Experimental Evidence for the S=+1 Pentaquark

• • • K.Imai (Kyoto)

- Discovery of Penta-quark Θ^+ at SPring-8
- € • • • • Evidences
- Questions to be solved
- Summary

• Discovery of Pentaquark • Q^+

M = **1540±10 MeV**
G **< 25 MeV**
Gaussian significance 4.6s

SPring-8 LEPS

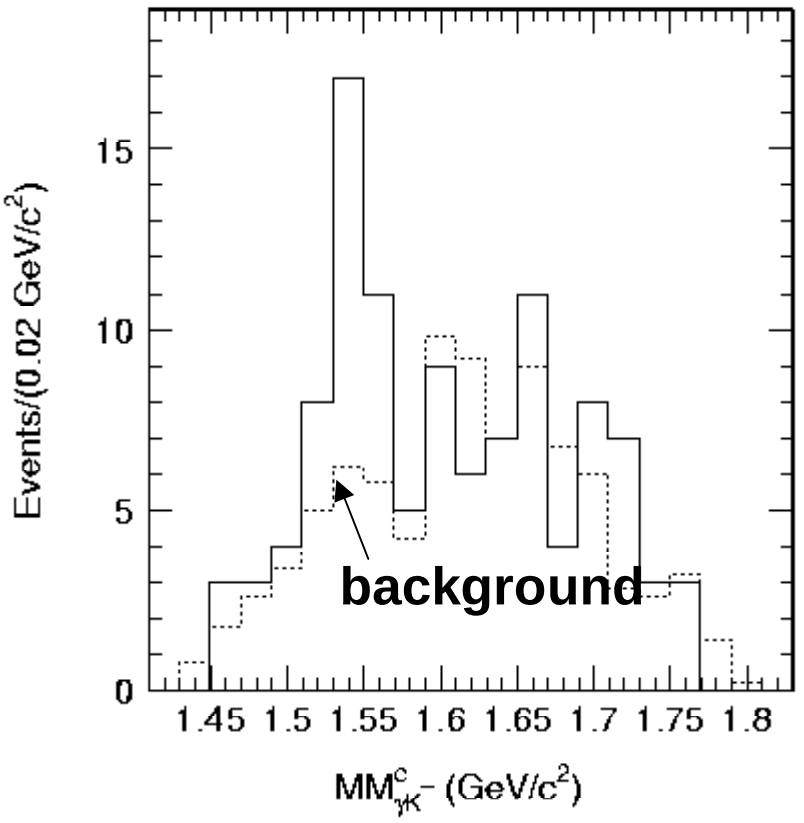
- g **+n -> K^- +K^++n,**
  Q^+ **-> K^+ n**

Q^+**: uudd s-bar**

T. Nakano et al.,

Phys.Rev.Lett. 91 (2003) 012002

hep-ex/0301020



The LEPS collaboration

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Miyazaki University

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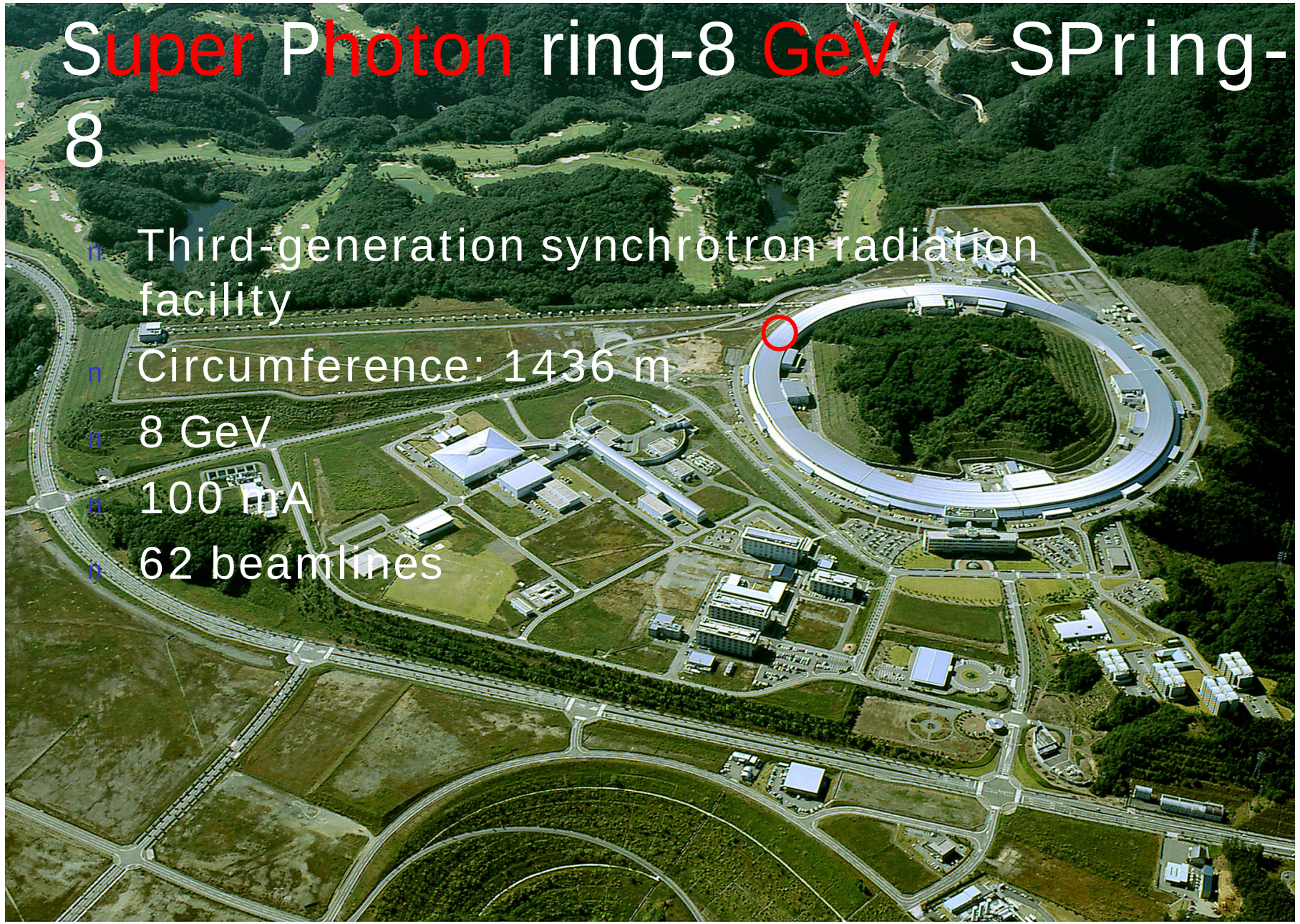
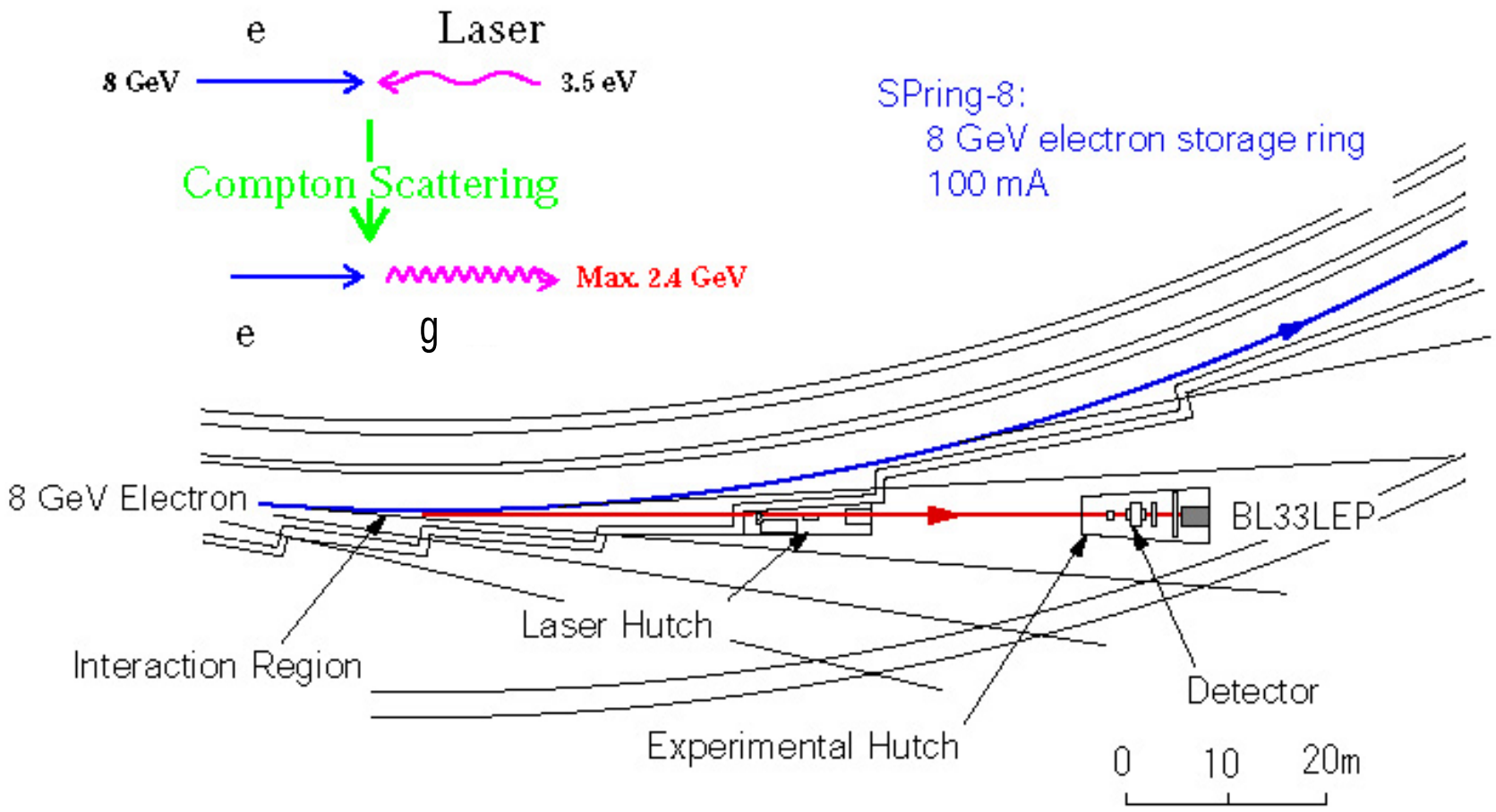
Super Photon ring-8 GeV SPring-8

