# Review of Booster and AGS setup for RHIC Run 23

RHIC Retreat 2022

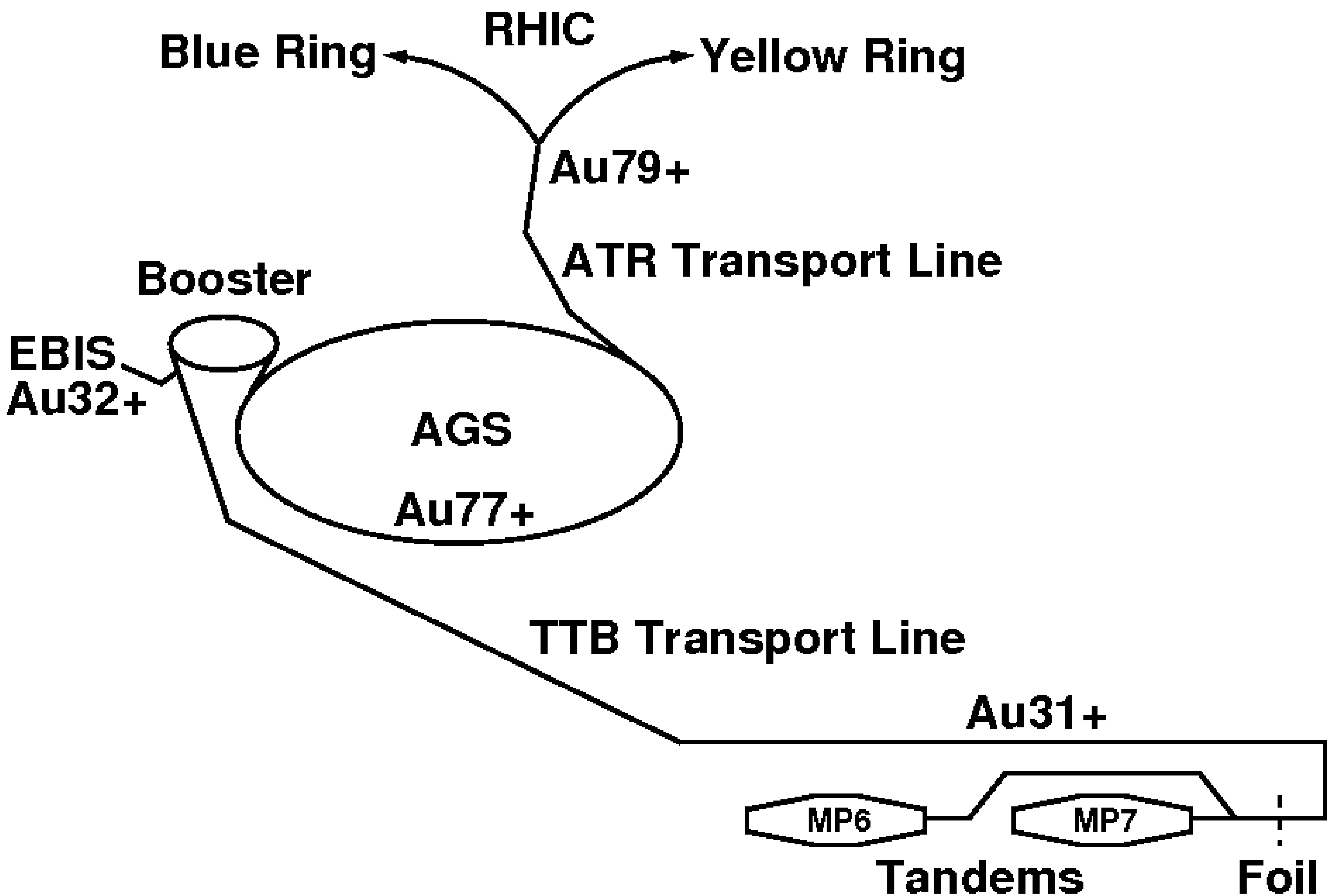
24 May 2022

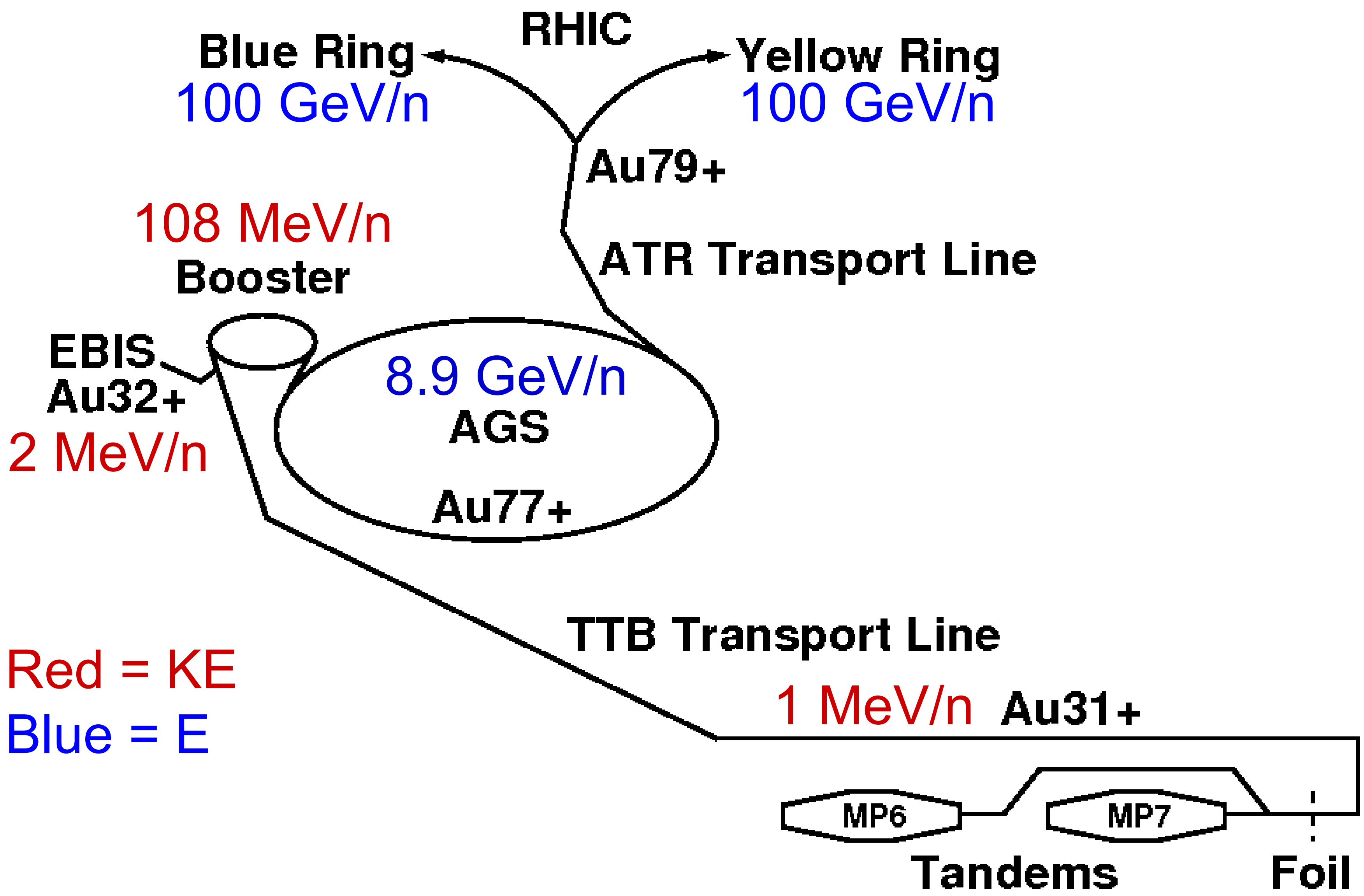
C. Gardner

# Outline

1) Orientation and tour
2) History of gold setups
3) Run 2023 setup
4) Protective limits on intensity
5) Tandem as spare source
6) References

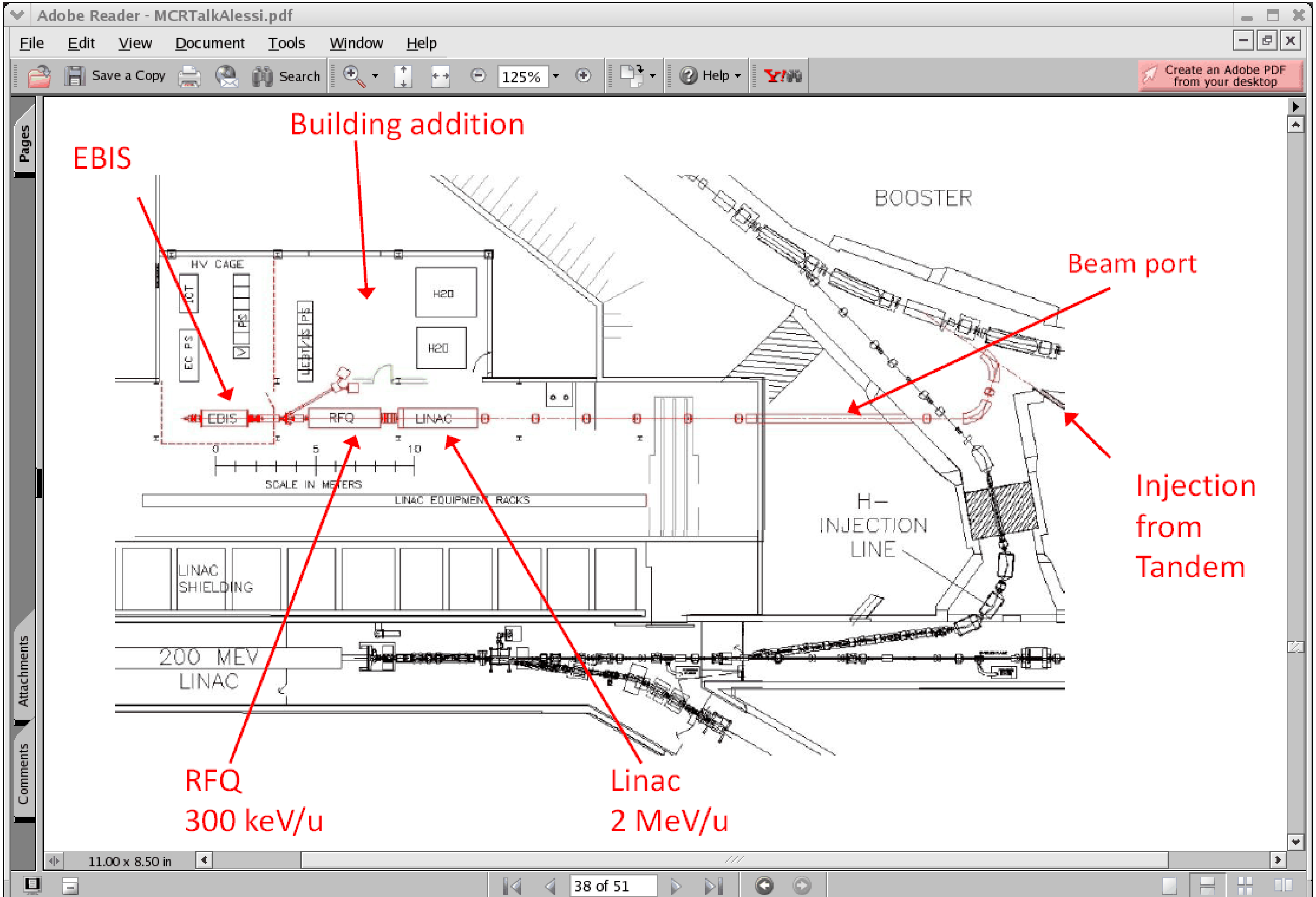
# Tour


RHIC
Blue Ring
Yellow Ring
Au79+
ATR Transport Line
Booster
EBIS
Au32+
AGS
Au77+
TTB Transport Line
Au31+
MP6
MP7
Tandems
Foil

