Jean-Paul Carneiro
on behalf of the PXIE team

Analysis of LEBT measurements (Nov. 2014 to June 2015)

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LEBT Goal

Matching in the RFQ

- TWISS at RFQ vane from `PARMTEQM`, 4D Waterbag at 5mA.
- TWISS at Alscan from `TRACK`, forward propagation of the RFQ input distribution on 17.56 cm (WB, 5mA, 3D space charge).

	Unit	TWISS at RFQ Vane	TWISS at Alscan
Alpha		1.6	-10.2
Beta	cm/rad	7.0	139
Emittance, n, rms	mm-mrad	0.14	0.14
RMS Size	mm	1.1	4.9

- The goal of this talk is an attempt to cross-check the measurement performed from Nov. 2014 to June 2015 with PIC code (`TRACK`).

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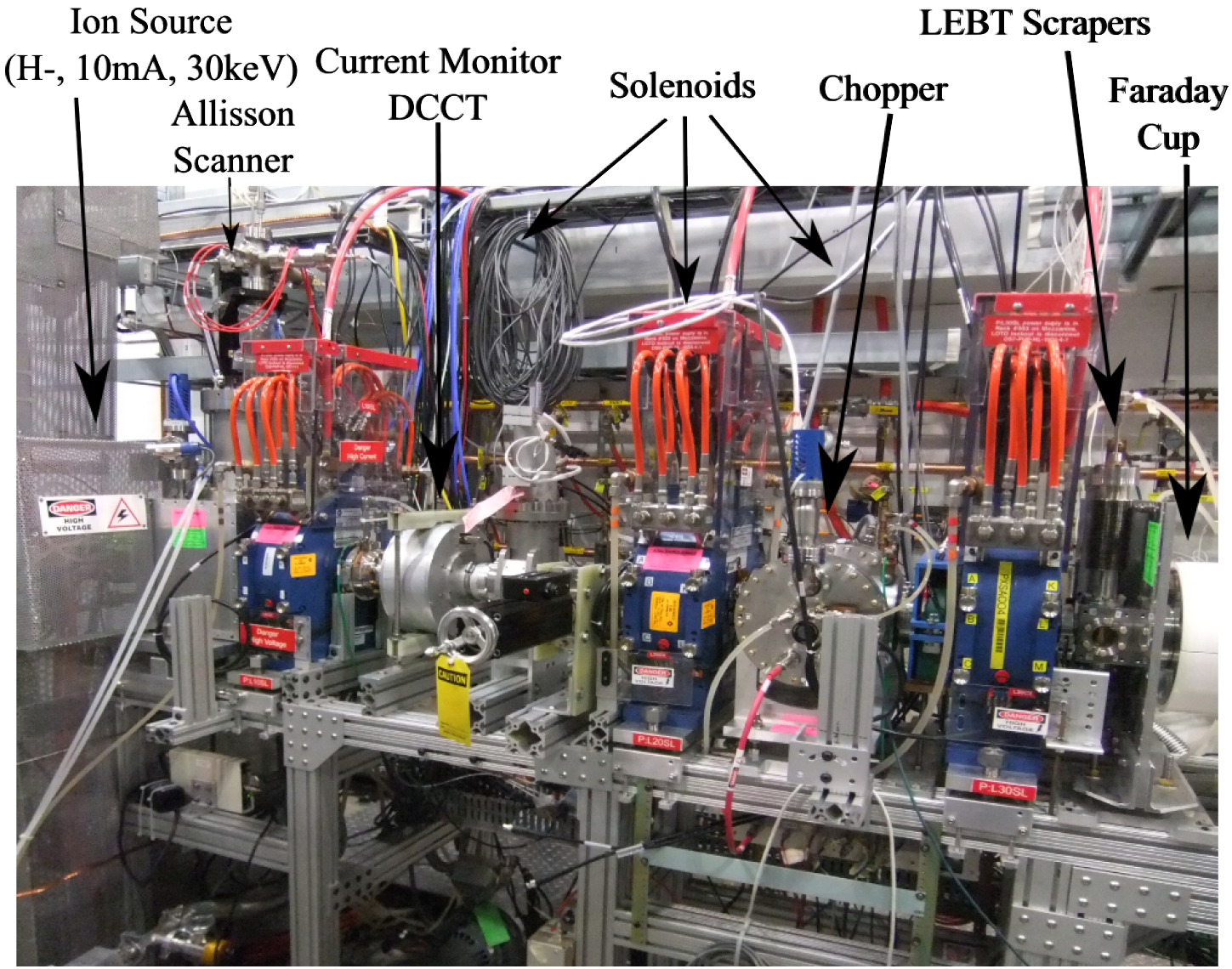
PXIE as of July 2015



Simulation Tools

- `TRACK`: ANL Code (P. Ostroumov), all 3D (fields, correctors, space charge, RFQ). Benchmarked in 2009 with `ASTRA` (DESY). Main tool. Launched mainly on FermiGrid.
- `TRACEWIN`: CEA-Saclay (Didier Uriot). 3D fields. Used mainly for benchmarking and matching. RFQ needs `TOUTATIS`.
- `PLOTWIN`: CEA-Saclay software used to convert Allison Scanner measured distributions into `TRACEWIN` input. Distribution converted then in `TRACK` input distribution using a python macro (Jean-François Ostiguy).
- `PBGuns`: has been purchased from `FarTech` in July 2015 to start Ion Source modeling (model from LBNL).
- `WARP`: installed. Input file provided by M. Chung. Not used.

