Hadron Physics at J-PARC
- current hadron physics programs & future possibility for J-PARC HI -

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2016/1/20 at Reimei WS

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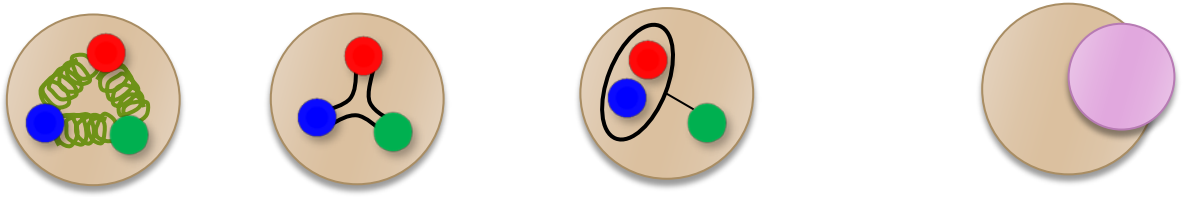
- Physics programs at the J-PARC Hadron Facility
  - Recent results
  - Near future programs
- Possibilities in HIC at J-PARC
- Summary

Hadron Structure

- composed of quarks and gluons
- How do they composed to produce its experimentally observed properties?

- description based on QCD
  - understand degree of freedom and interaction between them

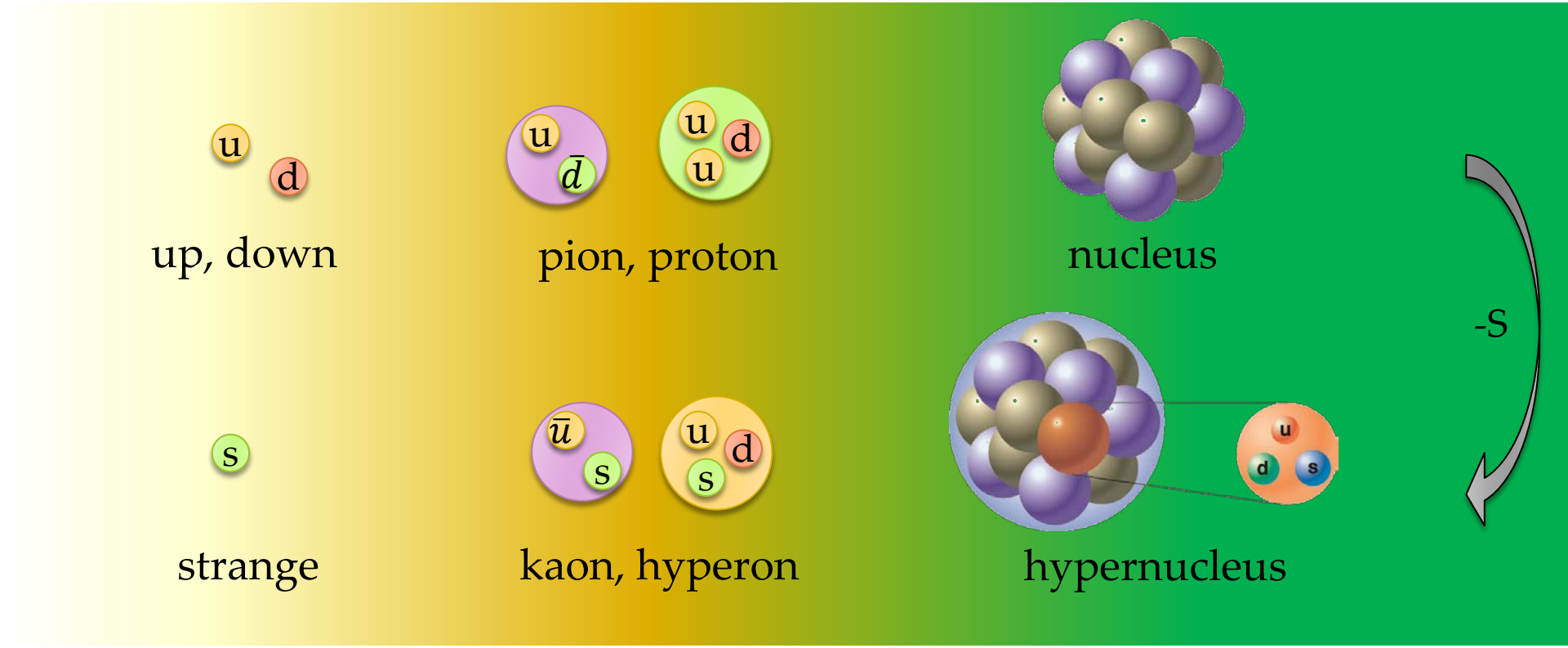
QM flux tube diquark meson-baryon



Strangeness

probe to investigate matter

QUARK HADRON NUCLEUS



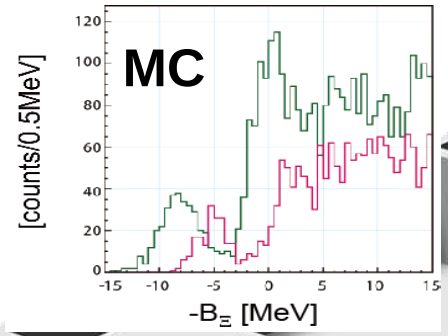
hadron spectroscopy
exotic hadron

hypernuclear physics

Hadron & Nuclear Physics at J-PARC

Strangeness Physics

Ξ hypernuclei in $^{12}C(K^-,K^+)^{\ 6}_{\Lambda\Lambda}He$ double-Λ



Pentaquark Θ⁺

Hadron Mass

kaonic nuclei

Λ(1405) in d(K⁻-,n)

Charmed Baryon spectroscopy

Beam line specifications

Name	Particles	P_{max}	Intensity
K1.8	π, K, $\bar{p}$	2.0 GeV/c	10^6 K^- 's
K1.8BR	π, K, $\bar{p}$	1.1 GeV/c	10^6 K^- 's
KL	neutral K		
K1.1BR	π, K, $\bar{p}$	0.8 GeV/c	10^6 K^- 's
K1.1	π, K, $\bar{p}$	1.1 GeV/c	10^6 K^- 's
High-p	proton	31 GeV/c	10^{10} p
High-p secondary	π/K/$\bar{p}$ (unseparated.)	20 GeV/c	10^6 K^- 's

new

$\sqrt{s}$ = 2.2 GeV → $\sqrt{s}$ = 6.2 GeV in 20GeV/c πp/Kp reactions

Current Hadron Physics Programs

Hadron Physics

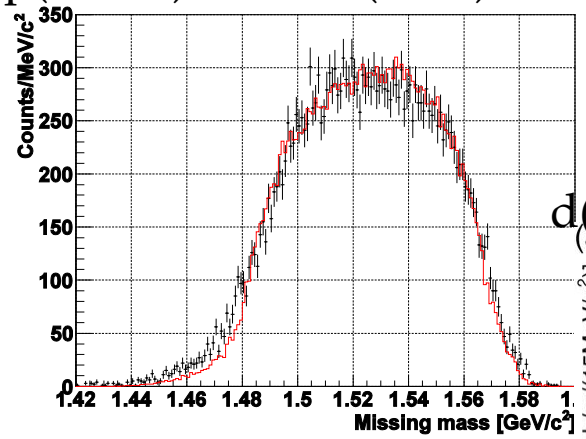
- Exotics
  - multiquark systems
    - pentaquark Θ^+
    - H dibaryon : J.K. Ahn's talk on Tuesday
  - hadronic molecular states
    - $\Lambda(1405)$
  - kaonic nuclei

