Fermilab

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

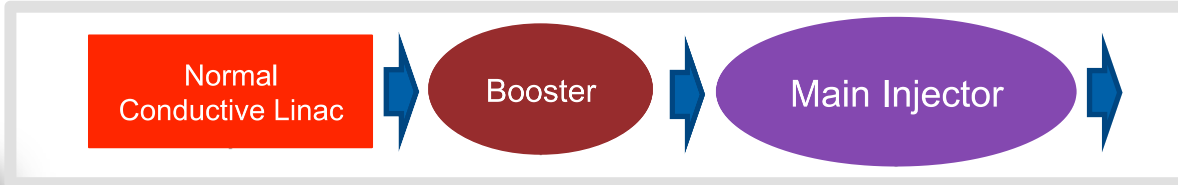
Beam Size Along the Pulse in PIP-II IT MEBT

Igor Lobach
Belarusian State University
Summer Intern, Program: PARTI
PARTI Meeting, August 10, 2016

Supervisors:
Alexander V Shemyakin
Lionel R Prost

Proton Improvement Plan-II (PIP-II)

Existing accelerator complex:



The plan is to

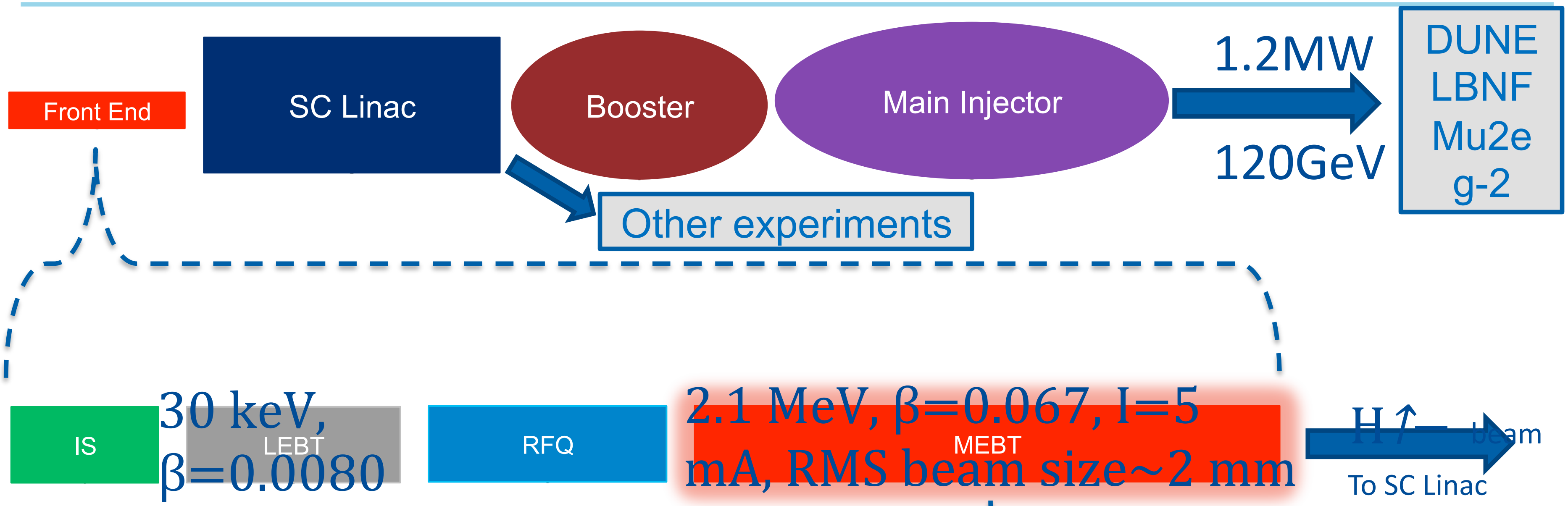
#1 Replace NC Linac with SC Linac

First, the Super Conductive Linac will work at low duty factor, but capability to operate in CW mode provides straightforward future upgrade path

