J-PARC Heavy-Ion Program Overview

H. Sako (*ASRC/J-PARC, JAEA*)

34th Reimei workshop
"Physics of Heavy-ion Collisions at J-PARC"
Tokai, 2016/8/8

Outline

1. Introduction
2. Physics goals
3. Experimental design and simulation
4. Summary

J-PARC-HI Collaboration

76 members : Experimental and Theoretical Nuclear Physicists and Accelerator Physicists

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H. Harada, P. K. Saha, M. Kinsho, Y. Liu, J. Tamura, M. Yoshii, M. Okamura, A. Kovalenko

ASRC/JAEA, J-PARC/JAEA, J-PARC/KEK, Tokyo Inst. Tech, Hiroshima U, Osaka U, U Tsukuba, Tsukuba U Tech, CNS, U Tokyo, Tohoku U, Nagasaki IAS, Kyoto U, RIKEN, Akita International U, Nagoya U, Sophia U, U Tokyo, YITP/Kyoto U, Nara Women's U, KEK, BNL, Mainz U, GSI Central China Normal U, Korea U, Chonbuk National U, Pusan National U, JINR, U Belgrade, Wigner RCP, KRF, Stony Brook U, Bhaba Atomic Research Centre, Far Eastern Federal U

Goals of J-PARC-HI

-Physics of extremely dense matter-

RHIC/LHC discovered QGP at high temperature and low density

No direct evidence for the c
point and phase boun
discovered.

Talks by Kweon, Milosevic (Aug 8)

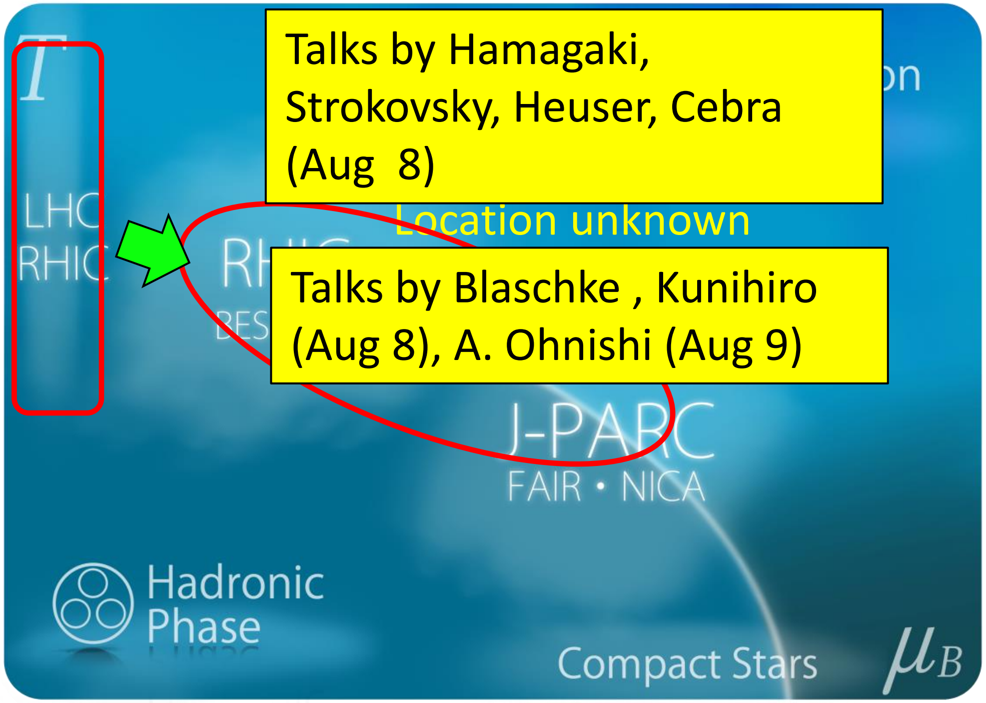
The highest density matter at J-PARC

5-10 ρ_0

~ neutron star core

Goals of J-PARC-HI

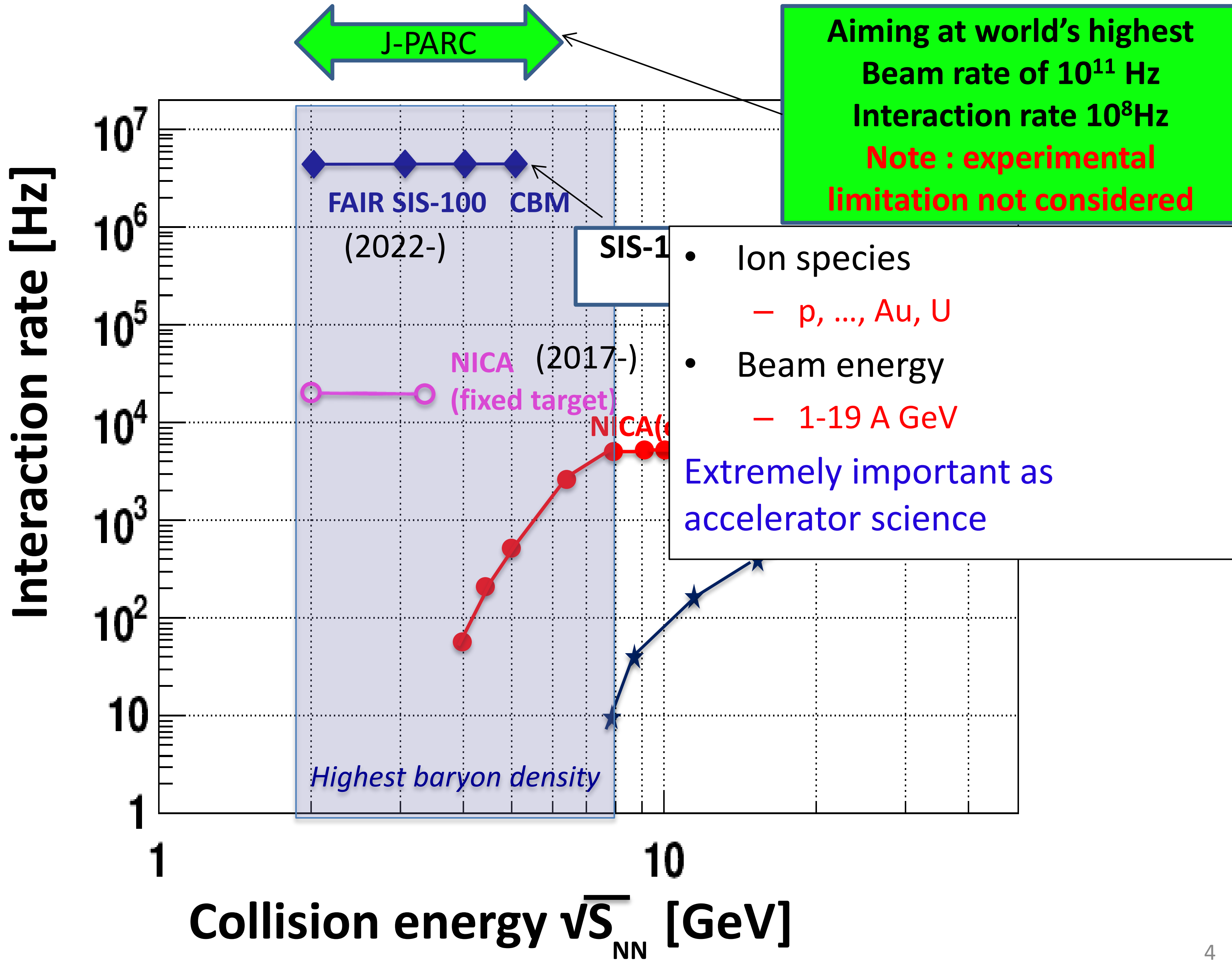
- Studies of phase structures
- Chiral restoration with dileptons
- Hadron properties (EOS) related to neutron star
- Search for strange quark matter