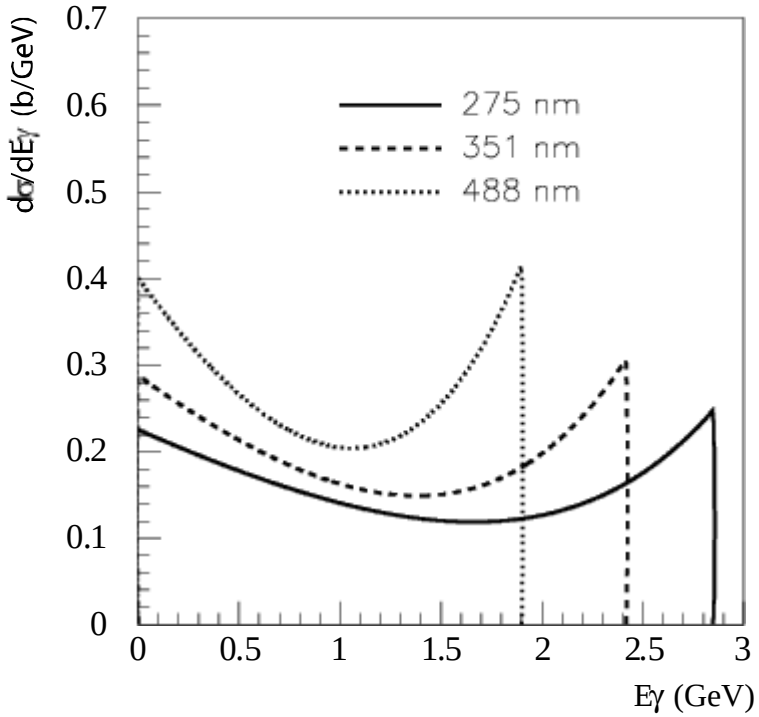


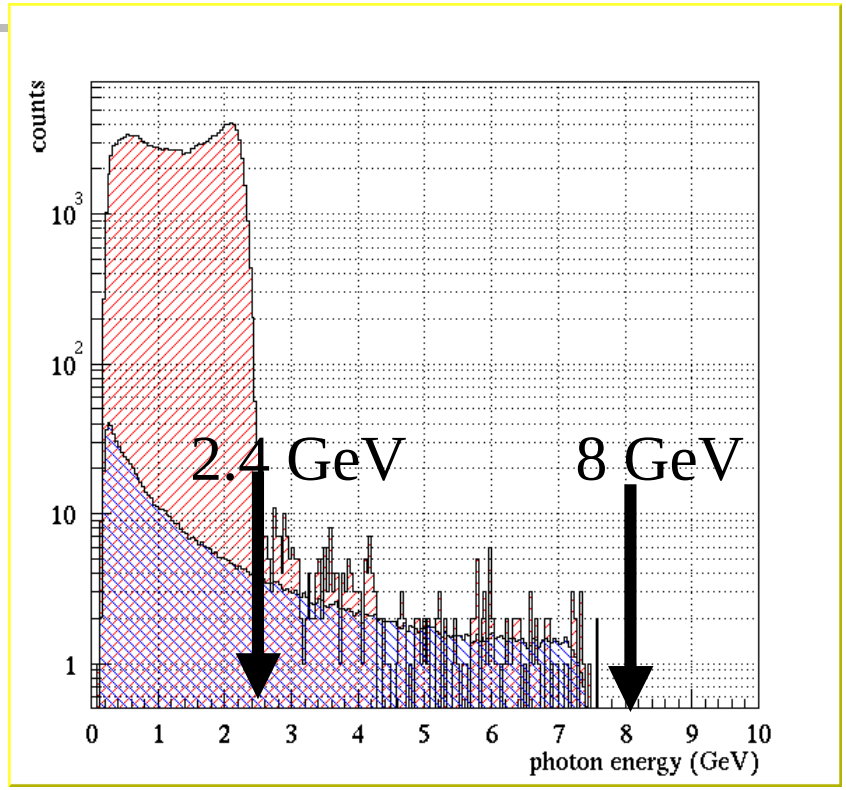
- Third-generation synchrotron radiation facility
- Circumference: 1436 m
- 8 GeV
- 100 mA
- 62 beamlines

Laser Electron Photon at Spring-8 (LEPS)



Energy Spectrum

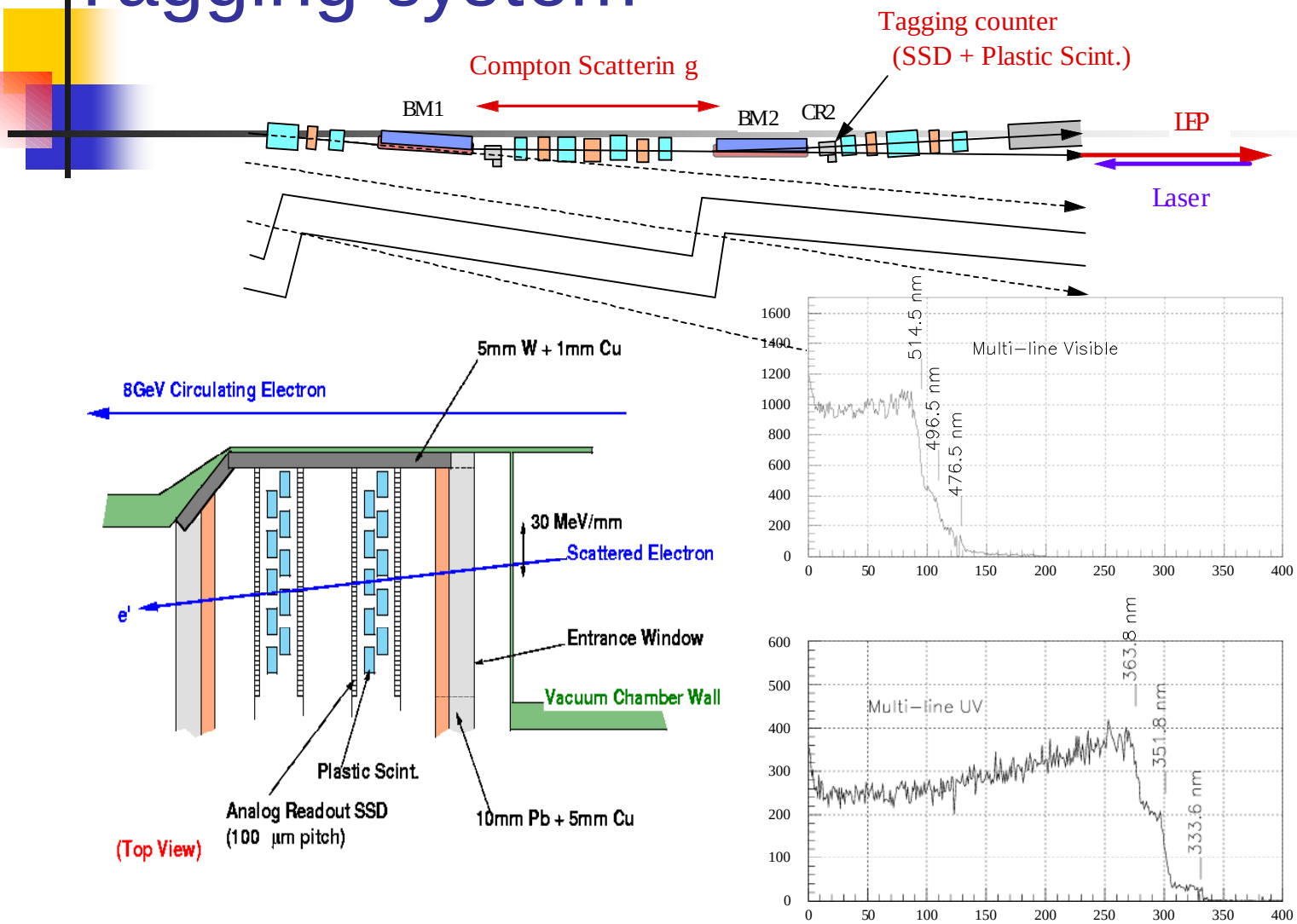




Intensity (Typ.) : 2.5 * 10^6 cps

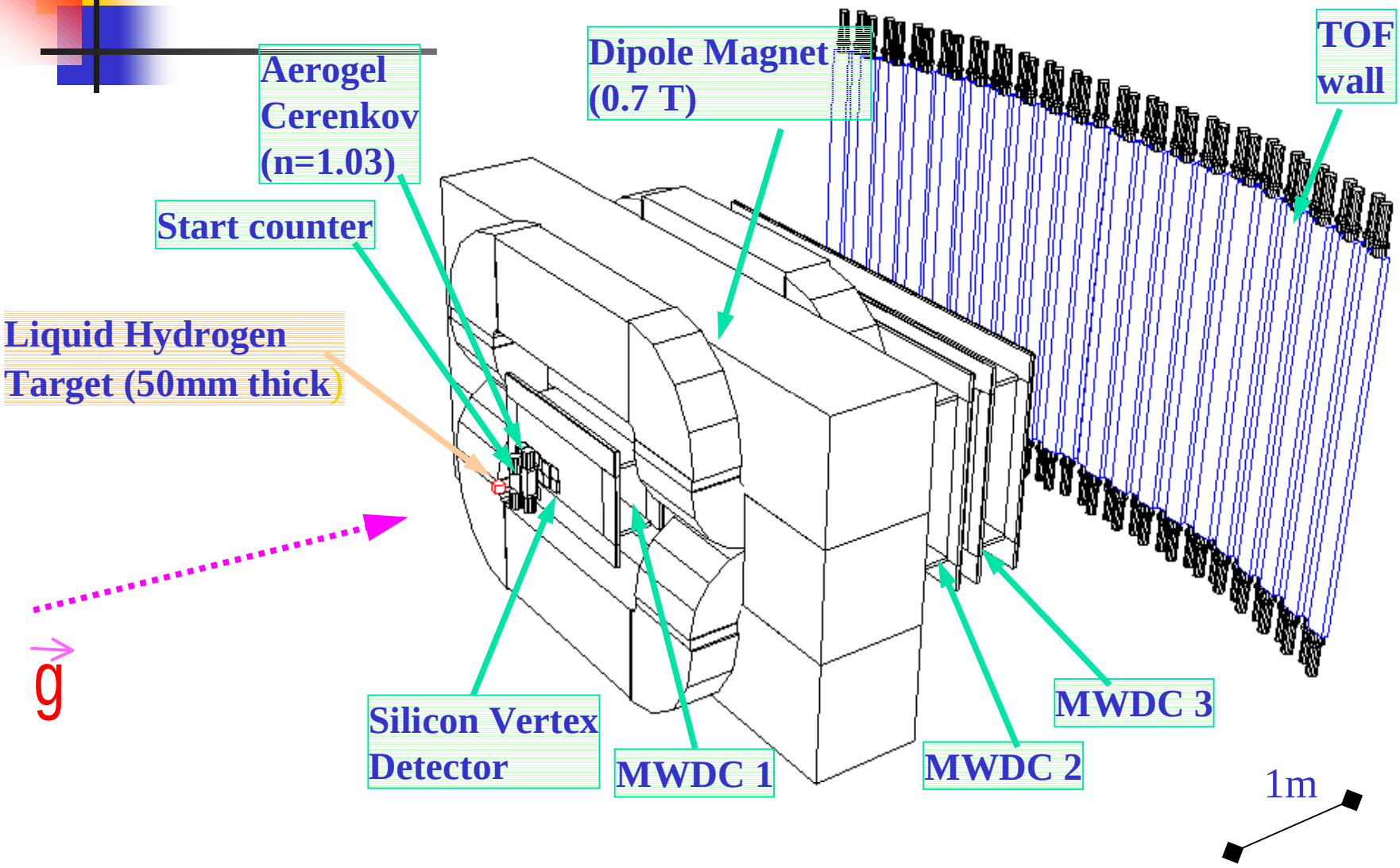
Linear Polarization : 95 % at 2.4 GeV

Tagging system



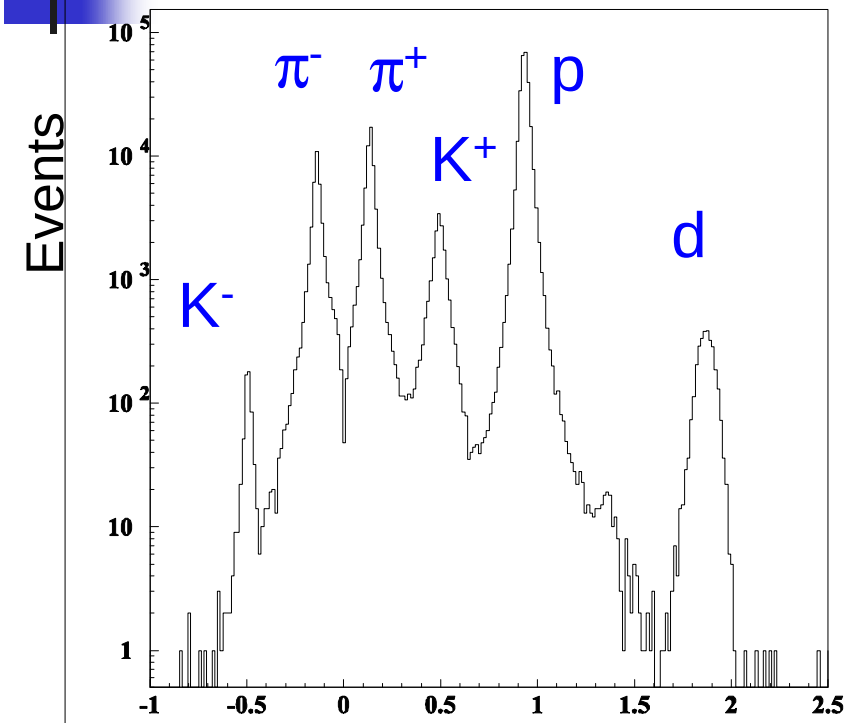
·Tagging Region : 1.5 GeV< E_γ < 2.4 GeV

