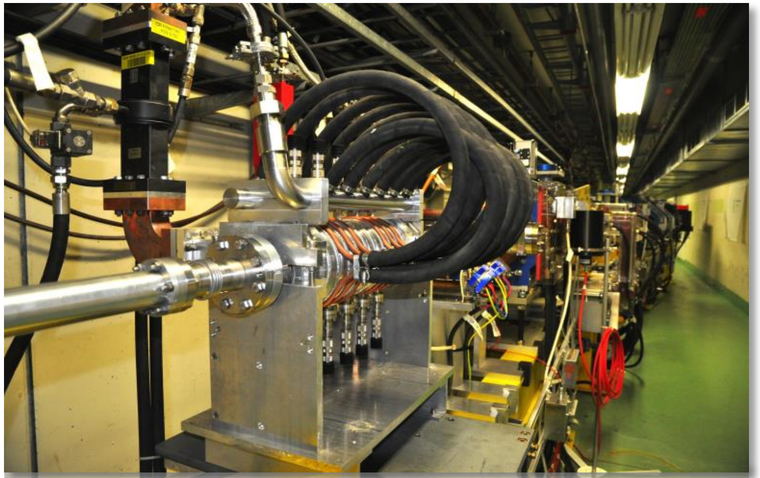
The future of CTF3

R. Corsini



CLIC Test Facility (CTF3)

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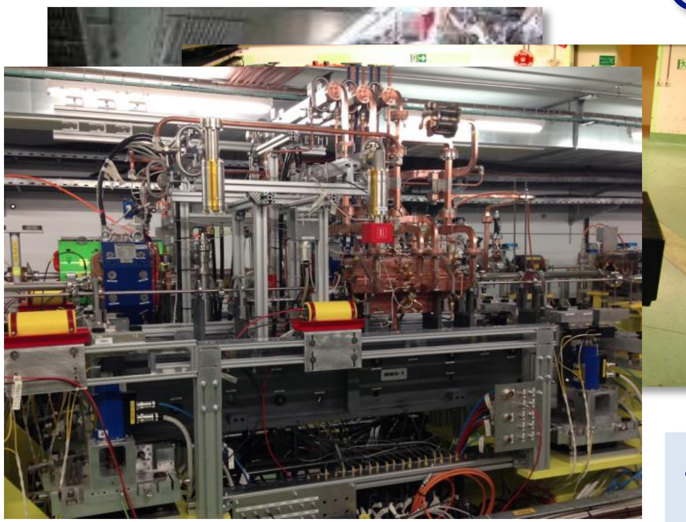
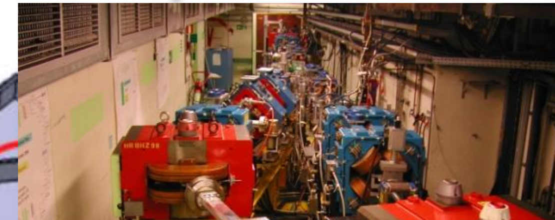
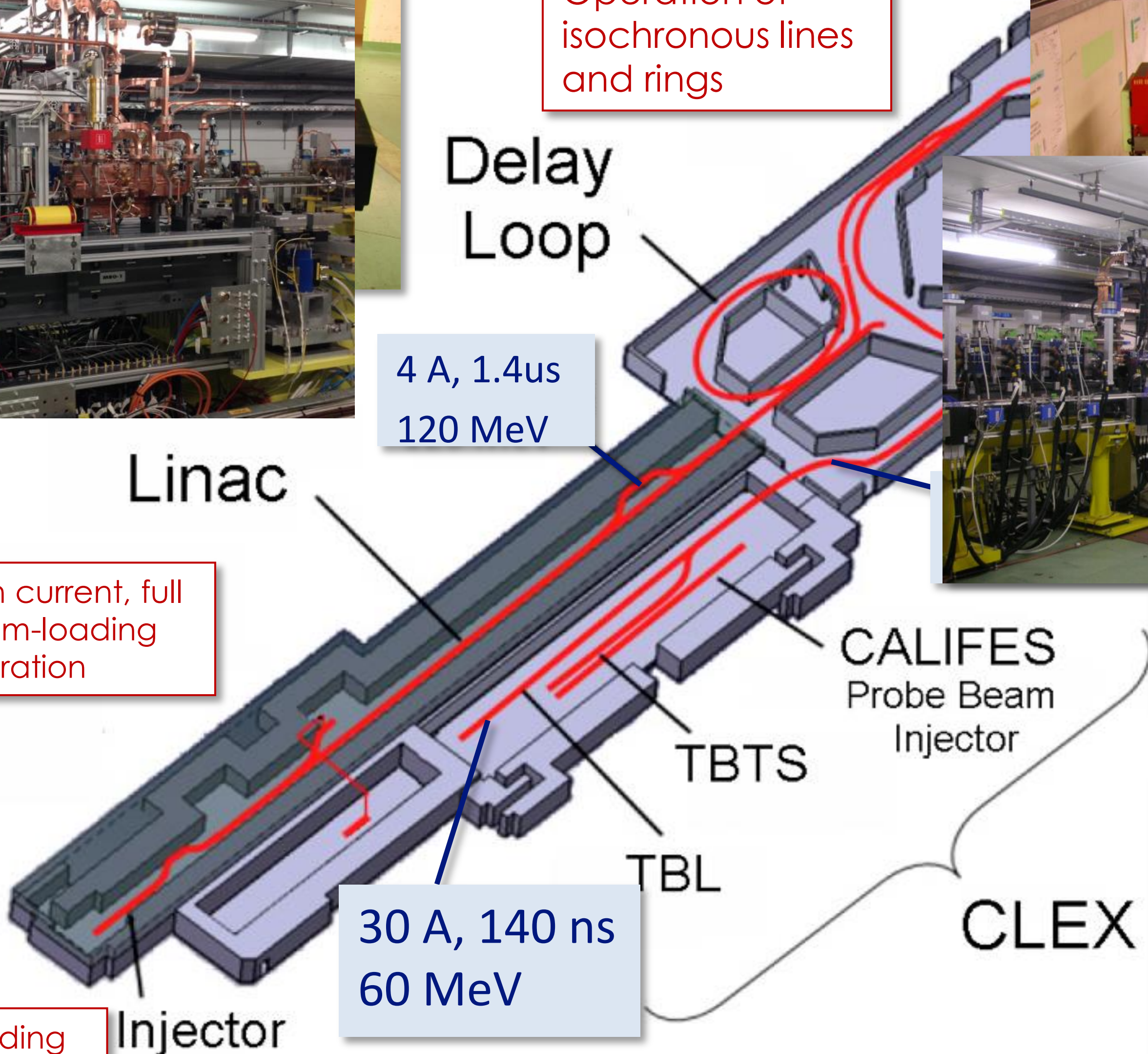






Operation of isochronous lines and rings

High current, full beam-loading operation

Bunch phase coding

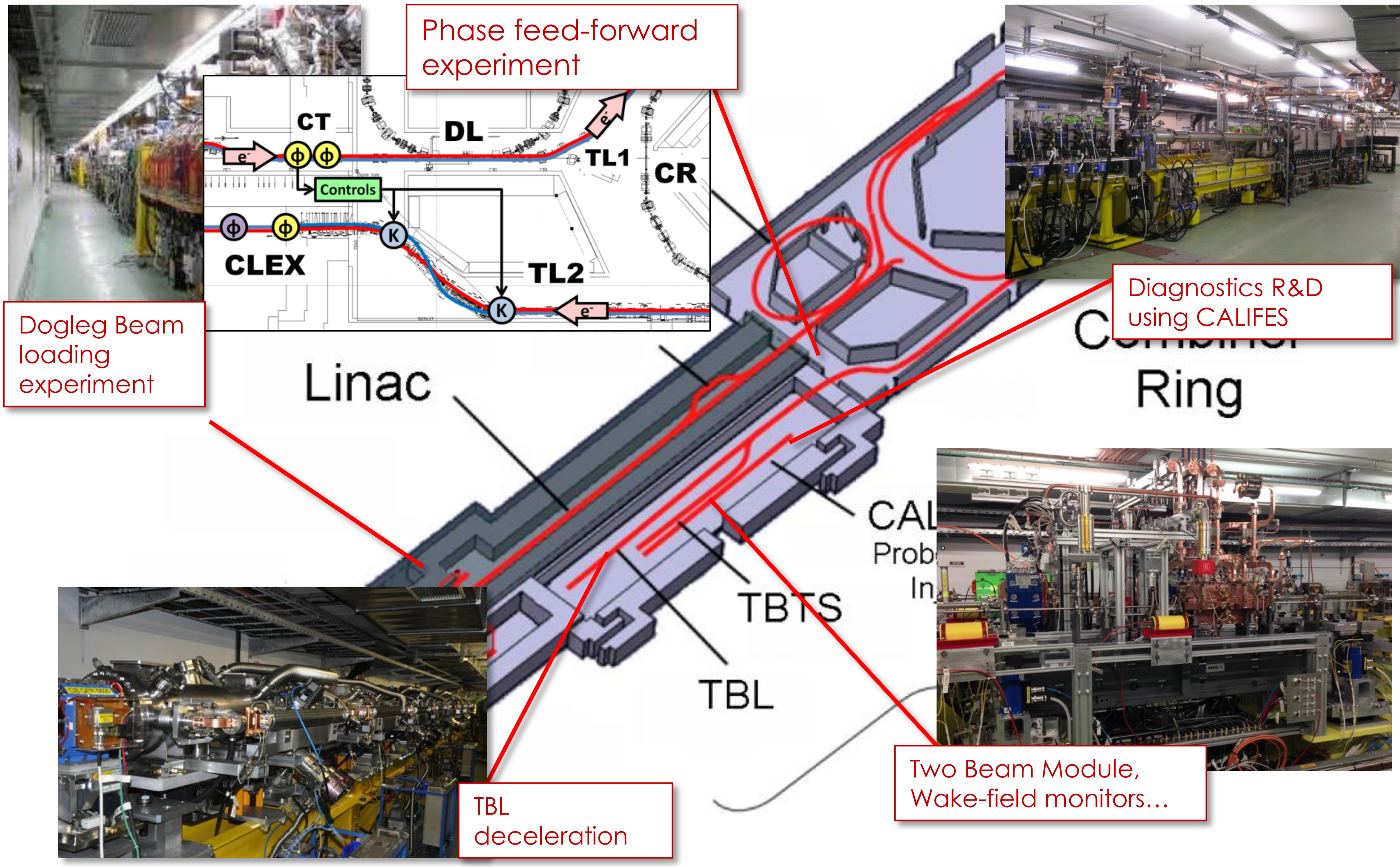
Beam recombination & current multiplication by RF deflectors

12 GHz power generation by drive beam deceleration

High-gradient two-beam acceleration

PETS ON/OFF

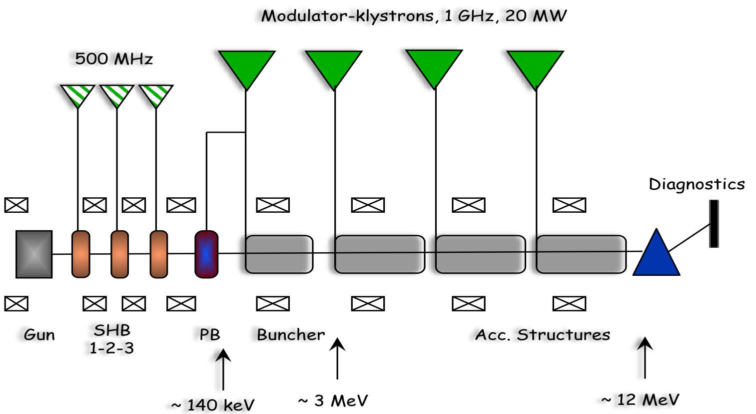
The next two years…



CLIC system tests beyond CTF3

S. Stapnes

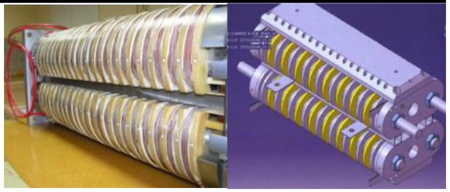
- Drive beam R&D beyond CTF3
  - RF unit prototype with industry using CLIC frequency and parameters
  - Drive beam front-end (injector), to allow development into larger drive beam facility beyond 2018



- Damping rings
  - Tests at existing damping rings, critical component development (e.g. wigglers) … large common interests with light source laboratories

- Super-conducting wigglers
  - Demanding magnet technology combined with cryogenics and high heat load from synchrotron radiation (absorption)
- High frequency RF system
  - 1 GHz RF system respecting power and transient beam
- Coatings, chamber design and ultra-low vacuum
  - Electron cloud mitigation, low-impedance, fast-ion instability
- Kicker technology
  - Extracted beam stability
- Diagnostics for low emittance

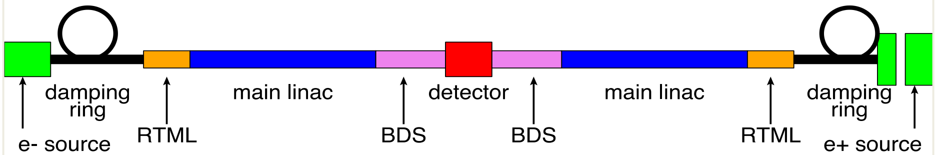
Parameters	BINP	CERN/Karlsruhe
B_{peak} [T]	2.5	2.8
λ_W [mm]	50	40
Beam aperture full gap [mm]	13	13
Conductor type	NbTi	$NbSn_3$
Operating temperature [K]	4.2	4.2



Experimental program set-up for measurements in storage rings and test facilities:

ALBA (Spain), ANKA (Germany), ATF (Japan), CESRTA (USA), ALS (Australia)…

- Main beam
  - Beam based alignment tests at FACET, FERMI, …



- Beam Delivery System
  - ATF/ATF2

Context

- CTF3 went well beyond its initial task of demonstrating CLIC two-beam scheme feasibility
- Has a well established scientific program until end 2016

- Definitely want to stop CTF3 after that (limited resources…)

  → *What to do with CTF3 hardware & building?*

- Discussions started beginning 2014. Current main proposals:

→ Install new DB front-end in CTF3 linac area (CLIC related).

→ Keep using *CALIFES* linac in CLEX for as a general test facility after 2016. Possibly interesting beyond CLIC scope (in CERN and outside).

