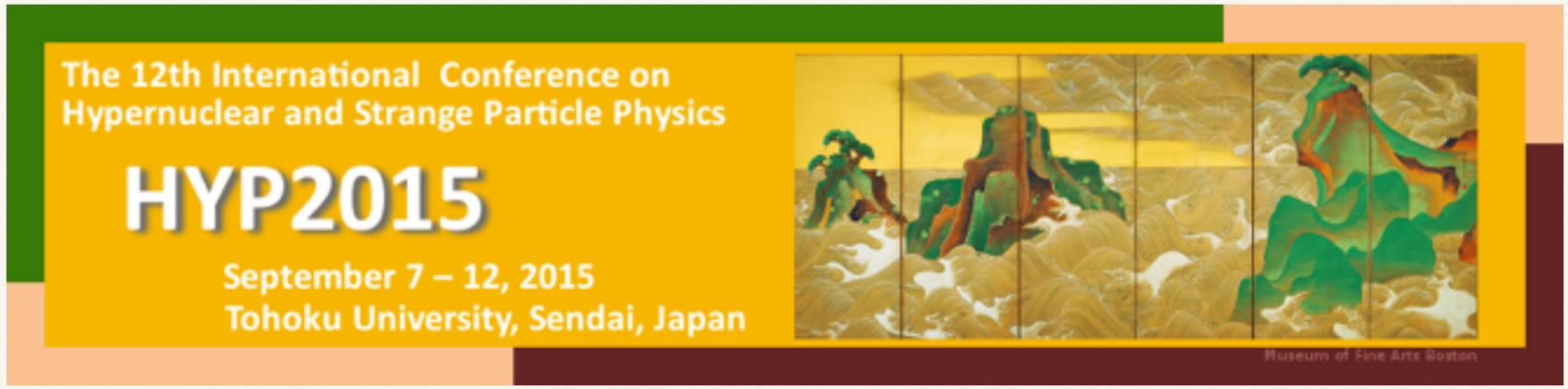


HYP2015, Sep. 10, 2015

Status of K^-pp search experiments

Tomofumi NAGAE
Kyoto University

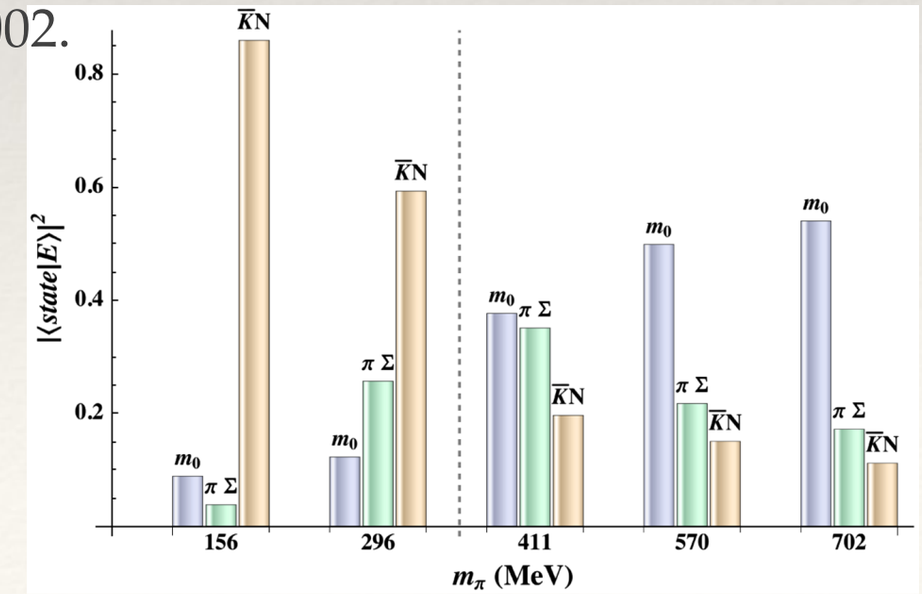
Contents

- Introduction to *"K^-pp"*
- Recent measurements
  - LEPS/SPring-8
  - HADES
  - J-PARC E15/ fwd "n"
  - J-PARC E27
- Discussion
- Summary

K^-pp

- $\overline{K}N$: attraction in Isospin=0
  - Kaonic hydrogen X-ray ; SIDDHARTA
    M. Bazzi et al., NPA 881 (2012) 88-97.
  - Low-energy scattering measurements + Branching ratios at threshold
    - $\Lambda(1405)$ below the K^-p threshold
      - $J^{\pi}=1/2^-$; Moriya et al., Phys. Rev. Lett. 112 (2014) 082004.
      - Antikaon-Nucleon Molecule from Lattice QCD
        ; J.M.M. Hall et al., Phys. Rev. Lett. 114 (2015) 132002.

- Possible existence of "K^-pp" : Y=1, I=1/2, $J^{\pi}=0^-$

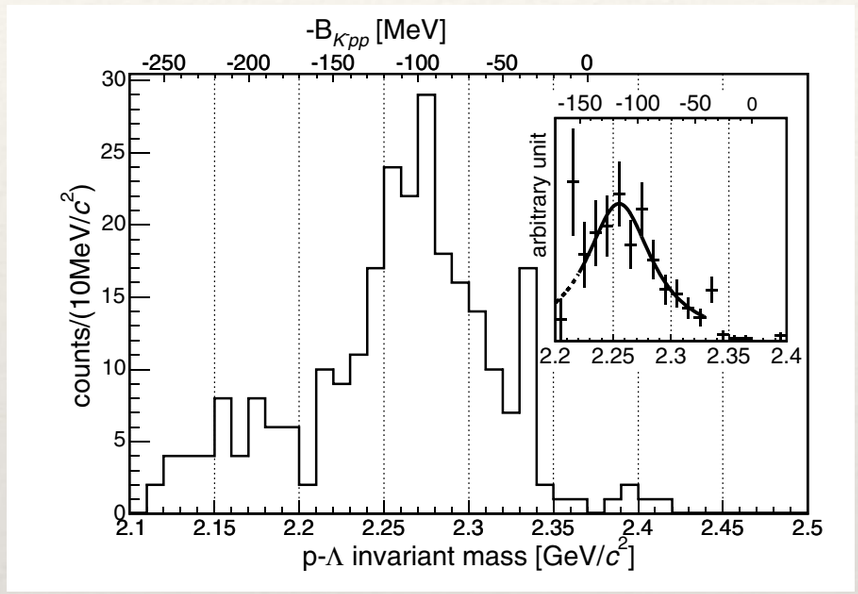


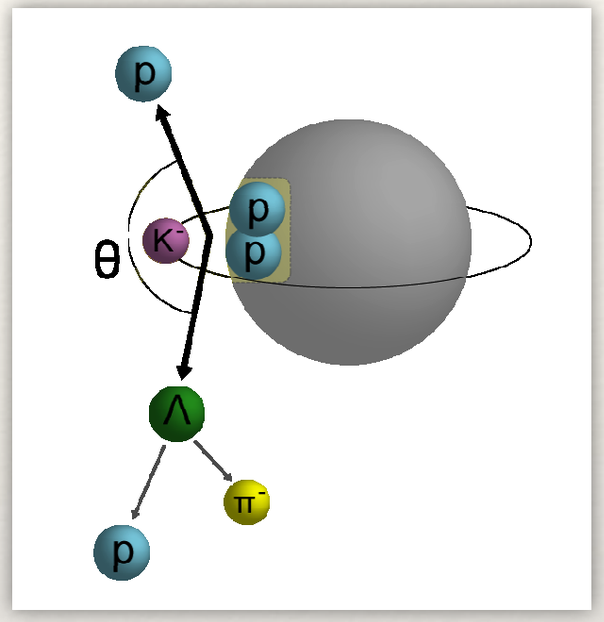
Past Experiments on K^-pp

- First evidence of K^-pp with ^{6}Li+^{7}Li+^{12}C by FINUDA

M. Agnello et al., PRL94, (2005) 212303

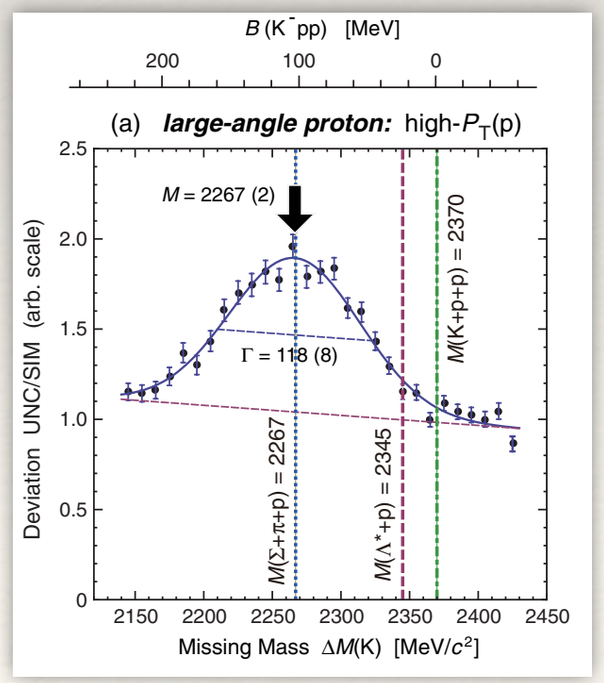
B=115+6/-5+3/-4 MeV
Γ= 67+14/-11+2/-3 MeV





- DISTO data: p+p→K^-pp (pΛ)+ K$^+$ at 2.85 GeV
  - M=2267±3±5 MeV / c^2
  - Γ= 118±8±10 MeV

T. Yamazaki et al., PRL 104 (2010) 132502.
P. Kienle et al., Eur. Phys. J. A 48 (2012) 183.



Theoretical calculations on K^-pp

- Methods : Variational vs. Faddeev
  → Almost same results by using the same interaction model

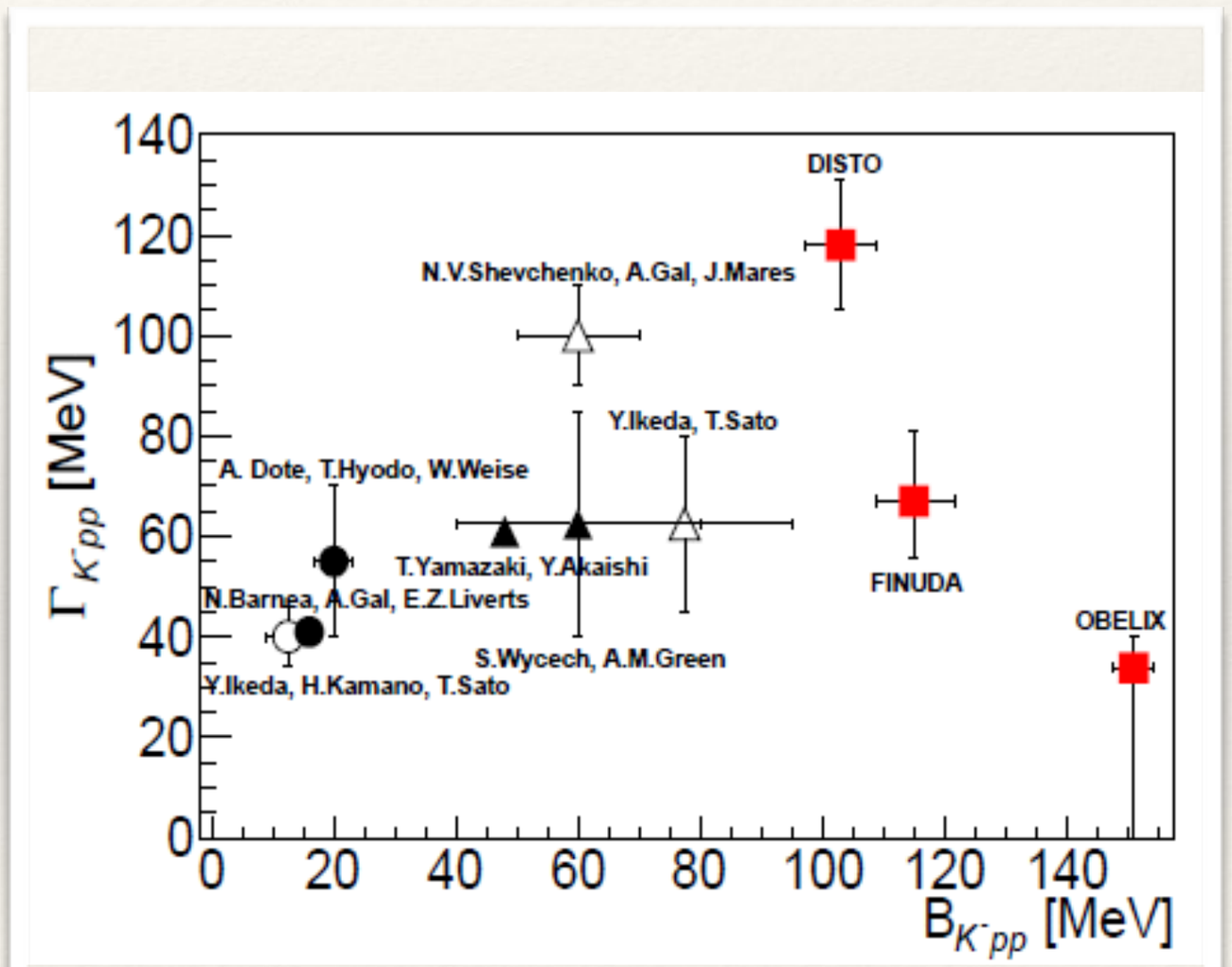
- $\overline{K}N$ Interaction Models :
  Chiral SU(3)-based (Energy dependent) → Shallow~20 MeV
  Phenomenological (Energy independent) → Deep~40-70 MeV

