KEK Theory Center Workshop “Hadron and Nuclear Physics in 2017”, 2017/1/9, KEK

Masakiyo Kitazawa
(Osaka University)

Heavy Ion Physics at J-PARC

J-PARC

Japan Proton Accelerator Research Complex

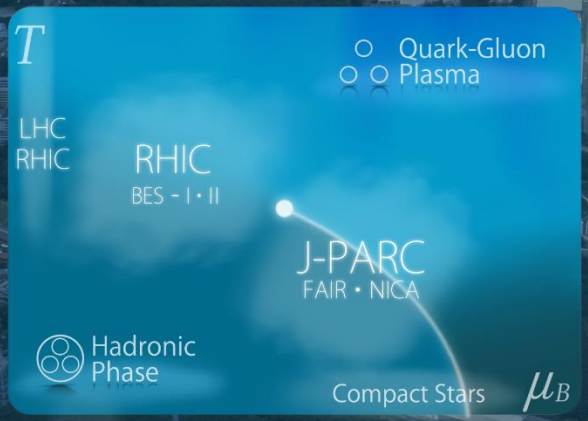
High-power Proton Beam

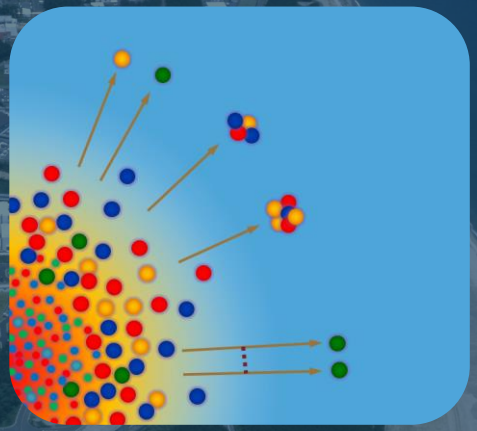
- T2K(Tokai-to-Kaminoka)
- Hadron physics
- etc…

J-PARC

Japan Proton Accelerator Research Complex

J-PARC-HI = J-PARC **H**eavy-**I**on Program





Dense Medium

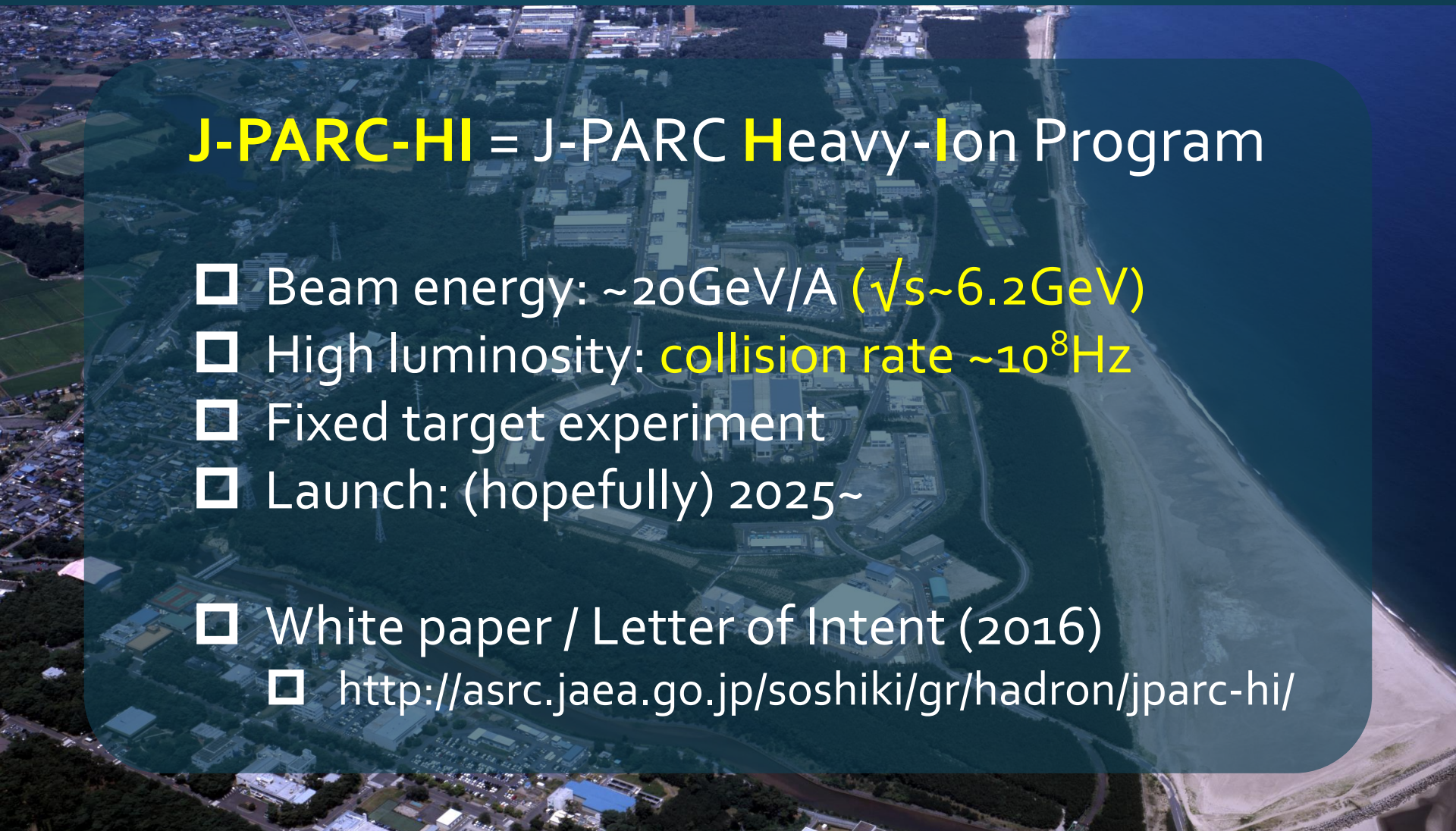
- QCD phase diagram
- 1st order transition
- Equation of state

Rare events

- Hypernuclei
- Exotic hadrons
- Hadron interaction

J-PARC

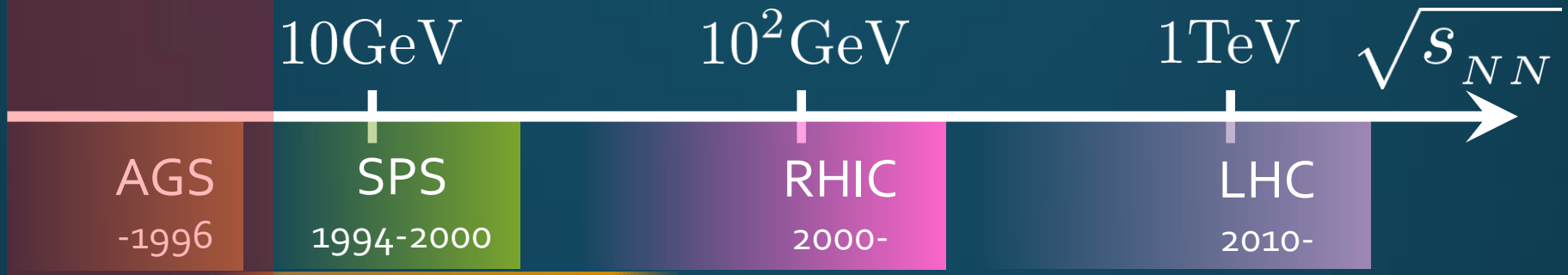
Japan Proton Accelerator Research Complex



J-PARC-HI = J-PARC **H**eavy-**I**on Program

- Beam energy: ~20GeV/A ($\sqrt{s}$~6.2GeV)
- High luminosity: collision rate ~10^8Hz
- Fixed target experiment
- Launch: (hopefully) 2025~

- White paper / Letter of Intent (2016)
  - http://asrc.jaea.go.jp/soshiki/gr/hadron/jparc-hi/



RHIC-BES
2010-

FAIR
2022-?

NICA
2025-?

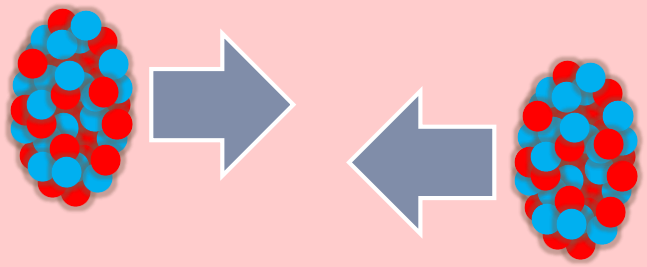
J-PARC-HI
2025~?
2-6.2 GeV

creation of quark-gluon plasma,
strongly-interacting QGP

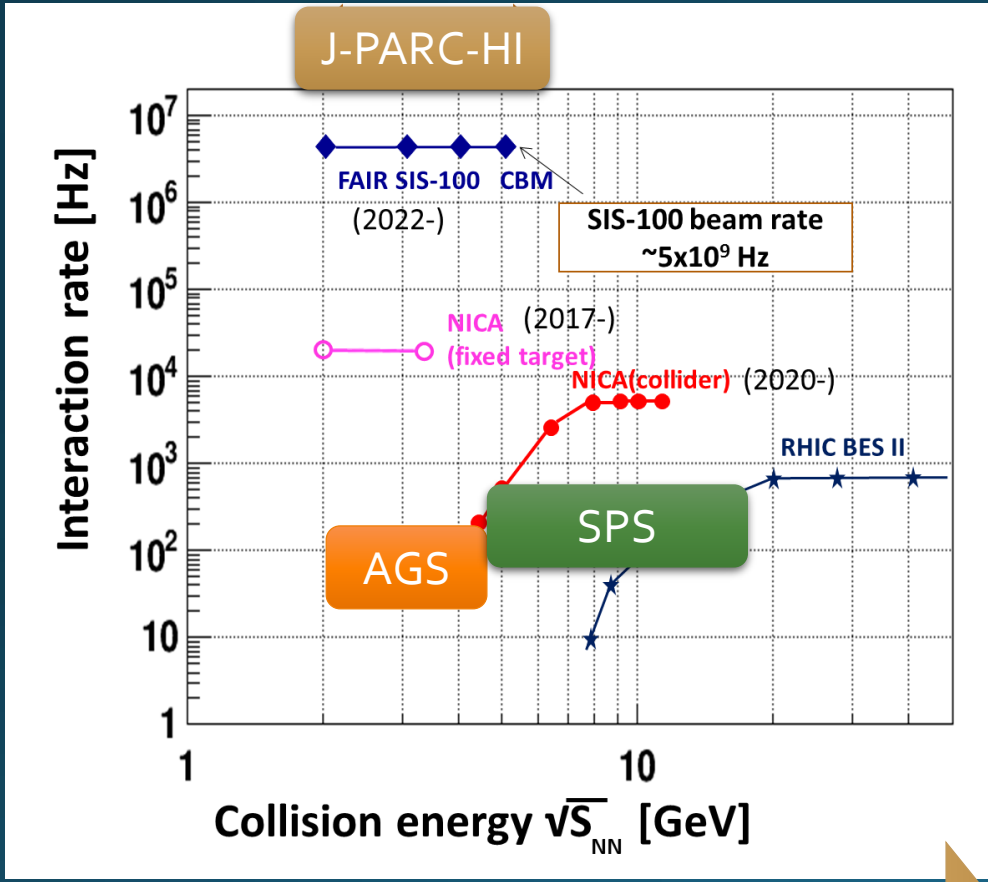
~2010
History of HIC = increasing energy

2010~
Beam-energy scan
Low-energy exp.

