Chopping and Limitations to MEBT; Injection to Recycler

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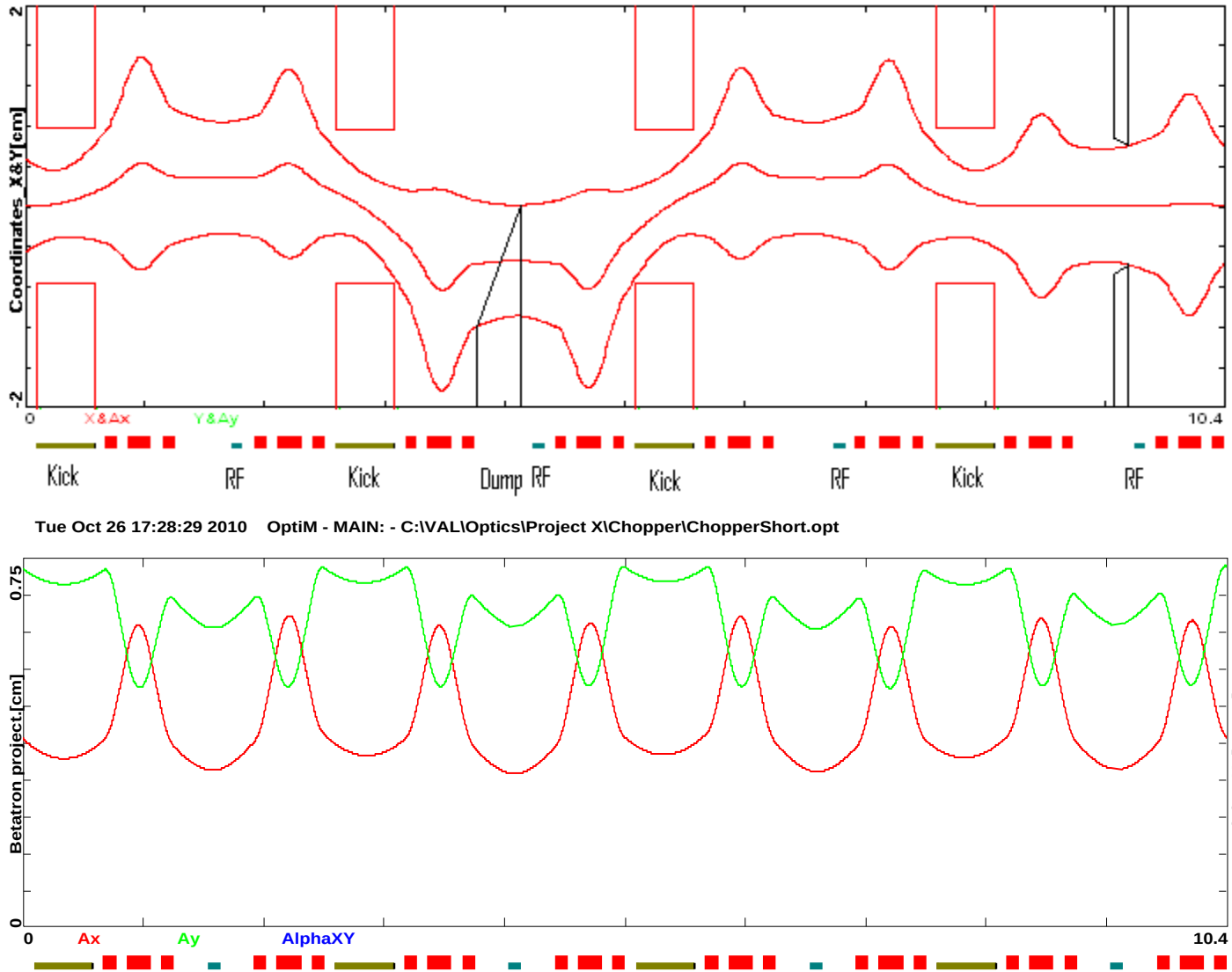
Project X Retreat
November 2, 2010

Chopper and MEBT

- MEBT Layout
- Limitations on the Chopper Design
- Chopper Bandwidth
- Alternative Approach for Chopper Design
- Beam Dump Heating by the Beam
- Beam Dump Space Limitations
- Beam Dump Lifetime
- Conclusions for Chopping

