NanoBeam2002

26th Advanced ICFA Beam Dynamics Workshop on Nanometer Size Colliding Beams

September 2-6, 2002, Lausanne, Switzerland

SIMULATION TOOLS

for LUMINOSITY PERFORMANCE

Stefano Redaelli

CERN SL-AP

CH-1211 Geneva 23

Switzerland

– Motivations for this work –

PhD student at Université de Lausanne (UNIL) – Institut de Physique des Hautes Énergies (IPHE)

CERN supervisor: **Dr. Ralph W. Aßmann** (SL-AP)

UNIL supervisor: **Prof. Tatsuya Nakada** (UNIL)

Thesis: **Demonstrate the feasibility of colliding beams with nanometre spot size for linear colliders (CLIC)**

- *Investigate achievable stability of quadrupoles* (→ talks tomorrow)
- *Predict machine performance with simulation tools*

↓ ↓

Goal of this work: Put error bars on results of simulations for luminosity performance

Work done in collaboration with:

R. Aßmann, H. Burkhardt, D. Schulte, F. Zimmermann – CERN, Geneva

Y. Nosochkov, T.O.Raubenheimer, A. Seryi, P.Tenenbaum – SLAC, Stanford

N. Walker – DESY, Hamburg

Additional thanks to:

H. Grote, G. Guignard, M. Hayes, J. Jowett, G. Rumolo,
R. Tomás, I. Wilson – CERN, Geneva

A. Wolsky – LBNL, Berkeley

M. Woodley – SLAC, Stanford

P. Raimondi – LNF, Frascati

G. A. Blair – Royal Holloway, London

A. Bay, T. Nakada – UNIL/IPHE Lausanne

Overview of my talk:

1. Introduction

2. Code comparison for the ***old*** CLIC lattice **`ffcol_v2FZ`**

3. Code comparison for the ***new*** CLIC lattice **`fflc02`**

4. Conclusions

1. Introduction

All future Linear Colliders aim at colliding beams with vertical spot sizes in the 1 nm to 5 nm range (energy from 0.25 TeV to 1.5 TeV)

Machine	Energy	Beam Size [nm]	Luminosity [$cm^{-2}s^{-1}$]
TESLA	800 GeV	392 x 2.8	5.3 10^{34}
NLC	1000 GeV	219 x 2.1	3.0 10^{34}
CLIC	1500 GeV	61 x 0.7	8.0 10^{34}

No test facility presently available to prove experimentally the **feasibility** of nanometer spot sizes + luminosity

⇩

Estimate of machine performance must *fully rely* on simulation codes for tracking + luminosity studies.

Code comparison as tool to assess the confidence in simulation results! → Systematic errors of performance predictions

Experimentally: input from CLIC Stability Study (→ see talks tomorrow)

Simulation codes used for comparison

Four codes used for tracking through CLIC *Beam Delivery System*:

- ♥ **MAD8** : All purpose simulation code, tracking with *transport formalism* — CERN
- ♦ **DIMAD** : tracks particle trajectories according to a *second order matrix formalism* (→ **MatLIAR**) — SLAC
- ♣ **Merlin** : performs charged particle tracking using first and second-order transport matrices — DESY
- ♠ **Placet** : program for LINAC simulations, upgraded to include high order multipoles and Syn. R. — CERN

⊗ Luminosity calculations with **GuineaPig** – full simulation of two beam interaction (hour-glass, pinch, beamstrahlung, e^+e^- production)

⇨ **GuineaPig** interfaced with all the programs! ⇦

*(For Comparison of LINAC+BDS (**no SR**) → **LCC-0091, Tesla-2002-08, CLIC-513**)*

