Maximizing He-3 polarization

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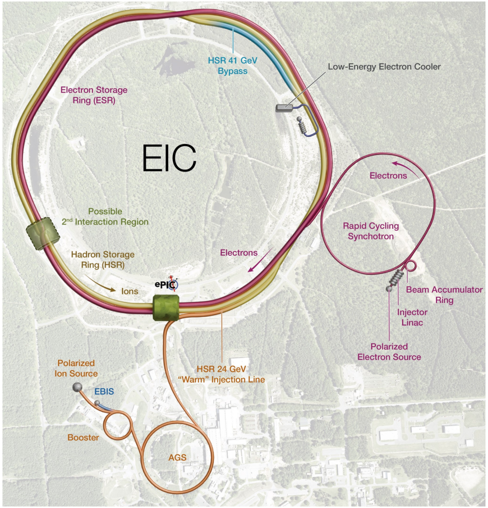
Polarized He-3 Introduction

Polarized He-3 will facilitate polarized neutron collisions for the Electron Ion Collider.

- Polarized He-3 beams will be produced at the Electron Beam Ion Source (EBIS) with an expected intensity of 2×10^{11} ions/pulse and 80% polarization.
- EBIS accelerates the beam to 2 MeV/u ($|G\gamma|$ =4.1932).
- Booster accelerates up to $|G\gamma| = 7.5$ or 10.5 to match stable spin directions with AGS.
- AGS accelerates up to $|G\gamma|$ =49.5, avoiding the strong $|G\gamma| = 60 - \nu_y$ intrinsic resonances.
- HSR will accelerate and store the beam up to $|G\gamma| = 820$.
- This is significantly higher than polarized protons with $G\gamma = 487$ (RHIC, achieved) and $G\gamma = 525$ (HSR, planned).
- The EIC requires He-3 with an intensity of 0.8×10^{11} ions/bunch and 72% polarization.

Parameter	Value	Unit
Mass	2808.39	MeV/c^2
q	2	e
G	-4.1842	-



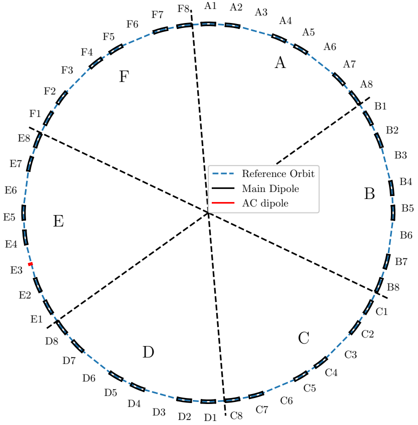
Spin Dynamics in Accelerators

The Thomas-BMT equation is the equation of motion for a particle's spin vector, $\vec{S}$, in a synchrotron (neglecting effects of $\vec{E}$)

$$\frac{d\vec{S}}{dt} = \frac{q}{\gamma m}\vec{S} \times \left[(1 + G\gamma)\vec{B_\perp} + (1 + G)\vec{B_\parallel}\right] \quad (1)$$

- Term $\propto \vec{B}_\perp$ is strongest due to presence of strong focusing quadrupoles
- Terms $\propto \vec{B}_\parallel$ is small.
- When the spin precession in the dipoles is in phase with the particle's sampling of the horizontal fields of a quadrupole, a resonance condition exists. These occur at:
  - $G\gamma = nP \pm \nu_y$, intrinsic resonance from vertical betatron motion
  - $G\gamma = n$, imperfection resonance due to vertical closed orbit.

Booster and AGS



The Booster will receive polarized He-3 from the EBIS at 2 MeV/u. The Booster:

- Has a superperiodicity of P=6, labelled A through F,
- Each superperiod contains 4 FODO cells and 6 main dipoles,
- Circumference of 201.78 m,
- $\nu_y < 4.5$ for polarized He-3 and $\nu_y > 4.5$ for polarized protons.
- Injecting at $\nu_y < 4.09$, the $|G\gamma| = 0 + \nu_y$ is avoided.
- There are three imperfection resonances up to $|G\gamma| = 7.5$.
- There are six imperfection resonances and two intrinsic resonances up to $|G\gamma| = 10.5$.

The AGS is the injector for RHIC

- Has a superperiodicity of 12 (labelled A through L) with a length of 807.12 m
- Tunes typically $\nu_y > 8.9$ for polarized protons.

