RHIC Operational Modes Enabled by Enhanced Beam Control

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Special thanks to W. Fischer, A. Marusic, M. Minty, T. Shrey and G. Marr for input on this talk

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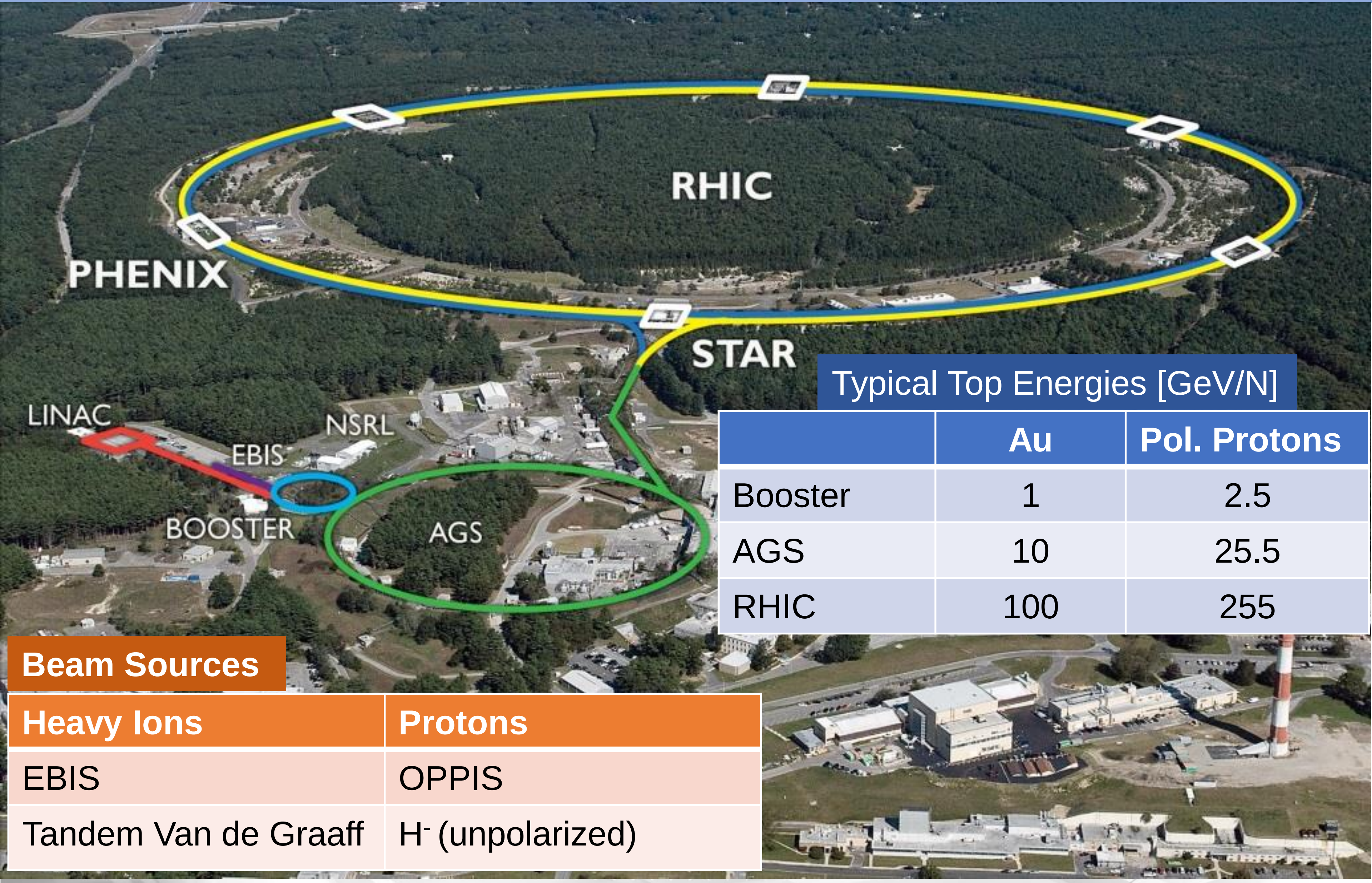
RHIC Accelerator Complex



Typical Top Energies [GeV/N]

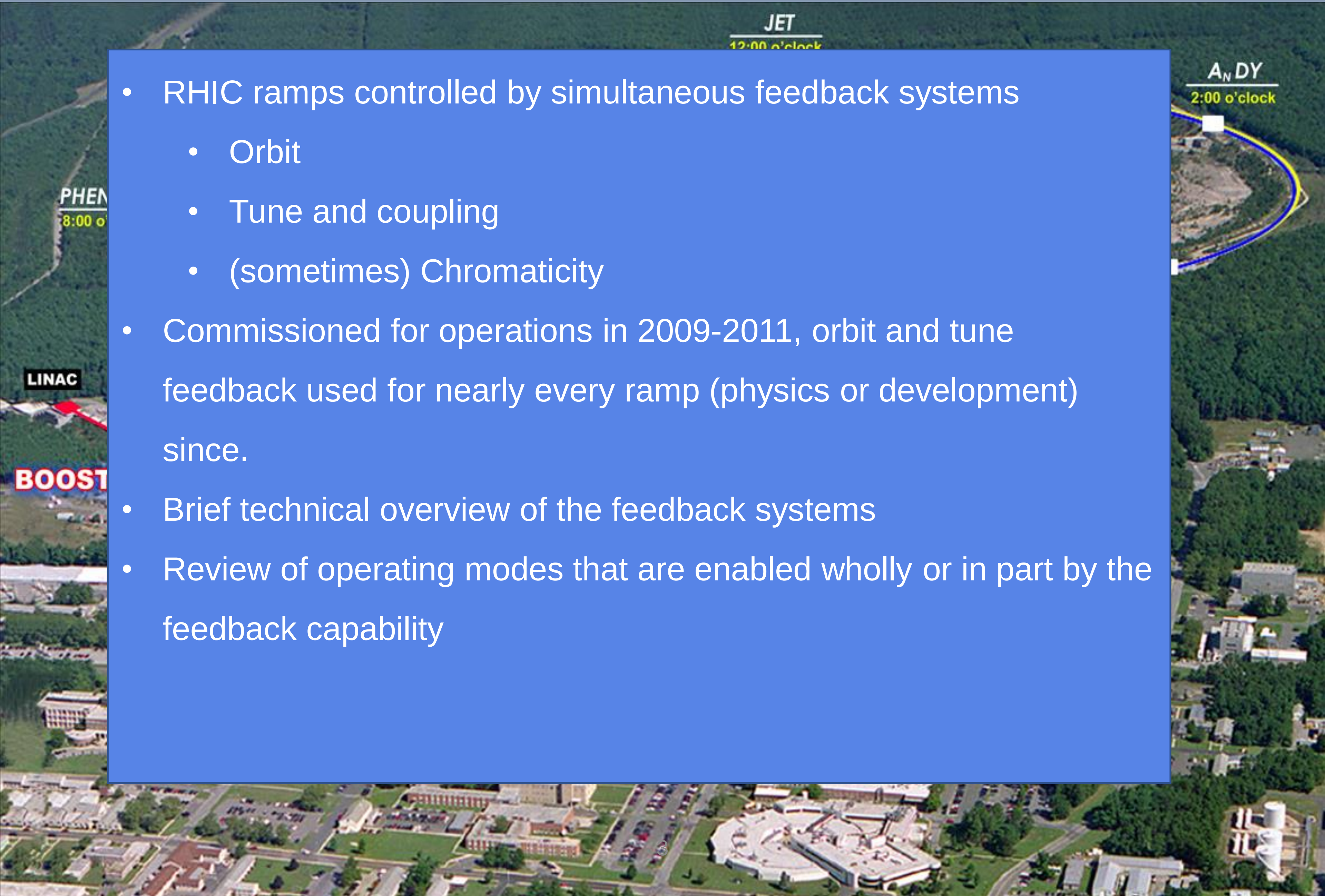
	Au	Pol. Protons
Booster	1	2.5
AGS	10	25.5
RHIC	100	255

