Reliability of RHIC Operations, Luminosity Projections, and Upgrades

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RHIC Program Review

by the Nuclear Physics Division of the U.S. Department of Energy

30 June 2004

1. Current reliability
2. Luminosity projections to 2008
3. Upgrades for RHIC and its injectors
4. Summary

Responses to Action Items from 2003 S&T Review:

1) BNL should develop a prioritized … plan that optimally exploits the RHIC accelerator and detectors, especially during the next 5-years before the heavy ion program begins at the LHC, paying particular attention to the integration of the beam schedule, the scientific program, risks and the available resources. …

2) … RHIC management should set a minimum performance goal that will be achieved with high priority. Furthermore, an effort should be made to improve the "up time" beam fraction from 20% to a value that is more comparable to other collider accelerators.

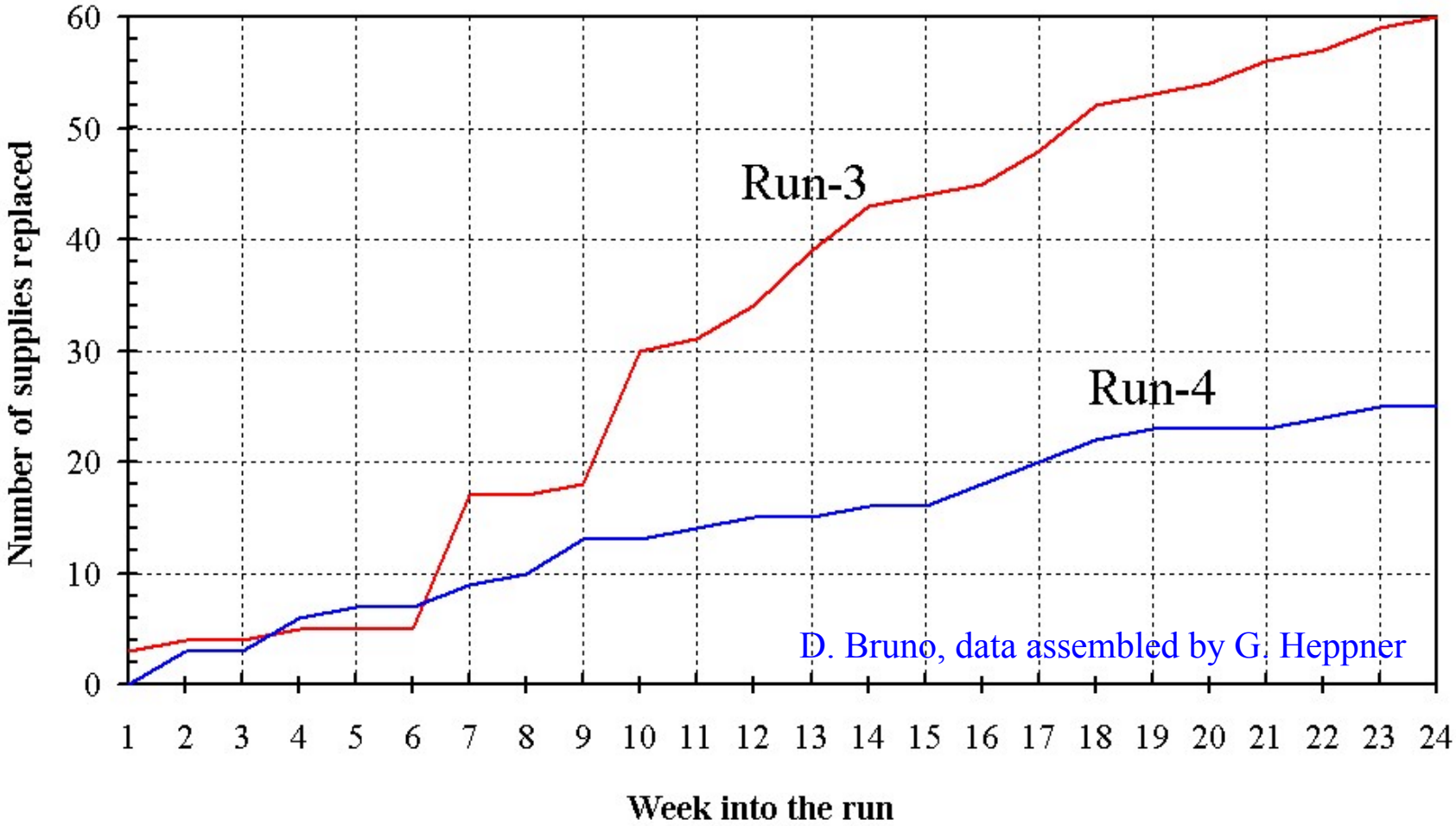
4) Construction and installation of a strong Siberian snake in the AGS should proceed expeditiously to improve the proton polarization. A long-term schedule with realistic goals and milestones for the polarized proton program needs to be developed.

