# The Potential of EIC Machines for Fixed Target Experiments

Chuyu Liu

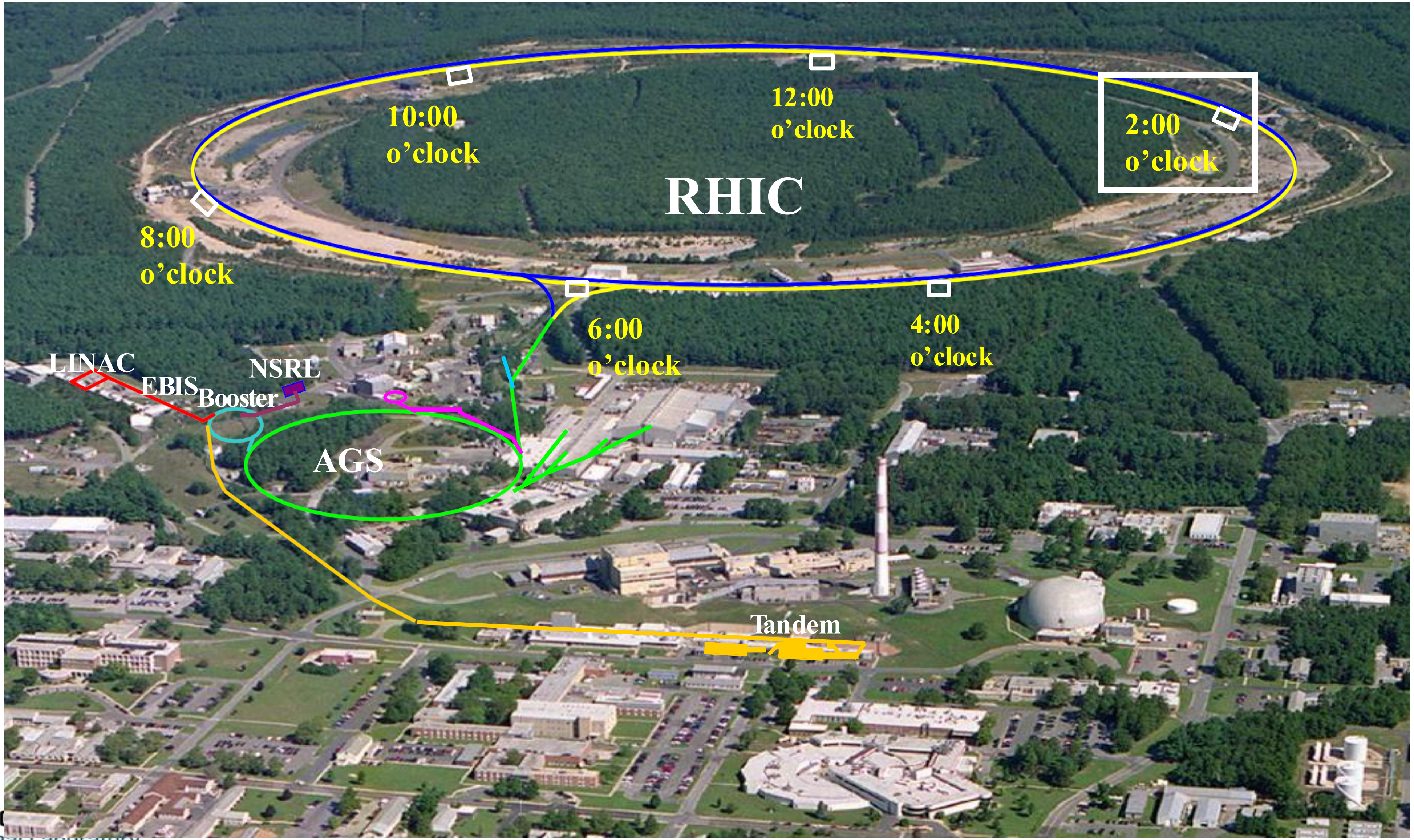
Collider-Accelerator Department, BNL

Exploring a Fixed-Target Program at the EIC workshop, Stony Brook University, USA, Sep 29-30, 2025

# Outline

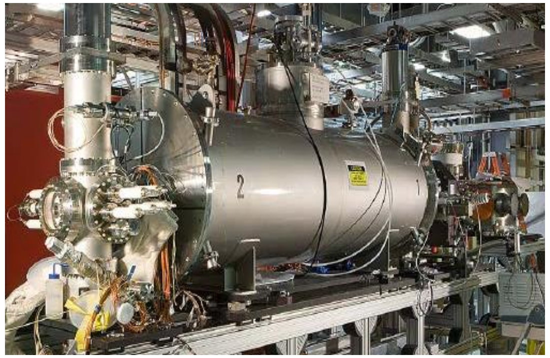
- RHIC Facility Overview
- RHIC STAR FXT Experience
- Electron-Ion Collider (EIC) Overview
- Hadron Beam Parameters
- Electron Beam Parameters
- Summary

# Aerial view of the RHIC facility




Brookhaven National Laboratory

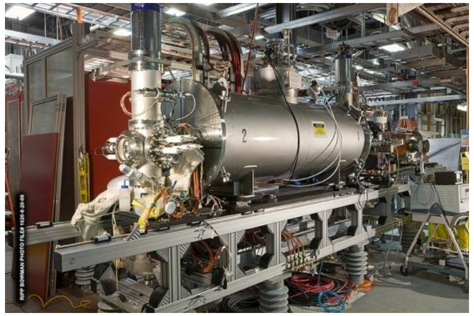
# Hadron Preinjector at BNL

| | Linac (1970) | EBIS injector (2010) | Tandem (1970) |
|---|---|---|---|
| |  |  |  |
| Ion: | $H^-$, $H^{-\wedge}$ | H-U | H-U |
| E: | 10 -200 MeV | 2 MeV/u | 14 MV(1+q) |
| $I_{ave}$ : | 200uA, | ~150 nA | ~10 µA |
| RR: | 10 Hz | 5 Hz | dc/pulsed |
| User: | **BLIP,** NSRL, RHIC | NSRL, RHIC | SEU, NSRL RHIC, |

Brookhaven National Laboratory

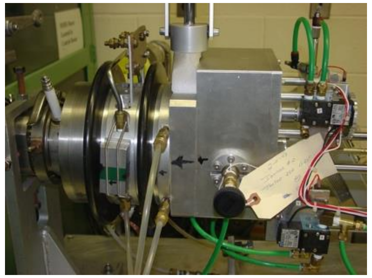
**Can serve all users simultaneously** Courtesy of Deepak Raparia

EBIS (Heavy Ion Linac)



H- U,

Cs sputter (Tandem)

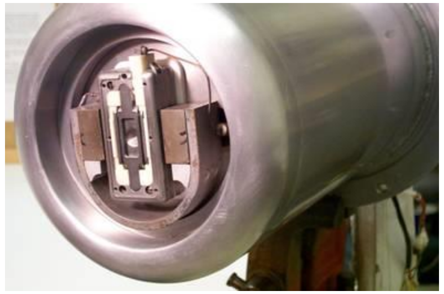


H-Au

OPPIS (Linac)

$\vec{H}$-

Magnetron (Linac)



H-

Single Event Upset


Relativistic Heavy Ion Collider

NASA Space Radiation Lab

Brookhaven Linac Isotope Producer

Brookhaven National Laboratory

**Ion Sources at Pre-Injector**

Courtesy of Deepak Raparia

# BNL LINAC Beam Parameters

| | |
|---|---|
| **Frequency** | **201.25 MHz** |
| **Injection Energy** | **0.750 MeV** |
| **Final Energy** | **10-200 MeV** |
| **Peak Current** | **~60 mA/ ~ .5 mA P^** |
| **Pulse Length** | **600 μs** |
| **Repetition Rate** | **6.67 Hz** |
| **Number of cavities** | **9** |
| **Length** | **144.8 m** |
| **Total Peak RF Power** | **22 MW** |

**RHIC Program**

Energy: 200 MeV ,
Intensity: ~400 μA ,
Pulse length: 300 μs
Pol: 85%
goals: max. pol. & min. emit.

**BLIP Program**

Energy: 66–200 MeV
Pulse length :~600 μs
Intensity 60 mA
Goals: uniform beam & min. losses.

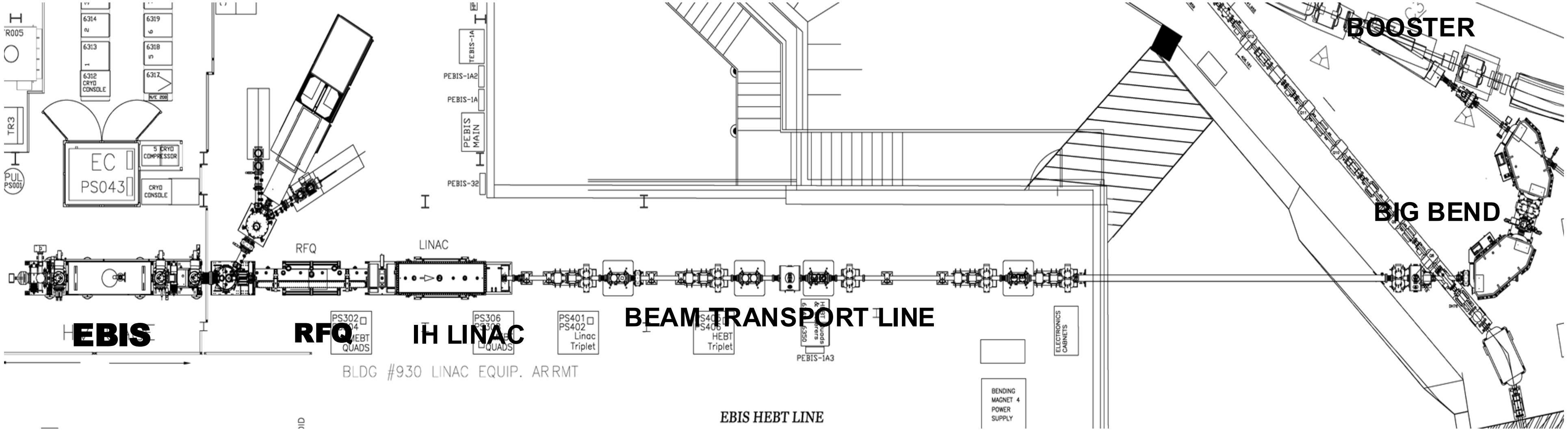
**NSRL Program:**

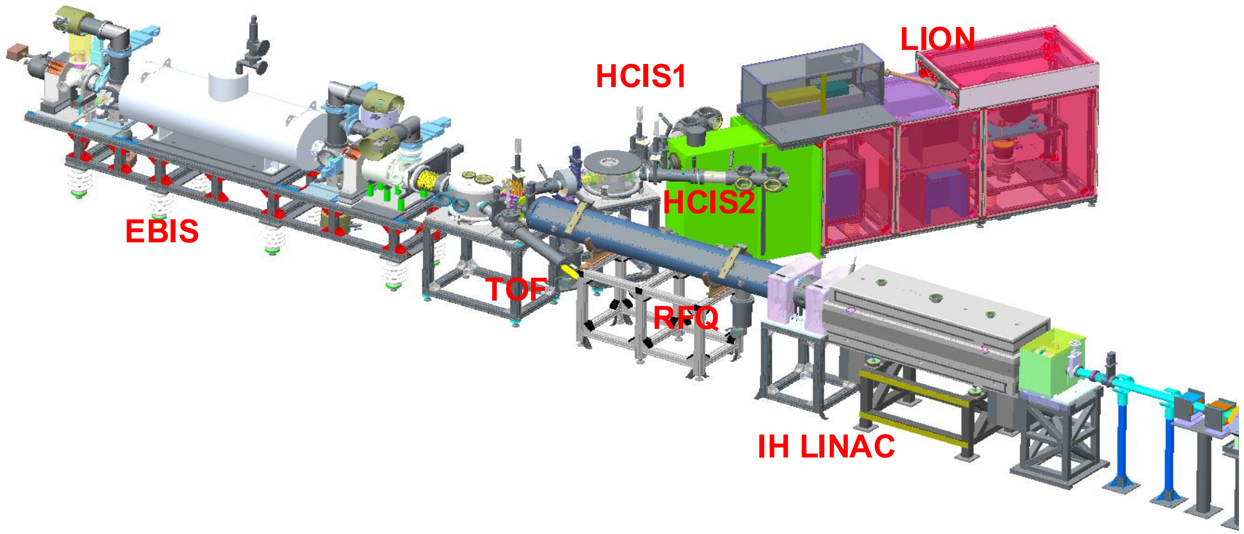
Energy : 200 MeV
Intensity: ~350 μA ,
Pulse length: 300 μs
Goal: schedule

