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accelerator physics, optics and instrumentation challenges

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with

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PPA’09 workshop - partially supported by the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579

optics needs

in front of plasma

- [adjustable] momentum compaction (R_{56}) ~ 1-5 m ?

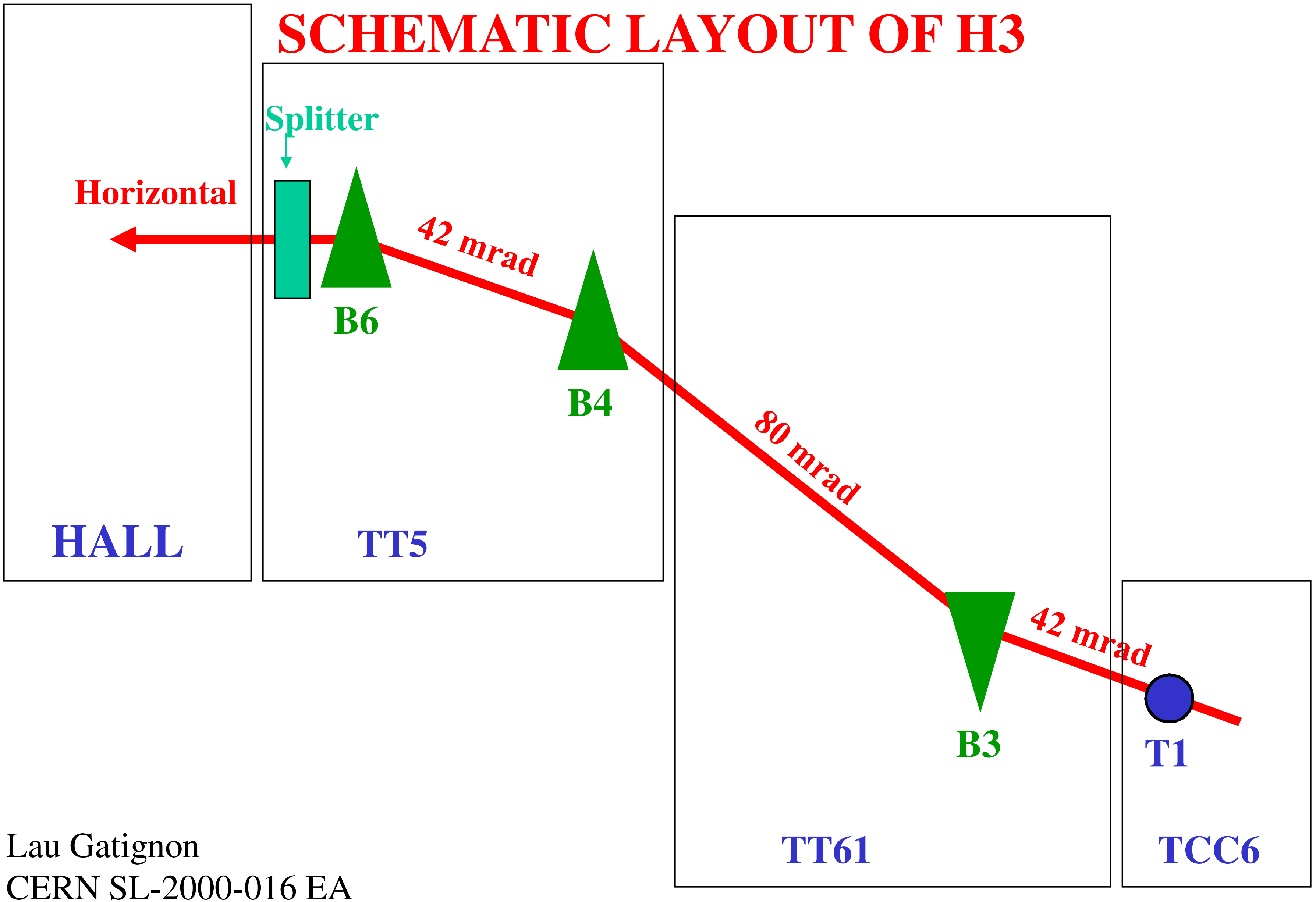
at plasma

- zero dispersion
- small beta function, but not smaller than plasma length (say ~5 m or more)

