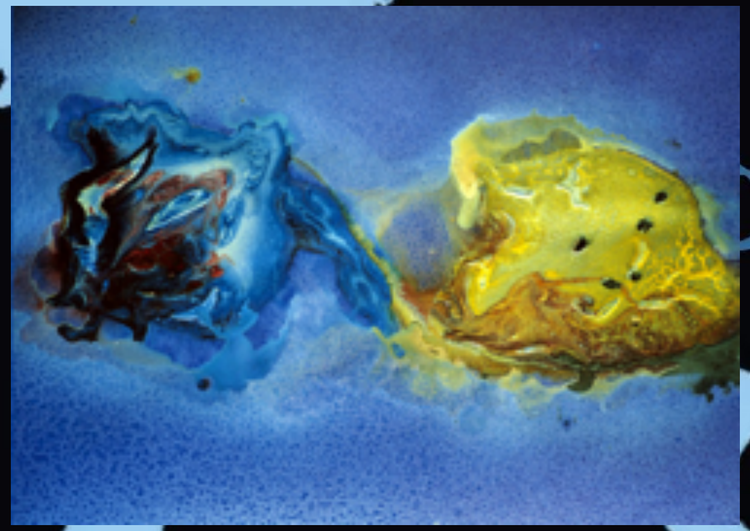
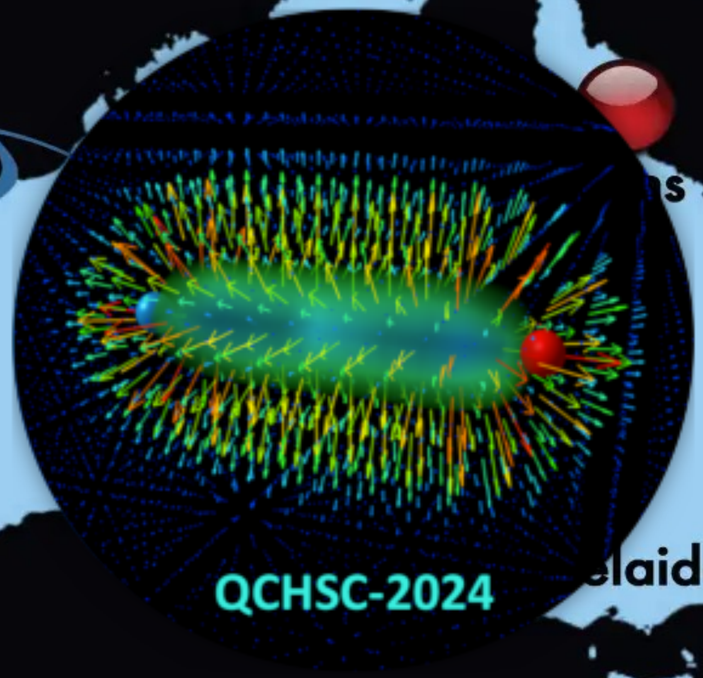
30 YEARS OF CONFINEMENT!

1994

Lake Como



2024



In the south at Thessaloniki

Makedonian
Queen
Yiota Foka
Chair 2016

In the south at Thessaloniki

Cleopatra

King of Vikings

Jonivar Skullerud, Viking Chair in the 2018 Maynooth edition

further north in our journey…..

Unmasked Thor

further north in our journey…..

Masked THOR

Alexander Rothkop
Chair 2020 (virtual), 2022
Stavanger

XVth Quark Confinement and the Hadron Spectrum Conference

2022 - University of Stavanger

Masked Thor Hammer and the

AYSE-BIRRANGULU

AYSE-BIRRANGULU

From Australian aboriginal Sources, **''Birrangulu''** was a Primordial Goddess (Creation), who served both as Bringer of Life and in some cases – death. However, if properly venerated, She would produce floods (from rain). Far from being ‘’destructive”, such deluges were seen as beneficial. Bringing rich silt (soil), helped with an abundance crops (and harvest).

and in fact…

DEEDS of AYSE-BIRRANGULU

and in fact…

DEEDS of AYSE-BIRRANGULU

Bringing all our community to see new stars

and in fact…

DEEDS of AYSE-BIRRANGULU

Bringing all our community to see new stars

With a lot of success: 270 participants, 28 plenary talks, 3 round tables, more than 270 parallel talks, a poster session

Giving structure to the conference: first time that all parallel talks are perfectly synchronized!

Gathering all the funds for a very expensive edition

Integrating young generations in the conference, see master class (credits also to Yiota and Jonivar), outreach, public talk

Preparing an overarching very stimulating scientific program acting as a melting pot of strong interaction cultures

Introducing an Asia-Pacific regional committee

Bringing the conference to Australia

Organizing Committee
U. Adelaide

Tony Thomas

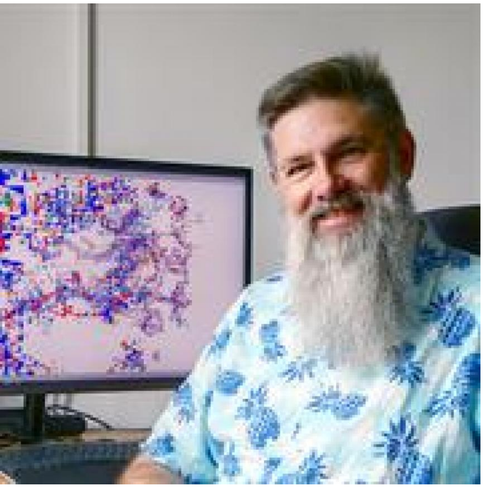
Martin White

N.Brambilla Co-chair (TUM)

Ayse Kizilersu CHAIR

Wally Melnitchouk (Jlab)

