Beam dynamics in the Linac4 to PSB transfer line (green field option)

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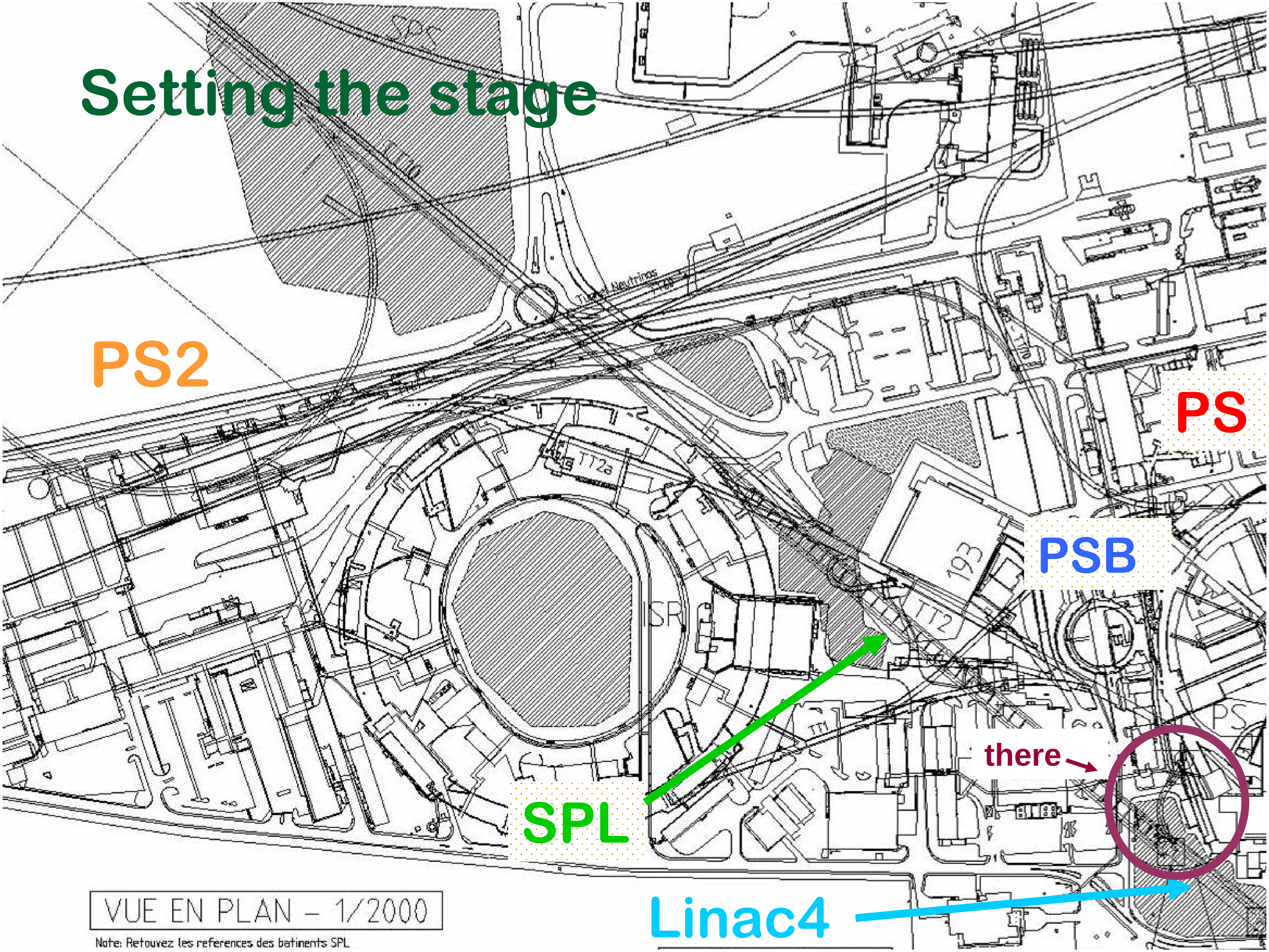
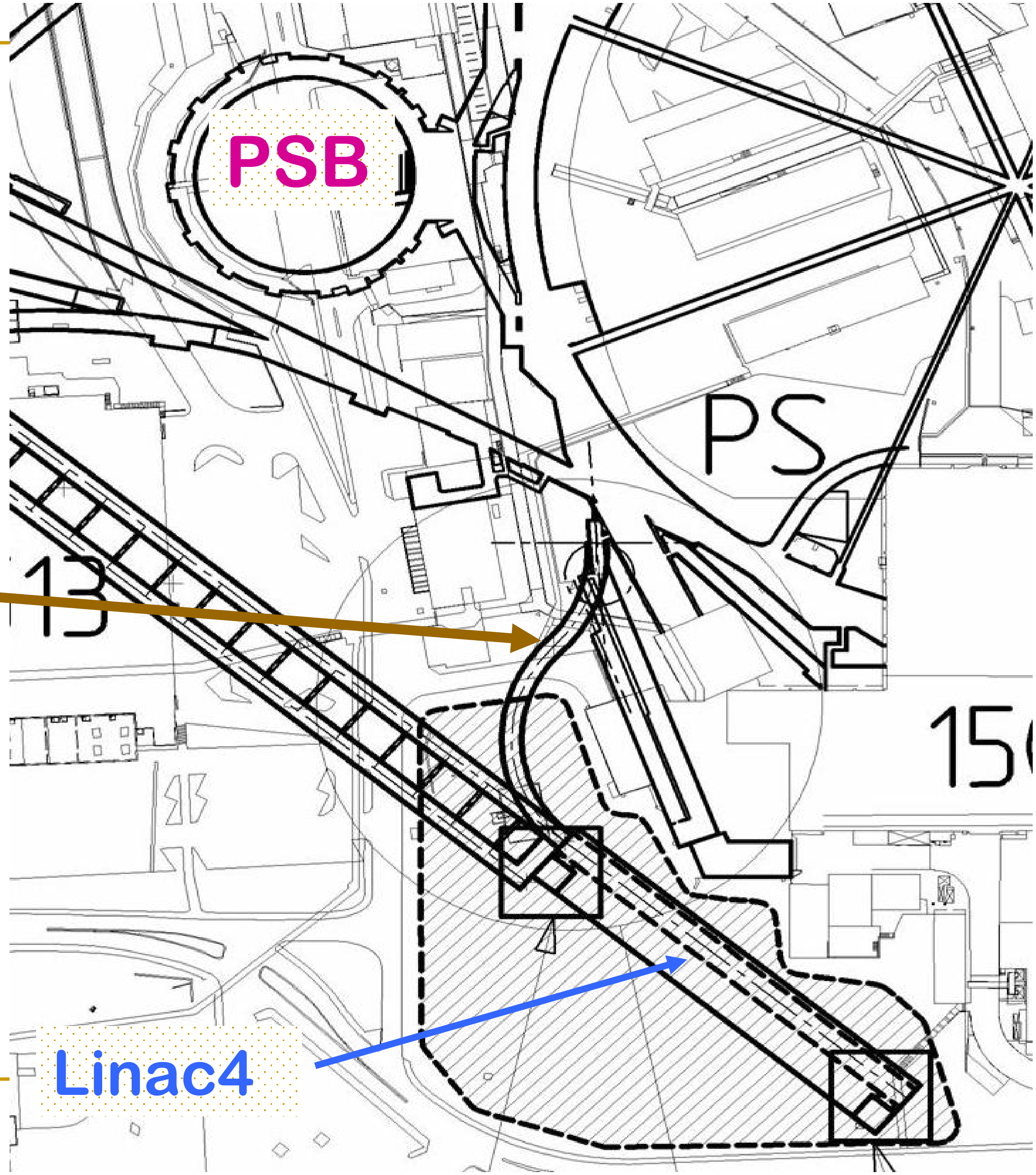
& thanks to discussions with Christian, Brennan, Maurizio etc.

