Current Status of J-PARC-HI

佐甲博之(JAEA / 筑波大)

2017年度 KEK 理論センター J-PARC 分室活動 総括研究会

2018年2月、東海

Outline

1. J-PARC-HIの概要
2. 現状
3. 課題
4. まとめ

J-PARC-HI Project
- Studies of densest baryonic matter in the universe -

High-T, low density region

Production of QGP (SPS/RHIC/LHC)

Phase transition of smooth cross-over

High density region

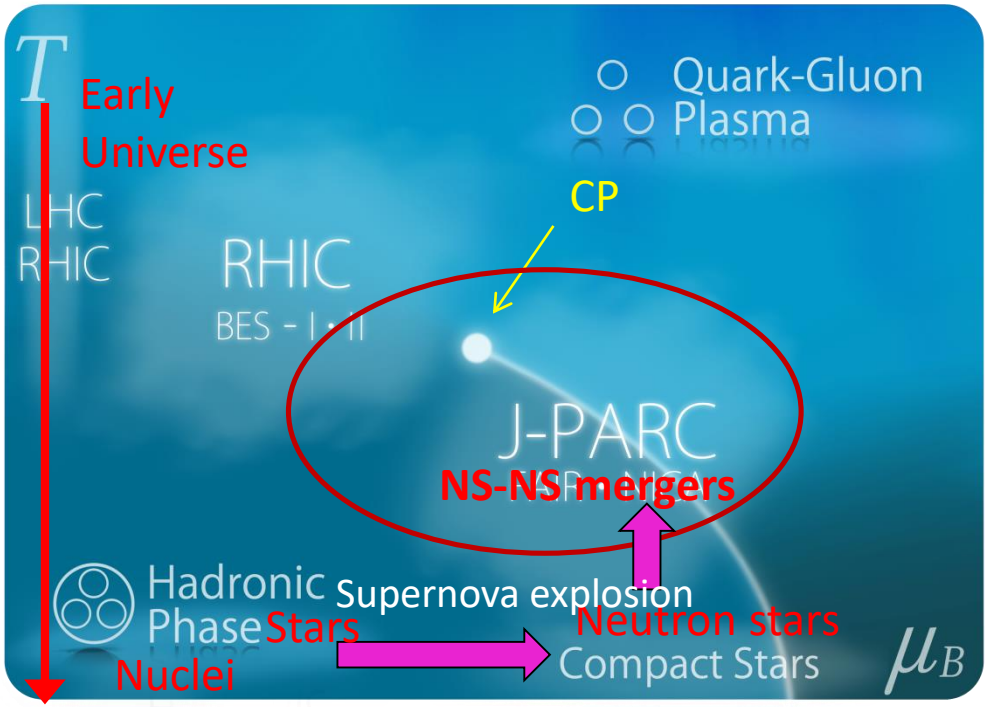
QCD phase structures (1st-order phase transition, Critical Point) not discovered

Heavy-ion Collisions at J-PARC

Unique experimental tool to explore the high density region

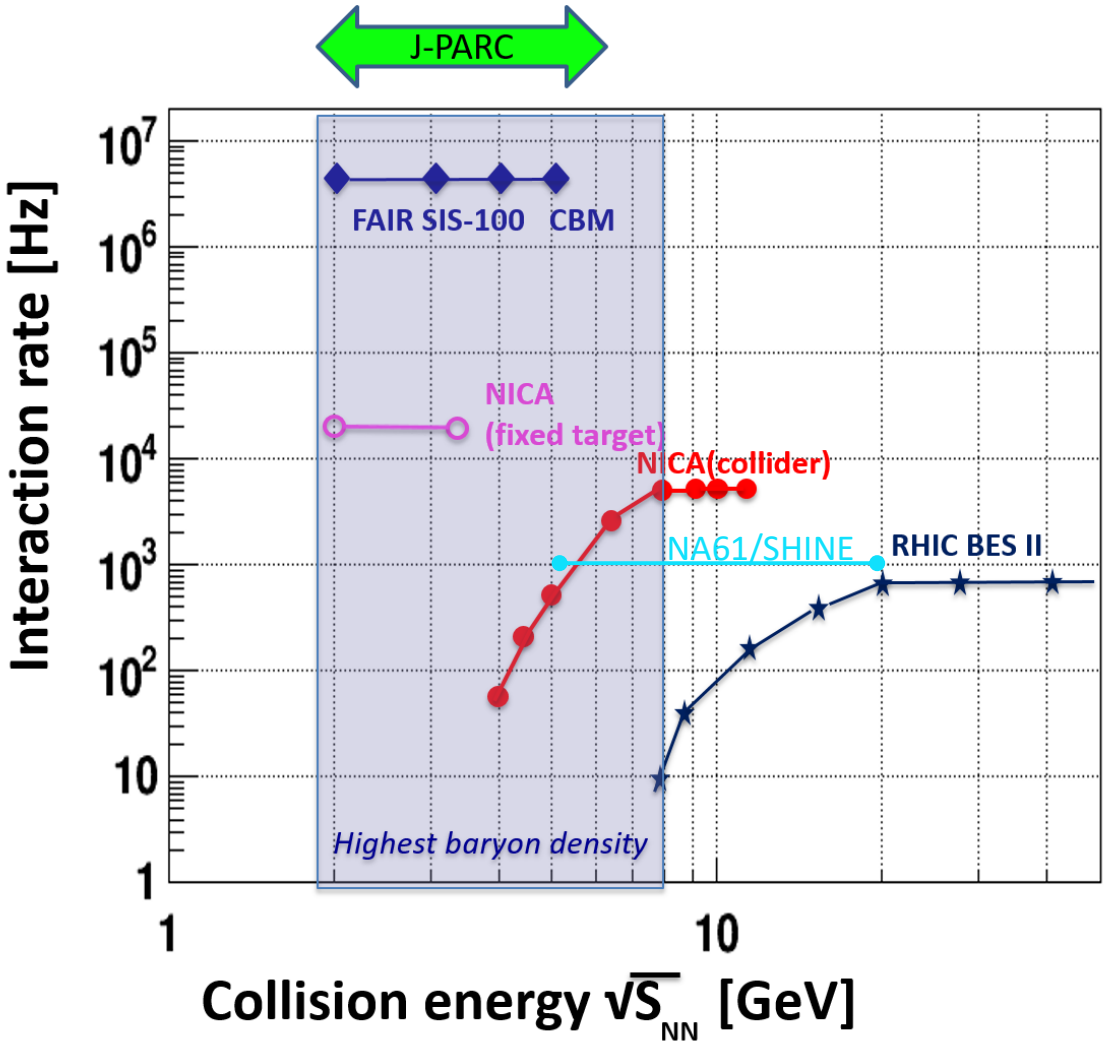
- QCD phase structure
- Properties of high-density matter (EOS etc)

