A new highly performing compression regime: the Laminar Bunching & GIOTTO, a code for extreme BD optimizations

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@ CERN 29 November 2018

The Laminar Bunching

(1) The goal

prove extreme high performances in compact LINACs (~20 m)

$E_n = 150 - 500\ \mathrm{MeV}$; $\varepsilon_{n,peak} \approx 0.3 - 1.0\ mm - mrad$;

$\boldsymbol{I_{peak}}$ **up to:** $\boldsymbol{4\ kA}$; $\boldsymbol{\sigma_E < 50\ keV}$
Ultra bright & Ultra cold: Dream beams

(2) The technique

Hybrid Laminar Velocity Bunching or Laminar Bunching (LB)

<==>

Velocity Bunching + Drift Laminar Bunching

Important notes:

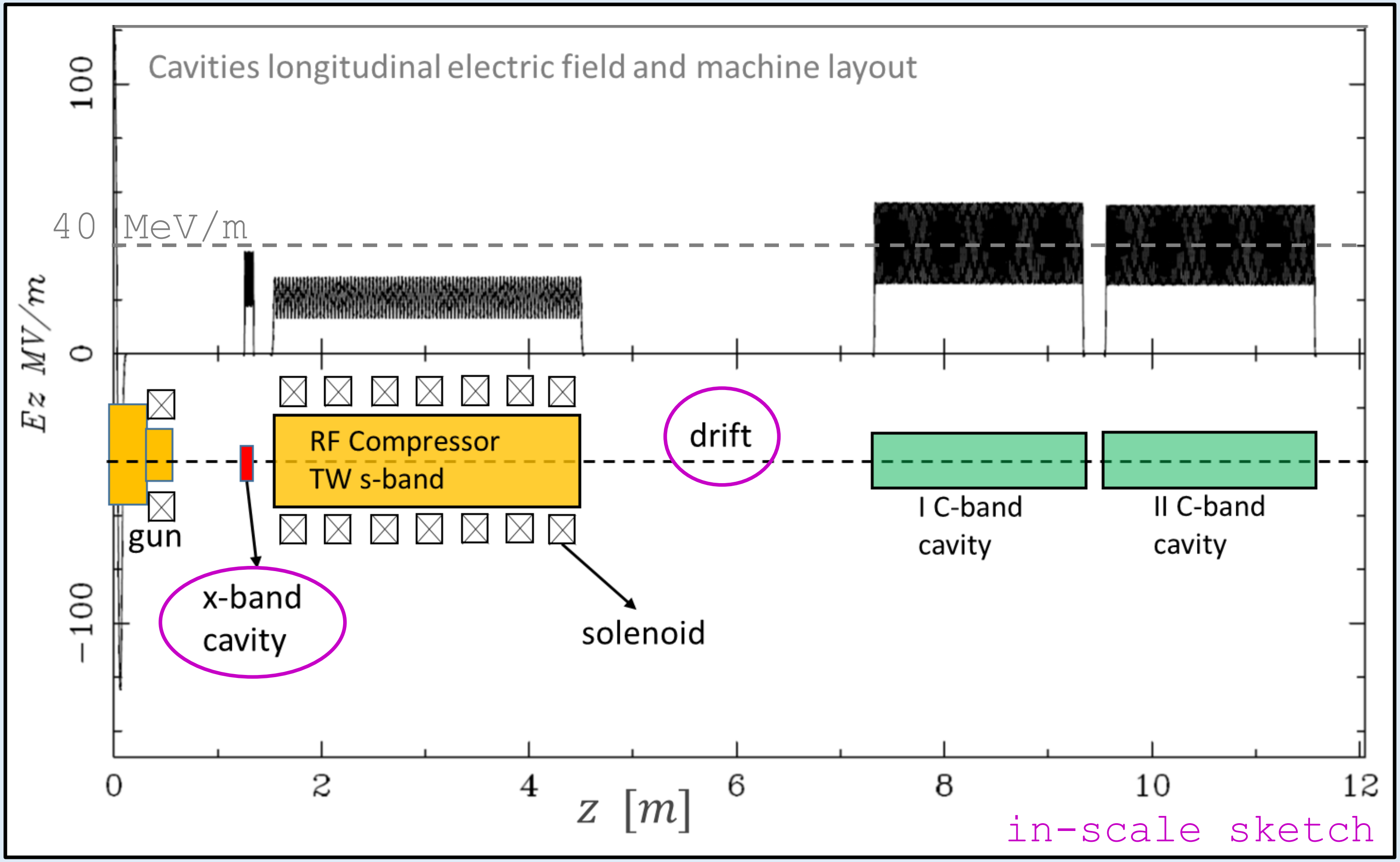
- ✓ charts show: $\sigma_x , \sigma_z , \varepsilon_{nx}, \sigma_E$
- ✓ ASTRA (*) Simulations
- ✓ Optimizations made in GIOTTO (**)

Outline

- ❑ Ad-hoc Laminar Bunching LAYOUT
- ❑ Point out the Laminar Bunching effects
- ❑ Laminar Bunching / Velocity Bunching COMPARISON
- ❑ Some Beam Dynamics: Laminarity parameter

(*) *K. Floettmann, ASTRA–A space charge tracking algorithm, http://www.desy.de/~mpyflo/*
(**) *A. Bacci, et al. "GIOTTO: A Genetic Code for Demanding Beam-dynamics Optimizations", doi: 10.18429/JACoW-IPAC2016-WEPOY03*

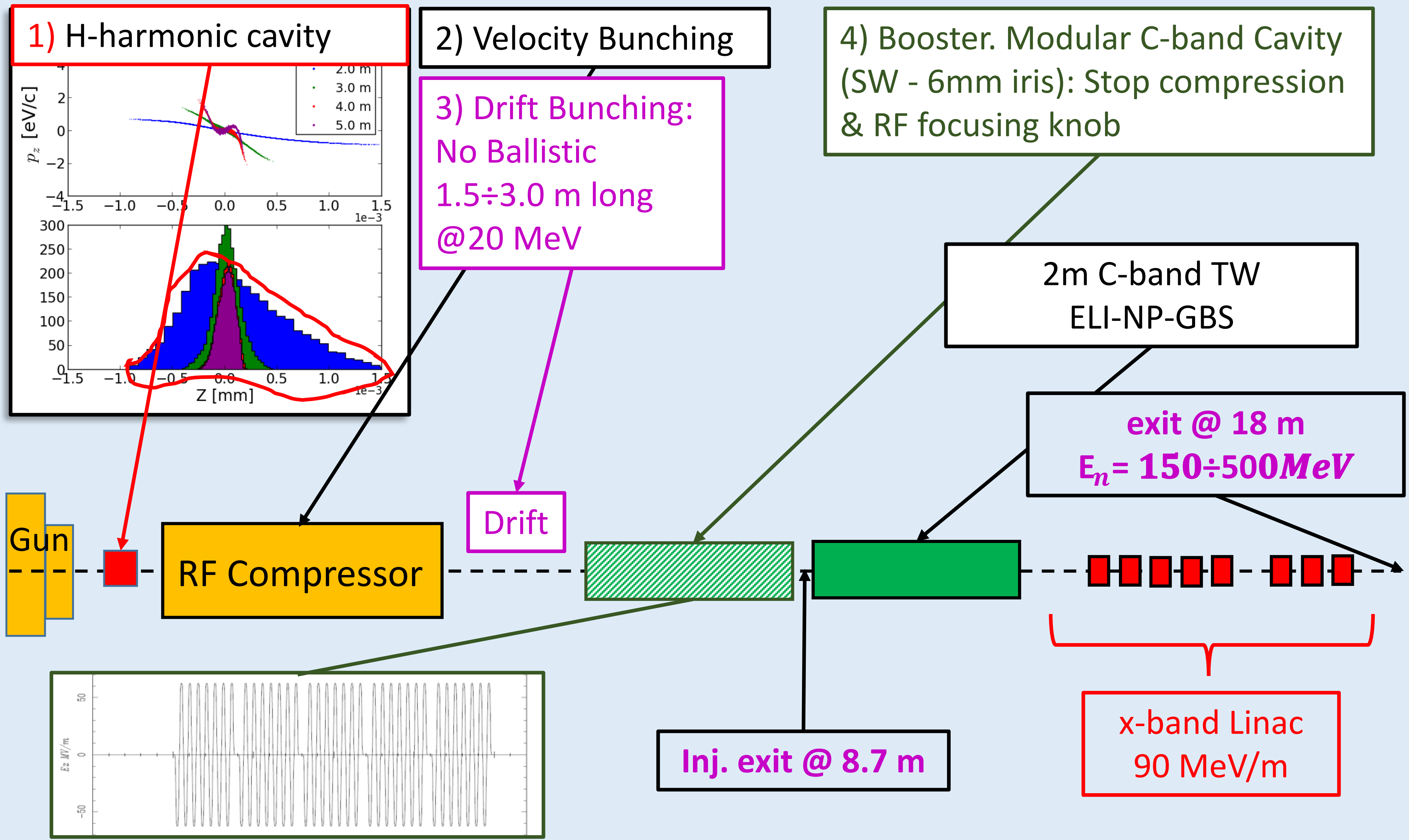
Ad-hoc layout for Laminar Bunching



For Velocity Bunching refs to: *M. Ferrario, et. al., PRL 104, 054801 (2010)*

A compact machine layout working in Laminar Bunching

1) HighHarm-cavity current pre-correction; 2) Velocity Bunch.;
3) Drift Laminar Bunching (balanced accordion effect);
4) RF-focusing tunable booster



High harmonic cavity current pre-correction

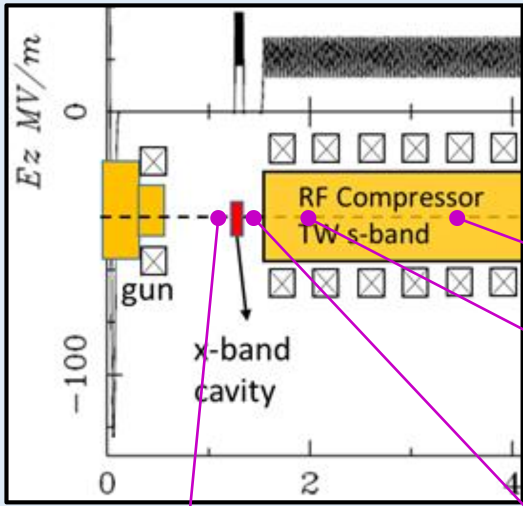


Table 1: C-band and X-band High Harmonic Correction Cavities Comparison and the Non-corrected VB Case

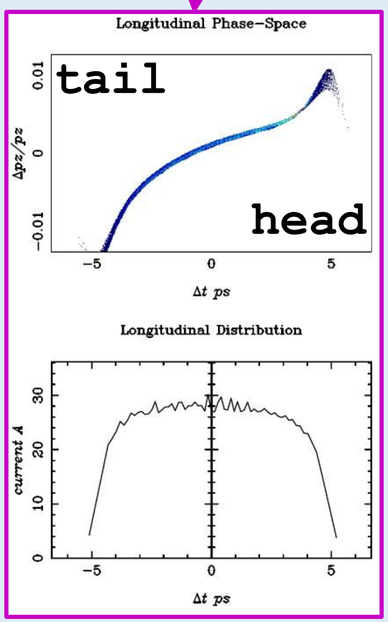
Type band	Grad. [MeV/m]	Decreased E [MeV]	$\sigma_z[\mu m]$	$\varepsilon_{n,x}[\mu m]$
Nothing	-	-	200	1.7
C-3 Cells	31	2.5	106	2.4
C-11 Cells	17.5	3.0	75	4.0
X-11 Cells	28	2.5	93	2.0
X-11 Cells	35	3.0	75	4.0

1.2 m

1.4 m

2.0 m

1.4 m



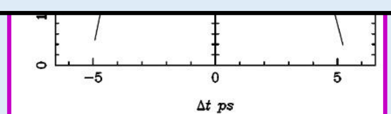
Many good effects:

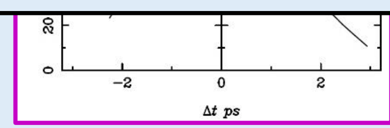
1) RF curvature pre-correction
2) Current pre-correction
3) Starts the compression (\ chirp)

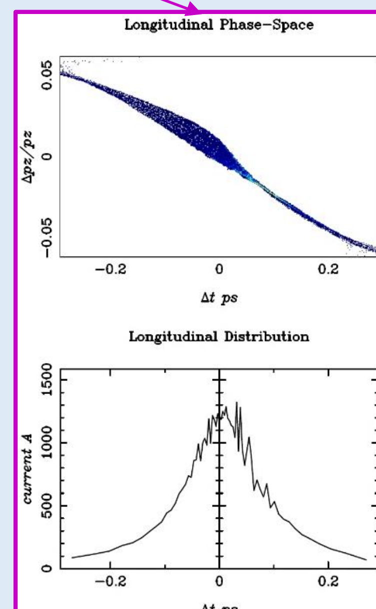
En decrease of 2.3 MeV on 6 MeV

↓

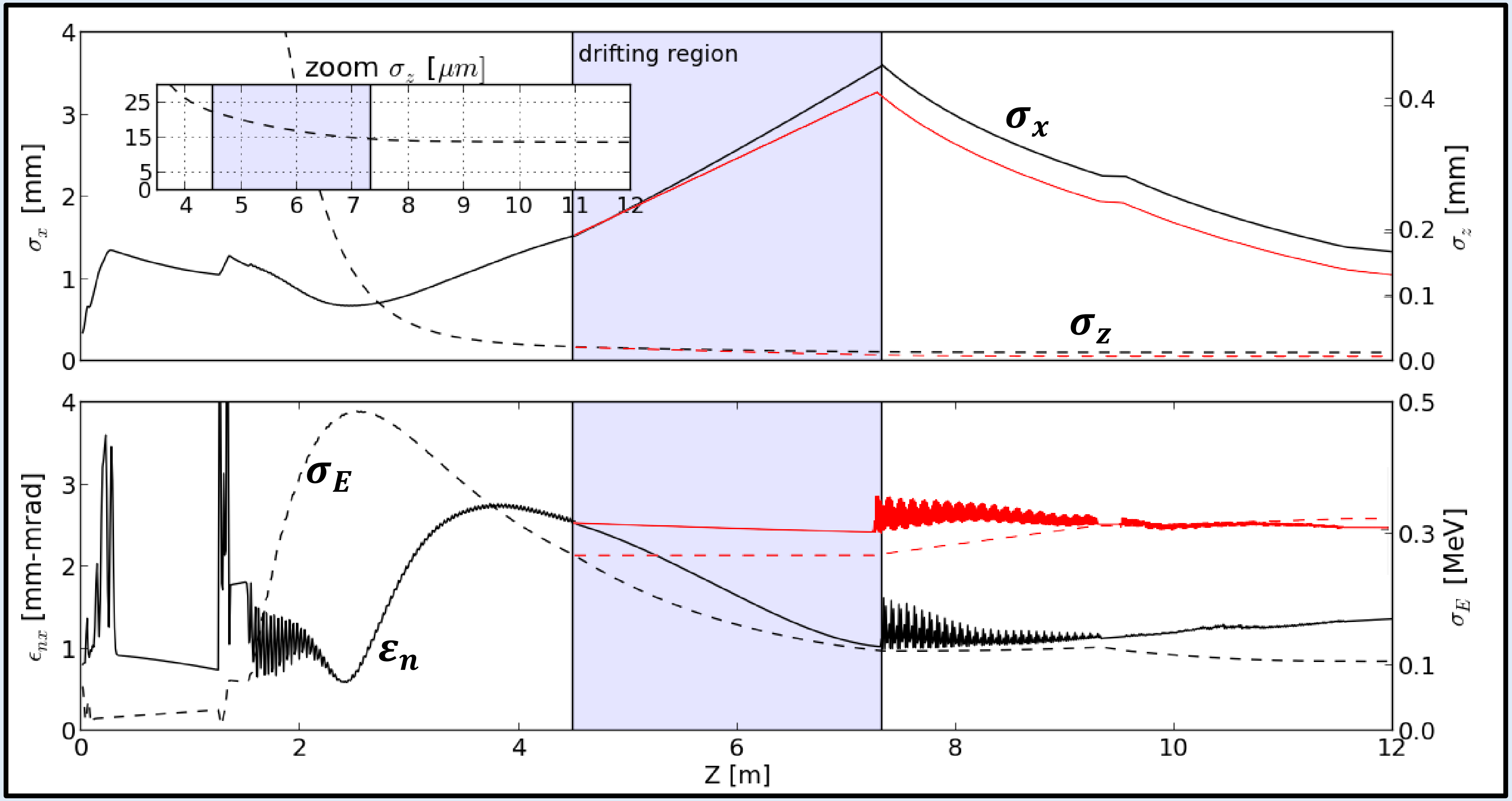
4) ρ_z falls down favoring compression
5) A lower Energy favors VB







σ_x , σ_z, ε_{nx}, σ_E curves in Laminar Bunching



Turning off the SPACE charge from the drift onward

- σ_x quasi linear rising
- σ_z hyperbolic decreasing
- σ_E a quasi full correction
- ε_n a quasi full correction

Both optimized by GIOTTO genetic algorithm

$\sigma_z, \varepsilon_{nx}, \sigma_E$

Laminar Bunching (LB)

Velocity Bunching (VB)

only a comparison

LB & VB are relatives, but their final results are different.

The aim:
outline **LB** peculiarities versus the **VB** known technique.

Both: Linear compression & same energies

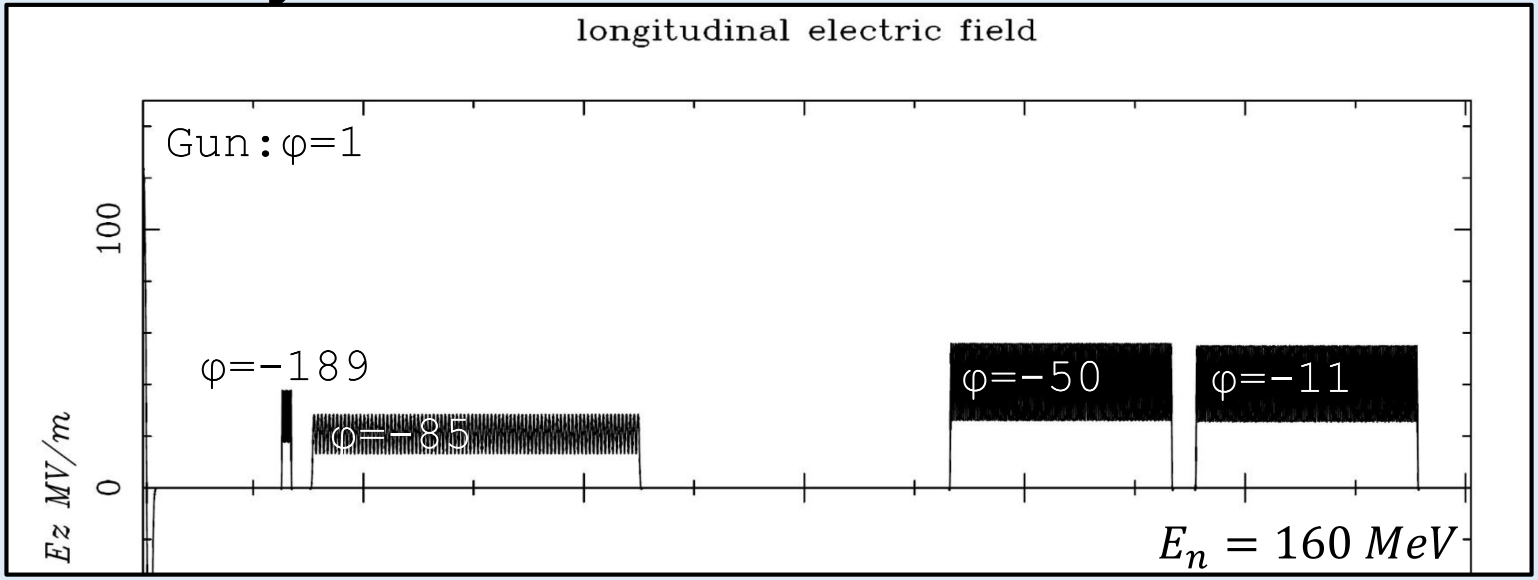
LB works on the whole bunch dist.

