# BEAM DYNAMICS OF CHINA ADS DRIVER LINAC

Zhihui Li

On behalf of IHEP-IMP Joint Accelerator Physics Group of C-ADS

Institute of High Energy Physics, CAS

The 52nd ICFA Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams, HB2012, Beijing, China

# C-ADS Project is ……



- A strategic plan to solve the nuclear waste problem for nuclear power plants in China;
- Study scientific problems and developing techniques associated with ADS;
- Three parts: accelerator, target and reactor;
- Goals: demonstration facility for wastes transmutation with capacity of 1GW thermal power;

# Key Parameters of C-ADS Linac



| | | |
|---|---|---|
| Particle | Proton | |
| Energy | 1.5 | GeV |
| Current | 10 | mA |
| Beam power | 15 | MW |
| RF frequency | (162.5)/325/650 | MHz |
| Duty factor | 100 | % |
| Beam Loss | <1 | W/m |
| Beam trips/year | <25000<br><2500<br><25 | 1s< t <10s<br>10s< t <5m<br>t >5m |

# Characteristics of C-ADS linac

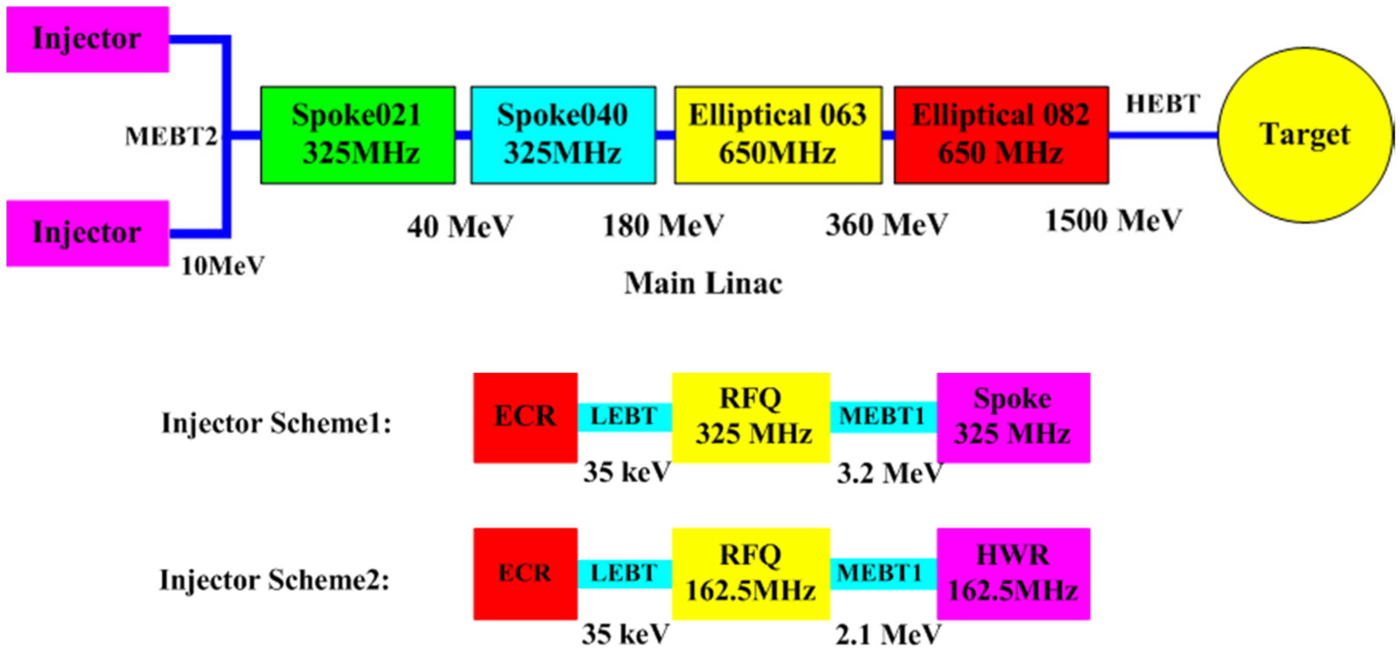


| | |
|---|---|
| High power | - Beam loss rate: <$10^{-8}$<br>- Dynamics: match, halo, resonance |
| High availability | - Potential "show stopper"<br>- Fault tolerance and redundancy design |
| CW | - Cavity type |

# Architecture



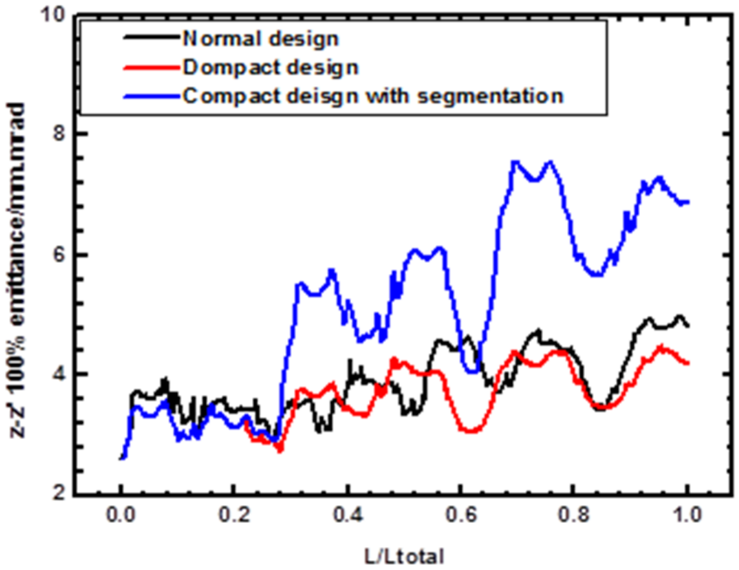
- Parallel backup (< 10MeV)
- Local compensation (>10MeV)
- 30% field is reserved for compensation
  - ✓ longitudinal match
  - ✓ Energy match
  - ✓ Phase match

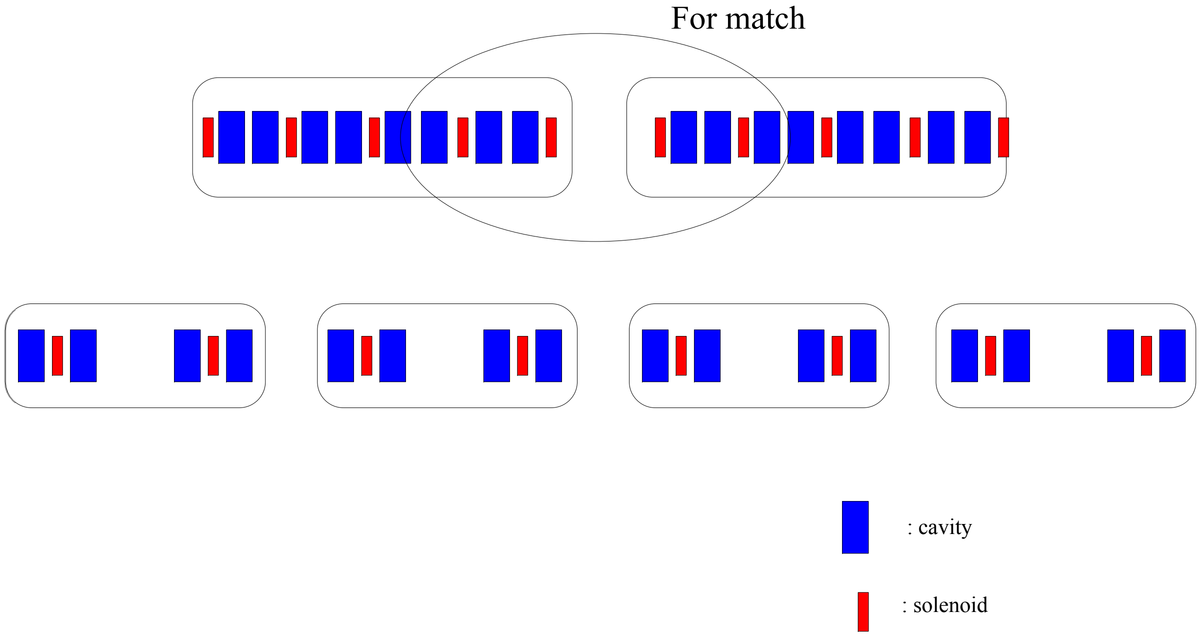



Local compensation is applicable for energy great than 10 MeV
---J.L. Biarrotte, EPAC2004, Lucerne, Switzerland, p. 1282.

