京都大学
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Search for η-mesic nuclei with (π, N) reaction at J-PARC

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International Symposium on Mesic Nuclei

16 June 2010

η mesic nuclei @ J-PARC

- Letter of Intent for J-PARC 50GeV PS (2007)
  K. Itahashi, H. Fujioka,
  S. Hirenzaki, D. Jido, and H. Nagahiro
  http://j-parc/NuclPart/Proposal_e.html

- Theoretical work:
  H. Nagahiro, D. Jido, and S. Hirenzaki
  PRC 80, 025205 (2009)

- *see also*: H. Fujioka, K. Itahashi, arXiv:1002.0201 [nucl-ex]
  (HYP09 proceedings)

Letter of Intent for J-PARC

Spectroscopy of η mesic nuclei by (π^-, n) reaction at recoilless kinematics

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Abstract

We are interested in the recoilless production and spectroscopy of η mesic nuclei by using the (π^-, n) reaction. The K1.8BR beamline of the J-PARC will offer unique opportunity for the experiment. The goal of the present experiment is to understand the nature of the η meson in the nuclear medium, which is expected to couple to the $N^*(1535)$-nucleon hole, and to step forward to the chiral symmetry of the baryons.

1 Introduction

We consider recoilless production and spectroscopy of η mesic nuclei by using the (π^-, n) reaction. The target candidates at present are ^{7}Li and ^{12}C. The experiment comprises an entrance channel spectroscopy by the missing mass measurement and decay channel spectroscopy by the invariant mass

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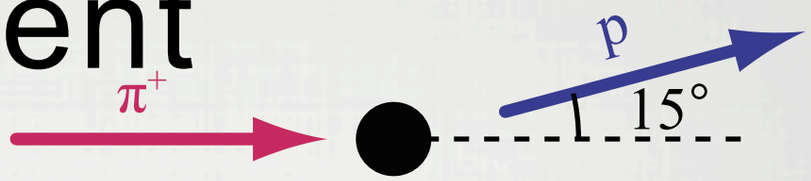
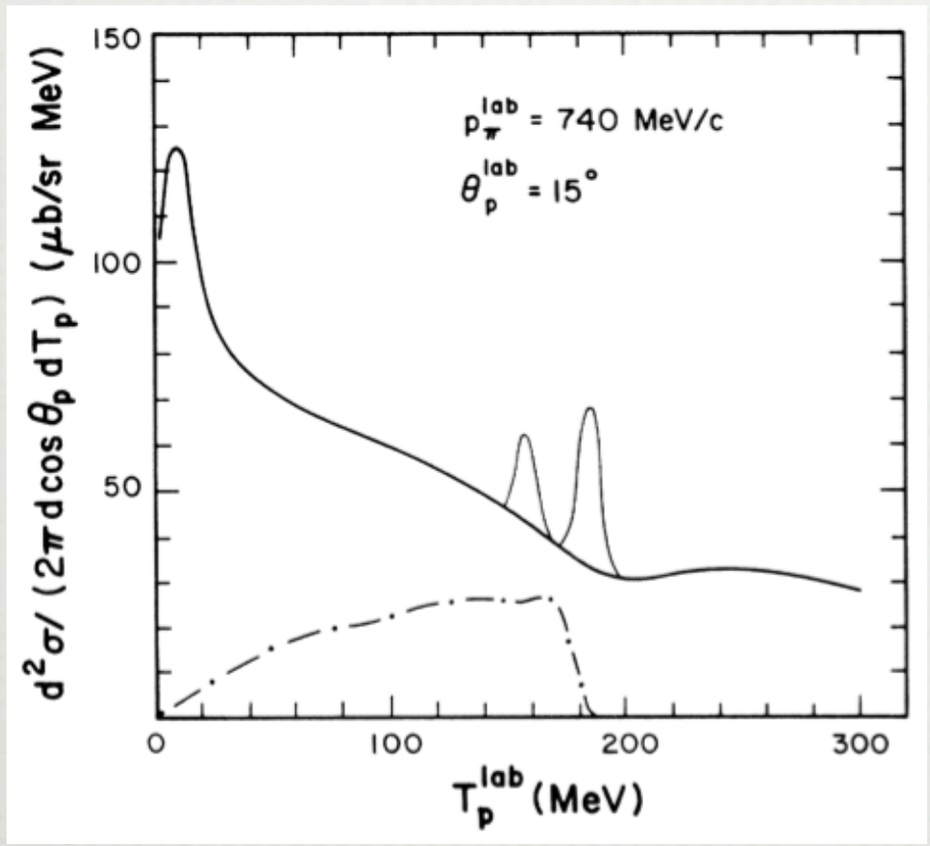
Why (π, N) reaction again?

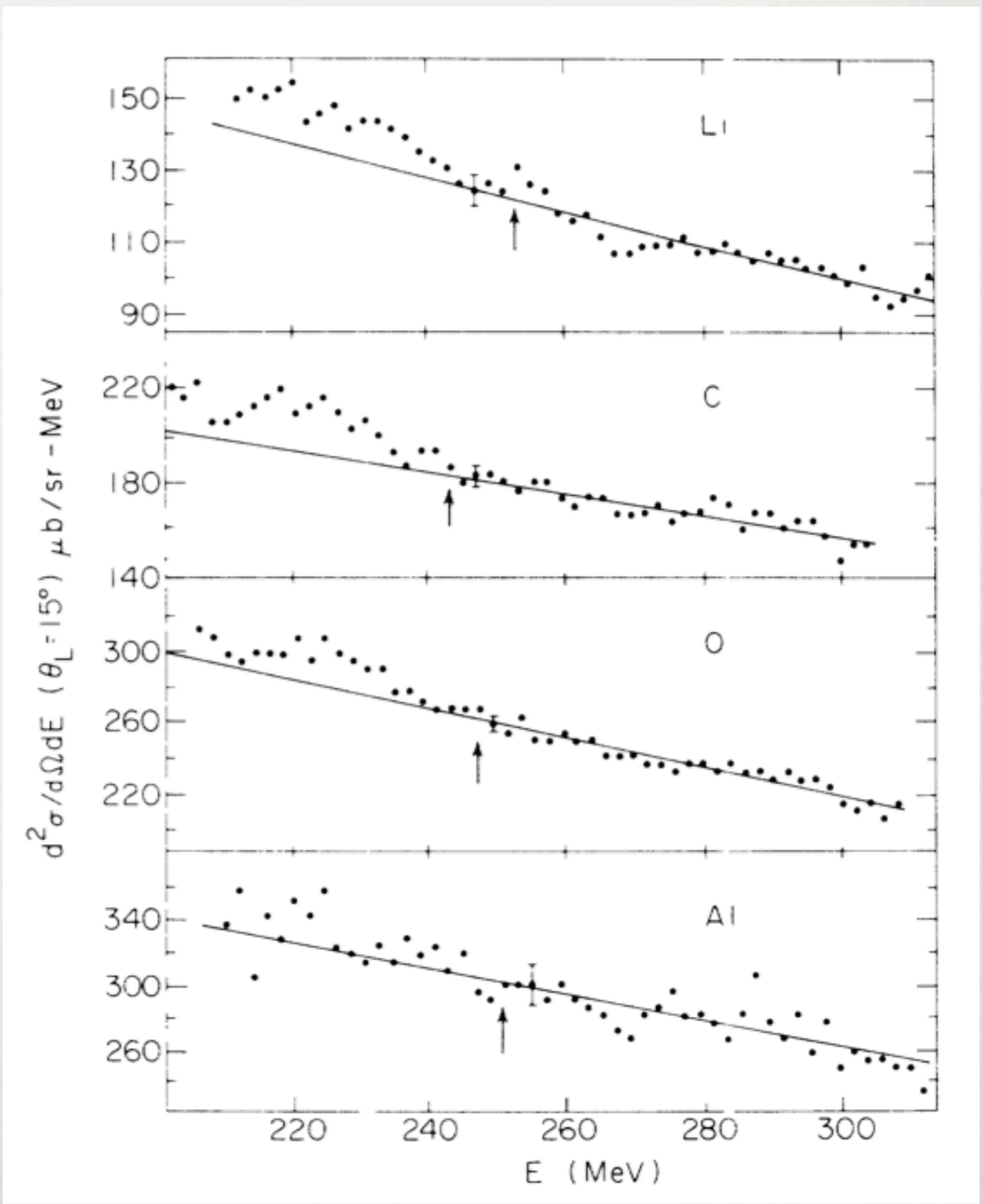
- R. Chrien *et al.*, Phys. Rev. Lett. **60**, 2595 (1988)
  - (π^+, p) reaction on Li, C, O, Al targets
  - scattering angle = **15°** → **finite** recoil momentum
  - only **inclusive** measurement

BNL experiment

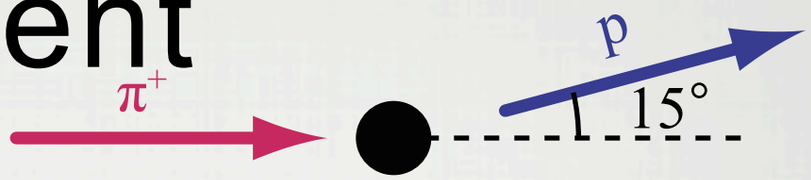


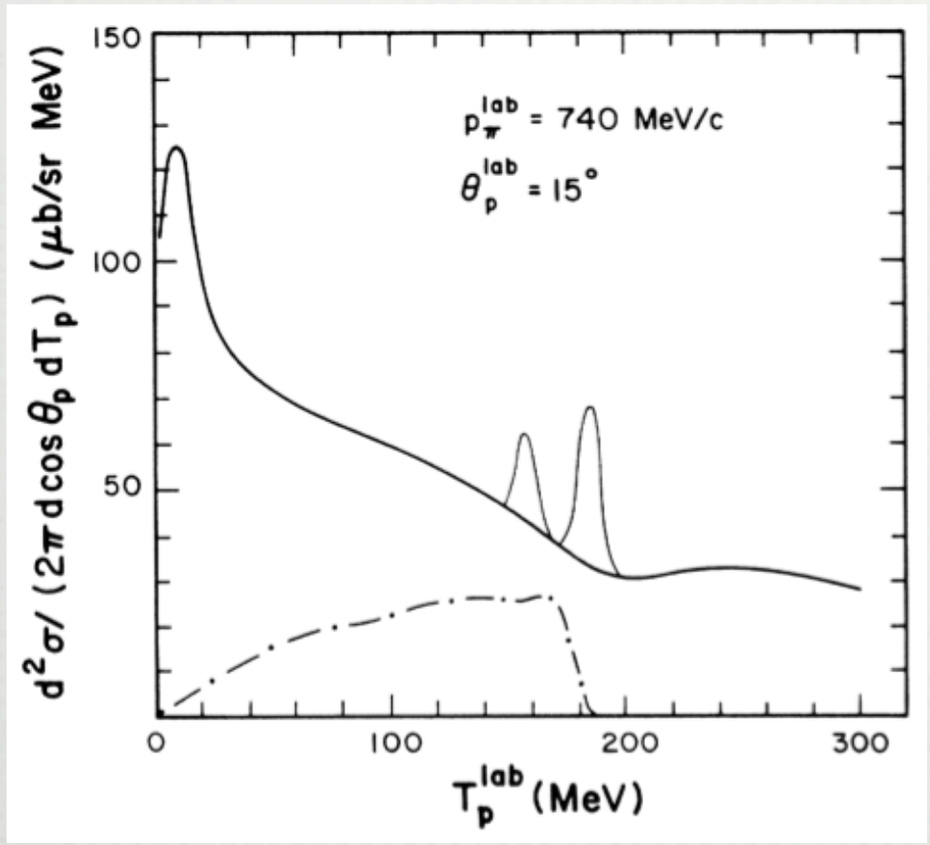


calculation by Liu and Haider
[PRC **34**, 1845(1986)]