VB favors one spike @ bunch head

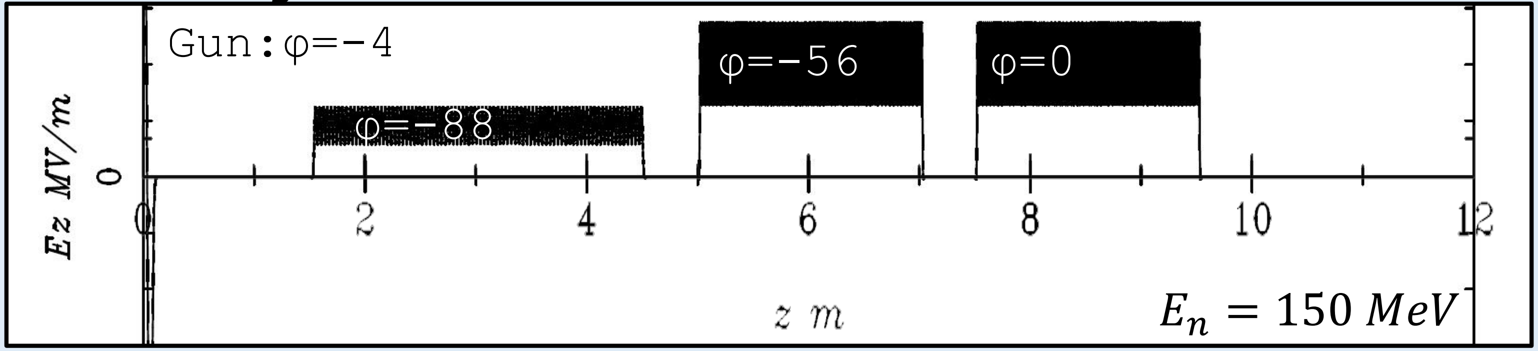
Laminar & Velocity Bunching Layout

@ chatode for both LB & VB	$Q_b\ [pC]$	$\tau_{Laser}\ [ps]$ flat-top	$\tau_{rising}\ [ps]$	ε_{th} [1μ /mm]	$\sigma_x\ [\mu m]$
	250	10	1	0.9	260

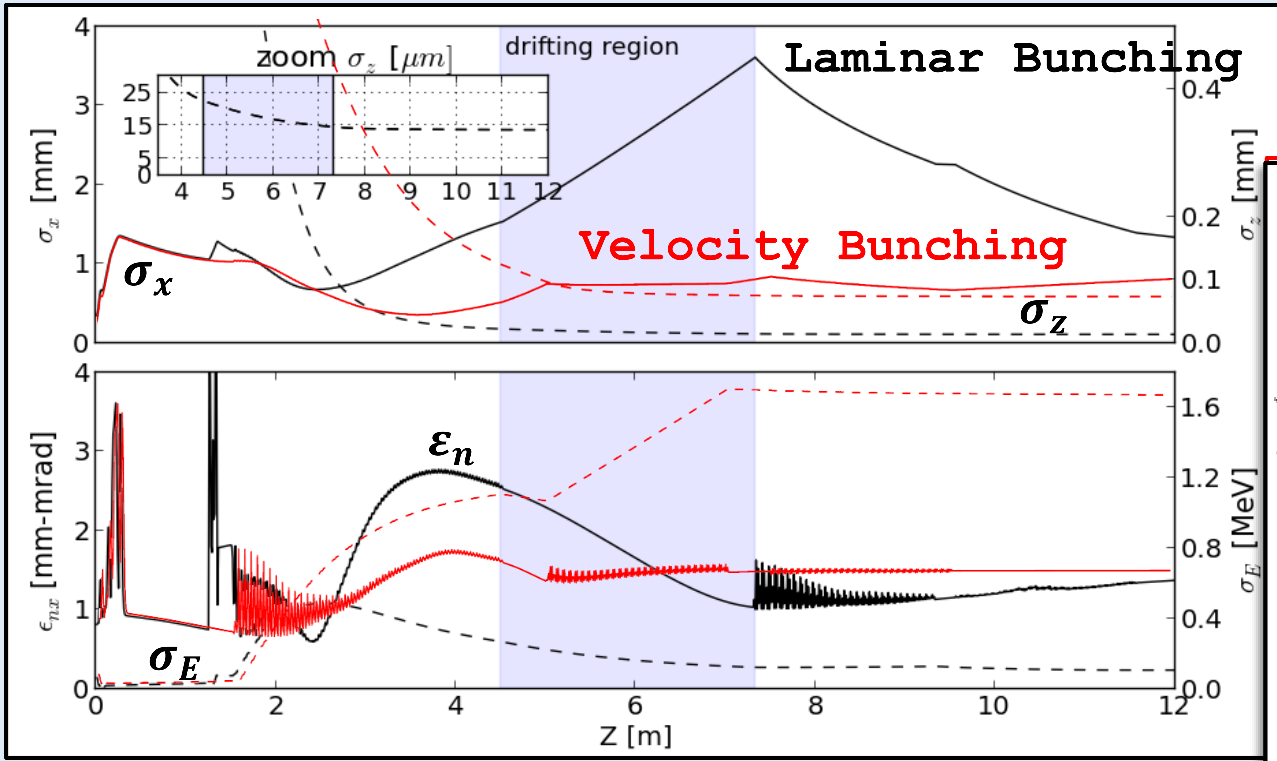
L.Bunching

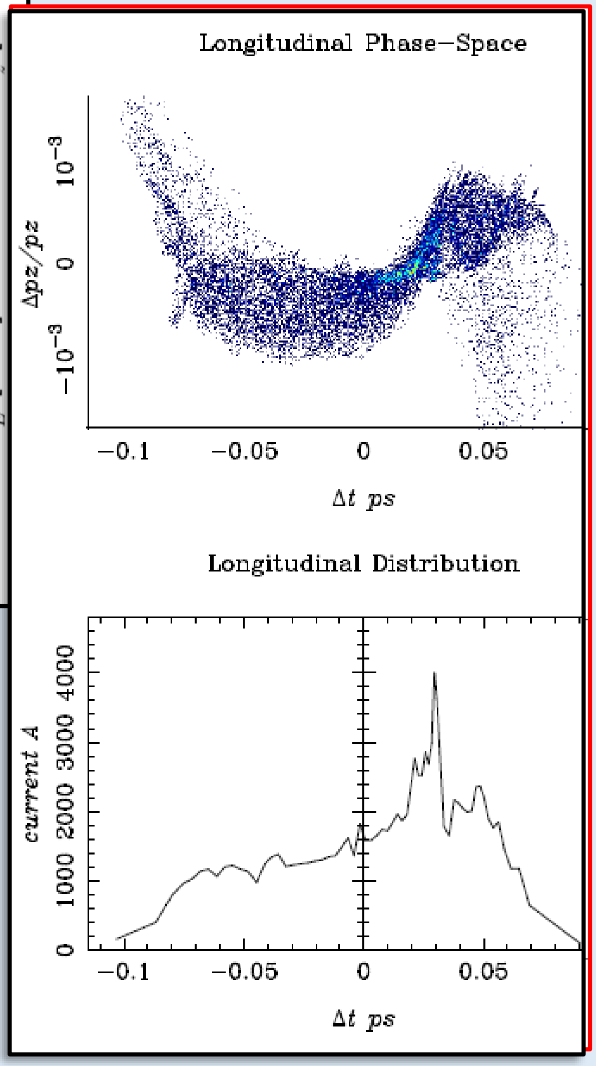


V.Bunching



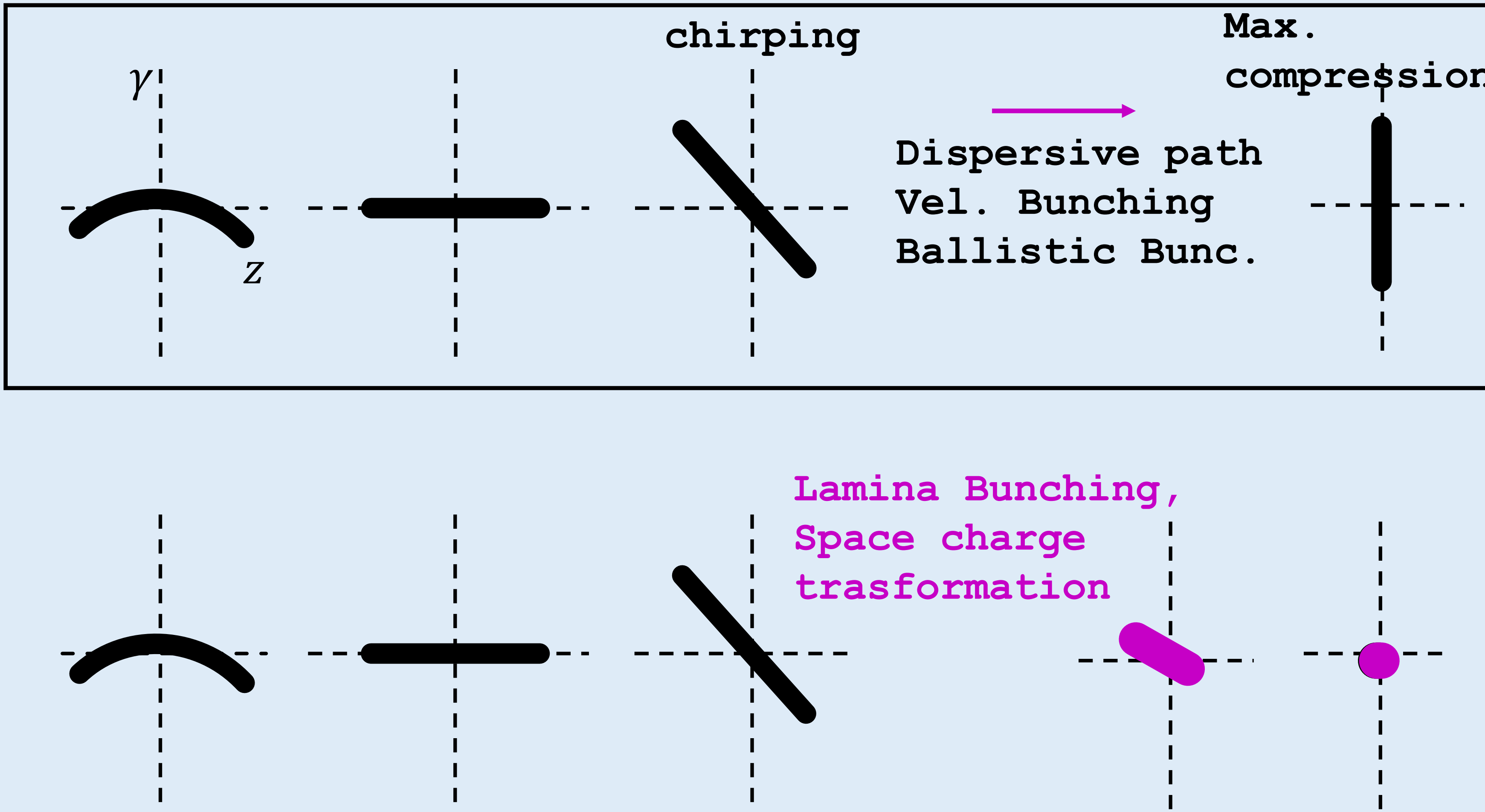
Laminar "▓" & Velocity "▓" Bunching comparison





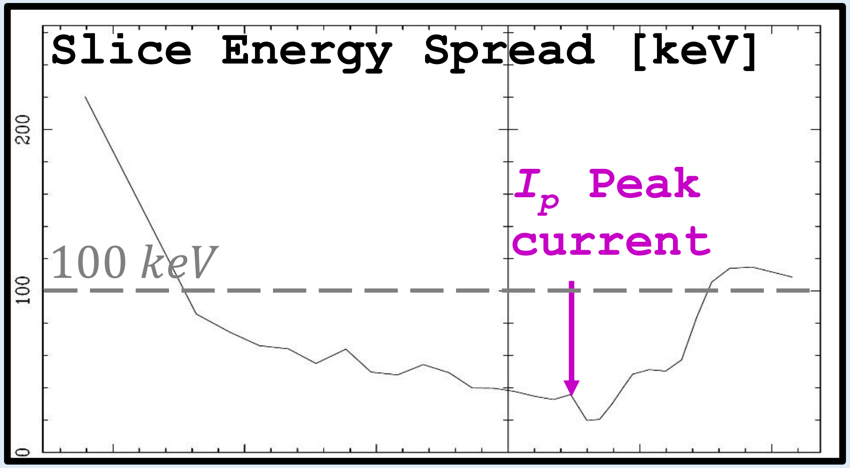
A strong simplification of the longitudinal phase space modification

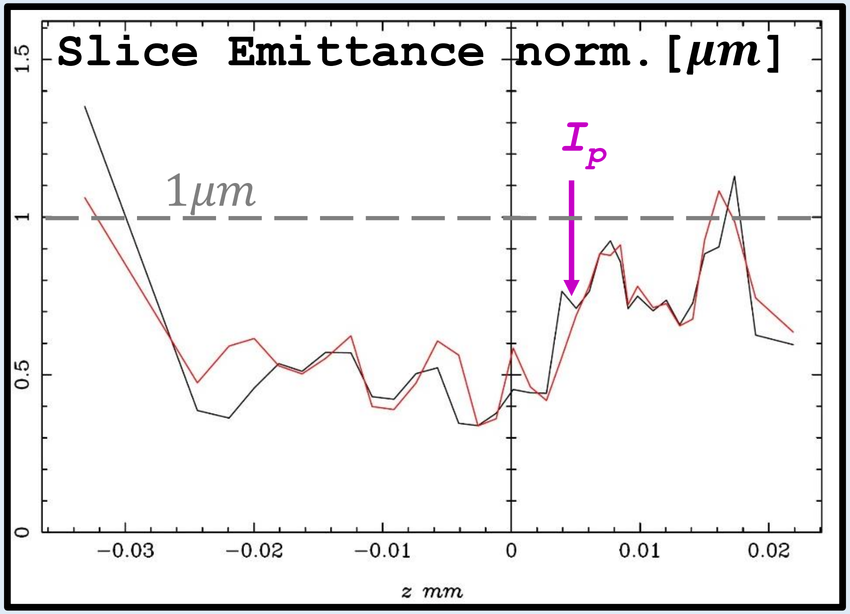
Classic methods



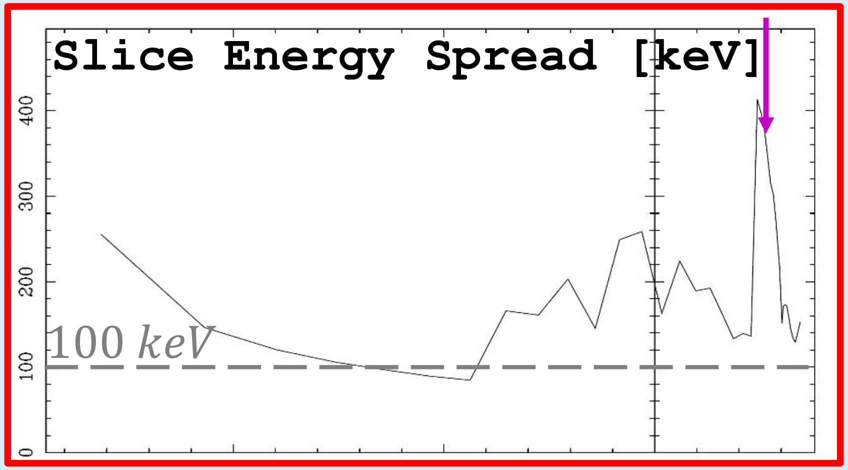
Laminar “▓” & Velocity “▓” Bunching comparison

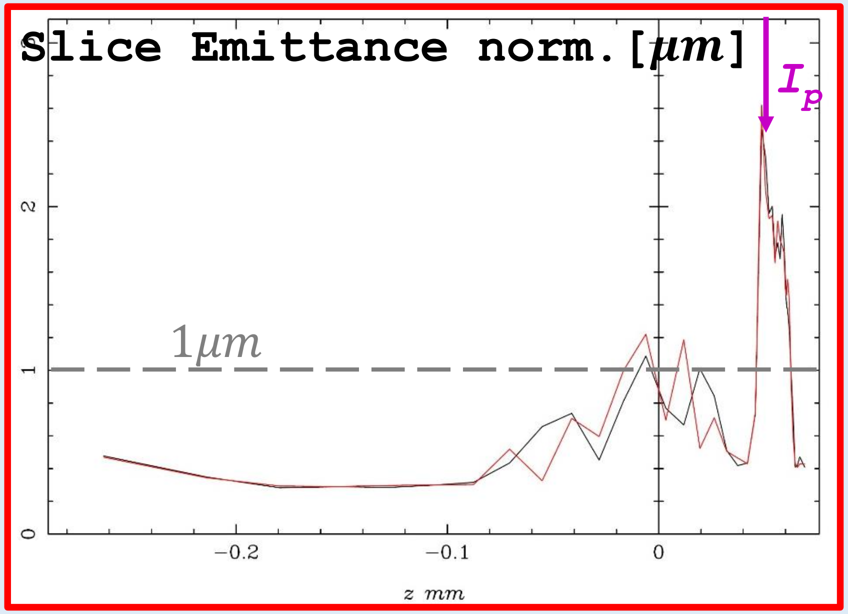
LB





LB





Some Beam Dynamics

Transverse envelope

$$\sigma'' + \frac{\gamma'}{\gamma}\sigma' + \left(\frac{k}{\gamma}\right)^2 \sigma = \frac{Qc}{2I_A\gamma^3\sigma_z\sigma} + \frac{\varepsilon_n^2}{\gamma^2\sigma^3}$$

Long. envelope equation

$$\sigma_z'' + K_z\sigma_z + \frac{3\gamma'\sigma_z'}{\beta^2\gamma} = \frac{Q_b c}{5\sqrt{5}I_A\beta^2\gamma^4\sigma_z\sigma} + \frac{\varepsilon_{nz}^2}{\beta^2\gamma^6\sigma_z^3}$$