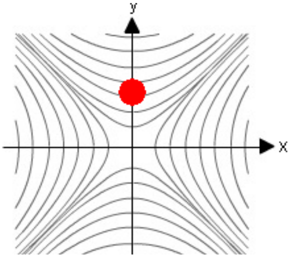
Booster Intrinsic Resonance Crossing with an AC Dipole

An AC dipole works by forcing all particles to undergo large amplitude vertical betatron oscillations.

- This is done with a horizontal magnetic field that oscillates in phase with the vertical betatron motion, at tune $\nu_m = f_m/f_{rev}$.
- The amplitude of these coherent oscillations is

$$Y_{coh} = \frac{B_m l}{4\pi B\rho\delta_m}\beta_y \tag{2}$$

  where $B_m l$ is the integrated strength of the dipole kick.
- The separation between the tune of the AC dipole, ν_m, and ν_y is the resonance proximity parameter, $\delta_m = \nu_y - (n + \nu_m)$.
- This creates a driven resonance at ν_m.

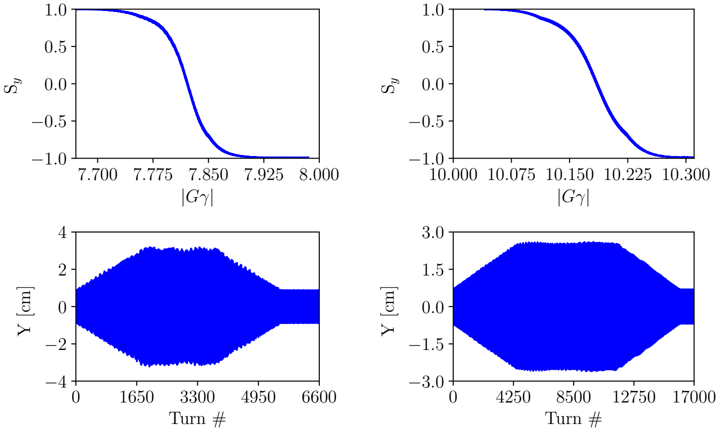


As f_m is fixed, ν_m can change as much as $\Delta\nu_m = 0.0028$ for He-3 crossing $|G\gamma| = 12 - \nu_y$ due to rapid change in f_{rev}

- The current configuration for the AC dipole supports up to 16.1 $\mathrm{G \cdot m}$ with $\delta_m = 0.01$.
- The design is 25 $\mathrm{G \cdot m}$ which requires two power amplifiers connected to the magnet. This approach is still being investigated.

Booster Intrinsic Resonance Crossing with an AC Dipole

He-3 crossing the $|G\gamma| = 12 - \nu_y$ (left) and $|G\gamma| = 6 + \nu_y$ (right)



- Full spin-flip achieved with $\mathrm{B_m l} = 16.5\ \mathrm{G \cdot m}$ ($|G\gamma| = 12 - \nu_y$) and $\mathrm{B_m l} = 20.5\ \mathrm{G \cdot m}$ ($|G\gamma| = 6 + \nu_y$), with $\delta_m = 0.01$.

Booster Imperfection Resonances: Harmonic Orbit Correction

For correcting the $|G\gamma| = k$ resonance, the h=k harmonic of the corrector dipoles is used. Harmonic h=k can be:

- corrected so no polarization is lost,
- or enhanced to induce a full spin-flip.

The Booster has 24 vertical orbit correctors placed adjacent to vertically focusing quadrupoles, and are used for creating and correcting orbit harmonics. These correctors are powered according to

$$B_{j,h} = a_h \sin(h\theta_j) + b_h \cos(h\theta_j) \tag{3}$$

where j is corrector number, θ_j is the location in the ring, a_h and b_h are the amplitudes for harmonic h. The total current on corrector j is

$$I_j = \sum_h I_{h,S} \sin(h\theta_j) + I_{h,C} \cos(h\theta_j) \tag{4}$$

where $I_{h,S}$ and $I_{h,C}$ are the corrector currents for the Sine and Cosine components. The maximum current of all correctors is

$$I_{max} = \max[|I_j|]. \tag{5}$$

This is an important parameter so as to avoid exceeding the maximum current of the supplies, 25 A.

