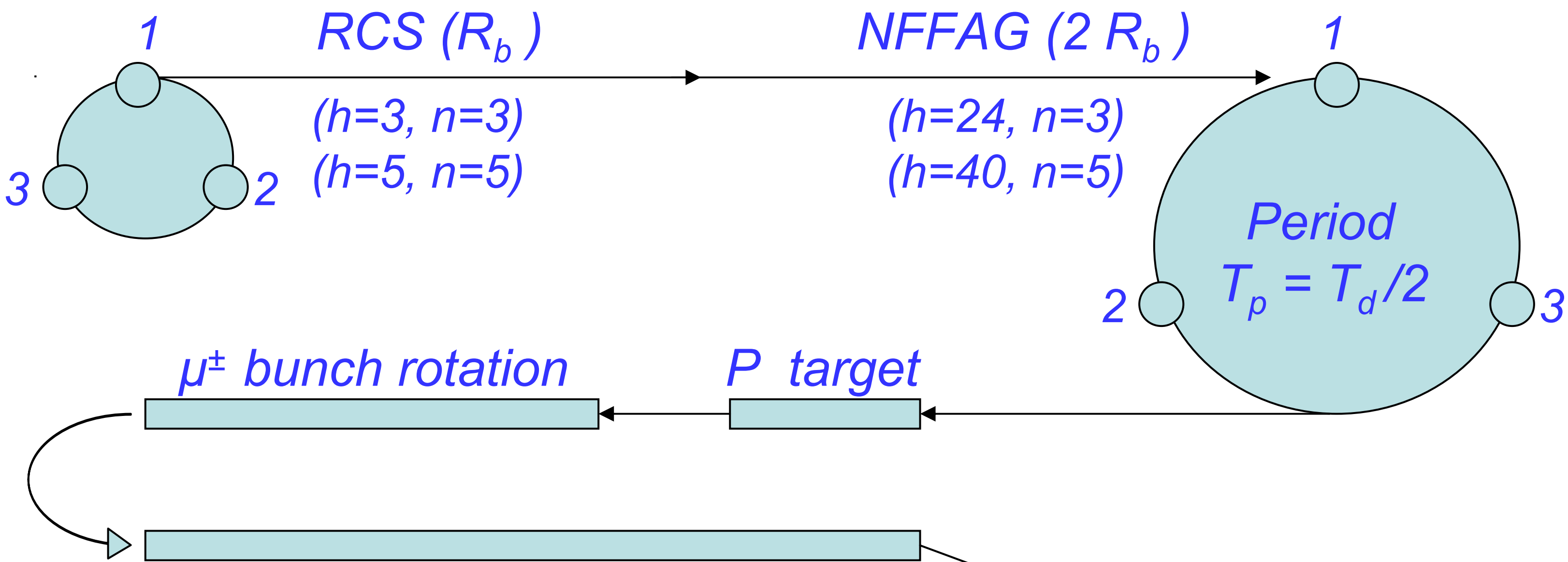
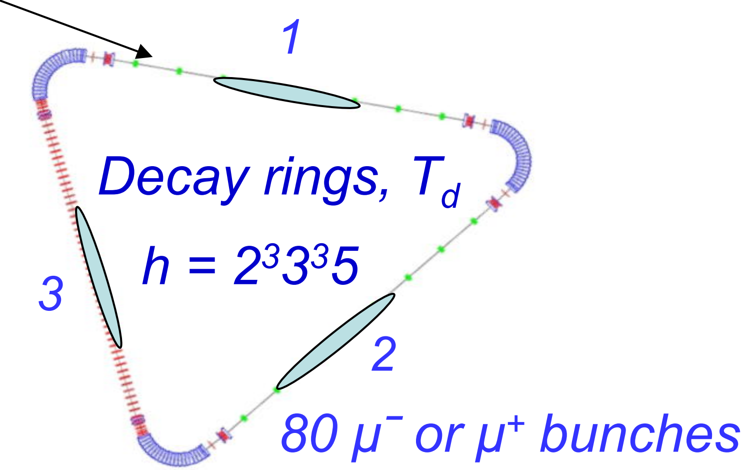
3 GeV,1.2 MW, Booster for Proton Driver

