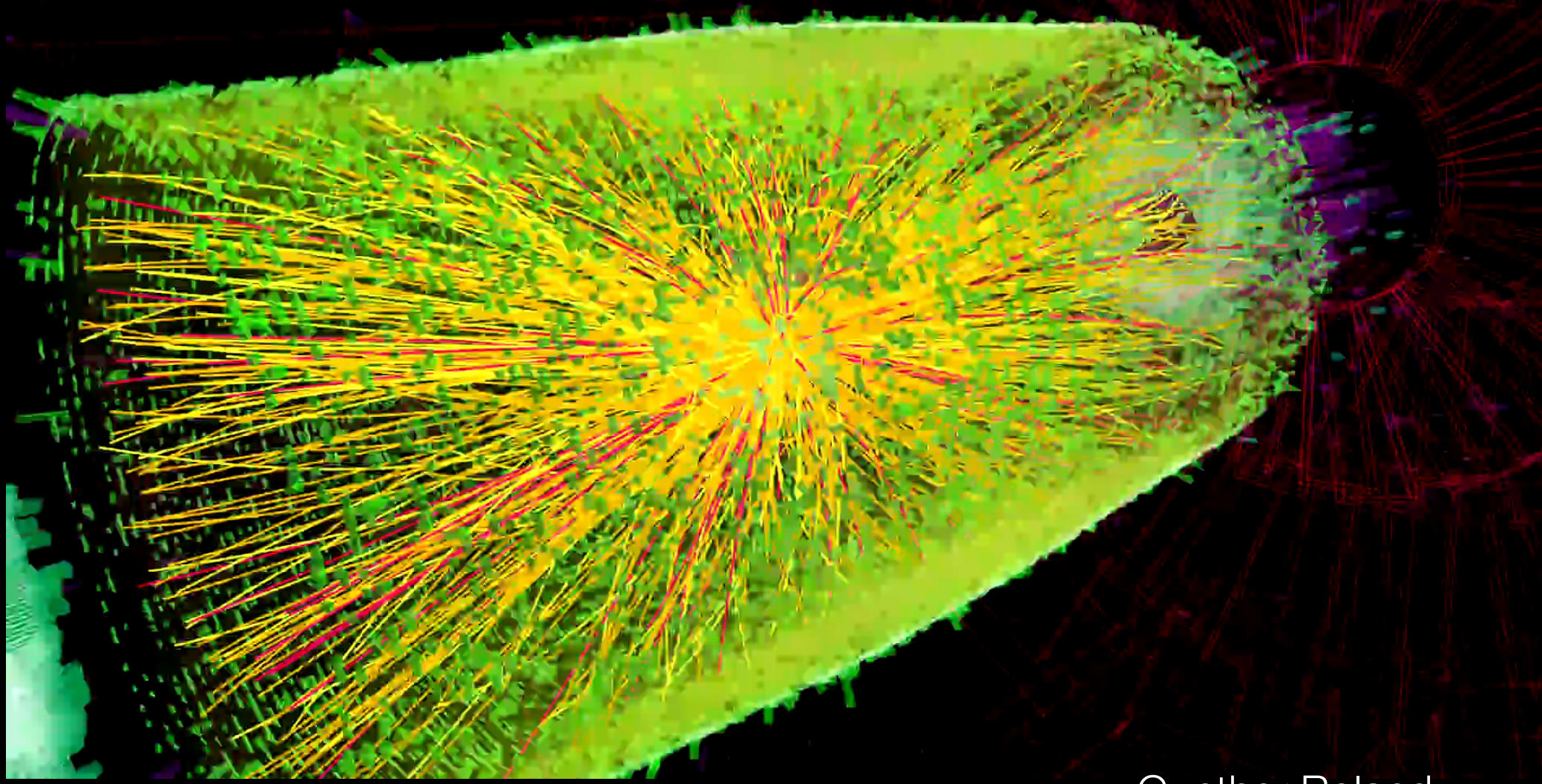
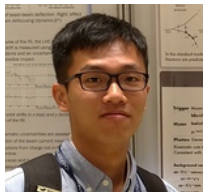
Hot QCD with the MIT Heavy Ion Group



Gunther Roland
MIT

MITHIG People

6 PhD Student(s)



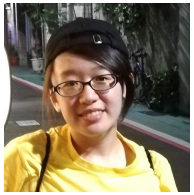
Hao Ren Jheng
Joined 2021

Pin-Chun Chou
joined 2020

Molly Taylor
joined 2018
NSF Fellow

Tzu-An Sheng
joined 2019

Michael Peters
joined 2017



Janice Chen
joined 2021

6 Research staff

Christof Roland
Principal Research
Scientist

Yi Chen
Senior Postdoc
joined 2019

Jing Wang
Postdoc
joined 2019

Yasser Morrales
Research Scientist

Ivan Cali
Research Scientist

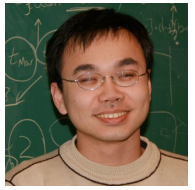
Cameron Dean
Senior Postdoc
Joined 2022

3+1 Faculty

Wit Busza
Friedman Professor
Emeritus

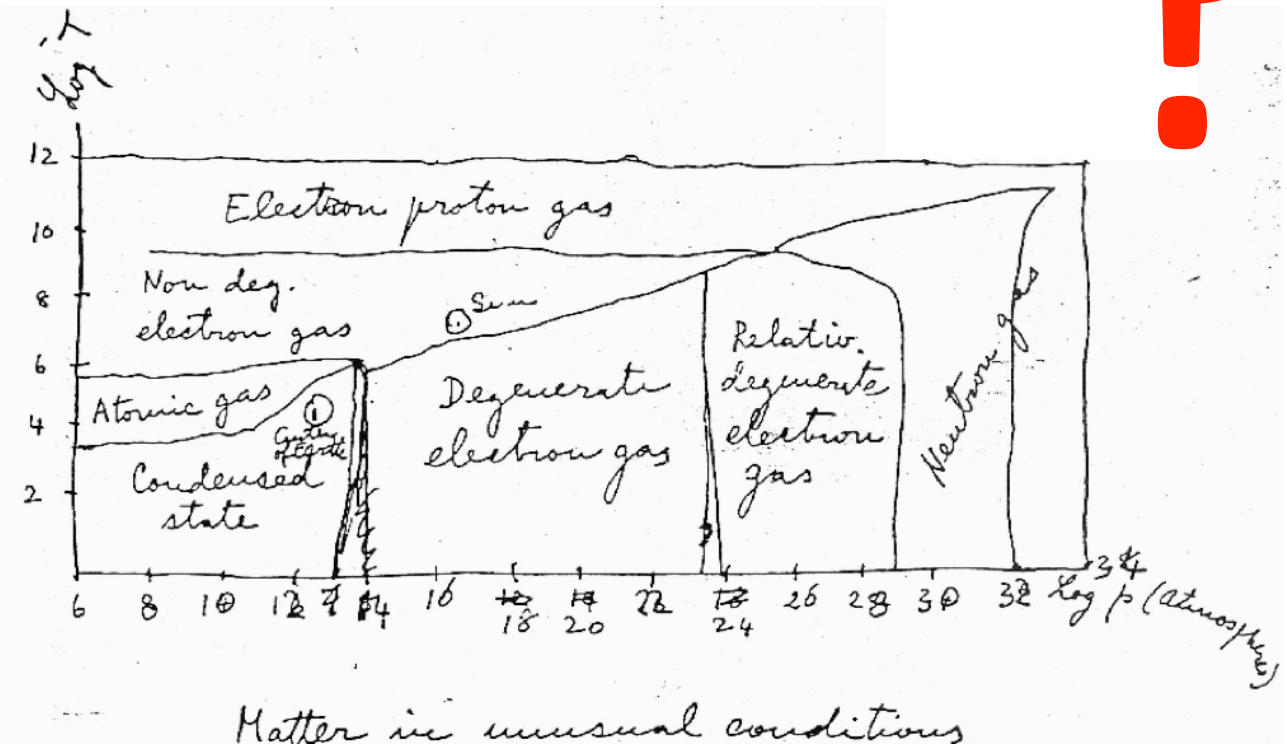
Bolek Wyslouch
Professor

Gunther Roland
Professor
Group Leader



Yen-Jie Lee
Associate Prof.

