# Halo formation and its mitigation in the SNS linac

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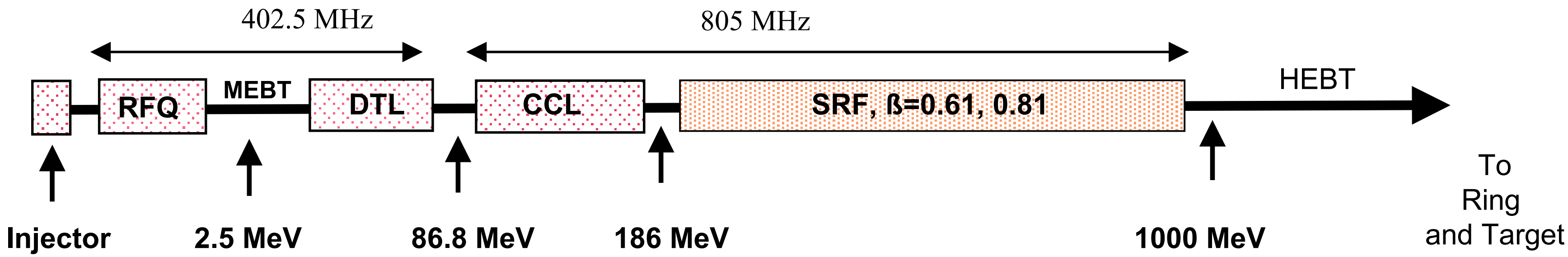
# Outline

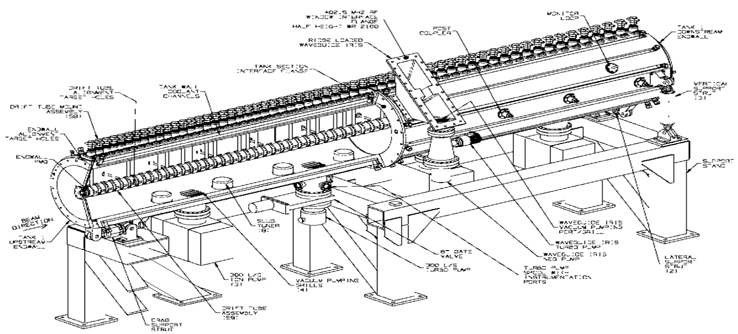
1. Introduction
2. FE halo formation and its mitigation
   - MEBT collimation
   - Alternative MEBT optics
   - Hybrid solution
3. DTL collimation
4. Summary

# Introduction

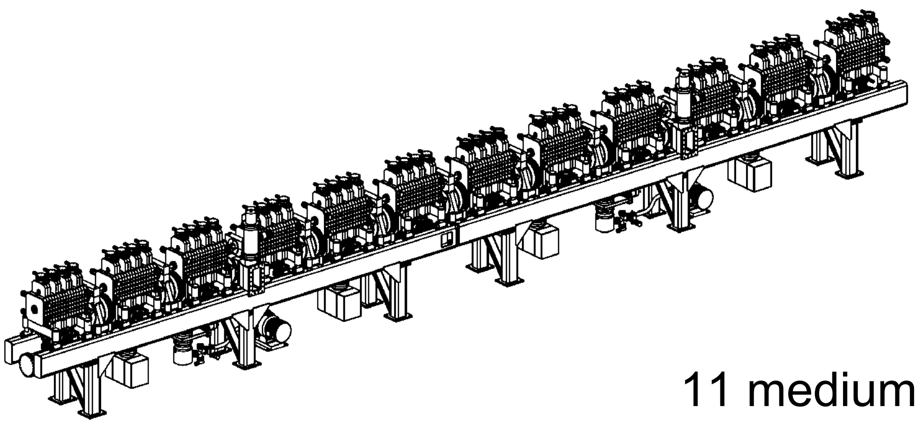
## Schematic view & its performance specification



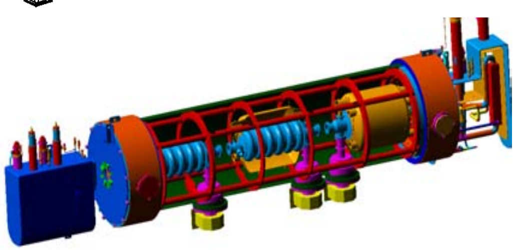

- Beam power: 1.44MW
- $W_{final}$: 1 GeV
- $\varepsilon_{foil}$ : ≈ 0.034 π cm-mrad (rms, norm)
- Beam loss: <1 W/m
- $I_{peak}$ : 38mA
- $I_{average}$ : 1.55mA
- Length : 332m
- $W_{final}$ stability: ± 0.2 MeV
- $W_{final}$ spread: ± 0.85 MeV (rms)



6 DTL tanks
FFODDO focusing structure ($6\beta\lambda$)



4 CCL modules
12 segments/module
FODO focusing structure ($13\beta\lambda$)



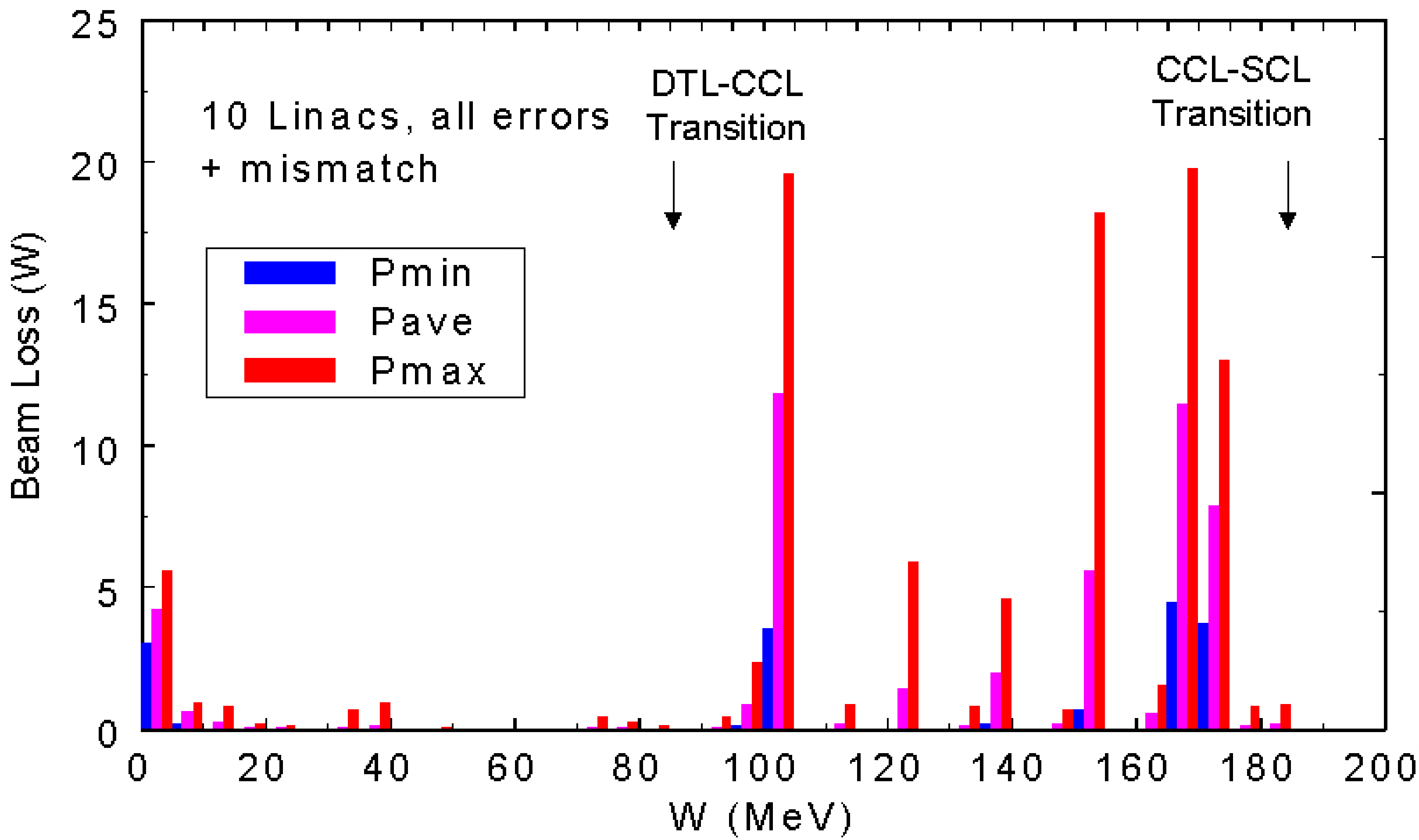
11 medium beta ($\beta$=0.61) cryomodules
3 cavities per cryomodule
5.839m period length
12 high beta ($\beta$=0.81) cryomodules
4 cavities per cryomodule
7.891m period length
Doublet focusing structure

# FE Halo formation and its mitigation

## Simulations show a beam loss in the linac

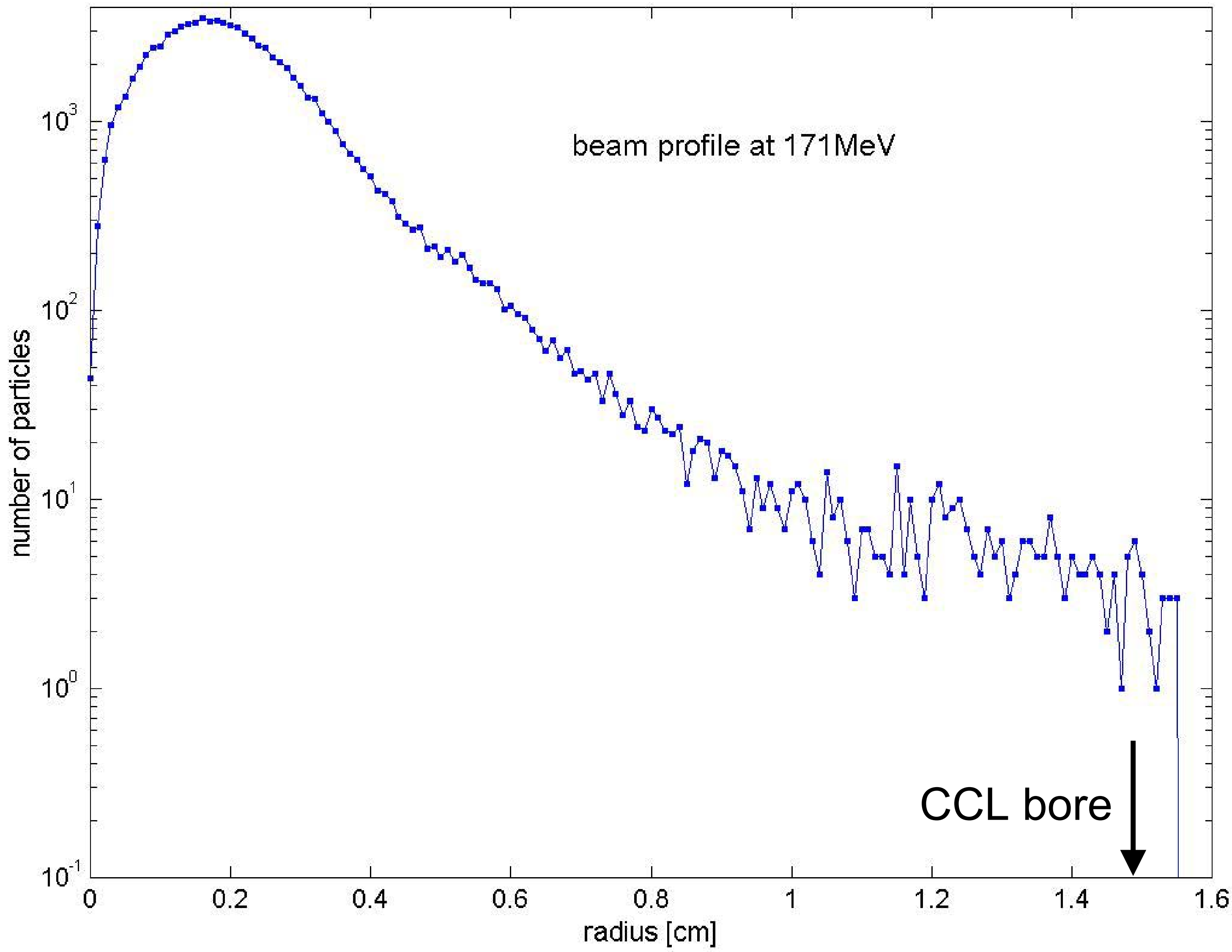
- Multiparticle simulation studies shows a development of a substantial halo that leads to beam loss and radio activation of the SNS linac, especially CCL.
- Beam distribution based on Front End (FE) emittance measurements is used.