MEBT Layout

- Triplet focusing
  - μ_H = 90 deg
- Hor. beam kick
- Reduced vertical focusing to increase beam width on dump
- ~70 kV per cavity
- Tight spacing in beam dump aria
- Large effect of beam space charge on beam focusing for 10 mA beam current and 162.5 MHz bunch frequency



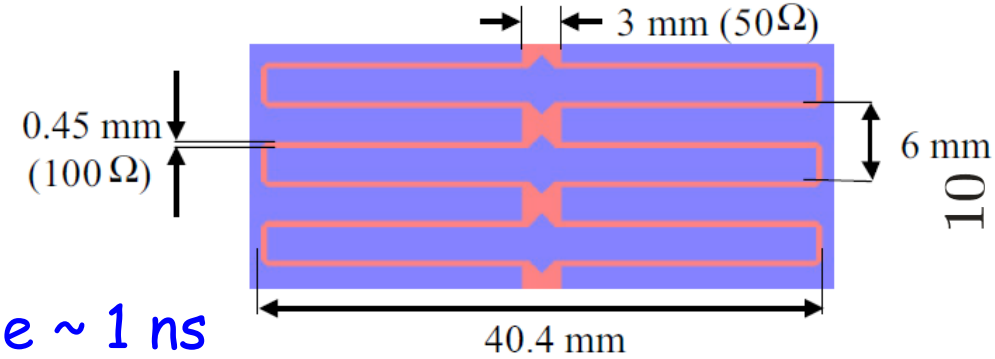
- Bipolar kicks: "+" – no chop; "-" – chop; "0" – half bunch chop
  - It allows the beam current regulation
  - It reduces voltage of power amplifier by 2 times (power by 4)

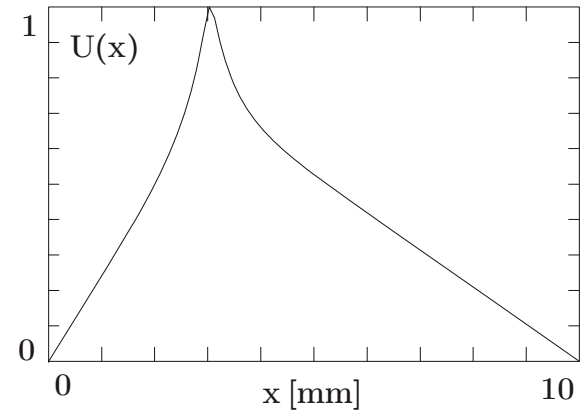
Limitations on the Chopper Design

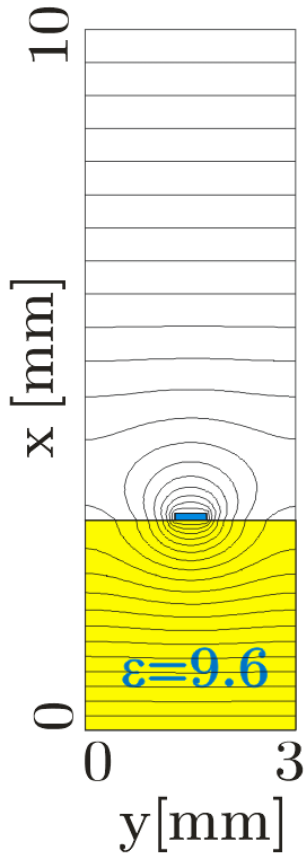
- Kicker parameters: 4 kickers, L=50 cm, U_{eff}=±400 V(gap 15 mm)
- Bandwidth (~1 GHz)
  - Bandwidth is limited by coupling between stripes and/or reflections from discontinuities
    + loss in conductor
- Power amplifier
  - CW regime, Pmax~3 kW
- Heating stripes by the beam halo
  - adequate protection has to be anticipated
- Beam dump - large beam power on the (~25 kW)
  - Heating
    - The problem is exacerbated by small space available
      $\Rightarrow$ ~70 cm for cavity and beam dump
  - Sputtering & blistering
  - Residual radiation is not negligible: copper @ 2.5 MeV
    - Nickel could address the problem but sputtering excludes it

