Overview of J-PARC Heavy-ion Project

H. Sako (*ASRC/J-PARC, JAEA*)
for J-PARC Heavy-Ion Collaboration

Reimei workshop 2015, Tokai, 2015/1/20

Outline

1. Introduction
2. Acceleration scheme
3. Physics goals
4. Experimental design and simulation
5. Summary and prospect

J-PARC HI Collaboration

Experimental and Theoretical Nuclear Physicists and Accelerator Physicists

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H. Harada, P. K. Saha, M. Kinsho, J. Tamura (J-PARC/Japan Atomic Energy Agency)

K. Ozawa, K. Tanaka, S. Sawada, K. Itakura, Y. Liu (J-PARC/KEK)

T. Sakaguchi, M. Okamura (Brookhaven National Lab.)

K. Shigaki (Hiroshima Univ.)

M. Kitazawa, A. Sakaguchi (Osaka Univ.)

T. Chujo, S. Esumi, Y. Miake, T. Nonaka, B. C. Kim, H. Masui (Univ. of Tsukuba)

M. Inaba (Tsukuba University of Technology)

T. Gunji, H. Hamagaki (CNS, Univ. of Tokyo)

H. Tamura, M. Kaneta (Tohoku Univ.)

K. Oyama (Nagasaki IAS)

M. Naruki (Kyoto Univ.)

S. Yokkaichi (RIKEN)

Y. Nara (Akita International Univ.)

T. R. Saito (Mainz Univ. and GSI)

C. Nonaka (Nagoya University)

T. Hatsuda (RIKEN)

T. Hirano (Sophia Univ.)

K. Fukushima (Univ. of Tokyo)

Goals of J-PARC HI Project -physics of extremely dense matter-

RHIC/LHC discovered QGP at high T and low ρ

No direct evidence for the critical point and phase boundaries discovered.

The highest density matter in the lab is created at J-PARC.

5-10 ρ_0

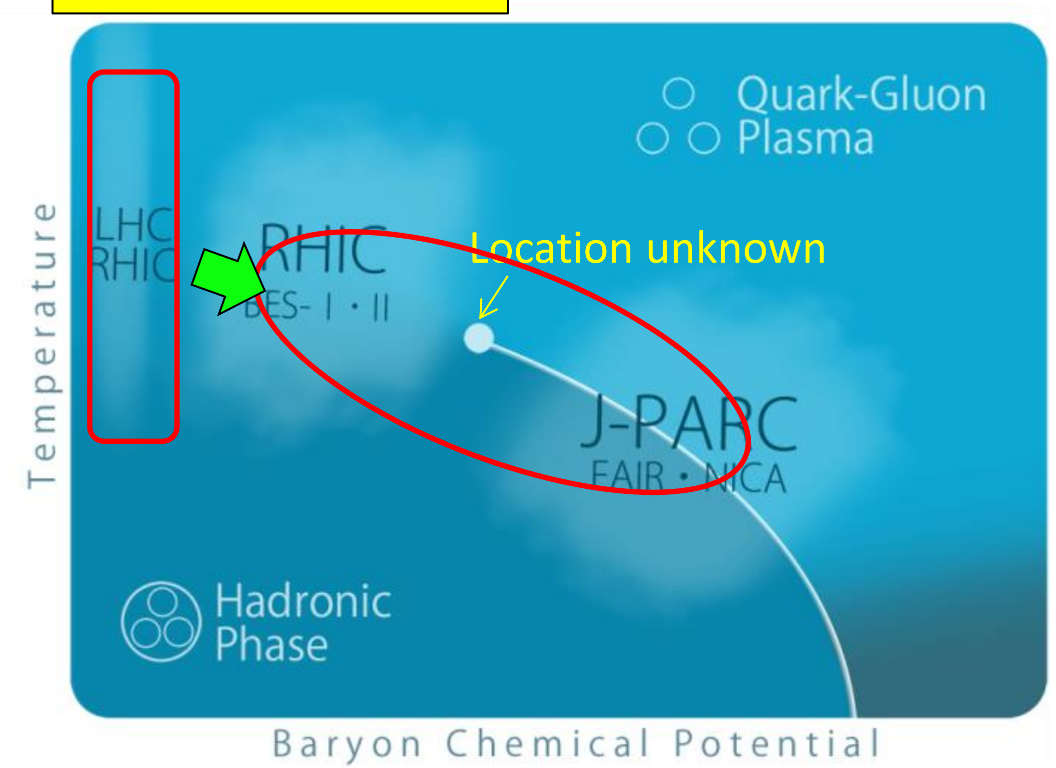
~ neutron star core

Goals at J-PARC

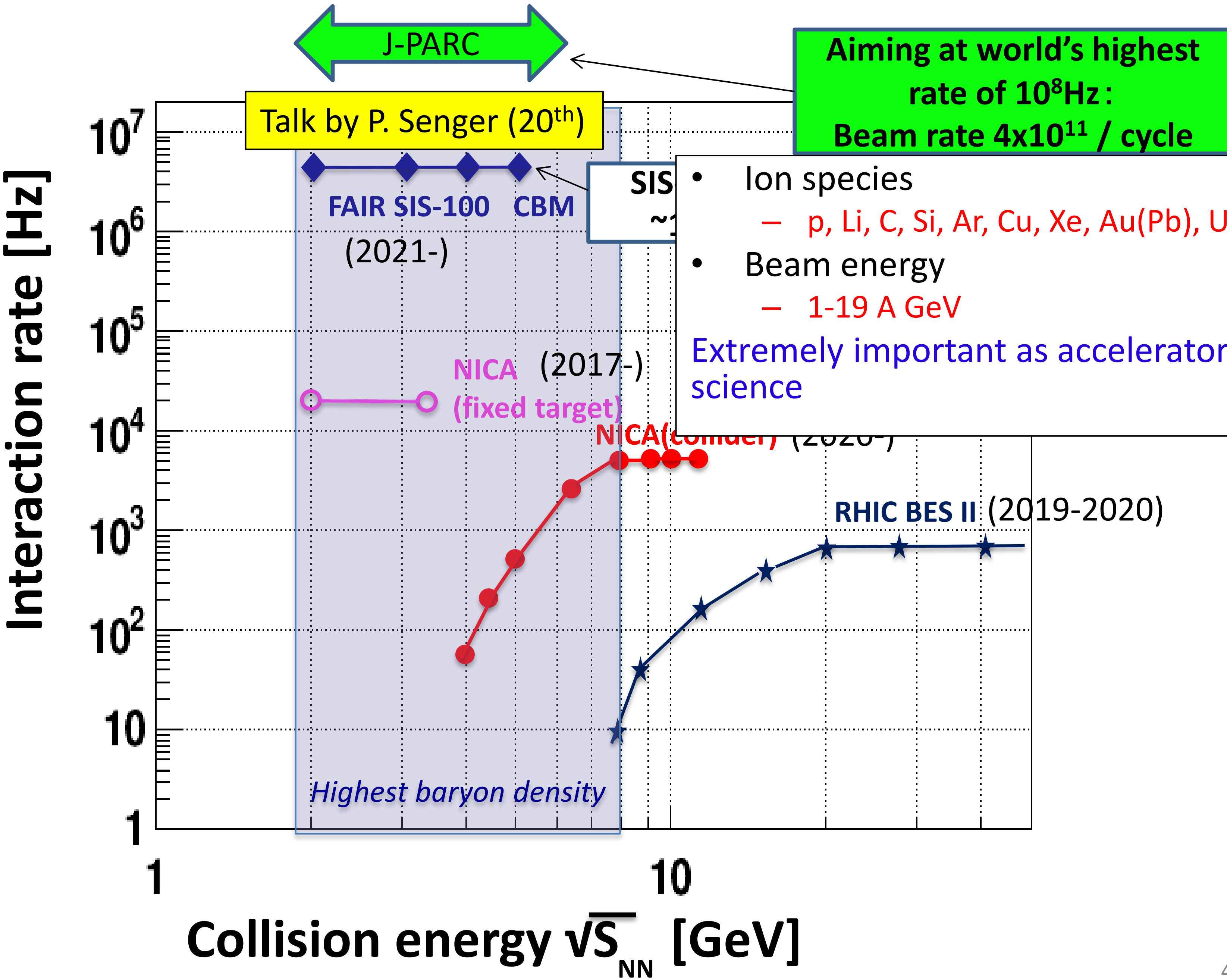
- Studies of phase structures
- Hadron properties at high density related to neutron star structures
- Search for strange quark matter