**Can be serve all programs simultaneously**

Courtesy of Deepak Raparia

# EBIS Preinjector  (2 MeV/u)



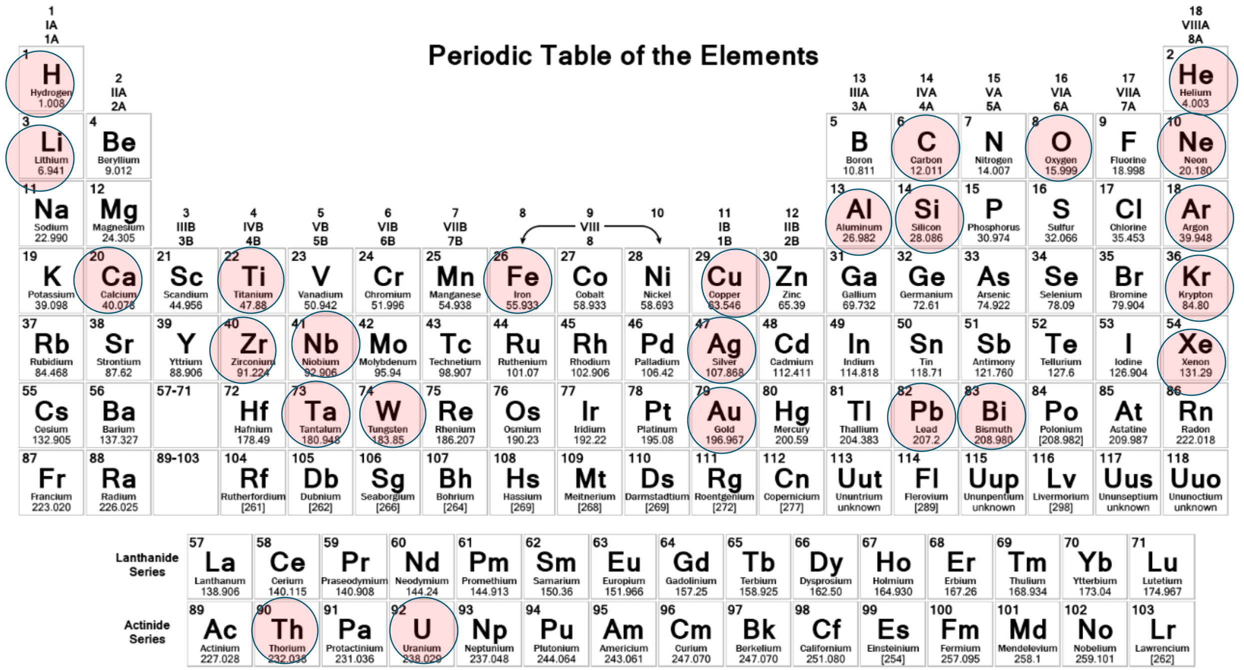




| | |
|---|---|
| Ions | H - U |
| Q / m | ≥1/6 |
| Current | > 1.5 emA (20 μs) |
| Pulse length | 10-40 μs |
| Rep rate | 5 Hz |
| Output energy | 2 MeV / u |
| Time to switch species | 1 second |

Courtesy of Deepak  Raparia

Brookhaven National Laboratory

# EBIS beams run to date




H, $H_2^+$, D, $^3He^{2+}$, $^4He^{1+,2+}$, $Li^{3+}$, $C^{5+,6+}$, $O^{7+}$, $Ne^{5+}$, $Al^{5+}$, $Si^{11+,12+}$, $Ar^{11+}$, $Ca^{14+}$, $Ti^{18+}$, $Fe^{20+,24+}$, $Cu^{11+}$, $Kr^{18+}$, **$^{90}Zr^{15+}$, $^{96}Zr^{16+}$,** **$Nb^{+16}$,$Ag^{+29}$** $Xe^{27+}$, $Ta^{38+}$, **$^{184}W^{31+}$**, $Au^{32+}$, $Pb^{34+}$, $Bi^{+39}$, **$^{232}Th^{39+}$**, $U^{39+}$

Red: RHIC. Blue: NSRL

***1 second switching*** between species (2, or more), alternating

<30 second switching among almost any 10, if loaded into external sources

$^3He^{+2}$ : will be installing 3He Gas cell summer 2026,
Capable of 2.5E11/pulse
polarization ~65% at 6 MeV
Goal: 85%

Courtesy of Deepak Raparia

Brookhaven National Laboratory

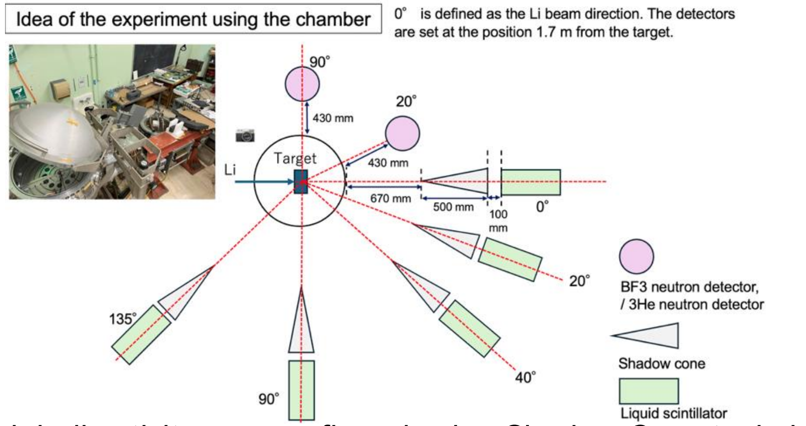
# Tandem Van de Graff Facility


ION: H-U
E: 14MV(1+Q)
I (Ave): ~ 10uA
RR. : Dc/Pulse

- Radiation Effects testing and Calibration
- Sigle Event Upset Test facility
- Ion irradiation/implantation
- Radiobiology Research Facility
- Also, backup for EBIS

### Neutron production experiment at Tandem

Masahiro, Toshiro, Madhawa, Antonino, Takeshi, Shunsuke, Dannie, Benedikt (Germany), Phillip (Germany)

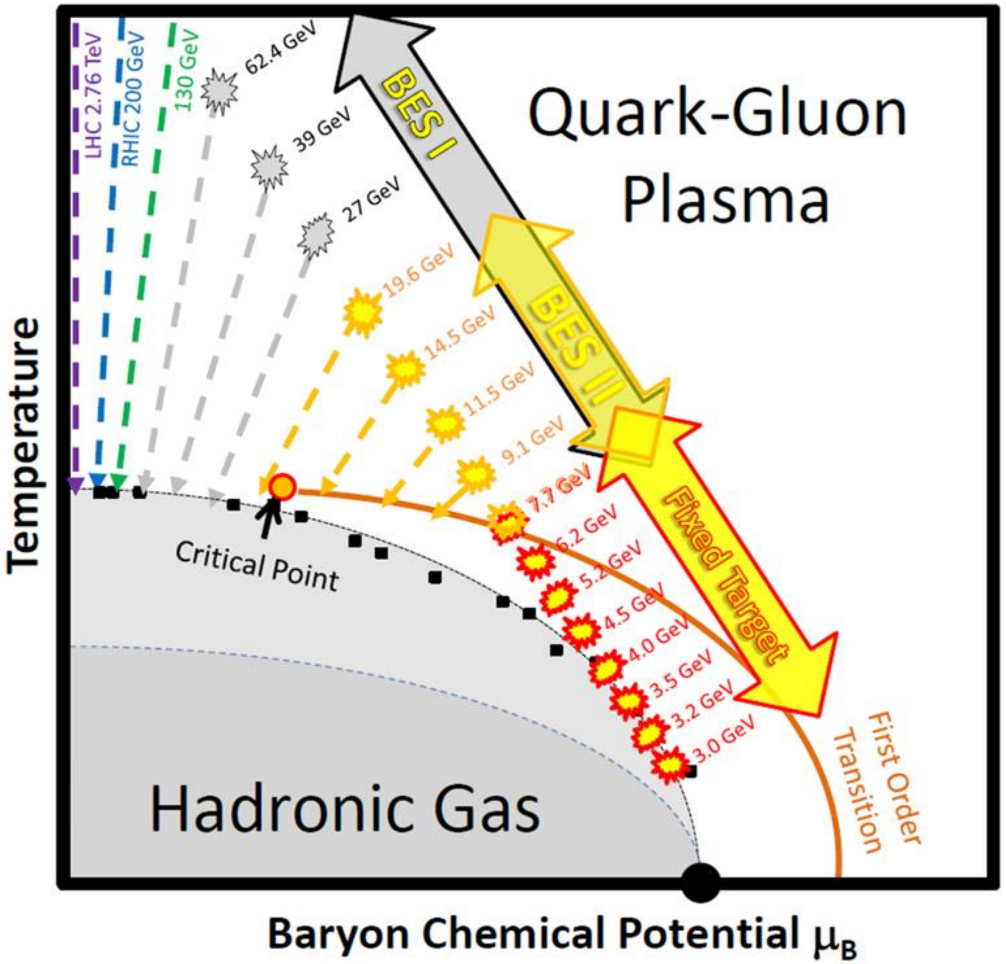



Very high directivity was confirmed using Shadow Cone technique

Courtesy of Deepak Raparia

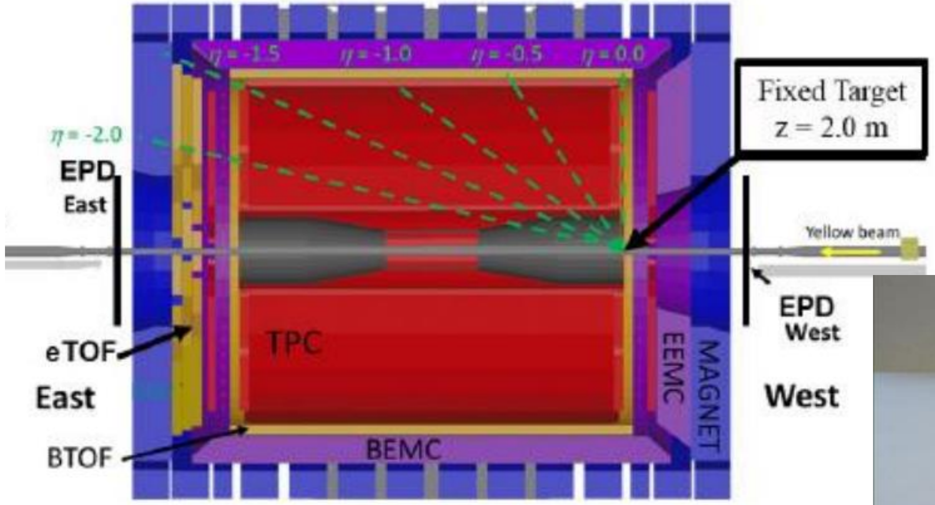
# RHIC STAR Halo-on-Target FXT Experiment Experience

# STAR FXT setup




Brookhaven National Laboratory

The beam energy scan I (BES-I) was completed during 2007-2014. However, the transition between QGP and hadronic gas has not been understood yet. The BES-I program offered limited statistics because the RHIC luminosity decreases steeply at lower energies. Therefore, the beam energy Scan II (BES-II) was performed with the luminosity improved by a factor of ~ 4 at multiple beam energies (3.85, 4.55, 5.75, 7.3 and 9.8 GeV/nucleon). In addition, FXT experiments were carried out to extend the energy reach out of the nominal beam energy range.