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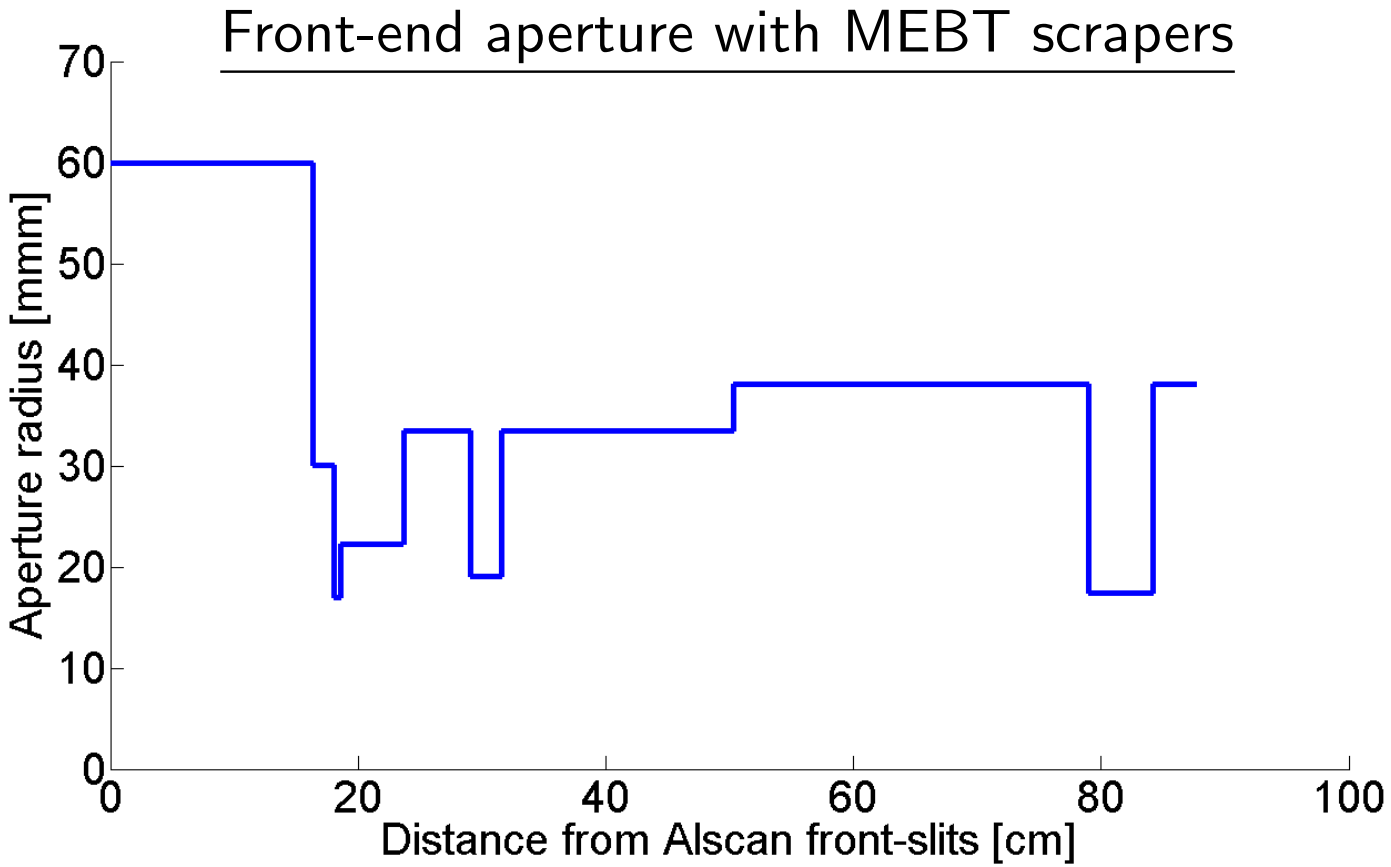
LEBT Apertures

- Each LEBT configuration has its own aperture limitations (Ion Source exit, MEBT scrapers, LEBT scrapers, EID#1 in Sol1, EID#2 in Sol2, Chopper ...).



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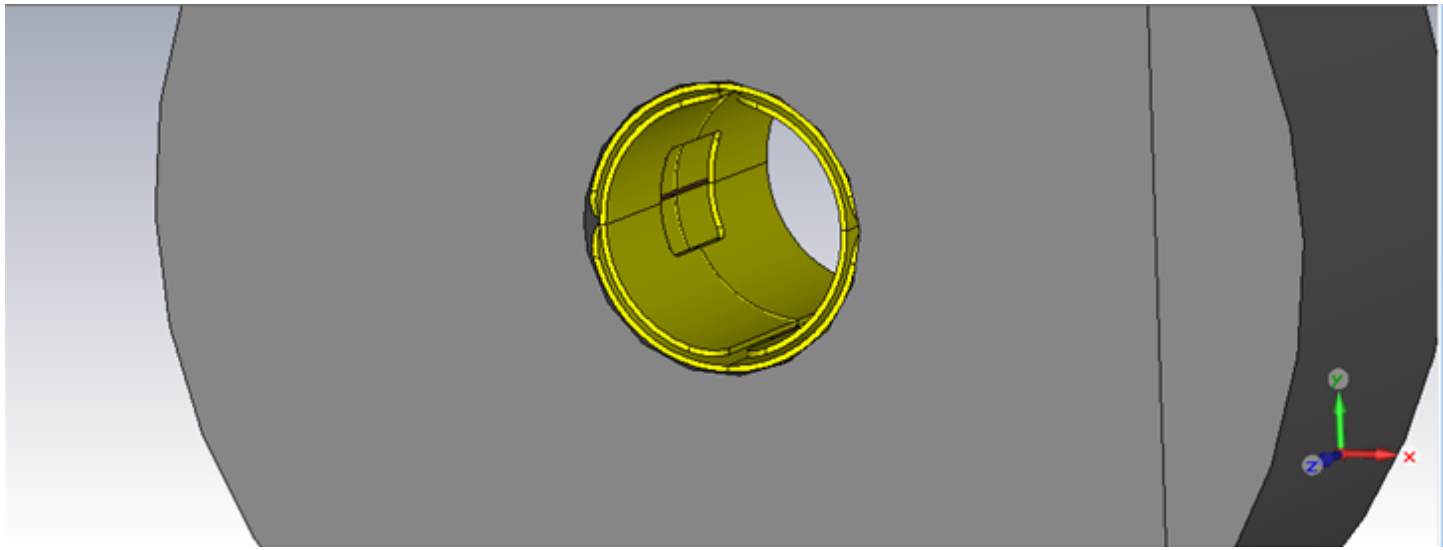
LEBT Fields

- Solenoid and Correctors have been modeled with CST-MWS. 3D solenoid and 3D corrector fields have been implemented in TRACK and TRACEWIN using measured field integrals for the normalization. Accuracy in beam motion estimated at few percent, beam angle about 10%.

PXIE Solenoid Correctors in CST-MWS



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LEBT Neutralization

- The vacuum in the LEBT range from 1×10^{-4} torr in the ion source exit down to 1×10^{-7} torr at the end of the LEBT.
- The neutralization time is estimated to be in the order of few tens of μs upstream of Sol1, about 100μs between Sol1 and Sol2 and about 2 msec downstream of Sol2.
- In `TRACK` there is no model for the neutralization, just a parameter *Cneutr* to change the beam current from full space charge *Cneutr=0* to zero current *Cneutr=1*. Usually in `TRACK` the beam is considered fully neutralized up to Sol2 and fully un-neutralized downstream of Sol2.
- In typical data acquisition, we use a 1.5 to 2 msec pulse and sample the end of the pulse.

