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May 24-28, 2021

"K-pp" Search in J-PARC E27 and E05

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- Kaonic nuclei search in Inclusive spectra
  - KEK-PS E548 : $^{12}C(K^-, p/n)X$
- Search @ J-PARC
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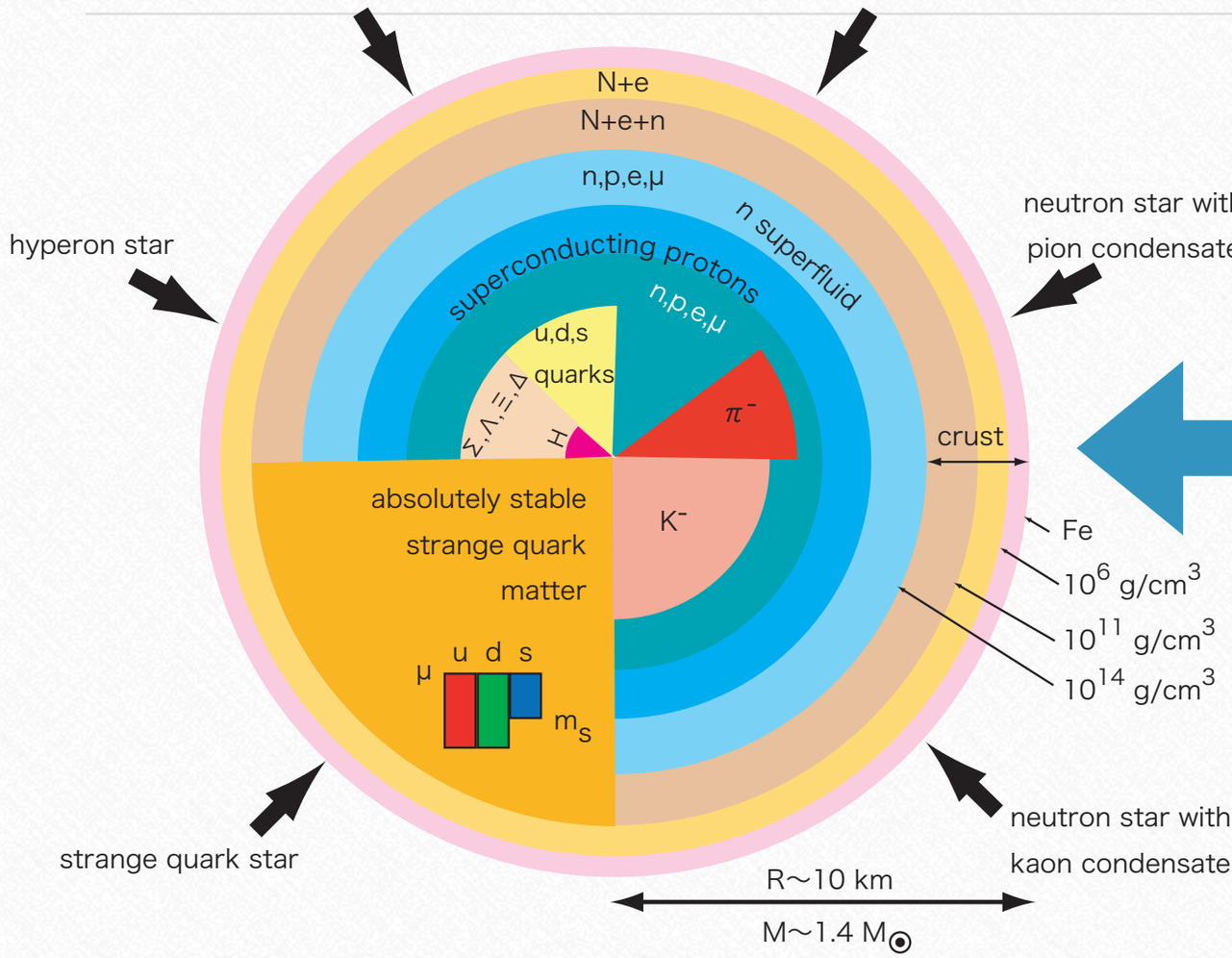
  - E27 : $d(\pi^+, K^+)X$, $d(\pi^+, K^+pp)$
  - E15 : $^{3}He(K^-,n)X$, $^{3}He(K^-,\Lambda p)n$
- Summary

What's in the Neutron Star Core ?

Strangeness is the Key



By F.Weber

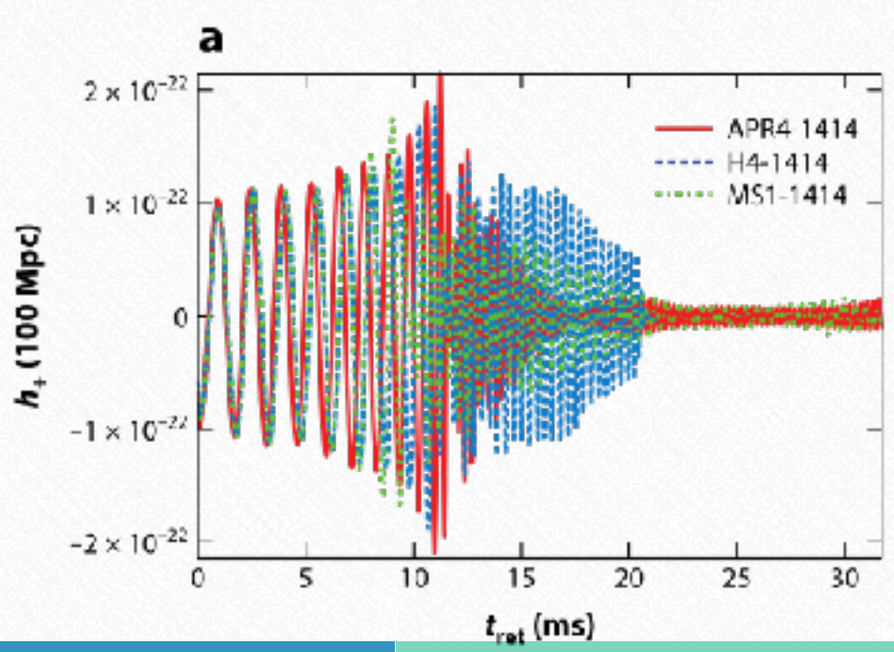


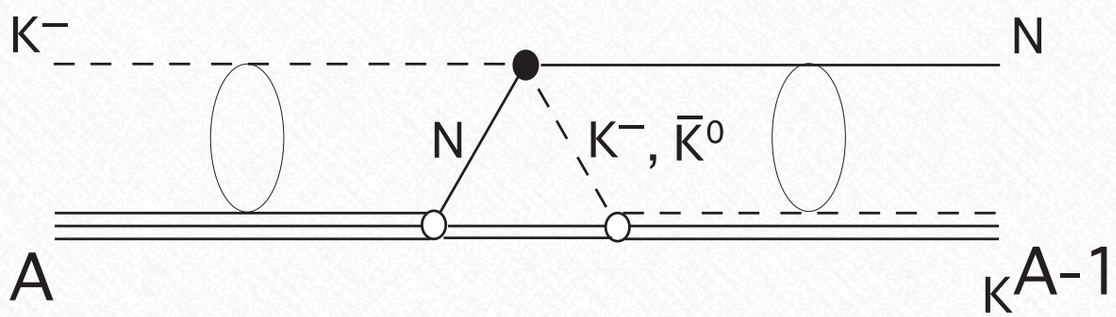
Figure 4

mples of the "plus" polarization component of gravitational waves
rce along the direction of the orbital angular momentum. The diffe
e (EOSs) of the neutron star matter, labeled APR4, ALF2, H4, and
MS1 EOSs give radii of 11.1, 12.4, 13.6, and 14.4 km, respectively. (a)

Chemical Potential: $\mu_B = m_B + \frac{k_F^{\,2}}{2m_B} + U(k_F)$

(K-, N) **Semi-**Inclusive Spectrum

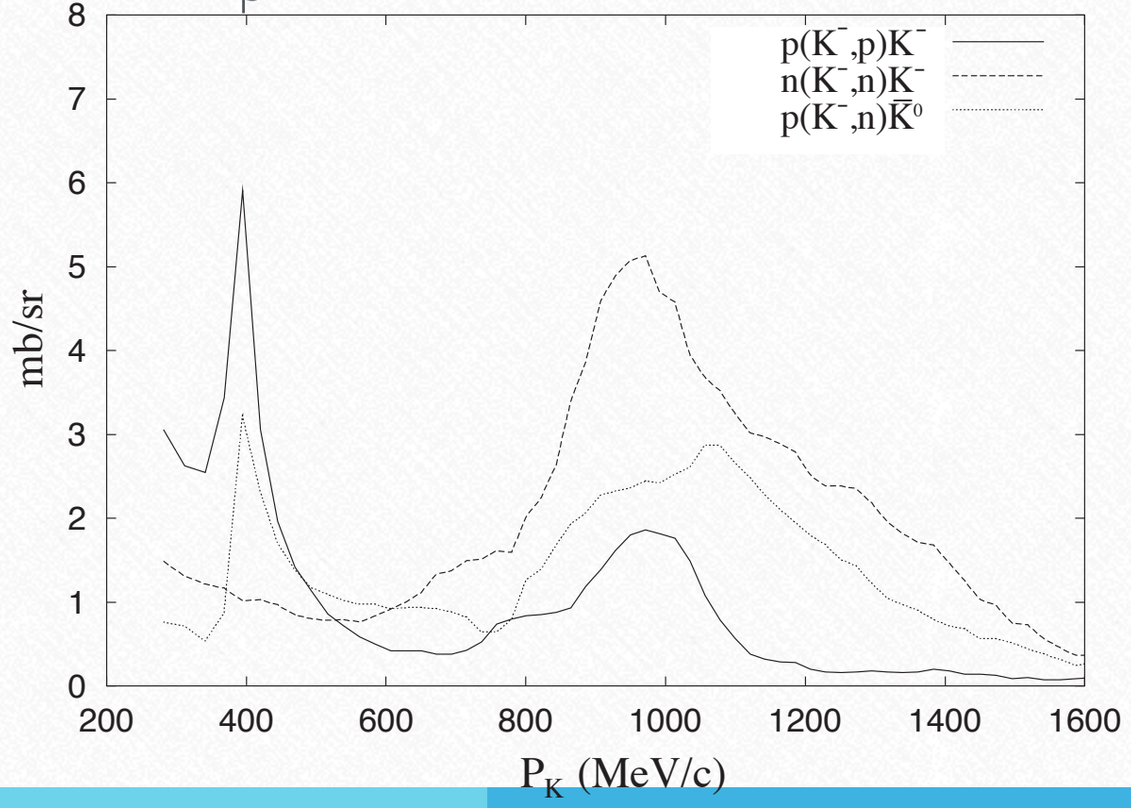
T. Kishimoto,
Phys. Rev. Lett. 83 (1999) 4701-4704.