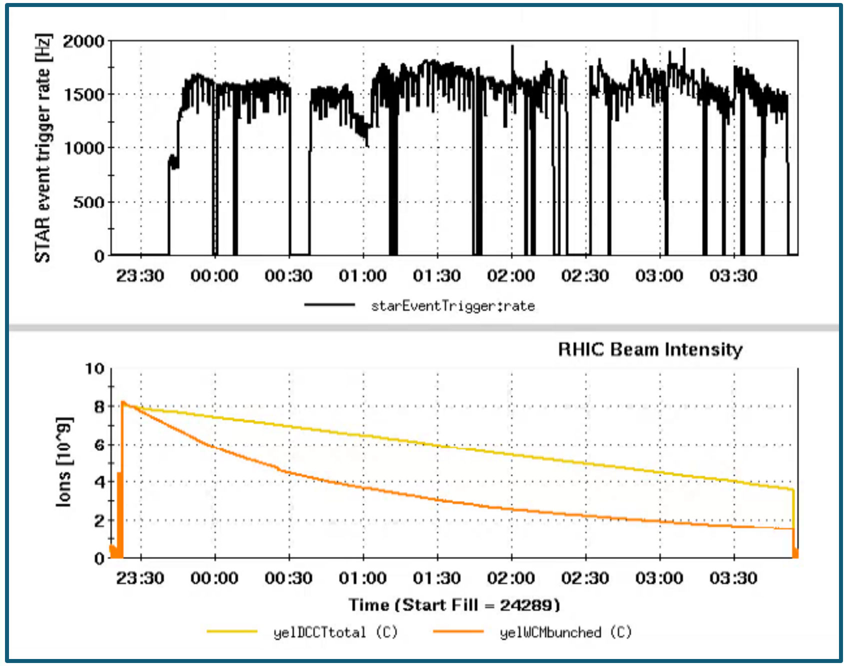



Au target

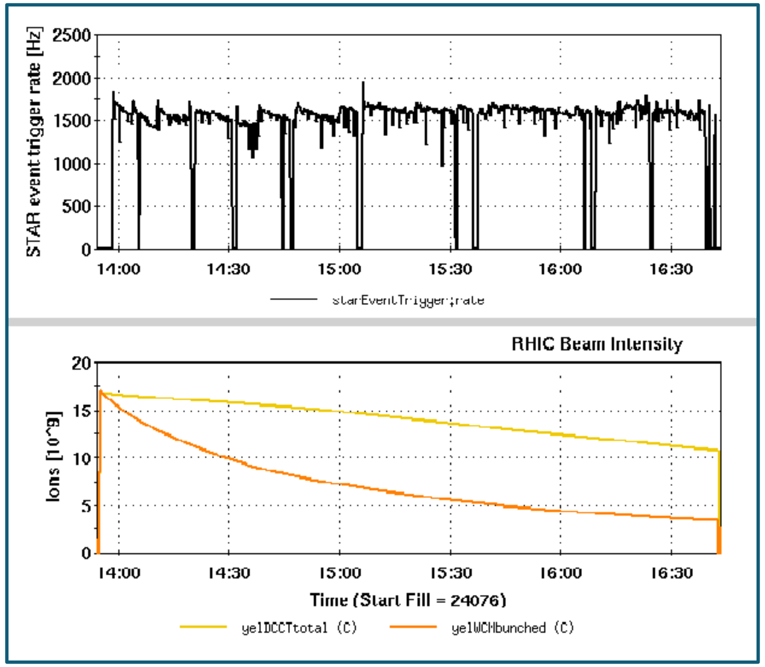
# FXT Operations in 2019

rate

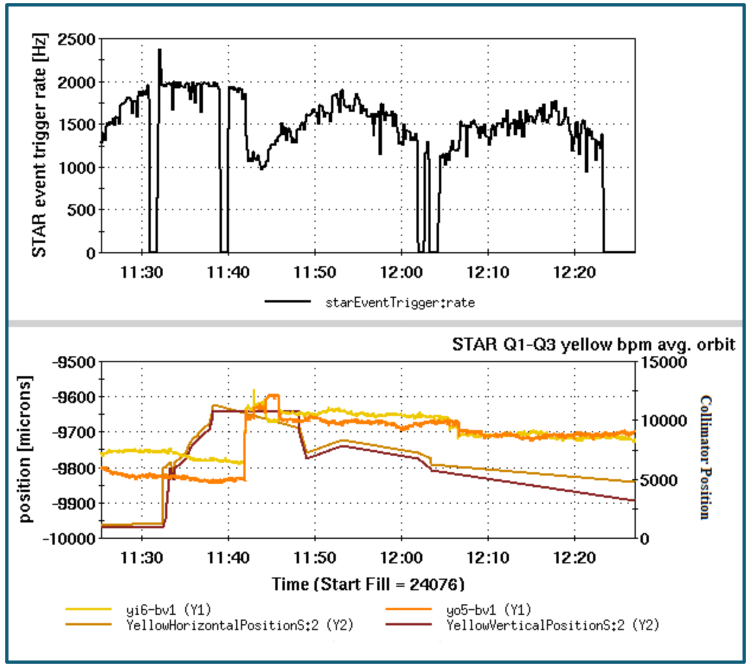
4.59 GeV/nucleon




7.3 GeV/nucleon



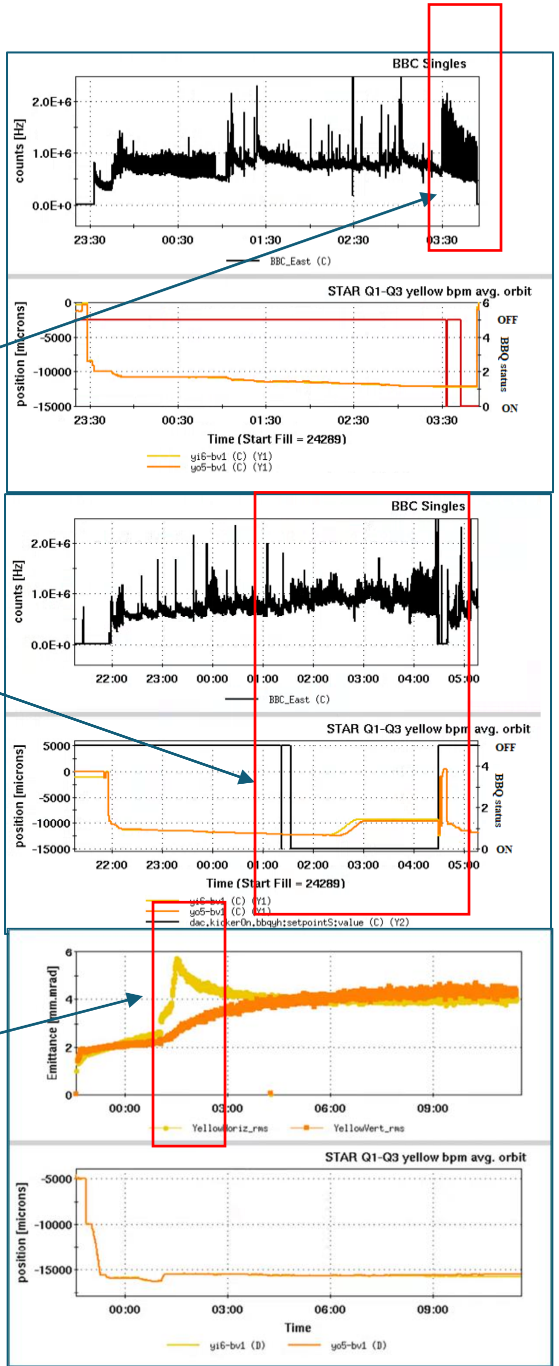

31.2 GeV/nucleon




Brookhaven National Laboratory

# FXT Operations in 2019 (cant.)

- Tune meter kicker was turned on towards the end of the 4.59 GeV/nucleon store to replenish beam halo therefore maintain the rates
- For the later half of the 7.3 GeV/nucleon store, the tune meter kicker was on to sustain the rate.
- The event rate at 31.2 GeV/nucleon was extremely sensitive to the beam position once the beam halo is scraping on the target. It was found that the BBQ kickers were not strong enough to blow up beam emittance in a reasonable amount of time. A desirable event rate was only achieved when the horizontal emittance was diluted by instability with a close to zero chromaticity.




Brookhaven National Laboratory

# FXT Operations in 2020

Table 1: Summary table for the fixed target experiments at RHIC in 2020

| Beam Energy (GeV/n) | CoM (GeV) | Tunes | $\beta^*$ (m) | Store Length (hrs) | Number of stores | Total Events (M) |
|---|---|---|---|---|---|---|
| 5.75 | 3.5 | 0.233/0.230 | 10 | 6 | 4 | 114 |
| 7.3 | 3.9 | 0.235/0.222 | 10 | 5 | 6 | 115 |
| 9.8 | 4.5 | 0.234/0.228 | 10 | 4 | 8 | 109 |
| 13.5 | 5.2 | 0.234/0.228 | 10 | 15 | 2 | 103 |
| 19.5 | 6.2 | 0.234/0.228 | 10 | 21 | 1 | 119 |
| 31.2 | 7.7 | 0.236/0.228 | 5 | 13.5 | 2 | 114 |

# Summary table for FXT during BES-II

| Beam Total Energy (GeV/u) | 3.85 | 4.59 | 5.75 | 7.3 | 9.8 | 13.5 | 19.5 | 26.5 | 31.2 | 44.5 | 70 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Au | Au | Au | Au | Au | Au | Au | Au | Au | Au | Au | Au |
| # of Bunches | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Ions/bunch | 1.7E9 | 0.65E9 | 1.0E9 | 1.0E9 | 1.25E9 | 1.0E9 | 1.0E9 | 0.2E9 | 1.5E9 | 1.5E9 | 1.5E9 | 1.3E9 |
| β* (m) | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 5 | 5 | 5 | 5 | 5 |
| Rms emit. (mm*mrad) | 1.1 | 1.25 | 2 | 1.4 | 2.0 | 2.4 | 1.5 | 1.5 | 3 | NA | NA | 15 |
| Rate control | Orbit control, controlled emittance blow-up with BBQ | Orbit control, controlled emittance blow-up with BBQ at the end of store | Orbit control | Orbit control | Orbit control | Orbit control | Orbit control | Orbit control , parallel to CeC | Orbit control with 50 um step, emit increase with small c hrom during acceleration | Orbit control | Orbit control | 17 mm orbit bump, injection mismatch, emit increase with small chrom, controlled emittance blow-up with BBQ |

