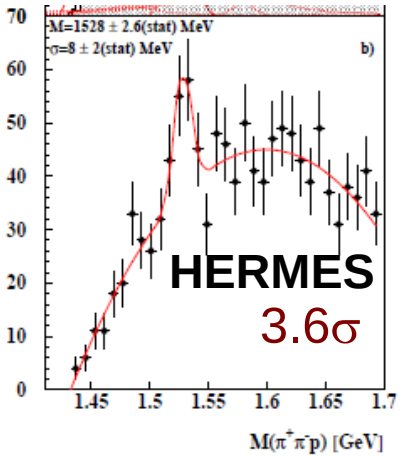


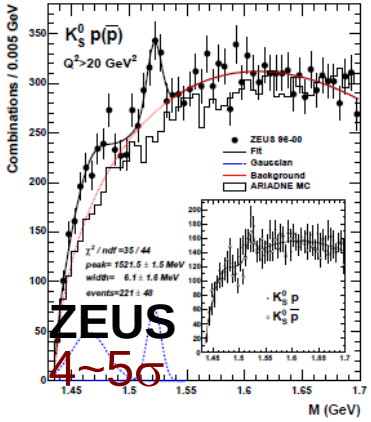


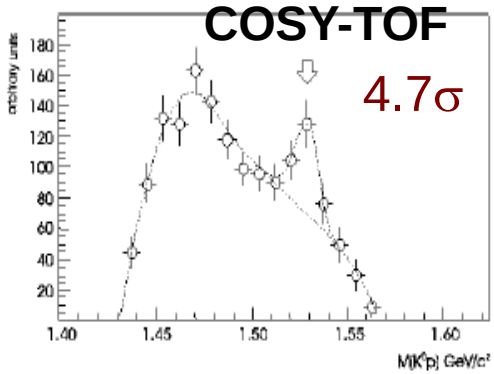


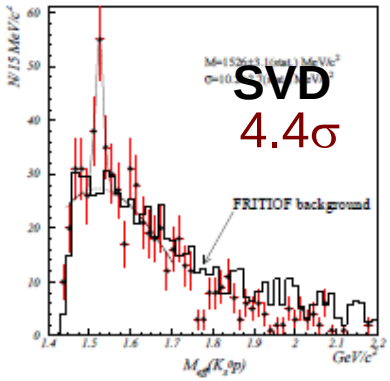






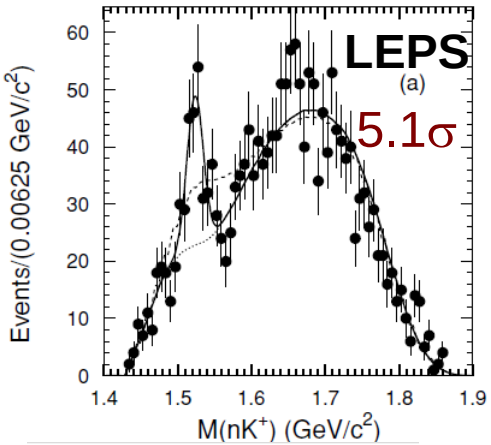


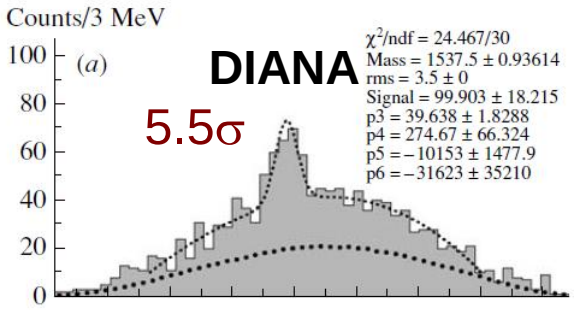


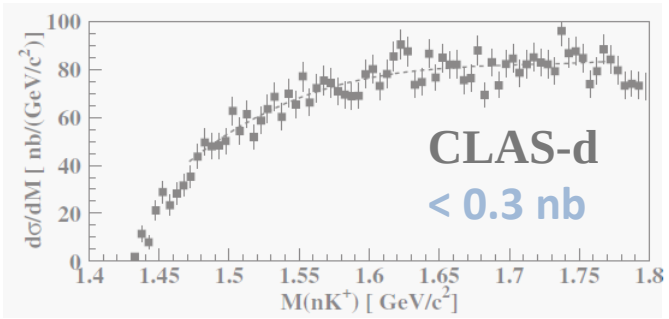


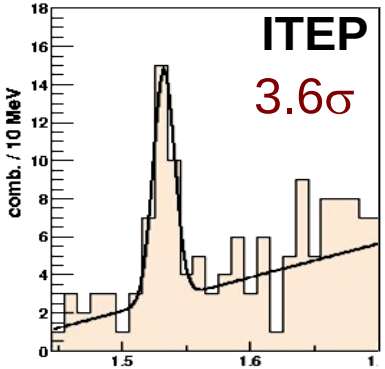
[CAUTION]
Significances ware recalculated by
significance = S/√(S+B) or S/dS

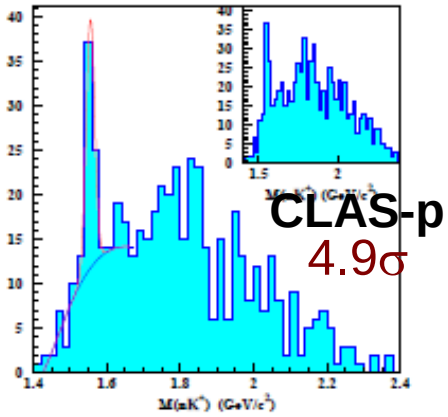
Positive Results (updated)

