Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY | Office of Science

BJÖRN SCHENKE - BROOKHAVEN NATIONAL LABORATORY

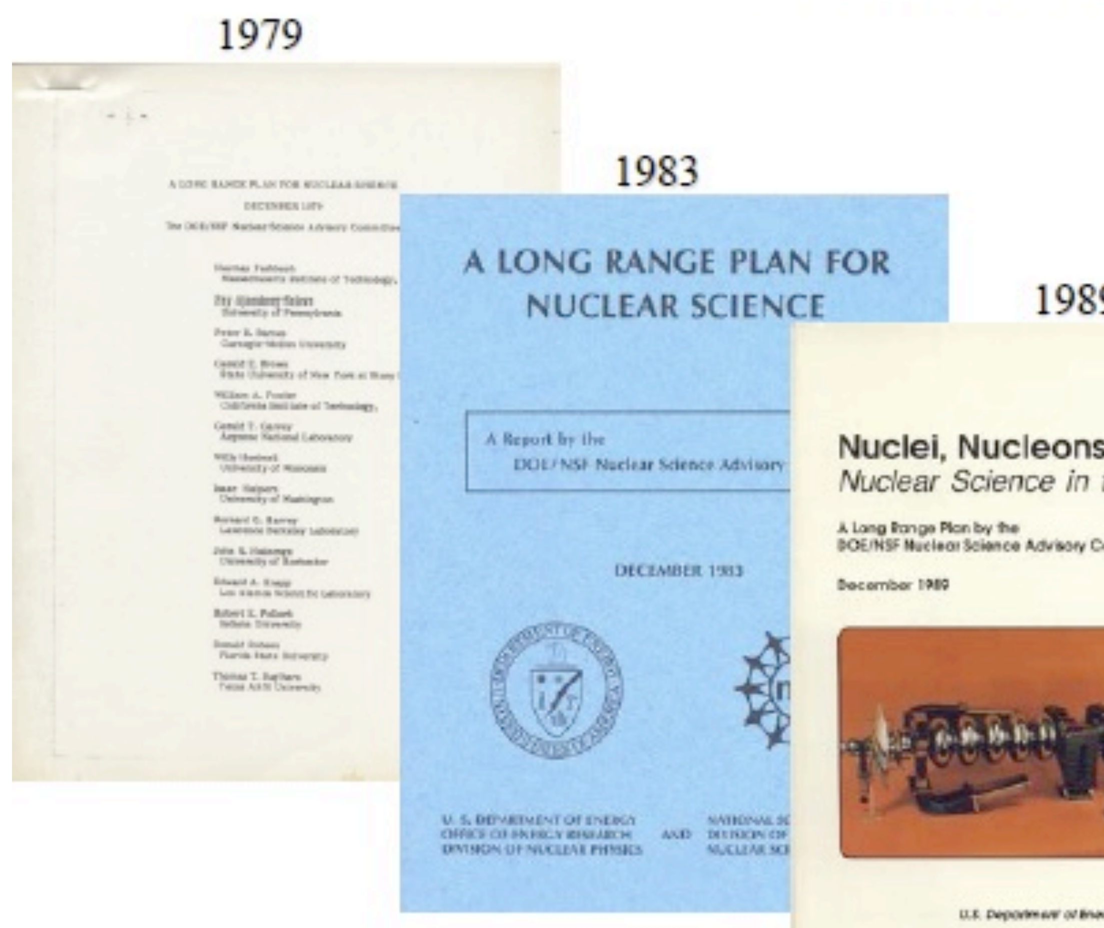
QCD IN THE NUCLEAR PHYSICS LONG RANGE PLAN

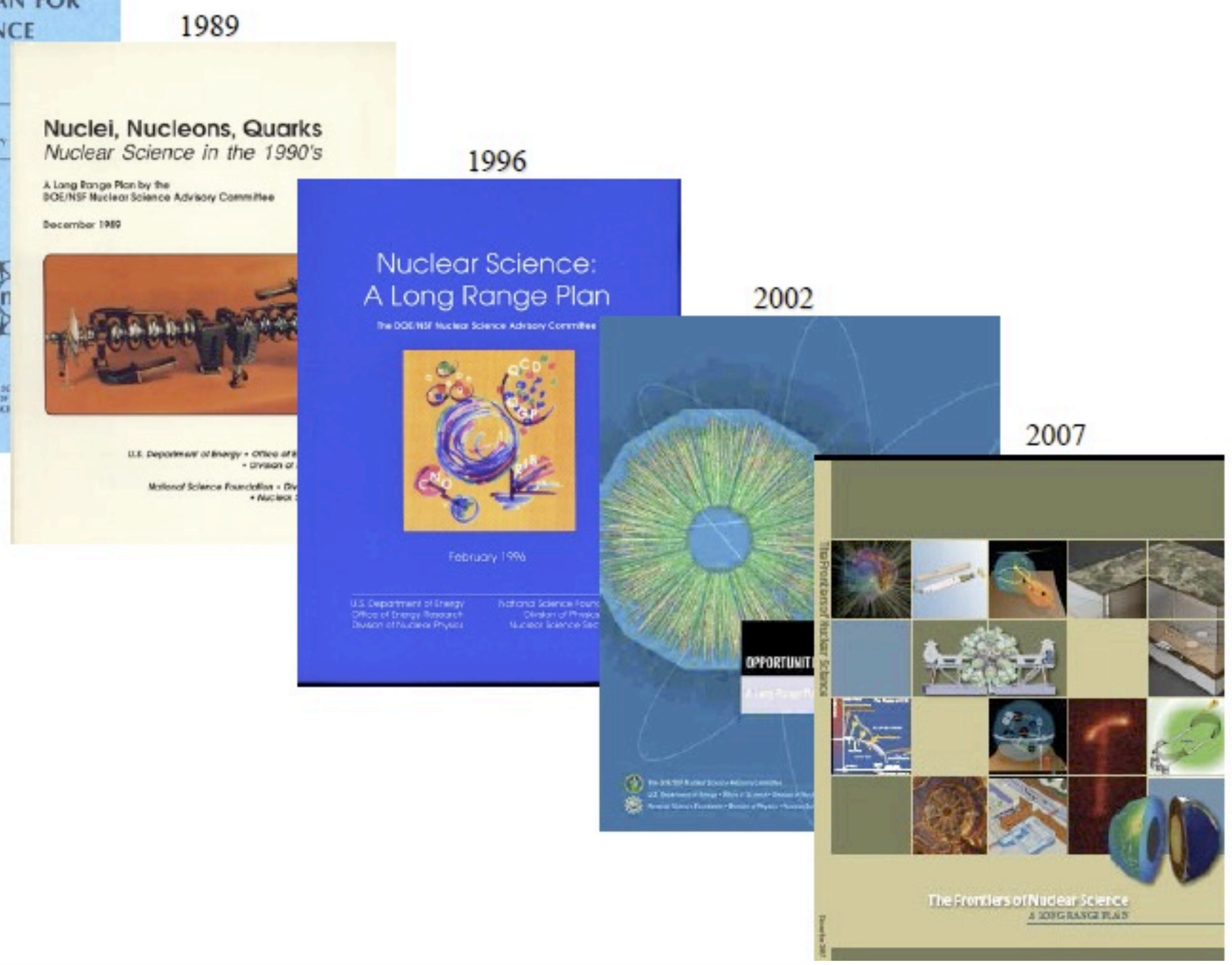
USQCD All Hands' Meeting 2024
04/18/2024

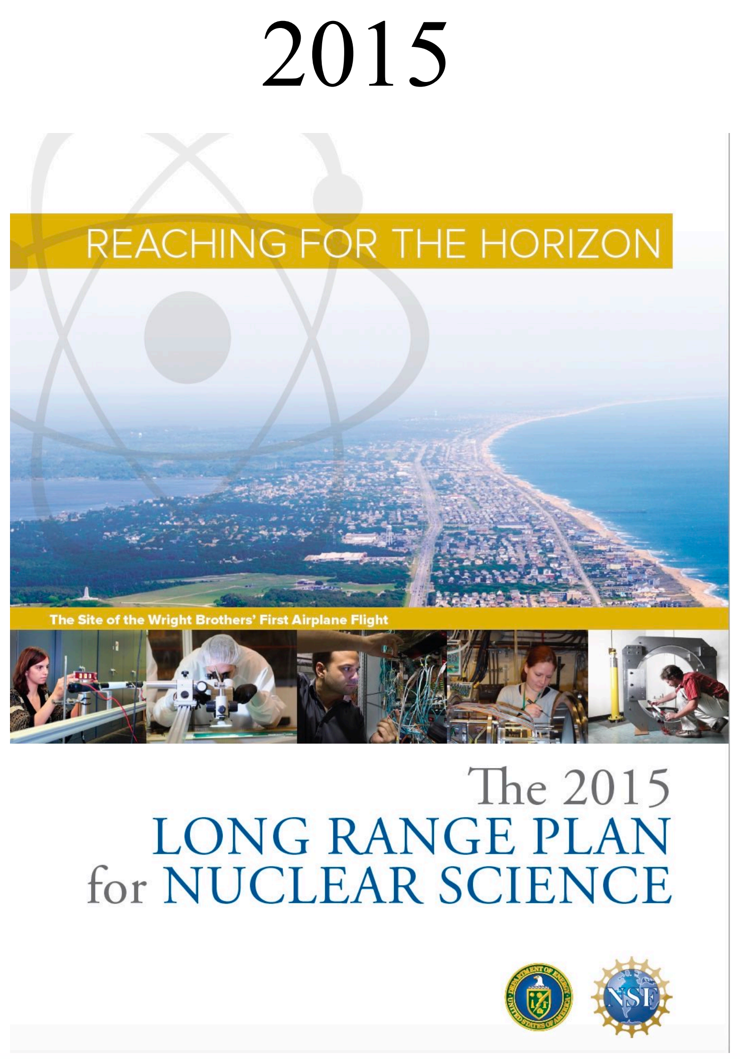
Successful History of Long Range Planning in Nuclear Science

Since 1979 the Department of Energy Office of Science and the National Science Foundation periodically have charged the Nuclear Science Advisory Committee, NSAC, to provide a framework for coordinated advancement of the Nation’s nuclear science research program.

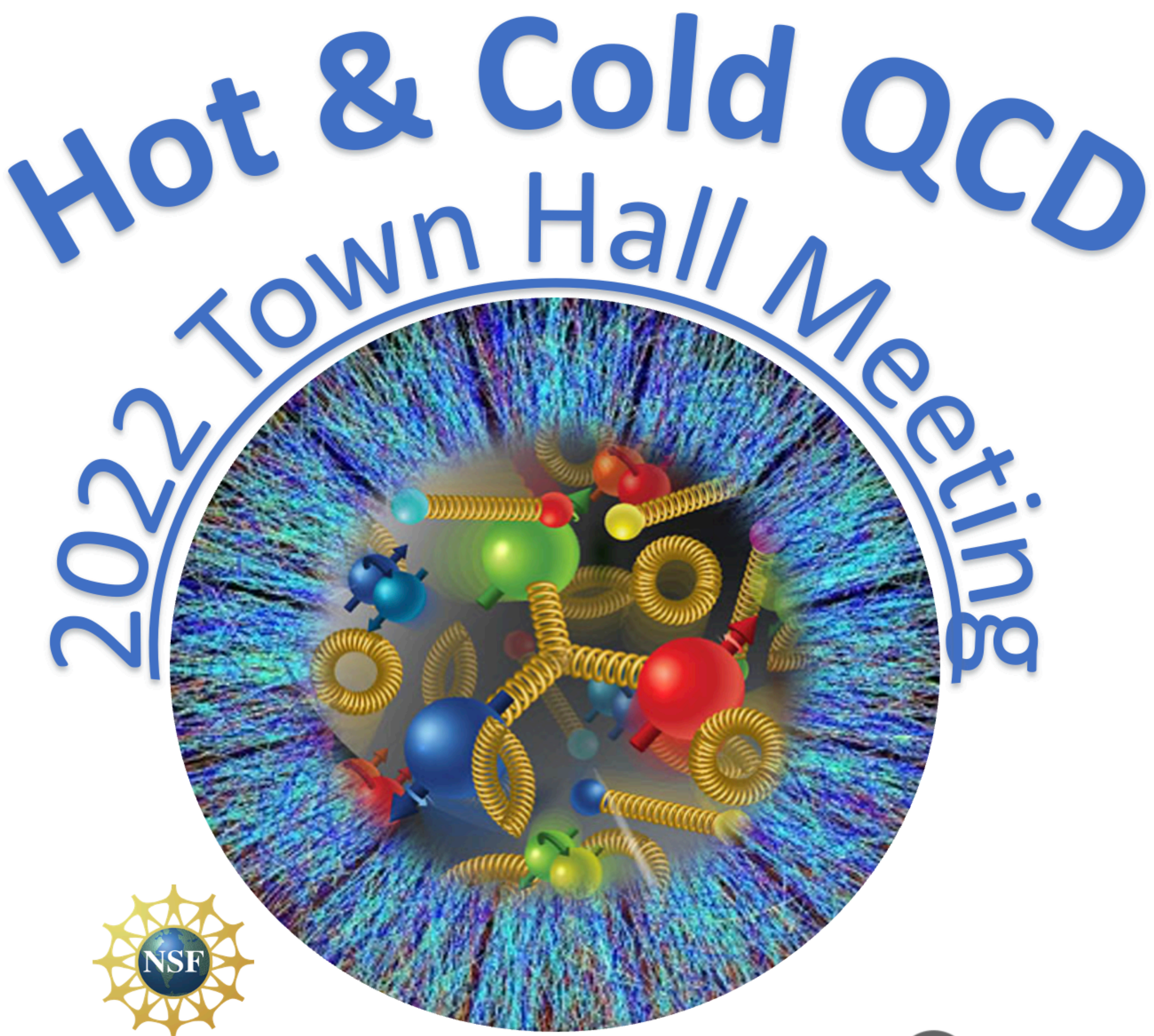
- A consistent, strategic plan for investments was developed every 5 – 7 years
- NSAC engaged the community though town meetings organized by the Division of Nuclear Physics of the American Physical Society



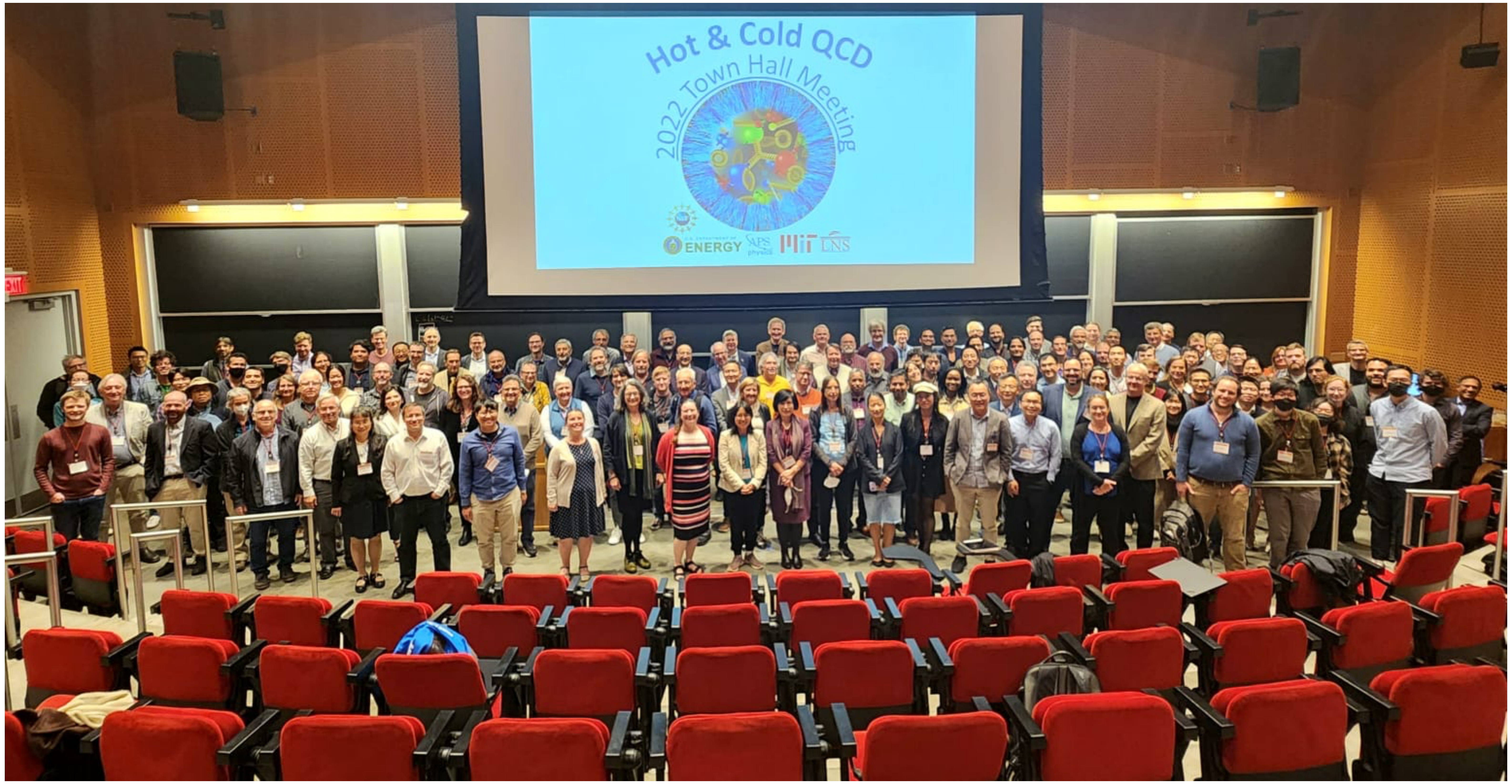




QCD TOWN MEETING



Hot & Cold QCD Town Meeting held 9/23-9/25 2022 at MIT



https://indico.mit.edu/event/538/

424 registered participants
(in-person and virtual)

NSAC Long Range Plan Town Hall Meeting on Nuclear Structure, Reactions and Astrophysics
Nov 14 – 16, 2022
Argonne National Laboratory

Fundamental Symmetries, Neutrons, and Neutrinos Town Meeting
Dec 13 – 15, 2022
University of North Carolina – Chapel Hill

QCD WHITE PAPER

- Submitted to NSAC on 02/28/2023
- Uploaded to the arXiv on 03/05/2023
- e-Print: 2303.02579 [hep-ph]

Town Meeting Organizing Committee:

Ian Cloet (ANL)
Or Hen (MIT)
David Lawrence (JLab)
Wei Li (Rice)
Swagato Mukherjee (BNL)
Björn Schenke (BNL) †
Anne Sickles (Illinois) †
Ramona Vogt (LLNL & UCD)
Feng Yuan (LBNL) †
Xiaochao Zheng (UVA) †