# Lattice Structure





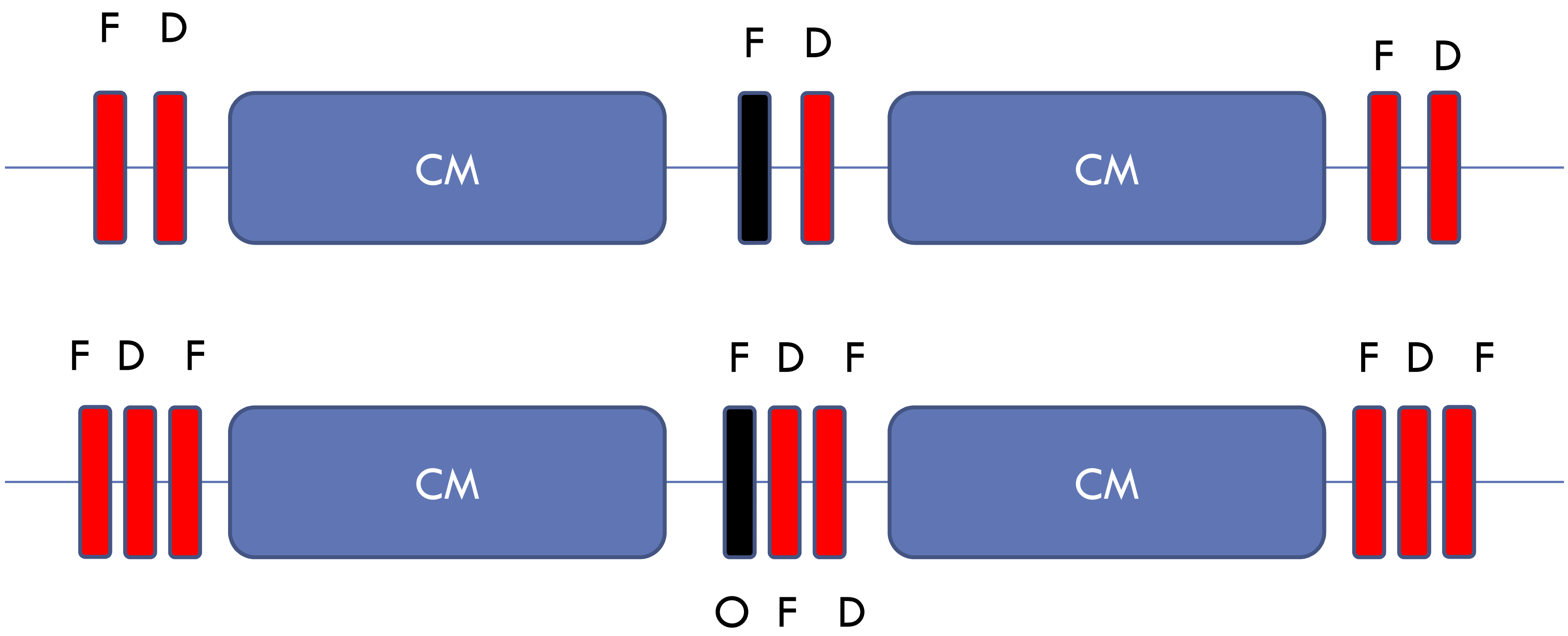




Period lattice:

easy for compensation;

robust in beam dynamics;

# Lattice structure

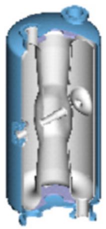
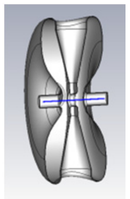
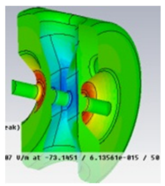
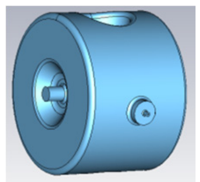
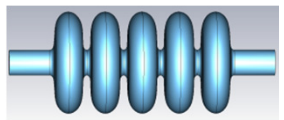
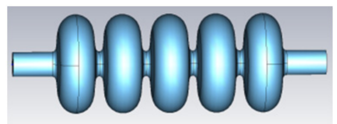



Triplet like quadrupoles are applied in elliptical sections;

# Cavities

- Emax<32.5MV/m for 325MHz cavity
- Emax<39 MV/m for 650MHz cavity
- Bmax<65 mT
- 3 types of Single spoke cavity/1 type HWR and two types of single spoke
- 2 types of 5-cell elliptical cavity

| Cavity type | βg | Freq. MHz | Uacc. Max MV | Emax MV/m | Bmax mT |
|---|---|---|---|---|---|
| HWR | 0.09 | 162.5 | | 25.0 | 50.0 |
| Single-cell spoke | 0.12 | 325 | 0.82 | 32.5 | 47.5 |
| Single-cell spoke | 0.21 | 325 | 1.64 | 23.95/31.14 | 50/65 |
| Single-cell spoke | 0.40 | 325 | 2.86 | 24.66/32.06 | 50/65 |
| 5-cell elliptical | 0.63 | 650 | 10.26 | 29.01/37.72 | 50/65 |
| 5-cell elliptical | 0.82 | 650 | 15.63 | 27.53/35.80 | 50/65 |

**1/3 capability is reserved for local compensation**

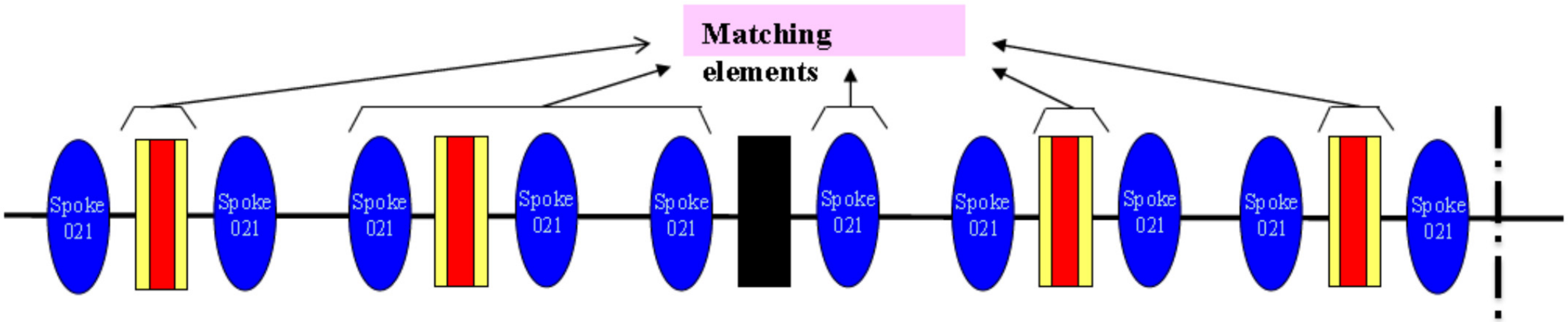
# Local compensation of Main linac



- Failures investigated:
  - Cavity failure;
  - Solenoid failure;
  - Quadrupole;
- Goals:
  - Twiss match;
  - Energy;
  - Beam quality;
- Cavity and quadrupole failures are easy to compensate, the mismatch factor after compensation is only about 1%, and RMS and 100% particle emittance growth nearly no significant change;
- Solenoid failure is the most difficult to compensate, and special measures have to be taken.