#2 Upgrade Booster, Recycler, Main Injector

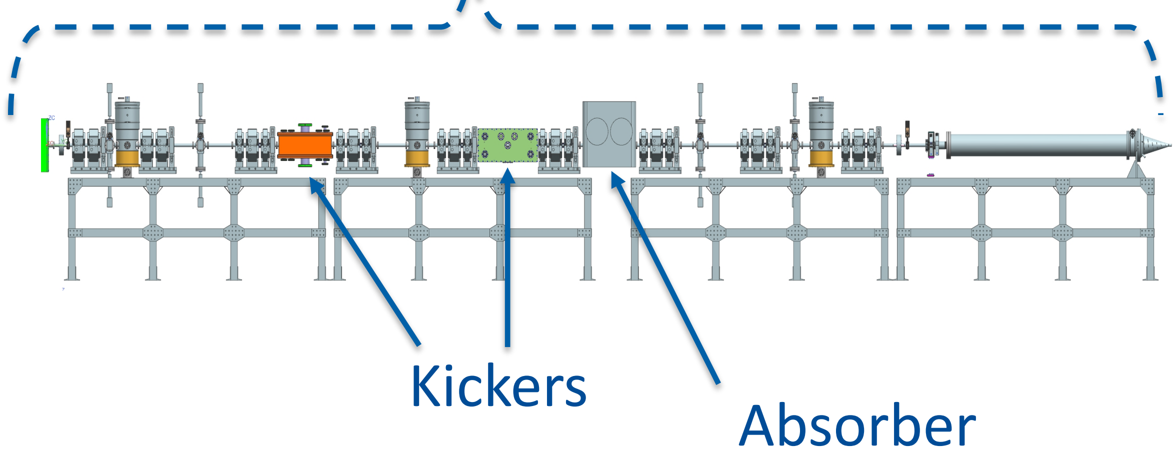
To accommodate new parameters of injected beam and provide higher intensity on the exit

Proton Improvement Plan-II (PIP-II)



IT = Injector Test is the test of Front End (in CMTF building)

The MEBT is longer than 10 m, because it has the chopper, which will produce desired structure of the beam

