Beam Preparation for Injection to CSNS RCS

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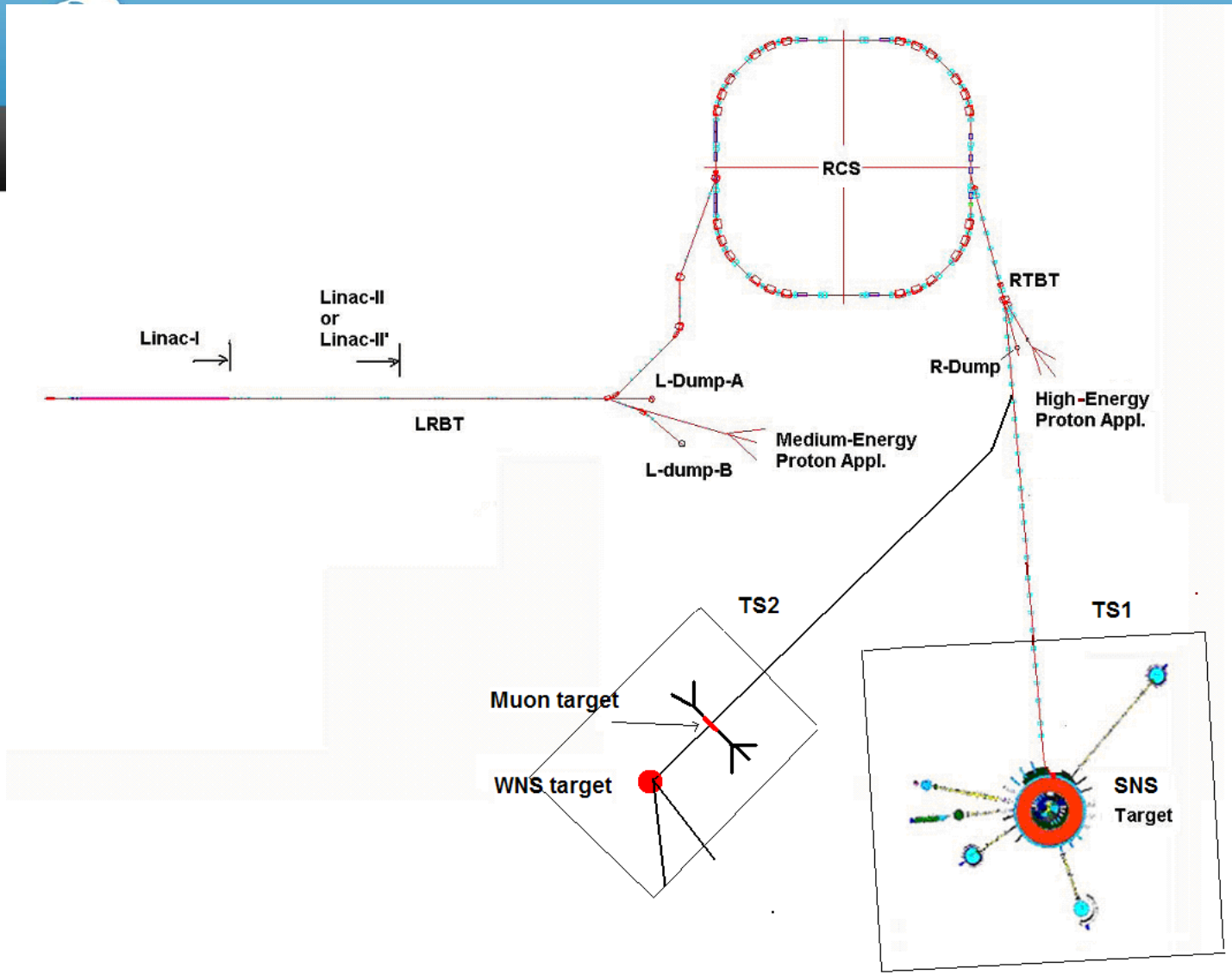
Main topics

- RCS injection design and requirements
- LRBT transport line
- Transverse halo collimation by triplets and foil scrapers
- SCOMT code and simulation results
- Momentum spread reduction and momentum tail collimation