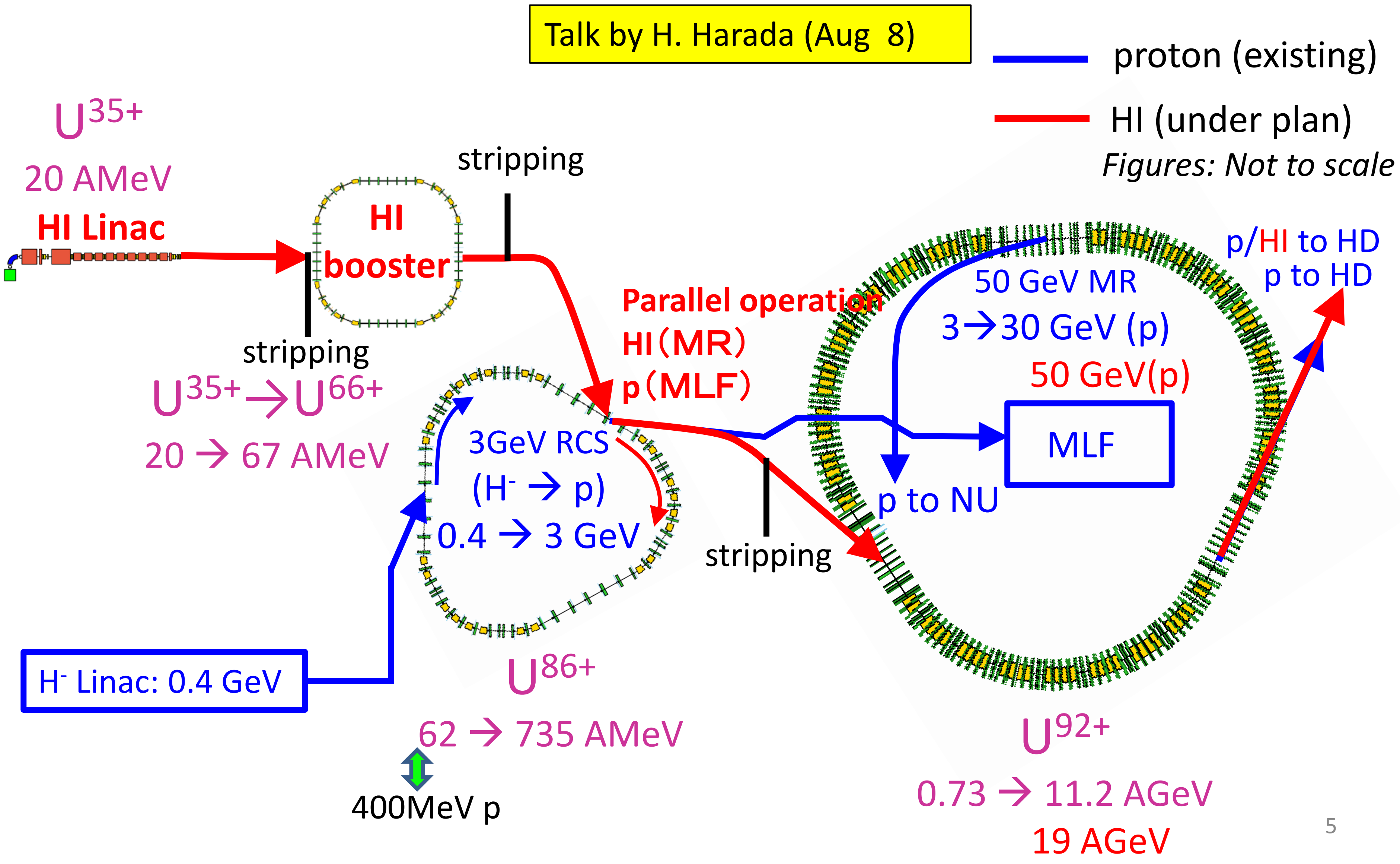
Talks by Hamagaki, Strokovsky, Heuser, Cebra (Aug 8)

Talks by Blaschke , Kunihiro (Aug 8), A. Ohnishi (Aug 9)

HI experiments for high density physics



HI accelerator scheme

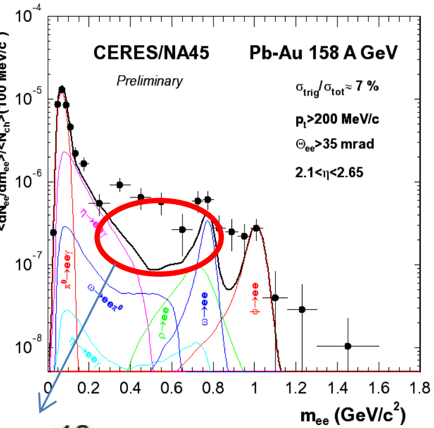


Physics list at J-PARC-HI

- Dileptons
  - Penetrating probes of dense matter
  - Modification of $\rho/\omega/\phi$ linked to chiral symmetry restoration
- Photons
  - Thermal radiations from QGP and hadron
  - Measurement of T at equilibrium
- Hadron measurements (high statistics)
  - Event-by-event fluctuations
  - (Multi-)strange hadrons/hypernuclei, strangelets (S=-1,-2,-3,…)
- Charm
  - J/ψ, D,…
    - Sensitive to initial dense matter?
    - D : mass change due to chiral restoration

Talks by Gubler and Suenaga (Aug 8)
Nagashima (Aug 9)

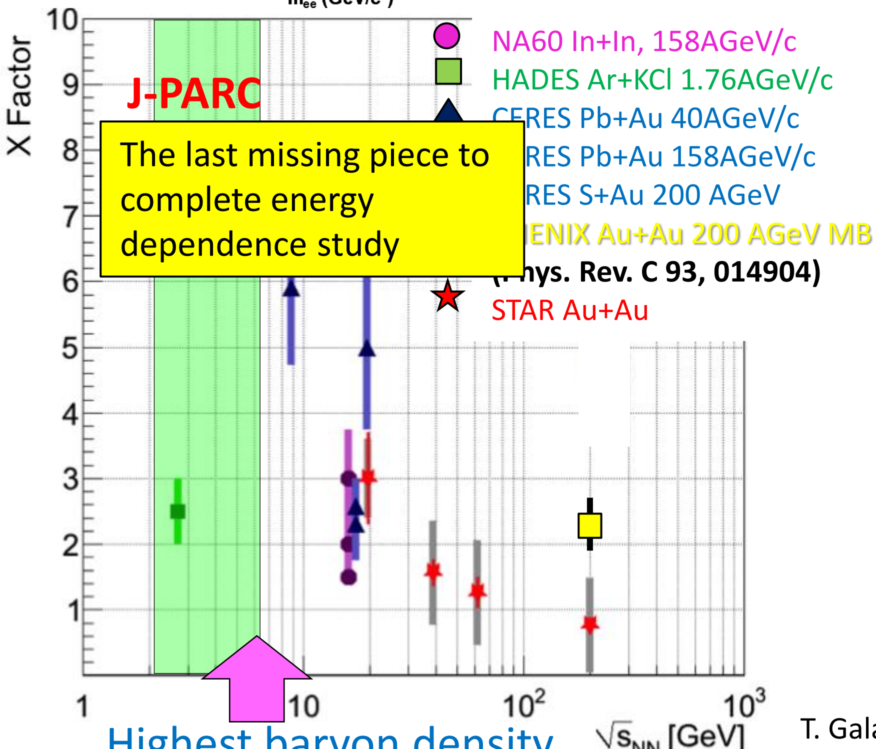
Dilepton low-mass enhancement



Dilepton Low-mass enhancement factor

Due to ρ spectrum change

Measured / cocktail in m=0.2-0.8 GeV/c²



Highest baryon density

(J. Randrup, PRC74(2006)047901)

T. Galatyuk, EM probes of Strongly Interacting Matter ECT*, Trento 2007

Maximum low mass enhancement around J-PARC energies?

- Dielectron
  - γ conversion at low mass (background)
- Dimuon
  - π,K → μ decay (background)
  - Higher rate beam can be used
- High statistics at J-PARC
  - Moment analysis

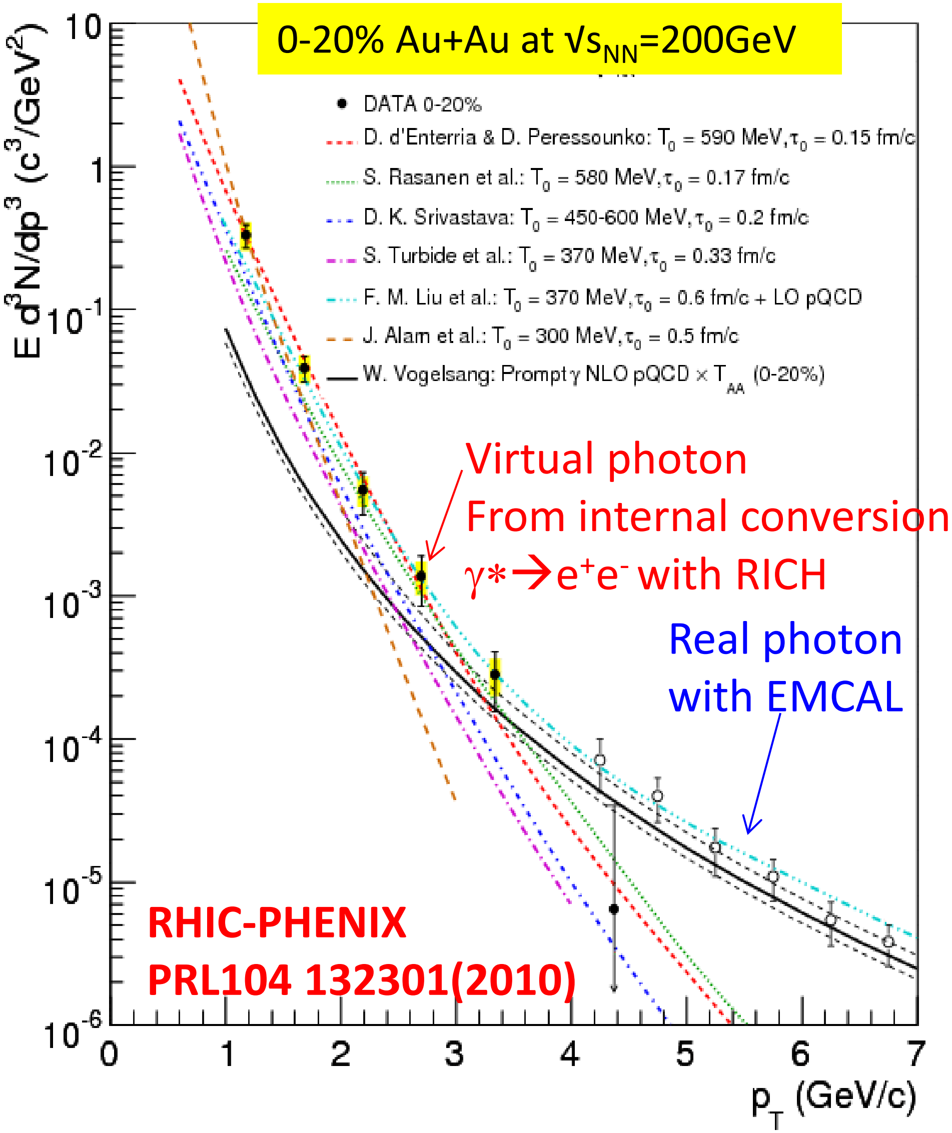
$$\int dm_{ee} N(m_{ee}) m_{ee}{}^{n}\ (n = 1,2,\ldots)$$