	Dote,Hyodo, Weise	Akaishi, Yamazaki	Barnea, Gal, Liverts	Ikeda, Sato	Ikeda, Kamano,Sato	Schevchenko ,Gal, Mares	Revai, Schevchenko	Maeda, Akaishi, Yamazaki
B (MeV)	17-23	48	16	60-95	9-16	50-70	32	51.5
Γ(MeV)	40-70	61	41	45-80	34-46	90-110	49	61
Method	Variational	Variational	Variational	Faddeev-AGS	Faddeev-AGS	Faddeev-AGS	Faddeev-AGS	Faddeev-Yakubovsky
Interaction	Chiral	Phenom.	Chiral	Chiral	Chiral	Phenom.	Chiral	Phenom.

FSI effects ? (V.K. Magas et al.), Λ*N bound state (T. Uchino et al.)

Comparison between Theory and Exps.

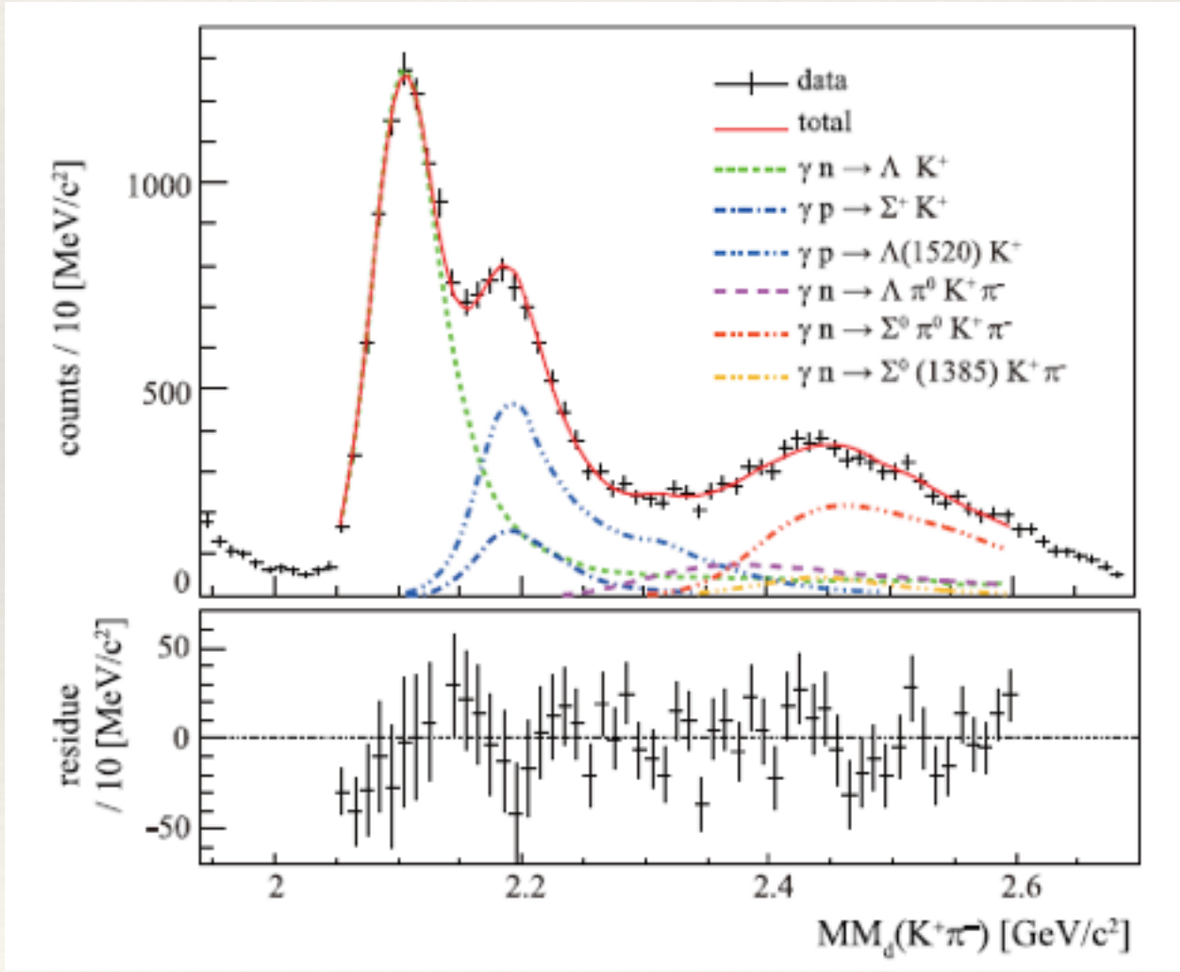
- Binding energy
  - Shallow case: B~20 MeV
  - Deep case: B~40-70 MeV
  - Observations: B>100 MeV
- Width
  - agreement: Γ~30-100 MeV



By Y. Ichikawa

Recent measurements

- LEPS/SPring-8 A.O. Tokiyasu et al., Phys. Lett. B 728 (2014) 616-621.
  - d(γ, $K^+\pi^-$) reaction (E_γ=1.5-2.4 GeV)
  - Inclusive missing-mass
    σ_m~10 MeV
    - Background
      $K^+\Lambda(1520)$, $K^+\pi^-\pi Y$
  - Upper limits:2.22-2.36 GeV/c^2
    < 1.1-2.9 μb for Γ=100 MeV,
    9.9-26% of KπY productions



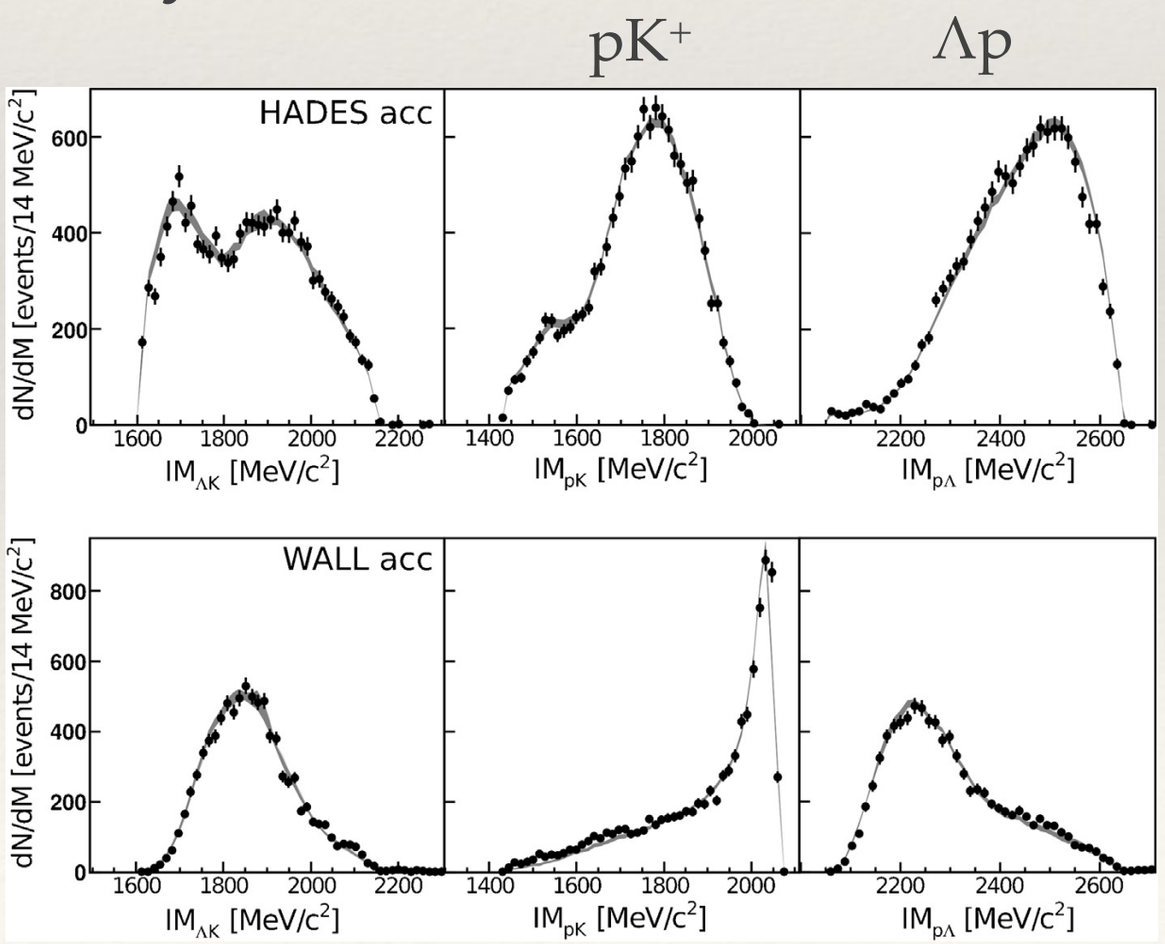
- HADES

G. Agakishiev et al., Phys. Lett. B 742 (2015) 242-248.

  - $p+p \rightarrow K^+ p \Lambda$ @3.5 GeV
  - Bonn-Gatchina Partial Wave Analysis well reproduces the data
  - $K^- pp$ production upper limit ~4 μb for Γ=70 MeV (2.22-2.37 GeV / c^2)

