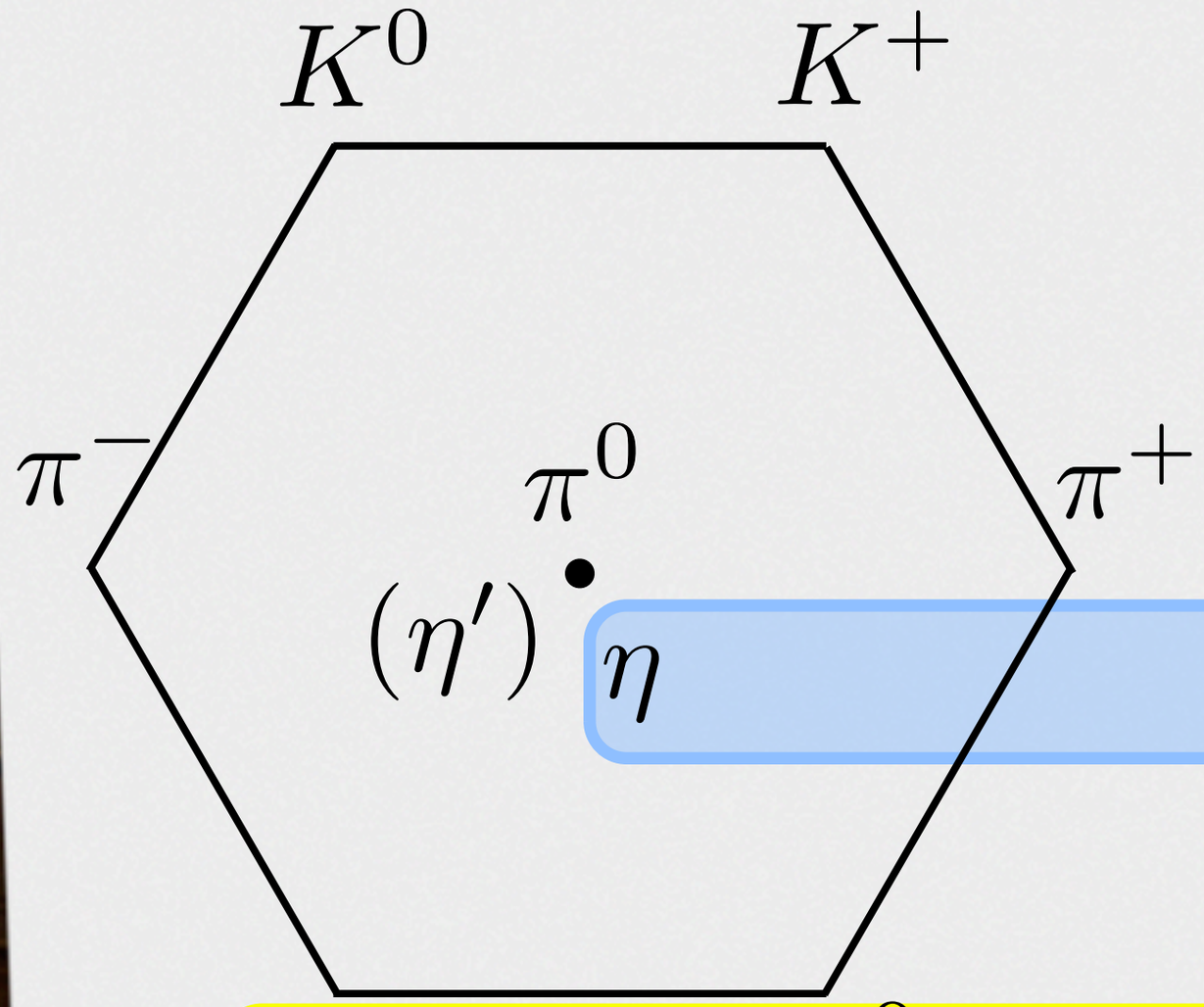
Experimental studies of mesic nuclei at J-PARC

Hiroyuki FUJIOKA (Kyoto Univ.)

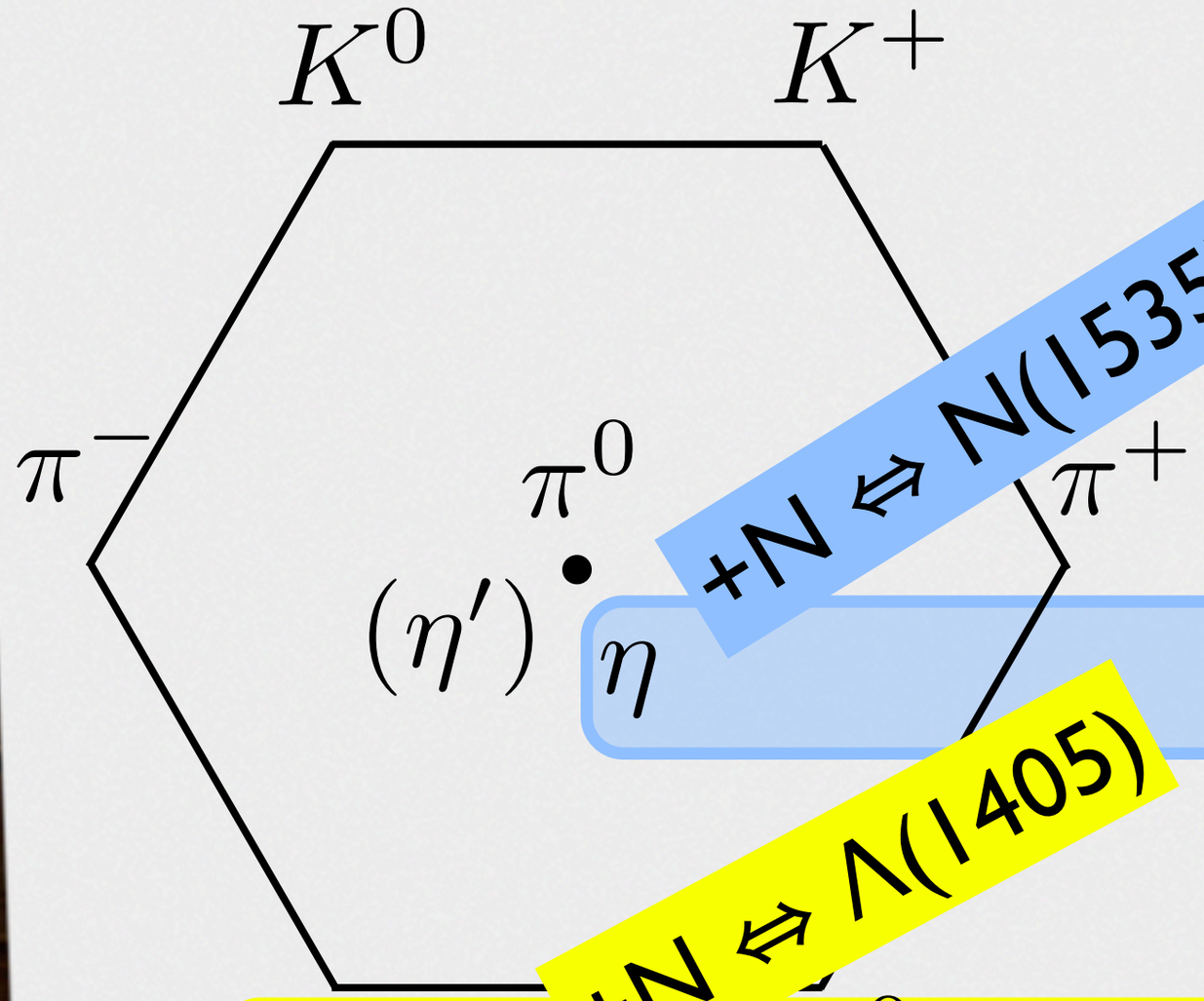
Pseudoscalar meson in nuclei



weakly attractive

K^- $\overline{K}^0$ attractive (strongly? weakly?)

Pseudoscalar meson in nuclei



+N ⇔ N(1535)

η weakly attractive

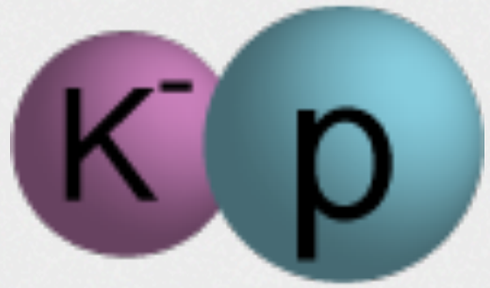
+N ⇔ Λ(1405)

K^- $\overline{K}^0$ attractive (strongly? weakly?)

Antikaon + Nucleon

$\Lambda(1405)\ S_{01}$

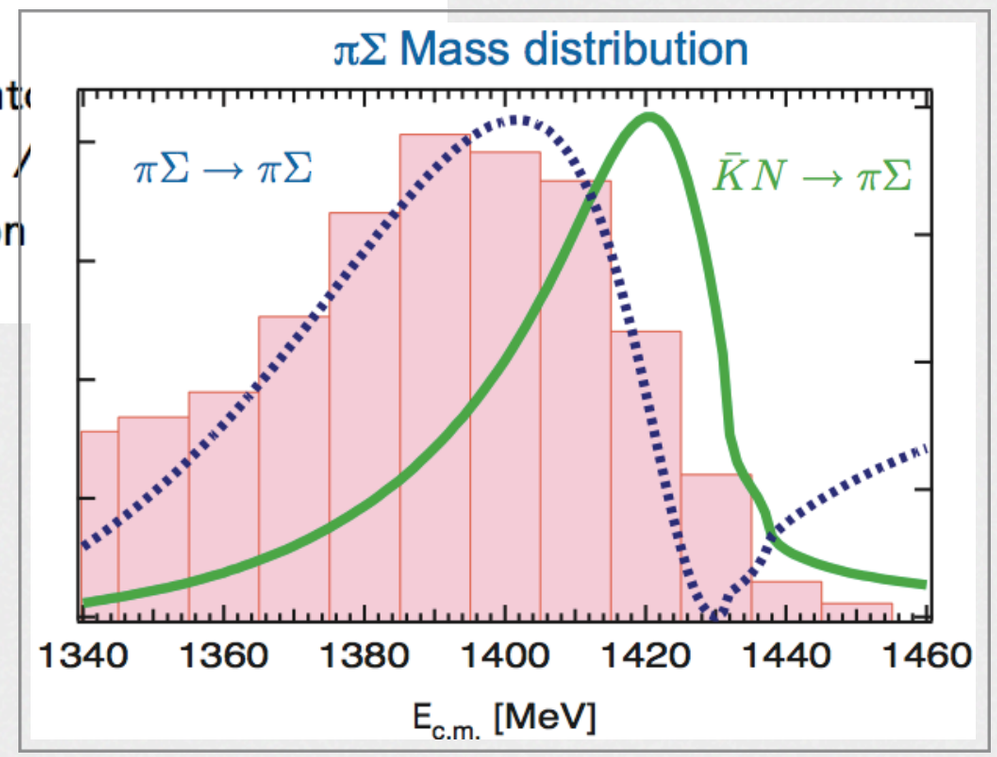
$I(J^P) = 0(\frac{1}{2}^-)$ Status: ****



It seems to be the universal opinion of the chiral-unitary community that there are two poles in the 1400-MeV region. For discussions and earlier references, see for example MAGAS 05 and JIDO 03. ZYCHOR 08 presents experimental evidence against the two-pole model, but this is disputed by GENG 07A. See also REVAI 09, which finds little basis for choosing between one- and two-pole models.

See also the "Note on the $\Lambda(1405)$" in our 2000 edition, The European Physical Journal **C15** 1 (2000).

A single, ordinary three-quark $\Lambda(1405)$ fits nicely int
$1/2^-$ SU(4) $\overline{4}$ multiplet, whose other members are the Λ
$\Xi_c(2790)^+$, and $\Xi_c(2790)^0$; see Fig. 1 of our note on
Baryons."



D. Jido et al., NPA 725, 181 (2003)

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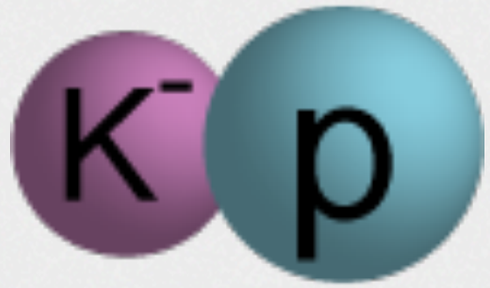

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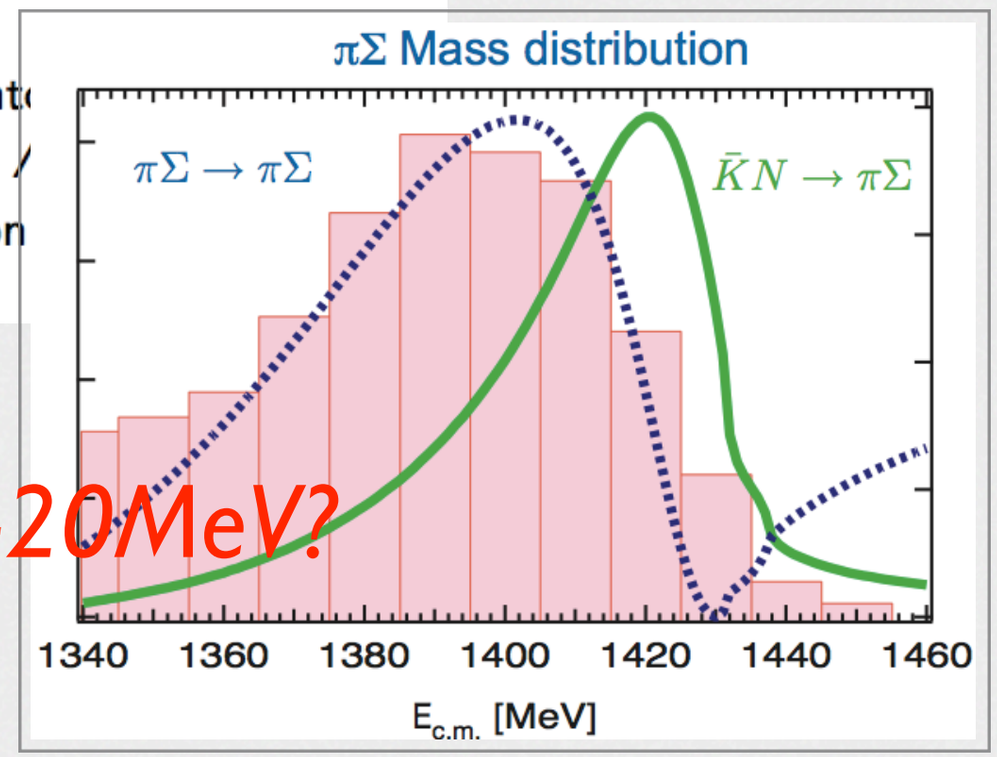
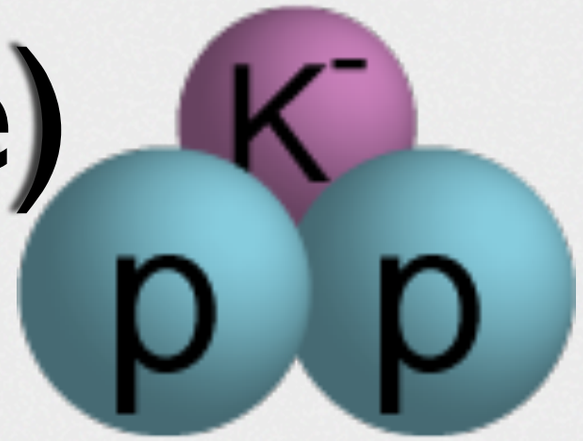


one-pole state? two-pole state?
$\bar{K}N$ bound state at 1405MeV? 1420MeV?

D. Jido et al., NPA 725, 181 (2003)

Antikaon + Two Nucleons ($\bar{K}NN$ bound state)



theory

Table 4: Summary of theoretical studies on the $\bar{K}NN$-$\pi\Sigma N$ system. We denote the mass of the states as the "binding energy" $B_{\bar{K}NN}$ measured from the $\bar{K}NN$ threshold. Γ_m represents the width of the mesonic decay into $\pi\Sigma N$ and $\pi\Lambda N$ channels. Ref. [210] found additional pole which is broad.

Refs.	[204, 205]	[202]	[206]	[208, 209]	[210]
interaction	Energy independent			Energy dependent	
	pheno.	pheno.	chiral	chiral	chiral
method	Faddeev	variational	Faddeev	variational	Faddeev
$\pi\Sigma N$ dynamics	explicit	effective	explicit	effective	explicit
$B_{\bar{K}NN}$ [MeV]	50-70	48	60-95	17-23	9-16
Γ_m [MeV]	90-110	60	45-80	40-70	34-46

The bound state will exist.

(B<100MeV, Γ: moderately large)

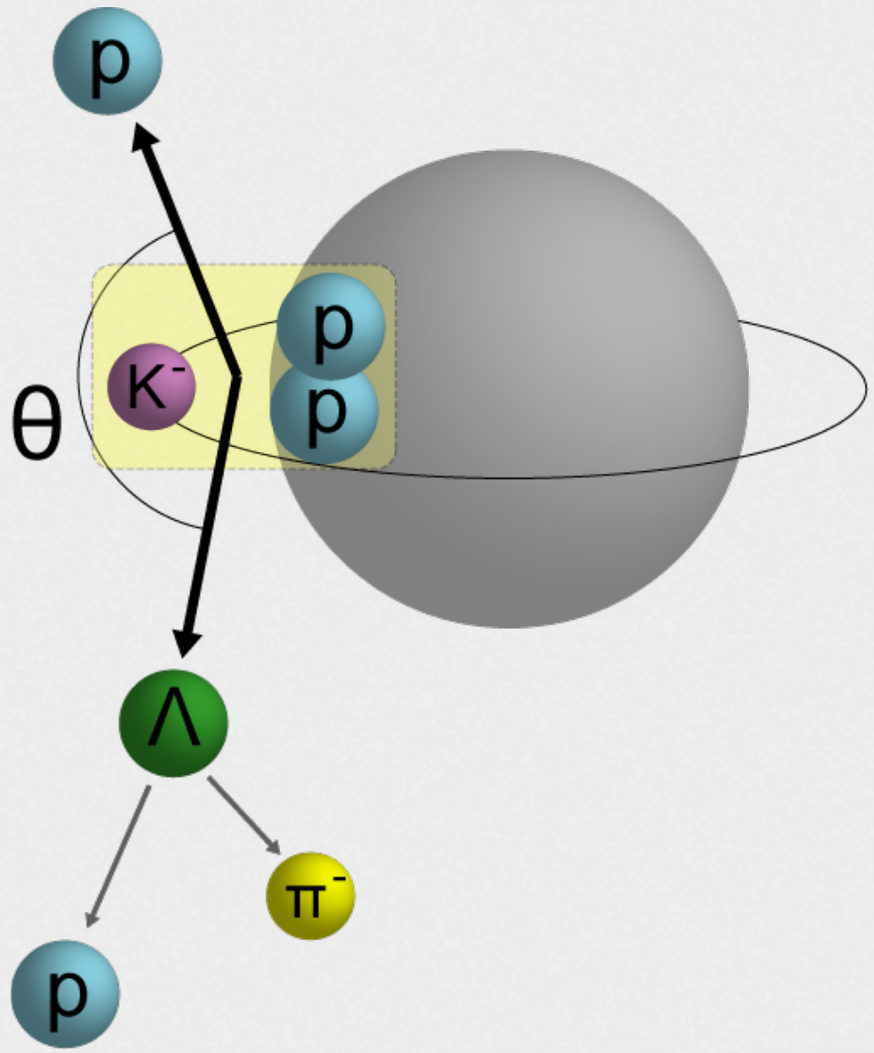
T. Hyodo and D. Jido, arXiv:1104.4474 [nucl-th]

Antikaon + Two Nucleons ($\bar{K}NN$ bound state)

experiment

FINUDA (2005) and DISTO (2010)

stopped K^- + A (Li, C) → p + Λ + X
(invariant mass spectroscopy)



Phys. Rev. Lett. 94, 212303 (2005)