→Direct comparison to theoretial models (e.g. QCD sum rules related to quark and gluon condensate)

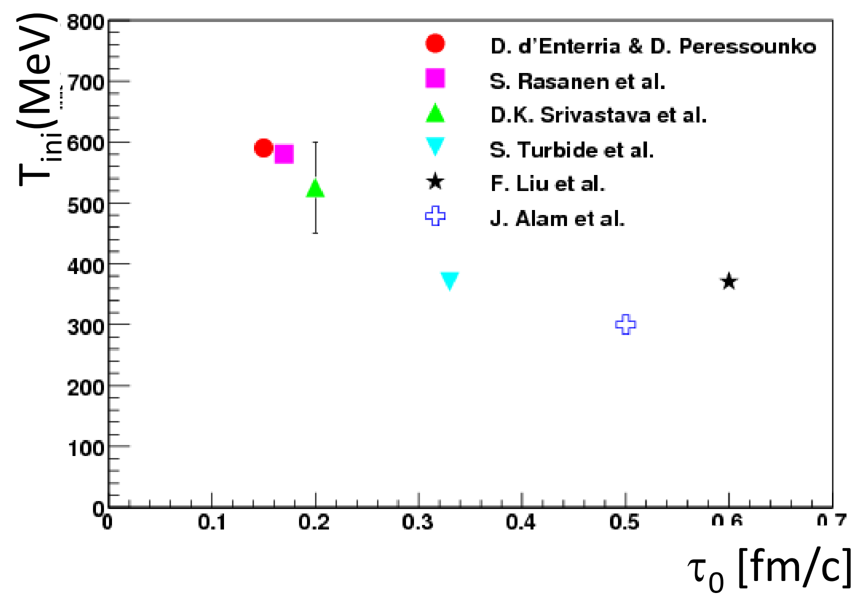
Hayano and Hatsuda, RMP**82**, 2949

In particular, ω and ϕ peaks!

Direct photon : observable for temperature at equilibrium



- Inverse slope = 220MeV (RHIC) > T_c (170MeV)
  - 304 MeV at LHC-ALICE
- Possibility to measure at J-PARC
- Theoretical model fits to data extract T (temperature) and τ_0 (thermalization time)



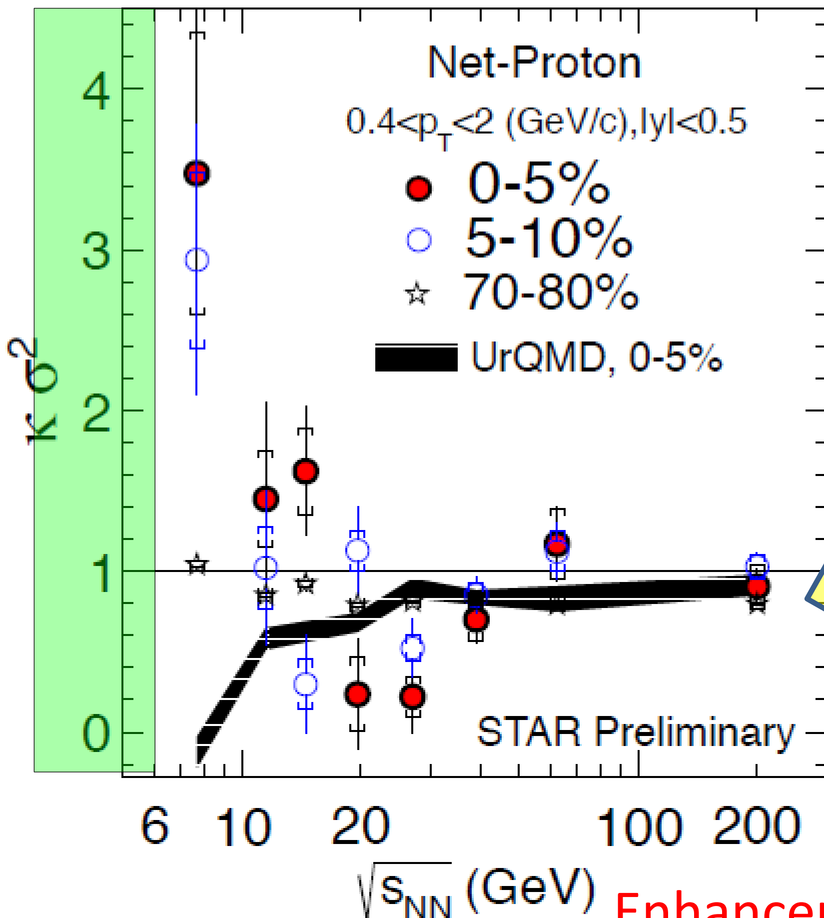
Net-proton fluctuations

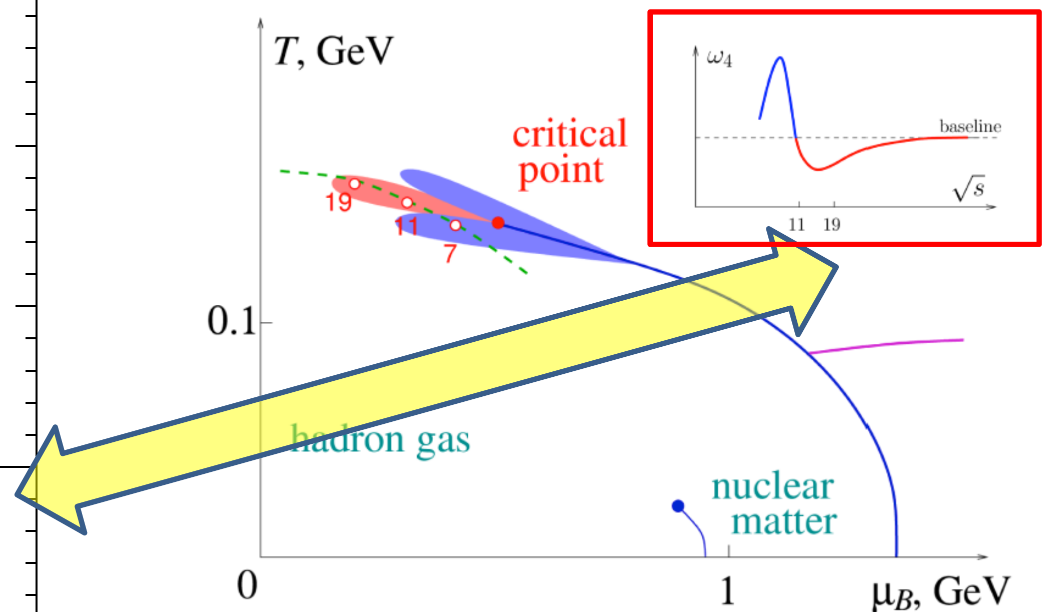
Ebe fluctuations : Probe to search for the critical point
w/ higher-order fluctuations

Theory

M.A. Stephanov,
PRL107, 052301 (2011).

J-PARC





Enhancement of 4th-order fluctuations at low energies

Indications of the critical point?