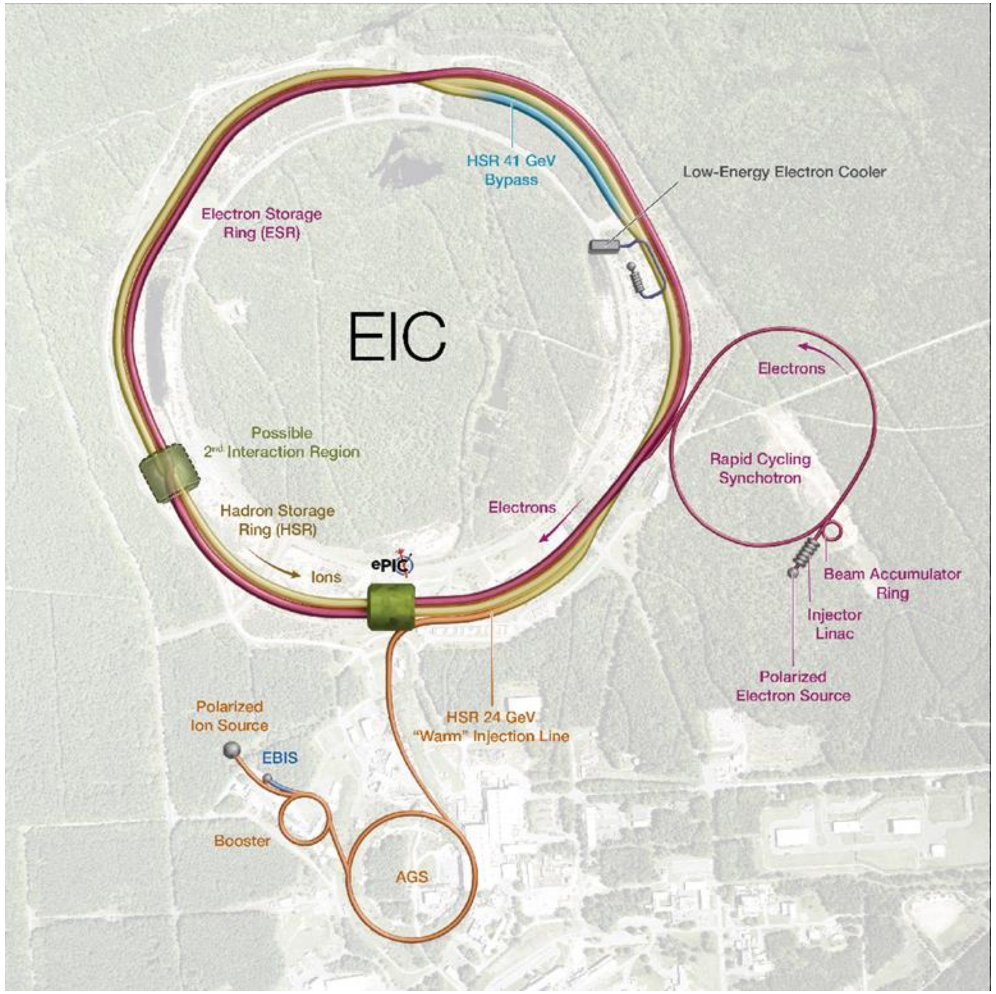
# Reasons that we liked FXT

- Easy to establish beam conditions required for FXT experiment.
- Substantial luminosity can be achieved for Halo-on-Target with very little beam intensity (1E9 ions) in the machine.
- FXT does not care much deteriorating beam conditions which are unfavorable for colliding beam
  - Rate can be maintained with decreasing beam intensity by measures mentioned in previous slides
  - Increasing beam size makes rate more controllable
  - The typically detrimental effects, such as intra-beam scattering and space charge, can actually aid in populating the beam halo.
- Background was not difficult to manage with collimators.

# Electron-Ion Collider Overview

# Electron-Ion Collider

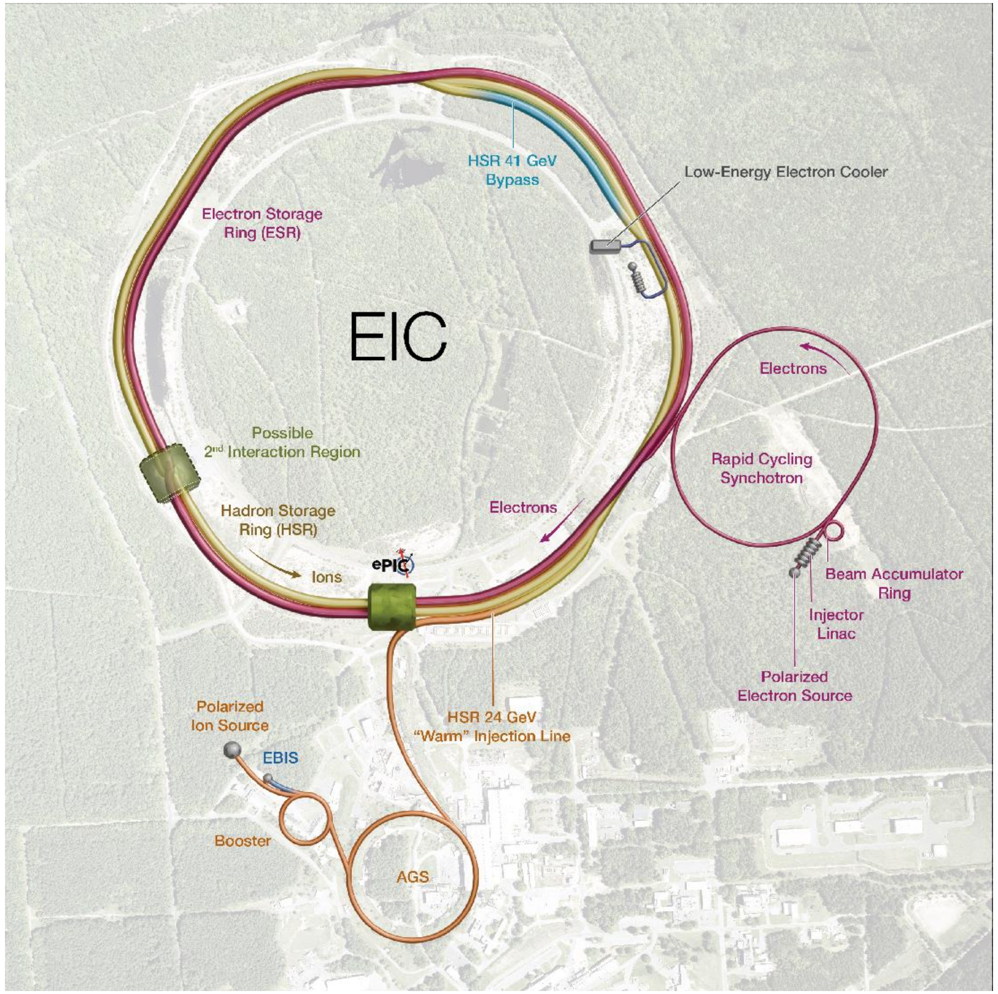
- **Hadron Storage Ring (HSR) 10-275 GeV**
  - Superconducting magnets (existing)
  - 1160 bunches, 1A beam current (3x RHIC)
  - Flat beam (11:1 ratio)
  - Beam cooling
- **Electron Storage Ring (ESR) 5 – 18 GeV**
  - large beam current, 2.5 A ➔ 9 MW S.R. power
  - S.C. RF cavities
  - Need to inject polarized bunches
- **Electron Rapid Cycling Synchrotron (RCS) 750 MeV- 18GeV**
  - 1 Hz
  - Spin transparent due to high periodicity
- **Electron Injector**
  - Warm Linac, 30 Hz
  - Beam Accumulation Ring, 1 Hz




Brookhaven National Laboratory

# HSR Machine

- Design is based on the existing RHIC Complex in BNL.
- HSR will be composed of Yellow ring only and new IR6.
- HSR warm injection line bring beams from AGS to HSR IR4, where the septum and injection kickers are located.
- Low Energy Cooler is located at IR2.
- 41 GeV bypass will be added between IR12 and IR2.



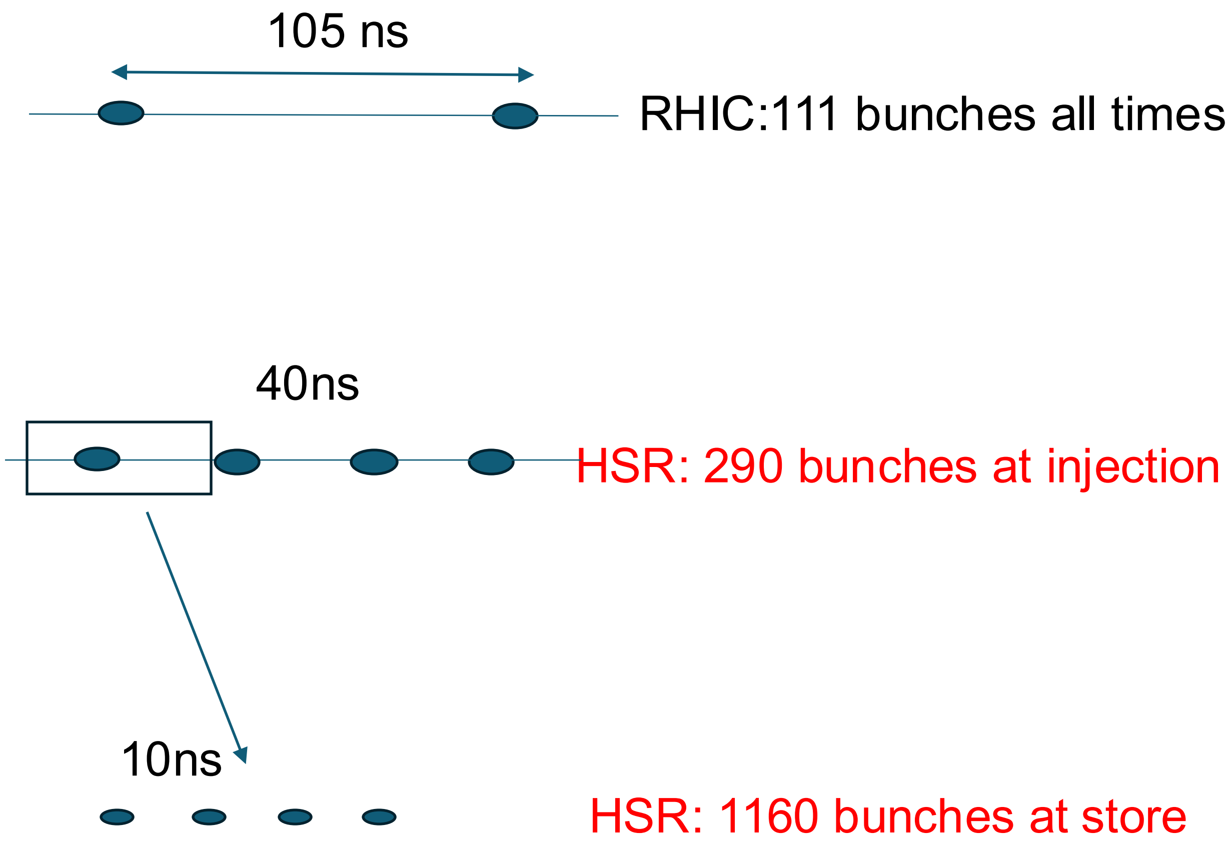
# HSR Machine (cont'd)

- Several upgrades must be realized in order to satisfy advanced requirements for EIC hadron beams, higher energy, higher current, high polarization, more bunches...