behind plasma

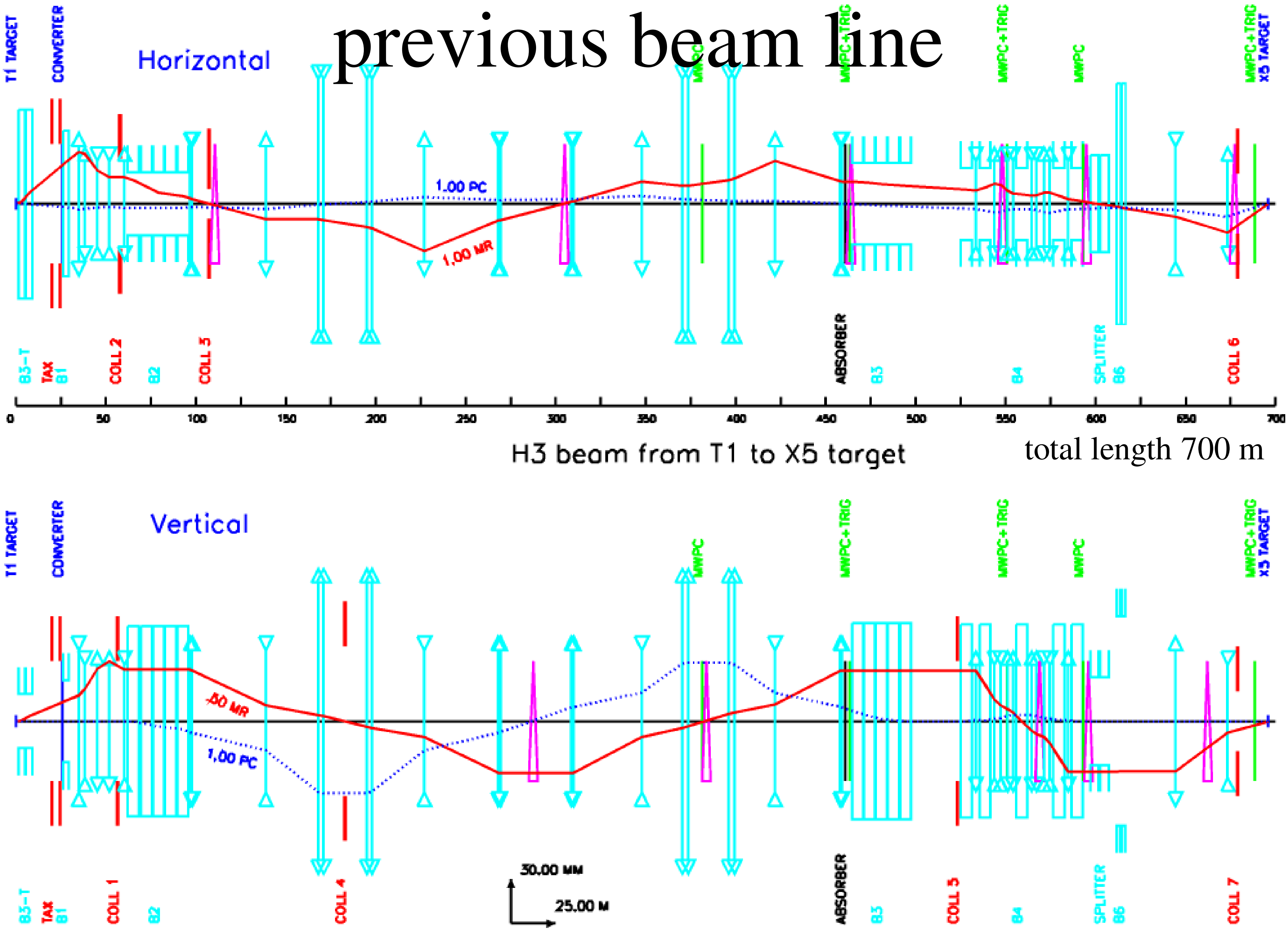
- “spectrometer” with large dispersion;100 MeV change is ~$2x10^{-4}$: dispersion of 1 m would lead to 0.2 mm displacement of particles with 100 MeV offset
- image point, 180 degrees phase advance from plasma (include or not include plasma focusing?); matching of outgoing optics for plasma effect?