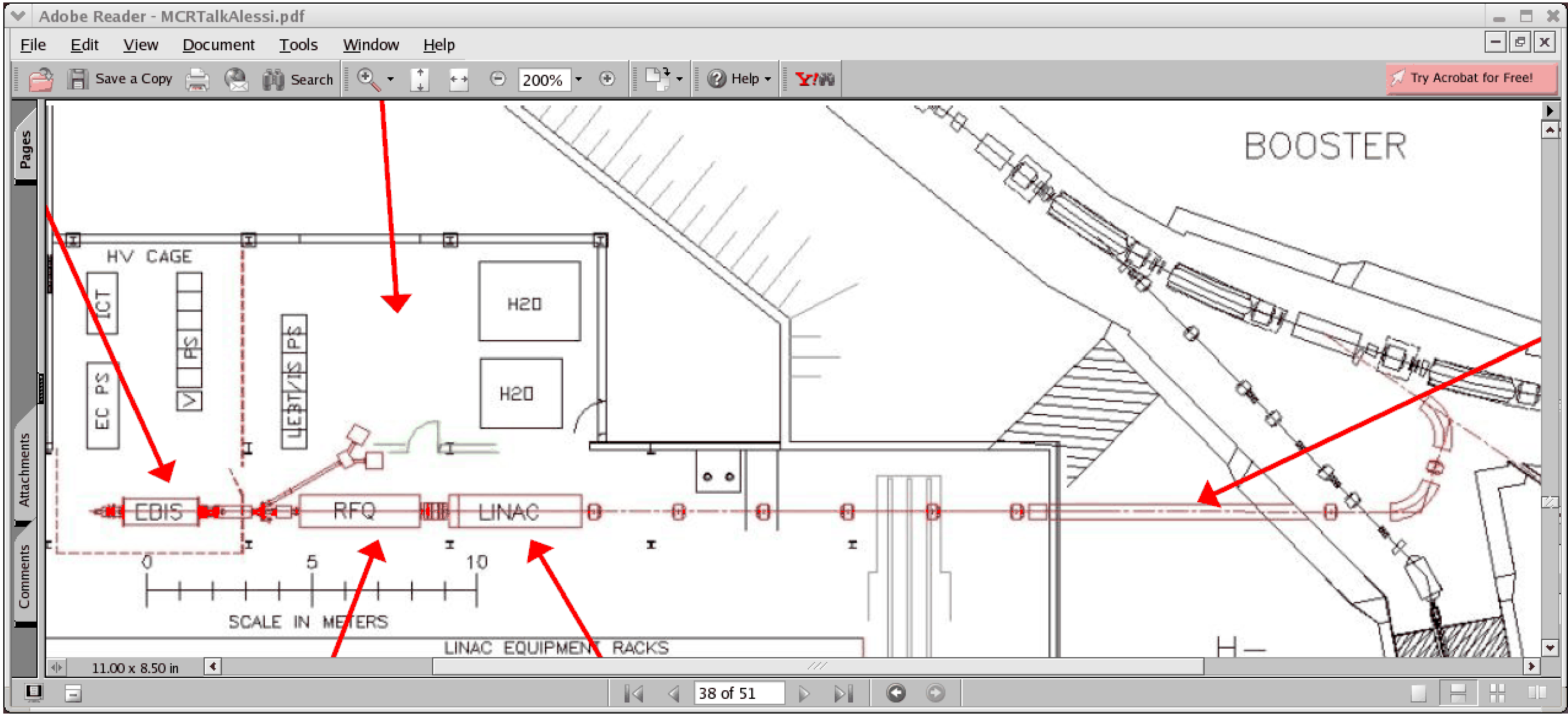


RHIC
Blue Ring
100 GeV/n
Yellow Ring
100 GeV/n
Au79+
108 MeV/n
Booster
ATR Transport Line
EBIS
Au32+
2 MeV/n
8.9 GeV/n
AGS
Au77+
TTB Transport Line
1 MeV/n
Au31+
MP6
MP7
Tandems
Foil
Red = KE
Blue = E