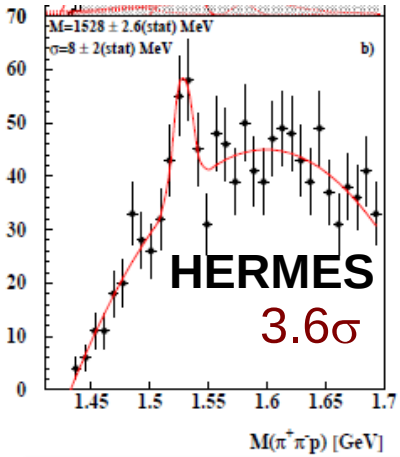


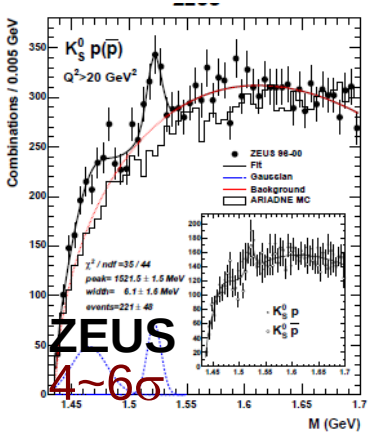


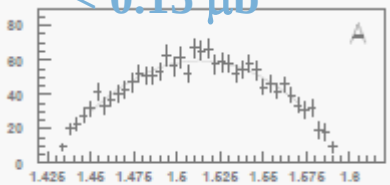


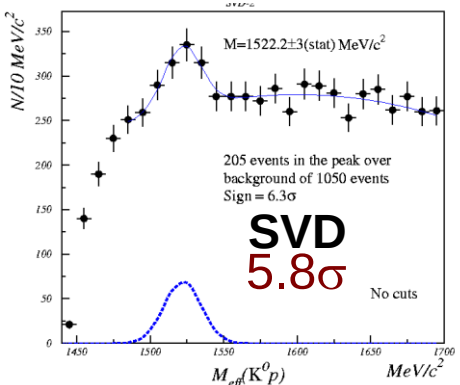








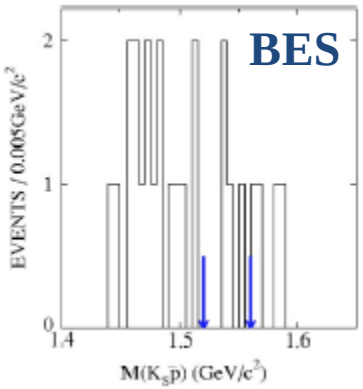


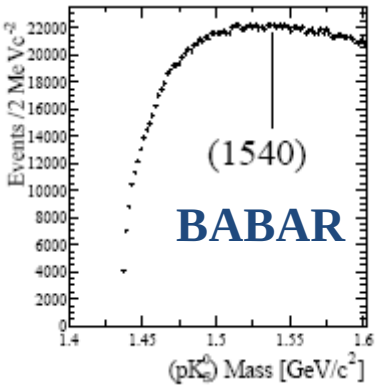


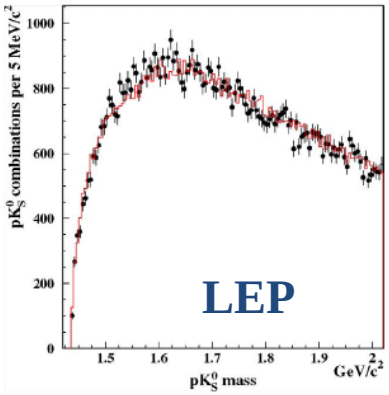
Some confirmed their evidence, but others did not...

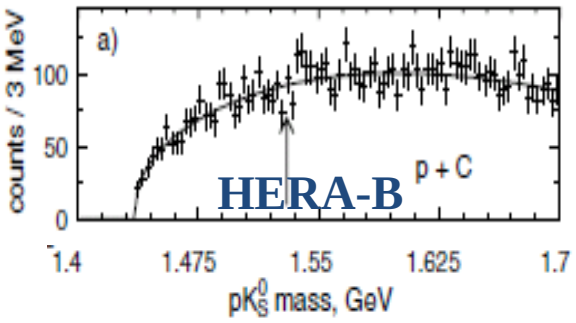
[CAUTION]
Significances ware recalculated by significance = S/√(S+B) or S/dS

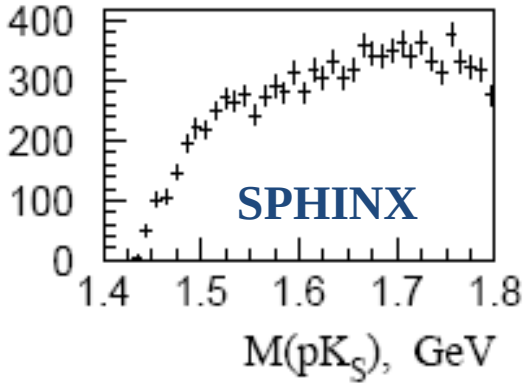
Negative Results

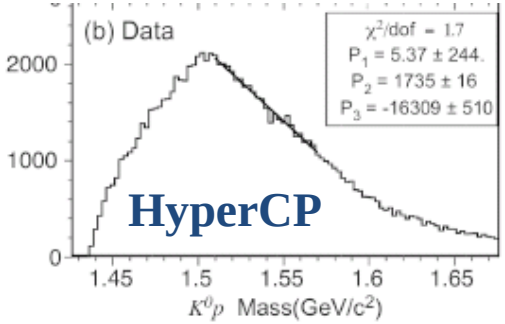


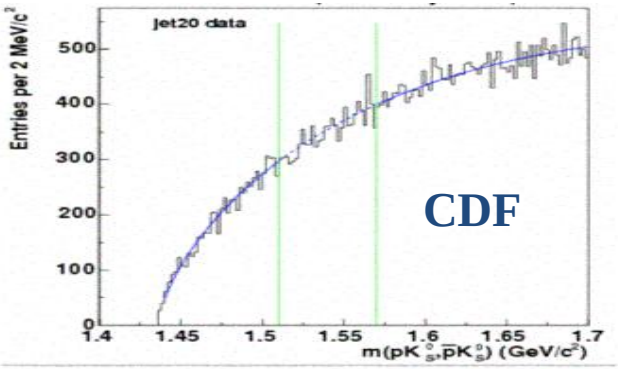


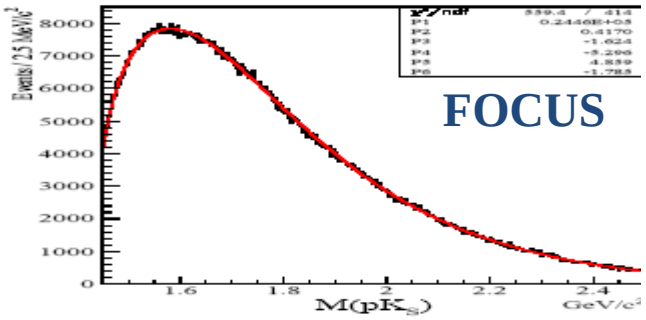


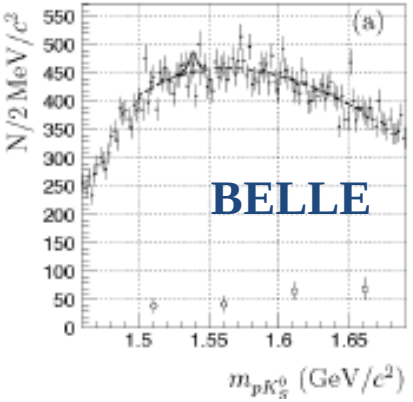


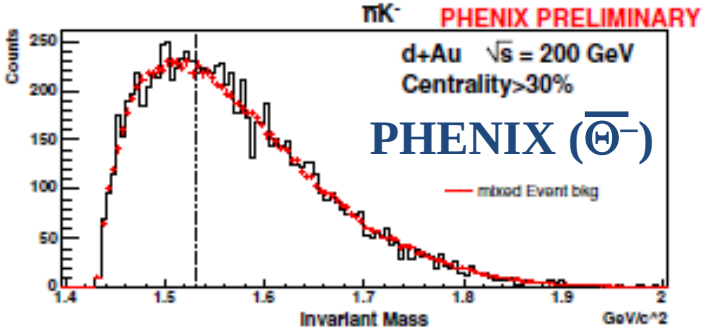








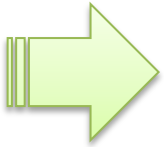




Present status on Θ^+

- Many positive and negative results. In general tendency,
  - Positive results
    - Low energy experiments
    - Low statistics
  - Negative results
    - High energy experiments
    - High sensitivity

