200 MHz Buncher Section

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Fermilab

with R. Palmer, V. Balbekov, A. Van Ginneken, C. Kim, G. Penn, ...

"Short Buncher" Results:

- **1-step** buncher (2-harmonic)

  captures ~75% of beam within cooling bucket (1-D)

  2-harmonic ~15% more capture than 1-harmonic

- **2-step** buncher ~10% better capture than 1-step

  ~2 × longer than 1-step

  Little advantage to second harmonic in 2-step

- Additional steps not much better

- Do not need (very) high-gradient cavities

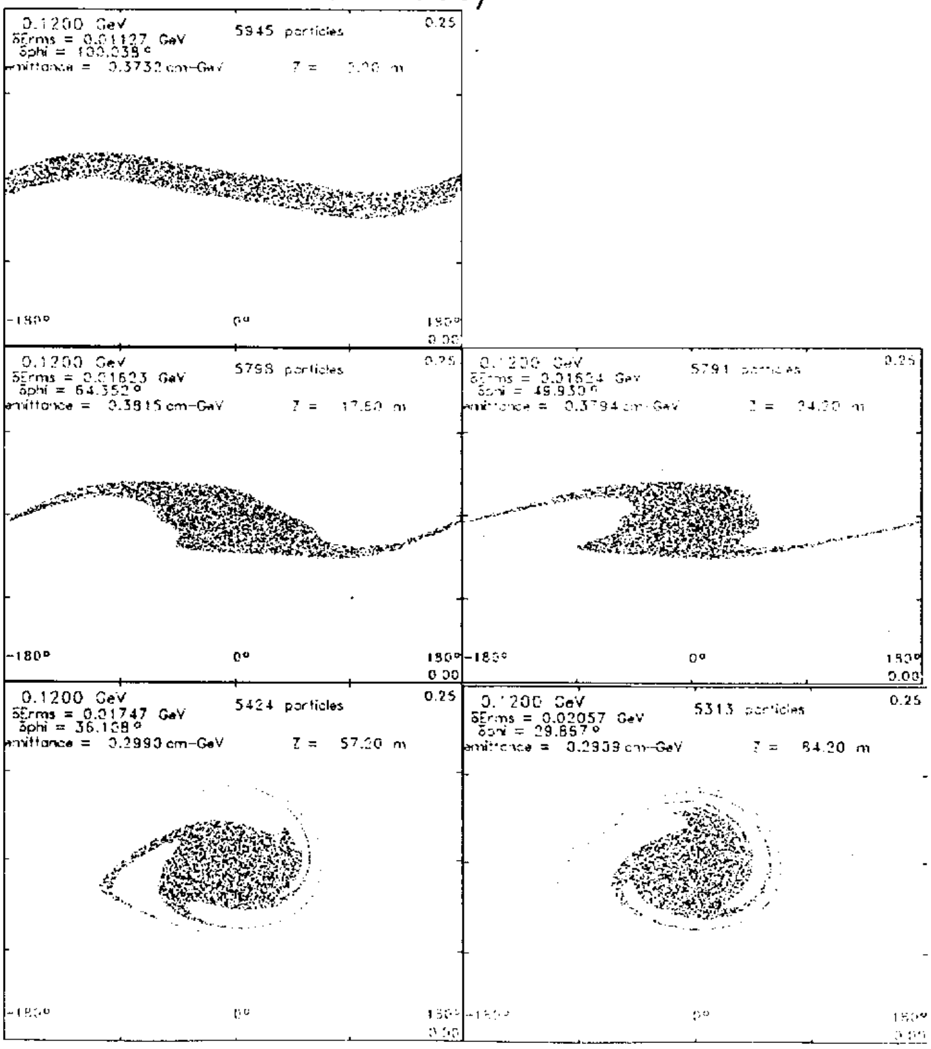
Two-step Buncher scenarios:

Example: ($P_\mu \cong$ 200 MeV/c)