LEPS • etector

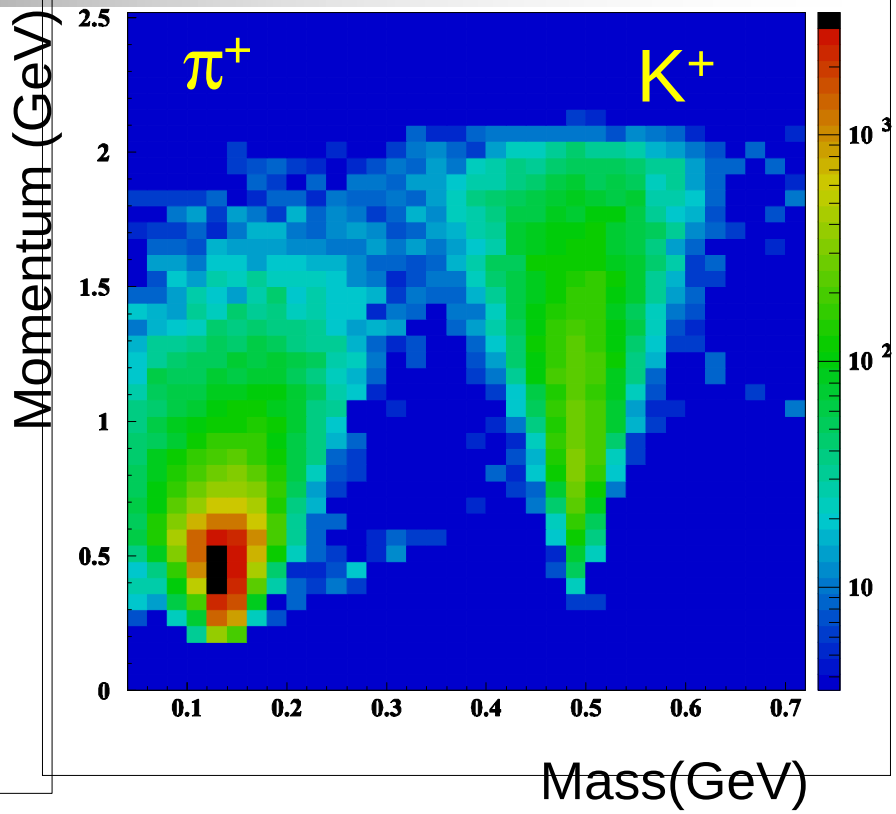


• • • Charged particle identification

Reconstructed mass



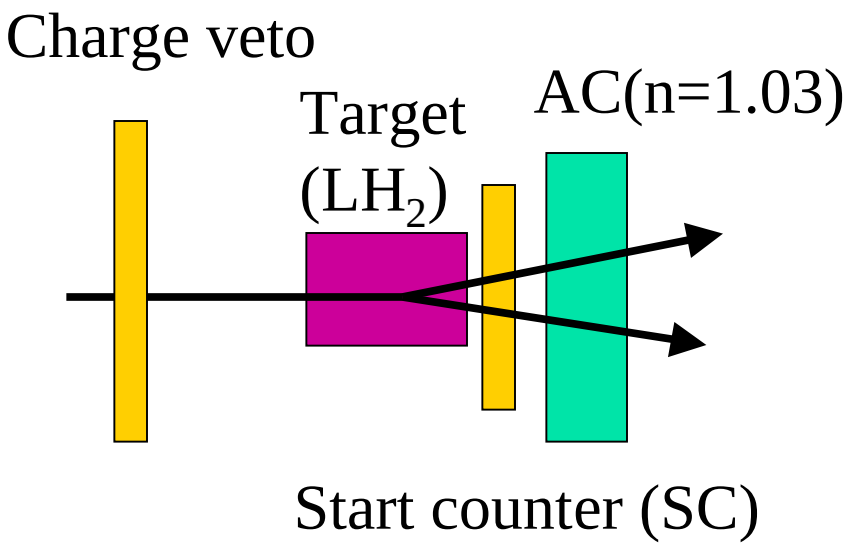
K/π separation (positive charge)



σ(mass) = 30 MeV(typ.) for 1 GeV/c Kaon

Target Region

30 Hz for 800 kHz@tagger



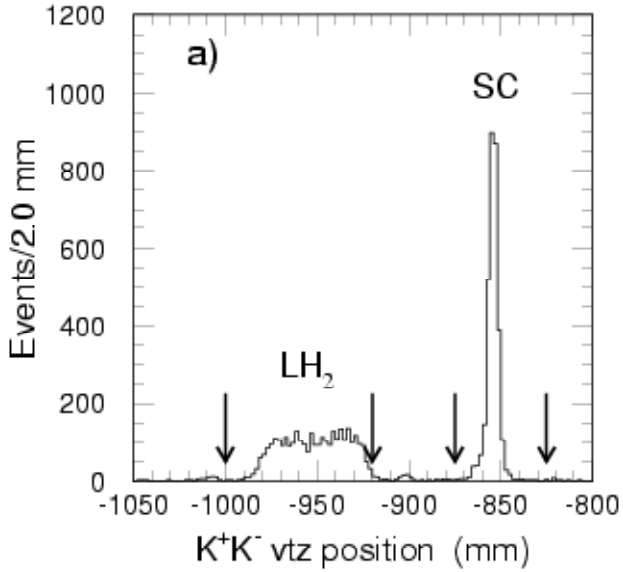
• • Identification of Q^+

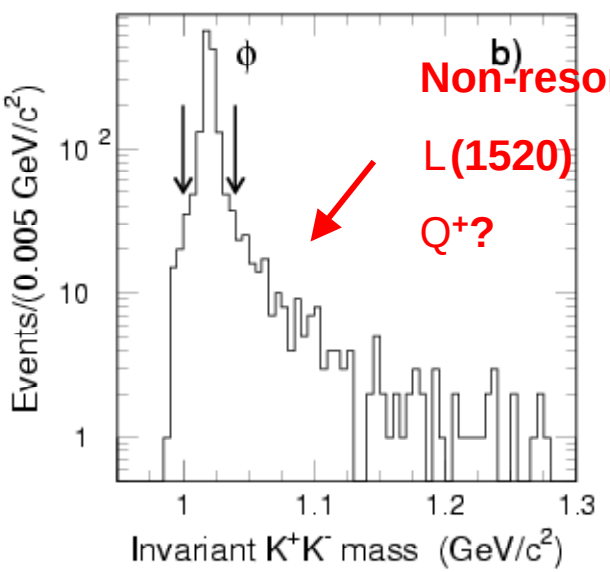
g n € K^- Q^+ € K^- K^+ n

- K^- missing mass gives Q^+ mass
- K^+K^- missing mass gives n

Problems:

- no neutron target
  - CH start counter (n is part of C!)
- "background"
  - f ® K^+K^- (produced from n & p)





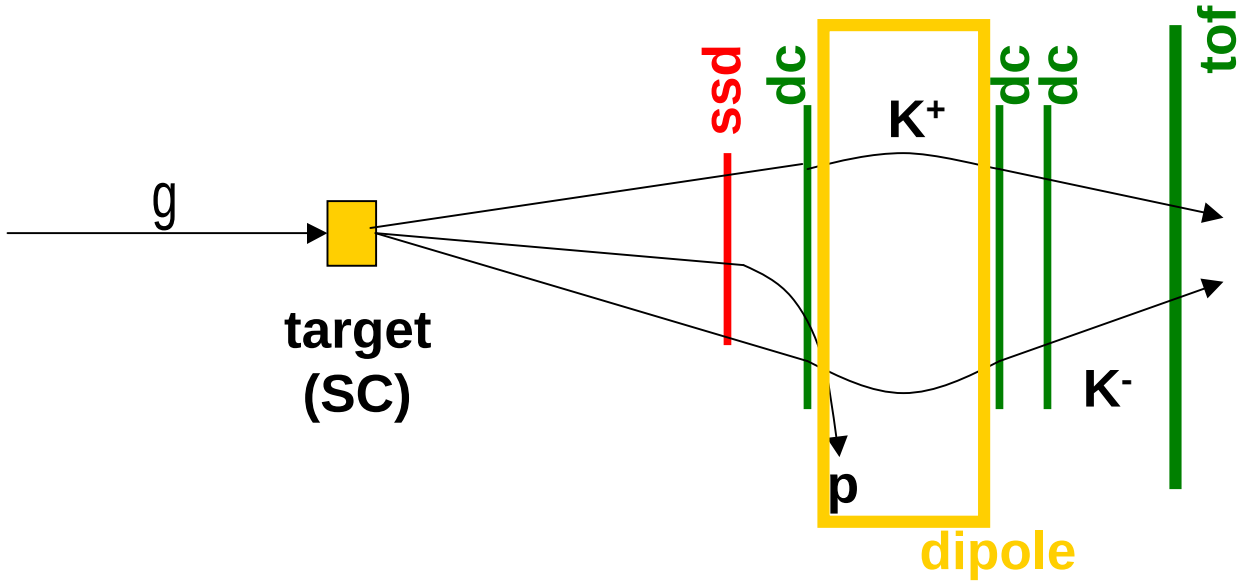
Non-resonant KK

L(1520)

Q^+?

Proton-recoil cut

- $\gamma n \rightarrow K^+K^-n$ no recoil proton • (proton is a spectator)
- $\gamma p \rightarrow K^+K^-p$ slow recoil proton is present
- **proton is too slow to be seen in full detector, but might be seen in SSD vertex detector.**



Remove all events for which proton is detected in SSD

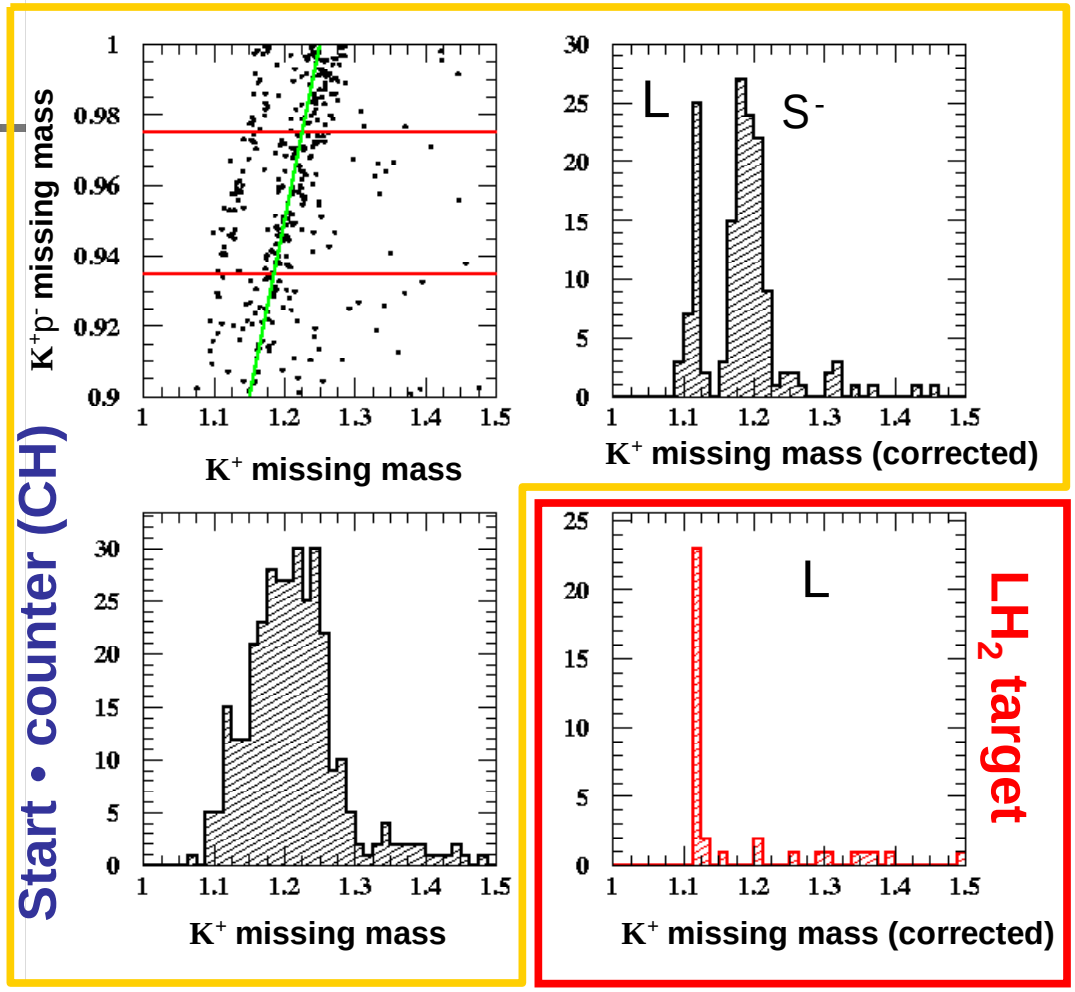
Fermi motion correction € (T.Nakano)