G H Rees, RAL

Bunch Train Patterns



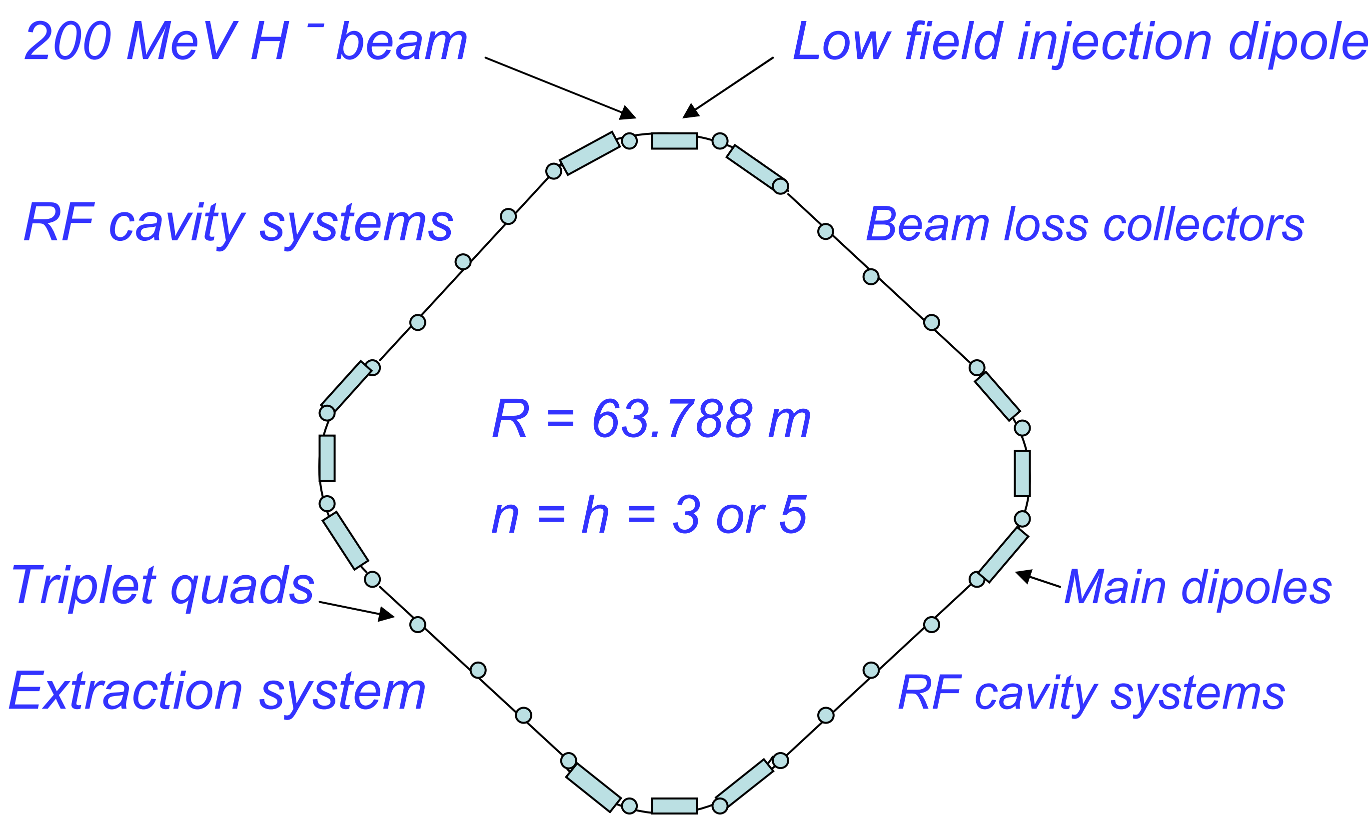
Accel. of trains of 80 $\mu^{\pm}$ bunches



NFFAG ejection delays:
$(p + m/n)\ T_d$ for m = 1 to n (=3,5)