- Dilepton

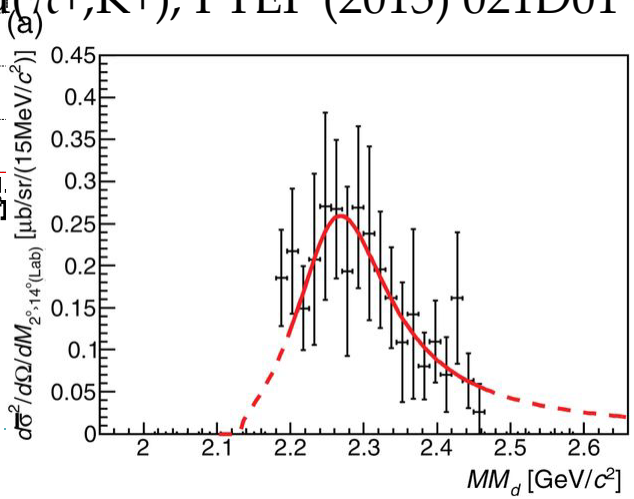
Exotics : Recent Results

- Search for pentaquark Θ^+ $d\sigma/d\Omega$=0.28μb/sr (lab.) Γ<0.36MeV
- Search for kaonic nuclei k^-pp in π/K-induced reactions
  - Sakuma-san's talk on Monday
- Spectral information of $\Lambda(1405)$

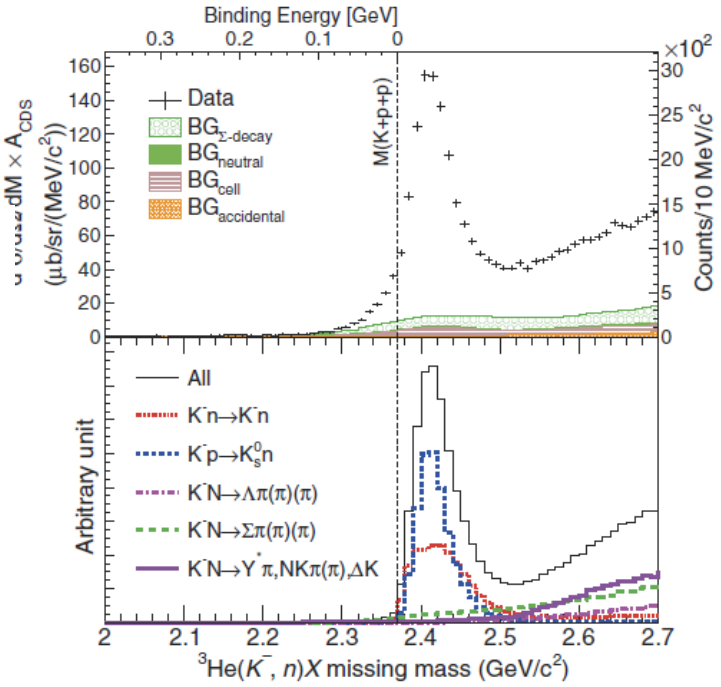
$p(\pi^-,K^-)$ PRL109(2012)132002



$d(\pi+,K+)$, PTEP (2015) 021D01

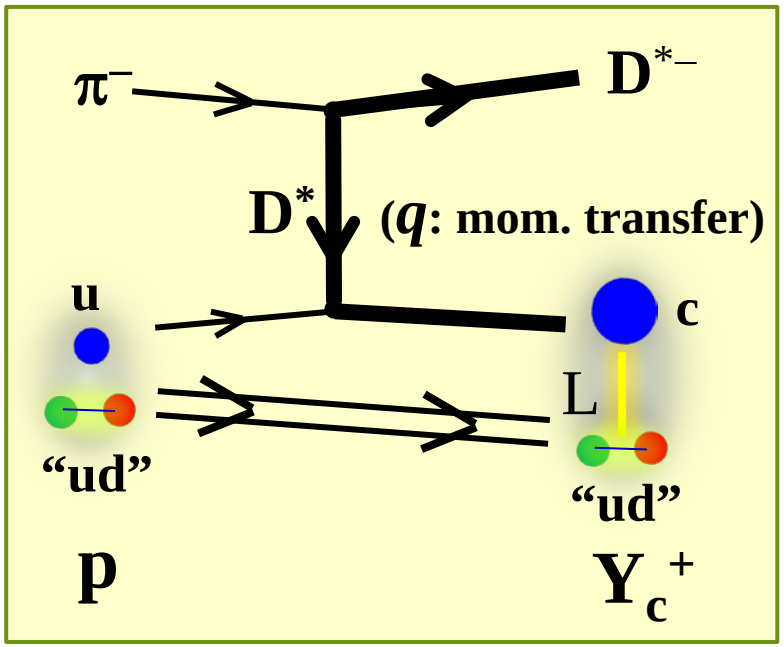


$^3He(K^-,n)X$: PTEP 2015, 061D01



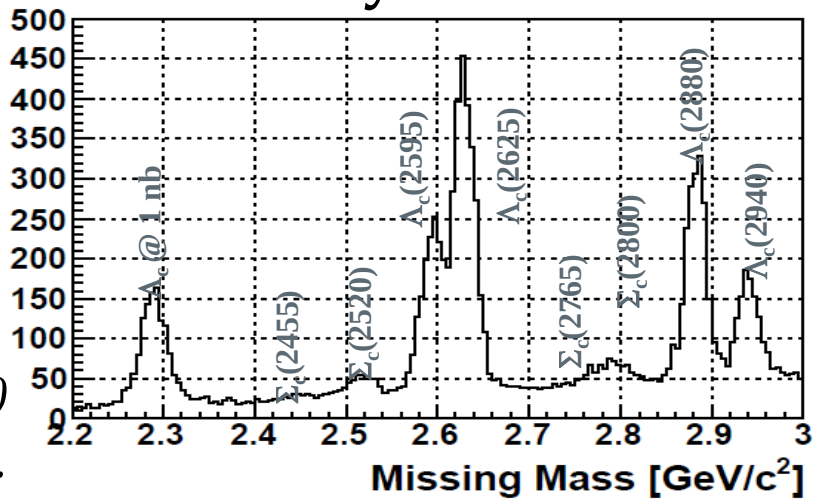
Toward Baryon Spectroscopy

- charmed baryon spectroscopy (E50) at the newly constructed high-momentum beamline
  - talk by K. Shirotori-san on Monday