BNL experiment





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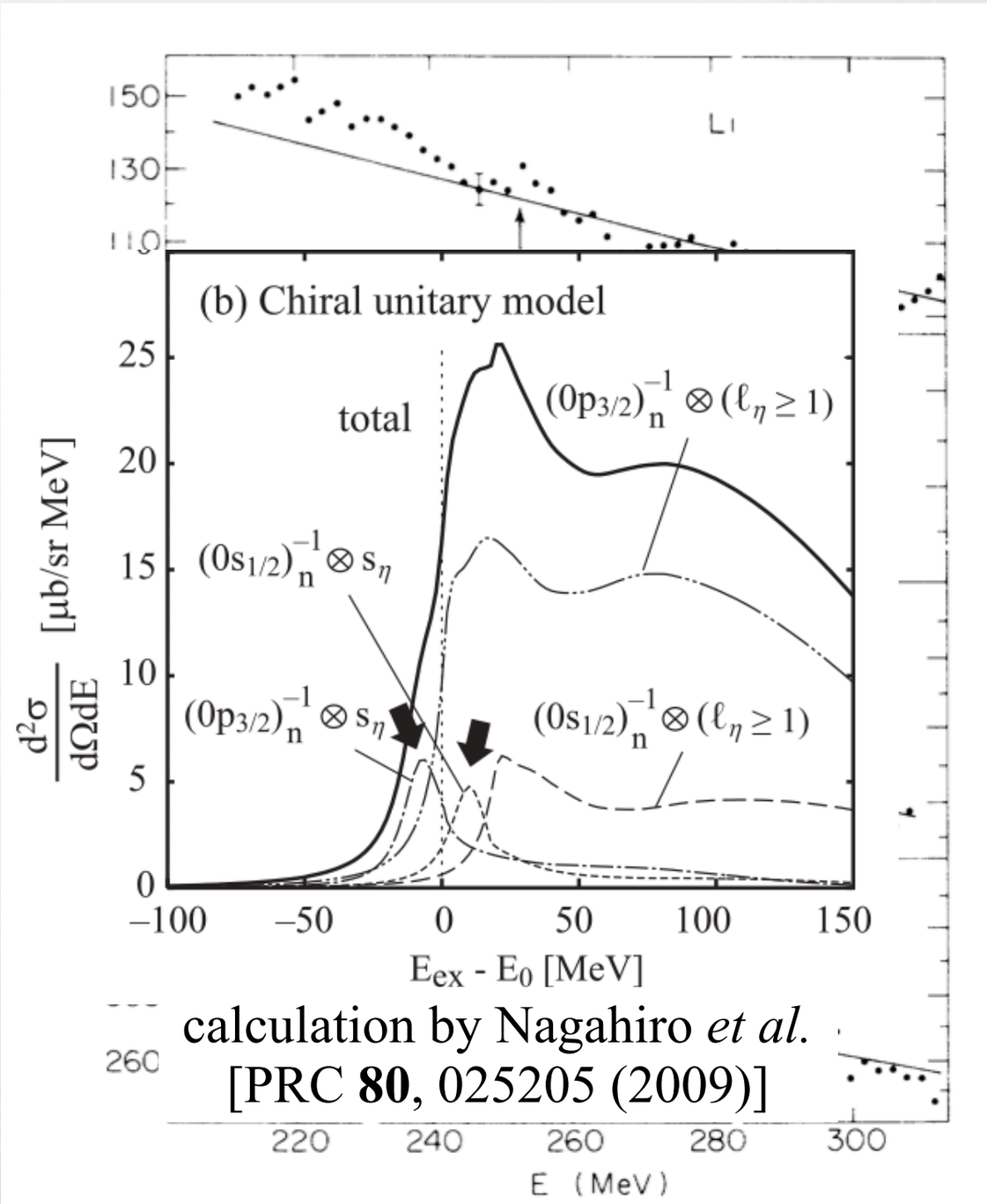
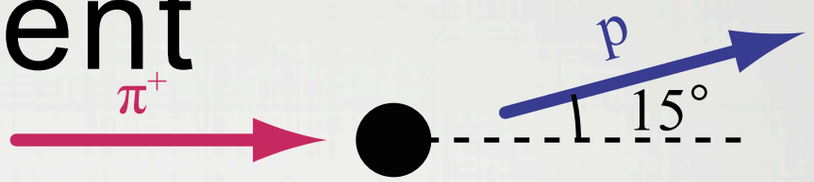
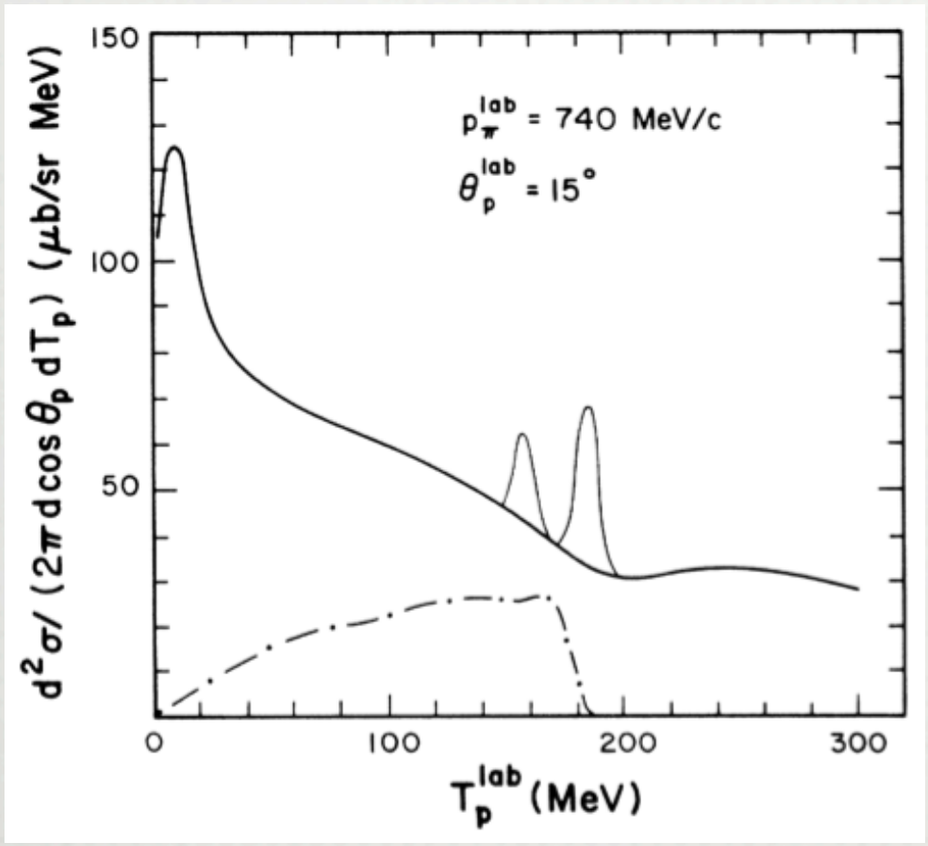


calculation by Nagahiro *et al.*
[PRC **80**, 025205 (2009)]

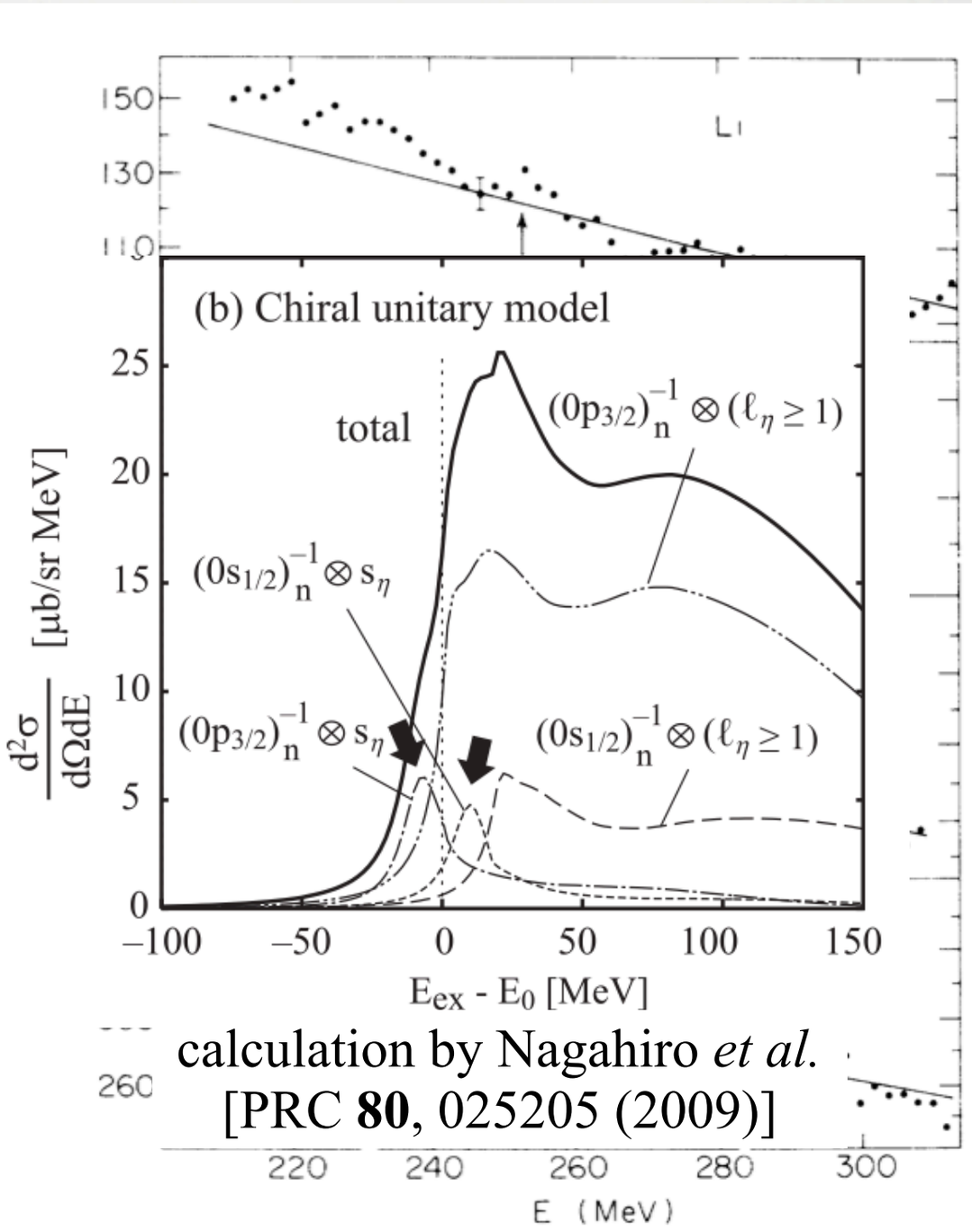
BNL experiment



Peak(s) might be masked by large quasi-free components.