Chopper Bandwidth

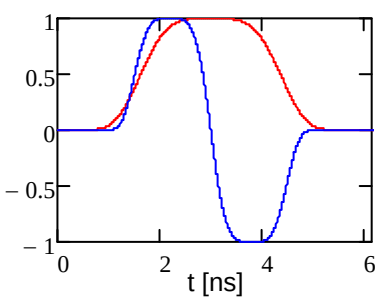
- CERN meander proposal
  - Total length 40 cm
  - Demonstrated rise time ~ 1 ns
  - Bandwidth ~500 MHz @3 Db
    - Large ε and ρ = 100 Ω
      => small stripe width
      => large resistance
      + Large stripe-to-stripe coupling: $C_1/C_0=L_1/L_0\approx0.2$
    - ~30% loss of the kick due to small stripe width

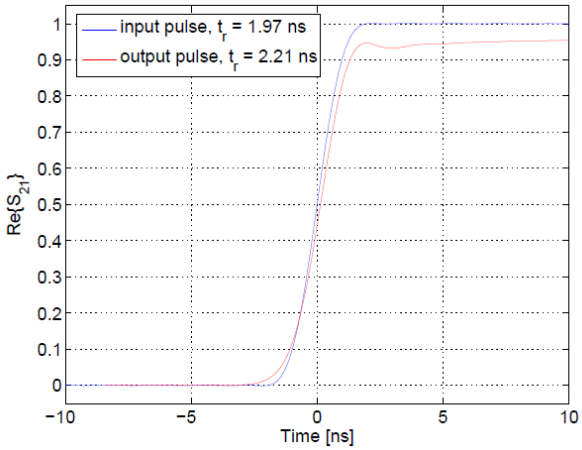






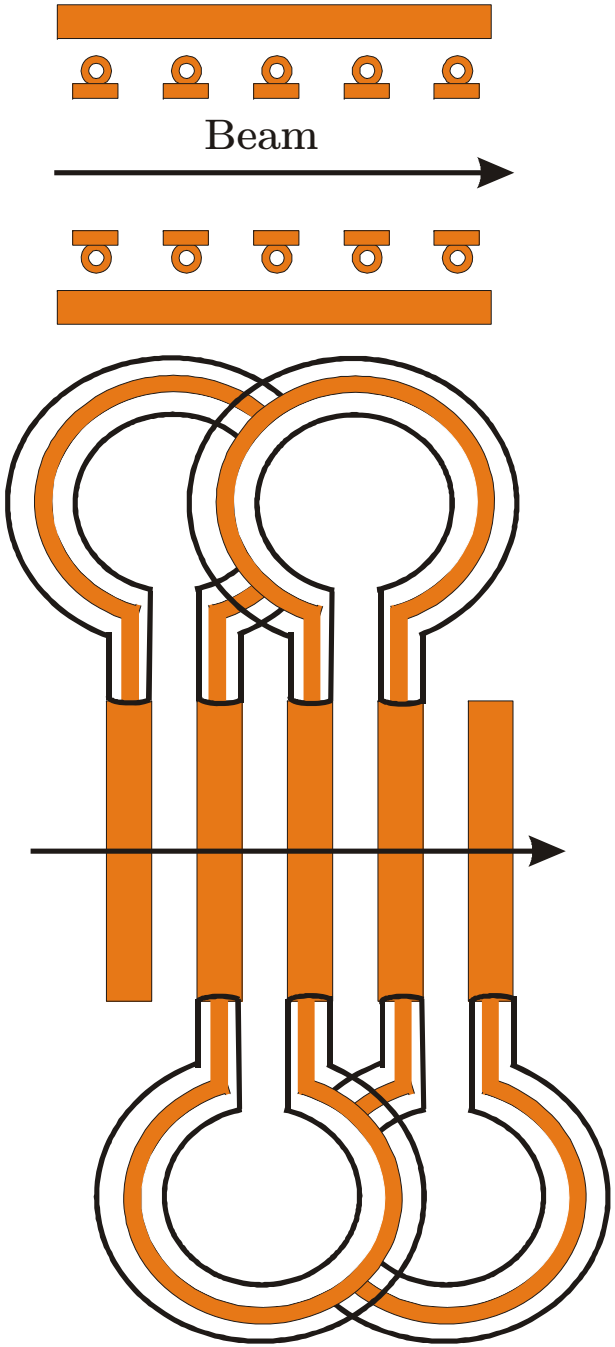
- Pulses of double versus single polarity
  - Double polarity
    => No DC
    - Preferable but needs ~0.5 ns rise time
    - DC current measur. – effective protection from beam heating