# Beam loss along the linac



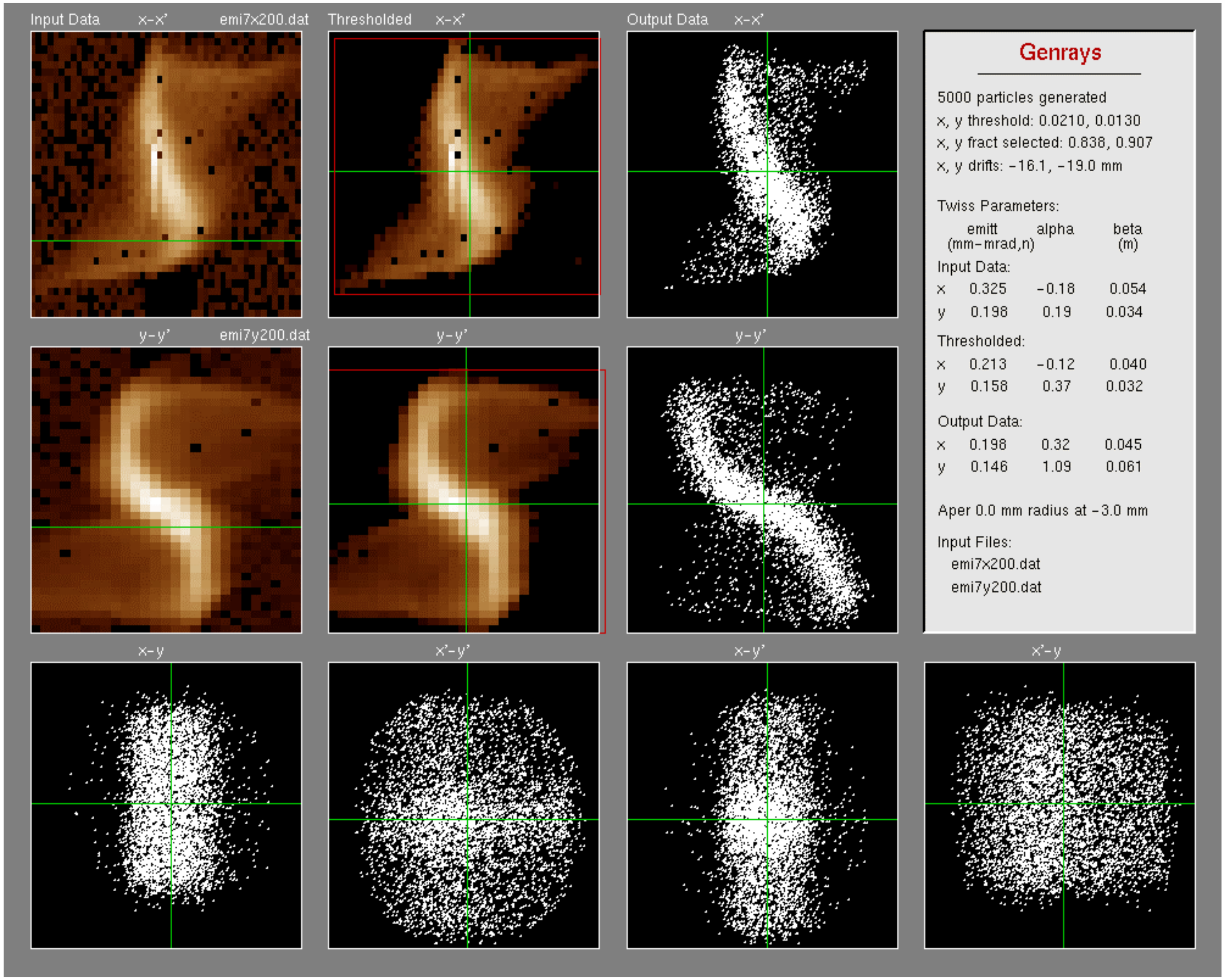

**Halo particles are lost primarily on the CCL bore**

# Radial beam profile at 171 MeV showing halo extending beyond the CCL bore



# Beam based on the FE emittance measurement at LEBT exit was used

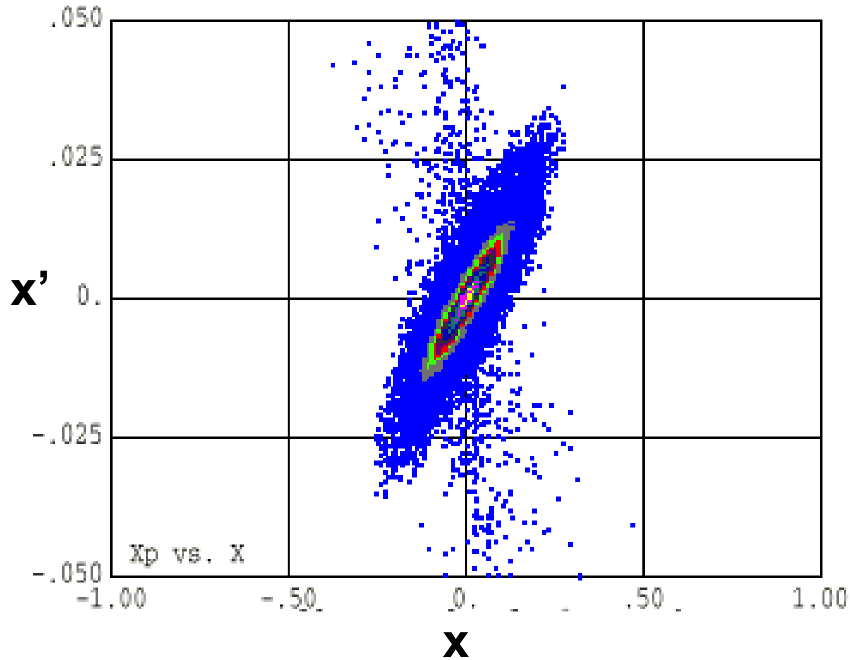
(Courtesy of J. Staples)

