TBA modules in CTF3

From one module to a long string

6th CLIC Advisory Committee

February 3, 2011

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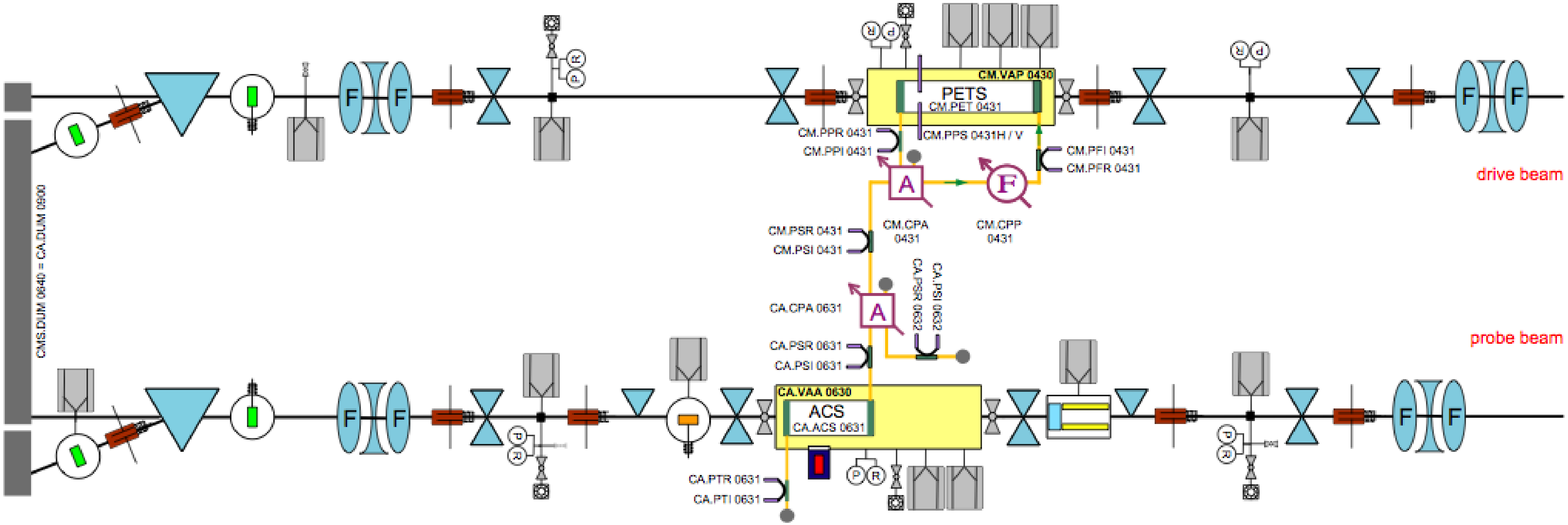
Outline

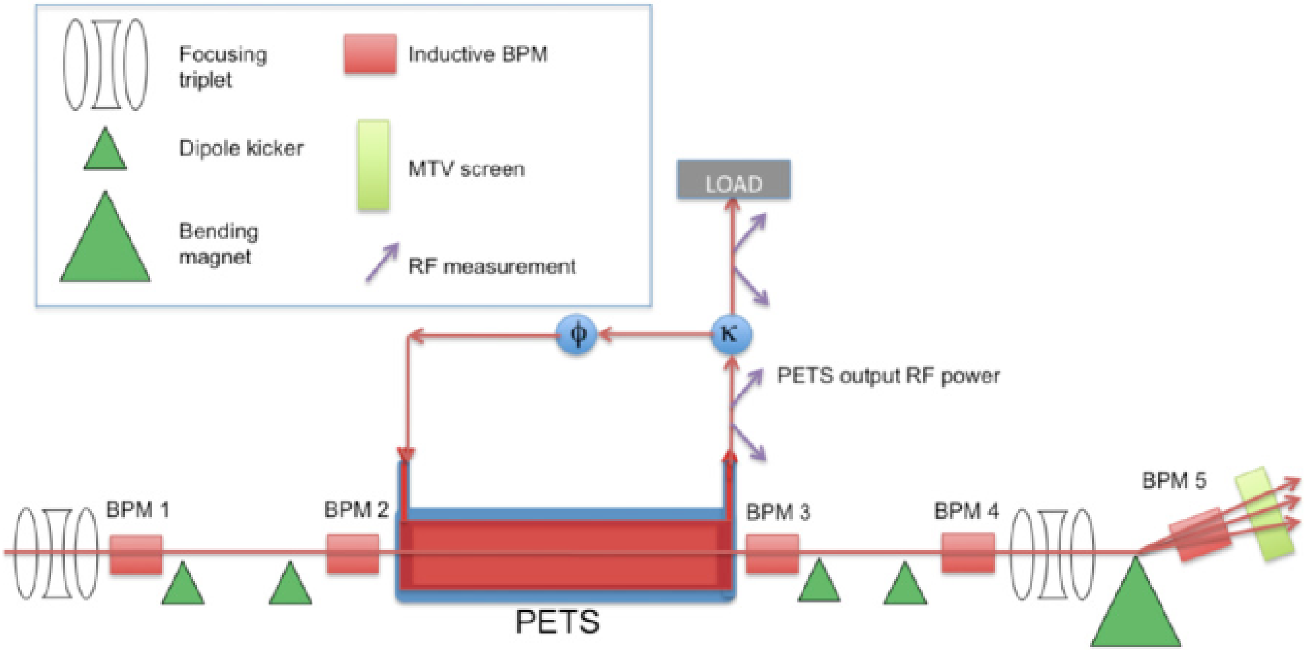
- **Two-Beam Test Stand (2008 ->)**
  - History
  - Current status
  - Activities still in progress
- **One CLIC Module (2012)**
  - What will it show?
  - What will be more difficult to measure?
- **Three CLIC modules (2013?)**
  - What will they show?
  - Challenges
- **Many CLIC modules (201?)**
  - How?
  - How many?
  - Challenges

Two-Beam Test Stand

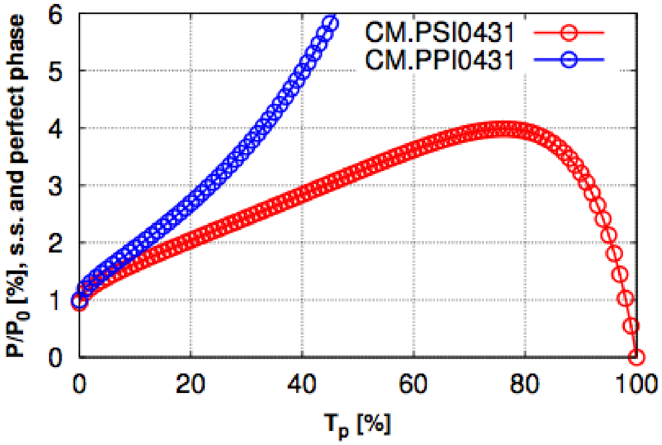
- TBTS: designed to test and analyze key concepts of Two-Beam Acceleration
- **Optimized for experiments**; double set of kickers, BPM on each side, triplets on each side (**not meant to resemble CLIC module**)
- PETS with recirculation (not meant to resemble CLIC module)



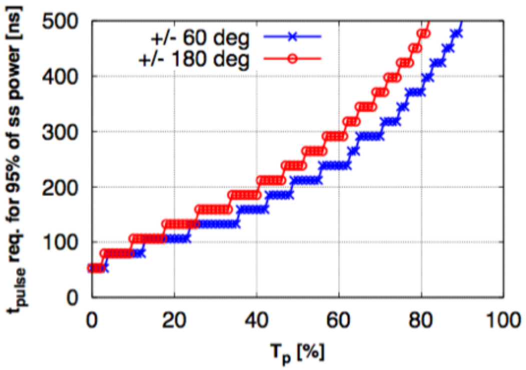
PETS recirculation



- TBTS PETS: designed as CLIC PETS, but x ~4 longer to compensate for x ~4 lower drive beam current in CTF3.
- In addition: recirculation loop to allow increased power production for commissioning drive beam current.



Advantage :
Approx. x 4 increase in power feasible.



