The Relativistic Heavy Ion Collider (RHIC) facility and its SBIR/STTR opportunities

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DOE-NP SBIR/STTR Exchange Meeting
Gaithersburg MD, 13-14 August 2019

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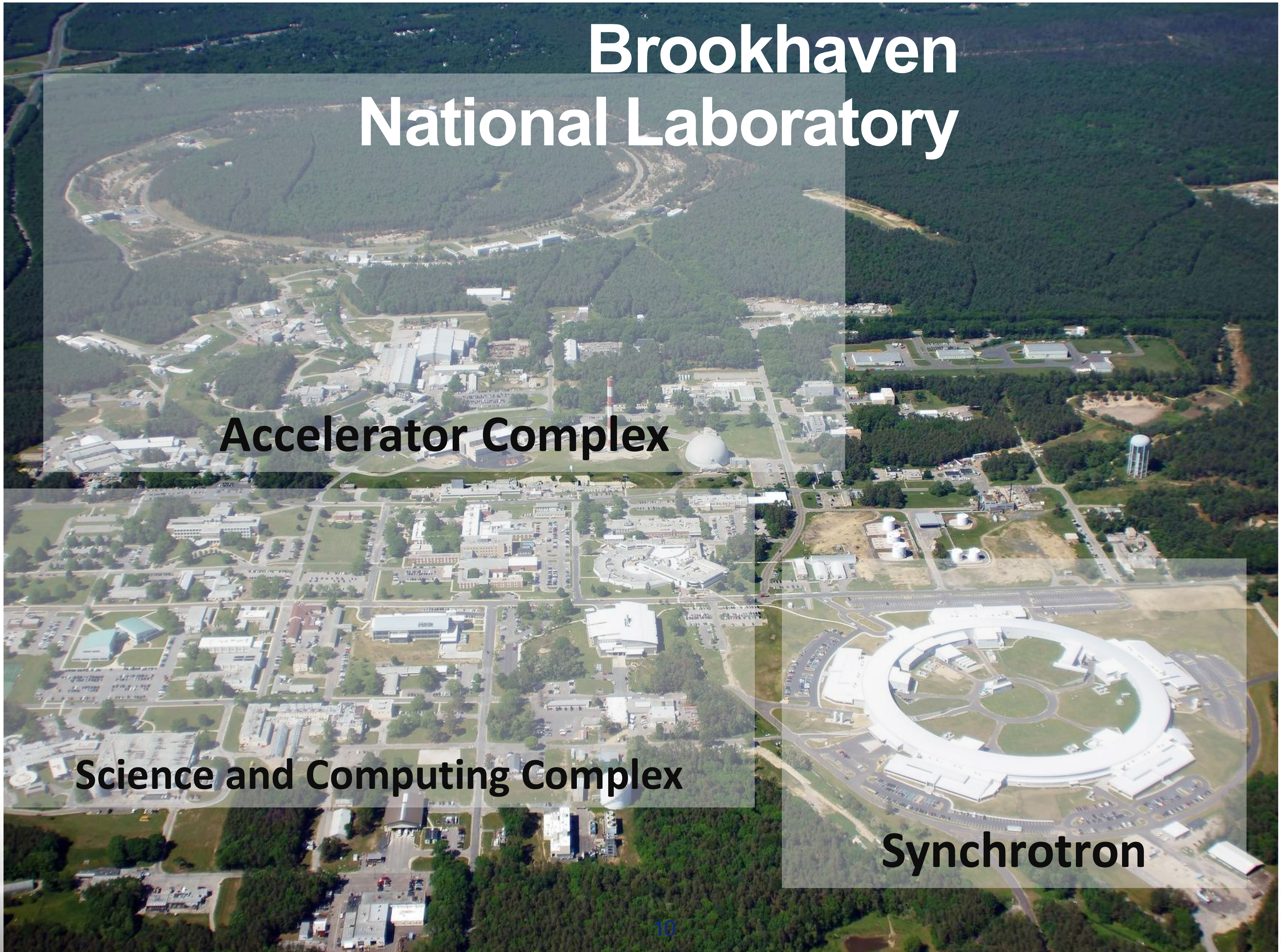


Brookhaven
National Laboratory
Accelerator Complex
Science and Computing Complex
Synchrotron
10


Brookhaven
National Laboratory
RHIC
NSRL
BLIP
BNL Scientific Data and
Computing Center
Interdisciplinary Energy
Science Building
CFR-I
ATF
CFN
NSLS-II
Long Island Solar Farm

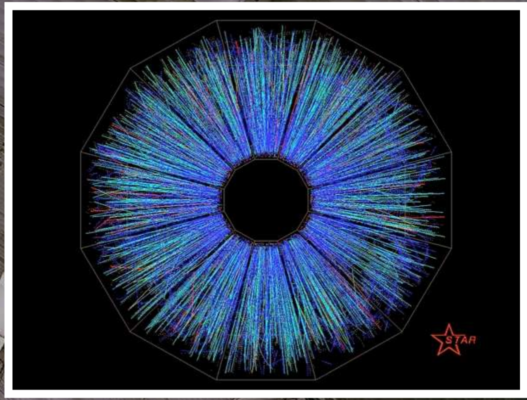
RHIC

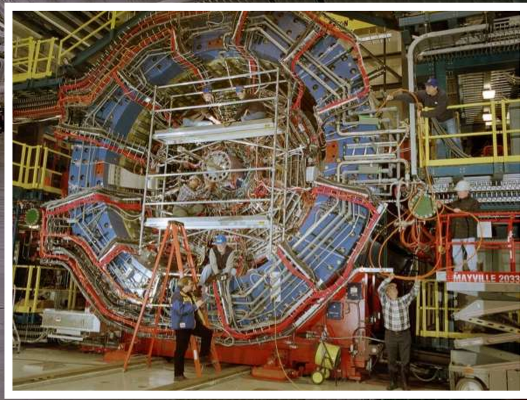
World's first machine capable of colliding heavy ions

World's only spin-polarized proton collider

World's highest energy machine for fundamental nuclear physics

- Used to explore the "strong force" and matter 0.00001 seconds after the birth of the universe
- Discovered quark-gluon plasma, a "perfect" liquid at 7 trillion degrees Fahrenheit





RHIC's Accelerator Complex

Space travel

- At the NASA Space Radiation Laboratory, particle beams from the RHIC accelerator complex simulate cosmic radiation to study health risks associated with longer missions in space and to Mars!

Radioisotopes—medical treatments—that save lives

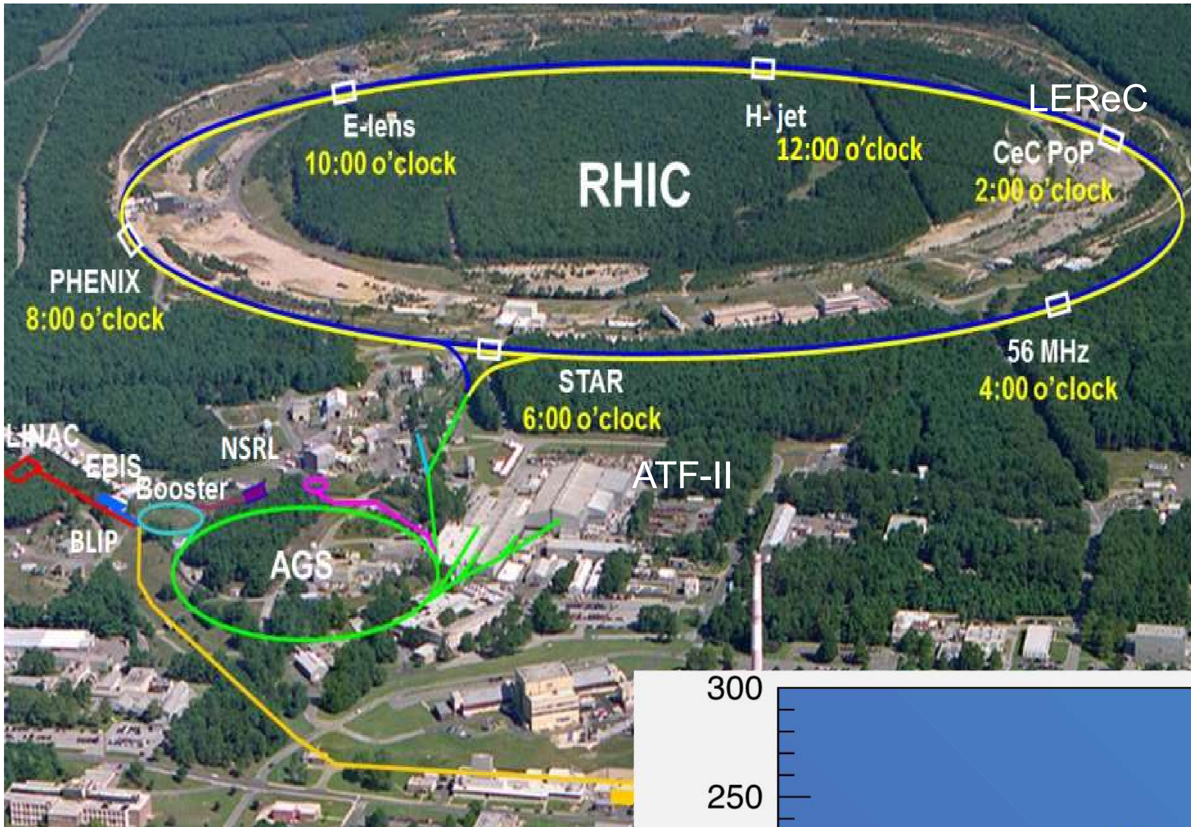
- Brookhaven Linear Isotope Producer for medical isotopes not commercially available
  - We produce half the United States' strontium-82 for generators to assess heart health
  - Collaborating on research for cancer therapy: Can produce Actinium-225, an "alpha-emitter" for noninvasive treatment, kills cancer cells with minimal damage to surrounding tissue

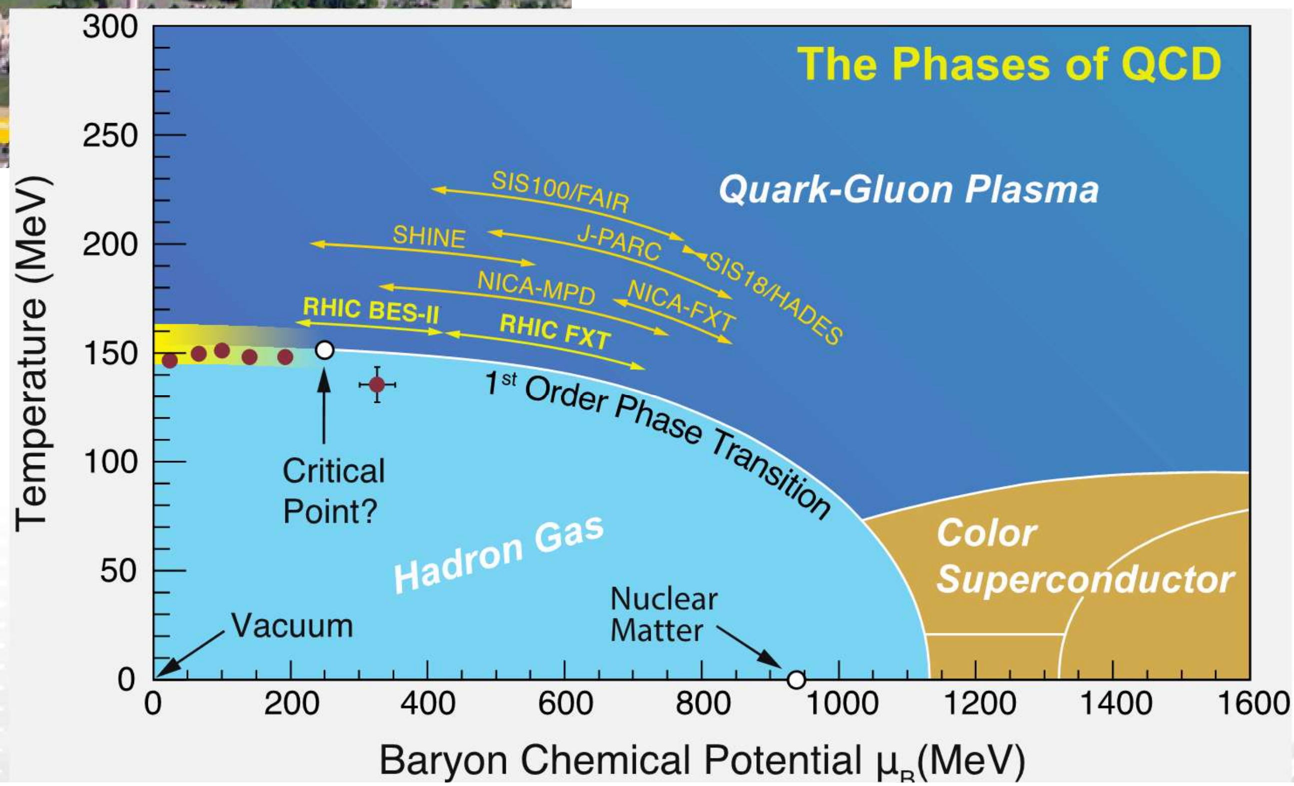
Particle detectors for health, national security

