Booster Beam Dynamics with Linac4 - Status Report

Christian Carli on behalf of many people contributing

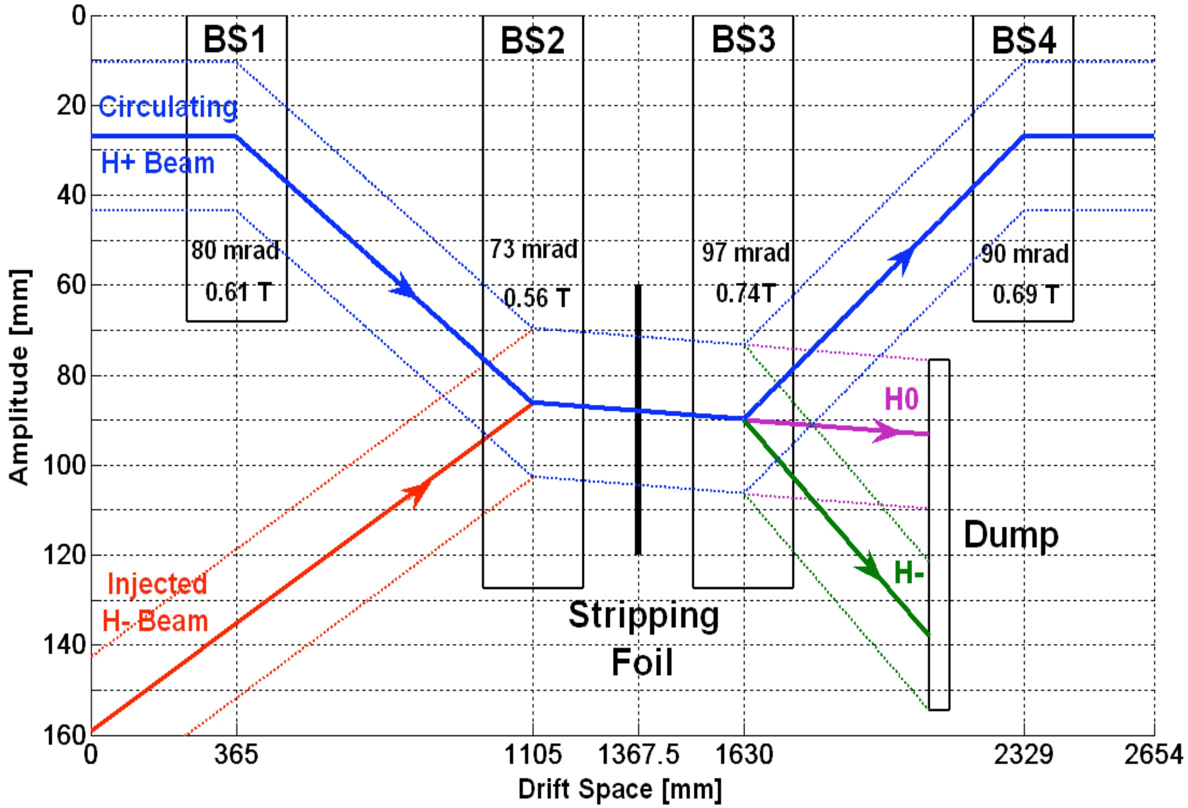
- Introduction: PS Booster with Linac4
- H^- charge exchange Injection:
  - Typical hardware for charge exchange injection
  - Why H^- charge exchange injection
  - Active longitudinal Painting
  - ORBIT Simulations of the Injection
- Benchmark efforts:
  - Measurements
  - ACCSIM and first ORBIT simulations
- Work Plan

