28-May-2020/ On-line

K-MESON AND Ξ-PARTICLE CLUSTERS

T. Nagae (Kyoto University)

BO1

- Introduction
- K-meson Clusters
  - K-pp
  - Λ*(1405)p
  - E05: $^{12}C(K^-, p)$ analysis
- Ξ-clusters
  - Ξ^-n bound state
  - E05: $^{12}C(K^-, K^+)$ Ξhyp.

CLUSTERS AT HADRON LEVEL

- Hadrons = Clusters of Quarks
  - No single quark in vacuum : quark has color   Quark Confinement
  - No (qq) cluster in vacuum ⇔ di-quark cluster in qqq, …
  - Baryons (qqq) + Mesons ($q\bar{q}$)
  - But why not $qq\bar{q}\bar{q}$, $qqqq\bar{q}$ at quark level : Exotic Hadrons
    - Recent observations of Pc, X(3872), d*(2380), etc.
- We can have "Hadron Clusters" as bound states of hadrons

State	M [MeV]	Γ [MeV]	(95% CL)	$\mathcal{R}$ [%]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)	$0.30 \pm 0.07^{+0.34}_{-0.09}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)	$1.11 \pm 0.33^{+0.22}_{-0.10}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$	(< 20)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

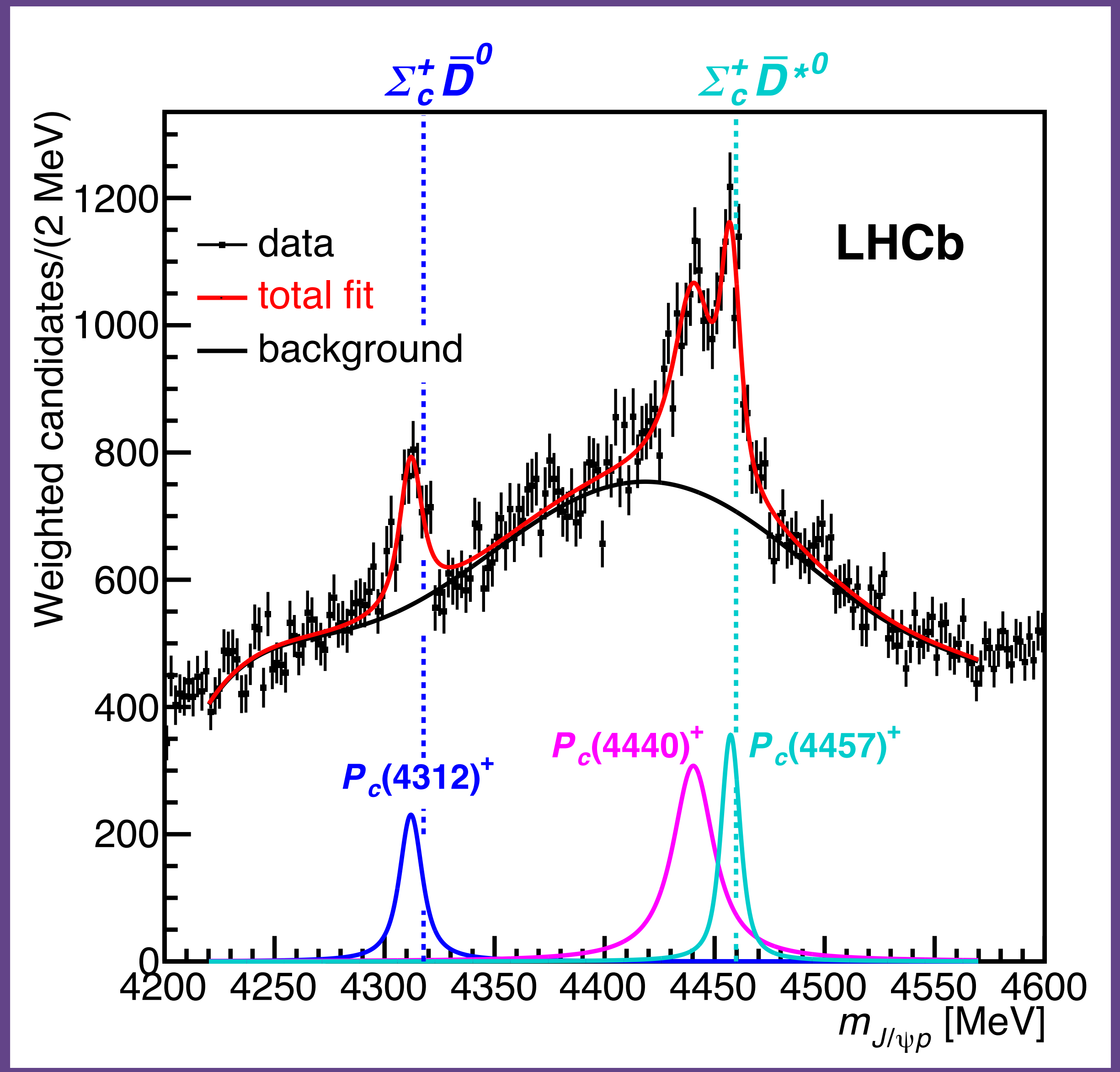
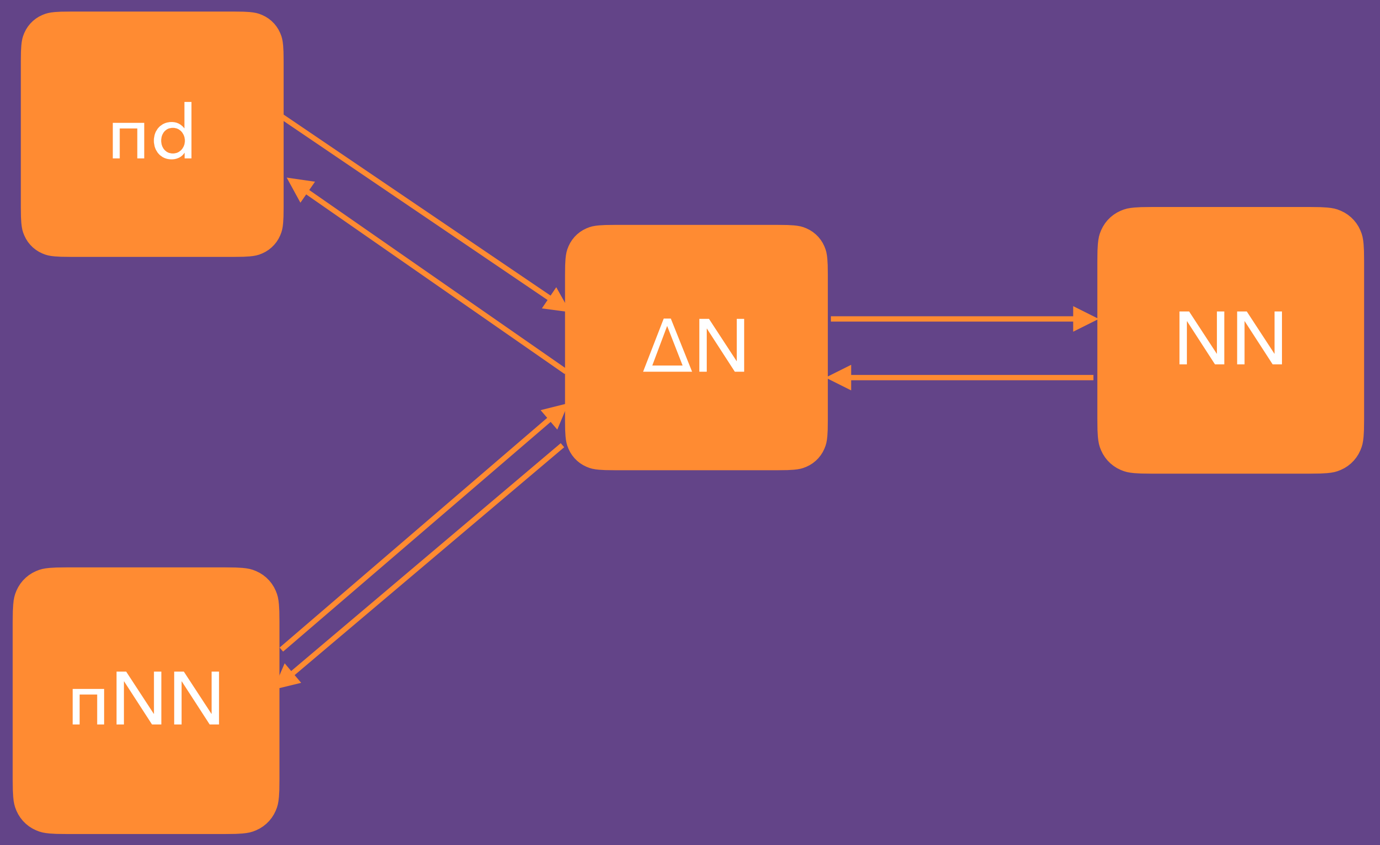
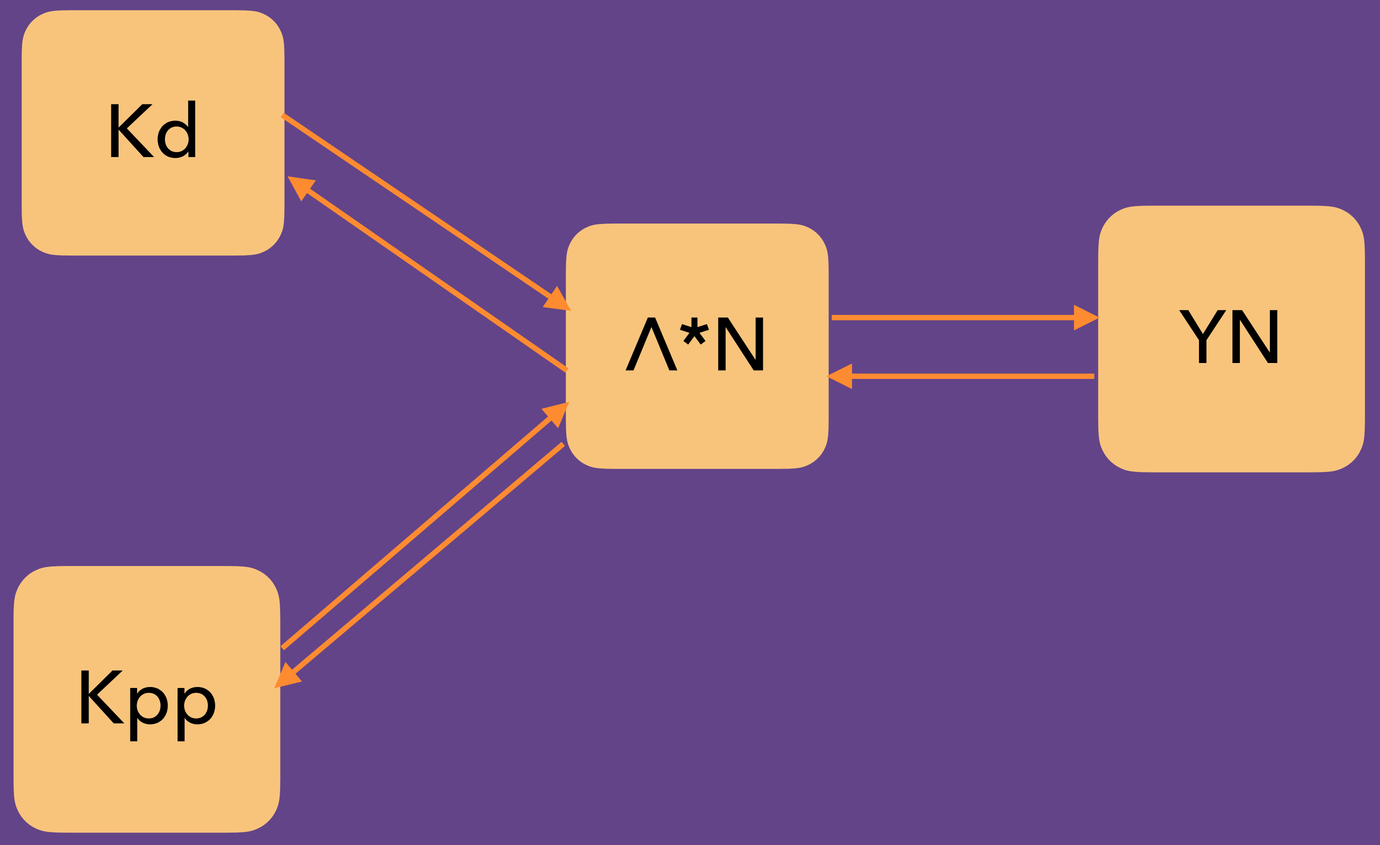


Figure 6: Fit to the $\cos\theta_{P_c}$-weighted $m_{J/\psi p}$ distribution with three BW amplitudes and a sixth-order polynomial background. This fit is used to determine the central values of the masses and widths of the P_c^+ states. The mass thresholds for the $\Sigma_c^+\bar{D}^0$ and $\Sigma_c^+\bar{D}^{*0}$ final states are superimposed.

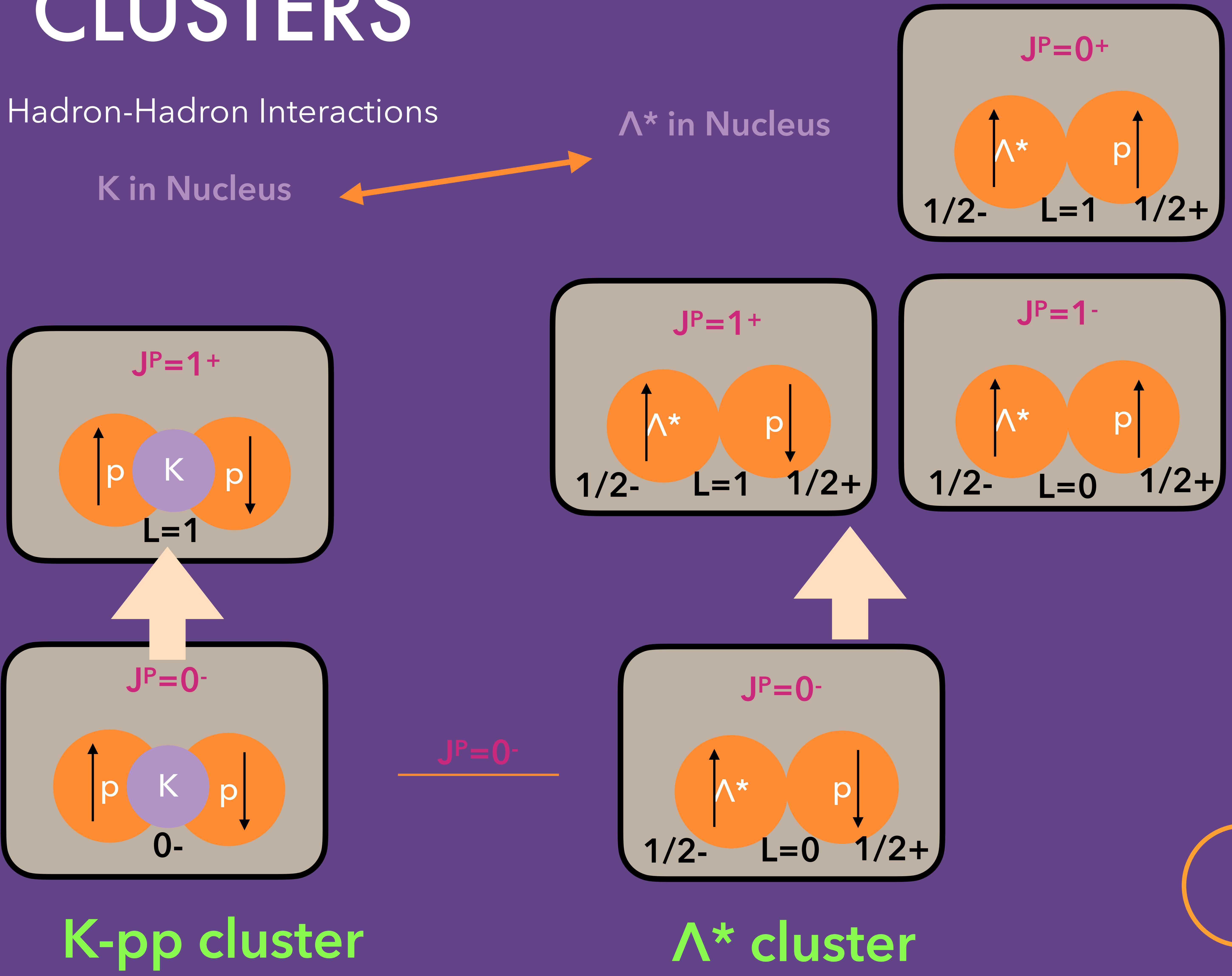
π (K) IN NUCLEI ⇔ Δ (Λ*) IN NUCLEI





HADRON CLUSTERS

- Binding mechanism : Hadron-Hadron Interactions



K-MESON CLUSTER

J-PARC E05 by Y. Ichikawa

An event excess observed in the deeply bound region of $^{12}\mathrm{C}(K^-, p)$ missing-mass spectrum

