# CURRENT STATUS ON ESS MEDIUM ENERGY BEAM TRANSPORT (HB14 TUO1AB04)

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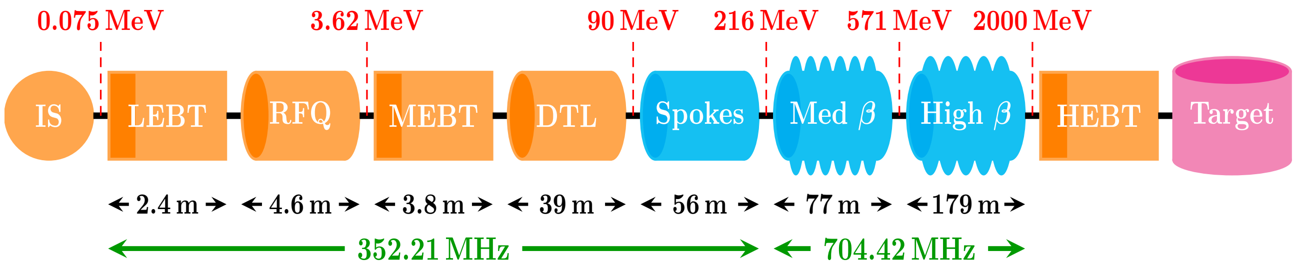
on behalf of ESS and ESS-Bilbao Teams

# Outline

- Introduction
- Summary of status
- Examples of details
  - Design and beam physics
  - Component design and prototyping

Caution: This presentation is heavily biassed toward beam physics due to the speciality of the speaker.

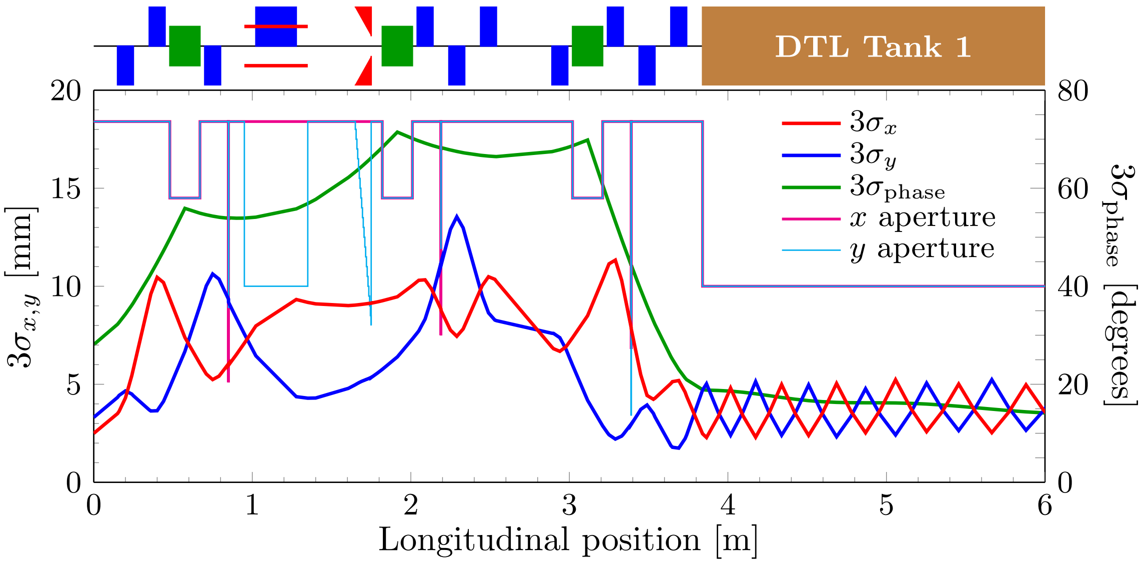
# ESS linac




- ESS related talks/posters:
  - Mon 11:55, M. Lindroos
    Beam dynamics
  - Tue 9:30, M. Eshraqi
    Linac design
  - Tue 10:50, A. Jansson
    Beam instrumentation
  - Poster, R. Miyamoto
    Beam dynamics (collimation)

| | |
|---|---|
| Ave power | 5 MW |
| Peak energy | 2 GeV |
| Peak current | 62.5 mA |
| Pulse length | 2.86 ms |
| Rep rate | 14 Hz |
| Duty cycle | 4% |
| RF freq | 352.21/704.42 MHz |

# ESS MEBT at a glance




- 3.62 MeV (was 3 MeV)
- Functions:
  - Chopping
  - Scraping
  - Diagnostics
  - Matching
- Components:
  - Bunchers (3)
  - Quads (10+1)
  - Fast chopper + dump
  - Scrapers (3)
  - Diagnostics devices
  - DN35 (18.4 mm R) pipe

# Status of lattice design & beam physics (1)

- **What's been done so far**
  - Lattice design (IPAC14 THPME045)
    - Some details in the following
  - Basic beam physics (IPAC14 THPME045, LINAC14 THPP045)
    - Matching to the DTL (tracking based)
    - Chopping efficiency
    - Beam quality optimization (as possible)
    - Low current modes for commissioning/tuning
    - …
  - Lattice error tolerances (IPAC'14 THPME044)
    - A part of the campaign to identify the linac-wide lattice error tolerances

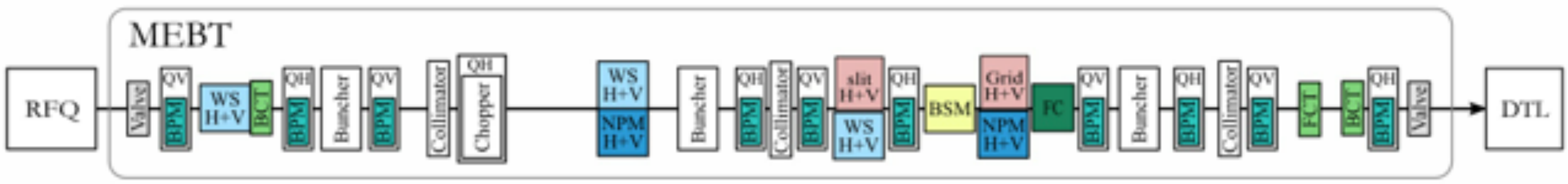
# Status of lattice design & beam physics (2)

- **What's been done so far (cont…)**
  - Partially-chopped bunches (LINAC14 MOPP039, HB14 MOPAB18)
    - The fast chopper rise/fall time specified as ~10 ns vs 2.84 ns of RF (352.21 MHz) and there are a few *partially-chopped* bunches.
    - Checked no significant beam loss, especially with scrapers.
  - Scrapers (IPAC14 THPME045, HB14 MOPAB18)
    - Some details in the following.
    - Detailed study of the linac-wide effect. (HB'14 MOPAB18)
- **(Near) future works**
  - Check the effect of
    - Buncher/quad/chopper field profiles
    - Quad multipoles
  - Tuning schemes (not just for the MEBT)
    - Trajectory, amplitude/phase scan, matching (beam size adjustments)

# Status of component design/prototyping

- Buncher (LINAC14 TUPP025)
  - Prototyping done for the 2012 design (50 mA and 3 MeV)
  - New design for 62.5 mA and 3.62 MeV in progress
- Quad (LINAC14 TUPP025)
  - Two configurations (steerer coils inside vs outside) being evaluated
  - Tender for prototyping planned soon
- Chopper and dump (LINAC14 TUPP025)
  - Based on a fast (~10 ns) voltage switch
  - Two configurations (a quad surrounding vs separated) being evaluated
  - Design and simulations of the dump in progress
- Scraper (This proceeding)
  - Design and simulations in progress (some details in the following)
- Alignment, support, …

# Diagnostics layout




- Faraday Cup (x1): also used as a beam stop
- Beam Current Transformer (BCT, x2): transmission from the difference
- Fast Current Transformer (FCT, x1): check the chopper
- Beam Position Monitor (BPM, x10?): also used to measure TOF
- Wire scanner (x3)
- A slit + grid system for emittance measurement (x1)
- Bunch Shape Monitor (x1)
- Non-invasive profile monitor (x2): proposed for the operation

– The layout being finalized.