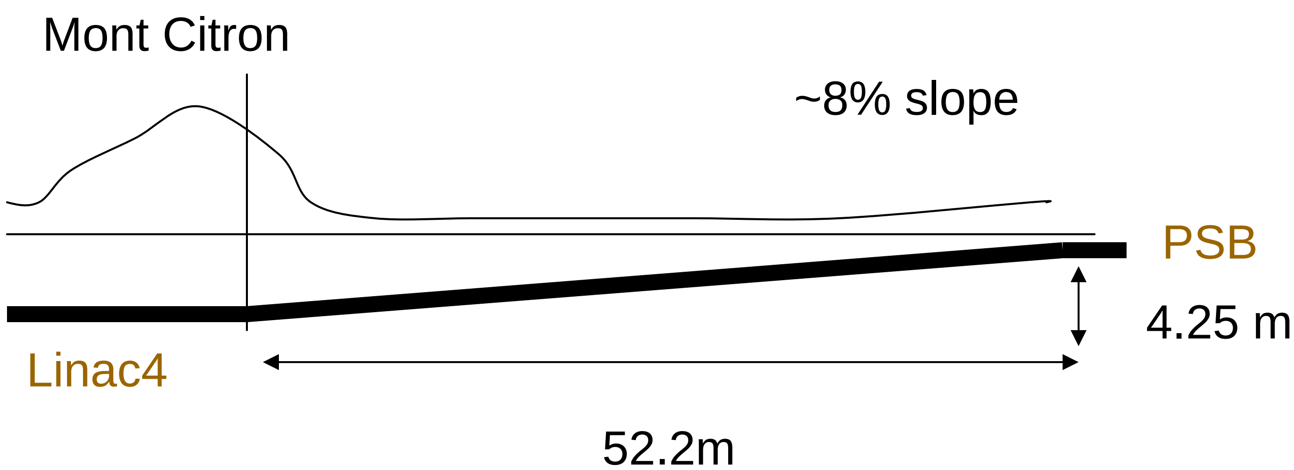
Setting the stage



Zoom



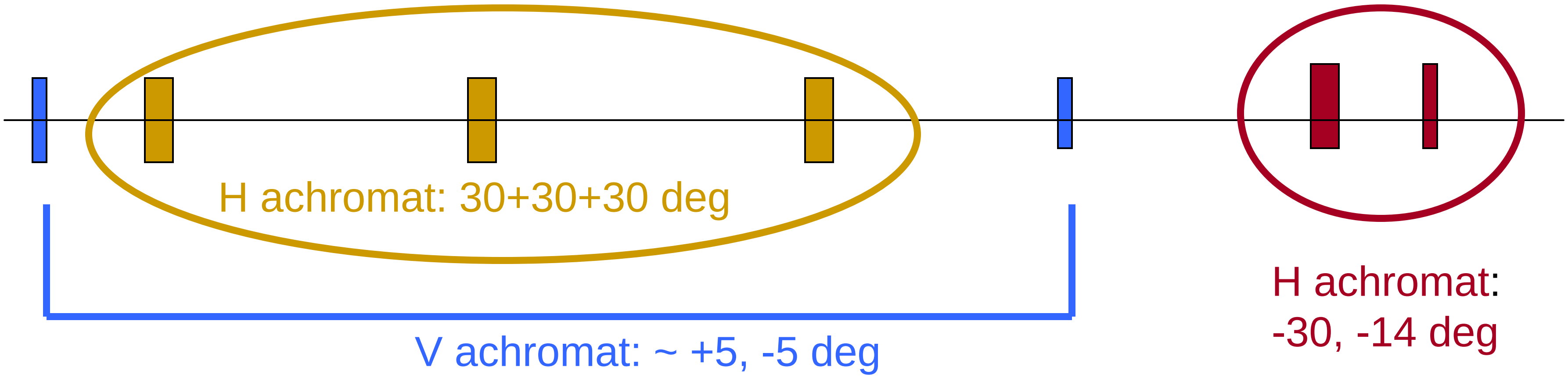
Vertical cut

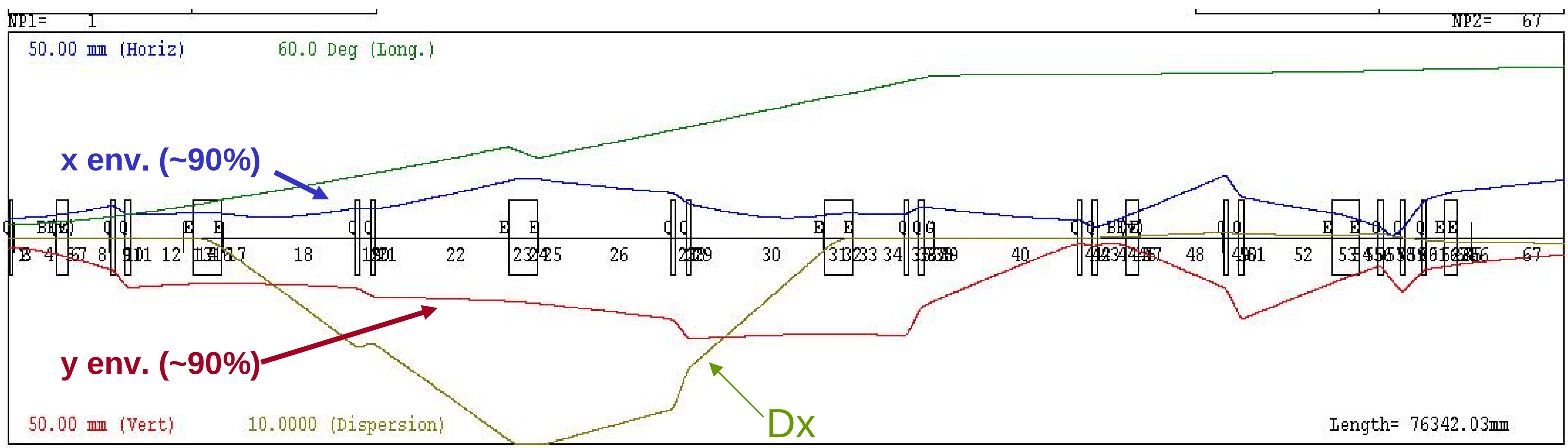


- *Constant slope solution* favoured over step to avoid lack of continuity b/w tunnel sections for installation and maintenance purposes.
- Current slope (8%) near limit for safe machinery utilisation

Layout

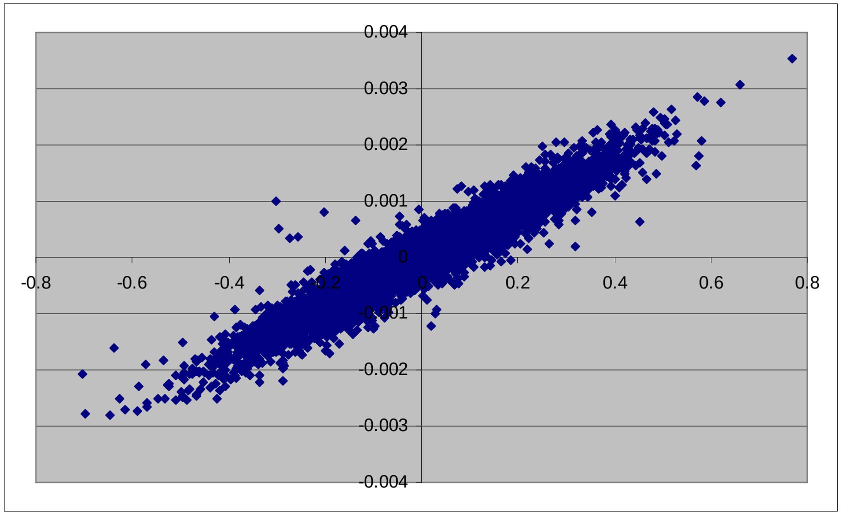
“Nested achromats” solution to minimise effects of dispersion on transverse emittance growth and coupling:



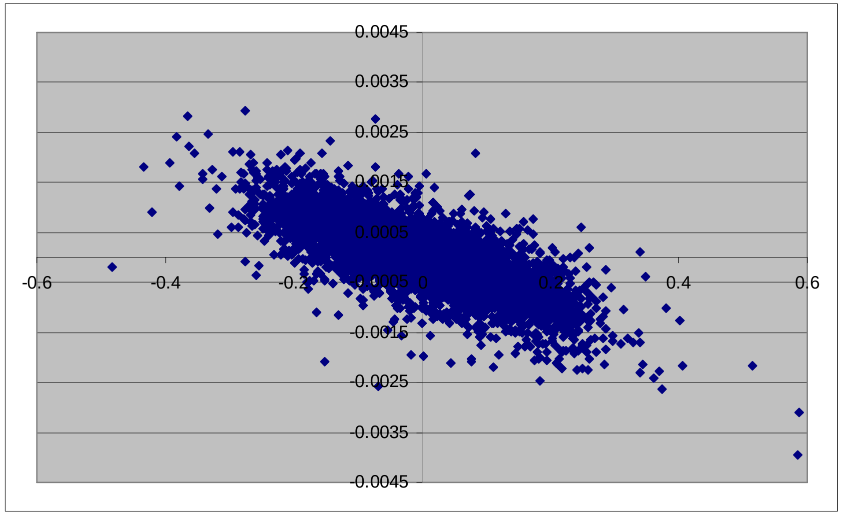


Transverse phase space at the end of Linac4

X-X' (cm rad)



Y-Y' (cm rad)



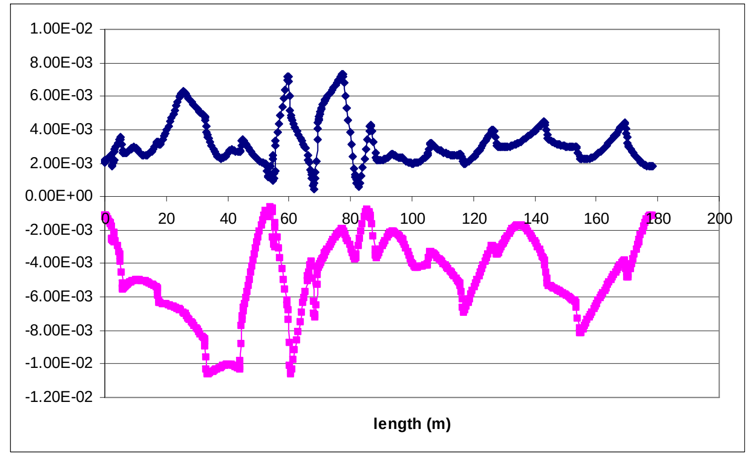
$\varepsilon_x = \varepsilon_y$=0.35 mm mrad (RMS norm.)

