# Painting in the course of PIP-II injection to Booster

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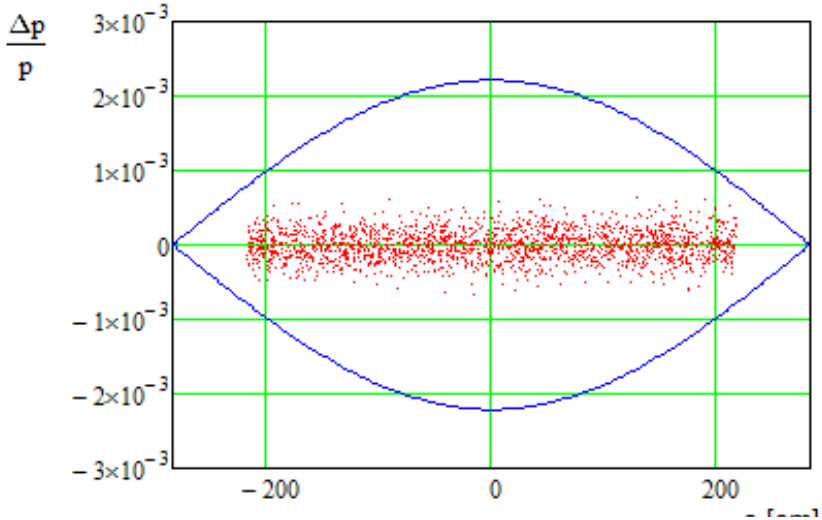
# Main parameters

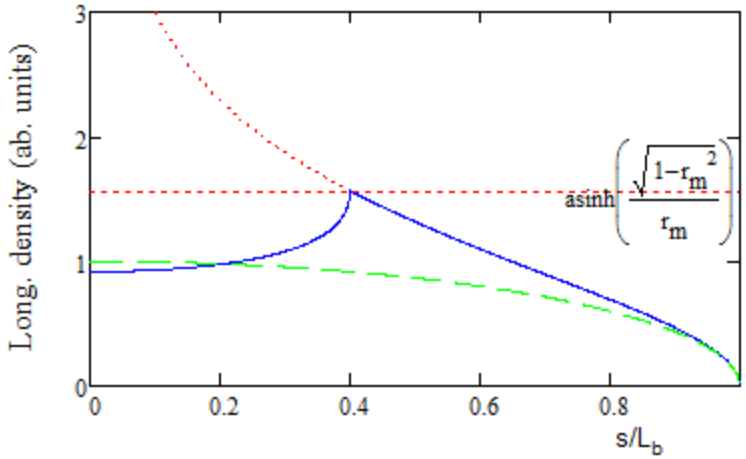
| | |
|---|---|
| Repetition rate | 20 Hz |
| Injection energy | 800 MeV |
| RF frequency | 44.7 MHz |
| Synchrotron tune | 0.024 |
| RF bucket area in Booster | 0.078 eV s |
| RF bucket height in Booster, $\Delta p/p$ | $2.2\times10^{-3}$ |
| RF bucket length | 5.64 m |
| Beam emittance, n95% (KV distribution) | 16 $\mu$m |
| Booster acceptance, norm. at 800 MeV | 55 $\mu$m |
| Linac base bunch frequency | 162.5 MHz |
| Linac rms long. emittance | $1.1\times10^{-6}$ eV s |
| Linac rms momentum spread | $2\times10^{-4}$ |
| Rms bunch length at the linac end | 1.1 mm |
| Linac rms norm. emittance | 0.3 $\mu$m |
| Injection time (294 turns) | 0.55 ms |