→ Last discussions at LCWS 2014 – Belgrade & CLIC Project Meeting:
https://agenda.linearcollider.org/event/6389/session/18/#20141009
http://indico.cern.ch/event/356495/

Rationale for uses of CTF3 hardware beyond 2016

- CLIC Collaboration interest: keep beam test capability for CLIC (diagnostics, components…) locally at CERN after CTF3 stop

- Some additional points:

    - Possibility of beam tests during long shut-downs
    - Keep experimental electron expertise alive at CERN, including laser and photo-cathodes – link with AWAKE
    - Complement high-gradient X-band activities for X-FELs, medical…
    - Provide training ground for young accelerator physicists at CERN and collaborating institutes

→ Find synergies with other potential partners (project/groups within and outside CERN) in order to gather enough resources and get approval from CERN management

Tuesday session on Future tests beyond CTF3: Scope and aim

- Concentrate mainly on CALIFES based proposals
- Review proposals and identify needs (basic and advanced), both in terms of beam parameters and for operation/hardware/infrastructure
- Try to define a list of beam parameters and of space/hardware requirements capable to satisfy most of the users
- Discuss and if possible decide on next steps needed to arrive at a proposal

Talk	Speaker	Location	Time
Motivations	*Steinar STAPNES*	*Council Chamber, CERN*	14:00 - 14:10
Overview of options/hardware	*Roberto CORSINI*	*Council Chamber, CERN*	14:10 - 14:30
Diagnostic tests	*Thibaut LEFEVRE*	*Council Chamber, CERN*	14:30 - 14:50
Impedance measurements	*Benoit SALVANT*	*Council Chamber, CERN*	14:50 - 15:10
Use of Electro-Optics Sampling for Impedance measurements	*steven JAMISON*		
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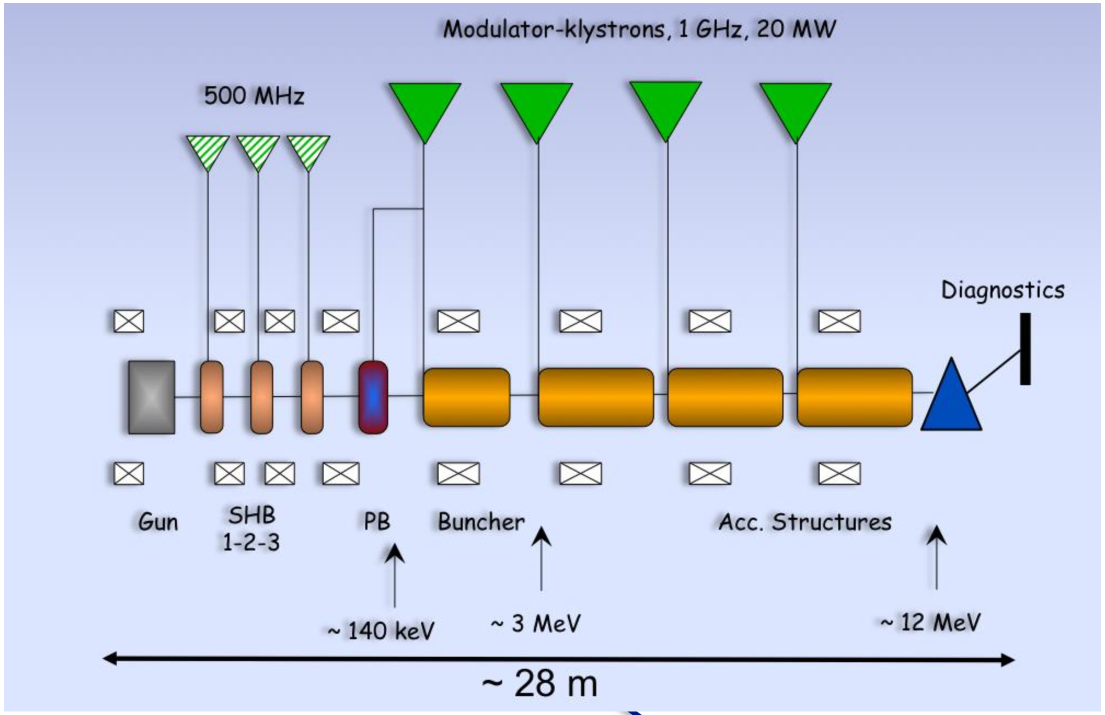
Drive Beam Front-End

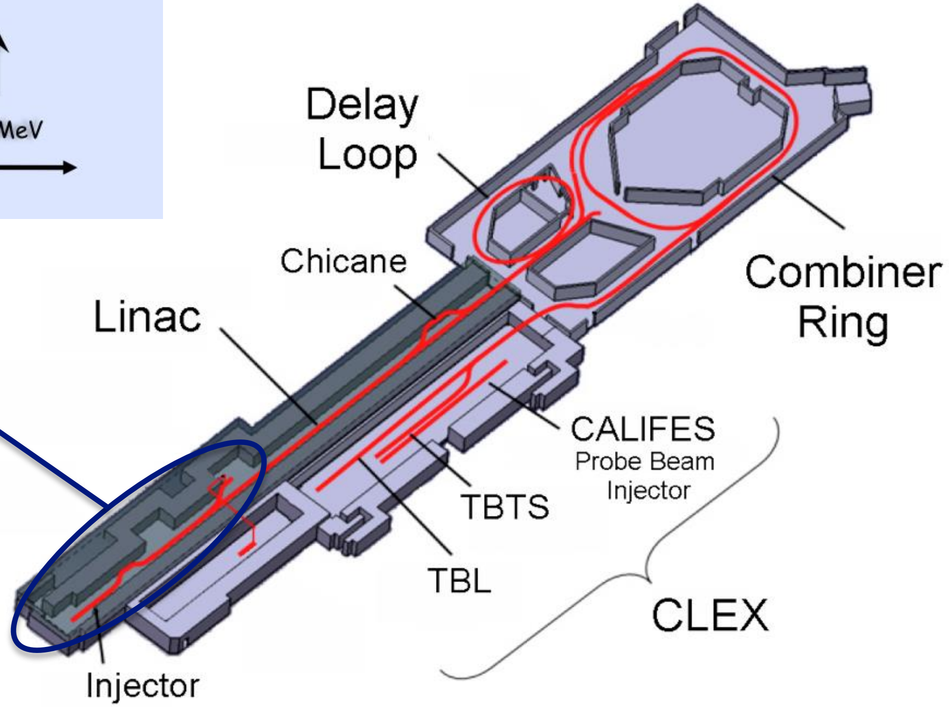


The drive beam front-end in the CTF3 building – F. Tecker, LCWS2014 http://agenda.linearcollider.org/event/6389/session/18/contribution/114/material/slides/0.pptx

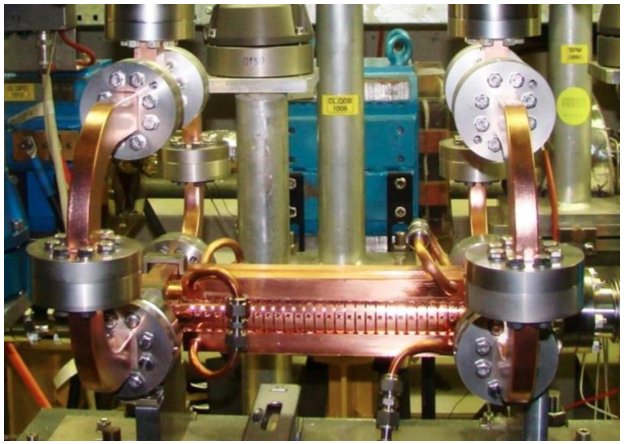
- Same peak current than present CTF3 injector (4 A)
- Longer pulse (140 us instead of 1.4 us)
- Higher rep rate possible (up to 50 Hz)

Option: keep operational also (part of) the present 3 GHz linac.

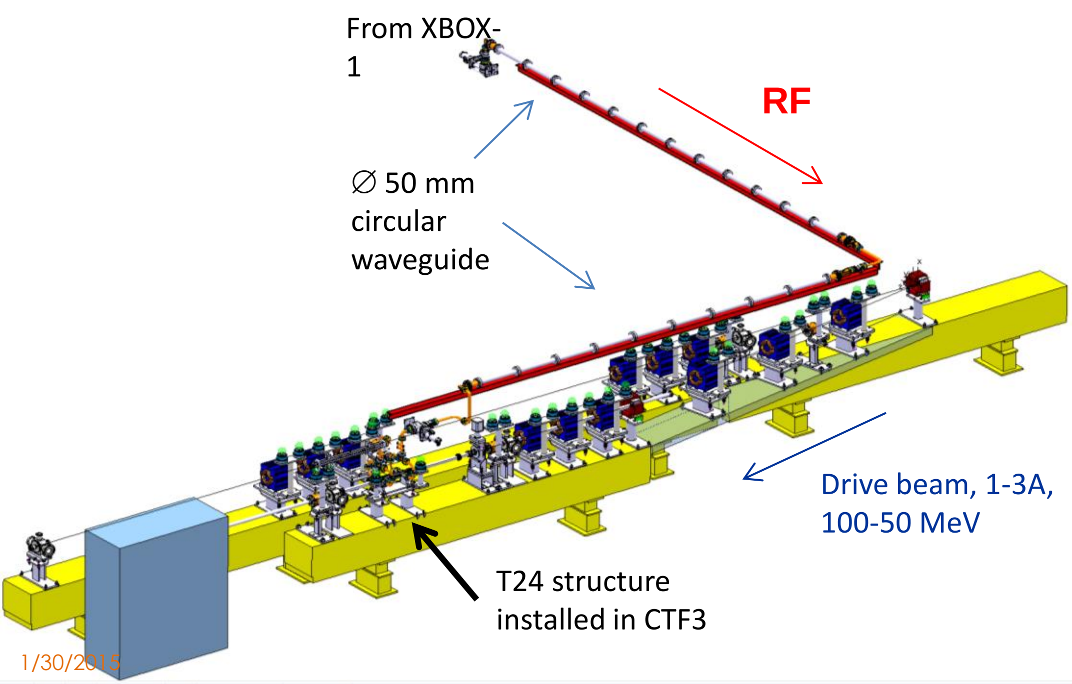
Will enable beam energies up to ~ 100 MeV with limited pulse length(~ 4 us max).

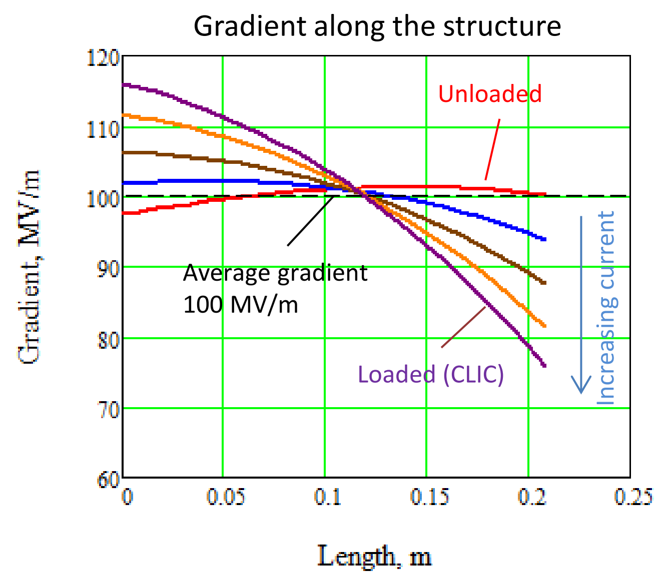


Beam Loading experiment - run beyond 2016?



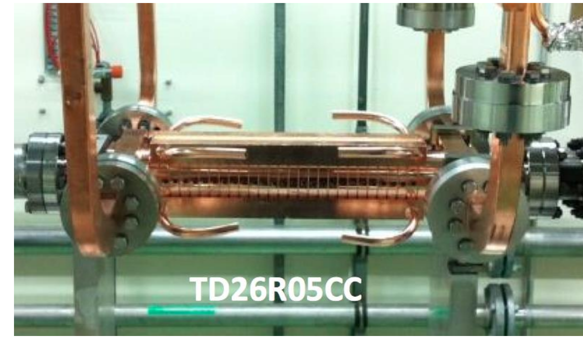
- Before 2016 ~ 3 test slots (one per year) – <u>not a large statistics</u>
- In this time scale could have a new CLIC structure prototype from re-baselining, may want to test it
- Want to explore structures with different (tapered-up) gradient profile
- Other potential users?
- Need relative small part of infrastructure – 5 MKS, first 50 m of linac / Compatibility with Front-end?

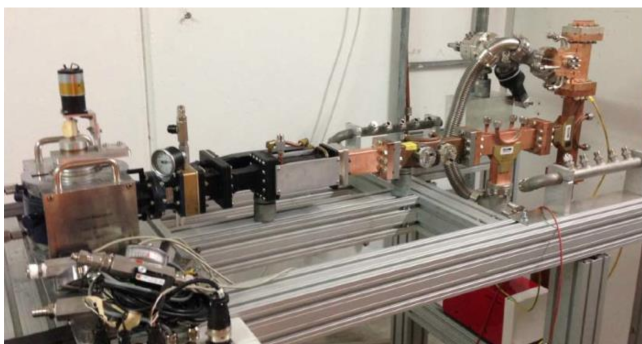


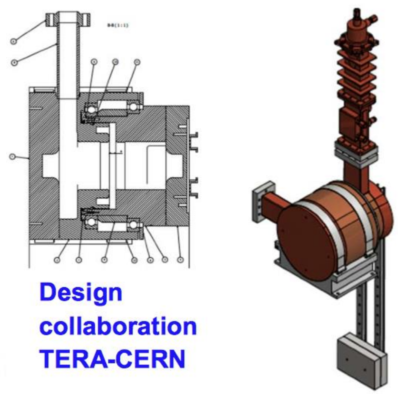


Former CTF2 area, X-band and S-band RF testing

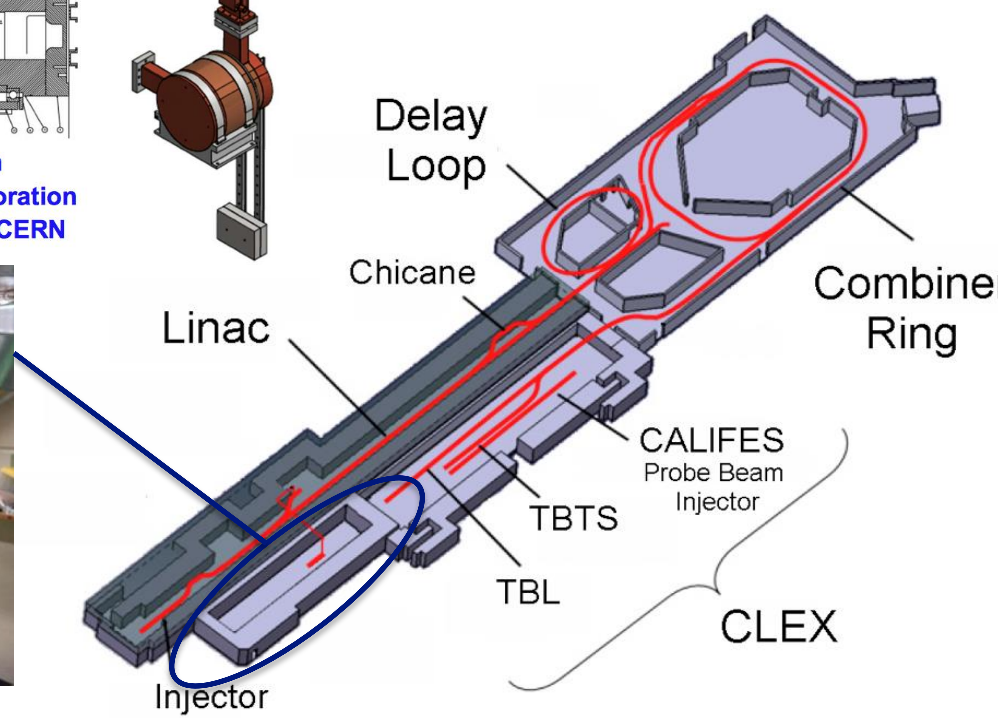
- X-band test area, connected to XBOX1
- Used also for 3 GHz structure and component testing (TERA, ADAM…)
- XBOX1 will stay, keep using the area also for 3 GHz
- Compatible with other options