Utilizing world's highest intensity HI beams

Talk by B. Hong (20th)



HI experiments for high density physics

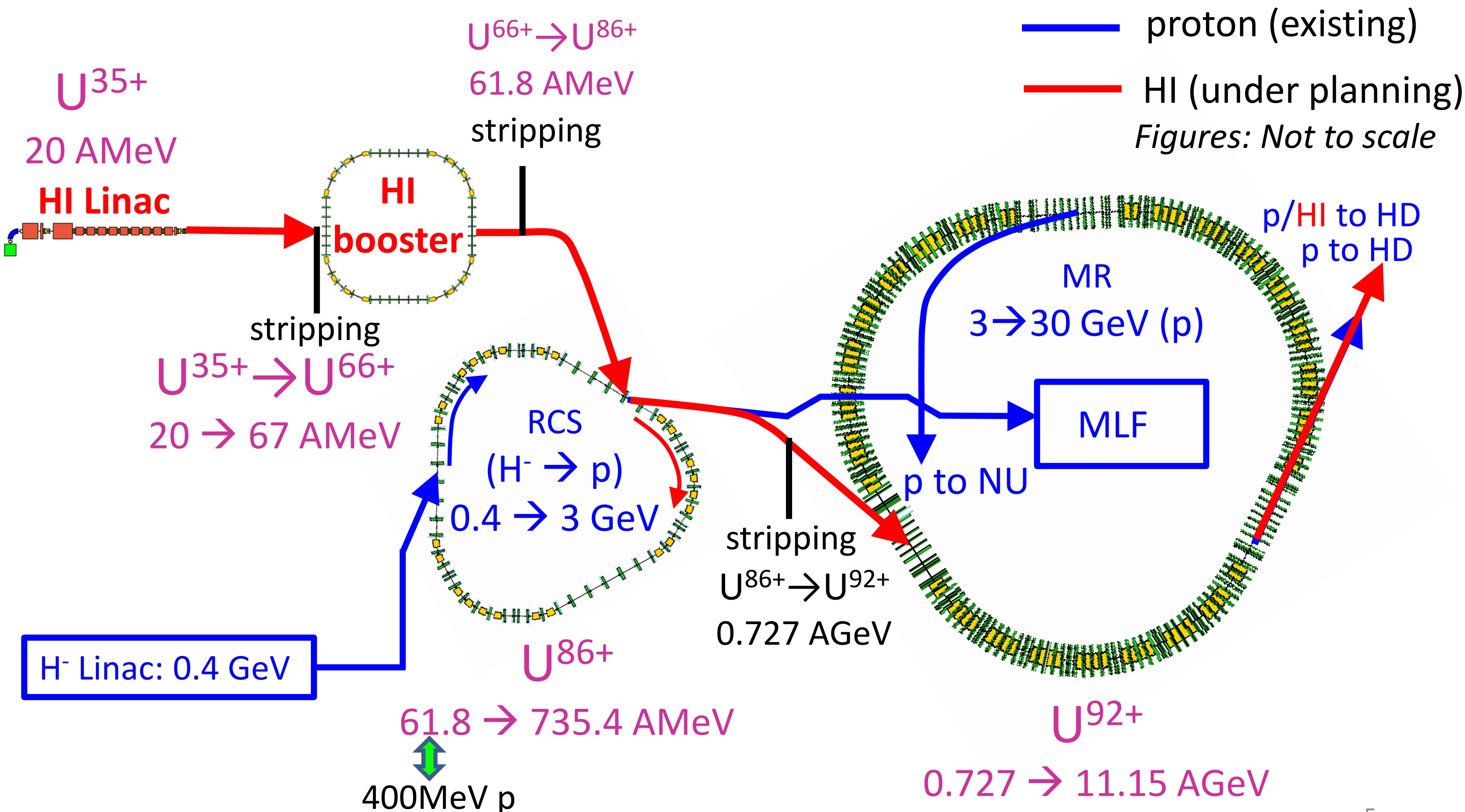


- Ion species
  - p, Li, C, Si, Ar, Cu, Xe, Au(Pb), U
- Beam energy
  - 1-19 A GeV

Extremely important as accelerator science

HI accelerator scheme

Talk by P.K. Saha (20th)
Talk by H. Harada (21th)



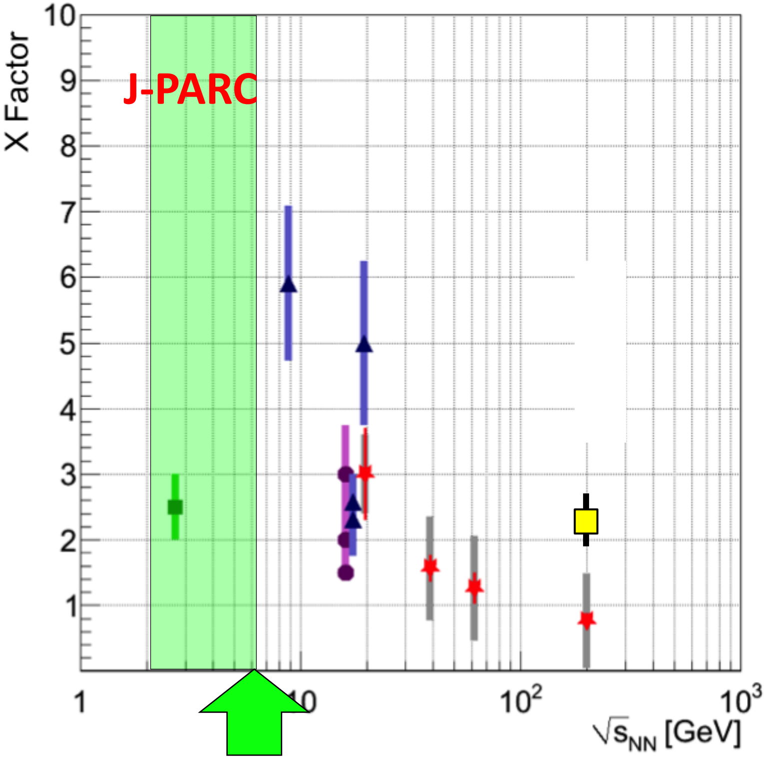
Observable for QCD phase structures

- Dileptons
  - Penetrating probes of dense matter
  - Modification of $\rho/\omega/\phi$ linked to chiral symmetry restoration
- Hadron measurements (high statistics)
  - Event-by-event fluctuations
  - (Multi-)strange hadrons, hypernuclei, strangelets
- Charm
  - J/ψ, D,…
    - Sensitive to initial dense matter?
- Photons
  - Thermal radiations from QGP