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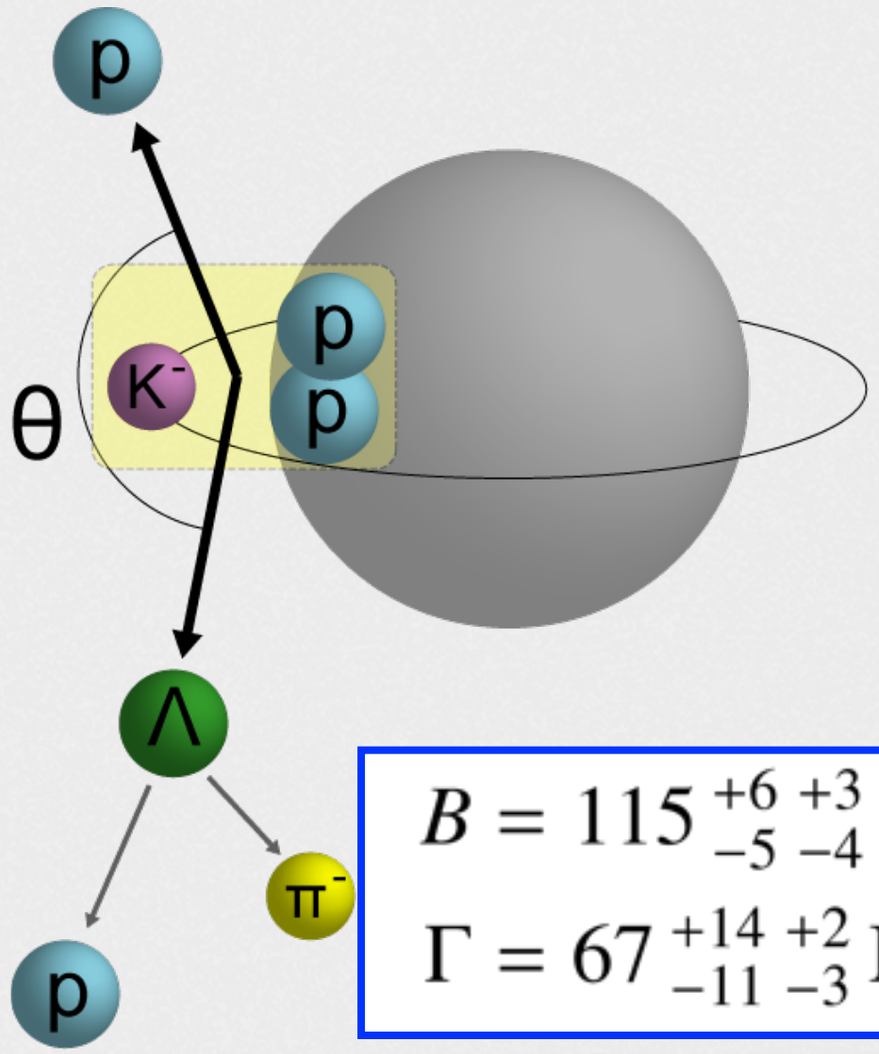
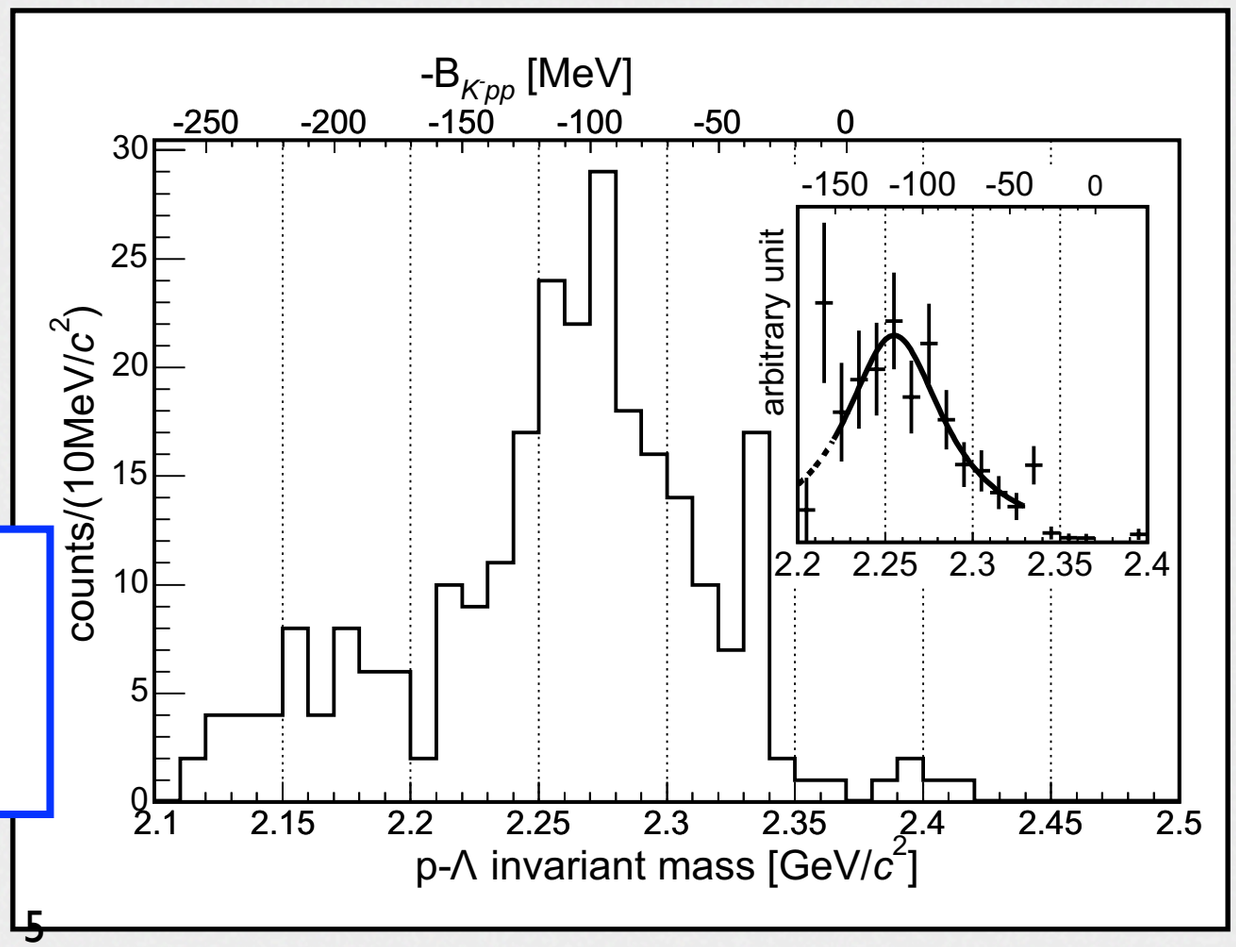


$$B = 115\ ^{+6}_{-5}\ ^{+3}_{-4}\ \text{MeV}$$

$$\Gamma = 67\ ^{+14}_{-11}\ ^{+2}_{-3}\ \text{MeV}$$

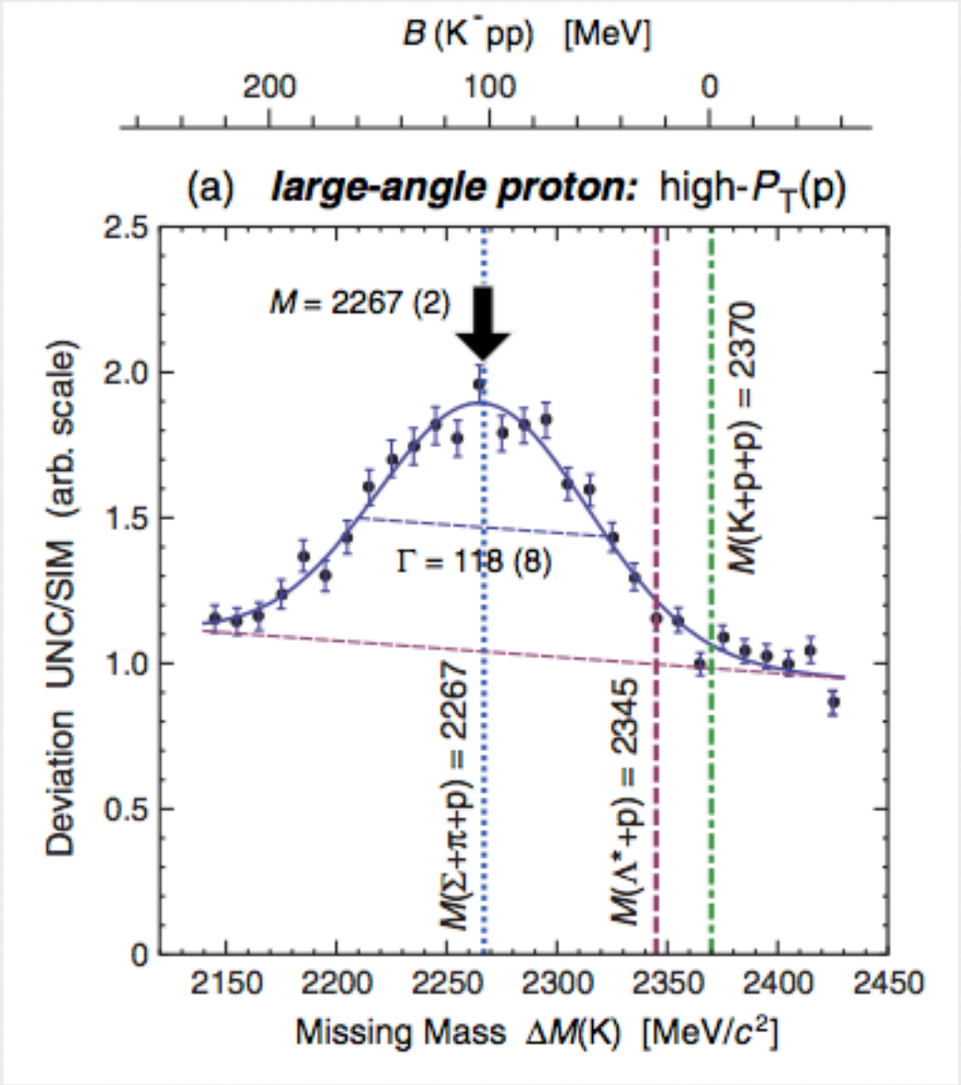


Phys. Rev. Lett. 94, 212303 (2005)

Antikaon + Two Nucleons ($\bar{K}NN$ bound state)

experiment FINUDA (2005) and DISTO (2010)

p + p → p + Λ + K^+ @ 2.85GeV
(missing mass spectroscopy & invariant mass spectroscopy)



M_X=2267±3±5MeV

Γ_X=118±8±10MeV

Phys. Rev. Lett. 104, 132502 (2010)

Present Status

- FINUDA
  - Magas et al. [Phys. Rev. C 74, 025206 (2006)] final state interaction after 2-nucleon absorption?
  - analysis with higher statistics data (2006-2007)
- DISTO
  - reanalysis @ 2.50GeV [arXiv: 1102.0482]
  - new experiment at GSI-FOPI

New experiments at J-PARC

toward confirmation of the (non-) existence of kaon-bound states

- E15 : ^{3}He(K^-, n)K^-pp, ^{3}He(K^-, p)K^-pn
- E27 : d(π^+, K^+)K^-pp
- LoI : stopped $\overline{p}+{}^3He \rightarrow K^+ + K^0 + K^- K^- pp$
- LoI : ^{3}He(stopped K^-, n)K^-pp

http://j-parc.jp/NuclPart/Proposal_e.html

J-PARC

Japan Proton Accelerator Research Complex

400MeV LINAC

3GeV333μA

RCS

ν to SK

~500m

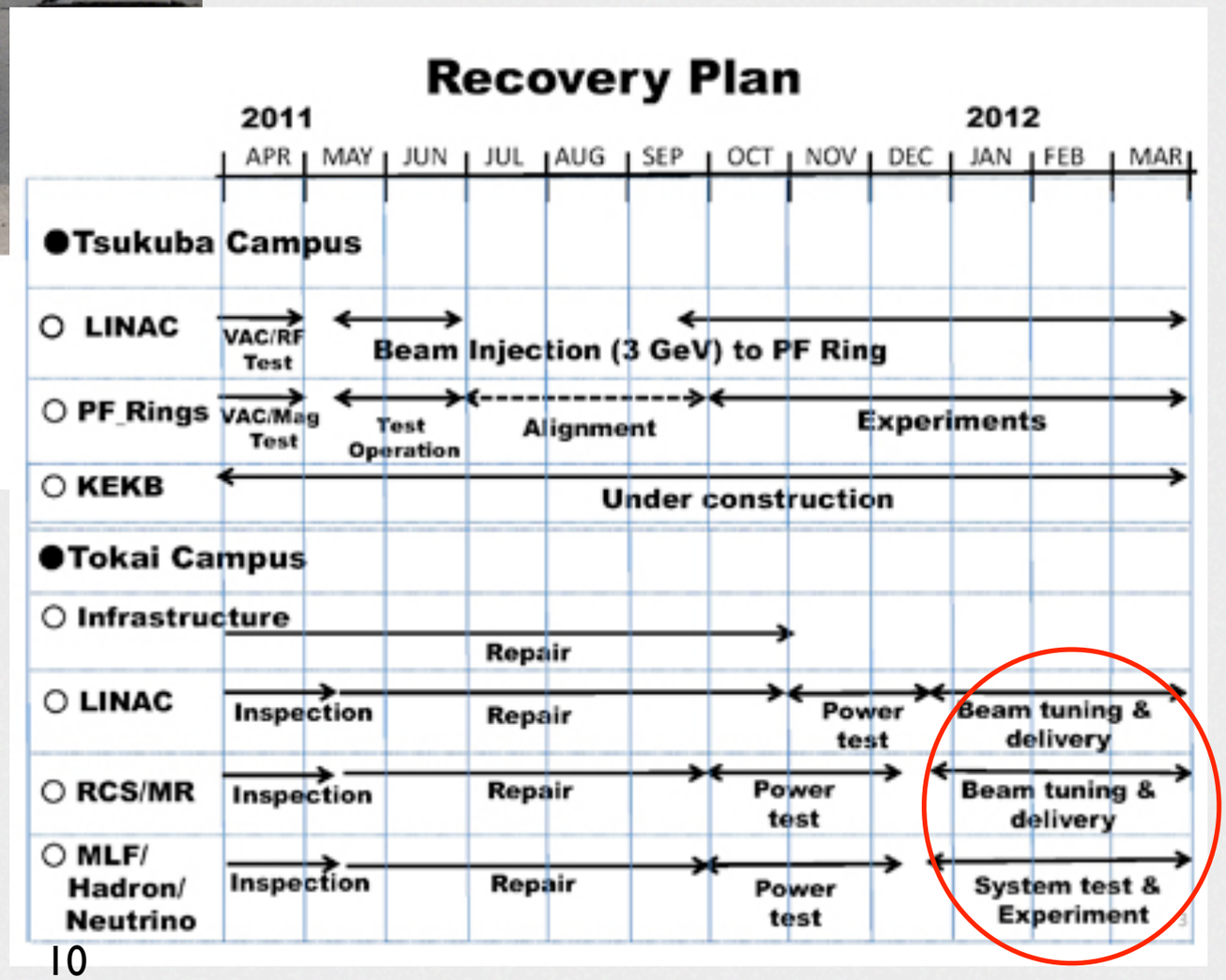
MLSF

50GeV-PS
15μA, 750kW

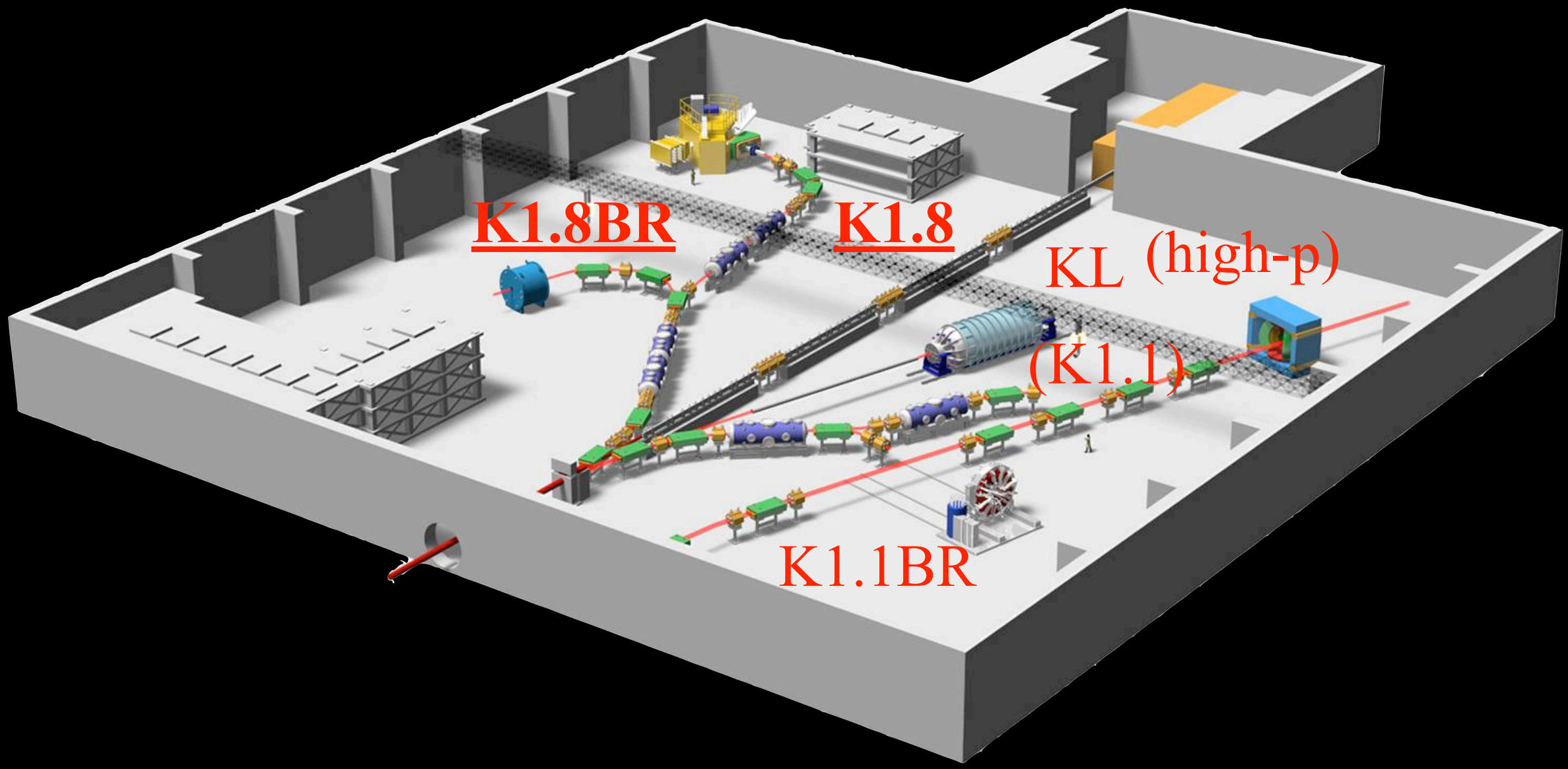
Bird's eye photo
in July 2009

Hadron Hall for Counter experiments

Giant Earthquake on 3.11



http://kek.jp


K1.8BR
K1.8
KL (high-p)
(K1.1)
K1.1BR

K1.8

K1.8BR

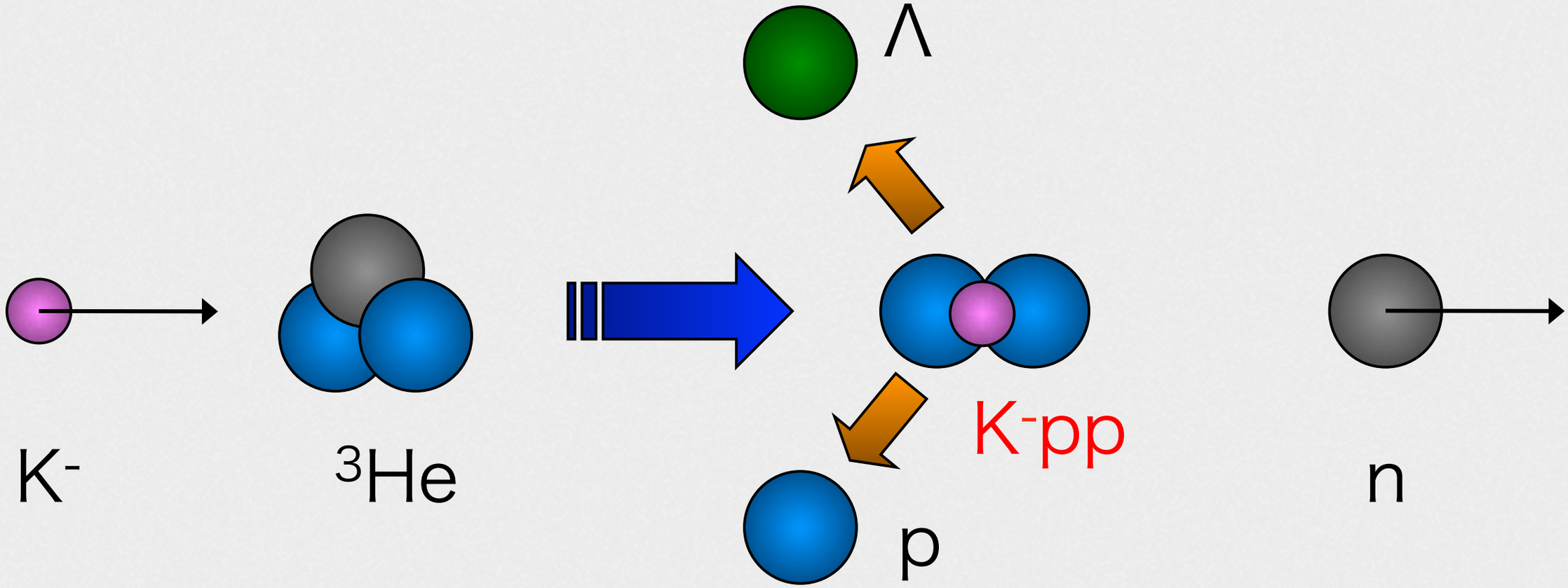
E27 (π^+, K^+)