2. Comparison for the *OLD* CLIC BDS lattice `ffcol-v2FZ` (PAC01)

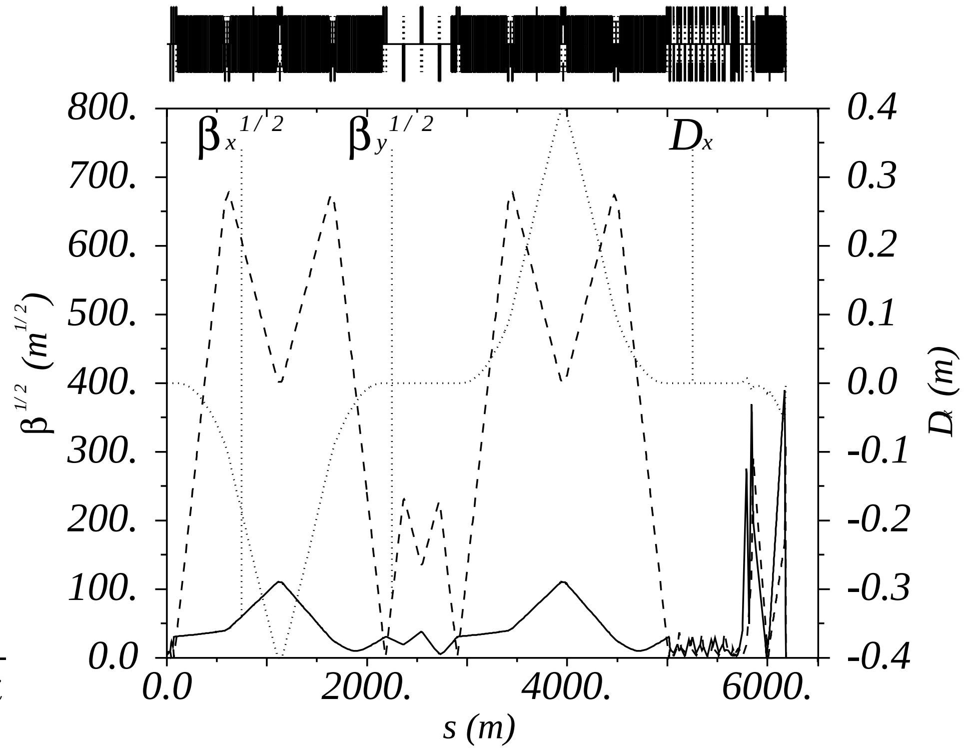
EPAC02, S. Redaelli *et al, Comparison of Different Tracking Codes for Beam Delivery Systems of Linear Colliders*

Compact design from P. Raimondi and A. Seryi

Beam parameters at BDS entrance	
E	1500 GeV
$\Delta E/E$	1 %(square dist. FW)
β_x	65 m
β_y	18 m
α_x	0 m
α_y	0 m
ϵ_x^*	680 nm
ϵ_y^*	20 nm
σ_z	30 μm

Beam parameters at IP	
β_x^*	8 mm
β_y^*	0.15 mm
σ_x	43 nm
σ_y	1 nm

theoretical $= \sqrt{\epsilon_i \beta_i}$



Lattice main parameters:

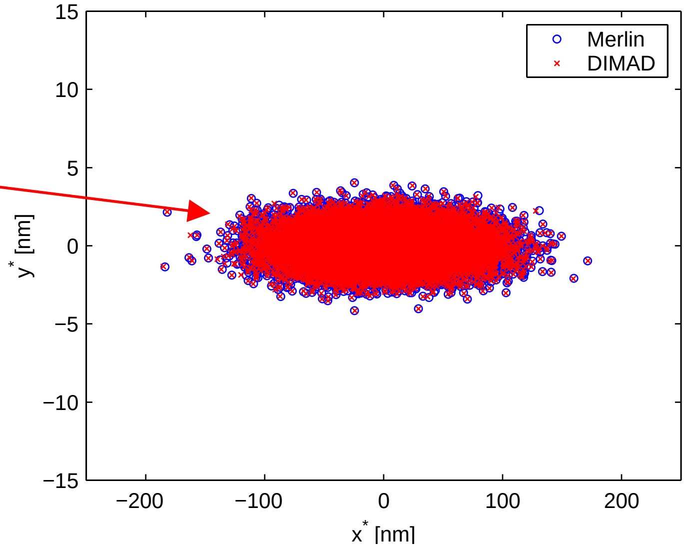
- Length = 6.2 km
- 80 quadrupoles
- 16 sextupoles

Some tracking results…

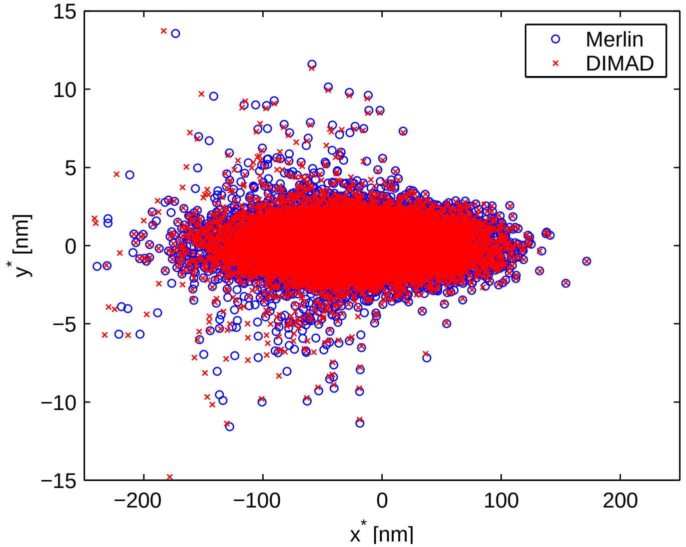
Transverse profile of the beam at the *Interaction Point*

Energy spread and Synchrotron Radiation perturb the Gaussian like particle distributions