6) BNL should explore the feasibility of mounting a joint effort with other national laboratories to ensure the availability of new and remanufactured LINAC power amplifier tubes.

- Cryo operation
  - 2MW reduction in average power → **$18k/week at current rate**
  - 10% reduction of quench recovery time → **0.5 days/run**
- Power supplies
  - Faster down ramps → **1.5 days/run**
  - Only 25 corrector PS replaced → **1.5 days/run**
  - No ice ball maintenance → **2 days/run**
- Fewer Quench Link Interlocks
  - Beam induced QLIs reduced by 22% (to 54) → **1 day/run** (mostly from reduction of abort kicker pre-fires)
  - Other QLIs reduced by 7% (to 186) → **1 day/run**

Further improvements possible in almost all areas.

Power supply replacements during the Run-3 and Run-4 after modification of all corrector power supplies

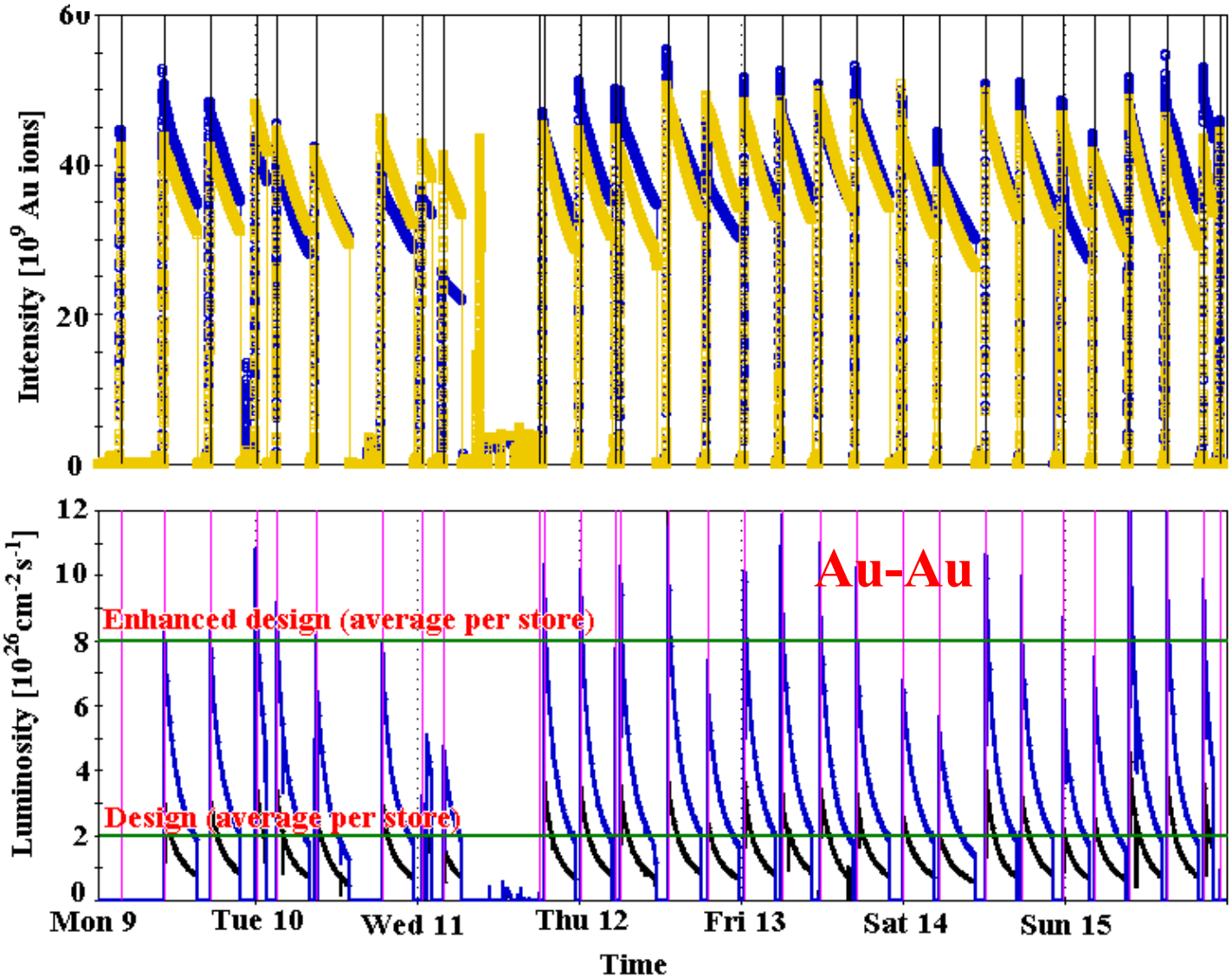


About 1.5h per power supply replacement.