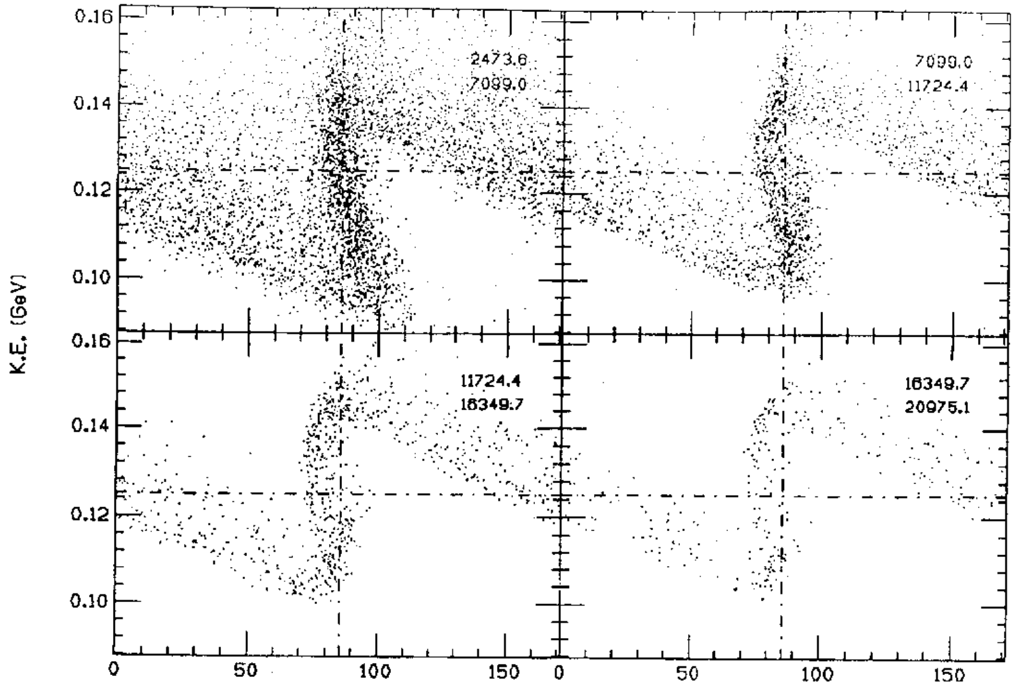
- **2.2m** (6MV/m at 175 MHz; -1.5MV/m at 350 MHz);
  13.2m drift

- **2.2m** (6MV/m at 175 MHz; -1.5MV/m at 350 MHz);
  8.8m drift

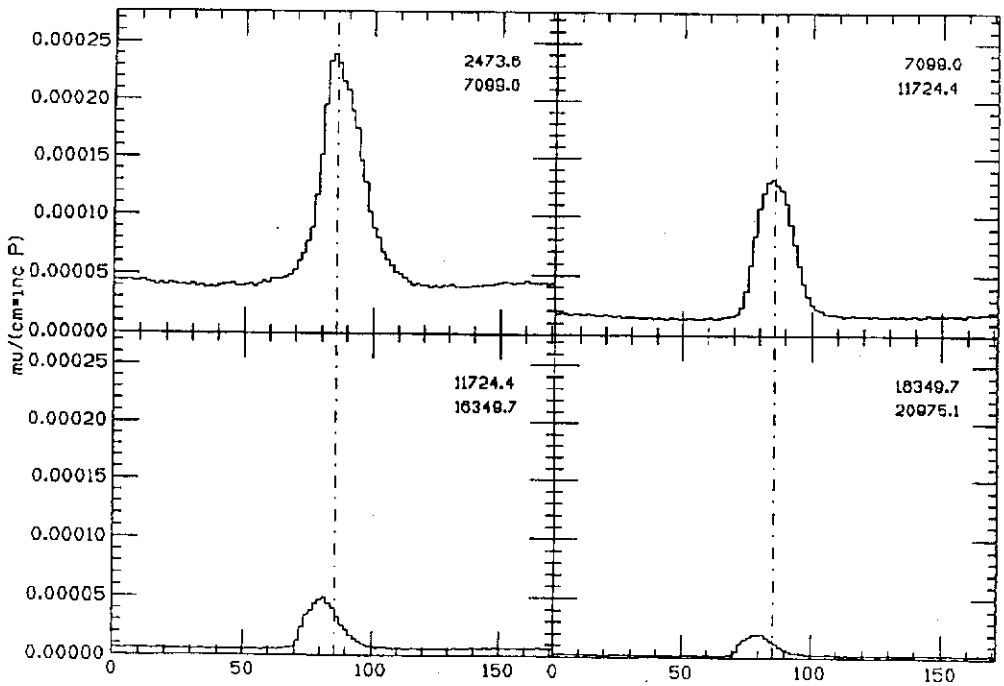
- **cooling system** (12MV/m 175MHz; De/dx = -6MV/m,
  30° Acc. Phase)



At 175 MHz rf bunch level:

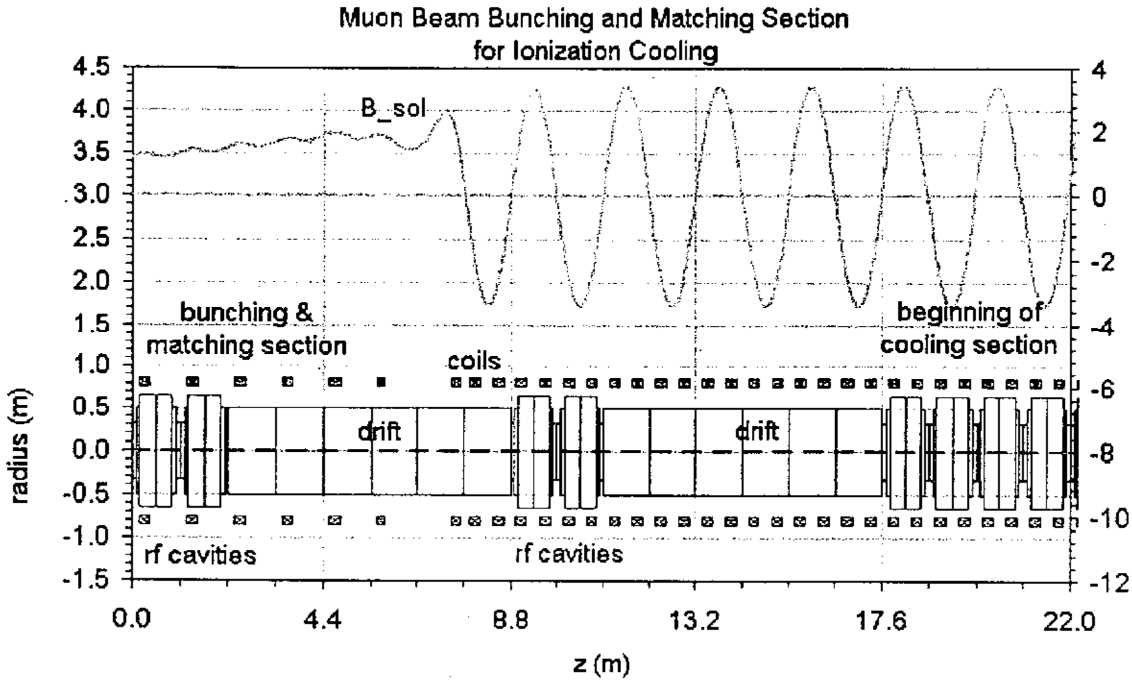


Longitudinal projection:



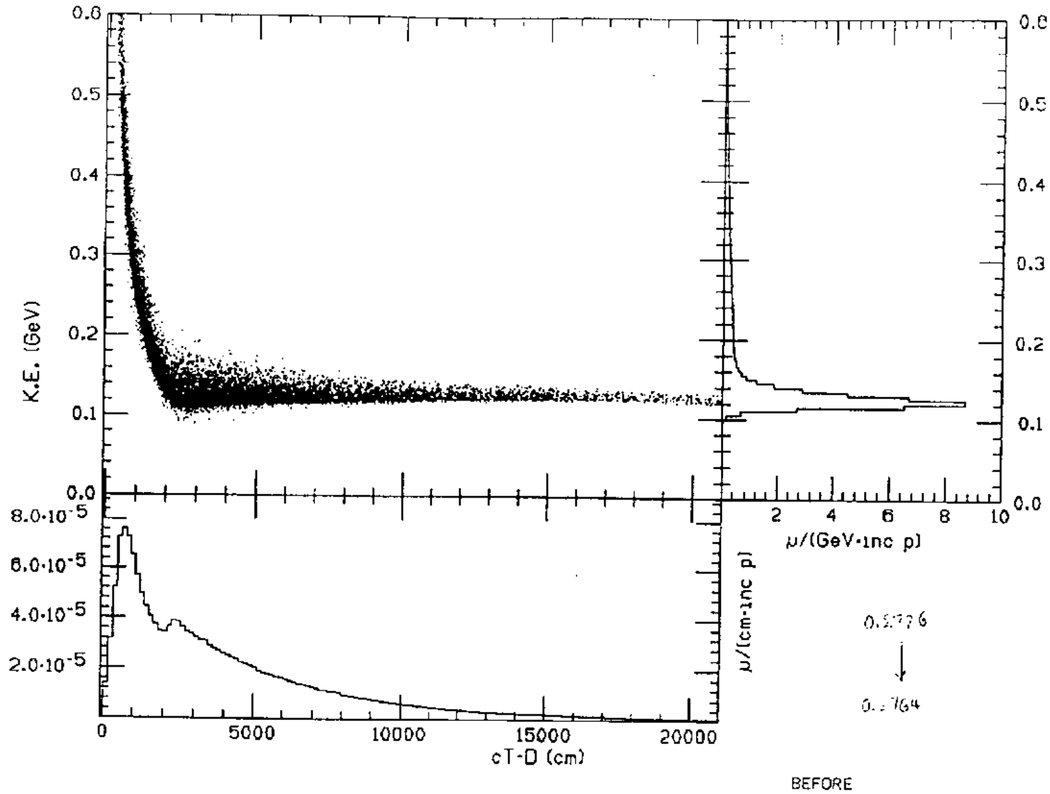
~ 60% are within cooling bunch acceptance

(C. Kim - 2-step buncher, 1.1m cells):