Low-mass dileptons

Low-mass dilepton enhancement factor

Measured / cocktail in m=0.2-0.8 GeV/c^2

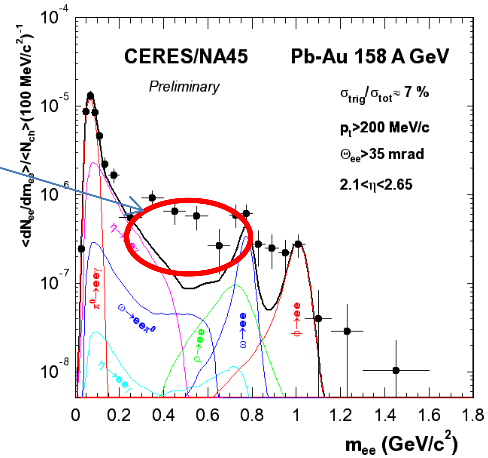


Highest baryon density 5-8GeV?

(J. Randrup, PRC74(2006)047901)

T. Galatyuk, EM probes of Strongly Interacting Matter ECT*, Trento 2007 (PHENIX data updated)

- ● NA60 In+In, 158AGeV/c
- ■ HADES Ar+KCl 1.76AGeV/c
- ▲ CERES Pb+Au 40AGeV/c
- ▲ CERES Pb+Au 158AGeV/c
- ▲ CERES S+Au 200 AGeV
- ■ PHENIX Au+Au 200 AGeV MB **(Phys. Rev. C 93, 014904)**
- ★ STAR Au+Au



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

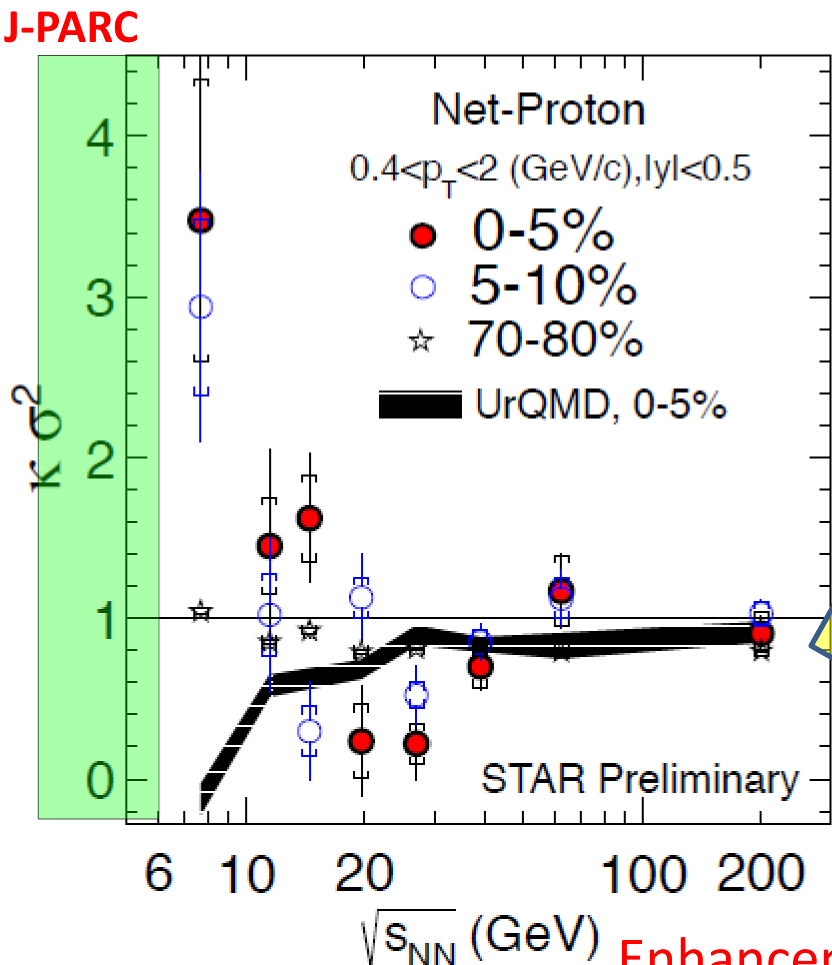
$$\int dm_{ee} N(m_{ee}) m_{ee}{}^{n}\ (n = 1,2, \ldots)$$

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

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

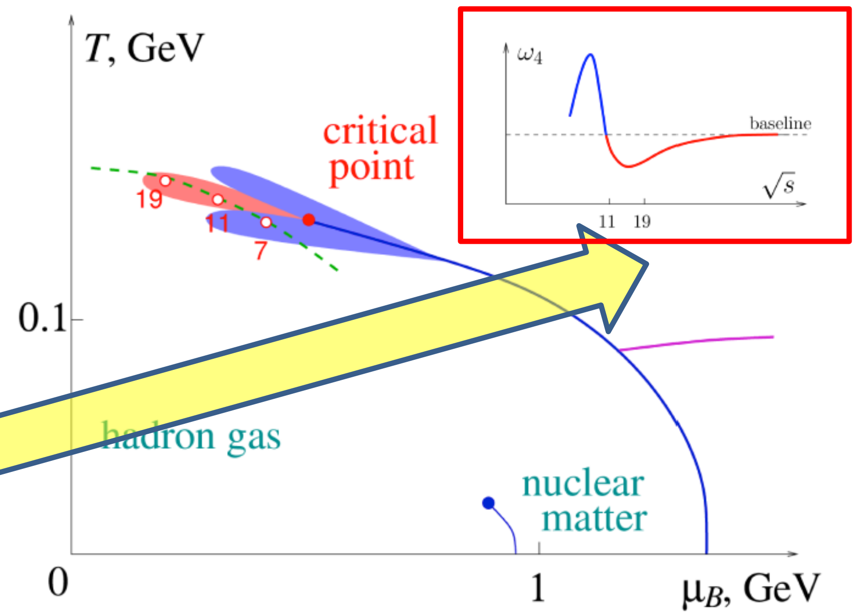
Net-proton fluctuations

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



Theory

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



Talk by X. Luo(20th)
Talk by K. Morita (20th)

Enhancement of 4th-order fluctuations at low energies

Indications of the critical point?