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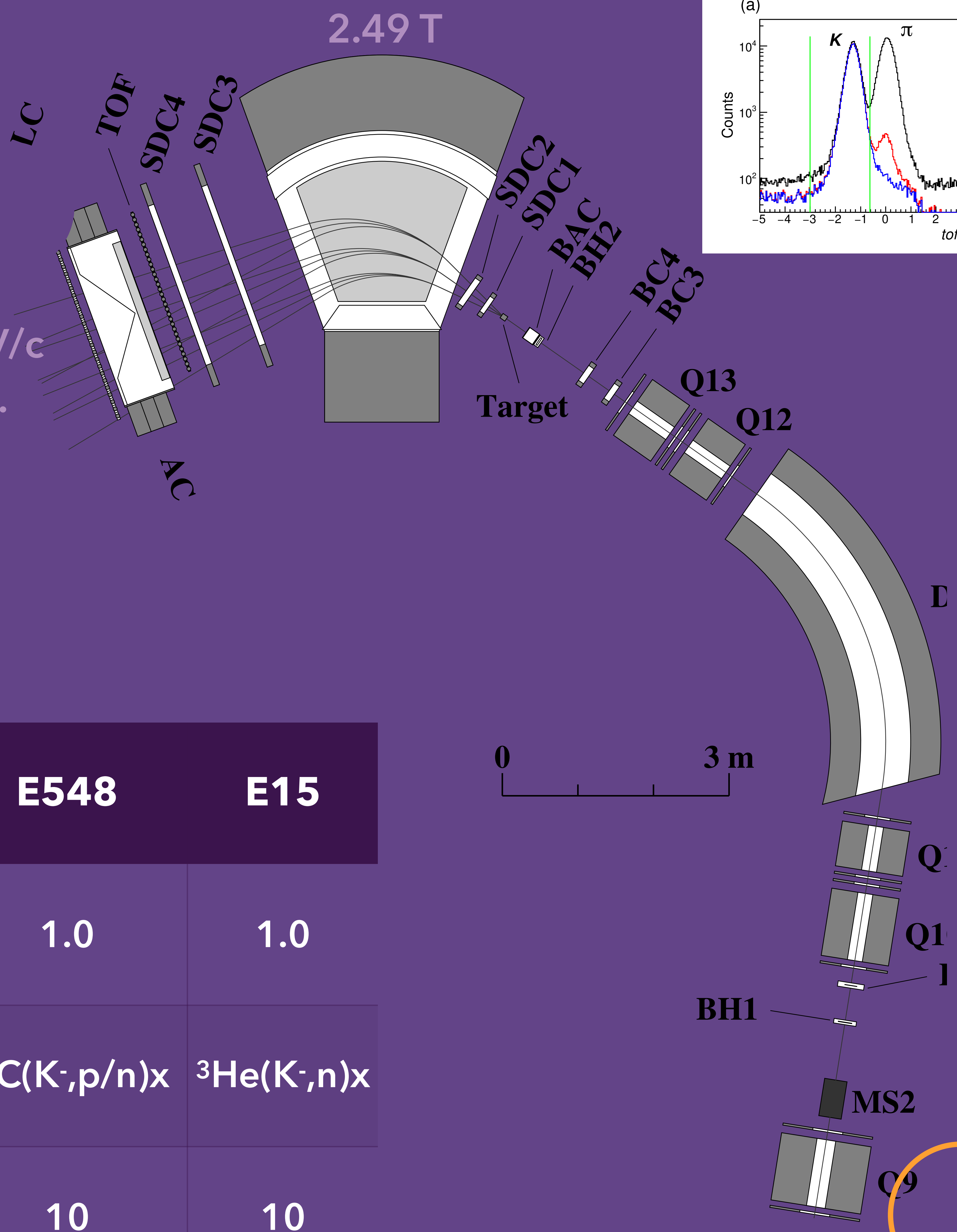
E05

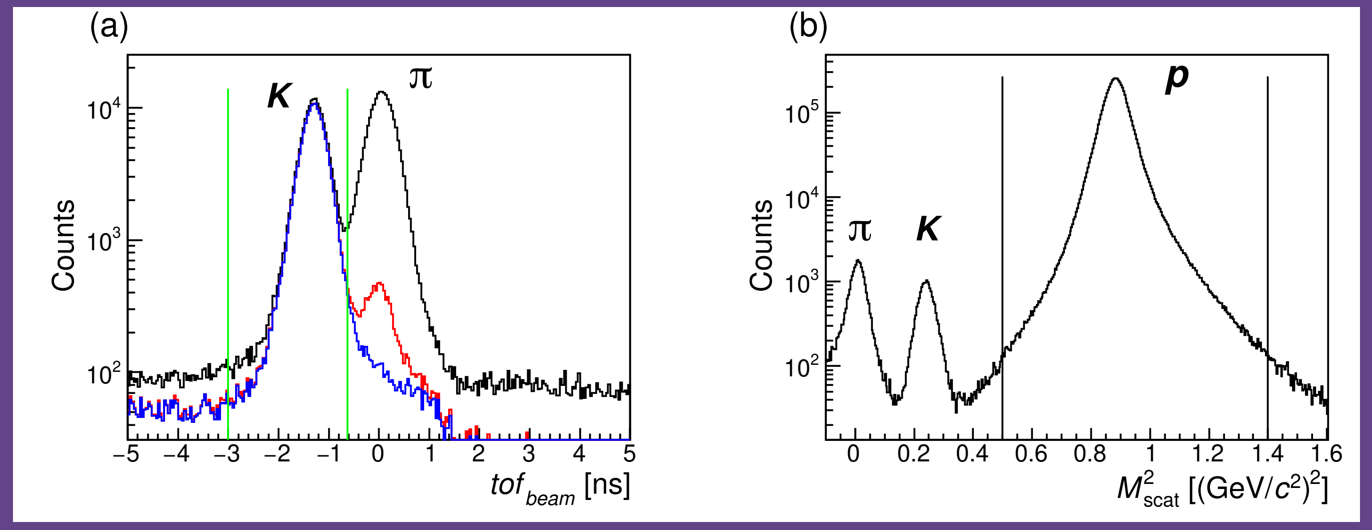
$^{12}C(K^-, p)$ @ 1.8 GeV/c

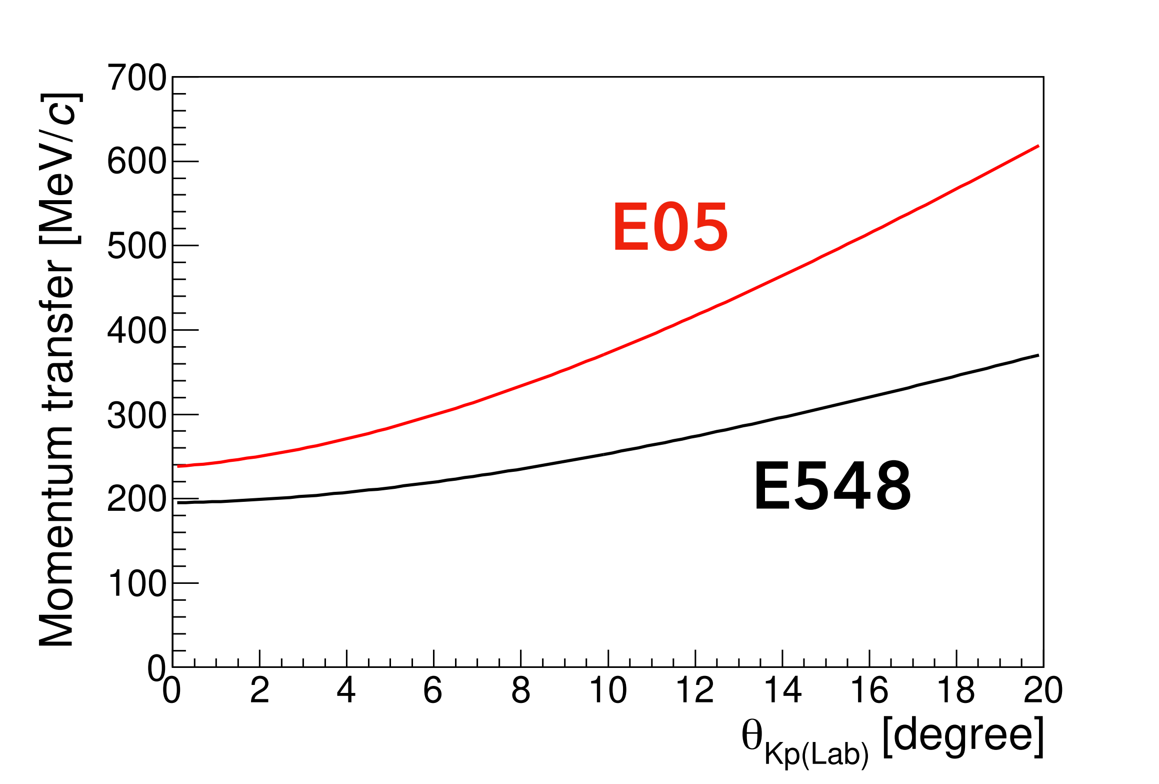
C : 9.364 g/cm^2

Inclusive Trigger

p: 2.2 GeV/c
θp<5 deg.





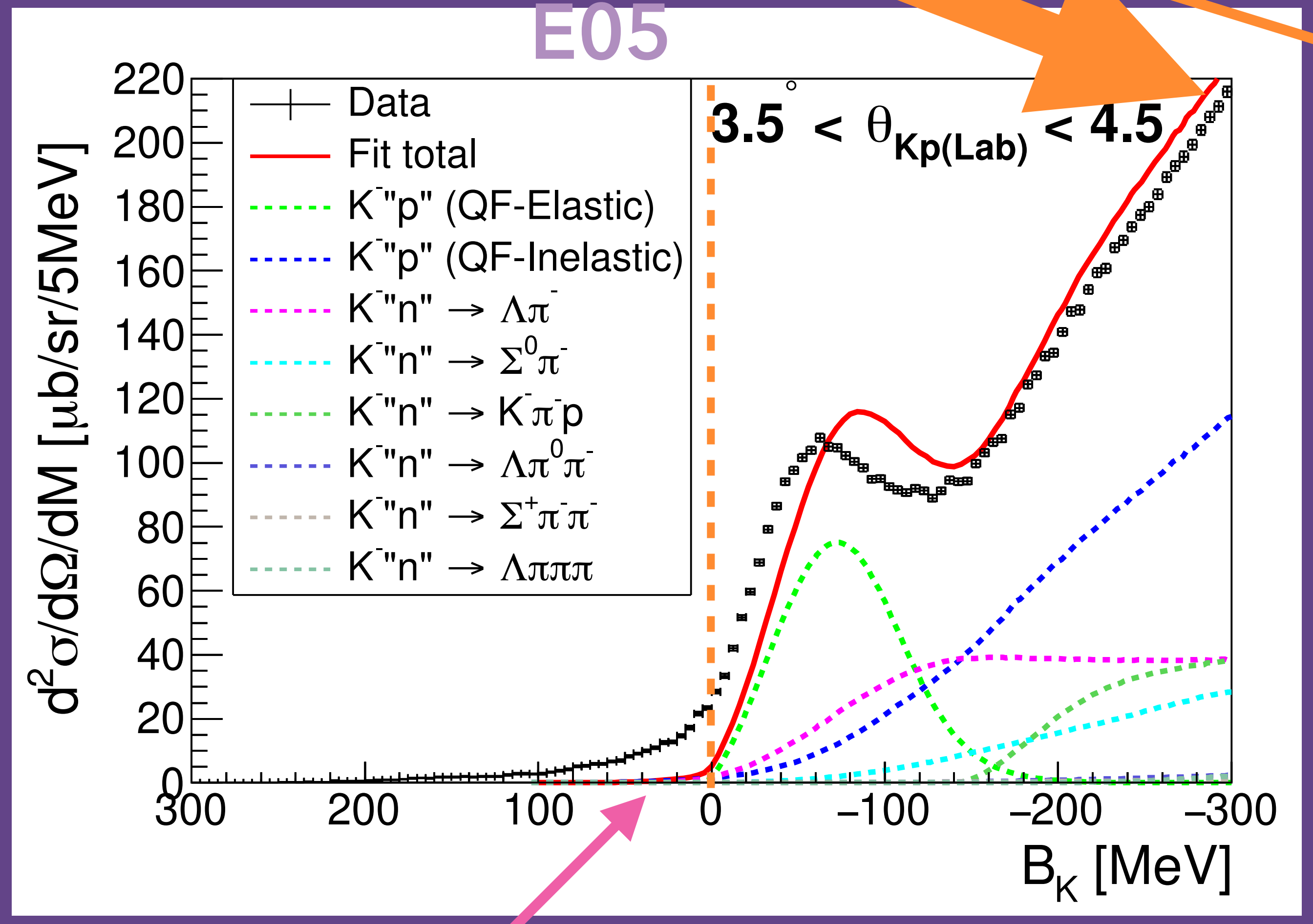


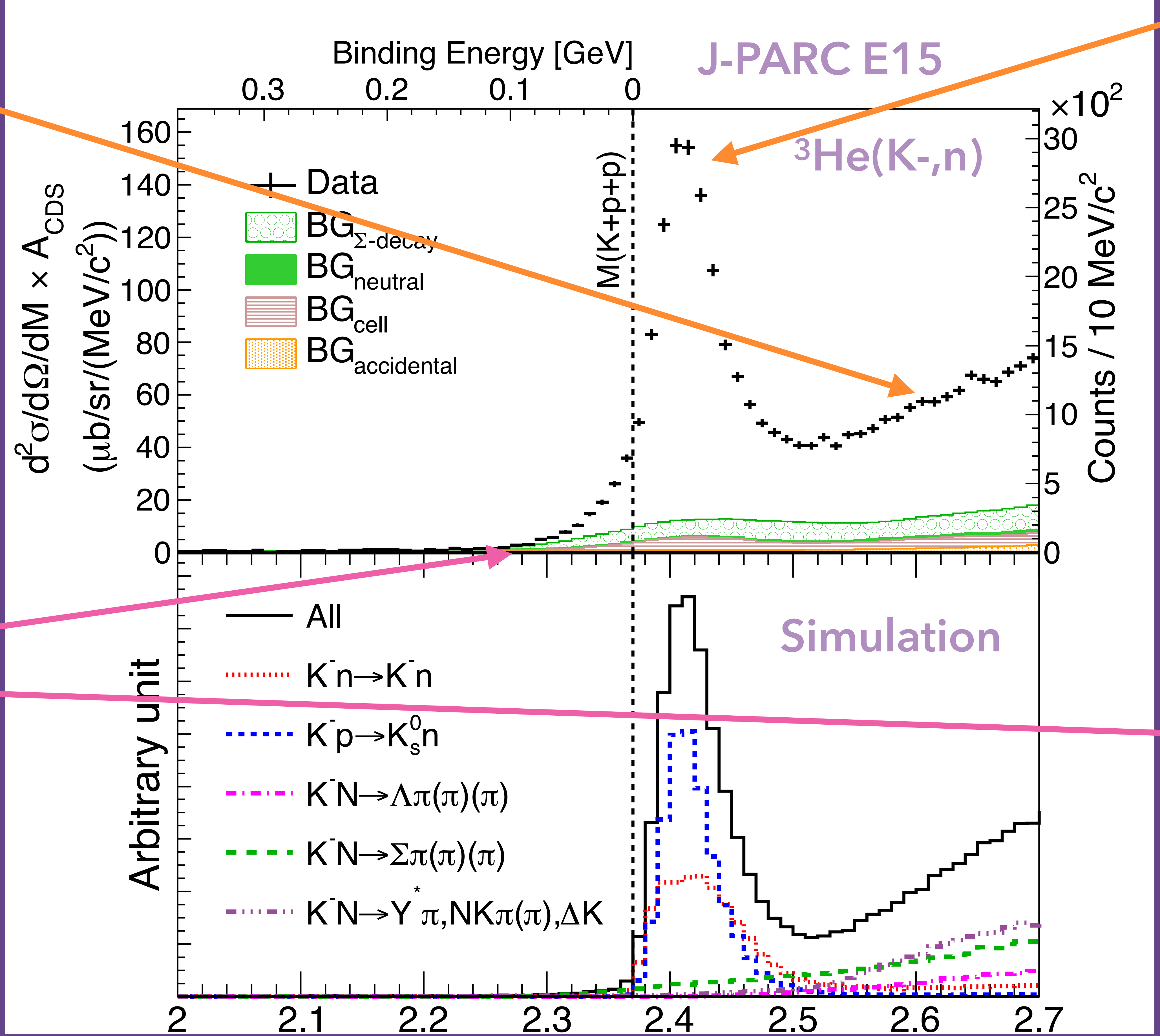
	E05	E548	E15
P_{K^-} (GeV/c)	1.8	1.0	1.0
Reaction	$^{12}C(K^-,p)$	$^{12}C(K^-,p/n)x$	$^{3}He(K^-,n)x$
σ_M (MeV)	4.2	10	10