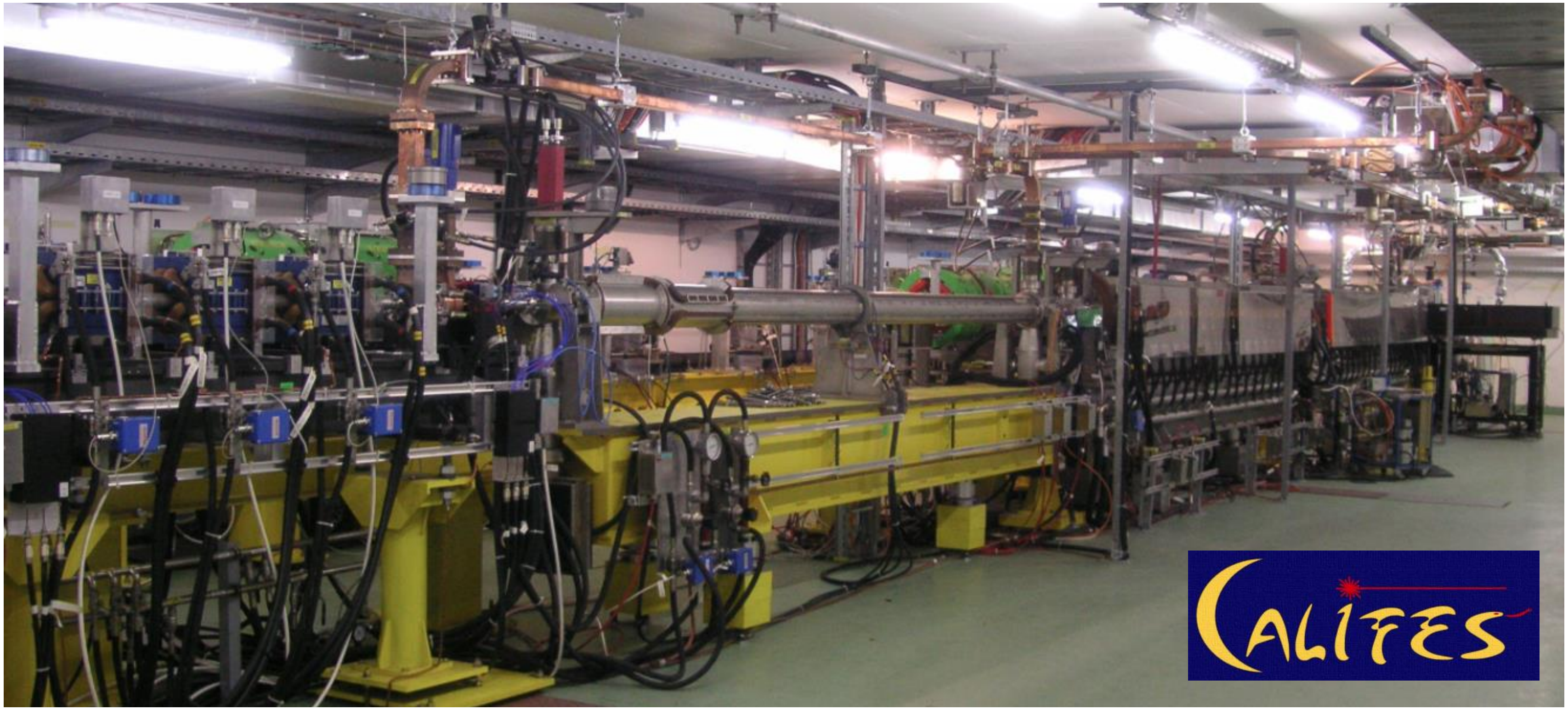


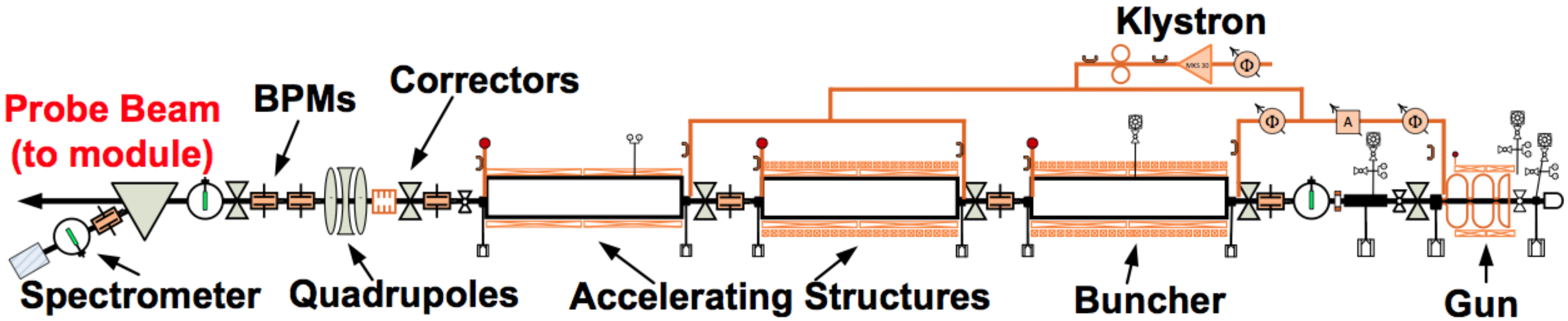


Design collaboration TERA-CERN



CALIFES


CALIFES


Klystron
Probe Beam
(to module)
BPMs
Correctors
Spectrometer
Quadrupoles
Accelerating Structures
Buncher
Gun

CALIFES Beam parameters

- 0.01-1.5 nC bunches, 1.5 (3) GHz spacing (0.667 ns/0.333 ns)
- From single bunch to 200 ns train
- Rep rate 1-10 Hz
- Energy 150 - 200 MeV
- Normalized emittance 4 μm
- Energy spread ± 0.5 %
- Bunch length 1-2 ps and above
- May provide lower energy (>10 MeV), need to study transport
- Typical beam sizes 0.25 × 0.25 mm, uniform beam sizes obtained up to now 5 mm × 5 mm, up to few cm surely feasible.

Potential interests for CALIFES based test facility

- Diagnostics R&D with beam tests (for CLIC, LHC & injectors, AWAKE…)
- X-band structure testing with beam (X-FEL, medical applications, wake-field monitors, deflecting cavities…)
- Impedance and wake-field measurements of components (LHC, CERN Injectors, HL-LHC, CLIC… for Cavities, diagnostics equipment, collimators, kickers…)
- Irradiation tests (ESA/JUICE Mission, CERN and others…)

- Plasma wake-field acceleration

- Beam tests of hardware (kickers, SC RF cavities)
- Other medical applications (X-ray imaging, therapy with e-, isotopes production…)
- Test beam for detectors
- Vacuum related tests
- …

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CALIFES for diagnostics R&D - Why

T. Lefevre

- Machine operation schedule @ CERN
  - Long periods without the capability of performing beam tests
  - Limited beam time available for Machine Developments combined with a high number of requests
- Hardware installation periods are limited
  - Any further improvements/modifications can not be implemented quickly
    - Testing at Independent Facility will faster the developments and ensure that we installed well-understood devices on operation machine
- Developing new concept versus Reliable operation
  - Operational machine have strict requirements in terms of vacuum-outgassing performance/ bakeability not always compatible with R&D needs
    - e.g. Testing gas ionization monitor and their performance as function of gas pressure

What for

T. Lefevre

- CERN accelerators
  - LHC, HL-LHC, LIU (SPS, PS, PSB) projects
  - CLIC/ILC, AWAKE, FCC studies

- Future Challenges in Beam Instrumentation
  - Unprecedented request for precision
    - Positioning down to below the micron level
  - Treatment of increasingly more data
    - Bunch by bunch measurements for all parameters:: Test of state of the art acquisition system (electric or optical domain)
  - Dealing with high beam powers
    - Non-invasive measurement techniques (Gas profile monitor, Quadrupolar PU, ..)
    - Robust and reliable machine protection and beam loss monitoring systems
  - Dealing with the (ultra) fast
    - Sub-picosecond bunch lengths in AWAKE and CLIC
    - Longitudinal tomography in LHC (picosecond range)
    - Fast transverse beam position monitors (HL-LHC Crab cavities and transverse beam Instability diagnostics)

What for

T. Lefevre

- A Test facility can not address all specific issues. But ….
- System performance under realistic conditions that are not easily achievable in laboratory
  - Test with realistic signals state of the art electronic
    - i.e. Response to short pulses with high signal amplitude
  - Test of UV, optical, X-ray monitors where no other source can reproduce beam induced radiation
    - Imaging technique and Beam halo monitoring
    - Use of electro-optical crystal
  - Validation of particle detector design (e.g. Beam loss monitor/ Luminosity monitor)
    - Sensitivity checks, linearity (or non-linearity) checks, ..
- Study the behavior of devices with respect to beam position / bunch length / bunch intensity variations

How

T. Lefevre

- Electron linac is the cheapest way to provide relativistic beams
  - Beam energy higher than 200MeV (3.5GeV max) – similar γ as on SPS (LHC)

- Photo-injector provides a modular bunch spacing
  - Single bunch capability
  - Bunch spacing similar to CERN beams (1ns, 5ns, 25ns, 50ns, ..)
  - Pump – probe experiment (wake-field study, impedance measurement, ..)

- Simplicity, Reliability and Flexibility

- Wish list for Beam parameters
  - Good emittance to reach small beam size (<50um)
  - Short and long bunches (100fs up to 200ps)
  - Large range of bunch intensity
  - Possibility to study time to position correlation (Crabbing)

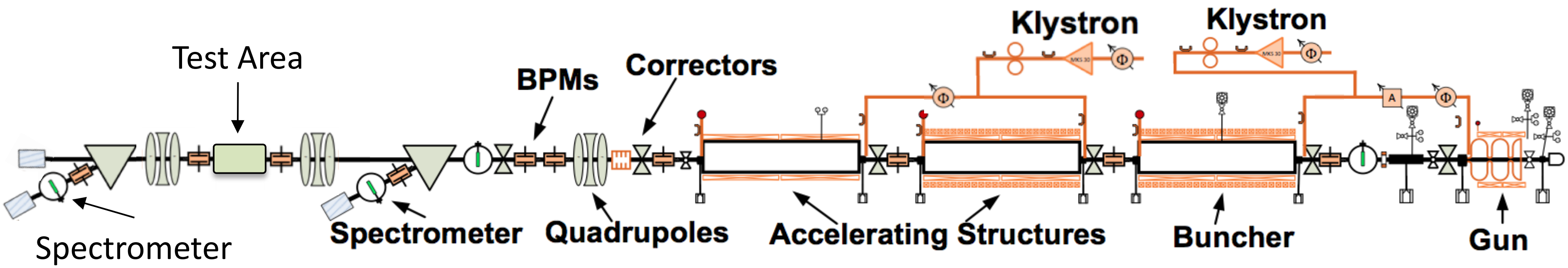
→ Slightly modified version of CALIFES

- Applications requiring high beam current would require Drive Beam Injector (Beam heating studies, ..)

Future CALIFES – minimum configuration

Present

Future: CALIFES for beam instrumentation test



- Add an available S-band klystron + modulator
- More RF power (beam energy), more flexibility (power in 1st structure, phase in structures 2 and 3), possibility of running without RF pulse compression

- Reconfigure present TBM area as test area

- Most (all) hardware already existing

Perspectives for a CALIFES test facility beyond 2016 – R. Corsini, LCWS2014

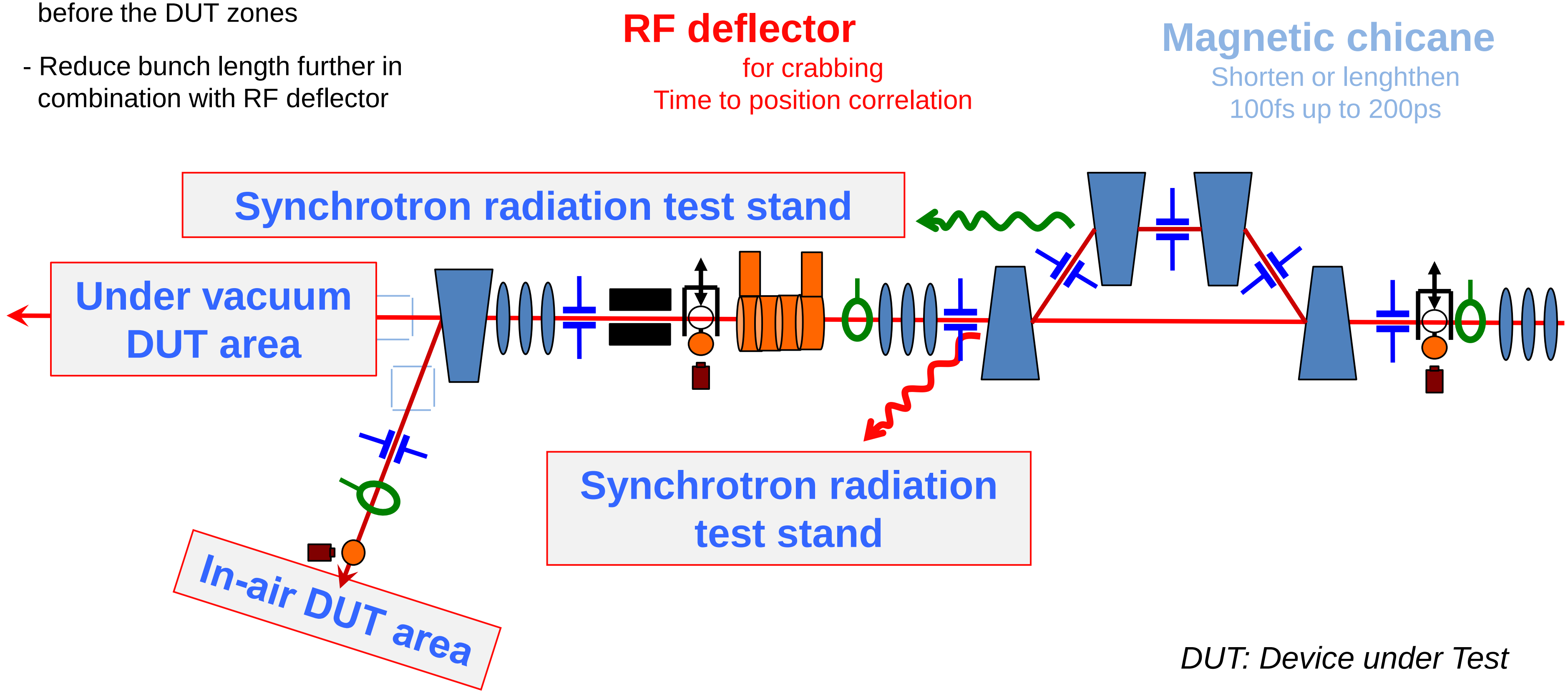
http://agenda.linearcollider.org/event/6389/session/18/contribution/115/material/slides/0.pptx

"Ultimate" test area layout to cover BI needs

T. Lefevre

Collimator

- Reduce the bunch intensity before the DUT zones
- Reduce bunch length further in combination with RF deflector



