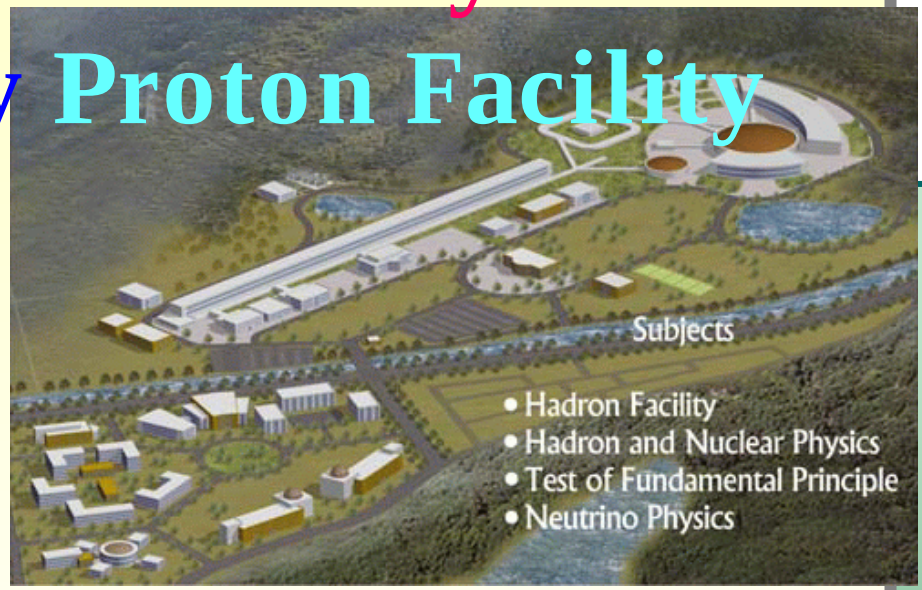
Strangeness Nuclear Physics @ High Intensity Proton Facility



Jung Keun Ahn

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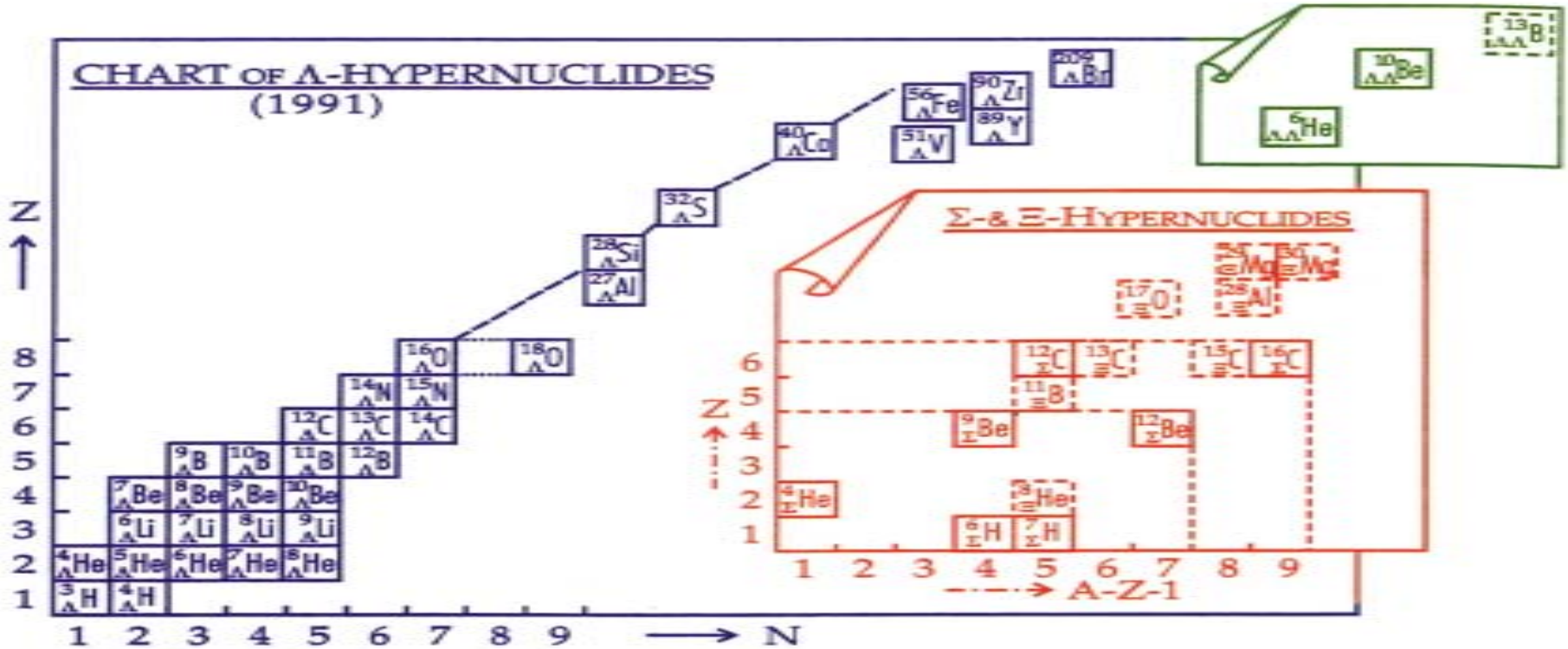
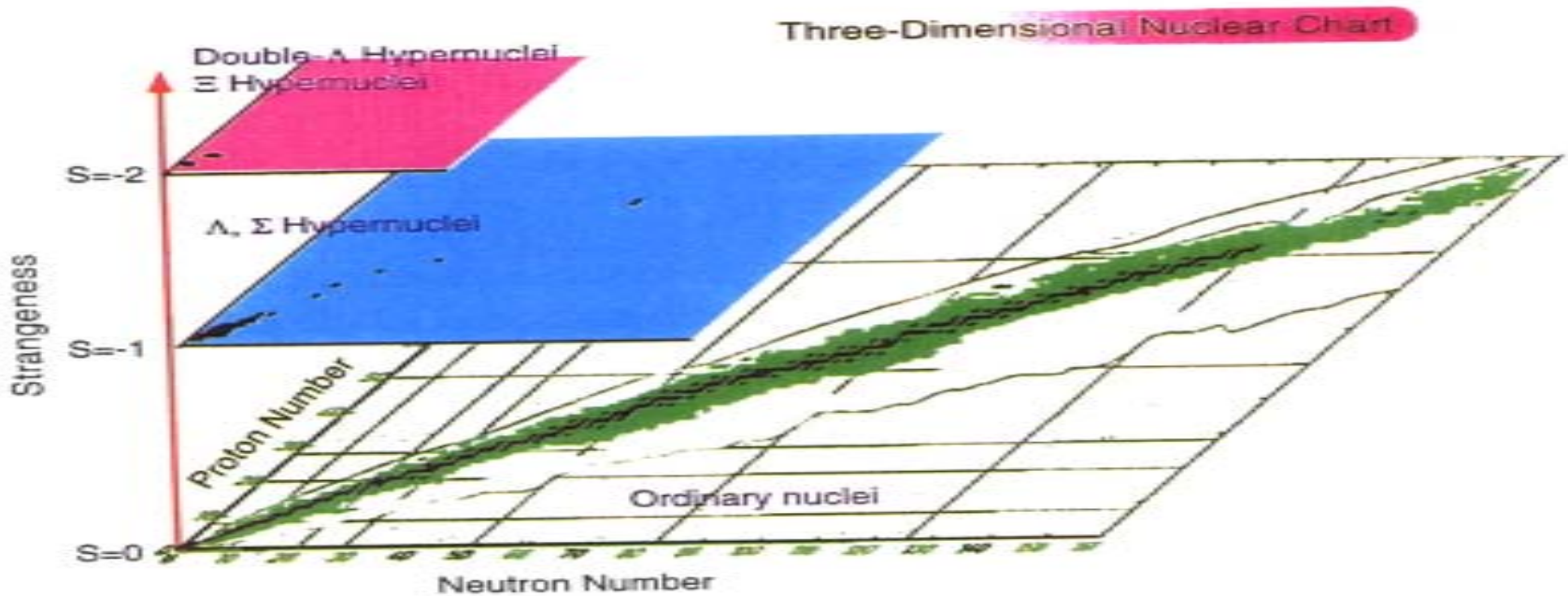
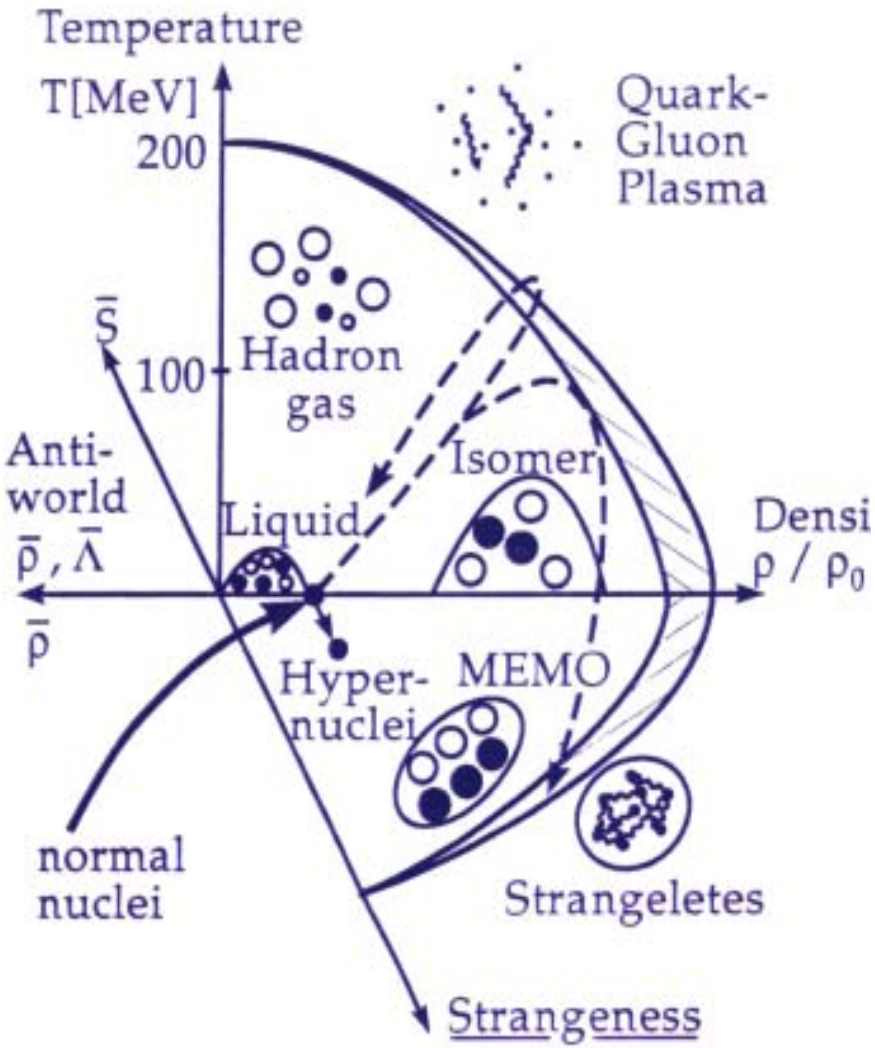
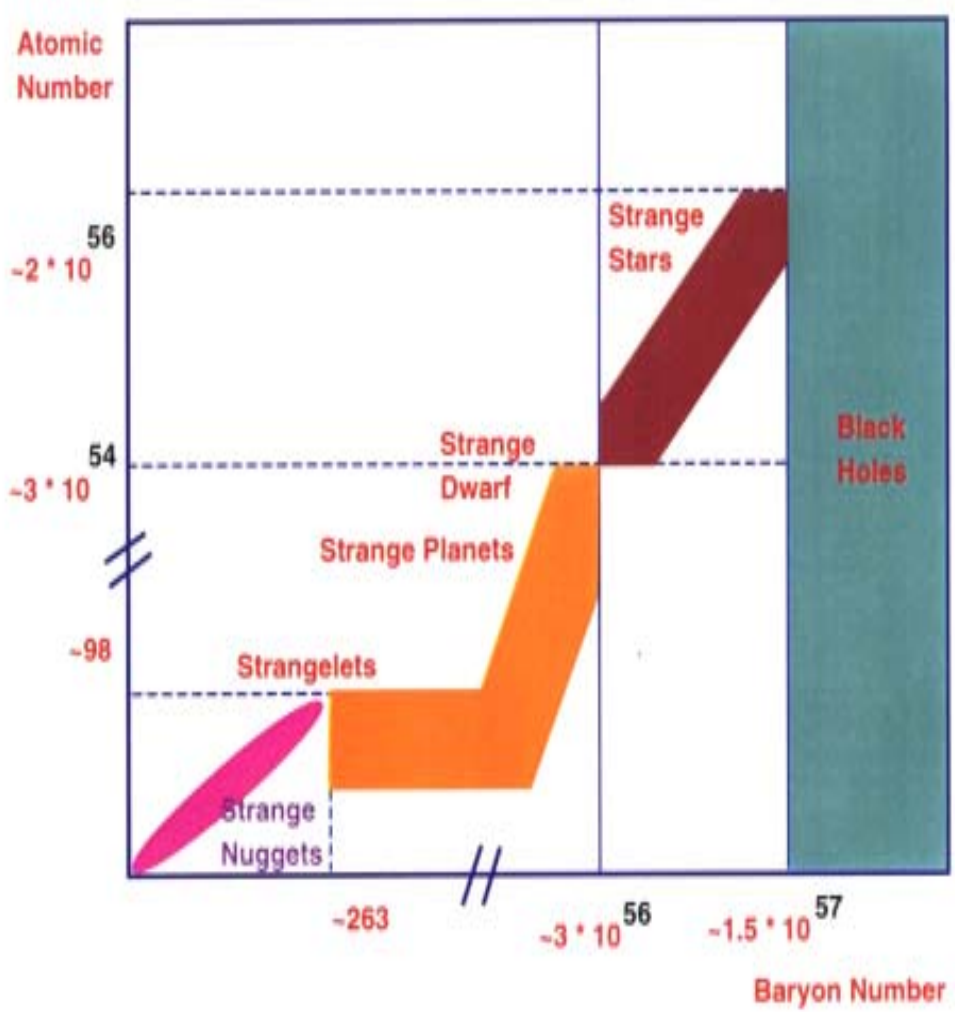