π, K, ... from production target

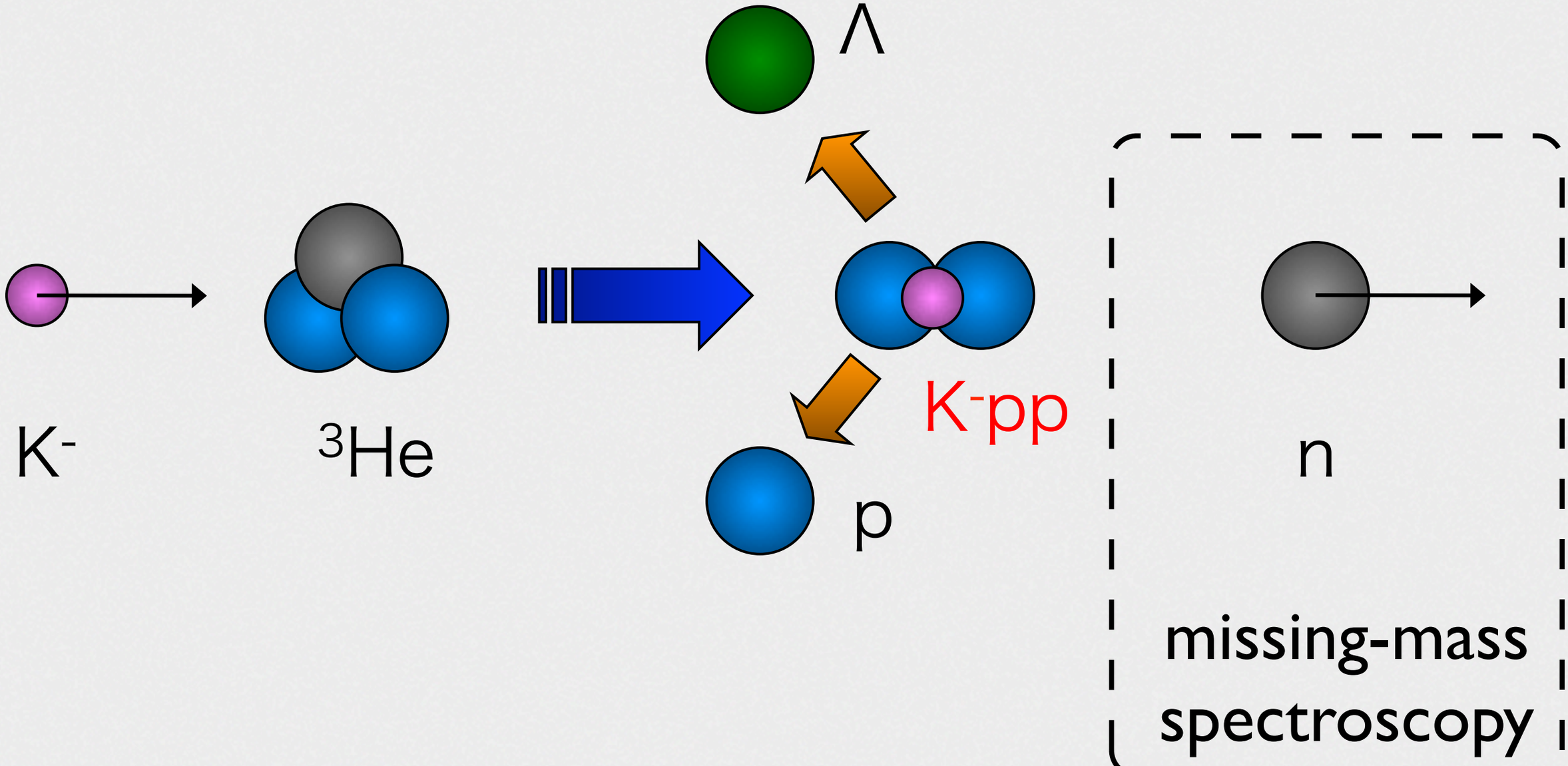
E15 (K^-, n)

(Feb. 2011)