– Tuning based on the planned diagnostics will be studied in near future.

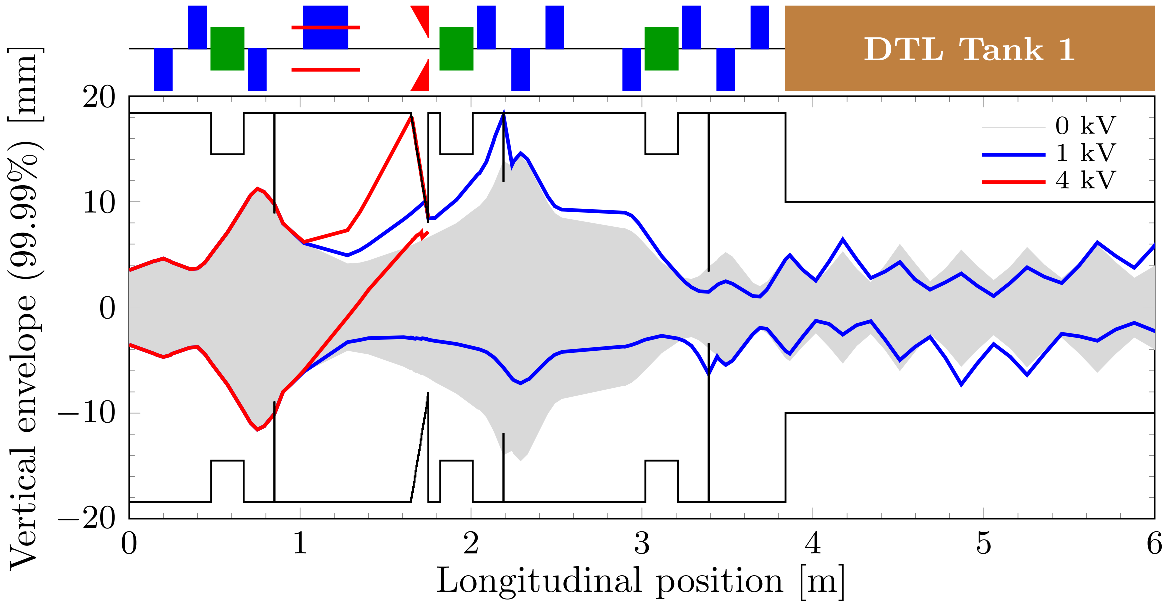
– Overview of the ESS diagnostics after the coffee.

# How we designed a MEBT (as a hindsight) (1)

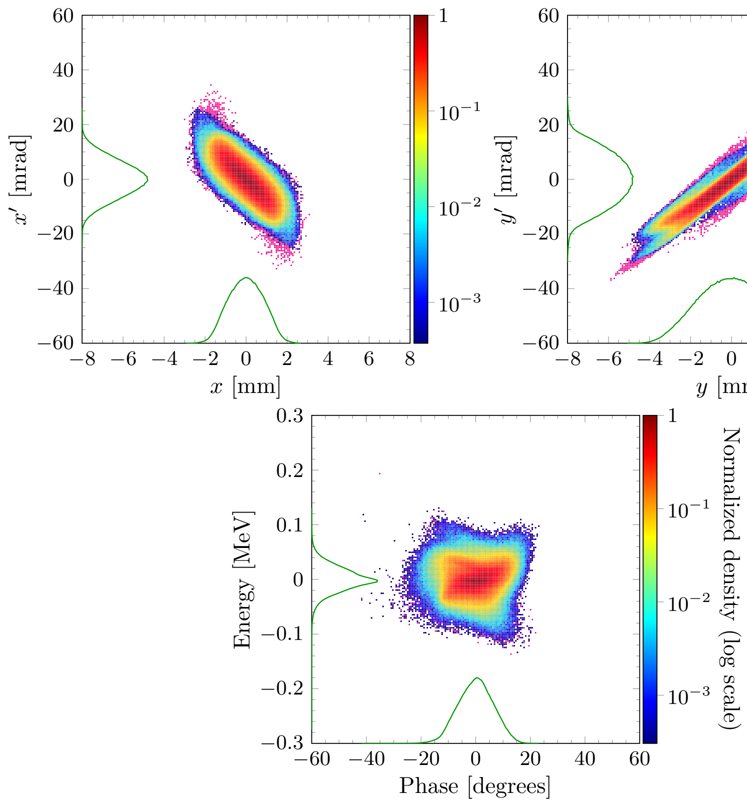
- No rule of thumb for the MEBT design (at least I don't know…)
  - Each MEBT is unique
  - Broken periodicity
  - The name of the game is **compromise** and **iteration**
- Design driven by the chopper engineering constraints
  - Chopper
    - LINAC4 like chopper+dump but only one with ~10 ns fast switch
    - 3 bunchers for the beam quality
    - 9+1 quad is possible but 10+1 for the matching
  - (Reasonable guesses of) quad/bunches size/strength (focusing not as strong in RFQ and DTL)
  - (Reasonable guesses of) spaces between elements for flanges and etc and diagnostics devices

# How we designed a MEBT (as a hindsight) (2)

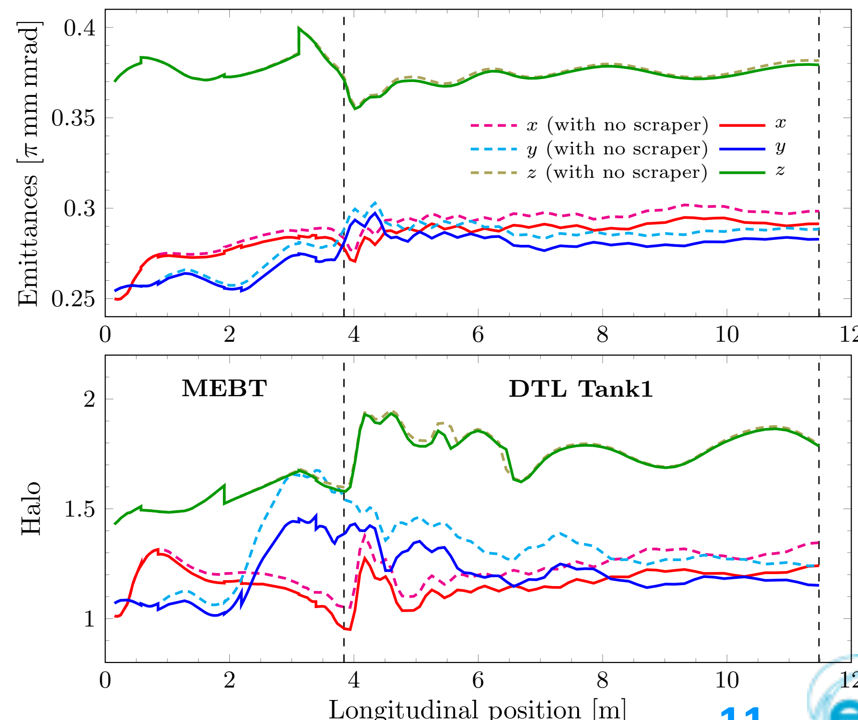
- Other beam physics constraints
  - Chopper efficiency (better than 99%)
  - Matching
- In addition, minimize losses and keep beam quality as possible
  - In a strong space charge environment (3.62 MeV + 62.5 mA)
  - Accept small beam quality degradation and don't "push" the beam too much (like when you play with a cat…)