DUT: Device under Test

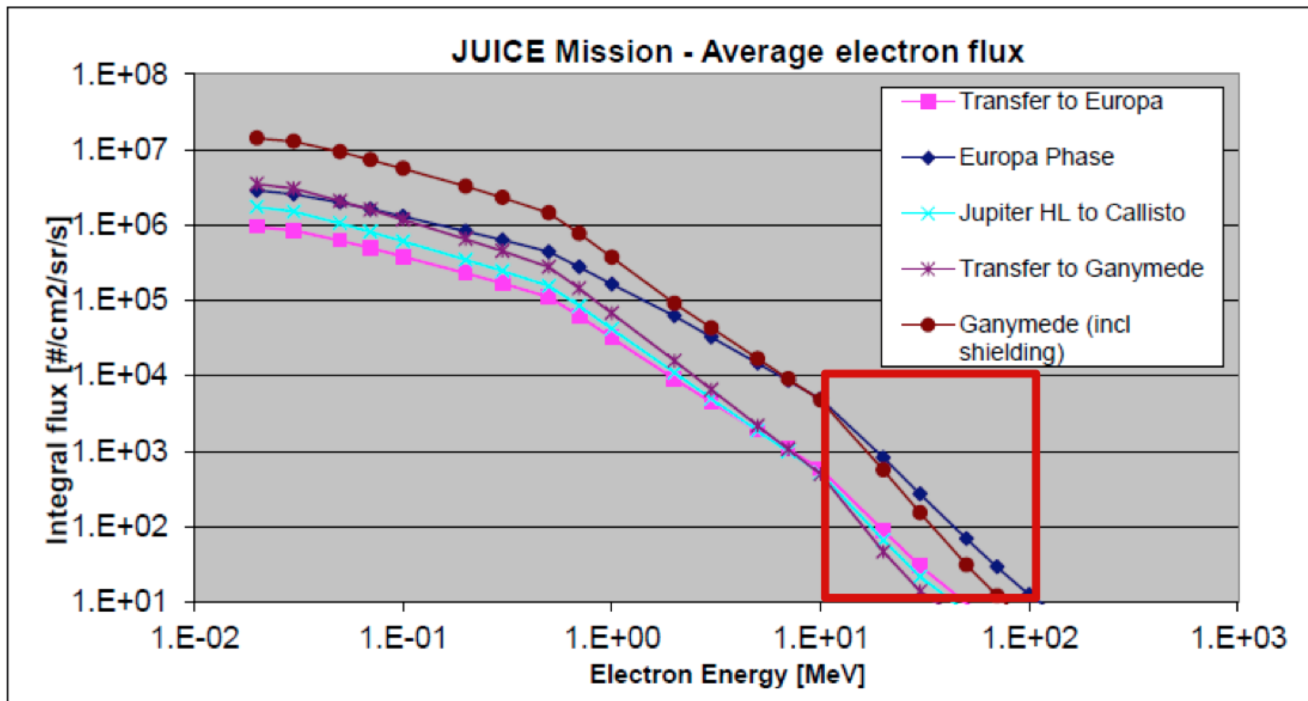
Irradiation testing with CALIFES

The JUICE Mission

M. Brugger,
R. Garcia Alia

- Characterise Ganymede, Europa and Callisto as planetary objects and potential habitats
- Explore the Jupiter system as an archetype for gas giants

Predicted average trapped electron flux per phase of the JUICE mission.



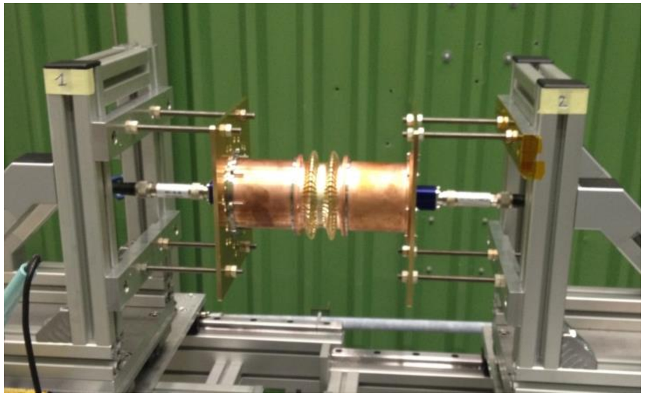
© ESA Mission TEC-EES Specification

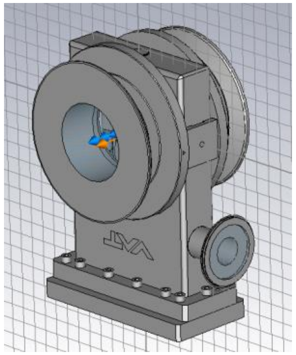
Impedance measurements - Context

B. Salvant - CERN

- Impedance team involved in design and approval of new and modified equipment in all CERN circular machines (in particular PSB, PS, SPS and LHC, but also AD, ELENA and CLIC damping rings).

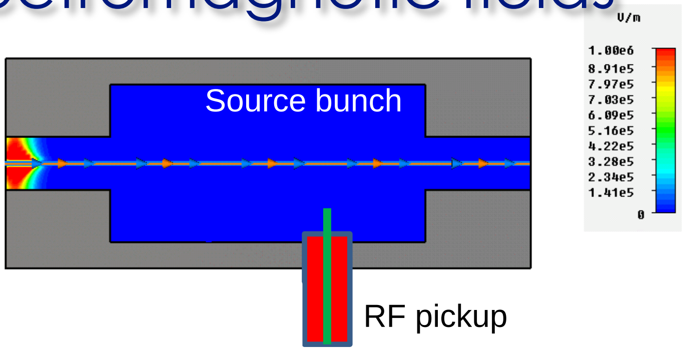
- Tools at our disposal:
  - Bench measurements with wires and probes
    → problem: not direct measurement of impedance or wake, and possibly strong perturbation of the EM fields
  - Numerical simulations
    → problem: difficulty to reproduce reality with a model (e.g. design errors, small features, coatings, matching errors) , simulated exciting bunch is not a delta function.





→ Measurement with electron bunches could be an interesting complement to these existing tools

Direct measurement of generated electromagnetic fields



- Possibility to measure EM fields from available antennas, buttons, striplines, wires, all mode couplers already in the device (or installed just for that reason).

  → See also proposal of electro optical pickup

- Indirect measurement in principle, but possibility of direct benchmark of CST Particle Studio simulations with fields monitors and check their validity

  → probe measurements only validate the Qs from eigenmode simulations

  → wire measurements can perturb significantly the modes.

  → real interest in using an electron source

- For the case of the wirescanners for instance, possibility to directly measure the signals that we need

  → current induced by the beam → beam induced heating

  → would be very important, and the only direct way of measuring the heat load to the wire (besides installing it in the SPS or the LHC).

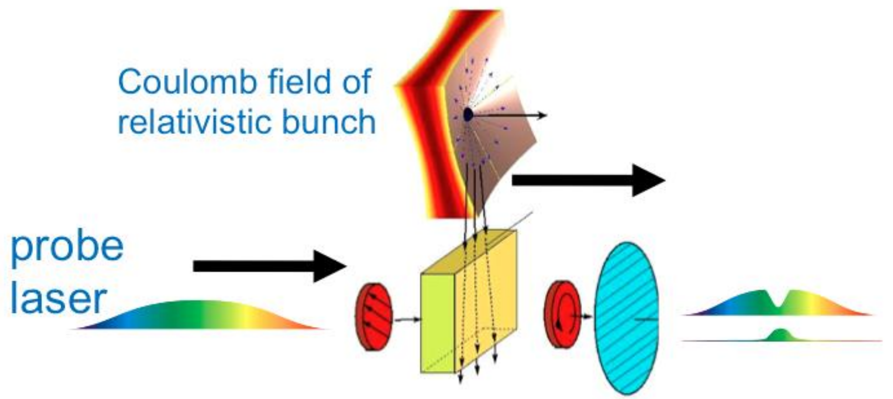
- For other devices, it would be an indirect measurement that could validate the model, meshing and simulation.

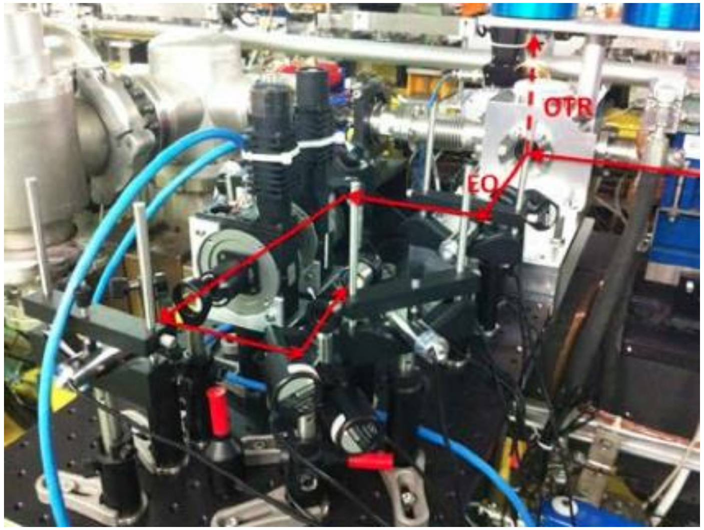
B. Salvant - CERN

→ Simple measurement, would not need any additional hardware
→ Requires pre installation of a probe in the device (if there is not already one).
→ Switch from ferrite damping to coupler damping is proposed to avoid beam induced heating

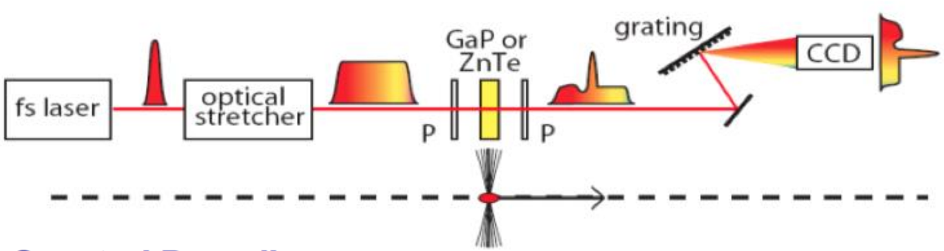
Electro-optic Diagnostics for Wake-field Characterisation

S. Jamison
ASTeC - Daresbury National Lab

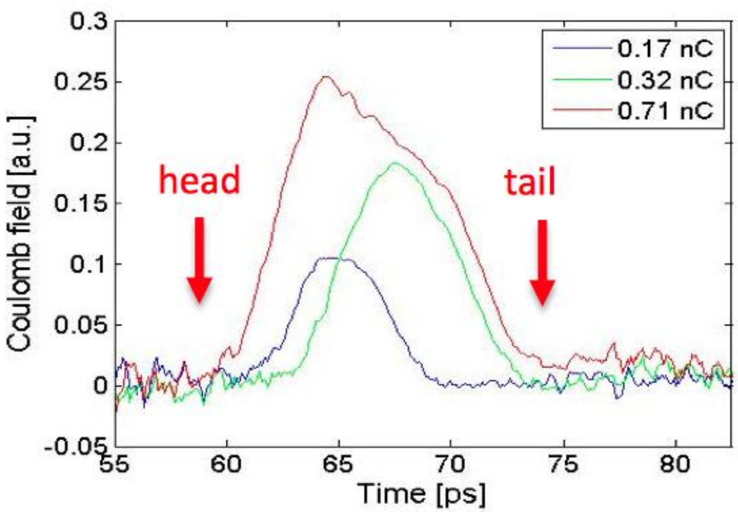




CALIFES EO Test



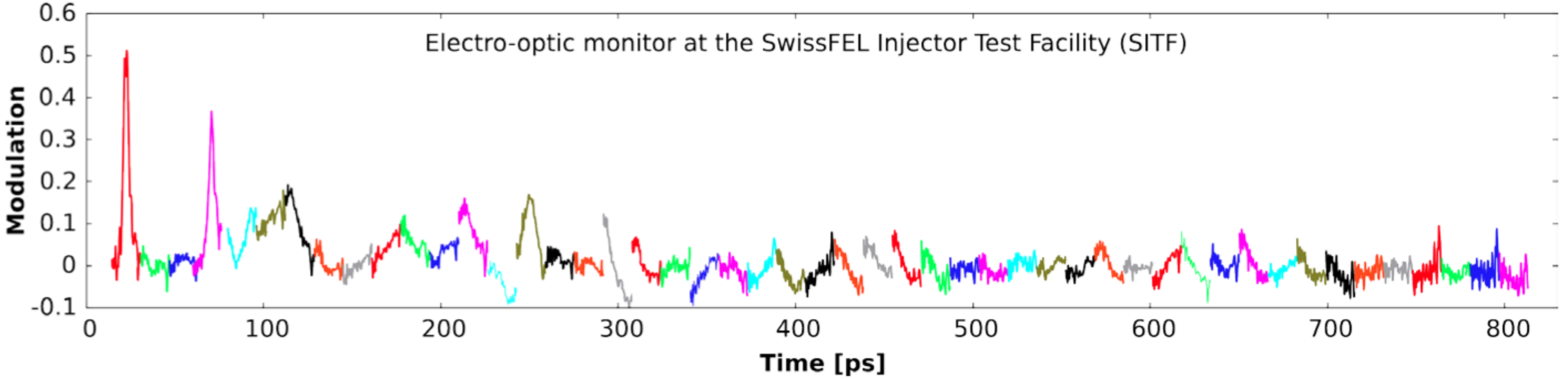
Spectral Decoding



- Chirped optical input
- Spectral readout
- Use time-wavelength relationship
- time resolution limited to > 1 ps

EO measurement of wake fields in Swiss Injector test facility

EO spectral decoding, stepped in time to give longer range wakes



Presented at PSI workshop on Longitudinal diagnostics, Jan 2015

Courtesy Yevgeniy Ivanisenko, PSI

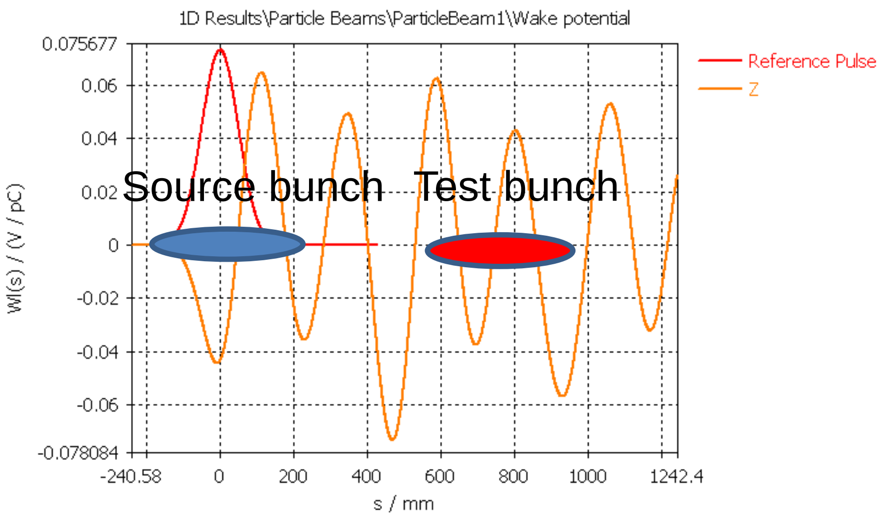
S. Jamison
ASTeC - Daresbury National Lab

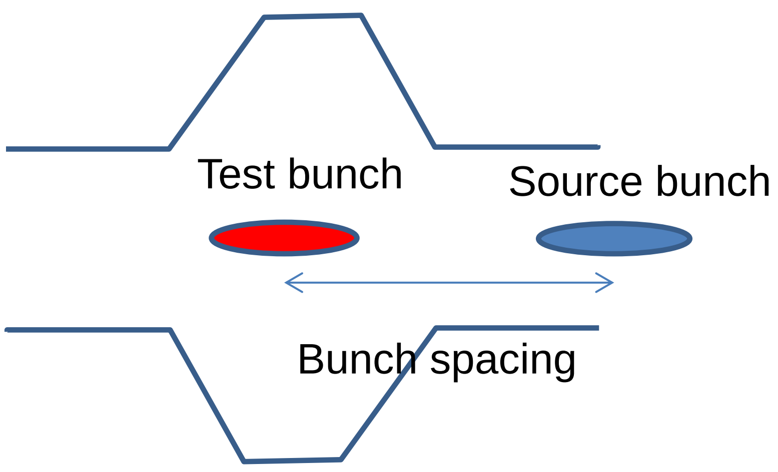
Direct measurement of "wake function"

B. Salvant - CERN

- Measurement of energy loss as a function of source/test bunch spacing → longitudinal wake
- Measurement of kick as a function of source/test bunch spacing → transverse wake
- In simulations, difficult to reach source bunch below 1 mm for standard devices due to mesh size.
- Very small bunch length achievable with electron beams (2 to 3 ps in CALIFES)

→ "wake function" could be measured provided the sampling is sufficient. Feasible?