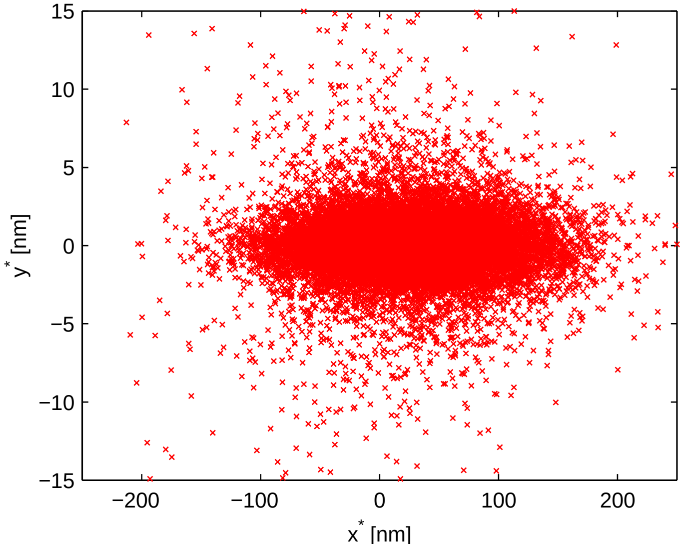
Perfect machine (no ΔE, no SR)



Bunch with initial energy spread



Bunch energy spread + SR



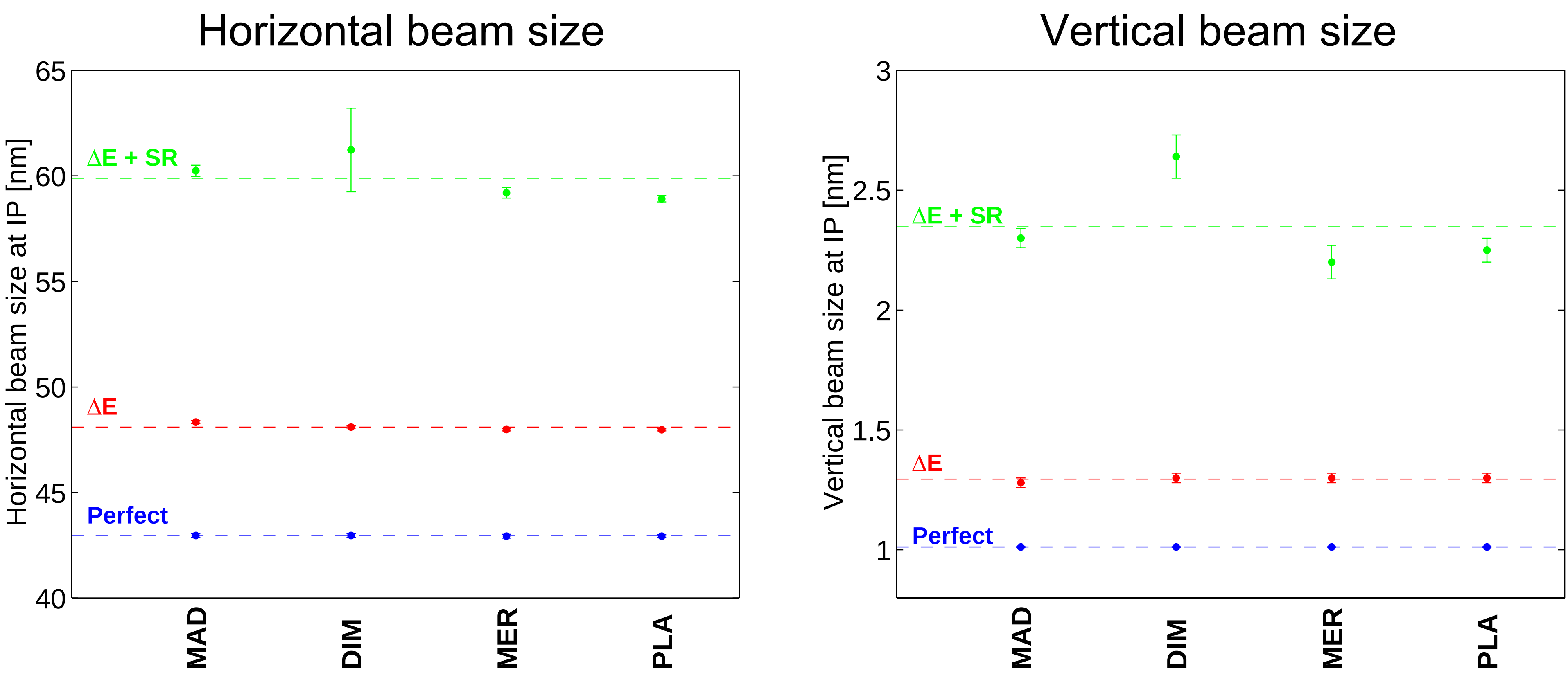
Comparison of the different codes

- Beam sizes calculated as Standard Deviation of particle positions
- 5 sets of 20000 particles (*same* particle distributions)