X. Luo, Quark Matter 2015

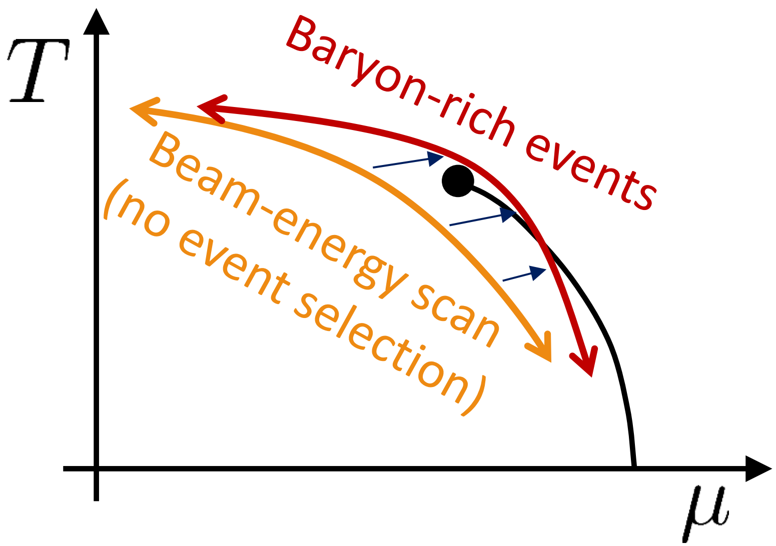
Event selection

Talk by M. Kitazawa (21th)
Talk by T. Sakaguchi (21th)

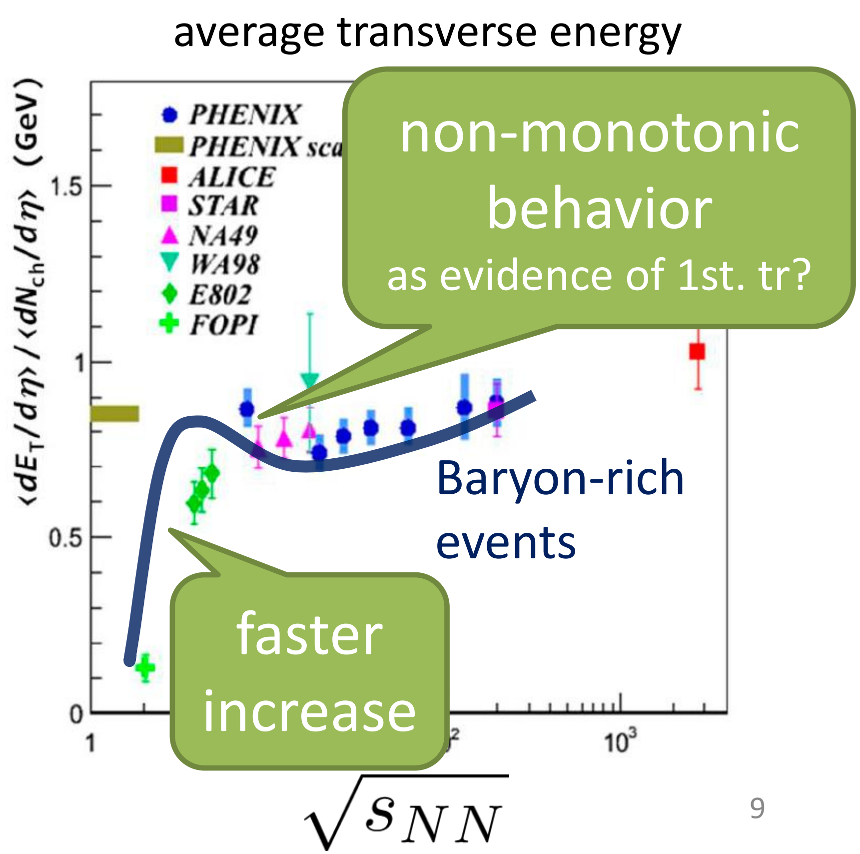
Advantage of J-PARC HIC program:

high-luminosity/statistics → **various event selections**

Example: event selection by
① **Net-baryon number**
② Total-strange number



High μ region can be studied by selecting baryon rich events



Courtesy of M. Kitazawa

Extension of Hadron nuclear physics with to high density at J-PARC

Normal nuclear density → Talk by M. Naruki (20th) → Neutron star density

Meson beam experiment

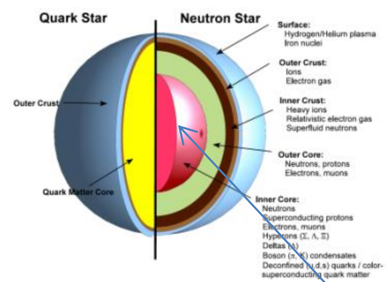
Exotic hadron
Pentaquark (E19)
H-dibaryon (E42)

Hypernuclei
|S|<=2
(E10,E13)

Kaonic nuclei : K^-pp(E27)

Chiral restoration in p+A (E16)

Neutron Star



YN YY interactions

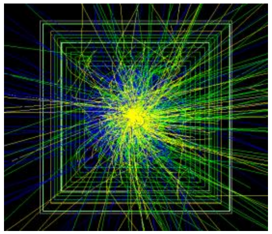
EOS

HBT

Collective flow

Talk by Y. Nara (20th)

HI experiment



Exotic hadron structure

|S|>=3 hypernuclei

Neutron-stardust

Λ* Cluster
Strangelet (strange quark matter)

Talk by T. Yamazaki(20th)

