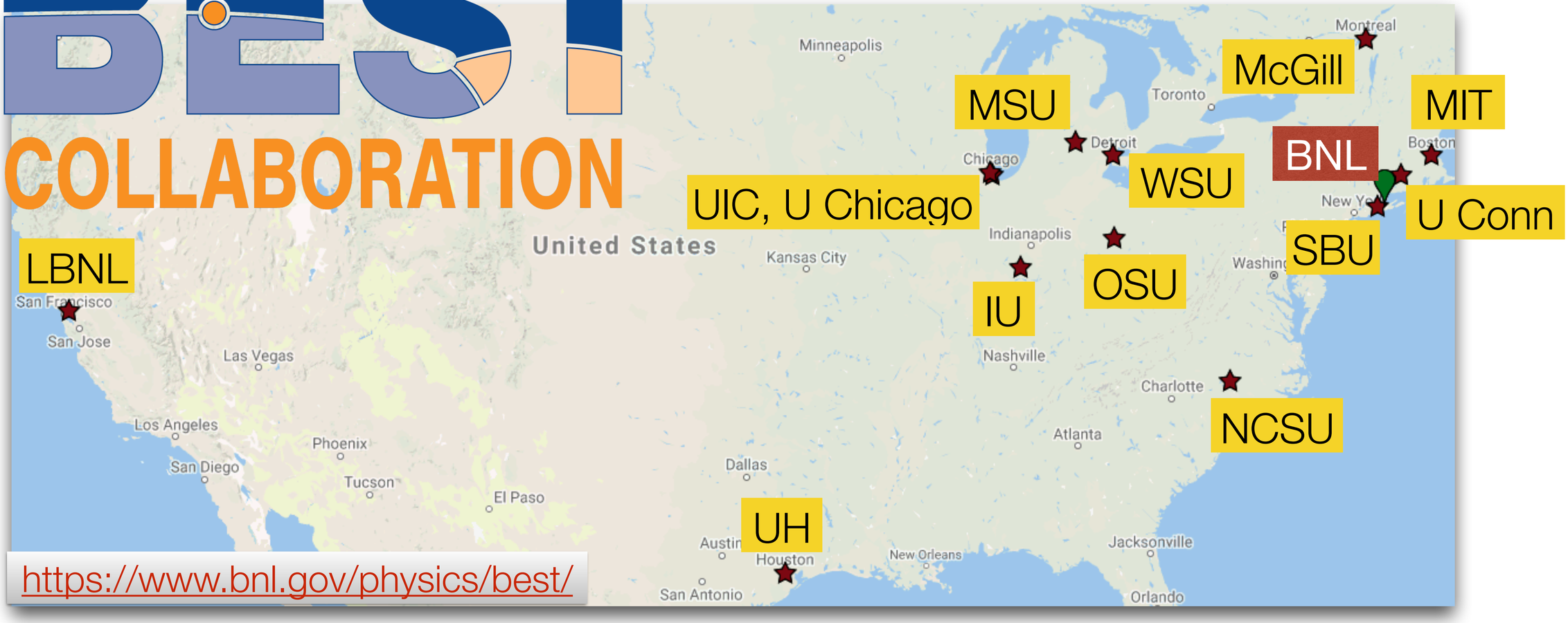
BEST COLLABORATION

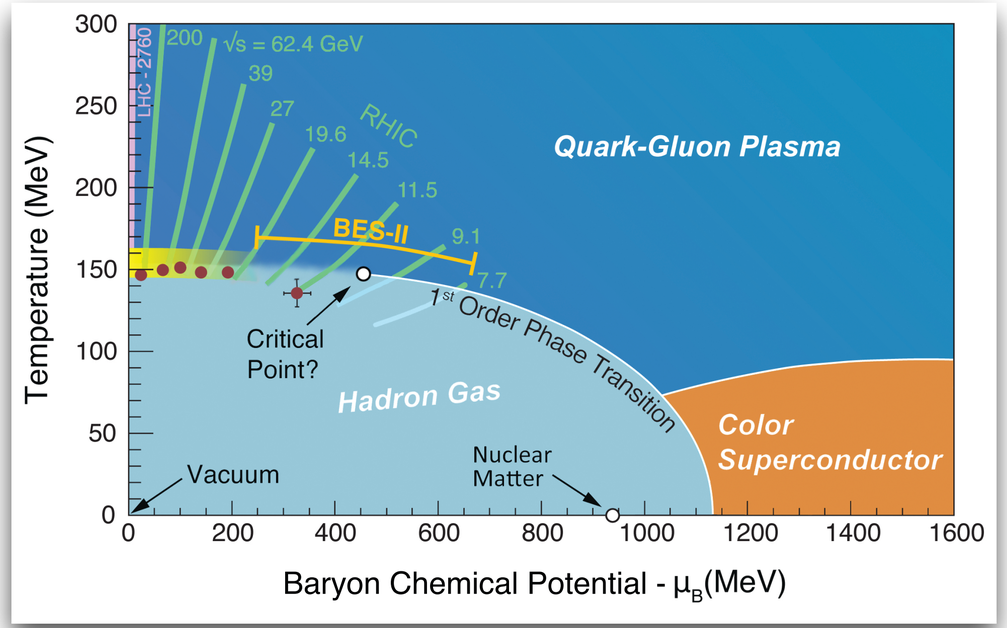


https://www.bnl.gov/physics/best/

Swagato Mukherjee

October, 2019, Virginia

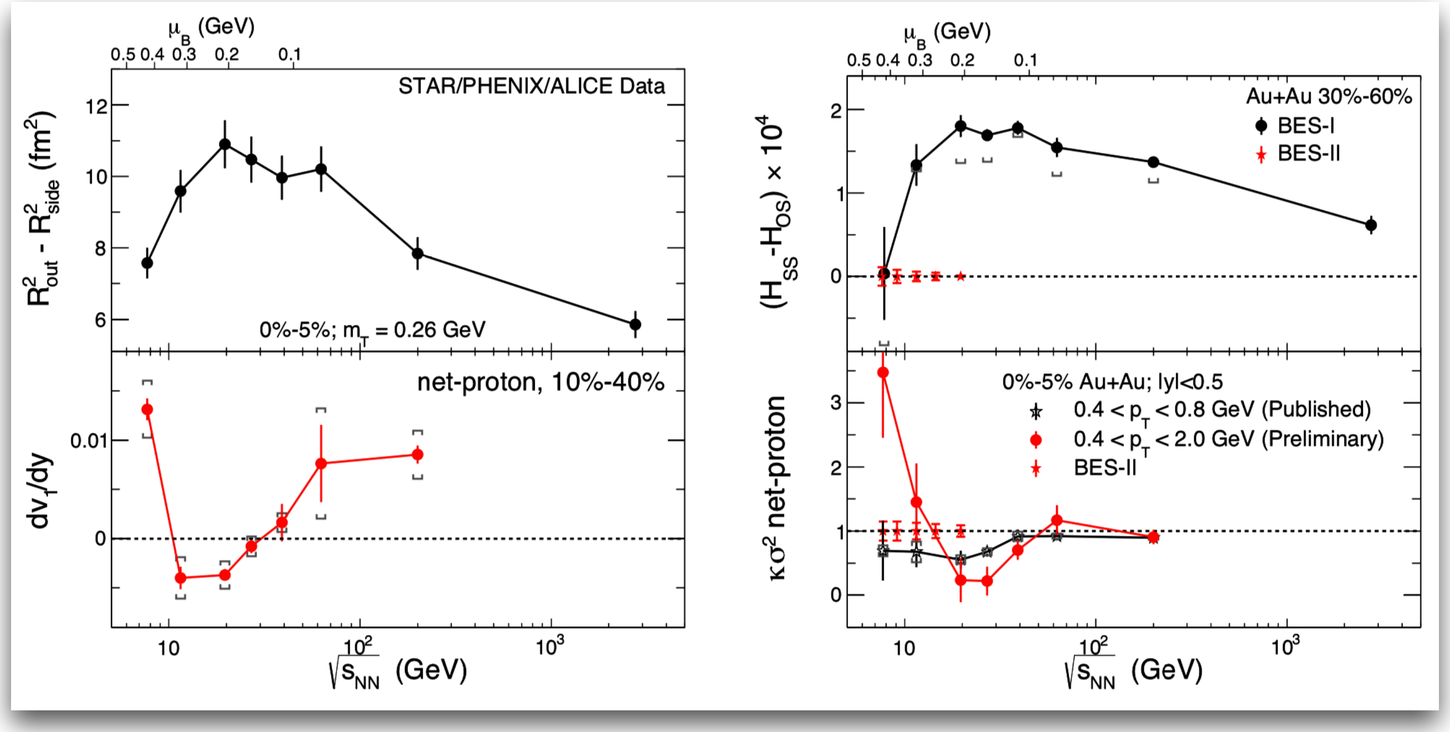
Beam Energy Scan (BES) @ Relativistic Heavy Ion Collider



phases and properties of baryon-rich QCD matter

- constraints on the existence of a critical point in the QCD phase diagram
- properties of baryon-rich QGP
- probe chiral symmetry restoration through chiral anomaly induced phenomena

