Summary beam dynamics group

Incomplete review of material and response on initial questionnaire

Halo definition

- part of beam exceeding ~ 3 σ that needs to be scraped
- tails exceeding Gaussian tails
- halo is whatever bothers you!

How complete is our understanding of halo mechanisms?

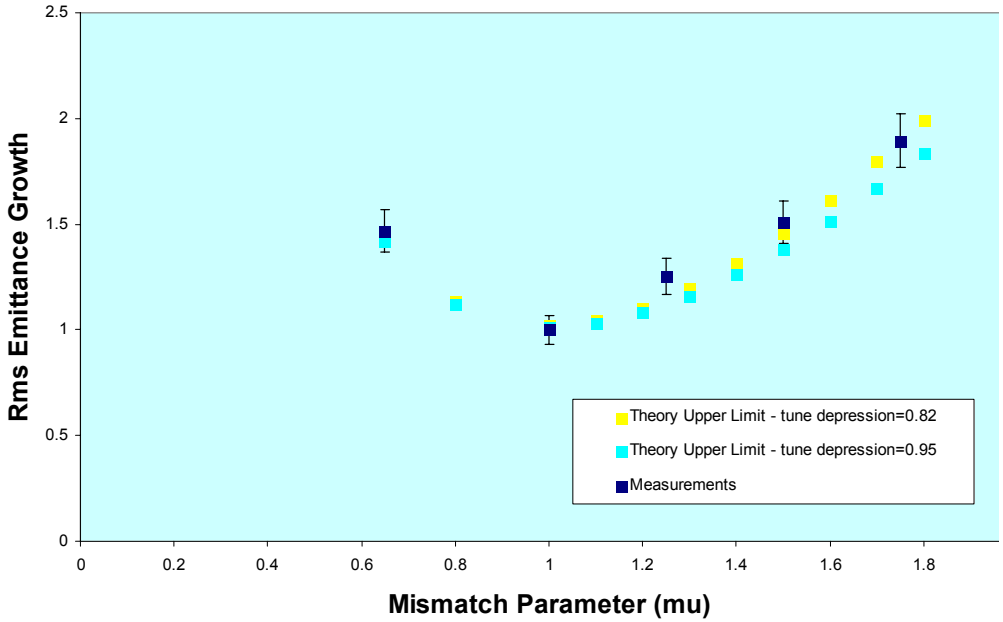
"Resonant halo"

Coherent motion drives halo

1. Envelope mismatch (parametric 2:1 halo) (T.Wangler, N.Pichoff, F.Gerigk, J.Qiang,	R + L
2. Random lattice errors (envelope or rotation) (F. Gerigk, P.Ostroumov, R.Kishek)	L
3. Dipole motion mismatch *) damped by halo or transverse (dipole) instability (V.Danilov) – *to be explored further for SNS ring*	R
4. Anisotropy resonance/instability (2:2) ~ low halo (JM.Lagniel, J.Qiang, D.Jeon)	R + L

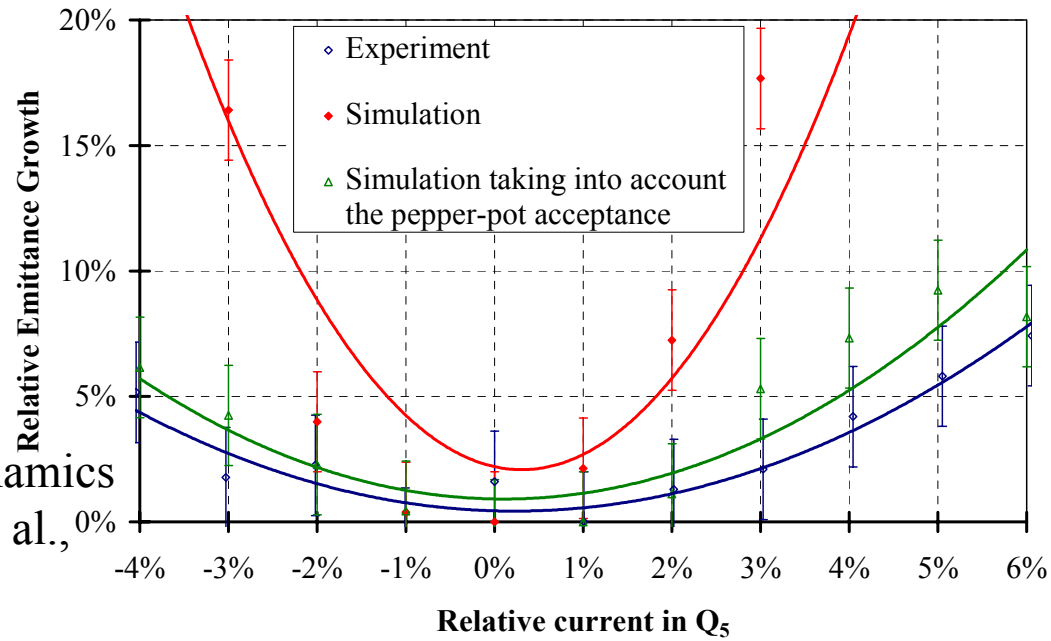
**) off-centered: in beam-beam group synchrotron radiation damps for electrons – not for hadrons*

