Overview of the strangeness physics program at MAMI

Kyo Tsukada
Tohoku University
for A1-hypernuclear collaboration

Contents

- Introduction
  - Motivations of hypernuclear study
  - Hypernuclear spectroscopy with electron beam
- Experimental apparatus at MAMI-C
- Experiment at MAMI-C
  - Elementary kaon production
  - Decay pion spectroscopy at MAMI
  - Future plan of Kaos
- Summary

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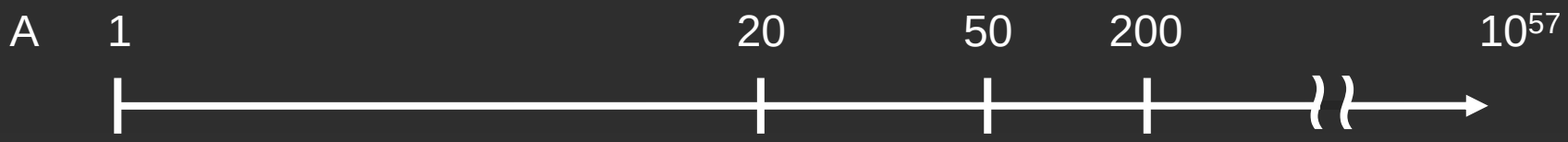
Objectives of hypernuclear physics



Elementary Process

Strangeness electro-production

Light Hypernuclei (s,p shell)

Neutron/Hyperon star,
Strangeness matter

Hyperonization →
Softening of EOS ?

Extend Nuclear Force to Baryon Interaction

CSB effect

ΛΣ coupling in large isospin hypernuclei

Medium - Heavy hypernuclei

Use Λ as a probe to see deep inside of nucleus

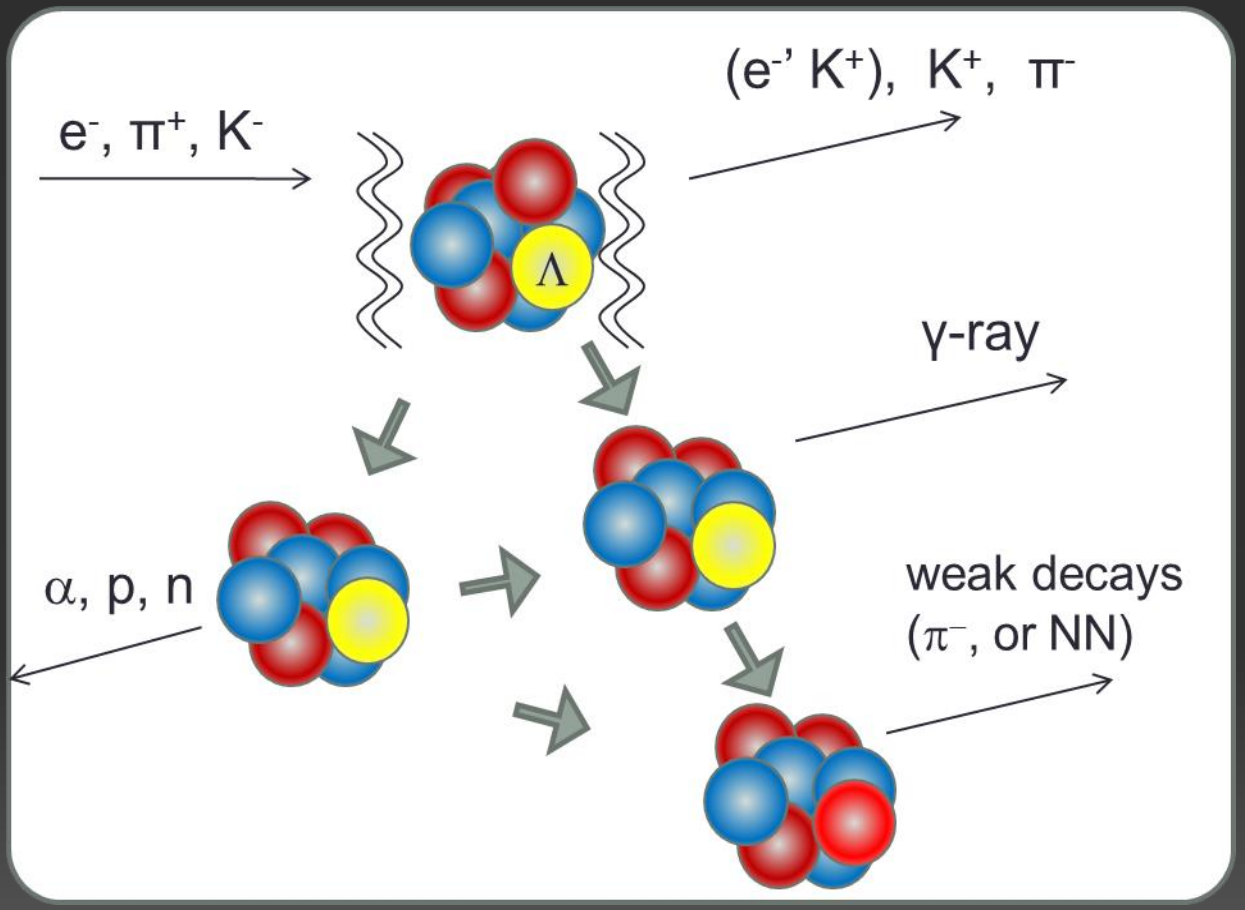
Single-particle potential

$U_0(r)$, $m_\Lambda^*(r)$, $V_{\Lambda NN}$, ...

Collective motion of nucleons

Deformation of nuclei

Measurements of Λ hypernucleus



Reaction spectroscopy
B_Λ, mass
JPARC, Jlab, etc …

γ-ray spectroscopy
level- splitting
JPARC

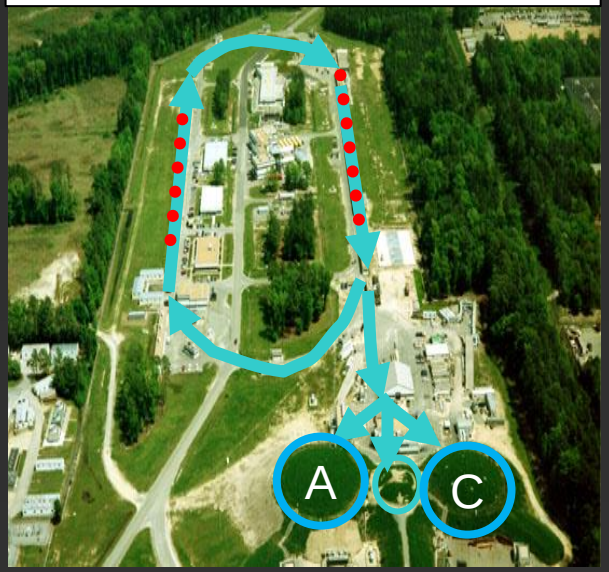
Emulsion
B_Λ, mass
JPARC

decay π^- spectroscopy
Mass
MAMI, JLab

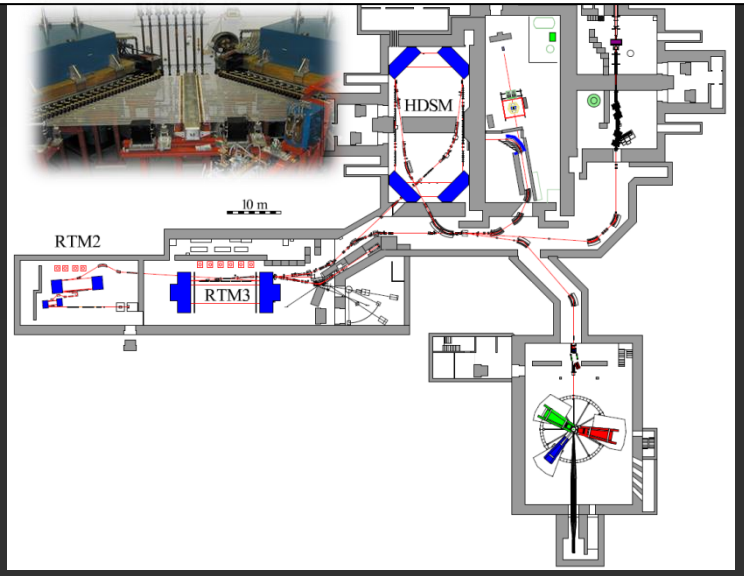
Study of Electro-produced hypernuclei at JLab and Mainz have been strongly conducted by Tohoku Group.