QCD phase diagram

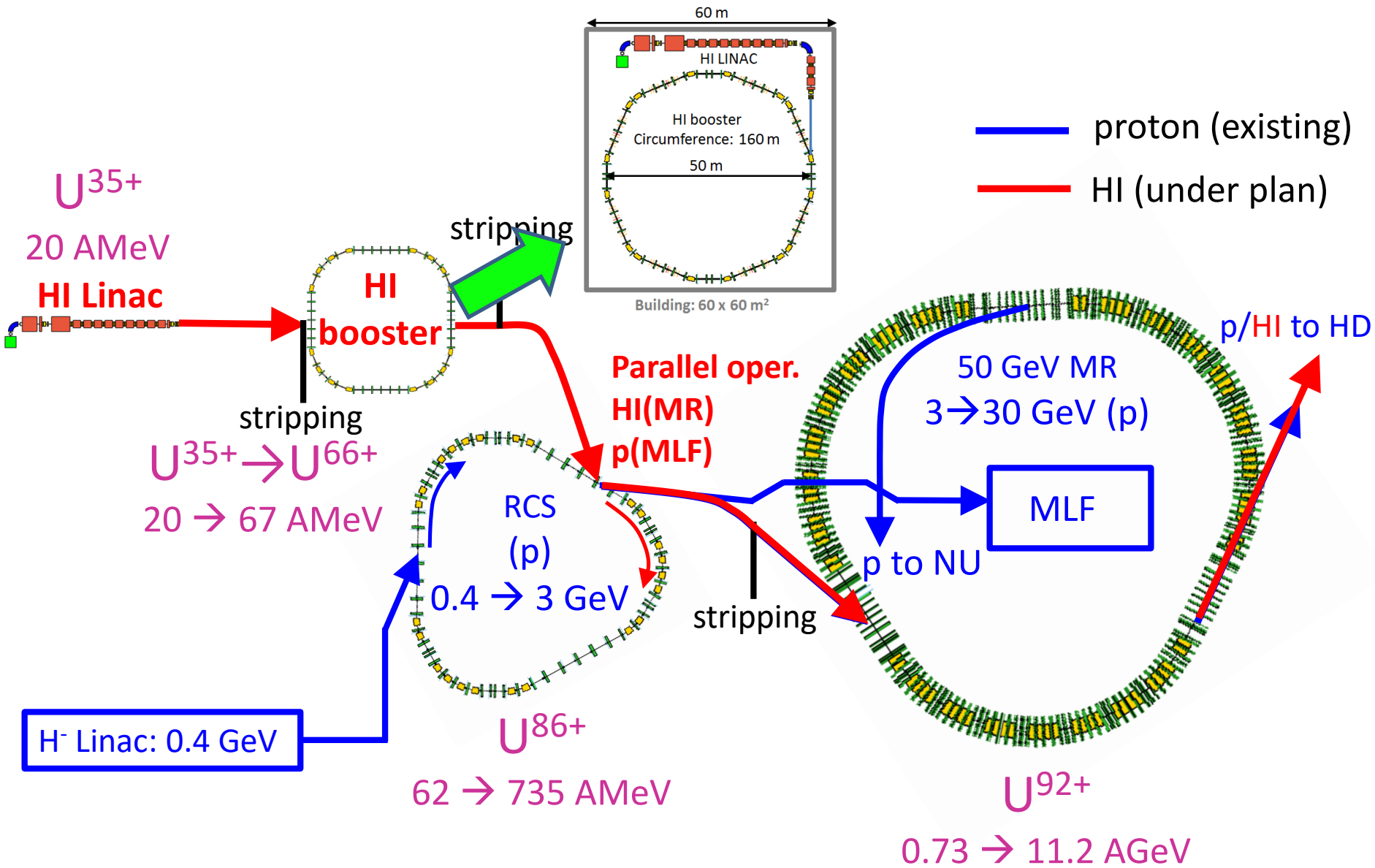


J-PARC-HI beam

- ***World's highest intensity*** ~10^{11} Hz, Interaction rate = 10^8 Hz
- E_{lab}=1-19AGeV, $\sqrt{s_{NN}}$=1.9-6.2GeV (U)
- Ion species: p, Si,…, Au, U



HI accelerator scheme



Particle production rates

Beam : 10^{10} Hz

0.1 % target

→ Min-bias event rate 10^{7}Hz

In 1 month experiment:

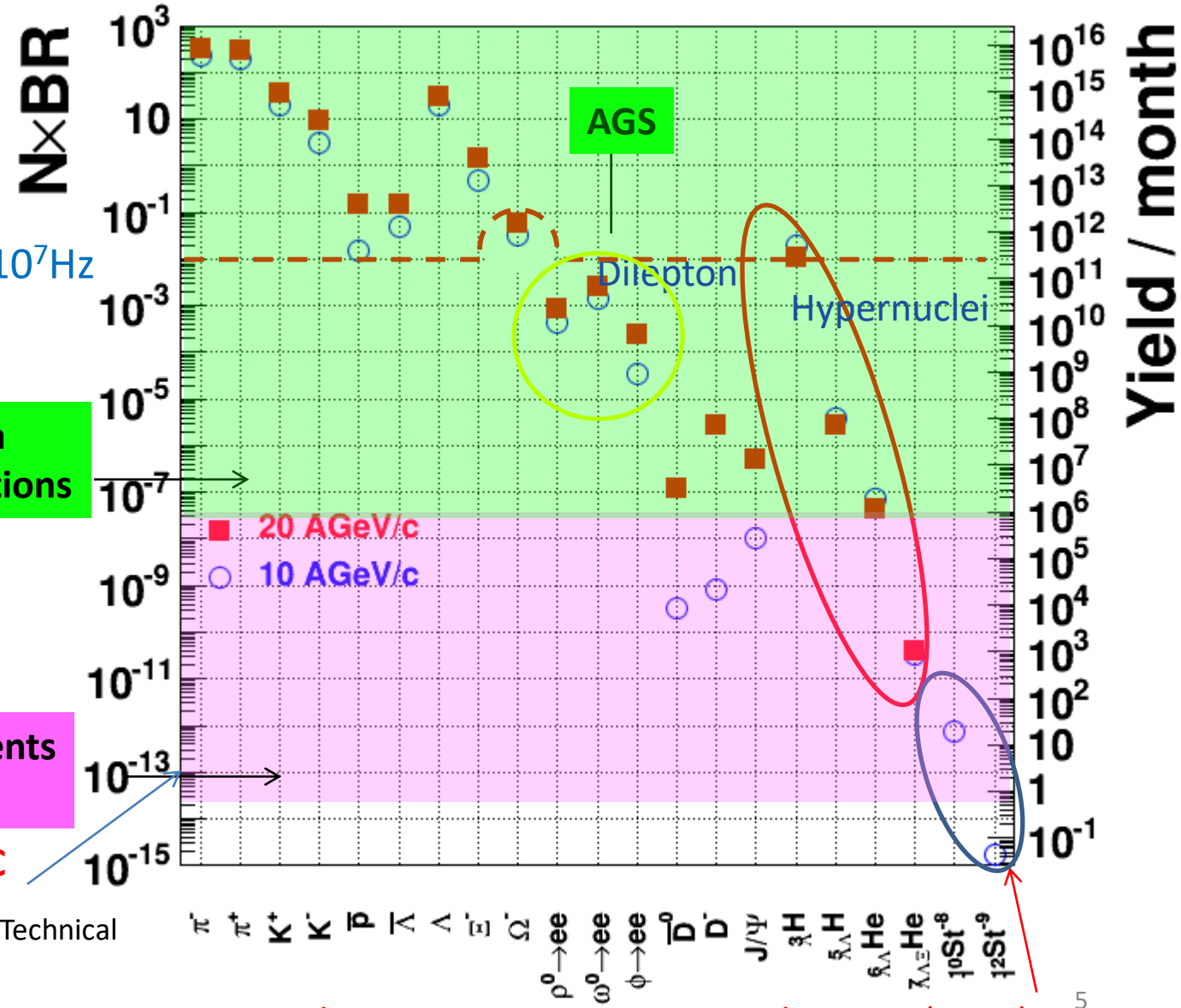
$\rho,\omega,\phi \rightarrow ee$ 1

Hypernuclei

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

Observables for QCD phase structures

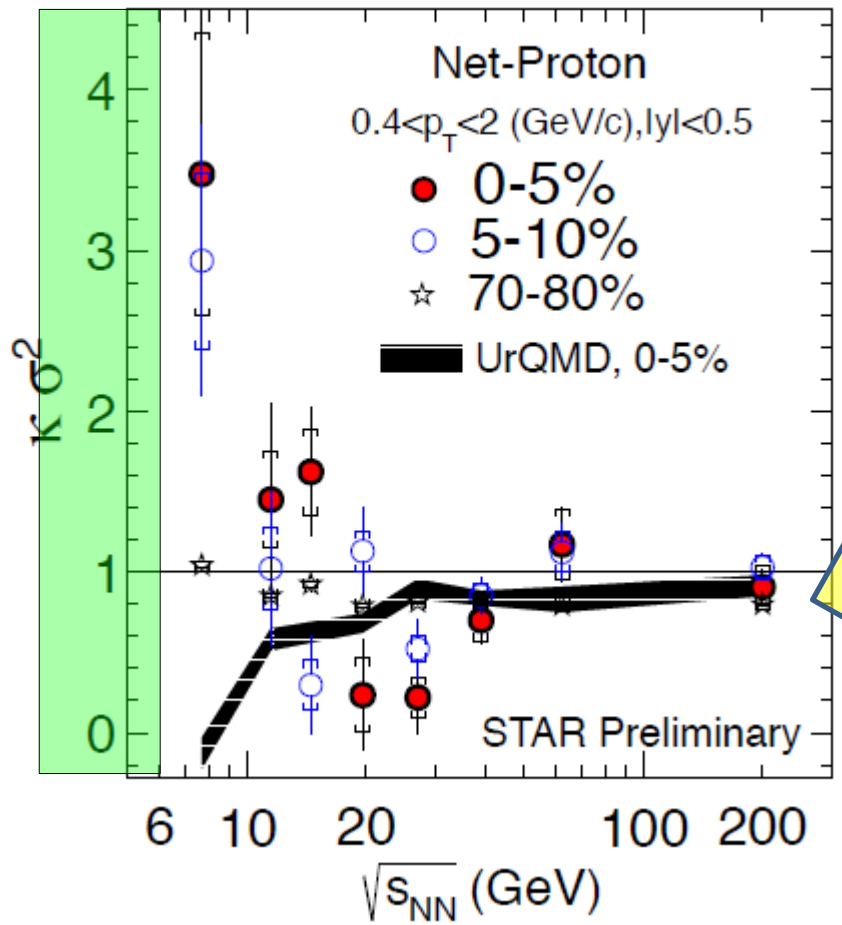
- Dileptons
  - Penetrating probes of dense matter
  - Modification of $\rho/\omega/\phi$ linked to chiral symmetry restoration
- Hadron measurements (high statistics)
  - Event-by-event fluctuations
  - Collective flow (search for 1st order transition)
- Photons (real and virtual)
  - Thermal radiations from QGP
- Charm
  - J/ψ, D,…
    - Sensitive to initial dense matter

Event-by-event fluctuations

Event-by-event fluctuations of conserved charge:

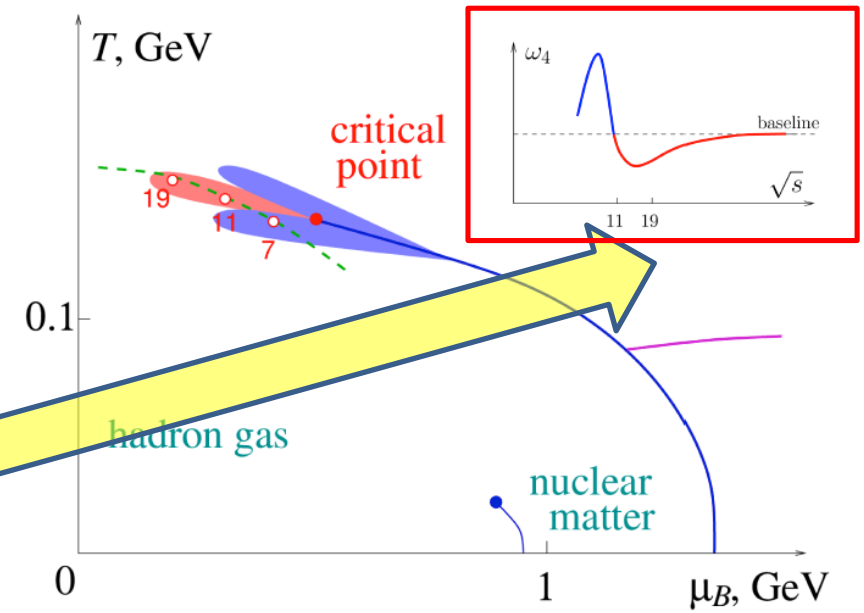
Probe to search for the critical point

J-PARC



Theory

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



Enhancement of 4th-order fluctuations at low energies

Indications of the critical point?

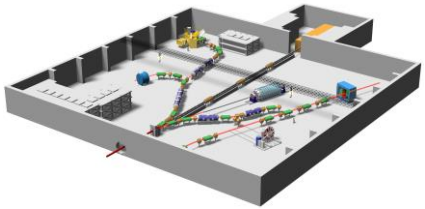
→ J-PARC-HI may answer that.

X. Luo, Quark Matter 2015

J-PARCハドロン物理の高密度への展開

通常原子核密度 → 高密度（～中性子星コア）

π/K/p beam experiments



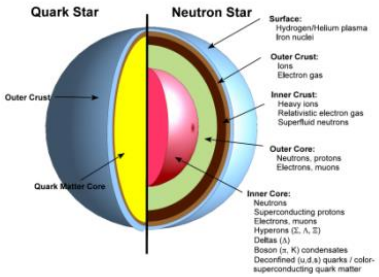
Exotic hadrons
Θ^+ Pentaquark
H-dibaryon

Hypernuclei
|S|<=2

Kaonic nuclei : K^-pp

Chiral restoration
dilepton in p+A

Neutron Star

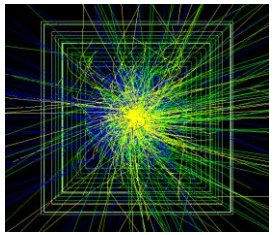


YN YY interactions

Hard EOS

Core Matter

HI experiment



Exotic hadrons
(distinguish structure by production yield)

2-particle correlation (HBT)

