Method and performance of K^+ meson identification in the ^{3}H$(e,e'K^+)$X experiment

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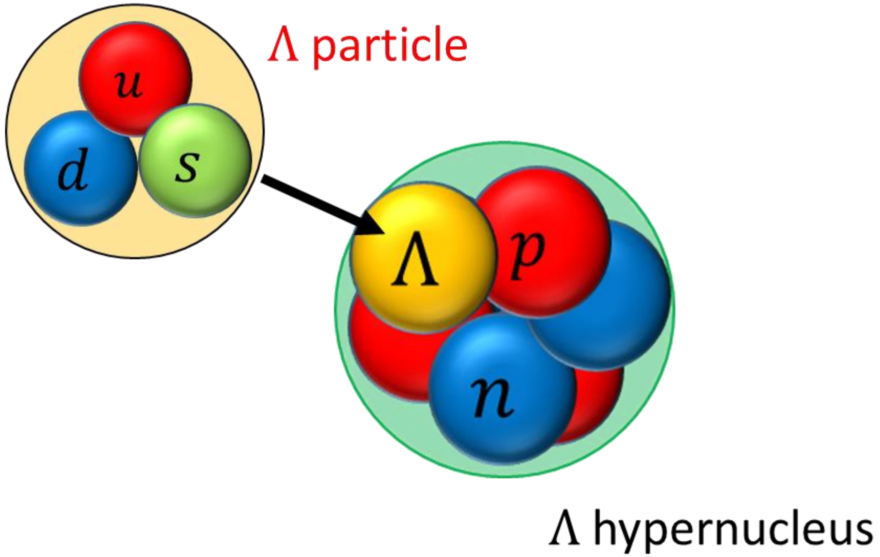
Λ hypernuclei



Λ particle

- Life time $\tau_\Lambda = 263.2$ ps
- Mass : $m_\Lambda = 1115.683\ \mathrm{MeV}/c^2$

Λ hypernucleus

- $\Lambda +$ nucleus

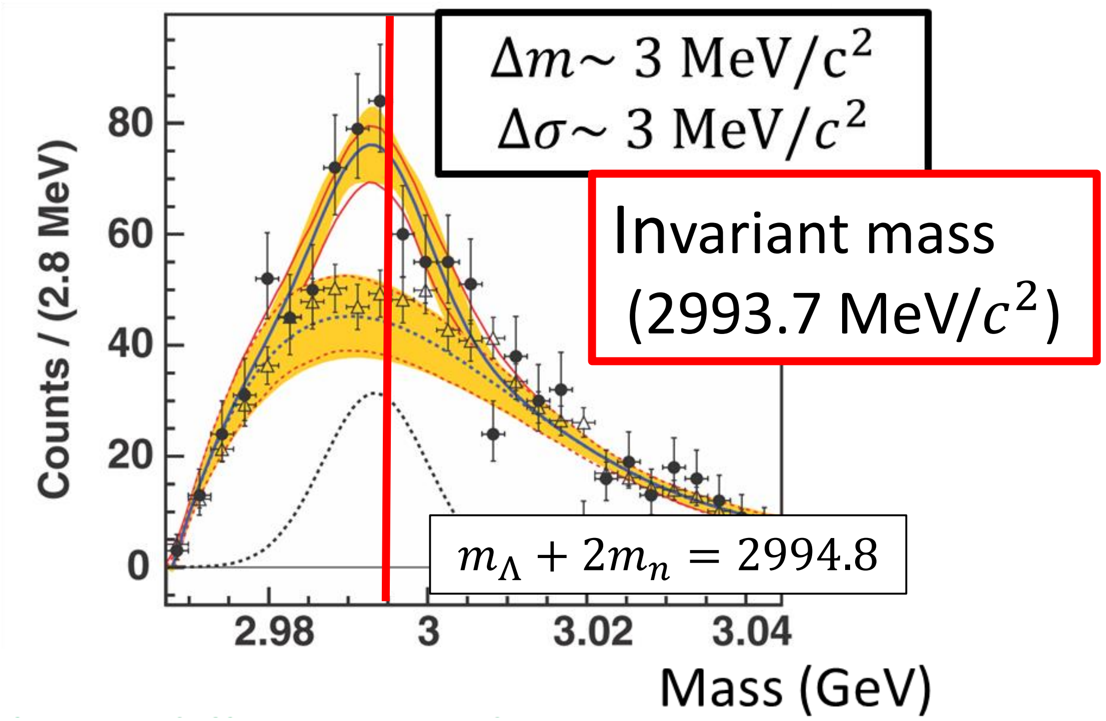
Measurement of the Λ hypernuclei

↓

$\Lambda - N$ interaction

Research for the $nn\Lambda$ experiment at GSI

Invariant mass $(t + \pi^-)$ distribution at GSI



C. Rappold *et al*. (HypHI Collabratin), *Phys. Rev. C* ***88***, 041001(R) (2013).

Theoretical model [1]
→Unbound

[1]E **Hiyama**, S Ohnishi, BF Gibson, TA Rijken - Physical Review C, 2014

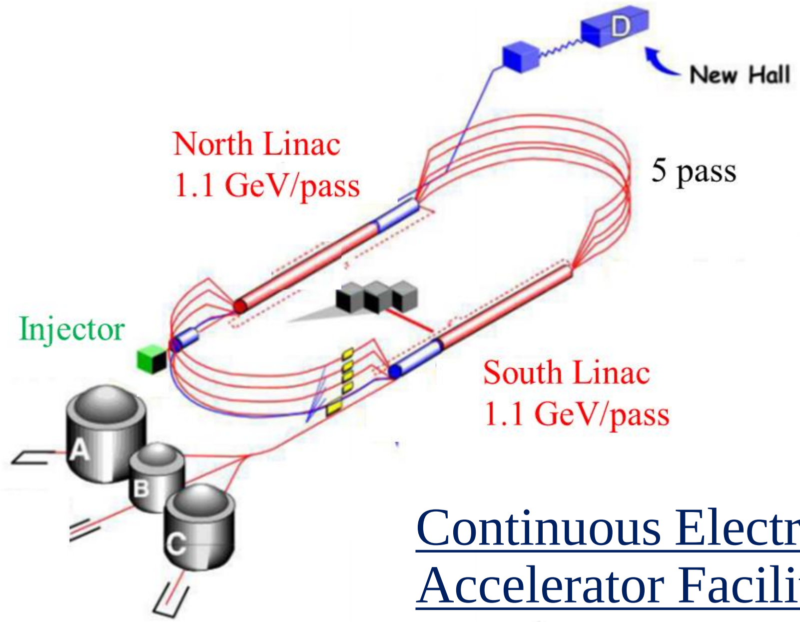
$nn\Lambda$ structure is not understood
→ $nn\Lambda$ state research at JLab

$nn\Lambda$ state research at JLab

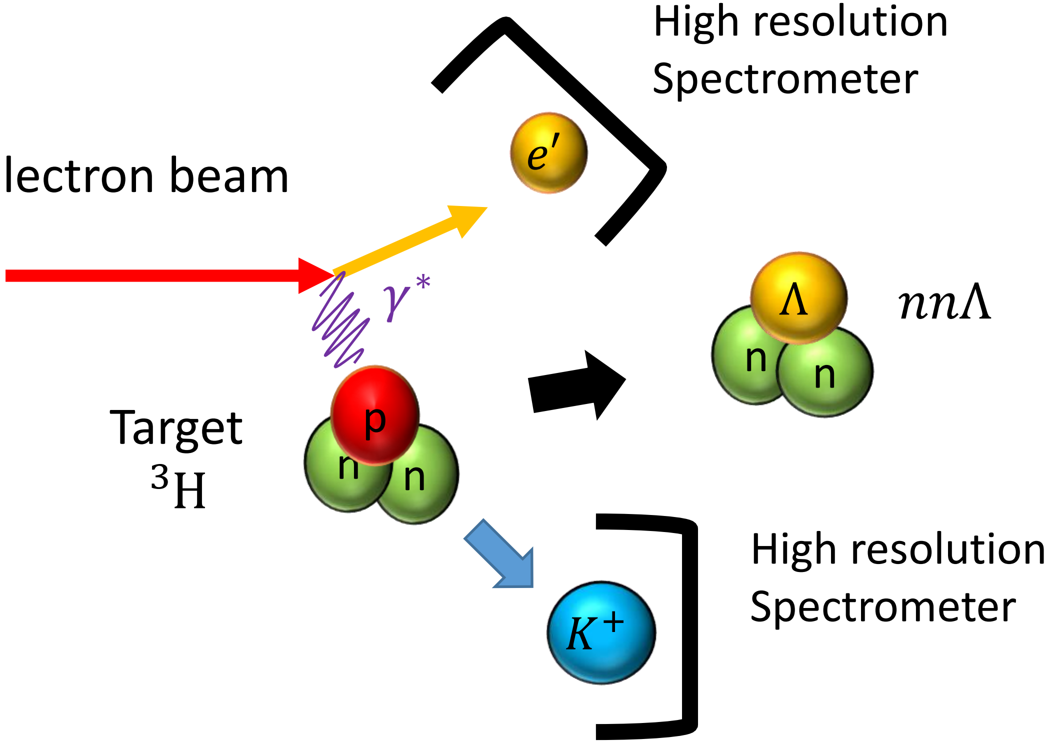
$^3\mathrm{H}(e,e'K^+)nn\Lambda$ experiment at JLab → 2018 Oct.— Nov.

High quality beam

$(\Delta E/E) < 1.8 \times 10^{-4}$ (FWHM)

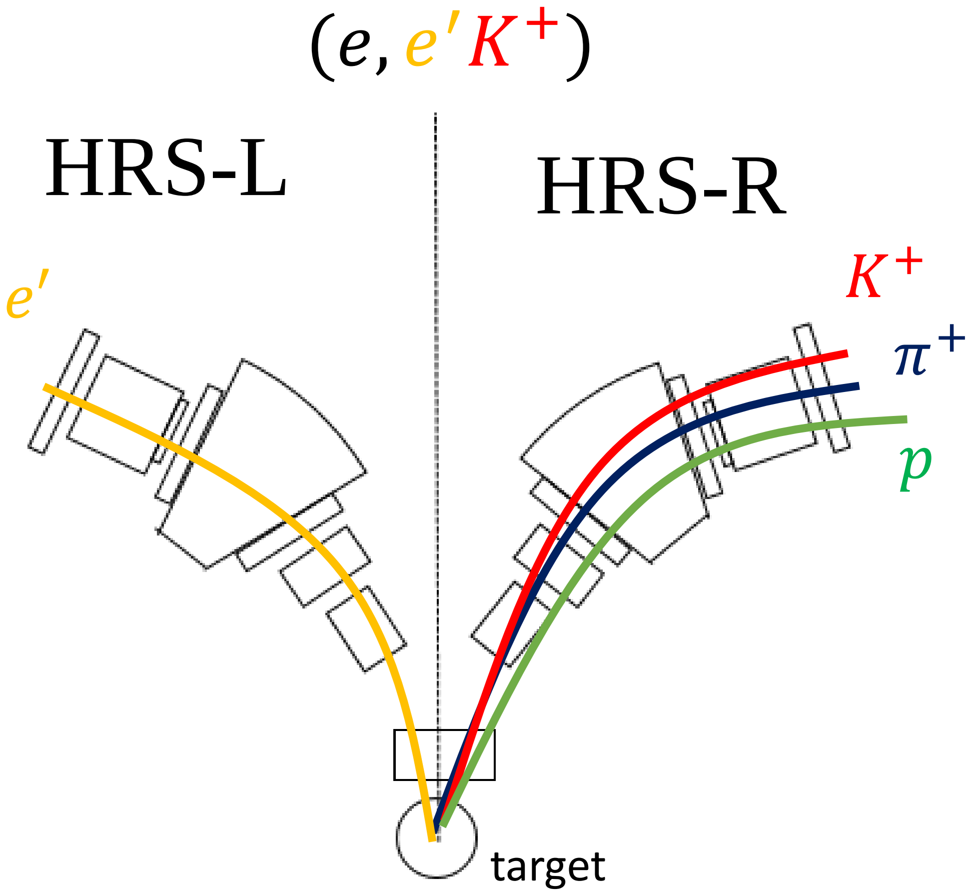


Continuous Electron Beam Accelerator Facility(CEBAF)



$$M_{nn\Lambda} = \sqrt{(E_e + m_{tri} - E_{e'} - E_K)^2 - (\vec{p_e} - \vec{p_{e'}} - \vec{p_K})^2}$$

Importance of kaon identification



HRS-R (K^+, π^+, p)

- K^+ : $nn\Lambda$ events
- π^+, p :Background $\sim 100 \times N_K$

Kaon identification (KID) is very important.

Purpose of my study

$^{3}\mathrm{H}(e, e'K^{+})nn\Lambda$ experiment at JLab

Kaon identification (KID) is very important.

Kaon identification analysis (KID)

- ✓ Performance check of aerogel Cherenkov detectors

  π^{+}, p rejection efficiency < 10 %

- ✓ Performance check of KID method

  Consistency check with published data (Λ Cross section)

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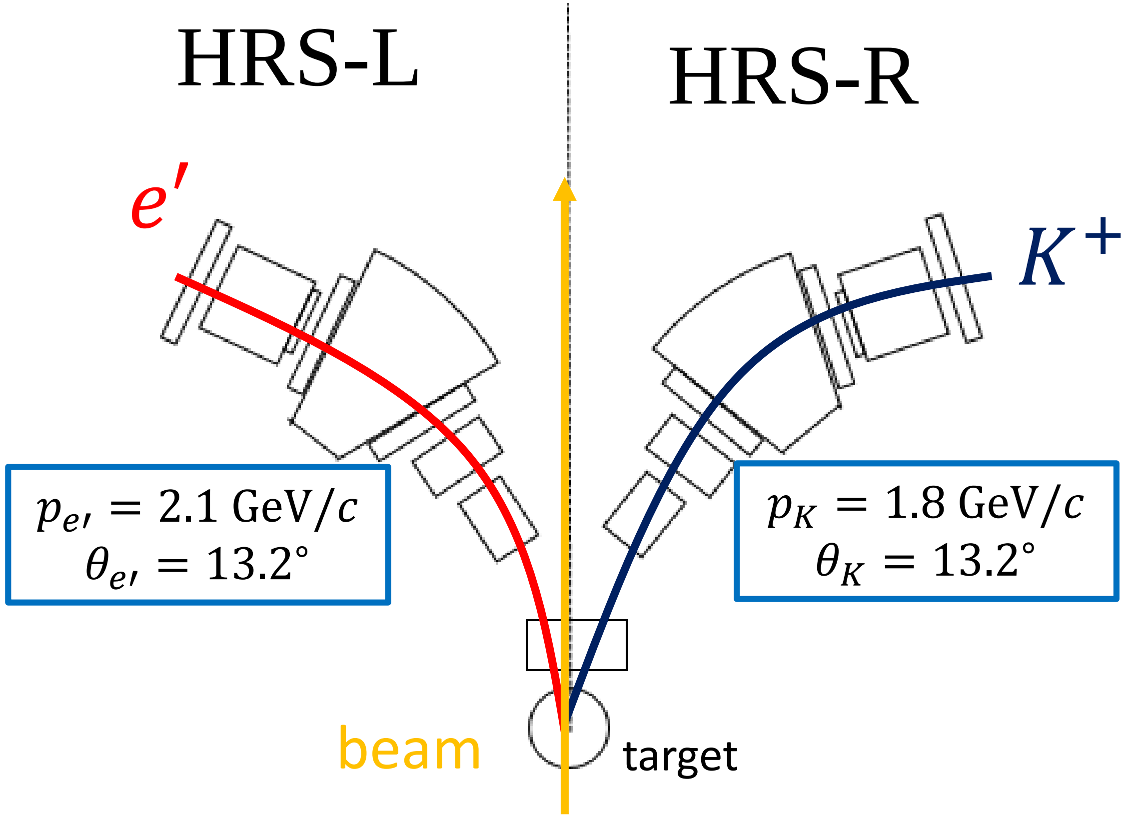
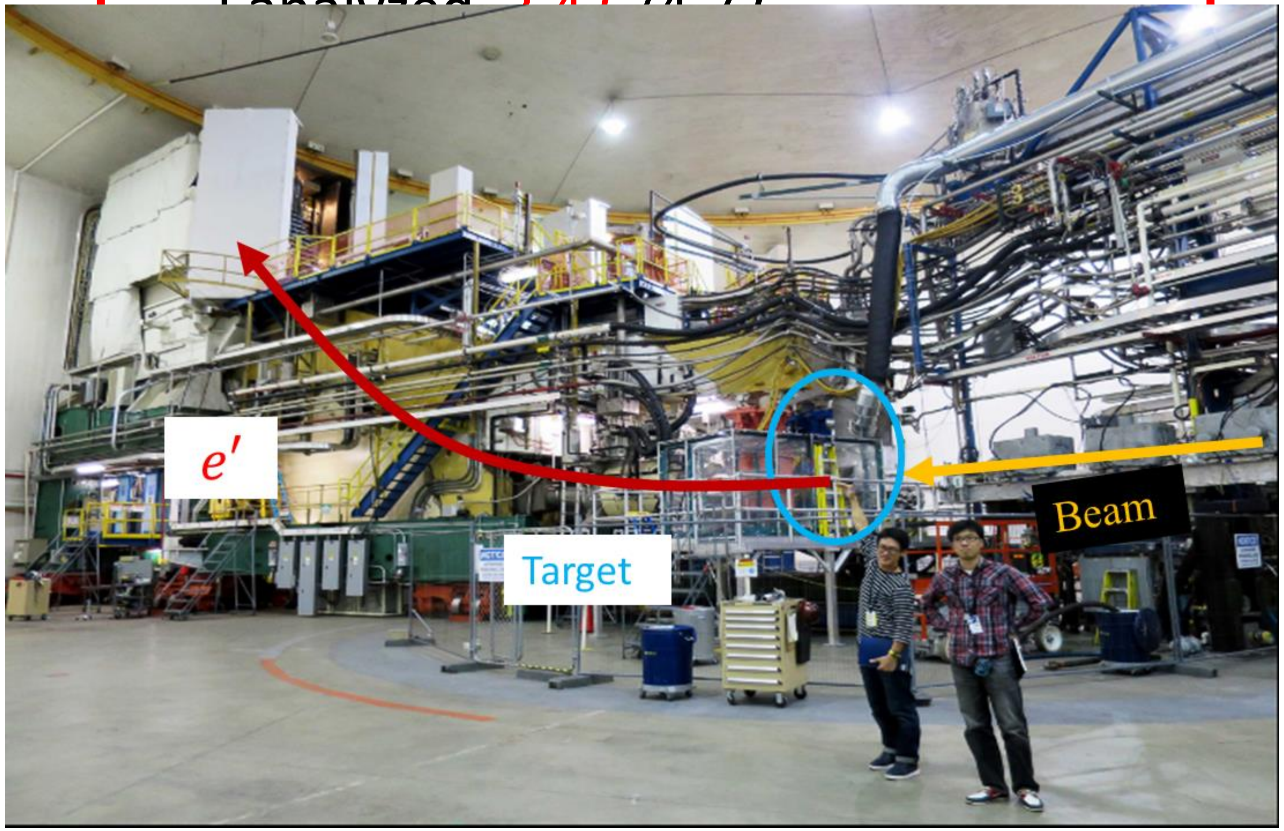
Experimental principle and setup