Heavy-Ion Collisions



Collision Rate



J-PARC-HI:

High-luminosity X Fixed target

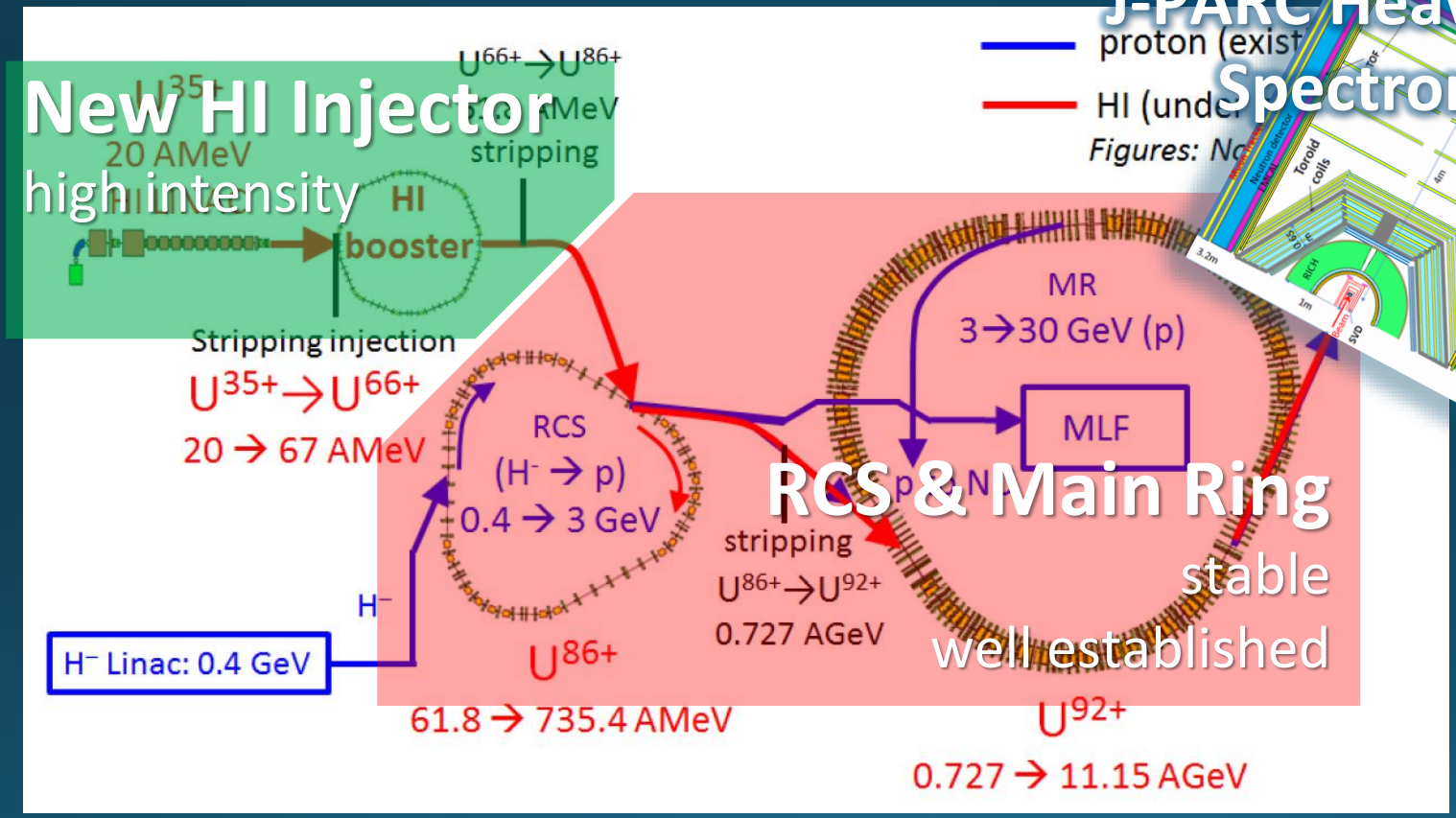
→World highest rate～10^8Hz

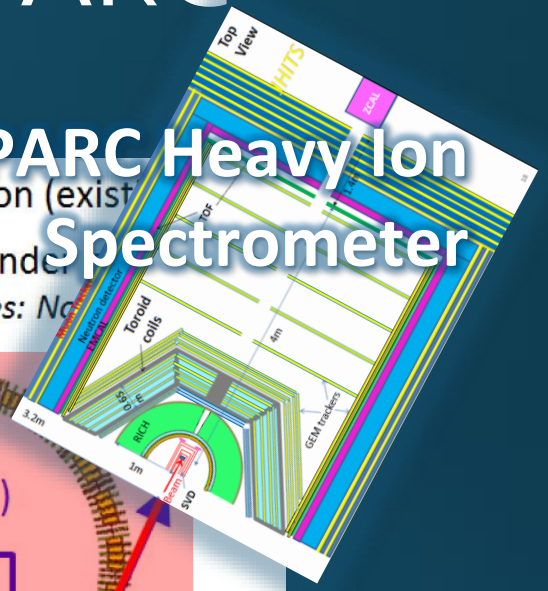
5-order higher than AGS,SPS

AGS, SPS 1 year = J-PARC-HI 5 min.

- High-statistical exp.
- various event selections
- higher order correlations
- search of rare events

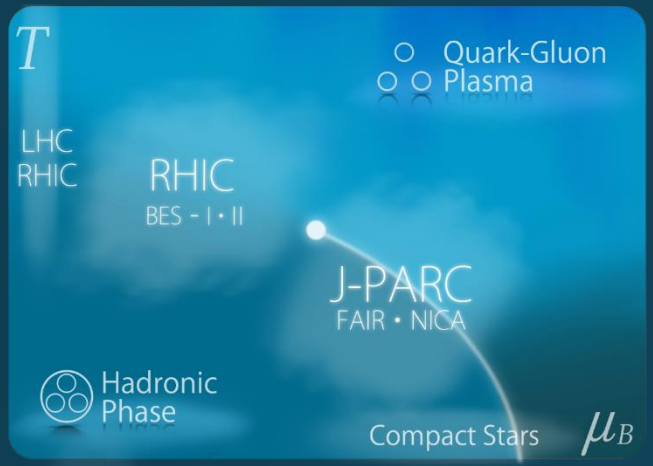
HI Acceleration @ J-PARC





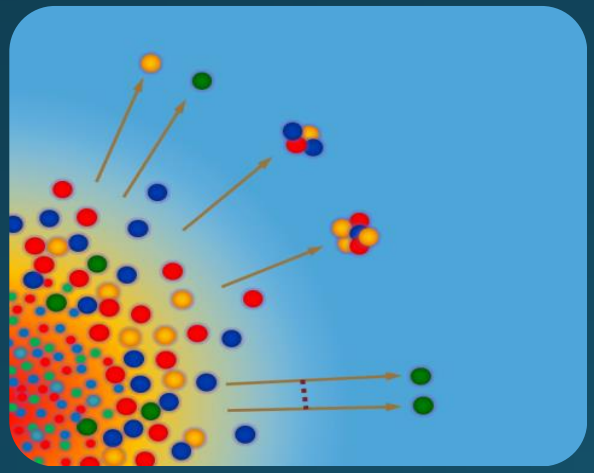
- Use of reliable / high-performance RCS & main ring
- →Reduce cost and time

2 Main Goals of J-PARC-HI



Exploring Dense Medium

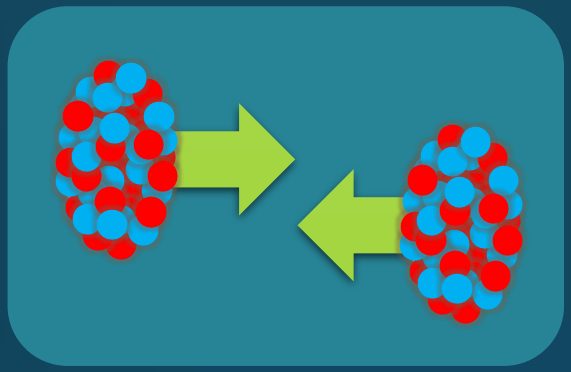
- QCD phase diagram
- 1st order phase transition
- equation of state



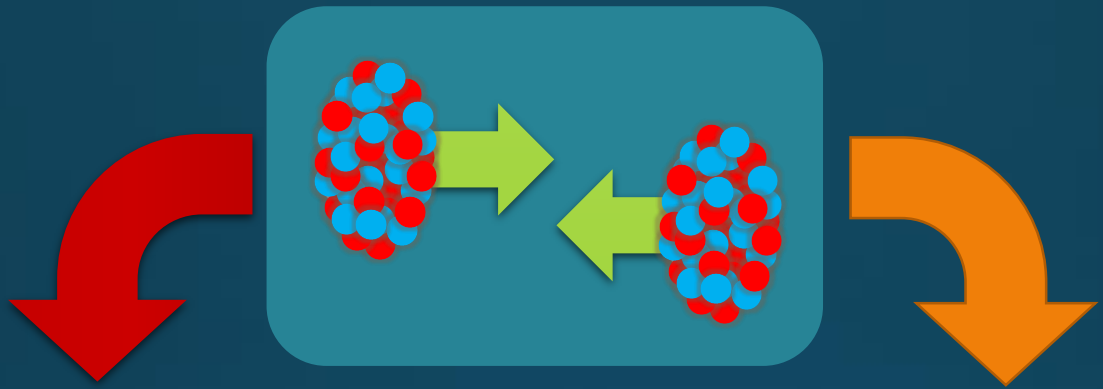
Rare-event Factory

- hyper nuclei
- exotic hadrons
- hadron interaction

Why Low-E Collisions?