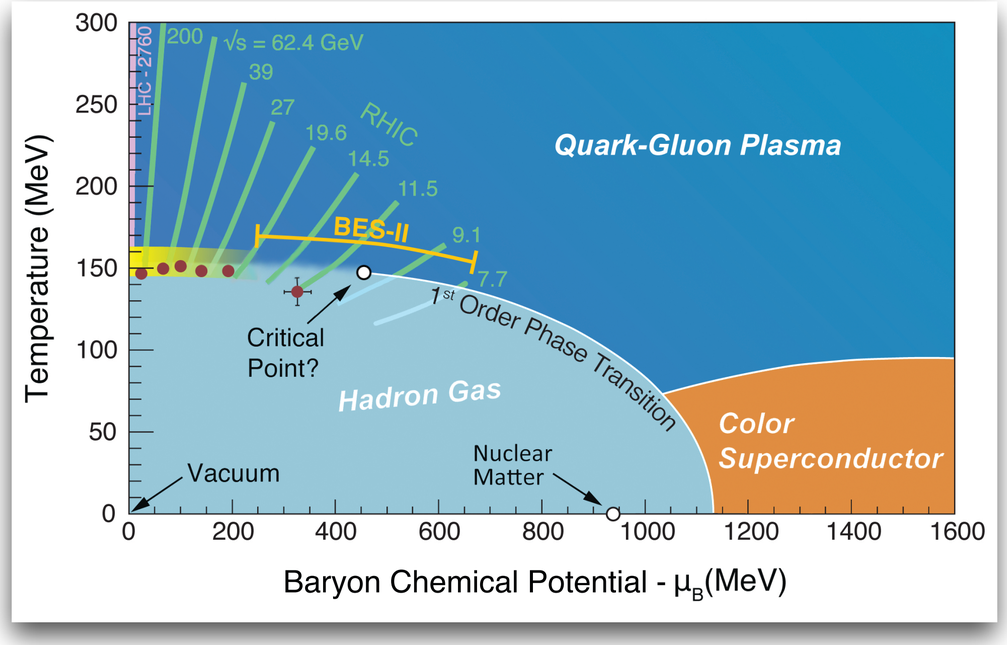
intriguing hints in many observables from BES-I

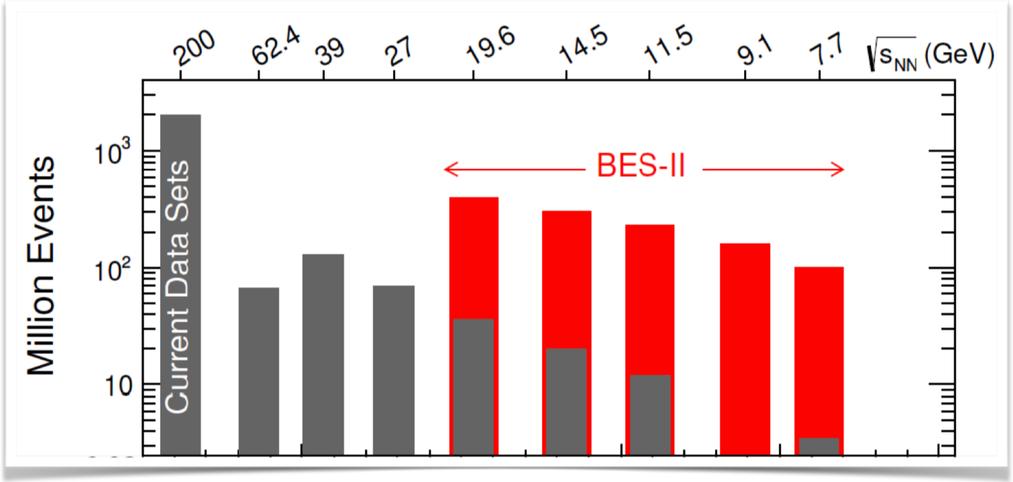


phase I of BES ended in 2014; scanned collision energies $\sqrt{s_{\rm NN}} = 200 - 7.7$ GeV