Ross Young

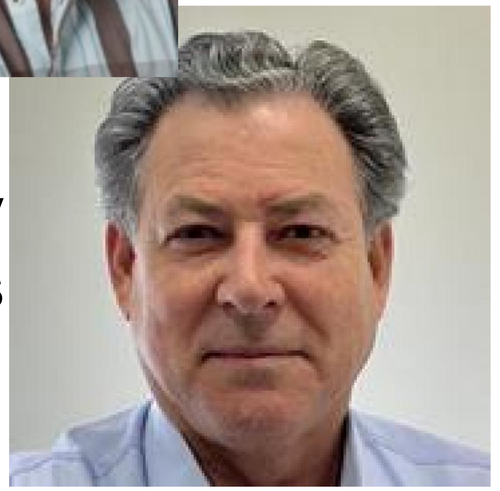


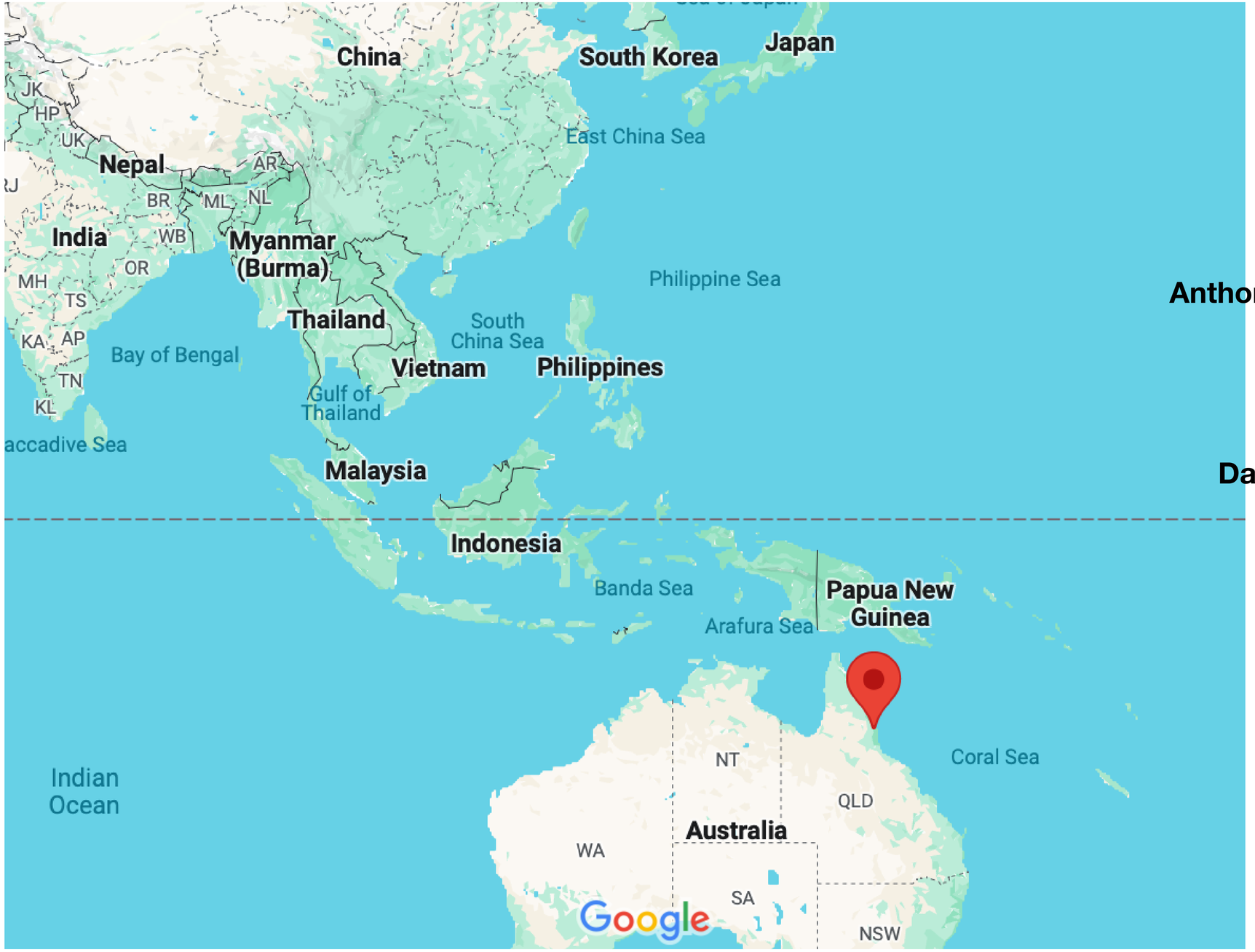
Derek Leinweber

James Zanotti

covering all areas of the QCHS in fact served as conveners in all sessions

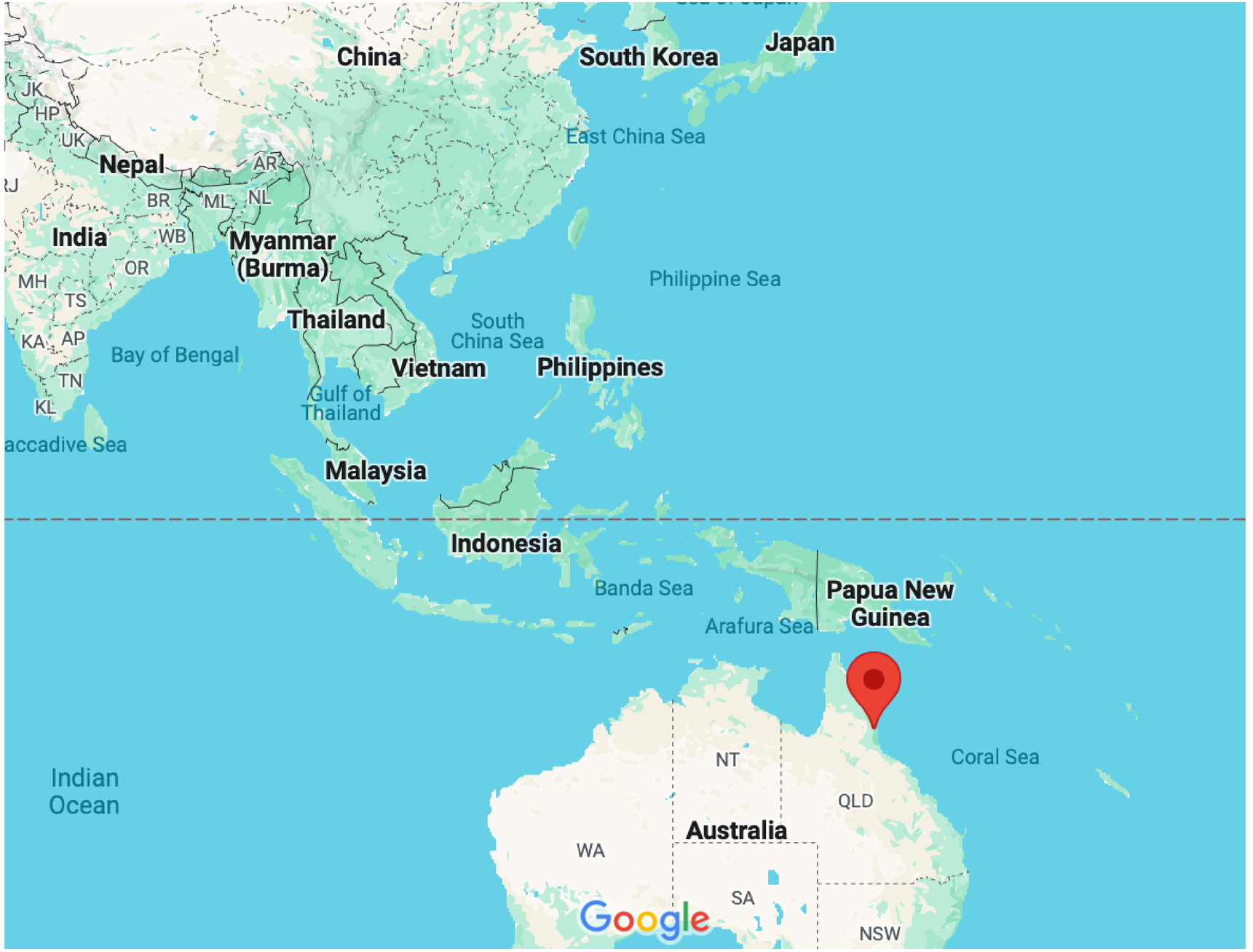
Anthony Williams



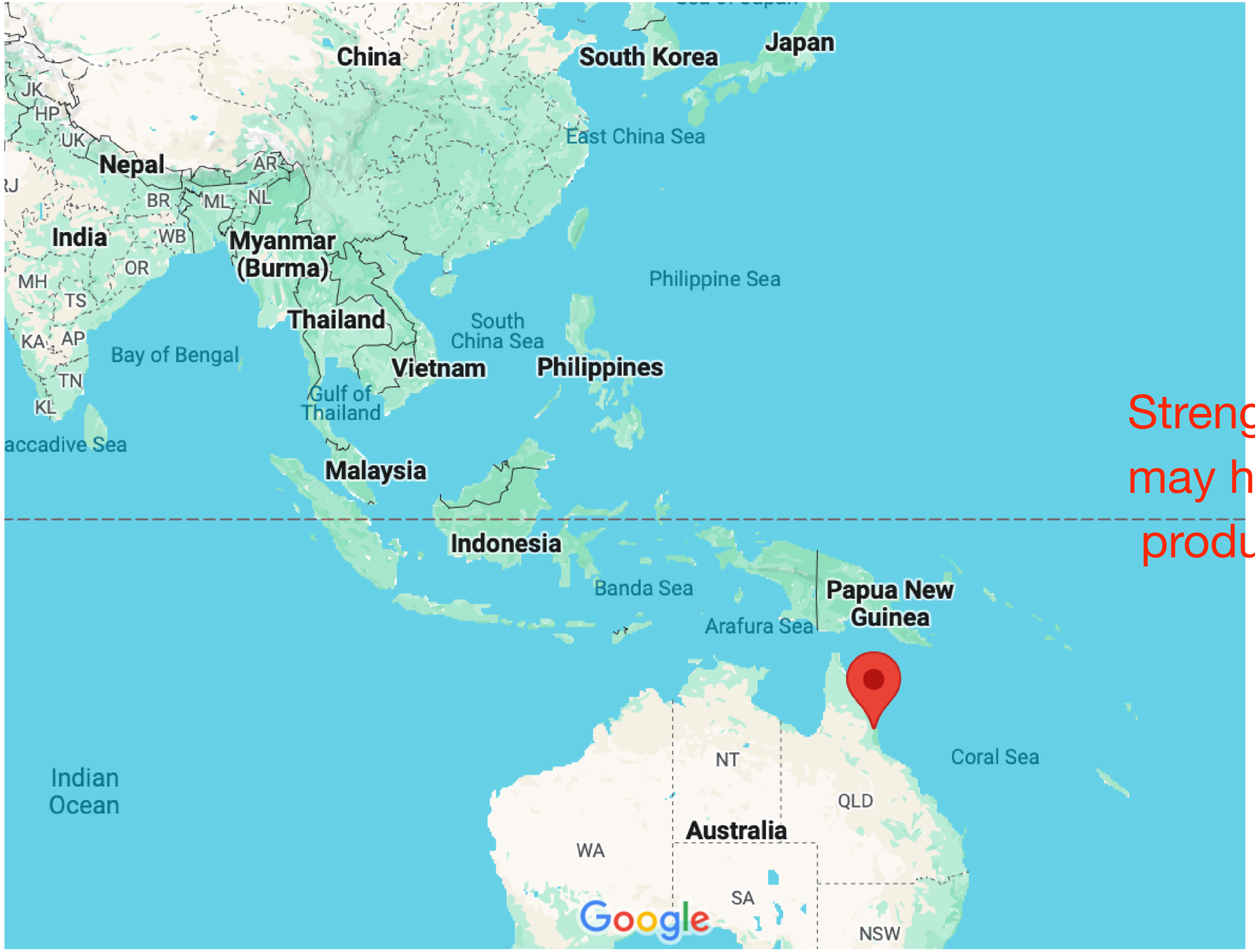


Asia- Pacific Regional Organising Committee

-Nicole Bell (U. Melbourne)
Jiunn-Wei Chen (Nat. Taiwan U.)
Victor Flambaum (UNSW)
Anthony Francis (National Yang Ming Chiao Tung
Tetsuo Hatsuda (RIKEN iTHEM)
Masakiyo Kitazawa (Kyoto U.)
Pyungwon Ko (Korean Inst. Adv. Study)
Su Houng Lee (Yonsei U.)
David Lin (National Yang Ming Chiao Tung U.)
Zhanwei Liu (Lanzhou U.)
Makoto Oka (RIKEN)
Craig Roberts (Nanjing U.)
Xiaoyan Shen (IHEP)
Cedric Simenel (Australian National U.)
Hideo Suganuma (Kyoto U.)
Ping Wang (IHEP)
Jiajun Wu (UCAS)
Chang-Zhang Yuan (IHEP)
Shi-Lin Zhu (Pekin U.)

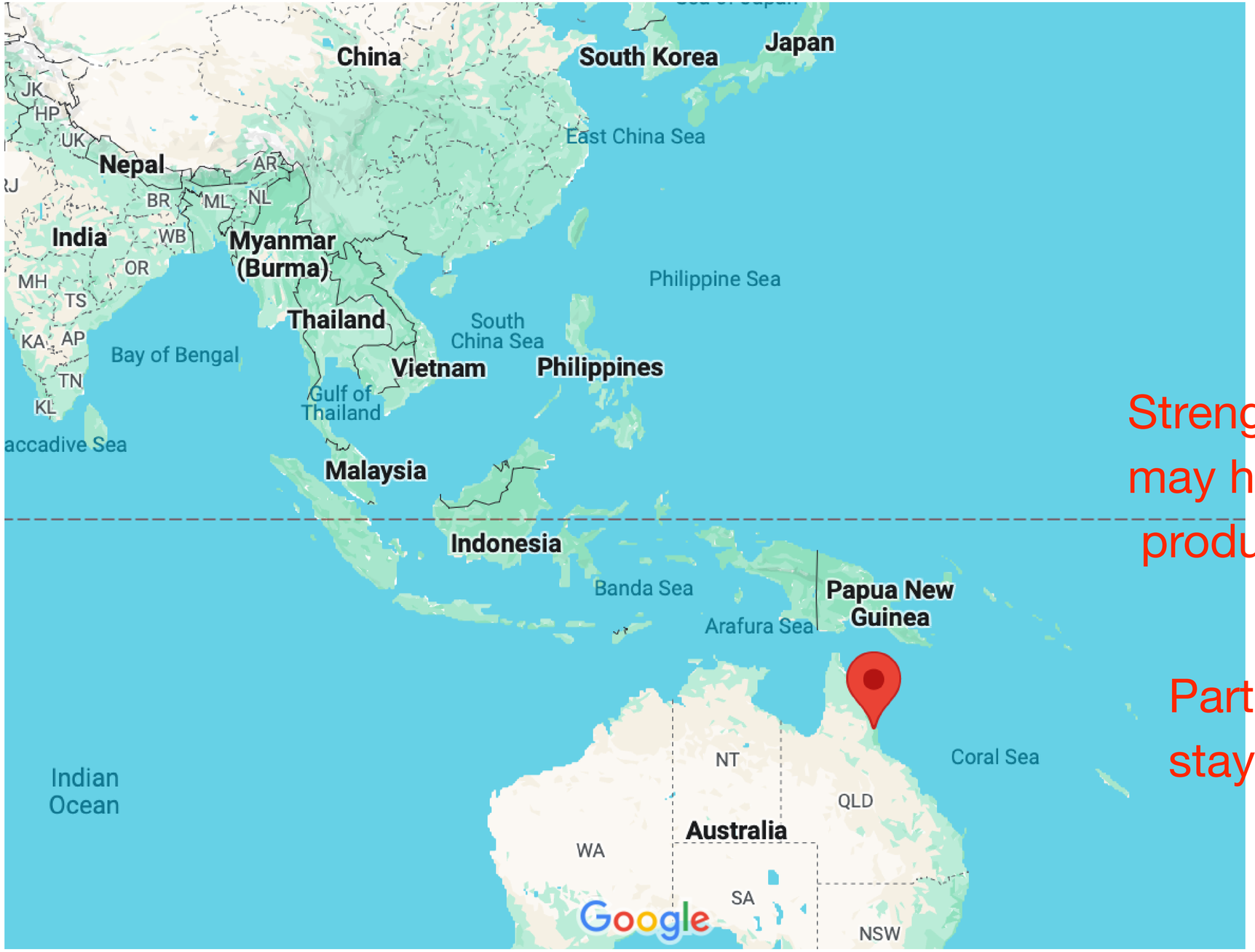


The Pacific area including Australia, Japan, Corea, China and Taiwan is a strong interaction high intensity reserach area



The Pacific area including Australia, Japan, Corea, China and Taiwan is a strong interaction high intensity reserach area

Strengthen ties and networks may help to increase, funds and productivity



The Pacific area including Australia, Japan, Corea, China and Taiwan is a strong interaction high intensity reserach area

Strengthen ties and networks may help to increase, funds and productivity

Participants confined so far stayed for the whole week

International Advisory Committee

A. Andrianov (St. Petersburg SU, Russia)

M. Baker (U. of Washington, USA)

G. Bodwin (Argonne NL, USA)

A. Buras (TU München, Germany)

G. Colangelo (Bern U., Switzerland)

M. Creutz (Brookhaven NL, USA)

G. Ecker (U. of Vienna, Austria)

E. Eichten (Fermilab, USA)

M. Faber (TU Vienna, Austria)

P. Foka (GSI, Germany)

N. Kaiser (TU München, Germany)

G. Krein (UNESP, Brazil)

W. Lucha (HEPHY, Austria)

T. Mannel (Siegen, Germany and Oxford, UK)

A. Manohar (U. of California, USA)

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G. Prosperi (U. of Milan, Italy)

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J. E. Ribeiro (IST Lisboa, Portugal)

A. Rothkopf (U. of Stavanger, Norway)

H. Sazdijan (IPN Orsay, France)

A. Shindler (Aachen U., Germany)

J.I. Skullerud (Maynooth U., Ireland)

M. Shifman (U. of Minnesota, USA)

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H. Toki (Osaka U., Japan)
A. Vairo (TU München, Germany)

Two commemorative talks
Sasha Andrianov (Domenech Espriu)
Carlo Guaraldo (Catalina Curceanu

Concert by Kalliopi Petrou and Tommaso Dorigo

Public Talk Tamara Davis

Poster session, Wine and poster prizes

Conference dinner with Jamie Seymour talk

The Unknown: tomorrow trips to The coral reef, the rainforest, the Aboriginal experience….

Backbone and living structure of the QCHS are the Sessions and the Conveners!

A: Vacuum structure and confinement

Mechanisms of quark confinement (vortices, monopoles, calorons…) and the structure of the vacuum in non-Abelian gauge theories. Chiral symmetry breaking, and the Dirac spectrum in the low-momentum region. Studies of ghost and gluon propagators. Confining strings and flux tubes, their effective actions. Renormalons and power corrections. Interface between perturbative and non-perturbative physics.

Conveners: D. Antonov (ITP, U. Heidelberg), J. Greensite (San Francisco State U.), M. Faber (Technical U., Vienna), T. Cohen (U. Maryland) ***Local Convener:*** D. Leinweber (U. Adelaide

Focus Subsection Topology and confinement at borderlines of particle physics and condensed matter: emergent confinement in cold atoms and Anderson criticality in the QCD deconfinement transition.

Conveners: I. Horvath (U. Kentucky), J. C. Halimeh (Ludwig Maximilian U. of Munich), M. C. Diamantini (U. Perugia)

B: Light Quarks

Chiral and soft collinear effective theories; sum rules; lattice calculations; Schwinger-Dyson equations; masses of light quarks; light-quark loops; phenomenology of light-hadron form factors, spectra and decays; structure functions and generalised parton distributions; exotics and glueballs; experiments.

Conveners: B. Ketzer (Bonn U.), M. Constantinou (Temple U.), H. Sazdjian (IJCLab, Orsay), N. G. Stefanis (Ruhr U. Bochum) Local Conveners: J. Zanotti, A. Kizilersu (U. Adelaide)

C: Heavy Quarks

Heavy-light mesons, heavy quarkonia, heavy baryons, heavy exotics and related topics: phenomenology of spectra, decays, and production; effective theories for heavy quarks (HQET, NRQCD, pNRQCD, vNRQCD, SCET); sum rules for heavy hadrons; lattice calculations of heavy hadrons; heavy-quark mass determinations; experiments.