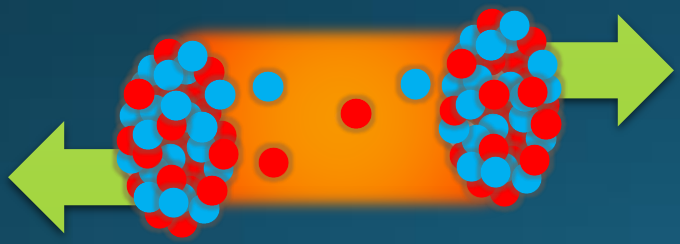


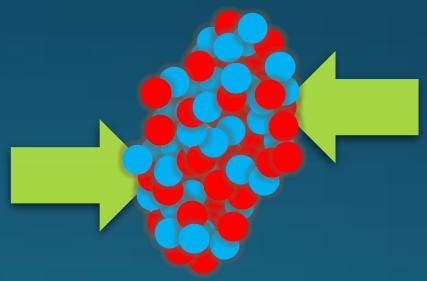
Why Low-E Collisions?



High energy

Low energy





Nuclear transparency

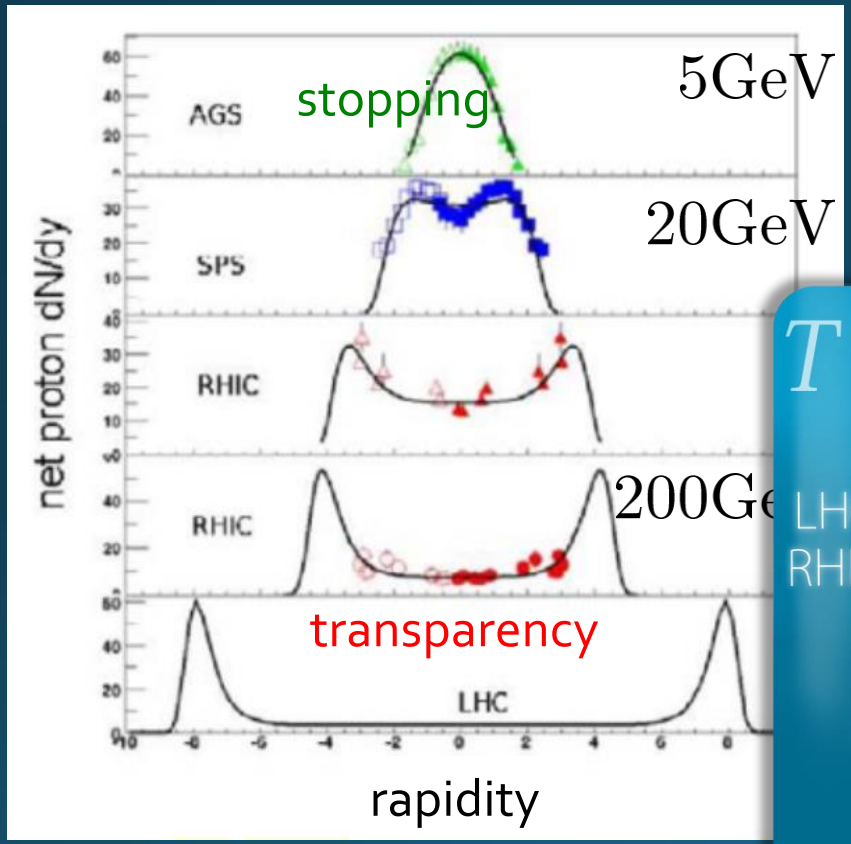
net-baryon #: small

Baryon stopping

net-baryon #: large

Baryon Stopping

rapidity dep. of net-proton #

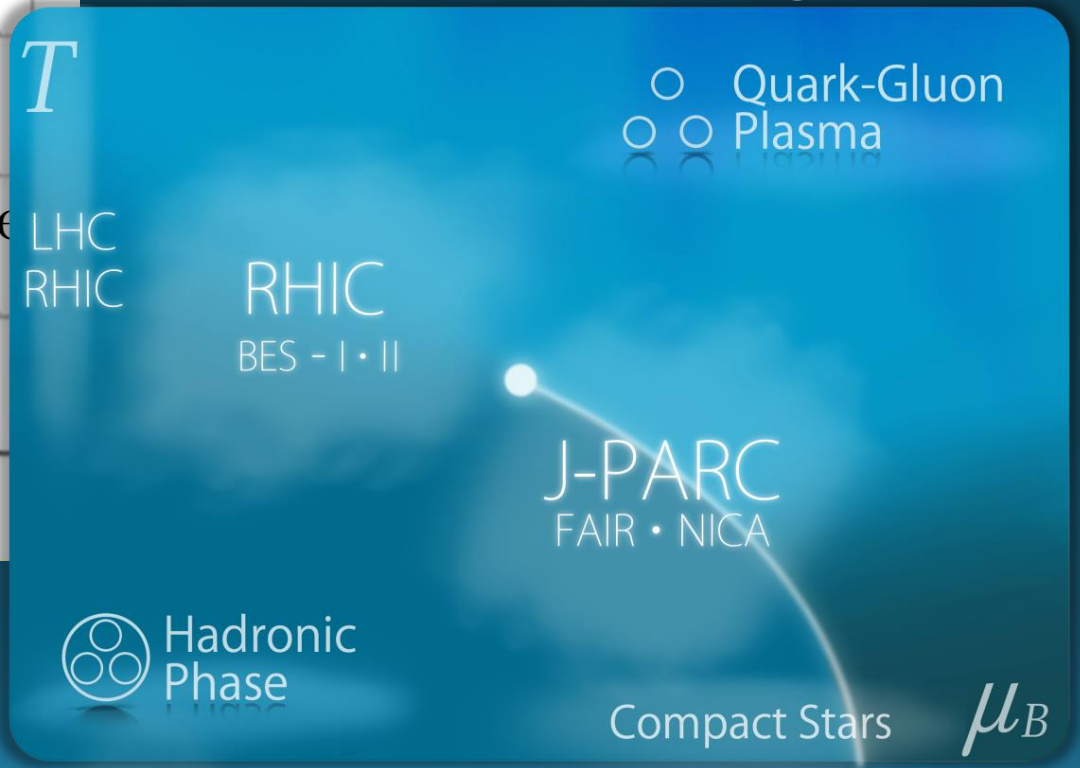


$\sqrt{s_{NN}} \simeq 4 - 6\mathrm{GeV}$

Baryons stop at collision point

$\sqrt{s_{NN}} > 10\mathrm{GeV}$

Baryons pass through

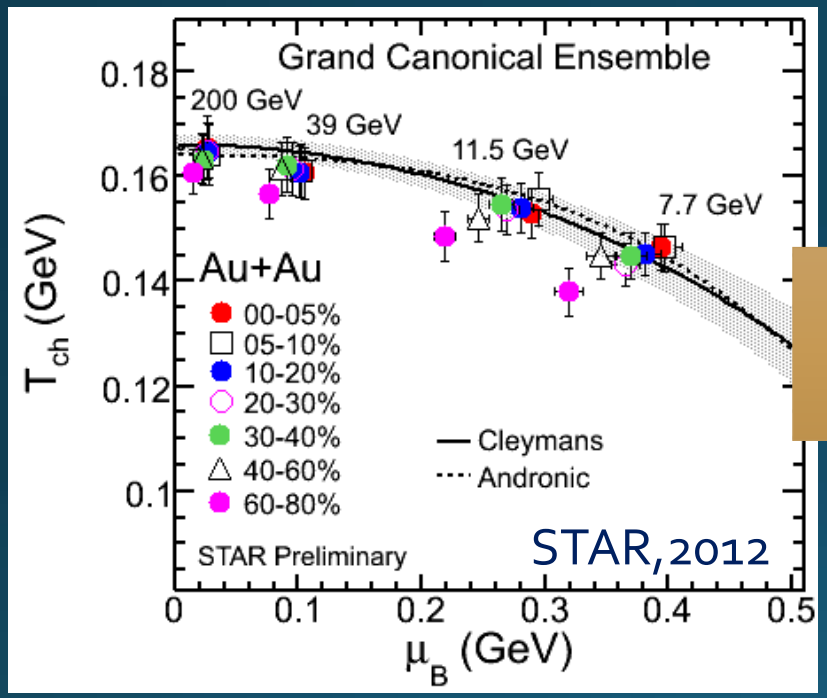


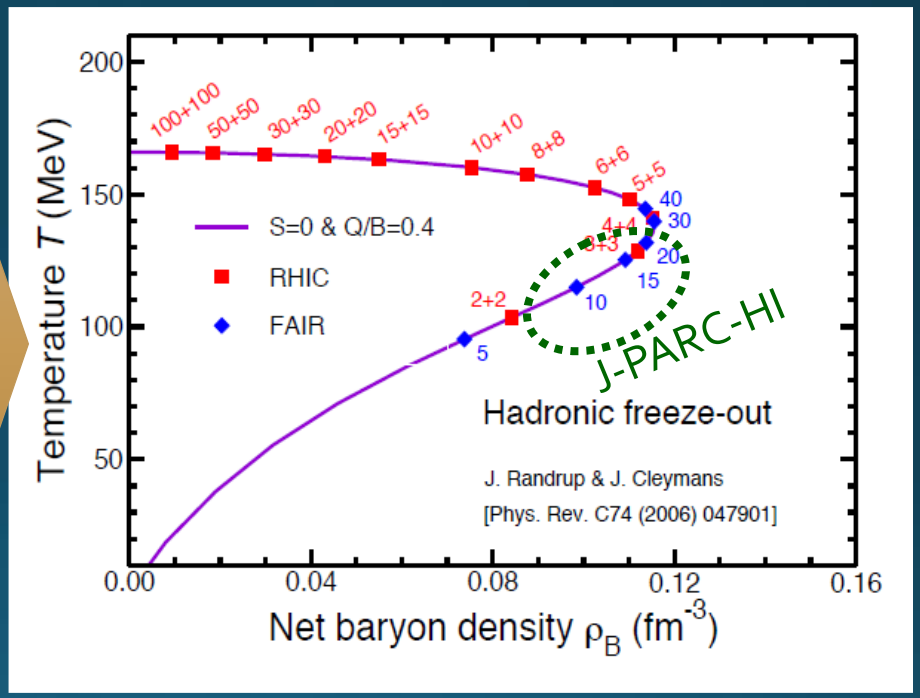
phase diagram from
J-PARC White Paper

Beam-Energy Scan

T, μ from particle yield

Translation to baryon density





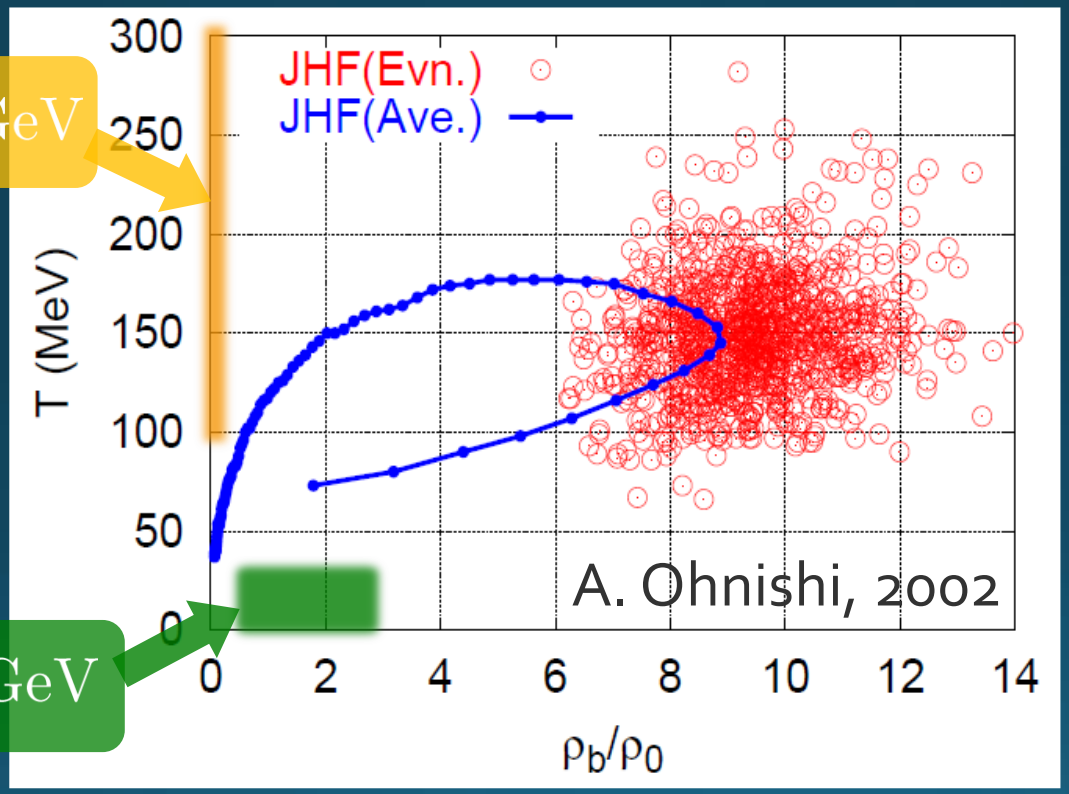
J-PARC energy = highest baryon density

Maximum Density

Time evolution in *T*-ρ plane by JAM

$\sqrt{s_{\rm NN}} > 100$ GeV

$E/A < 1$ GeV



$E/A = 20$GeV

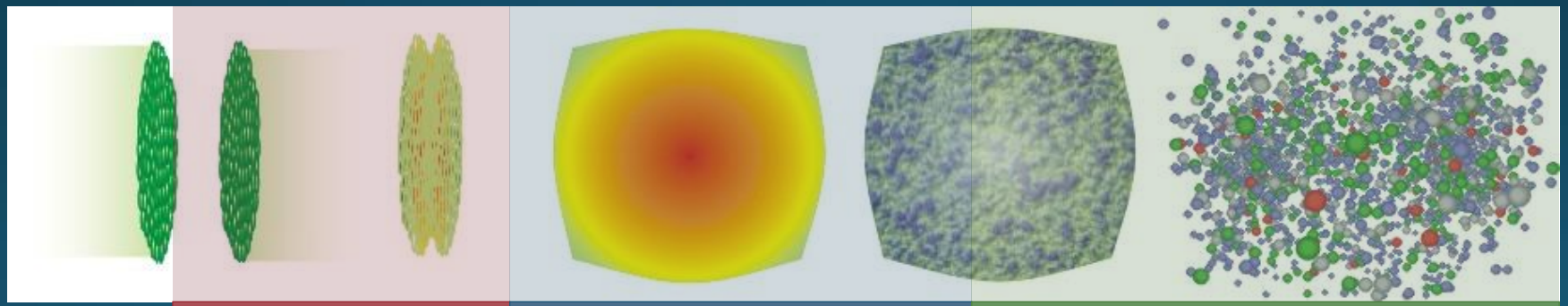
$\sqrt{s_{NN}} \simeq 6$GeV

