



Compton stacking ring update

Frank Zimmermann
on behalf of the POSIPOL Collaboration

Particular thanks to: Fanouria Antoniou, Robert Chehab,
Maxim Korostelev, Masao Kuriki, Tsunehiko Omori,
Yannis Papaphilippou, Louis Rinolfi, Junji Urakawa,
Alessandro Variola, Alessandro Vivoli, Vitaly Yakimenko

LAL, 1 December 2008

some Compton source history

physics/0509016
CARE/ELAN Document-2005-013
CLIC Note 639
KEK Preprint 2005-60
LAL 05-94
September 2, 2005

Conceptual design of a polarised positron source based on laser Compton scattering – **Snowmass'05**

Sakae Araki *et al.* CARE-ELAN-DOCUMENT-2005-013, CLIC-NOTE-639, KEK-PREPRINT-2005-60, LAL-05-94, Sep 2005. 39pp.

Contributed to 2005 International Linear Collider Physics and Detector Workshop and 2nd ILC Accelerator Workshop, Snowmass, Colorado, 14-27 Aug 2005. e-Print: **physics/0509016**

Updates & improvements:

POSIPOL2006 Geneva
POSIPOL2007 Paris
POSIPOL2008 Hiroshima
CLIC2008 Geneva

arXiv:physics/0509016v2 [physics.acc-ph] 15 Sep 2005

Conceptual Design of a Polarised Positron Source Based on Laser Compton Scattering — A Proposal Submitted to Snowmass 2005 —

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activity driven by J. Urakawa, T. Omori, M. Kuriki, A. Variola, K. Moenig, et al

Compton source basics

collide 1.3-1.8 GeV e- beam with laser pulse
stored in optical cavity ($\lambda \sim 1 \mu\text{m}$);

yield $\sim 0.2 \gamma/\text{e-}$ for single 600 mJ cavity *

convert Compton scattered photons to e+/e-,
and capture e+

yield $\sim 0.01 \text{ e+}/\gamma$ *

stack in accumulation ring

ex.: $6 \times 10^{10} \text{ e-}/\text{bunch} \rightarrow 10^8 \text{ e+} \rightarrow 40\text{-}60 \text{ stackings}$
needed to achieve $4.5 \times 10^9 \text{ e+} / \text{bunch}$ for CLIC;
unless we use several optical cavities like ILC

various scenarios

Compton sources

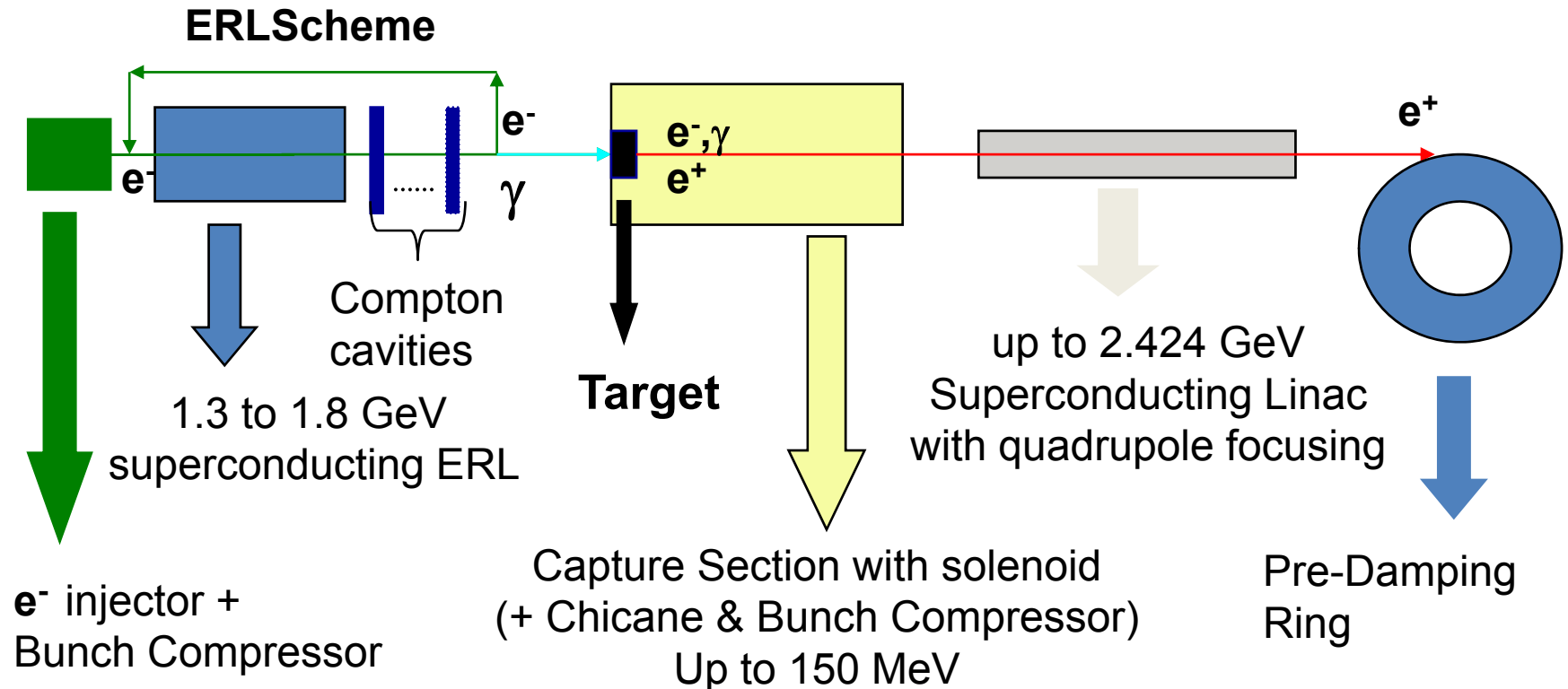
- **Compton ring – CR** (“pulsed”), or
- **Compton ERL – CERL** (“continuous”)

accumulation rings

- **ILC damping ring**
- **CLIC pre-damping ring**
- **dedicated accumulator ring?**

initial e+ parameters (from A. Vivoli's simulation)

parameter	value
#e+ / pulse	6.65×10^7
longitudinal edge emittance (10 x rms) at ~200 MeV	0.72 meV-s
transverse normalized edge emittance (10 x rms)	0.063 m-rad



ILC-CLIC comparison

- ❖ beam structure: CLIC has a **smaller bunch charge** (about 5x less) and **less bunches per pulse** (about 10x less) → *relaxed laser parameters*
- ❖ **bunch spacing: 0.5 ns (CLIC) instead of 2.8 ns (ILC)** → *do not stack on every turn in every bucket*, but e.g. every 40th turn with 20 ns e- spacing
- ❖ damping ring; CLIC damping ring needs to produce beam with extremely small emittance, limited dynamic aperture; → **pre-damping ring** is required; *we can use and optimize pre-damping ring for stacking polarized e⁺ from Compton source*
- ❖ CLIC **repetition rate is 50 Hz instead of 5 Hz** for ILC, but (pre-) damping ring damping times are more than 10 times shorter
→ *Compton scheme is easier for CLIC!*

(1) CLIC

- *Compton Ring or*

- *Energy Recovery Linac*

stacking simulations for CLIC CERL/CR scheme

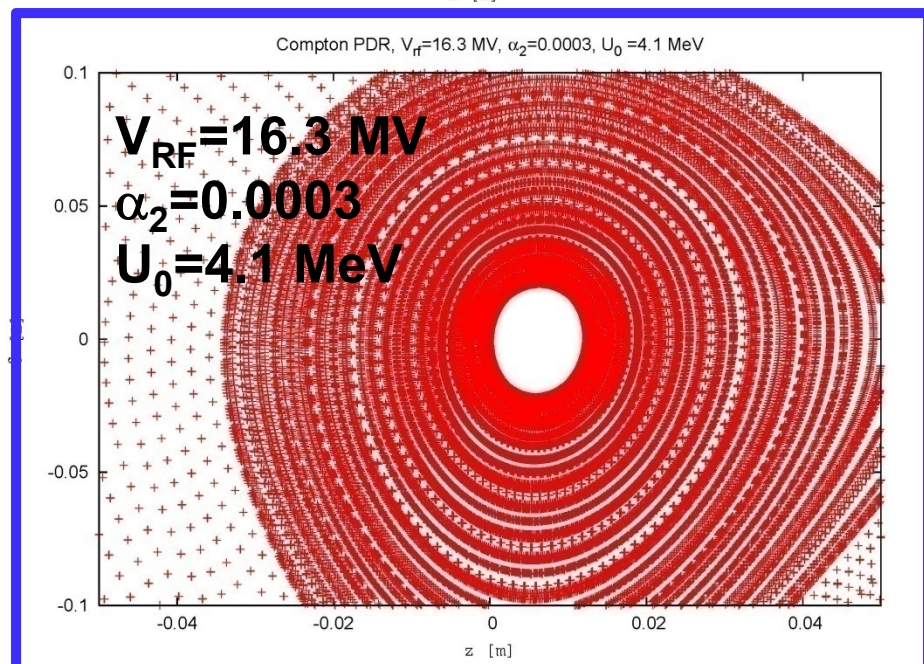
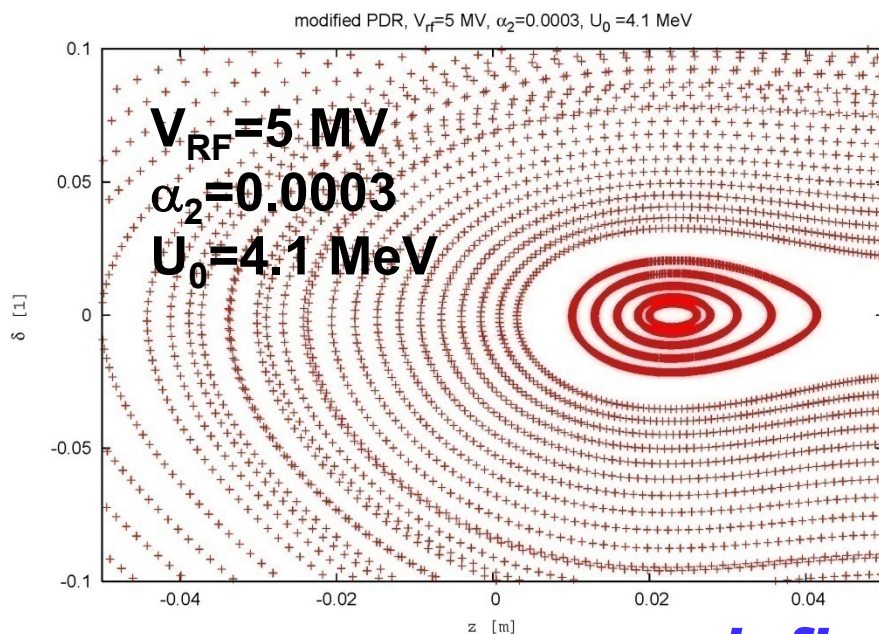
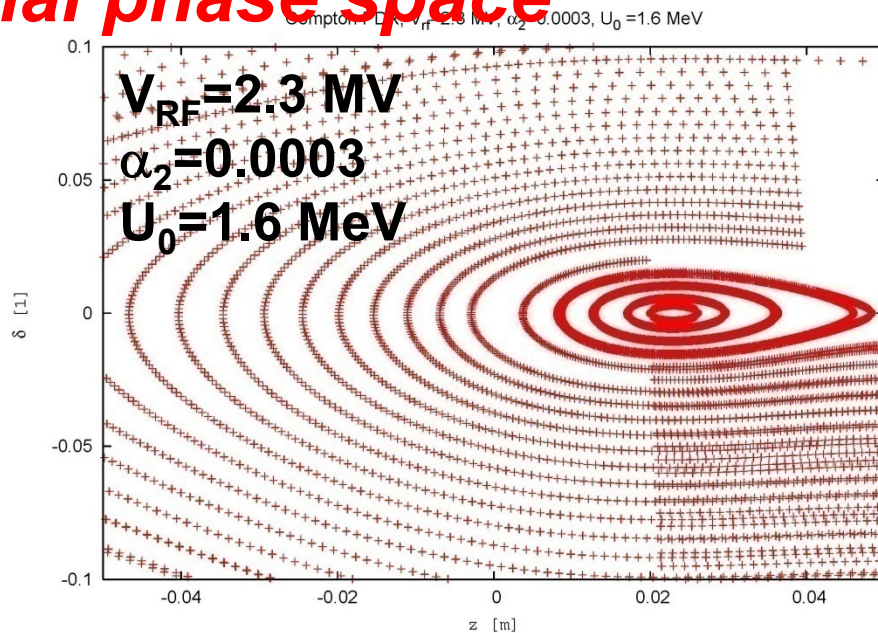
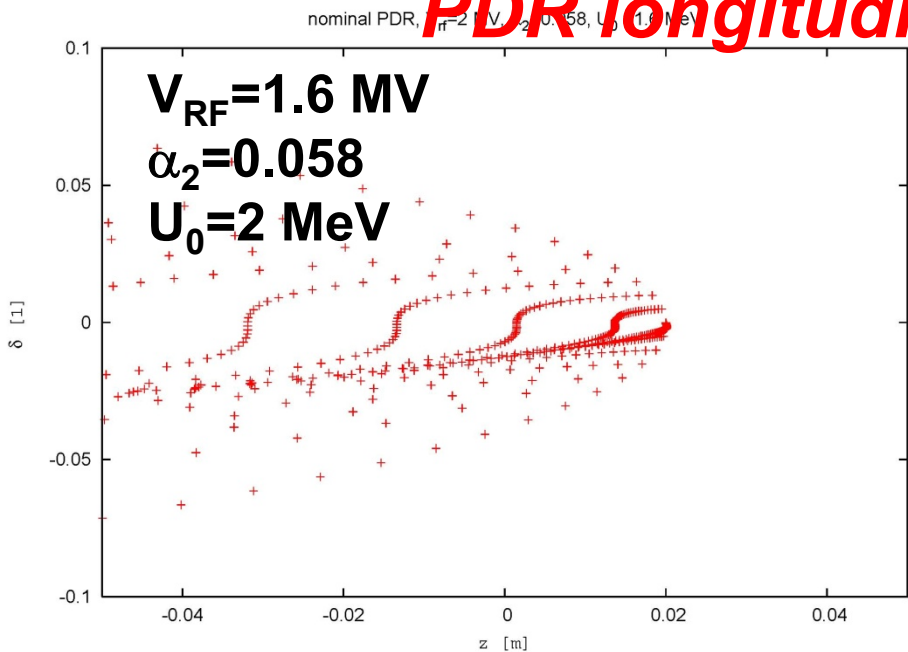
- **stacking is done in longitudinal phase space**
RF bucket \gg longitudinal edge emittance of injected e^+
- **ingredients: *sinusoidal rf, momentum compaction, 2nd order momentum compaction, radiation damping, quantum excitation, initial e^+ parameters* [A. Vivoli]**
- injection septum placed at location with large dispersion; septum blade \ll transverse beam size
- **inject every 40th turn into same PDR bucket** (20 ns bunch spacing for e^- beam; arranged by suitable CR/CERL-PDR circumference difference, e.g. 0.15 m); **fast small septum bump** at moment of injection (probably not needed)