Electron Beam Facilities

CEBAF @JLab, VA



MAMI-C, Mainz, Germany



	CEBAF	MAMI-C
Max. Beam energy [GeV]	6.0	1.6
Max. beam intensity [μA]	100	100
Beam size [μm in rms]	~100	~100
Energy resolution	$<10^{-4}$	$<10^{-4}$
Emittance [μm mrad]	20	27π

History of JLab and Mainz (e,e'K$^+$) experiments

2000

2004

2008

2012

2016

2000 E89-009

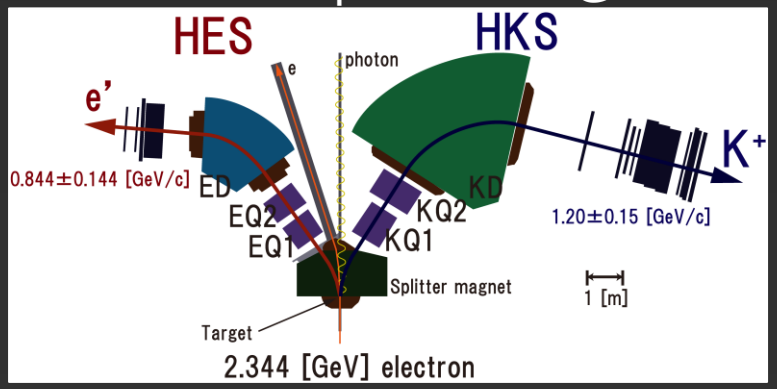
2004 E94-107
2005 E01-011

2009 E05-115

JLab Upgrade
6 GeV -> 12 GeV

Planning Next generation

Setup in Hall-C @2009



(e,e'K+) hypernuclear spectroscopy
A=1 to 52
Recent results by
T. Gogami tomorrow

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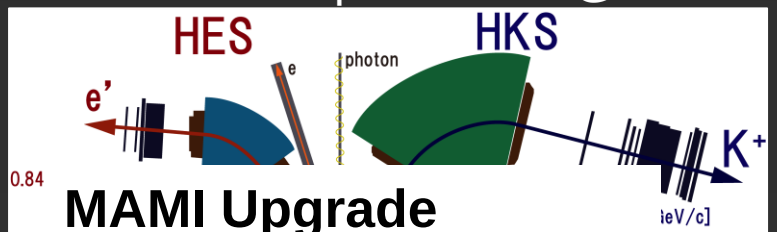

MAMI Upgrade
0.855 GeV -> 1.6 GeV

2008 p(e,e'K+)
2009 p(e,e'K+)

2011 p(e,e'K+)
Decay pion

2012 Decay pion

May/2014 Decay pion

ow

History of JLab and Mainz (e,e'K$^+$) experiments

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2008

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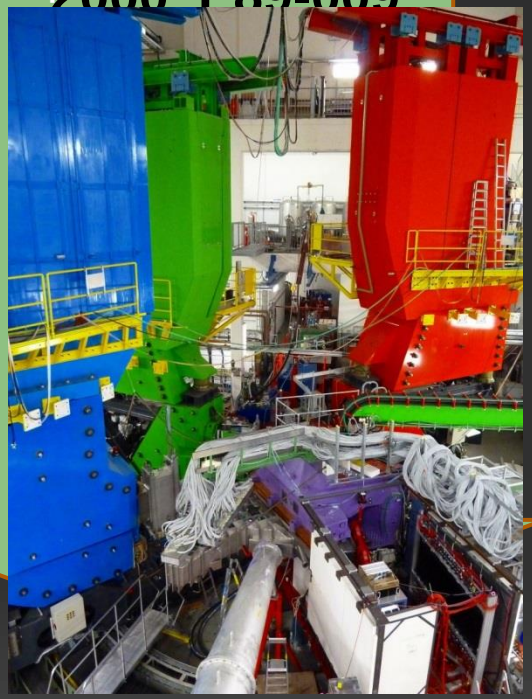
2016

Spectrometers in A1 hall



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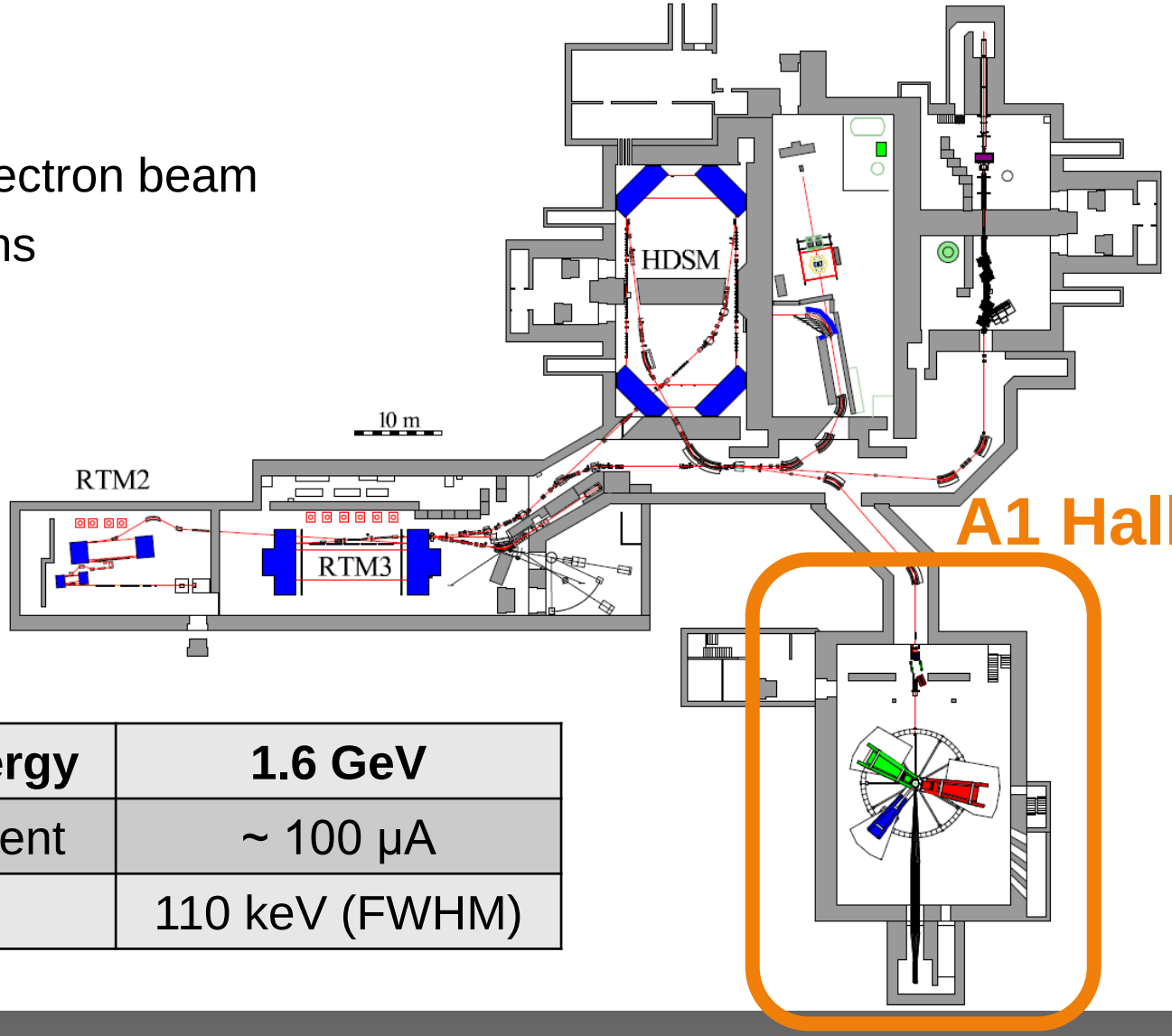
MAMI-C

Mainz Microtron

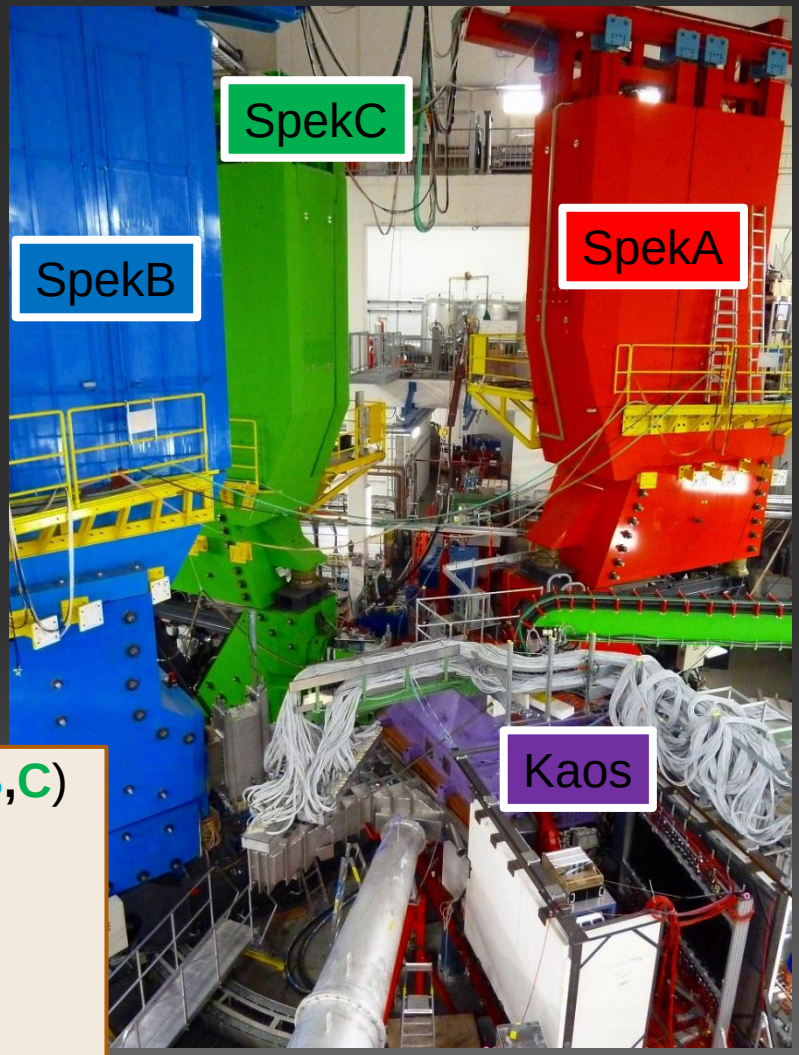
- Continuous wave electron beam
- LINAC & 4 microtrons