from hints to definitive answers …

BES-II: 2019-2021





significant accelerator and detector upgrades to insure high statistics

from hints to definitive answers …

BEST COLLABORATION

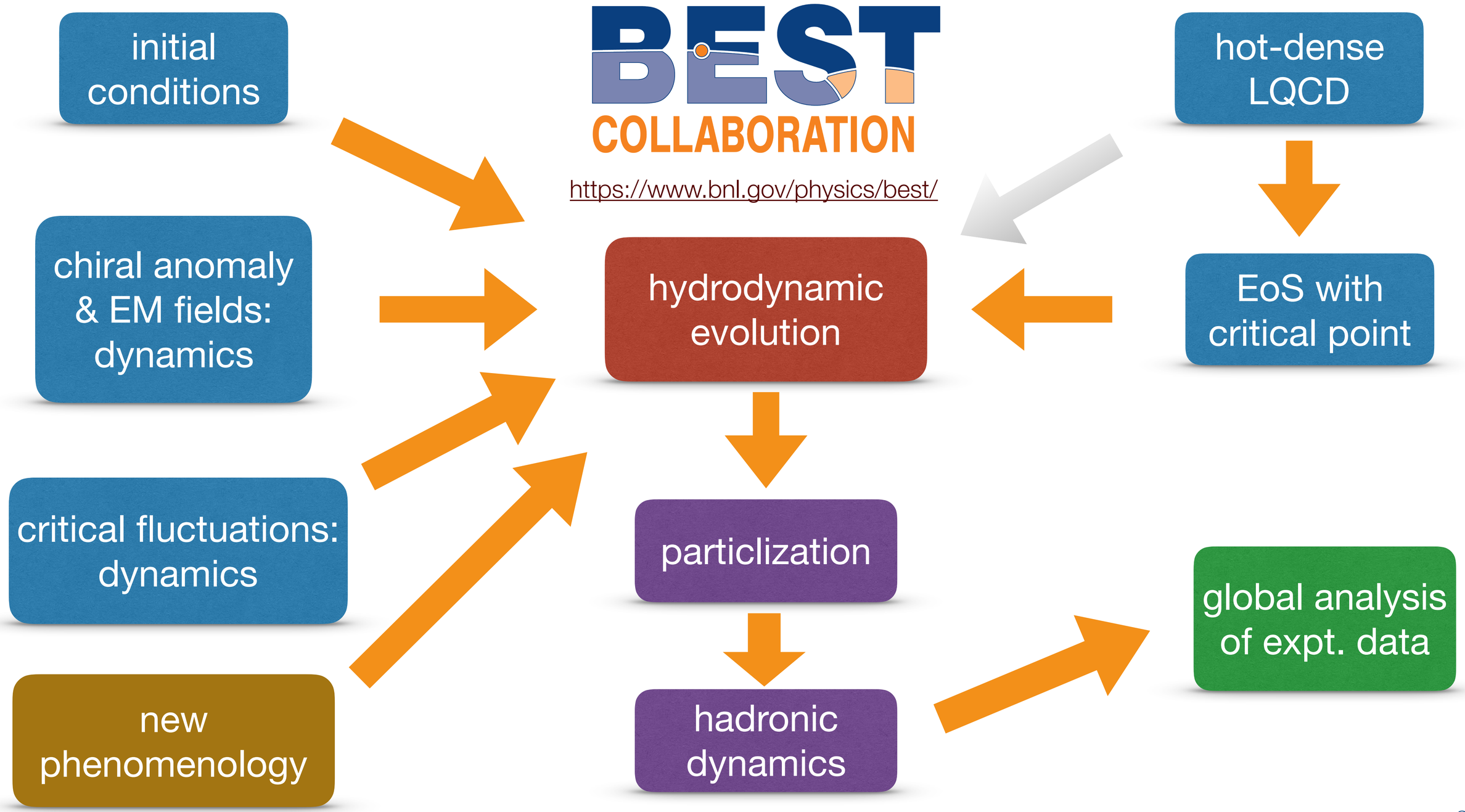
Beam Energy Scan Theory

Topical Collaboration in Nuclear Theory

funded by DOE Office of Nuclear Physics for 2016-2021

- construct a comprehensive theoretical framework for interpreting BES results

★ constraints on the existence of a critical point in the QCD phase diagram
★ properties of baryon-rich QGP
★ probe chiral symmetry restoration through chiral anomaly induced phenomena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the BEST science impact …

- 60+ published in journals
  - ★ total 1200+ citations
  - ★ 15 Letters
  - ★ 3 Editors' Suggestions
  - ★ 50+ conference proceedings

- 350+ talks
  - ★ 40+ plenary talks Quark Matter, CPOD, Strange Quark Matter, Lattice …
  - ★ 35+ colloquiums

- open access code repository https://bitbucket.org/bestcollaboration/

the BEST people …

core:

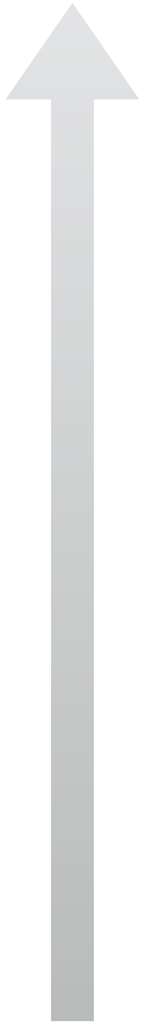
- 2 national labs & 12 universities
- 20 principal investigators
- 12 students, 6 postdocs

corona:

- ~15 active external collaborators
  - ★ 4 students, 2 postdoc: 100% funded by non-BEST sources
- ~10 close experimental contacts

the BEST research practice …

- steering committee: coordinate, disseminate
  - ★ Mukherjee (project director & co-spokesperson), Koch (co-spokesperson), Gale, Kharzeev, Rajagopal
- inter working groups: incorporate, amalgamate
  - ★ inter-WG video conferencing coordinated by the WG conveners
  - ★ inter-institution visits and exchanges of students & postdocs
- intra working groups (WG): communicate, assimilate, implement
  - ★ 5 WG: EoS & critical fluctuations, initial conditions, hydrodynamics, chirality anomaly, hadronic transport & data analyses
  - ★ regular intra-WG video conferencing lead by each WG convener
  - ★ inter-institution, inter-/intra-WG 1-4 week long visits of students & postdocs: ~15
- core institutions/groups: germinate, formulate, demonstrate
  - ★ many times same topics for 2 groups: independent formulations & reproduction
- annual all-hands-meeting: delineate, agreement, accept
  - ★ open, democratic, voluntary
  - ★ having pre-defined goals naturally helps the process



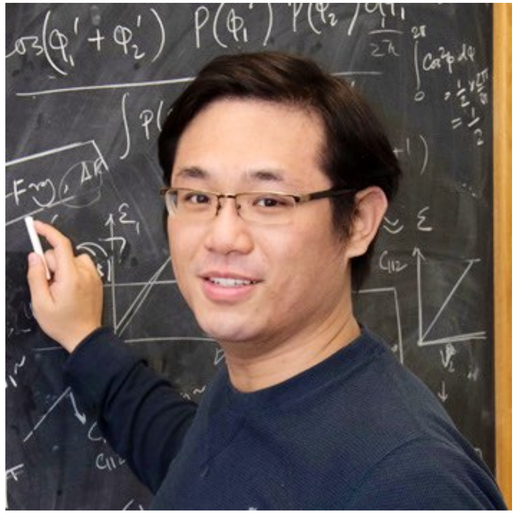
the BEST training practice …

- train: 12 graduate students so far
  - ★ ~50% funded by BEST, ~50% funded by non-BEST resources
  - ★ enormously helped by inter-institutional exchanges & visits
  - ★ interaction & direct collaboration with multi-institutional group

- retain: 6 postdocs so far
  - ★ if possible, from already trained BEST student pool: new collaborations, productive
  - ★ ~50% funded by BEST, ~50% funded by non-BEST resources
  - ★ senior postdocs becomes WG conveners (3+)
  - ★ students + postdocs: ~75% of total BEST budget

- broaden: 7 BEST postdocs have became faculties so far
  - ★ South Korea (1), France (1), China (2), US (3, including bridge positions)

the BEST bridge positions …



Chun Shen
Assistant Professor
Wayne State University

Vladimir Skokov
Assistant Professor
North Carolina State University

★ ~25% BEST for first 3 years (~20% of total BEST budget)
★ ~ 25% RIKEN-BNL Research Center for first 3 years; ~50% for next 2 years
★ ~ 50% universities for 5 years
★ both were active & important postdoc members of BEST

the BEST liaising with experimenters …

- ~10 close experimental contacts
- overview talks in annual STAR collaboration meetings
- lectures in STAR Junior's day for young experimenters
- co-authored research publications and review article with experimenters
- conferences and workshops organized with experimenters (~ 7)
  ★ with partial BEST support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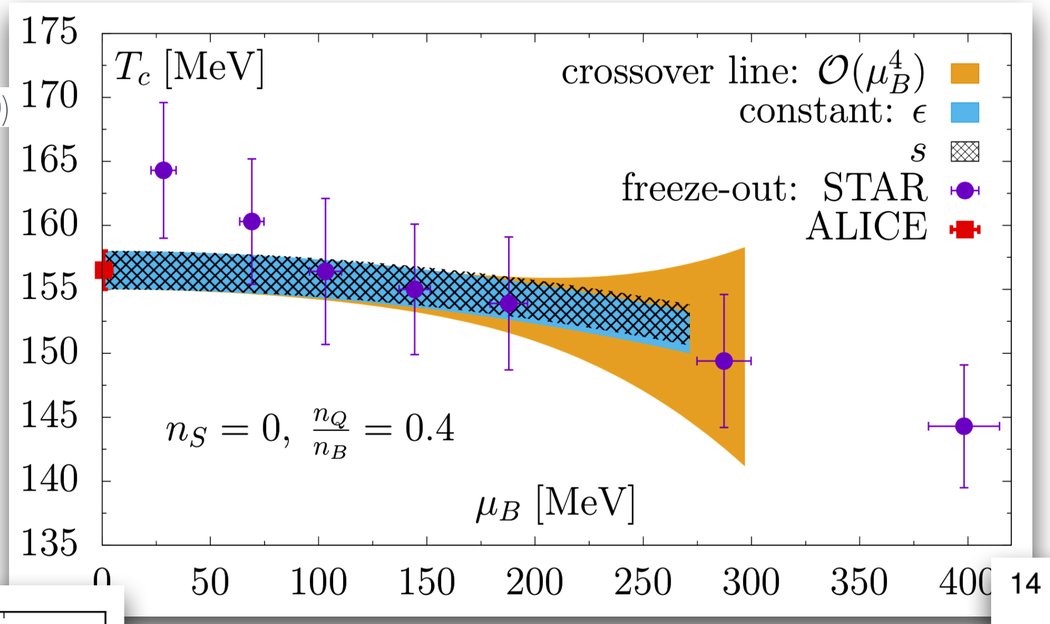
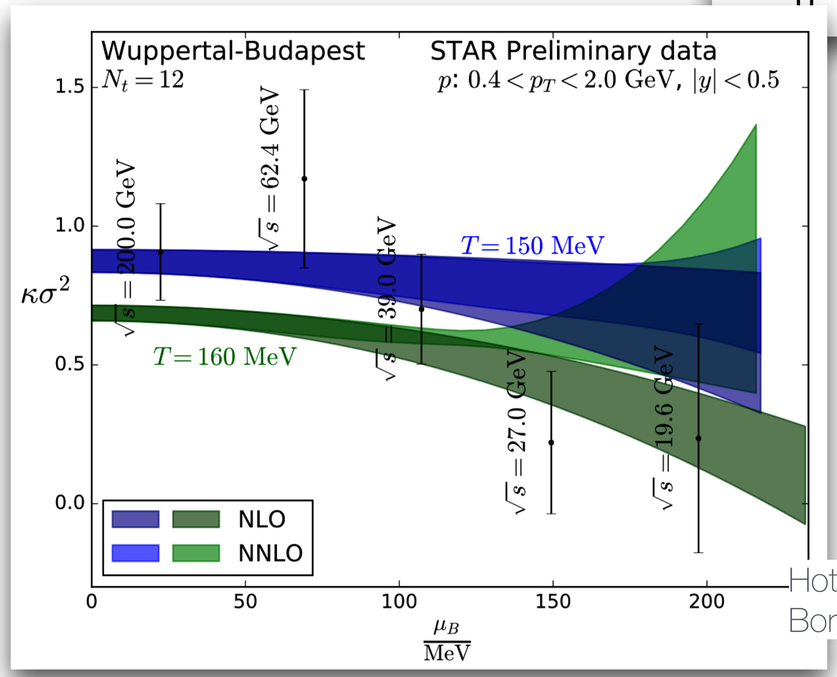
QCD phase boundary