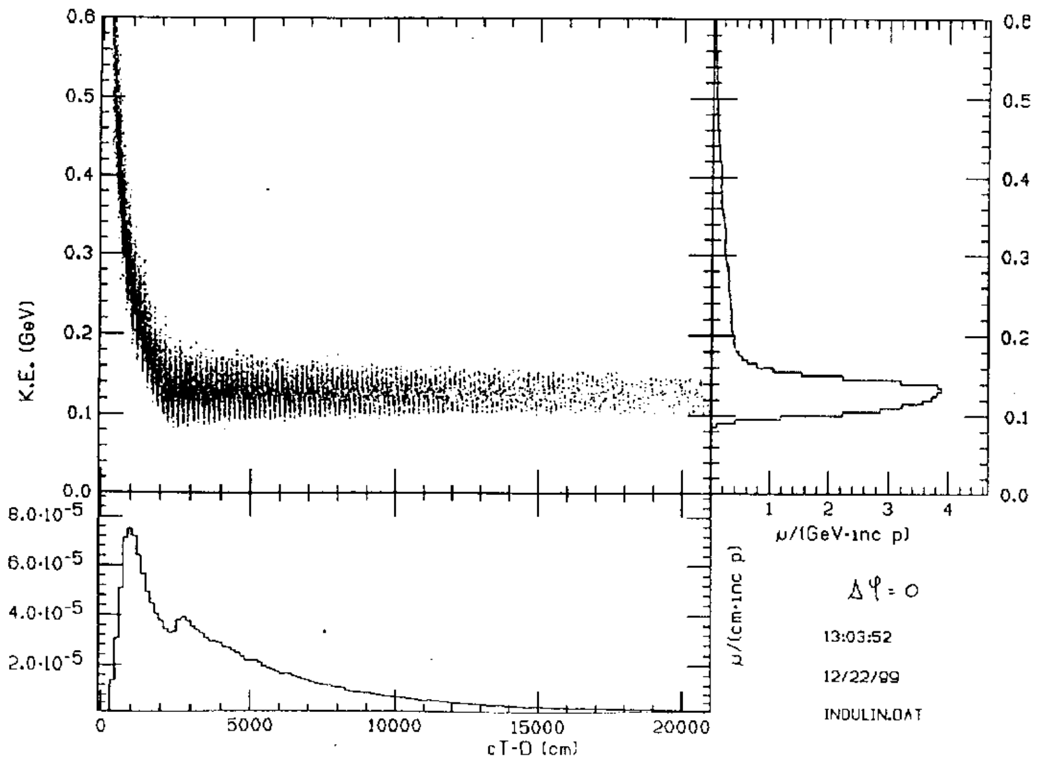


Case includes transverse matching solenoids

Beam before buncher (AVG 6-D simulation)

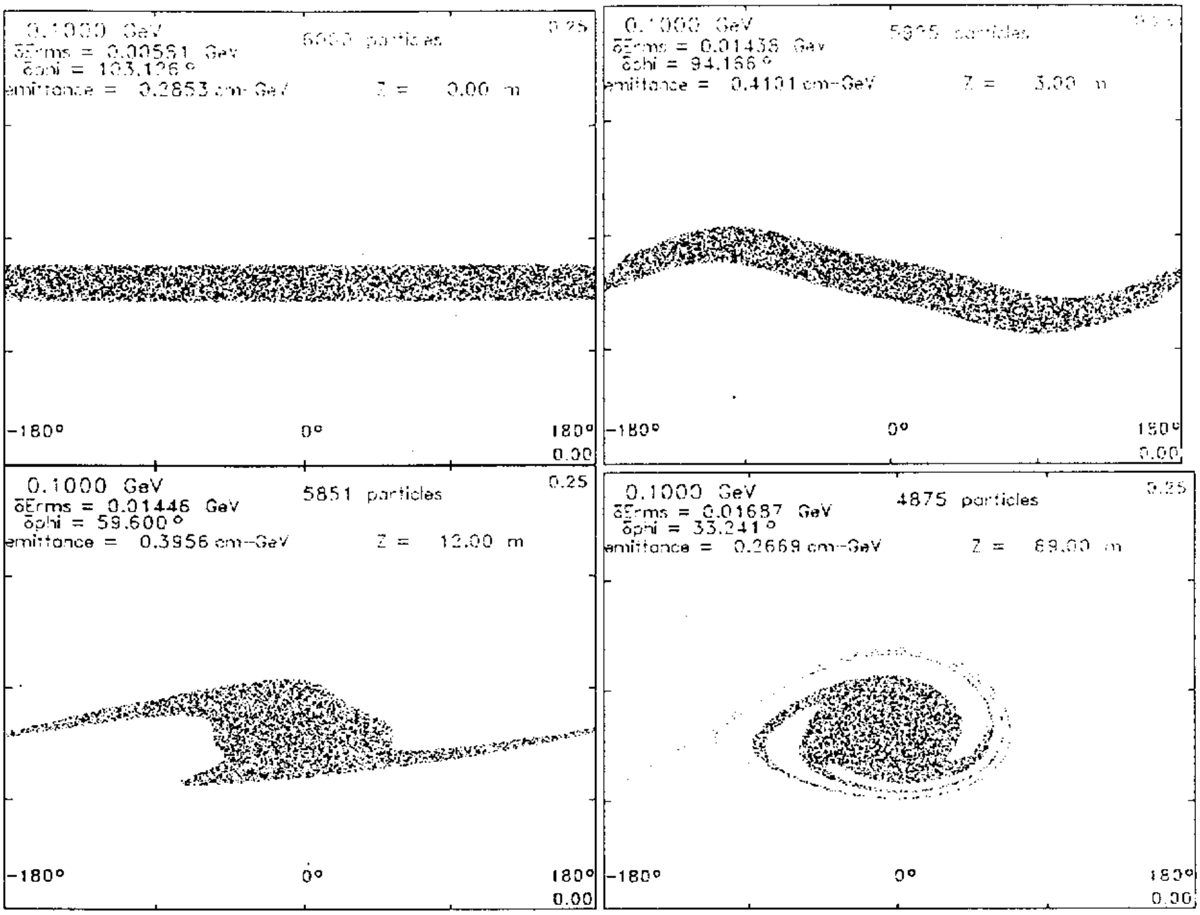


Beam after buncher (AVG simulation)