CHART OF Λ-HYPERNUCLIDES
(1991)
Σ-& Ξ-HYPERNUCLIDES
Z
N
A-Z-1


Three-Dimensional Nuclear Chart
Double-Λ Hypernuclei
Ξ Hypernuclei
Λ, Σ Hypernuclei
Strangeness
S=-2
S=-1
S=0
Proton Number
Ordinary nuclei
Neutron Number


Temperature
T[MeV]
200
100
Quark-
Gluon
Plasma
Hadron
gas
Anti-
world
Liquid
Isomer
Densi
ρ / ρ0
Hyper-
nuclei
MEMO
normal
nuclei
Strangeletes
Strangeness


Atomic
Number
56
~2 * 10
54
~3 * 10
~98
Strange
Stars
Strange
Dwarf
Strange Planets
Strangelets
Strange
Nuggets
Black
Holes
~263
~3 * 10 56
~1.5 * 10 57
Baryon Number

Strangeness in Hadron and Nuclear Physics

- ***Search for new types of baryonic matter***
  - *$\Lambda(1405)$ and $\overline{K}N$, $\Sigma(1750)$ and $\eta\Sigma$*
  - *$\Theta^+(1530)$ $uudd\bar{s}$*
- ***Studies of hyperon interactions and decays, and hypernuclei***
  - *$\Delta I=1/2$ rule test and $\Lambda N \rightarrow NN$*
  - *$\Lambda\Lambda$ and H dibaryon $uudds\bar{s}$*
  - *Ξ hypernuclear spectroscopy*

Exotics

Exotic : with quantum # that cannot be matched by qq'q".

For $SU_f(3)$, qqq generates

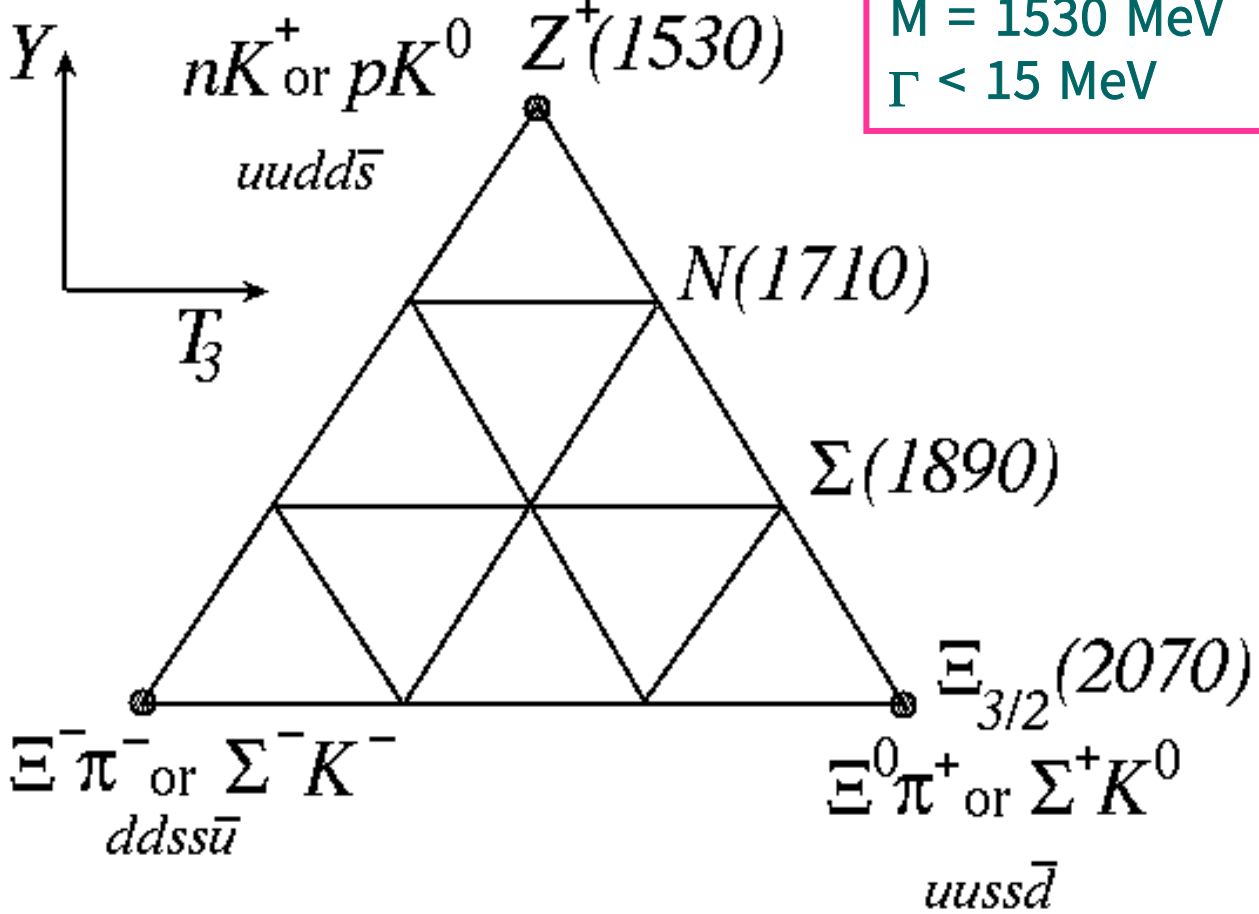
$$3 \times 3 \times 3 = 1 + 8s + 8a + 10$$

For meson-octet +baryon-octet,

$$8 \times 8 = 1 + 8 + 8 + 10 + \overline{10} + 27$$

$J^p = 1/2^+$

The Anti-decuplet of Baryons



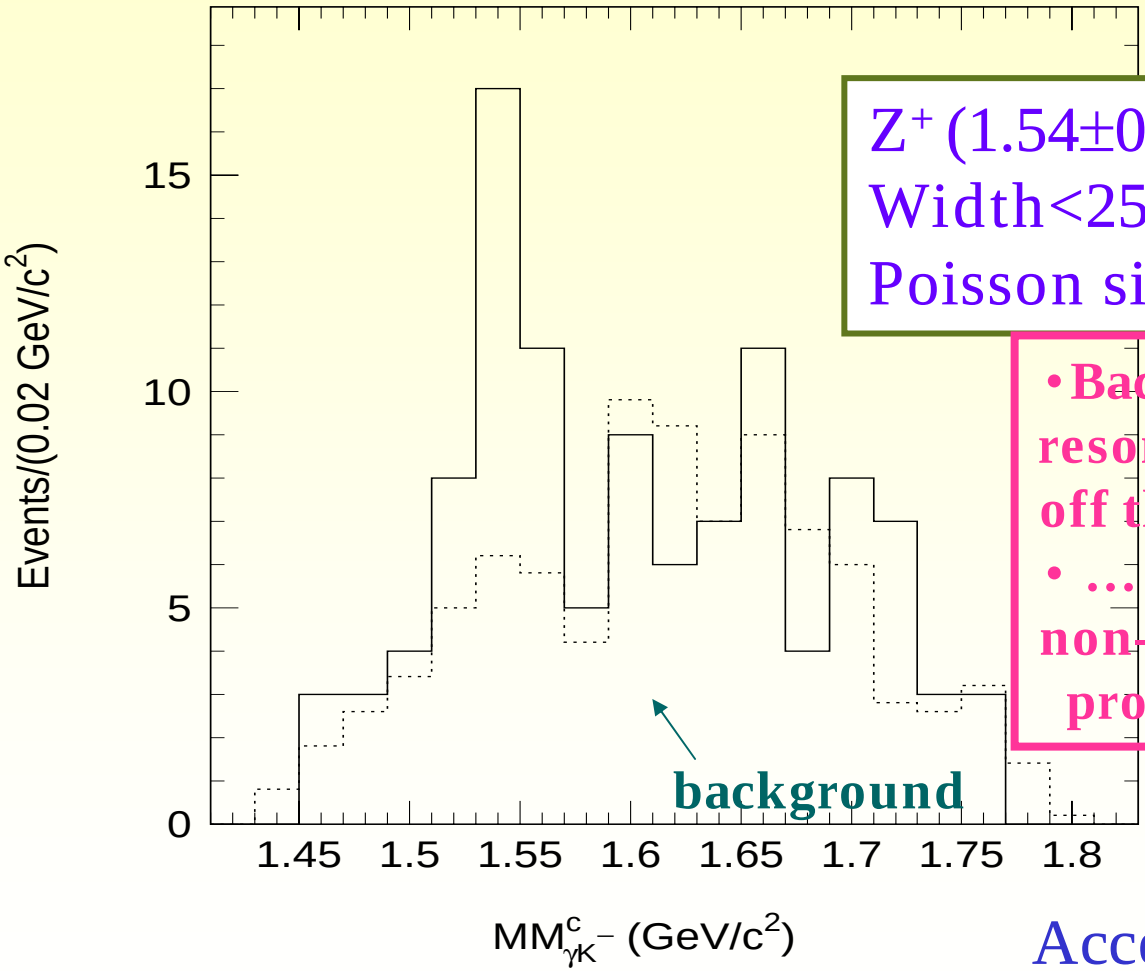
M = 1530 MeV
Γ < 15 MeV

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

M. Polyakov, and A. Rathke, hep-ph/0303138

Evidence for the Z+(Θ+) @SPring-8

$\gamma n \rightarrow K^- Z^+$



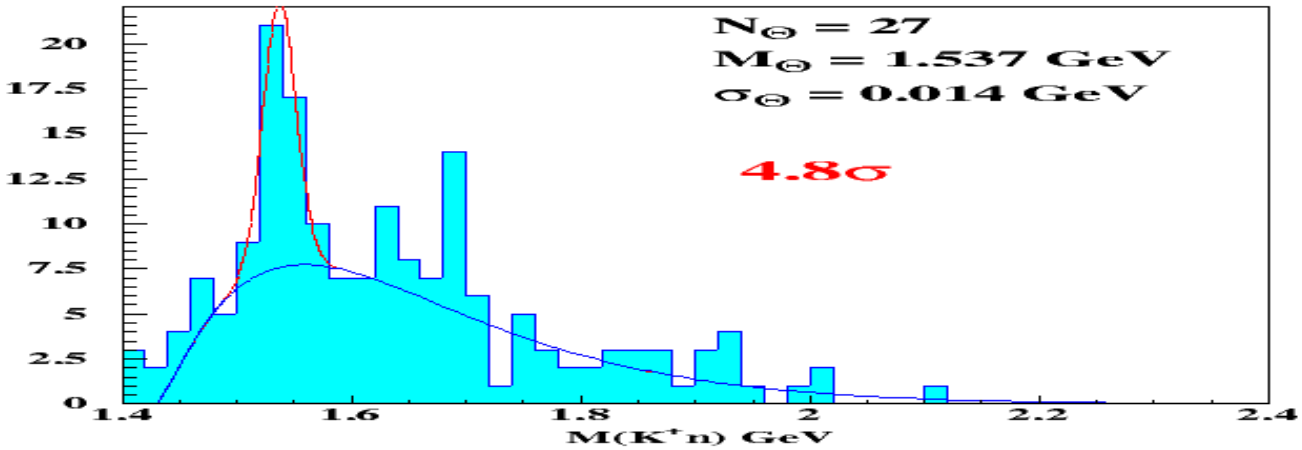
Z^+ (1.54±0.01) GeV / c^2
Width<25 MeV / c^2
Poisson significance 4.3 σ