Alternative Approach for Chopper Design (Ding Sun)

- Details
  - No dielectric
    - No charging of the surface
  - "RF cable" connection between stripes
  - Smaller effective coupling between lines
  - More effective kicks
  - Water or air cooling of stripes is possible
- Expected problems
  - Reflections at the transitions
- Prototype based on the cable delays is at the beginning of constriction phase



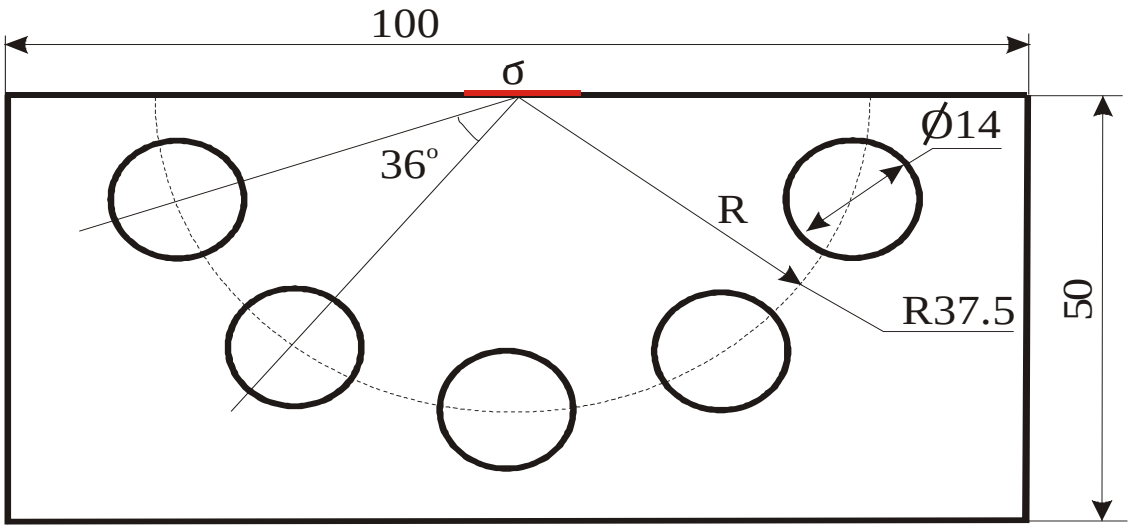
Beam Dump Heating by the Beam

- Heat removal requires large aria of water channels so that $dP/ds \leq 60\ W/cm^2$
- For Gaussian heating profile with σ = 6.4 mm and the linear power density dQ/dL=1.3 kW/cm the temp. differ. in the Cu

$$\Delta T \simeq \frac{1}{\pi\kappa}\frac{dQ}{dL}\ln\frac{1.89R}{\sigma}$$

~255 K (R=3.75 cm)

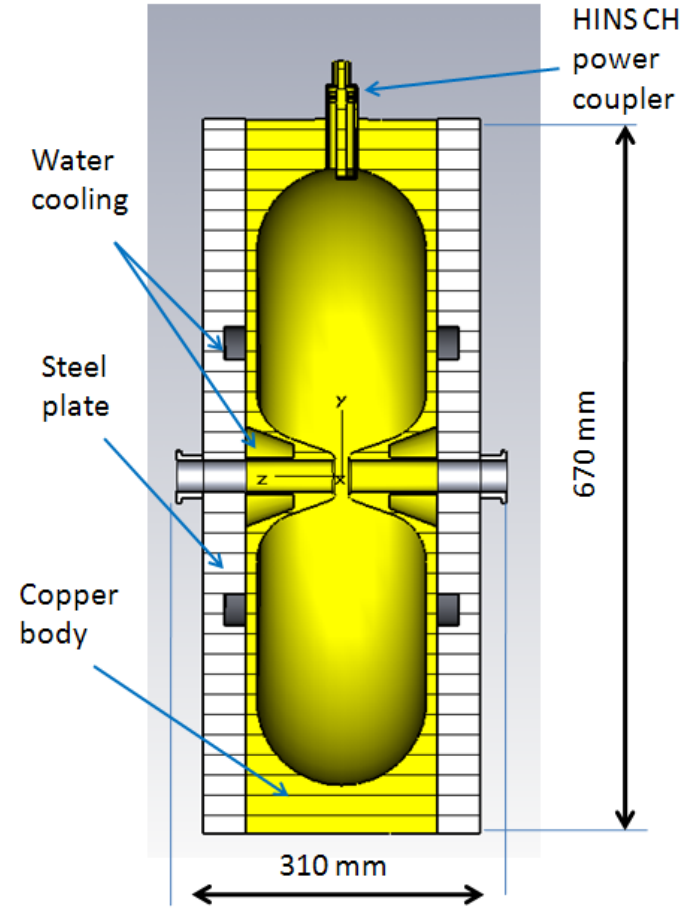
- Temperature difference (peak in copper to inlet water) ~285 C°