Missing mass spectroscopy:
$20\text{GeV/c}\ \pi^- + p \rightarrow Y_c^{*+} + D^{*-}$

sensitivity : 0.1nb



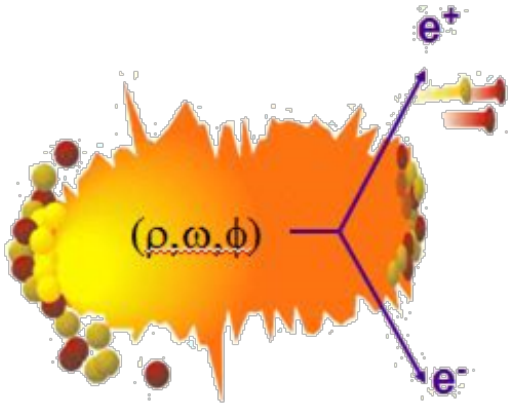
- ***Cascades*** *can be also studied with E50 spectrometer.*

Dilepton Measurement

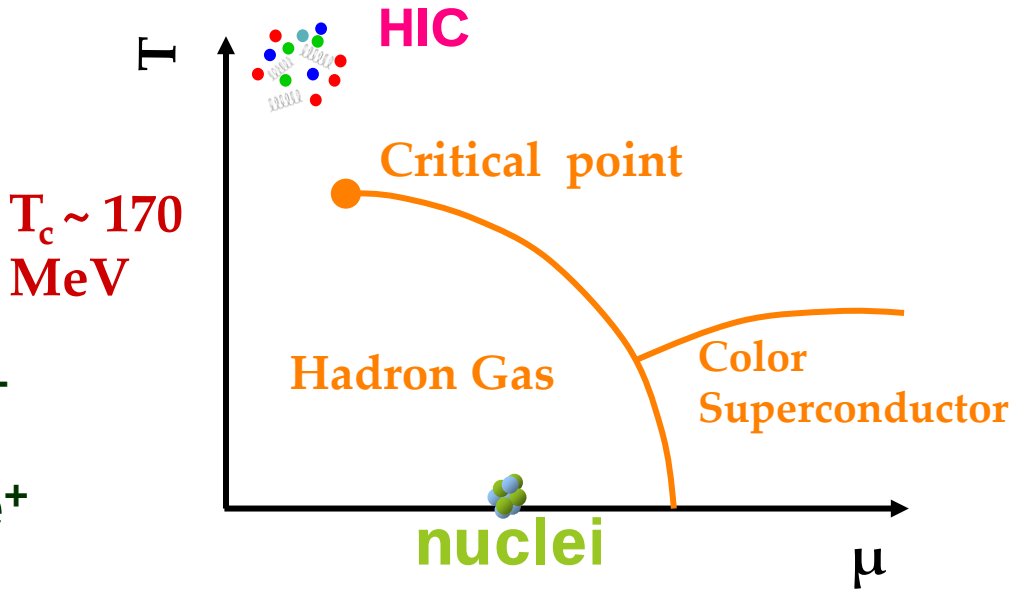
previous experiment KEK-PS E325

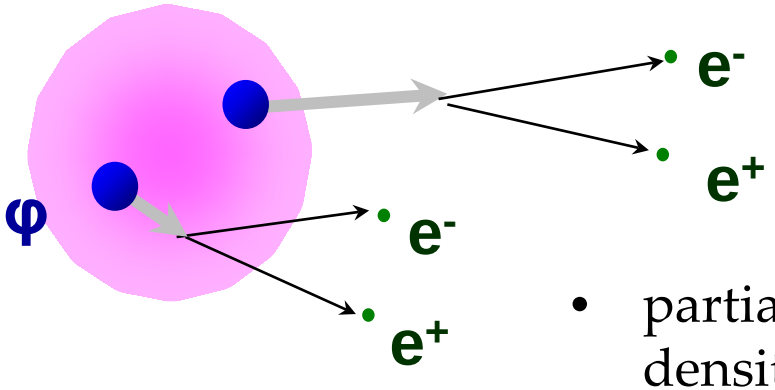
near future experiment : J-PARC E16

HIC vs. Cold Nuclear Matter



- extreme condiction at high temperature
- convolution of space-time evolution

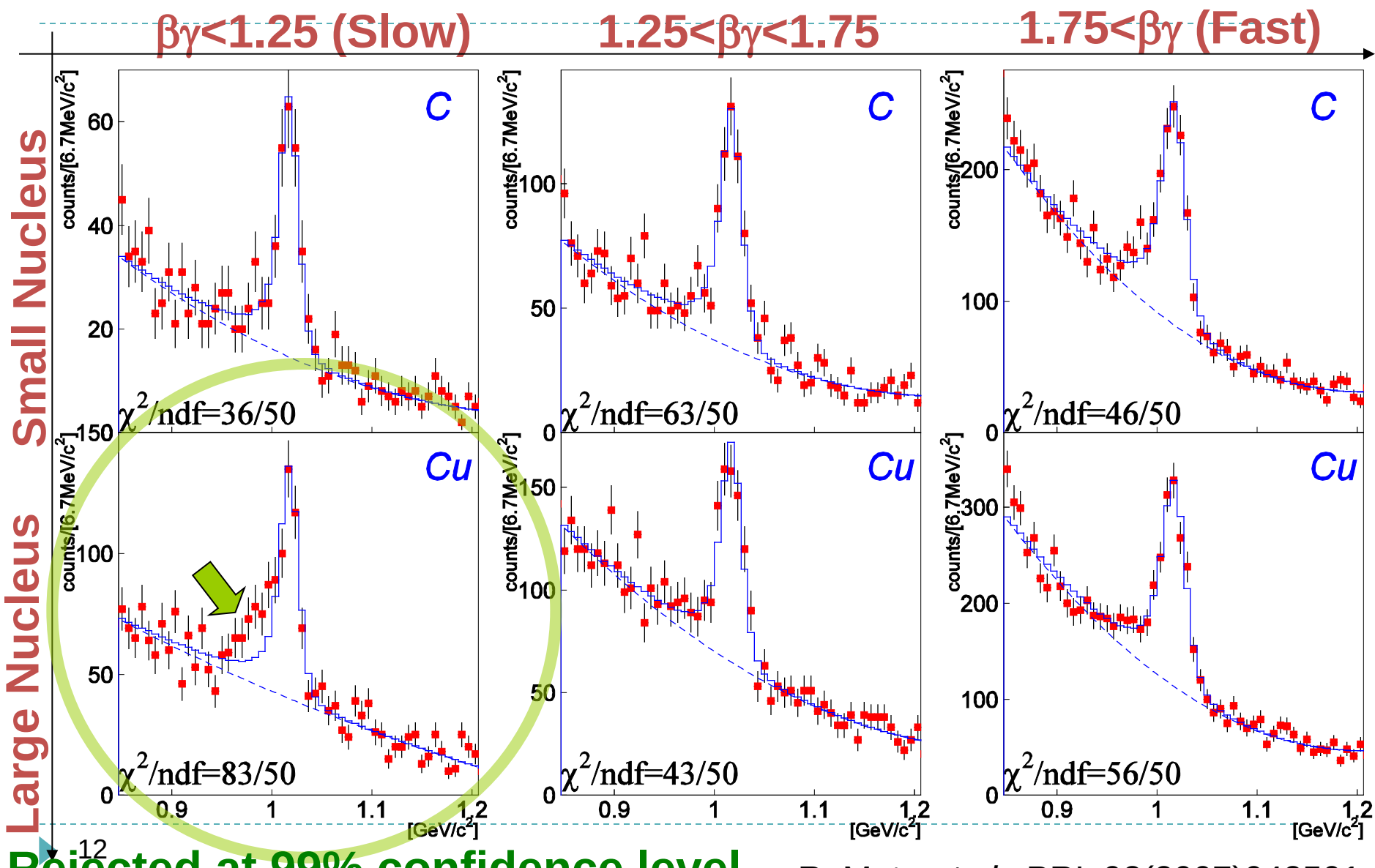




- partial restoration of CS at normal nuclear density