Maximum beam energy	1.6 GeV
Maximum beam current	~ 100 µA
Energy spread	110 keV (FWHM)

Strangeness electro-production off proton and nuclei target

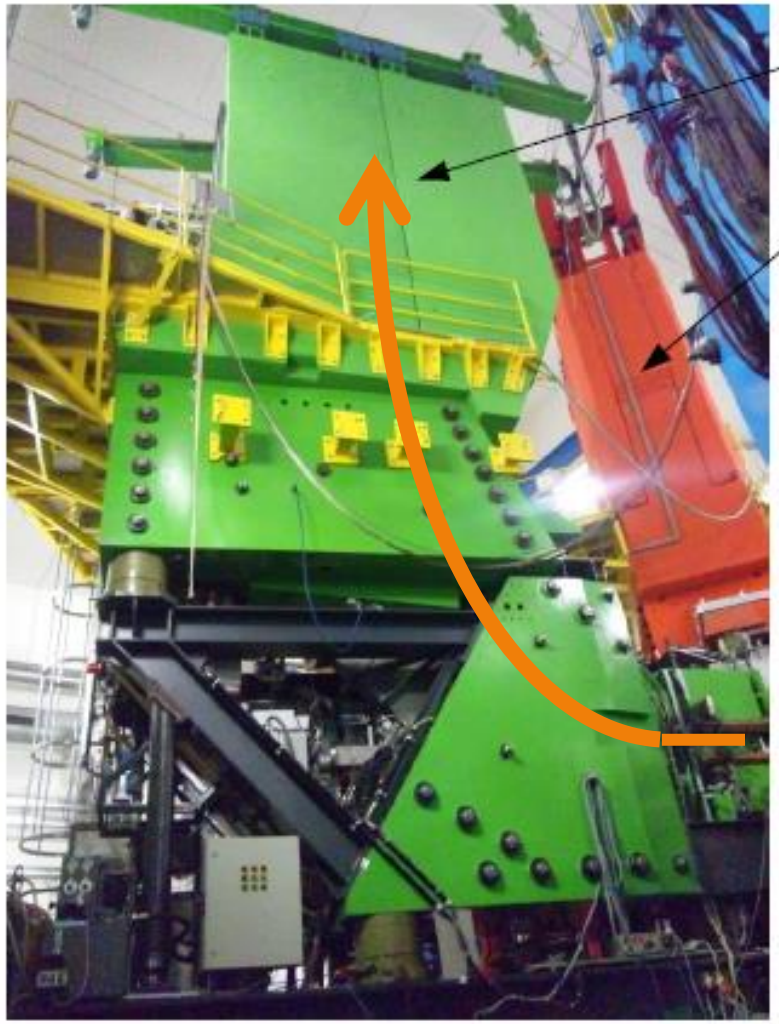
- **Elementary kaon production**
  - low Q^2 region
  - Polarized electron beam
  - 2008, 2009, 2011
- **Decay pion spectroscopy**
  - Pilot experiments
  - 2011, 2012, May/2014
- **Hypernuclear spectroscopy**
  - Under detector development



Three high resolution spectrometers (**SpekA**,**B**,**C**)
well established
$\Delta p/p \sim 10^{-4}$

One short orbit spectrometer (**Kaos**)
still developed

High resolution spectrometers in A1-Hall

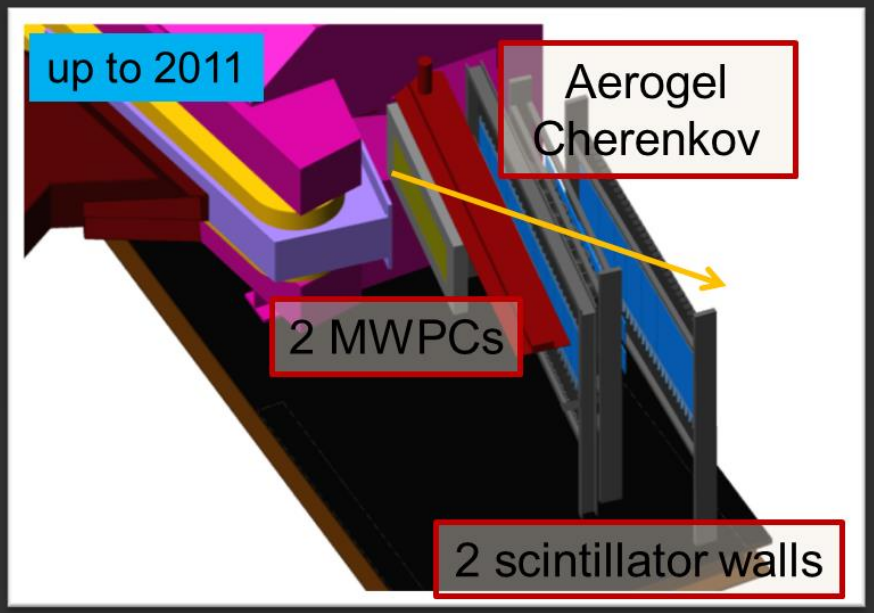


Spectrometer C (green)

Spectrometer A (red)

- Features:
  - Momentum resolution: $\frac{\Delta p}{p} = 10^{-4}$
    $\Delta p < 20\,keV/c$ (125 MeV central momentum)
    Mass resoluion: $\Delta m < 30\,keV/c^2$
  - Solid angle: 28 msr
  - Momentum acceptance:
    - Spec A: 20 %
    - Spec C: 25 %
  - Length of central trajectory:
    - Spec A: 10.75 m
    - Spec C: 8.53 m
  - Gas threshold Cherenkov for pion / electron separation

Kaos



Basic setup of Kaos for
Elementary kaon production experiments
&
1st decay pion experiment

- Solid angle : 20 msr
- Momentum acceptance : 50 %
- Length of Trajectory : 5.3 m
- Detectors
  - MWPCs
  - TOF walls
  - Aerogel cherenkov detector (n=1.05)

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Strangeness Photo-/Electro-production

$$\frac{d\sigma}{d\Omega_f dE_f d\Omega} = \Gamma \frac{d\sigma_v}{d\Omega}, \qquad \Gamma = \frac{\alpha}{2\pi^2}\frac{E_f}{E_i}\frac{k_\gamma}{Q^2}\frac{1}{1-\varepsilon}$$

$$\frac{d\sigma_v}{d\Omega} = \frac{d\sigma_T}{d\Omega} + \varepsilon_L \frac{d\sigma_L}{d\Omega} + \sqrt{2\varepsilon_L(1+\varepsilon)}\frac{d\sigma_{LT}}{d\Omega}\cos\phi + \epsilon\frac{d\sigma_{TT}}{d\Omega}\cos 2\phi + h\sqrt{2\varepsilon_L(1-\varepsilon)}\frac{d\sigma_{LT'}}{d\Omega}\sin\phi$$

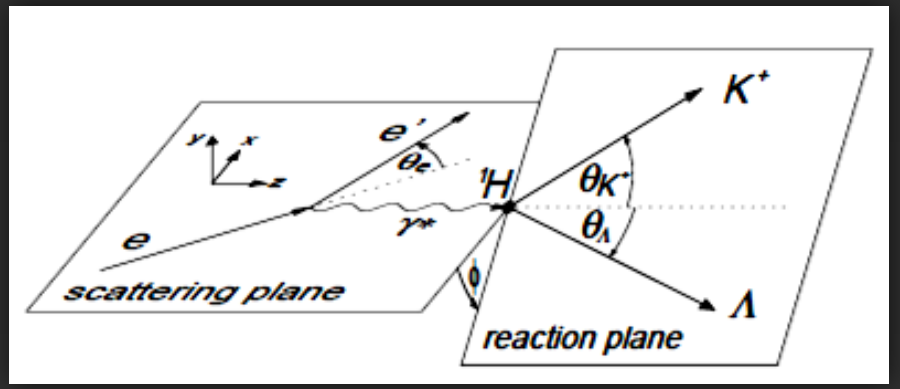


Photo-production :
- ✓ simpler mechanism
- ✓ basic information

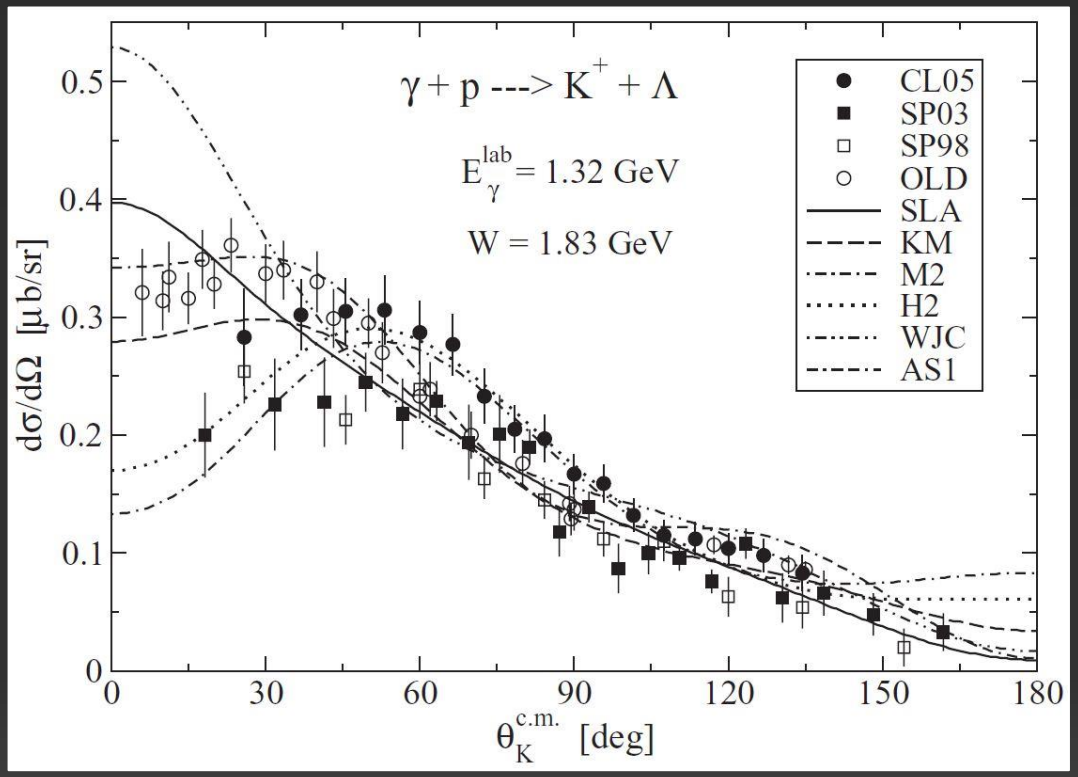
CLAS/Jlab
LEPS/Spring8
SAPHIR/ELSA
NKS,NKS2/ELPH
…