➔ ***Controversial situation***

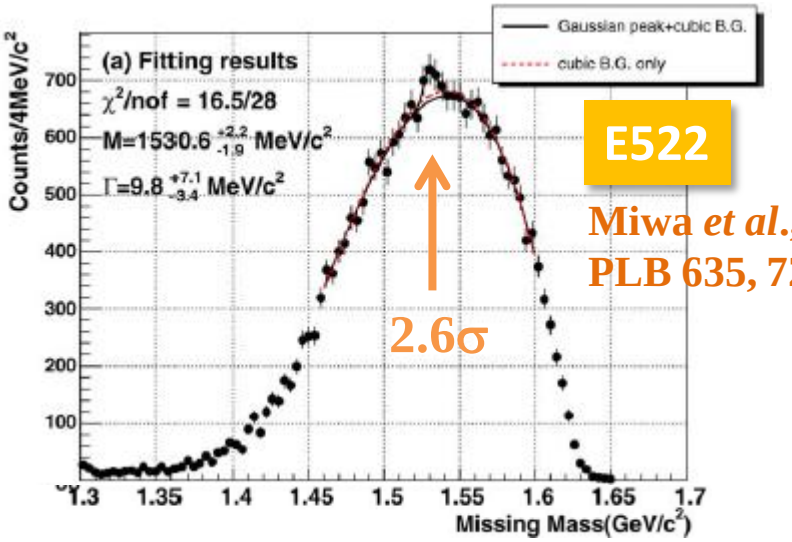


✓ Low energy hadronic reaction (π or K beam)
- Few data
- Expect sizable production cross section.
- Complementary to the photo-production.

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



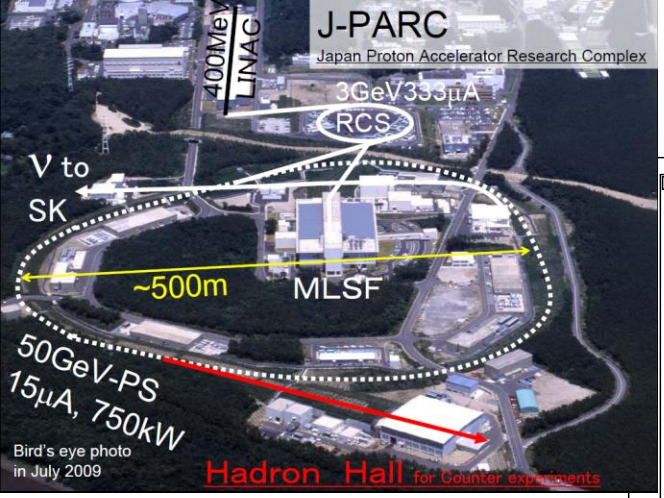
J-PARC E19 experiment

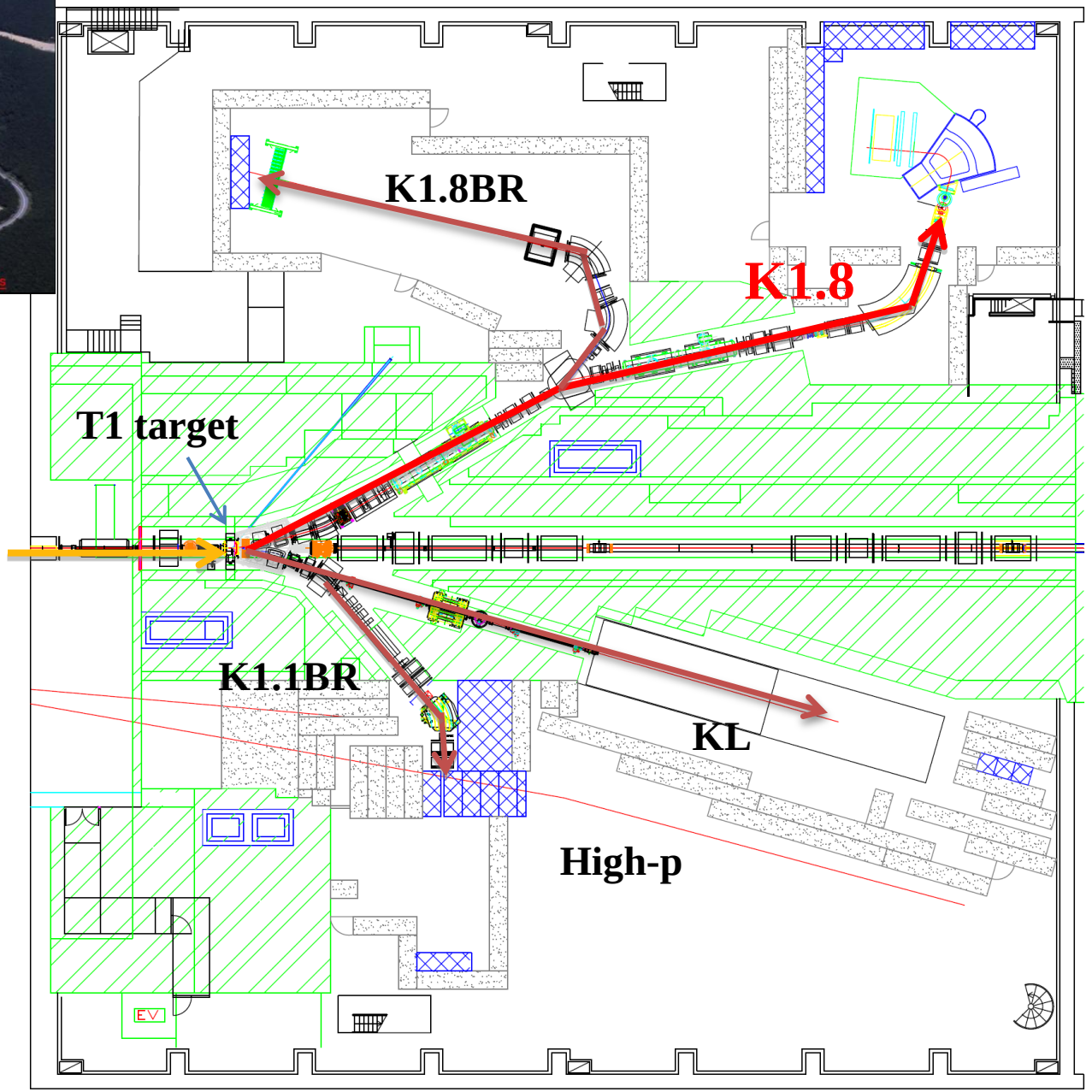
- same reaction as E522
- High resolution : SKS ➔ $\Delta M < 2$ MeV (FWHM)
- High statistics : High intensity beam at J-PARC