- **Background is from non-resonant K^+K^- production off the neutron/nucleus**
- **… is nearly identical to non-resonant K^+K^- production off the proton**

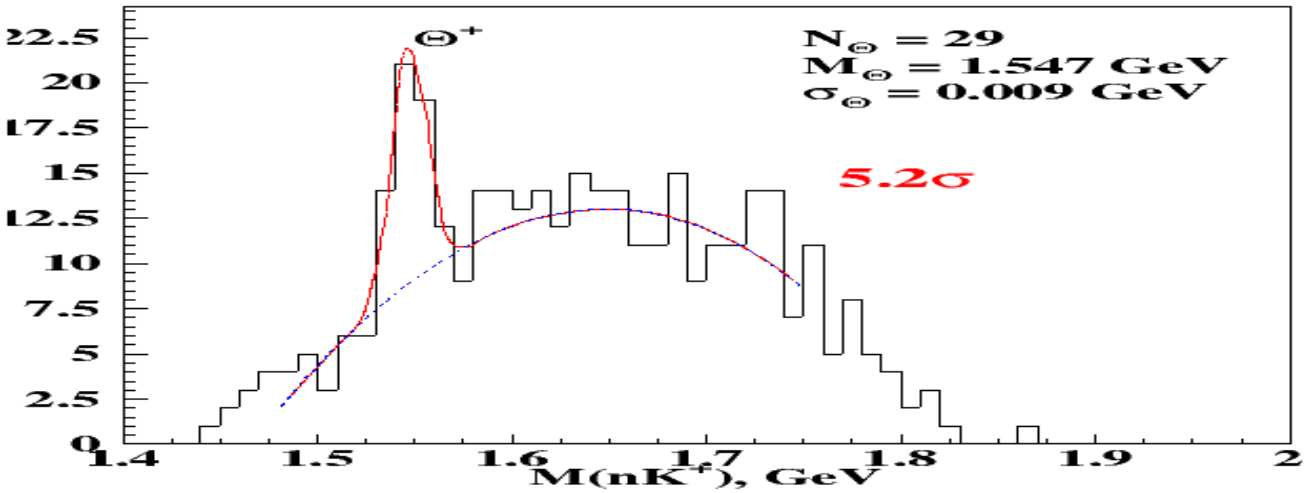
Accepted for PRL

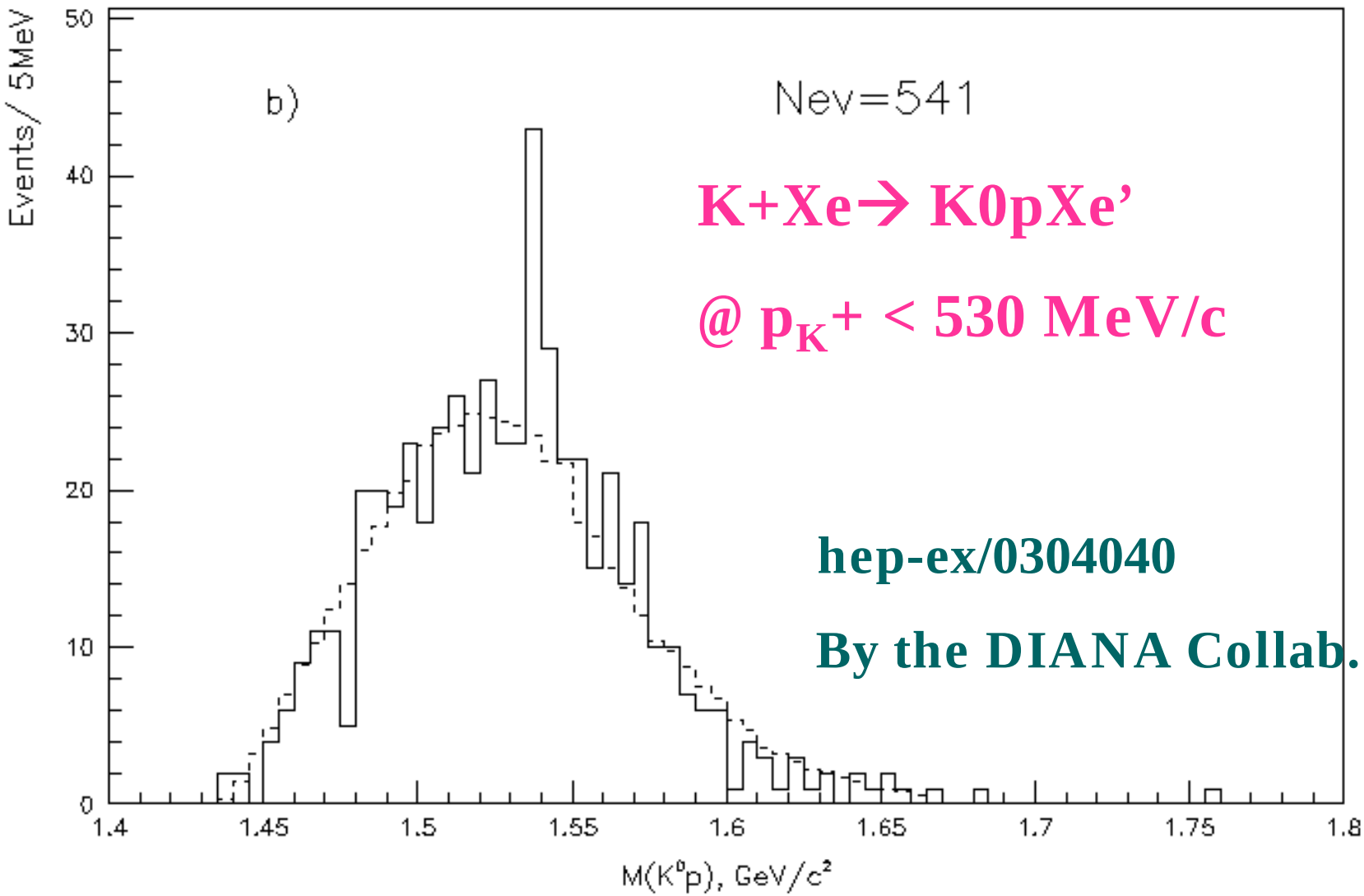
CLAS

$\gamma p \rightarrow \pi^+ K^- K^+ n$



$\gamma d \rightarrow p K^+ K^- n$





K+Xe→ K0pXe'

@ p_{K^+} < 530 MeV/c

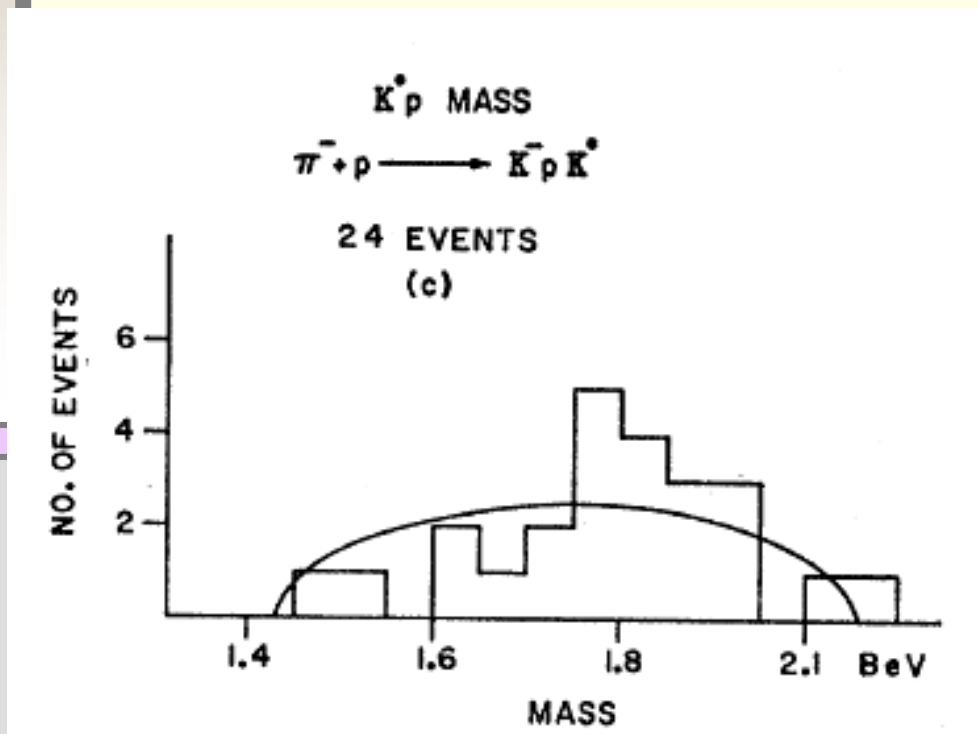
hep-ex/0304040

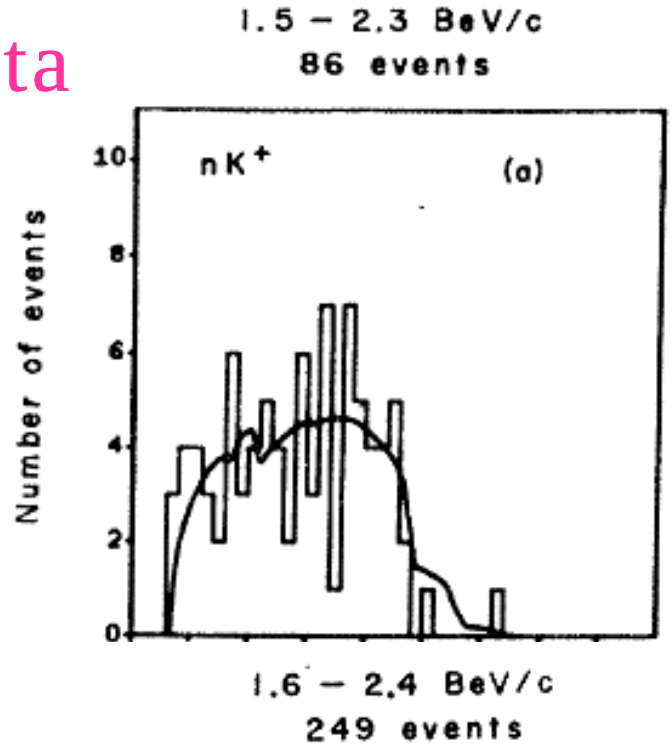
By the DIANA Collab.