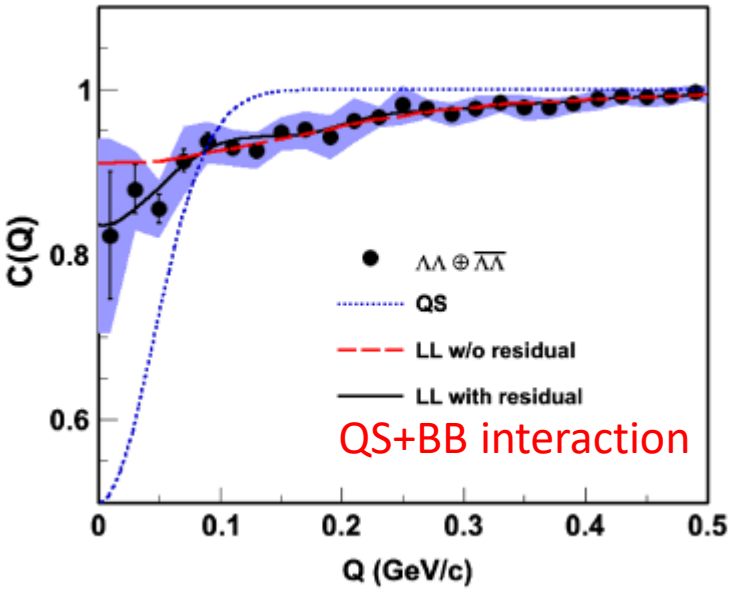
Collective flow

|S|>=3 hypernuclei

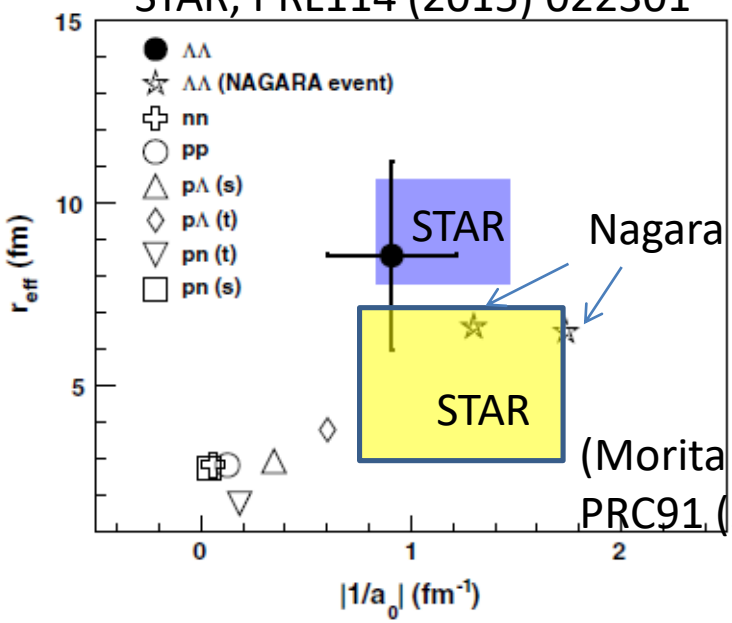
Strangelet (strange quark matter)

ハイペロン2粒子相関

ΛΛ correlation function



STAR, PRL114 (2015) 022301

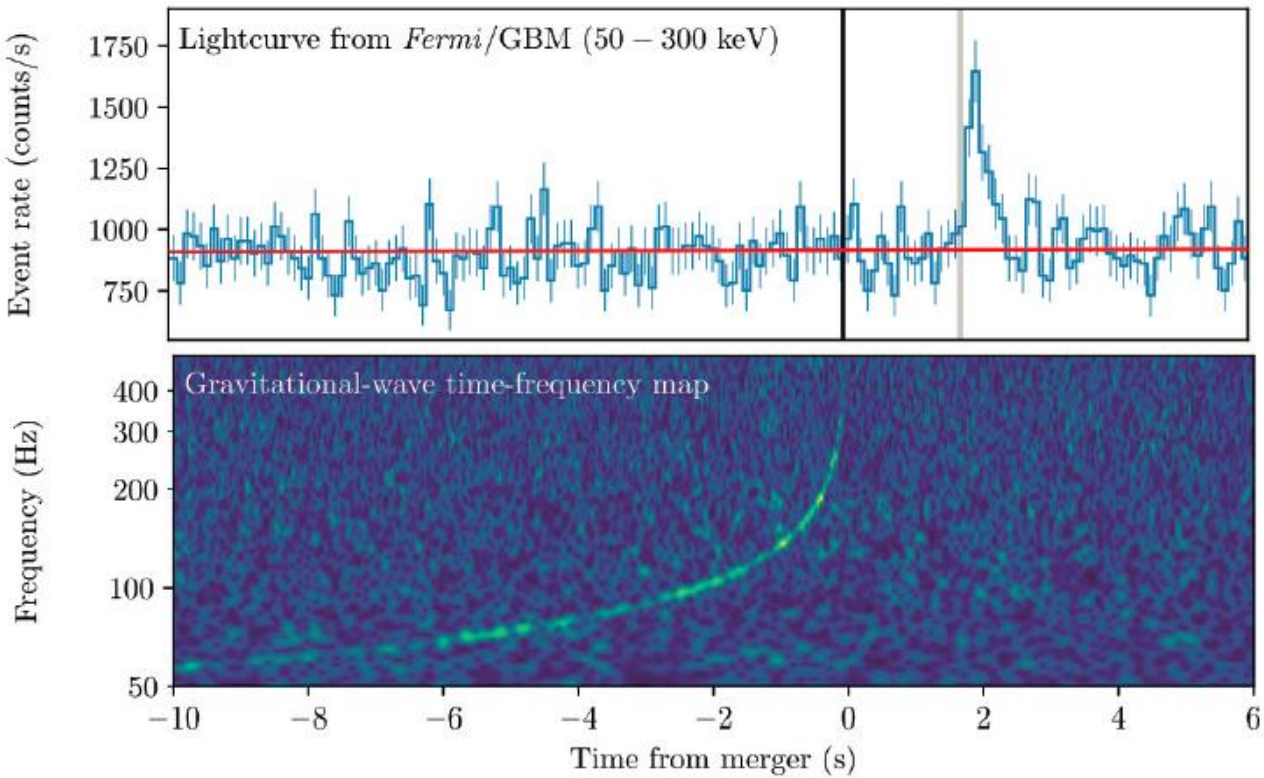


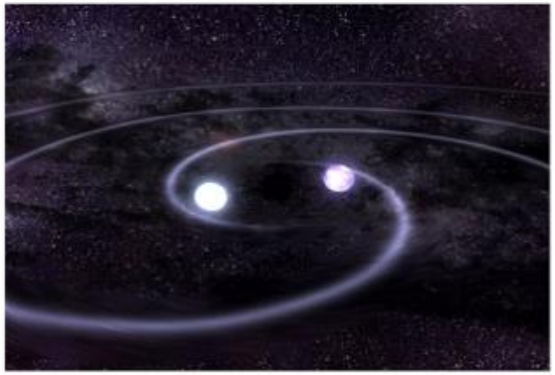
(Morita et al PRC91 (2015) 024916)

- Study of ΛΛ interactions from two-particle momentum correlation
- Other YN, YY, YYN correlation measurements possible
  - Ξ^- and Ω multiplicity = 0.6/0.03 at 10 AGeV
  - Ωp : K. Morita et al, Phys. Rev. C94 (2016) 031901