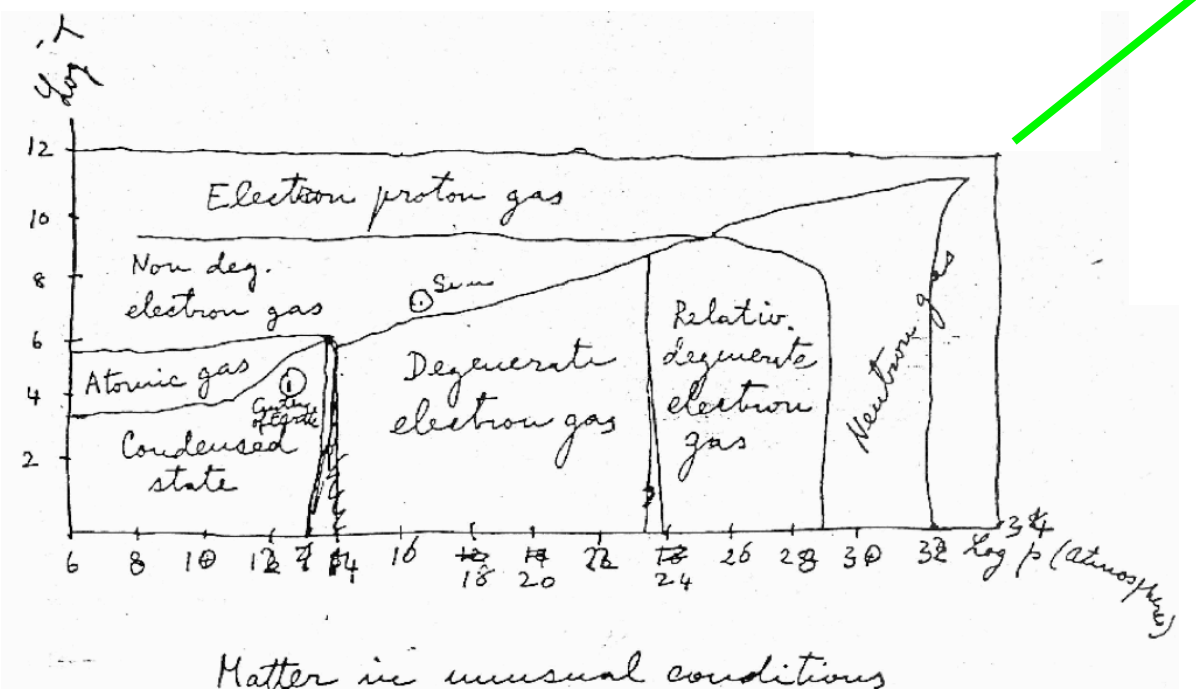
Big Question: Nature of matter at highest temperature?

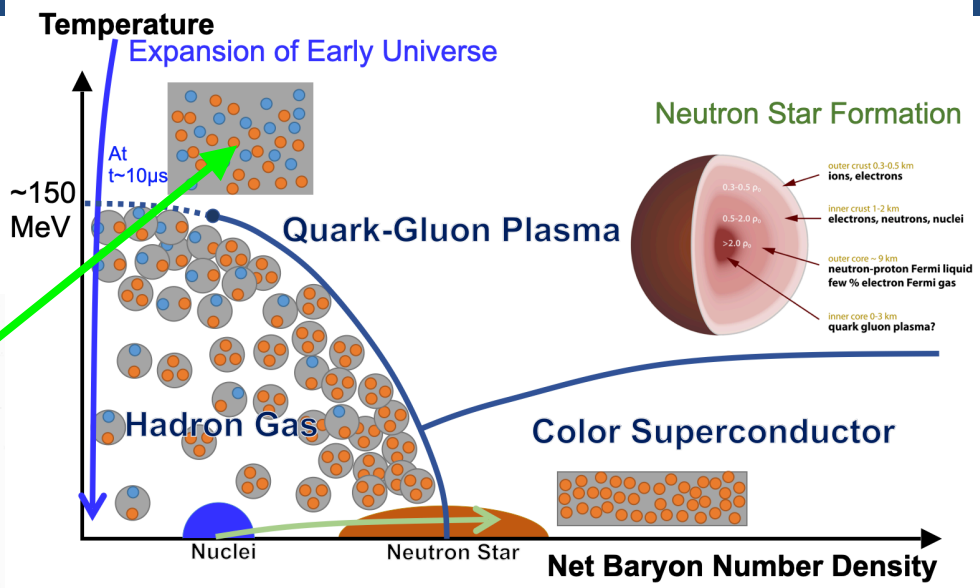


?

Fermi
"Notes on thermodynamics and Statistics", 1953

Big Question: Nature of matter at highest temperature?





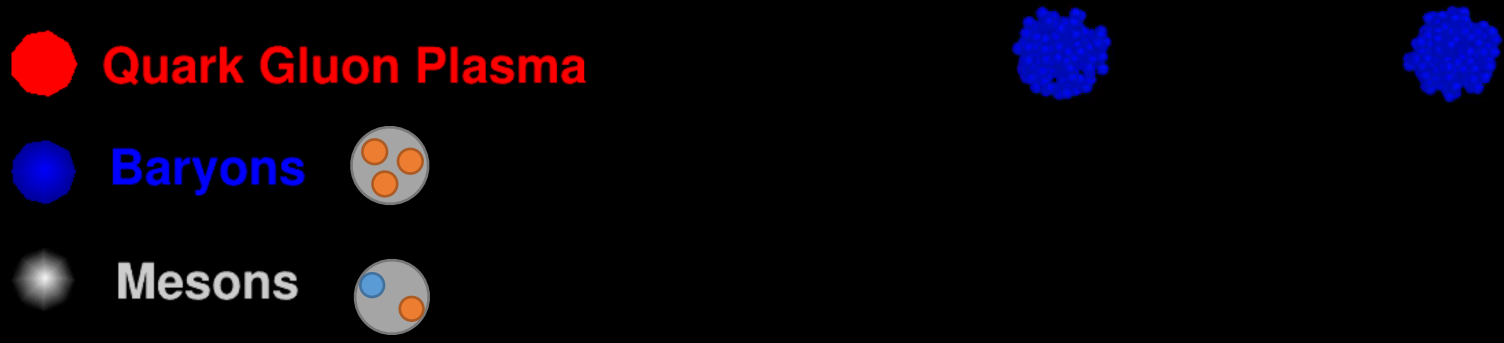
QGP

- How does one make it?
- Is it interesting?
- How does it work?