- Brookhaven experts have built detectors for countless experiments, PET detectors to diagnose disease, and radiation detectors that contribute to our nation's security

Exploring the Phases of Nuclear Matter

RHIC is the world's most versatile facility for the exploration of the phases of QCD matter from high temperature to high baryon density





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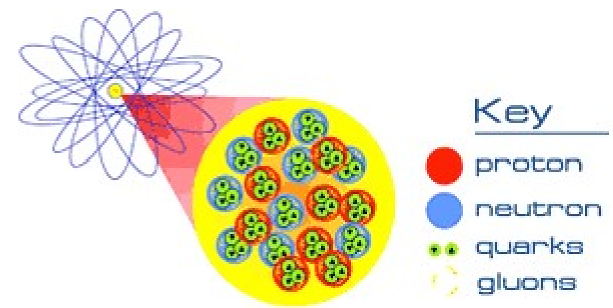
Inside RHIC

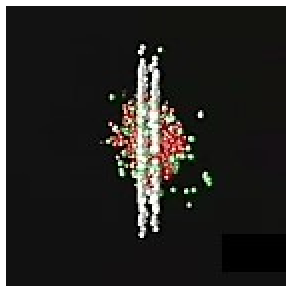
- Two concentric rings made up of 1,740 superconducting magnets, mounted end-to-end.
- 2.4 miles, 6 intersection points, 2 large detectors: **PHENIX detector** (for Pioneering High Energy Nuclear Interaction eXperiment) and **STAR detector** (for Solenoidal Tracker at RHIC)

Physics of RHIC



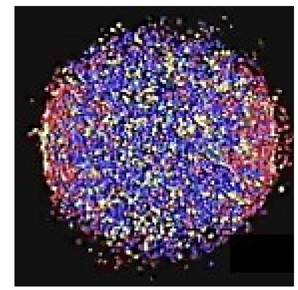
Heavy Ion Collisions

1. Ions about to collide



2. Ion collision

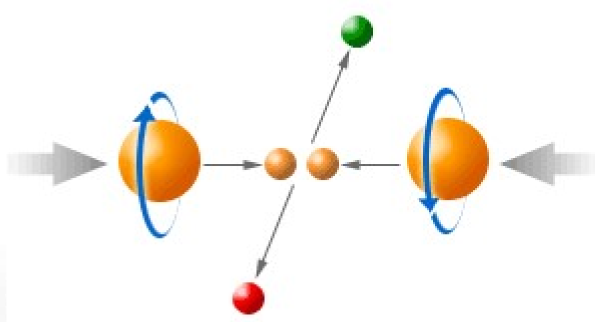
3. Quarks, gluons freed



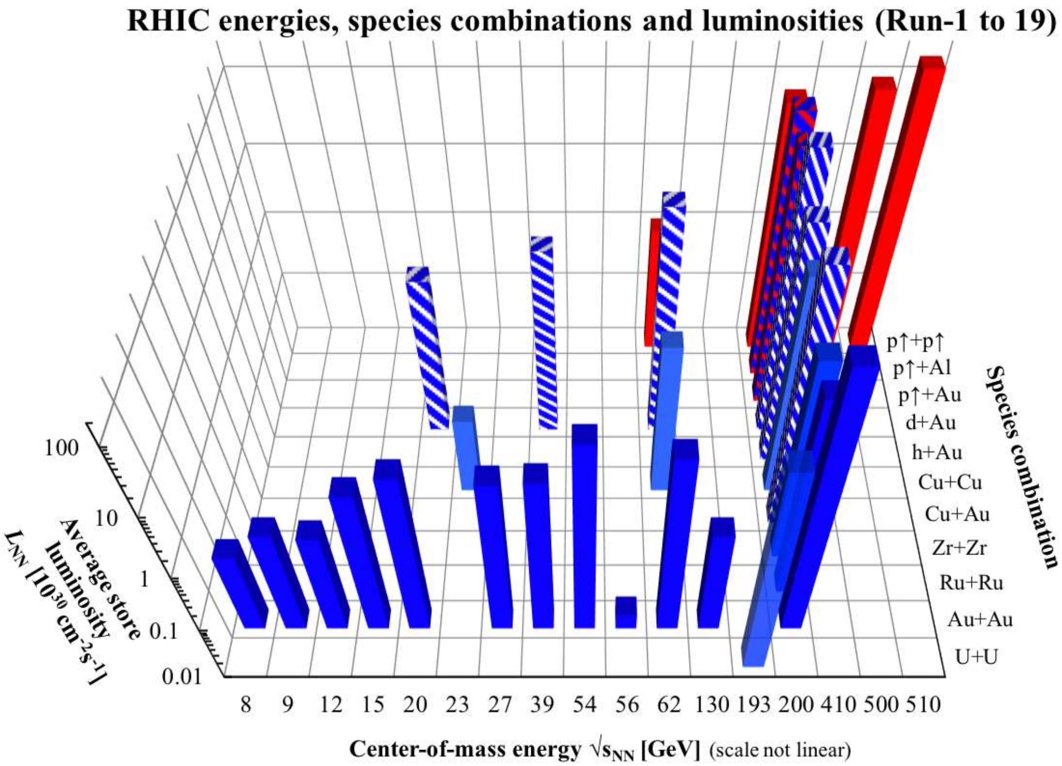
4. Plasma created

Spin Physics

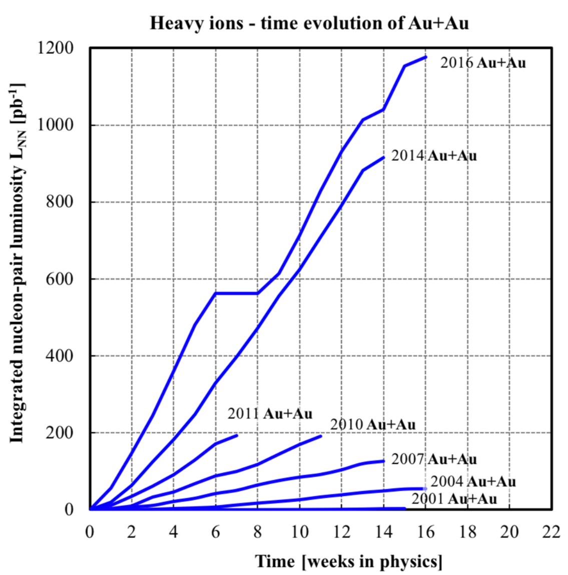
Exploring proton's missing spin

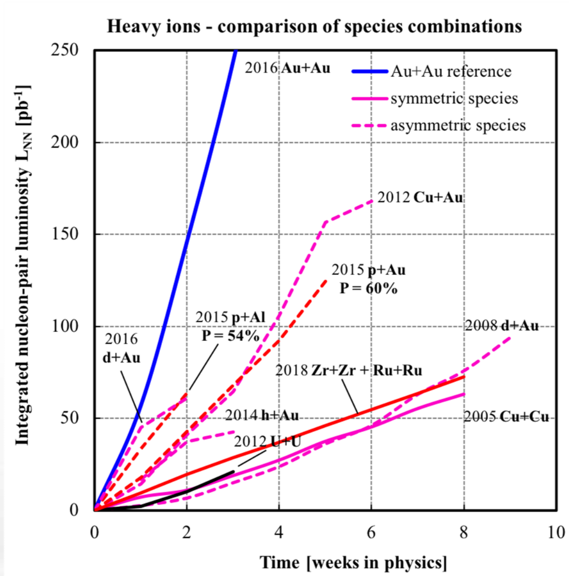


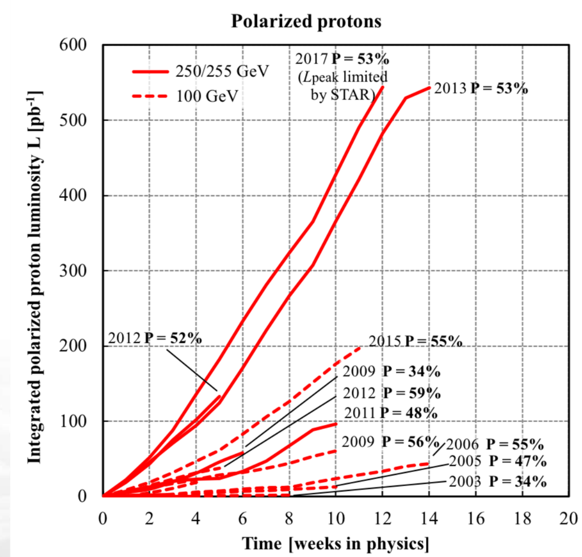
Proton-proton collision: spin shown as arrows circling the spherical particles; red and green particles represent reaction products from the collision which will be "seen" and analyzed by RHIC detectors.