- cold nuclear matter : stable system

Dilepton measurement in pA→φX

KEK-PS E325



Rejected at 99% confidence level

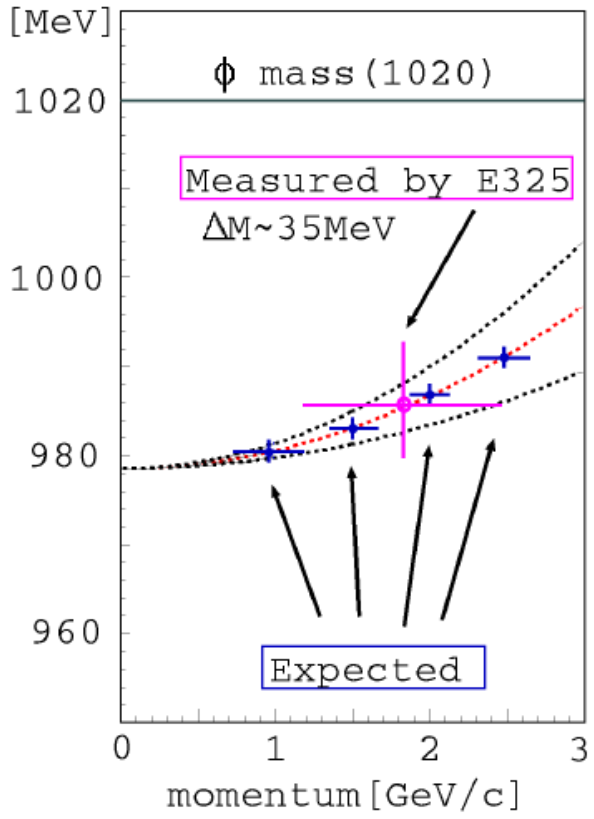
R. Muto *et al.*, PRL 98(2007)042501

Di-electron measurement at J-PARC

- vector meson production in 30GeV/c p+A
  - high rate capability ~10^7 interaction
    - GEM Tracker
    - electron ID : HBD + Lead Glass Calorimeter
  - Large Acceptance (5 X E325)
- high statistics & high mass resolution
- systematic study of in-medium mass
  - velocity dependence
  - A dependence (p → Pb)

