The Design of Beam Collimation System for CSNS/RCS

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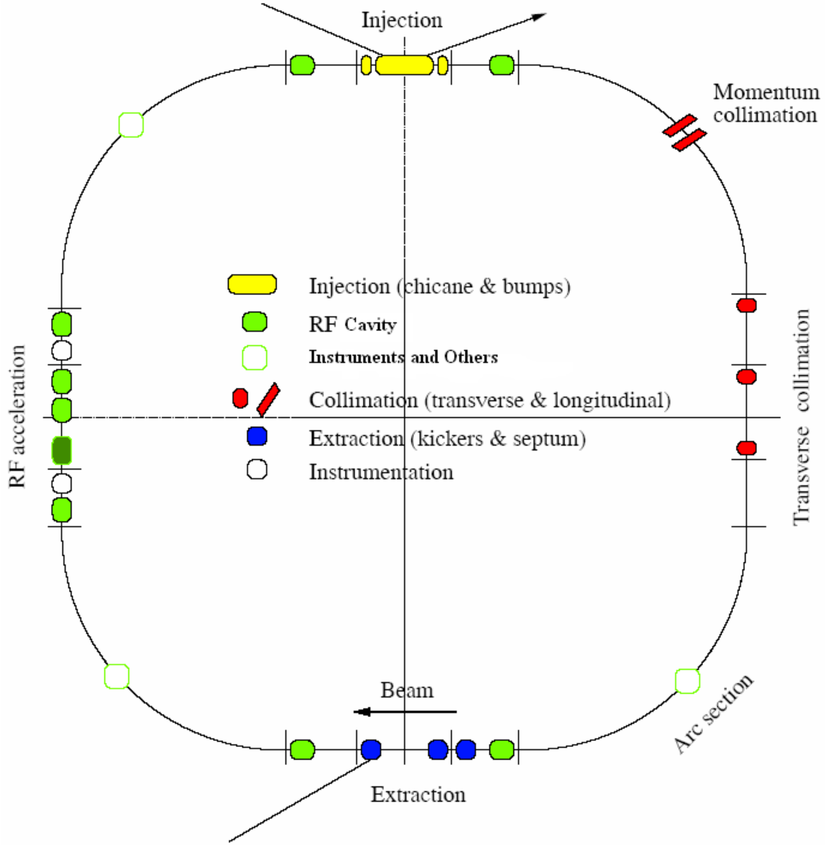
Outline

- Introduction
- Two-stage collimation system design
- Compare among different schemes
- Dependence of collimation efficiency on apertures
- Summary

RCS – 4 Fold Structure

- Four straight sections - beam injection, collimation, extraction, RF systems



Inj./Ext. energy	0.08/1.6 GeV
Power	100 kW
Beam current	62.5 μA
Beam population	1.56×10^{13}
Hamonic number	2
Repetition frequency	25 Hz
Circumference	228 m
Betatron tune	4.86/4.78
Ring acceptance	540 π μm