Test-case:

$\gamma n \bullet K^+ \Sigma^- \bullet K^+ \pi^- n$

$\gamma p \bullet K^+ \Lambda \bullet K^+ \pi^- p$

Correction works better when Q-value is small.



Correction: MM_{gK+} (corrected) = MM_{gK+} - MM_{gK+p-} + M_n

Q^+ identification

M = **1540±10 MeV**

G **< 25 MeV**

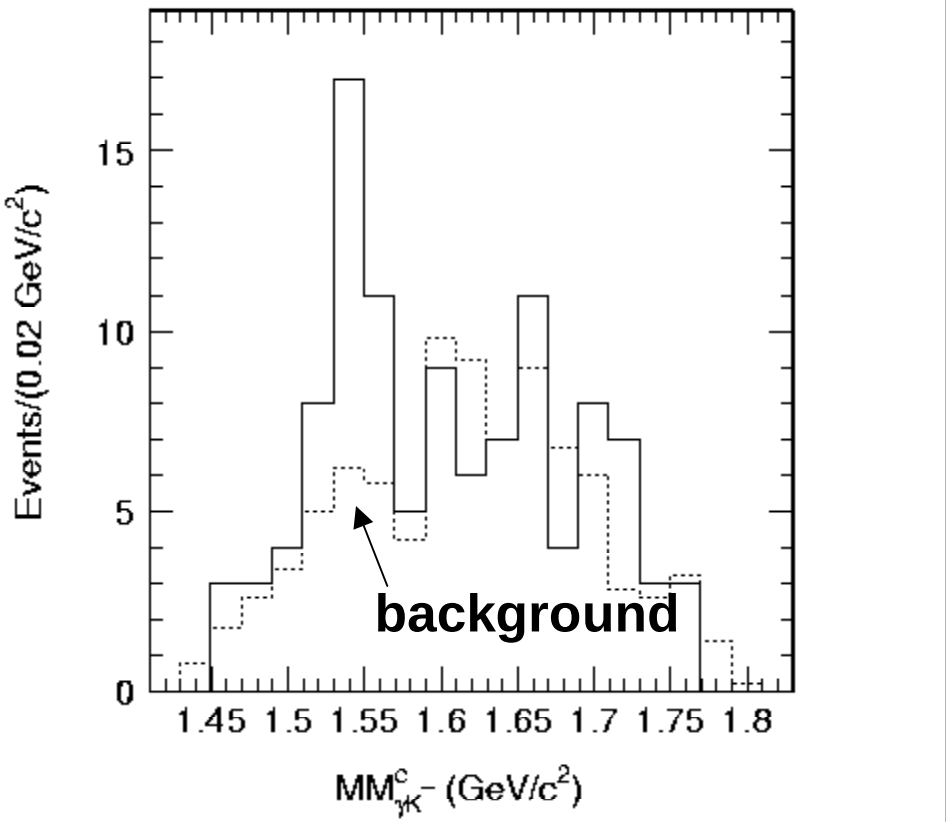
Gaussian significance 4.6s

- g • **n) -> K- K+ n**

- **Background is from non-resonant K^+K^- production off the neutron(nuclei) similar to non-resonant production off the proton.**

- • • **shape was estimated from events from LH_2 using the same cuts except for:**
  - **Proton-recoil cut is removed**
  - L**(1520) events are removed (only from p)**

g+**d ->K-K+n+p under analysis**



€ € $\Theta^+(Z^+)$ prediction of anti-decuplet

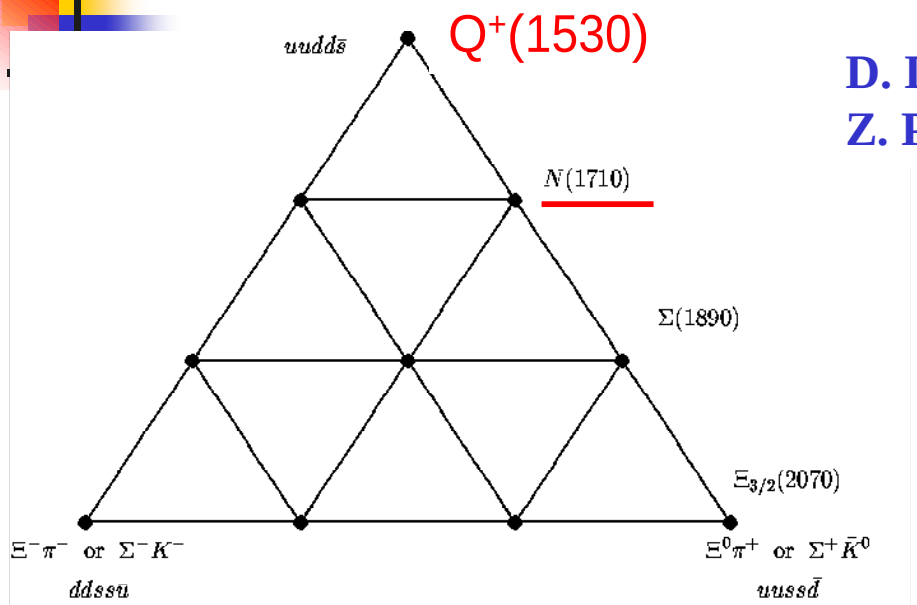


Figure 1: The suggested anti-decuplet of baryons. The corners of this (T_3, Y) diagram are exotic. We show their quark content together with their (octet baryon+octet meson) content, as well as the predicted masses.