# Booster injection region zoom



# Booster injection region zoom zoom



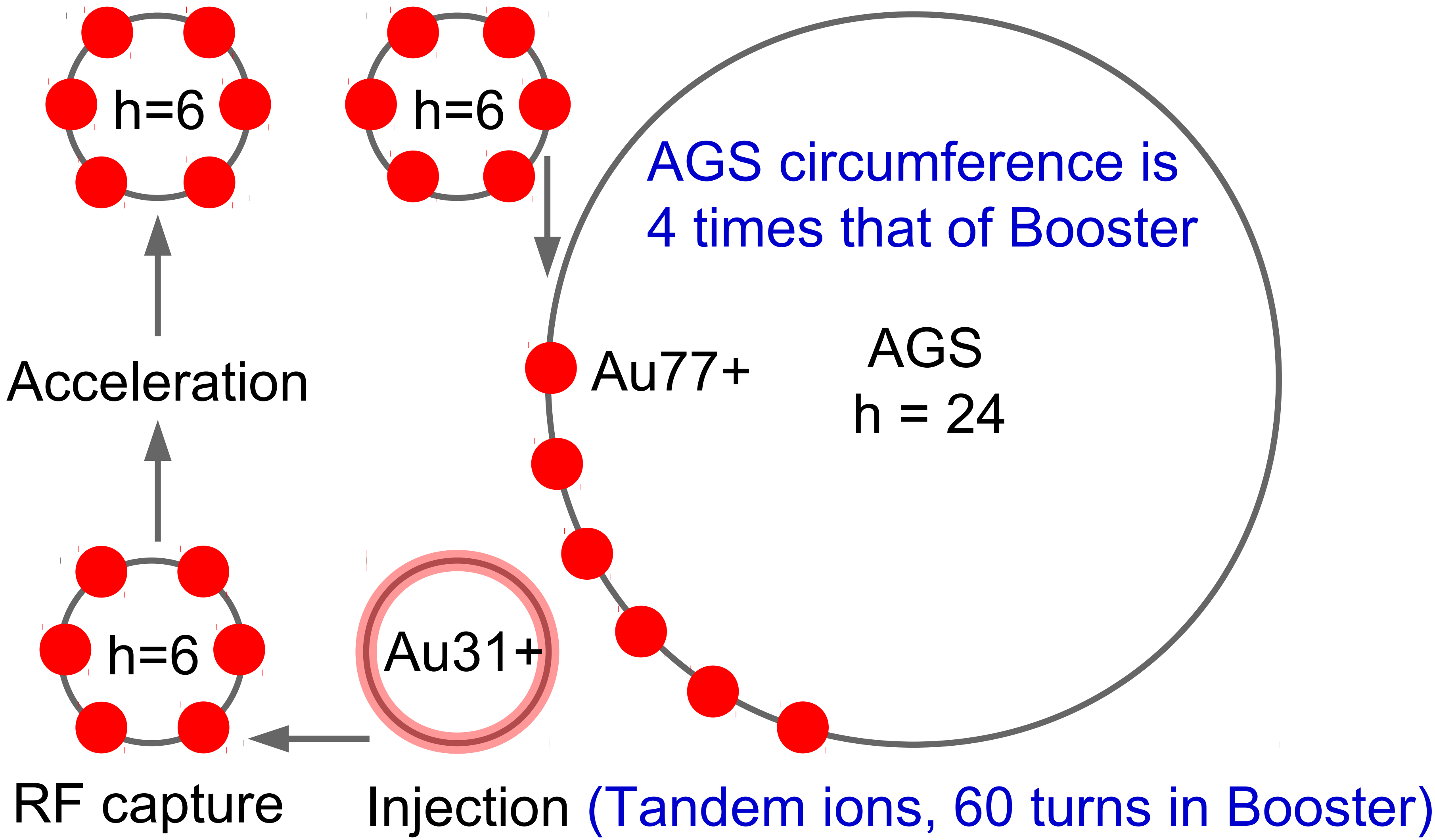
# Some History

## How did we get to the standard setup we use today?

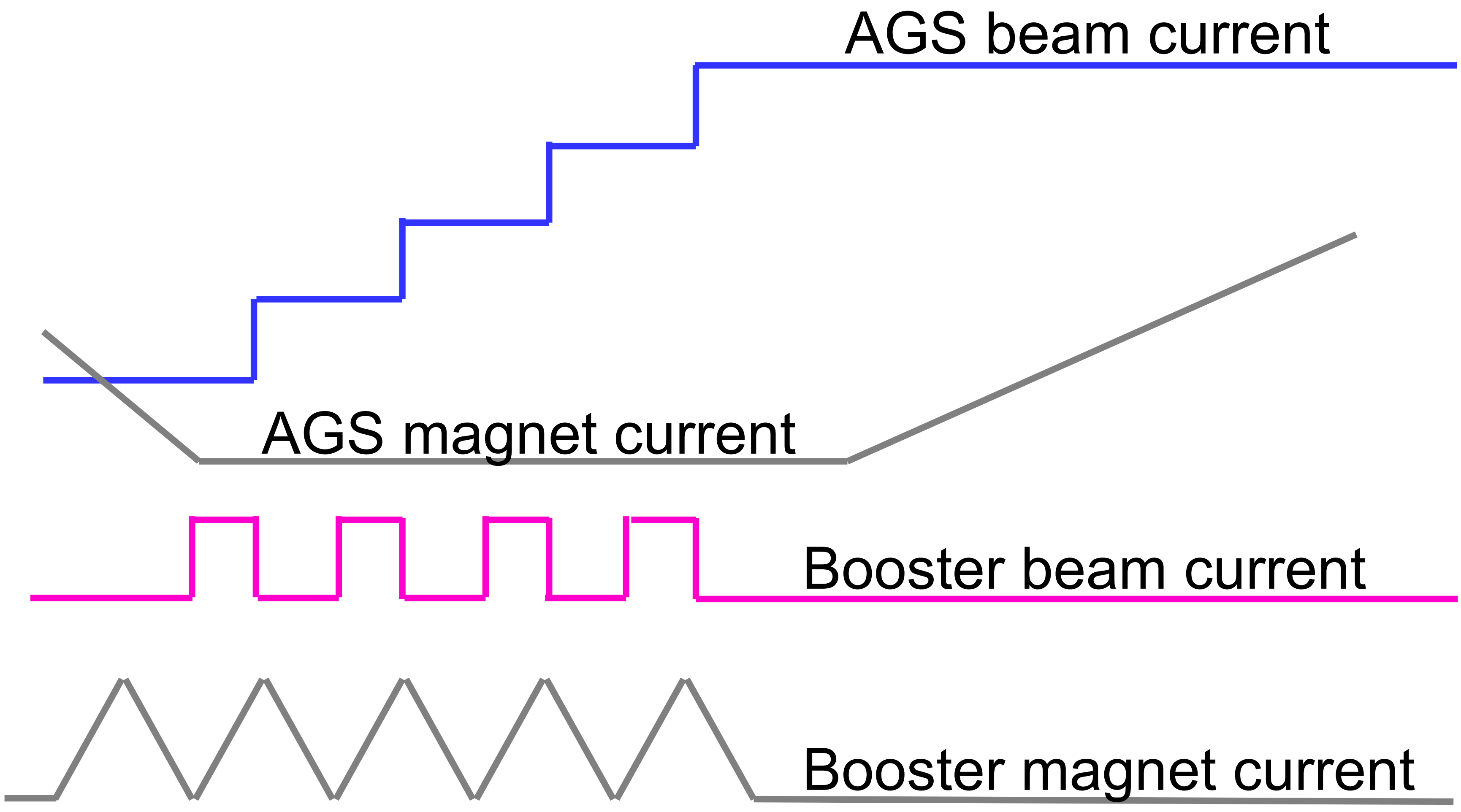
# The 2007 setup

## Standard setup until 2012

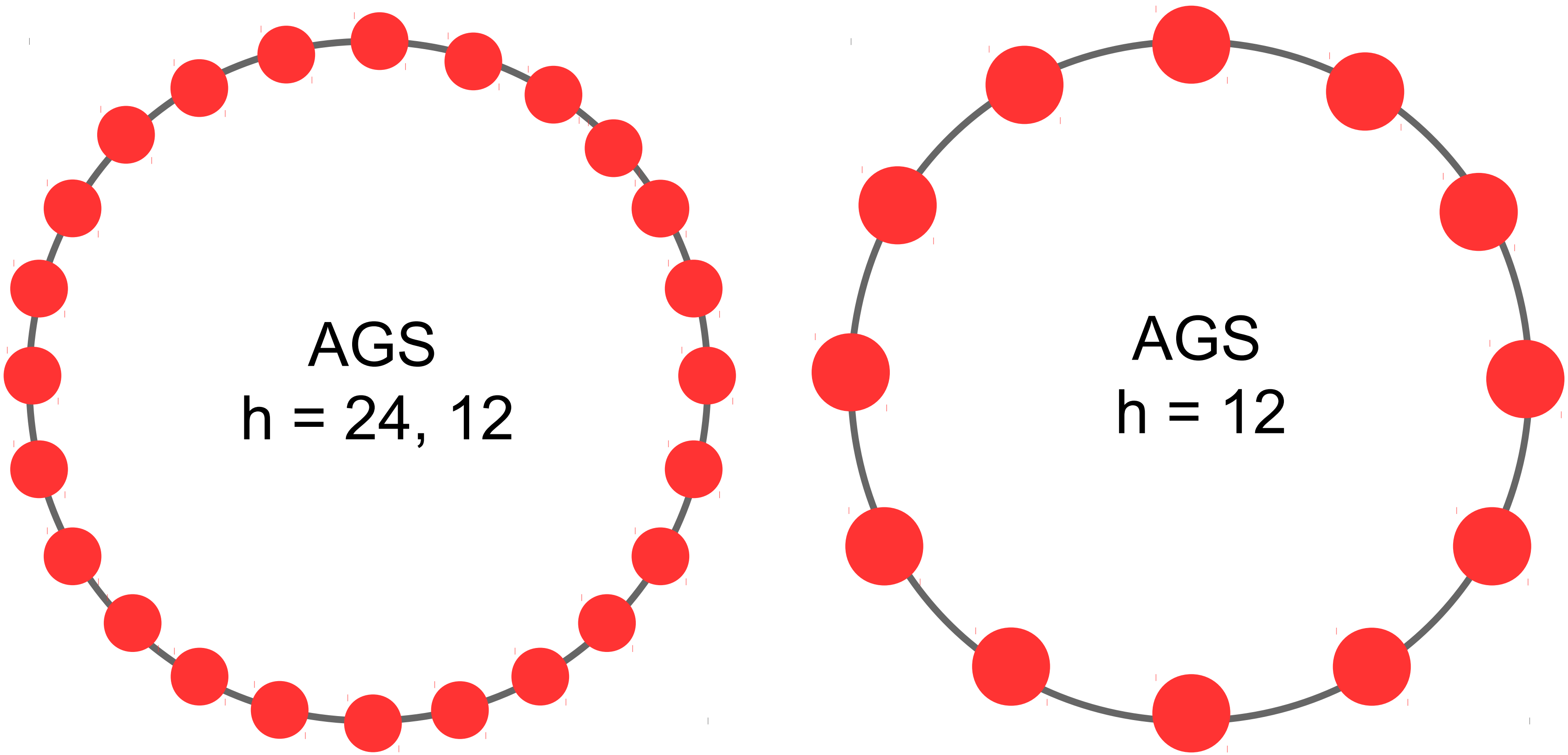
# 1 of 4 Booster loads to AGS



# Beam and magnet currents

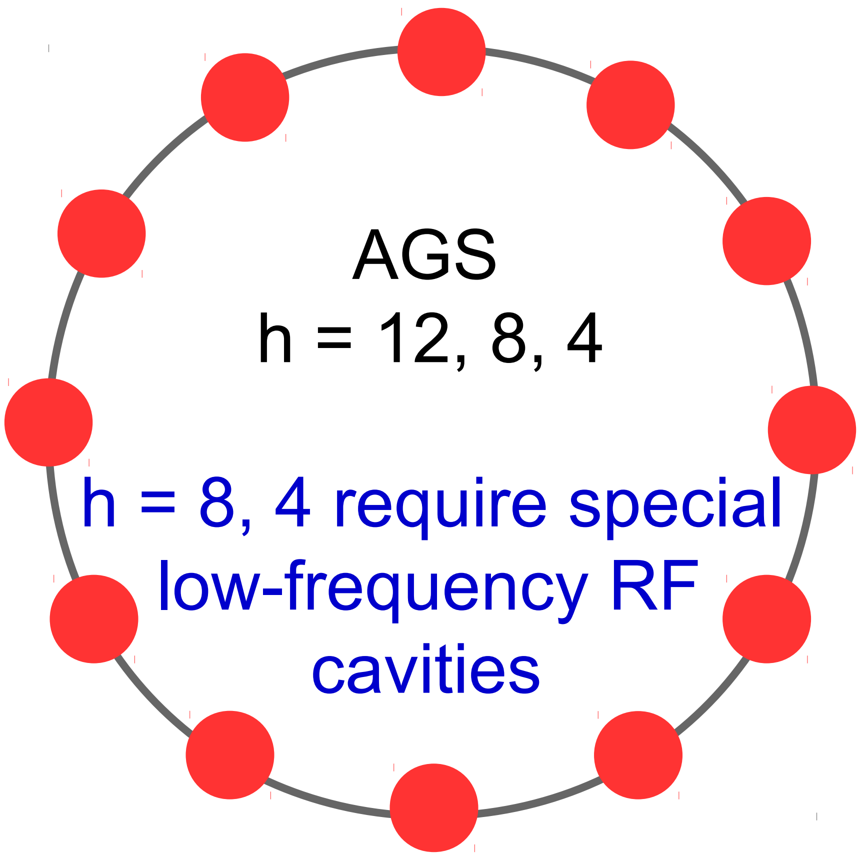


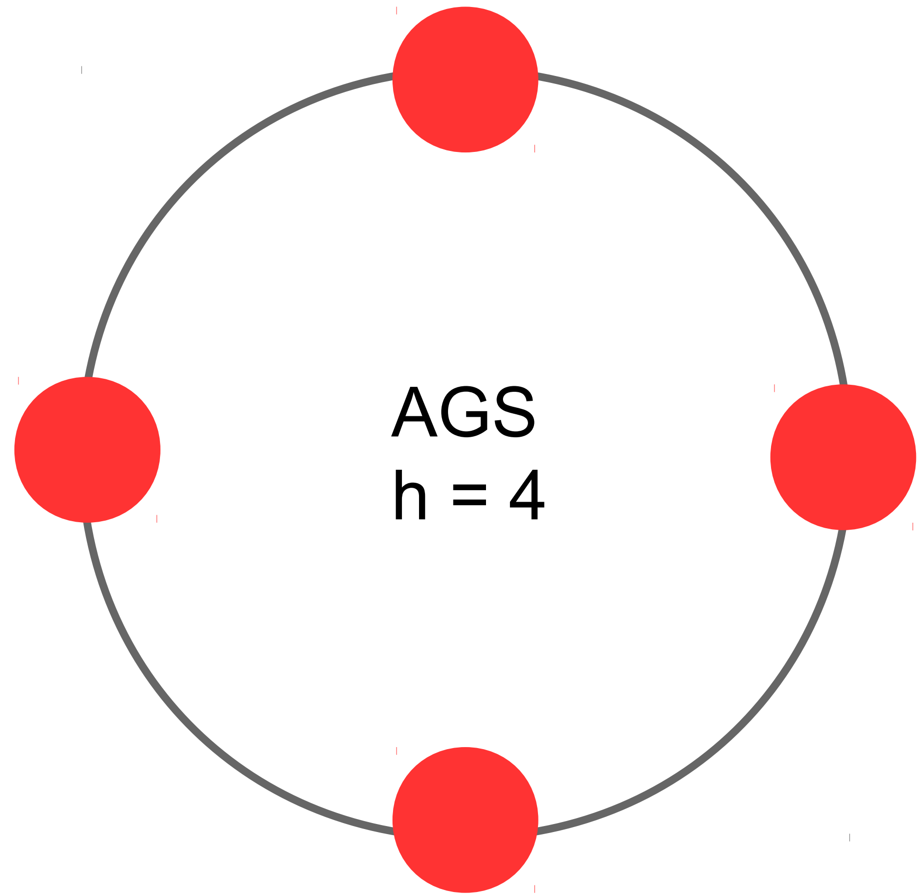
# Merge 24 bunches into 12




Each group of 2 bunches is merged
Into 1. Uses RF harmonics 24, 12.

# Merge 12 bunches into 4

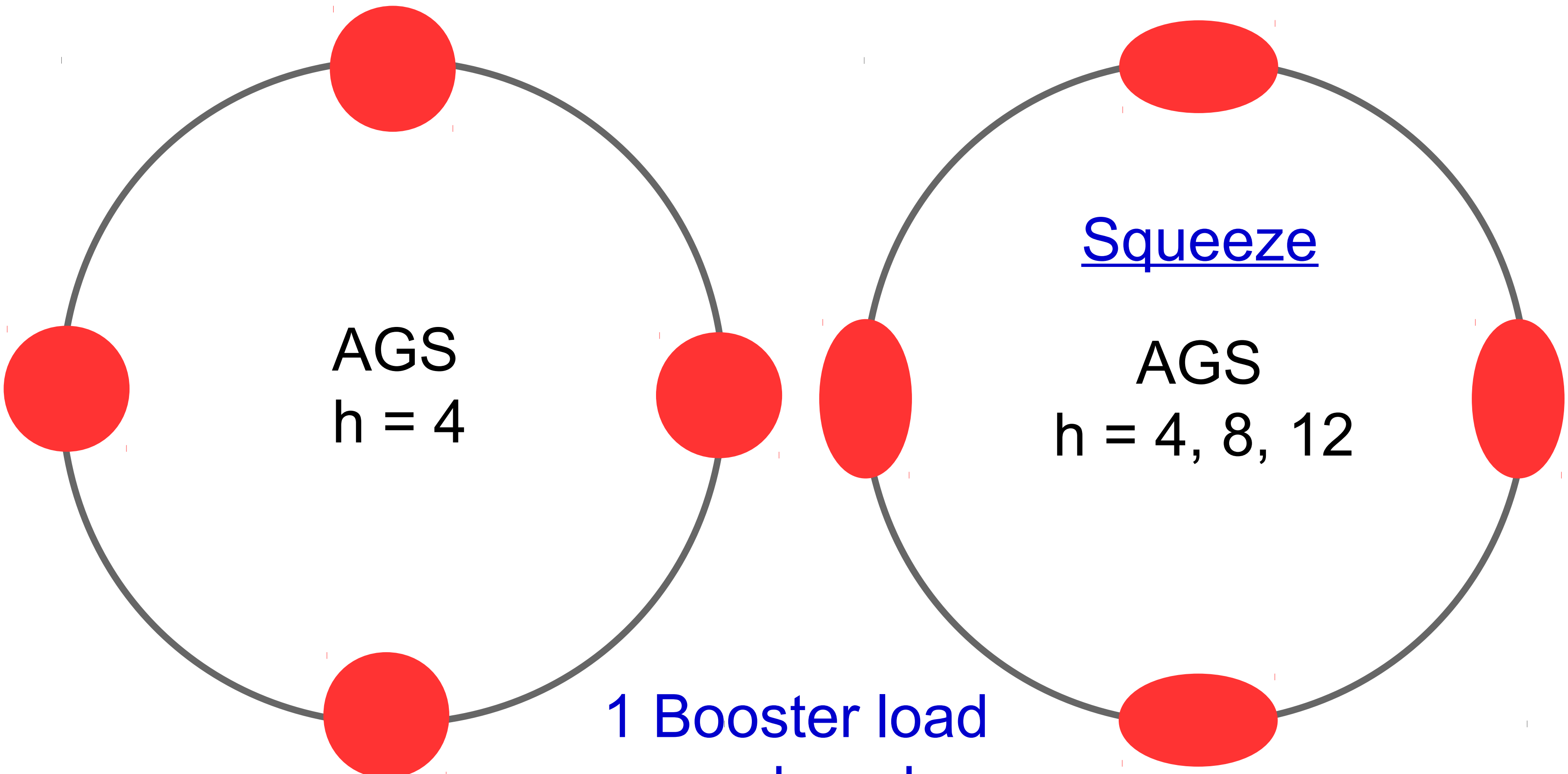



Each group of 3 bunches is merged into 1. Uses RF harmonics 12, 8 , 4.

1 Booster load per bunch

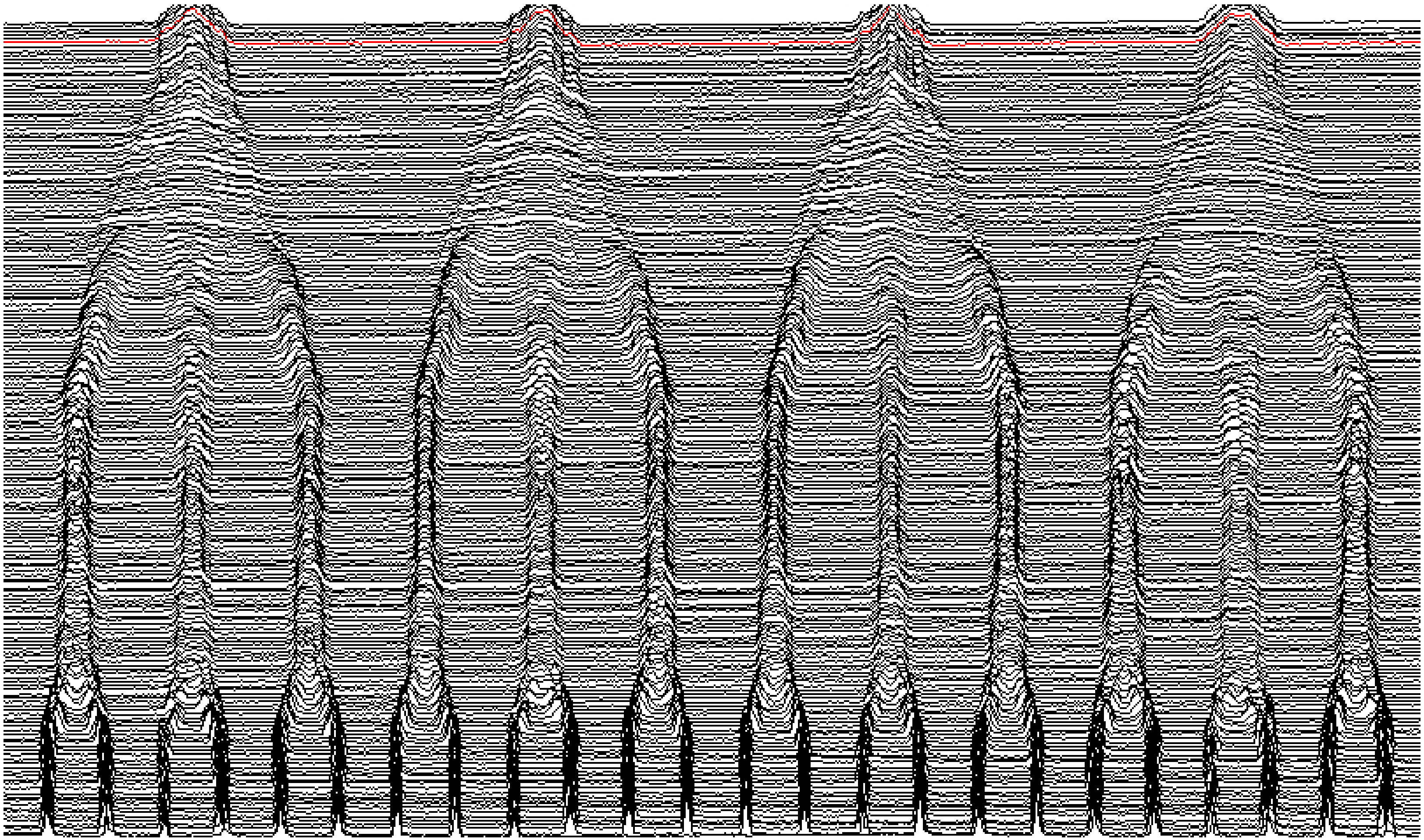
# Squeeze into harm 12 buckets for acceleration