γ power of 3

Coupled by σ_x

γ power of 4

Laminar Parameters

$$\rho_\perp = \frac{Q_b c\sigma^2}{2I_0\gamma\varepsilon_n^2}$$

$$\rho_z = \frac{Q_b c(\gamma\sigma_z)^2}{I_0\sigma\varepsilon_z^2}$$

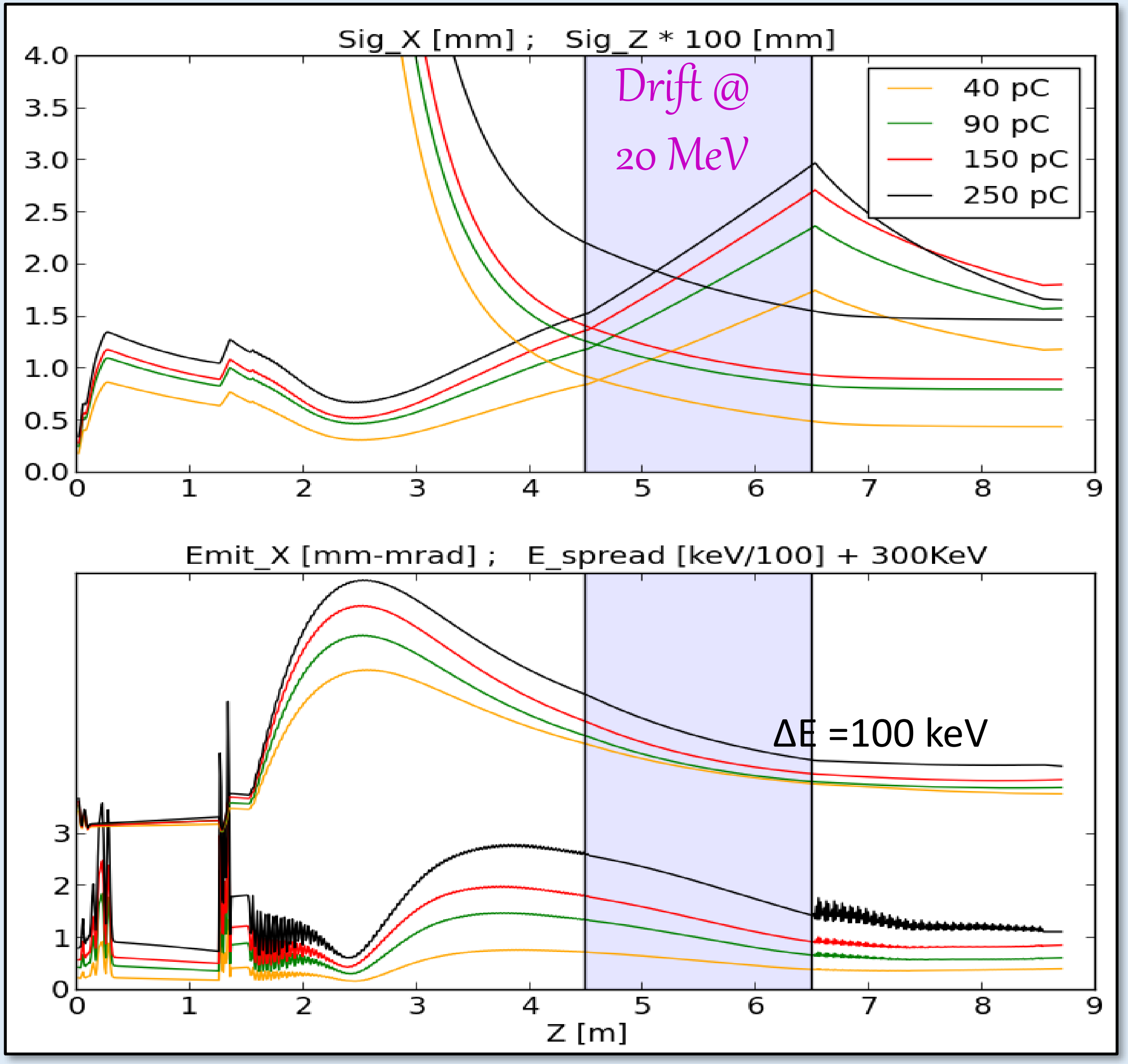
Emittance compensations

1) Longitudinal compression

&

2) bunch stiffness respet to the compression

LB perfomances VS. bunch-charge: 40;90;150;250 pC



@ booster end = 17 m (0.5 GeV)

$Q_b = 40\ pC$

$\sigma_z = 4.2\ \mu m$

$I_{peak} > 2.5kA$

$\varepsilon_{peak} = 0.3\ \mu m$

$B_{peak} = 3 \cdot 10^{16}$

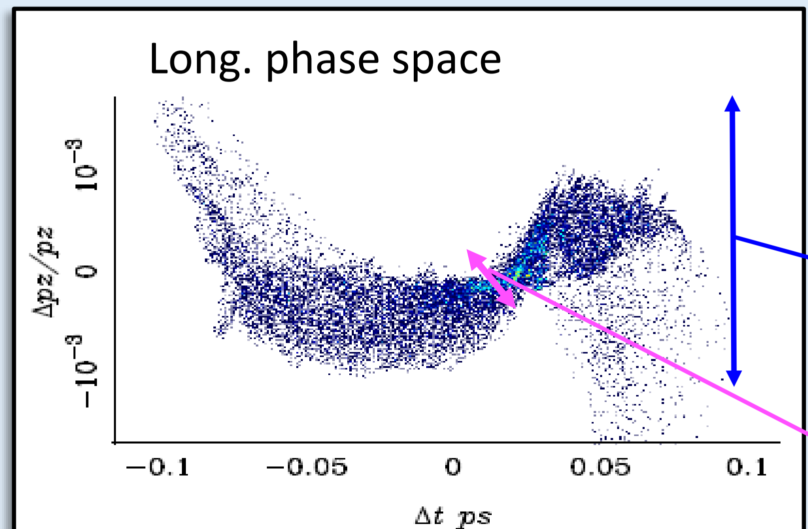
$(I_p = 1.5kA)$

$(\Delta\gamma/\gamma)_{@I_{peak}} \cong\ 8 \cdot 10^{-5}$

CONCLUSIONS

We saw a new compression technique: the Laminar Bunching

- ❑ **A compression that works on the whole bunch distribution**
- ❑ **It is reproduced for a large range of charge: 40-250 pC**
- ❑ **ULTRA brightness and ULTRA low energy spread ($10^{-4}\div 10^{-5}$);**
  A combination difficult to find!
- ❑ **Drawback: Large envelopes for $Q_b > 100\, pC$.**
  An Ad-hoc large iris cavity can be used (rf-focusing knob)
- ❑ **No Laser Heater (High un-correlated Energy Spread):**



Beam Dynamics study by using Genetic Algorithms

Alberto Bacci and
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@ CERN 29 November 2018

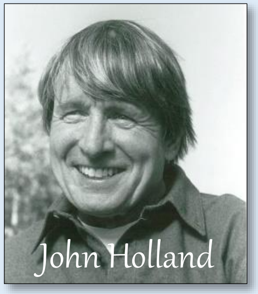
Outline

- **G**enetic **A**lgorithm**s (GAs) intro**

- **GAs applied to beamlines optimization**
  - From Beamlines to Chromosomes
  - Following Genetic Laws: Fitness, Reproduction, Mutations, …
  - e.g.: SPARC beam line Optimization in Thomson case

- **The GIOTTO code**
  - The GIOTTO Data-Based DB
  - Inputs & Outputs
  - Fitness function (or Idoneity) definition
  - Optimizations & Statistics **on some Specific Cases:**
    - ✓ **Ultra short bunches by Laminar Bunching**
    - ✓ **Comb bunches distributions**

❑ Intro: Genetic Algorithms **Historical Notes**



- **1970 John Holland - schemata theorem**

- **1975 J. Holland publication:** "*Adaptation in Natural and Artificial Systems: An Introductory Analysis with Application to Biology, Control, and Artificial Intelligence*". **The Seminal work**

- **1975 K. De Jong (J. Holland's student), Thesis:** "*An analysis of the behavior of a class of genetic adaptive systems*". Broad applicability of GAs

- **1989 David Goldberg Book:** "*Genetic Algorithms in Search, Optimization, and Machine Learning*"
  It deals with **the topic at high level** and **is considered a milestone in GAs story**. It reports techniques like Multi Objective GA (MOGA), today very trendy.

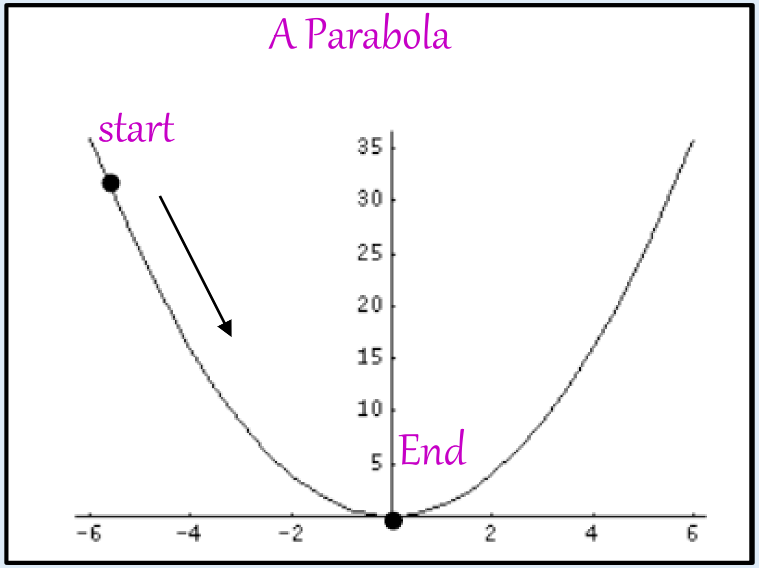
Intro: What are Genetic Algorithms (GAs)?

A Searching procedure based on a natural selection (genetic laws)

Why choosing GAs versus other techniques?

A basic answer:

Newton-Raphson methods (or **variants**) are based on local information. The Scan moves in direction of local-maxima or local-minima



Intro: Why Genetic Algorithms?

Despite, Newton-Raphson methods can overcame the local solutions issue by some tricks …

GAs are:

- naturally able to manage the local solutions issue
- naturally parallelizable
- usable with a minimum mathematical effort

by empirical results, show strong capability in problems where other methods fail

pros and cons

a suggested pub.

Genetic Algorithm Optimization Applied to Electromagnetics: A Review

Daniel S. Weile and Eric Michielssen, *Member, IEEE*

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 45, NO. 3, MARCH 1997

❑ GAs in Beam Dynamics Optimizations

GAs give strong advantages in

- multi-dimensional problems with variables strongly non-linearly correlated

Two main examples :

- Space Charge & its non-linear nature: correlates low energy beamline parameters
- Also frozen beams (space charge off), e.g.: complex matching lines (plasma accelerated beams)

example: **Thomson/Compton sources** (e.g. SPARC_lab, STAR, ThomX, ELI-np, Munich Compact Light Source) **ask for :**

- **High spectral density** that means: **very low DE/E**, **low Emit**
- **High the photon flux** that means: **high Q_{bunch}**, **small spot size**

❑ … or other exampes

considering **ultra short e-beams** (e.g. SPARC_lab, LCLS, REAGE, XFEL, EUPRAXIA, …):

- **Femtosecond light pulses (FEL/X-FEL)**, Atoms in chemical reactions, phase-transition, *Photosynthesis Water Splitting :* timescale 1-100 fs [2014 "first snapshots of water splitting" by LCLS; ScienceDaily; Nature]

- **Plasma Wave Acceleration:** λ_{plasma} order of 30-600 fs . The **Witness** much shorter, the **Driver** (pwfa) comparable to λ_{plasma}

- **Femtosecond Electron Diffraction (FED)**
  Molecular or atomic motion movies: phase transitions, …, . Timescale: few 10s of fs. Relativistic case: $E_b \approx 5MeV$, $Q_b \approx 100fC$, $\varepsilon_{tr}<0.1$ mm-mrad, $\sigma_z<30\mu m$ (100fs)

- **THz radiation (by CoTrRad)**
  0.1 up to tens THz is of great interest for both longitudinal electron beam diagnostics (fs scale) and spectroscopy in pump-and-probe experiments ....

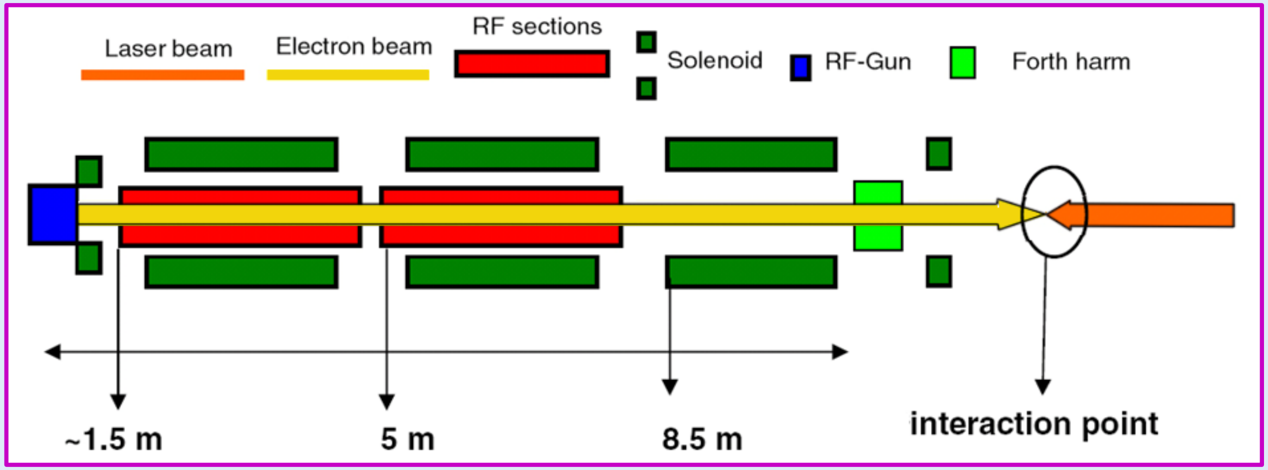
Genetic Algorithms applied to Beam-Line Optimization

❑ From **beamlines** to **chromosomes**

Genetic laws work on Chromosomes **==>** Chromosomes are made of genes (parameters)

Beamline setup ⇔ A genes array **.or.** One Chromosome

A BeamLine (exp. Thomson @ SPARC_lab)



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Chromosome

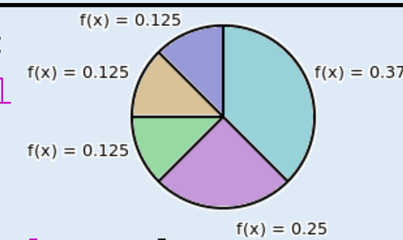
Gene	Reference case
$dE_g/dz\,(MV/m)$	120
$\phi_g\,(°)$	0
$B_g\,(T)$	0.2707
$dE_1/dz\,(MV/m)$	13.4
$\phi_1\,(°)$	-30
$B_1\,(T)$	0.12
$z_1\,(m)$	1.322
$dE_2/dz\,(MV/m)$	6.55
$\phi_2\,(°)$	88
$B_2\,(T)$	0.1145
$z_2\,(m)$	5
$B_3\,(T)$	0.1145
$z_3\,(m)$	8.5
$\phi_{IVH}\,(°)$	180
$z_{IVH}\,(m)$	11.7

❑ Following genetic laws: the Fitness Function

Gene	Reference case
dE_g / dz (MV/m)	120
ϕ_g (°)	0
B_g (T)	0.2707
dE_1 / dz (MV/m)	13.4
ϕ_1 (°)	-30
B_1 (T)	0.12
z_1 (m)	1.322
dE_2 / dz (MV/m)	6.55
ϕ_2 (°)	88
B_2 (T)	0.1145
z_2 (m)	5
B_3 (T)	0.1145
z_3 (m)	8.5
ϕ_{IVH} (°)	180
z_{IVH} (m)	11.7

Starts from random generation

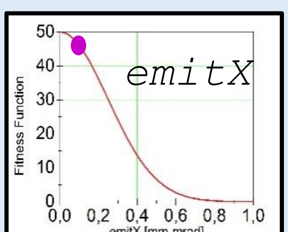
To pass generation ➔ in generation:
-> Selection: bluffed Roulette wheel
-> Mutations



…. & others methods & tricks. The rule: closest to Nature, best performances

Chromosomes sorting

$$== \; 50\cdot e^{-\left(\frac{eimtX}{0.35}\right)^2} + 50\cdot e^{-\left(\frac{E_{spread}}{250}\right)^2}$$



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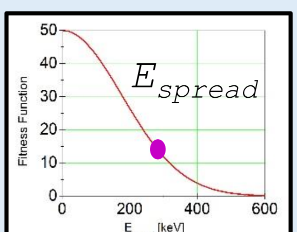
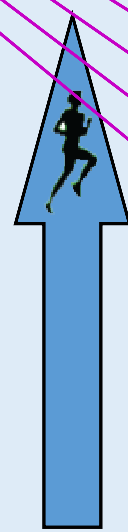
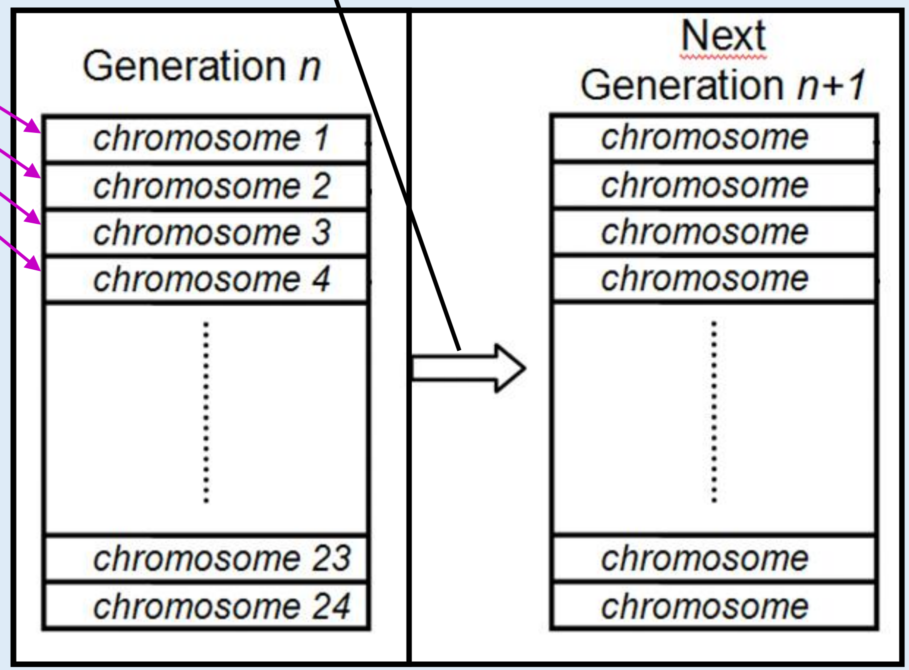




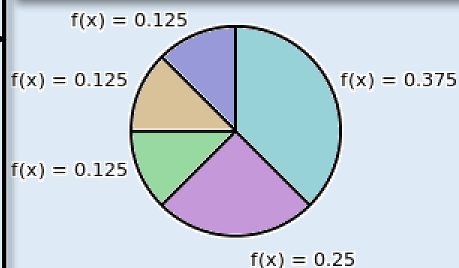


➢ Following genetic laws: Reproduction & Mutation

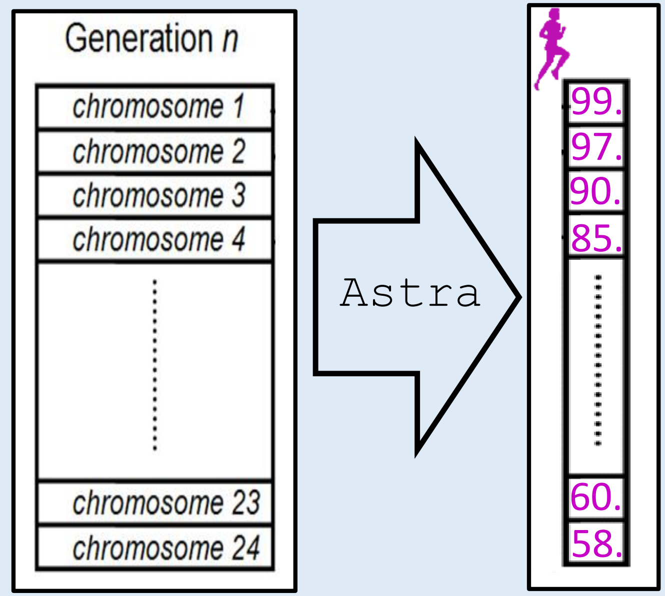
Chromosome Sorting

0 < 🏃 < 100

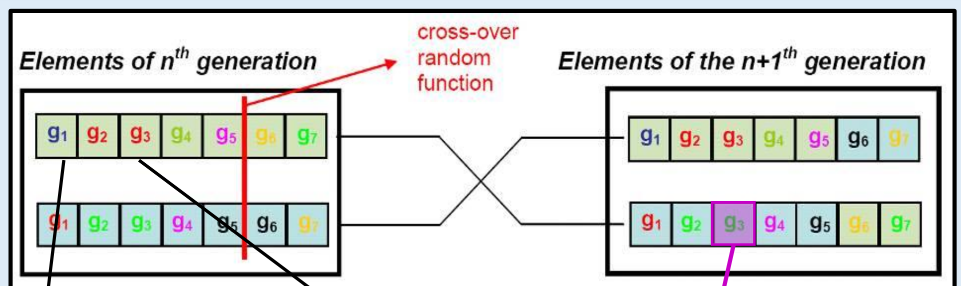
By the Roulette Wheel:
two Chromosomes



$$\sum f_p(x) = 1$$



Reproduction by cross-over oper.