- No AtR cooling problems
  - Flow switch clogging microbes starved to death → **2 days**
- More automation
  - Steering at beginning of store → **>3 days**
  - Collimator setting → **>3 days** (almost impossible manually)
  - Ramp orbit correction → **>3 days**
    (not just time saving, machine became reproducible over whole run, also saves time after STAR magnet reversal)
  - PHOBOS magnet setting
  - Elog entries
    → **allows for analysis of all ramps, early recognition of trends**
- Improved RHIC model → **>3 days**

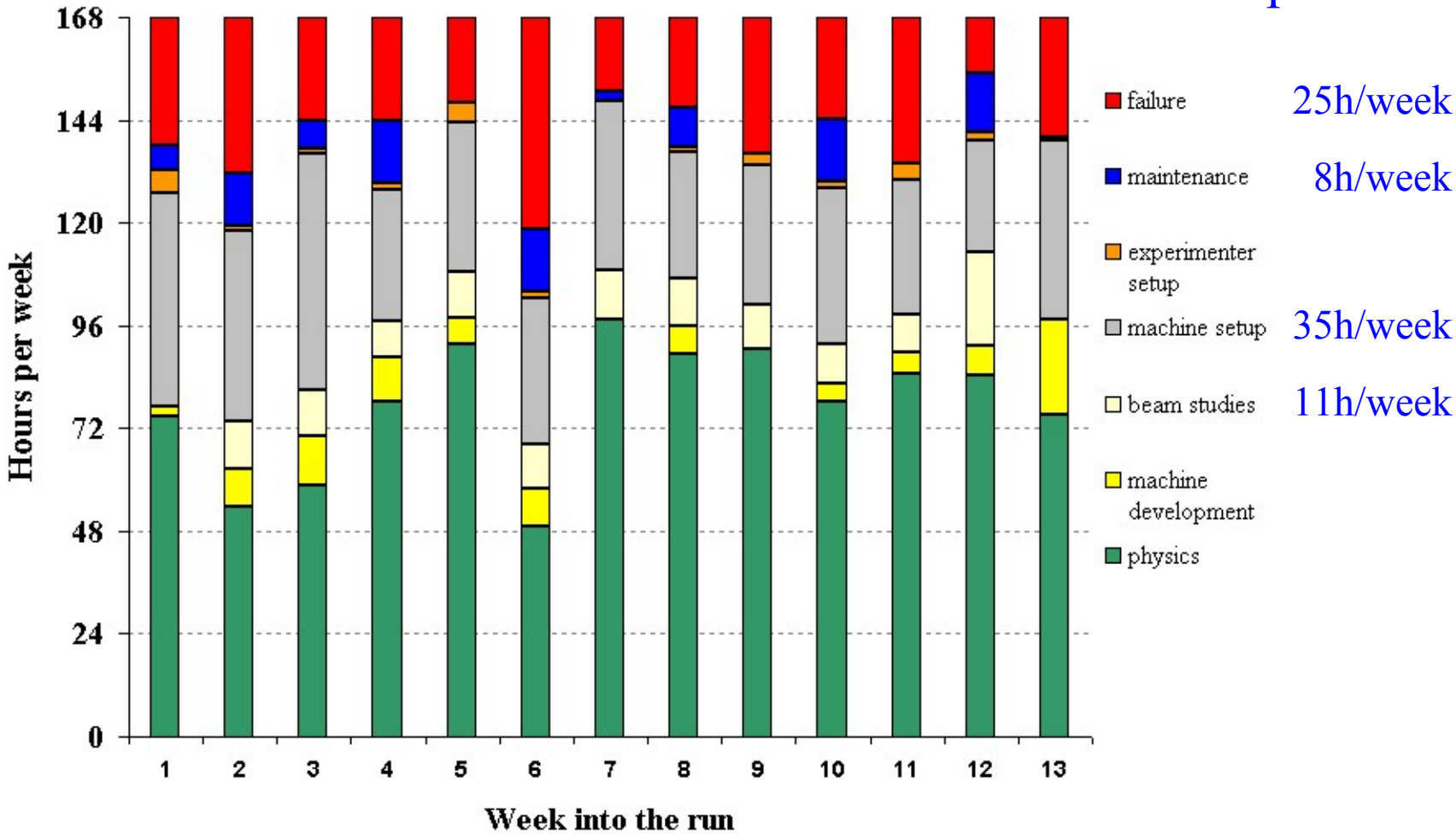
Further improvements possible in almost all areas.