1 Booster load per bunch

4 bunches to RHIC per AGS cycle

# 2007 Mountain range of merges



Scheme developed by M. Brennan and M. Blaskiewicz

# 2007 numbers

1) 5.0e9 Au31+ ions per pulse from Tandem
2) 4 bunches at AGS extraction
3) 1.6e9 Au77+ ions per bunch typical at AGS extraction. A high of 1.8e9 observed
4) 0.23 eVs per nucleon emit per bunch
5) Documented in PAC07 paper (Ref. 8)
6) This was our "workhorse" setup until 2012

In 2012 EBIS replaced Tandem as primary source of ions for RHIC

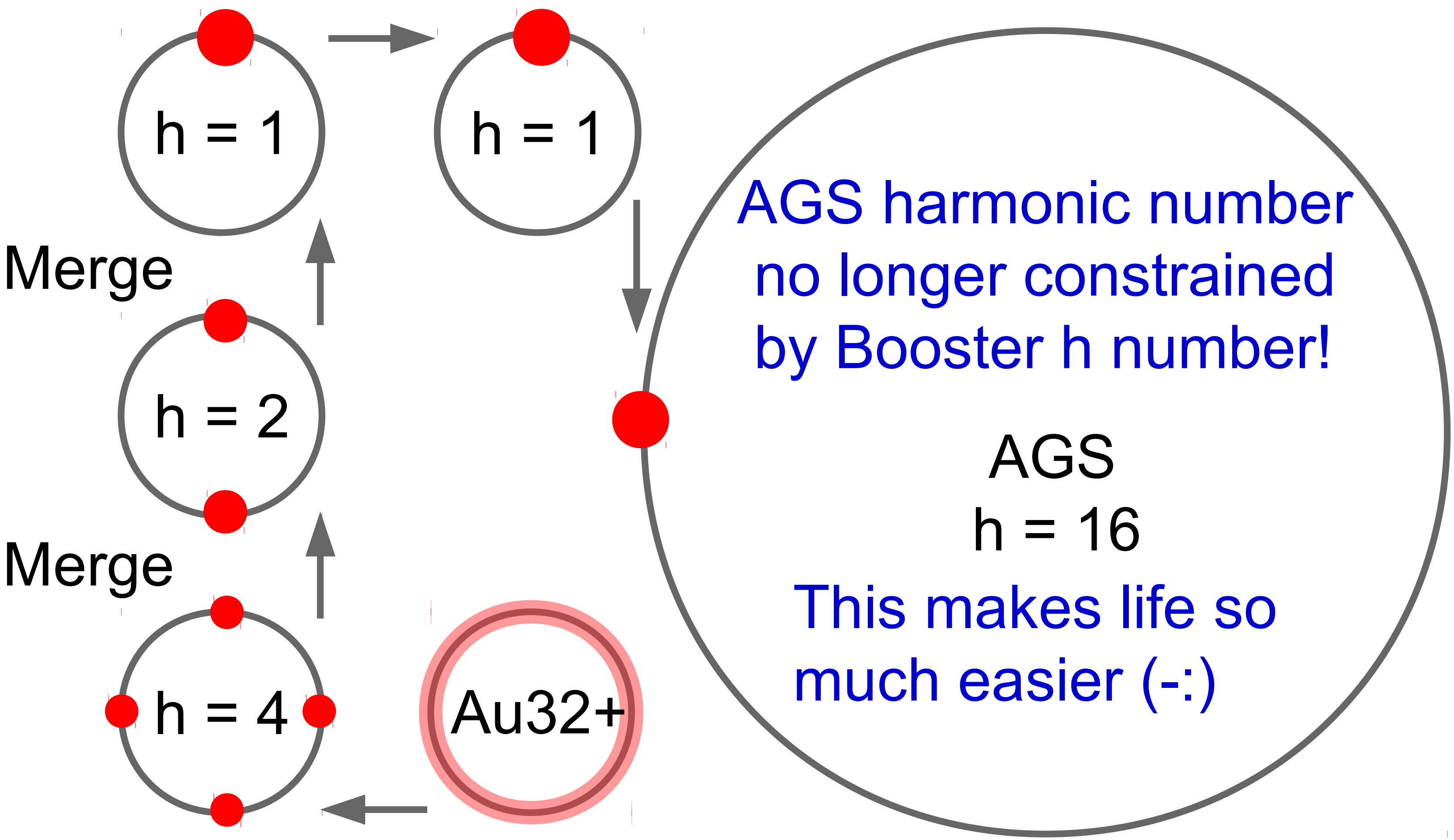
The switch to EBIS as the primary source for ions destined for RHIC presented a number of challenges, not least of which is the fact that while Tandem can deliver 5.0e9 (or more) Au31+ ions per pulse, EBIS can deliver just 1.2e9 AU32+ ions per pulse.

Several things were tried to overcome the consequences of this shortfall. These are discussed in the 2012 Retreat talks. The following slides show what finally worked...

# The big step forward was to merge 4 to 1 bunch in Booster

1) Inject EBIS beam into Booster, capture at h = 4 and accelerate to merging porch
2) Merge 4 bunches into 2, then the 2 into 1
3) Accelerate, and transfer 8 loads of 1 bunch to AGS
4) It was found that the Booster bunches fit into harmonic 16 buckets in AGS. That allowed for an 8 to 2 bunch merge.

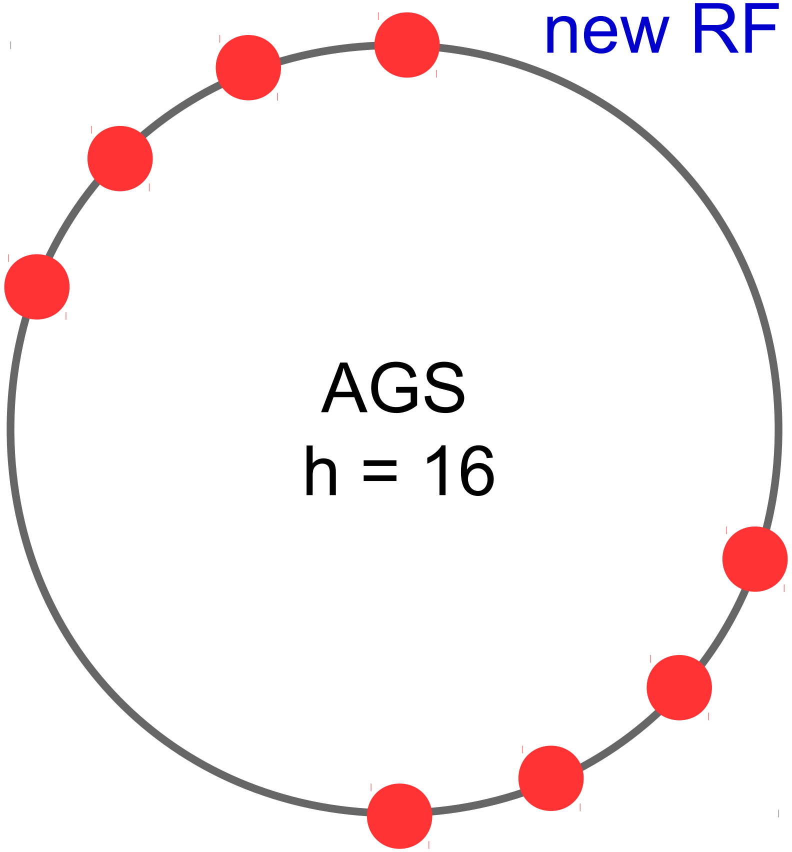
# 1 of 8 Booster loads to AGS



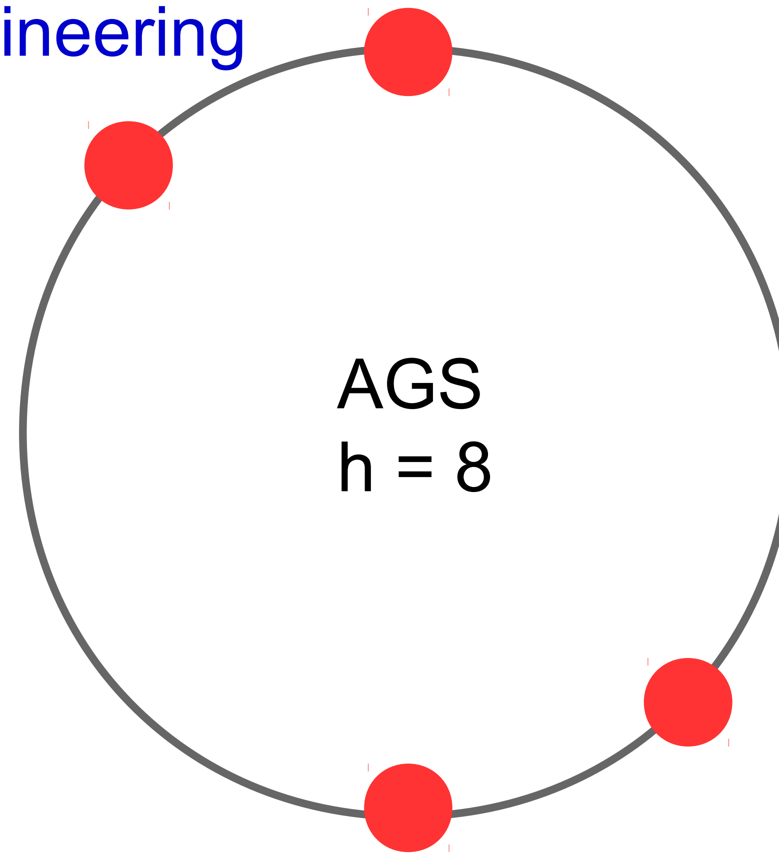

RF capture Injection (EBIS ions, 2 turns in Booster)