- Operation since 2000
- Currently run 19







RHIC Run Plan 2019-25

- ***Beam Energy Scan II* (2019-21):**
  - Low energy ($\sqrt{s_{NN}}$ = 7.7, 9.1, 11.5, 14.5, 19.6 GeV) Au+Au runs using electron cooling to increase luminosity
  - Fixed target runs at (3.0), 3.5, 3.9, 4.5, 5.2, 6.2, 7.7 GeV
  - Search for signs of critical phenomena in event-by-event fluctuations

- ***Forward spin run* (2022):**
  - 500 GeV p+p (enhanced by forward upgrades of STAR)
  - Spin physics measurements complementary to EIC

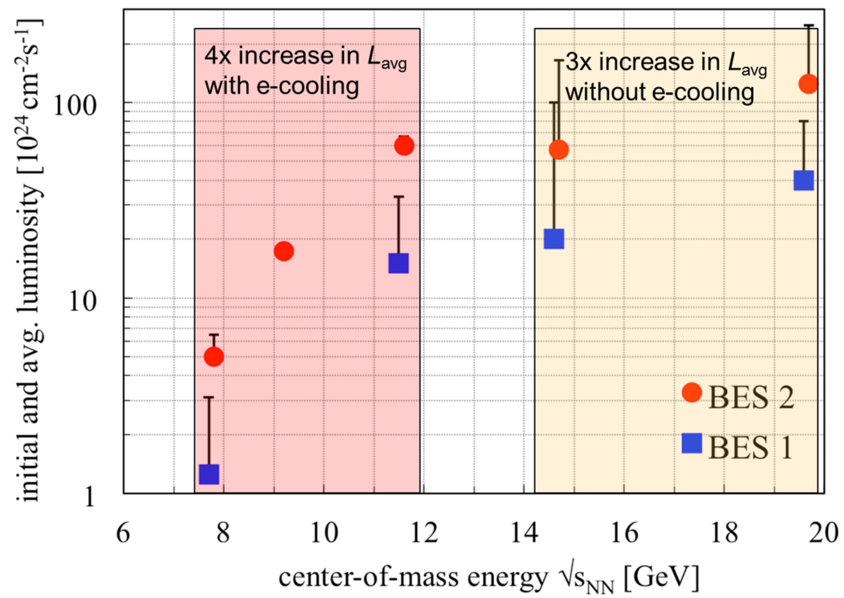
- ***Runs with sPHENIX* (2023-25):**
  - Full energy ($\sqrt{s_{NN}}$ = 200 GeV) Au+Au, p+p, p+Au
  - Precision measurements of fully resolved jets and Upsilon states

Beam Energy Scan II

To search for phase transition point, RHIC has to operate in energy range 3.85~10 GeV. Luminosity goal of phase II is 3-4 times higher than that of phase I.

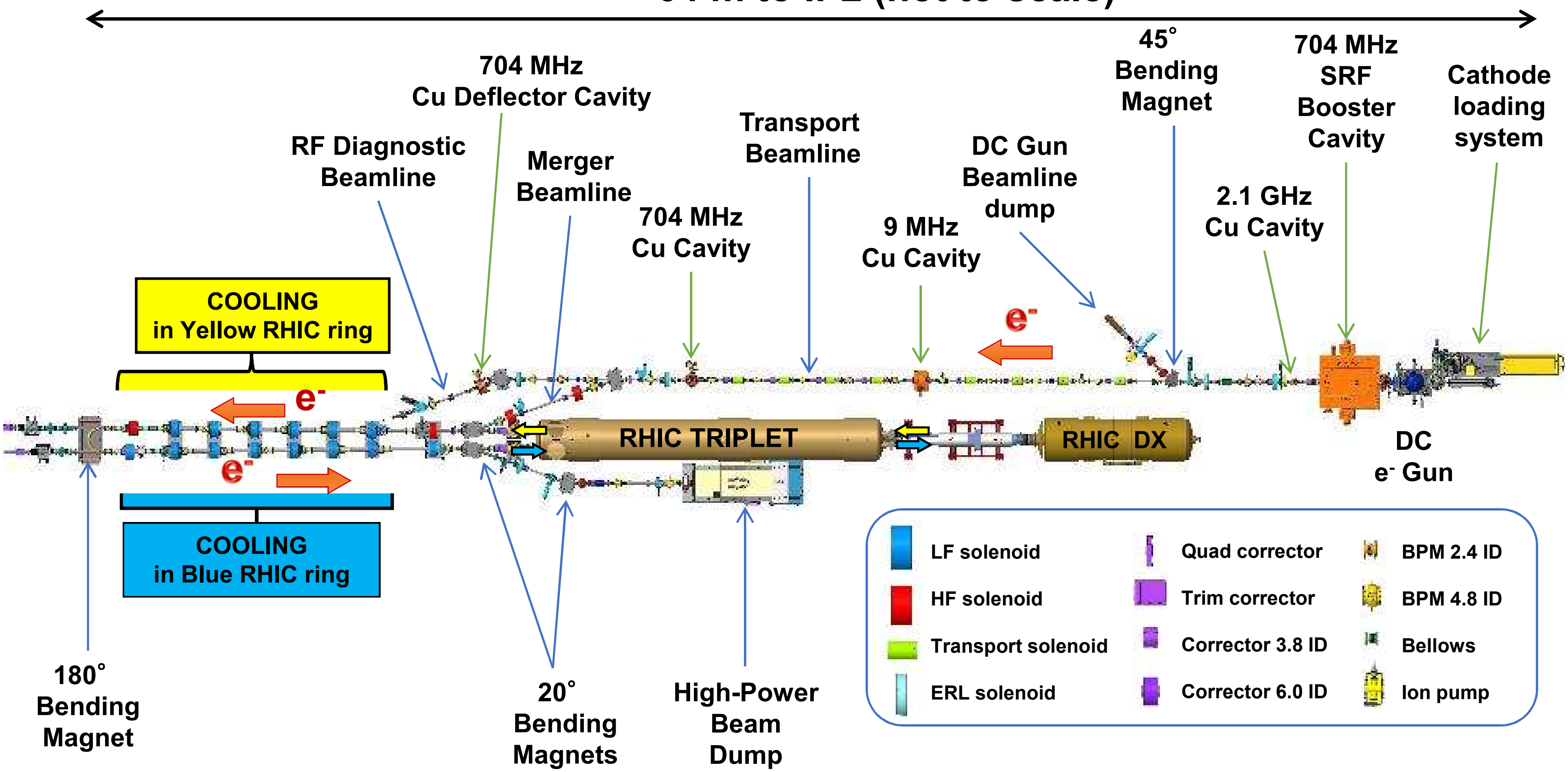
The challenges are:

- Intra-beam scattering
  solution: Low Energy RHIC electron cooling
- Space charge
  solution: 9 MHz instead of 28 MHz cavity
- Lattice nonlinearity contributed by persistent current
  solution: degaussing magnet cycle
- Beam-beam interaction
  solution: near integer working point



Low Energy RHIC e⁻ Cooling (LEReC)

A. Fedotov, J. Tuozzolo et al.



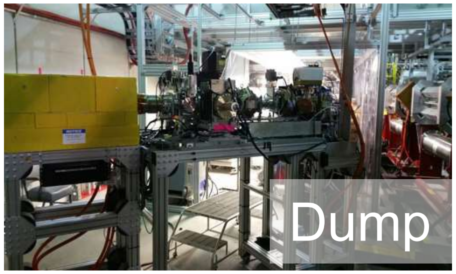
Energies E	:	1.6, 2.0 MeV
Beam current I_{avg}	:	27 mA
Momentum $\delta p/p$	:	5×10^{-4}
Luminosity gain	:	$4\times$

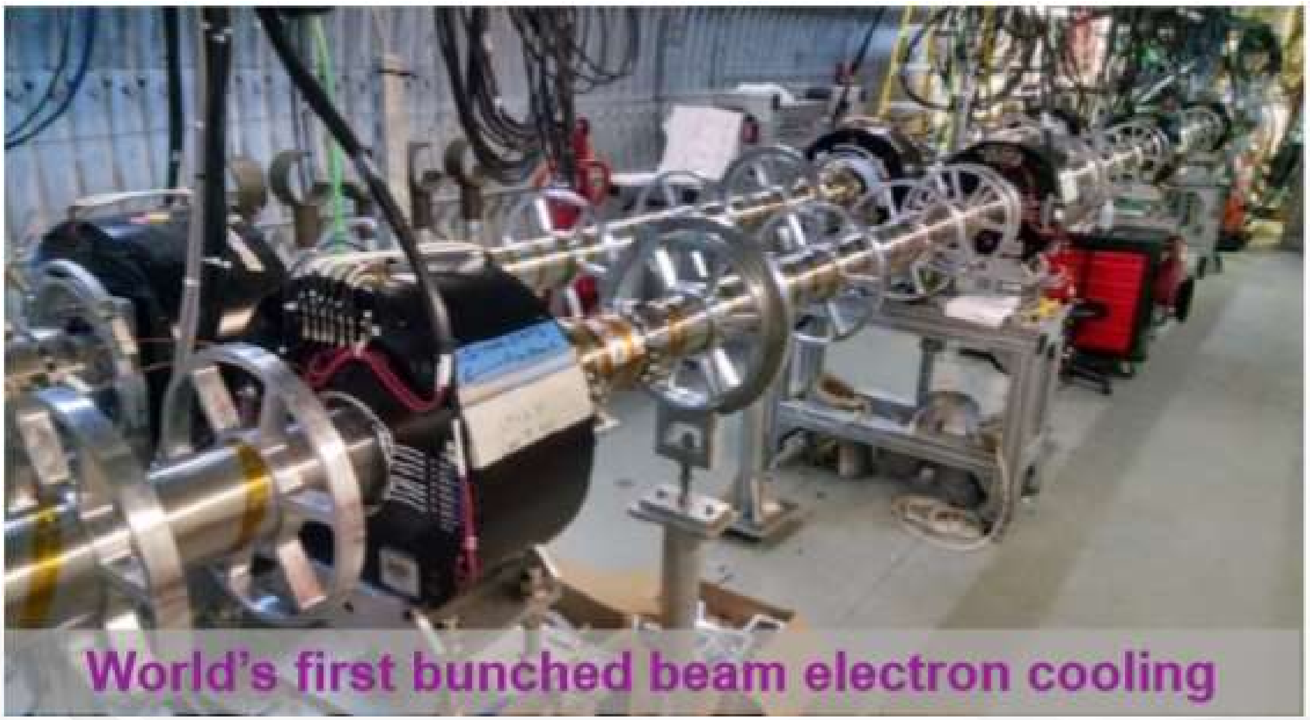
1st bunched beam electron cooler

Challenges: high power laser, stable electron gun, beam loading, SRF cavities, extremely small dp/p (5E-4), beam measurements…

Low Energy RHIC e^{-} Cooling (LEReC)

LEReC accelerator (100 meters of beamlines with the DC Gun, high-power fiber laser, 5 RF systems, many magnets and instrumentation devices)





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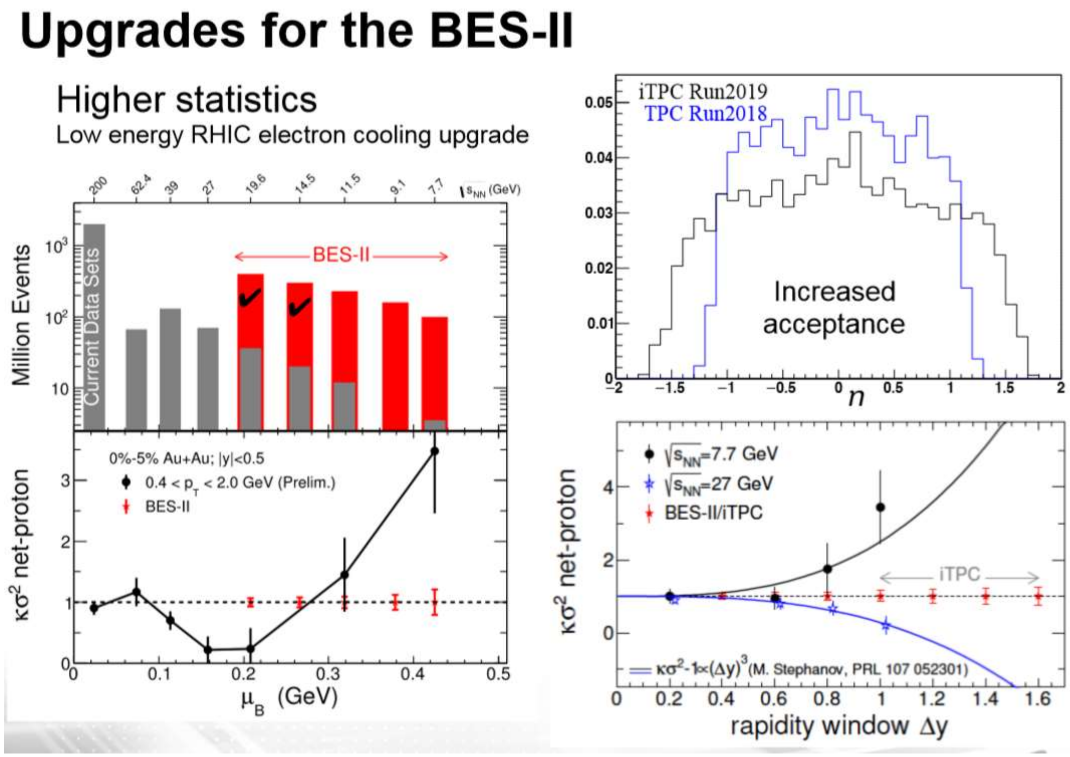
Beam Energy Scan Goals

• What is the phase boundary of ordinary nuclear matter, i.e. matter composed of baryons and mesons?