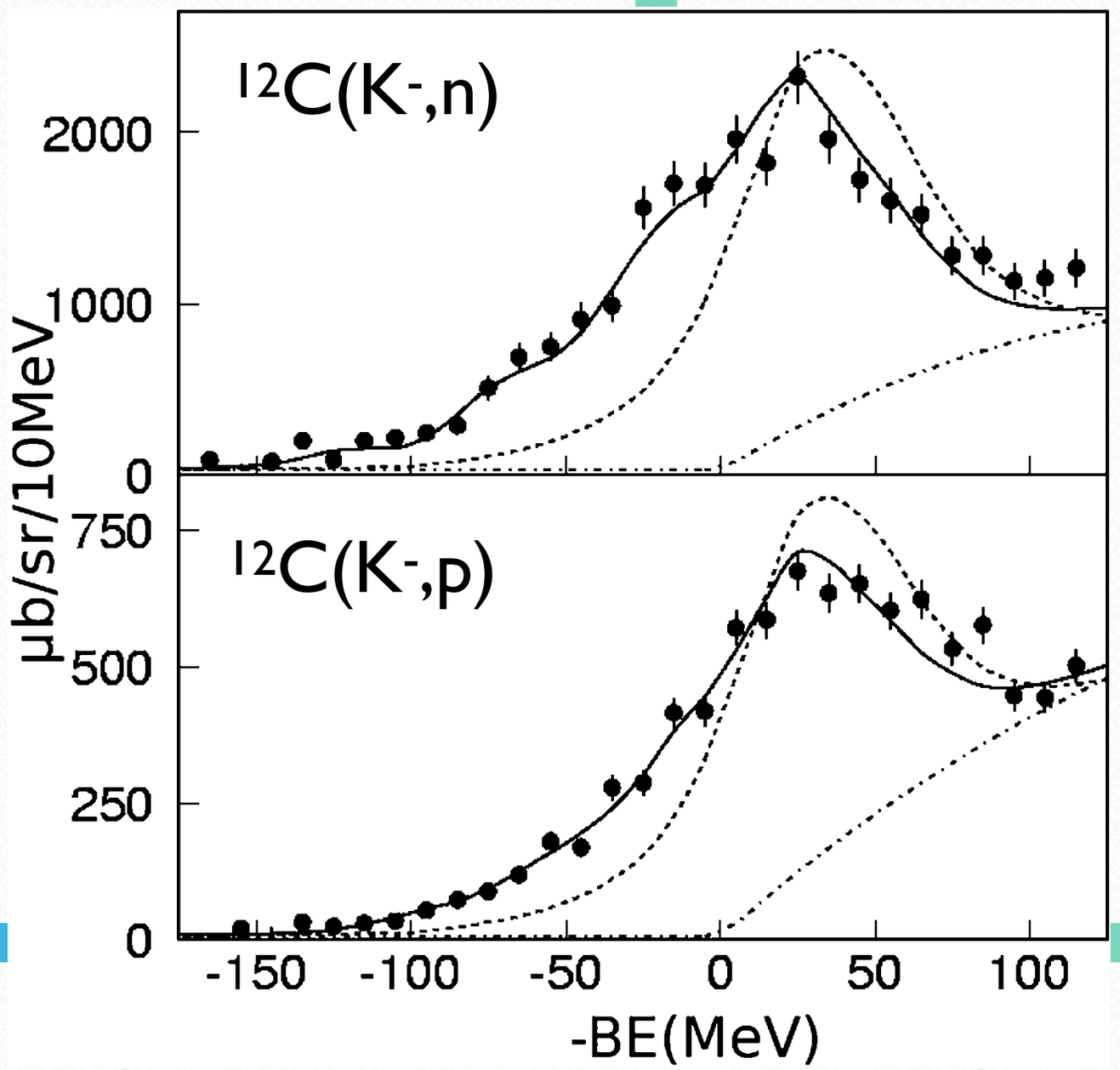


KEK-PS E548

$^{12}C(K^-, p/n)$ reactions at 1 GeV/c

- Not Inclusive !
- $\sigma_p \sim 10$ MeV/c





T. Kishimoto et al., Prog. Theor. Phys. 118 (2007) 181.

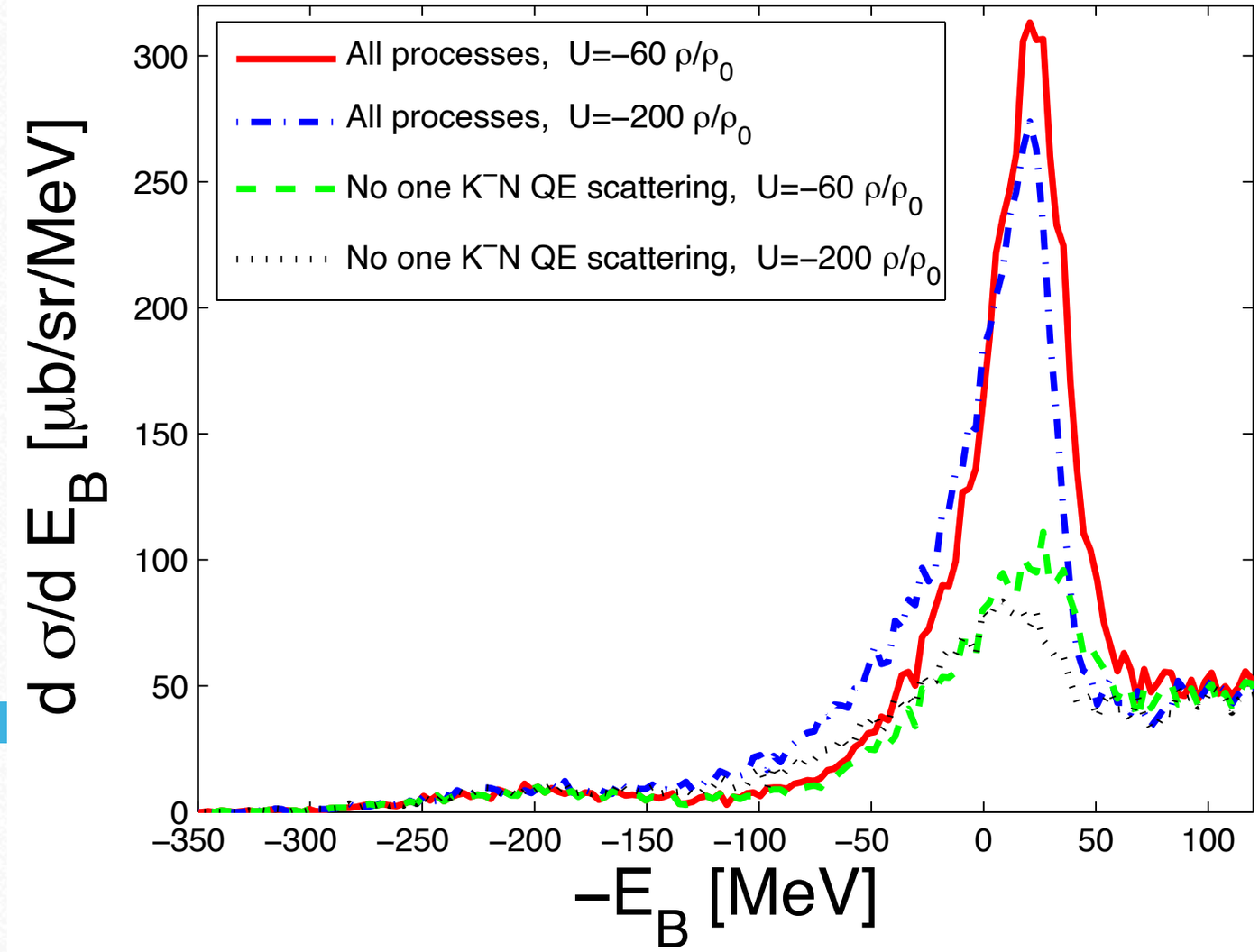
Not Inclusive !

(K-, p/n) velocity of p/n ↔ TOF in the forward direction L~10 m

Start timing = prompt reaction

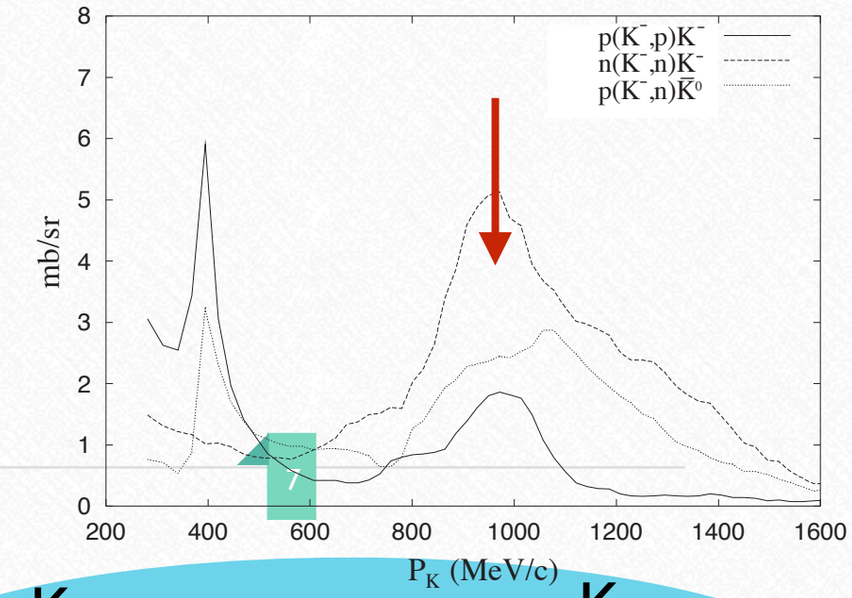
Danger to compare theoretical calculations with the data

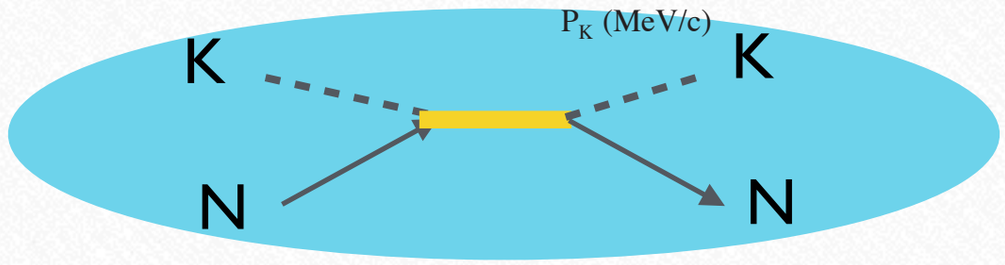
V.K. Magas et al.,
Phys. Rev. C 81 (2010) 024609.



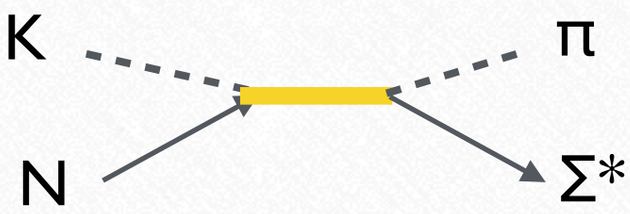
K-p reactions

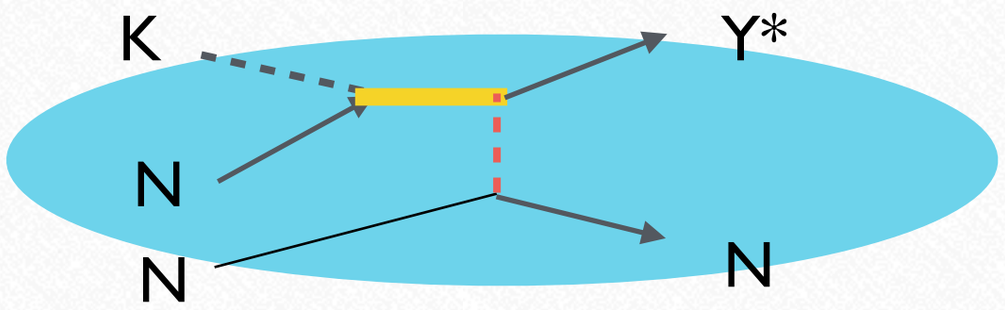
- s-channel resonance @ 1 GeV/c
- K-p → **Λ*(1800)** → KN, Σ*(1385)π, NK*
  - ~5mb/sr





- Quasi Elastic : K-N → NK-, high mom. N in FWD
- One-body absorption : K-N → πΣ
  - Λ* → Λπ ; forbidden
- Two-nucleon absorption : K-NN → YN/Y*N





These processes should overlap in the (K-,p) spectrum !