Pulse < 40 μs for liquid target
Pulse > 60 μs for solid targets

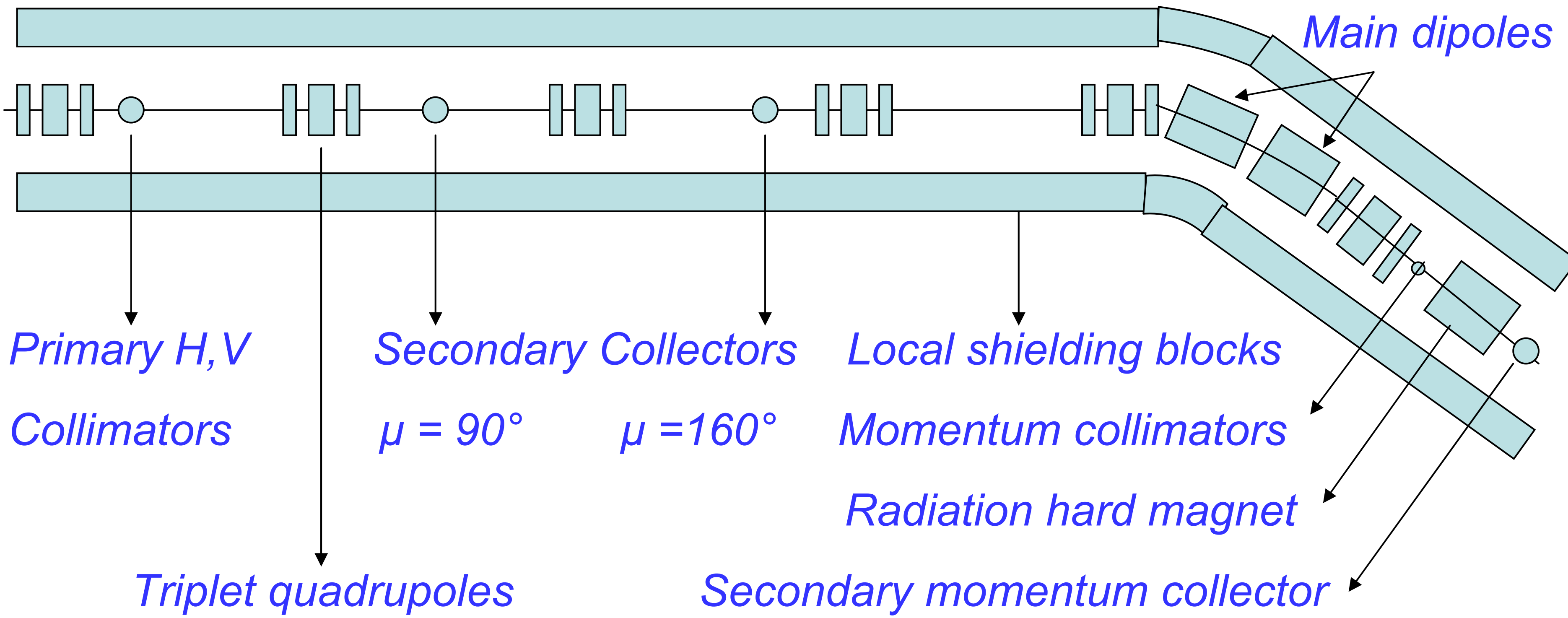
Schematic Layout of 3 GeV, RCS Booster



Parameters for 50 Hz, 0.2 to 3 GeV Booster

Number of superperiods	4
Number of cells/superperiod	4(straights) + 3(bends)
Lengths of the cells	4(14.0995) + 3(14.6) m
Free length of long straights	16 x 10.6 m
Mean ring radius	63.788 m
Betatron tunes (Q_v, Q_h)	6.38, 6.30
Transition gamma	6.57
Main dipole fields	0.185 to 1.0996 T
Secondary dipole fields	0.0551 to 0.327 T
Triplet length/quad gradient	3.5 m/1.0 to 5.9 T m^{-1}