CLIC-Compton Pre-Damping Ring Para's

parameter	value*	"Compton-PDR"
#bunches / train	312	
bunch spacing	0.5 ns	
final bunch charge	4.5×10^9	
circumference	251.6 m	
RF frequency	2 GHz	
harmonic number	1677	
RF Voltage	2 MV	16.2 MV
1 st order momentum compaction	8.98×10^{-5}	
2 nd order momentum compaction	0.058	3×10^{-4}
beam energy	2.424 GeV	
longitudinal damping time	1.25 ms	0.5 ms
equilibrium momentum spread	0.095%	~0.12%
equilibrium bunch length	0.786 mm	~0.47 mm

*Fanouria Antoniou, Yannis Papaphilippou, 9 October 2008

PDR longitudinal phase space



define this as new Compton PDR!

CLIC-CERL injection scheme

continuous stacking at 50 MHz (T. Omori, A. Variola)

80 injections over 2400 turns (~ 2.7 ms)

injecting every 40th turn ($\Delta\phi_s = 0.50 \times 2\pi$)

followed by 20647 turns (~ 17.3 ms) damping;

longitudinal damping time 0.5 ms

inject with constant offset δ , fast orbit bump at sept.

parameters of injected e⁺ bunchlets:

<Vivoli san's result:

~ 2.9 MeV at ~ 200 MeV

$$\sigma_{z0} = 11.4 \text{ mm}, \sigma_{\delta 0} = 8 \times 10^{-4} \text{ (2 MeV)}$$

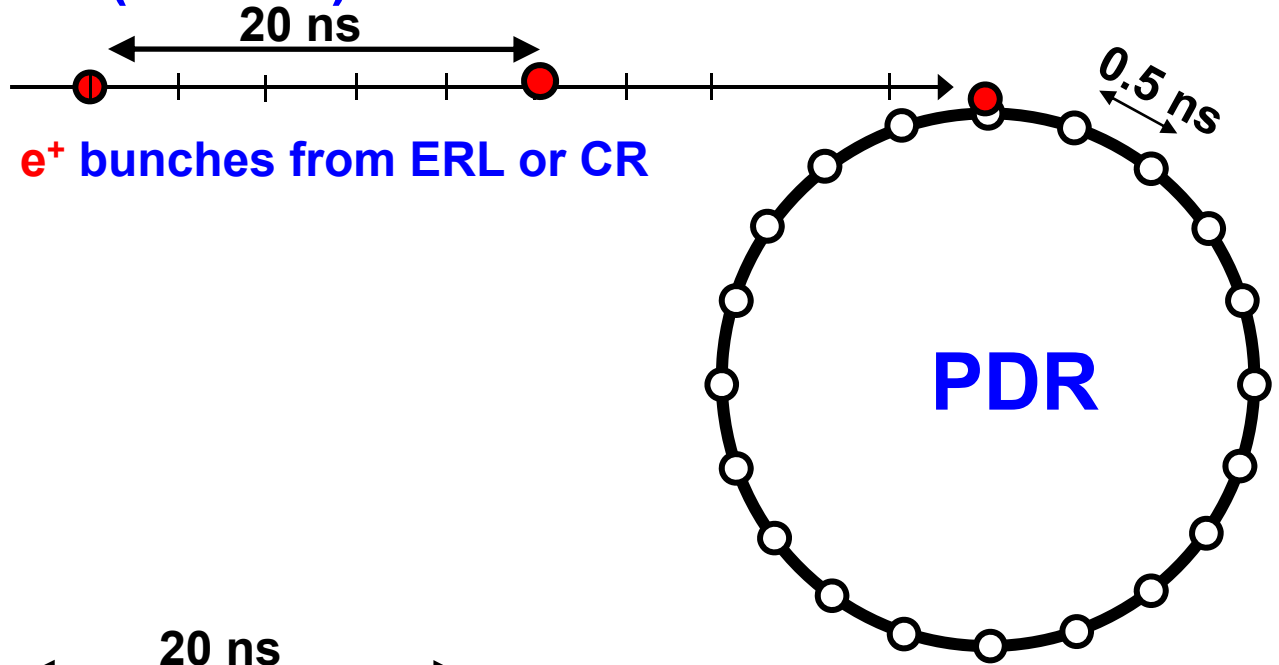
might require ***energy pre-compressor***

note:

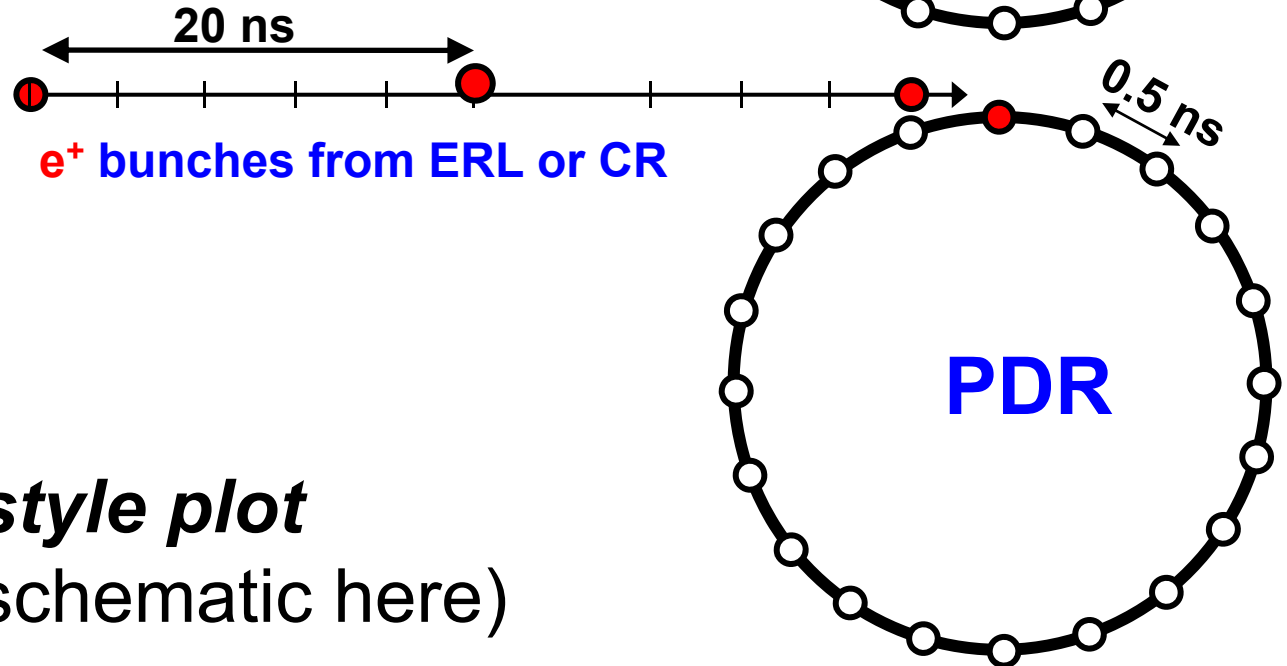
Omori-san proposed injection on “unstable point”

$T_{b\text{-to-b}}(\text{CR}) = 20 \text{ ns}$ (50MHz): 1st turn of PDR stacking

(1) 1st turn
begin



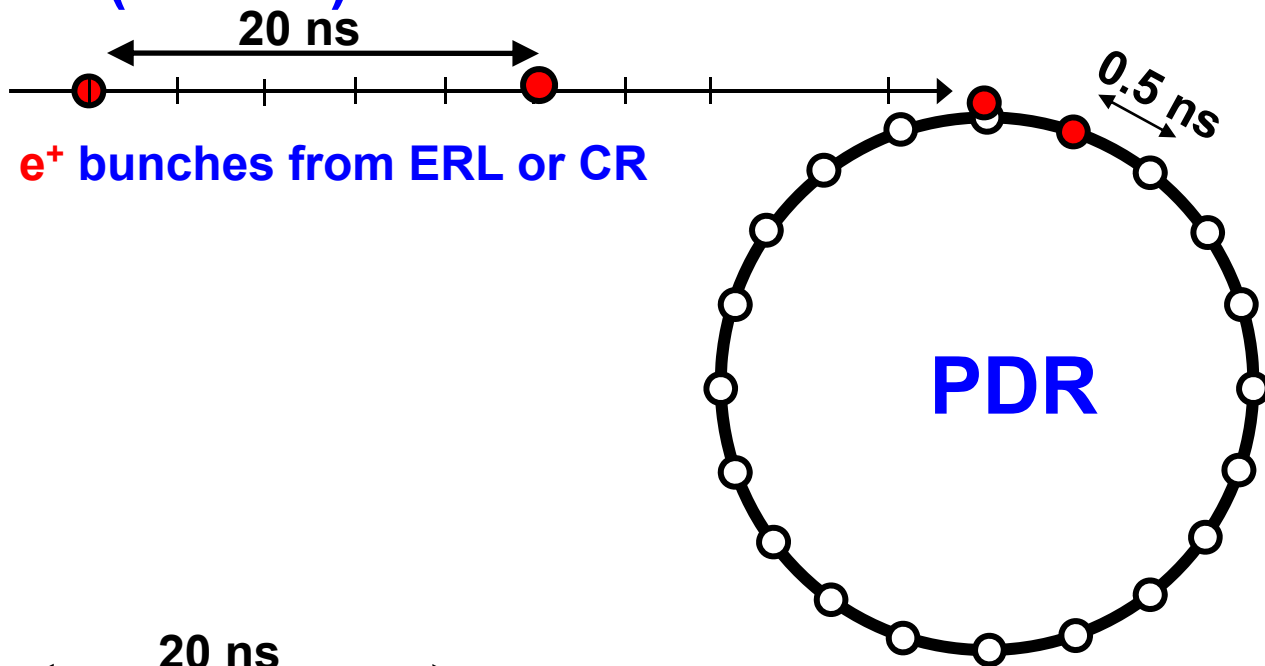
(2) 1st turn
end



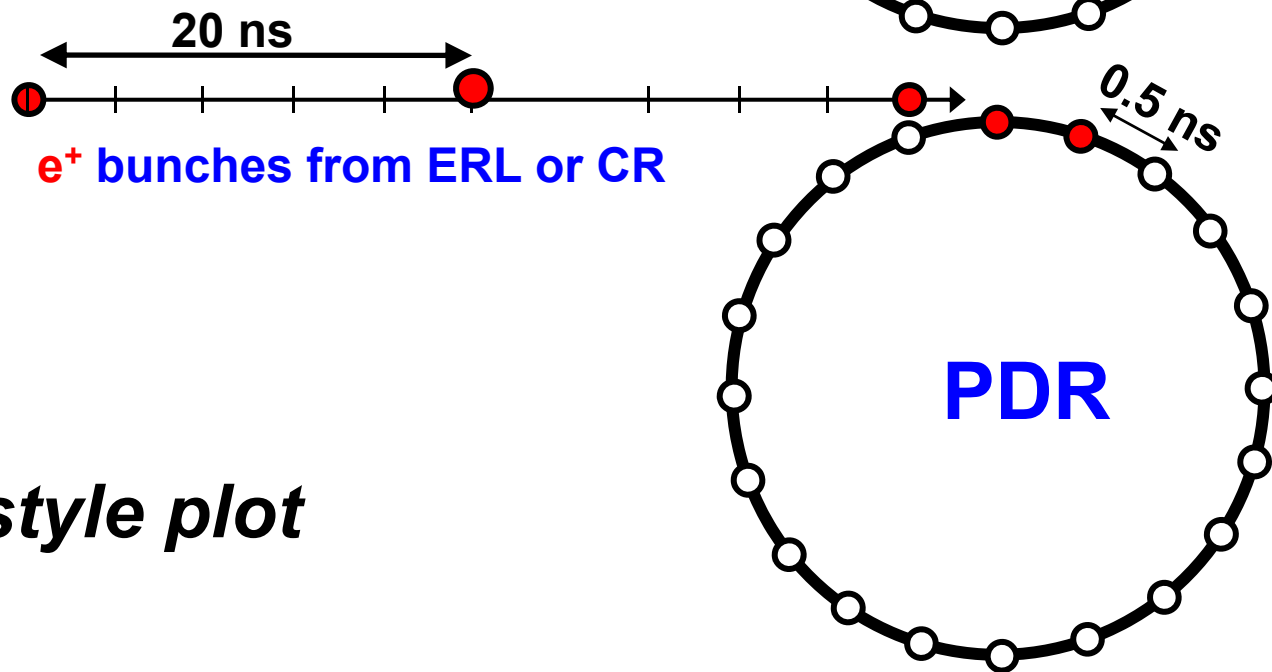
Omori-san style plot
(only rough schematic here)