RCS Injection Design

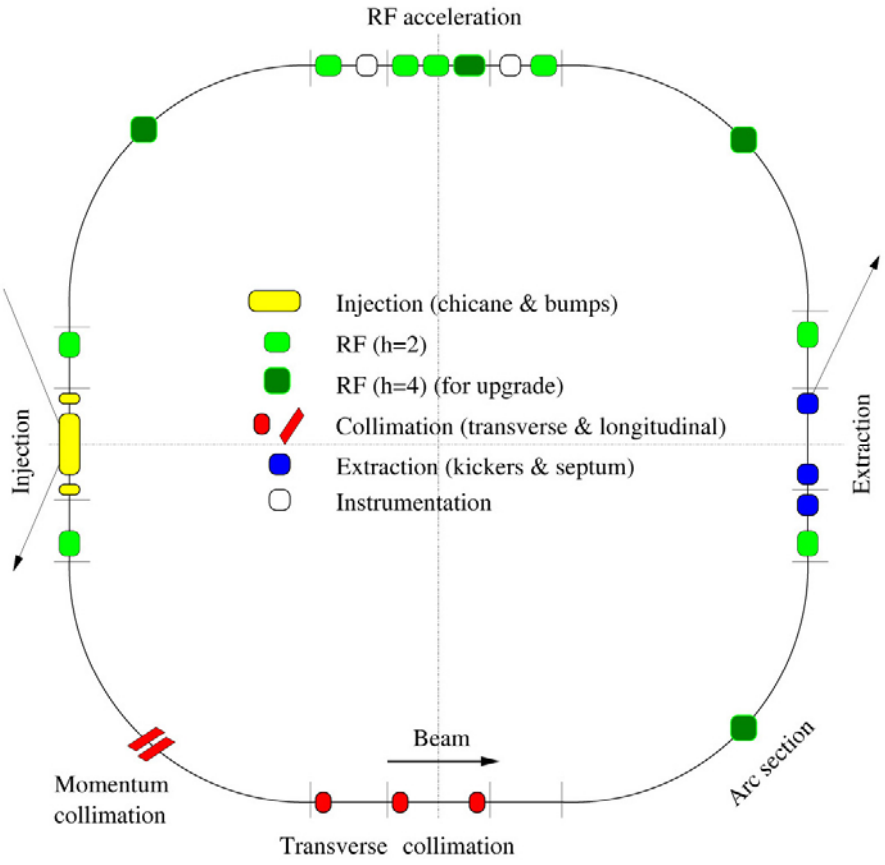
CSNS Main Parameters

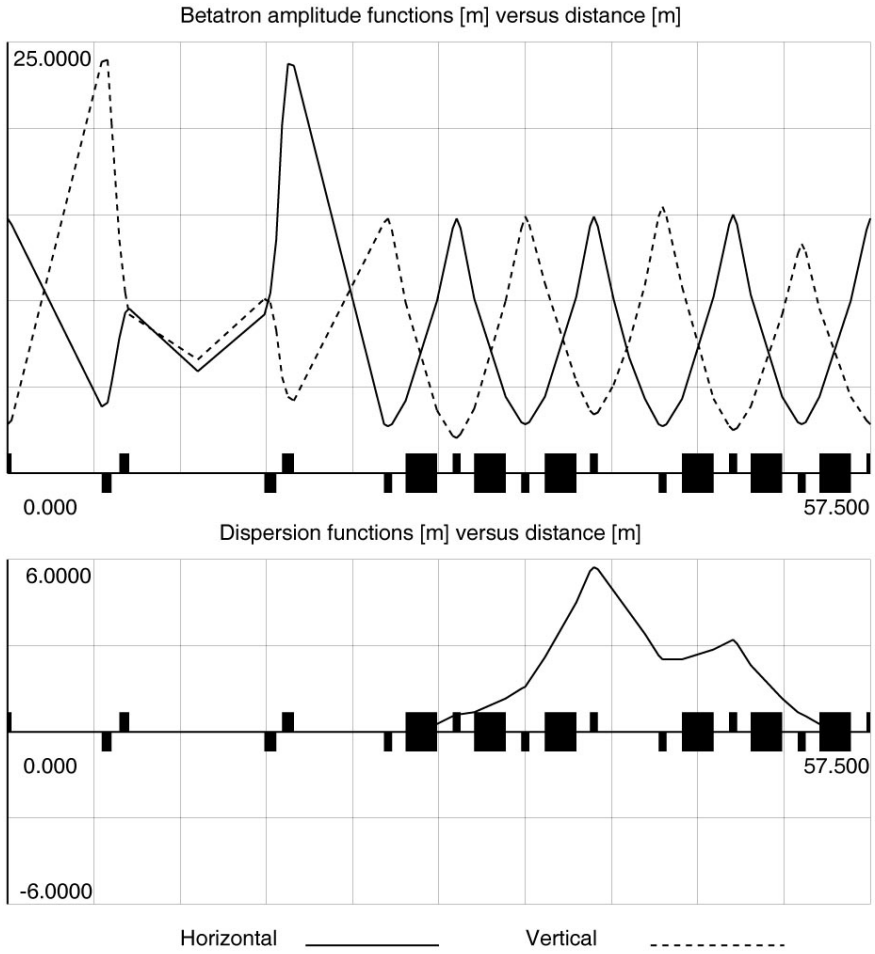
Phase	I	II	ultimate
Beam power on target [kW]	120	240	500
Beam energy on target [GeV]	1.6	1.6	1.6
Ave. beam current [μA]	76	151	315
Pulse repetition rate [Hz]	25	25	25
Protons per pulse [10^{13}]	1.9	3.8	7.8
Linac energy [MeV]	80	130	230
Linac type	DTL	DTL	DTL+SCL
Target number	1	1	2
Target material	Tungsten		
Moderators	H_2O (300K), CH_4(100K), H_2(20K)		
Number of spectrometers	5	18	>18



CSNS Layout Scheme

RCS Lattice & Injection





Design Criteria for Injection System

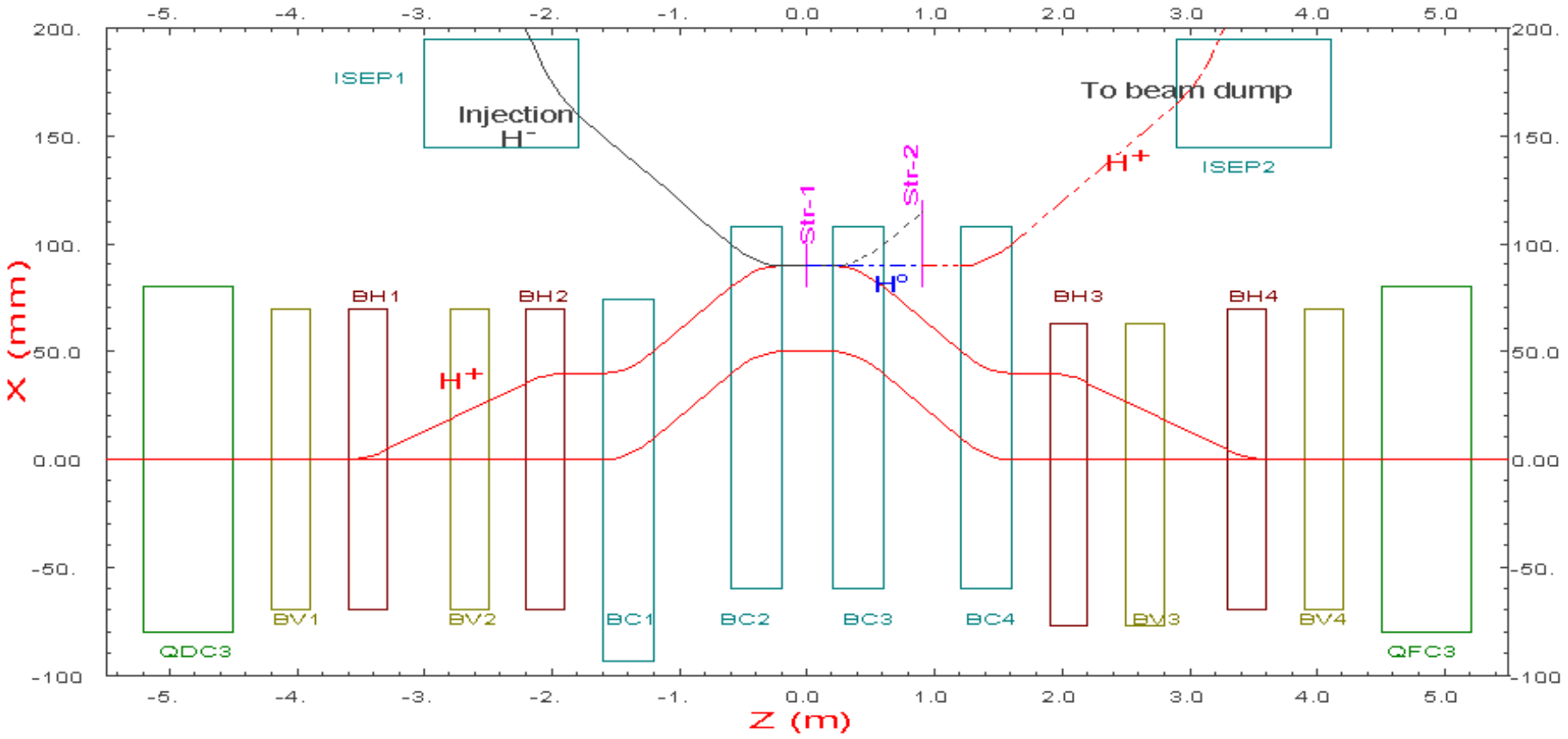
- **Layout**
  - Orbit bumping for facilitating installation of injection devices
  - Minimize proton traversal on stripping foil
  - Weak perturbation to ring lattice
  - Minimize local radiation level
- **Phase space painting**
  - Better uniform beam distribution to alleviate space charge effect
- **Requirement to injection devices**
  - Control difficulties of fabrication of the devices (magnets, PS, stripper)
  - Control power consumption

Injection Scheme

- **From lattice**
  - In one of dispersion-free long straights (9 m)
    - No residual dispersion
    - Possible due to low injection energy
    - minor perturbation to betatron matching
  - Doublets: double-waist
  - Closed-orbit chicane
    - Facilitate installation
    - DC+offset bumpers
- **Phase space painting**
  - **Keeping both correlated and anti-correlated schemes**
  - **Ring bumpers in both horizontal and vertical**

Injection energy (GeV)	0.08/ 0.13
Injection rigidity (Tm)	1.231 / 1.704
Accumulated particles	1.9/3.8 × 10^13
Injection time (ms)	0.15~0.30
Painting planes	H & V
Painting transverse emittance (pi.mm.mrad)	200~250
Injection emittance (pi.mm.mrad, r.m.s.)	1.0
Injection current (mA)	15~35

RCS Injection Layout



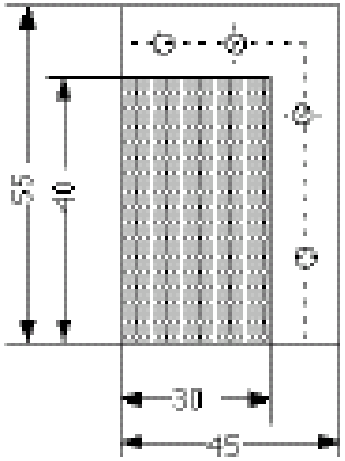
BC1~4: DC Chicane magnets; BH1~4: Horizontal painting magnets; BV1~4: Vertical painting magnets