Gravitational waves from neutron star mergers

On 17 Aug. 2017: Gravitational wave signal with associated electromagnetic counterpart across spectrum

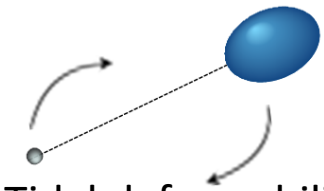




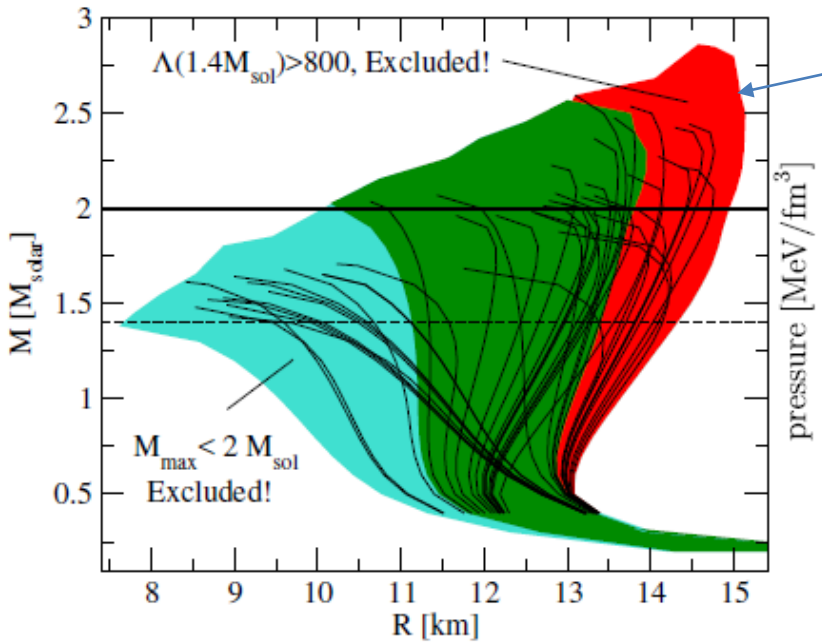
Gravitational waves: PRL. 119, 161101 (2017), γ-ray: APJ. 848 (2017) L13
Aslo: X-ray, UV, Optical, IR, Radio APJL, 848 (2017) L12

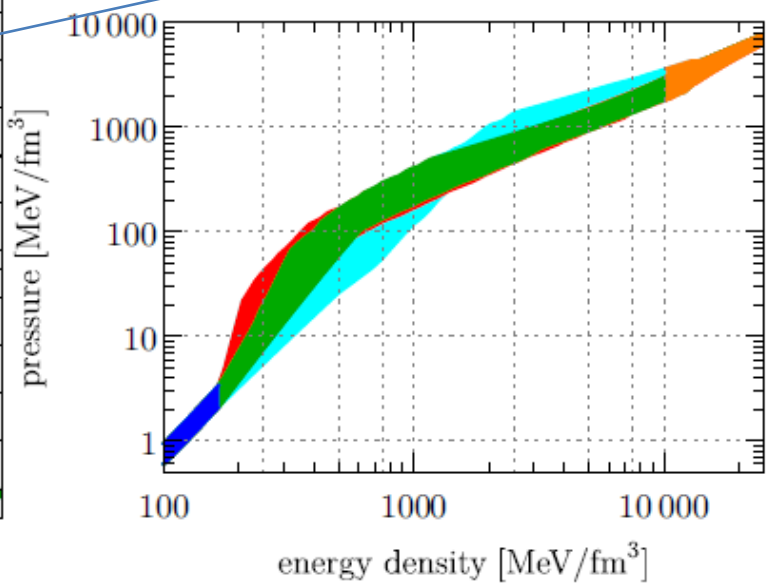
Talk in ALICE Week, Nov. 2017, Aleksi Kurkela

Constraining QCD using neutron star properties



Tidal deformability during inspiral





How HIC contributes to EOS?

- Requiring $\Lambda(1.4M_\odot) < 800$ implies that the matter is soft enough
- Upper limit for radius: $R(1.4M_\odot) < 13.4$km
- Uncertainty in $e(p)$ at worst $\pm 60\%$

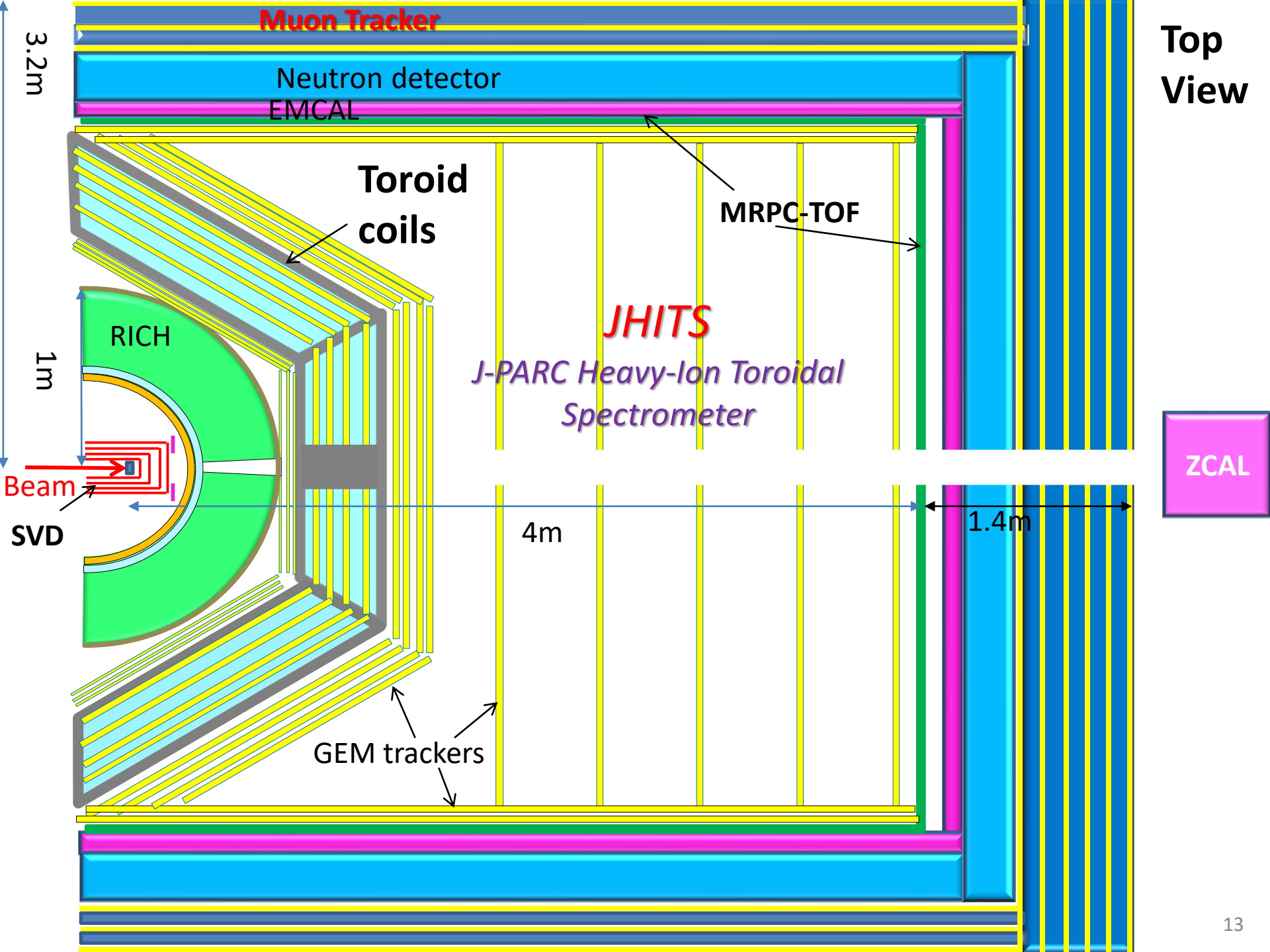
Talk in ALICE Week, Nov. 2017, Aleksi Kurkela