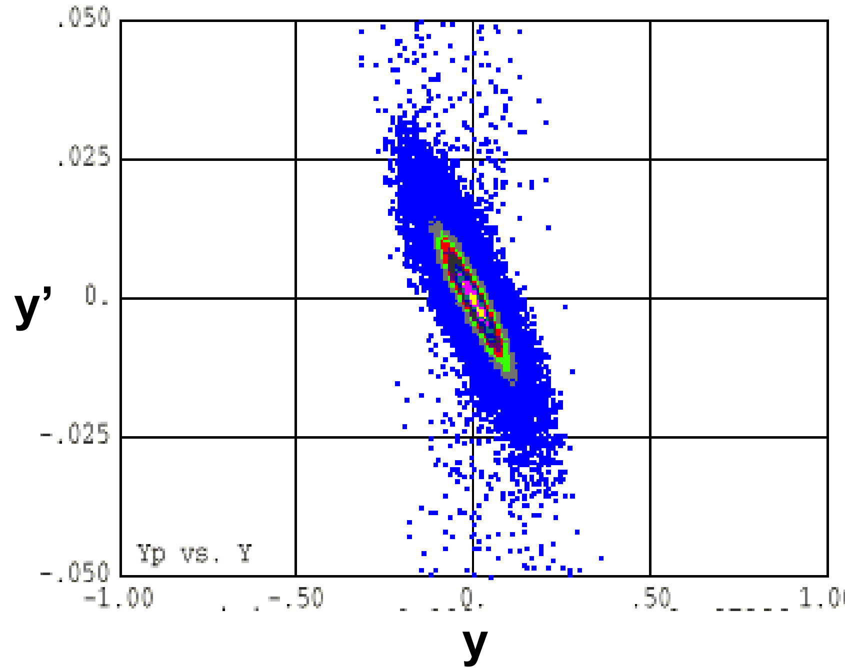



Raw data and derived “measured” beam distribution

# “measured” beam tracked to the RFQ exit is slightly worse than water-bag originated beam

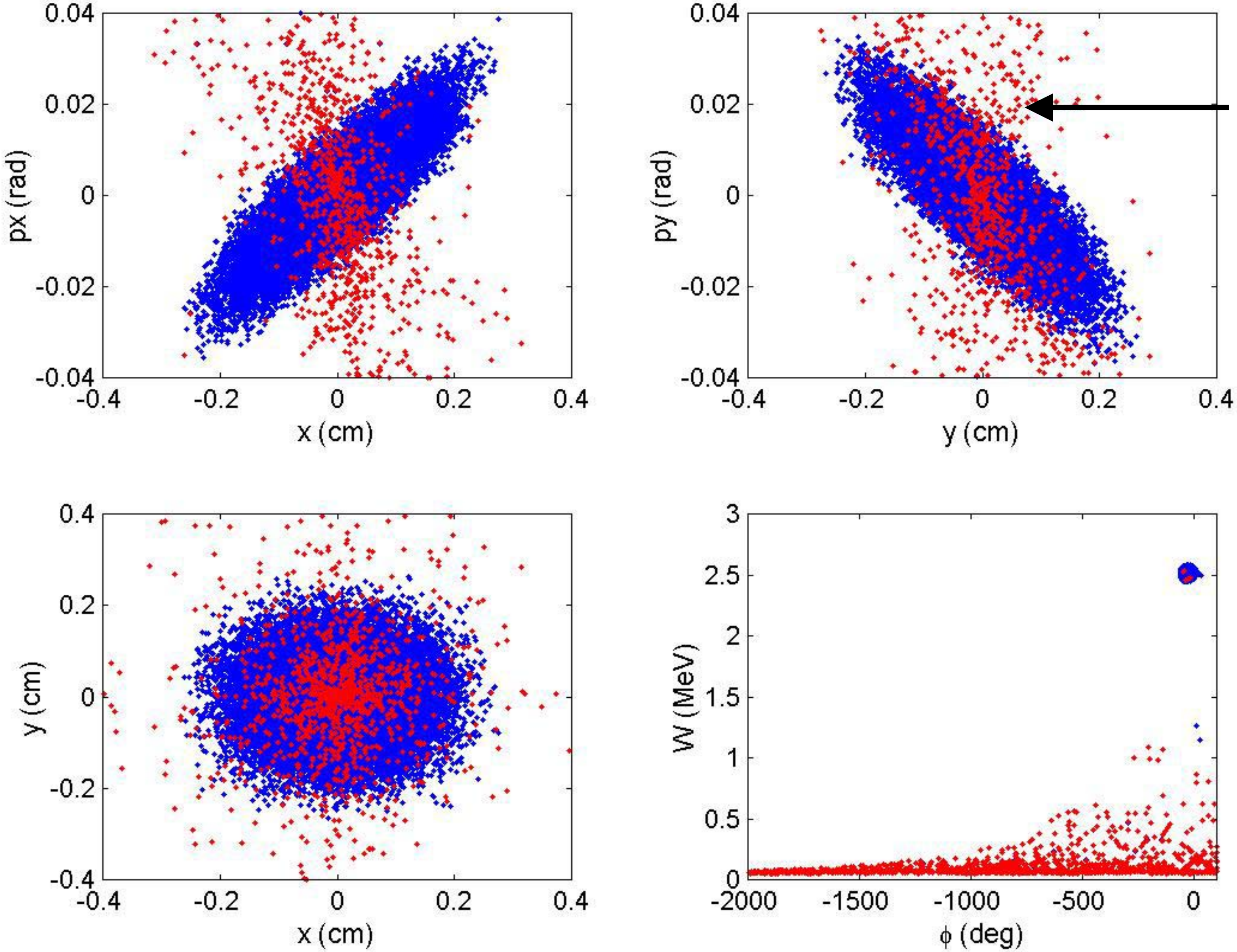
**at RFQ exit**



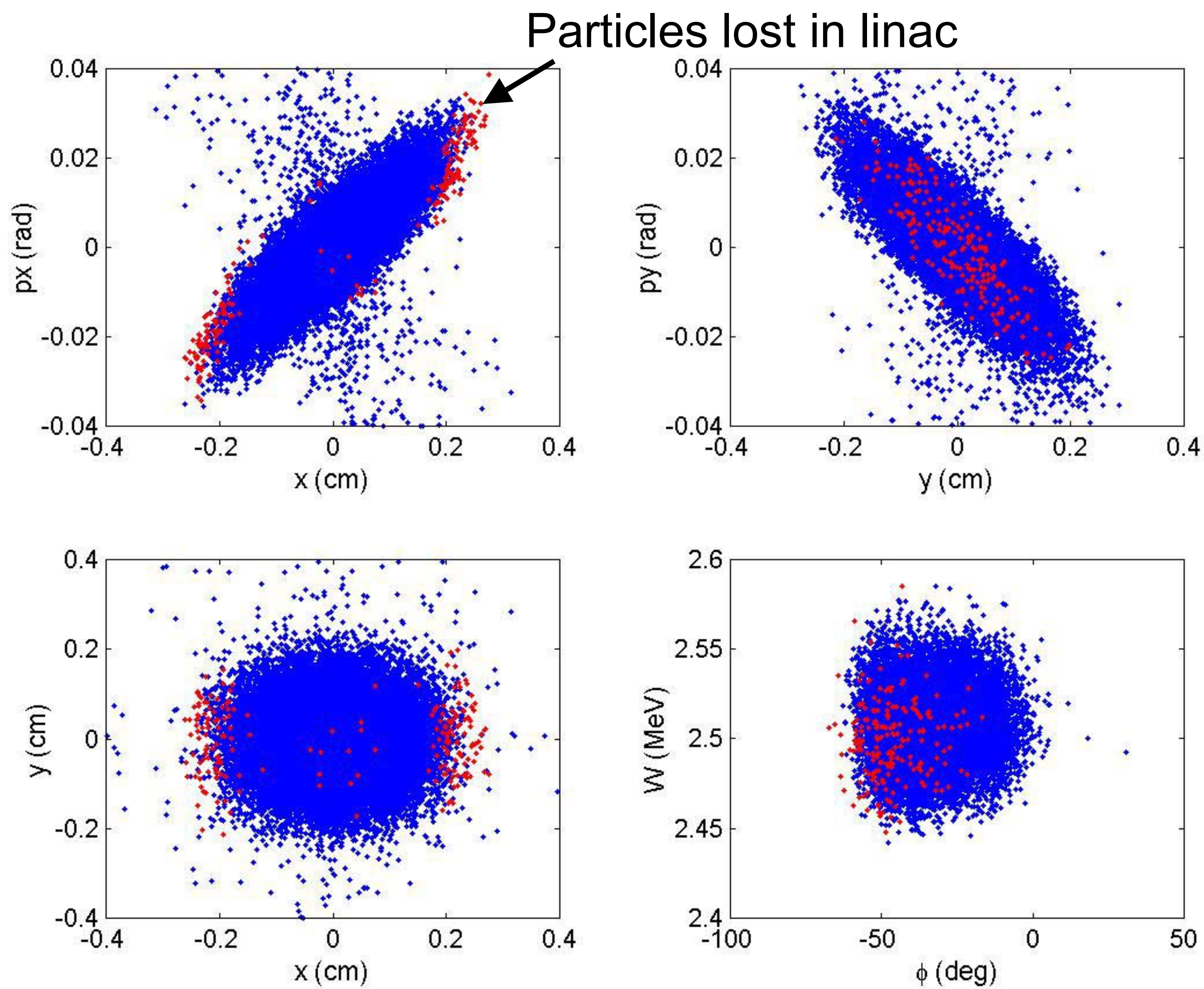




- This beam is only slightly worse than one originating from an initial water-bag distribution at the RFQ entrance
- The particles that appear to be scattered in the angular dimension correspond to low energy particles (~0.1MeV)

# Particles at RFQ exit. Particles lost in upstream of MEBT are low energy particles (~ 0.1MeV)

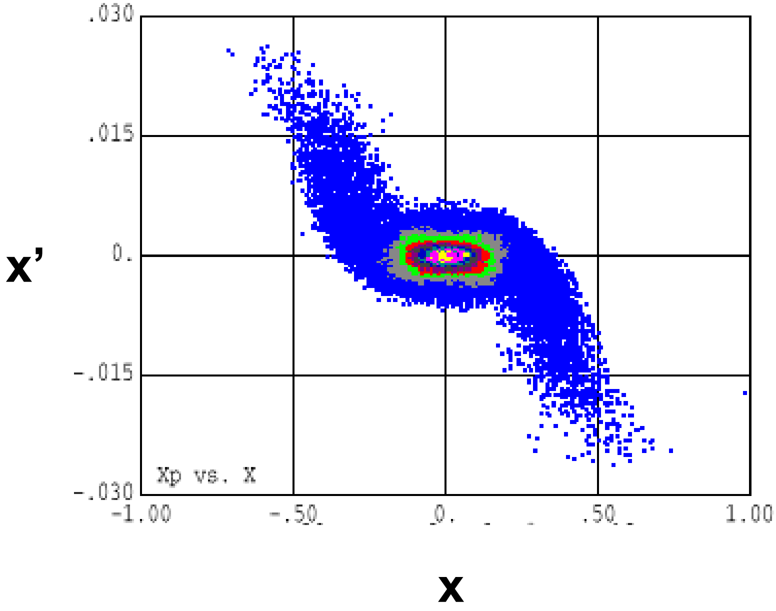


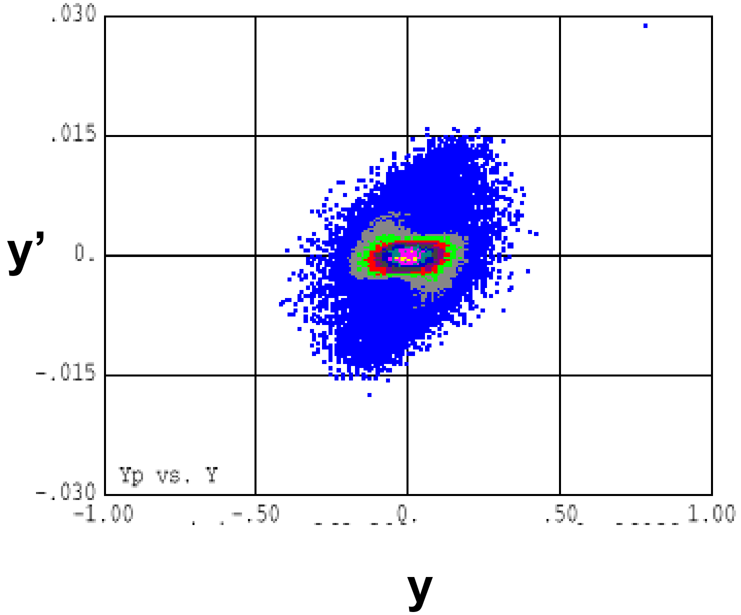
# Particles at RFQ exit. Particles lost in the linac (in red) are horizontal halo.



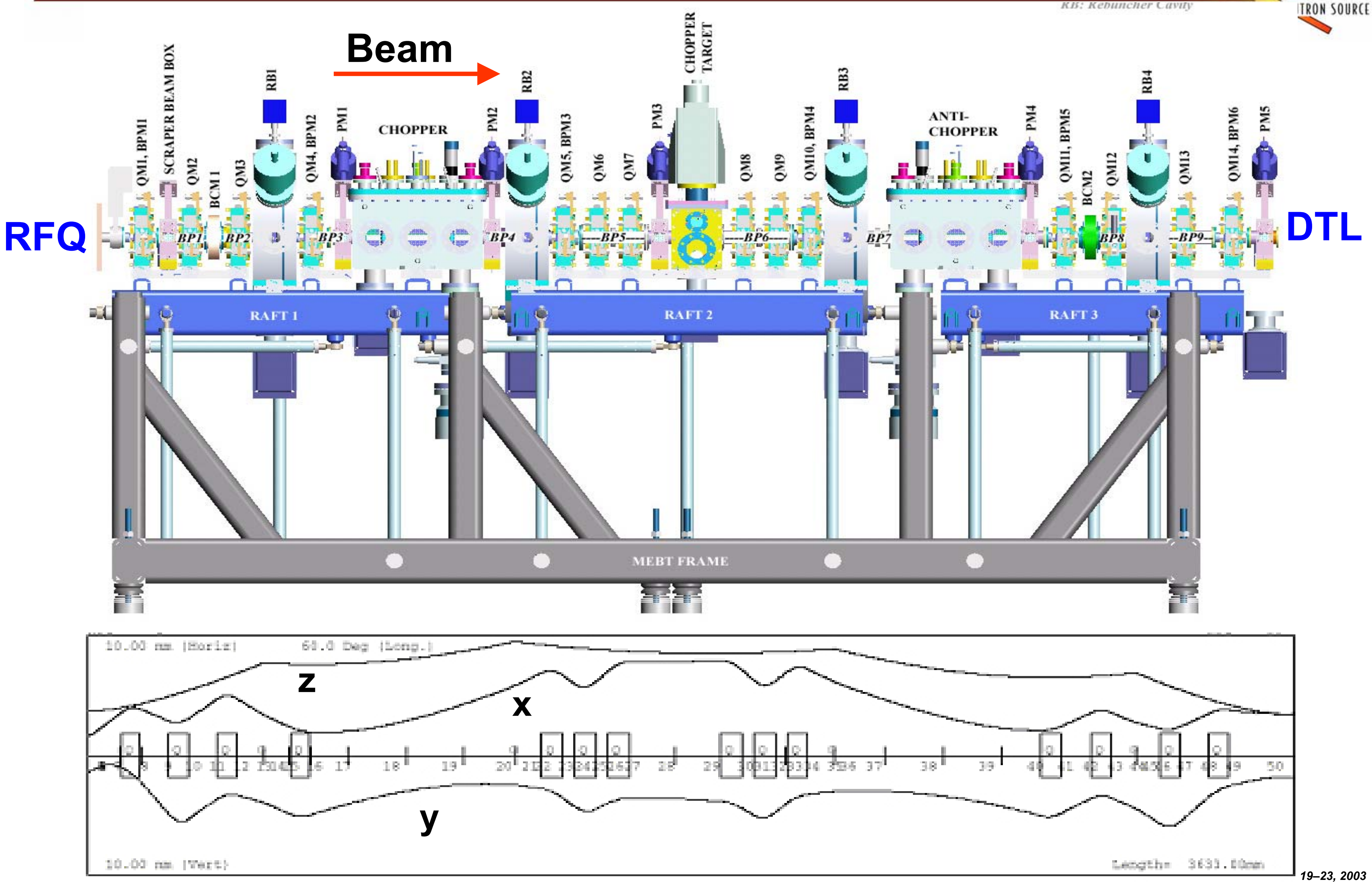
# Significant horizontal halo develops at the end of MEBT