The Present and Future of QCD

QCD Town Meeting White Paper – An Input to the 2023 NSAC Long Range Plan

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Chien[44,1], P.-C. Chou[40], X. Chu[16], E. Chudakov[1], E. Cline[32,40], I.C. Cloët[⋆11], P.L. Cole[45], M.E. Connors[44], M. Constantinou[17], W. Cosyn[46], S. Covrig Dusa[1], R. Cruz-Torres[13], U. D'Alesio[47,48], C. da Silva[49], Z. Davoudi[50], C.T. Dean[40], D.J. Dean[1], M. Demarteau[51], A. Deshpande[32,16], W. Detmold[40,52], A. Deur[1], B.R. Devkota[34], S. Dhital[53], M. Diefenthaler[1], S. Dobbs[54], M. Döring[3,1], X. Dong[13], R. Dotel[55], K.A. Dow[40], E.J. Downie[3], J.L. Drachenberg[56], A. Dumitru[57], J.C. Dunlop[16], R. Dupre[58], J.M. Durham[49], D. Dutta[34], R.G. Edwards[1], R.J. Ehlers[13,38], L. El Fassi[34], M. Elaasar[59], L. Elouadrhiri[1], M. Engelhardt[60], R. Ent[1], S. Esumi[61], O. Evdokimov[62], O. Eyser[16], C. Fanelli[18,1], R. Fatemi[63], I.P. Fernando[19], F.A. Flor[25], N. Fomin[64], A.D. Frawley[54], T. Frederico[65], R.J. Fries[66], C. Gal[1], B.R. Gamage[1], L. Gamberg[67], H. Gao[16,68], D. Gaskell[1], F. Geurts[23], Y. Ghandilyan[69], N. Ghimire[17], R. Gilman[70], C. Gleason[71], K. Gnanvo[1], R.W. Gothe[72], S.V. Greene[73], H.W. Grießhammer[3], S.K. Grossberndt[74,57], B. Grube[1], D.C. Hackett[40,52], T.J. Hague[13], H. Hakobyan[75], J.-O. Hansen[1], Y. Hatta[16,33], M. Hattawy[9], L.B. Havener[25], O. Hen[⋆40], W. Henry[1], D.W. Higinbotham[1], T.J. Hobbs[11], A.M. Hodges[8], T. Holmstrom[76], B. Hong[77], T. Horn[69,1], C.R. Howell[68,78], H.Z. Huang[79], M. Huang[80], S. Huang[32], G.M. Huber[81], C.E. Hyde[9], E.L. Isupov[82], P.M. Jacobs[13], J. Jalilian-Marian[57,74], A. Jentsch[16], H. Jheng[40], C.-R. Ji[83], X. Ji[50], J. Jia[32,16], D.C. Jones[1], M.K. Jones[1], N. Kalantarians[84], G. Kalicy[69], Z.B. Kang[79], J.M. Karthein[40], D. Keller[19], C. Keppel[1], V. Khachatryan[85], D.E. Kharzeev[32,16], H. Kim[86], M. Kim[38], Y. Kim[87], P.M. King[88], E. Kinney[89], S.R. Klein[13], H.S. Ko[13], V. Koch[13], M. Kohl[53,1], Y.V. Kovchegov[36], G.K. Krintiras[7], V. Kubarovsky[1], S.E. Kuhn[9], K.S. Kumar[90], T. Kutz[40], J.G. Lajoie[80], J. Lauret[16], I. Lavrukhin[5], D. Lawrence[⋆1], J.H. Lee[16], K. Lee[40], S. Lee[11], Y.-J. Lee[40], S. Li[13], W. Li[⋆23], Xiaqing Li[40], Xuan Li[49], J. Liao[85], H.-W. Lin[91], M.A. Lisa[36], K.-F. Liu[63,13], M.X. Liu[49], T. Liu[92], S. Liuti[19], N. Liyanage[19], W.J. Llope[93], C. Loizides[51], R. Longo[8], W. Lorenzon[5], S. Lunkenheimer[5], X. Luo[94], R. Ma[16], B. McKinnon[95], D.G. Meekins[1], Y. Mehtar-Tani[16,33], W. Melnitchouk[1], A. Metz[17], C.A. Meyer[96], Z.-E. Meziani[11], R. Michaels[1], J.K.L. Michel[40], R.G. Milner[40], H. Mkrtchyan[15], P. Mohanmurthy[40], B. Mohanty[97], V. I. Mokeev[1], D.H. Moon[86], I.A. Mooney[25,16], C. Morningstar[96], D.P. Morrison[16], B. Müller[68], S. Mukherjee[⋆16], J. Mulligan[38,13], C. Munoz Camacho[58], J.A. Murillo Quijada[98], M.J. Murray[7], S.A. Nadeeshani[34], P. Nadel-Turonski[32], J.D. Nam[17], C.E. Nattrass[64], G. Nijs[40], J. Noronha[8], J. Noronha-Hostler[8], N. Novitzky[51], M. Nycz[19], F.I. Olness[99], J.D. Osborn[16], R. Pak[16], B. Pandey[100], M. Paolone[60], Z. Papandreou[81], J.-F. Paquet[73], S. Park[34,101], K.D. Paschke[19], B. Pasquini[102,103], E. Pasyuk[1], T. Patel[53], A. Patton[40], C. Paudel[46], C. Peng[11], J.C. Peng[8], H. Pereira Da Costa[49], D.V. Perepelitsa[89], M.J. Peters[40], P. Petreczky[16], R. D. Pisarski[16], D. Pitonyak[104], M.A. Ploskon[13], M. Posik[17], J. Poudel[1,9], R. Pradhan[26], A. Prokudin[67,1], C.A. Pruneau[93], A.J.R. Puckett[55], P. Pujahari[26], J. Putschke[93], J.R. Pybus[40], J.-W. Qiu[1,18], K. Rajagopal[40], C. Ratti[28], K.F. Read[51,64], R. Reed[105], D.G. Richards[1], C. Riedl[8], F. Ringer[9,1], T. Rinn[16], J. Rittenhouse West[13], J. Roche[88], A. Rodas[1], G. Roland[40], F. Romero-López[40,52], P. Rossi[1,106], T. Rostomyan[107], L. Ruan[16], O. M. Ruimi[20], N.R. Saha[26], N.R. Sahoo[92], T. Sakaguchi[16], F. Salazar[79,13,38], C.W. Salgado[108,1], G. Salmè[109], S. Salur[70], S.N. Santiesteban[110], M.M. Sargsian[46], M. Sarsour[44], N. Sato[1], T. Satogata[1,9], S. Sawada[111], T. Schäfer[83], B. Scheihing-Hitschfeld[40], B. Schenke[†⋆16], S.T. Schindler[40], A. Schmidt[3], R. Seidl[112,33], M.H. Shabestari[113], P.E. Shanahan[40,52], C. Shen[93,33], T.-A. Sheng[40], M.R. Shepherd[85], A.M. Sickles[†⋆8], M.D. Sievert[60], K.L. Smith[49], Y. Song[25], A. Sorensen[114], P.A. Souder[41], N. Sparveris[17], S. Srednyak[68], A.G. Stahl Leiton[115], A.M. Stasto[116], P. Steinberg[16], S. Stepanyan[1], M. Stephanov[62], J. R. Stevens[18], D. J. Stewart[93], I. W. Stewart[40], M. Stojanovic[117], I. Strakovsky[3], S. Strauch[72], M. Strickland[118], D. Sunar Cerci[42,43], M. Suresh[53], B. Surrow[17], S. Syritsyn[32], A.P. Szczepaniak[85,1], A.S. Tadepalli[1], A.H. Tang[16], J.D. Tapia Takaki[7], T.J. Tarnowsky[91,49], A.N. Tawfik[119], M.I. Taylor[40], C. Tennant[1], A. Thiel[4], D. Thomas[120], Y. Tian[41], A.R. Timmins[28], P. Tribedy[16], Z. Tu[16], S. Tuo[73], T. 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LONG RANGE PLAN

- July 10-14 2023: Resolution Meeting

- October 6 2023: Rollout

QCD Subcommittee

Christine	Aidala
Paulo	Bedaque
Ian	Cloet
Evie	Downie
Jo	Dudek
Renee	Fatemi
Haiyan	Gao
Vicki	Greene
Auston	Harton
Tanja	Horn
Calvin	Howell
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Barbara	Jacak
Thia	Keppel
Richard	Milner
Jianwei	Qiu
Rosi	Reed
Lijuan	Ruan
Bjoern	Schenke
Daniel	Tapia Takaki
Derek	Teaney
Ramona	Vogt
Xiaochao	Zheng

RECOMMENDATIONS

RECOMMENDATION 1

The highest priority of the nuclear science community is to capitalize on the extraordinary opportunities for scientific discovery made possible by the substantial and sustained investments of the United States. We must draw on the talents of all in the nation to achieve this goal

- Increase research budget that advances the science program through support of theoretical and experimental research
- Continue effective operation of ATLAS, CEBAF, and FRIB, and completing RHIC science program
- Raise compensation of graduate researchers
- Expand policy and resources to ensure a safe and respectful environment for everyone

RECOMMENDATIONS

RECOMMENDATION 2

As the highest priority for new experiment construction, we recommend that the United States lead an international consortium that will undertake a neutrinoless double beta decay campaign, featuring the expeditious construction of ton-scale experiments, using different isotopes and complementary techniques

RECOMMENDATION 3

We recommend the expeditious completion of the EIC as the highest priority for facility construction

Recommendation includes a parallel investment in QCD theory and computing. “To maximize the scientific impact of the facility and to prepare for the precision expected at the EIC, theory must advance on multiple fronts, and new collaborative efforts are required.”

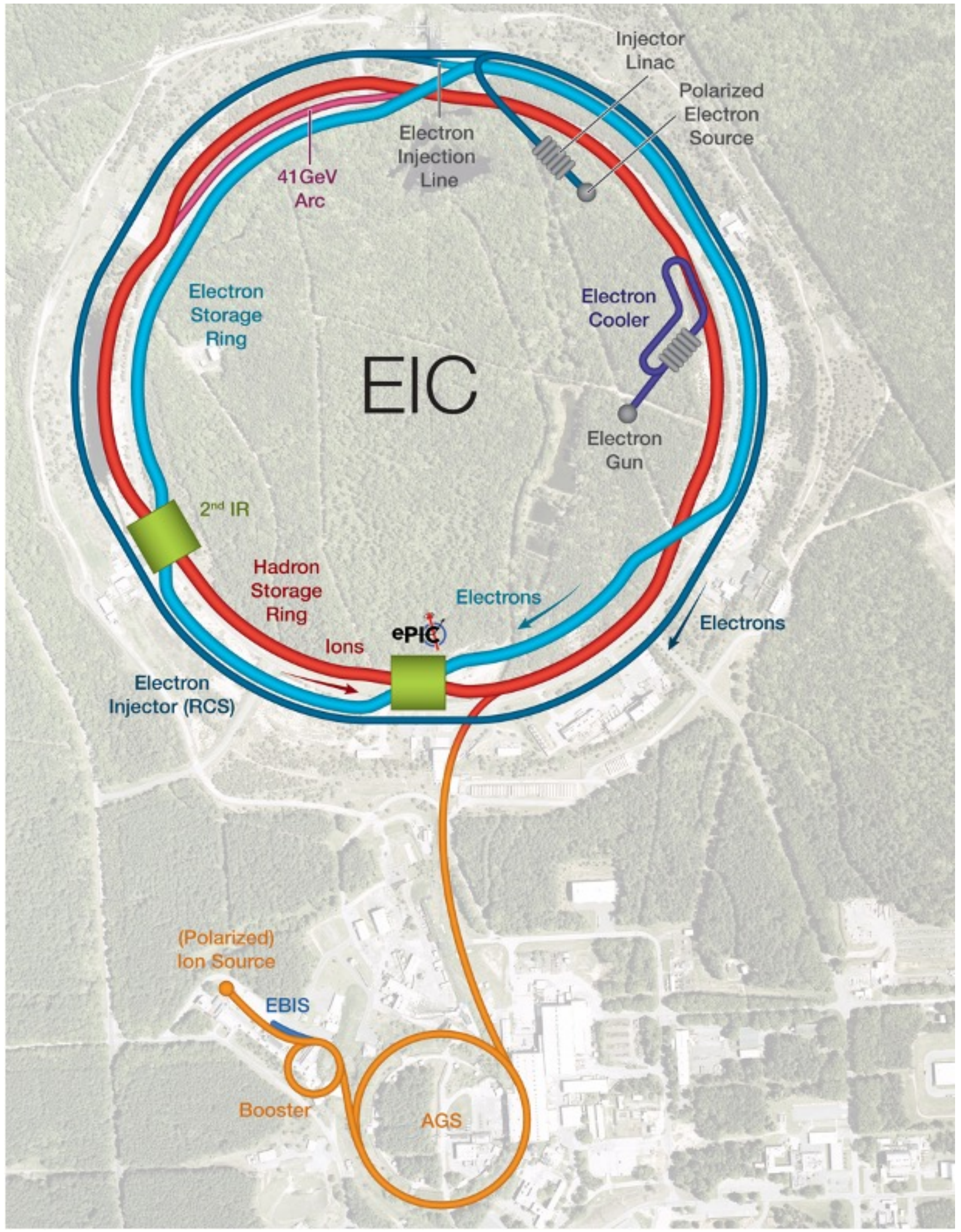
THE ELECTRON ION COLLIDER

Collisions of polarized electrons colliding with polarized protons, polarized light ions, and heavy ions to address:

- Mass and spin of the proton
- Spatial and momentum distribution of low-x partons
- Gluon saturation
- Nuclear parton distribution functions
- Hadron formation

The EIC is a partnership between BNL and Jefferson Lab.
Project is aiming for CD2/3 in 2025

ePIC detector design is advanced
Significant international support and participation (160+ institutions, 24 countries).



RECOMMENDATIONS

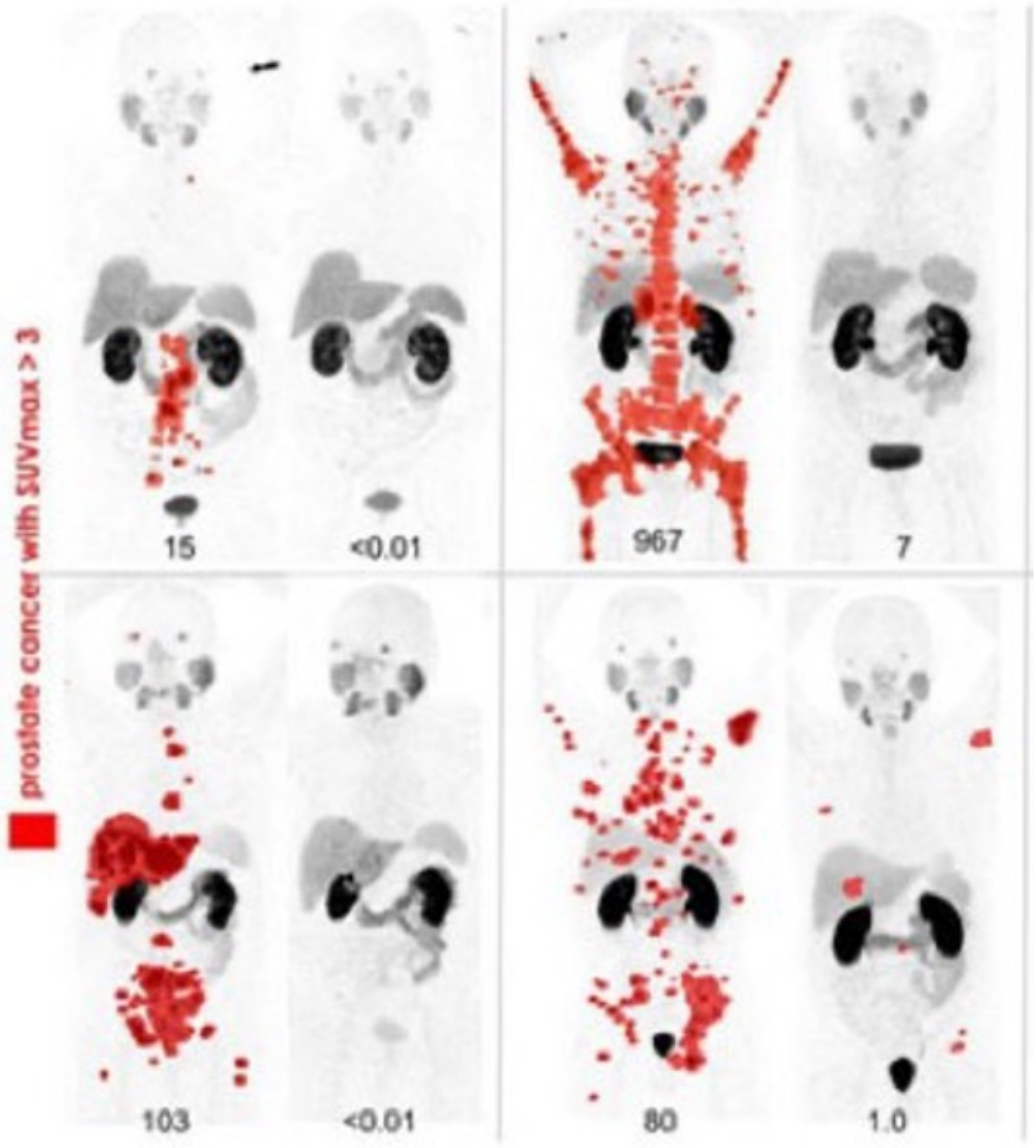
RECOMMENDATION 4

We recommend capitalizing on the unique ways in which nuclear physics can advance discovery science and applications for society by investing in additional projects and new strategic opportunities

- Opportunities to advance discovery: Lists FRIB400, SoLID at JLab, LHC Heavy Ion upgrades, emerging technologies for measuring neutrino mass and electric dipole moments, detector and accelerator R&D
- Cross-cutting opportunities: Quantum computing and sensing, support for AI/ML technologies in nuclear physics, and HPC: *Enhanced support for HPC, specifically highlighting DOE Scientific Discovery through Advanced Computing (SciDAC) and NSF Cyberinfrastructure for Sustained Scientific Innovation programs*
- Multidisciplinary centers: mainly geared at multi-messenger astronomy
- Nuclear data: Endorsement of collaboratively funded projects

BENEFITS TO THE NATION

- Synergy and impact on other fields, such as high energy physics, astrophysics and cosmology, accelerator science, atomic physics, condensed matter physics …
- Trained nuclear workforce affects many fields, including nuclear security, isotope production for medical and other needs
- Applications: energy, health care, environmental issues, radiation hardening for electronics, improved particle detection for homeland security
- Development of computational techniques



PET images using gallium-68 before (left) and after (right) treatment of prostate cancer with lutetium-177-PSMA-617

WORKFORCE

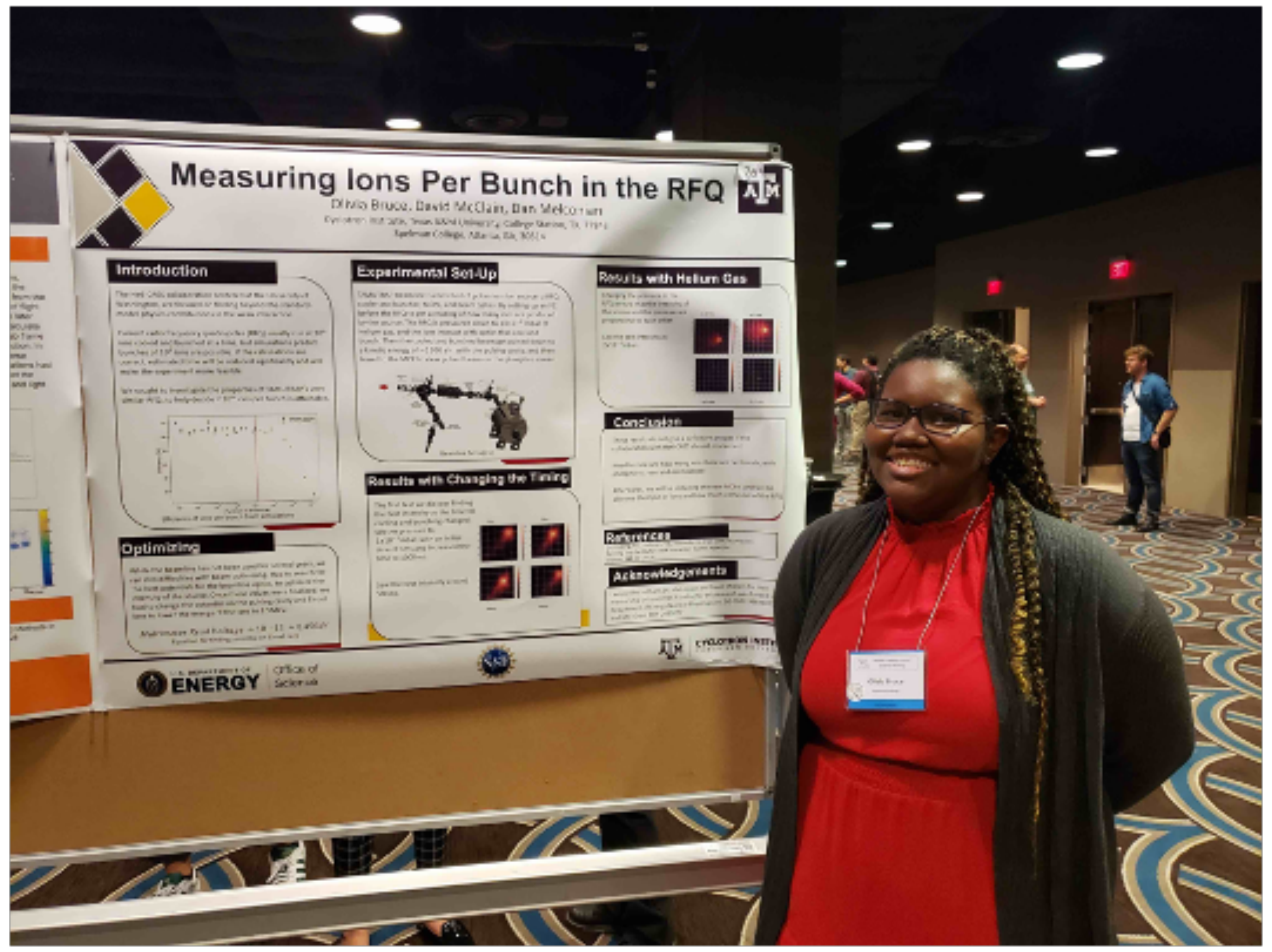
People are essential to accomplishing the goals in all areas of physics described in the Long Range Plan.