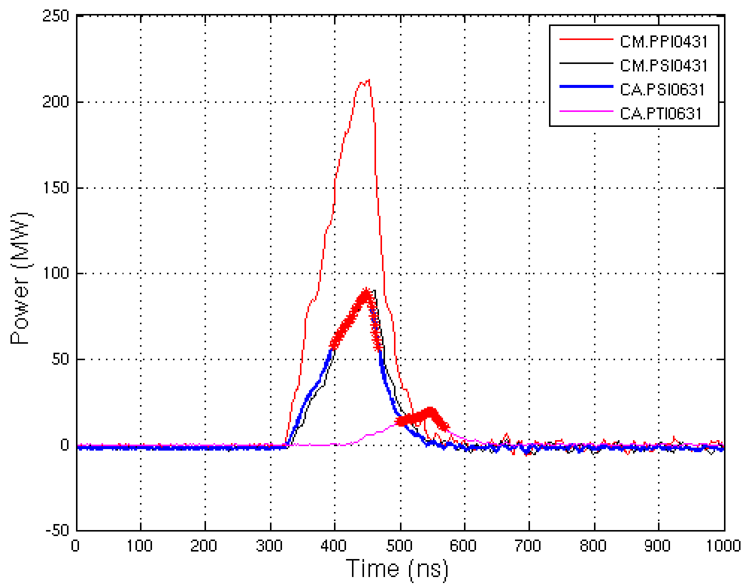
Calculated time needed to reach 95% s.s. (max. 5% diff from one step to another).

Disadvantage:
100-200 ns of pulse before steady state conditions are reached (flat top)

TBTS drive beam and PETS commissioning

Commissioning of beam line (2008 ->)

- Beam line commissioned to ensure full transport (2008)
- PETS with recirculation commissioned and PETS conditioned to routinely operate at > 200 MW in loop with break down rate not visible by "eye". Break down rate estimations still to be performed (2009-2010)
- Detailed optics verification still to be completed (2011)
- **Dispersion control** in CLEX drive beam to be improved



2010: routinely 200 MW in PETS recirculation loop with low break down rate.

(note the non-flat pulse, mostly due to steady-state of feedback not reached)

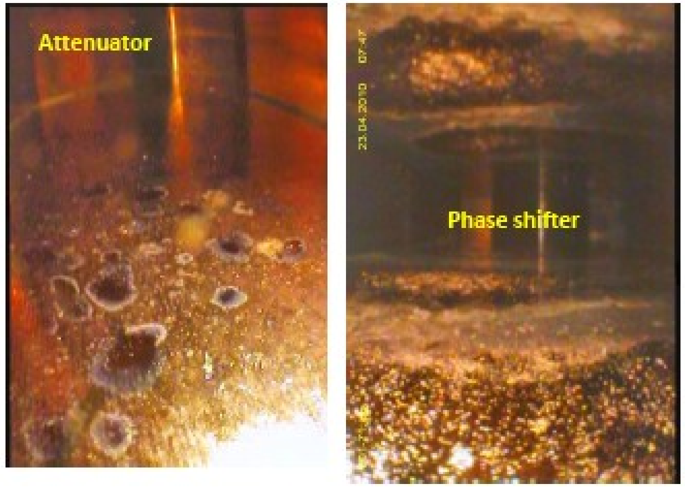
(this rf pulse is representative for the input power for the 106 MV/m gradient achieved in 2010)

PETS commissioning: not without problems

- PETS conditioning in 2009 impeded by break down activity in recirculation system. When reaching high power (~100 MW), activity and **damage in recirculation system** occurred :

The detailed analysis of the signals gave us a strong indication that in most of the cases the breakdown activity was associated with feedback loop and not the PETS itself.
We have opened attenuator and found multiple traces of breakdowns inside the attenuator splitter.

(I. Syratchev)

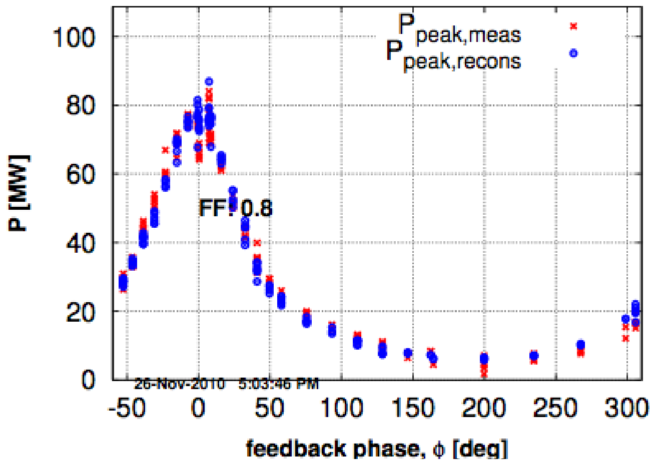


- The problem was likely due to fabrication problems, especially on cleaning procedures. A new power splitter, produced with an improved procedure, was installed in 2010 and showed a fast RF conditioning with few breakdowns.
- However the PETS recirculation loop not trivial to operate and to analyze -> **many new parameters introduced** (in particular: losses, reflections, exact settings of power split and phase shift). System has to be fully understood to fully characterize the two-beam acceleration.
- **The PETS recirculation increased significantly commissioning time**; compare TBTS PETS commissioning versus TBL PETS commissioning: **o.m. more**

TBTS: experiments

- Analysis of power production and deceleration performed (2010)
  - Coupler drive beam and PETS with recirculation to a large degree characterized (EA et al.) but on going efforts to improve models (AC, IS et al.)

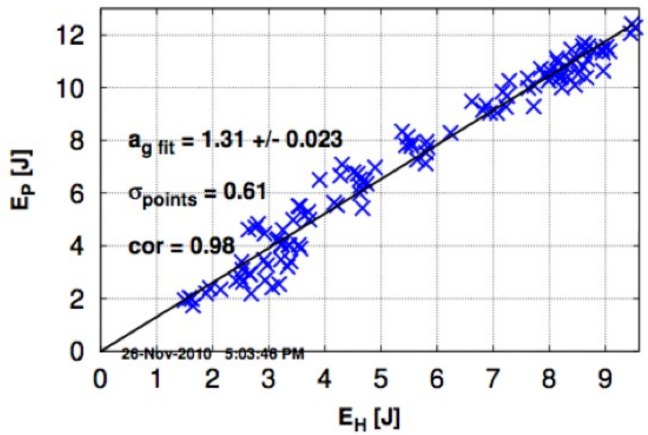
Measured and modeled rf power



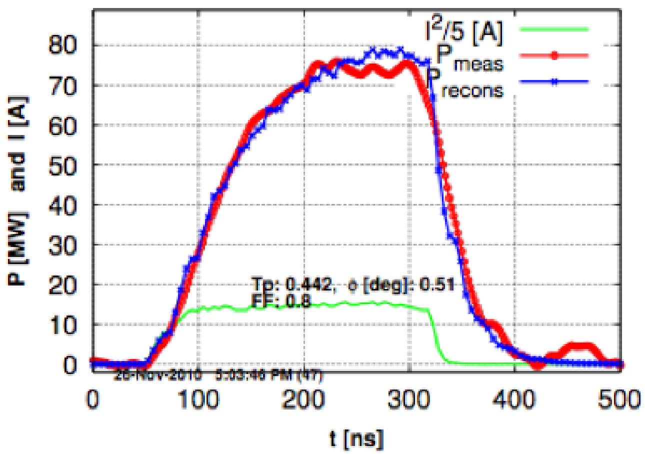
$$E_P = \int dt\{P_{out} + P_{lost}\}$$

$$E_H = \int dt UI$$

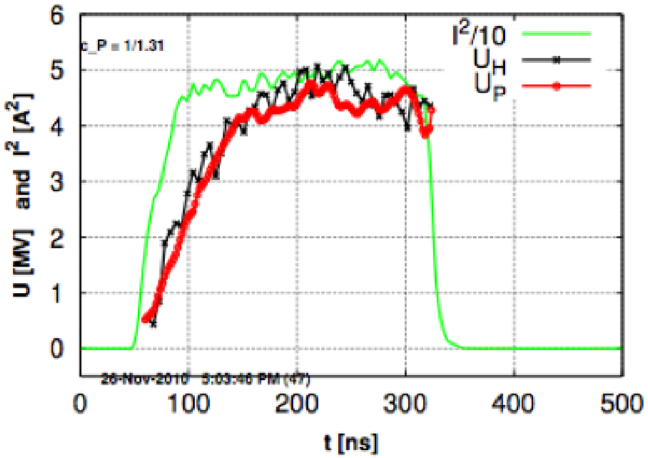
Power lost versus deceleration



Power production [MW]