Summary of He-3 Corrector Strength Requirements

The Froissart-Stora formula at a given resonance k, and harmonic h=k, as a function of corrector current is given by,

$$\frac{P_f}{P_i} = 2e^{-\frac{(I_{k,S}-I_{k,oS})^2}{2\sigma^2_{k,S}}} e^{-\frac{(I_{k,C}-I_{k,oC})^2}{2\sigma^2_{k,C}}} - 1 \quad (6)$$

To allow all He-3 imperfection resonances to be studied with the same orbit, the h=4 and h=5 harmonic corrections are scaled to all higher order resonances by the ratio of rigidity. That is

$$I(h=5, |G\gamma| = k) = I(|G\gamma| = 5)\frac{B\rho(|G\gamma| = k)}{B\rho(|G\gamma| = 5)} \quad (7)$$

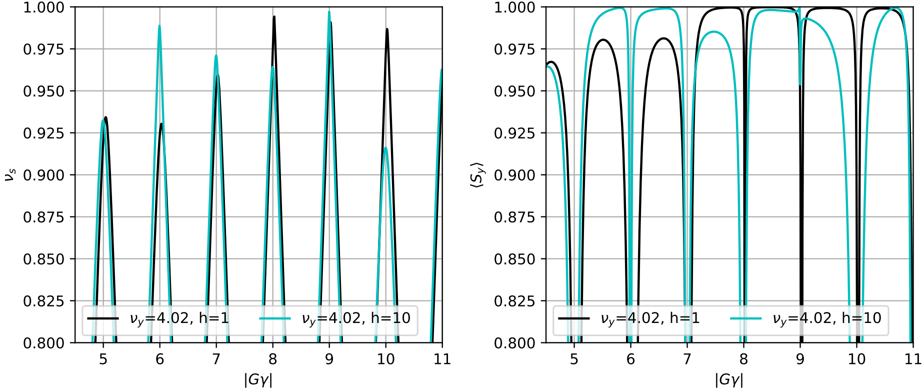
These corrector currents are [$I_{4,S}$, $I_{4,C}$, $I_{5,S}$, $I_{5,C}$]=[2.797 A, 0.669 A, 0.520 A, 4.296 A]

K	μ_S [A]	μ_C [A]	$I_{S,K}$	$I_{C,K}$	$I_{M,F}$	$I_{M,C}$
5	0.322	2.105	0.35	-1.71	4.33	6.44
6	0.567	-0.189	1.78	9.65	17.77	9.19
7	1.425	0.847	10.02	-8.14	22.4	13.95
8	-2.463	5.242	2.75	-9.39	21.98	22.37
9	-0.614	-0.222	-1.17	-14.35	29.71	17.59
10	-23.669	-0.477	-3.67	-0.477	22.86	39.43

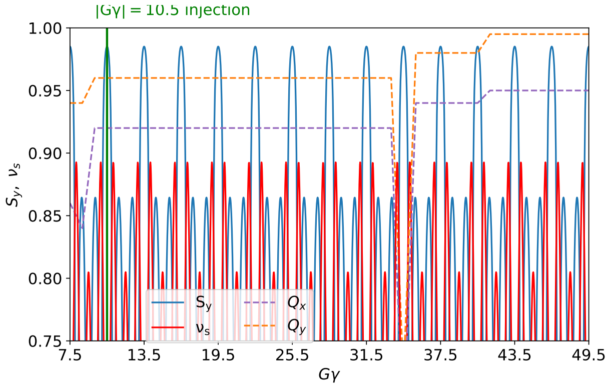
Polarized He-3 in the Booster, Possible Upgrades

Ongoing studies: corrector upgrades to produce sufficiently strong imperfection resonances to produce a ν_s gap to avoid the $|G\gamma| = 12 - \nu_y$ and $6 + \nu_y$ resonances.

- The 24 existing vertical Booster corrector magnets have a maximum strength of $24.4\ \mathrm{G \cdot m}$.
- To produce the 0.08 ν_s-gap at h=10, a strength of $406\ \mathrm{G \cdot m}$ is needed.
- This would require an overhaul of the Booster corrector packages.



Polarized He-3 in the AGS



Example horizontal and vertical tunes, along with spin tune and the projection of the stable spin direction on the vertical axis.

- At $G\gamma$=8, the $G\gamma = 8 \pm \nu_x$ and $G\gamma = 8 \pm \nu_y$ are potentially crossed.
- Below $|G\gamma| = 10.5$, simulations show a trade off between intensity and polarization.
- Simulations show no polarization loss above $|G\gamma| = 10.5$.