## At MEBT end



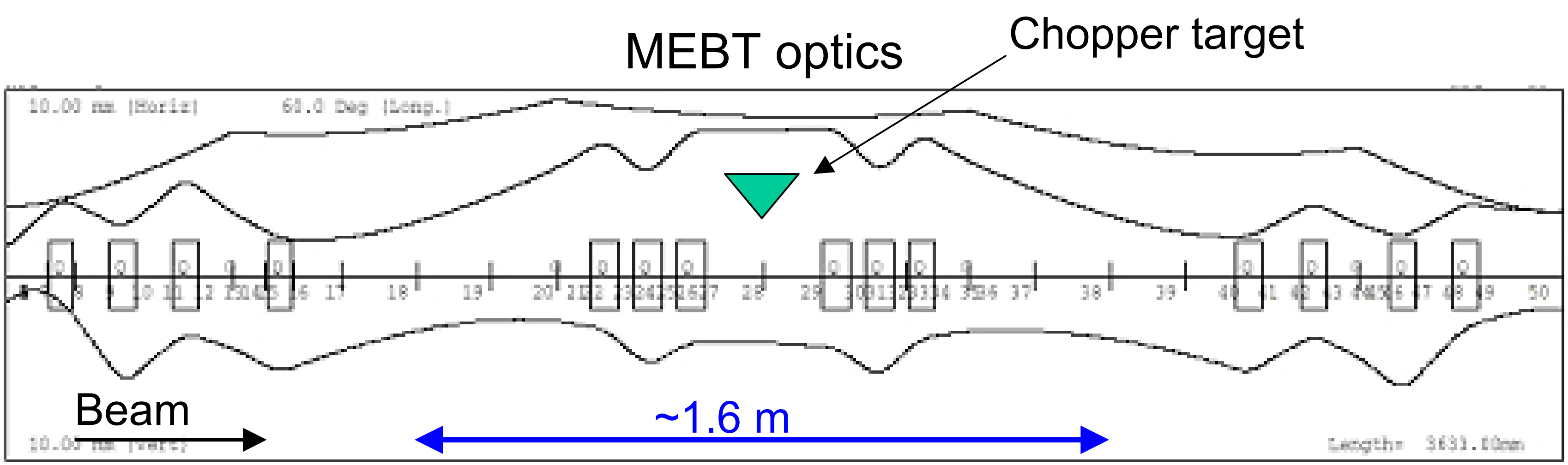
# MEBT and its optics




19–23, 2003

# Sources of FE halo generation

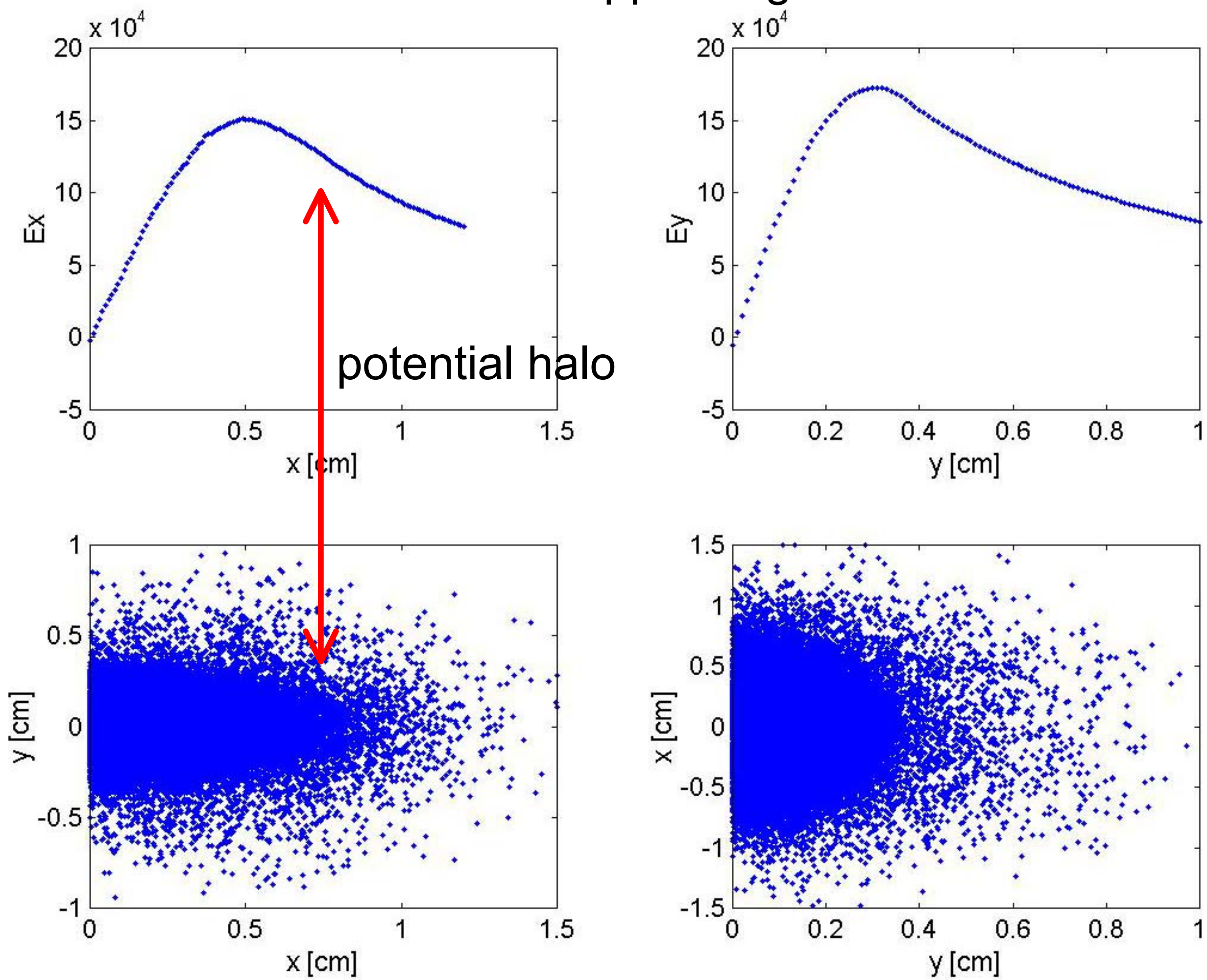
- MEBT is the largest contributor to FE halo generation
- Nonlinear space charge force stemming from a large transverse beam eccentricity generates halo in MEBT
- As minor contributors, several FE components and physical effects may contribute to the generation of beam halo




Region with a large transverse beam eccentricity ~2:1

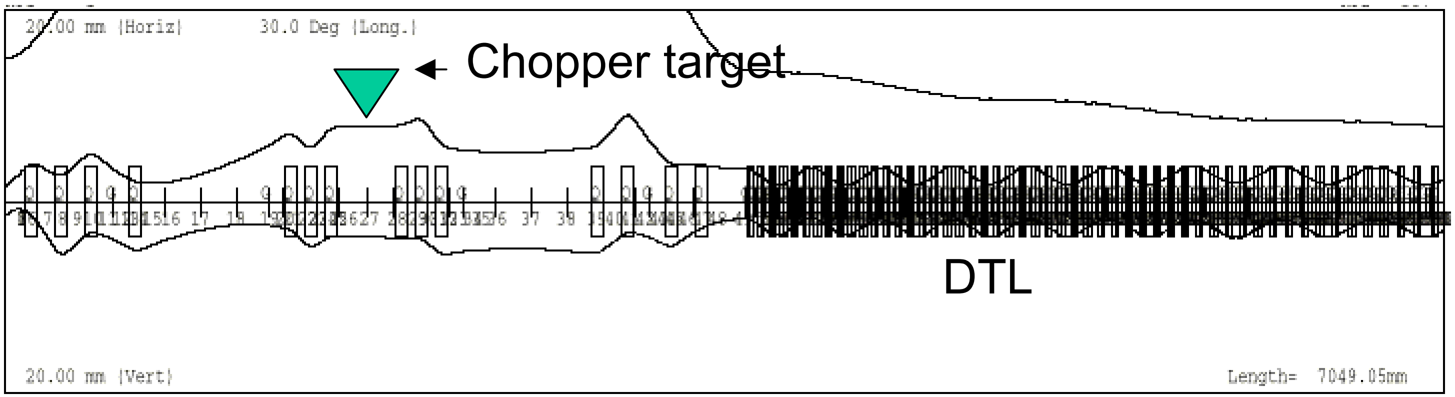
# Significant fraction of core in x space sees nonlinear space charge force, resulting in horizontal halo formation