# Merge 8 bunches into 4

Merges with empty buckets present required new RF engineering

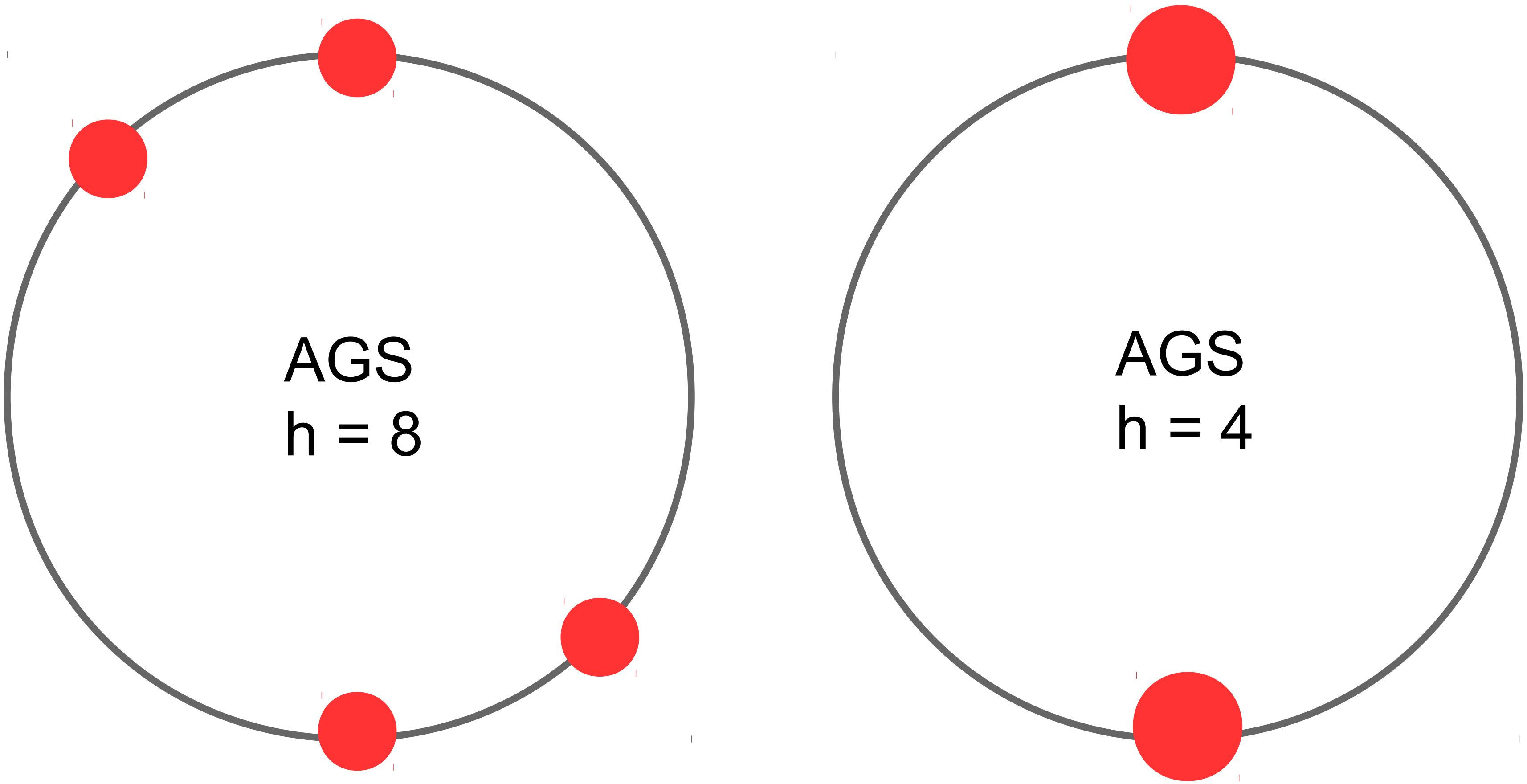



1 Booster load per bunch




2 Booster loads per bunch

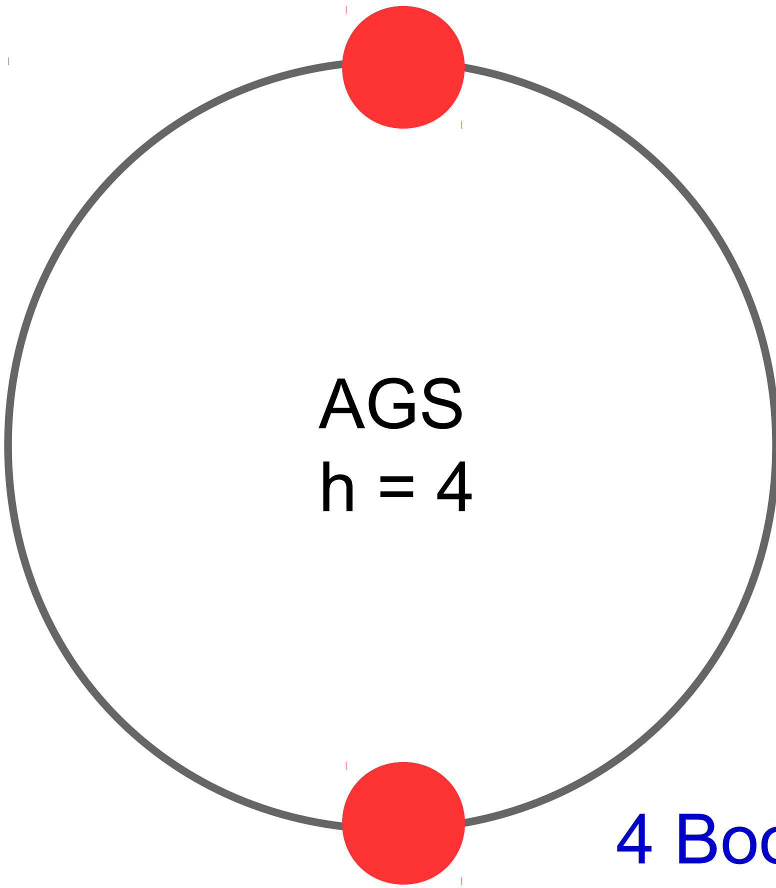
# Merge 4 bunches into 2

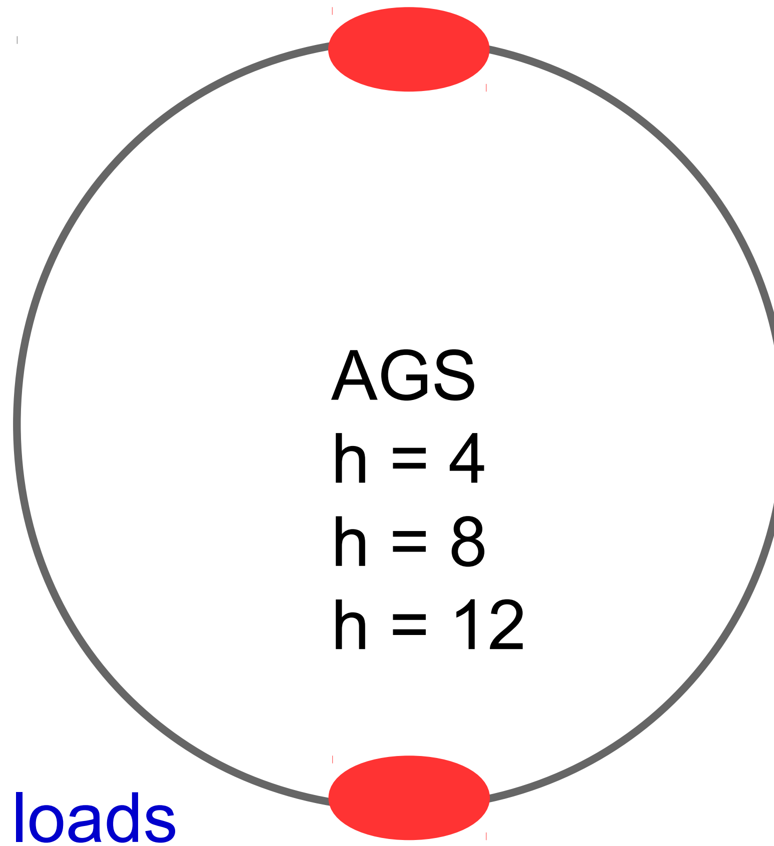



2 Booster loads per bunch

4 Booster loads per bunch!

# Squeeze into harm 12 buckets for acceleration




4 Booster loads per bunch

(But just 2 bunches to RHIC per AGS cycle)

# Numbers achieved in 2012

- 1.62e9 Au77+ ions per bunch at AGS ext
- 6.50e9 Cu29+ ions per bunch at AGS ext
- 3.8e8 U90+ ions per bunch at AGS ext
- 0.5 to 0.6 eV s per nucleon at AGS ext
- These met the needs of the RHIC Run 12 physics program
- Documented in IPAC15 paper (Ref. 7)

# Numbers achieved in 2014

1) There were significant upgrades to the RF system between 2012 and 2014
2) 2.1e9 Au77+ ions per bunch at AGS ext
3) 0.7 eVs per nucleon emit per bunch
4) Documented in IPAC15 paper (Ref. 7) and in Ref. 1

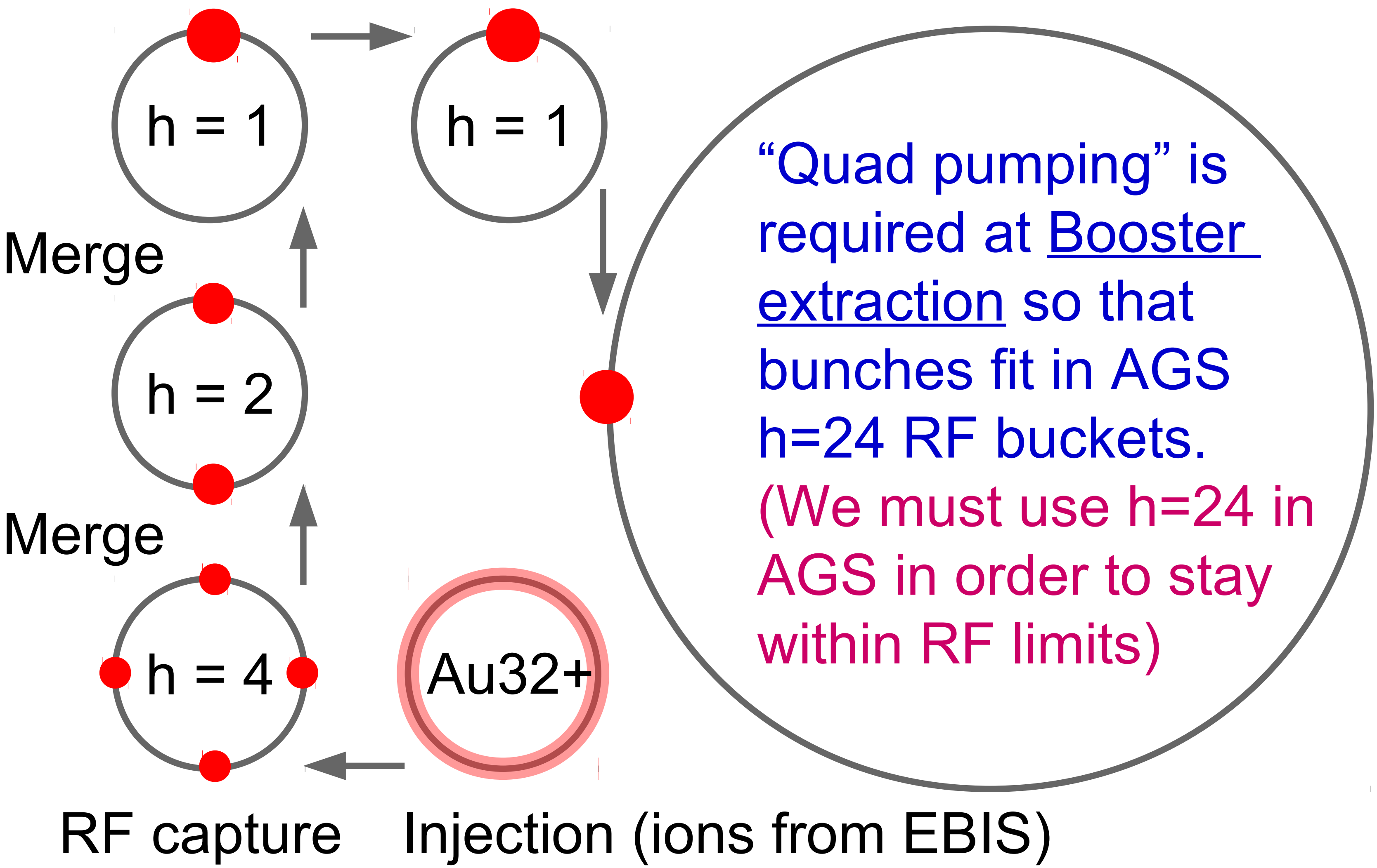
The next big step was to increase the number of transfers from Booster to AGS from 8 to 12 per AGS cycle.

This was done by K. Zeno in 2016 and is now the standard setup for delivery of Au77+ ions to RHIC.

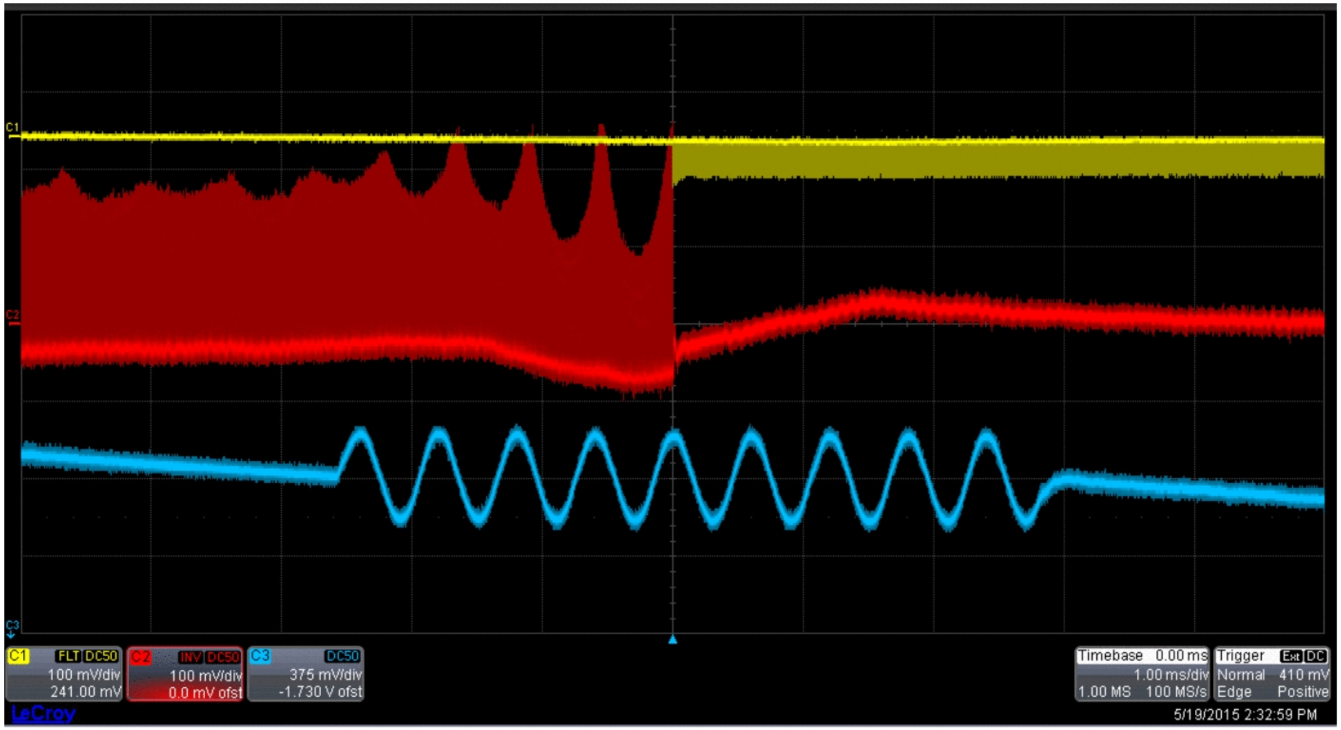
The setup is well documented in Refs 1, 2.