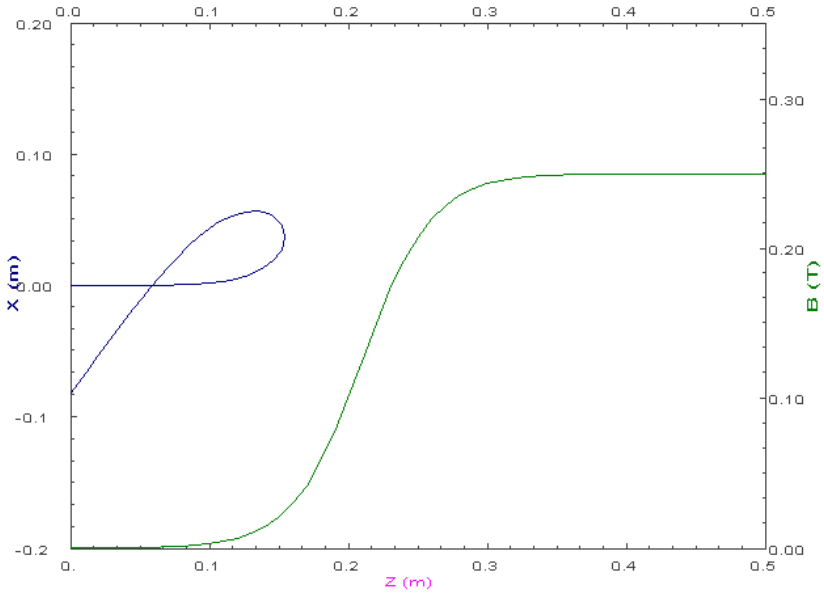
Main Characteristics of the Injection System

- **All bump magnets are in one long drift**
  - Possible due to low beam rigidity and long drift (9m)
  - Minimize injection errors due to beam jitter and injection matching (vertical steering)
  - Both correlated and anti-correlated painting
  - BCs, BHs and BVs are powered in series to reduce the field quality requirement and the cost (multipole field self-cancellation as two bumpers are close within each pair)
- **Non-stripped H-minus stopped directly by an absorber**
  - Maximum 10W at CSNS-II, even lower for thicker foil
  - Almost no H- particles missing the foil with a well defined beam (4~8 pi.mm.mrad)

Injection Strippers

- **Two Strippers**
  - Main stripper for converting at least 98% H- beam into H+
    - Alumina or Carbon ~80μg/cm^2
    - Two free sides
    - Surveillance and replacement
  - Auxiliary stripper for converting partially-stripped H0 beam to injection dump
    - Thicker alumina foil 200 μg/cm^2
    - One free side
- **Electron collector**
  - EP instability
  - Taking use of BC3 fringe field
  - Natural cooling (<18W)

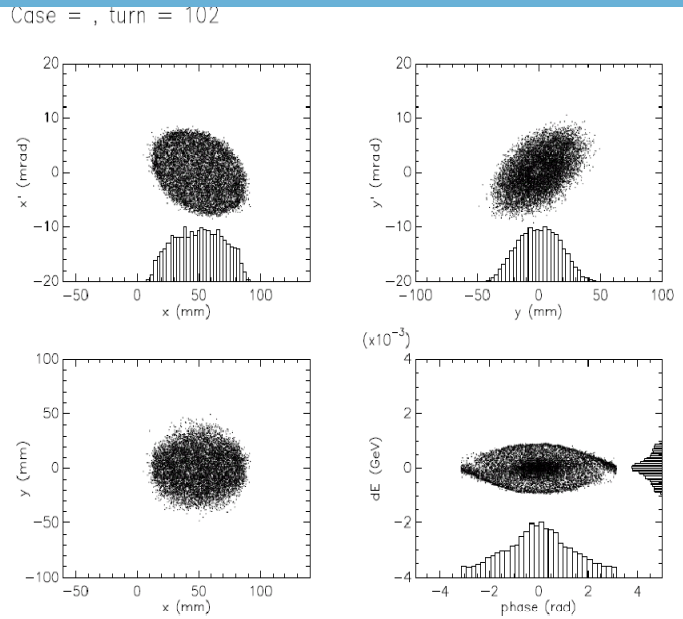




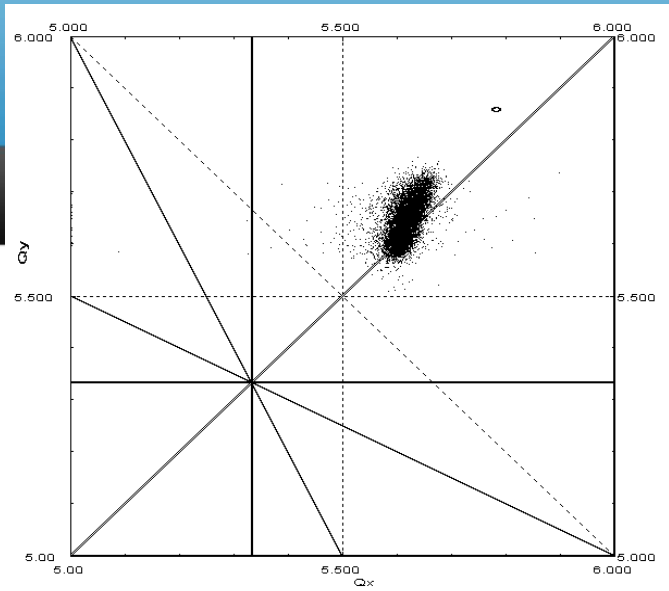
Detailed painting studies

- Using 3D ORBIT simulations including space charge
  - Focusing on: distribution uniformity, emittance blowup and foil traversal
- Different working points
- Correlated and anti-correlated painting schemes
- Linac peak current dependence
- Chopping rate dependence
  - Balance between transverse and longitudinal beam losses
- RF voltage curve dependence
- Longitudinal painting (only with momentum offset)

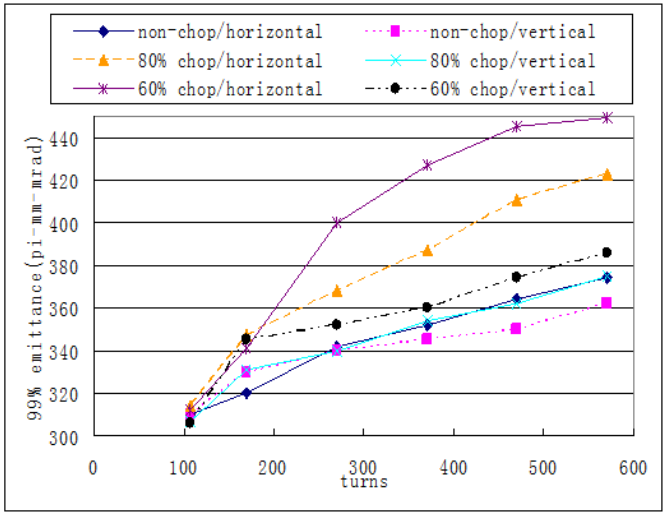
Some Simulation Results



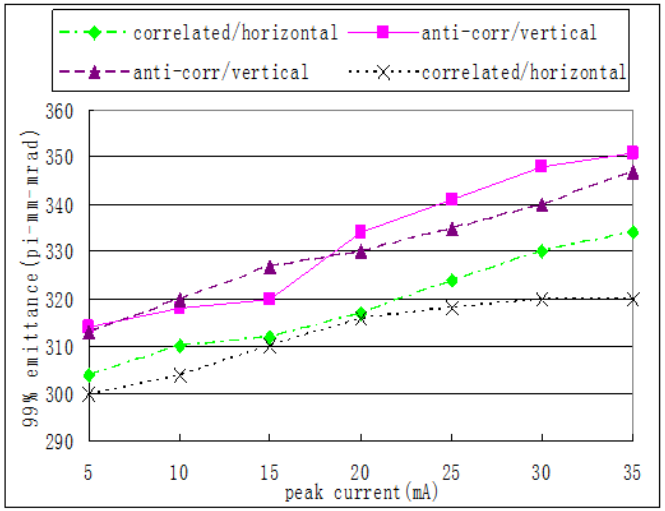
Anti-correlated painting



Tune spread at painting end (WP: 5.78/5.86)