previous beam line



Lau Gatignon
CERN SL-2000-016 EA

previous beam line



total length 700 m

Lau Gatignon, CERN SL-2000-016 EA

from old to new beam line

total length 700 m

in previous optics:

~zero dispersion from 500 m onward

"cell length" ~ 100 m

for plasma acceleration

plasma around 500 m point?! (or earlier?)

assume 90 degree phase advance / cell

consider FODO optics with **cell length 2*L*~50 m**

β_{max}**~85 m,** β_{min}**~15 m**

quadrupole focal strength:

$1/f \sim 0.057\ m^{-1}$

$$\beta_{max} = (2+\sqrt{2})L \sim 3.4L \quad \beta_{min} = (2-\sqrt{2})L \sim 0.6L$$

pole-tip radius a=2 cm, magnet length 4 m → B_{tip}**~1.65 Tesla, *OK***

may need a special focusing optics to reach β^*~5 m at plasma

$D \sim \theta_B 4L = 1$ m→ l_B**=10 m with** B**=1.5 T** would suffice

beam parameters

	"LHC" bunch	TOTEM bunch	"LHC" lead bunch
ion	p^+	p^+	$^{208}Pb^{82+}$
energy / nucleon [GeV]	450	450	177.4
ions/bunch [10^{10}]	11.5	3-6	0.007
rms longitudinal emittance/Z [eVs]	0.06	0.02	0.06
rms bunch length [ns]	<0.5	<0.3	0.33
relative rms energy spread [10^{-3}]	0.3	<0.18	0.4
rms transverse emittance [μm]	3.5	1.0	1.4
rms beam size at β^*~5 m	200 μm	100 μm	200 μm

1 bunch every ~30 s
or several bunches every 30 s

1 ns = 30 cm, 3×10^{-4} ns = 100 μm

getting shorter or “better” bunches

- RF bunch compression in beam line
- “shaping” the distribution e.g. steep edge
- bunch rotation via change in RF voltage or momentum compaction prior to extraction
- x(y)-z 4/6-D emittance exchange transformation
- creating microstructure at plasma wavelength
- combination of the above