Introduction: PS Booster with Linac4

- PSB Injection at 50 MeV - Intensity/Brightness bottleneck of the Complex:
  - PSB energy increased to 1400 MeV to mitigate direct space charge effects at PS injection
  - Bottleneck due to direct space charge in the Booster at low energy
- PS Booster with Linac4:
  - Goal: Increase of intensity within given normalized emittances by factor 2
    - Nominal LHC beam with PS single batch filling,
    - Save generation of ultimate LHC beam with PS double (and single ?) batch filling,
    - Decrease Losses and Increase of Number of Protons available
  - Increase of PS Booster injection energy from 50 MeV to 160 MeV and $\beta\gamma^2$ by factor 2
    - Keep the same direct space charge tune shift, but double brightness
    - (Beam stays (a bit) longer with large direct space charge detuning)
  - H^- charge exchange injection and Linac4 beam chopping:
    - Opens possibility for painting (in all three planes ?) and further gain in performance
  - Losses and activation ??
    - Losses (on septum) inherent to conventional multiturn injection disappear
    - Losses (during times with large direct space charge detuning) at higher energy
- Next bottlenecks at transfers PS Booster ⇨ PS and PS ⇨ SPS ?!

Injection - typical Hardware for charge exchange injection

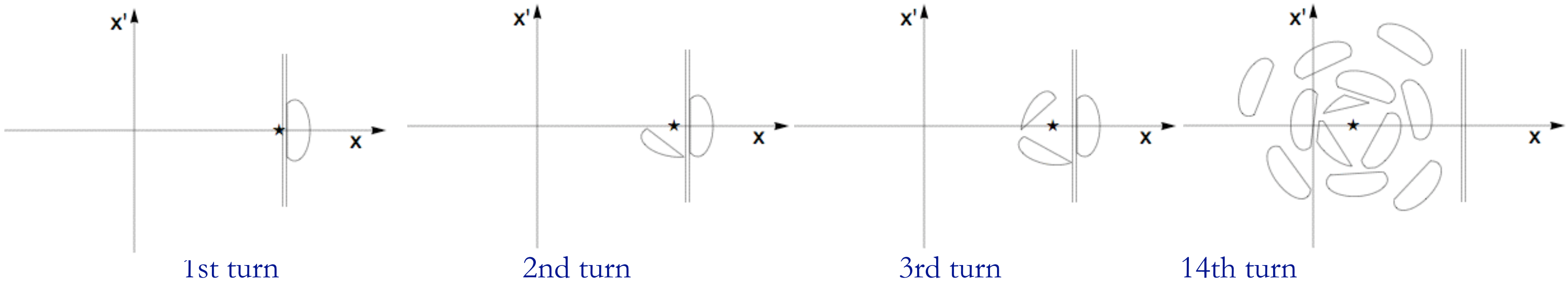
- Typical hardware … the one proposed by B. Goddard and W. Weterings for the PSB
- Two independent bumps:
  - Blue: sum of chicane and (maximum) injection bump
    - Possibly offset with respect to injected beam
  - Chicane (BS1 to 4)
    - BS2 Brings beams together ("replaces" septum)
    - Stays constant during injection
    - May collapse (fast in this proposal)
  - Injection (painting) bump
    - Linear decrease during injection
    - Allows shaping of distribution



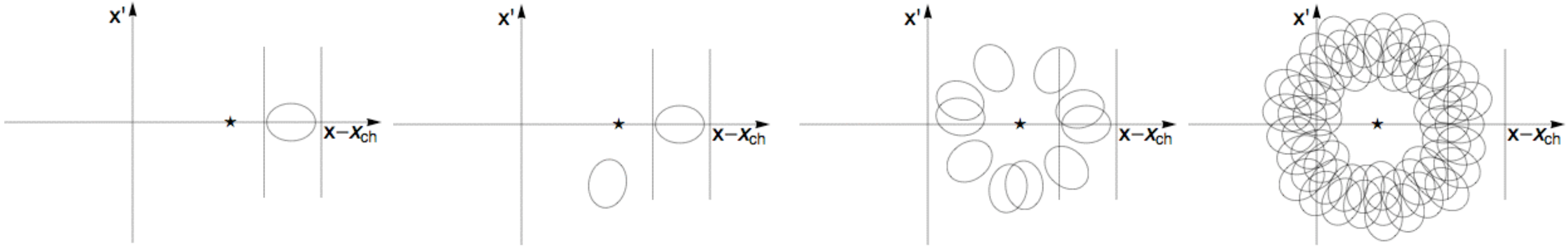
- Stripping Foil (heating) converts H^- into protons
- Asymmetric chicane to improve interception of unstripped particles