J-PARC E05

Y. Ichikawa et al.,
Prog. Theor. Exp. Phys. (2020) 123D01.

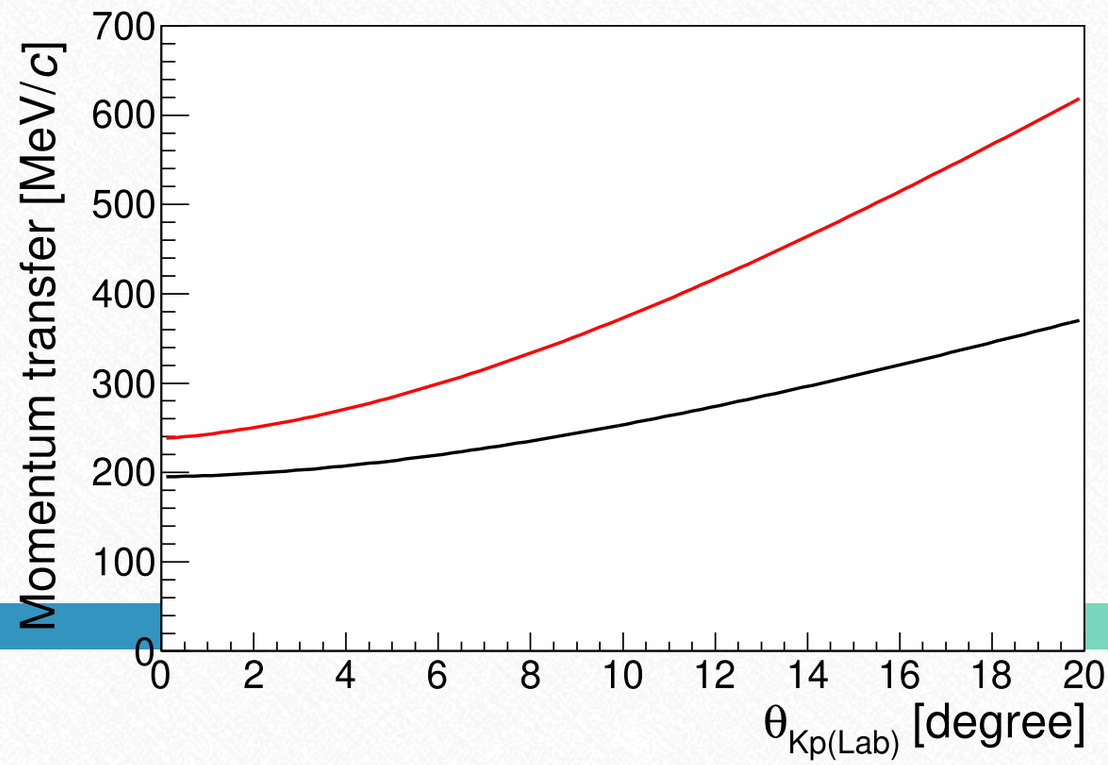
Real Inclusive measurement of proton ←

Magnetic spectrometer, not TOF

$^{12}C(K^-,p)$ at 1.8 GeV/c ~mb/sr, off-resonance

q_{E548}~0.2-0.3 GeV/c

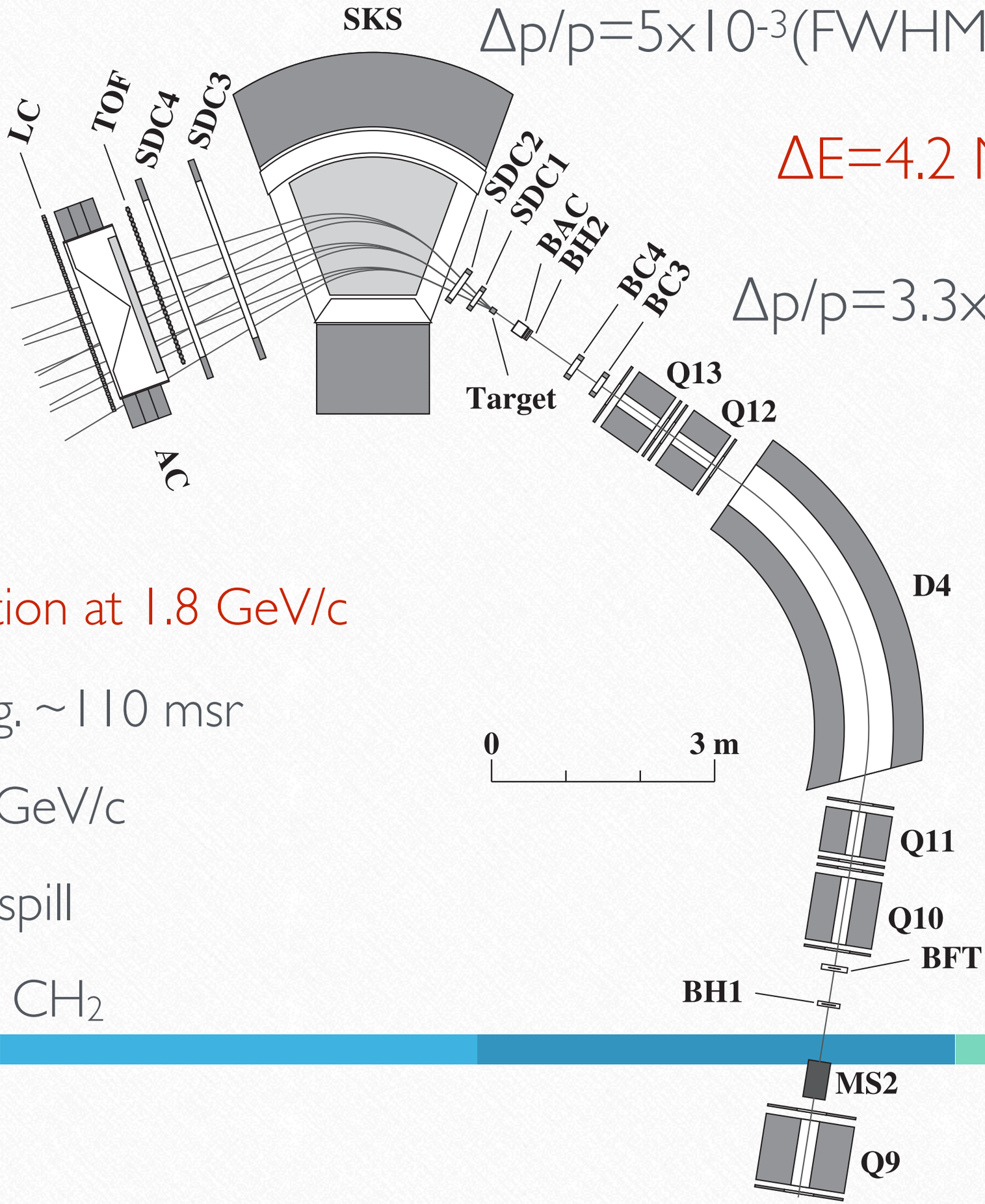
q_{E05}~0.25-0.4 GeV/c



$\Delta p/p=5\times10^{-3}$(FWHM)

$\Delta E=4.2$ MeV σ

$\Delta p/p=3.3\times10^{-4}$(FWHM)

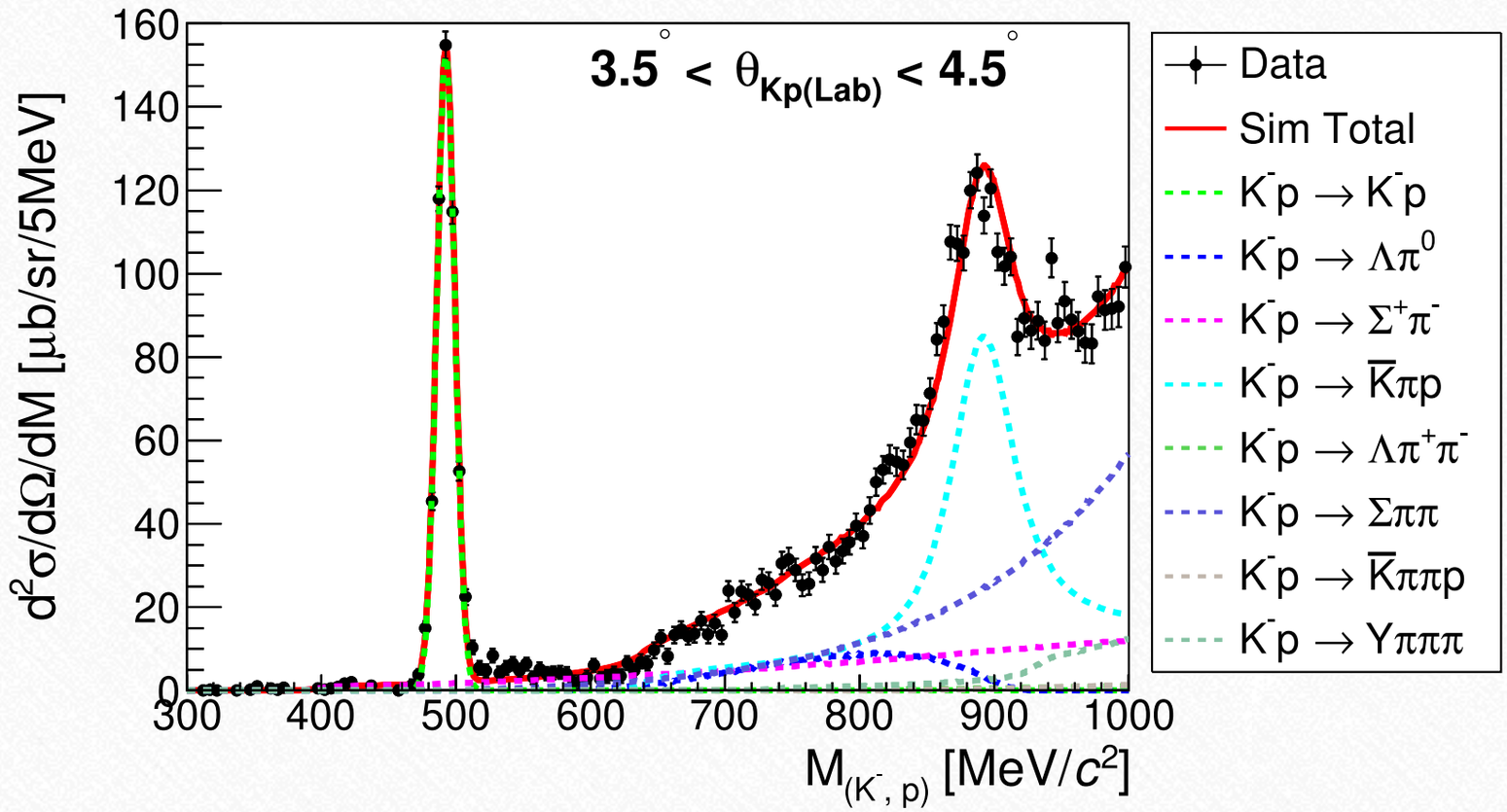


$^{12}C(K^-, p)$ reaction at 1.8 GeV/c

- θ_K<14 deg. ~110 msr
- p_K: 1.1-2.4GeV/c
- K^- : 6×10^5/spill
- Targets: C, CH_2