Beam Sources

Heavy Ions	Protons
EBIS	OPPIS
Tandem Van de Graaff	H^- (unpolarized)

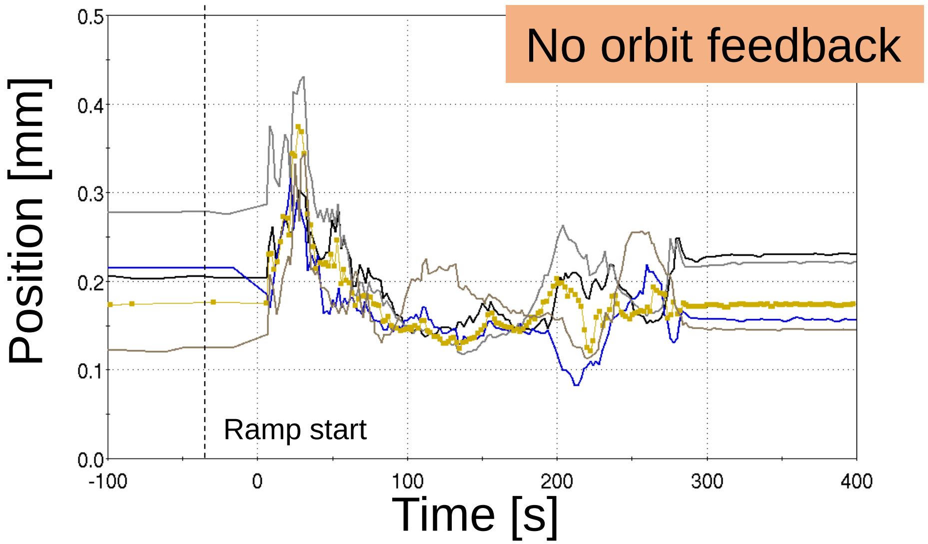
Outline

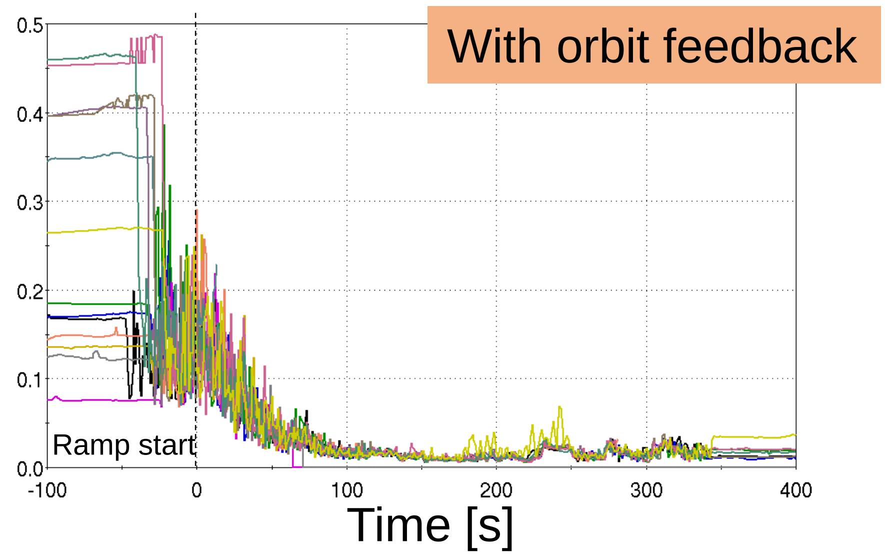
- RHIC ramps controlled by simultaneous feedback systems
  - Orbit
  - Tune and coupling
  - (sometimes) Chromaticity
- Commissioned for operations in 2009-2011, orbit and tune feedback used for nearly every ramp (physics or development) since.
- Brief technical overview of the feedback systems
- Review of operating modes that are enabled wholly or in part by the feedback capability



RHIC Feedback Systems: Orbit (Slow)

Orbit RMS During Several Ramps





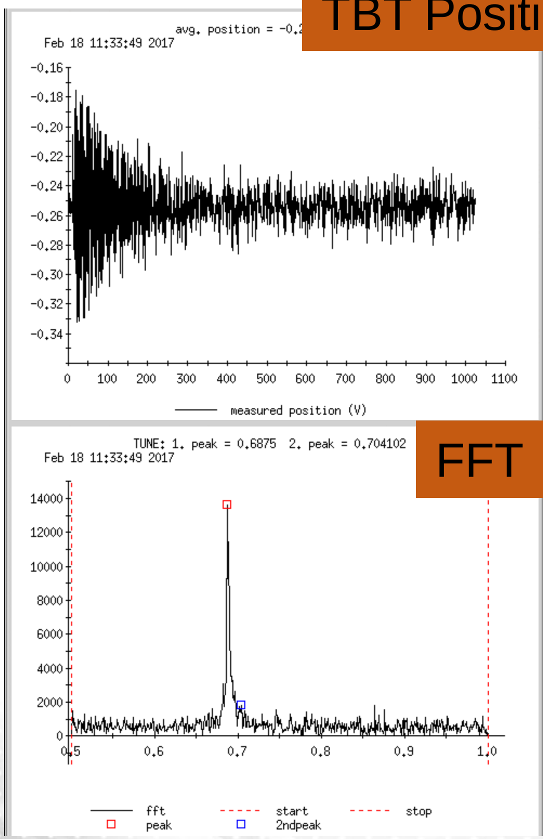
- 1 second avg orbit measurement
- Standard lattice orbit correctors
- Correction matrices pre-calc’d based on model, updated at 1Hz on ramp
- Iterated SVD corrections also at 1Hz
- BPM Filtering and model improvements
- Push-button for operations

RHIC Feedback Systems:
Tune, Coupling : Measurement during the ramp

Pre-2006:
Large single turn kick
FFT of free oscillation
No feedback on measurement