Beam Loss Collection System



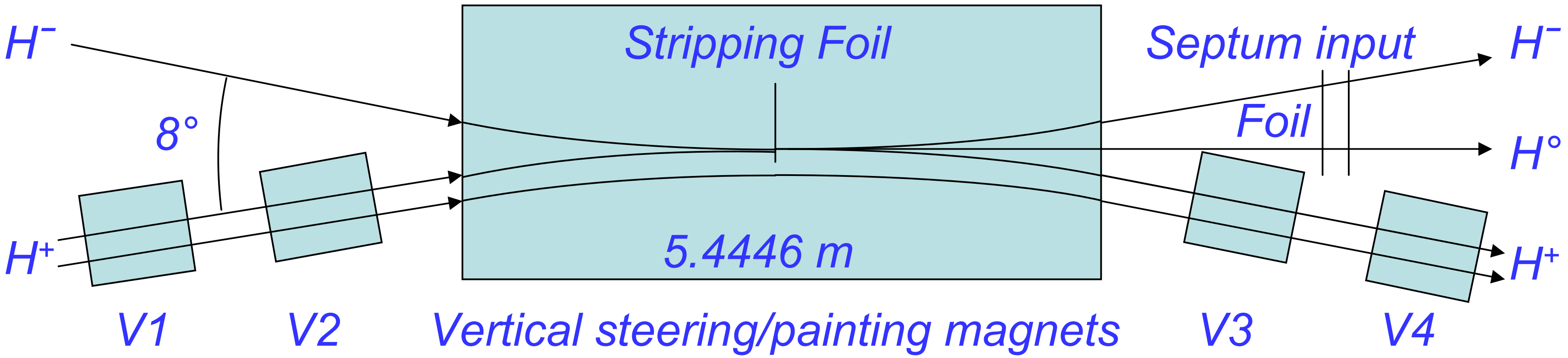
Choice of Lattice

- *ESS-type, 3-bend achromat, triplet lattice chosen*
- *Lattice is designed around the H^- injection system*
- *Dispersion at foil to simplify the injection painting*
- *Avoids need of injection septum unit and chicane*
- *Separated injection; all units between two triplets*
- *Four superperiods, with >100 m for RF systems*
- *Locations for momentum and betatron collimation*
- *Common gradient for all the triplet quadrupoles*
- *Five quad lengths but same lamination stamping*
- *Bending with 20.5° main & 8° secondary dipoles*

Schematic Plan of H^- Injection

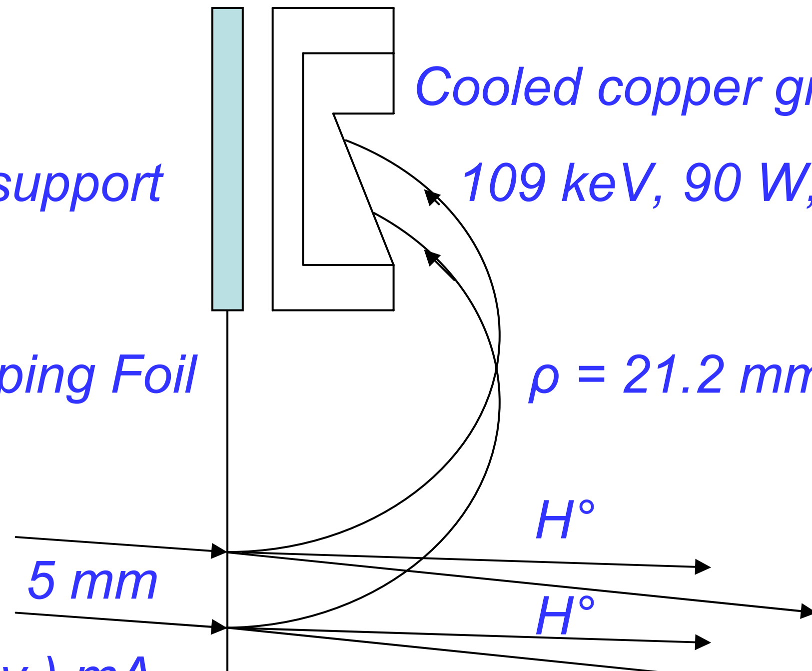
Optimum field for n = 4 & 5, H° Stark state lifetimes.

0.0551 T, Injection Dipole



- *Horizontal painting via field changes, momentum ramping & rf steering*
- *Separated system with all injection components between two triplets.*
- *H^- injection spot at foil is centred on an off-momentum closed orbit.*

Electron Collection after H^- Stripping



Foil lattice parameters : $\beta_v = 7.0$ *m,* $\beta_h = 7.8$ *m,* $D_h = 5.3$ *m,* $D_h/\sqrt{\beta_h} = 1.93\ m^{1/2}$

H^- *parameters at stripping foil ;* $\beta_v = 2.0$ *m,* $\beta_h = 2.0$ *m,* $D_h = 0.0$ *m,* $D_h' = 0.0$