COMPARISON WITH INCLUSIVE (K-,N) SPECTRA

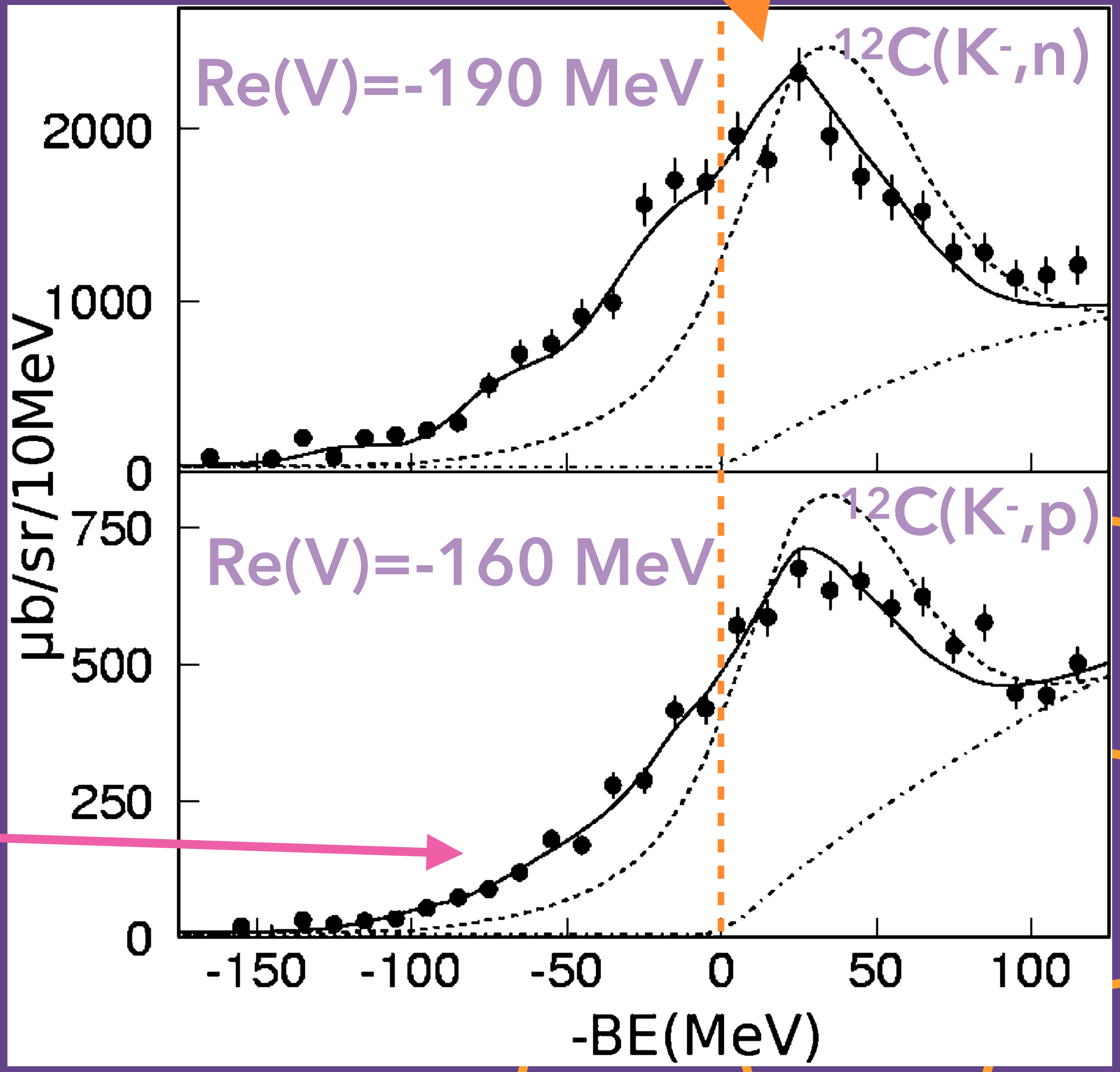
Large Inelasticity

Large trigger bias





KEK E548



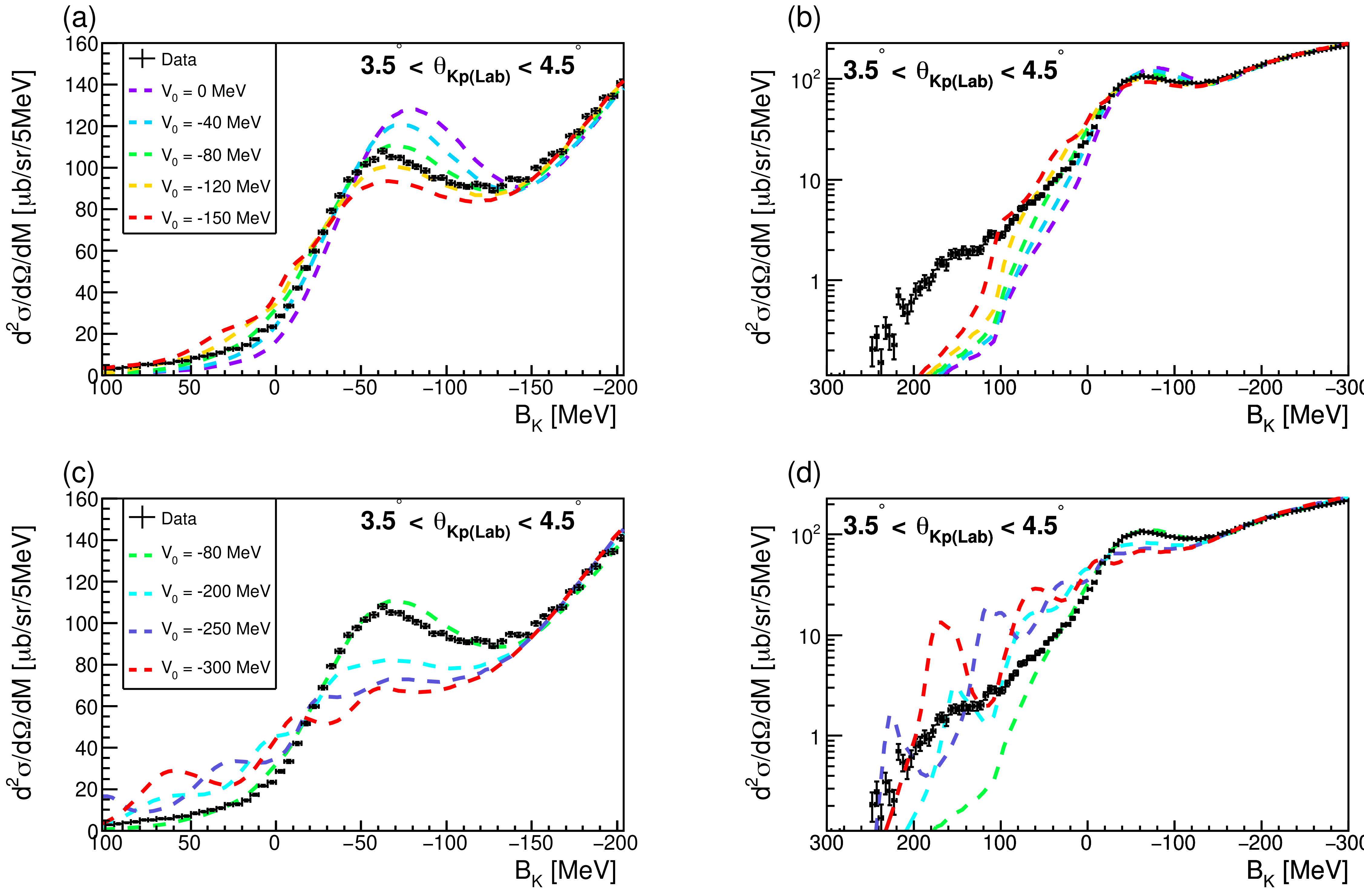
Similar Tail

THEORETICAL ANALYSIS: GREEN'S FUNCTION METHOD

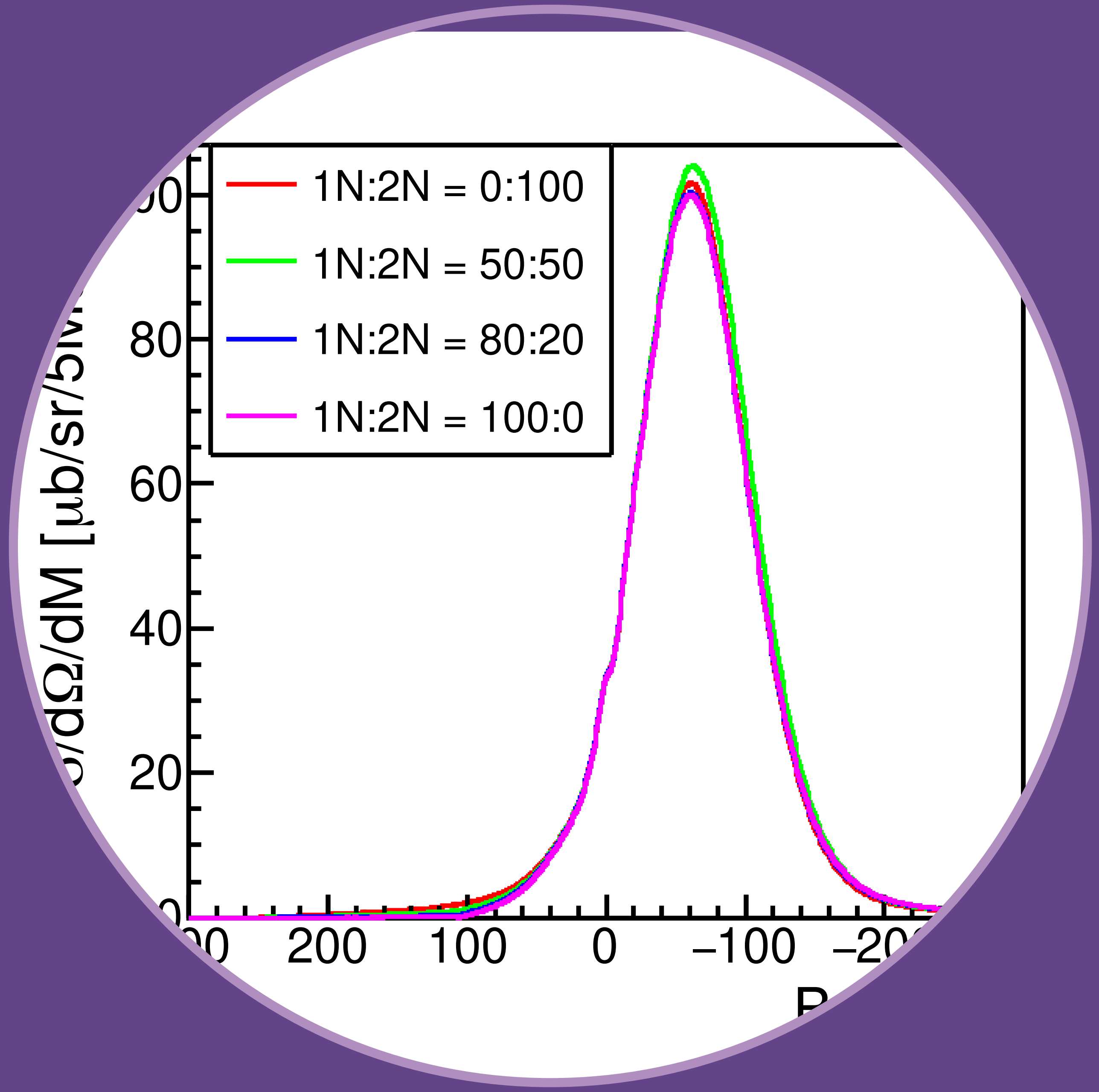
- Best fit: V_0=-80 MeV, W_0=-40 MeV

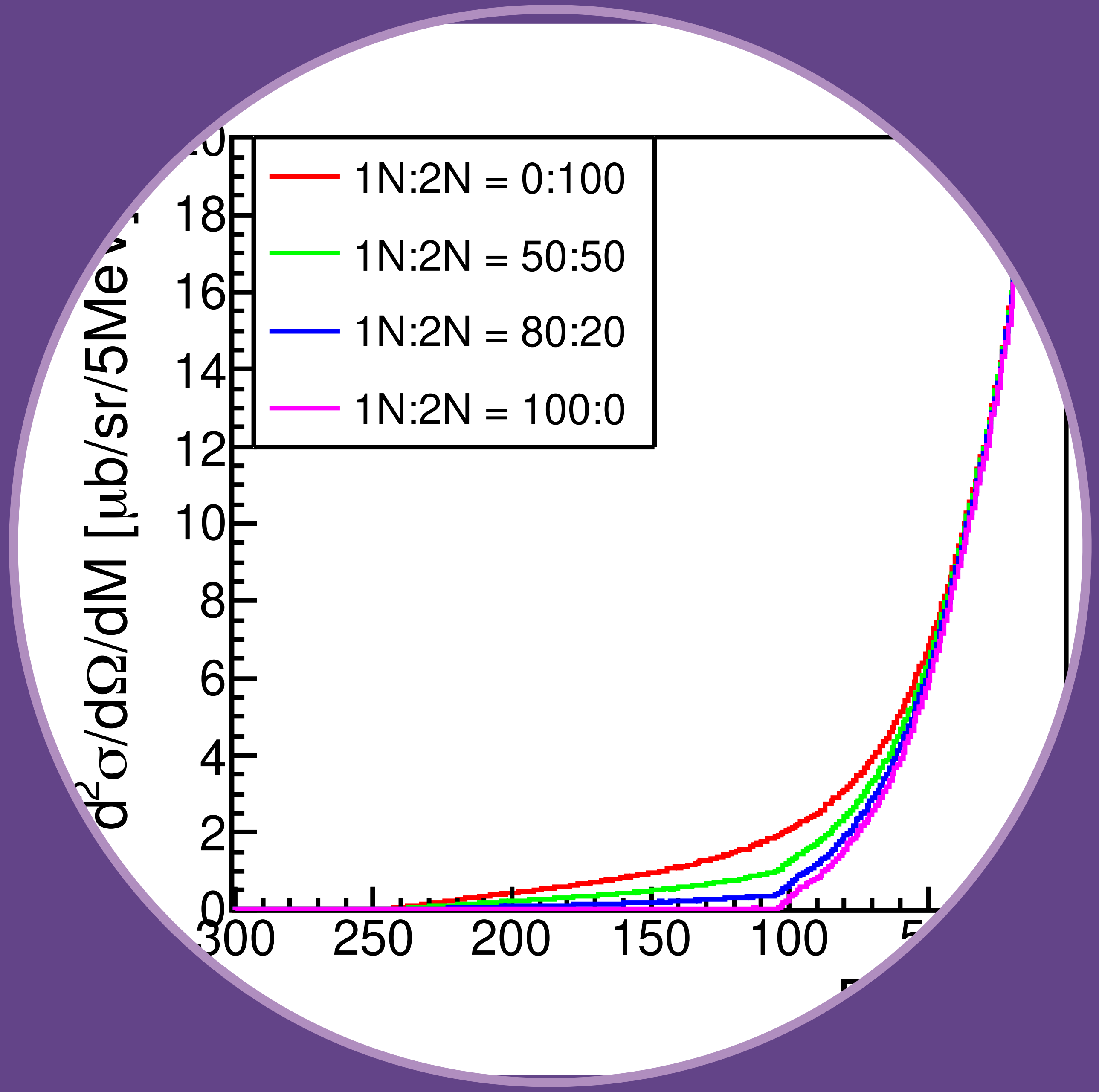
$$U(r,E) = (V_0 + iW_0 f_{\text{phase}}(E))\frac{\rho(r)}{\rho(0)}$$