X. Luo, Quark Matter 2015

Extension of Hadron nuclear physics to high density with HI beams

Normal nuclear density → Neutron star density

Proton and meson beam program at J-PARC

Exotic hadrons
Pentaquark (E19)
H-dibaryon (E42)

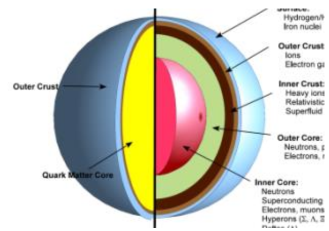
|S|<=2 hypernuclei
(E10,E13,E07,E05)

Kaonic nuclei : K^-pp(E15,E27)

Talks by Ozawa, Noumi, H. Ohnishi (Aug 9)

dilepton in p+A (E16)

Neutron Star



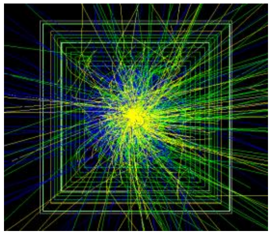
Neutron stars with $2M_{\odot}$
⇒Hard EOS
- YN 3 body force?
- Quark-hadron phase

Talks by Sekiguchi (Aug 9)

YN YY interactions

EOS

J-PARC-HI



Exotic hadrons
(structure by yield)

|S|>=3 hypernuclei

Strangelet (strange quark matter)
Λ^* Cluster

2-particle correlation (HBT)

Collective flow

Chiral restoration
dilepton in A+A

Particle production rates

Beam : 10^{10} Hz

0.1 % target

→ Min-bias event rate 10^7Hz

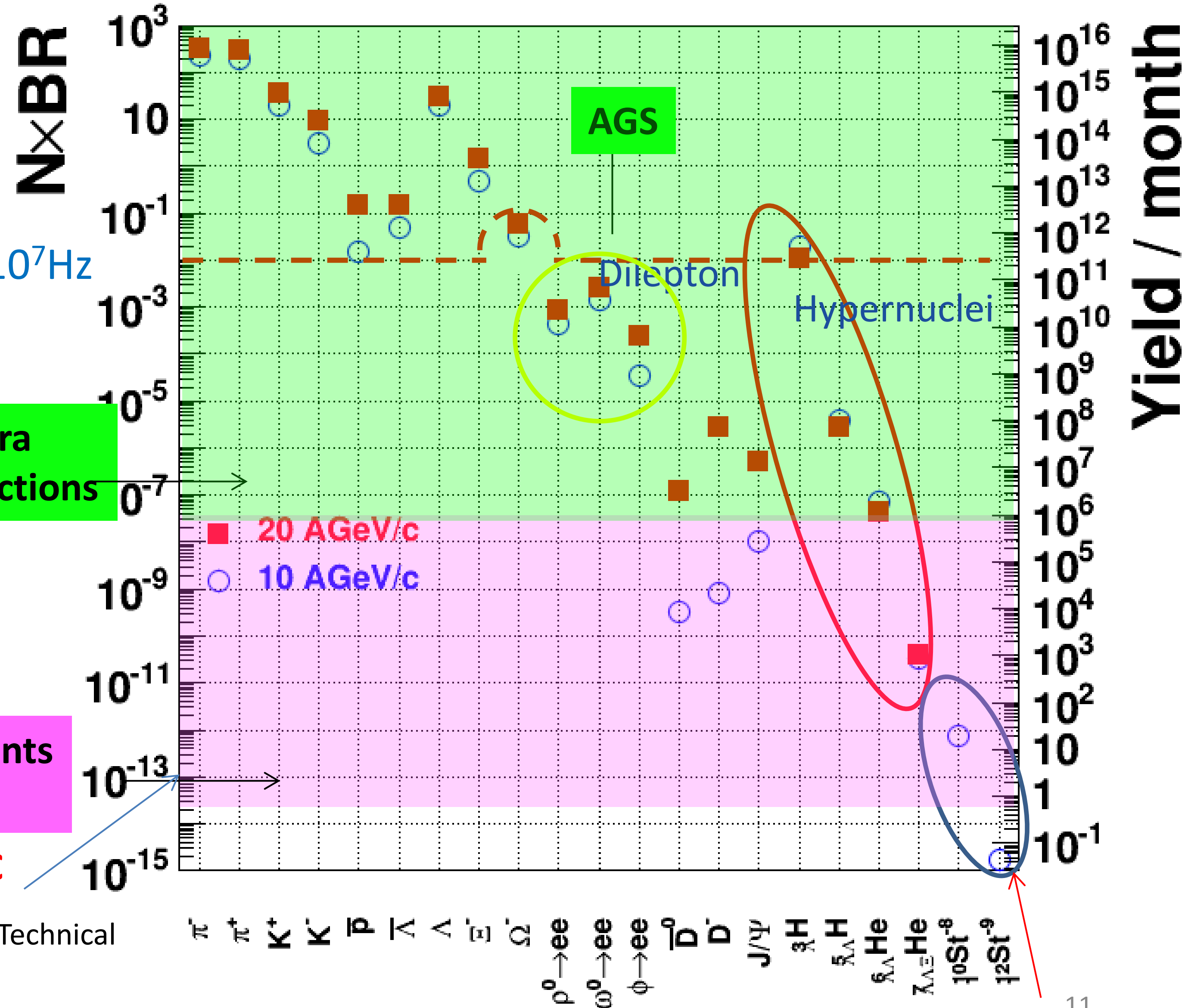
In 1 month experiment:

ρ,ω,φ→ee 10

Hypernuclei 1

Y, pt spectra

Event selections



Measurements and Search

10^{-13} sensitivity at J-PARC

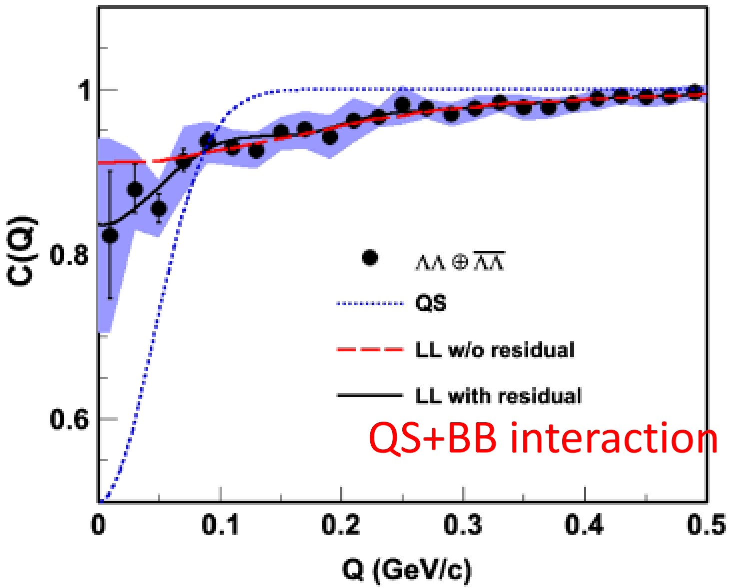
HSD calculations in FAIR Baseline Technical Report (Mar 2006)

A. Andronic, PLB697 (2011) 203

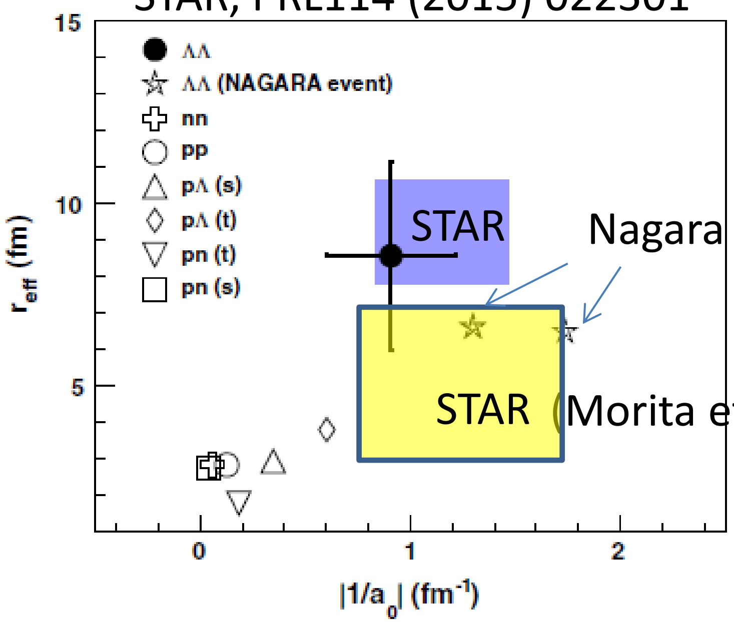
Strangelets: P. Braun-Munzinger J.Phys.G21 (1995)L17

ΛΛ correlation in HI collisions (STAR)

ΛΛ correlation function



STAR, PRL114 (2015) 022301



Morita et al, PRC91 (2015) 024916)

Talk by Morita (Aug 9)

- Information of baryon-baryon interactions can be obtained from two-particle momentum correlation
- Both hadron/nuclear experiment and HI experiment can approach with different methods