# Solenoid failure






Mismatch factor in transverse: 10%

RMS emittance growth: 7%

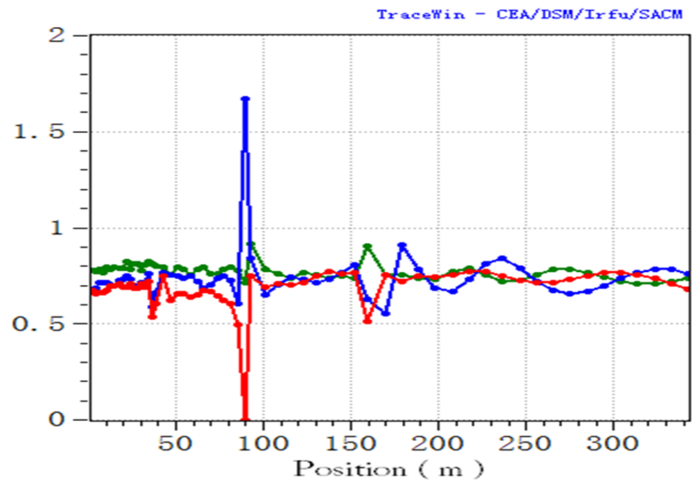
| | Civity-1 | Civity-2 | Civity-3 | Civity-4 |
|---|---|---|---|---|
| Initial phase | -33° | -33° | -33° | -33° |
| After rematch | -33.9° | 40.5° | -48° | -30.7° |
| Initial voltage/ MV | 1.24 | 1.26 | 1.35 | 1.37 |
| After rematch/ MV | 2.1 | 0.92 | 1.64 | 0.46 |

| | Solenoid-1 | Solenoid-2 | Solenoid-3 | Solenoid-4 | Solenoid-5 |
|---|---|---|---|---|---|
| Initial field /T | 3.21 | 3.34 | 3.48 | 3.56 | 3.52 |
| After rematch / T | 4.08 | 3.64 | ----- | 3.63 | 2.64 |

# Design Criteria



- $\sigma_0 < 90°$ for both longitudinal and transverse planes;
  - Space charge is not negligible: $\sigma/\sigma_0 \sim 0.7$
  - Parametric resonance: $L_{eff} < L_{period}$ at low energy part
- The external force is smooth and continues;
- Special care has to be taken to avoid the parametric resonance as well as space charge resonance;
  - Emittance exchange-Hofmann Chart
- Enough acceptance:
  - |Synch. Ph.|/|RMS Ph. width|>10
  - (Half aperture)/(RMS envelop)> 10



# Error analysis

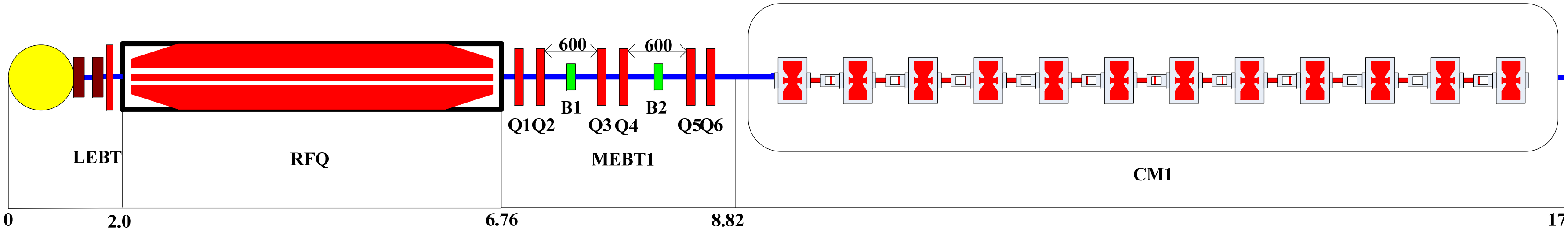
**- C. Meng et al., MOP219**



| Elements | Solenoid | Spoke cavity | Elliptical cavity | Quadrupole |
|---|---|---|---|---|
| errors | Alignment / Field error | Alignment / RF error | Alignment / RF error | Alignment /Field error |
| Δx (mm) | ±1 | ±1 | ±1 | ±0.2 |
| Δy (mm) | ±1 | ±1 | ±1 | ±0.2 |
| Δz (mm) | ±1 | ±1 | ±1 | ±0.5 |
| ϕx (mrad) | ±2 | ±2 | ±2 | ±2 |
| ϕy (mrad) | ±2 | ±2 | ±2 | ±2 |
| ϕz (mrad) | --- | ---±2 | --- | ±2 |
| ΔE(%)/ΔB(%) | ±0.5 | ±1 | ±1 | ±0.5 |
| ϕRF (°) | --- | ±1 | ±1 | --- |
| BPM accuracy | ±0.1 mm | | | |

# Injector I






**RFQ**
- Low inter-vane voltage and input energy
- Low longitudinal emittance

**MEBT1**
- Space: diagnostic devices
- Buncher: normal conducting and high effective voltage~120kV

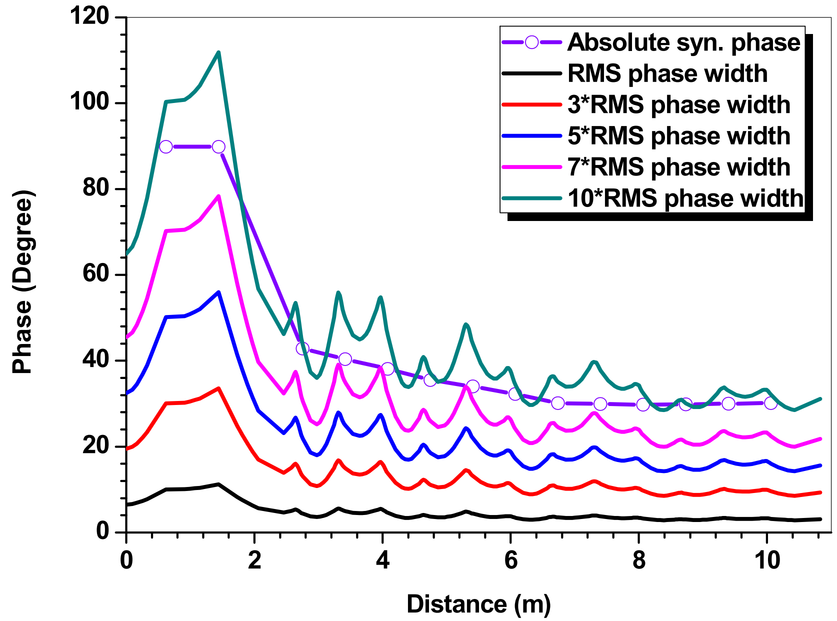
**CM1**
- Low energy, large phase width -> $\sigma_0$<90 degree
- Compact lattice structure -> fine segmentation