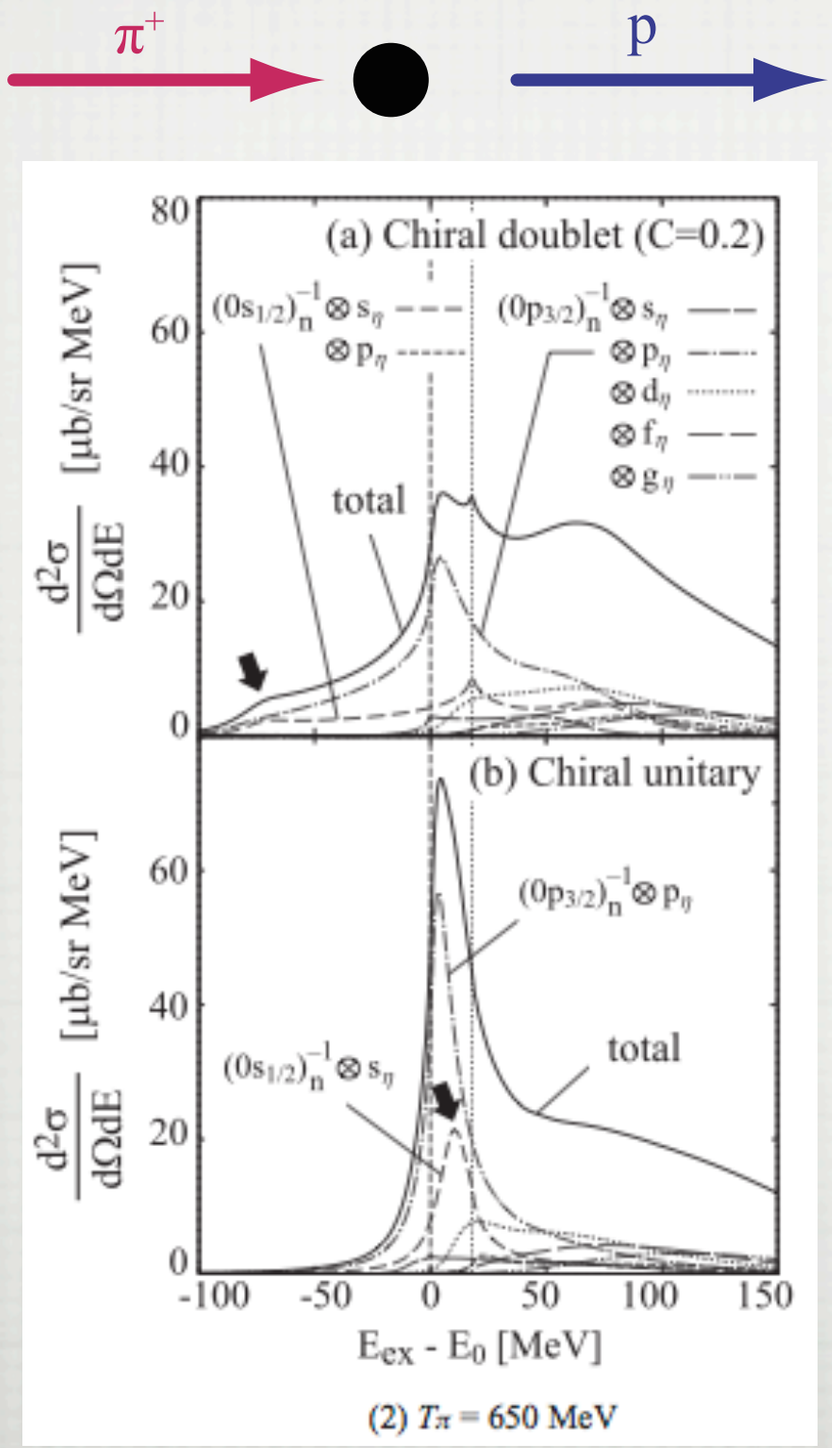


calculation by Liu and Haider
[PRC **34**, 1845(1986)]

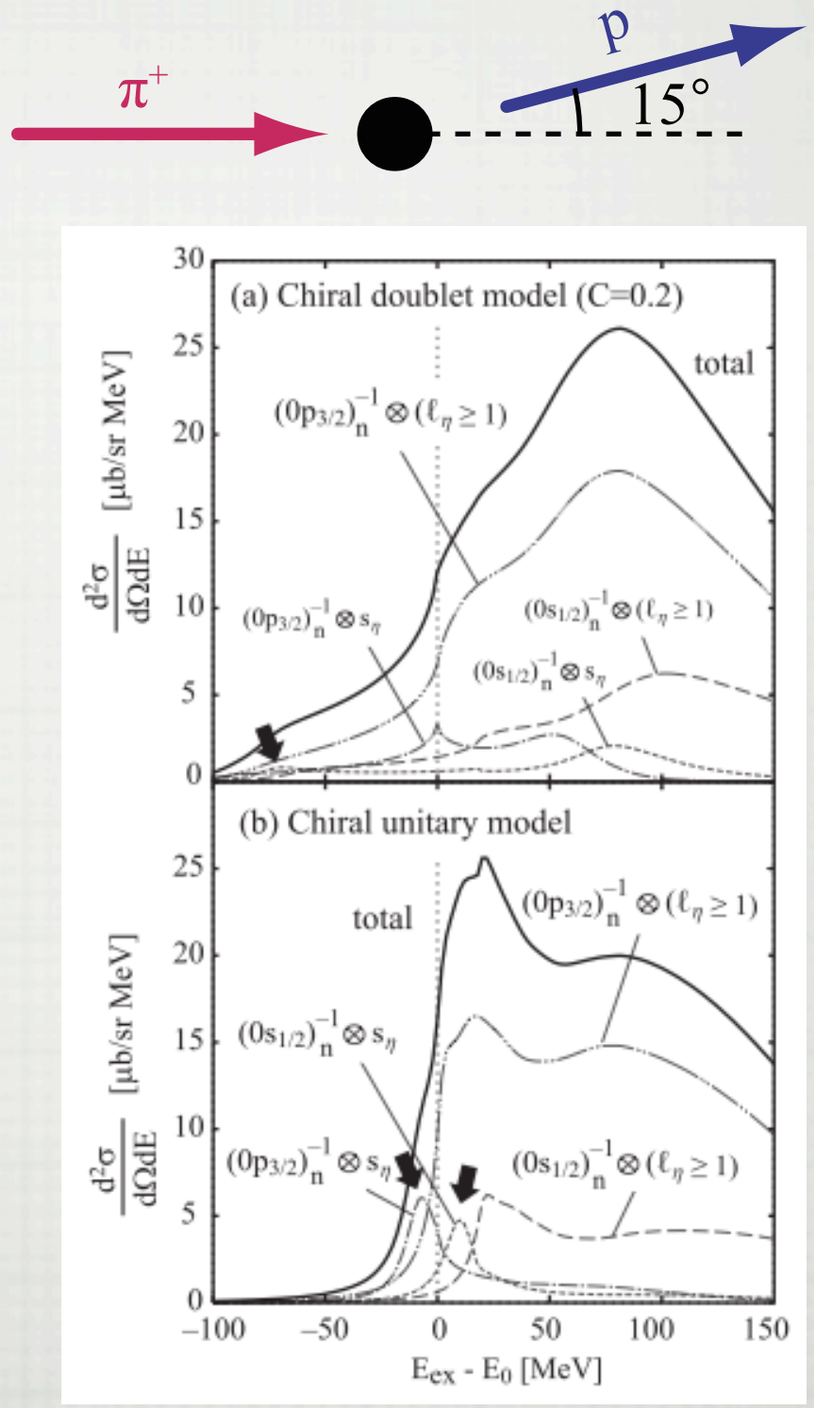


calculation by Nagahiro *et al.*
[PRC **80**, 025205 (2009)]

J-PARC LoI

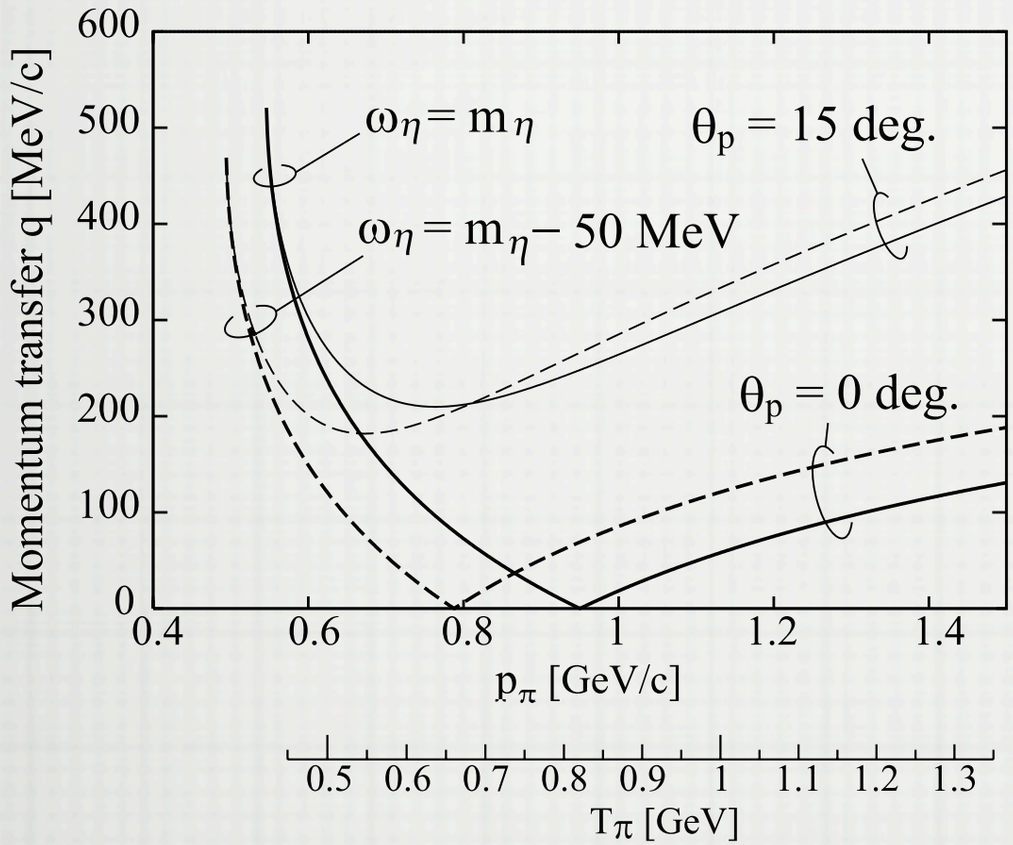


BNL (Chrien *et al.*)



Nagahiro *et al.*, PRC **80**, 025205 (2009)]

Momentum transfer



Nagahiro *et al.*, PRC **80**, 025205 (2009)]