$\mathrm{H}(e, e'K^+)\Lambda/\Sigma^0$

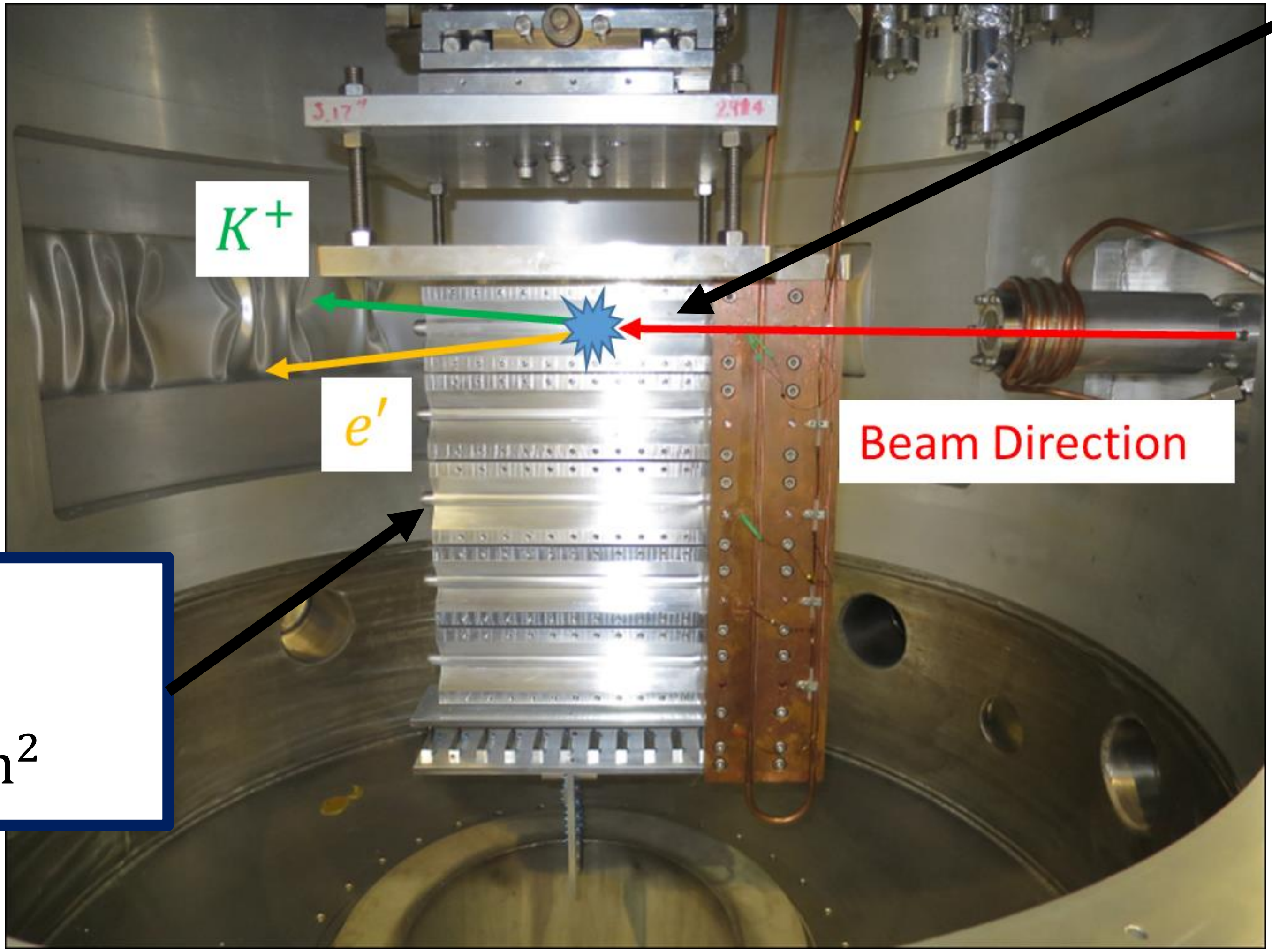
$^1\mathrm{H}(e, e'K^+)\Lambda/\Sigma^0$ data

Beam charge 4.7 C (~5 days)

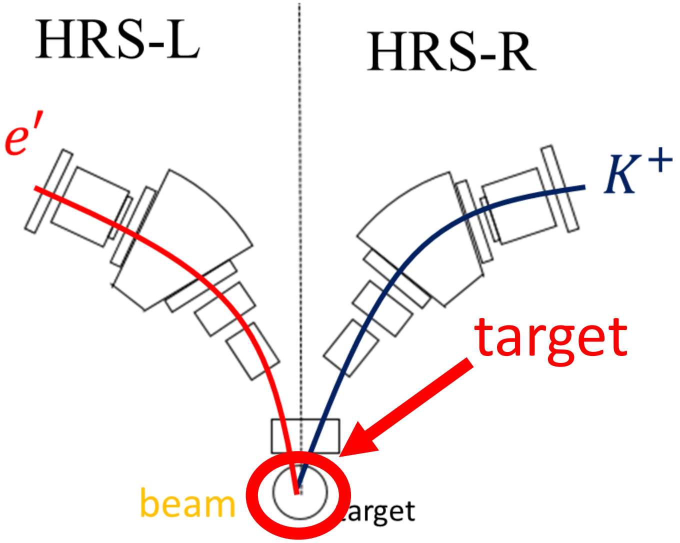


Gas target system

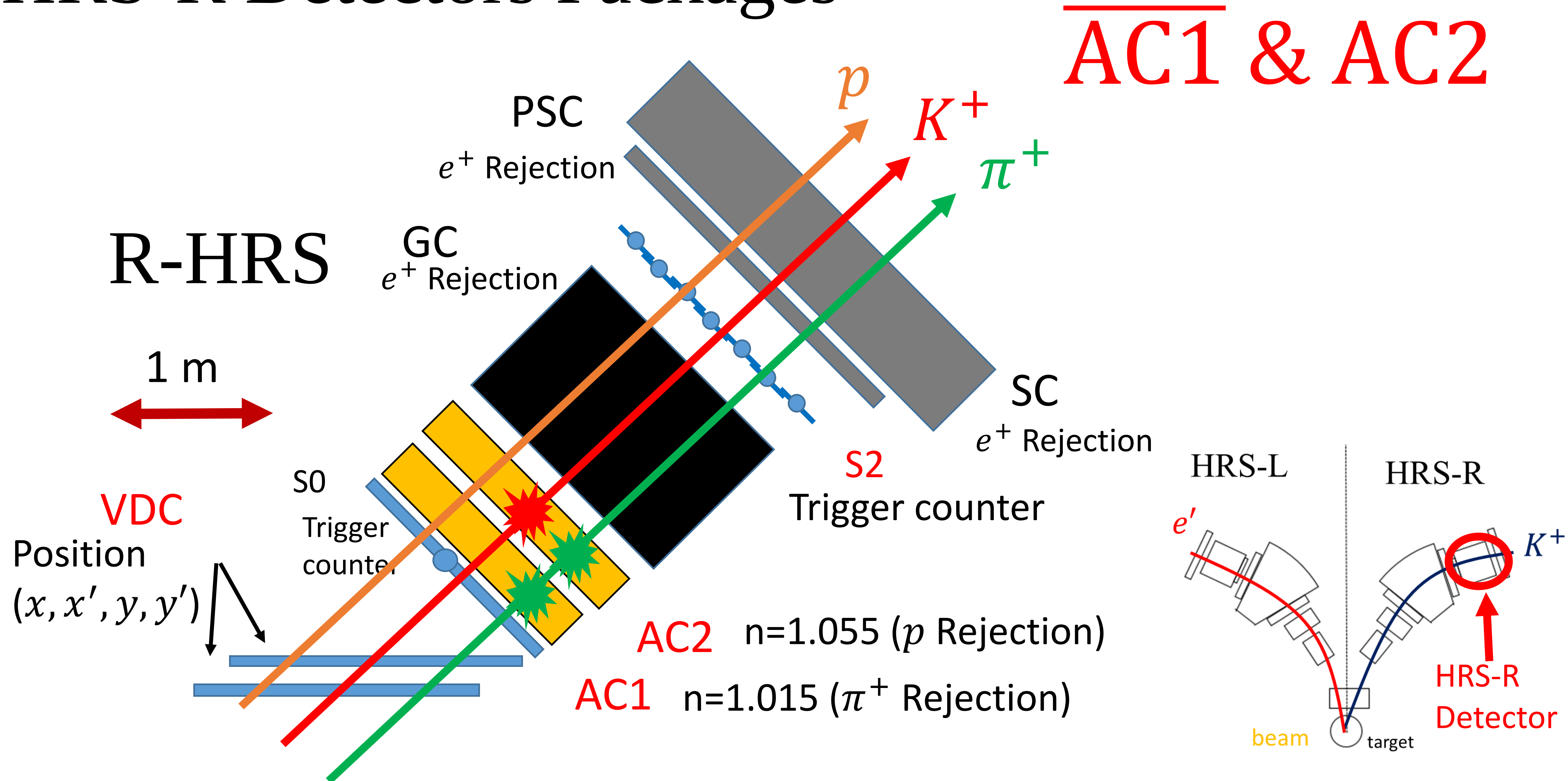
^{3}H gas target
- 40 K
- 40 TBq
- 77.0 mg/cm^2



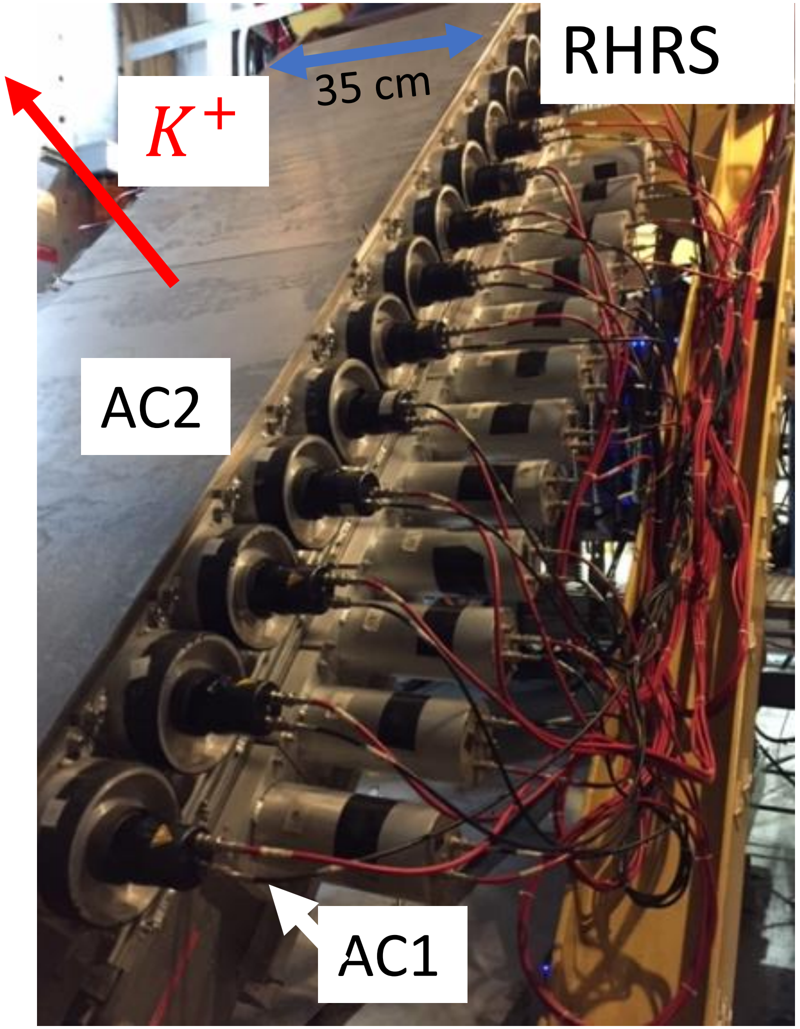
^{1}H gas target
- 40 K
- 70.8 mg/cm^2



HRS-R Detectors Packages



Aerogel Cherenkov Detectors (AC1, AC2)



	AC1	AC2
Refractive index	1.015	1.055
Aerogel	Matsusita silica aerogel SP15	Matsusita silica aerogel SP50
Thickness	9 cm	5 cm
PMT	Burle RCA 8854	Photonis XP 4572B
Number of PMT	24	26

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- Introduction
- Experimental principle & setup
- Kaon identification (KID) analysis
- Λ, Σ^0 cross section
- Summary

KID analysis overview

AC performance

(a) Calculation of coincidence

(b) checking π^+, p survival ratio with AC cut

KID check

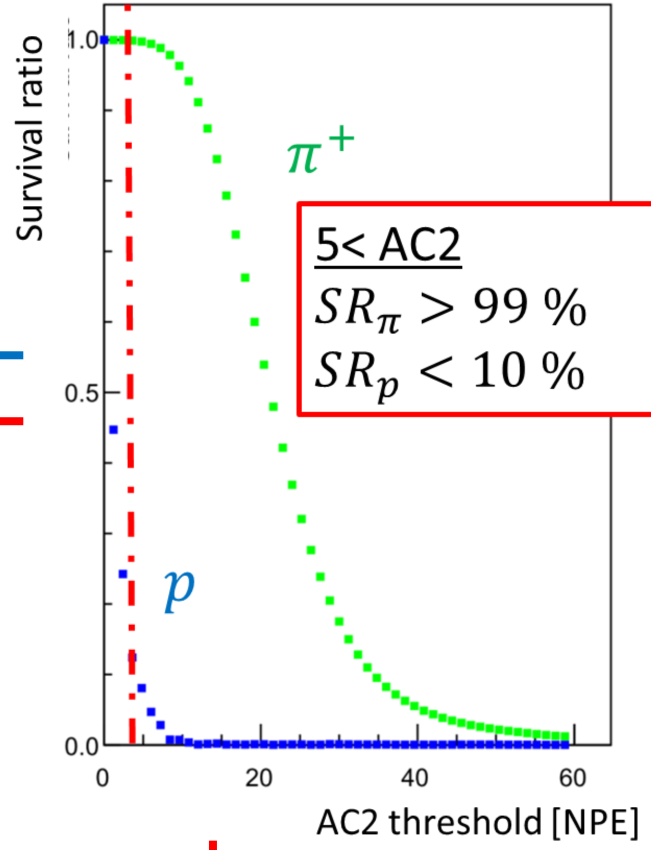
(a) Calculation of missing mass and Λ, Σ^0 identification