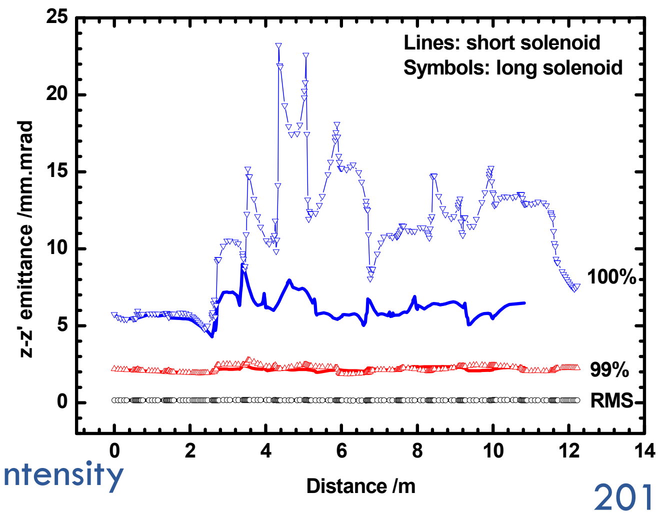
# Injector I



## Parameters of cavities

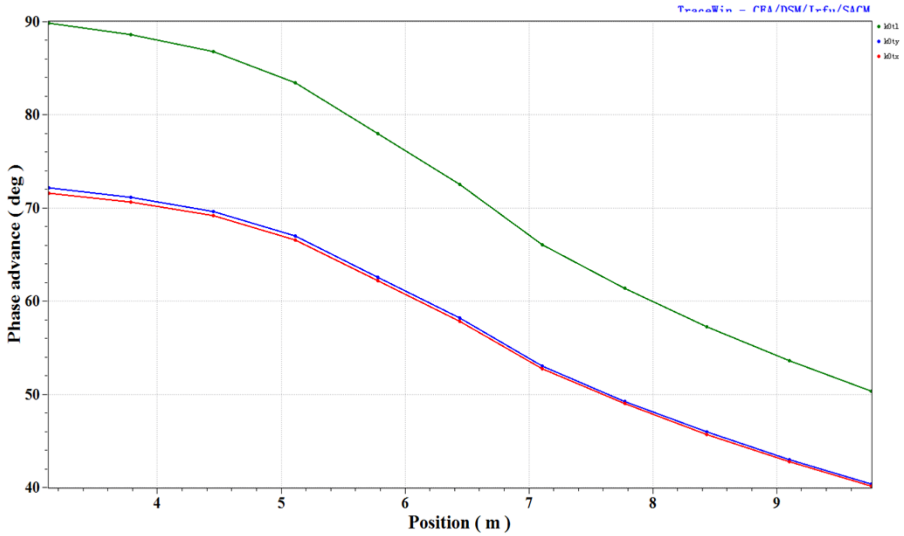
| Cavity # | phase | Field level |
|---|---|---|
| 1 | -43 | 0.92 |
| 2 | -40 | 1.0 |
| 3 | -38 | 1.08 |
| 4 | -36 | 1.16 |
| 5 | -34 | 1.21 |
| 6 | -32 | 1.27 |
| 7 | -30 | 1.3 |
| 8 | -30 | 1.3 |
| 9 | -30 | 1.3 |
| 10 | -30 | 1.3 |
| 11 | -30 | 1.3 |
| 12 | -30 | 1.3 |

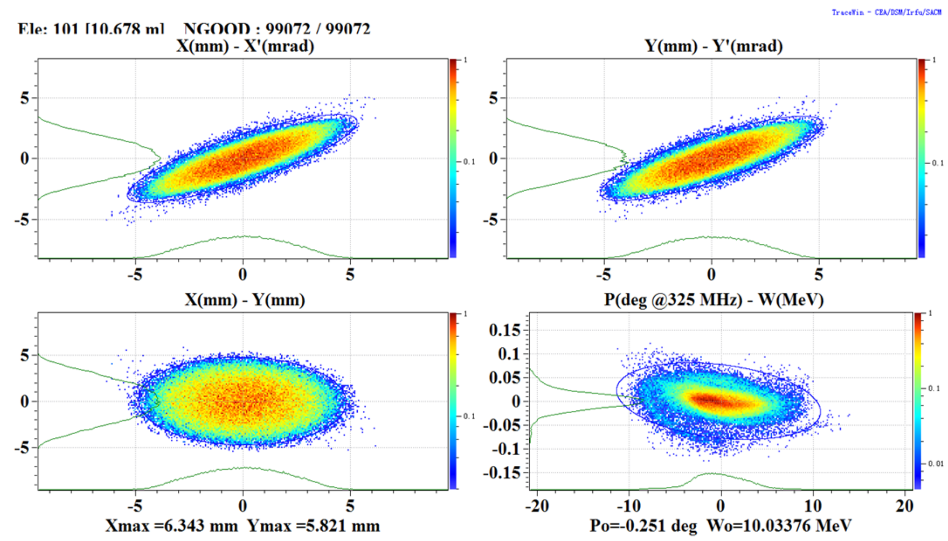


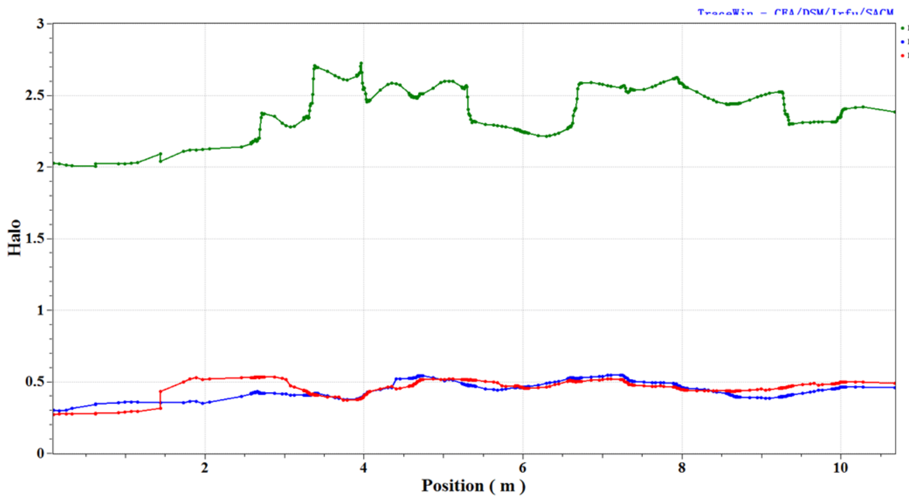



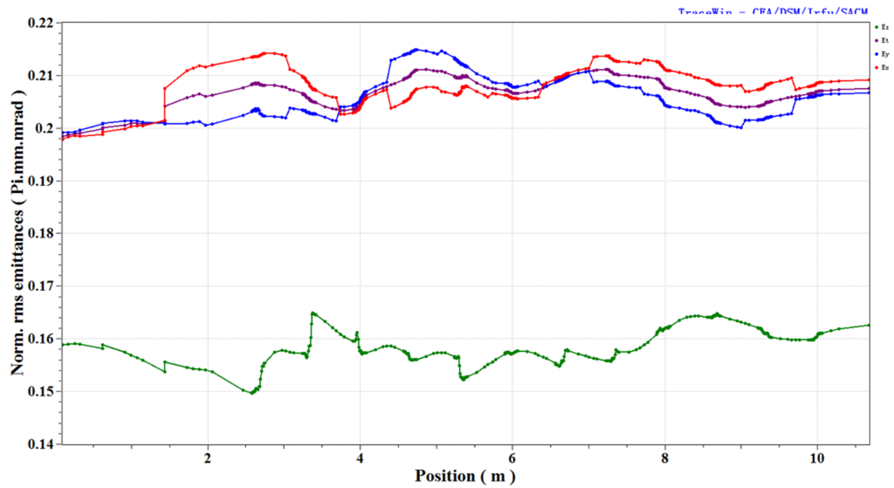
# Injector I




Phase advance ( deg )
Position ( m )