⇒ **Conclusive result by higher sensitivity.**

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

J-PARC Hadron facility





Experimental setup

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

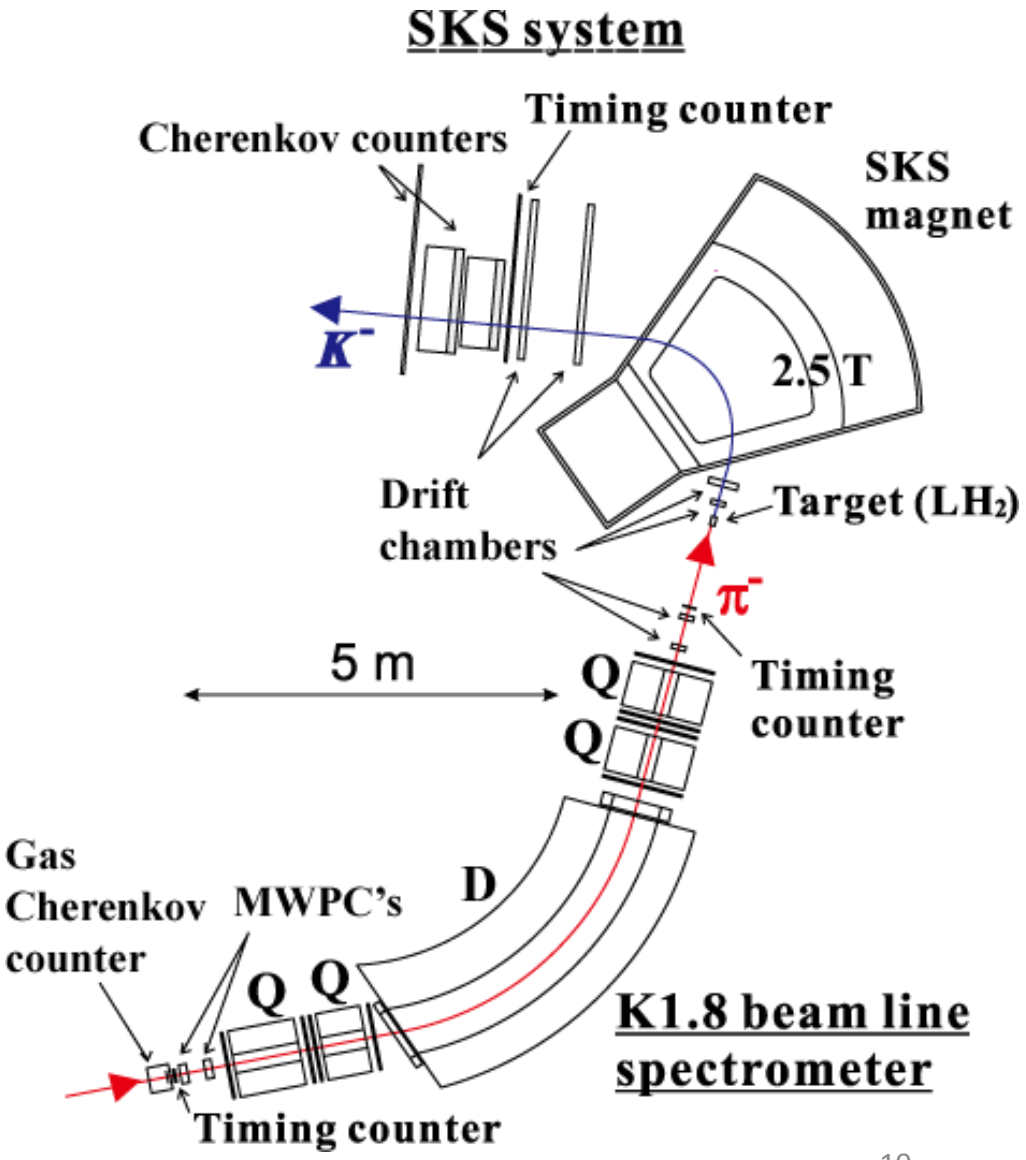
- **K1.8 beam line spectrometer : p_π**
  PID counters
  - Timing counters : TOF
  - Gas Cherenkov (π/e) : n=1.002

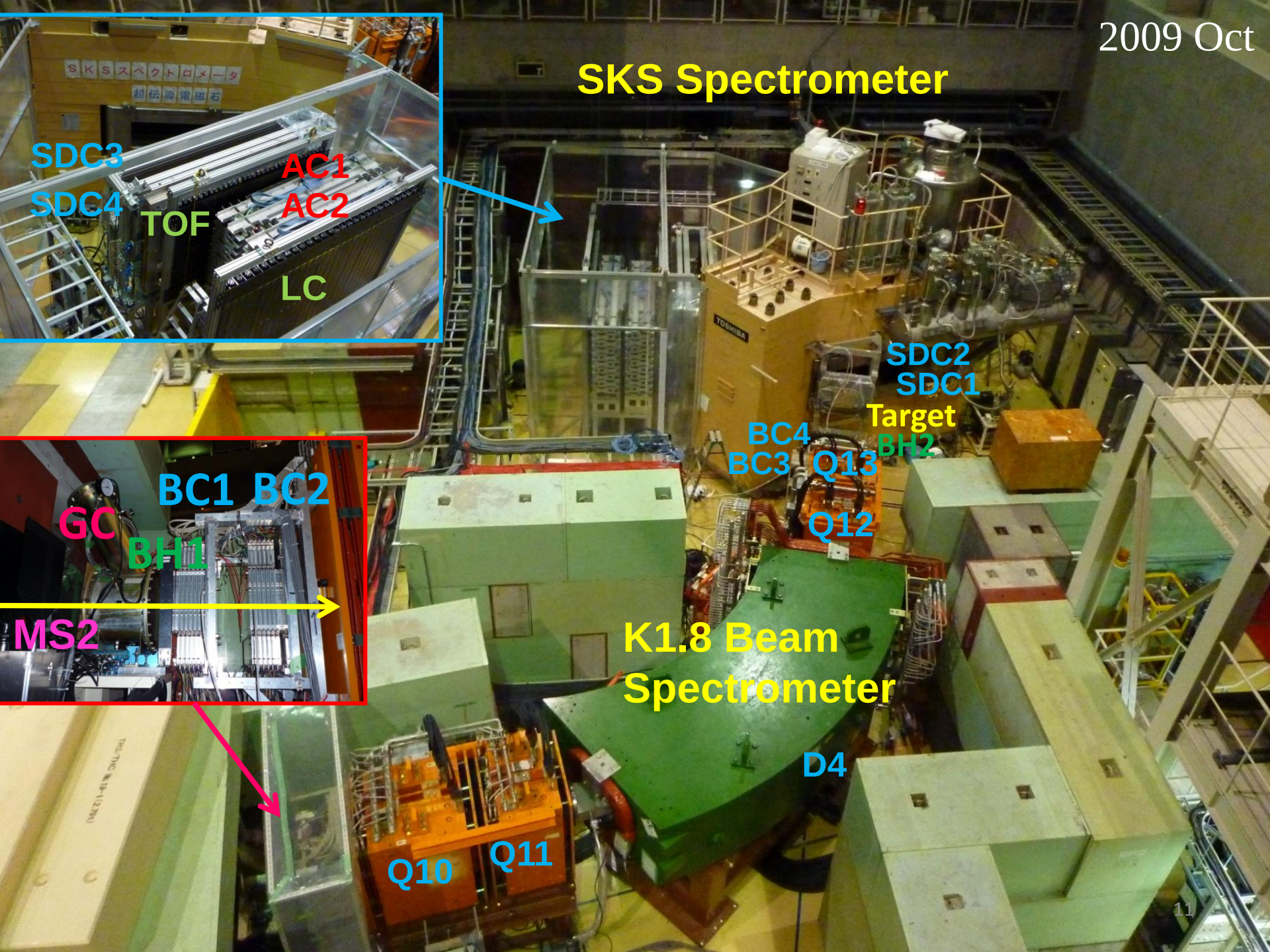
  Tracking
  - MWPCs : 1 mm pitch
  - MWDCs : 3 mm pitch