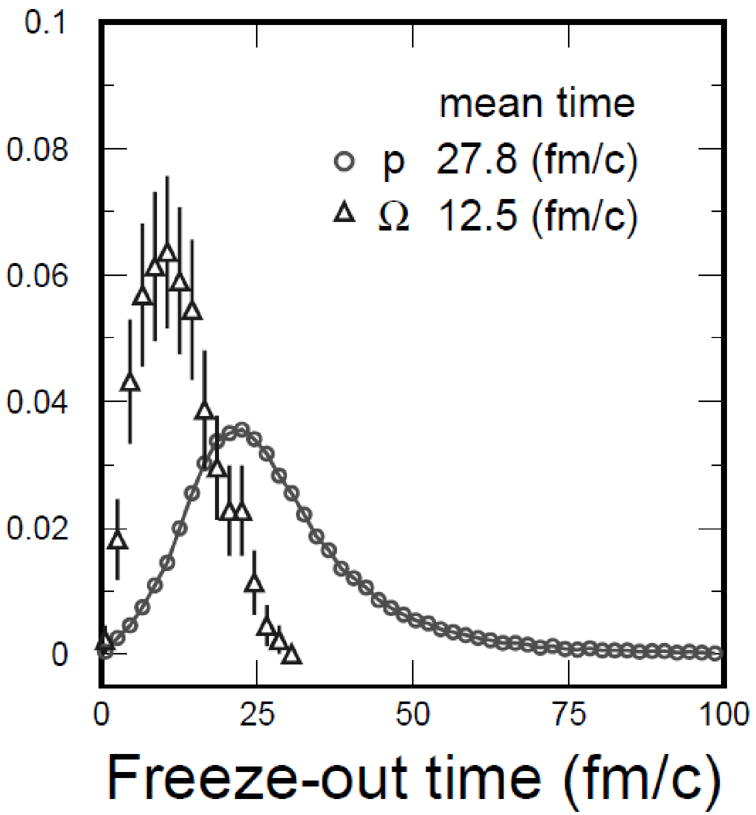
Ξ^- and Ω multiplicities = 0.6/0.03 at 10 AGeV

ΞN, ΩN correlation studies possible

Early freezeout of multi-strangeness hyperons

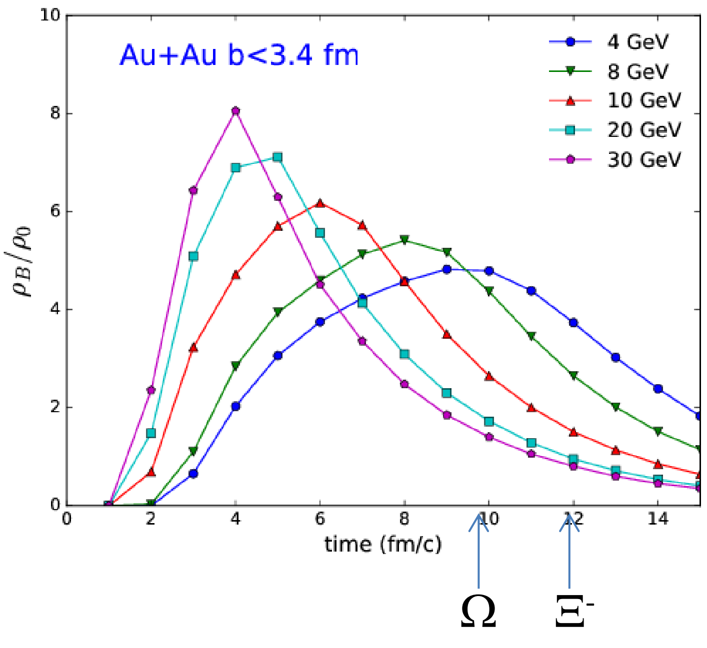
Multi-strange baryons probe higher density

JAM 1.622, U+U



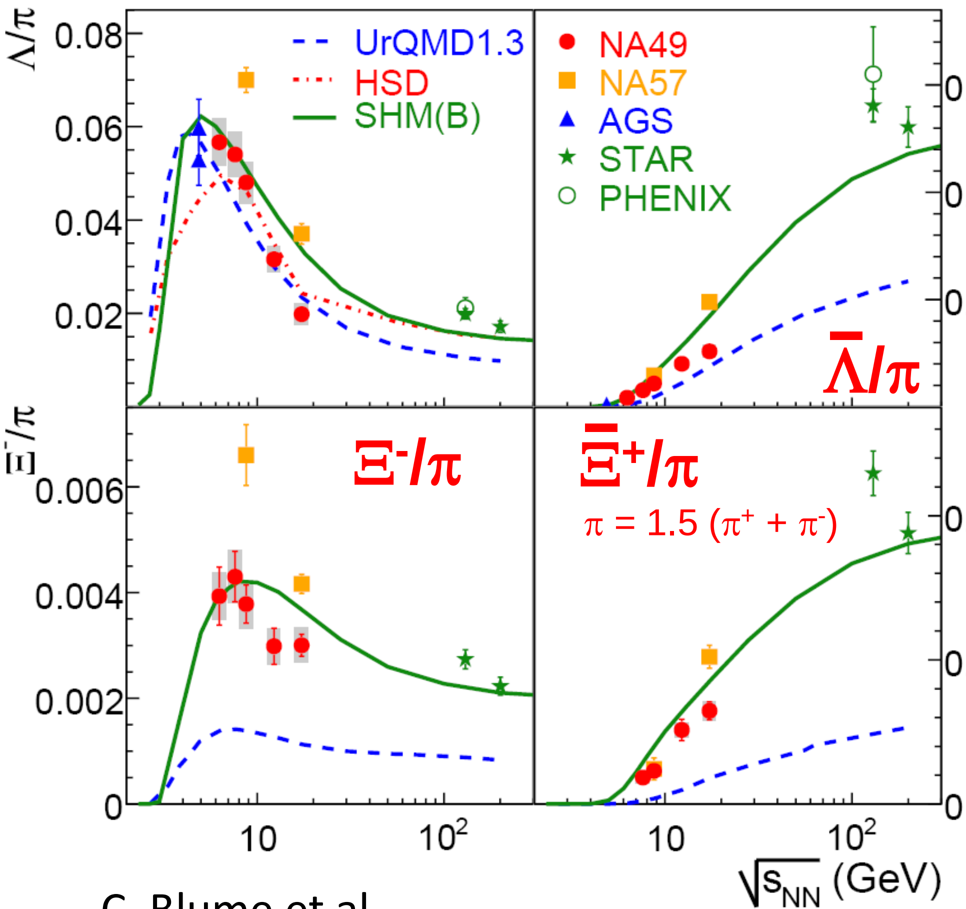
RQMD model Pb+Pb, 158AGeV/c

H. v. Hecke, H. Sorge, N. Xu, PRL81 (1998) 5764

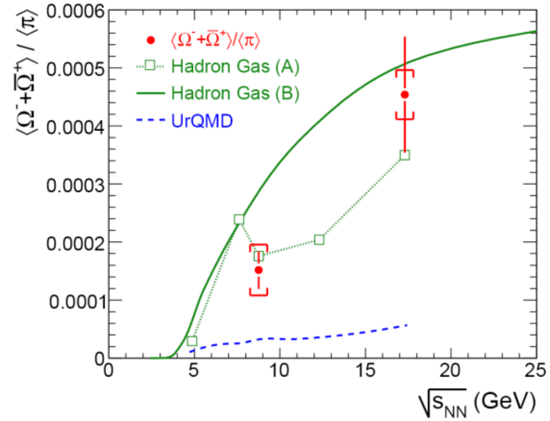


Peak freezeout time
Ω : 10fm/c
Ξ^- : 12fm/c
Λ : 21 fm/c

Hyperon yields



C. Blume et al
Prog. Part. Nucl. Phys. 66 (2011) 834



- UrQMD (hadron cascade) significantly underestimates Ξ,Ω data
- Thermal models qualitatively reproduce data