- Maximum density 5~10ρ_0 @ J-PARC energy
- Large event-by-event fluctuations?

Theoretical Challenges

RHIC / LHC

- creation of QGP
- hydro. models
- early thermalization
- (boost invariance)



Theoretical Challenges

RHIC / LHC

- creation of QGP
- hydro. models
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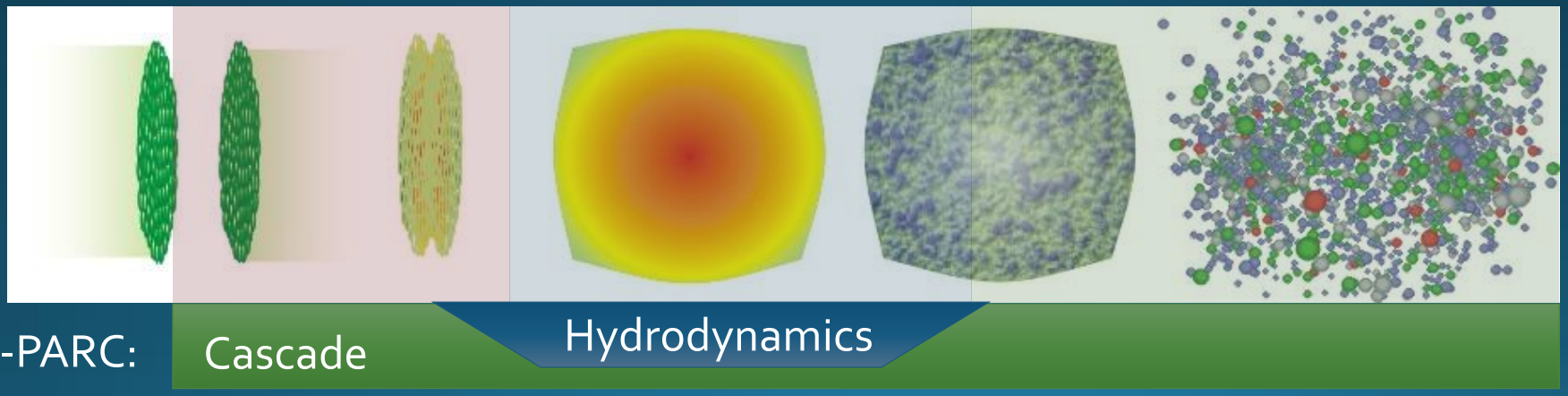
- (boost invariance)

Low-E Collisions

- Initial condition?
- Thresholod of QGP formation
- "Integrated" approach
  - Hydro x Cascade



Modelling Low-E Collisions

- Controlling EOS by changing interaction in cascade

  JAM/ Nara, Ohnishi, Stoecker, 2016-

- cascade + hydro + cascade

  UrQMD/ Petersen; Steinheimer

  Karpenko+, 2016-

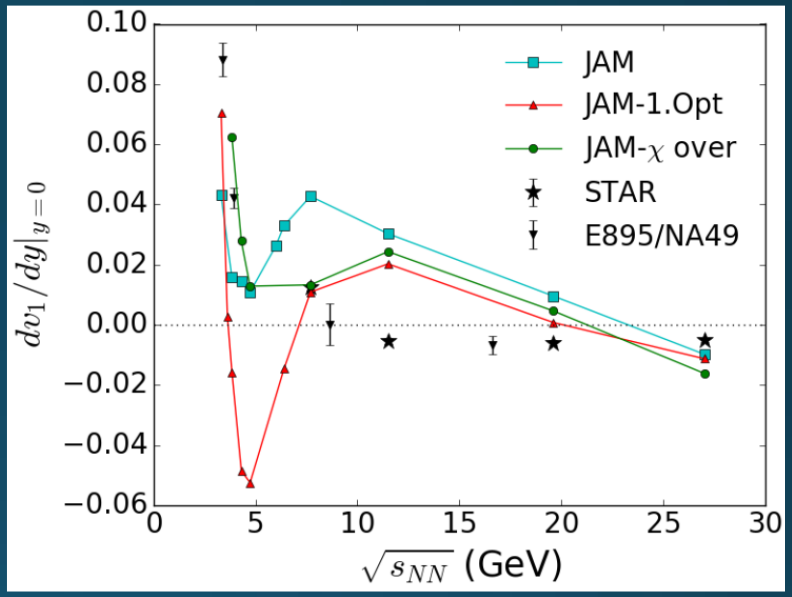
- 3-fluid dynamics

  THESEUS/ Blaschke, Ivanov, +, 2016

- PHSD + chiral restoration

  Cassing+, 2016; Palmese+, 2016

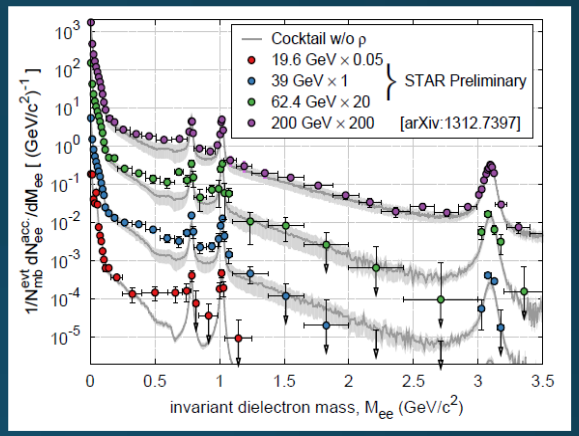
- Chiral fluid Dumitru+; Nahrgang+, 2014-; Song+, 2016-