D. Diakonov, V. Petrov, and M. Polyakov, Z. Phys. A 359 (1997) 305.

- Exotic: S = +1
- Low mass: 1530 MeV
- Narrow width: < 15 MeV
- $J^p = 1/2^+$

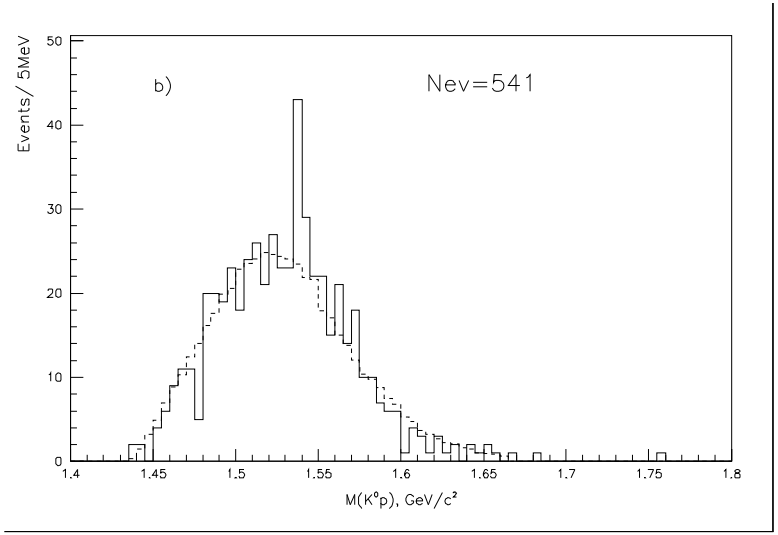
***M* = [1890-180*Y] MeV**

Confirmation from US and Russia

DIANA/ITEP

$K^+ Xe \in K^0 p X$

$(K^+ n \in K^0 p)$



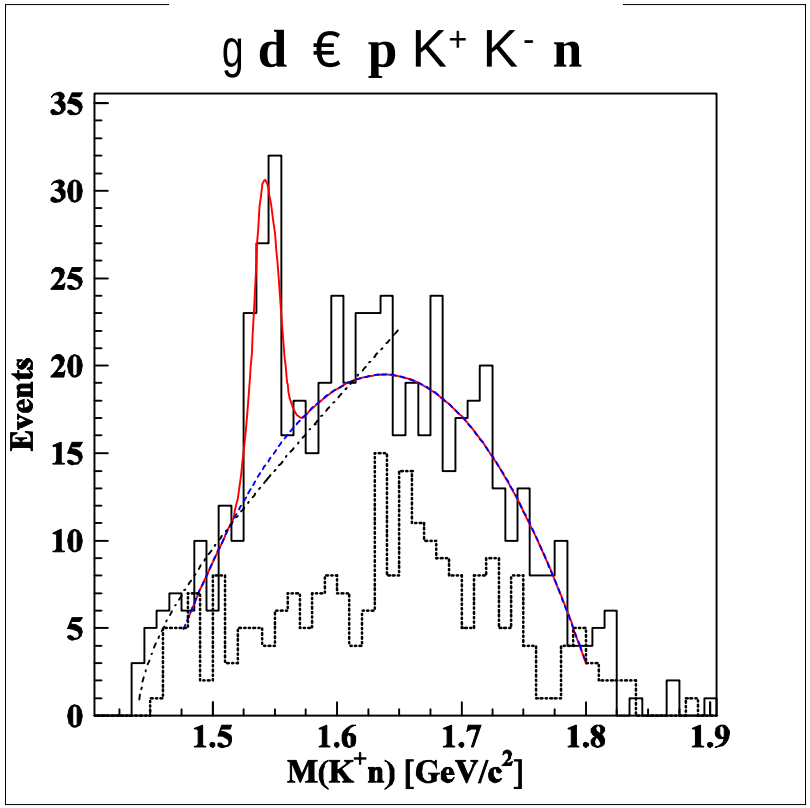
M = 1539±2 **MeV**

G < 9 **MeV**

hep-ex/0304040

CLAS/JLAB

$g d \in p K^+ K^- n$

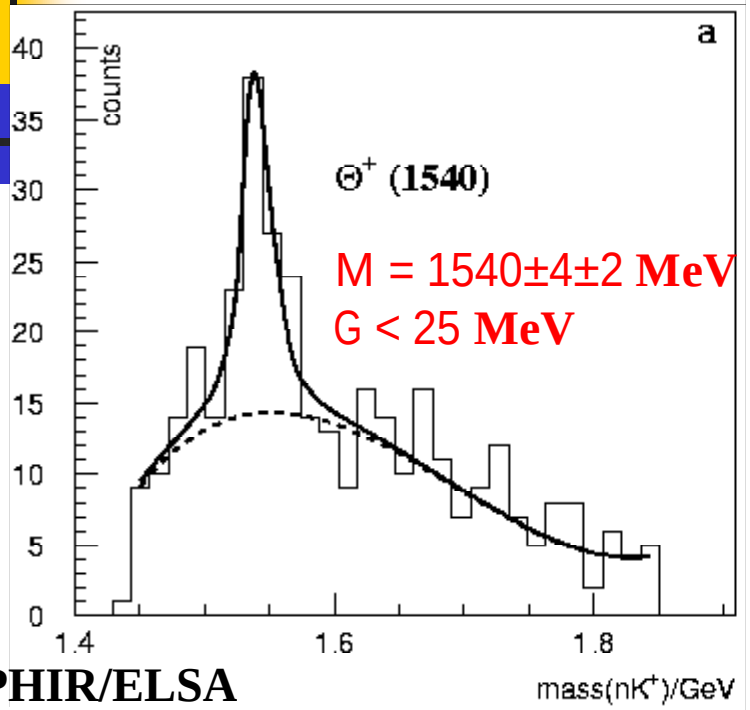


M = 1542±5 **MeV**

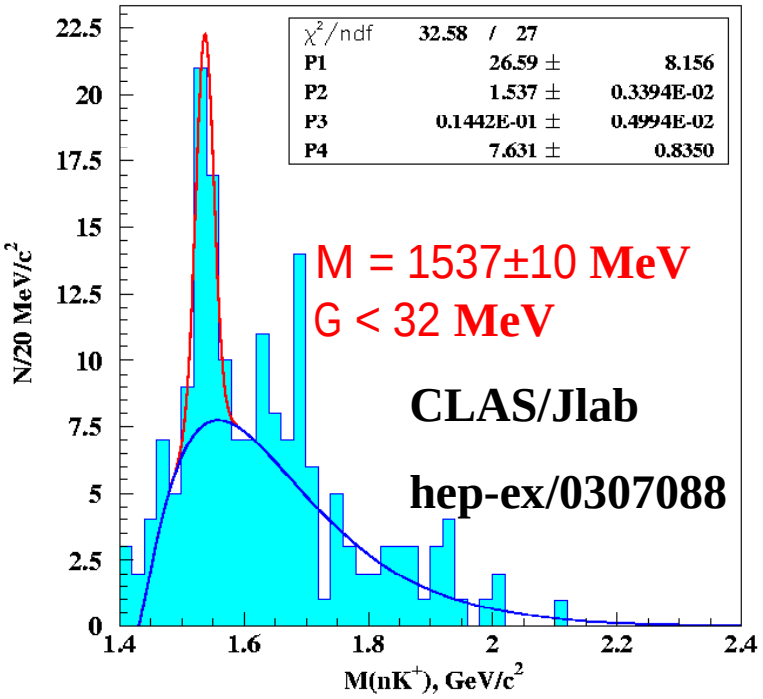
G < 21 **MeV**

hep-ex/0307018

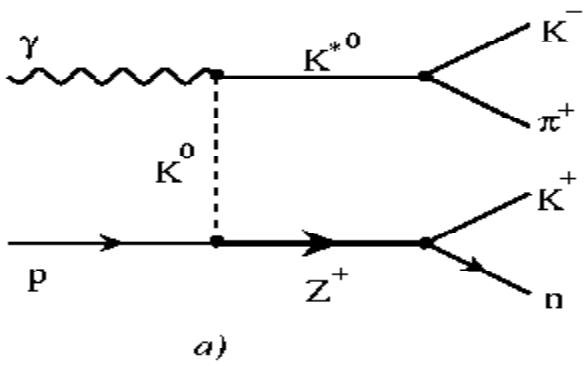
Further confirmation with proton target

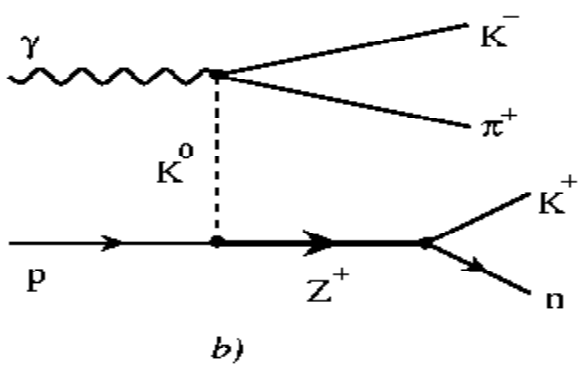


SAPHIR/ELSA



hep-ex/0307083





Neutrino scattering

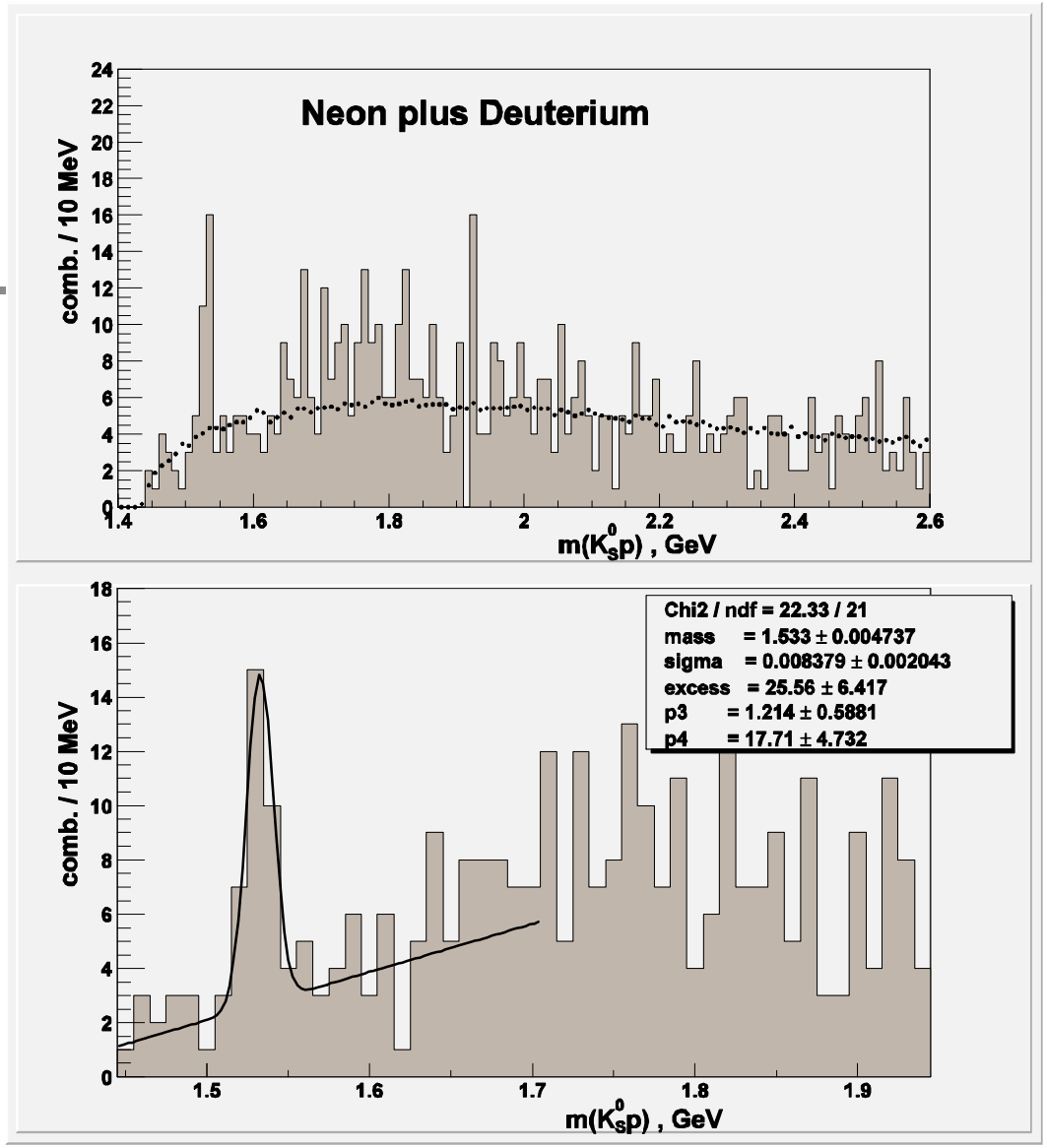
Reanalysis of bubble chamber experiments from WA21, WA25, WA59, E180, E632

A.Asratyan,A.Dolgolenko, M.Kubantsev

hep-ex/0309042

M = 1533± 5 **MeV**

G < 20 **MeV**



$M(K_s p)$ spectrum

E522 (KEK-PS)

- Search for H-dibaryon resonance via $^{12}C(K^-,K^+\Lambda\Lambda)$ and study of ΞN interactions

data taking 2002. 10-12

by-product ?

Q^+ search by $p(p-,K-)\,Q^+$ at $p(p-)=1.9$ GeV/c
(under analysis)

No peak was observed in old BC data (poor statistics)

First Manifestly Exotic Hadron in 40 Years

- The discovery of the $\Theta^+(1540)$ this year marks the beginning of a new and rich spectroscopy in QCD….

R.Jaffe

Renaissance of Hadron Spectroscopy !

(Birth of Exotic Hadron Spectroscopy)

Questions about Q^+

Spin-parity: $J^p = 1/2^+$ or $1/2^-$ or 3/2

-> selection of models

s-wave or p-wave ?

K+n -> K+n phase shift analysis (pol. d target)

pol.γ N -> K- Θ+ decay distribution of Θ+

(and spin of n or p)

angular dependence

-> Spring-8 TPC project

Questions: width

- upper limit from direct measurement: 9 (20) MeV
-
  - S.Nussunov (hep-ph/0307357) based on K^+d scattering data $\Gamma(\Theta+)<6$MeV
  - Arndt,Strakovski & Workman (nucl-th/0308012) based on existing K+N elastic scattering data $\Gamma(\Theta+)$ as small as 1 MeV

parallel 5 R.Workman

Invariant mass spectroscopy: K^O+p -> few MeV?

$K+p \rightarrow \pi+\Theta+$ KEK-SKS spectrometer € ($\Delta E \sim 1.5$ MeV)

Questions: Structure (size)

5 compact quarks or KN molecule?

KN potential range of 0.05 fm to reproduce
10 MeV width (Jaffe and Wilczek)

A-dependence of photo-production of Θ+
-> size of Θ+

To establish anti-decuplet

- Ξ^{--}

  n K^- -> K^+ Ξ^{--} , p K^- -> K^+ π^+ Ξ^{--}

- Ξ^+

  p K^- -> K^0 π^- Ξ^+

	S=-2	S=0
Diakonov	2070	1710 MeV
Jaffe, Wilczek	1750	1440 MeV

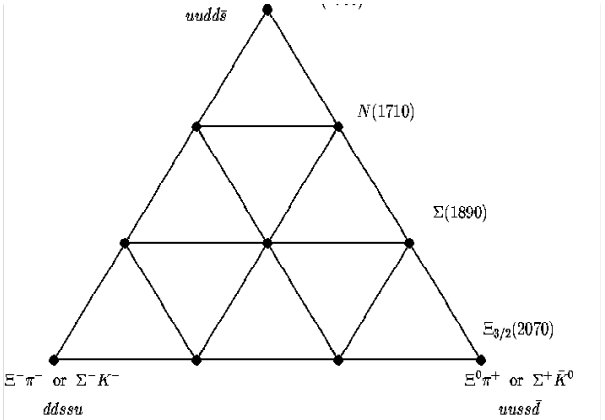


Figure 1: The suggested anti decuplet of baryons. The corners of this (T_3, Y) diagram are exotic. We show their quark content together with their (octet baryon+octet meson) content, as well as the predicted masses.

21

- If M(Ξ^{--}) ~ 1750 MeV (Jaffe & Wilczek, hep-ph/0307341)
  >2GeV/c K- beam (BNL or KEK or (J-PARC)) !