Coherent motion drives halo …



LEDA exp.
T. Wangler, J.Qiang et al.

Halo growth agrees with experiment at the level of rms emittance growth
– halo size open



CEA: Measurement of space charge-dynamics effects in a FODO channel, N. Pichoff et al., EPAC98

Have overlooked early – 1985 … - experiment
(M. Tiefenbach et al.) + simulation (O. Andersen) at LBL
(heavy ion fusion program)

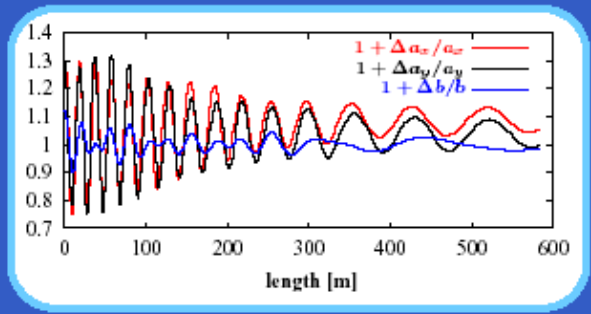
- in a ~ 50 quad transport channel
- to demonstrate structure resonances (envelope instability $\sigma_0 > 90°$, etc.) and compare with theory (1978-82)
- but measured also halo by mismatch for strong space charge

Halo growth by random error in worst cases comparable with initial mismatch

Transverse Errors (radial deviation)

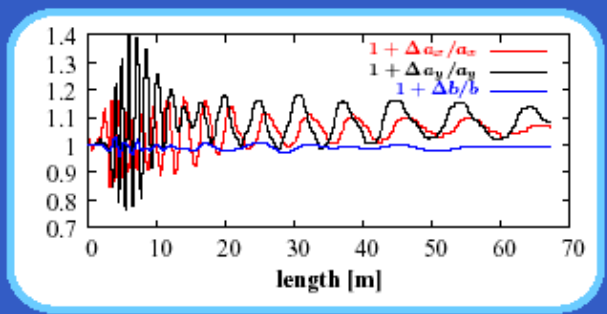
F. Gerigk

Halo in a nutshell: Halo particles are generated by parametric resonances between single particles and the oscillations of a mismatched beam core.



30 % fast mode excitation in a high-intensity linac

Radial deviation for the full Linac4:



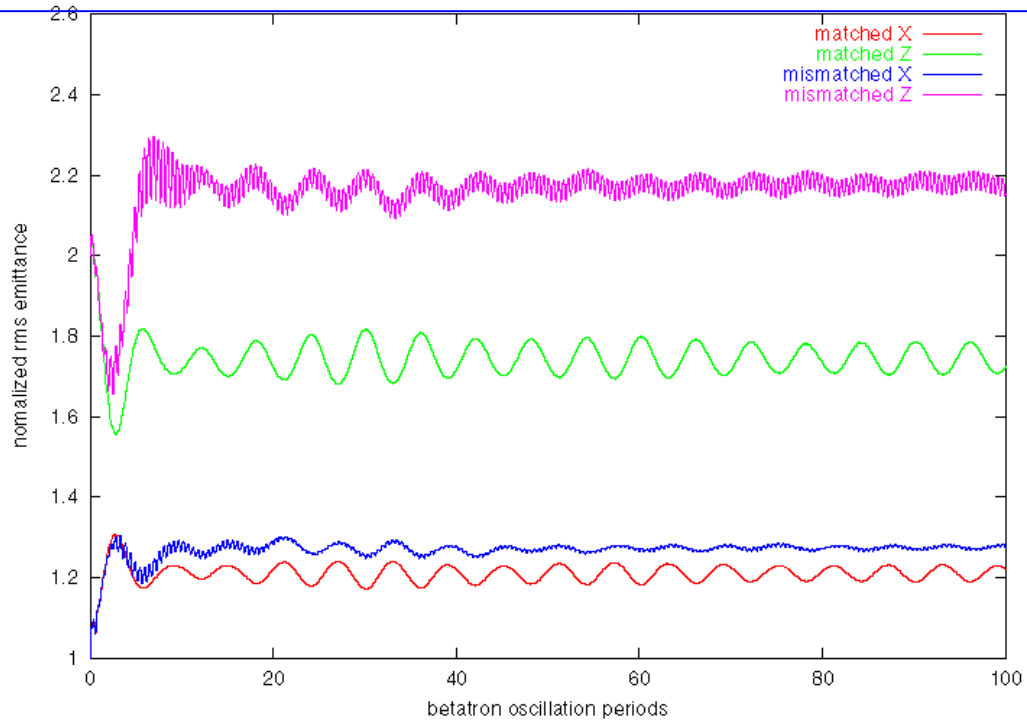
Δa_x, Δa_y, and Δb for the worst case in y (1% gradient variation)