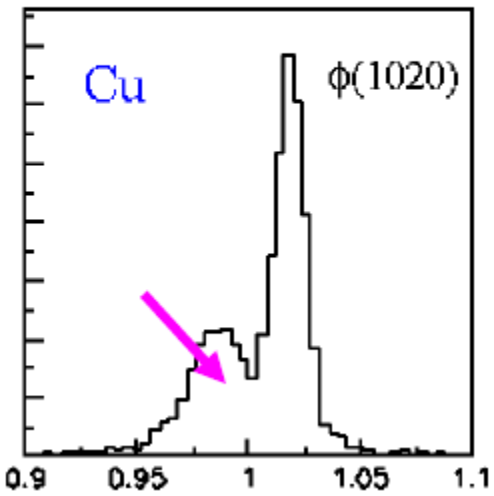
Expected Signals

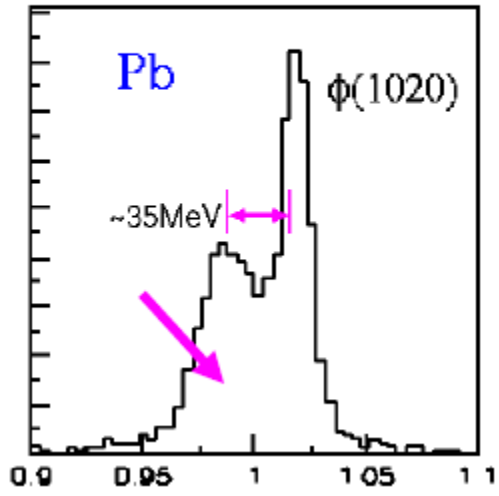
momentum dependence of mass



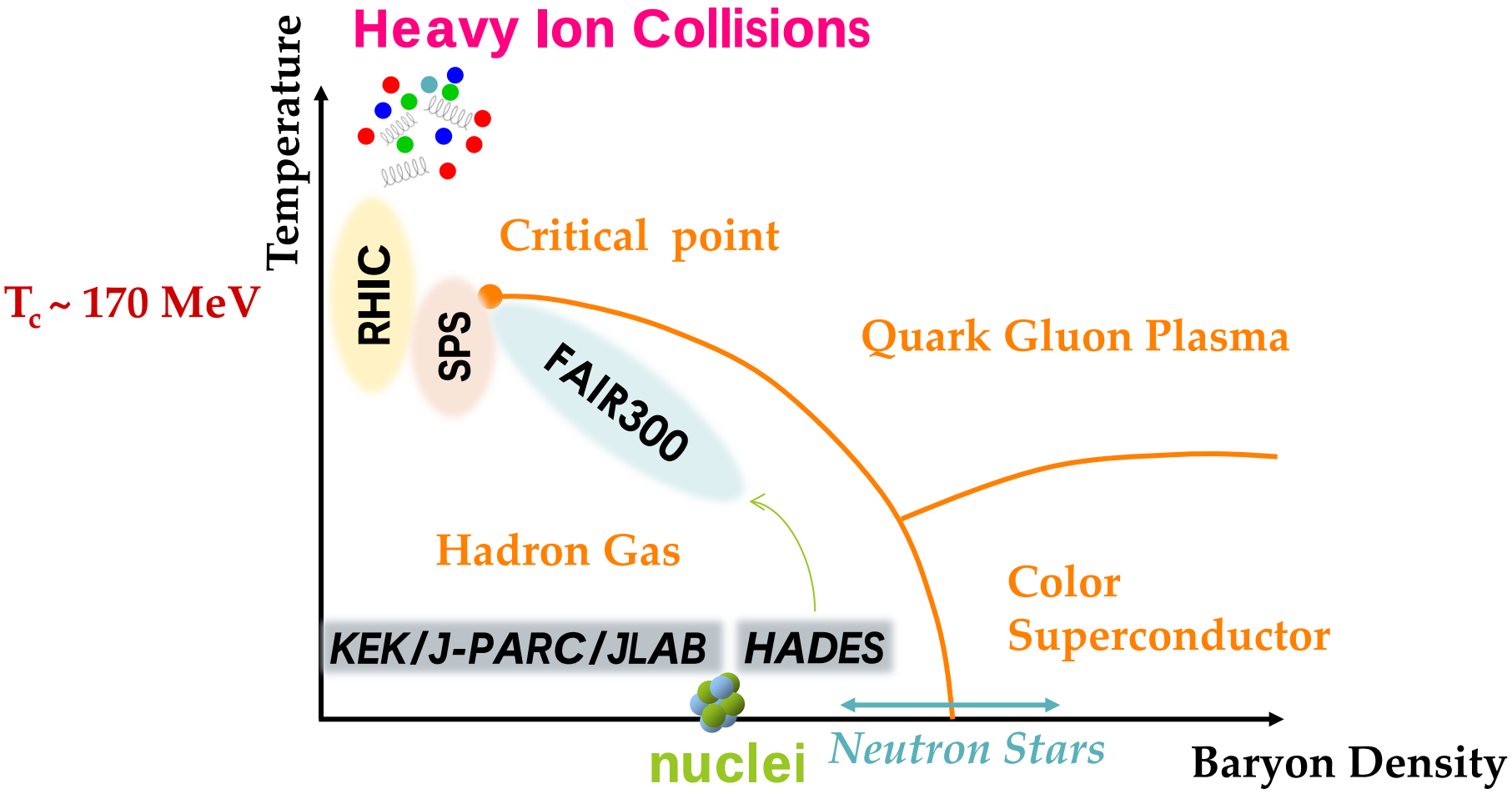
invariant mass spectra

βγ<0.5, σ=5 MeV





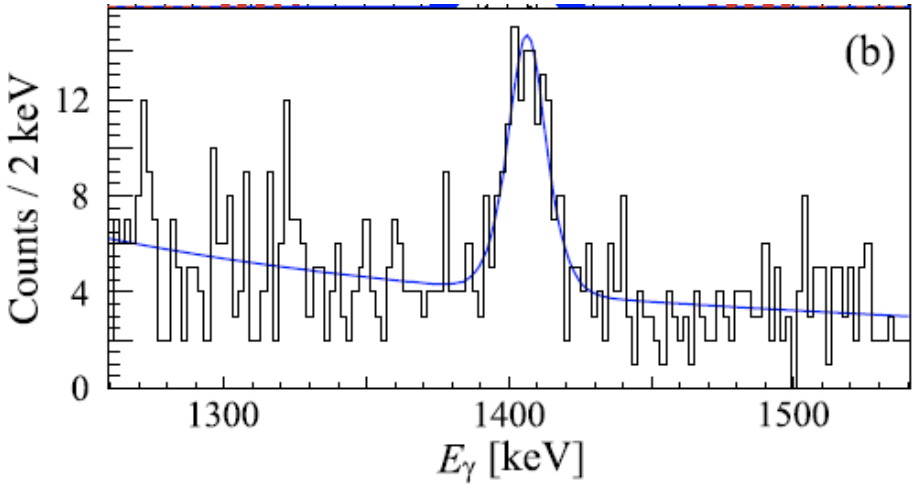
HIC vs. cold nuclear matter



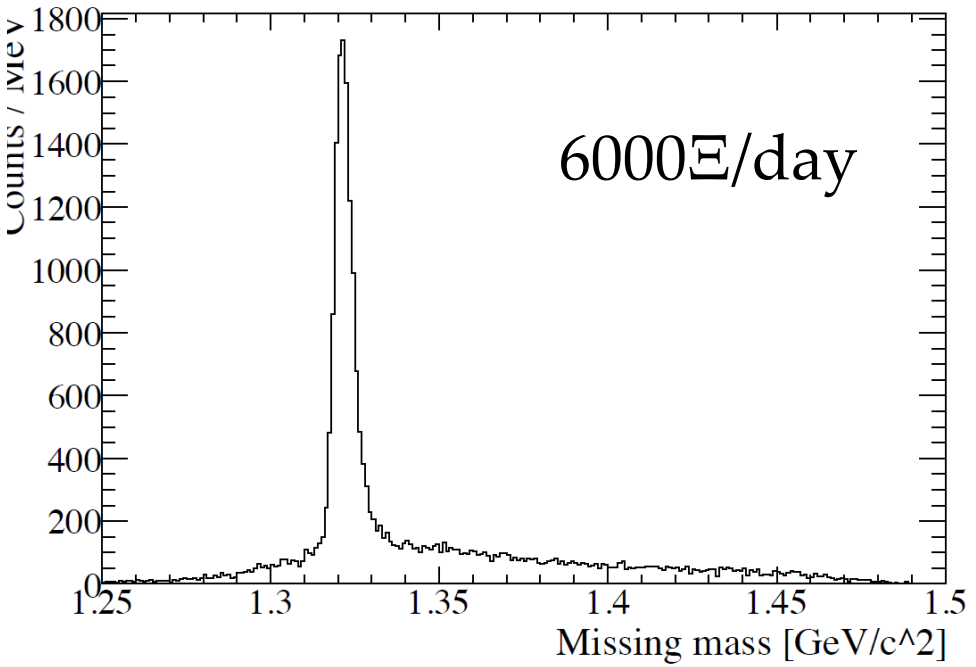
Recent Hypernuclear Experiments

- J-PARC E13 : Hosomi-san's talk on Tuesday
- J-PARC E05 : pilot run last autumn

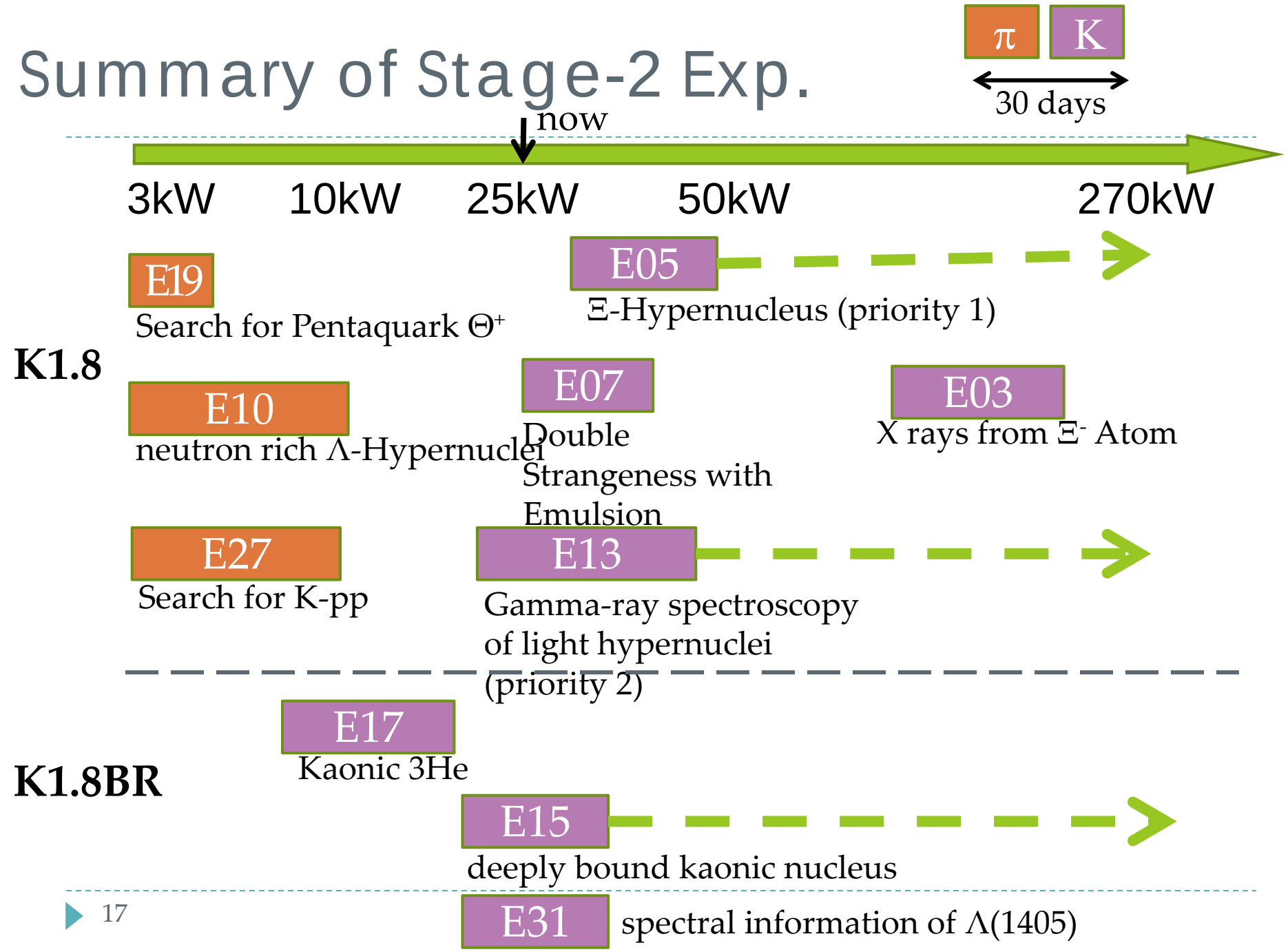
4He(K−,π−)$^4_\Lambda$H , PRL 115, 222501 (2015)



$CH_2(K^-,K^+)\Xi^-$ 2015 Autumn, E05 pilot run