Gun_Φ inj.

Gun gradient

Mutation, with probability < 1%

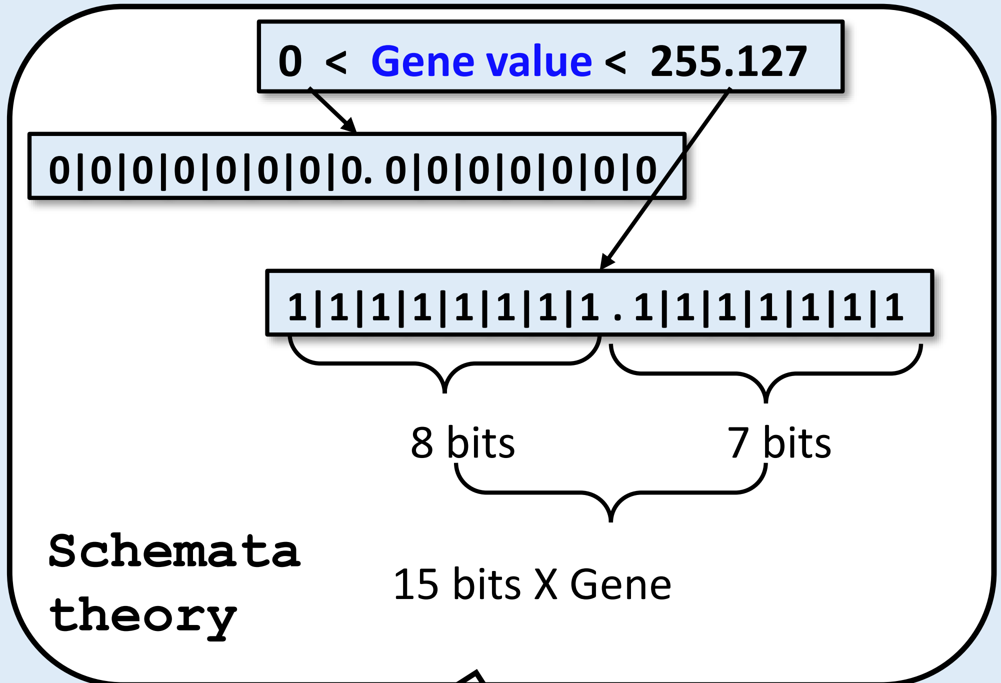
➢ Following genetic laws: real coding & the binary one

1) Genetic rules on Real Numbers → … as seen … before → main loop

Chromosome

Gene	Reference case
dE_g/dz (MV/m)	120
ϕ_g (°)	0
B_g (T)	0.2707
dE_1/dz (MV/m)	13.4
ϕ_1 (°)	-30
B_1 (T)	0.12
z_1 (m)	1.322
dE_2/dz (MV/m)	6.55
ϕ_2 (°)	88
B_2 (T)	0.1145
z_2 (m)	5
B_3 (T)	0.1145
z_3 (m)	8.5
ϕ_{IVH} (°)	180
z_{IVH} (m)	11.7

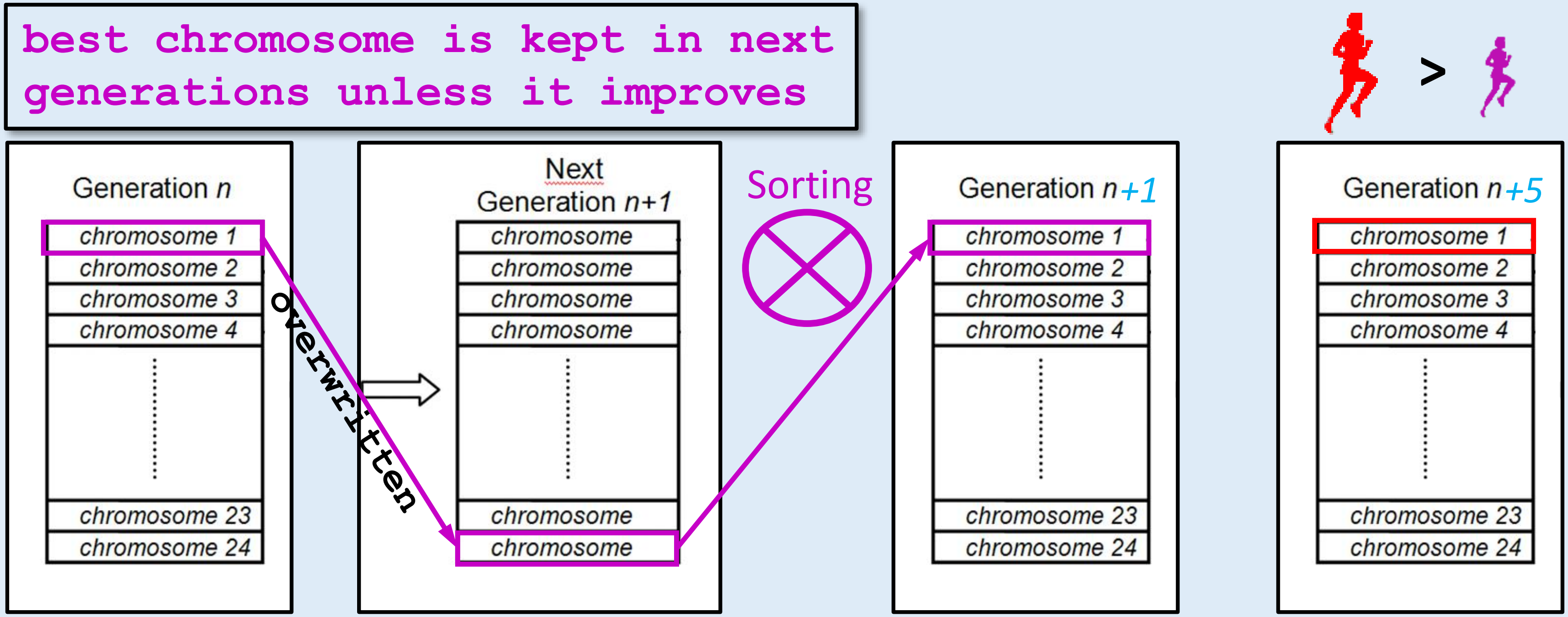
2) Binary Coding



genetic rules on binary arrays → decoding to decimal

➢ Following Genetic Laws: Elitism

best chromosome is kept in next generations unless it improves

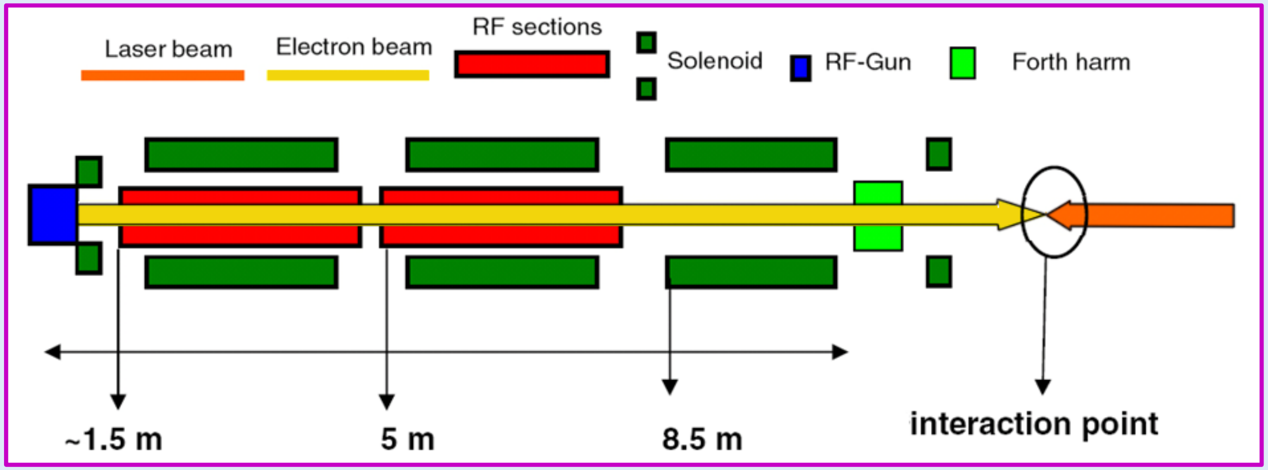


"quasi-classical" optimization techniques:

- elitism
- advanced mutation operators
- hill climbing
- regeneration from best solutions
- … … …

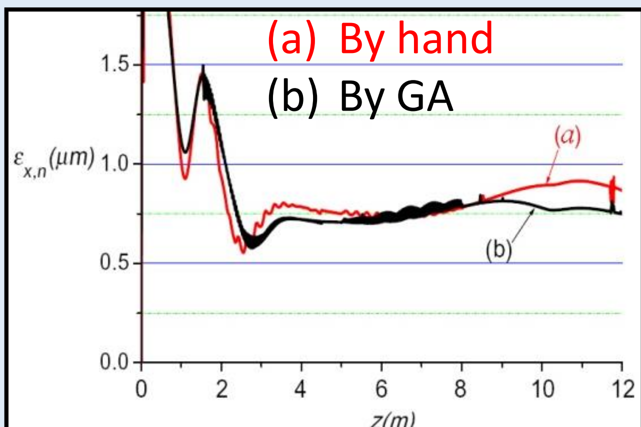
parallelization is-mandatory ⚠

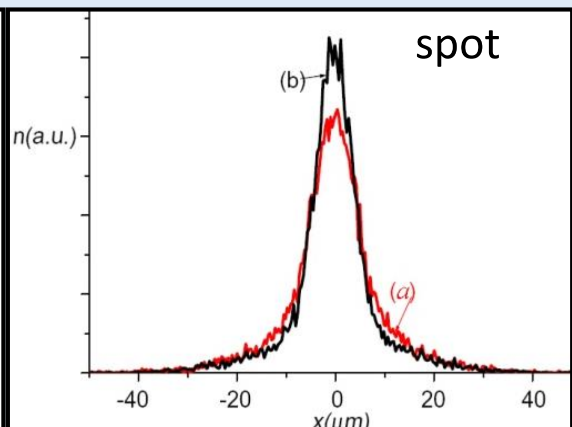
➢ SPARC beamline optimization in Thomson case

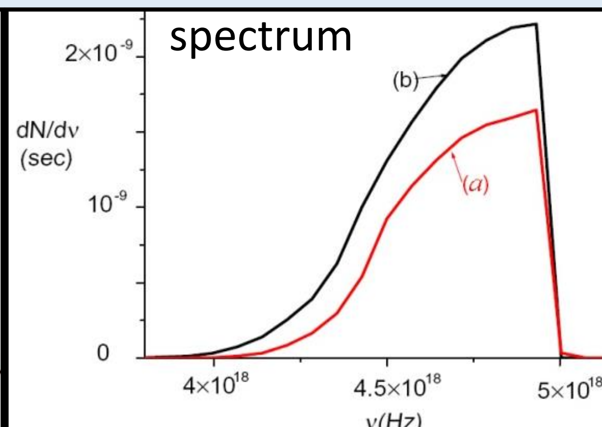


Old Kind of Fitness Function

$$F_{fitness} = \frac{1}{\varepsilon_{x,n} \cdot \frac{\Delta\gamma}{\gamma}}$$







"MAXIMIZING THE BRIGHTNESS OF AB ELECTRON BEAM BY MEANS OF A GENETIC ALGORITHM"

A. Bacci, C. Maroli, V. Petrillo, A. Rossi, L. Serafini - NIMB 263 (2007) 488-496

The
GIOTTO
code

GIOTTO: Genetic Interface for OpTimising Tracking with Optics

- The code was born in 2008; Language: Fortran 90/95
- … born for optimization of beamline parameters & statistical (Jitters) analysis
- INPUTS based on NameList & two internal DataBase
- CAN easily Drive different codes (NameList natively):
  Now: ASTRA's Generator, ASTRA, QFluid (Plasma acceleration, A. Rossi modifications)
- Current Version (Ver. 18.4):
  Linux & Windows 64 bit - (compilers gfortran or INTEL fortran compiled). Parallelized: OPEN-MPI (Linux), MS-MPI or INTEL MPI (Windows)
  Tested @ PSI (S. Bettoni),@ Desy-Pitz (Martin), LAL (Luca, Harsh)
- Code and Documentations:
  URL:http://pcfasci.fisica.unimi.it/Pagine/GIOTTO/GIOTTO.htm
  (server down, pardon!)
  Exist an User manual for version 8.5 2012 (needs updates)

GIOTTO – Genetic Interface for OpTimising Tracking with Optics

From 2008 up to day, the code is grew in power and capability

Optimization techniques: elitism; advanced mutation operators; hill climbing; ant colony; regeneration from best solutions

freely defined by the User, exploiting Astra outputs:
Targets: bunch PosZ, bunch Time, En, En_{spread}, SigZ, Xemit, sigX, divergX, Yemit, ….

Important GIOTTO's features:

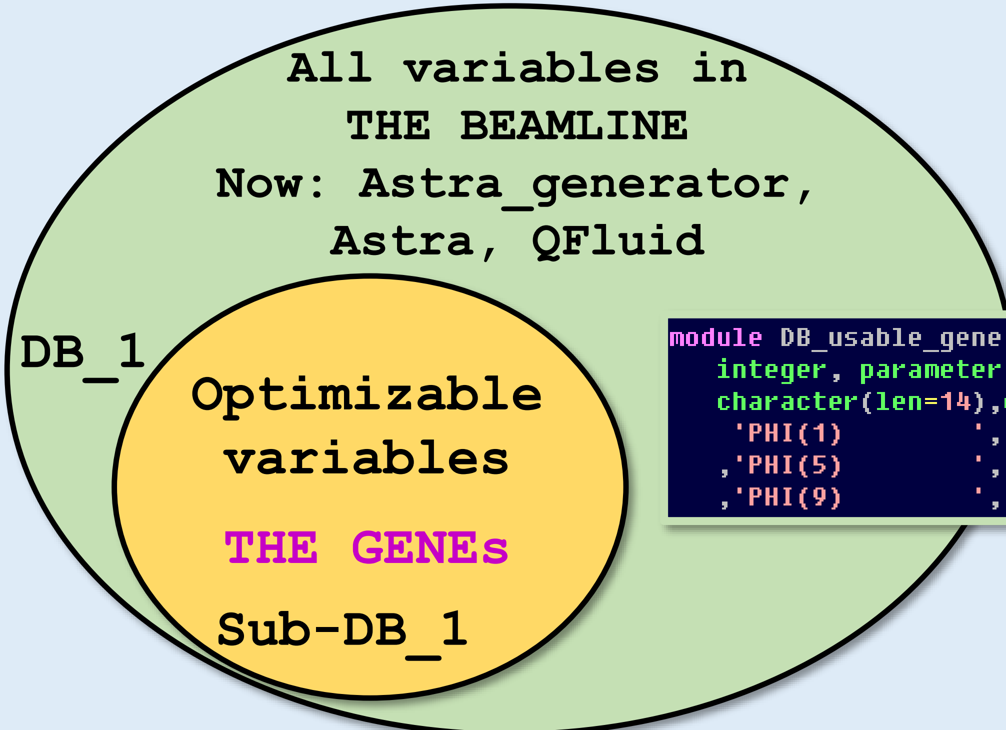
Every NameList 's variables can be used as a GENE (optimizable) **& Any code working with NameList is directly importable in GIOTTO.**
ASTRA: Phi(1)…Phi(50), MaxE(1:50), MaxB(1:50), sig_x (laser cathode) ,sig_clock (Laser @ cathode), …, … (no limit on the number)

Constraints freely defined by the user (under test)

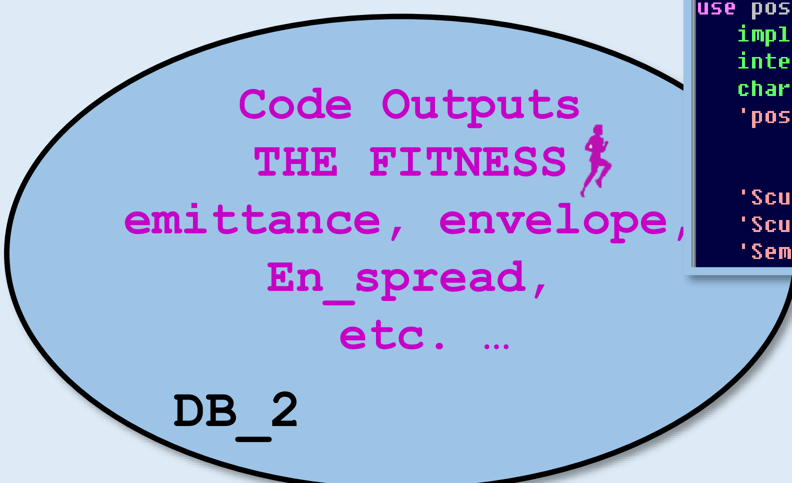
switches from Optimizations to Statistical analysis

