Creation of Hollow Bunches by Redistribution of Phase Space Surfaces

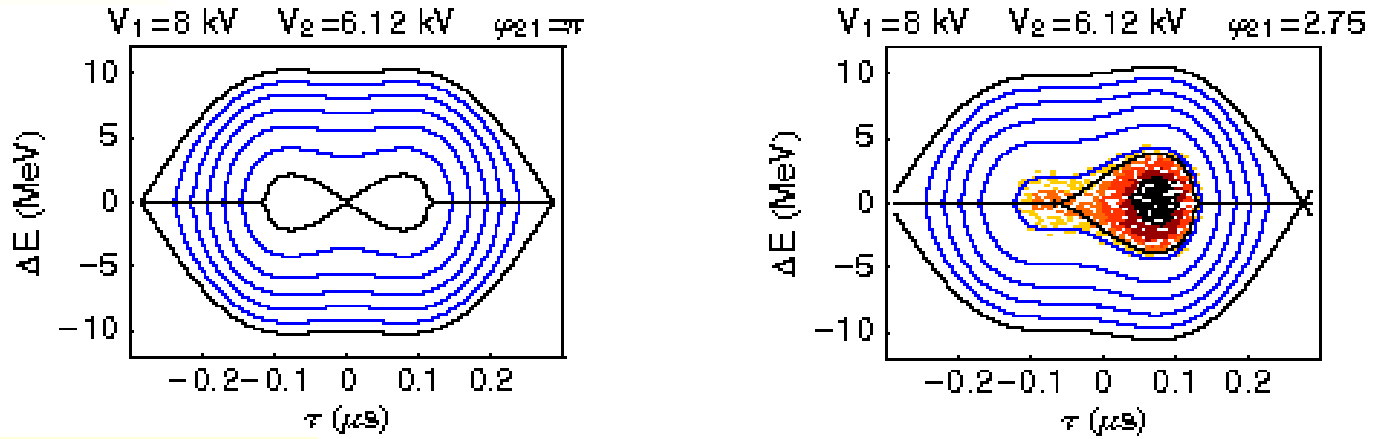
- Introduction and Motivation.
- Principle : Redistribution of Surfaces in longitudinal Phase space.
- Simulations.
- Experimental Results.
- Summary.

Introduction and Motivation

- Lower density in the center of the longitudinal phase space leads to flat profiles (without double harmonic RF).
- Reduces transverse (Laslett) tune shift.
- First attempts (at PSB) at low energy to improve the situation there by inserting empty phase space before bunching.
  - Recently this scheme got close to operational
  - However, a gain for the PSB is unlikely (bunch flattening with second harmonic RF), but the PS should benefit after transfer.
- Hollow bunch may be created anywhere in the cycle, also at high energy (already attempted).
- A new Method to create hollow bunches at high energy is presented.

Principle – Redistribution of Surfaces in Longitudinal Phase Space

- Double harmonic RF (in our case for the PSB h=1 and h=2) :
  - allows to create second harmonic sub-buckets.
  - phase $\varphi_{21} \neq \pi$ between the two RF systems makes structure asymmetric.



- Start of redistribution : One bucket just created + one large bucket.
- Initial bucket shrinks and releases surfaces, which are captured by the new growing bucket.
- Exchange of surfaces from the periphery and from the center.
- Redistribution without blow-up of total emittance.

Simulations

- To find suitable RF settings, only on flat-top.
- Integration of the equations of motion :