95% of the beam in 5/6 RMS

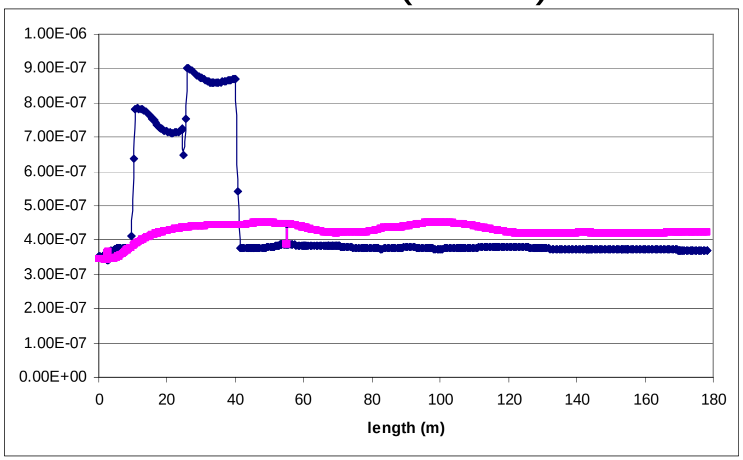
Dx=D'x=0 , zero coupling

Transverse beam transport

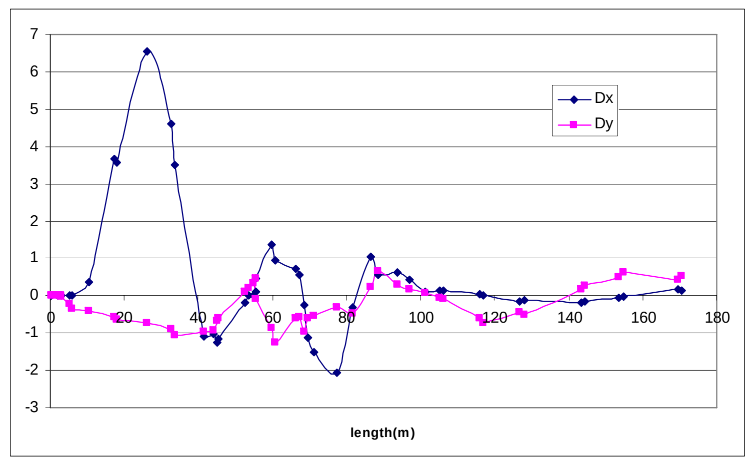
Envelopes (m)



Emittances (m rad)



Dispersion, H & V (m)



X

Y

Beam at PSB – transversally

- So far assumed Linac2-type conditions: α~0, small β (<10 m)
- Some freedom for tuning in 2nd part of the transfer line after BHZ30 (6 doublet pairs before injection foil):
  - *envelope matching*
  - *zero coupling*
  - *beam offset*

- At PSB: Dx=1.42 m & Dy=0

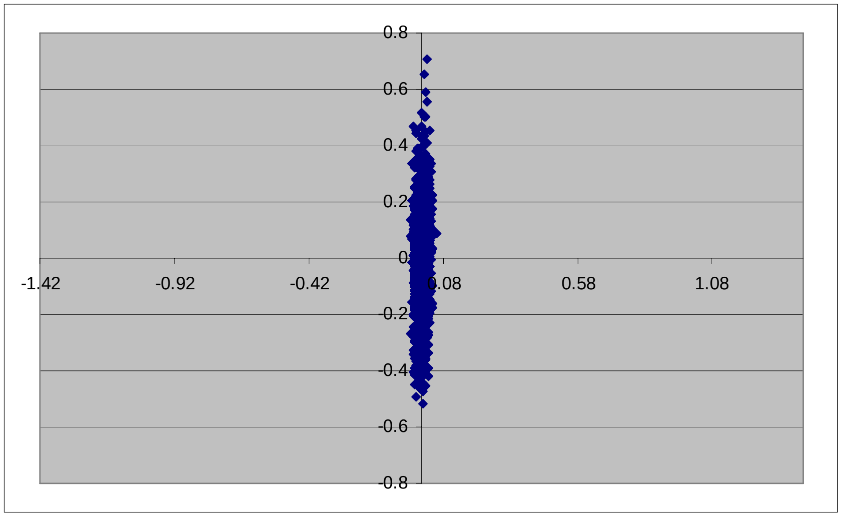
  what are the effects of any dispersion mismatch at injection?

- ***what is the interplay*** b/w longitudinal and transverse planes at injection?

Longitudinal phase space

Input beam (MeV-ns)