Programs such as the NSF REU and DOE SULI are essential to attracting talented students to nuclear science.

Central to our proposals is the necessity to reduce barriers to participation in nuclear science.

Our community is committed to establishing and maintaining an environment where all feel welcome and are treated with respect and dignity.

The training our students receive is very valuable in industry, national labs, and in critical areas of national need, such as nuclear nonproliferation and security.



COMPUTATIONAL FACILITIES

appearing in the Facilities Section:

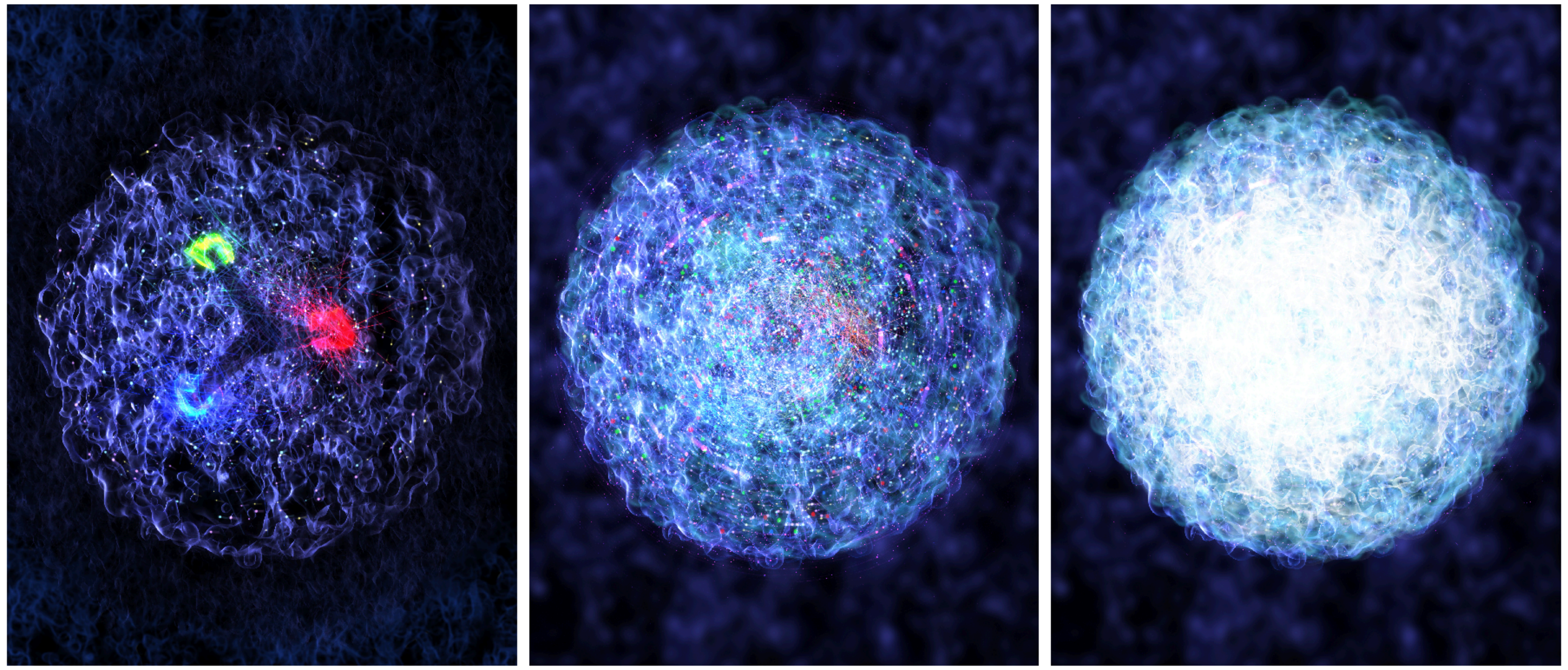
"The nuclear physics theoretical program has demonstrated [...] that lattice QCD is an unmatched tool for understanding strong interaction physics ranging from the partonic structure of nucleons to the QCD phase diagram. Lattice QCD is, at its core, an HPC endeavor."

"Lattice QCD is one of the critical applications selected for designing and benchmarking the exascale machines, for example, the Frontier supercomputer at the Oak Ridge Leadership Computing Facility. "

"The dedicated USQCD hardware located at Fermilab, BNL, and Jefferson Lab is an essential component for analysis."

COLD QCD - QUESTIONS IN THE LRP

- How does QCD generate the spectrum and structure of conventional and exotic hadrons?
- How do the mass and spin of the nucleon emerge from the quarks and gluons inside and their dynamics?
- How are the pressure and shear forces distributed inside the nucleon?
- How does the quark-gluon structure of the nucleon change when bound in a nucleus?
- How are hadrons formed from quarks and gluons produced in high energy collisions?



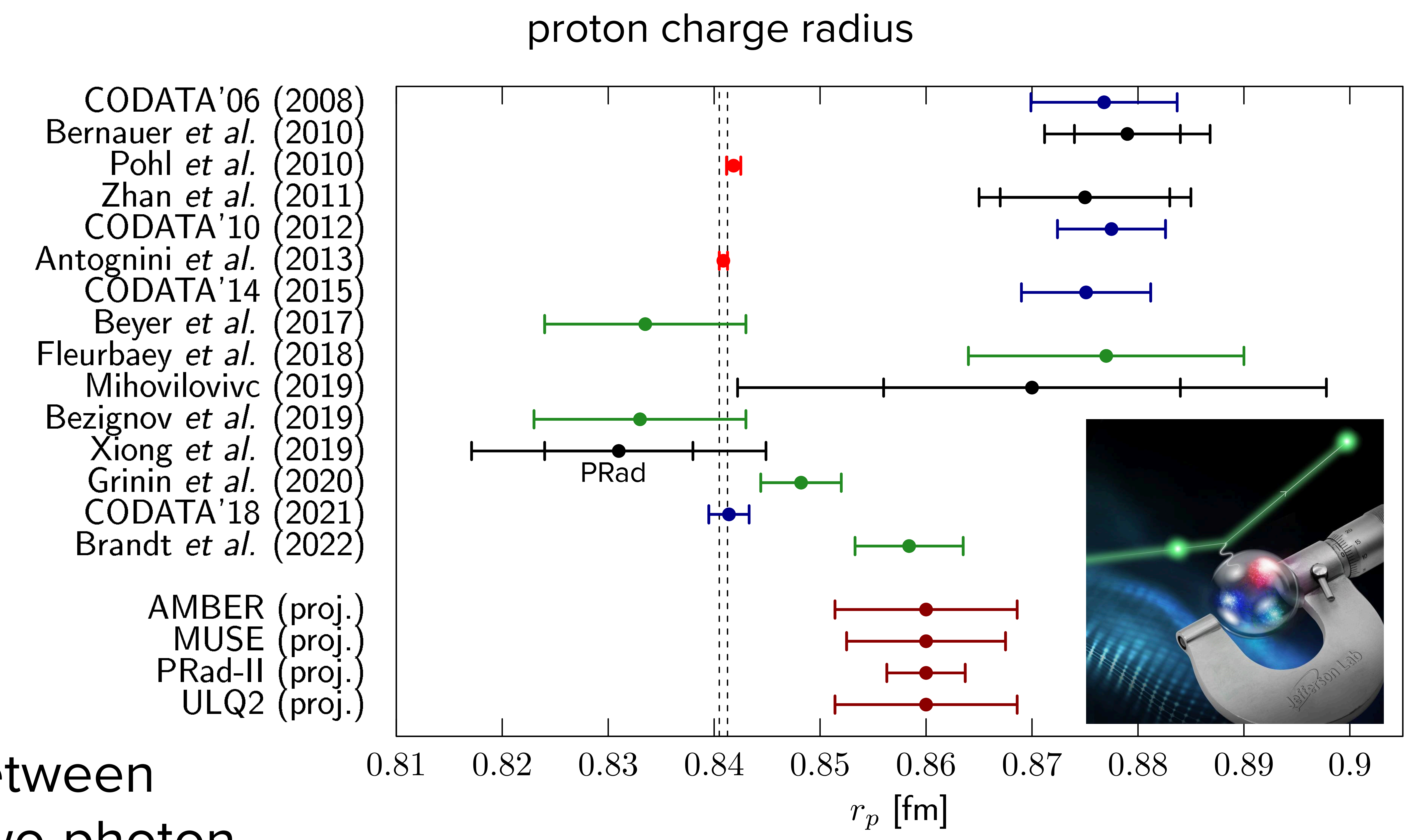
Images courtesy of James LaPlante, Sputnik Animation in collaboration with the MIT Center for Art, Science & Technology and Jefferson Lab.

HADRON PROPERTIES

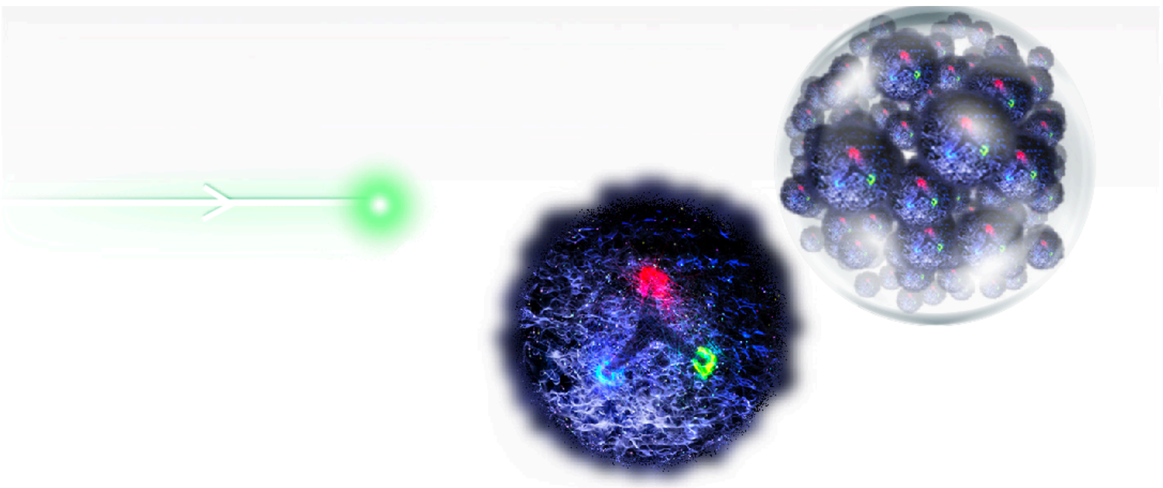
- **Proton charge radius**
  PRad at JLab
  PRad-II to increase precision (x4)
  also muon scattering with MUSE

- **Nucleon form factors at high-Q^2**
  Information on the fundamental constituent structure; Discrepancy between measurements; Understand role of two-photon exchange physics →*positron beam at JLab (mentioned)*

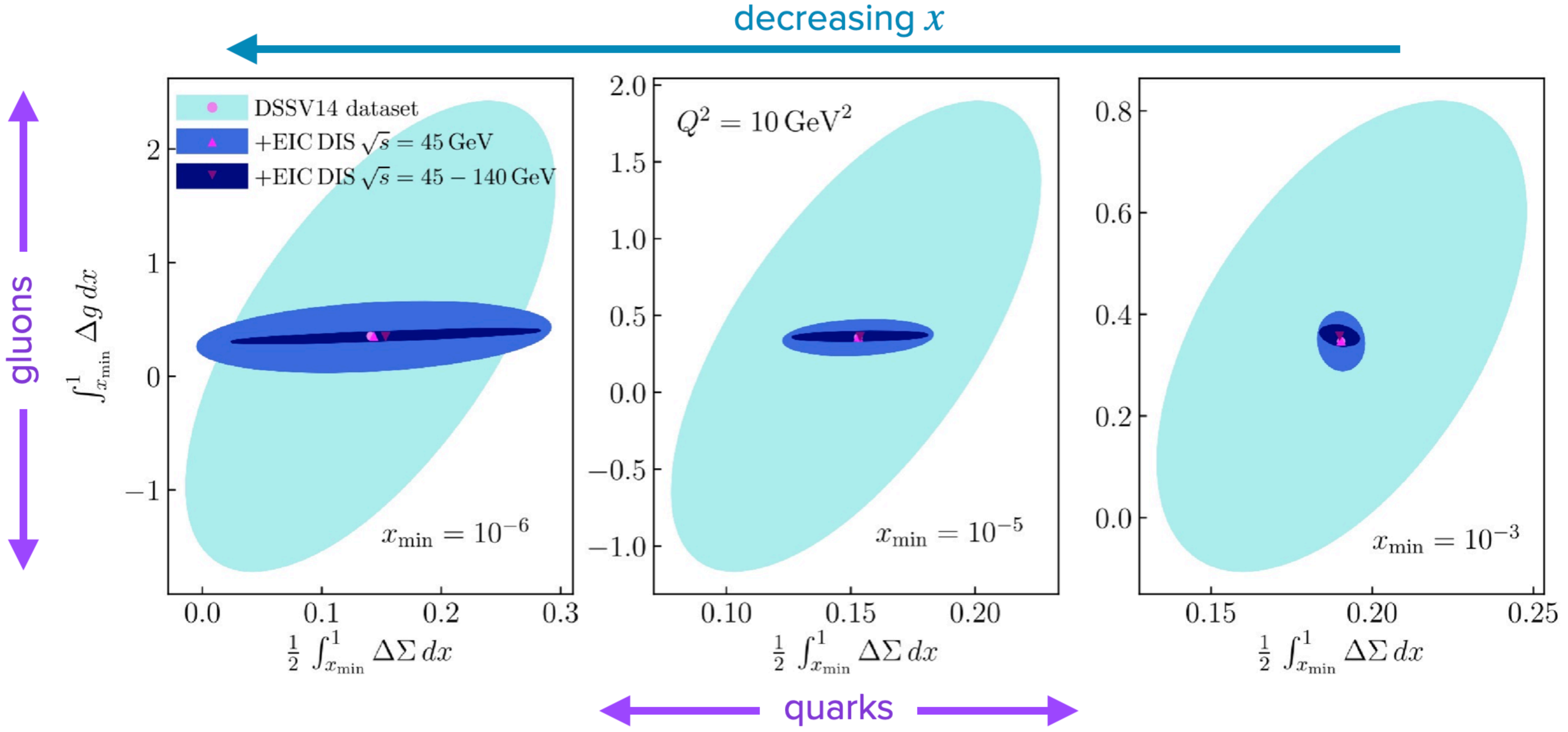
- **Nucleon polarizabilities**
  describe how the charged internal constituents of the nucleon react to external electromagnetic fields; extracted in different processes; stringent tests on Chiral Effective Field Theory and lattice QCD; *future measurements at MAMI and High Intensity Gamma-Ray Source HIGS*



HADRON PROPERTIES

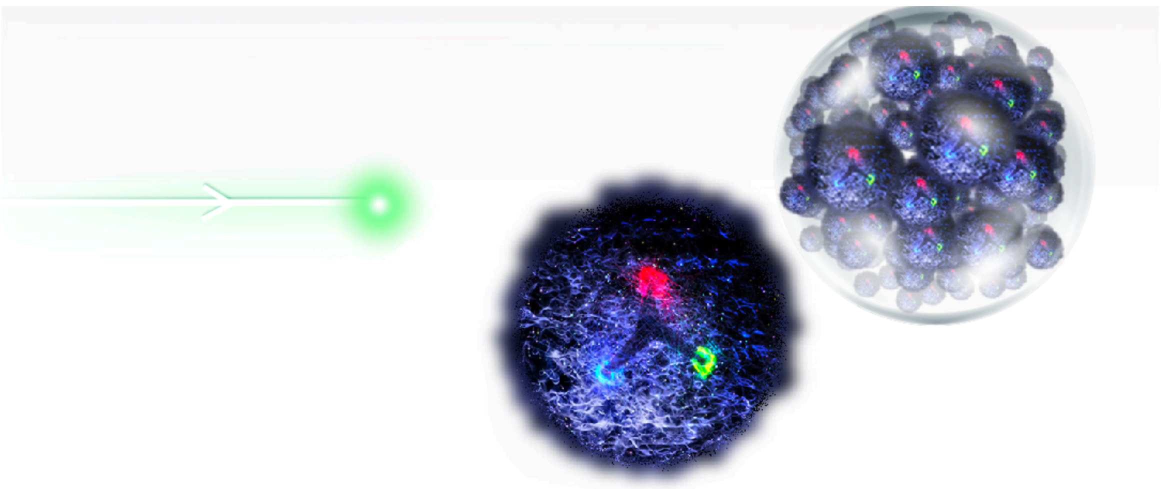


- **Quark and gluon polarizations inside the nucleon**
  DIS measurements with polarized beams and targets and polarized proton-proton collisions probe the polarized (helicity) quark/gluon distribution and the **origin of the proton spin**.
  Constraints on quark and gluon helicity distributions from RHIC - upgrade: *wider x reach and higher statistics.* Focus of the EIC, especially gluons