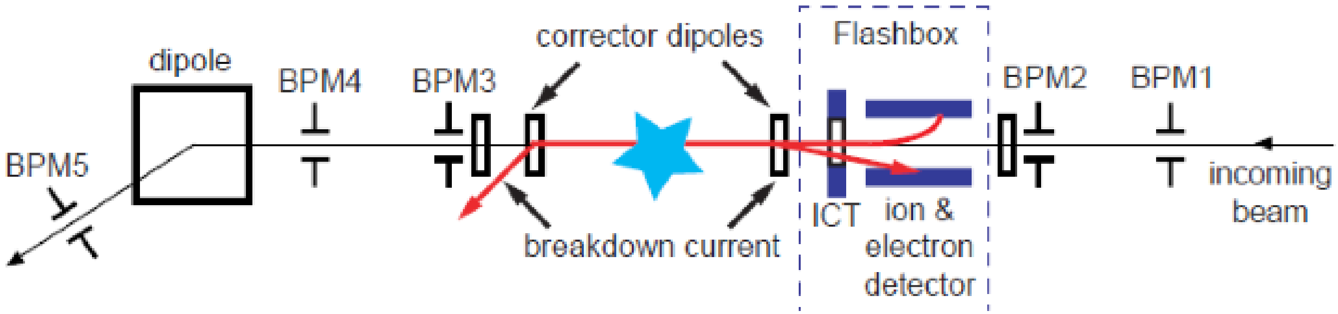
Drive beam deceleration [MV]



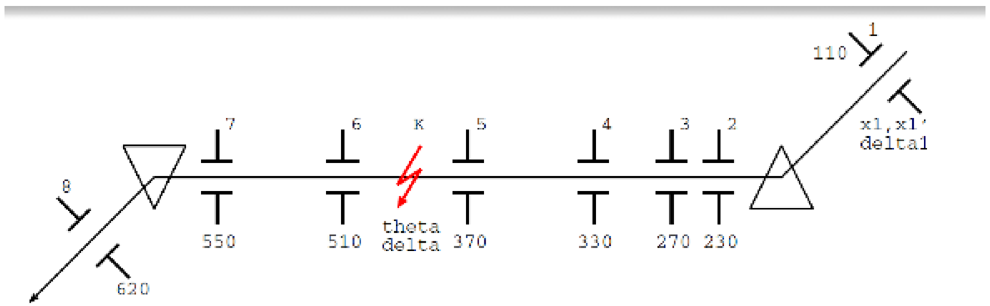
(E. Adli, University of Oslo)

TBTS: experiments

Break down measurements, including direct kick measurements correlated with flash-box (electron and ion measurements) **in progress**



- Direct kick measurements of transverse wake effects also feasible with TBTS, to complement HOM antenna measurements, **in progress**



- Both these measurements require better measurements conditions
  - Better drive beam stability
  - Improved optics model (to allow for detailed PETS and ACC kick measurements)

(R. Ruber, A. Palaia, Uppsala University)

TBTS: experiments

- Other TBTS experiments **still in progress**:
  - Detailed **power and energy budget** for full system drive beam and probe beam
  - Detailed study of **transverse effects** on drive beam and probe beam
  - **PETS on/off**
  - Fine-tuning drive beam and probe beam **timing**
  - Investigation of **cross talk** drive beam and probe beam
  - Drive beam versus **probe beam loss monitoring**

See R. Ruber, :Two-Beam Test Stand Experimental Program”

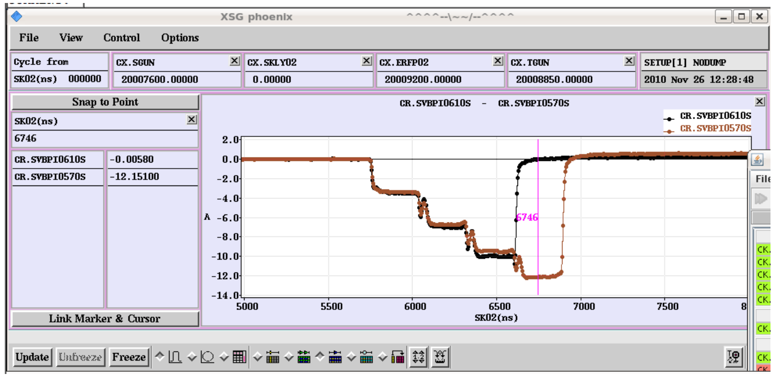
Compability with installation of CLIC module?

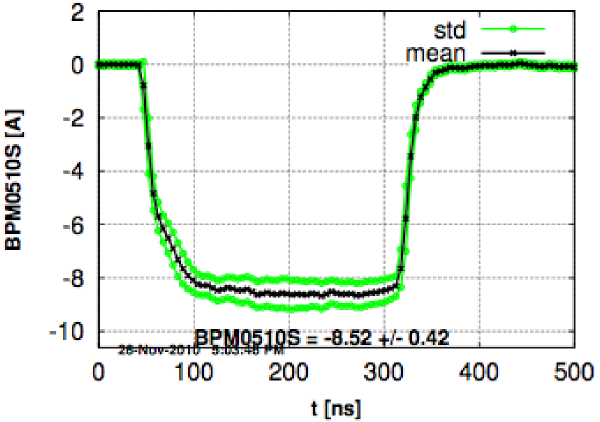
TBTS: example of drive beam stability

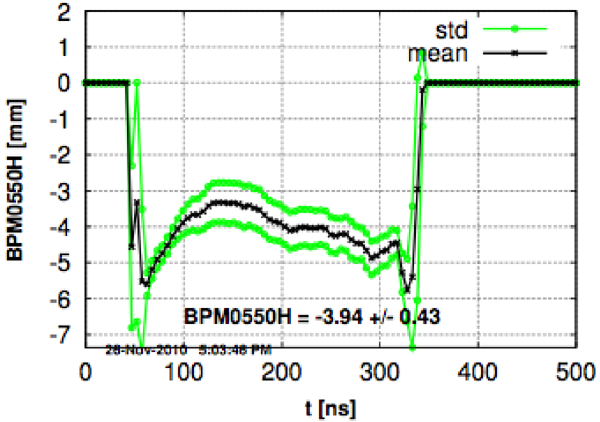
Example of TBTS signal pulse to pulse jitter, and along the pulse signals

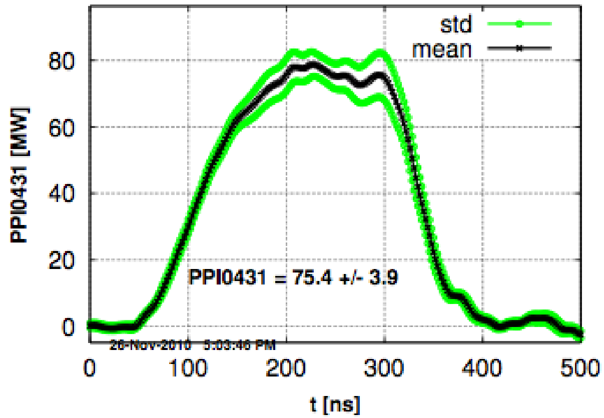
- Taken from measurements day for characterization of power and deceleration (machine optimized for stability, x 4 combination)
- My opinion: beam transport and stability this day good day quite good with respect to year (but cannot say whether it was one of the best)

(Nov 26, 2010)