HotQCD: Phys. Lett. B795, 15 (2019)



2 groups (BNL, UH),
2 approaches,
2 independent calculations,
excellent agreements!

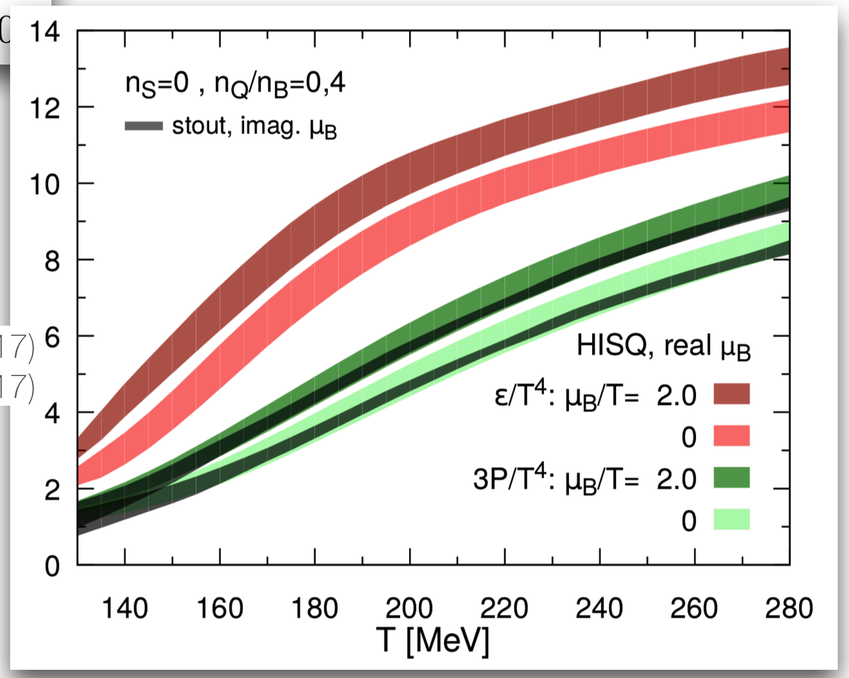
scaled kurtosis of net baryon number fluctuation



HotQCD: Phys.Rev. D96 no.7, 074510 (2017)
Borsanyi et. al.: JHEP 1810, 205 (2018)

HotQCD: Phys. Rev. D95, no.5, 054504 (2017)
Guenther at. al.: Nucl. Phys. A967, 720-723 (2017)

QCD EoS @ $\mu_B > 0$

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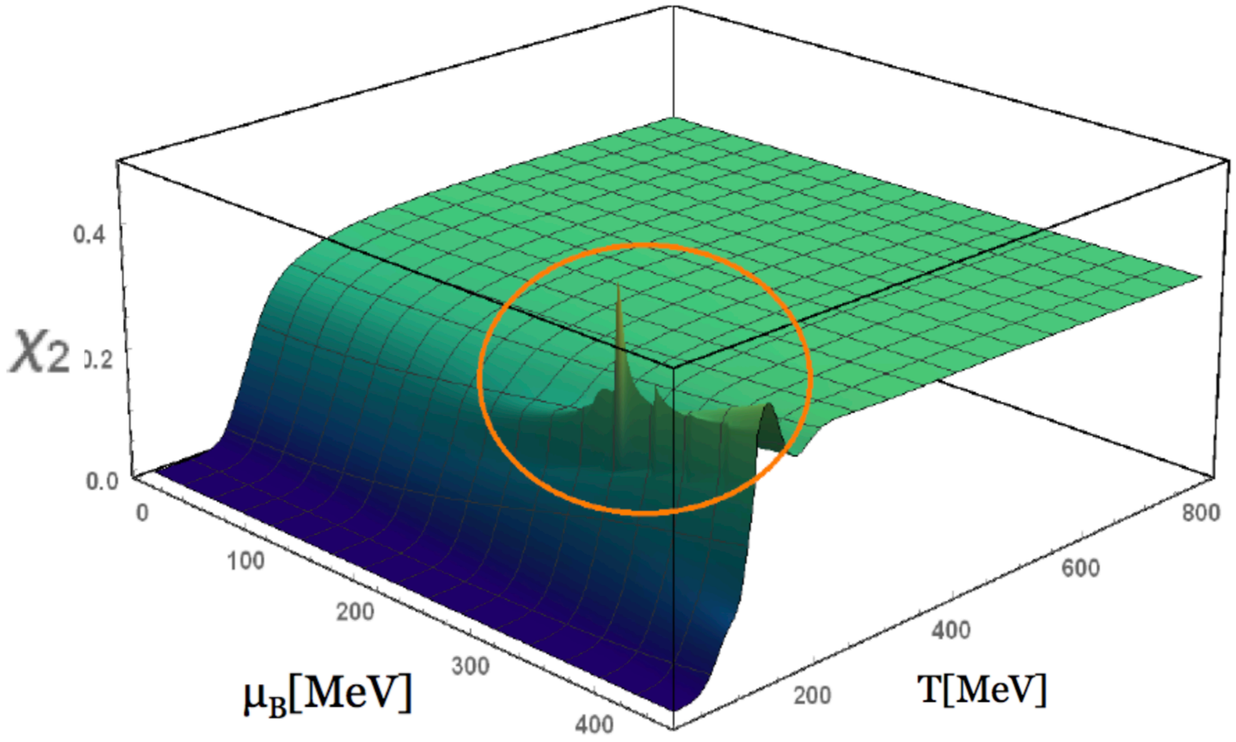
net baryon number fluctuation