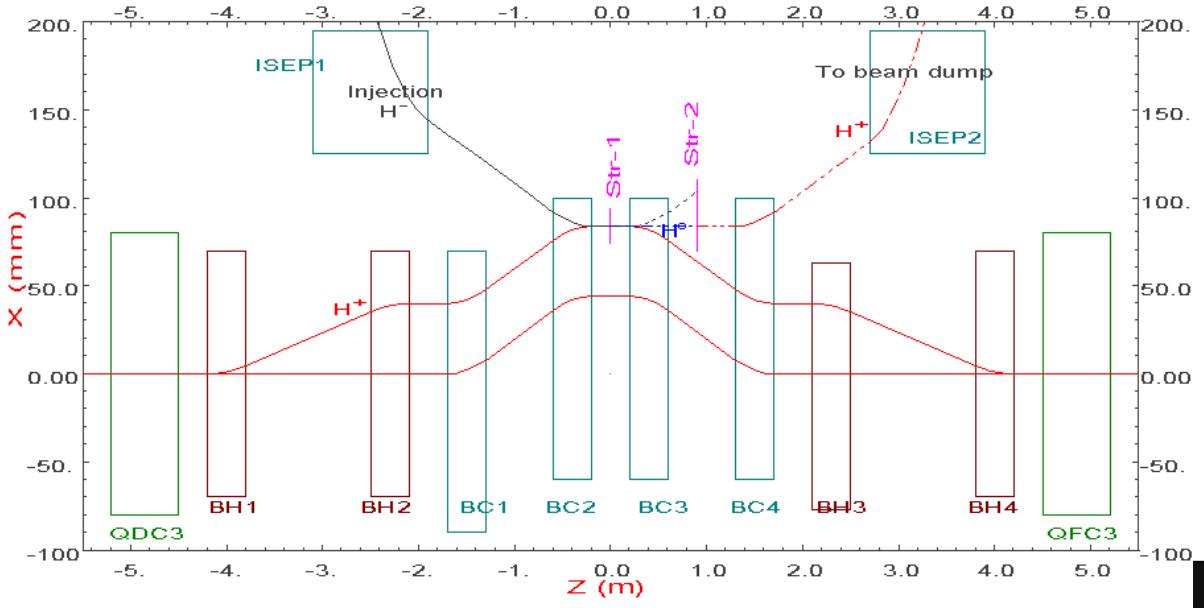
Emittance blowup vs chopping rate



Emittance blowup vs linac current

Upgrading potential with injection energy of 230 MeV

- **Preliminary Injection design for CSNS-II' (500 kW) has been carried out**
  - Vertical painting by steering magnets in injection line
- **Problems with increased energy of 230 MeV (or 250 MeV)**
  - H- Lorentz stripping in LRBT
  - H0 Stark states decay in bumpers