- Statistical errors also result in core oscillation!
- The highest radial deviation compared to the matched case is observed after the chopper line in the first DTL tank!

Interplay of non-equipartitioned and envelope mismatch may drive beam still further away from equipartition

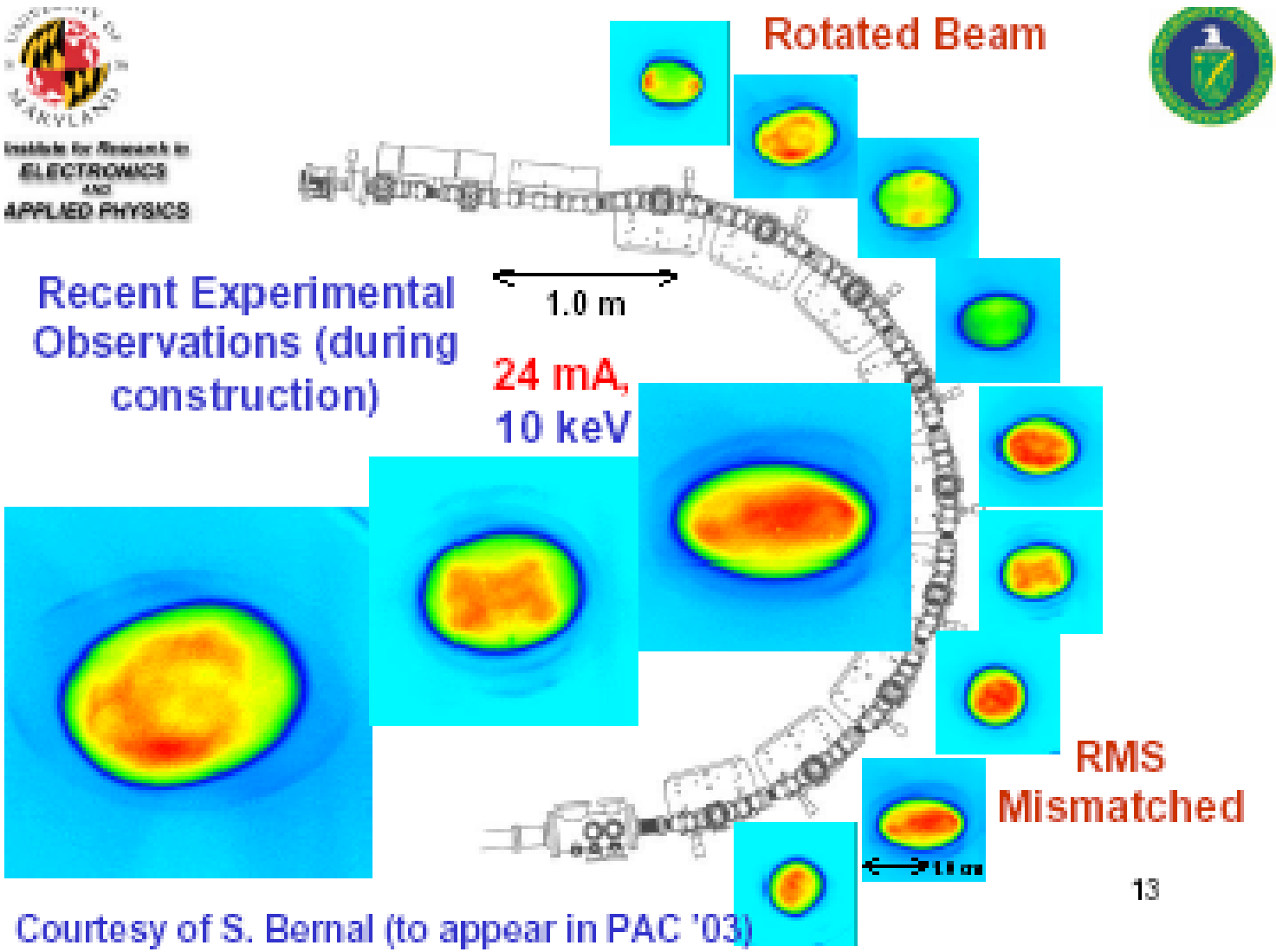
RMS Emittance Evolution in a Matched and Mismatched Anisotropic Beam