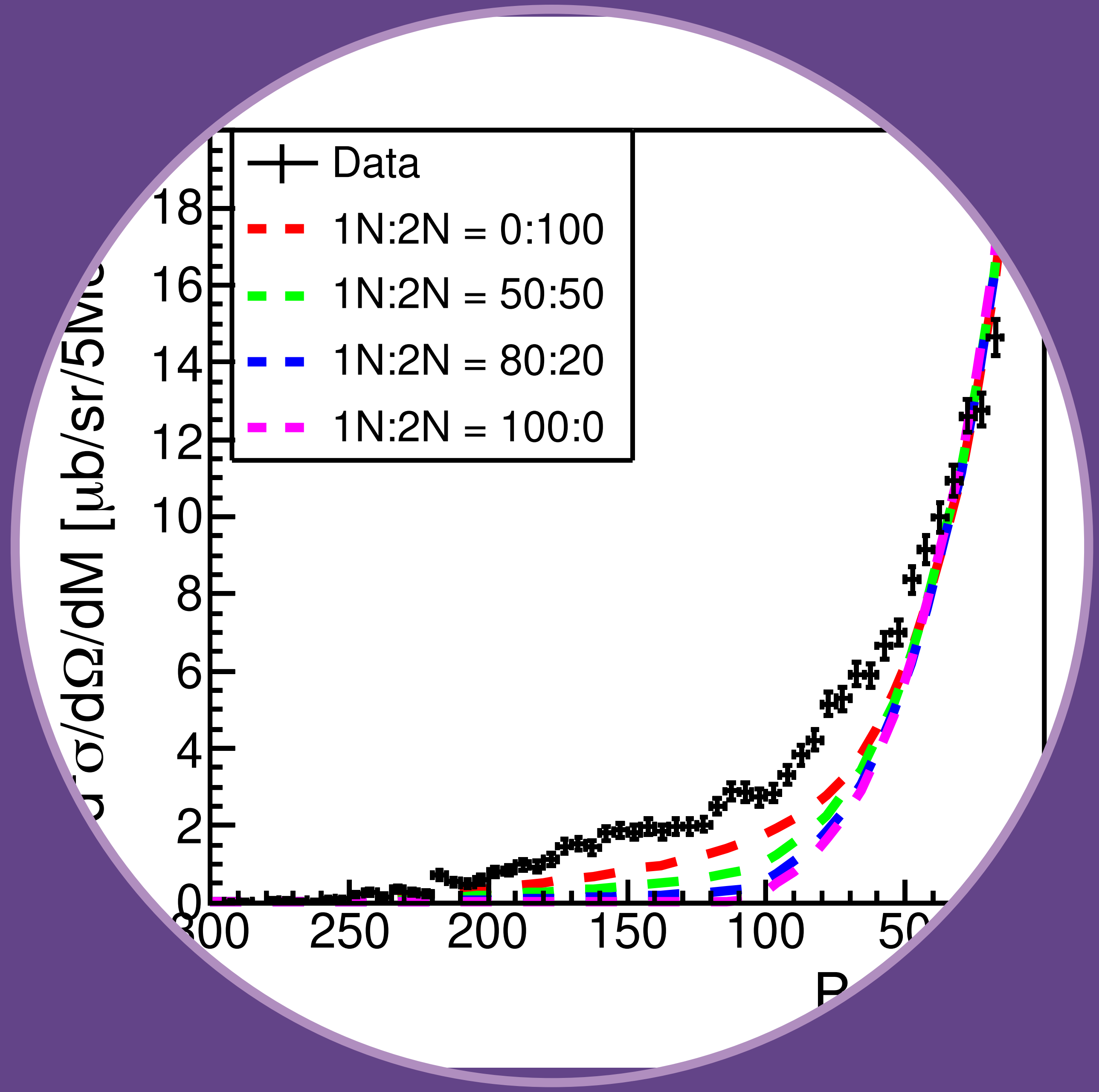
  - A long tail inconsistent with QF peak



How about enhancing the 2N/ 1N ?







SIMULATION

1N : 2N = 0:100

50:50

80:20

100:0

SIMULATION

Magnified

COMPARISON WITH DATA

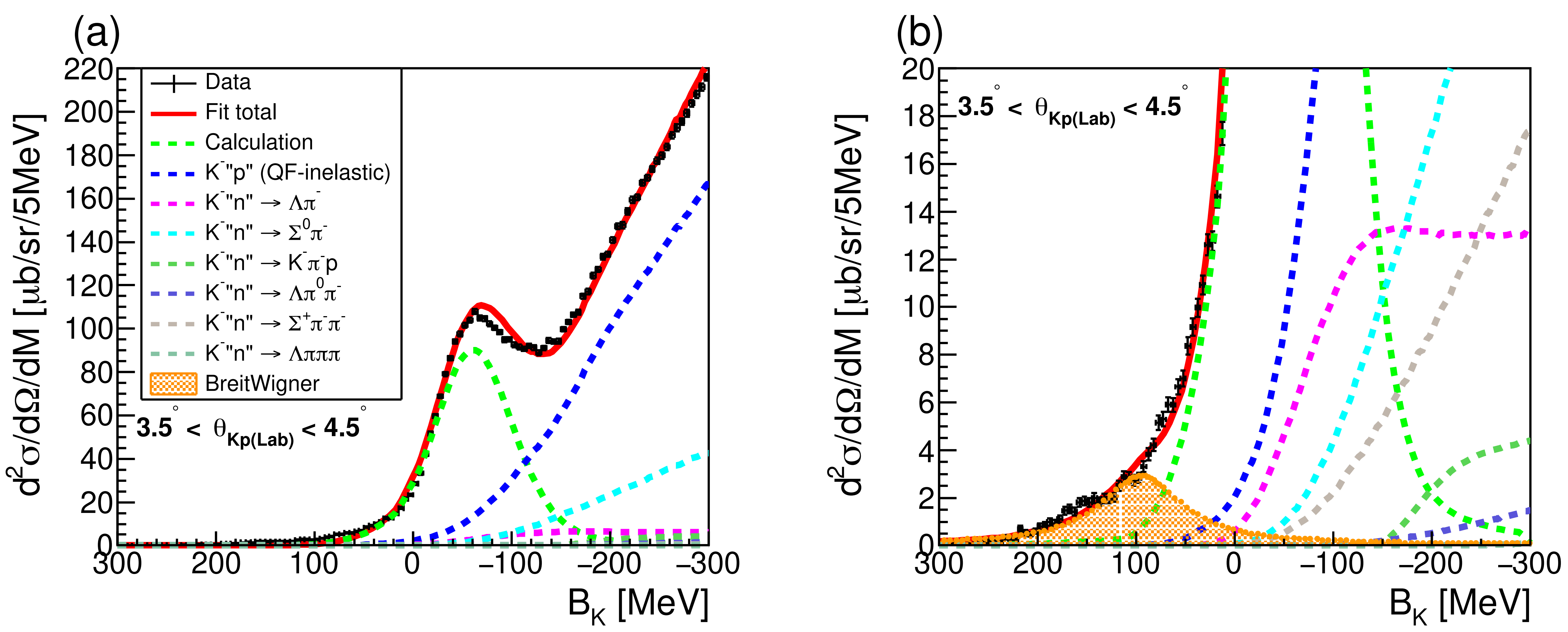
Not reproduced well even with 2N only.

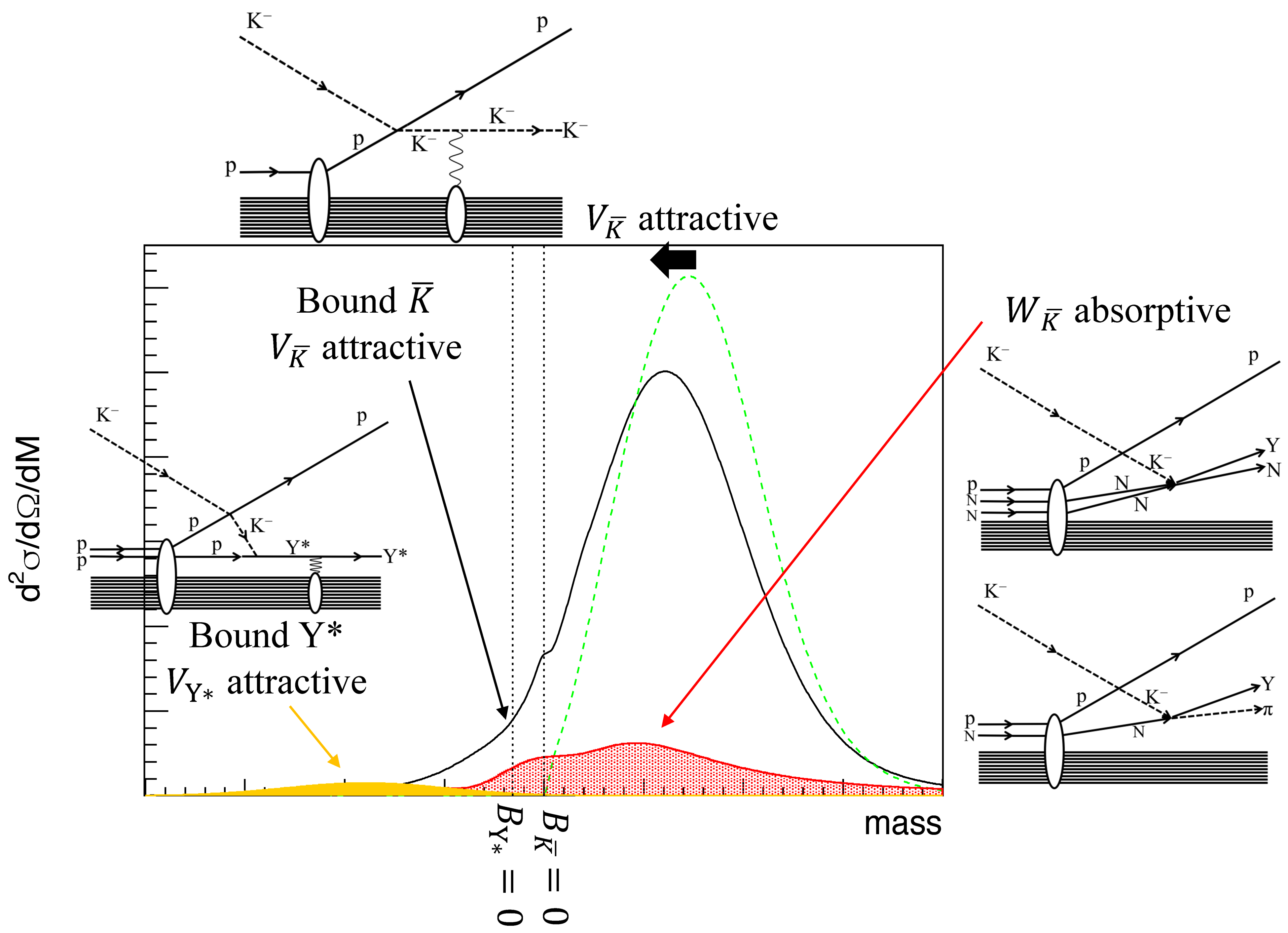
AN EVENT EXCESS

The template with $(V_0, W_0)=(-80, -40)$ + Breit-Wigner.

$\Lambda^* p \rightarrow \Lambda p$

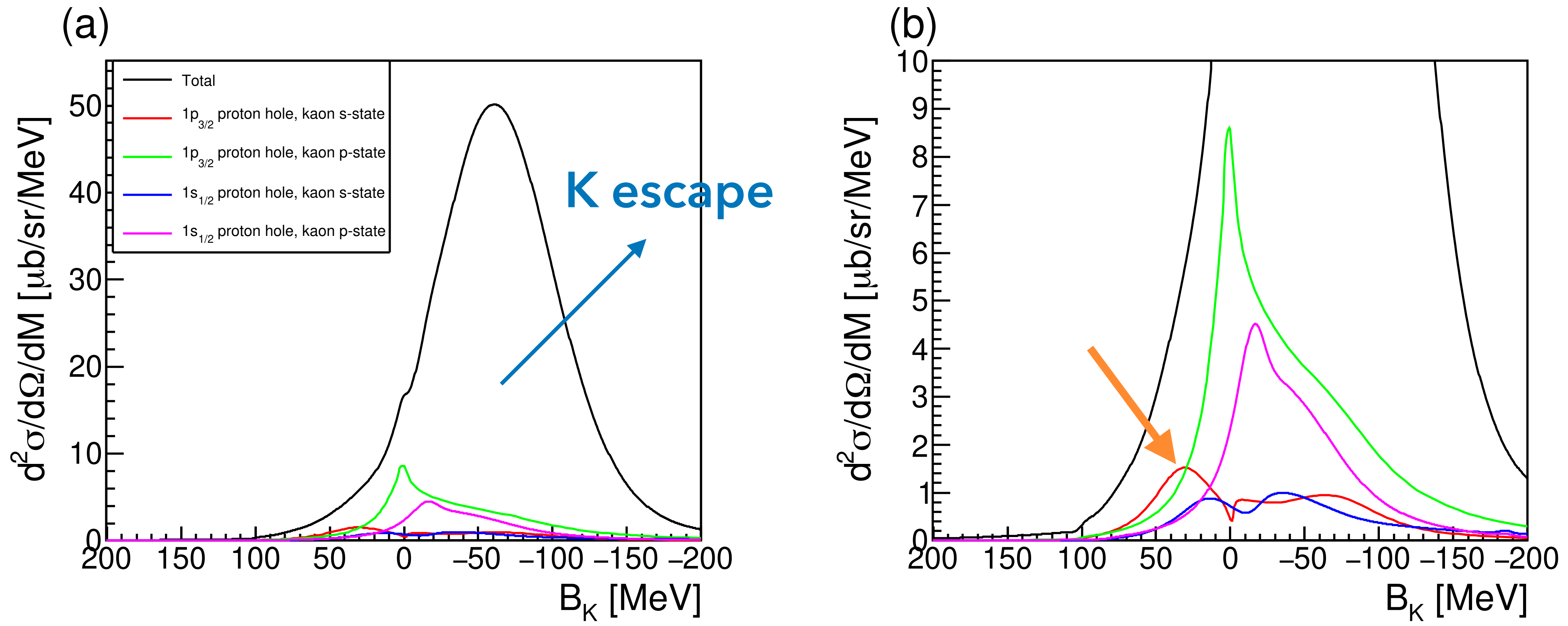
B_K=90 MeV, Γ=100 MeV





KAONIC NUCLEAR STATE

- With $(V_0, W_0) = (-80, -40)$ MeV
  a bound state really exist !!
  - Hard to see as a peak with W_0=-40 MeV
  - We can see only as a tail