Electro-production :
- ✓ Longitudinal mode
- ✓ interferences

CLAS/JLab : >0.5 $(GeV/c)^2$
KAOS/MAMI-C : ~0.05 $(GeV/c)^2$
…

complementary

Large ambiguity at forward region



P.Bydzovsky and T.Mart, Phys. Rev. C 76, 065202 (2007)

- At forward angle,
  - Lack of consistency between experimental data
  - Resulting large ambiguity for theoretical calculations
- Very serious problems for (e,e'K^+) hypernuclear calculations

(e,e'K^+) experiments at Mainz

- Sept/Oct 2008 : 1st experiment
- July 2009 : 2nd experiment
- Nov/Dec 2011 : 3rd experiment w/ polarized beam (P_{beam} ~ 87%)

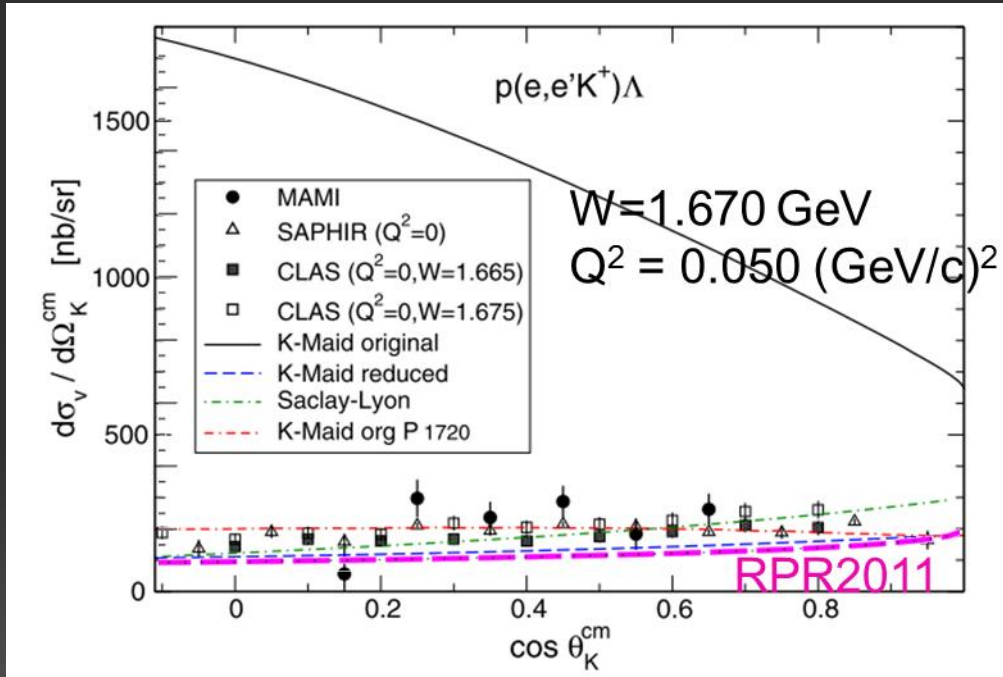
	Ee [GeV]	Q^2 [(GeV/c)^2]	W [GeV]	ε (trans.)	ω [GeV]	$P_{e'}$ [GeV/c]	$\theta_{e'}$ [deg]	$\phi_{e'}$ [deg]	P_{K+} [GeV/c]	θ_{K+} [deg]
1st	1.508	0.050	1.670	0.540	1.044	0.455	15.8	0	0.5	-31.5
2nd	1.508	0.036	1.750	0.395	1.182	0.327	15.5	0	0.530	-31.5
3rd	1.508	0.055	1.725	0.442	1.143	0.365	14.4	10	0.472	-37.6

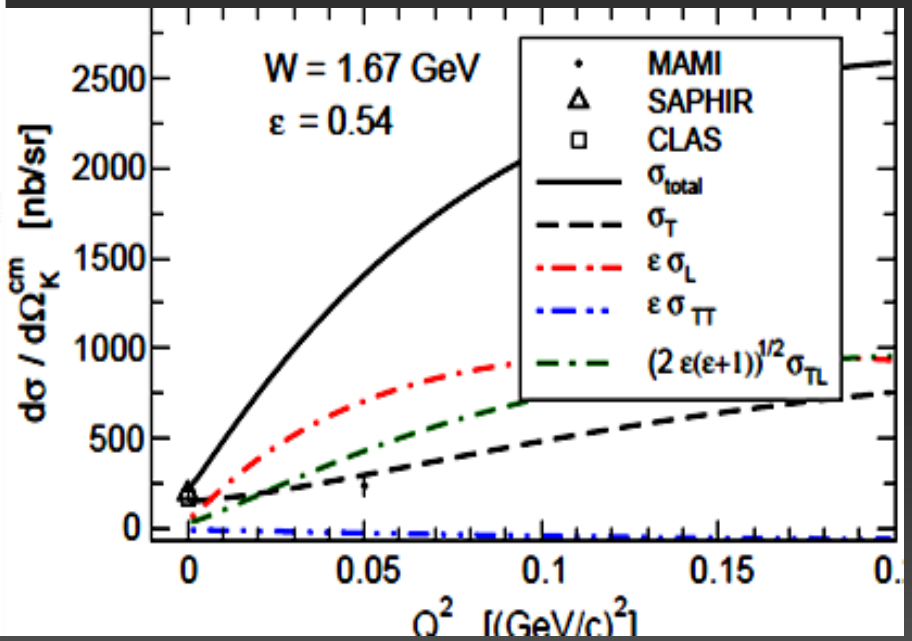
Q^2 range : 0.03 – 0.05 (GeV/c)^2
W : ~1.7 GeV
$\theta_{K,CM}$: $\lesssim$ 90 degree

target	liquid H_2
thickness	5 cm (370 mg/cm$^{2)}$

Results of 1st and 2nd experiments

- The transition from photo-production to electro-production is smooth.
- A model including strong longitudinal coupling cannot explain data.