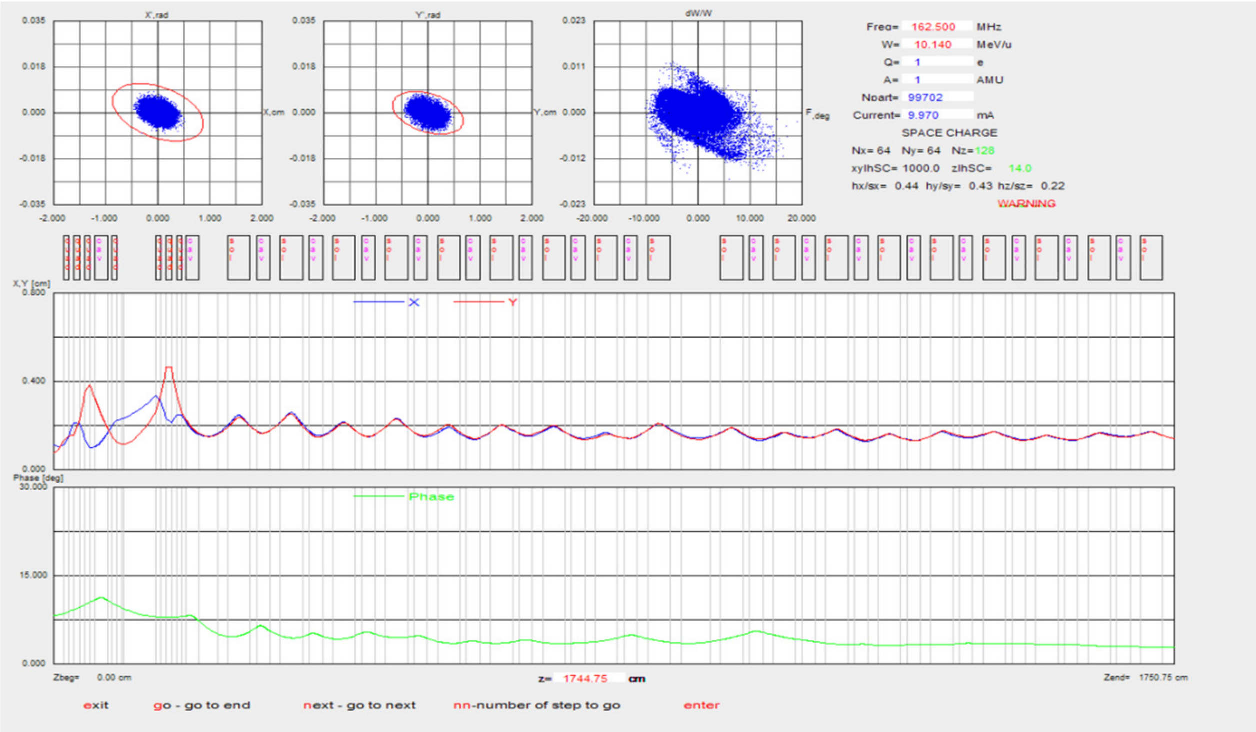

X(mm) - X'(mrad)
Y(mm) - Y'(mrad)
X(mm) - Y(mm)
P(deg @325 MHz) - W(MeV)
Xmax =6.343 mm Ymax =5.821 mm
Po=-0.251 deg Wo=10.03376 MeV

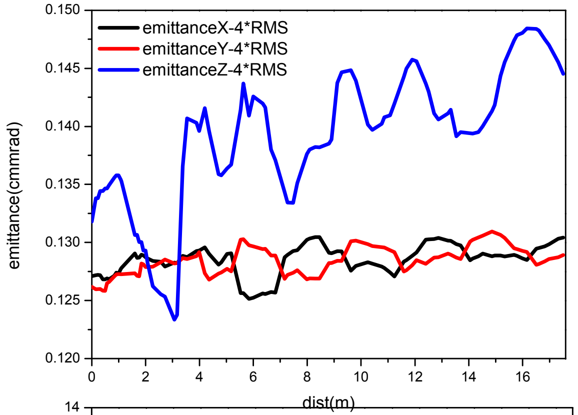

Halo
Position ( m )

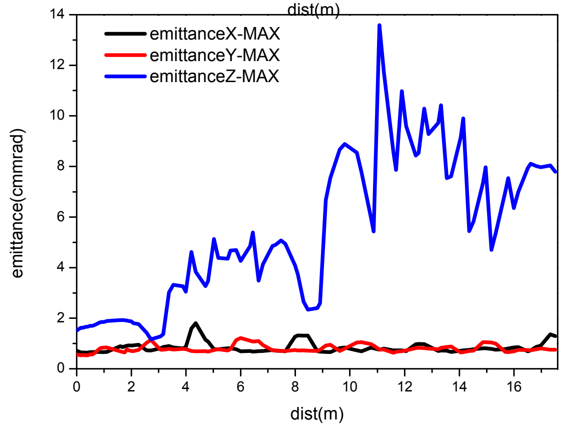

Norm. rms emittances ( Pi.mm.mrad )
Position ( m )

# Injector II

-S. Liu et al., MOP232
-H. Jia et al., MOP229




| Proportion of particles | 0.95 | 0.99 | 0.999 | 0.9999 | 1 |
|---|---|---|---|---|---|
| Emittance growth(%) | 23.7 | 14.9 | 12.6 | 20.5 | 413 |