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Ion Source Operation

- Typical operation: H^-, 0.5 to 7 mA, 2 msec (chopped at 1 msec), 60 Hz. Beam current is adjusted at the ion source exit by changing the extraction voltage V_{ext}. All other parameters are usually kept constant (gas flow to 15 sccm, plasma voltage to 3.3 V, arc voltage to 122 V and arc current to 13 A).
- V_{ext} extracts and focuses the beam at the ion source exit.
- 16 beam phase space portrait have been taken in June with the Allison scanner for an ion source extraction voltage ranging from $V_{ext} = 1.68$ kV up to $V_{ext} = 4.99$ kV. We observed a strong dependence of the beam TWISS as a function of V_{ext}.
- Each measured distribution at the Alscan has been converted into `TRACK` input using `PLOTWIN`.

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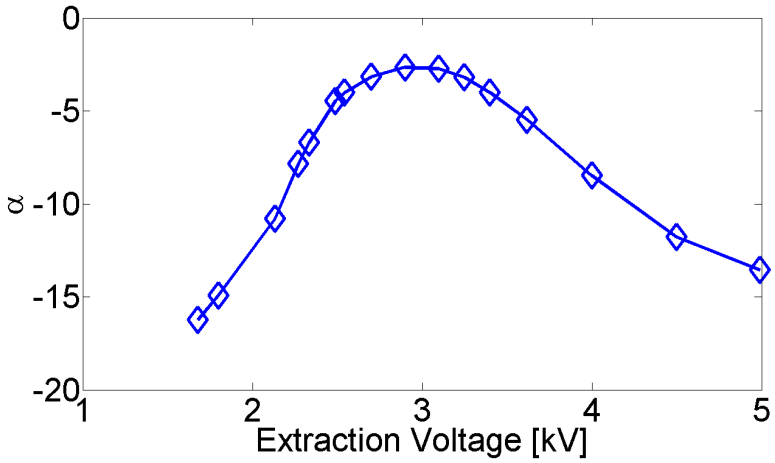
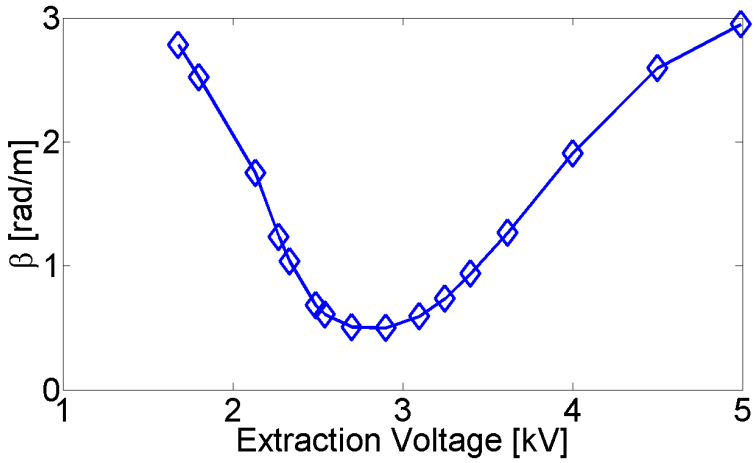
Alscan at the IS: TWISS

1.5 msec pulse, bin size=50μs, bin#28

TWISS α



TWISS β



Emittance ϵ_y

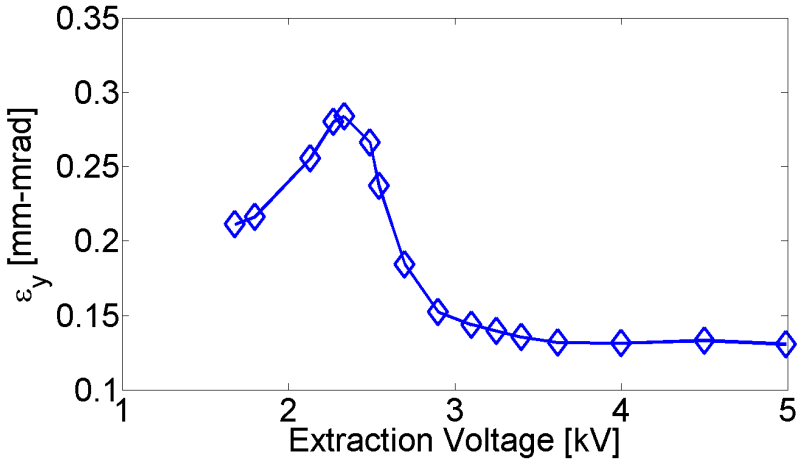
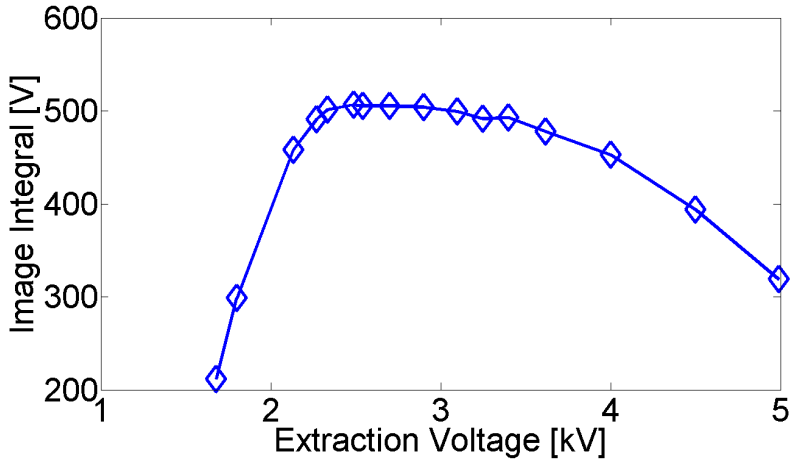