(b) Depend of Λ, Σ^0 survival ratio with AC cut

(c) AC cut tuning with Λ, Σ^0 peak significance

(d) Estimation of Λ cross section

(e) comparison with CLAS



5< AC2

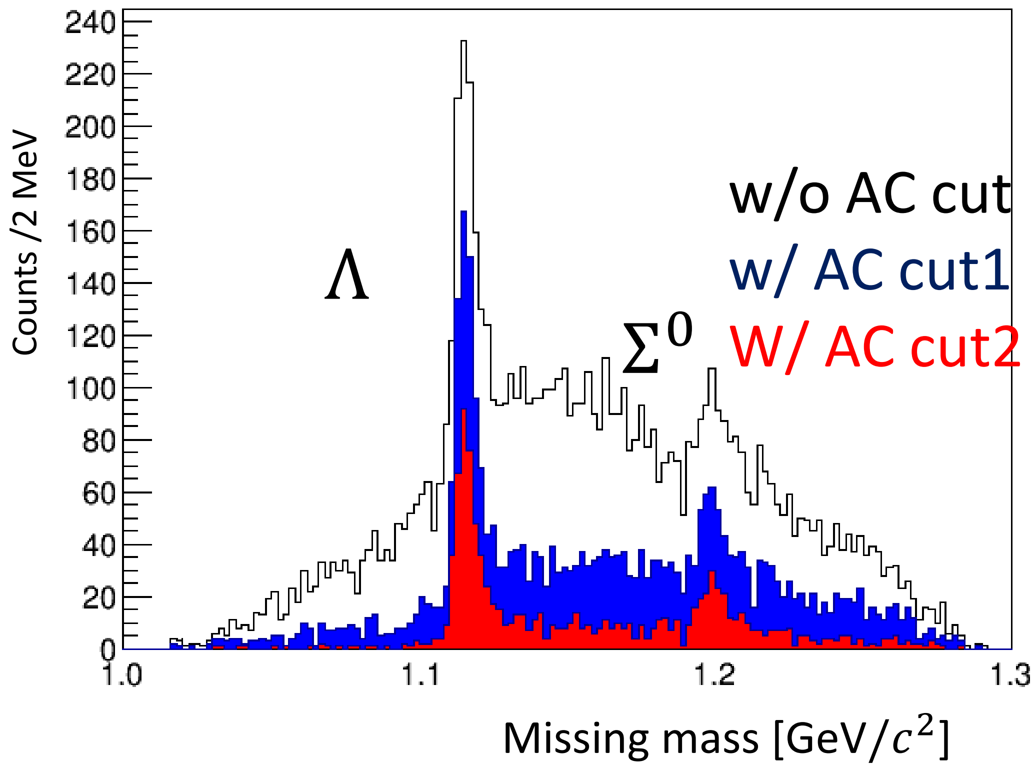
$SR_\pi > 99\ \%$

$SR_p < 10\ \%$

AC cut tuning with missing mass Λ/Σ^0

Λ, Σ^0 missing mass:

$$M_X = \sqrt{(E_e + m_p - E_{e'} - E_K)^2 - (\vec{p_e} - \vec{p_{e'}} - \vec{p_K})^2}$$



tuning AC cut: Peak significance (P.S.)

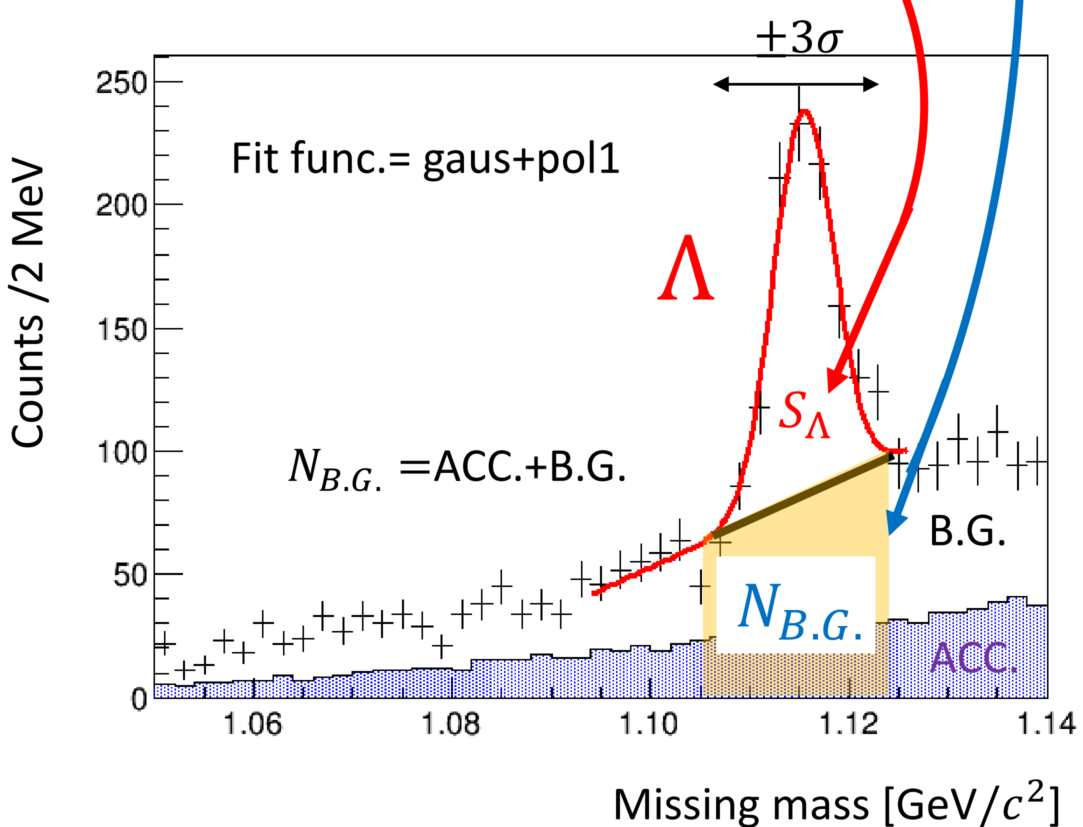
$$P.S. = \sqrt{S^2_{\Lambda,\Sigma^0}/N_{B.G}}$$

Maximum peaks significance

Tuning AC cut

Λ/Σ^0 peak fitting result (no AC cut)

Peak significance : $\sqrt{S^2_{\Lambda,\Sigma^0}/N_{B.G}}$



Particles	Events	Peak significance
Λ	796 ± 34	23
Σ^0	127 ± 19	4.1
$\Lambda + \Sigma^0$	923 ± 39	

I analyzed 2.4 C/4.7 C
Total $\Lambda + \Sigma^0$ ~ 1800 events

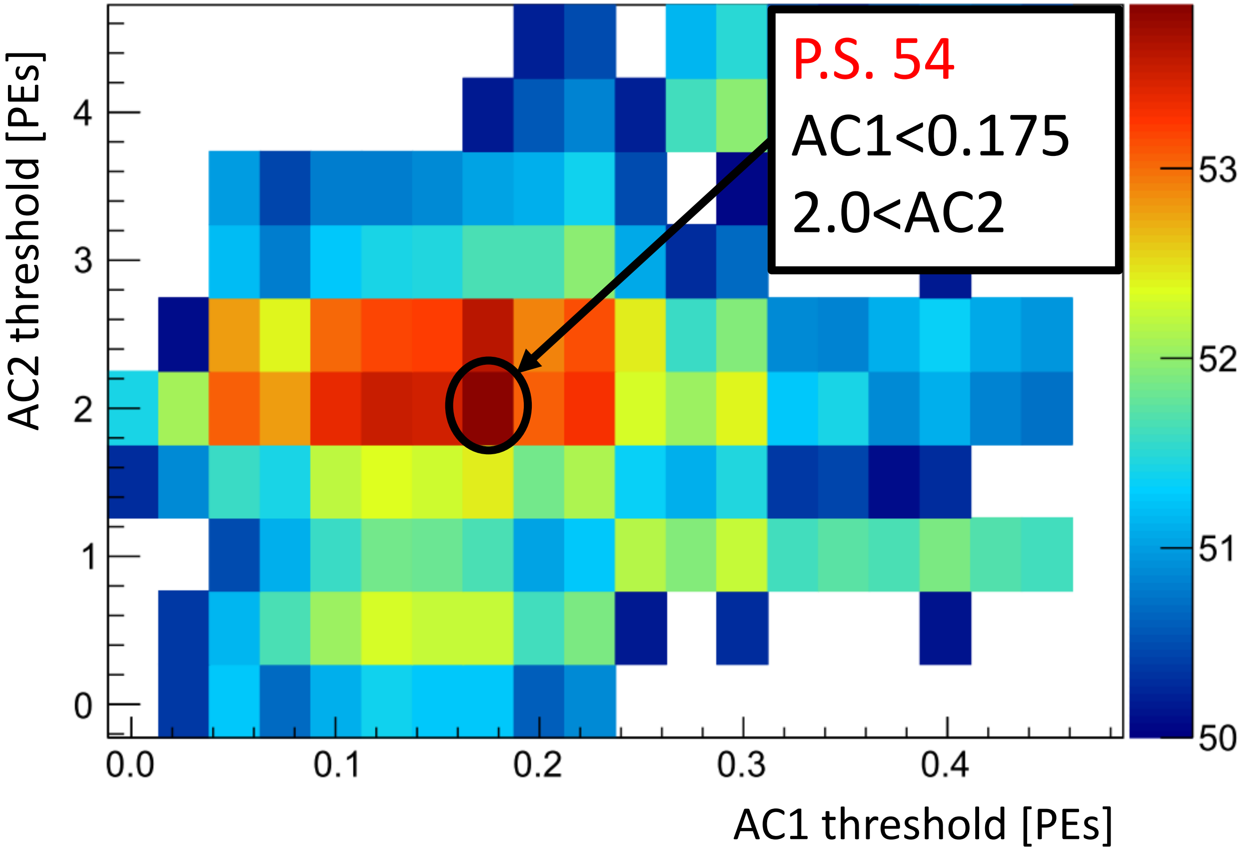
Maximum of peak significance (P.S.)

	π^+	K^+	p
AC1	○	×	×
AC2	○	○	×
Cut	AC1 & AC2	$\overline{\text{AC1}}$ & AC2	$\overline{\text{AC1}}$ & $\overline{\text{AC2}}$

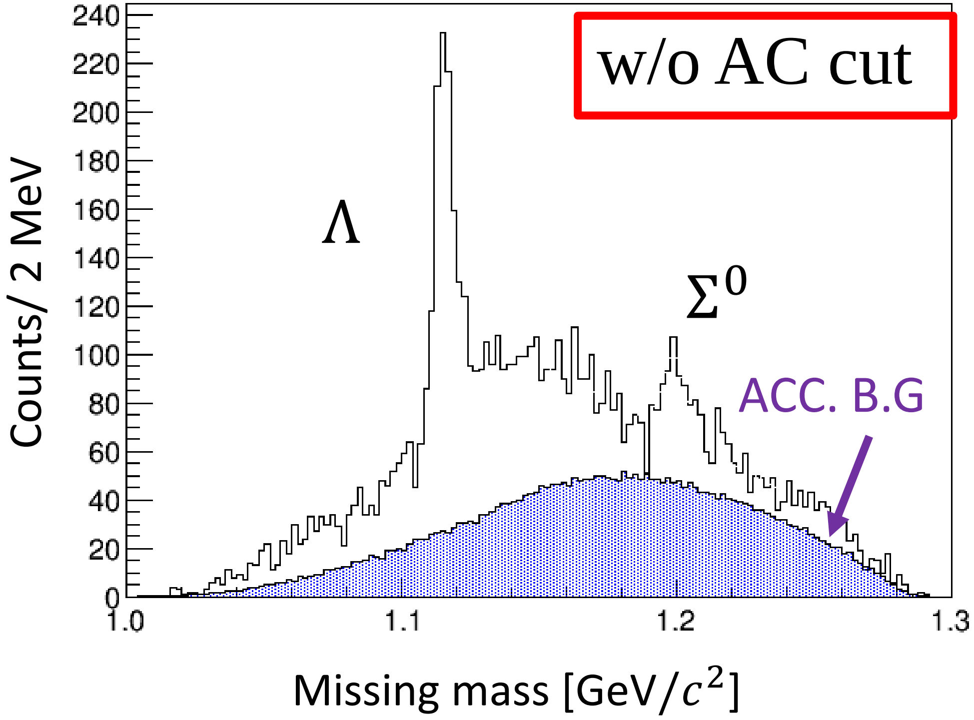
<u>Kaon cut condition</u>

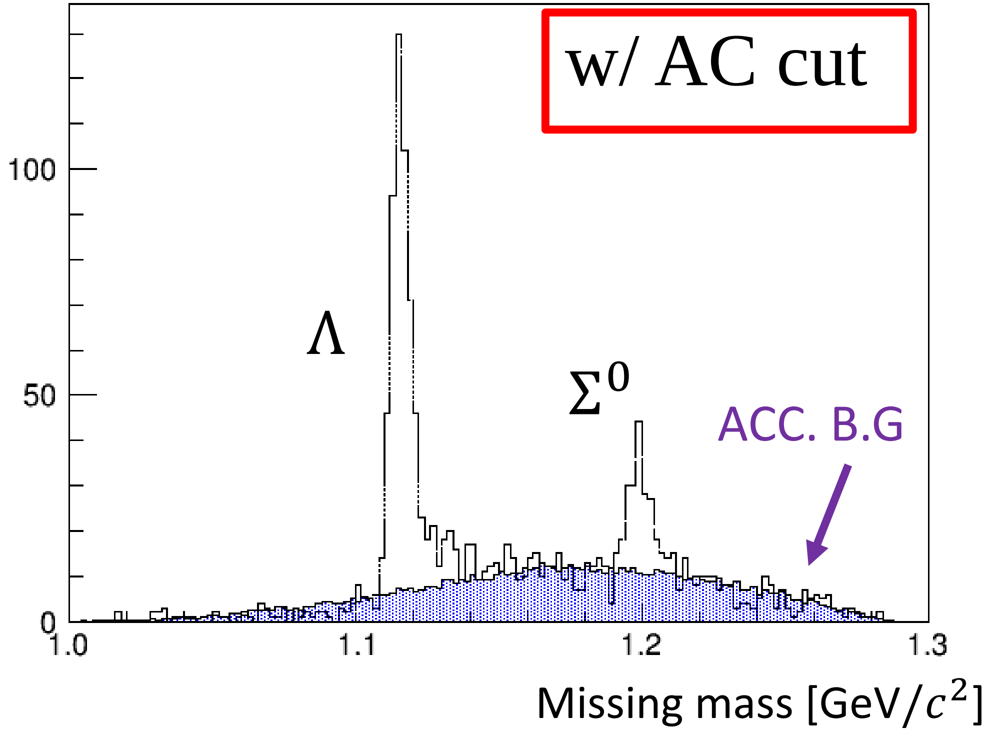
AC1 < threshold

threshold < AC2



Result of the KID analysis





$\Lambda + \Sigma^0$ events: 900 → 440

Λ Peak significance: 23 → 54

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Estimation of Λ cross section

$$\frac{d\sigma_{\Lambda}}{d\Omega} = \frac{1}{N_T} \times \frac{1}{N_{\gamma}} \times \frac{1}{\varepsilon_{SR}} \times \frac{1}{\varepsilon_K \Delta\Omega} \times N_{\Lambda} = 400 \pm 20\ nb/sr$$

N_{γ}: 1.4×10^{14}

ε_K: 0.5

N_{Λ}: 440 ± 26

N_T: 4.3×10^{22}

ε_{SR}: 0.17[1]

$\Delta\Omega$: 0.006 sr [2]

[1] https://hallaweb.jlab.org/equipment/high_resol.html
[2] L. Tang et al., PAC45 http : www:jlab:org=exp p rog=proposals=17=PR12 17 003:pdf

Estimation of Systematic Error

$1.4 \times 10^{14}{}^{+50\ \%}_{-30\ \%}$

$100^{+0}_{-10\%}$ (DAQ efficiency)

$$\frac{d\sigma_\Lambda}{d\Omega} = \frac{1}{N_T} \times \frac{1}{N_\gamma} \times \frac{1}{\varepsilon_{SR}} \times \frac{1}{\varepsilon_K \varepsilon_{DAQ} \Delta\Omega} \times N_\Lambda$$

Estimation of cross section

$$\frac{d\sigma_\Lambda}{d\Omega} = 400 \pm 20^{+190}_{-130}\ nb/sr$$

Λ cross section (CLAS at $\theta_{\gamma K} \sim 0$)

$$\frac{d\sigma_\Lambda^{CLAS}}{d\Omega} \sim 350\ nb/sr$$

Future analysis with KID method

KID analysis with $\mathrm{H}(e, e'K^+)\Lambda/\Sigma^0$ data

- Λ peak significance 23 → 54
- Λ cross section is consistent with CLAS's data

Ph.D. candidate

$^3\mathrm{H}(e, e'K^+)nn\Lambda$ data analysis

- Momentum calibration
- Background rejection (KID)

Summary

Introduction

- GSI reported evidence of $nn\Lambda$ state by $t + \pi^-$ final state.
- We performed $nn\Lambda$ experiment at JLab in Oct.— Nov. 2018.

Experiment

- $p_{e'}, p_K$ were measured with two HRSs.
- Large backgrounds ($\mathrm{K}^+ : \pi^+ = 1:100$) contaminated in K^+ side HRS.