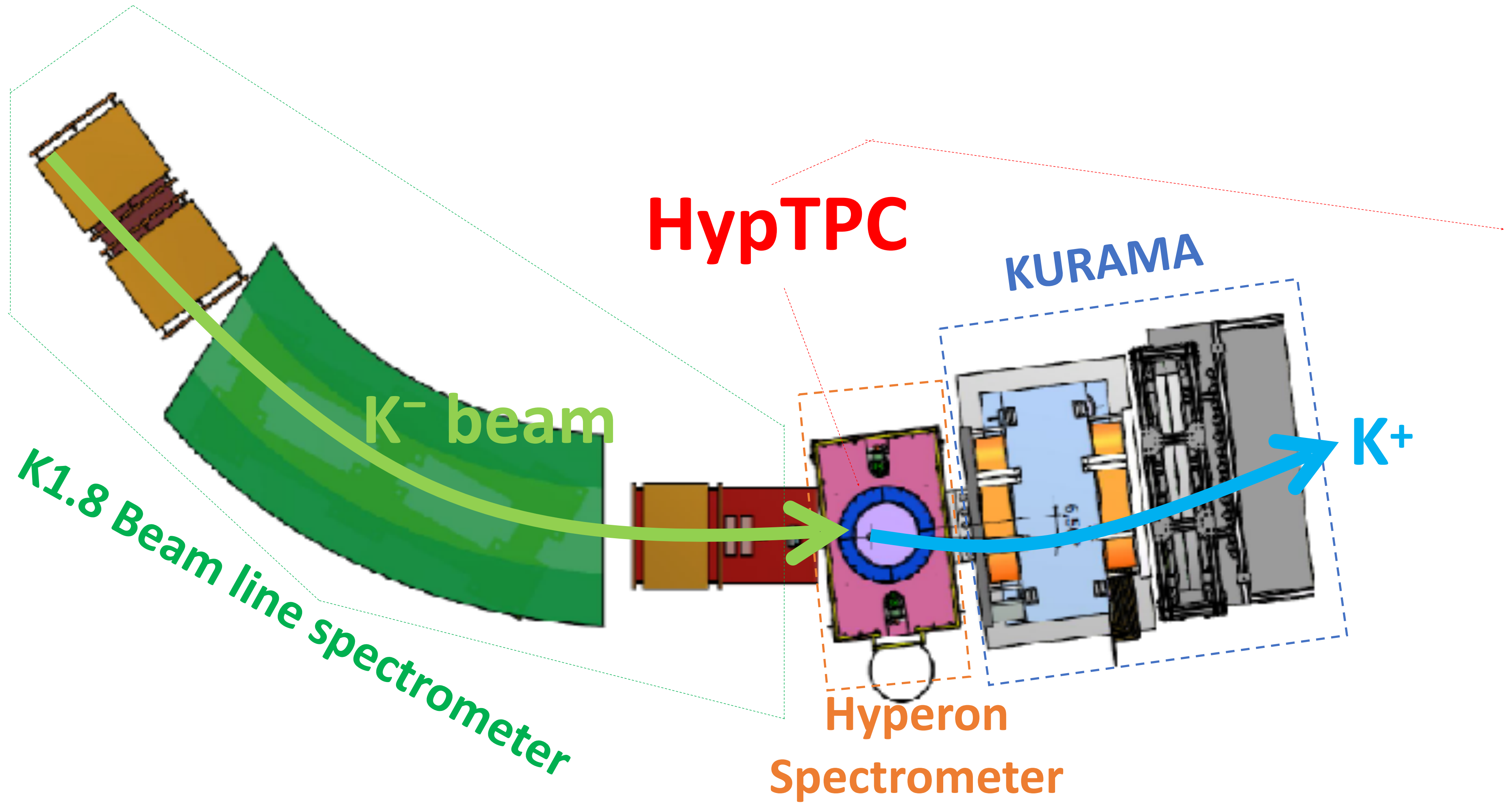
Suppress the K escaping part.