AGS Snakes, optical distortions

To quantify the optical defects, particles are tracked through only the cold snake to calculate the transport matrix. From the transport matrix, the total coupling (CP) and focusing (FC) are calculated from transport matrix elements m_{ij},[a]

$$CP = LL + UR \tag{8}$$

with

$$LL = m_{31}^2 + m_{32}^2 + m_{41}^2 + m_{42}^2 \tag{9}$$

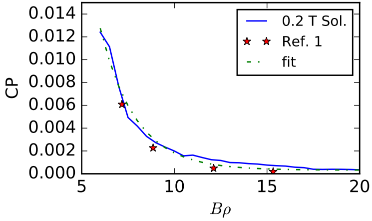
$$UR = m_{13}^2 + m_{14}^2 + m_{23}^2 + m_{24}^2. \tag{10}$$

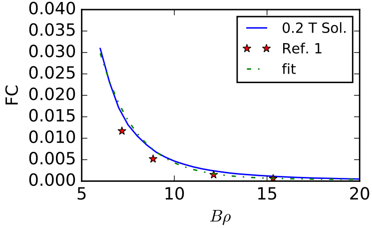
and

$$FC = m_{12}^2 + m_{34}^2 \tag{11}$$

[a] Ref 1, C-A/AP 128, Cold Snake Optimization by Modelling

These optical distortions reduce exponentially with $B\rho$.

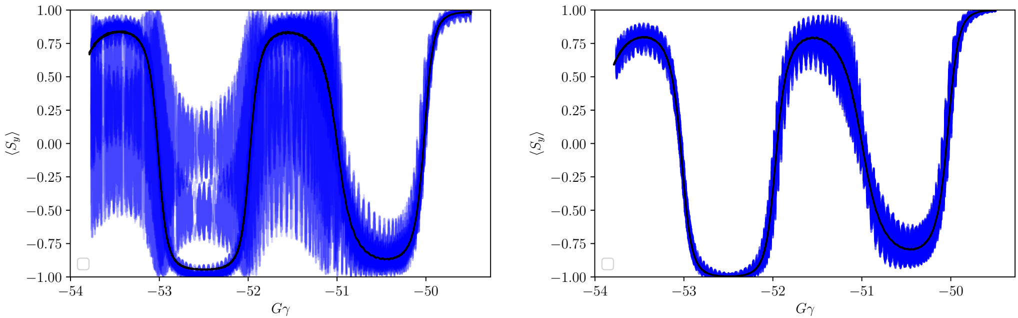




Polarized He-3 in the AGS, Possible Upgrades

In the current configuration, no polarization loss is expected in AGS above $|G\gamma| = 10.5$. **Adding a second cold snake would allow extraction above $|G\gamma| = 49.5$.** Crossing the $|G\gamma| = 60 - \nu_y$ resonance with 6D distributions

- Left: χ_c, χ_w =25, 14%, results in 4.4% polarization loss with $Q_x, Q_y = 0.95,\ 0.995$.
- Right: $\chi_w = \chi_c = 25\%$, results in 0.43% polarization loss with the same tunes of $Q_x, Q_y = 0.95,\ 0.995$.



The optics distortions from two cold snakes would necessitate higher Booster-to-AGS transfer energy.

- Studies of polarized He-3 in the spin-tune gap can also inform upgrades for polarized protons.

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Commissioning Plan

The commissioning plan spans to 2030. In that time there are several objectives and priorities. The research is also broken into two components, before and after the A5 kicker upgrade.
Objectives:

1. Commission polarized He-3 up to $|G\gamma| = 7.5$ in Booster.
2. Commission polarized He-3 up to $|G\gamma| = 49.5$ in AGS.
3. Commission polarized He-3 up to $|G\gamma| = 10.5$ in Booster after A5 upgrade.

Priorities:

1. Identify the maximum achievable efficiency to determine the number of bunch merges required to satisfy EIC intensity requirements.
2. Identify the maximum achievable polarization transmission with the proposed techniques and ensure the EIC polarization requirements can be satisfied.
3. Fully study the proposed alternatives in Booster and AGS if Priority #2 cannot be satisfied.
4. Identify and propose upgrades as needed to satisfy EIC requirements.

Booster Commissioning Plan

1. Low energy injection of He-3 into the Booster at high intensity.
2. Orbit harmonic corrections through six imperfection spin resonances.
   - $|G\gamma|$=5 to 7 with $|G\gamma|$ = 7.5 extraction prior to A5 kicker upgrade
   - Studies up to $|G\gamma|$ = 9 without A5 upgrade, no AGS snakes
   - Up to $|G\gamma|$=10 after A5 kicker upgrade
3. AC dipole studies through two intrinsic spin resonances.
   - Not used at $|G\gamma|$ = 7.5 extraction
   - Study $|G\gamma|$ = 12-ν_y resonance, no AGS snake
   - Study and optimize $|G\gamma|$ = 12-ν_y and $|G\gamma|$ = 6 + ν_y after A5 kicker upgrade
4. Maximize overall performance.