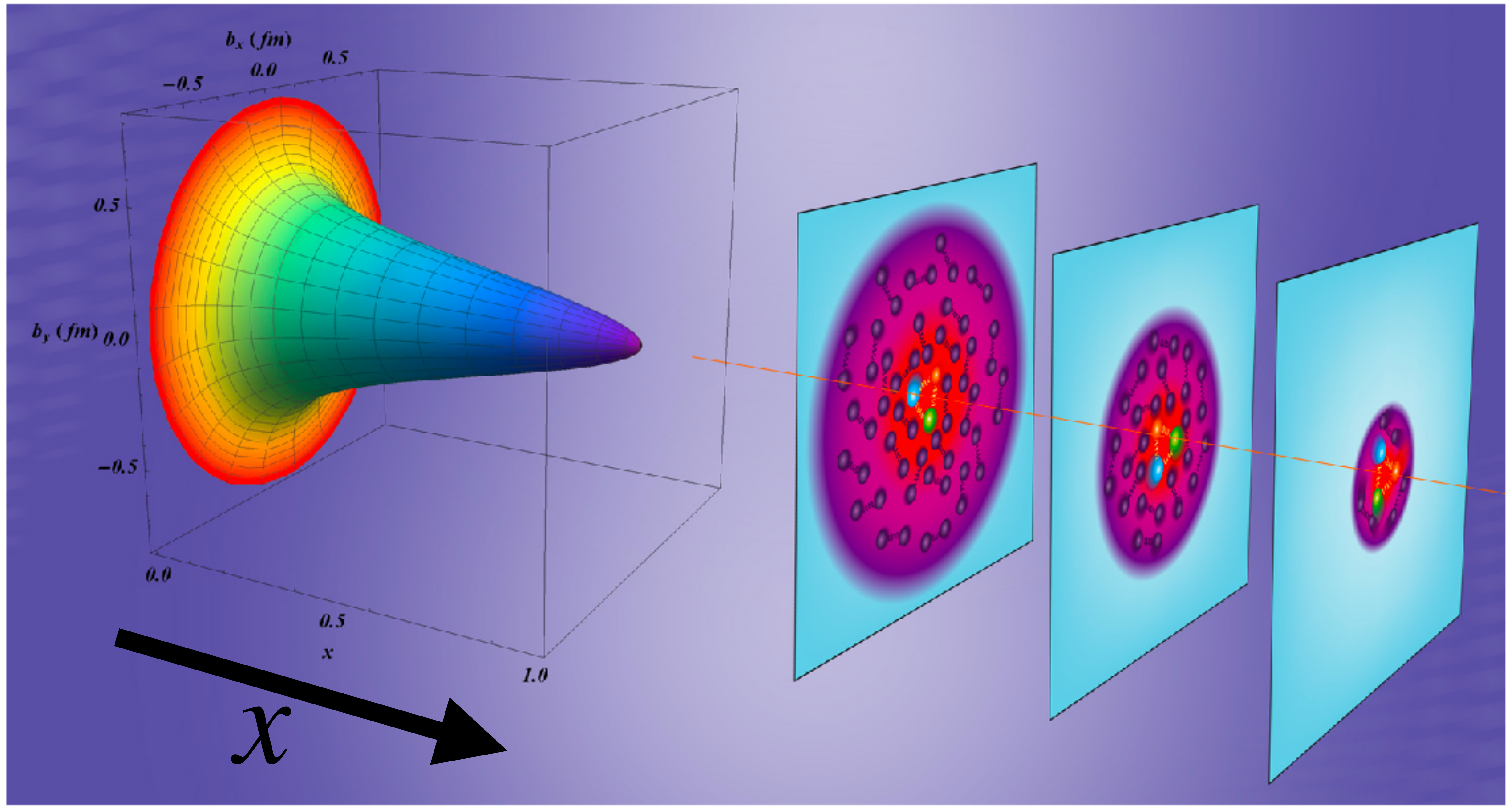


- **Quark distributions and polarizations at $x \to 1$:** Determine the longitudinal momentum and spin carried by valence quarks particularly d(x)/u(x); studied by MARATHON, BONuS12, Hal *and will be by SoLID in the future (avoiding nuclear effects)*

NUCLEON FEMTOGRAPHY

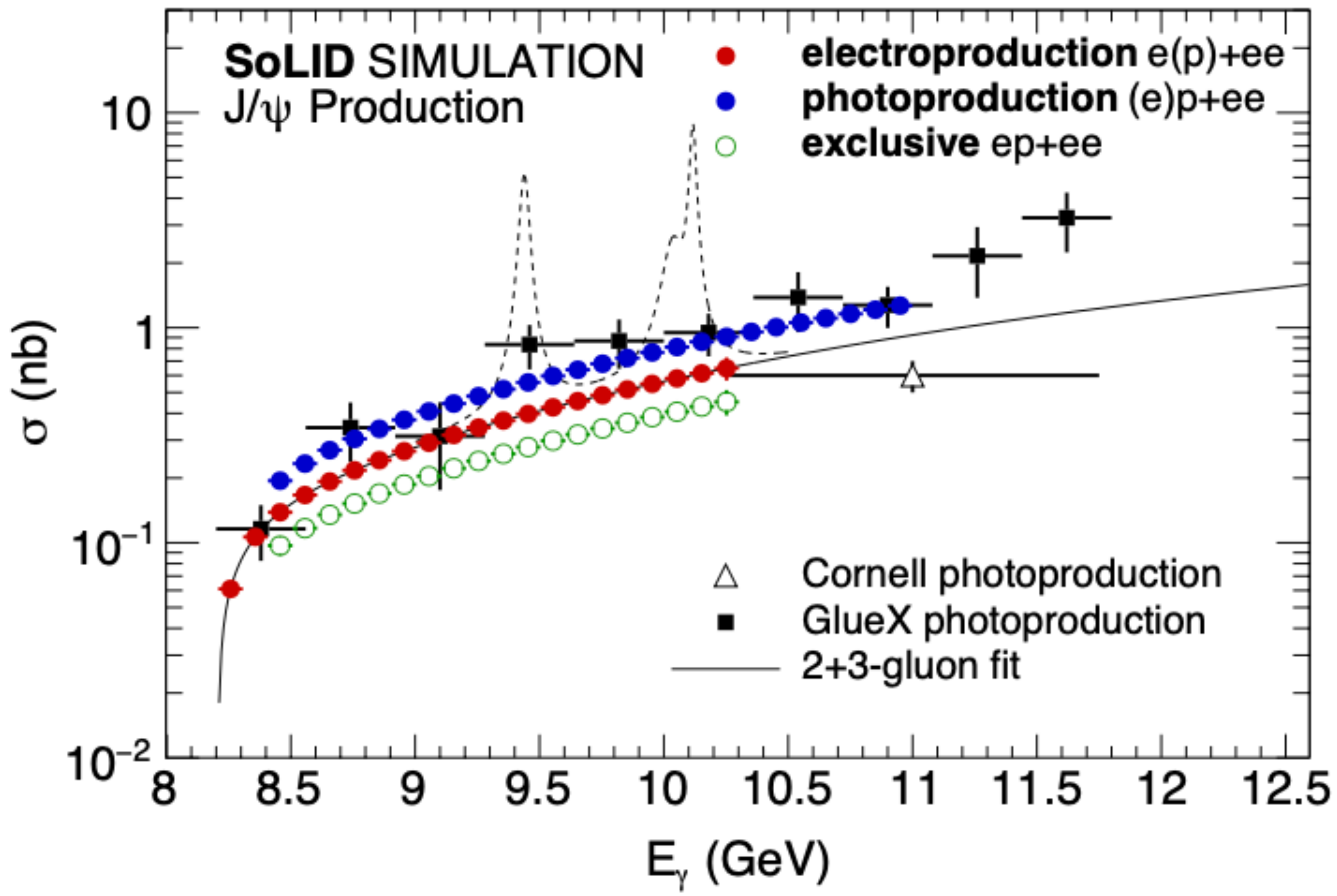


- Multi-dimensional mapping of the nucleon: TMDs, GPDs, ultimately Wigner distributions
- *Big component of the EIC science program*
- *New measurements at JLab and the EIC*



NUCLEON FEMTOGRAPHY

- **Origin of the proton mass**, mass radius, gravitational density distribution inside the proton: Quarkonium production near threshold, which is uniquely sensitive to the non-perturbative gluonic structure of the proton: GlueX, *and SoLID in the future,* *Also at the EIC (incl $b\bar{b}$ states) and via GPDs and DVCS*



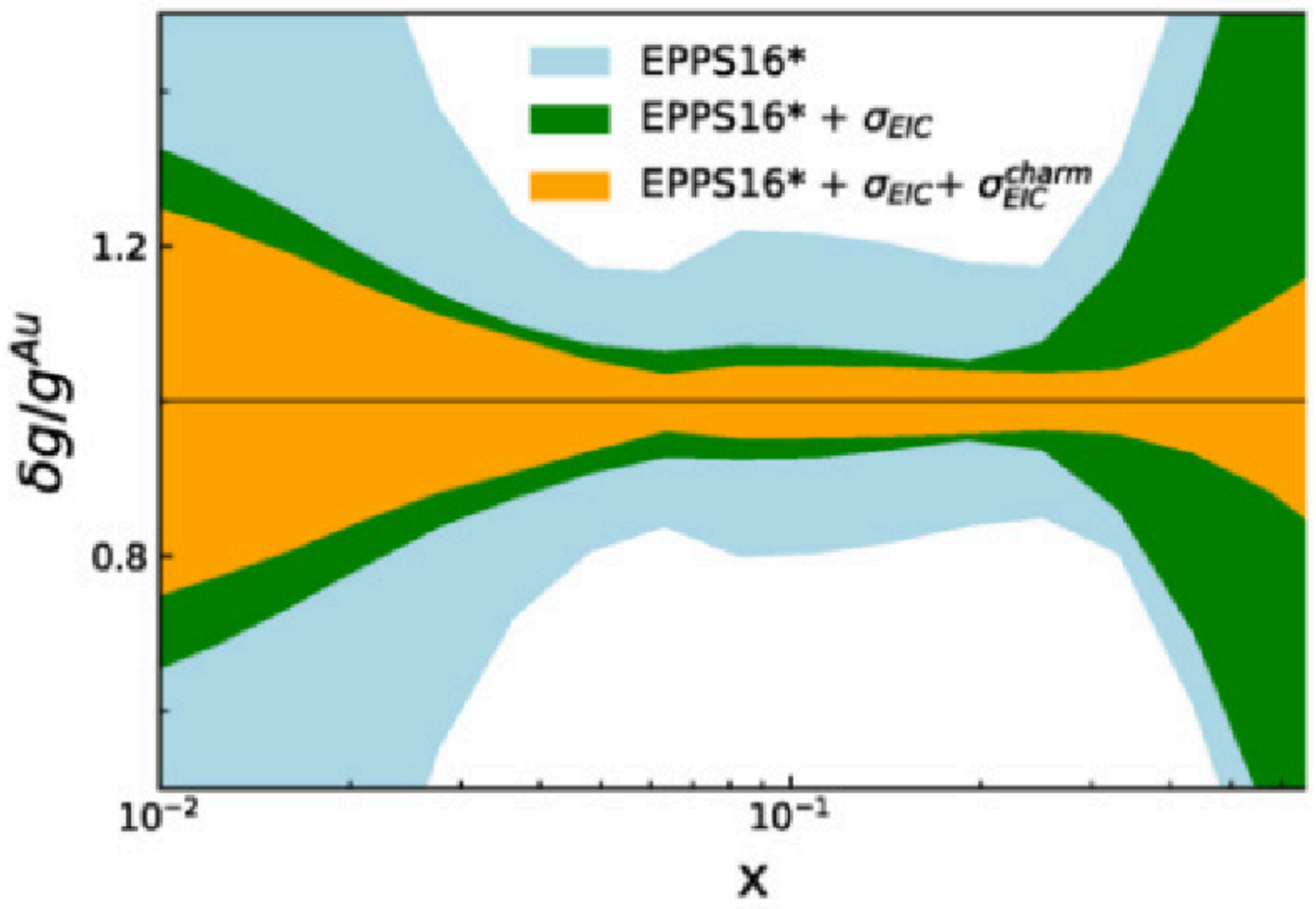
Then fit the cross section as a function of W and t to obtain gluon gravitational form factors

- **Momentum tomography of the nucleon** Insight into nontrivial QCD dynamics: QCD factorization, universality of the parton distributions and fragmentation functions, and their scale evolution; Azimuthal modulations in SIDIS from JLab and RHIC, Sivers and Collins asymmetries, *future measurements with SoLID at JLab and STAR at RHIC (upgrade extends to smaller and larger x)* EIC will use its high energy, high luminosity, and highly polarized beams to address this

QCD STUDIES OF NUCLEI

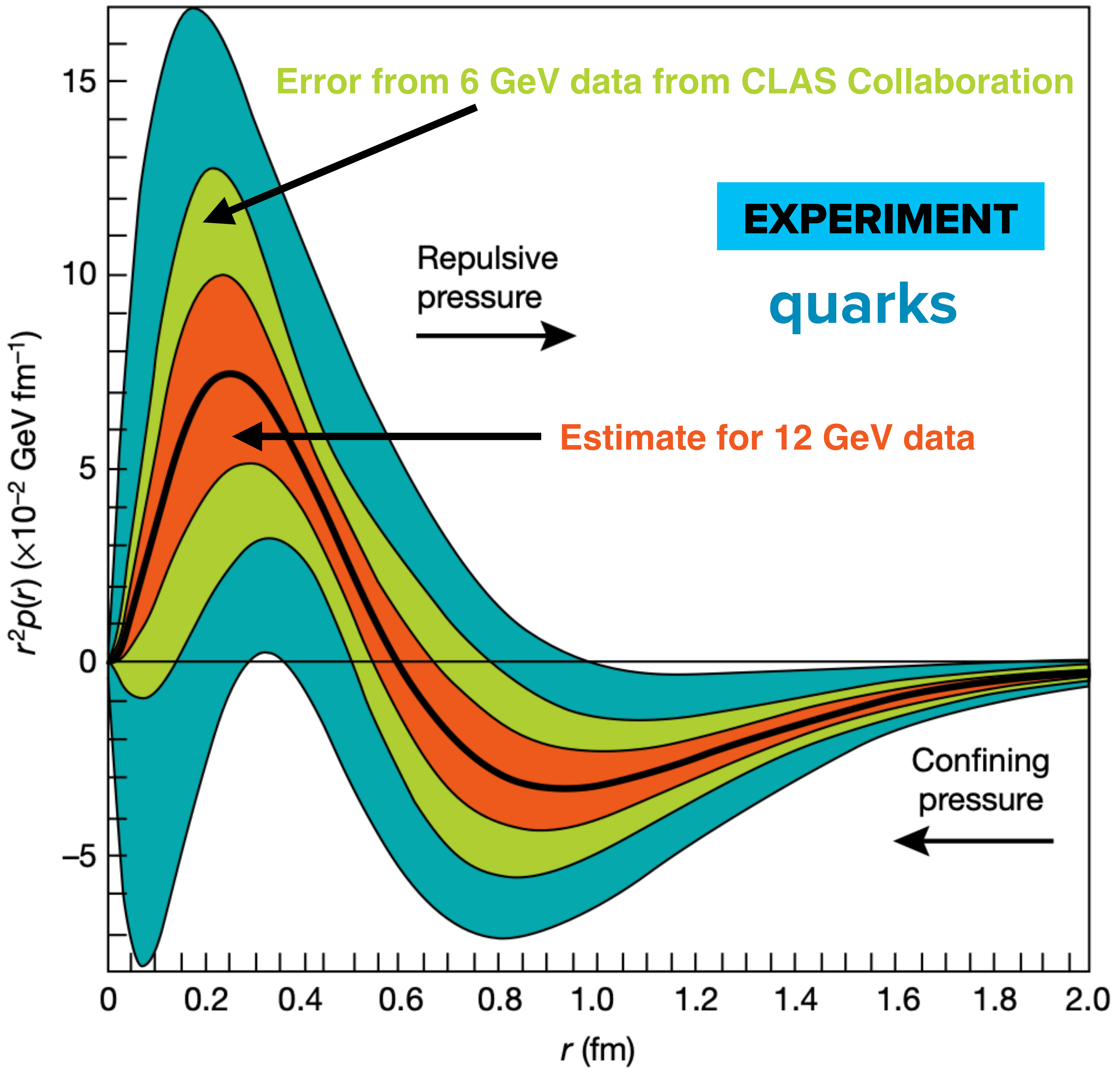
- **Nucleon PDF modification in nuclei**: EMC effect, role of short range correlations (SRC), *Parity-Violating DIS (PVDIS) SoLID: separate u and d PDFs, varying targets; spin dependent EMC effect, high-resolution hypernuclear experiments and efforts to isolate hyperon–nucleon scattering at JLab; EIC will reduce uncertainties on nuclear PDFs, especially for gluons*

- **Non-linear gluon dynamics and saturation**
  - RHIC: forward dihadron correlations (*Higher-precision with STAR forward upgrade*), *and other measurements*
  - LHC will impact PDF and nPDFs; *wide range of nuclei with SMOGII at LHCb, LHCSpin project with polarized target; ALICE FoCAL upgrade to study gluons at small x*
  - Many processes at the EIC should show sensitivity to saturation. Study A and *x* systematics

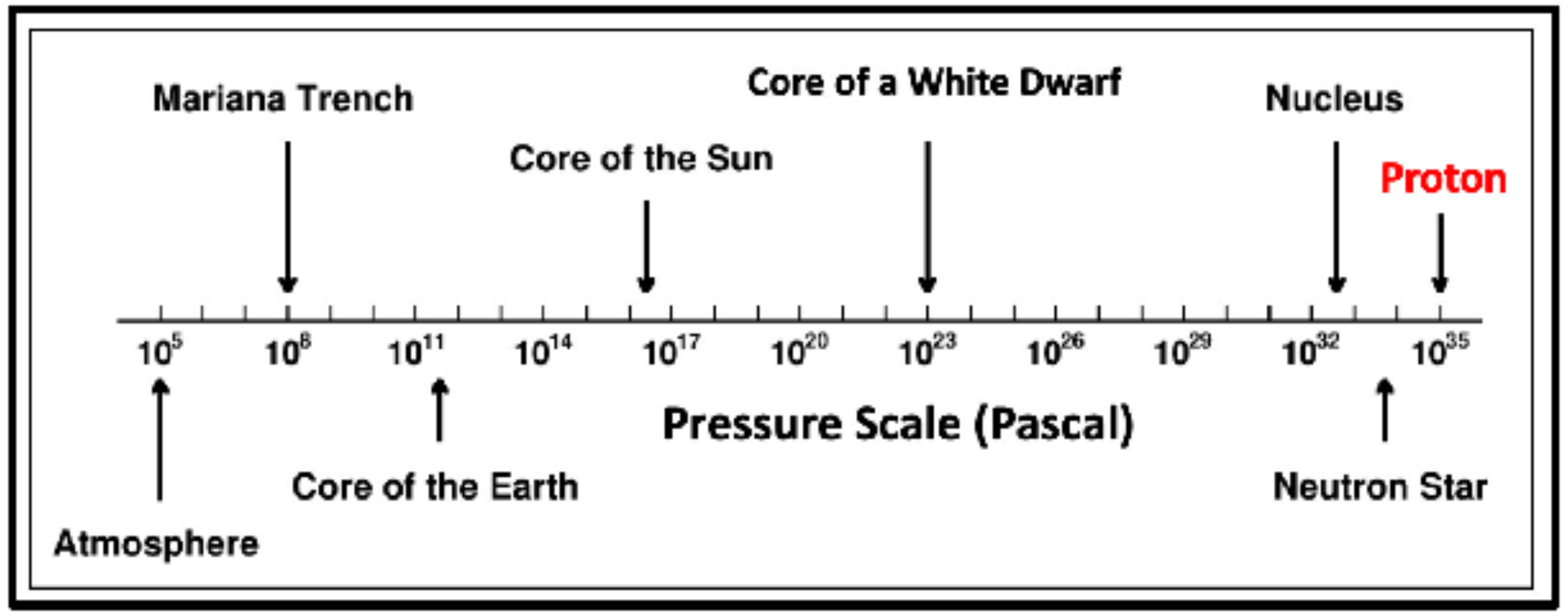


Relative uncertainty bands of the gluon density for gold at $Q^2 = 1.69\,\mathrm{GeV}^2$

