Machine Protection Issues for eRHIC

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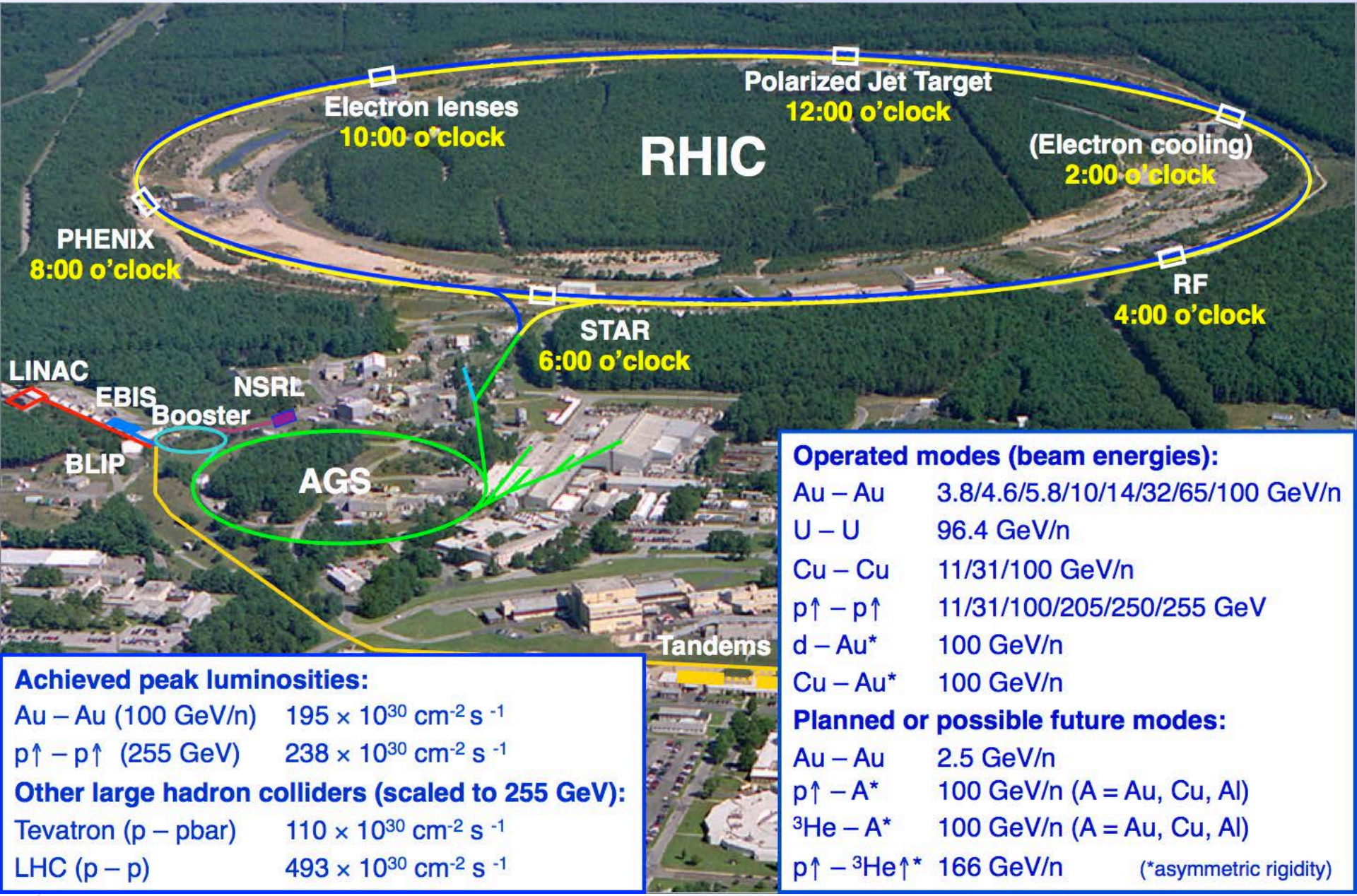
Outline

- Overview of RHIC & eRHIC (3 slides)
  - RHIC Capabilities & Operation Experience
  - eRHIC Capabilities
- RHIC Machine Protection Systems (3 slides)
  - Permit systems and Beam Dump
- Energy in Beams for eRHIC (2 slides)
- Dependability Issues for eRHIC (2 slides)
  - Categories of beam loss
  - Types of failures
- Reliability Analysis & Design Preparation (2 slides)
- Dumping the eRHIC beams (2 slides)
- Summary

RHIC – a High Luminosity (Polarized) Hadron Collider



Operated modes (beam energies):

Au – Au	3.8/4.6/5.8/10/14/32/65/100 GeV/n
U – U	96.4 GeV/n
Cu – Cu	11/31/100 GeV/n
p↑ – p↑	11/31/100/205/250/255 GeV
d – Au*	100 GeV/n
Cu – Au*	100 GeV/n

Planned or possible future modes:

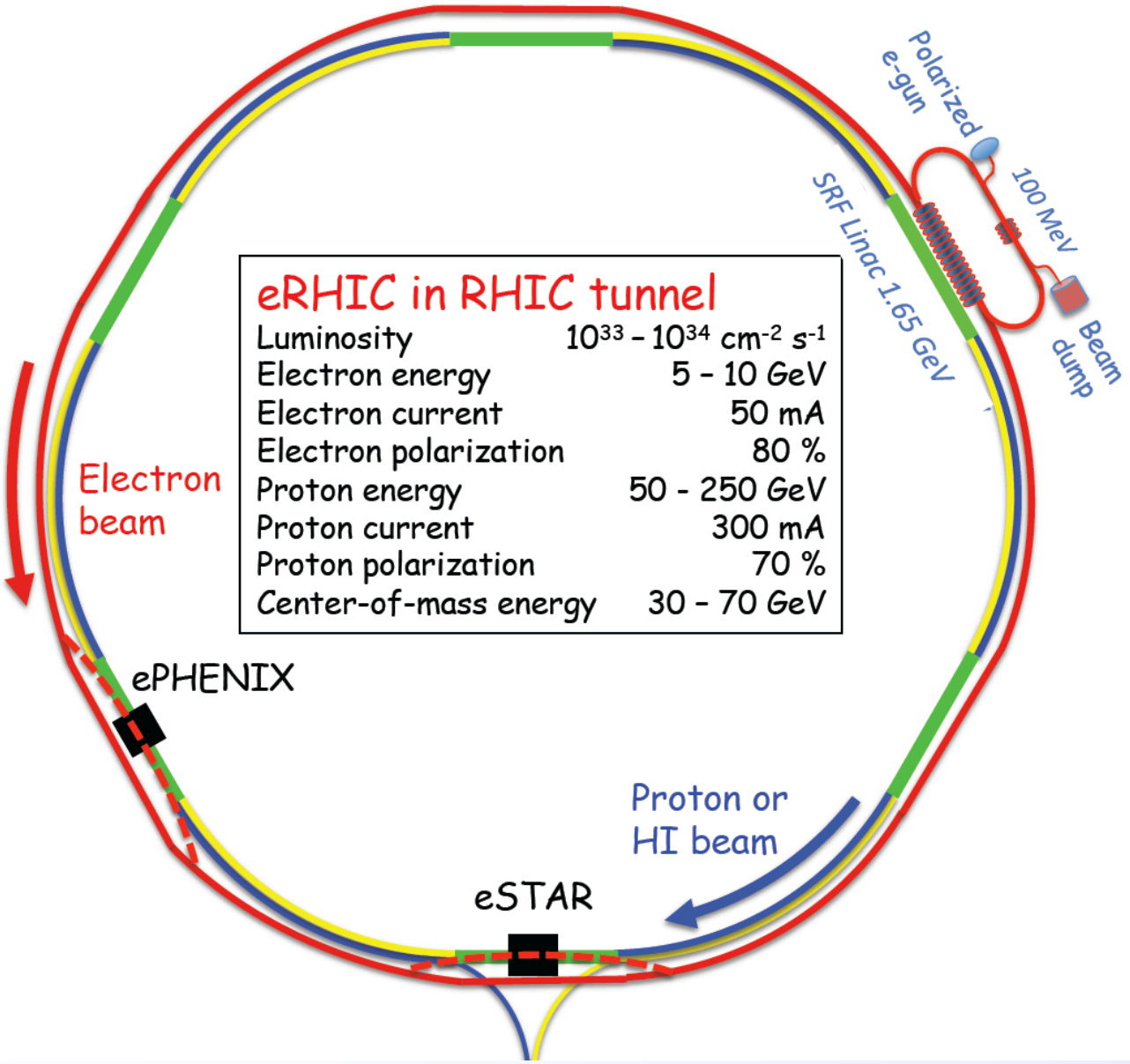
Au – Au	2.5 GeV/n
p↑ – A*	100 GeV/n (A = Au, Cu, Al)
^{3}He – A*	100 GeV/n (A = Au, Cu, Al)
p↑ – ^{3}He↑*	166 GeV/n (*asymmetric rigidity)

Achieved peak luminosities:

Au – Au (100 GeV/n)	195×10^{30} cm^{-2} s^{-1}
p↑ – p↑ (255 GeV)	238×10^{30} cm^{-2} s^{-1}

Other large hadron colliders (scaled to 255 GeV):

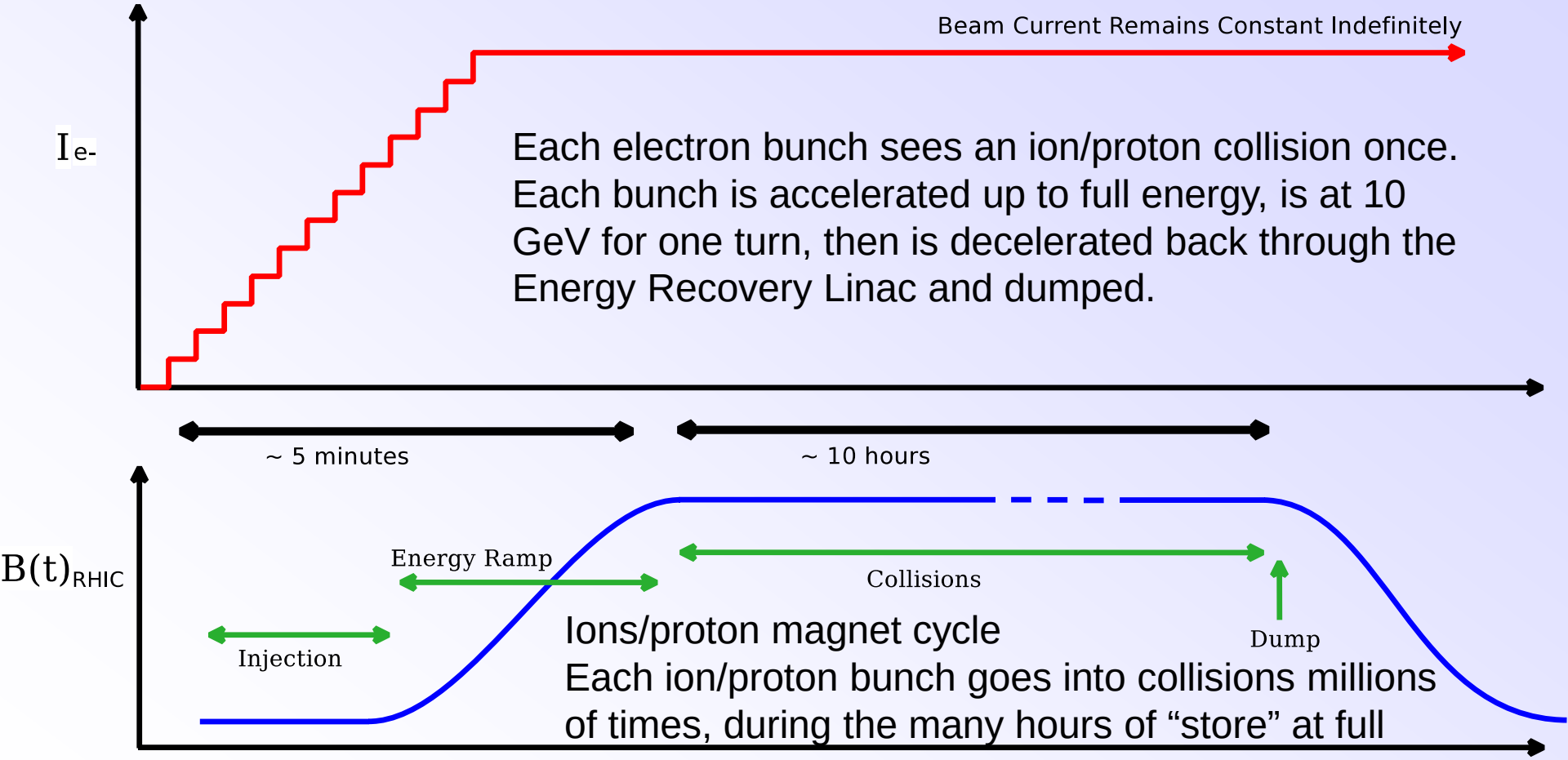
Tevatron (p – pbar)	110×10^{30} cm^{-2} s^{-1}
LHC (p – p)	493×10^{30} cm^{-2} s^{-1}