Image Integral



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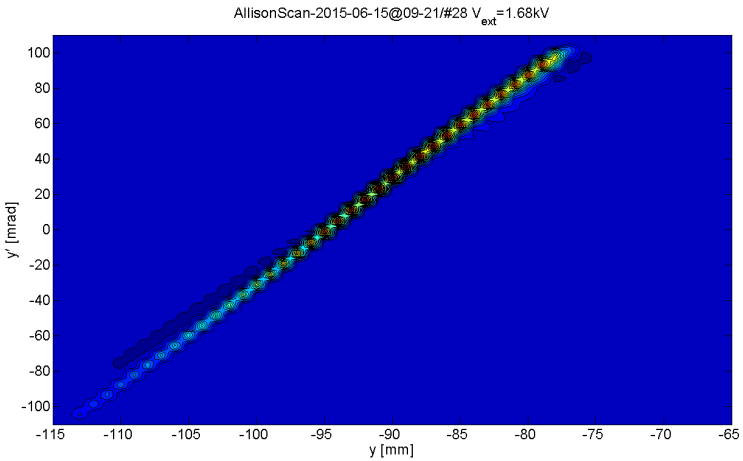
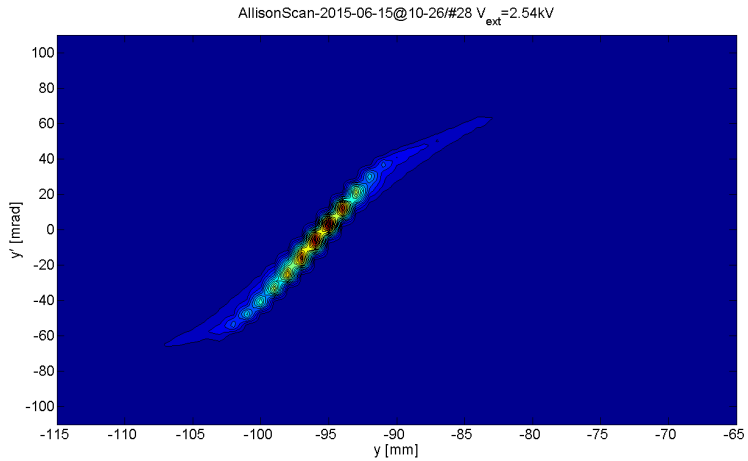
Alscan at the IS: $Y - Y'$ Vs V_{ext}

1.5 msec pulse, bin size=50μs, bin#28

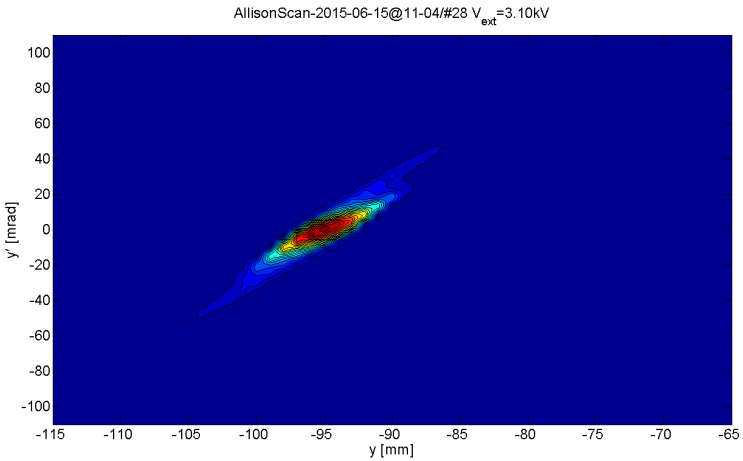
V_{ext}=1.68 kV



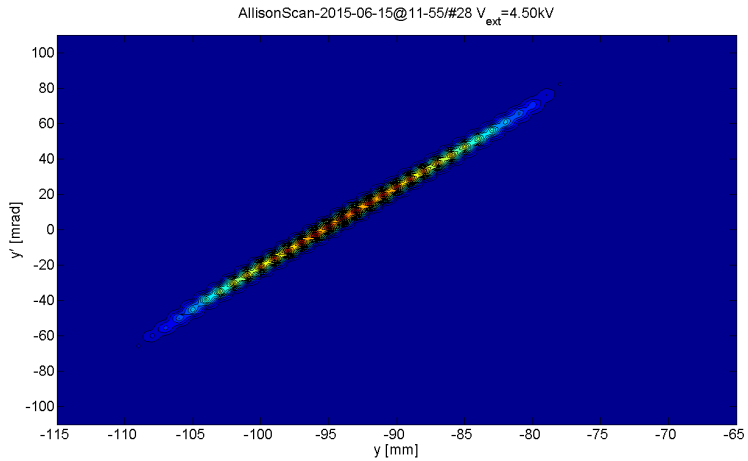
V_{ext}=2.54 kV



V_{ext}=3.10 kV



V_{ext}=4.50 kV



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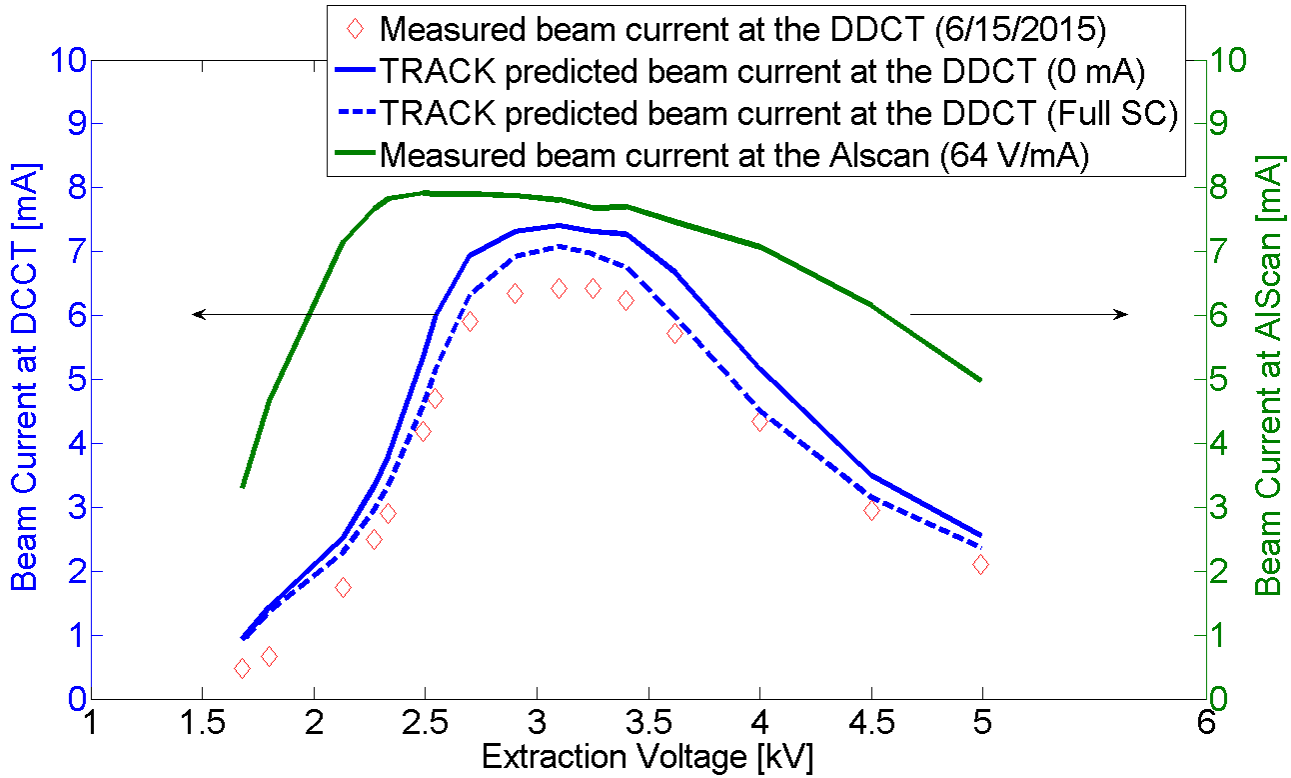
DCCT Current