    ⇅

    Λ(1405) production ~10μb

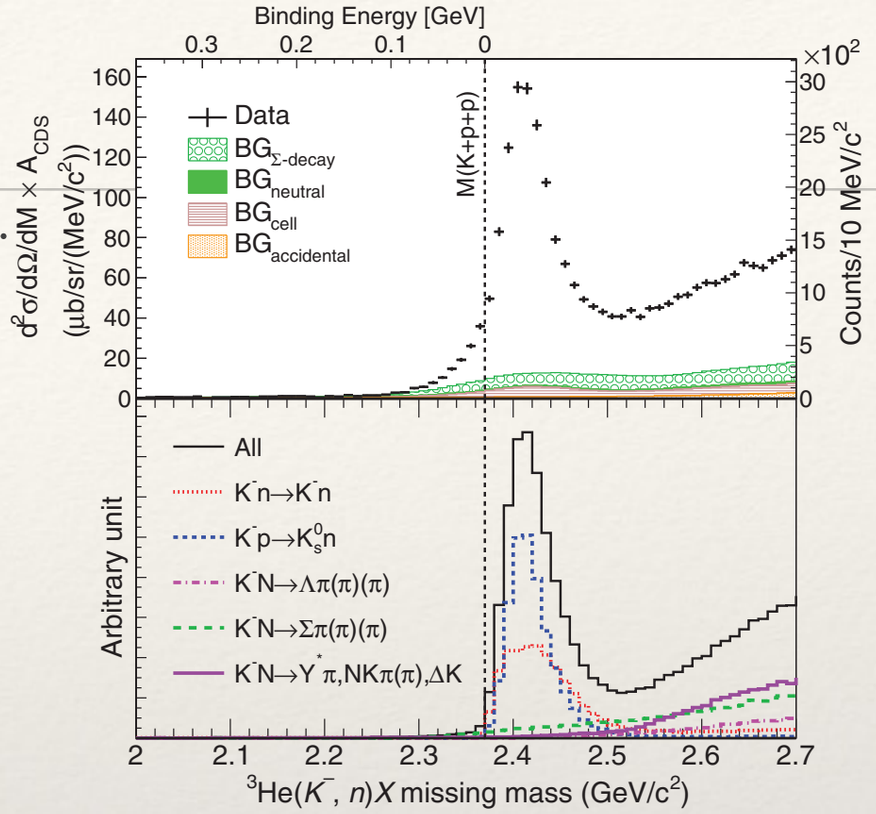


- J-PARC E15

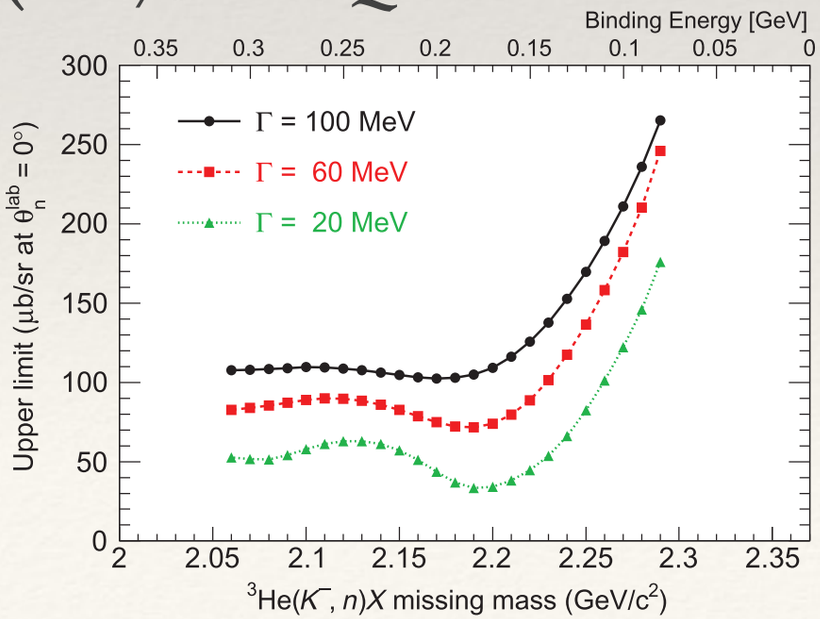
T. Hashimoto et al., PTEP (2015) 061D01.

  - ^{3}He(K^-,n) reaction @ 1 GeV/c
  - Semi-inclusive missing-mass

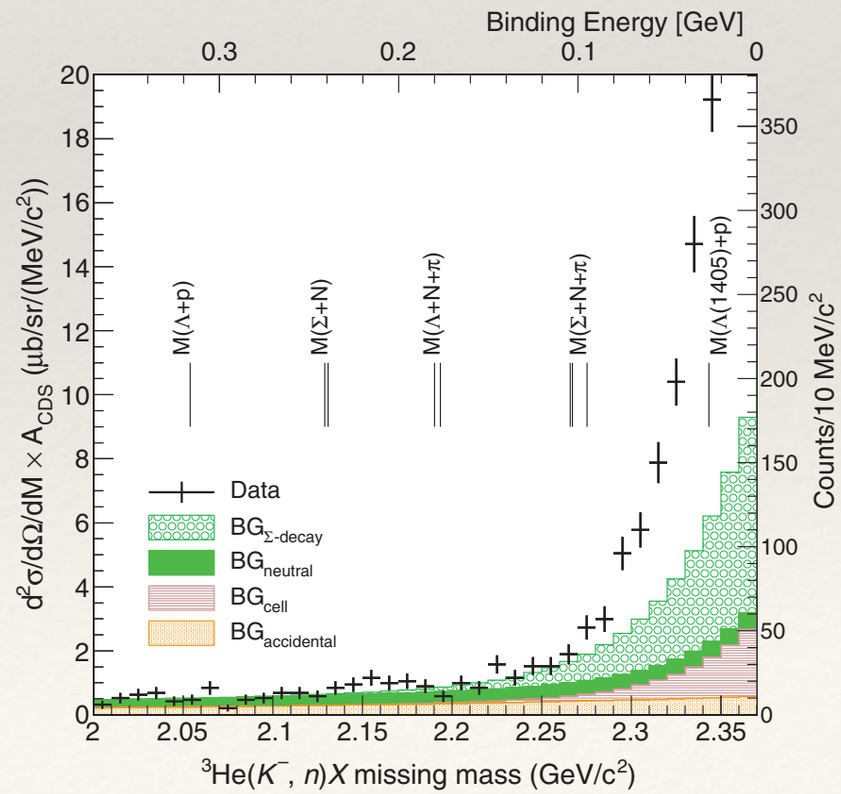
    σ_m:5-15 MeV



- K^-pp production upper limit 100-270 μb/sr for Γ=100 MeV (~5% of QF K^-n elastic)



2.06-2.29 GeV/c^2



Lessons

- It looks hard to observe the $K^- pp$ signal in inclusive measurements. (LEPS, J-PARC E15 fwd "n")
  - Small and Broad signature ; ~1 two-step reaction (two nucleons be involved)
  - Large and Widely distributed QF background ; >10~100 single-step reaction

J-PARC E27

- $d(\pi^+, K^+)$ reaction @1.69 GeV/c

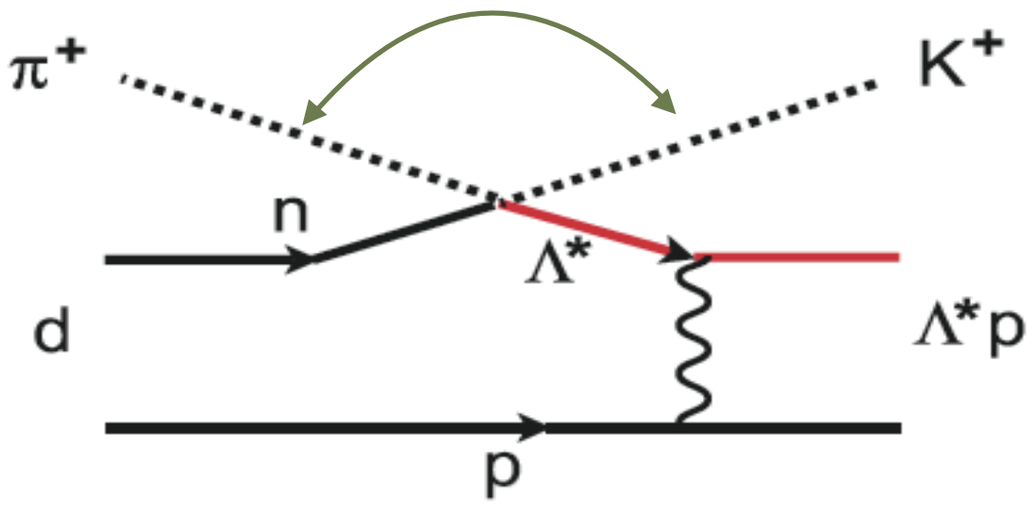
Y. Ichikawa et al., PTEP (2014) 101D03.
Y. Ichikawa et al., PTEP (2015) 021D01.

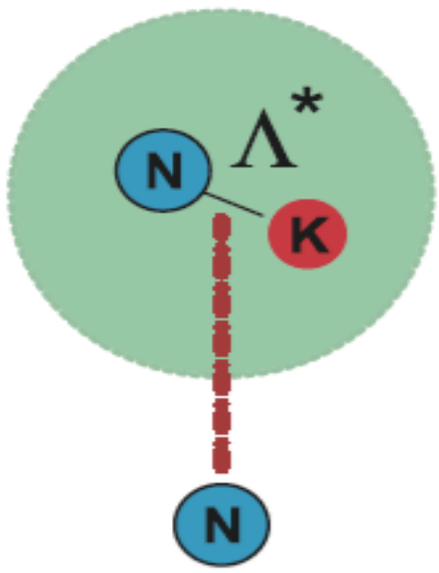
π^+ + "n" --> "Λ^*" + K^+

"Λ^*" + "p" --> bound K^-pp ***minor***

--> quasi-free Λ^* ***dominant***

Missing mass

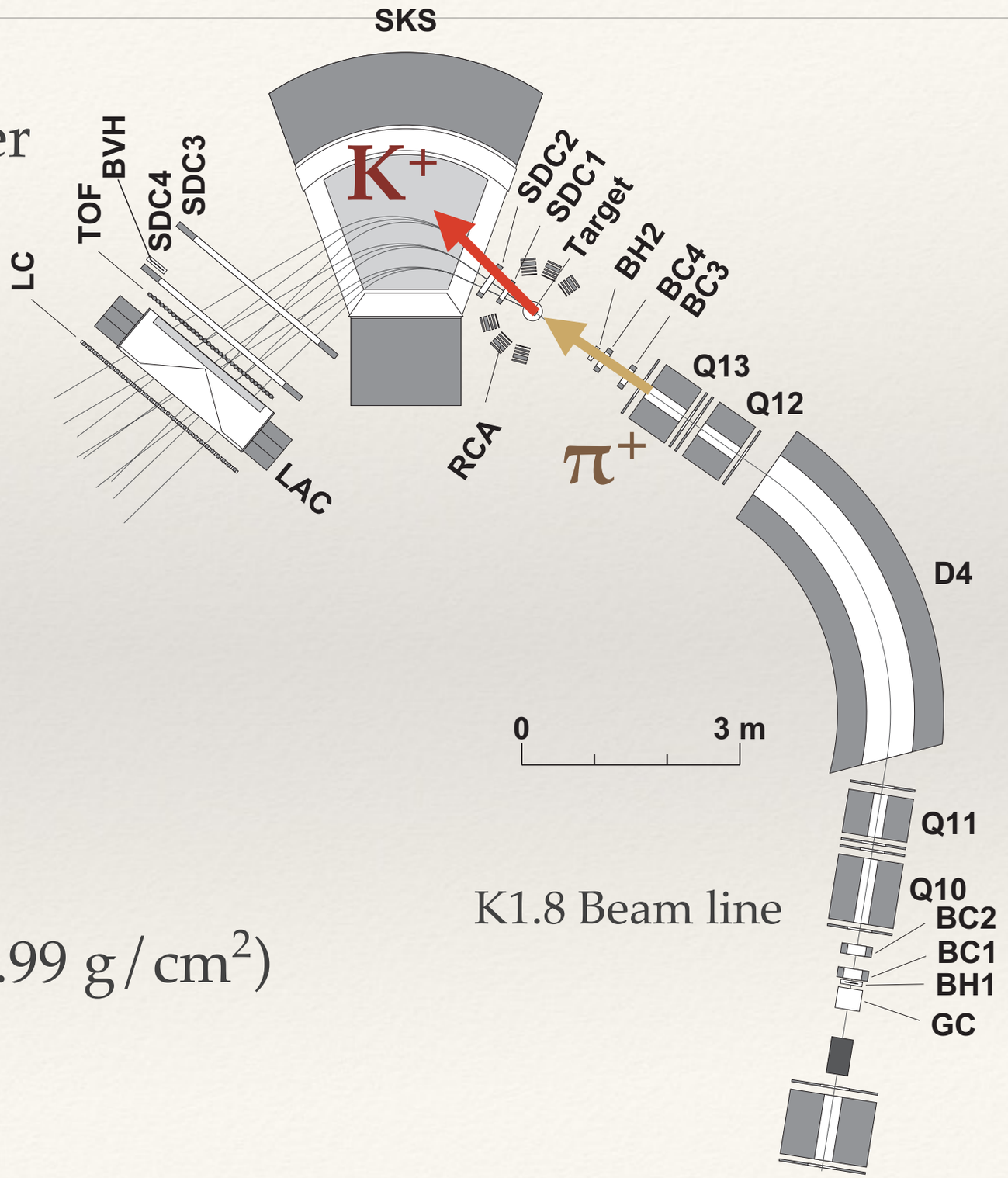




Yamazaki & Akaishi, Phys. Rev. C 76 (2007) 045201.