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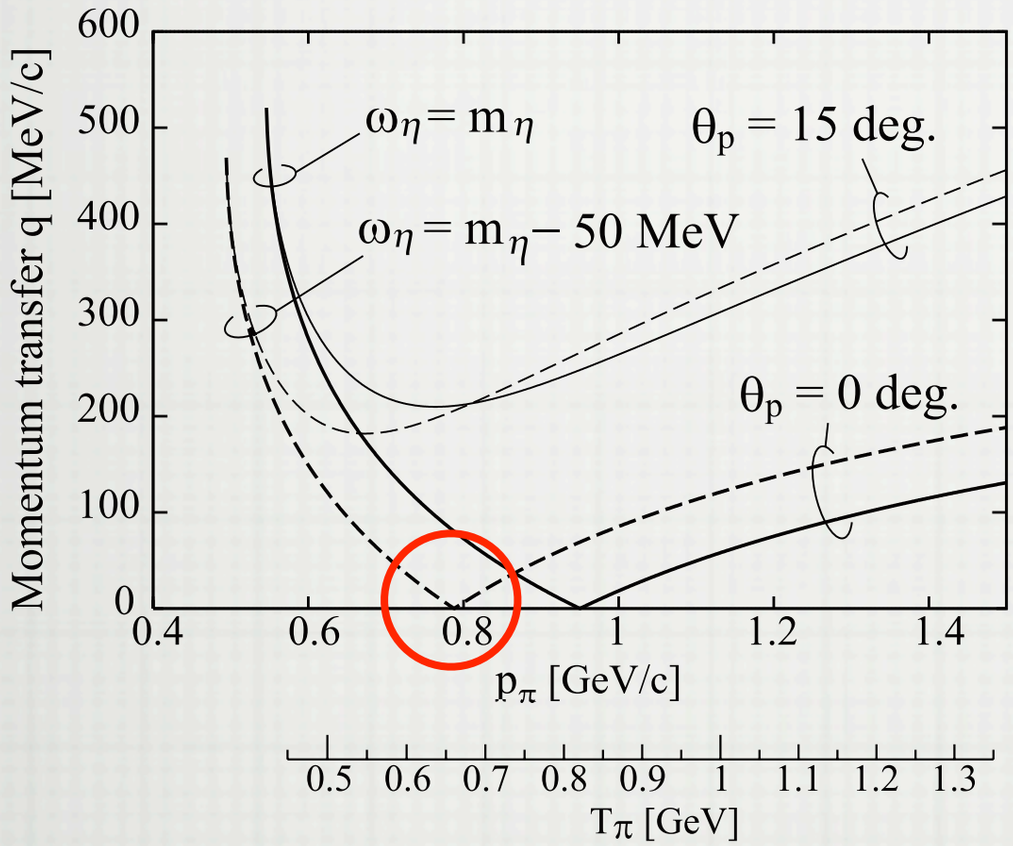
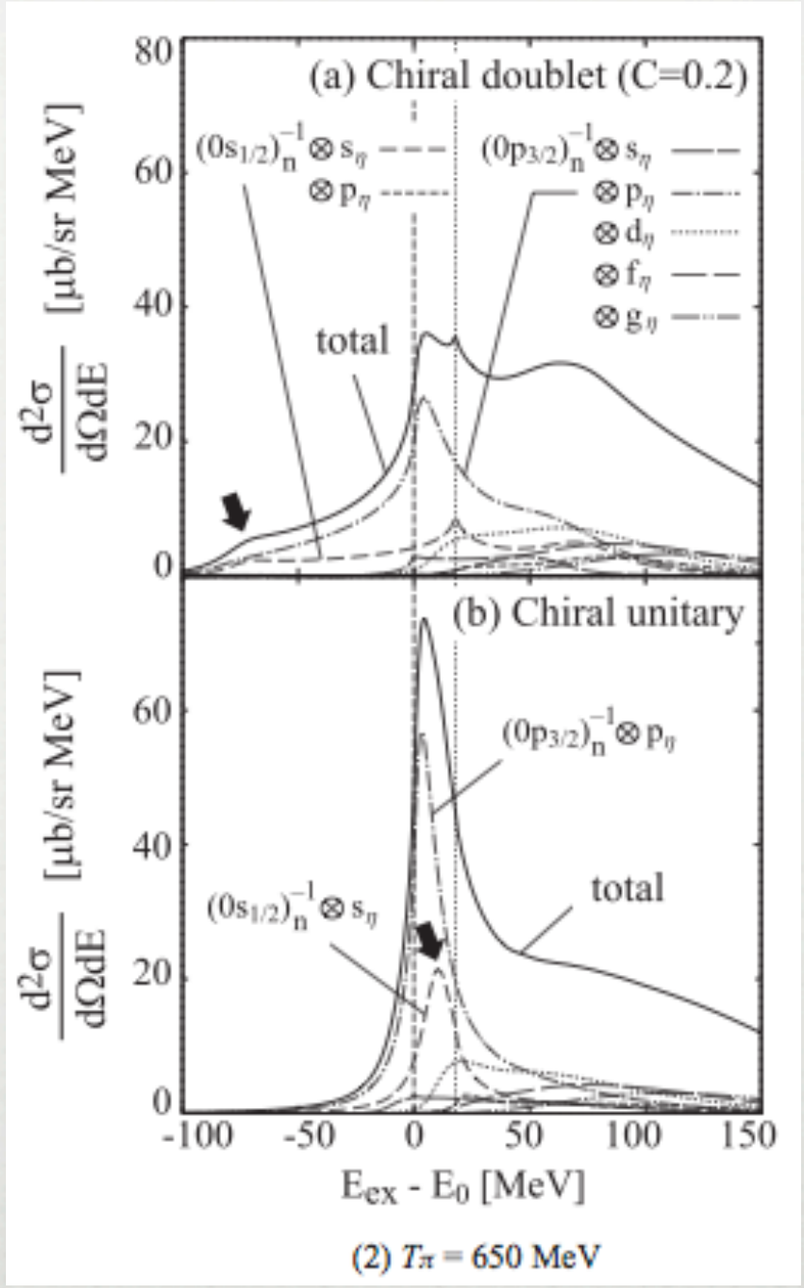
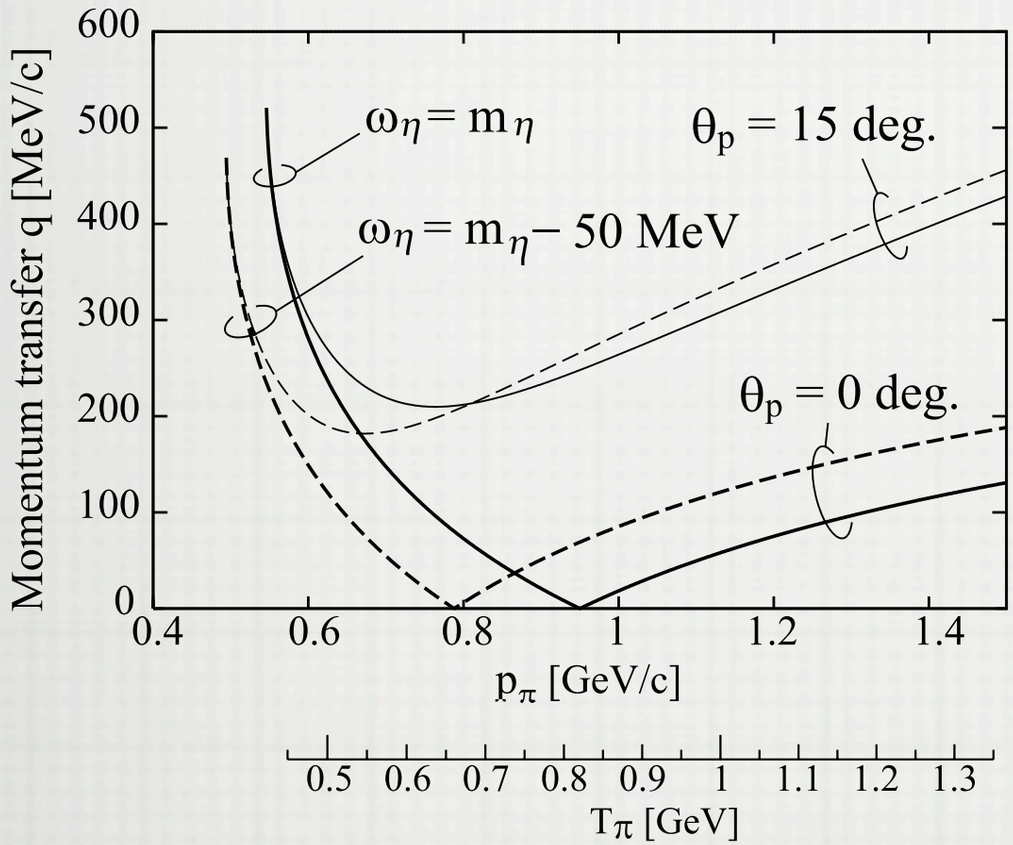




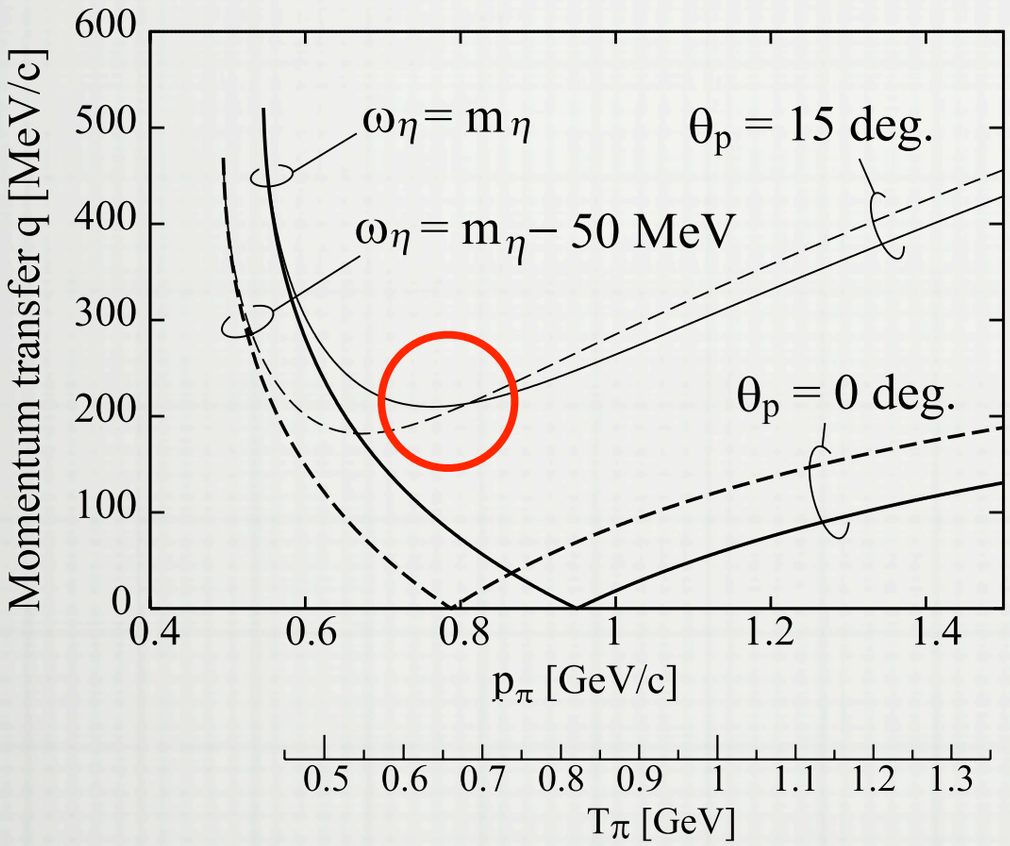
Nagahiro *et al.*, PRC **80**, 025205 (2009)]

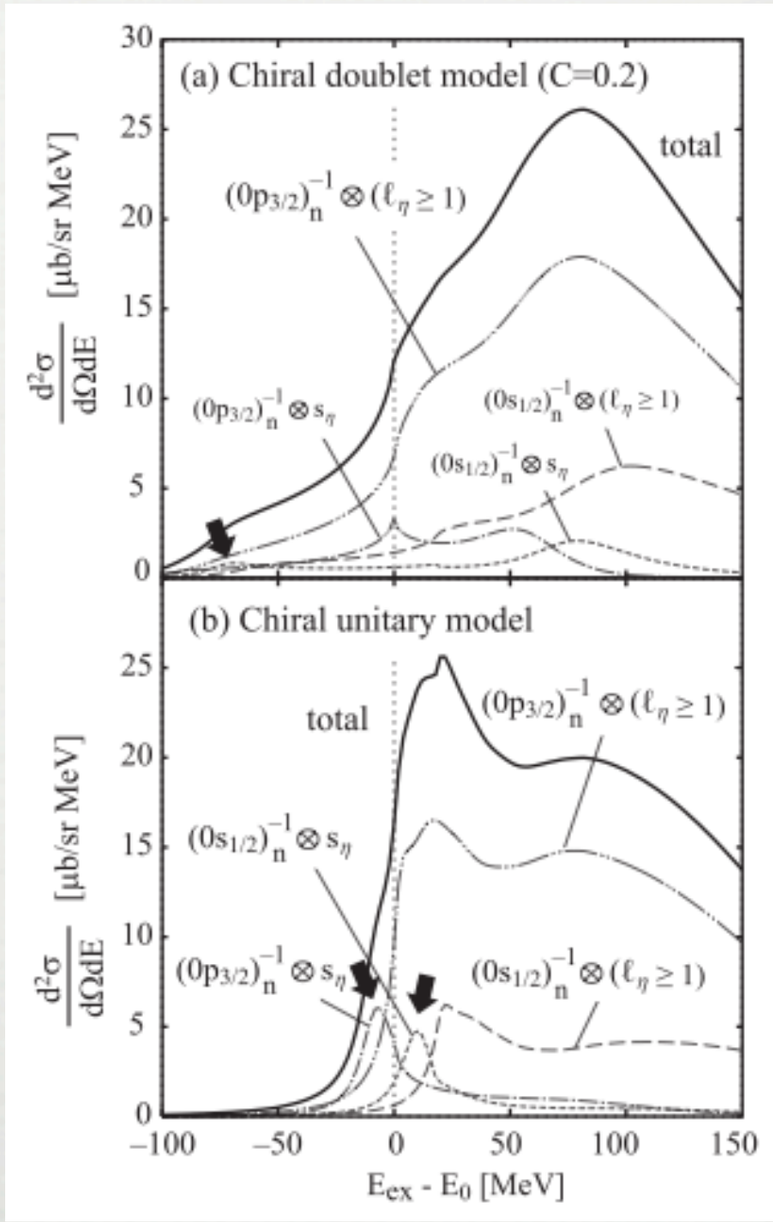
Momentum transfer



Nagahiro *et al.*, PRC **80**, 025205 (2009)]

Momentum transfer





Nagahiro *et al.*, PRC **80**, 025205 (2009)]