eRHIC in RHIC tunnel

Luminosity	$10^{33} - 10^{34}$ cm^{-2} s^{-1}
Electron energy	5 – 10 GeV
Electron current	50 mA
Electron polarization	80 %
Proton energy	50 - 250 GeV
Proton current	300 mA
Proton polarization	70 %
Center-of-mass energy	30 – 70 GeV

eRHIC Operation



Each electron bunch sees an ion/proton collision once. Each bunch is accelerated up to full energy, is at 10 GeV for one turn, then is decelerated back through the Energy Recovery Linac and dumped.

Ions/proton magnet cycle
Each ion/proton bunch goes into collisions millions of times, during the many hours of “store” at full energy.

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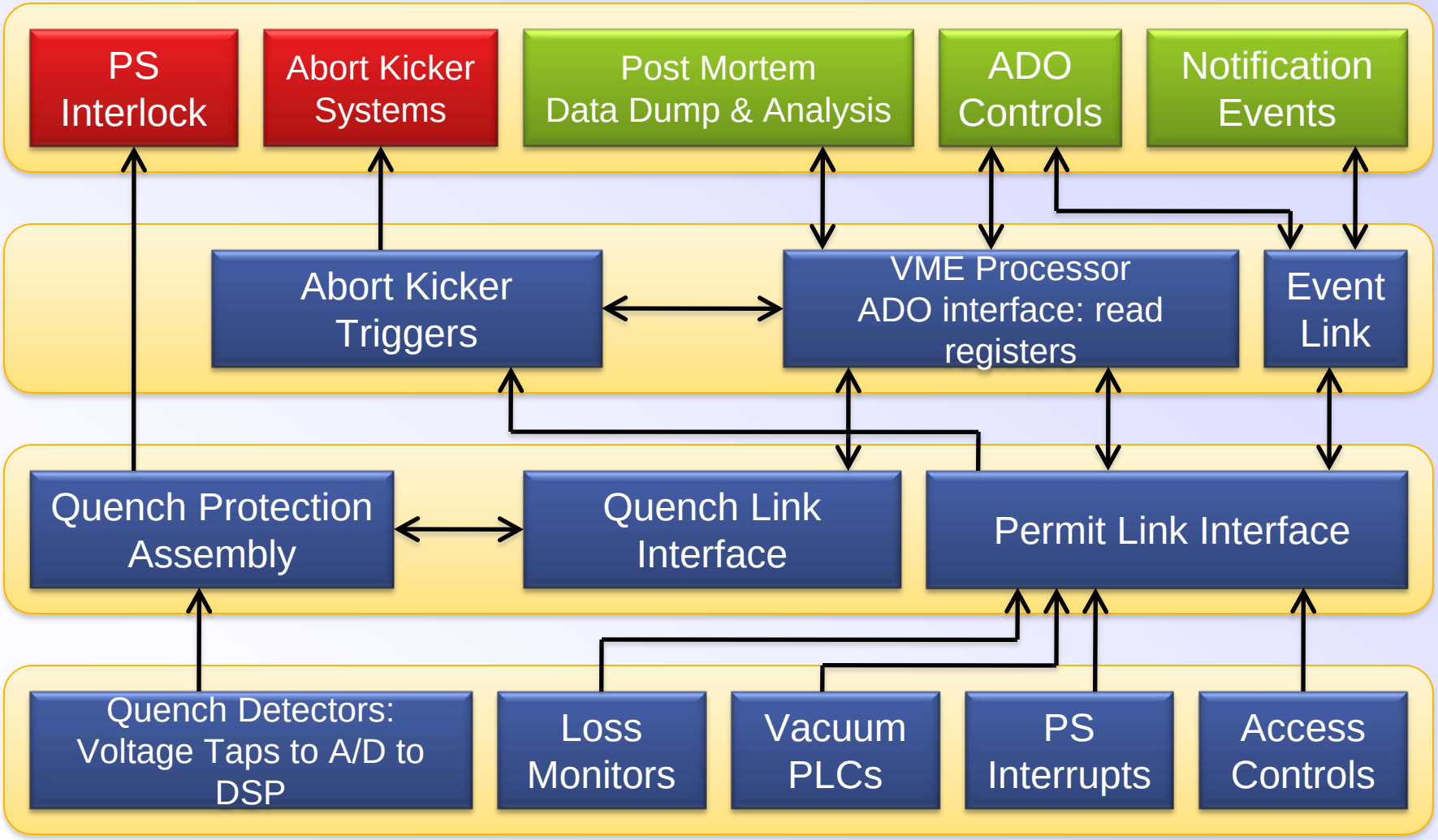
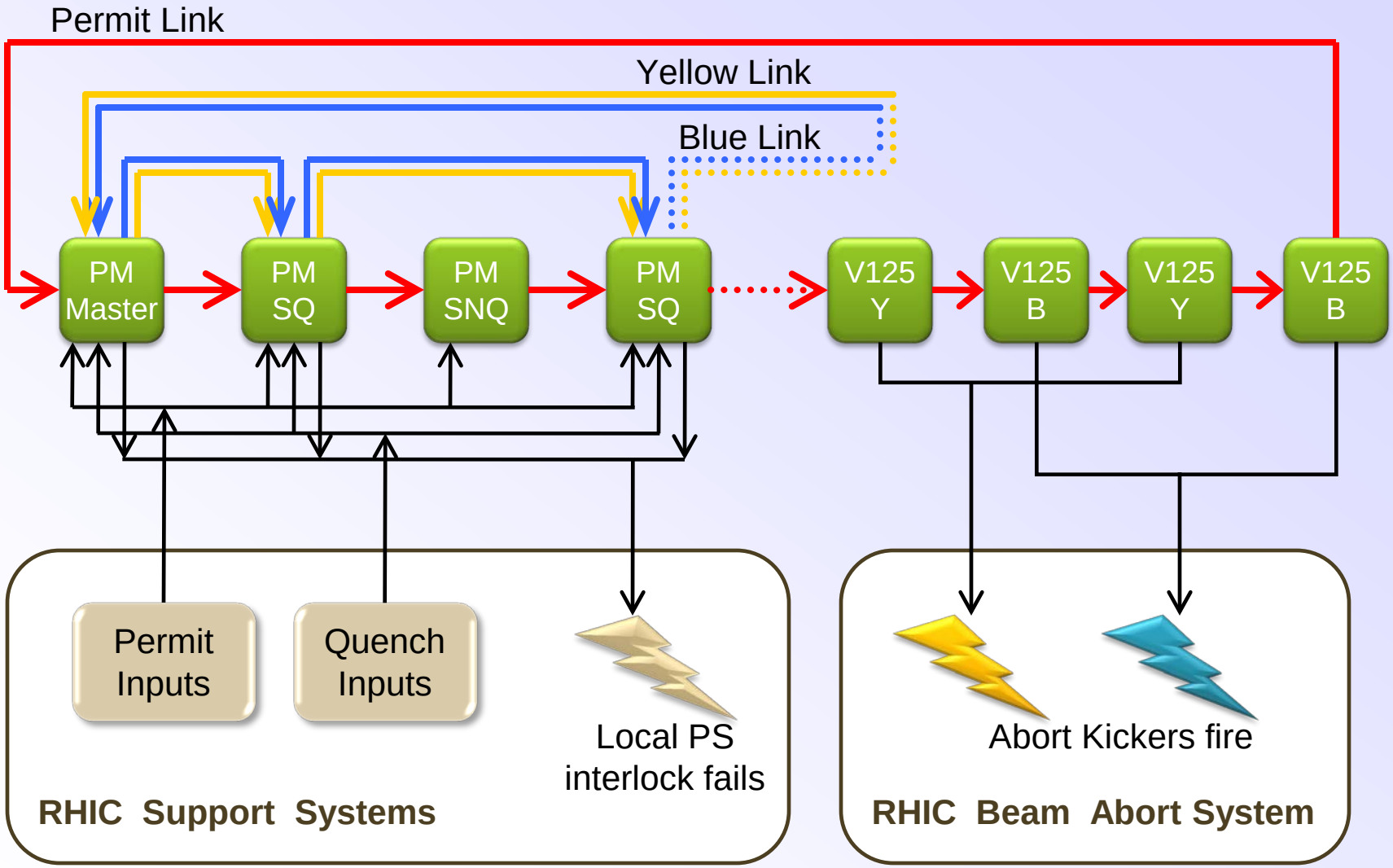
Layers in Protection



Beam Permit System



RHIC Beam Permit & Beam Dump

- 3 Permit Link systems
  - Beam Permit link
  - Blue ring Quench Permit Link
  - Yellow ring Quench Permit Link
  - 10 MHz carrier is monitored on each link
- Beam dump/abort kickers
  - One for each Ring (Blue/Yellow)
  - Redundant interface modules to permit links
- Two primary permit drops
  - Non-quench beam permit drop
    - Abort kickers fire, injection beam switch dropped
  - Quench permit drop
    - Additionally, magnet currents are dumped.