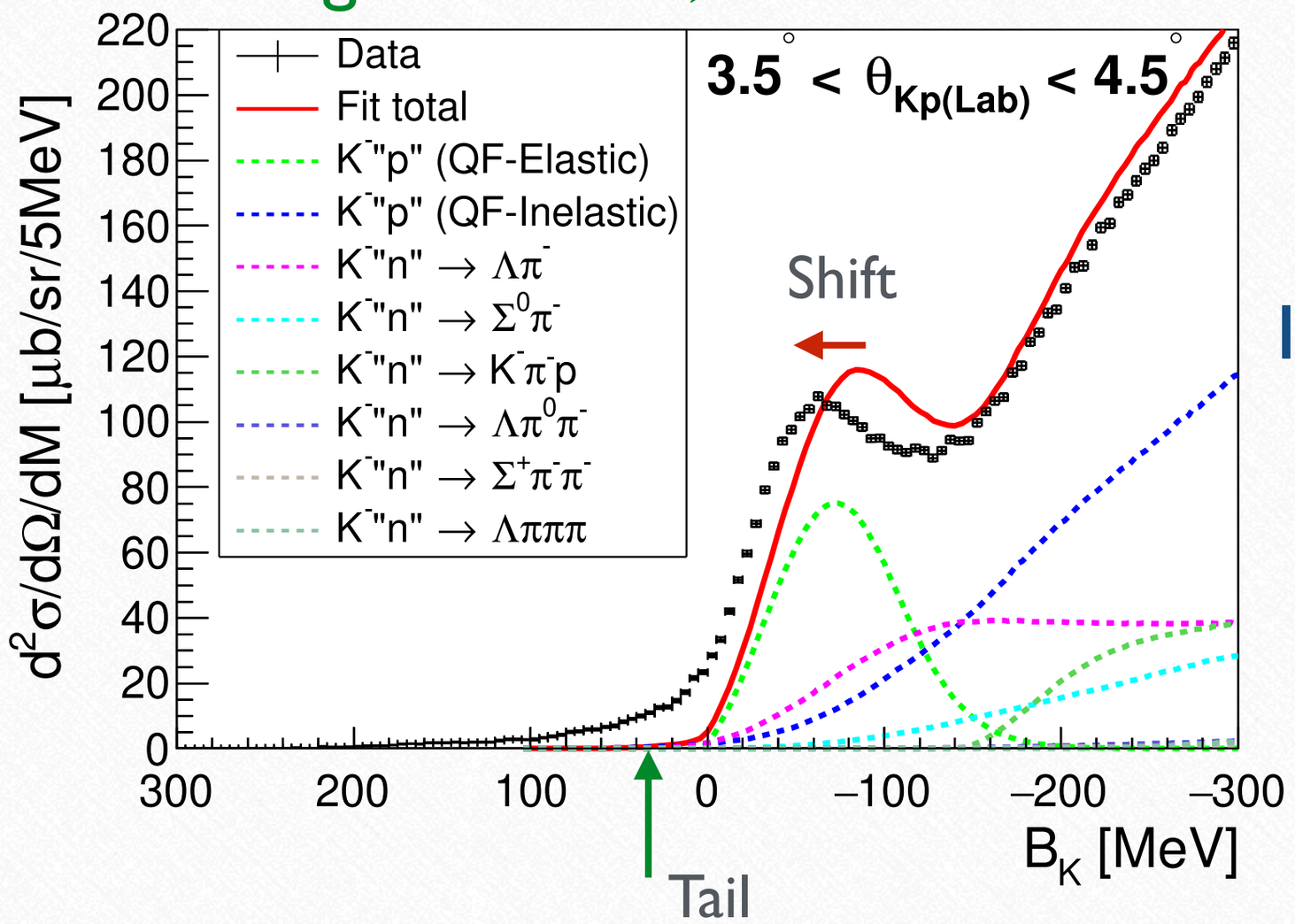
p(K-,p) spectrum

Larger inelastic scattering 1.8 GeV/c > 1 GeV/c



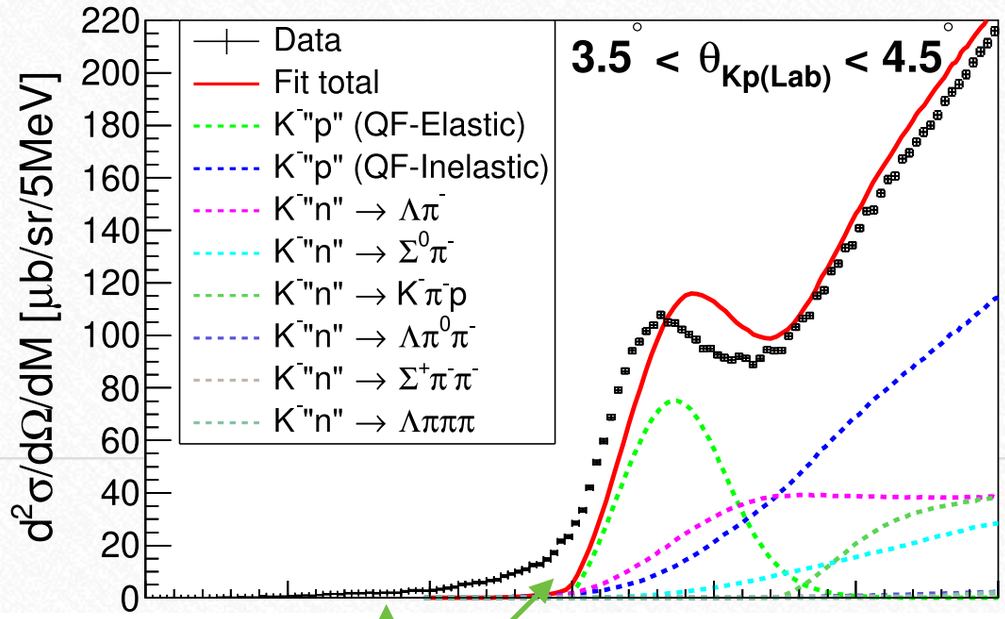
^{12}C(K$^-$,p) spectrum

High statistics, Unbiased



Inelasic

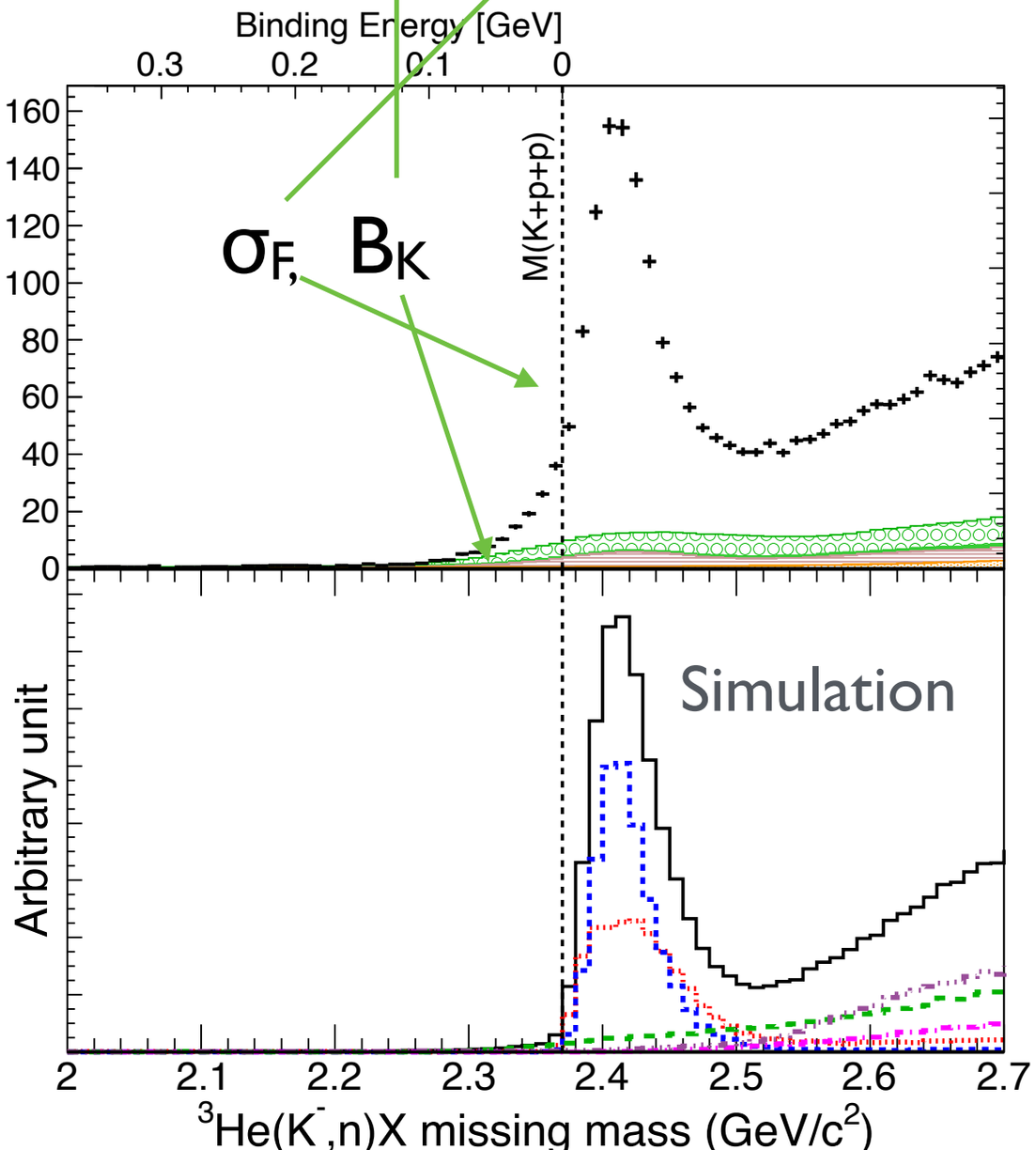
Inclusive 1.8 GeV/c



^{12}C E05 p

12

Semi-inclusive 1 GeV/c

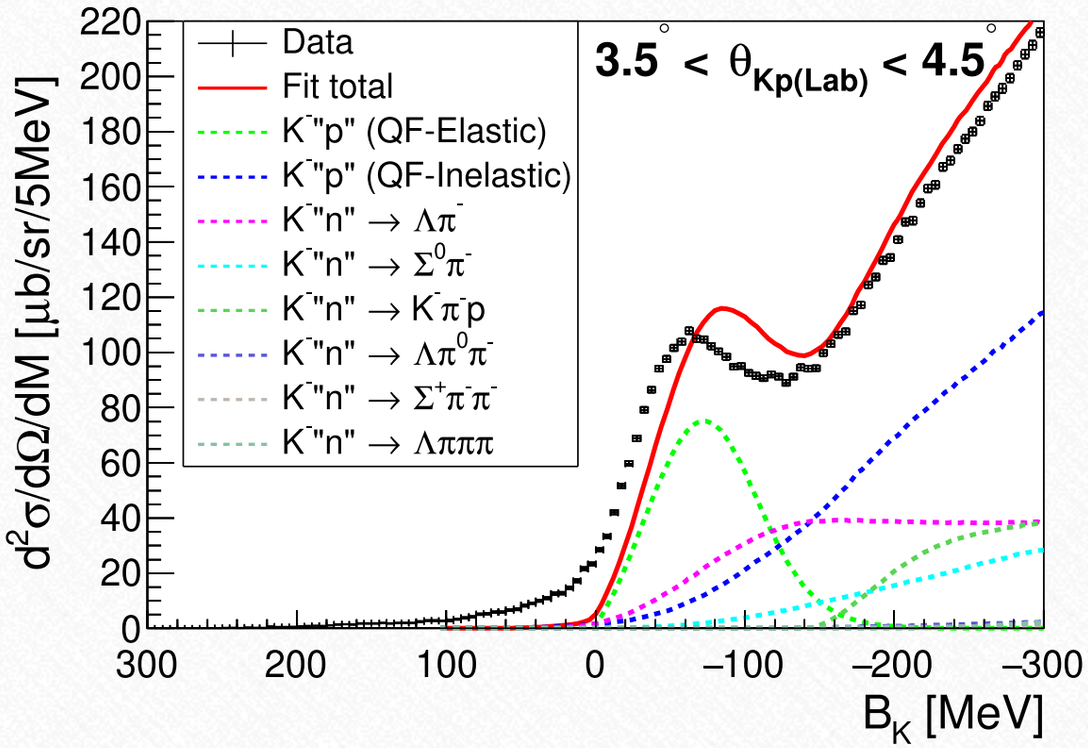


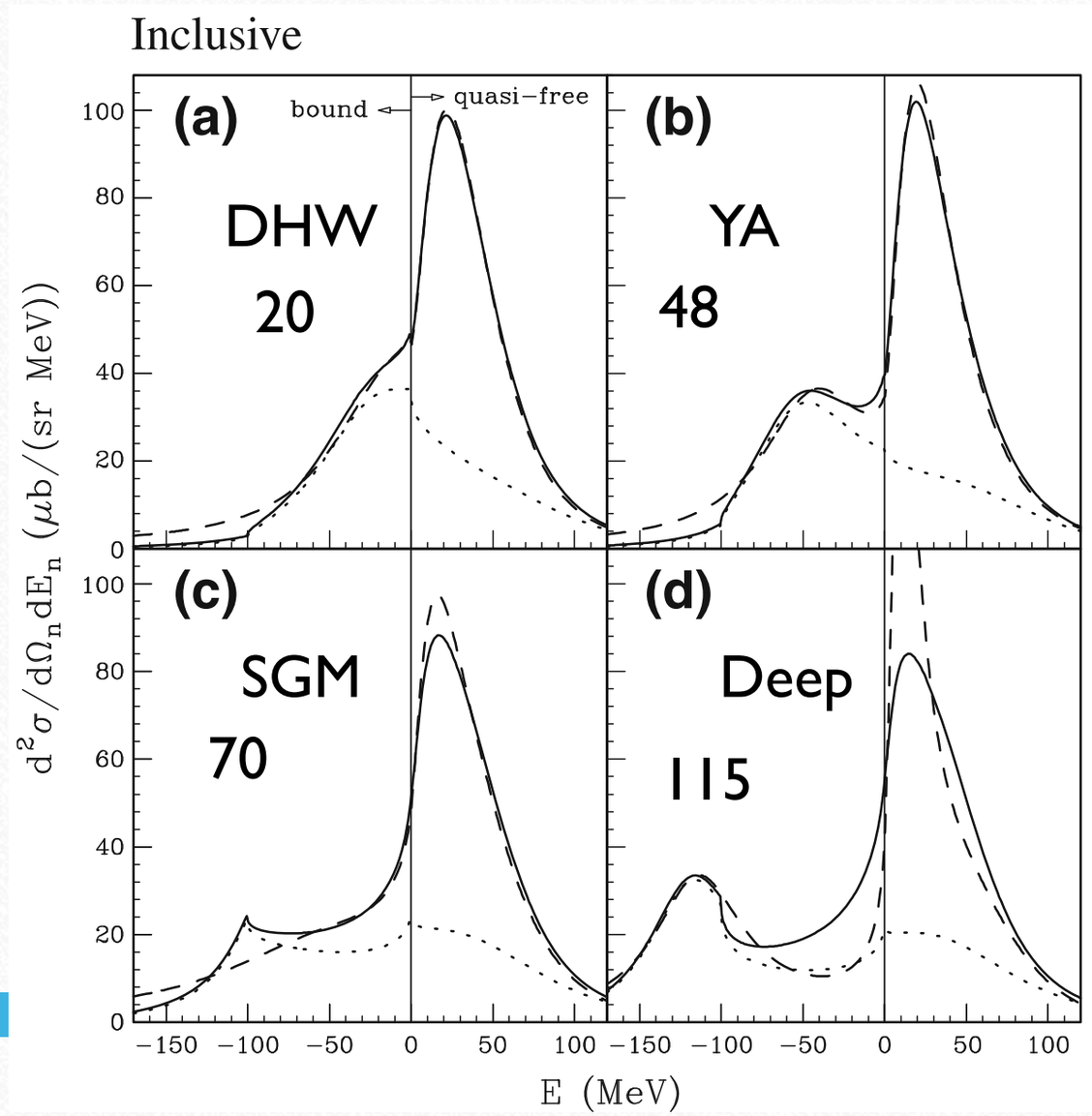
^{3}He E15 n

Theoretical Calcs.

T.Koike and T.Harada
Few Body Syst. (2013) 117-122.