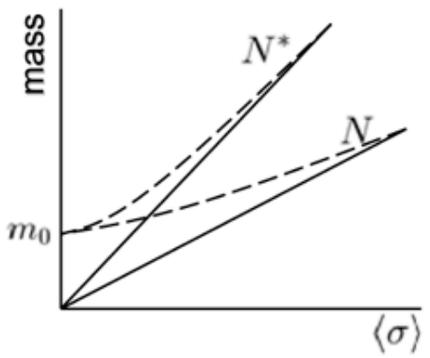
chiral unitary model v.s. chiral doublet model

What causes the level crossing ? : partial restoration of chiral symmetry

Chiral doublet model

DeTar, Kunihiro PRD39(89)2805
Jido, Nemoto, Oka, Hosaka NPA671(00)471
Jido, Oka, Hosaka PTP106(01)873
Kim, Jido, Oka NPA640(98)77

N* : Chiral partner of nucleon



mass difference of N* and N

$$m_N^*(\rho) - m_{N^*}^*(\rho) = (1 - C\frac{\rho}{\rho_0})(m_N - m_{N^*})$$

C ~ 0.2 : strength of chiral restoration at the saturation density ρ_0

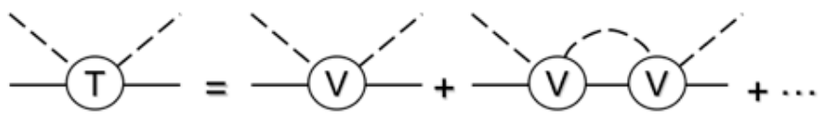
reduction of mass difference in the nuclear medium

Chiral unitary model

Kaiser, Siegel, Weise PLB362(95)23
Waas, Weise NPA625(97)287
Garcia-Recio, Nieves, Inoue, Oset PLB550(02)47
Inoue, Oset NPA710(02)354

N* : resonance dynamically generated
in meson-baryon scattering

→ quasi bound state of $K\Sigma$



coupled channel Bethe-Salpater eq. in medium

no Pauli blocking for Σ in nuclear medium

No mass shifts of N* is expected in the nuclear medium

Slide by Nagahiro @ HNP09

New experiment at J-PARC

- High statistics : ~10^6Hz π beam
- Recoilless condition ← zero-degree spectrometer
- exclusive measurement : tagging of decay products
  - N*(1535)→Nπ, N*(1535)N→NN

J-PARC

Japan Proton Accelerator Research Complex

400MeV LINAC

3GeV333μA

RCS

ν to SK

~500m

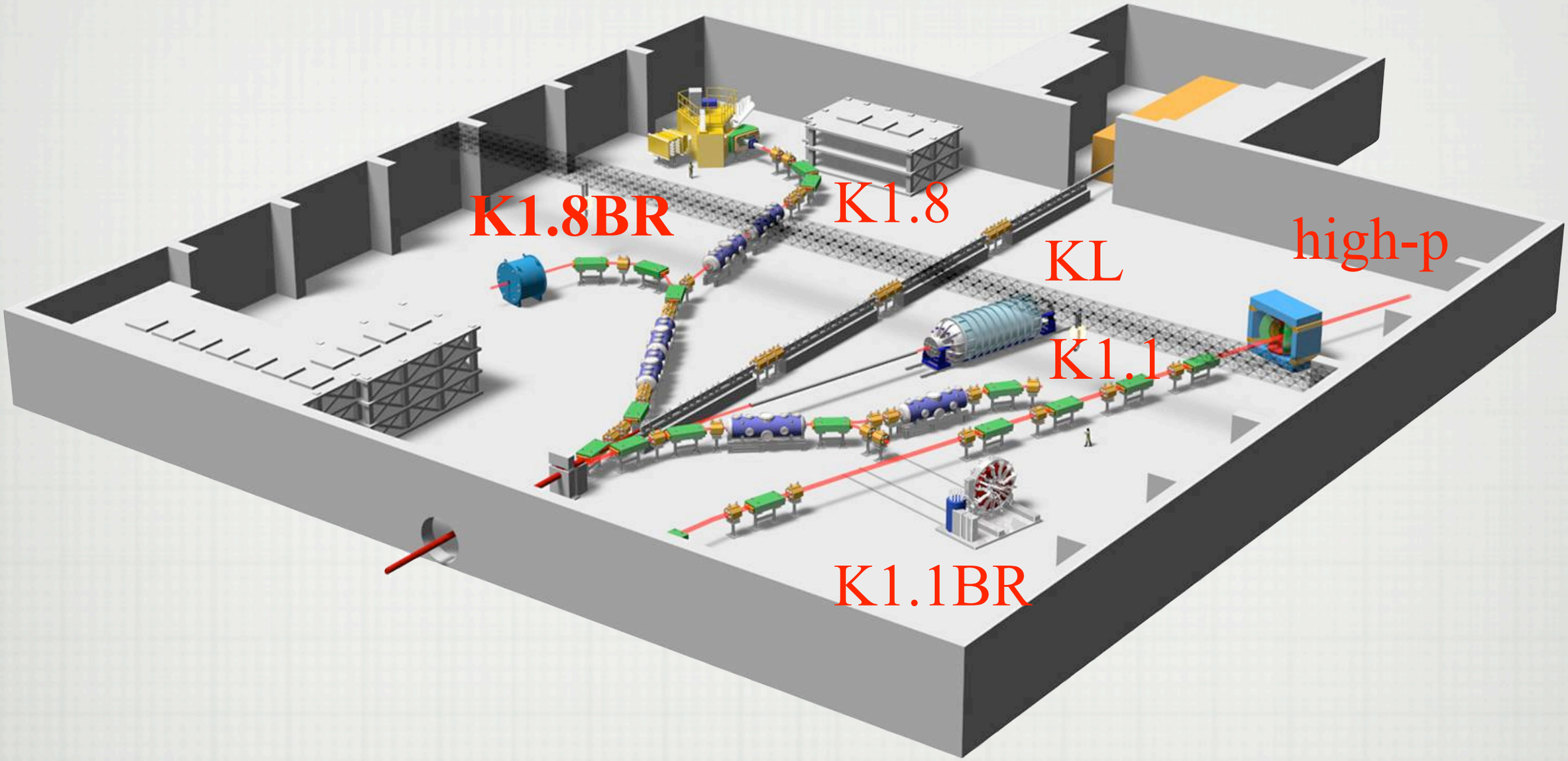
MLSF

50GeV-PS
15μA, 750kW

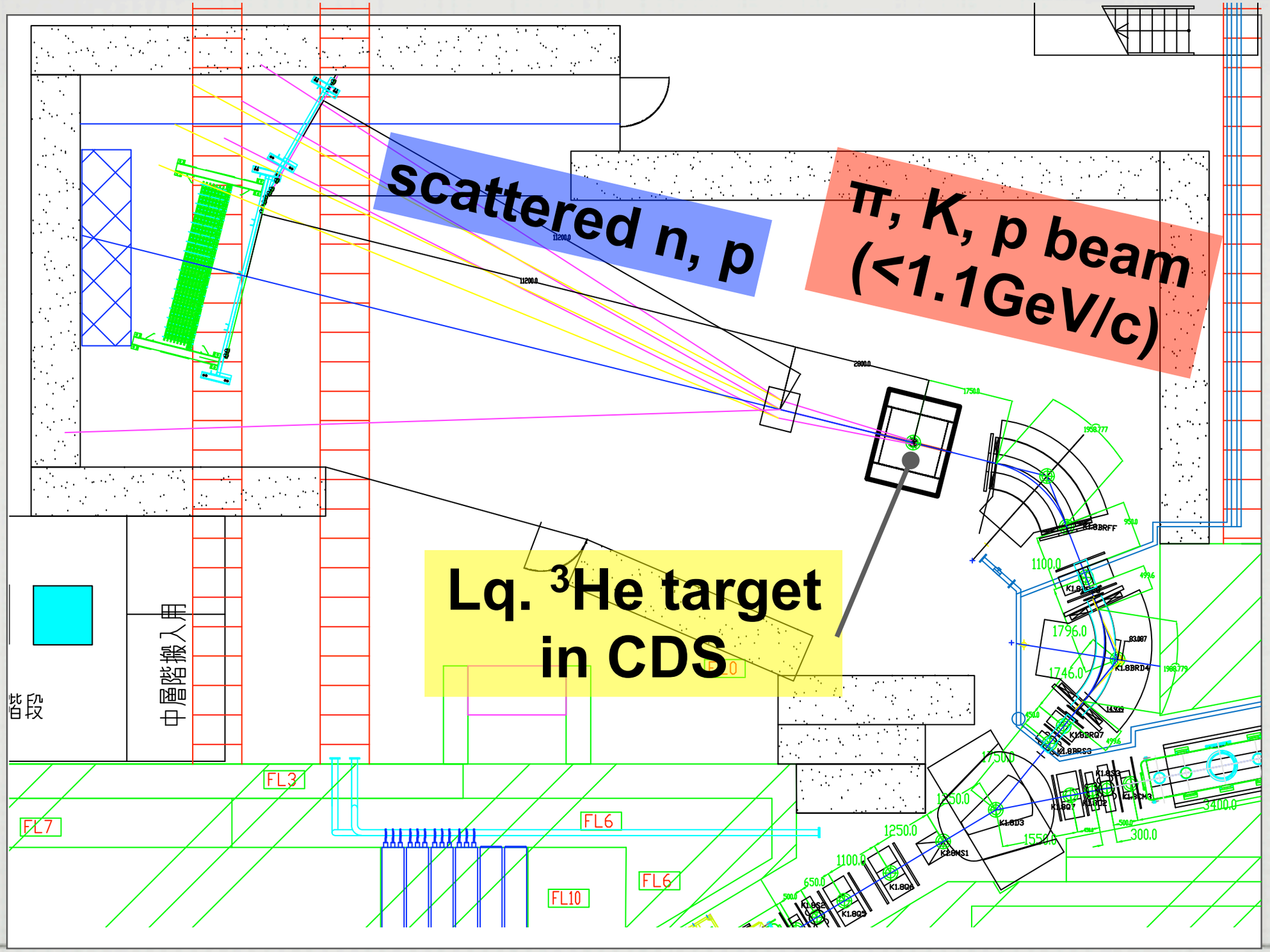
Bird's eye photo
in July 2009

Hadron Hall for Counter experiments

Hadron Experimental Hall



One possible idea with K1.8BR beamline will be discussed in this talk.



setup for E15 experiment @ K1.8BR beamline

J-PARC E15 experiment

- Search for K^-pp bound state
  (see talk by T. Hiraiwa @ MESON2010)

- missing-mass spectroscopy: $^3He(K^-, n)X$

- invariant-mass spectroscopy: $K^-pp \rightarrow \Lambda + p \rightarrow p + p + \pi^-$