- **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/cm^2
  - Free from Fermi motion effect




2009 Oct
SKS Spectrometer
SDC3
SDC4
AC1
AC2
TOF
LC
SDC2
SDC1
Target
BH2
BC4
BC3
Q13
Q12
BC1
BC2
GC
BH1
MS2
K1.8 Beam
Spectrometer
D4
Q10
Q11

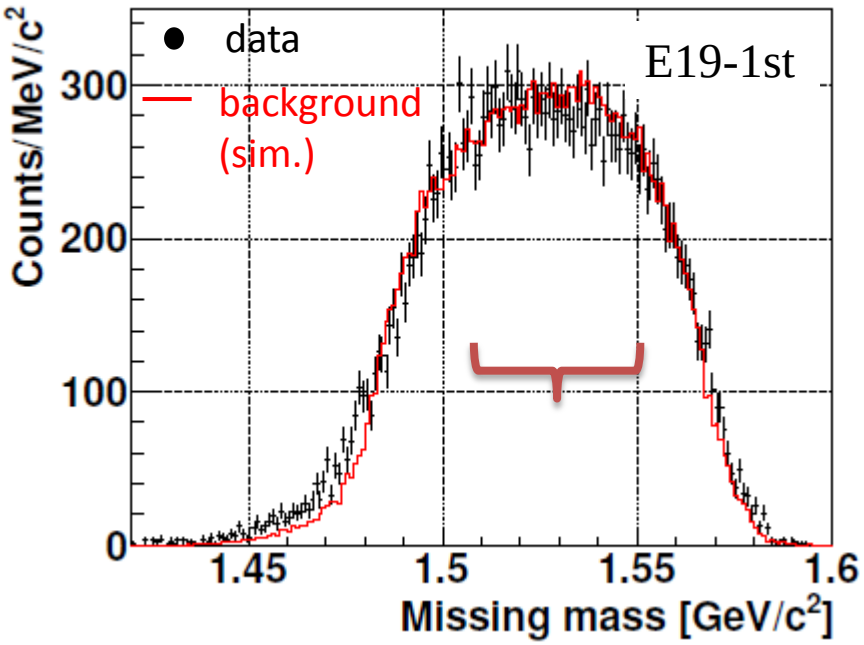
History of E19

0. 2009/10 ~
   - K1.8 beam line & detector commissioning start.
1. **1st run** (2010/10-11)
   - examine the 2.6σ bump structure observed in E522 at p_π = 1.92 GeV/c.
   - accumulated 7.8×10^{10} of beam π on target.
2. **2nd run** (2012/2)
   - new data at the highest beam momentum of 2GeV/c.
   - accumulated 8.7×10^{10} of beam π on target.

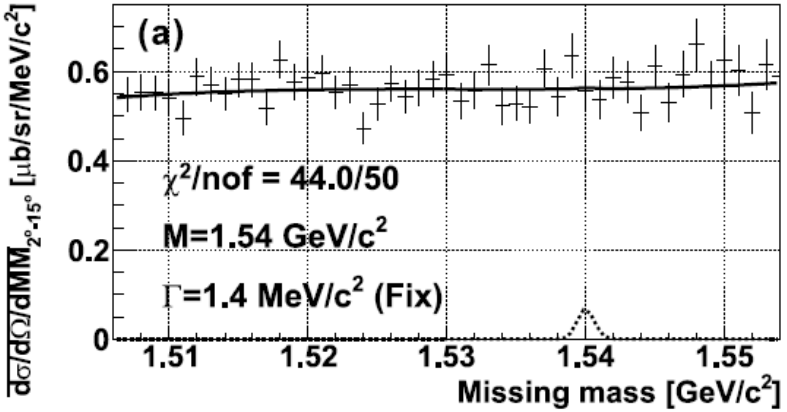
Successful completion of both 1st and 2nd run

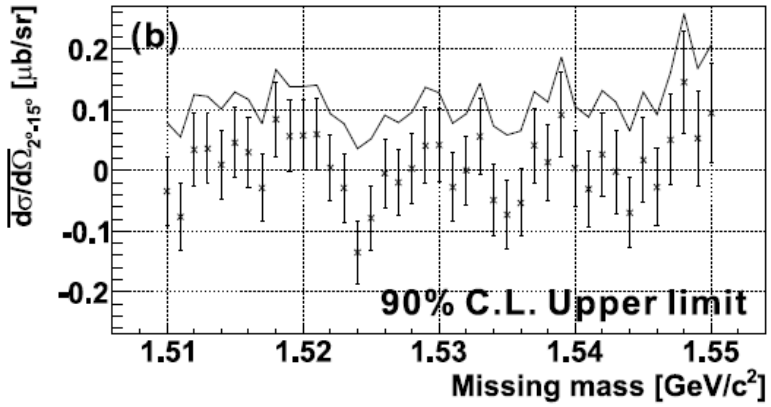
1st run result of E19

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



accepted in PRL, arxiv.1203.3604 [nucl-ex]

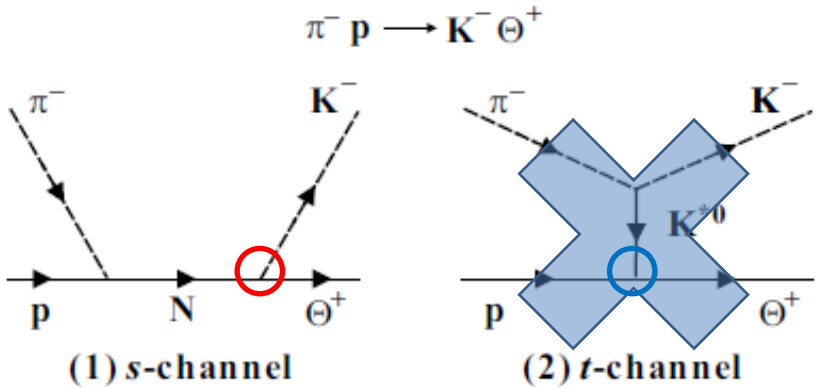




- 7.8 × 10^{10} π^- beam
- (E522 total beam × 10 times)
- **No prominent peak structure**
- Upper limit: **< 0.26 μb/sr** @ 1.51–1.55 GeV/c^2

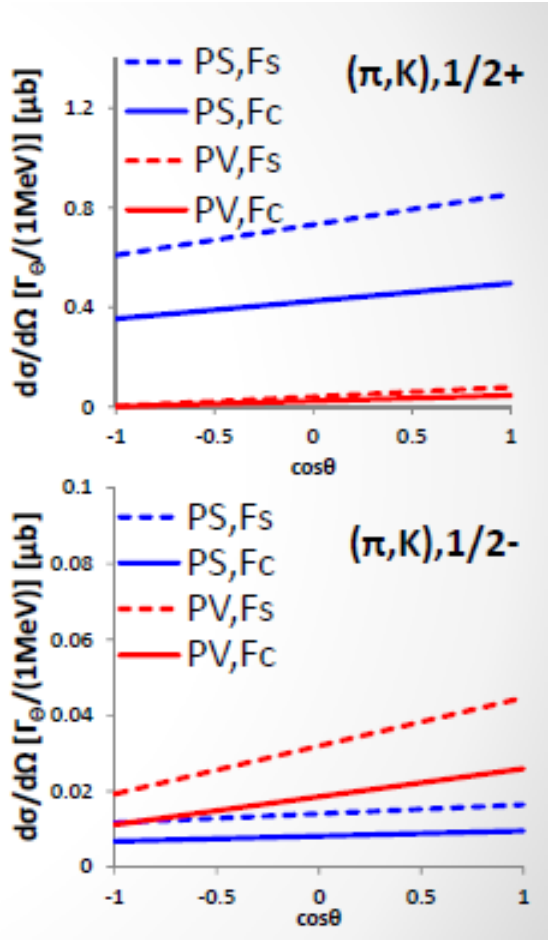
1st run result of E19

- **Decay width of Θ+**



$g_{K^*N\Theta} \sim 0$ by KEK-E559.
Miwa *et al.*, PRC77, 045203.