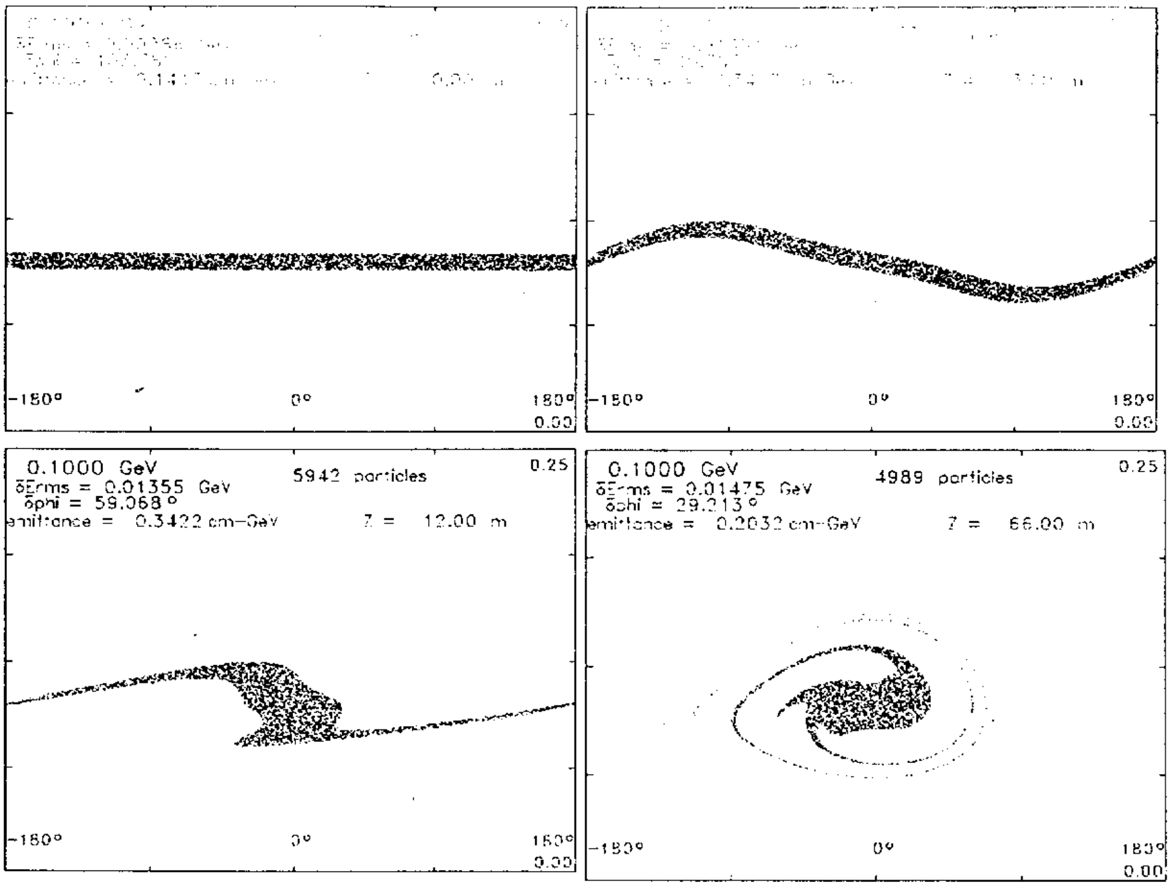
Example has ΔE too small (... PJK values)

⇒ Increase $\Delta E \times 2$ (to 6 MeV rms):



- ~Better fit (better match)
- ~80% capture into cooling rf bucket (but larger ε_L)
- cooling bucket more completely filled ...

Short (non-adiabatic) buncher example
(capture at E = 100 MeV)



Capture sequence

- **3m** (6MV/m at 175 MHz; -1.5MV/m at 350 MHz)

-**9m** drift

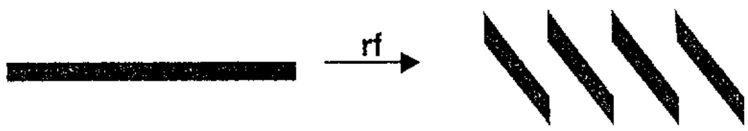
-**cooling system** (12MV/m 175MHz; De/dx = -6MV/m, 30° Acc. Phase)

Inner 2/3 of beam is captured with little dilution ...

Short buncher scenario (non-adiabatic)

- Use rf section to put 175MHz energy-position correlation on beam

  1 + 2 (+ ...) harmonic to obtain "linear tilt"



- Drift to obtain short bunches
  (~ ¼ synchrotron oscillation ...)