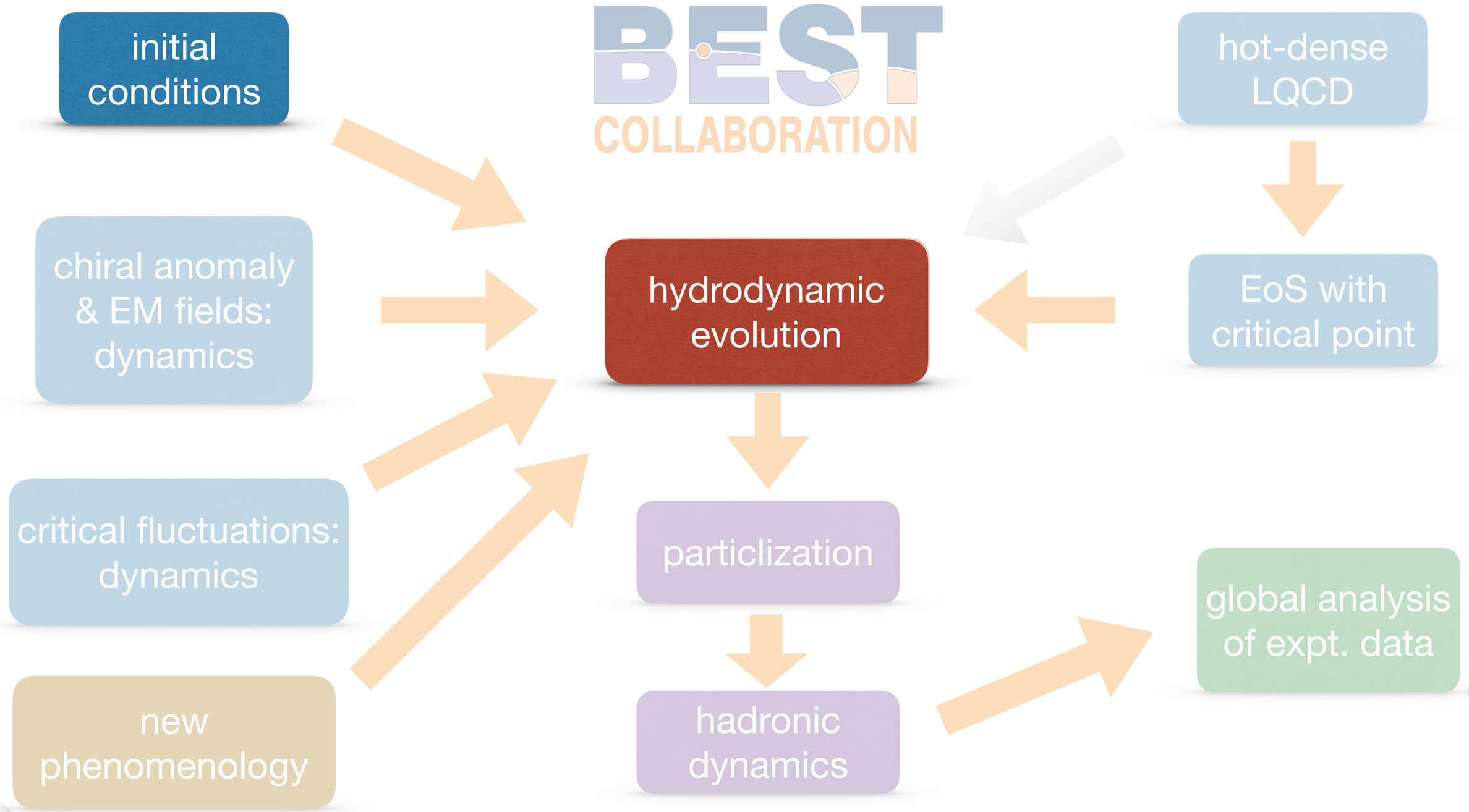
Parotto et. al.: arXiv:1805.05249

led by a UH grad student,
9 authors across 7 BEST institutions,
open access code

extended to transport coefficients (NCSU)

Martinez, Schäfer, Skokov: arXiv:1906.11306 [hep-ph]

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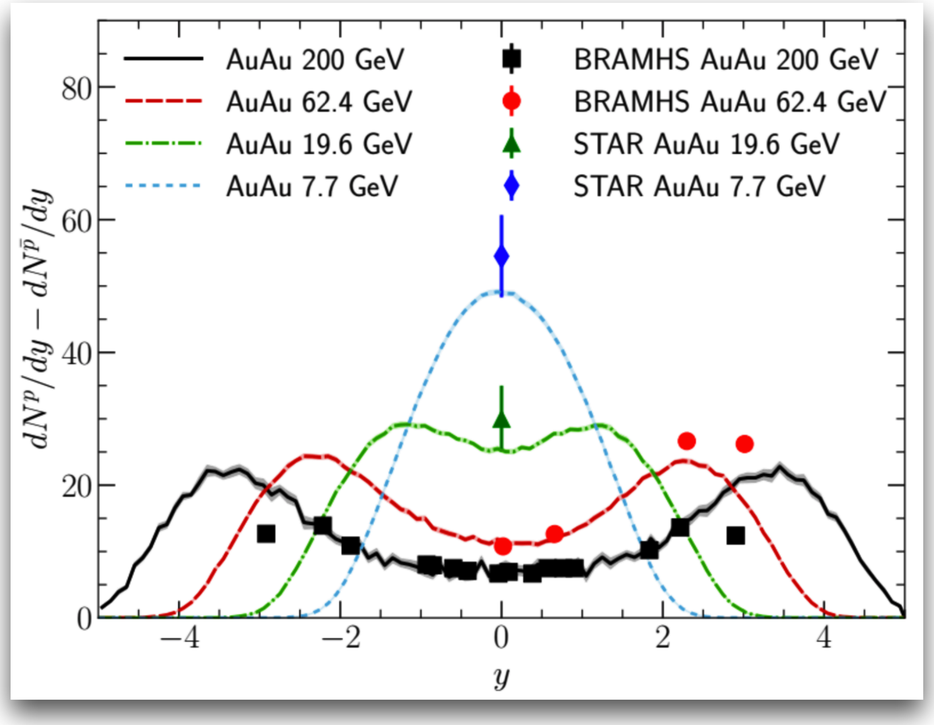
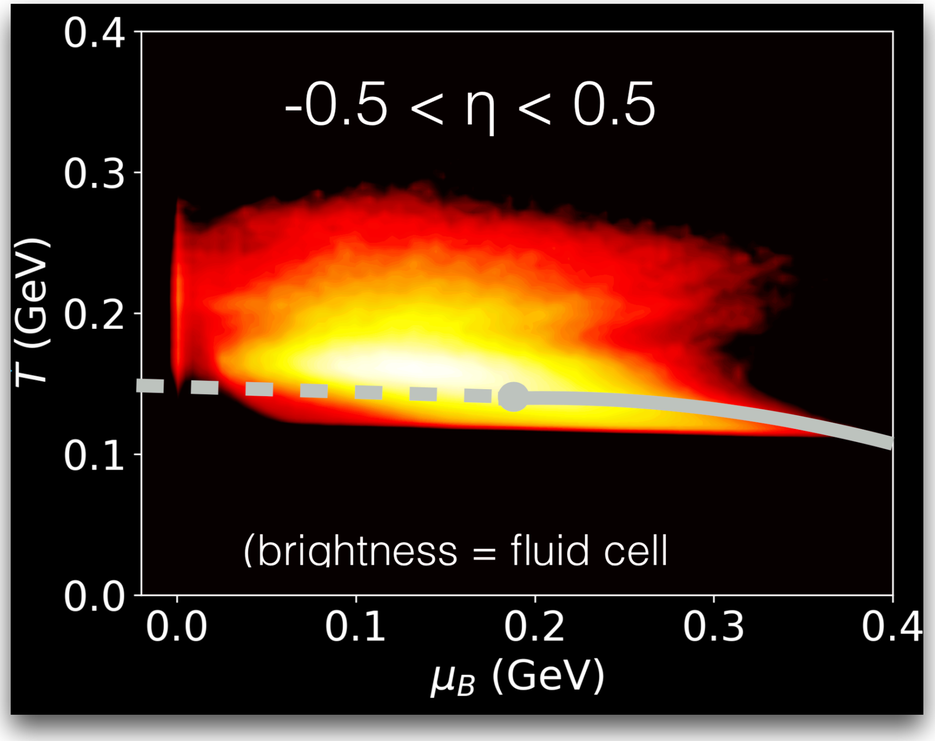
rapidity distribution of net proton