Week 9 Feb to 17 Feb 2003 [66% of calendar time in store, no maintenance]

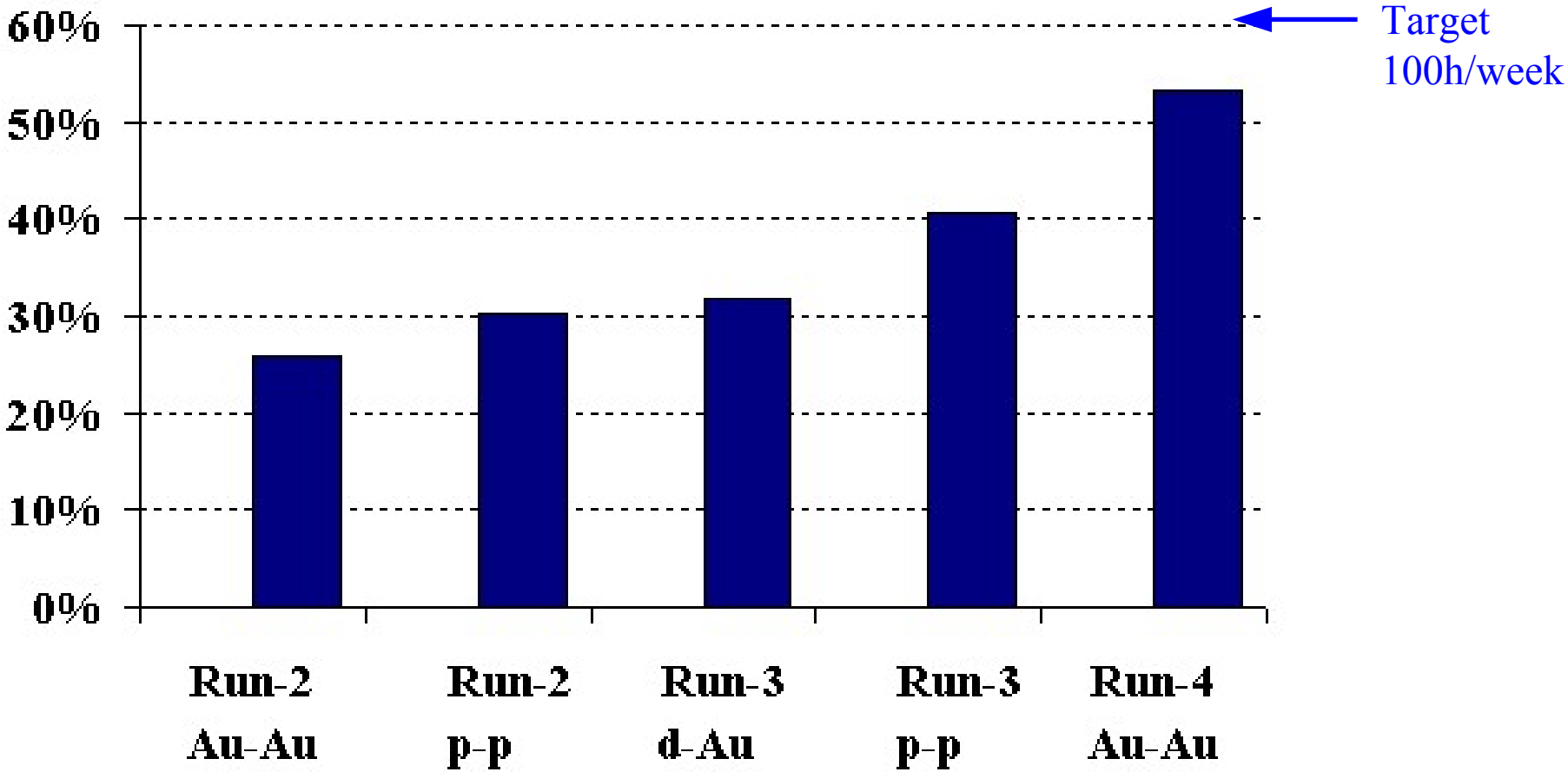


Note: RHIC Au stores are much shorter (4h) than proton stores (10h).