Injection - Why H^- Charge Exchange Injection

- Recap of conventional multiturn Injection:
  - Septum brings injected beam close to circulating beam (separates beams in space)
  - Orbit Bump decreasing linearly in Time
  - Typical mismatch of arriving beam (a factor 2 smaller than)



- H^- Charge Exchange Injection:
  - No septum separating the injected and circulating beam
  - No losses on septum (or foil) …. Different turns in same region of phase space

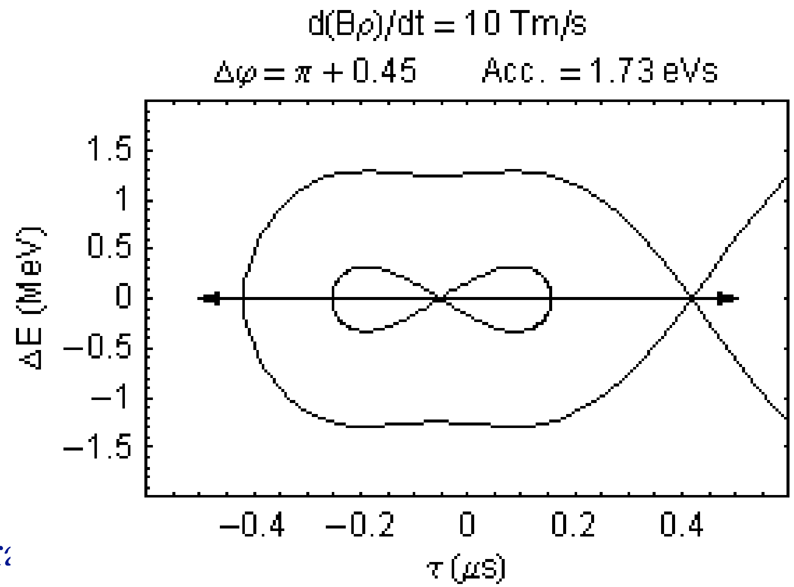


Options for H^- Injection Geometries

- Options for the Geometry of H^- Charge Exchange Injection:
  - Superposition of (fast) collapsing Chicane and Injection (Painting) Bump:
    - Scheme proposed for the PSB
    - Relatively small Injection Bump sufficient
      (extreme case: no Painting Bump at all at the FNAL Booster)
    - Fast Collapse of Chicane needed to move Beam away from Foil
  - Superposition of DC Chicane and larger Injection (Painting) Bump
    - Injection (Painting) Bump moves Beam sufficiently away from Foil
    - Chicane Collapse not needed to avoid Foil Hits
- Aperture/acceptance of PSB with Linac4:
  - Acceptance now defined by BeamScope Window (one single location)
  - Reduction of Acceptance:
    - Beams with the same normalized Emittance?
    - Gives more Freedom for Bumps and, thus, Injection Geometries
- Potential Limitations due to Stripping Foil:
  - Heating (Destruction of Foil), Blow-up due to Scattering