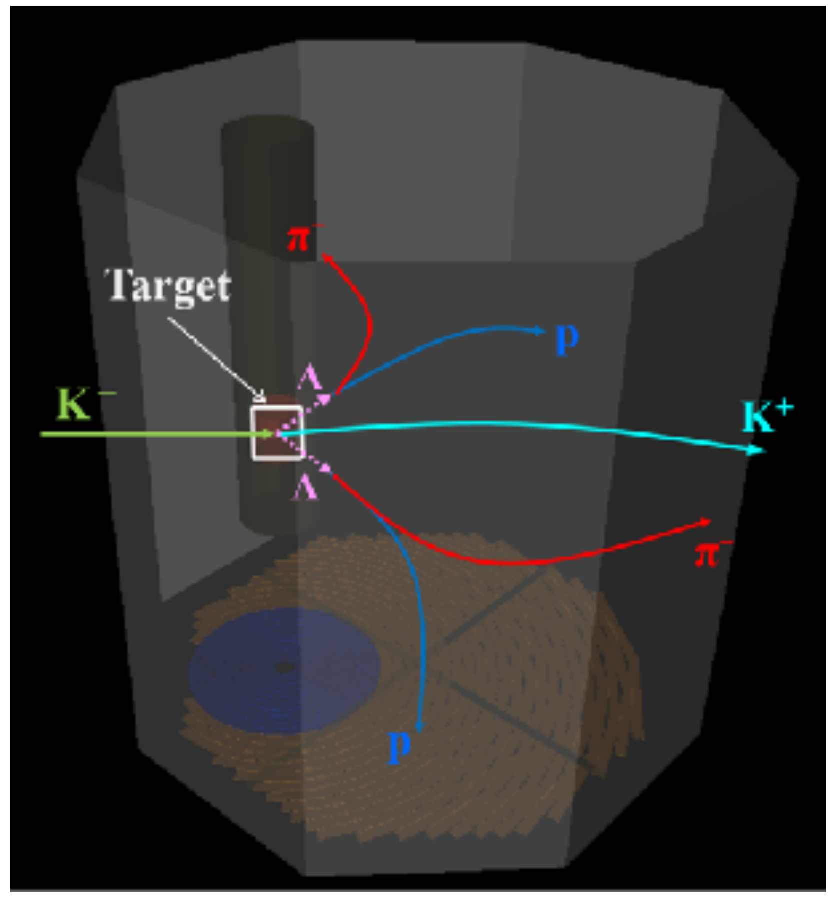
Beyond E05

$K^- + {}^{12}C \rightarrow p + {}^{11}{}_{K^-}Be / {}^{11}{}_{\Lambda^*}Be$

$\Rightarrow \Lambda + p + X$

A-dep. of binding energy
Decay modes





Ξ-CLUSTER

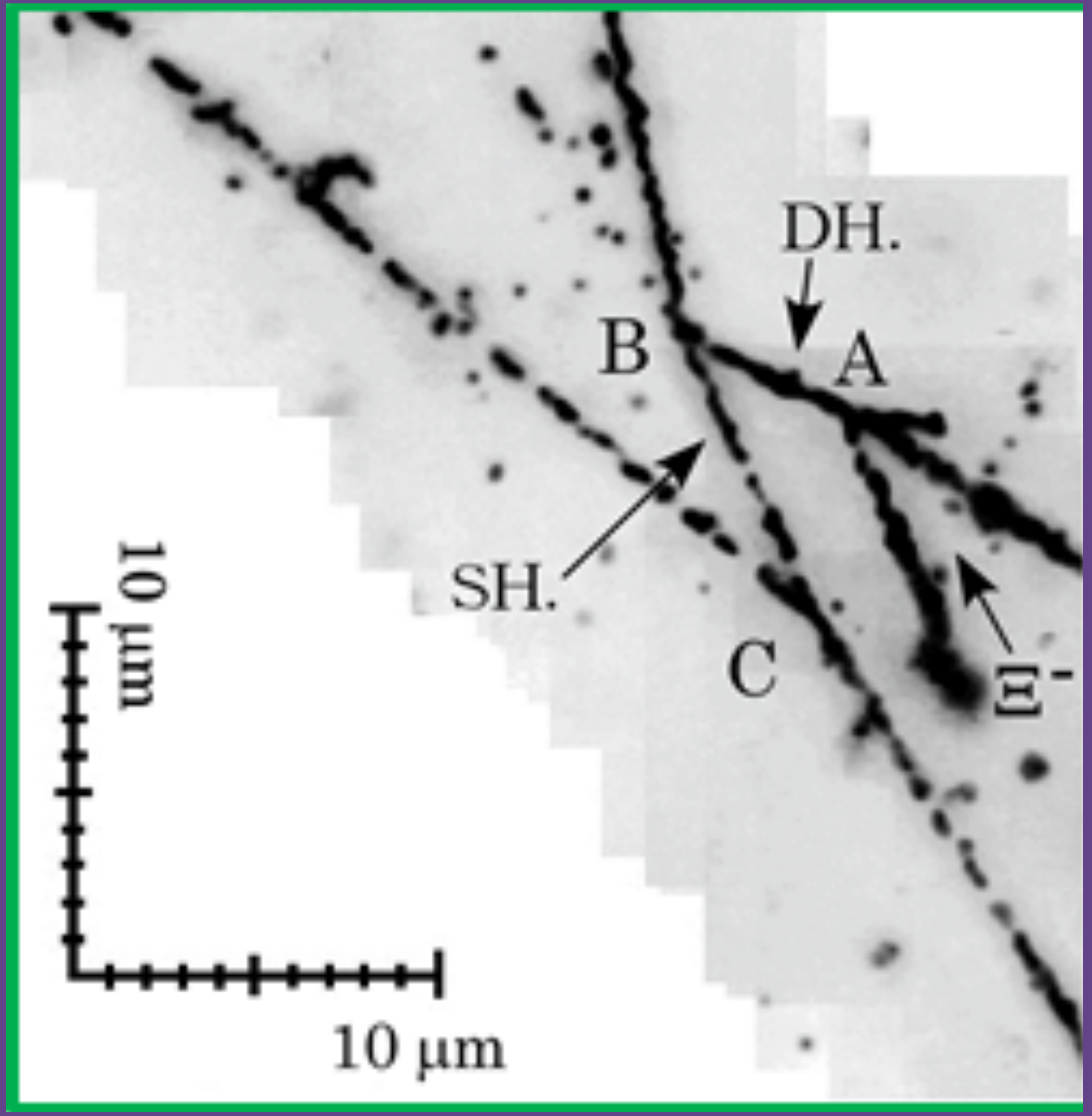
J-PARC E05 by S. Kanatsuki

S=-2 EMULSION EVENTS

KEK E373

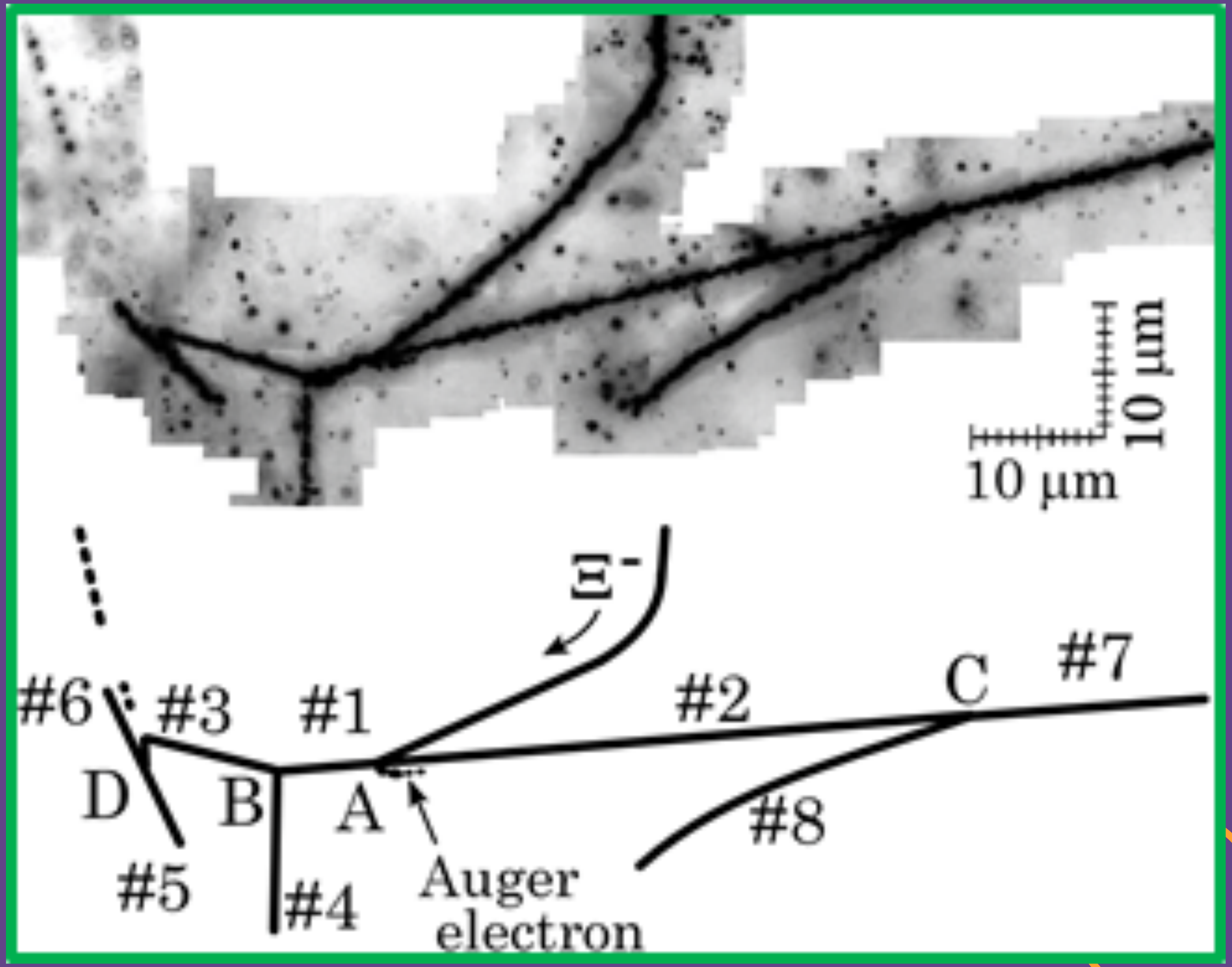
Nagara : $_{\Lambda\Lambda}{}^{6}He$

H. Takahashi et al., PRL 87, 212502 (2001)

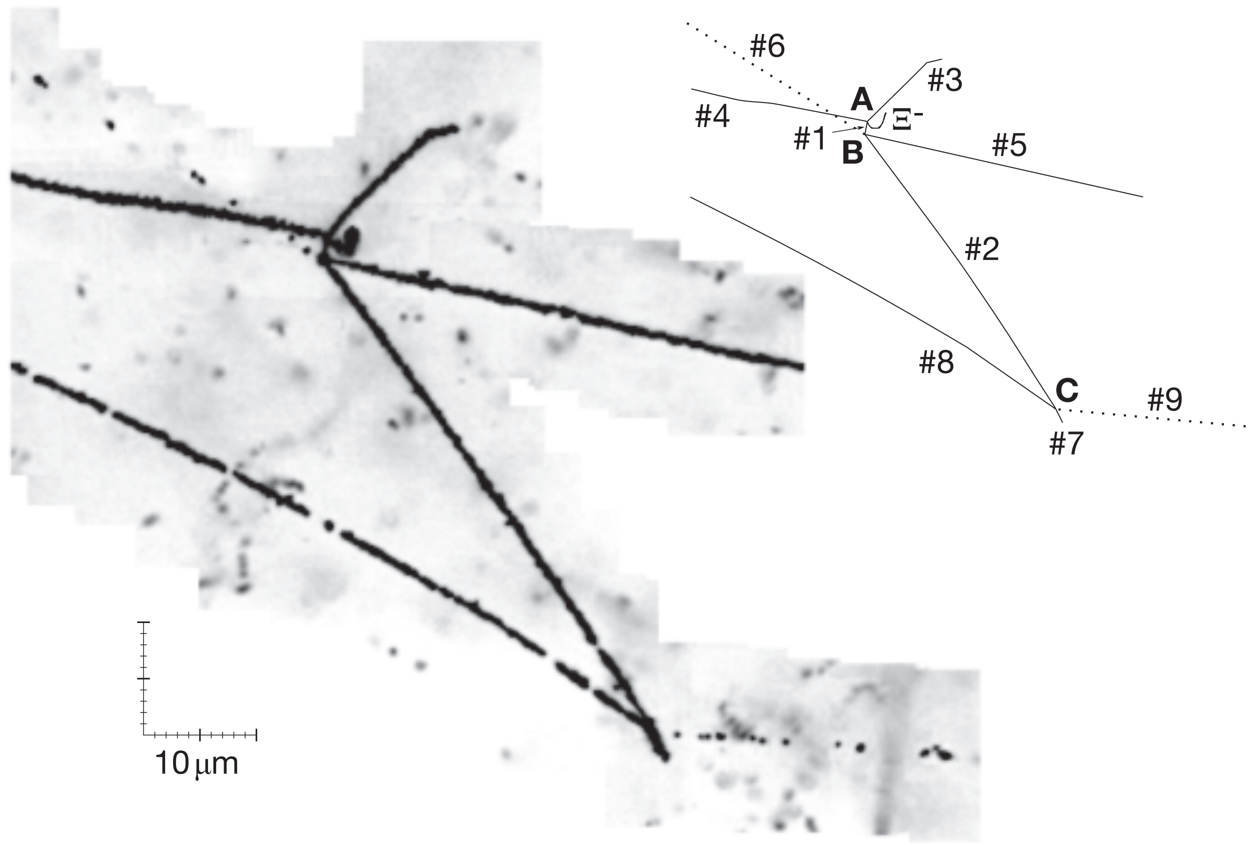


Kiso : $_{\Xi}{}^{15}C$

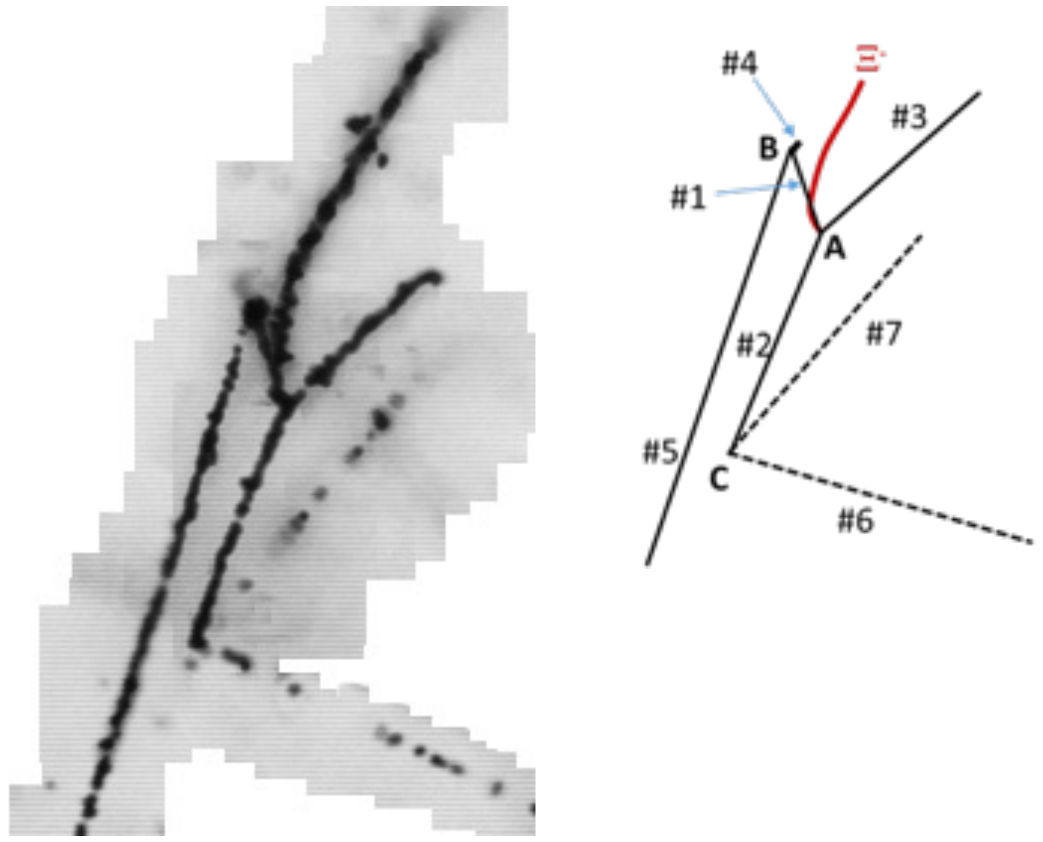
K. Nakazawa et al., PTEP33, D02 (2015)



NEW EVENTS IN E07



H. Ekawa et al., PTEP 2019, 021D02.
Mino Event $_{\Lambda\Lambda}$Be

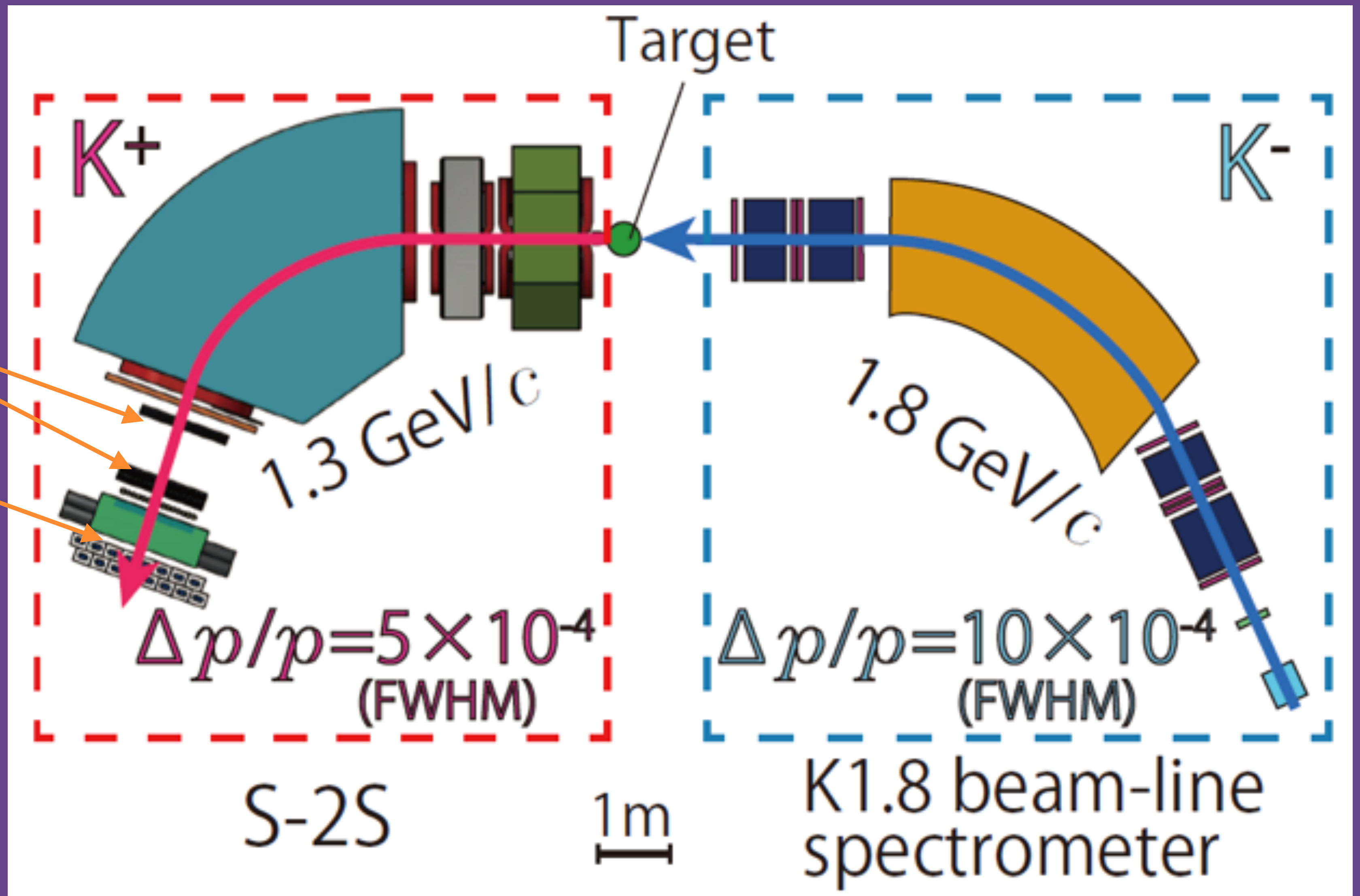


$^{15}_{\Xi}$C

J-PARC E70

SDC pins

AC



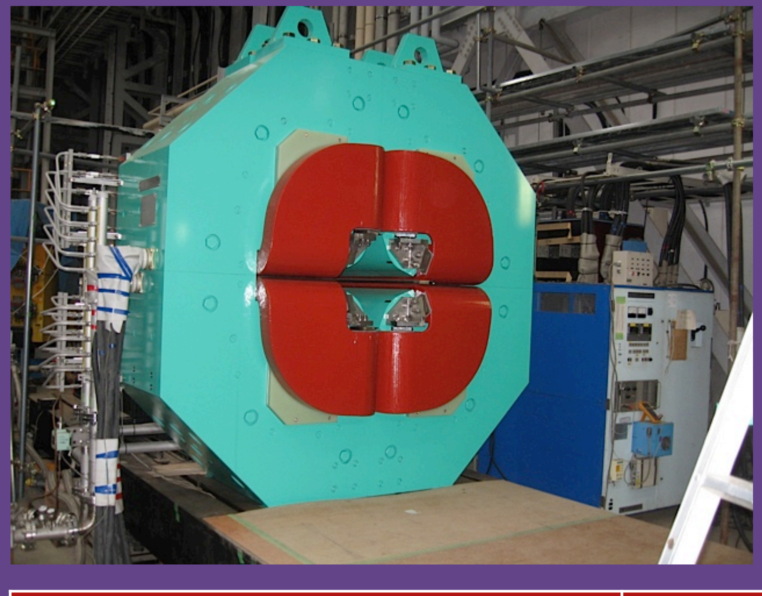
- Stage-2 approved for ^{12}C target run
- Active fiber target (CH)
- $\Delta E < 2$ MeV, > 100 peak counts

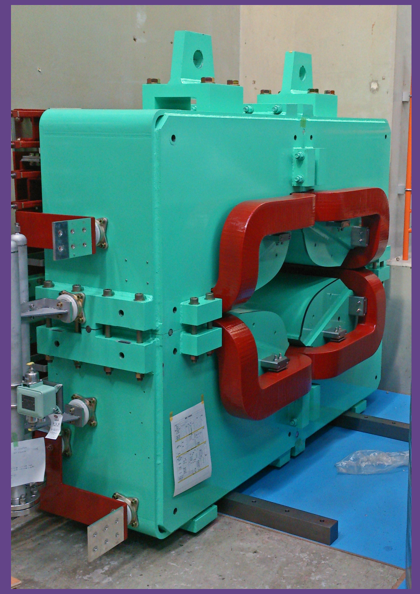
in 2022

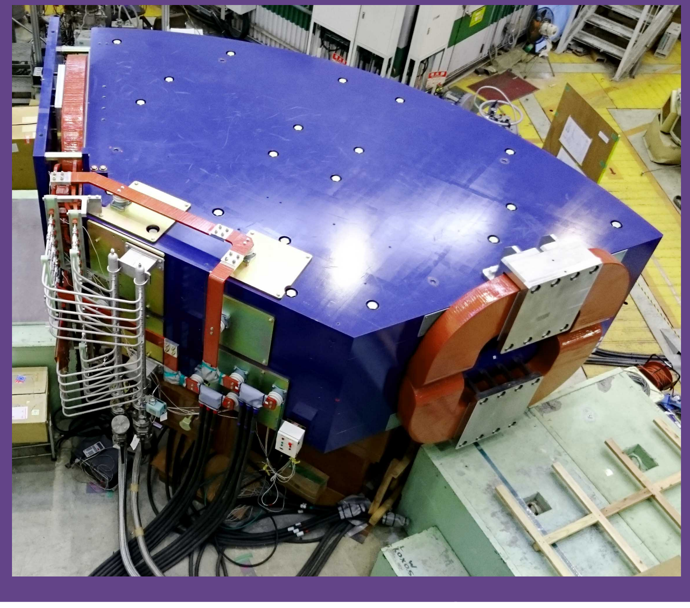
- With CD_2 target, we could take

  d(K^-,K^+) (Ξ^-n) data to search for (Ξ^-n) .

S-2S magnets: QQD







Quadrupoles	Q1	Q2
Field Gradient (T/m)	8.72	5.0
Weight (ton)	37	12
Aperture (cm)	31	36
Current (A)	2500	2500
Power (kW)	400	156

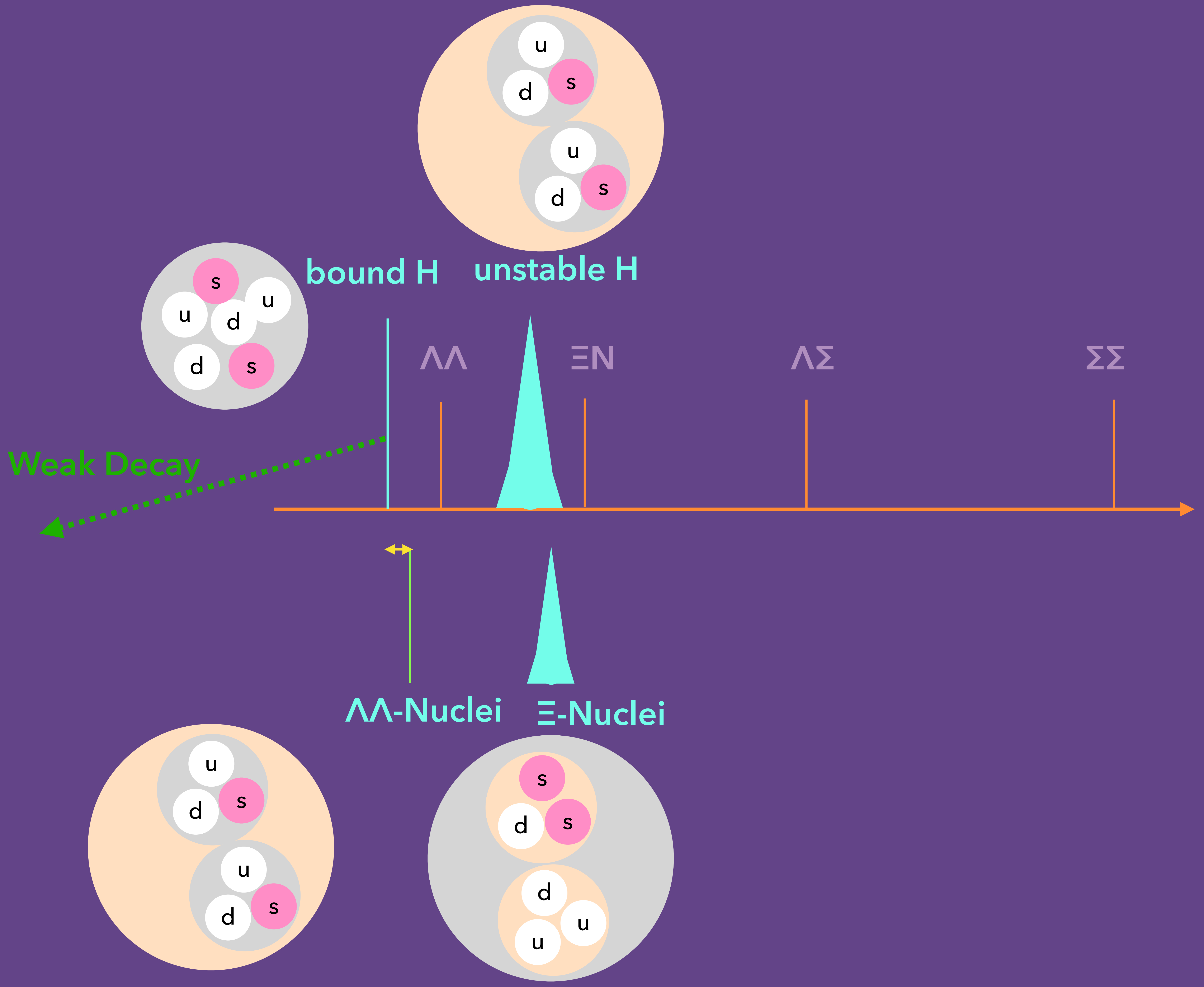
Dipole	D1
Field Strength(T)	1.5
Weight (ton)	86
Pole Gap (cm^2)	32×80
Current (A)	2500
Power (kW)	450