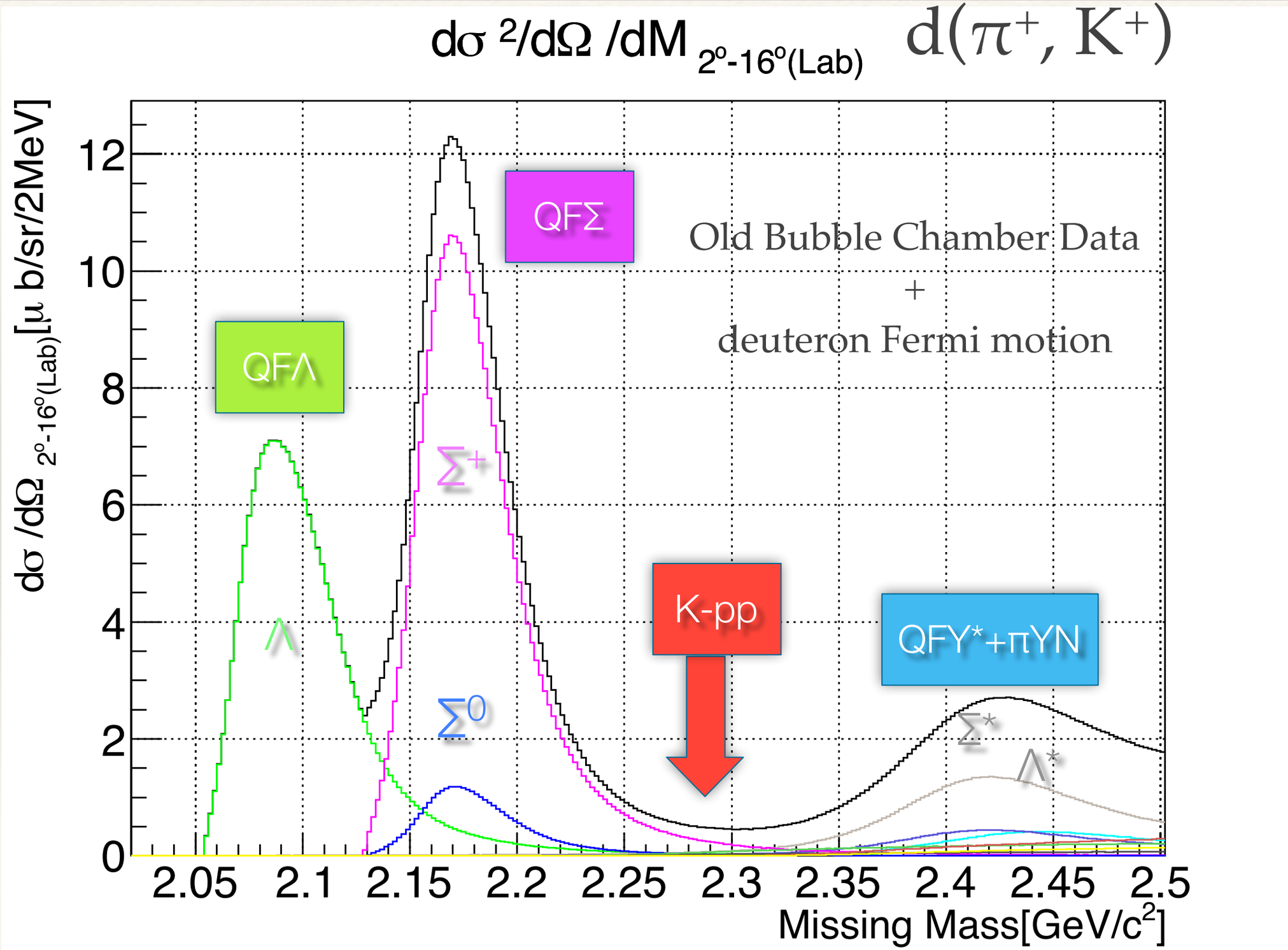
Experimental Setup

- K1.8 beam line spectrometer
  - 1.69 GeV/c π^+
  - $\Delta p/p \sim 2 \times 10^{-3}$
- SKS spectrometer
  - 0.8-1.3 GeV/c K^+
  - $\Delta p/p \sim 2 \times 10^{-3}$
  - $\Delta\Omega \sim 100$ msr
- Target : liquid deuterium(1.99 g/cm^2)