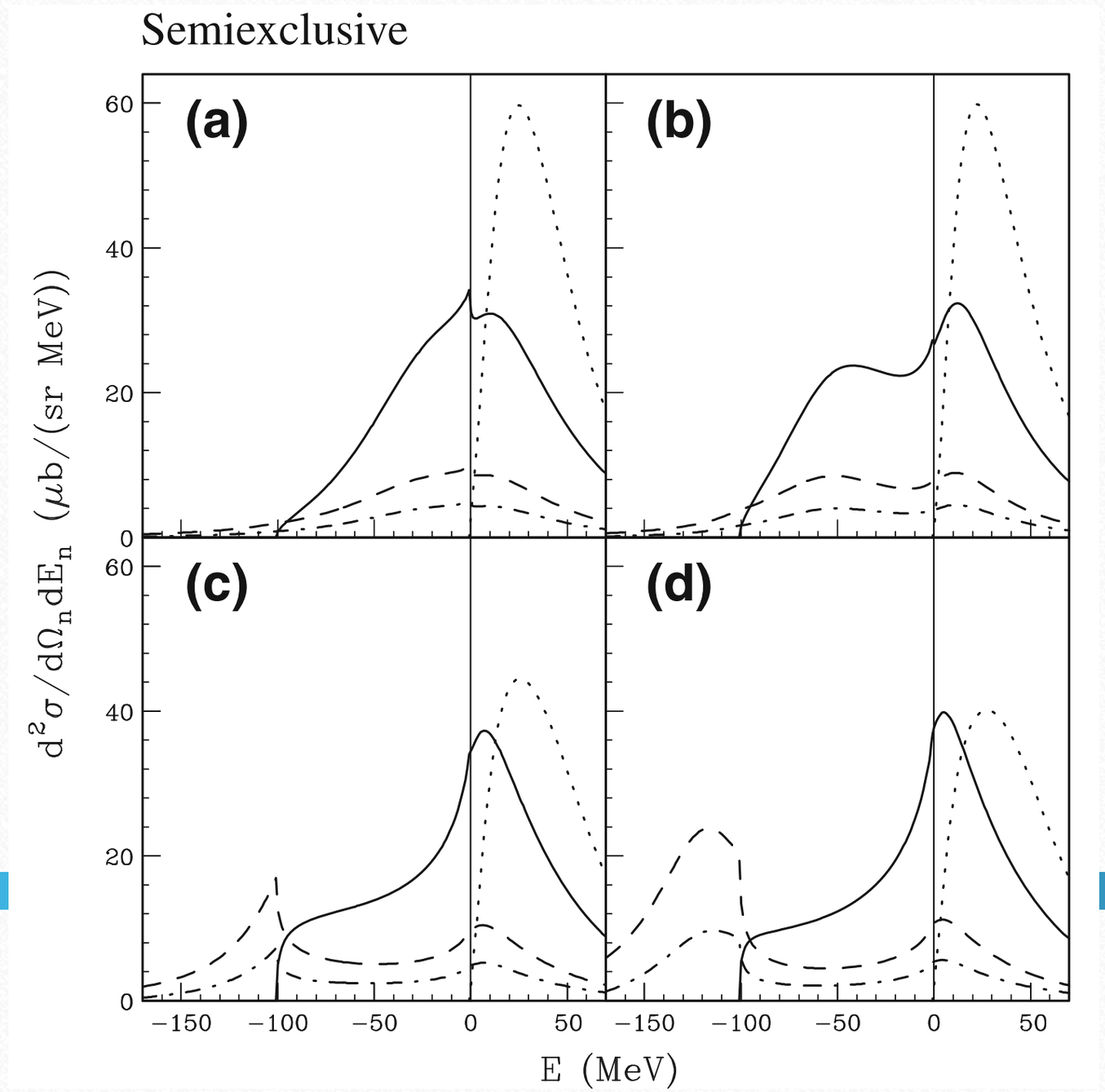
$d^2\sigma/d\Omega/dM$ near bound threshold : Kaonic bound state ~ KN-NKQF x1/2





