The CLIC Decelerator

Beam dynamics studies and test-facilites

CLIC Workshop

October 13, 2009

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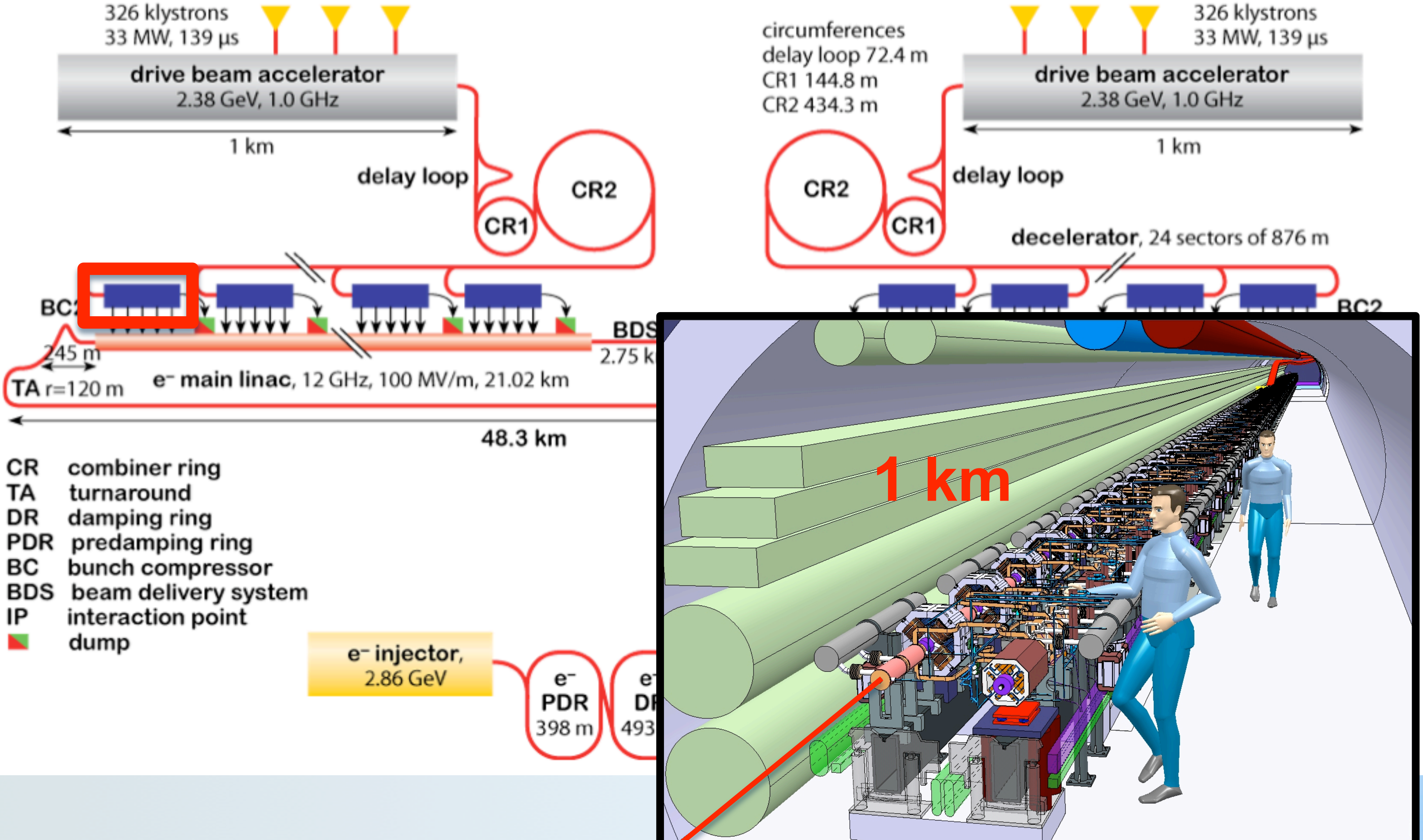
- Introduction to the decelerator
- How do we work?
- Challenge: PETS wake
- Challenge: misalignment
- Compontent specifications
- Test facilities
- Conclusions

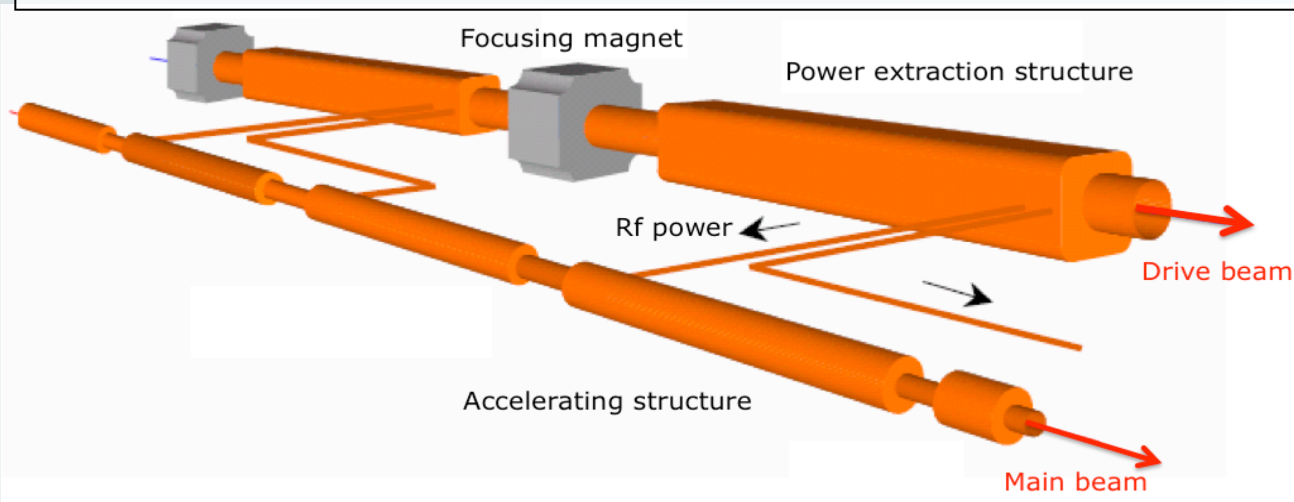
The decelerator

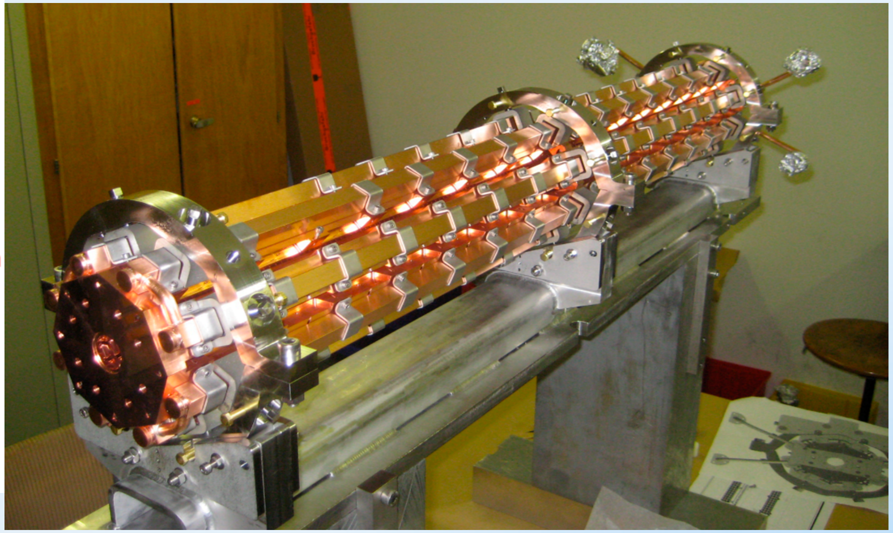


The decelerator

Objective of the drive beam decelerator:

- Produce rf power for accelerating structures, timely and uniformly along the decelerator. **Robust performance of 42 km beam line**.
- Achieving a high energy extraction efficiency, to ensure good machine wall-plug efficiency: baseline is **90% energy extraction** maximum
- Beam must be transported to the end with **very small losse**s
- Drive Beam: **101 A, 2.4 GeV**





1500 x 48 power extraction and transfer structures (PETS) will convert kinetic energy to rf power along 1 km decelerator sectors.