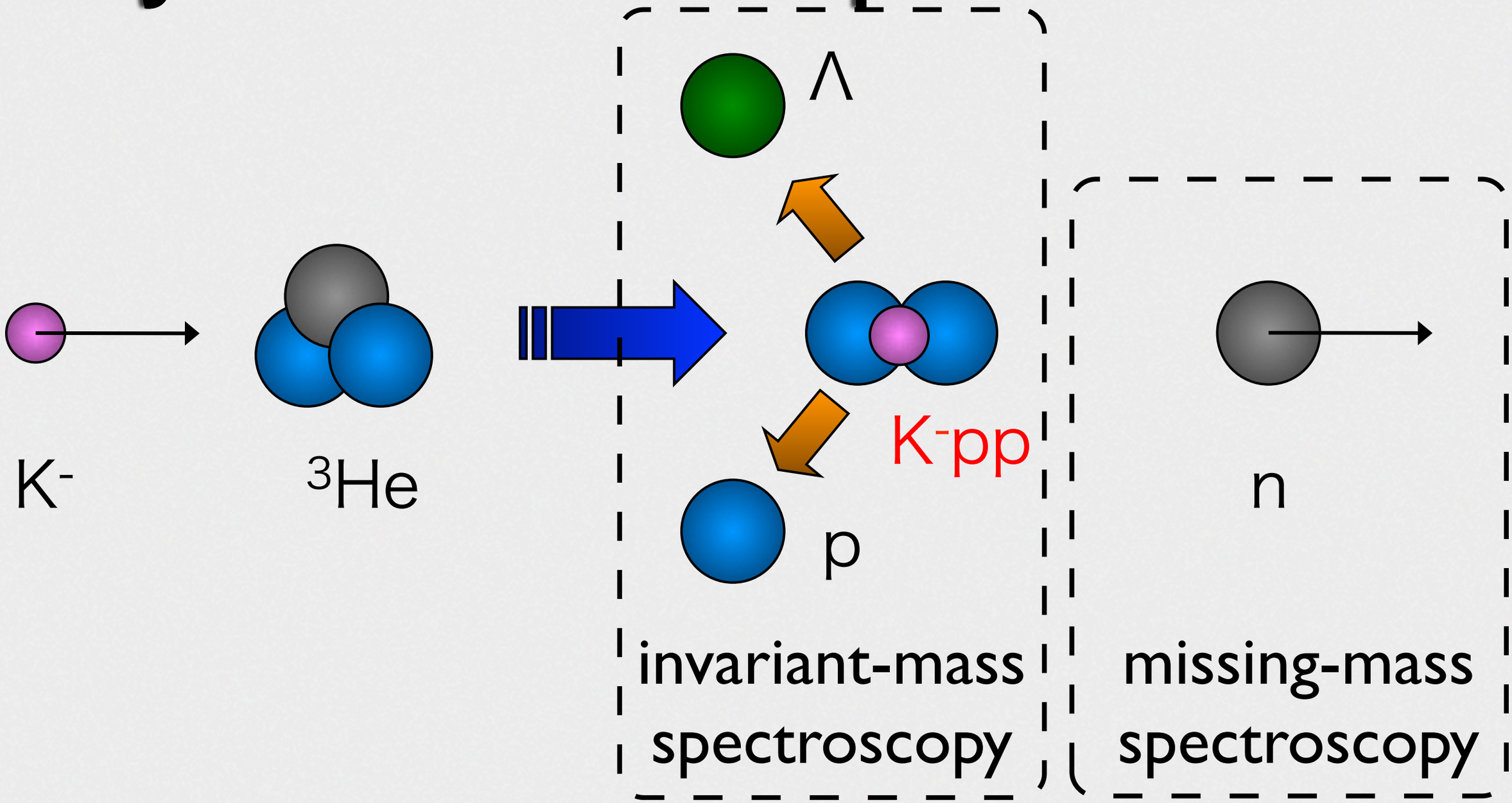
J-PARC E15 experiment



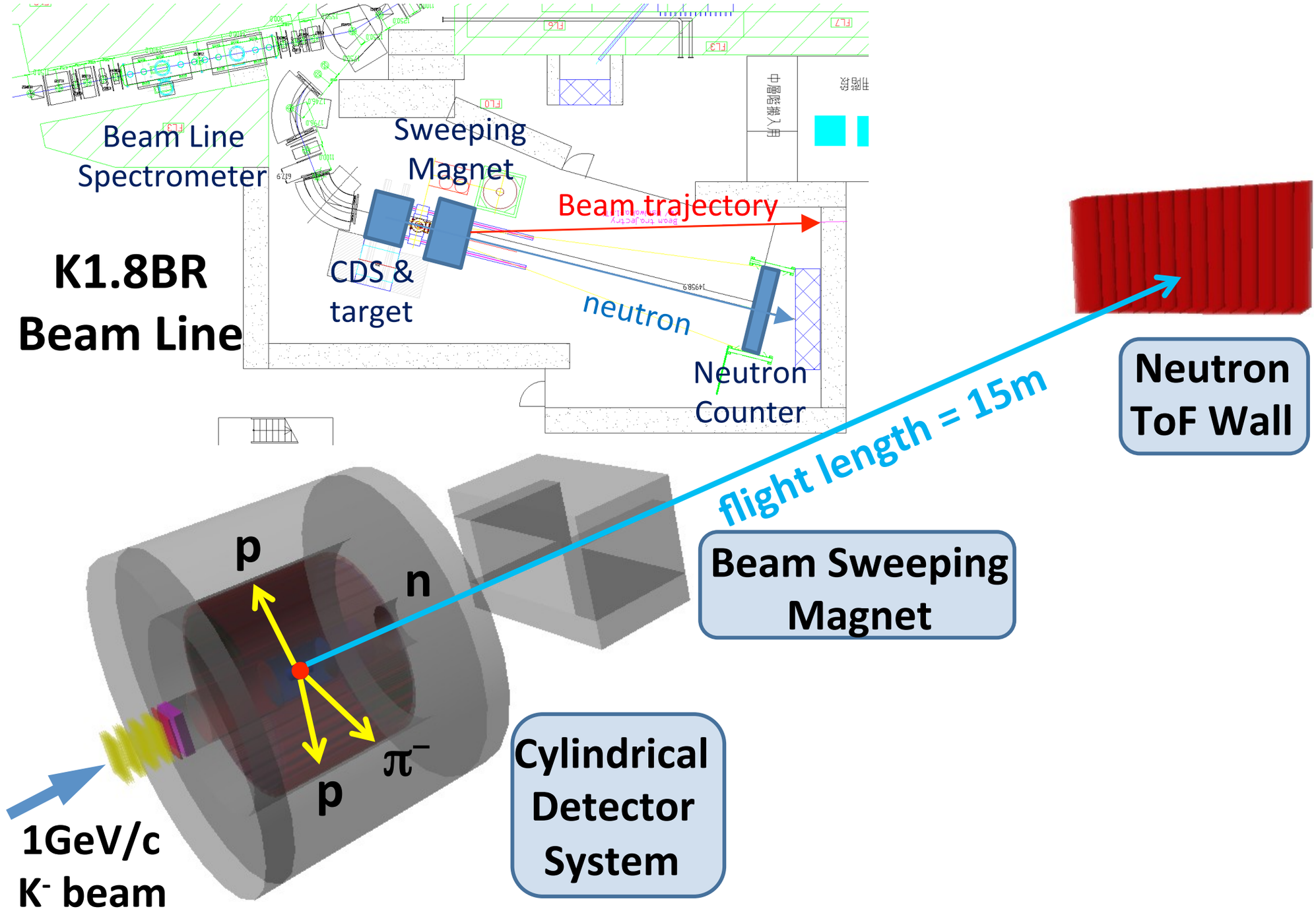
J-PARC E15 experiment



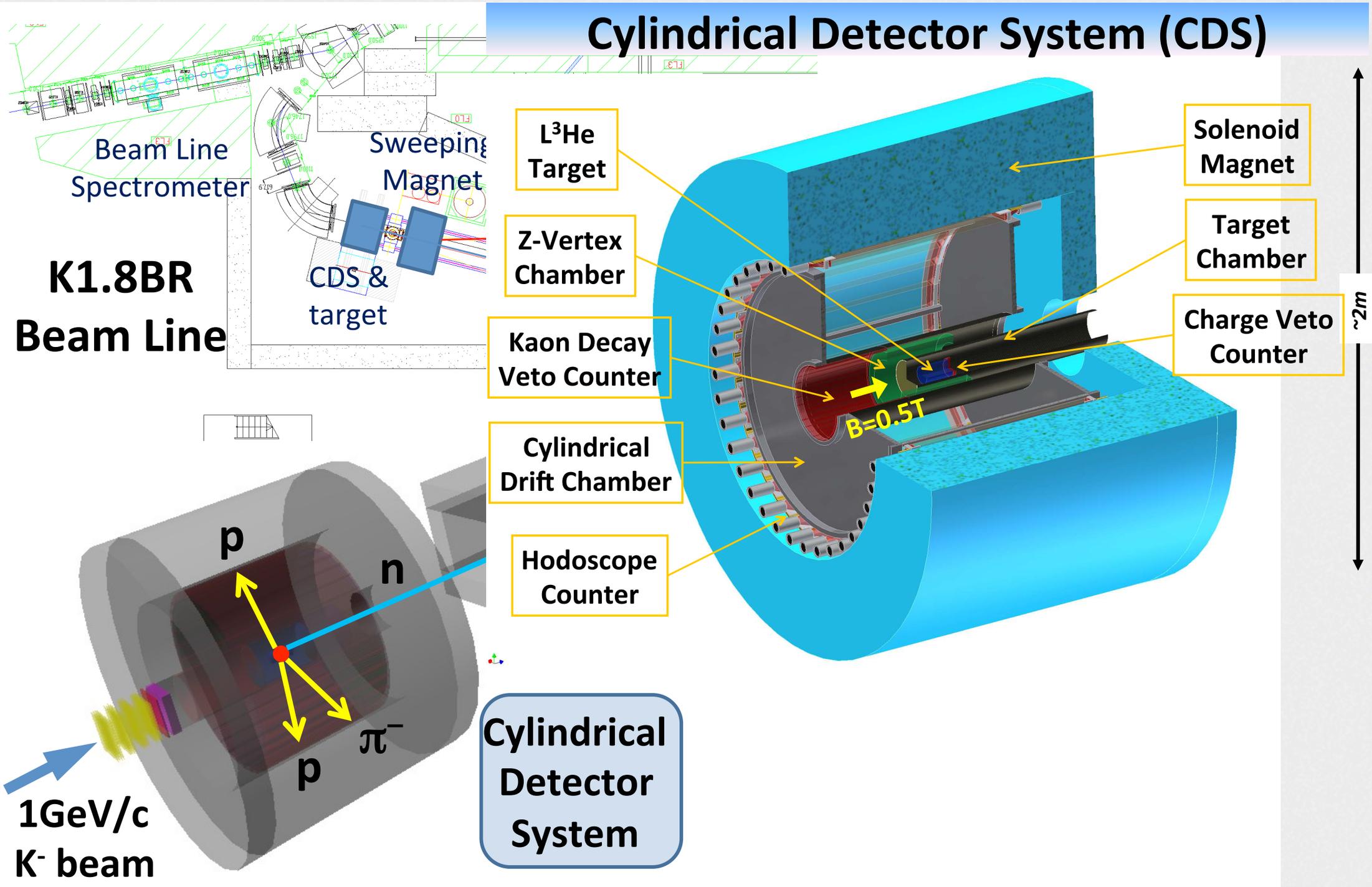
J-PARC E15 experiment



J-PARC E15 experiment

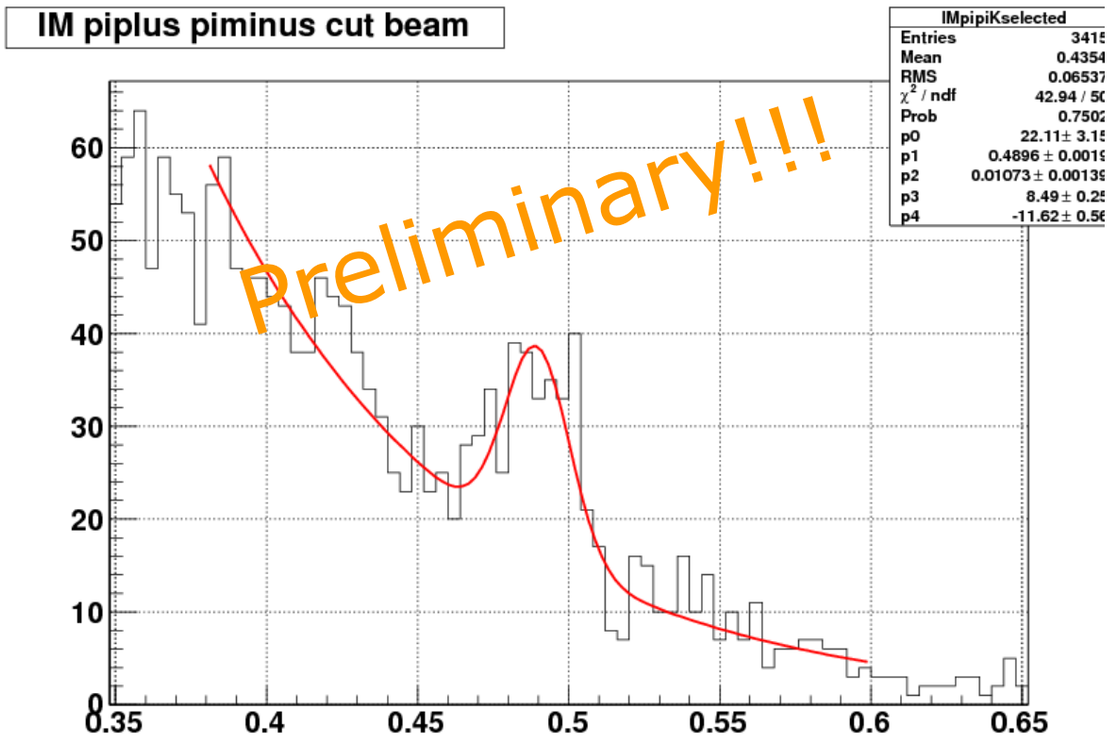


J-PARC E15 experiment

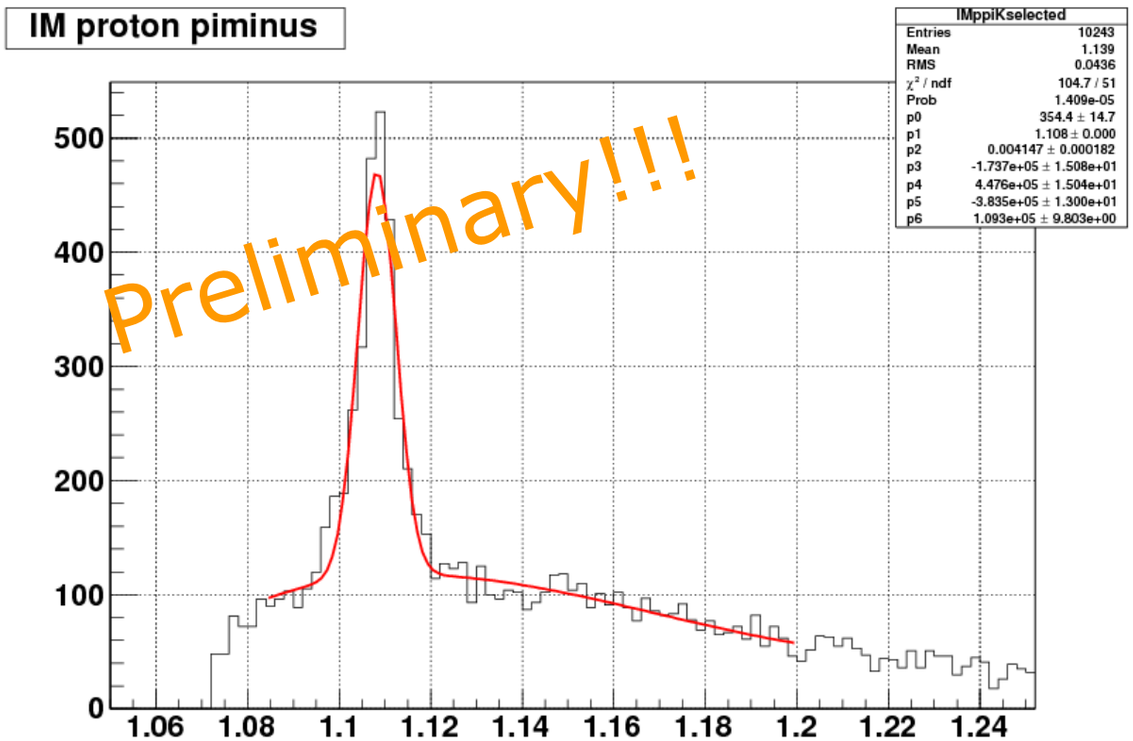


CDS commissioning

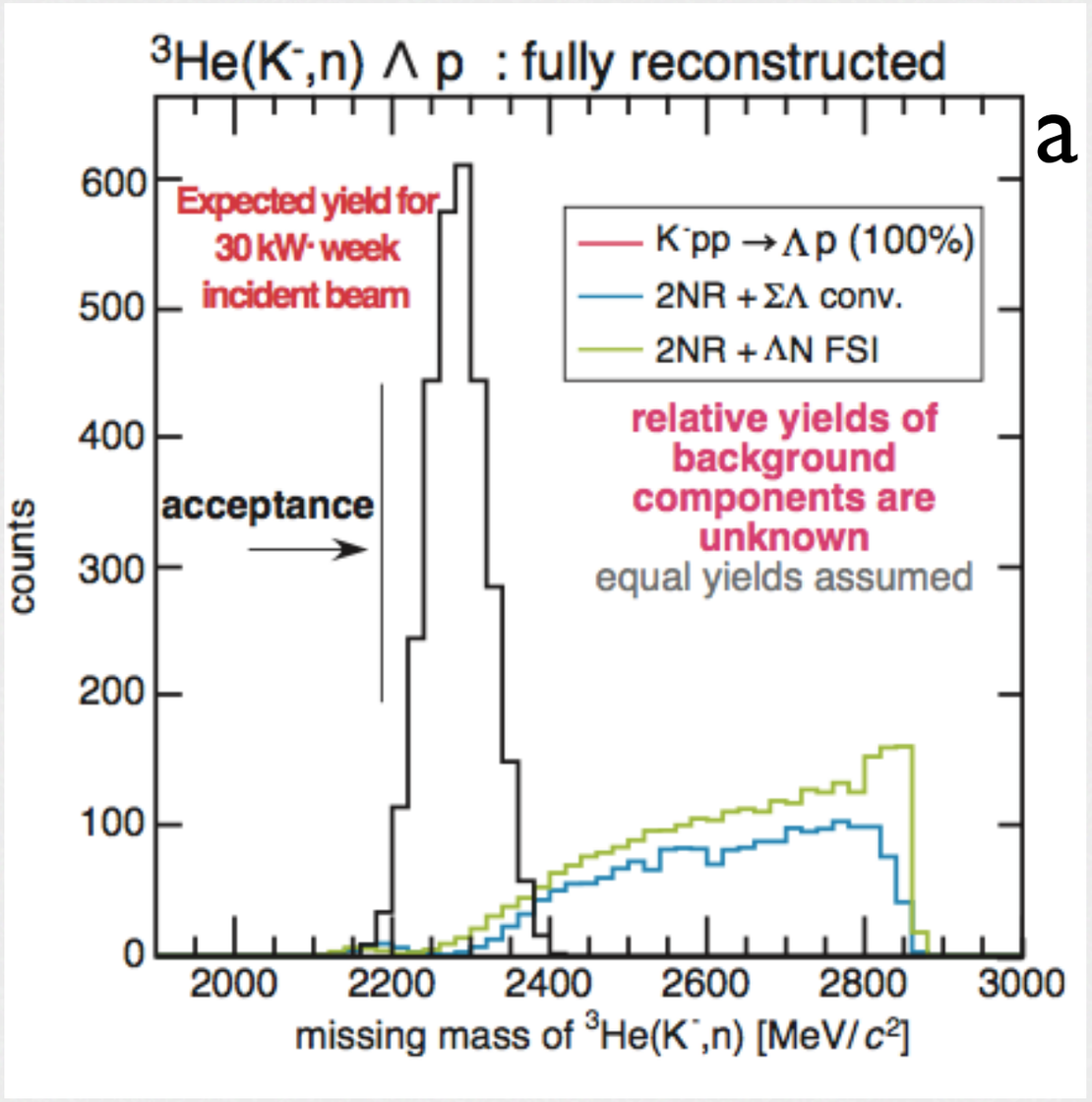
π beam on C, Cu target inside CDS (Oct. 2010)



$\pi^+\pi^-$ invariant mass [GeV/c^2]



$p\pi^-$ invariant mass [GeV/c^2]



a few mb/sr instead of 10 ub/sr?

[T. Koike, T. Harada, Phys. Rev. C80, 055208 (2009)]

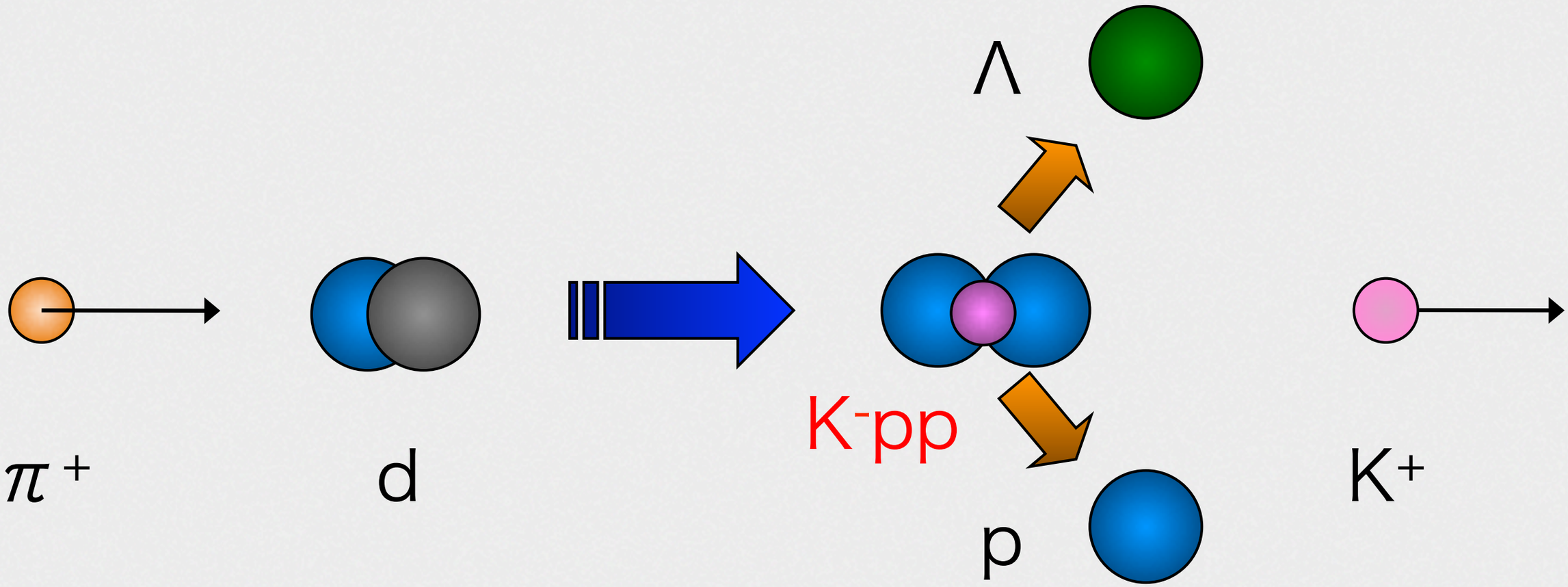
<u>assumption</u>

$d\sigma/d\Omega(0°) \times BR(\Lambda p) = 1\,mb/sr$

We can start the first physics run
even if the beam intensity is
~1/10 of the designed one.

(simulation by T. Hiraiwa)

J-PARC E27 experiment



cf. $d(K^-, \pi^-)$ reaction

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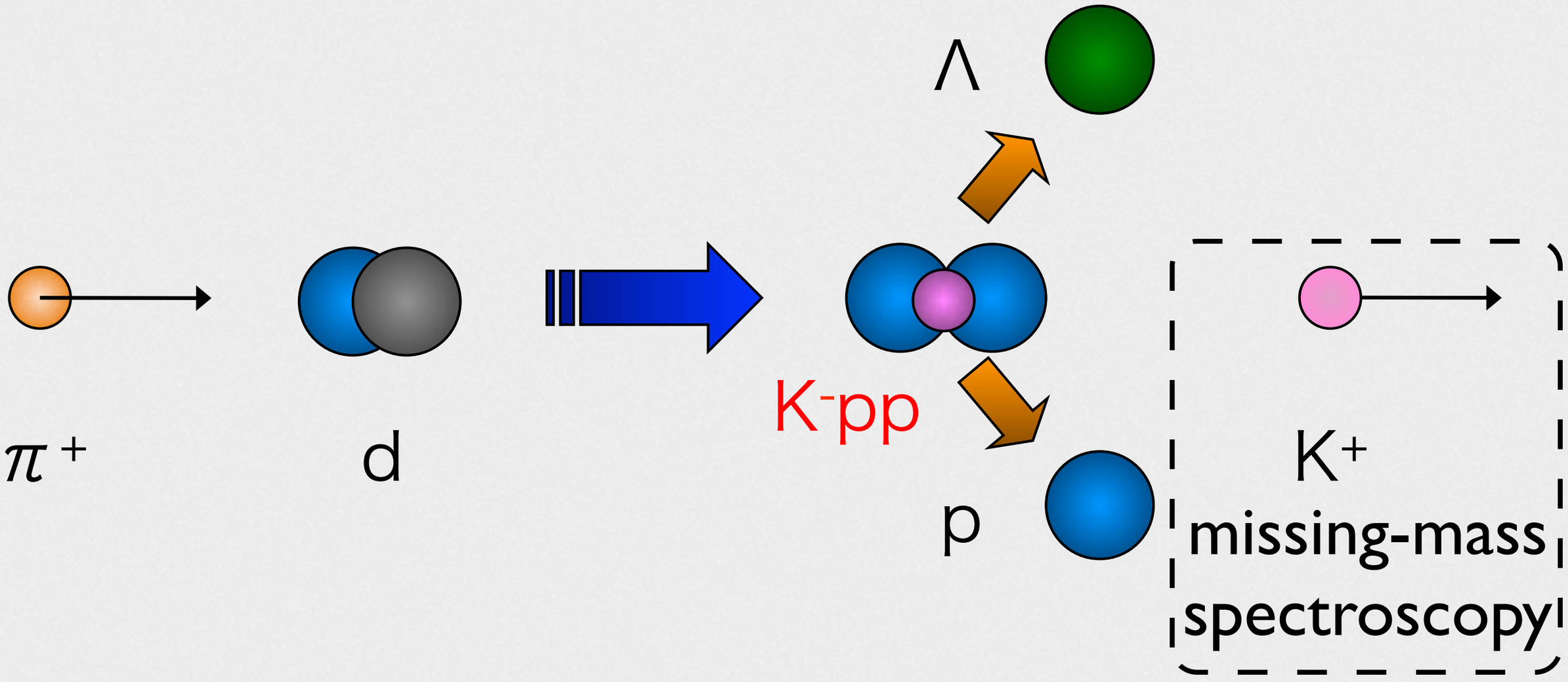

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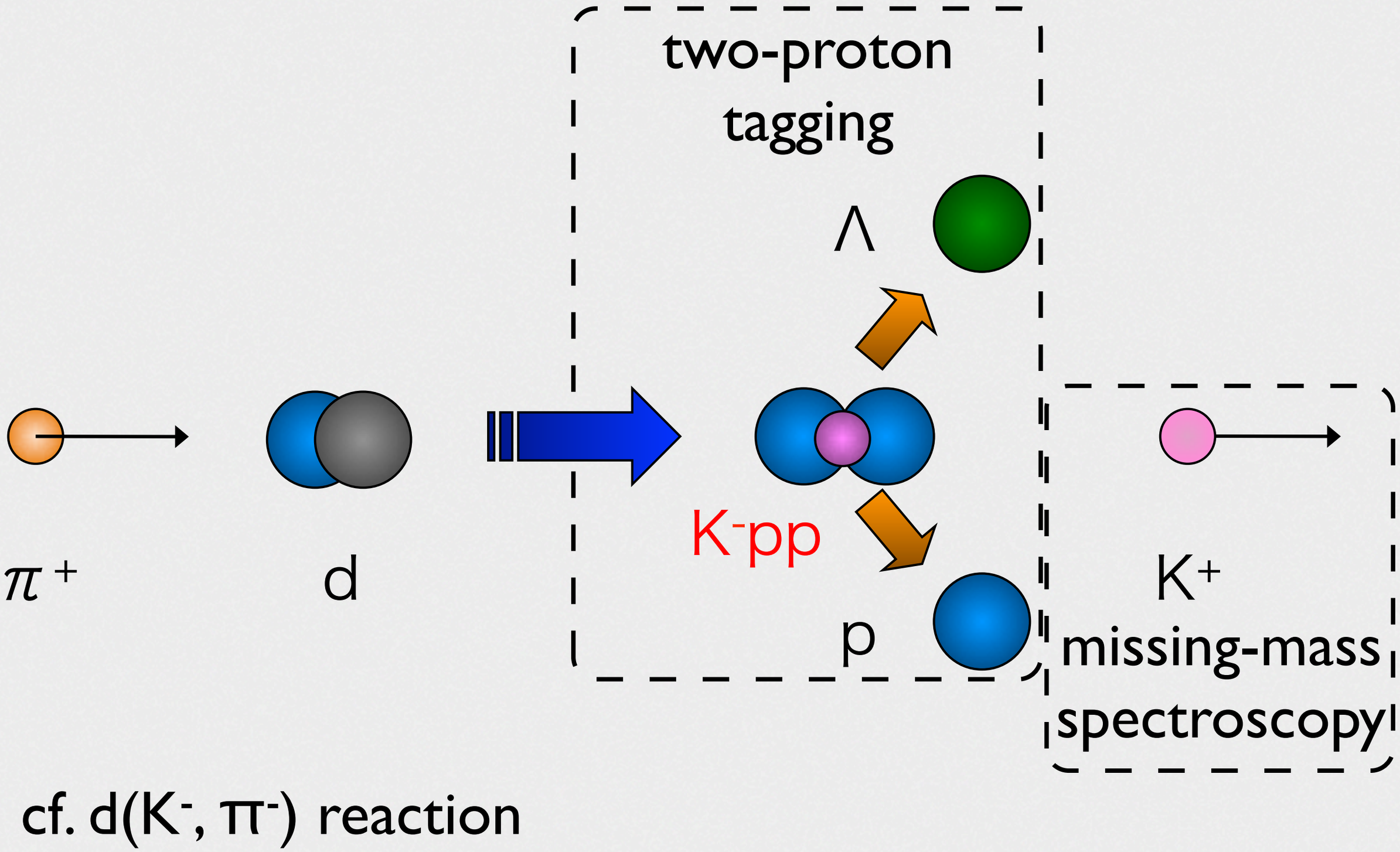

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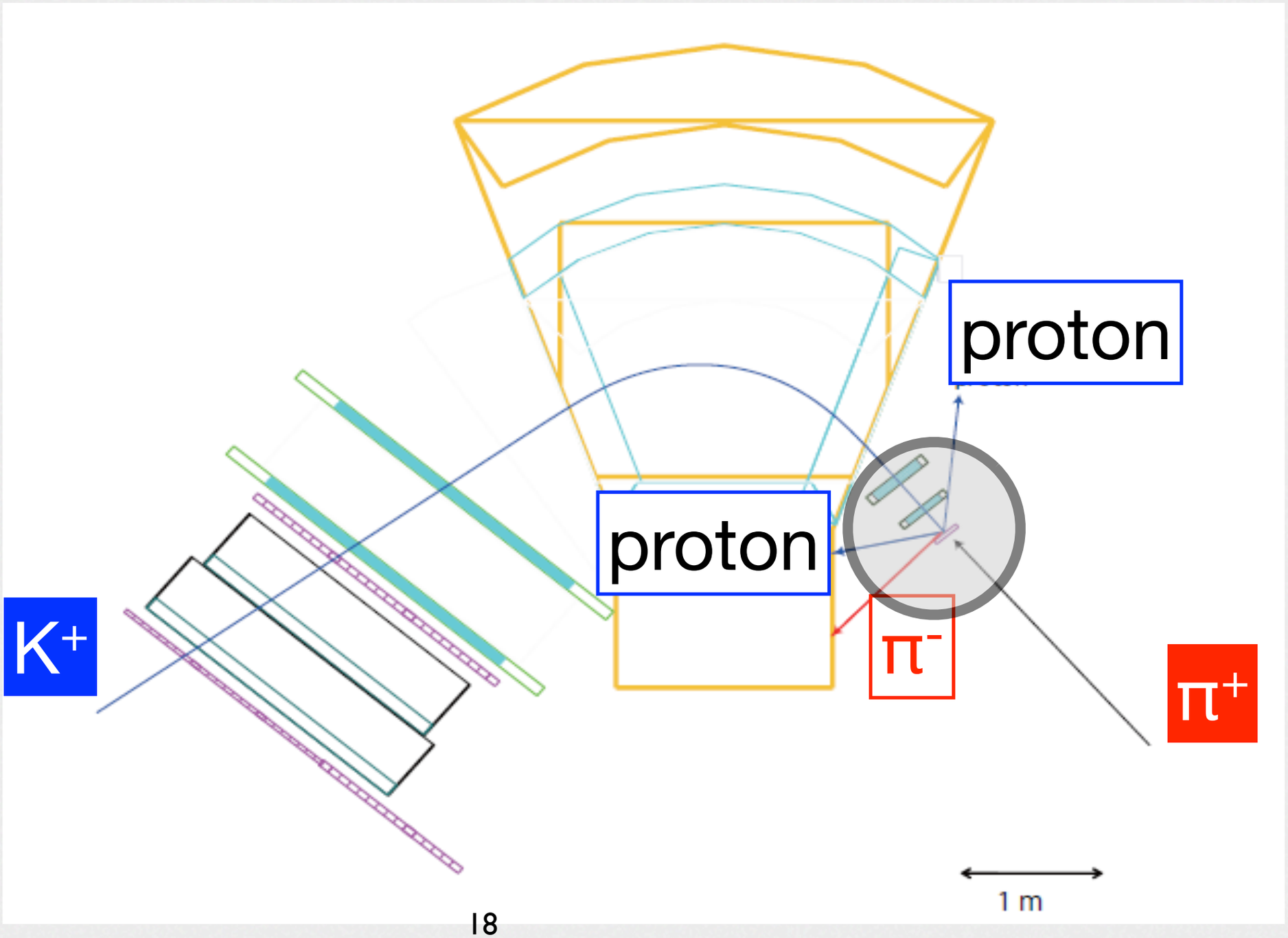