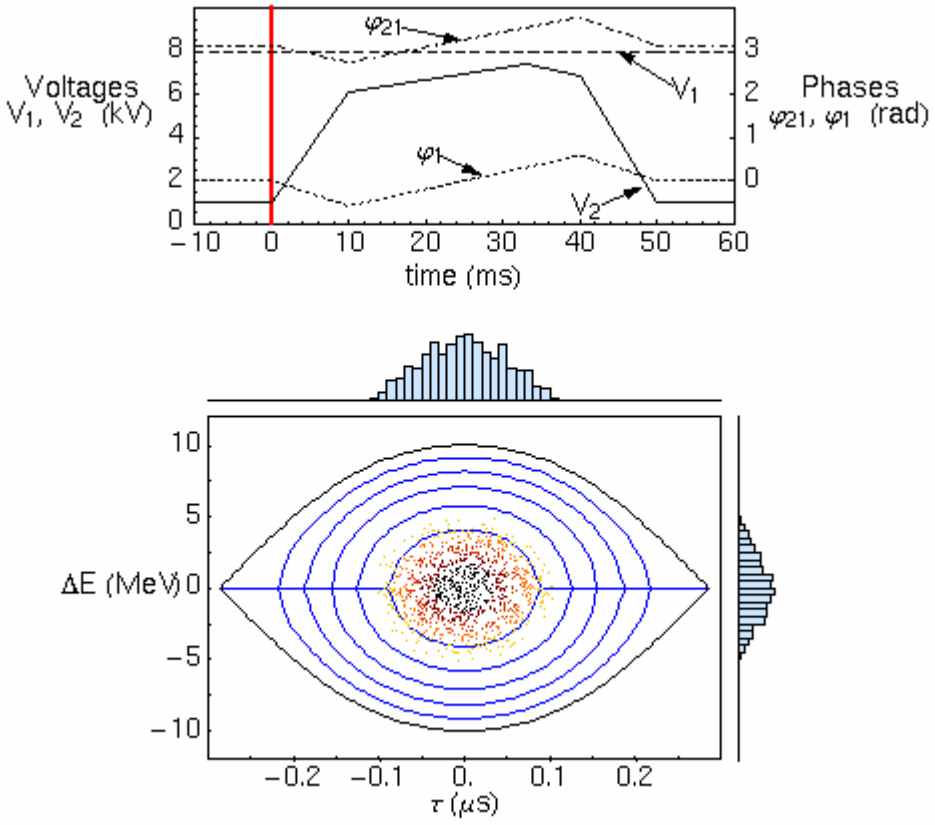
$$\frac{d}{dt}\tau = \frac{\eta}{\beta^2 \gamma E_r} \Delta E$$

$$\frac{d}{dt}\Delta E = \frac{q}{T_0}\left[V_1(t)\sin\left(2\pi\frac{\tau}{T_0} - \phi_1(t)\right) + V_2(t)\sin\left(4\pi\frac{\tau}{T_0} - (2\phi_1(t) + \phi_{21}(t))\right)\right]$$

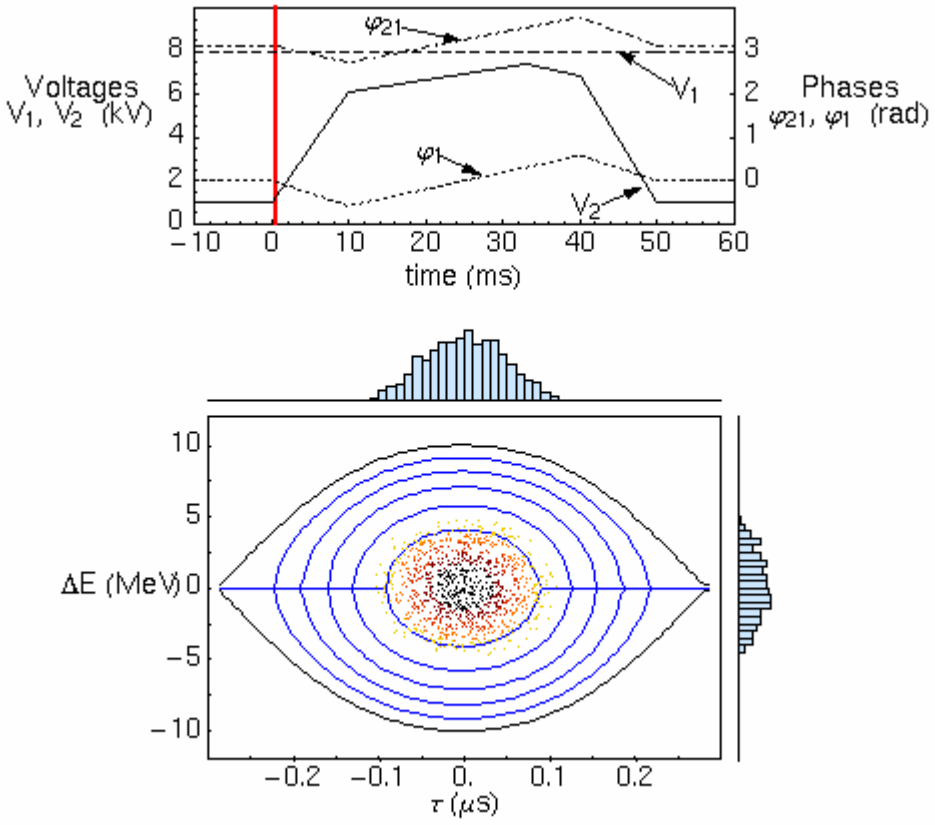
with RF functions defined as linear interpolations between points.