Conveners: H. S. Chung (Korea U.), R. Mussa (INFN Torino), J. Soto (U. Barcelona), A. Vairo (Technical U. Munich), F. Knechtli (U. Wuppertal) Local Convener: U. Can (U. Adelaide)

D: Deconfinement

QCD at finite temperature; quark-gluon plasma detection and characteristics; jet quenching; transport coefficients; lattice QCD and phases of quark matter; QCD vacuum and strong fields; heavy-ion experiments; experiments.

Conveners: Y. Foka (GSI), J. Ghiglieri (SUBATECH, Nantes), P. Petreczky (BNL), F. Ringer (JLab), J. Pawlowski (U. Heidelberg)

Backbone and living structure of the QCHS are the Sessions and the Conveners!

E: QCD and New Physics

Physics beyond the Standard Model from hadronic physics, including precision experimental data and precision calculations.

Conveners: W. Detmold (MIT), S. Gardner (U. Kentucky), W. Marinkovic (ETH Zürich), G. Ricciardi (U. Napoli), W. Korsch (U. Kentucky) ***Local Convener:*** R. Young (U. Adelaide)

F: Nuclear and Astro-particle Physics

Nuclear matter; nuclear forces; quark matter; neutron and compact stars.

Conveners: M. Alford (Washington U. St. Louis), D. Blaschke (U. Wroclaw), J. Marton (SMI Vienna), A. Schmitt (U. Southampton), E. Epelbaum (Ruhr U. Bochum) ***Local Conveners:*** A.W. Thomas (U. Adelaide), W. Melnitchouk (JLab, USA & U. Adelaide)

G: Strongly-Coupled Theories and Dark Matter

Hints on the confinement/deconfinement mechanisms from supersymmetric and string theories; strongly-coupled theories beyond the Standard Model; applications of nonperturbative methods of QCD to other fields; strongly-coupled scenarios of BSM and Dark Matter.

Conveners: D. Espriu (U. Barcelona), Z. Fodor (U. Wuppertal), R. Pasechnik (Lund U.), V. Vento (U. Valencia), M. Spannowsky (U. Durham) ***Local Convener:*** A.G. Williams (U. Adelaide

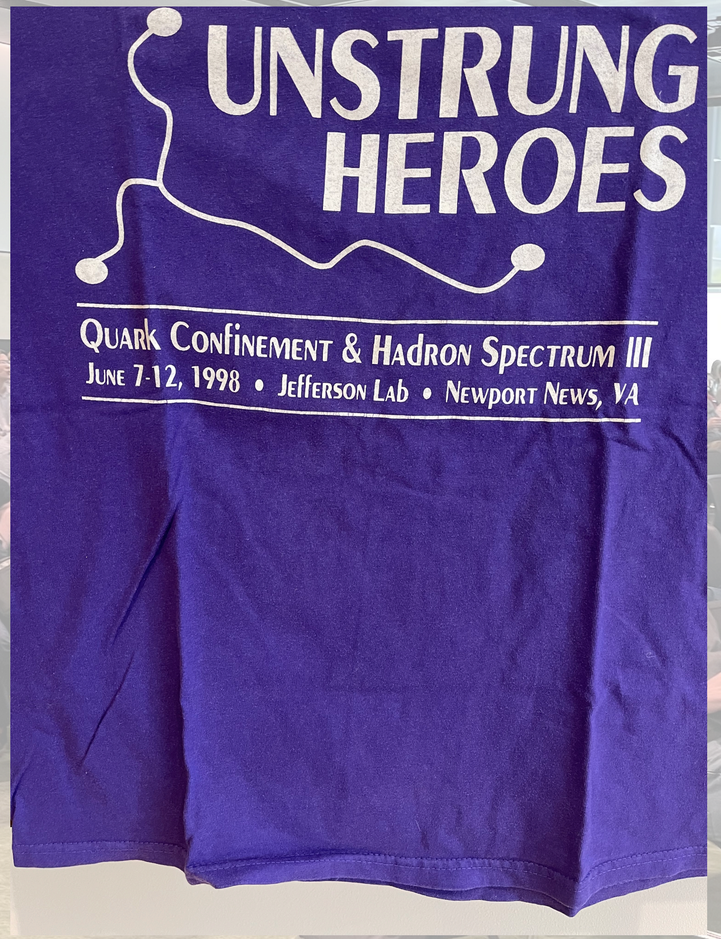
H: Statistical Methods for Physics Analysis in the XXIst Century

Machine learning techniques; data fitting and extraction of signals; new developments in unfolding methods; averaging and combination of results.

Conveners: T. Dorigo (U. Padova), S. V. Gleyzer (U. Alabama), E. Rinaldi (Quantinuum) ***Local Convener:*** M. White (U. Adelaide)

And of course the unstrung heroes of the confinement saga are the participants that endured DAYS OF TRAVEL to arrive here!

even carrying a bottle of wine!



unstrung heroes of Nathan Isgur
(and the flux tube) 1998 Jlab edition!

30 YEARS OF CONFINEMENT!

In 30 years that I organized this conference the field showed an immense vitality, the impact and richness of this research field

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It changed very much out of his original name, now obsolete, and developed new sessions on many new areas continuously incorporating novel tools and frontiers

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QCHS puts together practitioners in perturbative physics, effective field theories, models, lattice QCD, finite T and mu, Schwinger-Dysons, Strings, AdS/CFT, ML, holography, computations, functional renormalisation group…… theorists and experimentalists

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Most importantly..

QCD and strongly coupled gauge theories: challenges and perspectives

N. Brambilla*†,[1] S. Eidelman†,[2,3] P. Foka†‡,[4] S. Gardner†‡,[5] A.S. Kronfeld†,[6]
M.G. Alford‡,[7] R. Alkofer‡,[8] M. Butenschön‡,[9] T.D. Cohen‡,[10] J. Erdmenger‡,[11] L. Fabbietti‡,[12]
M. Faber‡,[13] J.L. Goity‡,[14,15] B. Ketzer‡§,[1] H.W. Lin‡,[16] F.J. Llanes-Estrada‡,[17]
H.B. Meyer‡,[18] P. Pakhlov‡,[19,20] E. Pallante‡,[21] M.I. Polikarpov‡,[19,20] H. Sazdjian‡,[22]
A. Schmitt‡,[23] W.M. Snow‡,[24] A. Vairo‡,[1] R. Vogt‡,[25,26] A. Vuorinen‡,[27] H. Wittig‡,[18]
P. Arnold,[28] P. Christakoglou,[29] P. Di Nezza,[30] Z. Fodor,[31,32,33] X. Garcia i Tormo,[34] R. Höllwieser,[13]
M.A. Janik,[35] A. Kalweit,[36] D. Keane,[37] E. Kiritsis,[38,39,40] A. Mischke,[41] R. Mizuk,[19,42]
G. Odyniec,[43] K. Papadodimas,[21] A. Pich,[44] R. Pittau,[45] J.-W. Qiu,[46,47] G. Ricciardi,[48,49]
C.A. Salgado,[50] K. Schwenzer,[7] N.G. Stefanis,[51] G.M. von Hippel,[18] and V.I. Zakharov[11,19]

We highlight the progress, current status, and open challenges of QCD-driven physics, in theory and in experiment. We discuss how the strong interaction is intimately connected to a broad sweep of physical problems, in settings ranging from astrophysics and cosmology to strongly-coupled, complex systems in particle and condensed-matter physics, as well as to searches for physics beyond the Standard Model. We also discuss how success in describing the strong interaction impacts other fields, and, in turn, how such subjects can impact studies of the strong interaction. In the course of the work we offer a perspective on the many research streams which flow into and out of QCD, as well as a vision for future developments.

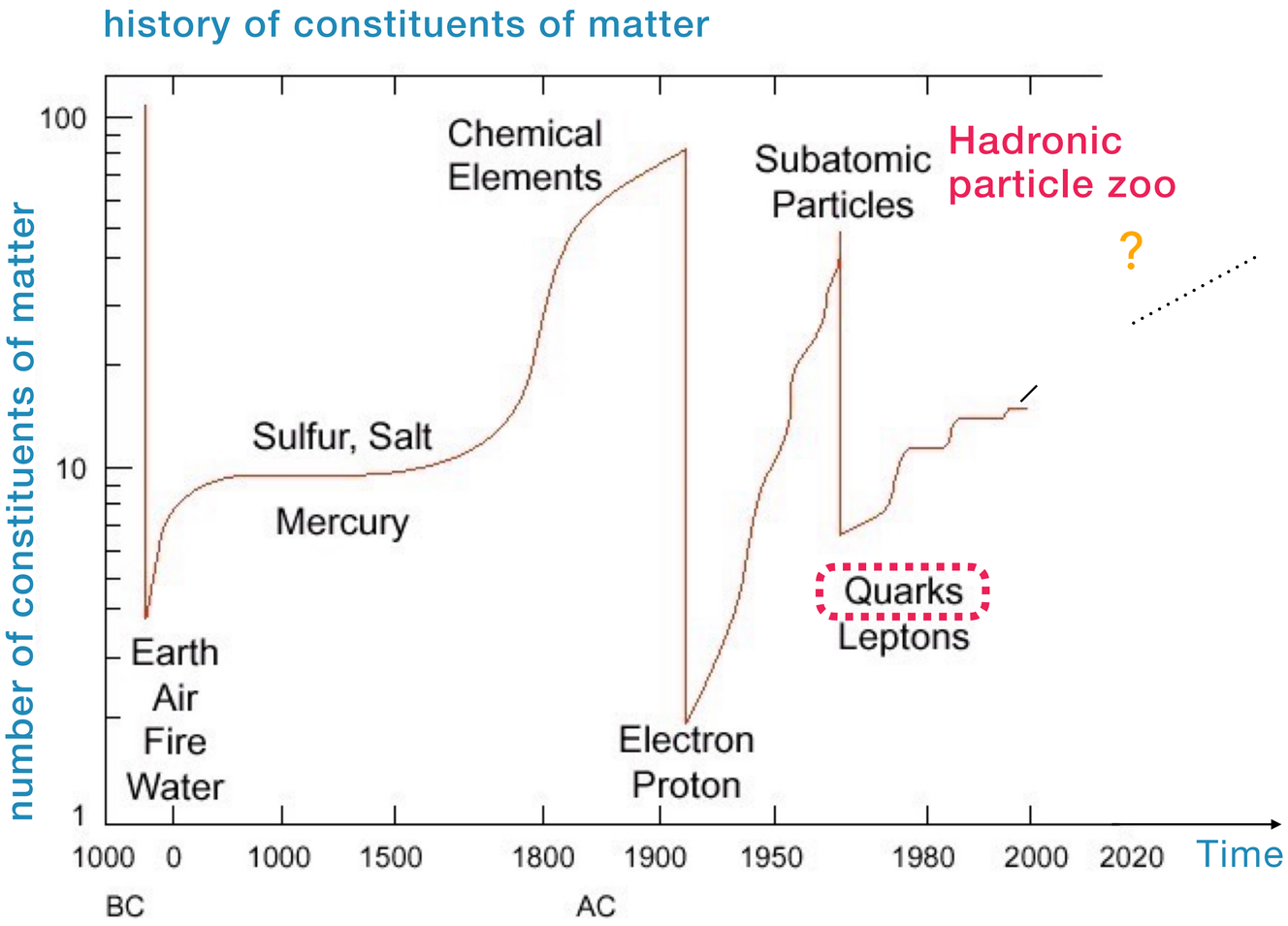
Main themes

Outstanding opportunities

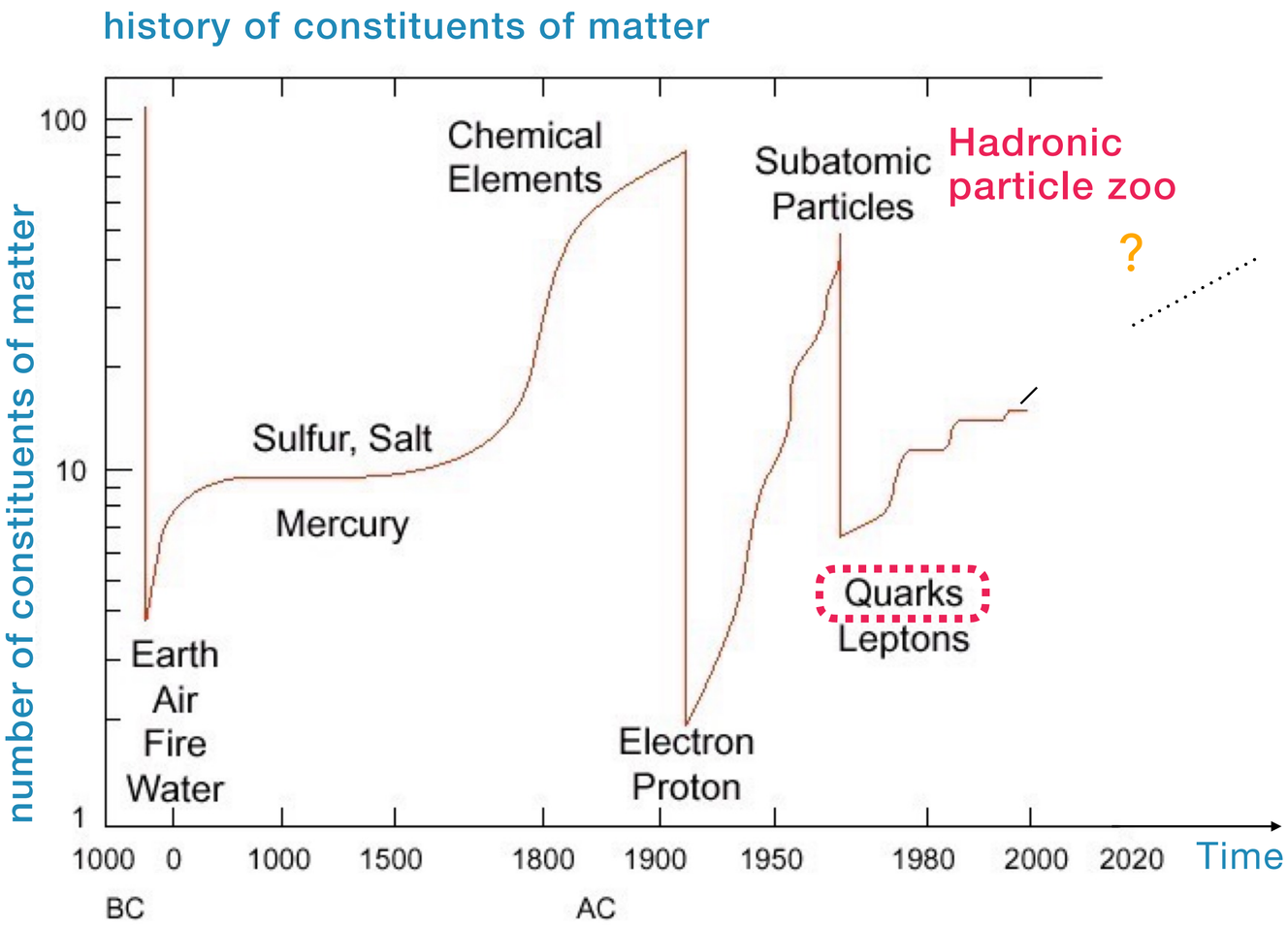
Take away messages

Tasks and to do!