(Kz0/Kx0 = 1.025, Kx/Kx0=0.6, Kz/Kx = 1.26, Ez/Ex = 2, Gaussian Distribution)



J.Qiang et al.

UMER/Maryland (R.Kishek)

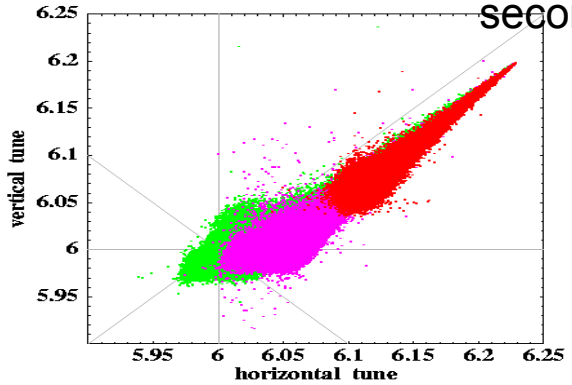


How complete is our understanding of halo mechanism?

"Resonant halo" cont'd

External driving term *(lattice harmonic)* is source

1. **Second order resonance** < 1ms R
   (A.Fedotov, SNS-ring) → pronounced coherent effect / advantageous
2. **Higher order resonance** R
   a) "space charge octupole" < 1 ms
      (S.Igarashi, S.Machida)
   b) nonlinearity + synchrotron motion > 10 …1000 ms
      (G.Franchetti, I.Hofmann) → ~ negligible coherent effect for Gaussian beams
      allows analytical space charge simulation
   c) tune modulation – different kinds