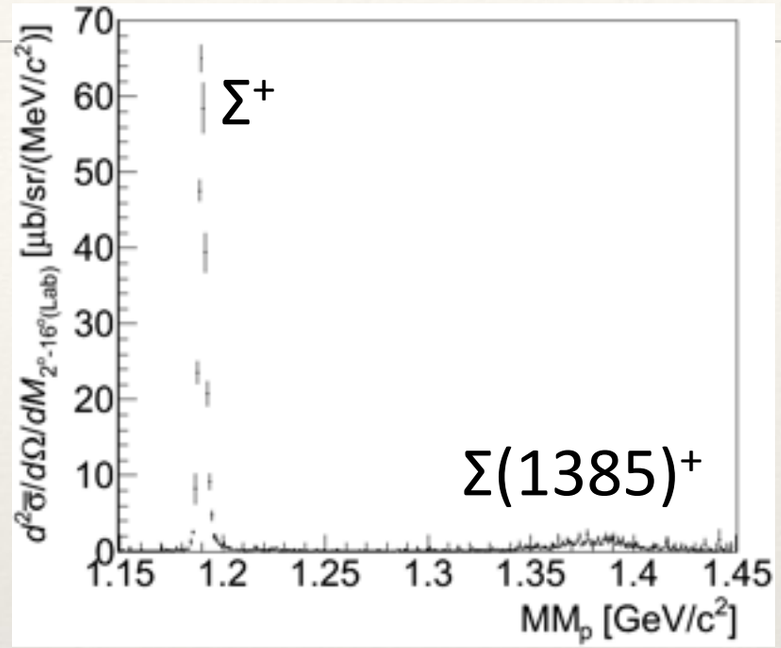
K1.8 Beam line

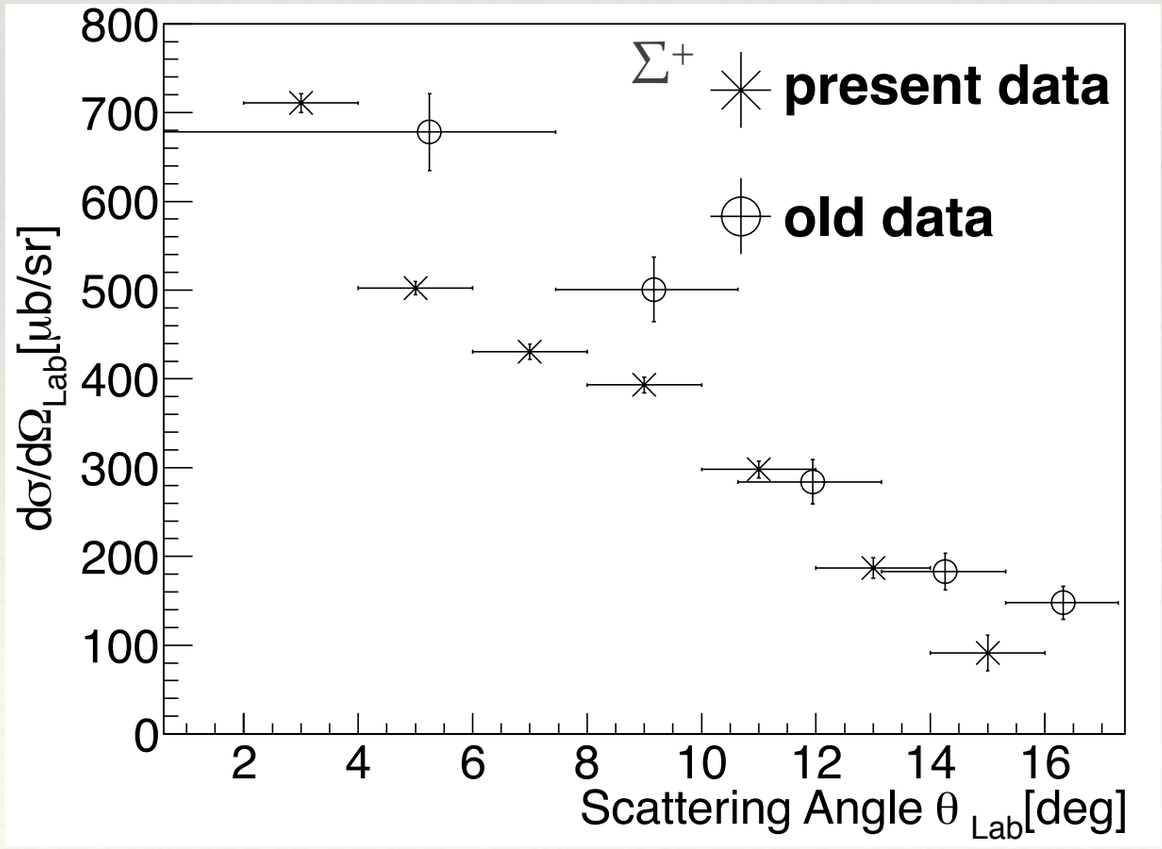
Expected Inclusive Spectrum

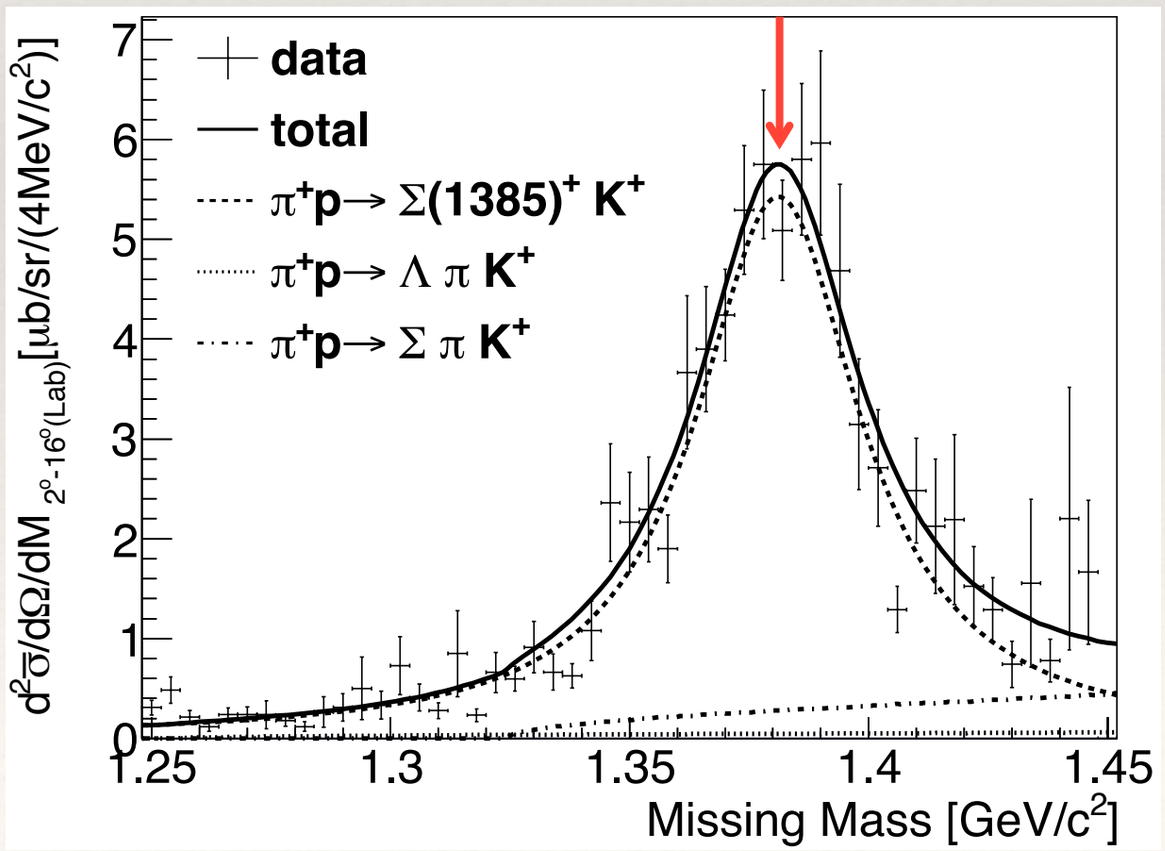


$p(\pi^+,K^+)\Sigma^+/\Sigma^*$ @1.69 GeV/c

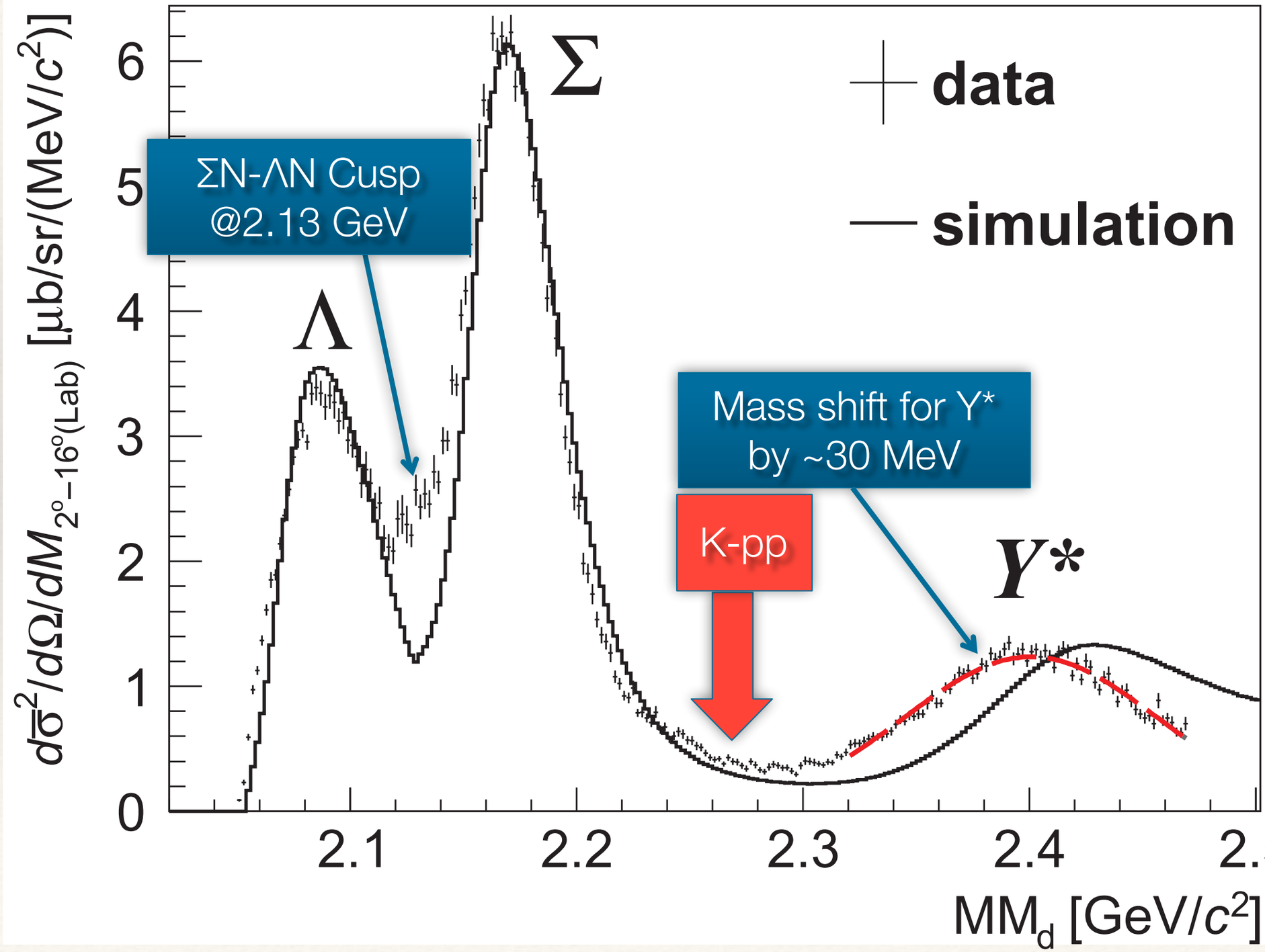
- Σ^+ and $\Sigma^+(1385)$: mass & width are consistent with PDG
  - Δm_{FWHM}=2.8±0.1 MeV/c^2



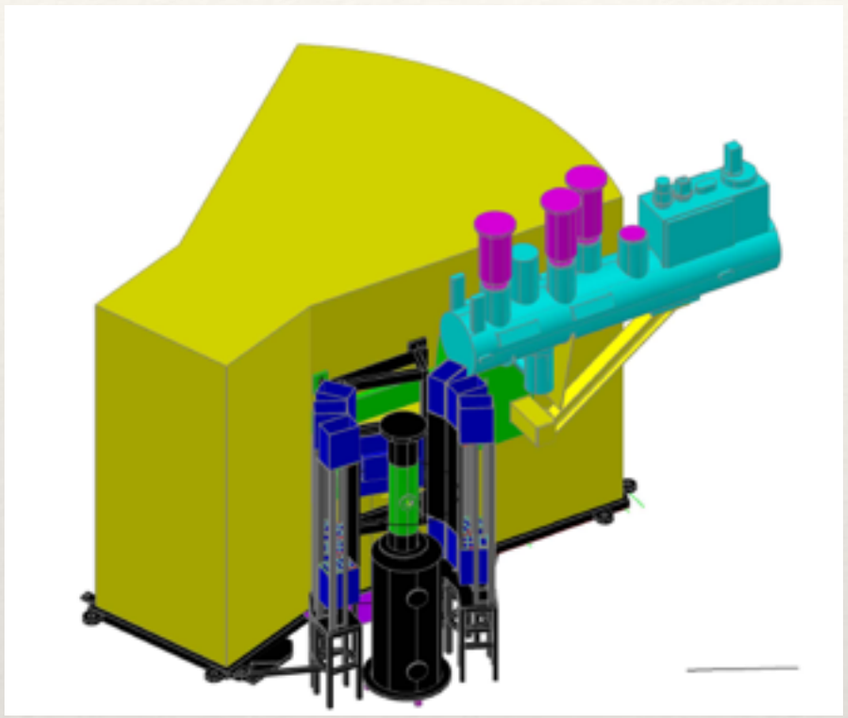




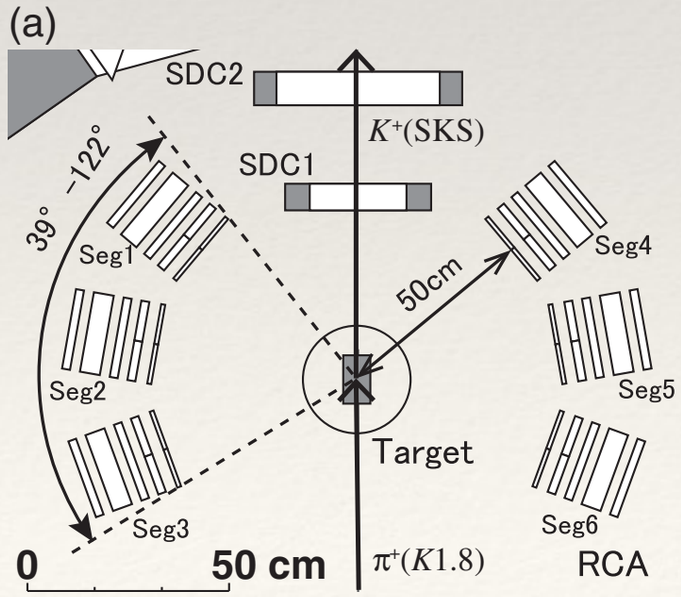
Measured d(π^+,K^+)X spectrum

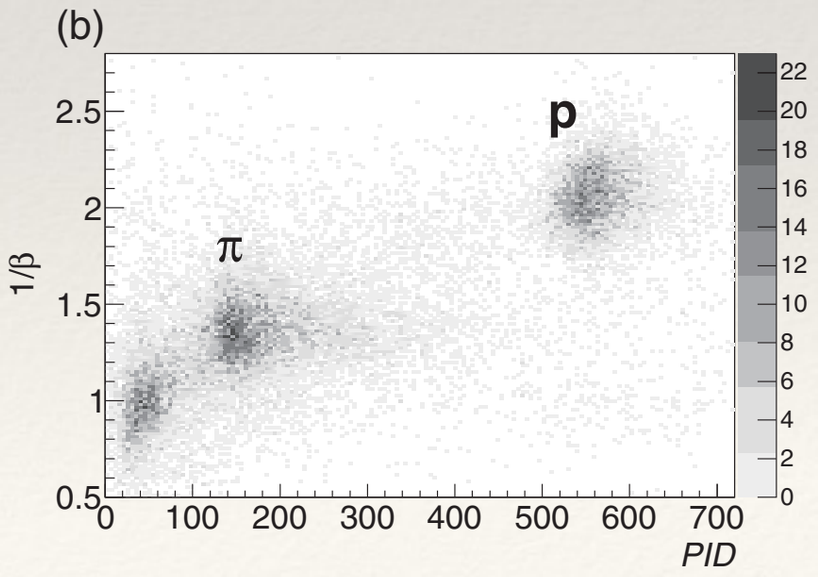


Range counter for Proton tagging



- Range Counter Arrays (RCA)
  - 5 layers(1+2+2+5+2 cm) of Plastic scinti.
  - 39-122 deg. (L+R)
  - 50 cm TOF → β_p