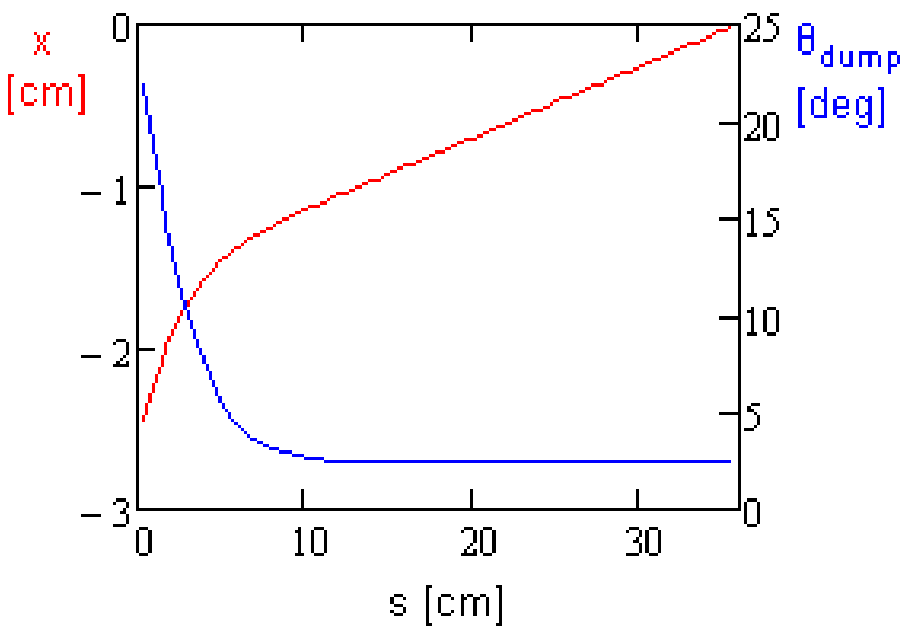


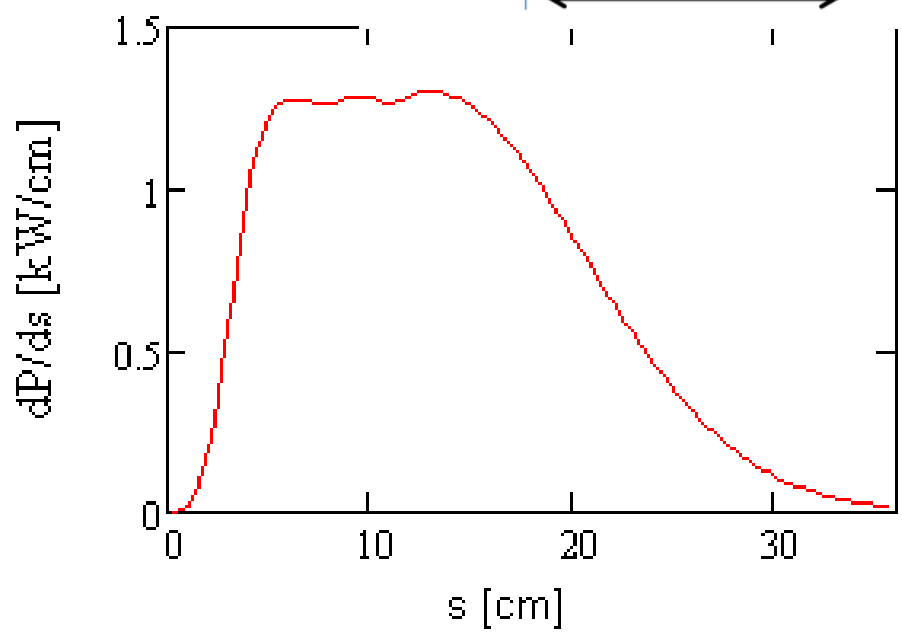
Length of the beam dump	36 cm
Max. linear power density	1.3kW/cm
Water pressure drop	2 atm.
Water pipes connection	serial
Total length of pipes	2.5 m
Water flow	1.1 l/s
Water ΔT (inlet-to-outlet)	5 C°
Power density (water-to-Cu)	45 W/cm^2
ΔT (water-to-Cu)	25 C°
Peak temperature	335 C°