- Measured current at the DCCT Vs V_{ext} and comparison with `TRACK`. Alscan distributions converted in `TRACK` input (using `PLOTWIN`). $I_{sol01} = 141.4$ A.
- Alscan calibration of 64 V/mA deduced from measurement when it was installed at the end of the beamline (using current from the DCCT and Faraday Cup).
- Taking 64 V/mA, the measured transmission does not agree with `TRACK`. Better agreement occurs at 70 V/mA if full space charge (SC) or at 74 V/mA if front-end considered fully neutralized. In progress.



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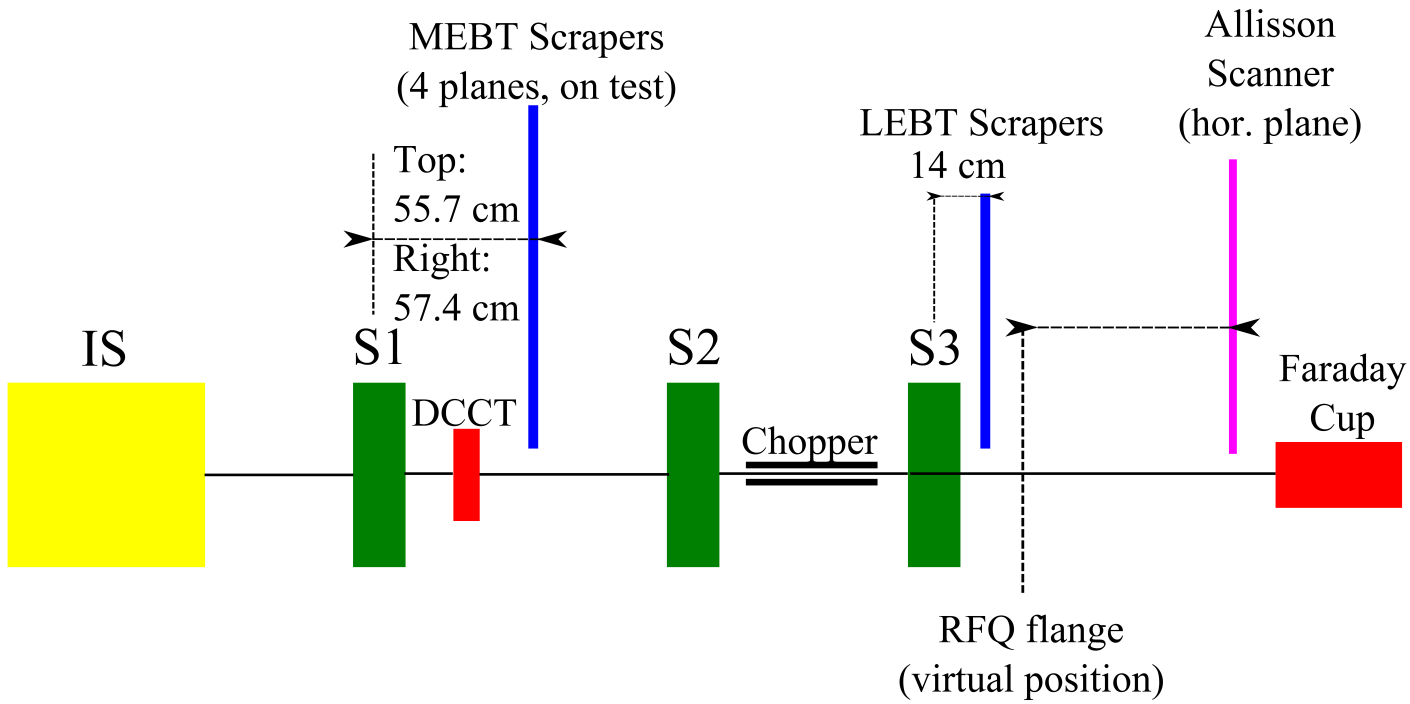
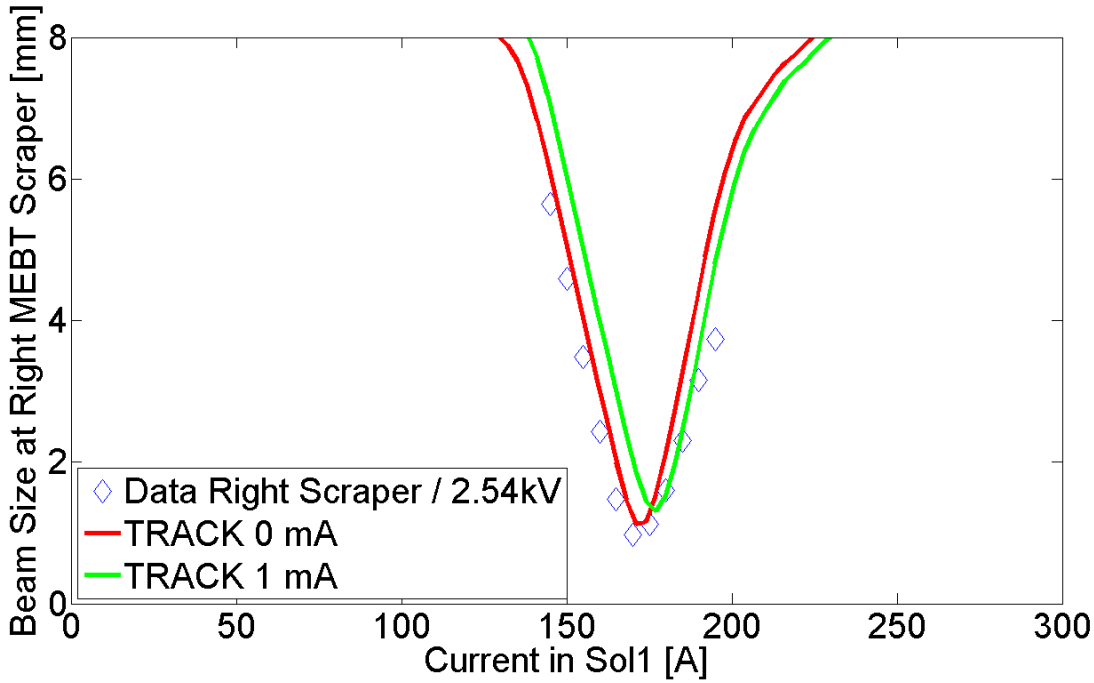
MEBT Scrapers

- The MEBT scrapers were installed in the LEBT for tests
- In May 2015, we measured the beam size using the top and right MEBT scrapers as a function of the current in the Sol1. We performed scans for 14 different IS extraction voltages, from $V_{ext} = 1.68$ kV to $V_{ext} = 4.5$ kV
- Each MEBT scraper scan has been compared with `TRACK` using the measured Alscan distribution as input in the code.