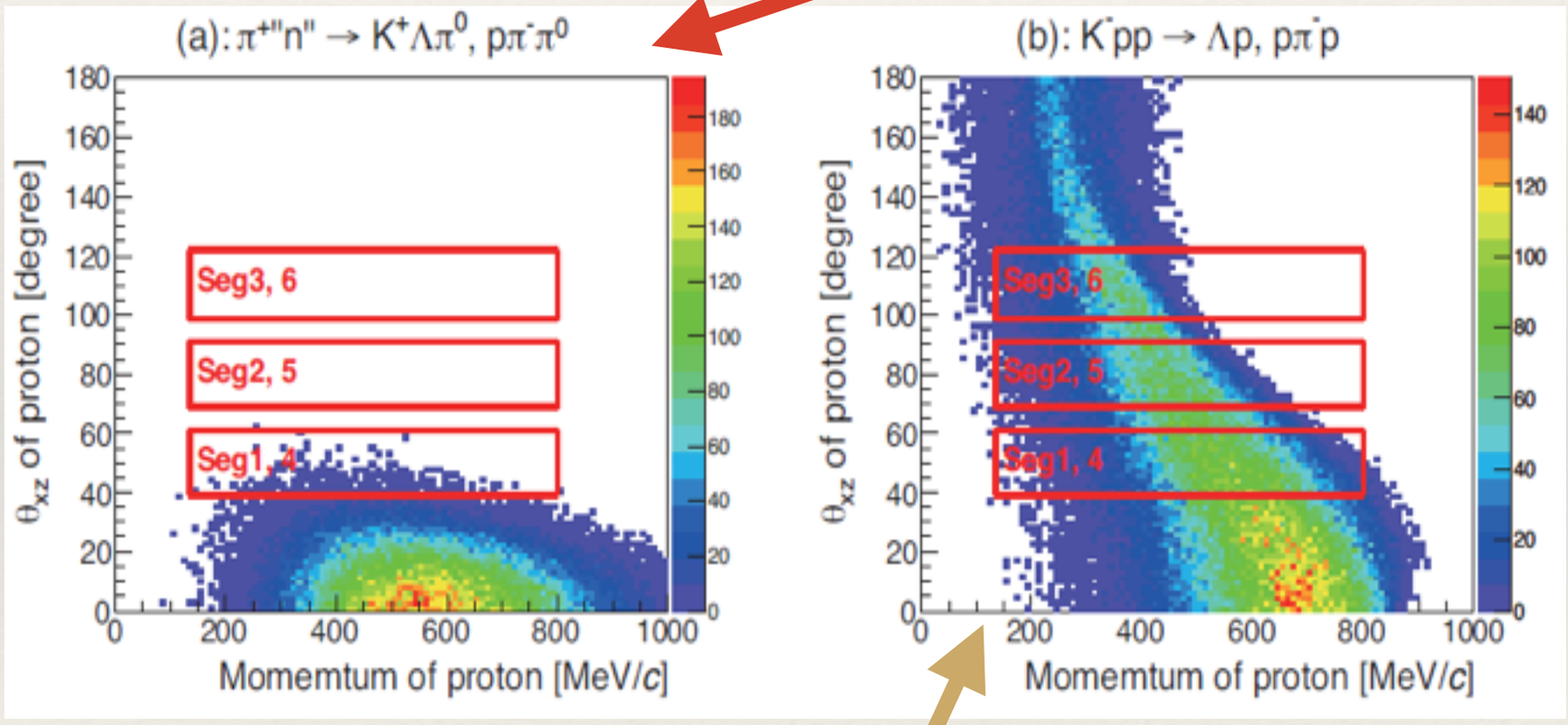




Proton Tagging

Simulation

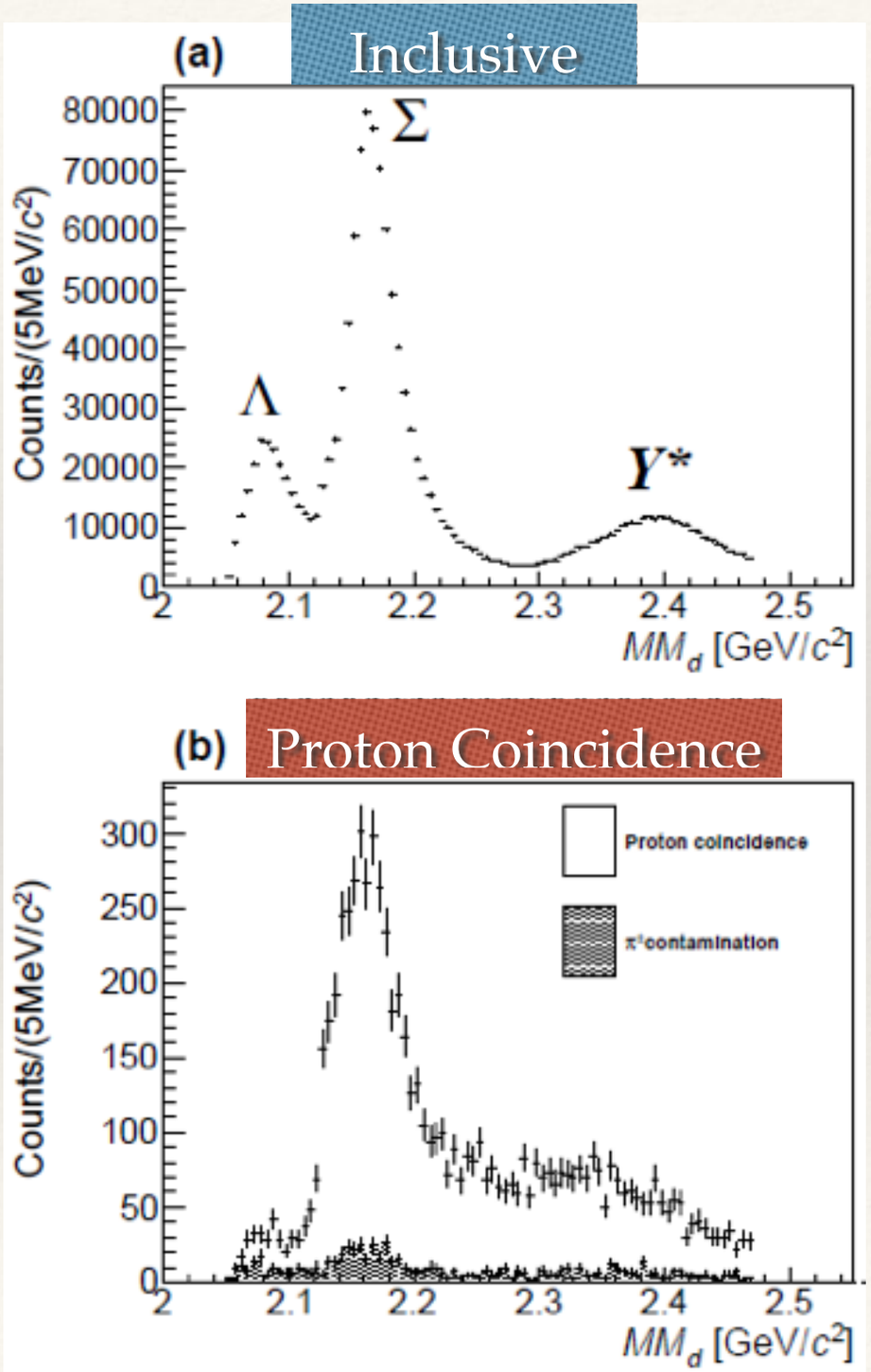
- Background: QF Y/Y* productions → Forward protons



- Signal: K^-pp decays → protons in RCA

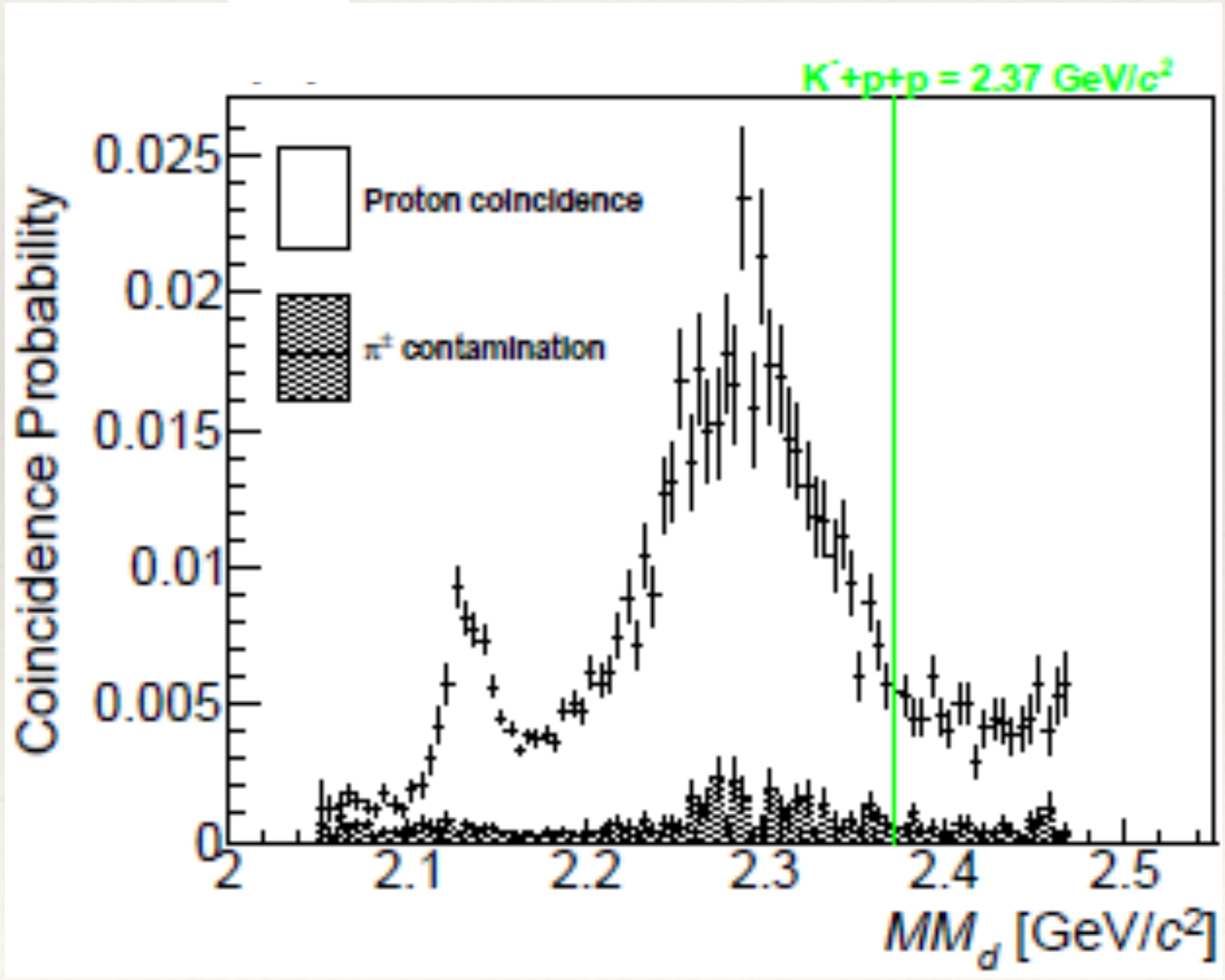
Coincidence Study

- Proton mom. >250 MeV/c
  - QFΛ, QFΣ, QFY*s are suppressed as expected !!
- What's left ?

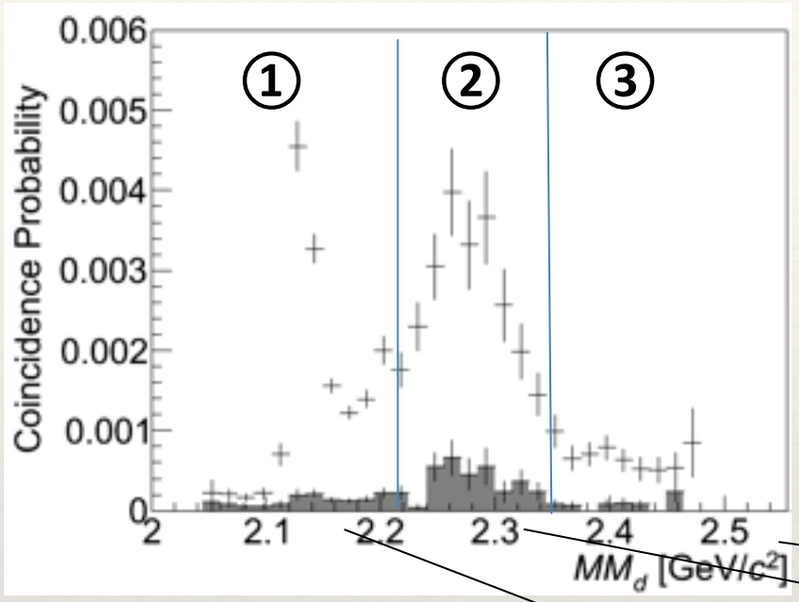


One-proton coincidence

- Coincidence Probability(MM)
  = One-proton coincidence(MM)/Inclusive(MM)
  - Enhancement near the ΣN threshold (2.13 GeV/c^2)
  - Broad bump at ~2.28 GeV/c^2



Two-proton coin. & Decay mode



- Two-protons in the final state :