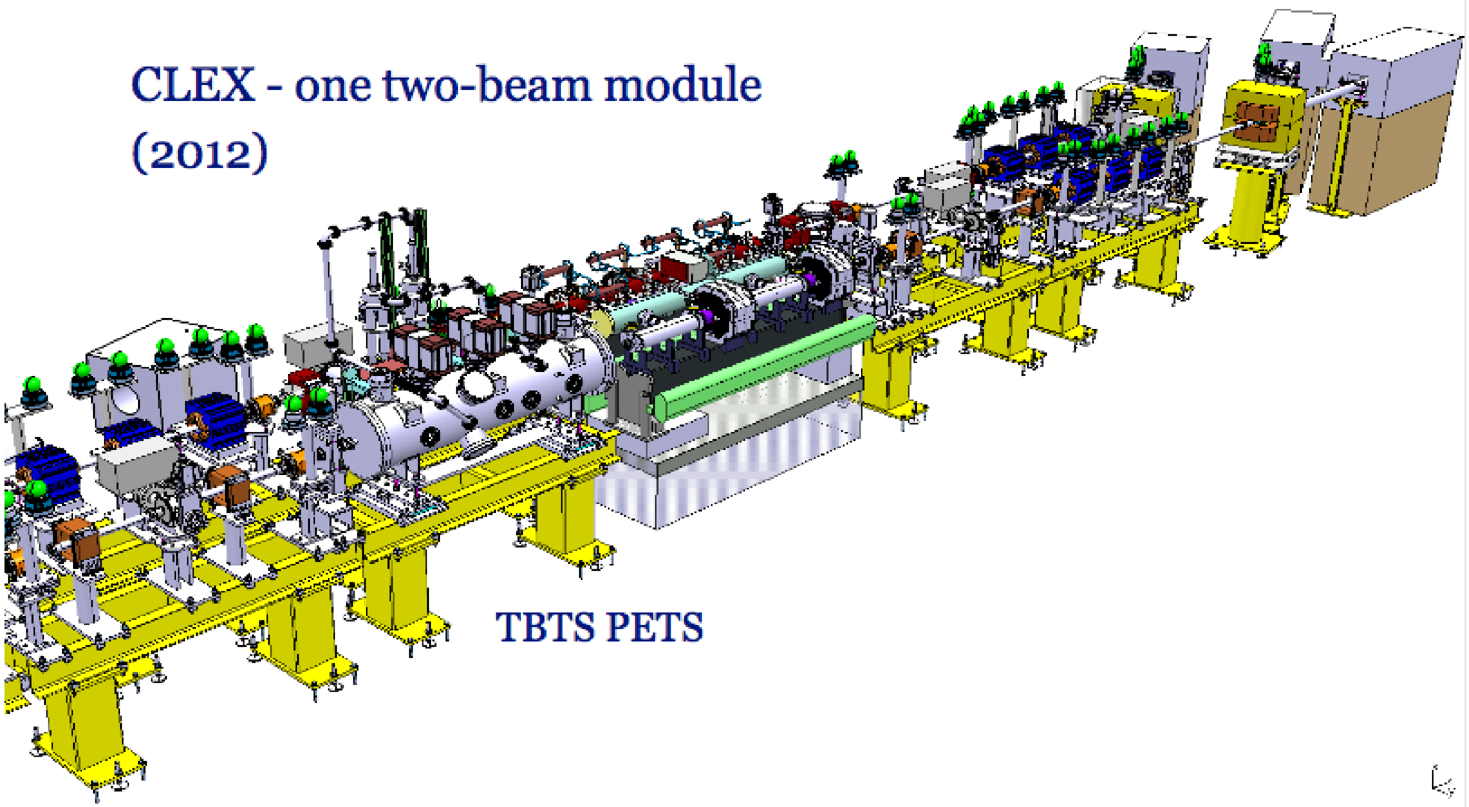


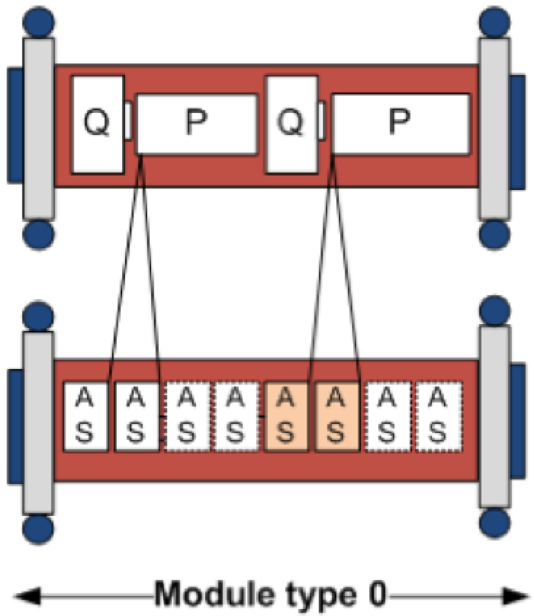
Shown: 1) current just after PETS, 2) H position just before spectrometer, 3) power in PETS loop :

- quite nice and flat current top of over > 200 ns
- many % pulse to pulse jitter
- dispersion not under control
- significant losses from ring to TBTS

Upgrade: TBTS + 1 module

- First upgrade of CTF3 two-beam acceleration test: **adding one full CLIC-type module**, in addition to TBTS.





- Clear goal: realistic beam **tests of a module** with all relevant components in CLEX.
- Notable differences from CLIC module; most prominent: two PETS of ~0.5 m instead of 4 PETS of 0.21 m, to increase power production (later slide)
- However, verification of break down effects from a single structure may be impeded; three PETS in a row and several ACCs in a row will make it **difficult to isolate activity in a single structure**.

TBTS + 1 module: optics

- For one module: **optics flexibility should still ok** (adds quads and BPMs with respect to current beam line).
- Except: current baseline is to remove current ACC tank. Might be of interest to keep old ACC if studies are still on-going (will take time to commissioning new ACCs in module). In this case, objects must be moved and optics limitations re-checked (but, should not be show-stopper).

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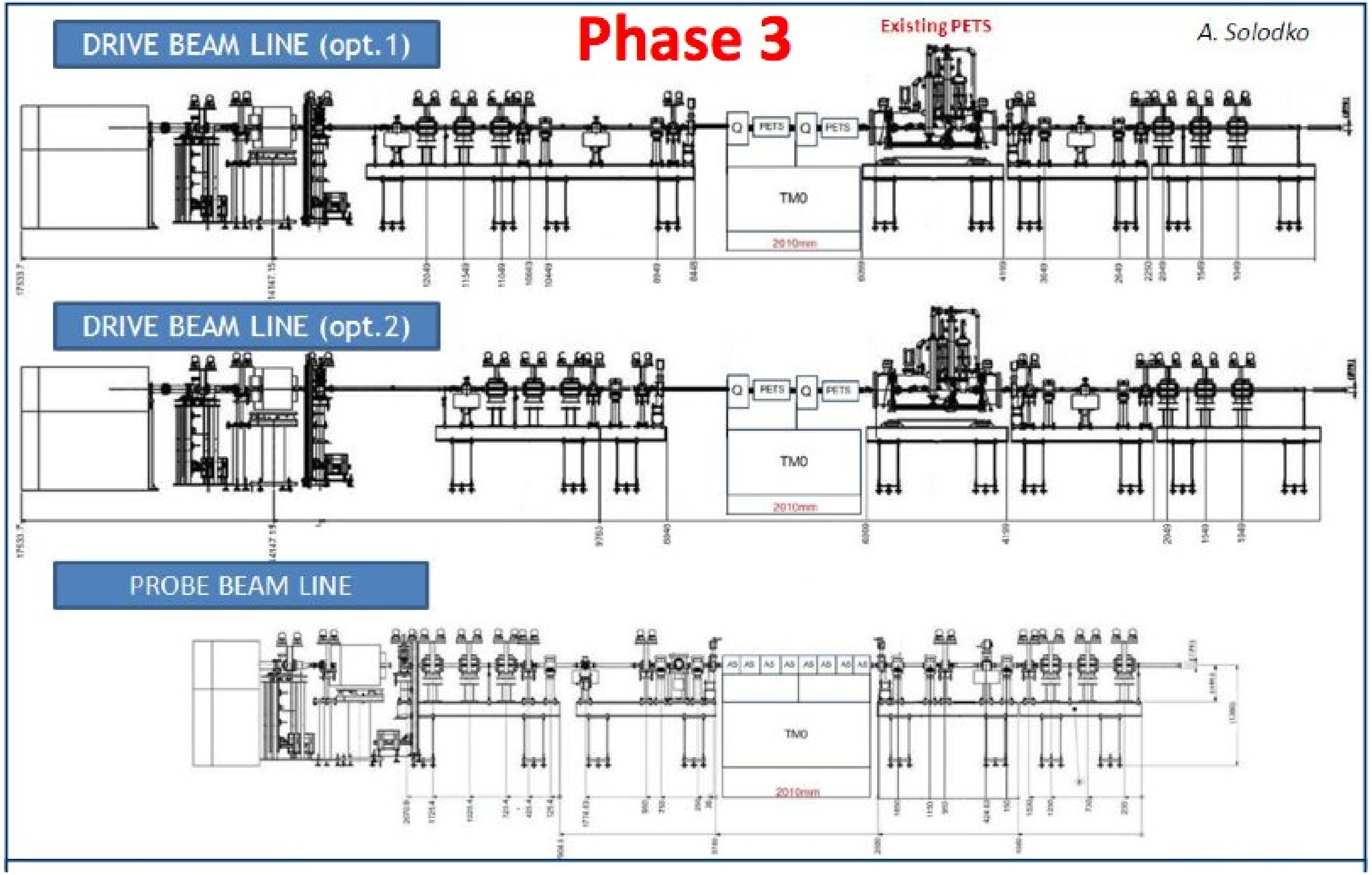
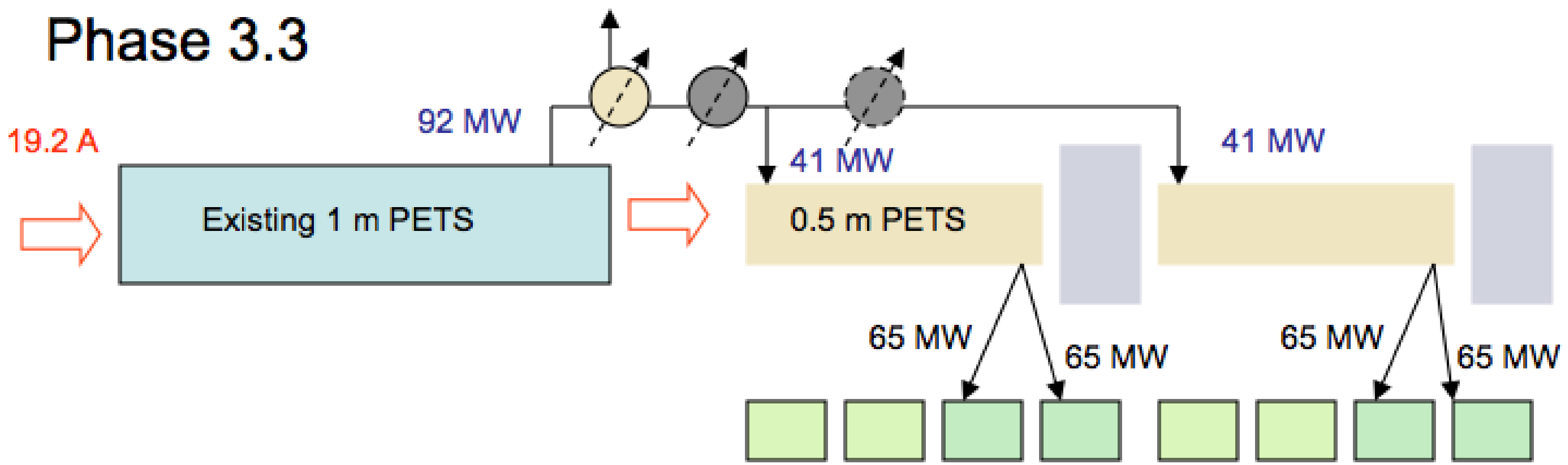