Jitters sampling interval Uniform or Gaussian

➢ GIOTTO's Data-Bases




```
module DB_usable_gene
   integer, parameter :: DB_extension=269
   character(len=14),dimension(DB_extension) :: DB_genes=(/&
    'PHI(1)          ','PHI(2)          ','PHI(3)          ','PHI(4)          '&
   ,'PHI(5)          ','PHI(6)          ','PHI(7)          ','PHI(8)          '&
   ,'PHI(9)          ','PHI(10)         ','PHI(11)         ','PHI(12)         '&
```




```
module charge_rpn_idon      !rpn reverse polish notation
use post_processors
   implicit none
   integer,parameter,private :: DB_out_dim=107
   character(len=10),dimension(DB_out_dim),private :: DB_out=(/&
   'posZ      ','time      ','En        ','sigZ      ','DEn       ','emitZ
                             'Xmed      ','sigX      ','divergX   ','emitX
                             'Ymed     ','sigY     ','divergY  ','emitY      ','
   'Scurr(1)  ','Scurr(2)  ','Scurr(3)  ','Scurr(4)  ','Scurr(5)  ',&
   'Scurr(6)  ','Scurr(7)  ','Scurr(8)  ','Scurr(9)  ','Scurr(10) ',&
   'SemitX(1) ','SemitX(2) ','SemitX(3) ','SemitX(4) ','SemitX(5) ',&
```

➢ GINxx.xx.ini GIOTTO's INPUT FILE

It is divided in two parts:

1) A **NameList** (**&GA**) giving all the directive to GIOTTO

2) Three **keyNames** defining: **CONSTRAINTS**, **FITNESS** and **GENES**

1)

```
&GA
Astra_in='Astra_23_Jan2014.exe','pls-start.in'
....
.....
/
```

2)

```
==============================From here Key_Names==================================
==================(lines after one blank-record are comments)=======================
====================================================================================
[constr01]
sigZ En * sqr emitZ sqr sigX * / 5300 * 1 >

[constr02]
sigZ En * sqr emitZ sqr sigX * / 6300 * 10 >

[idoneity] !must be used the Reverse Polish Notation
emitX 2.5 / sqr -1. * exp 50 *
sigZ 0.150 / sqr -1. * exp 50 * +
sigX 2.5 / sqr -1. * exp 50 * +

!Gene(i)___Delta___JoinGenes(i:i+N)___u-uniform___g-gaussian___JoingSign
[genes]
sig_clock    0.2E-3    1       u     1   0.0 0
SIG_x        0.02      1       u     1   0.0 0
MaxB(1)      0.08      1       u     1   0.0 0
MaxB(2)      0.08      1       u     1   0.0 0
```

➢ INPUT FILE: &GA NameList

```
&GA
Astra_in='Astra_23_Jan2014.exe','pls-start.in'
Gener_in='generator_Mar2013.exe','generator-start1.in'
Genes_number=7   !max value is 40
pop_size=8       !must to be a multiple of the nodes numbers
generations_number=410

keepADistribution=.false. !".f." start from "Gener_in", ".t." from Distribution
keepInParameters=.true.
!".t." the chrom in the first gen;".f." All rnd, the chrom as central values

!***********************Turn on and Control the constraints
 constraints=.false. !if "true" turn-on constraints--------
 minimumZ=1.0 !this is valid for all constraints
 constr_number=2 !max number of contraints is 10
 constr_name='[constr01]','[constr02]'
 lower_Zbound=1.6,5.0,16.0  !intervals where the constraint
 upper_Zbound=25.0,25.0,25.0

!****************Post processor for COMB bunch distributions*******************
 LaserComb=.false. !if true Gener_in is a generator input with SPIKES namelist--
 !if "true" uses "ID_bunch_LC" for the spikes analysis and compute the Fitness--
 LaserComb_PostPro=.false.
 PostPro_in_index=0012

!***********************Forced Optimization Process*************
 step_OP_forced=25
 variation_x100=5.0 !Best Cromosom Variation %. Every "step_OP_f
 !-----variation in % is halved----untill "step_OP_forced" X "Step2Start_x100"--
 Step2Start_x100=4
!****************************Statistical Analysis*******************************
 statistic=.false.
 Runs_Number=360      !must be a multiple of the pop_size
/
```

Under developing (it slows down heavily GIOTTO)

Optimization Rarely needs changes

Usually few variables are used

Fitness & Genes

➢ INPUT FILE: Key_Names

Rarely needed

```
==============================From here Key_Names===============================
=================(lines after one blank-record are comments)=================

!**********************Equation in Reverse Polish Notation**********************
!-----Variables that can be used are:---------------------------------------------
!-----PosZ time En DEn sigZ emitZ Xmed sigX divergX emitX Ymed sigY--------------
!-----divergY emitY---------------------------------------------------------------
!*********************************************************************************
[constr01]
sigZ En * sqr emitZ sqr sigX * / 5300 * 1 >

[constr02]
sigZ En * sqr emitZ sqr sigX * / 6300 * 10 >

[idoneity] !must be used the Reverse Polish Notation
emitX 2.5 / sqr -1. * exp 50 *
sigZ 0.150 / sqr -1. * exp 50 * +
sigX 2.5 / sqr -1. * exp 50 * +

emitX 0.4 - 0.05 / sqr -1. * exp 50 * sigZ 0.280 - 0.01 / sqr -1. * exp 50 * +
sigX sigY - 1.0 / sqr -1. * exp 50 * + Xmed 1000 - 10.0 / sqr -1. * exp 50 * +
SemitX(1) 4 / sqr -1 * exp SemitX(2) 4 / sqr -1 * exp
Sdist(1) 380E-6 - 100E-6 / sqr -1 * exp 50 * +

!Gene(i)___Delta___JoinGenes(i:i+N)___u-uniform___g-gaussian___JoingSign
[genes]
sig_clock    0.2E-3    1       u     1   0.0 0
SIG_x        0.02      1       u     1   0.0 0
MaxB(1)      0.08      1       u     1   0.0 0
MaxB(2)      0.08      1       u     1   0.0 0
Phi(1)       2.0       1       u     1   0.0 0
Phi(2)       2.0       1       u     1   0.0 0
Phi(3)       10.0      1       u     1   0.0 0

MaxE(5)      5.0       1       u     1   0.0 0
c_pos(5)     0.05      1       u     1   0.0 0
Q_grad(4)    0.002     1       u     1   0.0 1 Q_grad(6) 0
Zstop        0.05      1       u     1   0.0 0
```

Definition

Comments

GENES Definition

Comments

➢ GIOTTO: FITNESS FUNCTION

```
[idoneity] !must be used the Reverse Polish Notation
emitX 2.5 / sqr -1. * exp 50 *
sigZ 0.150 / sqr -1. * exp 50 * +
sigX 2.5 / sqr -1. * exp 50 * +
```

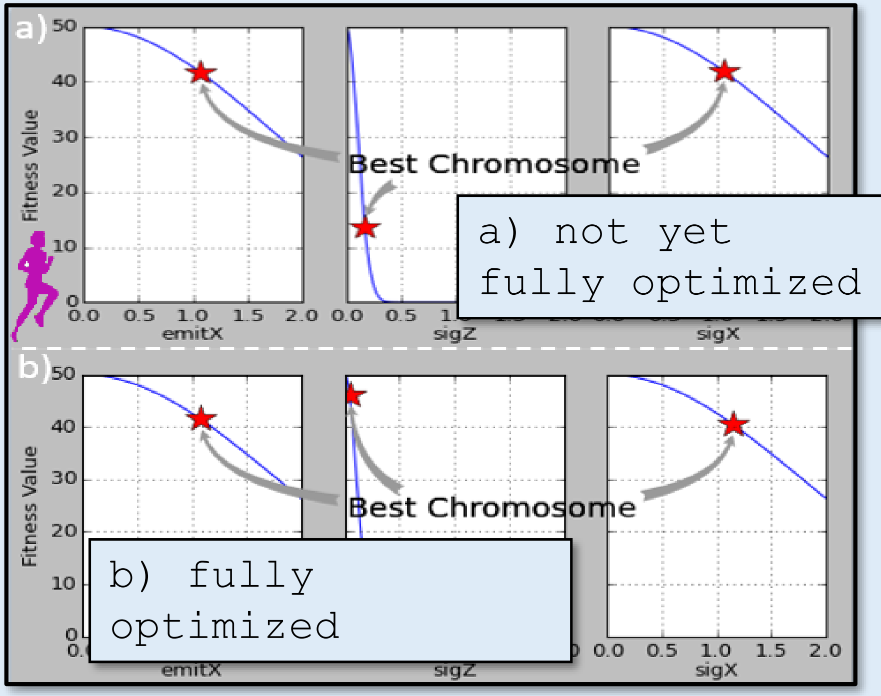
Reverse **P**olish **N**otation:

Opers Follow Operands

- ➢ 3 4 + = 7
- ➢ Stack based operation
- ➢ Does not need brackets

 =

$$50 \cdot e^{-\left(\frac{emitX}{2.5}\right)^2} + 50 \cdot e^{-\left(\frac{sigZ}{0.15}\right)^2} + 50 \cdot e^{-\left(\frac{sigX}{2.5}\right)^2}$$



Strategy to Cope with Multi Objectives Problems (MO):

- o One Single Criterium per Equation piece (Objectives Wights)
- o Close to the Goal mean close to the Gaussian Curve Top
- o The 'Far region' (referring to optimization) has to be on the maximum Gaussian slope
- o Change the  in real time (under implementation)
- o Lorentzian  dist.: very powerful if starting from scratch

➤ FITNESS FUNCTION if starting from scratch

Lorentzian much better than Gaussian

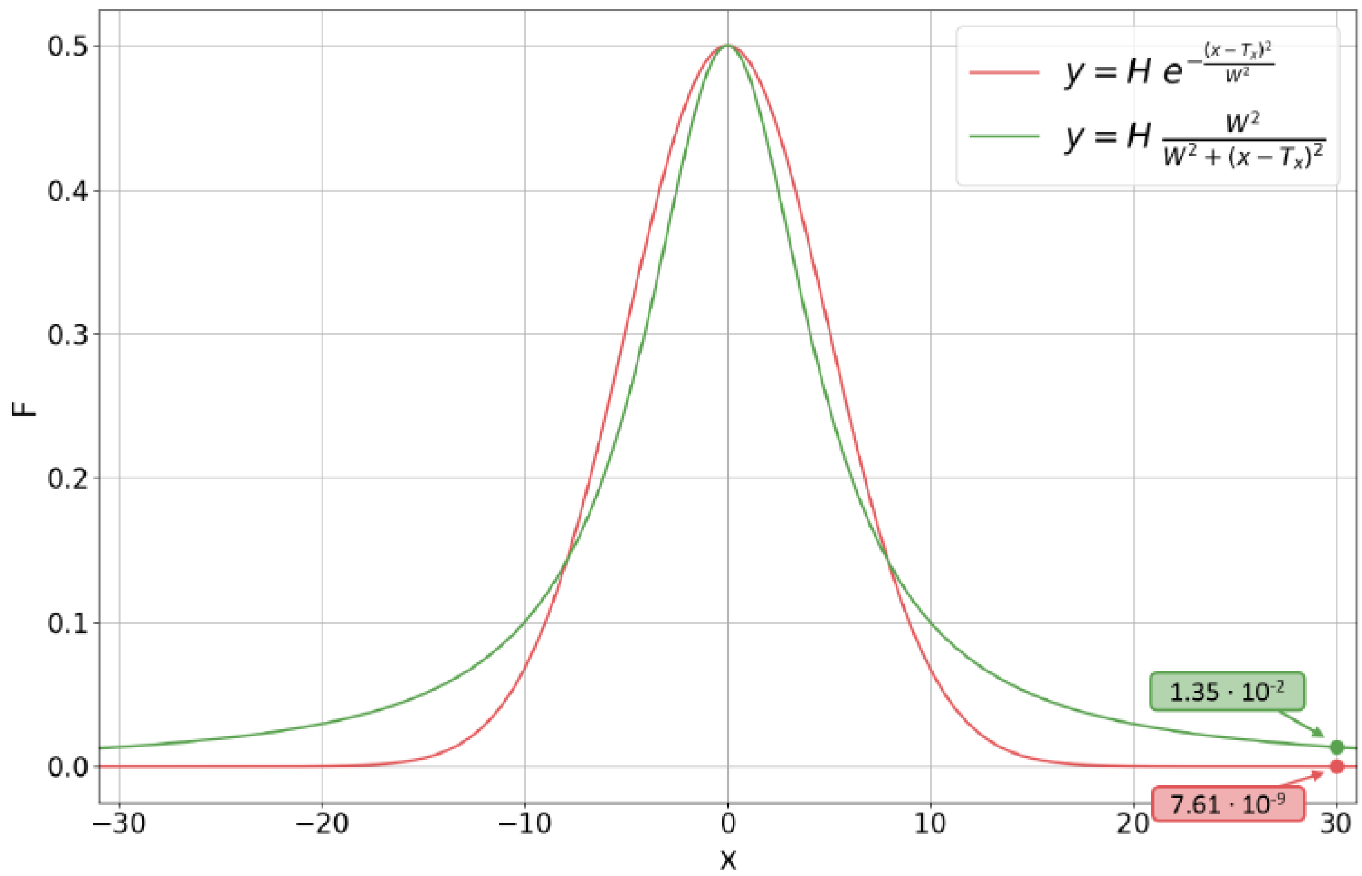


Figure 3.4: The figure shows the comparison between a Gaussian and a Lorenzian. The height, width and target value parameters are the same in both the functions ($H = 0.5$, $W = 5$, $T_x = 0$). Both functions are evaluated in the point $x = 30 = 6W$.

GIOTTO "RISULTATI.TXT" output file

```
[idoneity] !must be used the Reverse
emitX 1.2 / sqr -1. * exp 100 *
sigZ 0.016 / sqr -1. * exp 400 * +
DEn 200.0 / sqr -1. * exp 50 * +
```

GENES

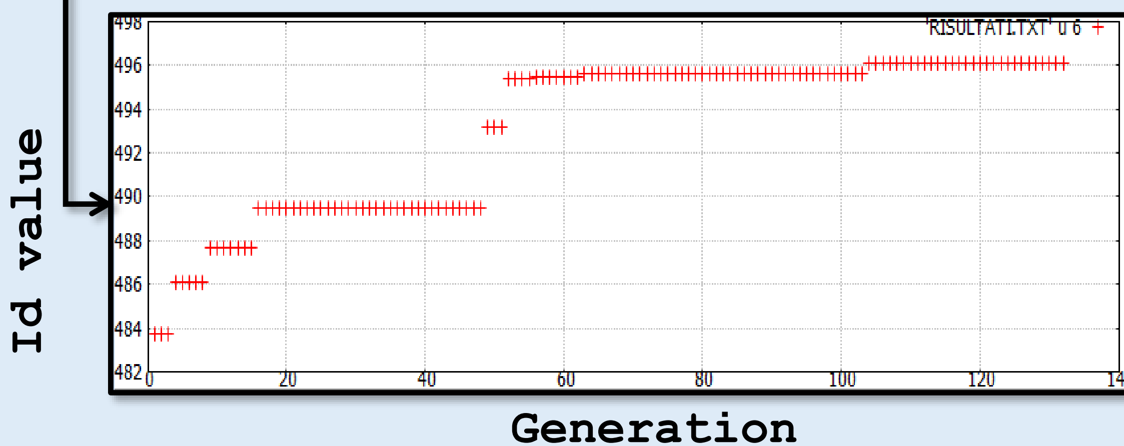
```
[genes]
MaxB(1)    0.003    1  u  1  0.0 0
MaxB(2)    0.01     1  u  1  0.0 0
Phi(1)     1.2      1  u  1  0.0 0
Phi(2)     1.5      1  u  1  0.0 0
Phi(3)     1.5      1  u  1  0.0 0
```

RISULTATI.TXT

Emit | sigZ | ΔE

1	MAXB(1)	MAXB(2)	PHI(1)	PHI(2)	PHI(3)	***id best***	***id_worst***	emitX	sigZ	DEn
2	3.33234E-01	5.76714E-02	2.34351E+00	1.91001E+02	-8.48726E+01	4.83694E+02	7.83022E+01	5.79140E-01	5.08770E-03	7.80340E+01
3	3.33234E-01	5.76714E-02	2.34351E+00	1.91001E+02	-8.48726E+01	4.83694E+02	1.72762E+02	5.79140E-01	5.08770E-03	7.80340E+01
4	3.33234E-01	5.76714E-02	2.34351E+00	1.91001E+02	-8.48726E+01	4.83694E+02	3.32879E+02	5.79140E-01	5.08770E-03	7.80340E+01
5	3.33234E-01	5.76714E-02	2.18337E+00	1.90543E+02	-8.50834E+01	4.86096E+02	3.06747E+02	6.46100E-01	4.62500E-03	7.56980E+01
6	3.33234E-01	5.76714E-02	2.18337E+00	1.90543E+02	-8.50834E+01	4.86096E+02	3.27456E+02	6.46100E-01	4.62500E-03	7.56980E+01
7	3.33234E-01	5.76714E-02	2.18337E+00	1.90543E+02	-8.50834E+01	4.86096E+02	2.90264E+02	6.46100E-01	4.62500E-03	7.56980E+01
8	3.33234E-01	5.76714E-02	2.18337E+00	1.90543E+02	-8.50834E+01	4.86096E+02	2.92544E+02	6.46100E-01	4.62500E-03	7.56980E+01
9	3.33234E-01	5.76714E-02	2.18337E+00	1.90543E+02	-8.50834E+01	4.86096E+02	3.01542E+02	6.46100E-01	4.62500E-03	7.56980E+01
10	3.33234E-01	5.76714E-02	2.34351E+00	1.90543E+02	-8.50834E+01	4.87645E+02	4.29286E+02	6.16760E-01	4.63930E-03	7.69790E+01
11	3.33234E-01	5.76714E-02	2.34351E+00	1.90543E+02	-8.50834E+01	4.87645E+02	4.31203E+02	6.16760E-01	4.63930E-03	7.69790E+01
12	3.33234E-01	5.76714E-02	2.34351E+00	1.90543E+02	-8.50834E+01	4.87645E+02	4.40076E+02	6.16760E-01	4.63930E-03	7.69790E+01
13	3.33234E-01	5.76714E-02	2.34351E+00	1.90543E+02	-8.50834E+01	4.87645E+02	4.40076E+02	6.16760E-01	4.63930E-03	7.69790E+01