KID analysis

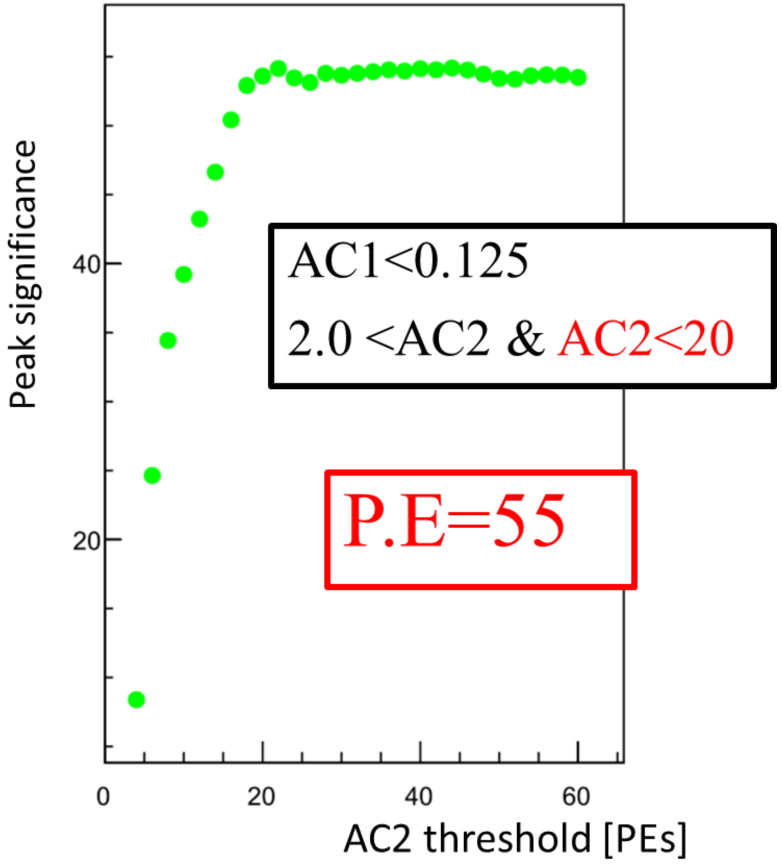
- I optimized AC cut by maximizing peak significance.
  Λ events → 55 %, Λ peak significance 23 → 54

Λ cross section

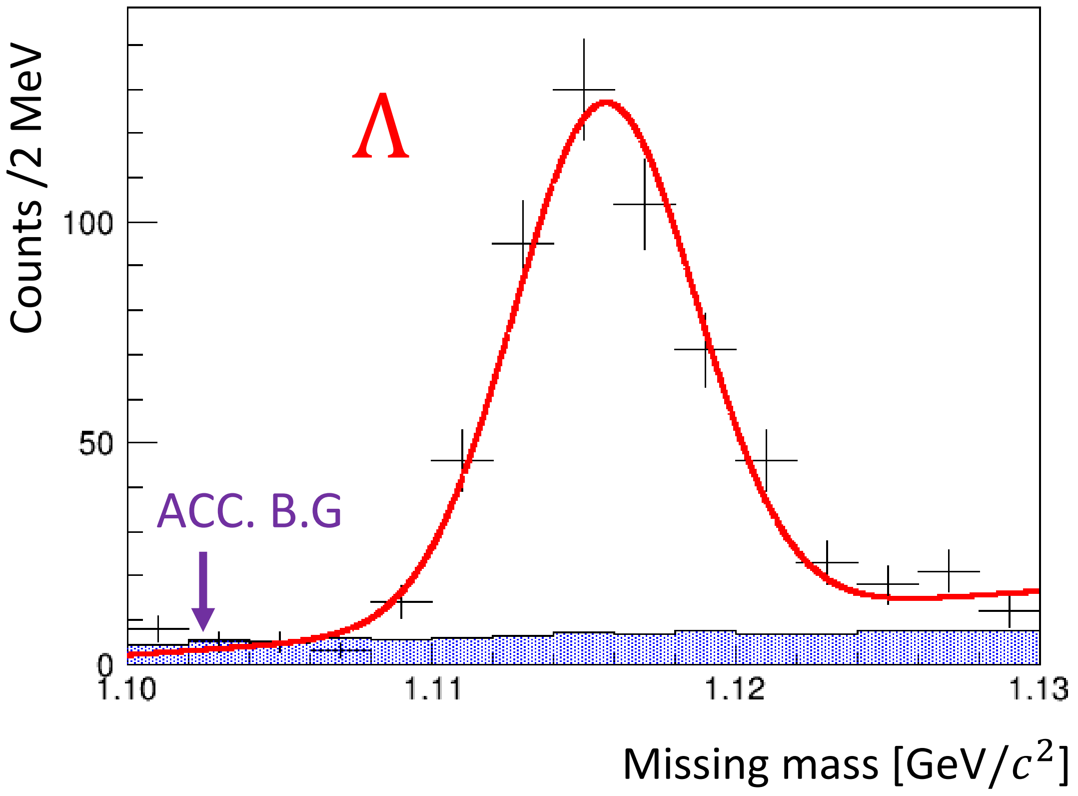
- With KID analysis, I estimated Λ cross section ($d\sigma_\Lambda/d\Omega = 400$ nb/sr)
- Λ cross section is consistent with CLAS's data ($d\sigma_\Lambda/d\Omega \sim 350$ nb/sr)
  - KID method is established. → $nn\Lambda$ analysis

Back UP

AC2 upper cut



Λ, Σ^0 fitting result with AC cut

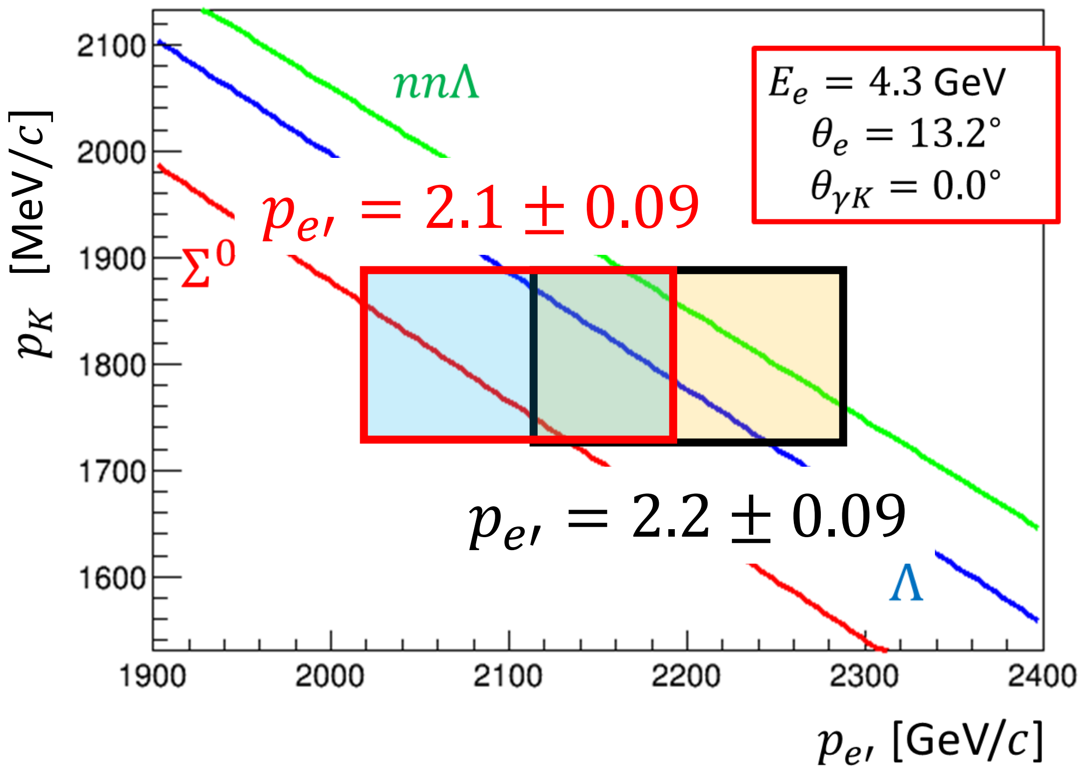


Particles	Events	Peak significance
Λ	440 ± 26	54
Σ^0	130 ± 18	11
$\Lambda + \Sigma^0$	570 ± 32	-

Experimental kinematics

HRS acceptance $\Delta p/p = 4.5$ %

$\Delta p_{e'} = 90$ MeV/c, $\Delta p_K = 80$ MeV/c



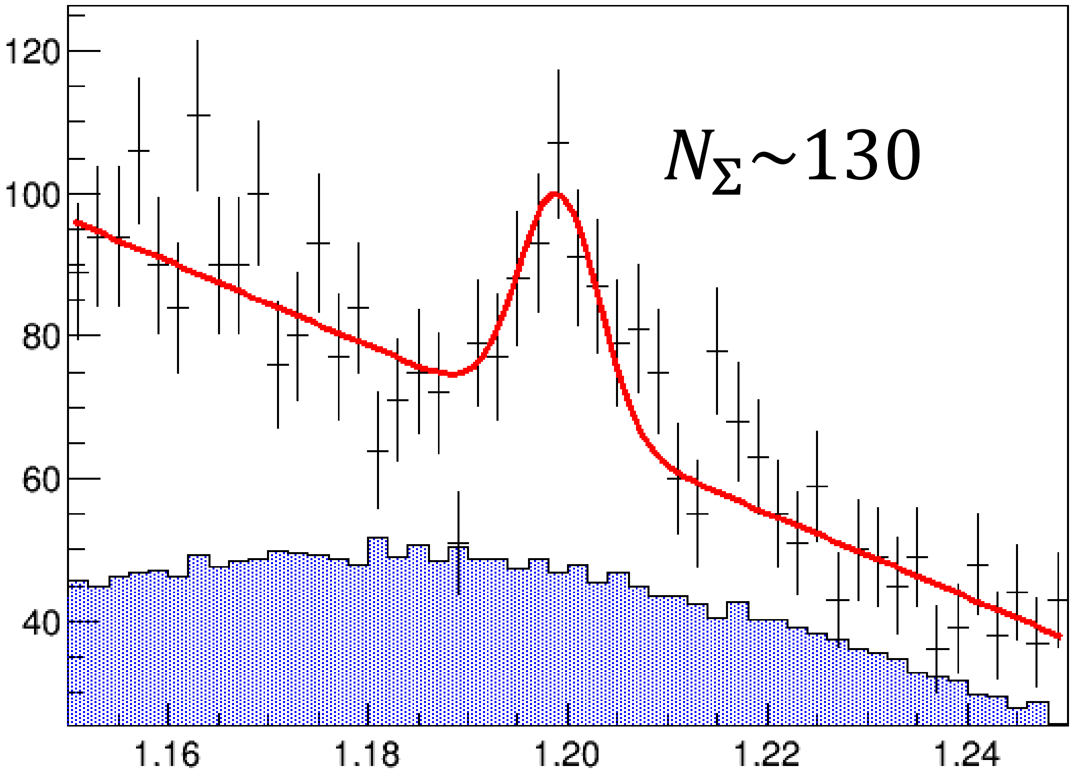
$^3\mathrm{H}(e, e'K^+)nn\Lambda$ data

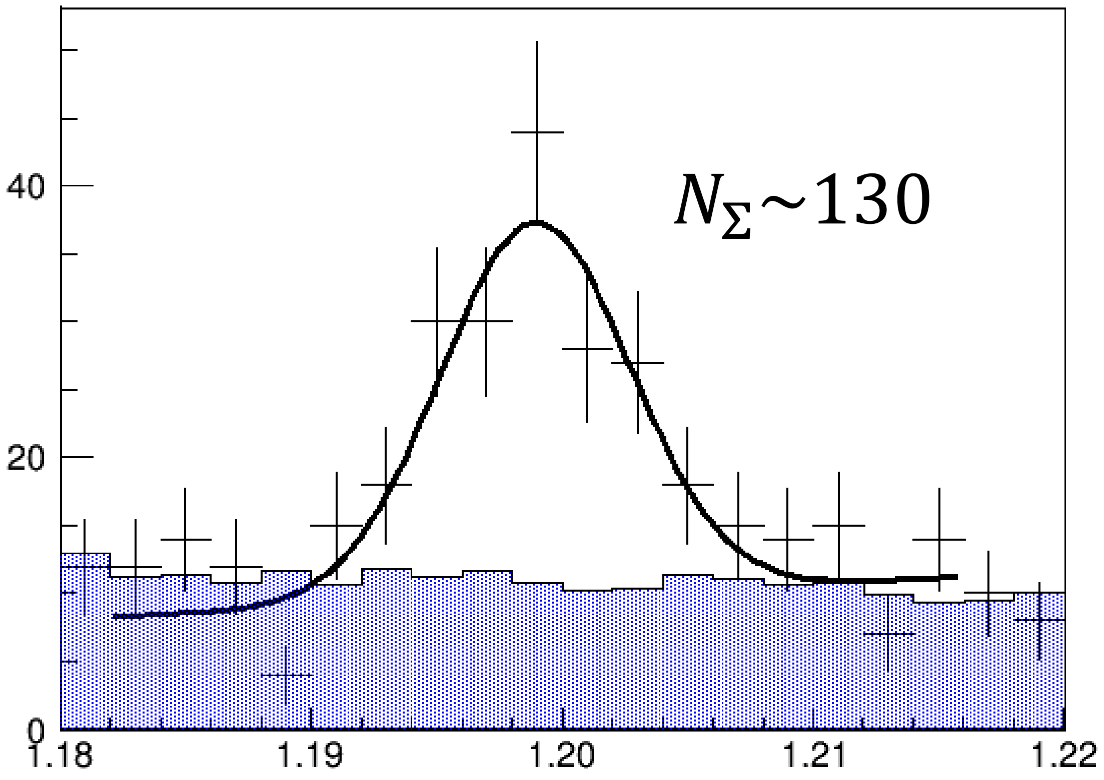
- $(p_{e'}, p_K) = (2.2, 1.8)$ GeV/c
- Beam charge 16 C (~16 days)

$^1\mathrm{H}(e, e'K^+)\Lambda/\Sigma^0$ data

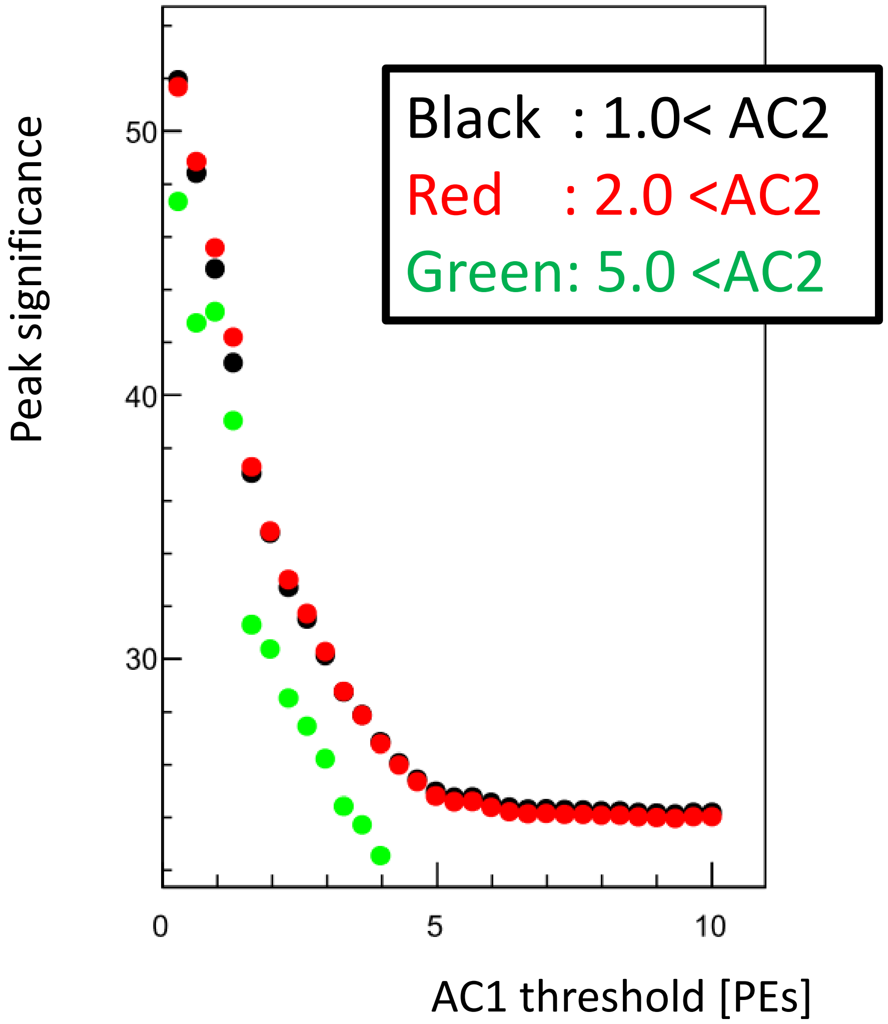
- $(p_{e'}, p_K) = (2.1, 1.8)$ GeV/c
- Beam charge 4.7 C (~5 days)
- I analyzed 2.4 C/4.7 C