# MEBT scrapers

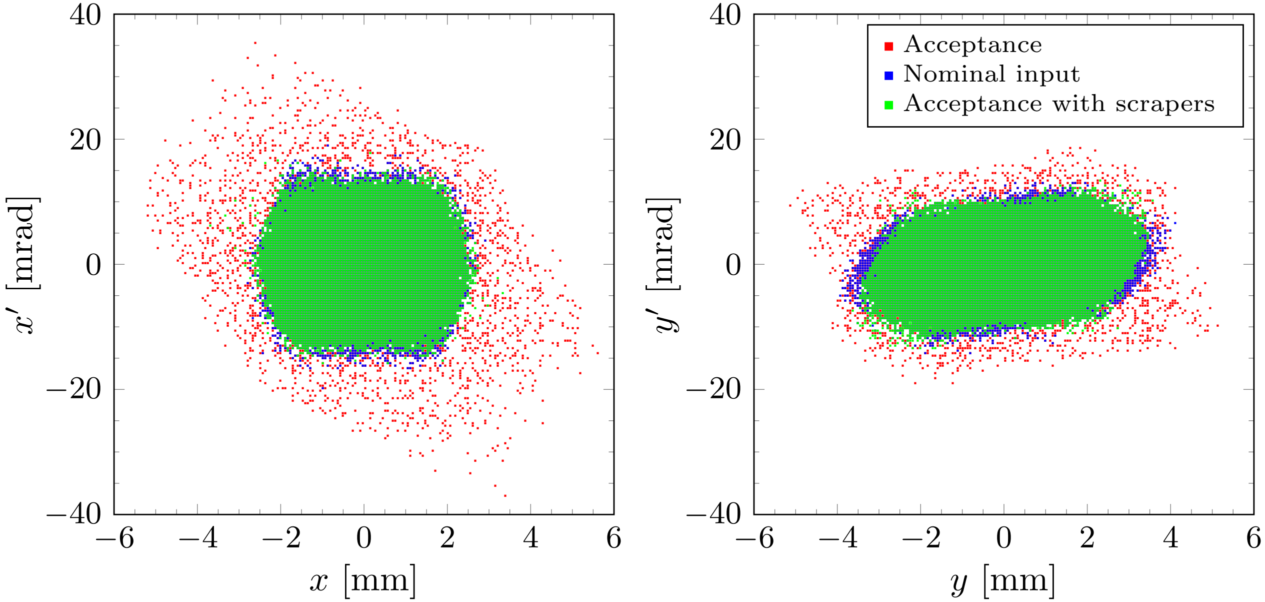



- The distance to the beam center is ~3 sigma.
- Improve quality of the beam going into/out-of the DTL.
- Further detail in MOPAB18.

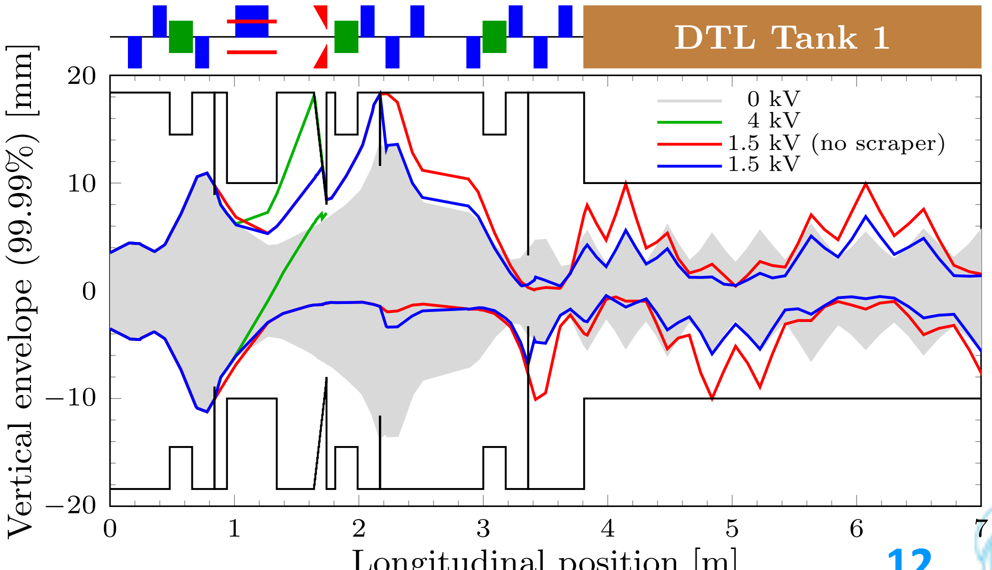



MEBT output distribution
with and without the scrapers

# Two more functions of the scrapers



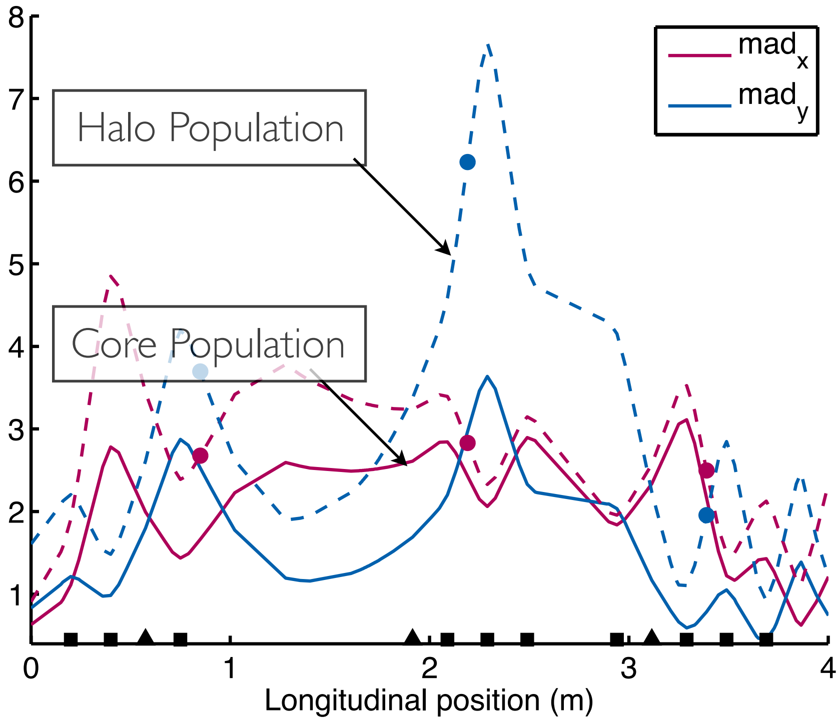

By limiting the acceptance, the scrapers effectively clean the halos in the RFQ output