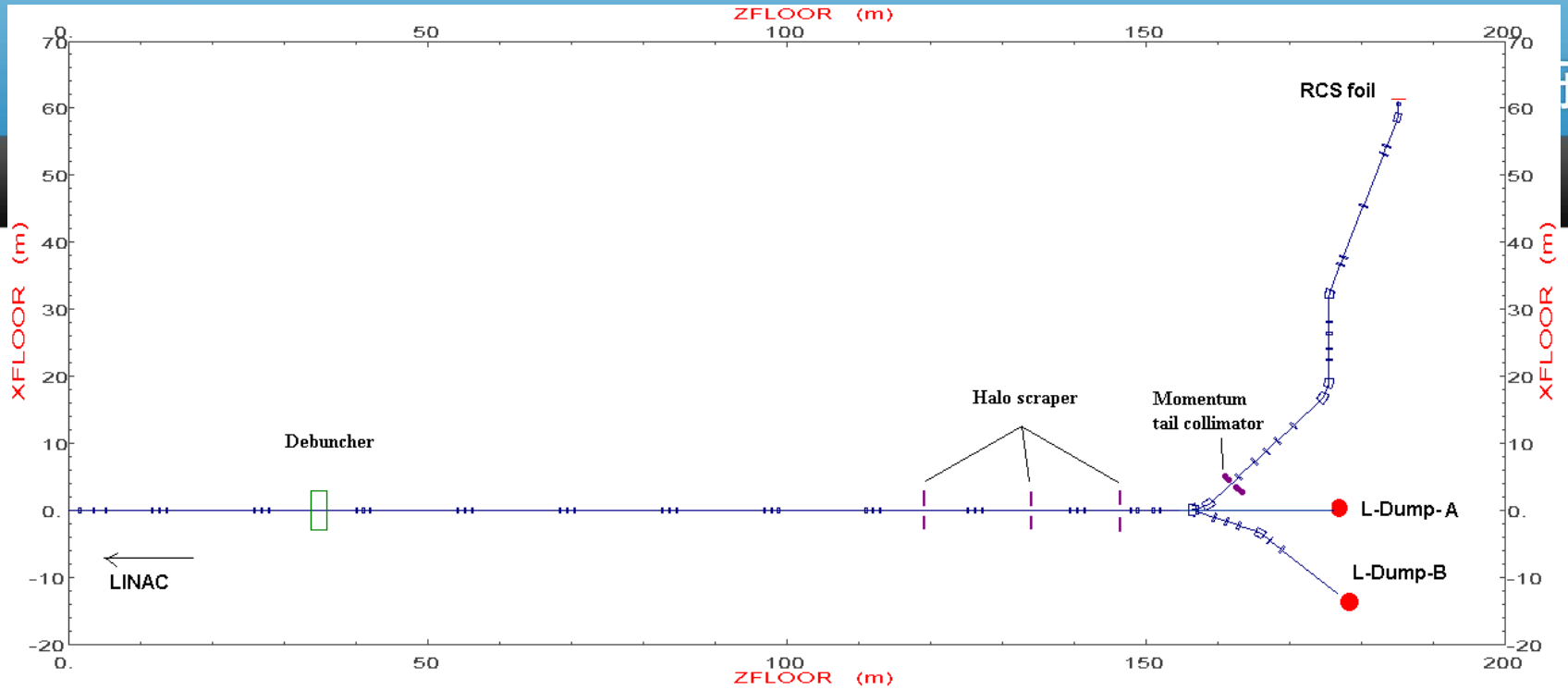
Linac to Ring Beam Transport Line

Main functions of LRBT

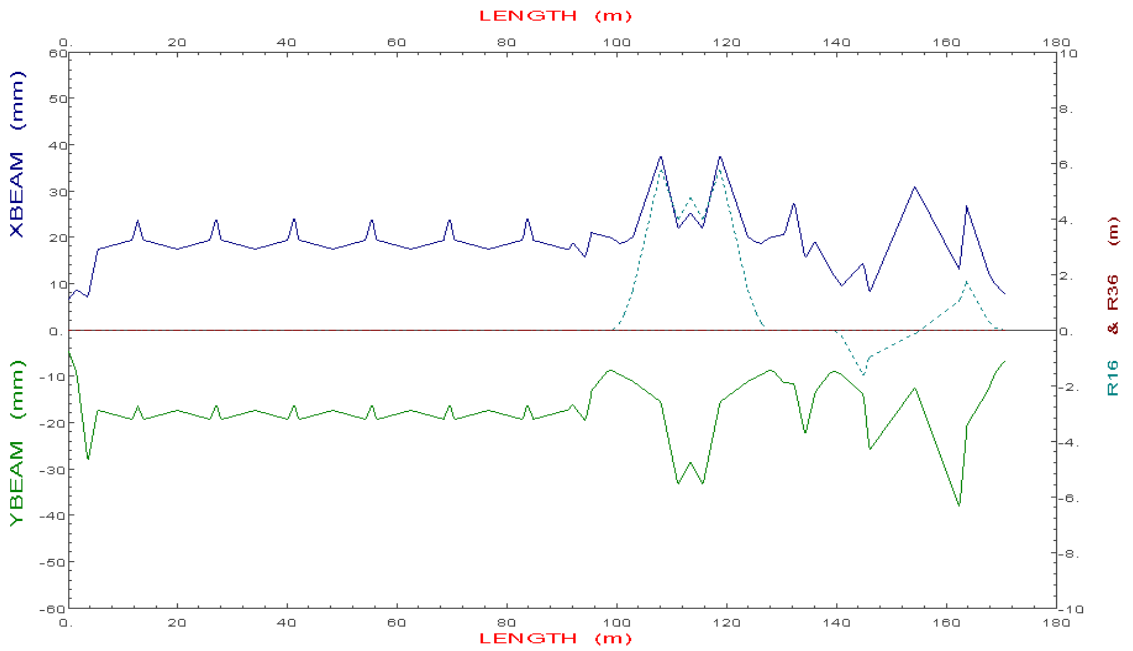
- Transfer H- beam from linac to RCS
- Transfer H- beam to linac beam dumps
- Match to transverse requirements at injection foil
- Debuncher to reduce momentum spread
- Transverse halo collimation
- Momentum tail collimation
- Reserved potential for upgrading
- Beam transport for medium energy proton applications

Main Beam Characteristics in the LRBT

Parameters	CSNS-I	CSNS-II	CSNS-II'
Ion species	H-minus	H-minus	H-minus
Beam energy (MeV)	80	130	230
Repetition rate (Hz)	25	25	25
Bunch frequency (MHz)	324	324	324
Gamma	1.085	1.139	1.245
Beta	0.389	0.478	0.596
Beam rigidity (T.m)	1.320	1.704	2.322
Average current (uA)	81	158	328
Peak current (mA)	20	40	50
Beam power (kW)	6.5	20.5	75.5
Emittance (π mm.mrad, r.m.s)	1	1	1
Acceptance (π mm.mrad)	25	25	25
momentum spread (%)	0.05~0.5	0.05~0.5	0.05~0.5



LRBT layout and beam envelope



Layout design of LRBT

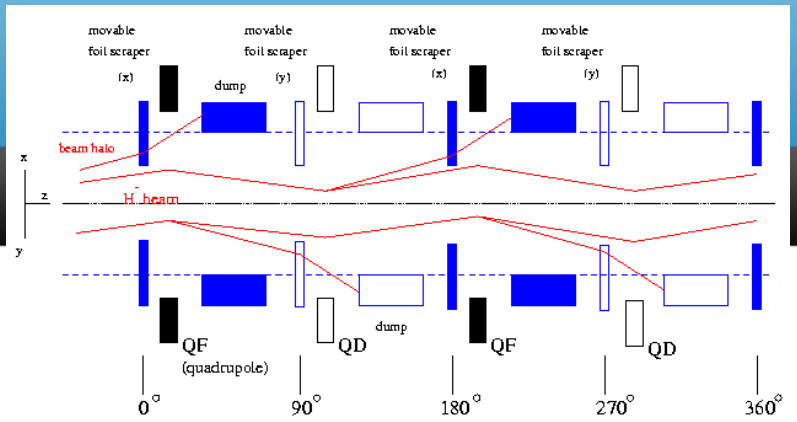
- **Long straight section**
  - Basically triplet cells of 60 degrees
  - Reserved space of 85 m for linac upgrading
  - Debunchers in different CSNS phases
  - Transverse halo collimation
  - Transverse matching to both linac and bending sections
- **Achromatic bending sections**
  - Two achromatic bending sections: symmetric 90° + anti-symmetric 20°
  - Modest dispersion for momentum collimation and resistant to space charge effect
- **Two beam dumps**
  - Dump-A: low as 200 or 400 W, straight end, for initial linac commissioning and dumping scraped H0
  - Dump-B: large as 6.5 kW, possible for full beam power commissioning, and for dumping scraped protons

Transverse Halo Collimation by Triplets and Foil Scrapers

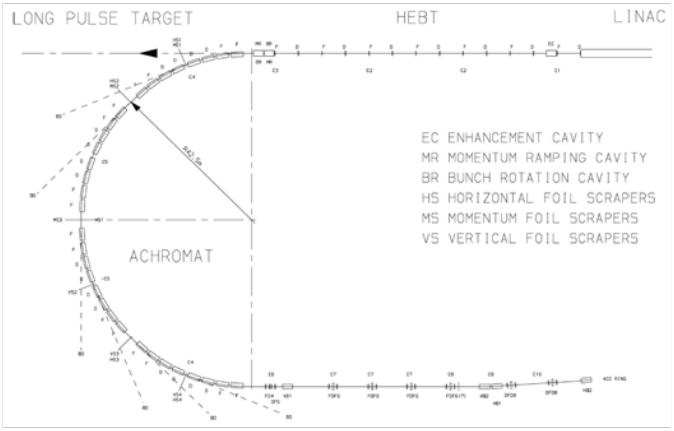
Transverse Halo Collimation in LRBT

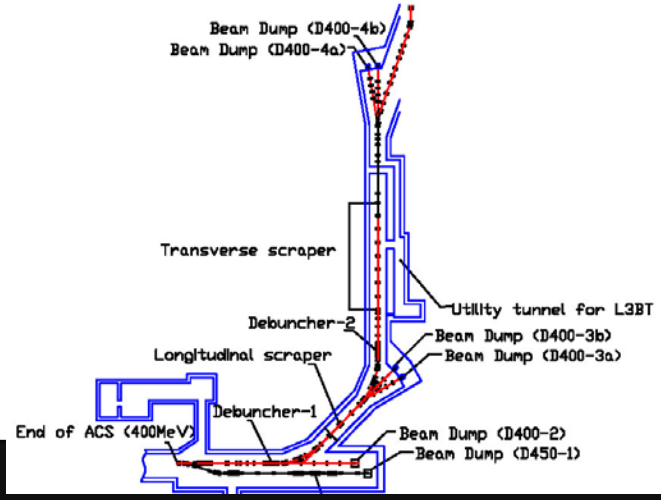
- **Purposes**
  - To avoid the missing hit of H- on the injection foil
  - To reduce the halo production during phase space painting
  - To reduce the beam losses in the injection magnets
  - To increase the collimation efficiency of the momentum tail
  - Stripped particles can be used for other application experiments while in normal operation