- RF functions adjusted to achieve redistribution of phase space surfaces.
- Direct space charge not taken into account.

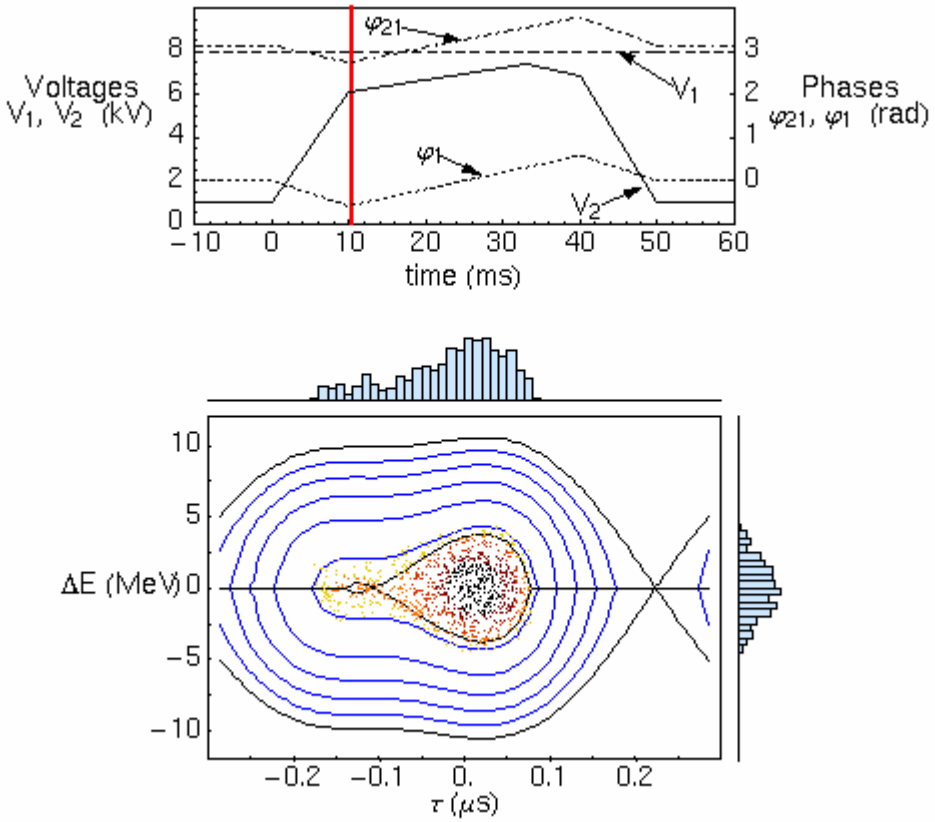
Simulations



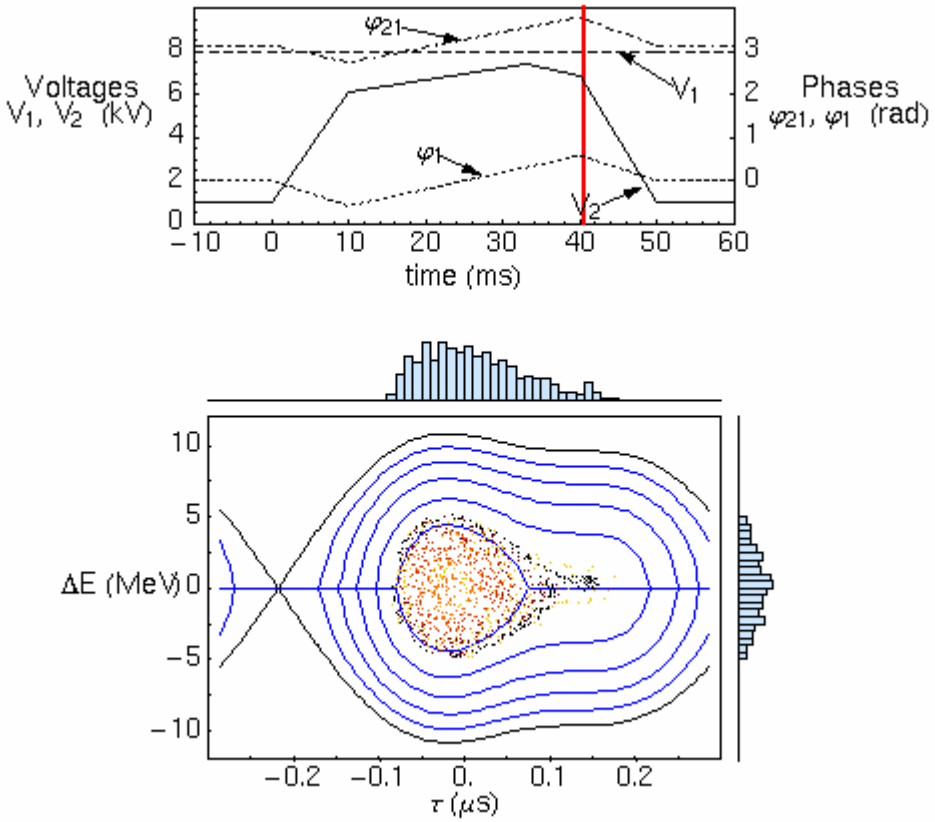
Simulations



Simulations