  $K^- pp \rightarrow \Lambda p, \quad \Sigma^0 p, \quad Y\pi p$

  $pp\pi, \; pp\pi\gamma, \; pp\pi\pi(\gamma)$

- $d(\pi^+, K^+ pp)X$

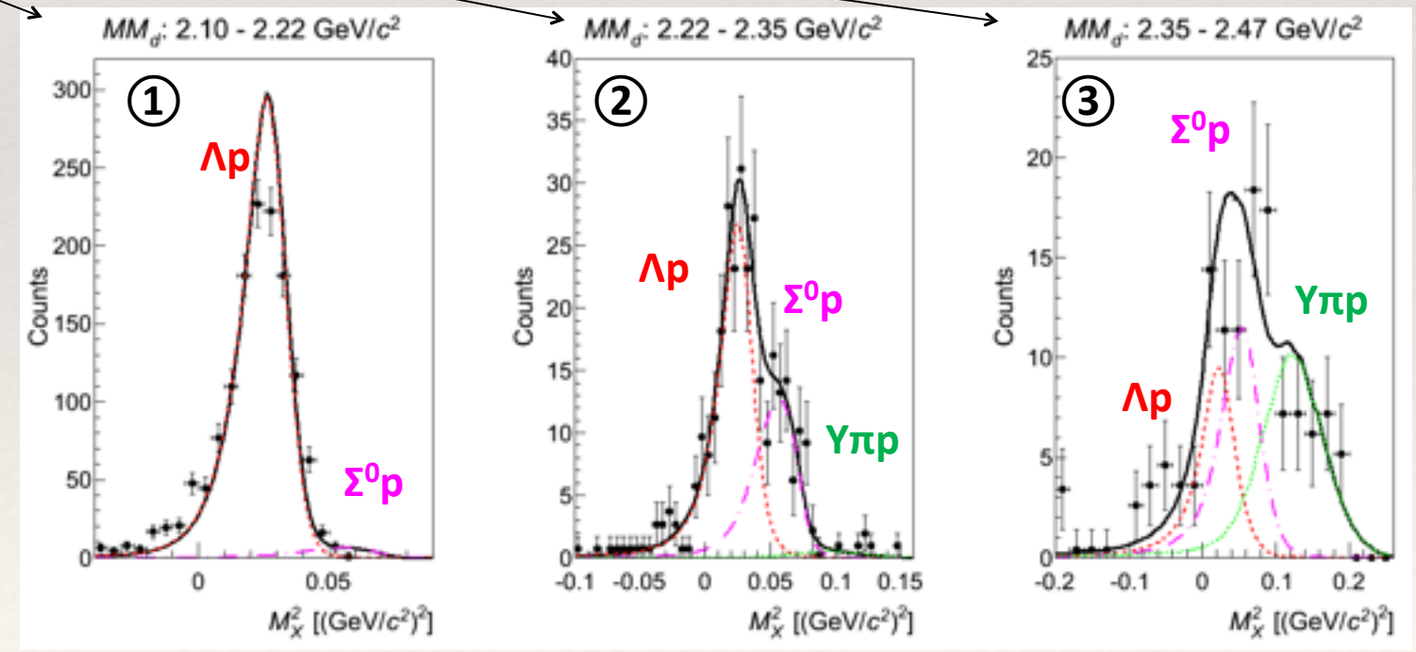
+ Data

— X = π (FS: Λp)

— X = πγ (FS: Σ^0p)

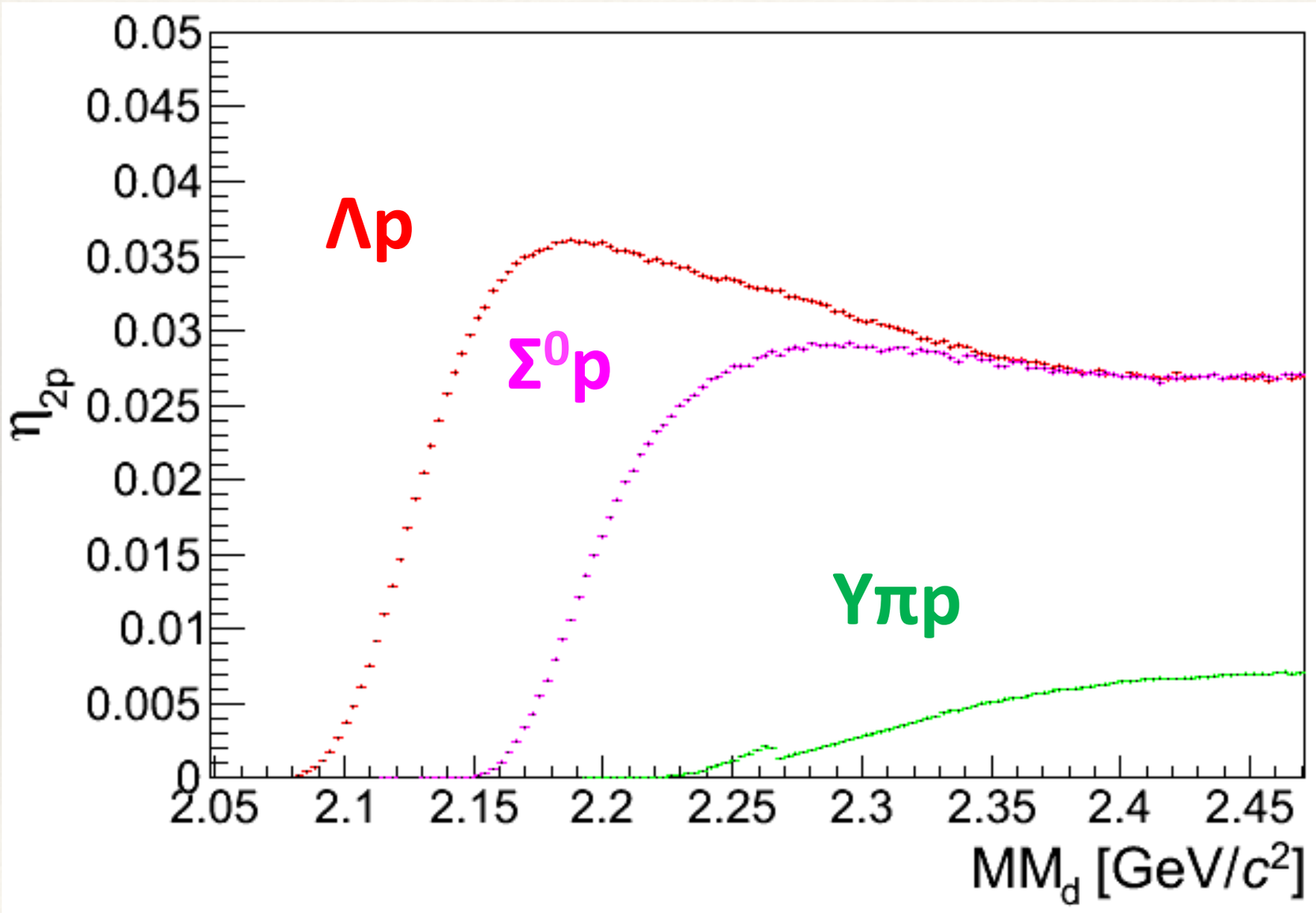
— X = 2π(γ) (FS: Yπp)

— Sum



Kinematically almost-complete measurement !

Mass-acceptance for each decay mode

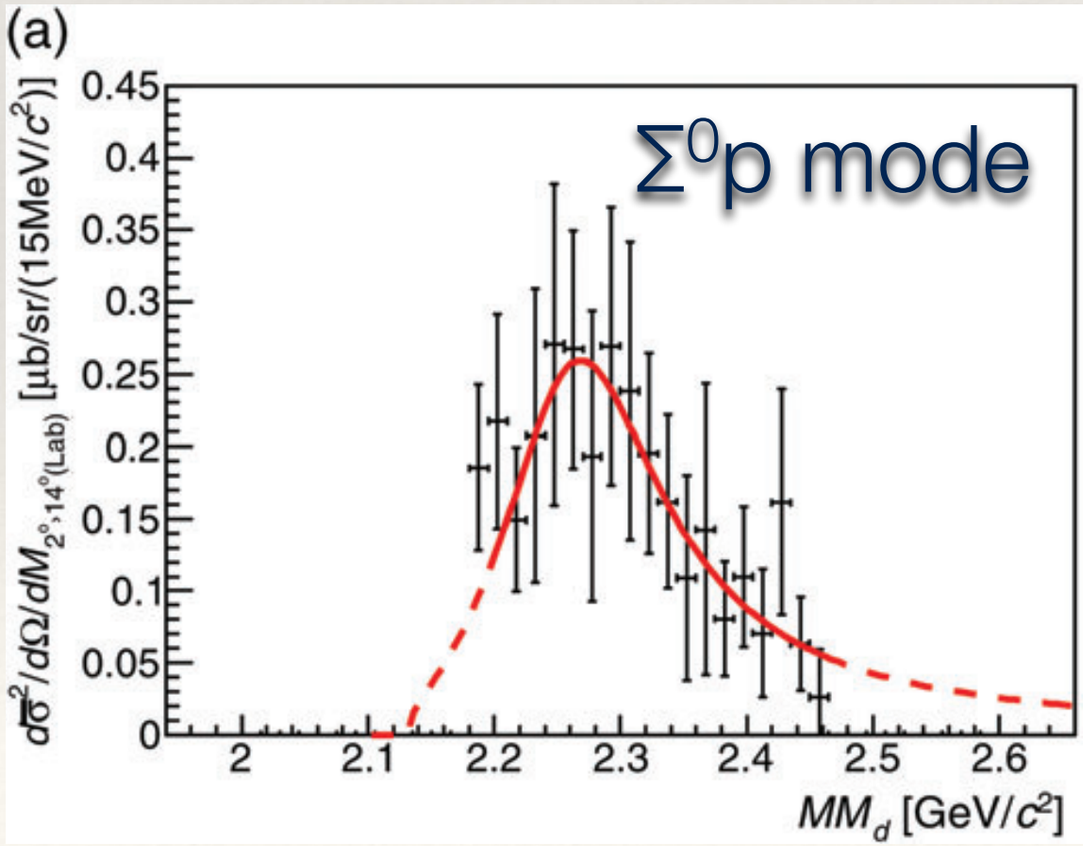


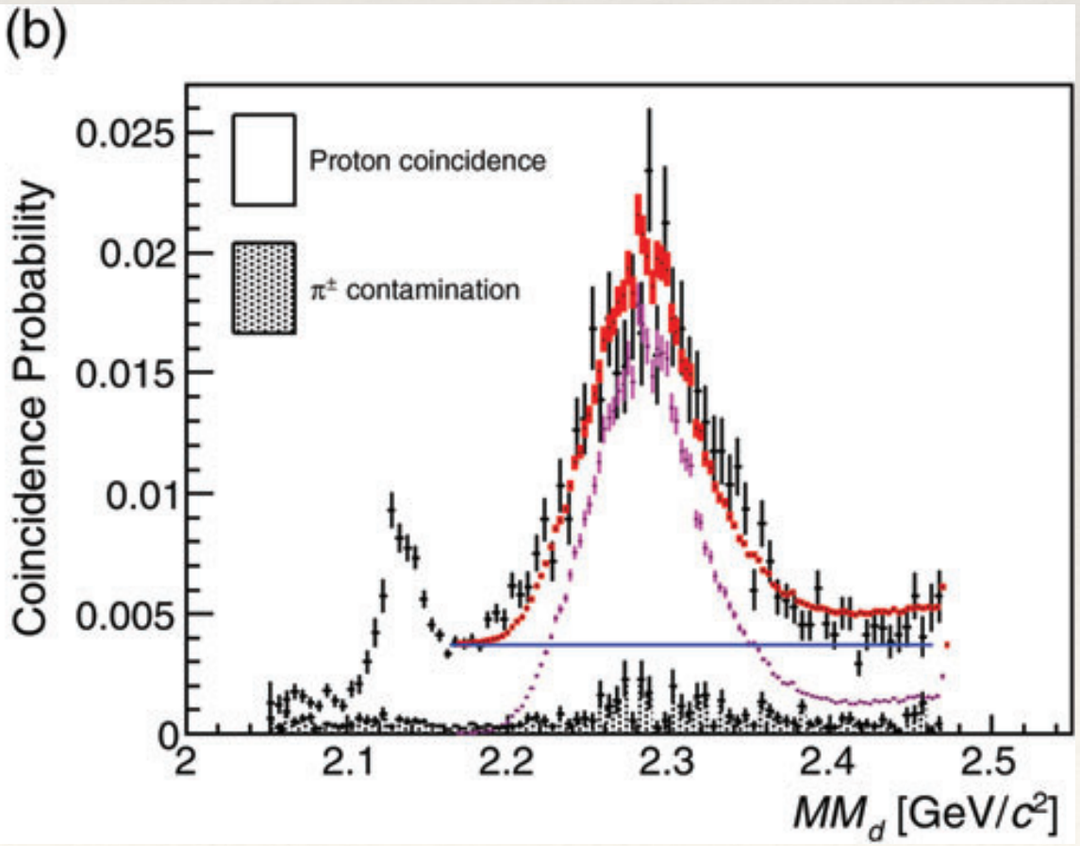
K^-pp-like Structure

- Mass : $2275^{+17}_{-18}(\mathrm{stat.})^{+21}_{-30}(\mathrm{syst.})\ \mathrm{MeV}/c^2$
- Width : $162^{+87}_{-45}(\mathrm{stat.})^{+66}_{-78}(\mathrm{syst.})\ \mathrm{MeV}$