Beam Dump Space Limitations

- 700 mm drift is allocated for the RF cavity and the beam dump
  - 300 mm cavity
  - 400 mm beam dump
    - 3σ scraping
    - Dump face is bend at the entrance to reduce the dump length







Beam Dump Lifetime

- Proton (H^-) beam destroys the dump surface
  - Sputtering
    - amplified by oblique incidence;
      estimate: ~0.1-0.5 mm/year
  - Blistering
    - Will be mitigated by
      - high temperature of the dump face
      - remelting of blistered material
        - Dump face should look up
  - Worst case estimate - chemistry: Cu+H=CuH; removing each CuH molecule from the surface would eat ~1 cm of copper per year

Beam Dump Lifetime (continue)

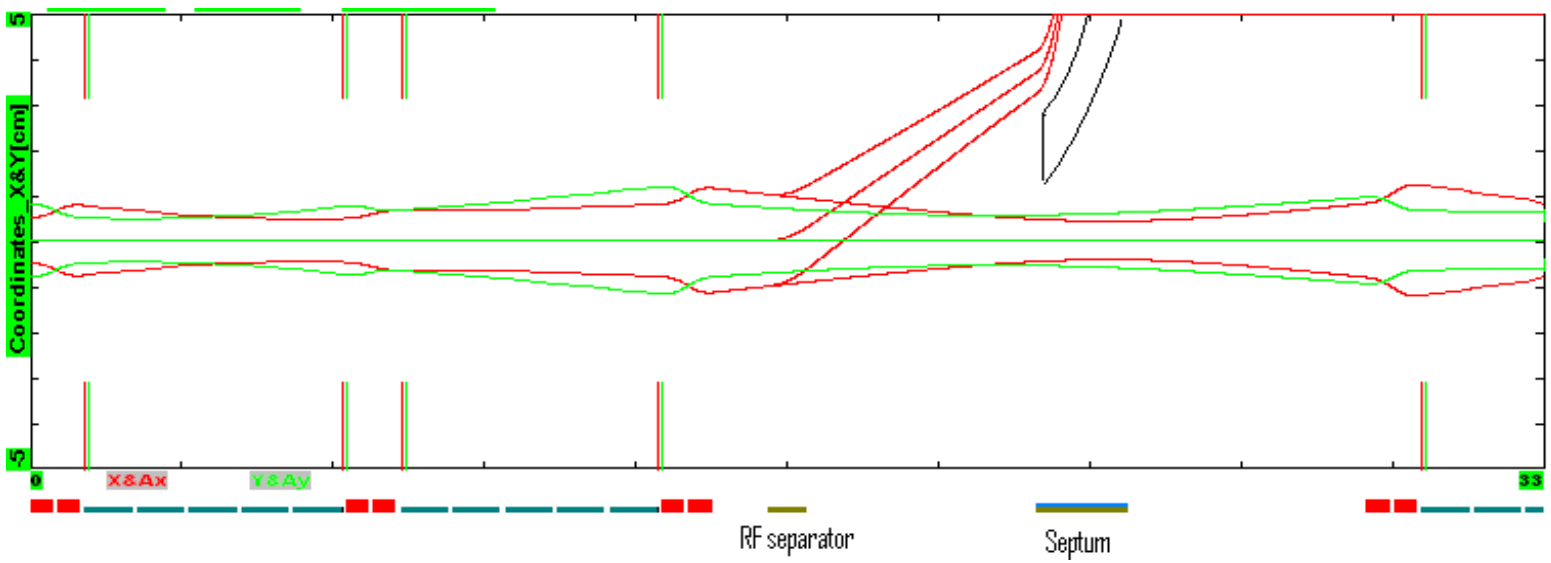
- MEBT energy of 2.5 MeV is at the boundary of neutron production
  - Copper looks as attractive material (good thermo-conductivity, resistant to thermal shocks)
    but it makes neutrons and will have some residual radiation
    - Numerical estimate is needed
  - Silver deserves to be looked (better thermo-conductivity, may be smaller sputtering (M_{Cu}/M_{Ag} helps, Z_{Cu}/Z_{Ag} does not)
    - no residual radiation
- High speed vacuum pumping is required to keep good vacuum in MEBT cavities
- Effective differential pumping is required to keep good vacuum in SC cavities
- All insulators in the close dump vicinity have to be protected from copper vapors