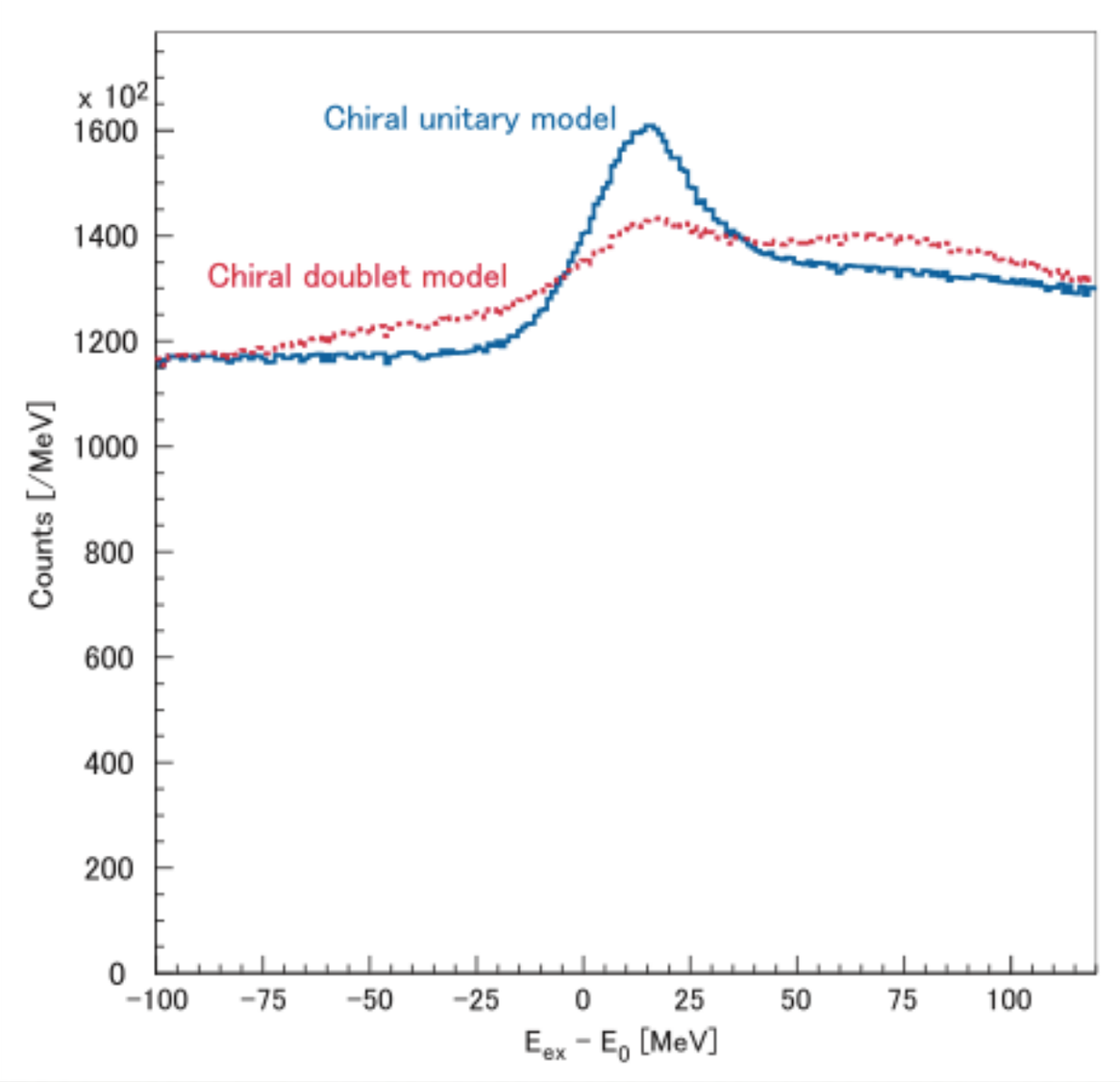
Analogy between E15 and eta nuclei exp. @J-PARC

- Search for K^-pp bound state → Search for eta mesic nuclei
  (see talk by T. Hiraiwa @ MESON2010)

- missing-mass spectroscopy: $^3He(K^-, n)X$
  → missing-mass spectroscopy: Li, $C(\pi^-, n)$ or (π^+, p)

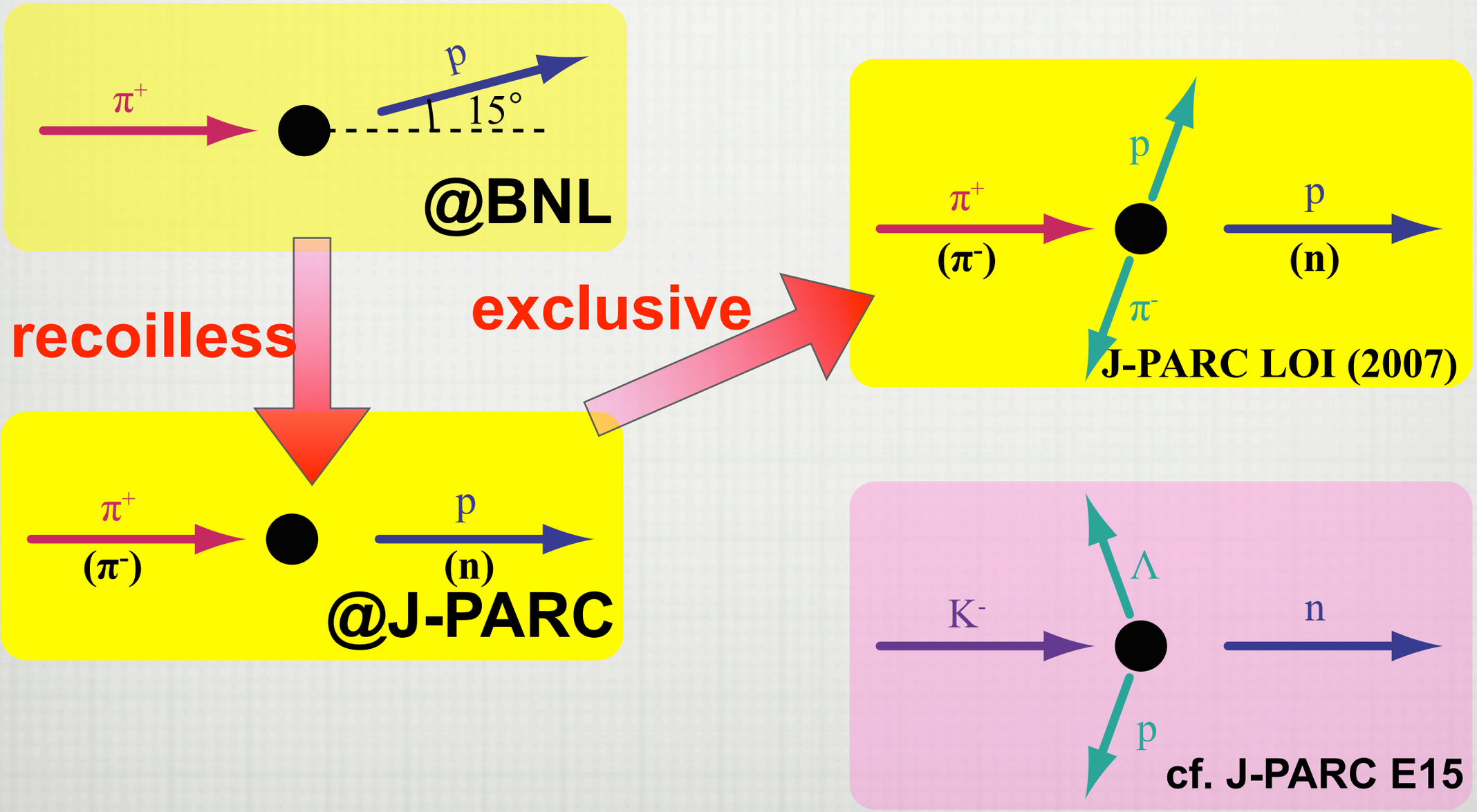
- invariant-mass spectroscopy: $K^-pp \rightarrow \Lambda+p \rightarrow p+p+\pi^-$
  → tagging of decay particles: $\eta N \rightarrow N^*(1535) \rightarrow \pi N$, $N^*N \rightarrow NN$

simulation: missing-mass spectra

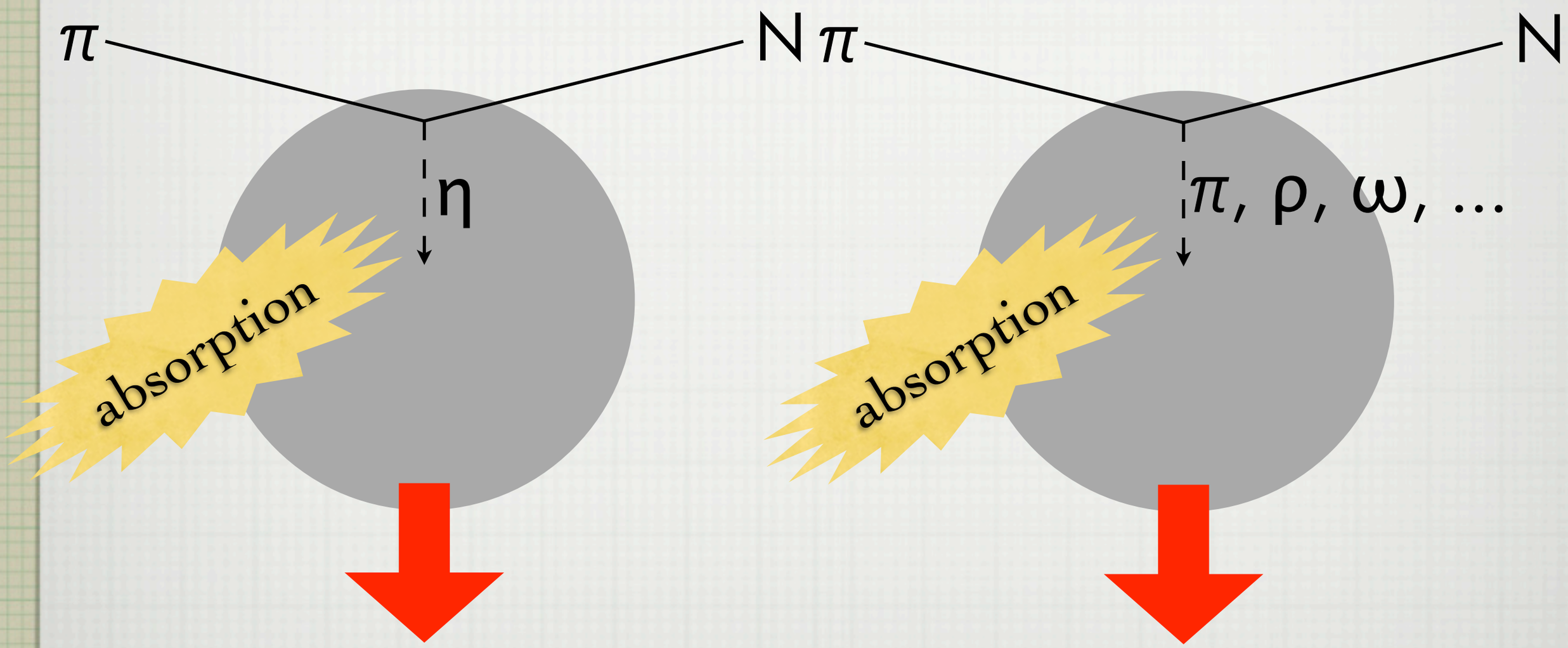


- ☐ ***inclusive*** ^{7}Li(π^-, n) reaction
- ☐ *constant* B.G., comparable with that obtained at BNL
- ☐ MM : 20MeV/c^2 (FWHM)
- ☐ Exclusive measurement will improve S/N ratio!

from BNL to J-PARC



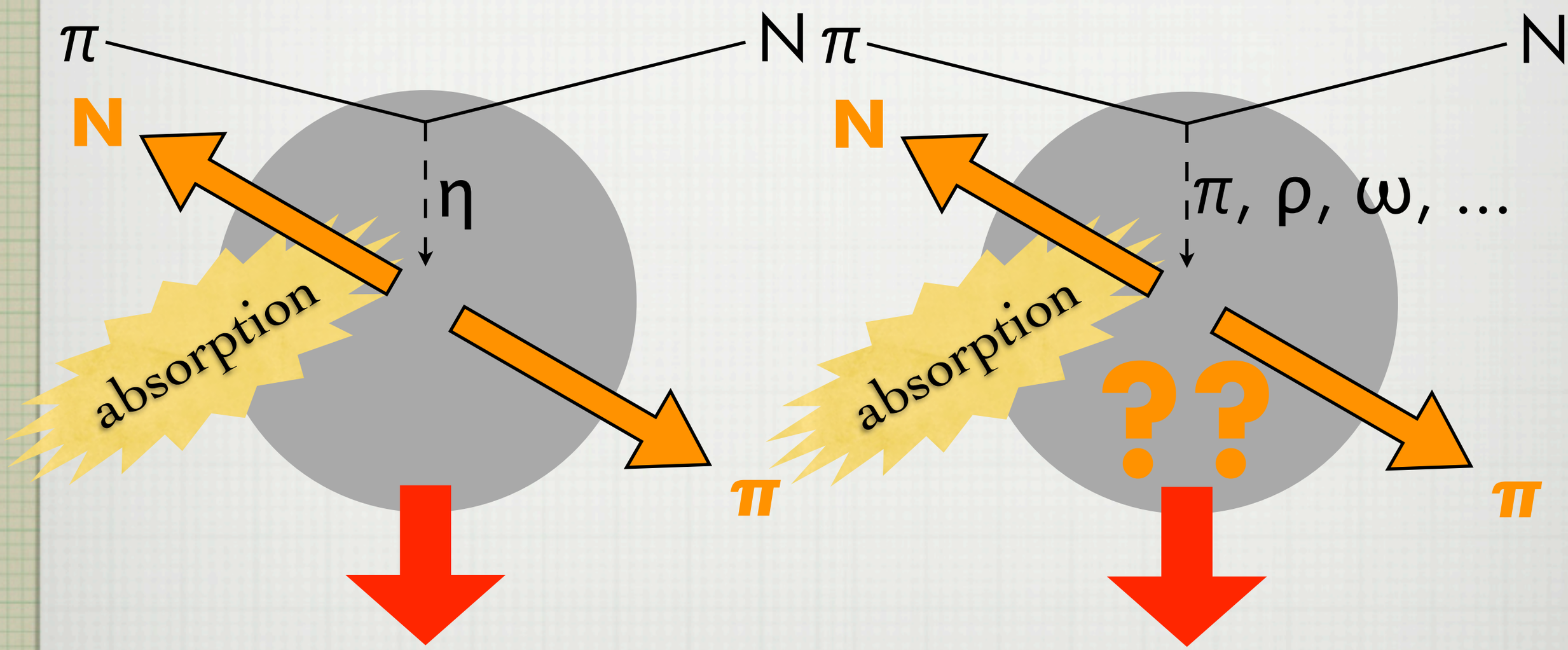
however, there are much more to be considered…



η-mesic nuclei!

background

however, there are much more to be considered...