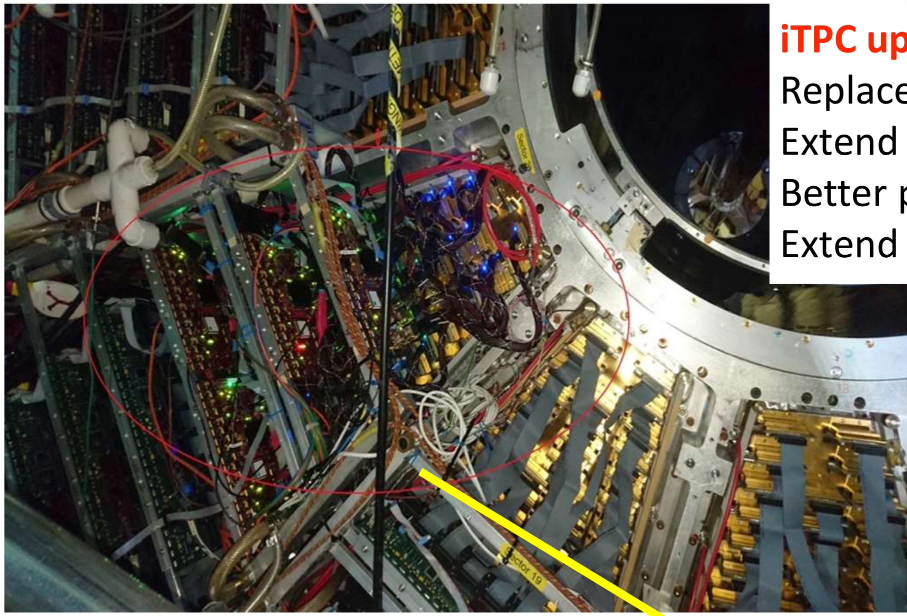
• Is there a critical point in the QCD phase diagram and, if so, where is it located?

− 3-year run program: 12 energies

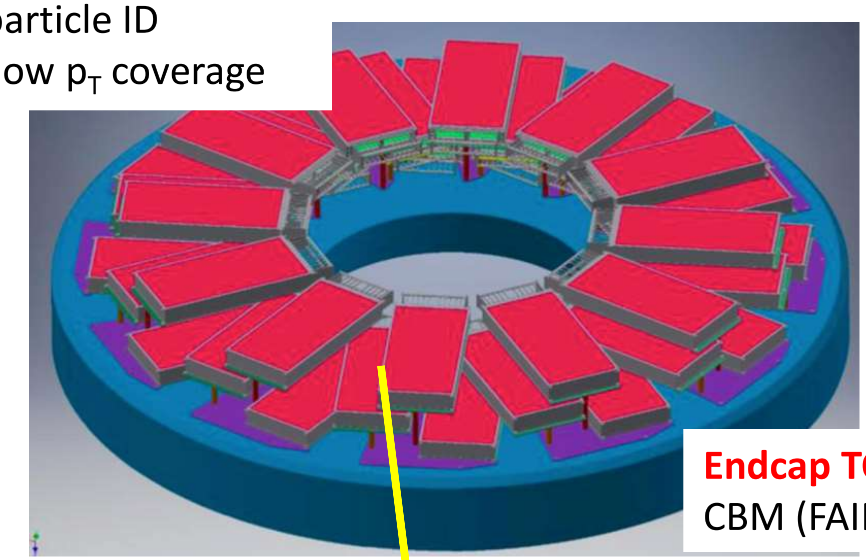
− Run-19 already exceeding goals



STAR Upgrades for BES-II

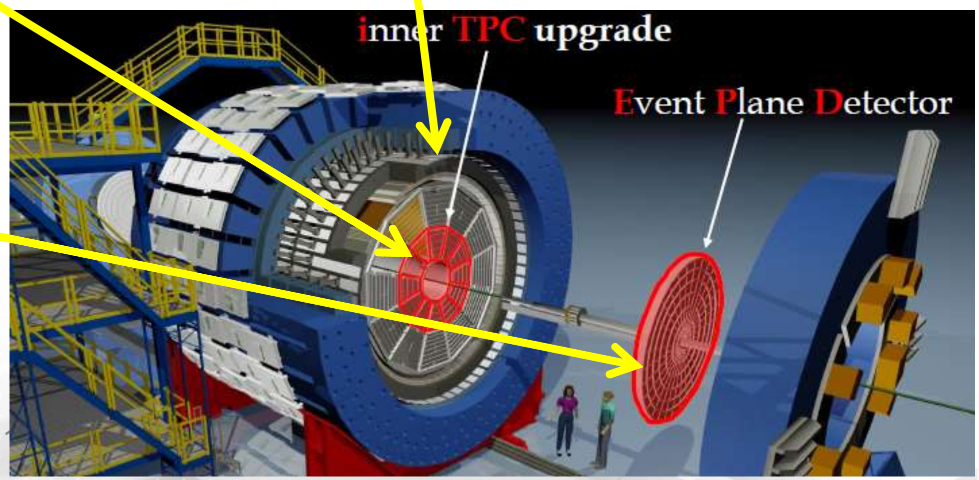


iTPC upgrade (2018)
Replace inner TPC Sectors
Extend rapidity coverage
Better particle ID
Extend low p_T coverage

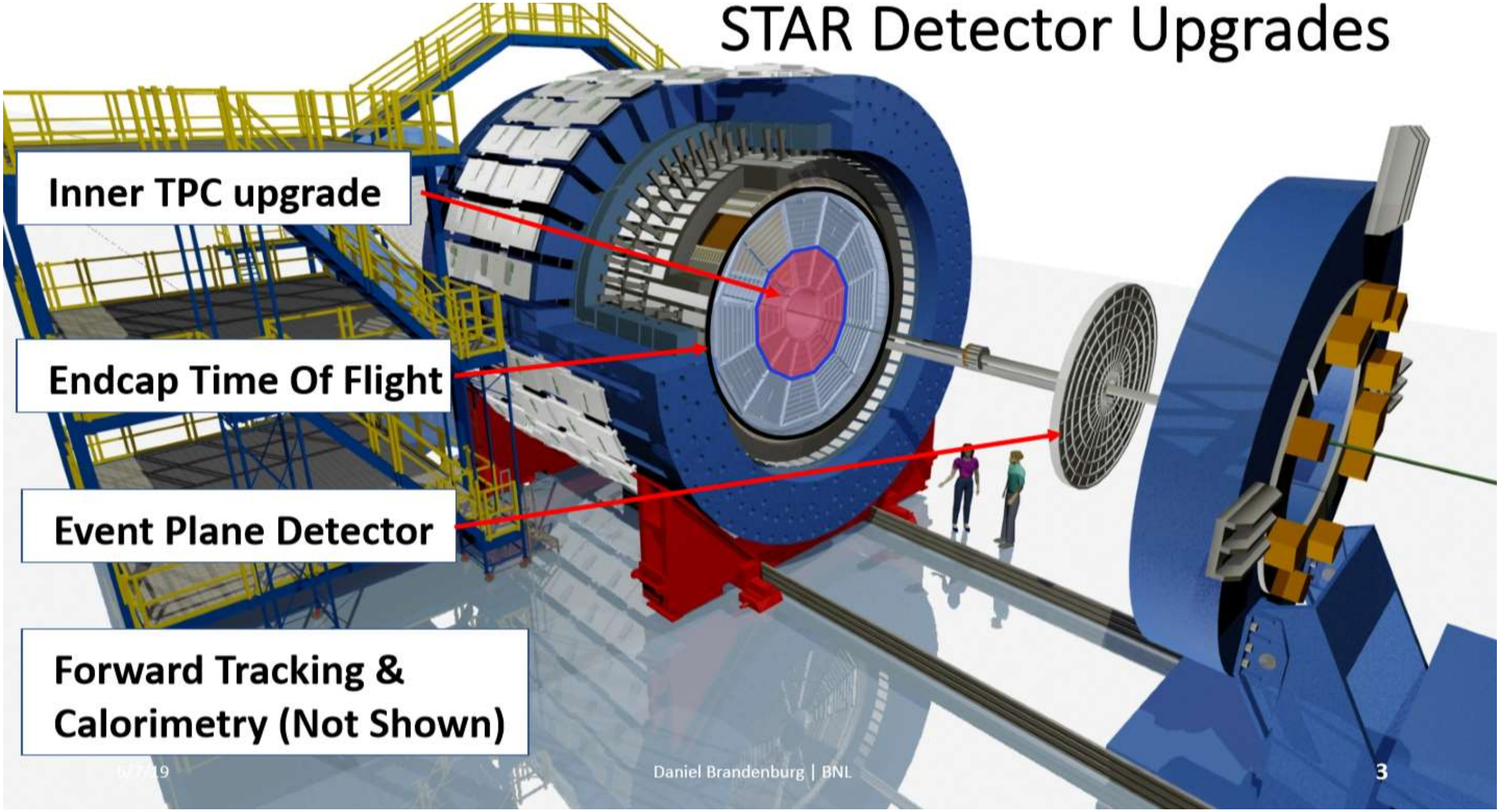


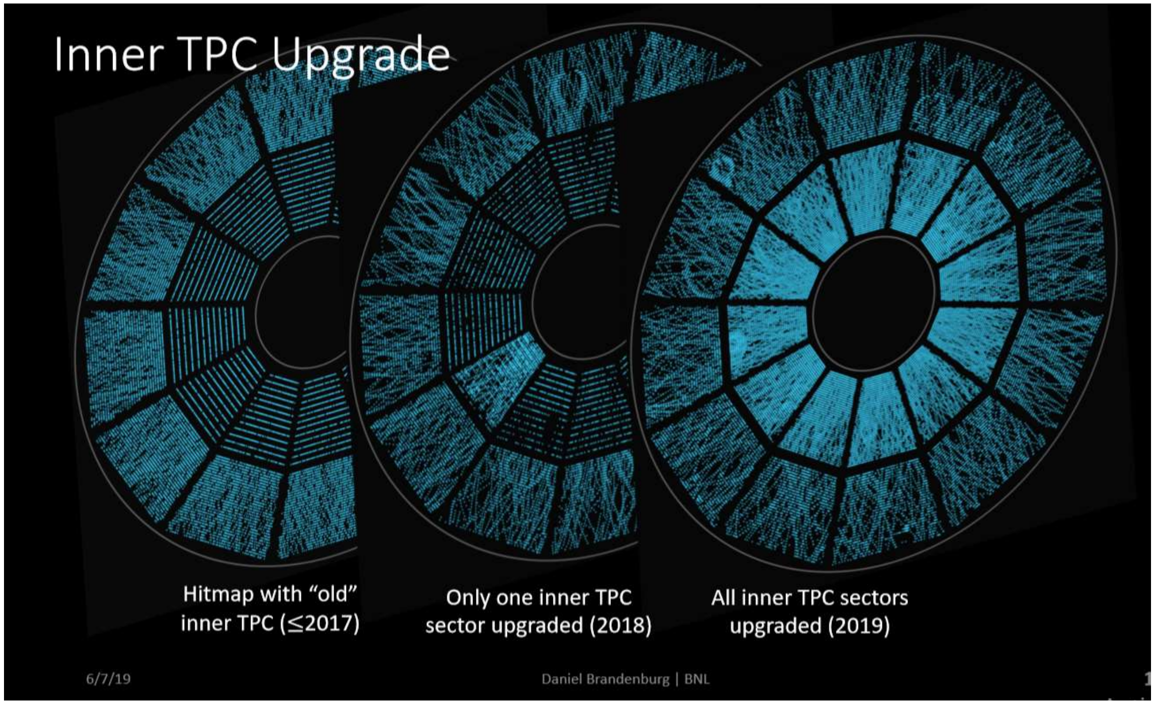
Endcap TOF
CBM (FAIR)