Constituents of matter and fundamental forces

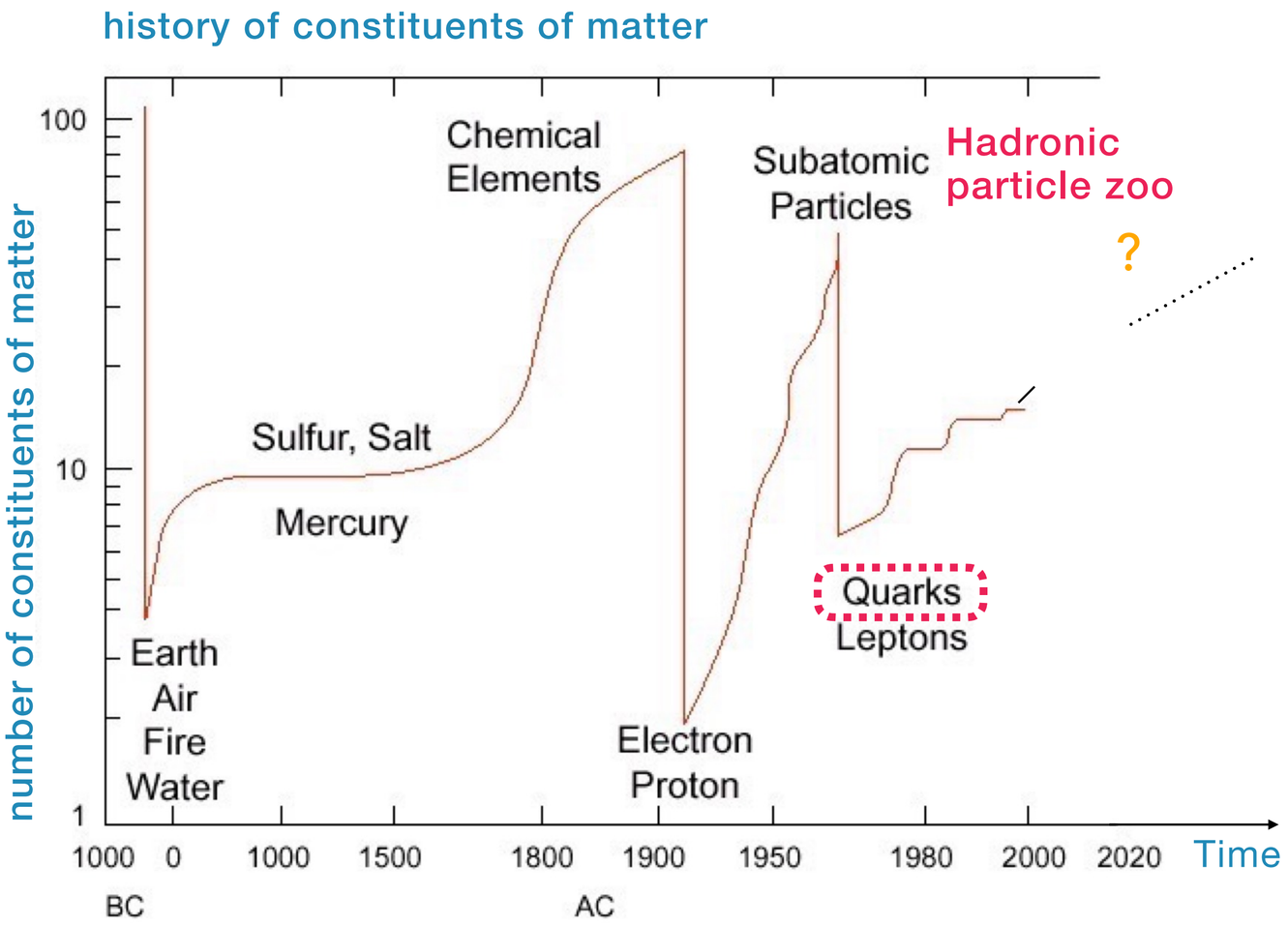


Constituents of matter and fundamental forces



Beyond the standard model of particle physics

Constituents of matter and fundamental forces



Beyond the standard model of particle physics

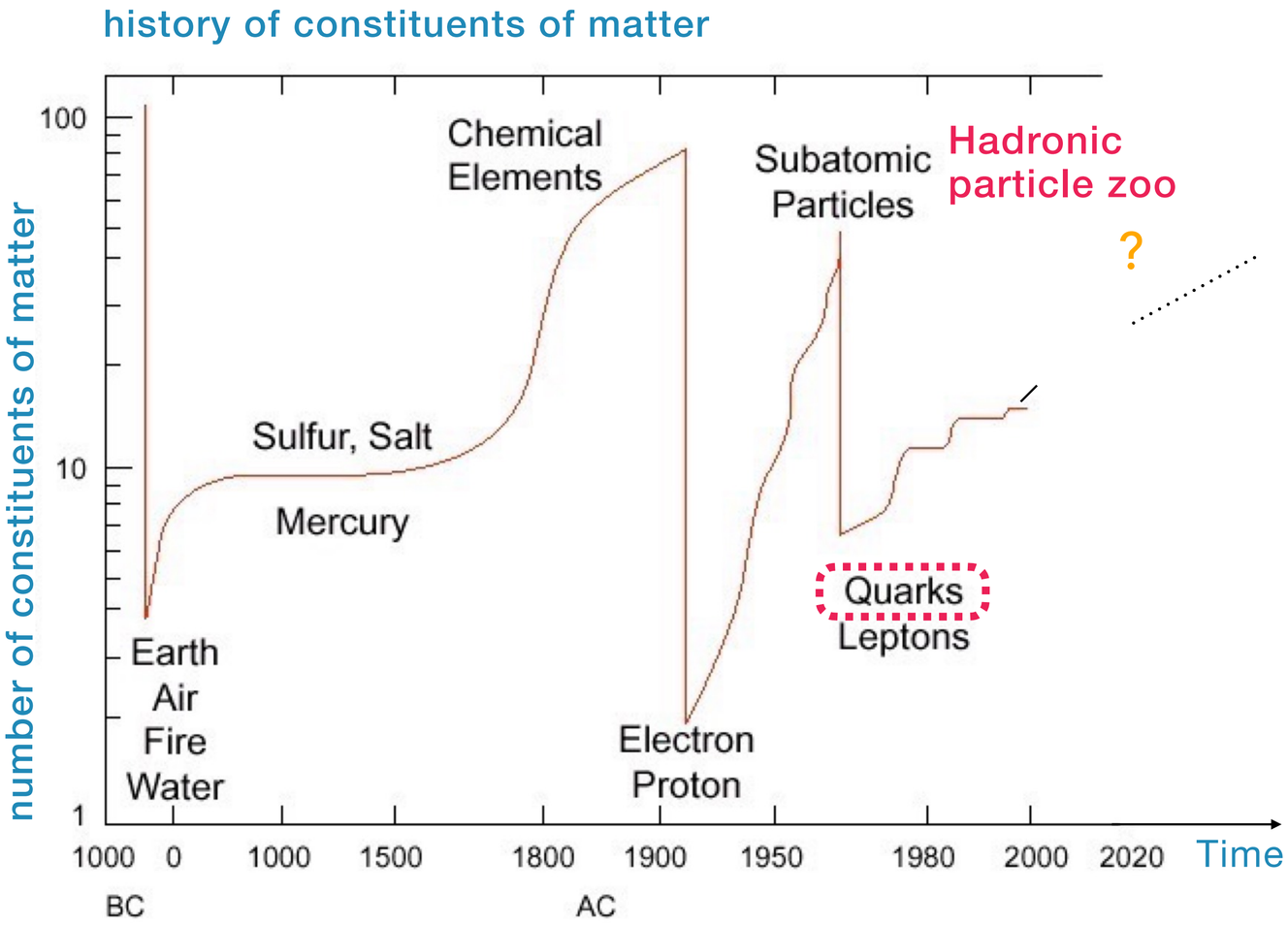
Strongly coupled landscape of BSM (DM, conformal th…)

Sannino, Strumia, Section G/E, Round Table E

Precise calculations at high intensity

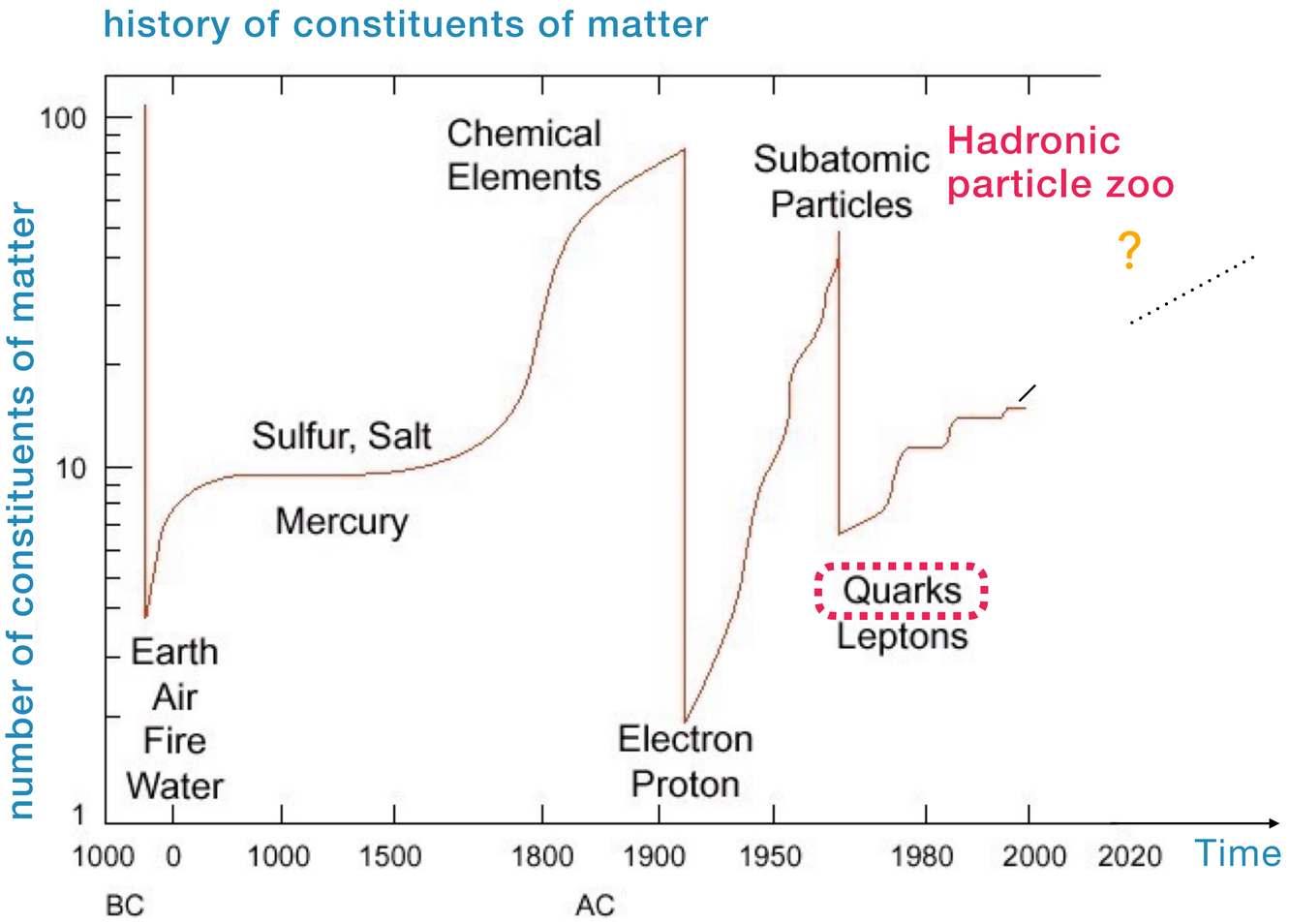
Gupta, Stokes, Walker-Loud,Wise, Section E,B,C