Chiral restoration in A+A

Particle production rates

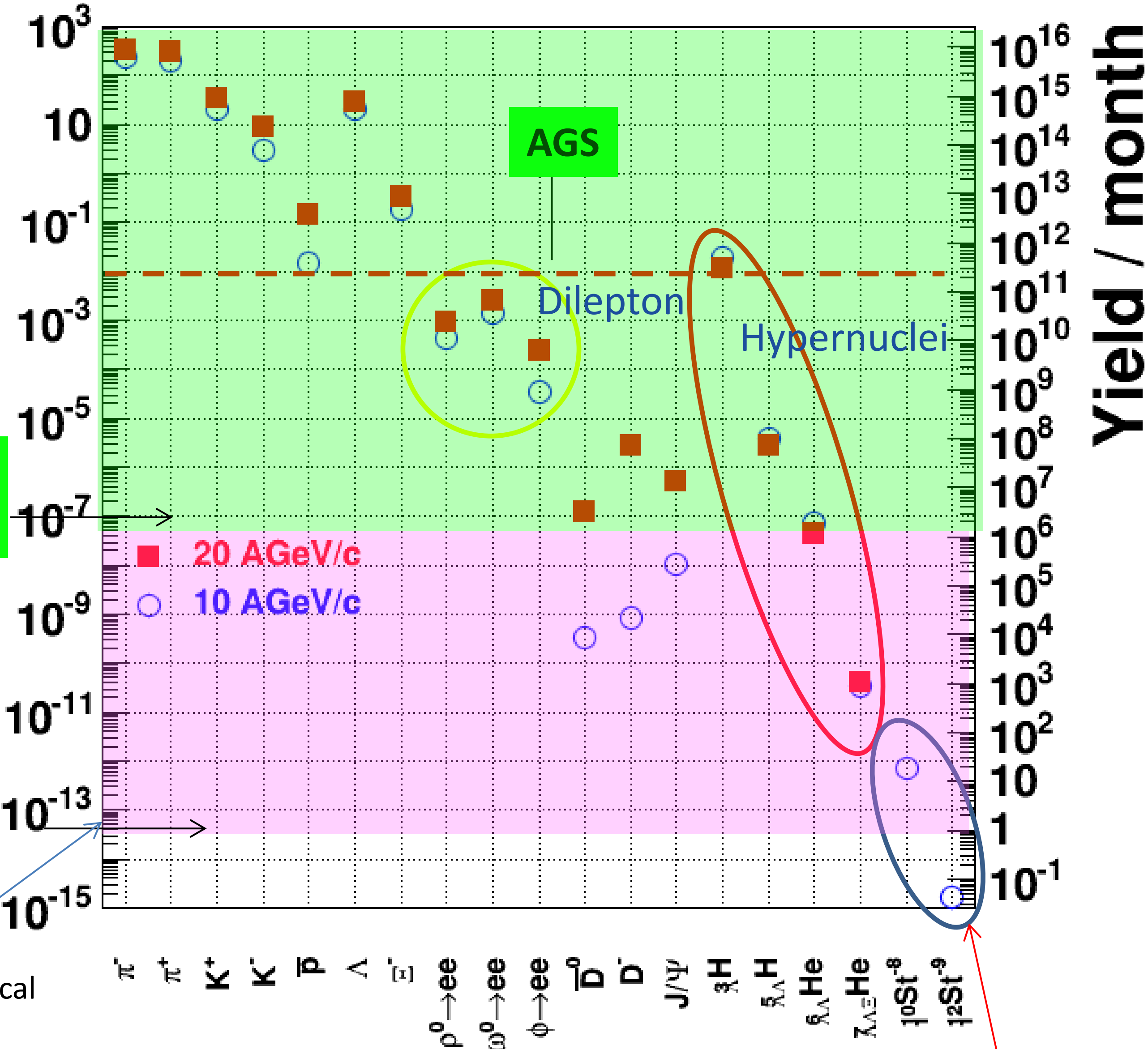
Beam : 10^{10} Hz
0.1 % target
→ Min-bias event rate
10MHz

In 1 month e
$\rho,\omega,\phi \rightarrow ee$ 1
Hypernuclei 10^3 -10^{11}

Y, pt spectrum
Event selections

Measurements and Search

10^{-13} sensitivity at J-PARC



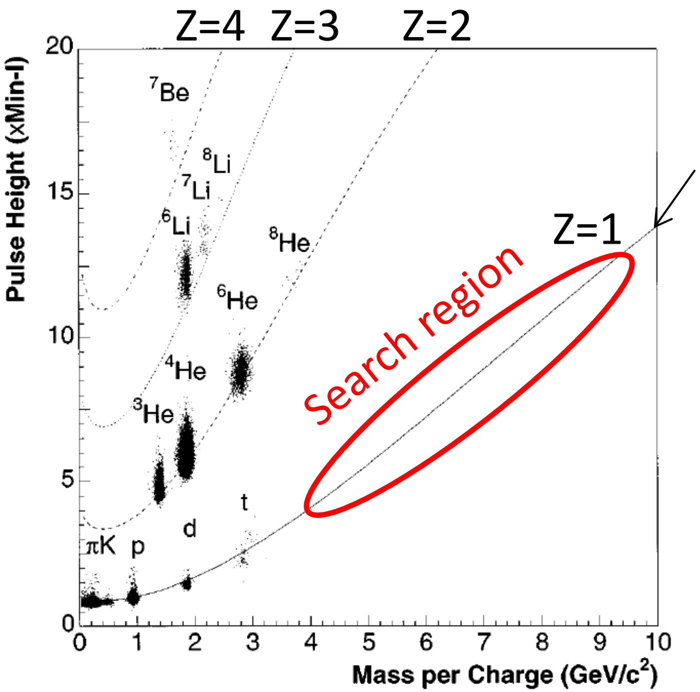
HSD calculations in FAIR Baseline Technical Report (Mar 2006)
A. Andronic, PLB697 (2011) 203

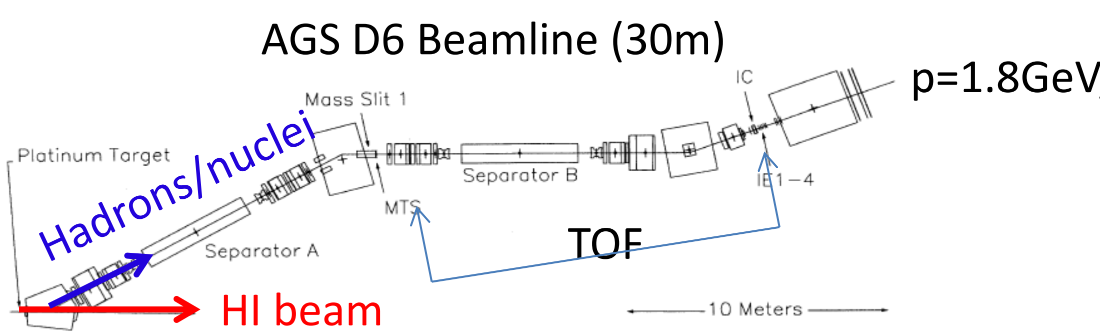
Strangelets: P. Braun-Munzinger JPhysG21 (1995)L17

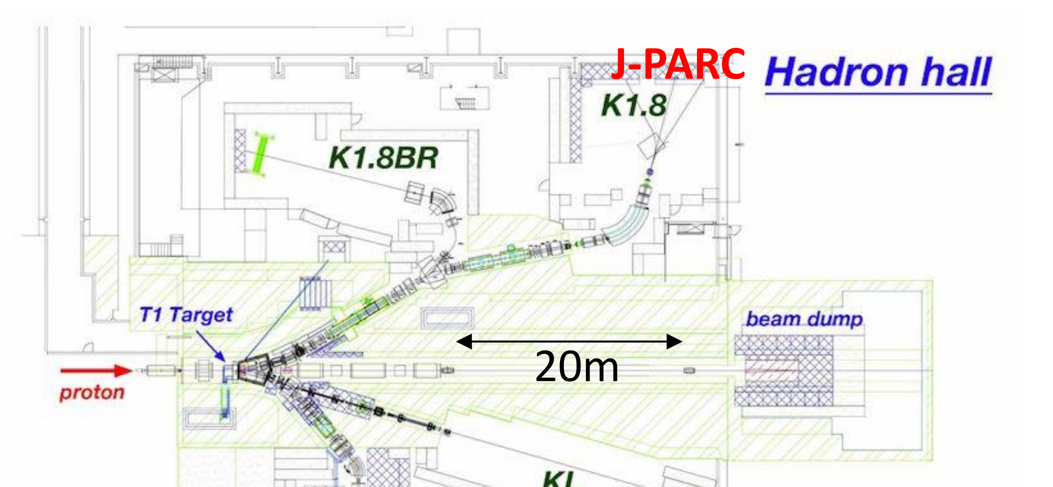
Search for strangelet at AGS-E886
~10^{-7} sensitivity (~ y_{beam})