SIDEBAR: PRESSURE INSIDE THE PROTON

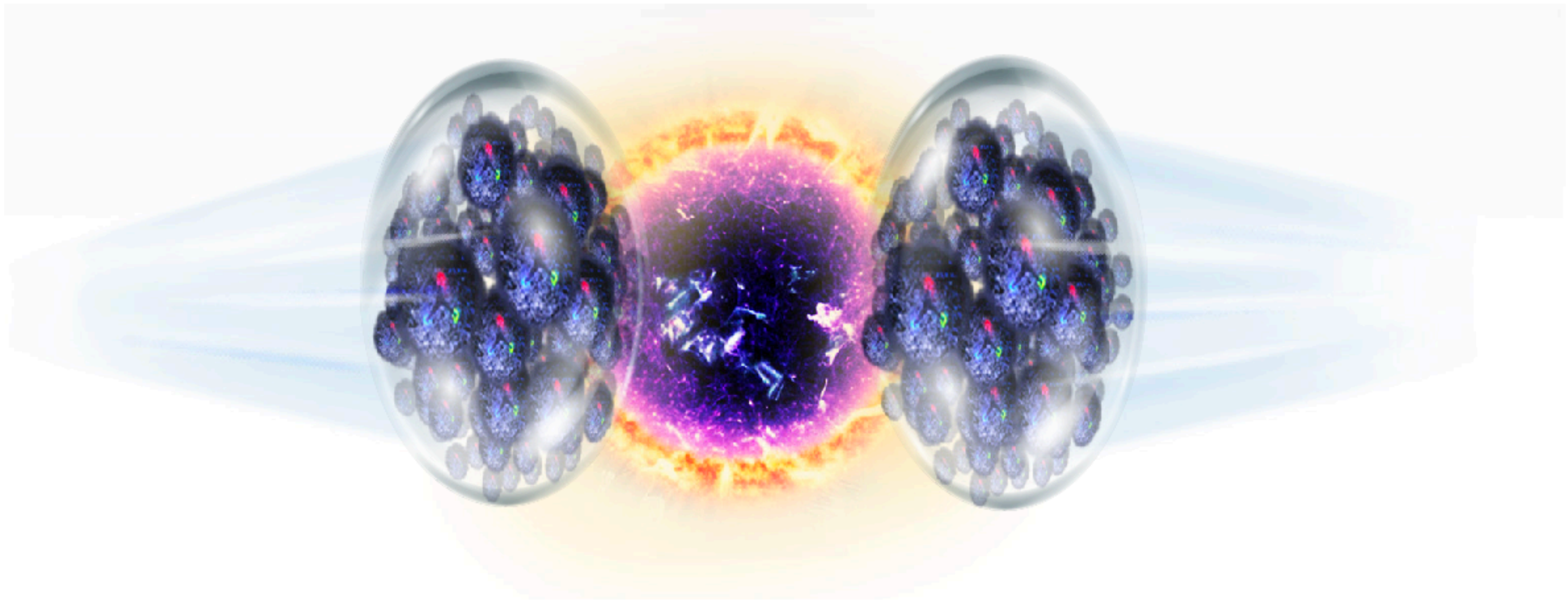


These results were based on the analysis of deeply virtual Compton scattering (DVCS) data, measured with the CEBAF Large Acceptance Spectrometer CLAS, and combined with information provided by generalized parton distributions (GPDs)

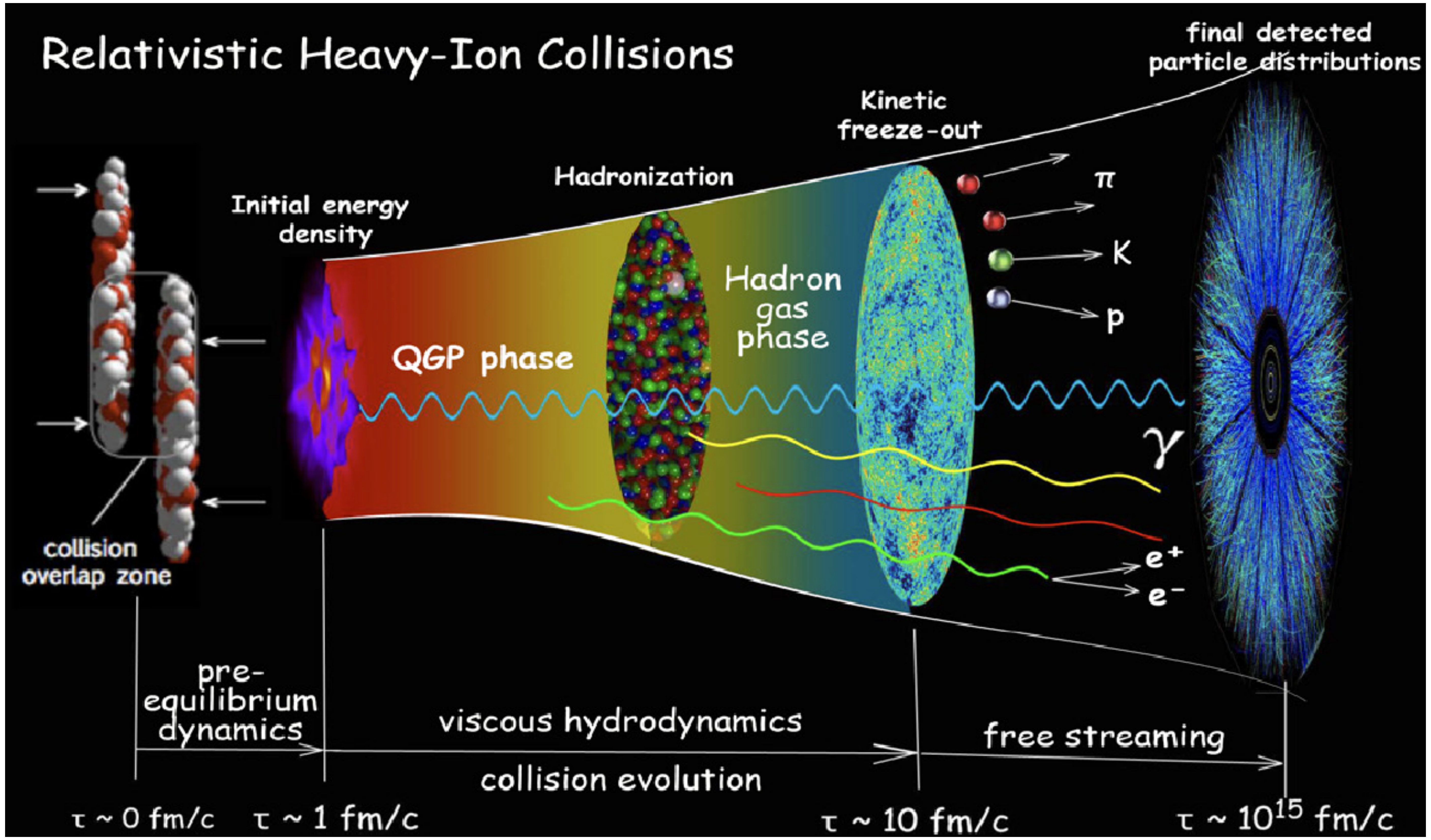


Lattice: P. E. Shanahan, W. Detmold, Phys. Rev. Lett. 122, 072003 (2019)
V. D. Burkert, L. Elouadrhiri, F. X. Girod, Nature 557, 396–399 (2018); Gluon GFFs: B.Duran et al., Nature 615 (2023) 7954, 813-816

HOT QCD - QUESTIONS IN THE LRP

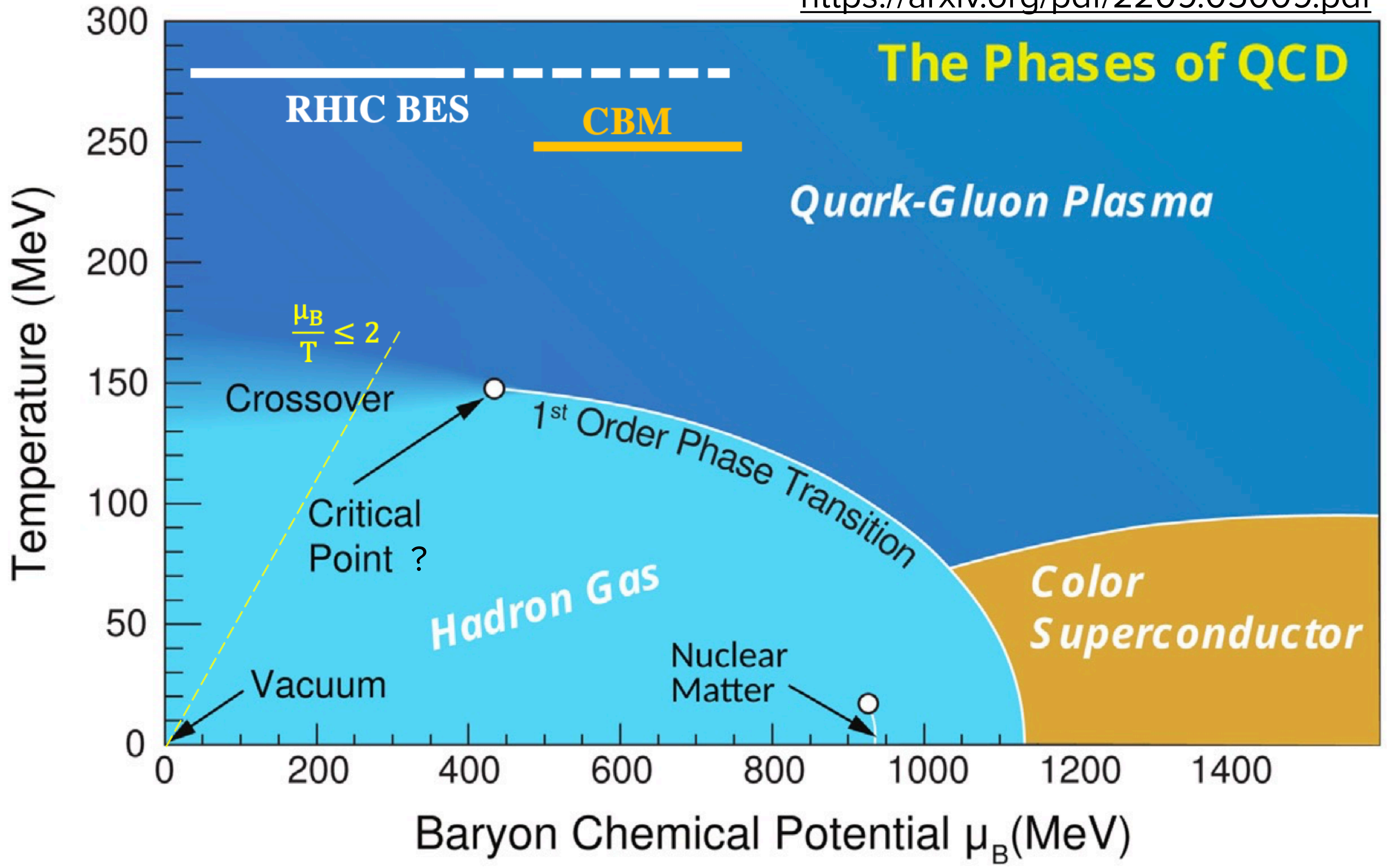


- How do the fundamental interactions between quarks and gluons lead to the perfect fluid behavior of the quark–gluon plasma?
- What are the limits on the fluid behavior of matter?
- What are the properties of QCD matter?
- What is the correct phase diagram of nuclear matter?



PHASE STRUCTURE OF NUCLEAR MATTER

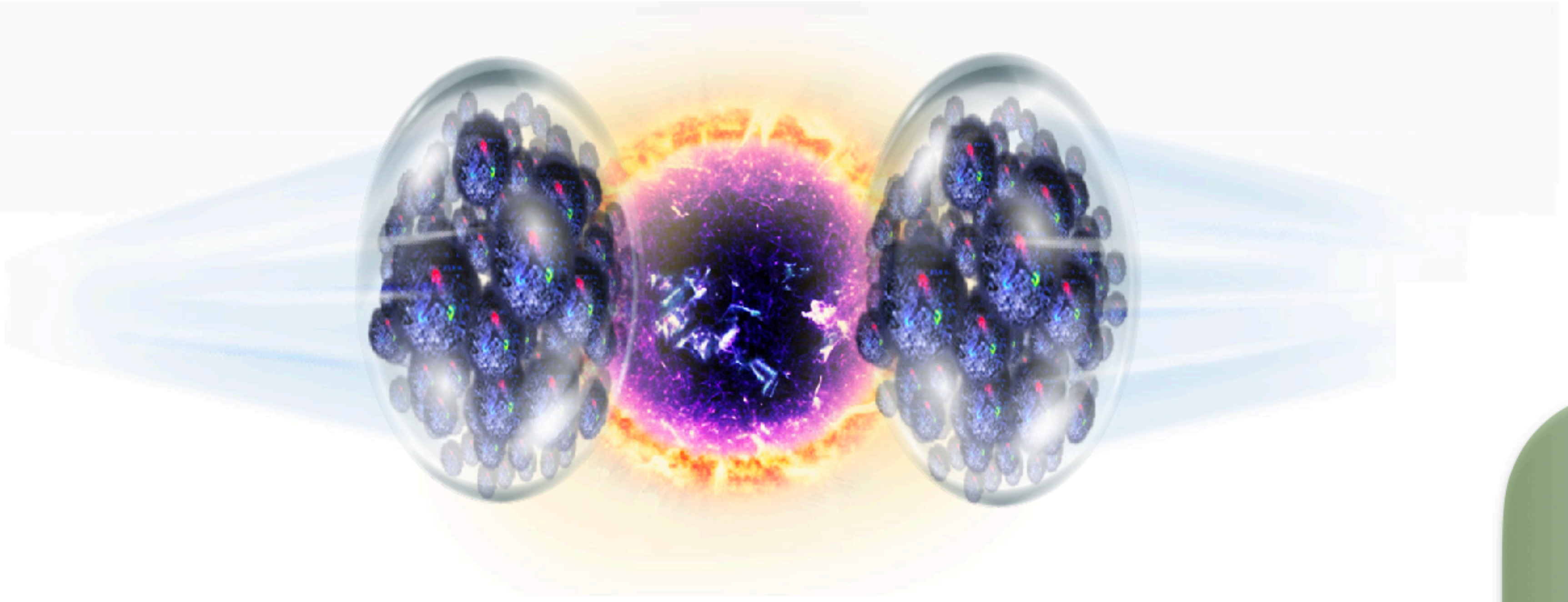
https://arxiv.org/pdf/2209.05009.pdf



- **Phase diagram** vs. *T* and net-conserved charges
- Vary collision energy. Analysis of RHIC BES-II data, future NA60+, CBM at FAIR
- Understand **deconfinement transition** and **chiral symmetry restoration** (e.g. using EM probes)
- **Critical point search**
- **Nuclear equation of state** from using complementarity of heavy ion collisions and neutron stars

- **Lattice QCD**: Extrapolate phase transition line to larger values of chemical potential and provide more stringent constraints on the location of the critical point
- **Modeling:** Hydrodynamics with all conserved currents and a 4D equation of state implementation (also with possible critical point), diffusion, viscosity, dynamic 3+1D initial conditions

FLUID BEHAVIOR

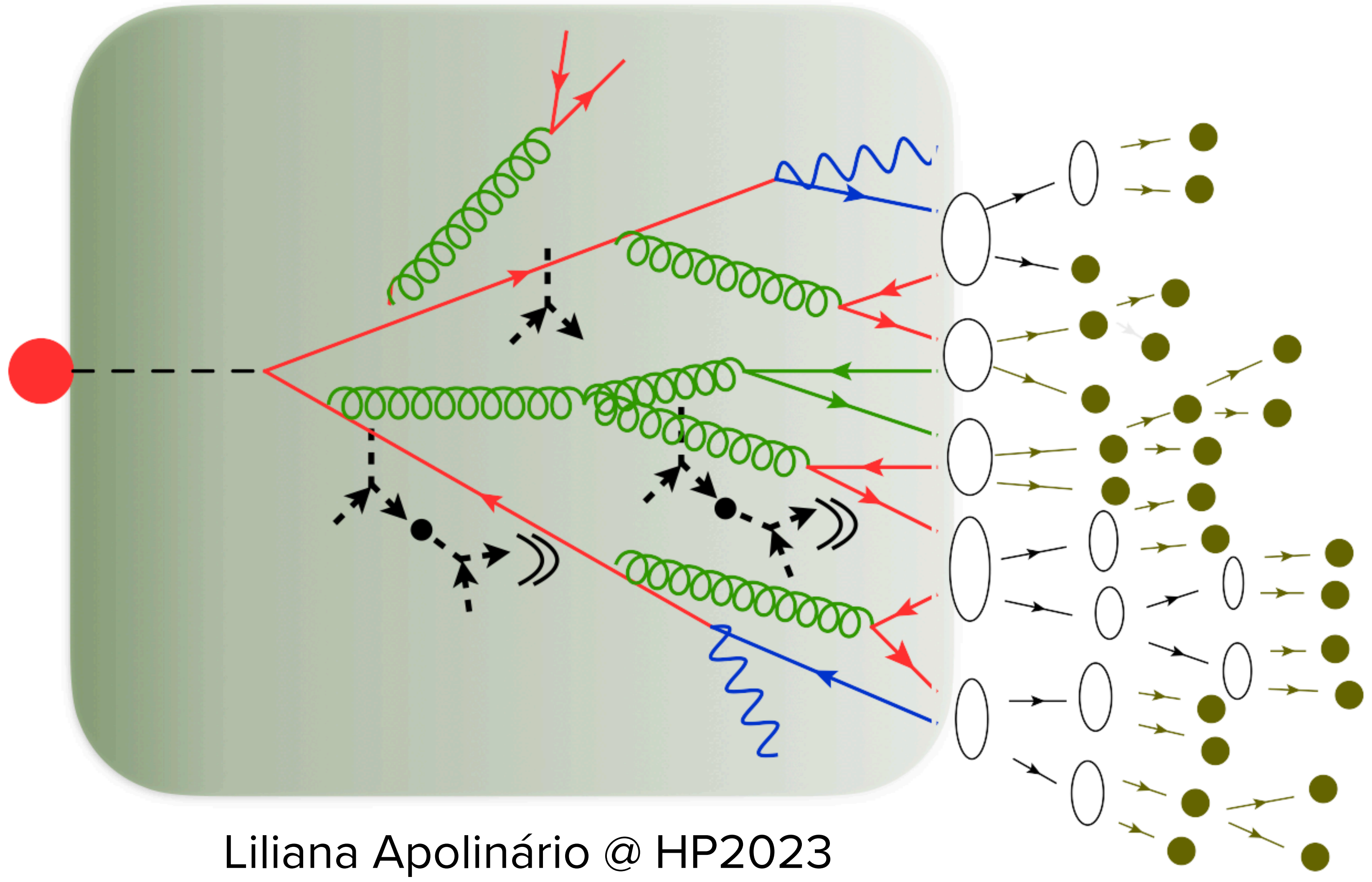


Understand the mechanisms that lead to the emergence of the fluid behavior of hot and dense nuclear matter

- Push the boundaries to **small collision systems** and better **constrain the initial state** from theory and complementary experiments