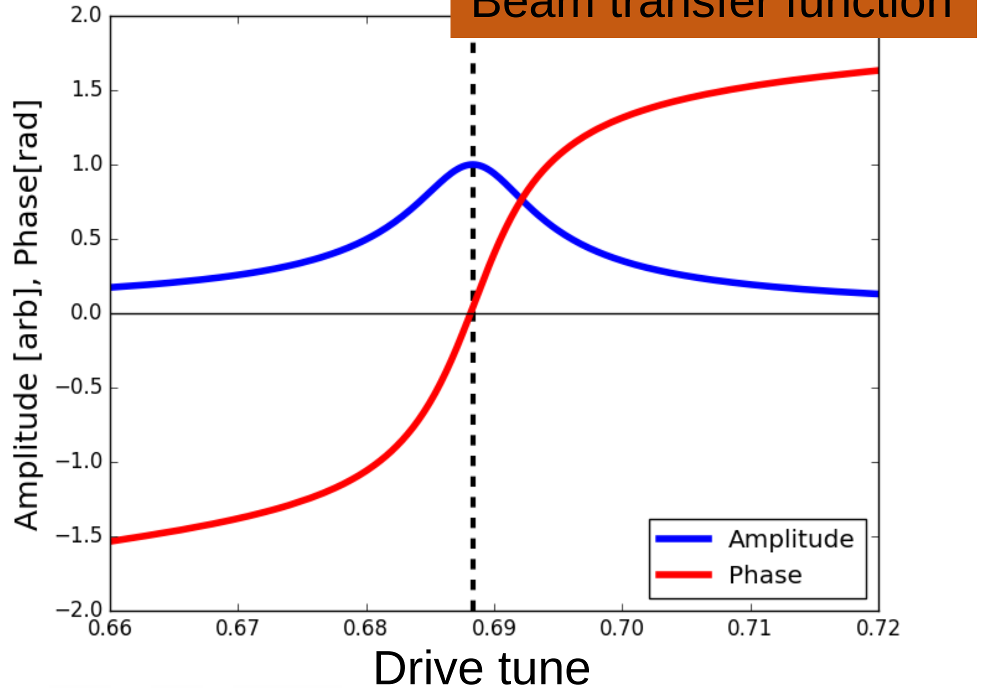
TBT Position

FFT



Post 2006:
Continuous driven oscillation
Zero phase determines resonance
Feedback possible

Beam transfer function



Phase = Δφ between kick and measurement

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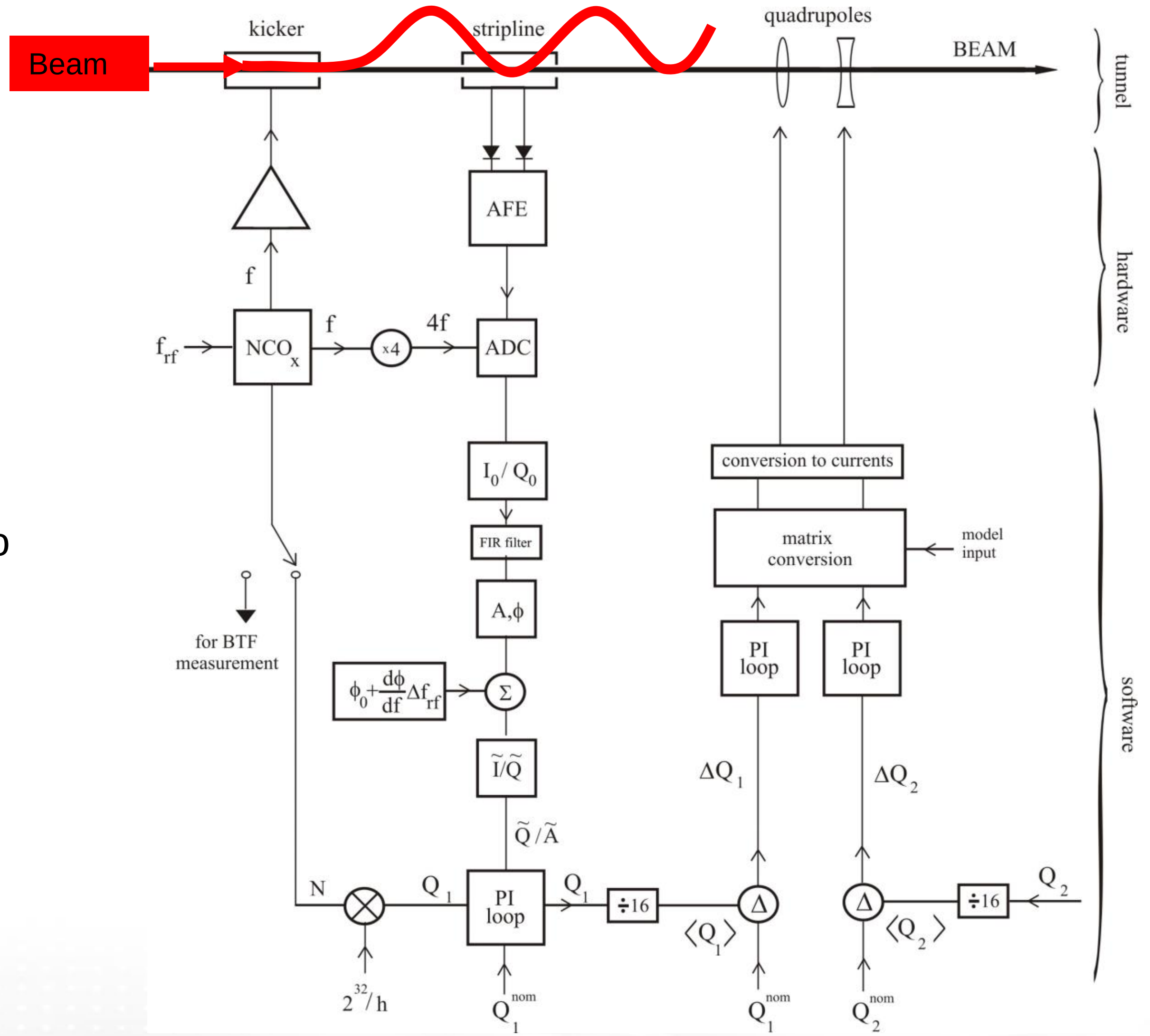
RHIC Feedback Systems: Tune, Coupling

- Sensitivity
  - Direct diode detection
  - Allows determination of tune with *very small (10-30 µm) excitation*
  - No emittance growth
- Precision
  - Phase-locked loop
  - Locks drive frequency to resonance
  - Tune determined to 10^{-5}-10^{-6}
- Control
  - Feedback to magnets
  - Model inputs



Beam Stability

Control of orbit, tune and coupling improve by factor of 10-100 over open loop operation

Coupling control critical to tune control
(Hor,Ver PLLs have to be able to clearly distinguish eigenmodes)

Parameter Stability Over Course of RHIC Ramp

	No feedbacks	With feedbacks
Orbit (x_{rms},y_{rms})	~ 500 µm	~20 µm
Tune (Q_x,Q_y)	~0.1	< 0.001
Coupling $\|C^-\|$	~0.1	< 0.01

Includes fast events like transition,snapback

But what can we DO with it?