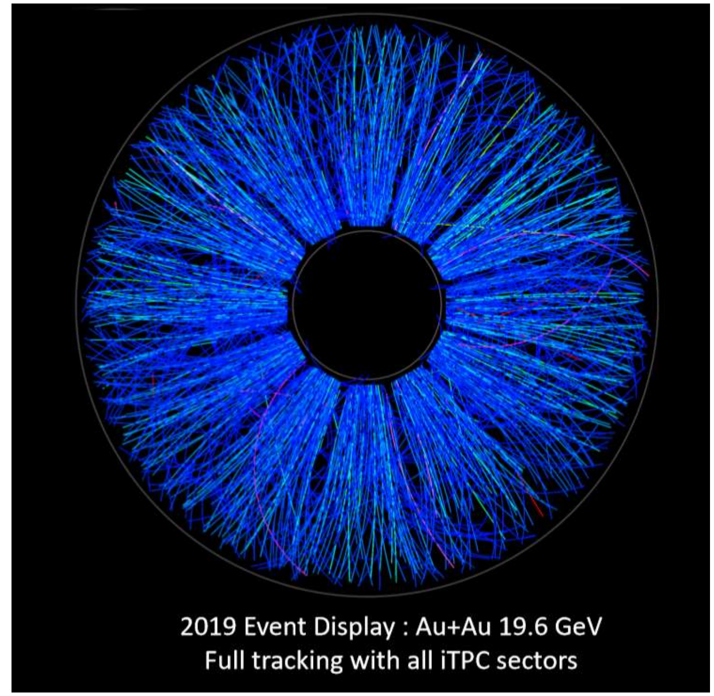
Event Plane Detector
Improved Event Plane Resolution
Centrality definition
Improved trigger



STAR Detector Upgrades







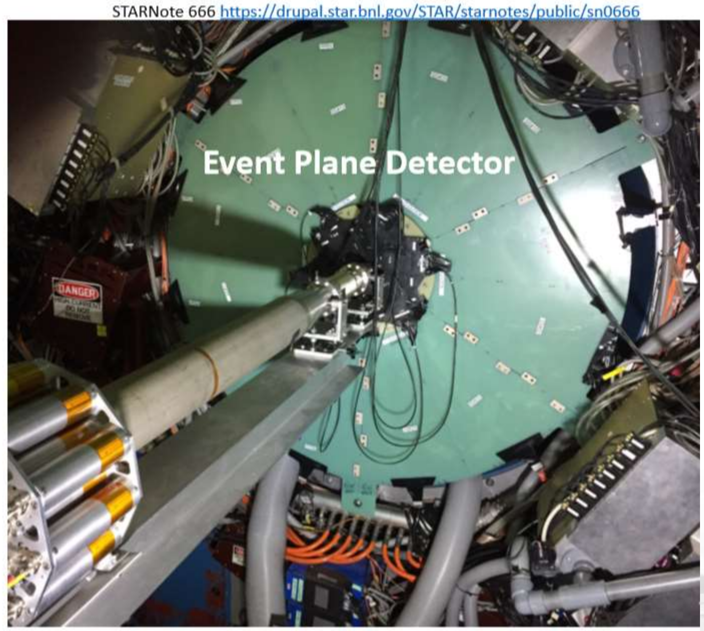
Event Plane Detector

- Replaces Beam-Beam Counter (BBC)
  - Improved triggering capabilities
  - Improves background rejection
- Coverage : $2.1 < |\eta| < 5.1$
- Greatly improves event plane resolution
  - Especially 1st order event plane
  - Crucial for achieving BES II physics goals
- Smooth installation (completed in 2018), commissioning, and operation
- Already used for physics analysis of 2018 data

Each (East, West) wheel:
- 16 tile “rows” at given radius
- 24 tiles per row (except 12 for innermost)

➢ 372 tiles x 2 = **744 tiles in total**

STARNote 666 https://drupal.star.bnl.gov/STAR/starnotes/public/sn0666



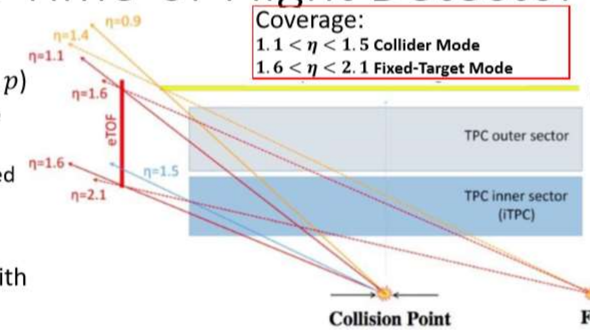
Event Plane Performance

1st order Event Plane Resolution →Significant improvement across all centrality

Added coverage from EPD →Allows measurement of $v1$ over ~10 units of η

Motivation: Endcap Time-of-Flight Detector

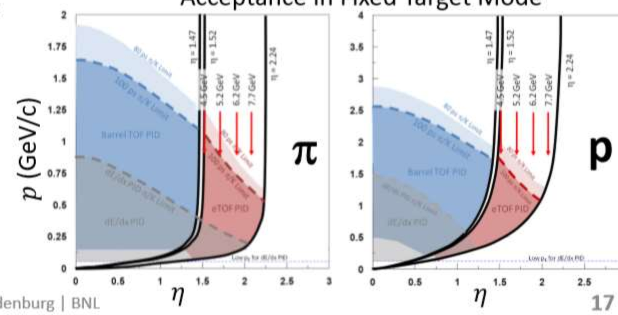
- ➢ Extend STAR's particle ID capabilities (π, K, p)
  - Complements the increased iTPC coverage $|\eta| < 1.5$
  - Essential for mid-rapidity particle ID in Fixed Target Program
- ➢ Allows "gap-less" scan of phase diagram with collider + Fixed Target Energies
  - Rapidity dependence of key bulk observables
  - Particle ID – needed for fluctuation measurements in the Fixed Target Program
- ➢ First streaming DAQ system at RHIC – important step towards the future
- ➢ Collaboration with CBM Fair phase 0



FXT Experiments

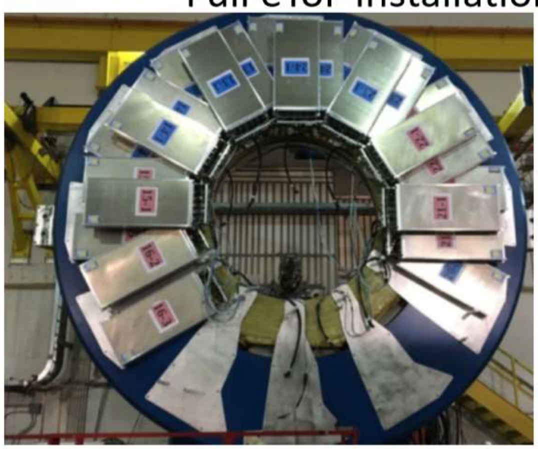
$\sqrt{s_{NN}}$ (GeV)	y_{CM}	μ_B (MeV)
7.7	2.1	420
6.2	1.9	487
5.2	1.7	541
4.5	1.5	589
3.9	1.4	633
3.5	1.2	666
3.2	1.1	699
3	1.0	720

Acceptance in Fixed Target Mode

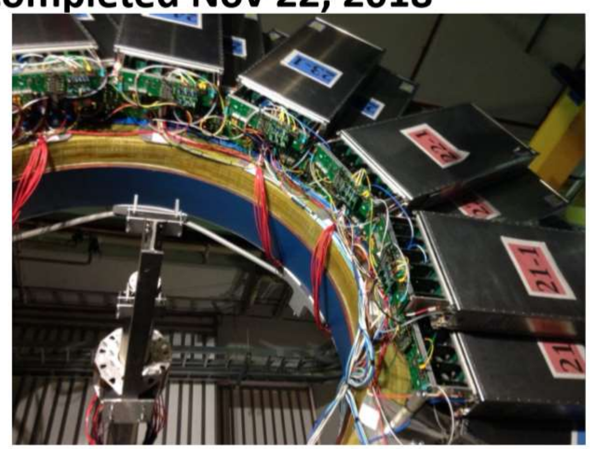


Endcap Time-of-Flight Detector

Full eToF installation : **completed Nov 22, 2018**



Inside face of east pole-tip, partially installed



Fully installed and cabled

ETOF Performance in 2019 Running

Extended coverage added by eTOF

Achieved expected time resolution

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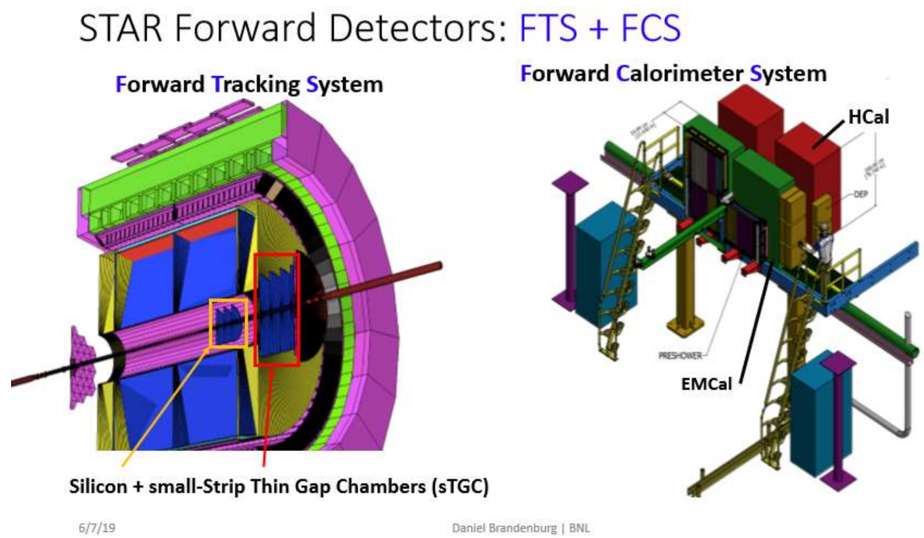
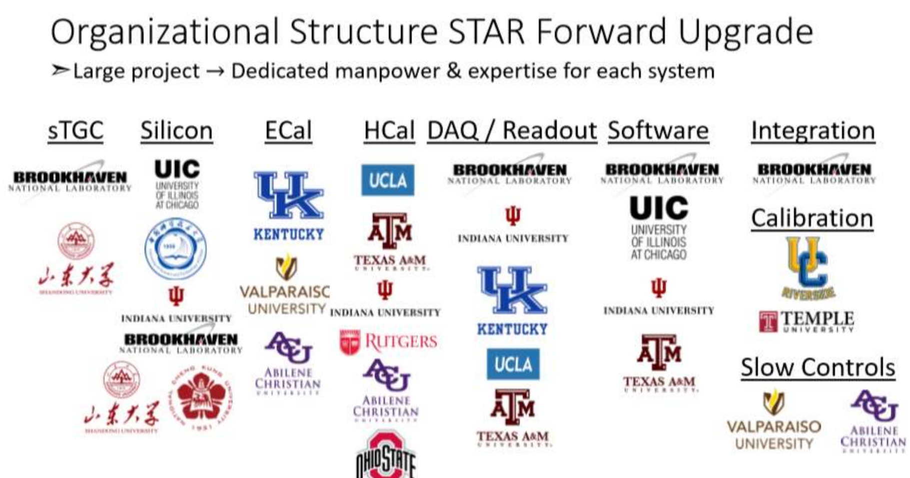
STAR Forward Upgrade

STAR collaboration is planning to implement forward upgrades for RHIC runs beyond BES-II

Physics program described in 2016 RHIC Cold QCD Plan - similar, but complementary to measurements planned for EIC.