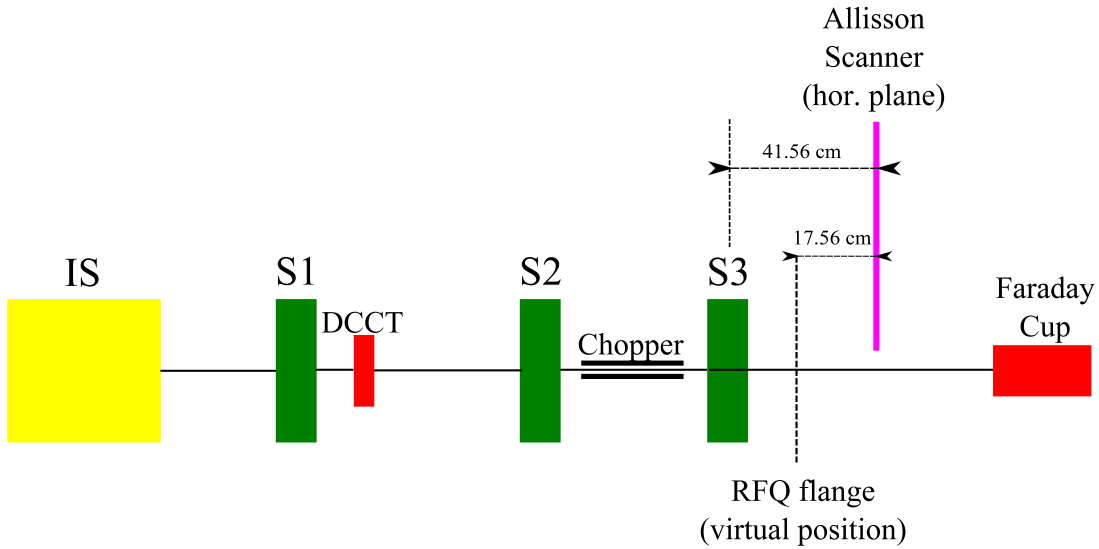
MEBT Scrapers

- Measured beam size with the right scraper Vs Sol1 and comparison with TRACK. $V_{ext} = 2.54$ kV (4.7 mA), 2 msec sampled at 1.05 msec.
- The minimum beam size and its location are properly reproduced with the code at 0 mA. The solenoid lens seems to be properly implemented in the code. The measured overall beam size is still smaller than the predicted one. When implementing ~80% neutralization, the simulation shifts to the right and up. This may be an indication of a full neutralization in the LEBT front-end.



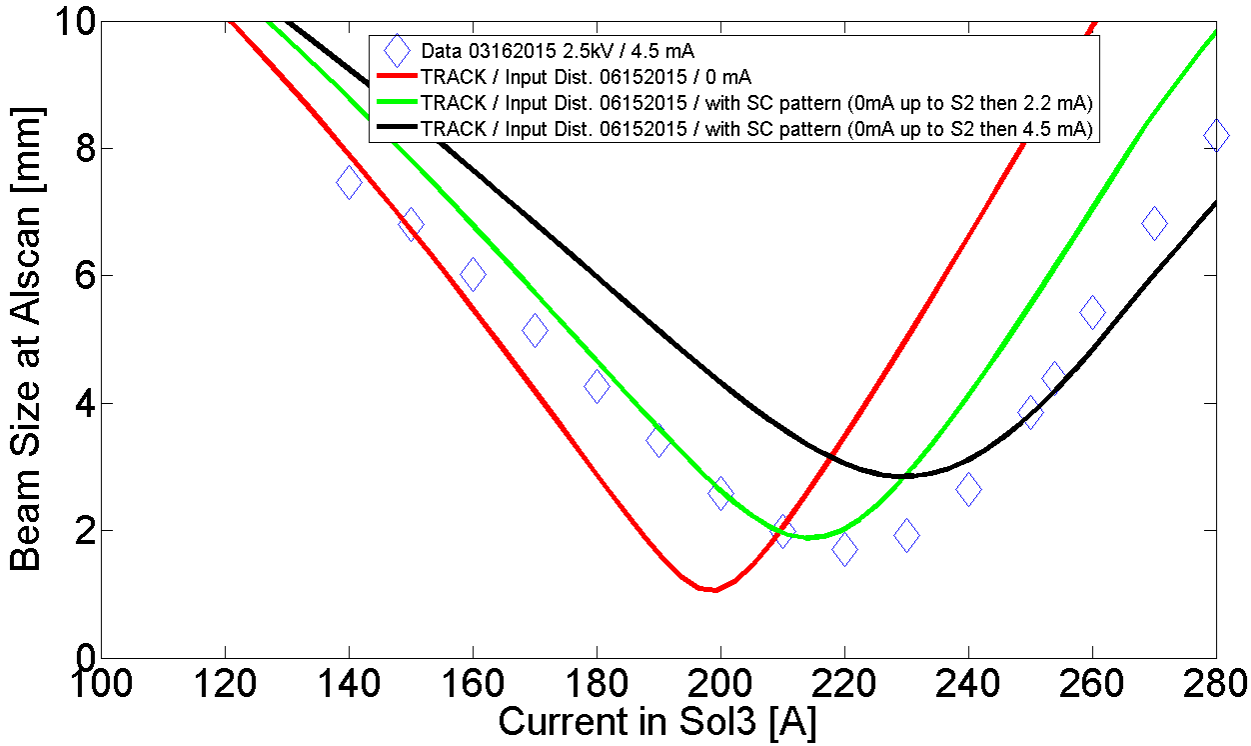
Allison Scanner

- From Nov. 14 to Mar. 15 we performed several Alscan measurements when the diagnostic was installed downstream of Sol3. We present a measurement done on 03/16 during which we took several images as a function of Sol3. With $V_{ext} = 2.5$ kV, I_{sol1}=141.4 A, I_{sol2}=158 A and the beam current at DCCT ∼4.5 mA. 2 msec pulse (chopped at 1 msec), bin=50μs, bin#18. We considered in `TRACK` the measured distribution (06/15) at 2.54 kV.
- For the space charge neutralization pattern, we considered 3 cases in `TRACK`: 1/ no space charge all along the LEBT, 2/ no space charge up to Sol2 then 2.2 mA (about 50% neutr.) and 3/ no space charge up to Sol2 then 4.5 mA (full space charge).