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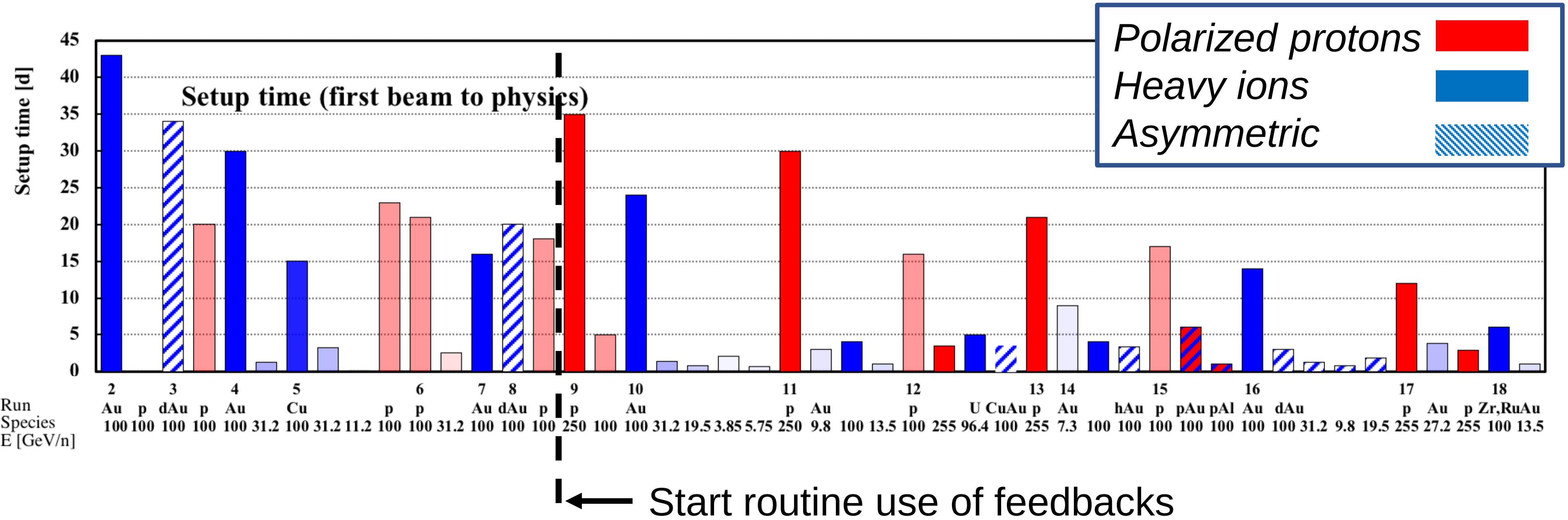
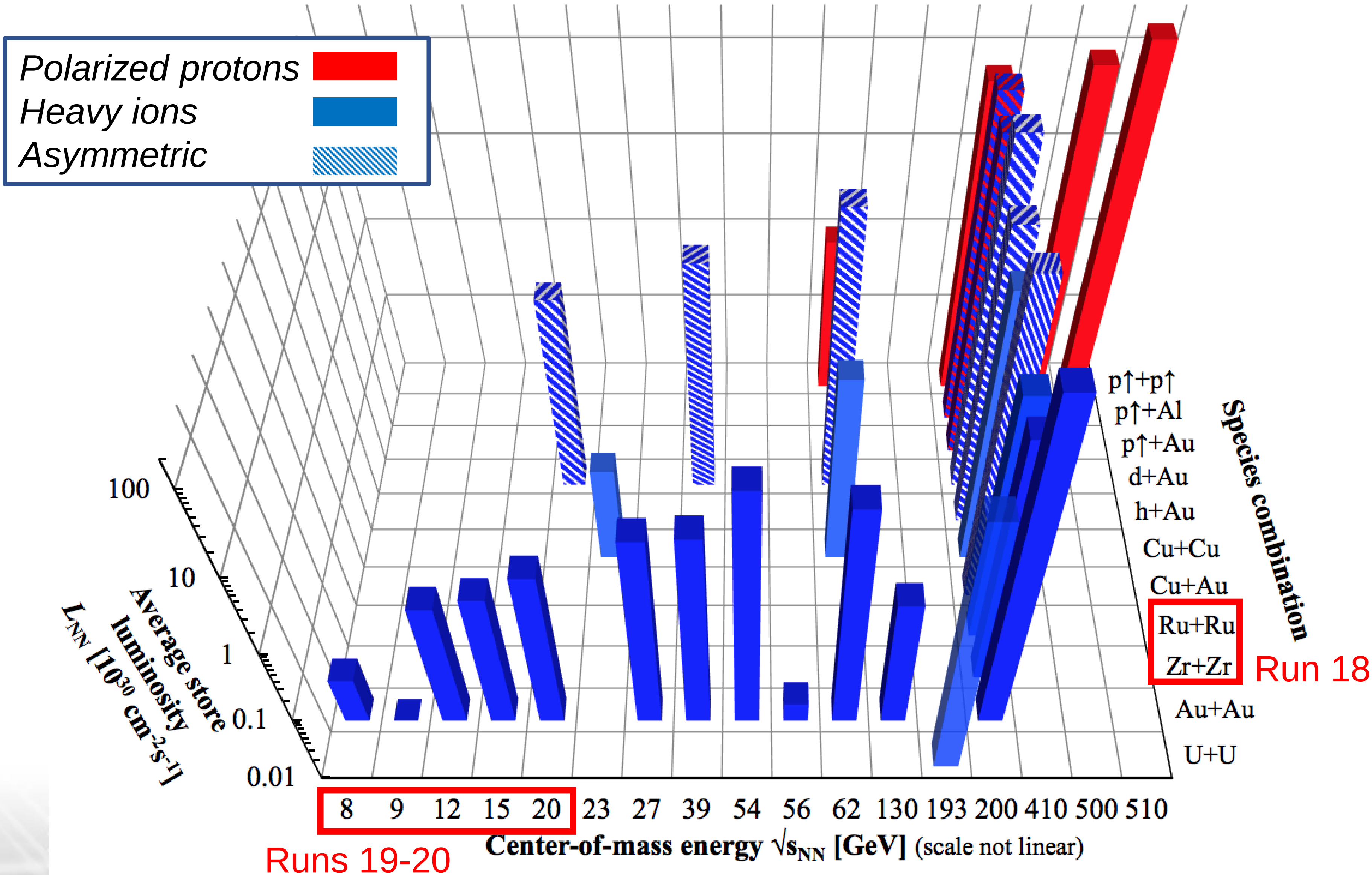
Startup Time Improvement



- Initial startup times drop from ~ 2-3 weeks, converging to <1 week
- First few days are often one shift/day of beam
- Beam to flattop often on first ramp
- Startups now often include setting up *all* the ramps we plan to use for the run at once

RHIC energies, species combinations and luminosities (Run-1 to 18)



More modes, then more, then more…

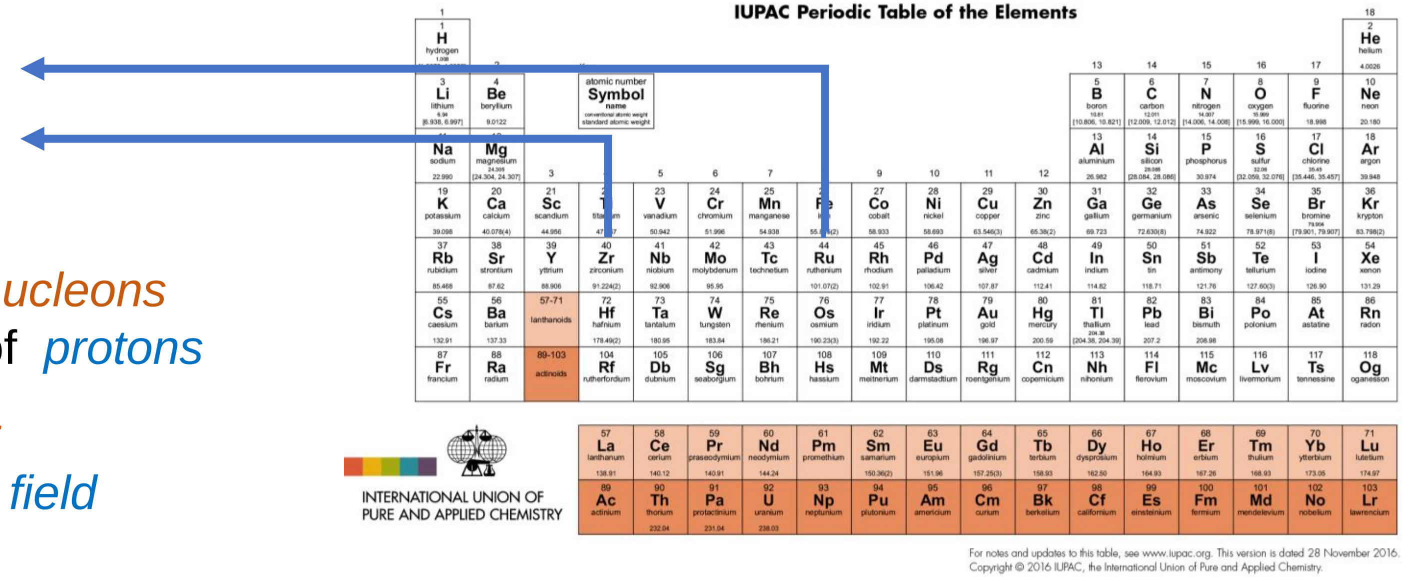
Faster setups means more setups….