Shen, Schenke: in preparation

thermal conditions of the fireball at different points

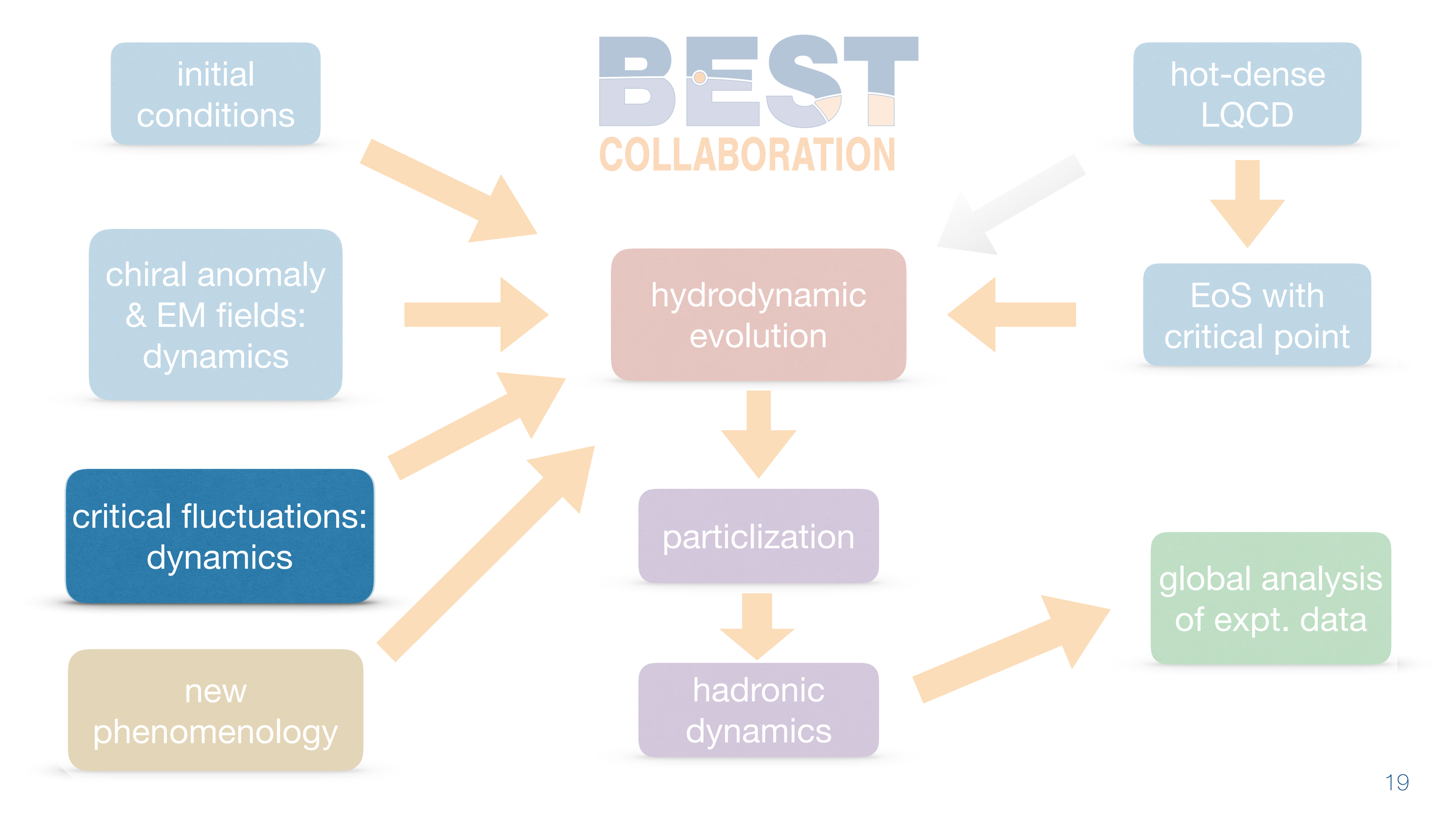


Shen, Schenke: Nucl. Phys. A982, 411 (2019)

led by C. Shen: postdoc (BNL) ⟶ faculty (WSU)

convener of the hydrodynamics WG

2 groups (BNL-McGill, OSU),
2 algorithms, reproducibility checked,
open access codes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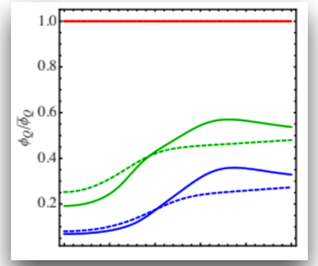
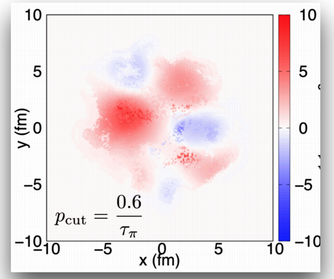
- full implementations of Hyrdo+ in BEST hydro codes are in progress



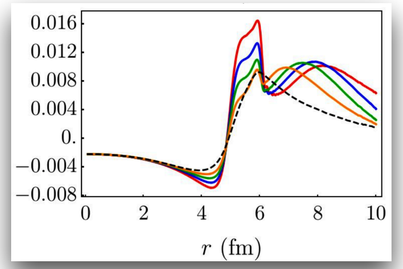


OSU+MIT: lead OSU grad student; possible by his MIT visit

McGill+WSU+BNL: completely different fluctuating hydro approach; lead McGill grad student; possible by his WSU, BNL visits

- numerical demonstration of Hydro+ at work in simple case (MIT)

Rajagopal, Ridgway, Weller, Yin, arXiv:1908.08539

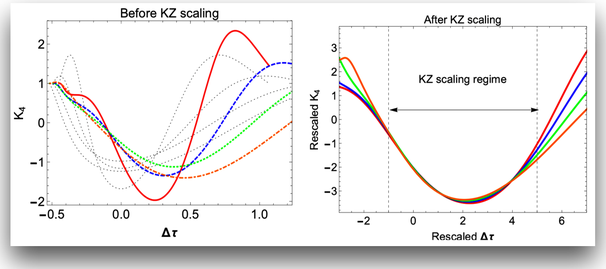


- Hydro+: include backreaction of critical fluctuations on hydrodynamics (MIT+UIC)

Stephanov and Yin: Phys. Rev. D98}, 036006 (2018)

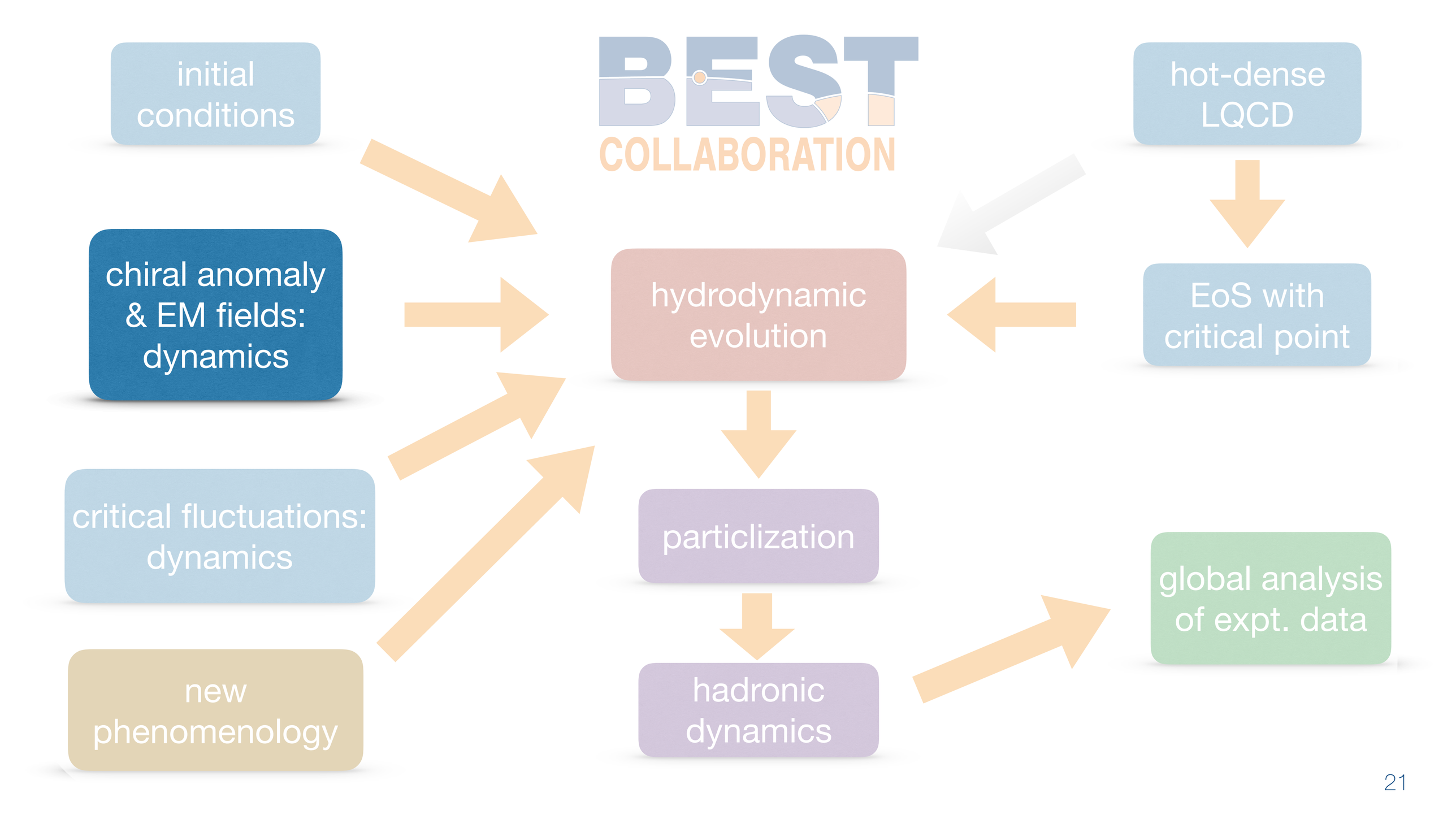
- dynamics of critical fluctuations on hydrodynamic background (BNL)