➔ **novel beam dynamic challenges** for the decelerator

No analogue studies for the ILC – CLIC works from scratch

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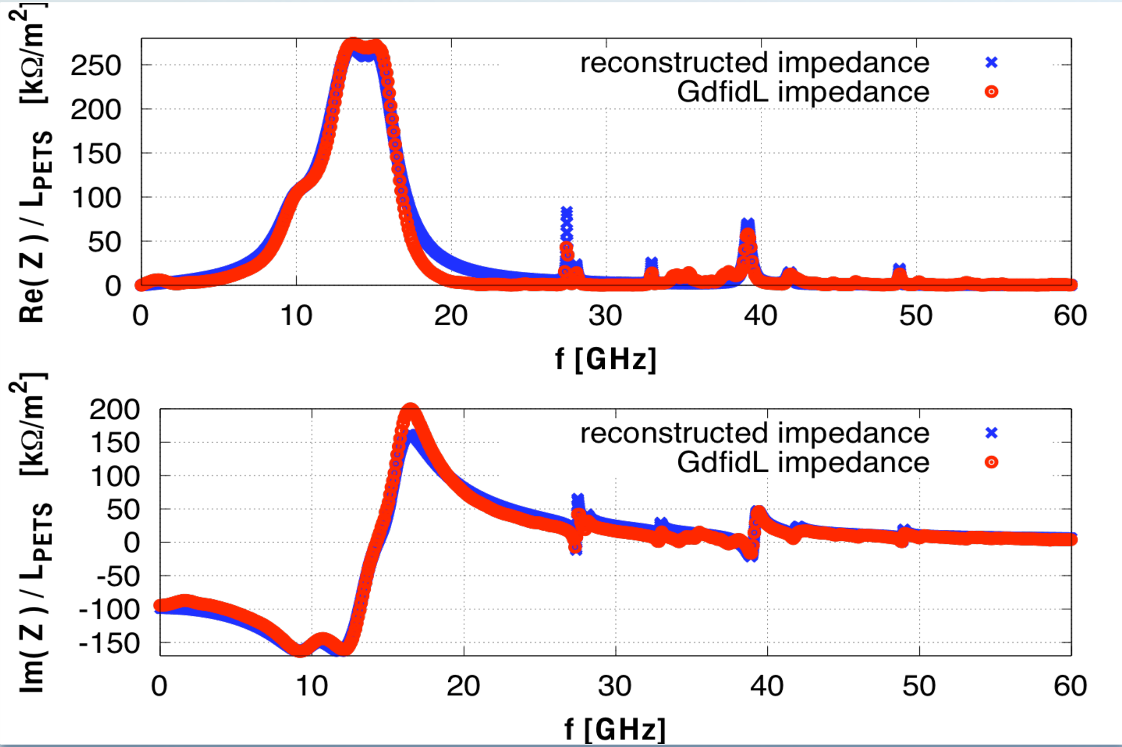
PETS rf design

- PETS designed with a fundamental mode 135 MW, 12 GHz rf power production from a 101 A drive beam
- The related transverse wakes will deflect the drive beam
- The **transverse dipole spectrum** are calculated by GdfidL time-domain simulations, and a set of discrete modes is fitted and implemented in the tracking code PLACET :

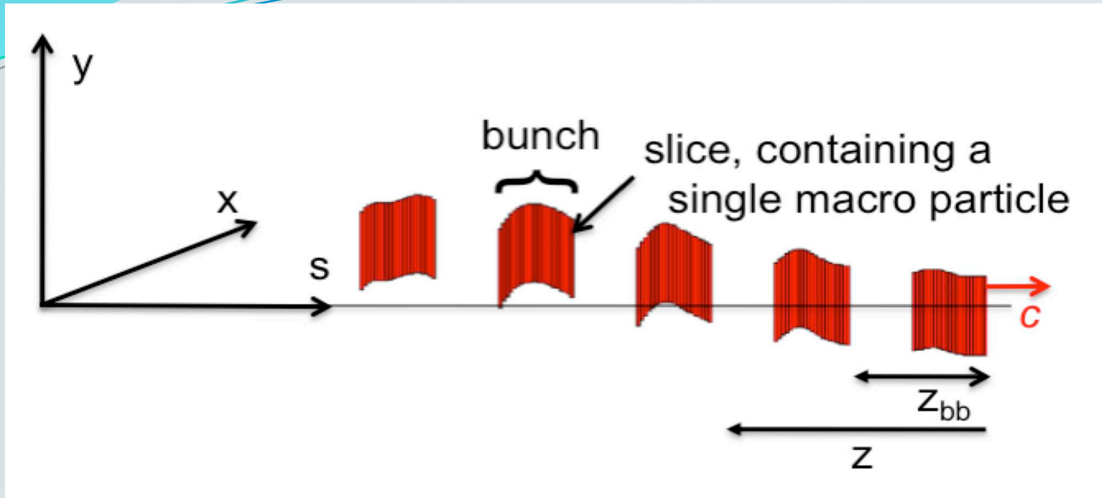


Estimate of PETS transverse dipole impedance (2007)

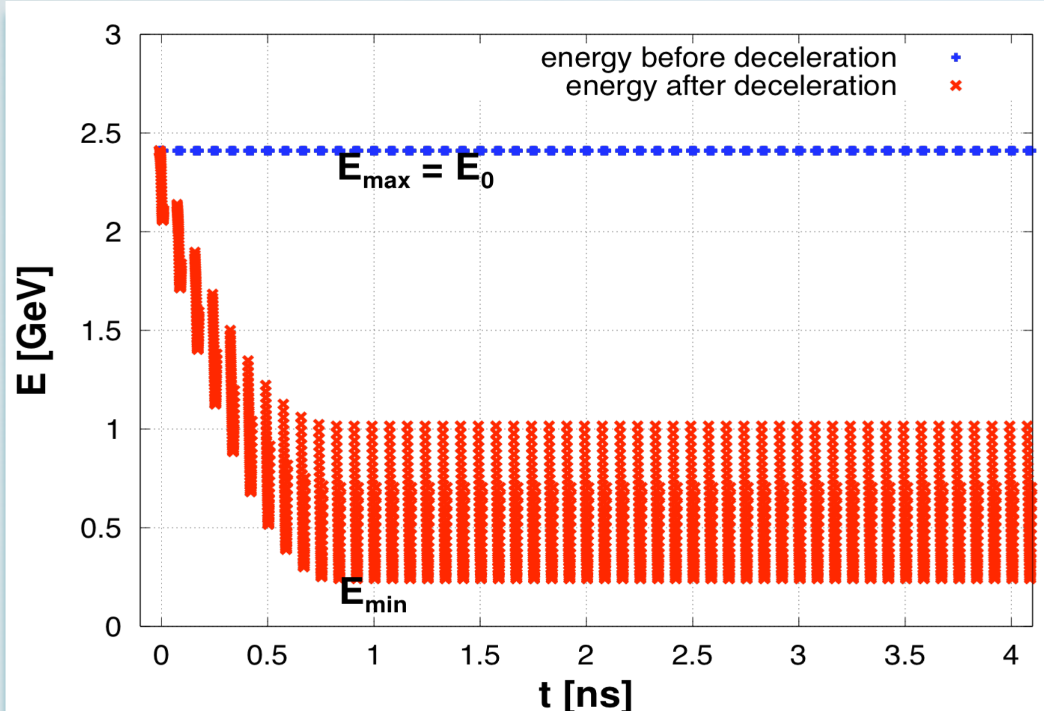
- a small number of modes (here nine) give a good fit of the calculated impedance
- PLACET represents a mode with **amplitude, frequency, Q-factor and group velocity**

See previous slides, "Progress in the PETS development", I. Syratchev, Monday 17:00

PLACET model of the drive beam



Example PLACET bunch train (transverse)



PLACET energy profile of beam at the end of the decelerator

Sliced bunches, where wakes are generated from each slice, – both **multi-bunch** and **single-bunch** wakes effects incorporated. Both effects important for studies of beam envelope growth.

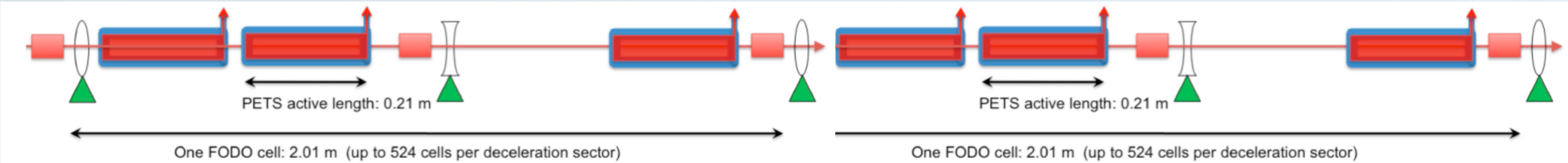
Beam loading automatically taken care of, as well as single-bunch **energy spread** due to bunch length.