TBTS + 1 module: power

- The x 2 PETS length cannot compensate the CTF3 drive beam reduction; at best $\mathbf{P_{CTF3MOD}}$ ~ (25/100)^2 x (0.5/0.21)^2 x $P_{CLICMOD}$~ **¼** $\mathbf{P_{CLICMOD}}$

- Possible work-around is **feed forward** PETS field from TBTS PETS in order to produce enough power to feed two accelerating structures

- Adds commissioning time and adds significant **complexity** to two-beam acceleration analysis (power and energy budgets)



(I. Syratchev, CERN)

Some conclusions: TBTS + 1 module

- Installing 1 CLIC module **allows for testing of all aspects of the module** (not discussed in this presentation)

- Detailed understanding of the two-beam acceleration aspects for a full CLIC module (power and energy budget) is fundamental

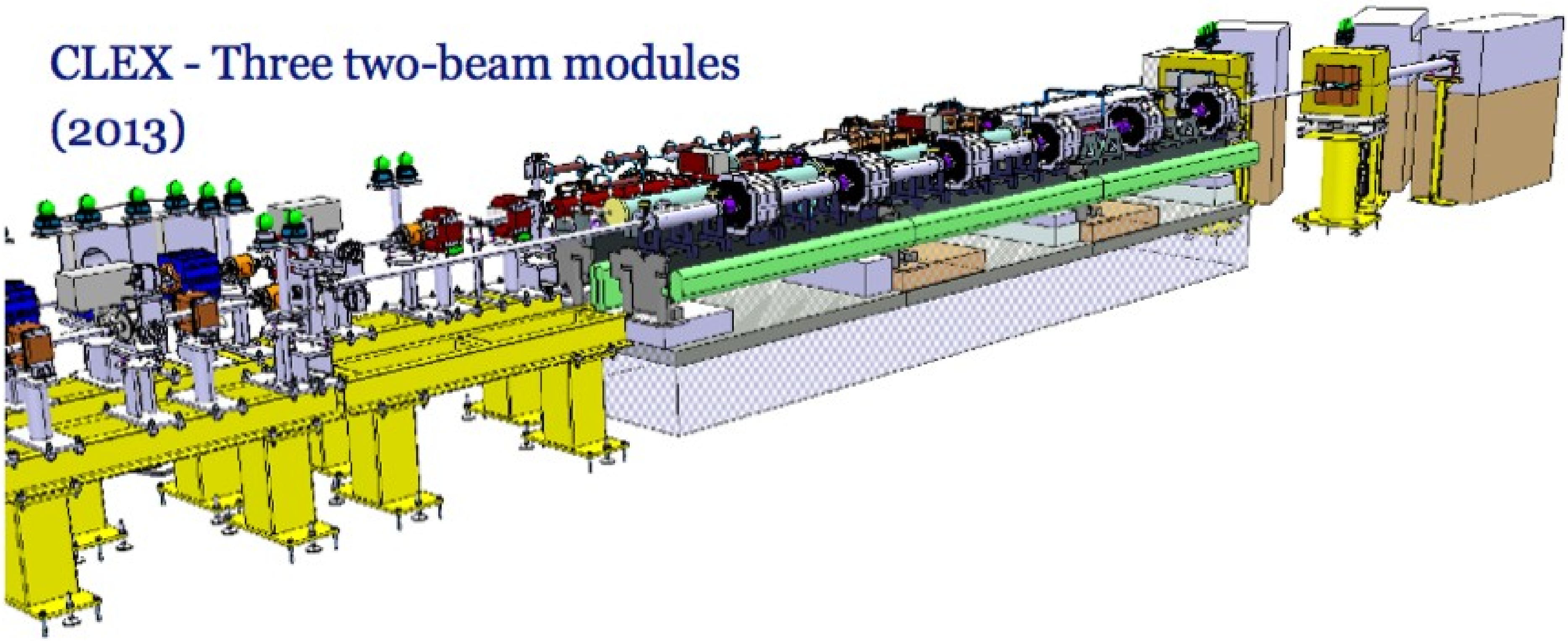
- Kick measurements and fundamental break down studies may be difficult when adding module (may **miss opportunity of doing fundamental physics**)

- Personal opinion: spend enough time **to finish major TBTS studies** in the current TBTS configuration, before installing the module. Many parts of the program requires :
  - Improved calibration of RF signals
  - improved optics knowledge (completion of optics commissioning)
  - better drive beam stability

- To consider: keep TBTS ACC structure if performance is good (not in baseline) -> work out layout and optics solution for this

3 modules

- Second upgrade of CTF3 two-beam acceleration tests: **adding two more CLIC-type modules**