RF bunch compression in line

minimum bunch length with full compression

$\sigma_{z,f}= R_{56}\, \sigma_{\delta,0}$

(1) require $\sigma_{z,f}$ =200 μm, take $\sigma_{\delta,0}$~2x10^{-4}

$\rightarrow$ $R_{56} < 1$ m OK

$V_{rf}\, f_{rf}= E\, c/e/R_{56}/(2\pi)$ for full compression

assume f_{rf}=3 GHz $\rightarrow$ $V_{rf} > 7$ GV

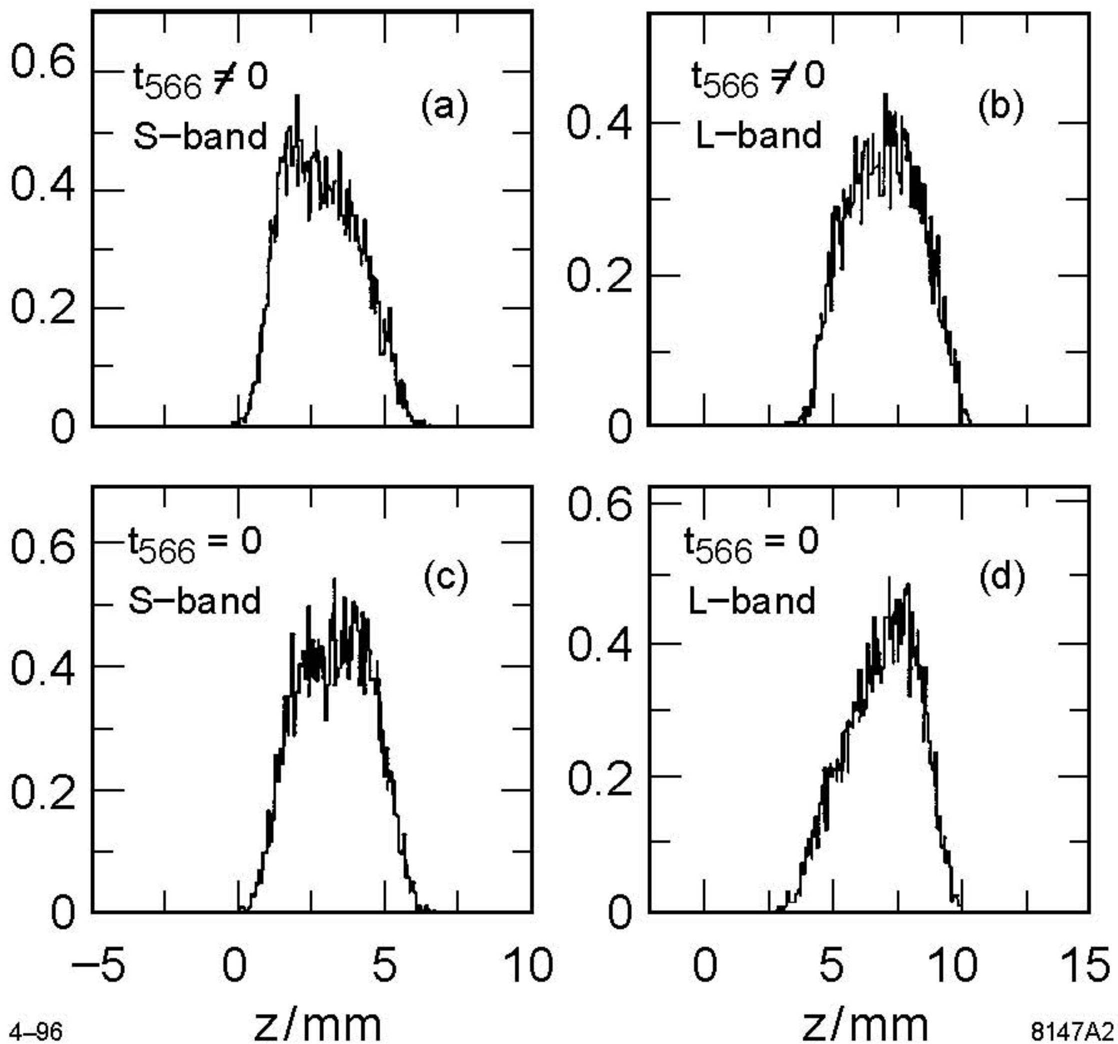
(2) require $\sigma_{z,f}$ =1 mm, take $\sigma_{\delta,0}$~2x10^{-4}