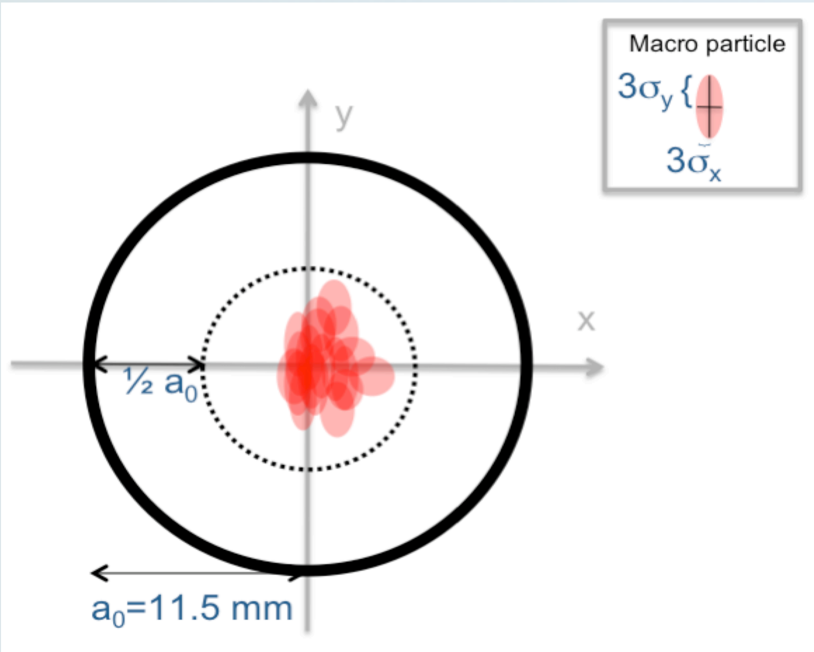
The baseline simulations reflect the fact that leading particles will be **10 times more energetic** than the most decelerated at the end of the decelerator.

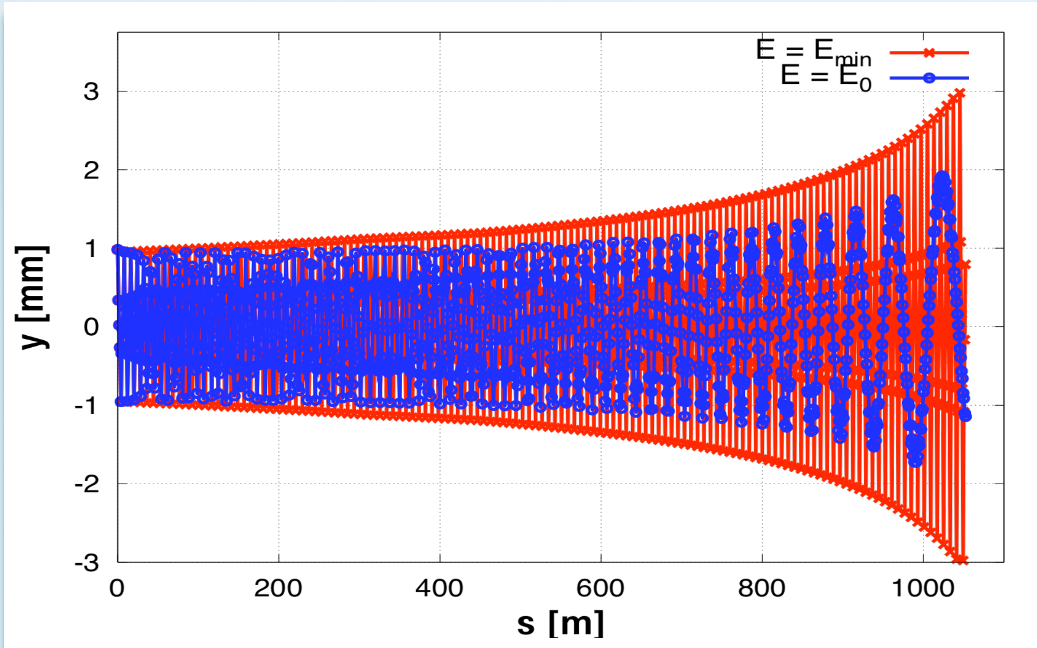
Decelerator beam transport

Uniform power production implies that the beam must be transported to the end with very small losses (< 1 % level). We require robust transport of the entire beam through the ~1 km decelerator sectors.

PLACET simulations are the main tool for the decelerator studies.







Simulation criterion:
3σ of *all* beam slices < ½ aperture (5.8 mm)

Beam transport along lattice, for ideal injection into a perfect machine : minimum envelope ~ 3 mm

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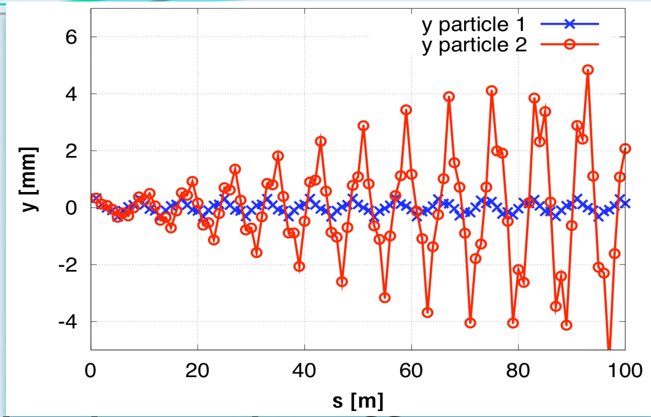
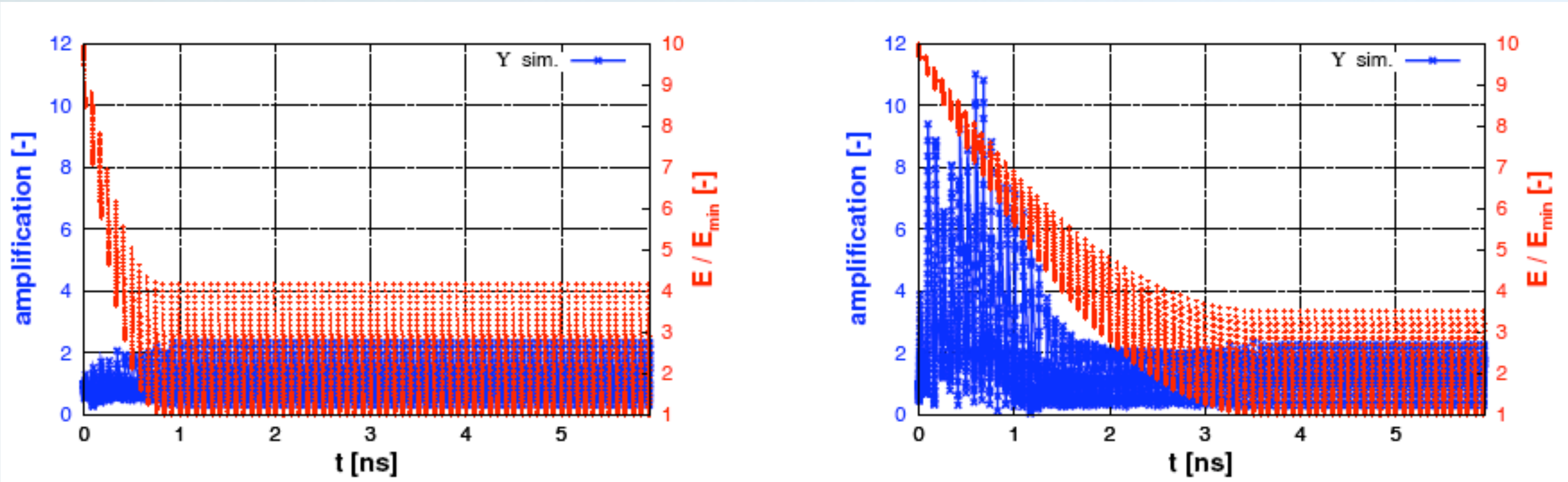
Effect of transverse wakes



Dipole wake: induces transverse force proportional offset of leading charge. Effect for ideal two-particle: linear growth.