- Hadron beams include:
  - Polarized protons
  - Polarized 3He ions
  - Unpolarized ion species up to Uranium

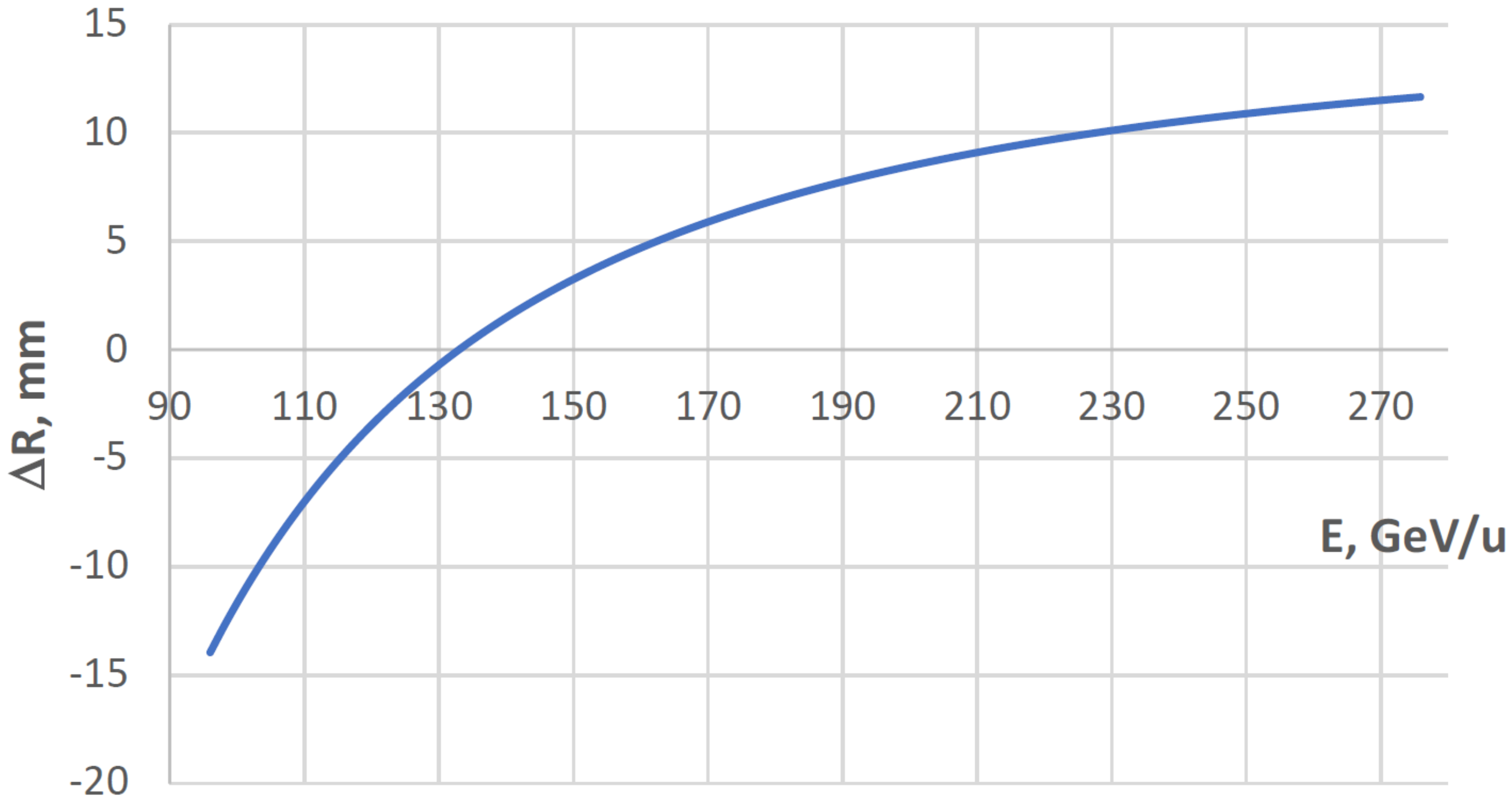
- Number of bunches and bunch pattern (at injection) can be flexible for FXT operation.

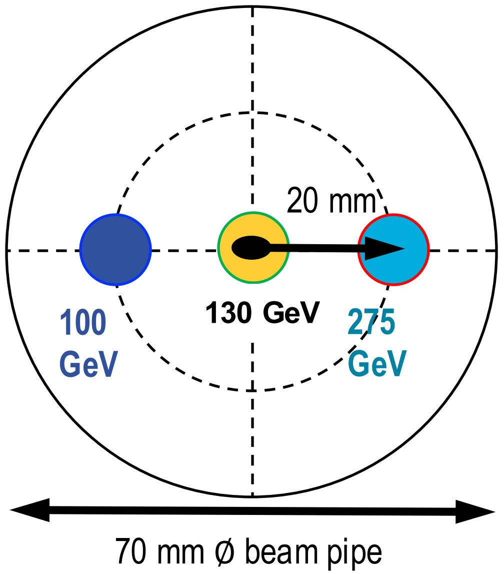
- At injection, a fully configurable bunch-by-bunch spin pattern is available, for experiments.




Brookhaven National Laboratory

# Beam Energy and Average Orbit Radius in the HSR



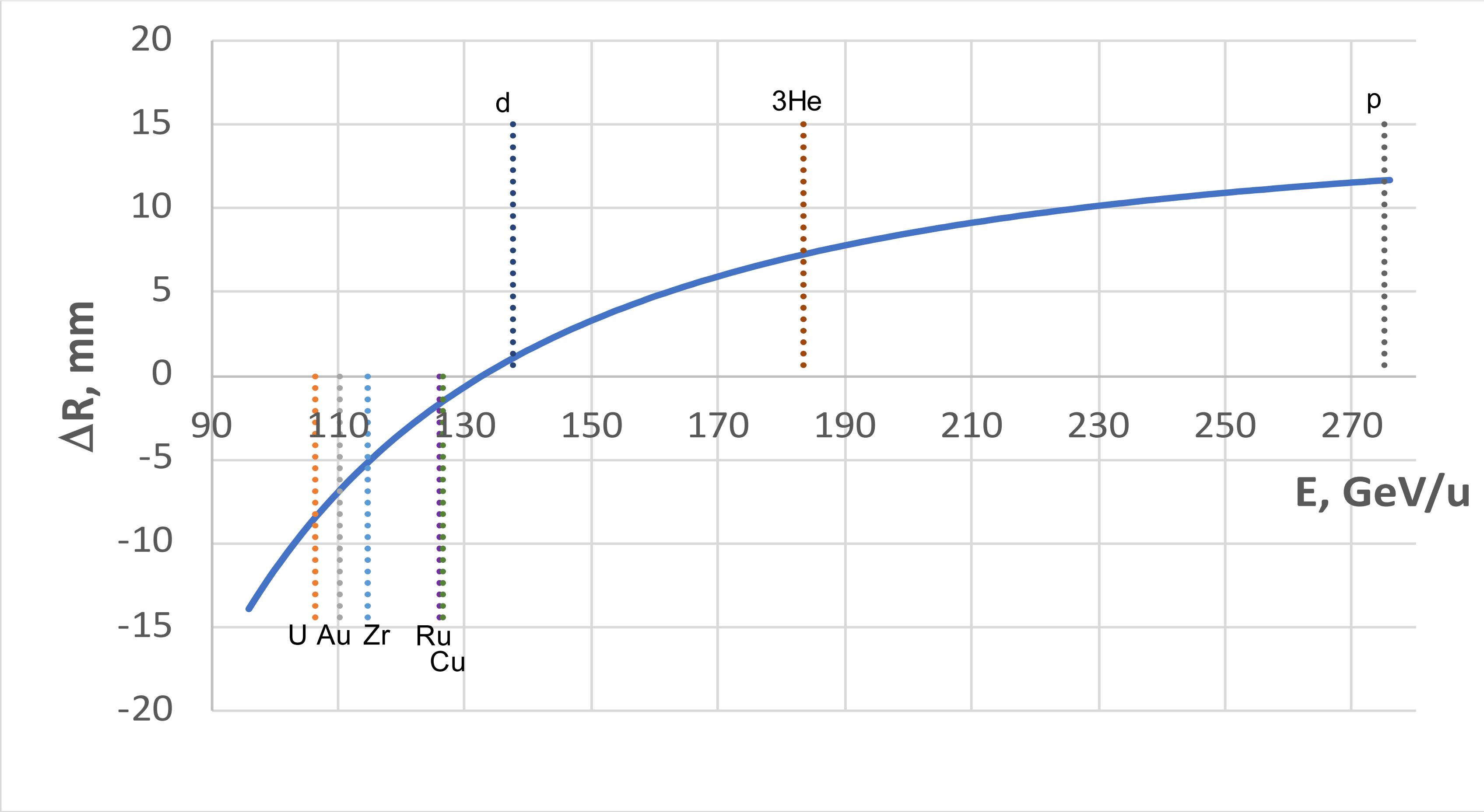




Since the electron revolution frequency is fixed, the hadron orbit must be adjusted with energy to keep the collisions in sync.

Courtesy of V. Ptitsyn

Brookhaven National Laboratory

# Energy and average orbit radius for different ion species at HSR maximum beam rigidity (917 T*m)



# Energy gaps for longitudinal spin

## Update 9/26/2025, Rotator Updates

- 2025 lattice has the V2H rotator moved from -17 mrad to -35.28 mrad.
- This move results in twice the dead-spots.
- 35.28 mrad cannot support 250/255 GeV.

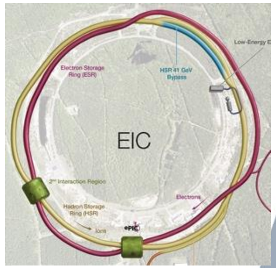
Current dead spots exist at:

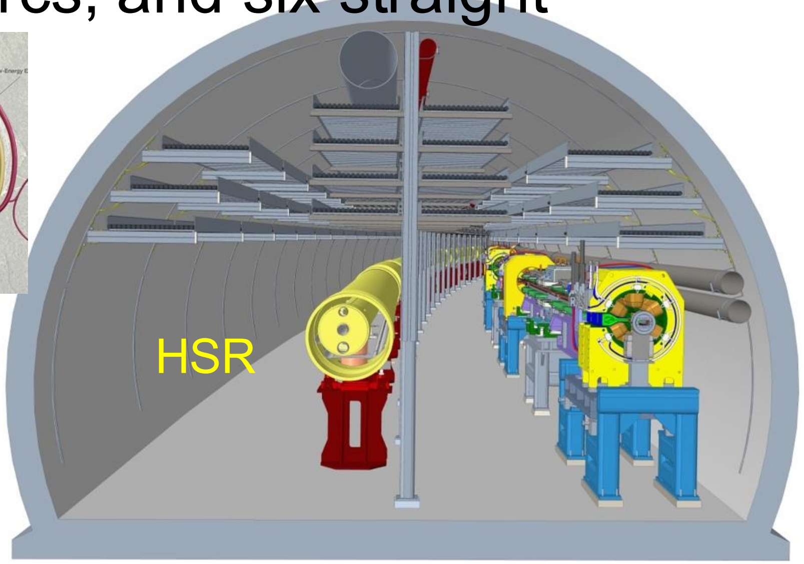
| V2H (35.28) | H2V (61.35) |
|---|---|
| 62.8-78.5 GeV | 62.8-71.7 GeV |
| 154.4-170.1 GeV | 116.2-125.1 GeV |
| 246.0-261.7 GeV | 169.6-178.5 GeV |
| | 222.9-231.8 GeV |

