Spectroscopic Study of Hyperon Resonances below $K^{bar}N$ Threshold via the (K^-,n) Reaction on Deuteron

H. Noumi, *Osaka Univ. RCNP*, for the E31 collaboration

S. Ajimura[1], G. Beer[2], H. Bhang[3], M. Bragadireanu[8], P. Buehler[4], L. Busso[5,6], M. Cargnelli[4], S. Choi[3], C. Curceanu[8], S. Enomoto[1], D. Faso[5], H. Fujioka[13], Y. Fujiwara[12], T. Fukuda[11], Y. Fukuda[10], C. Guaraldo[8], R. S. Hayano[12], T. Hiraiwa [13], A. Hirtl[4], M. Iio[14], M. Iliescu[8], K. Inoue[1], N. Ishibashi[7], Y. Ishiguro[13], T. Ishikawa[12], S. Ishimoto[14], T. Ishiwatari[4], K. Itahashi[9], M. Iwai[14], M. Iwasaki[9,10], S. Kawasaki[1], P. Kienle[15], H. Kou[10], Y. Ma[9], J. Marton[4], Y. Matsuda[12], Y. Mizoi [10], O. Morra[5], T. Nagae[13], H. Noumi [1], H. Ohnishi[9], S. Okada[9], H. Outa[9], L. Poli Lener[8], A. Romero Vidal[8], Y. Sada[13], A. Sakaguchi[7], F. Sakuma[9], M. Sato[12], M. Sekimoto[14], K. Shirotori[1], D. Sirghi[8], F. Sirghi[8], S. Suzuki[14], T. Suzuki[12], H. Tatsuno[8], M. Tokuda[10], D. Tomono[9], A. Toyoda[14], K. Tsukada[16], E. Widmann[4], O. Vazquez Doce[8], T. Yamazaki[9,12], K. Yoshida[17], H. Yim[3], J. Zmeskal[4] .

1. Research Center for Nuclear Physics, Osaka University, Japan

2. University of Victoria, Canada, 3. Seoul National University, South Korea

4. Stefan Meyer Institut fur subatomare Physik, Austria,

5. INFN Sezione di Torino, Italy , 6.Universita' di Torino, Italy

7. Osaka University, Japan, 8. Laboratori Nazionali di Frascati dell'INFN, Italy

9. RIKEN, Japan, 10. Tokyo Institute of Technology, Japan

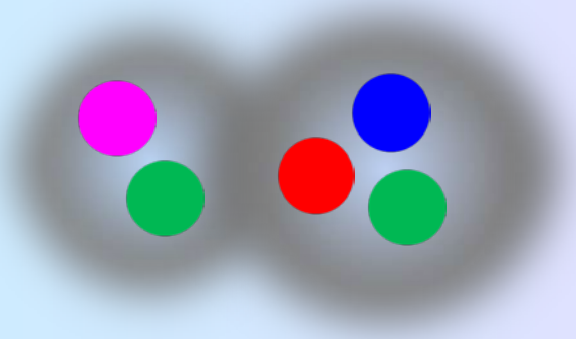
11. Osaka Electro-Communication University, Japan, 12. University of Tokyo, Japan

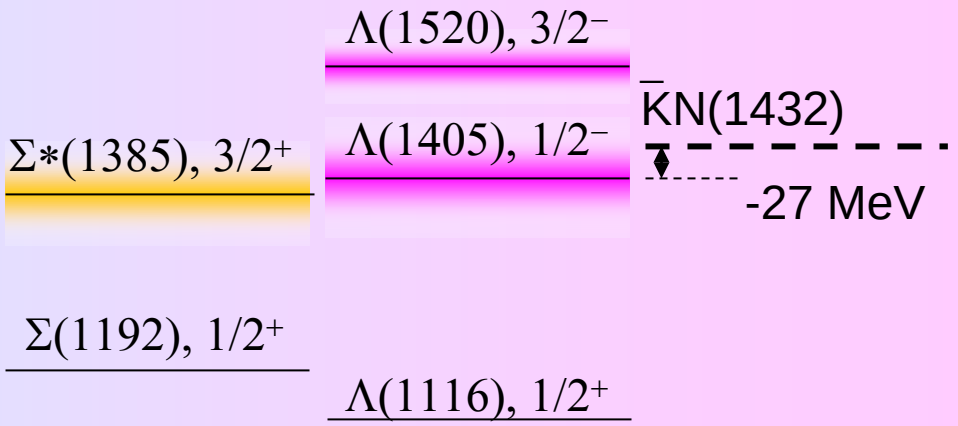
13. Kyoto University, Japan, 14. High Energy Accelerator Research Organization (KEK), Japan

15. Technische Universitat Munchen, Germany, , 16. Tohoku University, Japan

$\Lambda(1405)$: $1405.1^{+1.3}_{-0.9}$ MeV (PDG)

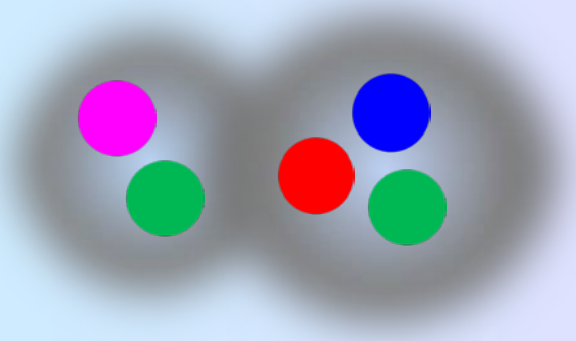
$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{\bar{K}N}$, lightest in neg. parity baryons

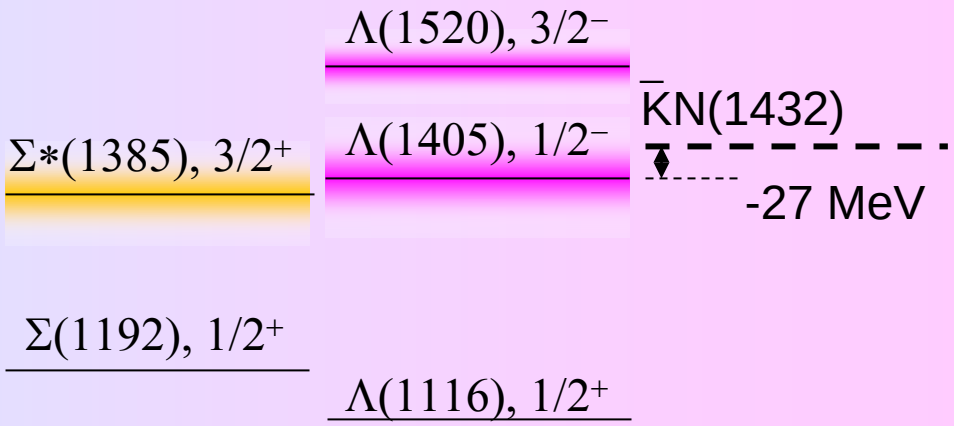


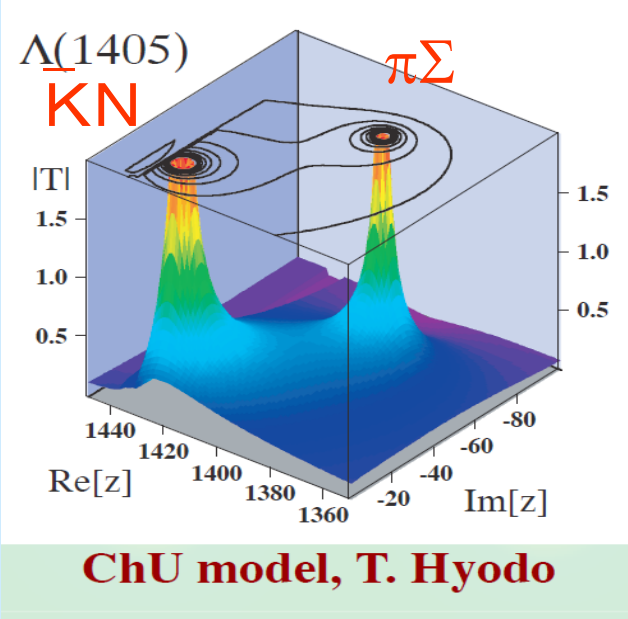


Λ(1405) : meson-baryon molecular state?

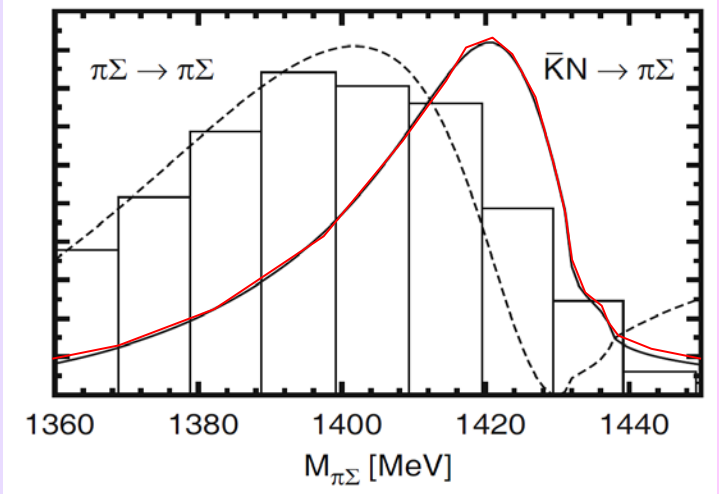
$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{\bar{K}N}$, lightest in neg. parity baryons







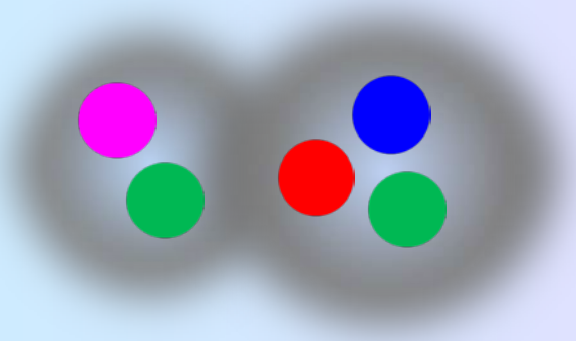
ChU model, T. Hyodo

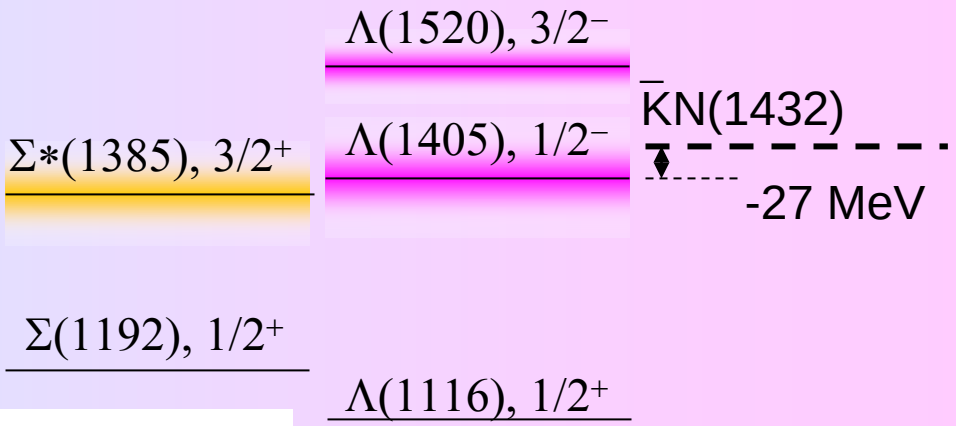


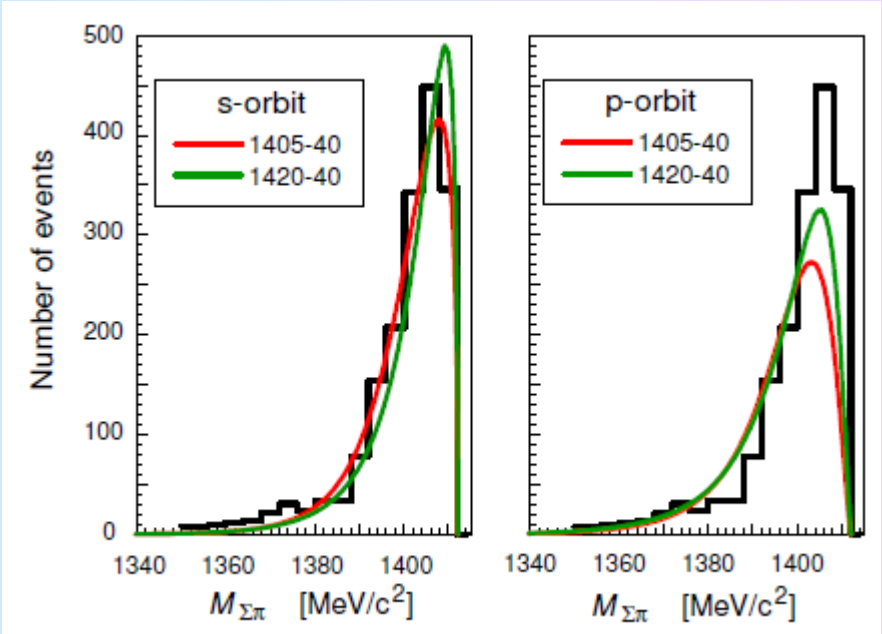
Chiral Unitary Model:
D. Jido et al., NPA725(03)181

Λ(1405) :

$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{K^{bar}N}$, lightest in neg. parity baryons



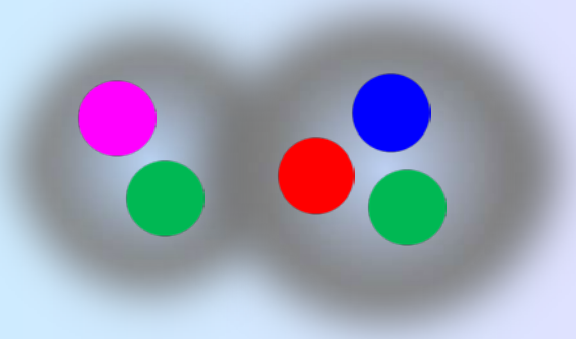


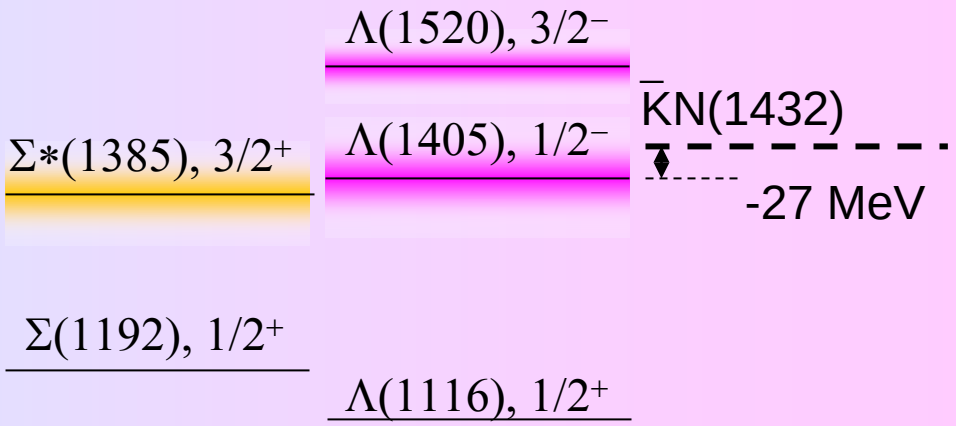


J. Esmaili et al: $\pi\Sigma$ IM Spec. of Stopped K^- on ^{4}He

Λ(1405) : meson-baryon molecular state?