Calculated differential cross sections, assuming Γ_Θ = 1MeV.



Hyodo et al., arxiv.1203.0598[nucl-th]

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

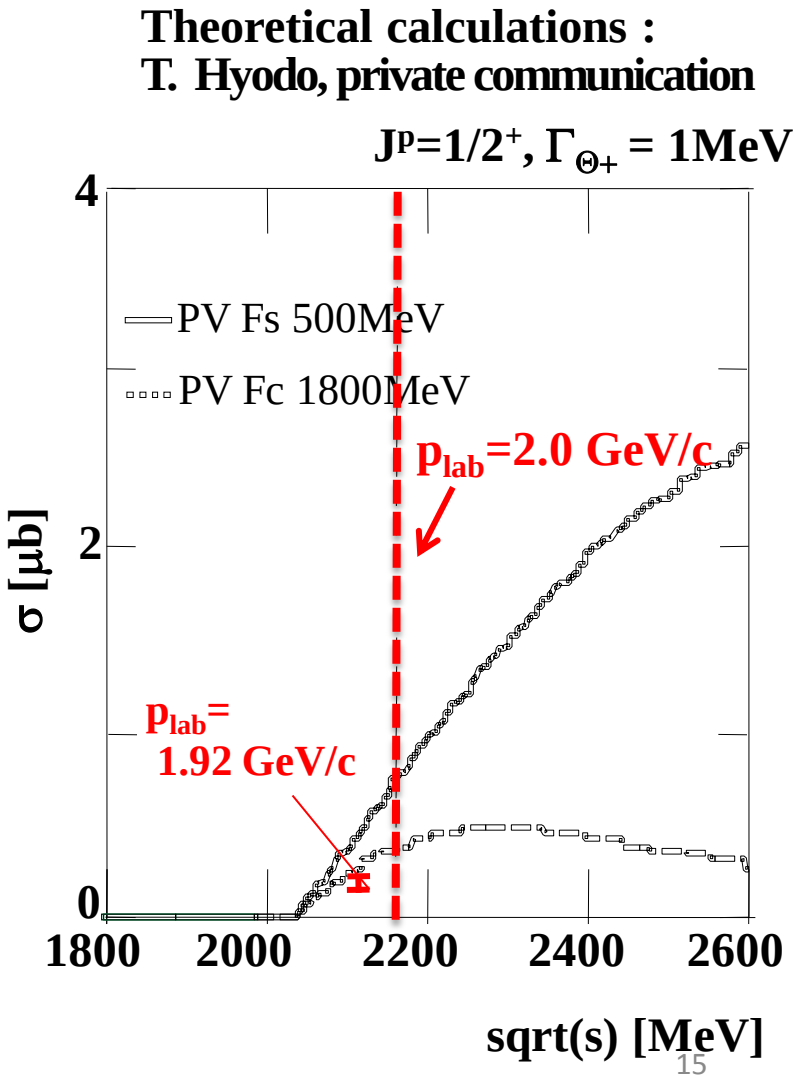
➔Upper limit of decay width

- 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.)
- Expect increasing cross section
  ➔ higher sensitivity

➔ Stringent restriction
on the Θ^+ production
via these hadronic reactions.