Monnai, Mukherjee, Yin Phys. Rev. C 95, 034902
Mukherjee, Venugopalan, Yin: Phys. Rev. Lett.117, no.22, 222301 (2016) (Editors' Suggestion); DOE Science Highlights
Mukherjee, Venugopalan, Yin: Phys. Rev. C92, 034912, (2015)



led by Y. Yin: Ph.D (UIC) ⟶ postdoc (BNL) ⟶ postdoc (MIT) ⟶ faculty (IMP, China)

convener of the EoS & critical fluctuation WG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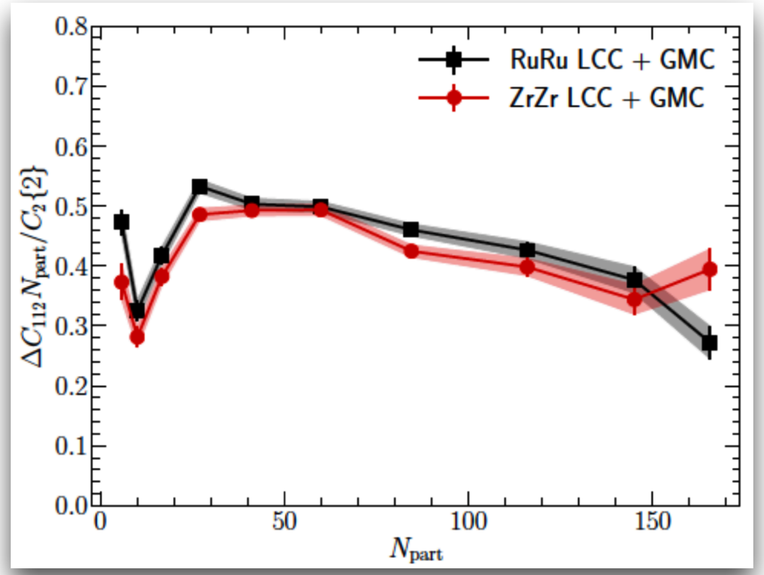
background characterization

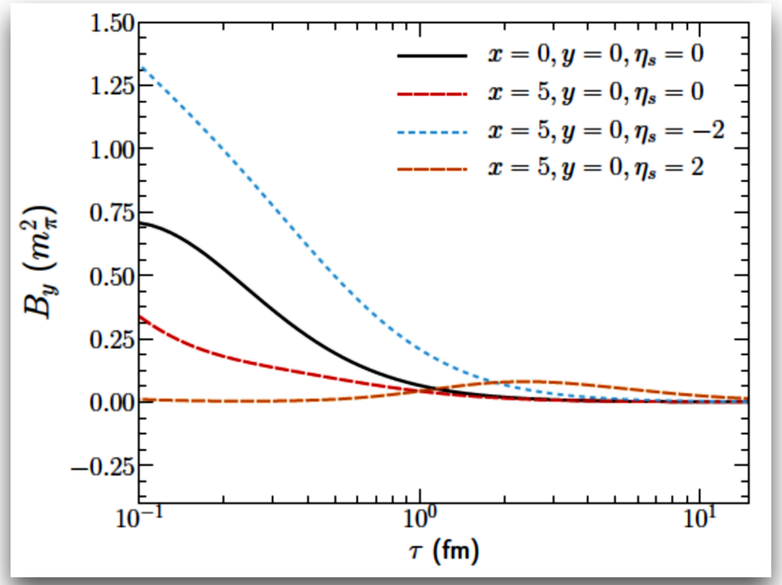
Schenke, Shen, Tribedy, Phys. Rev. C99, 044908 (2019)



collaboration with experimenter;
open access code

dynamics of magnetic field

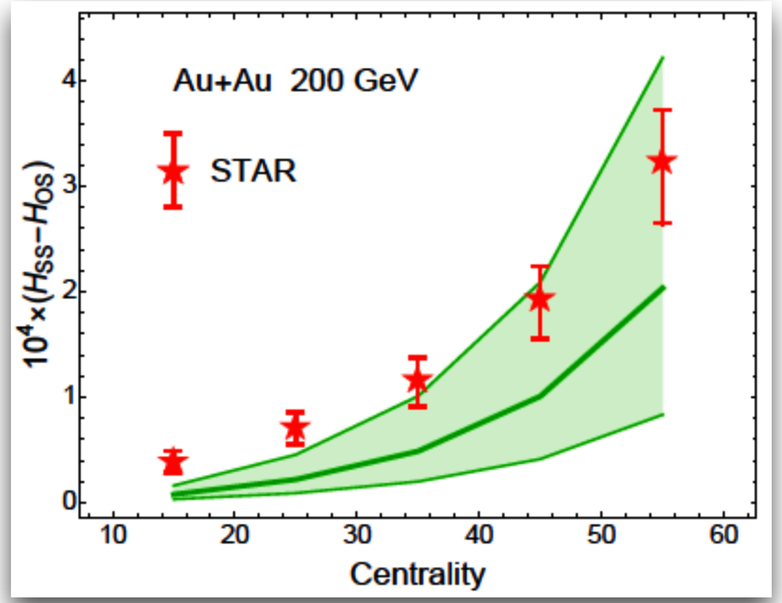
Gürsoy et. al. : Phys. Rev. C98, 055201 (2018)