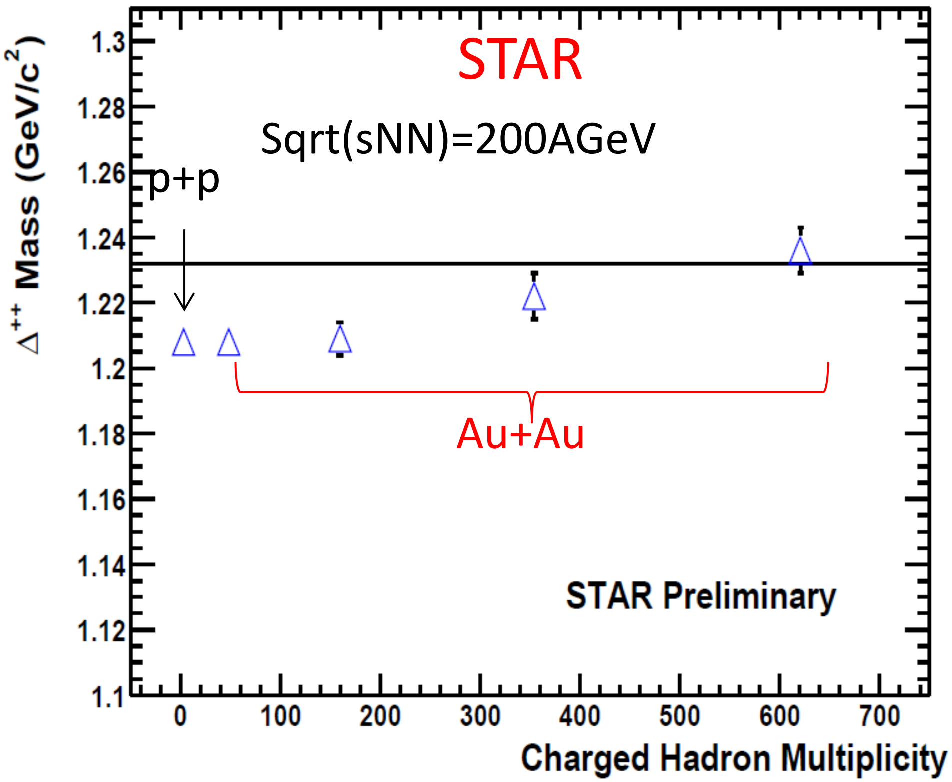
Non-trivial microscopic mechanisms for early chemical equilibrium?

- String fusion (E.G. Ferreiro, J. Phys. G**23** (1997) 1961)
- Color rope formation in RQMD (H. Sorge, PLB289 (1992) 6)
- Multi meson fusion (C. Greiner, JPG **27**(2001)L95)

To be resolved at J-PARC

Talk by M. Harada (Aug 8)

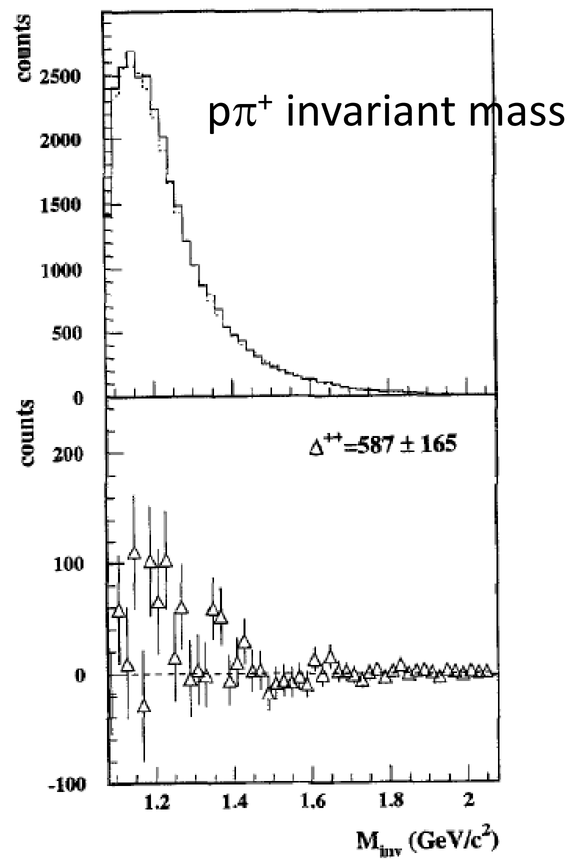
Δ^{++} vs centrality



H. Zhang, arXiv:nucl-ex/0403010 (2004)

Almost no data in AGS

AGS-E814



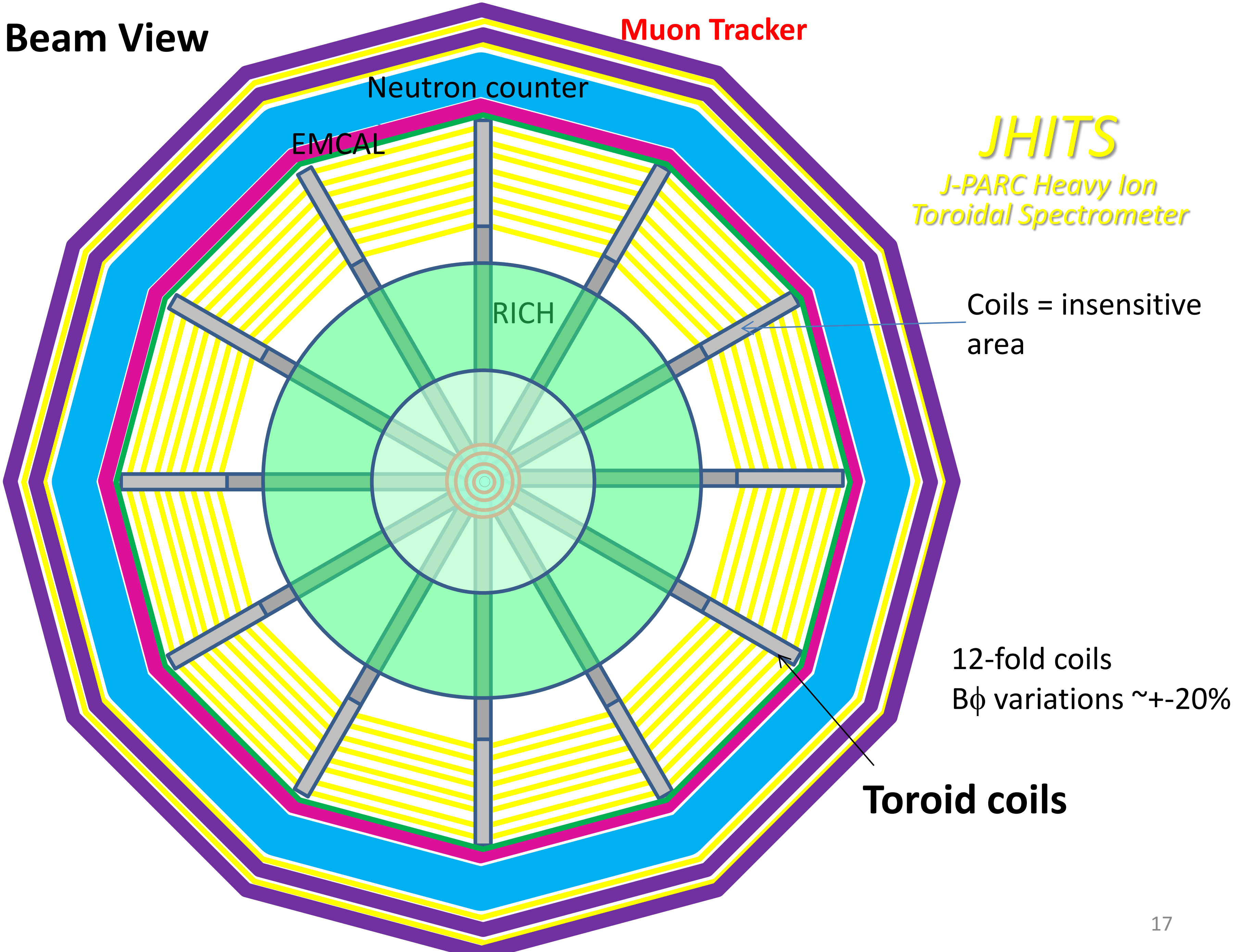
Hint for chiral restoration?