1. Only one mode at a time
    1. All experiments and development done with the physics ramp
2. Single day ramp setups are possible
    1. Often ions and polarized proton physics in alternating years, this allows polarized proton trials and experiments *during ion runs*, beneficial for prep ahead of time
3. Asymmetric collisions become *much* easier
    1. Polarized protons colliding with Au,Al in 2015
    2. p-Au required proton pre-acceleration: setup and maintain 3 ramps
4. *Culminates in the "Isobar Run" in Run 18*
    1. *Daily switching of accelerated species in the collider for the first time*

Isobars in Run 18

Ru-96

Zr-96



Same number of *nucleons*
Different number of *protons*

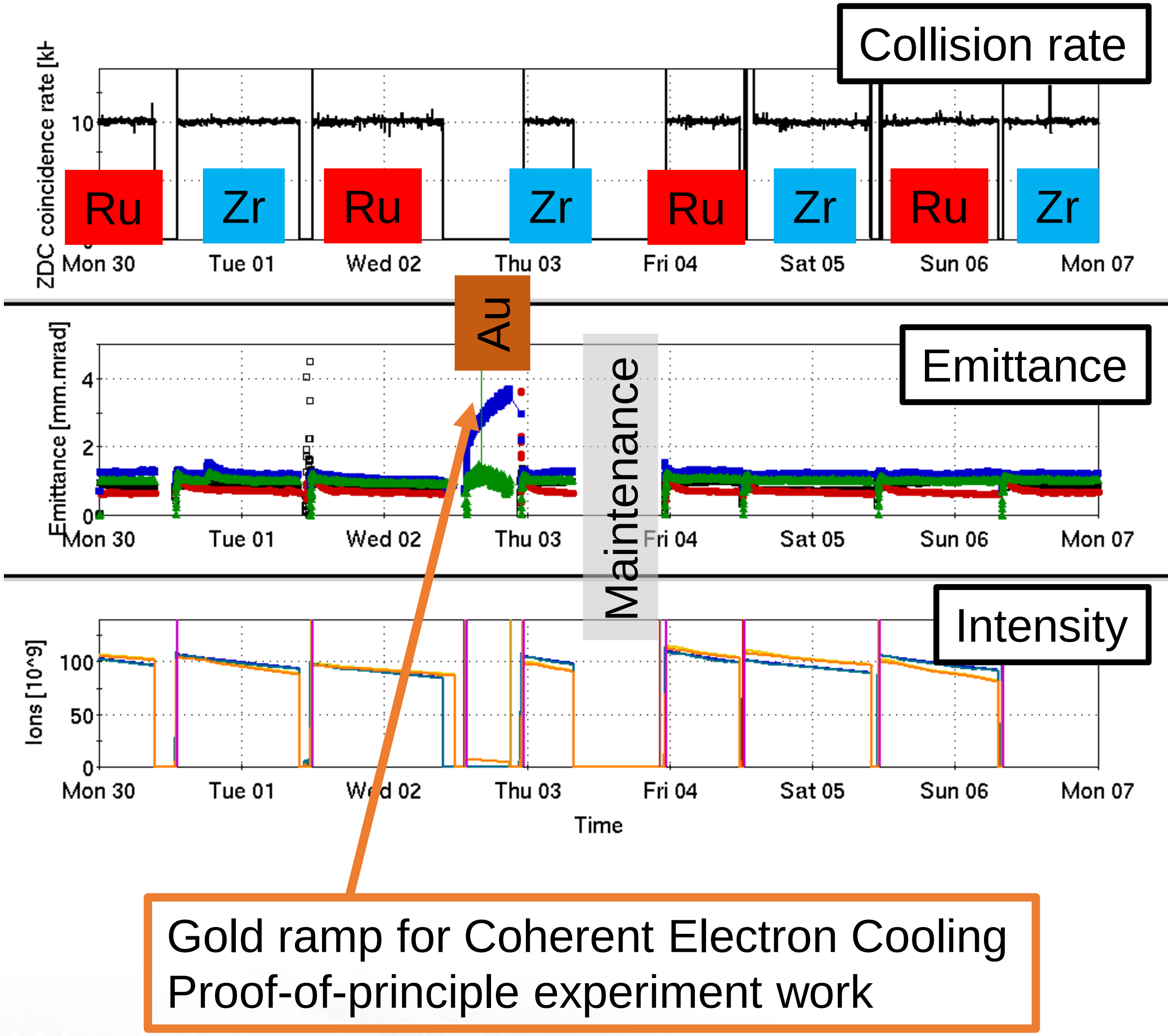
Same *QGP matter*
Different *magnetic field*

- Experimental requirement
  - Ru-Ru collisions and Zr-Zr collisions
  - Systematic error from instantaneous luminosity means luminosity leveling
  - Systematic error from detector aging over days and weeks

Third requirement rules out long run of Ru-Ru followed by long Zr-Zr run
Daily switching of species in the collider! (Never tried before!)

Ru-Ru and Zr-Zr

- Lumi leveling
  - Steering
  - 3D Stochastic cooling
- RHIC/switching reliability
  - Feedbacks!
  - Flexible sequencer app!
- Complex reliability
  - 20+ hour stores
  - Injector maintenance during physics!
  - Record 91% availability for Run 18