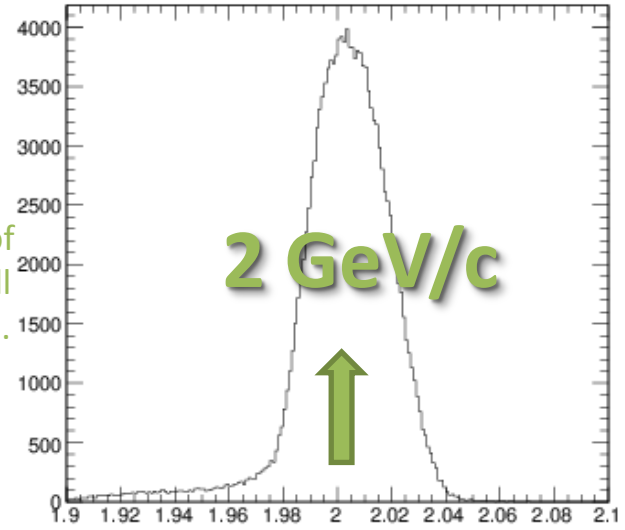


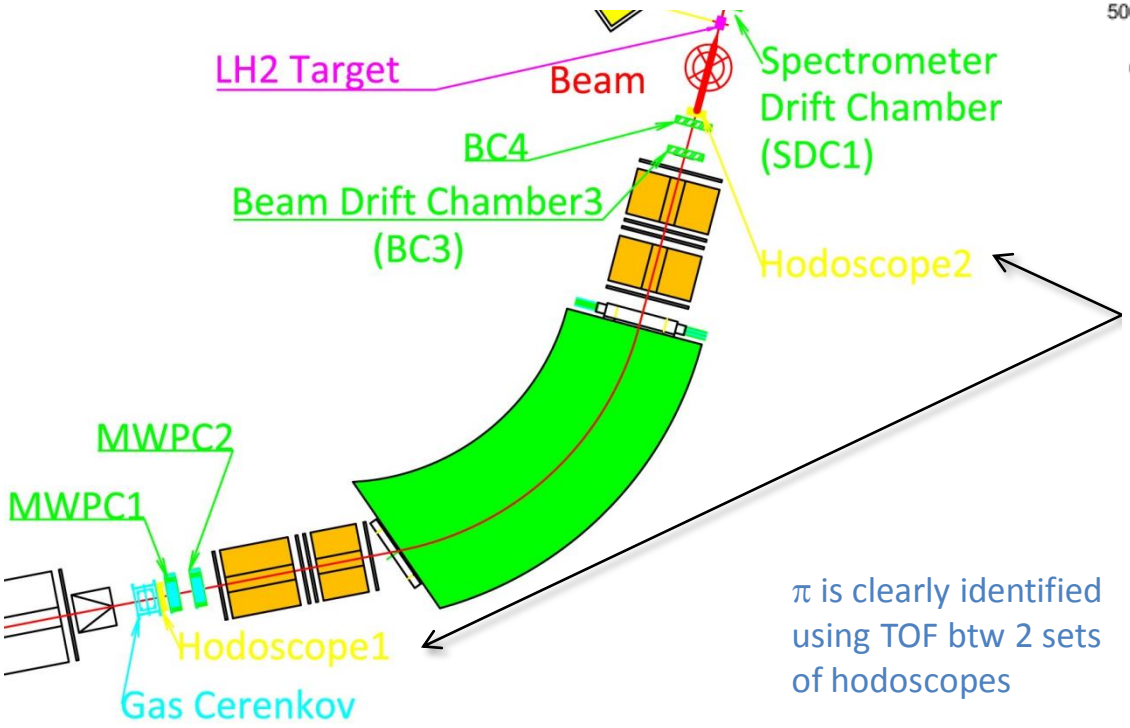
K1.8 Beam spectrometer

Beam Momentum

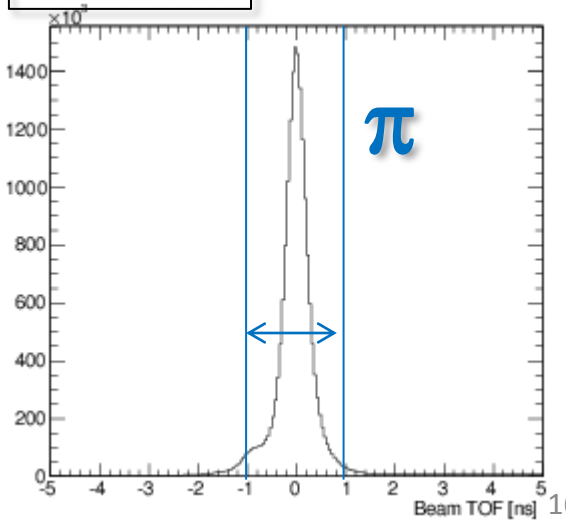
- **K1.8 beam line spectrometer : p_π**
  - PID counters
    - Timing counters : TOF
    - Gas Cherenkov (π/e) : n=1.002
  - Tracking
    - MWPCs : 1 mm pitch
    - MWDCs : 3 mm pitch

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





Beam TOF



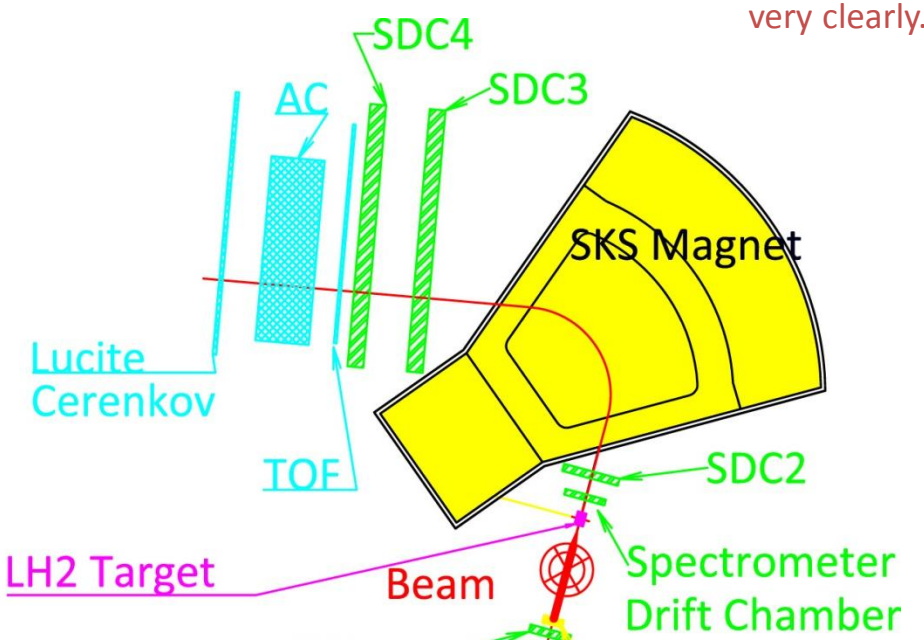
π is clearly identified using TOF btw 2 sets of hodoscopes

SKS spectrometer

- **SKS system : p_K**

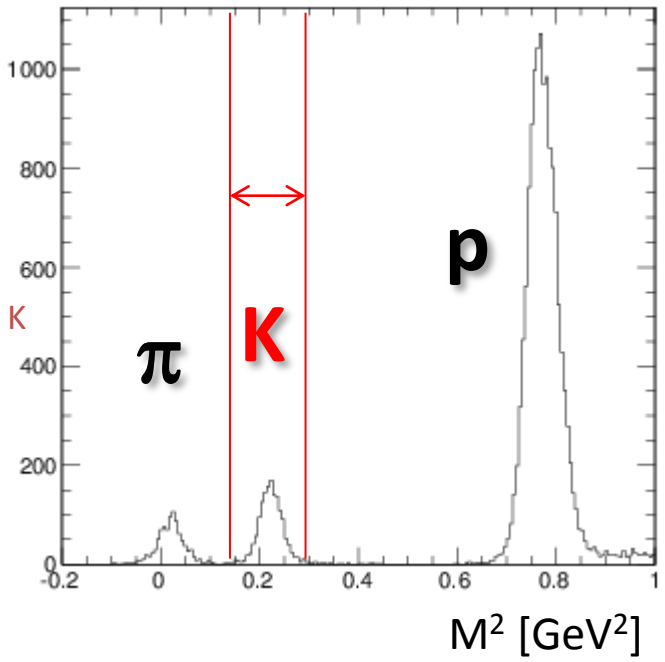
  PID counters
  - Timing counter
  - Aerogel Cherenkov (K/π) : n=1.05
  - Lucite Cherenkov (K/p) : n=1.49

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



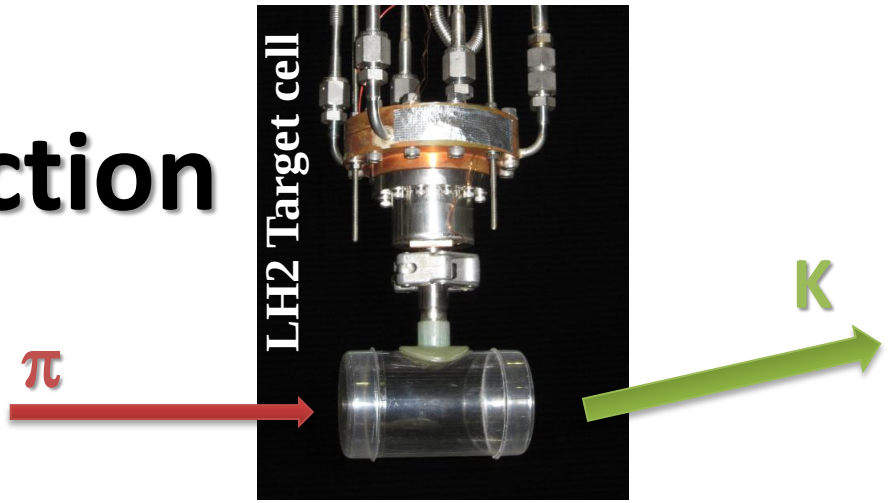
We can separate only K very clearly.