$T_{b\text{-to-}b}(\text{CR}) = 20 \text{ ns}$ (50MHz): 2nd turn of PDR stacking

(1) 2nd turn
begin



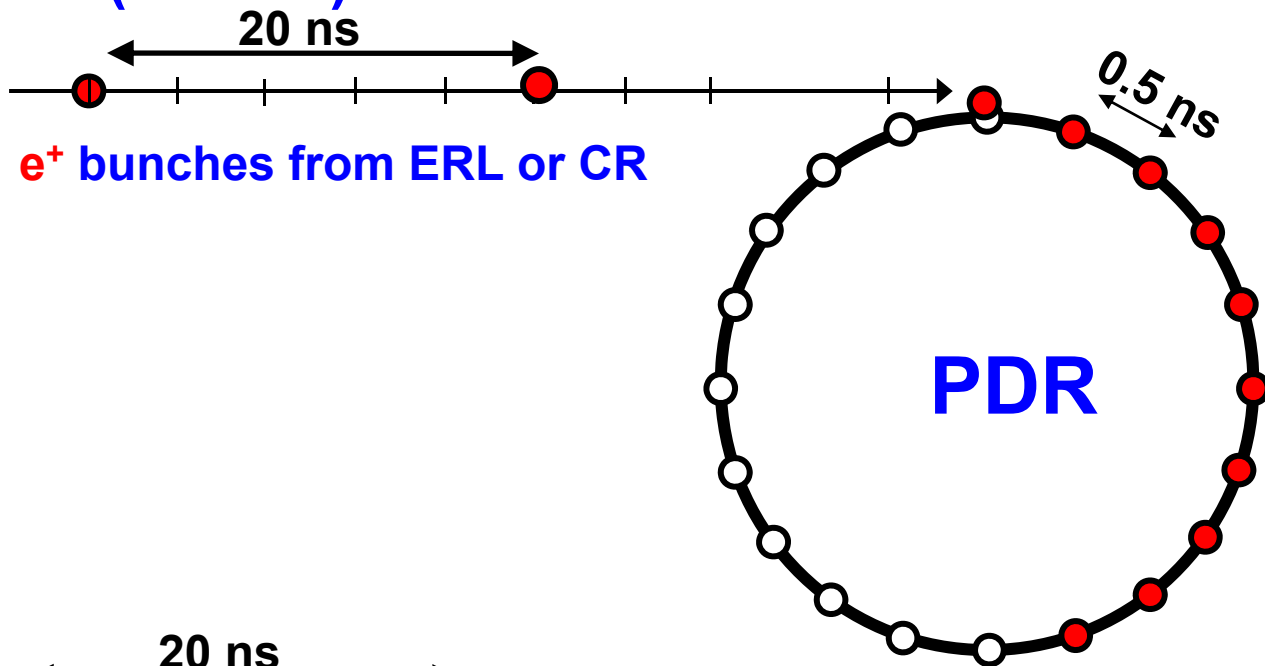
(2) 2nd turn
end



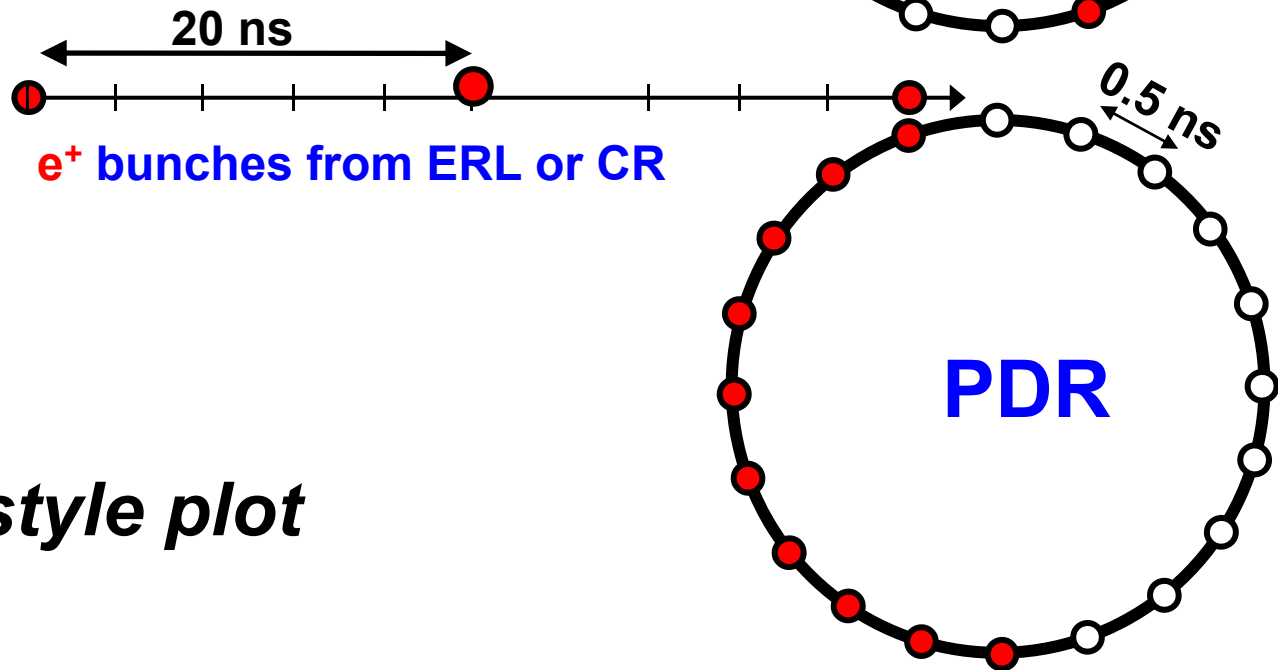
Omori-san style plot

$T_{b\text{-to-}b}(\text{CR}) = 20 \text{ ns}$ (50MHz): 40th turn of PDR stacking