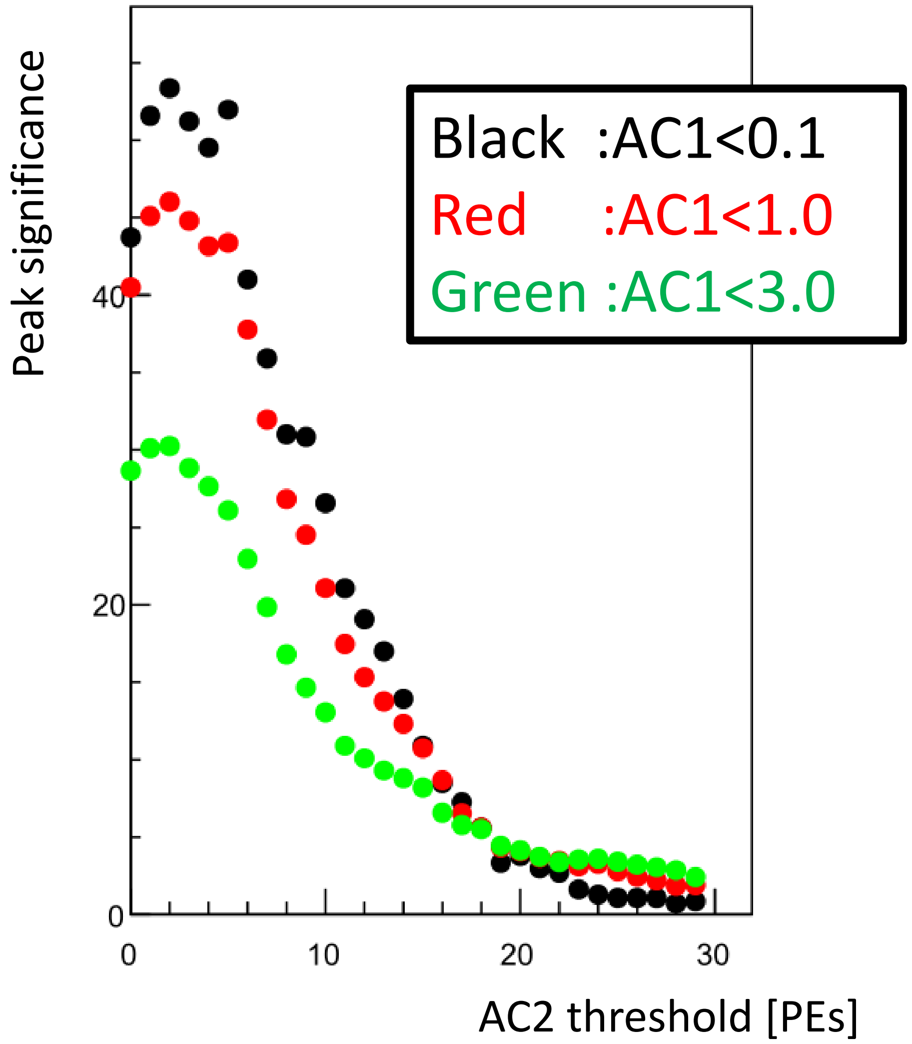
Σ^0 Fitting result



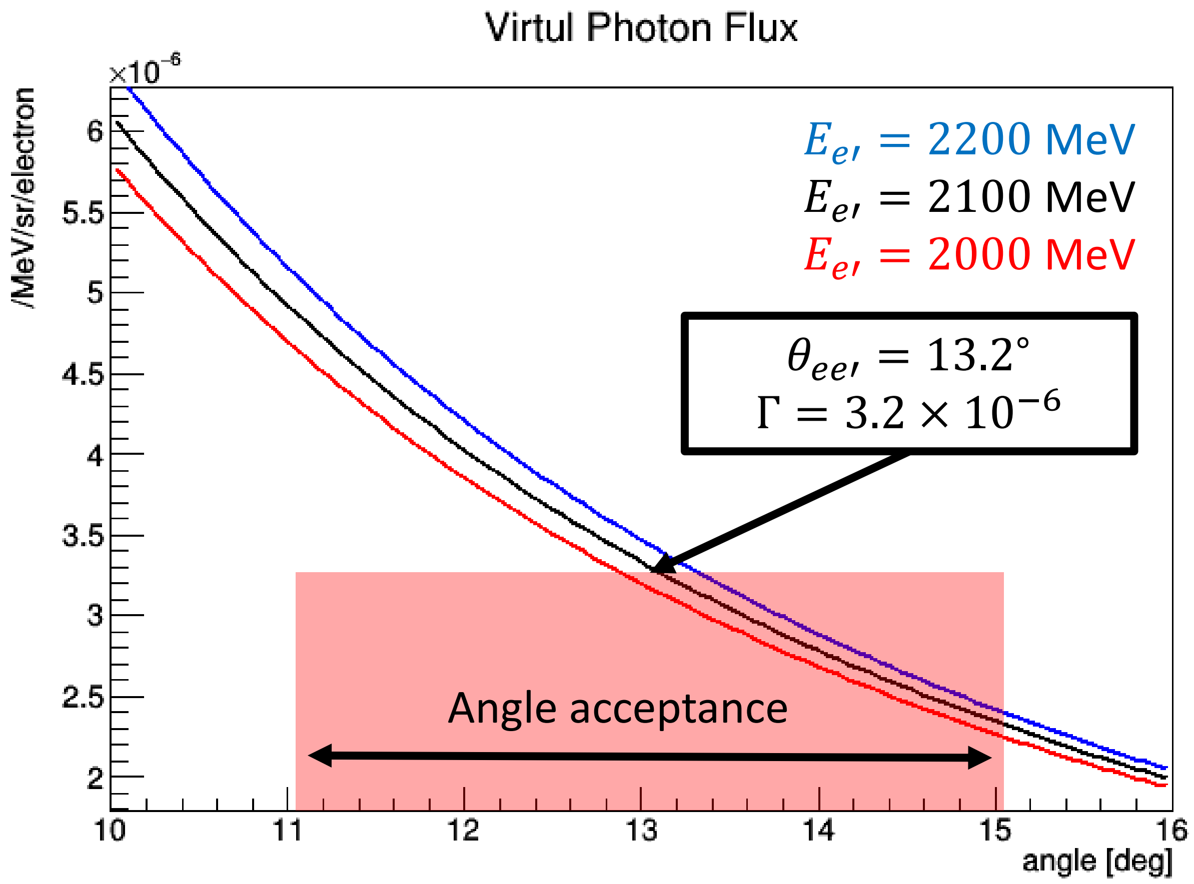


Peak significance with AC1, AC2 cut





Virtual photon flux statistical error



$E'_e = 2.1$ GeV

- Angle acceptance $\pm 2.0°$

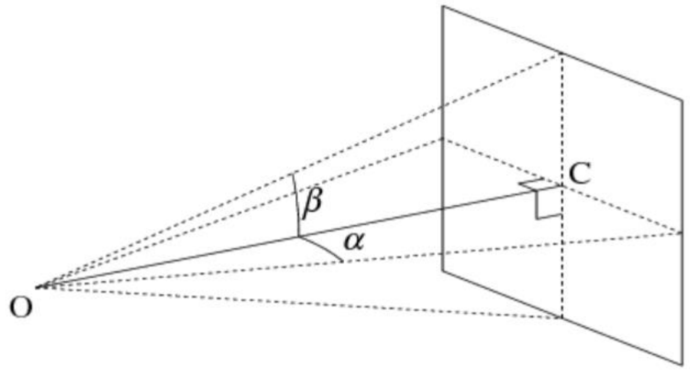
  $\Gamma = 3.2^{+1.5}_{-0.9} \times 10^{-6}$
- Momentum bite ± 100 MeV

$\theta_{ee'} = 11.2°, E_{e'} = 2200$ MeV
$\Gamma = 4.9 \times 10^{-6}$

$\theta_{ee'} = 15.2°,, E_{e'} = 2000$ MeV
$\Gamma = 2.2 \times 10^{-6}$

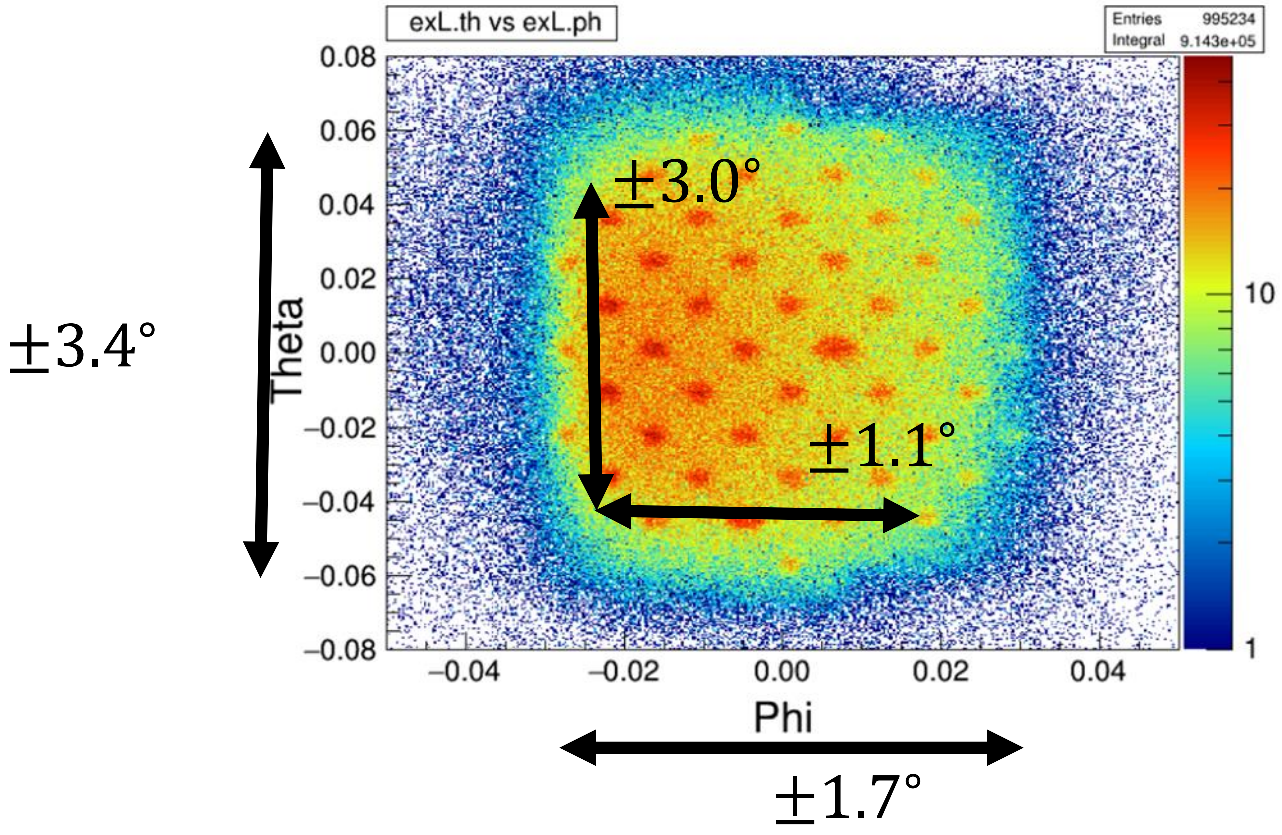
$\Gamma = 3.2^{+1.7}_{-1.0} \times 10^{-6}$

Acceptance



$$\Omega = 4 \times \arcsin(\sin\alpha \sin\beta)$$
$$= 7\ msr\ (\alpha = 1.7, \beta = 3.4)$$
$$= 4\ msr(\alpha = 1.1, \beta = 3.0)$$

$$6^{+1}_{-2}\ msr$$



Virtual photon Flux

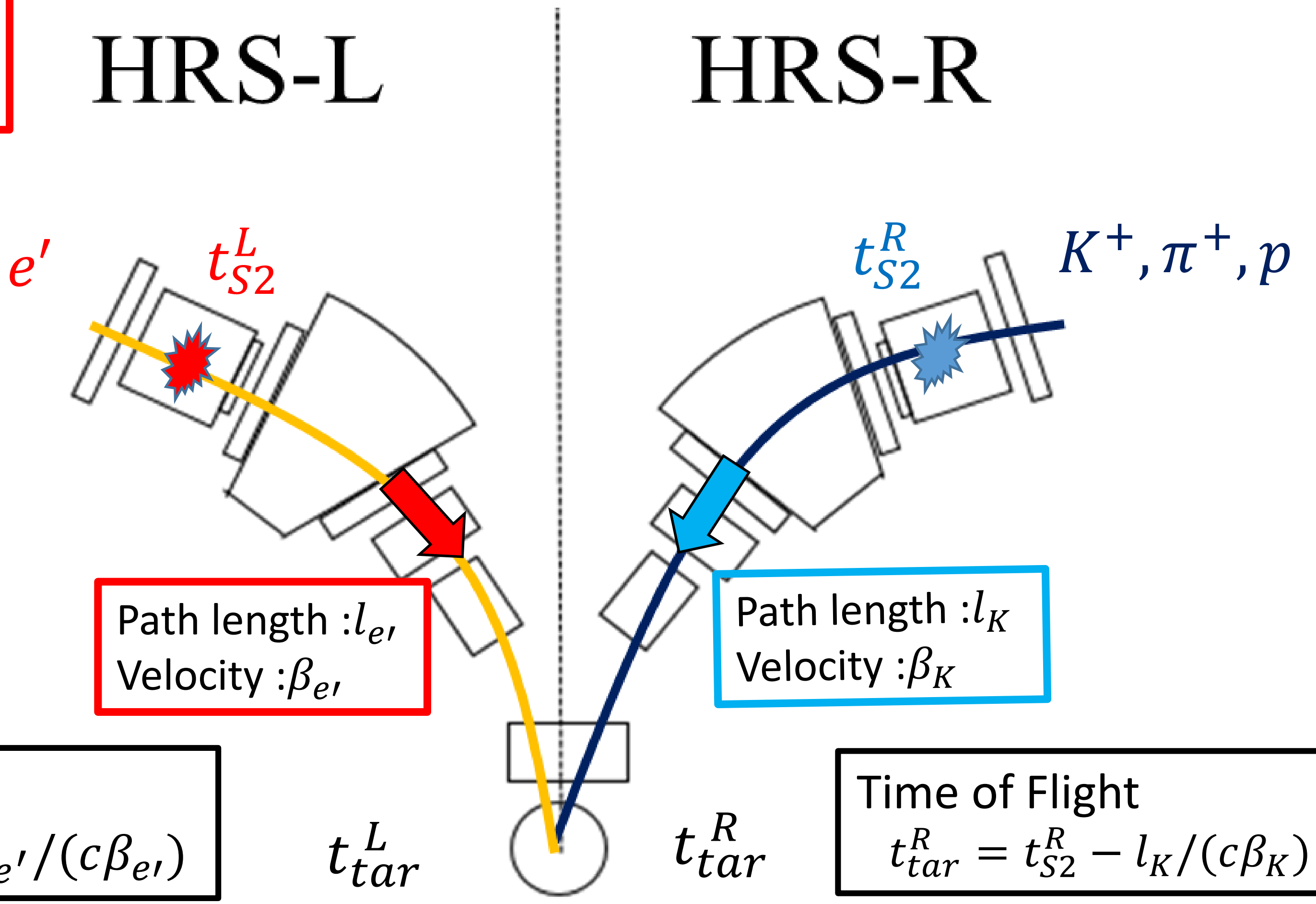
I corrected
$|\vec{q}|^2 \rightarrow -Q^2$

$$\Gamma = \frac{\alpha}{2\pi^2 Q^2} \frac{E_\gamma}{1-\varepsilon} \frac{E_e'}{E_e}, \qquad E_\gamma = \omega + \frac{q^2}{2m_p},$$