Summary of Stage-2 Exp.



Hadron Physics at J-PARC HI

- Structure of Hadron
  - production rate <-> structure
- Dilepton
  - spectral information at high density
- Nuclear Physics : Hypernuclei
  - production of hypernuclei which is not significantly produced in elementary productions

Structure of Hadron

- Experimental Approaches
  - properties such as mass, width
  - decay pattern
  - reaction rate

- Reactions
  - reactions between hadrons at low/mid-energies
  - production rate in HIC
    - production rate

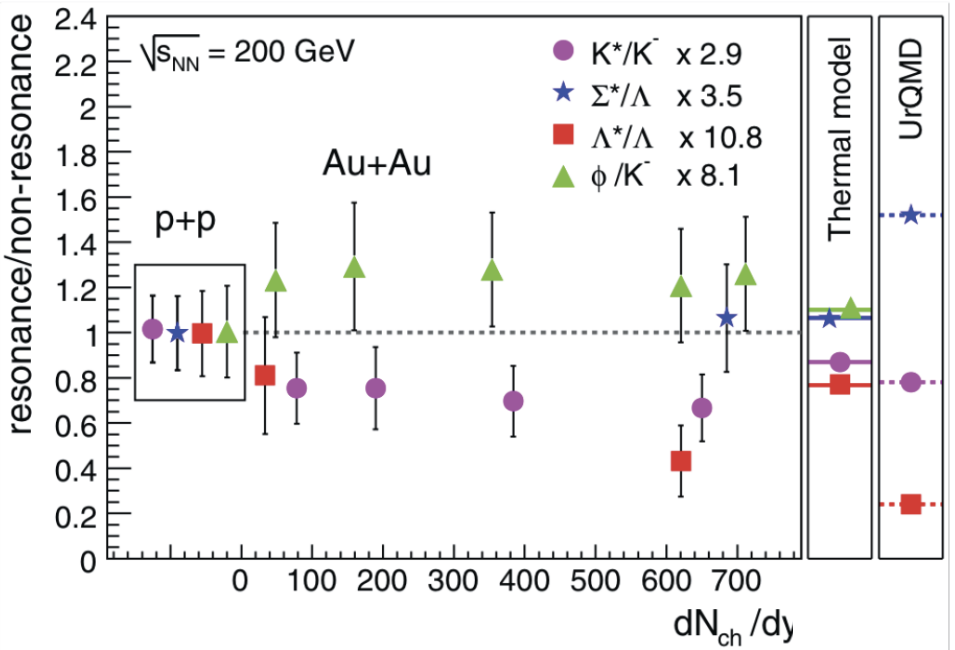
Suppression of Λ(1520)