(1) 40th turn
begin



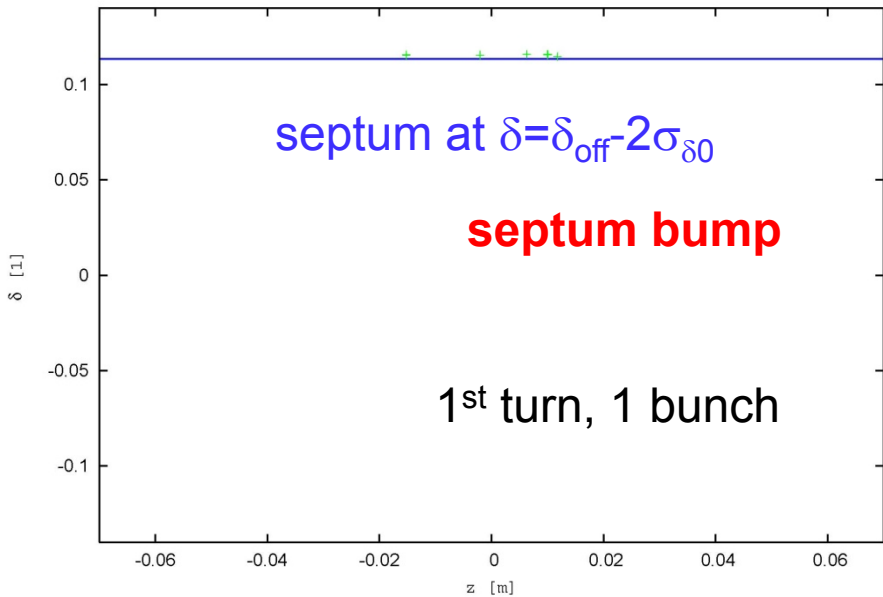
(2) 40th turn
end



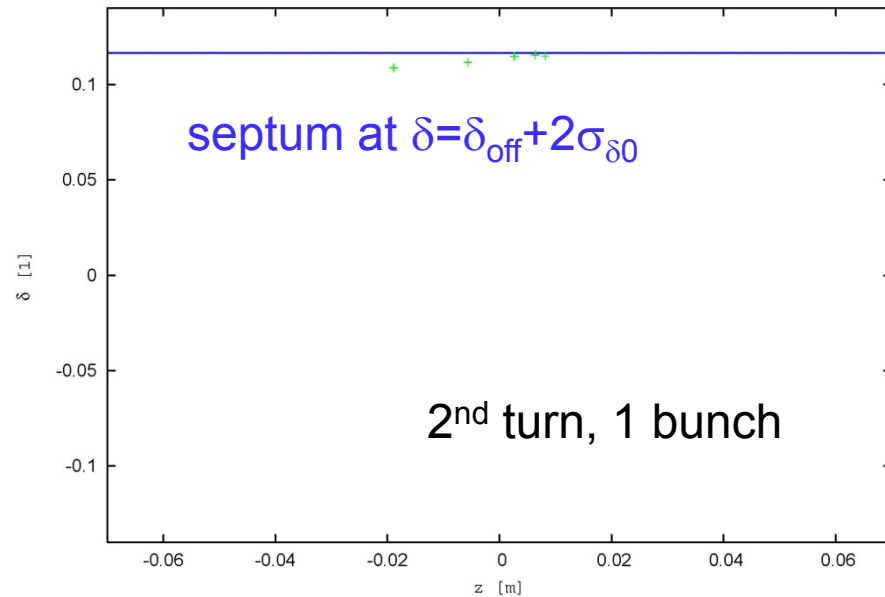
Omori-san style plot

CLIC PDR stacking simulation, example, $\delta_{\text{off}}=11.5\%$

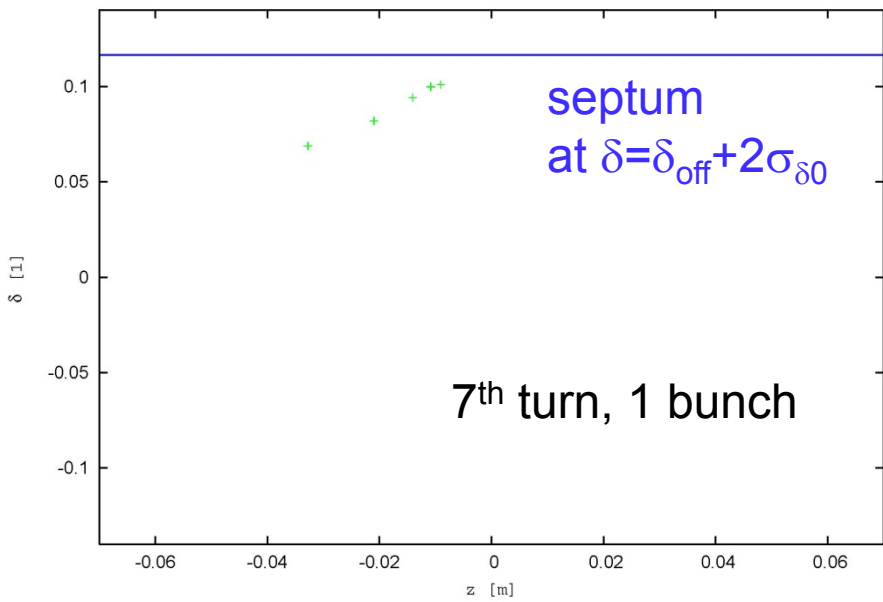
1st turn, 1 bunch



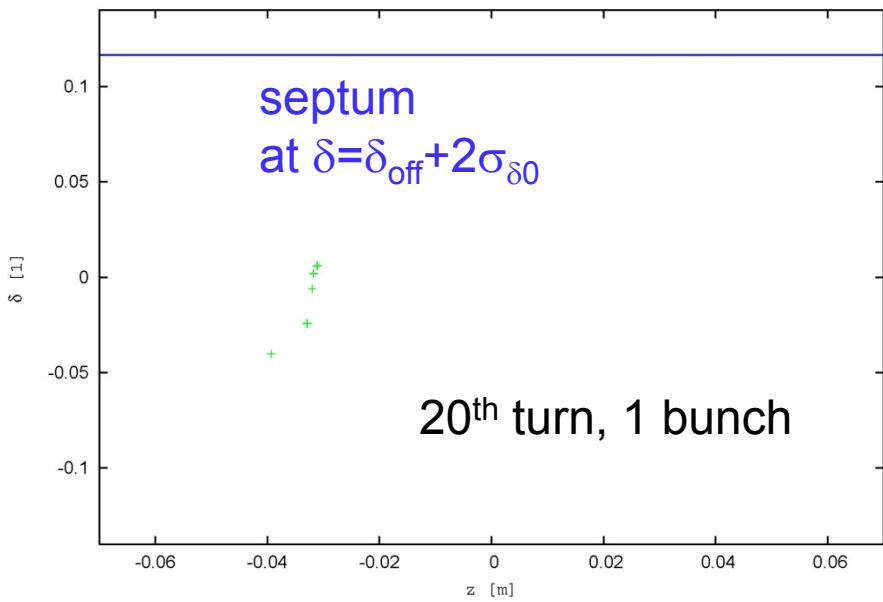
2nd turn, 1 bunch



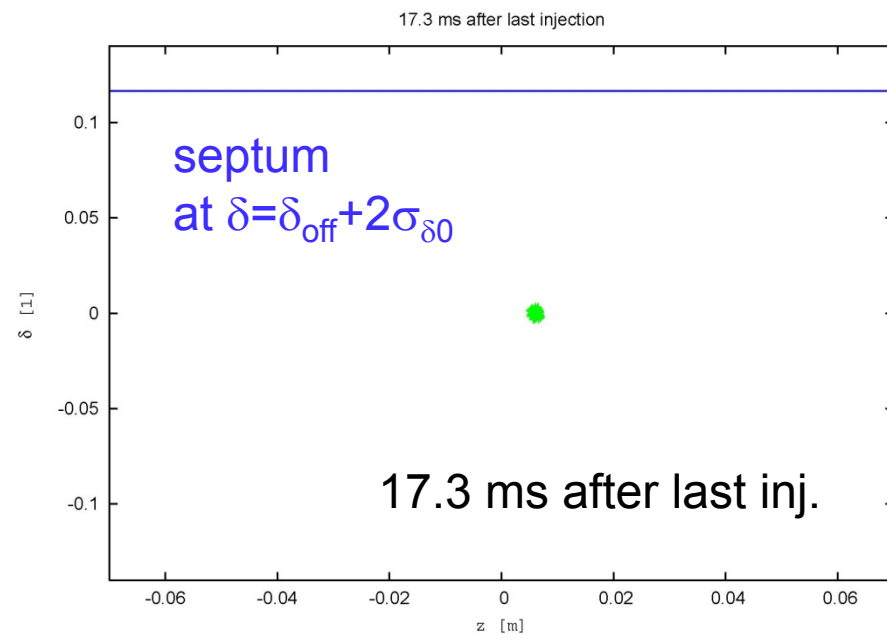
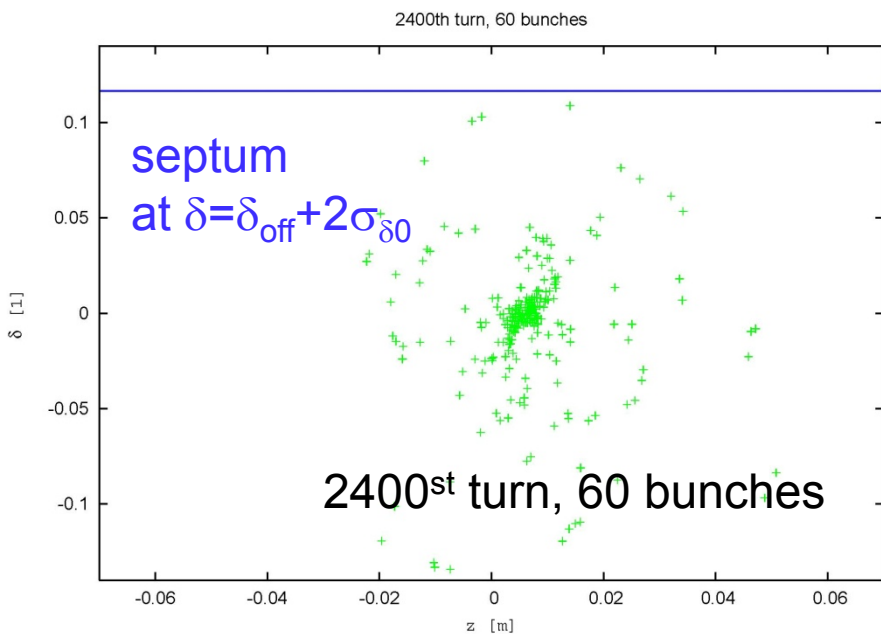
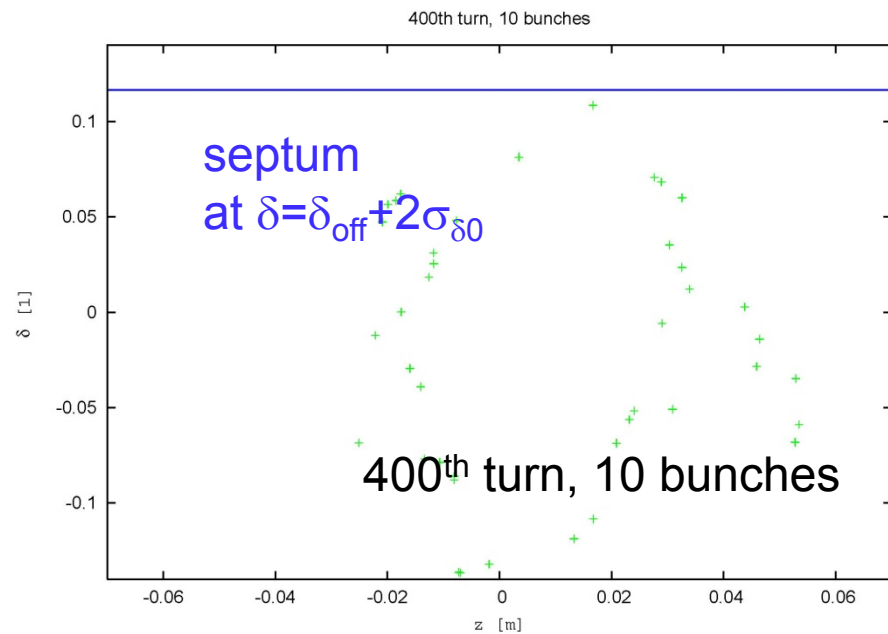
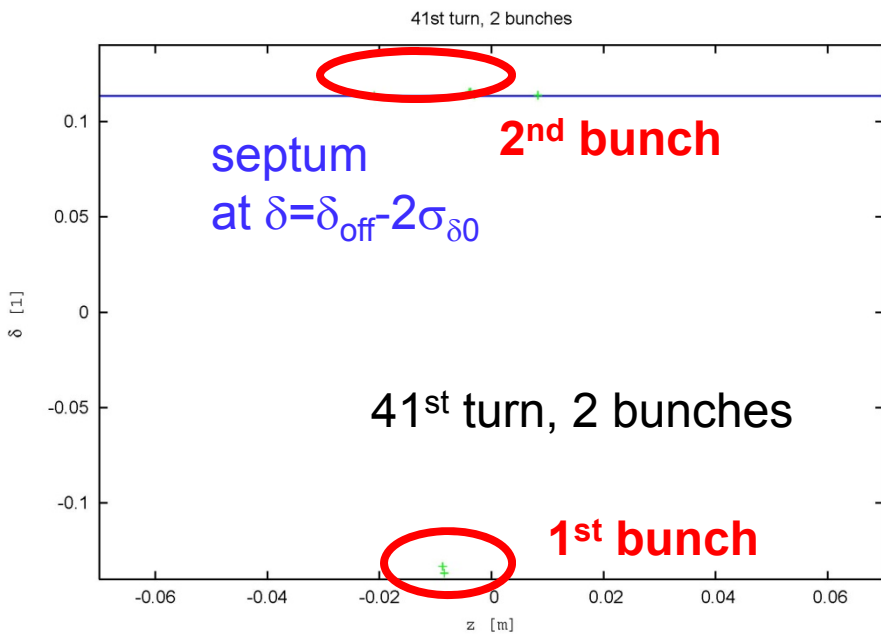
7th turn, 1 bunch



20th turn, 1 bunch



CLIC PDR stacking simulation, example, $\delta_{\text{off}}=11.5\%$



conditions for this stacking scheme to work:

$$E_{\text{loss}} \text{ (1 synchrotron period)} > 4 \sigma_{E0}$$

in our example:

$$328 \text{ MeV (80 turns)} > 8 \text{ MeV}$$

easily fulfilled

no septum bump needed if:

$$\Delta E \text{ (1 turn)} > 4 \sigma_{E0}$$

*this
should be
the goal!*

treatment of synchrotron radiation

R. Siemann, HEACC 1988

model A

$$z_{new} = z_{old} e^{-T_0/\tau_{\parallel}} + \xi \sqrt{2(1 - e^{-T_0/\tau_{\parallel}})} \sigma_{z,eq}$$

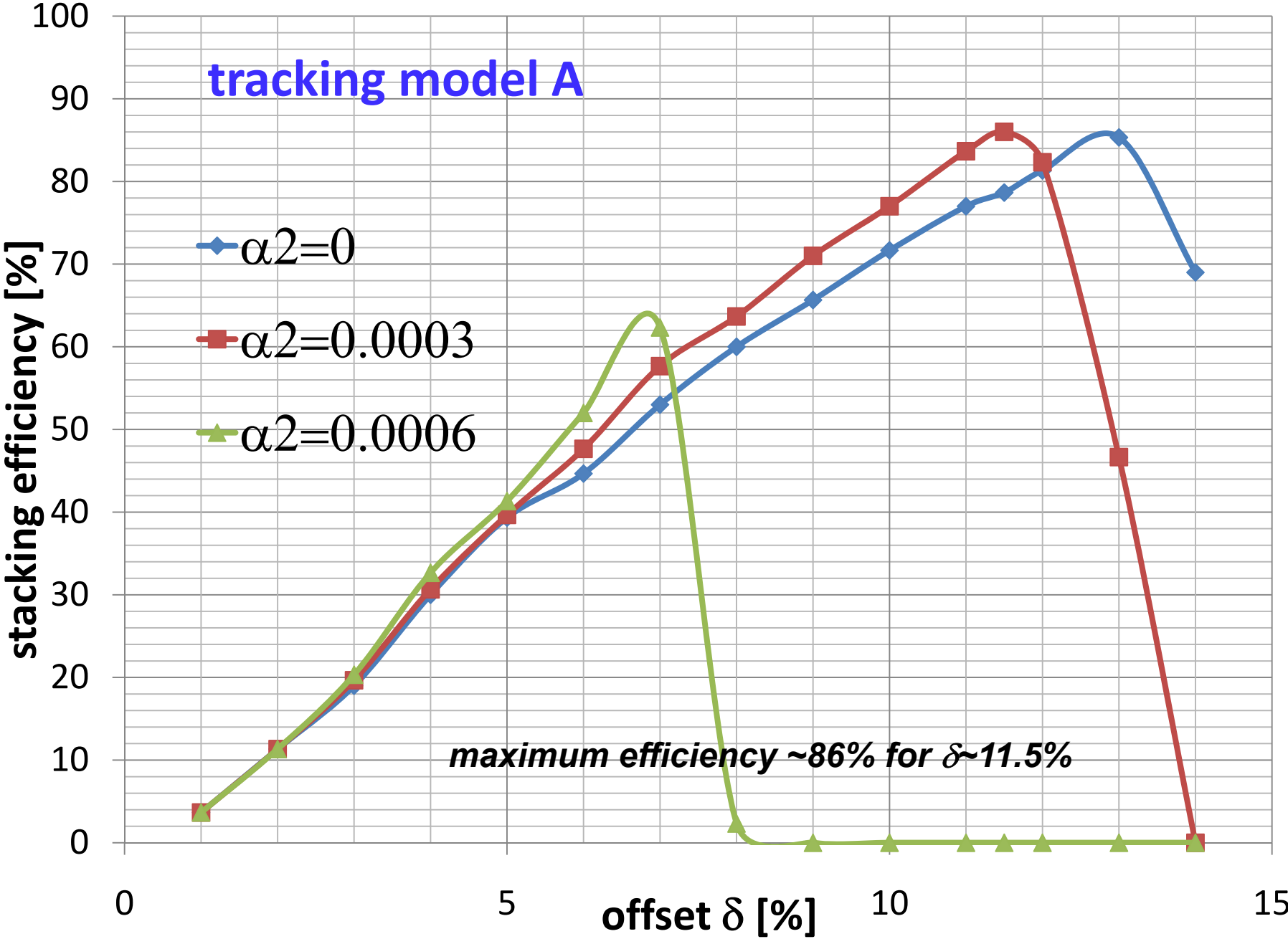
$$\delta_{new} = \delta_{old} e^{-T_0/\tau_{\parallel}} + \xi \sqrt{2(1 - e^{-T_0/\tau_{\parallel}})} \sigma_{\delta,eq}$$