Constituents of matter and fundamental forces



Beyond the standard quark model

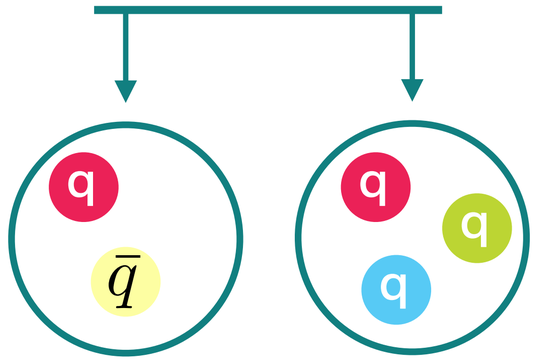
Constituents of matter and fundamental forces



Beyond the standard quark model

Quark Model 1964
Gell-Mann Zweig

observed only



$qq\bar{q}\bar{q}$ $qqqq\bar{q}\ldots$

possible but not observed before XYZ


Hatsuda, Hyodo,
Shen, Briceno,
Vairo, Eichmann,
Aoki Section C,
Round Table C
THE X FILES

Hatsuda, Hyodo,
Shen, Briceno,
Vairo, Eichmann,
Aoki Section C,
Round Table C

THE ECONOMIC TIMES

Scientists at CERN observe three "exotic" particles for first time

JARY 26, 2016 | 3 MIN READ

ysicists May Have Discovered a New "Tetraquark" Particle

Data from the DZero experiment shows evidence of a particle containing four different types of q

WIRED

'Impossible' Particle Adds a Piece to the Strong Force Puzzle

The unexpected discovery of the double-charm tetraquark gives physicists fresh insight into the strongest of nature's fundamental forces.

HARD SCIENCE — JULY 16, 2022

Tetraquarks and pentaquarks: "Unnatural" forms of exotic matter have been found

Scientists have found three new examples of a very exotic form of matter made of quarks. They can yield insights into the early Universe.

INDIA TODAY

Mysterious 'X' particles that formed moments after the big bang found in Large Hadron Collider

CORRIERE DELLA SERA

Nuova straordinaria particella scoperta al Cern: il pentaquark

Consentirà di saperne di più sulla «forza forte» che tiene unite le particelle nel nucleo ... e sui componenti della materia

BBC

Pentaquarks: scientists find new "exotic" configurations of quarks

Scientists have found new ways in which quarks, the tiniest particles known to humankind, group together.

of unknown nature discovered at ... ron sector with tw

Le Monde

Les surprises du tétraquark, « collage » de particules élémentaires

La découverte d'une nouvelle particule à la structure particulièrement stable pourrait permettre aux chercheurs de vérifier leurs théories sur l'interaction forte.

ZEIT ONLINE

Cern-Forscher entdecken neues Teilchen

Die Physiker am Kernforschungszentrum in Genf haben die Existenz des Pentaquark-Teilchens nachgewiesen. Bislang war es nur in theoretischen ... beschrieben worden.

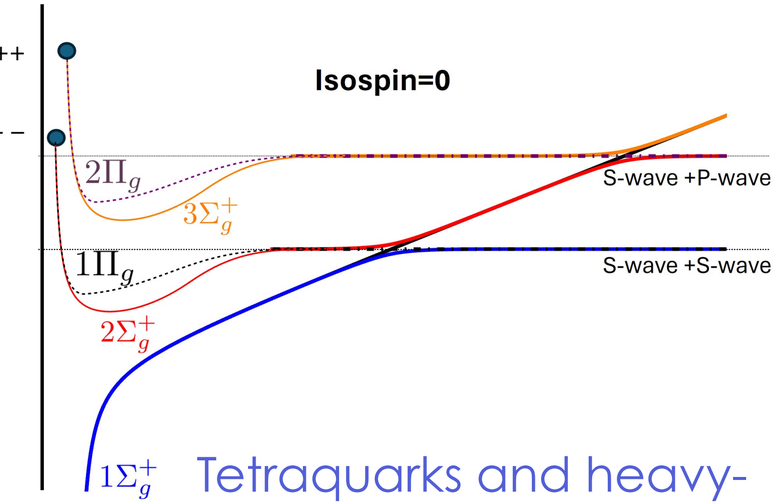
LHCb discovers longest-lived exotic matter yet

08/04/21 | By Sarah Charley

The newly discovered tetraquark provides a unique window into the interactions of the particles that make up atoms.

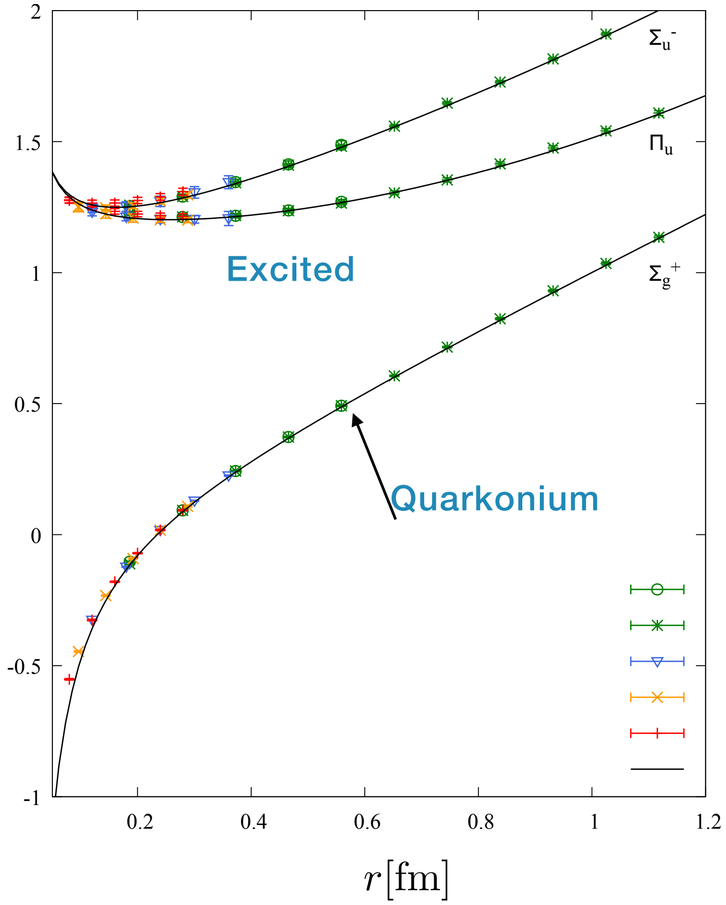
symmetry

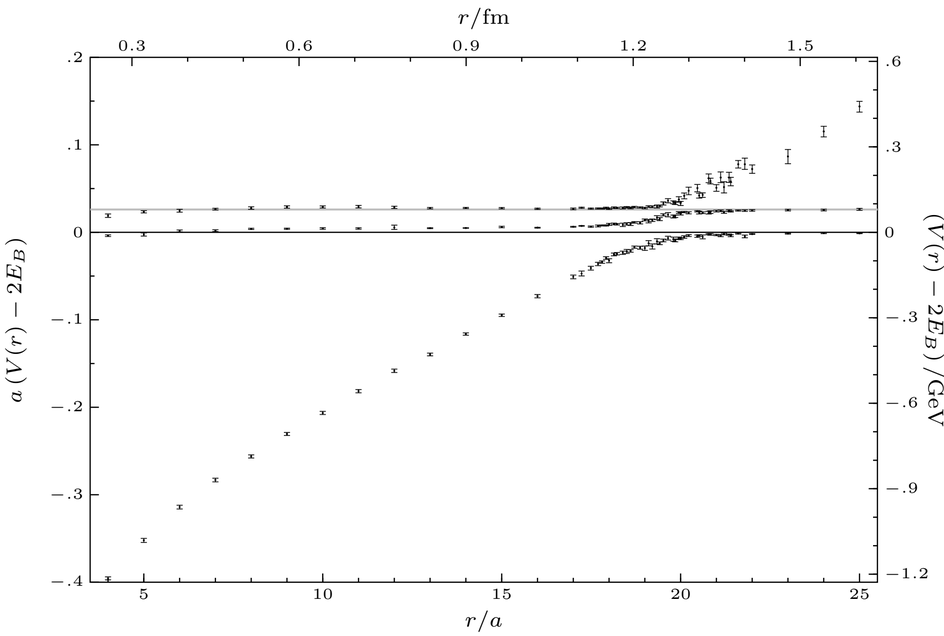
XYZ are a formidable opportunity to learn more about the fundamental strong force!



Tetraquarks and heavy-light

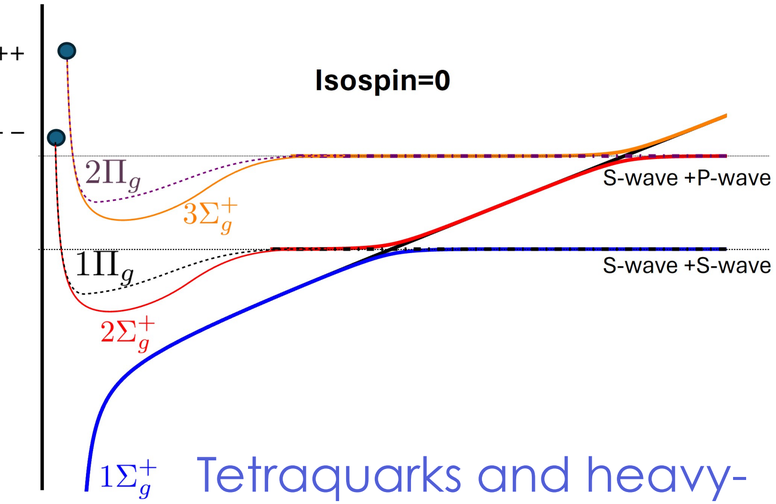
confinement force





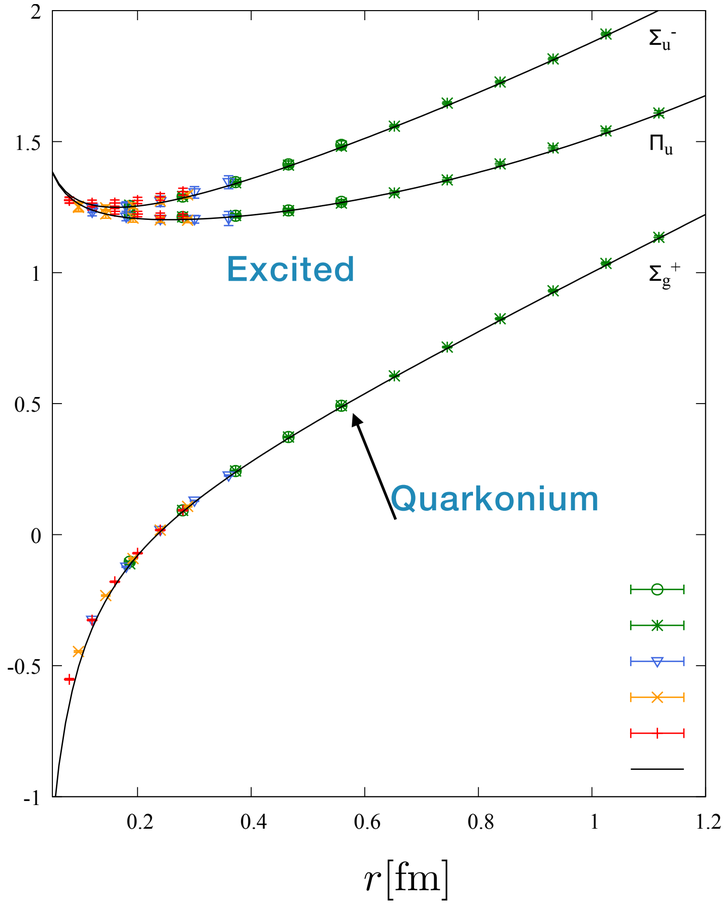
avoided level crossing

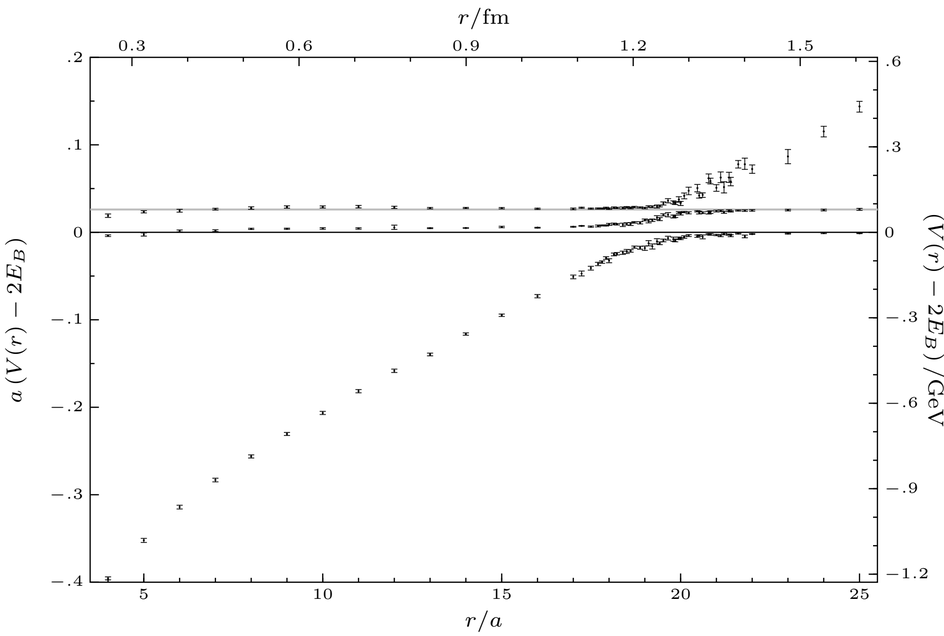
XYZ are a formidable opportunity to learn more about the fundamental strong force!