"Two-step" rotation adds second rf + drift;

spreads rotation over ~ ½ synchrotron oscillations

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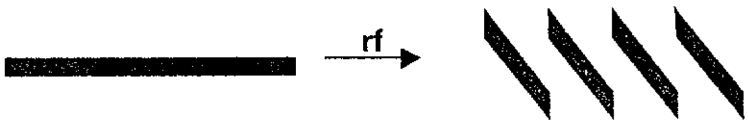

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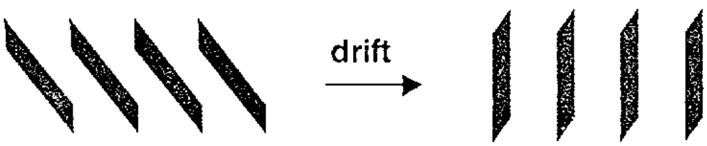

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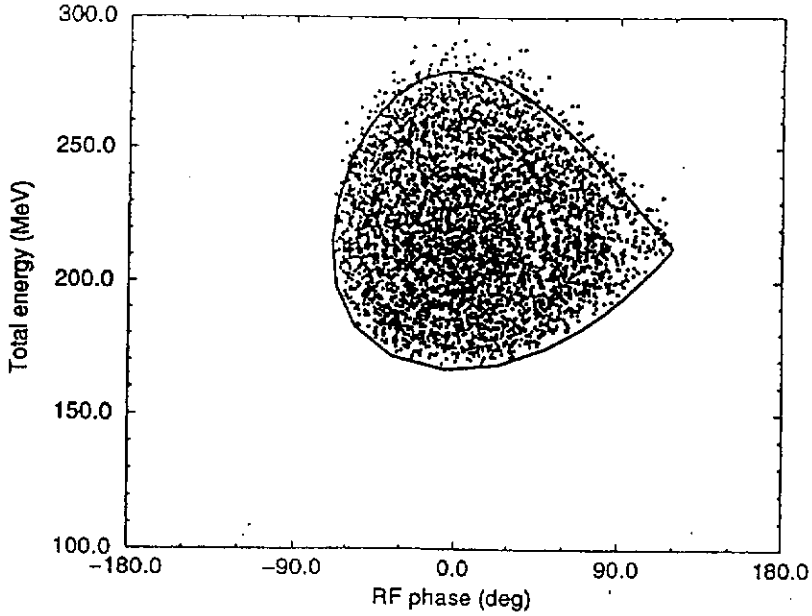
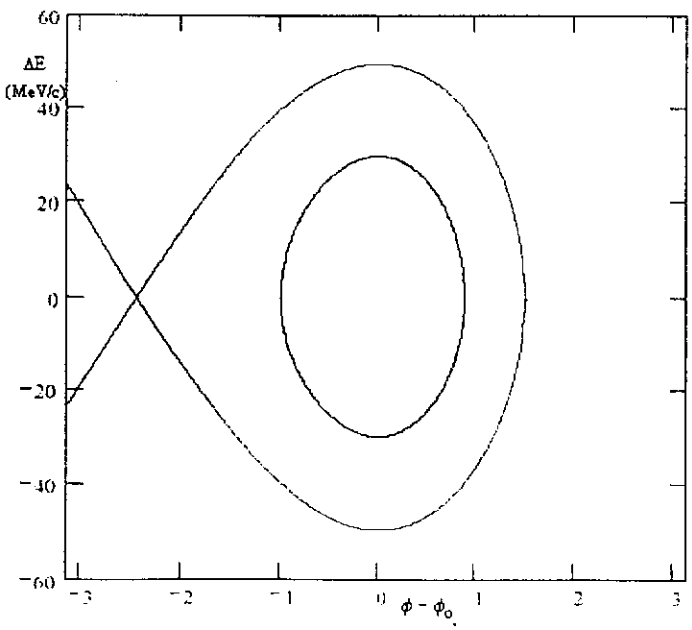
spreads rotation over ~ ½ synchrotron oscillations

Beam after induction linac rf rotation, mini-cool, adiabatic capture (VB):