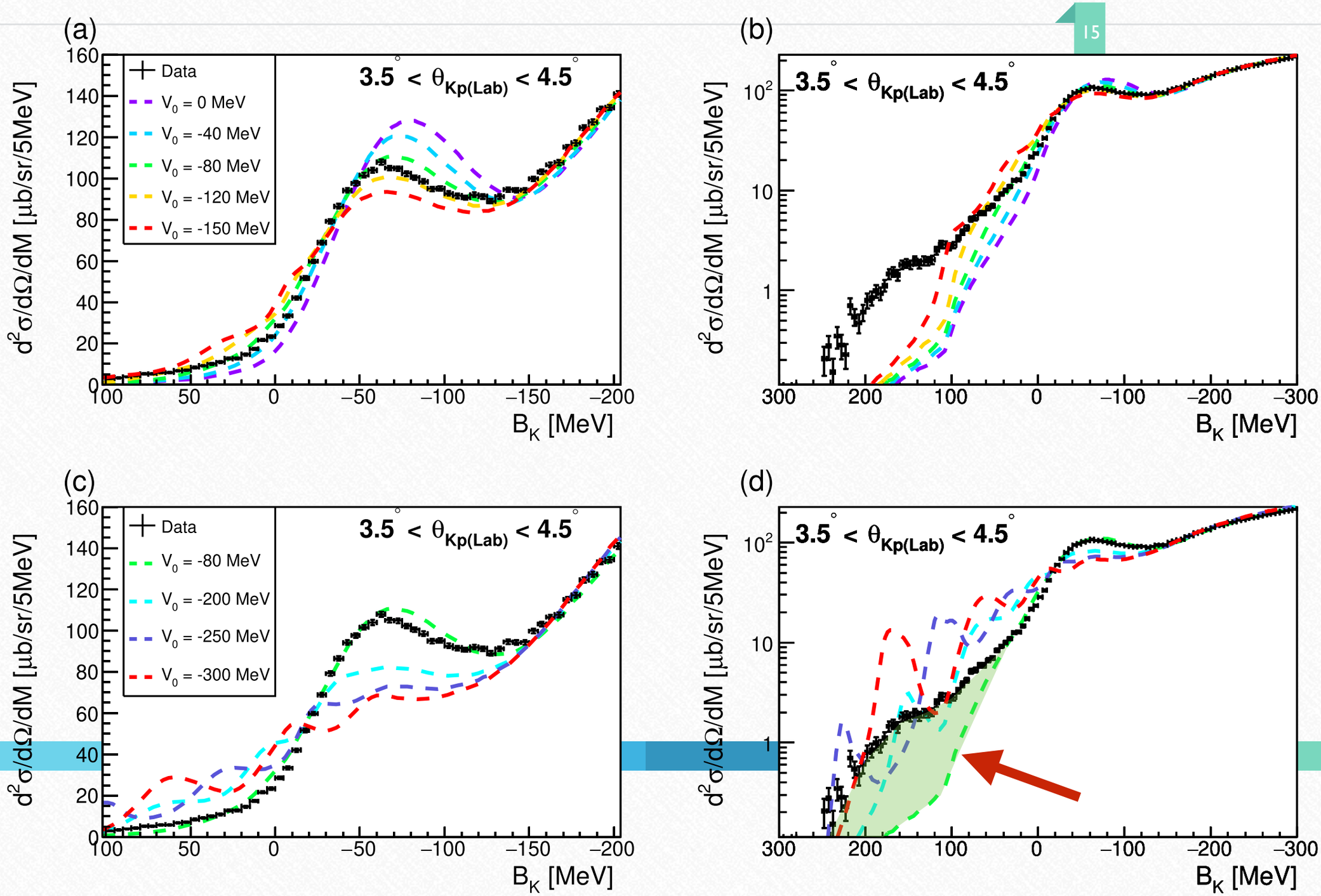
Coincidence Spectra

Signals in Coincidence ~ Inclusive

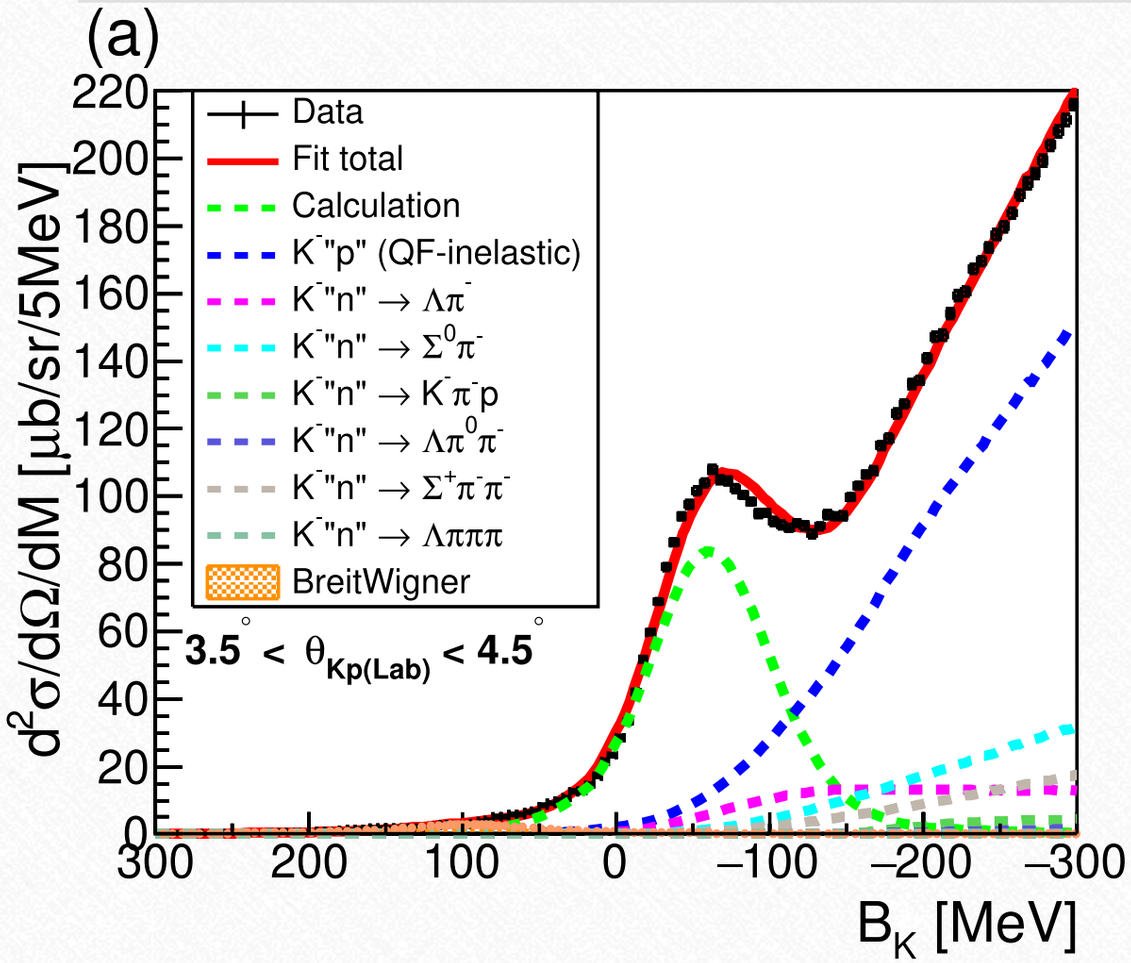


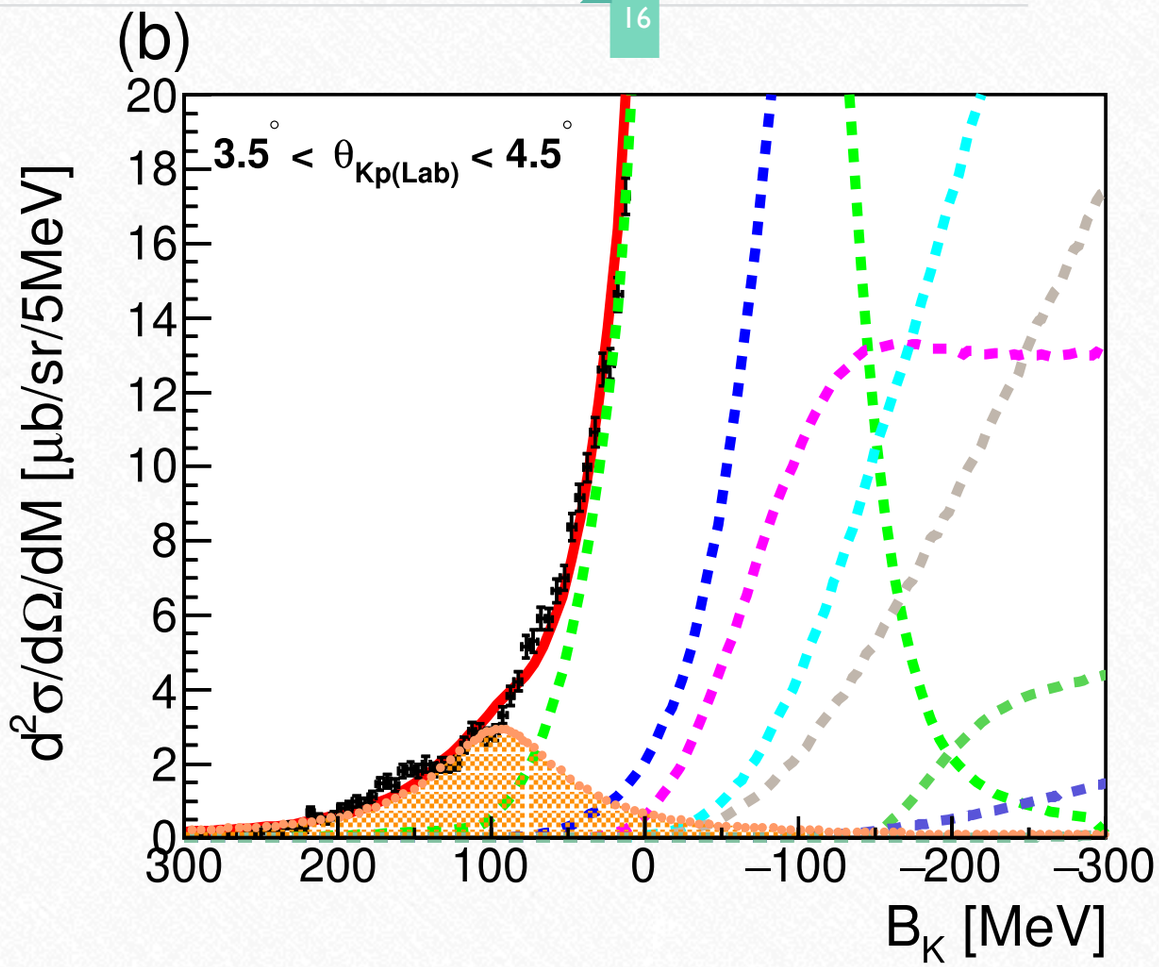
Imaginary is large → Broad

W_0=-40 MeV, V_0=-80 MeV



Excess in deep region



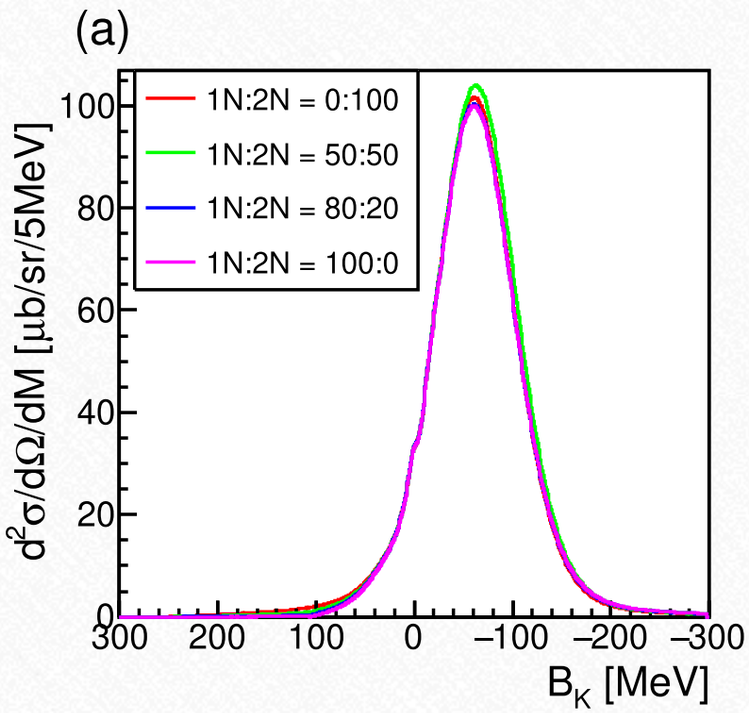


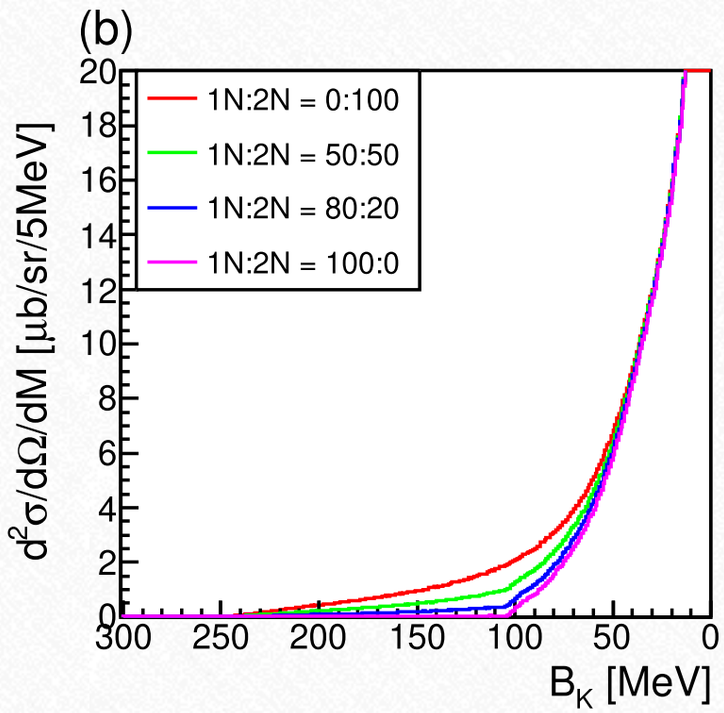
BK=90 MeV, Γ=100 MeV

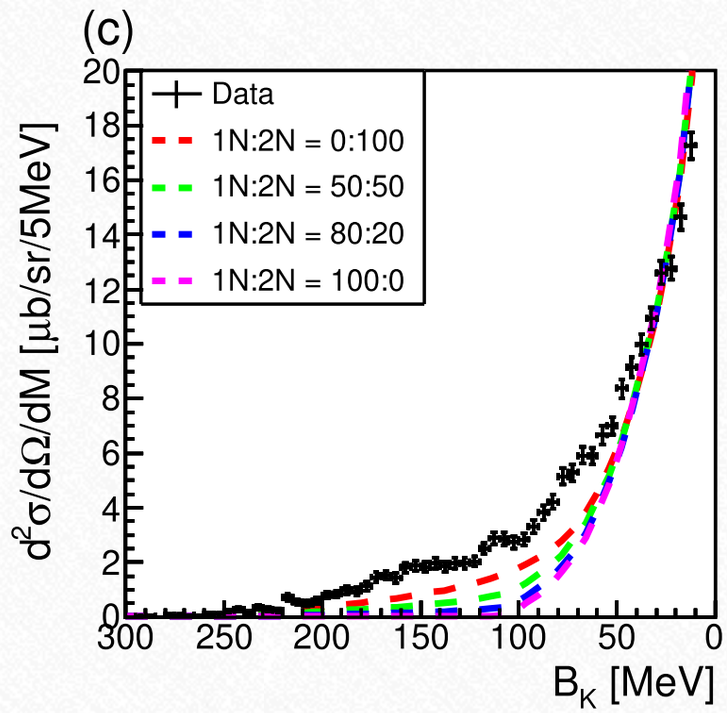
Two-nucleon Absorption ?

K-(pp)→Λ*p

1N : 2N ?







Not enough to explain the excess

W_0=-40 MeV, V_0=-80 MeV

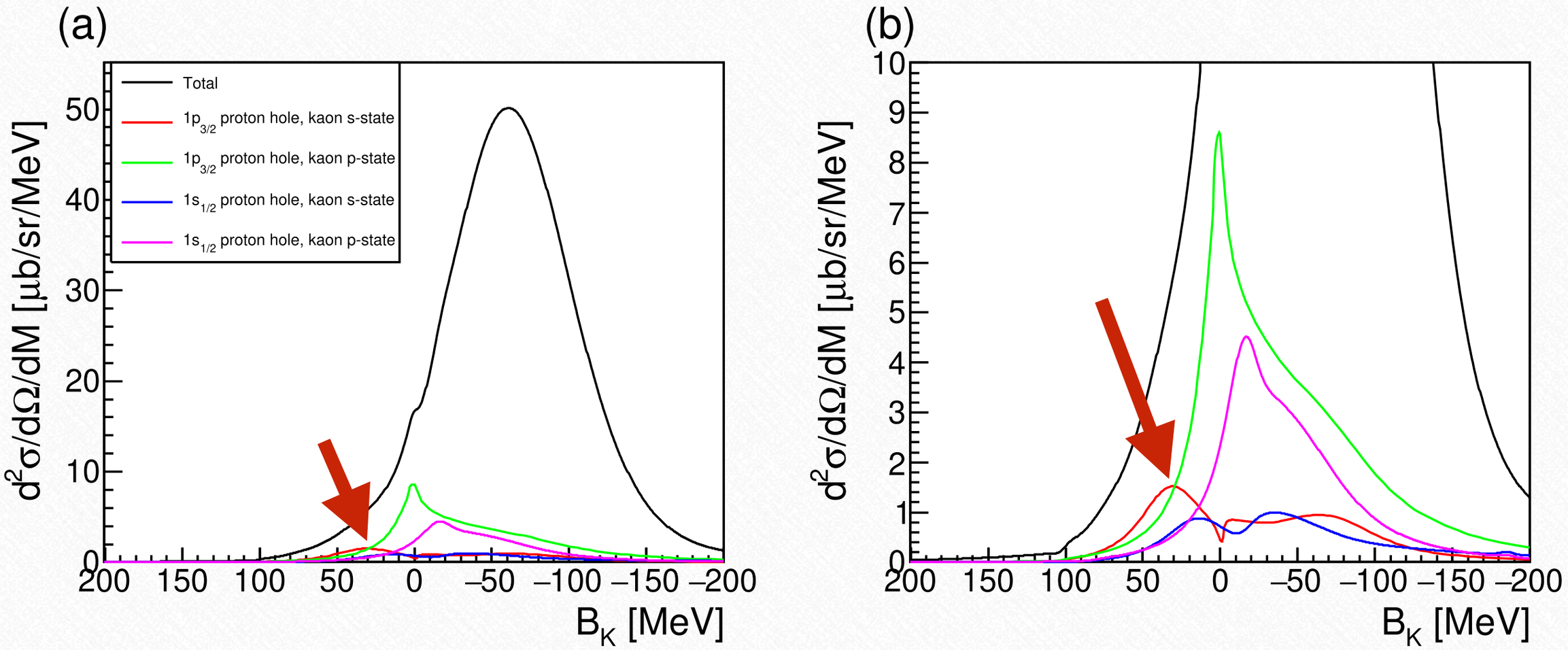
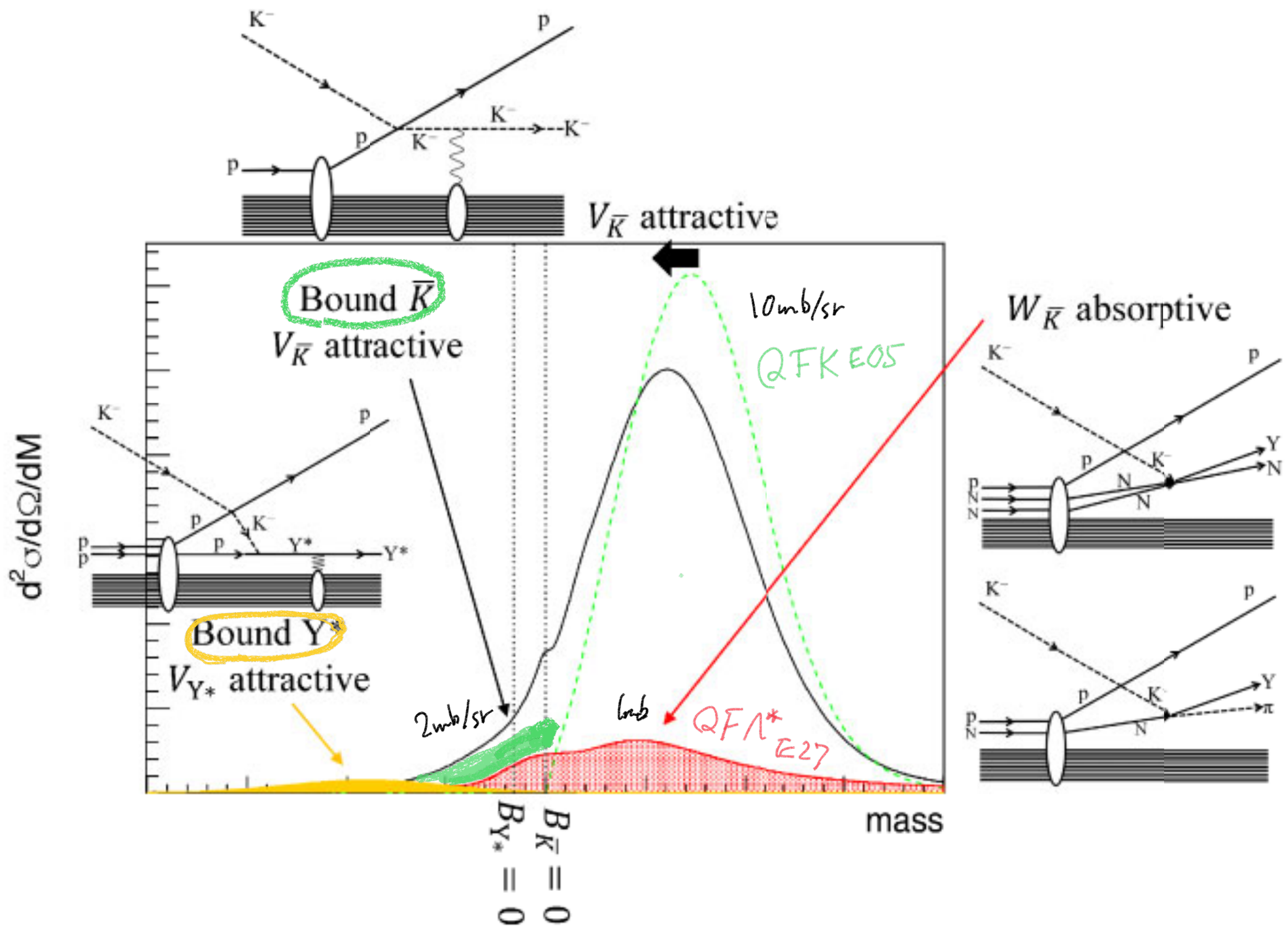


Fig. C.1. (a) Theoretical calculation with the optimum potential $(V_0, W_0) = (-80, -40)$ MeV. The black line displays the total spectrum. The solid lines in different colors show the subcomponents of the different proton holes, $1s_{1/2}$ or $1p_{3/2}$, and kaonic orbital states, s or p. (b) Magnified view of (a) to see the small cross section region.