It is the setup that will be used for Run 23.

# 1 of 12 Booster loads to AGS



# Quad pumping at Booster ext



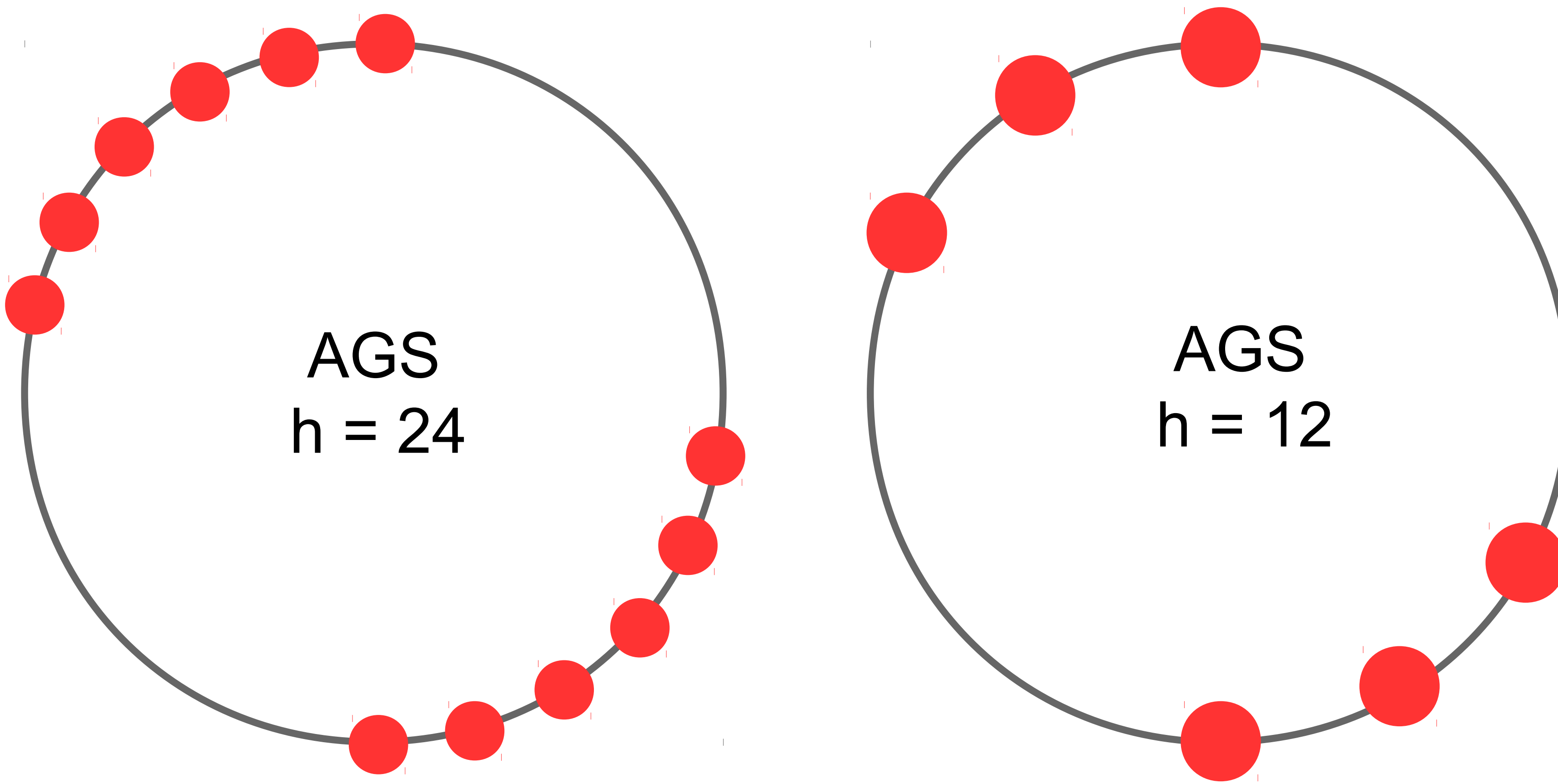

AGS WCM

Booster WCM

Modulated Booster RF voltage

The RF voltage is modulated at twice the synchrotron frequency (Fig. 7 from Ref. 1)

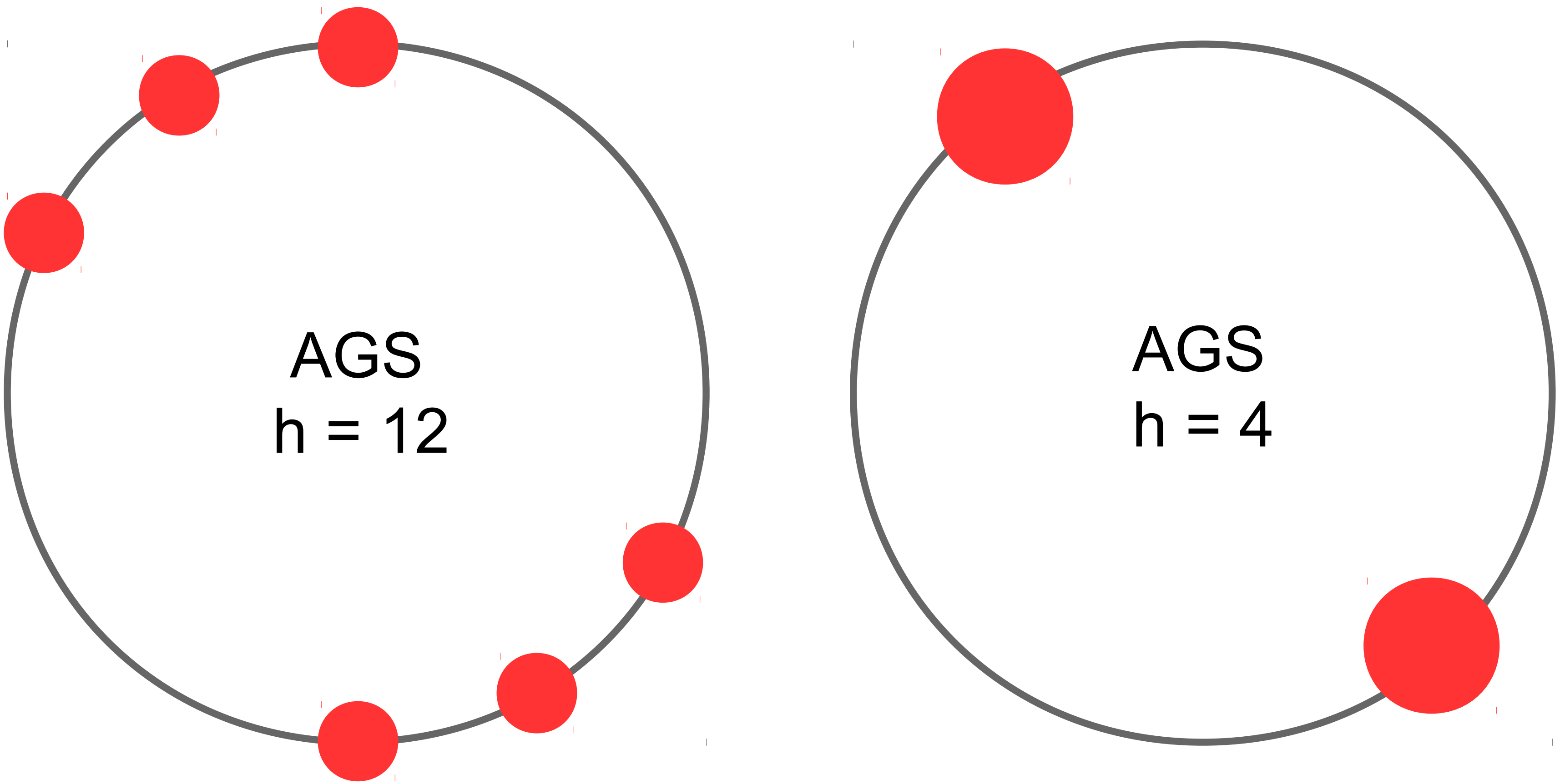
# Merge 12 bunches into 6




1 Booster load per bunch

2 Booster loads per bunch

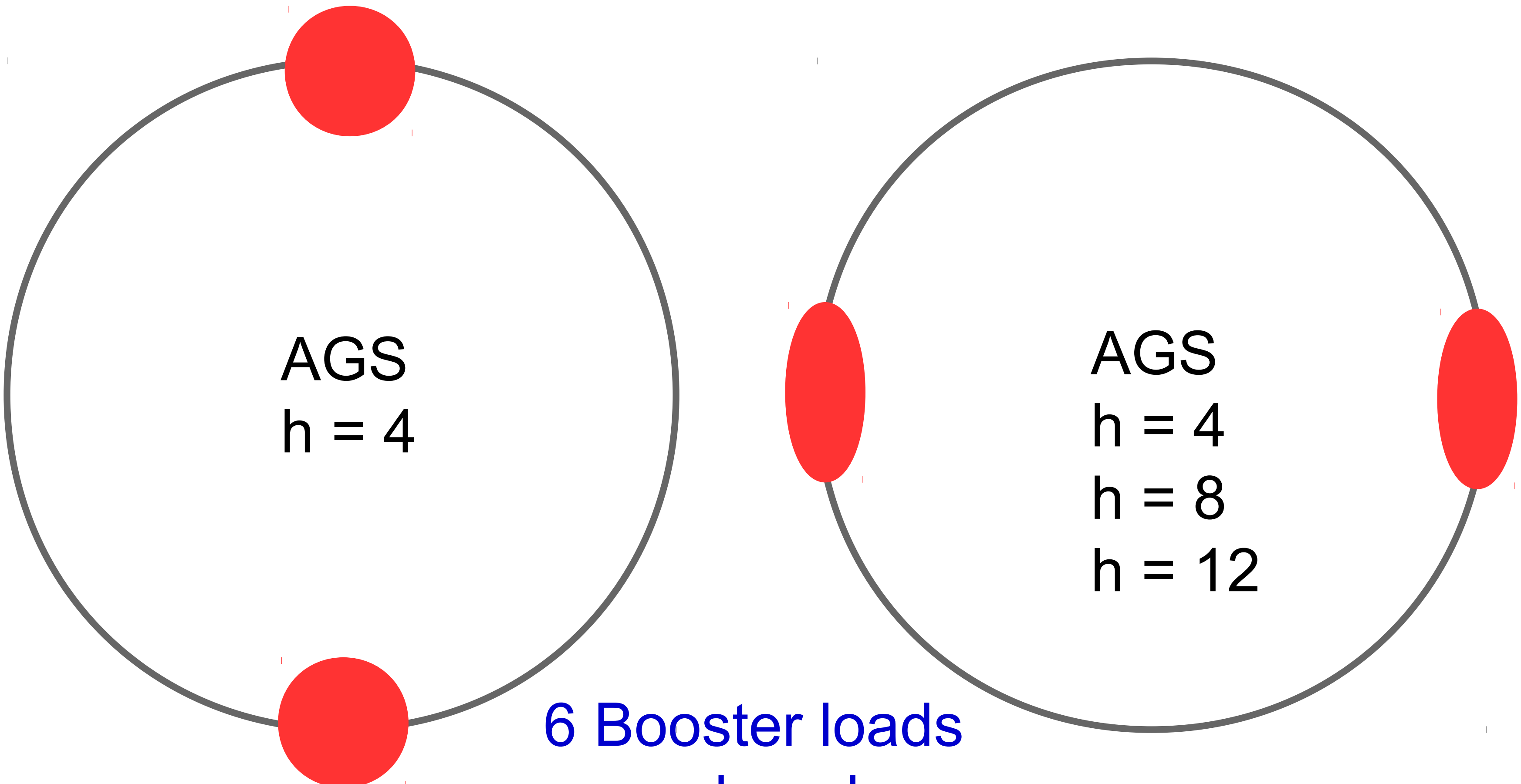
# Merge 6 bunches into 2




2 Booster load per bunch

6 Booster loads per bunch!

# Squeeze into harm 12 buckets for acceleration




6 Booster loads per bunch

2 bunches to RHIC per AGS cycle

# Numbers achieved (Ref. 1)

1) 3.1e9 ions per bunch at AGS extraction

2) The 2 bunches require some 12e9 ions in the BTA line per AGS cycle.