Rf bucket is filled before cooling

Longitudinal heating causes beam loss

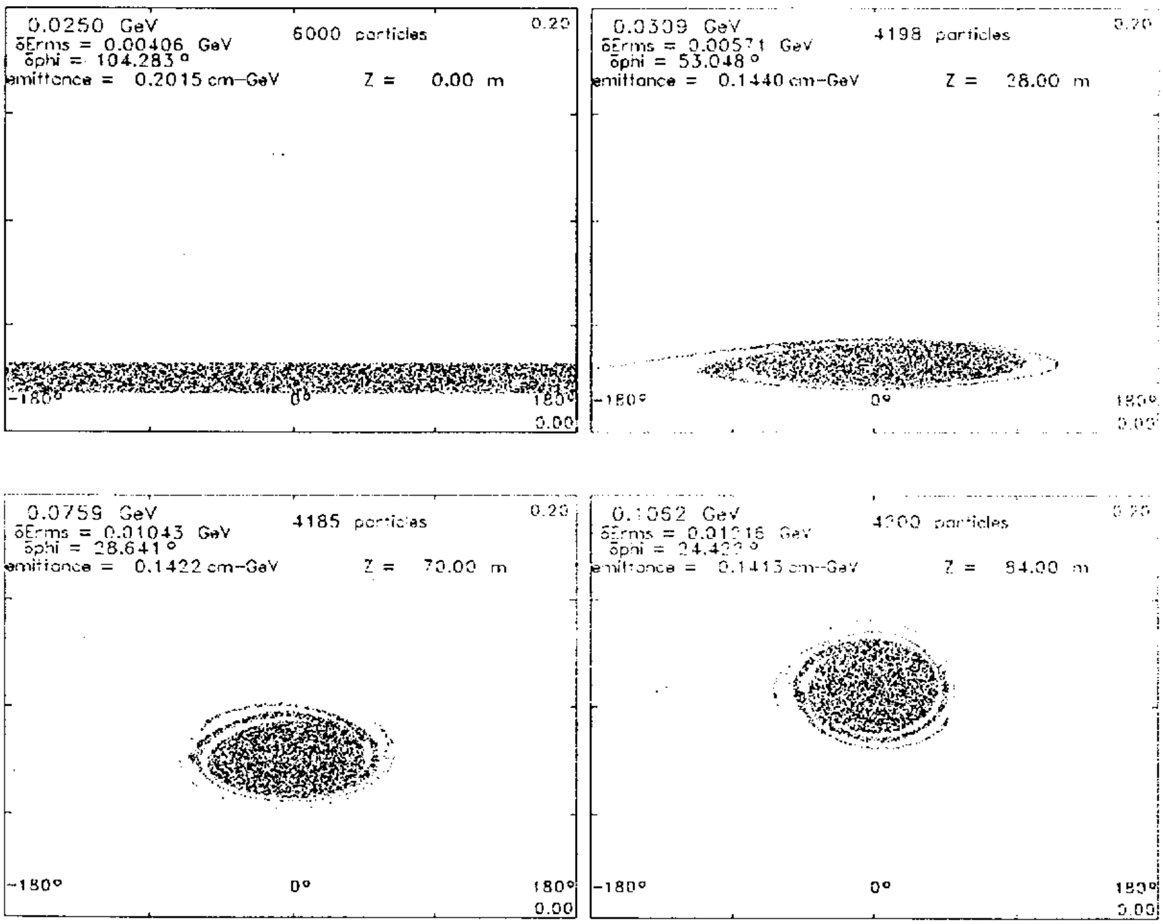


$T_0 = 120$ MeV, $V' = 10$ MV/m, $\phi_0 = 70°$

Adiabatic Capture (with minicooling)

Reduce energy to 25 MeV (p=77 MeV, β=0.59)
(by energy loss)

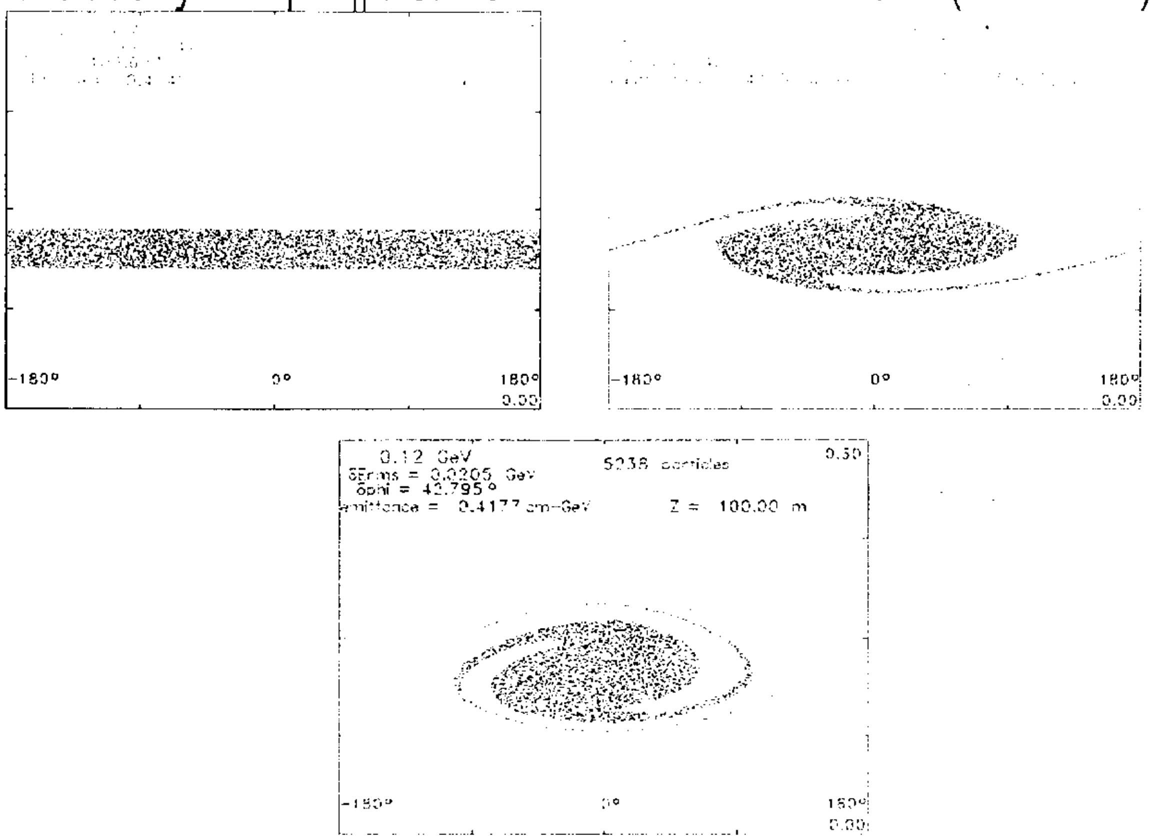
- momentum spread and bucket width are matched
- at p $\rightarrow$184, $\delta p/p \rightarrow$7.6%, $\sigma_{c\tau}$ ~11 cm, **70% capture**