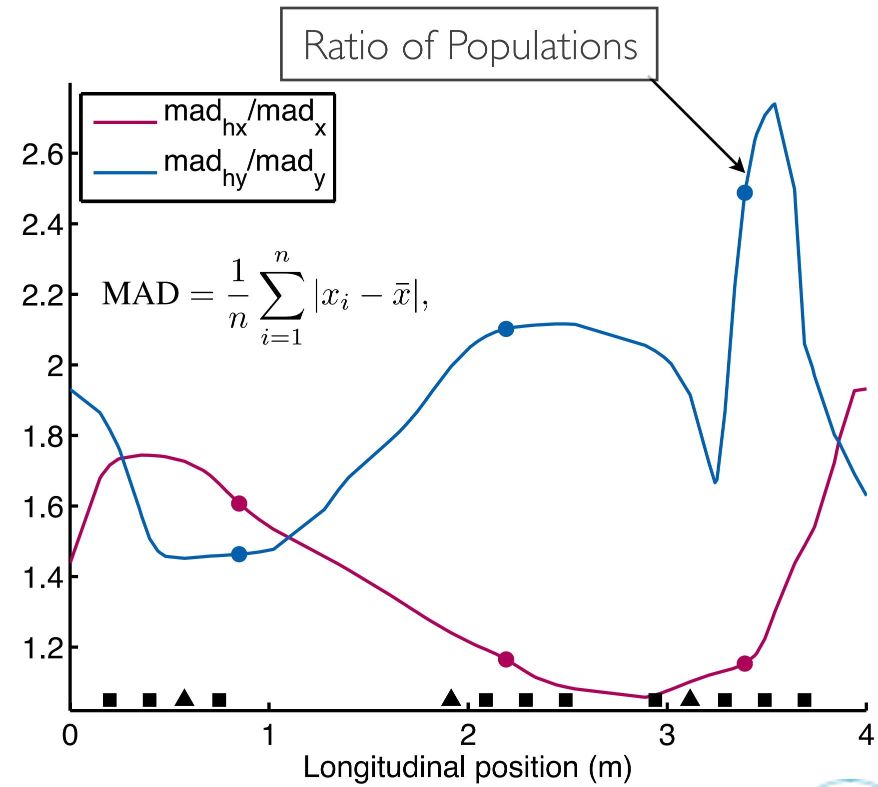



The 2nd and 3rd scrapers drastically improve the situation of the partially-chopped bunches (see also HB14 MOPAB18)

# Making sure the scraper locations optimized

Identifying the locations where the core and halo are most "separated".
("Core" and "halo" defined at the end of the DTL.)