Main sources for reductions:
Failures: QLIs
Setup: Automation



RHIC time in stores



LINAC power amplifier tubes Type 7835 (9 for operation)

- Only one manufacturer (Burle), only national labs buy 7835

Current solution

- Problem discussed with Fermilab
- Situation similar to other LINACs, only 1 or 2 suppliers
  → Technology change not a solution
- Burle also produces other tubes for the Navy
  → Reduced likelihood of Burle going out of business
- Producing or refurbishing tubes tried in-house
  → Burle will stop making 7835 if done on a large scale
- Letter of understanding with Burle
  → Can probably get technology if Burle stops making 7835
- Current inventory good for 1 year (5 tubes), increase to 2 years, could also operate RHIC for 1 year without protons
  → Up to 3 years to find solution if tubes cannot be bought

Enhanced Luminosity Goals

(before e-cooling, about to be reached when RSVP starts, 2008)

– For Au-Au, average per store, 4 IRs

$L = 8 \cdot 10^{26} cm^{-2} s^{-1}$ at 100GeV/u

4× design
2× achieved

– For p↑-p↑ average per store, 2 IRs

$L = 6 \cdot 10^{31} cm^{-2} s^{-1}$ at 100GeV

16× design
6× achieved

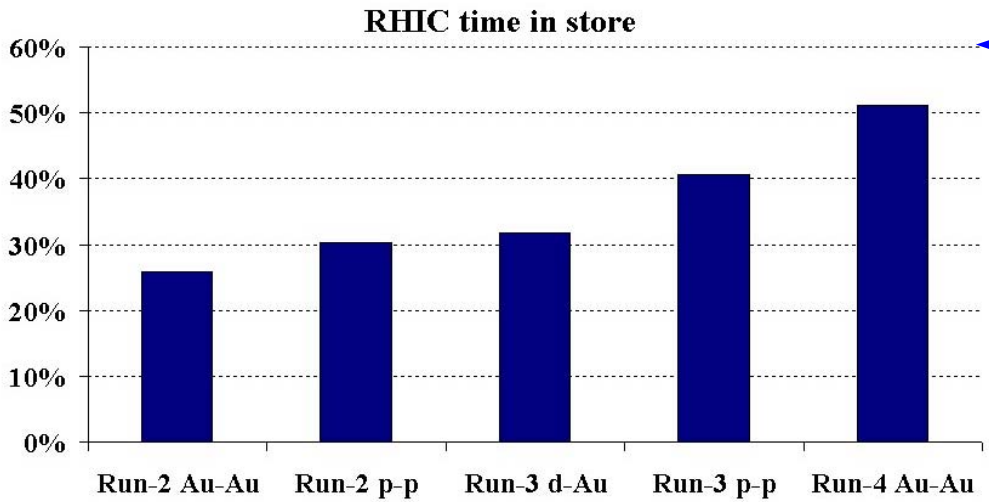
$L = 1.5 \cdot 10^{32} cm^{-2} s^{-1}$ at 250GeV

with **70% polarization**

1× design
2× achieved

Mode	No of bunches	Ions/bunch [10^9]	β* [m]	Emittance [μm]	L_{peak} [$cm^{-2}s^{-1}$]	$L_{store\ ave}$ [$cm^{-2}s^{-1}$]	L_{week}
Au-Au [Run-4]	45	1.1	1	15-40	15×10^{26}	5×10^{26}	160 μb^{-1}
d-Au [Run-3]	55	110/0.7	1	15	12×10^{28}	3×10^{28}	4.5 nb^{-1}
p↑-p↑ [Run-4]	55	70	1	20	6×10^{30}	4×10^{30}	0.9 pb^{-1}
Au-Au design	56	1	2	15-40	9×10^{26}	2×10^{26}	50 μb^{-1}
p-p design	56	100	2	20	5×10^{30}	4×10^{30}	1.2 pb^{-1}
p↑-p↑ design	112	200	1	20	80×10^{30}	65×10^{30}	20 pb^{-1}

[best store or week]



[incl. beam experiments and maintenance]

RHIC Collider Projections (FY2005 – FY2008)

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Last update: June 26, 2004

This note discusses in Part I possible operating modes for the RHIC Run-5 (FY2005) operating period including constraints from cryogenic cool-down, machine set-up and beam commissioning. In Part II a 4-year projection is given for gold-gold and polarized proton collisions, assuming that these modes are used in every run. This latest update is based on the experience gained during the Run-4 gold-gold and polarized proton operation.