Conclusions for Chopping

- Very serious problem and has to be actively pursued
- Looks doable for 162.5 MHz RFQ
  - 325 MHz looks preferable from all other points of view
    - It would basically eliminate the space charge problems but we are much less assured that the chopper can be built
- There are other possible approaches to chopper design
  - They have to be evaluated
- 2.5 MeV RFQ energy looks adequate for now
  - Better understanding of neutron production and residual radiation is required
- Partial chopping (bunch-by-bunch beam current regulation) is attractive option and has to be pursued

Beam Extraction at 1 GeV

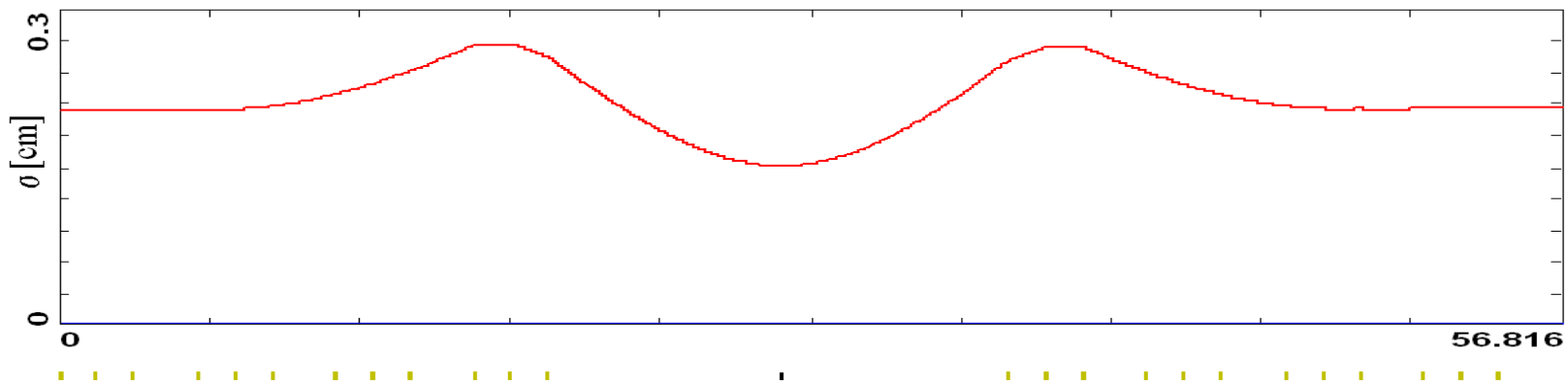
- Septum B_{max} is limited to 3.5 kG by Lorentz stripping
  - B = 3.5 kG, L = 2 m => 11 deg. kick, $W=1.4\cdot10^{-5}$($7.2\cdot10^{-6}$ m^{-1})
- One SC RF separators is required
  - 44 cm & 3.75 MeV each
  - ±3.4 mrad kick (6.8 mrad kick used for separation)
  - DC corrector compensates RF separator kick for the left-in-linac beam
  - Half of the buckets will be redirected to the extraction
- Total gap required for RF extraction of 1 GeV beam is ~15 m
- 5 m is sufficient if entire beam is extracted



5 $\sigma\perp$ transverse beam envelopes in the RF separation aria

Longitudinal Matching for Beam Extraction at 1 GeV

- To match the longitudinal beam envelope one needs
  - to increase the accelerating phase from 15° to 57° for 3 cavities at each side of the gap
  - and to zero phase for the next 5 cavities at each side