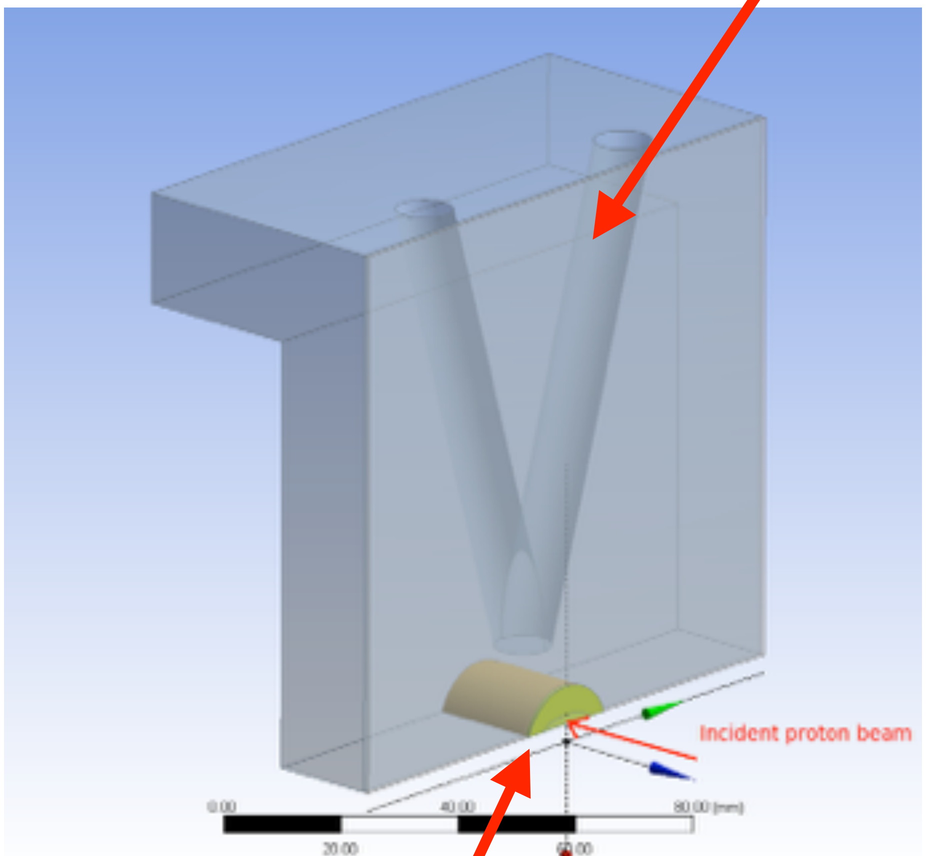


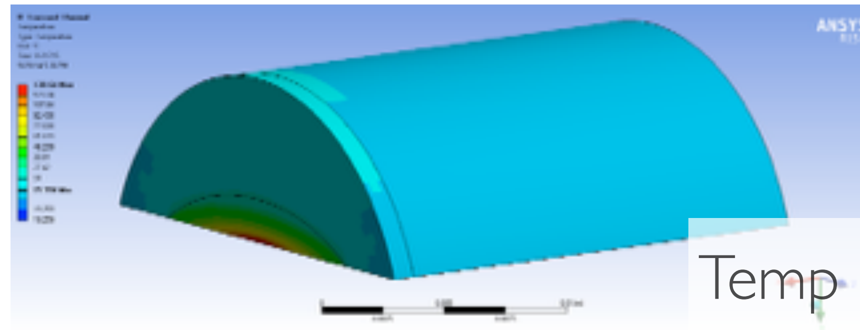



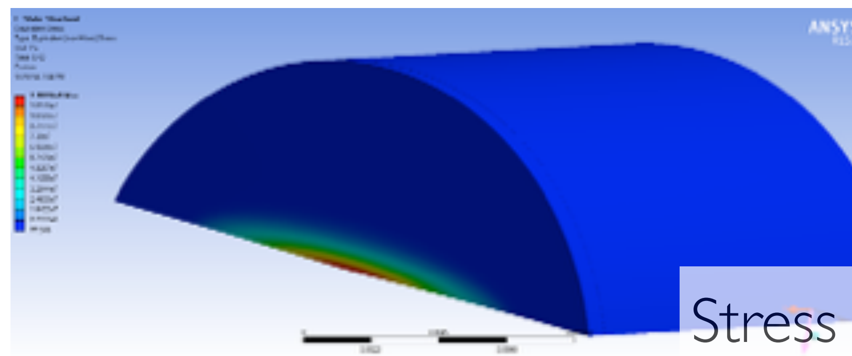

$$\mathrm{MAD} = \frac{1}{n}\sum_{i=1}^{n}|x_i - \bar{x}|,$$

# Scrapper thermo-mechanical calc (1)

Cooling channel



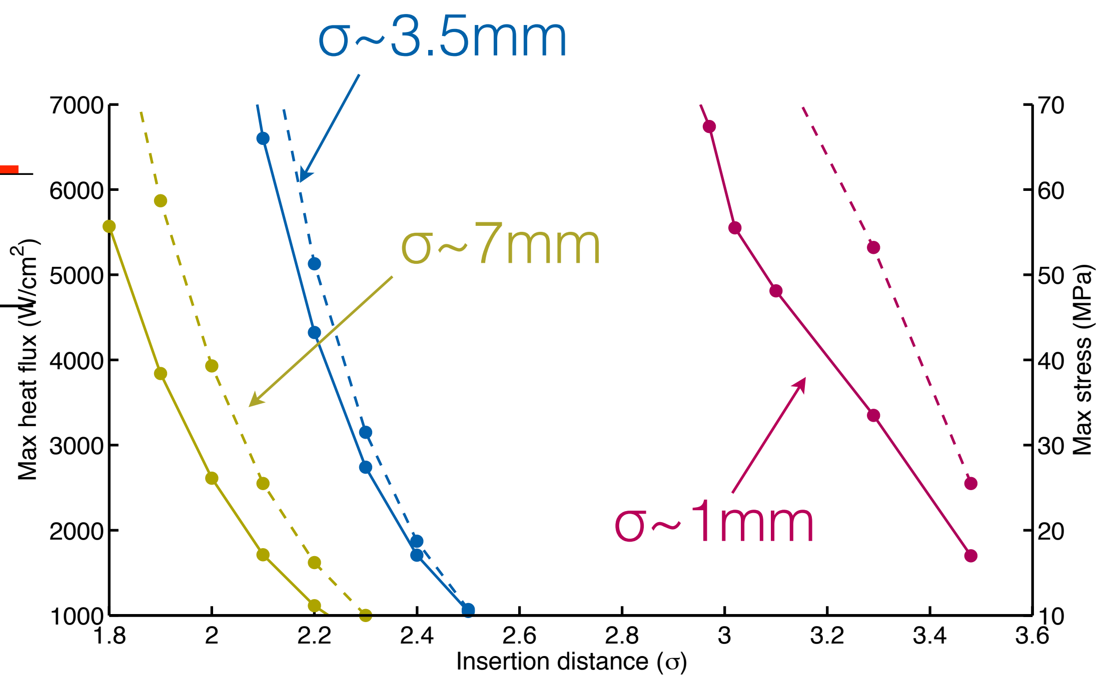




Temperature resistant material (tungsten)

# Scrapper thermo-mechanical calc (2)

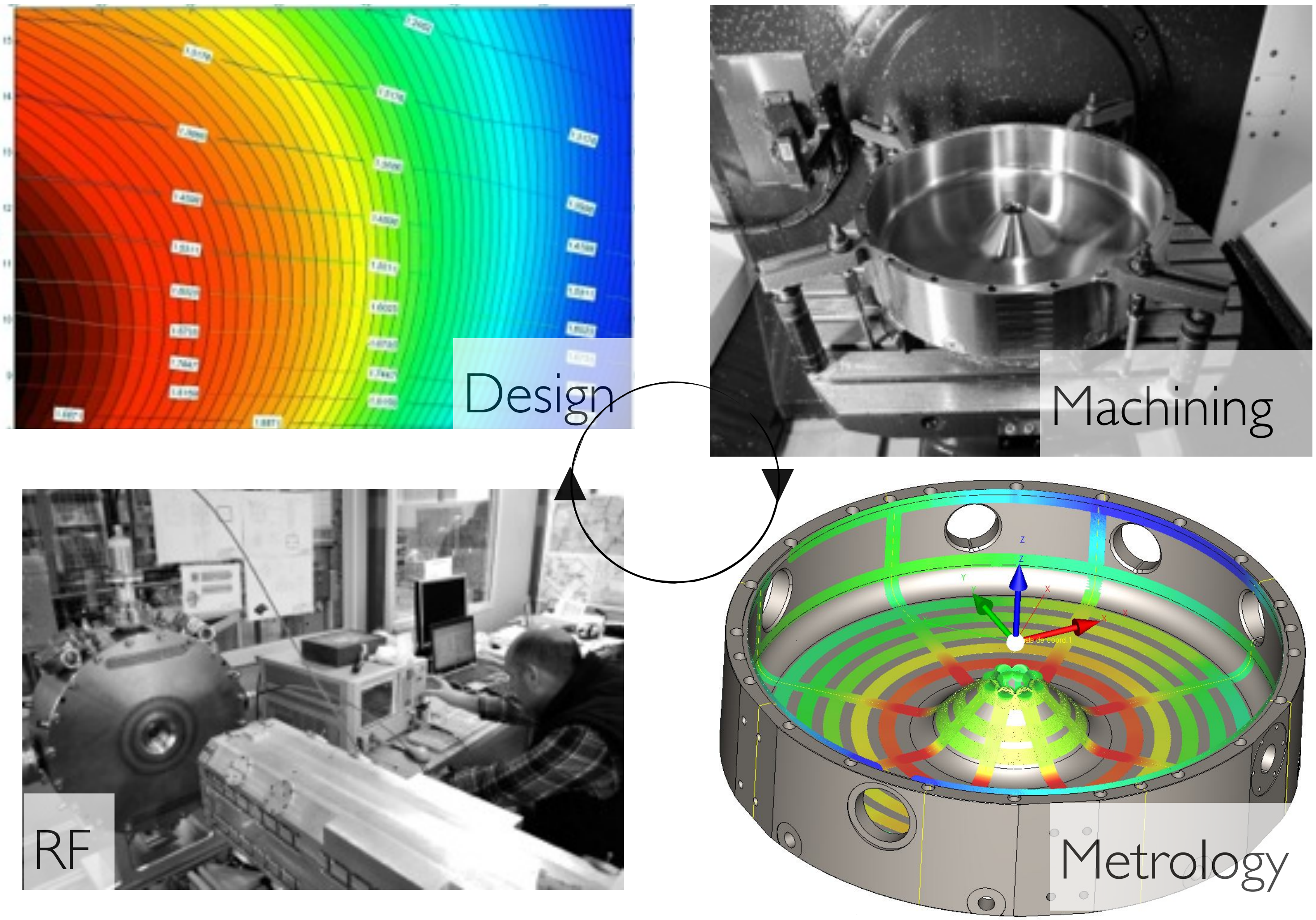
- Assumed $\sigma_x \sim \sigma_y \sim 1$ mm as an extreme case ($\sigma_x \sim 2$ mm and $\sigma_y \sim 1$ mm at the 3rd scraper)
- 100 MPa stress limit (tungsten) ⇒ ≥ 2.8σ or ≥ 0.15% looks feasible

| Insertion ($\sigma$) | Max. heat flux (W/cm$^2$) | Max Temp (°C) | Max Stress (MPa) |
|---|---|---|---|
| 3.48 | 1700 | 50.0 | 25.5 |
| 3.29 | 3350 | 80.0 | 53.2 |
| 3.1 | 4810 | 105.3 | 75.9 |
| 3.02 | 5550 | 120.4 | 90.3 |
| 2.97 | 6740 | 138.8 | 107 |
| 2.81 | 9130 | 185.7 | 149 |
| 2.67 | 12900 | 249.1 | 208 |
| 2.54 | 17600 | 334.0 | 283 |