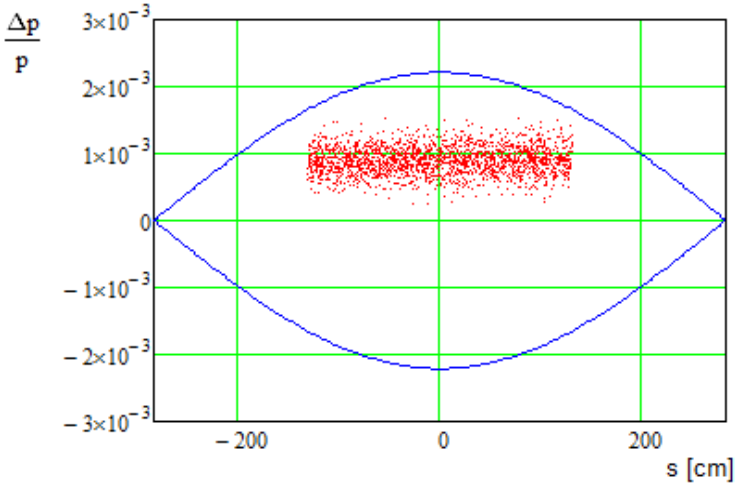
- Number of synchrotron periods in the course of injection – 7.04
- Bunch lengthening in the course of linac-to-Booster transport of 200 m, $\eta\approx1/\gamma^2$: $\sigma_s\approx1.1$ cm (rms)

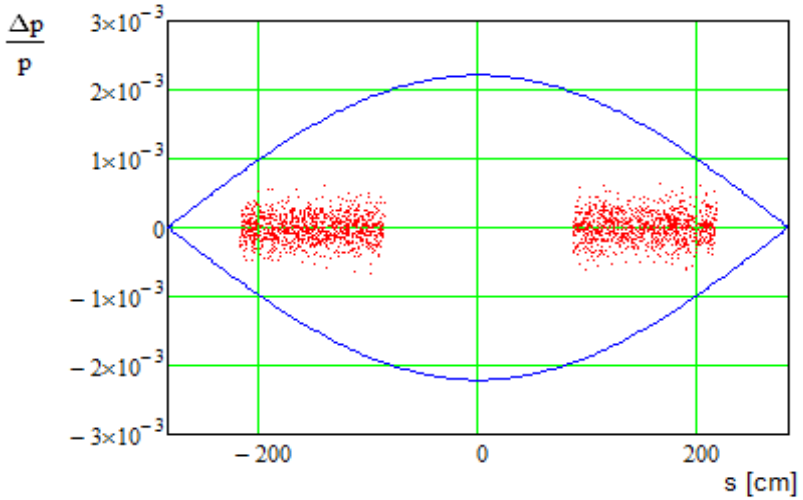
# Longitudinal Painting

- To minimize injection losses we require $4\sigma$ to the bucket boundary
- Injection without offset makes very large density in the center
- Two possibilities:
  - o Remove bunches from the center
  - o Use momentum offset
- In both cases it requires
  - o linac peak current ~4 mA
  - o Linac energy stability $\leq 10^{-4}$
- Distribution with a hole in the center is better for longitudinal stability