Tetraquarks and heavy-light

confinement force



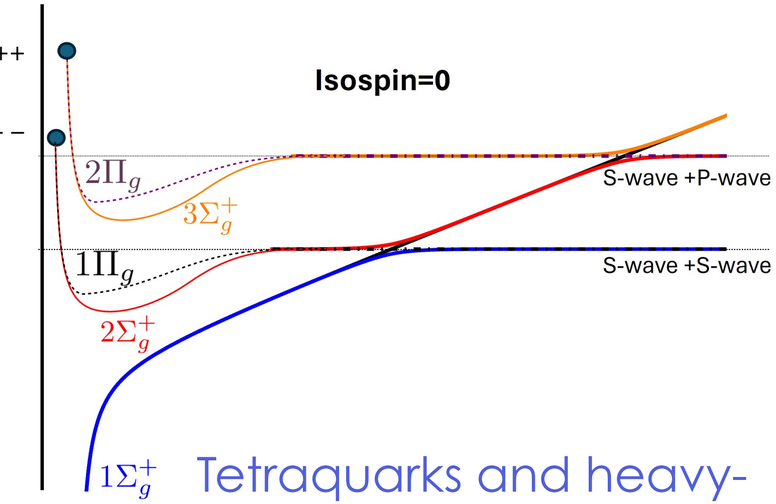


avoided level crossing

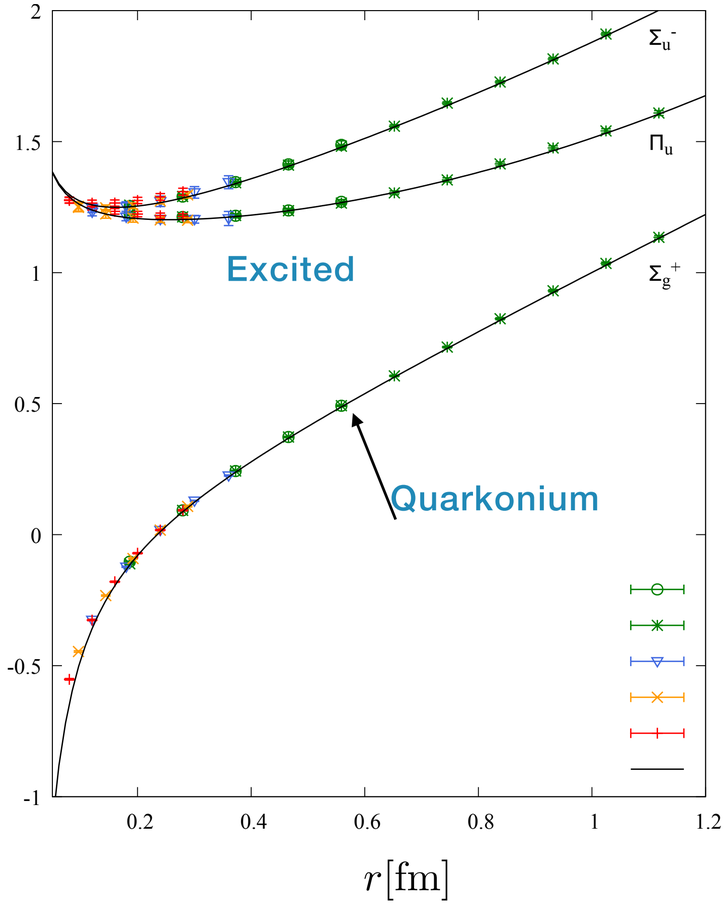
And of course the confinement mechanism is the main focus of Section A !

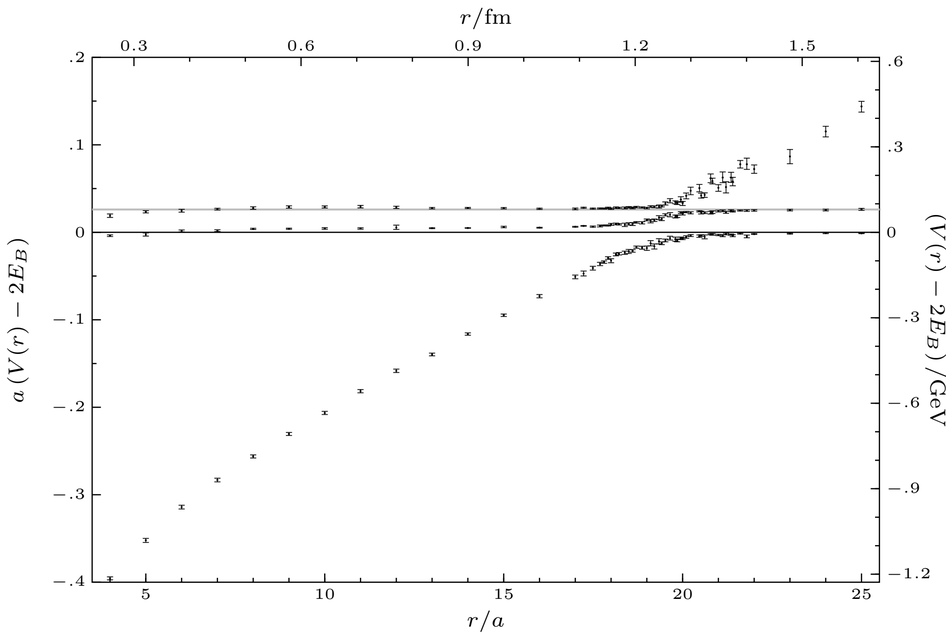
XYZ are a formidable opportunity to learn more about the fundamental strong force!

confinement force



Tetraquarks and heavy-light





avoided level crossing

And of course the confinement mechanism is the main focus of Section A !

And we can now study directly the modification of this force in perturbation theory and on the lattice

Weber

Snellings, Section D

Heavy Ions are no longer at the Frankestein phase

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But they offer a broad array of precise measurements and new opportunities

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Femtoscopy!! A new tool to investigate hadron interactions

Hatsusa, Hyodo, Section C, D,F

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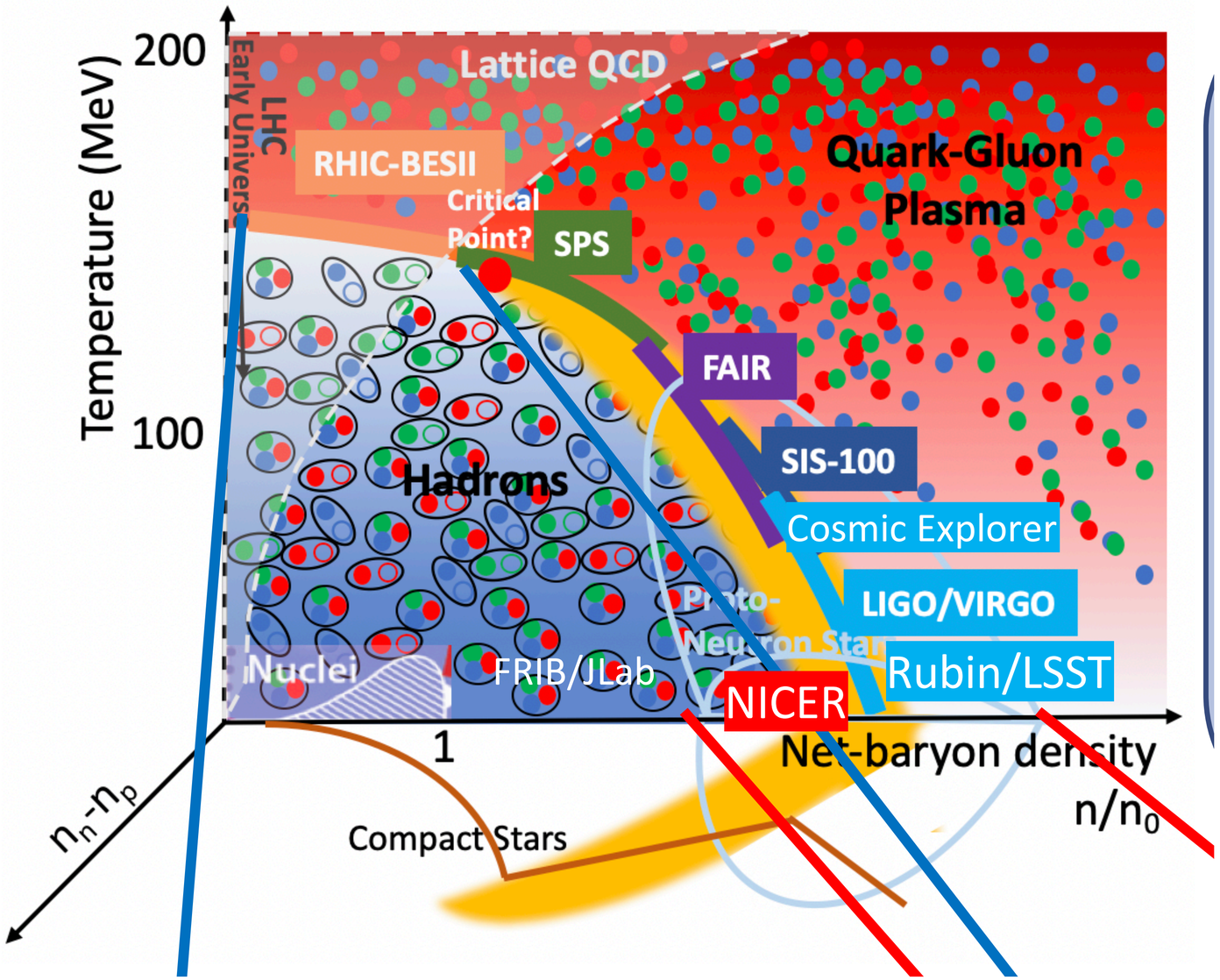
??Small system and small multiplicity (pp and pA) collectivity and hydrodynamics??

USE HEAVY IONS as a FACTORY of new states (like XYZ), new investigation tools, new effects (magnetic fields/polarization) laboratory measurements setup for neutron skin, antimatter production relevant for astrophysics, cosmology, neutron star and of course the QCD phase diagram

Dexheimer, Ratti, Rennecke, Snellings, Weber, Briceno, Hatsuda, Round table E, Section D,F



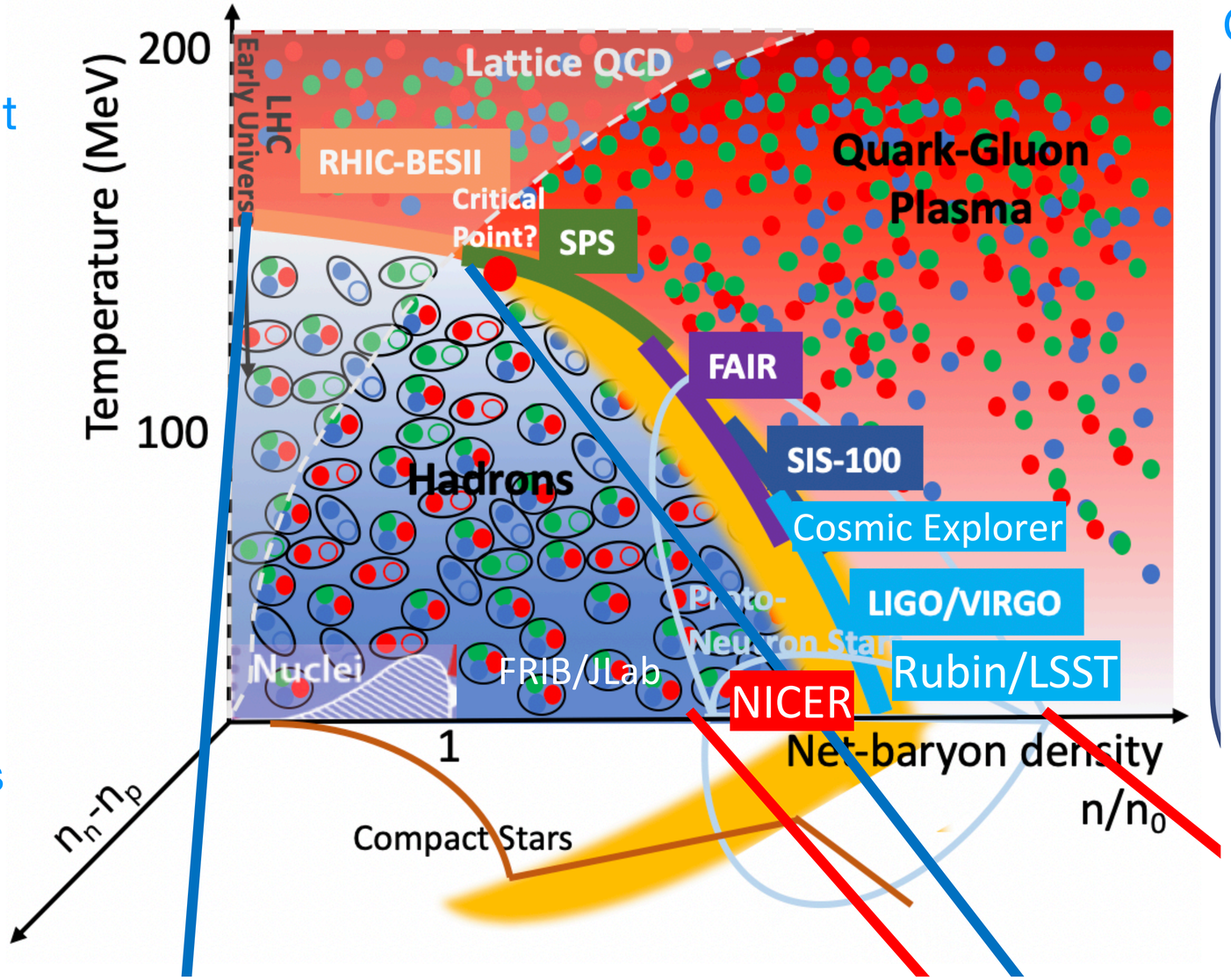
Dexheimer, Ratti, Rennecke, Snellings, Weber, Briceno, Hatsuda, Round table E, Section D,F