The time given as estimates on the next slides is derived from measurements with polarized protons and assuming a reduction in intensity (1×10^{11} ions/bunch). A reduction in intensity will further increase the time requirements or reduce the available statistics.

Booster Commissioning Plan, time requirements

1. Low energy injection of He-3 into the Booster at high intensity.
2. Orbit harmonic corrections through six imperfection spin resonances.
   - Single day for two harmonic scans
   - To study in detail, 4 days per resonance. Effects of tune changes, effects from other harmonics, etc.
3. AC dipole studies through two intrinsic spin resonances
   - From Booster AC dipole experiment, 6 days to study in detail for each resonance.
4. Maximize overall performance.

Notes

- General optimizations and initial setup will take three days (items 1 and 4).
- Resuming each year will require 6 days to re-establish polarization to $|G\gamma| = 7.5$, 10 days to re-establish polarization to $|G\gamma| = 10.5$. This is aside from nominal setup time.
- AGS injection is needed for all polarization studies to utilize the AGS polarimeter
- All times assume two 8-hour shifts/day.

AGS Commissioning Plan

1. Spin-tune gap studies:
   1.1 Polarized He-3 in the spin-tune gap at injection $|G\gamma|$ = 7.5 to 9.5 without A5 kicker upgrade.
   - Prior to A5 kicker upgrade, use jump/skew quads for $|G\gamma|$ = 8, 9, and 10, optimize transmission across $|G\gamma| = 0 + \nu_y = 8.9$ resonance.

   1.2 Study both tunes inside the spin-tune gap (38 imperfection resonances, 6 strong intrinsic resonances)
   - General polarization transmission.
   - How high does Qy need to be?
   - How high does Qx need to be?
   - Minimum separation of Qx to Qy for good transmission?
   - Can polarization be preserved across the $|G\gamma| = 60 - \nu_y$?
2. Maximize overall performance.

AGS Commissioning Plan, time requirements

1. Spin-tune gap studies:
   1.1 Polarized He-3 in the spin-tune gap at injection $|G\gamma|$ = 7.5 to 9.5 without A5 kicker upgrade.
      - 2 days

   1.2 Study both tunes inside the spin-tune gap (38 imperfection resonances, 6 strong intrinsic resonances)
      - Scan of Q_x and Q_y in the spin-tune gap using ramp polarization measurements. 2 days per scan. 20 days total.
      - Scan of Q_y at $|G\gamma|$ =0+ν_y, 12+ν_y, 36-ν_y, 24+ν_y, 48-ν_y, and 36+ν_y. Standard polarization measurements 2 days/scan. 12 days.
      - Different snake strengths. Repeat scan of Q_x and Q_y in spin-tune gap. 20 days total.
      - Polarization transmission up to $|G\gamma|$=55.5. Study Q_y at $|G\gamma|$=60-ν_y, 4 days.
2. Maximize overall performance.
   - 7 days

He-3 Commissioning time summary I

Booster commissioning Item	Duration (days)
Low energy injection with higher intensity*	1
Imperfection resonance crossings $\|G\gamma\| = 5$ to 7*	12
Imperfection resonance crossing $\|G\gamma\| = 8$ and 9	8
AC dipole at $\|G\gamma\| = 12 - \nu_y$	6
Maximize performance*	3
TOTAL	30

Booster annual restart items	Duration (days)
Low energy injection with higher intensity*	1
Imperfection resonance crossings $\|G\gamma\| = 5$ to 7*	3-6
Maximize performance*	3
TOTAL	7-10

After A5 kicker upgrade	Duration (days)
Reoptimize to $\|G\gamma\| = 7.5$	7-10
Imperfection resonance crossings $\|G\gamma\| = 10$	4
AC dipole at $\|G\gamma\| = 12 - \nu_y$ and $\|G\gamma\| = 6 + \nu_y$	8
Maximize performance	3
TOTAL	22-25

He-3 Commissioning time summary II

AGS commissioning Item	Duration (days)
Optimize injection, study transmission from |Gγ| = 7.5 to 10.5	2
Study polarization transmission up to |Gγ| = 48.5	52
Study polarization transmission up to |Gγ| = 55.5	4
Maximize performance	7
TOTAL	65