Enables polarized 500 GeV proton run in 2022, possibly continued running 2023-25





sPHENIX

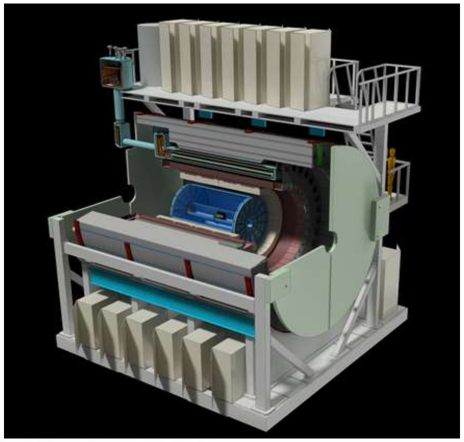
Operation with sPHENIX detector from 2023~2026, with e-lens for proton, 3D stochastic cooling and 56 MHz cavity for Au beam.

<u>sPHENIX is a major upgrade to the PHENIX detector</u>. It is a large-acceptance, high-rate detector for Heavy Ion physics that repurposes >$20M in existing PHENIX equipment, infrastructure and support facilities.

The detector is optimized to measure jet and heavy quark physics by incorporating a Tracker, full EM and Hadronic calorimeter coverage at $|\eta| < 1.1$, and a 1.4 T solenoidal magnetic field.

Schedule

- CD-0 received Sept 2016
- Early completion Dec 2021
- CD-4 Dec 2022 (proposed to DOE-ONP)



A schematic of the sPHENIX experiment

The solenoid magnet that will form the core of the sPHENIX detector

3D stochastic cooling, e-lens and 56 MHz cavity essential for sPHENIX operation

Electron Ion Collider (EIC)

What is the EIC:

A high luminosity ($10^{33} – 10^{34}$ $cm^{-2}s^{-1}$) polarized electron proton / ion collider with $\sqrt{s_{ep}}$ = 20 – 100 GeV, upgradable to 140 GeV

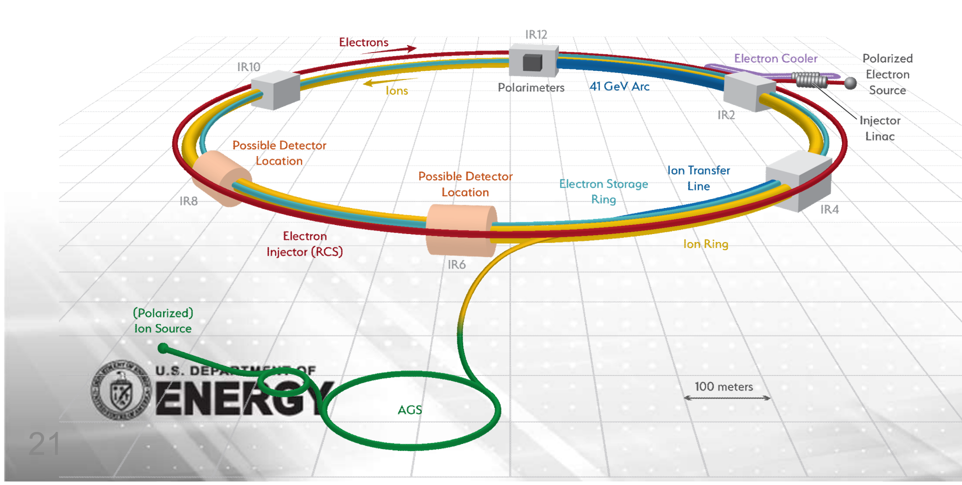
What is new/different:

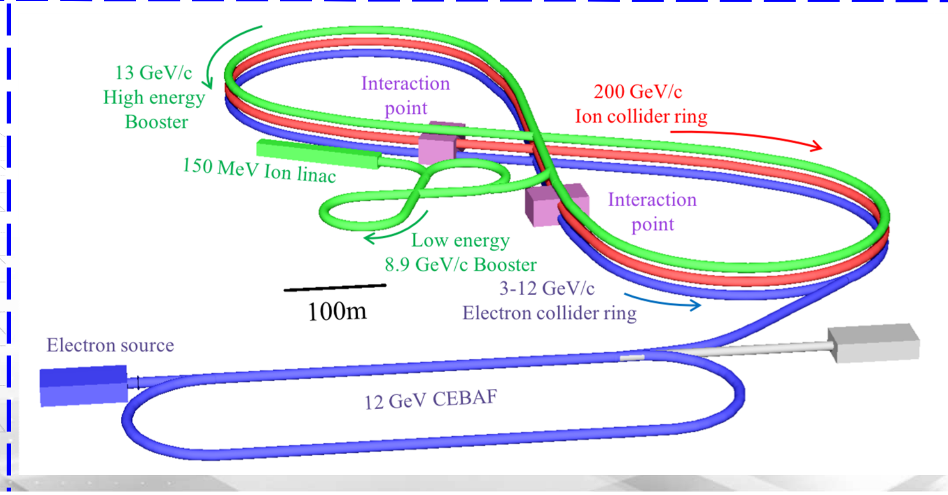
Hera: factor 100 to 1000 higher luminosity
both electrons and protons / light nuclei polarized
nuclear beams: d to U

Fixed Target Facilities i.e.:
at minimum > 2 decades increase in kinematic coverage in x and Q^2

Two realization plans:

eRHIC | JLEIC





EIC: compelling science case

NAS Study of the Science Case for a U.S. based EIC

In summary, the committee finds a compelling scientific case for such a facility. The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today. In addition, the development of an EIC would advance accelerator science and technology in nuclear science; it would as well benefit other fields of accelerator based science and society, from medicine through materials science to elementary particle physics.

EIC User community

Currently ~850 members from 180 institutions from 30 countries from 7 world regions
US: 44% Europe: 33% Asia: 17%

→ continuously growing

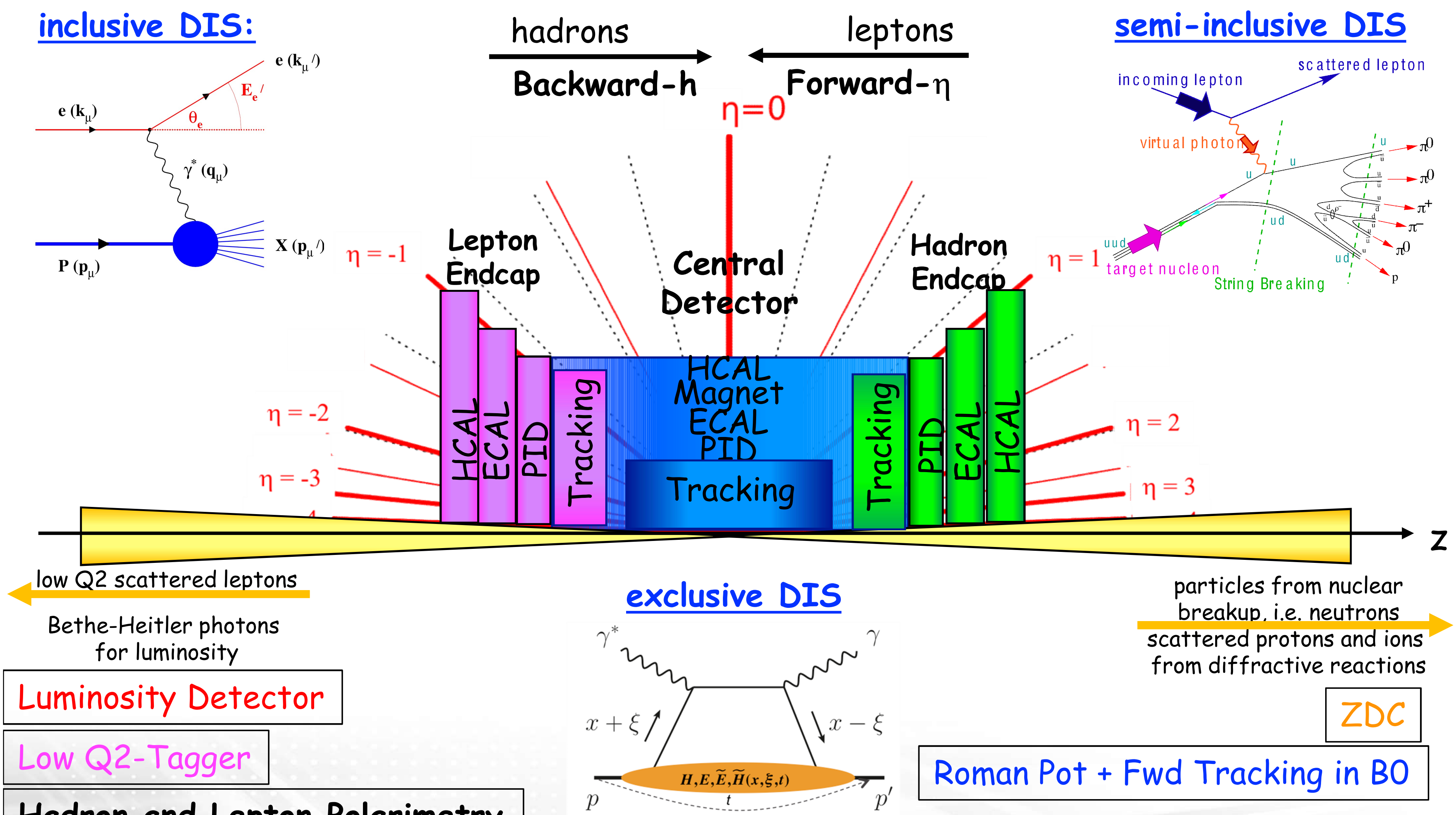
→ Please sign up and join us
http://www.eicug.org

- ❑ Very active generic EIC detector R&D program:
  https://wiki.bnl.gov/conferences/index.php/EIC_R%25D
  37 groups collaborate in tracking, calorimeter, PID consortia and …….

- ❑ Last EIC user group meeting:
  July 22nd – 26th 2019 PARIS, France

- ❑ EIC Conference series: POETIC (Physics Opportunities at an ElecTron-Ion Collider)
  16th – 20th of September 2019 LBNL, Berkley, USA

EIC General Purpose Detector Sketch



Electron-Ion Collider Detector Requirements and R&D Handbook

Version 1.1
January 10, 2019

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Editors Notes

This handbook is a community effort. Many colleagues have made substantial and valuable contributions to this document and the studies it is based on. We consider this a living document that, as we hope, gets frequently updated and thus stays relevant for those that work on the realization of an EIC. EIC User Group members and those involved in the EIC detector R&D programs are invited to contribute to this document. If you want to contribute please send text (MS Word) and plots (preferably in eps format).