model B

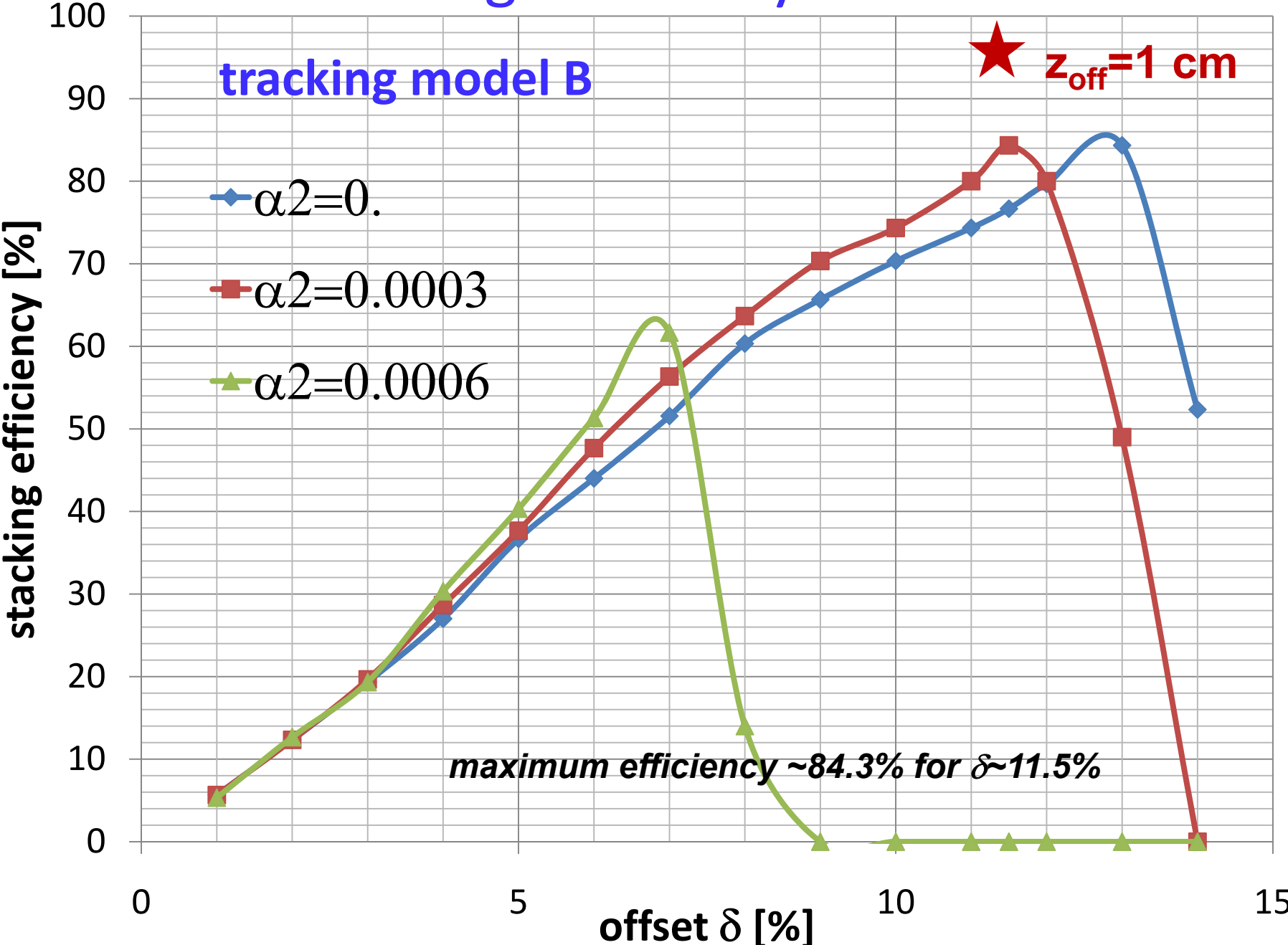
$$z_{new} = z_{old}$$

$$\delta_{new} = \delta_{old} e^{-2T_0/\tau_{\parallel}} + \xi \sqrt{2(1 - e^{-2T_0/\tau_{\parallel}})} \sigma_{\delta,eq}$$

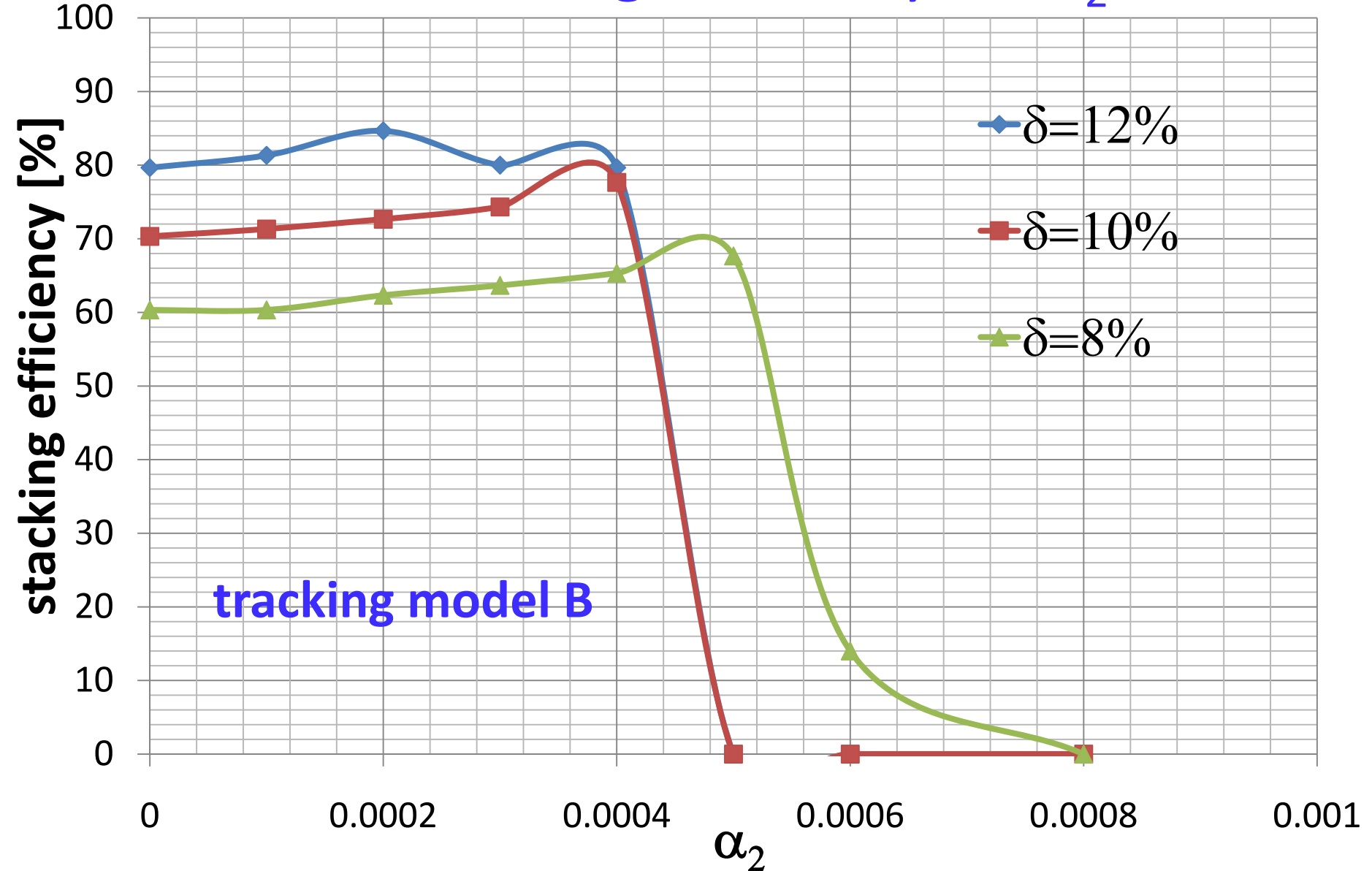
simulated stacking efficiency vs. initial δ offset



simulated stacking efficiency vs. initial δ offset



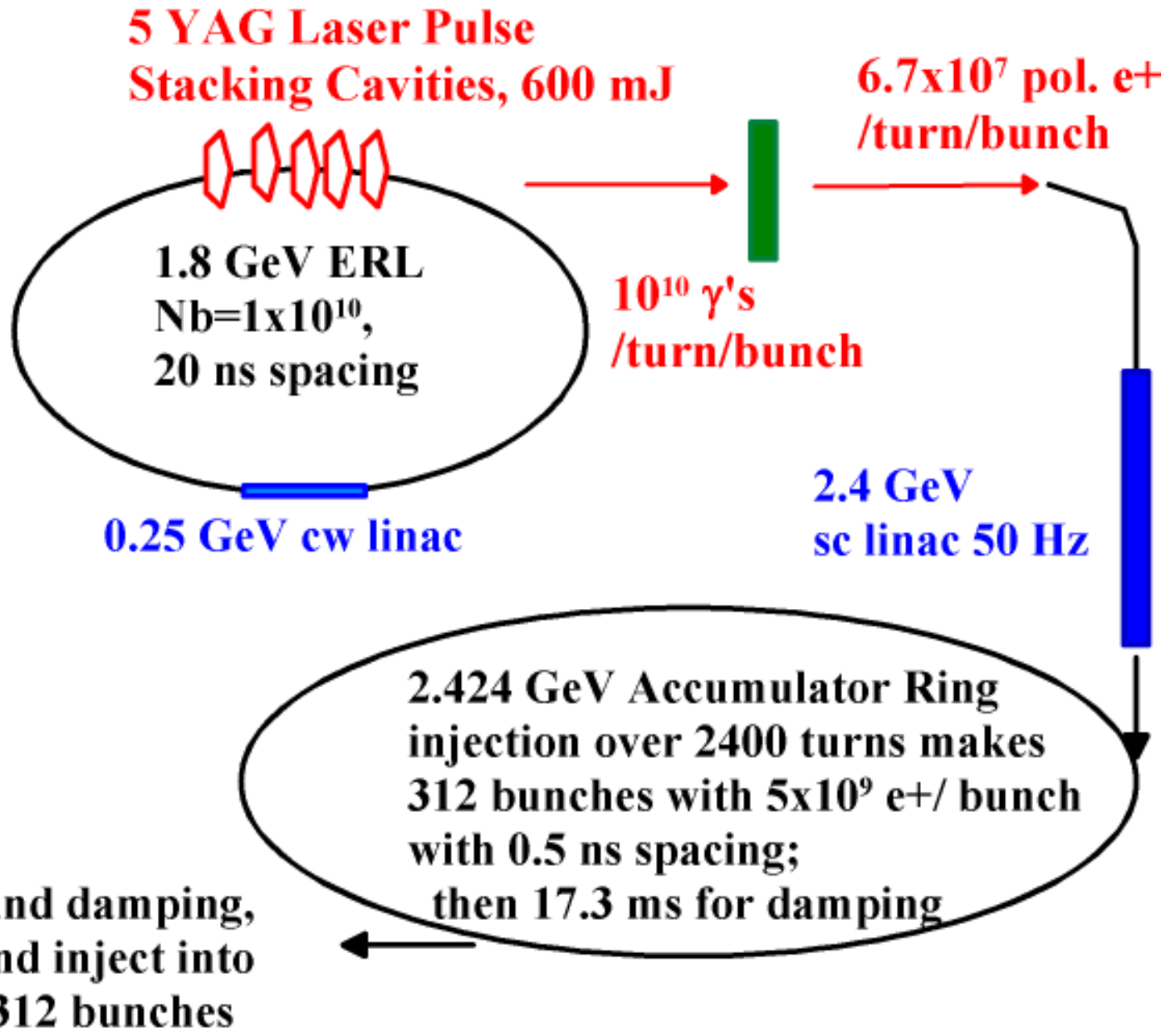
simulated stacking efficiency vs. α_2



Compton source megatable - 1	ILC-DR Snowmass '05 proposal	ILC 2008 – Compton “CR-B”	ILC 2008 – Compton “CERL-B”	CLIC pre-DR 2007 (NLC 2004)	CLIC 2008 (& CLIC CERL Compton vers.)
beam energy	5 GeV	5 GeV		1.98 GeV	2.424 GeV
circumference	3223 m	6695 m		230.93 m	251.6 m
particles per extracted bunch	2.4×10^{10}	2.0×10^{10}		4.0×10^9	4.5×10^9
rf frequency	650 MHz	650 MHz		2 GHz	2 GHz
harmonic number	6983	14516		1540	1677
no. trains stored in the ring	10 (10/pulse)	52.5 (52.5/pulse)		4 (1/pulse)	1
#bunches/train	280	50		312	312
bunch spacing	4.202 ns	6.15 ns		0.5 ns	0.5 ns
gap between trains	80 (336 ns)	~50 ns		73 (36.5 ns)	682.7 ns
#e+ / injection	2.4×10^8	6.65×10^7	6.65×10^7	6.65×10^7	6.65×10^7
#turns btw inj. in 1 bucket	1	2	5	40	40
injections/bucket per cycle	10	30	1020 (cont.)	3	80 (cont.)
injection frequency	~240 MHz	80 MHz	32 MHz	~50 MHz	50 MHz
full cycle length	200 ms	200 ms	200 ms	80 ms	20 ms
time between inj. periods	10 ms	10 ms	-	1.9 ms	-
#turns between cycles	930	450	(5155)	2470	(20647)
length of one inj.period	0.107 ms	1.34 ms	114 ms	0.046 ms	2.6837 ms
TI=total # injections/bucket	100	300	1020	60	80
ST=store time after last inj.	109 ms	97 ms	86 ms	42 ms	17.3163 ms
IP=interval with inj. periods	91 ms	103 ms	(114 ms)	38 ms	(2.6837 ms)
energy loss/turn	5.5 MeV	8.7x2 MeV	8.7x2 MeV	0.803 MeV	1.63MeV (4.08 MeV)
longitudinal damping time $\tau_{ }$	10 ms	6.4 ms	6.4 ms	2 ms	1.25 ms (0.5 ms)