Parallel 5 J.Price

S=-2 Penta-quark Ξ^{--}

M=1862 MeV Γ<18 MeV

NA49 collaboration

hep-ex/0310014

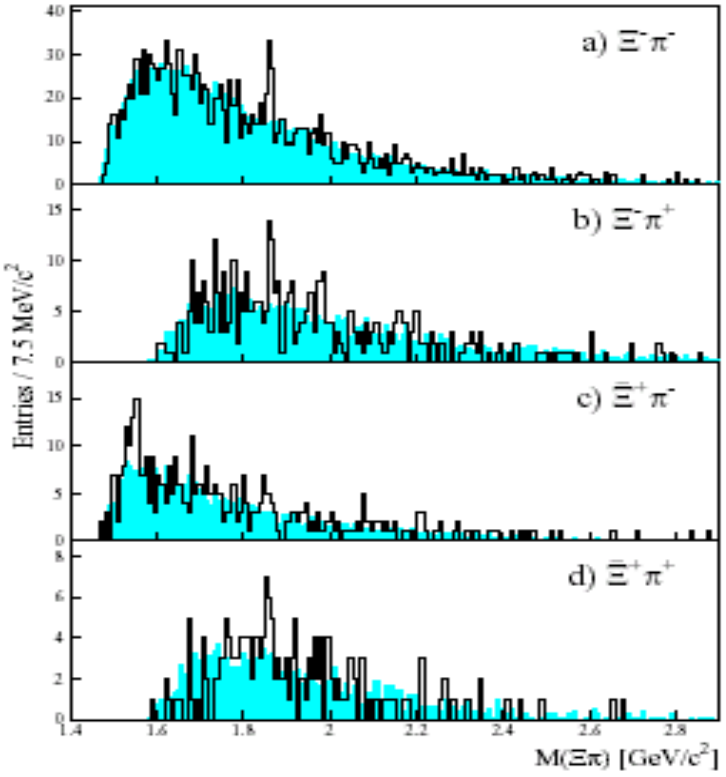


FIG. 2: (Color online) Invariant mass spectra after selection cuts for $\Xi^-\pi^-$ (a), $\Xi^-\pi^+$ (b), $\bar{\Xi}^+\pi^-$ (note that the $\bar{\Xi}(1530)^0$ state is also visible) (c), and $\bar{\Xi}^+\pi^+$ (d). The shaded histograms are the normalised mixed-event backgrounds.

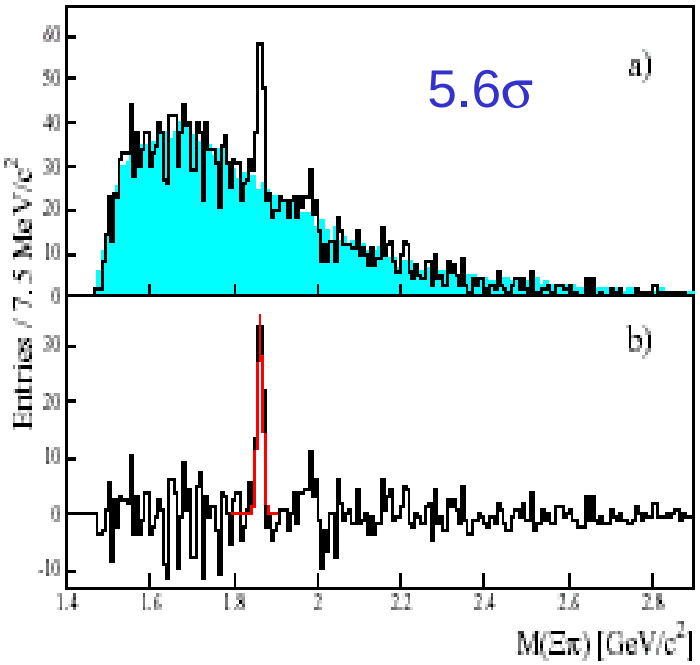


FIG. 3: (Color online) (a) The sum of the $\Xi^-\pi^-$, $\Xi^-\pi^+$, $\bar{\Xi}^+\pi^-$ and $\bar{\Xi}^+\pi^+$ invariant mass spectra. The shaded histogram shows the normalised mixed-event background. (b) Background subtracted spectrum with the Gaussian fit to the peak.

Recent theoretical works

- Exotic baryon states in topological soliton models
  Walliser, H ; Kopeliovich, V B, hep-ph/0304058

- Interpretation of the Theta+ as an isotensor resonance with weakly decaying partners
  Capstick, Page, Roberts, hep-ph/0307019

- Stable uudds-bar pentaquarks in the constituent quark model
  Stancu, Fl ; Riska, D O, hep-ph/0307010

- The Constituent Quark Model Revisited - Quark Masses, New Predictions for Hadron Masses and KN Pentaquark
  Karliner, Marek; Lipkin, Harry J, hep-ph/0307243

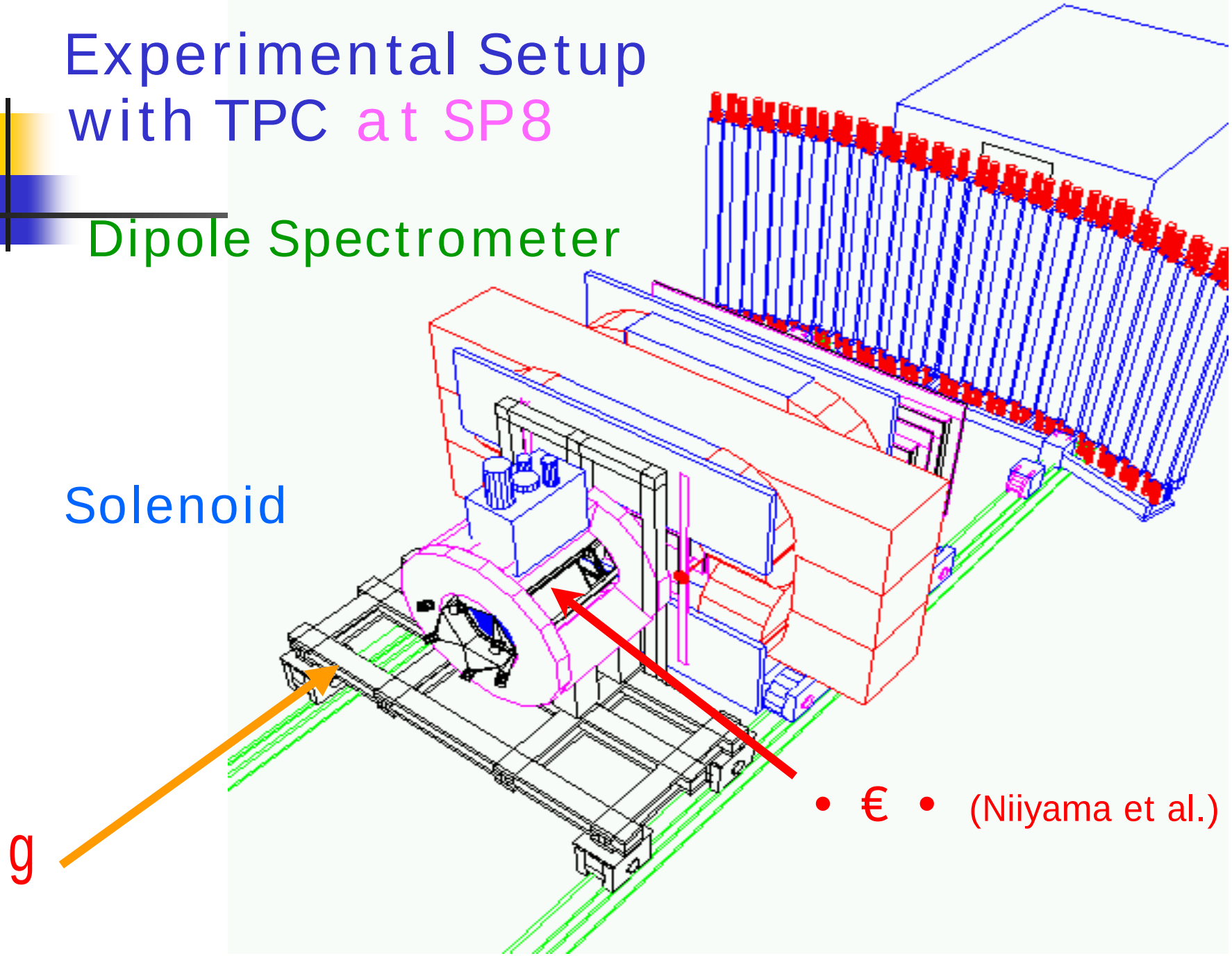
Recent theoretical works

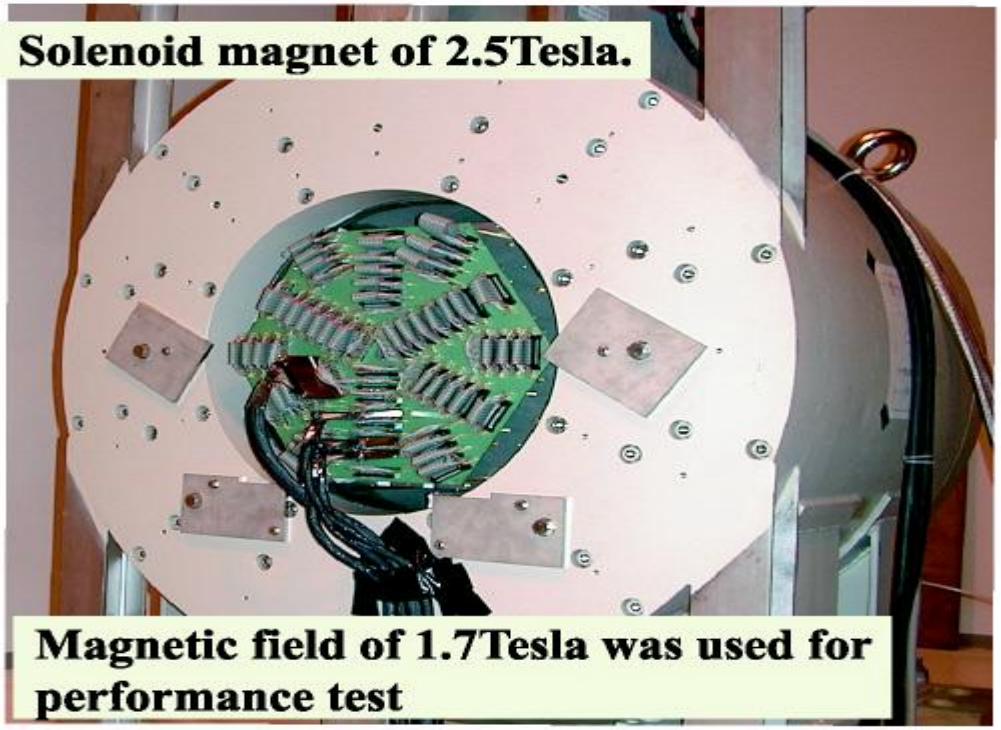
- Pentaquark states in a chiral potential
  Hosaka, Atsushi hep-ph/0307232
- Group theory and the Pentaquark
  Wybourne, B G, hep-ph/0307170
- Diquarks and Exotic Spectroscopy
  Jaffe, R L ; Wilczek, F, hep-ph/0307341
- Understanding Pentaquark States in QCD
  Zhu, Shi-Lin, hep-ph/0307345