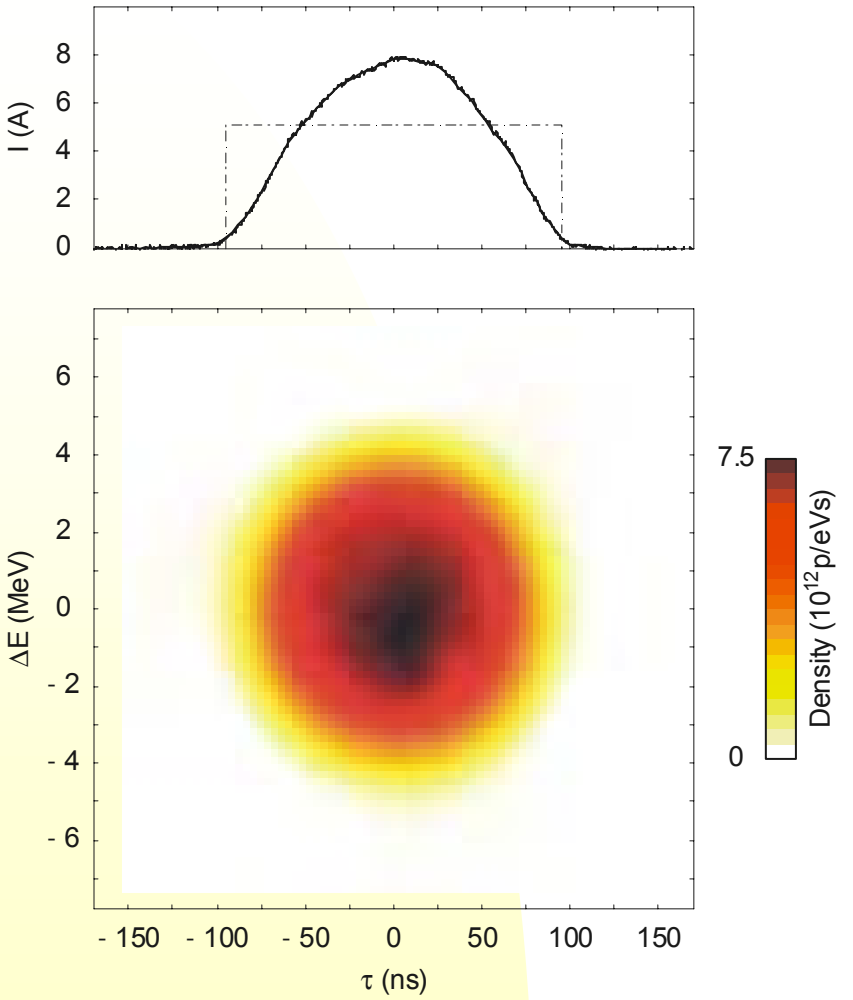
Simulations

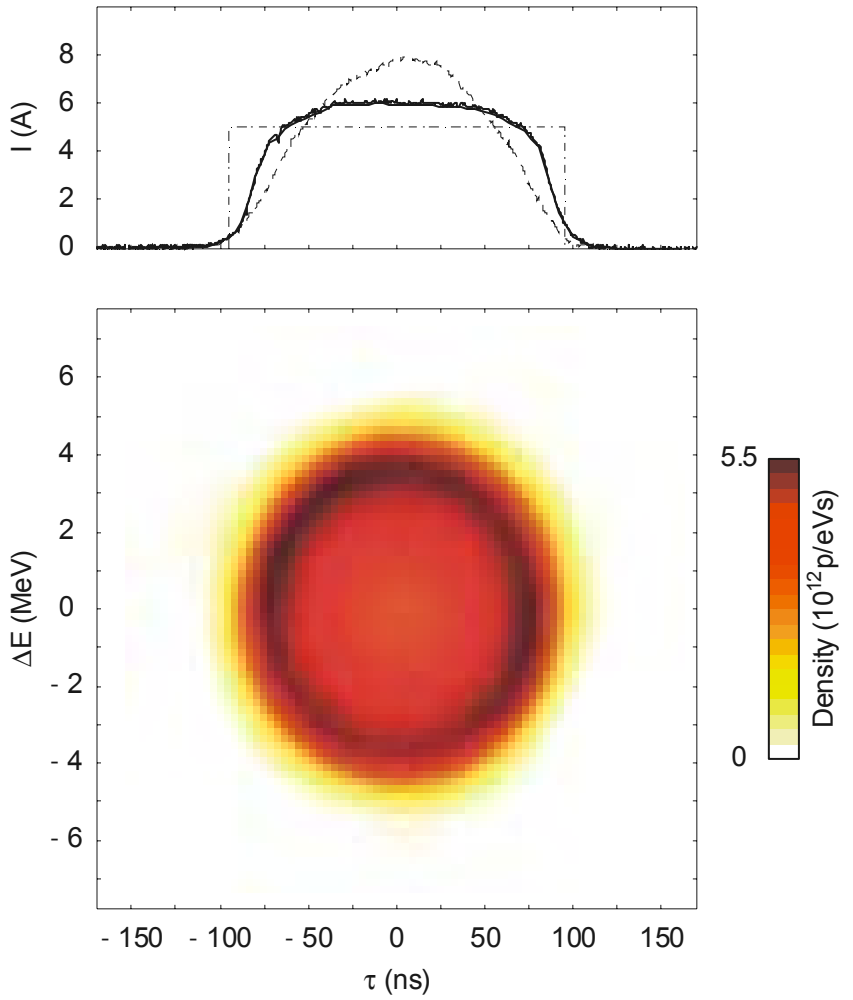


Experimental Results

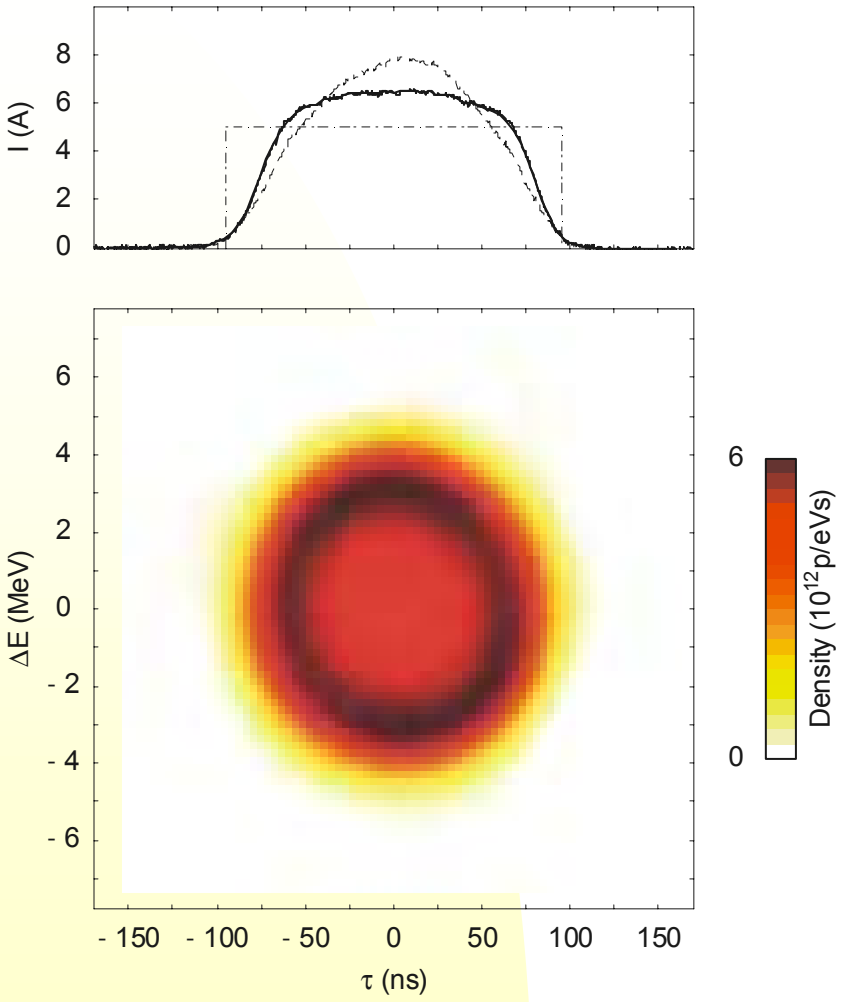
- After short set-up time, bunch flattening observed.
- Redistribution on ramp (more time available, no increase of cycle length) successful.
- In practice, reliable, robust and reproducible Method.
- Negligible increase of (total) emittance and bunch length.
- No intensity limitation observed (I.e. up to about 8×10^{12} per ring).