# Main Linac

F. Yan et al., MOP221

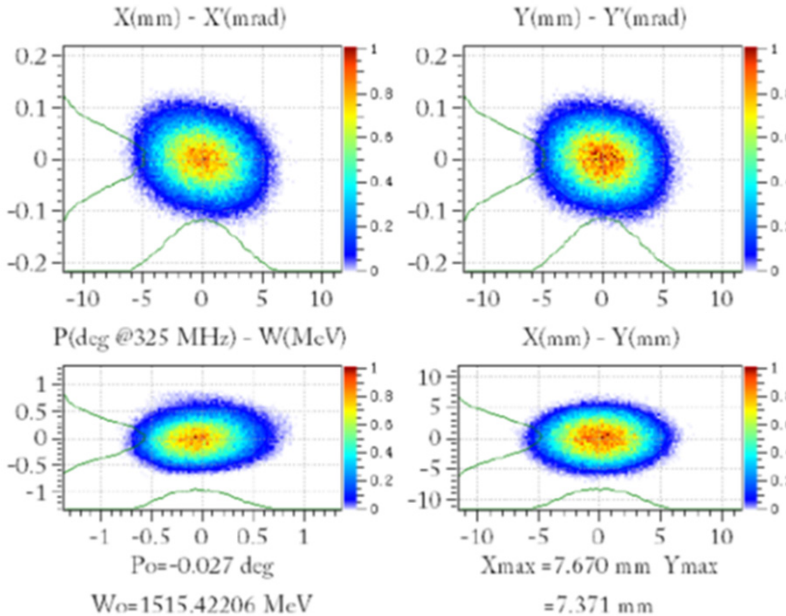


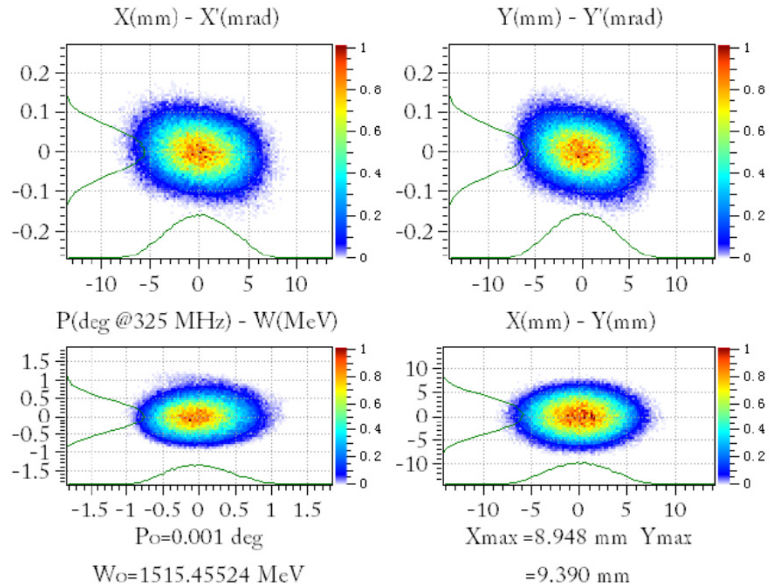
- Two types of design corresponding to the two Injector schemes:
  - Injector I : (Ez,Et)=(0.21, 0.25)
  - Injector I: (Ez,Et)=(0.37, 0.32)
- Solutions:
  - Apply the design corresponding to Injector I to two schemes of Injectors;
  - Totally new design by apply some HWR cavities at the beginning of the main linac;