Comparison among different collimation methods



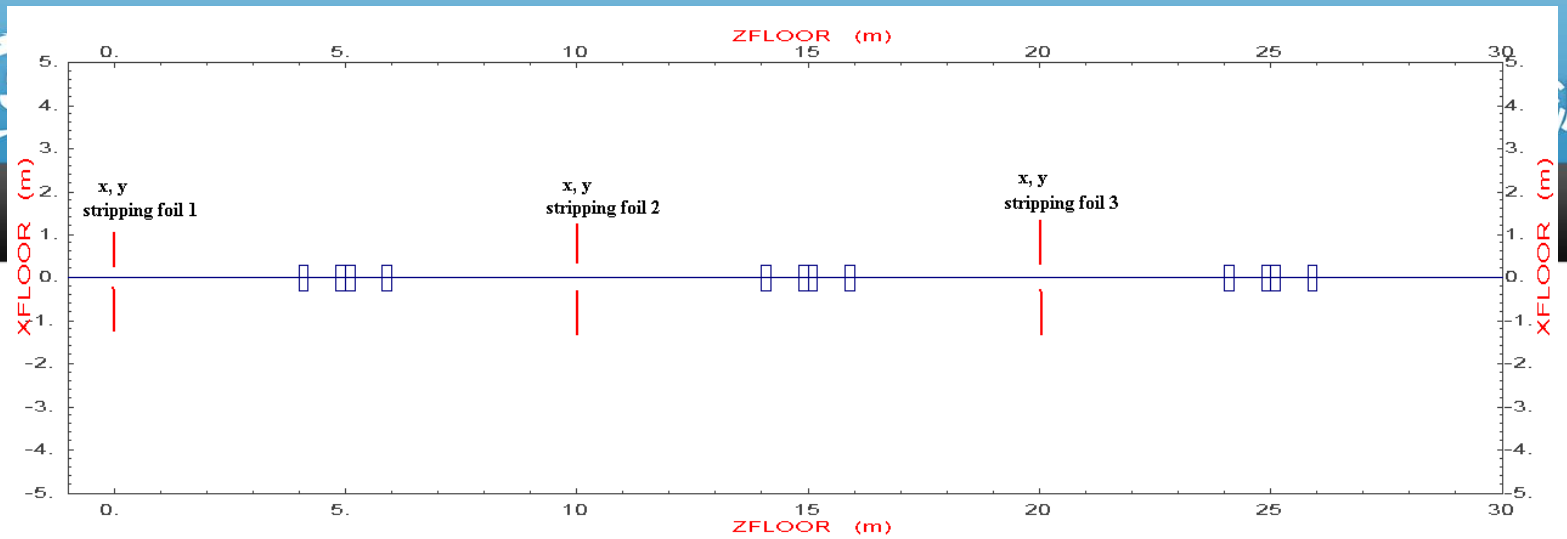
- **FODO cells and immediate beam dumps**
  - Used by SNS and AUSTRON
  - No need to enlarge Q apertures
  - More collimators and radiation
- **Achromat and remote beam bumps**
  - Proposed by ESS
  - Expensive with more beam line and dumps
  - Effective for very high beam power
- **FODO cells and remote beam dumps**
  - Used by J-PARC
  - Cheap with one beam dump
  - Relatively large beam loss



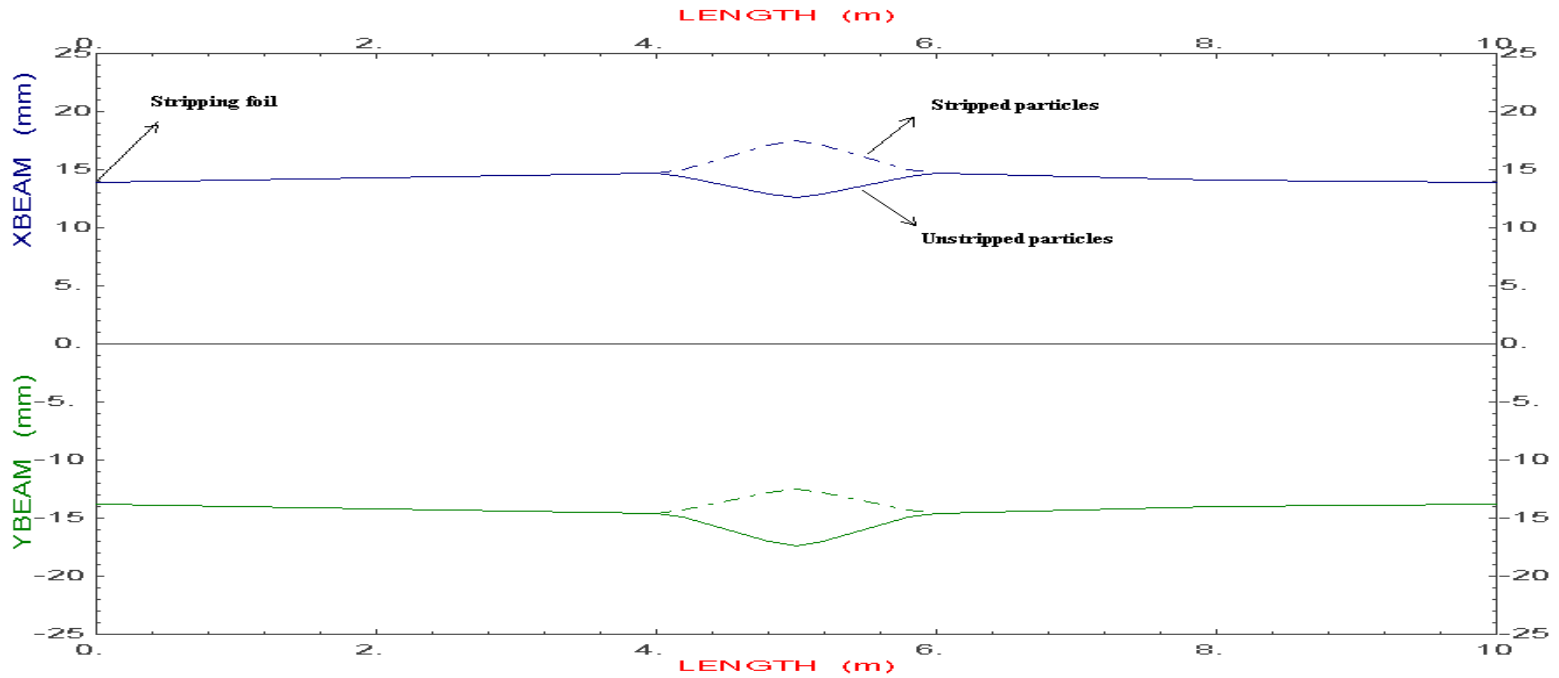


LRBT Collimation Scheme

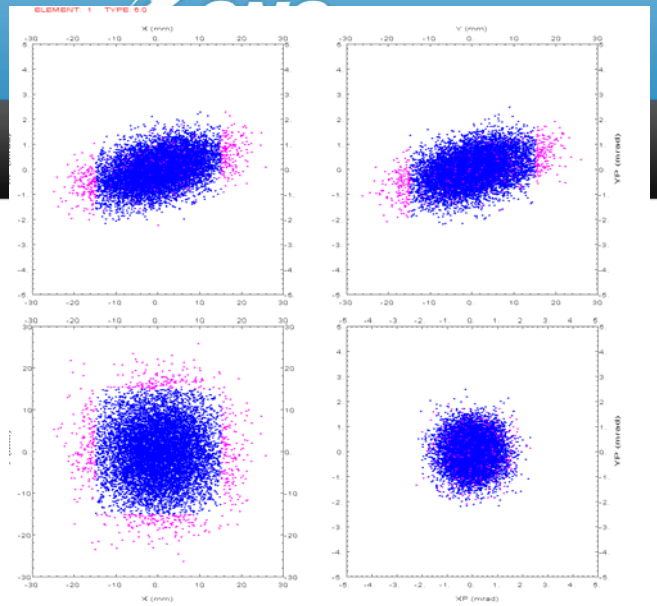
- **Scheme**
  - Two triplet cells of 60° in the straight section, three double-waists
  - Three pairs of scrapers (stripping foil) at each waist to make hexagonal emittance cut
  - H+, H0 and H- mixed transport, H+ guided to beam dump after the switch magnet
- **Merits**
  - No local beam dump or absorber, clean beam line
  - Only one beam dump➔low cost
  - H+ transported together with H- without beam loss, no aperture increase to the quadrupoles and the debuncher➔low cost
    - As a comparison, FODO or doublet cells have mismatched focusing for protons
  - Allowing deep collimation (about 2%), limiting emittance within 9 πmm.mrad
  - Scraped beam halo can be used for other applications