Motivation

- Localization of beam loss

  - High collimation efficiency

- Minimize uncontrolled beam losses

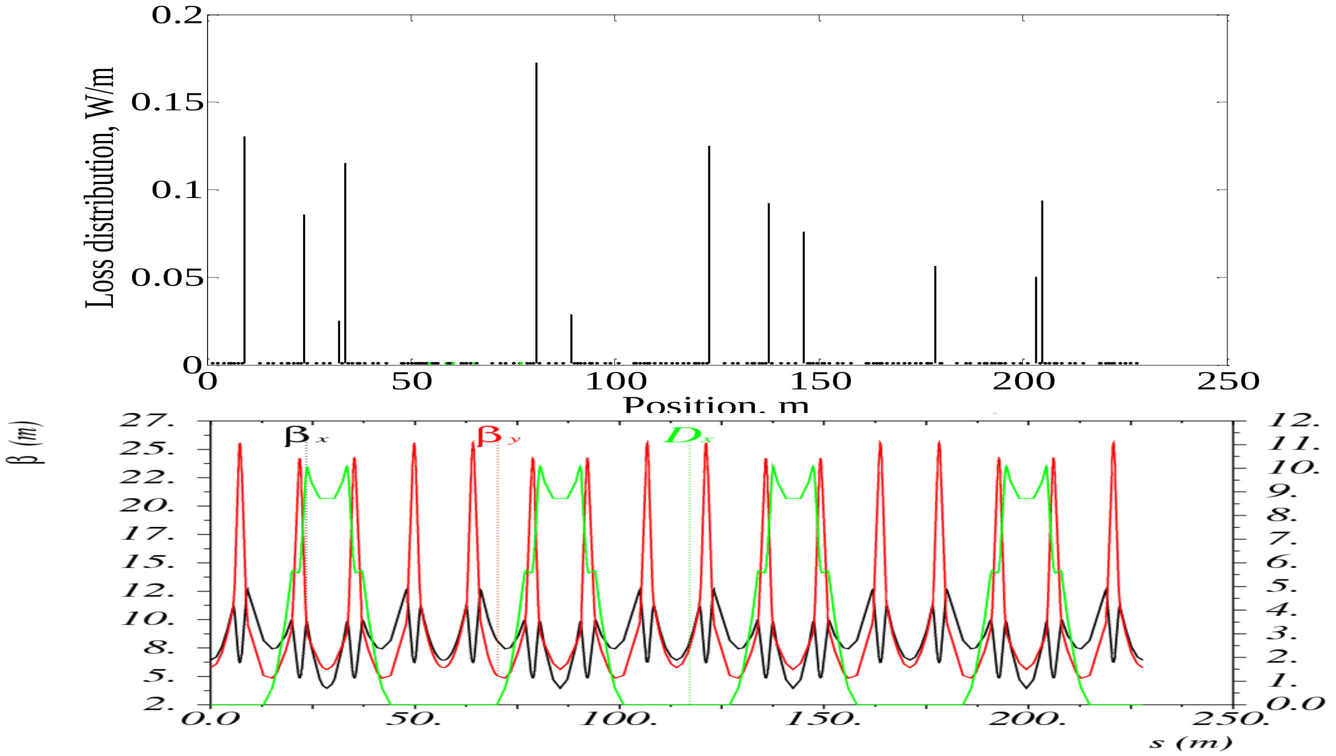
  - <1 Watt/meter for hands-on maintenance

- Beam halo cleaning

  - Small beam loss -> larger beam loss

Beam Loss Distribution (No Collimation)

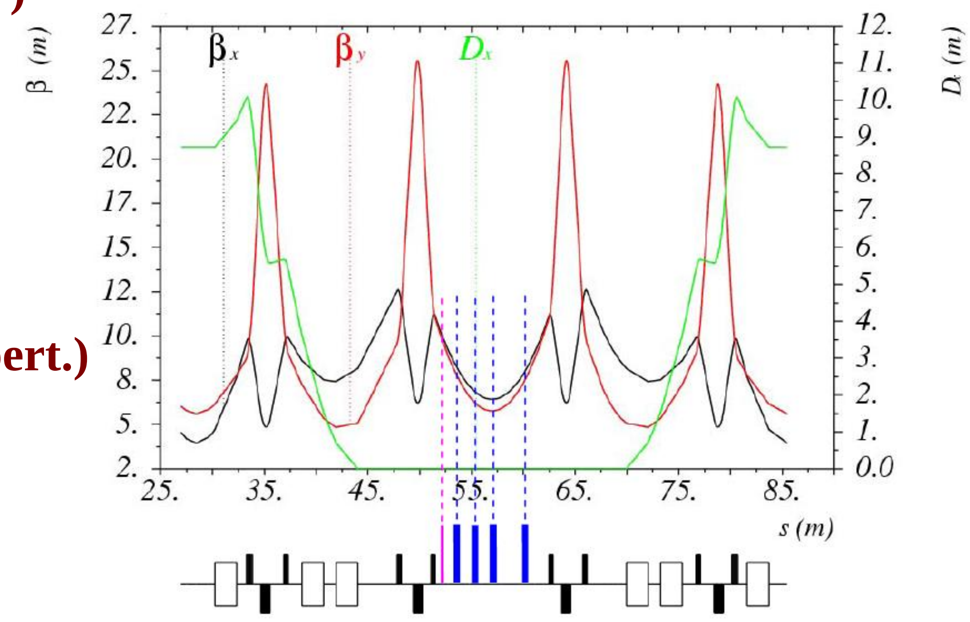
- The beam loss distribution (ORBIT)