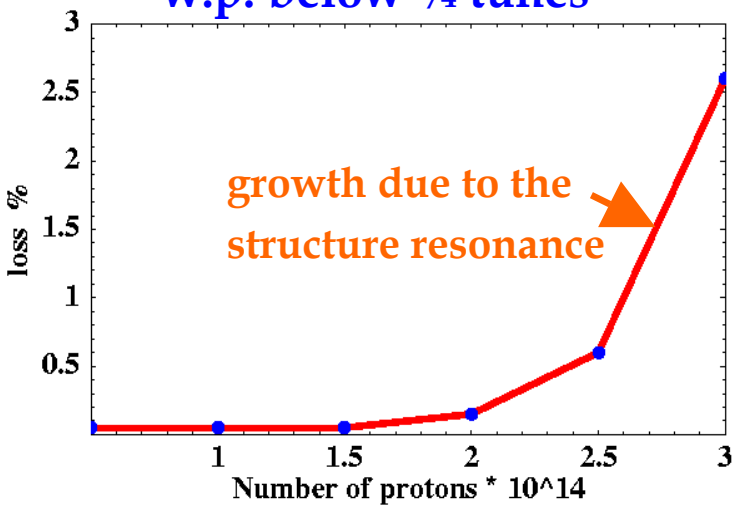


A. Fedotov

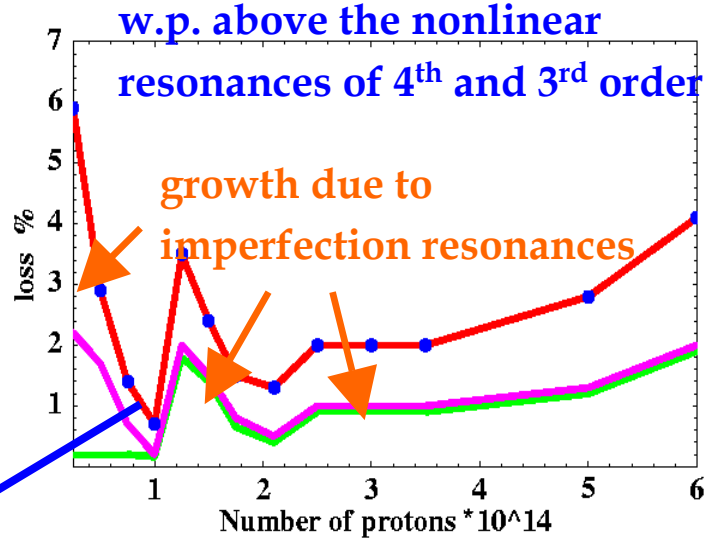
SNS examples

realistic simulations with the UAL code

w.p. below ¼ tunes



w.p. above the nonlinear resonances of 4th and 3rd order



requires resonances correction

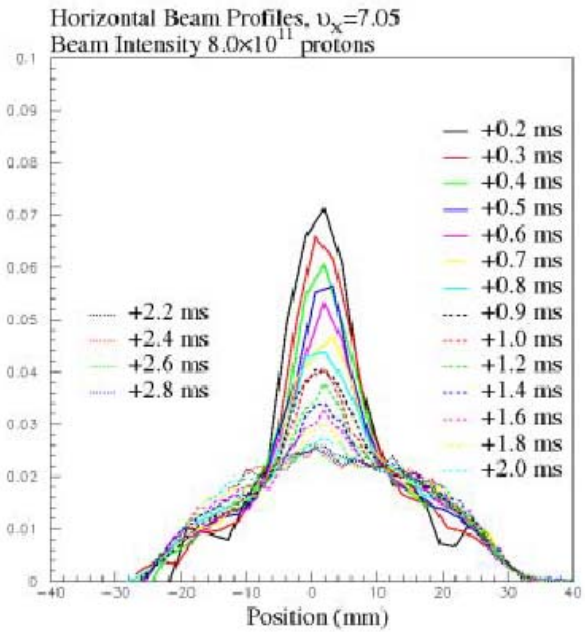
Igarashi et al.

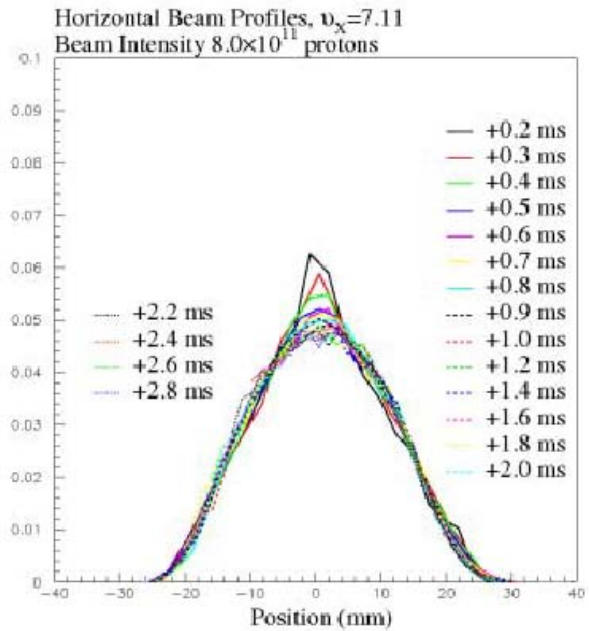
KEK main Synchrotron: observed and simulated shoulders (octupolar resonance)