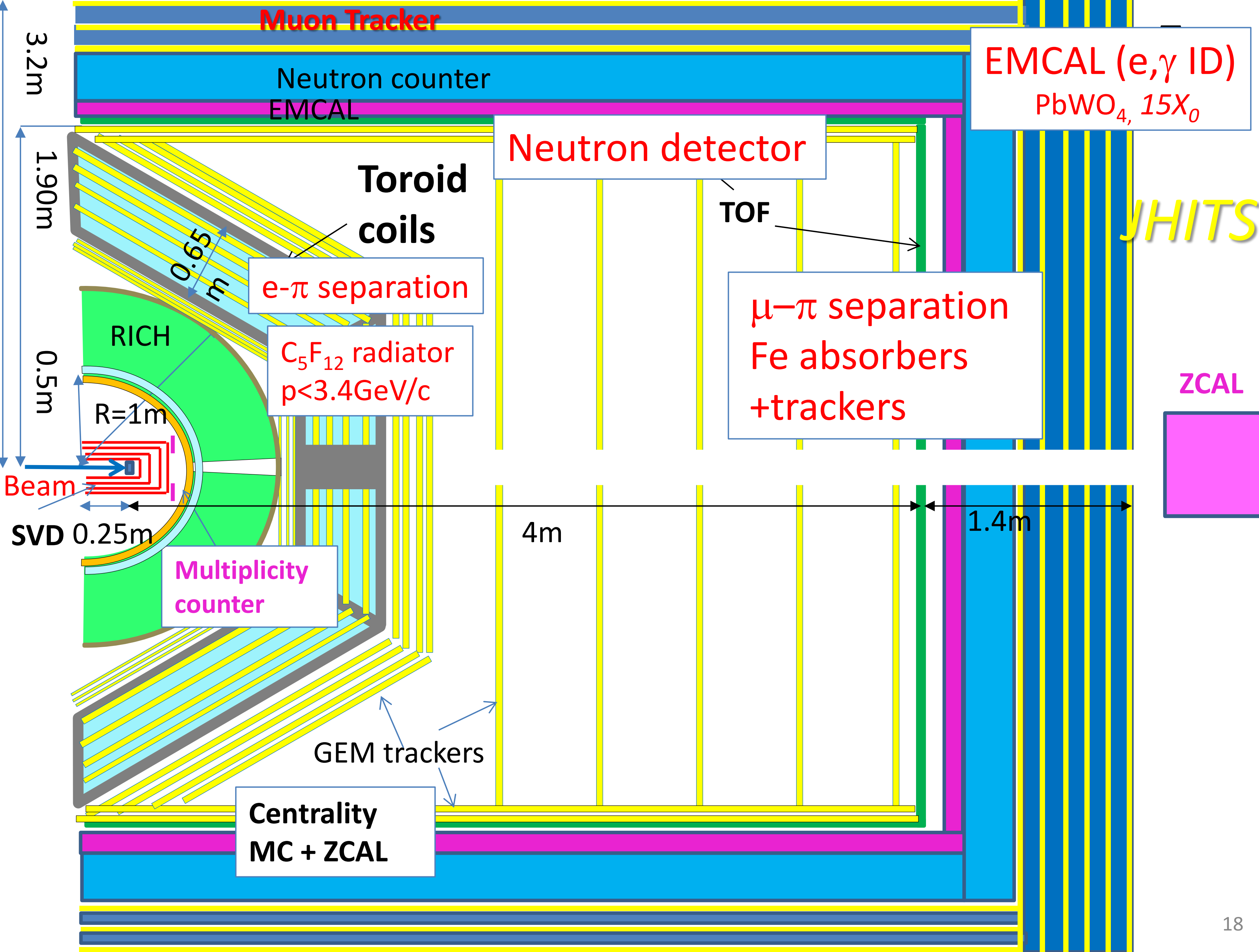
J. Barrete, PLB351 (1995) 93

Experimental challenges

- High rate capability
  - Fast detectors
    - Silicon trackers, GEM trackers, …
  - Pixel size < $3x3mm^2$
    (at 1m from the target, θ<2deg, 10% occupancy)
  - Extremely fast DAQ
    - Min-bias event rate = 10MHz
    → Triggerless DAQ
- Large acceptance (~4π)
  - Coverage for low beam energies
  - Maximum multiplicity for e-b-e fluctuations
- Electron measurement
  - Field free region for RICH near the target

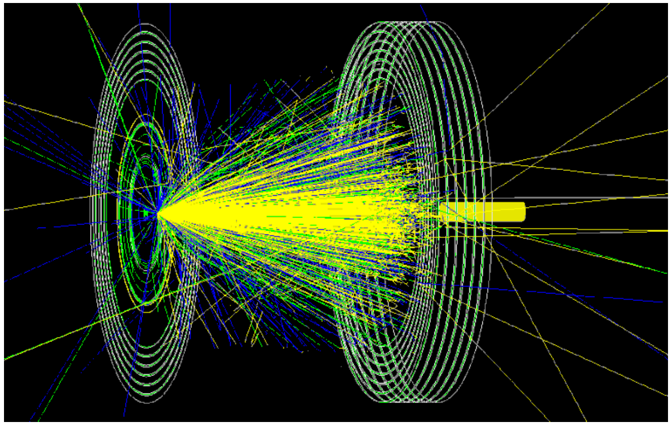
➡ Toroidal magnet spectrometer


Beam View
Muon Tracker
Neutron counter
EMCAL
RICH
JHITS
J-PARC Heavy Ion
Toroidal Spectrometer
Coils = insensitive area
12-fold coils
Bϕ variations ~+-20%
Toroid coils



Muon Tracker
3.2m
Neutron counter
EMCAL
EMCAL (e,γ ID)
$PbWO_4$, $15X_0$
1.90m
Toroid coils
Neutron detector
TOF
JHITS
0.65 m
e-π separation
RICH
C_5F_{12} radiator
p<3.4GeV/c
μ–π separation
Fe absorbers
+trackers
ZCAL
0.5m
R=1m
Beam
SVD 0.25m
4m
1.4m
Multiplicity counter
GEM trackers
Centrality
MC + ZCAL

Spectrometer performance



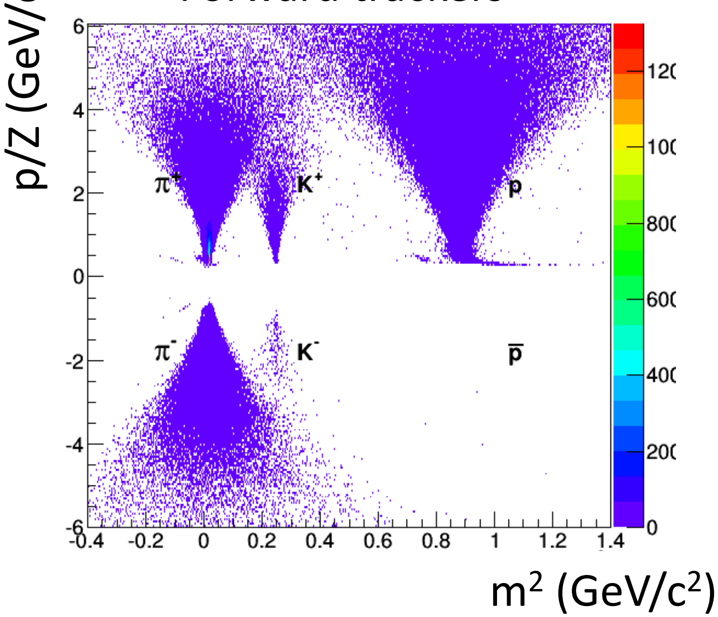
H. Sako, B.C. Kim

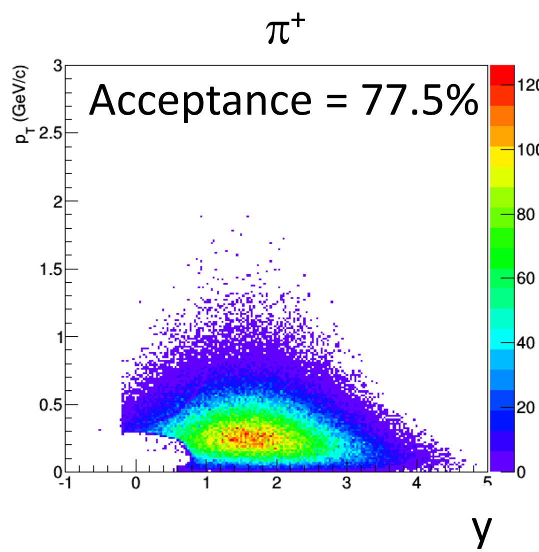
U+U at 10AGeV/c with JAM + GEANT4

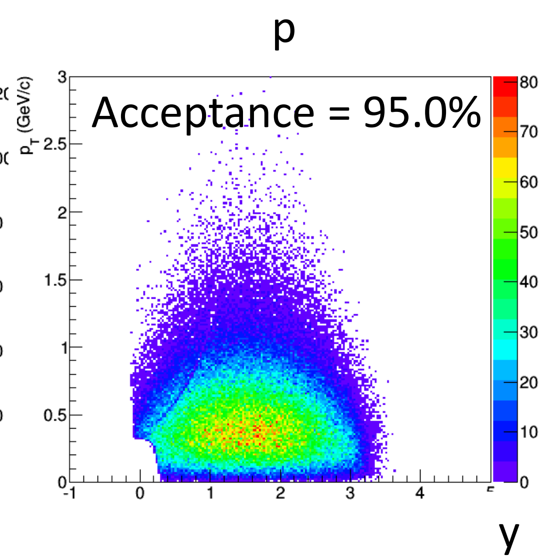
- Assumption for simplicity
  - Half-spherical toroidal shape
  - Uniform B_ϕ field
  - No dead area due to coils
- Acceptance >= 78 %
- π/K separation 2.5GeV/c (2.5σ)