Confinement-
Deconfinement
Transition

QGP transport
Coefficients

Nuclear physics
from QCD

Three and many body
Forces



Cosmology, Early universe

Muse

Neutron star mergers,
gravitational waves.
BSM: dark matter
and axions, black hole
formation

Dexheimer, Ratti, Rennecke, Snellings, Weber, Briceno, Hatsuda, Round table E, Section D,F

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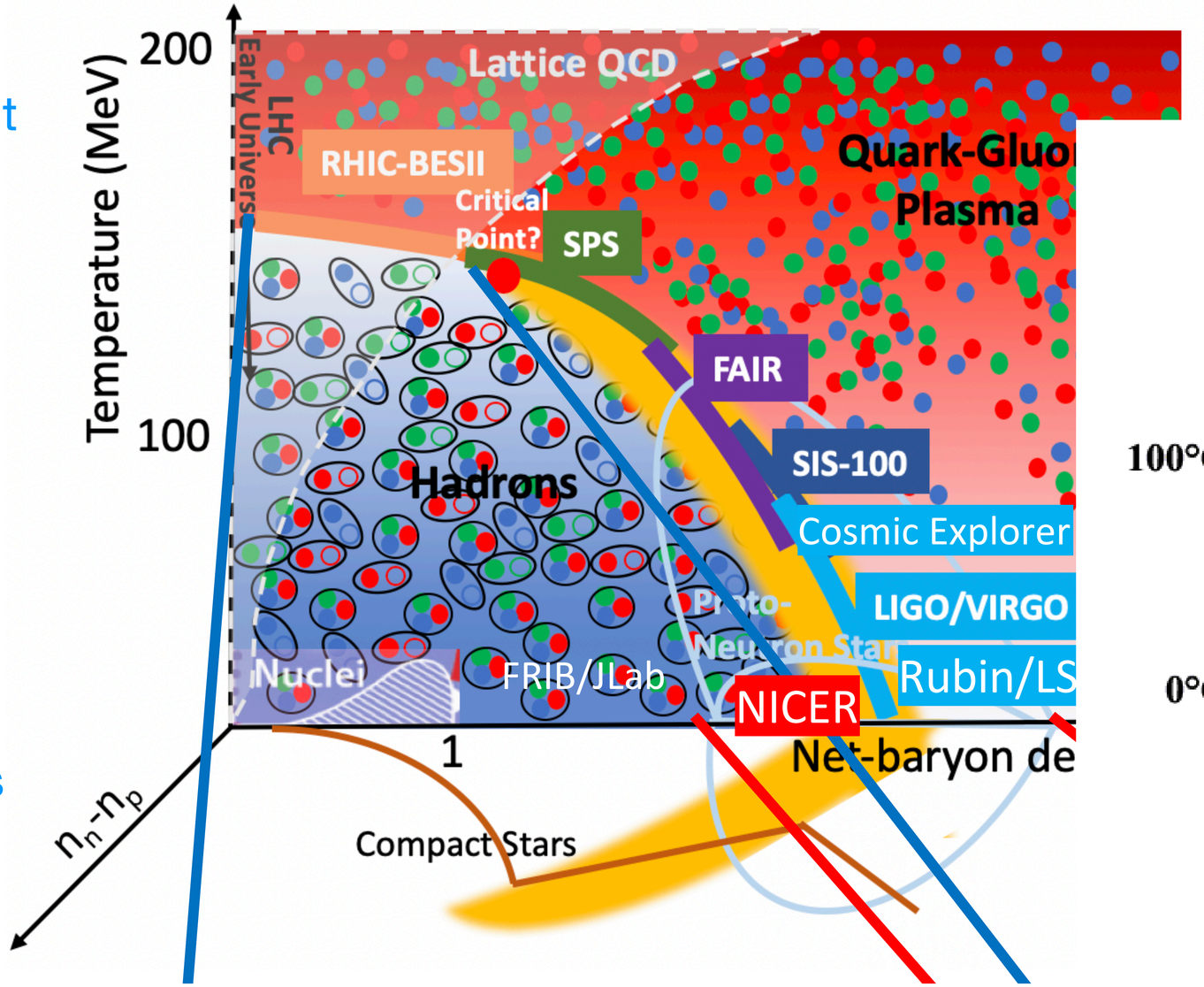

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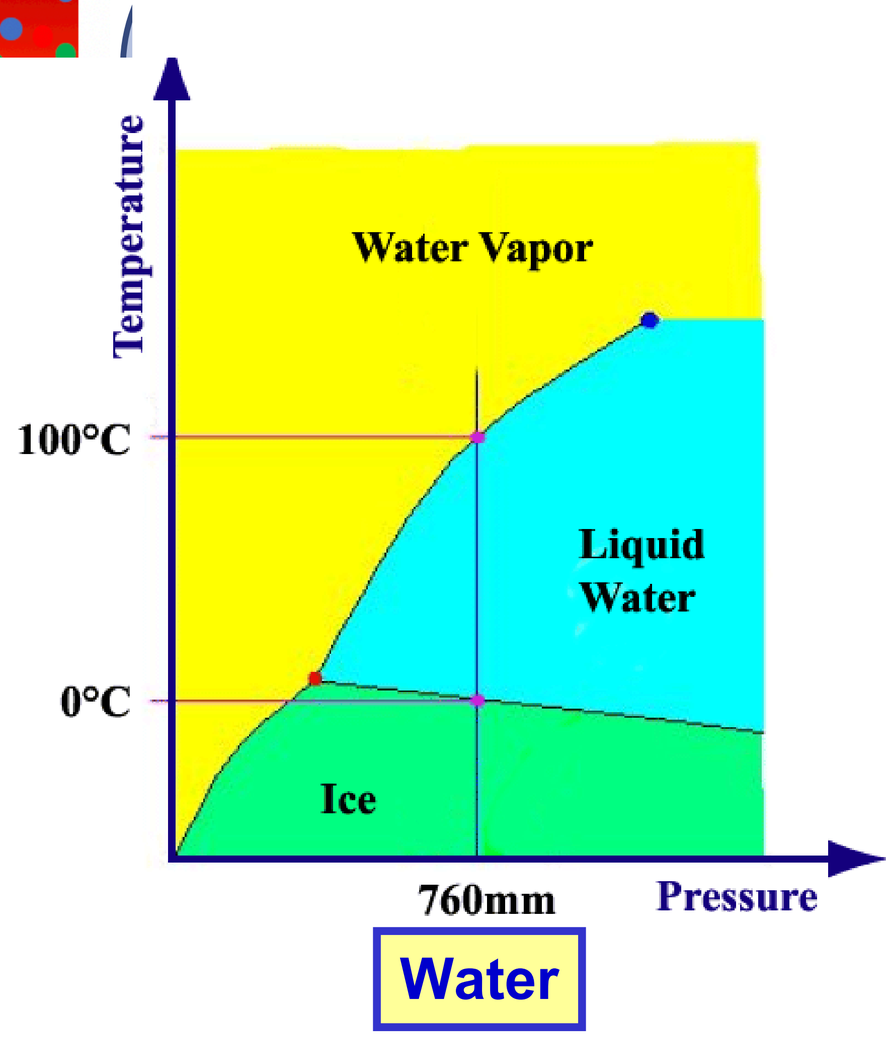

QCD looks a lot like condensed matter

Quantum field description of nonequilibrium evolution of probes in medium

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Akamatsu, Snellings, Weber, Section C, D, F

EFT based Quantum open systems and Linblad equations: describe quarkonium and jets evolution in strongly coupled Quark Gluon Plasma, lattice input on the transport coefficients

Can be applied to cold atoms (polaron), but also to neutrino fast conversion in supernova, dark matter pair evolution in early universe

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Transport like in condensed matter but the interface is huge: Jansen, Roberts Section A, A*, H

Emergent phenomena, synthetic gauge fields, topological configurations, emergent fermion fields, quantum computing

Quantum computing for calculating nonequilibrium, finite mu, real time phenomena

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Take away messages:

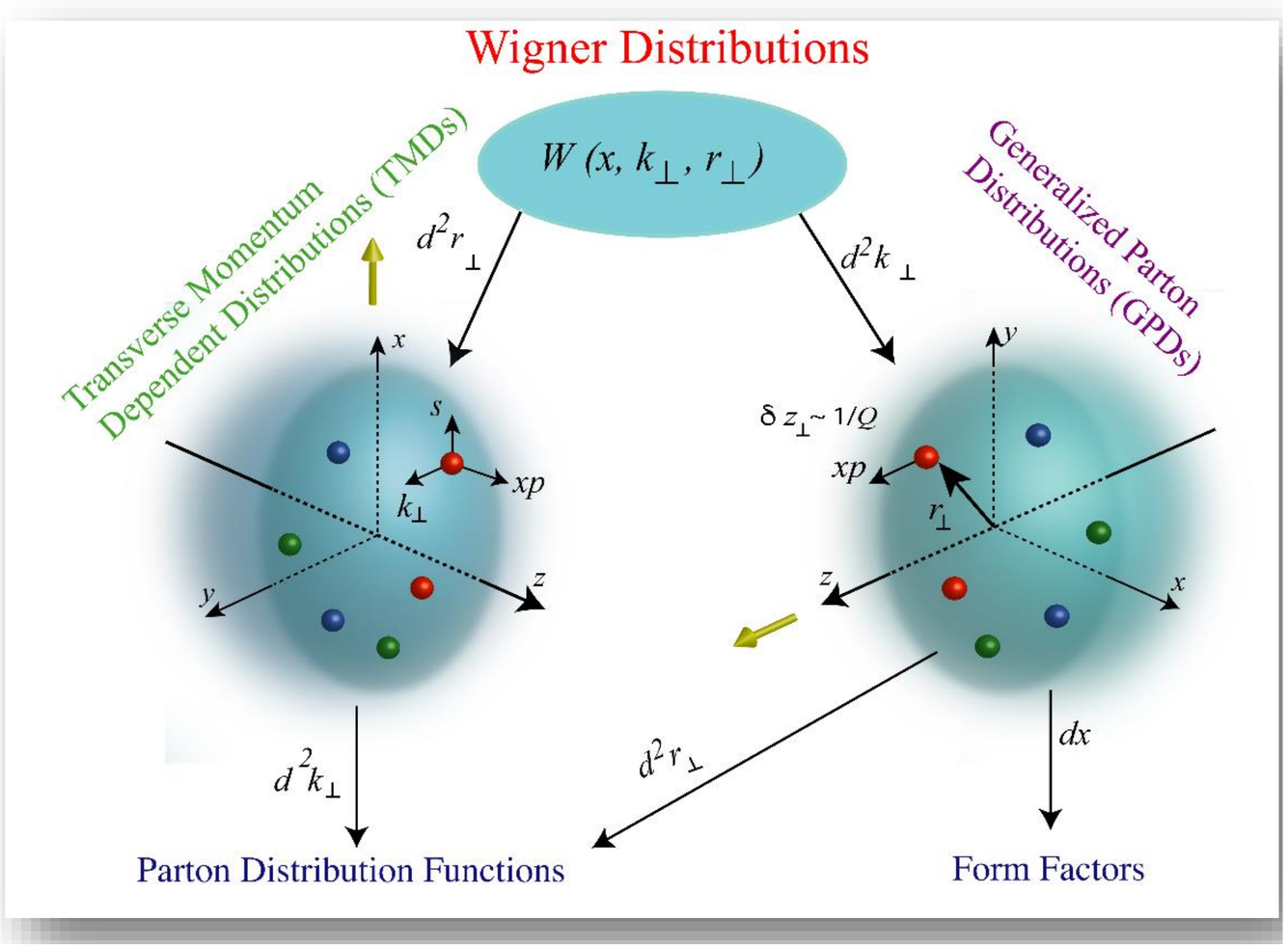
we should strengthen Section A* and the presence of condensed matter people at the QCHS

we should start apply Quantum Computing to concrete problems arriving at concrete results devising shortcut, for examples using traditional Montecarlo to fix the scale

Hadron structure and EIC, EicC : Nucleon tomography!