$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{K^{bar}N}$, lightest in neg. parity baryons





E31 aims:

- to conclude if the Λ(1405) as a bound $K^{bar}N$ state appears at ~1405 MeV or ~1420 MeV.
  - ✓ This gives basic information on a longstanding argument on a deeply bound kaonic nuclei.

Study of Kaon-induced Λ(1405) formation reaction is desired.

Λ(1405) Spectroscopy via the (K^-,n) reaction on ^2H

What do we measure?

✓ $K^{bar}N$ scattering below $K^{bar}N$ threshold

Employ d(K^-,n)Λ^*

Ideal to form the Λ^* directly coupled to $K^{bar}N$.

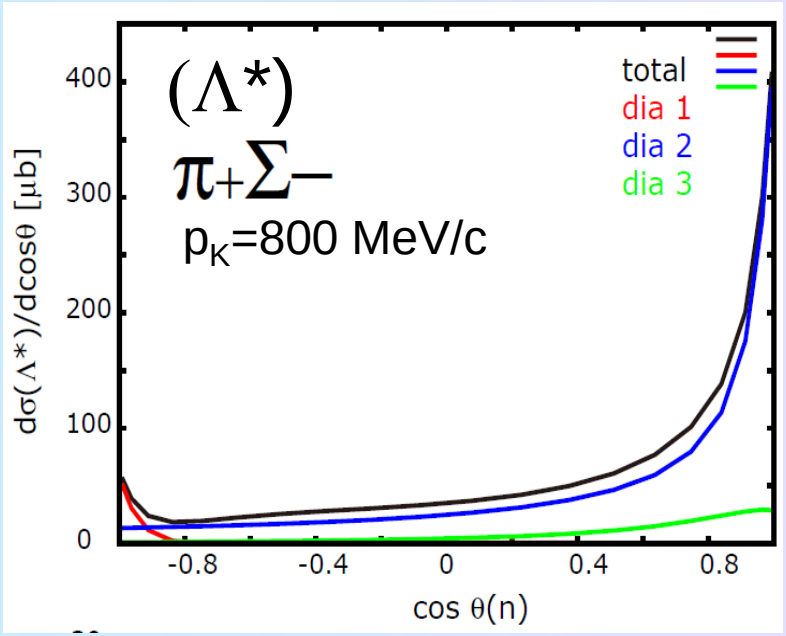
Enhancement of Λ^* production at θ_n=0
BG from Σ^* will be reduced.

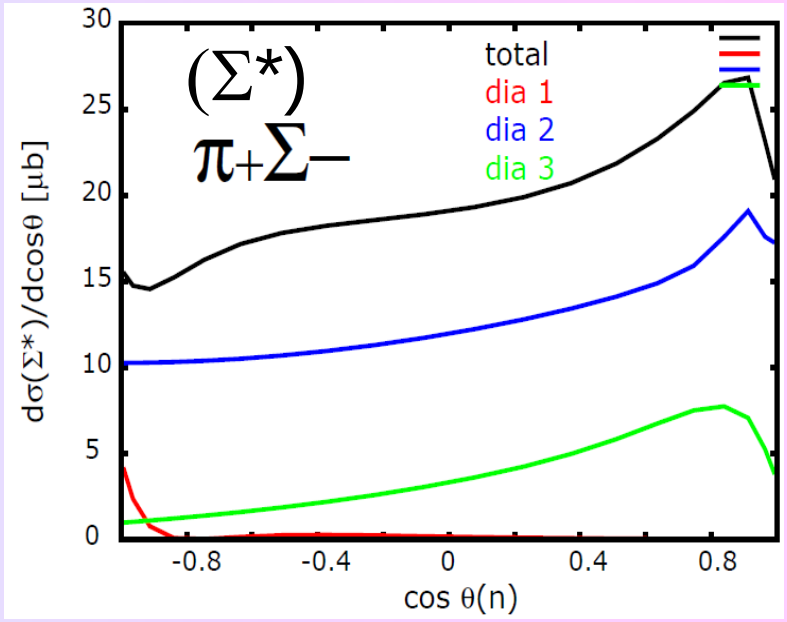
to be checked by d(K-,p)Σ^{*-}

Λ(1405): S-wave $K^{bar}N \rightarrow \pi\Sigma$ scattering below $K^{bar}N$ threshold

d(K^-,n) may enhance the S-wave scattering at θ_n = 0 degree.

J. Yamagata-Sekihara,T. Sekihara, and D. Jido





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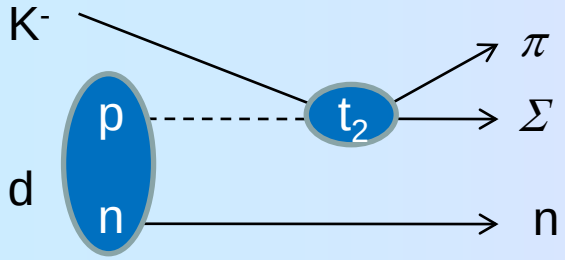
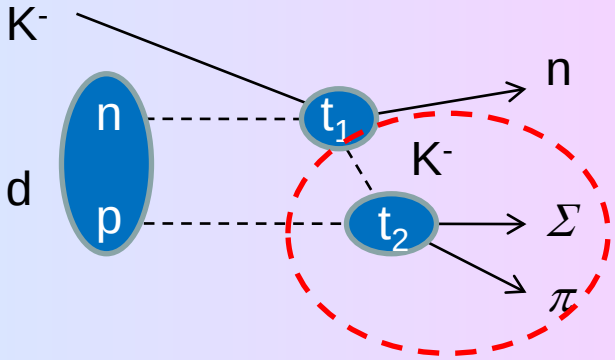
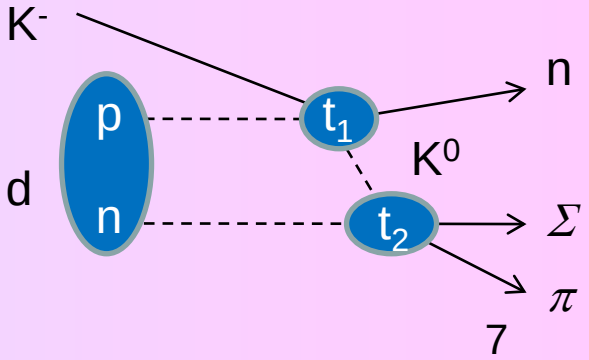


dia.2:dominant

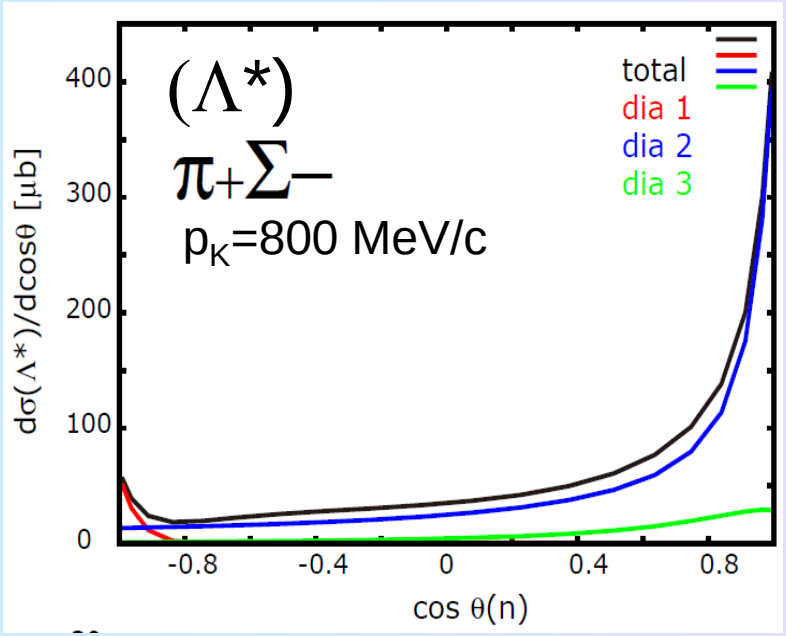


dia.3:Interference

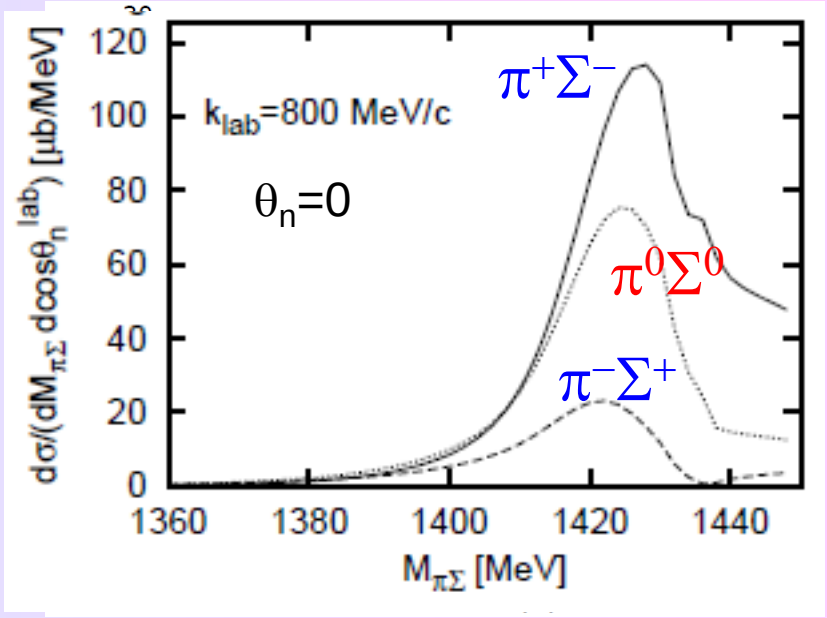


Λ(1405): S-wave $K^{bar}N \rightarrow \pi\Sigma$ scattering below $K^{bar}N$ threshold

d(K^-,n) may enhance the S-wave scattering at θ_n = 0 degree.



J. Yamagata-Sekihara,T. Sekihara, and D. Jido



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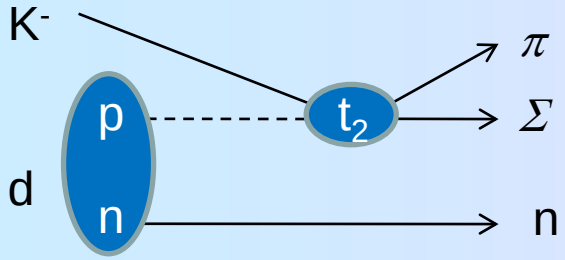

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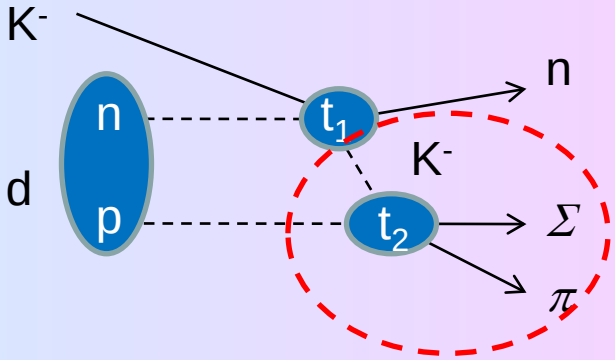

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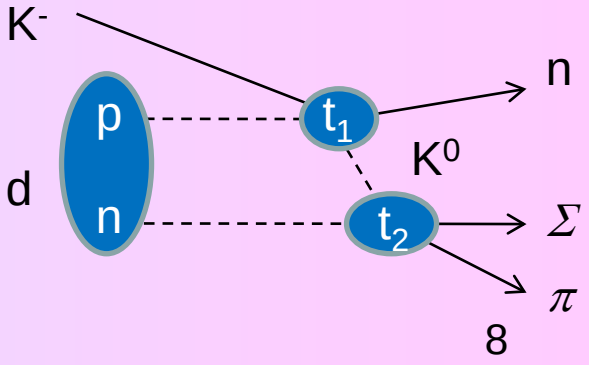


$\Lambda(1405)$ Spectroscopy via the (K^-,n) reaction on ^2H

What do we measure?

✓ $K^{bar}N$ scattering below $K^{bar}N$ threshold

Employ $d(K^-,n)\Lambda^*$

Ideal to form the Λ^* directly coupled to $K^{bar}N$.