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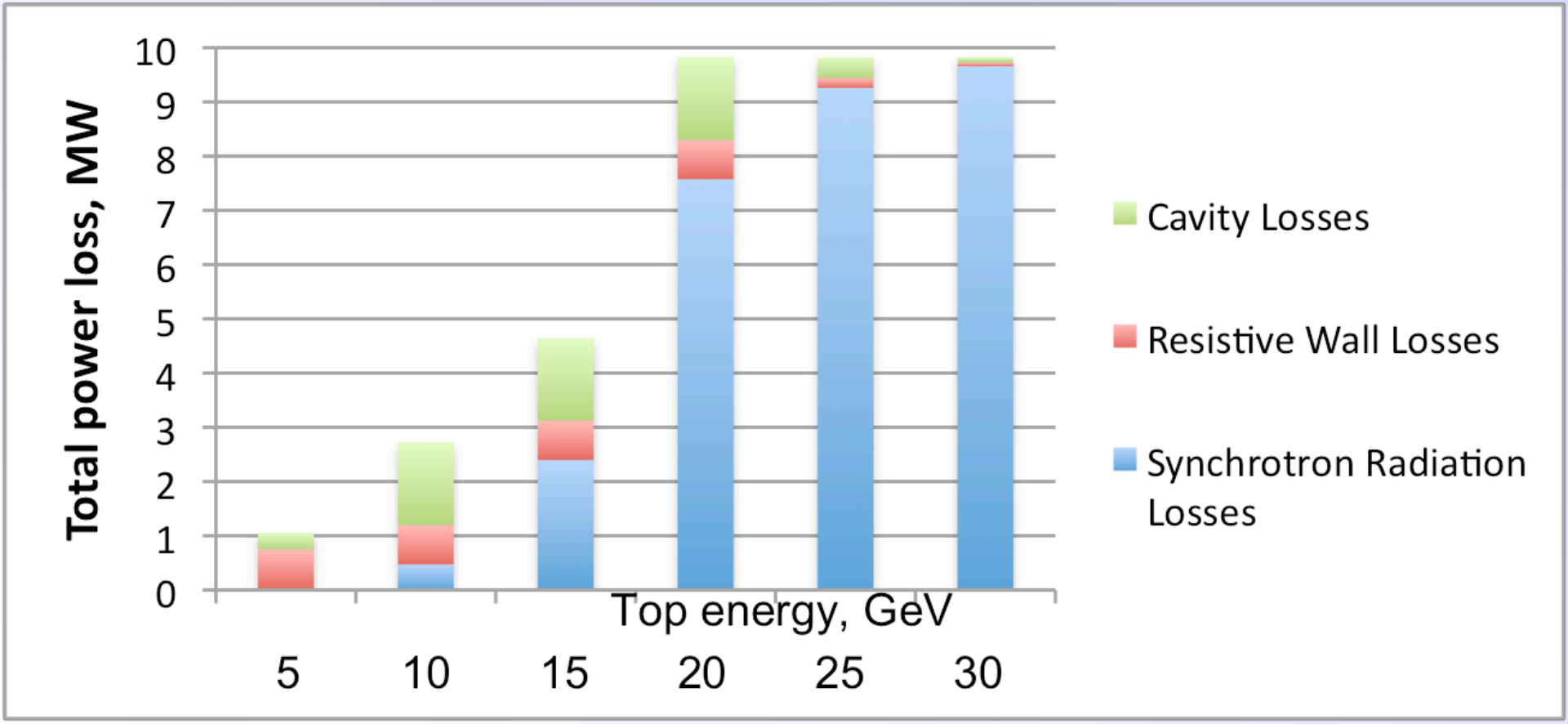
Energy in the Beams

	Electrons	Protons	$^{2}He^{3}$	$^{79}Au^{197}$	$^{92}U^{238}$	
Energy	10	250	167	100	100	GeV
#bunches	180	111	111	111	111	
Intensity/bunch*	3.6	10	6.0	6.0	6.0	10^{10}
Energy Deposited	62**	89	178	107	107	kJoule

- At 10 GeV, the electron beam has 62 kJ of energy and will deposit ~810 MW of power into the dump.

* intensity/bunch is in units of # nucleons (e.g., 6e10 Au nucleons = 3.6e8 Au ions)
** assumes 6 turns of 180 bunches simultaneously stored in eRHIC ring

Energy Loss in Normal Operation



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How to protect eRHIC?

eRHIC beam losses can be classified as

1. Ultra-fast: Losses that occur in less than 6 turns, or 77 microseconds.
   - Collimation
2. Fast: Losses that occur in more than 77 microseconds but less than 10 milliseconds.
   - Fast beam abort system
3. Intermediate: Losses that occur in less than 10 seconds.
   - Reduce beam current (automated), or
   - Fast beam abort system (if not fast enough)
4. Slow: Losses that occur in less than 100 seconds
   - Beam current can be dropped or turned off and problem corrected (or dumped if not fast enough)
5. Steady State: Anything longer than 100 seconds.
   - Beam current can be dropped and problem corrected

•All systems will be monitored and will alarm/notify.

Types of Failures?

- The MP prevents damage to equipment.
- What happens when it doesn't do what it is "suppose" to do?
- Two categories of these types of failures
  - Logic errors in the design/implementation
  - Component failures
  - Since all the systems are automated, human error fits into the logic errors category
- Regardless of type of failure, two modes of concern
  - Failsafe modes: system aborts beam, etc.
  - Blind modes: system enters state that prevents abort = These are most dangerous!

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Overview

- Reliability analysis of RHIC MPS (as an integral part of eRHIC MPS) with decision support for additional system for electron ring
- Initial step: BPS – takes active decision
- Analyzing the probability of occurrence of crucial system failures: false beam abort, false quench, blind, dirty dump
- Identification of failure prone components
- Impact of design configuration of modules

Stages

1. To find system failures probabilities*
   - A modular, multistate, dynamic reliability model of BPS using competing risks theory
   - Implemented as a Monte Carlo Simulation
2. To find failure rates for failure modes**
   - Fault Tree Analysis of BPS modules
   - Determine vulnerable components
   - Module failure rates serve as an input to stage 1

Two of yesterday's posters, for more details on Simulation and Fault Tree Analysis
*MOPPC075 : A Monte Carlo Simulation Approach to the Reliability Modeling . . .
**MOPPC076 : Quantitative Fault Tree Analysis . . .