K⁻
p
K⁻
K⁻
p
p
K⁻
$V_{\bar{K}}$ attractive
Bound $\bar{K}$
$V_{\bar{K}}$ attractive
10mb/sr
QFKE05
$W_{\bar{K}}$ absorptive
$d^2\sigma/d\Omega/dM$
Y*
Y*
Bound Y*
V_{Y*} attractive
2mb/sr
1mb
QFΛ*E27
$B_{\bar{K}} = 0$
$B_{Y*} = 0$
mass
Y
N
N
N
Y
π

E27 : $d(\pi^+,K^+)$ reaction at 1.69 GeV/c

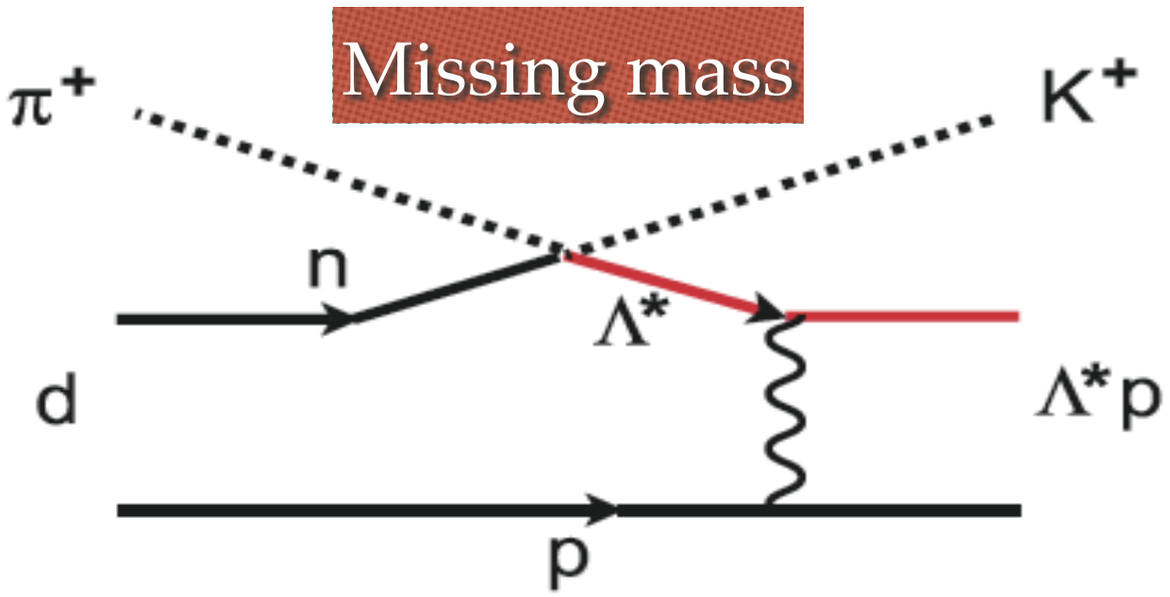
Y. Ichikawa et al., PTEP (2014) 101D03.
Y. Ichikawa et al., PTEP (2015) 021D01.

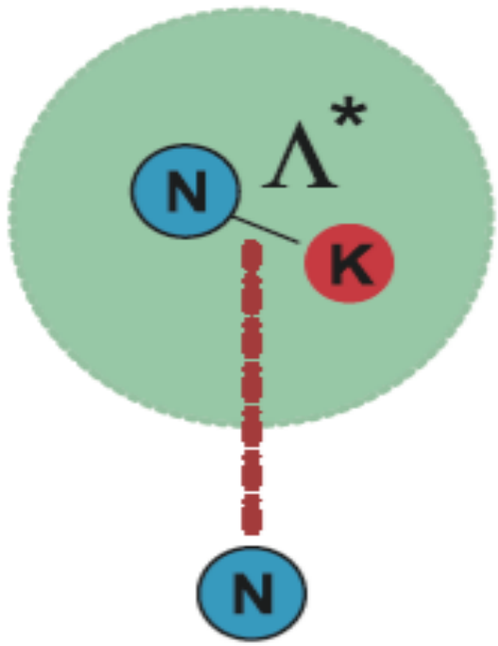
π^+ + "n" --> "Λ^*" + K^+

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

--> quasi-free Λ^* ***dominant***

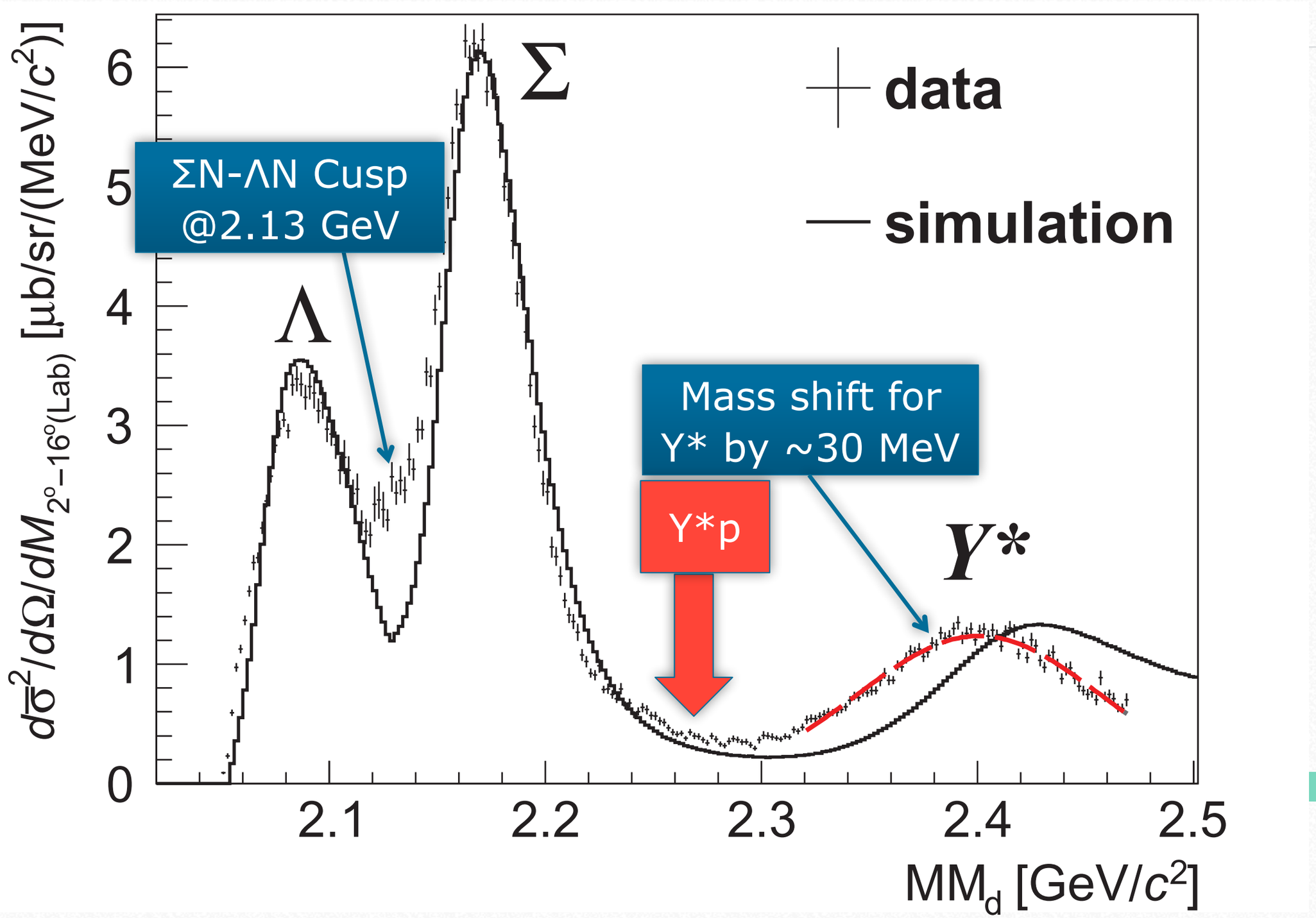
Missing mass





Yamazaki & Akaishi, Phys. Rev. C76 (2007) 045201.

d(π⁺, K⁺) @1.69 GeV/c

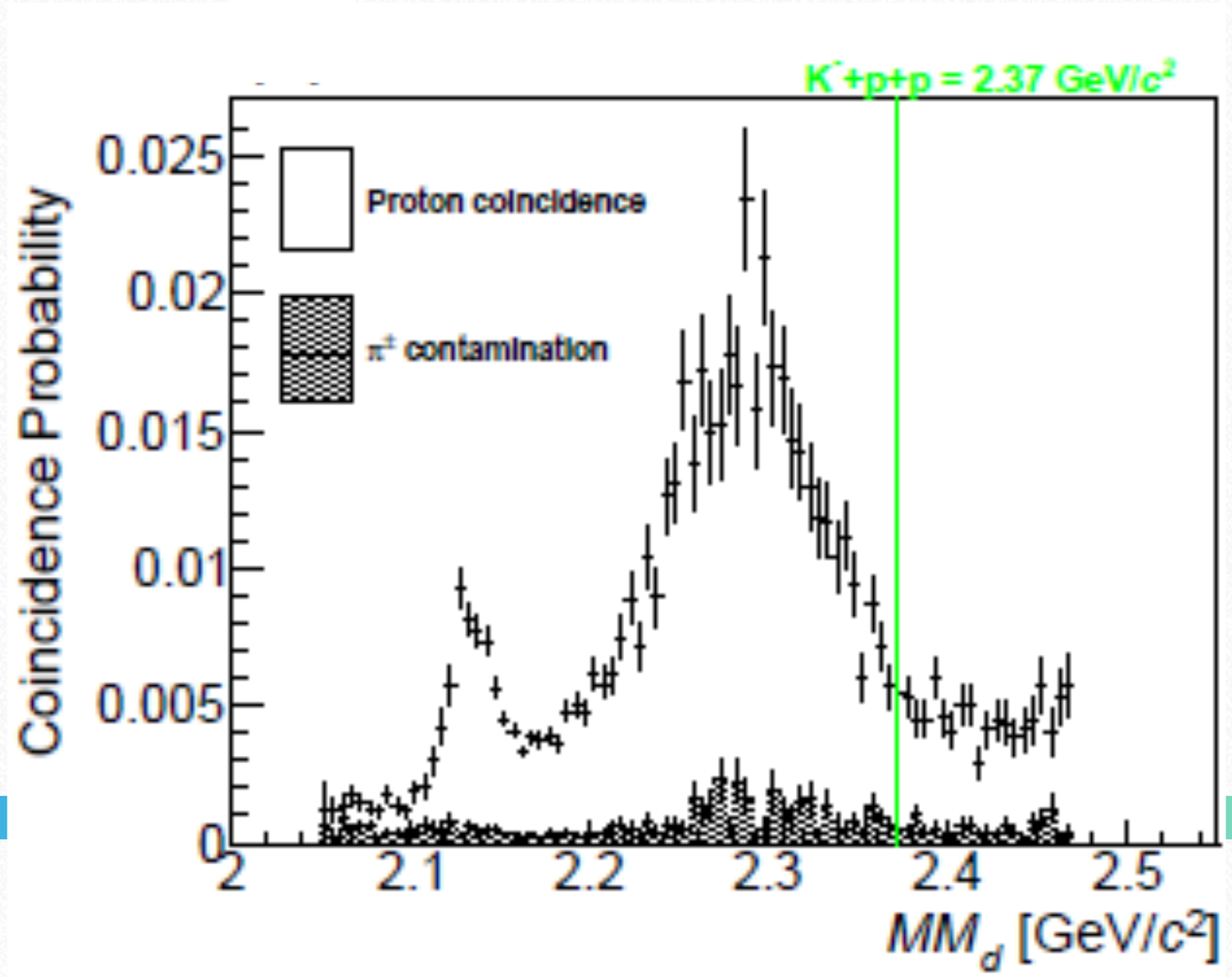

ΣN-ΛN Cusp
@2.13 GeV
Σ
Λ
data
simulation
Mass shift for
Y* by ~30 MeV
Y*p
Y*
$d\bar{\sigma}^2/d\Omega/dM_{2°-16°(Lab)}$ [μb/sr/(MeV/c^2)]
MM_d [GeV/c^2]
0
1
2
3
4
5
6
2.1
2.2
2.3
2.4
2.5