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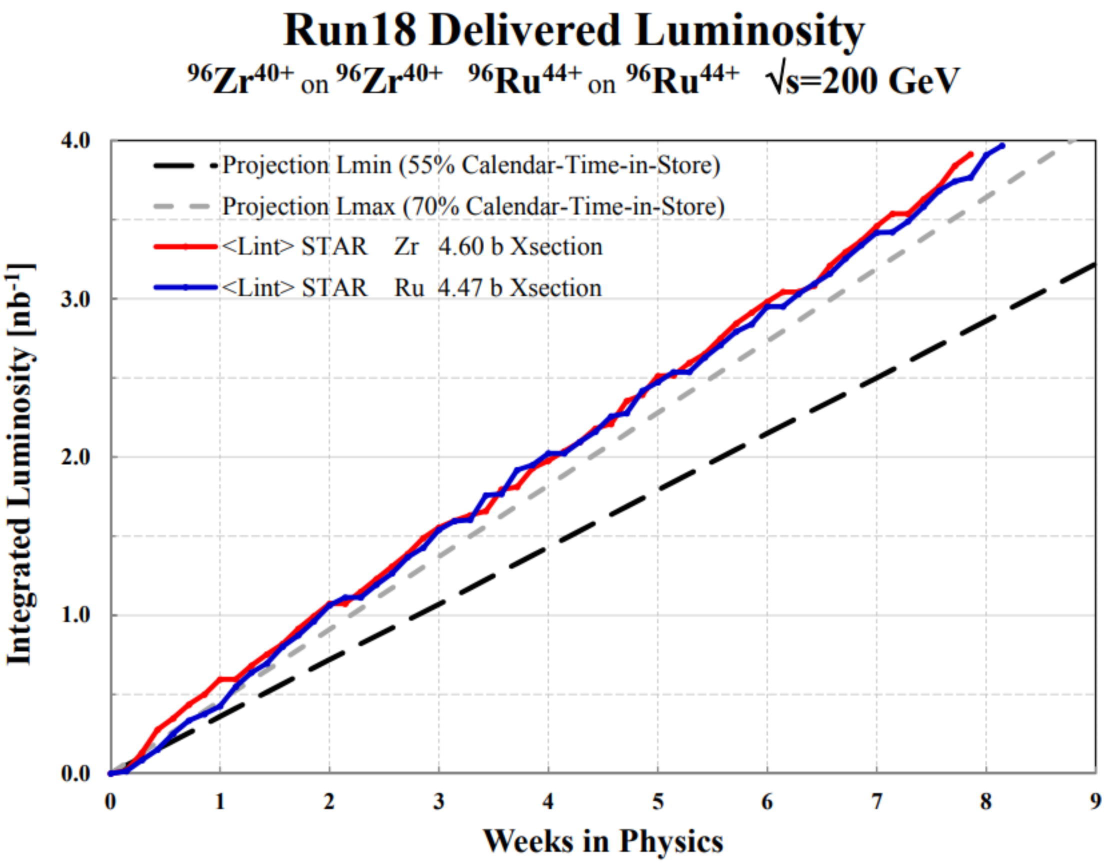


Of the weird things I did to the beam, I especially like things I did for polarization people.

-- Al, our local feedback guru

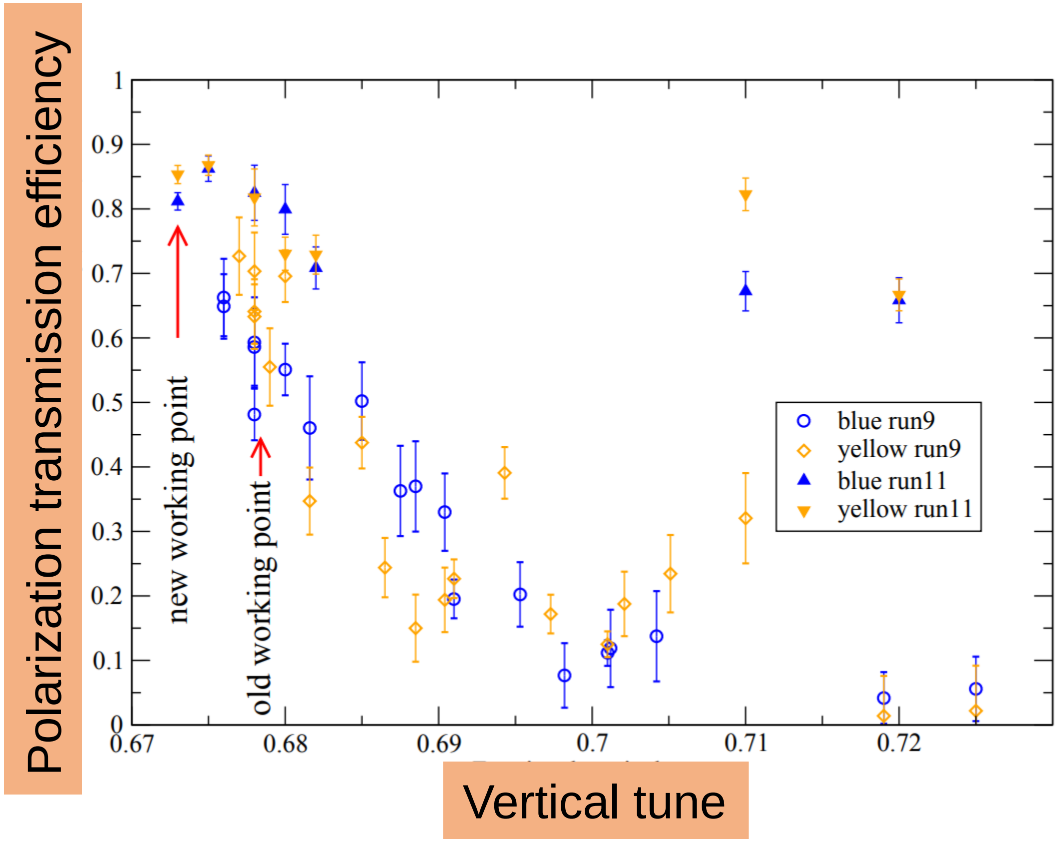
Acceleration Near 2/3 Resonance

Polarization transmission through RHIC acceleration is sensitive to the vertical tune

Snake resonance at : 7/10
Betatron resonance at : 2/3

Figure of merit for double-spin experiments:

FOM = (lumi) * (polarization)^4



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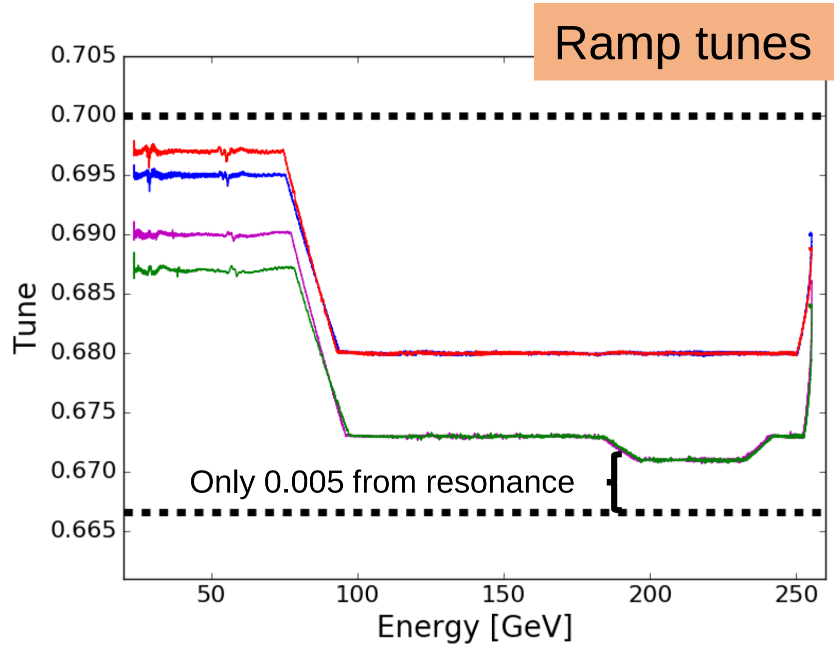
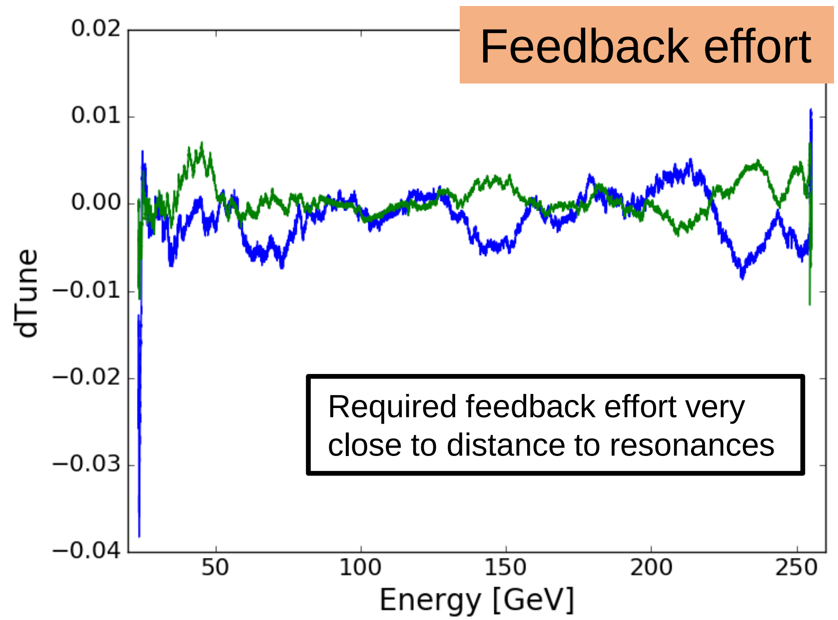