Coincidence time

Coincidence time

$$t_{coin} = t^{R}_{tar} - t^{L}_{tar}$$

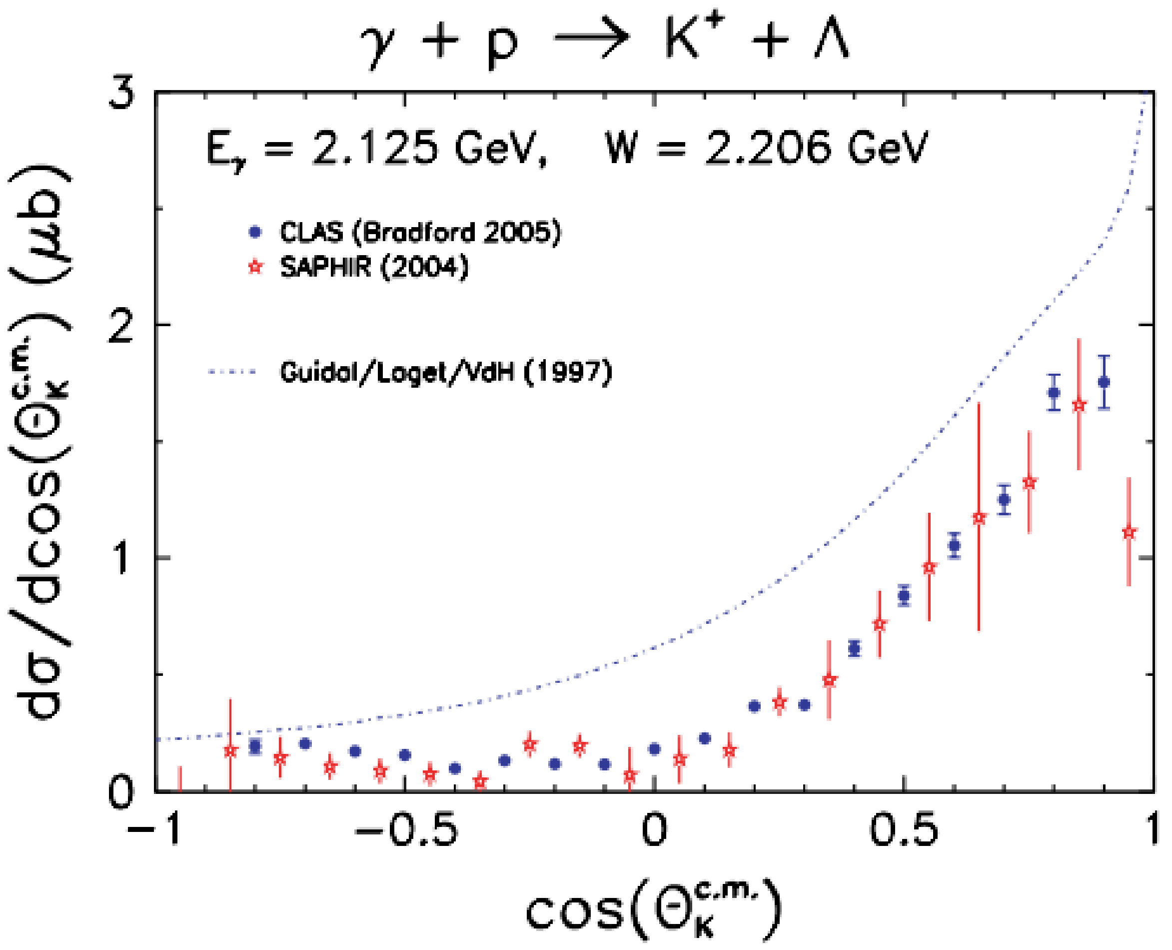


Time of Flight

$$t^{L}_{tar} = t^{L}_{S2} - l_{e'}/(c\beta_{e'})$$

Time of Flight

$$t^{R}_{tar} = t^{R}_{S2} - l_{K}/(c\beta_{K})$$

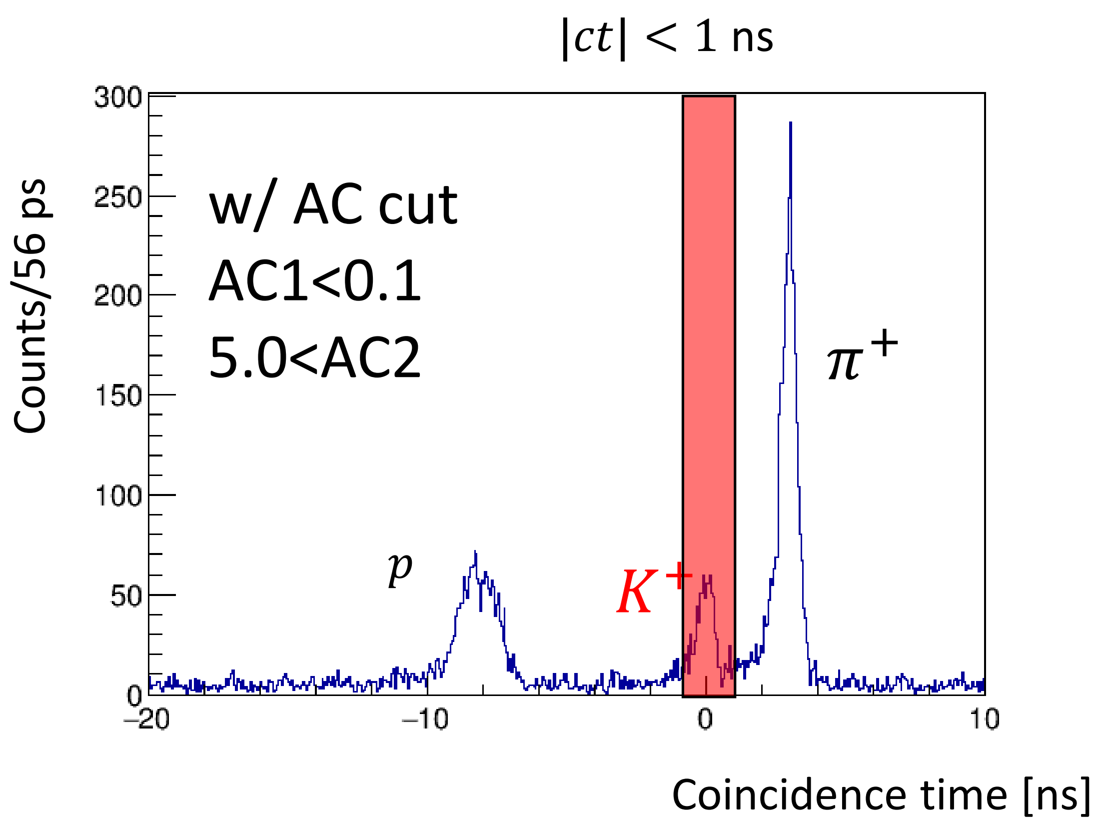


γ + p → K⁺ + Λ
E_γ = 2.125 GeV, W = 2.206 GeV
CLAS (Bradford 2005)
SAPHIR (2004)
Guidal/Laget/VdH (1997)
dσ/dcos(Θ_K^c.m.) (μb)
cos(Θ_K^c.m.)
3
2
1
0
−1
−0.5
0
0.5
1

Draft

Draft slide

Particle identification with coincidence time

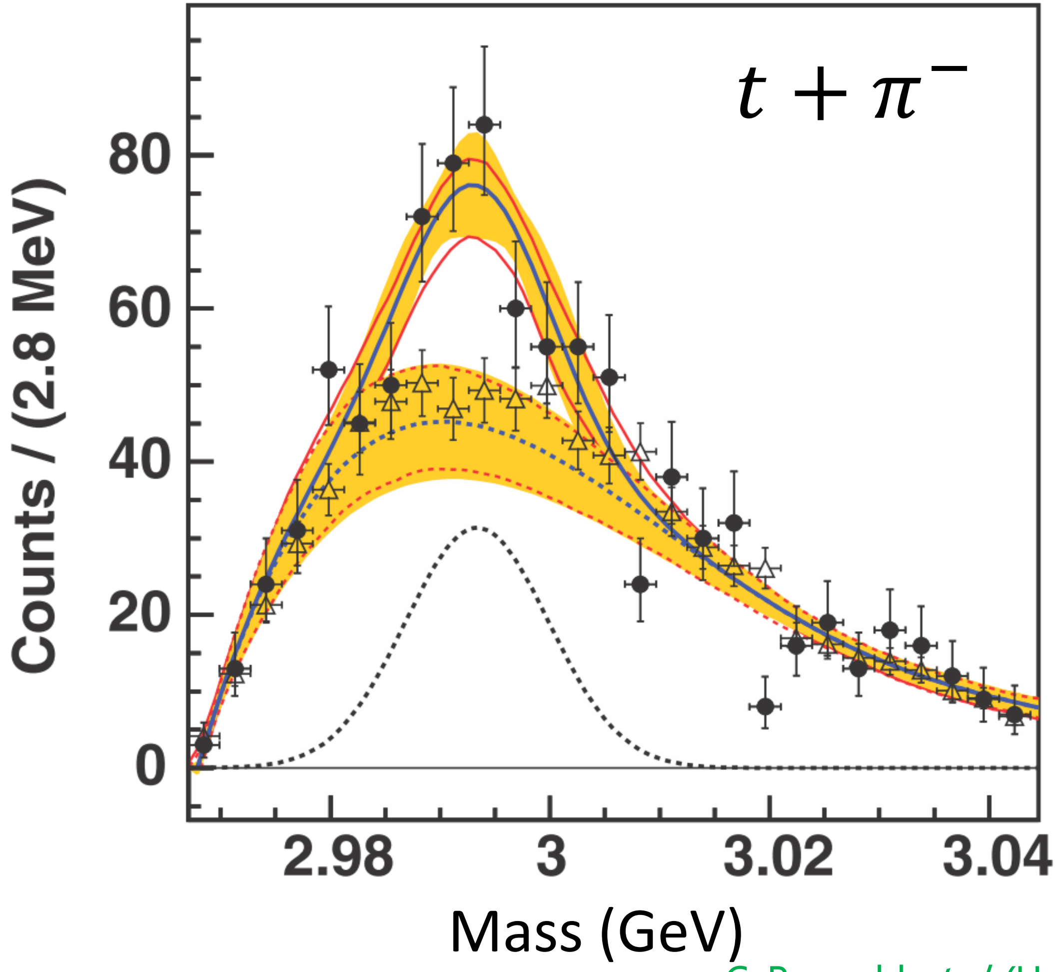


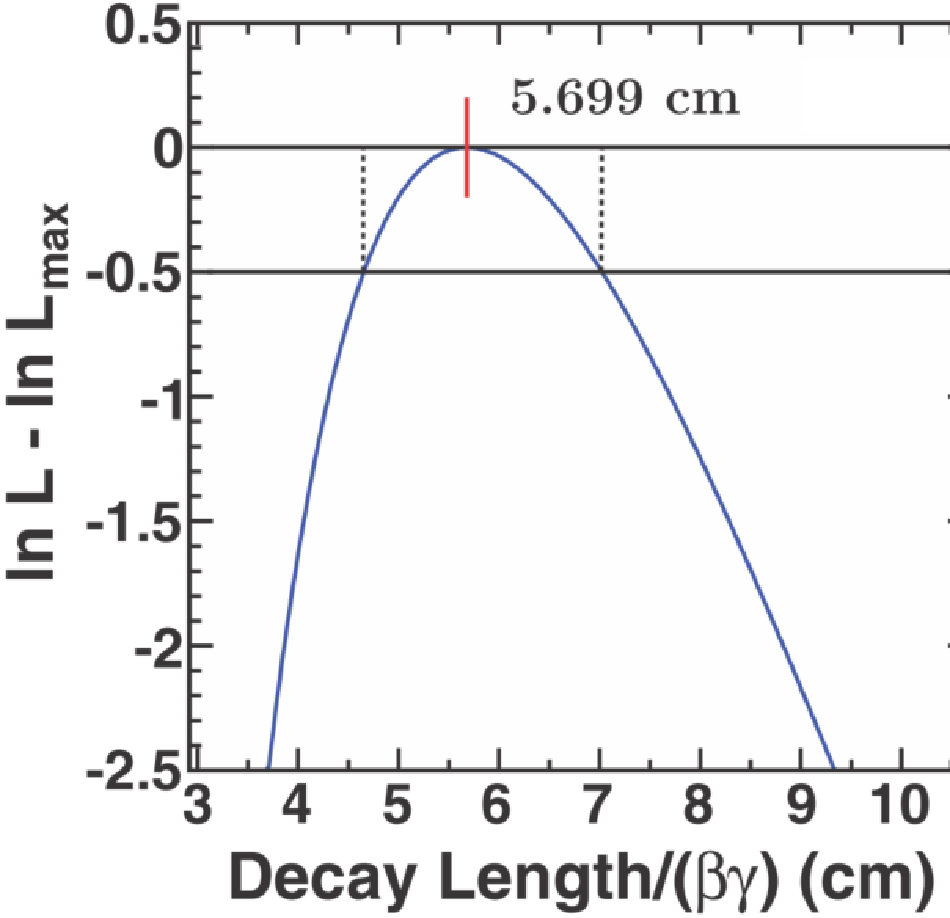
Coincidence time(ct) cut

$-1.0 < ct < 1.0$ ns

Missing mass

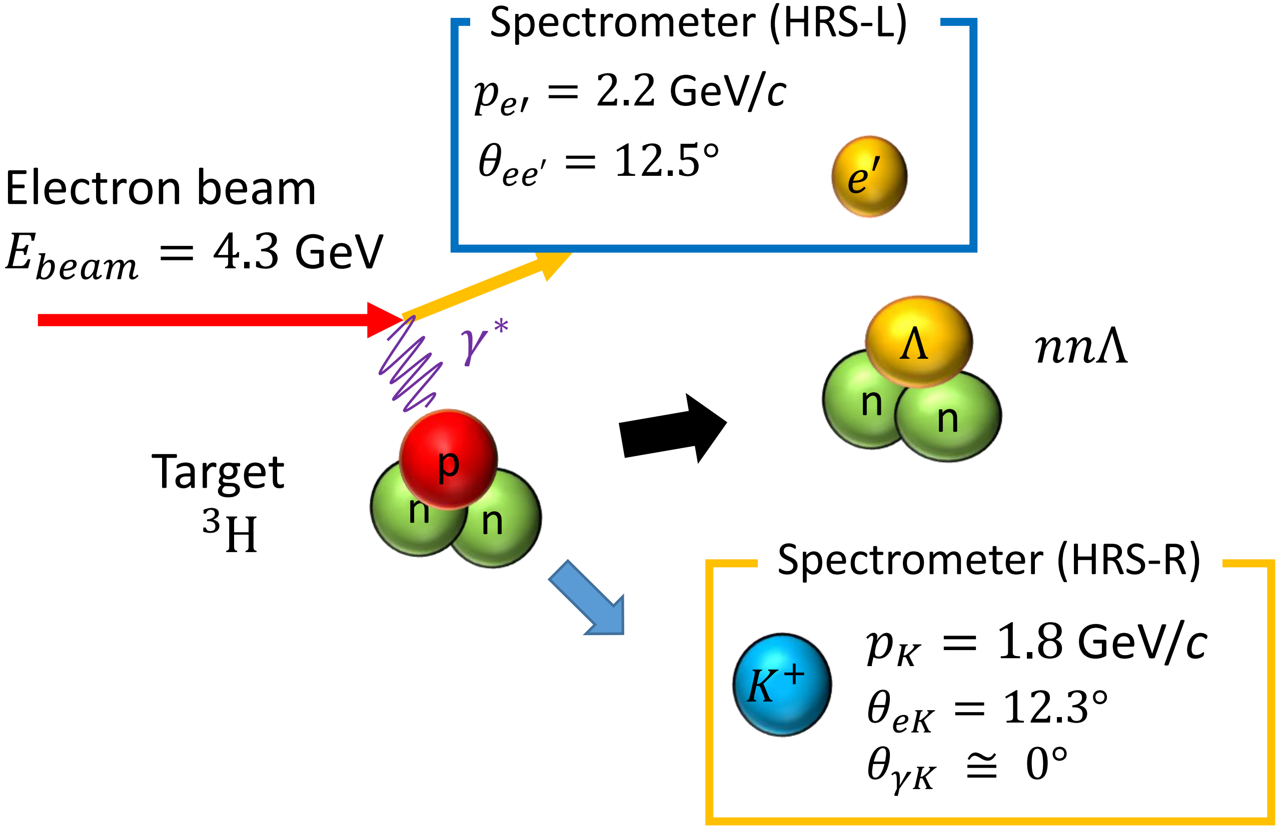
What is $nn\Lambda$ state??