Experimental challenges

- High rate capability
  - Fast detectors
    - Silicon Vertex Detectors, GEM trackers, …
  - Extremely fast DAQ of 10-100MHz

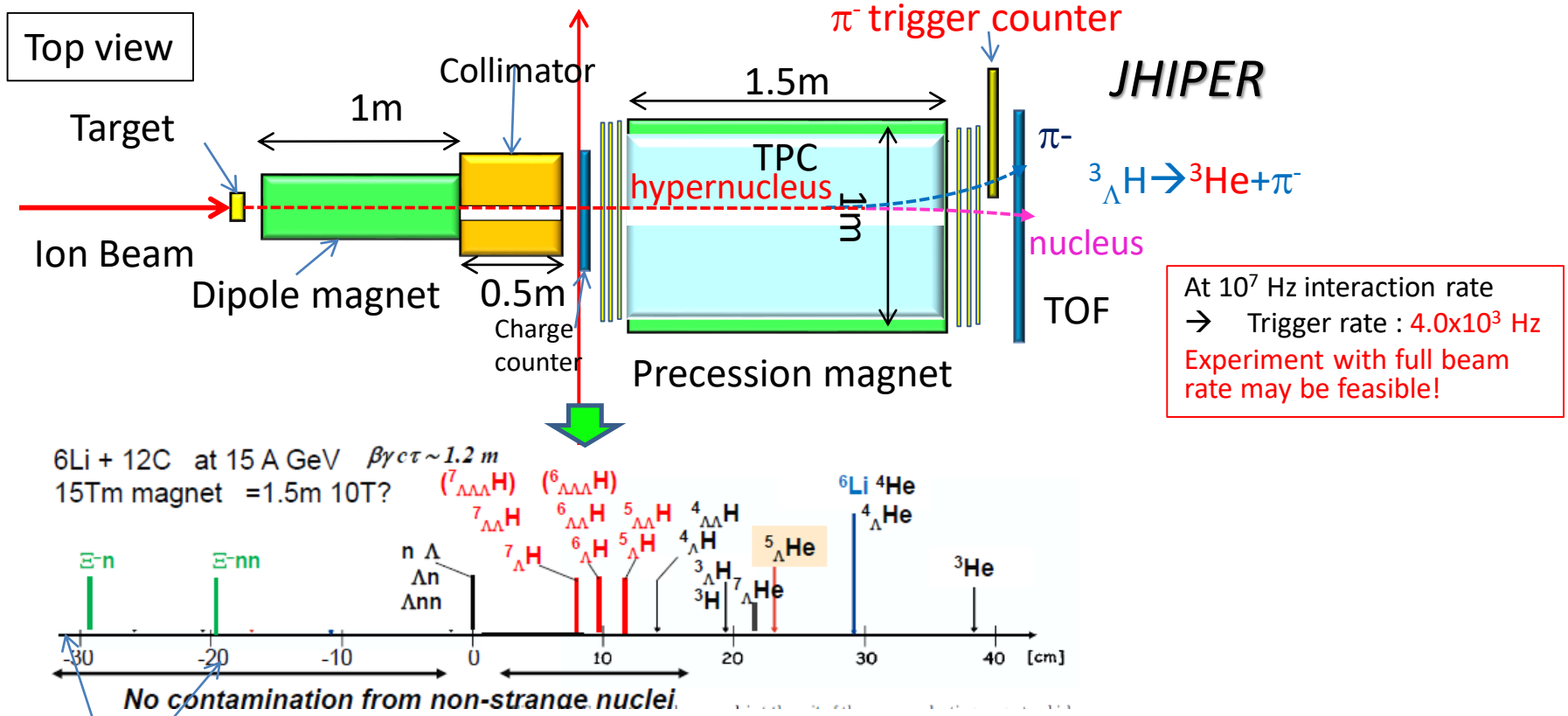
    → Triggerless continuous readout + online data reduction
- Large acceptance (~4π)
  - Rapidity dependence of e-b-e fluctuations

⇨ Toroidal magnet spectrometer


Muon Tracker
3.2m
Neutron detector
EMCAL
Top View
Toroid coils
MRPC-TOF
RICH
1m
JHITS
J-PARC Heavy-Ion Toroidal Spectrometer
ZCAL
Beam
SVD
4m
1.4m
GEM trackers

Hypernuclear spectrometer (JHIPER)

- Hypernuclear measurement at y_{beam}
  - Lifetime
  - Magnetic moment
  - S=-1,-2,-3,…
  - Strangelet



If found, discovery of negative nuclei

H. Tamura, Reimei Workshop, 10 Aug 2016, Tokai, Japan

Talks for J-PARC-HI (2017)

International conferences

- Feb. 2017 QM2017 (T. Sakaguchi)
- Feb. 2017 QCS2017 (H. Sako)
- Jul. 2017 SQM2017 (S. Sato)
- Aug. 2017 CPOD2017 (H. Sako)
  - Plenary talk (with FAIR, NICA, NA61/SHINE)
- Dec. 2017 Reimei Workshop & J-PARC-HI Collab Meeting, Tokai, Japan