1.6 MeV

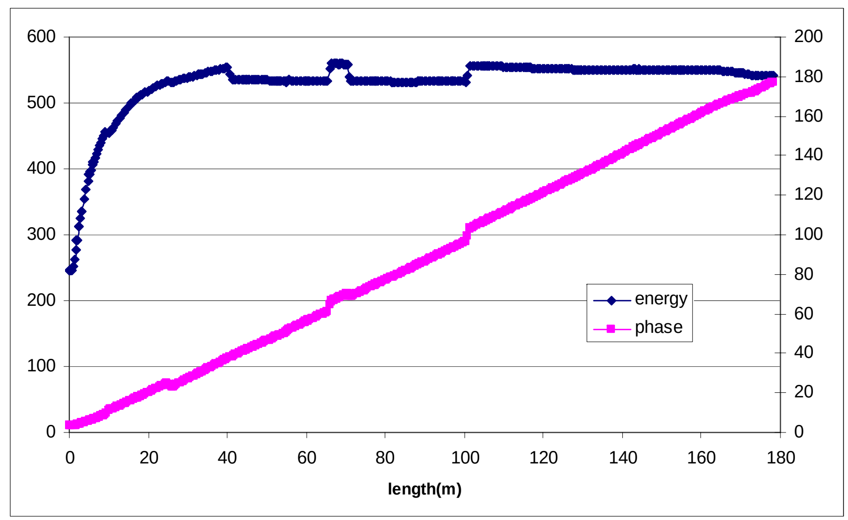


2.84 ns bunch spacing at 352.2 MHz

E=163.05 MeV

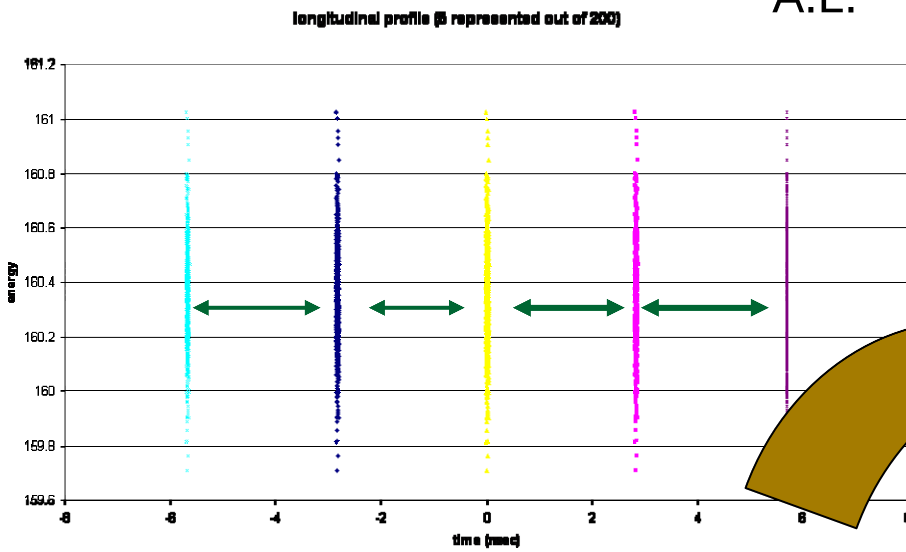
I = 65 mA

Energy spread (keV) and phase width (deg) under space charge forces



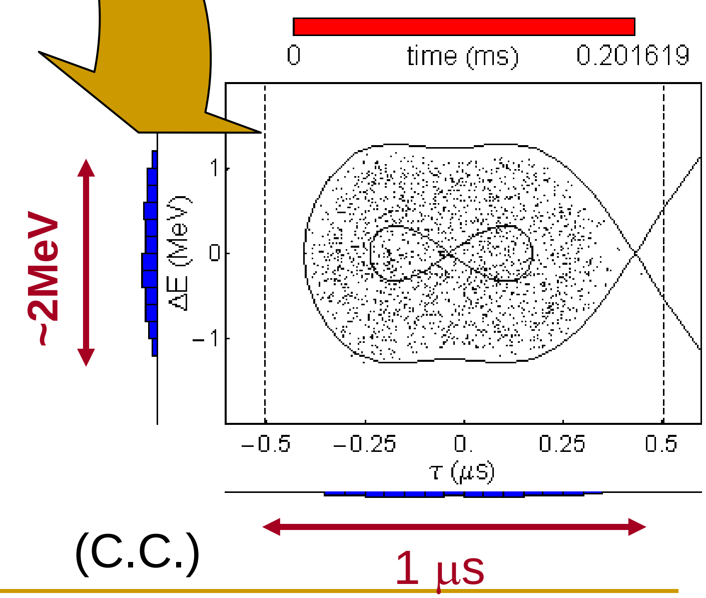
RF gymnastics

A.L.



2.8 ns spacing at 352 MHz

V1=8kV, V2=5kV



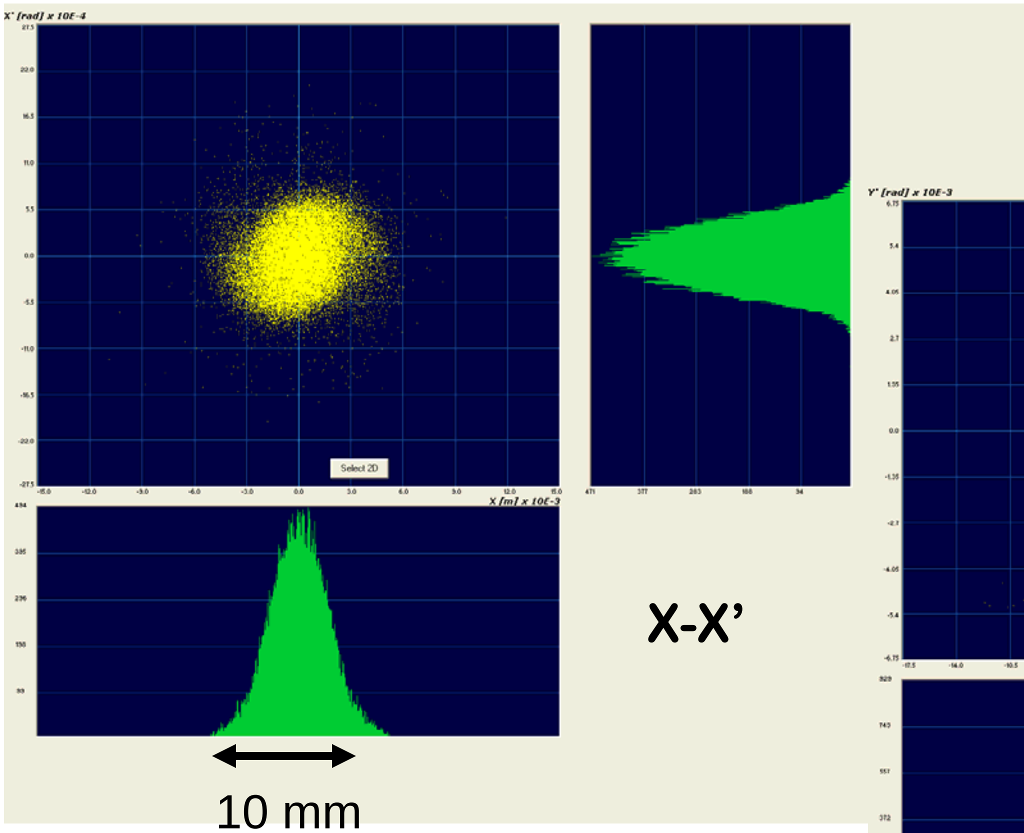
What game can we play longitudinally in the TL to fill the PSB bucket as homogeneously as possible over *n* turns?

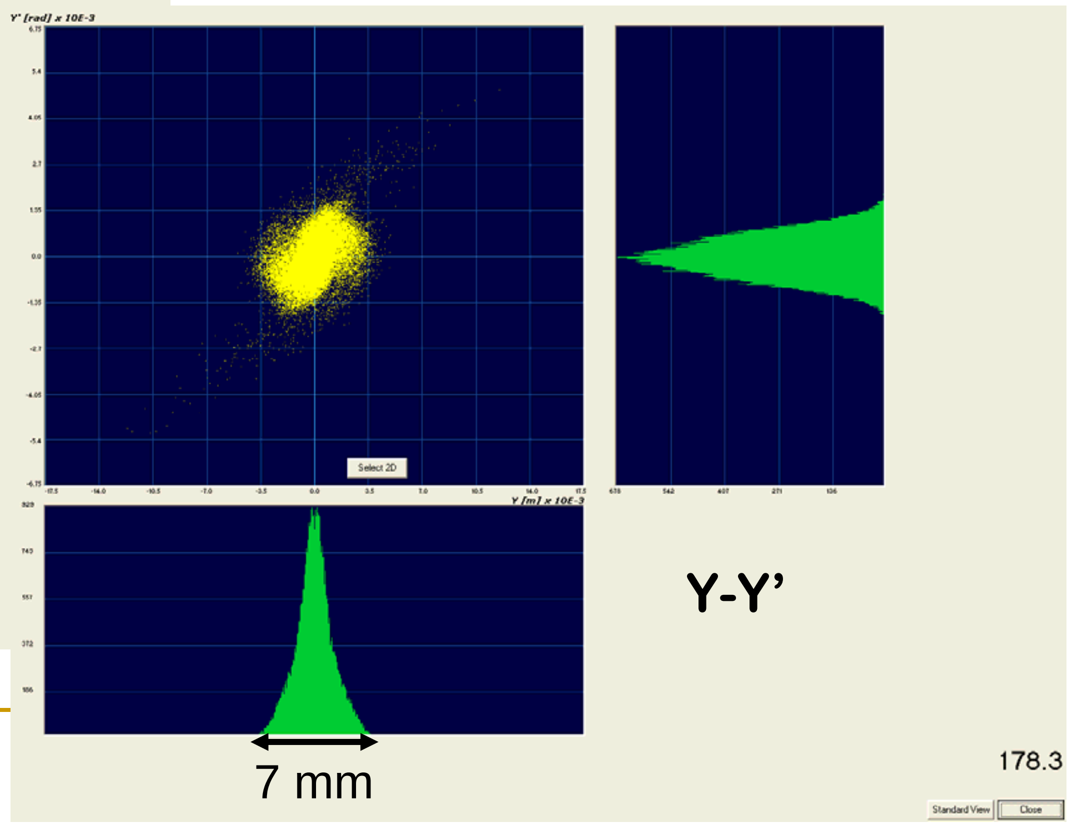
(C.C.)