- Total loss 2×10^{-4}, beam loss per component < 0.2 W/m
- The beam loss looks fine for an unperturbed machine, but worse performance are expected with errors or accidental cases

Two-stage Collimation System

- **Optics**
  - **- Separate straight section for transverse collimation**
  - **- Similar phase advance in *x* & *y* planes**
  - **- One 11 meter and two 3.8 meter dispersion free drift space**
  - **- $\Delta\phi$ < 180° (150 °, middle drift <90°)**
- **One primary collimators**
  - **- 4 movable scrappers**
  - **- Thin tungsten, *t* = 0.17 mm**
  - **- 350 πmm·mrad (first restrictive apert.)**
- **Four secondary collimators**
  - **- Adjustable or fixed**
  - **- Thick, *t* = 0.4 m, 400 πmm·mrad**

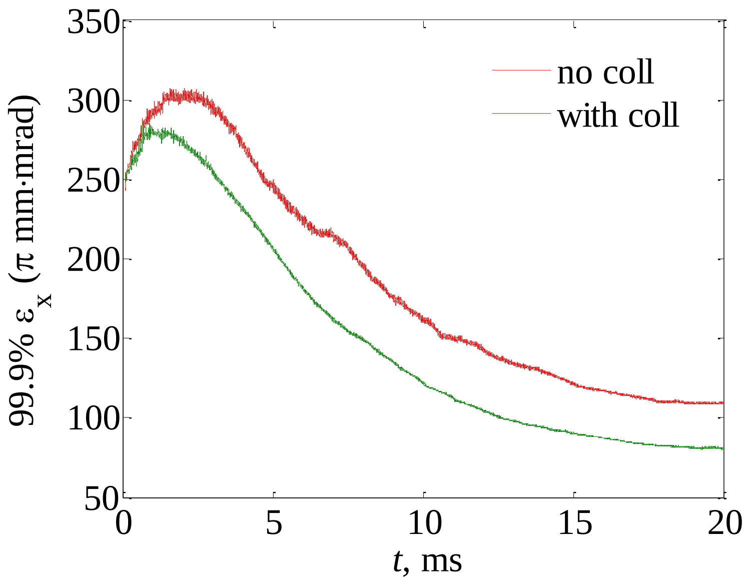


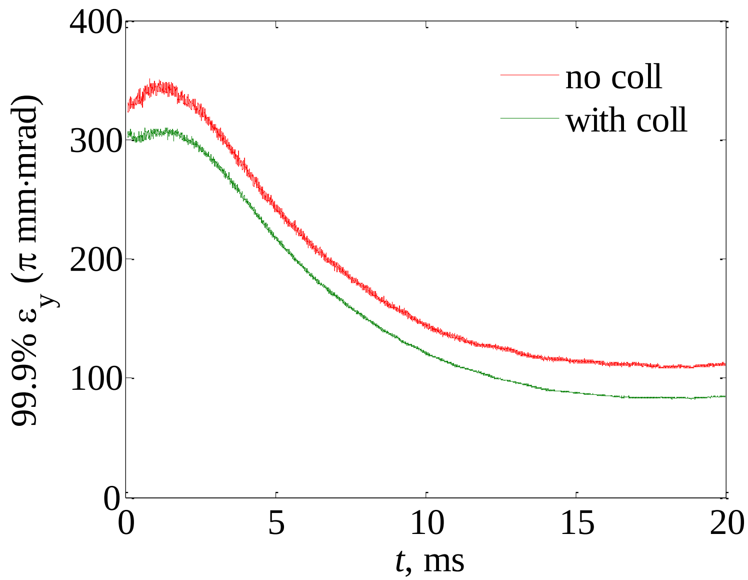
Comparison Among Collimation Schemes

- Collimation with up-right collimator jaws
- Collimation with DC bump
- Collimation with fixed elliptical apertures

1. Collimation with Up-right Collimator Jaws

- - Primary → four movable scrappers with 90° apart
- - Secondary → four movable vertical or horizontal jaws
- **Beam halo cleaning**