Beam at the chopper target

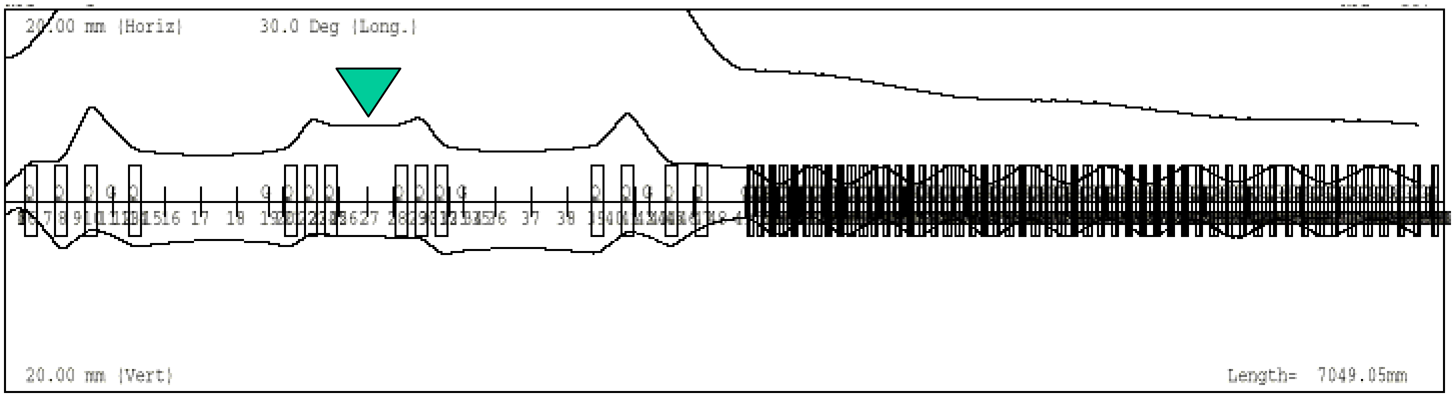



Space charge force and real space distributions

# MEBT optics are modified for the purpose of comparison

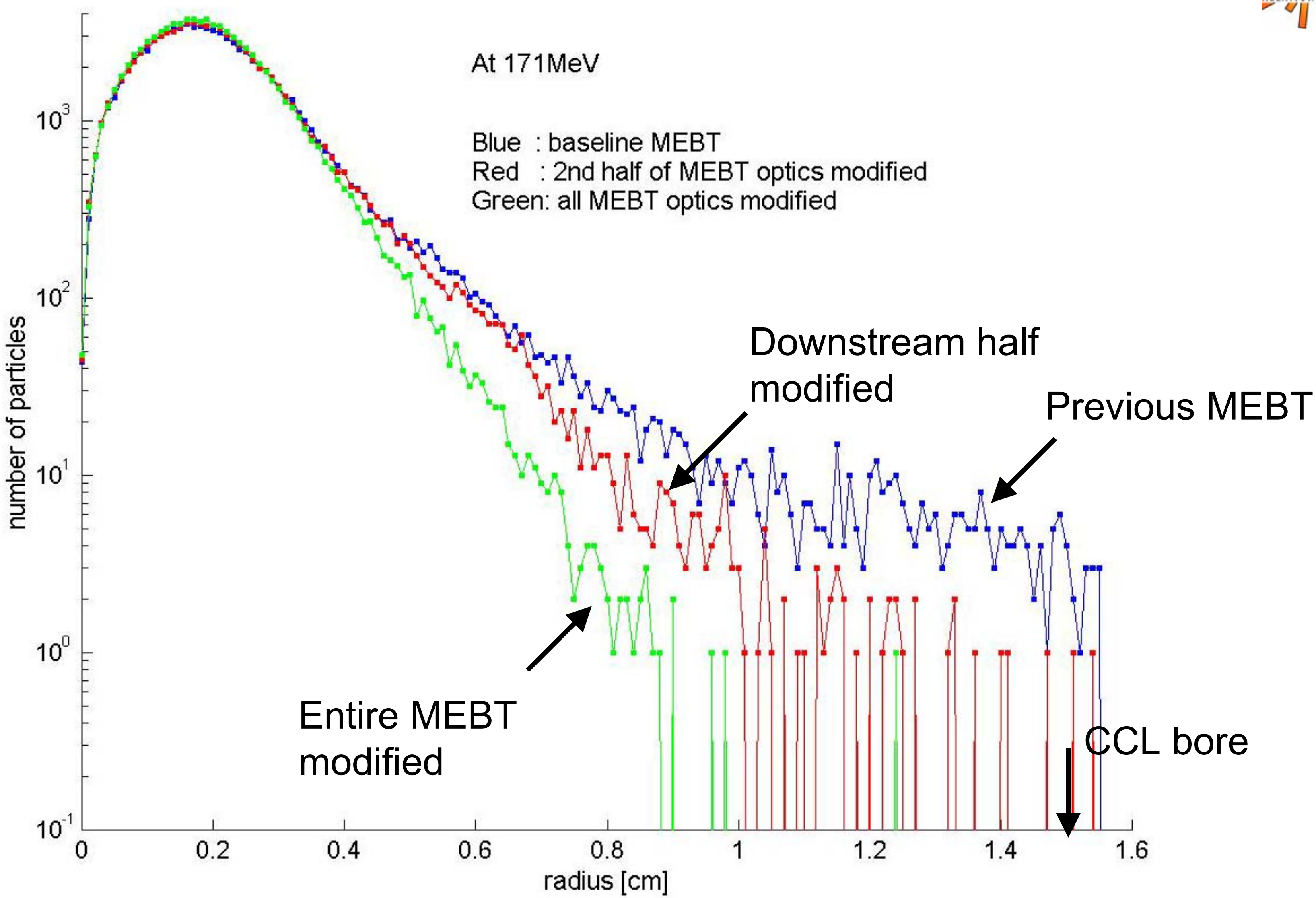



Downstream half is modified



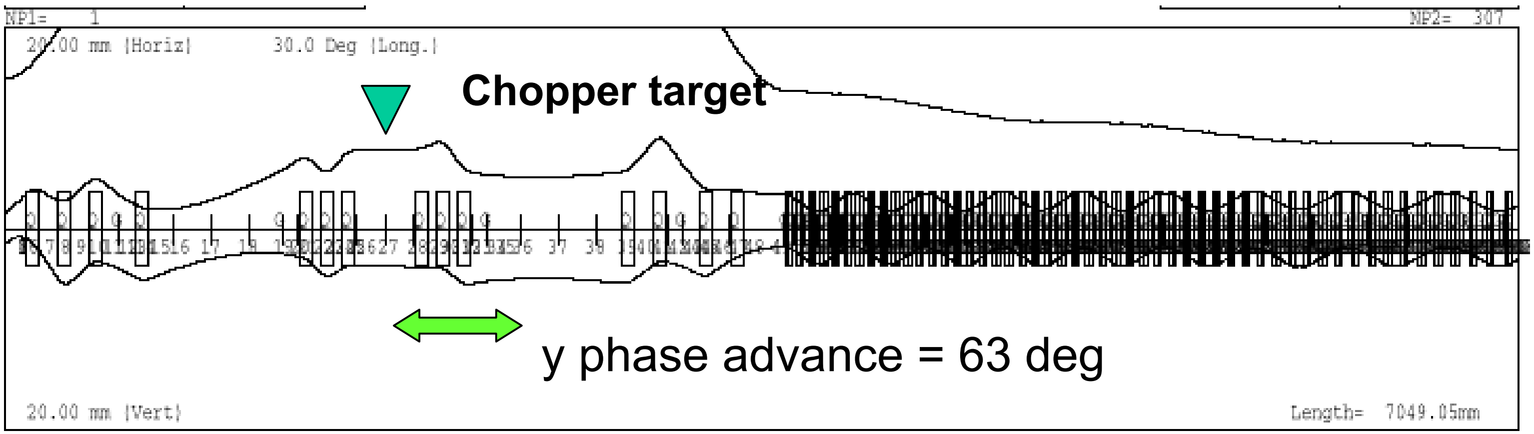

Entire MEBT modified

# Optics modification alone reduces halo at 171MeV significantly

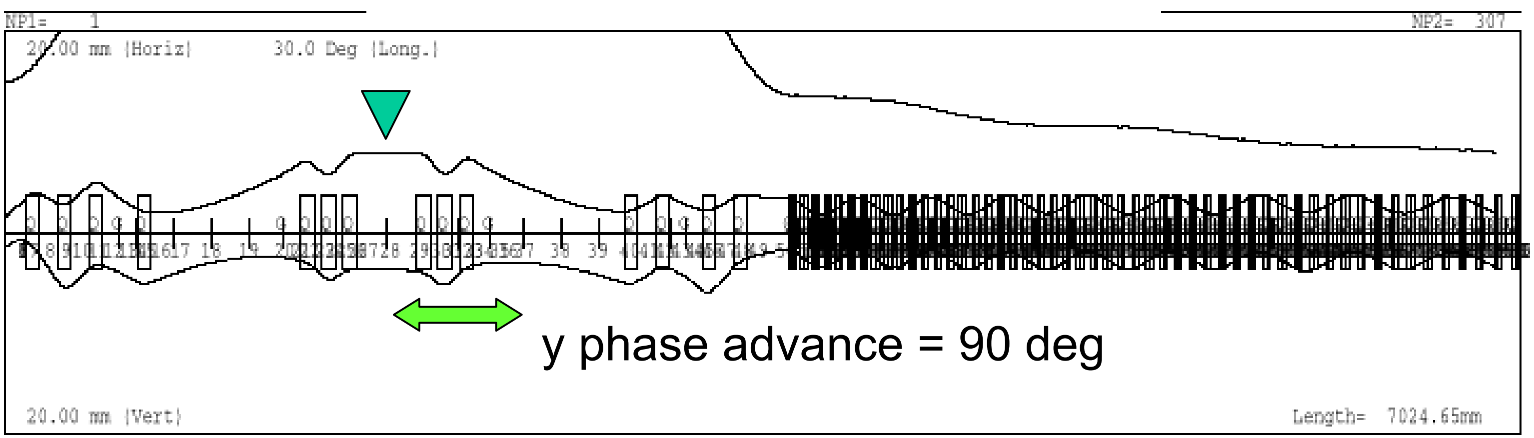


# Alternative MEBT optics

Upstream half of the MEBT optics is not modified to preserve MEBT chopping

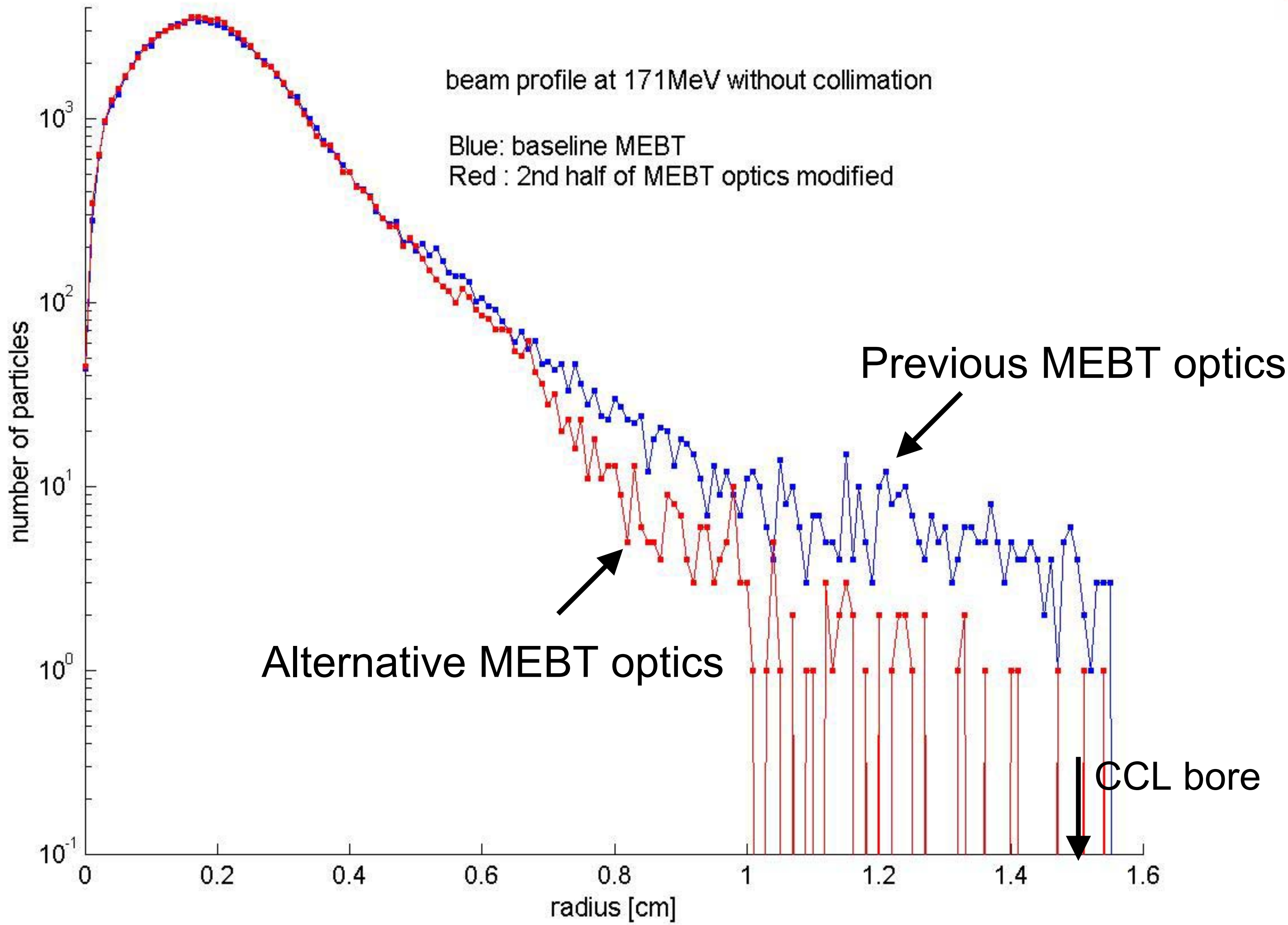



Alternative MEBT optics



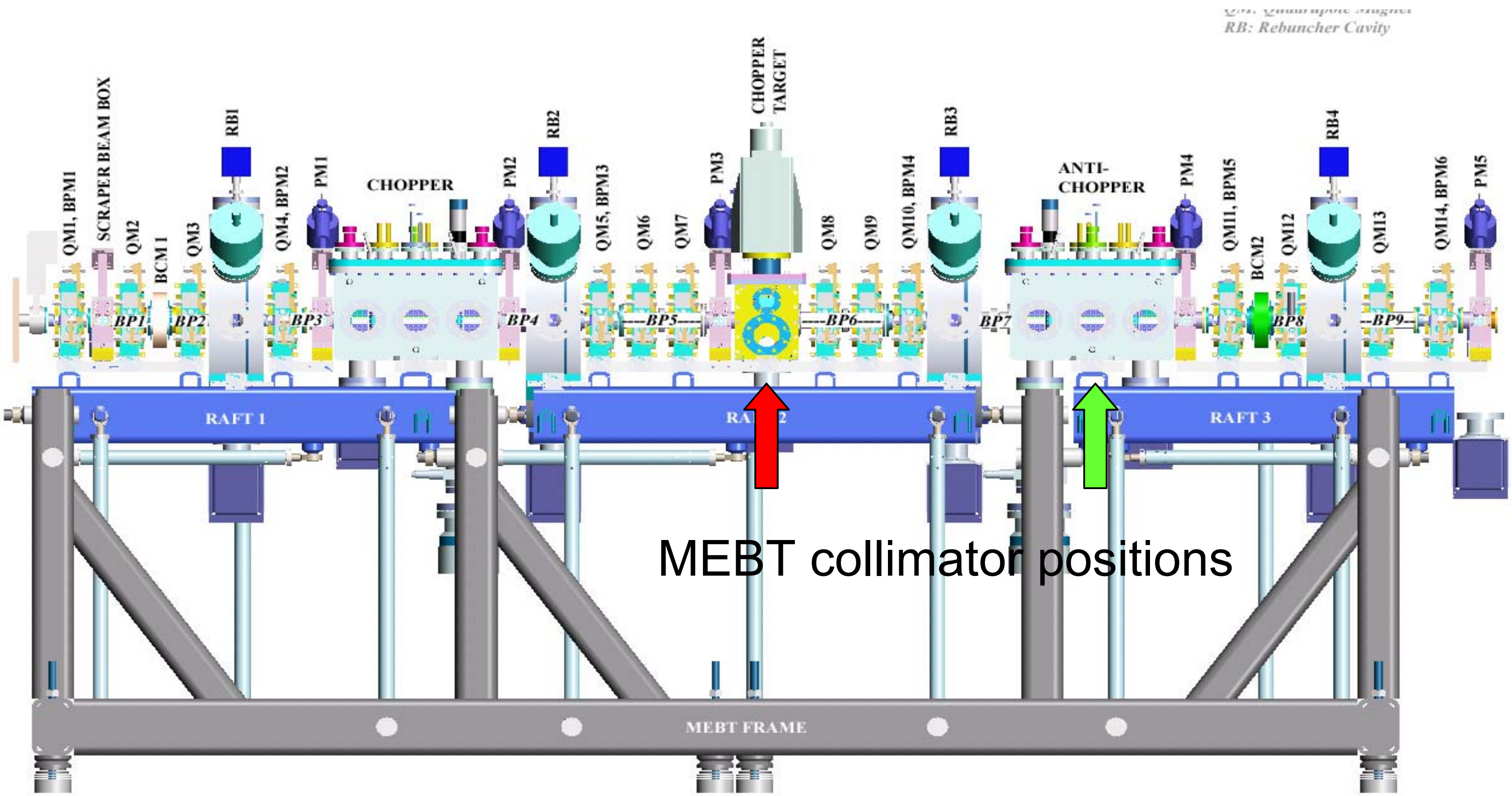

Previous MEBT optics

# Simple modification of the MEBT optics reduces halo with r > 9mm at 171MeV by 87%



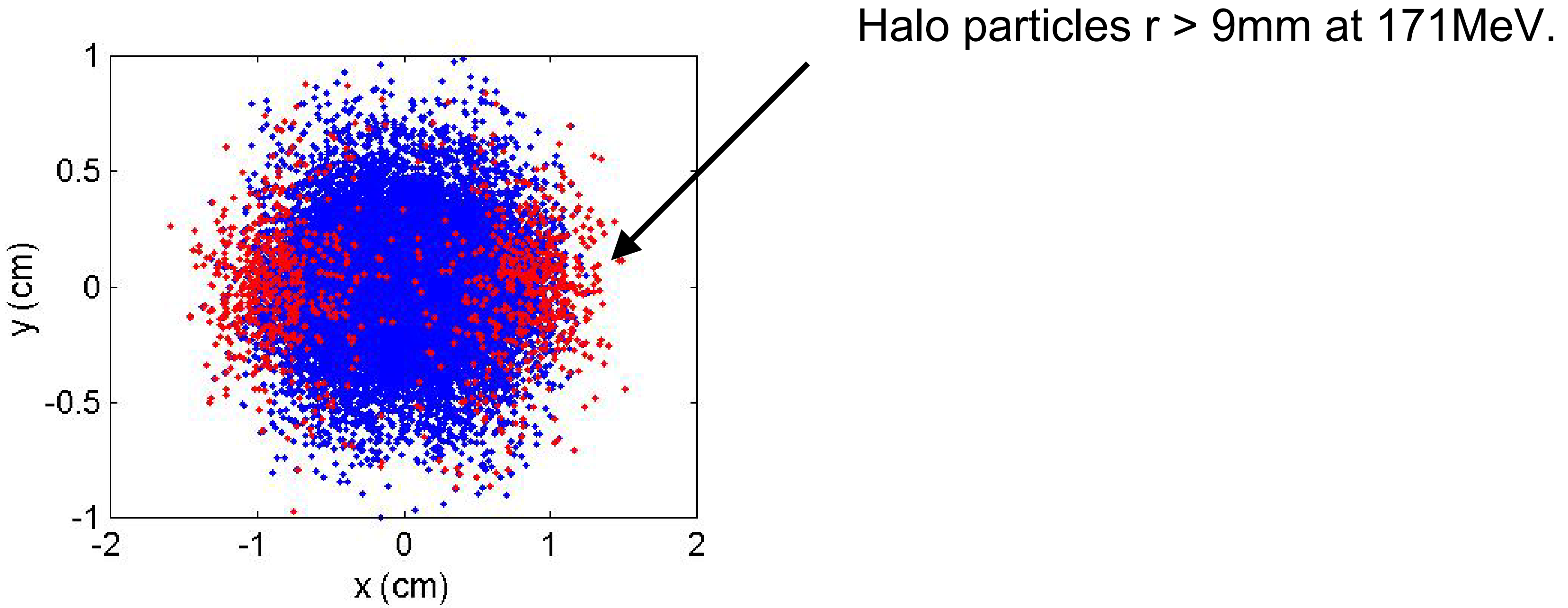
# MEBT collimation

There are only a few available positions for MEBT collimators.
One convenient place is at chopper target (red arrow).