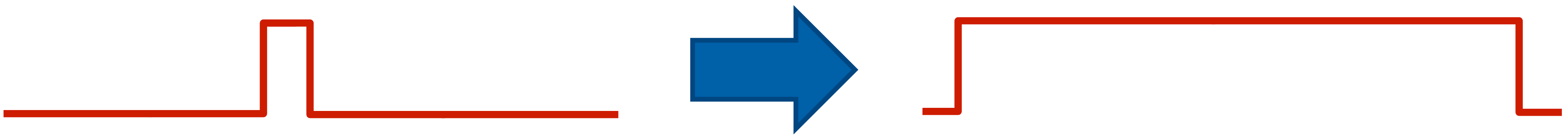


* The beam entering the MEBT already consists of bunches

** Existing MEBT ends before the kickers

Beam Size Along the Pulse in the MEBT

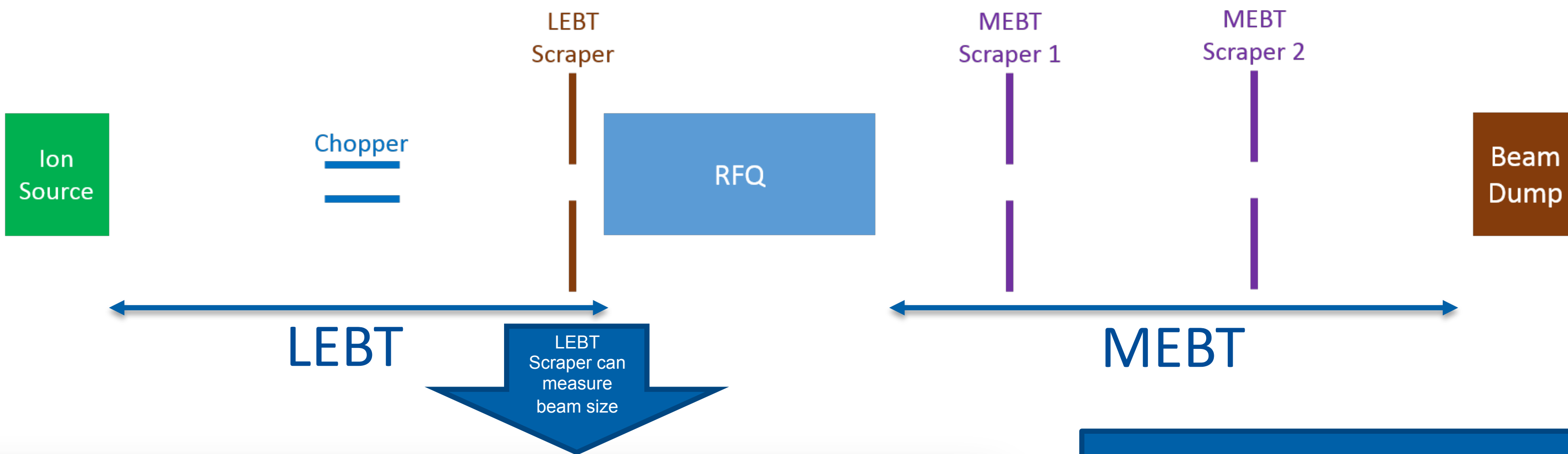
Motivation: **Does short pulse diagnostics describe behavior in CW mode?**

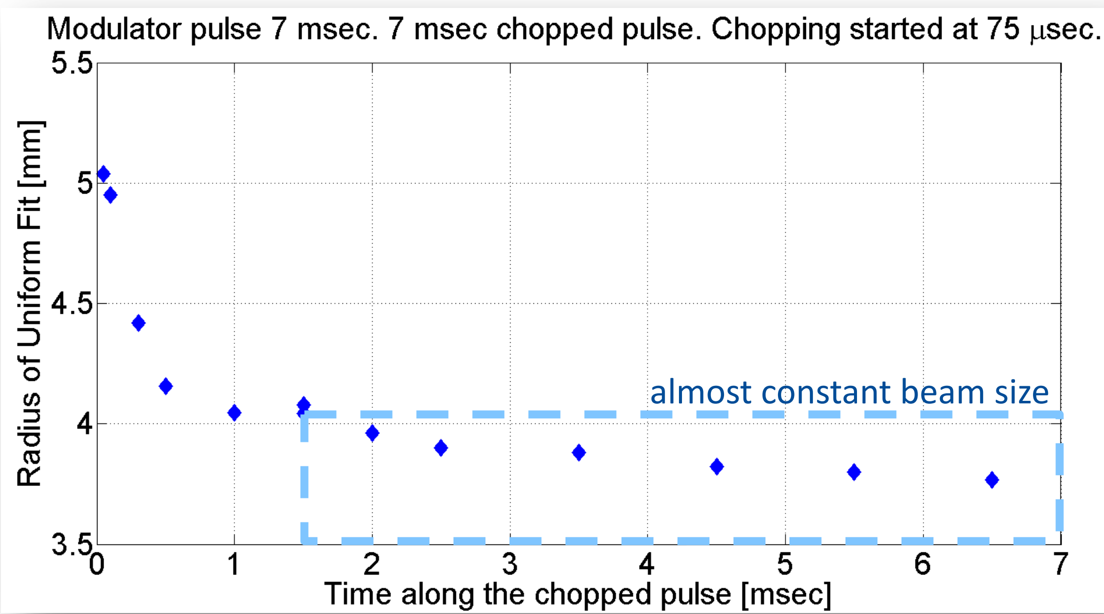


What physical effects can contribute to it?