AGS after A5 kicker upgrade	Duration (days)
Establish injection into the spin-tune gap	1
Re establish polarization transmission up to |Gγ| = 48.5	14
Further investigate different snake strengths	32
Maximize performance	7
TOTAL	22-54

Year	Commissioning actity	Time (days)
2027	Commission helium-3 in Booster up to |Gγ| = 7.5, study intrinsic and imperfection resonances above |Gγ| = 7.5 , and commission low energy injection into AGS.	30
2028	Reestablish polarized helium-3 in Booster. Optimize low energy in AGS, study transmission from |Gγ| = 7.5 to 10.5 to determine need for higher energy injection. Begin studies of Qx and Qy in spin-tune gap up to |Gγ| = 49.5.	28-48
2029	Determine maximum efficiency in Booster and AGS and number of merges to satisfy EIC intensity requirements.	14-28
2030	Study and optimize the transmission along the ramp. Finish incomplete studies.	34-48 days

Summary

Charge question: Are the accelerator R&D effort well executed, and future work well planned?

- To support the EIC requirements, polarized He-3 need near lossless transmission of both intensity and polarization in the injectors.
- The optimal configurations for the Booster and AGS have been identified for commissioning.
- Possible upgrades have been identified if the intended configurations fall short of EIC requirements.
- Commissioning goals have been set to support the EIC requirements.
- Polarized He-3 are currently requested at the EIC within the first five years of physics/commissioning. Additional upgrades will need to be identified, installed, and recommissioned before this time.
- A timeline of activities spanning to 2030 has been provided to make use of approximately one-month/year of AGS.

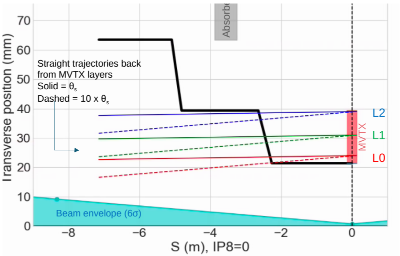
MAC-21 Recommendation #3

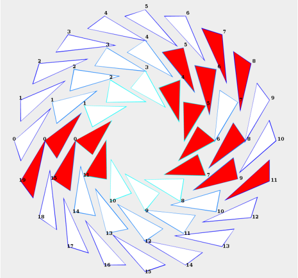
Experimental background in Run-24 and sPHENIX MVTX experimental background task force

3. Calculate the overall aperture bottle-neck for a betatron halo particle (at setting of H collimator, e.g. 8 sigma-beta-x) that at the same time has an energy offset at the momentum aperture (e.g. 4.5 sigma-E). Use the known local aperture, the horizontal beta function and the horizontal dispersion to see if such a particle can get lost at the second taper in front of sPHENIX or at another “high impact” location that can shine into the detector. Only if this is true, a global momentum collimation can safely protect the experiment. Otherwise local origins on off-momentum ions might be responsible, to be counteracted by local protection measures.

Refresher:

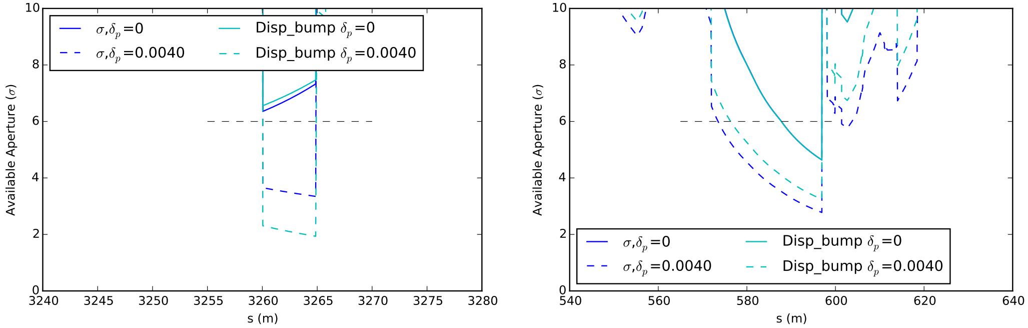
- Au particles were transiting the length of the MVTX detector, depositing a large amount of charge and causing the detector to go into an auto-recovery process.
- The auto-recovery process takes approximately 20 s during that time, data is not collected, reducing the acceptance of the detector.