Assuming TOF resolution of 50 ps

Forward trackers







Reconstructed dilepton spectra

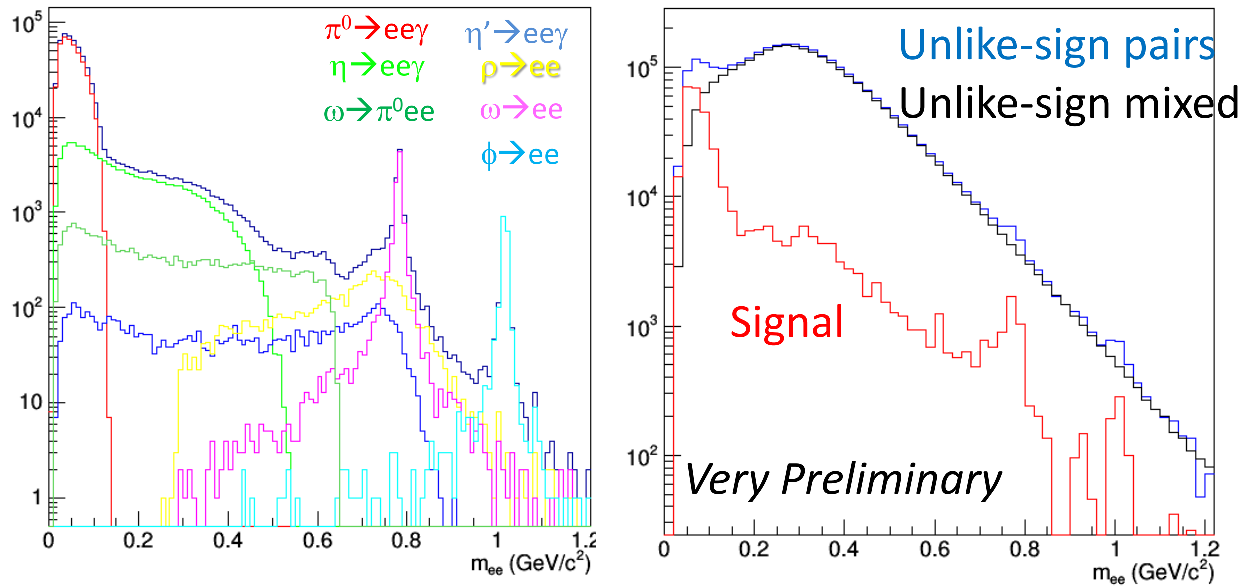
Dielectrons

$\theta_{ee}>5^o$
$2^o<\theta<80^o$
$p_T>0.1$ GeV/c

e^+e^- cocktail (8.6 M events)

No γ external conversion

Generated | Reconstructed

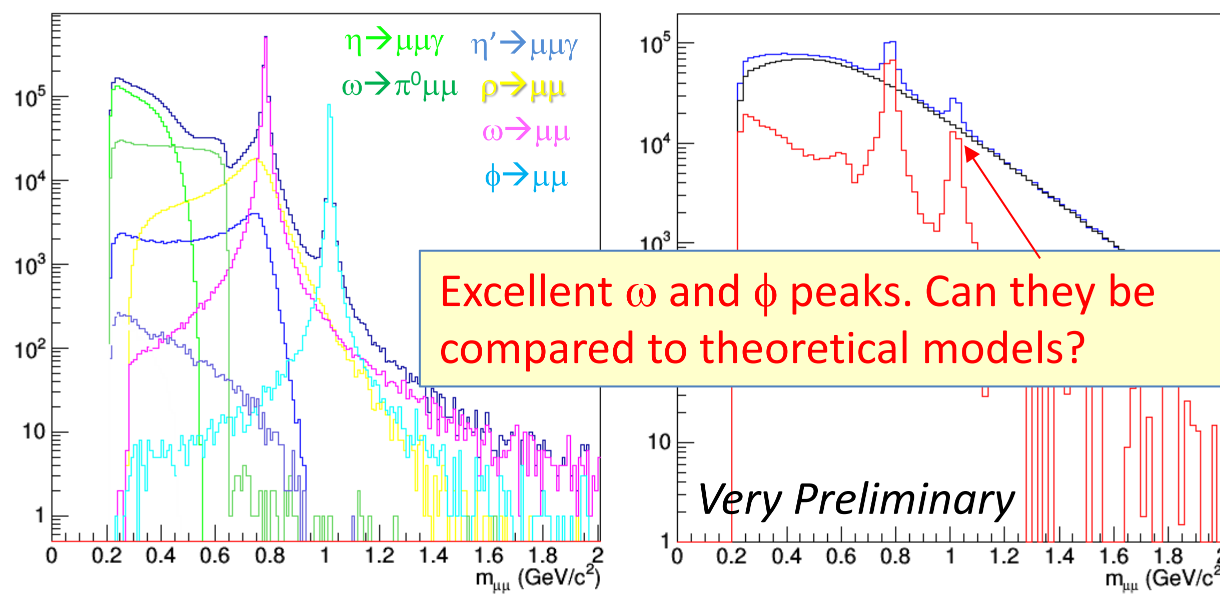


Dimuons

$\theta_{ee}>2^o$
$2^o<\theta<80^o$
$p_T>0.1$GeV/c

$\mu^+\mu^-$ cocktail (500 M events)

No K,π weak decays

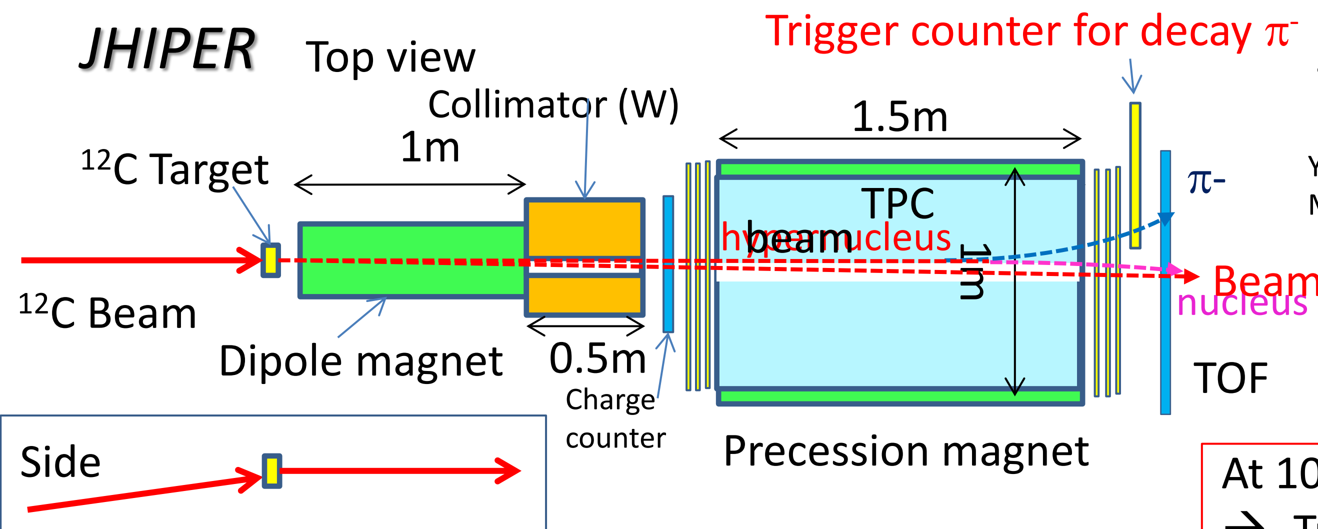


Excellent ω and ϕ peaks. Can they be compared to theoretical models?

20

Hypernuclear spectrometer

- Search for
  - |S|>=3 Hypernuclei
  - Strangelet
- Hypernuclear production at y_{beam}
  - Lifetime
  - Magnetic moment



C+C at 15 AGeV/c
JAM-1.622 (RQMD/S mode)
+ GEANT4

Y. Nara, et al, Phys. Rev. C61,024901(1999)
M. Isse, et al, Phys.Rev. C72 (2005) 064908

$^{3}_{\Lambda}H \rightarrow {}^{3}He+\pi^-$

BdL = 6Tm → Precession angle ~ 68°
(assuming μ_Λ)

At 10^7 Hz interaction rate
→ Track rate in TPC : 9.3×10^6 Hz
→ Trigger rate : 4.0×10^3 Hz
Experiment with full beam rate may be feasible!

Ideas based on
M. Asakawa et al, KEK Report 2000-11
T. R. Saito et al, HypHI Letter of Intent, 2005

Summary and Prospect

- J-PARC-HI aims at studies of QCD phase structures and hadrons at high density
- U beam of 1-19 AGeV at the world's highest 10^{11} Hz realized with new HI injector with existing RCS and MR
- Large acceptance toroidal spectrometer
- White paper completed (June 2016)
  - http://asrc.jaea.go.jp/soshiki/gr/hadron/jparc-hi/index.html
- LOI submitted to J-PARC PAC in July 2016

Prospects

- Accelerator R&D of booster, linac, and ion source
- Detector R&D
  - High resolution MRPC-TOF (U Tsukuba, JAEA, KEK) in J-PARC E16 (p+A)
  - Triggerless DAQ + online tracking (JAEA, Nagasaki IAS)
    - Collaboration with ALICE as an associate member (July 2016)
- Discussions in J-PARC and in nuclear physics community started

Start of the experiment : 2025 (earliest possible)