Relativistic Breit-Wigner

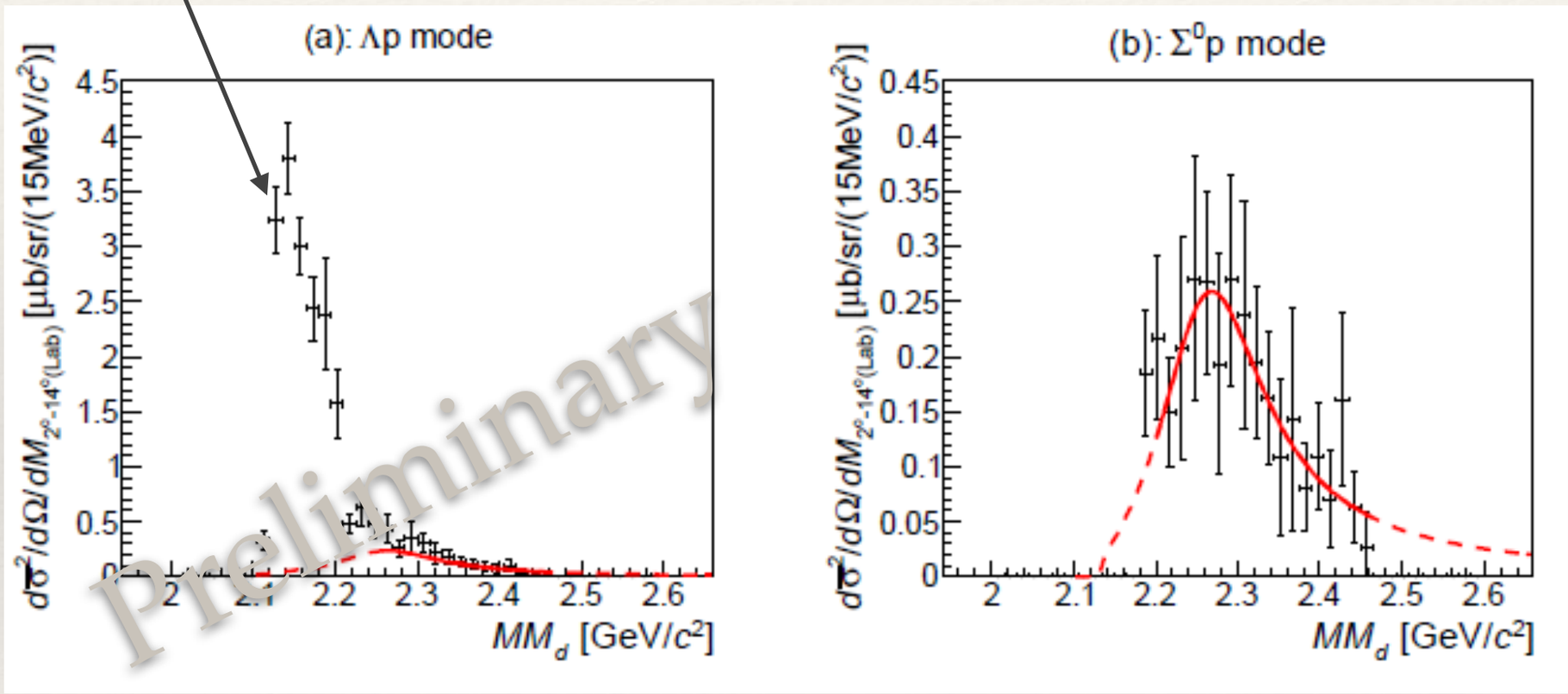
- Binding Energy $95\ ^{+18}_{-17}\ (\mathrm{stat.})\ ^{+30}_{-21}\ (\mathrm{syst.})\ \mathrm{MeV}$





$\Lambda p/\Sigma^0 p$ Branching Fraction

ΣN cusp +
ΣN→ΛN conversion



$$\frac{\Gamma_{\Lambda p}}{\Gamma_{\Sigma^0 p}} = 0.92^{+0.16}_{-0.14}(stat)^{+0.60}_{-0.42}(syst)$$

$$\frac{d\sigma}{d\Omega}_{K^- pp\to\Sigma^0 p} = 3.0 \pm 0.3(\text{stat})^{+0.7}_{-1.1}(\text{syst})\mu\text{b/sr}$$

$$\frac{d\sigma}{d\Omega}_{\Lambda(1405)} = 36.9\ \mu\text{b/sr} \quad \Rightarrow \quad \frac{d\sigma}{d\Omega}_{K^- pp\to\Lambda p/\Sigma^0 p} \Big/ \frac{d\sigma}{d\Omega}_{\Lambda(1405)} \approx (7/8)\%$$

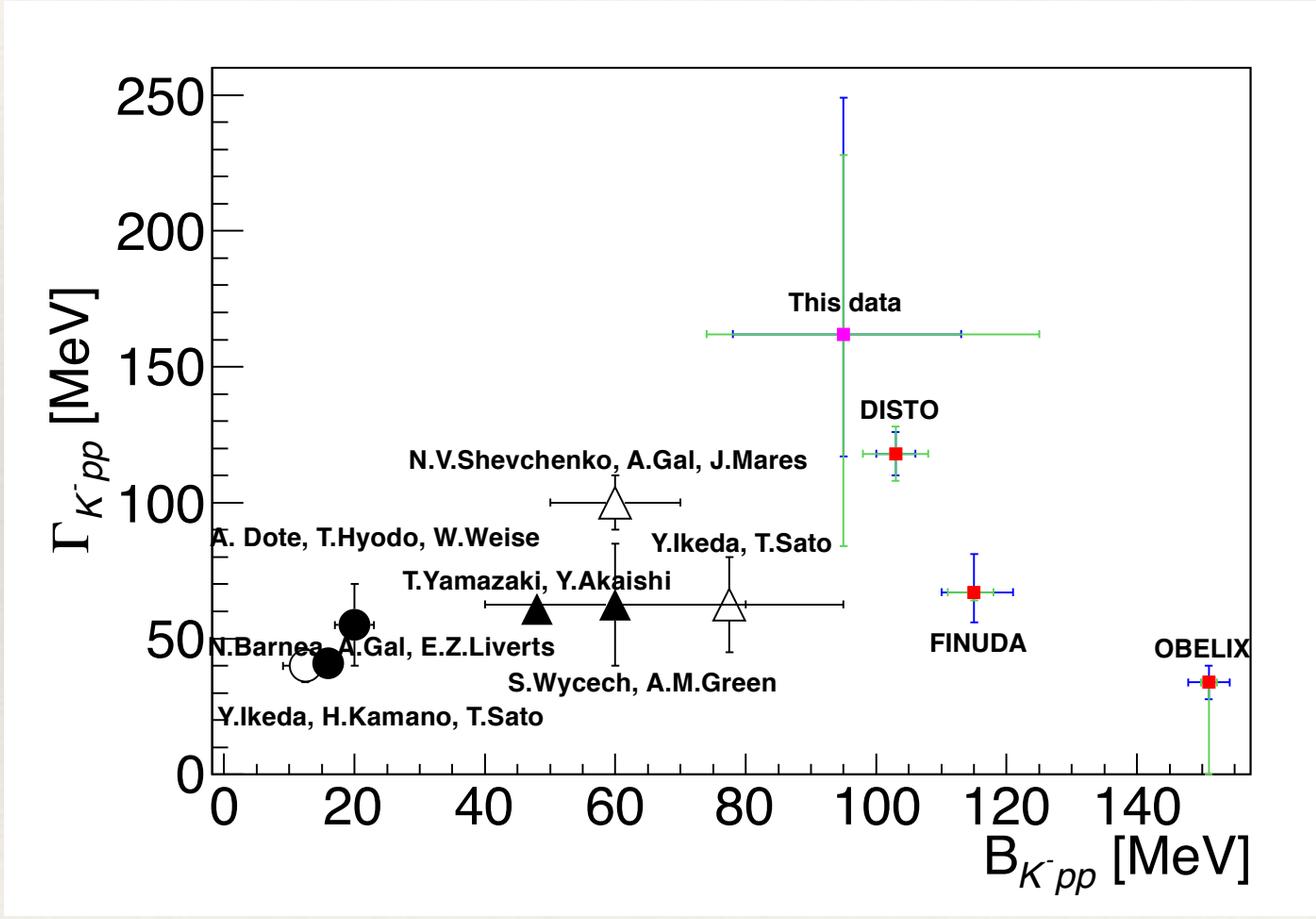
Remarks

- $\Lambda(1405)$ production seems to be necessary,
  - (OK for DISTO, HADES, J-PARC E27; △ for FINUDA, ? for E15)
  - but, not enough !
- Need to understand the $\Lambda^*(E)p \rightarrow K^- pp$ dynamics
  - →sensitivity of the measurements

    7% of $\Lambda(1405)$ in E27 ⇔ < 40% in HADES

Discussion on "*K⁻pp*"

- Binding Energy is large (~100 MeV), and the width is broad.
  - Not inconsistent with FINUDA, DISTO
  - Theoretical calcs. are difficult to reproduce the large binding.



Other possibilities

- Dibaryon as $\pi\Lambda N$-$\pi\Sigma N$ bound states

  H. Garcilazo, A. Gal, PLB 897 (2013) 167-178.

  $Y=1$, $I=3/2$, $J^{\pi}=2^{+}$;

  Λp ($I=1/2$) decay is prohibited.

- $\Lambda(1405)N$ bound state

  T. Uchino et al., NPA868 (2011) 53.

  $I=1/2$, $J^{\pi}=0^{-}$; not so large binding

- A lower $\pi\Sigma N$ pole of "$K^{-}pp$"
  a broad resonance near the $\pi\Sigma N$ threshold

  A. Dote, T. Inoue, T. Myo, PTEP (2015) 043D02.

- Enhanced $\bar{K}N$ interaction due to
  Partial restoration of Chiral symmetry;

  S. Maeda, Y. Akaishi, T. Yamazaki, Proc. Jpn. Acad., B 89 (2013) 418-437.

On-going activities

- AMADEUS : $^{12}C(+^{27}Al)(K^-_{stop},\Sigma^0p)X$
- HADES : Global Partial Wave Analysis with HADES +DISTO+FOPI+COSY datasets …
- J-PARC E15 : $^3He(K^-,np\Lambda)$
  coming data taking in Nov. for 10-times better statistics

Summary

- "*K⁻pp*"-like structure is observed in the d(π^+,K^+pp)X reaction at 1.69 GeV/*c* in the Σ^0p invariant mass, for the first time.
  - Binding Energy $95^{+18}_{-17}(\mathrm{stat.})^{+30}_{-21}(\mathrm{syst.})$ MeV
  - Width $162^{+87}_{-45}(\mathrm{stat.})^{+66}_{-78}(\mathrm{syst.})$ MeV
  - Branching Fraction $\frac{\Gamma_{\Lambda p}}{\Gamma_{\Sigma^0 p}} = 0.92^{+0.16}_{-0.14}(stat)^{+0.60}_{-0.42}(syst)$

- First evidence of Y=1, B=2, S=-1 bound system
  - No B=2, S=-1 hypernuclei; Λ: B=3, ${}^{3}_{\Lambda}$H, Σ: B=4, ${}^{4}_{\Sigma}$He
  - How about B=2, S=-2 ?? , ΛΛ-H dibaryon, ΞN