Anti-correlated, H^- Injection Painting

Vertical acceptance

H^- injected beam

Initial closed orbits

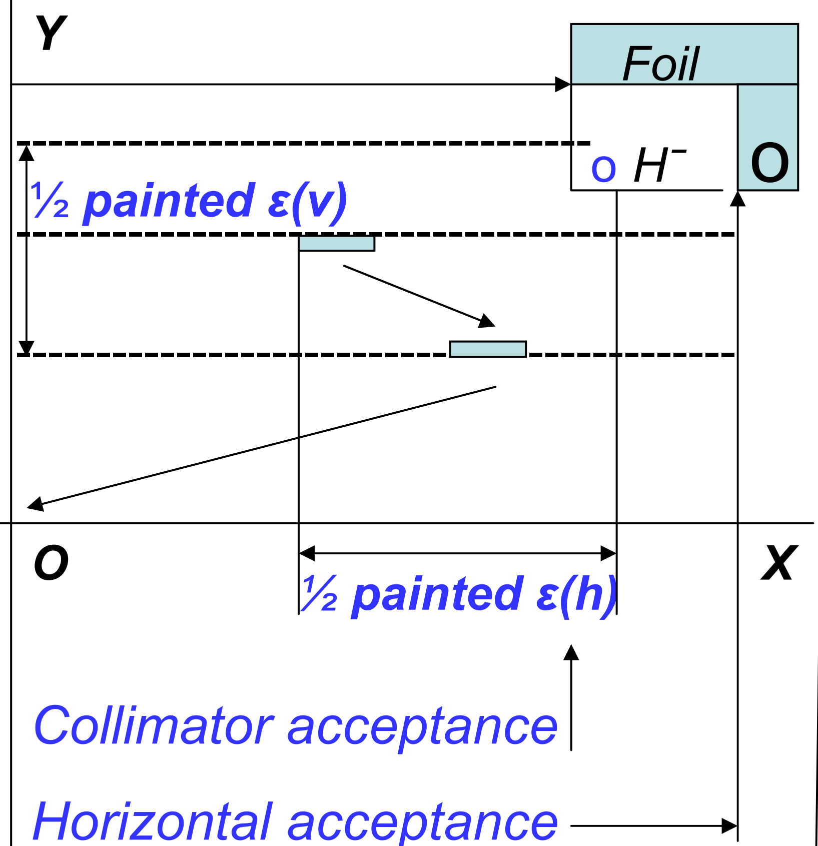
Final closed orbits

Collapsed closed orbits

Δp/p spread in X closed orbits

Small v, big h amplitudes at start

Small h, big v amplitudes at end.



For correlated transverse painting : interchange X closed orbits ⇄

Why Anti-correlated Painting?

Assume an elliptical beam distribution of cross-section (a, b).

The transverse space charge tune depressions/spreads are :

$$\delta Q_v = 1.5\,[1 - S/\!\int(\beta_v\, ds\, /\, b(a+b))]\ \delta Q_v\,(uniform)$$

$$4S = \int[\beta_v/b(a+b)^2]\,[(y^2\,(a + 2b)/\,2b^2\,) + (\,x^2/\,a)]\,ds$$

Protons with (x = 0, y = 0) have $\delta Q_v = 1.5\ \delta Q_v$ (uniform distrib.)

Protons with (x = 0, y = b) have $\delta Q_v \sim 1.3\ \delta Q_v$ (uniform distrib.)

Protons with (x = a, y = 0) or (x = a/2, y= b/2) have ~ 1.3 factor.

δQ shift is thus less for anti-correlated than correlated painting.

The distribution may change under the effect of space charge.

Emittances and Space Charge Tune Shifts

Design for a Laslett tune shift (uniform distribution) of $\delta Q_v = 0.2$.
An anti-correlated, elliptical, beam distribution has a $\delta Q_v = 0.26$.