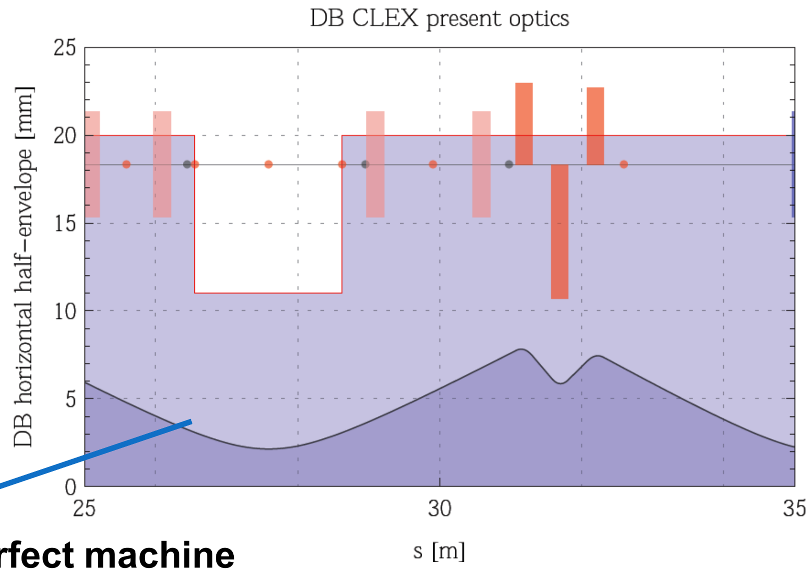


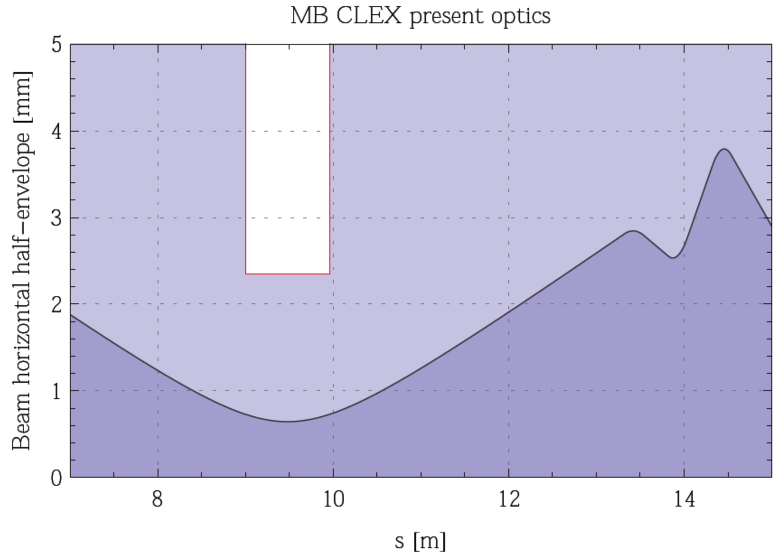
- Clear goal: realistic beam tests of different modules (type 0 and type 1) + interconnections.
- Optics: aperture limitations now start to become more challenging
- Power: drive beam limitations, (25/100)^2 ~ 1/16 is still a challenge

3 modules: optics

With three-module optics: DB acceptance as good as present optics (~6σ) while **MB acceptance degrades** from ~10σ to ~4σ (optics does not take into account PETS and ACC focusing).

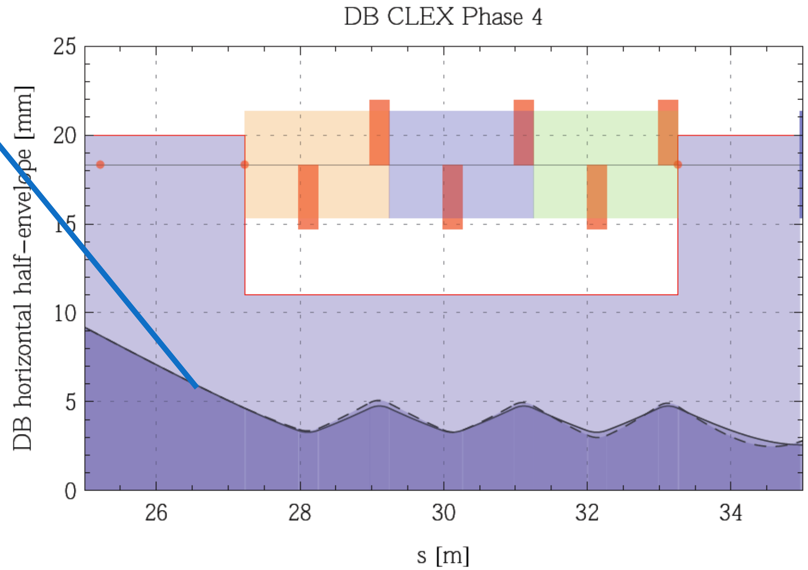
Present optics :
(DB 6σ and MB 10σ)

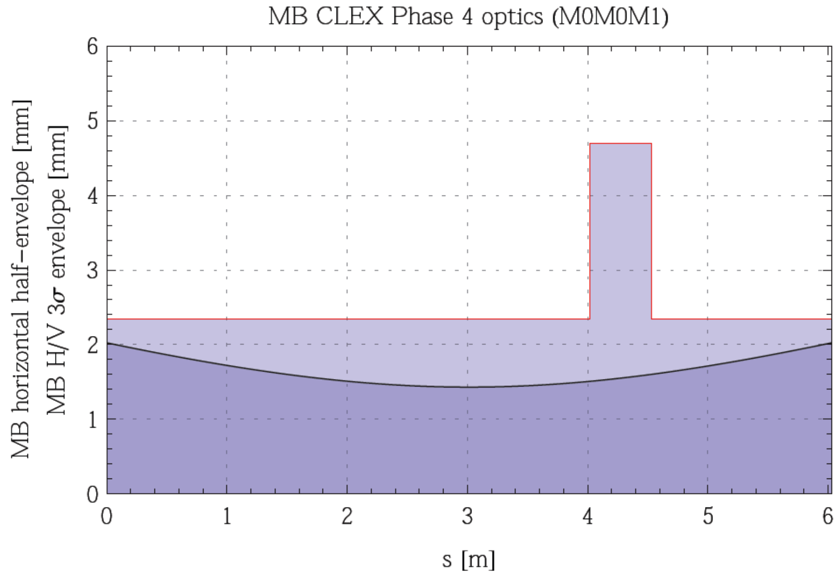




3 σ envelope, perfect machine

3 modules optics :
(DB 6σ and MB 4σ)



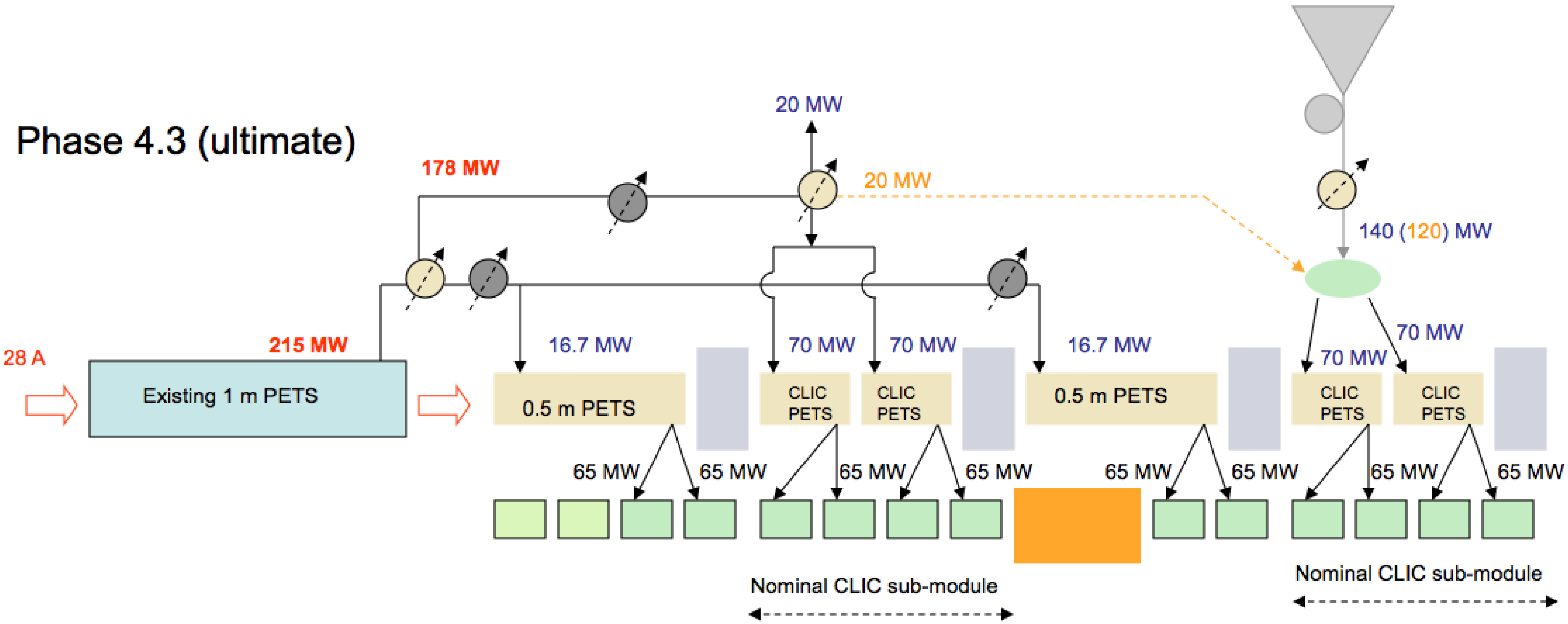


(this graph assuming all ACC installed)