Scattered particle M^2



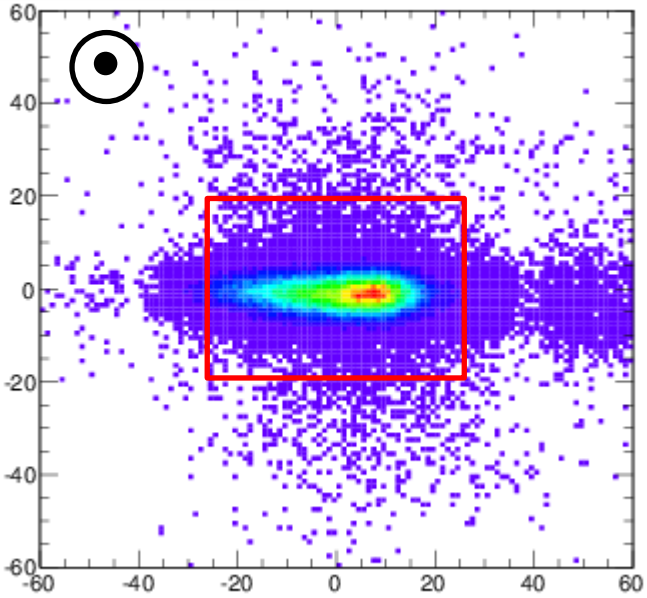
Good momentum reconstruction and PID !!

Vertex Reconstruction



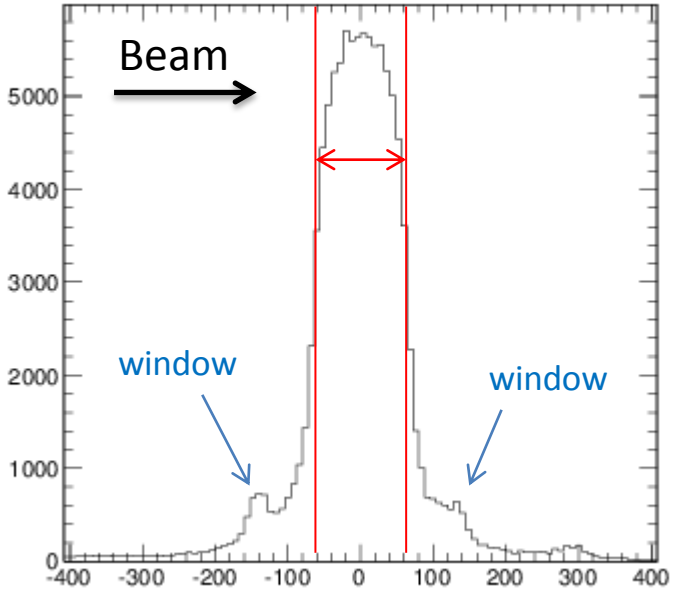
$\phi 67.8 \times 120$ mm

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

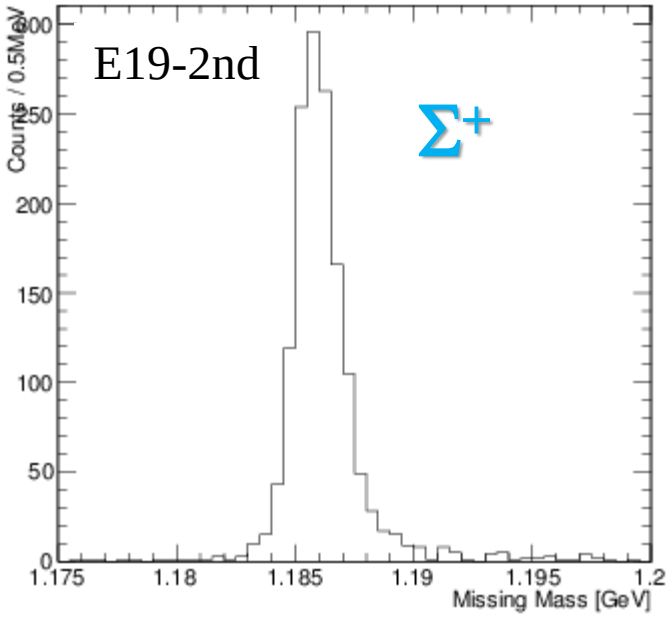
⇒ estimate Θ^+ case:

ΔM_Θ = 1.75 MeV (FWHM)

- Yield estimation (rough):

  Almost Consistent with the 1st run !!

Σ^+ Missing Mass

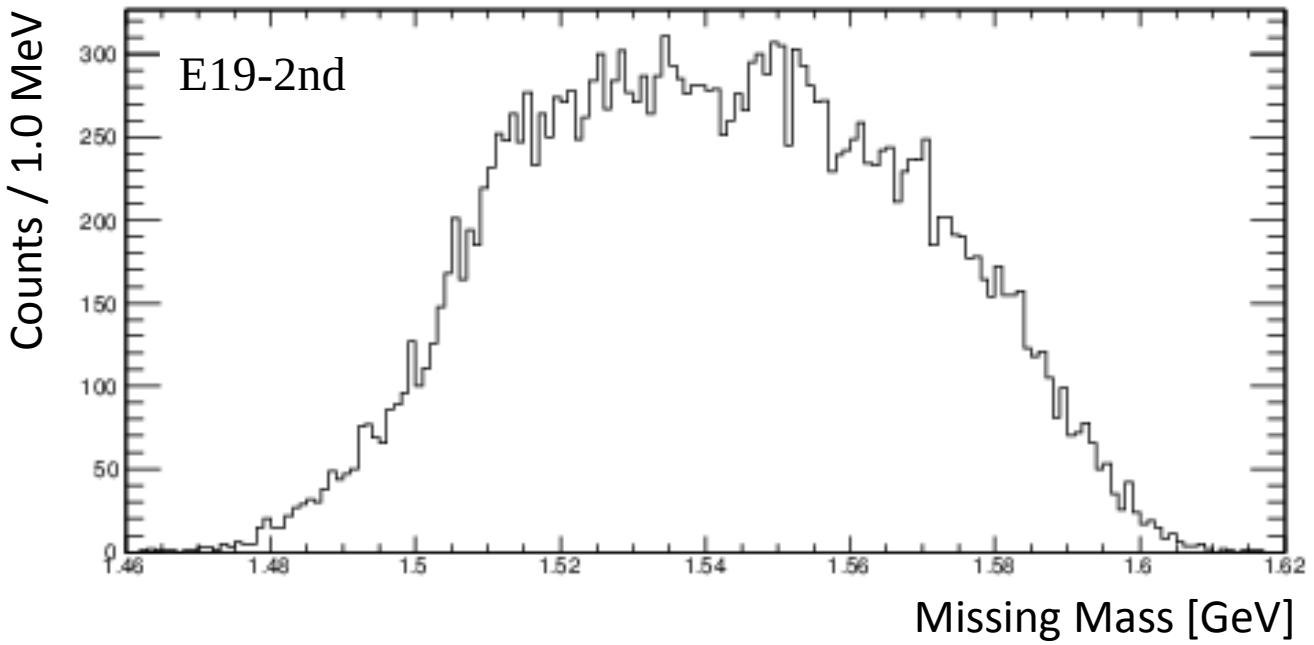


Γ = 2.02±0.06

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.
- Evaluation of efficiency is on-going.
- Tentative expected sensitivity ~ 0.3 μb/sr.

Summary

- J-PARC E19 : High-resolution search via π^- p → K^- Θ^+ reaction
  - The first physics experiment at the J-PARC hadron facility !

- 1st run result was accepted 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 on-going.