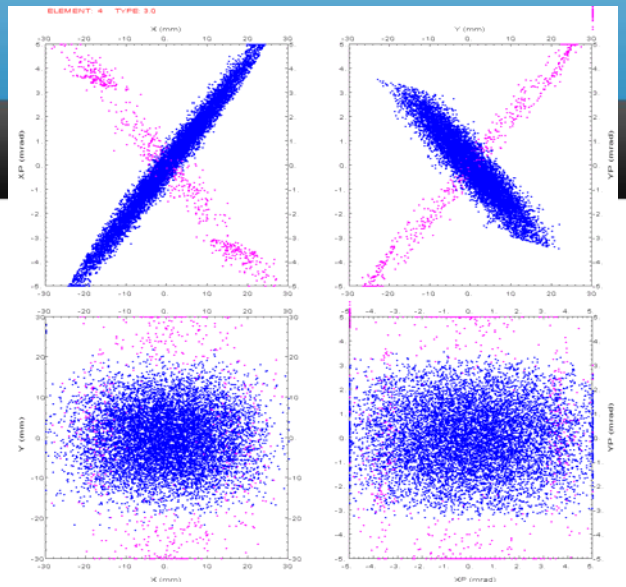


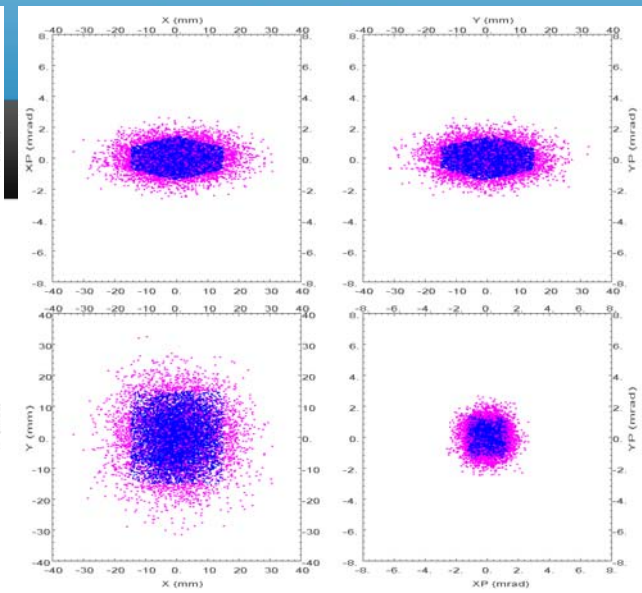
Triplet cells and foil scrapers



Beam envelopes of H- and proton beams within one triplet cells







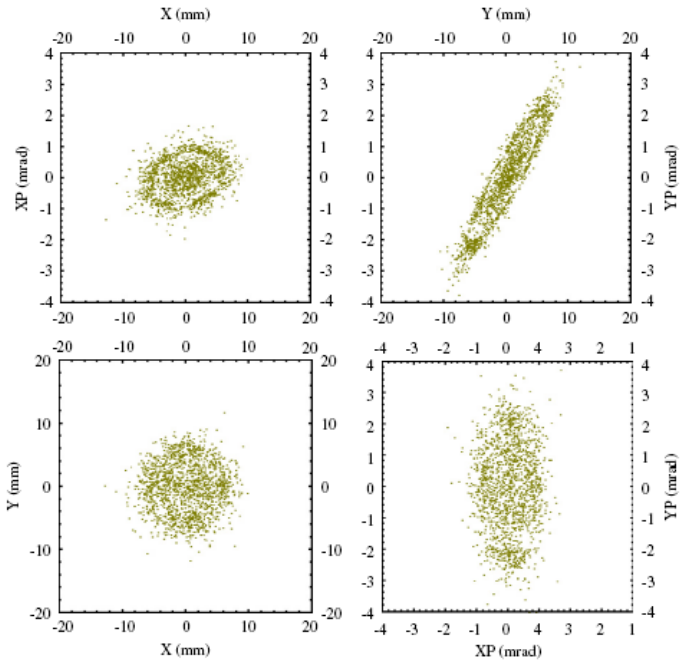
Plots in phase space

Left: after first scraper

Middle: at D quad exit

Right: at the third waist

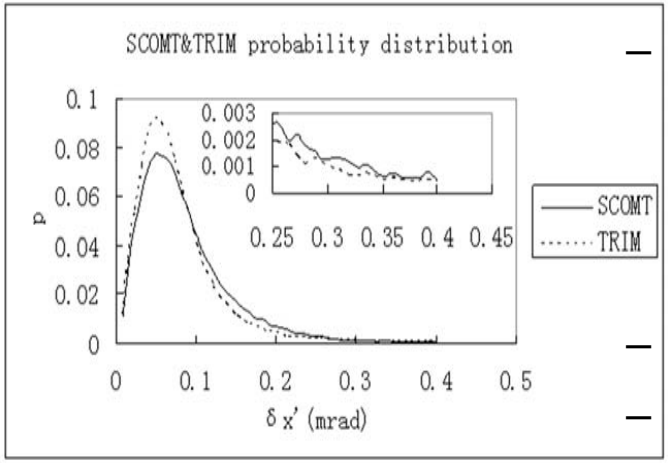
Lower: protons after switch



SCOMT Code and Simulation Results

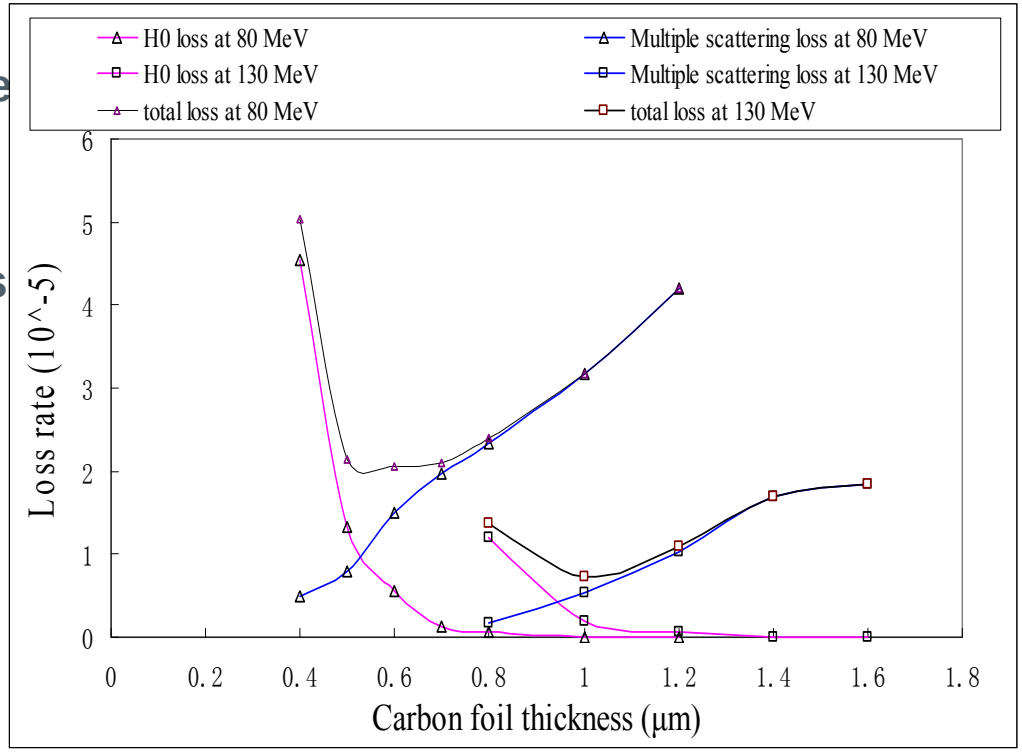
Simulation code SCOMT

- **A new simulation code – SCOMT has been developed to deal with beam transfer problems in LRBT**
  - No existing codes to tackle the problems concerning the transfer of mixed beams
- **Main functions of SCOMT:**
  - Macro-particles tracking thru beam line elements
    - With different input distribution options
  - Stripping process with probability when a particle hits a scraper foil (H- to H0, H- to p, H0 to p)
  - Nuclear interaction effect between a foil hitting particle and the foil (multiple scattering, Nuclear reaction)
    - Multiple scattering is based the Moliere theory with correction
    - Nuclear reaction is based on an empirical formulae
  - Statistical analysis
  - Linear space charge effect included