Fermi
"Notes on thermodynamics and Statistics", 1953

Making QGP at High Energy Colliders

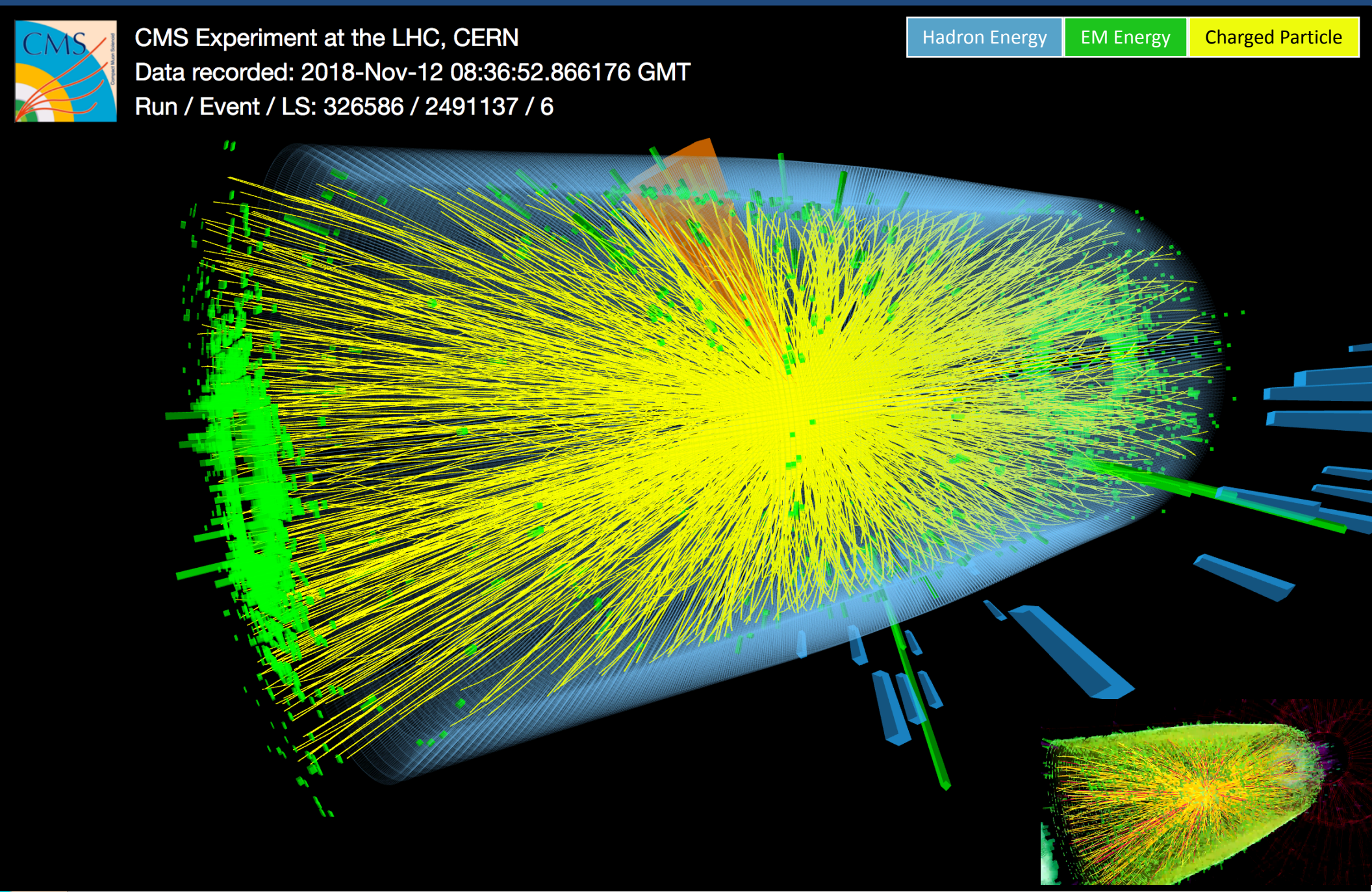
MIT Heavy Ion Event Display: Pb+Pb 5.02 TeV



Yen-Jie Lee, Andre S. Yoon and Wit Busza

Acceleration

Lead-Lead Collision Recorded by CMS (2018)



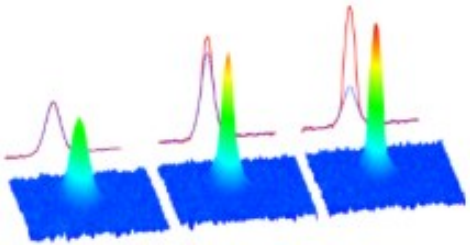
QGP: Near Perfect Fluid

Shear viscosity to entropy ratio

Water

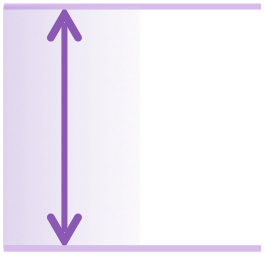
Helium

Fermi Gas



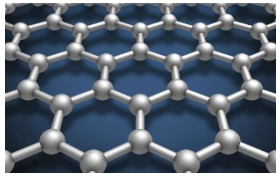
MIT cold atom group

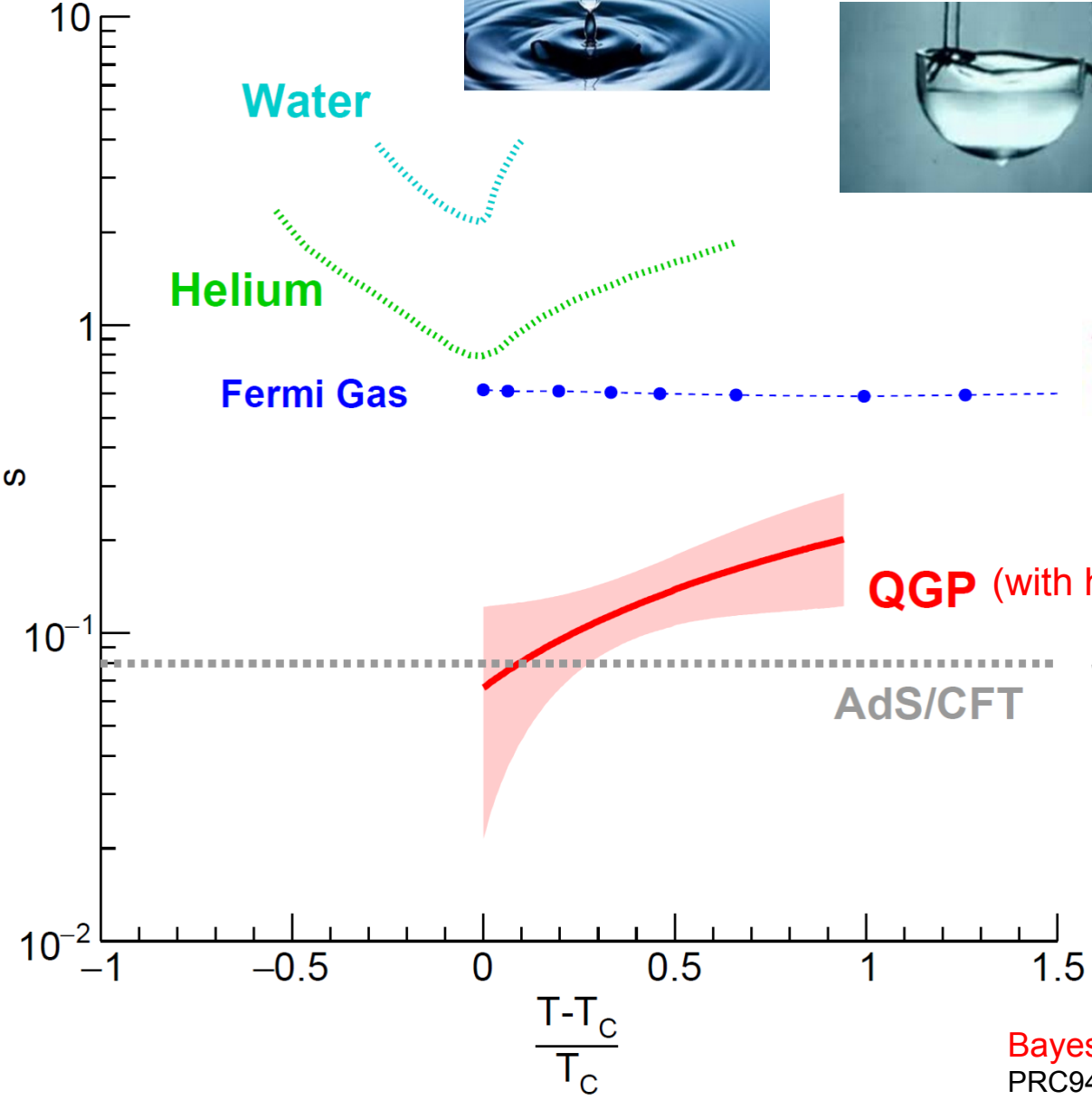
Calculation from
Annals Phys.326:770-796,20



Electron fluid in Graphene

PRL103,025301 (2019)

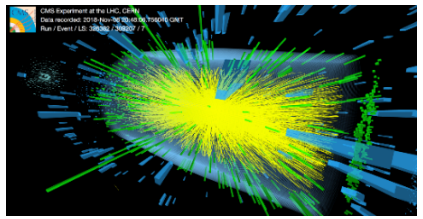




QGP (with hydrodynamics flow)

String theory

AdS/CFT



Bayesian Analysis on Data (Duke)

PRC94 (2016) no.2, 024907

Questions for the next decade

- How does the strongly interacting medium emerge from an asymptotic free theory?
- Can we see quasi particles (quarks and gluons) in the Quark-Gluon Plasma? What is the structure of QGP probed at different length scales?
- What are the transport properties of the medium?

How does QGP work?