Enhancement of Λ^* production at $\theta_n=0$
BG from Σ^* will be reduced.

to be checked by $d(K^-,p)\Sigma^{*-}$

✓ need to decompose I=0/I=1 amplitudes in the final states to understand formation mechanism

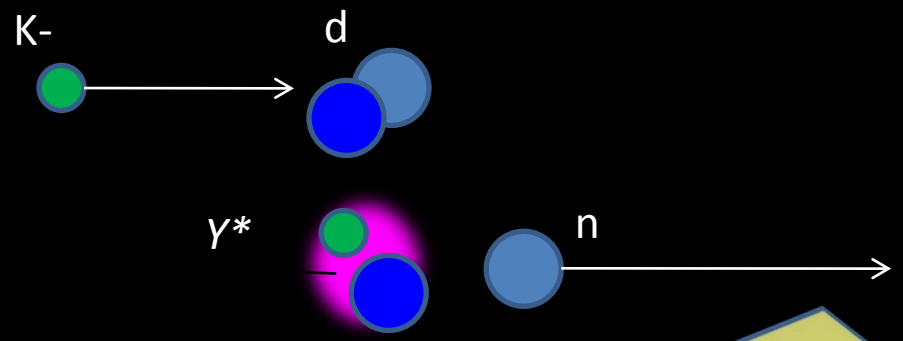
S-wave, I=0 → $\Lambda^*(1405)$ → $\pi^0\Sigma^0$, $\pi^{+/-}\Sigma^{-/+}$

S-wave, I=1 → non-resonant

P-wave, I=1 → $\Sigma^*(1385)$

→ $\pi^0\Lambda$, $\pi^{+/-}\Sigma^{-/+}$

Experimental Setup for E31



Neutron counter

TOF~15m

Proton counter

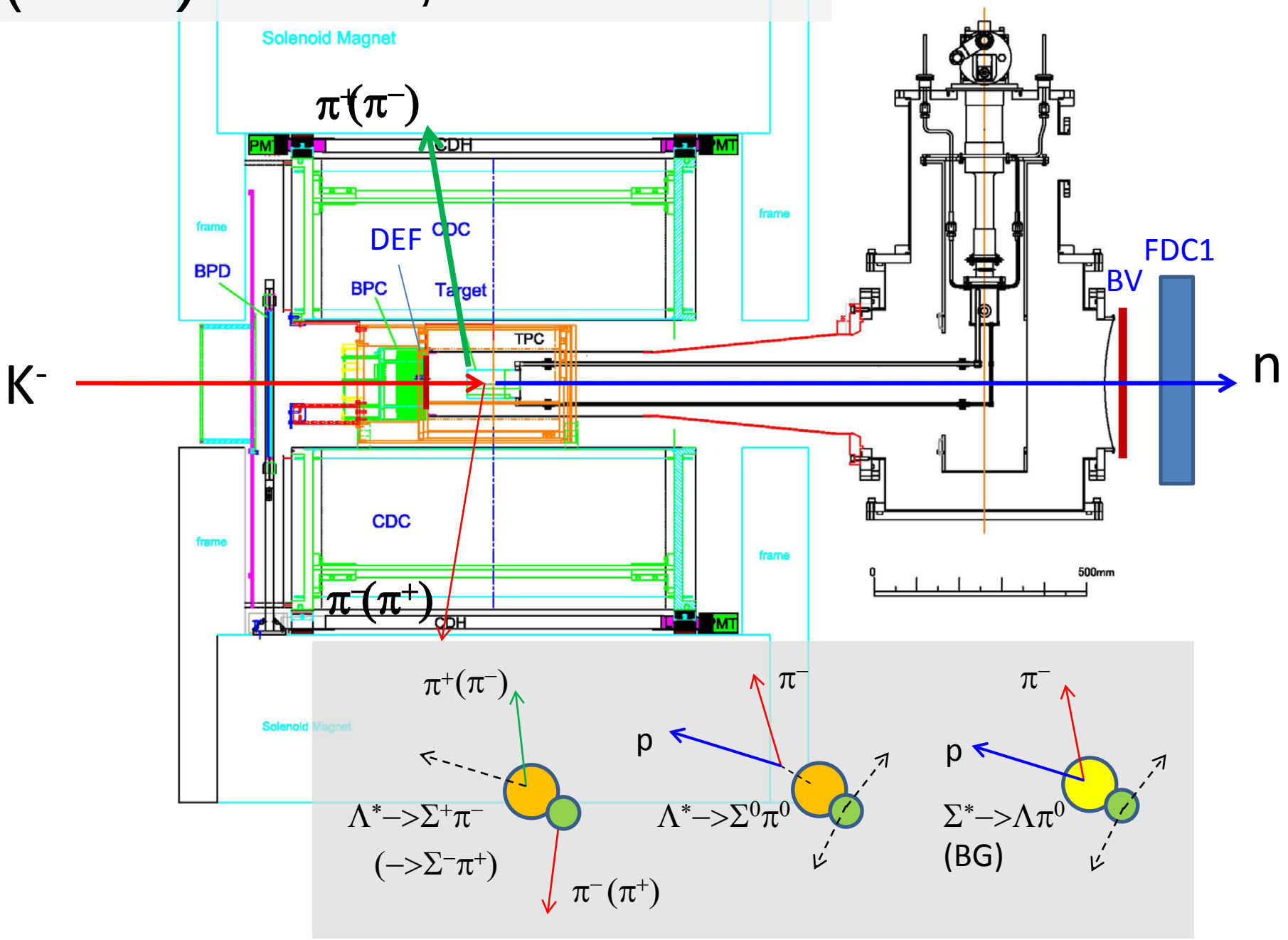
Cylindrical Detector System
(Solenoid Field 0.5T)

Beam Sweeper
(Ushiwaka)

K^- Beam Spectrometer
(K1.8BR-D5)