Part I – Run-5 Projections

Cryogenic operation – After the summer shutdown the two RHIC rings will be at room temperature. They will be first brought to liquid nitrogen temperature, in about 30 days. Then, two weeks will be required to cool down to 4 Kelvin. At the end of the run, one week of refrigerator operation is required for the controlled warm-up to room temperature.

Running modes – A number of running modes are considered in RHIC, such as Si^{14+}, Ni^{28+}, Cu^{29+}, Fe^{26+}, and polarized proton collision. When starting the run we plan for 2 weeks of

Projections document, continuously updated with new information.

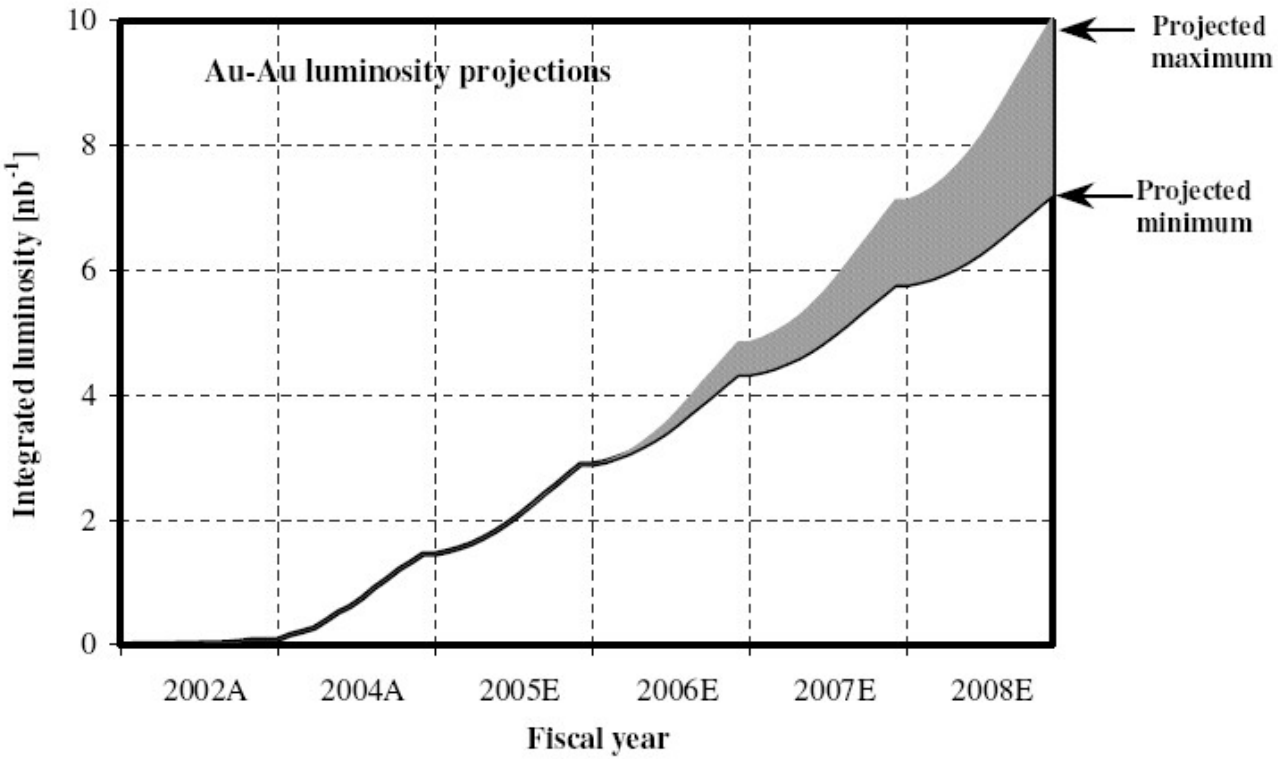
- 2 weeks for cool-down (80K to 4K), 1 week for warm-up
- For each mode (Au-Au, p↑-p↑, d-Au, etc.)
  - 2 weeks of start-up
    [machine operation 24h/day]
  - 2 weeks of ramp-up
    [machine operation 16h/day, experimental set-up 8h/day]
  - Continuous luminosity development in production
    [up to 8h/day, until no further progress is possible]
- For each additional mode
  - 1 weeks of start-up
  - 1 weeks of ramp-up
- For polarized protons 1 additional week of start-up
- 11h/wk beam experiments, 8h/wk maintenance