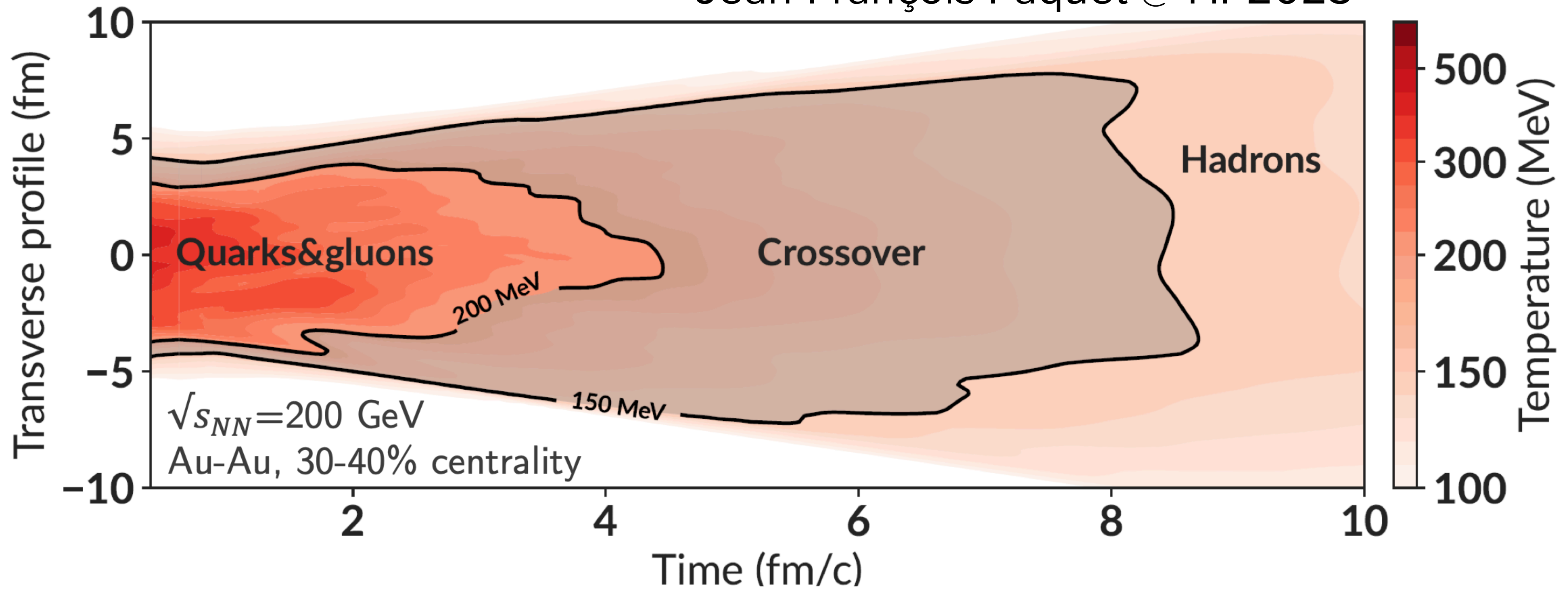
- Study **electromagnetic probes** for further information on early times and the full time evolution of the system Measurements from BESII and future results from NA60+, CBM, and ALICE in run 3 and 4, as well as ALICE3

- Study QGP at **short distance scales** using hard probes: **jets, heavy flavor hadrons, and quarkonia**

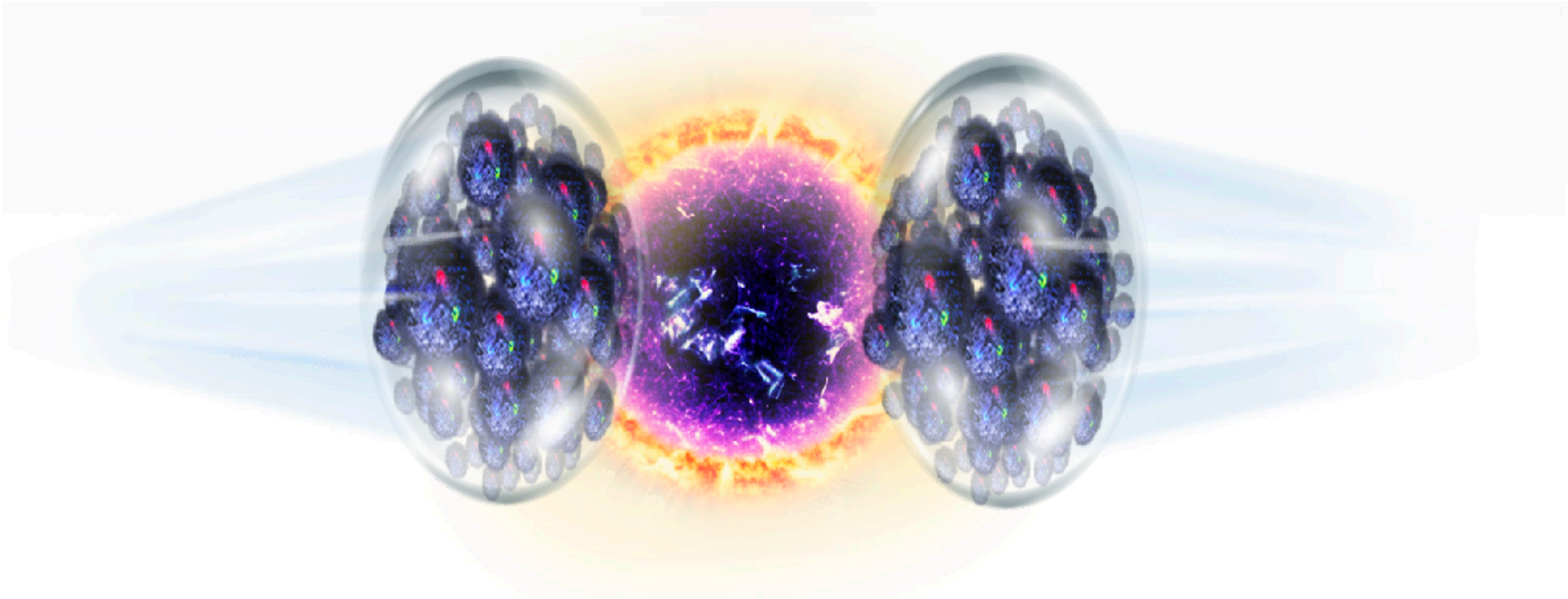


Liliana Apolinário @ HP2023

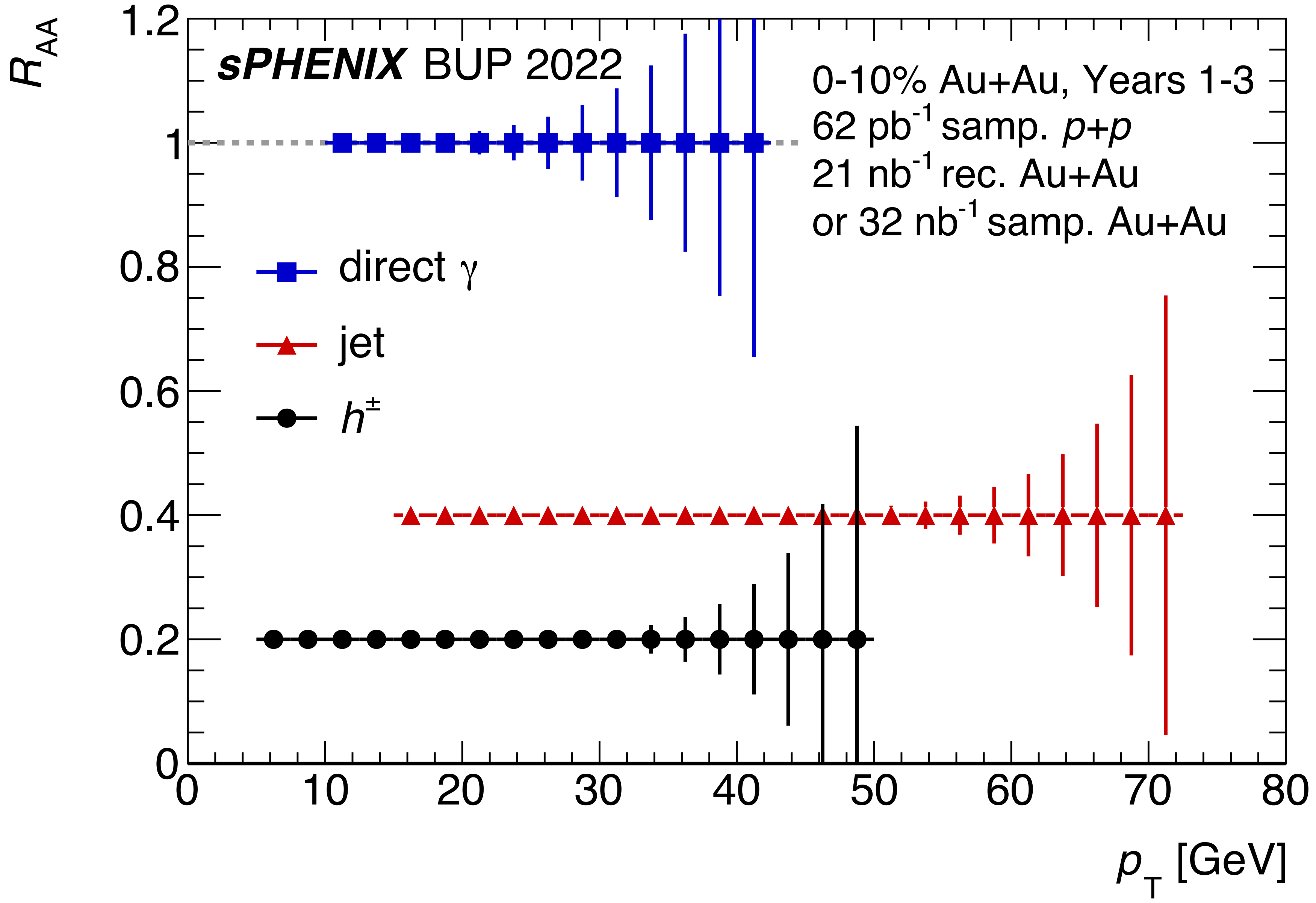
Jean-François Paquet @ HP2023



JETS

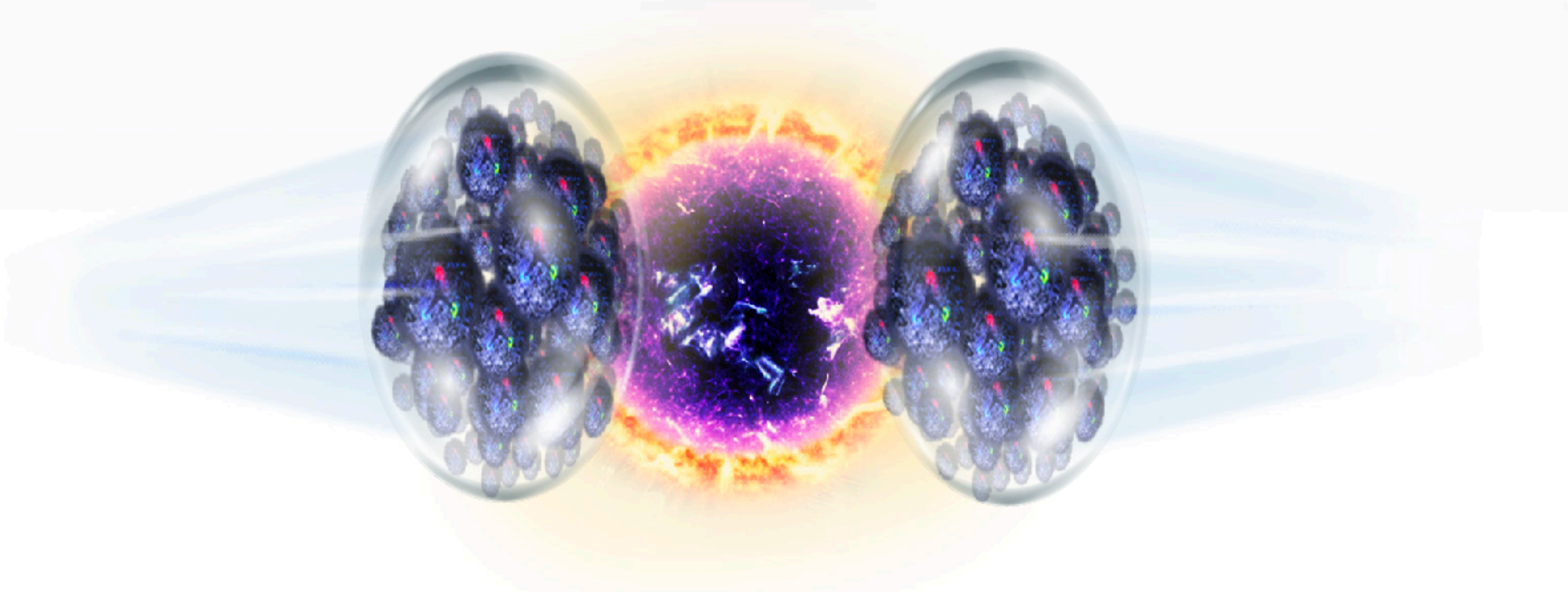


- Upcoming **high-luminosity data** from sPHENIX and STAR
- **sPHENIX** specifically optimized to measure jets
- **Jet substructure** measurements to answer how jet quenching and the jet shower structure are related - How well can the full (medium modified) jet structure be described within QCD?
- Select (light and heavy) quark and gluon initiated jets
- Explore the **transfer of energy from the jet to the medium**, including role of turbulence, vorticity around the jet, effects on hadronization

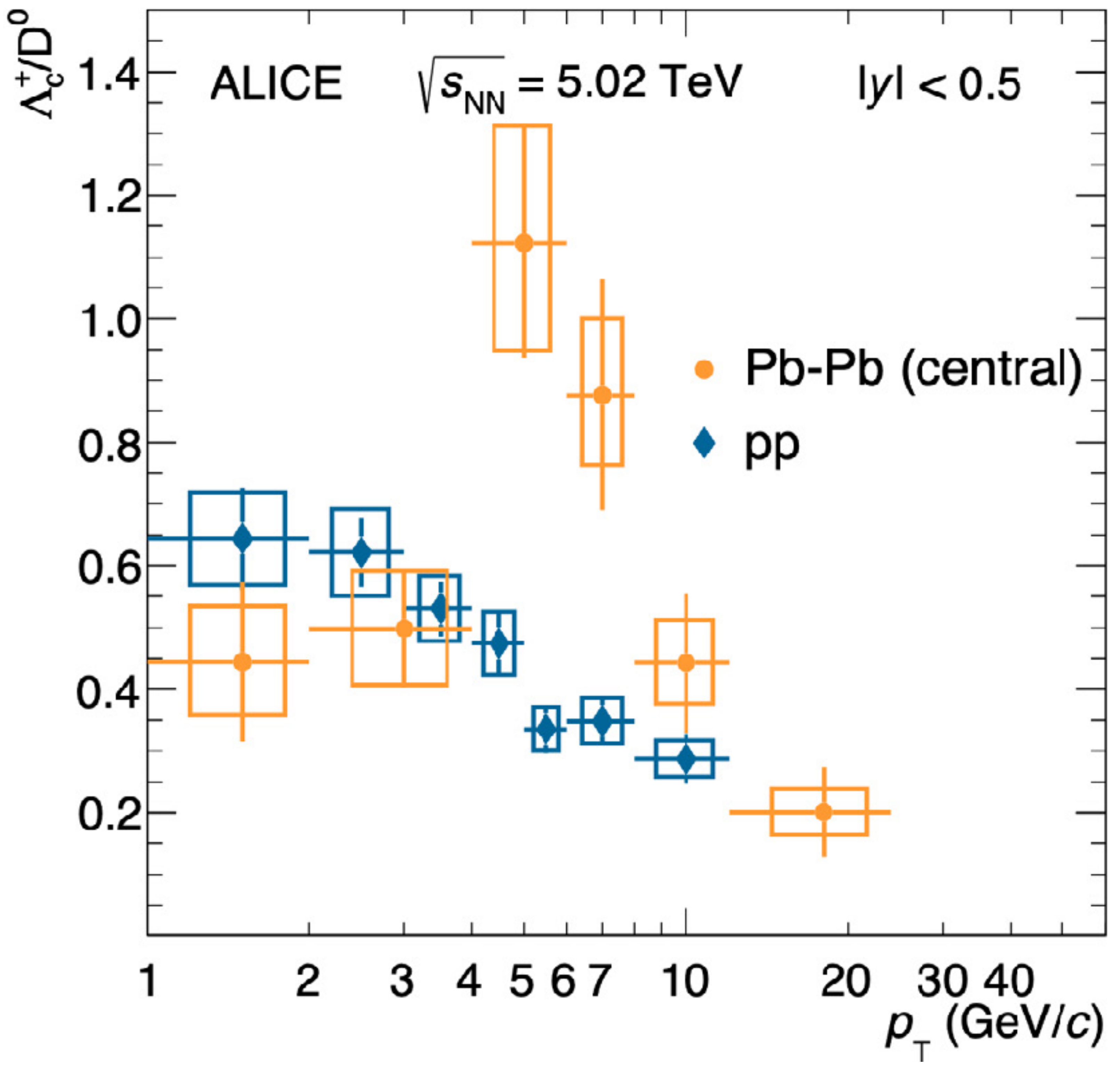


The nuclear modification factor R_{AA} as a function of p_T for 0-10% central Au+Au collisions expected from sPHENIX operation. The error bars show the statistical uncertainties only.

HEAVY FLAVOR



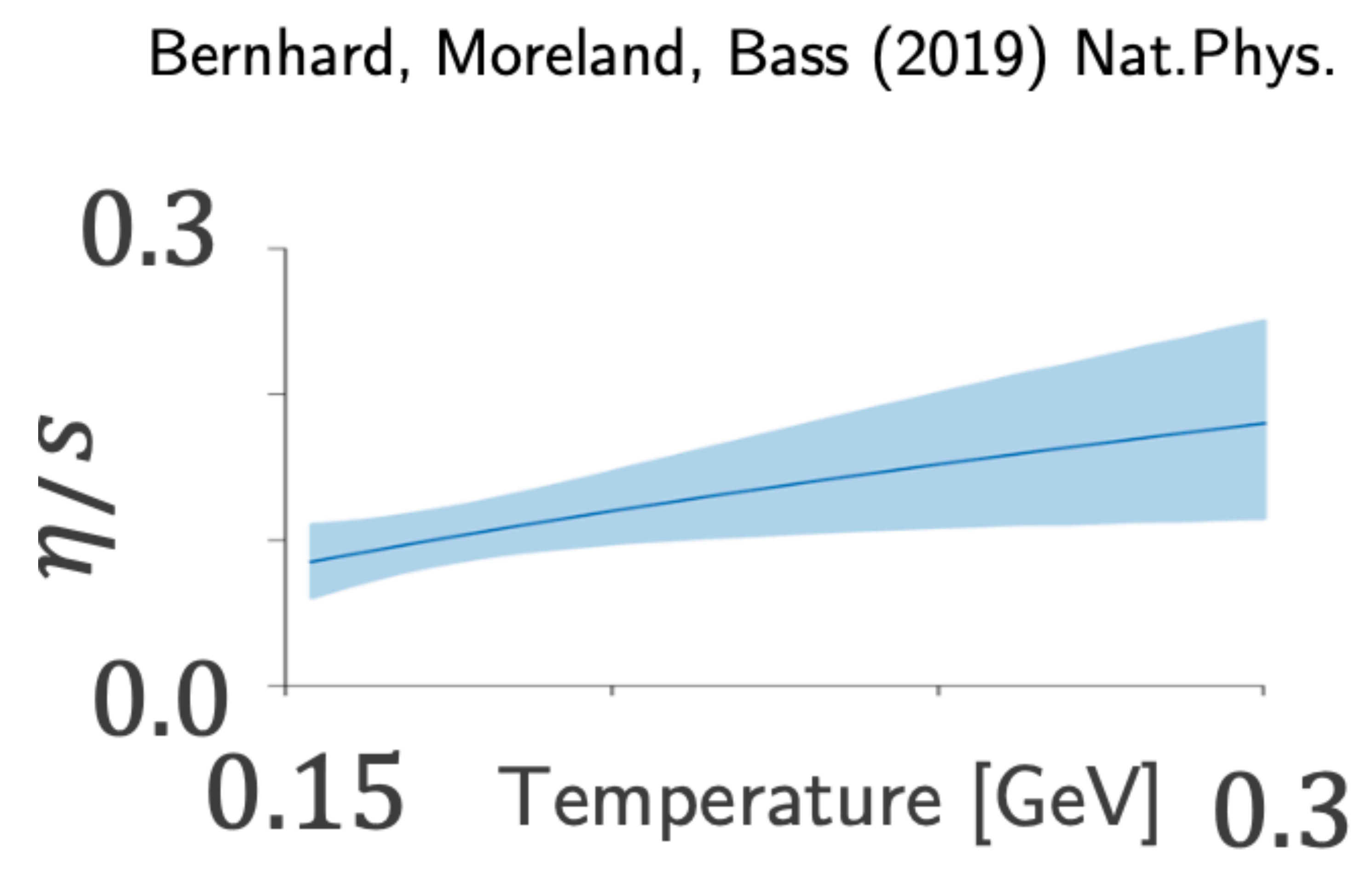
- **Detector upgrades and improved luminosities** at RHIC and LHC: Unprecedented precision of various heavy flavor observables, including precision R_{AA} and v_2 for open bottom hadrons
- sPHENIX can measure **nuclear modification of Upsilon states** with high precision in Au+Au collisions, including the Upsilon(3S) state
- New RHIC + LHC data will provide stronger **constraints on bottomonium suppression models**