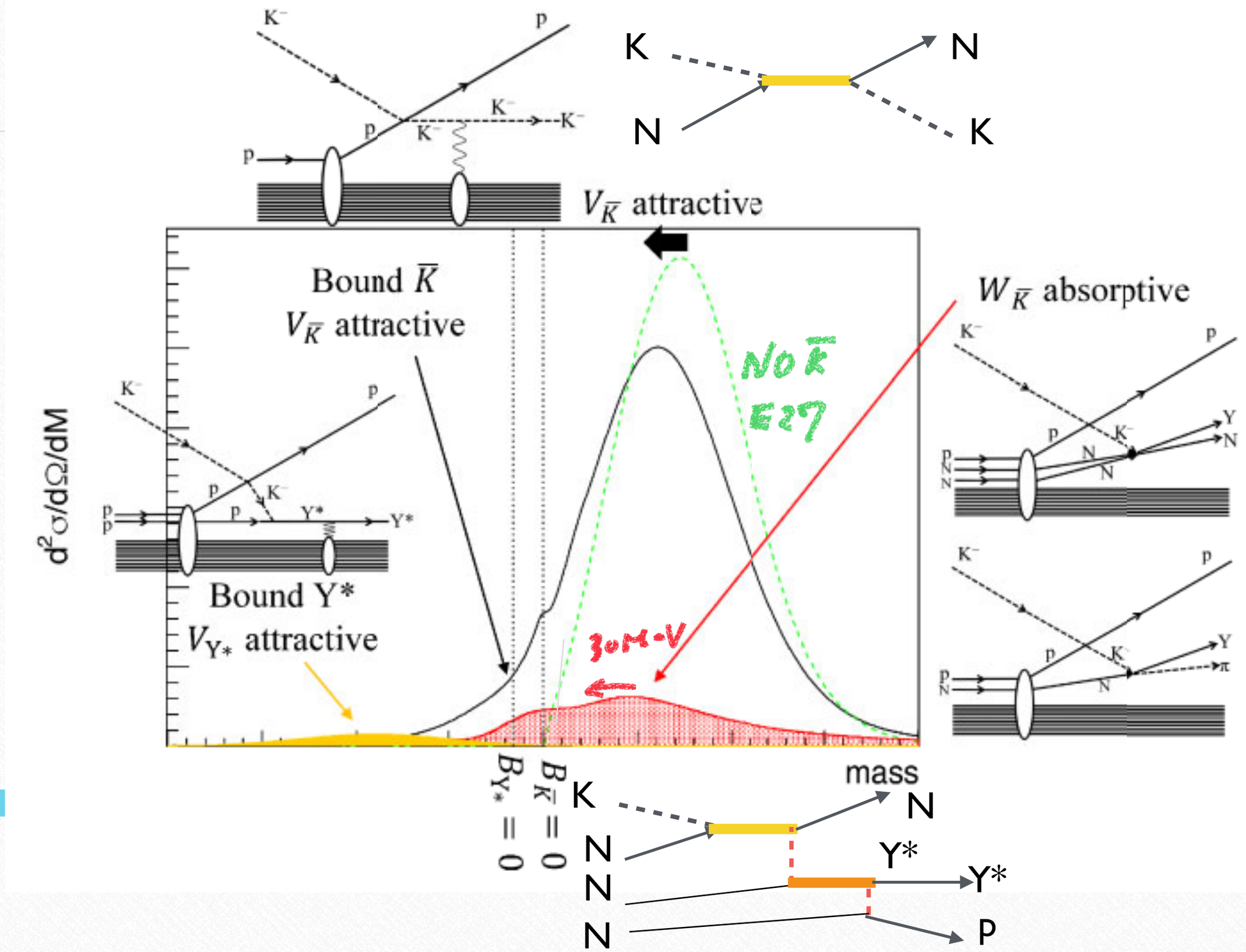
One-proton coincidence

Coincidence Probability(MM)
= One-proton coincidence(MM)/Inclusive(MM)

Enhancement near the ΣN threshold (2.13 GeV/c^2)

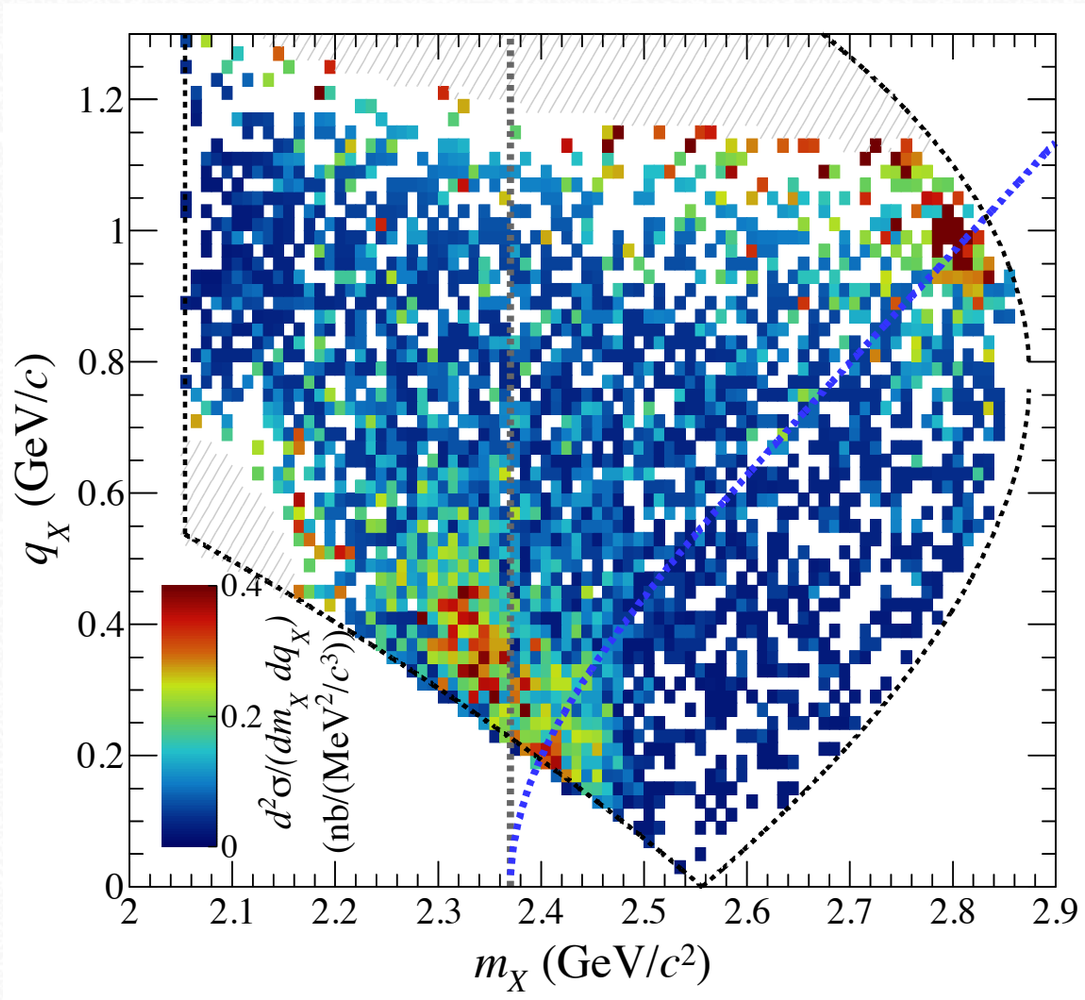
Broad bump at ~2.28 GeV/c^2

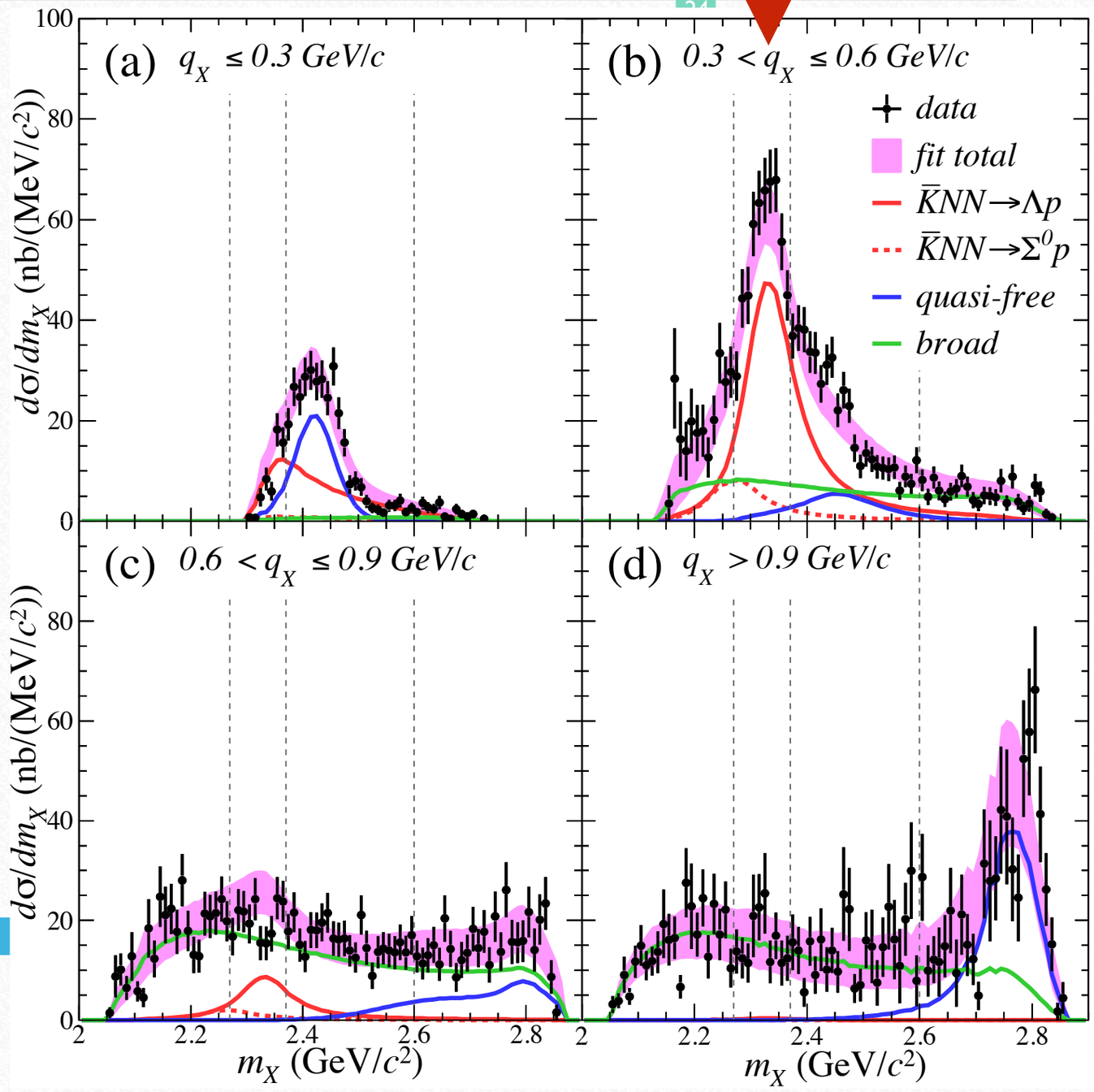



K⁻
p
K⁻
K⁻
p
p
K⁻
K
N
N
K
$V_{\bar{K}}$ attractive
Bound $\bar{K}$
$V_{\bar{K}}$ attractive
$W_{\bar{K}}$ absorptive
No $\bar{K}$
E27
$d^2\sigma/d\Omega/dM$
Y*
Bound Y*
V_{Y*} attractive
3quark-V
$B_{\bar{K}} = 0$
$B_{Y*} = 0$
mass
K
N
N
N
Y*
Y*
p
Y
N
π

Coincidence: K⁻pp→Λp

E15: ^{3}He(K$^-$,Λp)n





T. Yamaga et al., Phy. Rev. C102 (2020) 044002.

E15 fitting result

B_K=42±3 +3/-4 MeV,

Γ=100±7+19/-9 MeV

$\sigma^{tot} \cdot BR_{\Lambda p}$=9.3±0.8+1.4/-1.0 μb

$BR_{\Lambda p}/BR_{\Sigma^0 p}$~1.7

Compactness of K^-pp?

Summary 1

- Inclusive Spectra :
  - $^{12}C(K^-, p)$ measured in E05 for the first time.
    - $(V_0, W_0)=(-80, -40)$ MeV
  - (K-,N) semi-inclusive (not inclusive) E548(p/n) and E15(n)
    - A tail in the bound region. Consistent with E05 and Theory
      - →A bound state but broad.
      - →Should have a large cross section ~ as QF KN
- E27: $d(\pi^+,K^+)$; QF Λ^* production → 30 MeV shift

Summary 2

- Coincidence Spectra :
  - E27: d(π^+,K^+pp); B=95+18/-17 MeV, Γ=162+87/-45 MeV
    - Λ(1405)p bound state ?
  - E15: ^{3}He(K^-, Λp)n; B=42±3 MeV, Γ=100±7 MeV,
    σ•BR=9.3±0.8 μb
    - →Small fraction of Inclusive production cross section
      10 μb < 1mb

E05 - E15 – E27

- E05 (K,p) ; QF-K incl. + QF-Λ* Incl. +DB-Λ* Incl.
  ～E15 (K,n) semi-incl.　(background limited)

- E27 (π,K) ; QF-Λ* Incl.+DB-Λ* (Σ^0p decay)
- E15 (K,Λp)n ; QF-K + QF Λ*