Alexander Kiselev
Thomas Ullrich

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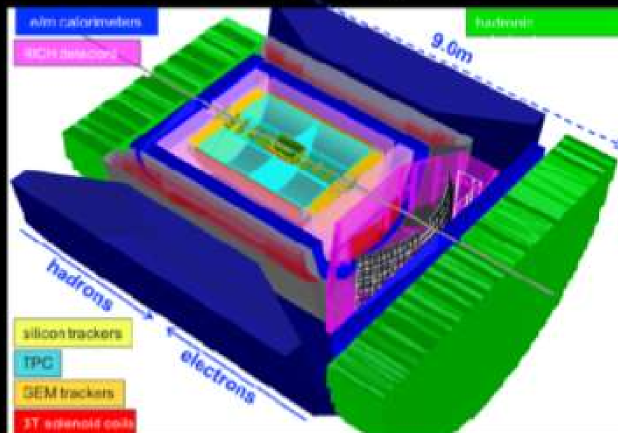
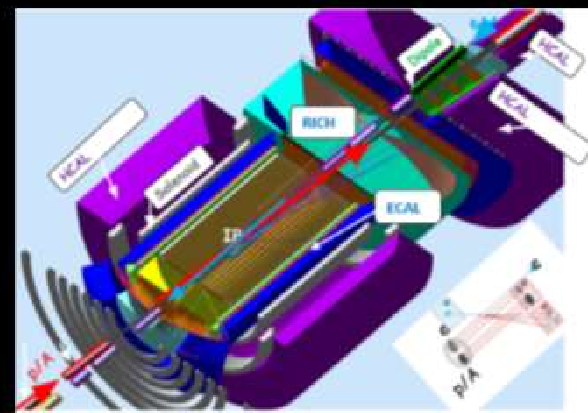
EIC detector concepts

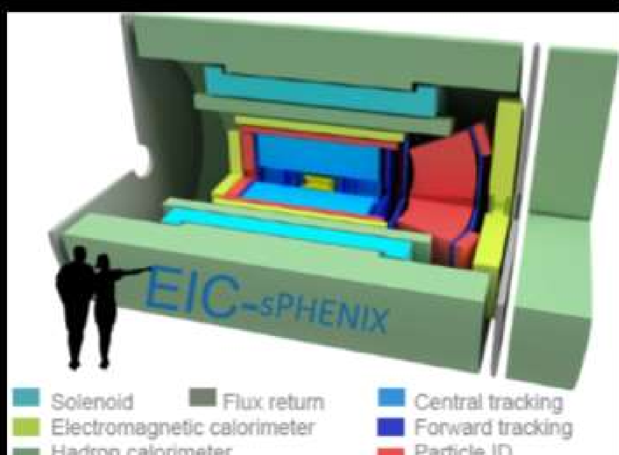
Brookhaven concept: BEAST



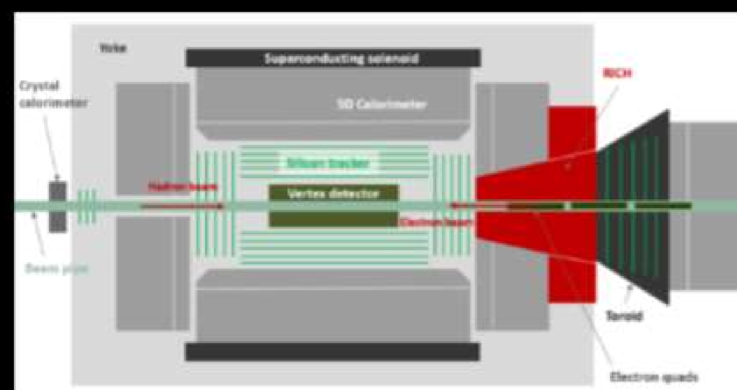
Jefferson Lab concept: JLEIC



sPHENIX → EIC



Argonne concept: TOPSiDE



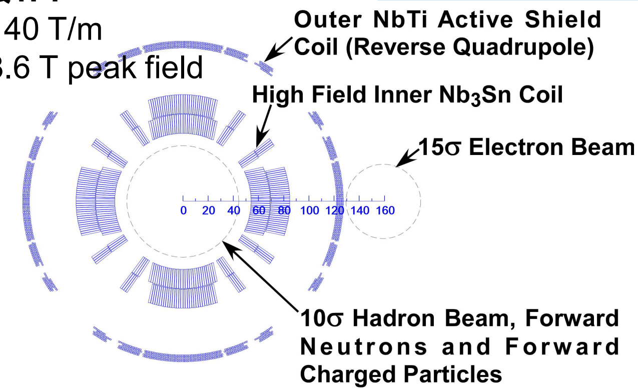
eRHIC R&D Program is underway

- Strong Hadron Cooling
  - Theoretical and simulation studies of advanced techniques (micro-bunched cooling; staged plasma-amplification)
  - Coherent electron Cooling experimental Proof-of-Principle test at RHIC
  - High-current multi-pass ERL using FFAG recirculation passes (CBETA facility at Cornell)
- In-situ coating of RHIC beam pipe (with copper and amorphous carbon)
- High charge polarized electron gun prototype
- Crab-cavities: prototypes and study of related beam dynamics
- e-p beam-beam effect simulation studies
- Polarized He3 production and acceleration
- High-current polarized electron source (large cathode or based on merging scheme) (for ERL-Ring)

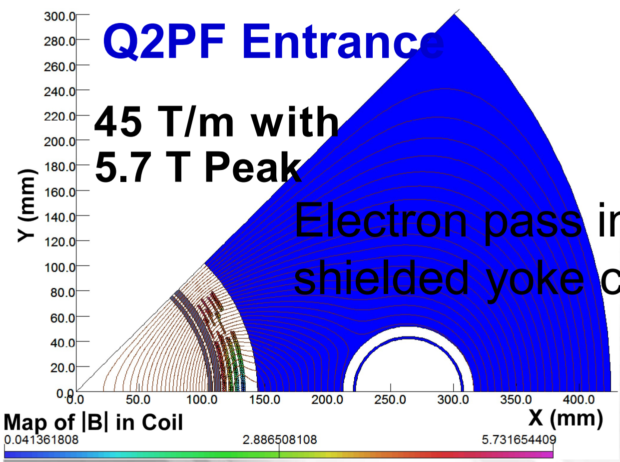
IR magnets

Variety of novel approaches is used for IR magnets

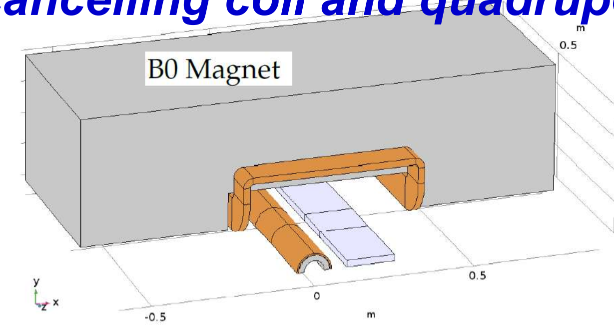
Q1PF
140 T/m
8.6 T peak field

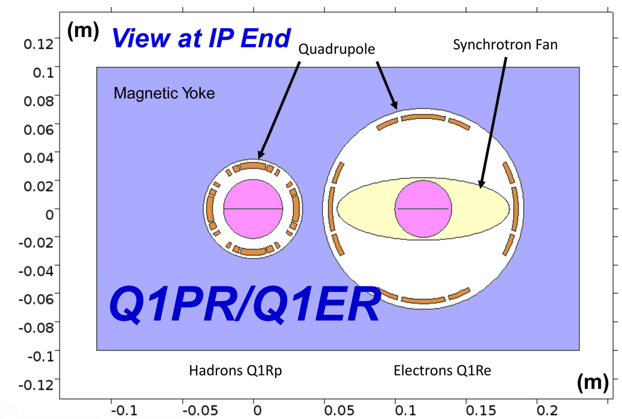


Funded **BNL/Jlab R&D effort**: designing, building and testing a short prototype based on existing Nb_3Sn coils (from LARP work) actively shielded by new NbTi coil.



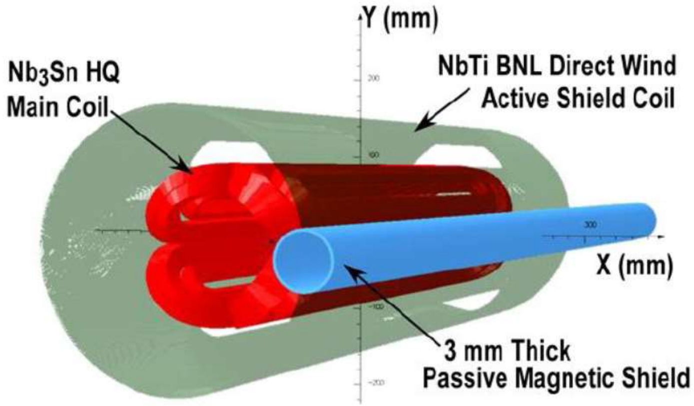
Hadron spectrometer magnet with detector elements inside. Superconducting coils. For electrons: dipole cancelling coil and quadrupole coils.

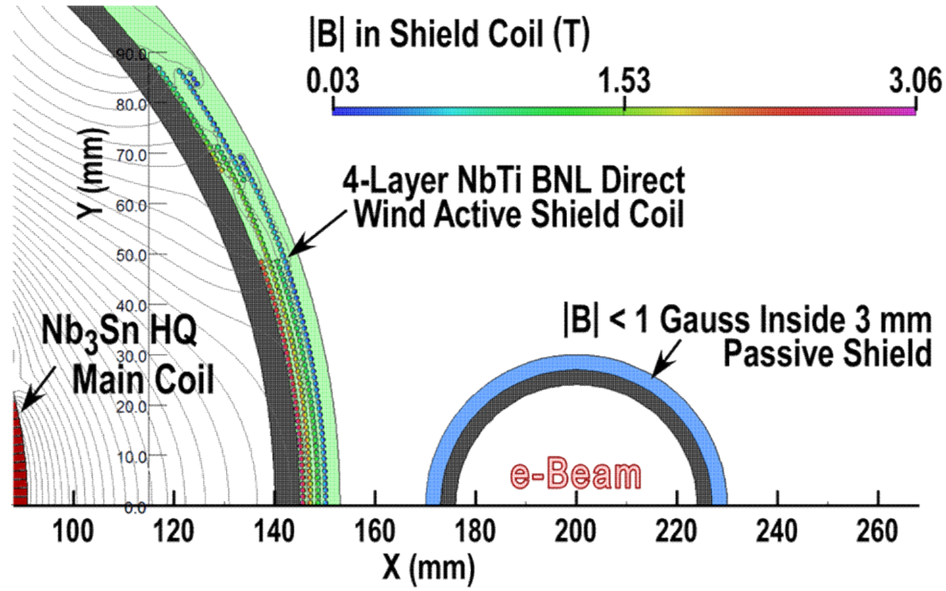




Concept for a Direct Wind tapered coil design for Q1PR that has a nearly constant gradient along its entire length

MgB2 shielding placement for eRHIC IR magnet





Brett Parker

Placement of MgB_2 tube for passive magnetic shielding for EIC at BNL (from the proposal)

DOE SBIR/STTR Program - “Superconducting MgB_2 Tubes for Passive Magnetic Field Shielding for Electron Ion Collider”

DOE NP Grant #DE-SC0019623, Start 21 March 2019

Development partners

Hyper Tech Research, Inc - MgB2 tube fabrication, Mr. Matt Rindfleisch, Dr. Mike Tomsic

BNL/SMD - Design and simulations, Dr. Honghai Song

OSU – material cauterization, Dr. Mike Sumption

Increasing proton intensity and repetition rate

Proton parameters	Achieved at RHIC	eRHIC nominal
Beam current, mA	330	1000
Bunch frequency, MHz	9.4	112.6
Peak current, A	12	24

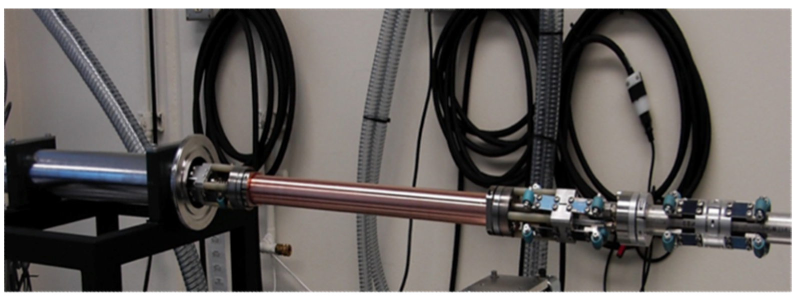
Electron cloud:

- Beam scrubbing is an efficient tool based on LHC experience
- But additional remedies may be needed

Required hardware upgrades:

- New injection kickers (<12 ns rise time)
- RF system upgrade to incorporate bunch splitting and bunch compression

In-situ copper coating of existing stainless steel beam pipe to reduce cryo-load from resistive heating.