New tools: Fast quarks scattered by QGP

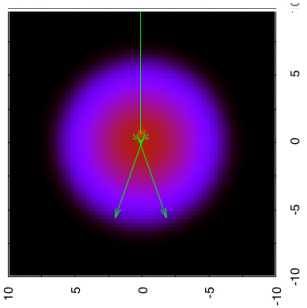
Strong QGP stopping power; O(10x) larger than normal nuclear matter

Quarks

QGP

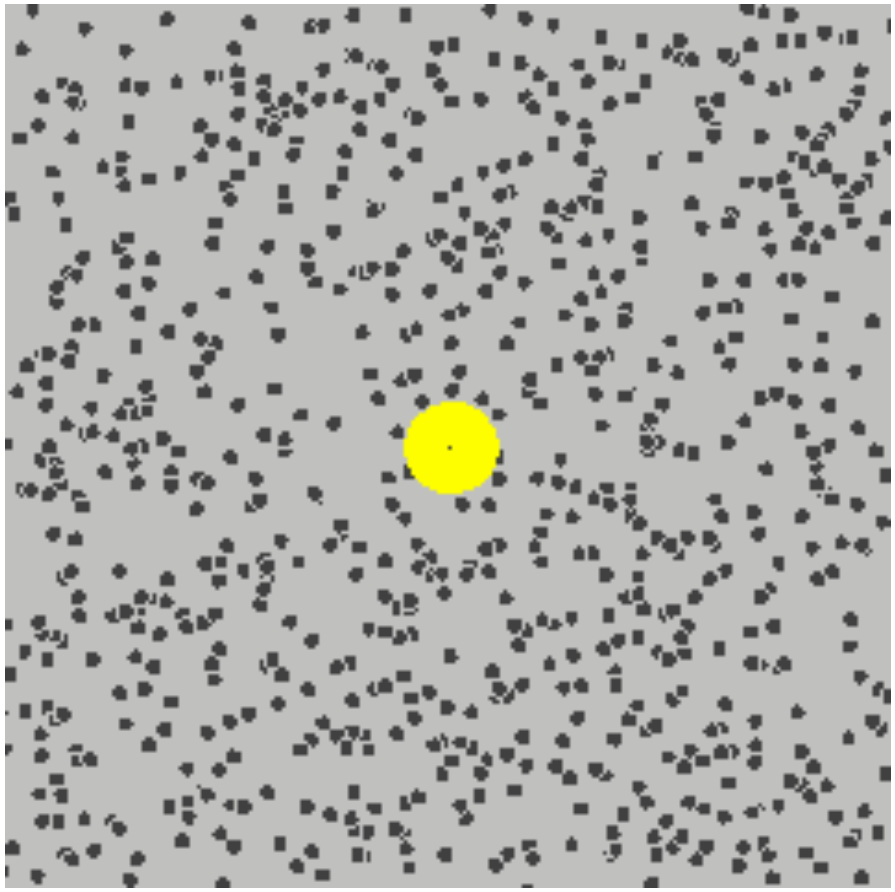
Photons or Z bosons

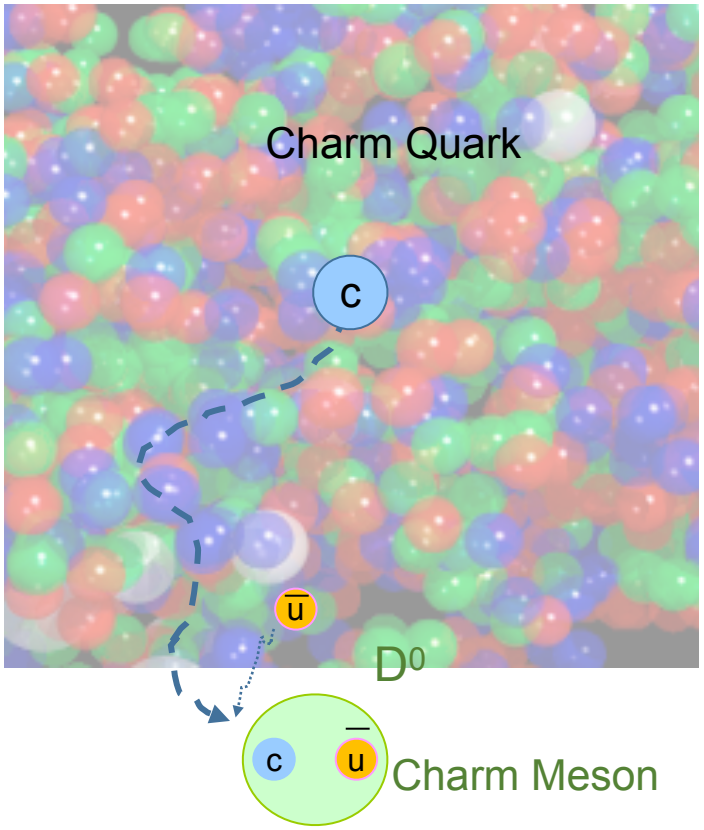
Indication of **medium recoil and QGP wake**



Are jets deflected by QCD quasiparticles in QGP?