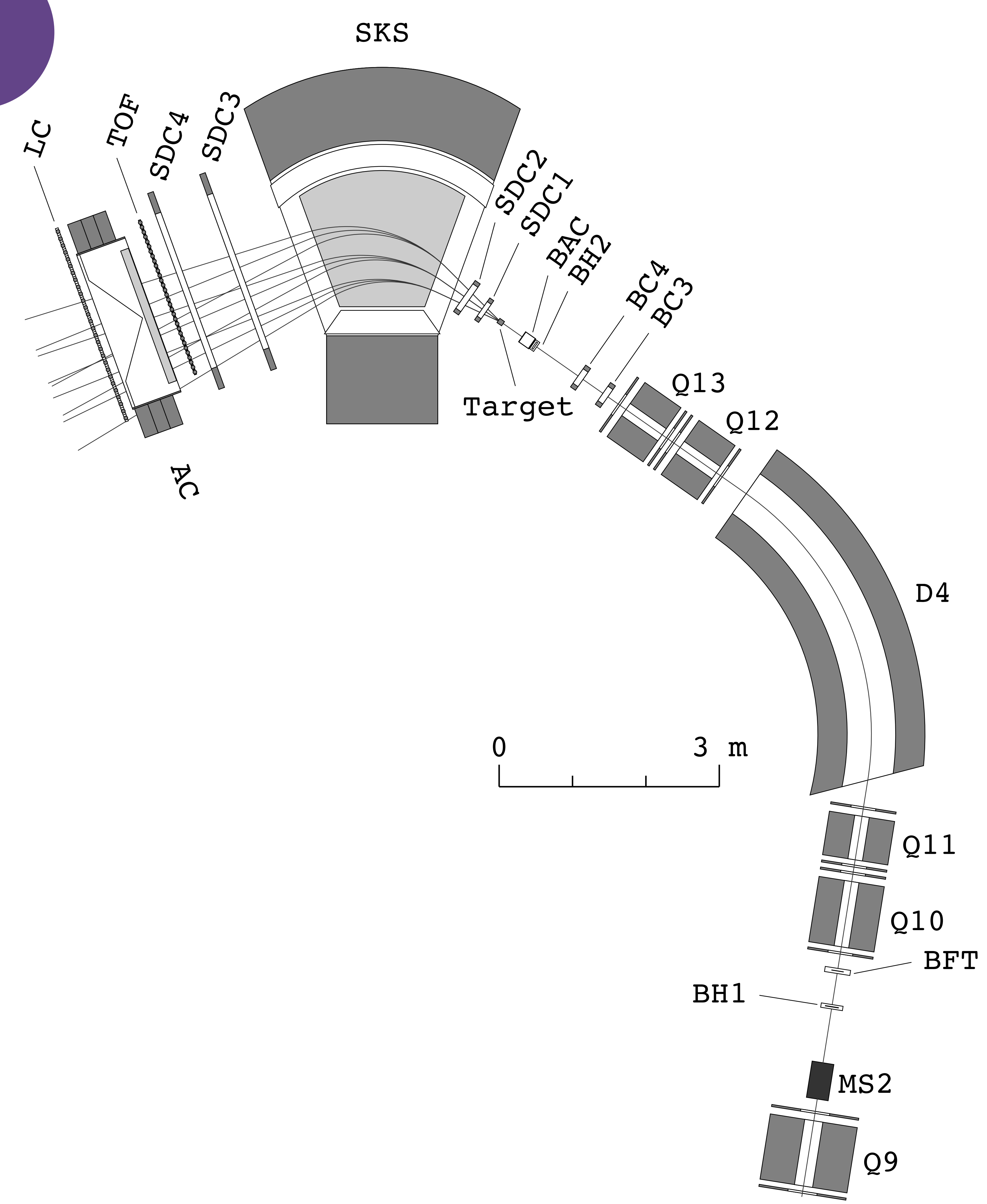
Ξ^-n BOUND STATE IN ESC08 MODEL

M.M. Nagels et al.,

- D* : a deuteron like state
  - Ξ^-n ($^3S_1$, I=1)
  - B_Ξ=1.56 MeV ; U_Ξ=-7.0 MeV, Γ_Ξ=4.5 MeV
  - Strong Tensor Force

Energy Spectrum of B=2, S=-2 systems

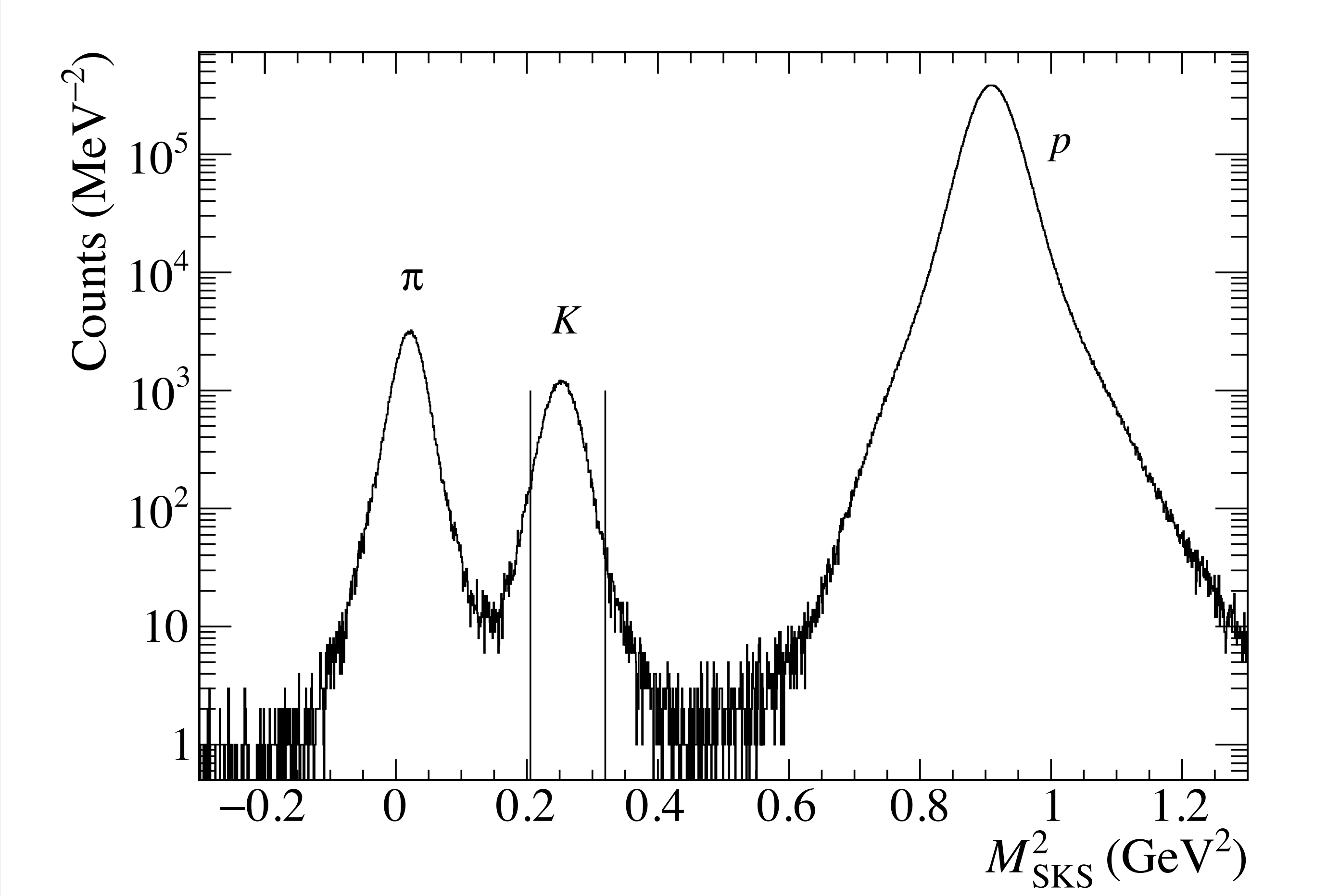




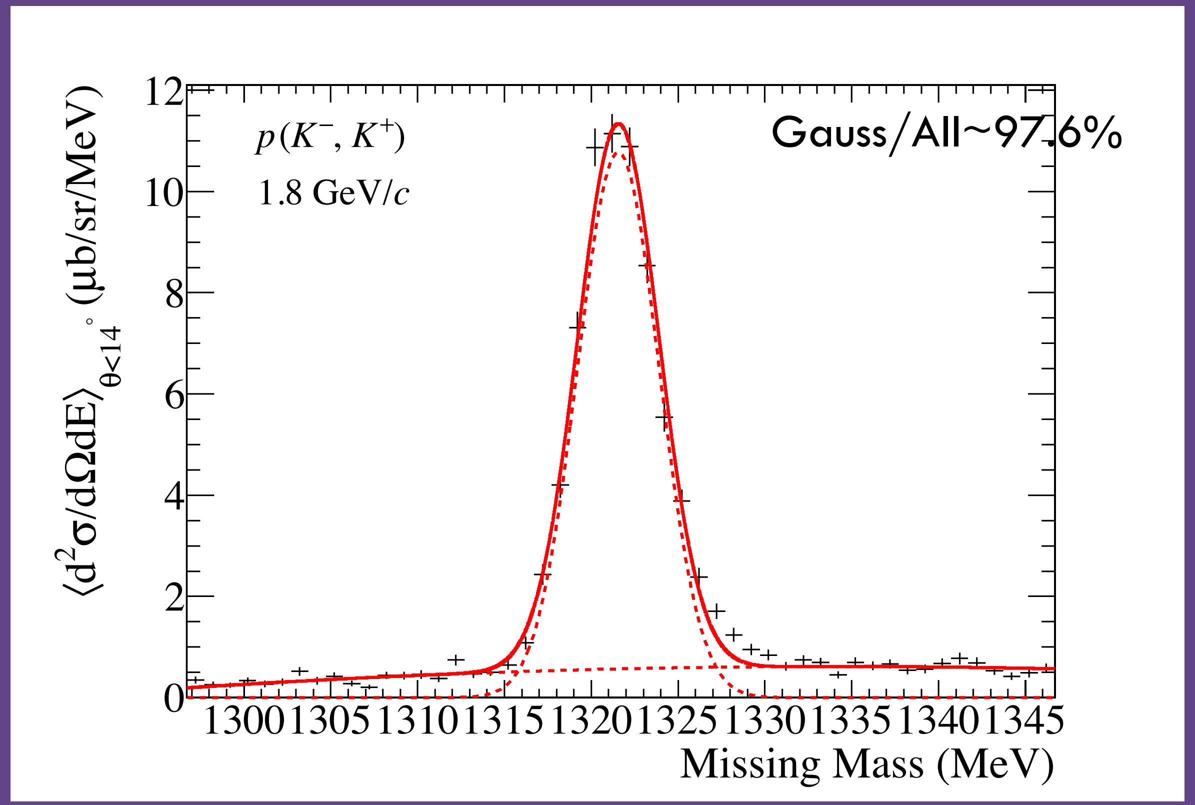
E05 ANALYSIS

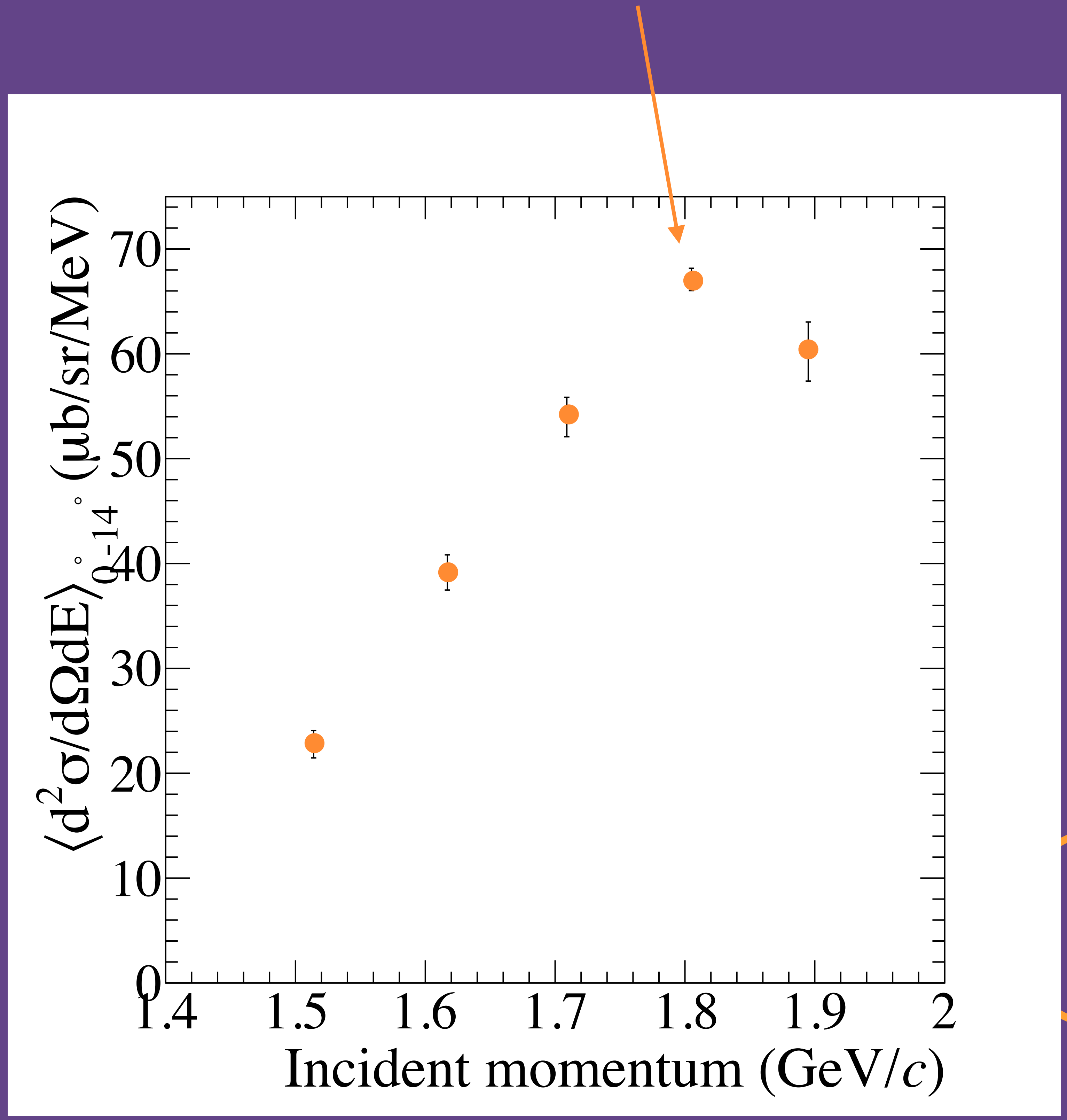
- $^{12}C(K^-,K^+)$ at 1.8 GeV/c
  - 26-Oct-2015 ~ 19-Nov-2015
  - K^- intensity : 6×10^5 K^- / spill
  - (5.52 seconds cycle) @ 39 kW
  - 9.36 g/cm^2 ^{nat}C; 10 days
  - 9.54 g/cm^2 CH_2; 2 days
- E05 Setup
  - $\Delta\Omega$ = 110 msr, $\Delta p/p_{SKS} = 3 \times 10^{-3}$.
  - ΔE = 5.4 MeV(FWHM) for $K^- p \rightarrow K^+ \Xi^-$.
  - Best performance for the (K^-,K^+) reaction