$\rightarrow$ $R_{56} < 5$ m OK $\rightarrow$ $V_{rf} > 1.4$ GV

with 30 MV/m gradient & 0.65 filling factor

this would need ~75 m of 3-GHz linac

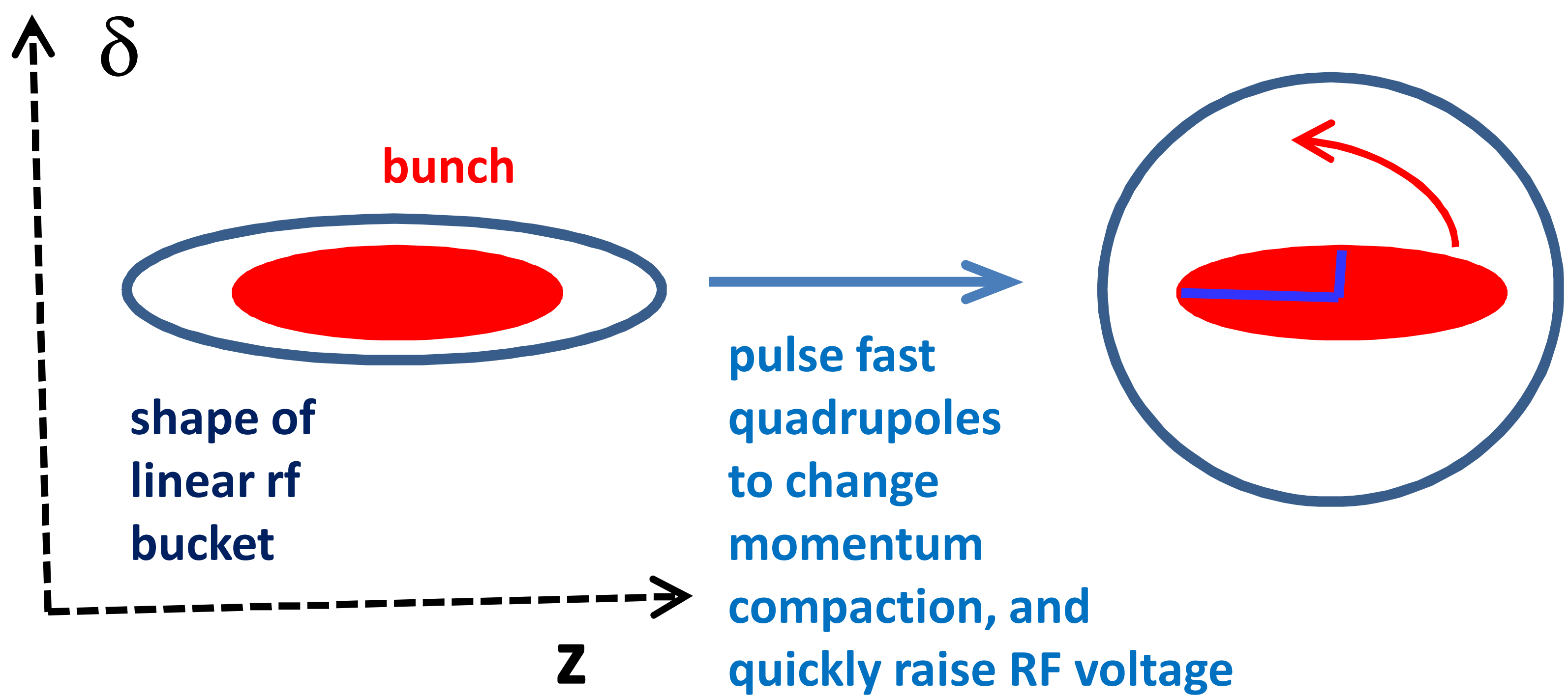
bunch shaping



modifications of the second order terms allow creating a sharp edge at the start or end of the bunch

F. Zimmermann
Simulation studies of the SLC Bunch Compressor, EPAC'96

bunch rotation prior to extraction



extract after ¼ synchrotron oscillation when bunch length is minimum

$$\sigma_{z,min} \approx 2\sqrt{\frac{V_{RF,initial}\,\alpha_{c,new}}{V_{RF,new}\,\alpha_{c,initial}}}\,\sigma_{z,initial}$$