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background

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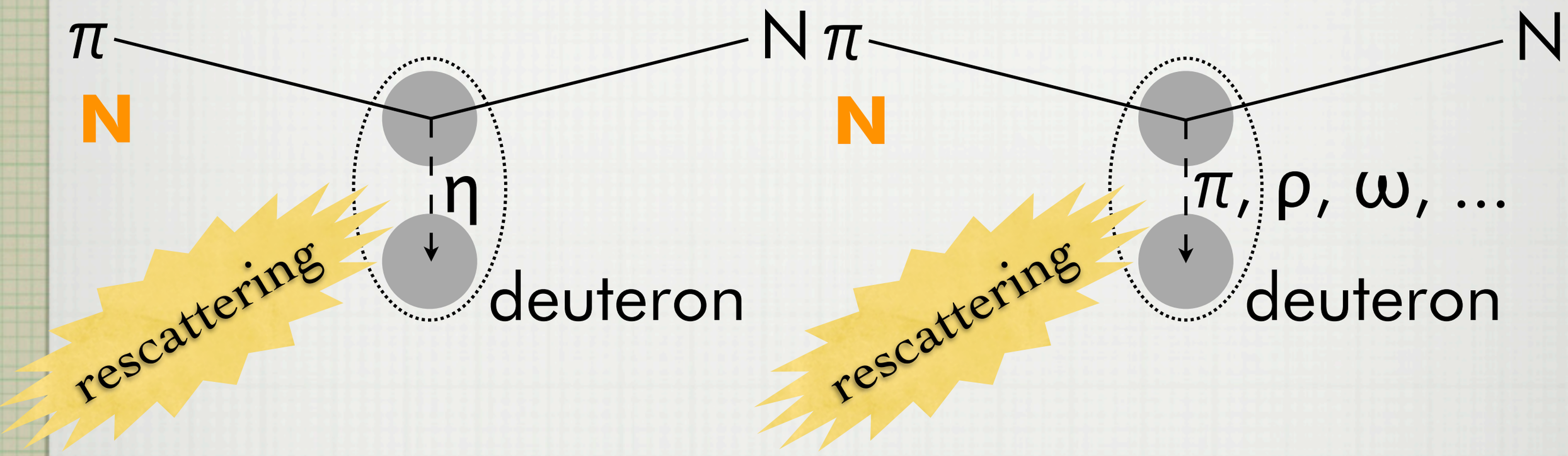


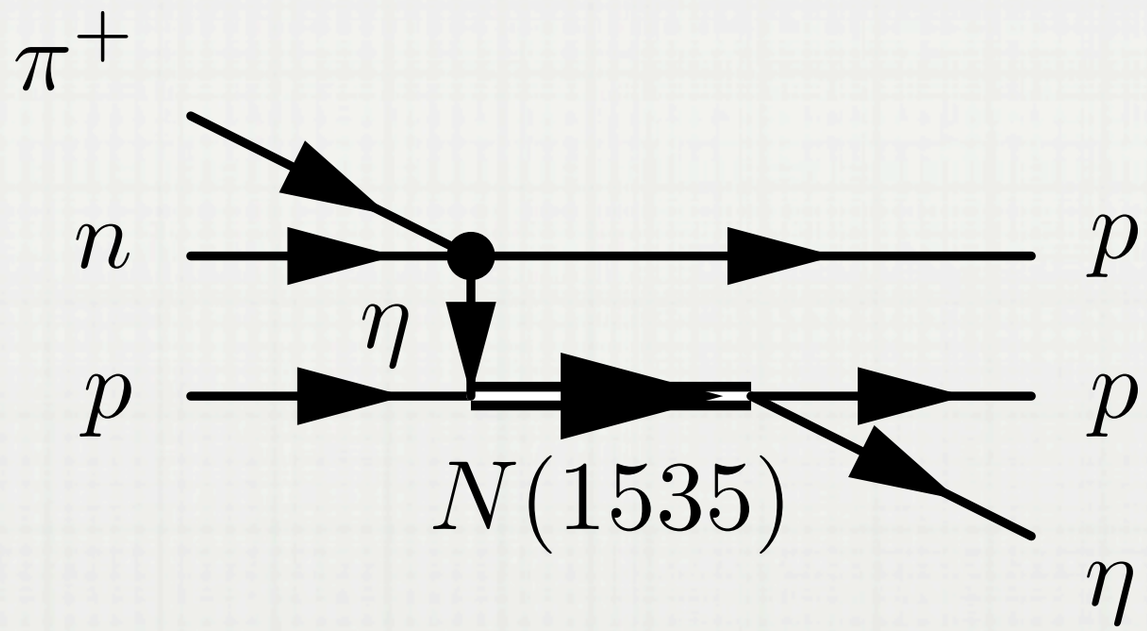
N*(1535)

background

Pilot experiment : d(π^+, p)p*

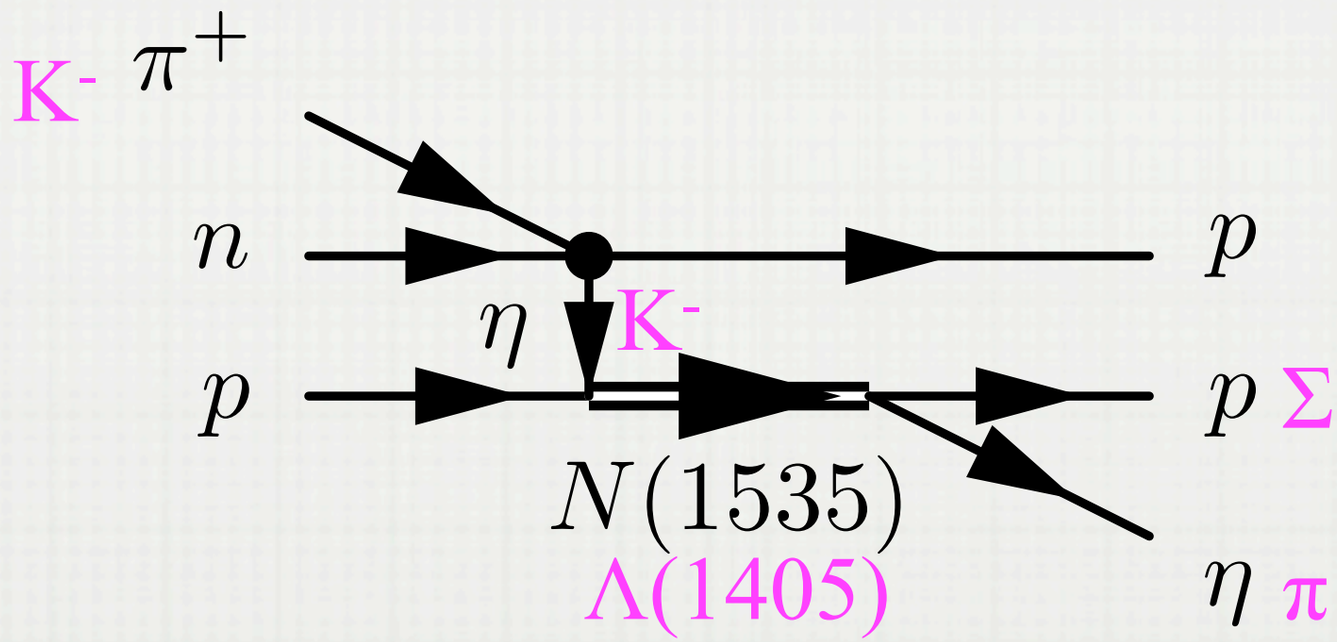
- N*(1535) ~ strongly couples with ηN
- [η-exchange] : N(1535) production : N(1535)→ η+N, π+N, ...
- [non-η-exchange] : rescattering of meson+N → π+N, ~~η+N~~, ...
- measurement of π+d→ppη, ppπ^0 reactions and estimation of N(1535) production cross section

double-scattering process



- cf. $K^- + d \to \Lambda^*(1405) + n$, $\Lambda^* \to \Sigma + \pi$ (J-PARC E31 experiment)
- low-energy $\eta N \to \eta N$ interaction might be investigated.