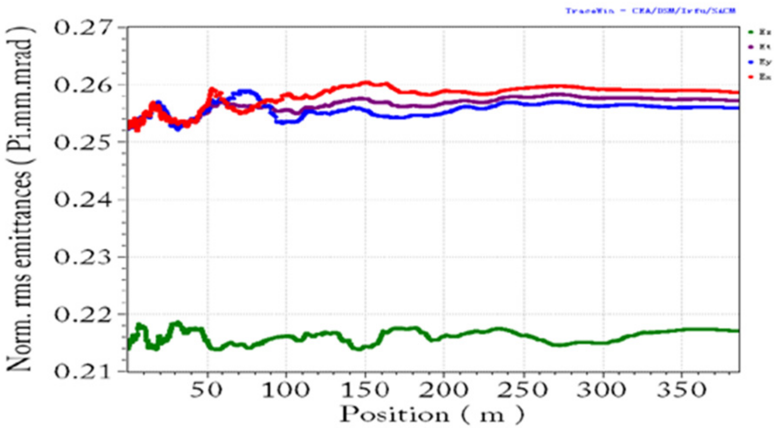
# Main linac

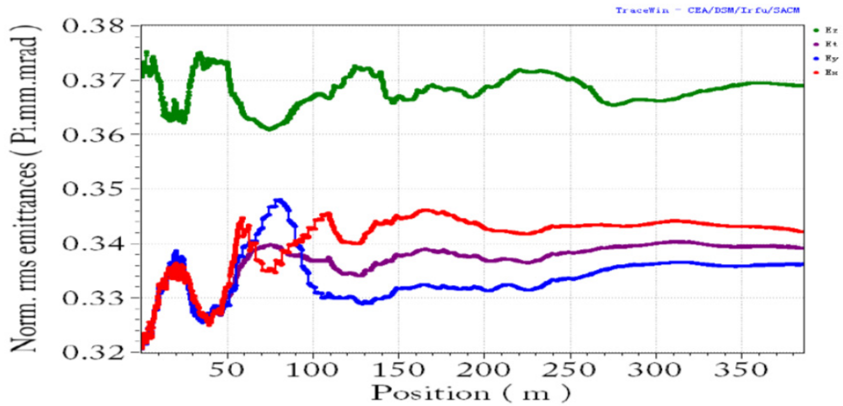
**F. Yan et al., MOP221**





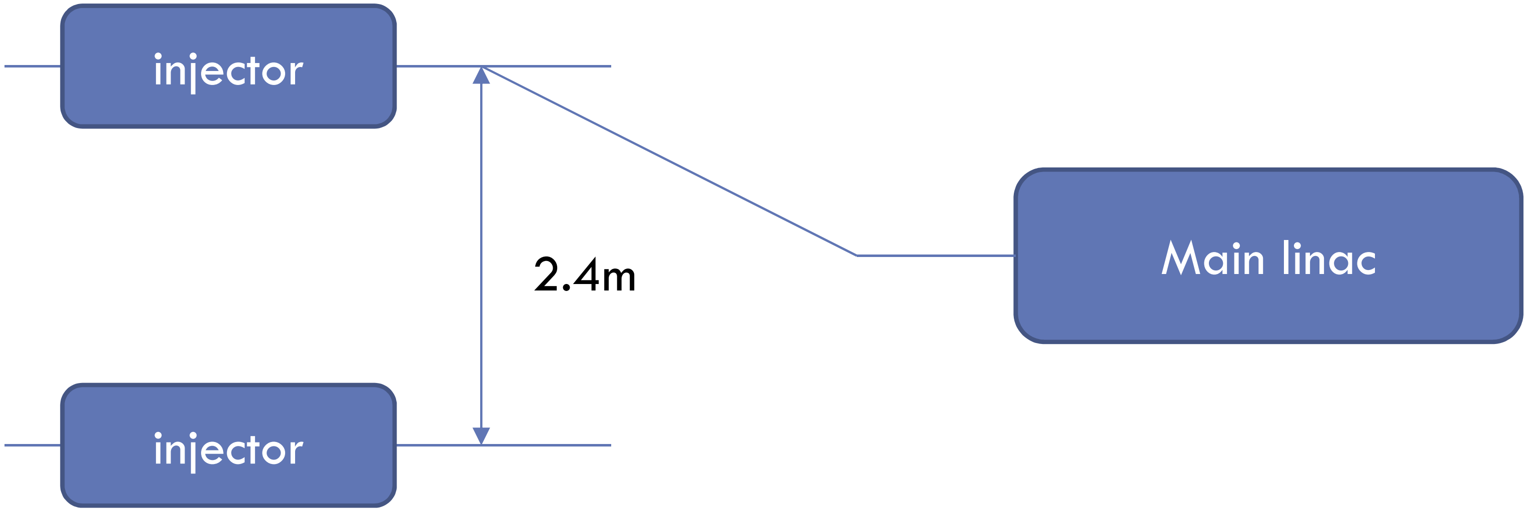



# MEBT2



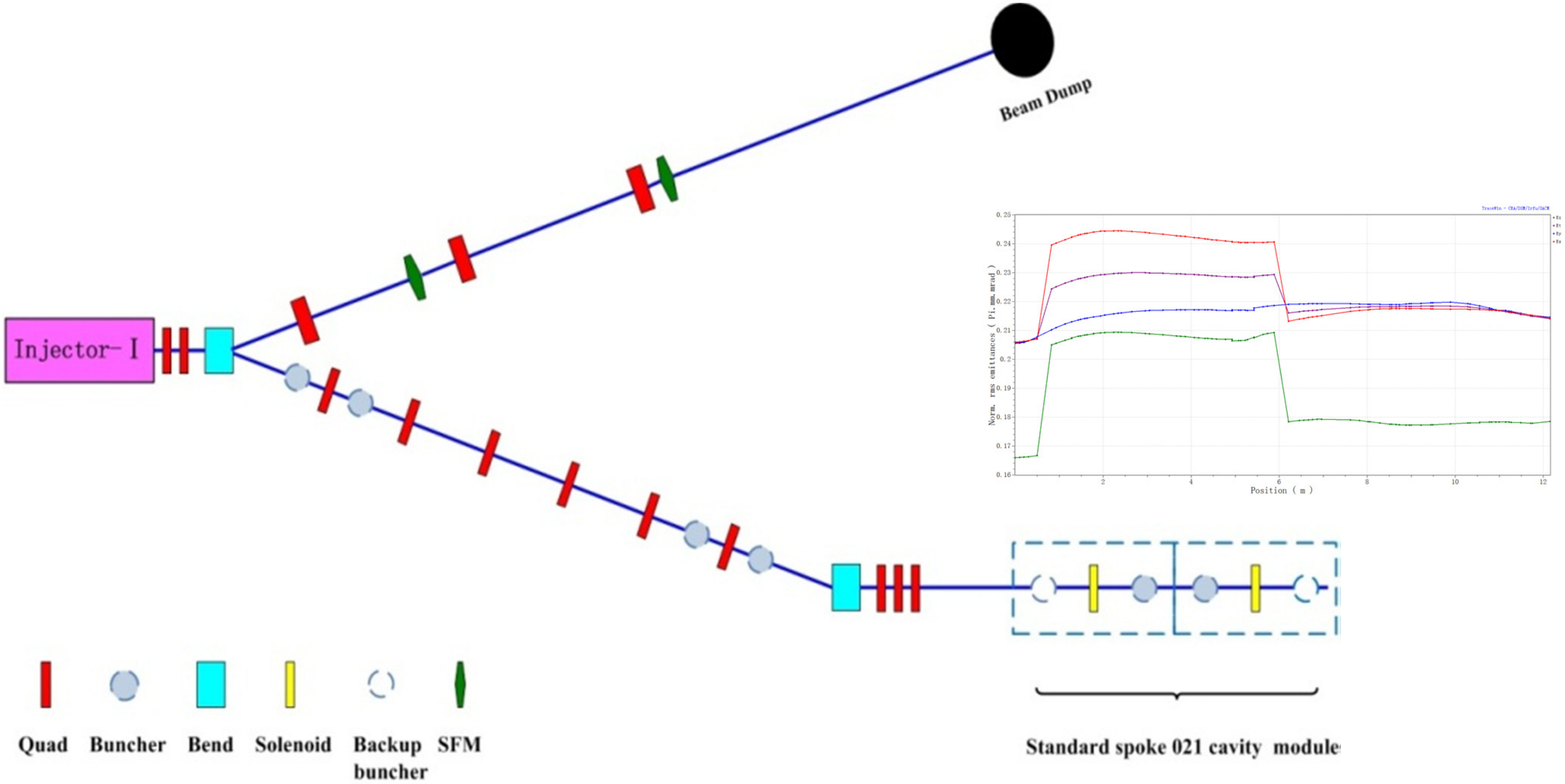



- Length: about 4 m for the bending section;
- Low energy: space charge effect;
- Buncher outside the bending section: phase width is hard to control;