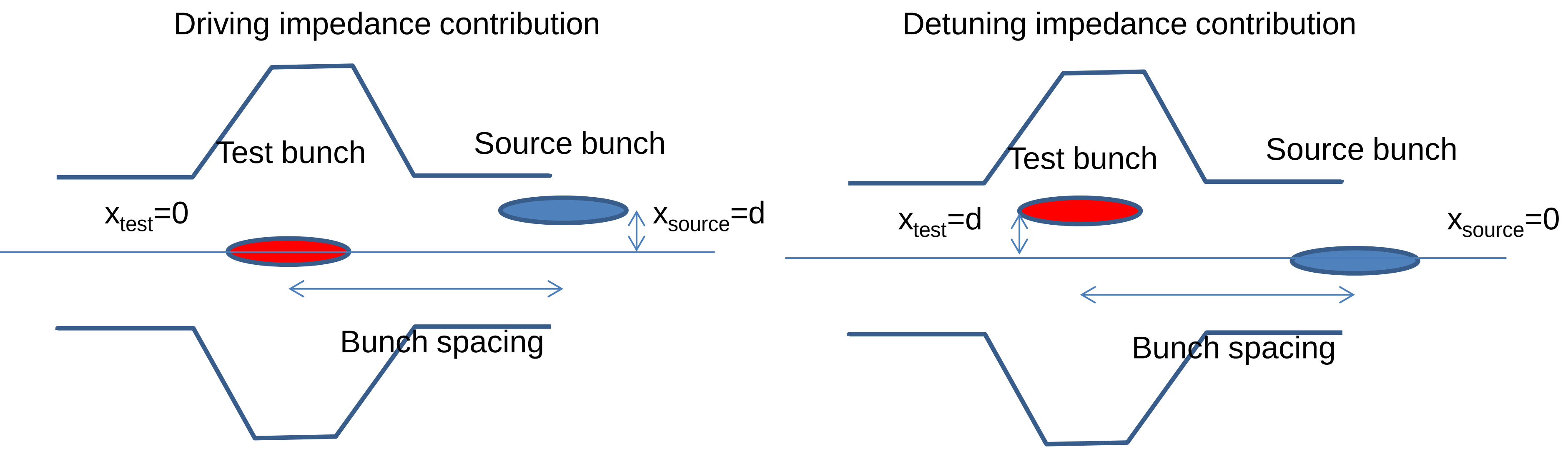




Direct measurement of "wake function"

B. Salvant - CERN

- Important to disentangle the "dipolar" impedance contribution from the "quadrupolar" contribution to assess the impact on collective effects



→ All particles in the test bunch receive the same kick
→ Coherent effect
→ Drives instabilities

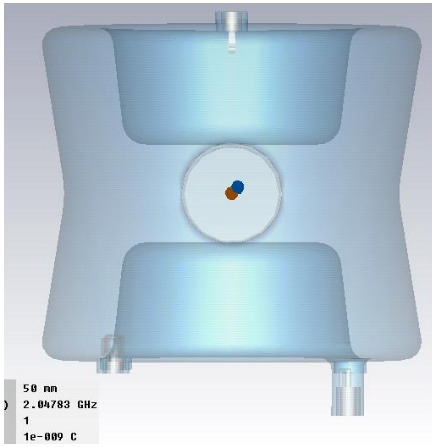
→ All particles in the test bunch receive a kick proportional to their position
→ Incoherent effect
→ Impact on instability depends on the type of instability

→ Can the orbits of the source and test bunches be controlled separately?

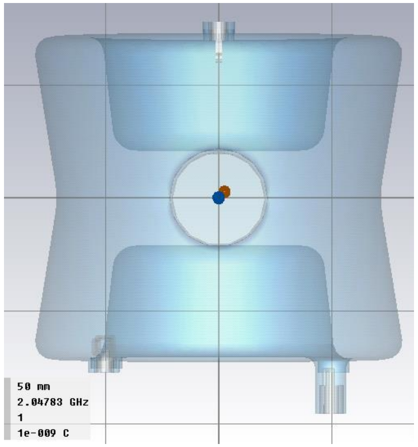
Example: LHC crab cavities

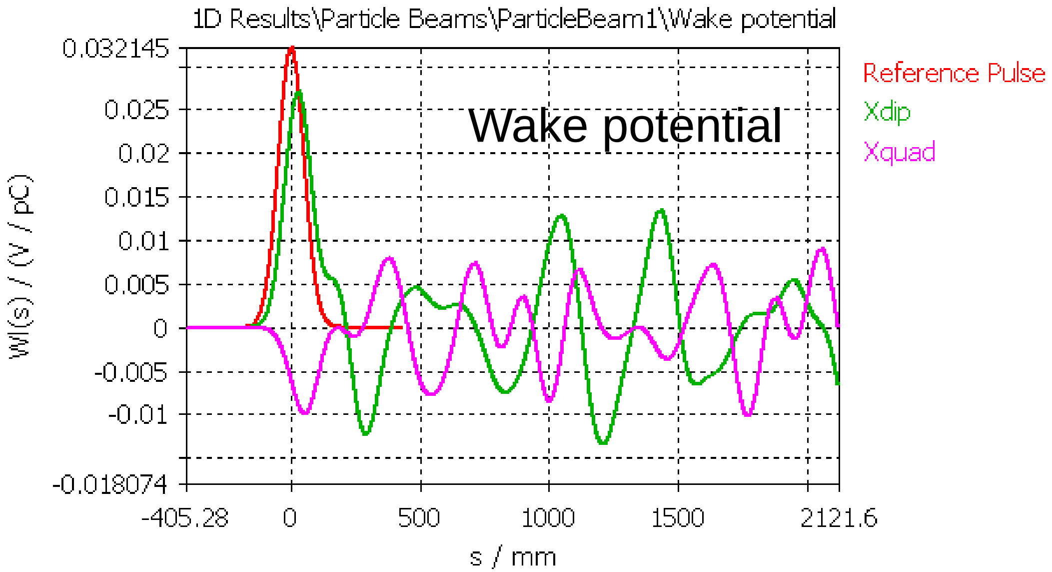
B. Salvant - CERN

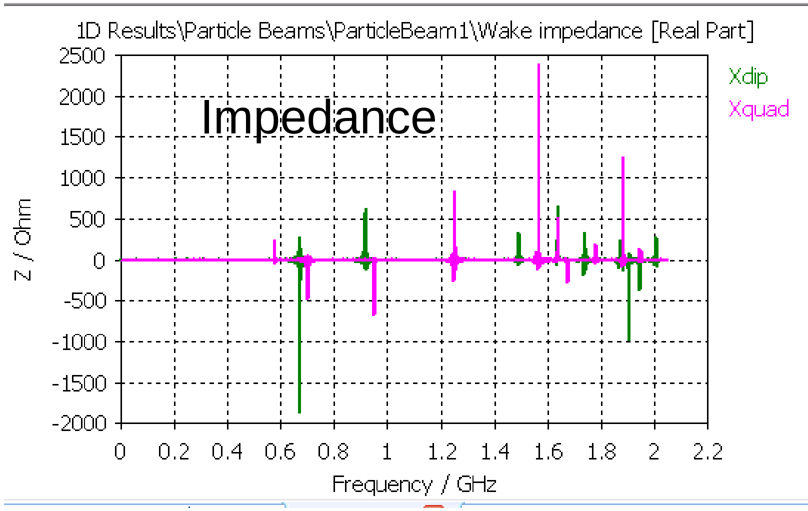
Driving impedance (also called dipolar impedance)



Detuning impedance (also called quadrupolar impedance)







- → Very different features between driving and detuning impedance and very different effects.
- → Detuning impedance generally small for cylindrically symmetric structures
- → Detuning impedance is very significant for SPS kickers (for instance) and tricky to obtain from wire measurements
- → Need to control separately source and test bunches

Potential limitations

B. Salvant - CERN

- **Minimum kick strength observable with the BPM resolution**
  - → Many components are in the 1 to 10 kOhm/m range for the transverse impedance, in the mOhm range for the longitudinal impedance
  - → Previous studies show that the kick is of the order of 10 microns after 1 m for 10 kOhm/m
  - → Roberto Corsini proposed possibilities to amplify this kick using lever arms
  - → This could require 3 BPMs before the device and 3 BPMs after the device (H. Schmickler)
  - → Reducing the energy of the test bunch would help!

- **Need to disentangle between the test and source bunch**
  - → Can we resolve 0.1 ns between two bunches? Challenging together with resolution requirements
  - → Would need special BPM development
  - → Could a high bandwidth kicker be used (prototype installed in SPS to work in GHz range)?

- **Accurate control of the orbit and spacing of test vs source**
  - → difficult to do with one electron source, contrary to FACET
  - → ideas to delay the bunch, delay the laser pulse to control the spacing
  - → ideas to move the laser pulse transverse position to control independently the transverse position
  - → this could be the main limitation for the setup

- **Control of intensity of both bunches** (highest on source and low on test)

- **Available length** (for both device installation and for observation)
  - → some critical elements are very long (SPS septa, LHC TDI and kickers).

- **Need for large flexibility in length and radius of input device**
  - → the facility may become a tapering factory.

- **Contribution from the BPMs and tapers should not dominate** (from 40 mm/20 mm radius to the aperture of the element)

Table of "ideal" requirements (draft, for discussion)

B. Salvant - CERN

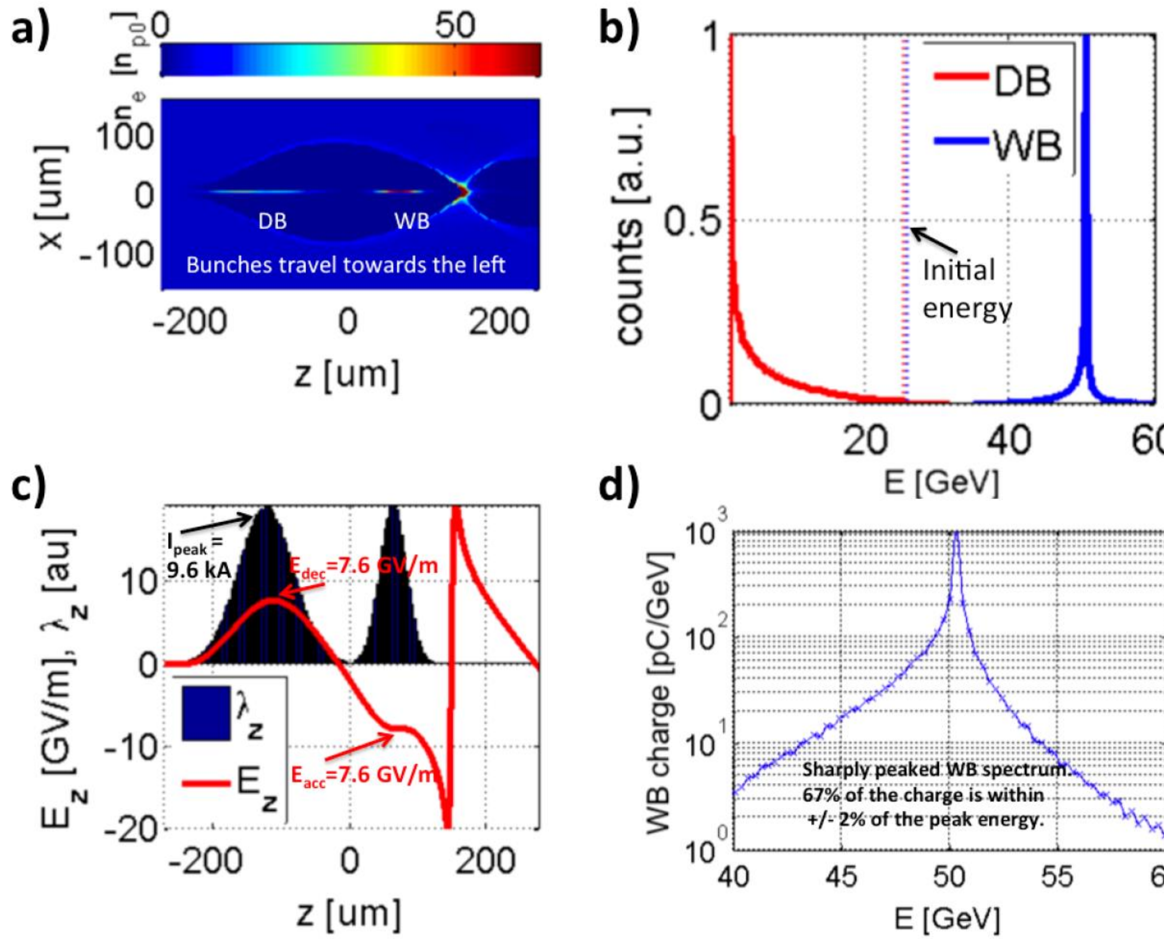
	Direct measurement	Wake function reconstruction
Intensity of the source bunch	~1 nC	~1 nC
Intensity of the test bunch	-	Not critical
Number of bunches	-	At least 2 bunches
Minimum bunch spacing	-	0.1 ns – 0.3 ns
Maximum bunch spacing	-	25 ns – 1 ms
Sampling in bunch spacing	-	0.1 ns within the first 5 ns, 0.3 ns after the first 5 ns
BPM resolution (time)	-	0.1 ns - 0.3 ns
BPM resolution (position)		1 micron
Source bunch energy	-	200 MeV
Test bunch energy	-	Would help if lower than 200 MeV
Available installation length	1.5 m for devices + 1 m for taper = at least 2.5 m	At least 2.5 m

Beam driven PWFA

E. Adli – Oslo University

Beam driven PWFA:
Two-bunch acceleration. A drive bunch drives a plasma wake, being decelerated. A witness bunch extract the wake energy, being accelerated.

PWFA has potential for:
- High gradient (>10 GV/m)
- High efficiency (>50%)
- Low energy spread (<1%)
- High charge (~nC)
- Emittance preservation



Above: PIC simulation based on example parameters from the PWFA-LC design study.