V_{rf} = 1 + 1*J MV/m; ϕ_{rf} = 3*J °, f = 175 MHz
J = 1 … 6, incremented every 14 m

Adiabatic Buncher Example ($\delta p_0 \cong 10$ MeV/c)

Gradually ramp V_{rf} from 0 to 4 MV/m over 100m (175 MHz)



- **Better match** with larger initial σ_p (8 MeV/c) , **but** beam is now larger than cooling rf bucket; adiabatic capture length is long

⇒ (relatively) **large losses** in following cooling channel

Recent approaches and results:

- Decelerate beam (with absorbers)
  - reduces synchrotron period, rf bucket size,
  - can provide low-energy "mini-cooling" section

    but increases δp

- **δp is not small** after rf rotation (8–12 MeV/c)

  dilution is not so great ...
  - can adiabatically bunch at 200 MeV/c

"mini-cooling" increases beam loss

Beam naturally (over)fills cooling rf bucket

No great advantage for adiabatic bunching

Adiabatic Capture Studies

⇒ gradual increase of E_{rf} – can capture beam with little phase space dilution

Synchrotron period is long at P_μ = 200 MeV/c, f = 200 MHz

- 25m at $E_{rf} \cong 10$ MV/m

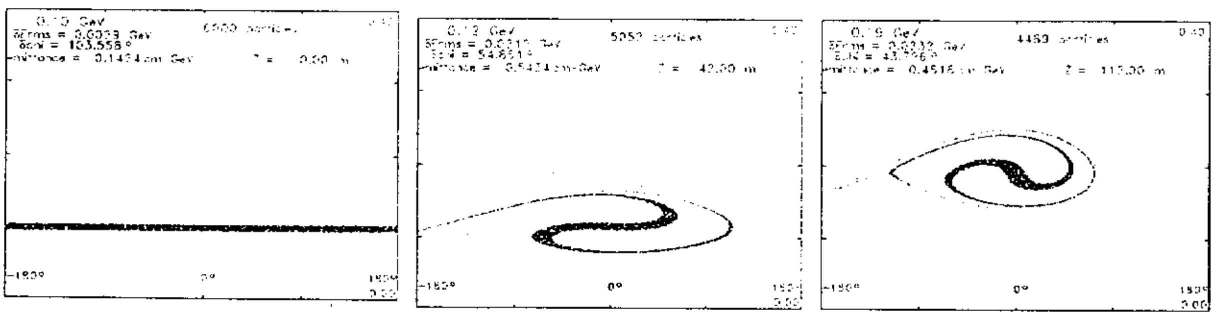
⇒ **long** adiabatic bunching section (100m)

Large mismatch to cooling rf bucket

if δp is small after buncher (PJK → δp ≅ 4 MeV/c)

Adiabatic Capture at 100 MeV – small δp

-1-D simulations:



-large phase-space dilution

Problems:

- **Some losses are unavoidable (200 MHz $\neq$ continuous)**

- **If δp** (after rf rotation) **is large,**
  beam overflows cooling bucket $\rightarrow$ more losses
  δp = 4 MeV/c (PJK baseline)
  $\Rightarrow$ **$\delta p \geq$ 8 MeV/c** (large) ,

- **Transverse mismatch**

  Chromaticity,
  Changes in angular momentum,
  correlation function(δp-A^2)

Buncher requires 200 (or 175 MHz) rf system
+ transverse matching optics

Options

- **adiabatic match** - gradual increase in rf voltage (up to ~100m)
  - at ~ 200 MeV/c
  - with minicool to low energy (~80 MeV/c)

- **short buncher**

  rf(175 + 350 MHz) + drift match

  A - 1-step (3m rf + 9m drift)

  B - 2-step (~2m rf + ~10m drift +~2m rf + 6m drift)

  ...

Transverse match

Obtain with 1 (or two ...) solenoids