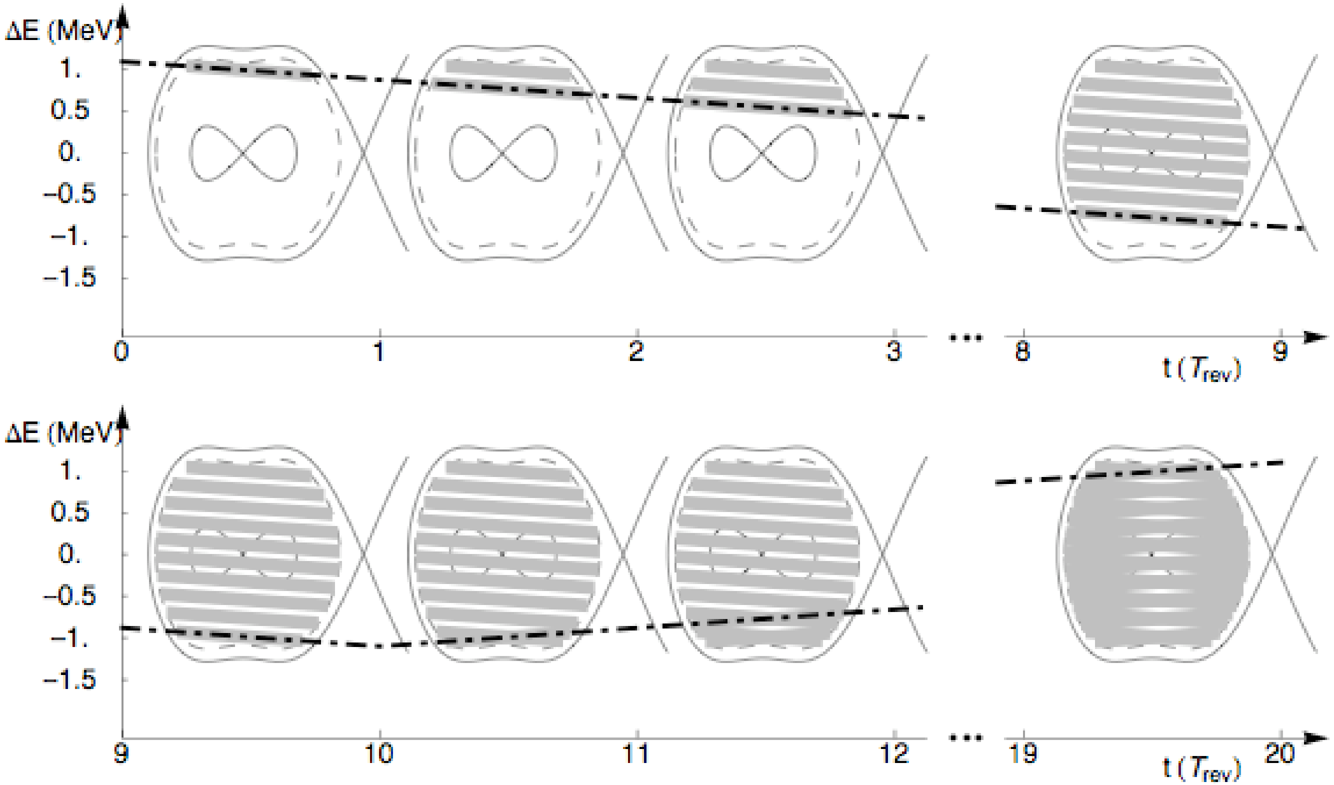
Injection - active longitudinal Painting

- With Linac4: similar RF system than at present
  - Double harmonic
    - fundamental h=1 and h=2 systems to flatten bunches
    - reduces maximum tune shifts



  - Injection with d(Bρ)/dt = 10 Tm/s (no need for injection with small ramp r…
  - Little (but not negligible) motion in longitudinal phase space.
  - No way for painting from synchrotron motion (large harmonic numbers and RF voltages ruled out)
  - ➢ Need for active painting (aim: fill bucket homogeneously) and energy modulation