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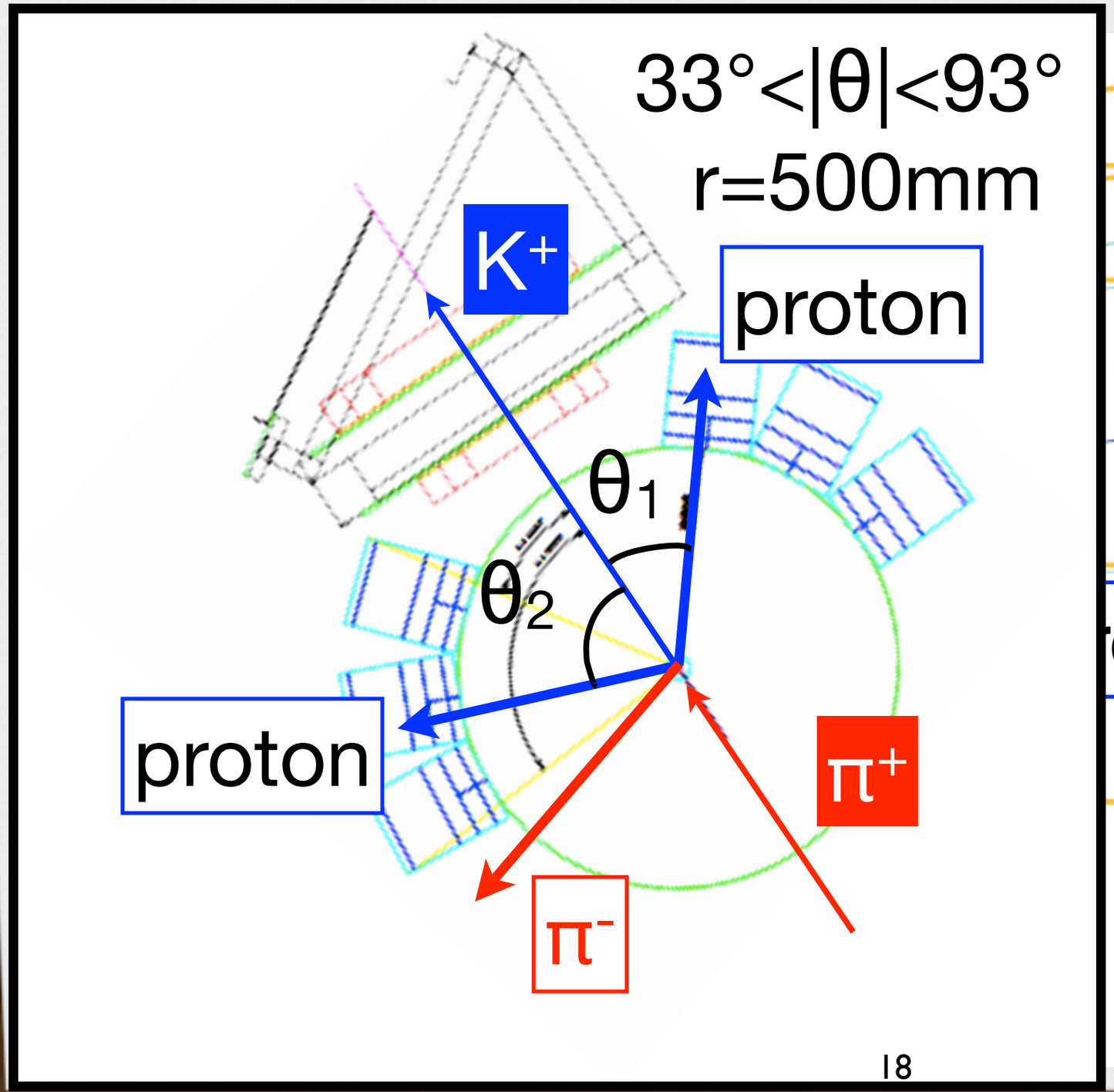
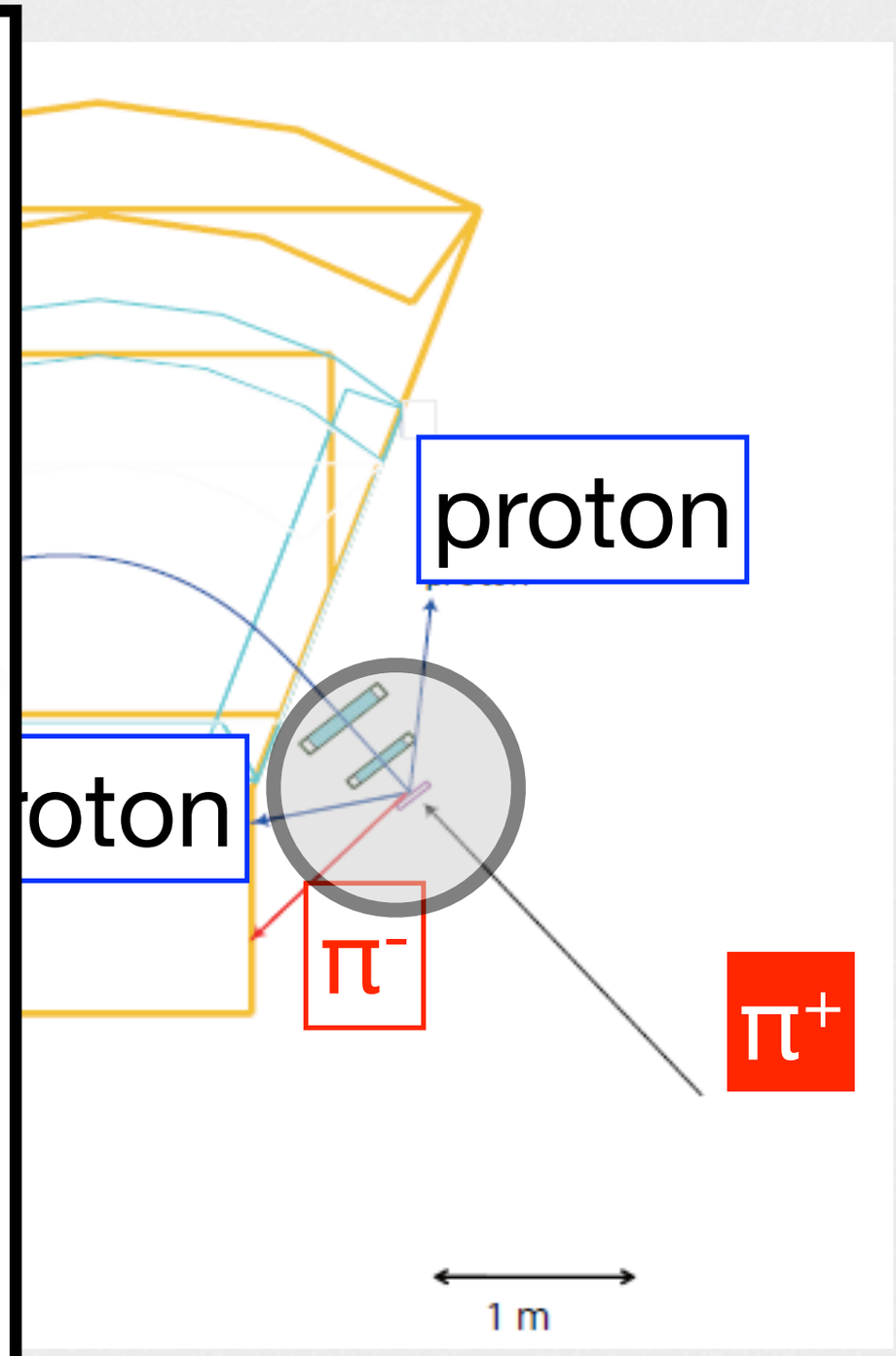
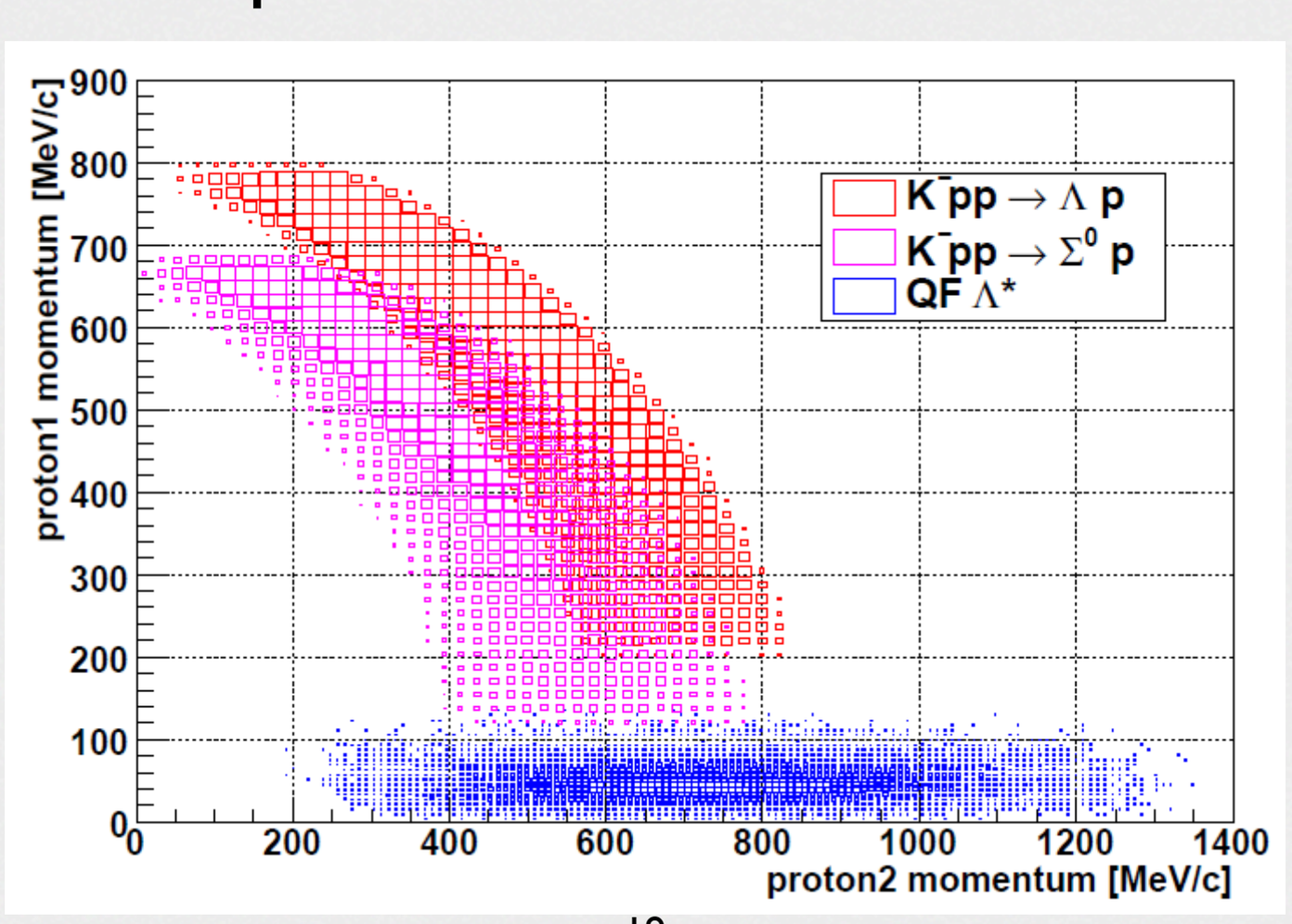


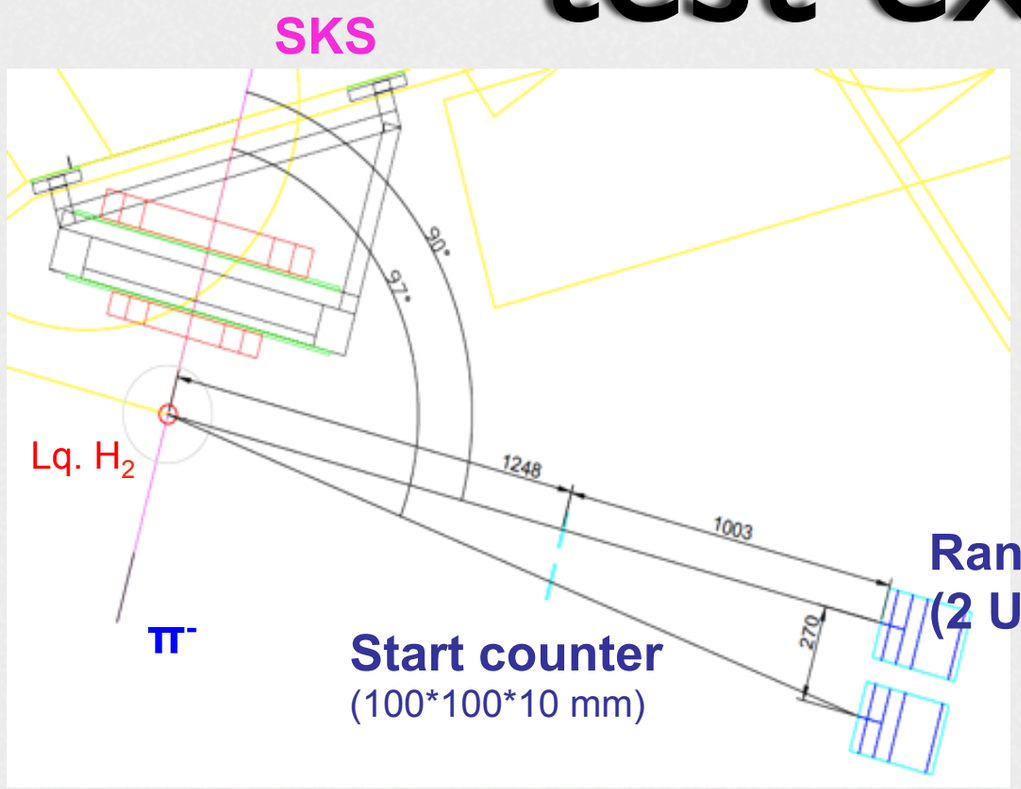


Two-proton tagging

- two fast protons from K^-pp decay
- cf. very slow proton as a spectator from quasi-free processes



range counter and test experiment

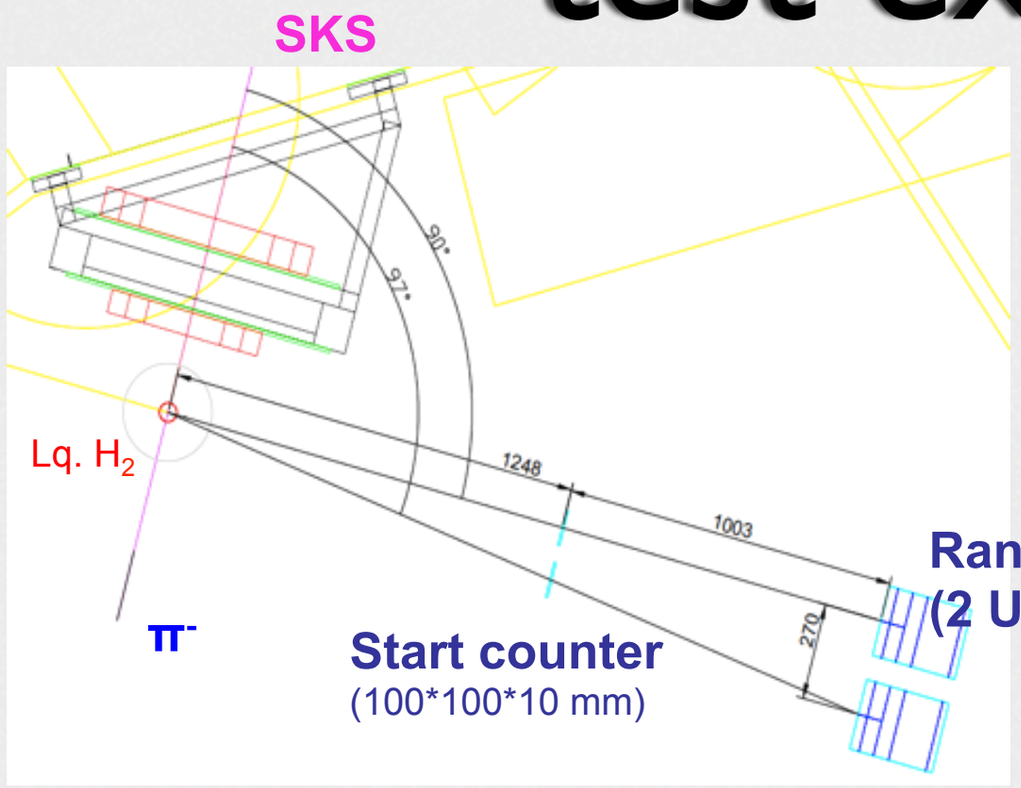


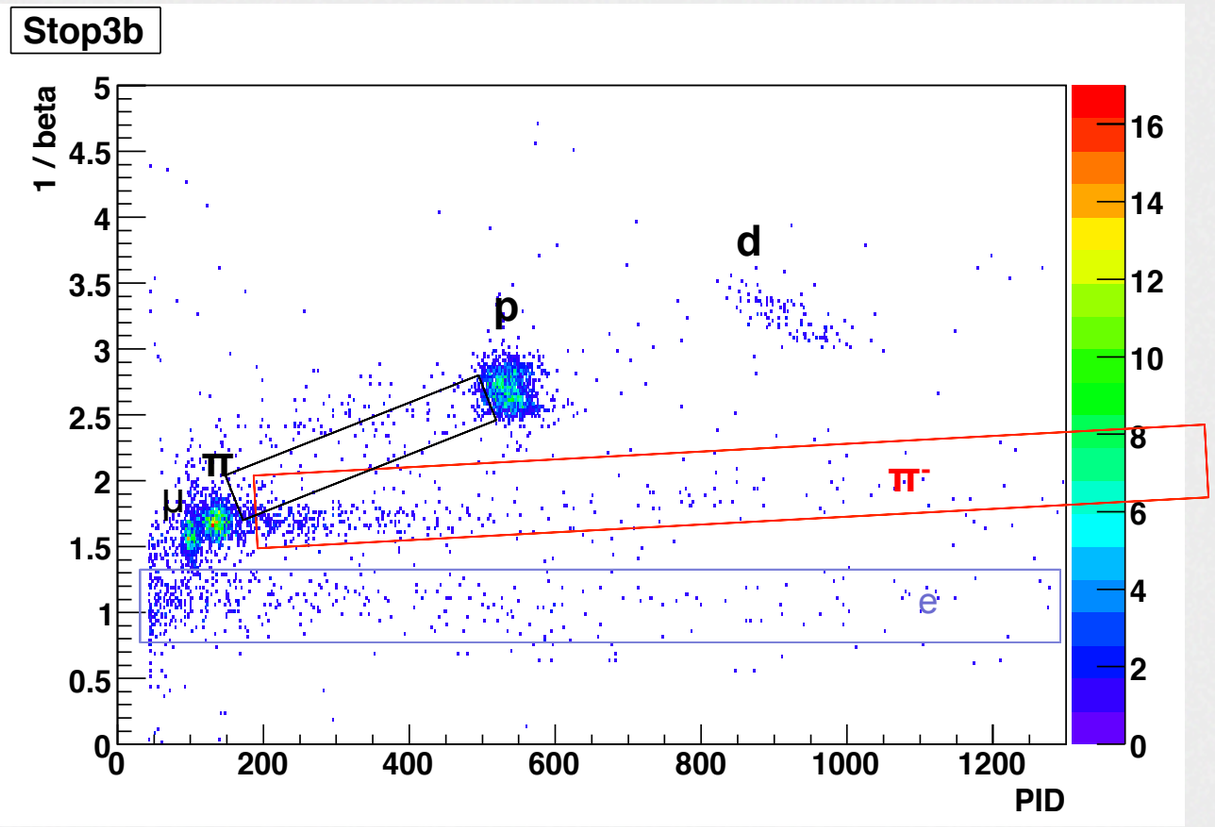
$\pi^{\pm}$, p from π^-+p reaction

parasite of E19 experiment

(Θ^+ search experiment)

range counter and test experiment





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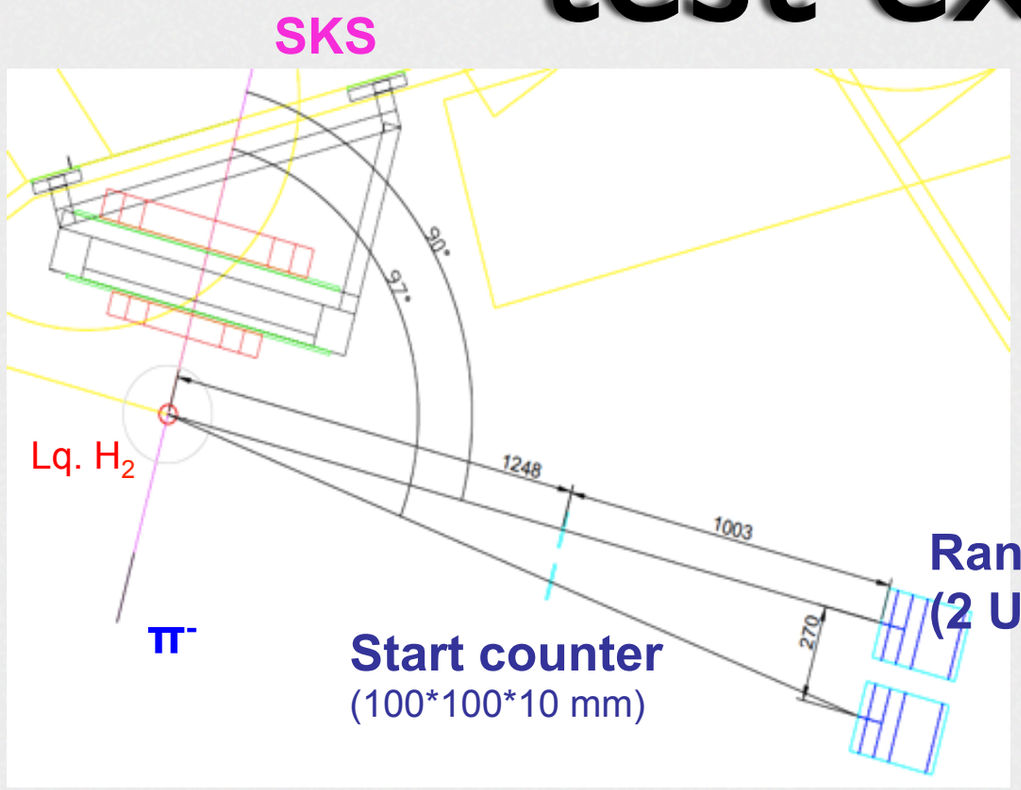

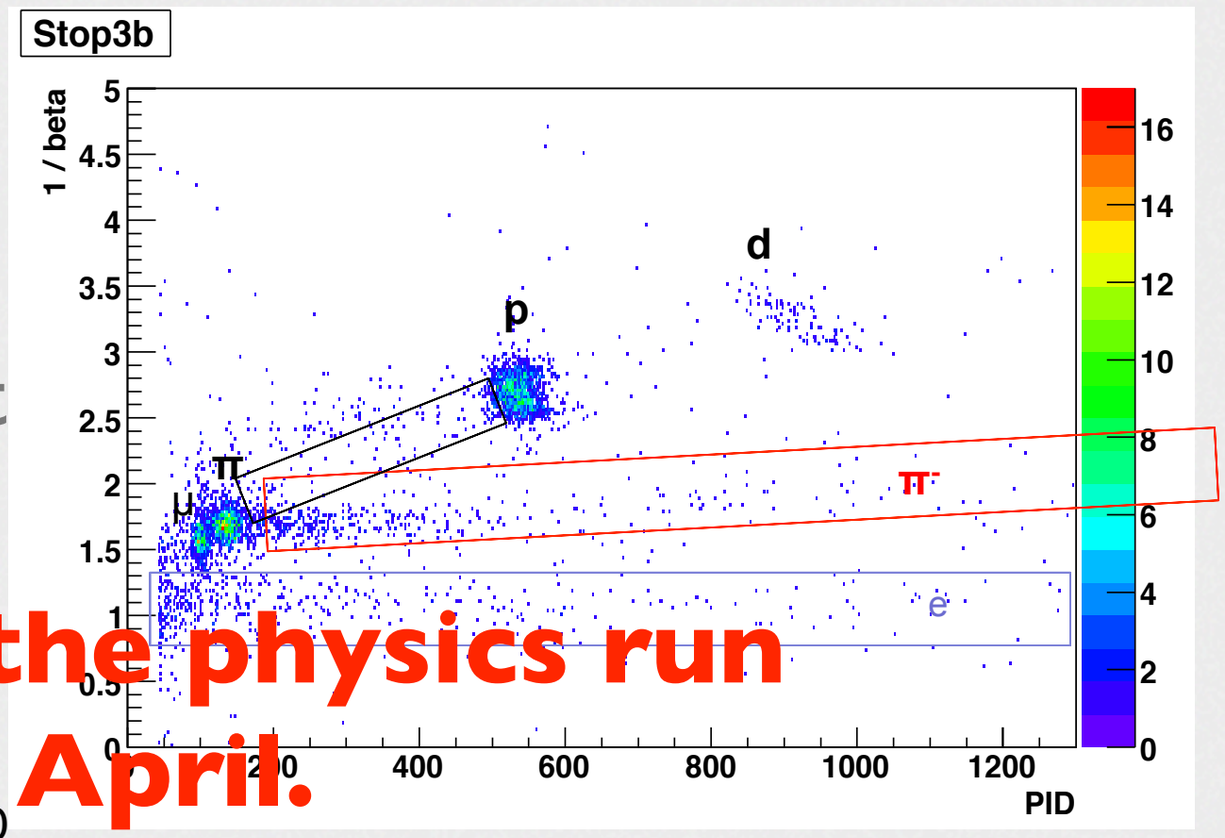

$\pi^{\pm}$, p from π^-+p reaction

parasite of E19 experiment

(Θ^+ search experiment)

We were to start the physics run from this April.