More particles can be scraped for a larger beam

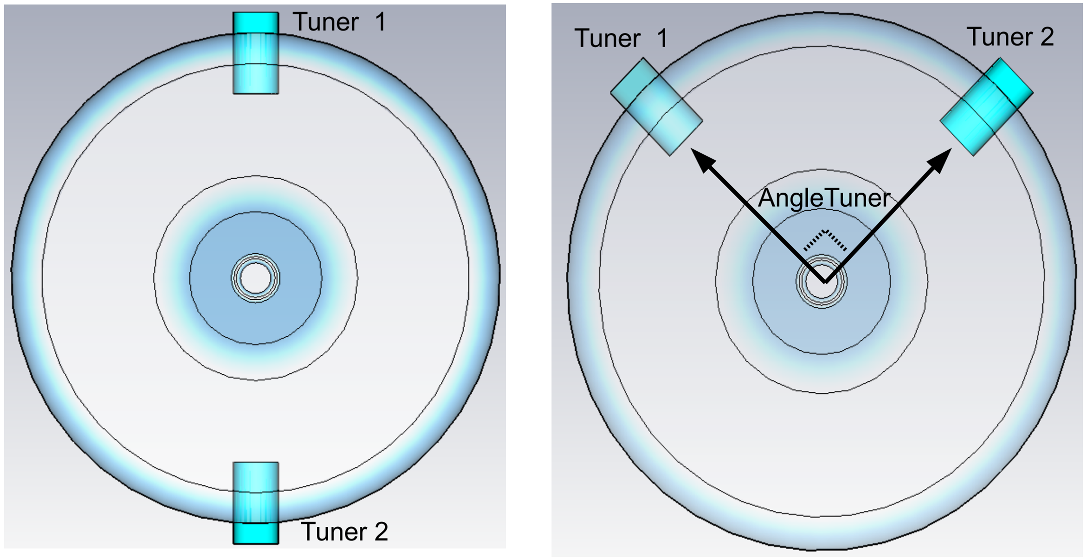
# Buncher prototyping cycle




- Prototyping done for the 2012 parameters.
- The new electromagnetic design in progress.

# Buncher challenges

- Layout: optical design & engineering design.
- For an $E_0TL \sim 150$kV, get higher $ZT^2$ width compromise.
- Best diameter and location for the tuners.
- Efficient cooling circuit (max temp. in the “nose cone” is ~194°C).
- Power coupler to hold ~15 kW peak power.
- ….



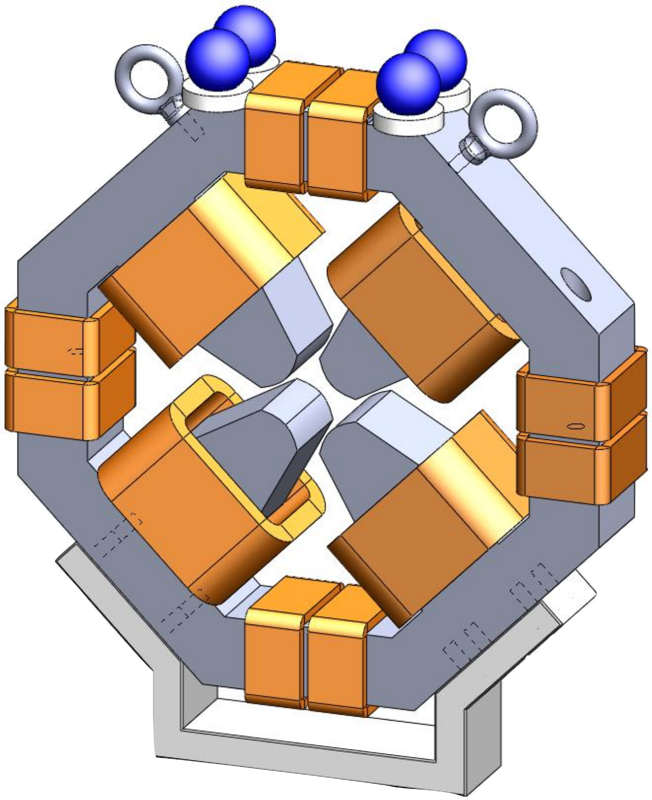

(a) (b)

# Quad

- The limited space biases the magnet design to a small number of turns N and high current I
- Two configurations (steerer coil inside/outside) being evaluated.

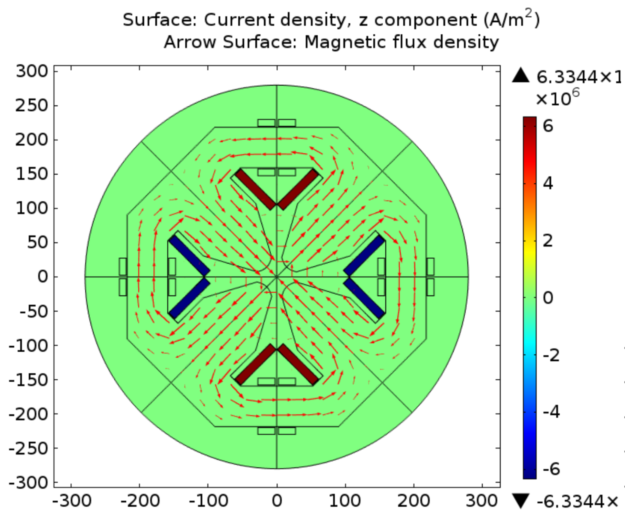
| **QuadrupoleInputParameters** | **Quadrupole** |
|---|---|
| $\mathbf{R_{ap}}$ [mm] | 20.50 |
| $\int \mathbf{B}$ [T] | 2.5 |
| **Provisional** $\mathbf{L_{eff}}$ [mm] | 75 |
| **G** [T/m] | 33.4 |
| $\mathbf{I_Q}$ [A] | 300 |
| $\mathbf{N_Q}$ [turns] | 19 |

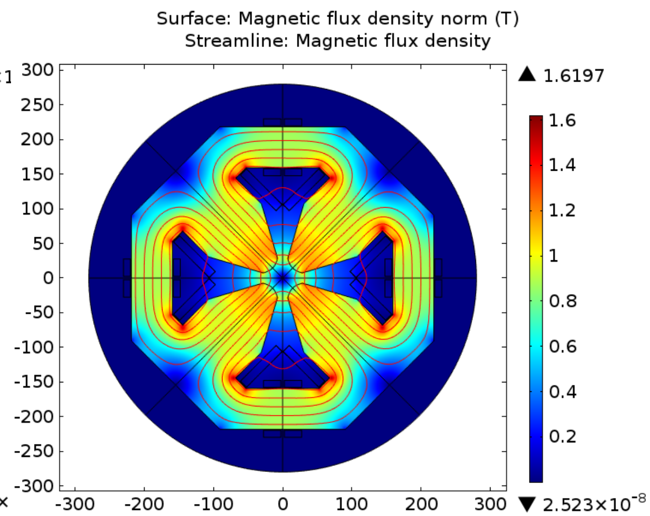
| **DipoleInputParameters** | **Dipole** |
|---|---|
| **g** [mm] | 37 |
| $\mathbf{G_D}$ [G·m] | 18 |
| **Provisional** $\mathbf{L_{eff}}$ [mm] | 75 |
| $\int \mathbf{B_D}$ [G] | 247 |
| $\mathbf{I_Q}$ [A] | 40 |
| $\mathbf{N_Q}$ [turns] | 18 |
| $\mathbf{\lvert B \rvert_{Ymax}}$ [T] | 1.20 |
| **B3** [units] | 1163 |
| **B5** [units] | 40 |
| **B7** [units] | -12 |