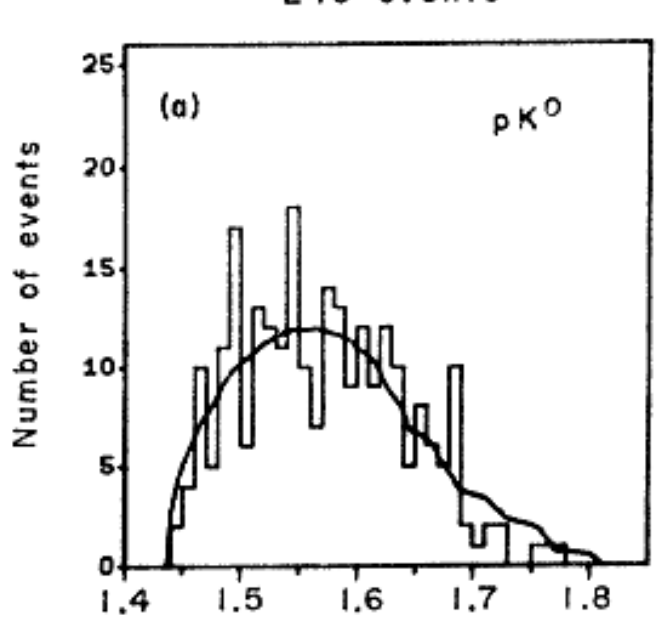
Old $(\pi^-,K^-)pK^0/nK^+$ Data

O.I.Dahl et al., Phys. Rev. 163,1377 (1967)

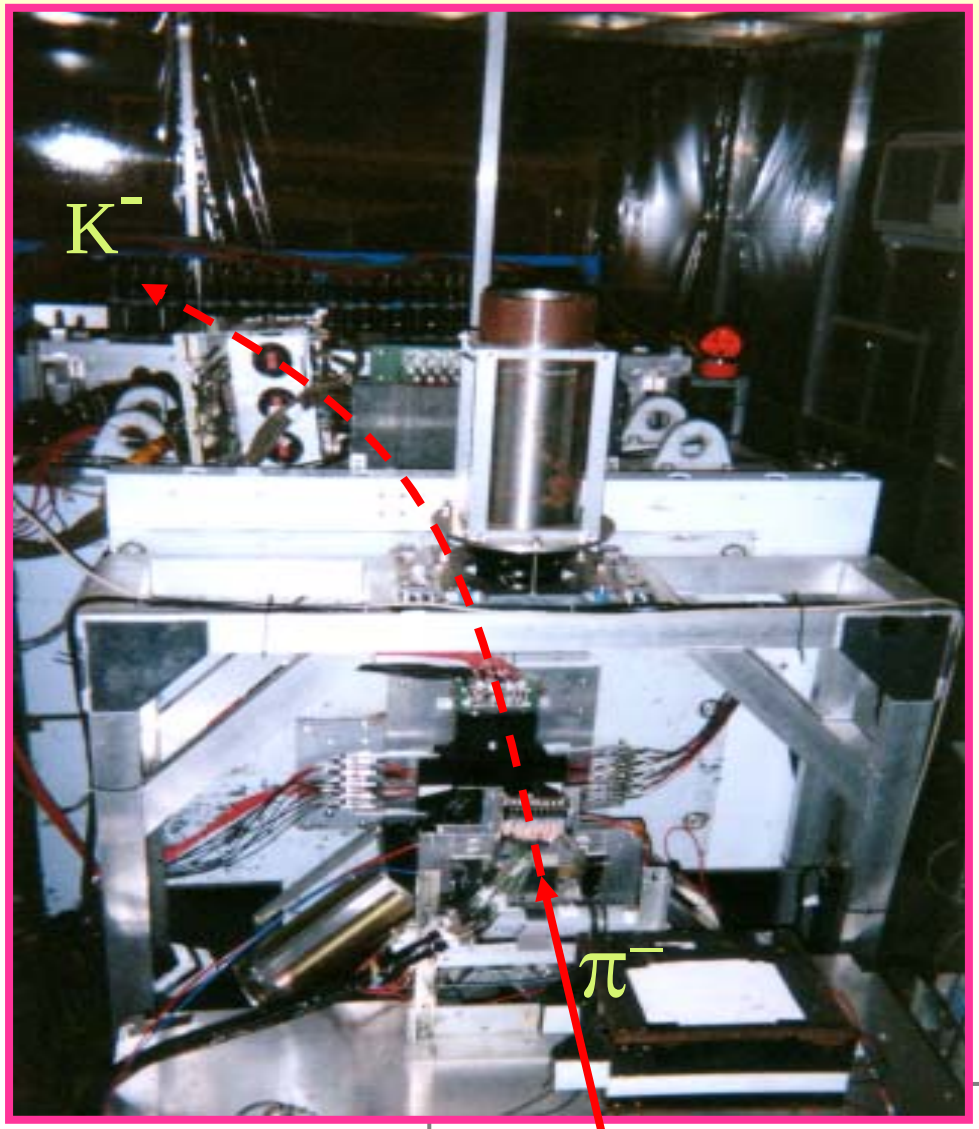
T.P. Wangler et al., Phys. Rev. 137 B414 (1965)





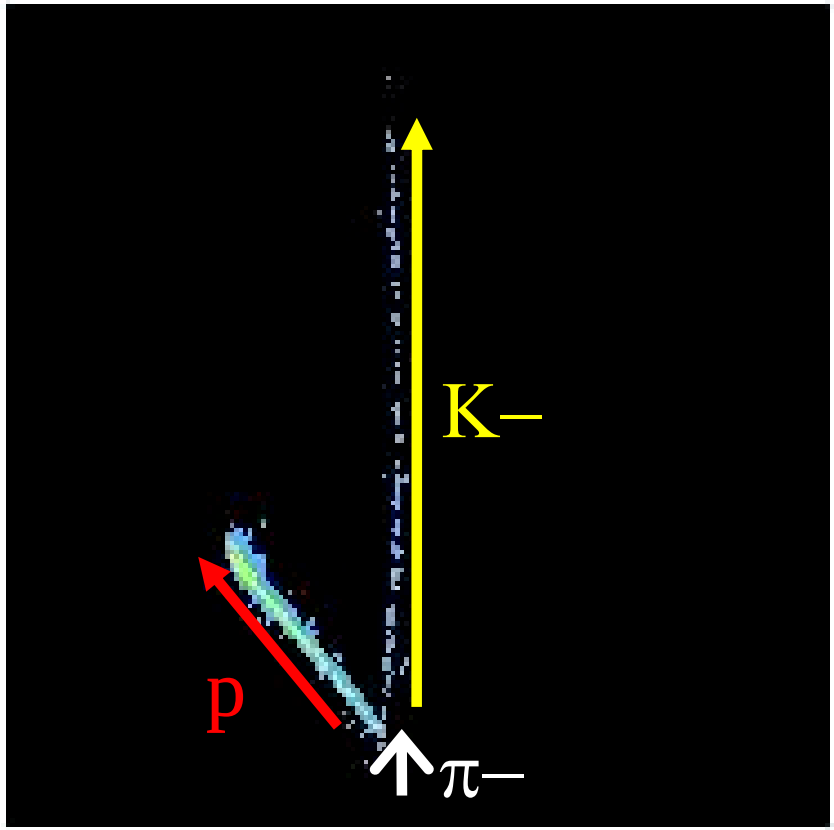


KEK-E522 ($\Lambda\Lambda$ / Ξp / $^{11}_{K-}$B / Z+)

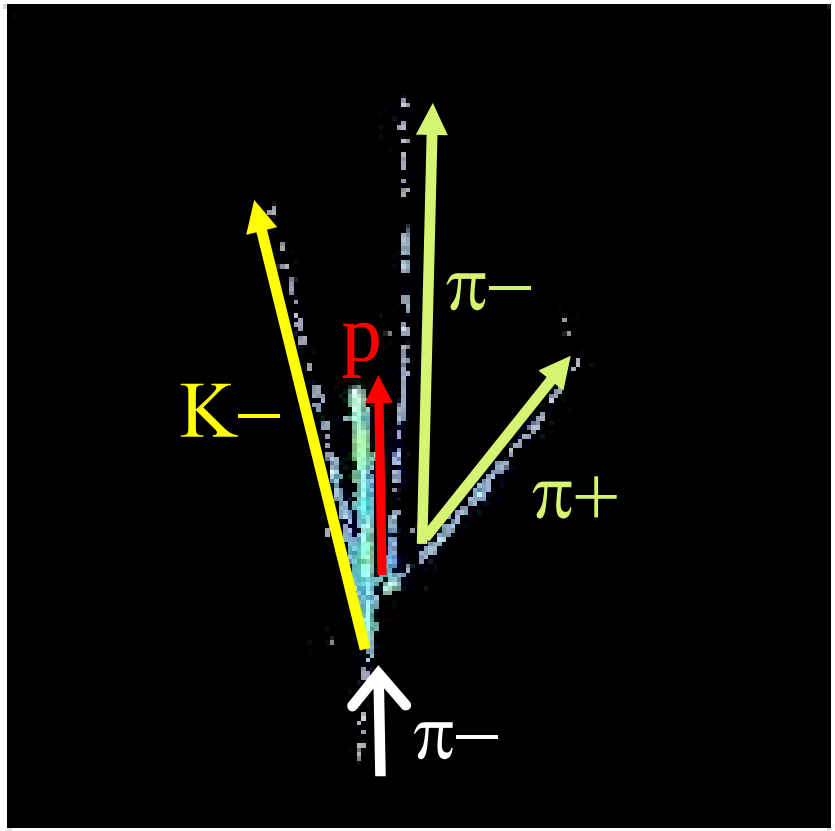


- 1.9 GeV/c π^-
- KEK-PS K2 Beam
- π-p→K-Z+ reaction, followed by Z+ → K^0p / K+n
- Kurama Spectrometer
- 20cm long SCIFI target