New tools: Heavy quarks as probe particles in QGP

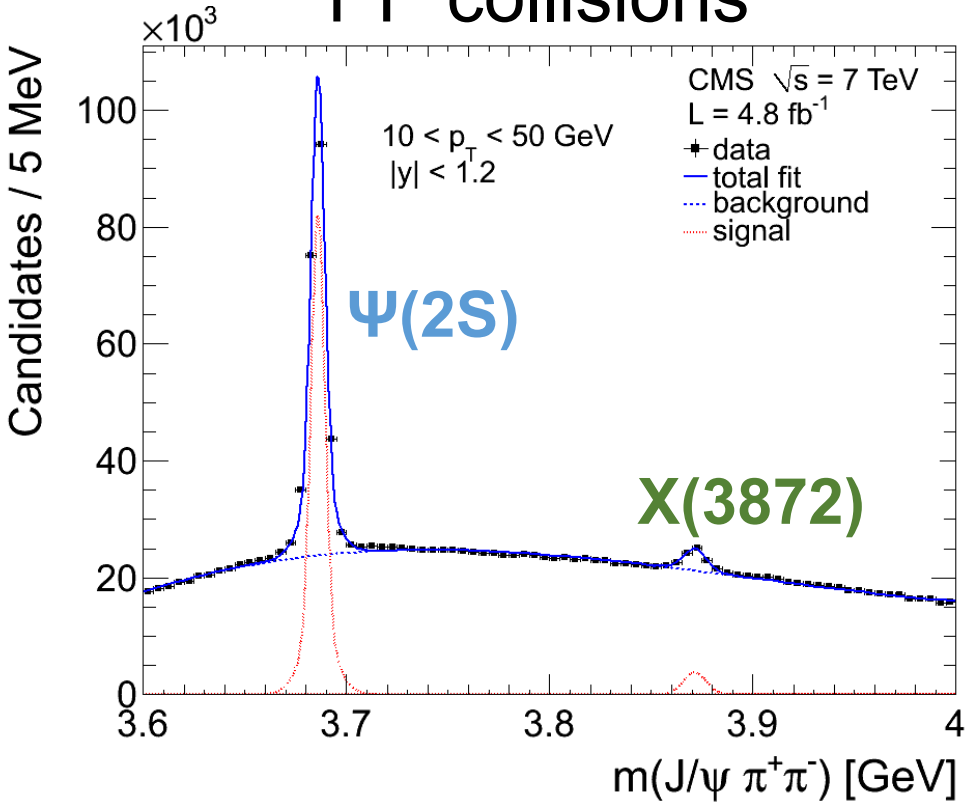




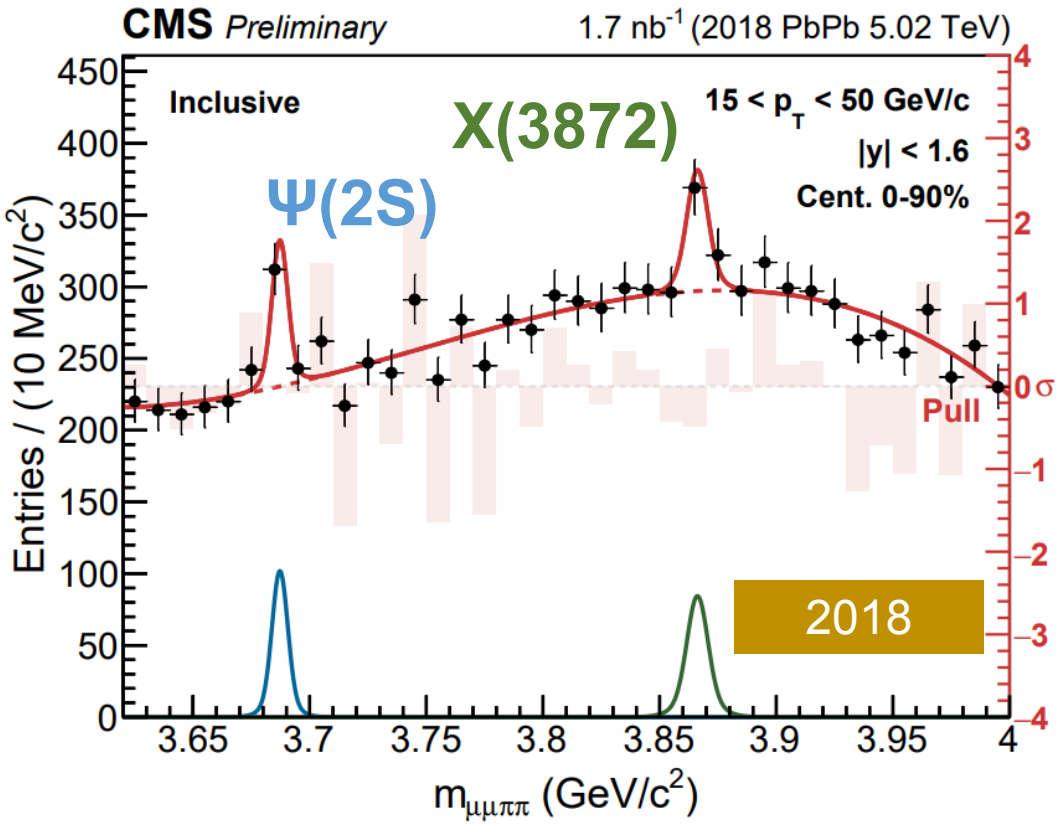
- **Charm** and **beauty** quarks (heavy quarks) are produced before QGP formation (<0.2 fm/c)
- Low momentum heavy quarks are then "kicked around" by quasi-particles (Brownian Motion)
  →**A direct window on the in-medium QCD force!**

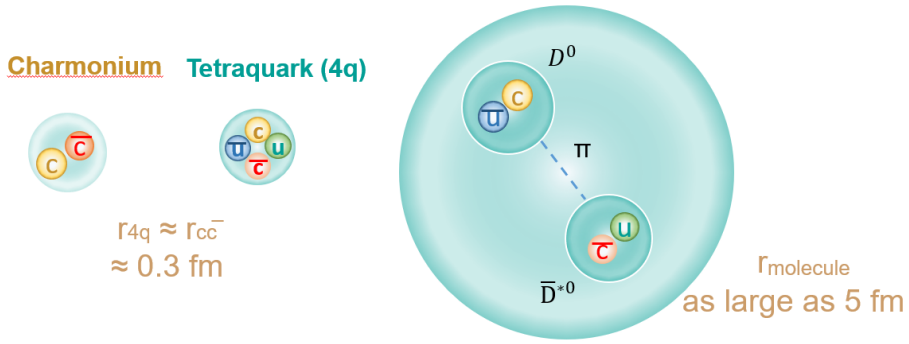
New tools: QCD Exotica as probes of hadronization

PP collisions



PbPb collisions





2018 data: First evidence of inclusive X(3872) production in heavy ion collisions!

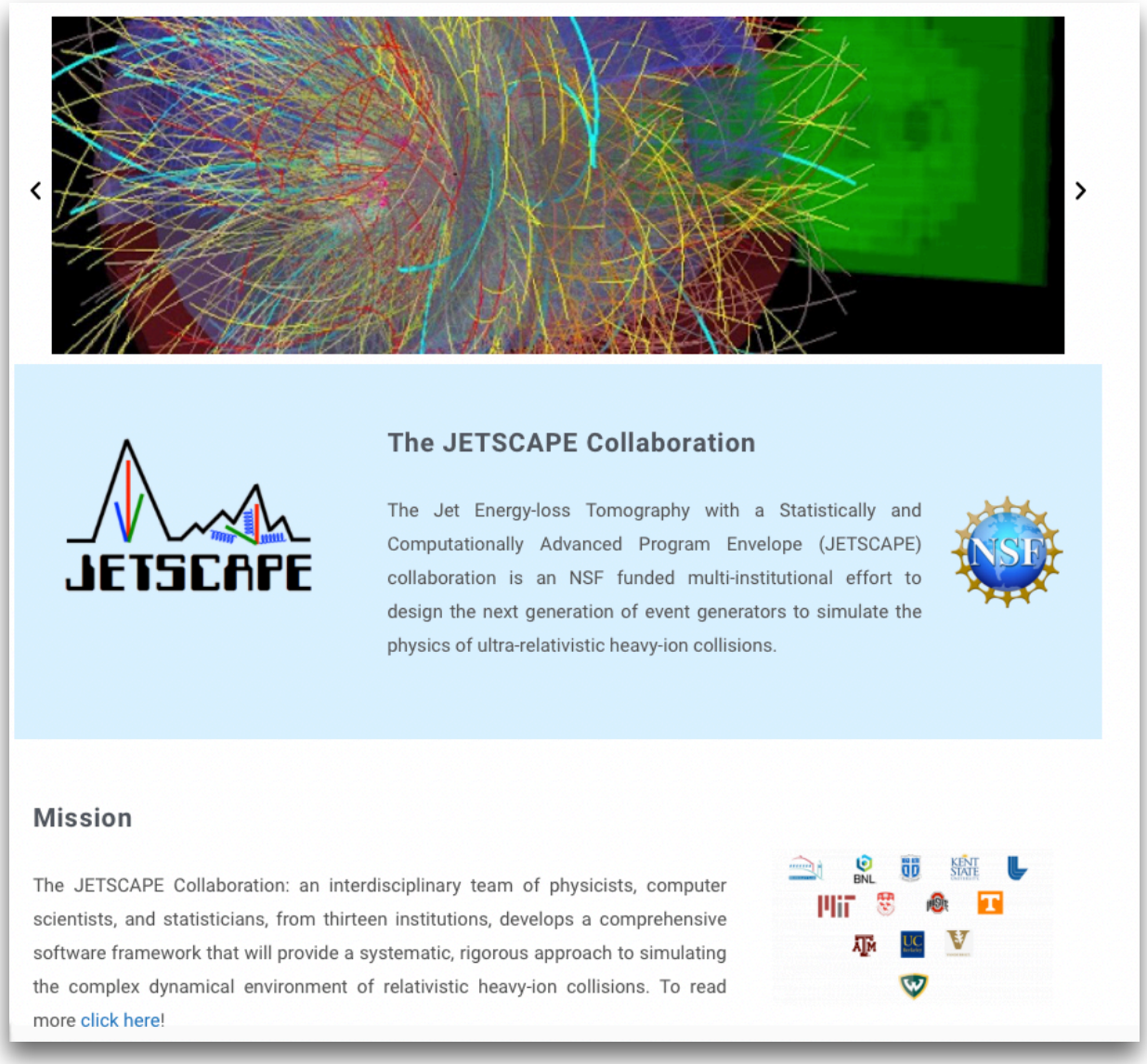
(statistical significance ~ **4σ**)

PRL 128, 032001 (2022)

Observation **of X(3872) is expected (>5 σ) in Run3**

Run3+4: Enables more differential studies (vs. p_T and centrality)