Allison Scanner

- Measured beam size at the Allison Scanner Vs Solenoid 03 and comparison with `TRACK`
- Clear disagreement between the measured beam size and `TRACK`.
- The case 50% neutralized downstream of Sol3 seems to be the most favorable.



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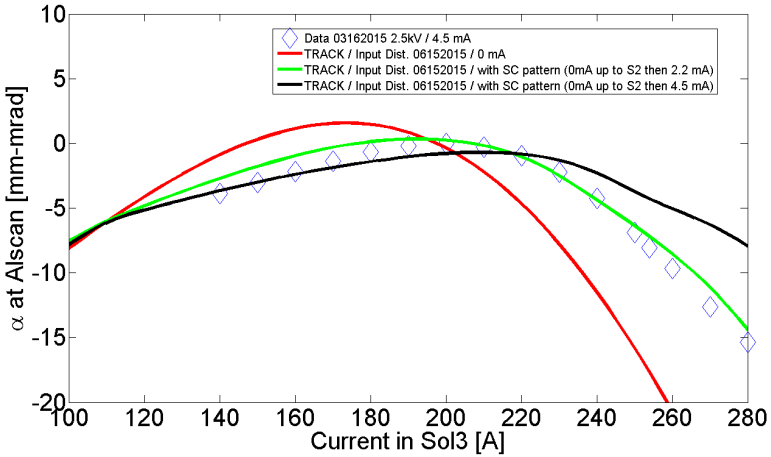
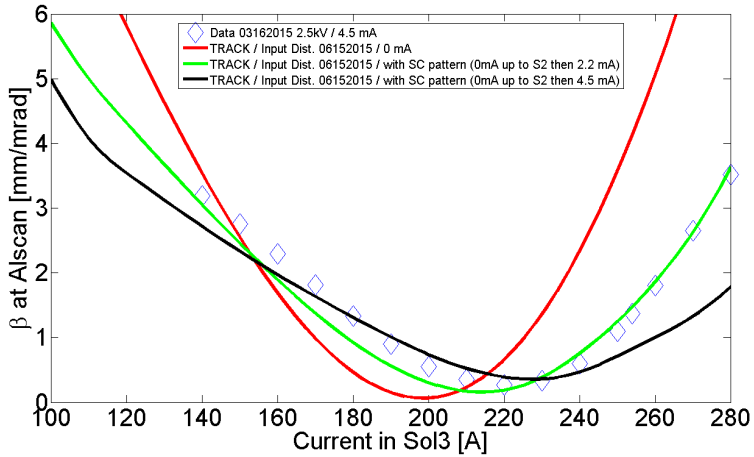
Allison Scanner

- Measured α and β at the Allison Scanner Vs Solenoid 03 and comparison with `TRACK`
- As for the beam size, the measured TWISS do not agree with the prediction from `TRACK` and the most favorable case is for a beamline 50% neutralized downstream of Sol2.
- A neutralization model (`WARP` ?) may be necessary to better understand the beam dynamics in the LEBT end.

Alpha



Beta



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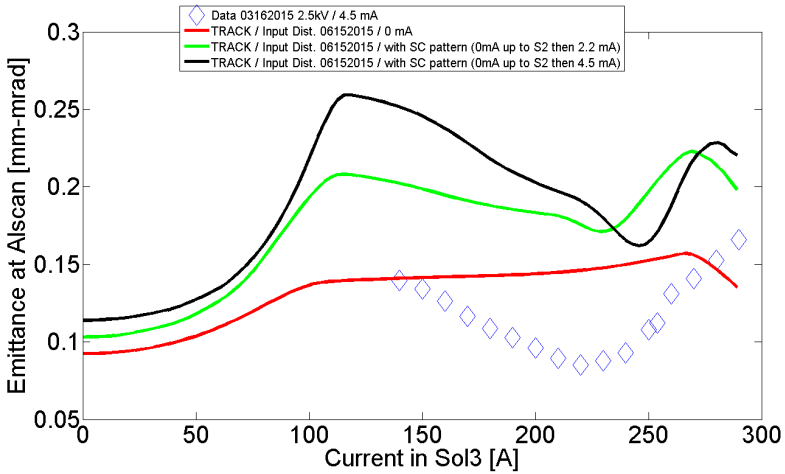
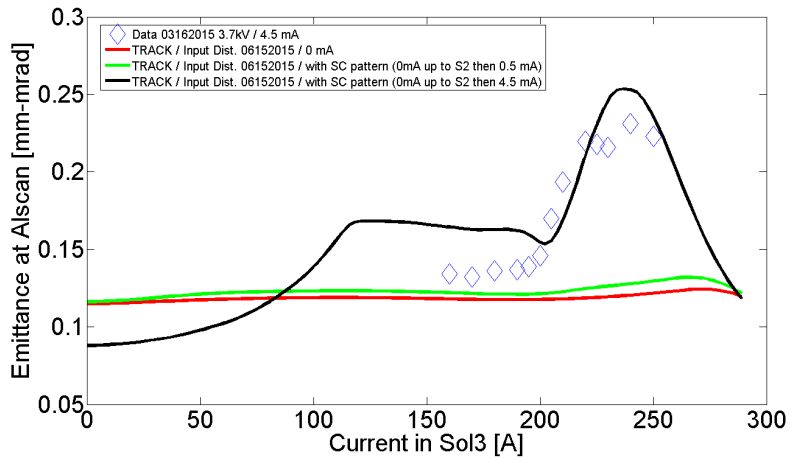
Allison Scanner

- Emittance measurements as a function of Sol3 with the Alscan downstream of Sol3 show a "V-shape" for IS extraction voltages below ∼3 kV (often mentioned as "low side"). For higher extraction voltages, the "V-shape" is not observed.
- TRACK and the measured emittance are in complete disagreement for low extraction voltages. In particular TRACK does not predict the overall "V-shape" and the measured emittance is significantly lower than predicted.
- For higher extraction voltages (shown below an example with $V_{ext} = 3.7$ kV), the agreement is better. TRACK does predict a *plateau* followed by an emittance increase.