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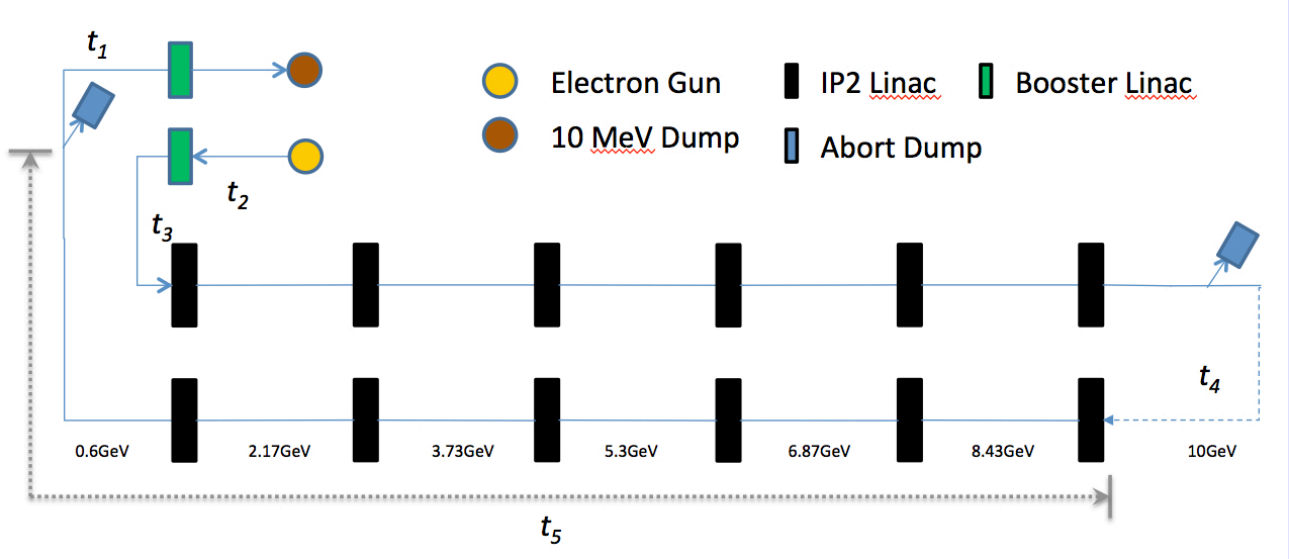
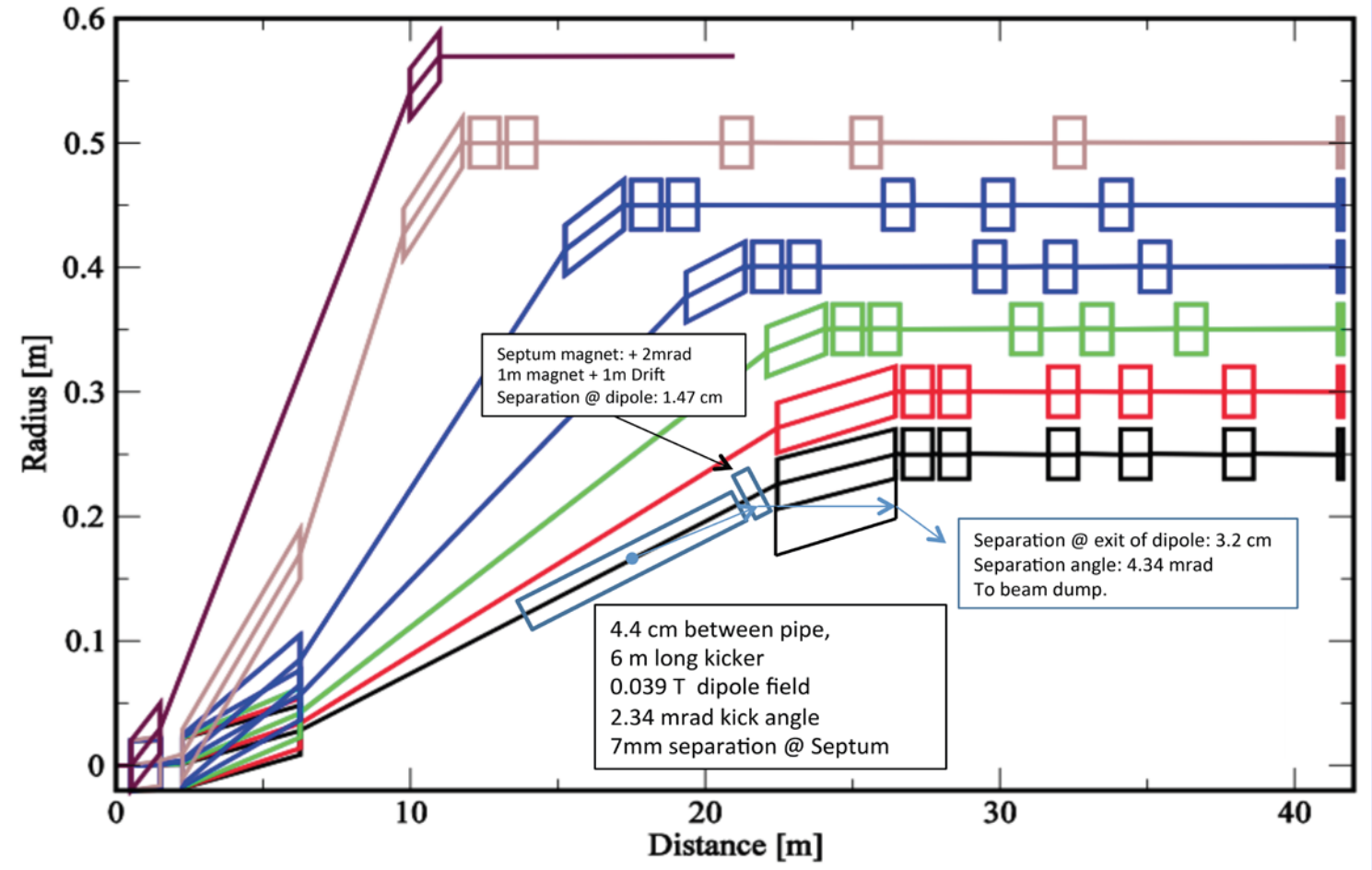
Beam Dumping modes



- During beam abort, the number of accelerating bunches and decelerating bunches should be identical to avoid over-power/under-power SRF cavities.
- One beam dump at 10 GeV arc.
- One beam dump at one of the two 0.6GeV beam line.
- Additional beam dumps, if necessary, could be added to reduce response time.
- The relative timing of the abort kickers depends on their locations and is critical for keeping energy compensation in LINACs.