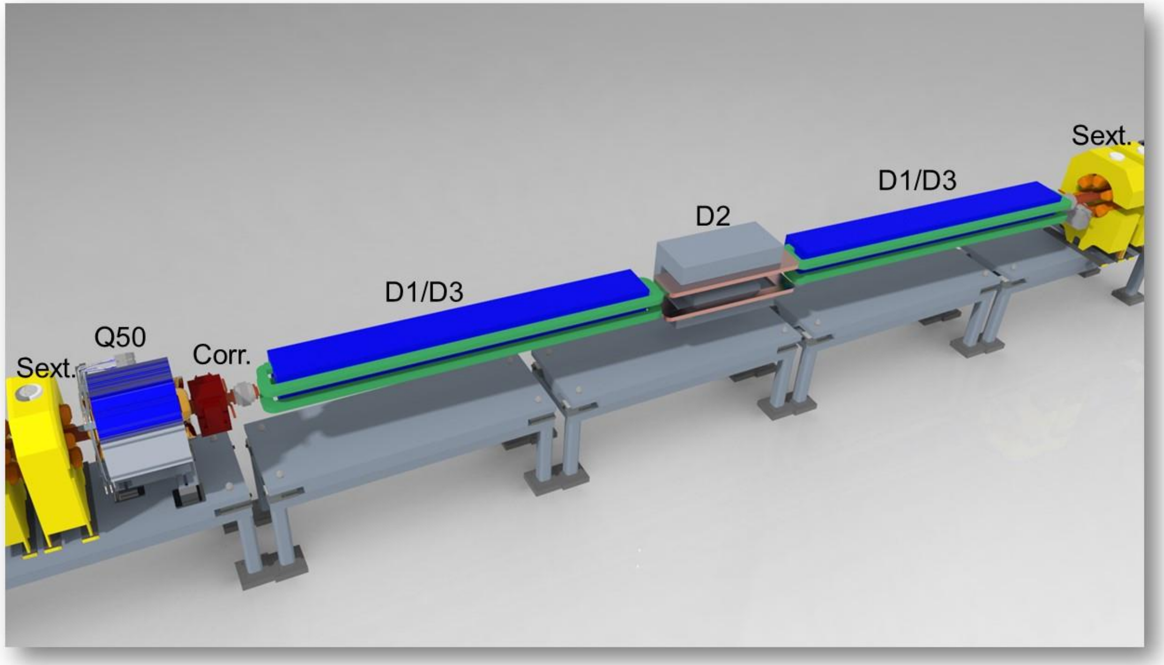
Courtesy of K. Hock

# EIC Electron Storage Ring

- Electron Storage Ring (ESR) consists of six FODO-cell arcs, and six straight sections (IRs)
- High-intensity (28 nC), short (7 mm) bunches
- Swap-out injection
- Circulating beam current ~2.5 A and the synchrotron radiation power of ~10MW



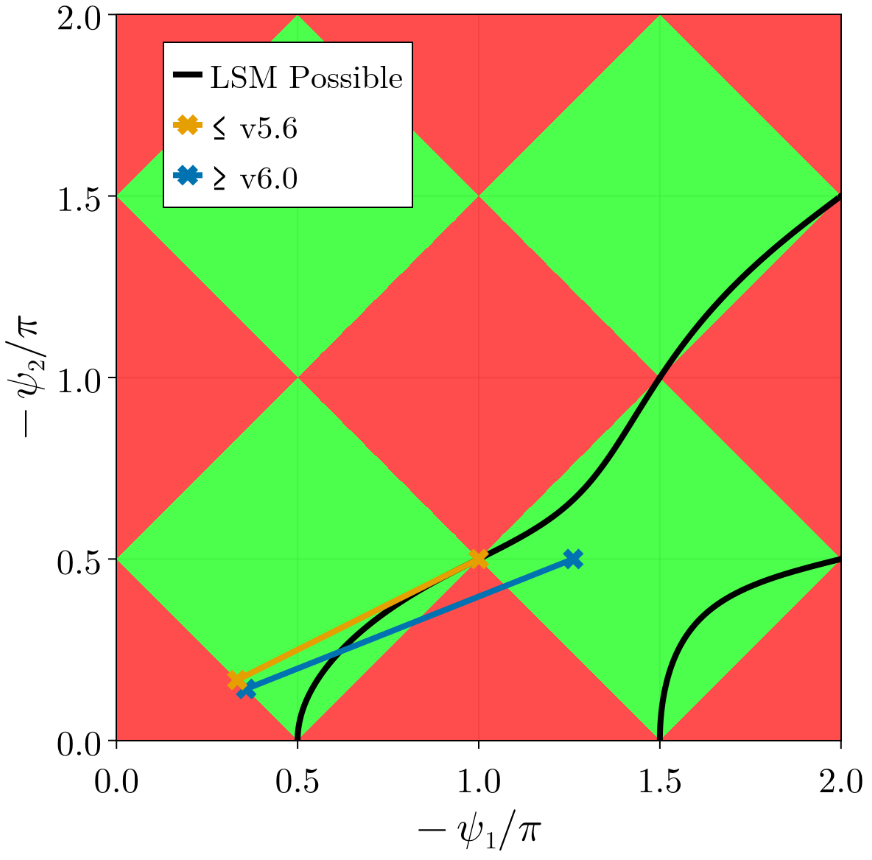




EIC needs nearly constant (20 to 24 nm) emittance from 5 to 18 GeV for optimum luminosity, but equilibrium emittance in an electron storage ring depends on beam energy.

‘Super bends’ (reverse bends) for emittance control below 10 GeV. Optimized for 5 GeV, compatible with 3 GeV. It reduces damping time therefore allowing for larger beam-beam.

Courtesy of C. Montag

# Longitudinal spin energy gap




The psis correspond to the bend module spin precession, and the phis the solenoid modules. In a bend psi= -theta*a*gamma, where theta is the bend angle. So for some psi_2/psi_1 = theta_2/theta_1 the geometry is fixed.

The energy exclusion range is 11.7275 - 15.2024 GeV

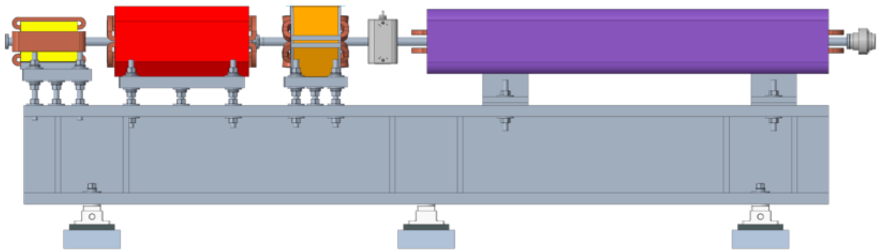
Courtesy of M. Signorelli

Brookhaven National Laboratory

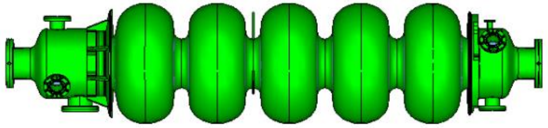
# Electron Injector

Concept modeled after the ANL APS-U injector

**Function**: Deliver electron bunches of up to 28 nC at a 1 Hz repetition rate for injection into the ESR at various energies of 5 – 18 GeV.



RCS magnet assembly
Vacuum chamber: stainless steel, copper coated (50 um)



RCS SRF Cavity, 591 MHz


RESEARCH ARTICLE | JUNE 17 2024

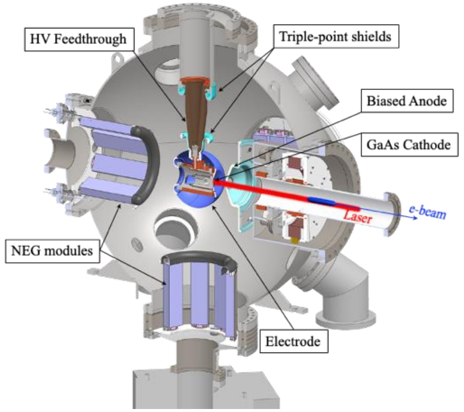
**High-intensity polarized electron gun featuring distributed Bragg reflector GaAs photocathode**

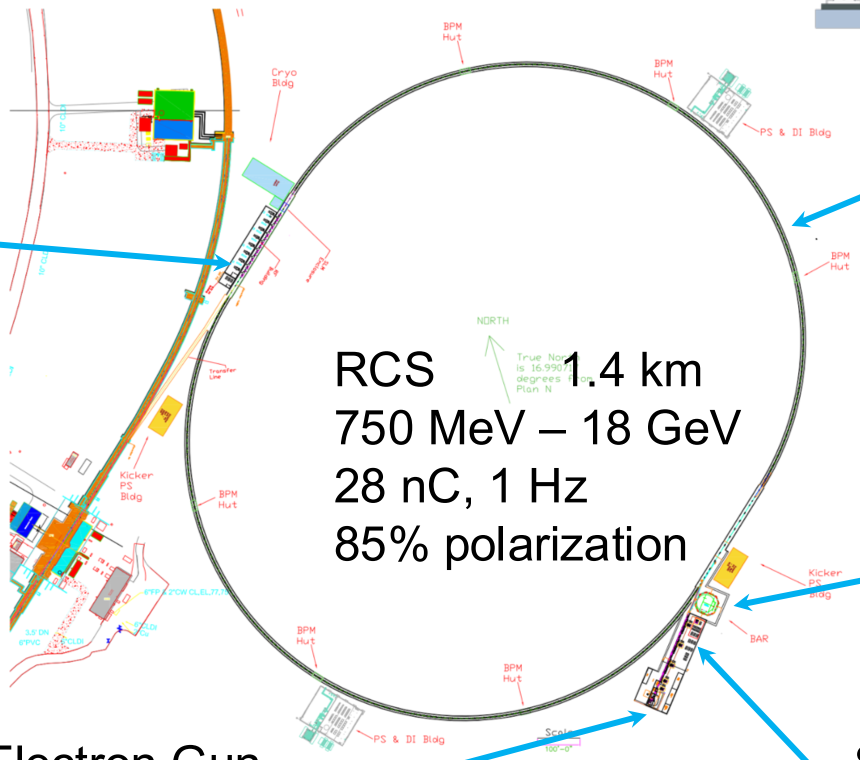
Erdong Wang; Omer Rahman; Jyoti Biswas; John Skaritka; Patrick Inacker; Wei Liu; Ronald Napoli; Matthew Paniccia

Check for updates

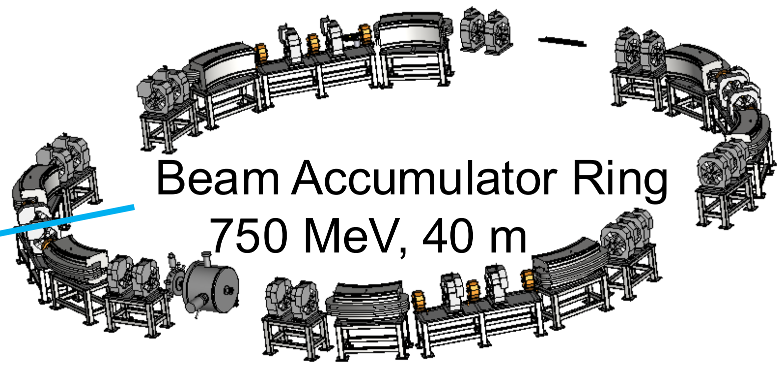
Appl. Phys. Lett. 124, 254101 (2024)

https://doi.org/10.1063/5.0216694




RCS 1.4 km
750 MeV – 18 GeV
28 nC, 1 Hz
85% polarization



Beam Accumulator Ring
750 MeV, 40 m

Polarized Electron Gun
1-nC, 30 Hz

S-band linac, 750 MeV, 30 Hz, 1 nC single bunch

Brookhaven National Laboratory

Courtesy of Q. Wu

# EIC beam parameters

- Hadron beam and electron beam operate at a few discrete energies in collider mode, while it is not a constraint for FXT.
- The bunch charge and beam currents are constrained by injector capability, beam-beam and synchrotron radiation in the collider. The assumption is that FXT would not need higher current than that in colliding mode.
- Emittance, beta star and beam size at IP are designed to have 11:1 aspect ratio in collider mode, which is no longer true in FXT mode.