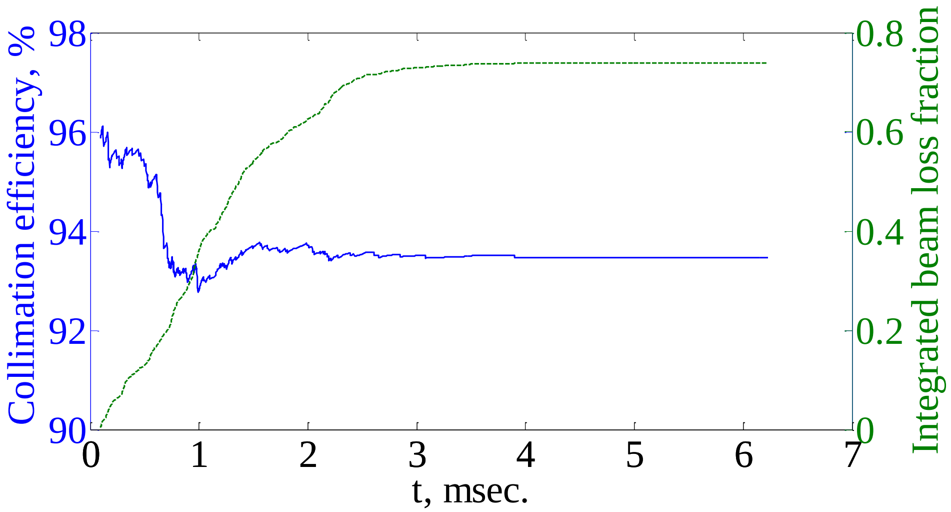


- The emittance is depressed by the collimation, and the extract beam emittance decreased about 25% in both planes.

1. Collimation with Up-right Collimator Jaws

- **Collimation efficiency**

$$\frac{\text{particles absorbed by the collimation system}}{\text{total number of particles lost in the RCS}}$$



- Total beam loss 0.8%

- Collimation efficiency 93.5%

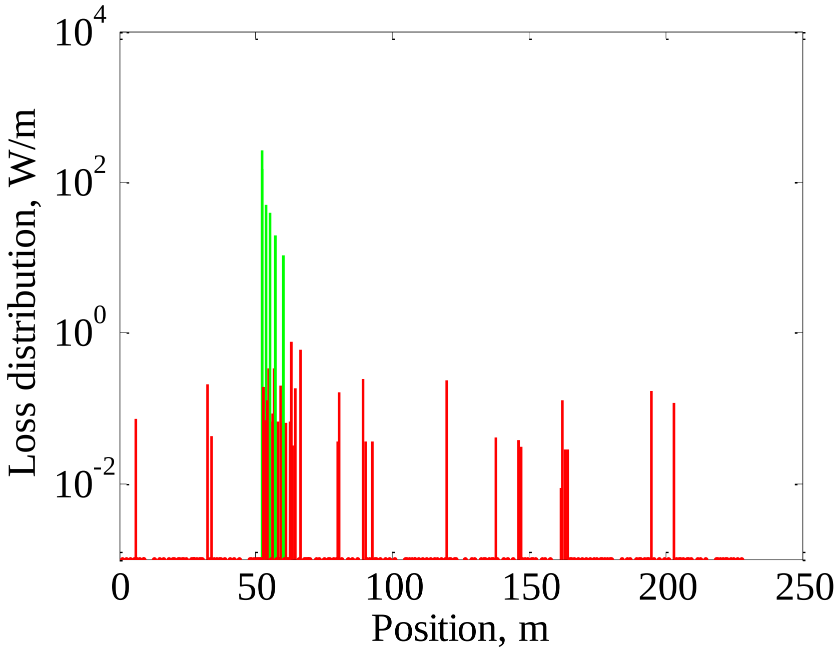
- The beam losses mostly occur in the first three milli-seconds

- Average energy is 100 MeV

- **The collimation efficiency varies with time as the impact parameter changes along with the expected emittance blow-up.**