R3-II, Calculations of aperture and momentum aperture

Mask fully inserted (left), collimator (right)



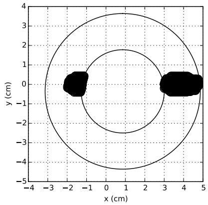
- Only in the case of high δp and using a lattice to increase the dispersion at the mask location, was the mask more efficient than the collimator at removing high momentum particles.
- The mask was installed and modifications to the γ_t quads were performed to support the dispersion bump.

R3-III, Local origin of backgrounds

Through tracking, it was determined the source of the background was in the D4 section, upstream of the triplets.

- The yellow mask was located there and removed.
- The jaws of the mask were mechanically frozen open, but limited the aperture to ± 2.48 cm from the nominal 3.4 cm.
- Forward tracking from this location showed particles with a momentum error as low as $P = 0.5P_o$ would strike the MVTX (example taper hit map shown on right).
- Removal of the mask had an auto-recovery rate similar to the best mitigation in Run24.

Configuration	$\langle ARR \rangle$	improvement
12 yellow bunches, 2024 baseline	1.2	-
12 yellow bunches+pfp+orbit, 2024	0.067	17.9
12 yellow bunches, 2025 baseline	0.089	13.5



MAC-21 Recommendation #6

Injector upgrade plans over the next decade

Recommendations:

6. Continue optimizing the modernization plan and for next year's review produce a prioritized list of tasks.

- Funds for modernization plan amount to $3 M/year.
- This list is optimized to maximize the available funds.
- Table on left was presented as part of the DOE Operations Review.

Hadron injector upgrade funding plan - included in DOE Operations Review presentation, Sept 2025 — All costs are k$