2) 0.75 eVs per nucleon emittance per bunch

3) These numbers are baseline for Run 23

4) Getting more intensity will require some work

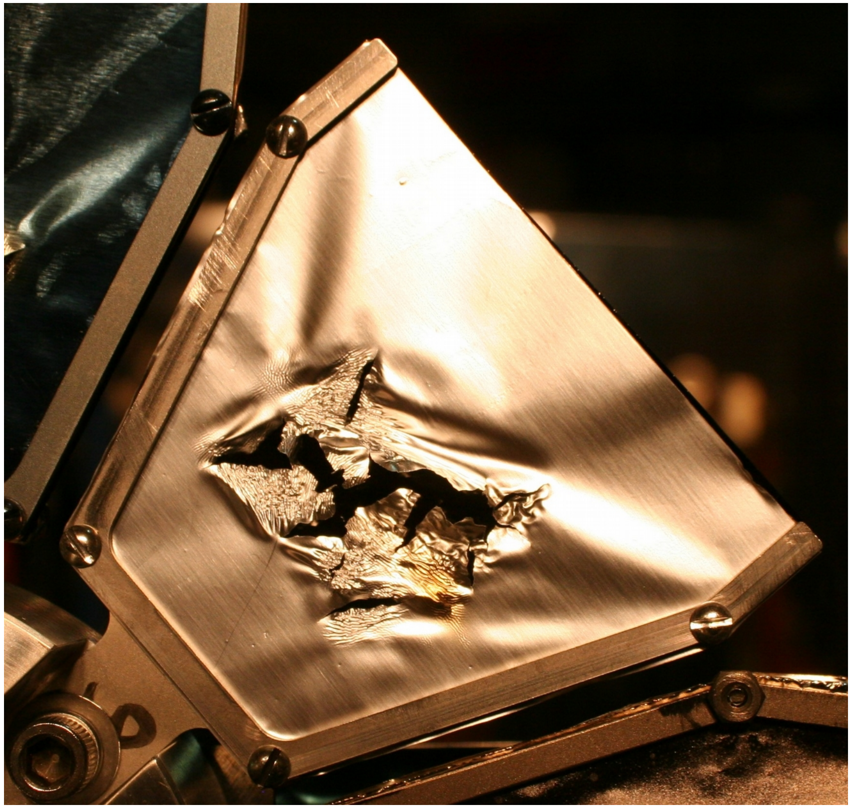
5) As per Ref. 5, we are not allowed to have more than 8e9 Au77+ ions circulating in AGS at extraction. This would give 2 bunches with 4e9 ions per bunch, and would require 16e9 ions in the BTA line.

# Protective limits on intensity

# First of all, the BTA stripping foils (Ref. 6) need protection

1) These strip Au32+ ions to produce Au77+ ions for injection into AGS.
2) As documented in Refs. 3, 4, 5 the foils are sensitive to the amount energy deposited in them per AGS cycle
3) The foils show no signs of degradation if no more than 12e9 gold ions pass through them per AGS cycle. At some point between12e9 and 16e9 ions, signs of degradation begin to appear.
4) For the low-energy runs, as many as 20e9 gold ions passed through the foils per AGS cycle. This produced severe degradation.

# Veteran BTA foil from 2020 run



This is the upstream Al portion of the Al-C "sandwich" foil developed by P. Thieberger

# BTA foil inventory for Run 23

1) There are 3 Al-C foils in the BTA foil changer. Two of these have not been exposed to beam. The remaining one has seen some beam, but still has unused areas on it.
2) These should be adequate for the run provided we stay sufficiently below 16e9 gold ions in BTA per AGS cycle.

# We must also have protections in place for the AGS (Ref. 5)

1) Au77+ ions can do serious damage in AGS if not handled with care.
2) Energy deposited during ion loss is proportional to charge squared and is capable of putting holes in the AGS vacuum chamber!
3) It is absolutely essential that the Ring Loss Monitor system be set up to "pull the beam permit" if any local loss is too high.

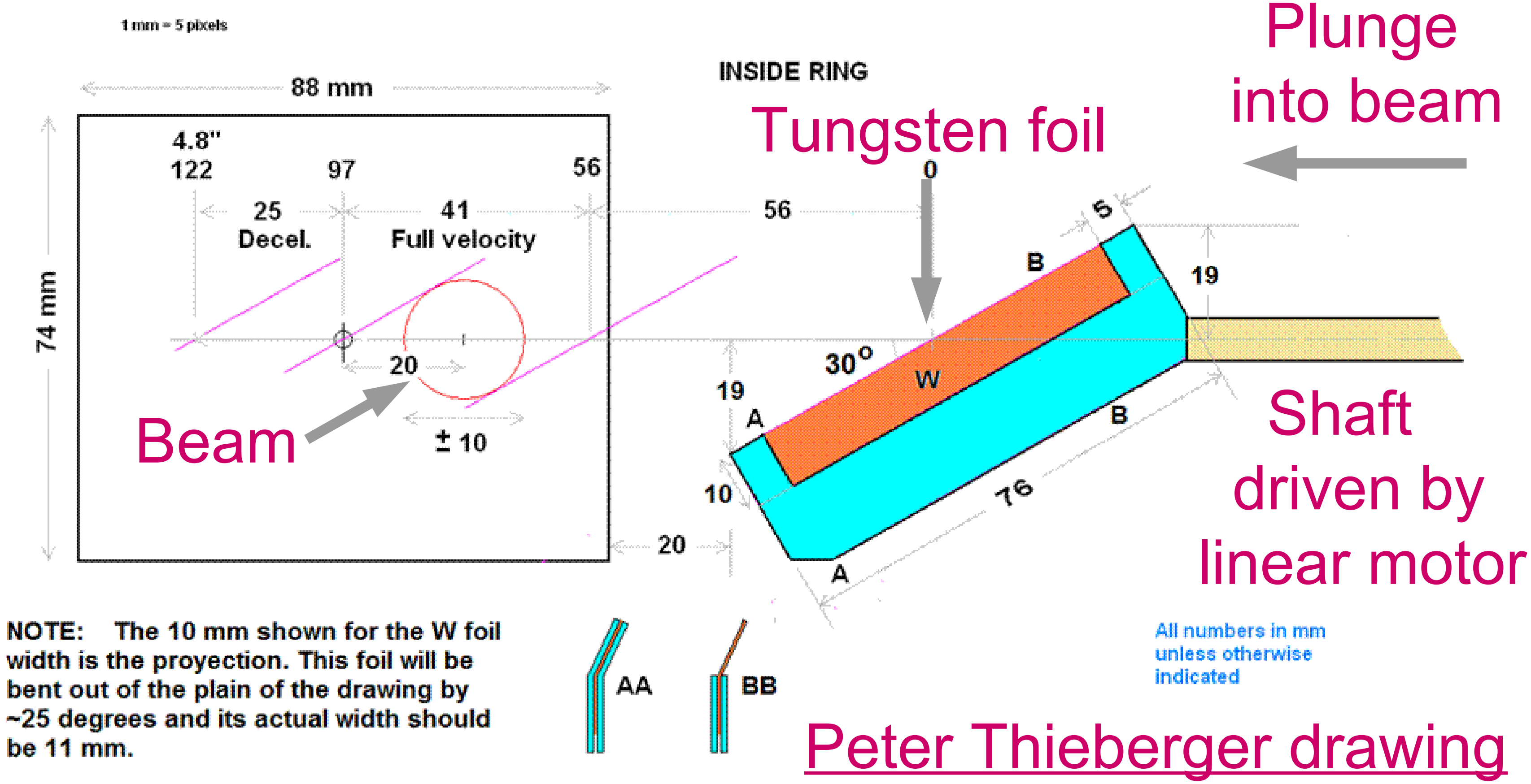
# For beam not extracted we must use the beam dump and PSF

1) Any beam not extracted from AGS must be put into the water cooled copper absorber of the beam dump.

2) This is done by means of a local orbit "bump" at the dump and a plunging stripping foil (PSF) that sits upstream of the dump

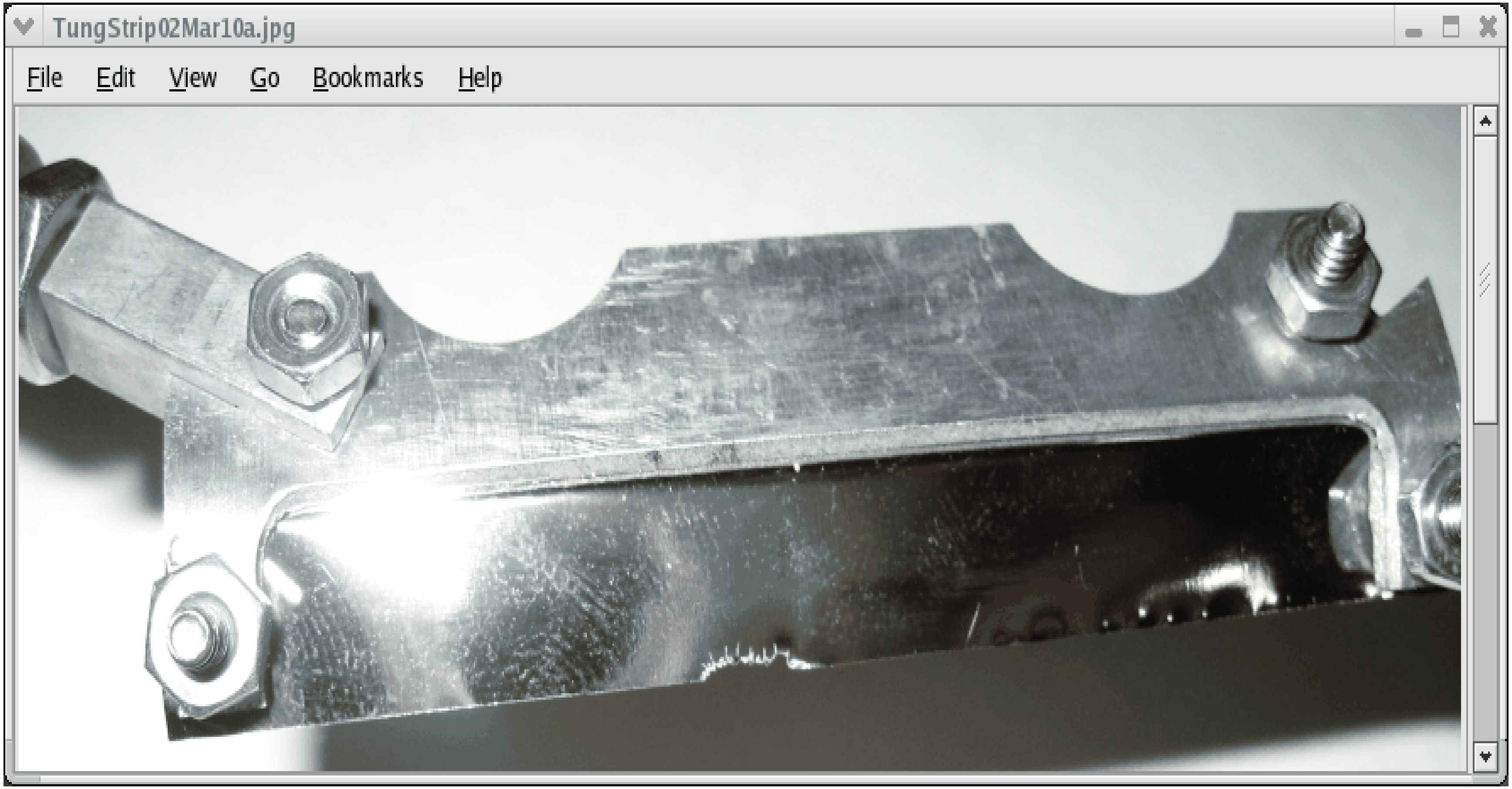
3) The dump bump and the PSF must be operational in order to allow gold beam circulating in AGS.