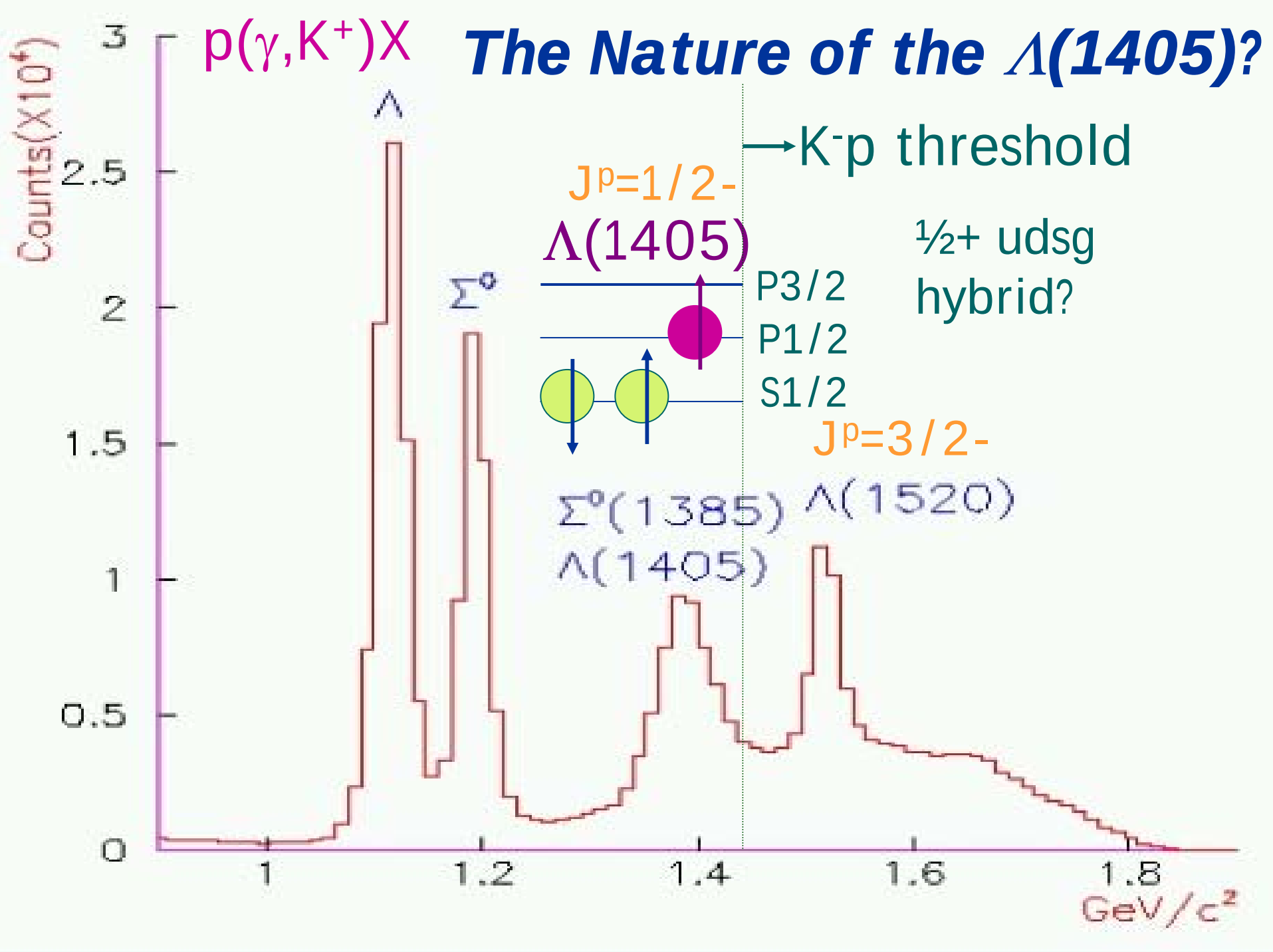
SCIFI Image Data



771 events



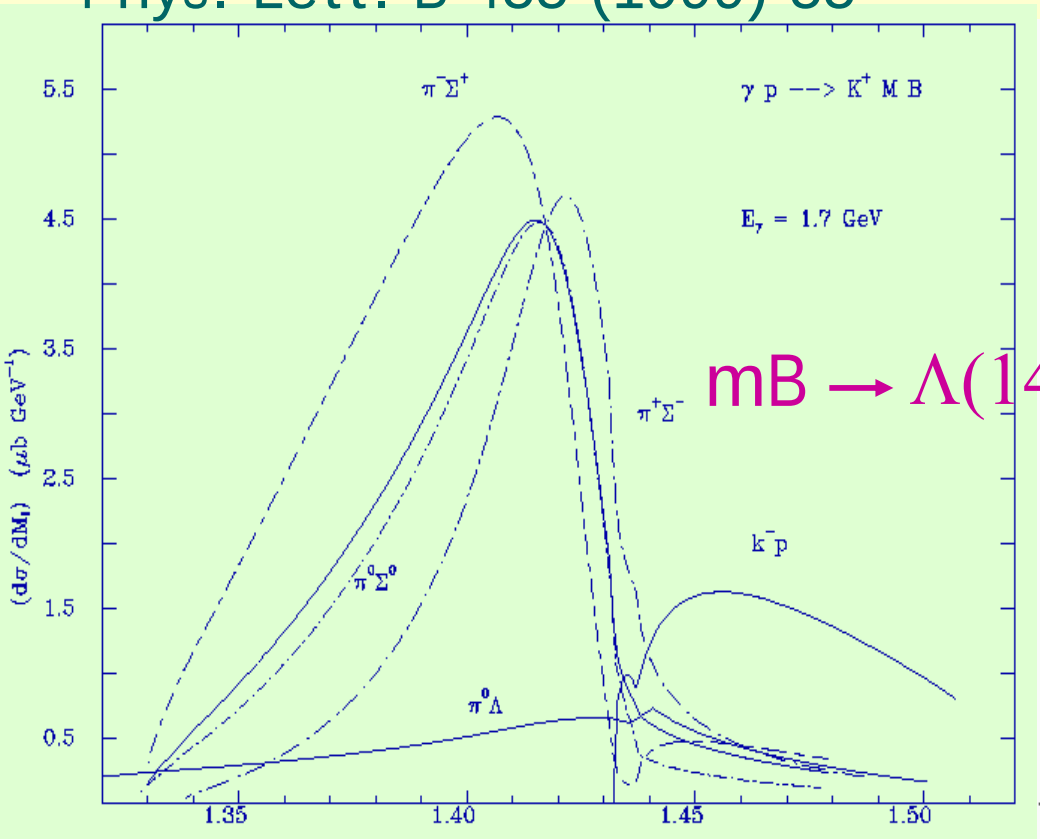
137 events


p(γ,K+)X
The Nature of the Λ(1405)?
Counts(X10⁴)
3
2.5
2
1.5
1
0.5
0
Λ
Σ°
→K-p threshold
Jp=1/2-
Λ(1405)
½+ udsg
hybrid?
P3/2
P1/2
S1/2
Jp=3/2-
Σ°(1385)
Λ(1520)
Λ(1405)
1
1.2
1.4
1.6
1.8
GeV/c²

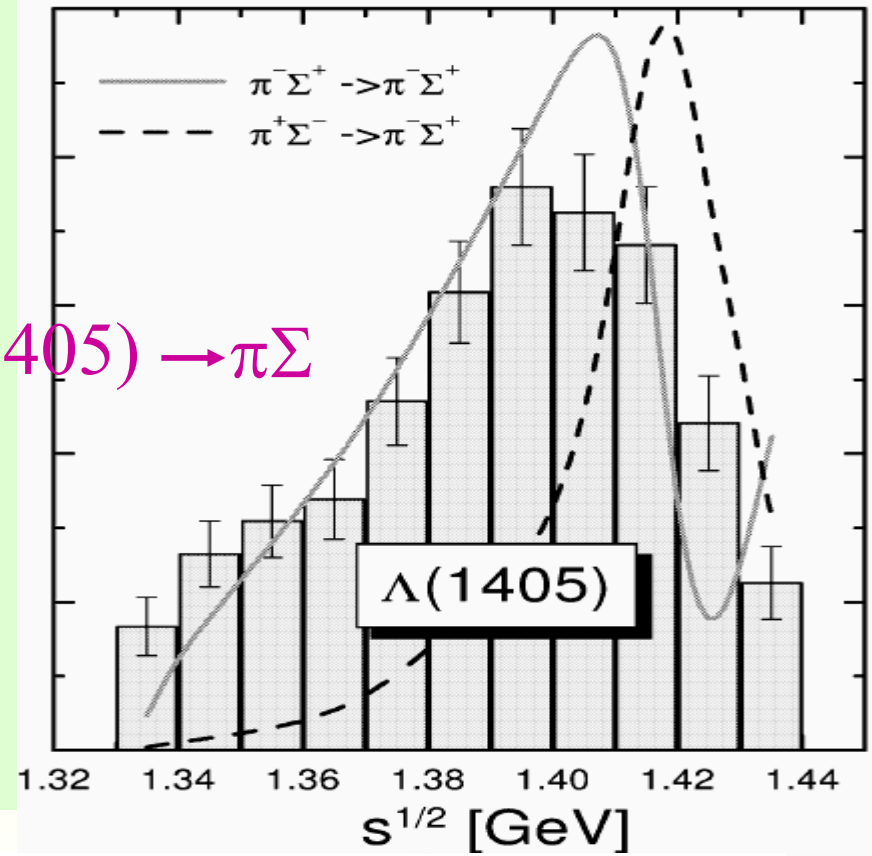
Coupled-channel χ-dynamics

Nacher, Oset, Toki, Ramos
Phys. Lett. B 455 (1999) 55

Lutz, Kolomeitsev
Nucl. Phys. A 700 (2002)193

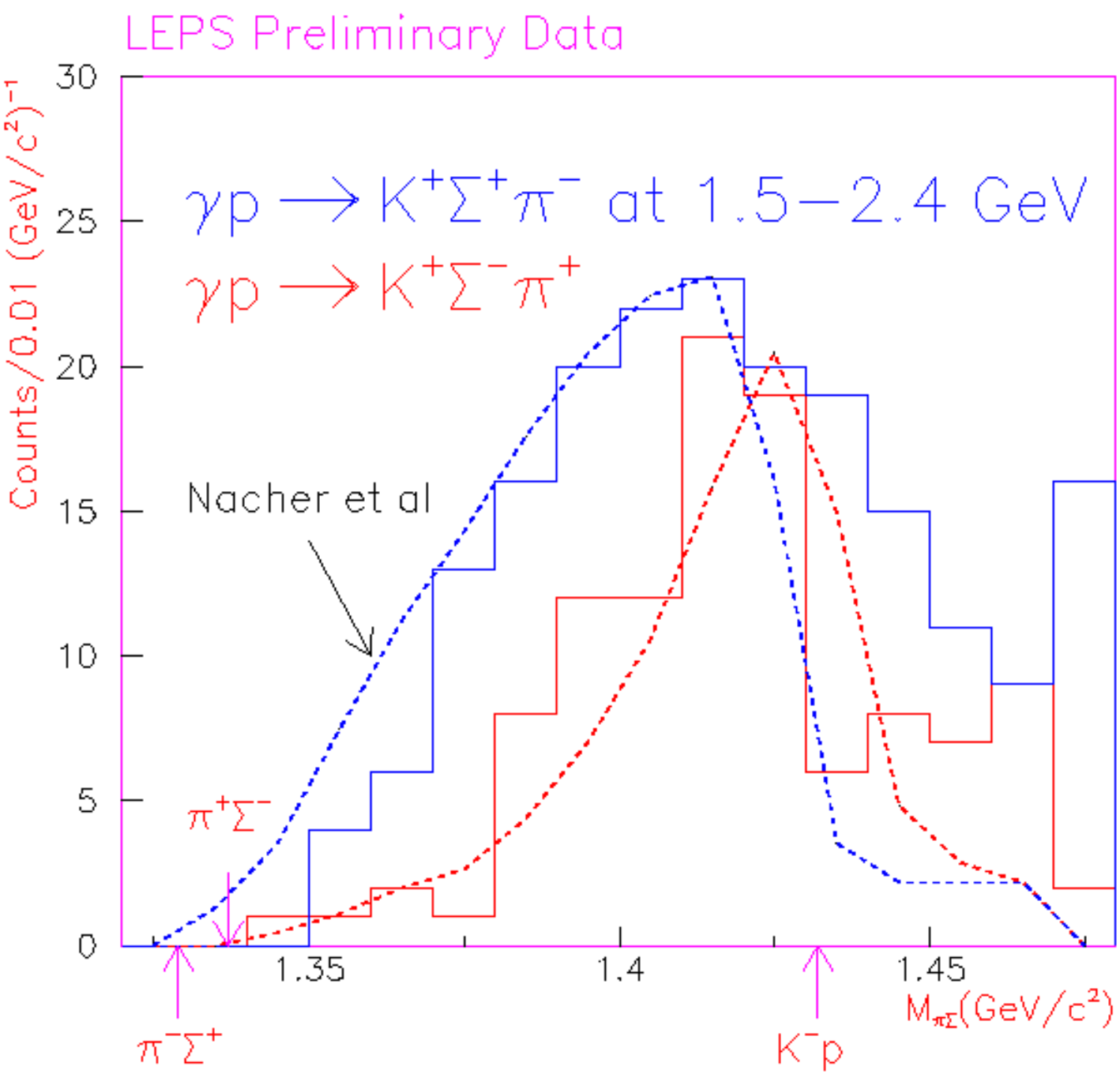


mB → Λ(1405) → πΣ

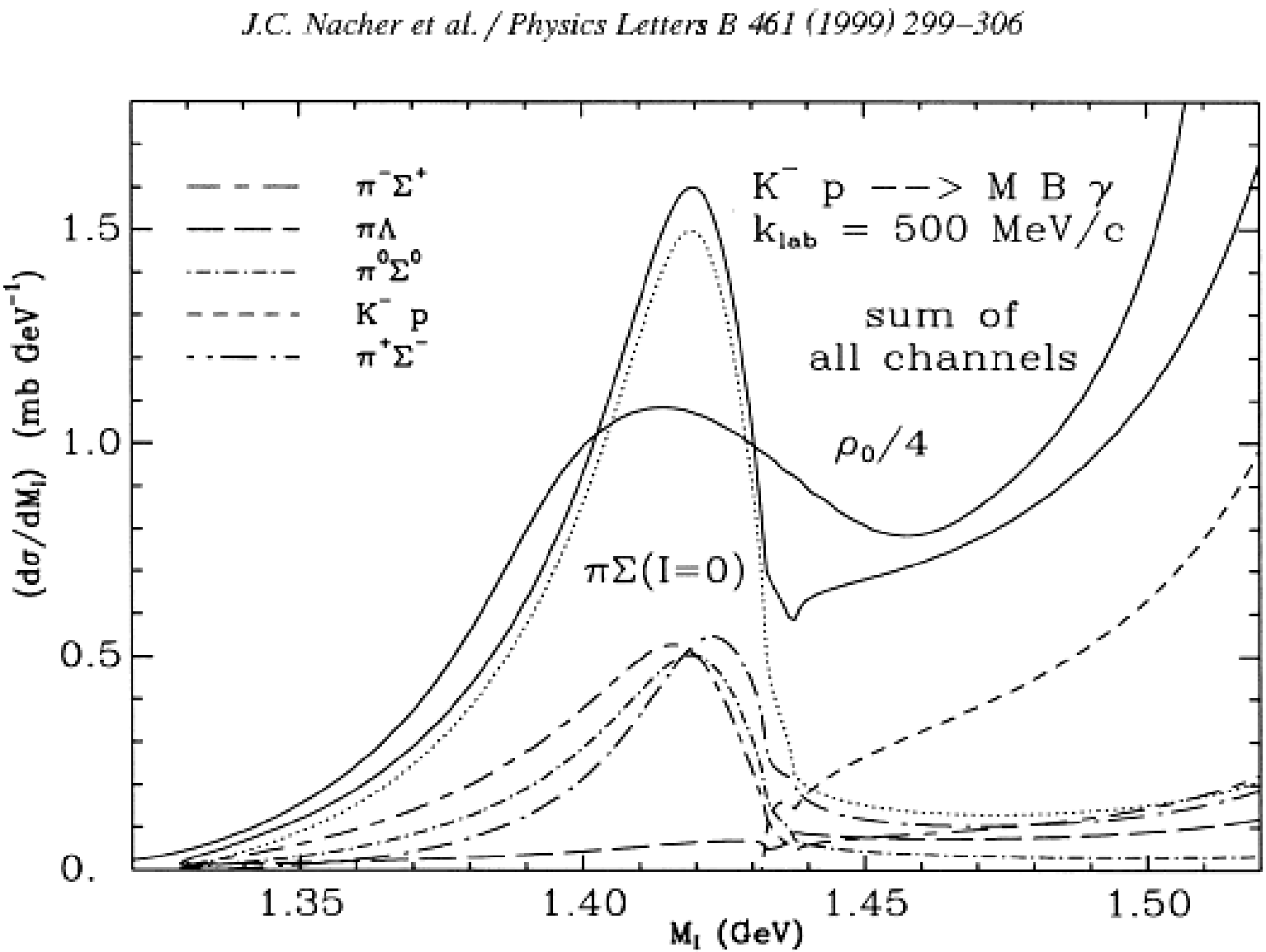


$$\frac{\mathrm{d}\sigma(\pi^+\Sigma^-)}{\mathrm{d}M_I} \propto \frac{1}{3}|T^{(0)}|^2 + \frac{1}{2}|T^{(1)}|^2 + \frac{2}{\sqrt{6}}Re|T^{(0)}T^{(1)*}|^2$$