  → Average beam size → Error = StdDev / $\sqrt{N_{set} - 1}$

	No ΔE - No SR	ΔE/E=1% - No SR	ΔE/E=1% - SR
Horizontal beam sizes			
MAD	42.96 nm±0.09 nm	48.34 nm±0.07 nm	60.24 nm±0.27 nm
DIMAD	42.96 nm±0.09 nm	48.10 nm±0.05 nm	61.23 nm±1.98 nm
Merlin	42.93 nm±0.09 nm	47.98 nm±0.06 nm	59.20 nm±0.25 nm
Placet	42.93 nm±0.07 nm	47.97 nm±0.05 nm	58.92 nm±0.15 nm
Vertical beam sizes			
MAD	1.012 nm±0.001 nm	1.28 nm±0.02 nm	2.30 nm±0.04 nm
DIMAD	1.012 nm±0.001 nm	1.30 nm±0.02 nm	2.64 nm±0.09 nm
Merlin	1.012 nm±0.001 nm	1.30 nm±0.02 nm	2.20 nm±0.07 nm
* Placet	1.012 nm±0.001 nm	1.30 nm±0.02 nm	2.25 nm±0.05 nm

* **Placet** simulations by D. Schulte



The codes show a good agreement !

- No significant differences for results of tracking without SR
- With SR differences up to 4 % (horiz.) and 20 % (vert.), differences not exceeding 0.5 nm

So far so good, but …

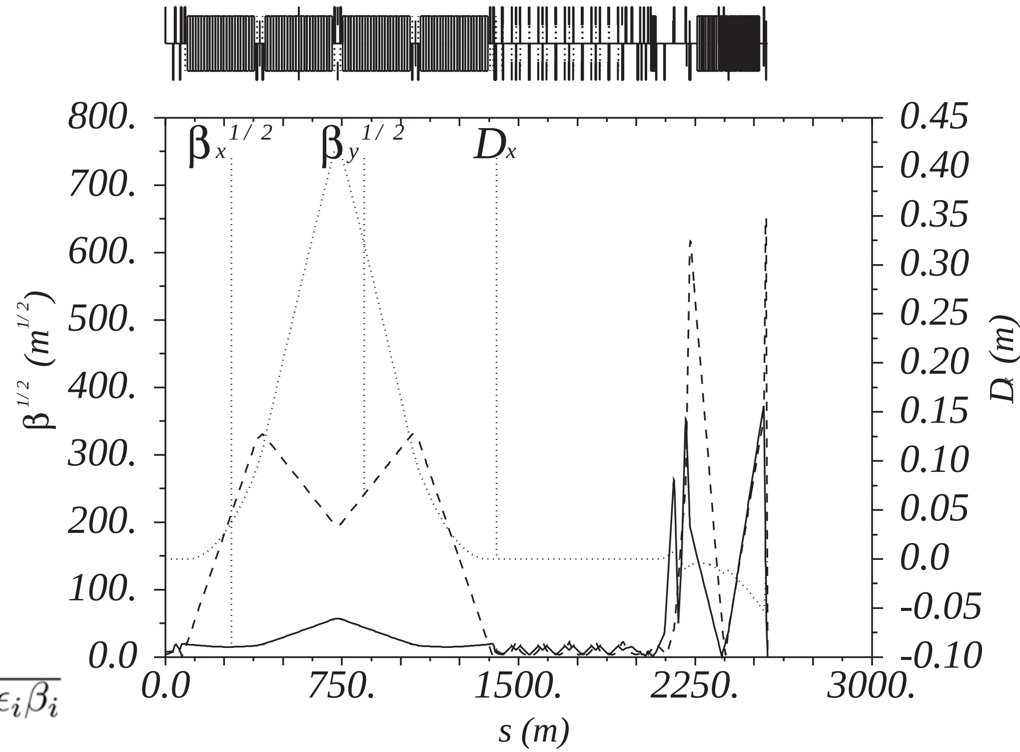
3. Comparison for the *NEW* CLIC BDS lattice (`fflc02`)

First presented at LC02 (Feb. 2002), performance presented at EPAC2002

Beam parameters at BDS entrance		
Matched to linac	E	1500 GeV
	$\Delta E/E$	1 %(square dist. FW)
	β_x	64.171 m
	β_y	18.000 m
	α_x	-1.95 m
	α_y	0.61 m
	ϵ_x^*	680 nm
Smaller!	ϵ_y^*	10 nm
	σ_z	35 μm

Beam parameters at IP		
Smaller!	β_x^*	6 m
	β_y^*	0.07 m
	σ_x	37.28 nm
	σ_y	0.49 nm