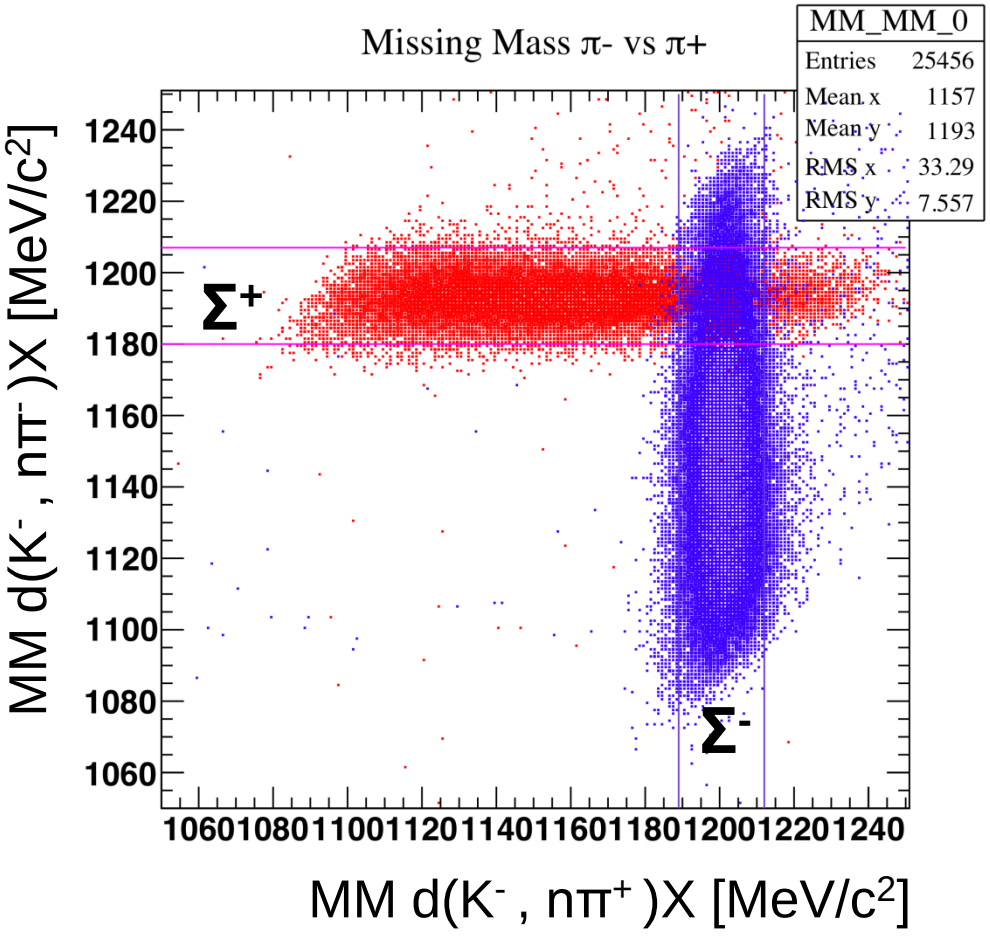
σ_{MM} ~ 9 MeV/c^2 at p_{K^-}=1 GeV/c

Λ(1405)→π⁻Σ⁺ , π⁺Σ⁻ modes

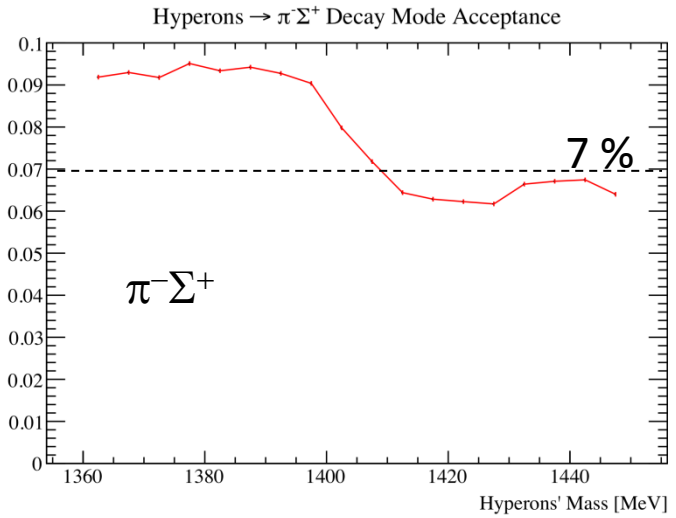


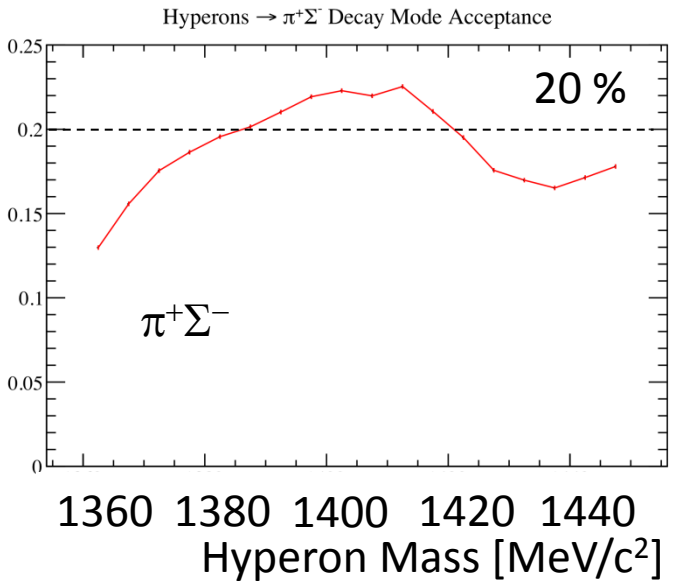
Λ(1405)→π⁻Σ⁺ , π⁺Σ⁻ modes

Red : Λ(1405)→π⁻Σ⁺ mode
Blue : Λ(1405)→π⁺Σ⁻ mode

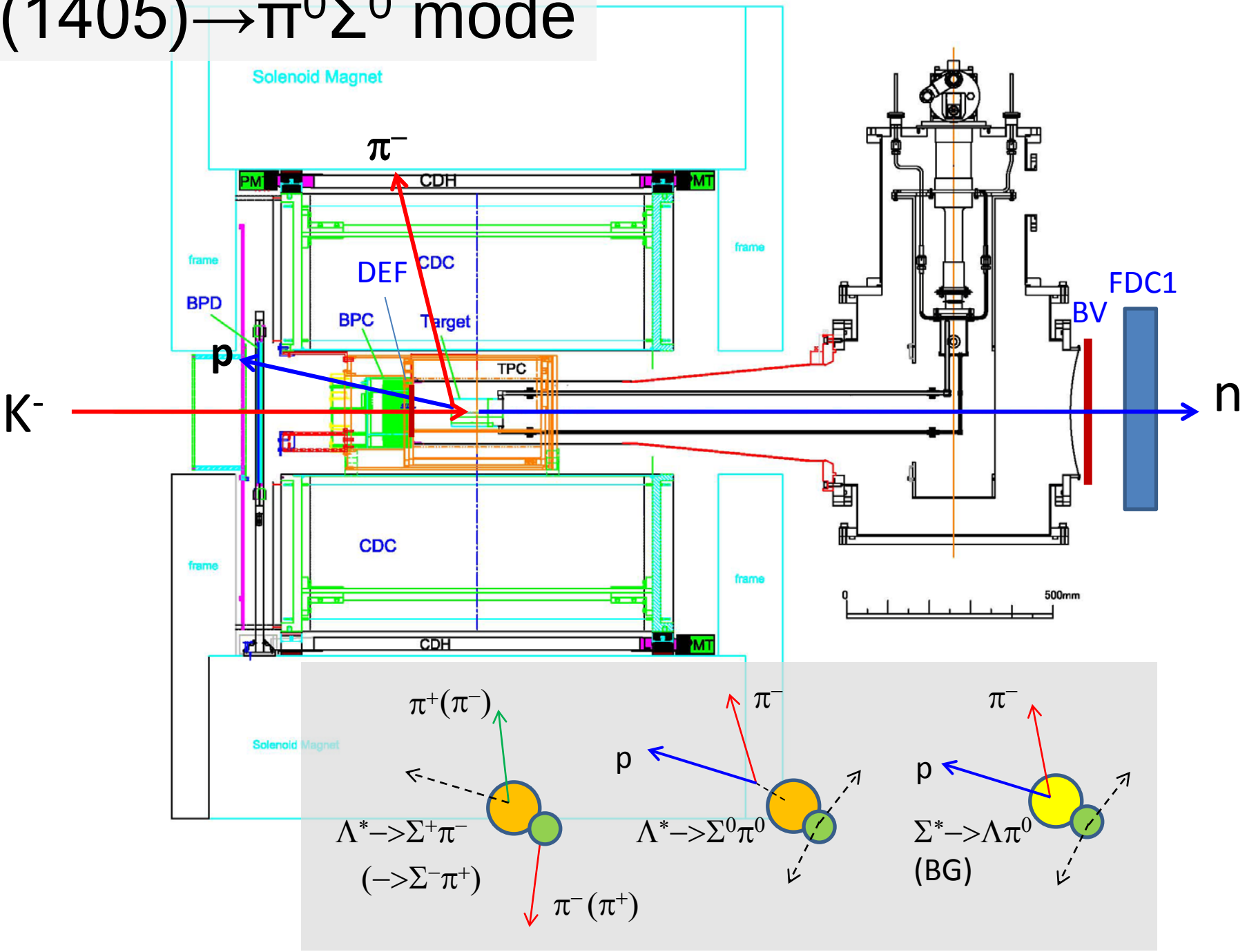


Acceptance



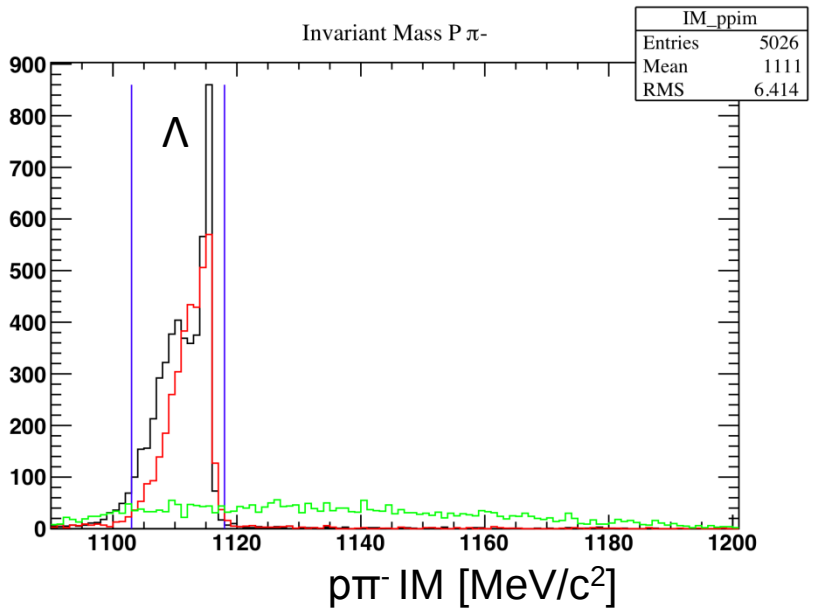


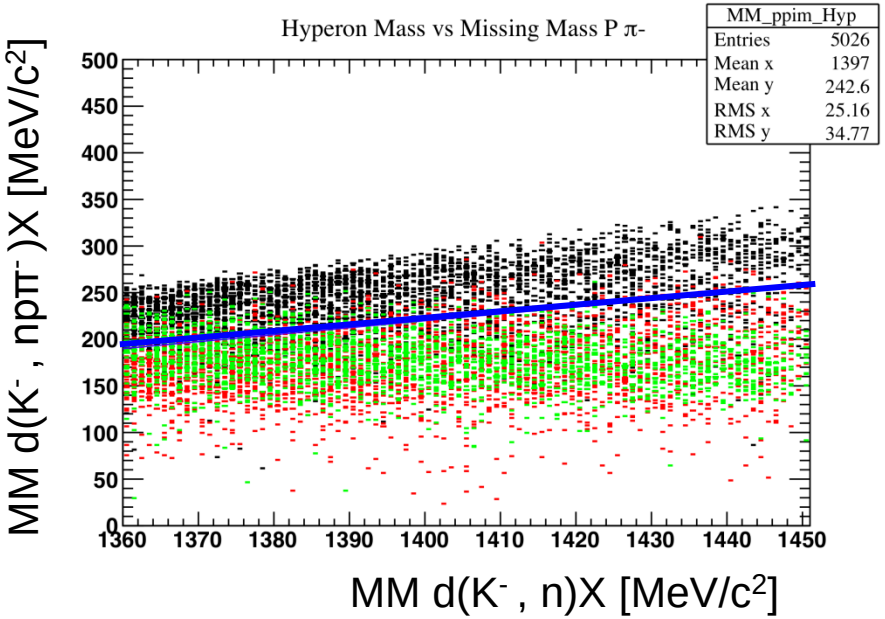
$\Lambda(1405) \rightarrow \pi^0\Sigma^0$ mode



$\Lambda(1405) \rightarrow \pi^0\Sigma^0$ mode

Black : $\Lambda(1405) \rightarrow \pi^0\Sigma^0 \rightarrow \pi^0\gamma\pi^0 p$
Red : $\Sigma(1385) \rightarrow \pi^0\Lambda \rightarrow \pi^0\pi^- p$
Green : $\Lambda(1405) \rightarrow \pi^-\Sigma^+ \rightarrow \pi^- p\pi^0$





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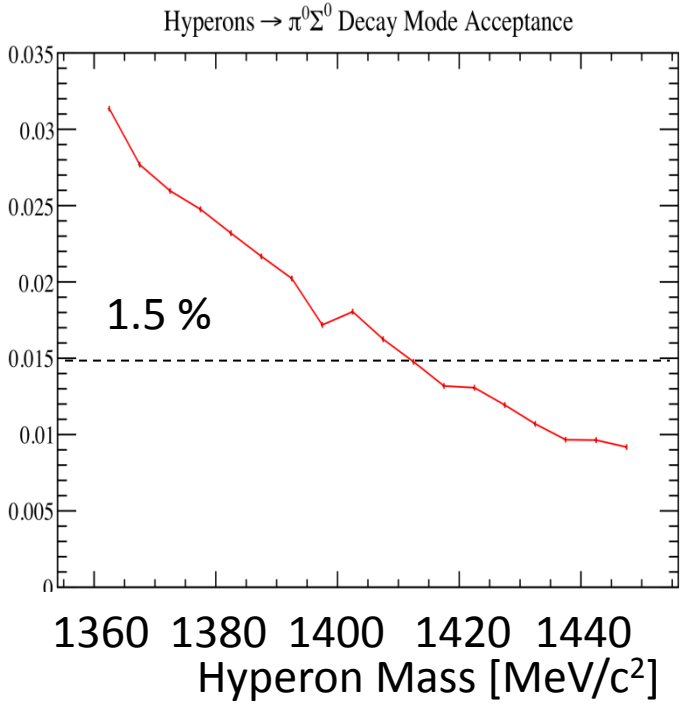
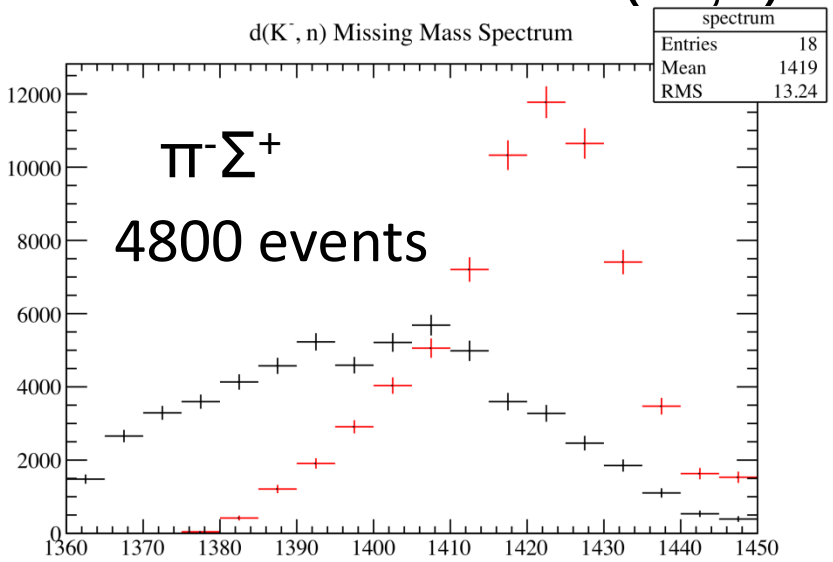
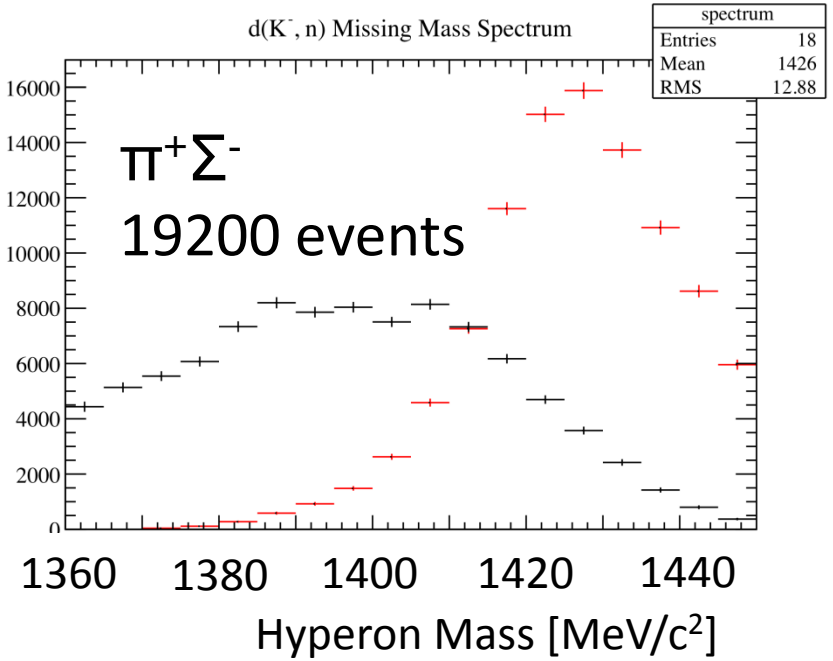
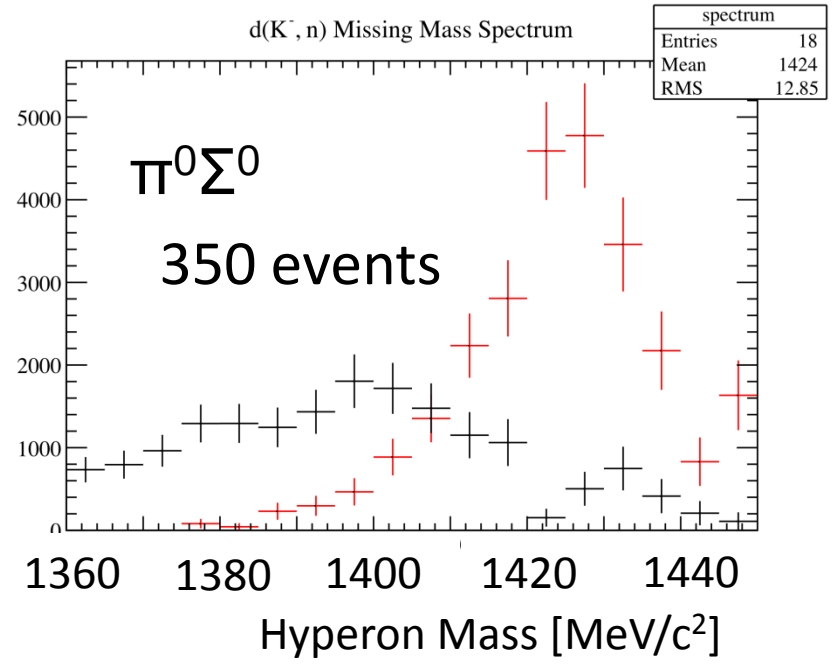


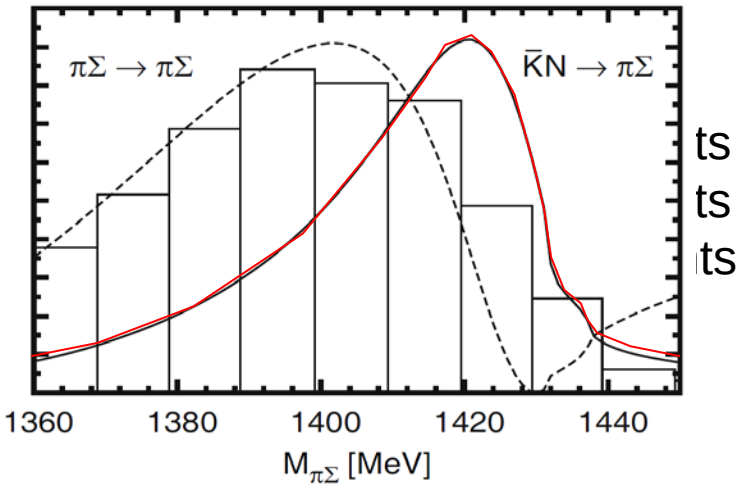
Simulation: $MM_{d(K^-,n)X}$ Spectra (Acceptance Corrected)







Red : Chiral Unitary Model
Black : Hemingway's data

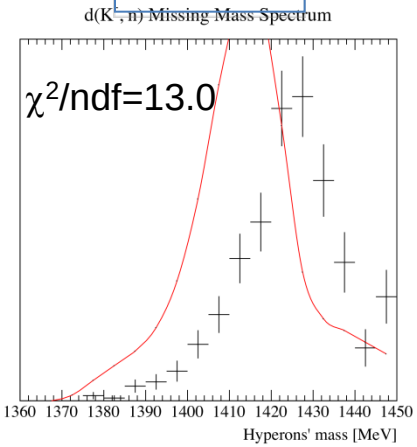


Demonstrate a Peak fitting for 350 events

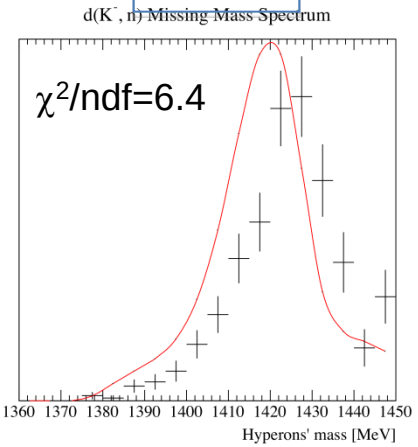
Chiral Unitary Model

($\pi^0\Sigma^0$ mode)