PID of fragments is done with TOF and Z measurements

A. Rusek, PRC54 R15





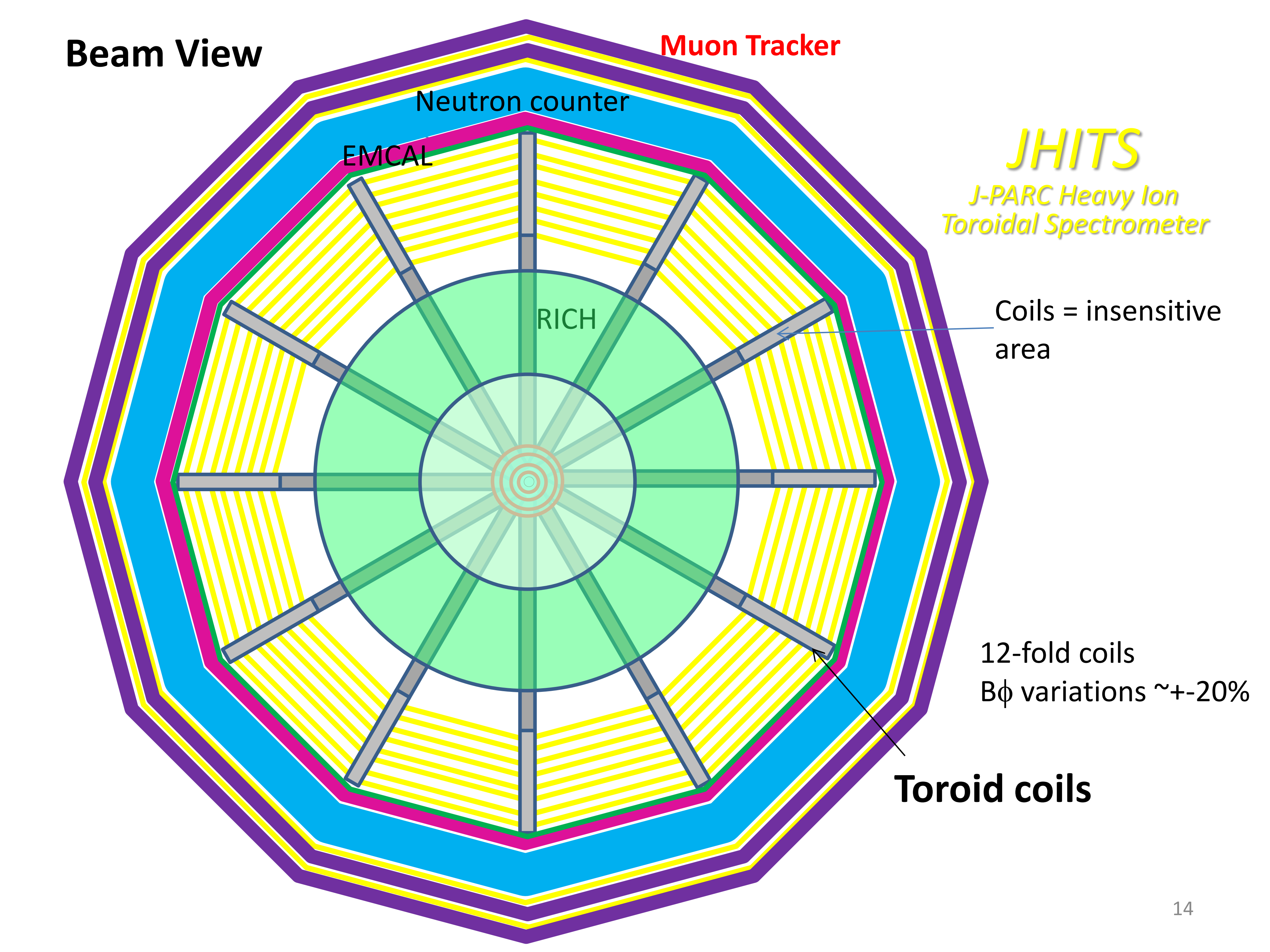


Experimental challenges

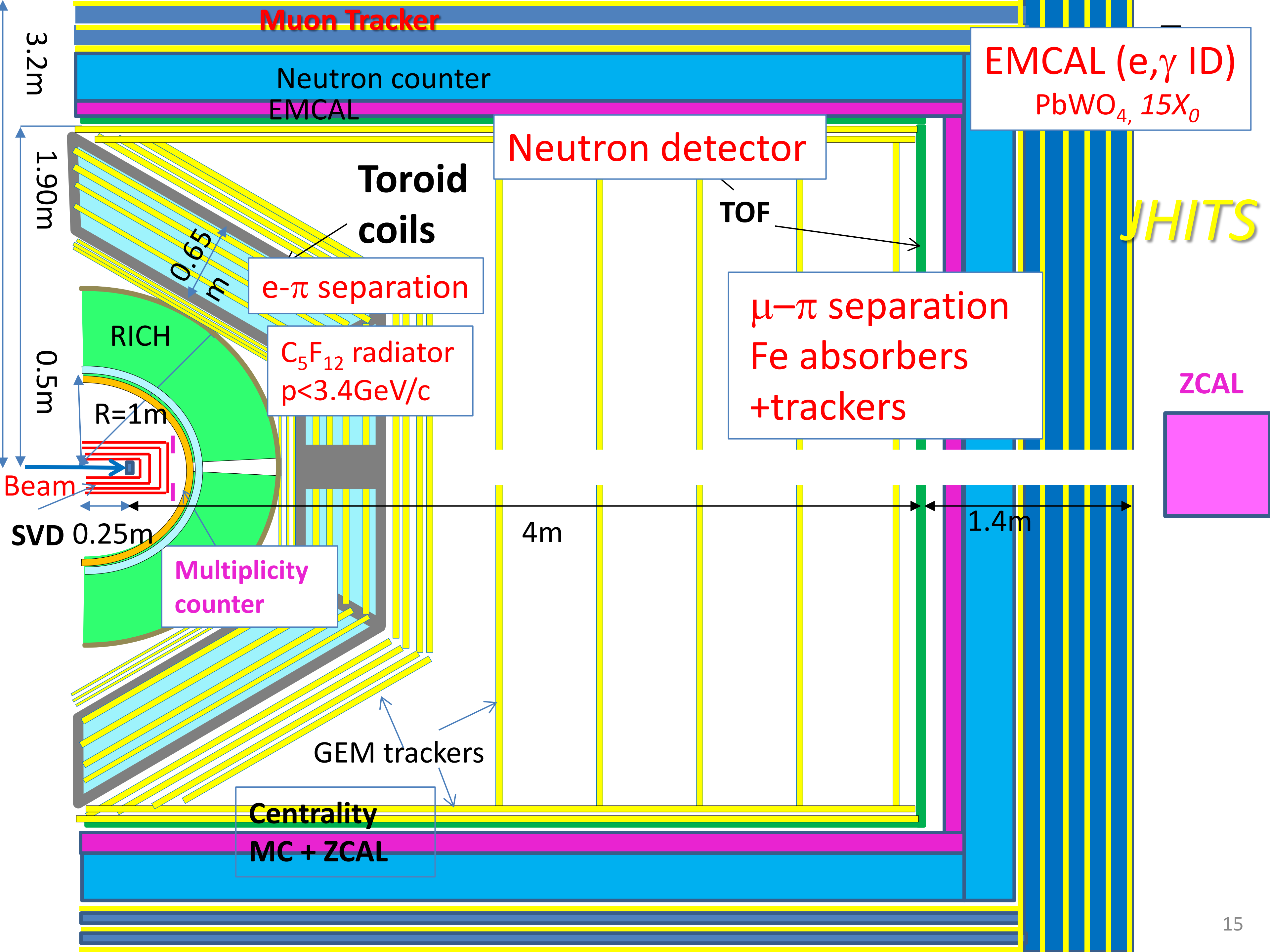
- High rate capability
  - Fast detectors
    - Silicon trackers, GEM trackers, …
  - Pixel size < 3x3mm^2
    (at 1m from the target, θ<2deg, 10% occupancy)
  - Extremely fast DAQ
    - Min-bias event rate = 10MHz