theoretical $= \sqrt{\epsilon_i \beta_i}$

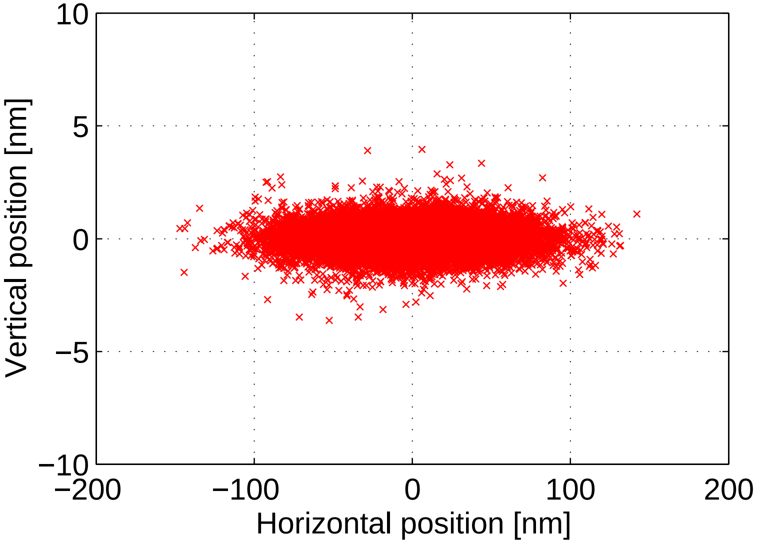


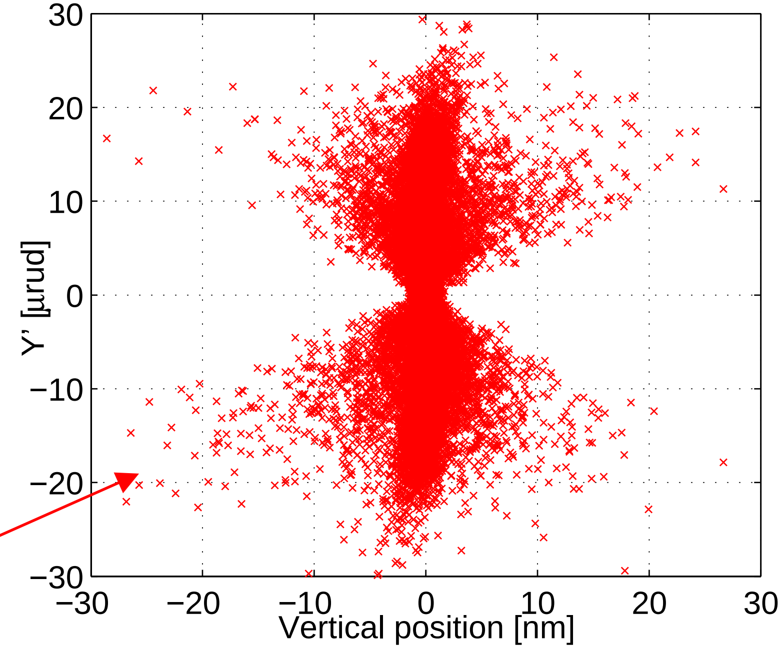
Lattice main parameters:

- Length = 2.55 km ← Much shorter!
- ~ 60 quadrupoles
- 11 sextupoles
- 2 (thin) octupoles

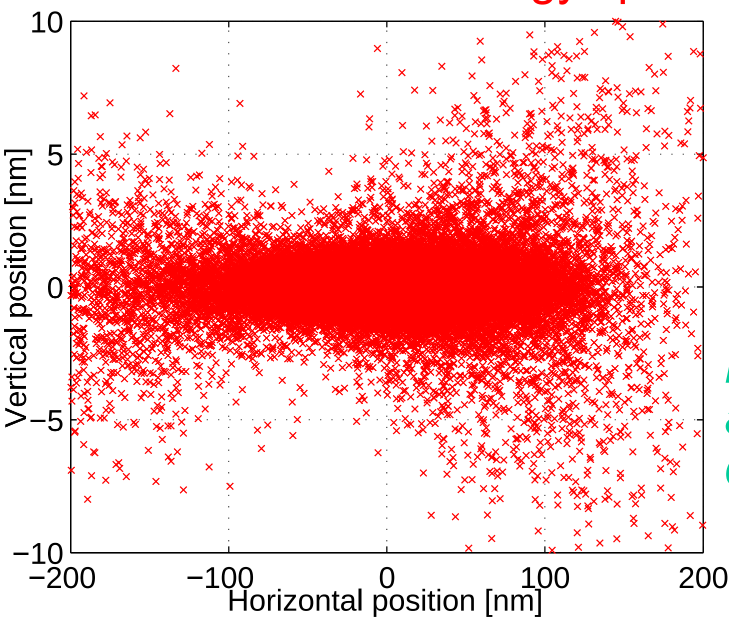
How does the beam look like, now??