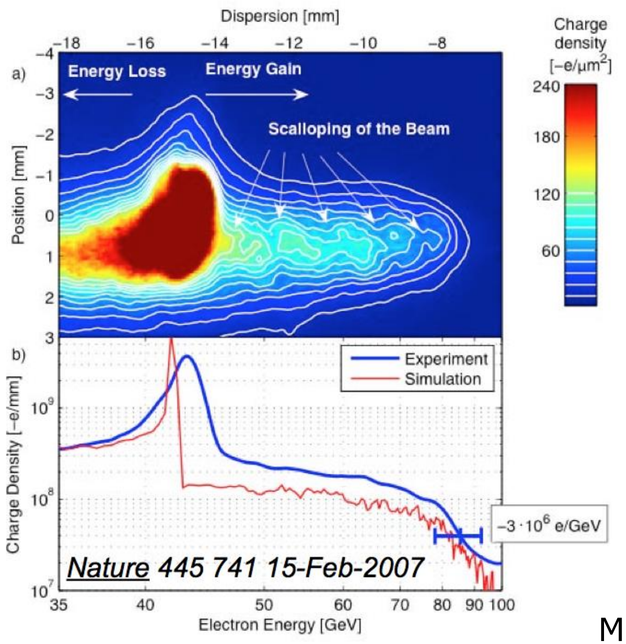
PIC simulations performed with the code QuickPIC (W. An, W. Mori, UCLA)

Not discussed here: laser driven plasma wakefield acceleration.

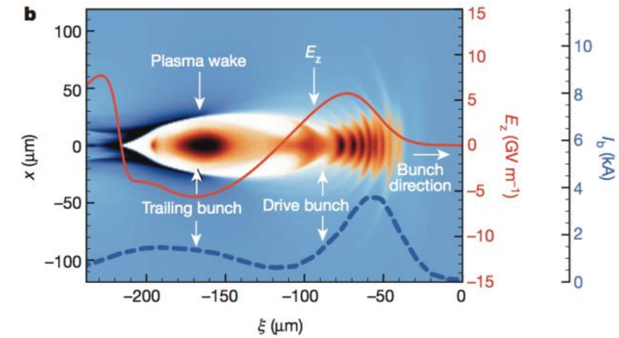
Experimental progress in PWFA

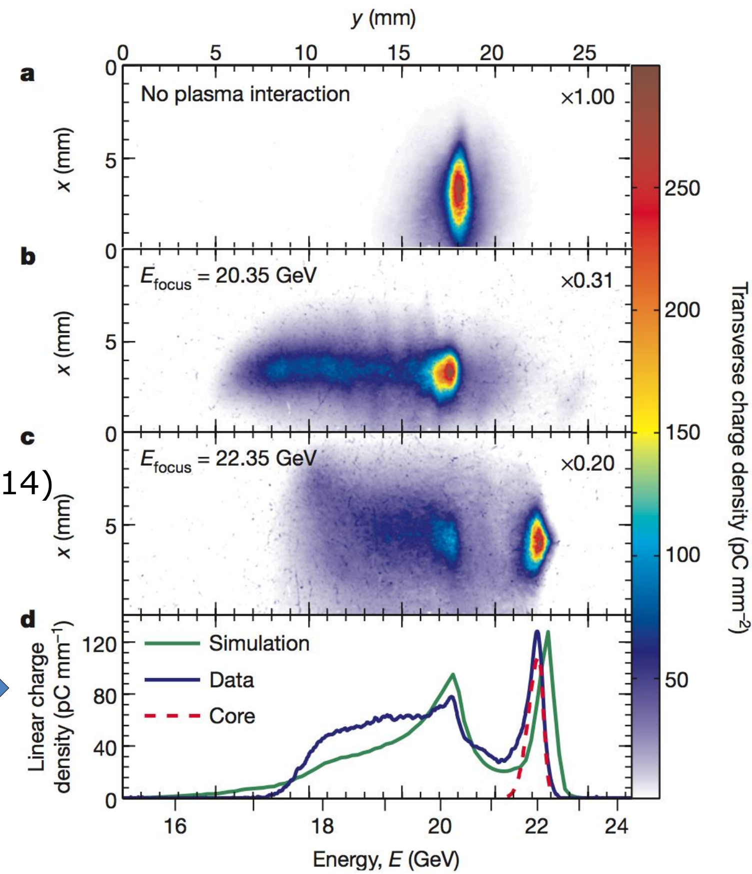
E. Adli – Oslo University

High gradient (~50 GV/m) demonstrated several years ago; SLAC linac energy doubling of beam tail.



Blumenfeld, I. et al. Nature 445, 741 (2007).





M. Litos et al., Nature 515, 92 (2014)

Acceleration of a witness beam, with high efficiency (>30% wake to beam), high gradient (5 GV/m) and low energy spread (~1%) recently demonstrated at SLAC/FACET.

See CERN A&T seminar with C. Joshi, Dec 18.

Plasma wake-field, CTF3 parameters

E. Adli – Oslo University

Even at n_0 ~ 10^{14} /cm^3 the DB and WB bunches must be shorter than what is currently available in CTF3.

On the next slides I will show a few PIC simulations where I use parameters based on the new DB injector as plasma DB, and CALIFES as plasma WB. Bunches is shortened as much as needed. Bunch shortening in CTF3 can be performed by new bunch compressors.

	CALIFES	CTF3 DB	New DB injector	Ideal for test facility
E	~200 MeV	~150 MeV	~100-150 MeV	~> 150 MeV (DB and WB)
ε_N	2 μm [low Q] ~4 μm	100 μm	100 μm	few 10 μm (DB)
σ_z	300μm [low Q] to 1.2 mm	1 mm	3 mm	**~150 μm (DB and WB)**
σ_E/E	1 %	1 %	1 %	1%
f	5 Hz	100 Hz	100 Hz	$\geq$ 1 Hz
f_{micro}	1.5 GHz	1.5-3 GHz	0.5-1 GHz	**single bunch**
N_{micro}	single, up ~100	~1,000	~70,000	**single bunch**
Q_{micro}	0.01 nC to 1.5 nC	1-3 nC	8 nC	$\geq$ 1.5 nC
$\hat{I}$	~50-100 A ?		~300 A	**$\geq$ 1kA (for DB)**
n_b	1e13/cm3		~1e14/cm3	$\geq$1e15/cm3 (for DB)
$\phi_{stability}$	dep. on laser	?	0.05 deg@1 GHz=50 fs	~few 10 fs

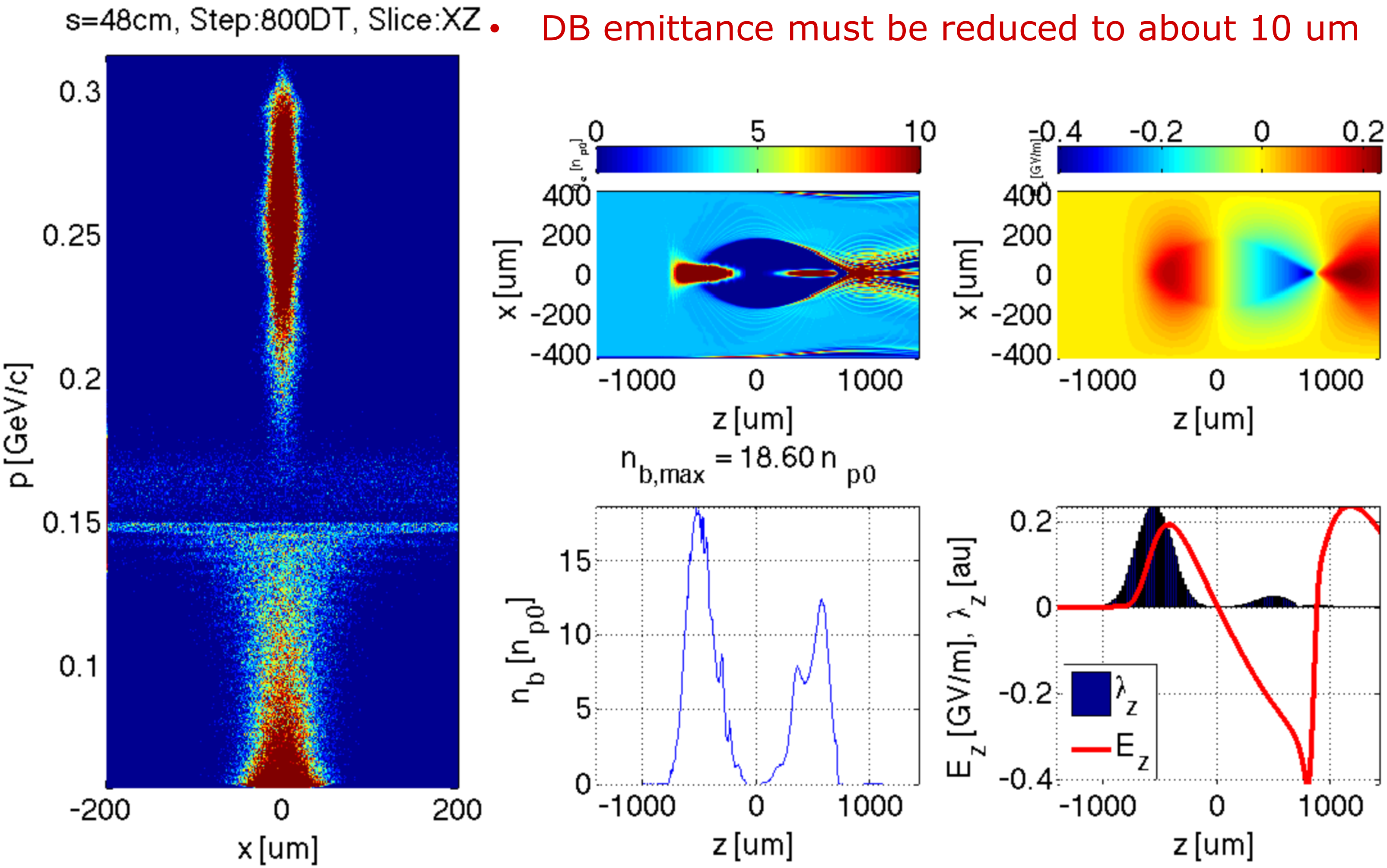
DB optimized parameters

E. Adli – Oslo University

σ_z = {150, 150} um
n_0 = 3.1 x 10^{14}/cm3
$\varepsilon_{zN,DB}$ = 10 um
s = 0.5 m

In this scenario, the blow-out is clean until the full drive beam depletion. Excellent emittance preservation of the WB is predicted by the simulations.

- DB and WB must be shortened to about 150 um
- DB emittance must be reduced to about 10 um



Summary of requirements for PWFA@CTF3

E. Adli – Oslo University

- Two independent co-linear electron beams: ~adjustable relative timing with accuracy of ~10 fs
- Required upgrades to CALIFES :
  - <~ 150 um bunch length
  - as large single bunch charge as possible (ideal is >~ 1 nC, but this is not a hard requirement)
- Required upgrades to the DB
  - <~ 150 um bunch length
  - >~ 100 MeV beam energy
  - <~ 10 um normalized emittances (linked to other parameters, like peak current; to be further studied)
  - possibility to extract single shot (to be studied further)
- Required upgrades to CTF3 complex
  - Installation of plasma cell and diagnostics
  - Co-linear injection/extraction (energy based)

PWFA - Conclusions

E. Adli – Oslo University

- In order to demonstrate the feasibility of plasma for accelerator applications, there is **need for additional test facilities**.

- CTF3 has potential to perform plasma experiments; relevant to a PWFA-LC. Complementary to AWAKE. Some overlap with FACET-II, FF. The more **precise** we can control and diagnose bunches, the more attractive CTF3 is.

- Unique possibility to do multi-bunch plasma heating experiments possible (up to 1 GHz)

- Bunches would need to **be compressed by a significant factor**

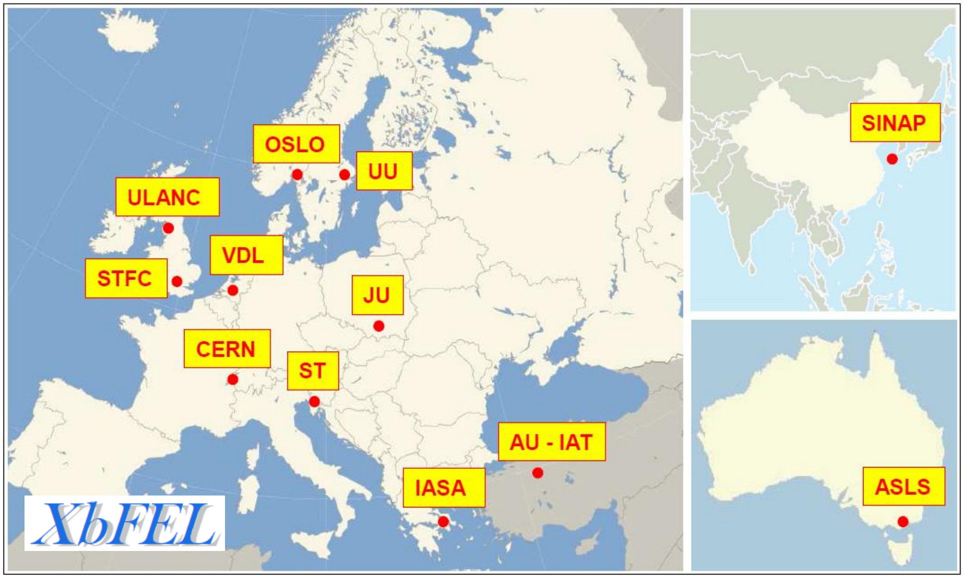
- **Single bunch** capabilities for the DB strongly desired

- We are interested in further developing this proposal with CLIC/CTF3

X-band technology for FELs

G. D'Auria – Elettra Trieste

XbFEL is a collaboration among several laboratories aimed at promoting the development of X-band technology for FEL based photon sources.



ST	*Elettra - Sincrotrone Trieste, Italy.*
CERN	*CERN Geneva, Switzerland.*
JU	*Jagiellonian University, Krakow, Poland.*
STFC	*Daresbury Laboratory Cockcroft Institute, Daresbury, UK*
SINAP	*Shangai Institute of Applied Physics, Shanghai, China.*
VDL	*VDL ETG T&D B.V., Eindhoven, Netherlands.*
OSLO	*University of Oslo, Norway.*
IASA	*National Technical University of Athens, Greece.*
UU	*Uppsala University, Uppsala, Sweden.*
ASLS	*Australian Synchrotron, Clayton, Australia.*
UA-IAT	*Institute of Accelerator Technologies, Ankara, Turkey.*
ULANC	*Lancaster University, Lancaster, UK.*

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Science & Technology Facilities Council

SINAP

VDL

NTUA

IASA

UPPSALA UNIVERSITET

Australian Synchrotron

LANCASTER UNIVERSITY

Potential tests for an X-band FEL using the CALIFES beam

#	Applications	Tests
1	X-band linearizer	· Check the first CLIAPSI structure CERN-PSI-Elettra (with the 400 μm misalignment)
2	Wake Field monitors	· Activation and calibration · Acquisition systems
3	High frequency bunch spreader/separator	· Bunch separation with RF cavities · Possibility to work out with bunch distances from ns up to μsec · Beam quality degradation (emittance, energy spread)
4	X-band deflectors	· Beam tests · Time resolution (< 10 fs)
5	High frequency Photoinjector	· Beam tests and characterization (i.e. C-band)
6	Bunch compression	· Beam compression studies · Emittance preservation · Longitudinal diagnostics and instrumentation
7	Timing and synchronization	· RF synchronization measurements
8	Low energy test stand for X-band FELs (adding an X-band module downstream the bunch compressor)	· Beam acceleration studies
9	Advanced beam dynamics tests	· Purely-magnetic compression schemes, CSR-free DBA, beam-based measurements

New hardware required | Hardware already available

A. Latina (CERN) with relevant inputs from G. D'Auria, S. Di Mitri (ELETTRA), M. Pedrozzi (PSI), A. Dexter and G. Burt (Cockcroft, Lancaster)

Extension of CALIFES for XFEL oriented developments.