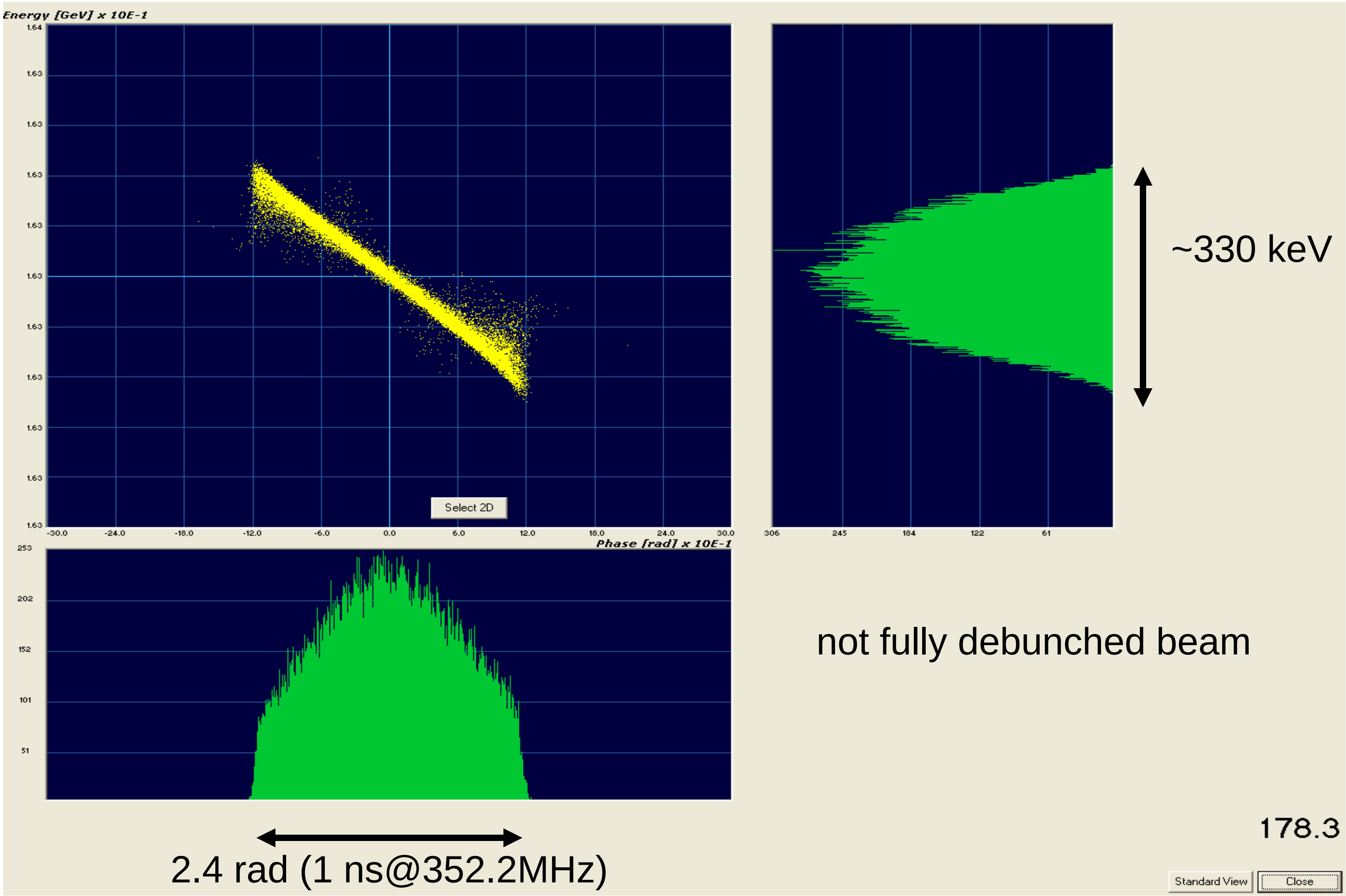
1) Linac2-type injection:

Beam at Booster:

Use debuncher cavity (~0.8 MV at 40m from linac4 exit and Dx~0) to control energy spread and jitter






Energy [GeV] x 10E-1
Phase [rad] x 10E-1
Select 2D
~330 keV
not fully debunched beam
2.4 rad (1 ns@352.2MHz)
178.3
Standard View
Close

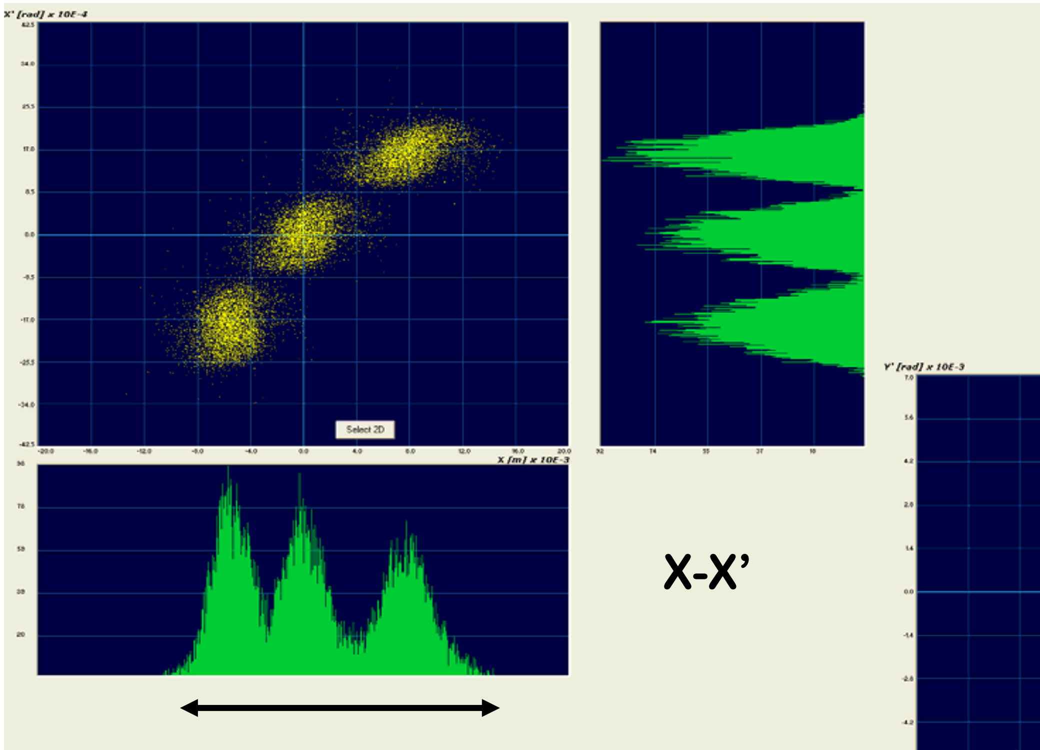
2) Linac3-type injection:

Energy ramping and longitudinal painting:

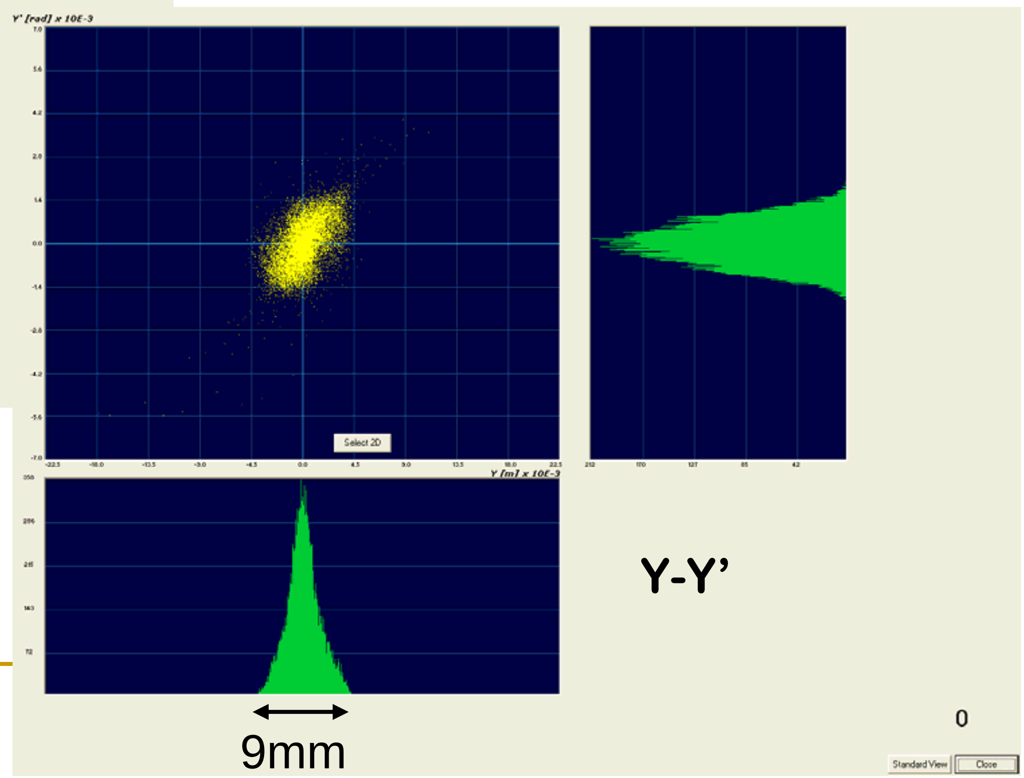
One ramping cavity (2.4 MV) just after Linac4

Linear ramp (energy vs time):
[-30 deg, -1.2 MeV] to [30 deg, 1.2 MeV] in 10 μs triangular sweep