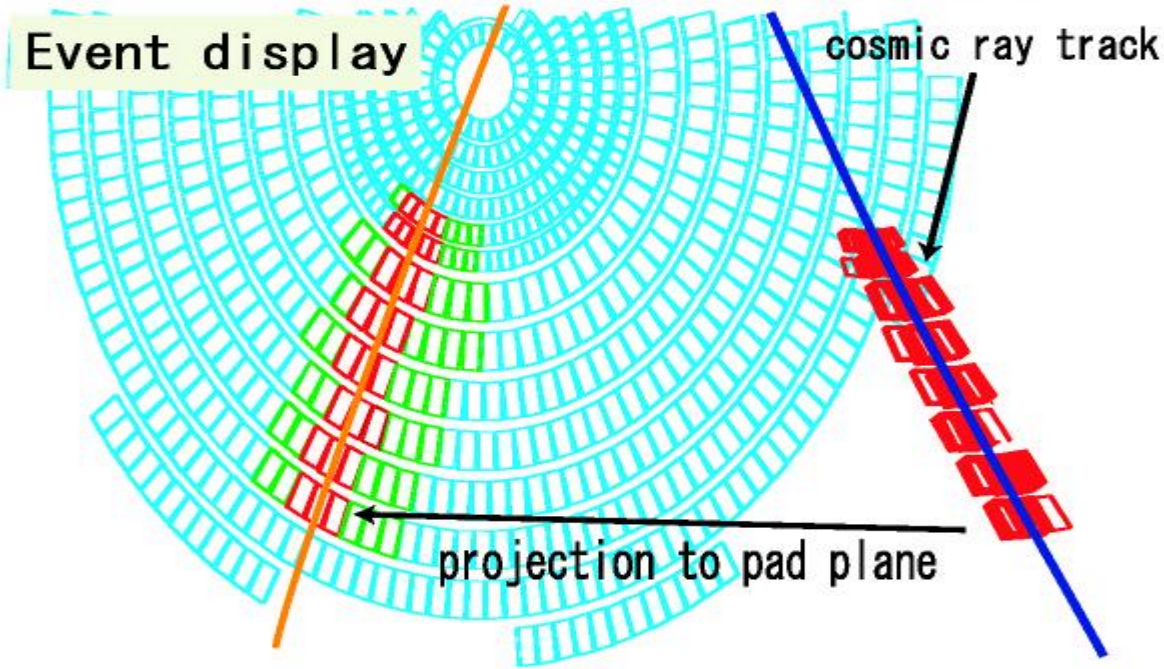
Experimental Setup with TPC at SP8

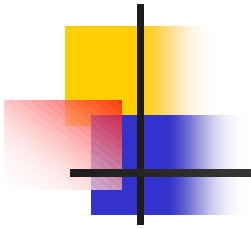
Dipole Spectrometer

Solenoid




Solenoid magnet of 2.5Tesla.
Magnetic field of 1.7Tesla was used for performance test


Event display
cosmic ray track
projection to pad plane



$\Lambda(1405)$

- 3-quark or KN bound state ?

  old question but current topics

  (K-nuclei, Pentaquark)

- Photo-production from H and A-target (SP8)

  $\Lambda(1405) \rightarrow \Sigma\pi$, $\Sigma \rightarrow \pi N$

  measurement of Σ with ~cm flight length

  -> Time Projection Chamber (TPC)

Summary

Penta-quark (Q^+) discovered at SPring-8 has been confirmed by several experiments.

M~1540, Γ<9 (20)MeV

- Further studies of Q^+ are needed.

Spin-Parity and width

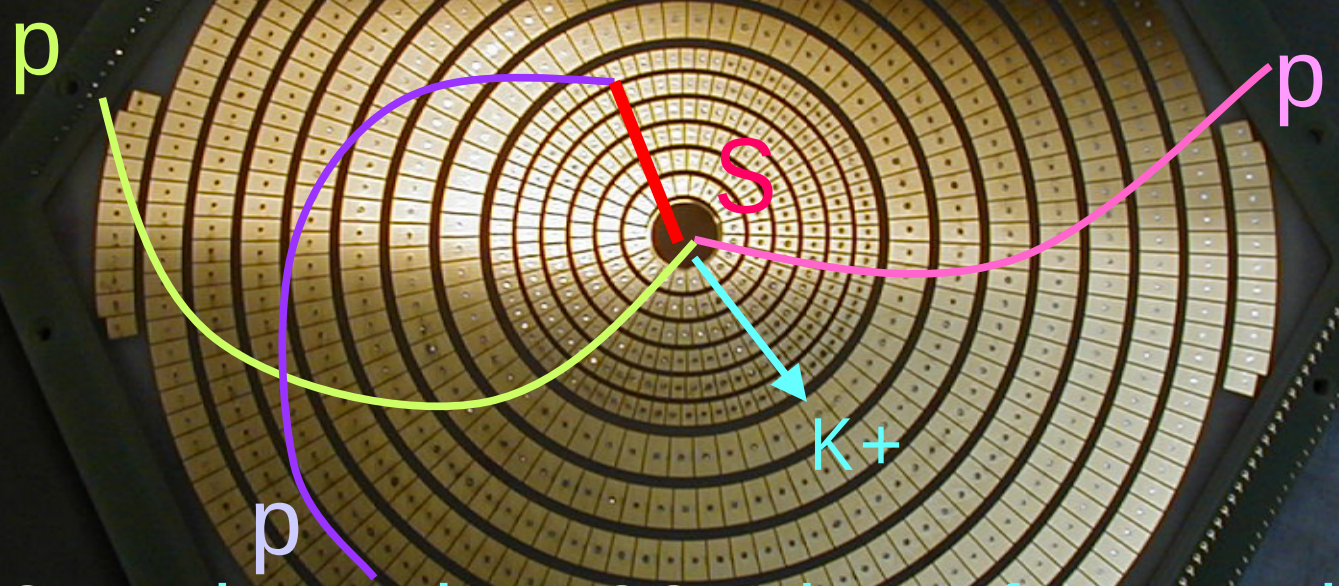
SP-8 TPC, KEK-SKS,,,,,,,?

To establish anti-decuplet, Ξ--, Ξ+ ,,, should be searched for (KEK, BNL, Jlab or J-PARC?)

confirm NA49 result (1862 MeV Ξ--) !

- Beginning of exotic hadron spectroscopy and new QCD physics. -> J-PARC, GSI, JLab(upgrade)