Perfect machine – No ΔE, no SR (`Merlin`)

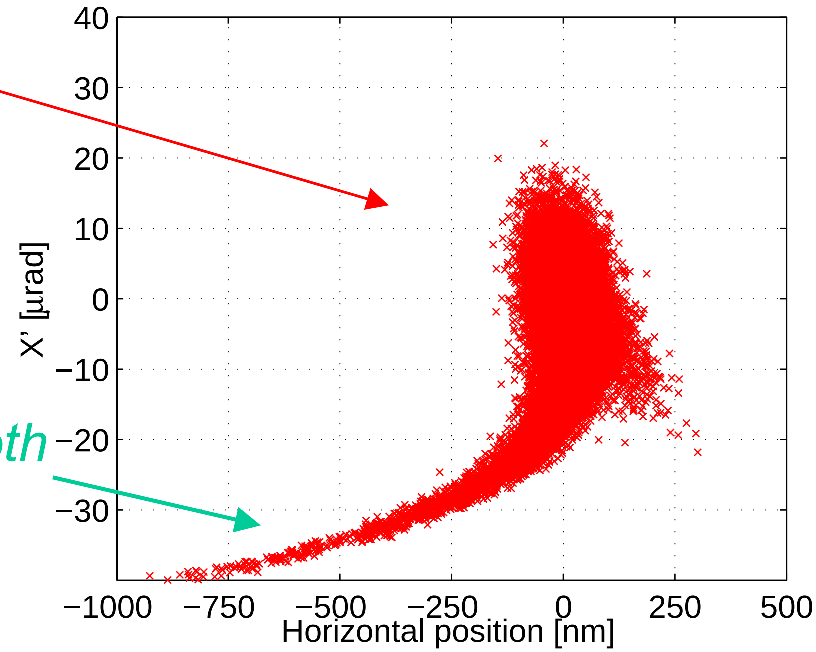




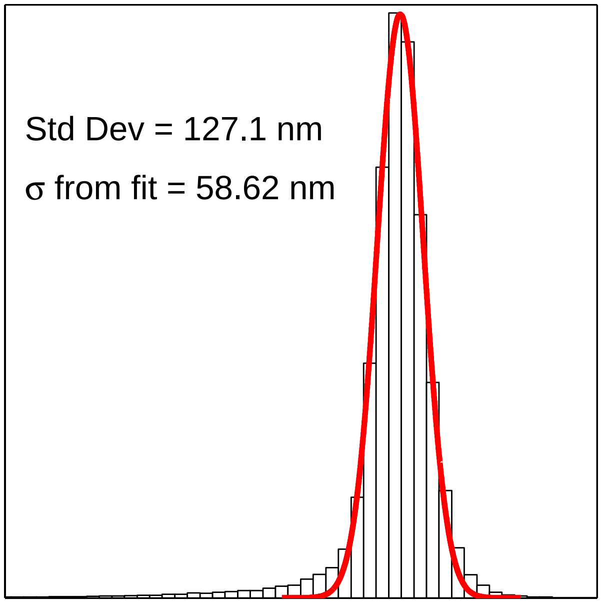
Bunch with initial energy spread



Beam halos appear in both directions!



And with Synchrotron Radiation…..



*Horizontal: 3.3/50 particles > 3 σ (**~ 6.6 %**)*

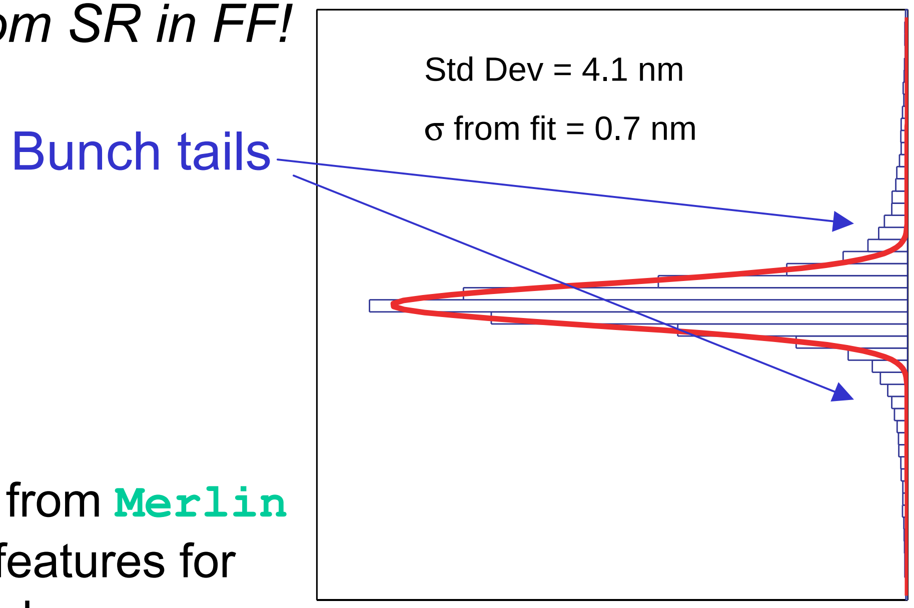
*Vertical : 7.6/50 particles > 3 σ (**10-15 %**)*