η-mesic nuclei

- Predicted by Haider and Liu
  [Phys. Lett. B172, 257 (1986)]
- first experiment @ BNL : (π^+, p) reaction
  [R. E. Chrien et al., Phys. Rev. Lett. 60, 2595 (1988)]
  "*narrow bound states were not observed.*"
- J-PARC LoI (2007)

  (K. Itahashi, H. Fujioka, S. Hirenzaki, D. Jido, and H. Nagahiro)

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

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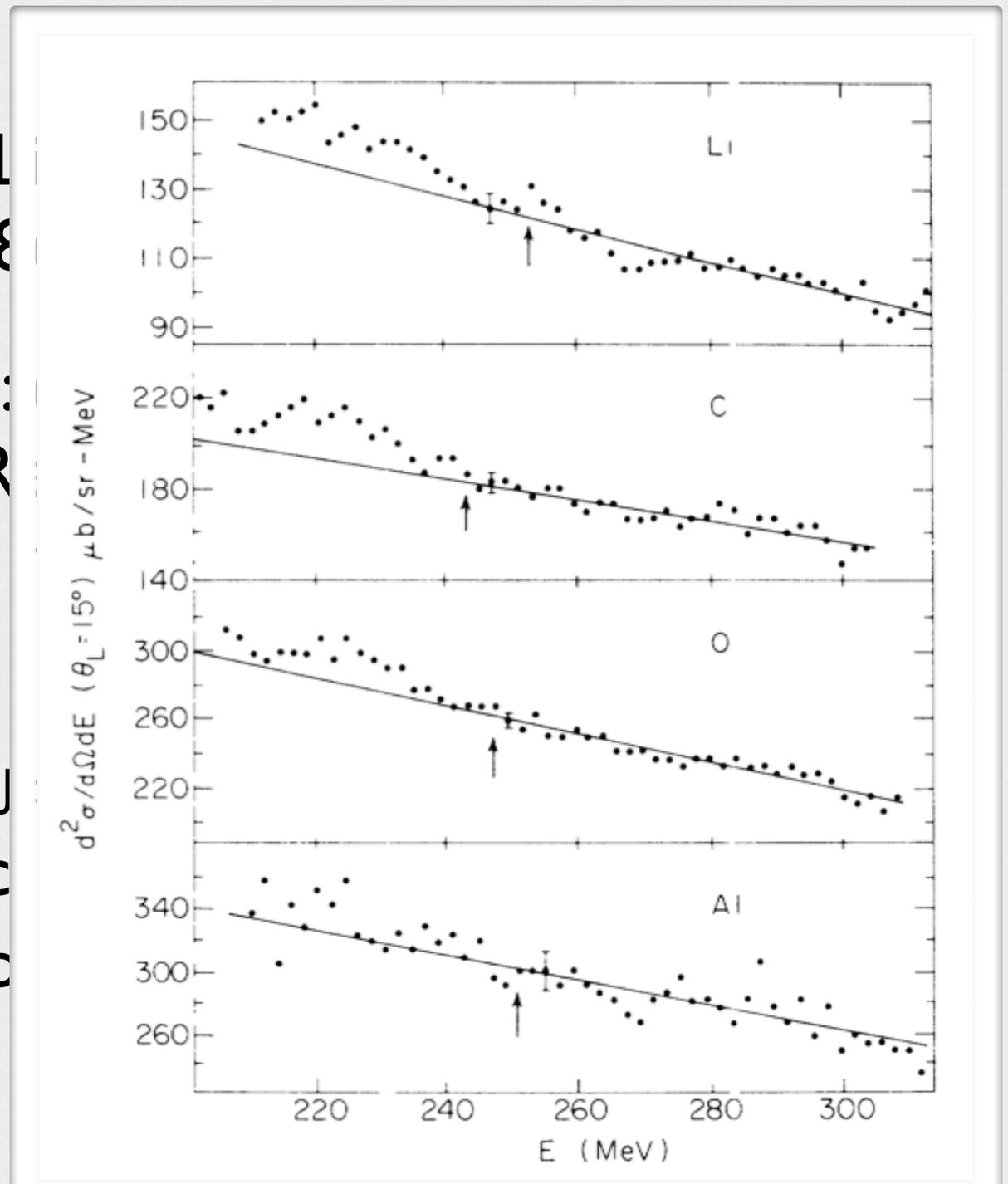

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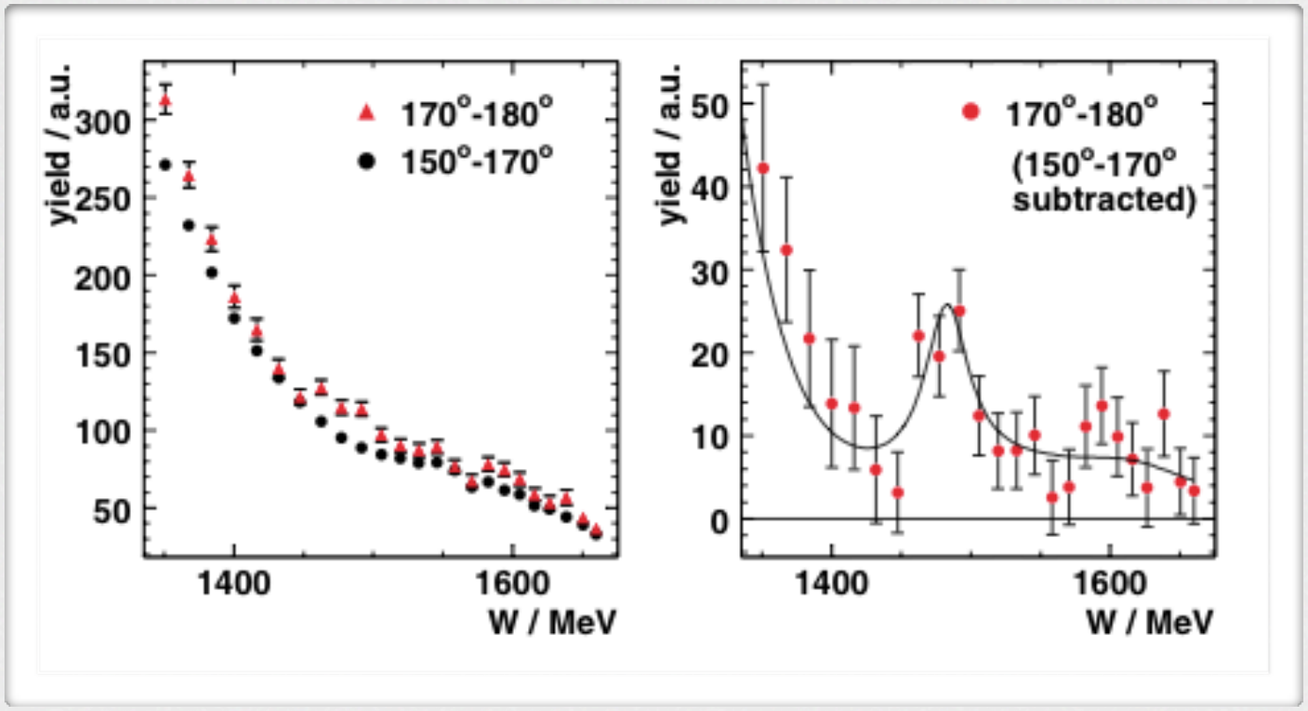
TAPS @ MAMI

$\gamma + {}^3He \rightarrow \pi^0 + p + X$



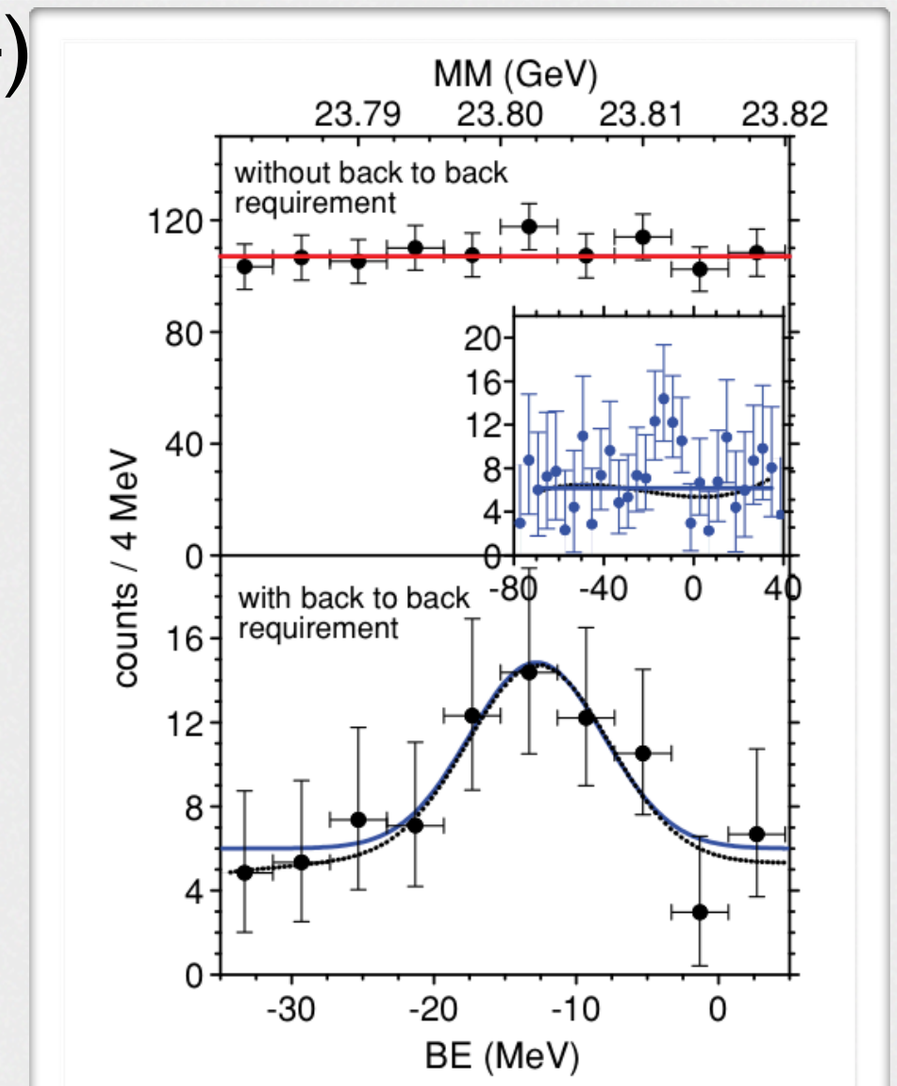
M. Pfeiffer et al., PRL 92, 252001 (2004)

COSY-GEM

$p + {}^{27}Al \rightarrow {}^{25}Mg\text{-}\eta + {}^3He$

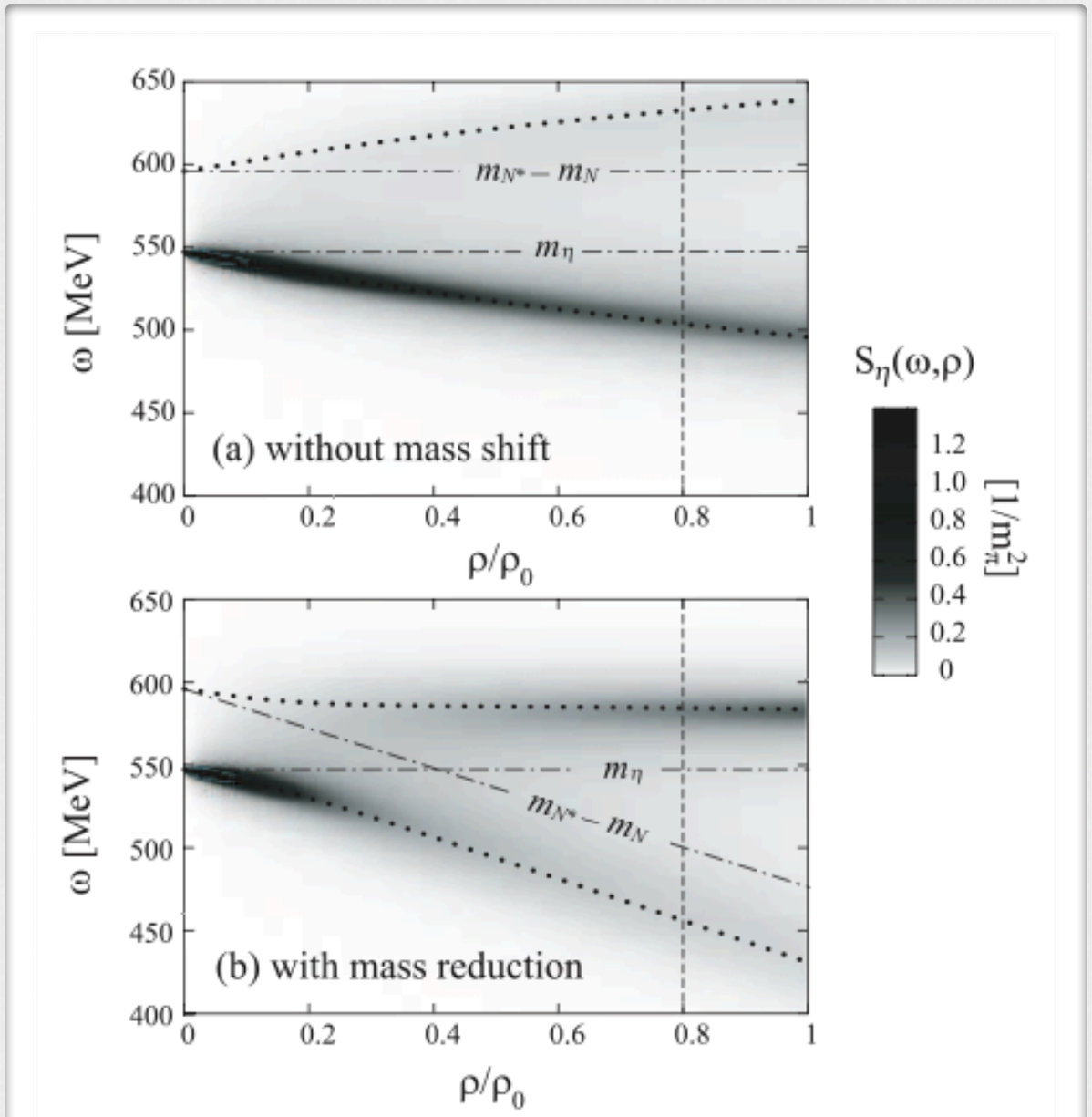
$\hookrightarrow \pi^- p$ pair (back-to-back)

A. Budzanowski et al., PRC 79, 012201(R) (2009)



η-mesic nuclei and N*(1535) in medium

- strong coupling between η mode and N*(1535)-hole mode
- The N* mass may be reduced at finite density, which alter the η-nucleus interaction.



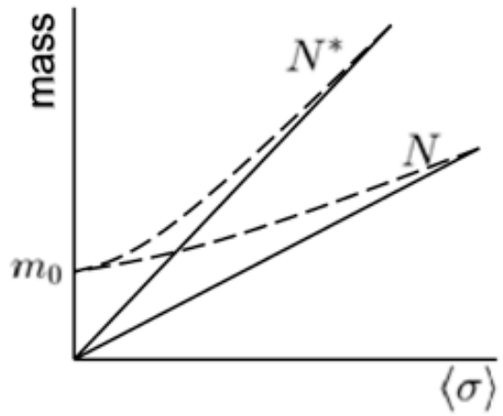
Nagahiro et al.,Phys. Rev. C 80, 025205 (2009)

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

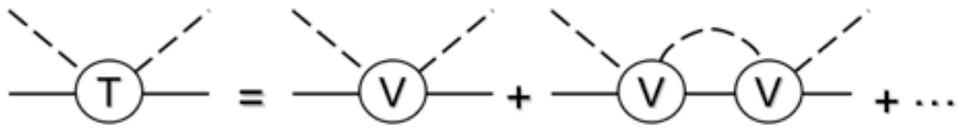
Chiral unitary model

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 $K\Sigma$

no Pauli blocking for Σ in nuclear medium



coupled channel Bethe-Salpater eq. in medium

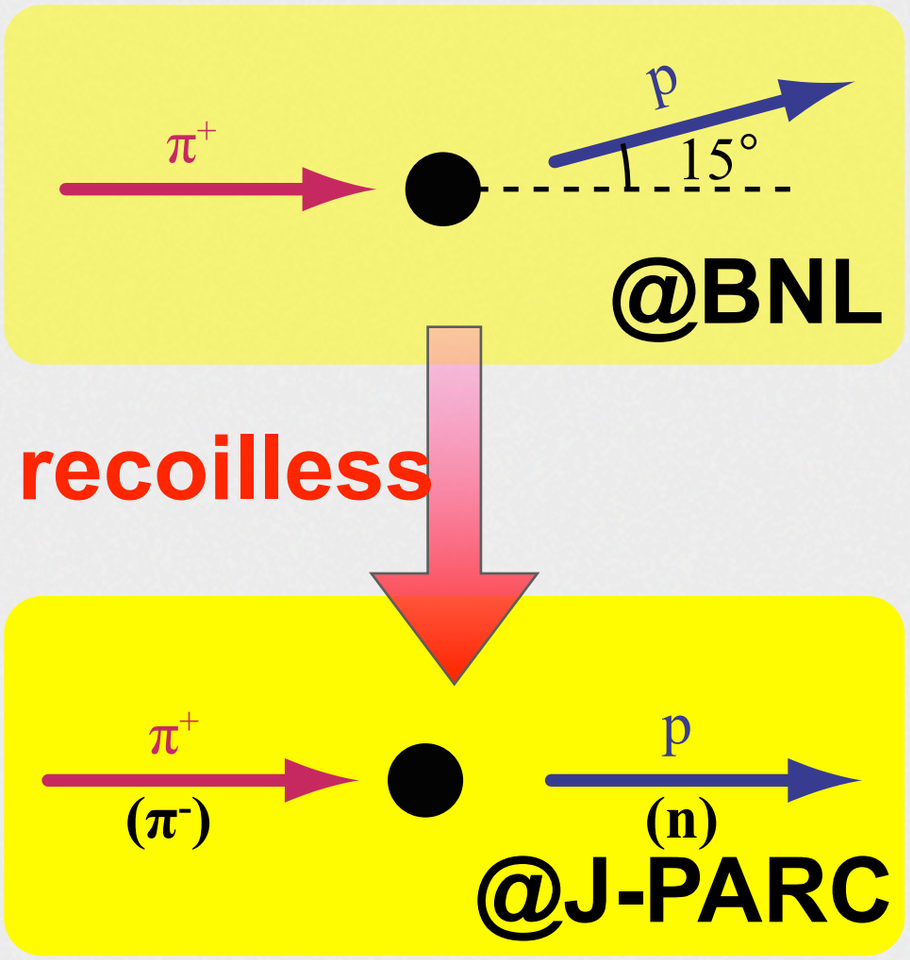
No mass shifts of N* is expected in the nuclear medium