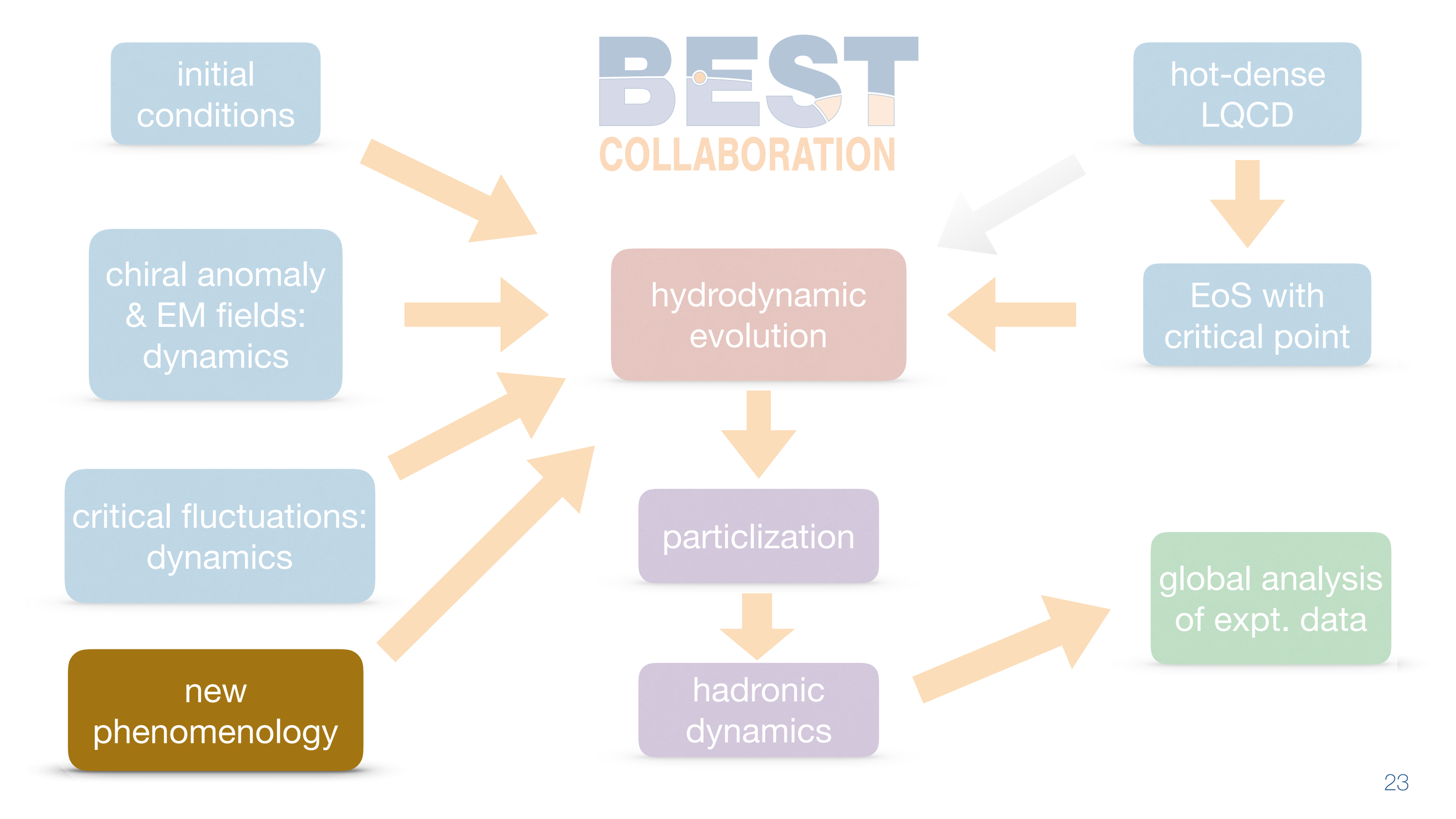
SBU + BNL + MIT + WSU;
open access code

chiral anomaly + viscous hydro

Shi et. al.: Annals Phys. 394, 50 (2018)



lead former IU grad student;
now postdoc in McGill;
possible by visits to OSU (hydro)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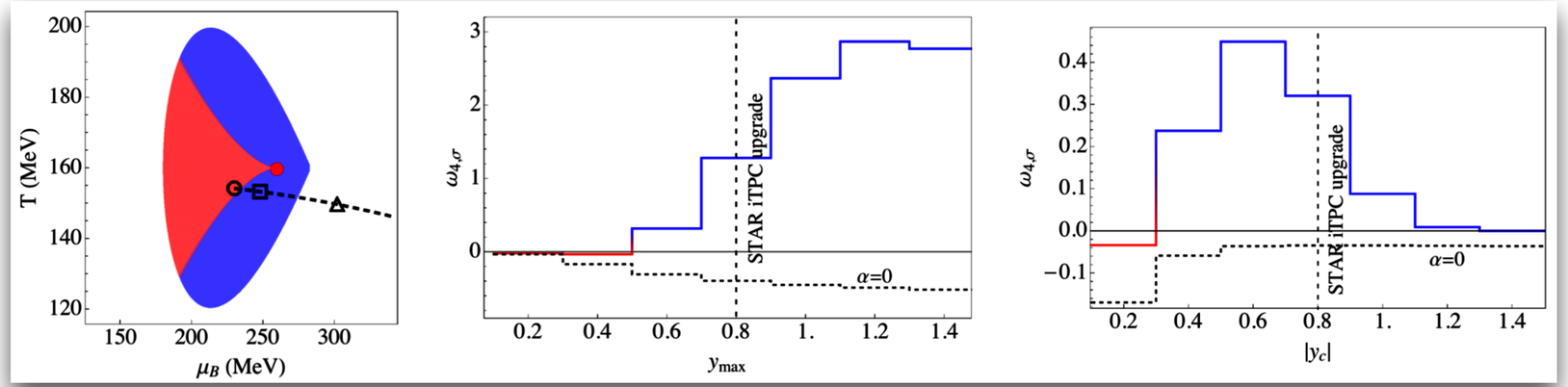
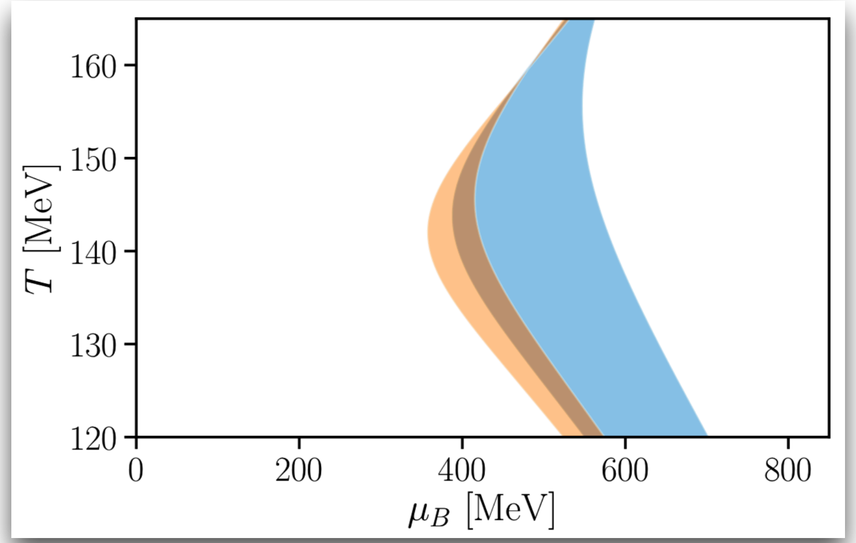
critical point search using rapidity dependence of proton cumulants

Brewer, Mukherjee, Rajagopal, Yin: Phys.Rev. C98, no.6, 061901 (2018) (Editors' Suggestion)



constraints on μ_B-range of validity of LQCD calculations

Mukherjee, Skokov: arXiv:1909.04639



out of unexpected collaborations!

(MIT-BNL; NCSU-BNL)

difficulties encountered …

- small pot of money for a single institution
  - ★ unable to support a full student/postdoc
  - ★ success of TC critically dependent on other fundings
  - ★ difficulties in retaining trained talent pool; hard to maintain codes
- had to choose student/postdoc visits & exchange over summer school due to lack of money
- prioritizing research deliverables severely limited money for bridge positions
  - ★ w/o RIKEN/BNL help even one bridge position would have been difficult
- bridge positions might not materialize within the planned budget-year due extraneous factors
  - ★ flexibility to continuing the bridge position support beyond the TC's lifespan might help

summary …

- BEST: delivering excellent world-leading science; on track to achieve goals
  - ★ tackling big problems — bigger than the sum of its parts
  - ★ generating new ideas & innovative solutions
  - ★ producing unique results
  - ★ making those open access
- BEST: effective in training & retaining talent pool
- BEST: successful in facilitating, promoting junior faculty positions
- BEST: excelling in connecting, liaising outside nuclear theory
- the Topical Collaboration framework is essential for this success
  - ★ invigorates, coalesces, focuses large communities
  - ★ encourages communities to address big, difficult open issues
  - ★ generates new collaborations, leading to new ideas, solutions
  - ★ attracts additional supports, fundings
  - ★ insures long-term success of communities well beyond its lifespan