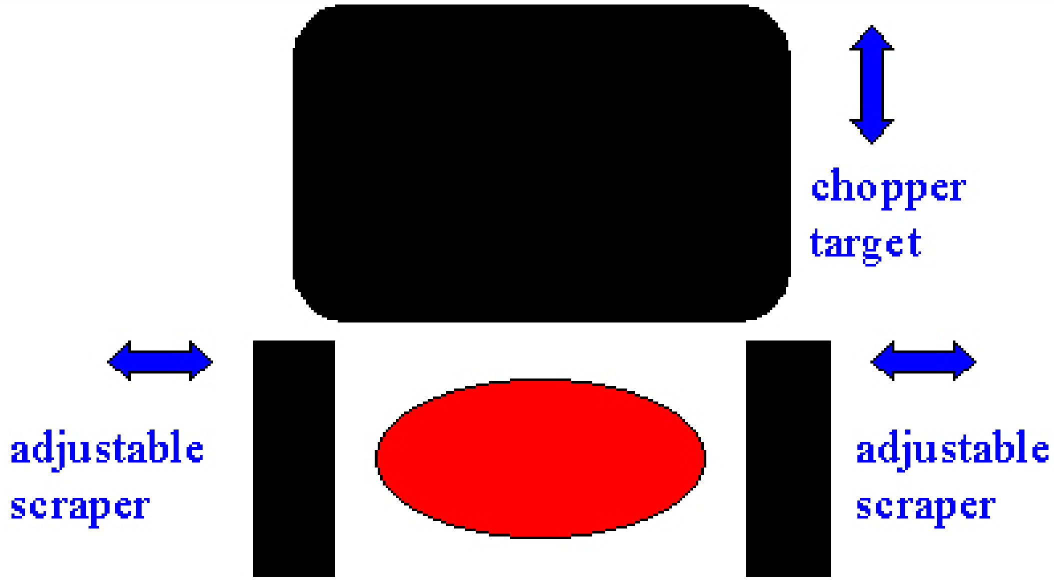
# Horizontal collimators at the chopper target are effective

- Beam distribution at the chopper target (in the middle of MEBT) indicates that two horizontal collimators will be very effective in removing downstream halo particles.



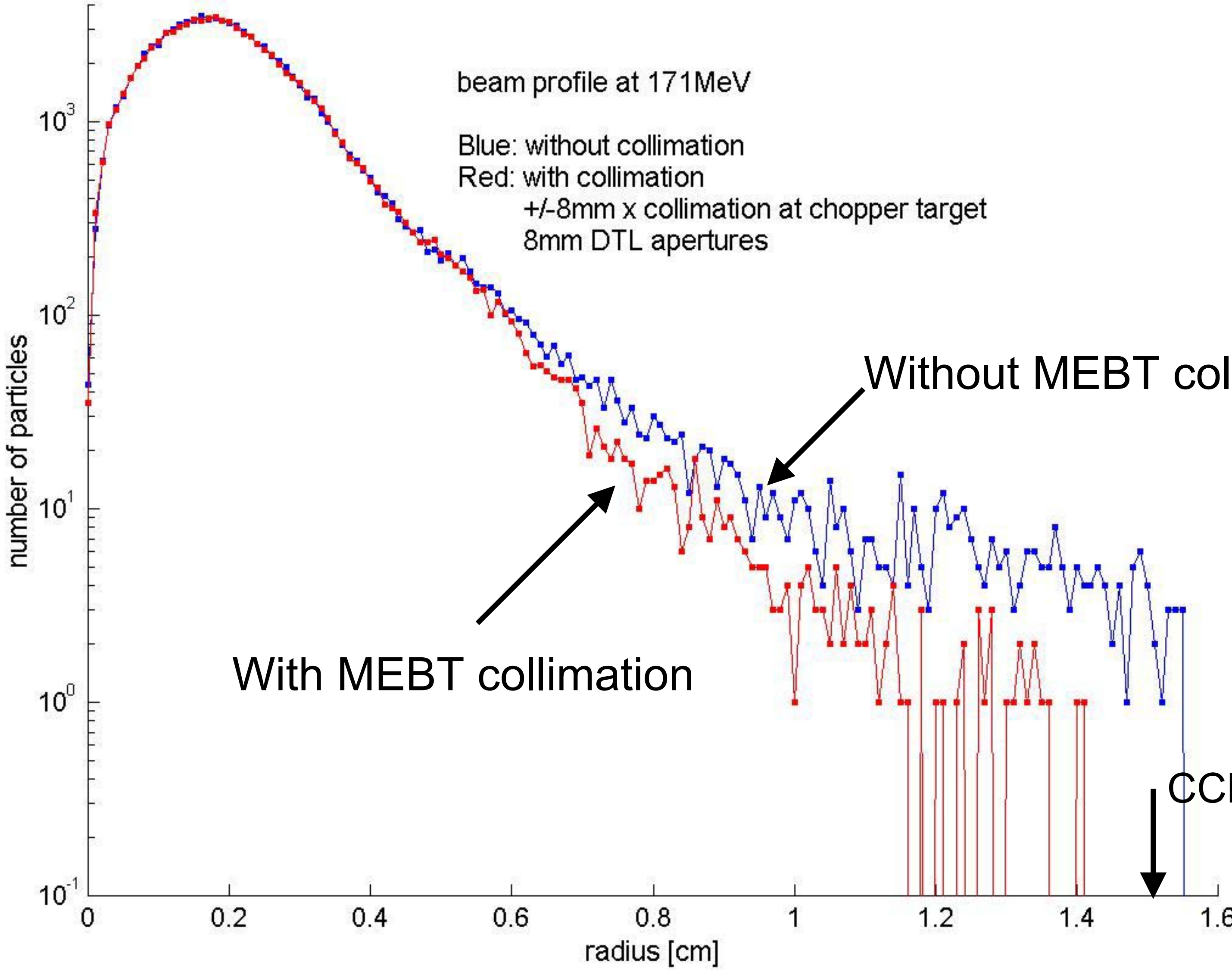

Beam distribution at the chopper target

# Schematic view of MEBT collimators at chopper target




- Scrapers mounted on horizontal actuators will not interfere with the function of the target.
- It is readily adjustable to accommodate the actual beam conditions, which are expected to vary with different operating conditions.
- removes potential halo created in the chopper before it becomes integrated into the core.

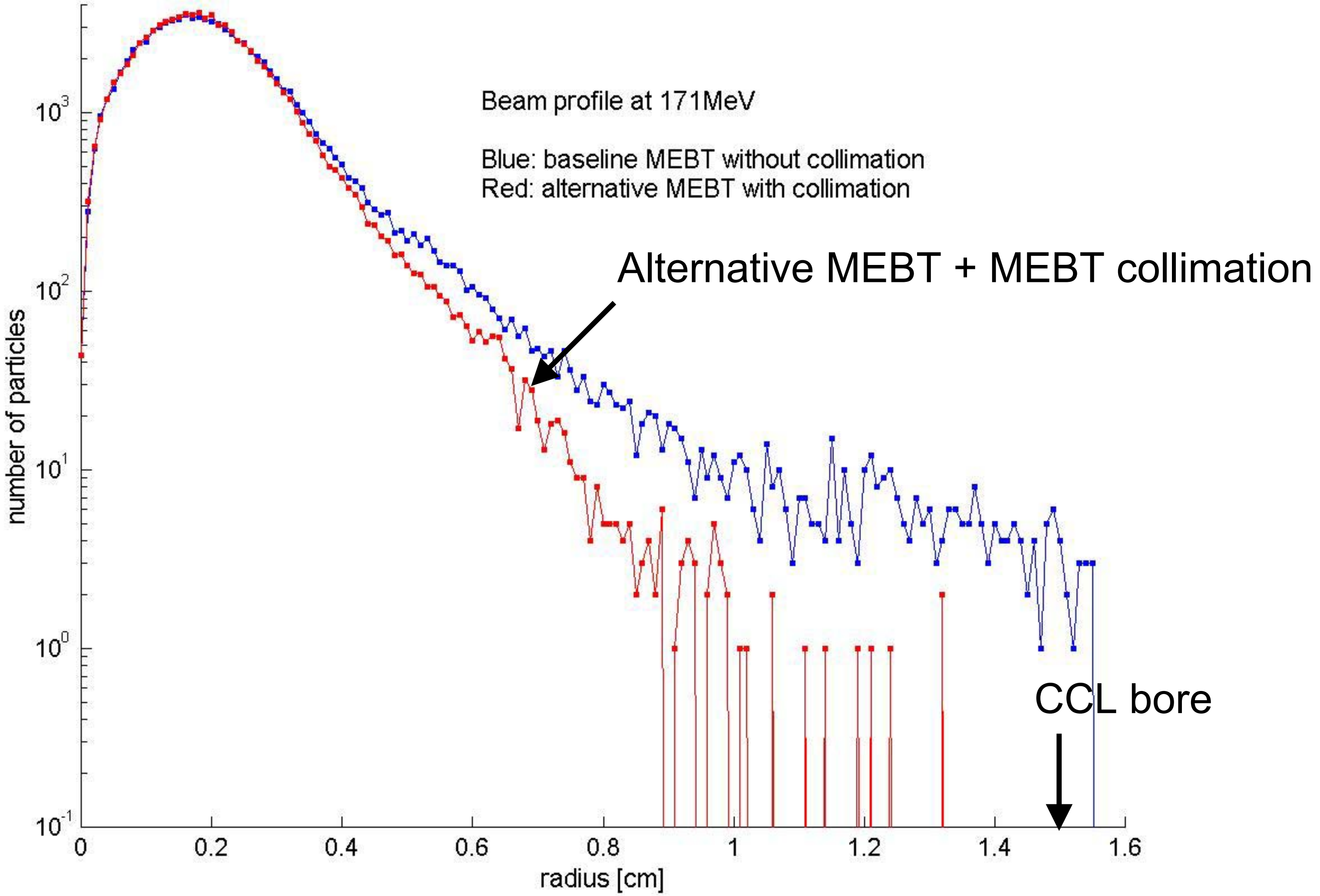
# Beam profile at 171MeV with (red curve) and without MEBT collimation (blue curve) at ±8mm. Halo is reduced by 84%



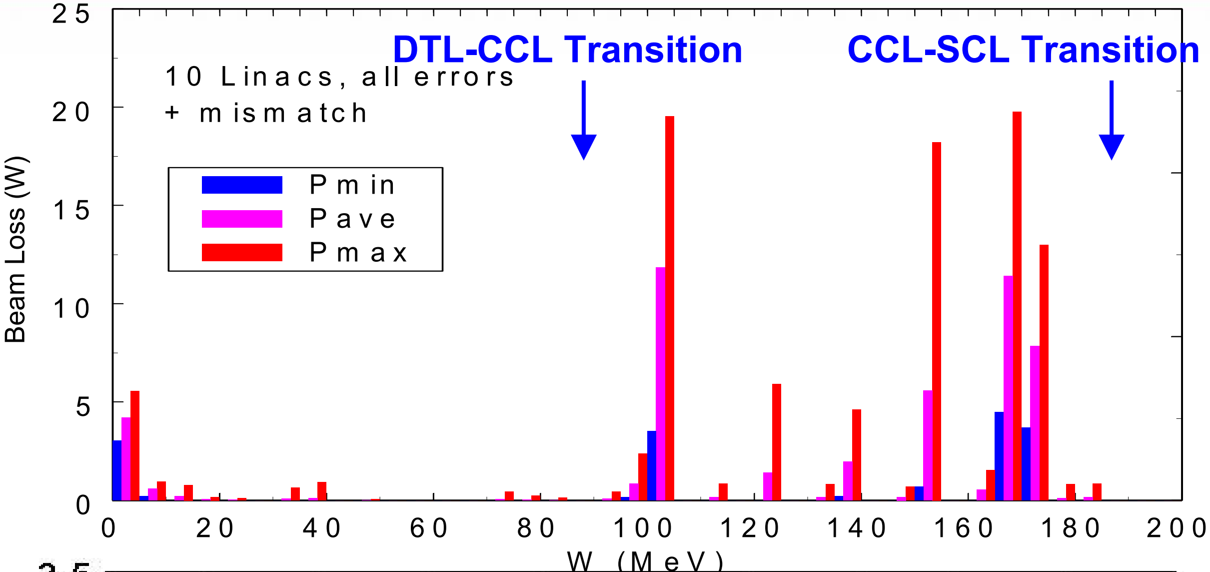
# Adopted halo mitigation scheme

## Alternative MEBT optics + MEBT collimation

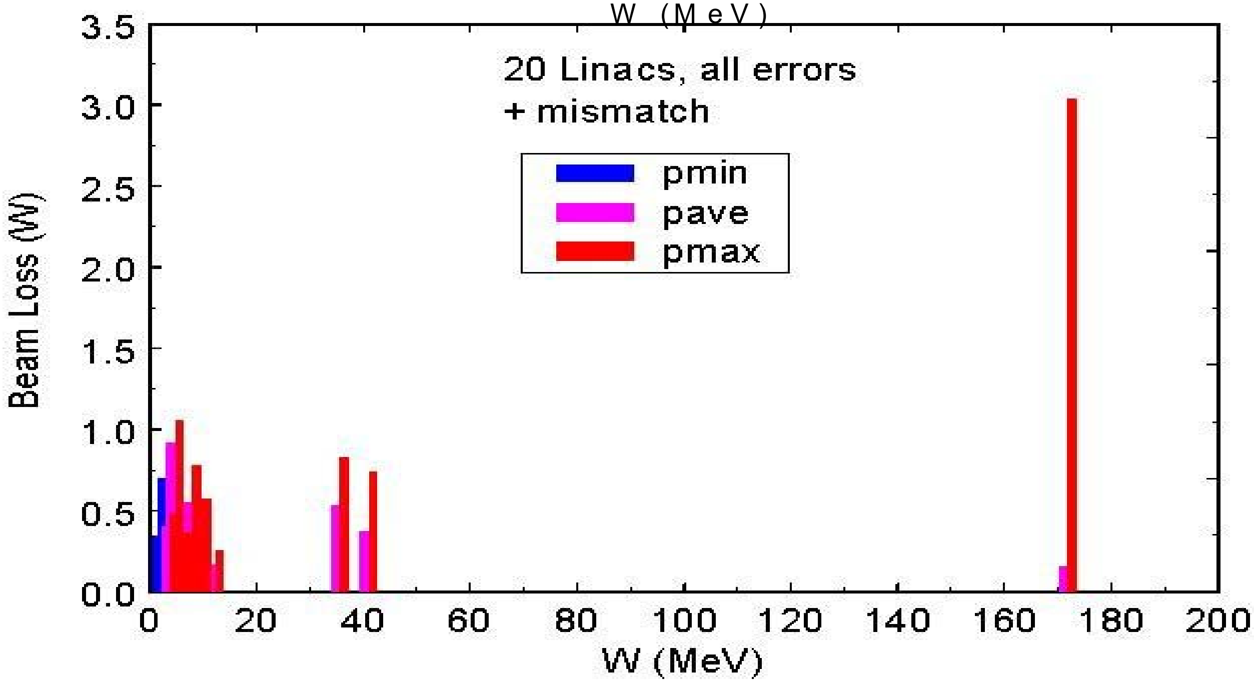
### reduces beam halo with r > 9mm by 97% at 171MeV