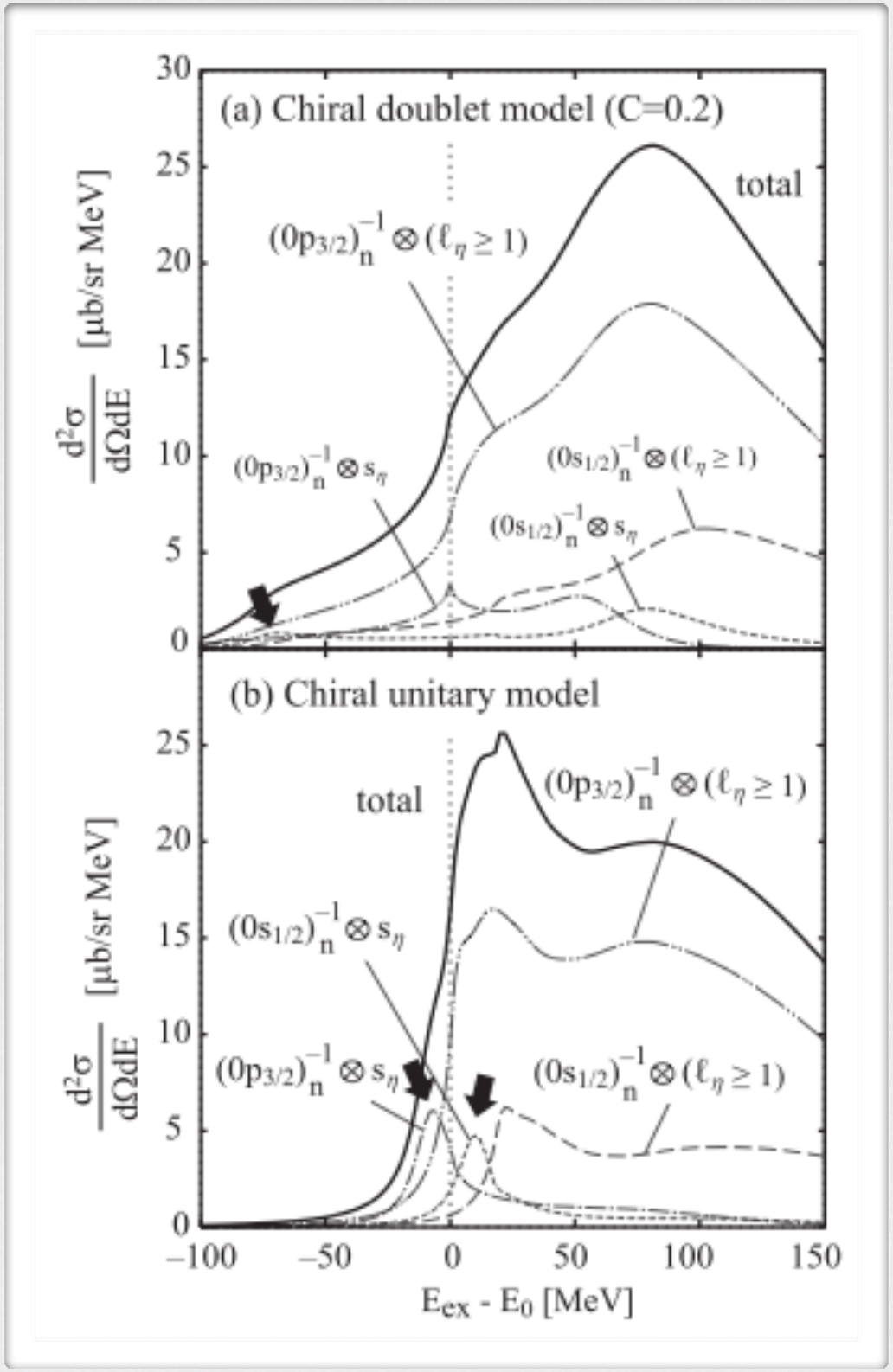
6

HNP09 @ Arata Hall, Osaka University, 19 Nov. 2009

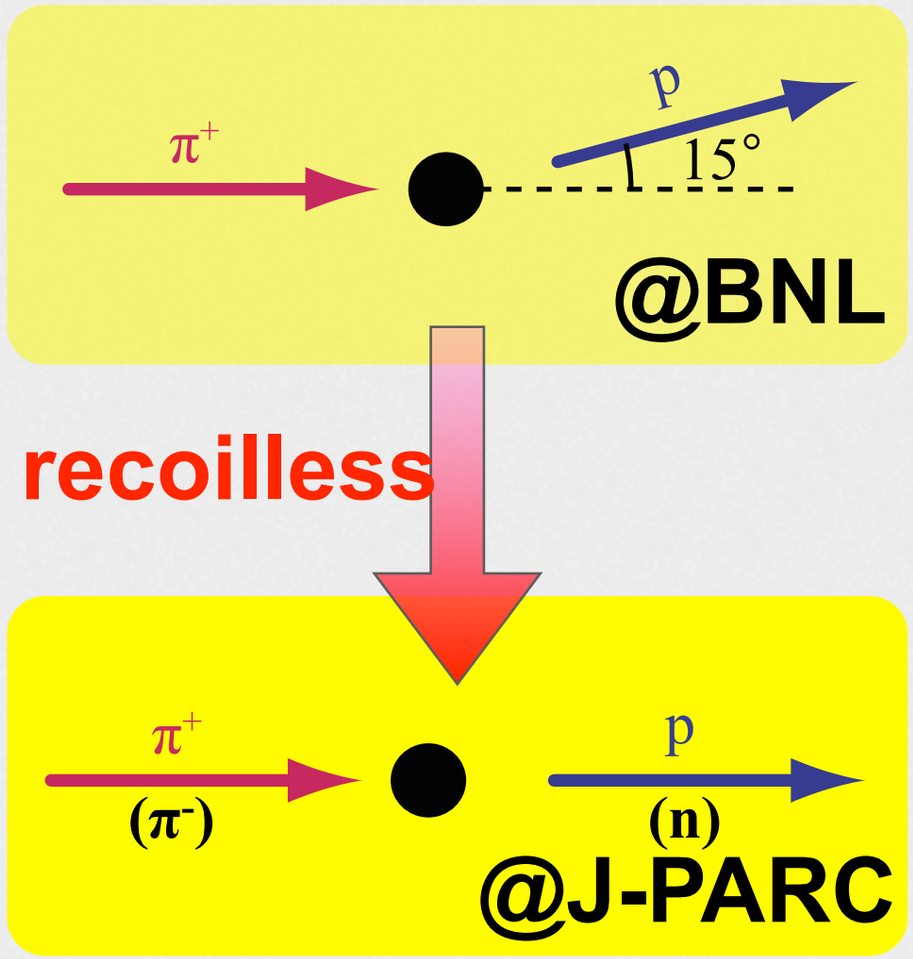
Slide by Dr. Nagahiro @ HNP09

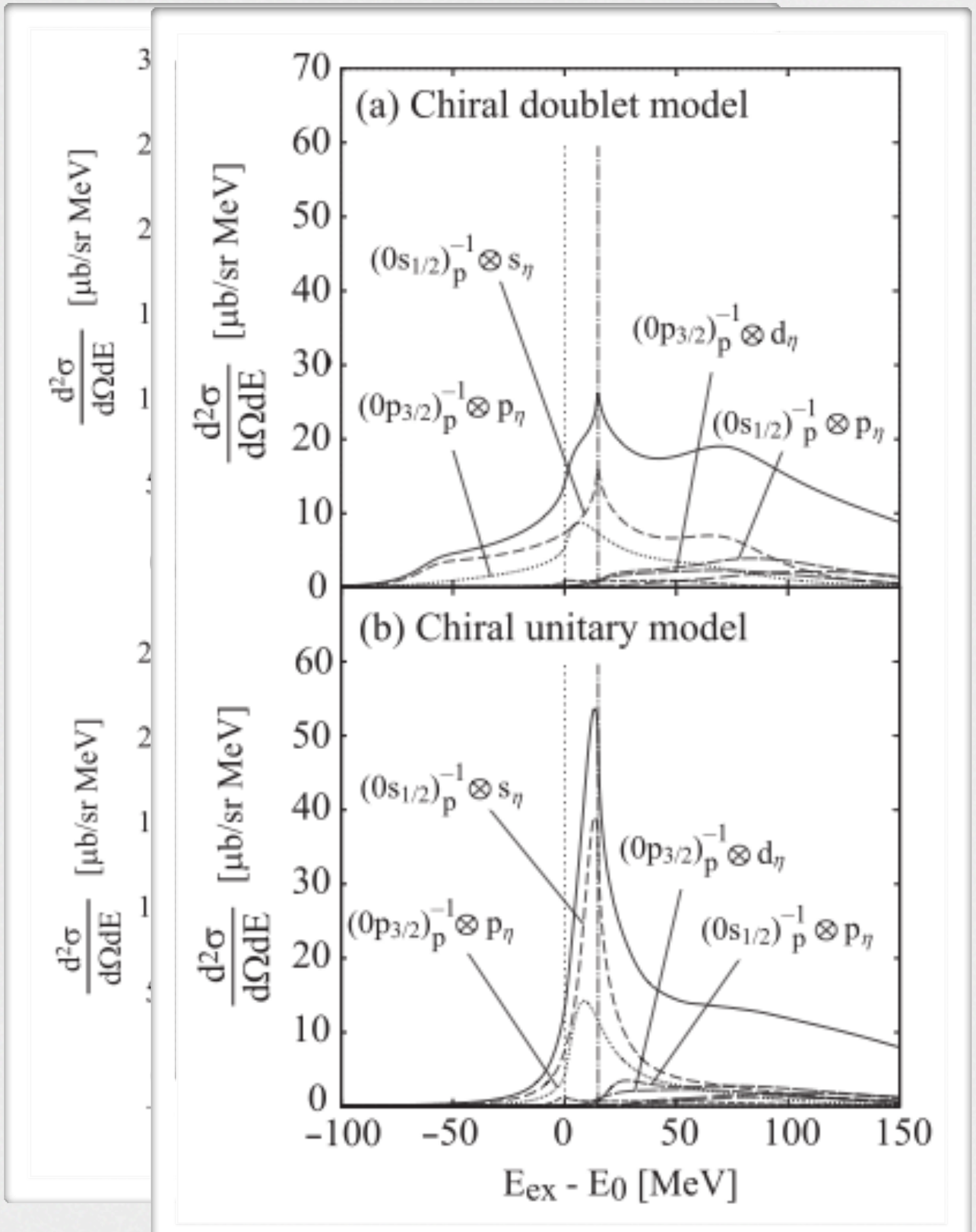
Nagahiro et al.,Phys. Rev. C 80, 025205 (2009)



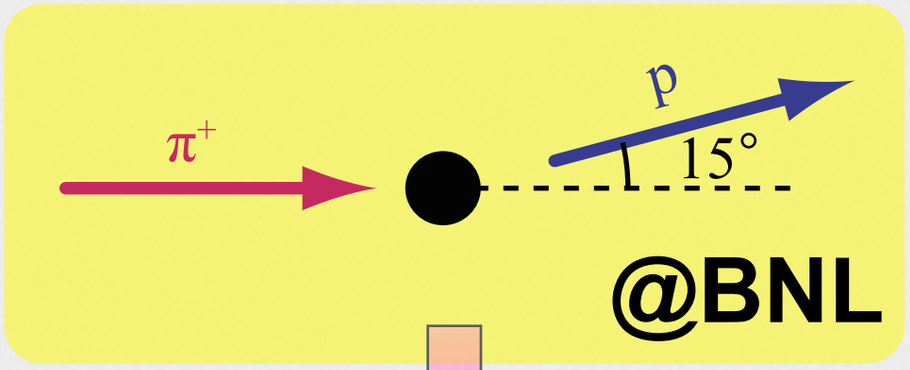


Nagahiro et al.,Phys. Rev. C 80, 025205 (2009)

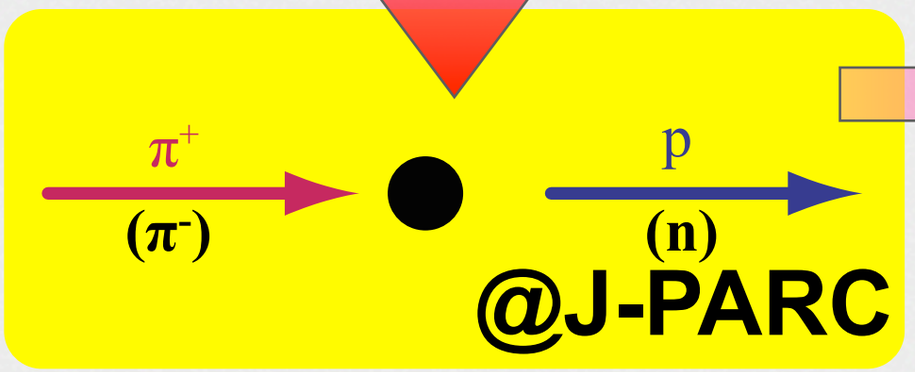


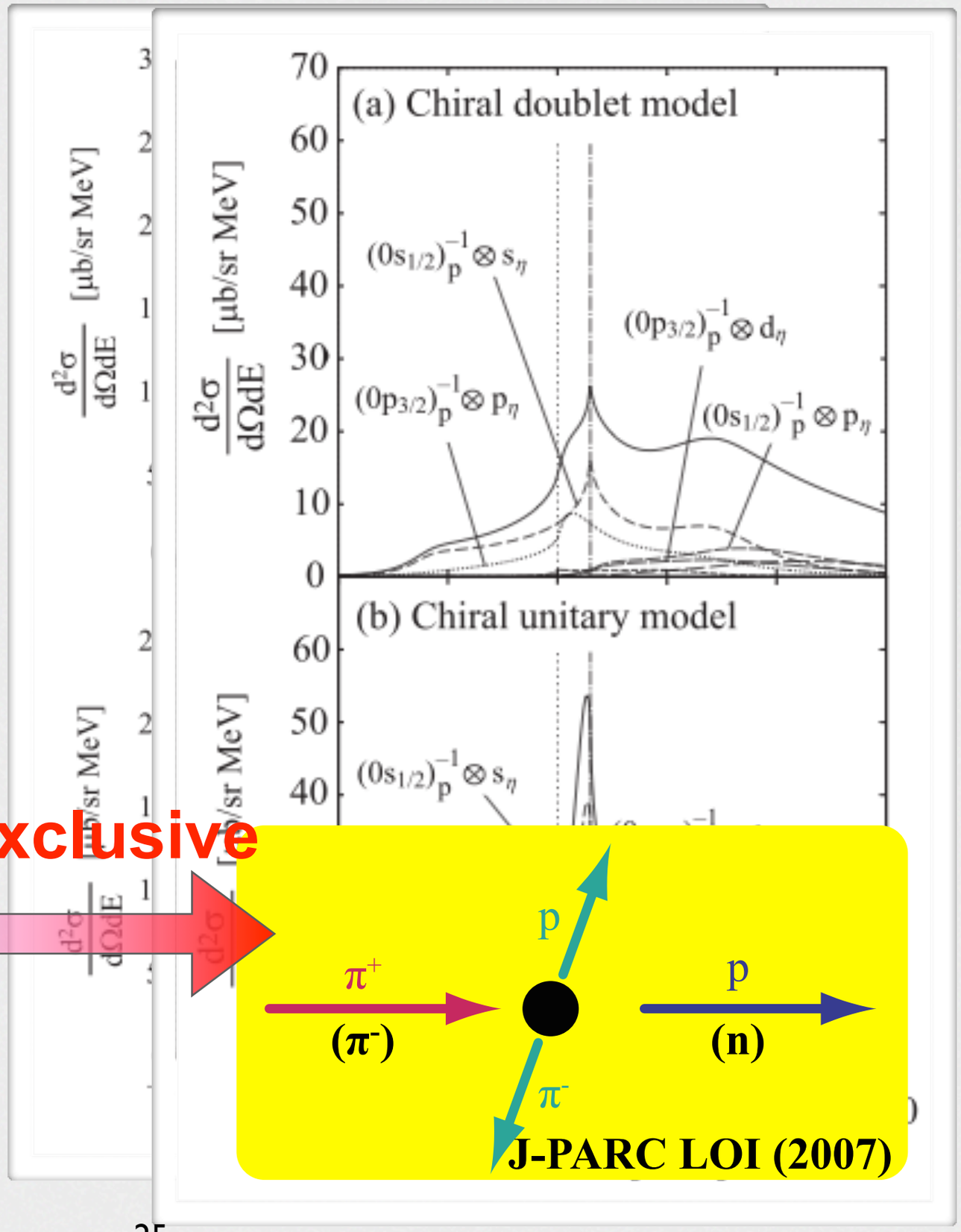


Nagahiro et al.,Phys. Rev. C 80, 025205 (2009)