double-scattering process



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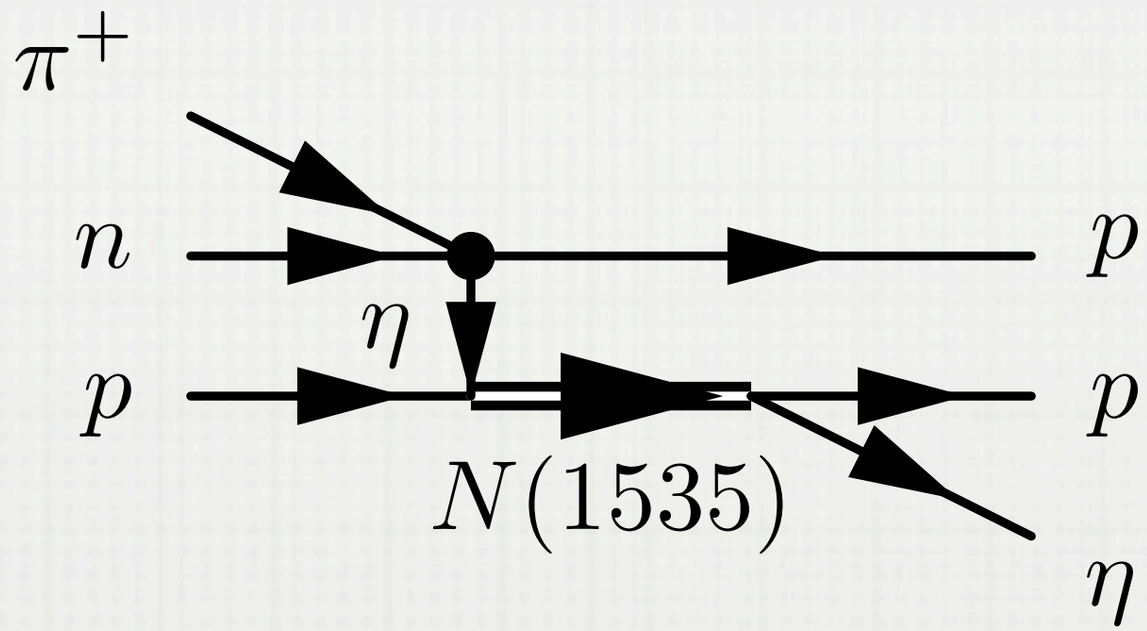
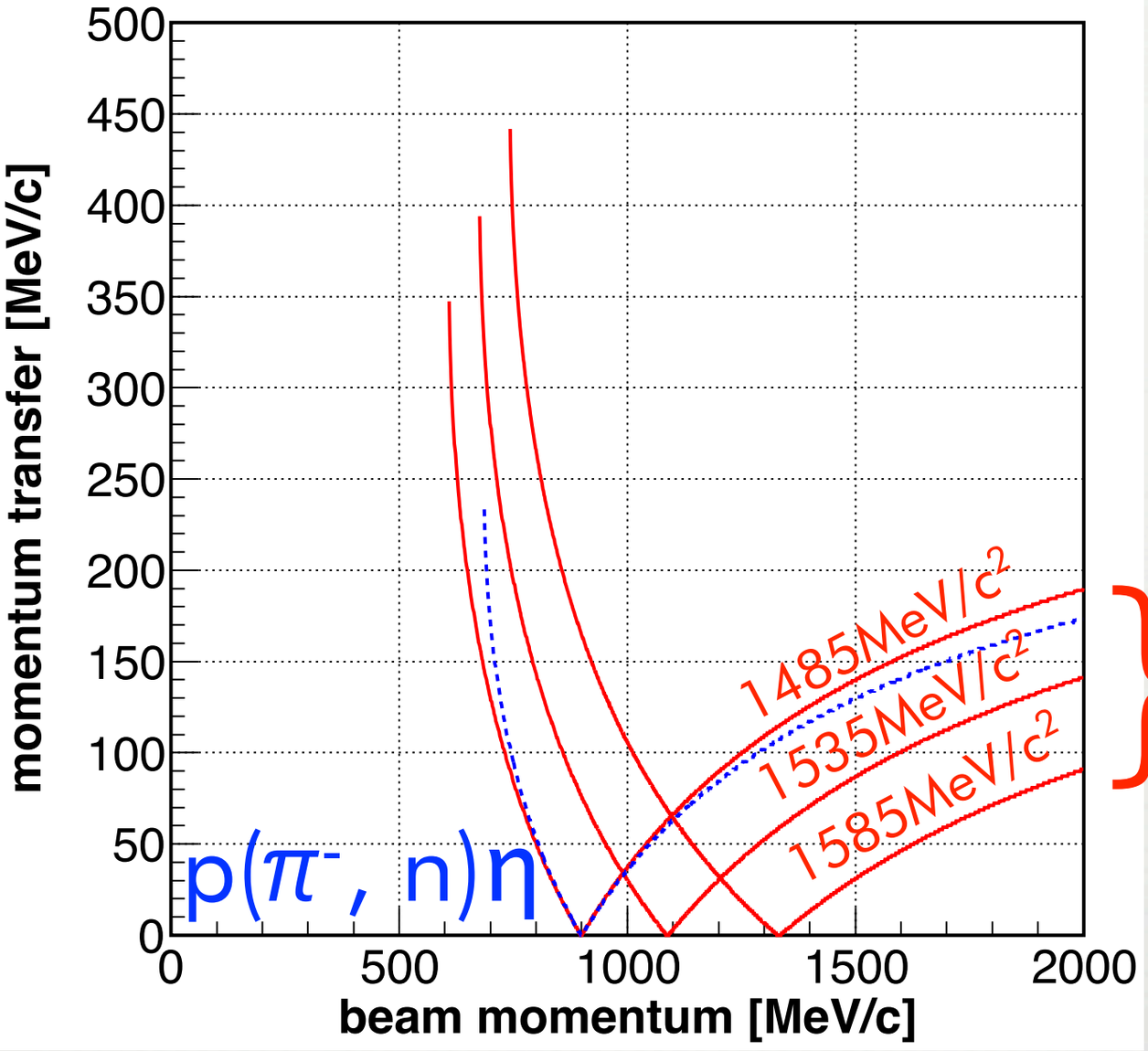


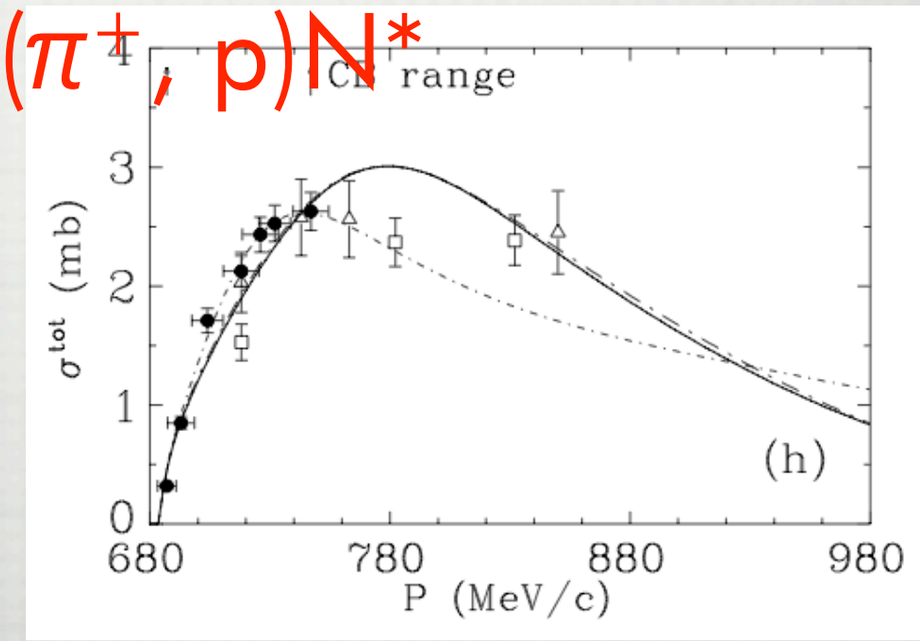
- cf. $K^- + d \to \Lambda^*(1405) + n$, $\Lambda^* \to \Sigma + \pi$ (J-PARC E31 experiment)
- low-energy $\eta N \to \eta N$ interaction might be investigated.

momentum transfer



- The beam momentum will be around 0.8GeV/c, where the cross section is almost maximum, and the recoil momentum is relatively small.

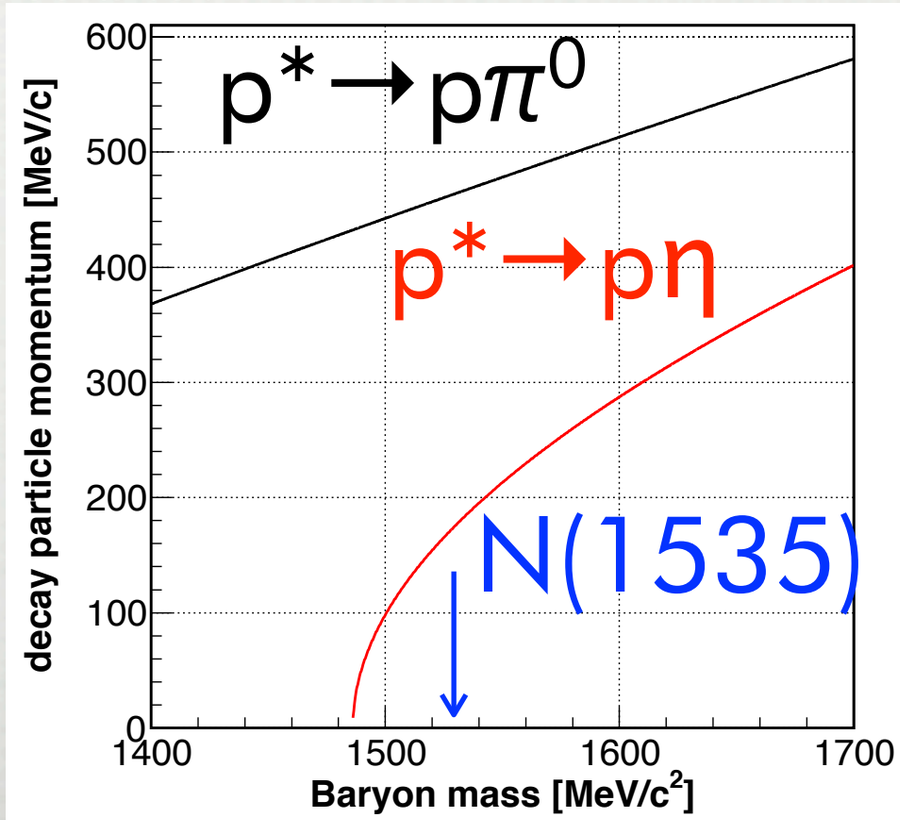
d(π⁺, p)N*

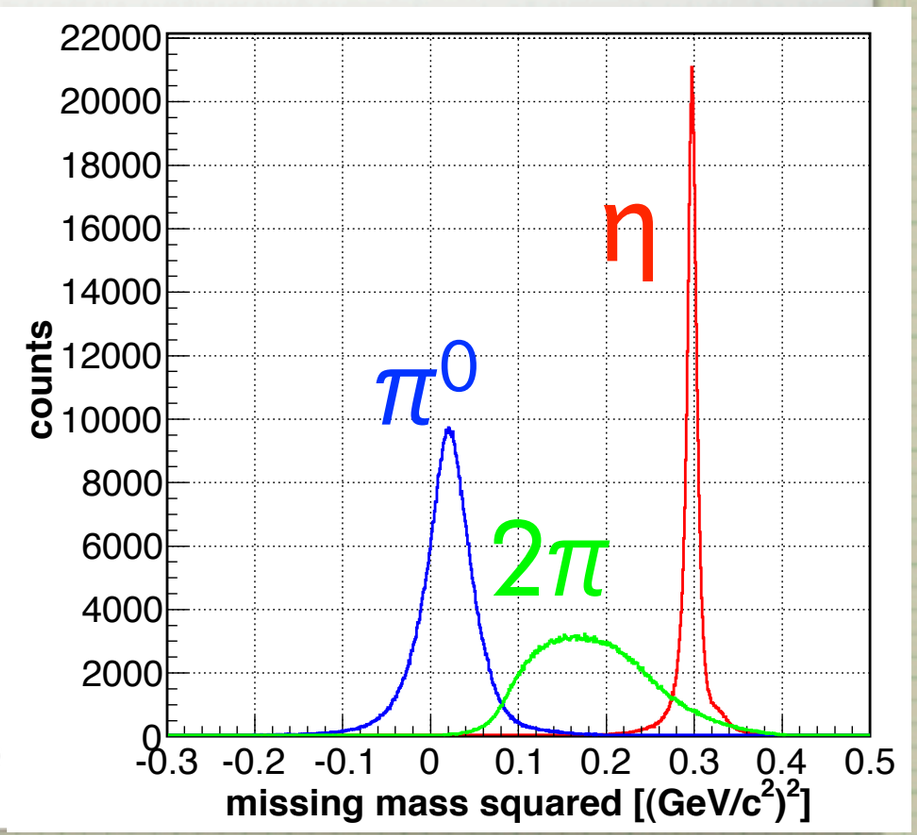


experimental setup (idea)

- a forward proton (N* production) and
  a sideward proton (N* decay) to be detected.
  → π^0 and η are identified by the missing-mass d(π^+, pp)X

- target : deuterium gas (<1MPa), in order to detect as slow protons as possible.





Summary -1-

- Search for η-mesic nuclei by use of the (π, N) reaction
  - GOOD: recoilless condition, exclusive measurement
  - BAD: huge background, even after Nπ coincidence ?
- Pilot experiment with deuterium gas target : $d(\pi^+, p)$
  - N(1535) production v.s. background contribution
  - final state ppη (signal) v.s. $pp\pi^0$ (signal+background)

Summary -2-

- $d(\pi^+, p)p^*(1535)$
- $^3He(\pi, N)\eta NN$: unbound?
- $^4He(\pi, N)\eta NNN$: can $^3He\eta$ be bound?
- $^{6/7}Li(\pi, N)$: smaller $(0p_{3/2})_N^{-1}(0p)_\eta$ contribution that for ^{12}C
- $^{12}C(\pi, N)$: $(0s_{1/2})_N^{-1}(0s)_\eta$ and $(0p_{3/2})_N^{-1}(0p)_\eta$ states overlaps!
- Inputs from η-mesic nuclei community (both experimentally and theoretically) are very welcome!!

What should we do?