K-Maid reduced

-8.99 -> 0.39 for $P_{13}(1720)$

10.3 -> -0.04 for $D_{13}(1895)$

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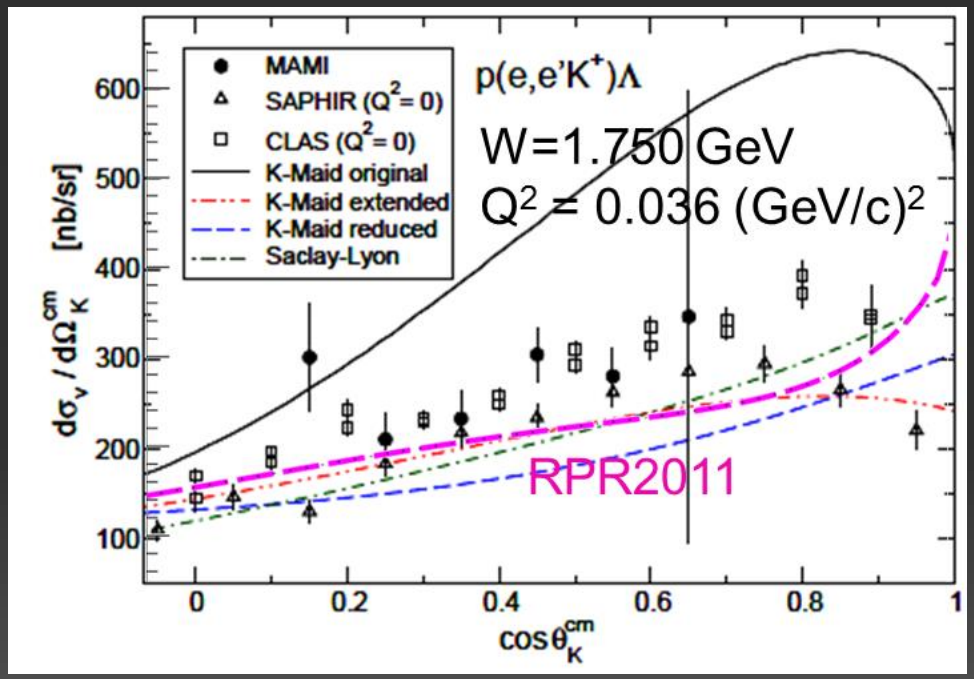
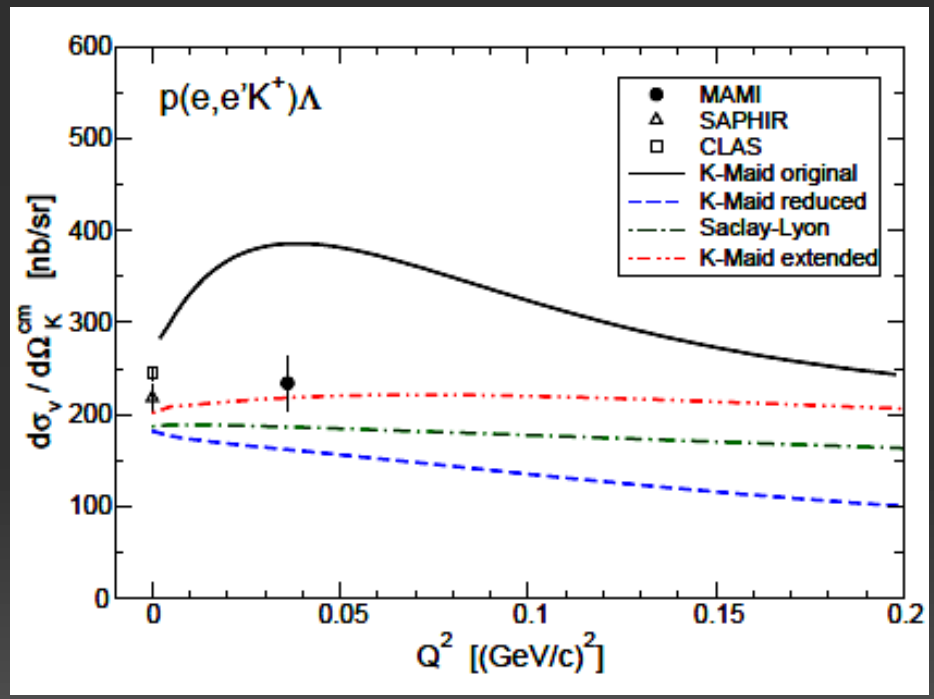




K-Maid reduced

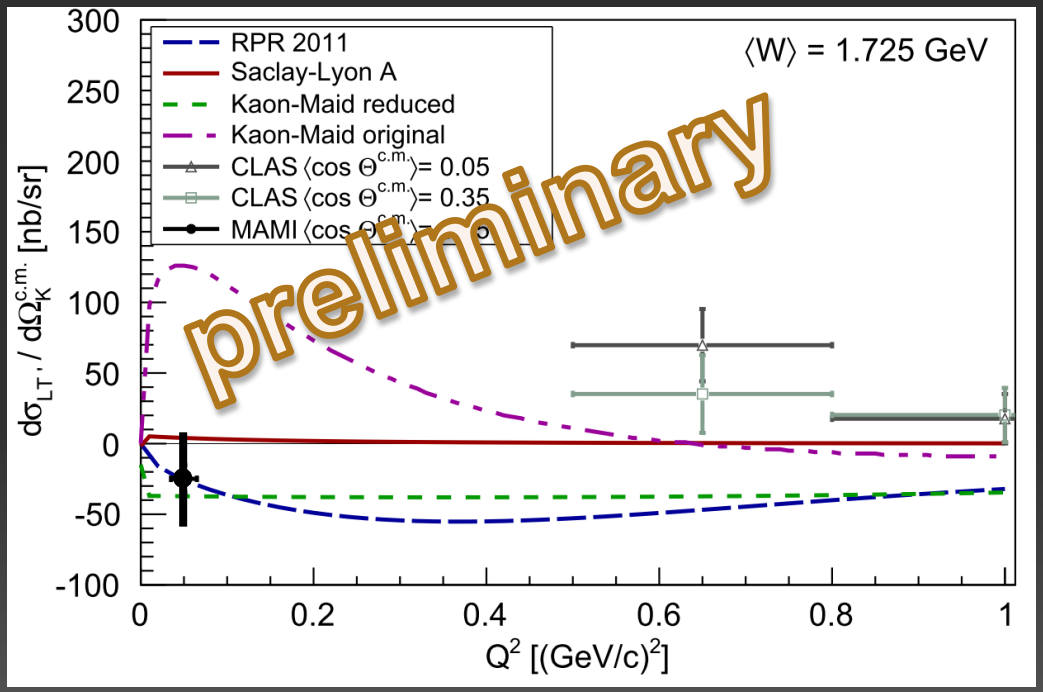
-8.99 -> 0.39 for $P_{13}(1720)$

10.3 -> -0.04 for $D_{13}(1895)$

Results of 3rd experiment

- Data at 2011
  - Liquid Hydrogen target
  - Polarized electron beam (~ 87%)
  - ε = 0.44, ϕ=40º

$$\frac{d\sigma_v}{d\Omega} = \frac{d\sigma_T}{d\Omega} + \varepsilon_L \frac{d\sigma_L}{d\Omega} + \sqrt{2\varepsilon_L(1+\varepsilon)}\frac{d\sigma_{LT}}{d\Omega}\cos\phi + \epsilon\frac{d\sigma_{TT}}{d\Omega}\cos 2\phi + h\sqrt{2\varepsilon_L(1-\varepsilon)}\frac{d\sigma_{LT'}}{d\Omega}\sin\phi$$



Recent models are consistent with our results.
But, the tendency among all data set can not be explained.

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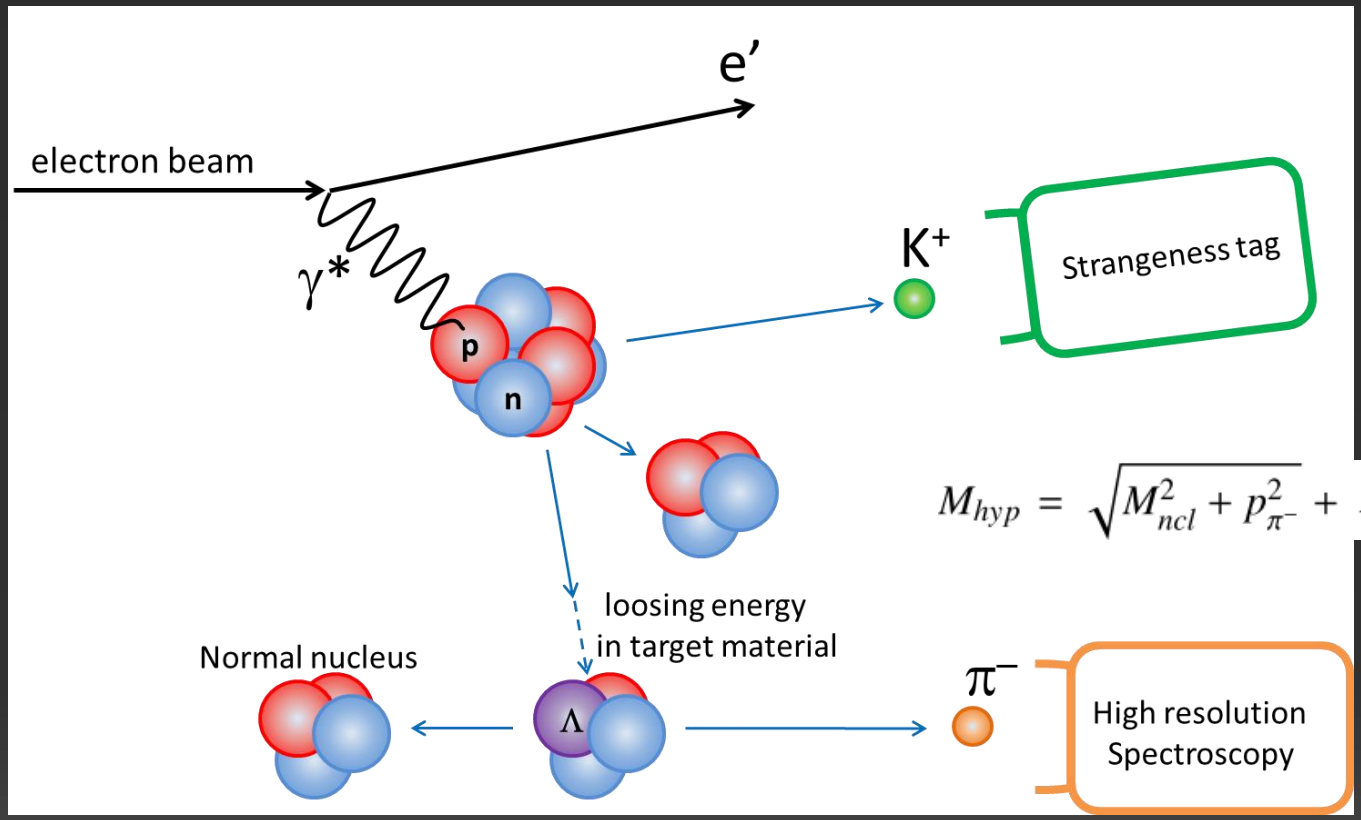
Concept of decay pion spectroscopy



Energy straggling in target
-> Thin, but thick enough to stop HY (~ 10 mg/cm^2)
Small production cross section (~ 100 nb/sr)