1. Collimation with Up-right Collimator Jaws

- **Beam loss distribution**



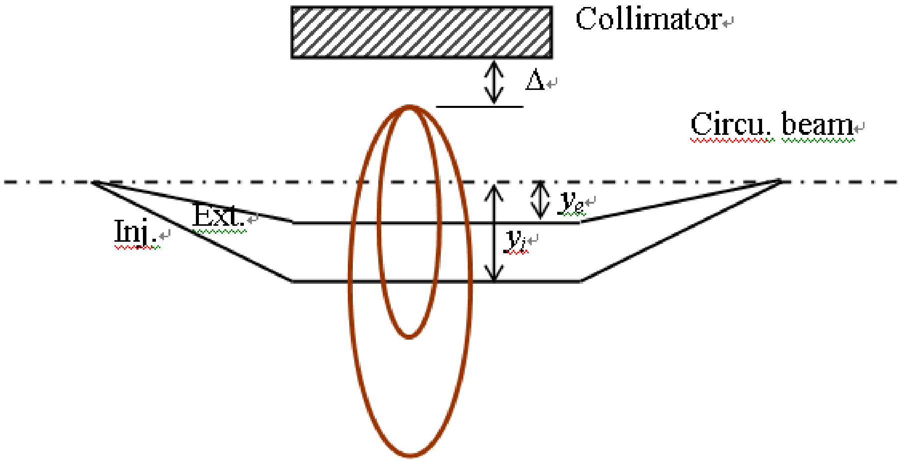
Region/Element	**% of Scraped Beam Lost**
Scrapers	0.1
First Secondary collimator	39.4
Second Secondary collimator	30.4
Third Secondary collimator	15.5
Fourth Secondary collimator	8.1
Total in the collimation section	96.2

- **The uncontrolled beam losses < 1 W/m.**
- **Over 96% of the beam lost within the collimation section.**

2. Collimation with DC Bump

- **Principle**
- **- In RCS, emittance shrinks during beam acceleration**
- **- DC bump → halo collimation in the early acceleration stage**

  → smaller beam emittance at the extraction



Δ: Clearance space

y_i: Orbit bump at injection

y_e: Orbit bump at extraction

$$y_{\mathrm{bump,e}} = y_{\mathrm{bump,i}} \frac{(B\rho)_{\mathrm{i}}}{(B\rho)_{\mathrm{e}}}$$

J.Y. Tang, Nucl. Instr. Meth. Phys. Res. A 575 (2007) 328-333.