Compton source megatable - 2	ILC-DR Snowmass '05 proposal	ILC 2008 Compton “CR-B”	ILC 2008- Compton vers. “CERL-B”	CLIC pre-DR 2007 (NLC 2004)	CLIC 2008 (& CLIC CERL Compton vers.)
transv. normalized edge emittance at inj. (10x rms)	0.05 rad-m	0.063 rad-m		0.063 rad-m	0.063 rad-m
transv. normalized dynamic aperture (Ax+Ay)gamma	>>0.05 rad-m?	0.4 rad-m		0.2 rad-m	0.2 rad-m?
rms bunch length at injection	3 mm	9 mm	11.4 mm	3.8 mm	11.4 mm
rms energy spread at injection	0.14%	0.06%(3MeV)	0.04%	0.28%	0.08% [2 MeV]
final rms bunch length	6 mm	5.2 mm		5.12 mm	0.79 mm (0.47 mm)
final rms energy spread	0.14%	0.091 %		0.089%	0.095% (0.12%)
longit. “edge” emittance at inj.	0.7 meV-s	0.72 meV-s		0.72 meV-s	0.73 meV-s
rf voltage	20 MV	36 MV		1.72 MV	2 MV (16.3 MV)
momentum compaction	3×10^{-4}	4.2×10^{-4}		1.69×10^{-3}	9×10^{-5}
2 nd order mom. Compact.	1.3×10^{-3}	-		-	$5.8 \times 10^{-2} (3 \times 10^{-4})$
synchrotron tune	0.0356	0.084		0.0188	0.0045 (0.0127)
bucket area	292 meV-s	129 meV-s		10 meV-s	12meVs (234meVs)
ICM=bckt area/edge emit. / π	133	57		4	(102)
RMIN=TI/ICM	0.75	18		15	(0.59)
IP/RMIN/ τ_{\parallel}	12	1		1.3	(9.1)
IP/RACT/ τ_{\parallel}	0.09	0.15		0.31	(0.09)
synchronous phase	15.58°	28.97°		26.47°	(14.49°)
separatrix phases 1&2	164.42°, -159.19°	151.03°, -82.64°		153.53°, -95.66°	(165.51°, -163.83°)
max. momentum acceptance	+/-2.7%	+/- 1.6%		+/- 1.0%	+/-1.6% (+/- 13%)
injection offset δ, z	ramped in δ	ramped in d	+1.5%,0.01m	ramped in δ	(+13.20%, 0 m)
simulated stacking efficiency	82%	~95%	~94%	not comp.	95.5%
final # positrons / bunch	2×10^{10}	1.94×10^{10}	6×10^{10}	not comp.	5.1×10^9

2008
CLIC e+
Compton
scheme
-
example



(2) ILC - Compton Ring

similar assumptions as for Snowmass'05

- **stacking in longitudinal phase space**
- ingredients: sinusoidal rf, momentum compaction, radiation damping and quantum excitation
- injection septum placed at location with large dispersion; septum blade \ll transverse beam size
- between successive injections orbit at the septum is varied with fast bumper magnets
- energy of injected beam is ramped such that the **transverse septum position is always separated by $2\sigma_{\delta 0}$ from injected beam centroid**

ILC-CR injection scheme

- ILC 2008: **inject every second turn (80 MHz) into the same bucket - 30 times; then wait 10 ms (~450 turns, ~1 damping time) and repeat 9 times; total injections/bucket: 300**; synchrotron phase advance between two injections: 0.134
- simulation result (February'08) :
35% loss / cycle, total loss 76%!

improving ILC-CR stacking efficiency

possible approaches not yet used:

- ❑ smaller momentum compaction factor
- ❑ increased acceptance with 2nd harmonic rf
- ❑ reduced synchrotron tune
- ❑ larger interval between cycles

(but nominal interval already too long for vertical

damping – Vitaly Yakimenko's comment;

see next slide)

ILC DR “*trouble*” (Vitaly Yakimenko)

final $\gamma\varepsilon_{y,rms}=0.017$ micron

initial $\gamma\varepsilon_{y,rms}=6$ mm

minimum store time T_{store} follows from
 $0.017 * \exp(2 T_{store} / \tau_y) \mu\text{m} = 6000 \mu\text{m}$

$\rightarrow T_{store} > 6.4 \tau_y = 164$ ms

leaving only 36 ms for stacking

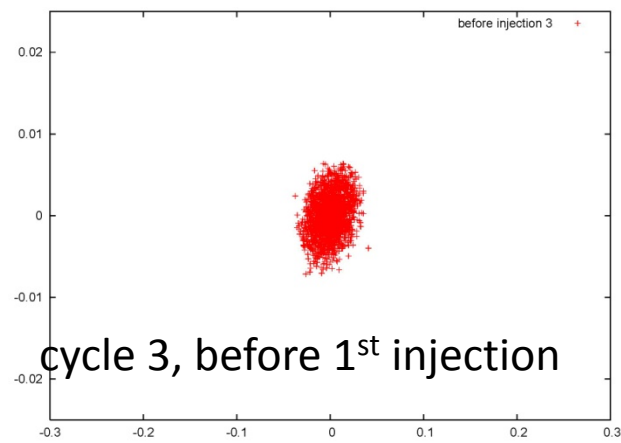
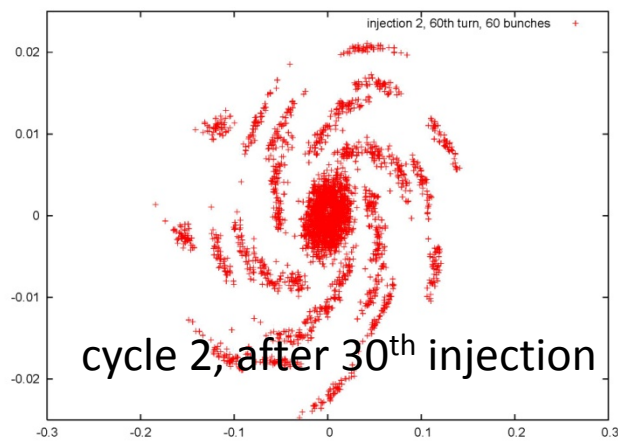
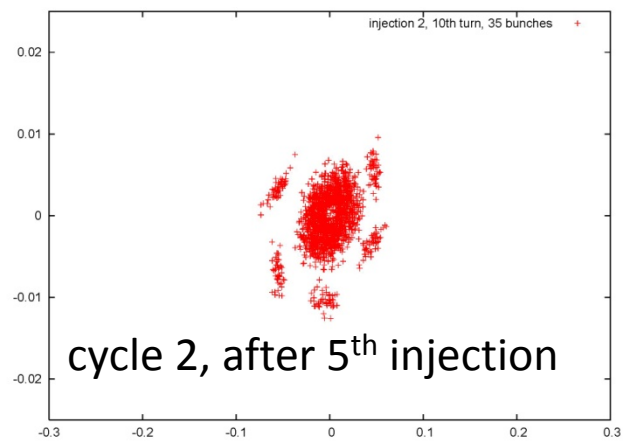
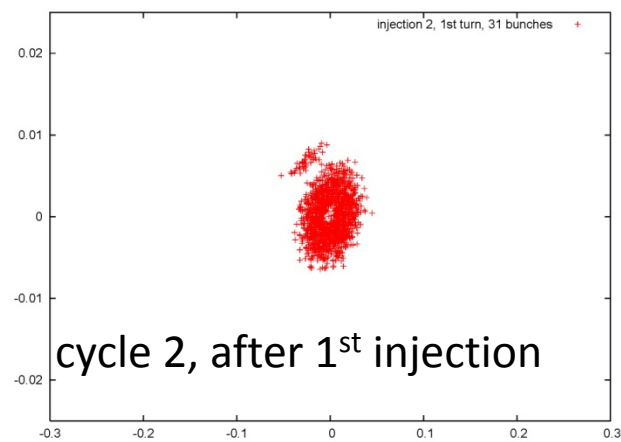
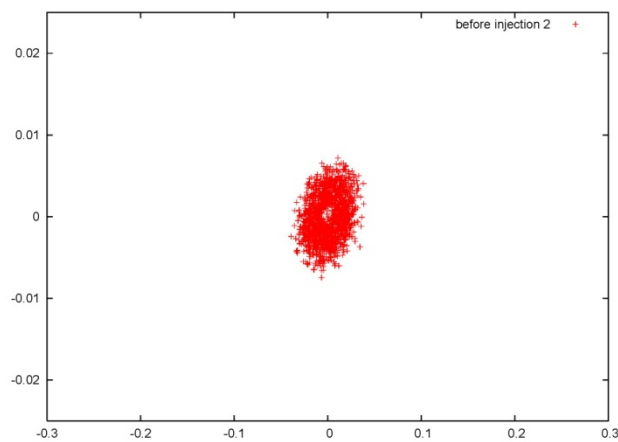
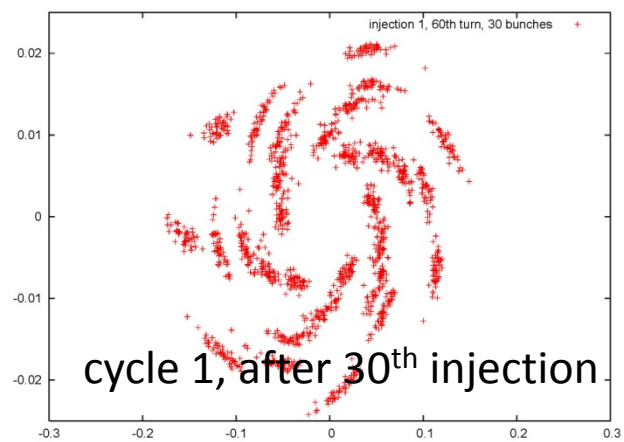
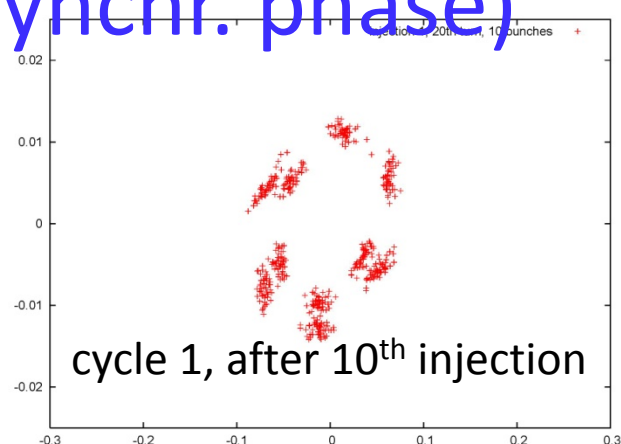
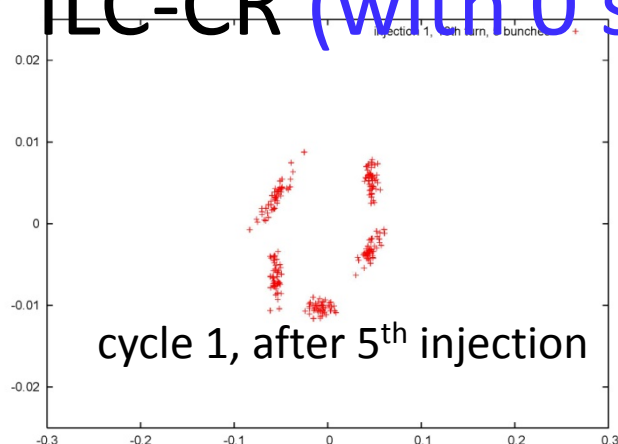
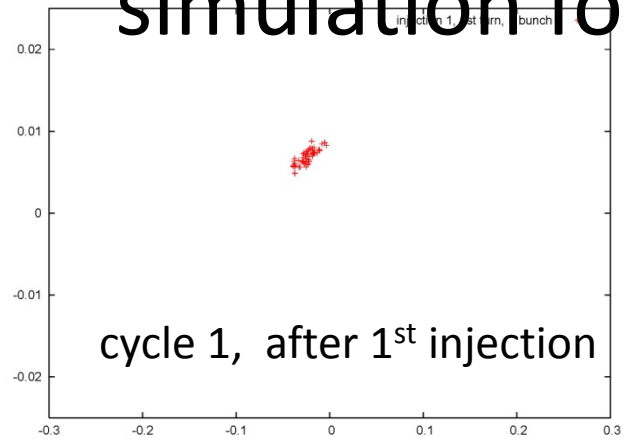
improving ILC-CR stacking efficiency

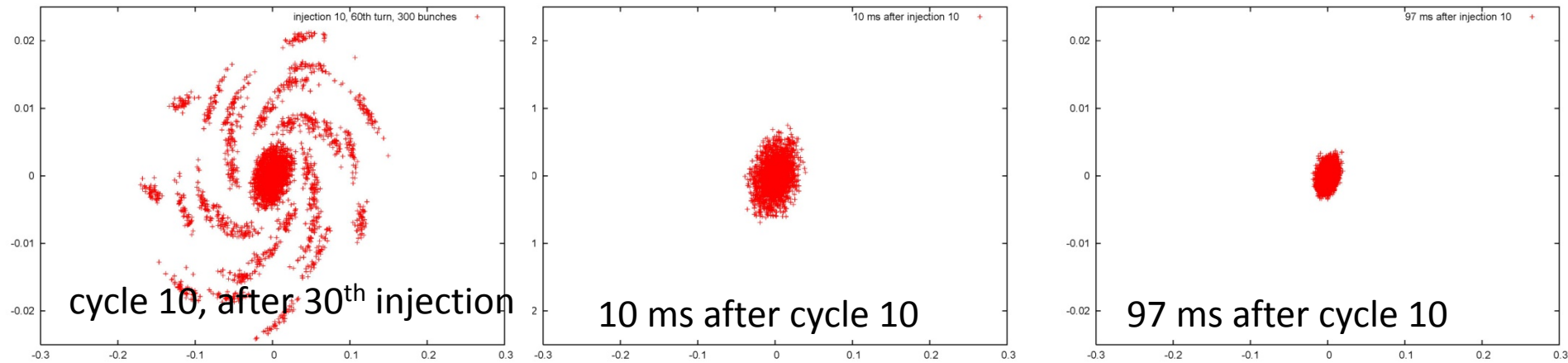
methods chosen:

- ✓ energy pre-compression [x3] (R. Chehab)
- ✓ addt'l DR wigglers for faster damping [x2]
- ✓ larger rf voltage [x 1.5 or more!]