New tools: JETSCAPE Theory framework



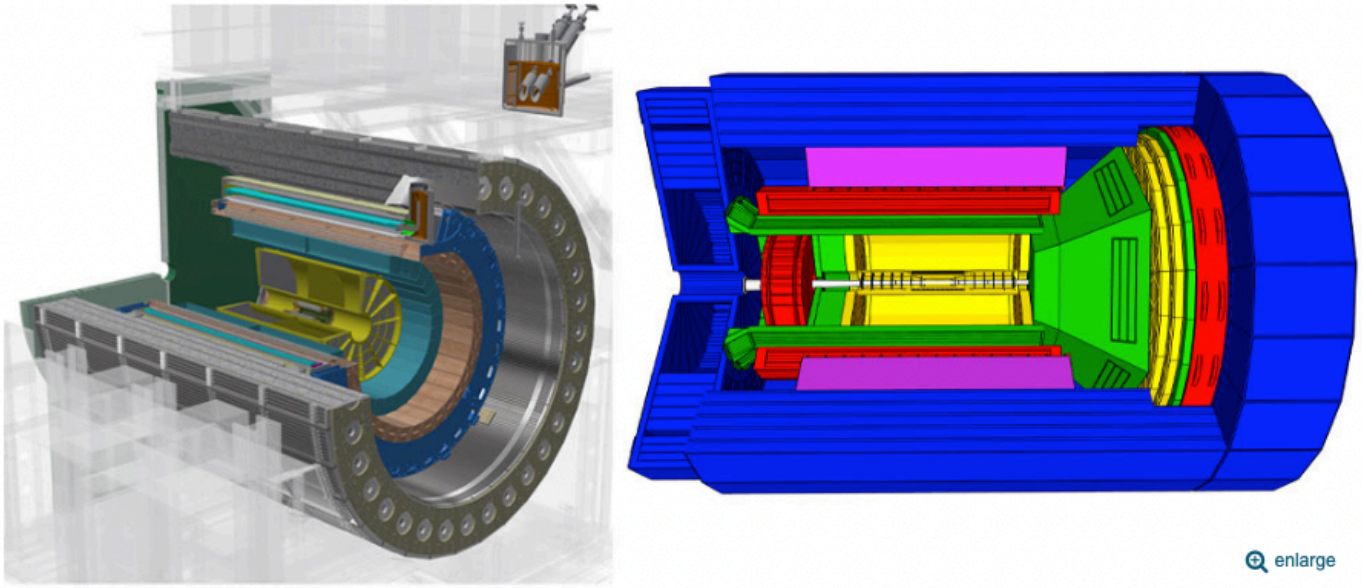
MITHIG is part of the JETSCAPE collaboration developing a theory framework for nuclear collisions

New tools: AI/ML

Department of Energy Announces $5.7 Million for Research on Artificial Intelligence and Machine Learning (AI/ML) for Nuclear Physics Accelerators and Detectors

Projects will advance understanding of atomic structure and the nature of matter and antimatter

December 3, 2021



enlarge

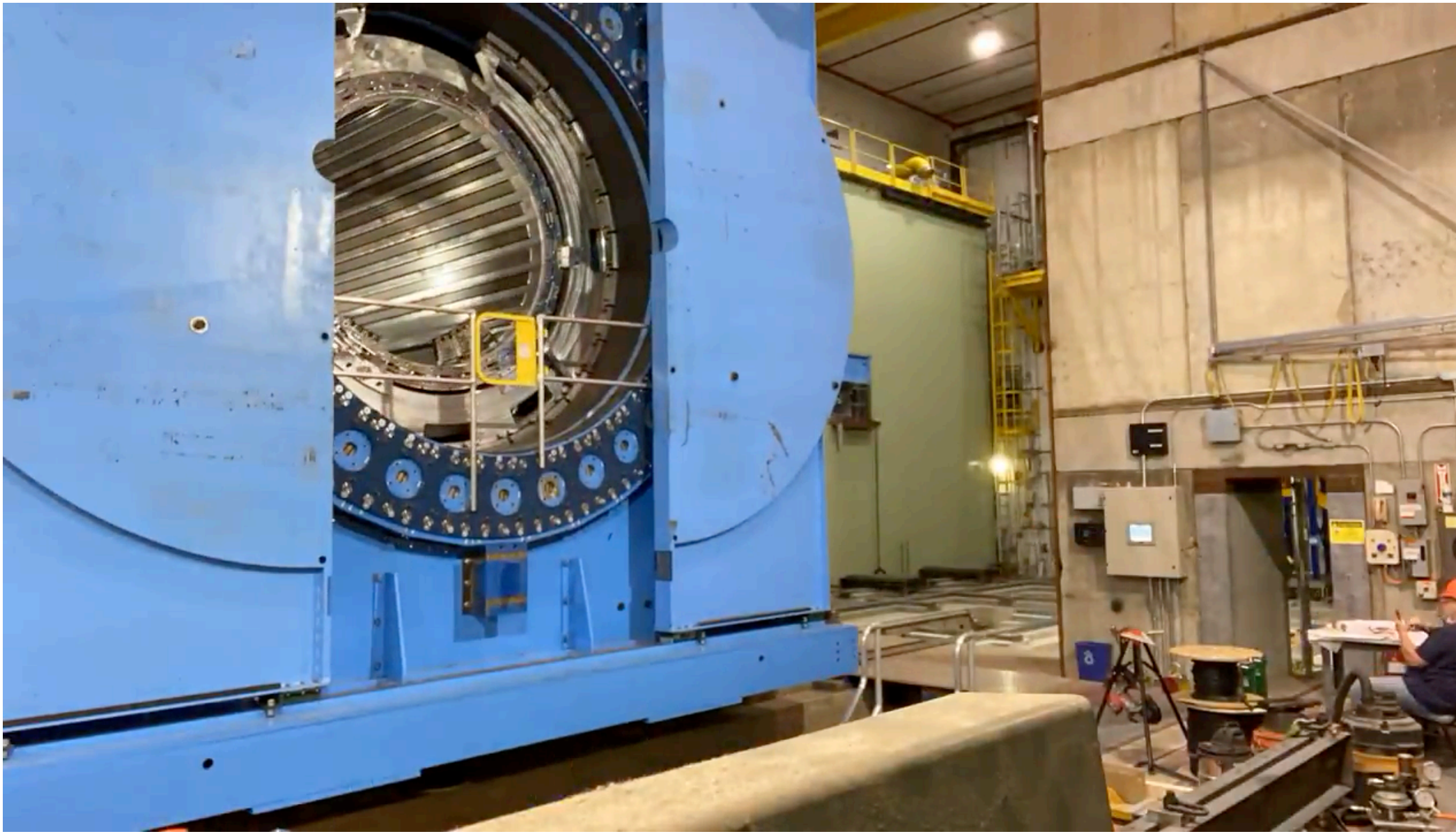
Schematic for the sPHENIX detector at the Relativistic Heavy Ion Collider (left) and a preliminary concept for a future Electron-Ion Collider detector (right).

WASHINGTON, D.C. - Today, the U.S. Department of Energy (DOE) announced $5.7 million for six projects that will implement artificial intelligence methods to accelerate scientific discovery in nuclear physics research. The projects aim to optimize the overall performance of complex accelerator and detector systems for nuclear physics using advanced computational methods.