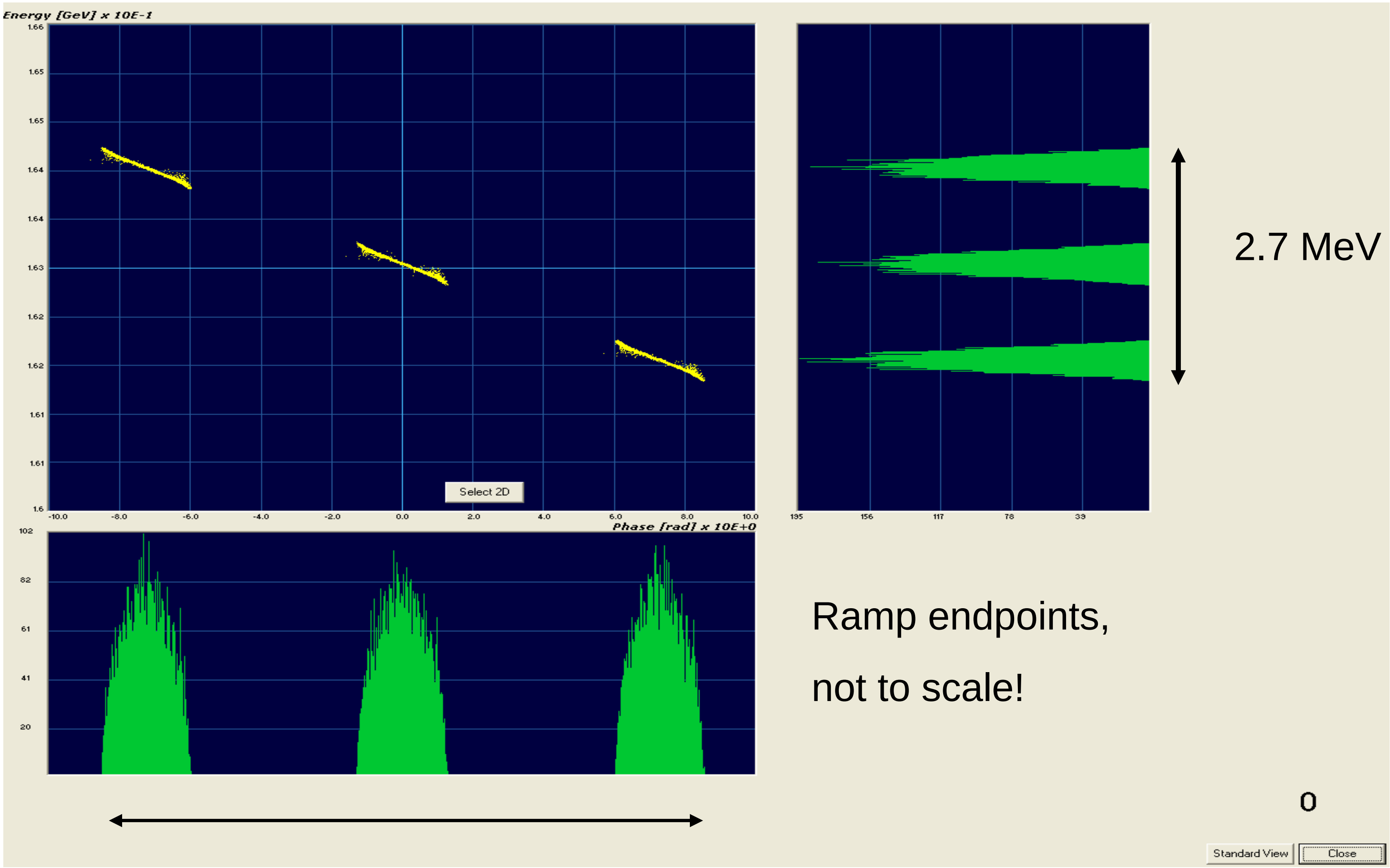
Phase-modulated debuncher cavity downstream



20mm

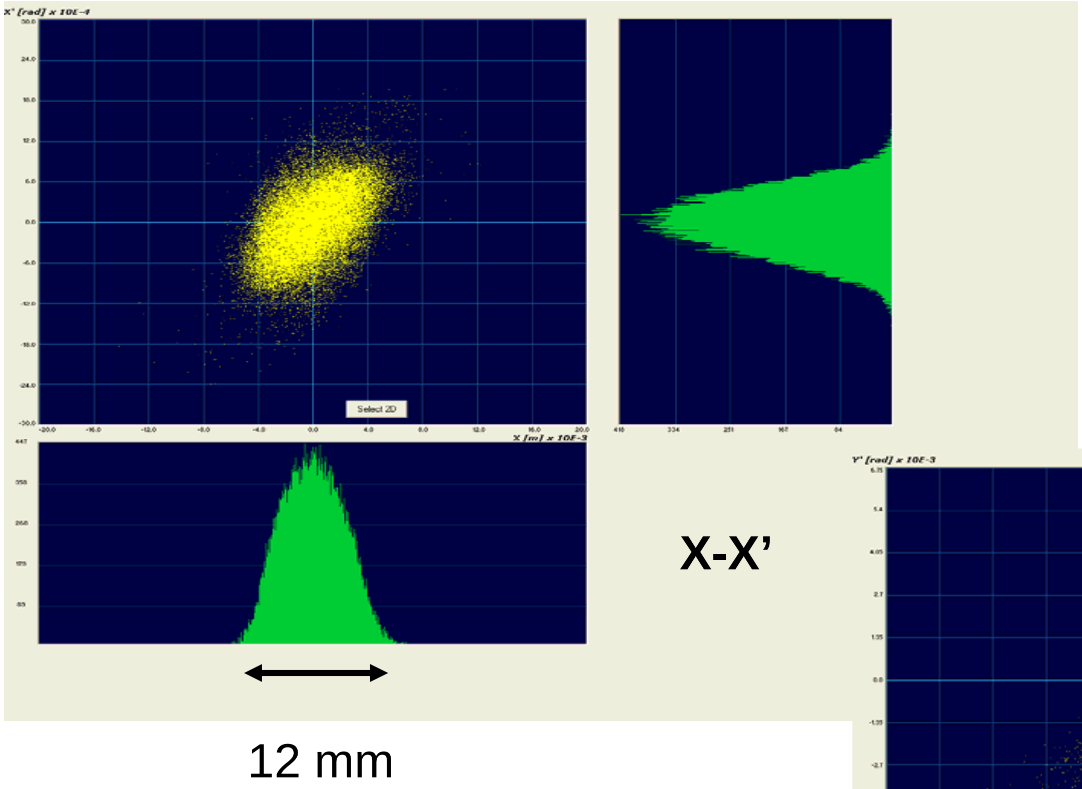


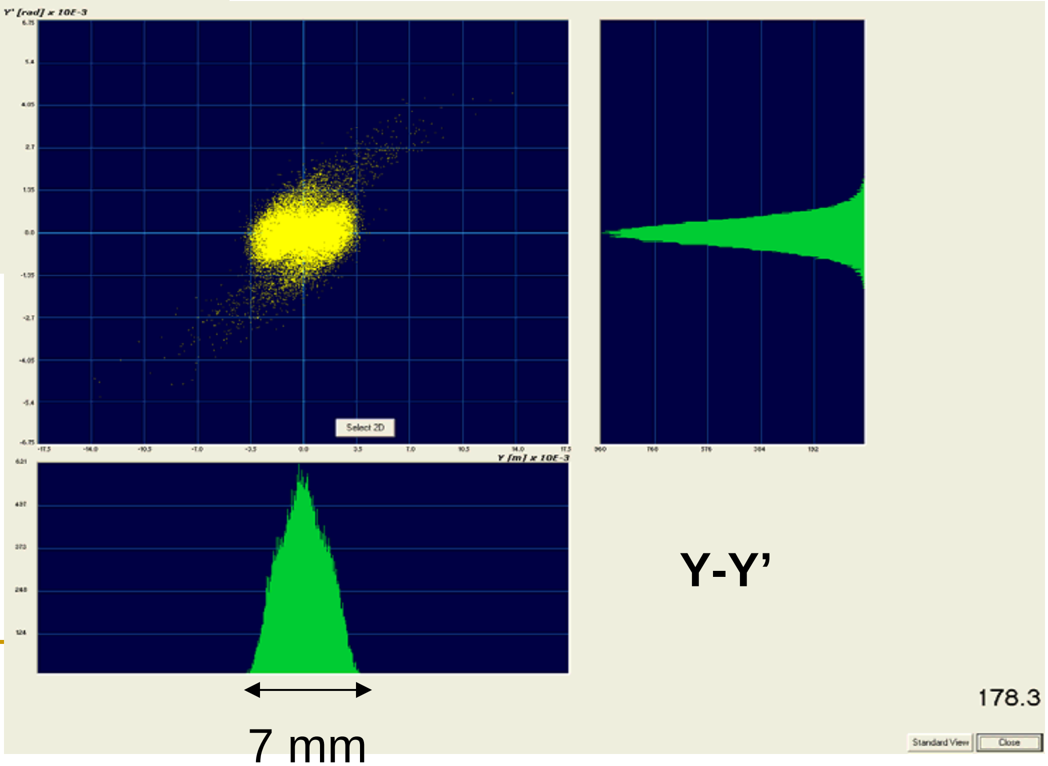
10 μs time-scale
(energy ramp sweep)