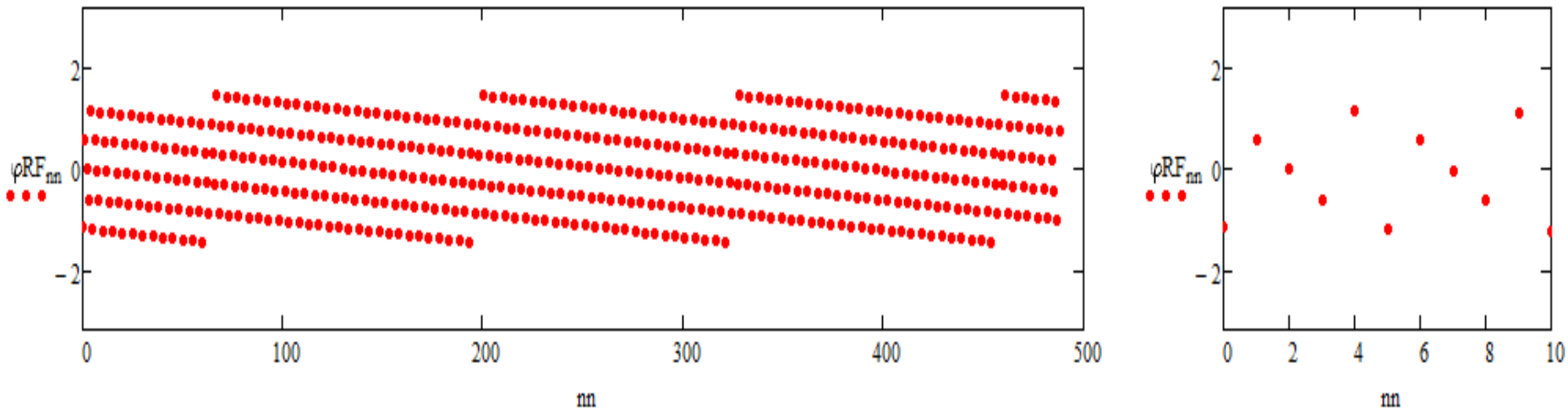



# Longitudinal Painting (continue)

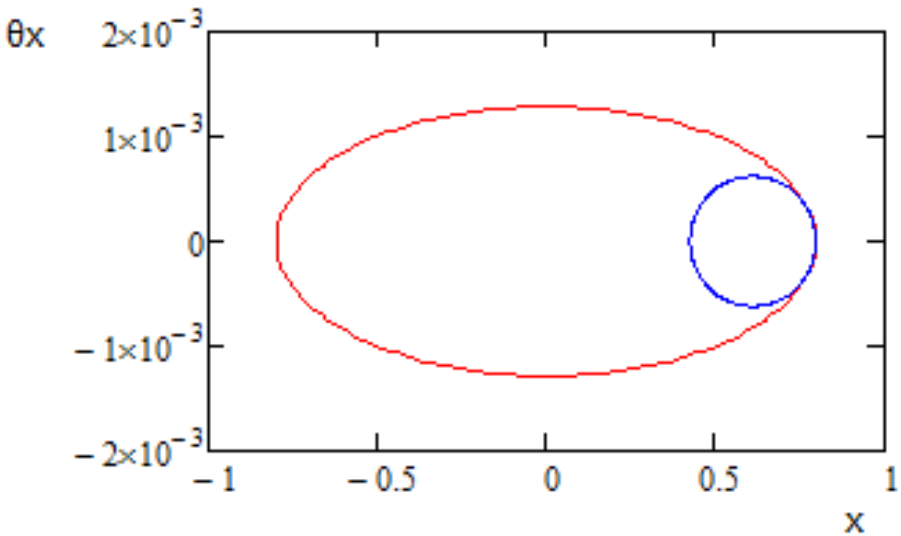
- If uncompensated the Booster momentum changes by $1.52\times10^{-3}$ in the course of injection
  - This change can be compensated by Booster correctors (margin ~10)
- Injection with positive momentum offset is preferable because synchrotron oscillations reduce probability for particles to hit the foil

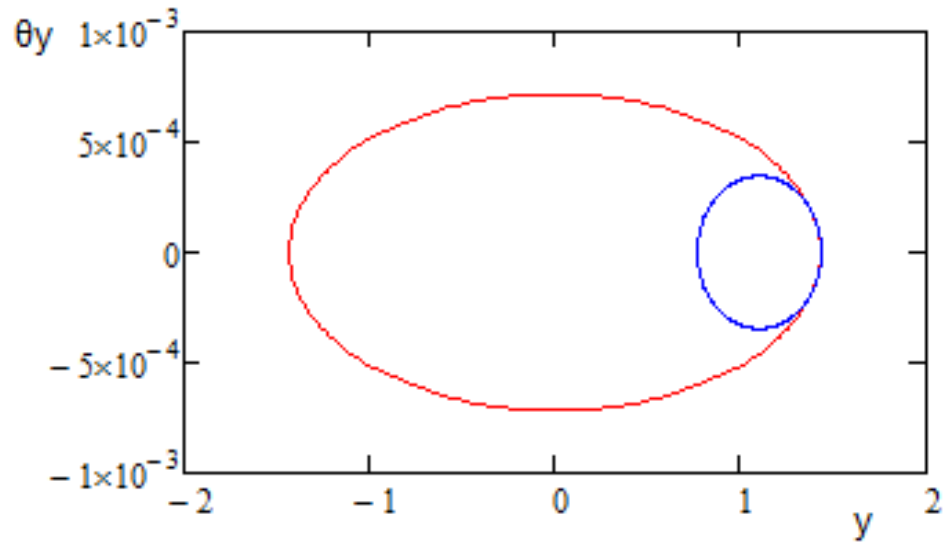



Phases of linac bunches which arrive to a single Booster bucket

- ~500 linac bunches arrive to a Booster RF bucket after 294 injection turns
- Bunches are comparatively uniformly distributed in the RF phase which makes good uniform distribution