$V_{ext} = 2.5$ kV



$V_{ext} = 3.7$ kV



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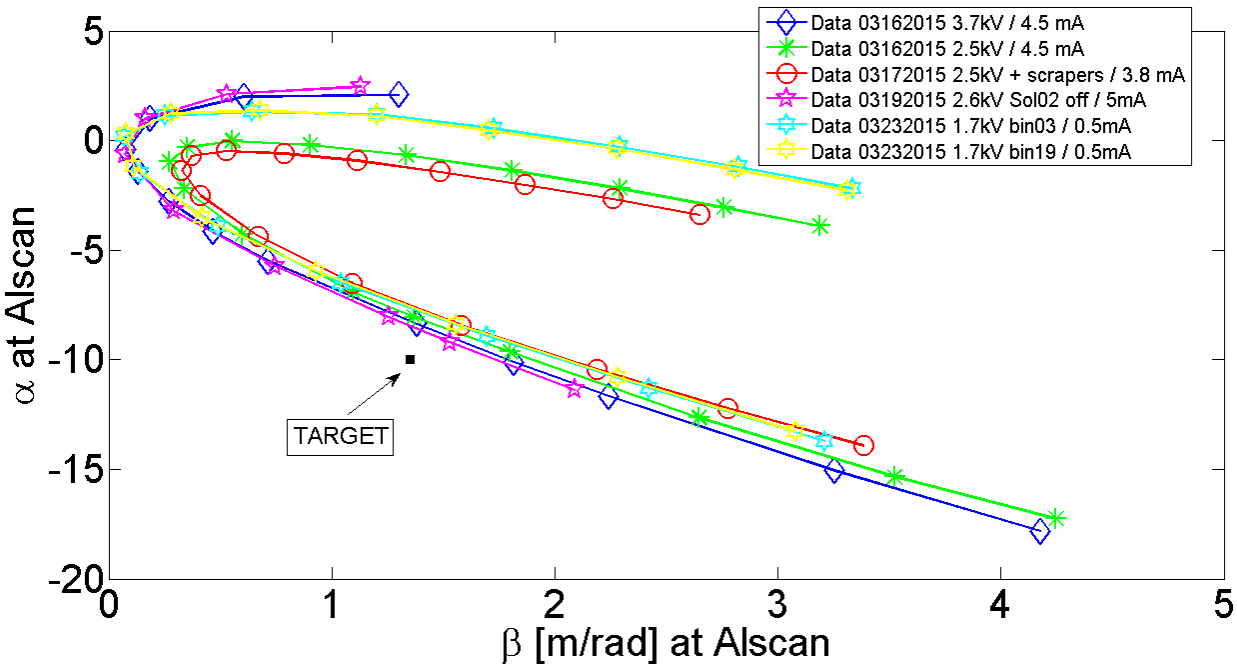
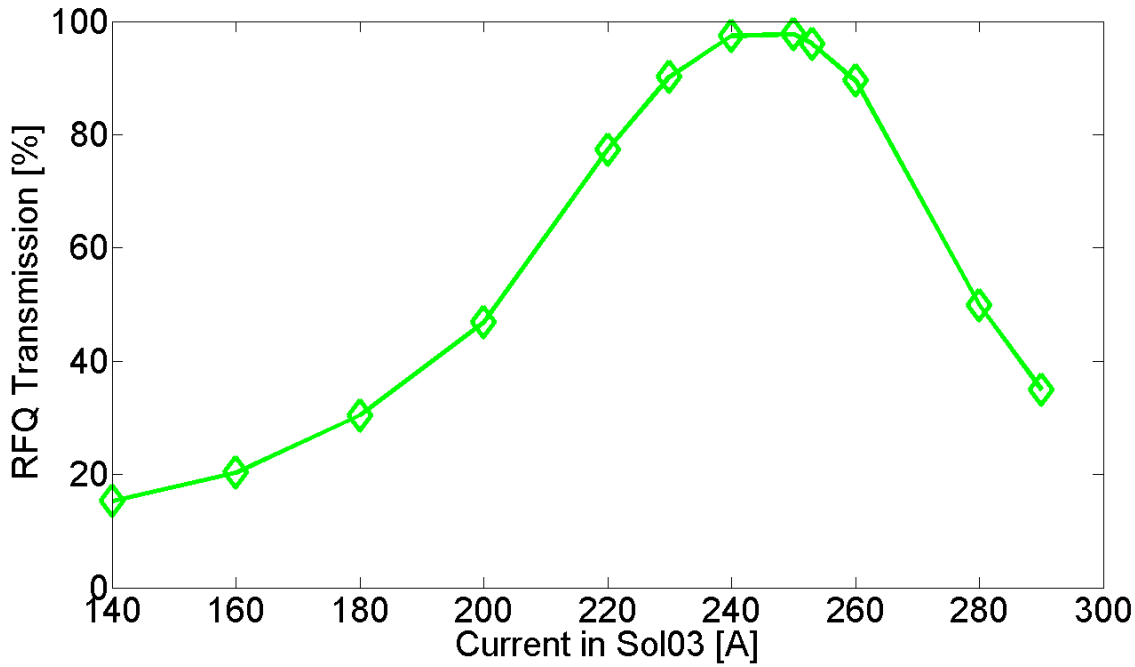
TWISS at Alscan

- Measured TWISS at the Allison Scanner and comparison with the target goal ($\alpha = -10.2$ and $\beta = 1.39$ m/rad).
- *Best matched* : $\alpha = -8$ and $\beta = 1.4$ m/rad. Matched in β and $\sim 20\%$ lower in α.



RFQ Transmission

- Backpropagation (17.56 cm) with `TRACK` of the beam distribution measured at the Allison scanner and forward propagation in the RFQ using 3D fields.
- V_{ext} = 2.5 kV, 4.5 mA (DCCT), I_{sol1}=141.4 A, I_{sol2}=158 A.
- RFQ transmission of ∼97% is predicted by `TRACK`.



Conclusion

- The IS extraction voltage significantly changes the TWISS at the IS exit. Using measured phase phases as input in `TRACK` is important for our model.
- The optics in the LEBT front-end seems reasonably understood. We should confirm the degree of neutralization in the LEBT front-end (closer to 100% or 80% ?). We should also continue our understanding of the transmission in the front-end.
- The optics in the end of the LEBT (downtream of Sol2) is not reproducible with `TRACK`. A better understanding of the neutralization is necessary. We have indications of $\sim$50% neutralization.
- The measured "V-shape" for the emittance is not predicted by `TRACK`.
- Backpropagation of the measured distribution predicts a transmission in the RFQ of about 97% at 5mA.