(G. Sterbini, CERN)

3 modules: power

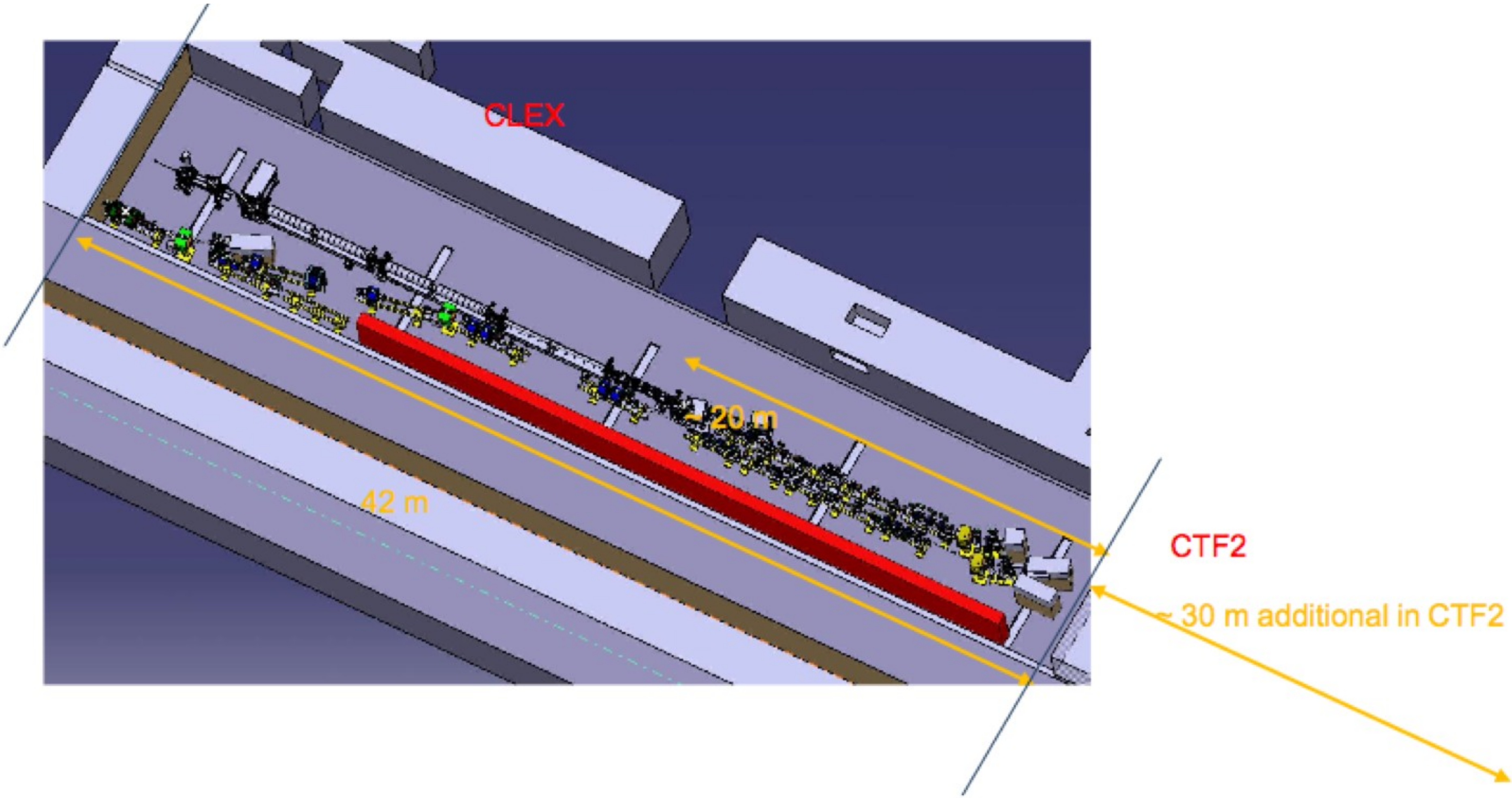
- Nominal CLIC power in PETS and filling of a large fraction of the structures can only be fulfilled with **complex feed-forward solutions and additional X-band klystron** (eventually, only Klystrons, at added cost).
- What is required to test fully the CLIC-type modules?
  - Do we need to feed a large fraction of structures?
  - Do we need to produce nominal CLIC power in PETS?



(I. Syratchev, CERN)

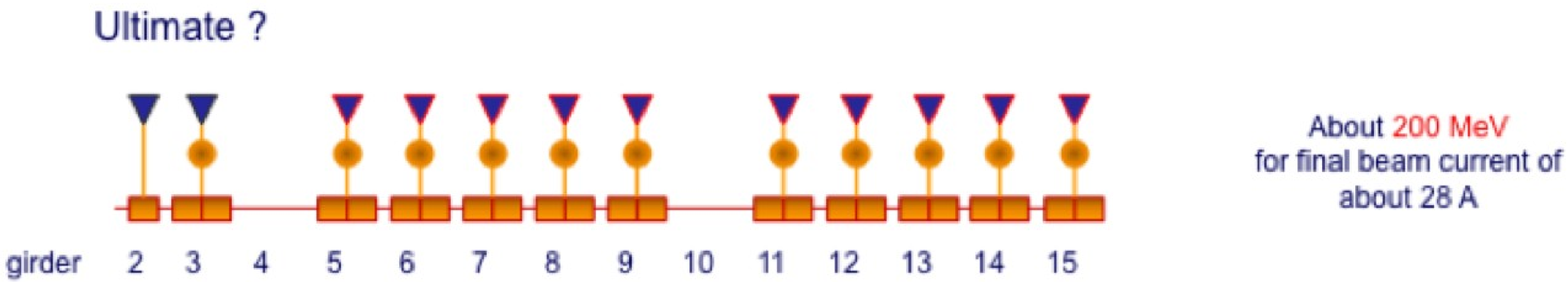
N modules

- There is room to install up to 20-25 modules in total, in existing building masses.
- How many is "optimal" ?



N modules: deceleration limits

- For N modules, **deceleration** starts to become an **limiting factor**.
- Depends on initial energy and number of ACC powered. Consider TBL the limit (studied in detail); $\mathbf{E_0}$ **= 150 MeV** (design CTF3) 16 PETS, equivalent **to 32 ACCs**, yields final energy of ~60 MeV.
- Possibilities to increase CTF3 E_0 :



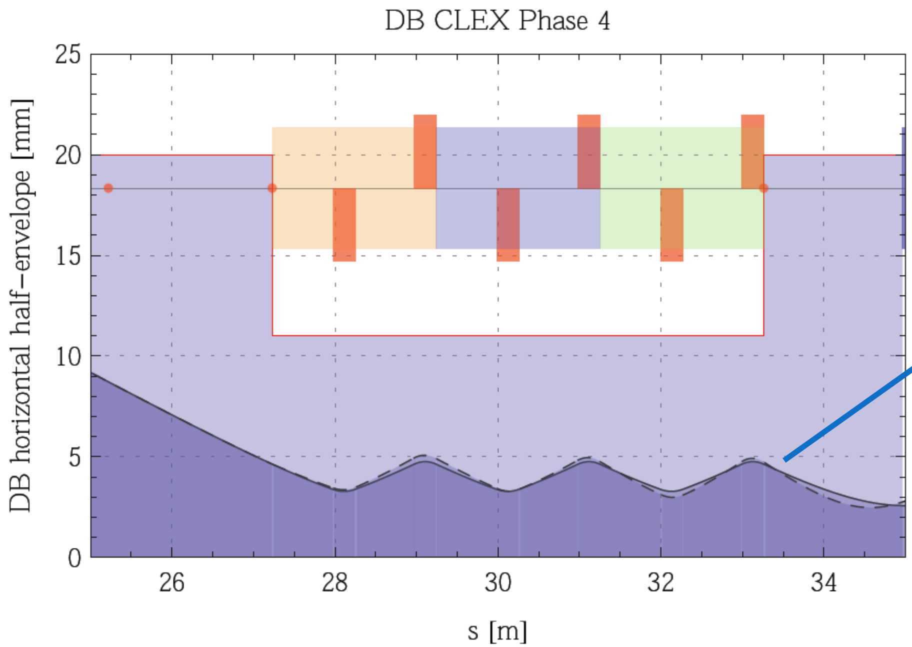
Two more klystrons (assuming none burns) and two more structures; E_0 ~200 MeV

(R. Corsini)

- $\mathbf{E_0}$ **= 200 MeV** allows for max. **~50 ACCs** to reach final energy of ~60 MeV.