# The plunging stripping foil



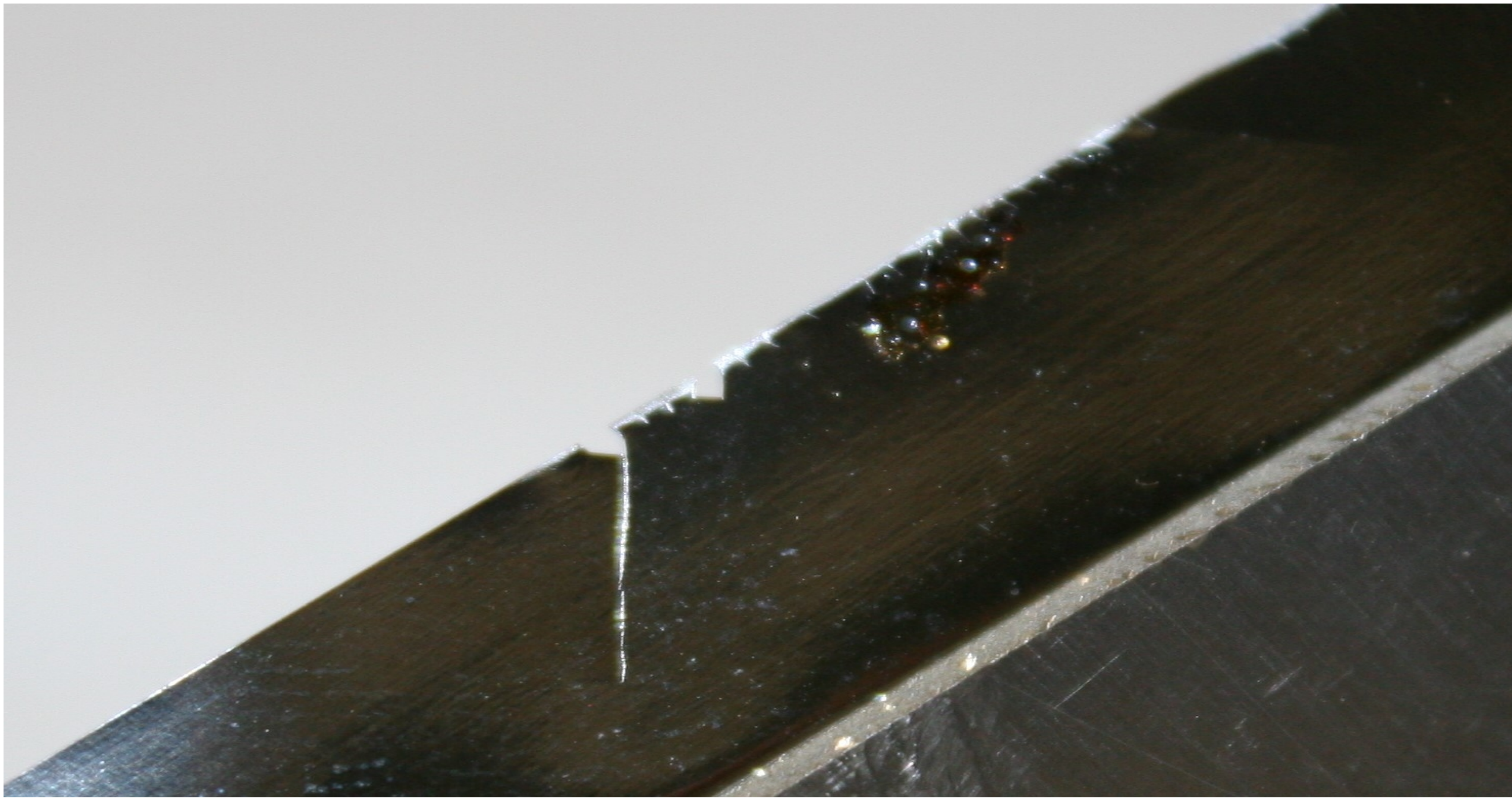

Strips Au77+ to Au79+ and gives cleaner deposition of beam on the copper absorber of the dump

# Tungsten foil erosion




At intensities of 8e9 Au77+ ions per AGS cycle we have seen evidence of melting and also cracking due to thermal stress

# Cracking seen at high intensity during low-energy RHIC runs



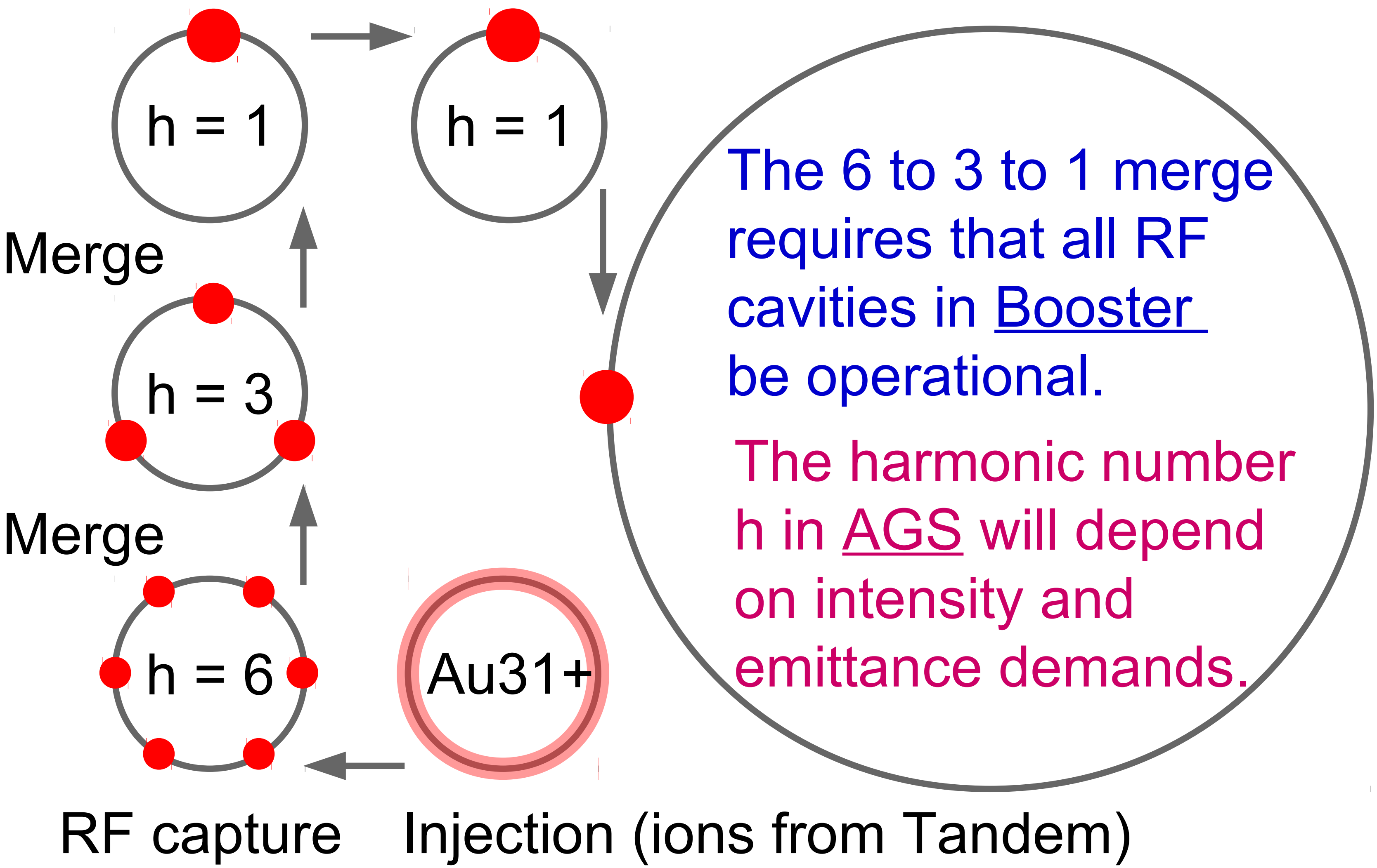
At intensities of 9.6e9 Au77+ ions per AGS cycle, this cracking required replacement of the foil during the run

# The dump itself must be protected

1) No more than 8e9 Au77+ ions may be put into the copper absorber of the dump per AGS cycle. (9.6e9 ions per AGS cycle were allowed during runs 20 and 21 under the conditions specified in Ref. 5.)

2) Calculations of energy deposition in the dump are difficult. The limits given above are based on periodic inspections of the dump after running periods.

# Tandem as source

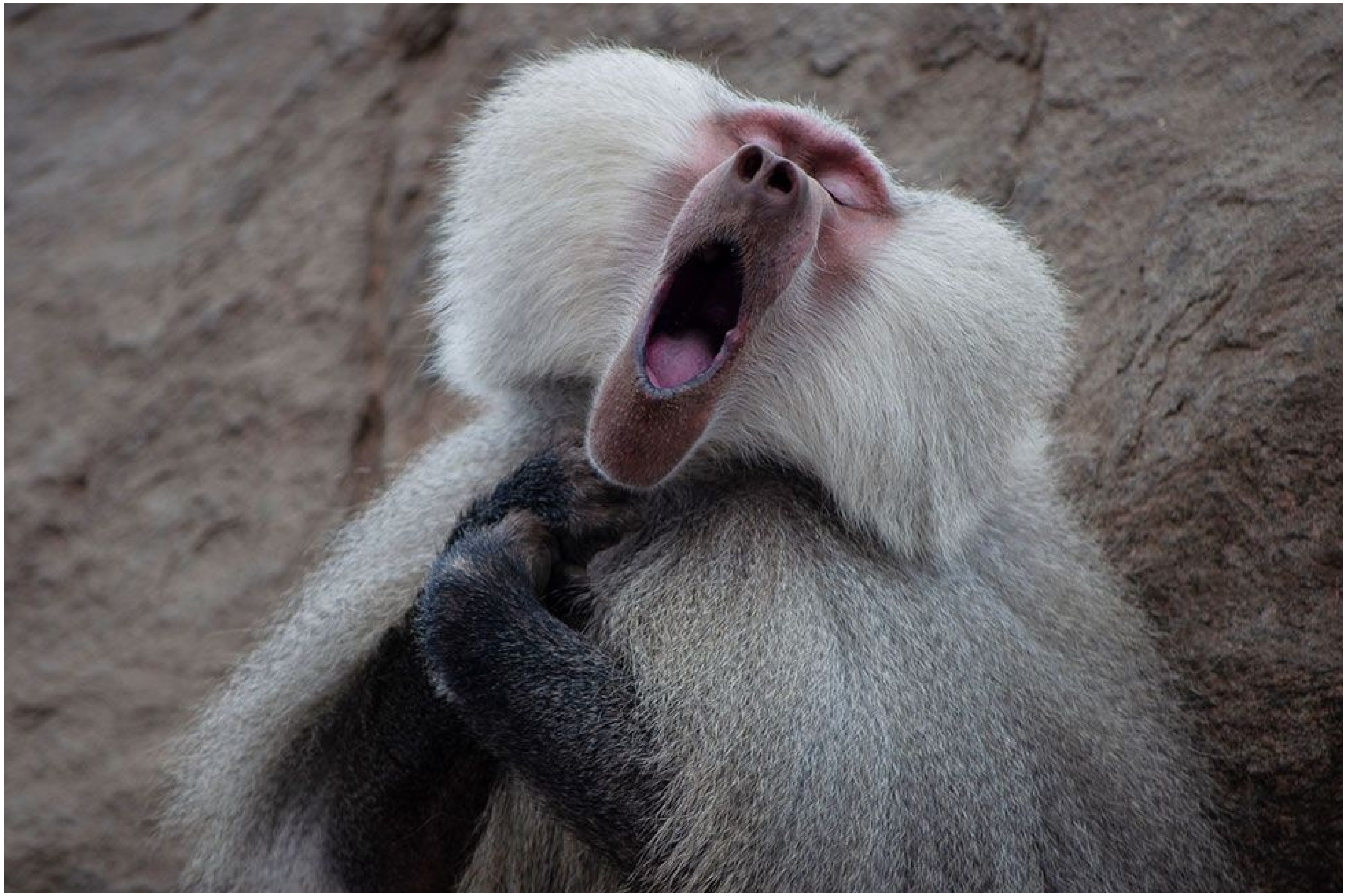


In Ref. 1 (C-A/AP/Note 571, Sept 2016) K. Zeno lists several advantages that EBIS has when compared to Tandem as the source of ions destined for RHIC.

Since the time of that note, we have had to provide high intensity and low longitudinal emittance gold bunches in RHIC for the low-energy runs 20 and 21. Tandem is the desirable choice in this case because it can easily provide the required intensity with fewer bunch merges in AGS. Having fewer merges gives bunches with lower longitudinal emittance.

It would be useful to take advantage of this fact in the setup of Booster and AGS for use of Tandem as the spare source during Run 23.

# It isn't over until…



Thank you for your attention!

# References

1) K. Zeno, C-A/AP/Note 571, Sept 2016
2) C. Gardner, C-A/AP/Note 574, Oct 2016
3) K. Zeno, C-A/AP/Note 638, Dec 2020
4) C. Gardner, C-A/AP/Note 639, Feb 2021
5) C. Gardner, C-A/AP/Note 640, Feb 2021
6) C. Gardner, C-A/AP/Note 649, Aug 2021
7) C. Gardner, et. al., IPAC2015, p.3804
8) C. Gardner, et. al., PAC07, p.1862