Decelerator beam particularities:

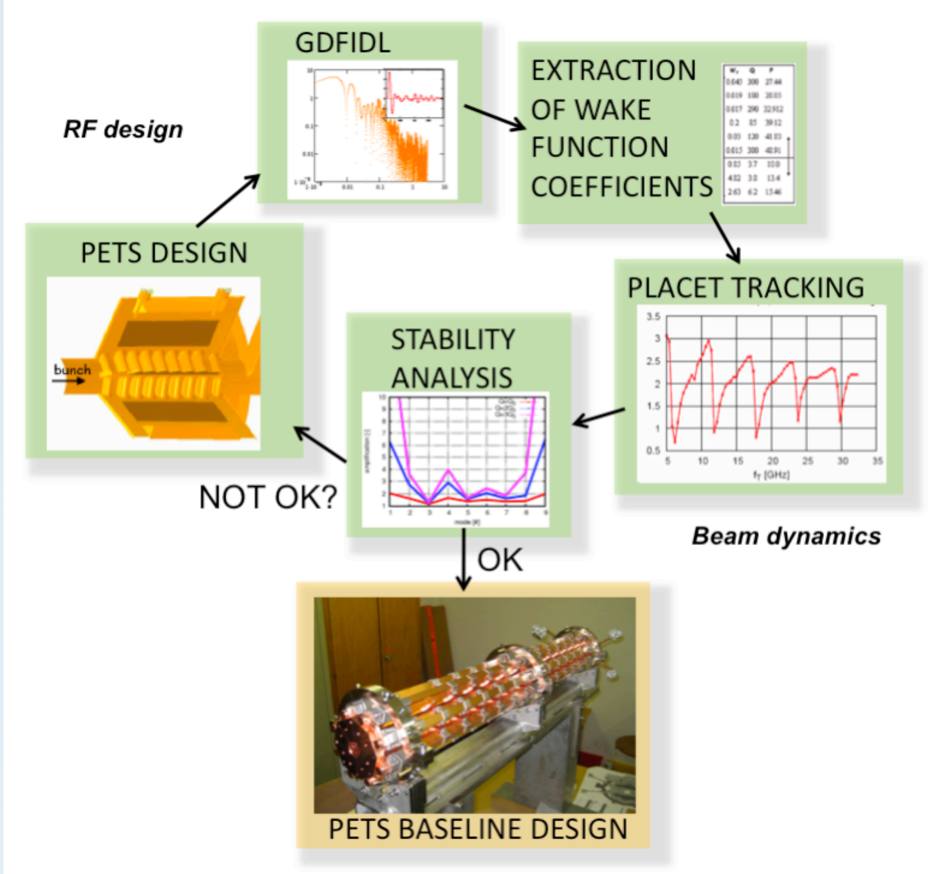
- long bunches yields potentially severe single-bunch effect
- large energy spread decoheres wakes
- **PETS design** must not only minimize wakes, avoid resonant frequencies, but also ensure sufficient energy spread

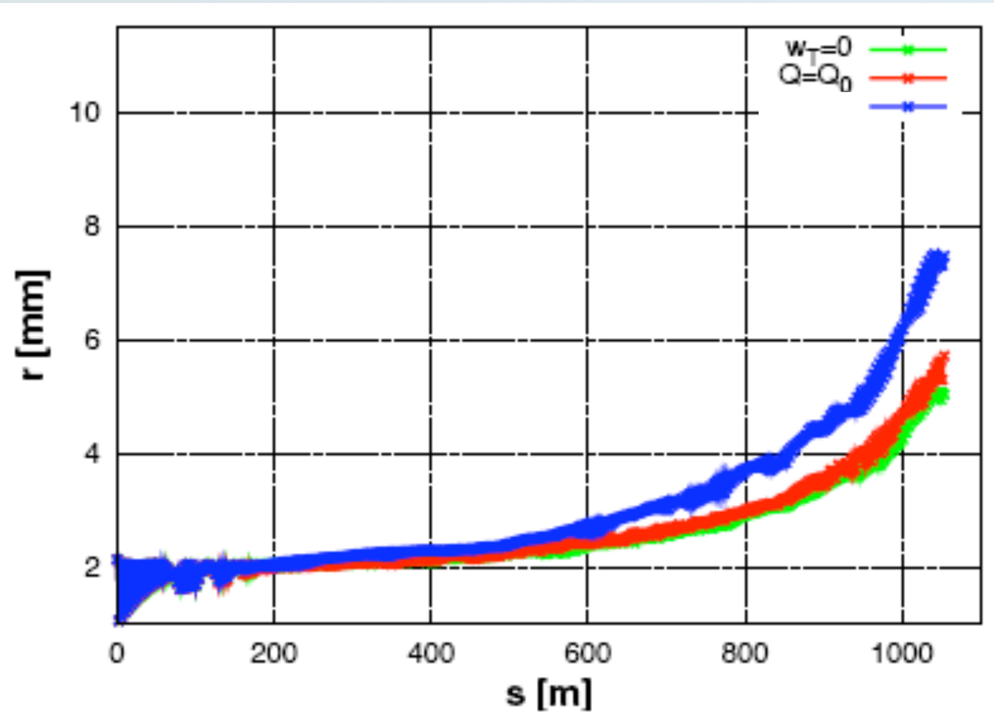


Amplification of action at decelerator end, due to transverse wakes for PETS with higher (left) / lower (right) group velocity

PETS baseline

Reaching a satisfactory PETS design, with sufficient mitigation of the transverse wakes, has been a challenging process; must be robust with respect to misalignment, injection errors and jitter at all frequencies ➔





Simulation studies show that the **PETS baseline design yields acceptable performance** [but, to be confirmed by experiments].

See previous slides, "Progress in the PETS development", I. Syratchev, Monday 17:00

Example: amplification of beam envelope along the decelerator, for cases w/o wakes and with transverse wakes

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- **Challenge: misalignment**
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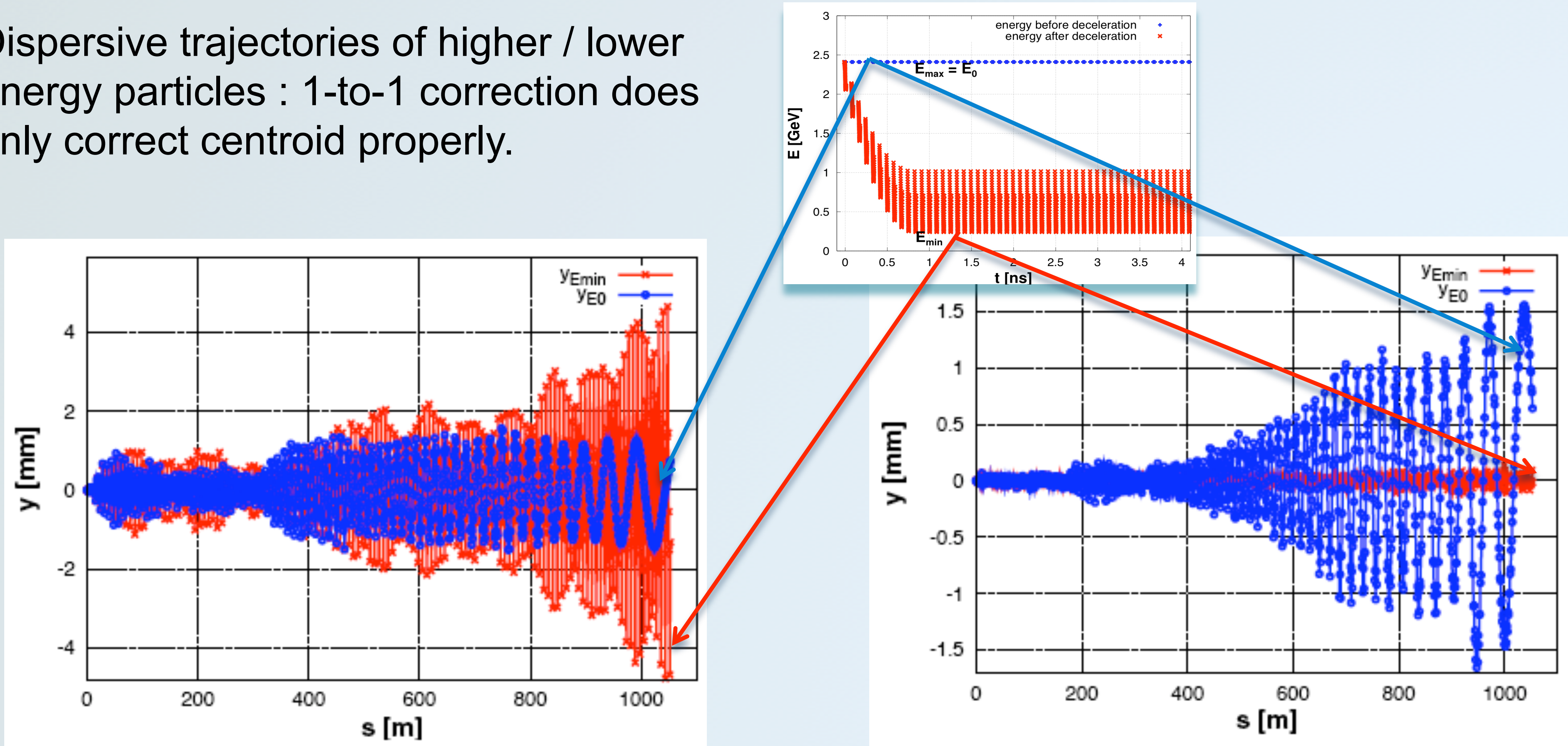
Effect of machine misalignment

Second challenge is the effect of machine misalignment. In particular:
kicks from misaligned quadrupoles will drive beam envelope far out of vacuum chamber, even for very tight pre-alignment of 20 um.