bunch length scales with the square root of pulsed momentum compaction factor

SPS initial momentum compaction

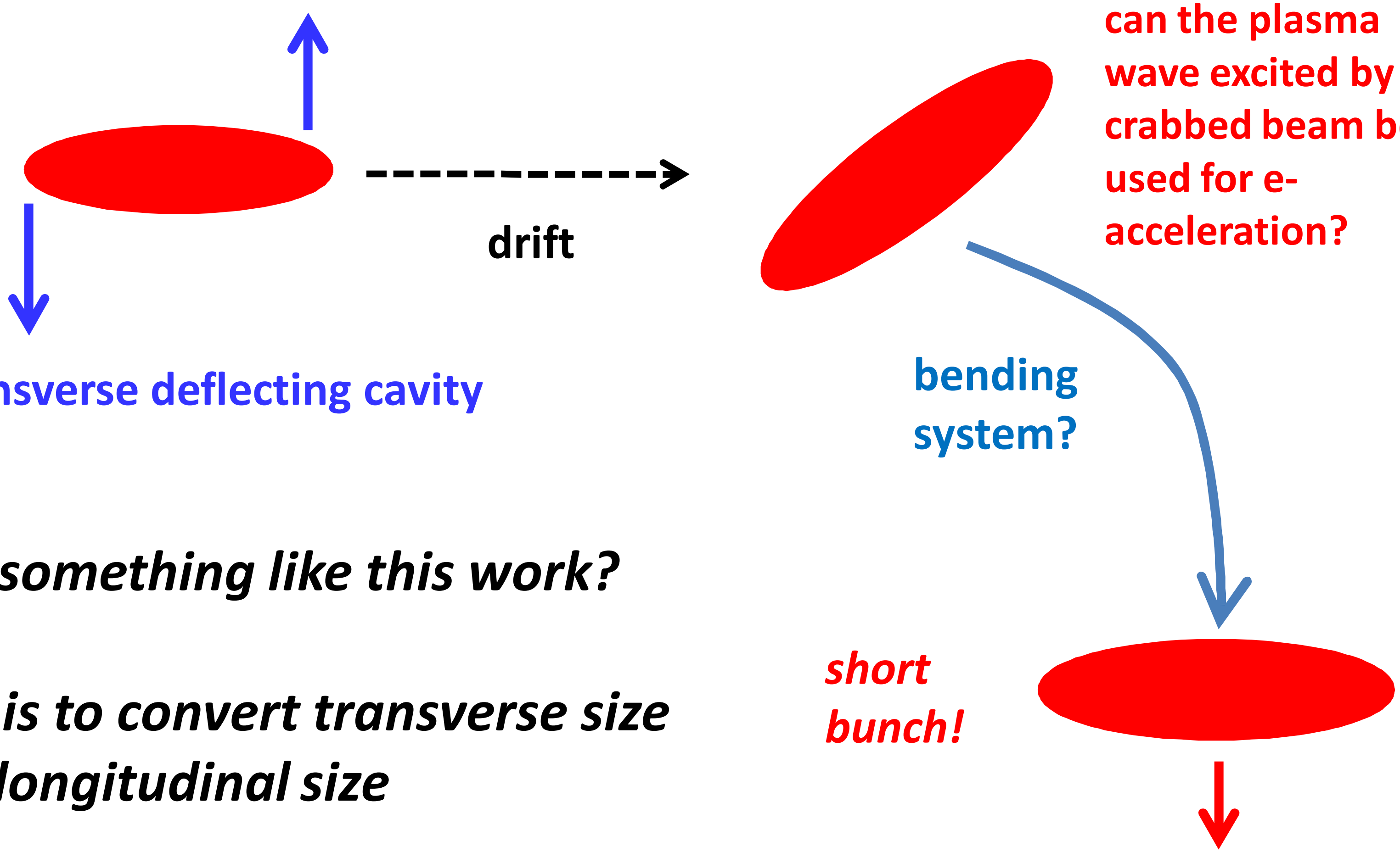
$\alpha_{c,initial} \sim 0.00186$

with new optics & additional magnet circuits
we may hope for $\alpha_{c,new} \sim 10^{-4}$

initial RF voltage ~ 7 MV
may we "hope" for final RF voltage ~ 10x higher (70 MV) ??

→ then expect compression by factor
$2 \times 10^{-1} / \mathrm{Sqrt}(10) \sim 0.06 \sim 1/16$

transverse deflecting cavity+ bending system



can something like this work?

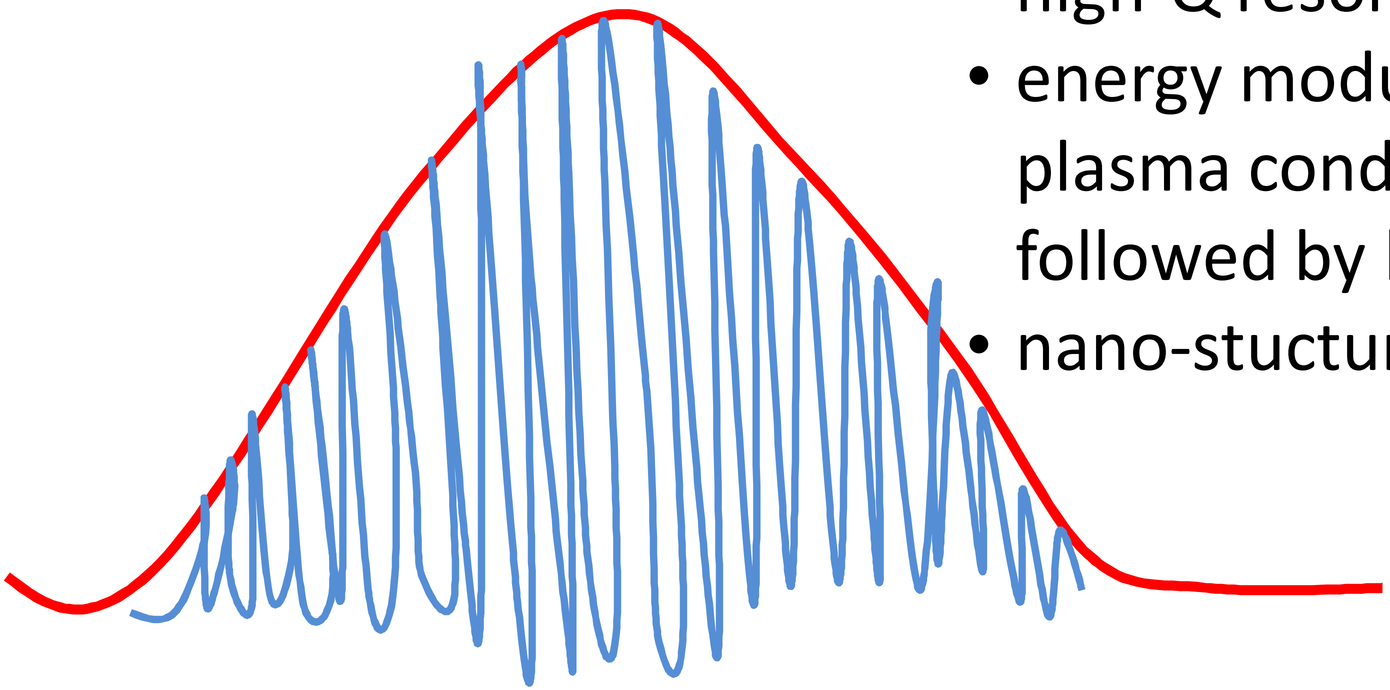
idea is to convert transverse size into longitudinal size