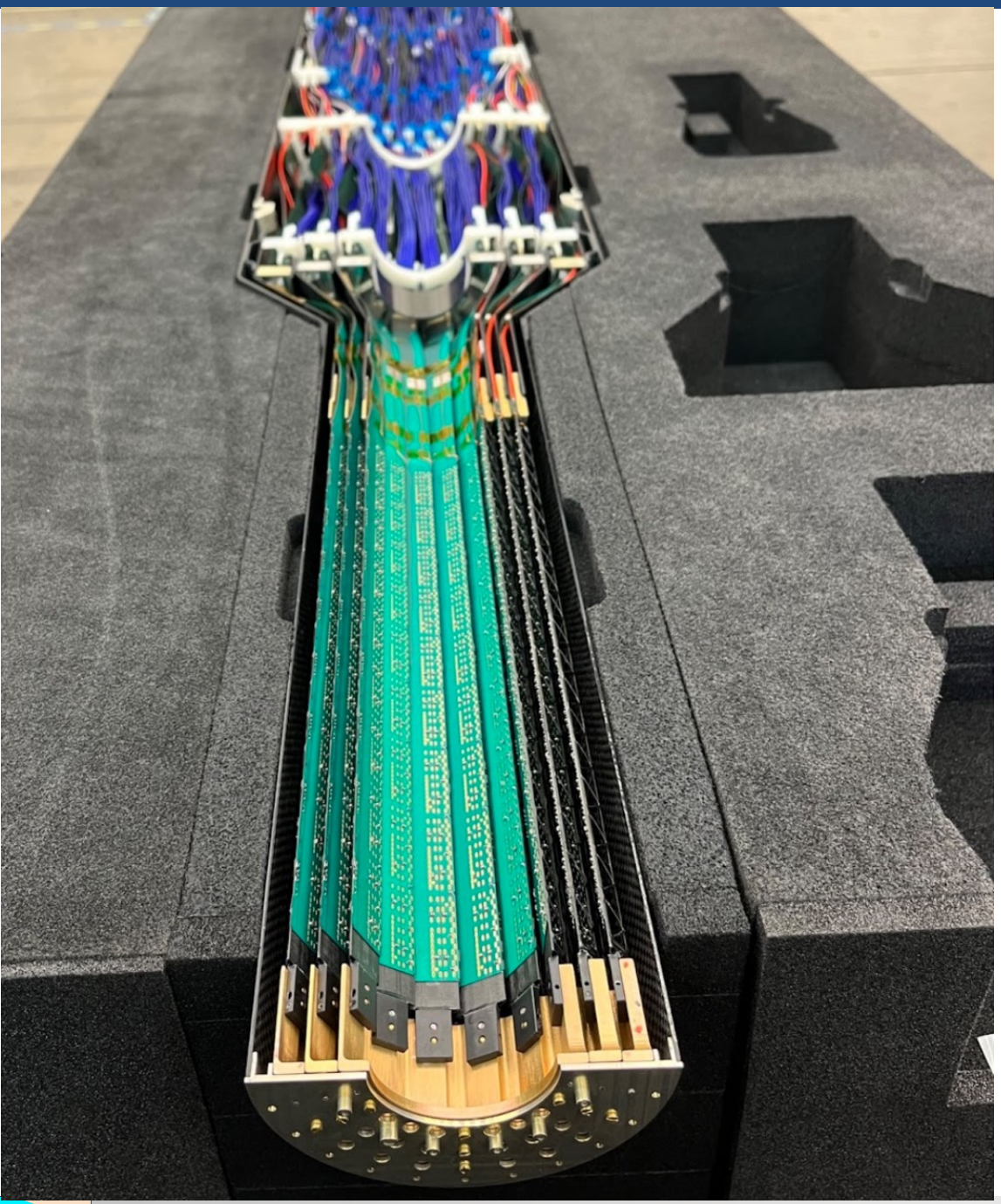
"Artificial intelligence has the potential to shorten the timeline for experimental discovery in nuclear physics," said Timothy Hallman, DOE Associate Director of Science for Nuclear Physics. "Particle accelerator facilities and nuclear physics instrumentation face a variety of technical challenges in simulations, control, data acquisition, and analysis that artificial intelligence holds promise to address."

MITHIG + other MIT groups part of collaboration developing real-time AI applications for sPHENIX and EIC

New tools: sPHENIX at RHIC



New tools: MVTX HF tracker in sPHENIX



Built by team including LANL, LBNL, MIT, MIT-Bates

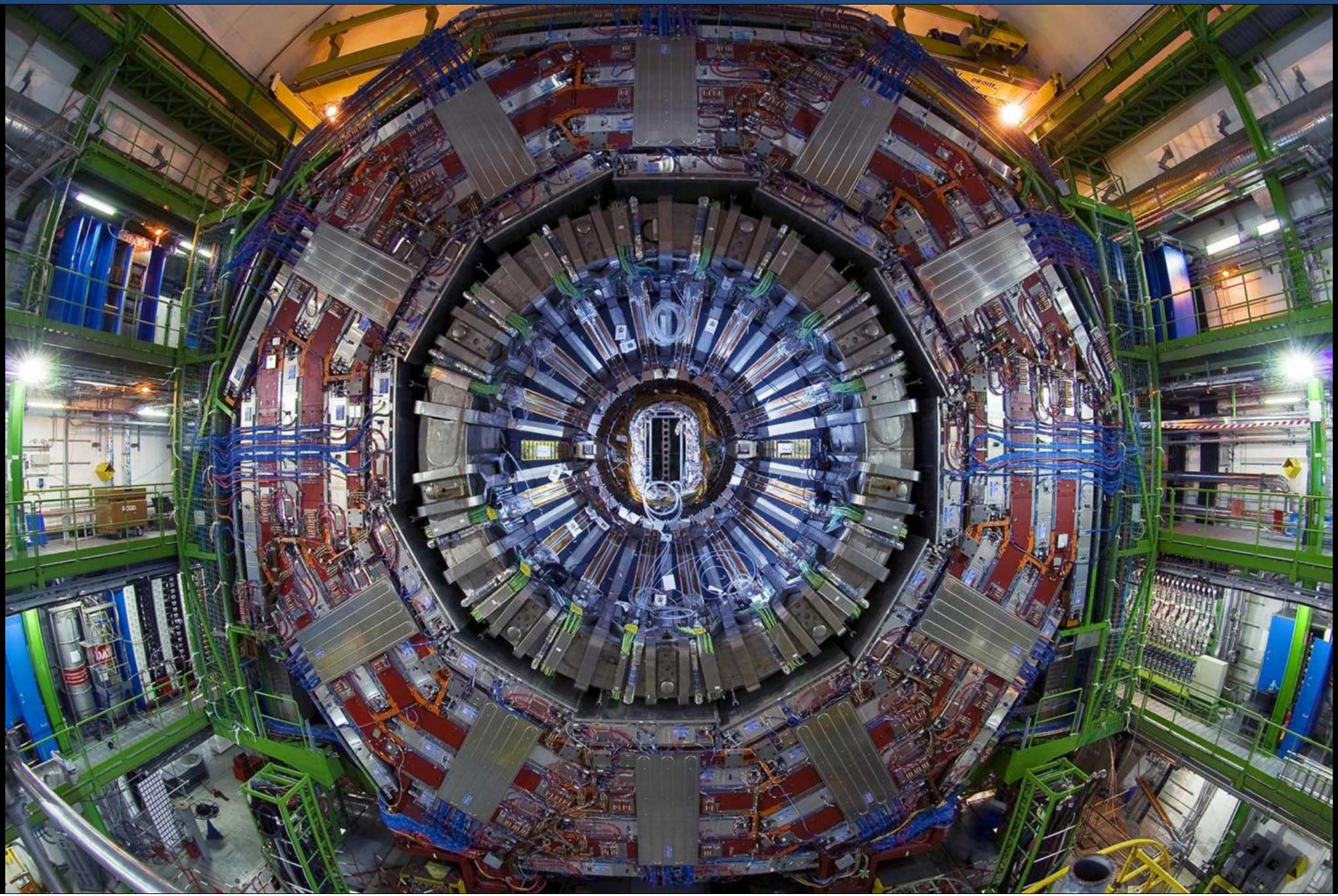
Enables sPHENIX heavy-flavor program

Camelia
(now in Paris)

Cameron
(HF convener)

Yasser
(just joined)

Old tool with new tricks: CMS + phase1/2 upgrades



LHC, RHIC and EIC Timeline

LHC

pO, OO, pPb

HL-LHC

PbPb 1.8 nb^{-1}

PbPb 7 nb^{-1}

PbPb 7 nb^{-1}

Run 2	Long shutdown 2	Run 3	Long Shutdown 3	Run 4

LHCb SMOG

LHCb SMOG2 (x100 higher rate)

CMS/ATLAS Phase 1 Upgrade

CMS/ATLAS Phase 2 Upgrade

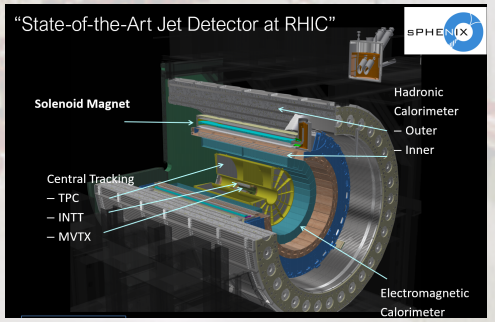
ALICE Upgrade (fast readout 50kHz)