Injection - active longitudinal Painting



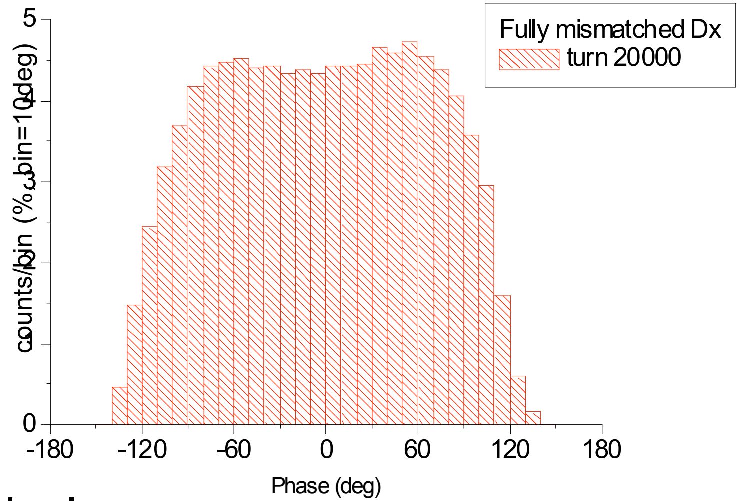
- Principle:
  - Triangular energy modulation (slow, ~20 turns for LHC)
  - Beam on/off if mean energy inside a contur ~80% of acceptance
  - Nominal LHC: intensity with 41mA (!!!) after 20 turns
  - High intensity: several and/or longer modulation periods
- Potential limitations: Linac4 jitter, debunching of Linac4 structure in Booster
- Dispersion at end of injection line: matched to PSB or D=0m ?

Painting & tracking with ORBIT (1/3)

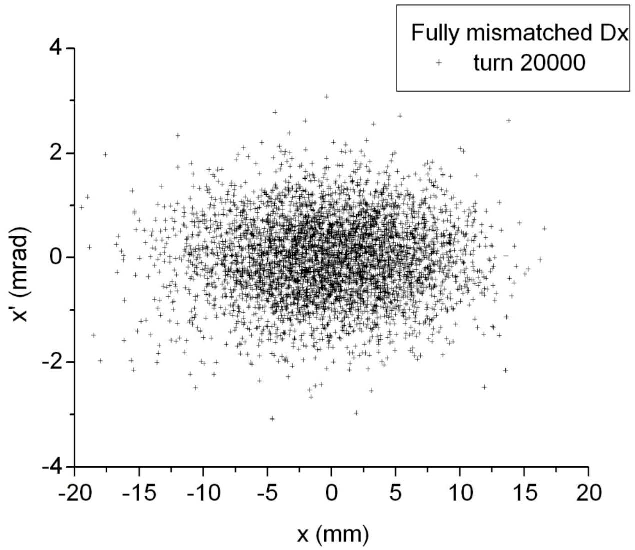
Slides from M. Aiba with contributions from B. Goddard

- 160 MeV LHC type beam
- Long. and Trans. painting with reading 20 files containing particle distribution at the end of transfer line
- Tracking up to 20,000 turn with S.C.