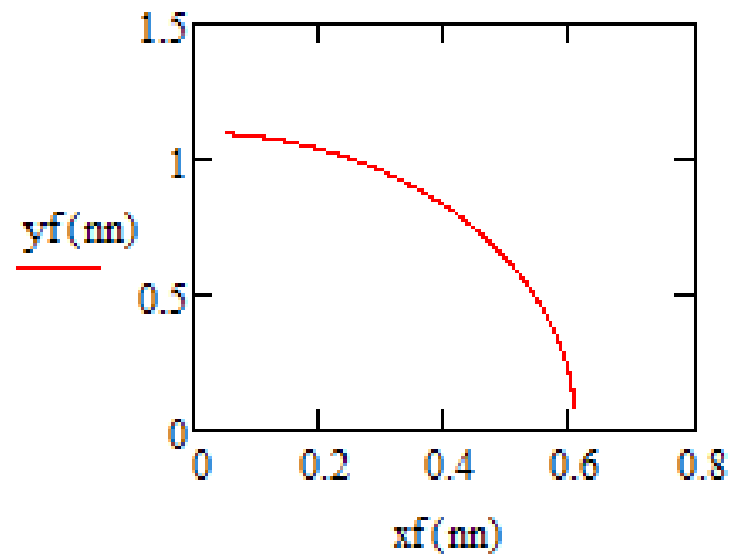
# Transverse Painting



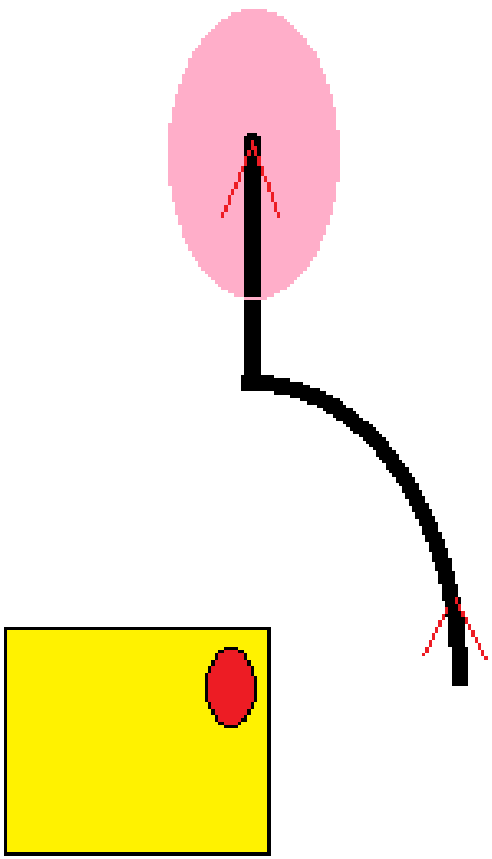

Horizontal and vertical phase spaces for Booster (red, 95%) and linac (blue 95%)

- X-Y painting
  - Single pass along the ellipse
    - Close to KV-distribution
    - Starts from x deviation and goes to y deviation
      - Amplitudes: Ax=6 mm, Ay=11 mm
- Zero dispersion of incoming linac beam reduces its motion on the foil and reduces power density on the foil



# Transverse Painting (continue)

- Vertical painting is performed by the injection dogleg
- Horizontal painting by Booster correctors
- Both start from maximum and go to zero



Booster

$\beta_x = 621$ cm

$\alpha_x = 0$

$\beta_y = 1997$ cm

$\alpha_y = 0$

$D_x = 185$ cm

Linac

$\beta_{xL} = 299.806$ cm

$\alpha_{xL} = 0$

$\beta_{yL} = 964.111$ cm

$\alpha_{yL} = 0$

$D_{xL} := 0$ cm

# Conclusions

- Compared to the 2 GeV RCS considered in ICD-2 to following conclusions can be drawn
  - Number of synchrotron periods is increased from ~0.2 to 7 which makes very good longitudinal painting
  - Transverse painting is similar but
    - faster due to smaller number of turns
      - ✓ Only one pass is used
    - Smaller heating on the foil
    - Less scattering and loss
- Further details will follow soon