Art Custer, Ady Hershcovitch

Pool Ventura Inc -SBIR phase II funded project titled: *"Techniques for energetic ion assisted in-situ coating of long, small diameter, beam pipes with compacted thick crystalline copper film"*

Goal is to develop an ion assisted deposition (IAD) technique for coating the cold bore sections of RHIC with crystalline copper in order to reduce RHIC vacuum tube resistivity at cryogenic temperatures.

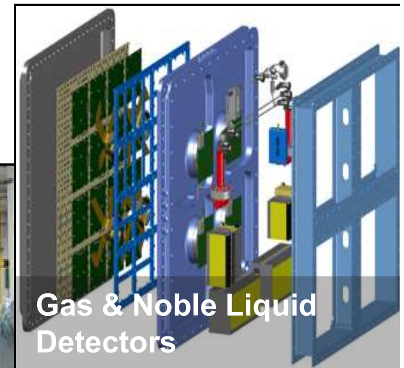
Mission-focused Detector R&D Platform – Instrumentation Division

SBIR with RMD

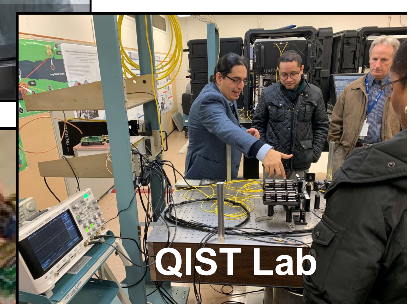
Develop and steward key capabilities enabling BNL Programs:

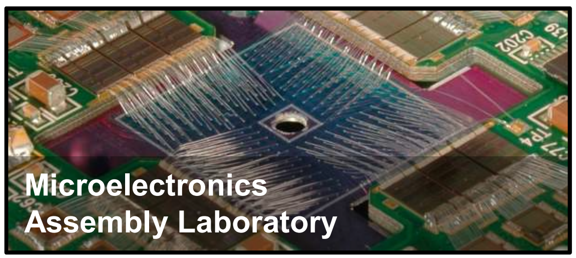
- Silicon Sensor Development Laboratory
- Gas & Noble Liquid Detector Laboratory
- Application Specific Integrated Circuits (ASICs) Development Facility
- Computer Aided Design for Device & Board Level Circuit Designs
- Microelectronics Assembly and High Density Interconnect Laboratory
- High throughput Data Acquisition
- Photocathode Development & Production Facility (for detector and accelerator applications)
- Quantum Information Science & Technology Laboratory

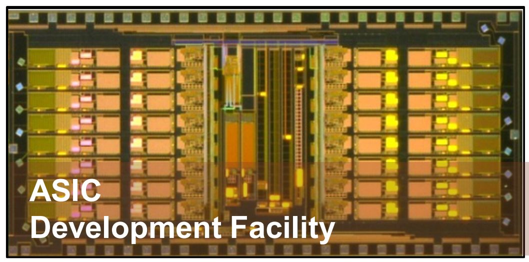

Photocathode Facility

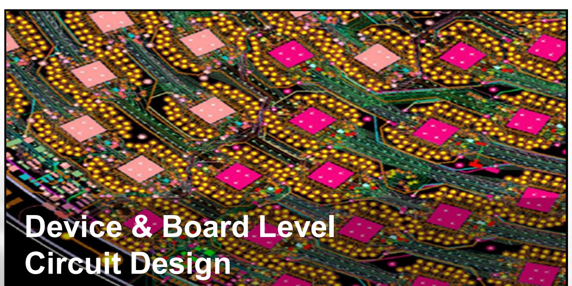

Gas & Noble Liquid Detectors


Si Sensor Development Lab

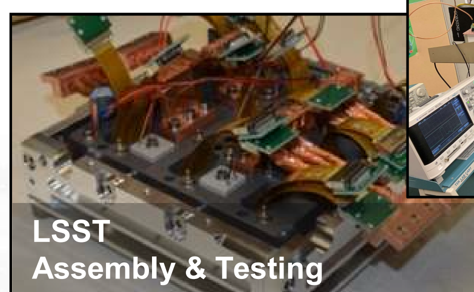

QIST Lab


Microelectronics Assembly Laboratory


ASIC Development Facility


Device & Board Level Circuit Design


High Throughput Data Acquisition


LSST Assembly & Testing

SBIR/STTR opportunities

- Accelerator technologies
  - cavities, control, sources, guns
- Detector and system technologies
  - sensors, readout and control electronics, DAQ, interconnects (e.g. radiopure for nEXO)
  - fast, non-invasive beam diagnostics
- Data analytics
  - ML/AI
- QIST
- …

Looking to the future: discovery park

Addressing multiple needs

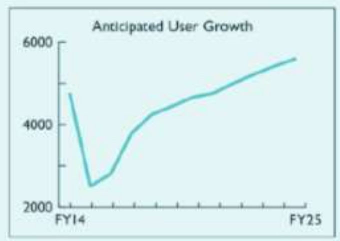
Infrastructure Renewal

- Enables demolition of 250,000 SF of old inadequate wood buildings
- Eliminates $34M of repair and ESH legacy deficiencies

Facility Type (Total 4.75M SF)	Adequate	Sub-standard	Inadequate
Mission Unique Facilities	21%	9%	1%
Conventional Facilities	17%	29%	23%

User Accommodation

- Enhanced one-stop guest/user experience
- Renewed user housing and collaboration space
- Accessible conference center
- Attractive "sense of place"



Economic Development

- Technology transfer, growth, and impact

Opportunities for Discovery Park Tenants
Supply Chain Relationships
"Implant Laboratories"
Joint Institutes
Technology Incubators

2012
Initial idea to repurpose land
Created early master plan

2013
Initial public discussion at invitation of Town of Brookhaven

2014
Campus development plan and BSA Contract proposal
Engaged GSA

2015
Became a "recognized project"
Awarded $1.8M NYS grant

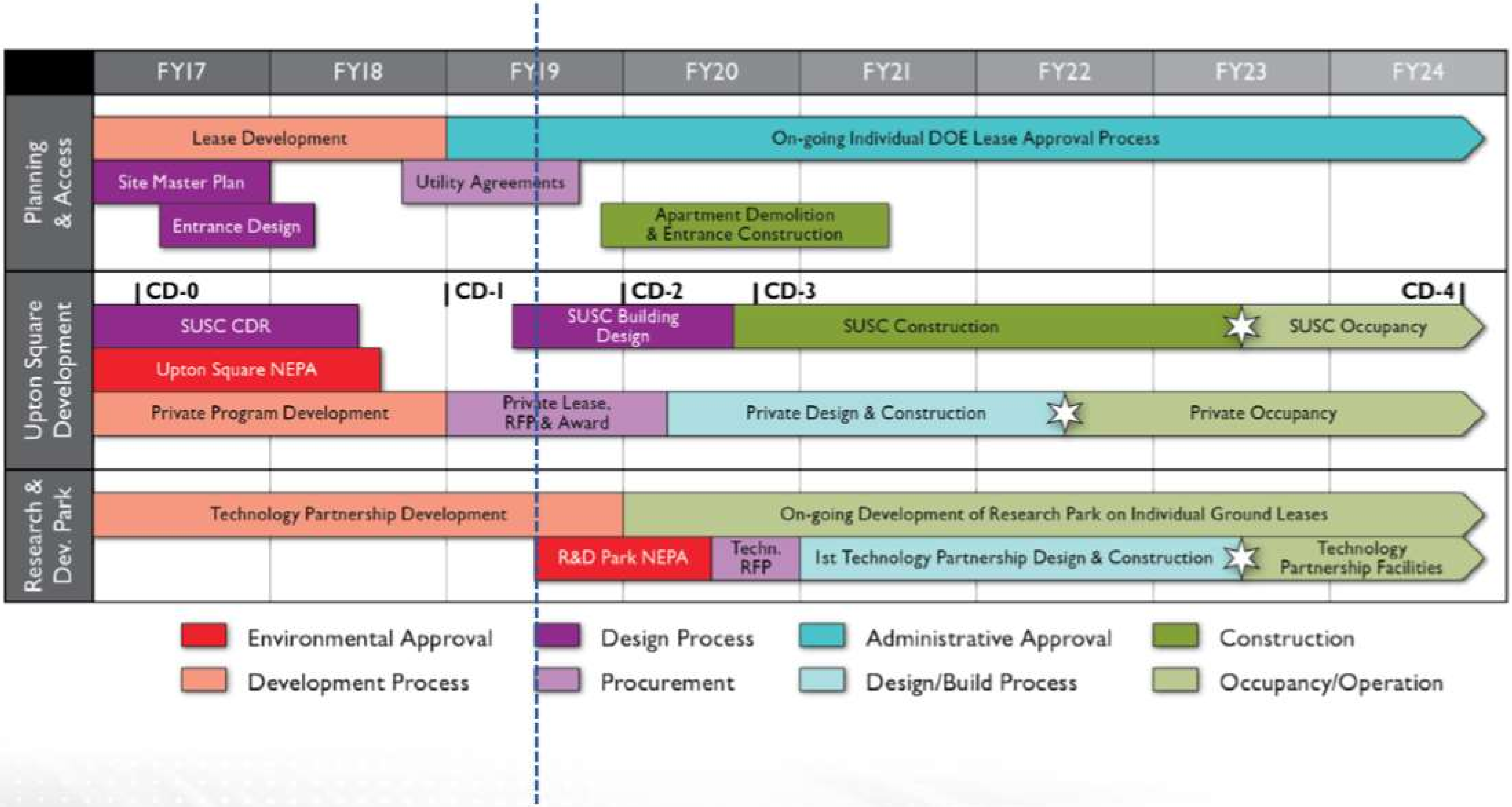
2016
Completed Feasibility Study
Received DOE endorsement for a Federal anchor building

2017
Received SUSC CD-0
Created Upton Square as initial development focus

2018
SUSC funding proposed
Planning CD-1 approval

2019
SUSC funded, design underway
Private lease development
LIRR relocation study

Discovery park: schedule



Thank you!