Others

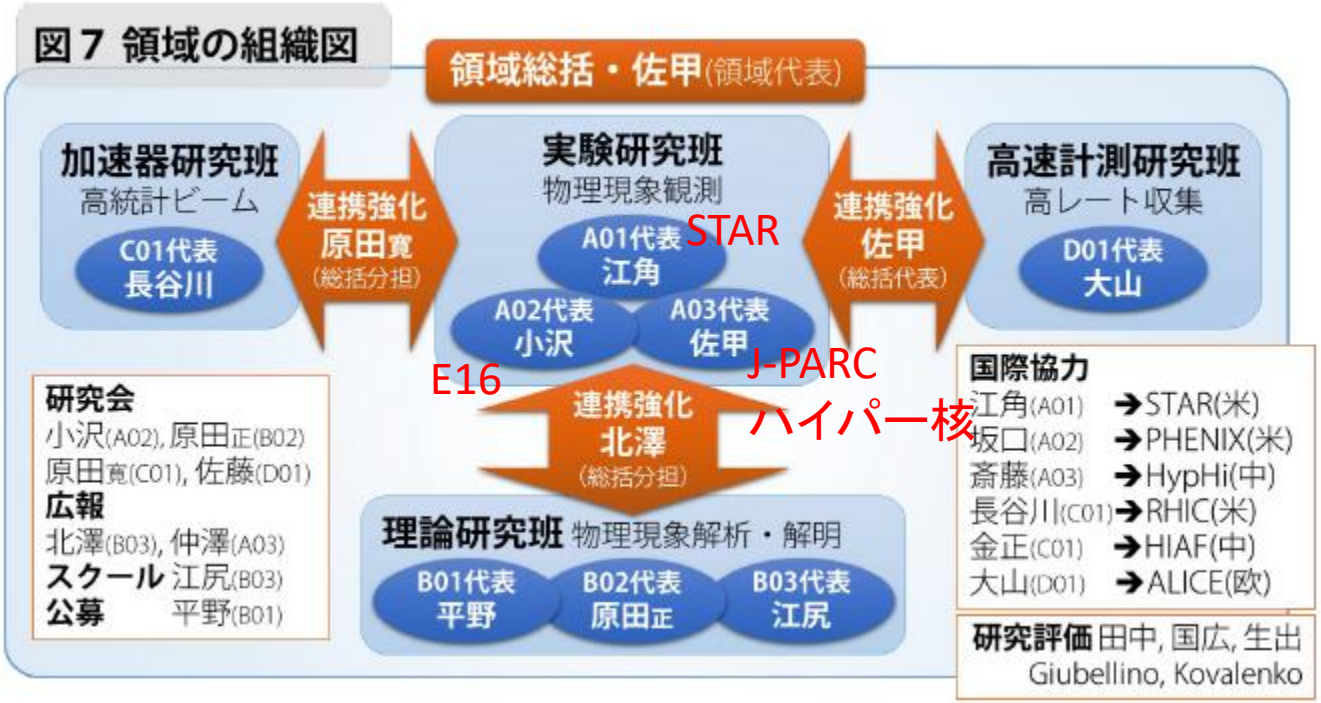
- 2017/10/24 Meeting with a JAEA Director, S. Watanabe
  - Introduction of J-PARC-HI
  - 文部科学省概算要求資料から見る平成30年度の文科省施策についての説明会

International conferences in 2018

- May 2018 Quark Matter 2018, Venezia (H. Sako)
- Sep. 2018 CPOD2018, Corfu, Greece (T. Sakaguchi)

Grants-in-Aid for Scientific Research on Innovative Area for JFY2018
H30科研費（新学術）への応募

- 「強い力」が創り出す超高密度物質世界の探究（超高密度物質）
  - Proposal of new research field for densest matter in the universe
  - Lots of discussions among experimentalists (J-PARC, RHIC, LHC), theorists and accelerator scientists
  - This framework will lead to plans of J-PARC-HI



R&D status

- Fast Data Acquisition System
  - Participation in ALICE-Online-Offline Computing (O^2) (RIKEN, Nagasaki IAS, CNS U. Tokyo, U. Tsukuba)
  - Continuous triggerless readout, online clustering/tracking
- Detectors
  - MRPC-TOF (JAEA, U. Tsukuba, KEK)
    - Aimed for 60ps time resolution, test with hadron measurements in p+A at J-PARC E16
- Theory : Development of dynamical model at J-PARC energy
  - M. Kitazawa, T. Hirano, A. Ohnishi, Y. Nara, C. Nonaka, Y. Akamatsu, K. Morita, …

J-PARC-HIを進めるための課題（理論、実験）

理論（実験）

- 厳選した明確な物理目標（CP/1st order phase transitionのステップとなる目標）を立て、必要な統計量を明確にする

- 重力波観測と相補的にEOSを測定するというシナリオ？
  - Observable and statistics to discover CP and 1st order phase transition
  - How to constrain EOS with flow, etc

- ベースである動的衝突模型の構築が必須（J-PARCエネルギー）

実験

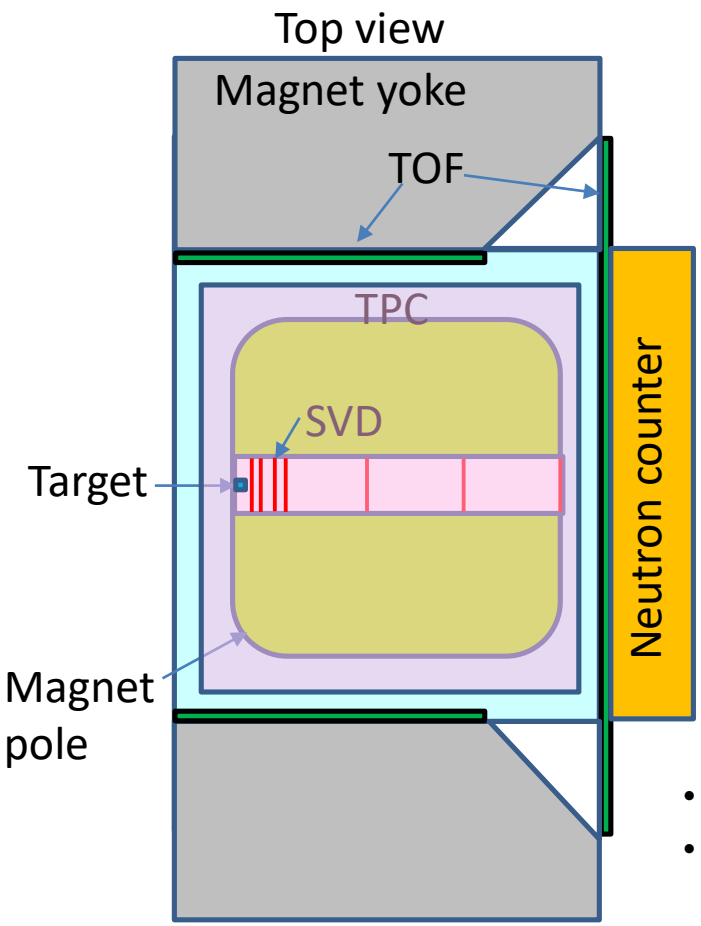
・高レートHIビームをどのように有効的に利用するか

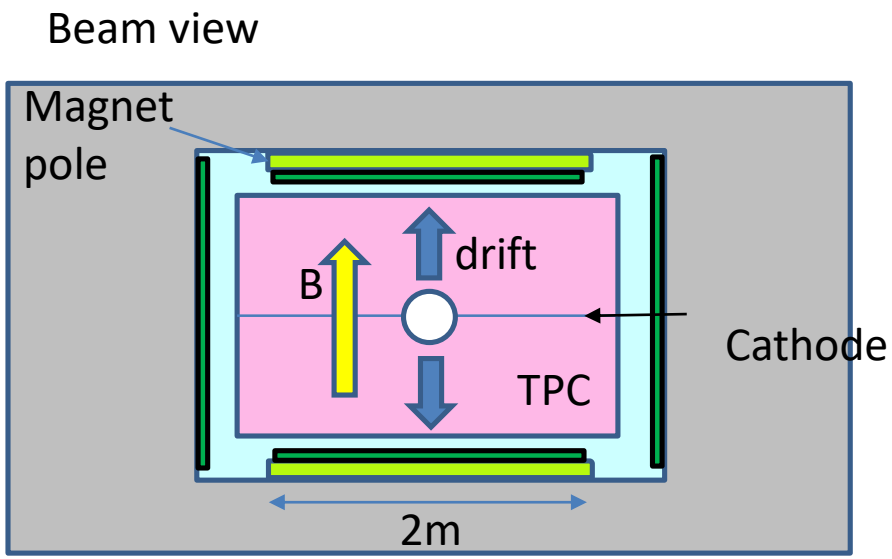
　　各物理量に最適な強度のビームを、現実的な検出器技術で利用する計画

J-PARC-HI Proposalに向けて

- A possible realistic strategy
  - Low rate experiment based on TPC for identified hadrons (~a few 100KHz interaction rate)
    - High-order fluctuations
      - 4π acceptance, with neutrons for baryon fluctuations
    - Flow
    - 100Hz (STAR-BES), 2kHz (STAR fixed target), sPHENIX (100-200kHz), 50kHz (ALICE run3)
  - High rate experiment for dimuon and strange fragments (~10MHz interaction rate)
    - Modification of vector mesons with high statistics
    - Hypernuclei
    - Search for strangelets