# MEBT2

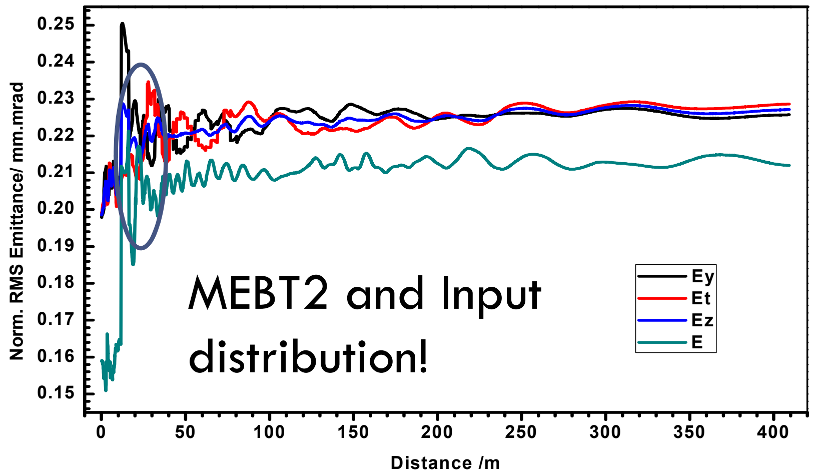


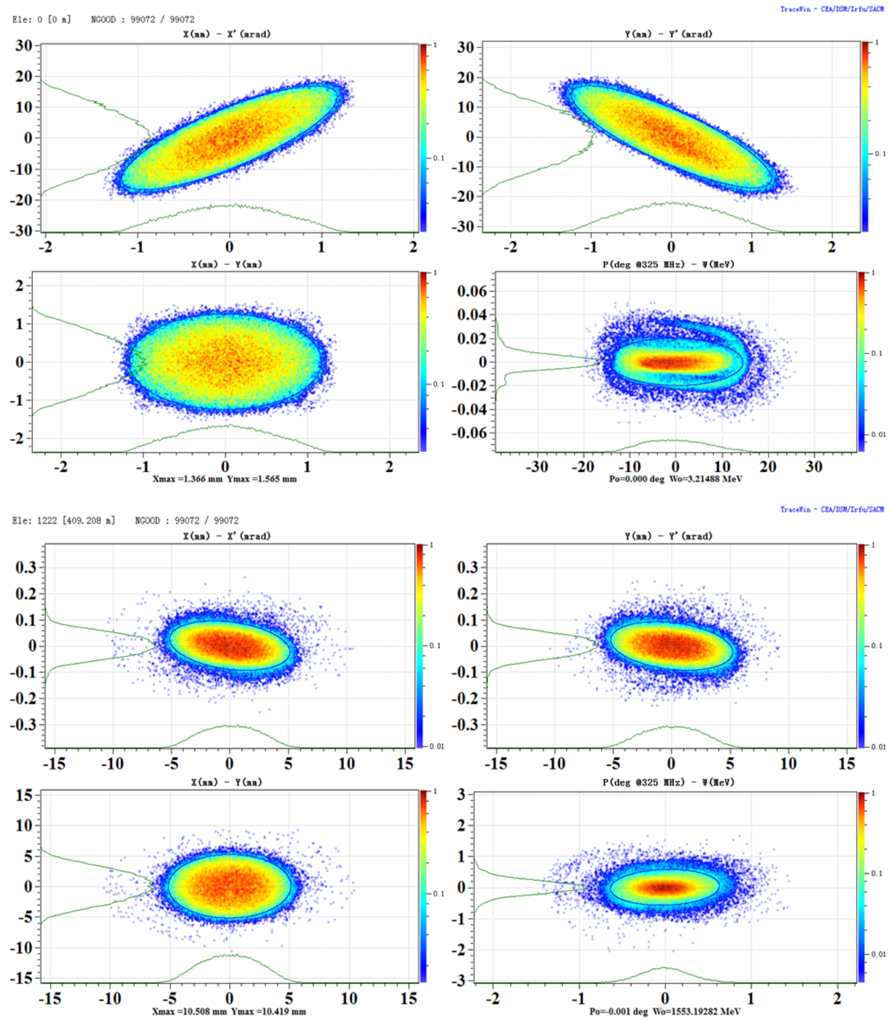
**Z. Guo et al., MOP217**



# End to End Simulation

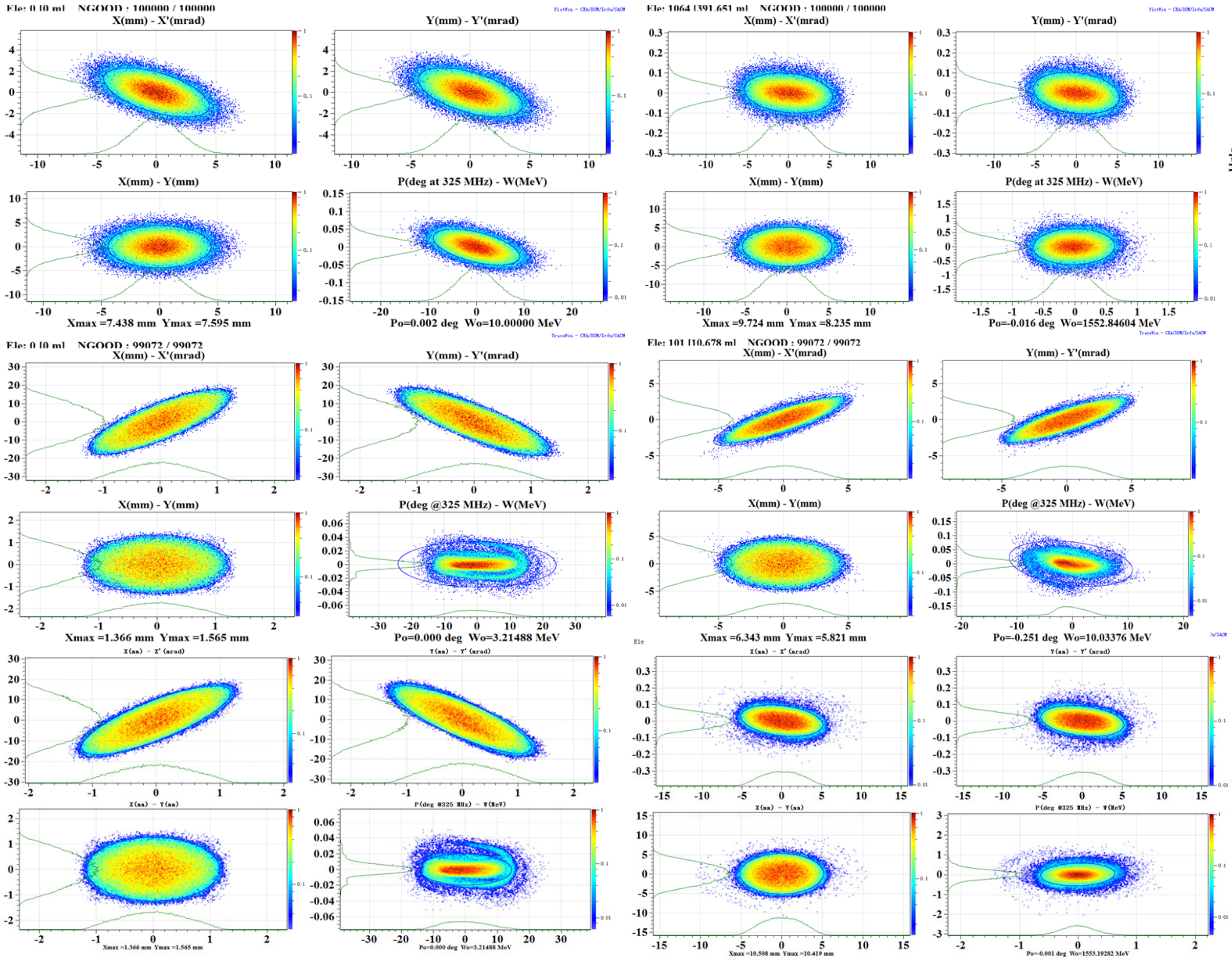
- RMS Emittance growth
  - ✓ 15% in transverse;
  - ✓ 40% in longitudinal ;
- Halo particles
- Particle loss with errors;

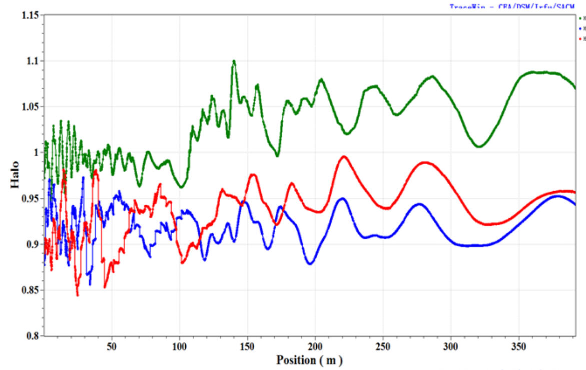


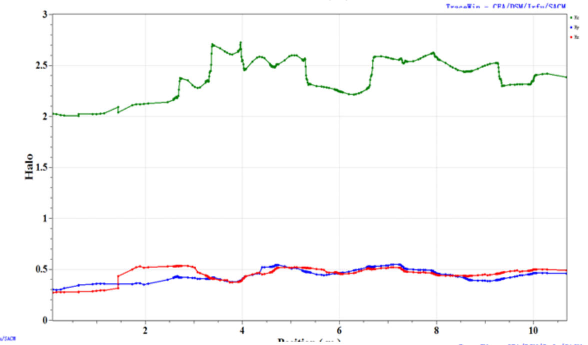



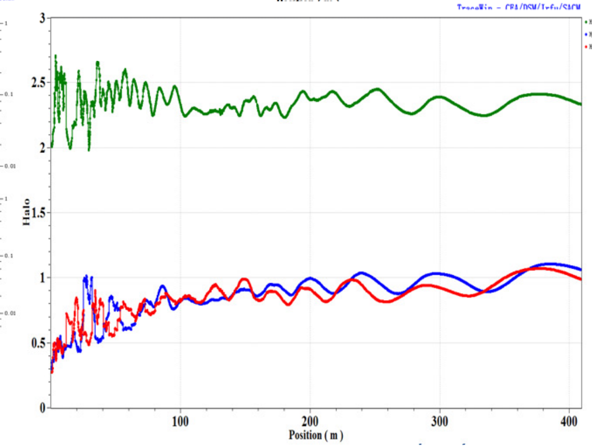
# Thank you for your attention!

Backup slides


Ele: 0 [0 m] NGOOD : 100000 / 100000
X(mm) - X'(mrad)
Y(mm) - Y'(mrad)
X(mm) - Y(mm)
P(deg at 325 MHz) - W(MeV)
Xmax =7.438 mm Ymax =7.595 mm
Po=0.002 deg Wo=10.00000 MeV
Ele: 1064 [391.651 m] NGOOD : 100000 / 100000
Xmax =9.724 mm Ymax =8.235 mm
Po=-0.016 deg Wo=1552.84604 MeV
Ele: 0 [0 m] NGOOD : 99072 / 99072
P(deg @325 MHz) - W(MeV)
Xmax =1.366 mm Ymax =1.565 mm
Po=0.000 deg Wo=3.21488 MeV
Ele: 101 [10.678 m] NGOOD : 99072 / 99072
Xmax =6.343 mm Ymax =5.821 mm
Po=-0.251 deg Wo=10.03376 MeV


Halo
Position ( m )


Halo


Halo
Position ( m )

# Implementation of the Criteria



## Section design

$\sigma_0<90$, $\sigma_{t0}/\sigma_{l0}=\varepsilon_l/\varepsilon_t$
Phase for acceptance

Envelop smooth, emittance growth

- Period length
- Synchronous phase
- Field level
- Transverse focusing

## Linac design

$\sigma_0/l$ smooth and continues
Match between sections

$\sigma_{0i,end}/l_{i,period}=\sigma_{0i+1,start}/l_{i+1,period}$
Envelop and emittance

- Match
- Smooth focusing strength

## Error analysis

Error settings
Front to end simulation

Envelop and emittance
Particle loss

- Error settings
- Correction schemes
- Design check