Again, **90% energy spread** of decelerator beam poses a challenge :

Dispersive trajectories of higher / lower energy particles : 1-to-1 correction does only correct centroid properly.



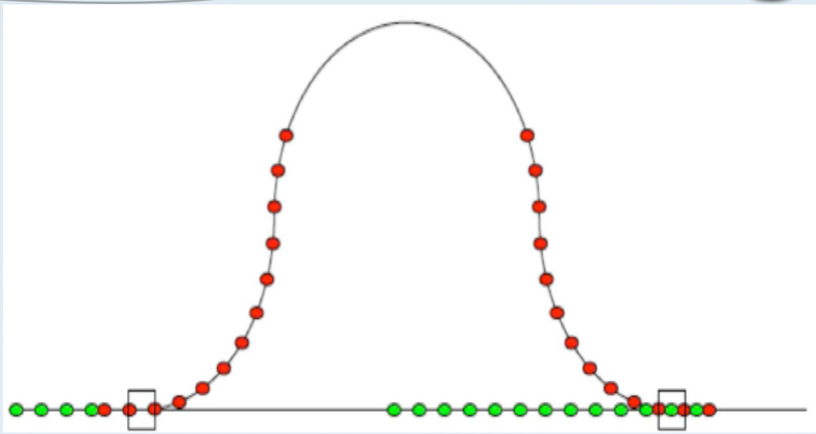
Beam transport for ideal injection into a *misaligned machine*

Beam transport for ideal inj. into a *1-to-1 corrected machine*

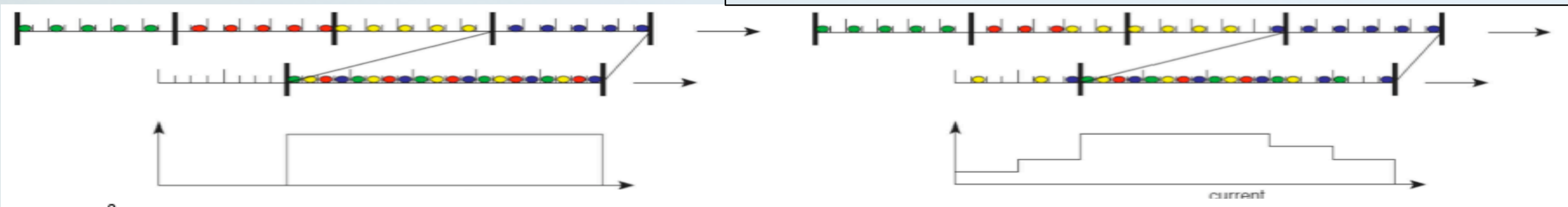
Dispersion-free steering

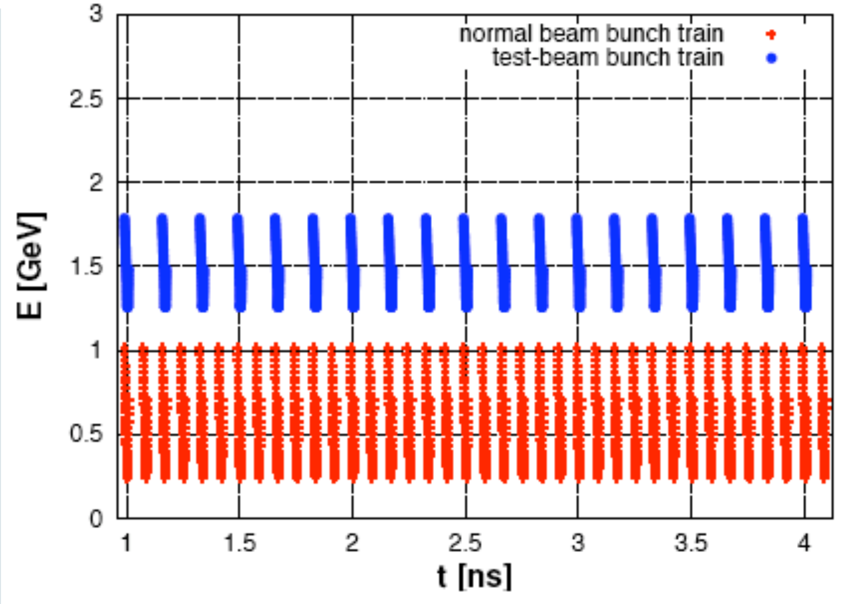
We improve the situation by imposing that particles of different energy shall all follow the BPM center trajectory – i.e. minimizing the energy dependence of the trajectories.

We propose a scheme based on drive beam **bunch-manipulation** and exploiting **PETS beam loading**, to generate a test-beam :

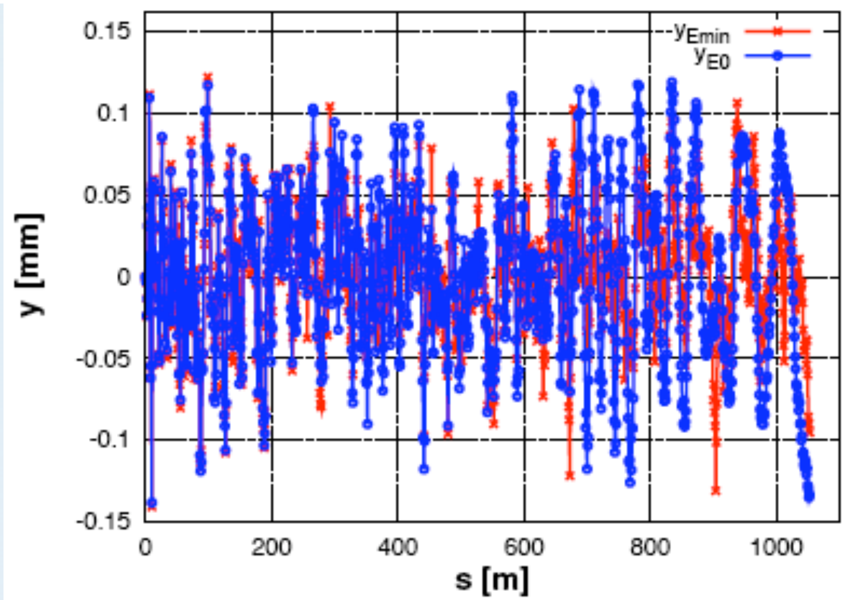


See EA and D. Schulte, "Beam-Based Alignment for the CLIC Decelerator", *EPAC'08*





Energy profile of main beam and example test-beam



Beam transport for ideal inj. into a *dispersion-free steered machine*

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Specifications

Ultimate goal of beam dynamics studies:
pin-point component specification

Lattice component specifications are driven by wake mitigation and correction strategies

Need tight focusing for sufficient wake mitigation.

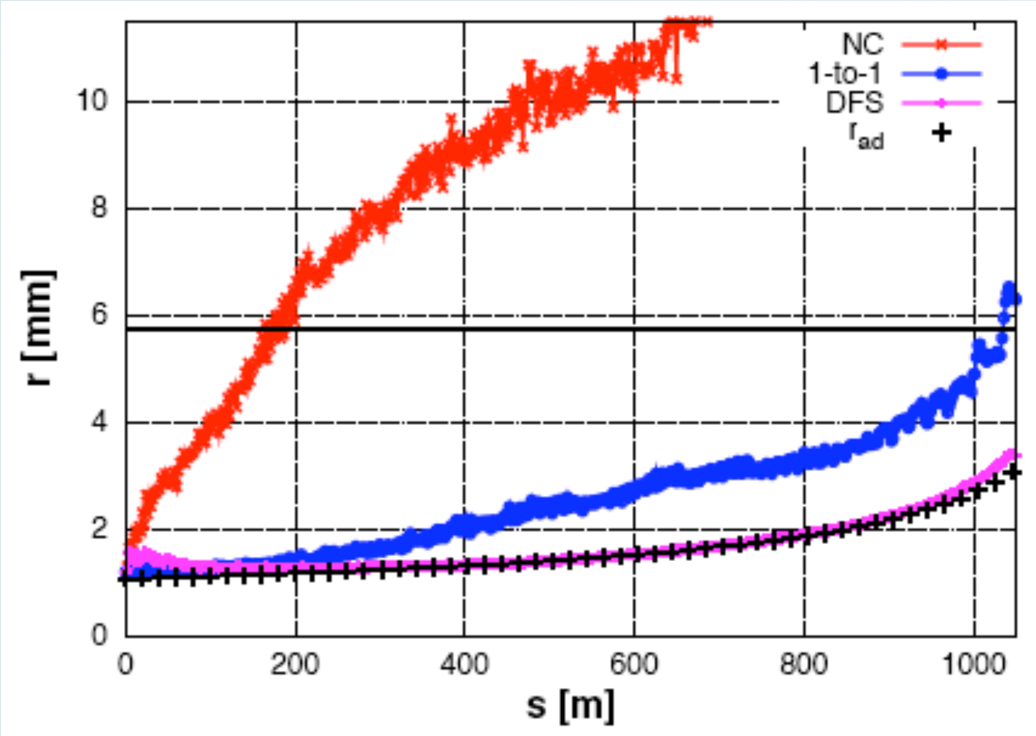
- Baseline**: one quadrupole per meter** (<β> = 1.25 m)

Need sufficent component alignment precision for initial correction.