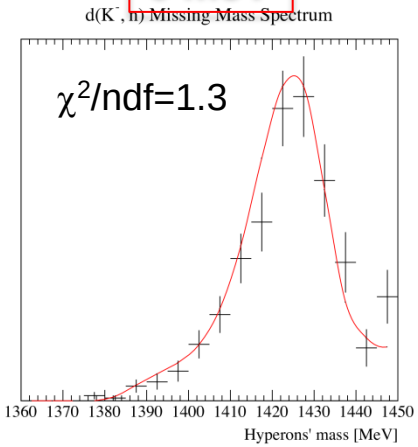
-10MeV



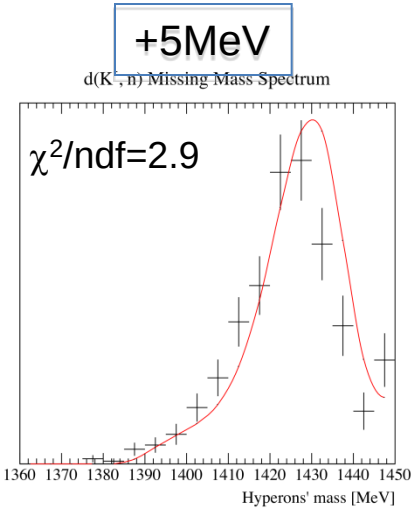
-5MeV



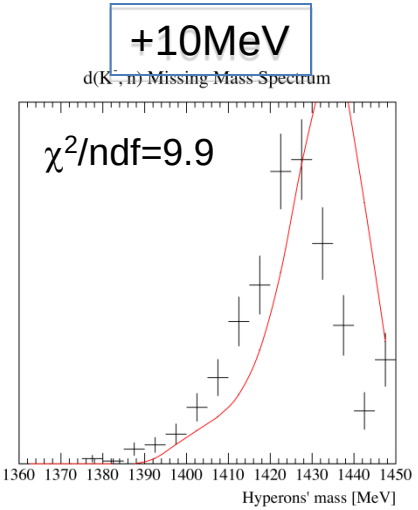
0 MeV



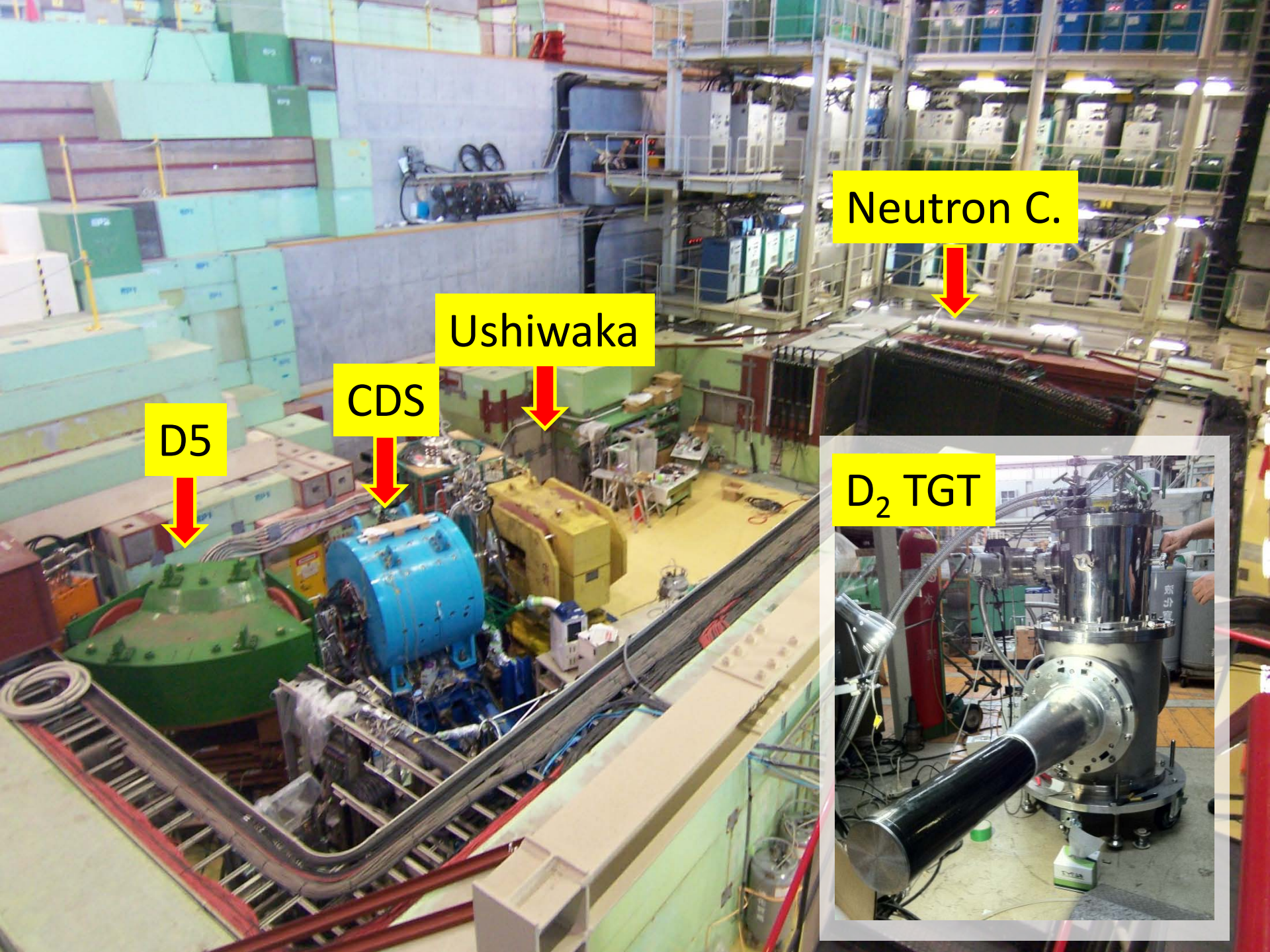
+5MeV



+10MeV



center	N	χ^2	χ^2/ndf
-10MeV	16	207.707	12.984
-5MeV	15	96.266	6.418
default	14	18.605	1.329
+5MeV	13	37.596	2.892
+10MeV	12	118.150	9.856


Neutron C.
Ushiwaka
CDS
D5
D_2 TGT

Milestones

- We expect 350 events for $\Lambda(1405)\text{->}\pi^0\Sigma^0$.
  - Request 120 shifts at 27 kW (~150 kW*week)
- We wish to confirm that the (K-,n) reaction is enhance S-wave $K^{bar}N$ scattering.
  - Let us look for $\Lambda(1405)\text{->}\pi^+\Sigma^-$, $\pi^-\Sigma^+$ modes.
  - "20 kW*week" seems reasonable.

    >2000 events for $\pi^+\Sigma^-$, >500 events for $\pi^-\Sigma^+$

    confirm Old DBC data($\pi^+\Sigma^-$) w/ higher stat.

    obtain new data of $\pi^-\Sigma^+$.
  - Check BG (non-resonant/ Σ^* amplitudes)

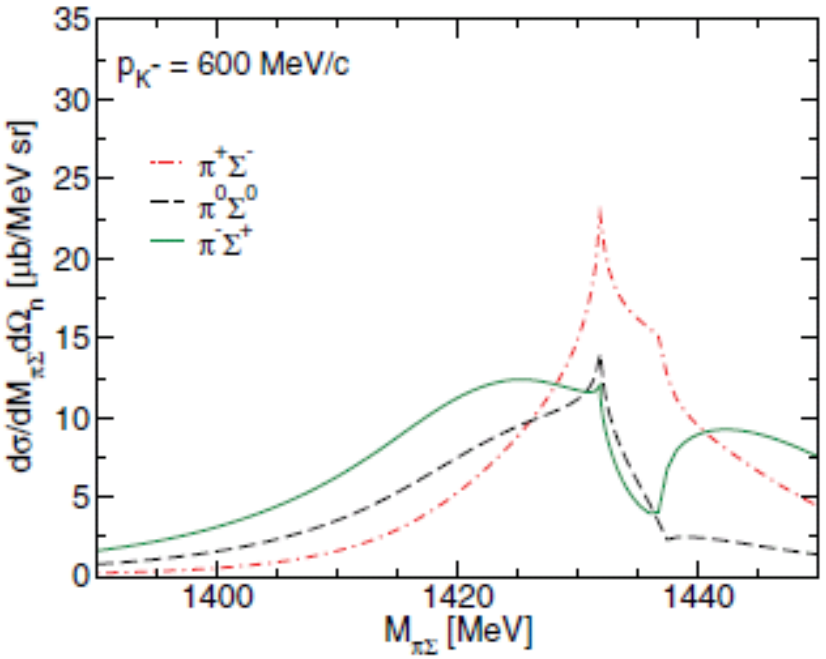
Summary

1. Kaon-induced data are desired to conclude if the $\Lambda(1405)$ as a KbarN bound state appears at 1405 or 1420 MeV/c^2.
2. It is demonstrated that E31 data can discriminate the two.
3. E31 is ready to run.
4. We request stage-2 approval.
5. We would like to have a short term run:

   "20 kW*week" seems reasonable to measure the spectra for charged decay modes ($\Lambda(1405)$->$\pi^+\Sigma^-$, $\pi^-\Sigma^+$).

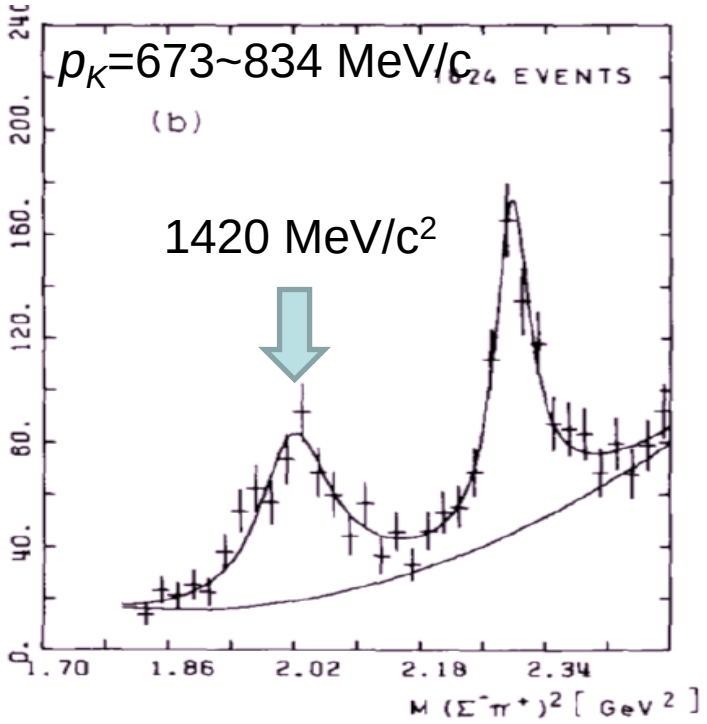
Thank you

Fadeev Calculation



K. Miyagawa and J. Haidenbauer, PRC85, 065201(2012)

K-d -> $\pi^+\Sigma^-n$(Bubble C.)



O. Braun et al., NPB129, 1(1977)

The spectra must be confirmed by E31 with higher statistics.

A part of recent arguments on $\Lambda(1405)$

- PDG 2012 gives the mass of $1405.1^{+1.3}_{-1.0}$ MeV, adopting two theoretical analyses by:
  - R.H. Dalitz et al: $\pi\Sigma$ IM Spec. in $K^-p \rightarrow \pi\pi\Sigma$, w/ M-matrix
  - J. Esmaili et al: $\pi\Sigma$ IM Spec. of Stopped K^- on ^4He
- Two-pole structure
  - Chiral Unitary Model: D. Jido et al., NPA725(03)181
  - Evidence in $K^-p \rightarrow \pi^0\pi^0\Sigma^0$, Magas et al, PRL95(05)052301
- New Experimental data are coming:
  - $pp \rightarrow pK^+\pi^0\Sigma^0$, $\pi\Sigma$ MM spec., I. Zychor et al, PLB660(08)167
    -> disputed by L.S. Geng and E. Oset, EPJA34, 405(2007)
  - $pp \rightarrow pK^+(\pi\Sigma)^0$ MM spec., G. Agakishiev *et al.*, arXiv: 1208.0205v1 [nucl-ex]
    -> M. Hassanvand et al, arXiv: 1210.7725v1 [nucl-th], 2012
  - $\gamma p \rightarrow K^+\pi\Sigma$, $\pi\Sigma$ MM spec., M. Niiyama et al, PRC78(08)035202
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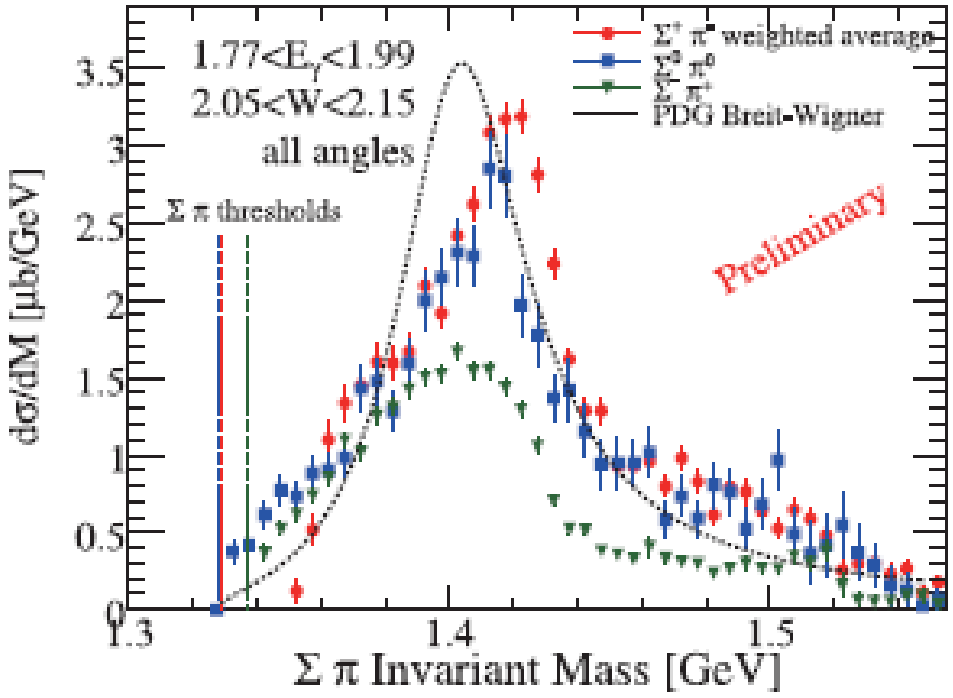
CLAS: $\gamma p \rightarrow K^+\Sigma\pi$
K. Moriya et al., PTP Suppl.186, 234(2010)



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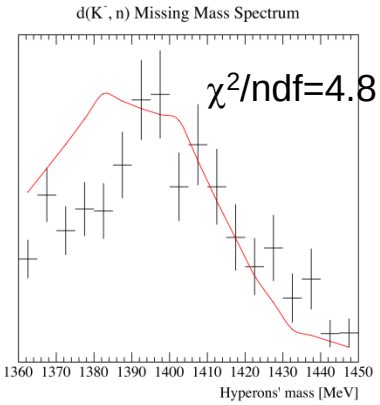
✓ Data of different reactions are necessary to understand the dynamically generated state.