PAUL SCHERRER INSTITUT PSI

M. Dehler, M. Pedrozzi, M. Leich – PSI

Problematic:

- Accessibility to the accelerator facility for beam dynamics and hardware developments is extremely limited on FEL user facilities, running 24/7 for production

Ideal requirements for CALIFES:

- S-Band RF-Photoinjector system: high brightness beam could require some optimization of the lattice and the laser system (SITF experience is a good guideline)
- S-Band injector linac (~200-250 MeV)
- X-band longitudinal Phase space linearization (one cavity is sufficient)
- Magnetic chicane for compression: PSI could lend the mechanics, the connecting long vacuum chambers and eventually the magnets of the SITF compressor (12m long, angle adjustable between 0° and 5°)
- S-Band deflector system for slice measurements
- Optics + high resolution COTR insensitive transverse monitor for emittance measurements: SITF design (R. Ischebeck) and experience could be used

Study ideas:

1. Study of short pulse regime: CSR effects and development of instrumentation (in particular longitudinal)
2. Test of new generation RF photo injectors: for example S-band coaxial or C-Band (advanced design available at PSI)
3. Development and test with beam of X-band deflector systems (post undulator instrumentation)
4. Test of X-Band acceleration modules with beam: RF aspects, alignment issues, short and long range wake.
5. Study of HOM coupler for alignment purposes (cavity + electronics): one CLIAPSI cavity available at CERN, electronic development ongoing at PSI (M. Dehler)

If enough space available

- Demonstration of non-linear magnetic compression with negative R56 and adjustable T566. Preliminary design study available at PSI (A. Streun). Required ~30 m and multipole magnets. Complex but:
  X-band linearization not required, one important source of jitter removed ⇒ increases of compression stability.

Courtesy of M. Pedrozzi, M. Dehler, M. Leich

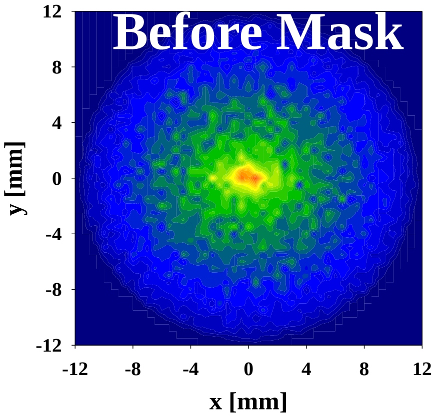
Advanced Beam Physics

S. Di Mitri – Elettra Trieste

- Compare the performances of a purely-magnetic compression scheme, w.r.t. one including velocity bunching, both in terms of macroscopic properties of the beam as well as in terms of micro-bunching
- Micro-bunching gain measurements and comparison with analytical models
- Electron beam shot-noise bunching suppression + lasing (some undulators would be needed)
- Tests of Double-Bend Achromat (DBA) with CSR suppression
- Electron comb generation using masks in a dispersive region, and transport control
- Tests of bunch compression with sextupoles in the dispersive region (verify the impact on the longitudinal phase space)
- Measurement of emittance scaling with the photo-injector charge (models predict a shift from power of ½ to 1/3 but needs more accurate studies)

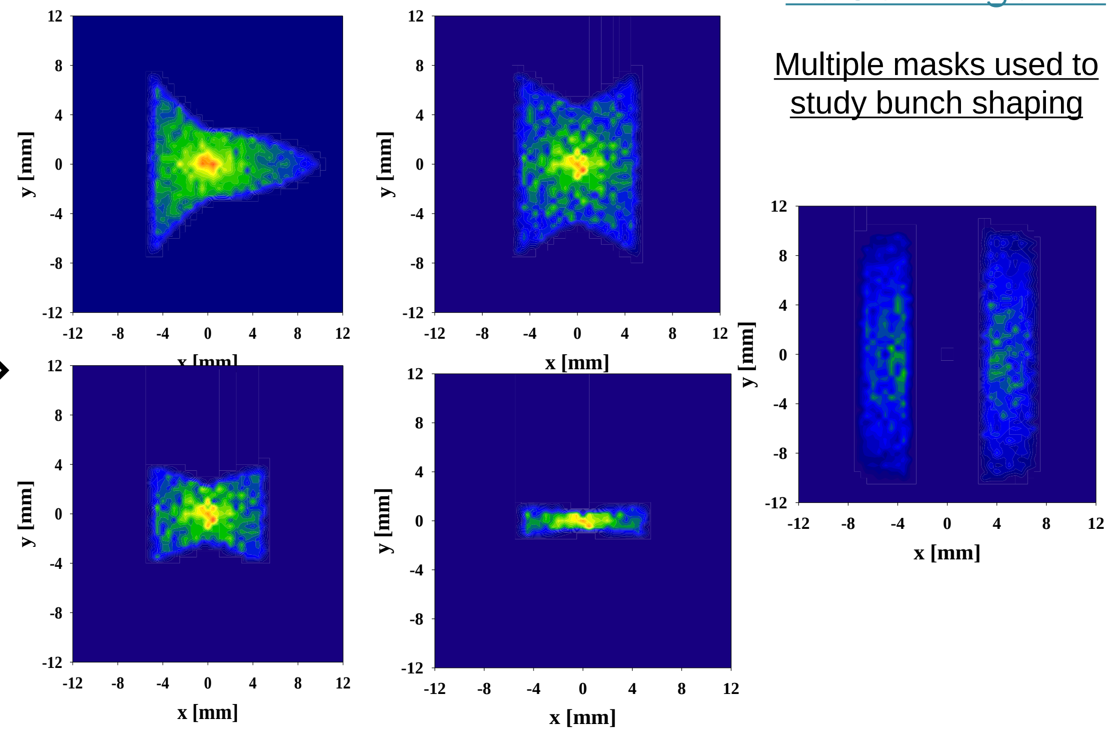
Shaping ability of Masks

W. Gai – Argonne



Apply

Mask

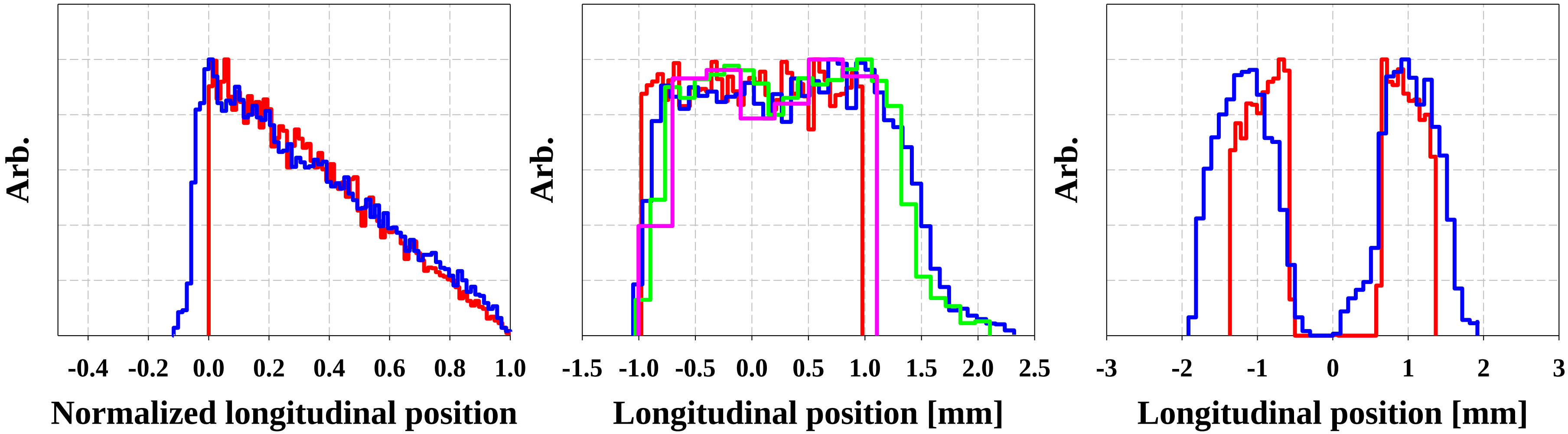


Multiple masks used to study bunch shaping

PARMELA Simulation results

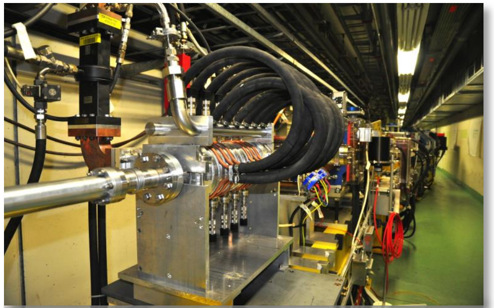
Horizontal profile after the mask

Final current profile



Bunch length flexibility

- In many cases a (very) short bunch length is required
- May be accessible using a magnetic chicane or dogleg (need some compression studies, implications on off-crest phase, short range wake-fields)
- Other possibility, RF deflector + collimator (crabbing). May also implement a two-deflector solution (RF bump) to remove crabbing
- Should continue bunch compression studies in CALIFES 2015-2016 with streak camera, EOS and possibly RF deflector



Other flexibility requirements

- Flexibility for single bunch / multibunch operation
- Flexibility in bunch charge – if high charge is needed, a switch between CALIFES gun and PHIN is still possible?
- Need of double pulse (drive + probe) for impedance/wake-fields measurements (and possibly plasma applications?). Flexibility in drive/probe bunch distance and independent control of transverse position/bunch charge may be critical aspects.

Conclusions

- CTF3 in its present configuration will complete its program by end 2016 and stop operation
- There is a strong interest by the CLIC collaboration in keep using some of its hardware and infrastructure beyond 2016
  - Drive beam front-end
  - Dogleg beam loading experiment
  - RF testing (Xbox1, S band)
  - CALIFES for equipment testing
- In particular CALIFES may be a reasonably cheap multi-purpose test facility
  - Useful within the CLIC study – potentially much wider interest
  - Clear synergies with other projects/labs may help in gathering resources and support
  - CALIFES will be extremely useful already in its present form, but staged upgrades will enhance flexibility/usefulness
- Will develop an integrated proposal including cost/resource assessment and evaluation of scientific case of the different options

THANKS
for your attention

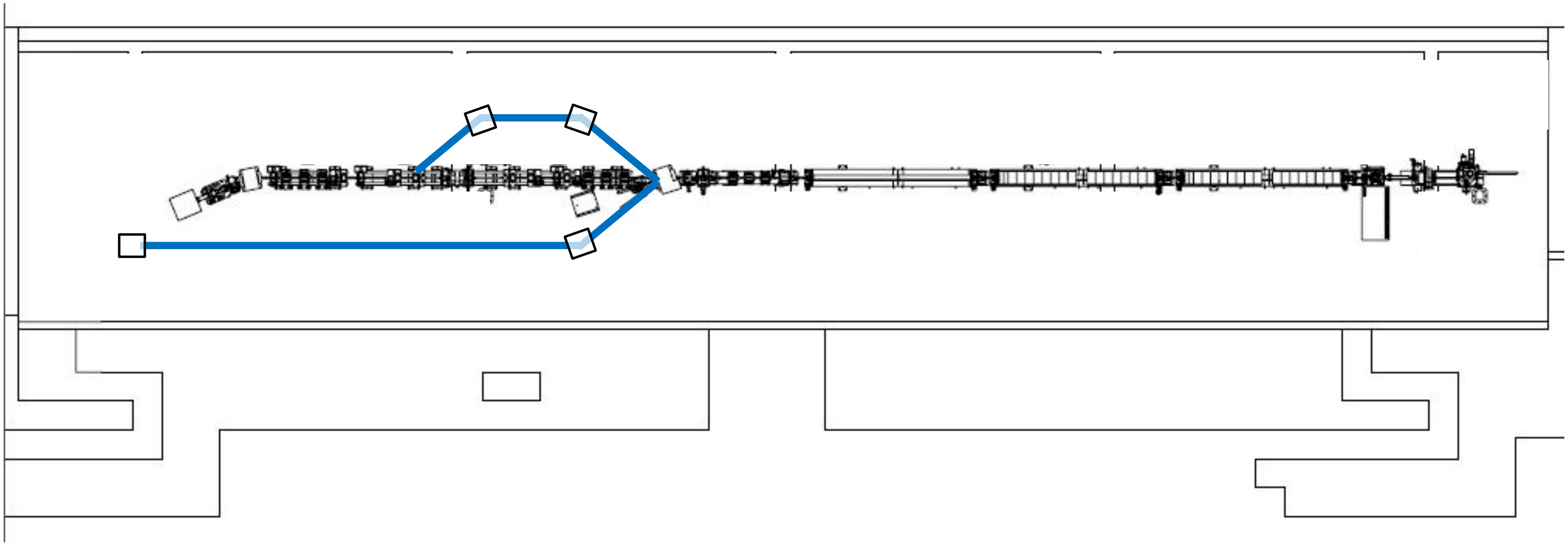
Summary of (some) possible upgrades

- Keep CALIFES for beam instrumentation test
  - Add an available S-band klystron, modify waveguides
  - Add a chicane, another dedicated klystron for deflector
  - Change the deflector to a CR one
  - Closed RF bump + collimator for bunch length control
  - (Switch for the PHIN gun for higher charge)

- ~~(Push the beam line toward the X-Box1 in CTF2)~~
- Or transport the 12 GHz power to CLEX
  - Add a 12 GHz crab cavity for bunch length diagnostic
  - (Add an undulator, a Compton scattering experiment…)

- Produce special beams for Impedance/Wakefield studies
  - 2 bunches of different energies with adjustable delay
  - Single bunch, short range wakes

Previous studies – the Instrumentation Beam Line



- A preliminary study has been done: *"Short Pulse Capabilities of the Instrumentation Beam Line – V. Ziemann – 6 May 2010"*
  - Short pulses (200 fs – 35 μm) are necessary to mimic the CLIC main beam for instrumentation tests
  - Pulses of 20 μm are achievable with a chicane R_{56} = 2 cm and energy encoding of 10^{-3} , maximum energy reduced to 78% of the on-crest one
- Other option ➔ four-bend chicane
- All equipment will be available from the DB lines (magnets, powers, chambers…)