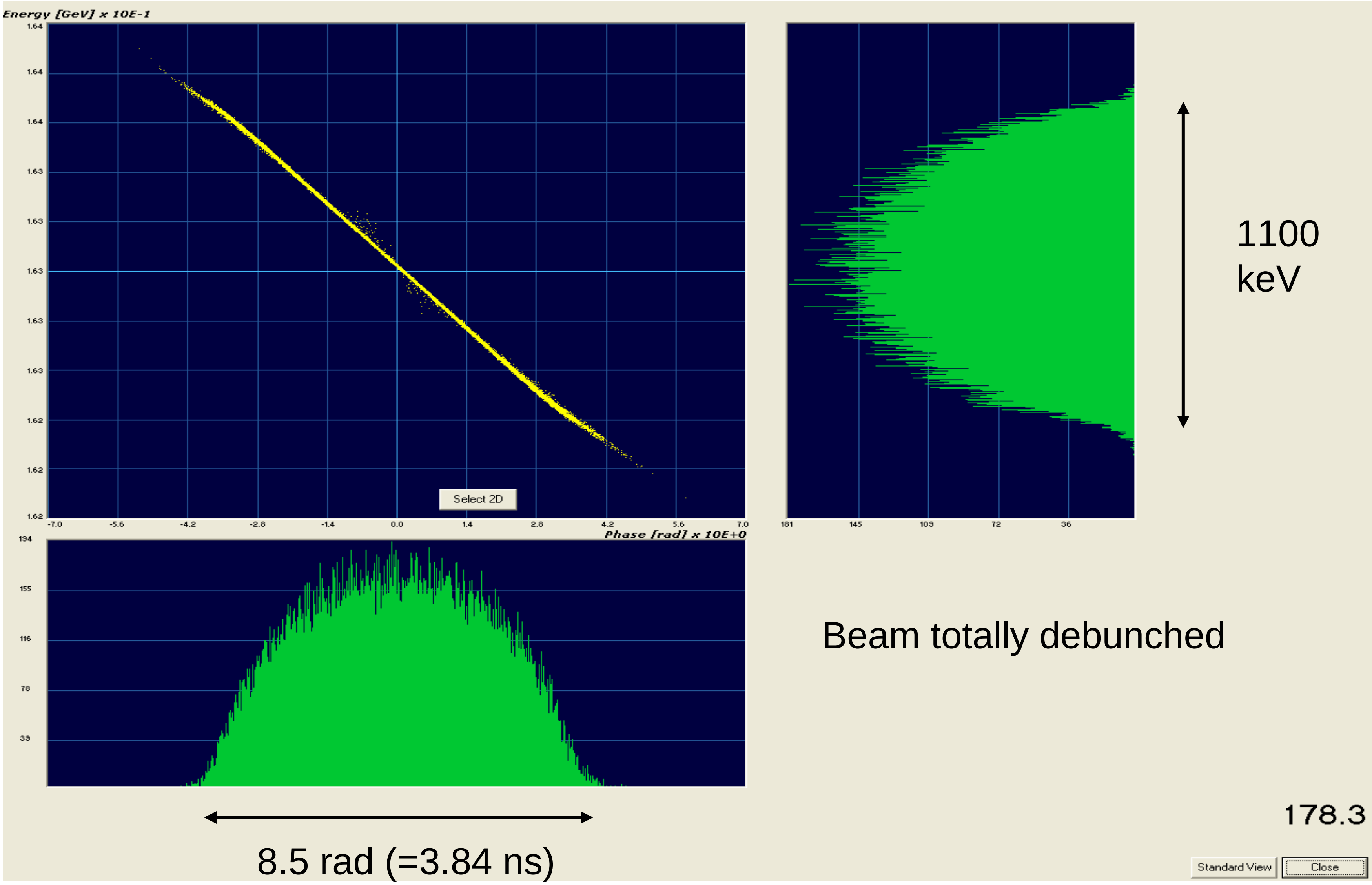

Energy [GeV] x 10E-1
Phase [rad] x 10E+0
Select 2D
2.7 MeV
Ramp endpoints,
not to scale!
0
Standard View
Close

10 μsecs

3) Radical: no manipulations







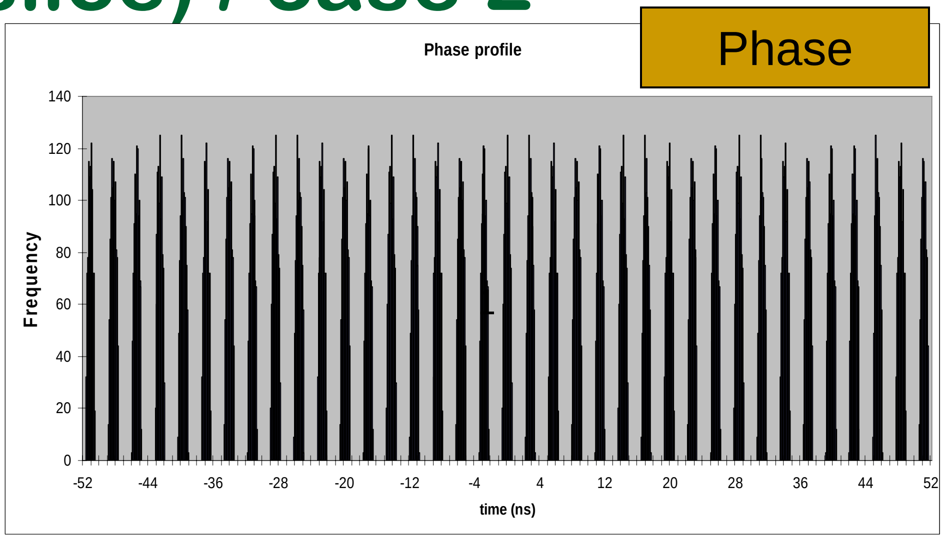
Energy [GeV] x 10E-1
Phase [rad] x 10E+0
Select 2D
1100
keV
Beam totally debunched
8.5 rad (=3.84 ns)
178.3
Standard View
Close

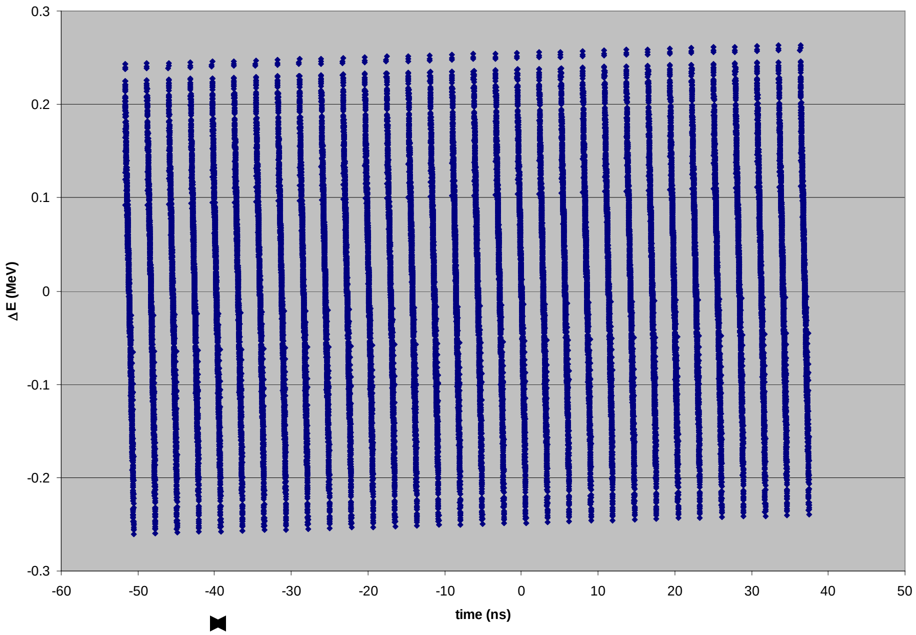
All 3 at a glance..