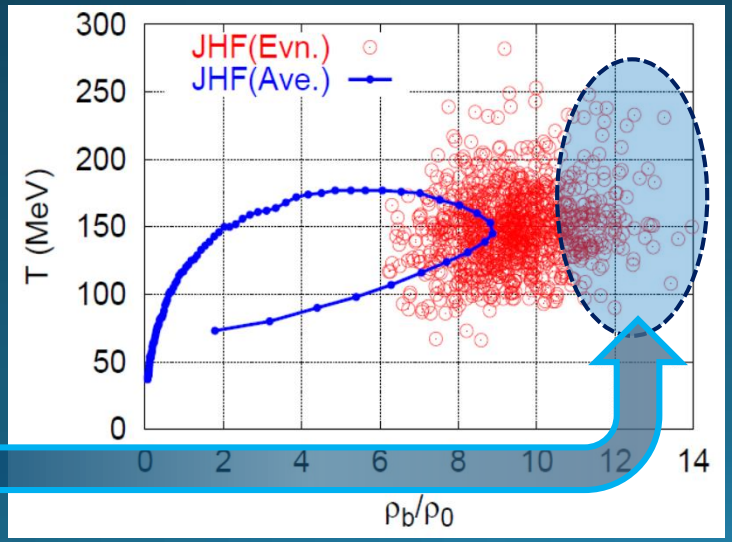


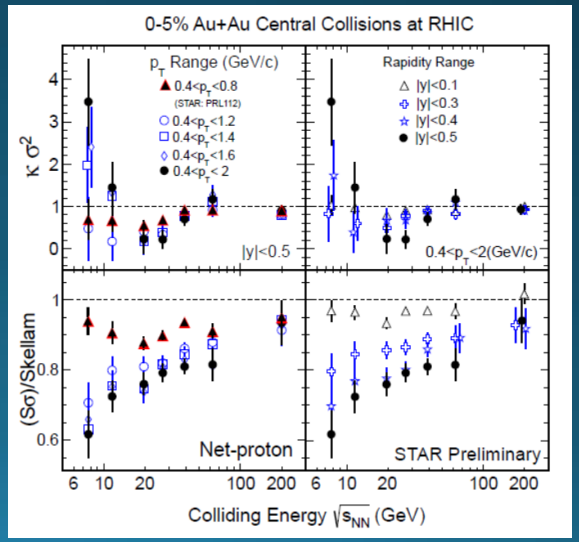
Various New Observables

- Dilepton / photon
- Fluctuations, higher-order cumulants
- Ξ, Ω, …

- Sophisticated event selections
- Various correlations







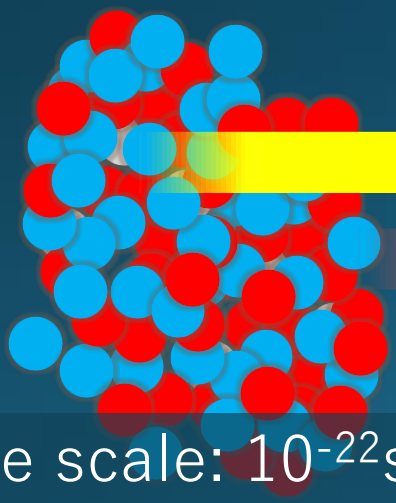
Can we select these events??

MK, Sakaguchi, Sako, Nara, Ohnishi, …

Lepton & Photon: Hierarchical Observation

gravitational wave

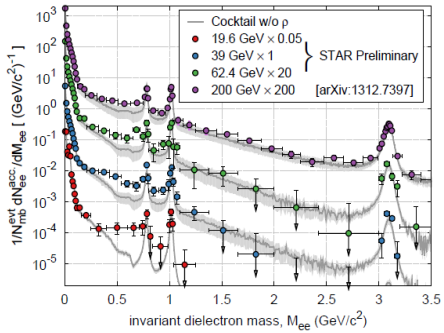
photons



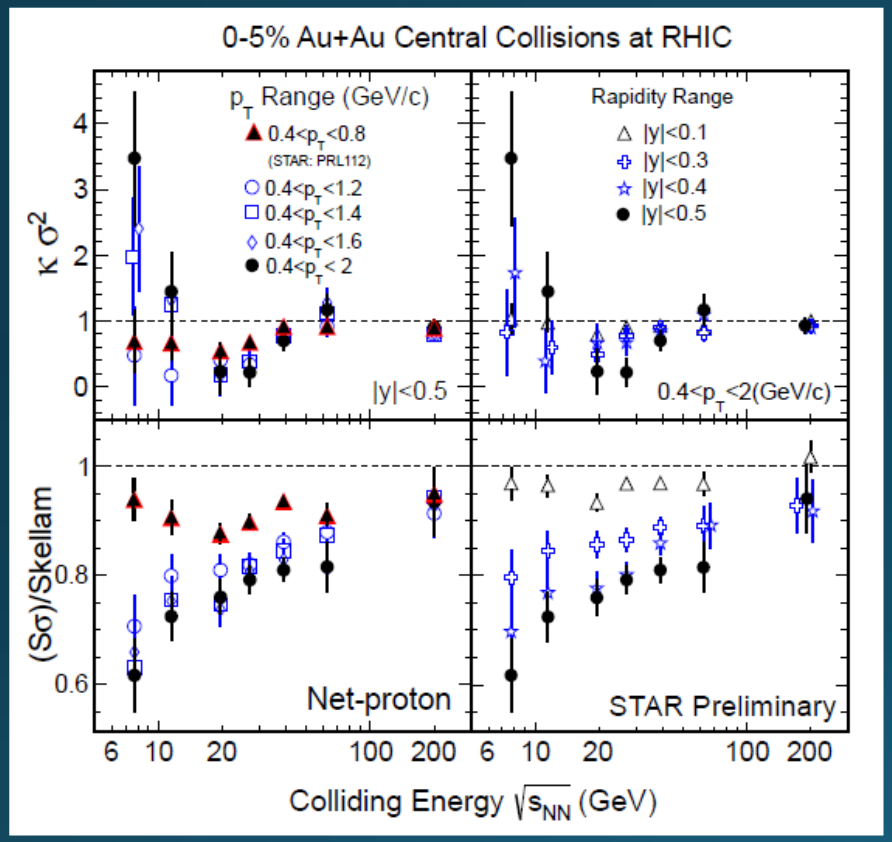
EM probes

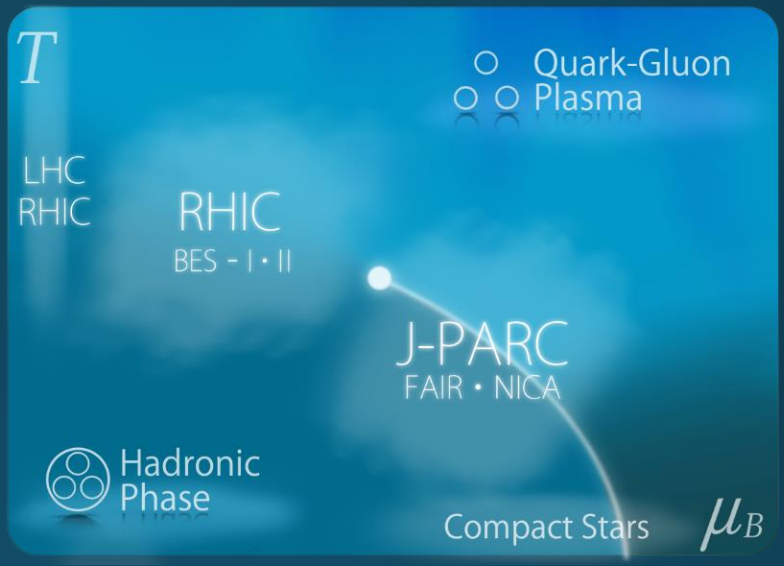
hadronic observables

di-lepton yield



Fluctuations & QCD Critical Point





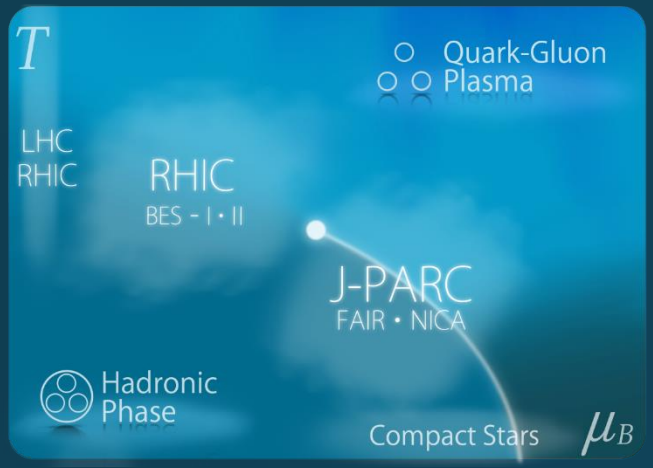
Is the signal of QCD-CP indicated in fluctuation observables??

Careful theor./exp. analyses are needed!

Non-eq. effects / rapidity dependences / experimental cuts / etc.