- #1 Beam neutralization ☆☆
- #2 Beam loading of RF cavities
- #3 The beam might enter the MEBT with variable size along the pulse because of effects in the preceding sections ☆
- #4 Unforeseen effects

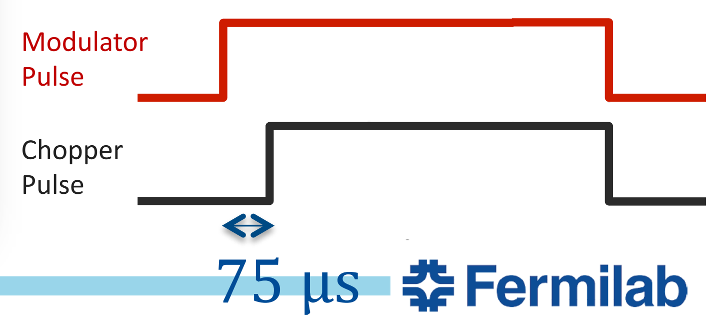
Existing Front End. Effects in the preceding sections



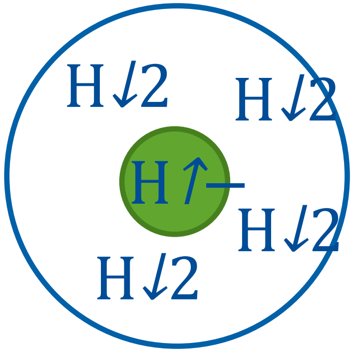


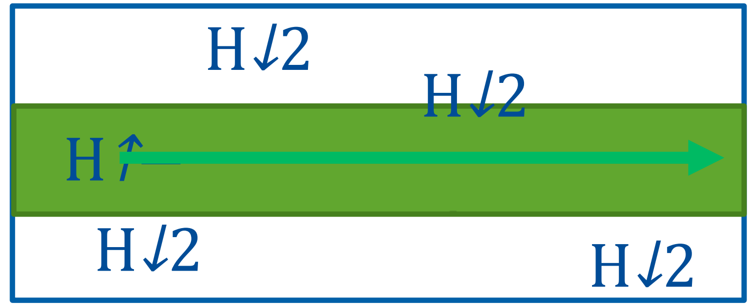
The LEBT has its own Chopper

It is used in PIP-II Injector Test in order to skip the head of the pulse with variable size and send a pulse with virtually constant transverse size in the RFQ



Beam Neutralization in the MEBT.





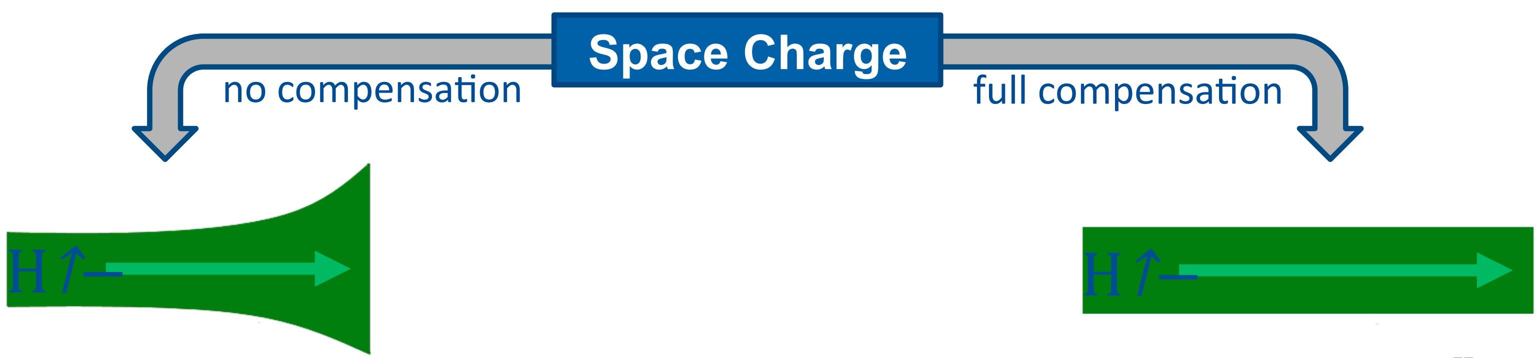
*assume that residual gas is H_2

$$H^- + H_2 \rightarrow H^- + H_2^+ + e^-$$

Beam particles (H^-) ionize residual gas (H_2) in the beam line

Electrons readily escape (repelled)