	Case 1		Case 2		Case 3	
	no jitter	*jitter*	*no jitter*	*jitter*	*no jitter*	*jitter*
ε_x mm mrad (RMS norm)	0.38 (+8%)	0.385 (+10%)	1.92 (x5, effective)	1.96 (effective)	0.59 (+68%)	0.75 (+120%)
ε_y mm mrad (RMS norm)	0.48 (36%)	0.48 (36%)	0.58 (+66%)	0.58 (+66%)	0.53 (+52%)	0.53 (+52%)
ΔE (90%) keV	165	~200	painting		540	810
$\Delta\phi$ (90%) rad	1	~1.6	painting		3.1	4.8

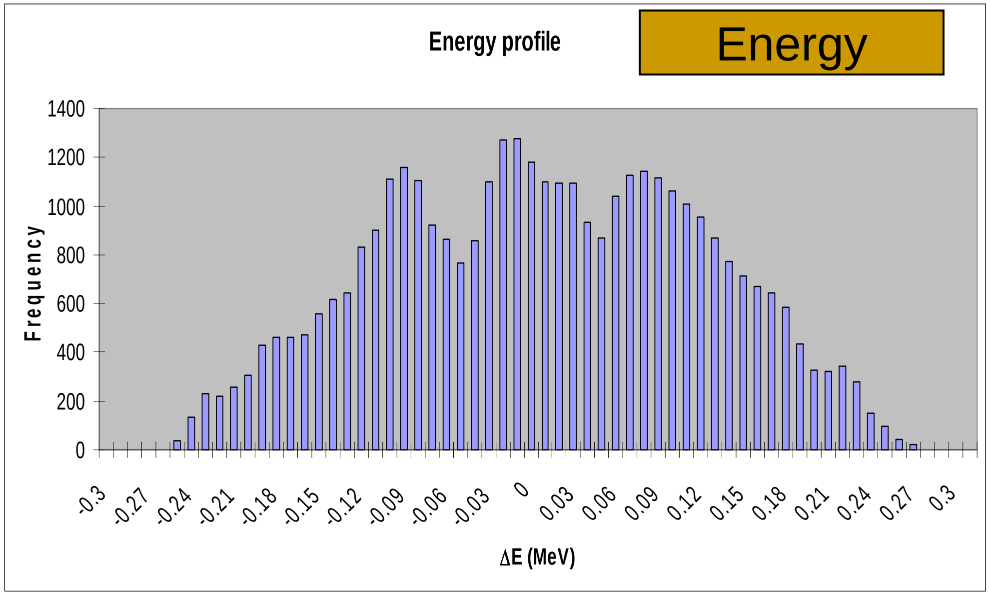
Jitter due to Linac RF errors: σ_E=270 keV, σ_ϕ=1.8 deg RMS at 352 MHz

PSB bucket (0.1 μs slice) / case 2

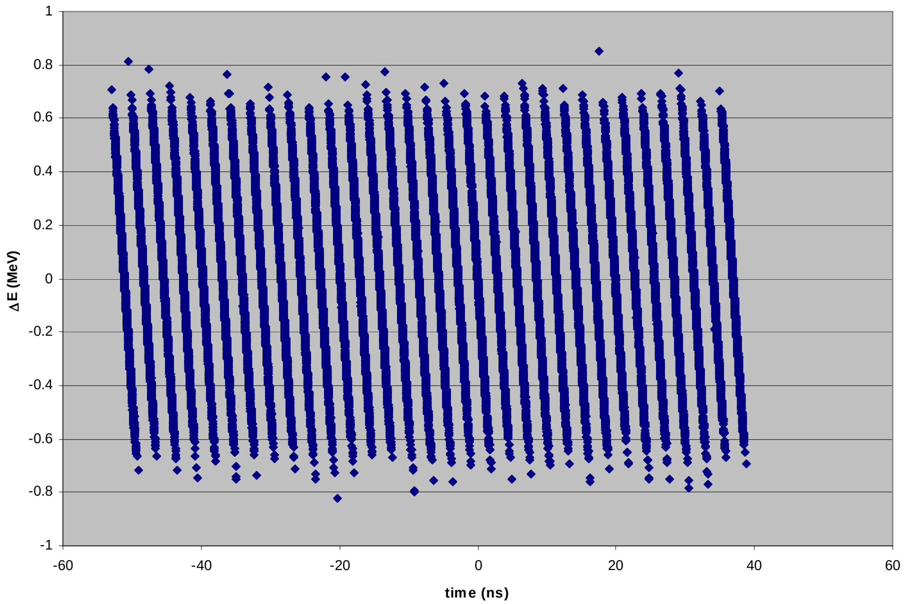


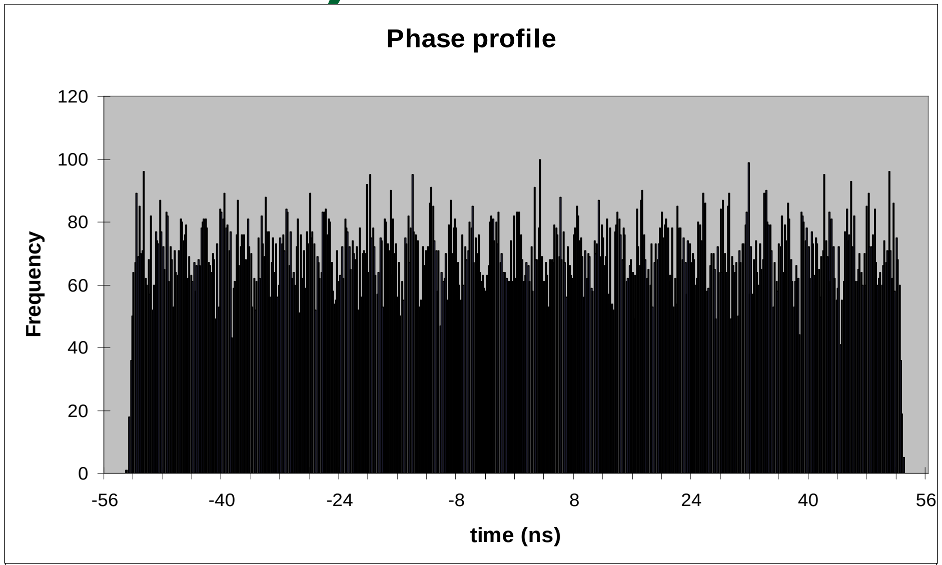


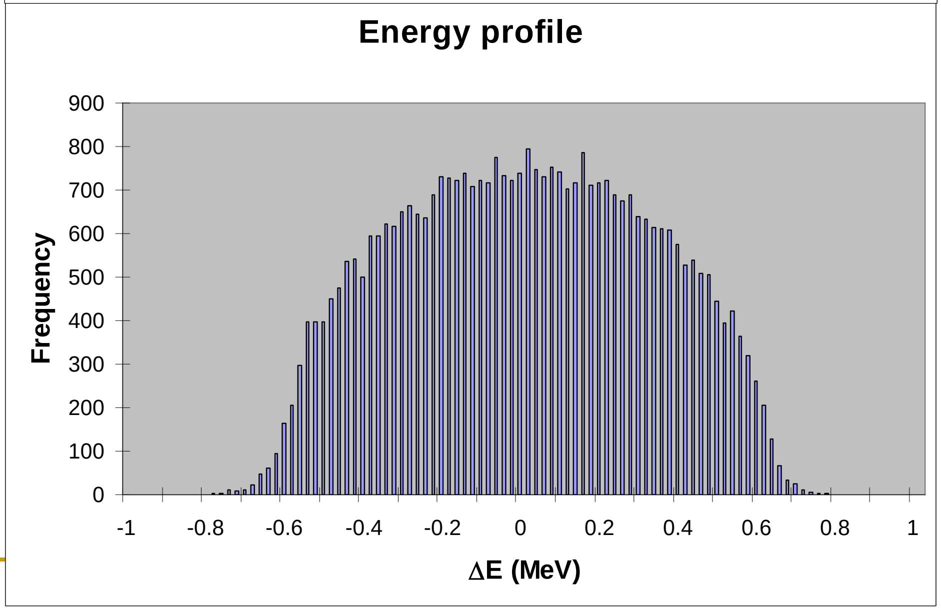
352.2 MHz linac structure still evident!



PSB bucket (0.1 μs slice) / case 3







More uniform distributions!

Next?

- Worth considering a

  case 4: more “relaxed” energy modulation & no debuncher cavity to take advantage of ‘natural’ energy spread? what about uncontrolled jitter effects?
- Continue beam simulations in the Booster (in transfer line approximation)
- Combine transverse & longitudinal studies:
  - effects of dispersion at injection (transverse emittance blowup, correlation b/w transverse and longitudinal phase spaces..)
  - consequences for stripping foil
  - transverse emittance budget?
  - is energy modulation feasible with planned injection HW equipment?
  - line acceptance and required physical aperture?
  - effects of H/V coupling
  - effect of energy jitter due to Linac RF errors…
- Beam dump and diagnostics