SYSTEM	PROJECT DESCRIPTION	Fund source	Est. mat.	Subtotal	Avail.Fund	FY26 Est.	FY27 Est.	FY28 Est.	FY29 Est.	FY30 Est.	FY31 Est.	FY32 Est.	FY33 Est.	Total	Deferred
Power Supplies	AGS quadrupole and sextupole power supply upgrade (qty:4)	CE	$ 1,100		$ 1,100									$ 1,100	$ -
	AGS PEI power supply replacement in multipole room	Ops	$ 175		$ 175									$ 175	$ -
	AGS B1 quadrupole power supply in B18	Ops	$ 150		$ 150									$ 150	$ -
	AGS B3 quadrupole power supply in B18	Ops	$ 150		$ 150									$ 150	$ -
	AGS Siemens cycloconverter upgrade	AIP	$ 5,000		$ 5,000									$ 5,000	$ -
	AGS Siemens main magnet power supply maintenance	Ops	$ 1,500			$ 1,500								$ 1,500	$ -
	Booster quadrupole and sextupole power supply upgrade	AIP	$ 1,000								$ 1,000			$ 1,000	$ -
	AGS main magnet Exciter power supply	AIP	$ 2,000										$ 2,000	$ 2,000	$ -
				$ 11,075											
RF	AGS RF anode power supplies (qty:11)	AIP	$ 3,000				$ 2,000	$ 1,000						$ 3,000	$ -
	RF Booster (qty:6) & AGS (qty:10) ENI power amplifier upgrade	Ops	$ 500						$ 250		$ 250			$ 500	$ -
	Booster RF Anode power supplies (qty:4). (equip. in-house)	Ops	$ 1,500		$ 1,500									$ 1,500	$ -
				$ 5,000											
Cryogenics	AGS cold snake cryo upgrade	CE	$ 800				$ 800							$ 800	$ -
				$ 800											
Vacuum	Linac roughing pump systems, all tanks	AIP	$ 1,000					$ 1,000						$ 1,000	$ -
	Booster sector valves, gauges and controllers, ion pup controllers, bakeout system, PLC system, fast valves and controls	AIP	$ 1,000							$ 1,000				$ 1,000	$ -
	AGS ion pumps and controllers, PLC system	CE	$ 600								$ 600			$ 600	$ -
	ATR X line ion pups, fast valves and controls, PLC system	CE	$ 500									$ 500		$ 500	$ -
				$ 3,100											
Instrumentation	AGS and booster beam position monitor electronics upgrade	CE	$ 800		$ 800									$ 800	$ -
	Linac HEBT laser profile monitor	CE	$ 375			$ 175	$ 200							$ 375	$ -
	Research and select new system for chipmunk radiation monitoring	Ops	$ 200					$ 200						$ 200	$ -
	Current transformers	AIP	$ 1,000						$ 1,000					$ 1,000	$ -
	AGS transverse damper	AIP	$ 1,000						$ 1,000					$ 1,000	$ -
	Multiwire profile monitors	AIP	$ 1,000							$ 1,000				$ 1,000	$ -
	Loss monitor systems	AIP	$ 1,000								$ 1,000			$ 1,000	$ -
	Motion systems	Ops	$ 600					$ 100	$ 100	$ 100	$ 100	$ 100	$ 100	$ 600	$ -
				$ 5,975											
Pulsed Power	AGS tune meter (in progress)	Ops	$ 150		$ 150									$ 150	$ -
	AGS extraction septum H10	CE	$ 425			$ 425								$ 425	$ -
	Booster tune meter	CE	$ 100			$ 100								$ 100	$ -
	EBIS solenoid modulator	Ops	$ 75			$ 75								$ 75	$ -
	Booster injection kicker C1, C3, C7, D1	CE	$ 475					$ 475						$ 475	$ -
	Booster extraction septum A5	CE	$ 550					$ 550						$ 550	$ -
	Booster extraction BLW bumps A1, F7, F4, F2	CE	$ 300						$ 300					$ 300	$ -
	AGS injection septum L20	CE	$ 450							$ 450				$ 450	$ -
	AGS injection kicker F6	CE	$ 525							$ 525				$ 525	$ -
	EBIS HV anode platform pulser	Ops	$ 100							$ 100				$ 100	$ -
	HE-3 Pulser	Ops	$ 100							$ 100				$ 100	$ -
	AGS DC bumps G09C, H11C	CE	$ 400								$ 400			$ 400	$ -
	Booster extraction kicker F3	Ops	$ 250										$ 250	$ 250	$ -
	AGS tune jump I5, J5 (maybe not needed)	CE	$ 400											$ -	$ 400
	AGS gamma-tr A17, C17, E17, G17, I17, K17	CE	$ 1,000										$ 1,000	$ 1,000	$ -
				$ 5,300											
Electrical Power	Booster 13.8 kV breaker retrofit or new	Ops	$ 100						$ 100					$ 100	$ -
	Substation E 13.8 kV primary switch	Ops	$ 115						$ 115					$ 115	$ -
	AGS RF 13.8 kV breaker retrofit or new	Ops	$ 150								$ 150			$ 150	$ -
	RHIC ring 13.8 kV road side switches, 1004, 1006, 1008	CE	$ 500									$ 500		$ 500	$ -
	1005H 4160 MCC	Ops	$ 410									$ 410		$ 410	$ -
	13.8 kV feeders, transformers 3,4,5,6,7	AIP	$ 6,000											$ -	$ 6,000
	Replacement of AGS exterior rusted disconnect switches (qty TBD)	Ops	$ 450			$ 100	$ 100	$ 100					$ 150	$ 450	$ -
				$ 7,725											
AGS cable trays	AGS cable tray replacements, and cable replacements as needed	AIP	$ 2,000			$ 2,000								$ 2,000	$ -
				$ 2,000											
Bldg HVAC	Service building cooling system replacements (1002B, 1004A, 1004B, 1006B, 1008B, 1010A, 1012A	AIP	$ 5,000									$ 2,000	$ 500	$ 2,500	$ 2,500
				$ 5,000											
Water cooling systems	Cooling tower 3	CE	$ 300			$ 300								$ 300	$ -
	Linac cooling water equipment	Ops	$ 500				$ 500							$ 500	$ -
	Building 911 cooling water equipment	Ops	$ 200					$ 200						$ 200	$ -
	Buildings 928, 929 cooling water equipment	CE	$ 700						$ 700					$ 700	$ -
	Building H10 cooling water cooling water equipment	Ops	$ 200							$ 200				$ 200	$ -
	Building 1000P cooling water equipment	Ops	$ 100								$ 100			$ 100	$ -
				$ 2,000											
	TOTAL		**$ 47,975**		**$ 9,025**	**$ 4,675**	**$ 3,600**	**$ 3,625**	**$ 3,565**	**$ 3,475**	**$ 3,600**	**$ 3,510**	**$ 4,000**	**$ 30,050**	**$ 8,900**
	TOTAL CE funding					**$ 1,000**	**$ 1,000**	**$ 1,025**	**$ 1,000**	**$ 975**	**$ 1,000**	**$ 1,000**	**$ 1,000**	**$ 8,000**	
	TOTAL AIP funding					**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 16,000**	
	TOTAL Operations funding					**$ 1,675**	**$ 600**	**$ 600**	**$ 565**	**$ 500**	**$ 600**	**$ 510**	**$ 500**	**$ 5,550**	

Thank you

Thank you and questions.