Horizontal Beam Profiles

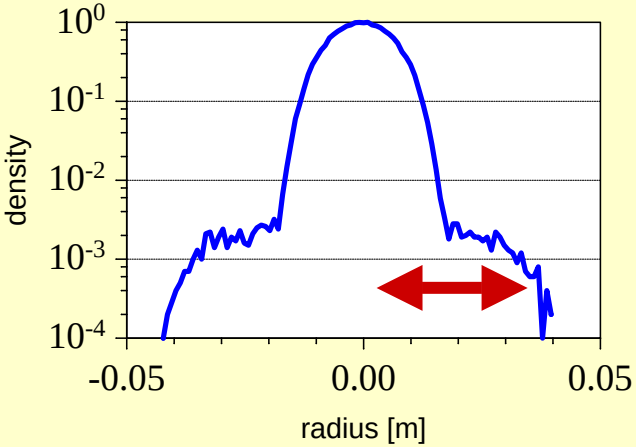
0.2 ms ~ 2.8 ms after Injection

Beam Intensity 8.0×10^{11} protons



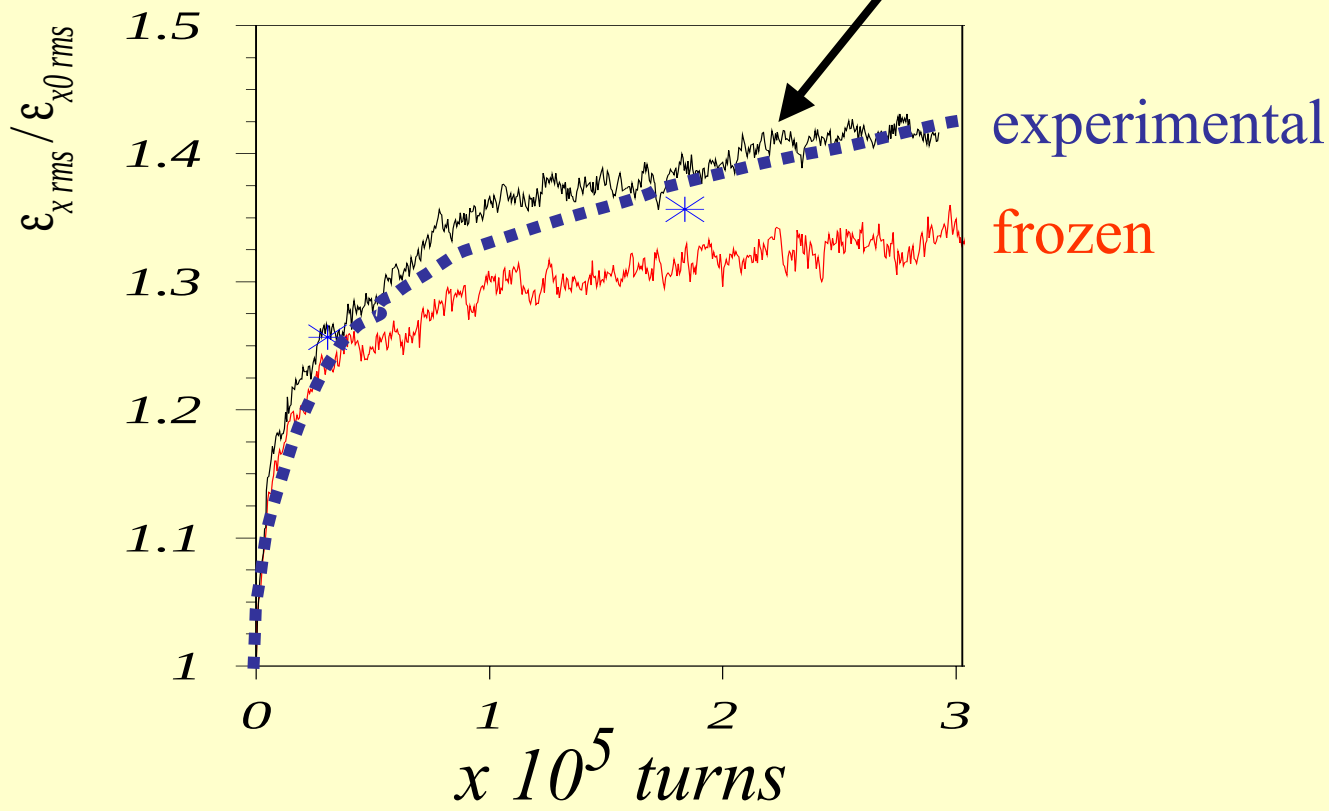


Lattice harmonic driven halo …



CERN-PS halo benchmarking experiment: halo unbounded and particle amplitudes go in and out over many synchrotron periods

$Q_x = 6.29$



How complete is our understanding of halo mechanism?