1σ longitudinal beam envelope in the RF separation aria

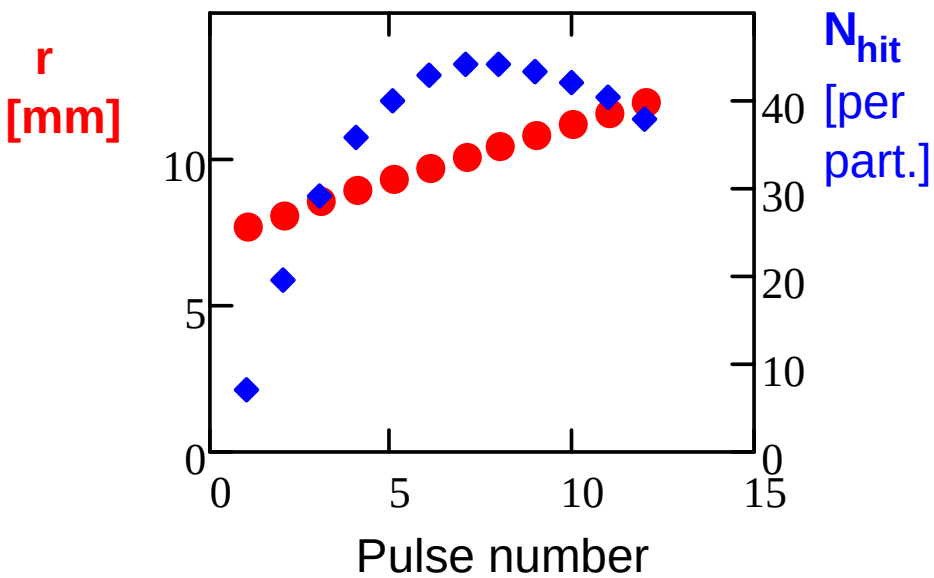
- Total loss of acceleration is equivalent to 2 lost cavities

Conclusions for 1 GeV extraction

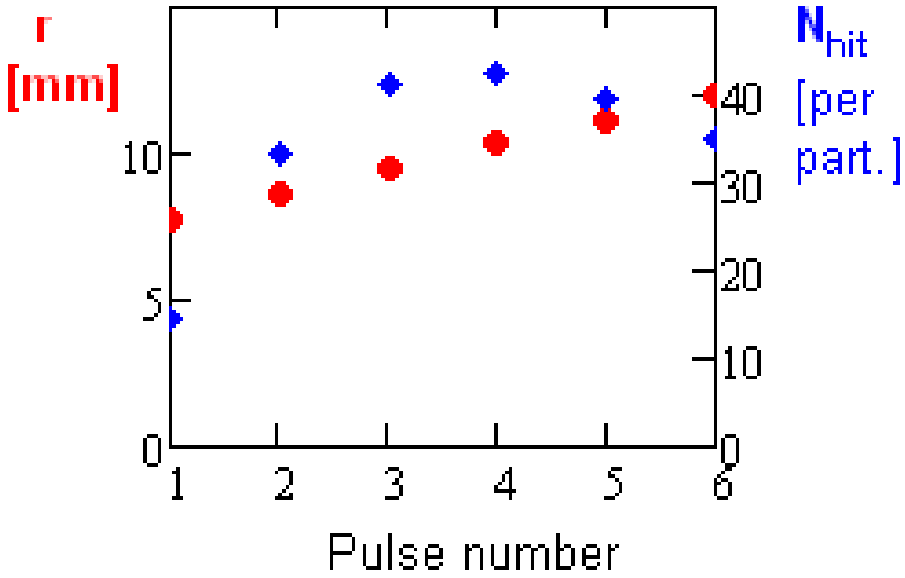
- It is not as bad as one could expect
- It requires
  - additional 2 SC cavities to compensate the acceleration lost for rebunching
  - 1 SC RF cavity for RF separation
  - 15 m longer tunnel
- It splits all RF buckets into 2 equal parts
- For operation with 1 MW at 1 GeV it takes all the beam available

Foil heating at Injection to Recycler

- Total charge to be delivered to Recycler is 26 mA*ms
- 10 and 20 Hz operation look quite similar in the total number of foil hits and particle loss
  - Foil temperature stays in good region for both regimes
    - It will be smaller for 20 Hz operation



20 Hz, 2.15 ms, 1 mA, 12 pulses



10 Hz, 4.3 ms, 1 mA, 6 pulses

- Beam current >1 mA results in further reduction of foil heating
- 20 Hz operation requires twice faster kickers