1. Vacuum (electron clouds, desorption from beam loss)
   - – Vacuum instabilities
   - – Experimental background
   - → Use optimized bunch patterns
   - → Installation of NEG coated pipes in warm regions
2. Intrabeam scattering (Au)
   - – Leads to luminosity lifetime of a few hours
   - → Fast refills needed to increase average luminosity
   - → Ultimately need cooling at full energy (stochastic, electron)
3. Beam-Beam (p, lighter ions)
   - – Can limits number of experiments to 2 (out of 4)
   - → New working point
4. Instabilities
   - – Vulnerable near transition (short bunches, no ξ-jump)
   - → Chromaticity control on ramp, octupoles for transition crossing (transverse)
     Landau cavities (longitudinal)

Fiscal year		2004A	2008E
No of bunches	…	45	112
Ions/bunch, initial	10^9	1.1	1.1
Average store luminosity	10^{26} cm^{-2}s^{-1}	4.0	9.0
Time in store	%	53	60
Maximum luminosity/week	μb^{-1}	160	327

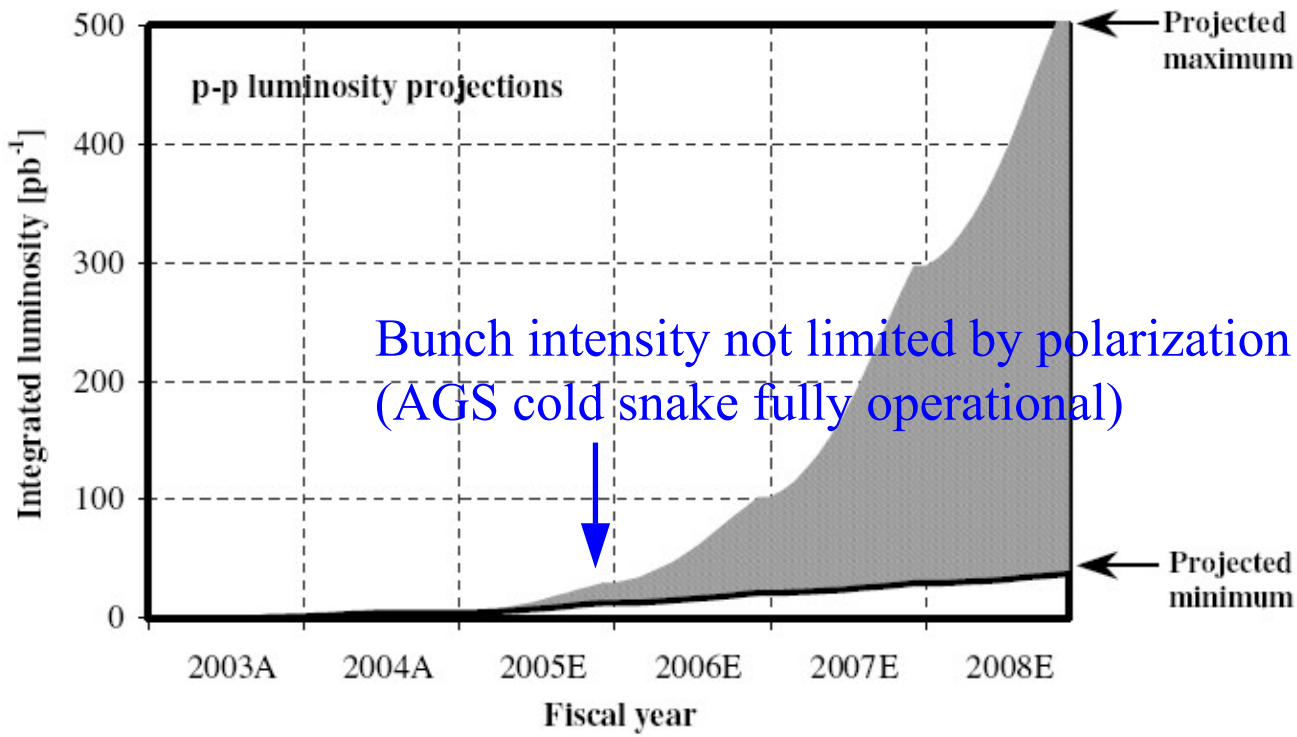
Assume
- **12 weeks production in every year**
- **8 weeks of linear luminosity increase**
- **only 2 experiments**
- **completion of improvements**

2× increase



Fiscal year		2004A	2008E
No of bunches	…	56	112
Ions/bunch, initial	10^{11}	0.7	2.0
Average store luminosity	10^{30} cm^{-2}s^{-1}	4	72
Time in store	…	38	60
Maximum luminosity/week	pb^{-1}	0.9	26.0
RHIC store polarization, average	%	40	70
Maximum LP^4/week	nb^{-1}	24	6230

Assume
- **12 weeks production in every year**
- **8 weeks of linear luminosity increase**
- **only 2 experiments**
- **completion of improvements**



250× increase !