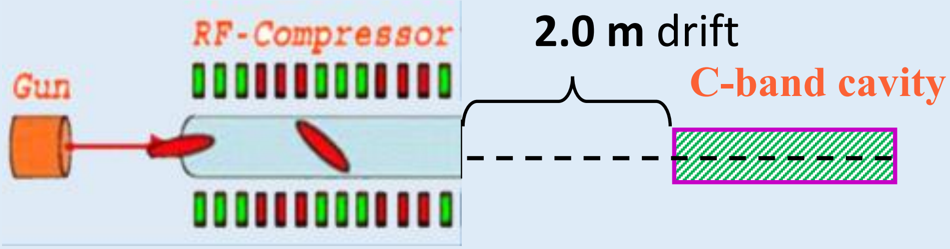
Best Chromosome of the Generation N.5

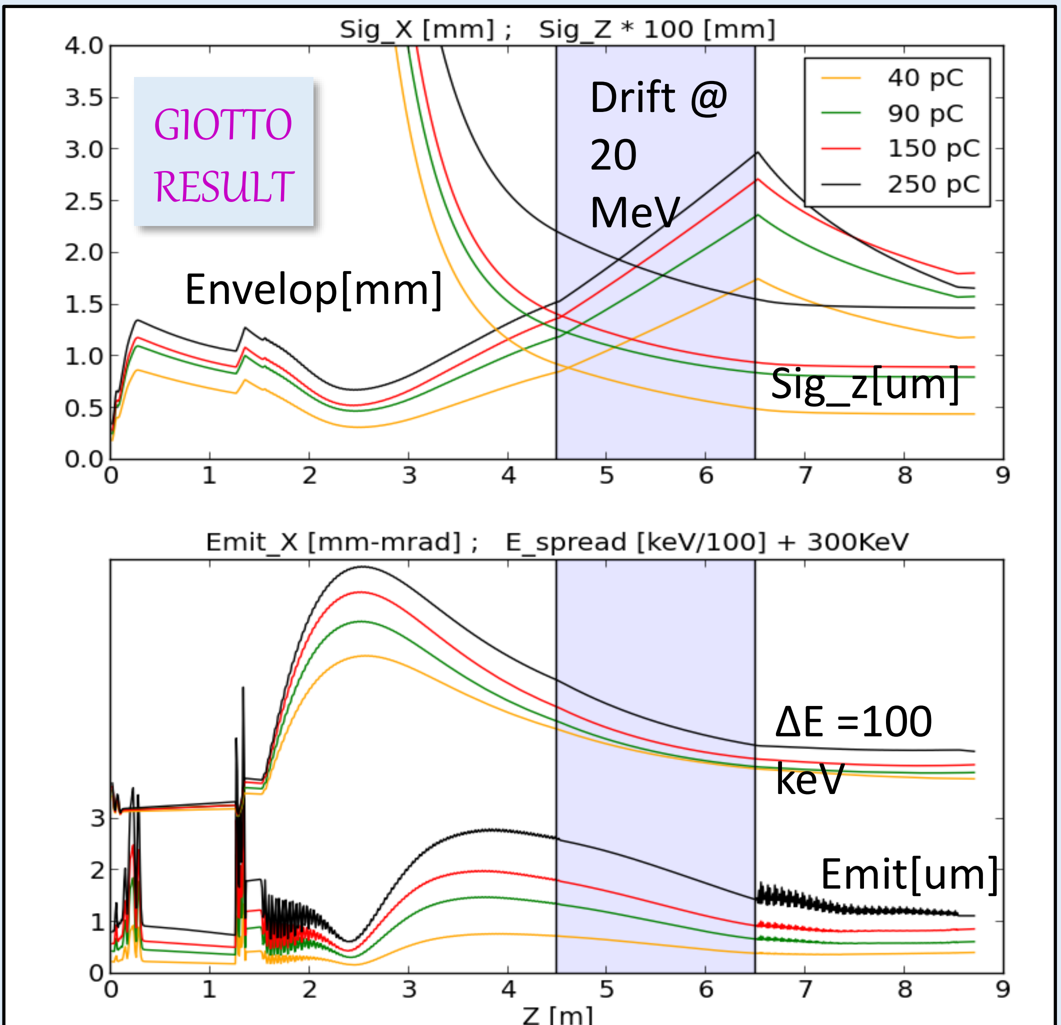


GIOTTO

Optimization
&
Statistical analysis

Beamline Optimization for: ultra short, ultra cold, High brightness bunches





GOALS :

- Low Emittance
- Low Energy Spread
- Sig_Z hundred of nm

A Beam-Line studied with:

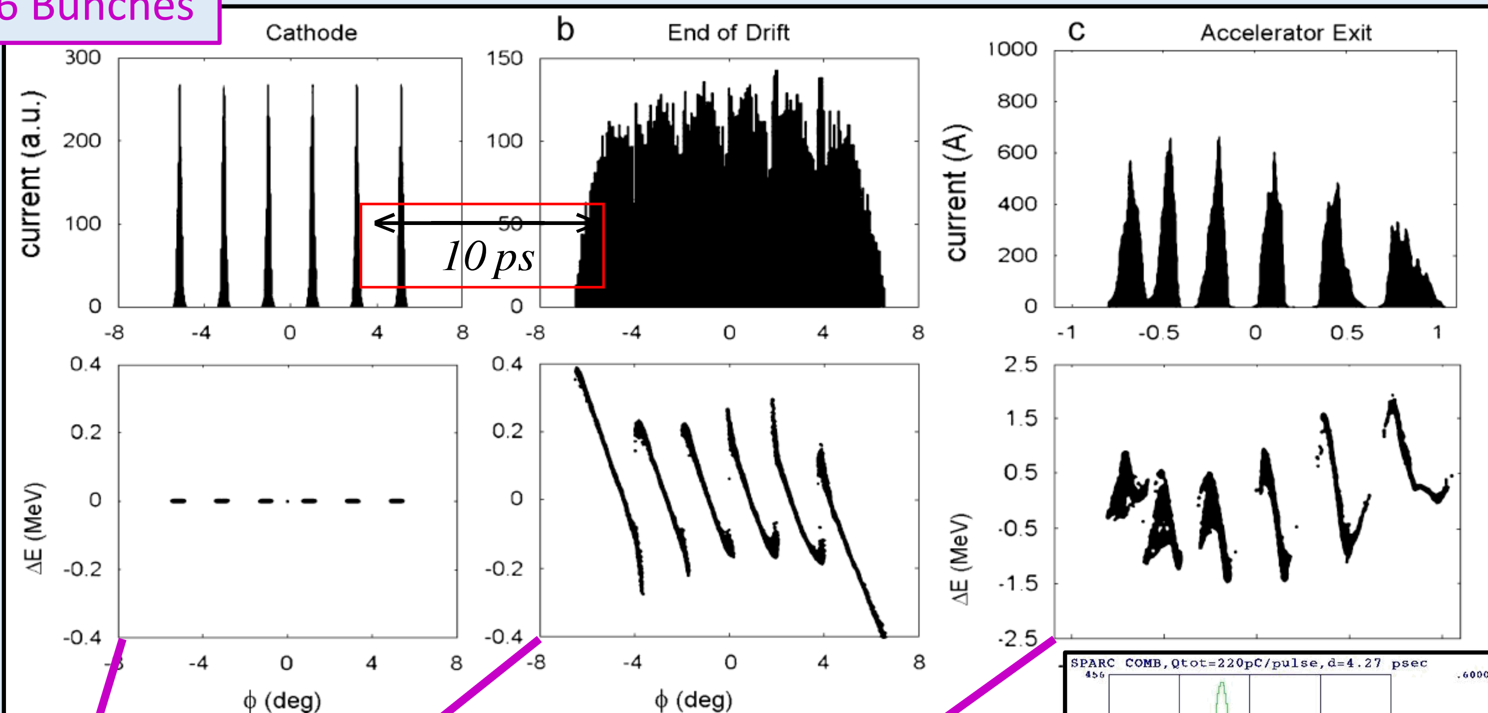
- Experience
- An Ad hoc GIOTTO use

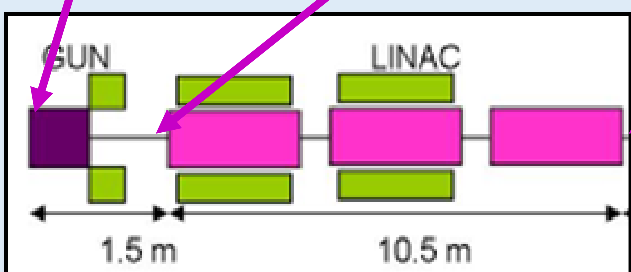
GENES in the Optimization:

- Gun:
  - (1) Phase & (2) Solenoid (B_z)
- TW cavity (RF- Compressor):
  - (3) Phase & (4) Solenoids
- C-band cavity: (5) Phase

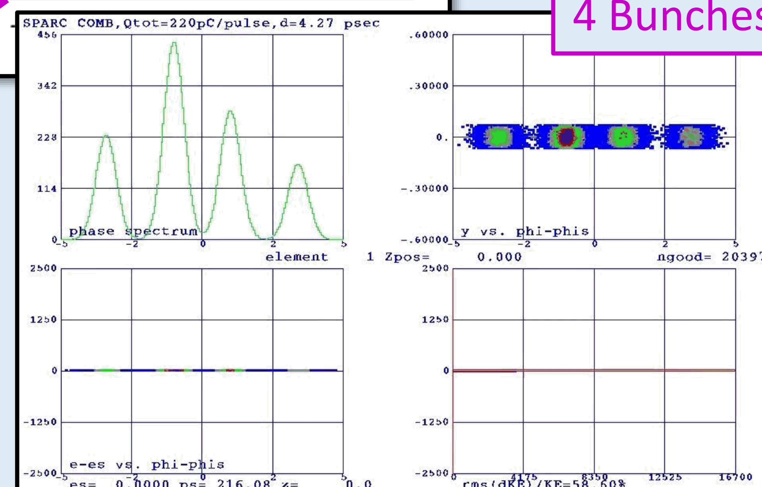
Beam-Line STATISTIC for Laser Comb (ECHO Bunch Generations)

6 Bunches





4 Bunches

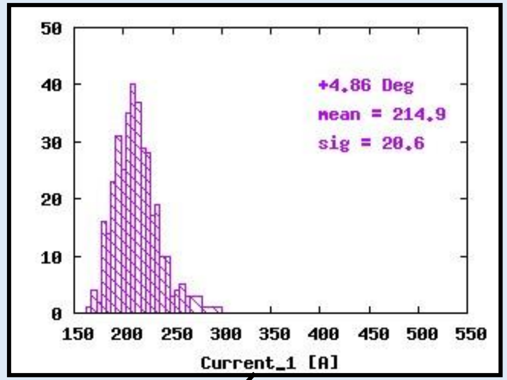


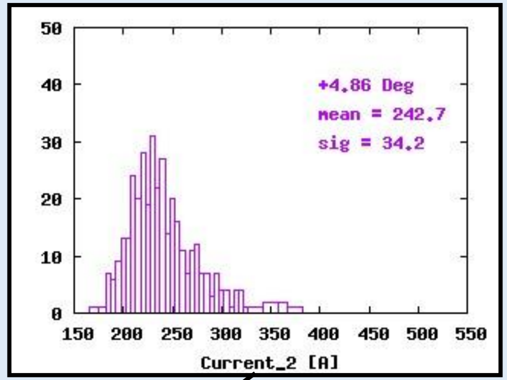
- P.O.Shea et al., Proc. of 2001 IEEE PAC, Chicago, USA (2001) p.704.
- M. Ferrario. M. Boscolo et al., Int. J. of Mod. Phys. B, 2006 (Taipei 05 Workshop)

Beamline STATISTIC Laser Comb two **bunches case**

```
!****************************Statistical Analysis*******
statistic=.true.
Runs_Number=360        !must be a multiple of the pop_size
!*******************************************************
```

```
[genes]
phi(1)      0.9        1      g      1
phi(2)      0.9        1      g      1
```





360 cases

bacci@pcsimul2:~/Doc_Lavoro/08_SPARC/03_LaserComb/02_Simulazioni/05_Giotto/02b_Titti_comparison/02_result_p5

5	posZ	time	En	sigZ	DEn	emitZ	zXEpMed	Xmed
6	12.0000000	40.1020012	127.5899963	0.1931200	315.2000122	49.8079987	181.1999969	-0.0012153
7	12.0000000	40.0989990	127.5899963	0.1988300	287.4100037	47.6329994	158.7799988	-0.0011859
8	12.0000000	40.1010017	127.5999985	0.1907200	329.6600037	51.0439987	192.4600067	-0.0012634
9	12.0000000	40.0989990	127.5899963	0.2004300	282.3500061	47.5709991	152.9400024	-0.0012552
10	12.0000000	40.0999985	127.5899963	0.2022500	275.6199951	47.2900009	145.9199982	-0.0012090
11	12.0000000	40.0970001	127.6399994	0.1682500	445.8599854	58.4290009	279.6300049	-0.0011903

sigX	divergX	emitX	xXxpMed	Ymed	sigY	divergY	emitY
0.1552100	0.0777850	1.6316000	0.0655140	0.0003971	0.1546800	0.0778750	1.6328000
0.1575600	0.0799780	1.5186000	0.0701300	0.0004734	0.1574000	0.0801450	1.5223000
0.1577300	0.0770300	1.7099000	0.0637480	0.0002847	0.1572100	0.0771520	1.7097000
0.1560300	0.0800730	1.4665999	0.0707510	0.0005361	0.1559900	0.0802450	1.4737000
0.1585100	0.0807810	1.4794000	0.0716900	0.0005785	0.1585100	0.0810230	1.4844000
0.1906800	0.0691680	2.5023999	0.0452270	0.0004415	0.1896900	0.0691130	2.5088999
0.1604000	0.0805670	1.5132999	0.0712350	0.0005018	0.1602400	0.0807310	1.5175000

yXypMed	Scurr01	Scurr02	SemtX01	SemtX02	SemtY01	SemtY02	Sdist01	Sdist02
0.0655090	216.6100006	234.6699982	1.0002000	1.6055000	1.0131000	1.5854000	0.0003813	0.0000000
0.0702470	227.5399933	218.2200012	1.0061001	1.6256000	1.0204000	1.6002001	0.0003928	0.0000000
0.0638020	209.6300049	244.7700043	1.0125999	1.7193000	1.0254000	1.7012000	0.0003765	0.0000000
0.0708450	230.9100037	215.6799927	0.9868600	1.6118000	1.0041000	1.5850000	0.0003960	0.0000000
0.0718970	234.2200012	212.6699982	1.0067000	1.6318001	1.0206000	1.6045001	0.0003997	0.0000000
0.0446640	170.4299927	359.5400085	1.0303000	1.6545000	1.0482000	1.6513000	0.0003305	0.0000000

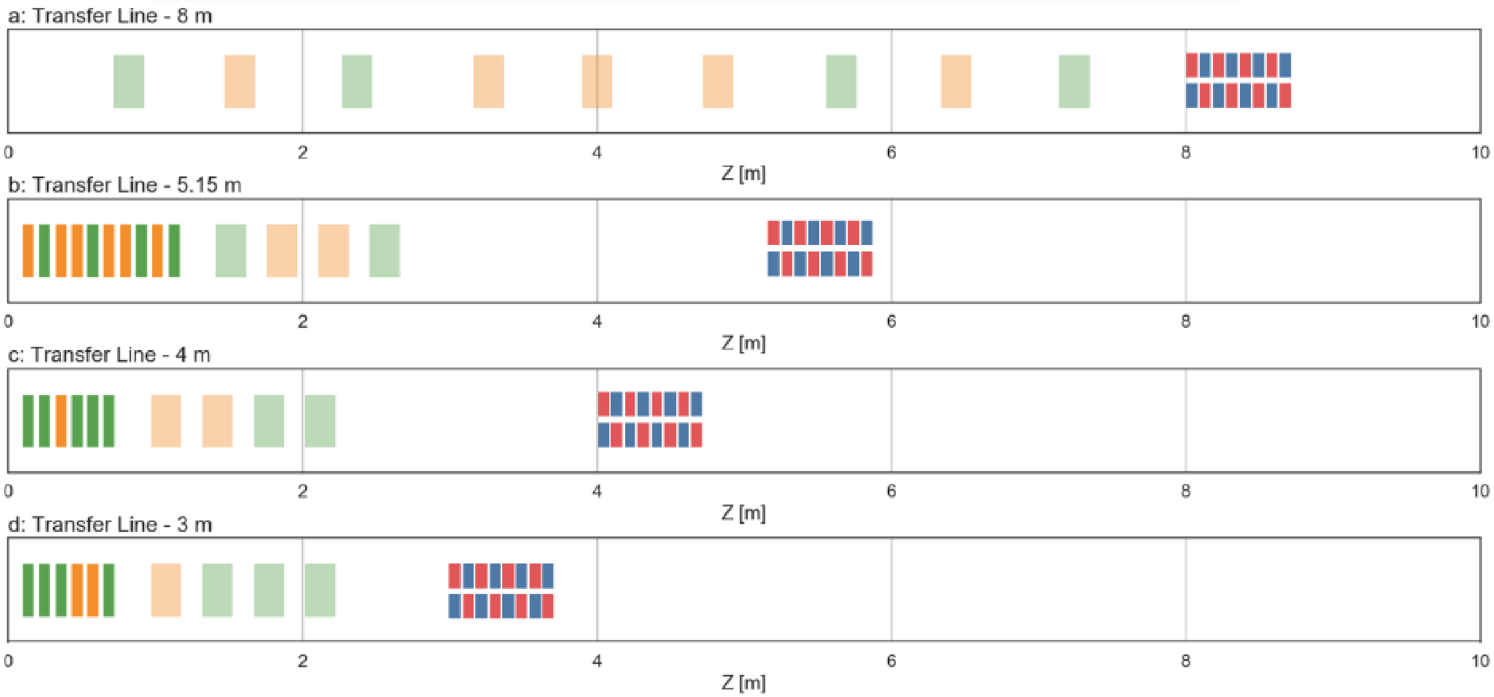
Quads matching lines for plasma acc. beams – from scratch

EUPRAXIA project
From
Marcello Thesis

Table 3.3: Magnetic elements in the 4 different TLs shown in Fig. 3.10

	Len.	EMQ	EMQ len.	EMQ bore	PMQ	PMQ len.	PMQ bore
A	8 m	9	20 cm	1 cm			
B	5.15 m	4	20 cm	1.5 cm	10	7 cm	1 cm
C	4 m	4	20 cm	1.5 cm	6	7 cm	1 cm
D	3 m	4	20 cm	1.5 cm	6	7 cm	1 cm

GIOTTO starts with all K=0 and matched all the lines



matching lines for plasma acc. Beams (same line diff. energy)