$$\frac{\mathrm{d}\sigma(\pi^-\Sigma^+)}{\mathrm{d}M_I} \propto \frac{1}{3}|T^{(0)}|^2 + \frac{1}{2}|T^{(1)}|^2 - \frac{2}{\sqrt{6}}Re|T^{(0)}T^{(1)*}|^2$$


LEPS Preliminary Data
$\gamma p \rightarrow K^+\Sigma^+\pi^-$ at 1.5−2.4 GeV
$\gamma p \rightarrow K^+\Sigma^-\pi^+$
Nacher et al
$\pi^+\Sigma^-$
$\pi^-\Sigma^+$
K^-p
Counts/0.01 (GeV/c^2)$^{-1}$
$M_{\pi\Sigma}$(GeV/c^2)
0
5
10
15
20
25
30
1.35
1.4
1.45

$K^- p \rightarrow \Lambda(1405)\,\gamma \rightarrow \pi\,\Sigma\,\gamma$



Weak decay of hypernuclei

- In free space,

  $\Lambda \rightarrow p + \pi^-$ (63.9%, Q = 38 MeV)

  $n + \pi^0$ (35.8%, Q = 41 MeV)

- $\Delta I = 1/2$ rule holds well.

  - initial state: I=0, final state: I=1/2 or 3/2

    if I_f = 1/2, branch is 2:1

    3/2, 1:2

  - this rule is global in strangeness decay, but no one knows why.

- This mesonic decay is suppressed in hypernuclei due to Pauli blocking for the final state nucleon.

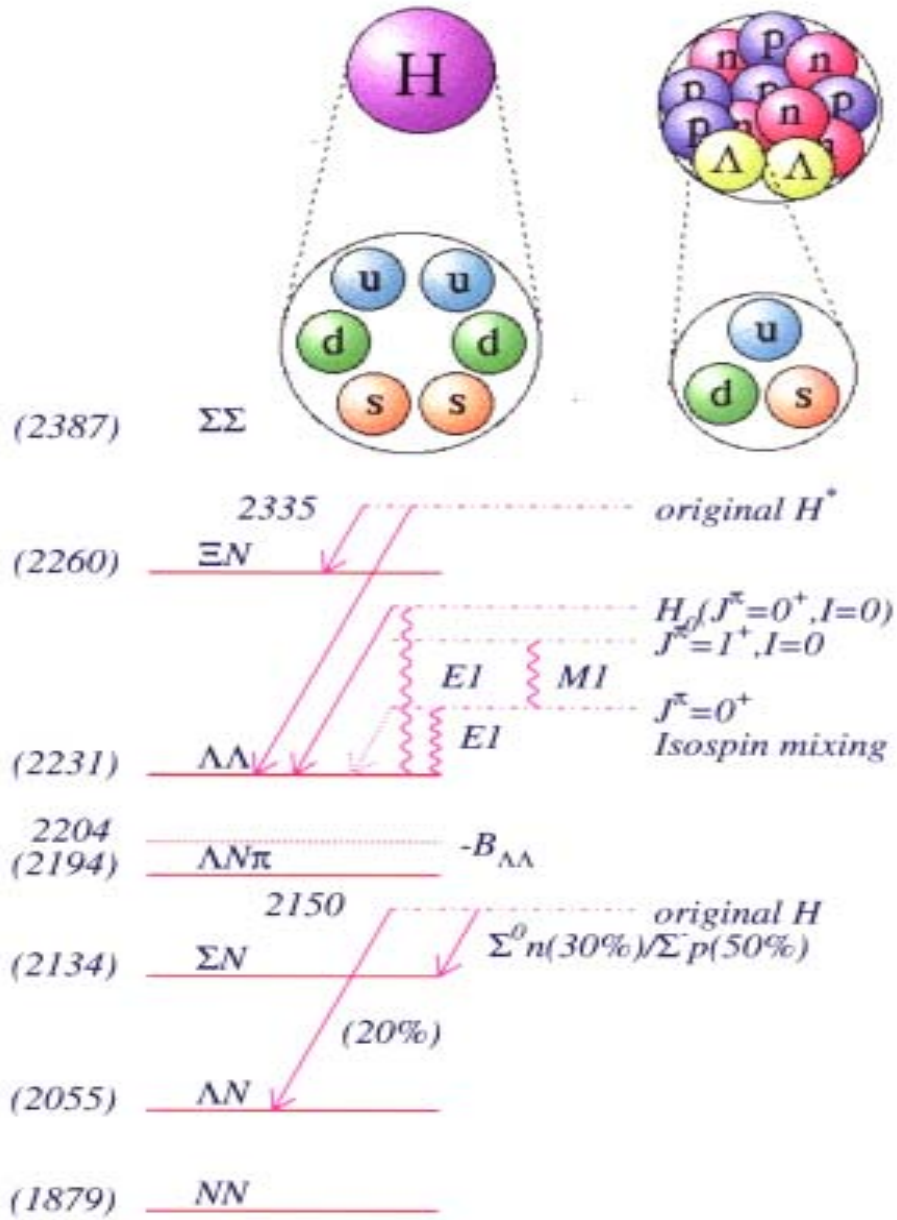
- Instead, non-mesonic decay occurs in hypernuclei, such as

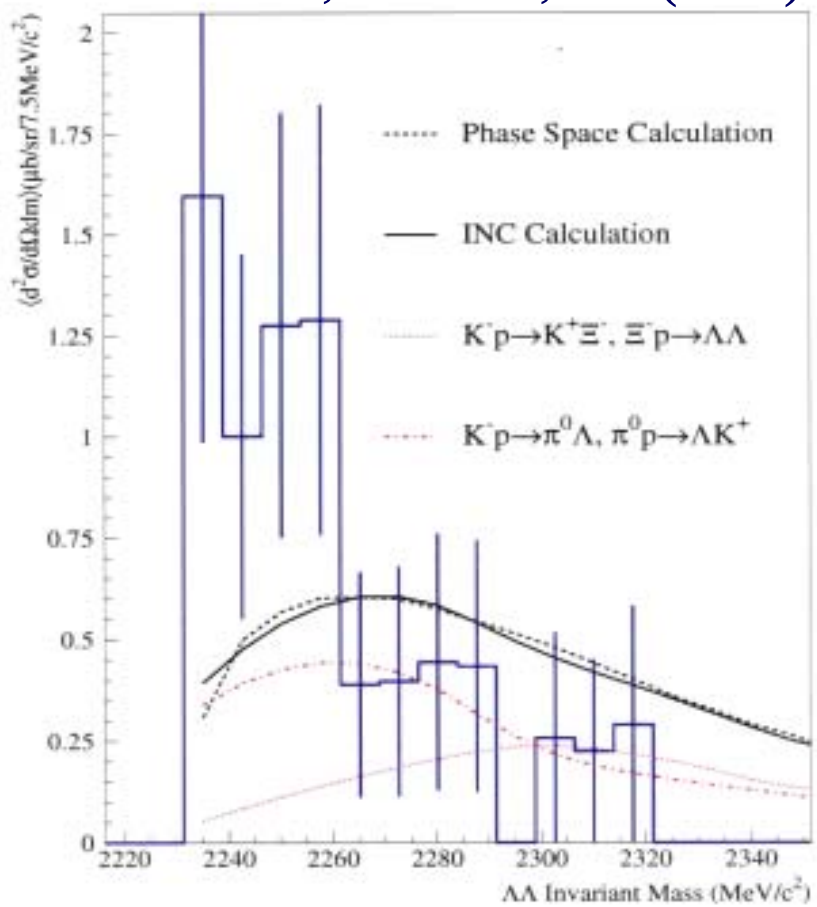
  $p + \Lambda \rightarrow p + n$,

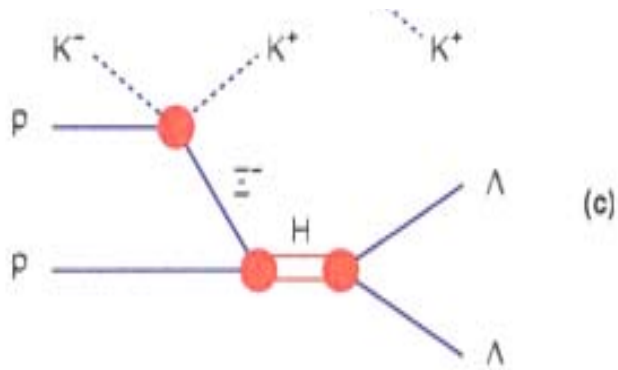
  $n + \Lambda \rightarrow n + n$, ...

H-dibaryon?

J.K. Ahn et al., PLB 444, 267 (1998)







H-Search Experiments

(K^-,K^+)	BNL E836	^{3}He (K^-,K^+)**H**n, ^{6}Li (K^-,K^+)**H**X
	BNL E885	^{12}C (K^-,K^+)**H**X
	KEK E224	^{12}C (K^-,K^+)**H**X
Stopped Ξ^-	BNL E813	$(\Xi^- d)_{atom} \rightarrow$ **H**n; monoenergetic n
p+A	BNL E888	weak decay
		2 candidates: background
Σ^- +A	WA89	weak and strong decays
Relativistic HI	BNL E810, E896	

Hyperon-Proton Scattering

Baryon-Baryon Interaction extending to SU(3) space

Meson Exchange Picture or Quark Picture ?