EIC beam parameter table for one of the collider operation modes

*Table 1.1b* Main collision related parameters for electron-proton collisions in the High Divergence operation mode, at the EIC Full Capability.

| Parameter | | Units | p+ | e- | p+ | e- | p+ | e- | p+ | e- | p+ | e- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Energy | | GeV | 275 | 18 | 275 | 10 | 100 | 10 | 100 | 5 | 41 | 5 |
| Gamma | | - | 294 | 35226 | 294 | 19570 | 108 | 19570 | 108 | 9786 | 45 | 9786 |
| CM energy | | GeV | 140.70 | | 104.90 | | 63.20 | | 44.70 | | 28.60 | |
| Bunch intensity | | $(10^{10})$\(nC) | 19.1\30.6 | 6.2\9.9 | 6.9\11.1 | 17.2\27.6 | 6.9\11.1 | 17.2\27.6 | 4.8\7.7 | 17.2\27.6 | 2.6\4.2 | 13.3\21.3 |
| Number of bunches | | - | 290.00 | | 1160.00 | | 1160.00 | | 1160.00 | | 1160.00 | |
| Average beam current | | A | 0.69 | 0.23 | 1.00 | 2.50 | 1.00 | 2.50 | 0.69 | 2.50 | 0.38 | 1.93 |
| Normalized emittance | H | µm rms | 5.2 | 845 | 3.3 | 391 | 3.2 | 391 | 2.7 | 196 | 1.9 | 196 |
| | V | | 0.47 | 71 | 0.3 | 26 | 0.29 | 26 | 0.25 | 18 | 0.45 | 34 |
| Unnormalised emittance | H | nm rms | 18 | 24.0 | 11.3 | 20 | 30 | 20 | 26 | 20 | 44 | 20 |
| | V | | 1.6 | 2.0 | 1.0 | 1.3 | 2.7 | 1.3 | 2.3 | 1.8 | 10 | 3.5 |
| Beta | H | cm | 80 | 59 | 80 | 45 | 63 | 96 | 61 | 78 | 90 | 196 |
| | V | | 7.1 | 5.7 | 7.2 | 5.6 | 5.7 | 12 | 5.5 | 7.1 | 7.1 | 21 |
| IP RMS beam size | H | µm | 119 | | 9.5 | | 138 | | 125 | | 198 | |
| | V | | 11 | | 8.5 | | 12 | | 11 | | 27 | |
| Kx | | - | 11.10 | | 11.10 | | 11.10 | | 11.10 | | 7.30 | |
| Divergence | H | µrad rms | 150 | 202 | 119 | 211 | 220 | 145 | 206 | 160 | 220 | 101 |
| | V | | 150 | 187 | 119 | 252 | 220 | 105 | 206 | 160 | 380 | 129 |
| BB parameter | H | $10^3$ | 3 | 93 | 12 | 72 | 12 | 72 | 14 | 100 | 15 | 53 |
| | V | | 3 | 100 | 12 | 100 | 12 | 100 | 14 | 100 | 9 | 42 |
| Longitudinal emittance | | $10^{-3}$eV·s rms | 36 | - | 36 | - | 21 | - | 21 | - | 11 | 53\42 |
| 90% longitudnal bunch area | | eV.s | 0.216 | - | 0.216 | - | 0.126 | - | 0.126 | - | 0.066 | 0.32\0.25 |
| Bunch length | | cm rms | 6.0 | 0.9 | 6.0 | 0.7 | 7.0 | 0.7 | 7.0 | 0.7 | 7.5 | 0.7 |
| Relative momentum spread $\sigma_p/p$ | | $10^{-4}$ rms | 6.8 | 10.9 | 6.8 | 5.8 | 9.7 | 5.8 | 9.7 | 6.8 | 10.3 | 6.8 |
| Maximum space charge | | - | 0.0 | Neg | 0.0 | Neg | 0.0 | Neg | 0.0 | Neg | 0.1 | Neg |
| Piwinski angle | | rad | 6.3 | 2.1 | 7.9 | 2.4 | 6.3 | 1.8 | 7.0 | 2.0 | 4.2 | 1.1 |
| Longitudinal IBS time | | hrs | 2.0 | - | 2.9 | - | 2.5 | - | 3.1 | - | 3.8 | - |
| Transverse IBS time | H | hrs | 2 | - | 2 | - | 2.0 | - | 2.0 | - | 3.4 | - |
| | V | | Lrg. | - | Lrg. | - | 4.0 | - | 4.0 | - | 2.1 | - |
| Hourglass factor H | | - | 0.91 | | 0.94 | | 0.90 | | 0.88 | | 0.93 | |
| Luminosity | | $10^{33}cm^{-2}s^{-1}$ | 1.54 | | 10.00 | | 4.48 | | 3.68 | | 0.44 | |

*H=Horizontal, V=Vertical, Lrg= Large enough to not require cooling, negl= Negligible.*

Brookhaven National Laboratory

# HSR beam parameters for FXT experiment

| Parameters | Value | Notes |
|---|---|---|
| Beam species | Polarized p, He, unpolarized species up to U | Use Au as a representative for the rest of beam parameters |
| Beam Energy | 3.85 to 110 GeV/nucleon | The updated IR6 might be aperture bottleneck for energies below 9.8 GeV. Near transition energy is not available. |
| Beam Rigidity | 31 to 916 T-m | |
| No. Bunches | 12 to 1160 | Bunch split or not? |
| Average current | Up to 1 A | Lower if below injection |
| Normalized emittance | H: ~ 2 um, V: 0.25 to 2 um | One can always blowup emittance, except for low energies when aperture is limited. |
| Bunch length | 6 cm | Longer is better for lifetime |
| Beta star | H: 80 cm to 10 m,<br>V: 7.1 cm to 90 cm | Preference? |
| Crab cavity | No need | |
| Radial shift | No need | |
| Low energy bypass | No need | |

# ESR beam parameters for FXT experiment

| Parameters | Value | Notes |
| --- | --- | --- |
| Beam species | e | |
| Beam Energy | 3 – 18 GeV | Any energy in the range, energy below 5 GeV, 11.7-15.2 GeV w/o longitudinal polarization |
| Spin direction | Longitudinal, vertical | |
| No. Bunches | 1 to 1160 | Bunch split or not? |
| Average current | Up to 2.5 A | 0.2 A @18 GeV |
| Normalized emittance | H: 196 – 845 um<br>V: 18 – 70 um | Emittance is tunable with super-bend and external excitation, vertical orbit bumps (bagels technique) |
| Bunch length | 0.7 cm | Longer is better for lifetime |
| Beta star | H: 103 to 306 cm,<br>V: 9.2 to 30 cm | |
| Crab cavity | No need | |

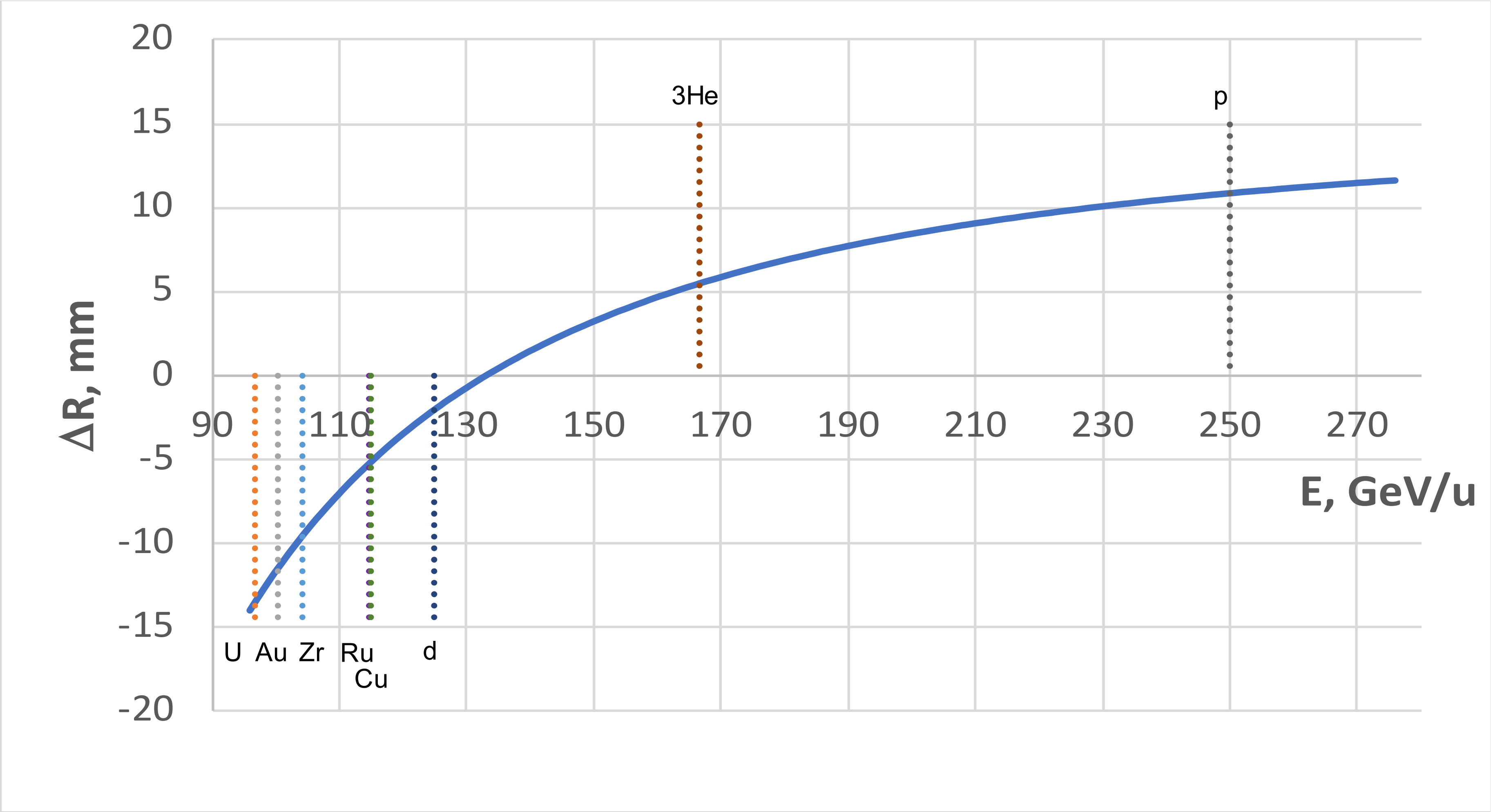
# Summary

- The operational conditions for fixed-target (FXT) experiments at the EIC are generally less demanding, as they do not require crab cavities, radial shifts, or beam-beam collisions.
- The relevant beam parameters for the HSR and ESR in FXT mode are summarized. Detailed beam requirements will need to be revisited once the target specifications are further defined.
- The hadron beam exhibits a well-defined Gaussian-like transverse distribution with a gradually evolving halo primarily driven by physical processes such as intra-beam scattering. In contrast, the electron beam develops a rapidly replenished halo due to quantum excitation effects.
- Although both beams can be delivered over a wide range of energies, certain gaps exist where longitudinal polarization cannot be achieved.
- Extraction of RCS beam for FXT experiment is possible in principle however costly. In addition, operation of EIC at 18 GeV would require non-stop operation of the RCS (1Hz).