- Baseline: BPM and quadrupole **alignment of 20 um**

Need sufficient BPM precision for dispersion-free steering performance

- Baseline**: BPM precision of 2 um**



Beam envelopes for decelerator baseline, 1-to-1 correction, and dispersion-free steering

Tolerance	Value	Comment
PETS offset	100 μm	$r_c < 1$ mm fulfilled
PETS angles	~ 1 mrad	$r_c < 1$ mm fulfilled
Quad angles	~ 1 mrad	$r_c < 1$ mm fulfilled
Quad offset	20 μm	Must be small to be able to transport alignment beam
BPM accuracy (incl. static misalignment and elec. error)	20 μm	Must be small to be able to perform initial correction
BPM precision (diff. measurement)	~ 2 μm	Allows efficient suppression envelope growth due to dispersive trajectories

Static tolerances

Tolerance	Value	Comment
Quadrupole position jitter	1 μm	$r/r_0 < 5$ %
Quadrupole field ripple	$1 \cdot 10^{-3}$	$r/r_0 < 5$ %
Current jitter	< 1%	Stability req. only – RF power constraints might be tighter.
Beta mismatch, $d\beta/\beta$	~10 %	$r/r_0 < 5$ %

Dynamic tolerances

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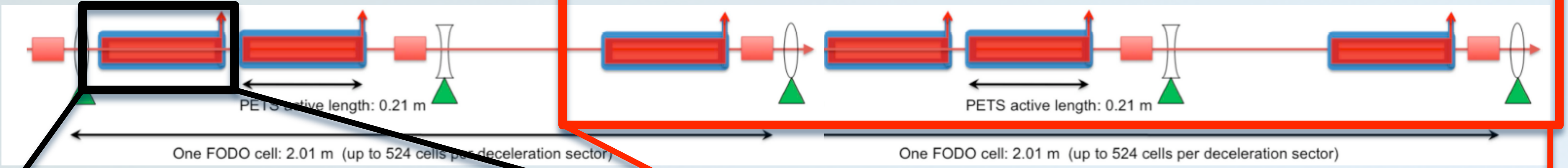
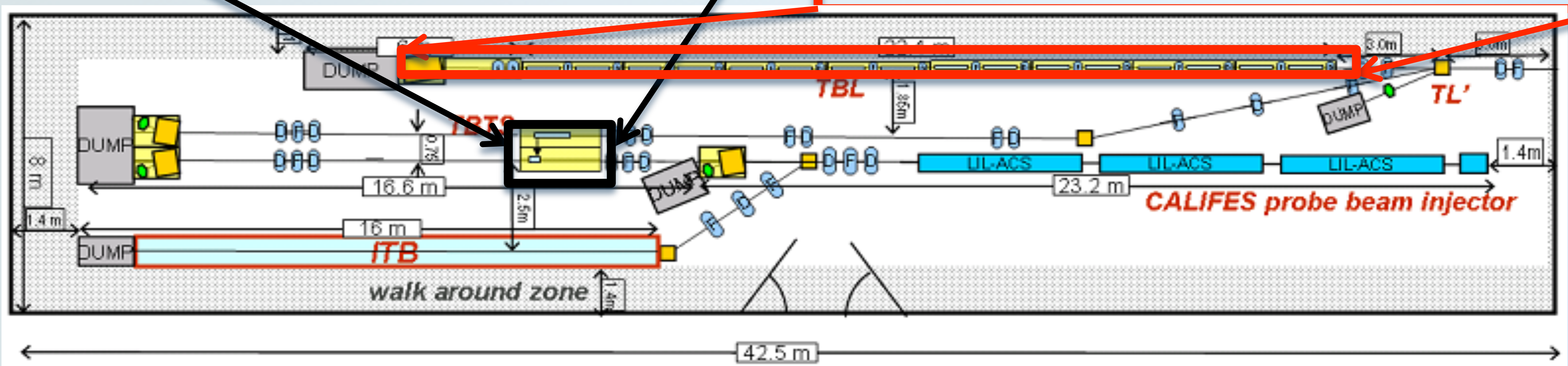
Decelerator test-facilities

Decelerator sector: ~ 1 km, 90% of energy extracted



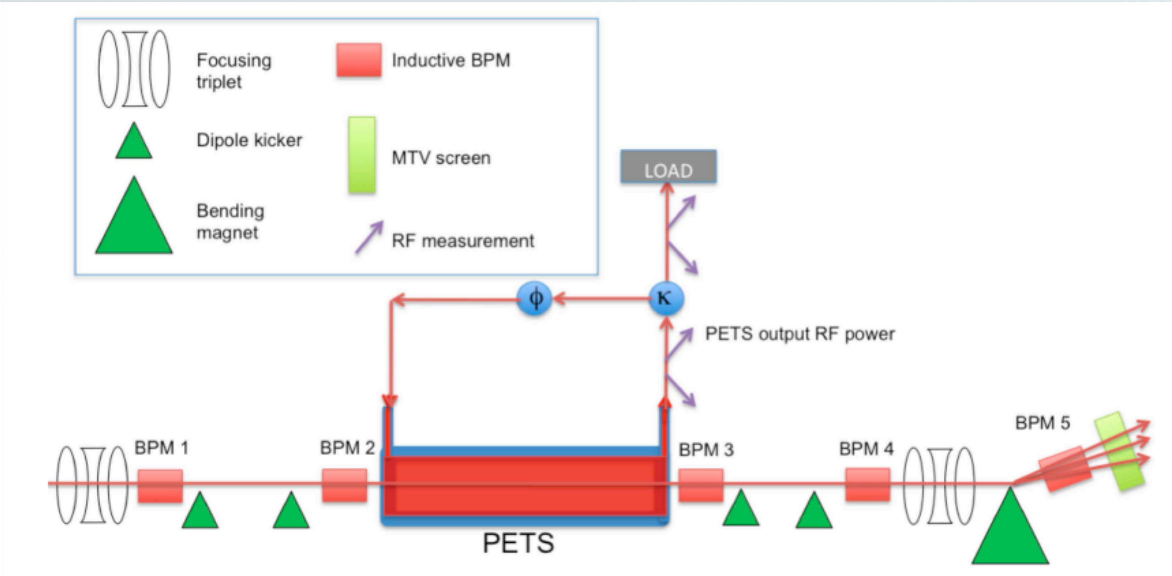
Two-beam Test Stand: test the characteristics of a **single** PETS

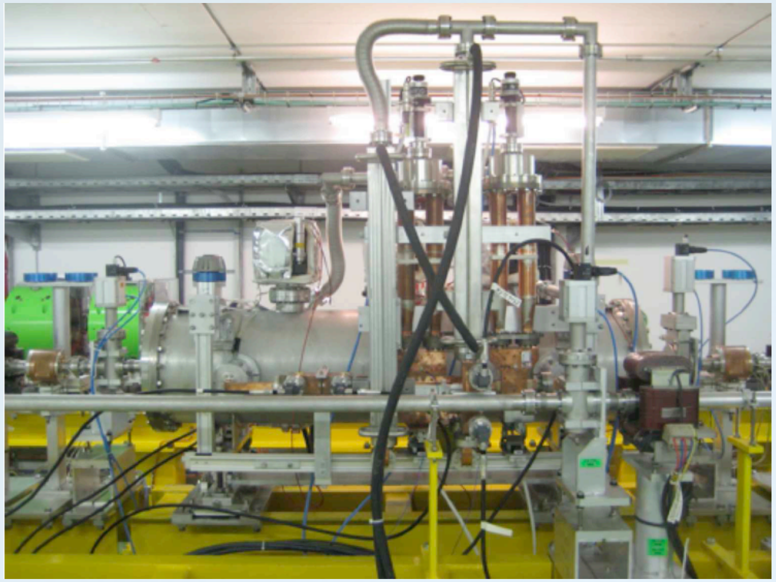
Test Beam Line: test of **beam transport** where a large fraction of the energy is extracted, under betatron motion (16 PETS)