Lack of the Experimental Data

E251: $\Sigma^+ p \rightarrow \Sigma^+ p$

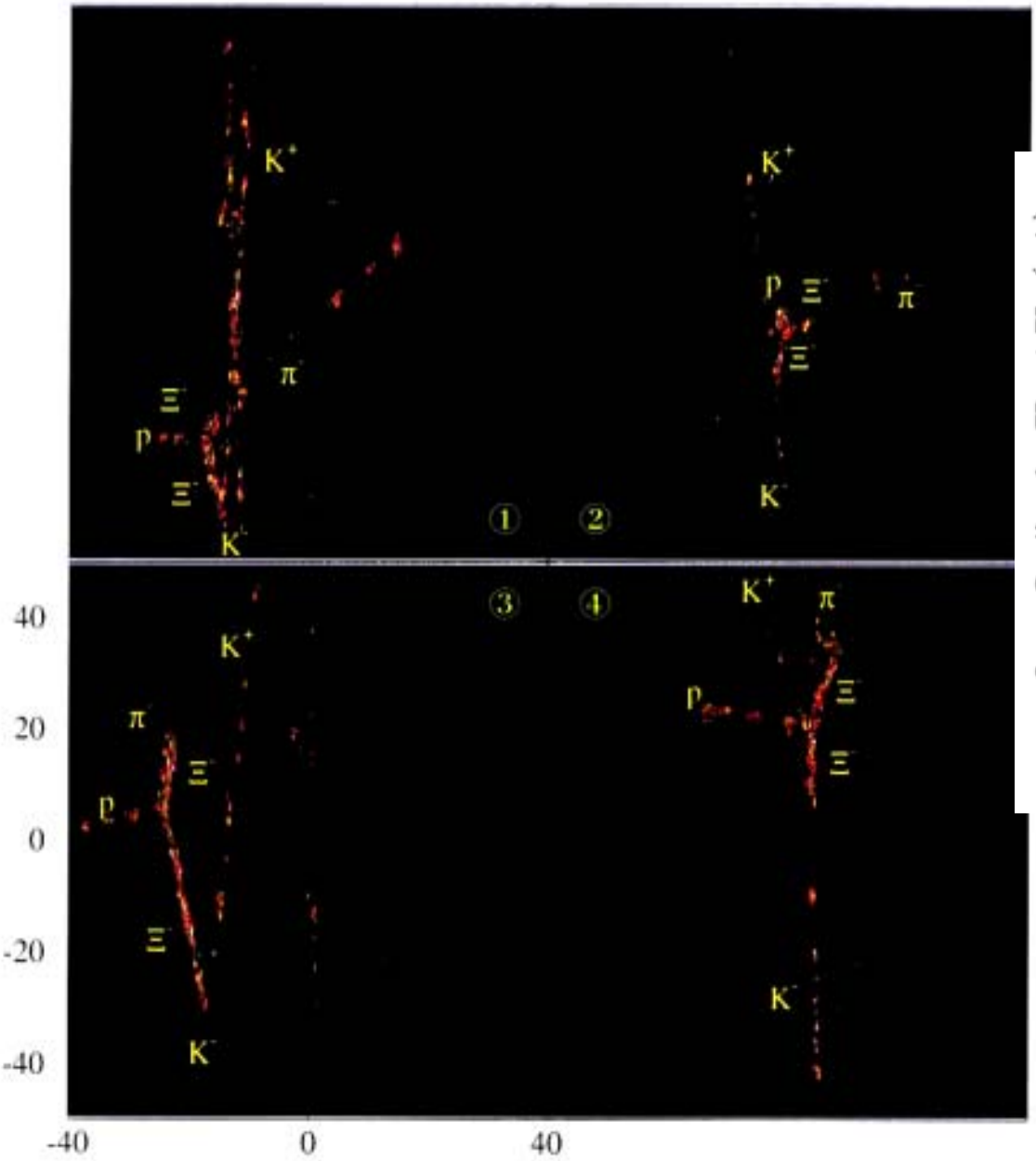
E289: $\Sigma^+ p \rightarrow \Sigma^+ p$, $\Lambda p \rightarrow \Lambda p$, $\Sigma^- p \rightarrow \Sigma^- p$

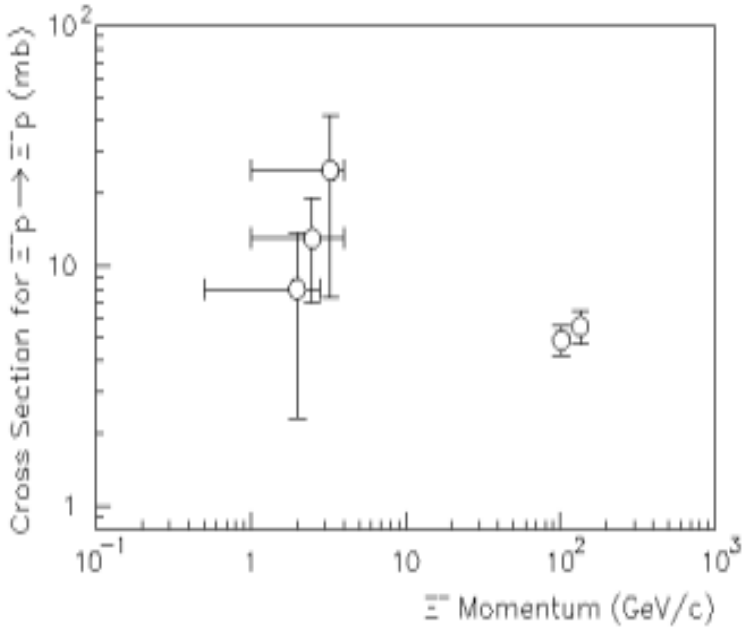
using SCIFI Detector as Production and Scattering Targets

JHF: Ξ^- production via (K^-, K+) at 1.6 GeV/c 1×10^7 [/sec]

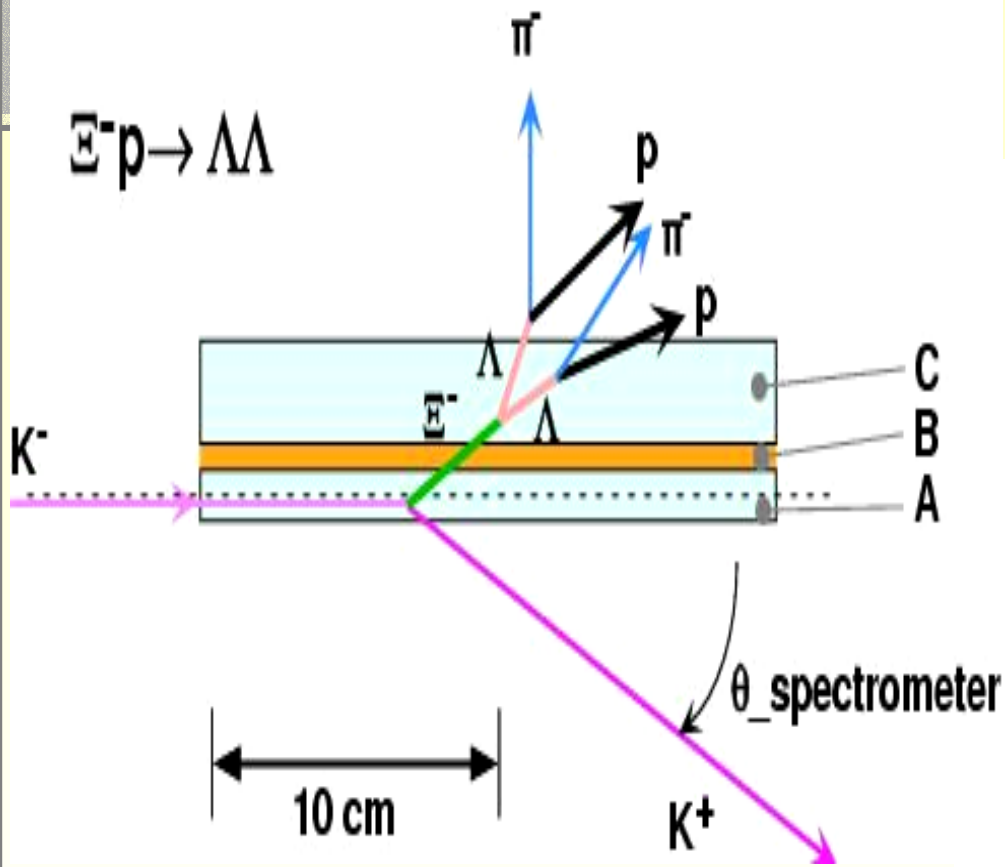
Observe $\Xi^- p \rightarrow \Xi^- p$, $\Xi^- p \rightarrow \Lambda\Lambda$