E05 : (K-, K+) ANAYSIS



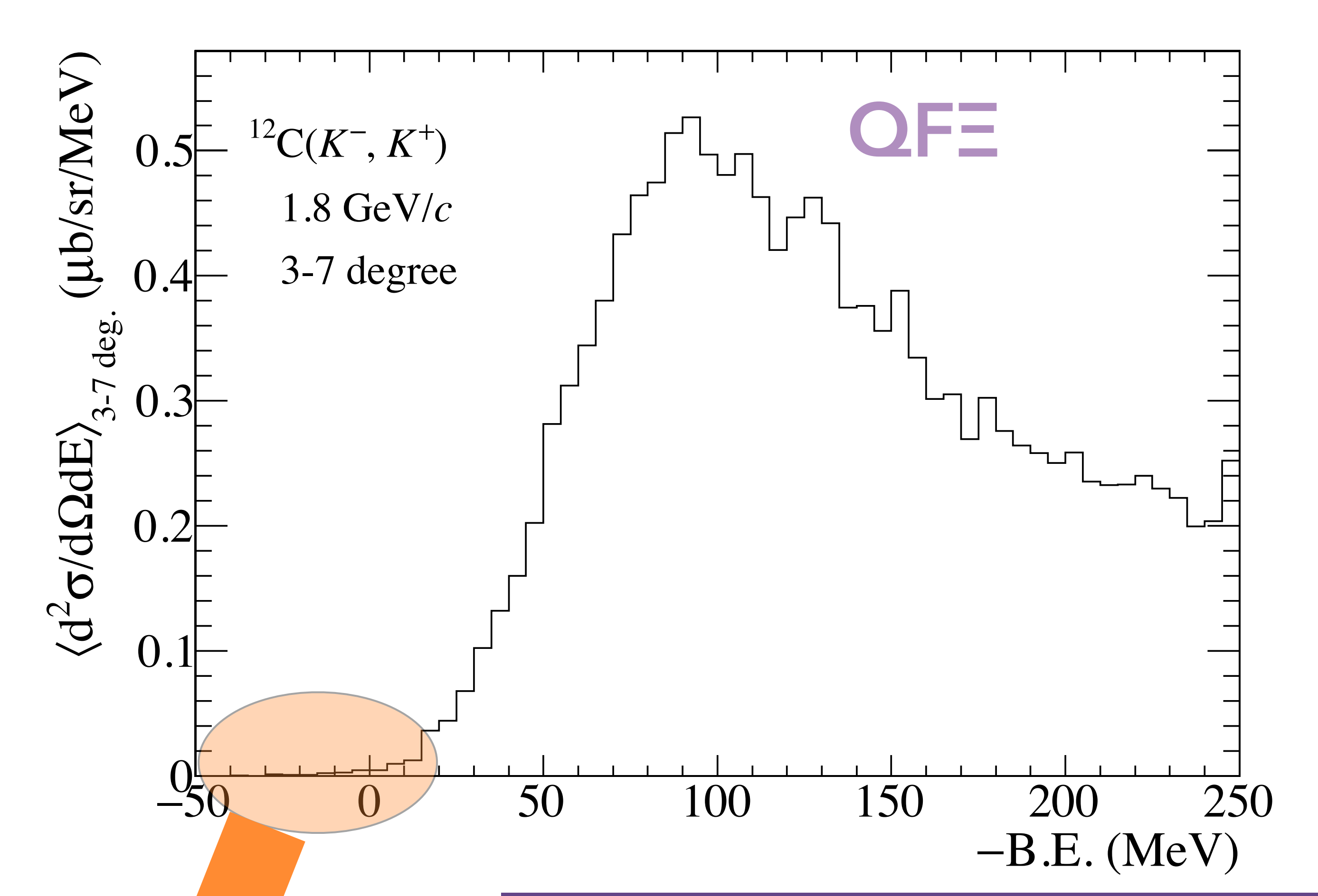
$CH_2(K^-,K^+)\Xi^-$

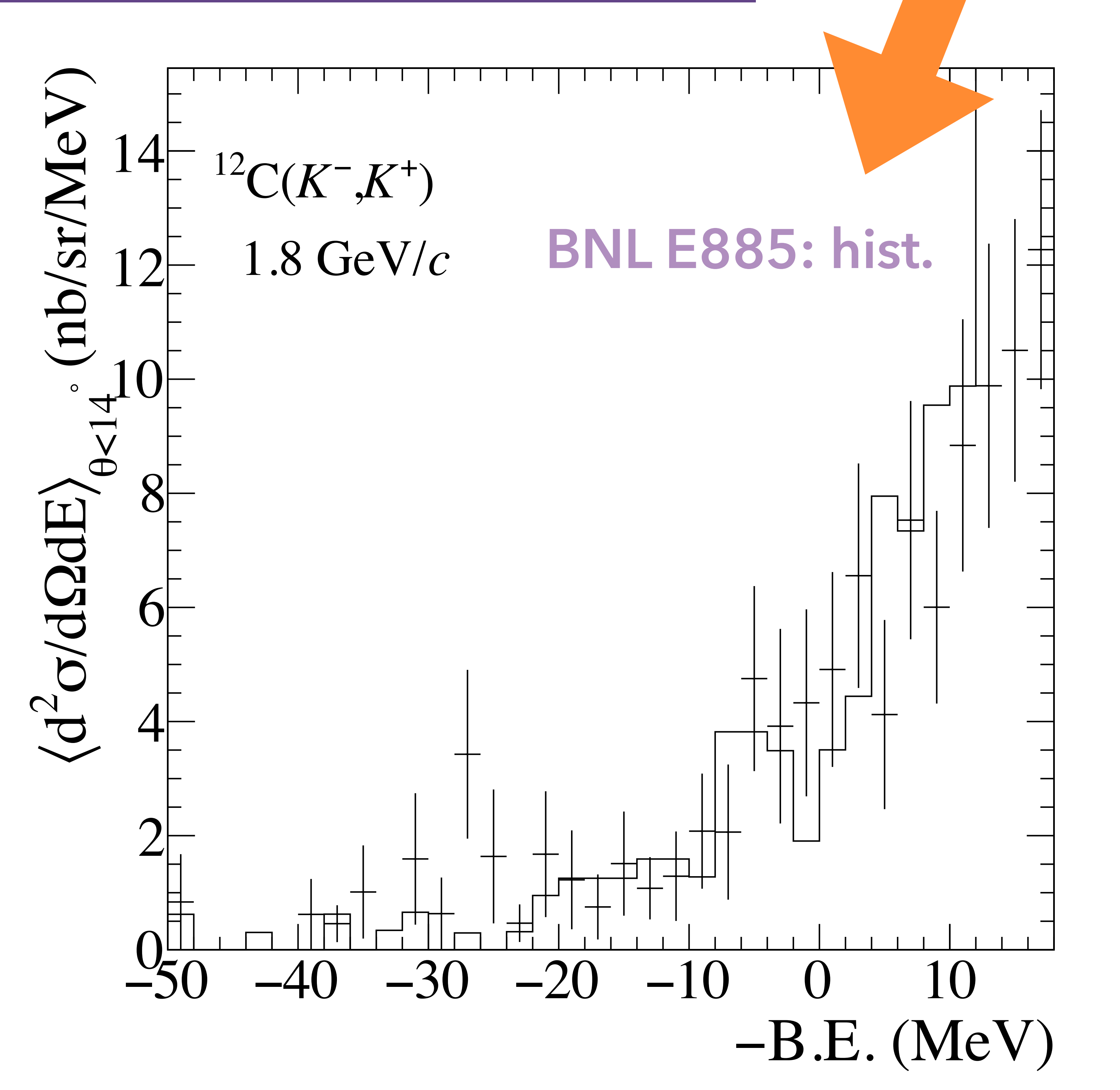




E05 : (K-, K+) ANAYSIS

- Comparison with BNL E885 data with cross section basis.
- Please note that the BNL ΔE=14 MeV, so that an enhancement at 27 MeV was smeared out.

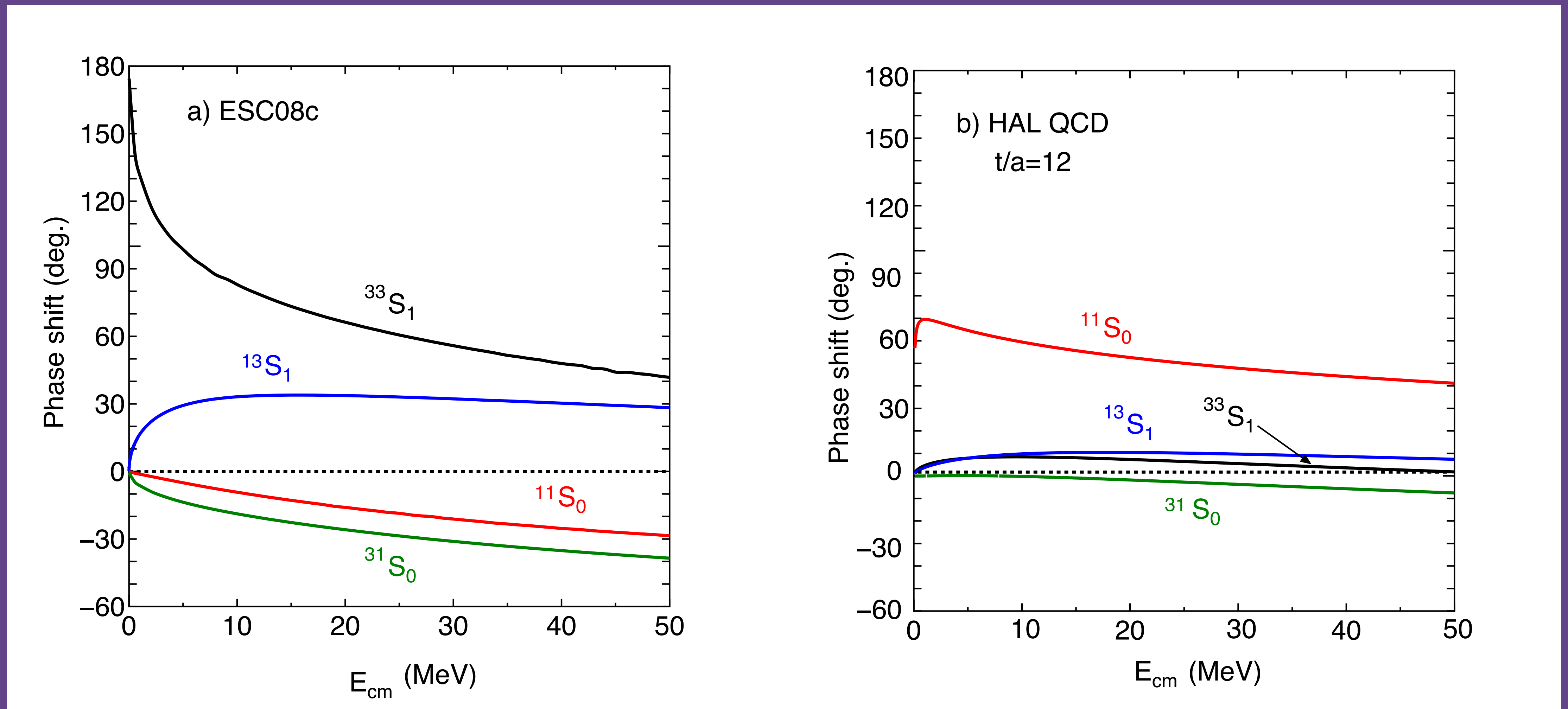


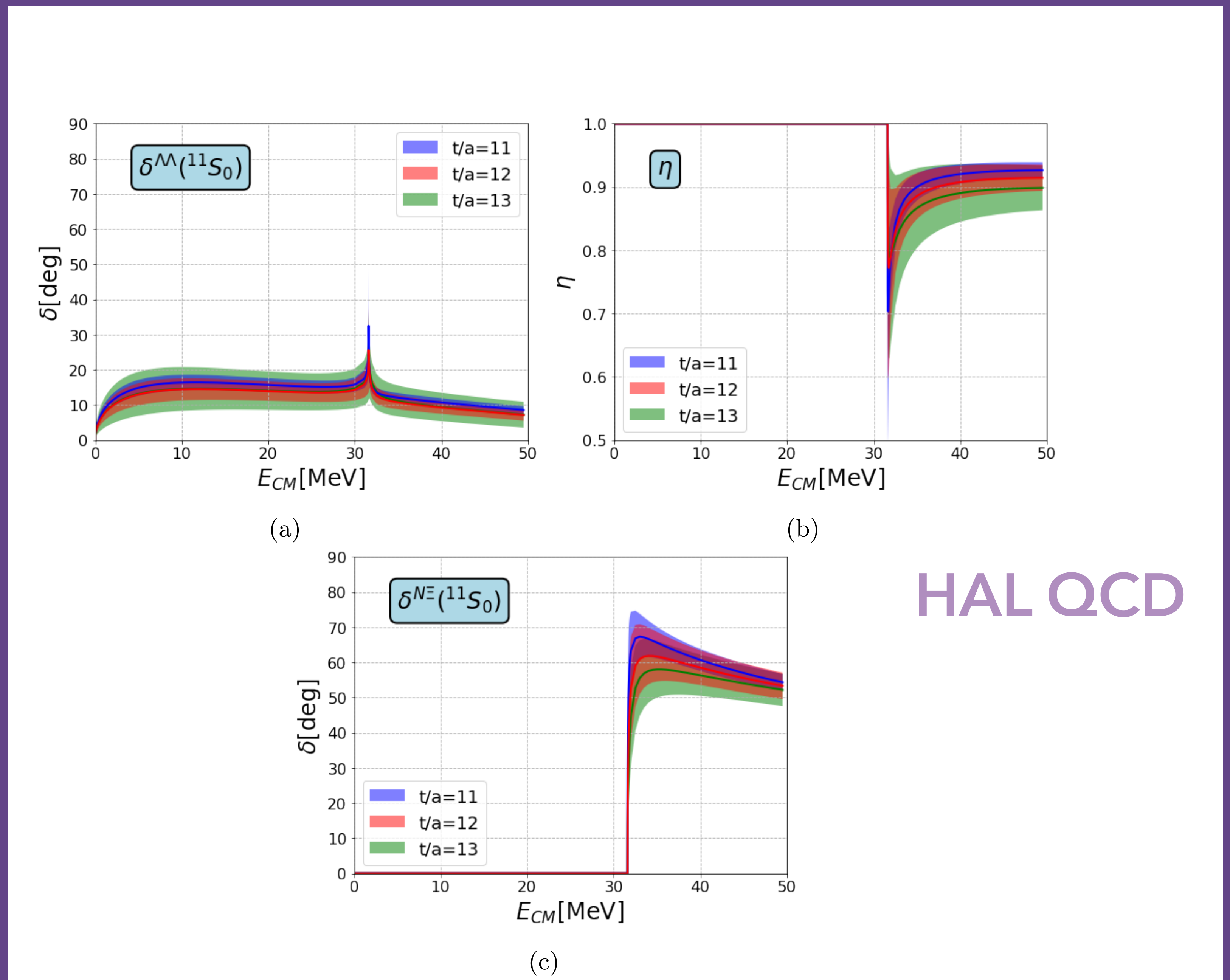


THEORETICAL MODELS

- ESC08c v.s. HAL QCD
  - Lightest Ξ-hyper nucleus ? NNNΞ

E. Hiyama et al., PRL 124 (2020)9, 092501.





	ESC08c	HAL QCD
$^{33}S_1$	Attraction	Weakly Attractive
$^{13}S_1$	Weakly Attractive	Weakly Attractive
$^{11}S_0$	Repulsive	Attraction
$^{31}S_0$	Repulsive	Weakly Repulsive

SUMMARY

- Kaonic Nuclei vs Λ*(1405)-nuclei
  Shallow Deep
  - Both states are Broad Γ~100 MeV.
- Future directions :
  → B_K or B_{Λ^*} A-dependence
  → Br(πΣN)/ Br(Λp, Σp) ?
- Ξ-hyper nucleus vs H-nucleus
  - Lightest Ξ-hypernucleus