Two-beam Test Stand

TBTS: the primary test-bed for single PETS performance

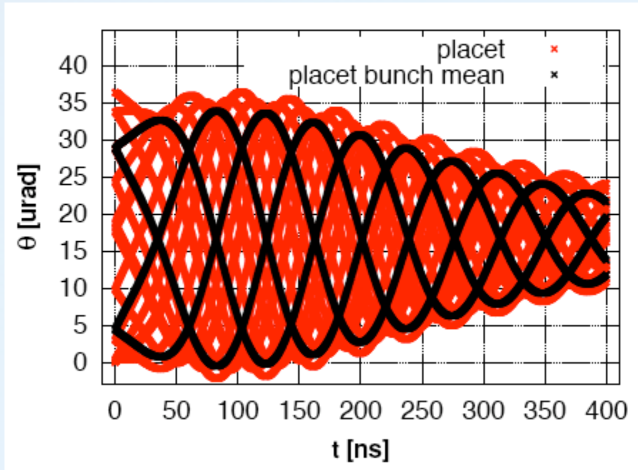




Particular interest for the decelerator studies: verification of transverse wake :

- measurement of **beam deflection**, TBTS kick angle measurement precision of 10 urad (expected kick; few 10 urad/mm centroid offset (5 A)) – **first benchmarking of PETS code**
- direct measurement of transverse wake with rf **antennas**

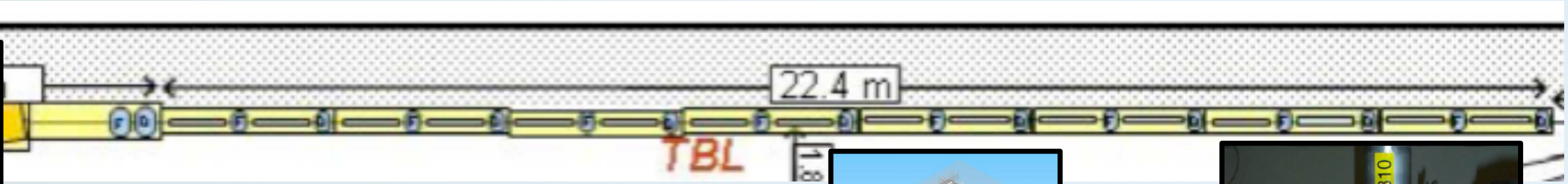
On-going work

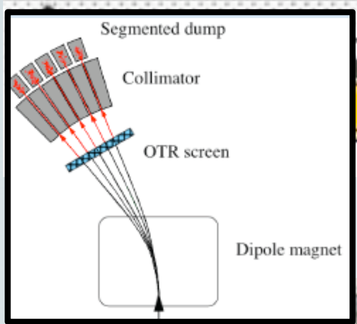


See talk "**Status and progress of the Two-beam Test Stand**", R. Ruber, today 14:35

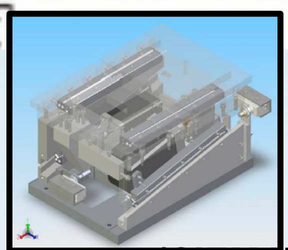
Test Beam Line

Test Beam Line: **Transport** of the **28 A** CTF3 Drive Beam, while **extracting more than 50% of the energy** using 16 PETS, each producing CLIC level rf power, with **small loss level**.

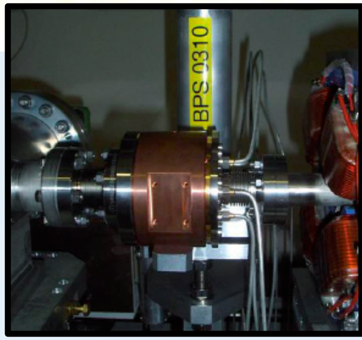




Optimized segmented dump for complete energy measurement (M. Olvegård, Uppsala U./CERN)



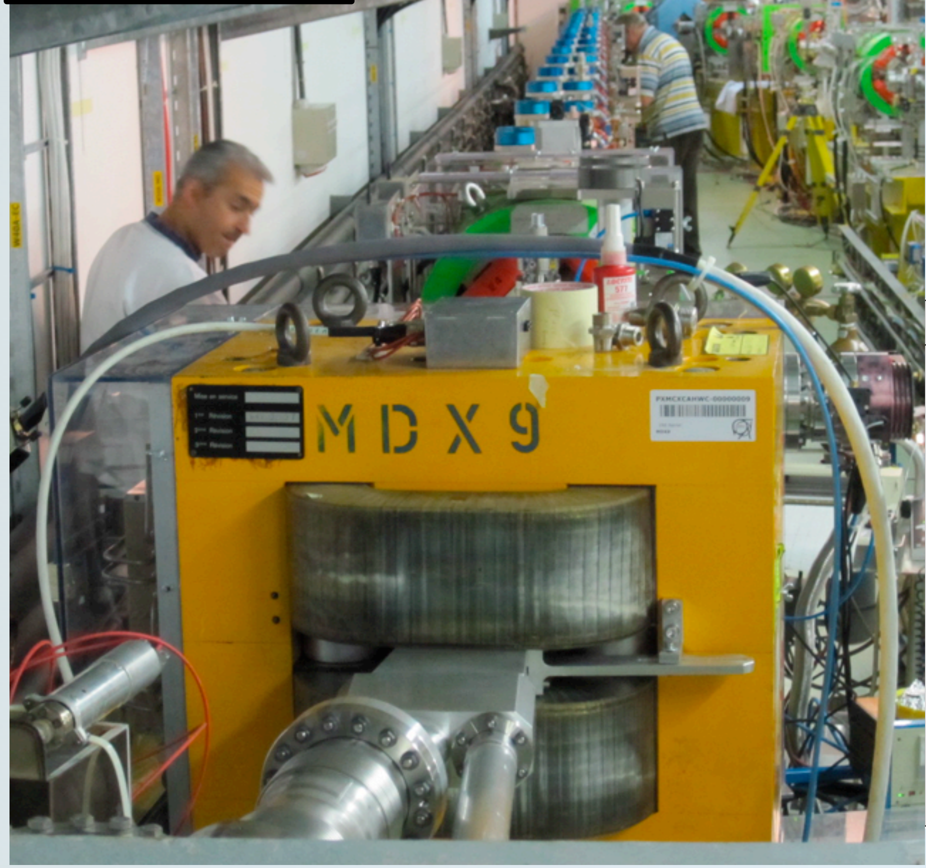
Quadrupole movers (CIEMAT)



Precision inductive BPMs (IFIC ES.)

See talk, A. Dabrowski, "Instrumentation at CTF3 and relevance to CLIC", Thursday 12:05

Loss monitors (Cockroft I.)

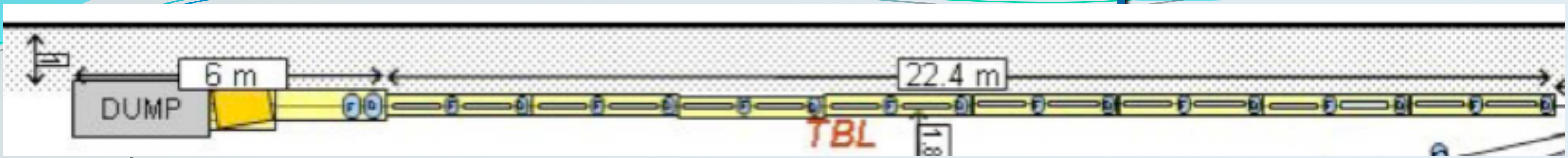


Test Beam Line – October 12, 2009

Parameters	Symbol	TBL value	CLIC value	Unit
Number of FODO cells	N_{cell}	8	500	-
Bunch separation	z_{bb}	25	25	mm
Bunch rms length	σ_z	1	1	mm
Pulse length	t_{pulse}	140	240	ns
Transient length	$t_{transient}$	3	1	ns
Initial average current	I_0	30	100	A
Power production	P	159	135	MW
Initial energy	E_0	150	2400	MeV
Final min. energy	E_{min}	59	240	MeV
Final max. energy spread	S	61	90	-
Initial norm. emit.	$\epsilon_{n\,x,y}$	150	150	μm rad

Parameters CLIC versus TBL

Test Beam Line: experiments



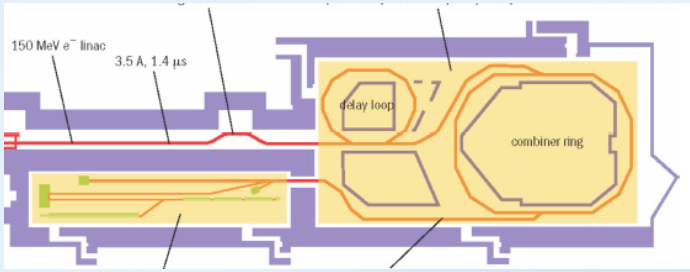
3) <- 1) 2) ->

• Precision correlation of 1) expected energy extraction (from intensity and bunch form), 2) rf power measurement and 3) dump energy measurements. Precision correlations (aiming for ~ 5 %) will show