A very complicate landscape
PDFs, GDPs, TMDs!

Huey-Wen Lin, Roberts, Eichmann, Round Table B



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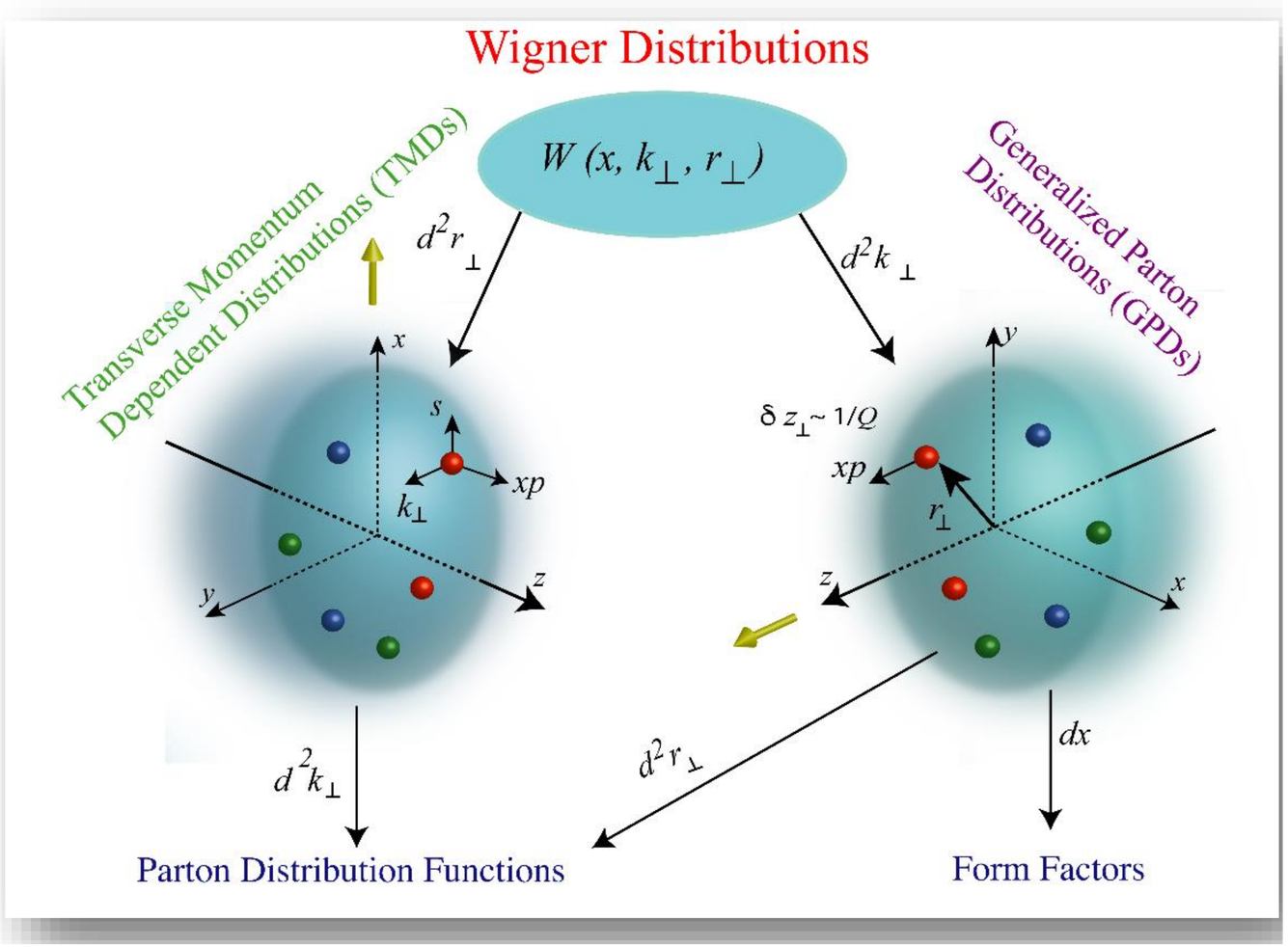

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This is seen in many results: Vairo, Walker-Loud, Section B,C
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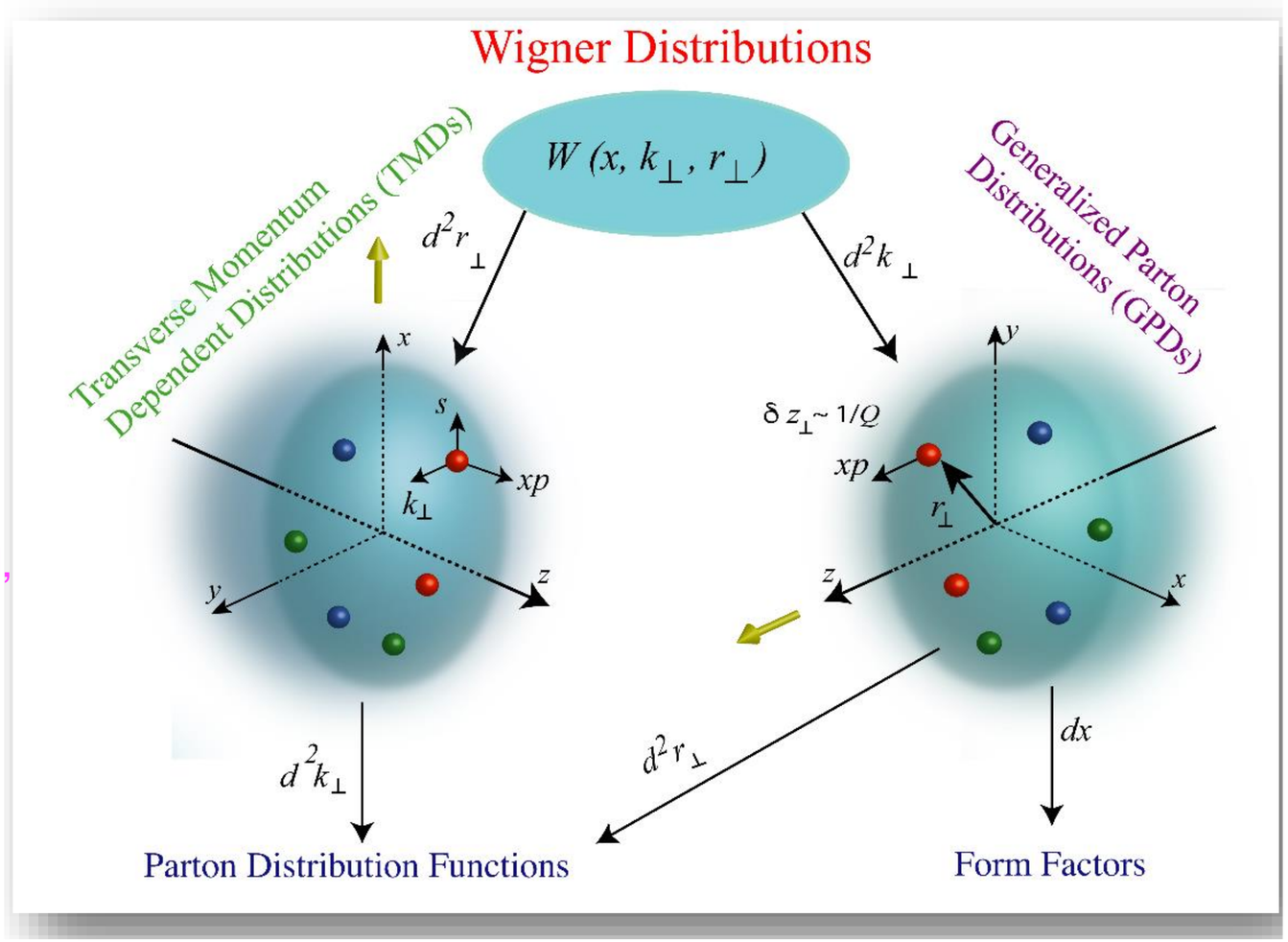

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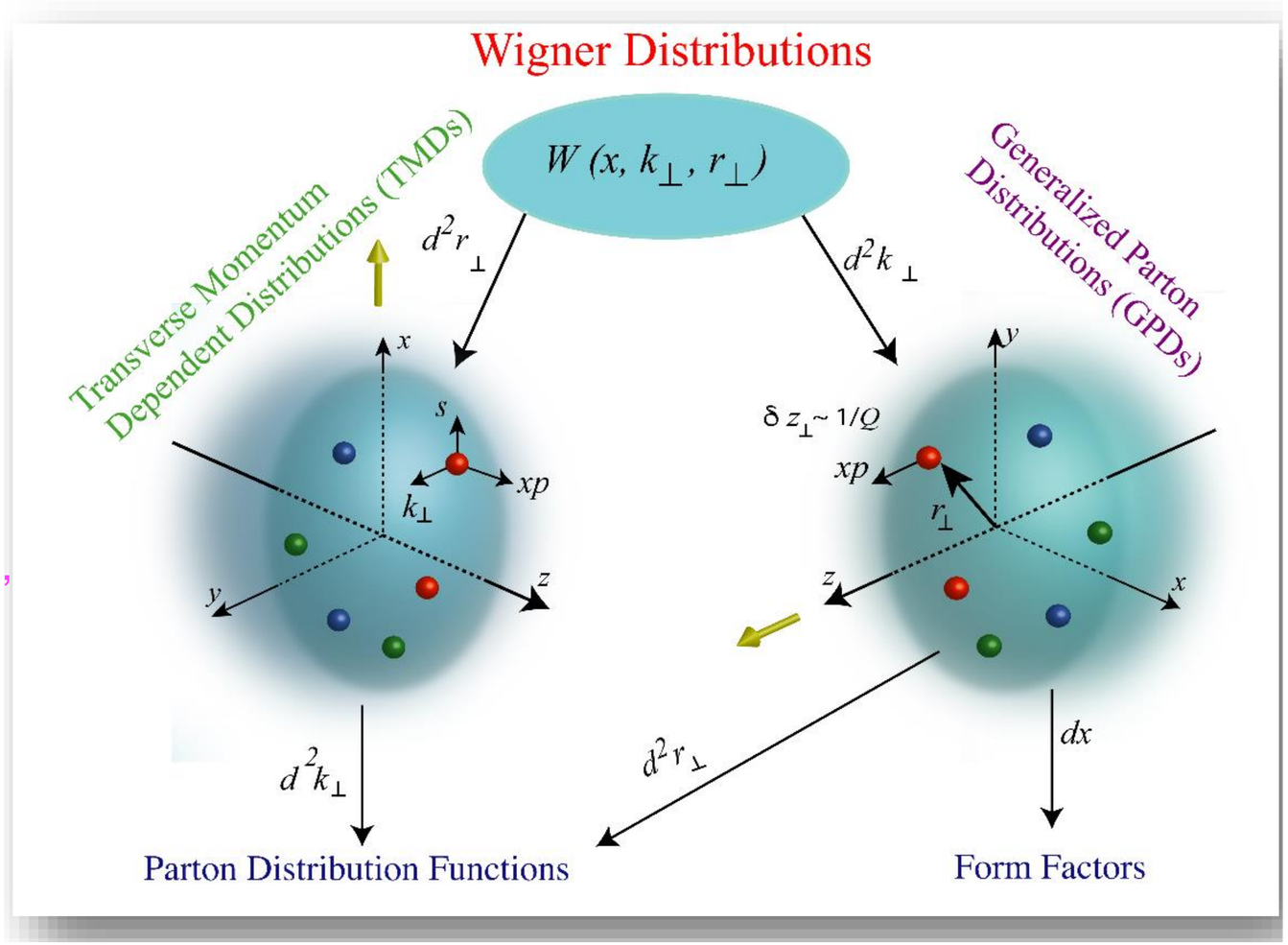

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Take away messages:

Use the scale hierarchy: factorize, simplify, get a structure and power counting, evaluate on the lattice the low energy part

This entails to develop new lattice tools (gradient flow) as well as the interface between lattice and perturbatio theory

QCD: perturbative or nonperturbative?

Kronfeld, Vairo, Round table B, Section A, B, C

Perturbative and nonperturbative terms are strictly entangled in QCD, perturbation theory itself signals the existence of nonperturbative contributions

Power corrections arise, perturbative expansions suffer of renormalon ambiguities (that on the lattice become cutoff divergences) we need to develop better schemes and to interface better perturbative/nonperturbative

Perturbative series at T=0 and finite T works better when one uses appropriate schemes

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QCD: statistics, machine learning (classical and quantum), quantum computing

Matorras, Jansen, Section H

Transversal to all the subjects of QCHS !

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Outlook

THANKS FOR THIS BEAUTIFUL VENUE!!!

THANKS TO ALL PARTICIPANTS FOR MAKING THE CONFERENCE SO LIVELY!

STAY TUNED AND SEE YOU AT CONFINEMENT2026!!