Multipole wrt steerer (B1=10000)
B1:B2 ~1:10

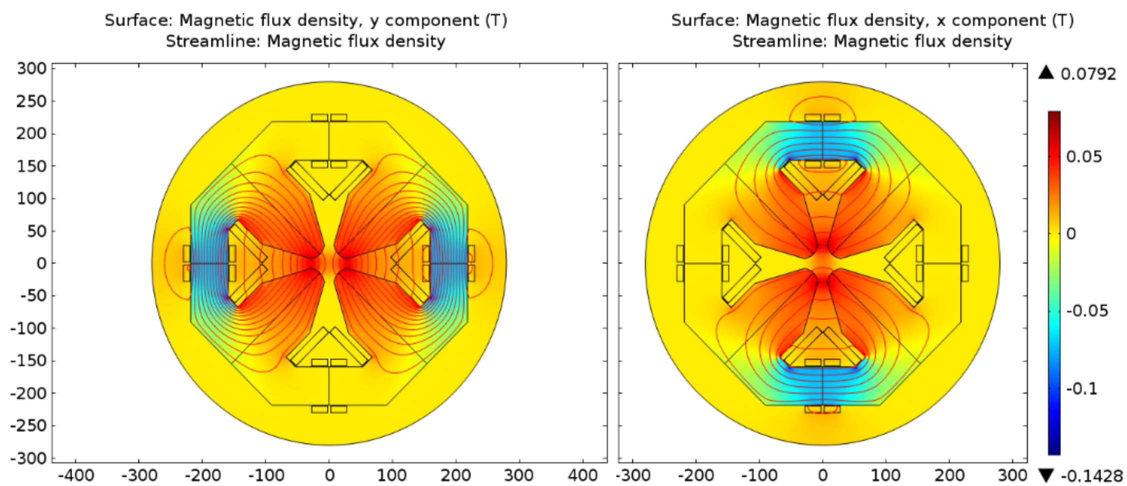
# Quad and steerer fields




Jz component and magnetic flux arrow surface.

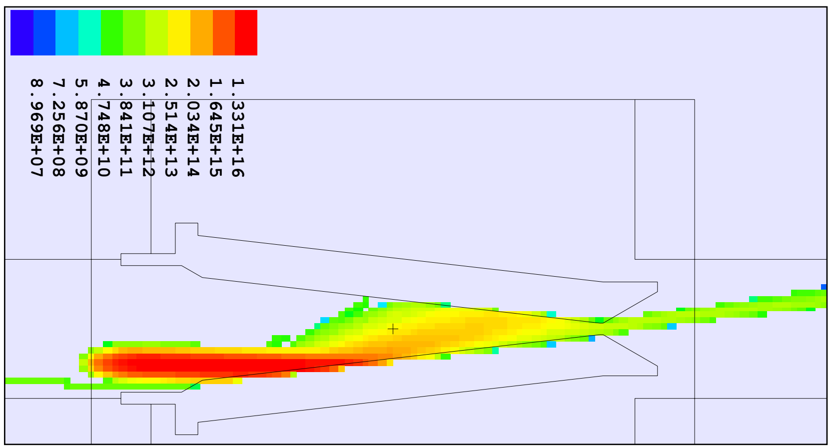
IBI map with only excitation from the quadrupole coils.



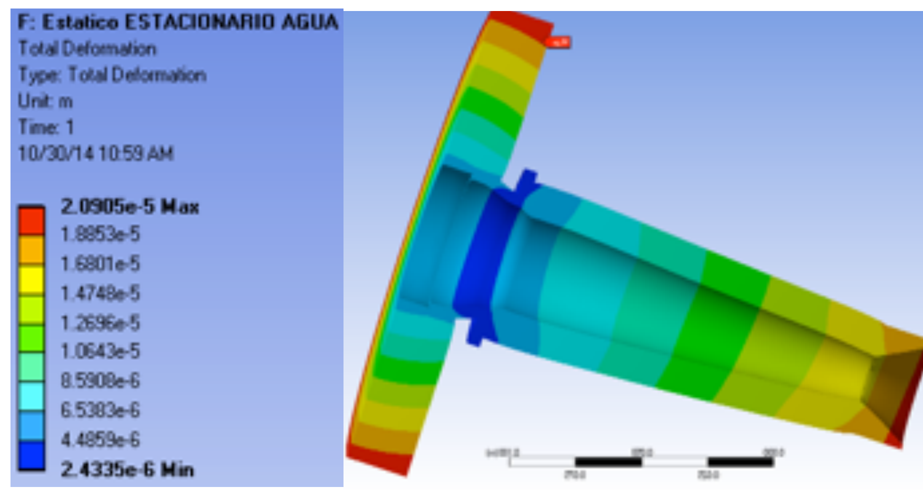

**By** and **Bx** dipole steerer fields. No significant saturation.

# Beam dump

- Different materials are under study (GLIDCOP AL60-LOX seems best candidate)
- Circular or rectangular cross-section?




Calculation with MCNPX. Small fraction (0.13%, ~keV) scattered downstream.




Cooling and thermo-mechanical calculations done by ANSIS.

# Conclusions

- Status of the ESS MEBT development is presented.
- Lattice design and basic beam physics calculation is done. The next step is to include the engineering details (quad multipoles, filed profiles, and etc) and study the tuning schemes.
- Designs and simulations for all the components are progressing and some are already close for prototyping.

# Backup slides

# Tolerances and RFQ errors

| Sect | Elem | Mode | $\delta x, \delta y$ mm | $\delta\theta_x, \delta\theta_y$ deg | $\delta\theta_z$ deg | $\delta E, \delta B$ % | $\delta\phi$ deg |
|---|---|---|---|---|---|---|---|
| MEBT | Quad | Stat | 0.2 | 0 | 0.06 | 0.5 | — |
| | Cav | Stat | 0.5 | 0.115 | — | 1 | 1 |
| | Cav | Dyn | 0 | 0 | — | 0.2 | 0.2 |
| DTL | Quad | Stat | 0.1 | 0.5 | 0.2 | 0.5 | — |
| | Cav | Stat | 0 | 0 | — | 1 | 0.5 |
| | Tank | Stat | 0 | 0 | — | 1 | 1 |
| | Tank | Dyn | 0 | 0 | — | 0.2 | 0.2 |
| SC | Quad | Stat | 0.2 | 0 | 0.06 | 0.5 | — |
| | Cav | Stat | 1.5 | 0.129 | — | 1 | 1 |
| | Cav | Dyn | 0 | 0 | — | 0.1 | 0.1 |
| HEBT | Quad | Stat | 0.2 | 0 | 0.06 | 0.5 | — |
| | Bend | Stat | 0.2 | 0 | 0.06 | 0.05 | — |