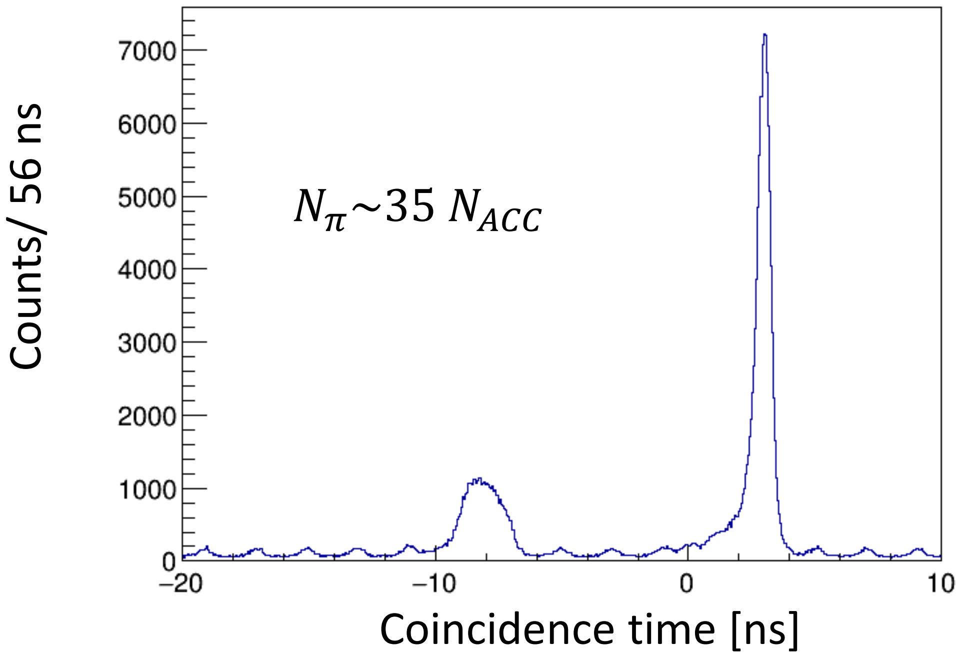
C. Rappold *et al.* (HypHI Collaboration)
Phys. Rev. C 88, 041001(R) – Published 10 October 2013

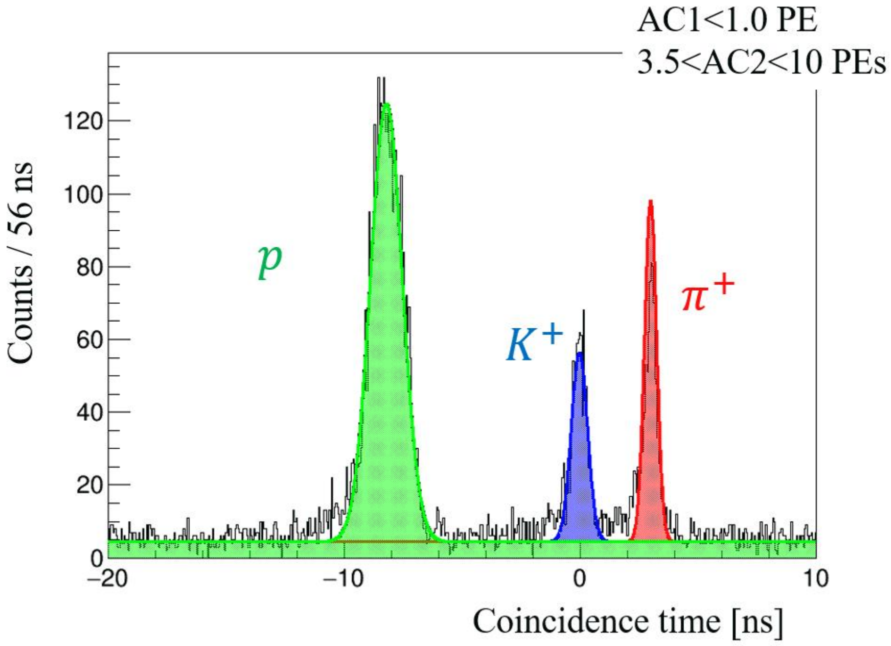
$^{3}\mathrm{H}(e,e'K^{+})nn\Lambda$ experiment at JLab



$$M_{HYP} = \sqrt{(E_{beam} + M_{target} - E_{e'} - E_K)^2 - (\vec{p}_e - \vec{p}_{e'} - \vec{p}_K)^2}$$

π^+ rejection estimation





Requirement

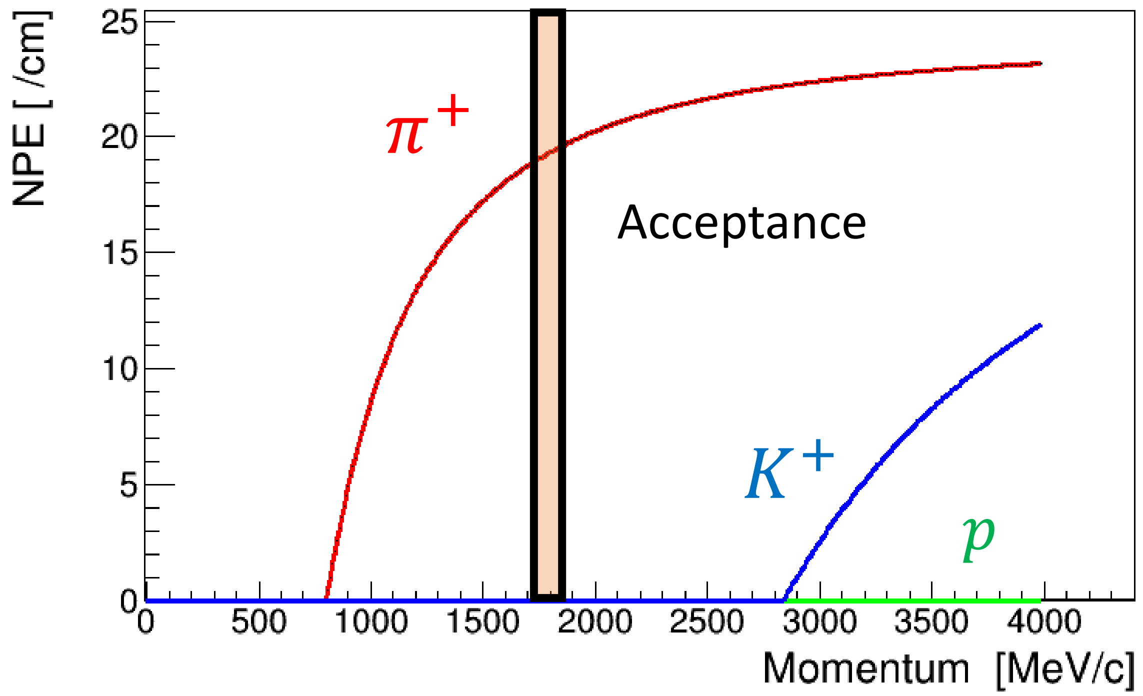
$$\frac{N_K}{N_{ACC}^{cut}} > 3$$

$(N_{ACC}^{cut} = SR_\pi \times N_{ACC})$

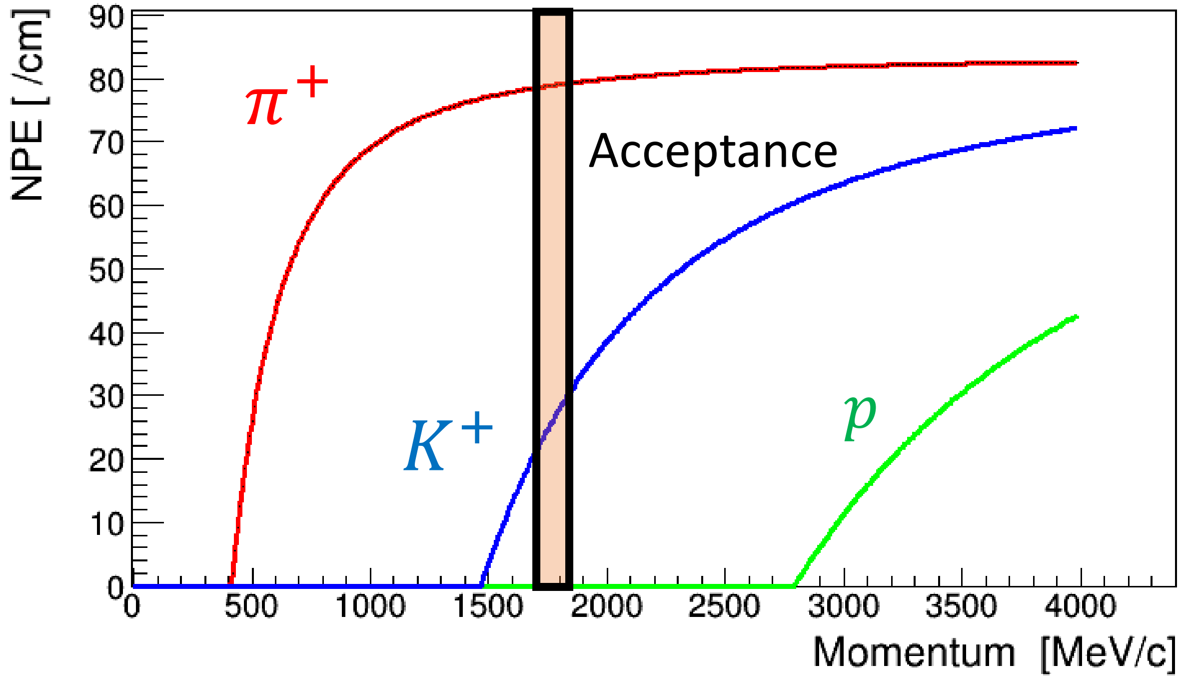
$$\frac{35/100 N_{ACC}}{3 N_{ACC}} \sim 0.10 > SR_\pi$$

$N_K \sim 1/100\ N_\pi$

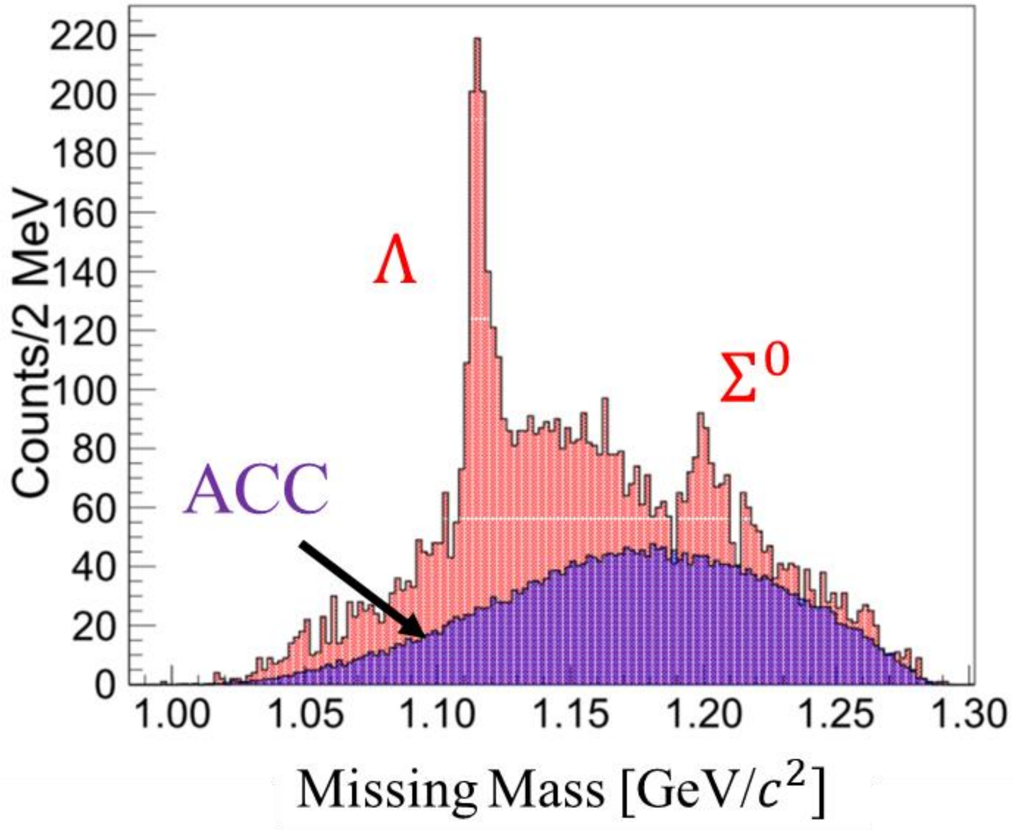
Number of Photon Electronswith AC1



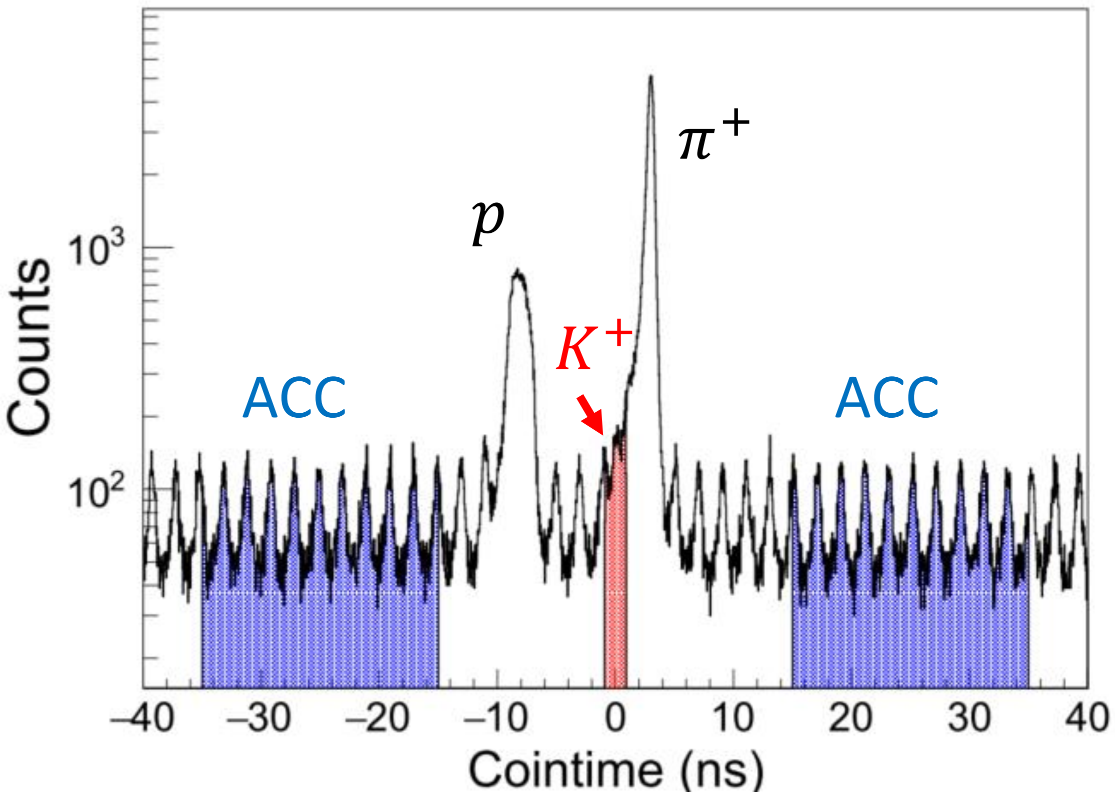
Number of Photon Electronswith AC2



Coin ACC

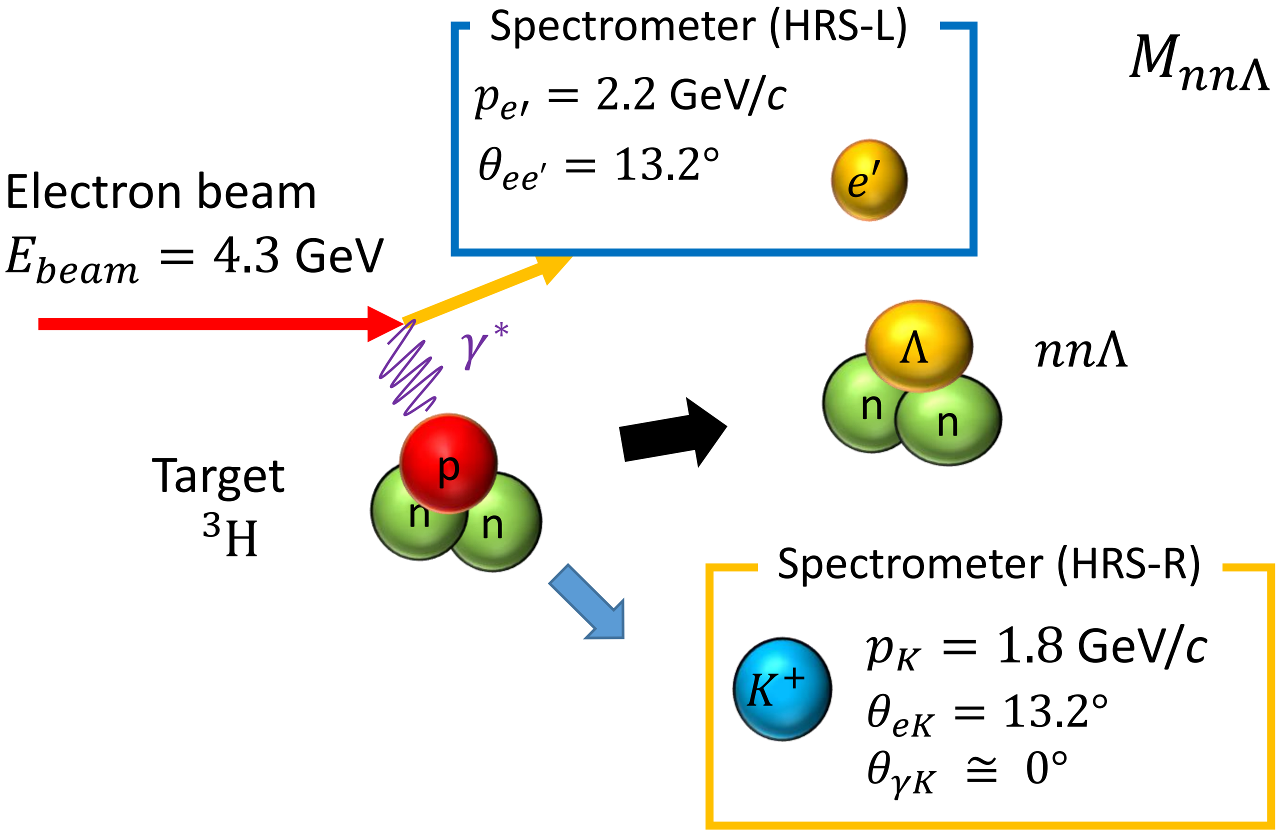


Counts/2 MeV
220
200
180
160
140
120
100
80
60
40
20
0
1.00
1.05
1.10
1.15
1.20
1.25
1.30
Missing Mass [GeV/c^2]
Λ
Σ^0
ACC