High intensity (max. 100μA)
& resolution beam

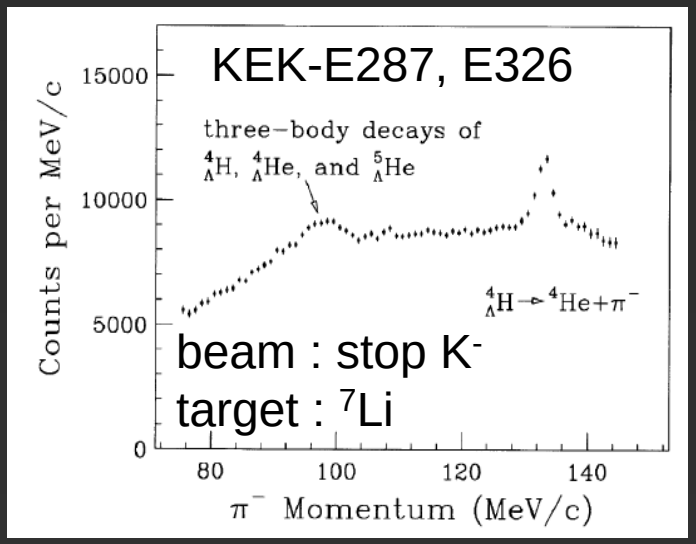
Mass resolution : 100 keV
Mass accuracy : 30 keV

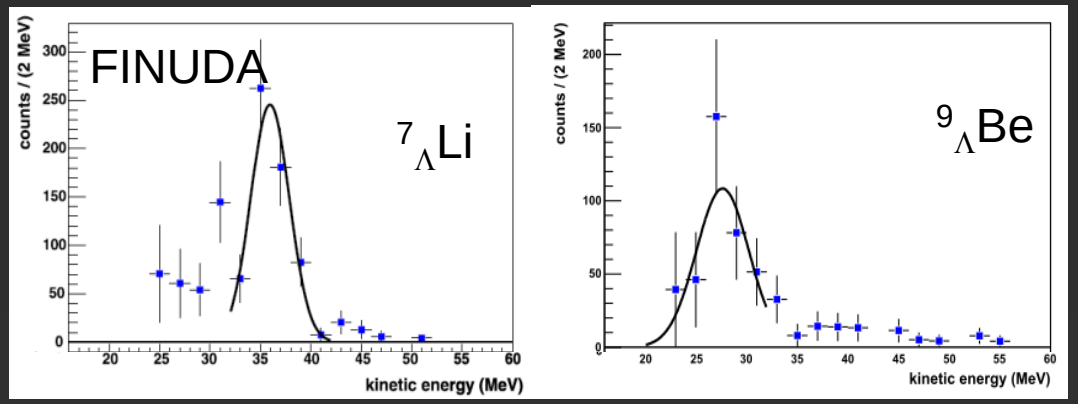
Hypernuclei from ^{9}Be target

break-up mode	Q value (MeV)	π^- decay	p_π (MeV/c)
$^{9}_{\Lambda}$Li	-	^{9}Be + π^-	121.18
p + $^{8}_{\Lambda}$He	-13.817	^{8}Li + π^-	116.40
n + $^{8}_{\Lambda}$Li	-3.756	^{8}Be + π^-	124.12
2p + $^{7}_{\Lambda}$H	-40.328 (B_Λ=6.1)	^{7}He + π^-	135.17
d + $^{7}_{\Lambda}$He	-12.568	^{7}Li + π^-	114.61
2n + $^{7}_{\Lambda}$Li	-12.218	^{7}Be + π^-	108.02
^{3}He + $^{6}_{\Lambda}$H	-29.608 (B_Λ=5.1)	^{6}He + π^-	133.47
^{3}H + $^{6}_{\Lambda}$He	-9.745	^{6}Li + π^-	108.39
3n + $^{6}_{\Lambda}$Li	-18.957	^{6}Be + π^-	100.58
α + $^{5}_{\Lambda}$H	-11.749 (B_Λ=4.1)	^{5}He + π^-	133.42
n + α + $^{4}_{\Lambda}$H	-12.005	^{4}He + π^-	132.95
^{6}He + $^{3}_{\Lambda}$H	-18.183	^{3}He + π^-	114.29

Other targets, ^{7}Li or ^{12}C or so, should be measured in future.

π^- spectra of past experiments

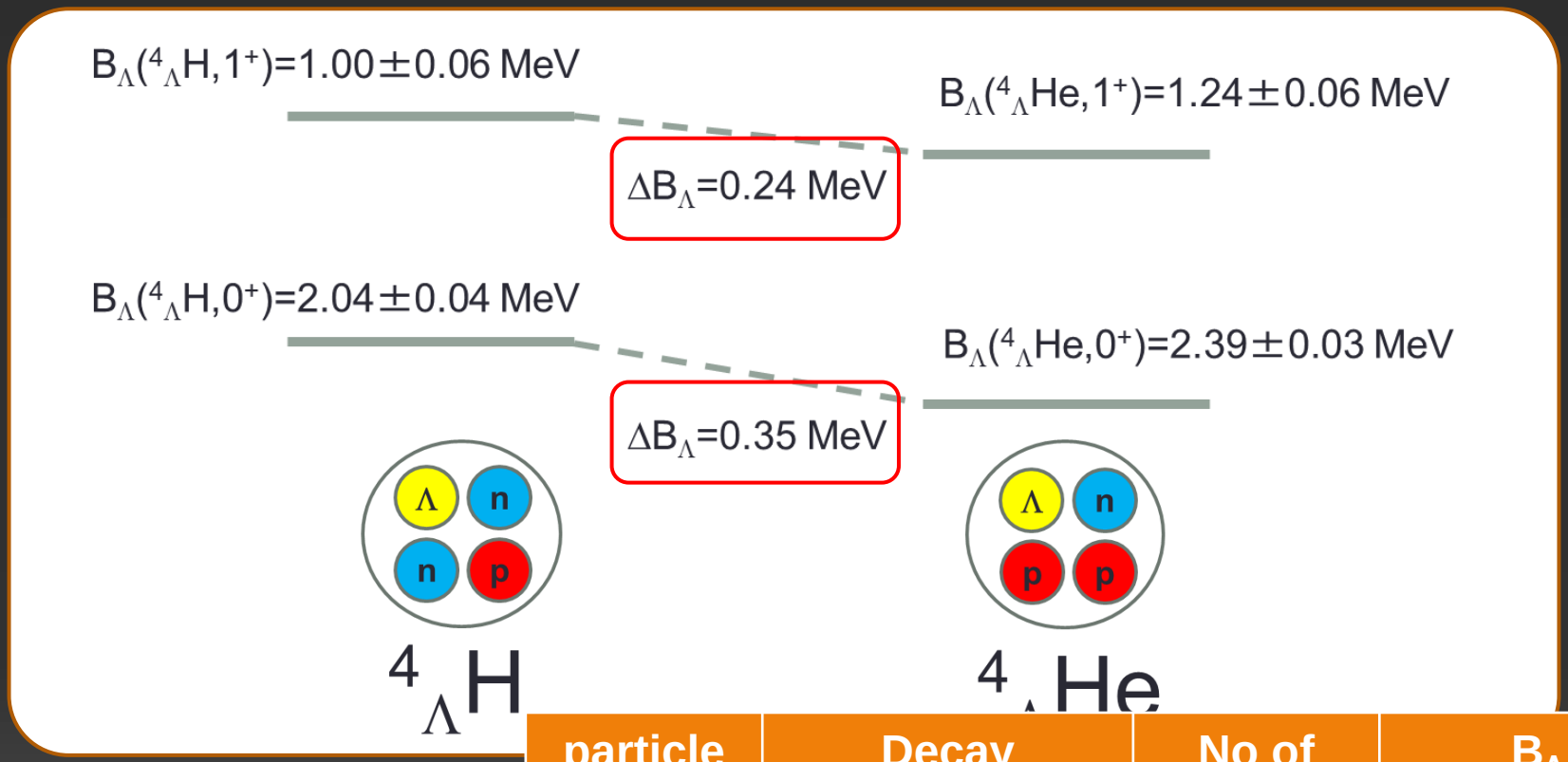




M. Agnelo., *et al*., Phys Rev. B 681 (2009) 139

- Better resolution is required to determine the absolute mass accurately
- $^{4}_{\Lambda}$H is
  - suitable to check the feasibility of experiment
  - important to understand the energy levels of light hypernuclei.
- Relative yields among hypernuclei are also important for further studies.
  - Exp. data
  - Calculation