Simulation results in LRBT

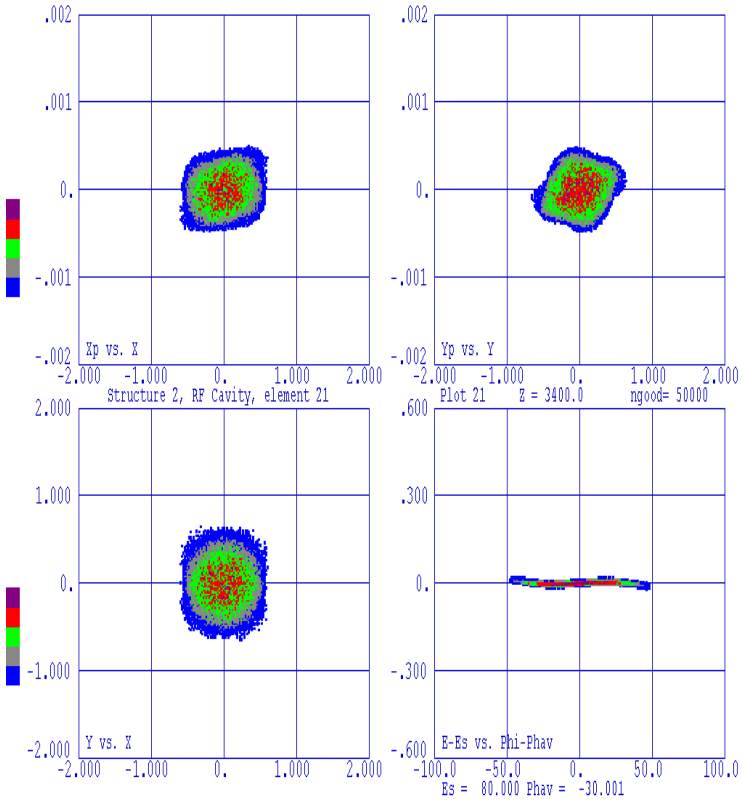
- **Main beam losses in LRBT**
  - Multiple scattering: some become large halo
  - Nuclear reaction or large angle elastic scattering: immediate loss
  - Partial stripping (H- to H0), some will lose when hitting a downstream foil
- **Optimization of foil thickness**
  - Thicker foil: better stripping efficiency, larger scattering
  - Existing optimum foil thickness
- **Stability studies**
  - With linac beam wobbling, no large variation on current intensity (even for scraped proton beam, <5%)



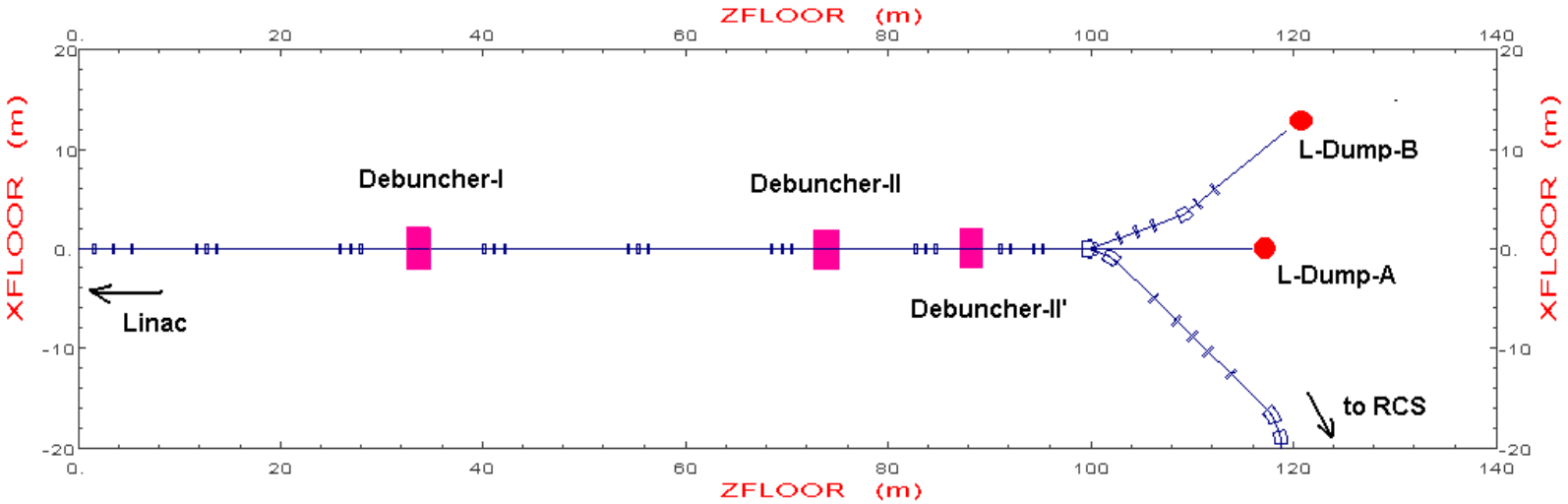
Momentum Spread Reduction and Momentum Tail Collimation

Debunchers to reduce momentum spread

- **To reduce momentum spread**
  - At linac exit: about ±0.1%
  - Enhanced by longitudinal space charge
- **To correct jitter of average momentum**
  - Variation of linac RF phase and voltage
- **Foreseen for three phases**
  - Higher linac energy➔higher voltage, longer drift distance
  - Different cavities due to different β values
  - Different locations
- **Detailed study including longitudinal space charge (PARMILA)**



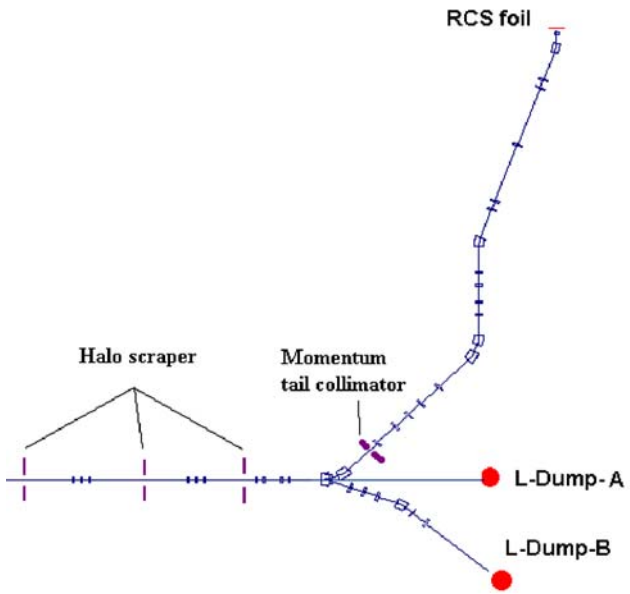
Debunchers at difference phases



	CSNS-I	CSNS-II	CSNS-II’
Energy (MeV)	80	130	230
Drift distance (m)	30	40	50
Eff. voltage (kV)	360	550	1050

Momentum Collimation in the LRBT

- **Necessity of momentum collimation in LRBT**
  - Momentum tail has been observed in many linacs. It might damage the injection devices and increase radioactivity in the region.
  - It is too large (δ>0.005) for the debuncher to correct it.
  - A momentum collimator is used to scrape the tail
- **Momentum collimator**
  - One stage of momentum collimator is planned at a dispersive location
  - With the bending angle of 45° and long drift, modest dispersion of 5m➔cutting all particles with δ>0.005
  - Collimator to absorb particles of energy up to 250MeV



Thanks for your attention!