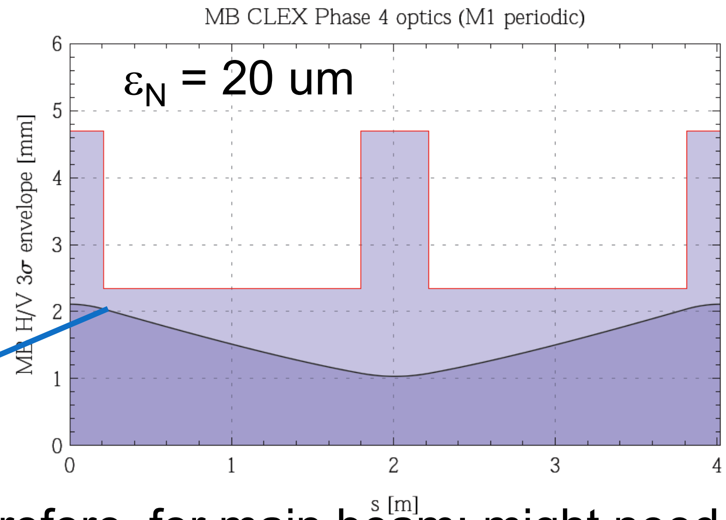
N modules: optics

Drive beam: suggested optics for 3 modules were already periodic solution, with ~6 σ acceptance **(ok)**. In addition comes effect of adiabatic undamping, 50 MeV final energy gives ~4 σ (ideal machine) – tight :

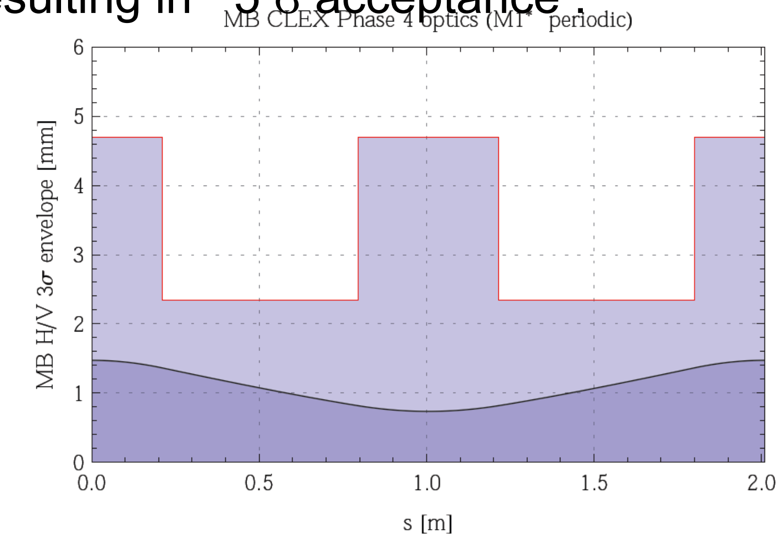


3 σ envelope, perfect machine

Main beam: periodic solution with module type 1 (quad + 6 acc), only ~3 σ acceptance! (**tight**). Adiabatic damping not included :



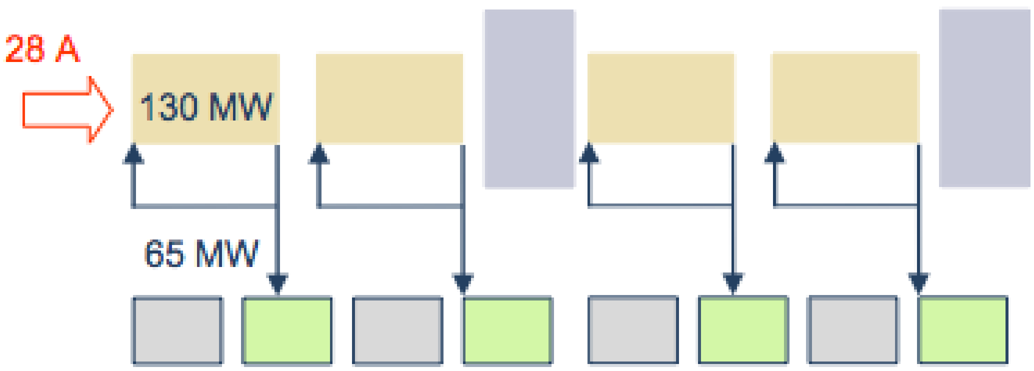
Therefore, for main beam: might need to consider **extra quadrupoles** every meter. Resulting in ~5 σ acceptance :



(G. Sterbini, CERN)

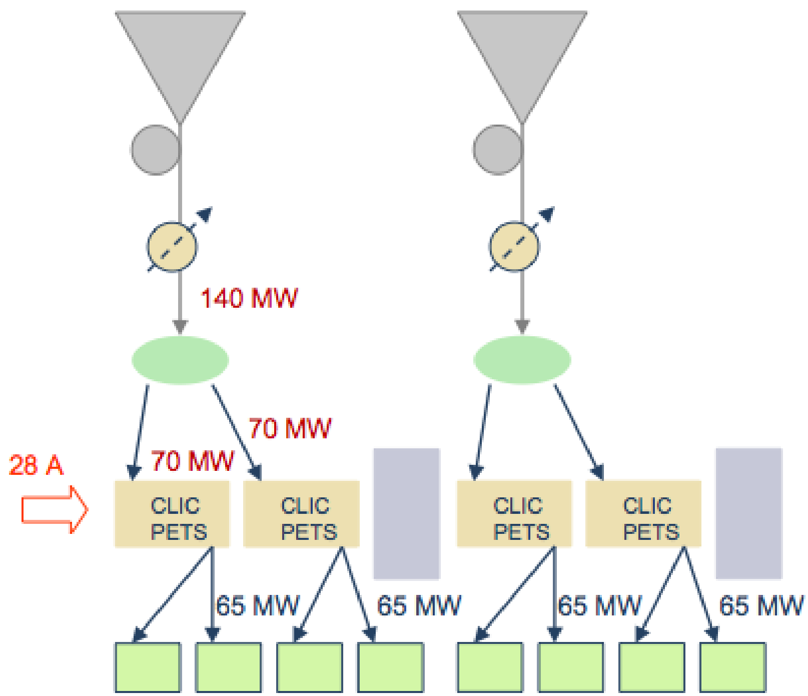
N modules: power

- N modules: should to be as **CLIC-like as possible** (?) (reuse) -> PETS length should be CLIC nominal (up to 4 PETS of 0.21 m per module).
- With ~28 A drive beam, without ”tricks”, we get only ~1/16 of CLIC PETS power. Need recirculation, forwarding or klystron priming of rf power (but this is not CLIC-like neither ?) .



Recirculation: can fill every second ACC, however only 140 ns pulse length, and hardly any flat rf power top. Is it important to have a long flat top?

Feed complete modules by using priming



Priming: can fill all ACCs, main beam can reach ~ 2.5 GeV, but expensive.

(I. Syratchev, R. Corsini)

Summary

- **TBTS**: currently achieved good results, but many important experiments still in progress; some of these (in particular break down studies) **require substantial improvement in commissioning** of both incoming drive beam, dispersion control and beam line optic
- Installation of **1 CLIC module** with feed-forward rf power to module **may complicate analysis** for the above -> argument to finish major part of TBTS experiments before installing the module
  - How long can/should we wait?
- **3 modules**: optics acceptance for probe beam will be tighter than the present set-up. Nominal power production requires f.f., recirculation and/or priming
- **N modules**
  - Limit in deceleration due to initial energy. **Do we need to show deceleration**? I.e. push towards max. acceptable deceleration? **We already have TBL for this purpose.**
  - Limit in acceleration due to low power production due to CTF3 nominal drive beam current. **How much acceleration do we need to show**? Is it worth investing in e.g. up to 10 X-band klystrons for priming, to achieve an acceleration of ~2.5 GeV?
- General challenge: how **to combine fast schedule with need to do detailed studies** (e.g. precision measurements of relevant beam and rf parameters) and basic research (e.g. break down studies) **?**