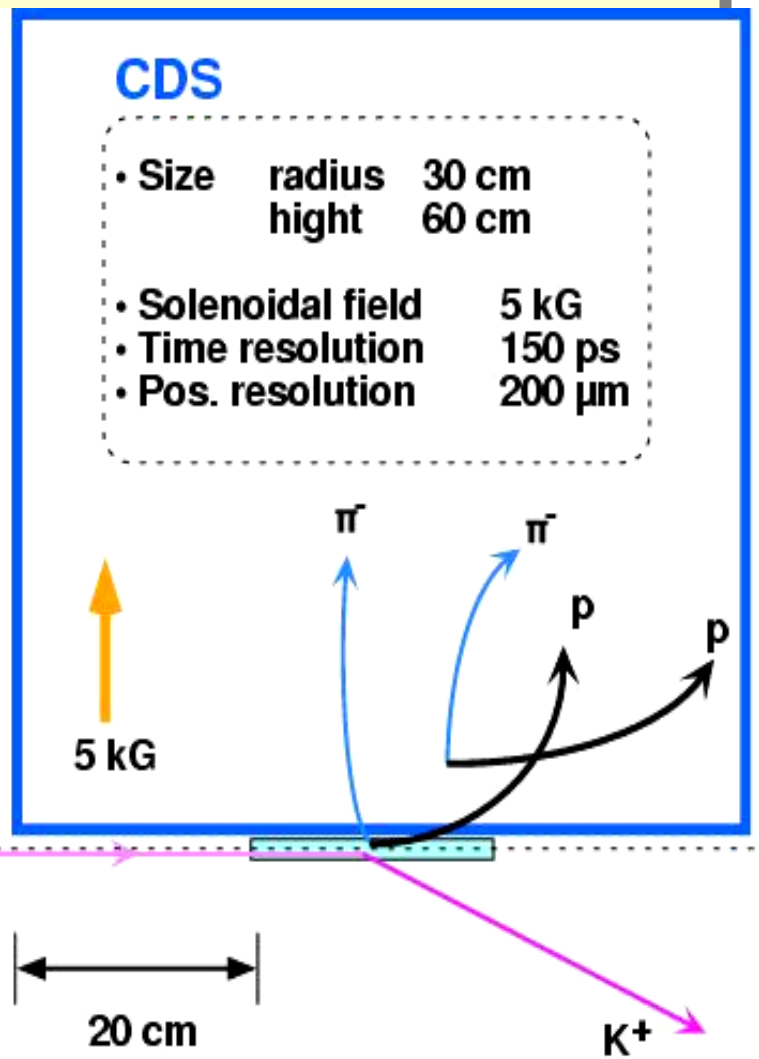
$\Xi^- p$ Scattering





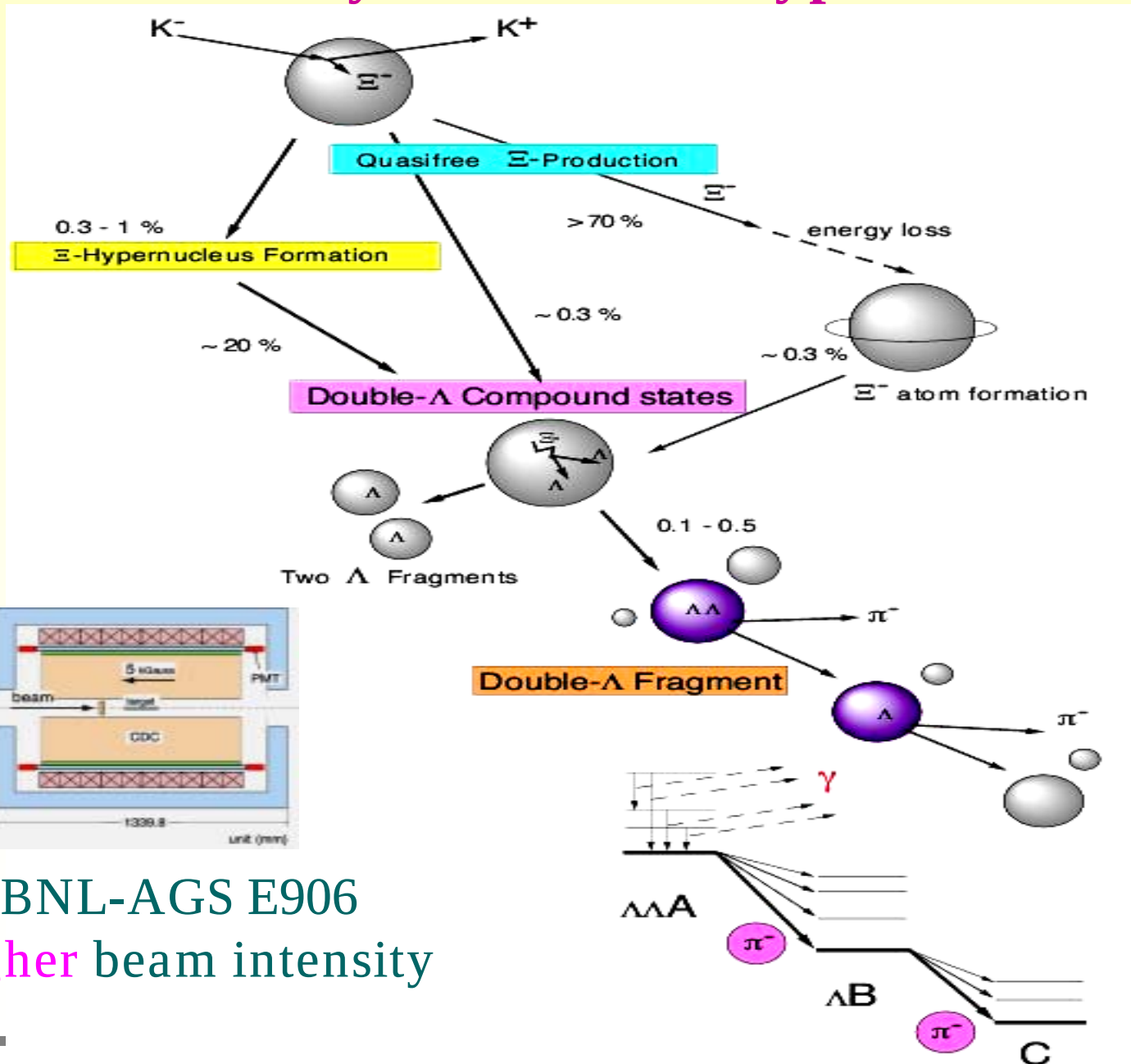
KEK-E224





By M. Ieiri @ KEK

Sequential Pionic Decays of Double Hypernuclei

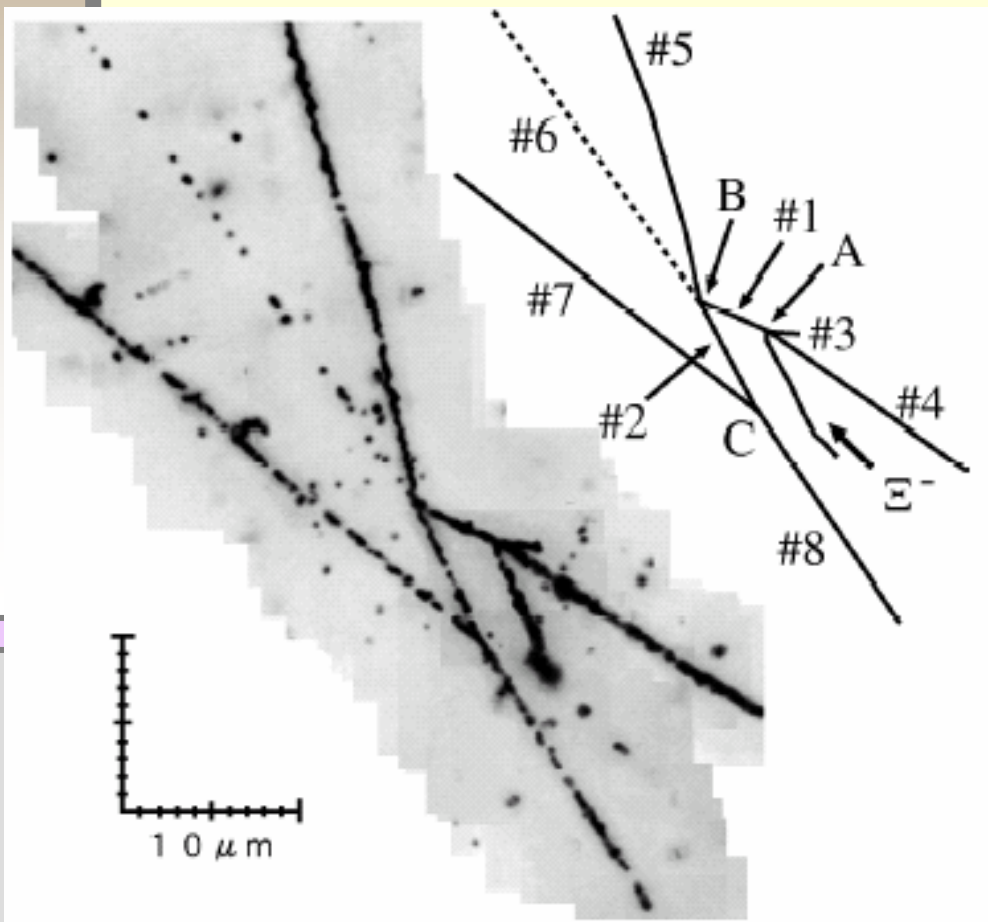


Upgrade of BNL-AGS E906

10 times higher beam intensity

Hybrid emulsion experiment KEK-E373

- Hybrid emulsion -- C(K^-,K^+) reaction to produce Ξ^- then stop it in emulsion
- NAGARA event found (H. Takahashi et al., PRL87(2001)212502)



- Track #1 is the ${}^{6}_{\Lambda\Lambda}\mathrm{He}$
- Binding energy of ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ is found to be
  $B_{\Lambda\Lambda} = 7.3 \pm 0.3$ MeV
  (from $\alpha+2\Lambda$)
- In order to extract $\Lambda\Lambda$ interaction, we take
  $\Delta B_{\Lambda\Lambda} = B_{\Lambda\Lambda} - 2B_{\Lambda}({}^{5}_{\Lambda}\mathrm{He})$
  $= 1.0 \pm 0.3$ MeV
  → weakly attractive

HYPERBALL Experiments

- KEK-PS E419 (1998)
  - spin-spin force in $^{7}_{\Lambda}$Li
  - glue-like role
- BNL-AGS E930 (1998)
  - spin-orbit force in $^{9}_{\Lambda}$Be
- BNL-AGS E930 (2001)
  - tensor force in $^{16}_{\Lambda}$O
  - in analysis
- KEK-PS E509 (2002)
  - stopped K
  - in analysis
- KEK-PS E518 (2002)
  $^{11}_{\Lambda}$B

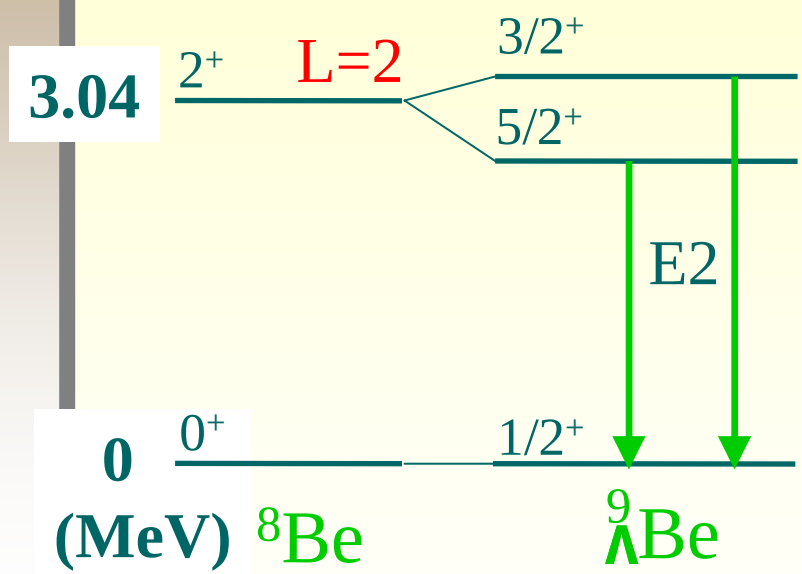
BNL-AGS E930

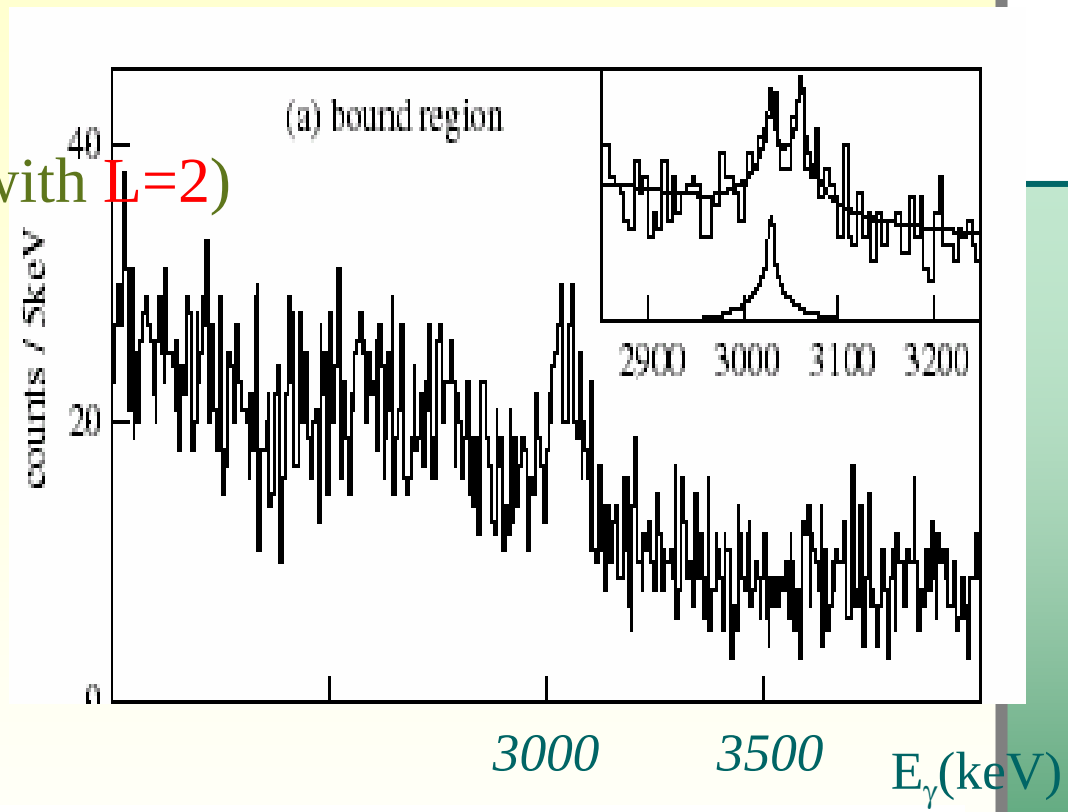
$5/2^+,3/2^+ \rightarrow 1/2^+$

$\Delta E(5/2^+,3/2^+)$

→ ΛN spin-orbit force, S_Λ

(core structure: 2α rotating with L=2)





- Two peaks separated!
- $|\Delta E| = 31 \pm 3$ keV - very small indeed
  → surprisingly small spin-orbit force (~ 1/100 of NN case)
  (H. Akikawa et al., PRL88(2002)082501)

On-going and Proposed Experiments

- KEK-PS
  - E521: study of neutron rich hypernuclei by (π^-,K^+) reaction
  - E518: γ-ray spectroscopy of ${}^{11}_{\Lambda}B$
  - E522: study of $\Lambda\Lambda$ final state interaction
- BNL-AGS
  - E964: study of $\Lambda\Lambda$ hypernuclei with hybrid-emulsion method and X-ray spectroscopy of Ξ^- atoms
- CEBAF(JLAB, Virginia, USA)
  - E01-011: spectroscopy of hypernuclei with $(e,e'K^+)$ reaction
  - E02-017: weak decay study
  - E94-107: high-resolution study with $(e,e'K^+)$ reaction
- More activities expected at Frascati (Italy), Dubna (Russia), Juelich, GSI(Germany), RCNP (Osaka, Japan).

Proposed Programs @ JHF

- Much more intense kaon (and other) beam available at JHF.
  - Systematic γ-ray spectroscopy of single Λ hypernuclei
    → not only ΛN force, but ΛNN force
  - Hyperon-Nucleon scattering (ΛN, ΣN, ΞN)
  - Spectroscopy of Ξ hypernuclei with (K^-,K^+) reaction
  - Production of relativistic hypernuclei using primary beams
    → measurement of magnetic moment
  - Study of ΛΛ hypernuclei and their weak decay
  - Charmed hypernuclei (charm quark instead of strange)
- Hypernucleus will be a main subject at JHF
  - Rich field for both theoretical and experimental studies.

Strangeness Physics @ HIPF

- ***Search for new types of baryonic matter***
  – *Λ(1405) , Σ(1750) ,Θ+(1530), H-dibaryon*
- ***Studies of hyperon interactions and decays, and hypernuclei***

→ ***Need High intense secondary beam lines up to a few GeV/c***