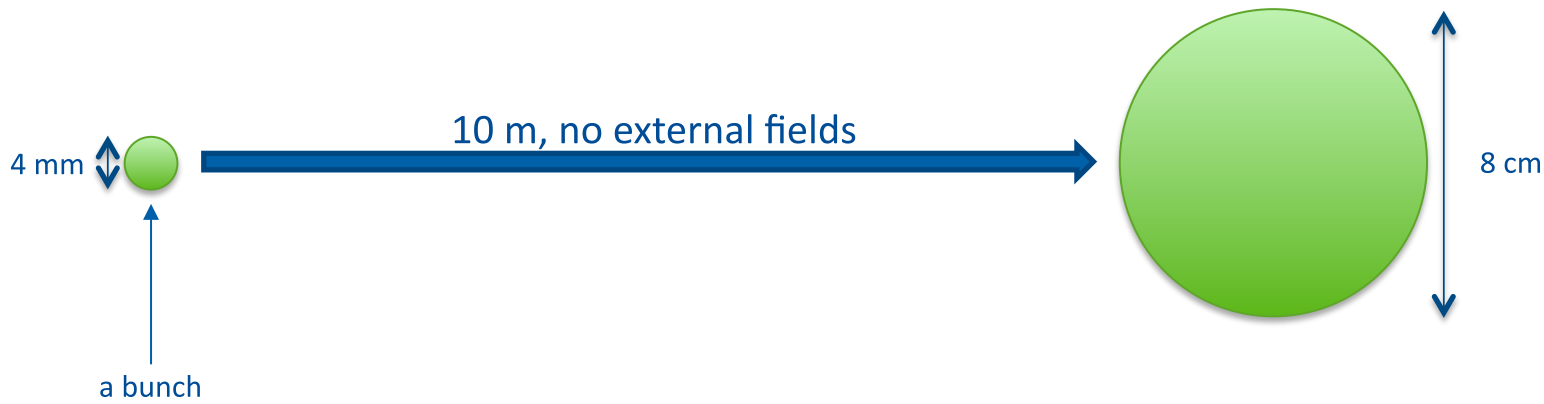
Produced ions (H_2^+ of thermal energy) may accumulate within the beam area and compensate its charge



Beam Neutralization in the MEBT.

The MEBT might be vulnerable to beam neutralization, because

#1 Space charge in the MEBT is considerable



* in the PIP-II IT MEBT the bunches are close to spheres, it is not commonplace

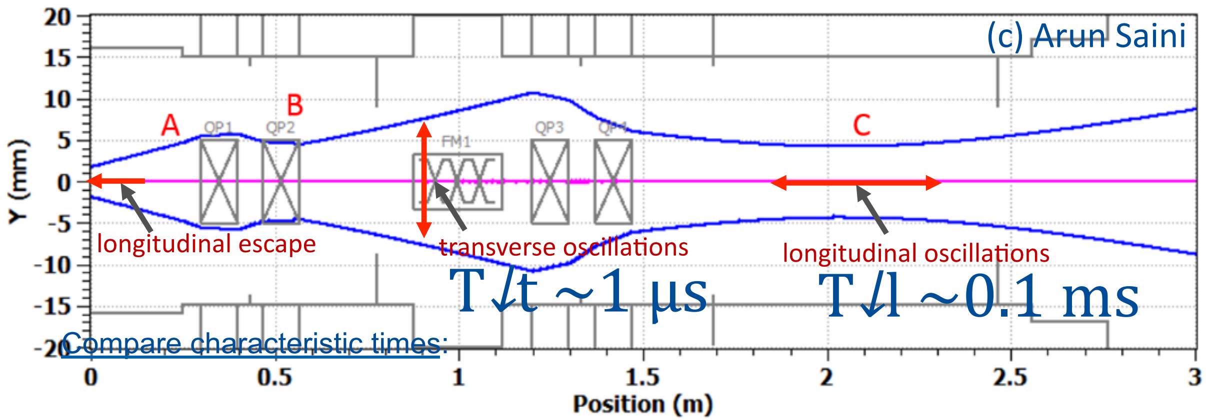
#2 There is no accelerating longitudinal field which would remove H_2^+ ions