ALICE LS3 Upgrade

2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030

sPHENIX construction

sPHENIX Installation commissioning



RHIC

Run 1	Run 2 ?
pp, pAu	pp, ArAr, OO

EIC

AuAu 30 nb^{-1}

AuAu 30 nb^{-1}

Physics Goal for the Next Few Years

- **Thermalization and Hadronization of Heavy Quarks**
  - Modification of Heavy quark hadronization with fully reconstructed D_0, D_s, D^*, B^+, B^0, B_s, Λ_c, Λ_b
  - Extension to doubly charmed baryons
  - Direct detection of charm diffusion: jet-D^0 and γ-D^0 angular correlation
  - $D\bar{D}$ correlations: studies of heavy quark energy loss mechanism

- **Extraction of Medium Properties at Various Length Scales**
  - Photon- and Z-tagged jets and hadrons
  - Jet substructure as a tool for the study of QGP constituents (“Moliere scattering”)

- **Quark Gluon Plasma Formation in Small Systems**
  - Flow correlation in high statistics peripheral PbPb collisions
  - Search for jet quenching in high multiplicity pp, pPb, pO and OO collisions
  - Search for QGP signal in e^+e^-

- **Studies of the Internal Structure of Exotic Particles**
  - Probe the inner structure of X(3872) with QGP
  - Search for other exotic particle such as T_{CC}

Life in MITHIG as a PhD Student

- **2022**: Join the group. Get started with CMS Run II data and sPHENIX simulation.
- Get involved in the sPHENIX construction, detector commissioning. Get involved in the CMS data-taking strategy preparation.
- **2022 Nov/Dec**: High Luminosity CMS data-taking at CERN
- **2023**: The first sPHENIX data-taking at BNL
- **2023-27** Physics analysis with high statistics CMS data and/or sPHENIX data, prepare for graduation.
- **2027-28** Most likely, become a postdoc and stay in academia

MITHIG PhD's and Postdocs since 2000

Heinz Pernegger
Postdoc
1997-2000
CERN Staff
ATLAS-HEP

Patrick Decowski
PhD 2001
Assoc. Professor
(Amsterdam)
Neutrinos

Kristjan Gulbrandsen
PhD 2003
Assoc. Prof. (NBI)
ALICE

Pradeep Sarin
PhD 2002
Assoc. Prof. (IIT Mumbai)
CMS

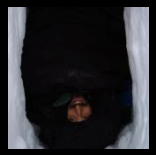
Carla Vale
PhD 2004
CMU (MBA)

Jay Kane
PhD 2004
Research Engineer

Conor Henderson
PhD 2005
Assistant Prof. (U
Alabama)
CMS-HEP

Gabor Veres
Postdoc 2000-2005
Professor (Eötvös
Loránd University)
CMS-HI

Christof Roland
Postdoc 2000-2004
Scientist (MIT)
CMS-HI



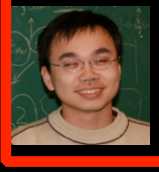
Corey Reed
PhD 2006
StubHub
Data Scientist

Burak Alver
PhD 2010
Scientific director
Harvard
Computational
Biology

Constantin Loizides
Postdoc 2005-2010
Divisional Fellow
(Oak Ridge)
ALICE

Edward Wenger
PhD 2010
Deputy Director,
IDM, Research
Technology

Wei Li
PhD 2009
Assoc. Prof.
(Rice U.)
CMS-HI



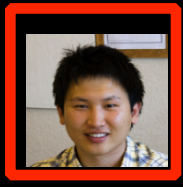
Yen-Jie Lee
PhD 2011
Assoc. Prof. (MIT)
CMS-HI

Krisztian Krajzcar
Postdoc 2012
Data Scientist
Alphagen

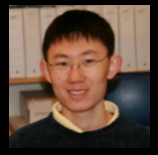
Andre Yoon
PhD 2012
Co-founder & CEO
at MakinaRocks

Siarhei Vaurynovich
PhD 2012
Quantitative Researcher/
Developer at Millennium
Management

Yetkin Yilmax
PhD 2013
Data scientist



Yongsun Kim
PhD 2013
Assistant Professor
Sejong University
CMS-HI



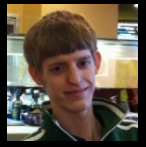
Frank Ma
PhD 2013
Google

Doga Gulhan
PhD 2016
Postdoc (Harvard)
Park Lab

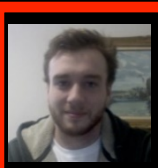
Yue Shi Lai
Postdoc 2016
Project Scientist
(Berkeley)
ALICE

Gian Michelle Innocenti
Postdoc 2014-2018
CERN Staff
ALICE

Ta-Wei Wang
PhD 2019
Quantitative Researcher
DRW

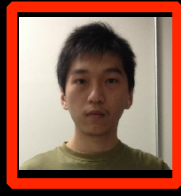


Austin Baty
PhD 2019
Rice Academy
Fellow
CMS



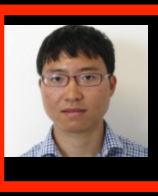
Chris McGinn
PhD 2019
Postdoc
CU Boulder
ATLAS

Jing Wang
PhD 2019
Postdoc (MIT)
CMS



Ran Bi
PhD 2020
Postdoc
CU Boulder
ATLAS

Kaya Tatar
PhD 2020
CERN Fellow
CMS

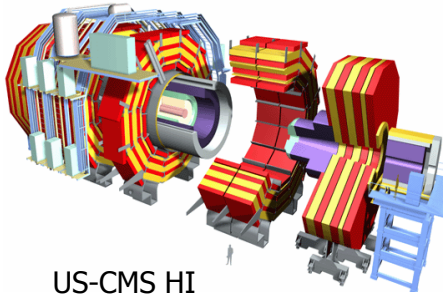


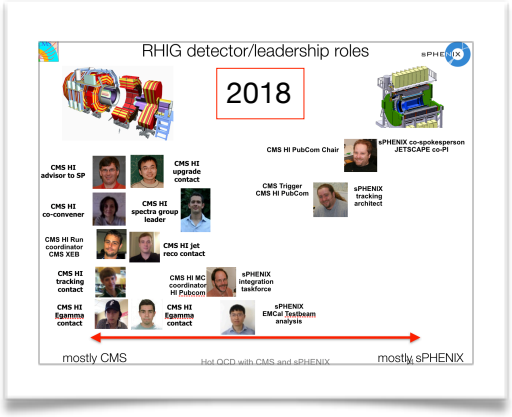
Zhaozhong Shi
PhD 2021
Director's
Postdoctoral Fellow
LANL
sPHENIX

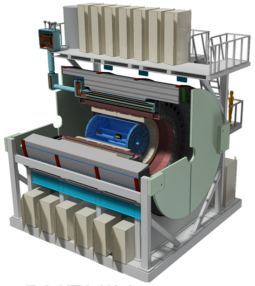
Camelia Mironov
Postdoc - 2022
Directeur de recherche au
CNRS
Dune

Stay in the field

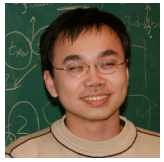
MITHIG in CMS & sPHENIX







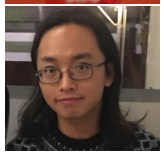
US-CMS HI Program manager
HI Computing center



MIT CMS physics
XSCAPE co-PI
HI upgrade contact

sPHENIX co-spokesperson (2016-2019,2019-2022, 2022-2025)
JETSCAPE co-PI

CMS Jets



CMS HI Run coordinator
CMS XEB

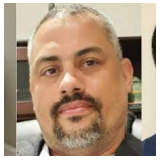
CMS Trigger
CMS HI PubCom

sPHENIX Calibration coord.
tracking architect

CMS Heavy Flavor

CMS Photon-Jet analysis

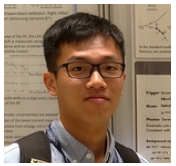
sPHENIX MVTX



sPHENIX MVTX / Heavy Flavor

CMS HF analysis

CMS Photon-Jet analysis



sPHENIX readout

sPHENIX HF reconstruction

CMS HI HF Analysis
sPHENIX HCAL

sPHENIX tracking/ MVTX/HCAL
CMS L1 trigger

sPHENIX MVTX Tracking

mostly CMS

mostly sPHENIX

Backup