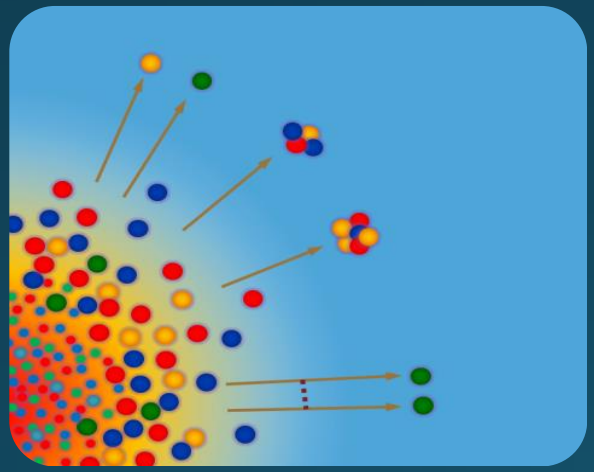
Asakawa, MK, Prog. Part. Nucl. Phys. (2016)

2 Main Goals of J-PARC-HI



Exploring Dense Medium

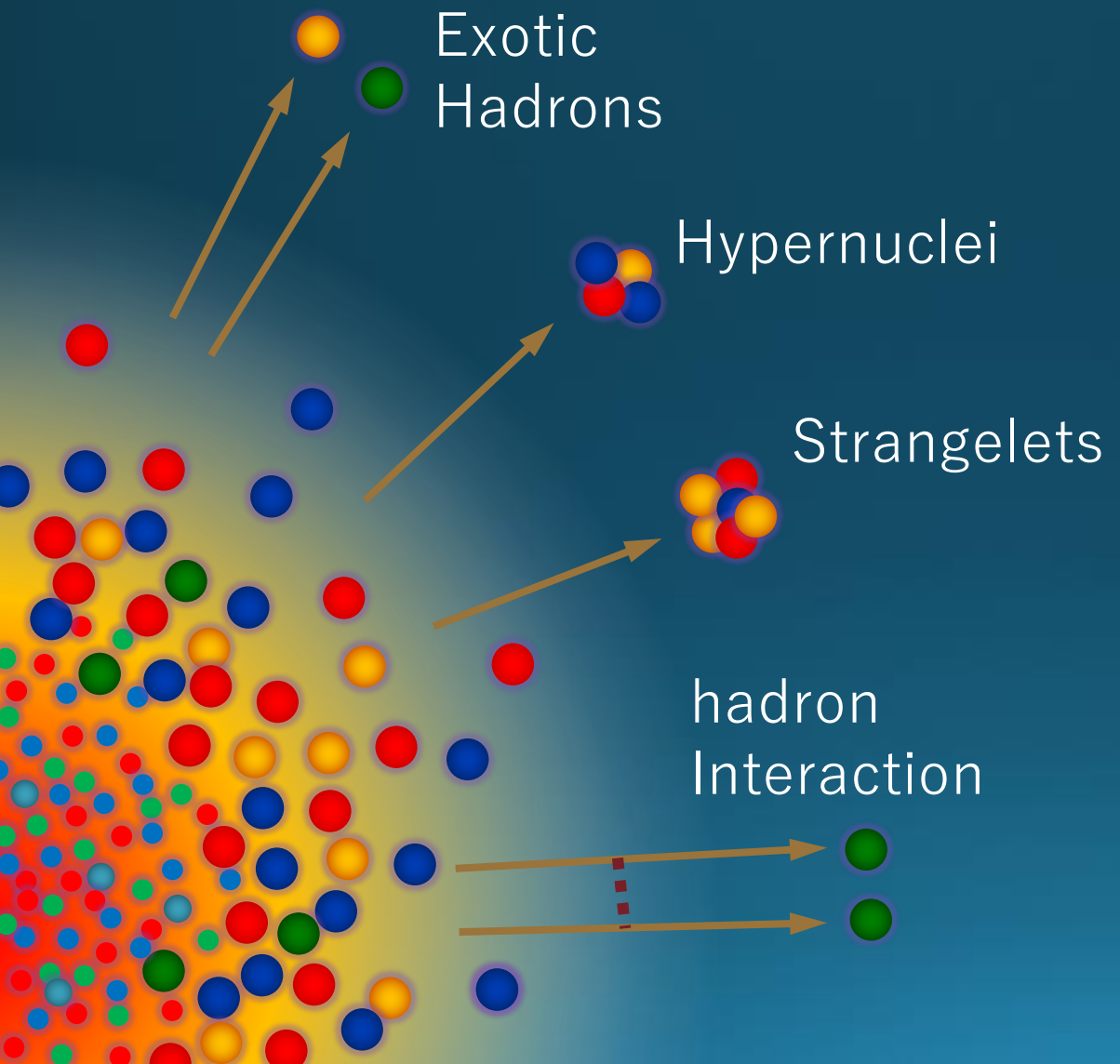
- QCD phase diagram
- 1st order phase transition
- equation of state



Rare-event Factory

- hyper nuclei
- exotic hadrons
- hadron interaction

Search of Rare Events



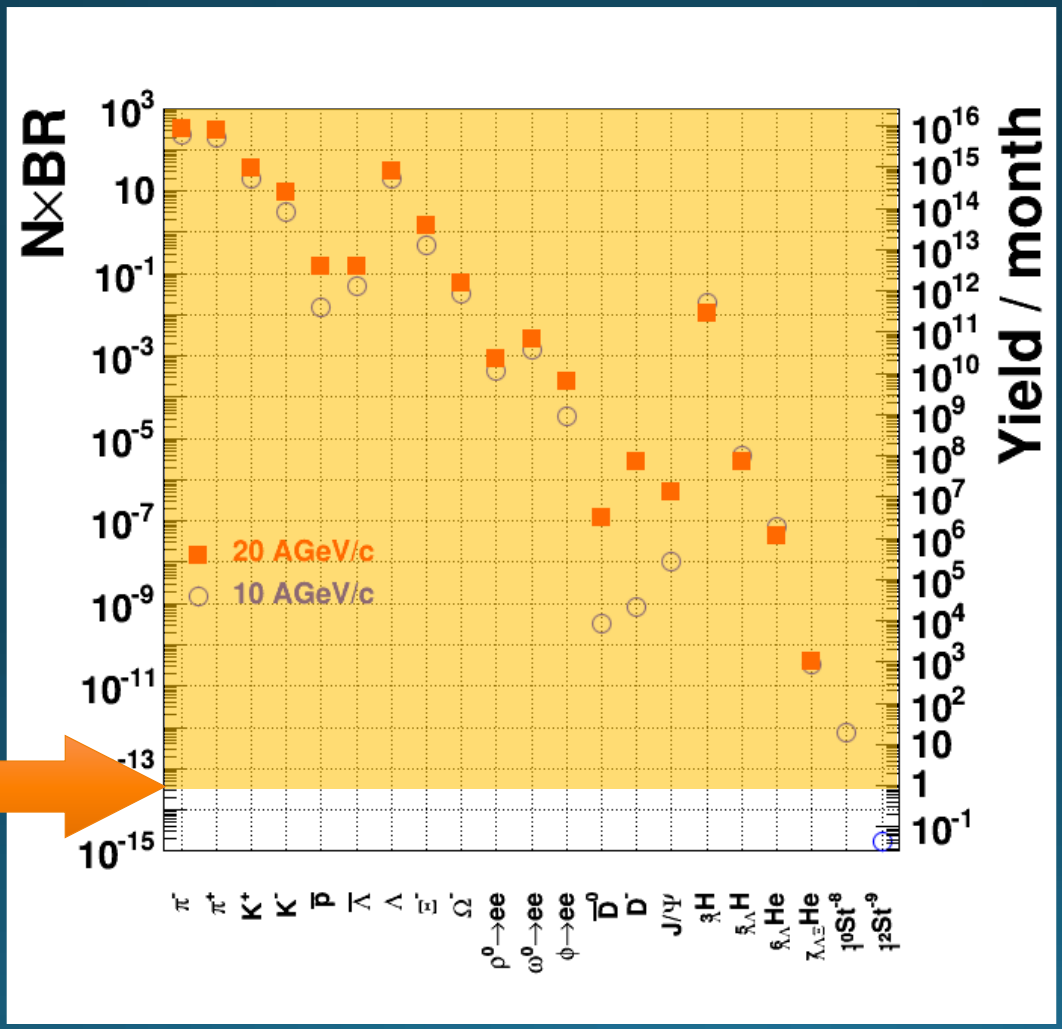
- High density
- High luminosity
- High strange yield