# Anticipated Improvement from FE Halo Mitigation



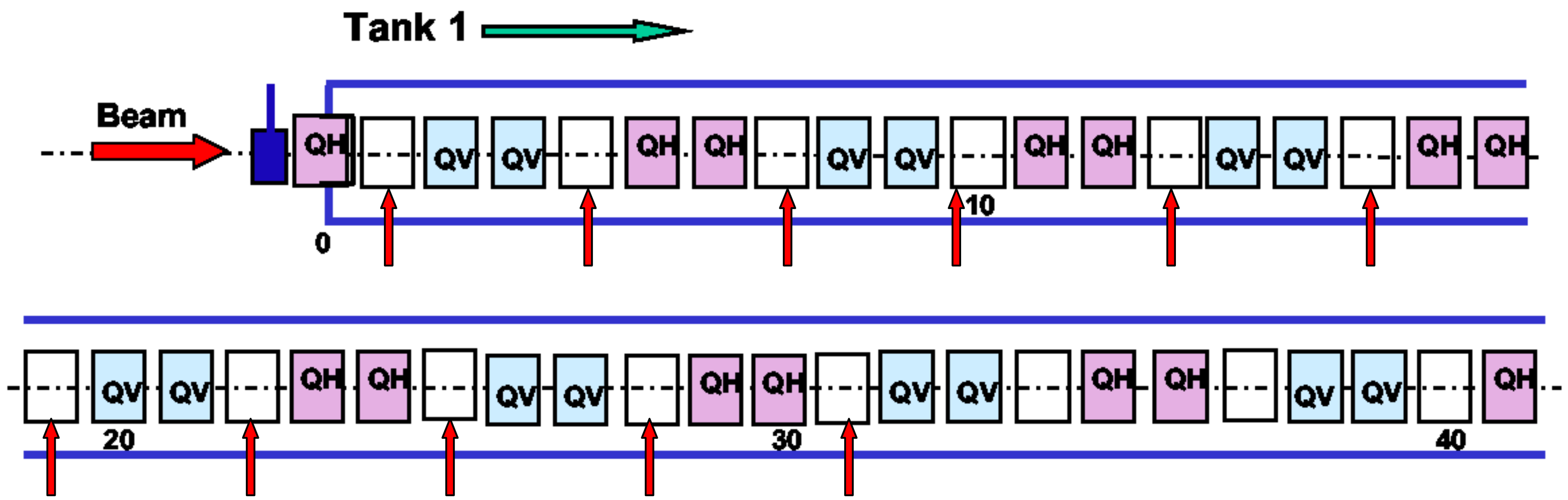

Without mitigation plan




With mitigation plan

# DTL collimation studies

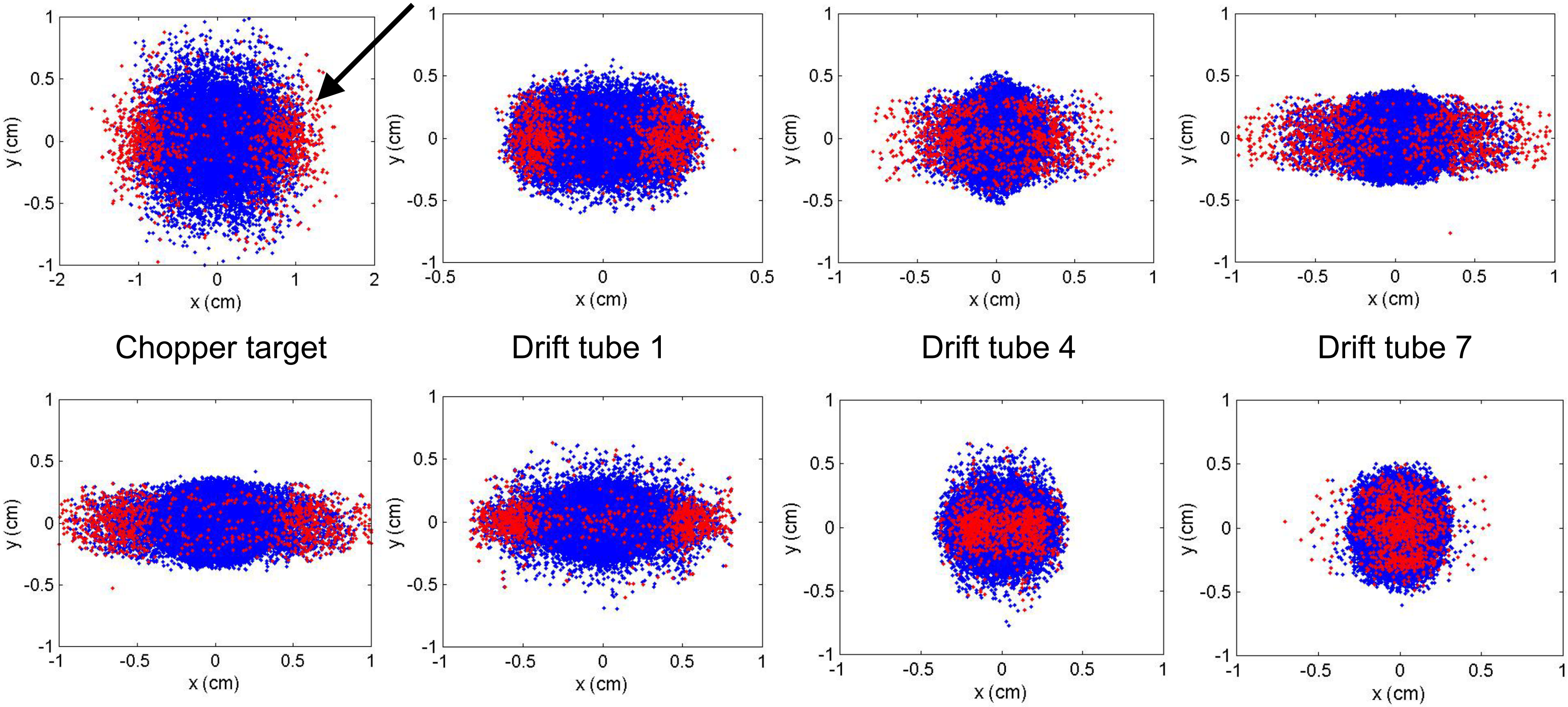
For the purpose of studies, we assumed circular apertures placed only at empty drift tubes, which avoids over-heating of PMQs.




Assumed DTL aperture positions

# Real projections of beam at chopper target and at the first 7 of proposed DTL apertures

Halo particles with r > 9mm at 171MeV.

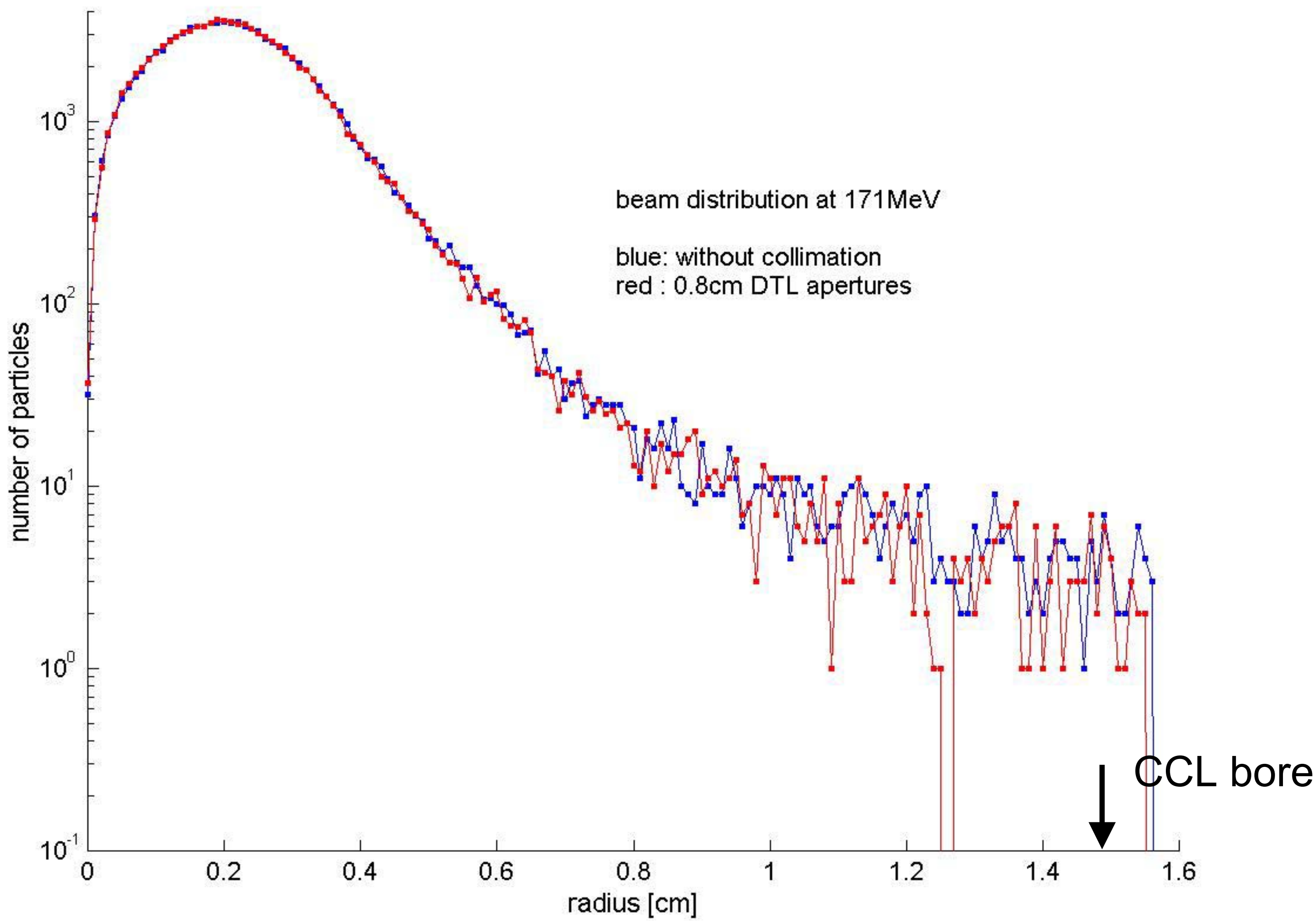



Chopper target — Drift tube 1 — Drift tube 4 — Drift tube 7

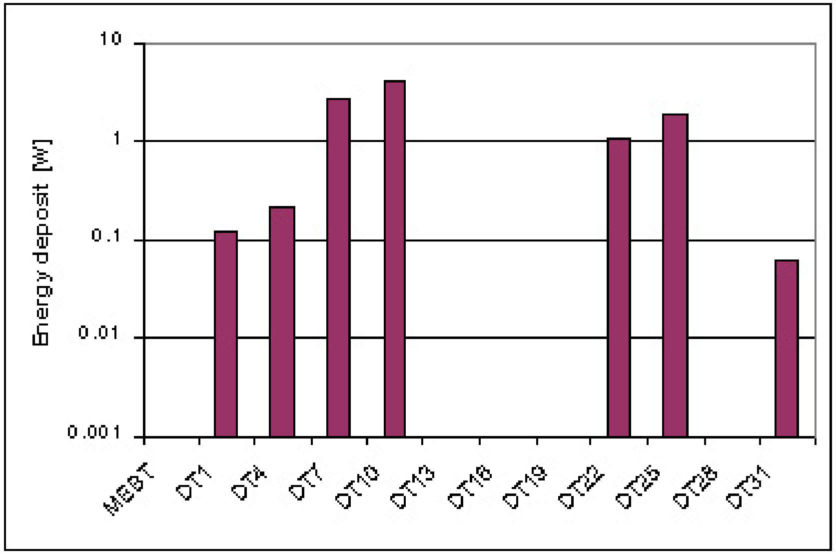
Drift tube 10 — Drift tube 13 — Drift tube 16 — Drift tube 19

- Halo particles oscillate through the core with large amplitudes,
- spending only part of their time on or near the beam perimeter.
- integrated with the core of the beam at a certain positions.