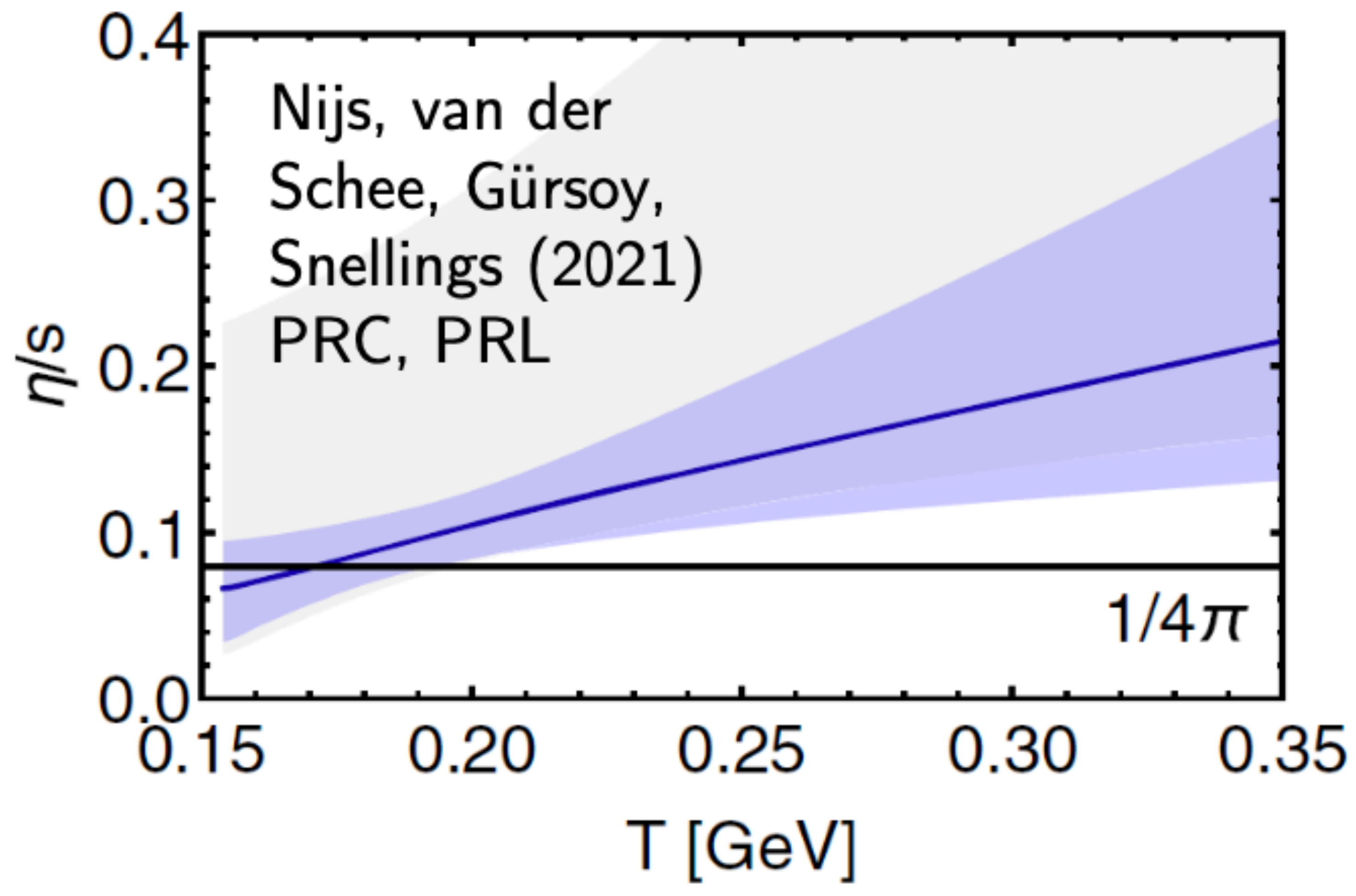


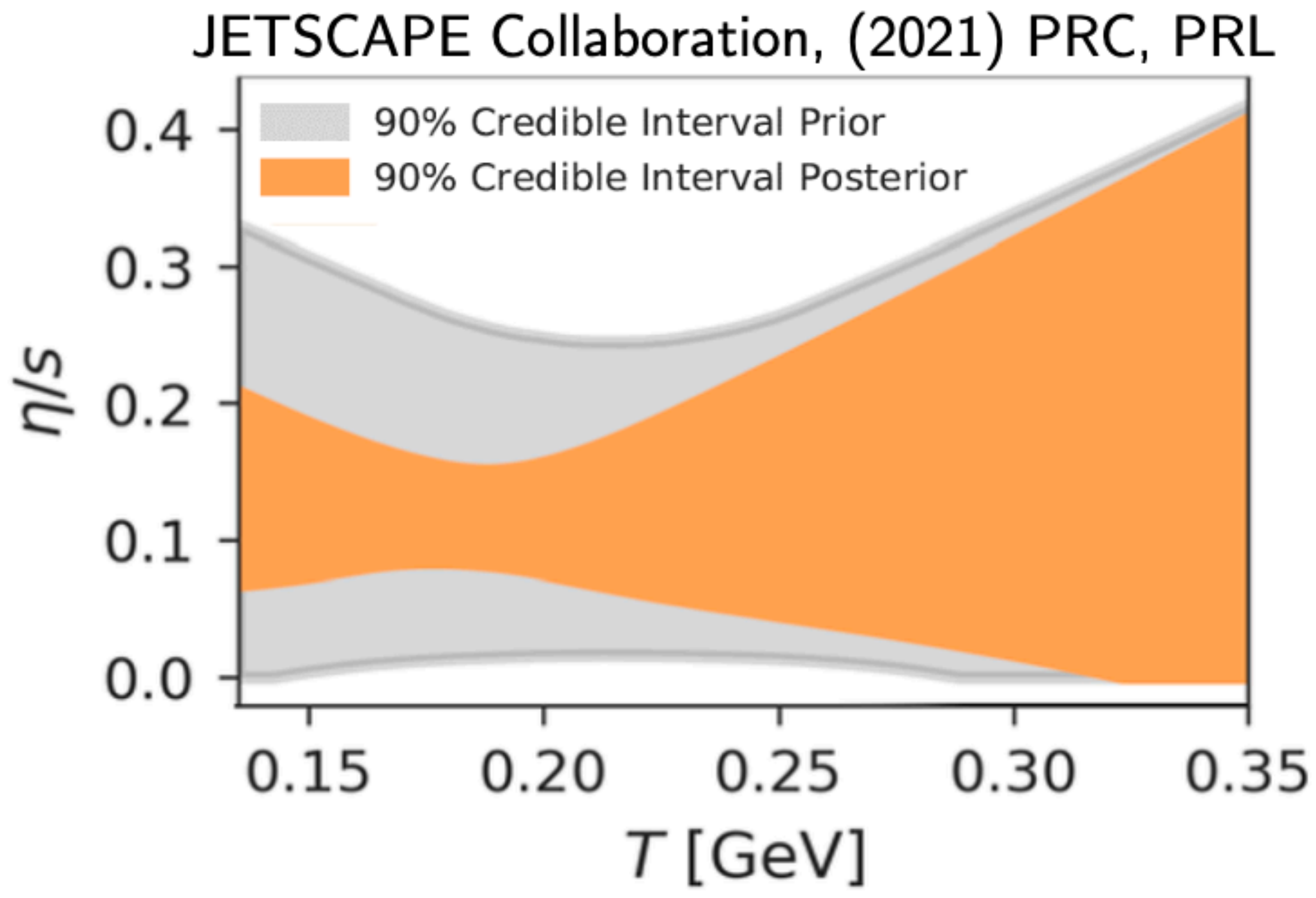
ALICE measurement of Λ_c^+/D^0
Enhancement explained with coalescence in Pb+Pb collisions

SIDEBAR: COMPREHENSIVE EXTRACTION OF PHYSICS THROUGH MULTIFOLD OBSERVABLES

- Make use of wide range of different obserables, collision energies and systems
- Higher integrated luminosities at HL-LHC and detector upgrades at ALICE, ATLAS, CMS, LHCb
- Build modular frameworks; Collaborative efforts like theory collaborations
- Bayesian analyses:







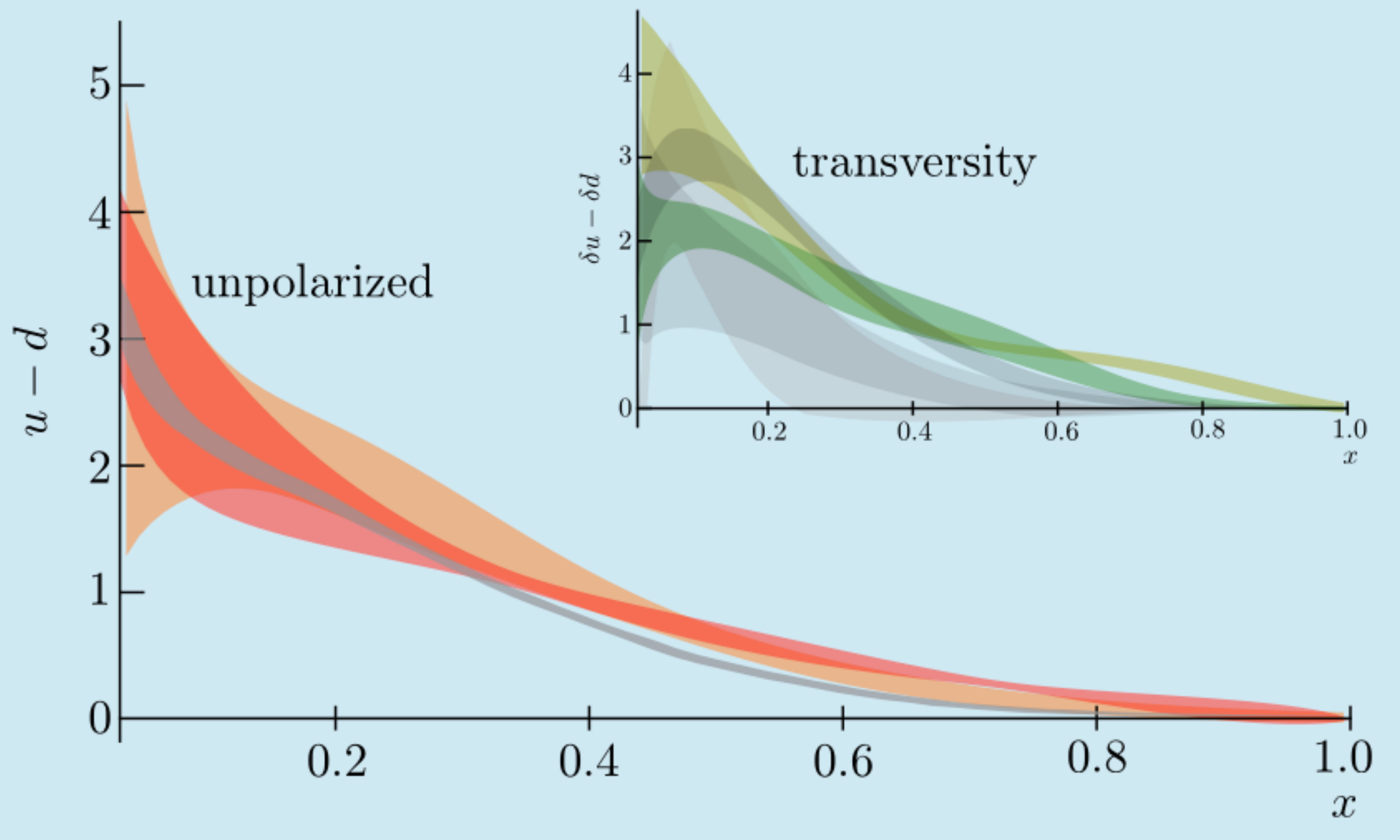
UTILIZE THE BROAD PHYSICS REACH OF HEAVY ION COLLISIONS

Heavy ion collisions provide an incredible amount of information that allows for physics studies far beyond the QGP and even QCD:

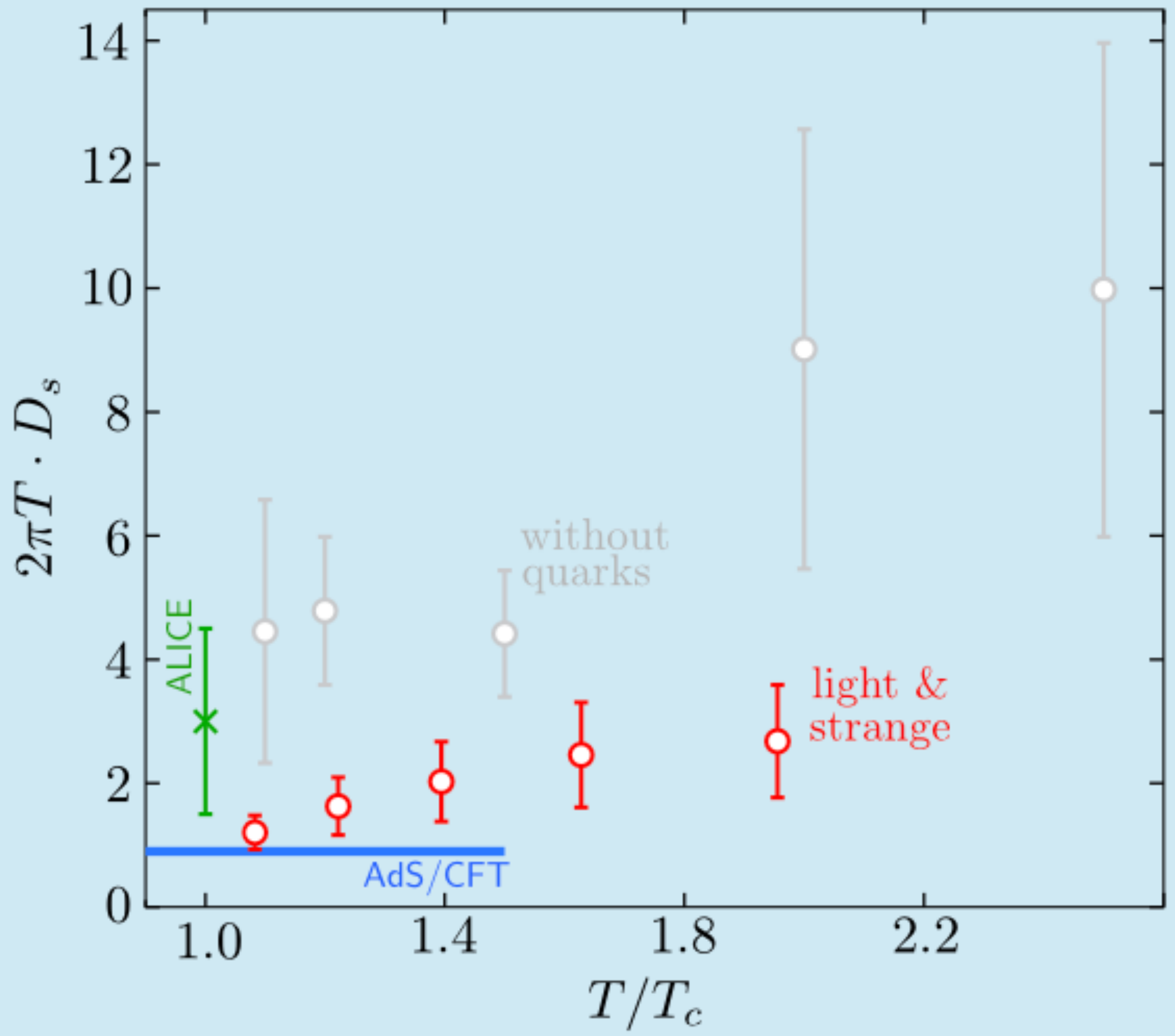
- **Ultra-peripheral collisions** to access quark and gluon distributions inside nuclei, study gluon saturation
- Study **quantum anomalies** via the chiral magnetic effect
- **Vorticity** of the QGP from spin polarization measurements
- Study the detailed **nuclear structure** of the colliding nuclei
- Synergy with **nuclear astrophysics**: Equation of state, hydrodynamics

SIDEBAR: TRANSFORMATIVE PROGRESS IN LATTICE QCD

Sidebar with 4 examples:
PDFs from the lattice, hadron–hadron scattering amplitudes (incl. coupled channel scattering), axial charge of the nucleon, heavy quark diffusion coefficient



Unpolarized and transversity proton PDFs from Lattice QCD compared to global fits to experimental data (gray)



Heavy quark diffusion vs. temperature

SUMMARY

- LRP released October 6 2023
- R1: Capitalize on investments: includes operation of ATLAS, CEBAF, FRIB, and RHIC and increased research budget
- R2: Neutrinoless double beta decay
- R3: EIC
- R4: Additional projects and strategic opportunities: includes QIS, AI/ML, nuclear data, and HPC.
- Theory is highlighted in recommendations 1-3 and throughout the science chapter

https://nuclearsciencefuture.org/

https://science.osti.gov/-/media/np/nsac/pdf/202310/NSAC_LRP_2023.pdf

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- Theory (Filomena Nunes)
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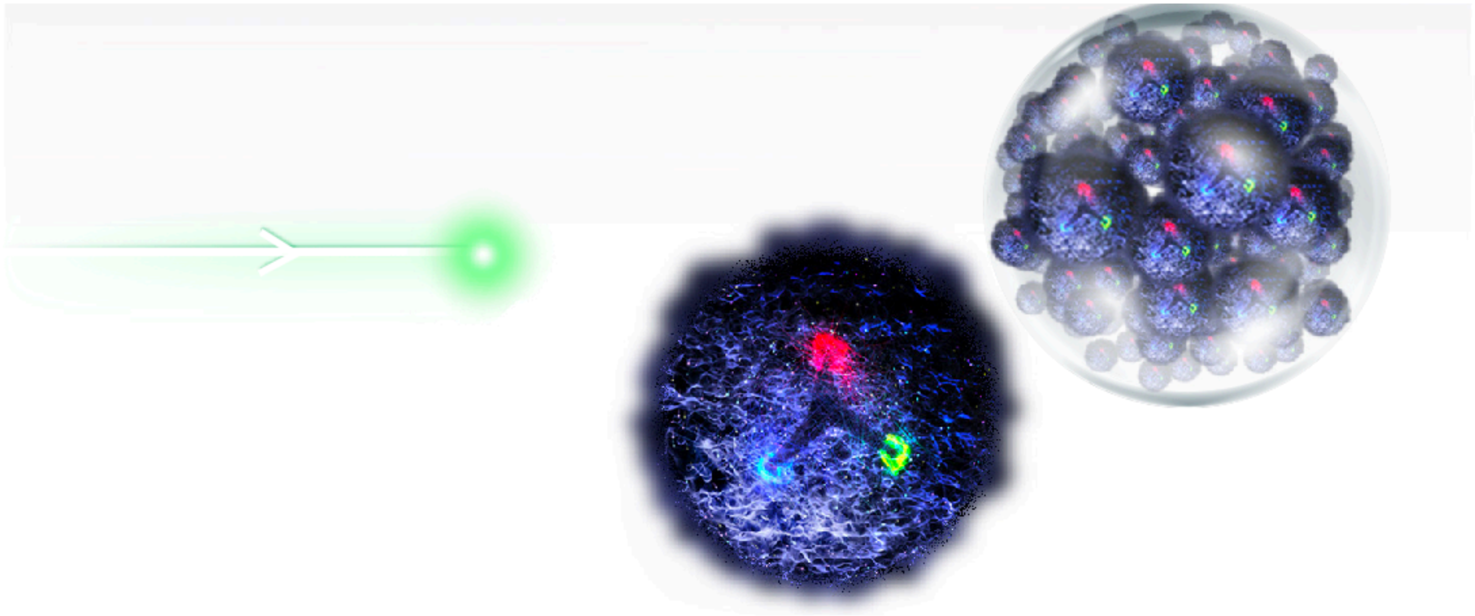
- Impact and synergies with other fields (Jorge Piekarewicz)
- Facilities (Haiyan Gao)
- International Context (Krishna Kumar)
- Budget (Sherry Yennello)