# Additional slides

Brookhaven National Laboratory

# Energy and average orbit radius for different ion species at RHIC maximum beam rigidity (833 T*m)




Brookhaven National Laboratory

# Subproject EIN Scope Defined

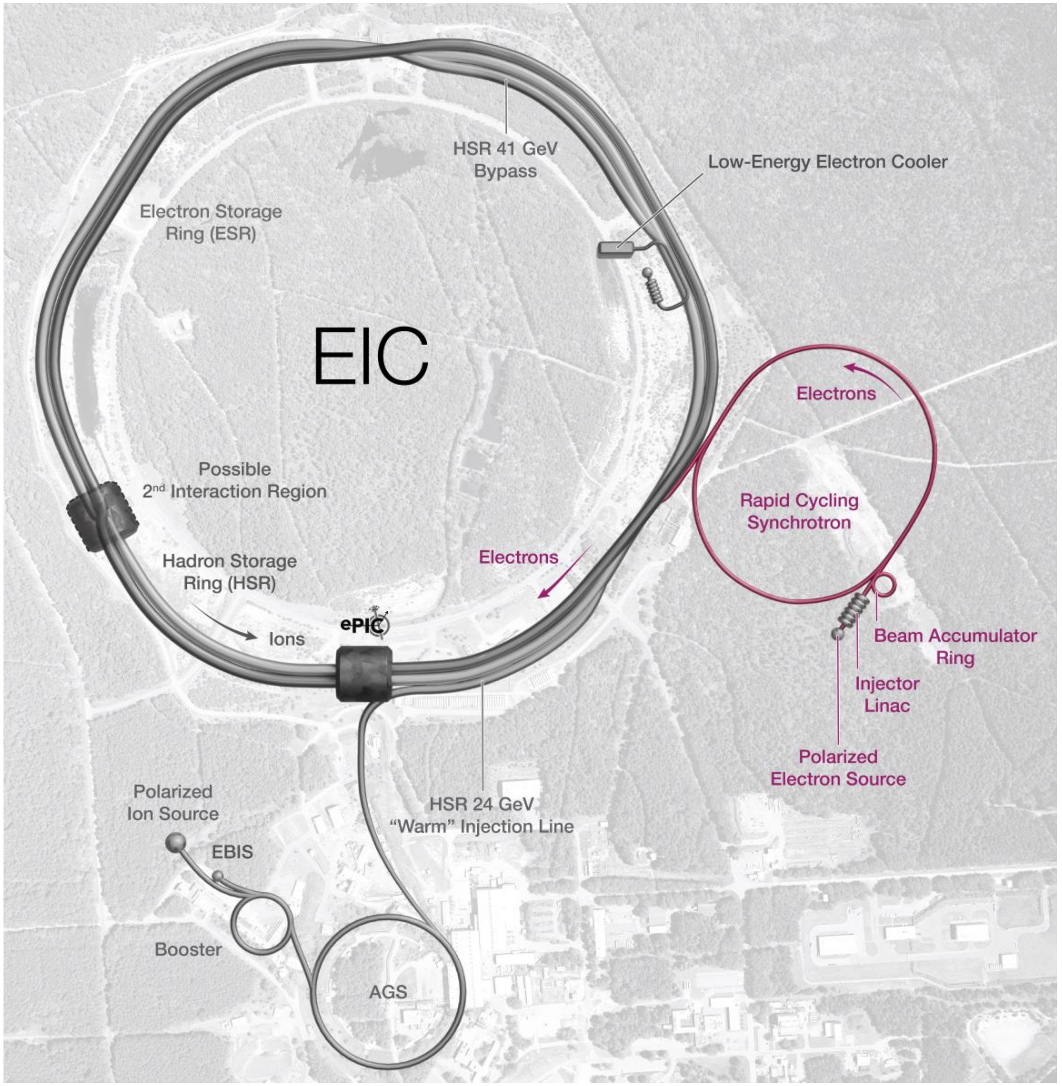
The Electron Injectors Subproject includes the following systems:

1. Pre-Injector
2. Beam Accumulator Ring
3. Rapid Cycling Synchrotron
4. Electron Storage Ring injection and swap-out systems
5. Infrastructure and utilities limited to the local systems, services, and connections required specifically for the systems listed above.

**Design of the above accelerator systems** to support the full operational requirements of the EIC electron beam, including up to 11 nC at 18 GeV and 28 nC at 10 GeV.

**Design of supporting infrastructure and utilities** necessary to enable the start of the EIC physics program.

**Installation and hardware commissioning** of the above systems, once integrated with other subprojects, are essential for starting the physics program.




Brookhaven National Laboratory

# Proposal for EIC Science Program in the First Years

### Year - 1

Start EIC Science

Commission electron polarization in parallel

**Collider:**
10 GeV electrons on 115 GeV/u heavy ion beams (Ag or Nb)

### Year - 2

+Long. electron polarization

Commission proton polarization in parallel

**Collider (base goal):**
10 GeV long. polarized electrons on 130 GeV/u Deuterium

**Collider (stretch goal):**
Last weeks: 10 GeV long. polarized electrons and 130 GeV polarized protons

### Year - 3

+Long. electron polarization
+ Proton polarization

Commission hadron spin rotators

**Collider (base goal):**
10 GeV long. polarized electrons on 130 GeV transverse-polarized protons

**Collider (stretch goal):**
Last weeks switch to longitudinal proton polarization

### Year - 4

+ Long. electron polarization
+ Proton polarization
+ Hadron spin rotators

Commission hadron accelerator to operate with off-center orbits

**Collider (base goal):**
10 GeV long. polarized electrons on 100 GeV Au

**Collider (stretch goal):**
10 GeV long. polarized electrons on 250 GeV transverse and longitudinal polarized protons

### Year - 5

+ Long. electron polarization
+ Proton polarization
+ Hadron spin rotators
+ Hadron beams with off-center orbits

**Collider (base goal):**
10 GeV long. polarized electrons on 100 GeV Au

**Collider (stretch goal):**
10 GeV long. polarized electrons on 166 GeV transverse and longitudinal polarized He-3

Time to construct the ELR subproject

# Overall Run Status (2018)

| Energy | Start | Finish | First Run | Last Run | HLTgood | Target |
|---|---|---|---|---|---|---|
| 3.85 FXT | May 31$^{st}$ | June 4$^{th}$ | 19151029 | 19155022 | 258 M | 100 M |
| 26.5 FXT | June 5$^{th}$ | June 18$^{th}$ | 19156034 | 19169017 | 155 M | none |
| 27 GeV | May 10$^{th}$ | June 17$^{th}$ | 19139960 | 19168040 | 558 M | 1000 M |

Summary tables provided by D. Cebra

# Overall Run Status (2019)

| Energy | Start | Finish | First Run | Last Run | HLTgood | Target |
|---|---|---|---|---|---|---|
| 19.6 | Feb 25th | April 3rd | 20056032 | 20093036 | 582 M | 400 M |
| 14.6 | April 4th | June 3rd | 20094048 | 20154013 | 324 M | 310 M |
| 3.85 FXT | June 9th | June 9th | 20160024 | 20160027 | 3.7 M | 5 M |
| 7.3 FXT | June 18th | June 18th | 20169029 | 20169055 | 52.7 M | 50 M |
| 7.7 | June 3rd | June 27th | 20154047 | 20178014 | 2.9 M | 4 M |
| 4.59 FXT | June 28th | July 2nd | 20179040 | 20183025 | 200.6 M | 200 M |
| 9.2 | June 28th | July 8th | 20179016 | 20189017 | 1.0 M | none |
| 31.2 FXT | July 8th | July 9th | 20190006 | 20190024 | 50.6 M | 50 M |
| 200 | July 11th | July 12th | 20192001 | 20193026 | 138 M | 140 M |

# Overall Run Status (2020)

| Energy | Start | Finish | First Run | Last Run | HLTgood | Target |
|---|---|---|---|---|---|---|
| 11.5 GeV | Dec 10th | Feb 24th | 20056032 | 21055017 | 235 M | 230 M |
| 31.2 FXT | Jan 28th | Jan 29th | 21028011 | 21029037 | 112.5 M | 100 M |
| 9.8 FXT | Jan29th | Feb 1st | 21029051 | 21032016 | 108 M | 100 M |
| 19.5 FXT | Feb 1st | Feb 2nd | 21032049 | 21033017 | 118 M | 100 M |
| 13.5 FXT | Feb 2nd | Feb 3rd | 21033026 | 21034013 | 103 M | 100 M |
| 7.3 FXT | Feb 4th | Feb 5th | 21035003 | 21036013 | 117 M | 100 M |
| 5.75 FXT | Feb 13th | Feb 14th | 21044023 | 21045011 | 115.6 M | 100 M |
| 9.2 GeV | Feb 24th | Sep 1st | 21055032 | 21245010 | 161.8 M | 160 M |
| 26.5 FXT | July 29th | Sep 14th | 21211028 | 21258004 | 316.9 M | none |
| 7.7 GeV | Sep 2nd | Sep 11th | 21246012 | 21255021 | 3.2 M | none |

# FXT with eTOF (2020 and 2021)

| Energy | Percent w/ eTOF | HLTgood total | Target w/ eTOF |
|---|---|---|---|
| 31.2 FXT | 90.4 % | 101.7 M | 100 M |
| 19.5 FXT | 68.1 % | 80.4 M | 80 M |
| 13.5 FXT | 86.3 % | 88.9 M | 70 M |
| 9.8 FXT | 67.3 % | 72.7 M | 65 M |
| 7.3 FXT | 90.9 % | 106.4M | 50 M |
| 5.75 FXT | 86.0 % | 99.4 M | 70 M |
| 26.5 FXT | 94.3 % | 298.7 M | none |
| 3.85 FXT | 98.8 % | 305.3 M | 300 M |
| 44.5 FXT | 93.3 % | 50.3 M | 50 M |
| 70 FXT | 97.5 % | 50.4 M | 50 M |
| 100 FXT | 99.8 % | 50.6 M | 50 M |
| 3.85 FXT | | | |

2020 (rows 31.2 FXT through 26.5 FXT)

2021 (rows 3.85 FXT through 3.85 FXT)

# Overall Run Status (2021)

| Energy | Start | Finish | First Run | Last Run | HLTgood | Target |
|---|---|---|---|---|---|---|
| 7.7 GeV | Jan 31st | May 1st | 22031042 | 22121018 | 100.9 M | 100 M |
| 3.0 FXT | May 1st | May 5th | 22121036 | 22125011 | 306.6 M | 300 M |
| 9.2 FXT | May 6th | May 6th | 22126010 | 22126029 | 53.9 M | 50 M |
| 11.5FXT | May 7th | May 7th | 22126045 | 22127018 | 51.7 M | 50 M |
| 13.7 FXT | May 8th | May 8th | 22128001 | 22128011 | 50.7 M | 50 M |
| O+O 200 | May 11th | Min Bias | 22131011 | 22136010 | 403.9 M | 400 M |
| O+O 200 | May 16th | Central | 22136011 | 22141016 | 212.4 M | 200 M |
| O+O 200 | May 21st | Flip Field | 22141039 | 22144006 | 125.0 M | 100 M |
| 17.3 GeV | May 25th | June 7th | 22145017 | 22158019 | 256.1 M | 250 M |
| 3.0 FXT | June 7th | June 28th | 22159051 | 22179022 | 1796 M | 1.7 B |
| d+Au 200 | June 28th | July 7th | 22180043 | 22188007 | 216.9 M | 200 M |
| 7.2 FXT | June 3rd | July 3rd | 22154936 | 22184019 | 88.6 M | none |