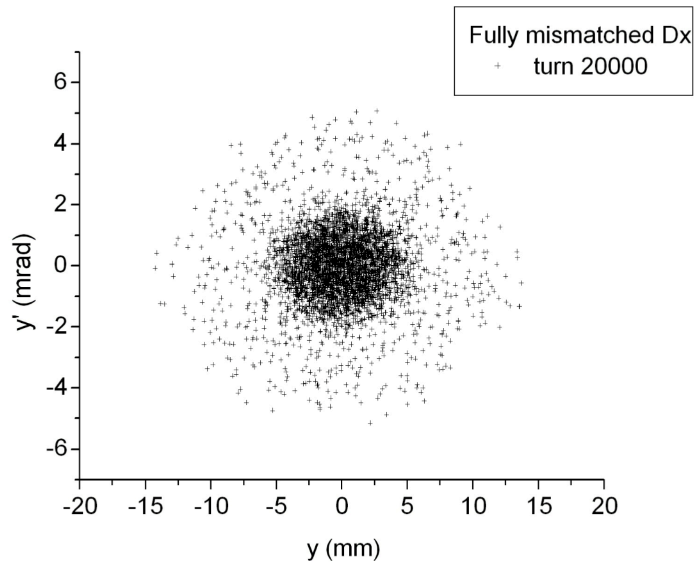
Longitudinal



Horizontal



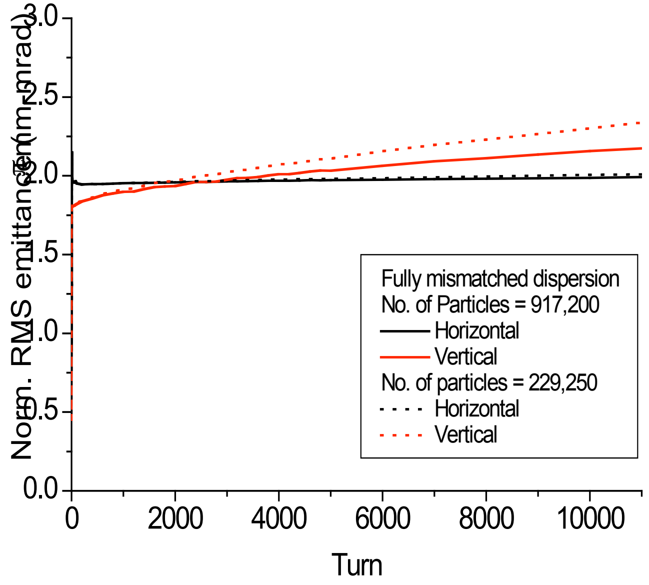
Vertical



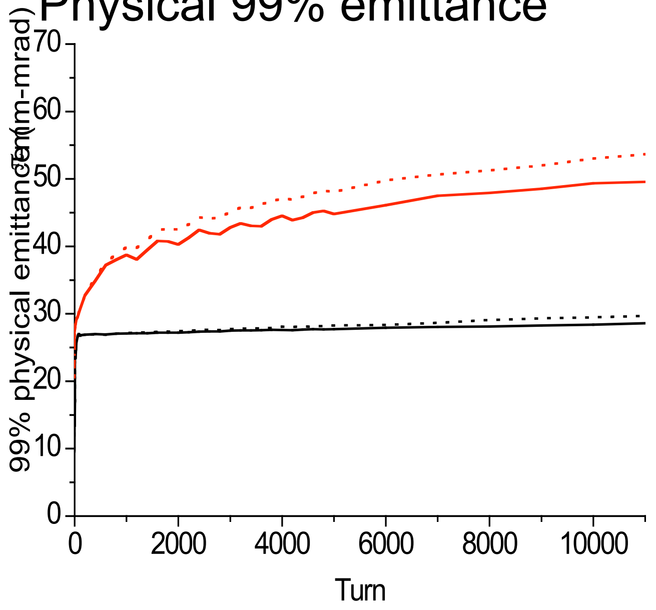
Slides from M. Aiba with contributions from B. Goddard

- 160 MeV LHC type beam
- Painting and Tracking up to 12,500 turn with S.C.
- Macro particles 229,250 (dashed line) and 917,200 (solid line)
    - Larger number of particles, smaller blow-up