→ 2008 ILC DR Compton version

simulation for ILC-CR (with 0 synchr. phase)





~ 2.8% of injected e⁺ are lost!

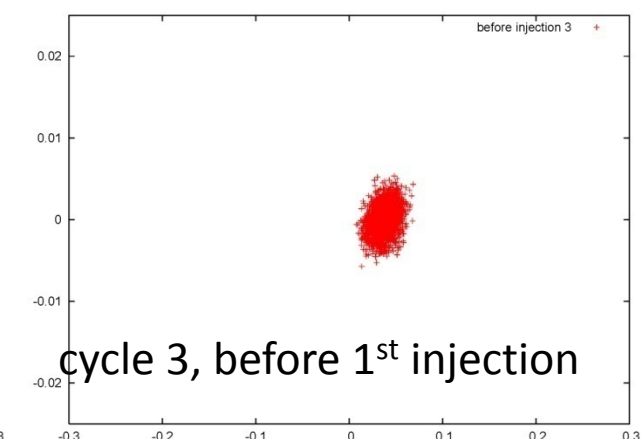
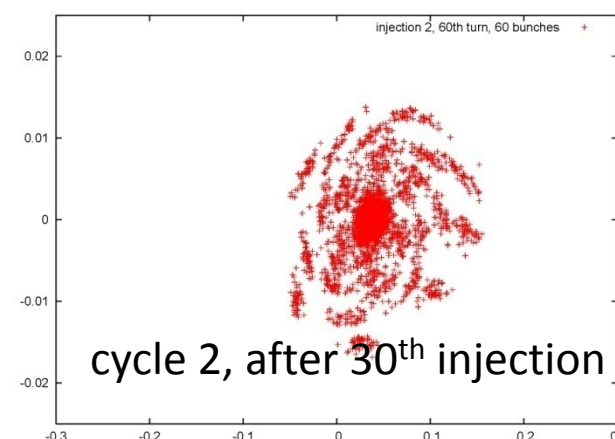
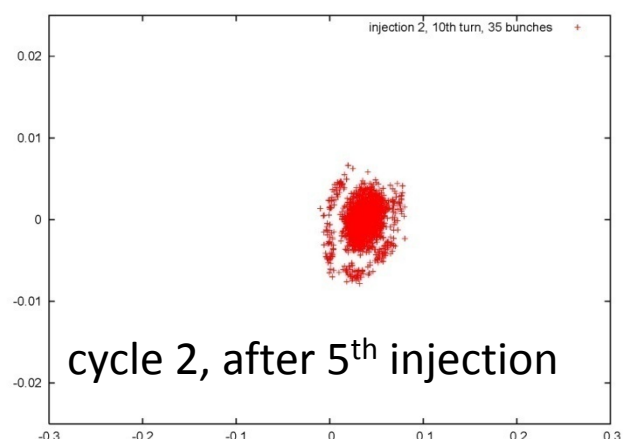
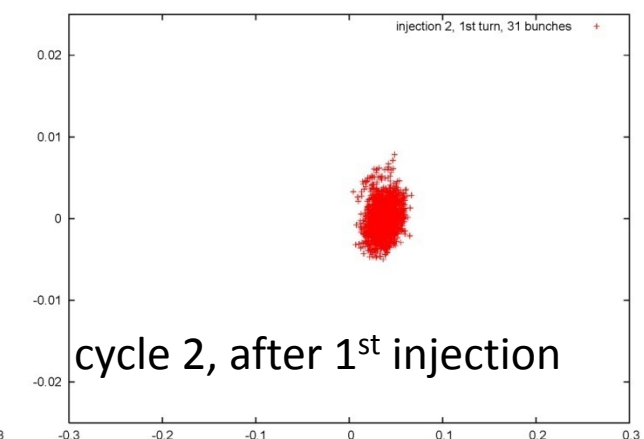
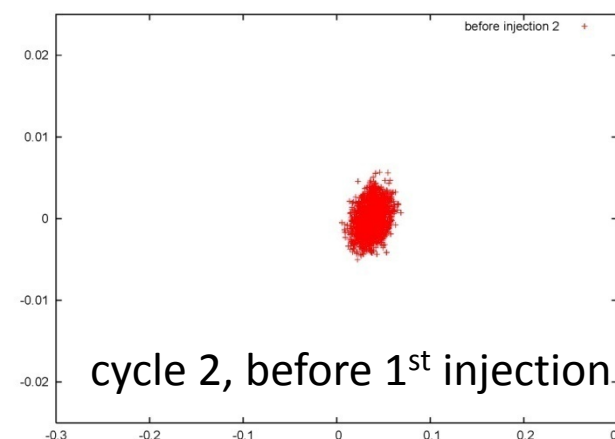
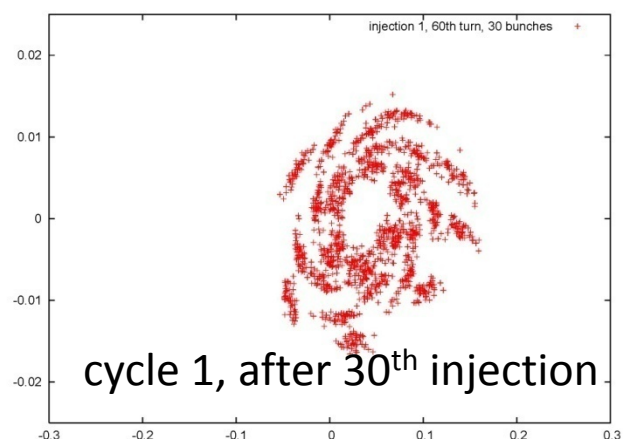
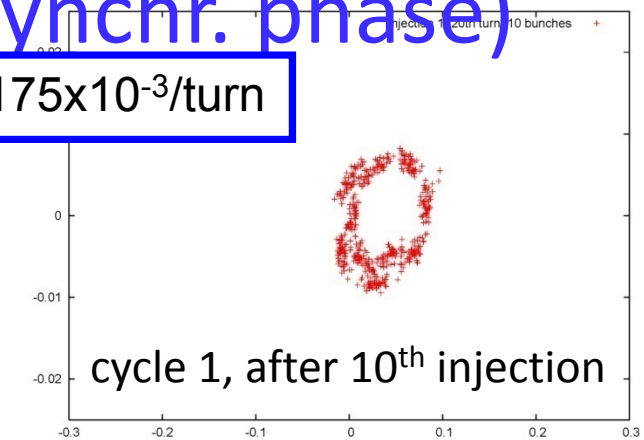
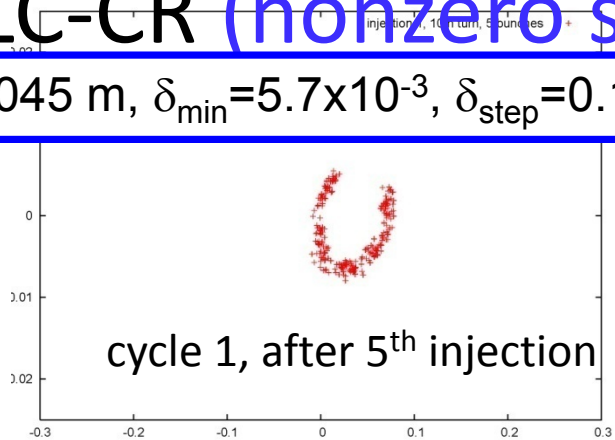
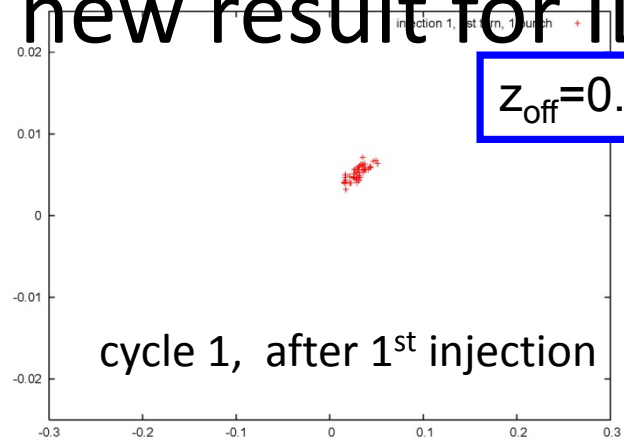
similar loss fraction for single cycle

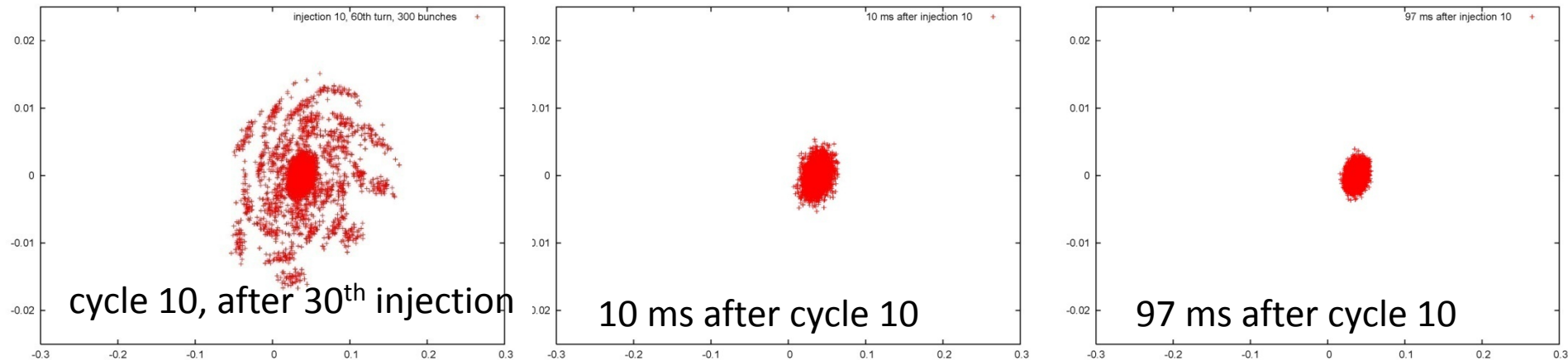
→ stacking efficiency ~97.2%

(but for 0° synchronous phase)

new result for ILC-CR (nonzero synchr. phase)

$$z_{\text{off}}=0.045 \text{ m}, \delta_{\text{min}}=5.7 \times 10^{-3}, \delta_{\text{step}}=0.175 \times 10^{-3}/\text{turn}$$





~ 5.3% of injected e⁺ are lost!

similar loss fraction for single cycle

→ stacking efficiency ~94.7%

(for actual synchronous phase;
not yet fully re-optimized)

questions & comments for ILC-CR

- 2x3 km ring is option from Andy Wolski; it could reduce the damping times by factor 2, if we do not reduce the length of the wigglers
- ring parameters can be considered somewhat flexible; at present parameters are optimized for the undulator based source
- can we reduce initial energy spread to 2 MeV rms?
- option of pre-damping ring for ILC?

*(3) ILC - Compton Energy
Recovery Linac*

ILC-CERL injection scheme - A

continuous stacking (ERL option), ~27MHz (Omori san,

Variola san) **850 injections** over 5100 turns

(inject every 6th turn), followed by 5155 turns

(~100 ms) damping; damping time 6.4 ms;

inject with constant offset $\delta=1.2\%$

*<Vivoli san's result:
~ 2.9 MeV*

$\sigma_z=9$ mm, **$\sigma_{\delta_0}=1 \times 10^{-4}$** (0.5 MeV, small!!): **63.7% loss**

Omori san asked about “unstable point” injection

offset $\delta=1.2\%$ or **0.4%**, **$z=0.1$ m: 99.8% loss**

offset $\delta=0.2\%$, $z=-0.1$ m: 99.9% loss

offset $\delta=0.5\%$, $z=0.01$ m: 72.8% loss

offset $\delta=0.7\%$, $z=0.01$ m: 50% loss!! Method works!?

offset $\delta=0.8\%$, $z=0.01$ m: 41.8% loss!

offset **$\delta=0.9\%$** , **$z=0.01$ m: 36.7% loss! 63% efficient**

ILC-CERL injection scheme - B

over 6 turns synchrotron phase advance $\sim 0.5!$?

perhaps better inject every 5th turn?!