Rare-event Factory

- creation
- properties
- interaction

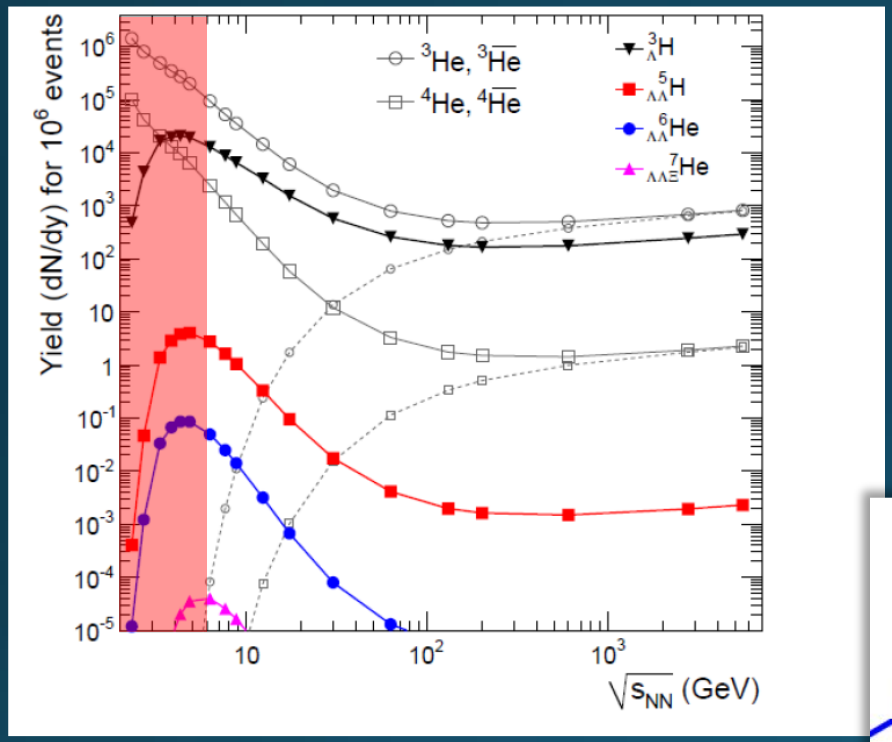
Production Rate

Accessible
@ J-PARC

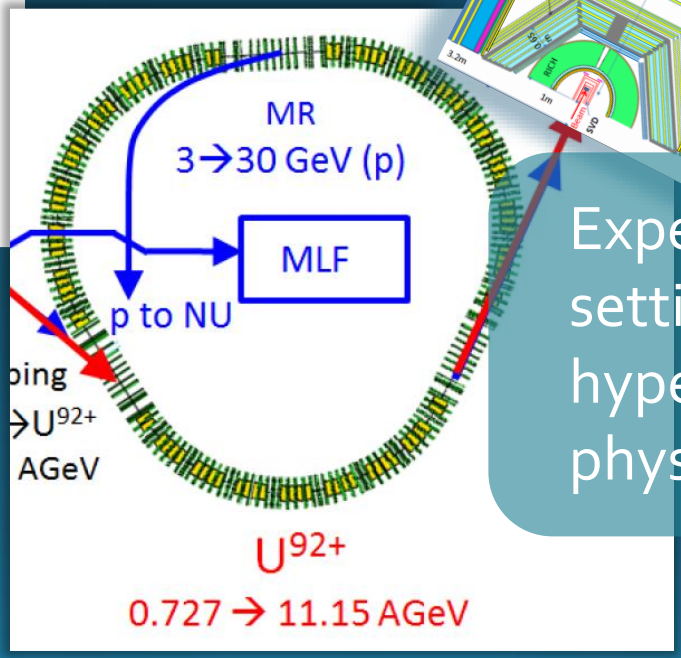


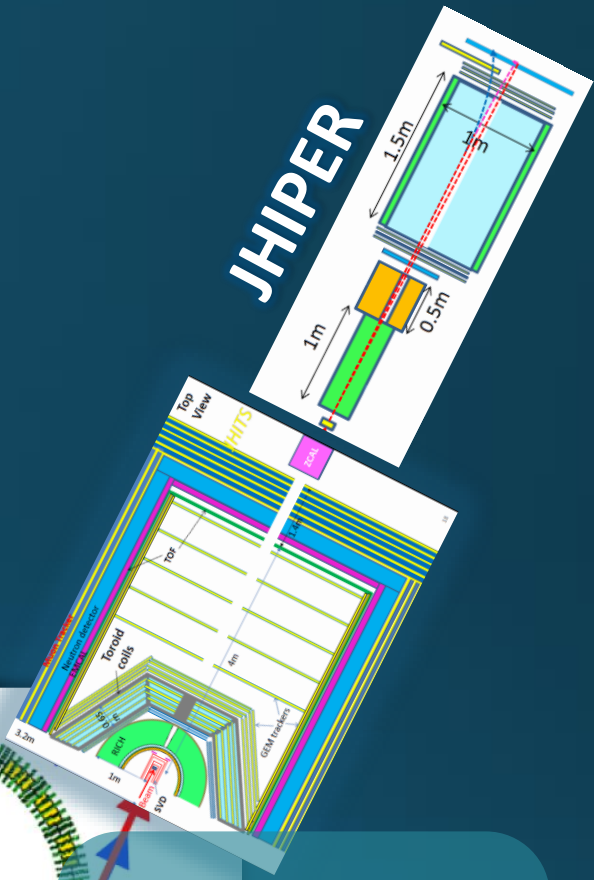
Particle yield in thermal model

Hypernuclei



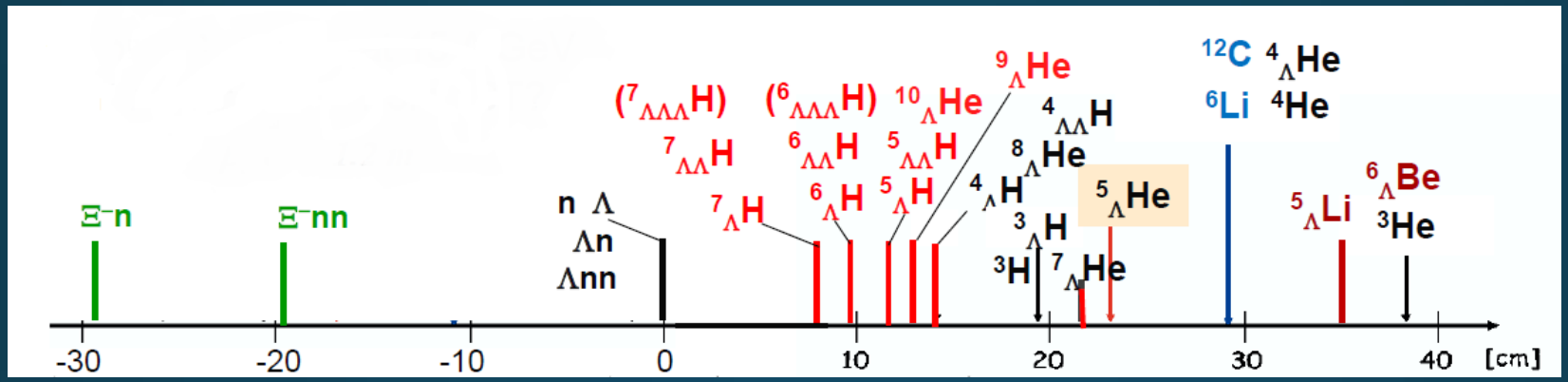
Particle yield in thermal model has a maximum around J-PARC energy





Experimental setting for hypernucler physics

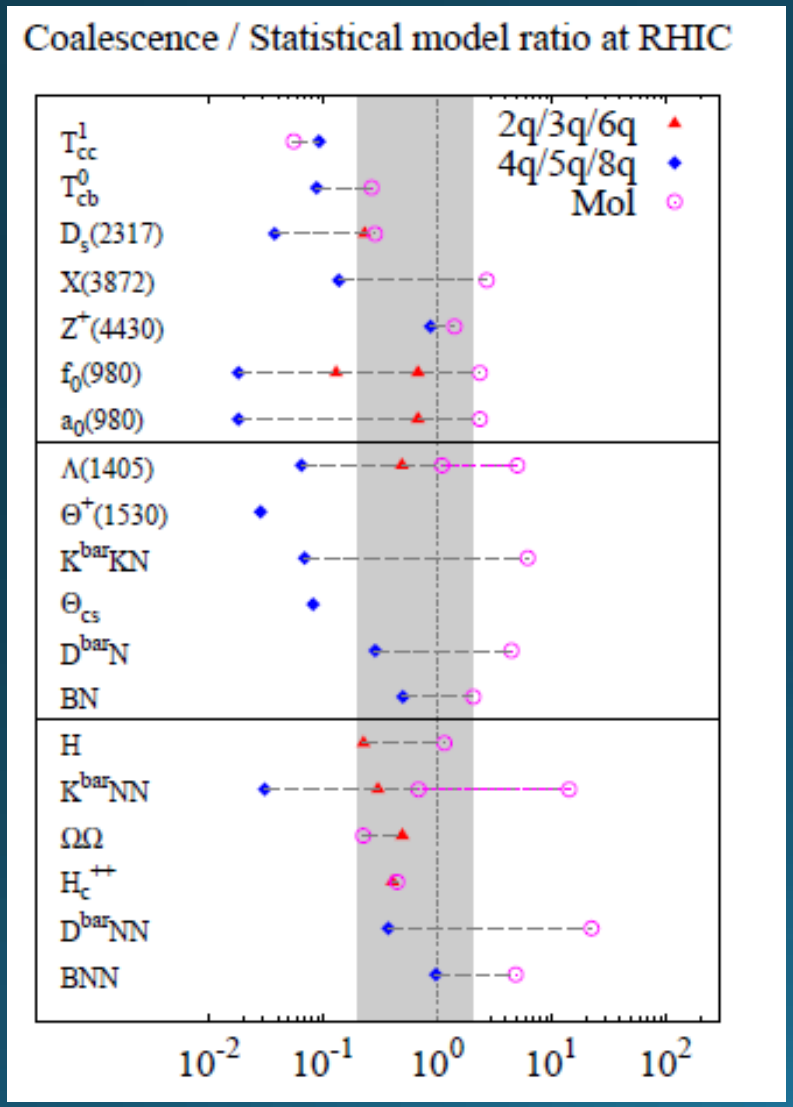
Hyper-Nuclear Phyics @ J-PARC

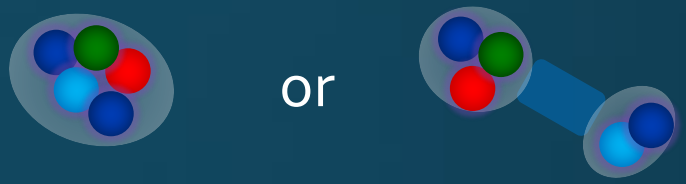


- Negatively-charged hypernuclei (Ξ^-n, Ξ^-nn, …)
- Nuclear strangelets
- n-rich / p-rich hypernuclei

- Measurement of magnetic moments

Creation, Properties





or

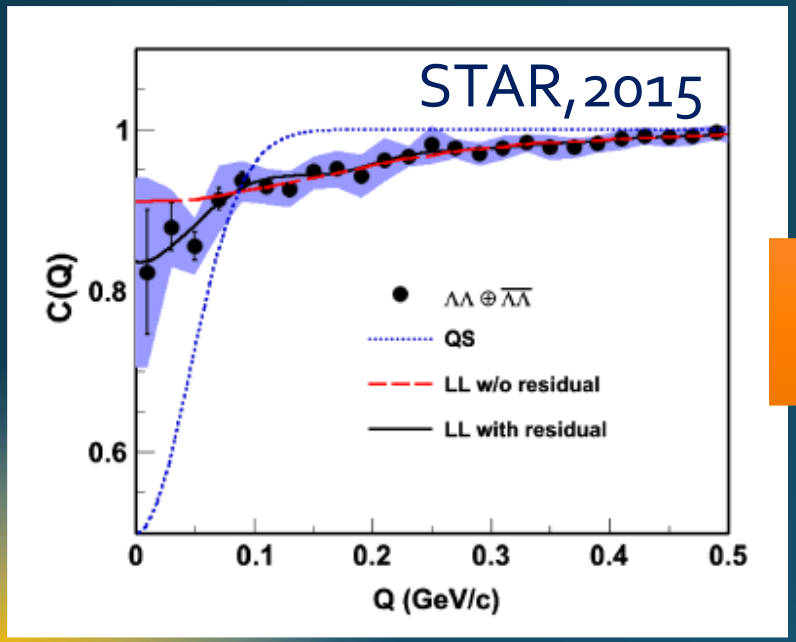
Structure of Hadrons

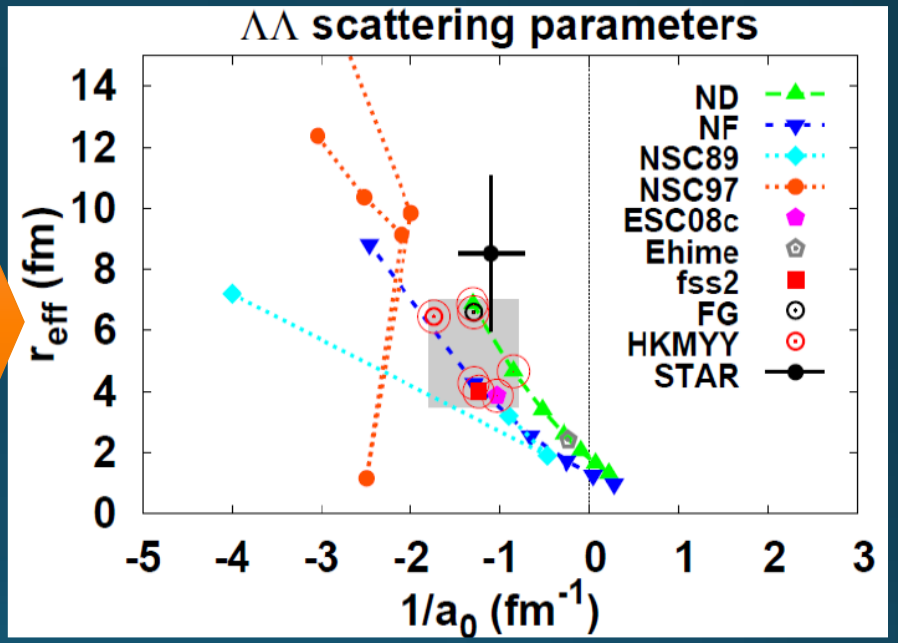
Particle yields

ExHIC Collaboration, 2012

Hadron-hadron Interaction

ΛΛ Correlation function





Hadron interaction can be studied from correlation function.

emission source func. + relative wave func.