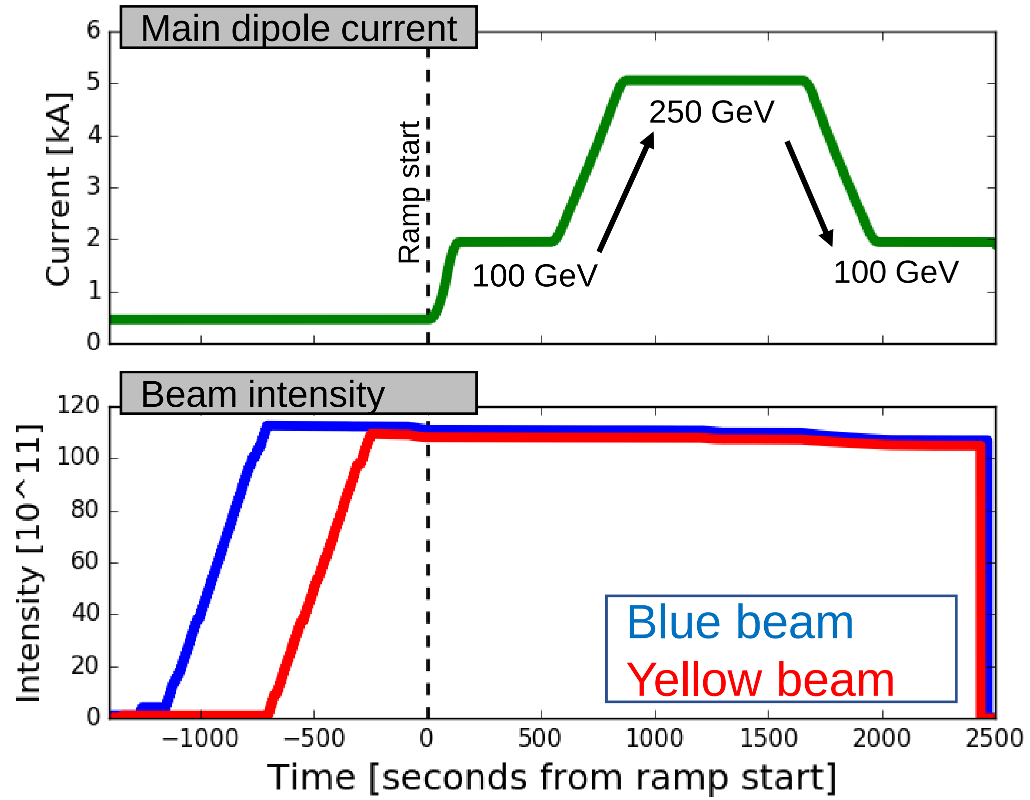


100-250-100 GeV ramp

Polarimeter analyzing power is energy dependent

Useful calibration is to accelerate-decelerate to an energy plateau and compare polarization

- Model uncertainty on down ramp
- Chromaticity feedback
  - RF freq modulated at 0.5 Hz
  - Tune feedback effort deviations over each modulation cycle used to calculate a chrom
  - Update sent to the sextupoles



Chrom feedback effort during the down ramp was up to 40 units!
Successful measurement completed in one shift with feedback
Would have taken days without it => Would never have been done

Stable Spin Direction

Run 12,15: Observed tilt of stable spin direction away from vertical (ideal)

Spin closed orbit a function of energy and orbit

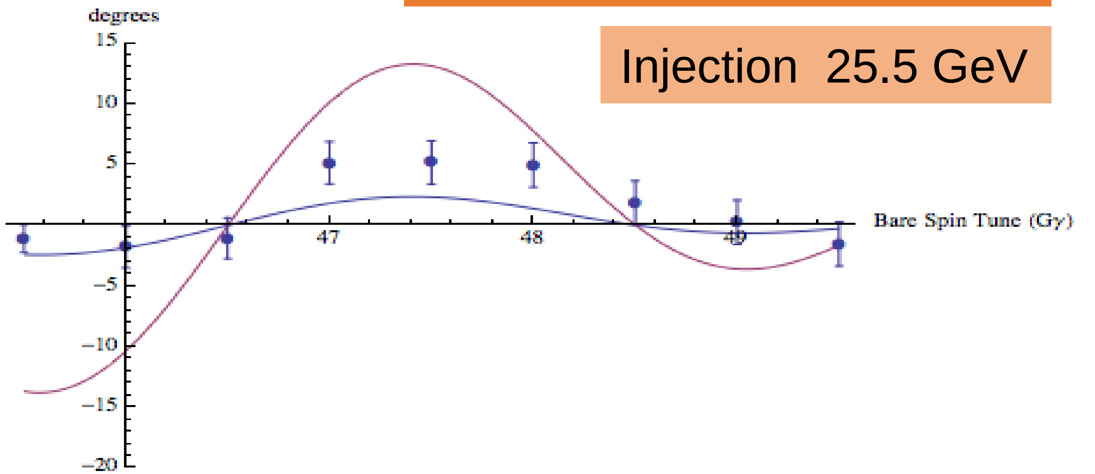
Depolarizing resonances a function of betatron tune and energy