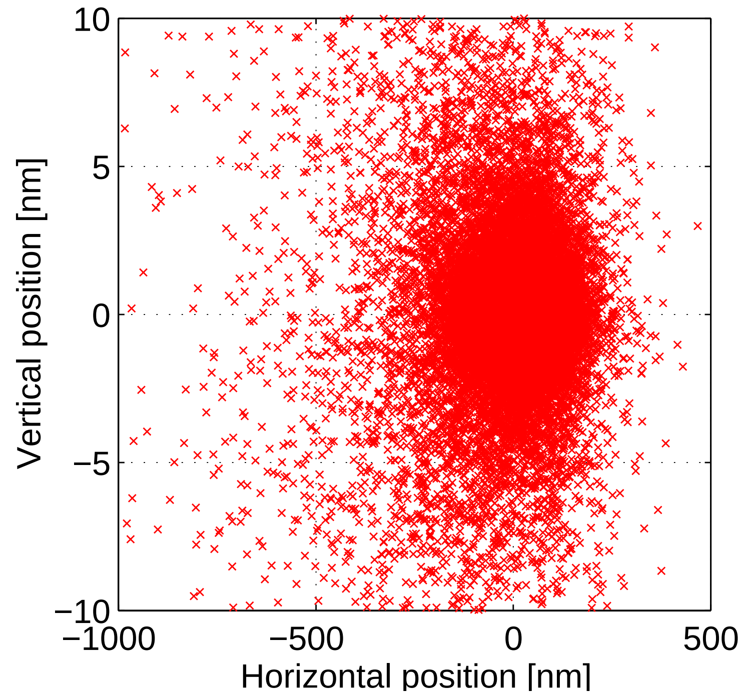
*3.8/50 particles > 6 σ (**~ 7.5 %**) **!!***

Now the bunch looks much bigger….

but the its core is still "small"!

Issue for the Collimation? They do not come only from SR in FF!





Results from `Merlin` - same features for other codes.

Comparison of the different codes (1)

- 5 sets of 50000 particles (*same* part.) → Avg beam size → Err = StdDev/$\sqrt{N_{set}-1}$

Horizontal beam sizes

	No ΔE - No SR	ΔE/E=1% - No SR	ΔE/E=1% - SR
`MAD`	38.87 nm±0.06 nm	74.91 nm±1.09 nm	96.28 nm±0.73 nm
`DIMAD`	37.60 nm±0.05 nm	106.32 nm±1.38 nm	99.04 nm±1.42 nm
`Merlin`	37.53 nm±0.05 nm	103.33 nm±1.37 nm	129.65 nm±1.51 nm
`Placet`	37.09 nm±0.05 nm	108.99 nm±1.47 nm	99.33,nm±1.31 nm

Vertical beam sizes

	No ΔE - No SR	ΔE/E=1% - No SR	ΔE/E=1% - SR
`MAD`	0.937 nm±0.002 nm	1.432 nm±0.013 nm	3.050 nm±0.036 nm
`DIMAD`	0.562 nm±0.001 nm	1.824 nm±0.012 nm	3.349 nm±0.056 nm
`Merlin`	0.569 nm±0.001 nm	1.814 nm±0.012 nm	4.038 nm±0.033 nm
* `Placet`	0.571 nm±0.001 nm	1.904 nm±0.013 nm	3.416 nm±0.026 nm

Relevant differences if the particle standard deviations are considered

(Differences up to 30 % for bunches with energy spread)

- *Without SR*, **`MAD`** shows larger discrepancies. **`Merlin`** larger discrepancies *with SR*.

* **`Placet`** simulations by D. Schulte

Comparison of the different codes (2)