Normalized r.m.s. emittance



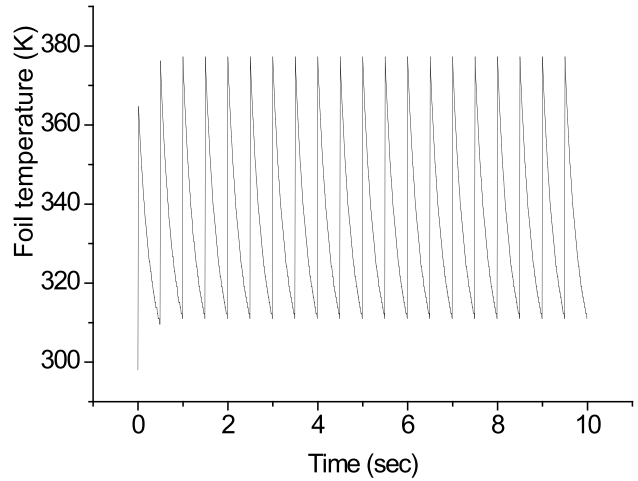
Physical 99% emittance

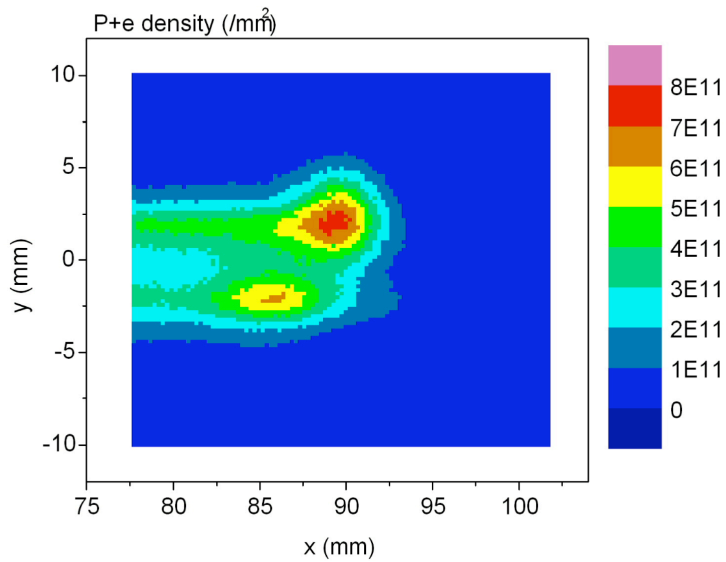


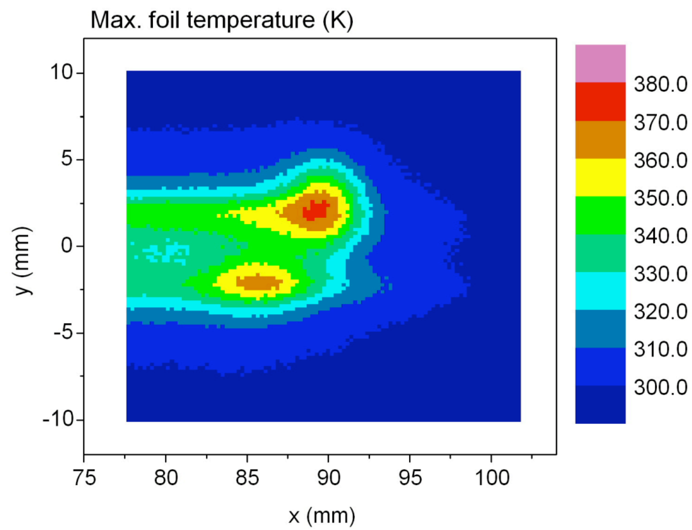
Painting & Tracking with ORBIT (3/2)

Slides from M. Aiba with contributions from B. Goddard

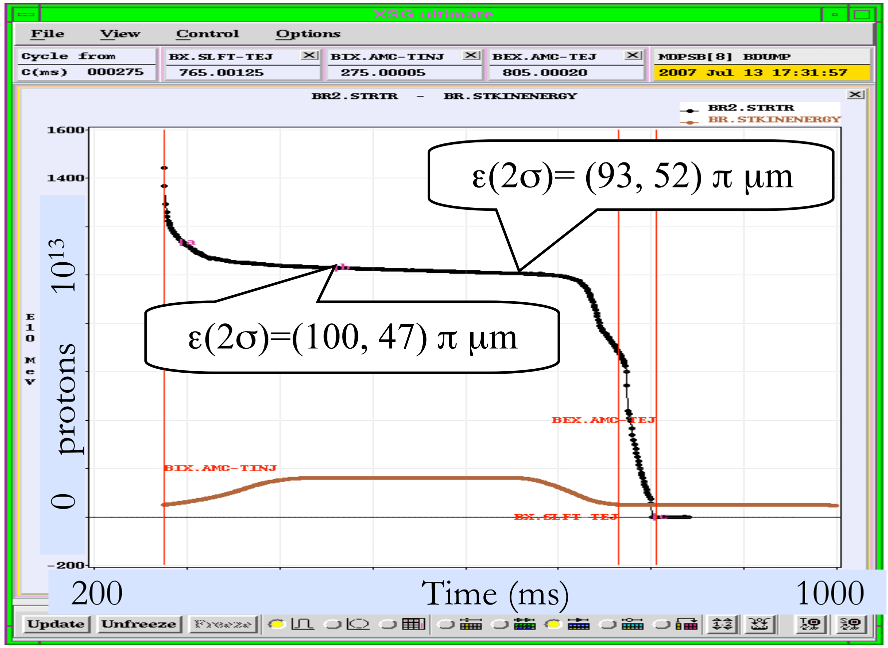
- Output particle density and foil temp.
  - Assume Stephan-Boltzmann law and ignore thermal conducting
- Integrated official ORBIT source code
- Output example for 160 MeV LHC type beam