2. Collimation with DC Bump

- **Simulation**

  - Vertical bump at primary collimator

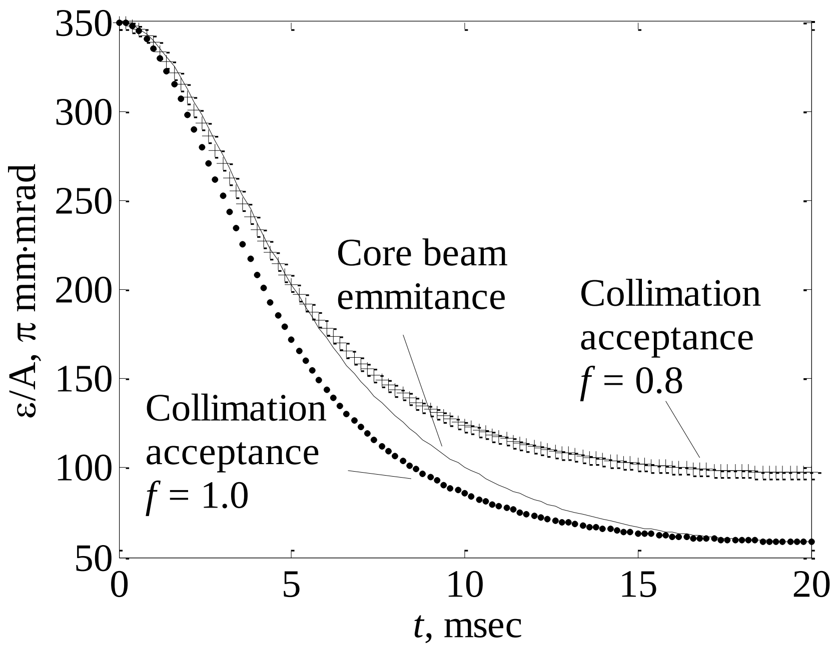
  - Reduced bump factor *f* = 0.8

- **Emittance**

  - vertical → 20 % ⬇

  - horizontal → 16 % ⬆

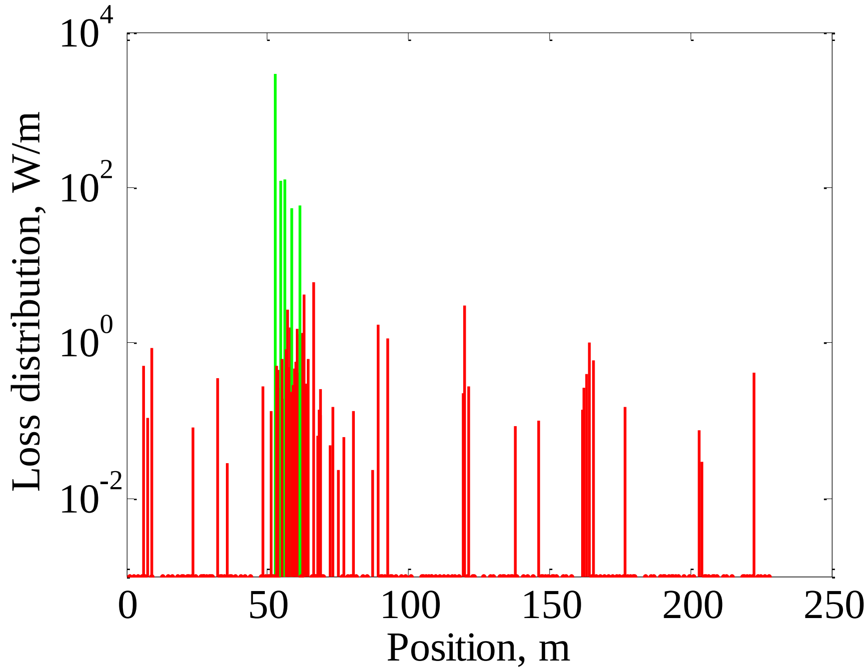
  (compare to the case without bump)



2. Collimation with DC Bump

- **Collimation efficiency**

  - Total beam loss 1.7% with collimation efficiency of 90%

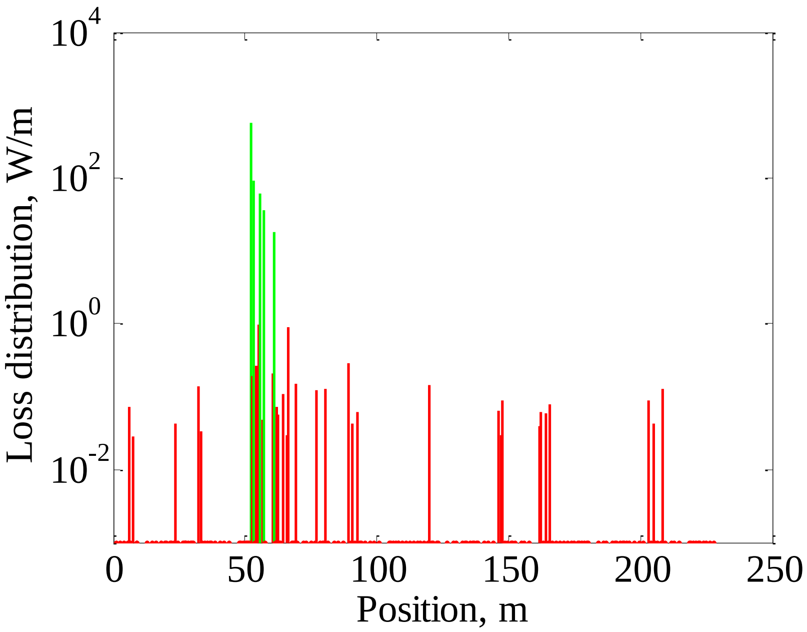


  - Larger number of beam loss locations

  - Exceed 1W/m at some position

3. Collimation with Fixed Elliptical Aperture

- - Primary: four scrappers placed 45° apart to approximate the elliptical aperture
- - Secondary: fixed elliptical aperture
- - Total beam loss 1.6% with resulting efficiency of 95.2%
- - Similar loss pattern as the scheme with up-right collimator jaws