Charge Symmetry Breaking effect in ΛN interaction



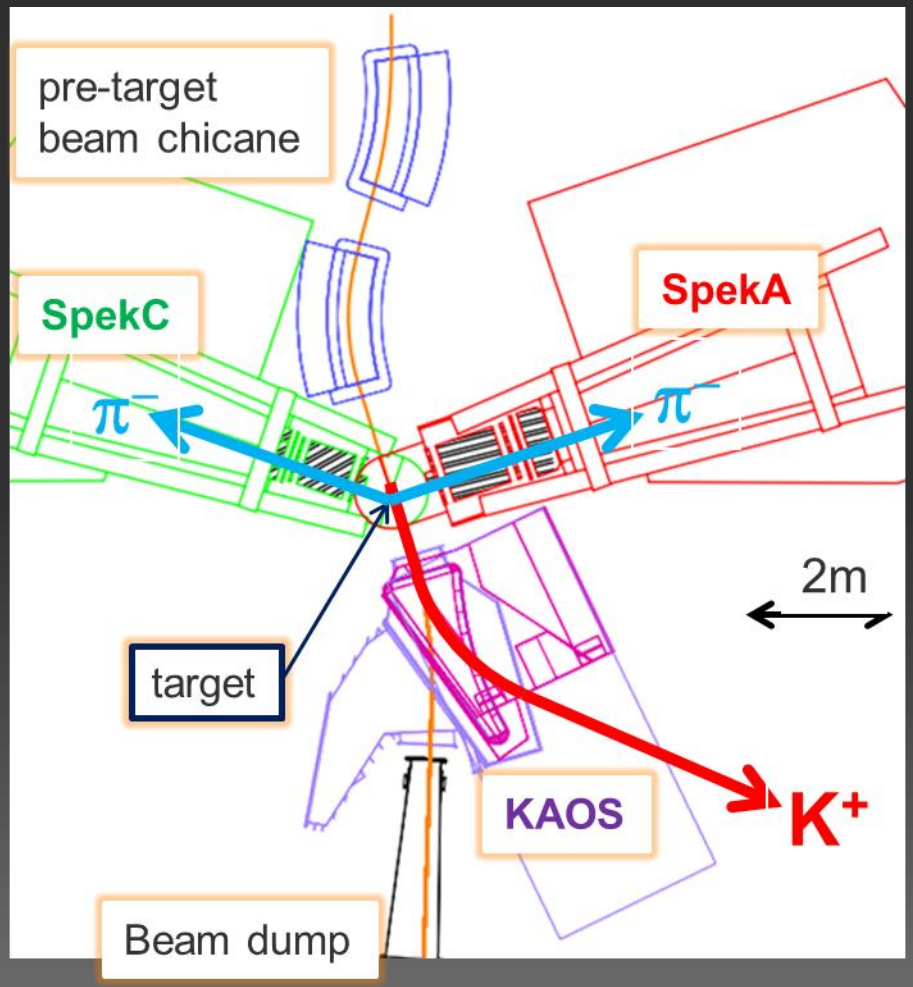
Coulomb effect
- $-\Delta B_C = 0.050\pm0.02$ M
- $-\Delta B_C{}^*=0.025\pm0.015$ M

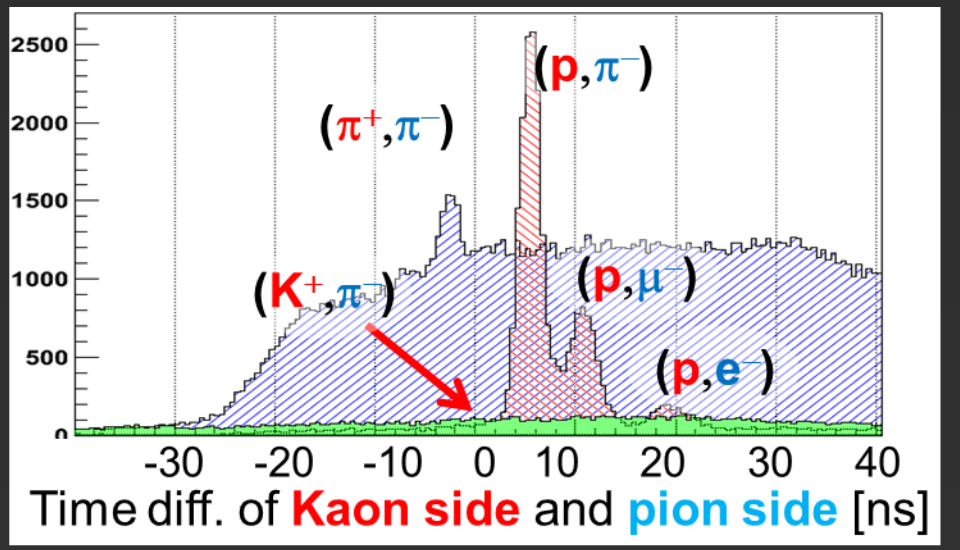
particle	Decay mode	No of events	B_Λ (MeV)
$^4_\Lambda H$	π- + p + ^3H	56	2.14±0.07
	π- + ^2H + ^2H	11	1.92±0.12
$^4_\Lambda He$	π- + p + ^3He	83	2.42±0.05
	π- + p + p + ^2H	15	2.44±0.09

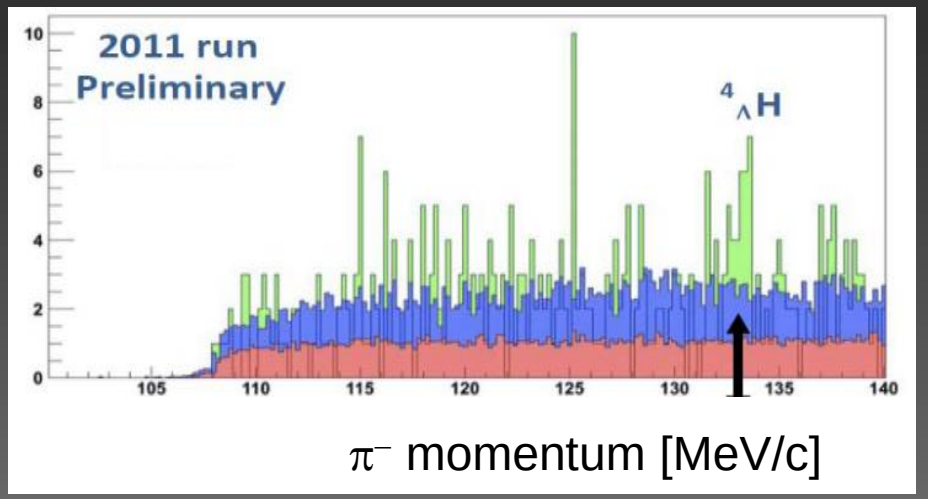
Data from
M. Juric, et.al., Nucl.Phys.B **52** (1973) 1
M. Bedjidian, et.al., Phys.Lett. B**83** (1979) 252

1st pilot experiment and consequence

Date : Jul/Aug 2011
Target : ^{9}Be (125 μm=22 mg/cm^2)
Beam intensity : 2 μA

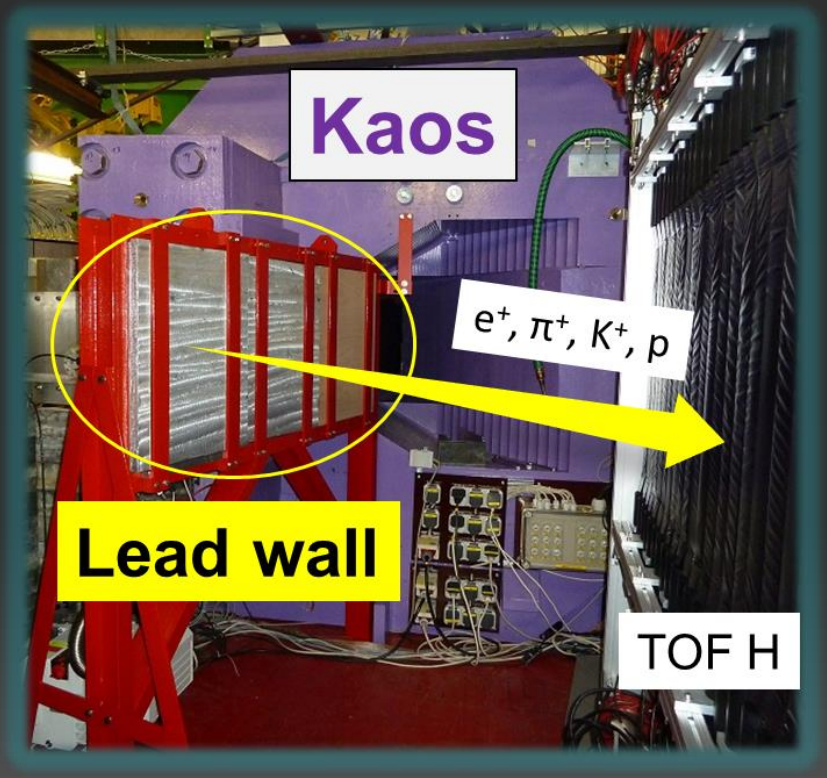


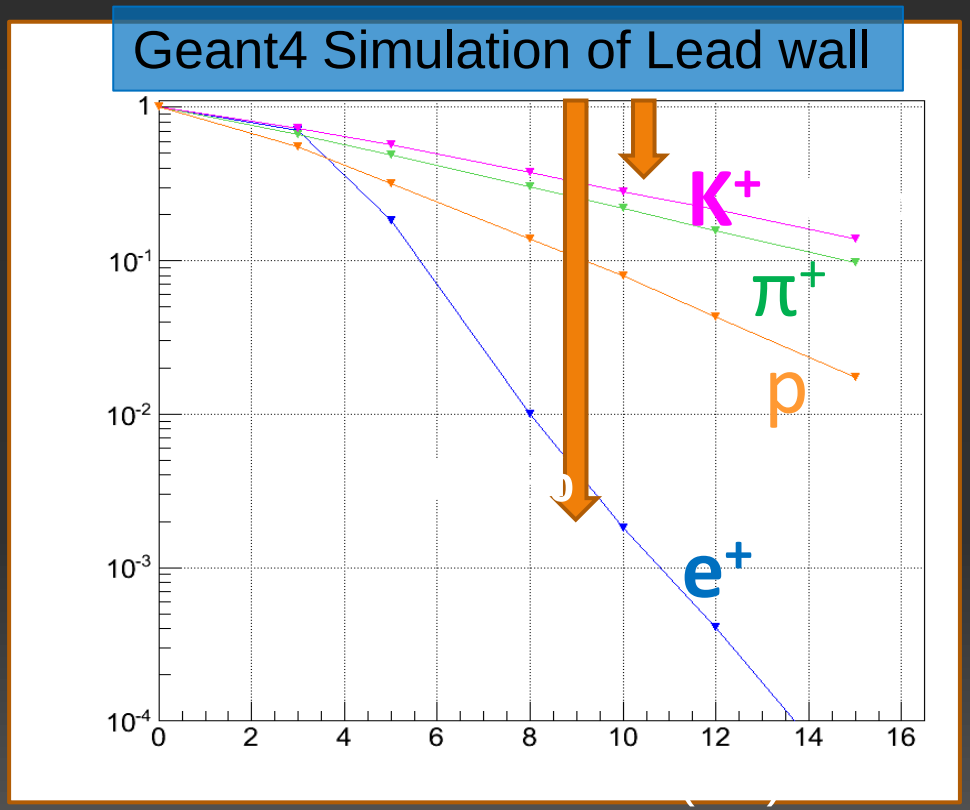




Modification for decay pion spectroacopy

- Momentum resolution : No relation with mass resolution
- Positron background : Seriously high (1MHz / 1 μ A)





2nd experiment at Oct 2012, and planning 3rd experiment at May/Jun 2014 will be reported by **Sho Nagao** tomorrow.