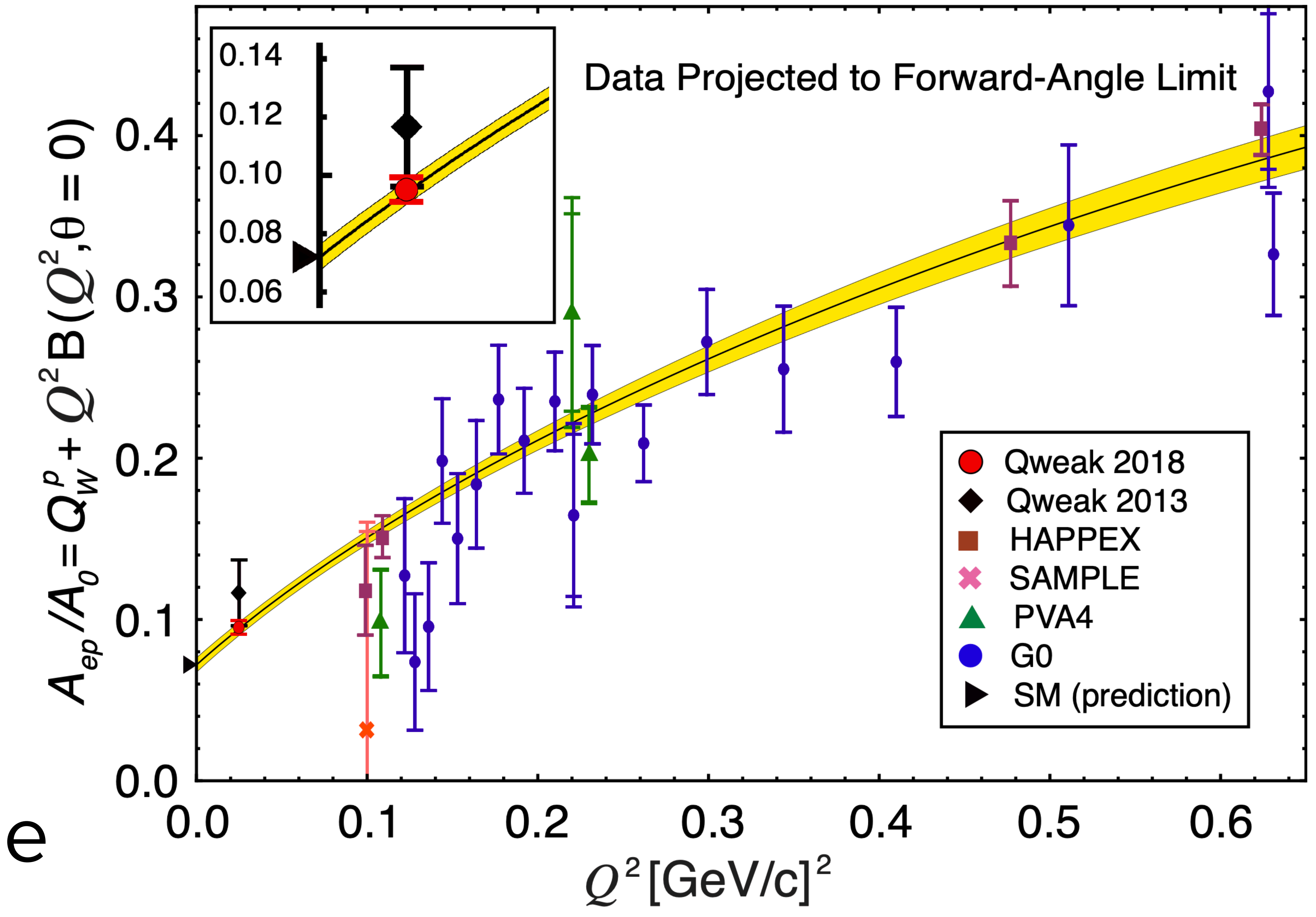
COLD QCD

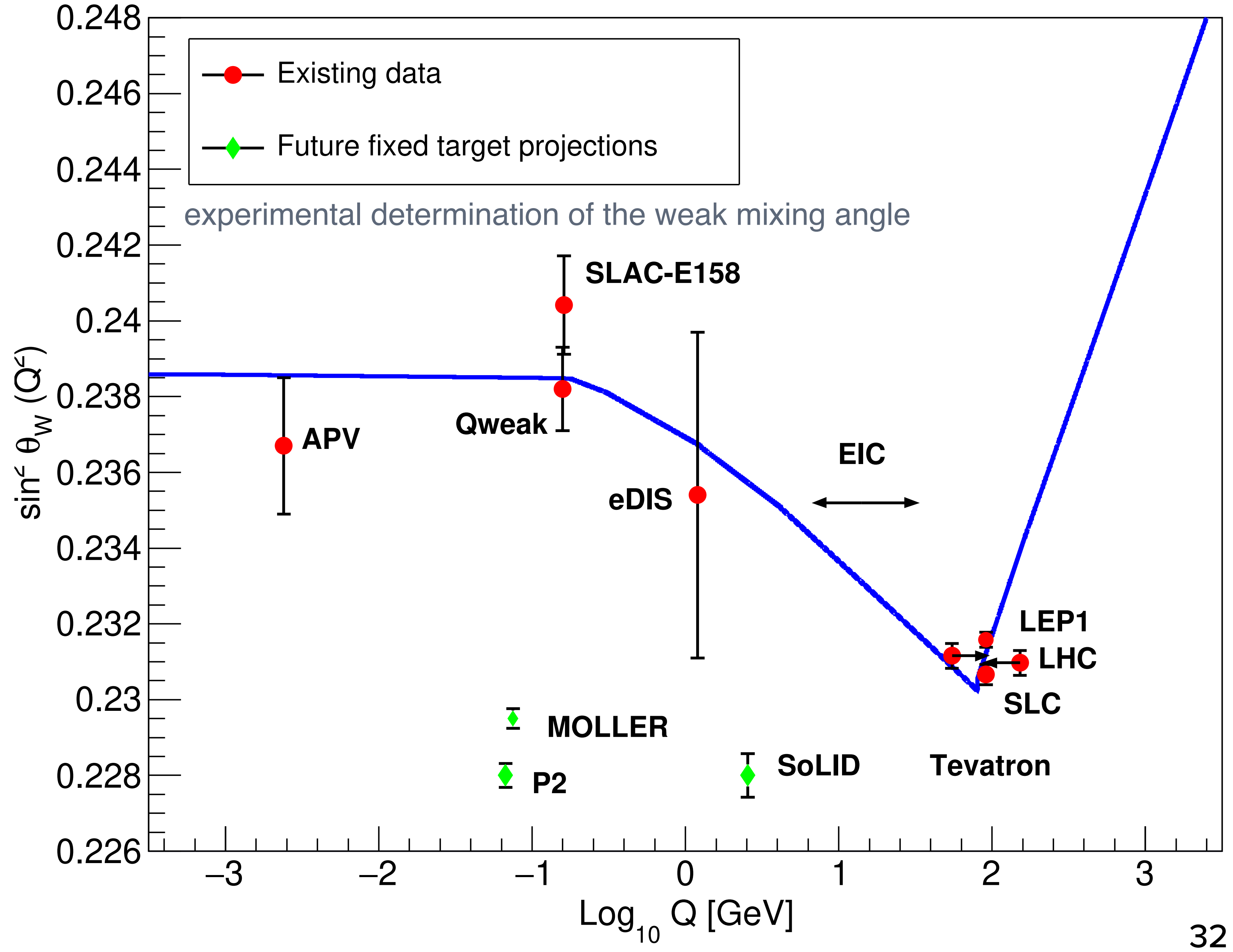


Connections to other NP fields

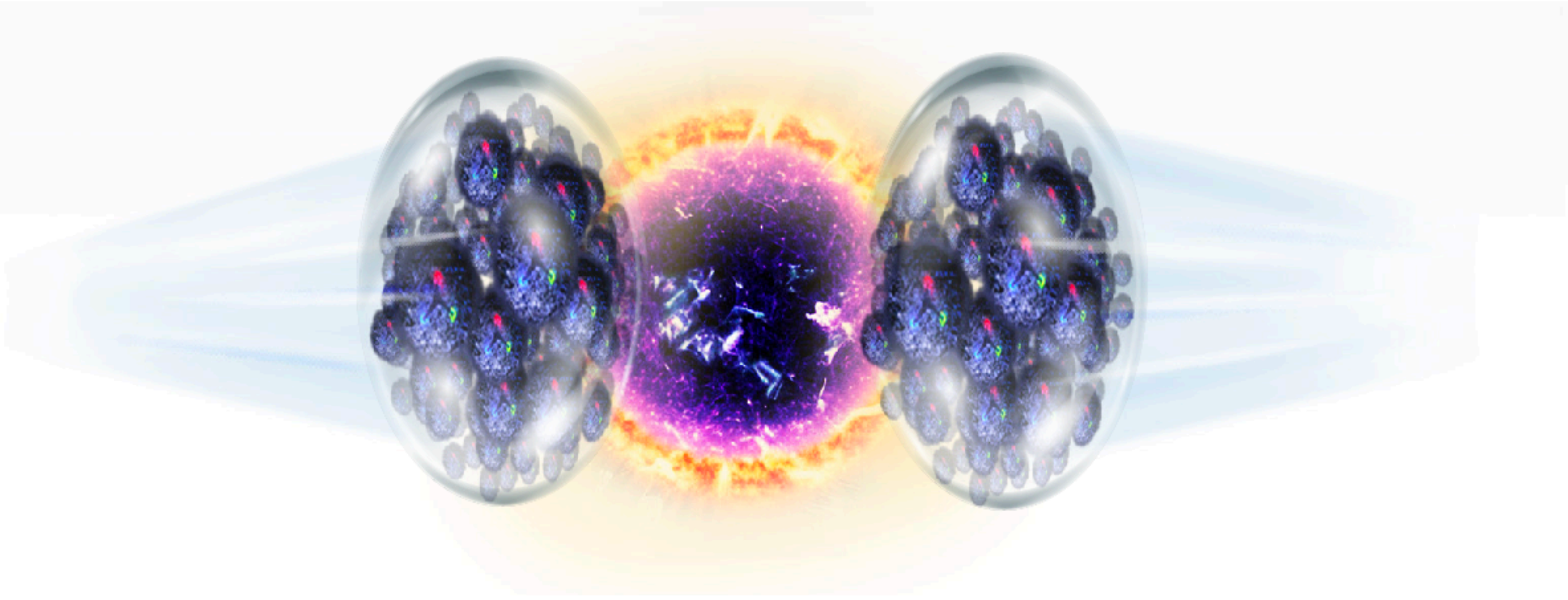
Parity-Violating Electron Scattering (PVES), electroweak, and beyond the standard model physics

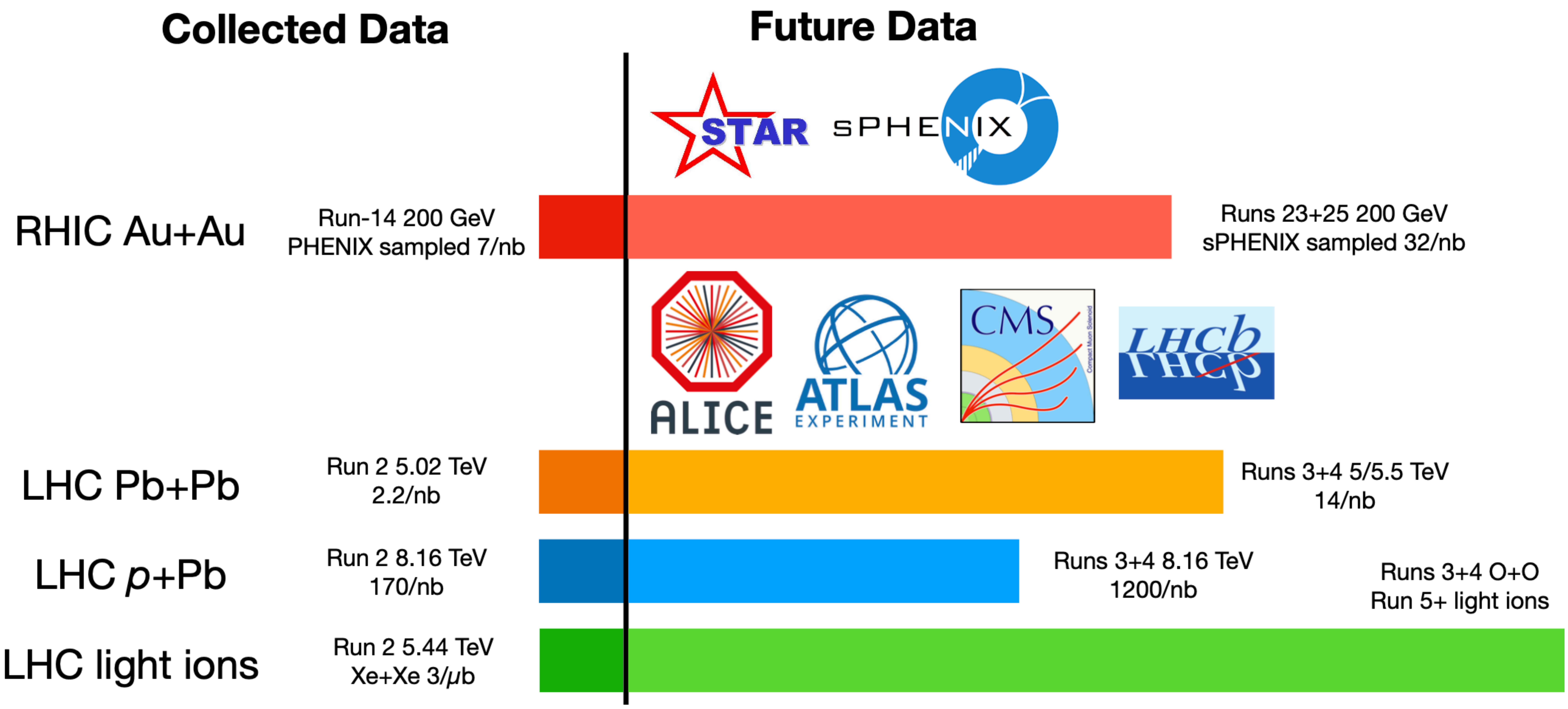
- QWeak experiment at JLab measured the proton weak charge
- *Purely leptonic weak neutral current interaction: MOLLER*
- *Parity violation DIS and effective electron-quark couplings: SoLID PVDIS*
- PREX-2 and CREX: Direct, model independent measurement of the difference between the weak and electromagnetic form factors





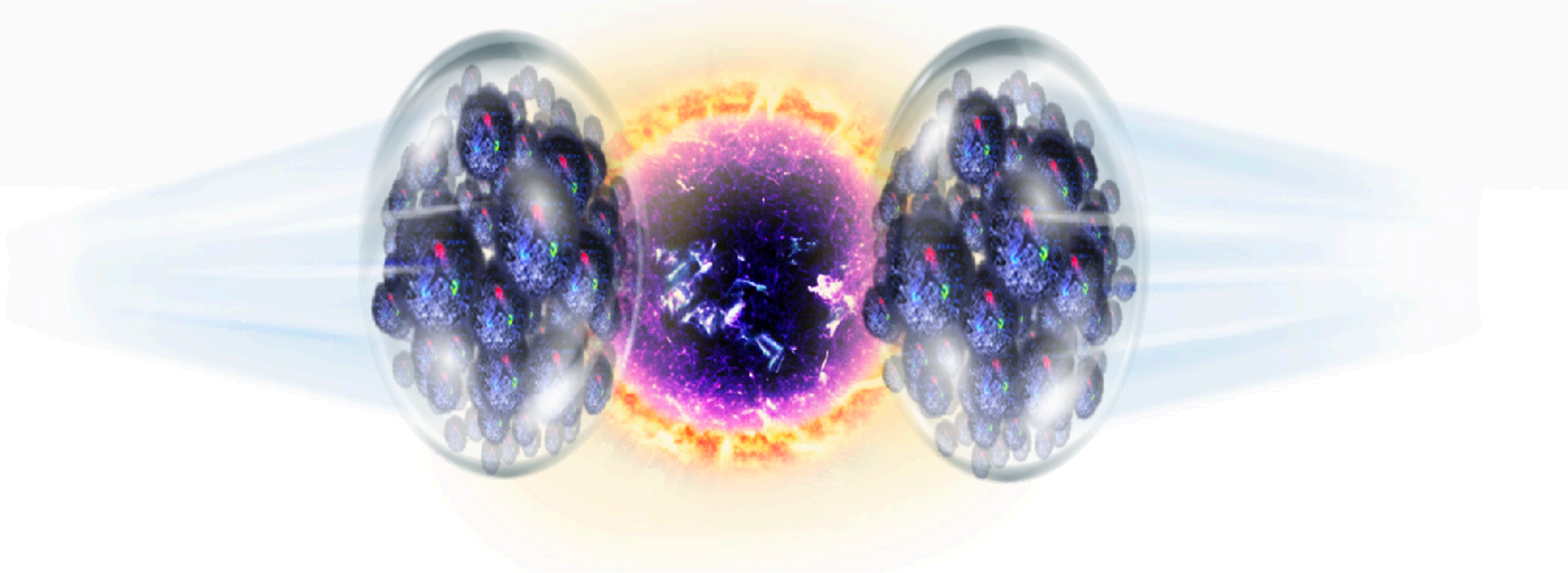
HOT QCD





from D. Perepelitsa at QCD Town Meeting

INITIAL STATE AND SMALL SYSTEMS



Initial state and small *x*

- Increasing experimental precision requires **improved modeling** (nuclear deformation, short-range correlations, and alpha-clustering, sub-nucleon structure, 3 dimensions, gluons+quarks, all conserved charges, intermediate pre-equilibrium evolution before hydro, …)
- **Range of collision systems** to disentangle initial state from final state properties
- **Ultra-peripheral collisions** can constrain the spatial and momentum structure of nuclei at small *x*. ALICE FoCAL can look for gluon saturation in particular

Small size limit of the Quark Gluon Plasma

- **New data on small systems** will come from sPHENIX and STAR p+Au runs
- Existing and new data, especially with intermediate systems (e.g. O+O) can enable **mapping from small to large systems**, and e.g. help better understand **jet quenching in small systems**
- Strongly interacting final state in UPCs?