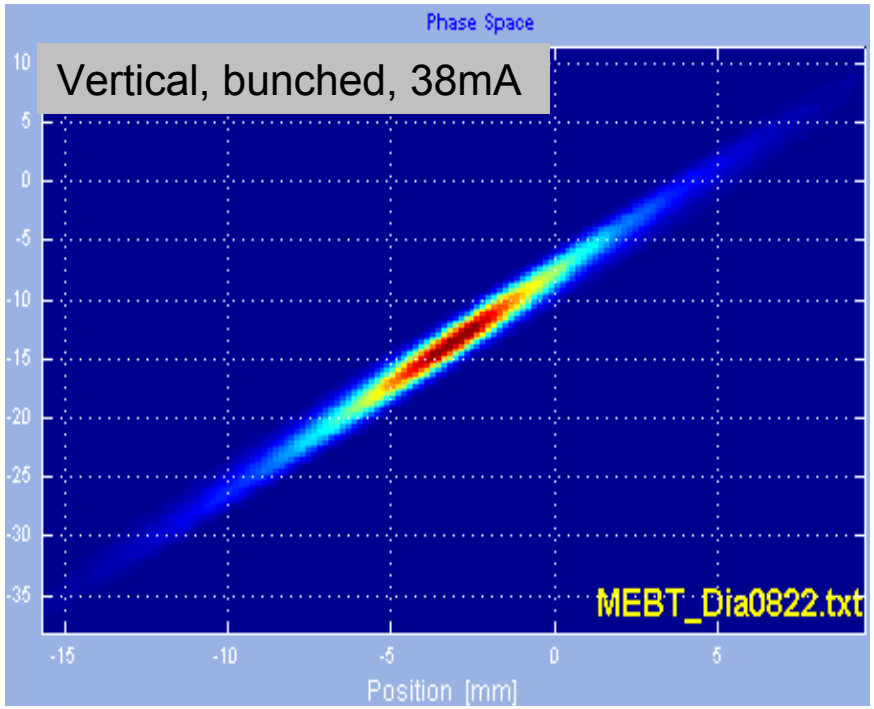
Scattering induced halos *(non-resonant)* R + L
(N.Pichoff, G.Turchetti) *IBS only in R*

Further machine specific sources *(non-resonant)*

1. RF bunching mismatch responsible for ~ 800% emittance growth in LANSCE
2. In SNS and J-PARC MEBT line “spherical aberration” (octupolar force from space charge or RF)
   observed in experiment and modeled by simulation (D.Jeon, M.Ikegami)
3. H- stripping / Interaction with residual gas / Image effects etc.

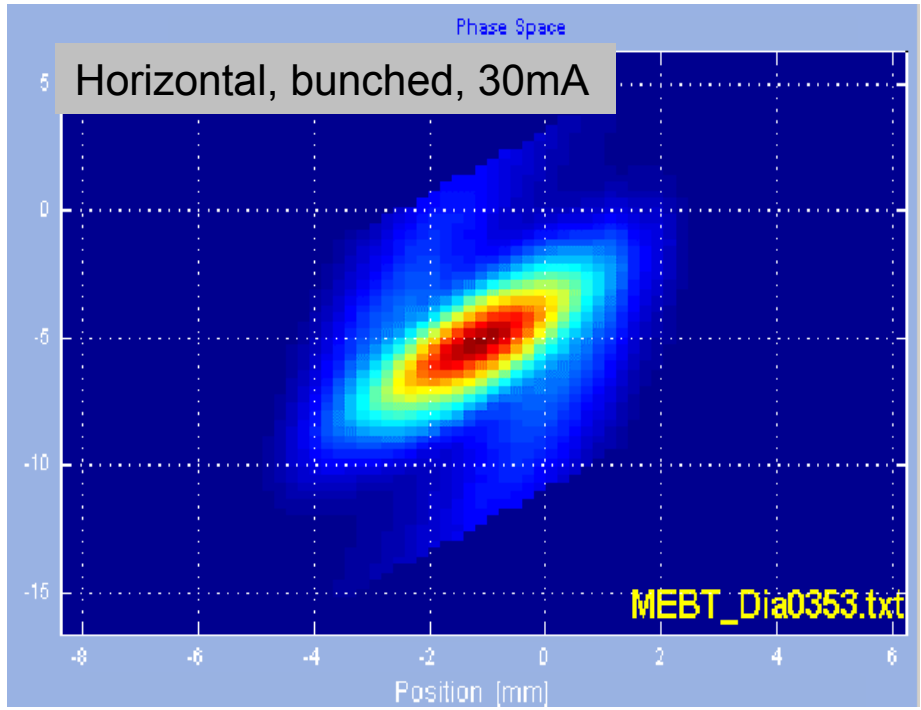
Transverse emittance at the MEBT exit (II)