    → 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

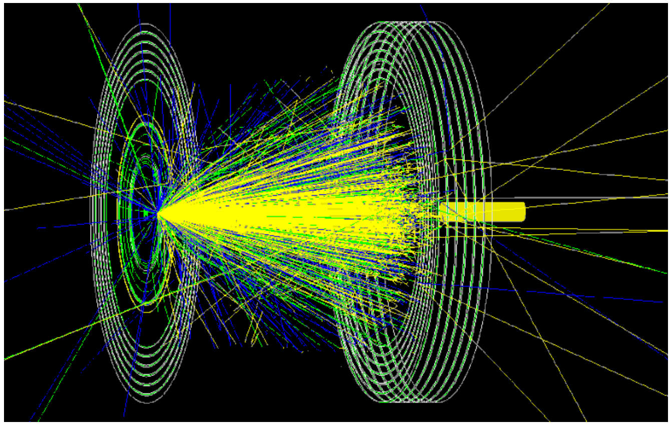


Beam View
Muon Tracker
Neutron counter
EMCAL
RICH
JHITS
J-PARC Heavy Ion
Toroidal Spectrometer
Coils = insensitive area
12-fold coils
Bϕ variations ~+-20%
Toroid coils



Muon Tracker
EMCAL (e,γ ID)
PbWO4, 15X0
Neutron counter
EMCAL
3.2m
1.90m
0.65 m
0.5m
Toroid coils
Neutron detector
TOF
JHITS
e-π separation
RICH
C5F12 radiator
p<3.4GeV/c
μ–π separation
Fe absorbers
+trackers
ZCAL
R=1m
Beam
SVD 0.25m
4m
1.4m
Multiplicity counter
GEM trackers
Centrality
MC + ZCAL

Spectrometer performance



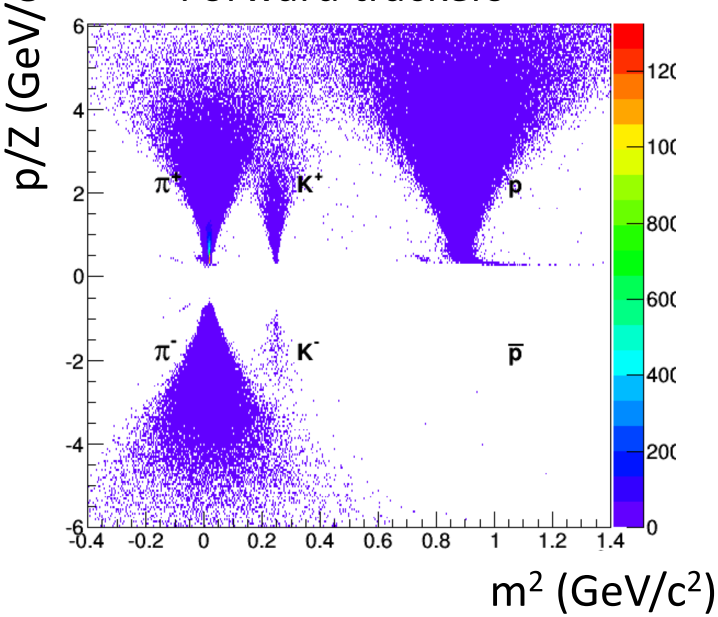
H. Sako, B.C. Kim

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

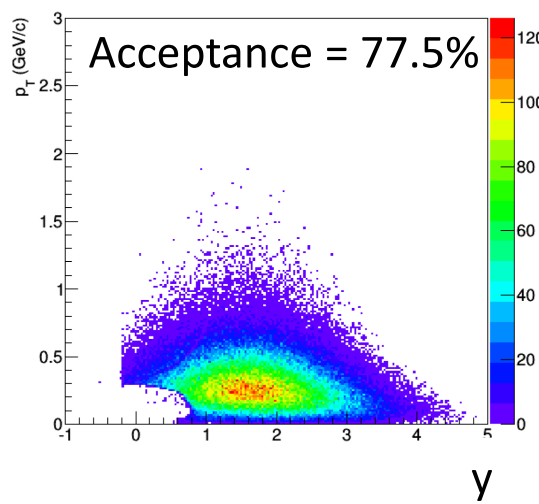
- Assumption for simplicity
  - Half-spherical toroidal shape
  - Uniform B_ϕ field
  - No dead area due to coils
- **Acceptance >= 78 %**
- **π/K separation 2.5GeV/c (2.5σ)**