(above schematic ignores x-dependent energy change from crab cavity)

or transverse crab cavity followed by “slit”?

generating microstructure

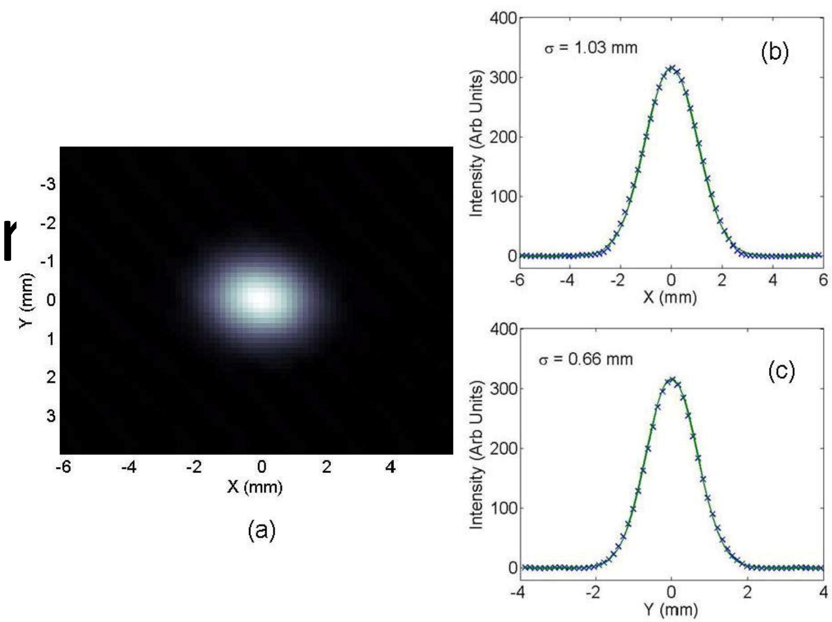
- microwave instability with high-Q resonator
- energy modulation from plasma conditioner followed by bends
- nano-stuctured chopper



schematic of a bunch with longitudinal microstructure [blue] superimposed on an original smooth bunch shape [red] —horizontal axis is time; vertical shows charge density

instrumentation

- beam position monitors along the line
- at spectrometer/image point we need a 2-D profile monitors (OTR or other screen, pixel detector, …?)
- streak camera?
- or fast kicker for time resolution inside bunch?
- synchrotron radiation from SC bend or plasma?



OTR image of 150 GeV protons at the Tevatron, (V. Scarpine et al, 2006)

source, optics & instrumentation for e- beam

no work & no thinking done so far (by me at least)

- need space and location for e- injector
- need to match and inject into plasma
- need synchronization and alignment with *p* beam

some experience from LEP, SLC, CLIC, CTF-3

conclusions

- optics looks feasible; 50 m cell length, 1.65 T pole-tip field
- beam parameter sets
- several schemes for achieving moderate bunch compression or bunch shaping
- e- injector & e- optics to be looked at