9× from Polarization

18× from Luminosity

(another 2.5× for 250GeV)

- Upgrades for more luminosity
  - Bunch intensity for all species (injector rf manipulations, EBIS)
  - RHIC warm vacuum for all species (NEG coated pipes)
  - Intrabeam scattering for Au (fast RHIC refill, stochastic & e-cooling)
  - Instabilities in RHIC (instrumentation, broadband damper)
- Upgrades for more polarization
  - Polarization is injector limited (AGS cold snake, OPPIS solenoid)
  - RHIC polarization at 250GeV is orbit limited (BPM system)
- Upgrades for more time in store
  - Replacement of obsolete infrastructure (cooling, cables, Tandem)
  - Replacement of obsolete equipment (electronics, vac pumps, …)
  - More reliable equipment (radiation hard, PS, …)
- Upgrades for power savings (further 1.5MW in cryo operation)

AIPs for next 3 years:

- AGS MMPS transformer and ripple reduction: $3.2m
  - Due to size only small part can be done in parallel to EBIS
- OPPIS superconducting solenoid: $0.5m
  - 5% more polarization at 2× higher bunch intensity
- RHIC cryo upgrade Phase III: up to $2.0m
  - 1.5MW power saving, break even after 5years at current electricity rate (rates will rise in FY2005, probably by 50%)
  - Not entirely possible with EBIS contribution out of AIP
- EBIS: $2.1m/yr during construction or
  Tandem reliability upgrade: $9m total
  - $2.5m annual operating savings with EBIS
- Stochastic cooling: ~$3m total
  - Can start earlier if no EBIS contribution out of AIP

[Separate effort to upgrade injectors for RSVP.]

FY2004

- Capital projects total: $1.2m
  - Replacement of LINAC cooling tower
  - RHIC BPM electronic relocation
  - RF test equipment
  - Operations server upgrade
- AIP total: $2.9m
  - AGS cold snake Phase II: $1.1m
  - RHIC cryo control upgrade: $0.5m
  - RHIC vacuum upgrade of warm pipes (NEG): $1.2m

FY2005 (presidential budget)

- Capital projects total: $1.2m
  ($2.2m revised budget request)
  - AGS/RHIC rf low level upgrade
  - RHIC BPM system upgrade
  - Replacement of cooling tower 1 including main
  - AGS vacuum pump upgrade
  - Replacement of obsolete controls equipment
- AIP total: $3.1m ($3.3m revised request request)
  - AGS MMPS transformer (Phase I): $2.0m
  - OPPIS superconducting solenoid: $0.5m
  - RHIC cryo upgrade: $0.6m

Revised budget request allows capital projects and AIPs scheduled for later years.

FY2006 projection

- Capital projects total: $2.3m
  - AGS/RHIC rf low level upgrade
  - AGS vacuum pump upgrade
  - Replacement of obsolete controls equipment
  - RHIC cryo upgrade
- AIP total: $3.4m
  - AGS MMPS transformer (Phase II): $1.3m
  - EBIS or Tandem reliability upgrade: $2.1m

FY2007 projection

- Capital projects total: $2.3m
  - AGS/RHIC rf low level upgrade
  - Replacement of obsolete controls equipment
  - RHIC cryo upgrade
  - RHIC broadband amplifiers
- AIP total: $3.4m
  - EBIS or Tandem reliability upgrade: $2.1m
  - RHIC stochastic cooling (Phase I): $1.3m

- **Significant progress in RHIC reliability**
  - Time is store increased to 53% of calendar time
  - Target is 60% (100hrs/week)
- **Enhanced Luminosity Goals** (before e-cooling)
  - For Au-Au, average per store
    $L = 8 \cdot 10^{26} cm^{-2} s^{-1}$ at 100GeV/u
  - For p↑-p↑ average per store, 2 IRs
    $L = 6 \cdot 10^{31} cm^{-2} s^{-1}$ at 100GeV
    $L = 1.5 \cdot 10^{32} cm^{-2} s^{-1}$ at 250GeV
    with **70% polarization**

4× design
2× achieved

16× design
6× achieved

1× design
2× achieved

- **To reach enhanced luminosity goals need to complete upgrades successfully**