- Measured Λ(1520)/Λ(1115) is smaller than thermal model prediction
- coalescence model works taking into account the p-wave state of strange quark in Λ(1520)
  - 0.5~0.6, Y. Kanada-En'yo & Müller, PRC 74 (2006) 061901(R)
  - coalescence factor :

    s-wave : 0.360

    p-wave : 0.093

    d-wave : 0.029



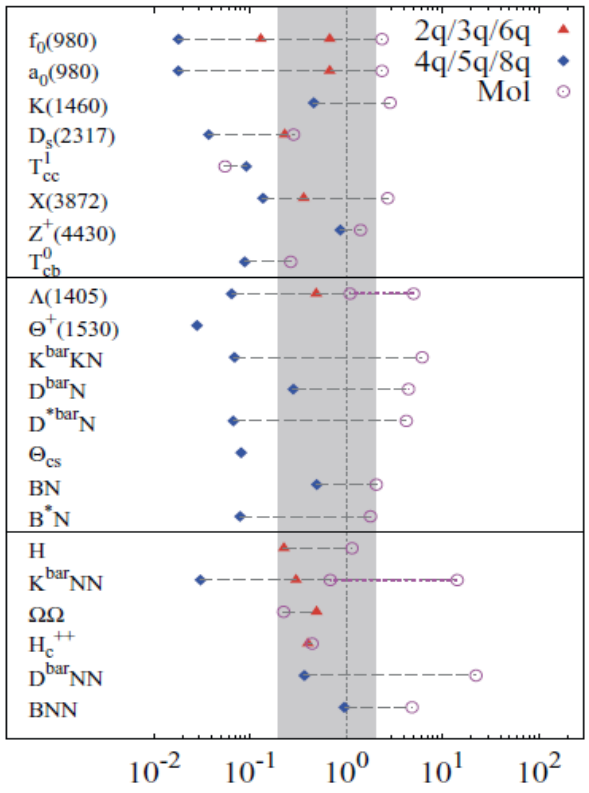
STAR, PRL97 (2006)132301

Production Rate based on Statistical Model

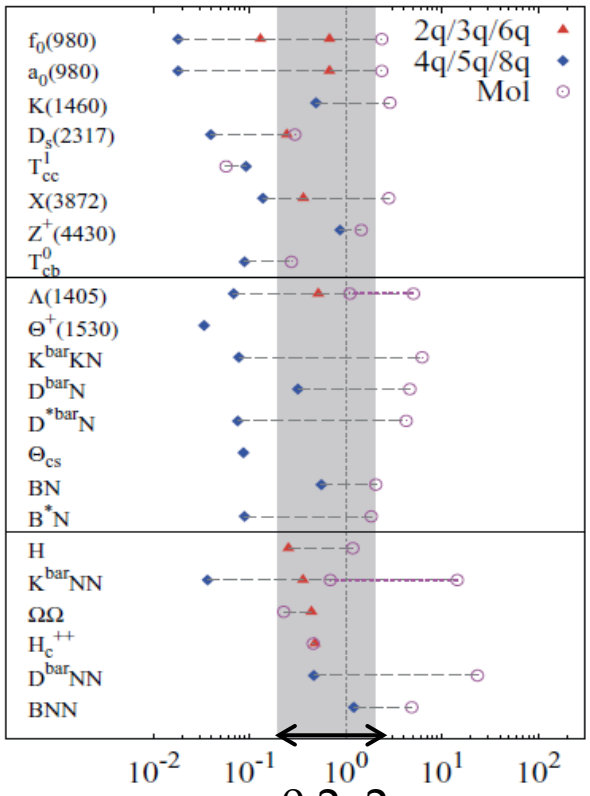
- 2q/3q configurations are in the range of 0.2 ~ 2 (gray zone).

ExHIC, PRL 106 (2011) 212001

Coalescence / Statistical model ratio at RHIC



Coalescence / Statistical model ratio at LHC



quark / molecular coalescence

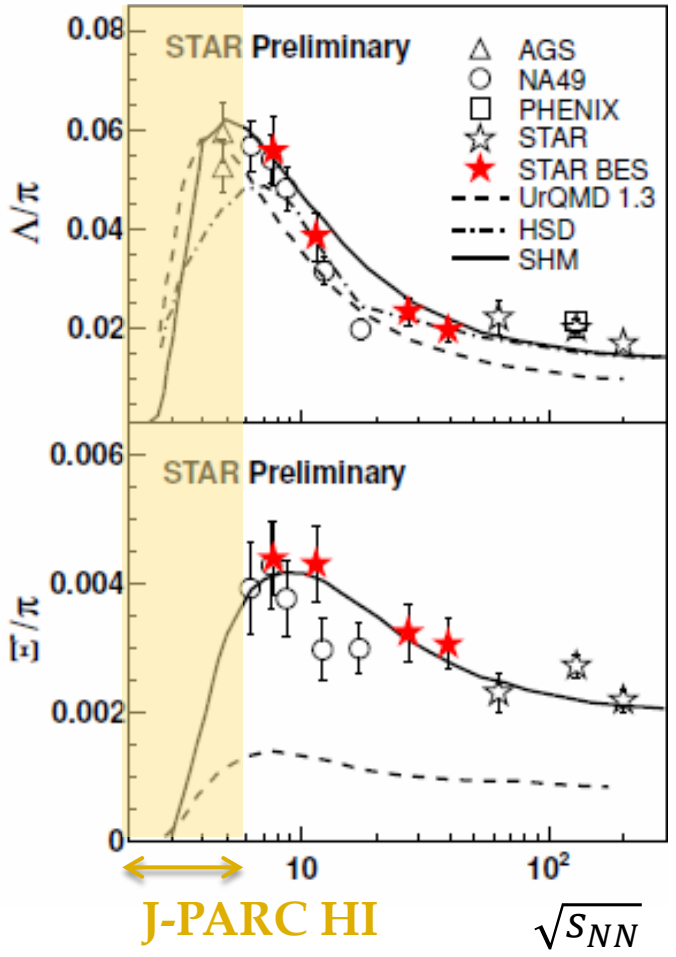
- yield of compact multiquark states
  - ~1/10 of normal 2q/3q, since the coalescence of additional quarks is suppressed.
- molecular states
  - larger yields from coalescence model compared with that of statistical model
  - large yield of loosely bound states
    - large size <-> large coalescence probability
    - cf. $\Lambda(1405)$ as a deeply bound state has the smaller yield

production rate in HIC may be a good tool to approach the structure of hadron

Strangeness Production

- agree with the statistical model
- ratios to pions seem to be enhanced at the J-PARC energies.
  - S=-1 $\Lambda/\pi \sim 0.1$
  - S=-2 $\Xi/\pi \sim 0.01$
  - S=-3 $\Omega/\pi \sim 0.001$