#3 The MEBT is very long (> 10 m) and, consequently, the beam envelopes are sensitive

Fermilab

Estimations. The destiny of H_2^+ ions in the MEBT.

Simulated 3-σ beam envelopes in the existing MEBT



$T_t \sim 1\ \mu s$ $T_l \sim 0.1$ ms

Compare characteristic times:

Potential drop due to field of the beam	
Transverse	12 eV
Longitudinal	4.5 eV
Thermal energy	
0.025 eV	

The motion of ions of residual gas is mainly determined by the field produced by the H^- beam.

Time between two bunches =

Period of transverse oscillations =

Period of longitudinal oscillations =

Time of neutralization =

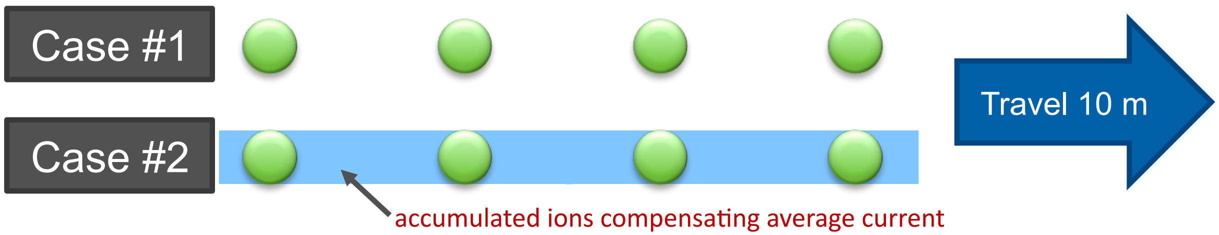
Transverse thermal escape =

Longitudinal thermal escape =

Fermilab

Possible observable effects of neutralization in the MEBT

Space charge is proportional to peak current ($\sim 61\ mA$), whereas neutralization compensates average current ($\sim 5\ mA$).



Relative difference between final transverse beam sizes $\sim 3\%$

Phase shift between the two cases

Hill's equation: $x''(s) + K(s)x(s) = 0$

focusing strength & space charge

$$x''(s) + (K(s) + \Delta K)x(s) = 0$$

due to accumulated ions

$$\sqrt{K} \sim 0.8\ m^{-1}$$

General solution:

$$x(s) = Aw(s)\cos(\psi(s) + \delta)$$

$$\Delta\phi = \Delta K / 2\sqrt{K} \times 10\ m = 0.13\ r$$

Fermilab

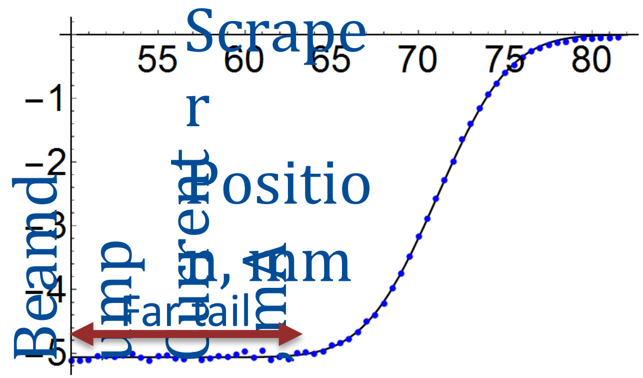
Method to measure beam size in the MEBT for long pulses