4π hadron spectrometer (under consideration)

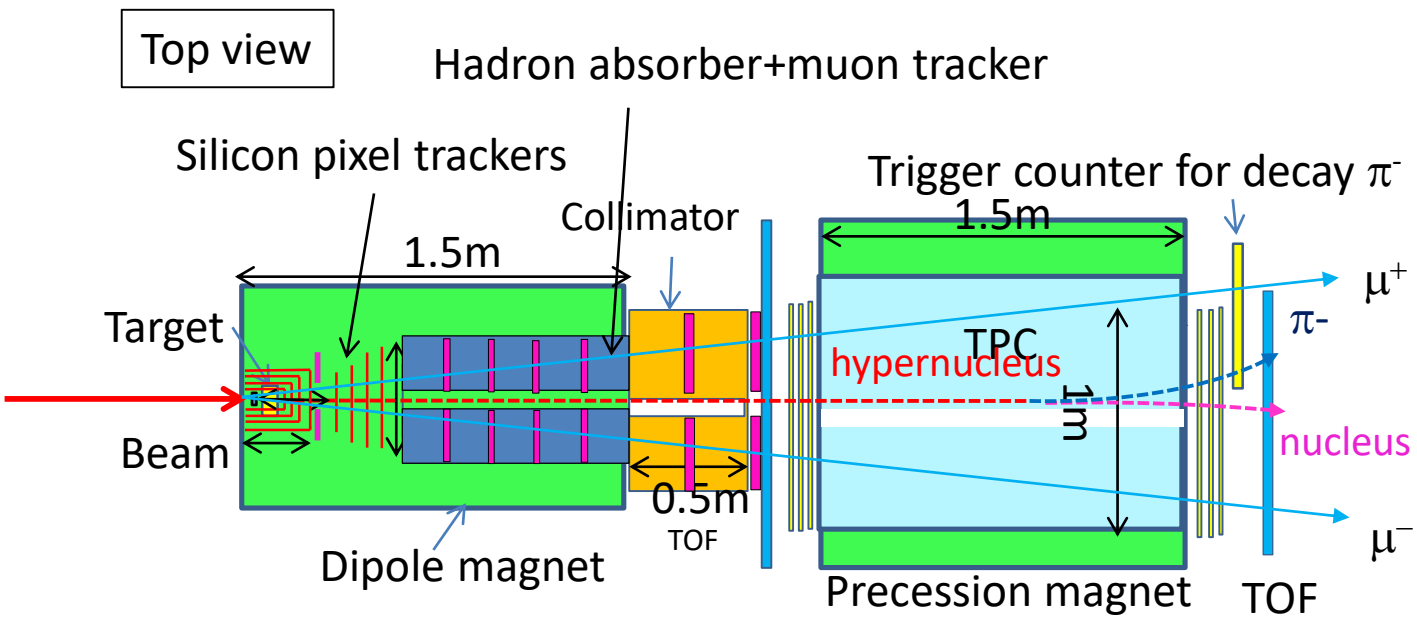




- Dipole field → Large and uniform acceptance
- Rate : 50kHz at ALICE (Collider)→ a few 100k Hz at J-PARC-HI?
  - Multiplicity : ALICE/J-PARC = 20
  - Higher track density with Lorentz boost : J-PARC-HI (fixed target)
- Continuous triggerless readout required

Hypernuclear/muon spectrometer (under consideration)

- Add hadron absorber to hypernuclear spectrometer
- To reduce weak decay background, absorber should be in upstream part
- High invariant mass resolution desirable
- Dimuon trigger possible



まとめ

J-PARC-HI： 宇宙最高密度物質を生成し、QCD相構造と高密度物質EOSの解明に迫る

- 世界最高強度の重イオンビーム（10^{11} Hz）を目指す
- fluctuations, dilepton, multi-strangeness hadronの測定
  - Large acceptance dipole spectrometer
  - Dimuon and hypernuclear spectrometer

計画の展望

- Letter-Of-IntentをJ-PARC PACへ提出(2016年)

  https://j-parc.jp/researcher/Hadron/en/pac_1607/pdf/LoI_2016-16.pdf
- J-PARC-HI実験 Proposalの提出 (2019年1月を目標)
  - J-PARC内での議論
- 日本学術会議の大型研究計画マスタープラン（2019年３月）
- 実験開始目標（最速～2025年）

J-PARC-HI Collaboration

94 members :

Experimental and Theoretical Nuclear Physicists and Accelerator Scientists

Experiment

H. Sako, S. Nagamiya, K. Imai, K. Nishio, S. Sato, S. Hasegawa, K. Tanida, S. H. Hwang, H. Sugimura, Y. Ichikawa K. Ozawa, K. H. Tanaka, S. Sawada, M. Chu, G. David, T. Sakaguchi, K. Shigaki, A. Sakaguchi, T. Chujo, S. Esumi, Y. Miake, O. Busch, T. Nonaka, B. C. Kim, S. Sakai, K. Sato, H. Kato, T. Ichizawa, M. Inaba, T. Gunji, H. Tamura, M. Kaneta, K. Oyama, Y. Tanaka, H. Hamagaki, M. Ogino, Y. Takeuchi, M. Naruki, S. Ashikaga, S. Yokkaichi, T. Hachiya, T. R. Saito, X. Luo, N. Xu, B. S. Hong, J. K. Ahn, E. J. Kim, I. K. Yoo, M. Shimomura, T. Nakamura, S. Shimansky, J. Milosevic, M. Djordjevic, L. Nadjdjerdj, D. Devetak, M. Stojanovic, P. Cirkovic, T. Csorgo, P. Garg, D. Mishra

Theory

M. Kitazawa, T. Maruyama, M. Oka, K. Itakura, Y. Nara, T. Hatsuda, C. Nonaka, T. Hirano, K. Murase, K. Fukushima, H. Fujii, A. Ohnishi, K. Morita, A. Nakamura, Y. Akamatsu, M. Asakawa, M. Harada

Accelerator

H. Harada, P. K. Saha, M. Kinsho, Y. Liu, J. Tamura, M. Yoshii, M. Okamura, A. Kovalenko, J. Kamiya, H. Hotchi, A. Okabe, F. Tamura, Y. Shobuda, N. Tani, Y. Watanabe, M. Yamamoto, M. Yoshimoto

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