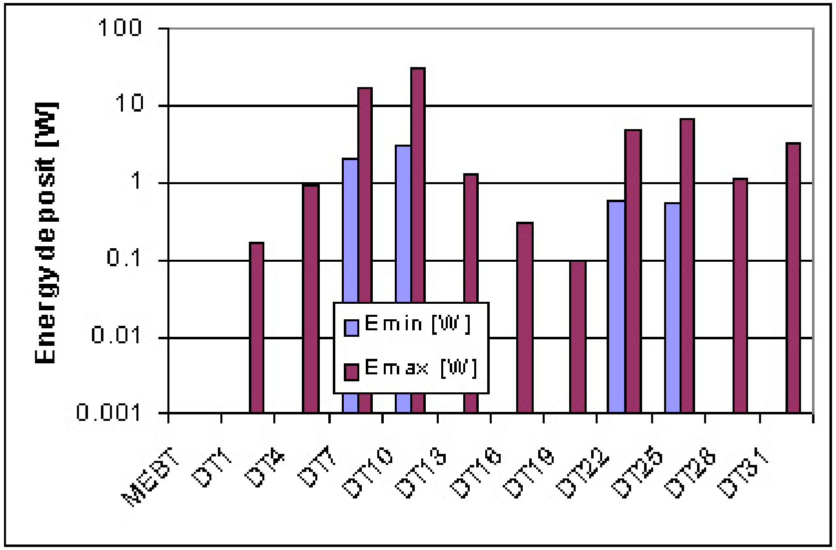
# 8mm-DTL apertures (scraping 0.22% of beam) are not effective



# Energy deposit is not severe to 8mm-DTL apertures




without machine imperfections




With machine imperfections

max and min energy deposit out of 100 linacs

Quads:

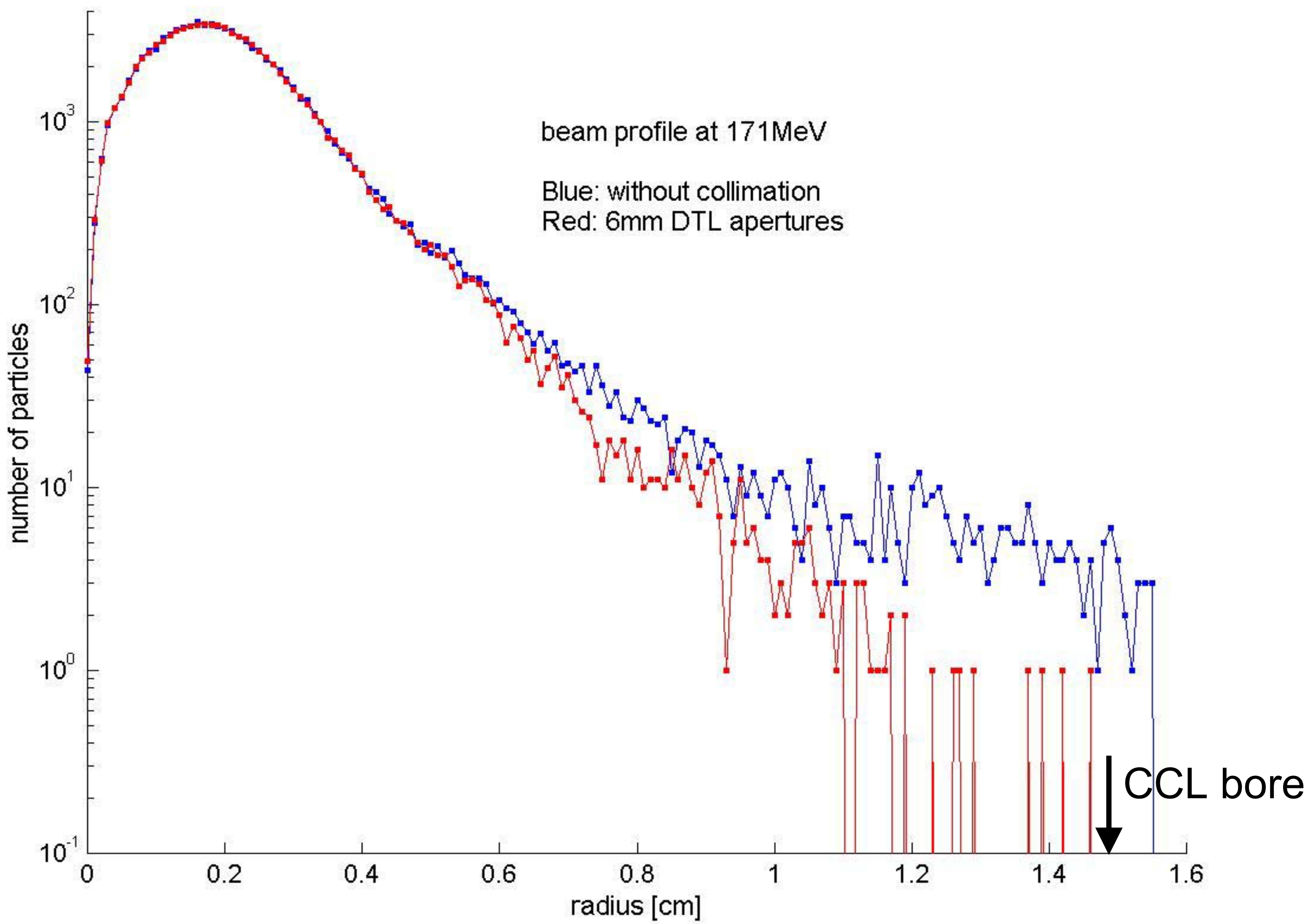
dx=5mil, dy=5mil, roll=5 mrad

pitch, yaw=10 mrad, $\Delta K$=1.7%

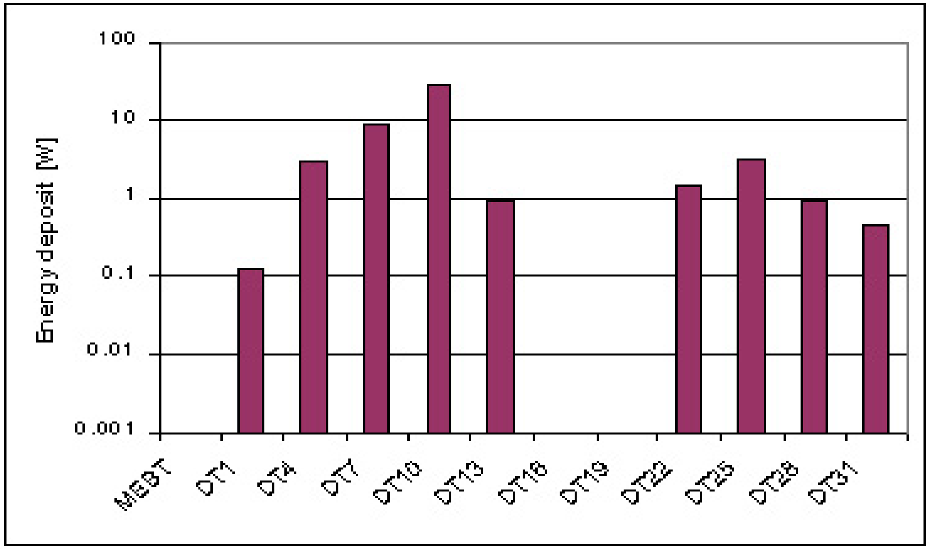
RF:

$\Delta A$=0.5%, $\Delta\phi$=0.5º

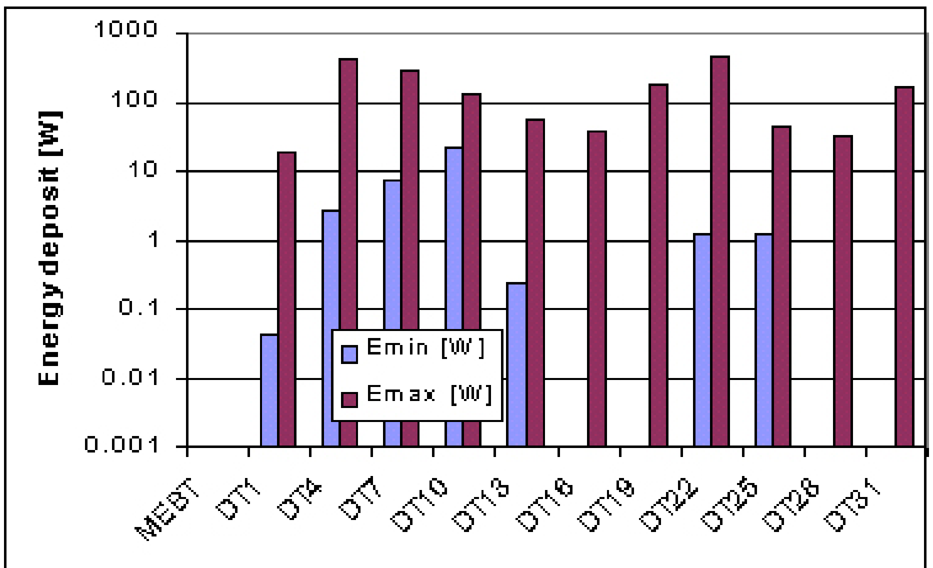
# 6mm-DTL apertures (scraping 1% of beam) reduce halo with r > 9 mm at 171MeV by 90%



# Energy deposited to DT's can be ~ 6 times of design DT cooling circuit capacity



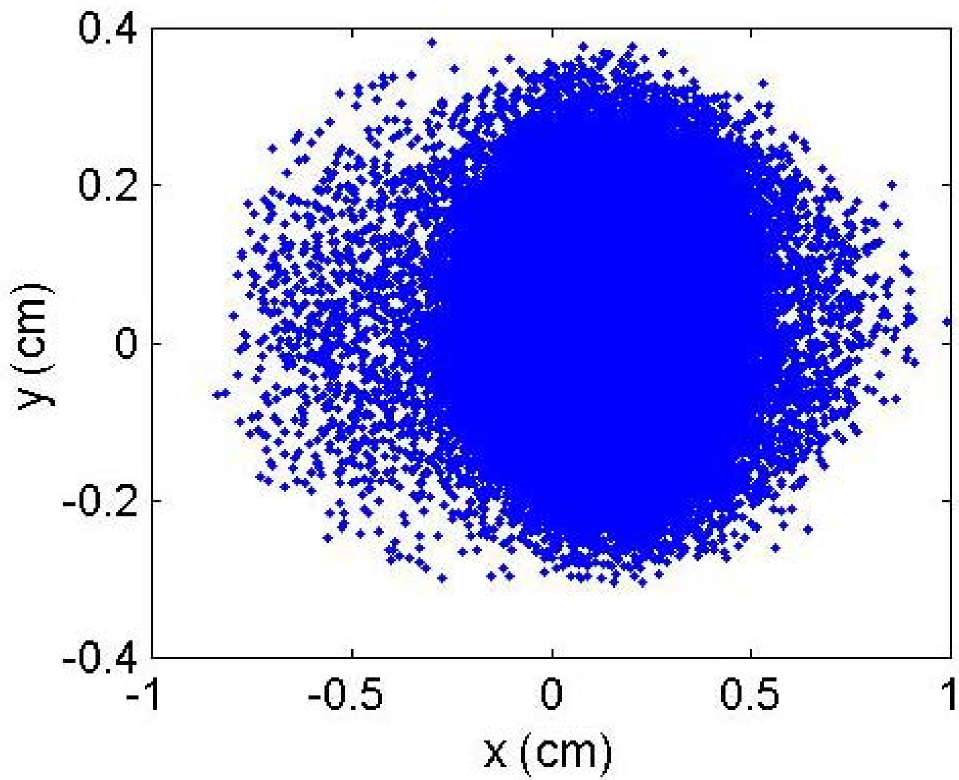

Without machine imperfections




With machine imperfections

Energy deposit to DT22 ~ 440W
~ 6 times of design cooling capacity of this drift tube

# DTL scrapers may scrape asymmetrically depending on imperfections




Proper steering for the DTL apertures is not available:

- The random misalignment of the PMQs steers the beam.
- 1st dipole steerer is at further downstream of proposed aperture positions (49th Drift Tube).
- There are no BPMs in DTL tank 1.

# Summary

MEBT collimation is effective:

- Modifying the MEBT optics and introducing adjustable scrapers as needed is preferred.
- The hybrid solution does not involve any redesign that would impact the construction schedule.
- Because the quads and scrapers are all adjustable, this scheme is adaptable to any operational scenario.

DTL collimation does not effectively remove halo:

- too small an aperture is required.
- severe thermal loading of the drift tubes.
- lack the flexibility required to accommodate beam matching and steering.
- asymmetric scraping, resulting from errors and lack of steering of SNS DTL tank 1.