Counts
10^3
10^2
−40
−30
−20
−10
0
10
20
30
40
Cointime (ns)
π^+
p
K^+
ACC
ACC

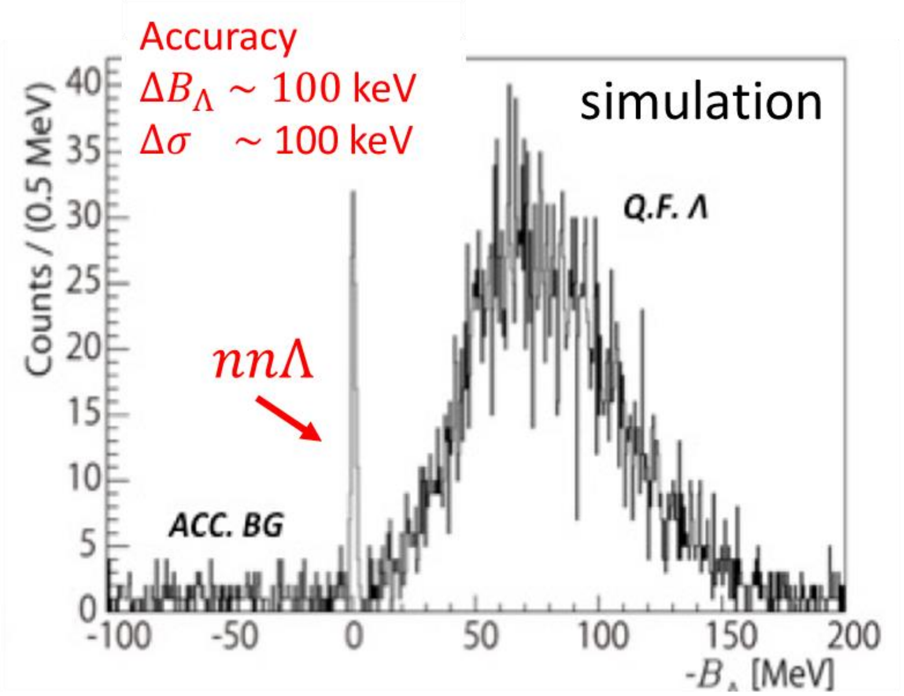
Experimental principle



Identification of $nn\Lambda$ mass and binding energy

$$M_{nn\Lambda} = \sqrt{(E_e - E_{e'} - E_K)^2 - (\vec{p_e} - \vec{p_{e'}} - \vec{p_K})^2}$$

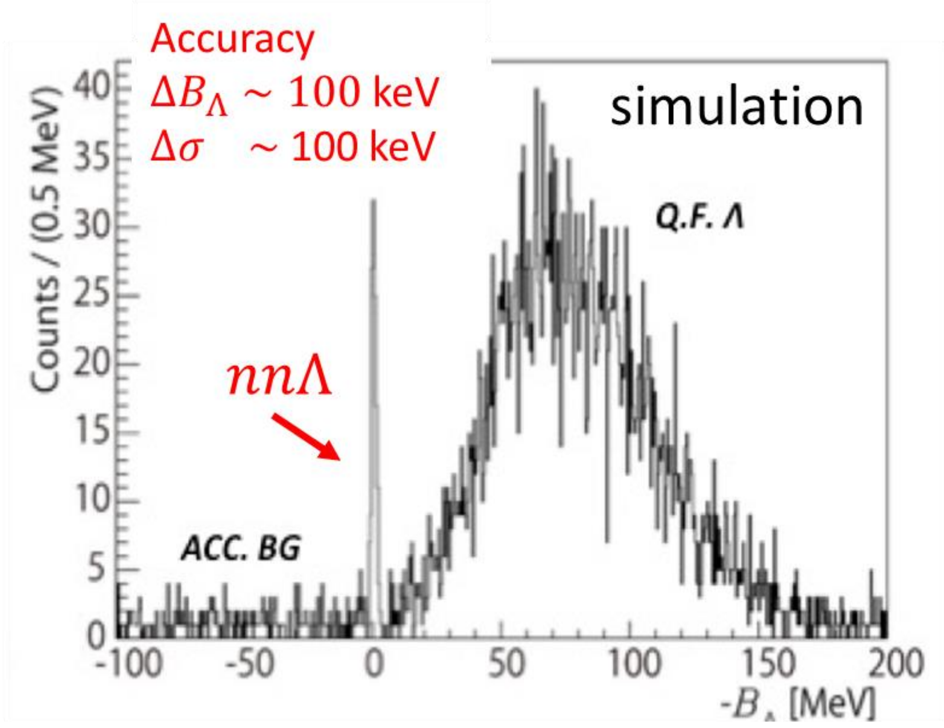
$$-B_\Lambda = -(2m_n + m_\Lambda) + M_{nn\Lambda}$$



L.Tang, et al., Proposal to Jefferson Lab PAC45 (2017).

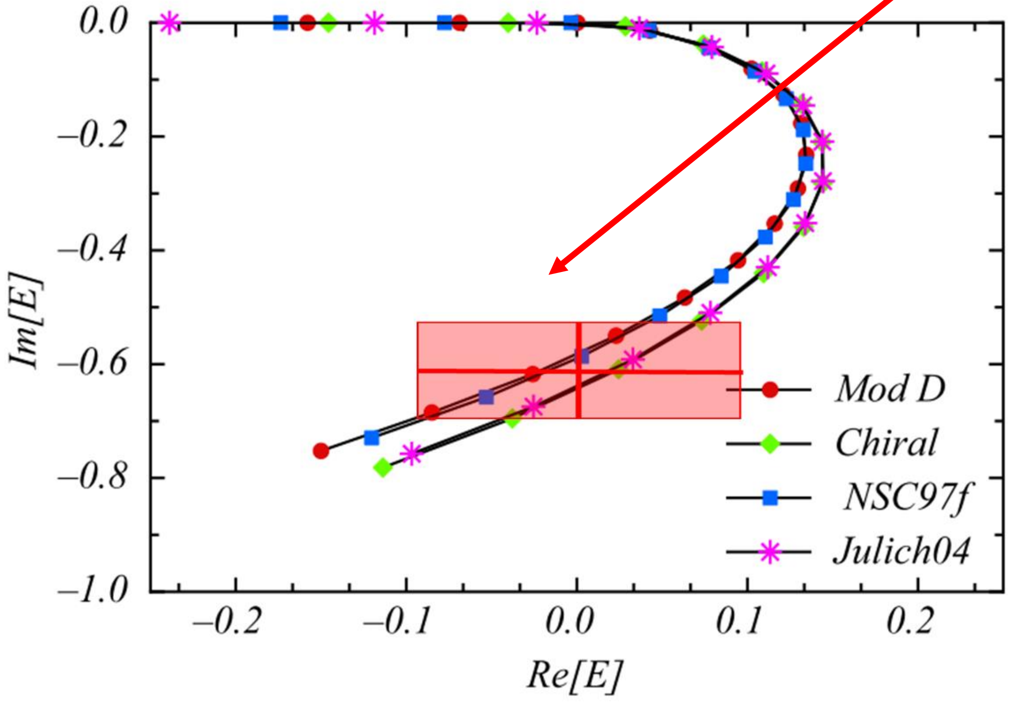
Research for the $nn\Lambda$ state at JLab

High resolution and accuracy is achieved at JLab
Precise accuracy : $\Delta B_\Lambda \sim 100$ keV, $\Delta\sigma \sim 100$ keV



L.Tang, et al., Proposal to Jefferson Lab PAC45 (2017).

Restriction of $\Lambda - n$ interaction within 5 % accuracy in each potential model

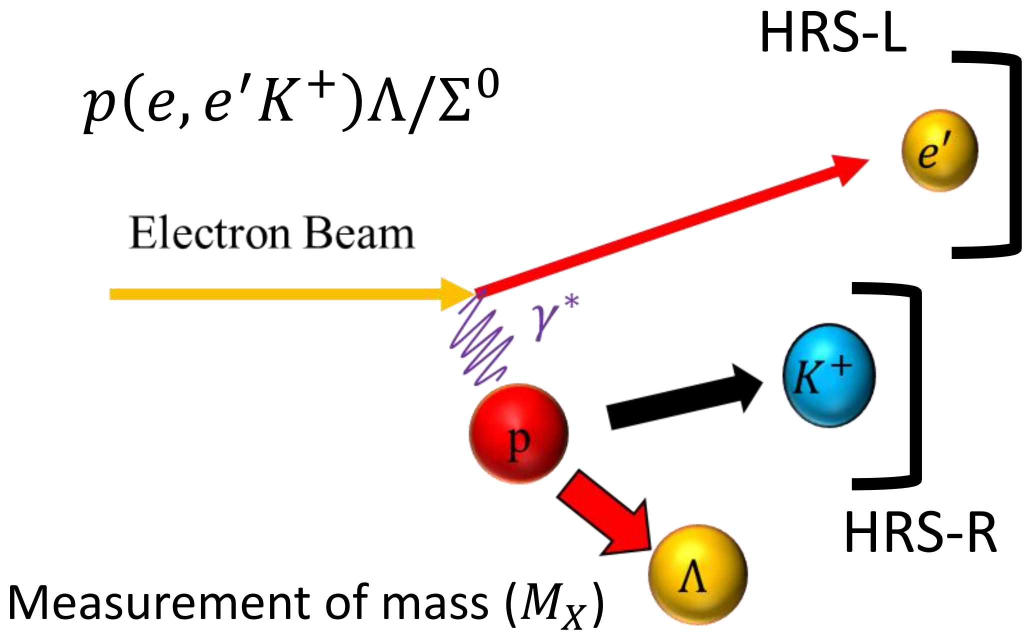


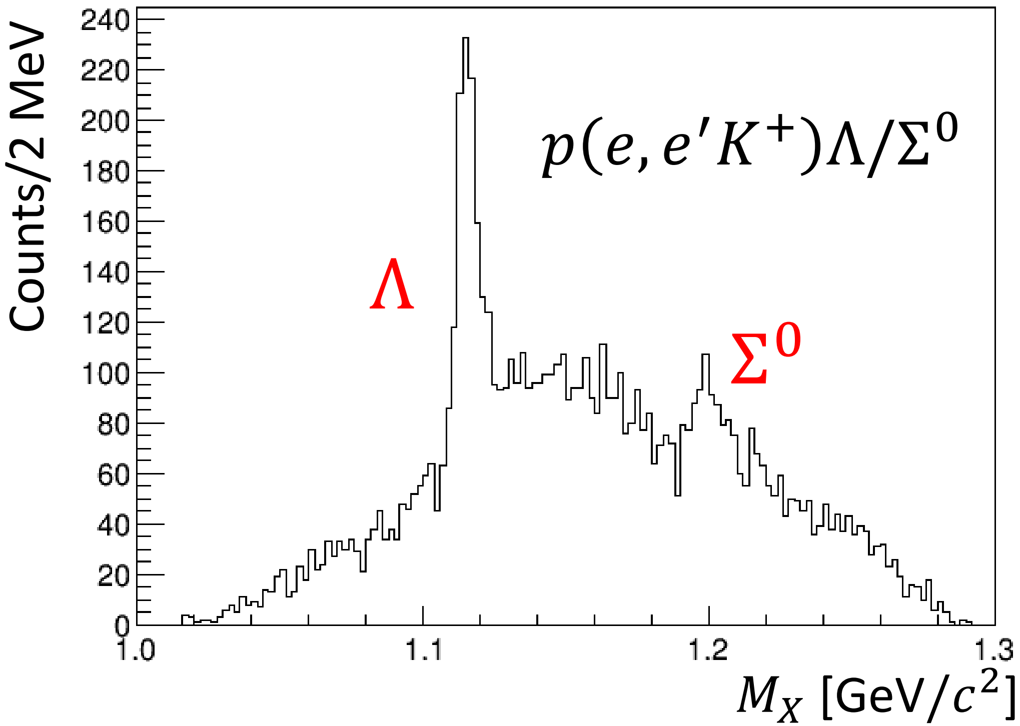
R Afnan, BF Gibson - Physical Review C, 2015 - APS

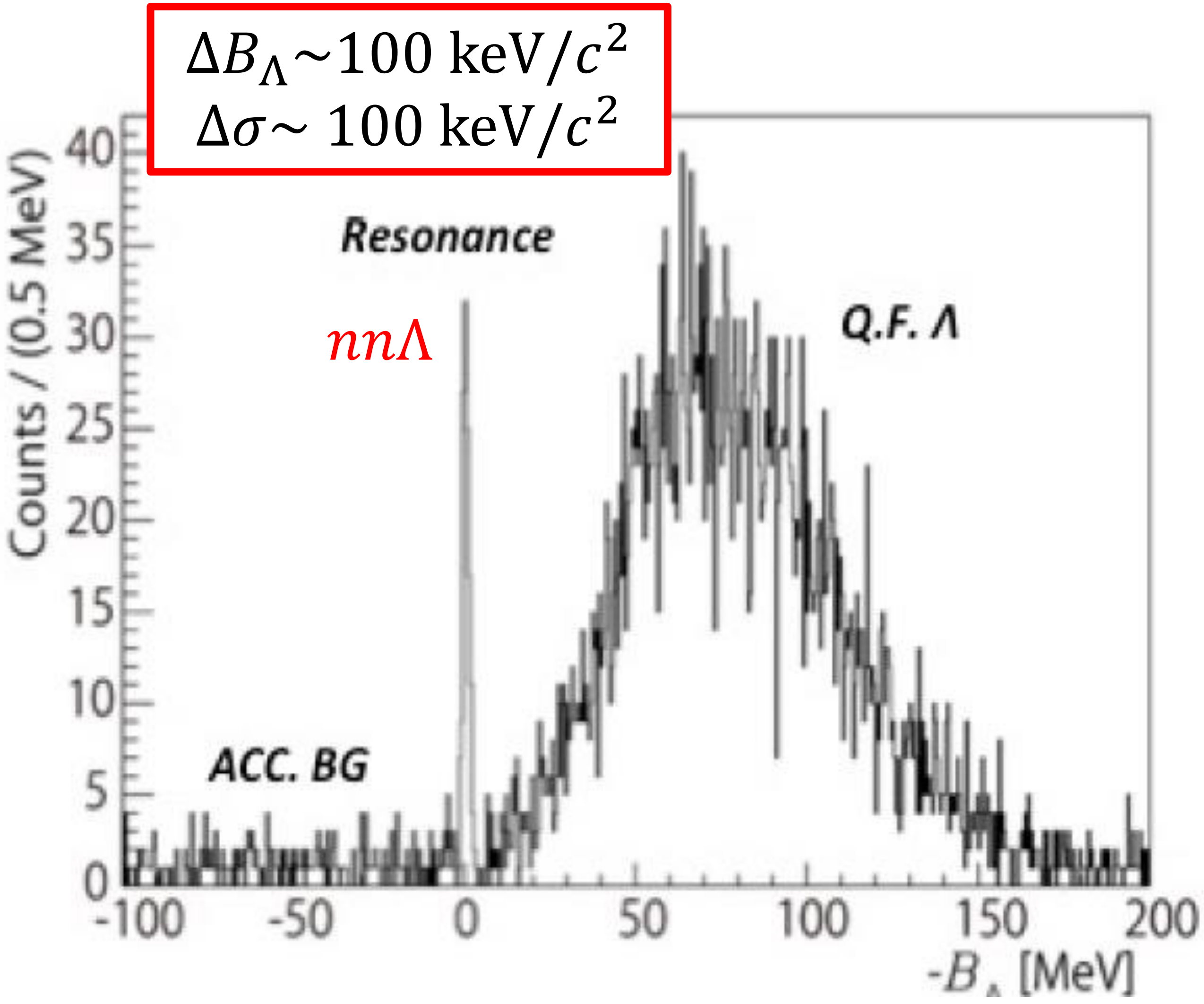
Missing mass distribution

Λ, Σ^0 missing mass:

$$M_X = \sqrt{\left(E_e + m_p - E_{e'} - E_K\right)^2 - (\overrightarrow{p_e} - \overrightarrow{p_{e'}} - \overrightarrow{p_K})^2}$$







$\Delta B_\Lambda \sim 100\ \mathrm{keV}/c^2$
$\Delta\sigma \sim 100\ \mathrm{keV}/c^2$
Resonance
$nn\Lambda$
Q.F. Λ
ACC. BG
Counts / (0.5 MeV)
40
35
30
25
20
15
10
5
0
-100
-50
0
50
100
150
200
$-B_\Lambda$ [MeV]