again continuous stacking (ERL option), ~ 32 MHz,

1020 injections over 5100 turns

(inject every 5th turn), followed by 5155 turns

(~ 100 ms) damping; damping time 6.4 ms;

inject with constant offset $\delta=0.9\%$, $z=0.01$ m

$\sigma_z=9$ mm, $\sigma_{\delta_0}=\mathbf{1 \times 10^{-4}}$ (0.5 MeV, small!!): **36% loss**

offset $\delta=1.0\%$, $z=0.01$ m: **33% loss**

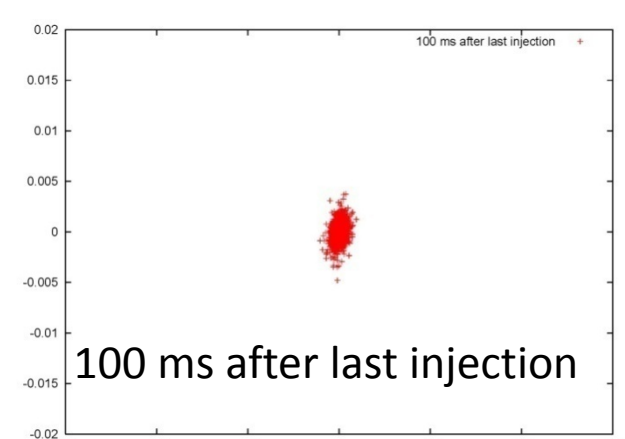
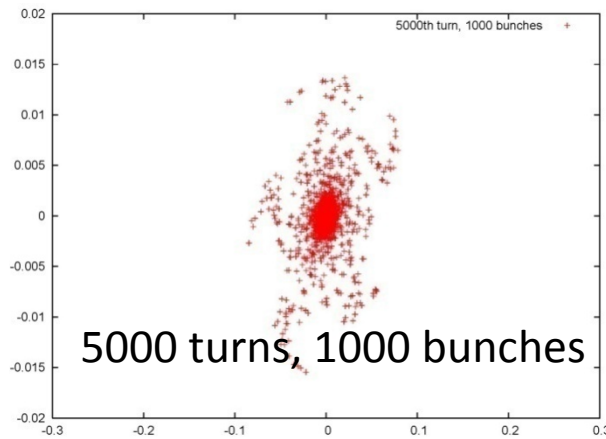
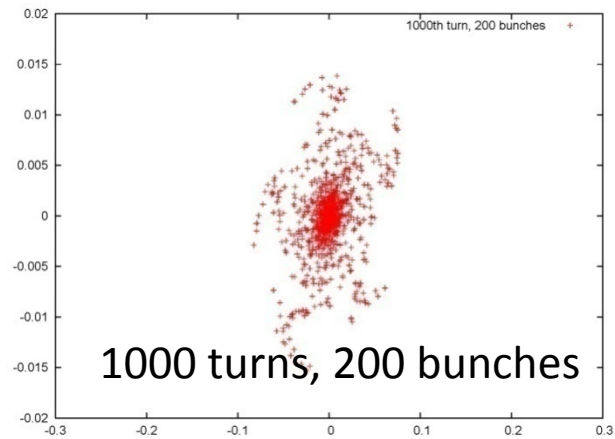
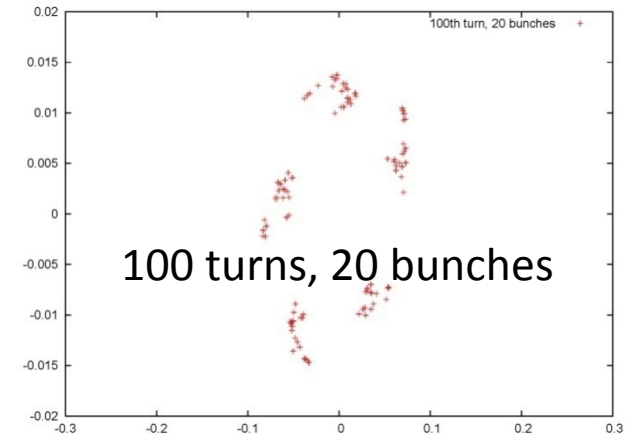
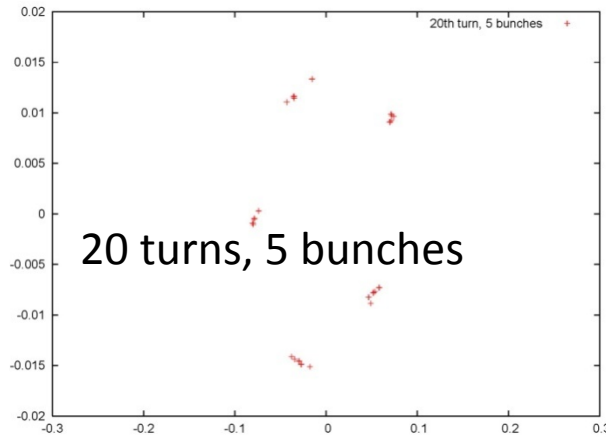
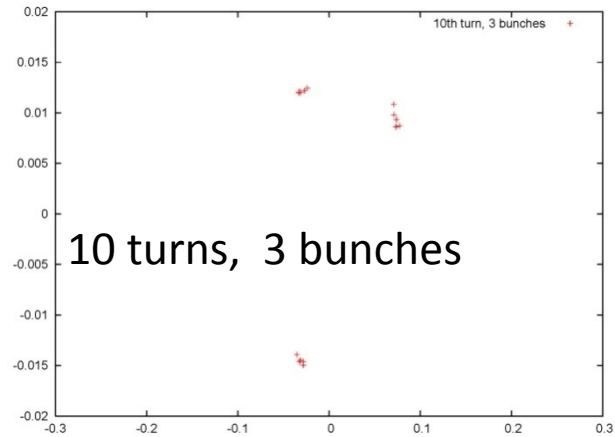
offset $\delta=1.2\%$, $z=0.01$ m: **27% loss! 73% efficient**

offset $\delta=1.3\%$, $z=0.01$ m: **23% loss! 77% efficient**

offset $\delta=1.4\%$, $z=0.01$ m: **16% loss! 84% efficient**

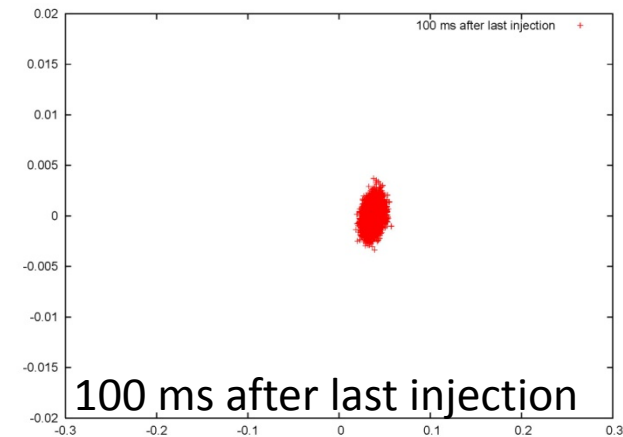
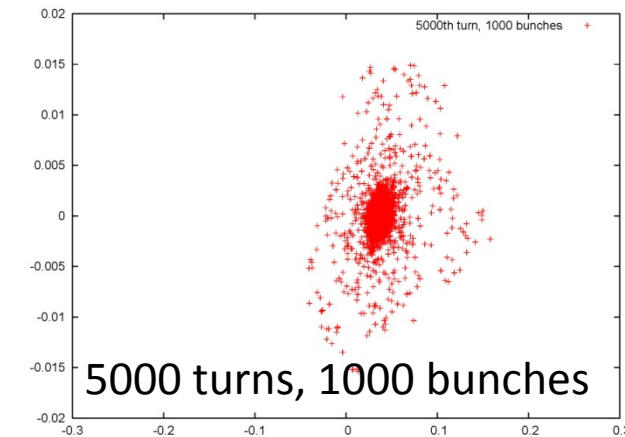
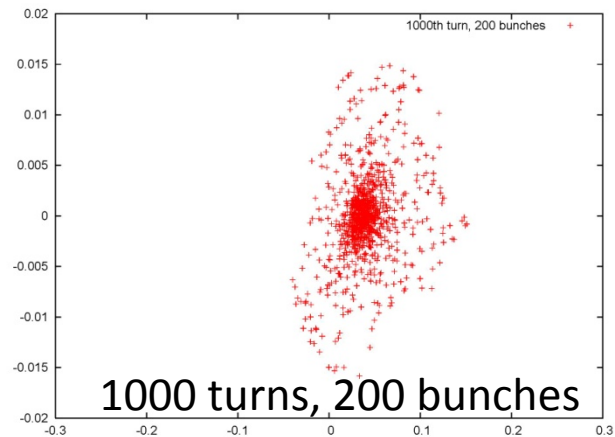
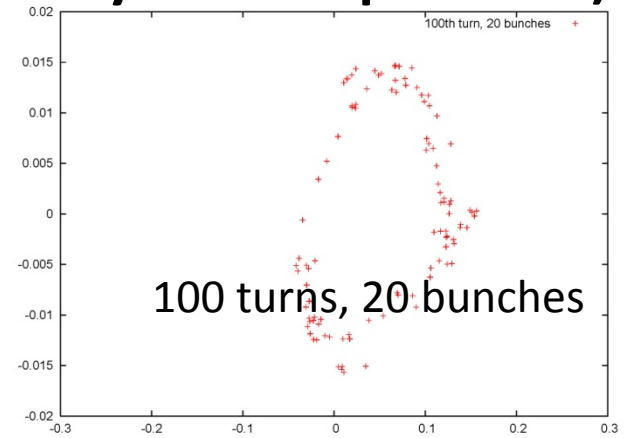
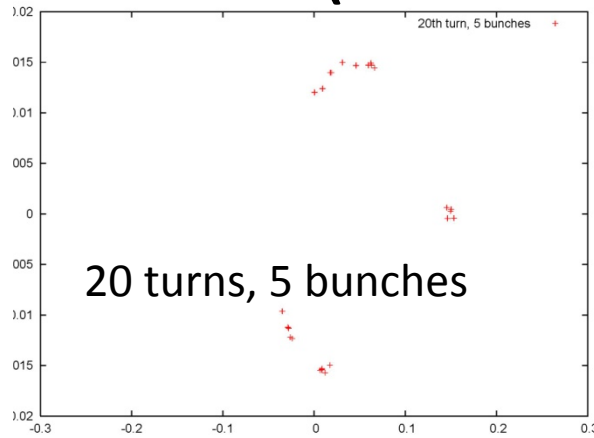
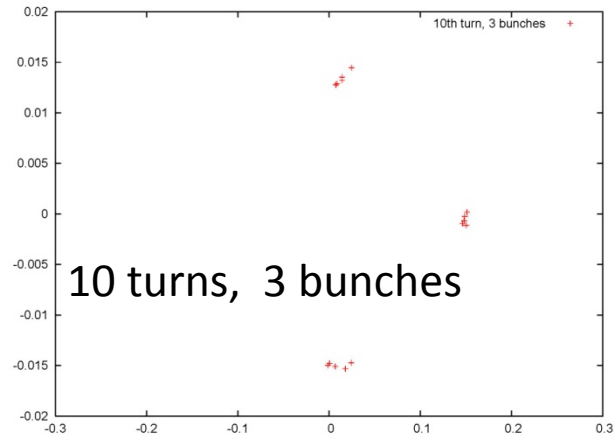
offset $\delta=1.5\%$, $z=0.01$ m: **9% loss! 91% efficient!**

simulation for ILC-CERL (with 0 synchr. phase)



→ stacking efficiency $\sim 91\%$ (but $\phi_s=0$)

new result for ILC-CERL (nonzero synchr. phase)



→ stacking efficiency $\sim 94.2\%$

*(4) summary &
outlook*

some conclusions

- CLIC/ILC Compton source w ERL or CR
- e+ emittance preservation after capture
- CLIC PDR & ILC DR parameters adapted for stability and stacking, $\alpha_2 \downarrow \downarrow$, $V_{RF} \uparrow$, $\tau_{||} \downarrow$
- stacking simulation: >90% efficiency with off-momentum off-phase injection
- (P)DR off-momentum dynamic aperture must be adequate (huge! >several %)
- quite some flexibility (# optical cavities vs. e- bunch charge)
- but a few challenges for PDR & DR design

stacking is helped by:

- short damping time
- small energy spread (which value is possible?)
- large ring momentum acceptance
(low α , low α_2 , large V_{RF} , higher harmonic rf)
- sufficient store time

simulation results:

95% for ILC-CR (300 inj's, $\sigma_\delta=3$ MeV spread)

94% for ILC-CERL (1020 inj's! $\sigma_\delta=0.5$ MeV)

95.5% for CLIC-CR/CERL (80 inj's, $\sigma_\delta=2$ MeV)

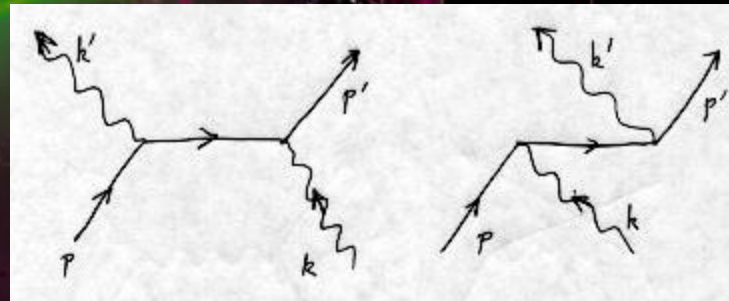
last 2 with energy pre-compression - **Compton**
version of ILC-DR acceptable? #e+ / pulse for
CERL schemes?

next steps & ideas:

- determine “optimum” (pre-)DR parameters
- optimize **synchrotron tune, opt. α_1, α_2**
- **energy pre-compressor ; higher-harmonic rf**
- combined **longitudinal/transverse** stacking
- **off-momentum dynamic aperture**

thank you for your attention!

*please help to push the
Compton frontier!*



comments:

try negative momentum compaction?

2.8 ns \rightarrow 6.18 ns (bunch spacing for ILC)

share stacking between pre-DR and DR?

large momentum acceptance for CLIC?

use FFAG-like scheme?

new energy compression scheme at LAL
(RF deflecting structure)