Fitting the high energy dump?



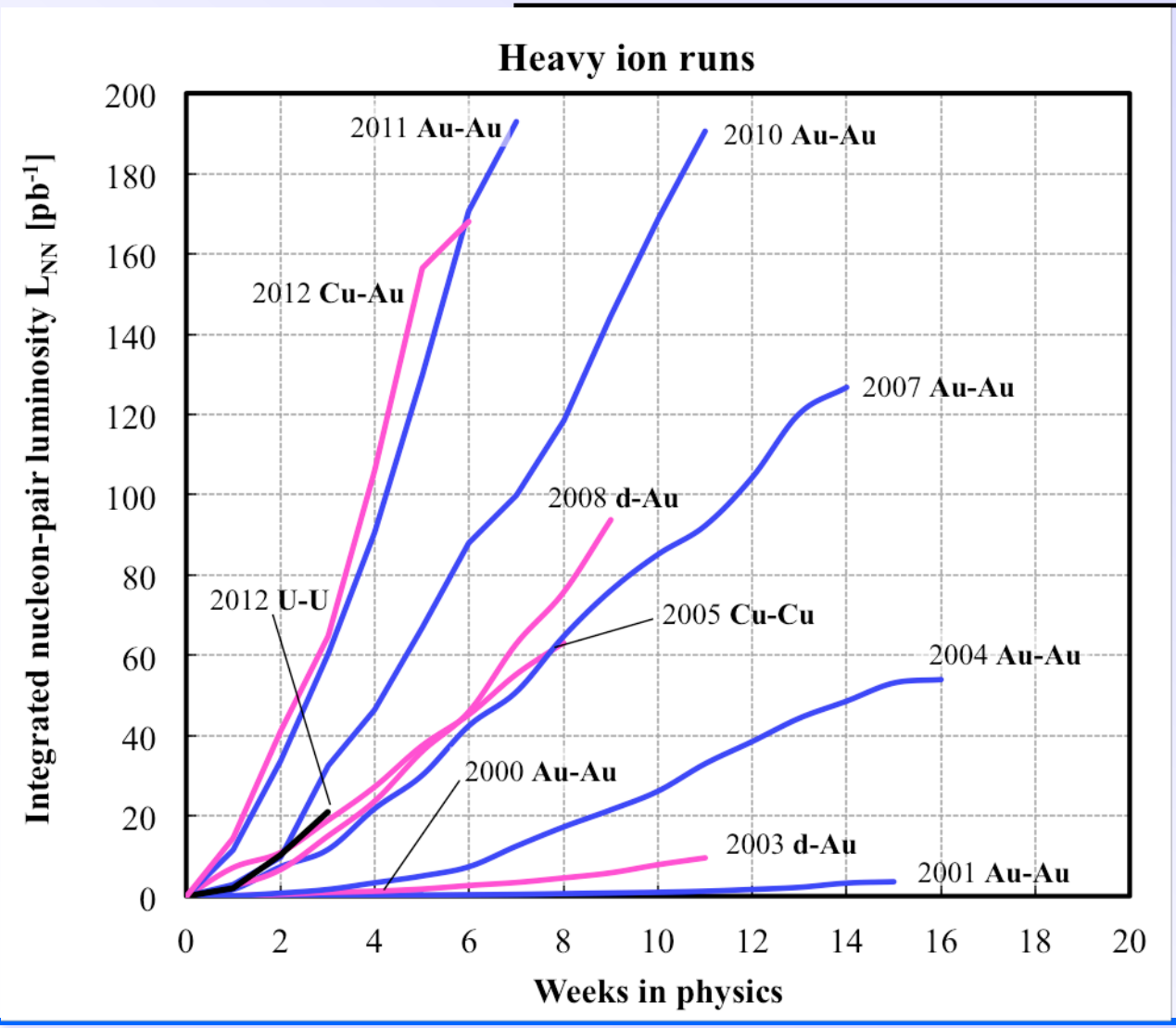
Summary

- eRHIC beams are powerful enough to damage equipment.
- eRHIC has new challenges both in response time and types and number of systems that get included in the machine protection systems.
- Dependability analysis is a critical part of the design process and helps identify blind failure modes in the MP systems
- We are well on the way to identifying key design features that will be implemented to improve the RHIC and eRHIC MP systems.

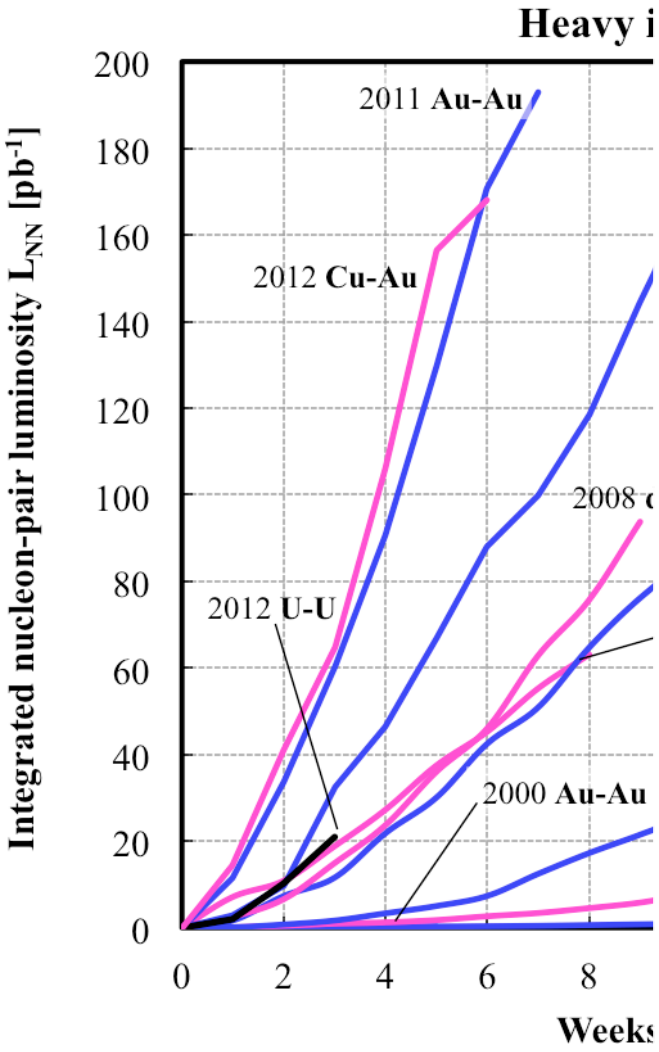
Thank You !