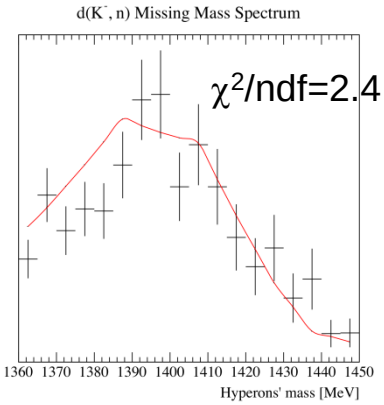
Fitting $\pi^0\Sigma^0$ mode change center (1405MeV)

Hemingway's data

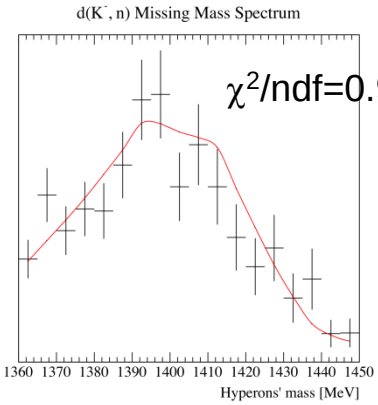
-10MeV



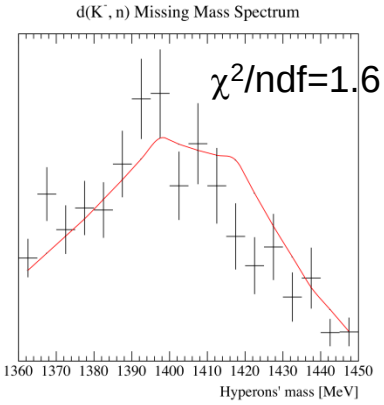
-5MeV



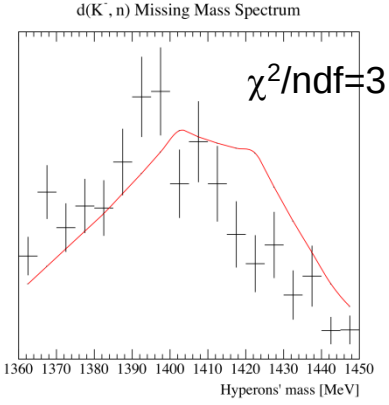
Default



+5MeV



+10MeV

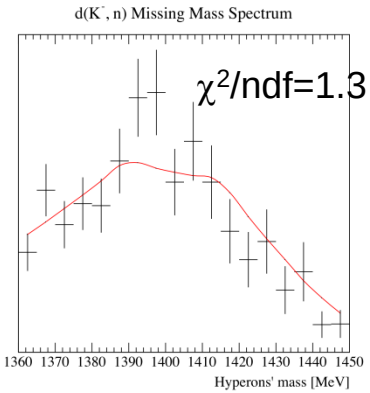


center	N	χ^2	χ^2/ndf
-10MeV	17	81.737	4.808
-5MeV	18	43.114	2.395
default	18	16.638	0.924
+5MeV	18	27.961	1.5534
+10MeV	18	56.591	3.144

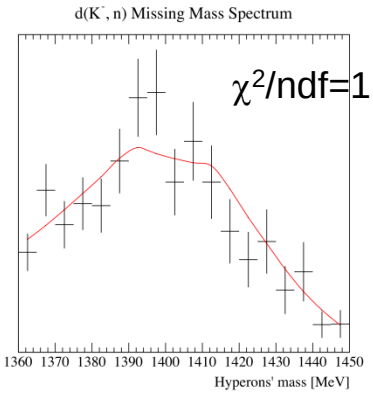
Fitting $\pi^0\Sigma^0$ mode change width (1405MeV)

Hemingway's data

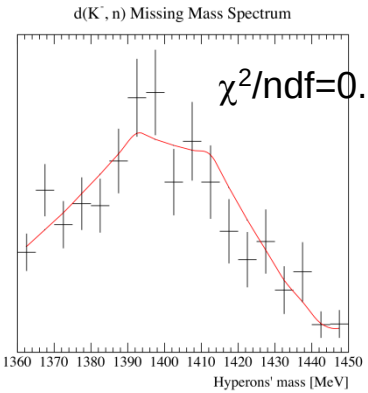
Width +20%



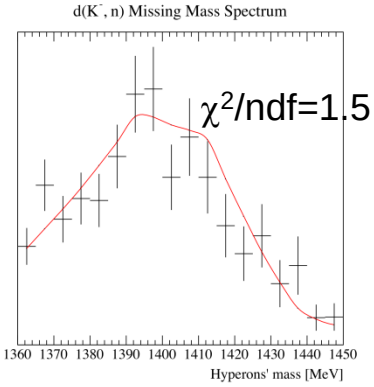
Width +10%



Default



Width -10%



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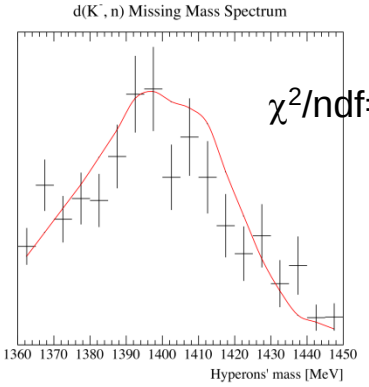
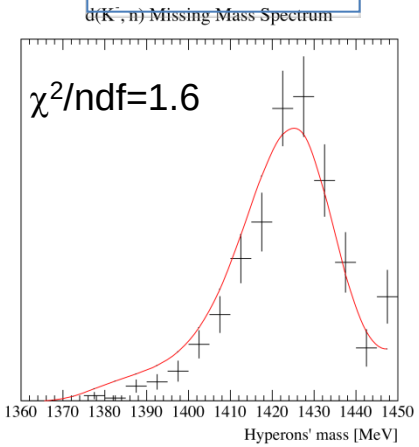


width	N	χ^2	χ^2/ndf
-20%	18	54.856	3.048
-10%	18	27.402	1.522
default	18	16.638	0.924
+10%	18	17.208	0.956
+20%	18	22.969	1.270

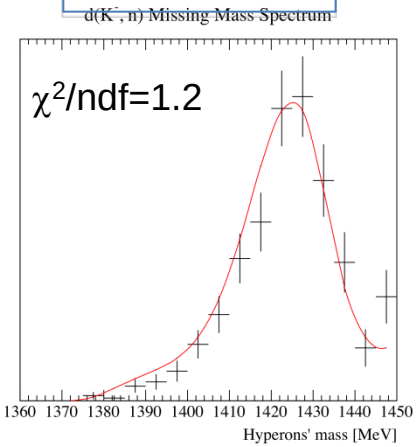
Fitting $\pi^0\Sigma^0$ mode change width (1420MeV)

Chiral Unitary Model

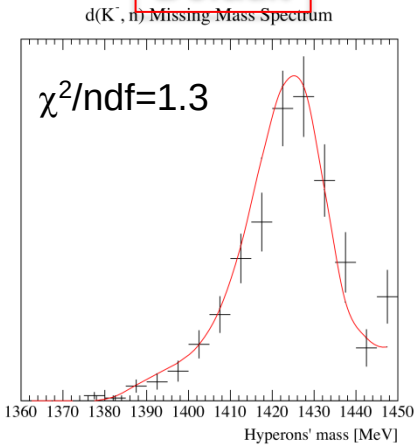
Width +20%



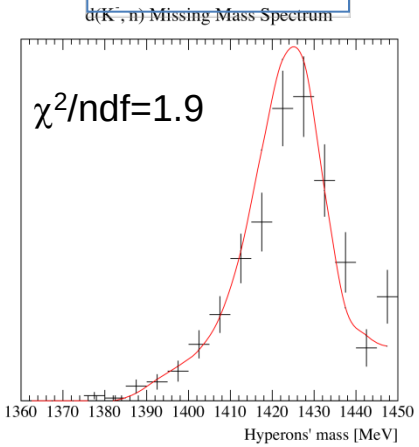
Width +10%



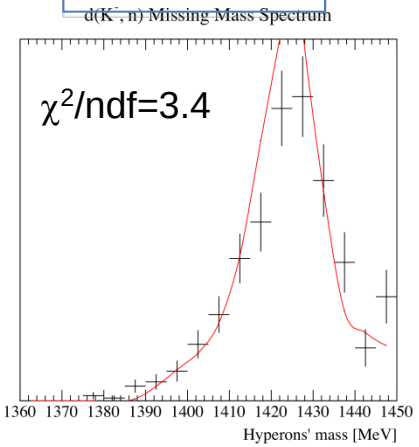
Default



Width -10%



Width -20%

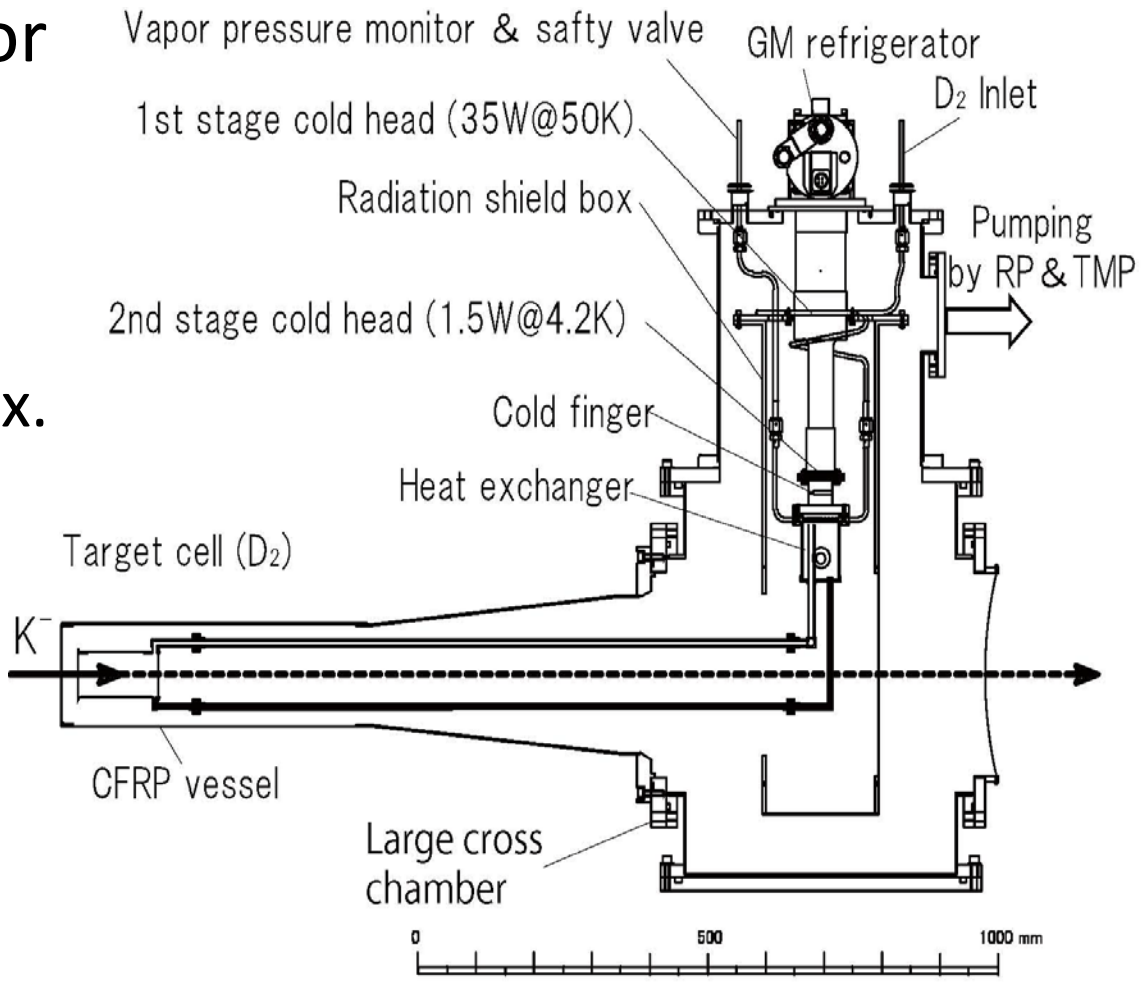


width	N	χ^2	χ^2/ndf
-20%	13	44.302	3.408
-10%	14	25.993	1.857
default	14	18.605	1.329
+10%	16	19.790	1.237
+20%	17	27.273	1.6043

Liq. D_2 Target

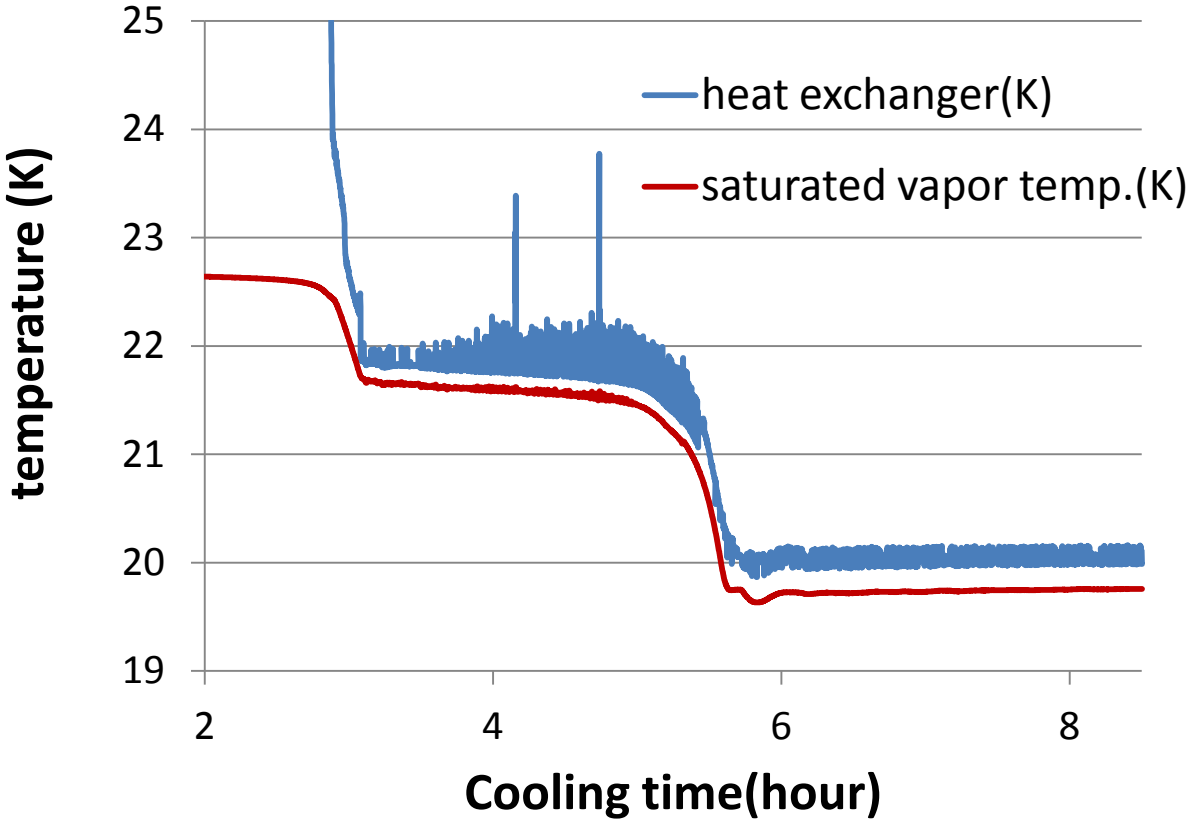
S. Kawasaki, S. Ishimoto, S. Suzuki, M. Iio, T. Ohta

- 4K G-M refrigerator to liquify D_2
  - Easy to control temperature w/ a heater at a Heat Ex.