Short pulses ($20\ \mu s$)

One can move the scrapers all over the beam

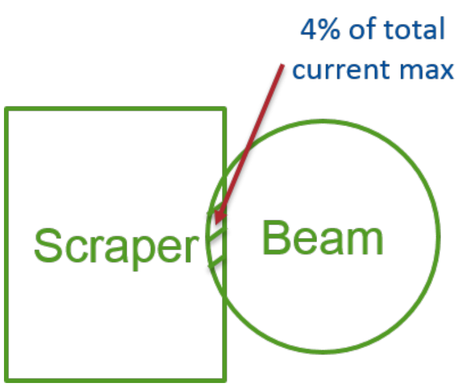
The profile is Gaussian with error $<1\%$

Standard deviation in the far tails (signal noise) is about 0.04 mA



Long pulses ($10\ ms$)

The scrapers can intercept only a small fraction (4%) of total beam current, otherwise they brake



Proposal:

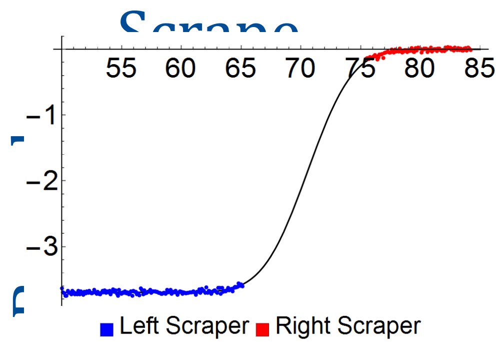
#1	Make a scraper scan of the far tails
#2	Assume that for long pulses beam profile is still Gaussian
#3	Fit the far tails with Gaussian curve and obtain RMS beam size

Method to measure beam size in the MEBT for long pulses

The method was tested with short pulses

The beam size was measured by
- Full scraper scan
- Proposed method (far tails)

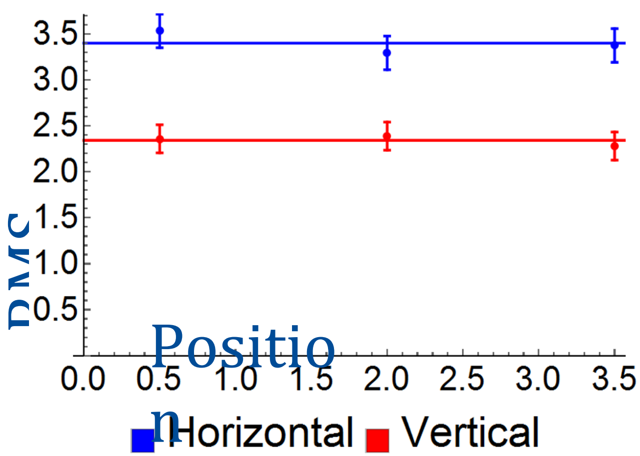
Then the results were compared



Scraper scan of the far tails

	Sigma horizontal	Sigma vertical
Full Scraper Scan	2.87 mm	1.83 mm
Proposed Method	2.96 mm	1.86 mm
Relative error	3.1%	1.3%

Preliminary results of beam size measurement in the MEBT for long pulses (3.5 ms)



Some difficulties of the method:

#1	Thermal expansion of the scrapers (~ 0.15 mm)
#2	Long measurements (1 point ~ 30 min)
#3	Noise in the beam dump current reading

Summary

- Motion of ions of residual gas is mostly defined by the field of the H^- beam (when neutralization is weak)
- The ions "feel" averaged field of the beam
- They compensate average current. Space charge is proportional to peak current.
- The effect of neutralization in the LEBT was observed, the region of constant size along the pulse was found
- The procedure to measure beam size for long pulses in the MEBT was developed