Assuming TOF resolution of 50 ps

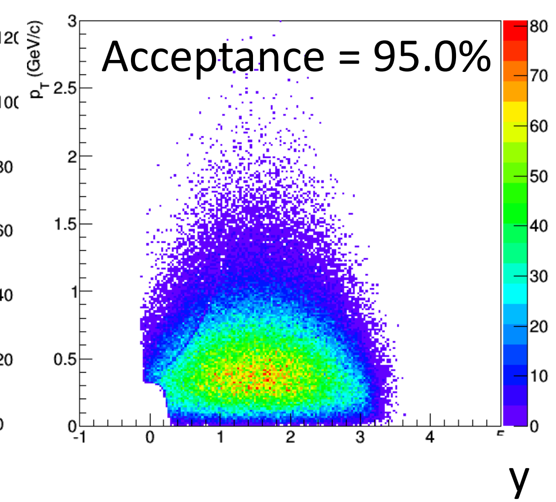
Forward trackers



π^+



p



Reconstructed dilepton spectra

Generated

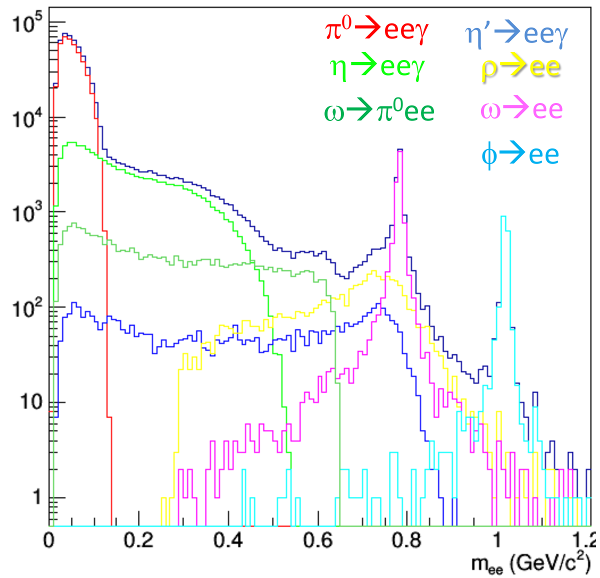
Reconstructed

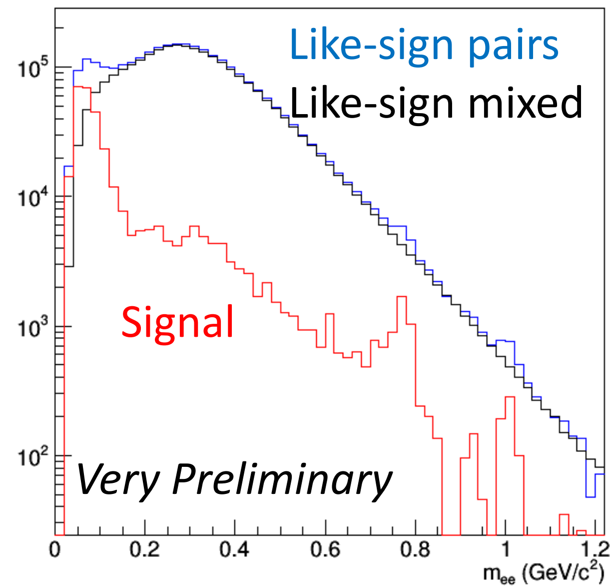
Dielectrons

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

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

No γ external conversion



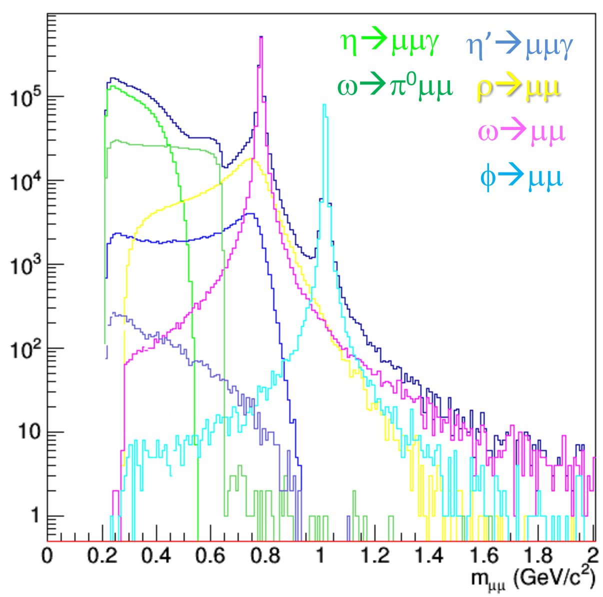


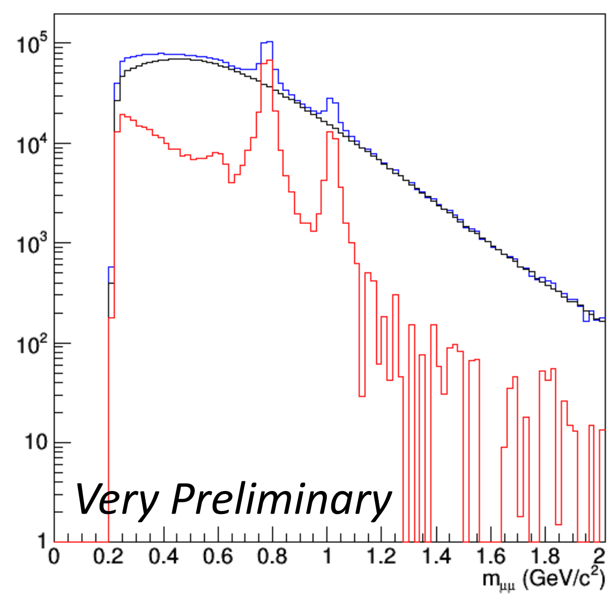
Dimuons

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

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

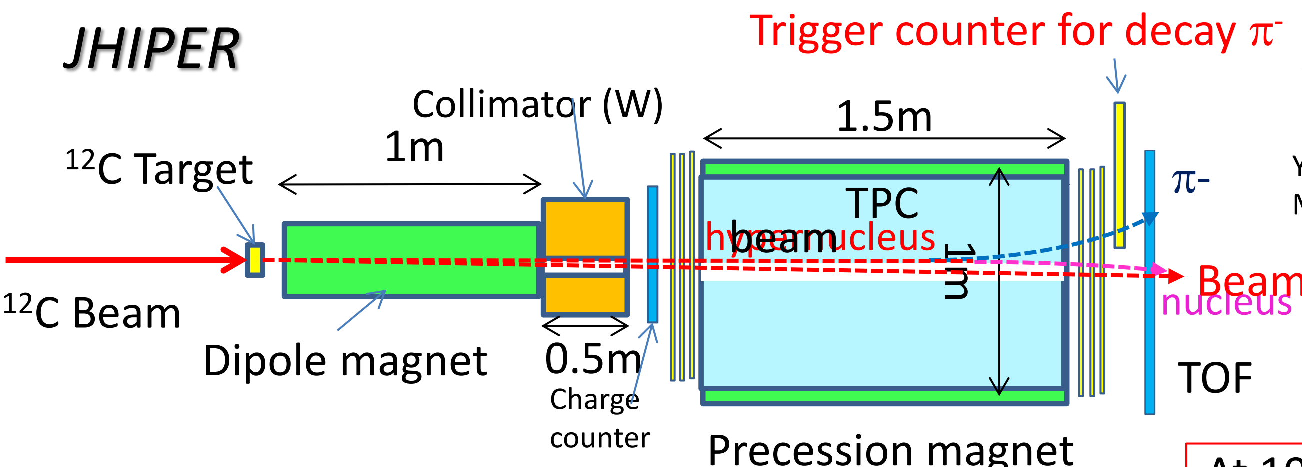
No K,π weak decays





Hypernuclear spectrometer

- Hypernuclei in ion collisions
  - |S|>=3 Hypernuclei
  - Strangelet
- Hypernuclear measurement at y_{beam}
  - Life time
  - 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

- Rich and precise physics for phase structures and
  Talk by K. Itakura, K. Murase(21th)
- Acceleration at $4x10^{11}$/cycle by adding a linac and a booster to RCS and MR
- Large acceptance toroidal spectrometer for lepton and hadron measurements
- Hypernuclear spectrometer utilizing full beam intensity

Prospects

- Accelerator R&D of booster, linac, and ion source
- Detector R&D with the high-p beamline experiments at J-PARC (E16, E50) and heavy-ion experimentalists
  Talk by T. Chujo, K. Ozawa (21th)
  - MRPC-TOF (Tsukuba, JAEA, KEK) in J-PARC E16 (p+A)
  Talk by K. Oyama (21th)
  - DAQ (JAEA, Nagasaki IAS)
- White paper in Mar 2016, LOI to J-PARC PAC in Jul 2016
- Discussions in J-PARC and in nuclear physics community started

Collaborations from the world and from hadron/nuclear physics desired

We proceed with the project with strong collaboration of experimentalists, theorists, and accelerator scientists!
Goal : start within 10 years