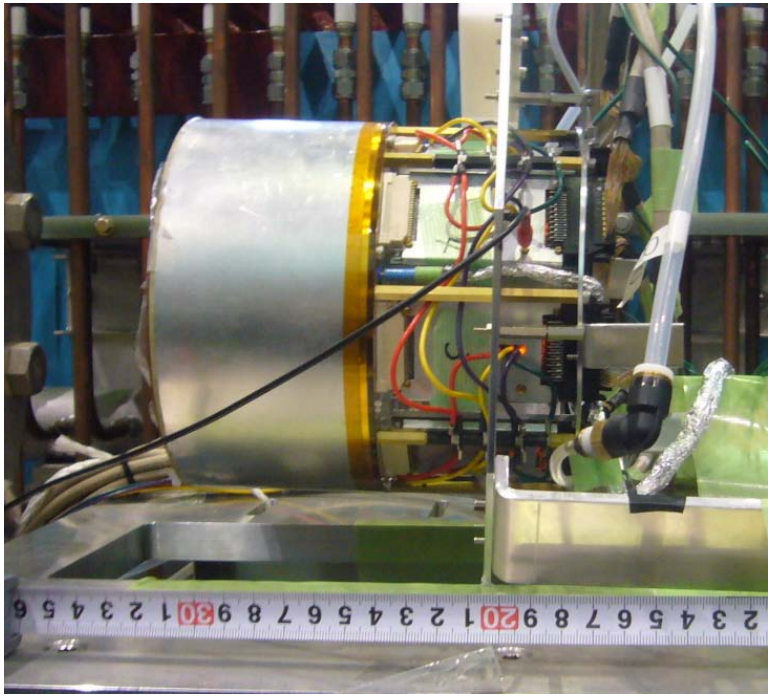
Liq. D_2 Target

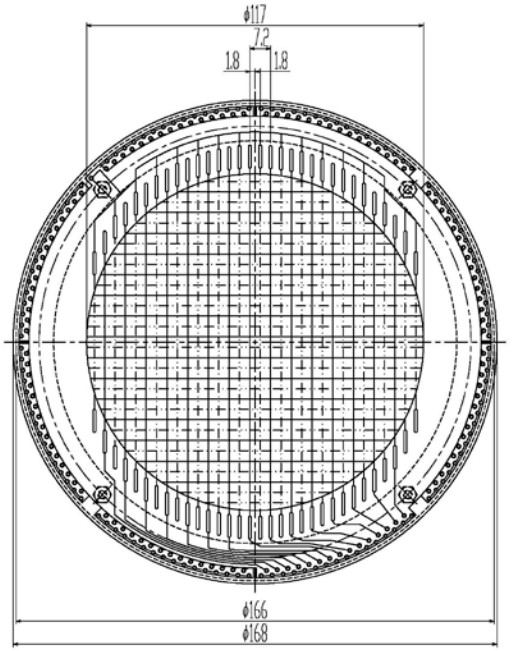
- Demonstration to liquify Hydrogen



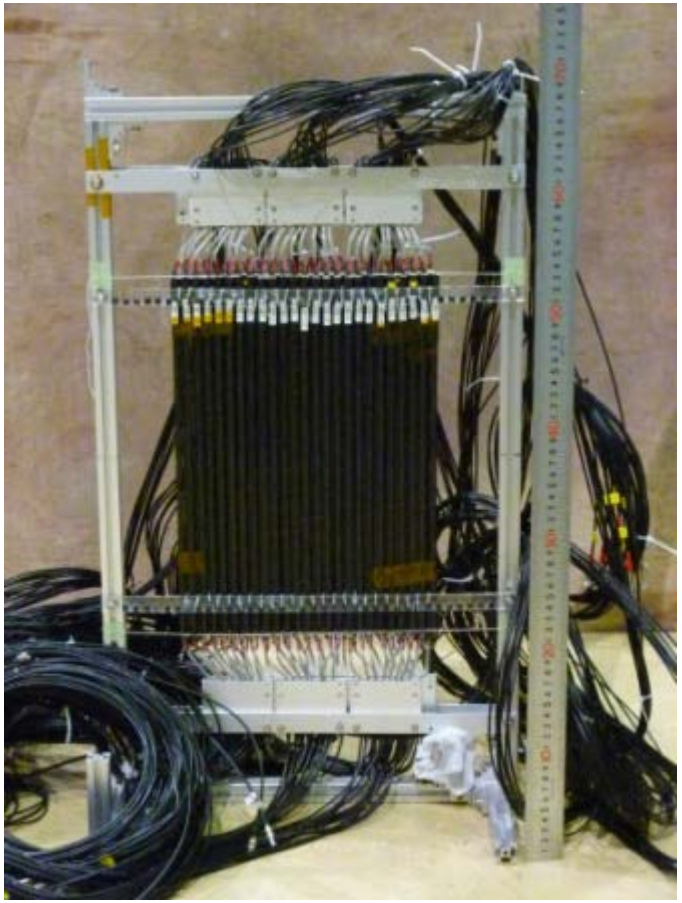
BPC

- planar type, 8 planes (XX'YY'XX'YY')
  ±3.6 mm drift space, ϕ112.6mm sensitive area
- 8 Compact Pre-amps, 4 ASD chips in a amp.
- Operation Gas: Ar-Isobutan (80:20)





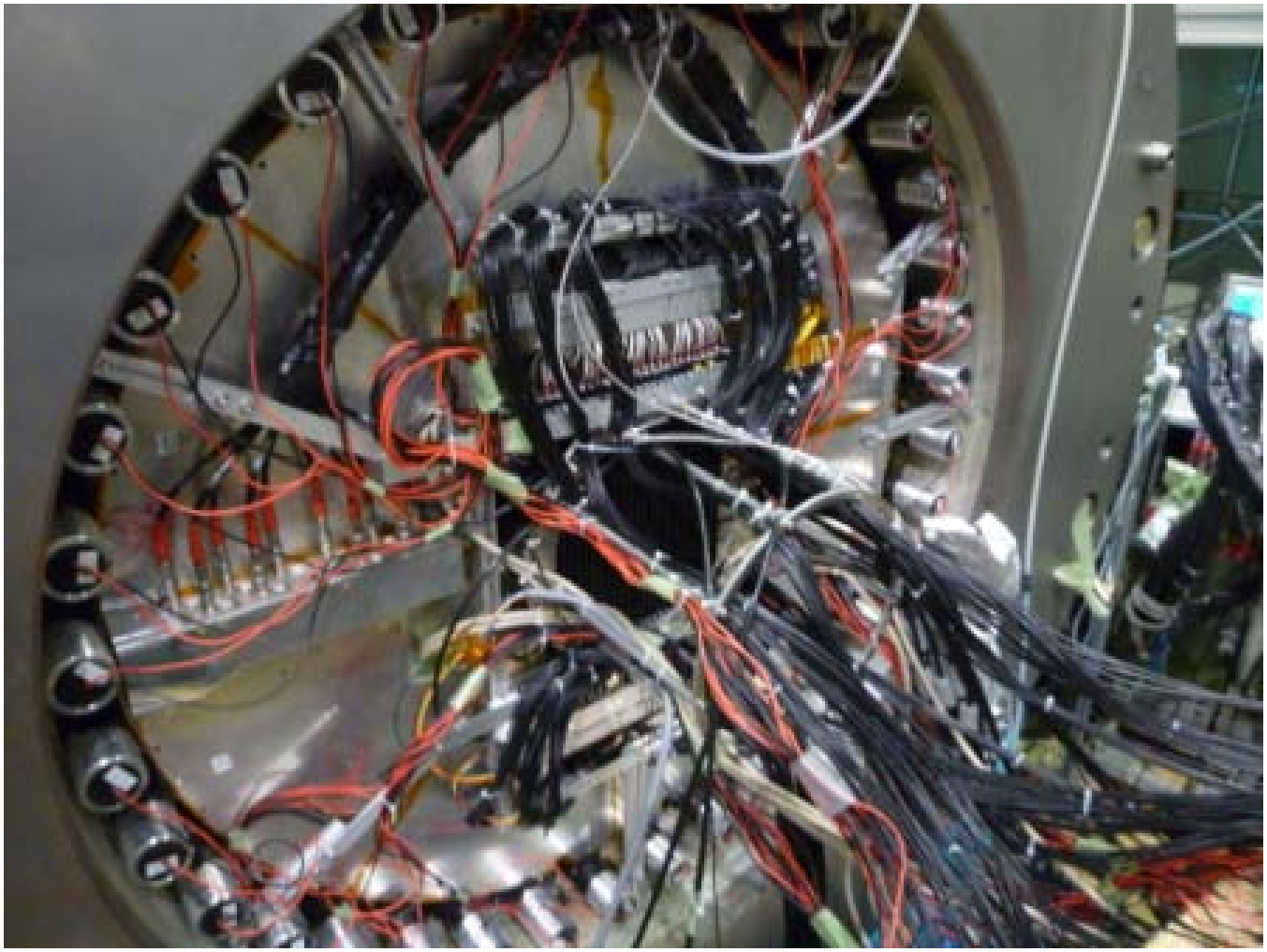
BPD



- 70 slabs of plactic scint.
  - 340 x 5 x 5 mm^3
- MPPC photo sensor
  - 3 x 3 mm2
  - No matter in a Magnetic Field
  - Fast time response, <200ps

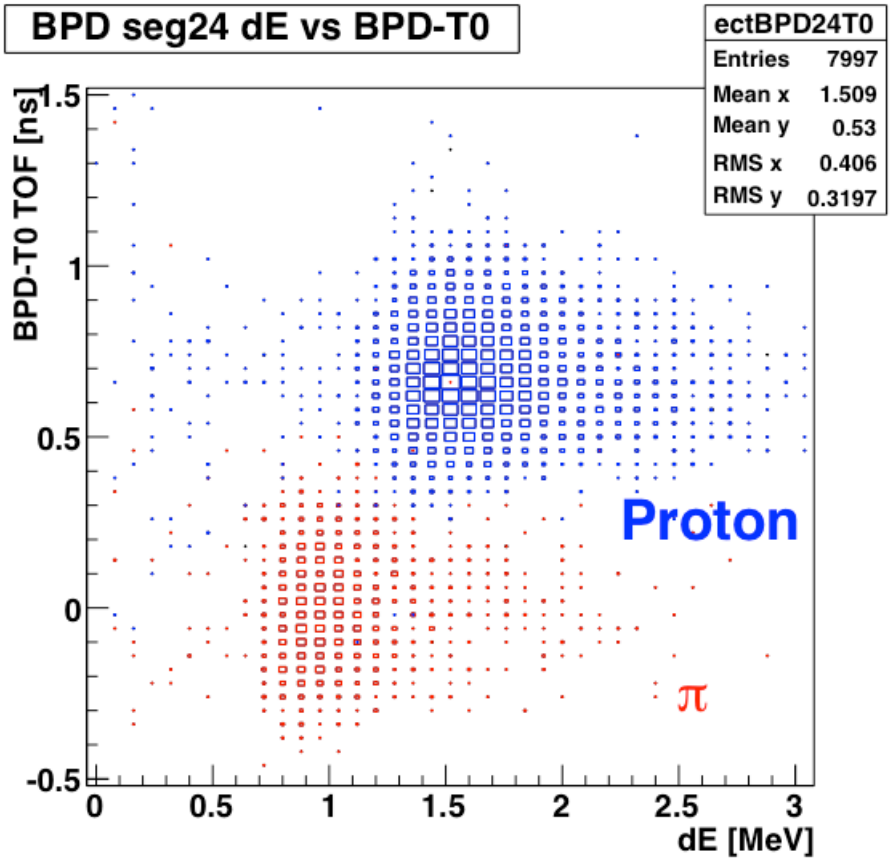
BPD

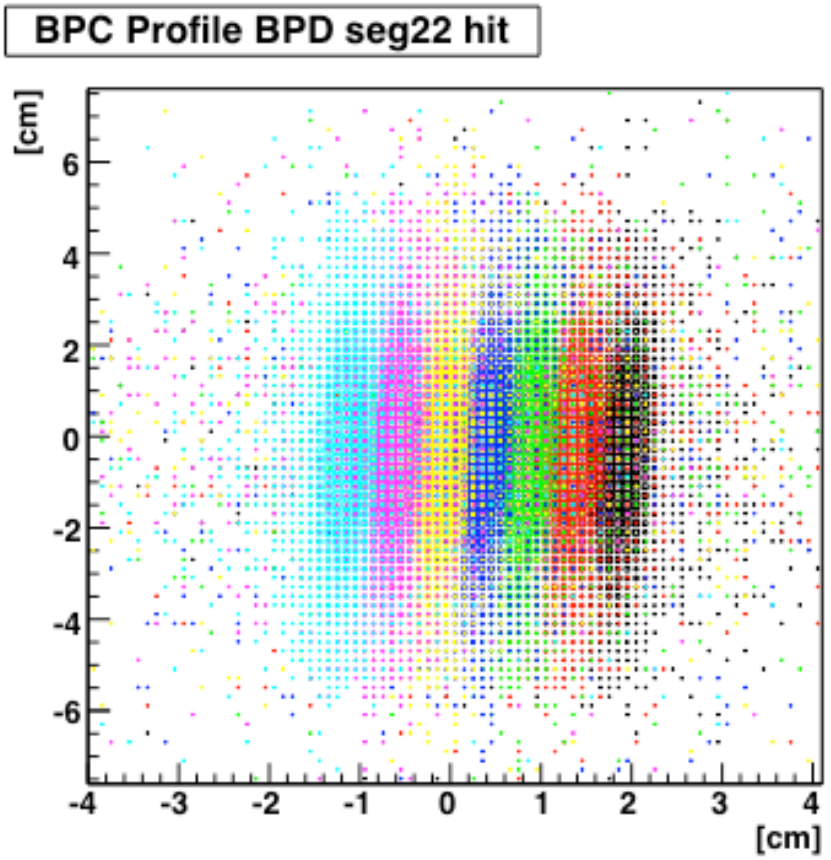
- Installed in CDS



BPC and BPD

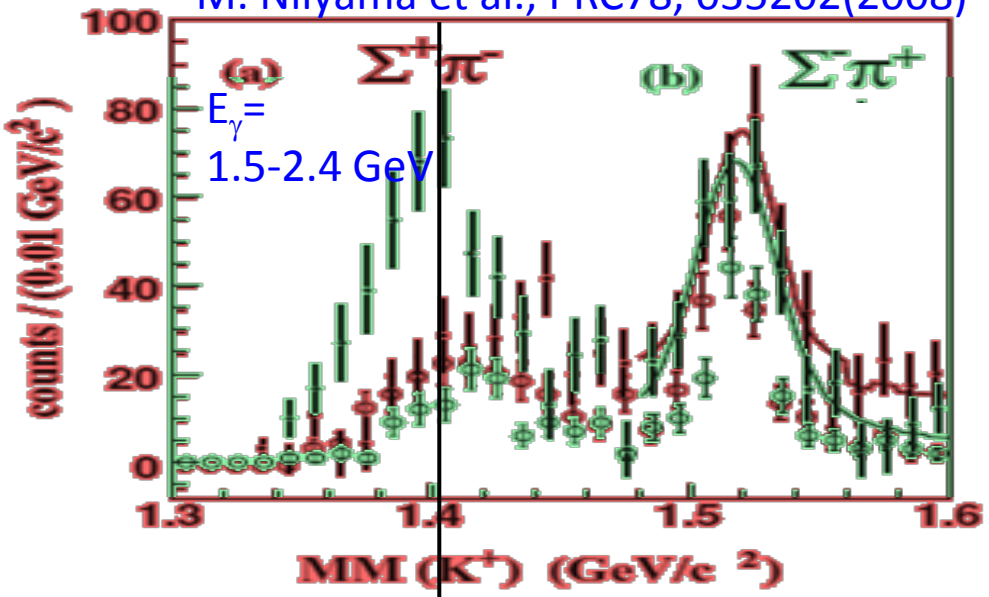
- Response for pion and proton beams at 1 GeV/c
- BPD image reconstructed by BPC (no rotation corrected)