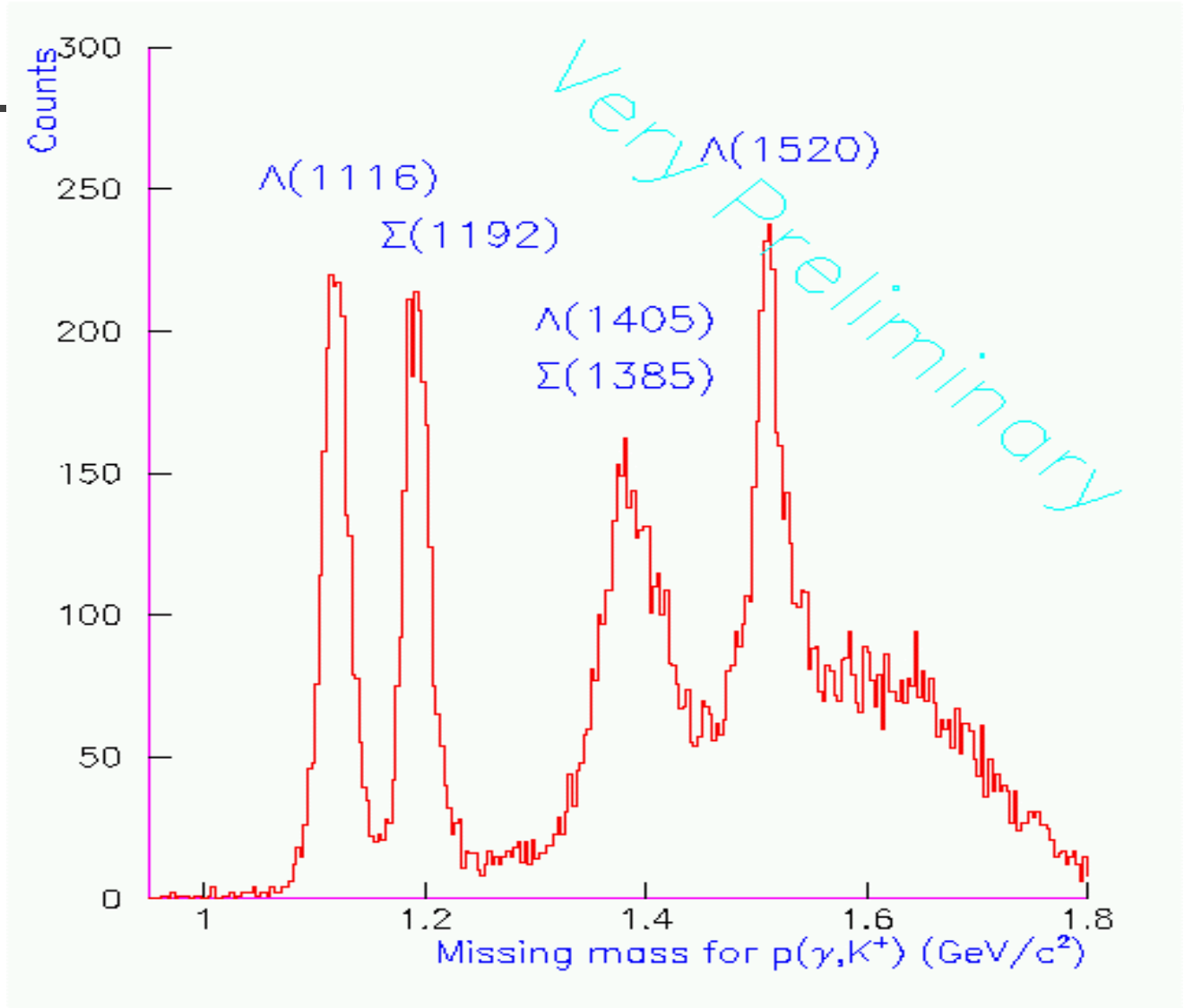
TPC Readout Chamber

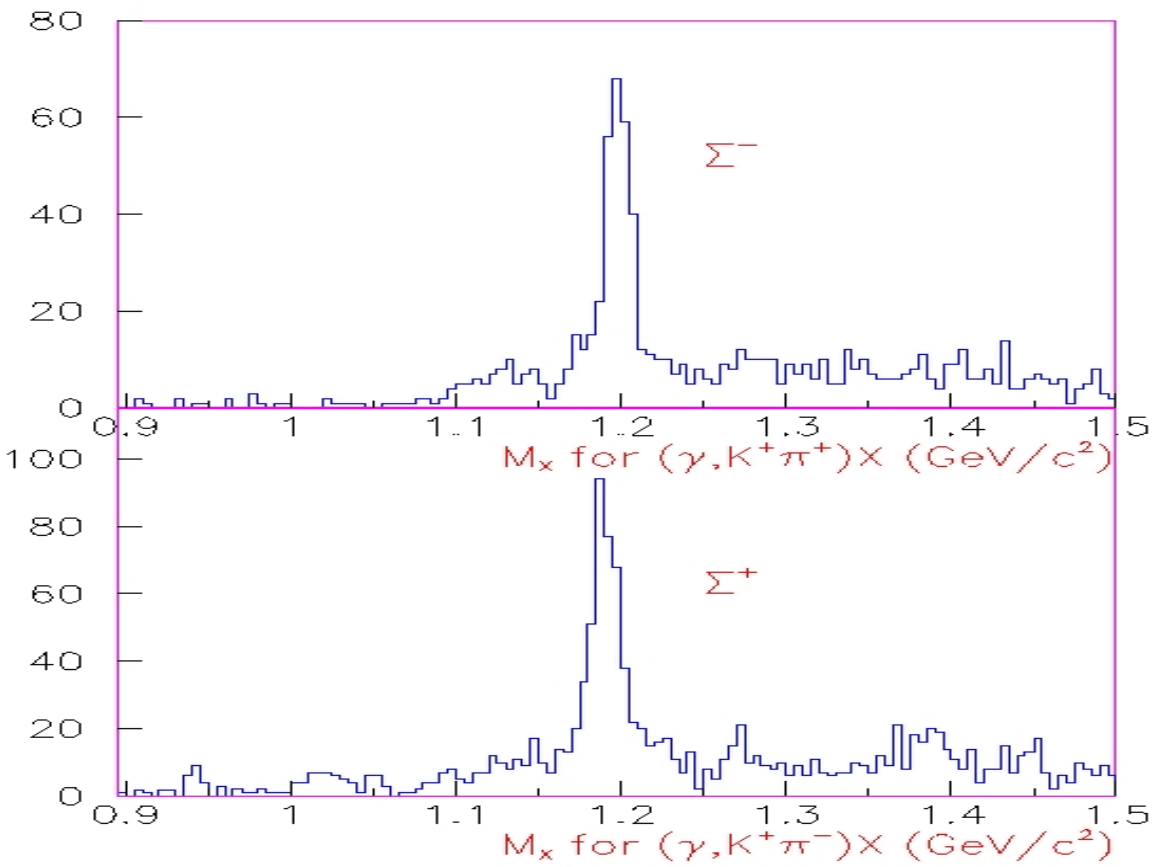


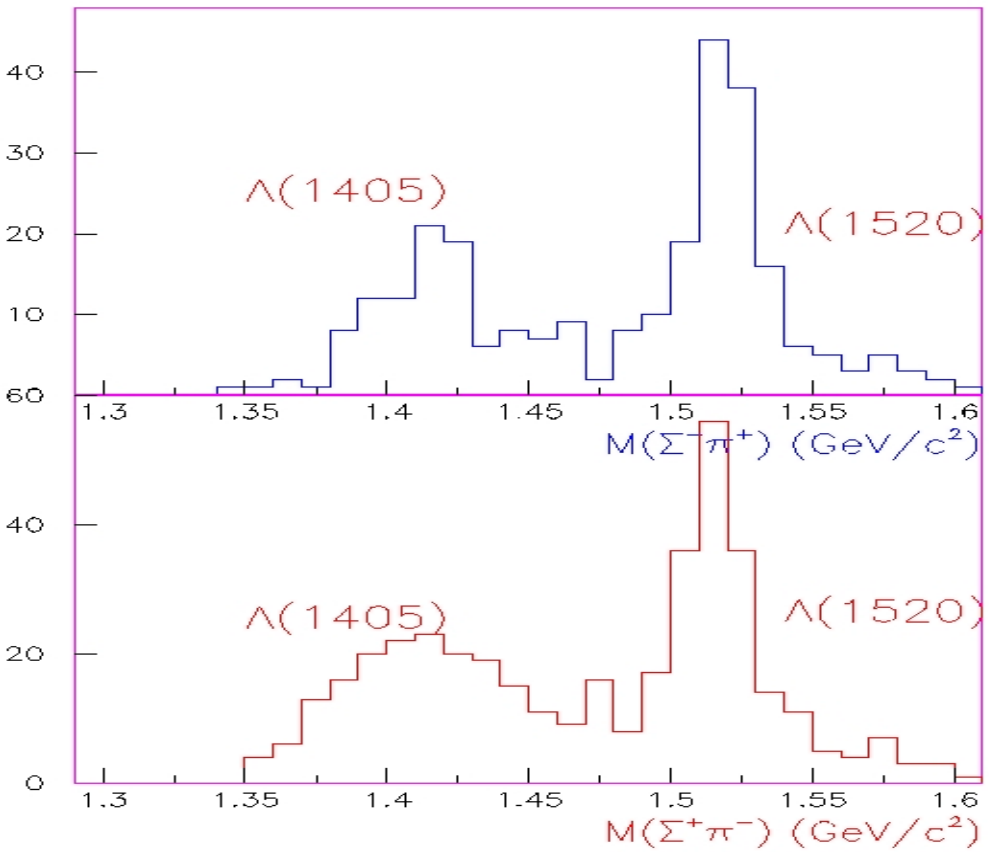
- ~1000 pads and ~100 wires for readout
- s_{xy} ~350mm and s_z ~ 500mm
- DM/M ~ 0.5% for L(1405) mass
- B = 1.5 ~ 2.5T

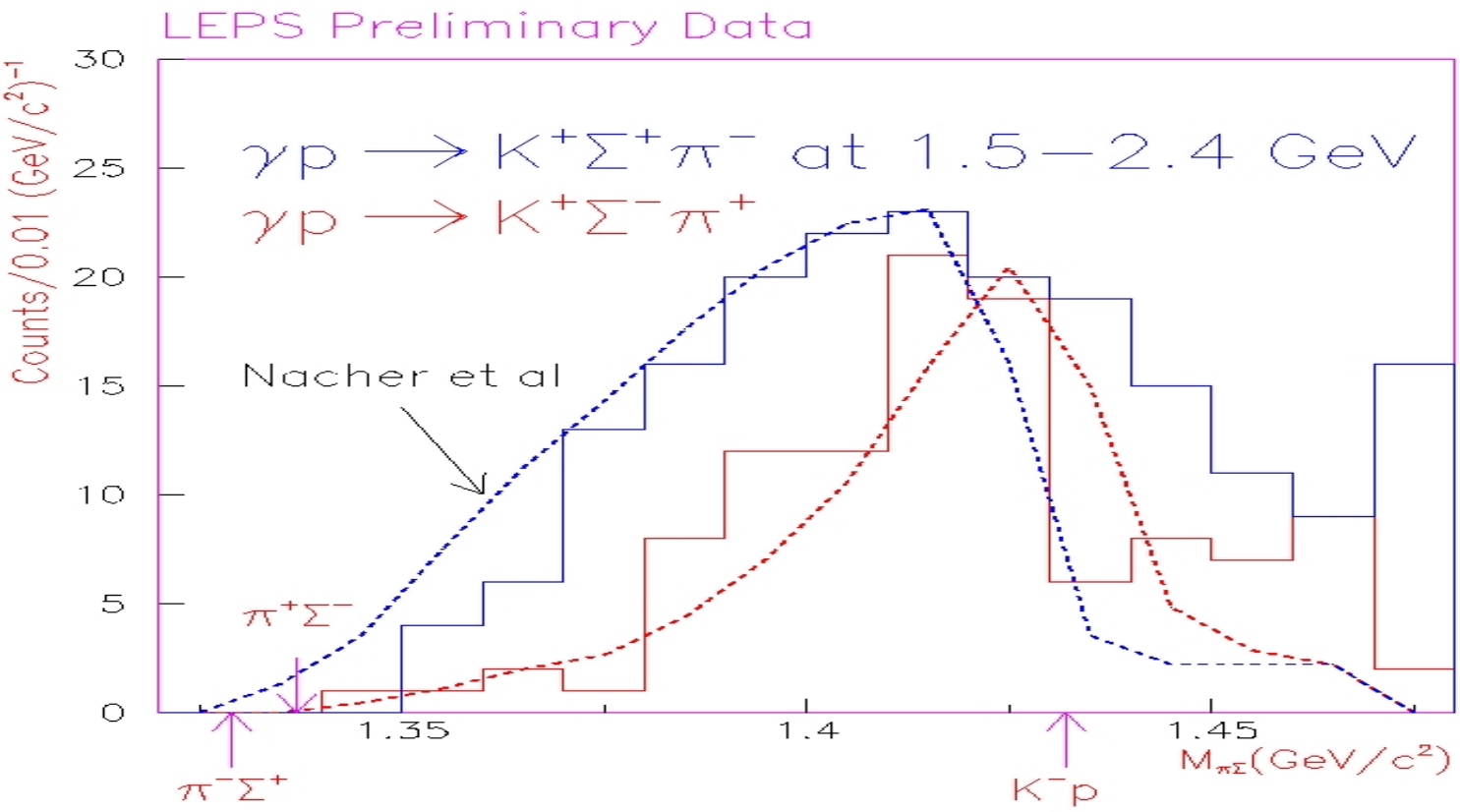
p(g,K$^+$(p^{+-})) at SP8

by J.K.Ahn

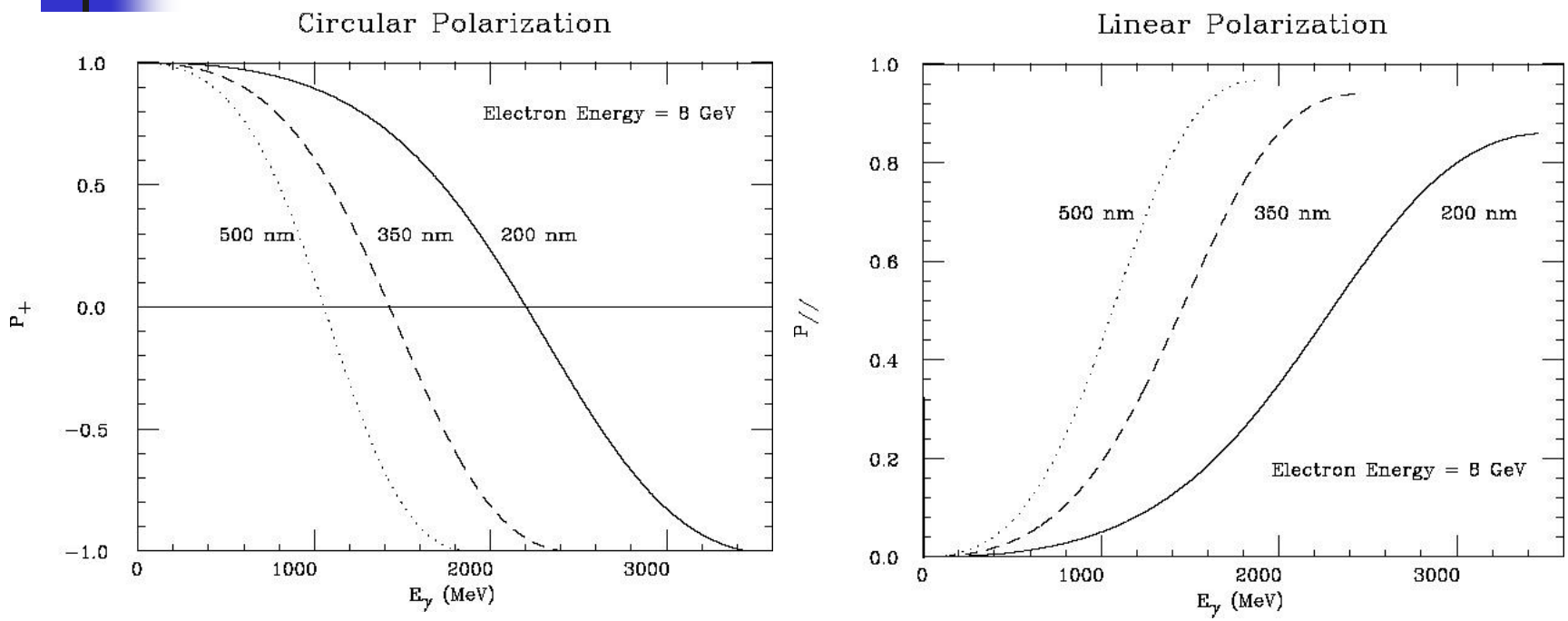



80
60
40
20
0
Σ^-
0.9
1
1.1
1.2
1.3
1.4
1.5
M_x for $(\gamma, K^+\pi^+)X$ (GeV/c^2)
100
80
60
40
20
0
Σ^+
0.9
1
1.1
1.2
1.3
1.4
1.5
M_x for $(\gamma, K^+\pi^-)X$ (GeV/c^2)


40
30
20
10
60
Λ(1405)
Λ(1520)
1.3
1.35
1.4
1.45
1.5
1.55
1.6
M(Σ⁻π⁺) (GeV/c²)
40
20
0
Λ(1405)
Λ(1520)
1.3
1.35
1.4
1.45
1.5
1.55
1.6
M(Σ⁺π⁻) (GeV/c²)


LEPS Preliminary Data
γp → K⁺Σ⁺π⁻ at 1.5−2.4 GeV
γp → K⁺Σ⁻π⁺
Nacher et al
π⁺Σ⁻
Counts/0.01 (GeV/c²)⁻¹
30
25
20
15
10
5
0
1.35
1.4
1.45
Mπ Σ(GeV/c²)
π⁻Σ⁺
K⁻p

Polarization of LEPS Beam



Linear Polarization : 95 % at 2.4 GeV