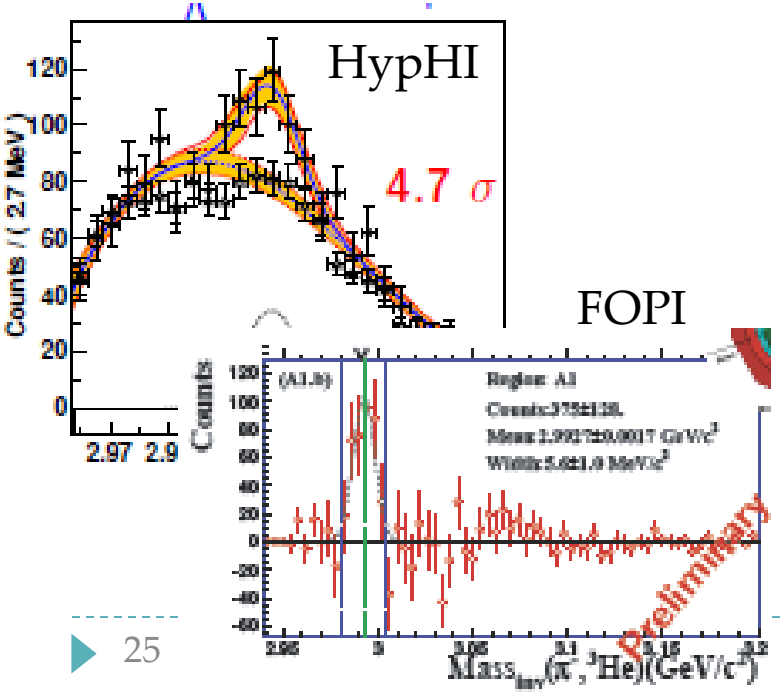
  at maximum



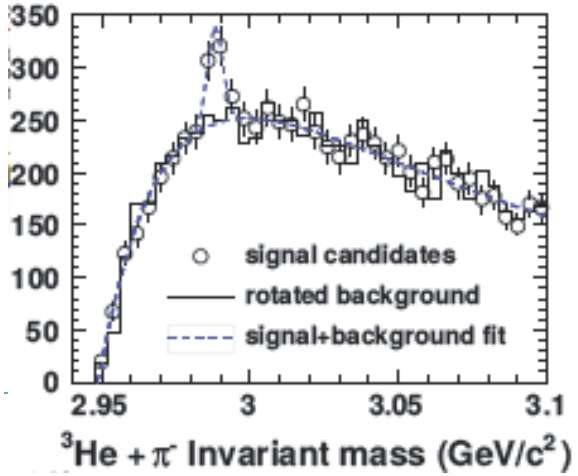
X. Zhu et al., JoP C.S.509(2014)012004

Hypernuclear Production in HIC

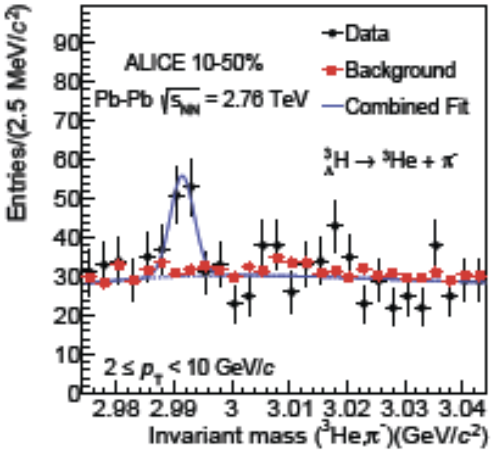
- at RHIC/LHC energies : yields are consistent with the statistical model
- HypHI exp. 6Li + 12C @ 2.7GeV : ${}^{3}_{\Lambda}H$ ~4μb
- FOPI exp. Ni + Ni @ 2.67GeV ${}^{3}_{\Lambda}H/\Lambda \sim 0.52$



STAR Au+Au@200GeV



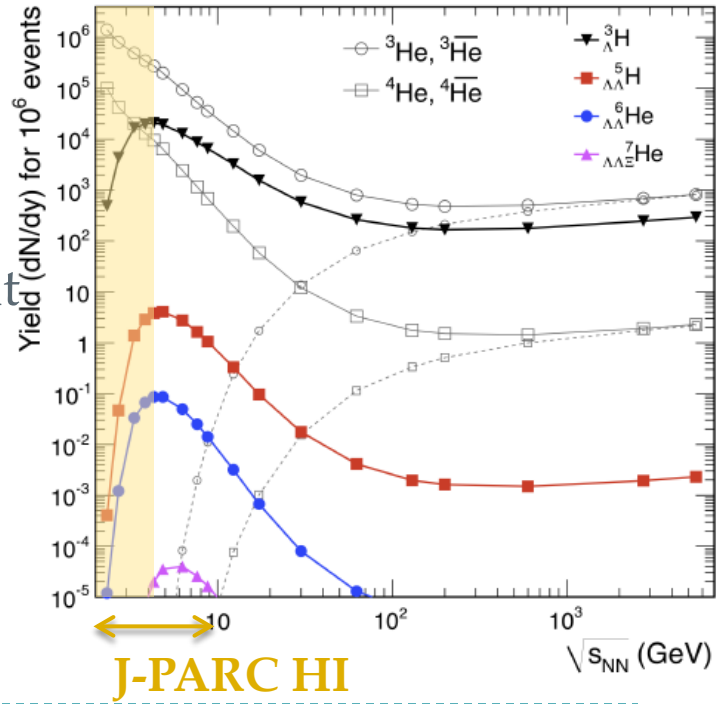
ALICE Pb+Pb@2.76TeV



Hypernuclear Production

- Cross Section
  - ~ GeV/c π + C → K + $^{12}_{\Lambda}$C : ~ 10μb/sr
  - ~ GeV/c K + C → K + $^{12}_{\Xi}$Be : ~ 0.1μb/sr
  - ~ GeV/c A + C→$^{3}_{\Lambda}$H + X : ~0.1μb

Andronic et al., PLB697(2011)203



  - 5 AGeV A + A in the coalescence model
    - single-Λ hypernuclei ~μb
    - double-Λ hypernuclei 0.1nb
    - Ξ hypernucleai ~ 10nb
  - Statistical Model : largest yield is expected at J-PARC HI especially for double-Λ hypernuclei

- 10^6 K beam * 1% target : 10^4 int.
- 10^{10} A beam * 0.1% target : 10^7 int.

Summary

- The operation of the J-PARC Hadron Facility has been successfully resumed and a variety of results has been reported.
  - search for Θ
  - Kpp productions in meson-induced reactions
  - hypernuclei
- Dilepton measurement & Charmed baryon spectroscopy will be performed at the high-momentum beamline being newly constructed.
- Future progress & complimentary studies are expected in the J-PARC HI project.