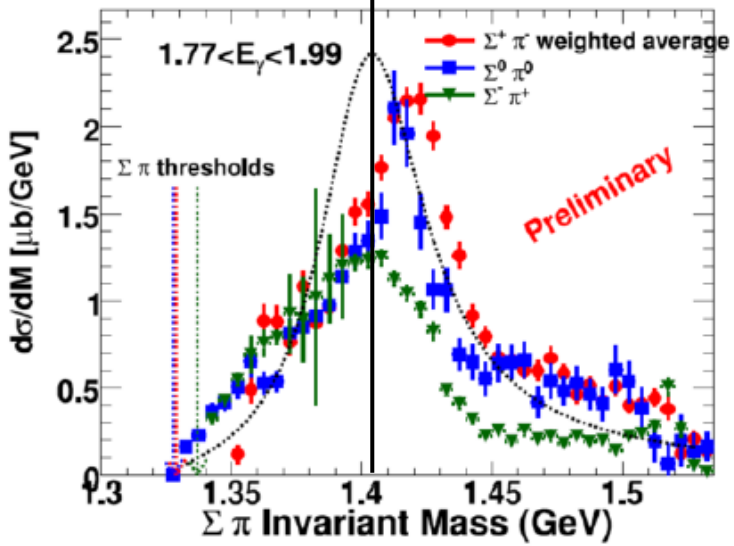


LEPS:

M. Niiyama et al., PRC78, 035202(2008)



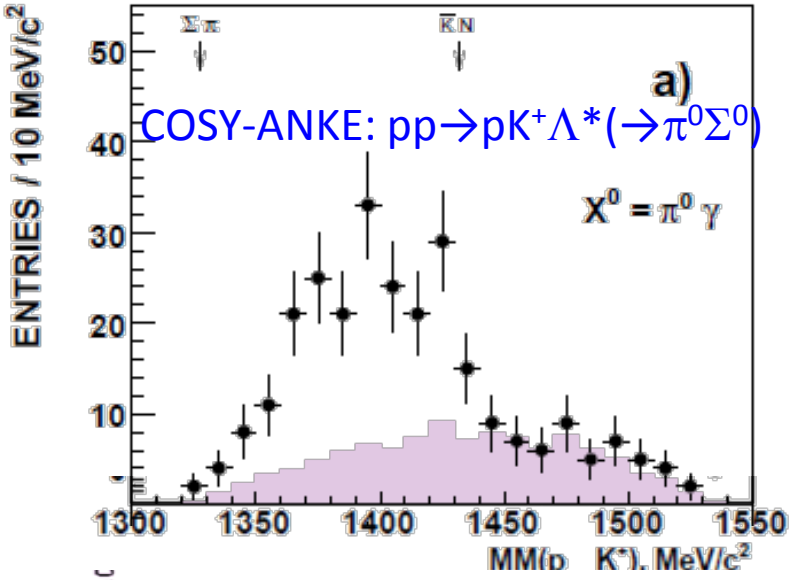
E_γ= 1.5-2.4 GeV



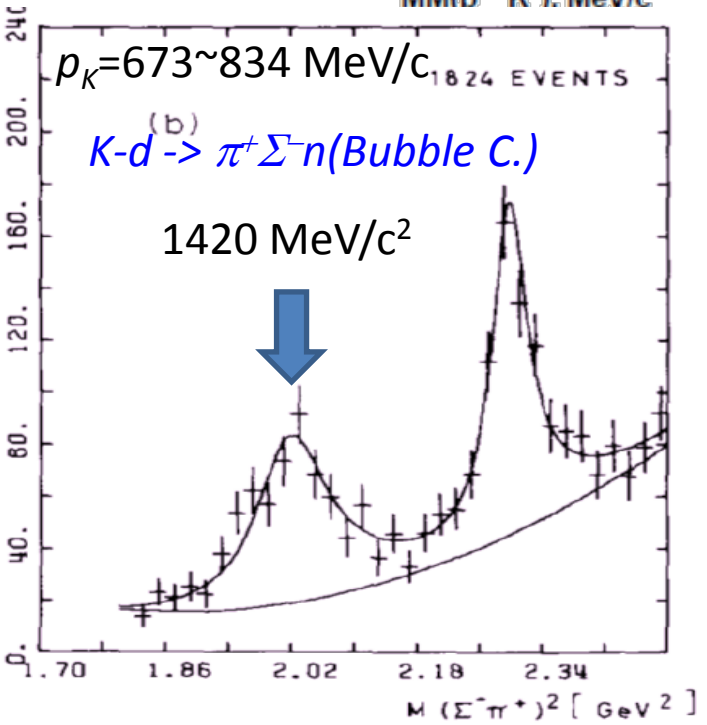
CLAS:

K. Moriya et al., NPA835, 325(2010)

I. Zychor et al. PLB660, 167(2008)



COSY-ANKE: $pp \to pK^+\Lambda^*(\to \pi^0\Sigma^0)$



p_K=673~834 MeV/c

K-d -> $\pi^+\Sigma^-$n(Bubble C.)

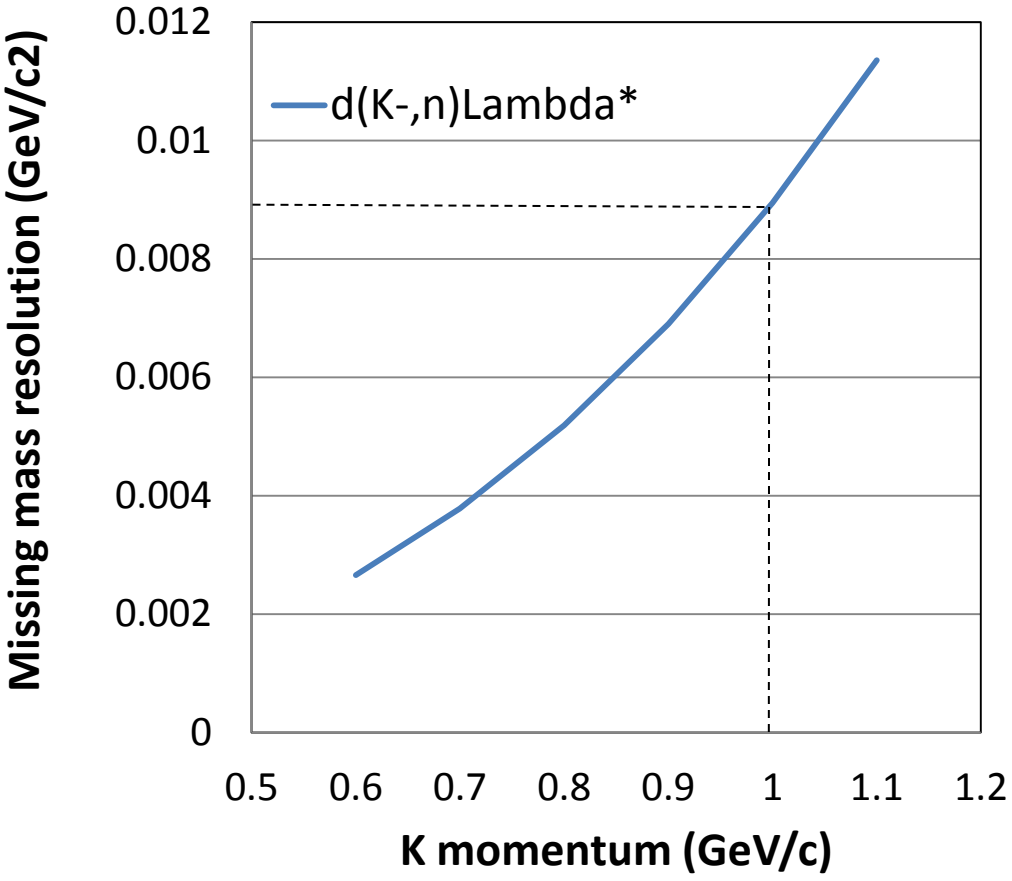
O. Braun et al., NPB129, 1(1977)

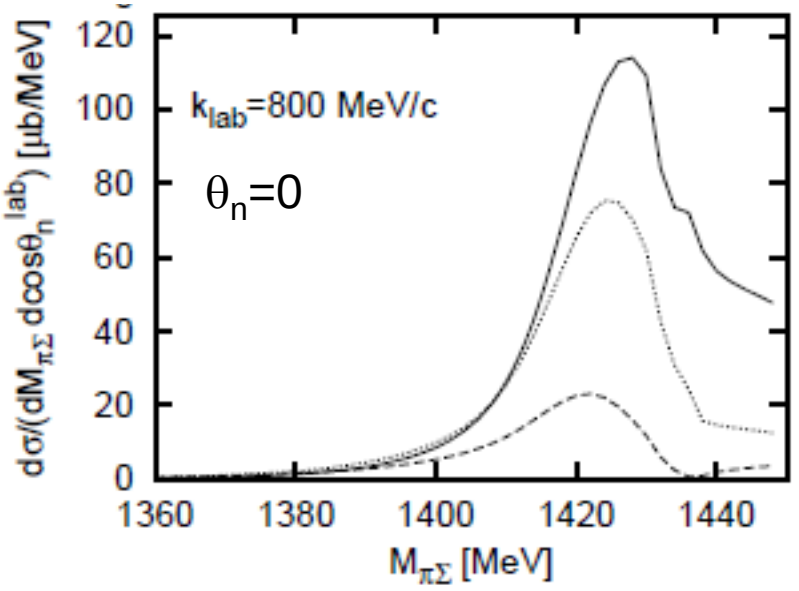
Missing Mass Resolution in the d(K⁻, n)X reaction

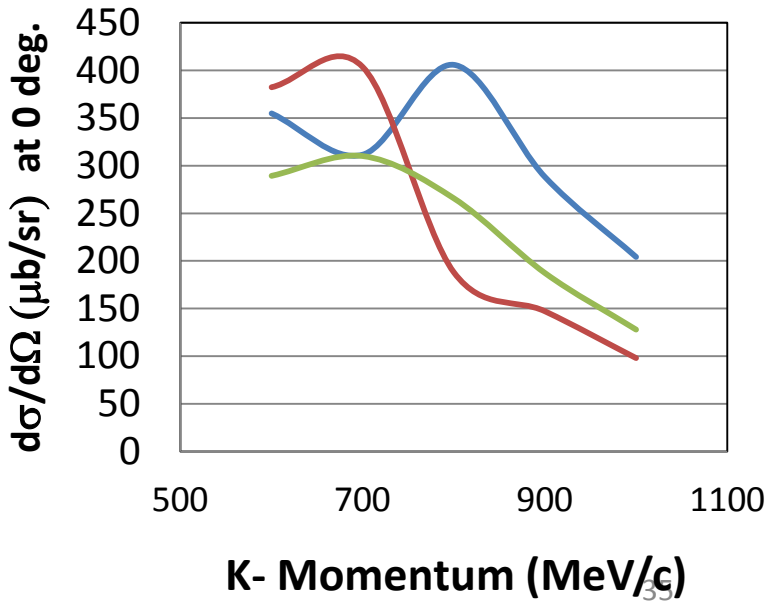
Dominant sources of ambiguity…

dt~120 ps (NC) dL_V~2cm, dL_T~5cm, F.L.=15m

σ_{MM} ~ 9 MeV/c at p_{K^-}=1 GeV/c







Yield Estimation

Item	Mnemonic		Comment
Intensity	I_b	2.0E+5 ppp	30GeV-27kW(6s)
# of target nuclei	n	4.1E+23	D:8cm, 0.169g/cc
Reaction X section	$d\sigma/d\Omega$	220 μb/sr 97 128	$\Lambda^* \to \pi^+\Sigma^-$ $\Lambda^* \to \pi^-\Sigma^+$ $\Lambda^* \to \pi^0\Sigma^0$
Solid angle	$\Delta\Omega$	0.020 sr	
Reconstruction eff. DAQ Beam Tracking Neutron detection	ε_P	0.24	 0.9 0.9 0.3
Decay mode eff.	ε_M	0.20 0.07 0.015	$\Lambda^* \to \pi^+\Sigma^- \to \pi^+\pi^- n$ $\Lambda^* \to \pi^-\Sigma^+ \to \pi^-\pi^+ n$ $\Lambda^* \to \pi^0\Sigma^0 \to \pi^0\pi^- p$
Analysis eff.	ε_A	0.8	
Yield	Y	~19200 ~4800 ~350	$\Lambda^* \to \pi^+\pi^- n$ (120 shifts) $\Lambda^* \to \pi^-\pi^+ n$ (120 shifts) $\Lambda^* \to \pi^0\pi^- p$ (120 shifts)