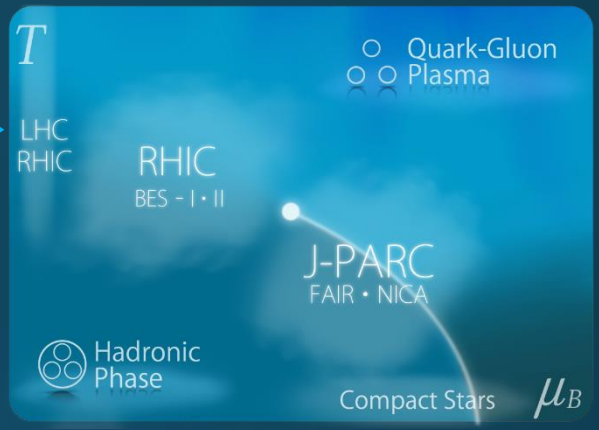
Morita, Furumoto, Ohnishi, 2015

The most difficult Problem…

Future Plan

Recent activities:

June 2016	**White Paper** uploaded
July 2016	Submission of LOI
Aug. 2016	International Workshop
Sep. 2016	Symposium @ JPS meeting



Visit J-PARC-HI Web Page
http://asrc.jaea.go.jp/soshiki/gr/hadron/jparc-hi/

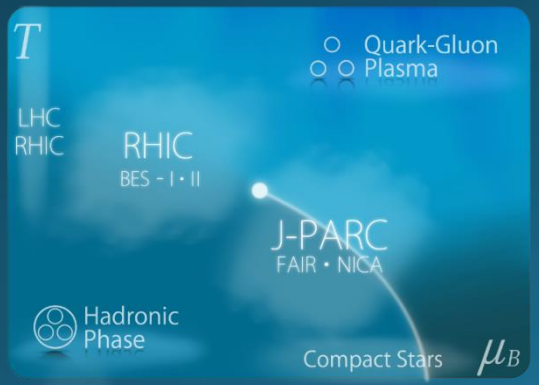
Future plan:

2020	**Funding request to MEXT**
2021	**Earliest approval of funding**
2021-2022	Construction of HI Injector
2021-2023	Construction of HI injection system in RCS
2023-2024	Construction of HI spectrometer
2025	First collision

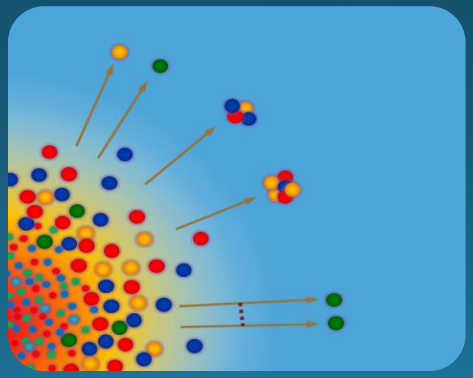
Summary

- J-PARC-HI will explore extremely dense medium with world's highest statistics.

- It will reveal many interesting aspects of



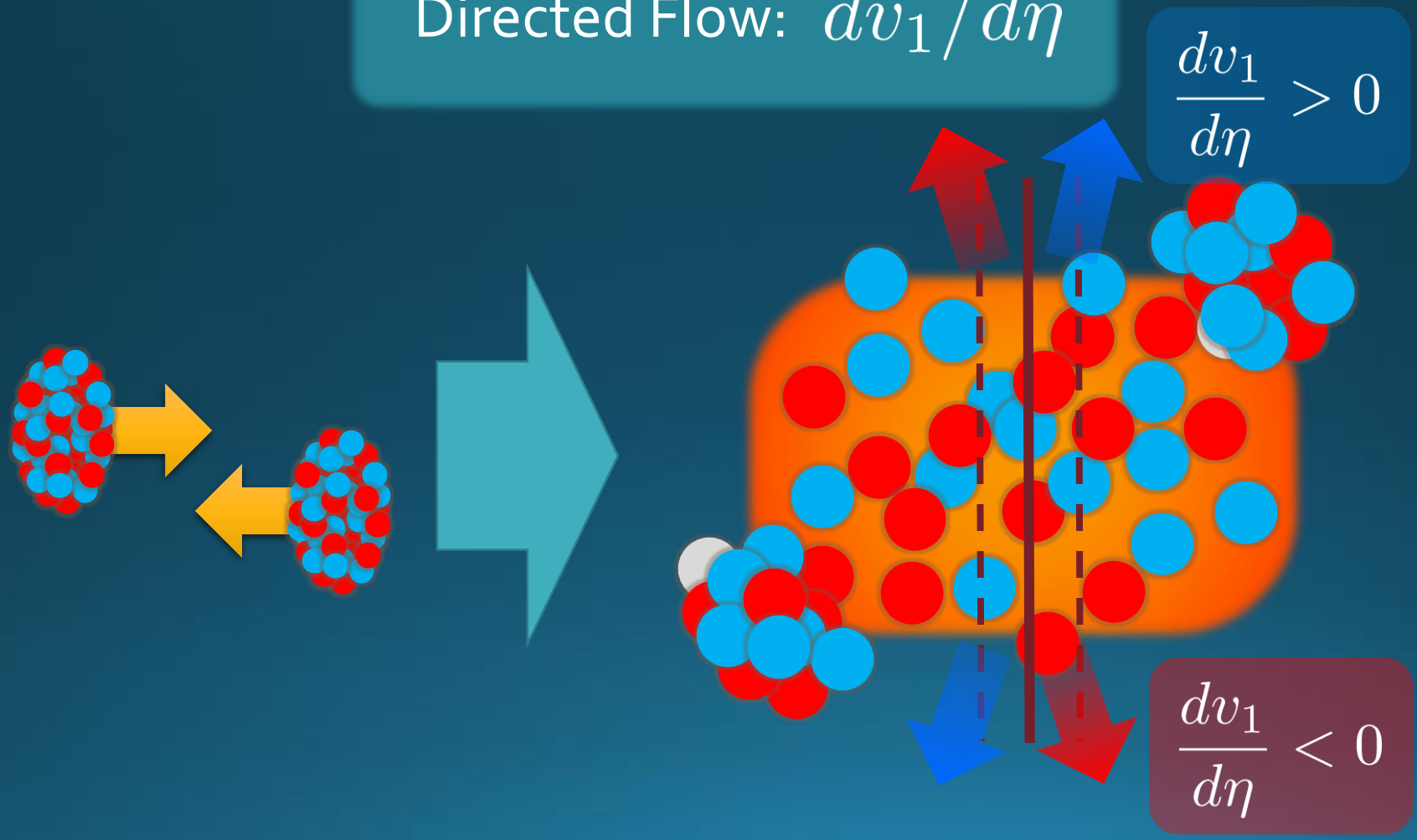
Dense medium



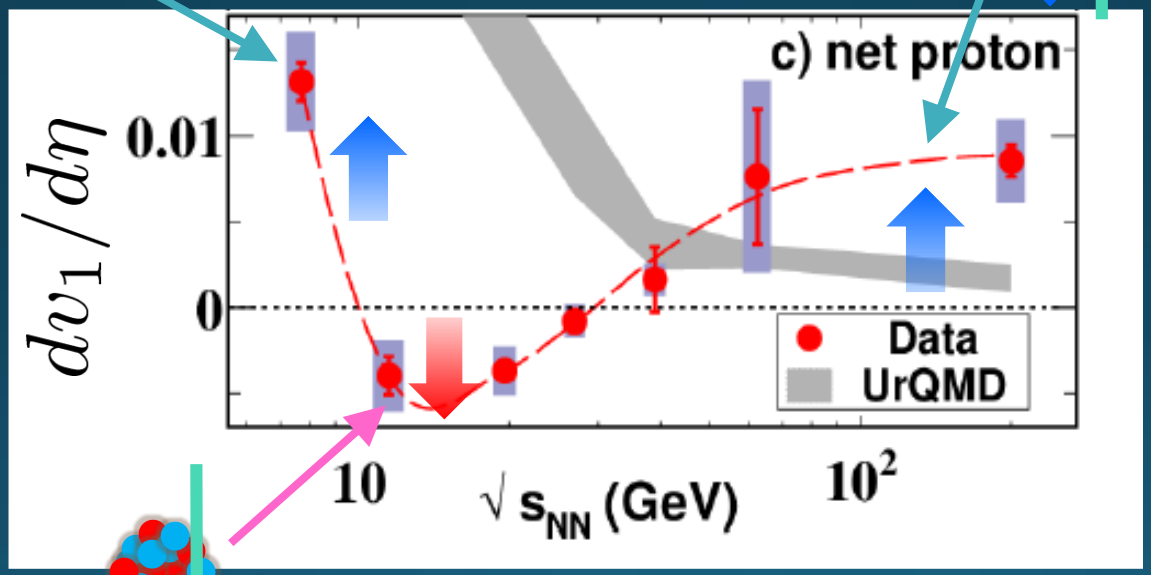
Rare events

Directed Flow

Directed Flow: $dv_1/d\eta$



Directed Flow: $dv_1/d\eta$



- dv_1/dy: two sign change
- No transport models can reproduce it quantitatively


collision rate
$\sqrt{s_{NN}}$
J-PARC
FAIR
NICA
RHIC-BES
SPS
AGS
RHIC
LHC
collision rate
$\sqrt{s_{NN}}$
J-PARC
FAIR
NICA
RHIC-BES
SPS
AGS
RHIC
LHC

S