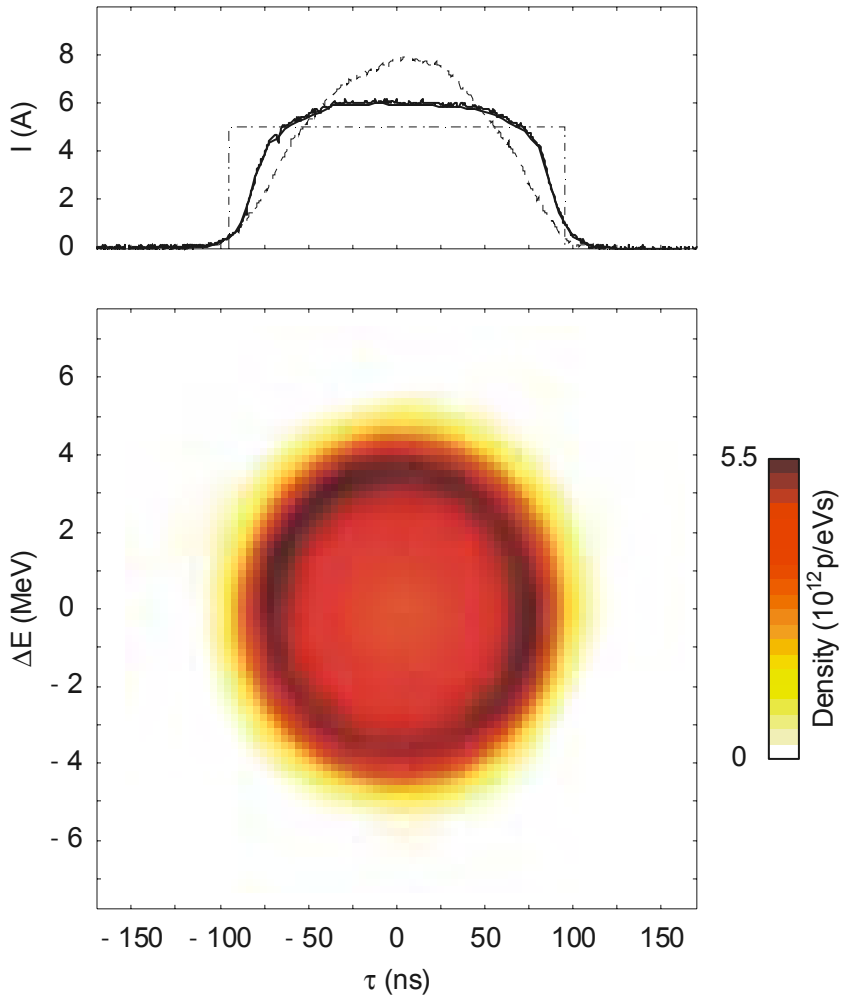
Experimental Results





Experimental Results





Summary

- New Method to create hollow bunches :
  - Redistribution of surfaces in longitudinal phase space by RF gymnastics,
  - Intended for a receiving machine without double harmonic RF,
  - Simulated for a flat-top,
  - In practice applied during the acceleration,
  - Simple, robust and reliable.
- Next step :
  - Transfer hollow bunches to a receiving machine (PS) and verify that space charge problems are reduced.

Acknowledgements

We would like to thank :

- our colleagues (and especially Steve Hancock) from the RF group for discussions on longitudinal dynamics,

- Adrian Fabich for help with informatics problems during the preparation of this talk.