Scan energy: don't hit a resonance, don't change the orbit

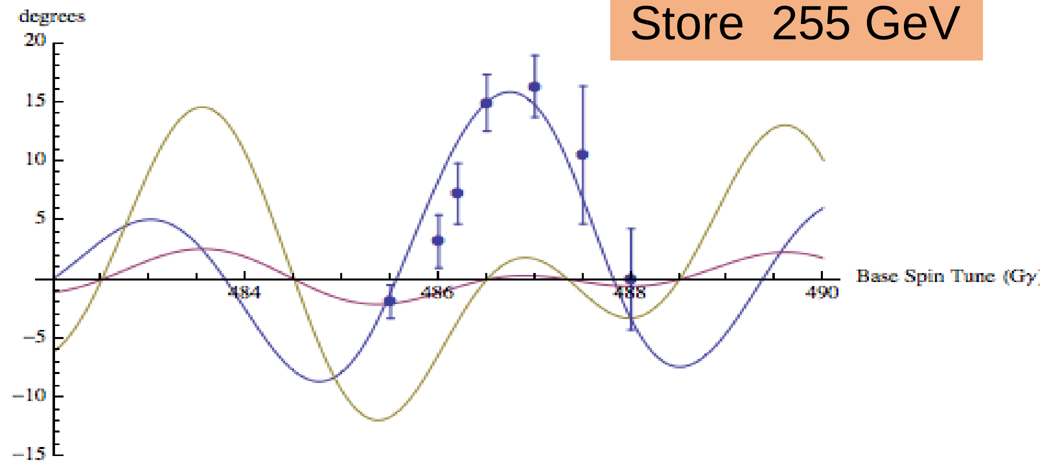
Hysteresis in mains -> corrections can change during repeated scans

Spin projection onto H plane

Injection 25.5 GeV



Store 255 GeV



Energy (Gγ)

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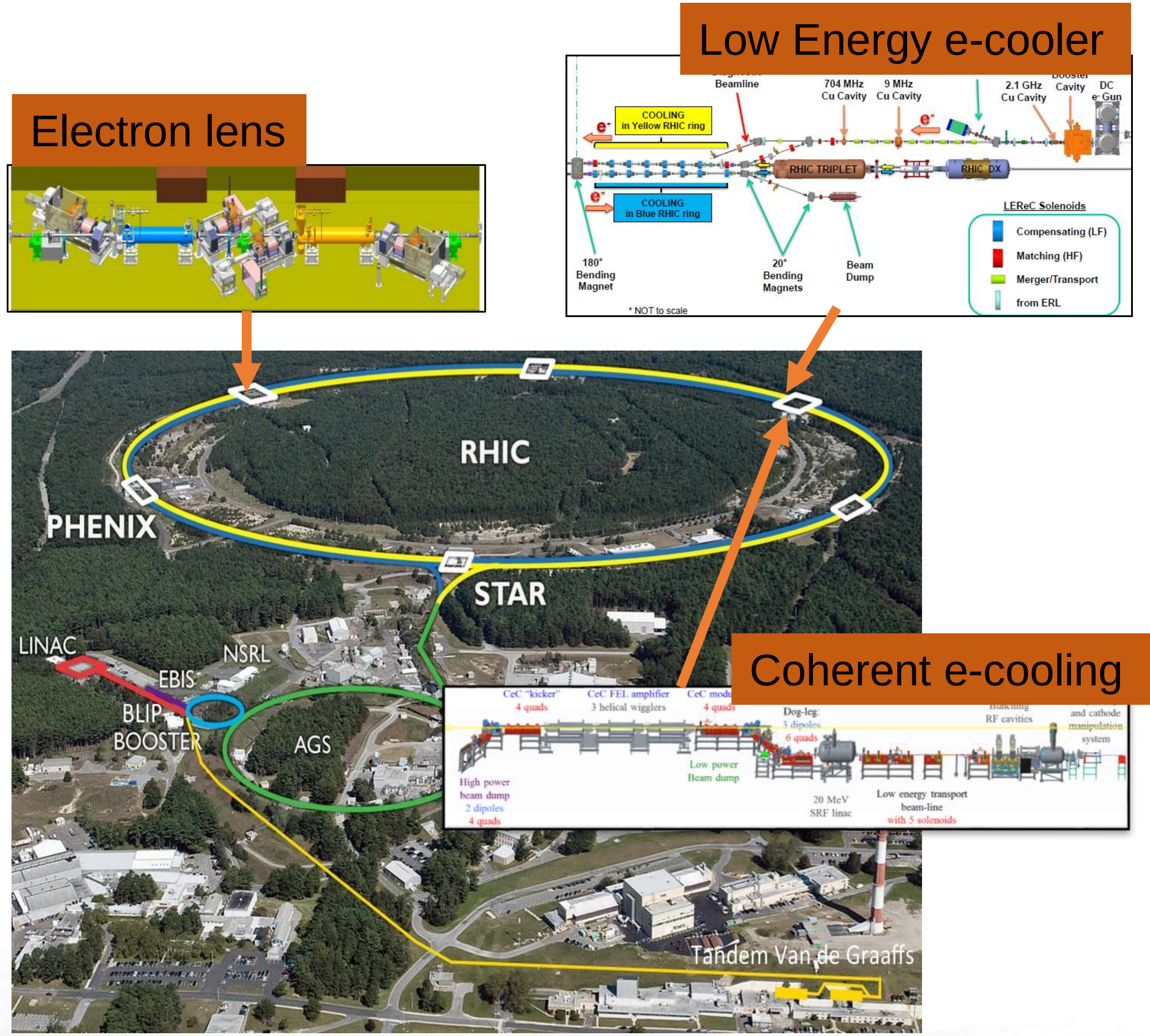
Introduction of New Facilities

New facilities added

- Fringe fields
- Common elements with ion beam
  - Strong solenoids
  - Merge dipoles
- Changing fields during RHIC injection and stores

> “Feedback will handle it”
>
> -- people who previously would have spent several shifts incorporating the new facilities into RHIC.



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Summary

- Enhanced beam control led to drastic reduction in setup times
  - Enabled new kinds of physics operation and experiment, notably recent daily changes of species in the collider
- RHIC's most demanding program is polarized protons but the feedback 'lessons learned' are widely applicable to other facilities
  - Near resonance operation: Enlarging the possible configuration space (near integer for space charge)
  - Acceleration-Deceleration: Experiments with configurations well outside the model assumptions (magnets in saturation, large momentum offset…)
  - Stable spin direction: "Delicate" experiments (for us polarization, for a high intensity facility, feedback might allow experiments that would otherwise be unacceptably risky)
- Enhanced beam control has operational impacts in reliablility and flexibility that go beyond the immediate improvement in precision

References

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  - Direct diode detection
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  - Phase locked loop tune measurement
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    - P. Cameron et al, Simultaneous tune and coupling feedback in the Relativistic Heavy Ion Collider, and possible implications for the Large Hadron Collider commissioning, Phys Rev ST AB, 9, 122801, 2006
  - Chromaticity Feedback
    - A. Marusic et al, Chromaticity Feedback at RHIC, IPAC10, Kyoto, Japan

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  - Global slow orbit feedback
    - M. Minty et al, Global Orbit Feedback at RHIC, IPAC10, Kyoto, Japan
- Operational experience with simultaneous feedbacks
    - M. Minty et al, Simultaneous Orbit, Tune, Coupling and Chromaticity Feedback at RHIC, PAC 2011
    - M. Minty et al, Precision Beam Instrumentation and Feedback-based beam Control at RHIC, IPAC 2011

Backup Slides

RHIC Feedback Systems: Orbit (Fast)

- Triplet vibrations cause ~10 Hz horizontal oscillation
- Fast enough to evade 1 Hz correction
- Slow enough to affect 1 Hz avg

- 12 dedicated warm air-core magnets (per ring)
- 36 fast (10kHz) BPMs