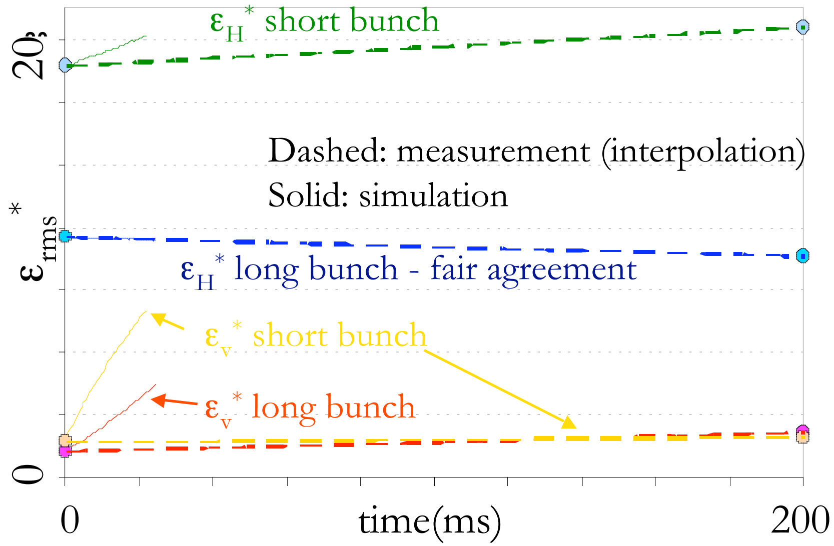






Benchmark Efforts - ACCSIM/ORBIT versus Measurements





- Benchmark measur'ts (M. Chanel):
  - High intensity (10^{13} protons in one ring) beam at 160 MeV plateau
  - Time evolution of emittances and intensity
  - Long bunches (see fig.) tune shifts ~0.25
  - Short bunches (second harmonic RF in phase) -> more losses
  - Different working points ….

- Simulation (M. Martini) ACCSIM/ORBIT:
  - Only short times (computation time)
  - ACCSIM:
    - Overestimation of growth rates (except long bunches & hor. plane)
    - Insufficient statistics ?
  - ORBIT (preliminary):
    - Blow-up rate comparable to measurements
- ACCSIM⇔ORBIT benchmark effort:
  - Moderate agreement only so far

Work Plan

- Injection studies with validation & optimization of the painting scheme (well advanced):
  - Add Injection Foil (done), Acceleration and, possibly, machine imperfections
  - Tracking over longer times, check parameters to avoid numerics problems
  - Check filamentation of structure from injection - especially with dispersion mismatch (seems o.k)
  - Limitations: Linac4 energy jitter, energy spread due to debunching in Booster (seems o.k.)
- Integration into the CERN Complex - Elaborate detailed scenarios for all beams needed
- Check limitations of present Booster hardware:
  - Instabilities (existing damper with higher intensities)
  - (Beam loading problems of h=2 cavities for h=1 beams … limitations ISOLDE beams ?)
- Beam Losses, Activation ("normal" losses, failure scenarios …):
  - Losses at Injection (Line and Ring) in collaboration with or by injection hardware team ?
  - Feasibility of rough Collimation System
- Possibly Simulations of Dynamics with strong direct Space Charge:
  - Are available Programs (e.g. ORBIT) viable Tools for such Studies ?
    (Most (all) accelerators with large direct space charge designed without detailed simulations)
  - ➢ Successful Completion of Benchmark mandatory !
  - (Slow) Blow-up and associated Losses, estimate/optimize Performance))