Beam Imperfection Studies
- Status of RF coupler asymmetry studies

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- Field simulation using asymmetric model (with coupler)
- Field map implementation
- Beam dynamics simulation using a field map
- Summary
Introduction

- To identify the source for imperfections in beam profiles / phase spaces

Phase spaces at EMSY1 (BSA=1.6 mm, 1 nC)

Simulation → Measurement

Beam Profiles at EMSY1

Simulated X-Y  Measured X-Y

→ Simulations including coaxial RF couplers
RF field simulations in CST-MWS

- Simulation models

Symmetric model
(mesh view)

Asymmetric model
(PEC)
Quantifications of field asymmetries

- Defined quantities for field asymmetries:

1. Peak field amplitude
2. Flatness: ratio of peak field amplitudes, flatness=1: no asymmetries
3. Offset of zero-crossing: offset of field zero crossing from axis
Quantifications of field asymmetries

Hx along vertical lines at different z positions

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Quantifications of field asymmetries

- Peak field amplitude
- Flatness
- Offset of field zero crossing from axis
RF field map implementation

- Quantifications for all E and H components

  - **Hx along y** → flatness: 1 (resonator) to ~0.8 (entering beam pipe); Offset: 0 to ~2 mm
  - **Hy along x** → flatness: ~1; Offset: ~0.01 mm
  - **Hx along x, Hy along y, Hz** → very weak contributions
  - **Ez along x/y/z** → no asymmetries found
  - **Ex along x** → flatness: 1; Offset: ~0.1 mm
  - **Ey along y** → flatness: ~2% change; Offset: ~0.3 mm
  - **Ex along y, Ey along x** → very weak contributions

- Implementation of 3D RF field map (real number)
  - Fields computed with CST-MWS
  - Field map implemented with ASTRA
  - Field map settings
    - **Scale** (for $\sigma_{rms} = 0.4$ mm): transversely ~20 mm; longitudinally ~350 mm
    - **Grid setting**: uniform grid sets; $Dx = Dy \leq 0.1$ mm, $Dz \leq 0.2$ mm (grid size in each direction)
ASTRA simulations using RF field map

- **ASTRA simulations**
  - $XY_{\text{rms}} = 0.4 \text{ mm}, Q = 1\text{nC}$
  - Flat-top bunch of $\sim 21.5 \text{ ps}$
  - Uniform transverse distribution
  - $E_{\text{max}} \approx 60\text{MV/m}$, at MMMG phase, $B_{\text{max}} \approx 0.227901\text{T}$, booster included

- **Comparisons between 3 cases**

  **Case A: Using Paraxial field with symmetric model**
  Given only the on-axis ($z$) electric field, the transverse field components are analytically calculated from the derivatives of the on-axis field.

  **Case B: Using 3D RF field map with symmetric model**
  RF fields computed from CST-MWS simulations without RF couplers.

  **Case C: Using 3D RF field map with asymmetric model**
  RF fields computed from CST-MWS simulations with RF couplers.
ASTRA simulations using RF field map

(Paraxial fields) **Case A vs. Case B** (3D fields using symmetric model)

**Case A**
- Emittance: $\varepsilon_{xy} = 0.6872$ mm mrad

**Case B**
- Emittance: $\varepsilon_{xy} = 0.6867$ mm mrad

Transverse phase spaces @ EMSY1

**Transverse beam profiles** @ EMSY1
ASTRA simulations using RF field map

(3D fields using symmetric model) **Case B vs. Case C** (3D fields using asymmetric model)

- **Case B**
  - $(X-PX)$
  - $(Y-PY)$
  - $z \approx 3 \text{ m}$
  - Center

- **Case C**
  - $(X-Y)$
  - $z \approx 3 \text{ m}$
  - Center

**Kick**

**Case B**

**Case C**
ASTRA simulations using RF field map

(3D fields using symmetric model) **Case B vs. Case C** (3D fields using asymmetric model)

**Case B**

- Transverse beam profiles @ EMSY1 $z \approx 5.7$ m

**Emittance:** $\varepsilon_{xy} = 0.6867$ mm mrad

**Case C**

- Transverse phase spaces @ EMSY1 $z \approx 5.7$ m

**Emittance:** $\varepsilon_x = 0.7055$ mm mrad $\varepsilon_y = 0.7158$ mm mrad

**Transverse beam profiles** @ EMSY1 $z \approx 5.7$ m
Location of the kick

- Transverse kick
  - Before booster: ~0.6 mm in x and ~0.45 mm in y at z ≈ 3 m
  - At EMSY1, smaller kick~0.3 mm

- Source of the kick
  - Region: from the full cell (end) of the gun to the beam pipe
  - Source: RF coupler asymmetries induced field asymmetries
Summary

1. Field simulations including RF couplers
2. RF field asymmetries found in the transition region due to the coaxial coupler
3. RF field map implemented and used in ASTRA simulations
4. A transverse kick to the whole bunch (~0.6 mm at z≈3 m before booster), beam size nearly conserves, emittance slightly higher