Comparison Among Collimation Schemes

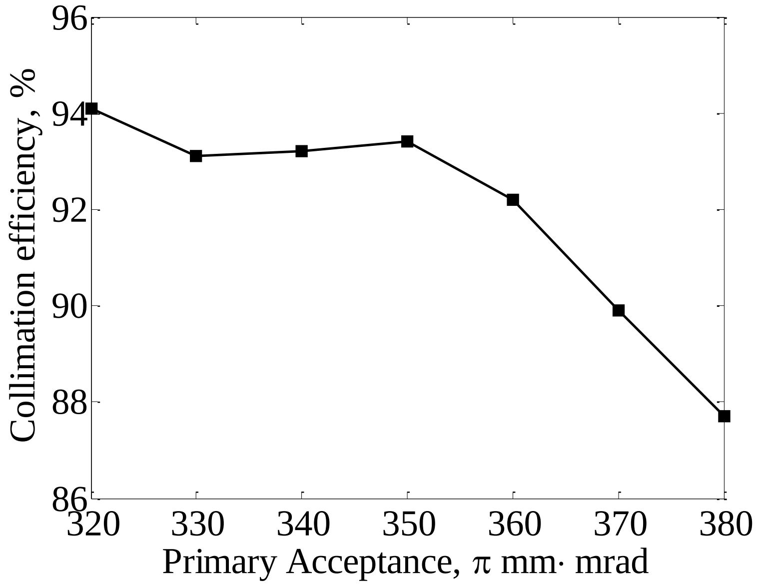
Schemes	Up-right jaws	DC bump	Fixed aperture
Collimation efficiency	93.5%	90%	95.2%
Total beam loss	0.8%	1.7%	1.6%
Loss in collimation section	96.2%	94.5%	97.7%
Uncontrolled loss	5.2E-4	1.7E-3	7.7E-4
Flexibility	flexible	flexible	less flexible
Extraction emittance, 99.9%	↓26% in x ↓24% in y	↓22% in x ↓31% in y	-
<1 W/m	yes	no	yes

- Collimation efficiency better than 90%.
- Scheme 1 has moderate collimation efficiency and smallest beam loss.
- Scheme 2 shows lowest collimation efficiency and highest beam loss, enables halo collimation at early acceleration stage and results in smaller beam emittance.
- Scheme 3 shows best collimation efficiency, and main drawback is less flexibility.

Dependence of Collimation Efficiency on Primary Acceptance

- **The primary acceptance varies with a constant ratio between the acceptance of the primary and secondary collimators**
- **The collimation performance is strongly dependent on the acceptance of the primary collimators.**

- **The collimation efficiency decreases when $\varepsilon_{primary}$ > 350π.**
- **Higher efficiency at 320 π with larger impact parameter and larger fraction of beam loss.**

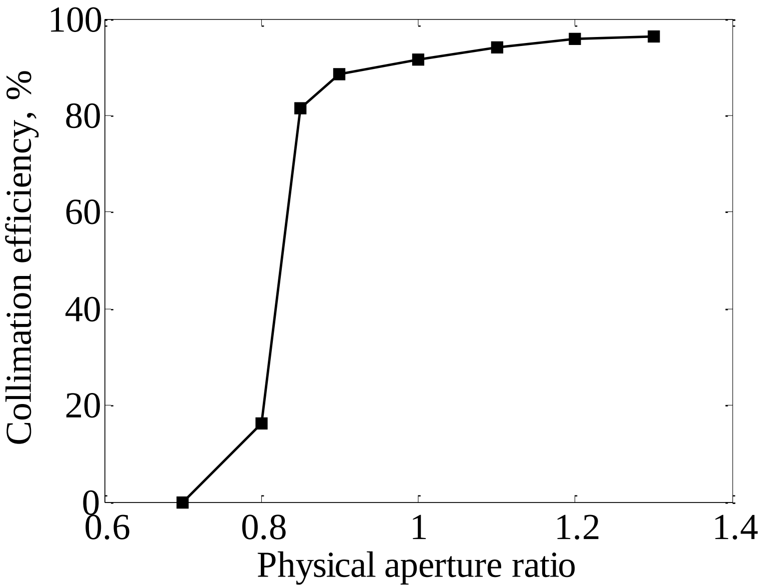


Dependence of Collimation Efficiency on Physical Aperture

- **A large enough acceptance gap between the collimator and the ring physical aperture is necessary in order to ensure good collimation efficiency.**

•The collimation efficiency increases with the aperture ratio.

•The design value is moderate for the performance of the collimation system.



Summary

- Beam cleaning and collimation are necessary for beam loss localization for overall maintenance.
- A collimation system has been designed and studied for the CSNS RCS. The collimation efficiency is larger then 93%, and the maximum uncontrolled beam losses are less than 1 W/m along RCS.
- All results obtained so far refer to an unperturbed machine, works need to be done to include the magnetic errors, misalignments, COD, collective instabilities, et al…
- Accidental case should be studied in the future work.

Thanks for your attention!