Now beam sizes calculated as σ of the fitting Gaussian distribution

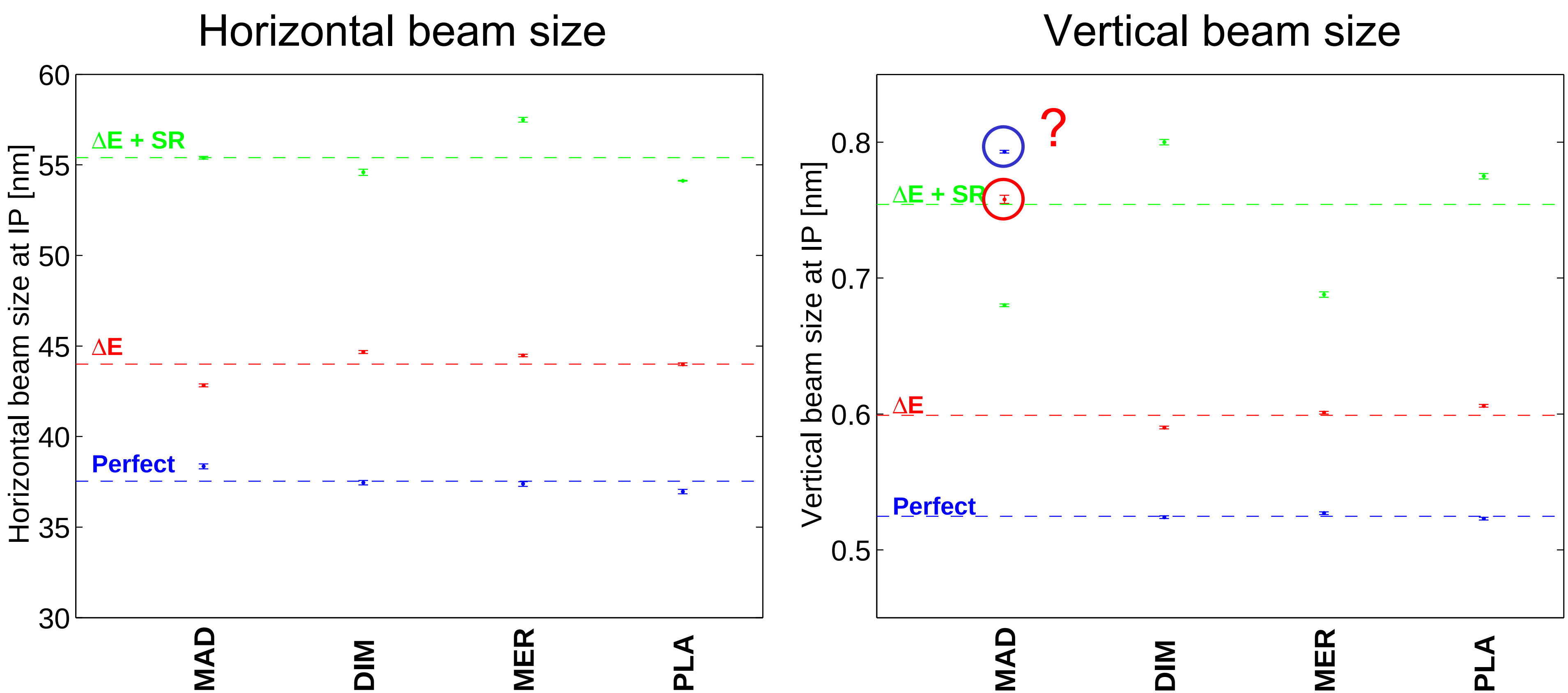
Horizontal beam sizes

	No ΔE - No SR	ΔE/E=1% - No SR	ΔE/E=1% - SR
MAD	38.35 nm±0.14 nm	42.83 nm±0.08 nm	55.39 nm±0.07 nm
DIMAD	37.45 nm±0.12 nm	44.67 nm±0.08 nm	54.59 nm±0.17 nm
Merlin	37.38 nm±0.13 nm	44.48 nm±0.07 nm	57.49 nm±0.13 nm
Placet	36.96 nm±0.12 nm	43.99 nm±0.08 nm	54.12 nm±0.17 nm

Vertical beam sizes

	No ΔE - No SR	ΔE/E=1% - No SR	ΔE/E=1% - SR
MAD	0.793 nm±0.001 nm	0.758 nm±0.003 nm	0.680 nm±0.001 nm
DIMAD	0.524 nm±0.001 nm	0.590 nm±0.001 nm	0.800 nm±0.002 nm
Merlin	0.527 nm±0.001 nm	0.601 nm±0.001 nm	0.688 nm±0.002 nm
*Placet	0.523 nm±0.001 nm	0.606 nm±0.001 nm	0.775 nm±0.002 nm

* **Placet** simulations by D. Schulte



- Now much smaller beam size (close to theoretical values)
- Sigmas agree with effective beam sizes from **`GuineaPig`** simulations (D.S.)
- Better agreement between the codes (but **`MAD`** different without SR)

*What 'bout the ultimate **luminosity** prediction??*

… what really matters…

Comparison of the different codes (3)

Luminosity calculated with **GuineaPig** for "real" case (ΔE + SR)

Luminosity - $\Delta E/E = 1\%$ + SR $[10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$

		Placet
MAD	0.817 ± 0.003	0.820 ± 0.003
DIMAD	0.747 ± 0.005	0.755 ± 0.005
Merlin	0.704 ± 0.002	0.679 ± 0.003

Different models for SR: **MAD** → Re-accelerate beam after SR losses
DIMAD → No compensation
Merlin → Rescale magnet strength
Placet → Can simulate all above cases!

- Difference between codes related to different models for SR
  Good agreement if same model is used (**Placet** results, by D. Schulte)
- Differences in luminosity predictions up to **15 %** (~ **0.1 10^{35} cm^{-2} s^{-1}**)
- *Side remark* – CLIC nominal luminosity of ~ **0.75 10^{35} cm^{-2} s^{-1}** *(→ FZ' talk…)*

4. Conclusions

- Detailed comparison of tracking codes for BDSs of linear colliders has been presented, in view of the simulation of luminosity performance
- All tools are set up and ready for luminosity performance study
- Comparison based on *Gaussian fits* of particle distributions and on *luminosity calculations* *(standard deviation of particle position not adequate for bunches with long tail)*

  Estimated beam sizes are consistent with the effective values from ***GuineaPig*** *luminosity simulations*

- Codes in ***good agreement*** for luminosity prediction if same SR model is used – all suitable for future studies
- Considerable differences for halo particles at large amplitudes (say > 3σ). *Important??* $\rightarrow$ *Question for the specialists…*