- Transverse emittance for optimized settings is within specified limits (<0.3 □ mm mrad)



normalized r.m.s. = 0.3 □ mm*mrad

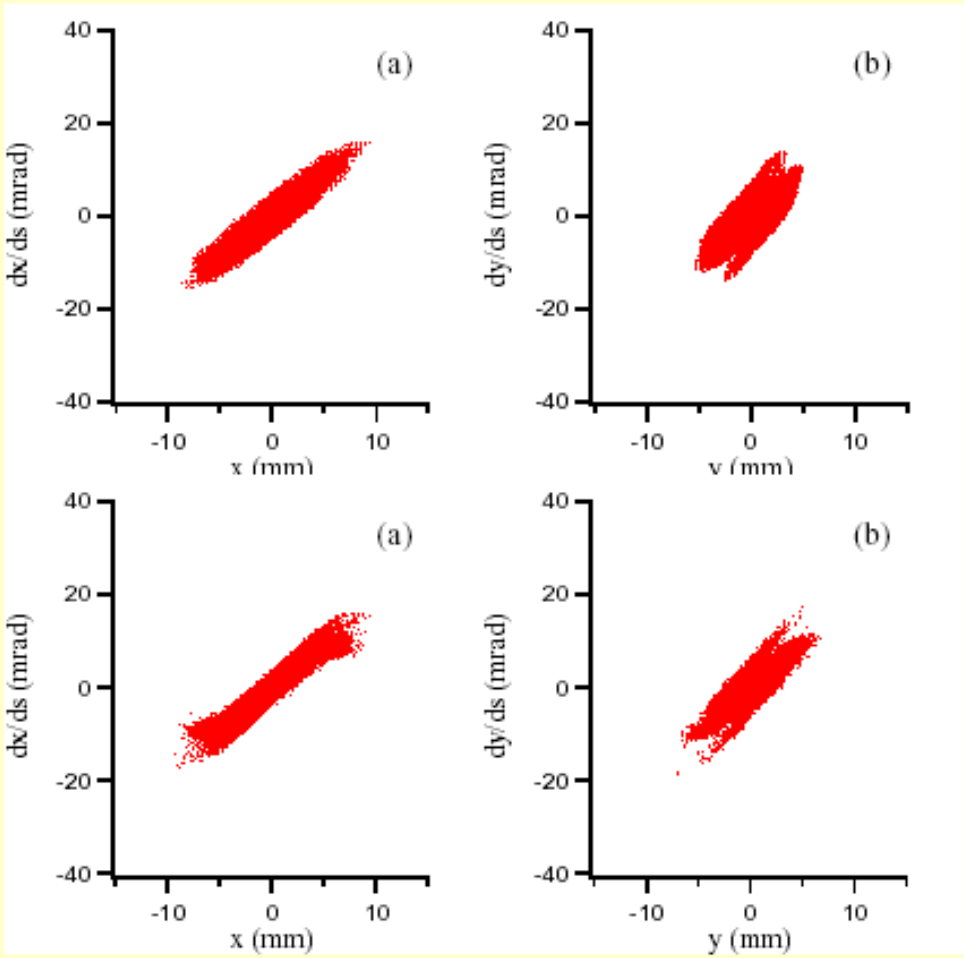
normalized enclosed 90% = 1.8 □ mm*mrad



normalized r.m.s. = 0.24 □ mm*mrad

normalized enclosed 90% = 1.58 □ mm*mrad

Comparison of phase-space profile (GA)



Experiment

J-PARC Linac
M. Ikegami

Simulation

How complete is our understanding of halo mechanism?

Studies on specific machines: halo impact

1. BNL Linac/AGS 1MW upgrade for neutrino factory discussing effect of stripping foils and many others (W. Weng)
2. RIA Linac (P. Ostroumov) – **basically halo free design!**
3. CERN sc Linac (F. Gerigk)
4. J-PARC Linac (M. Ikegami)

What determines size of halo?

- Parametric 2:1 halo: 10^{-4} may reach (MM=1.3, upper limit?) ~ 3 σ → 5-7 σ
- Coupling long-transv may enhance halo size
- Random error halo: ~ same ?
  more work may be needed
- Space charge octupole (KEK) shoulders
- Nonlinearity + synchrotron oscillation (CERN-PS) 3 σ → unbounded

Dominant mechanisms of halo production

Linac:

1. Initial mismatch from poor matching between sections – in principle cured by sufficient diagnostics
2. Random errors (gradients, misalignment, …) – do we find pronounced parametric halo?
   a. profiles of simulation for some error sets of CERN-SPL indicate halo up to 5 σ?
   b. need more systematic work!
3. Source halo, scattering, …?

Ring:

1. Initial mismatch “parametric halo” with bunch transfer should be possible to minimize
2. Nonlinear resonances – depends on time scale 1 ms - 100-1000 ms

Conclusion

Lots of work left for

- experiments +
- design-close dynamics studies