Isseu: the emittance conservation by chromatic effects

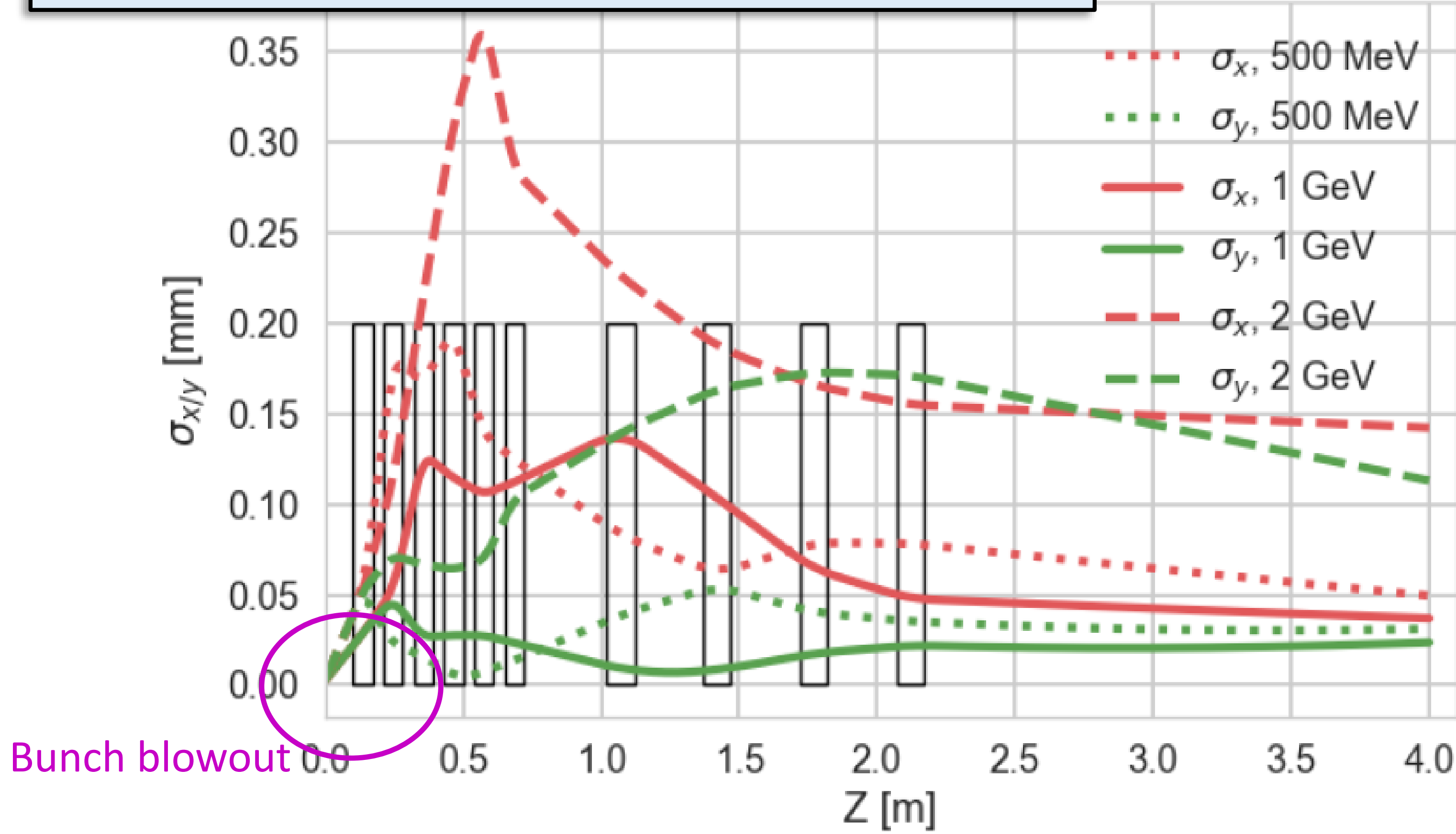
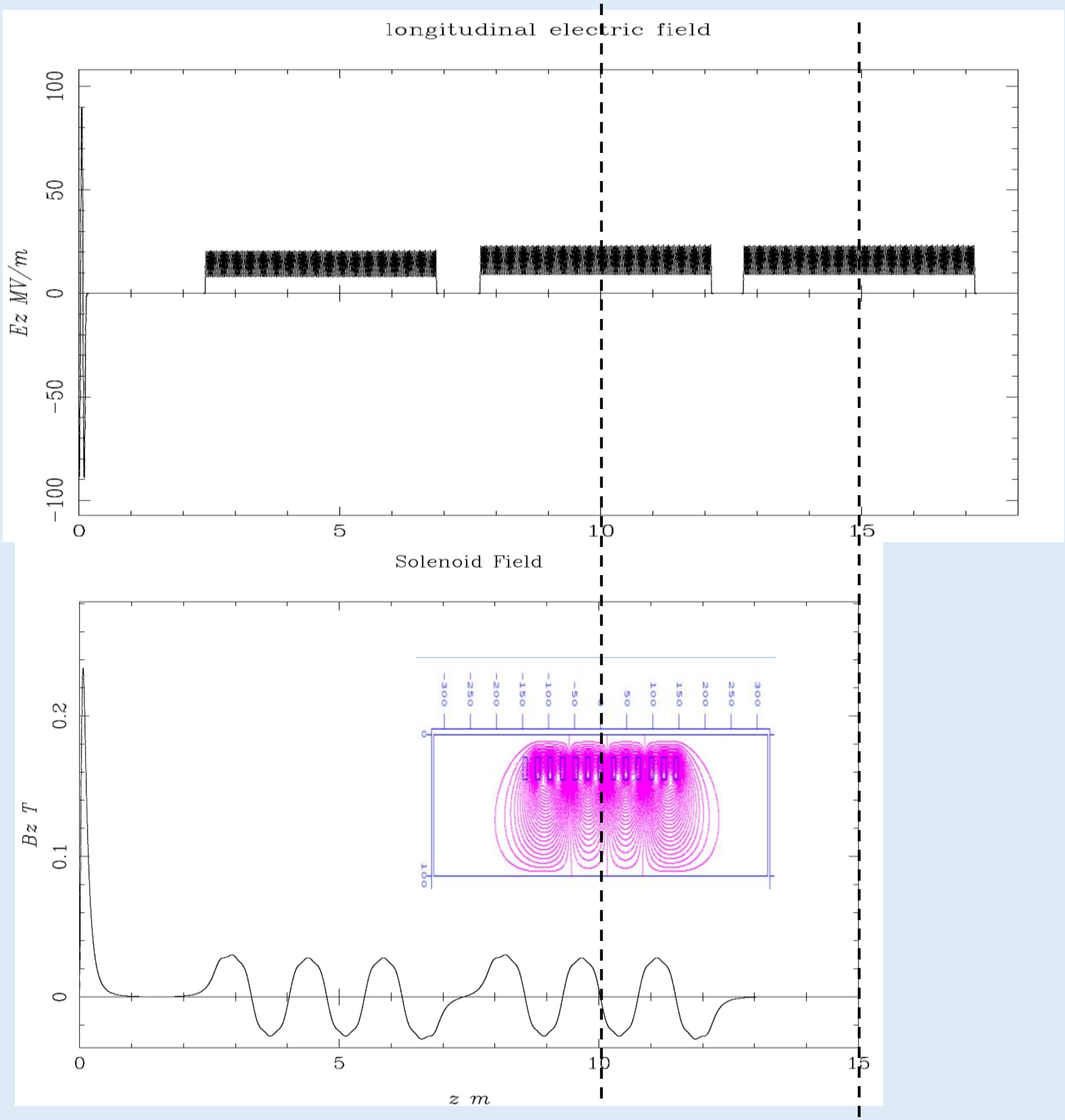


Figure 3.11: Comparison between the beams envelopes for matched bunches of significantly different energies. The position and the dimension of the elements of the line is the same in the three cases (rectangles), only the quads strengths are changed.

Velocity bunching test on CLEAR machine (1)



Velocity bunching test on CLEAR machine (2)

```
&NEWRUN
      RUN=2
      Distribution = 'Q_80_FD_300_AB.ini'
      TRACK_ALL=T, AUTO_PHASE=T, PHASE_SCAN=T
      check_ref_part=F,
      RefS=T,
      EmitS=T,
      PhaseS=T,
      Lmagnetized=F,
      H_max=0.002
      ZSTART=0.00, ZSTOP=18.00,
      Zemit=1800,
      Zphase=1,
/
&CHARGE
       LSPCH=T,
       Nrad=5, Nlong_in=10,
       Cell_var=2.0,
       !min_grid=0.4D-6,
       min_grid=0.0,            !AB
       Max_scale=0.1,
       Max_count=20             !AB
       Lmirror=T
/
&CAVITY
  LEfield=T,
  File_Efield(1)= 'sonde_ideal_SF_100.txt',phi(1)=0.0,maxE(1)=90.0, nue(1)=2.99855,c_pos(1)=0.0
  File_Efield(2)= 'TWS_LIL.txt',phi(2)=-40,maxE(2)=20.5,nue(2)=2.99855,c_numb(2)=132,c_pos(2)=2.3904
  File_Efield(3)= 'TWS_LIL.txt',phi(3)=-0,maxE(3)=23.0,nue(3)=2.99855,c_numb(3)=132,c_pos(3)=7.6592
  File_Efield(4)= 'TWS_LIL.txt',phi(4)=-0,maxE(4)=23.0,nue(4)=2.99855,c_numb(4)=132,c_pos(4)=12.7079
/
&SOLENOID
  LBField=T,
  File_Bfield(1) = 'profile.txt',          MaxB(1)=0.234153, S_pos(1)=0.00
  File_Bfield(2) = 'TW_LIL_Solen_4VB.dat',MaxB(2)=0.03, S_pos(2)=4.640
  File_Bfield(3) = 'TW_LIL_Solen_4VB.dat',MaxB(3)=0.03, S_pos(3)=9.9092
/
```

really negligeble Velocisty Bunching.
compression starts @ phi=-80deg
don't knowing machine behaviour I
din't want to lose the beam

Velocity bunching test on CLEAR machine (3)

```
&GA
Astra_in='Astra_Mar2018.exe','phi_3LIL_Clear.in'
Gener_in='',''
Genes_number=6  !max value is 40
pop_size=32       !must to be a multiple of the nodes numbers
generations_number=1600

use_generator=.false.
del_NORRAN=.false.        !if .true. the Generator starts from a static seed
keepInParameters=.false.
!.true.: the starting values are used as a cromosom,
!.false.: " ...." are used only as sampling intervals central values

!**                                                                      ***
!--                                                                      ---
!--                                                                      ---
!--                                                                      ---
!--                                                                      ---
!--                                                                      ---
!**                                                                      ***
[id
2 sqr emitX  sqr 2 sqr + / 50 *
1 sqr sigZ  sqr 1 sqr + / 50 * +

5 sqr Den 1 -  sqr 5 sqr + / 60 * +
0.4 sqr emitY 0.8 -  sqr 0.4 sqr + / 150 * +

!Gene(i)___Delta___JoinGenes(i:i+N)___u-uniform___g-gaussian___JoingSign
[genes]
Phi(1)      3.0     1      u     1   0.0 0 !buncher
Phi(2)      15.0     1      u     1   0.0 0 !booster
Phi(3)      30.0     1      u     1   0.0 0 !booster
MaxB(1)     0.015     1      u     1   0.0 0  !solenoid peak field
MaxB(2)     0.02     1      u     1   0.0 0  !solenoid peak field
MaxB(3)     0.03     1      u     1   0.0 0  !solenoid peak field
```

- The optimization after few runs:
  bunch_lengh= 2ps, emit: 1.2 mm-mrad

- After 4 hours (16 core working station -2012 machine-):
  bunch_lengh=0.5ps, emit:0.9 mm-mrad

Concluding: some publications to deepen the topics discussed

Daniel S. Weile and Eric Michielssen “**Genetic Alforithm Optimization Applied to Electromagnetics: A Review**”, IEEE Trans. On Antennas and Propagation, Vol 45, NO. 3, March 1997

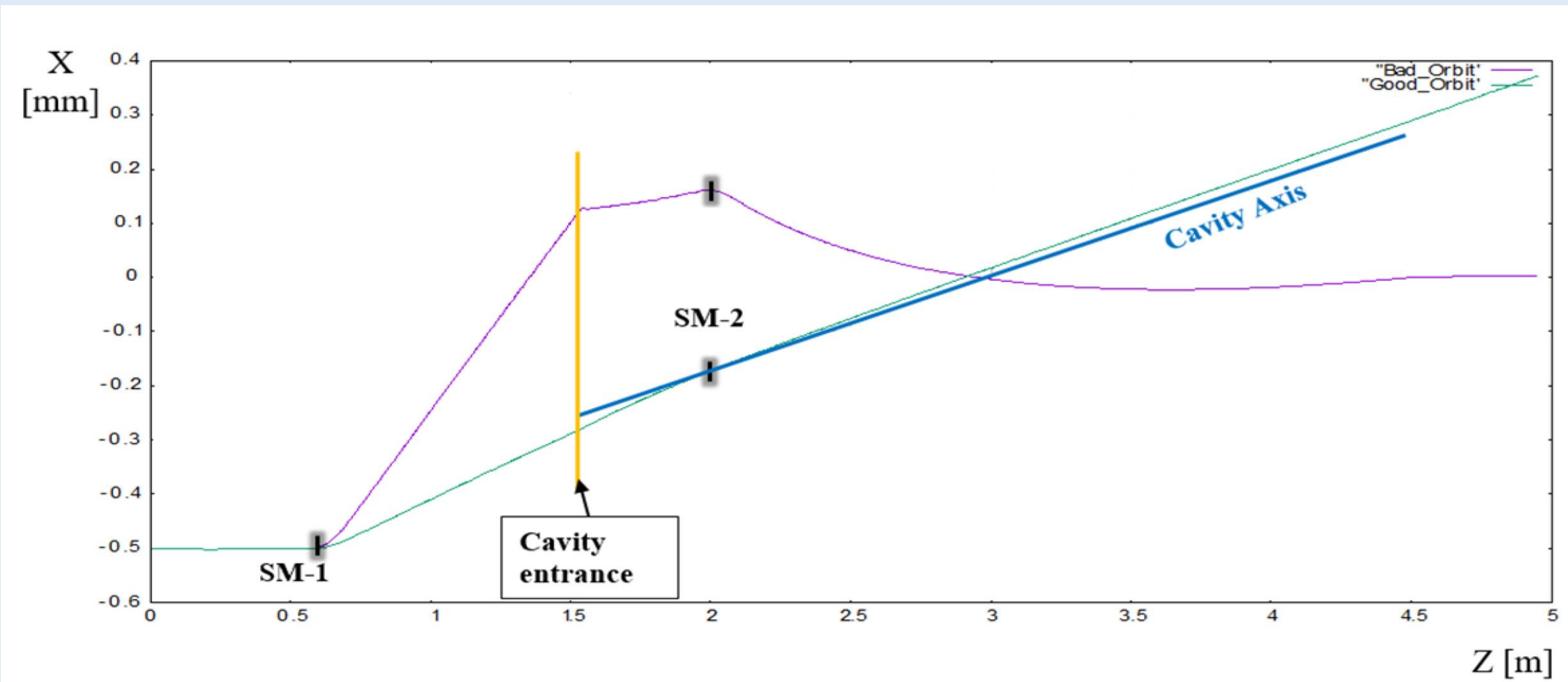
A. Bacci, et al. “**GIOTTO: A Genetic Code for Demanding Beam-dynamics Optimizatio**ns”, doi: 10.18429/JACoW-IPAC2016-WEPOY03

M. Rossetti Conti, A. Bacci “**Beam based alignment methods for cavities and solenoids in photo-injectors**”, Proceedings of IPAC2016, Busan, Korea THPMB011

A. Bacci, S. Gallo, et al., “**STUDY OF A C-BAND HARMONIC RF SYSTEM TO OPTIMIZE THE RF BUNCH COMPRESSION PROCESS OF THE SPARC BEAM**” IPAC 2015 doi:10.18429/JACoW-IPAC2015-TUPW

Thanks for your attention

M. Rossetti Conti, A. Bacci "Beam based alignment methods for cavities and solenoids in photo-injectors", Proceedings of IPAC2016, Busan, Korea THPMB011



A Radio Frequency (RF) Knob

Catching beams @ different envelope sizes MEANS:
a strong control on Focal Lengths of the RF lens, MEANS:
a KNOB to focus Adiabatically and in Full (x,y) Symmetry

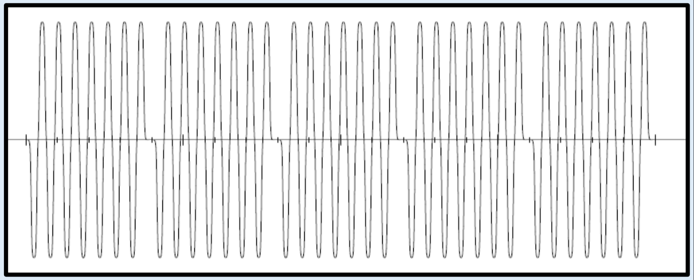
NO Quadrupoles
→Symmetric Beams
→Very Good for BD

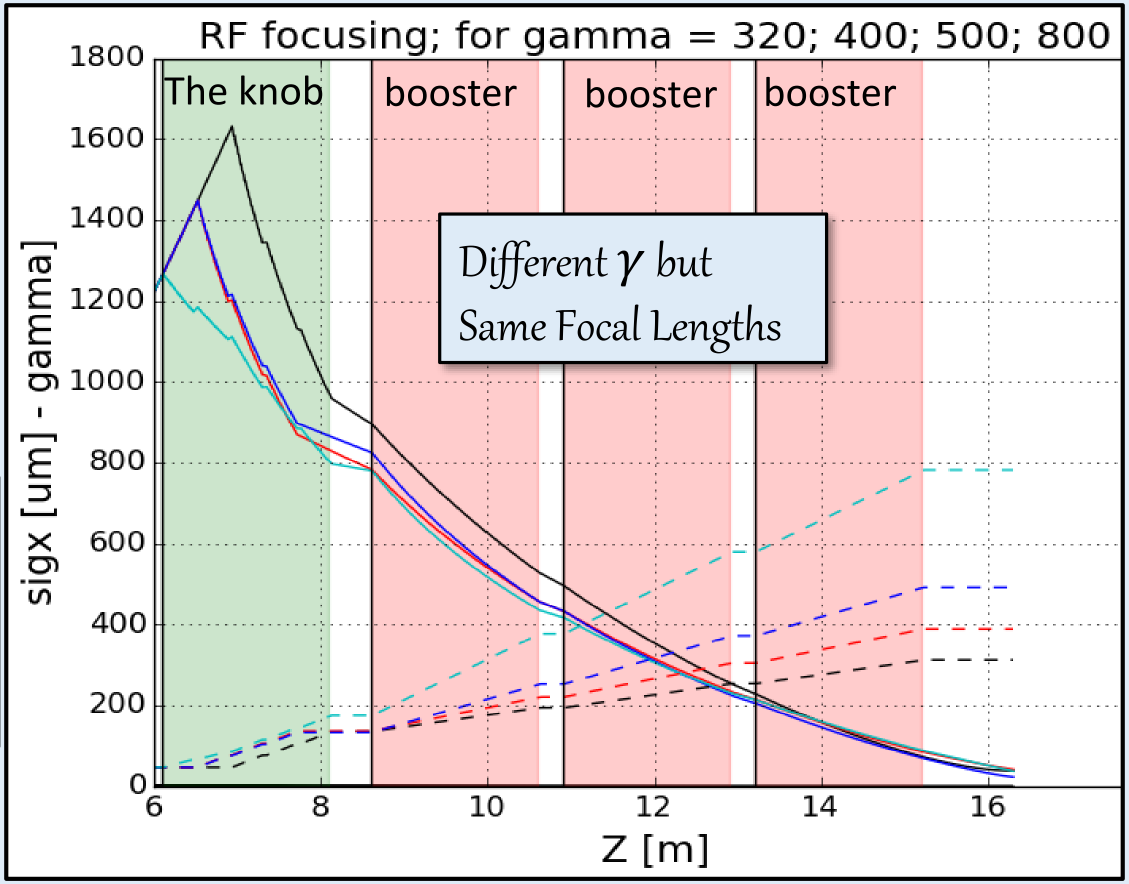
The knob

C-band five sectors Standing Wave (SW) cavity. Why C-band and SW:

- Irises large enough
- One feeder for sector
- A bit stronger focusing effect

The knob - field



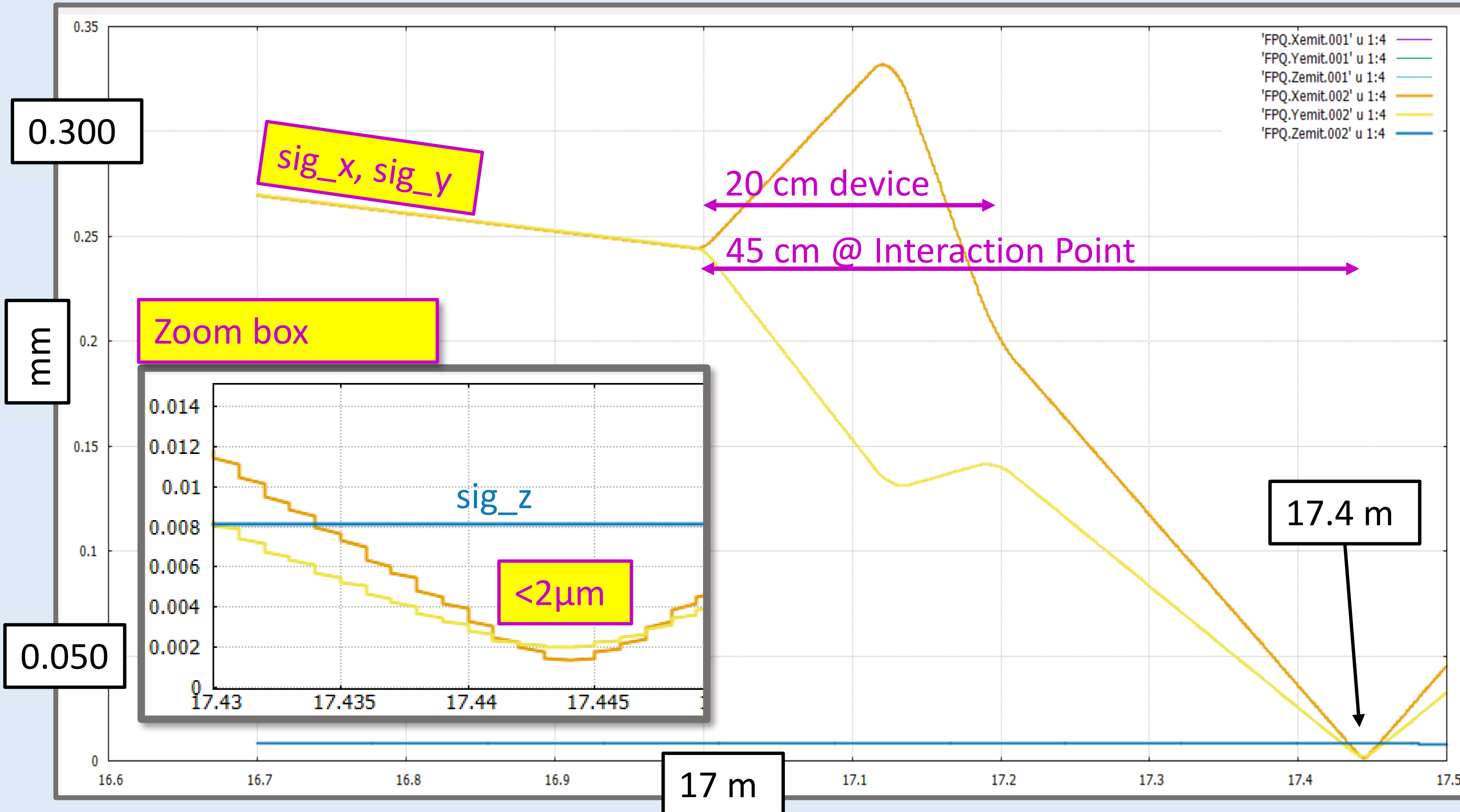


A Radio Frequency (RF) Knob – Final focus

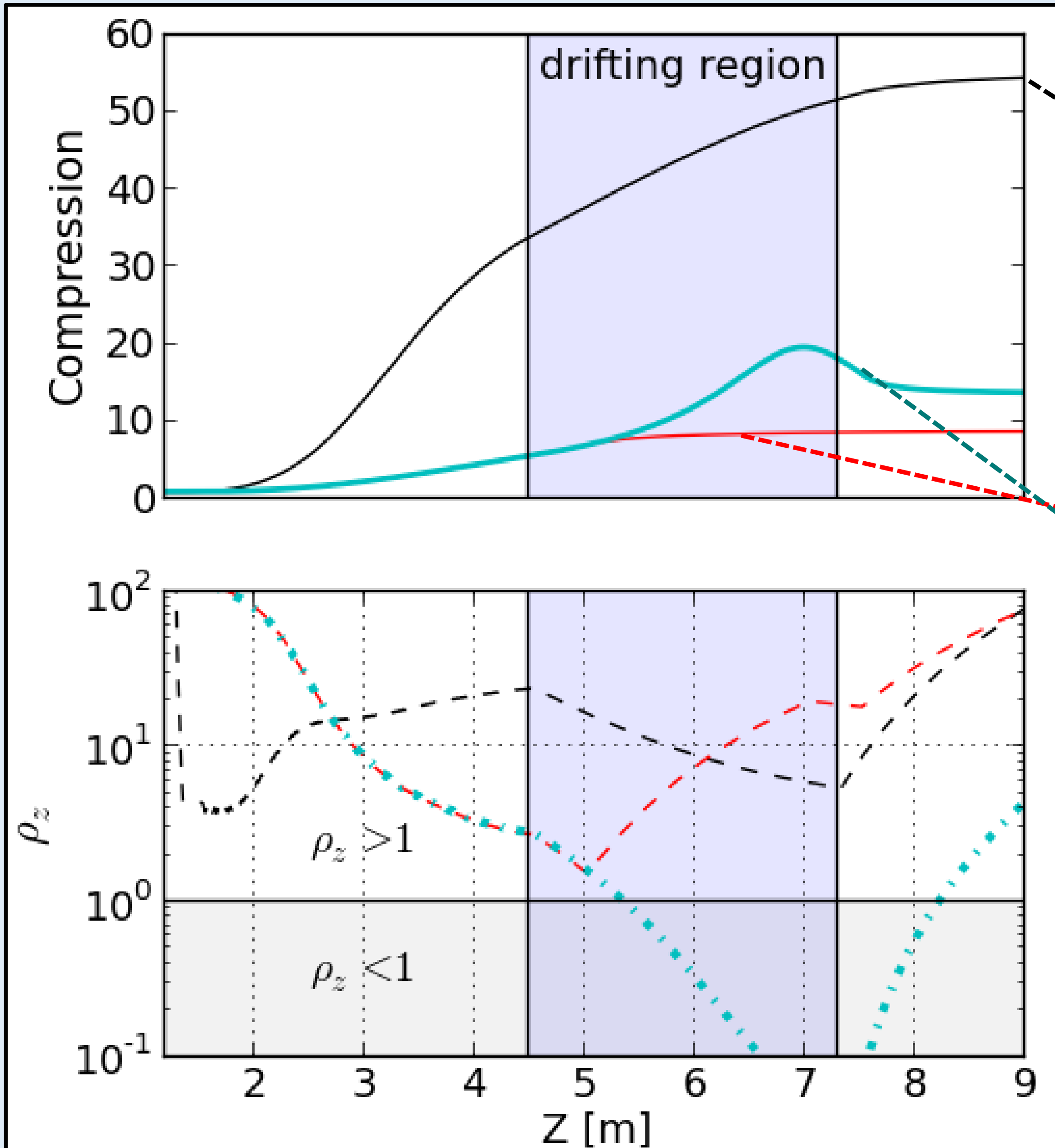
An IMPORTANT question:

Can we focus the bunch at Linac exit after RF focusing down to final focus specs?

Final focusing channel by 5 Permanet Quads (20 cm)



ρ_z Laminar parameter for LB & VB

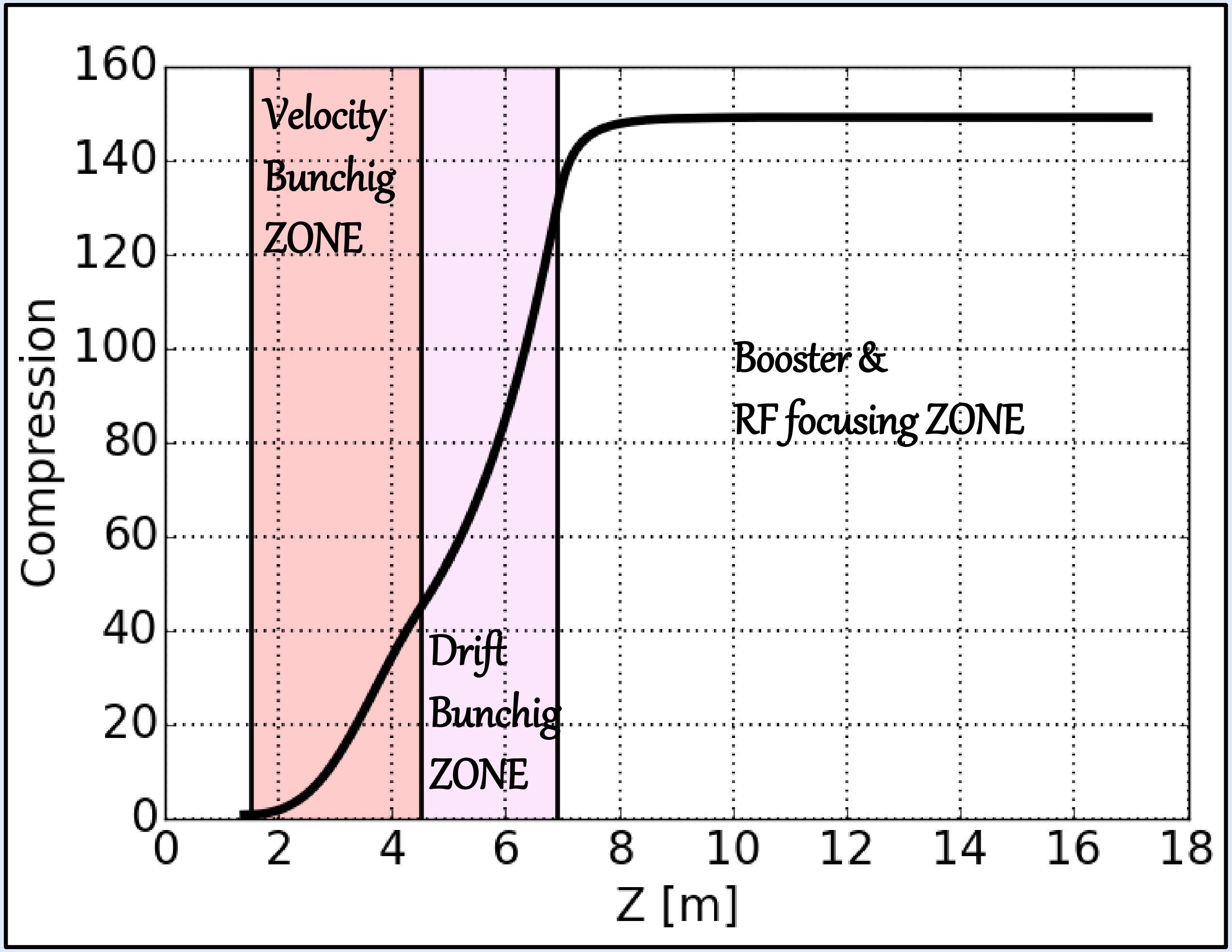


Laminar Bunching
ρ_z is low but > 1
A soft bunch for the compression

Velocity Bunching NO DRIFT (STANDARD case)
ρ_z starts >> 1
A bunch stiff to be compressed

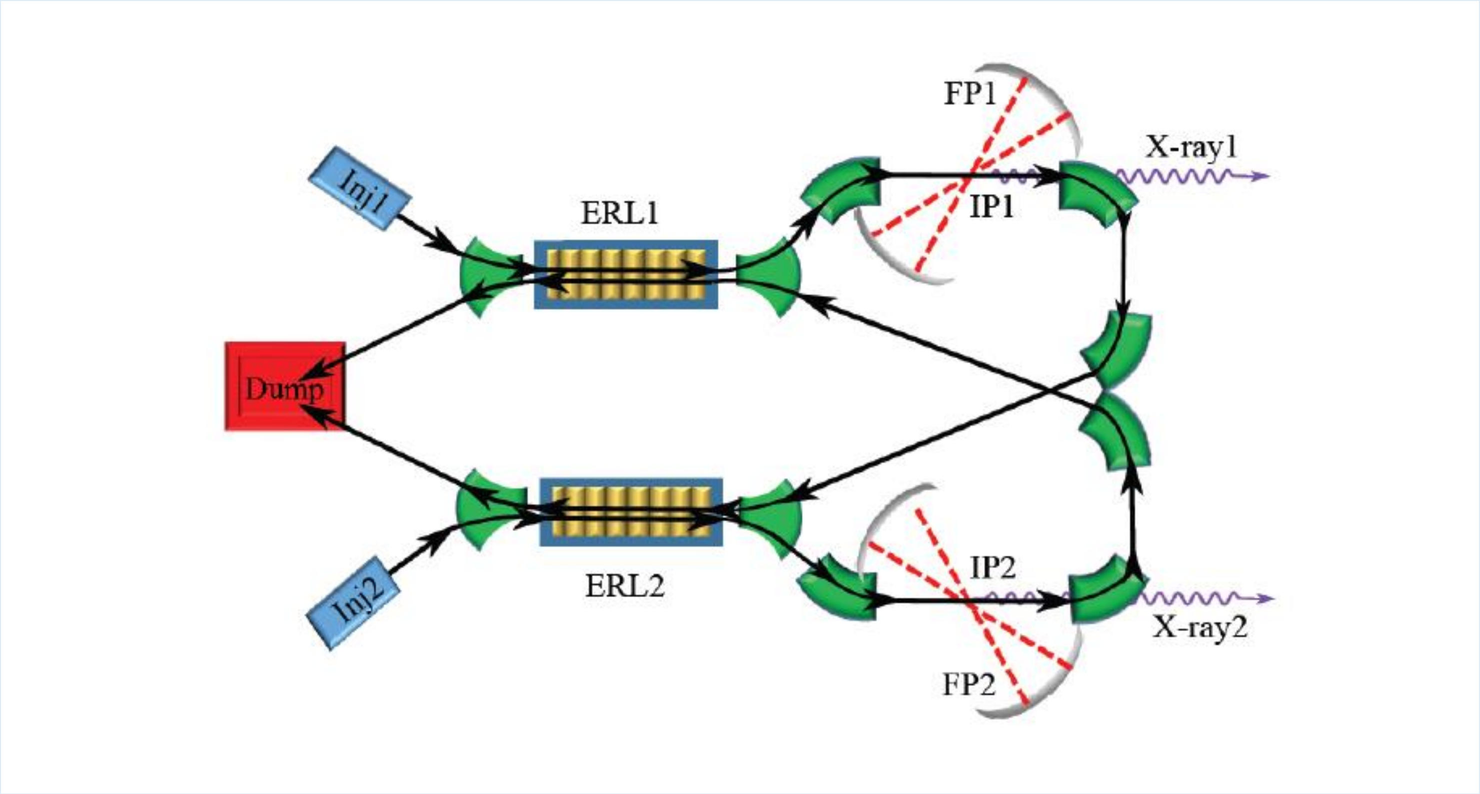
Velocity Bunching SI DRIFT(TEST case)
Laminarity is lost
ρ_z < 1

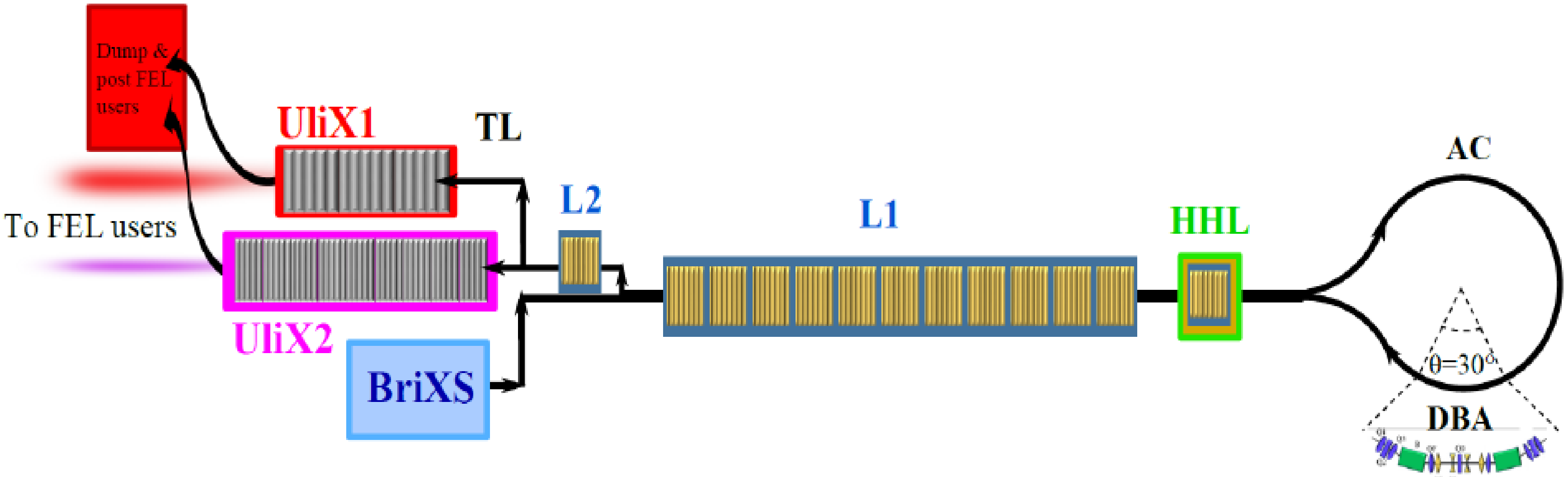
compression factor 40 pc case



@ booster end
= 17 m (0.5 GeV)

$Q_b = 40\ pC$
$\sigma_z = 4.2\ \mu m$
$I_{peak} > 2.5 kA$
$\varepsilon_{peak} = 0.3\ \mu m$
$B_{peak} = 3 \cdot 10^{16}$
$(I_p = 1.5 kA)$
$(\Delta\gamma/\gamma)_{@I_{peak}} \cong\ 8 \cdot 10^{-5}$


FP1
X-ray1
Inj1
ERL1
IP1
Dump
IP2
Inj2
ERL2
X-ray2
FP2


Dump &
post FEL
users
UliX1
TL
L2
L1
HHL
AC
To FEL users
UliX2
BriXS
θ=30°
DBA