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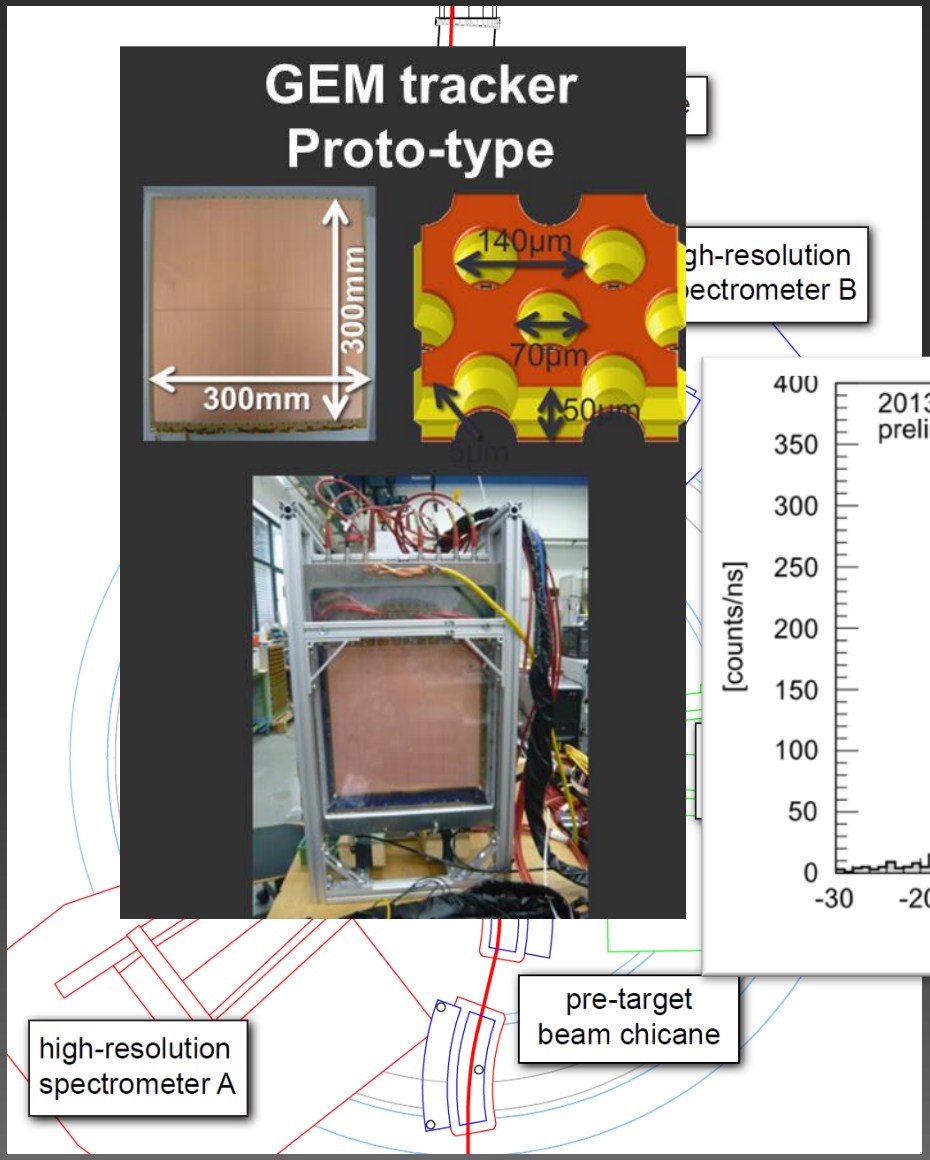
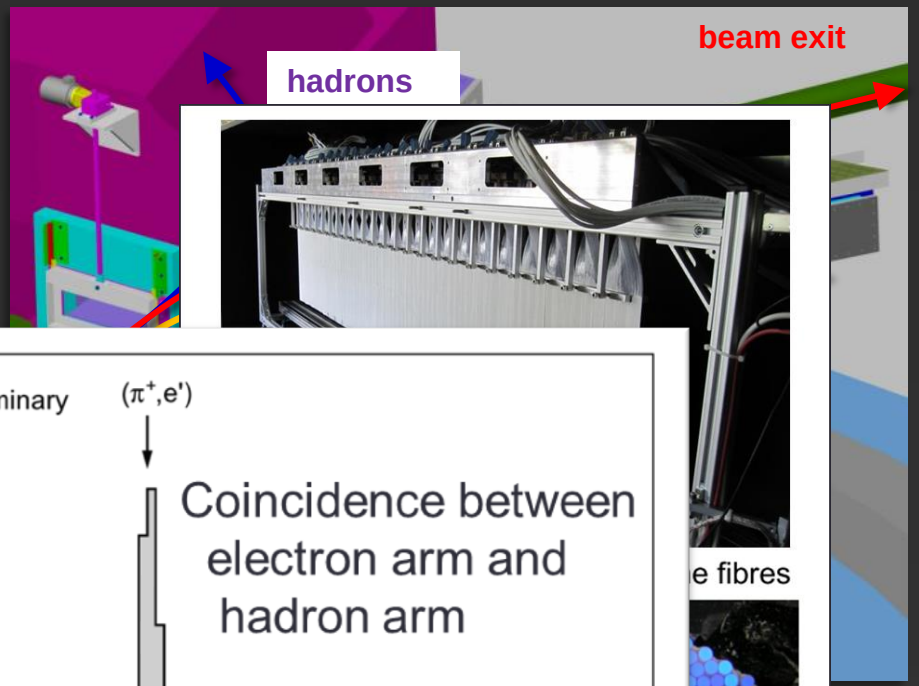
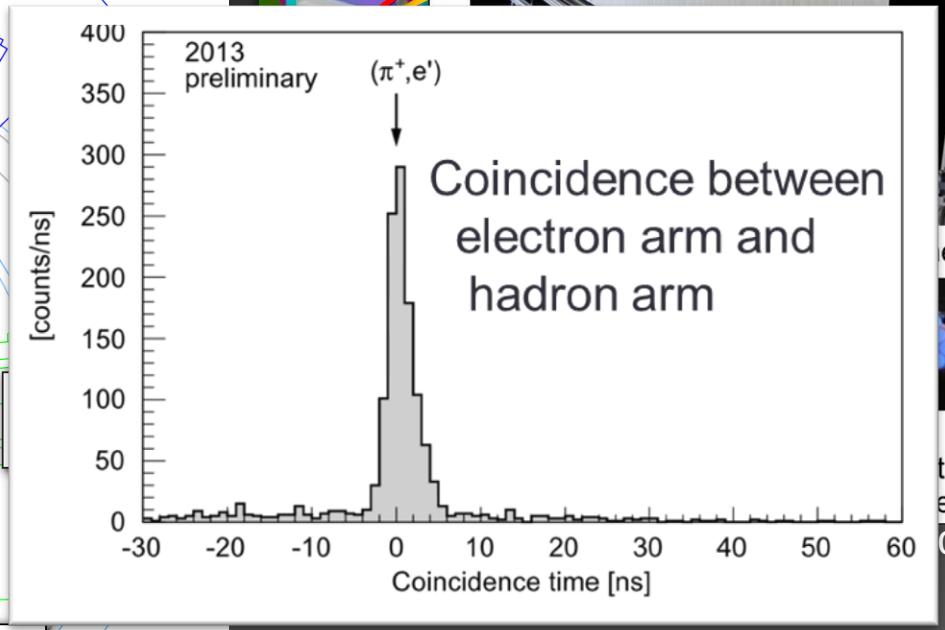
Kaos spectrometer upgrade in future







- low-Z targets, H_2, D_2, He, ^{6,7}Li, ^{9}Be, …
  (elementary, Λn correlation, hypernuclei, …)

Summary

- Hypernuclear spectroscopy
  - Important for expanding NN interaction to YN interaction
- We have performed strangeness physics at MAMI-C since 2008.
  - Complementary to JLab experiments
  - Elementary Kaon production
    - Old models were excluded.
    - New measurements, $d\sigma_{LT'}/d\Omega$
  - Decay pion spectroscopy
    - Kaon couldn't be identified due to huge background at the first experiment
    - 2nd experiment was performed with lead block absorber
    - 3rd experiment will be performed 2014
  - Kaos upgrading is ongoing.
    - Scintillation fiber tracker for scattered electron side
    - GEM tracker for hadron side