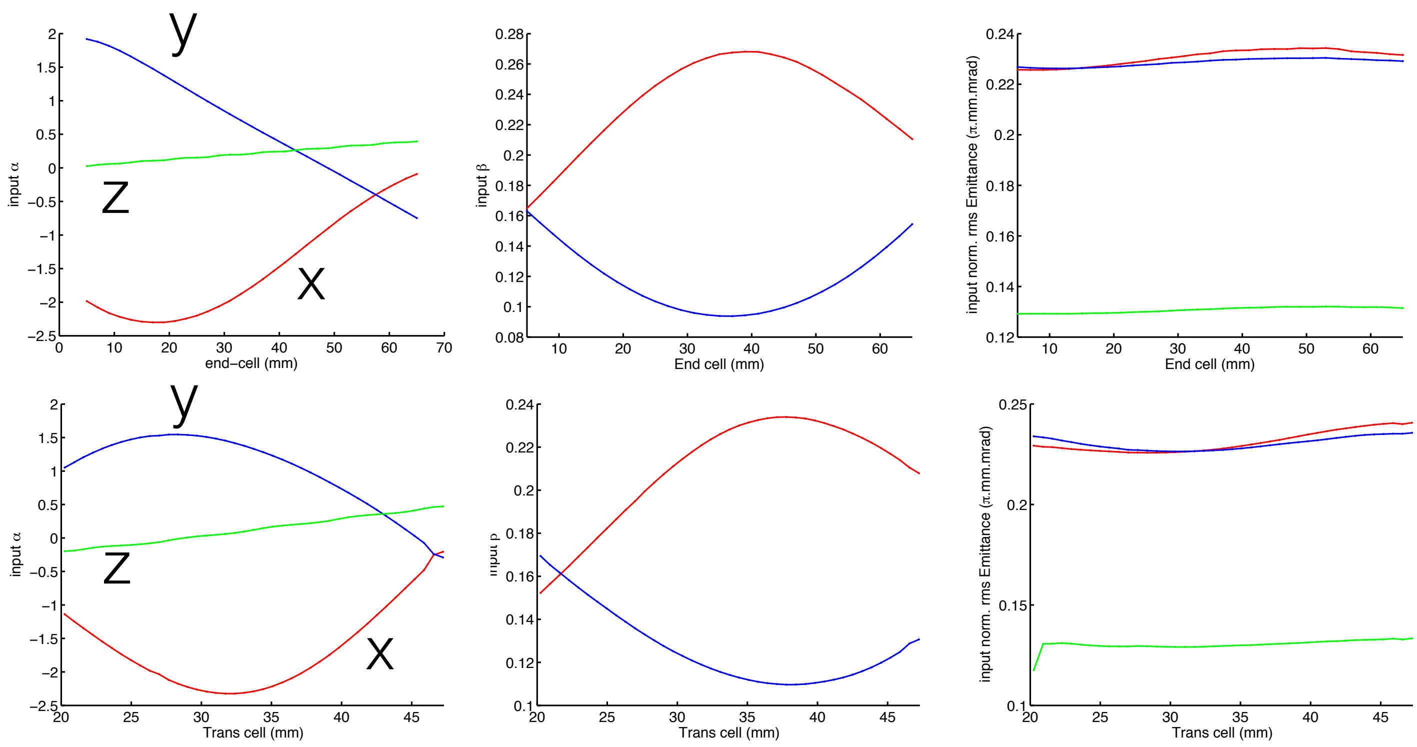
| Parameter | Unit | Value |
|---|---|---|
| $\delta x, \delta y$ | mm | 0.3 |
| $\delta x', \delta y'$ | mrad | 1 |
| $\delta\phi$ | degrees | 0 |
| $\delta W$ | keV | 10 |
| $\delta\epsilon_x, \delta\epsilon_y, \delta\epsilon_z$ | % | 5 |
| $M_x, M_y, M_z$ | % | 5 |
| $\delta I$ | mA | 0.625 |

# **Beam Physics:** Best inputs for MEBT

- two sets of possible inputs

end-cell 31

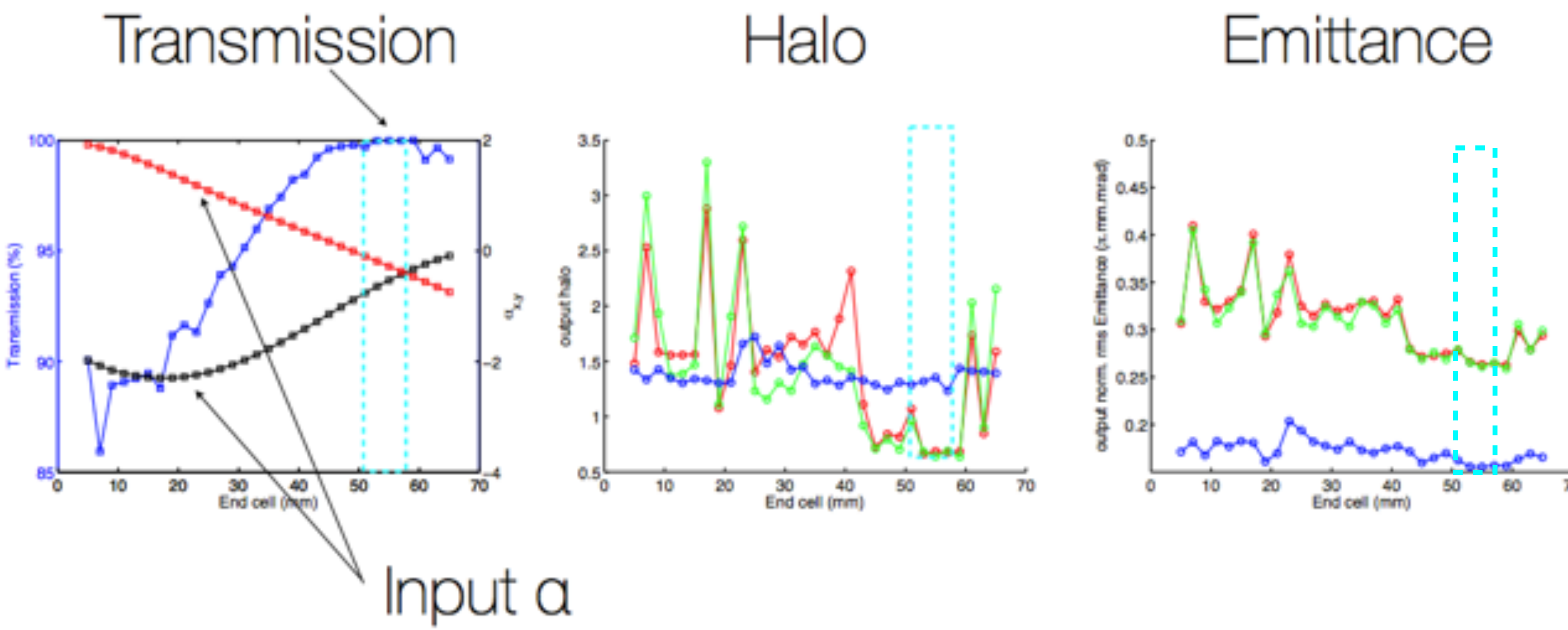
trans-cell 41




α β e

# **Beam Physics:** Best inputs for MEBT

- Overall, results at the end of the LINAC are quite different in transmission and beam quality.
- Higher ß values might obtain better results, it is not the critical parameter
- Lower values of α are desirable.



# MEBT alignment

1. Components are aligned in each raft
2. Rafts are aligned between them
3. Fiducial points also used to align MEBT with the rest of the accelerator