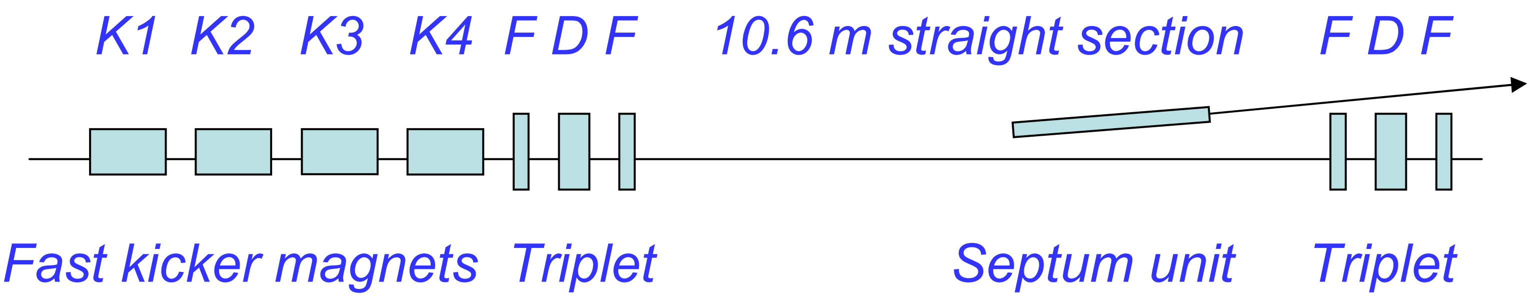
For 5 10^{13} protons at 200 MeV, with a bunching factor of 0.47, the estimated, normalised, rms beam emittances required are:

$$\varepsilon_{\sigma\, n} = 24\ (\pi)\ \text{mm mrad}$$
$$\varepsilon_{max} = 175\ (\pi)\ \text{mm mrad}$$

The maximum, vertical beam amplitudes (D quads) are 66 mm.
Maximum, horizontal beam amplitudes (in F quads) are 52 mm.

Maximum, X motions at high dispersion regions are < 80 mm.
Max. ring/collimator acceptances are 400/200 (π) mm mrad.

Fast Extraction at 3 GeV



- *Horizontal deflections for the kicker and septum magnets*
- *Rise / fall times for 5 (3) pulse, kicker magnets = 260 ns*
- *Required are 4 push-pull kickers with 8 pulser systems*
- *Low transverse impedance for (10 Ω) delay line kickers*
- *Extraction delays, ΔT, from the booster and NFFAG rings*

- *R & D necessary for RCS, Driver and Decay ring pulsers*

RF Parameters for 3 GeV Booster

- *Number of protons per cycle* — *$5\ 10^{13}$ (1.2 MW)*
- *RF cavity straight sections* — *106 m*

- *Frequency range for h = n = 5* — *2.117 to 3.632 MHz*
- *Bunch area for h = n = 5* — *0.66 eV sec*
- *Voltage at 3 GeV for $\eta_{sc} < 0.4$* — *417 kV*
- *Voltage at 5 ms for $\varphi_s = 48°$* — *900 kV*

- *Frequency range for h = n = 3* — *1.270 to 2.179 MHz*
- *Bunch area for h = n = 3* — *1.1 eV sec*
- *Voltage at 3 GeV for $\eta_{sc} < 0.4$* — *247 kV*
- *Voltage at 5 ms for $\varphi_s = 52°$* — *848 kV*

BNL, FNAL & CERN, 4MW Drivers?

Parameters needed so that comparisons may be made with:

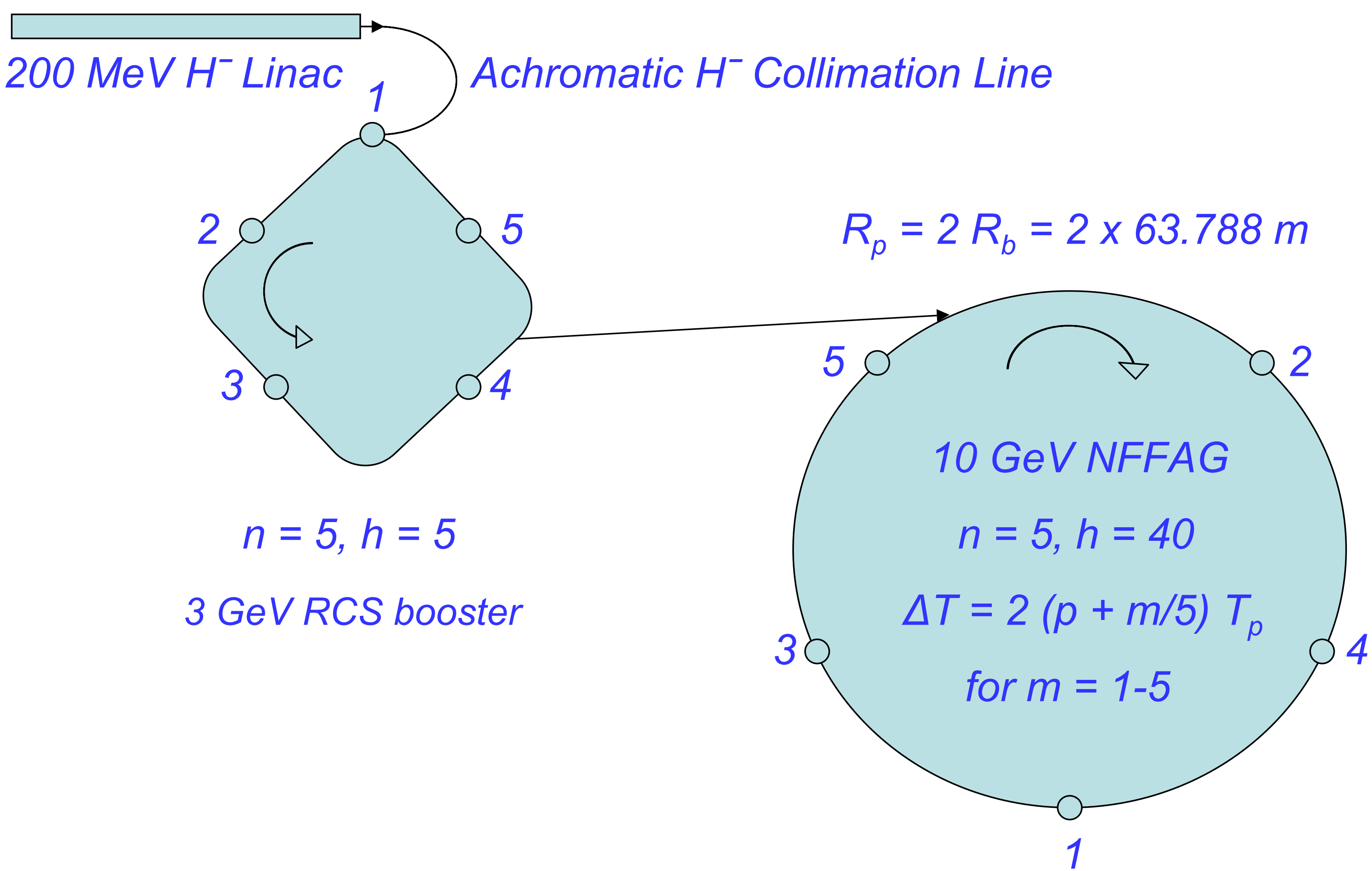
- *BNL's scheme of single, 25 GeV bunches (15/50 Hz)*
- *FNAL's, 8 GeV linac-accumulator-compressor scheme*
- *CERN's, 5 GeV SPL-accumulator-compressor scheme*

The 50 Hz, 3 GeV booster is not well suited to BNL option as:

- *A 3 GeV and a 25 GeV holding ring would be needed*
- *The booster rf system would be at very low frequency*

FNAL/CERN options need compatible rings, 1-turn extractions, non-adiabatic bunch compression & multiple trains in $\mu^{\pm}$ rings. Linacs need low chopping duty cycles and hence long pulses.

4MW, 50 Hz,10 GeV Proton Driver



Bunch Compression at 10 GeV

For 5 proton bunches:
Longitudinal areas of bunches = 0.66 eV sec
Frequency range for a h of 40 = 14.53-14.91 MHz
Bunch extent for 1.18 MV/ turn = 2.1 ns rms
Adding of h = 200, 3.77 MV/turn = 1.1 ns rms

For 3 proton bunches:
Longitudinal areas of bunches = 1.10 eV sec
Frequency range for a h of 24 = 8.718-8.944 MHz
Bunch extent for 0.89 MV/ turn = 3.3 ns rms
Adding of h = 120, 2.26 MV/turn = 1.9 ns rms

Booster and Driver tracking studies are needed

R & D Requirements

Development of FFAG space charge tracking code.
Injection tracking with space charge in the booster.
Space charge tracking for booster and driver rings.

Building an electron model for NFFAG proton driver.
Study of NFFAGs as possible muon accelerators.

Development of multiple pulse kicker systems.

RCS, NFFAG & Decay ring, magnet design & costing.

Site lay-out drawings & conventional facilities design