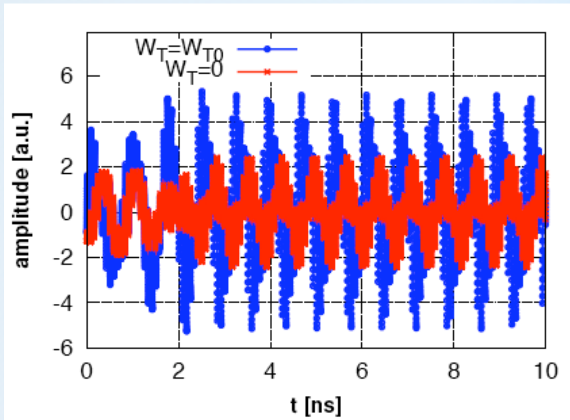
- that we **fully understand** and can **operate** the drive beam rf power generation
- that neither wakes nor energy spread impede transport (loss monitoring)
- performance tests of first series of 12 GHz PETS and couplers

• Test of the proposed decelerator orbit correction-schemes, using bunch manipulation and exploitation of the beam loading

-proof of principle demonstration for decelerator correction
-performance tests of BPMs and quadrupole movers



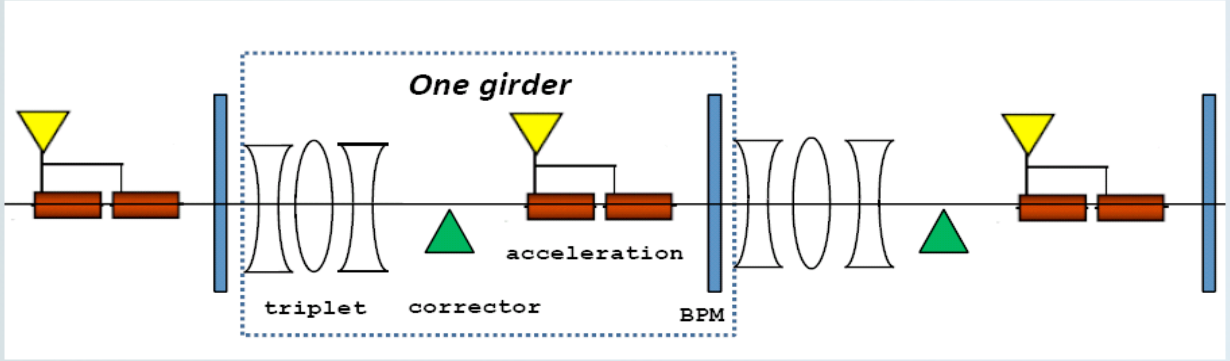
• Potential verification of resonant wake build-up (might require resonant kickers/BPMs)

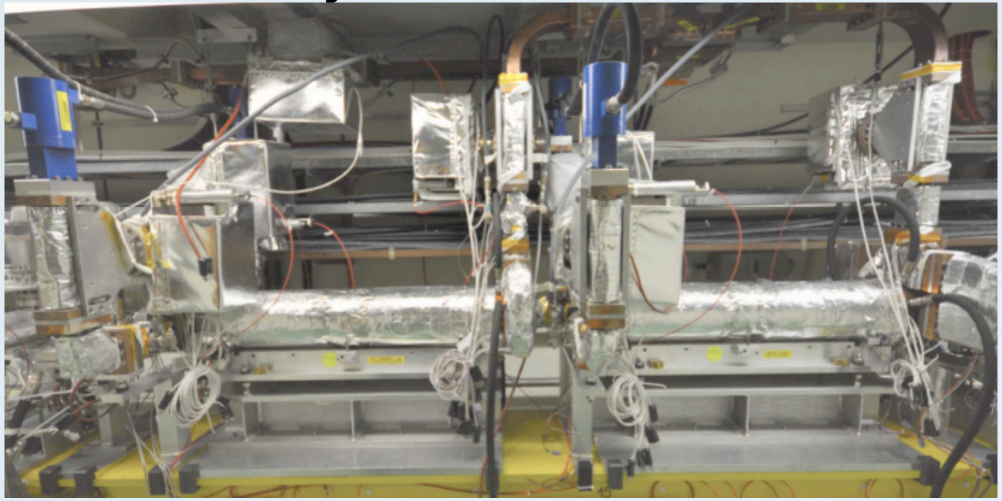


• Benchmarking of drive beam / PETS part of the PLACET code

CTF3 linac: Dispersion-free steering

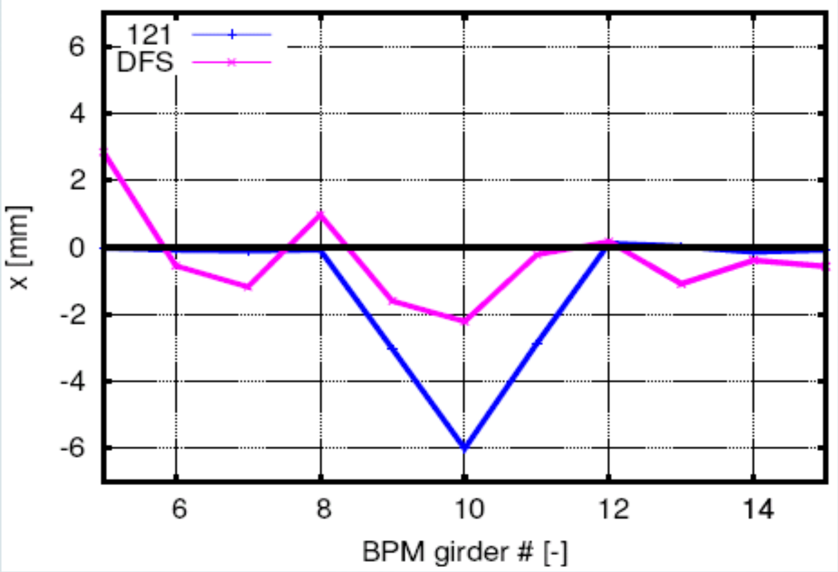
- As a test-case Dispersion-Free Steering was applied to the **CTF3 fully loaded linac :**

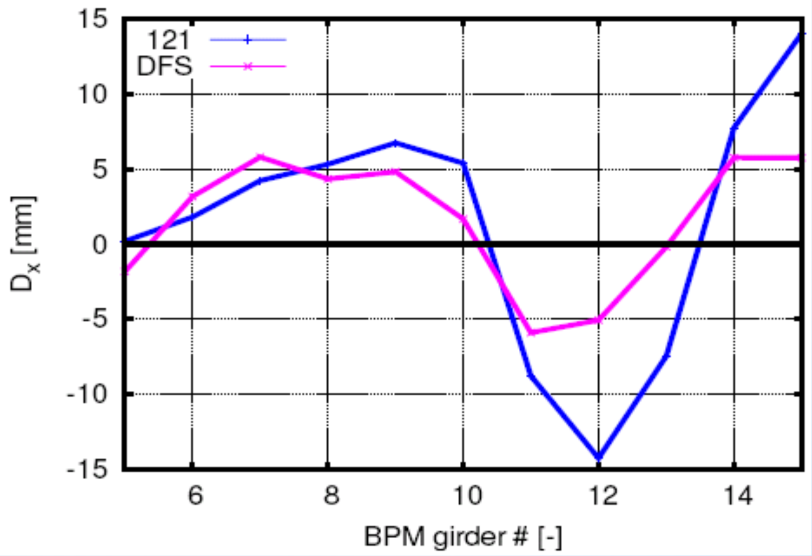




CTF3 linac structures

- Test-case with large simulated BPM offsets was defined :





- Steering close to real center trajectory instead of (artifically) offset BPM centers
- in practice: DFS indicate where problems are located
- Disperison reduced by a factor 3 with respect to 1-to-1

EA et al., "Status of an Automatic Beam Steering for the CLIC Test Facility 3", ***Proceedings of Linac'08***

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Conclusions

Decelerator: **novel beam dynamics challenges** due to the 90% energy extraction

42 km of beam line as the rf power source**: must ensure robust beam transport**

Simulation **studies show satisfactory performance** for the decelerator, following from

- sufficient mitigation of PETS wakes
- dispersion-free correction scheme
- tight, but feasible, component tolerances

What remains: **experiment tests** of beam transport with large energy extraction

Post-TBL: see talk by R. Corsini "The R&D programme beyond the CDR" later today

For an introduction to the CLIC decelerator: see EA, "A Study of the Beam Physics in the CLIC Decelerator", Ph.D. thesis, University of Oslo, available November 2009

Thank you for your attention