recoilless

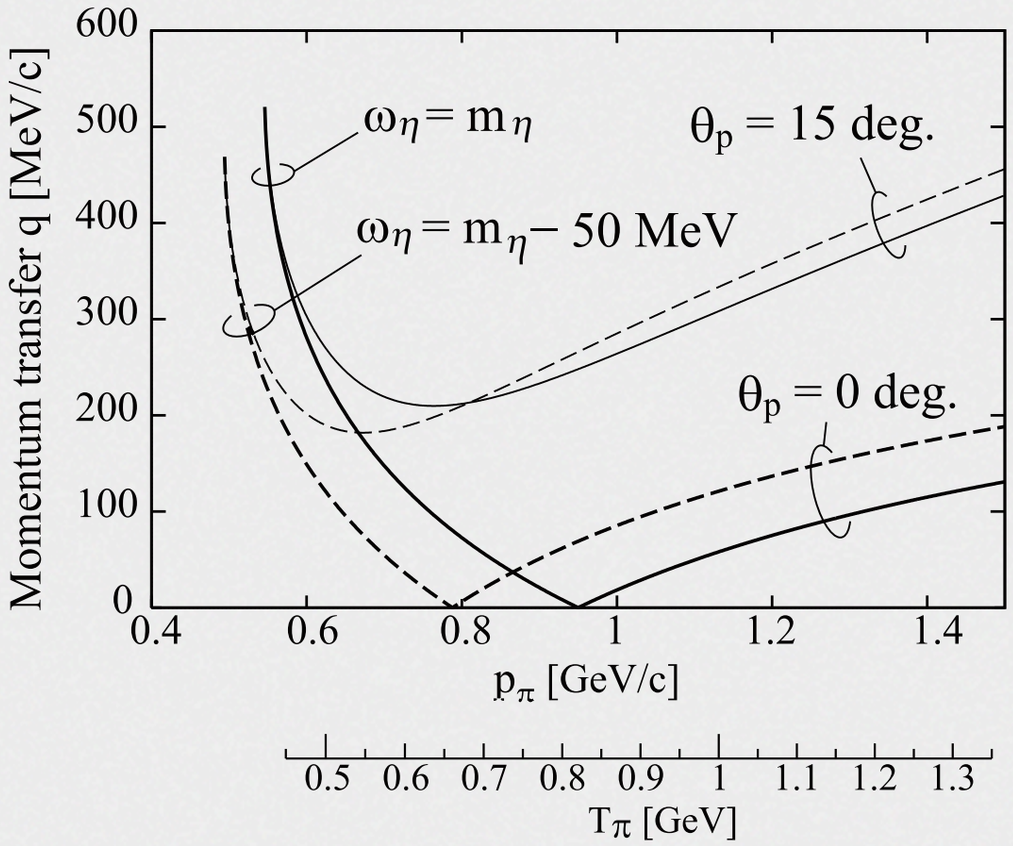


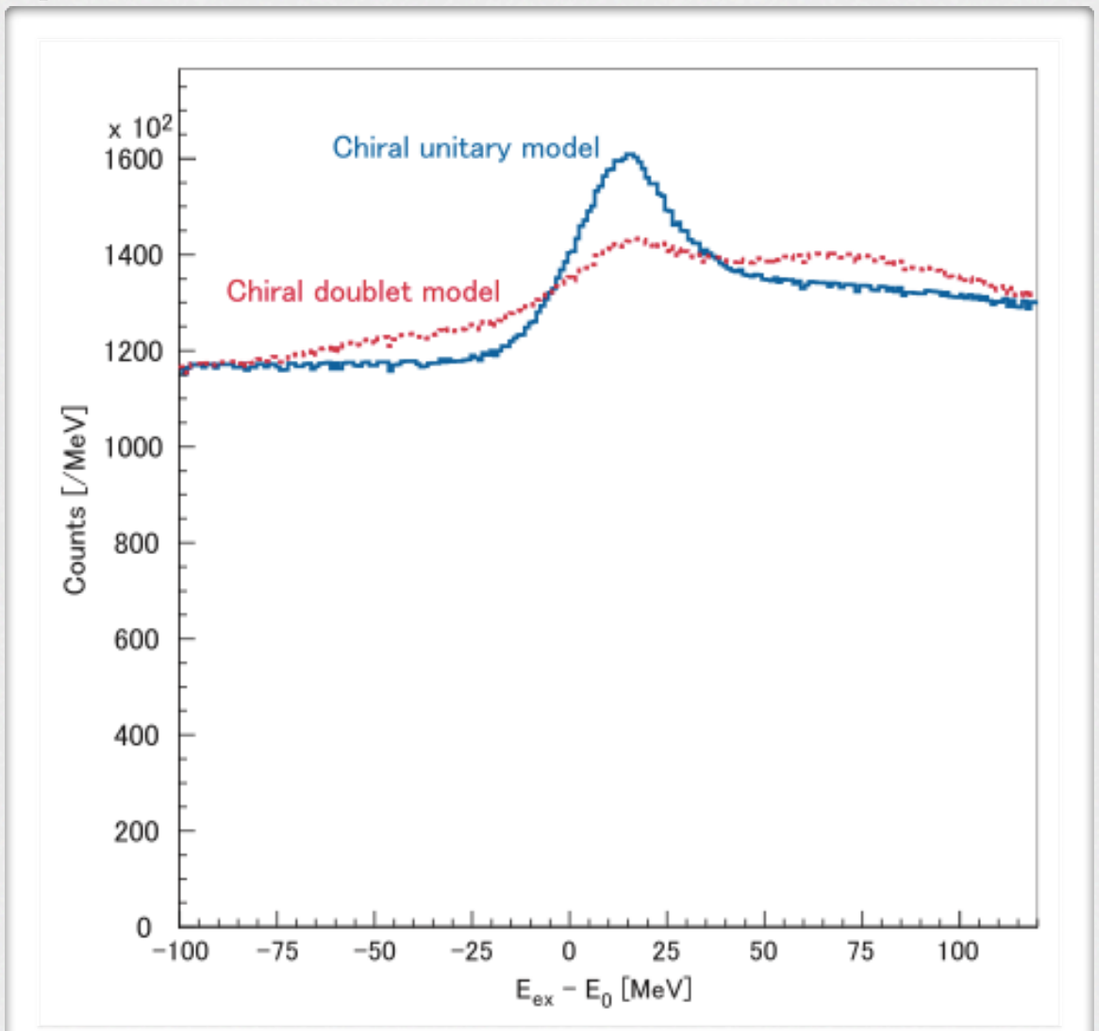


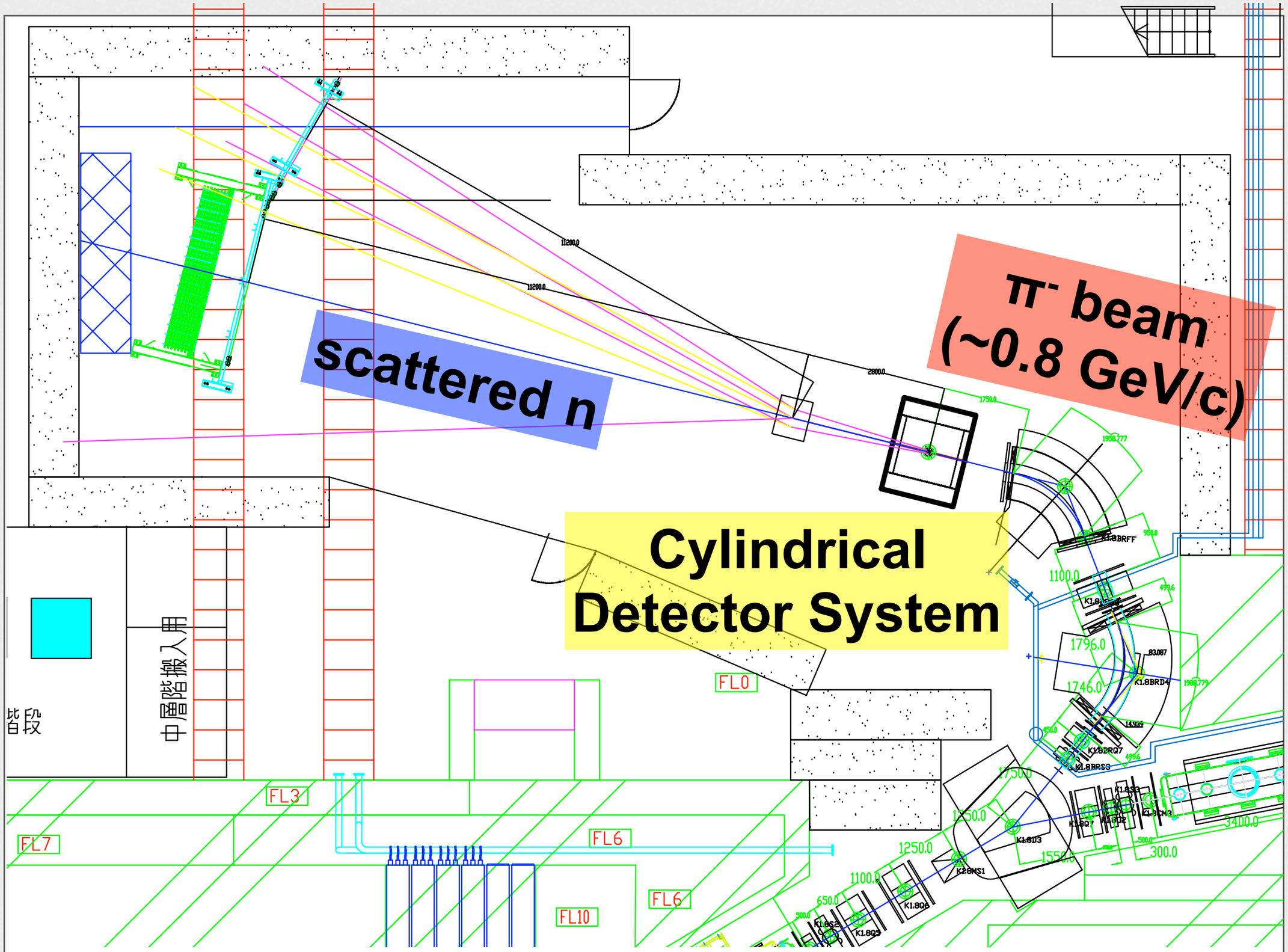
exclusive

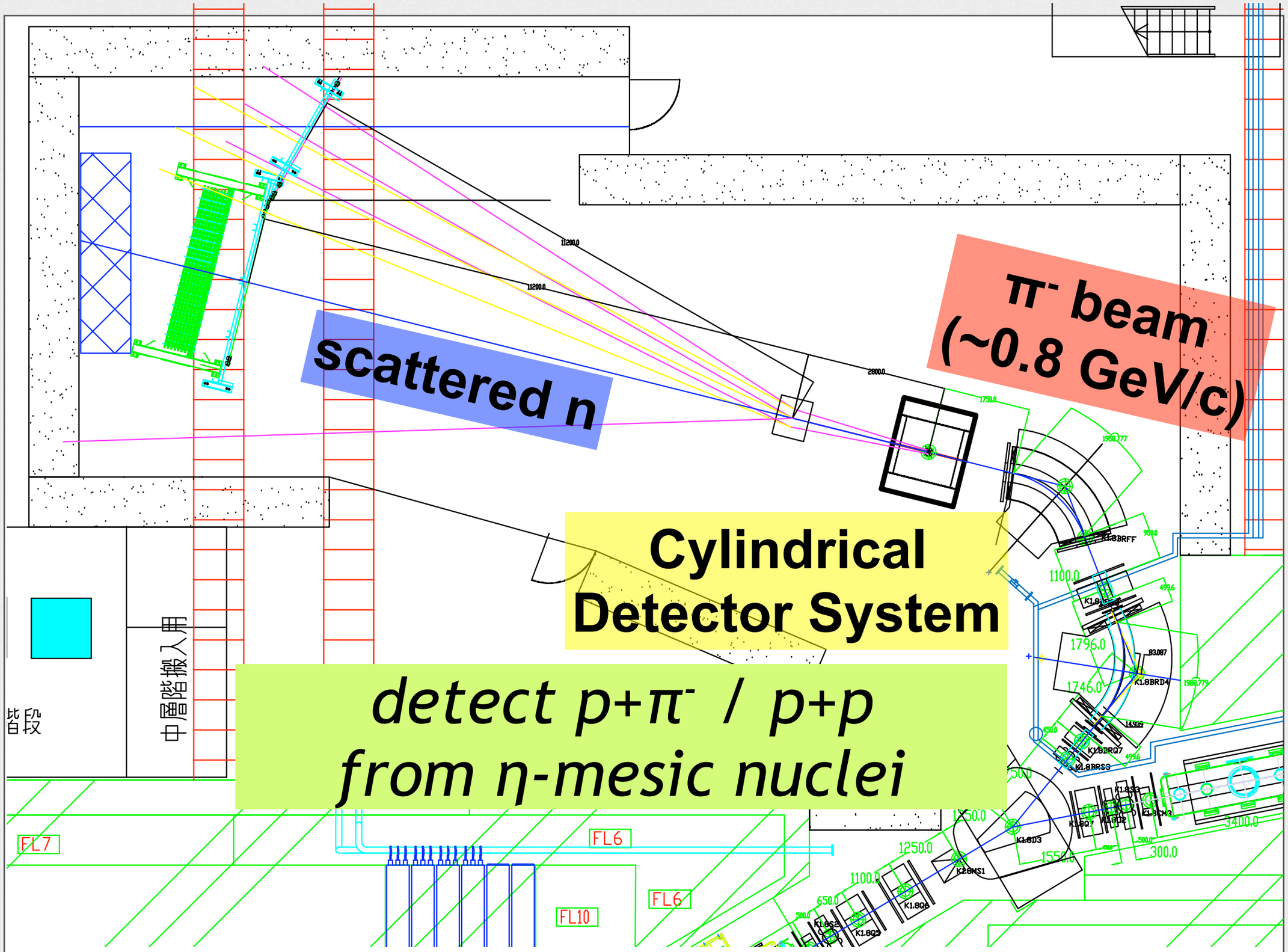
Experimental idea

- momentum : 0.8-1.0 GeV/c (magic momentum)
- similar setup as the E15 experiment





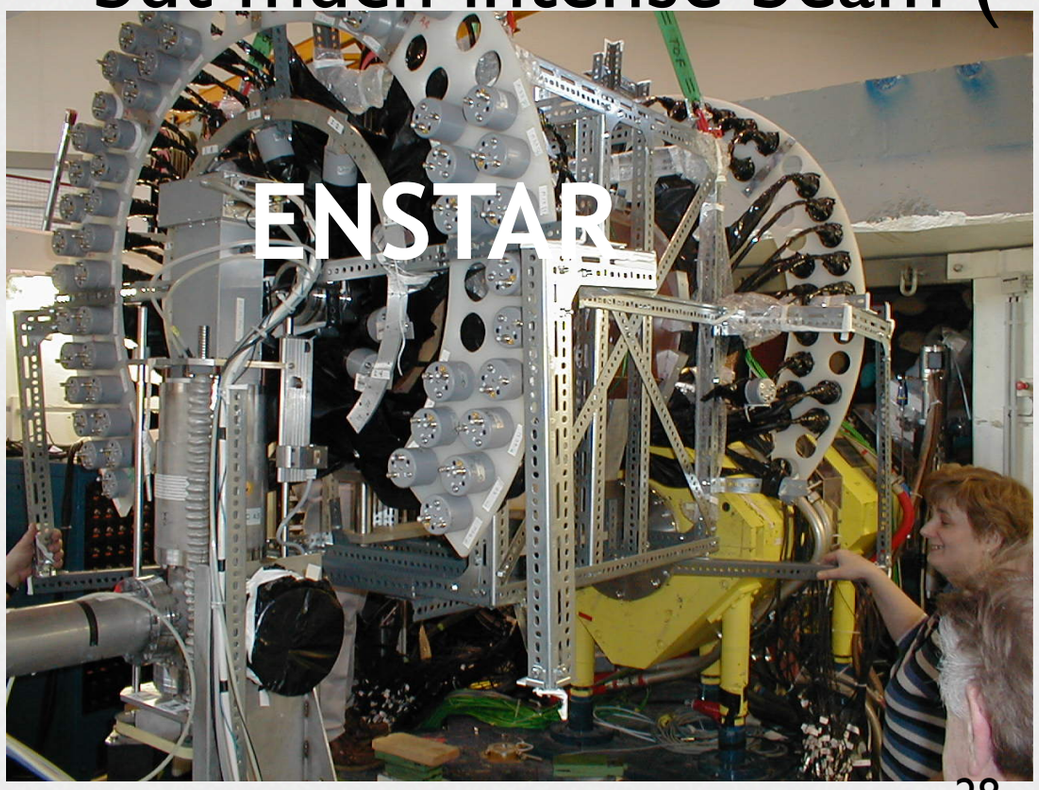

scattered n
π⁻ beam
(~0.8 GeV/c)
Cylindrical
Detector System
FL0
FL3
FL6
FL6
FL7
FL10
中層階搬入用
11200.0
11200.0
2800.0
1750.0
1100.0
1796.0
1746.0
1250.0
1250.0
1550.0
1100.0
650.0
3400.0
300.0


scattered n
π⁻ beam
(~0.8 GeV/c)
Cylindrical
Detector System
detect p+π⁻ / p+p
from η-mesic nuclei
11200.0
11200.0
2800.0
1750.0
1938.777
950.0
1100.0
499.6
1796.0
83.087
1746.0
1938.779
450.0
14.939
1250.0
3400.0
300.0
1550.0
650.0
500.0
FL7
FL6
FL6
FL10
中層階搬入用
階段

(p, ^{3}He) reaction

-- discussion with Prof. Machner and Prof. Roy --

- ^{6}Li (=α-d) target → ^{4}He-η system
- detection of decay particles ($N^* \rightarrow \pi^- p$)
- may be possible at J-PARC,
  but much intense beam (>10^7Hz) is needed.



low-energy η-N interaction

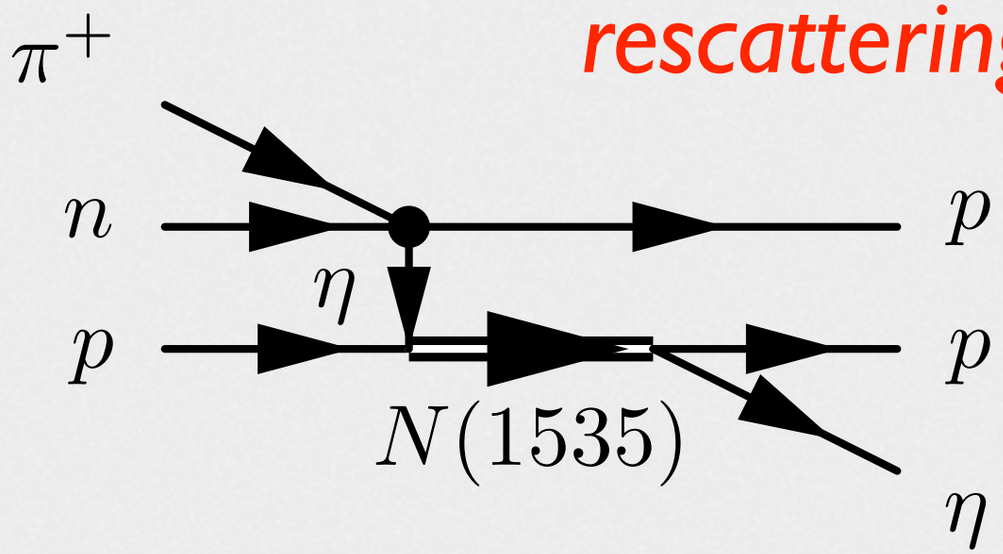
TABLE I. η-nucleon s-wave scattering lengths $a_{\eta N}$.

$a_{\eta N}$ (fm)	Formalism or reaction	Reference
$0.270+0.220i$	Isobar model	Bhalerao and Liu [2]
$0.280+0.190i$	Isobar model	Bhalerao and Liu [2]
$0.281+0.360i$	Photoproduction of η	Krusche [23]
$0.430+0.394i$		Krusche [23]
$0.579+0.399i$		Krusche [23]
$0.476+0.279i$	Electroproduction of η	Tiator *et al.* [22]
$0.500+0.330i$	$pd\rightarrow{}^3\mathrm{He}\,e\,\eta$	Wilkin [24]
$0.510+0.210i$	Isobar model	Sauermann *et al.* [14]
$0.550+0.300i$		Sauermann *et al.* [14]
$0.620+0.300i$	Coupled T matrices	Abaev and Nefkens [16]
$0.680+0.240i$	Effective Lagrangian	Kaiser *et al.* [17]
$0.750+0.270i$	Coupled K matrices	Green and Wycech [12]
$0.870+0.270i$	Coupled K matrices	Green and Wycech [13]
$1.050+0.270i$		Green and Wycech [13]
$0.404+0.343i$	Coupled T matrices	Batinić *et al.* [18]
$0.876+0.274i$		Batinić and Švarc [19]
$0.886+0.274i$		Batinić and Švarc [19]
$0.968+0.281i$		Batinić *et al.* [20]
$0.980+0.370i$	Coupled T matrices	Arima *et al.* [21]

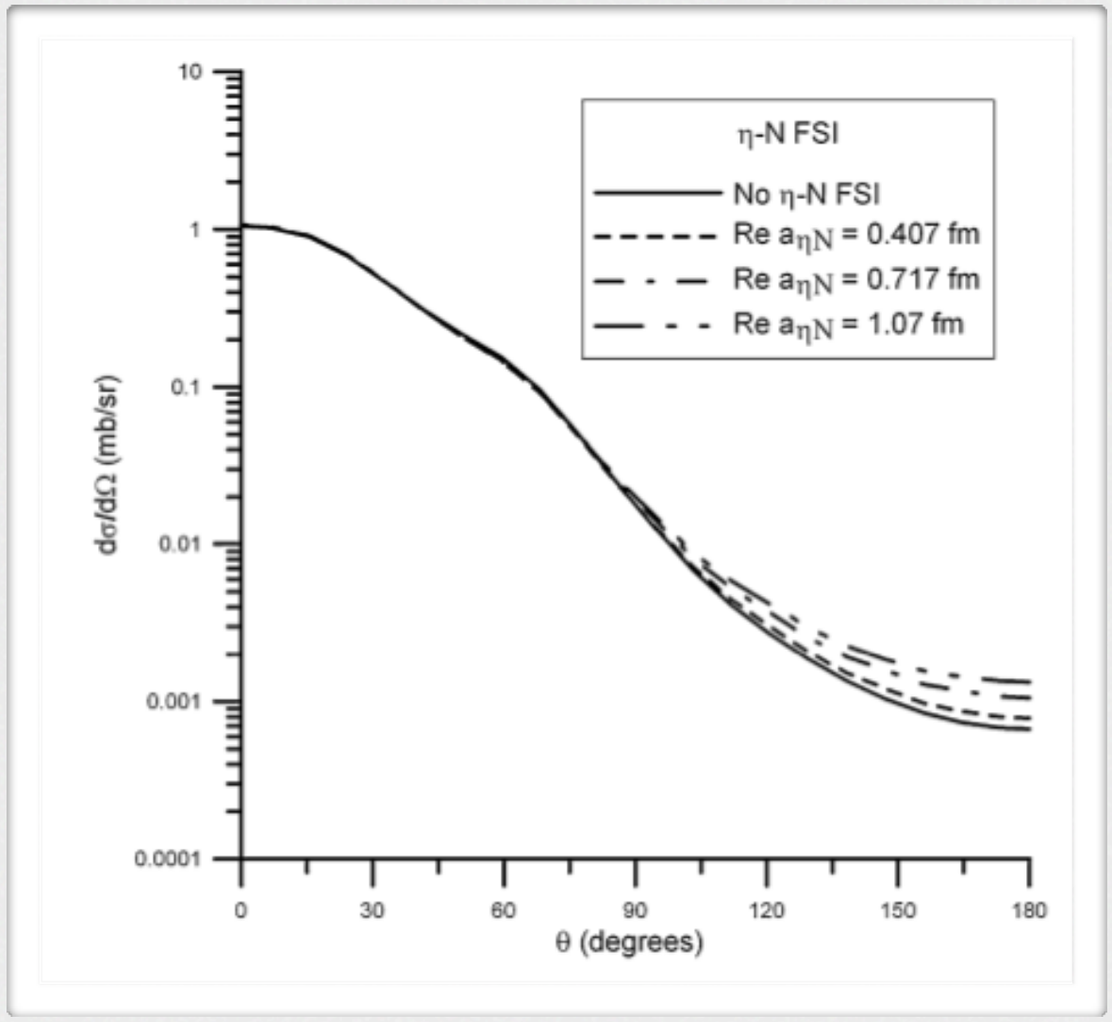
Haider and Liu, PRC 66, 045208 (2002)

d(π⁺, p)N*(1535) reaction

rescattering of η meson inside deuteron



- η angular distribution
- two-proton detection from π⁺+d reaction



H. Garcilazo and M.T. Peña, Phys. Lett. B696, (2011)

Summary (kaonic nuclei)

- Missing-mass spectroscopy with π/K beam
- search for kaonic nuclei
  (two approved proposals + LoI)
  - E15: preparation in progress
  - E27: *was* almost ready to start

Summary (η-mesic nuclei)

- Missing-mass spectroscopy with π/K beam
  - search for η-mesic nuclei
    - LoI: ^{7}Li(π^{-}, n)
    - ^{6}Li(p, ^{3}He)
- extraction on the strength of ηN interaction
  - $\pi^{+}+d \rightarrow p+p+\eta$ (pη rescattering)

J-PARC E15 collaboration list

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(J-PARC E15 Collaboration)

J-PARC E27 collaboration list

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