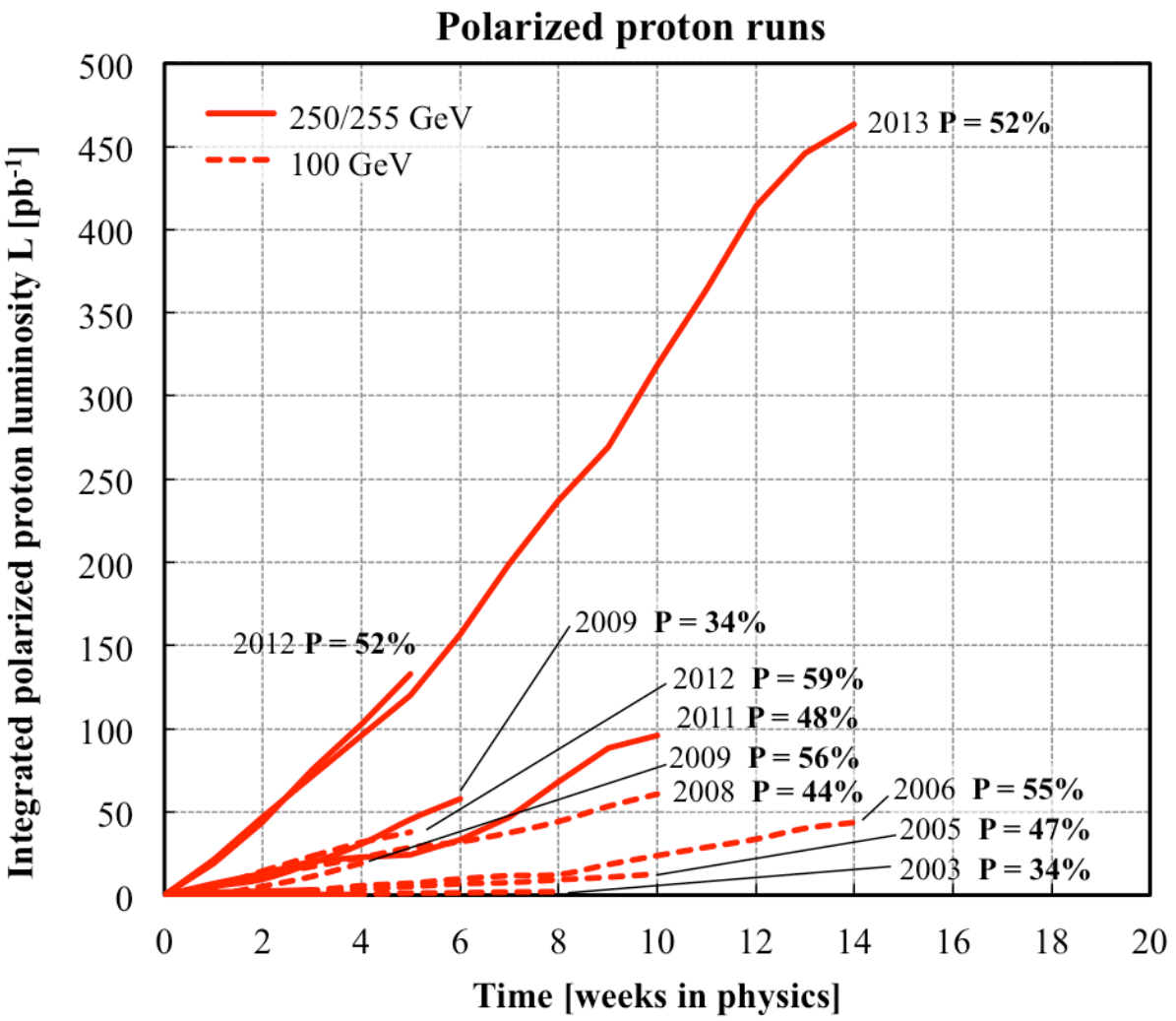
Backup Slides

RHIC Performance



RHIC Performance





RHIC Beam Permit & Beam Dump

- RHIC Magnet Systems
  - 1740 superconducting magnets over 2.5 miles
  - LHe Refrigerator operates at 4.5° K
  - Cold power interface quench protection
    - Bypass diodes during quench
    - Dump resistors switch in during quench
    - Quench detection primarily via voltage tap monitors on groups of magnets
- Other Systems
  - Vacuum interlocks
  - 382 beam loss monitor detectors
  - External radiation interlock systems
  - Access controls interlocks

Post Mortem Analysis

- Permit drops initiate high frequency data dumps of
  - Beam loss monitors
  - Magnet waveforms
  - Beam position monitors
  - Permit module data/timestamps
  - Quench detector data
- Automatic analysis is performed to help categorize the cause of the beam dump
  - Quench analysis
  - PS analysis