Some consideration on resources

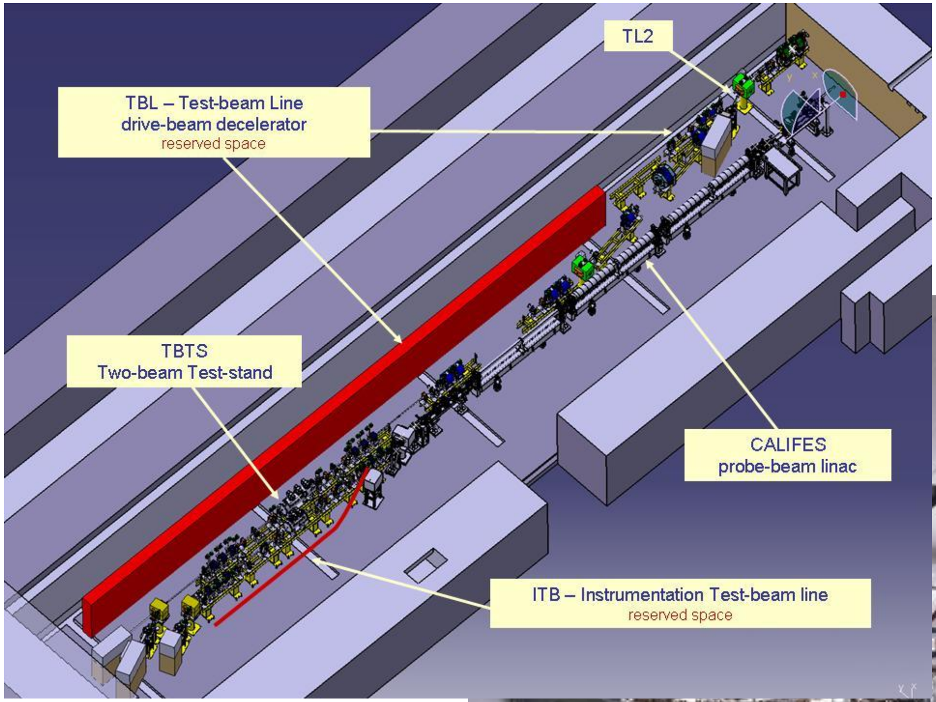
- Given the present CTF3 material budget/manpower, one may roughly evaluate the resources needed to keep CALIFES running after 2016 to about:
  - 200-300 kCHF/year (including M to P – students and PJAS)
  - About 5 FTEs (staff and fellows)
- The above would include a minimum upgrade (1 ½ additional klystron, rearrangement of test area)
- Must do a more precise evaluation for the more ambitious upgrade options

Beam parameters

- CTF3 Drive beam (present)
  - 4 A, 1 us pulses (trains of 1-3 nC bunches, 1.5/3 GHz spacing)
  - rep rate 1-50 Hz
  - 50 – 125 MeV
  - May provide lower energy (>10 MeV), need to study transport
  - Typical beam sizes 1 × 1 mm, may easily fill round chamber, 4 cm diameter.

- CTF3 Drive beam (new Front-End)
  - 4 A, up to 140 us pulses (trains of 1-6 nC bunches, 0.5/1 GHz spacing)
  - rep rate 1-50 Hz
  - 10 – 100 MeV
  - Typical beam sizes 1 × 1 mm, may easily fill round chamber, 4 cm diameter.

CALIFES hall & infrastructure



CLEX

- Convenient hall (42 x 8 x 2.6 m^3) with proper concrete shielding (2.8 m) and large access.
- Instrumentation & klystron gallery just above
- An up-to-date Laser lab, (80 m laser beam line, partly under vacuum)
- Fully equipped (conditioned air, water, access control. No crane.

JUICE - CALIFES

T. Lefevre – M. Brugger

- JUICE (JUpiter ICy moons Explorer) Mission
  - http://sci.esa.int/juice/55055-juice-mission-gets-green-light-for-next-stage-of-development/
  - Launch a mission in 2022 to explore Jupiter and its potentially habitable icy moons
  - Strong electron cloud environment around Jupiter
    - *Need to test components to electron irradiation*
  - ESA-CERN Collaboration Agreement
    - *Involvement and support of CERN KT group*

- Turning CALIFES in an Electron Irradiation facility
  - Both for Total Integrated Dose and Single Event Effect
  - Beam energy ranging from 10-200MeV
  - Large irradiation area (5x5cm minimum)
  - Required fluence of $10^7/10^8$ electron/cm^2
  - 1st test in 2015

Perspectives for e- beam irradiation tests in CTF3/CALIFES – R. Corsini, ESA visit @CERN
https://indico.cern.ch/event/357271/

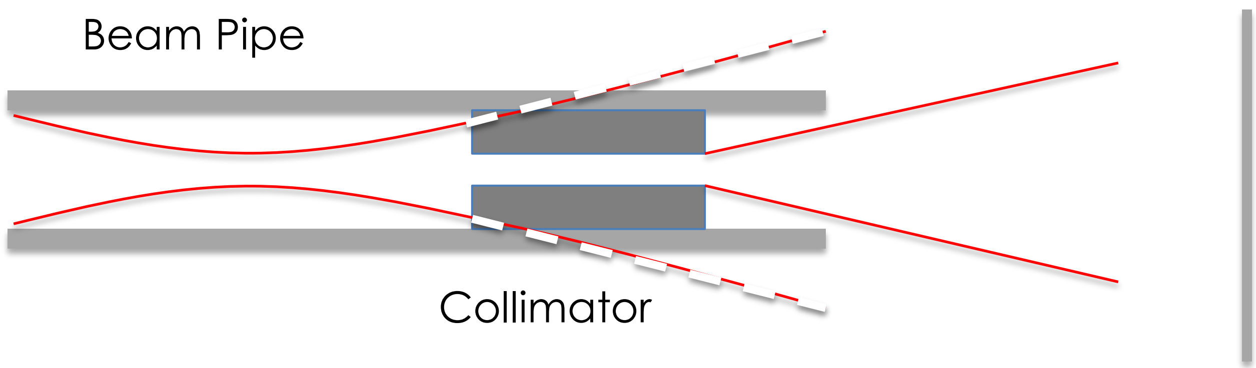
Challenges for CALIFES

- Run at (much) lower beam energy (down to 10MeV)
  - *New RF acceleration scenario (to be tested)*
  - *New test Area in CALIFES after the Gun or after 1st Acc. Structure*
- Need very low flux and large and homogeneous irradiation area
  - *Need to qualify the beam quality (possibly cutting tails with collimators ultimately)*
  - *Characterization and 1st testing possible on CALIFES Dump line*

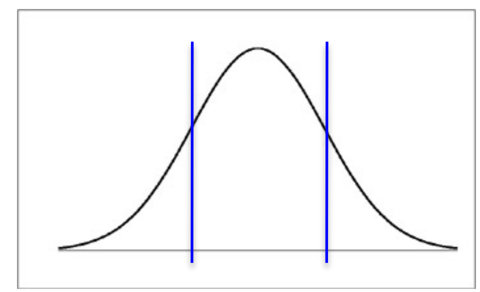
Open issues/questions

- Verify needed fluxes (test pieces, needed area…)
- Energy range – how critical? Verify low energy capabilities in CALIFES.
- How uniform should be the beam?
- What about the time structure (average vs. peak flux)?
- Total dose needed, testing time, running scenario…
- Layout of irradiation region – activation of collimator, air activation, dump…
- Timescale (before and/or after 2016)
- …

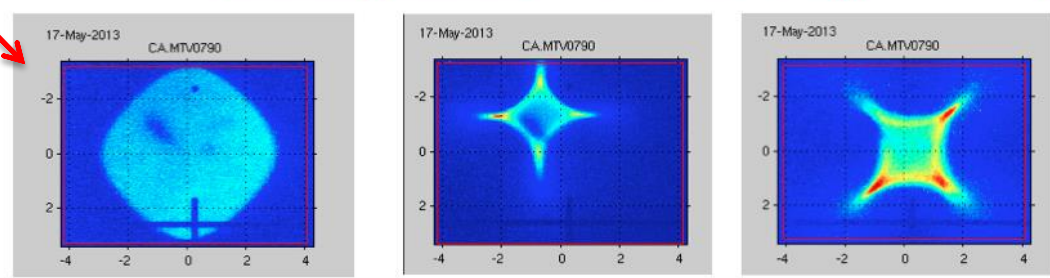
Uniform beam - Filling the aperture



Test area



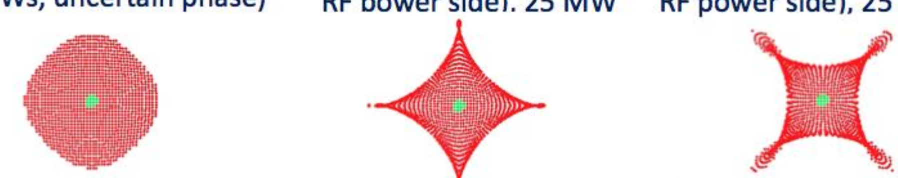
Octupolar field study



For very weak RF power (few MWs, uncertain phase)

At zero-crossing (rising RF power side), 25 MW

At zero-crossing (falling RF power side), 25 MW



Ray-tracing model through octupolar fields

Fluxes

- 1 nC pulses @ 1 Hz (CALIFES, few bunches)

  ➔ 6.25 10^9 e^- s^{-1}

- Assume round beam, 40 mm x 40 mm, 90% cut

  ➔ 5 10^7 e^- cm^{-2} s^{-1}

A. Latina - Measurement of Short-Range Longitudinal Wakefields at CALIFES

Longitudinal wake-fields

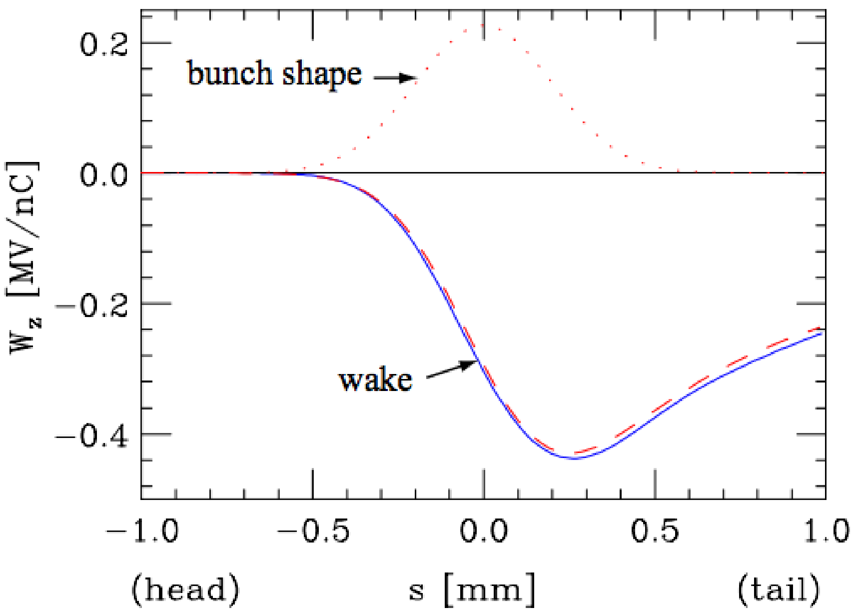
Longitudinal wakes cause energy loss and correlated energy spread (chirp)

Idea:

1. Compensate the correlated energy spread with small off-crest acceleration, and measure the energy spread using a spectrometer

2. Perform a phase / voltage scan to locate the minimum (i.e. compensation)

3. Infer wake-field characteristics from
- energy spread vs phase scan,
- energy spread vs voltage scan



Setup, parameters, and simulation of phase scan

CALIFES-like parameters:

- Two CLIC AS with a/λ = 0.11
- Bunch charge = 1 nC
- Average energy = 200 MeV

Two bunch configurations considered:

- Bunch uncorrelated espread = 0.25 %
- Bunch length = 1200 um

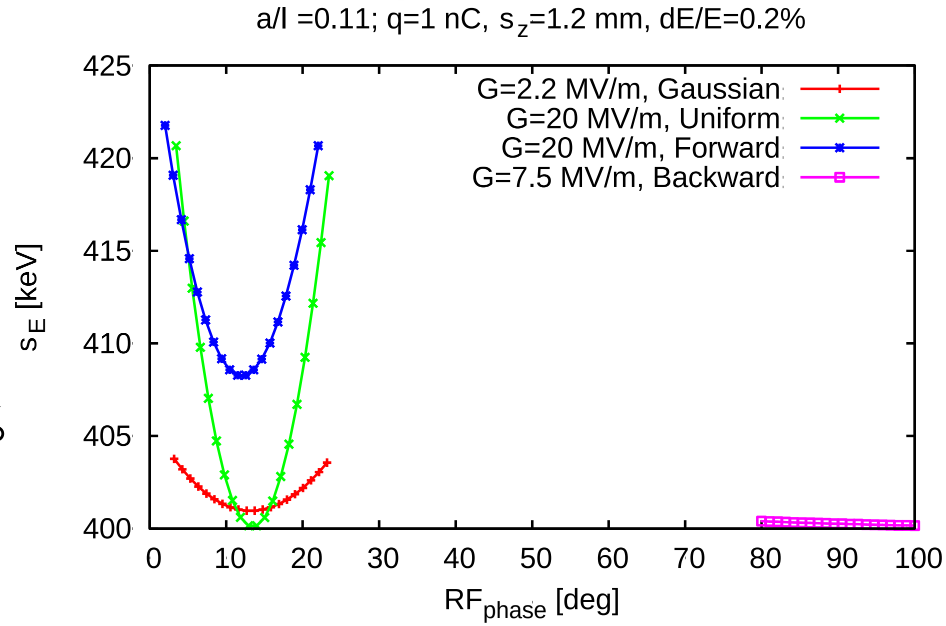
and:

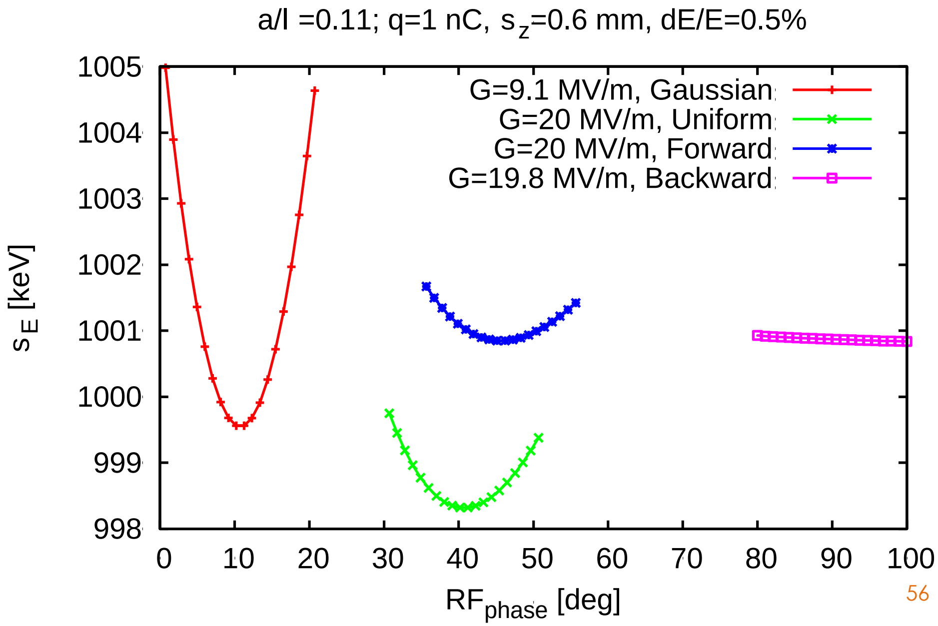
- Bunch uncorrelated espread = 0.5 %
- Bunch length = 600 um

Four different longitudinal distributions

- Gaussian
- Uniform
- Forward
- Backward

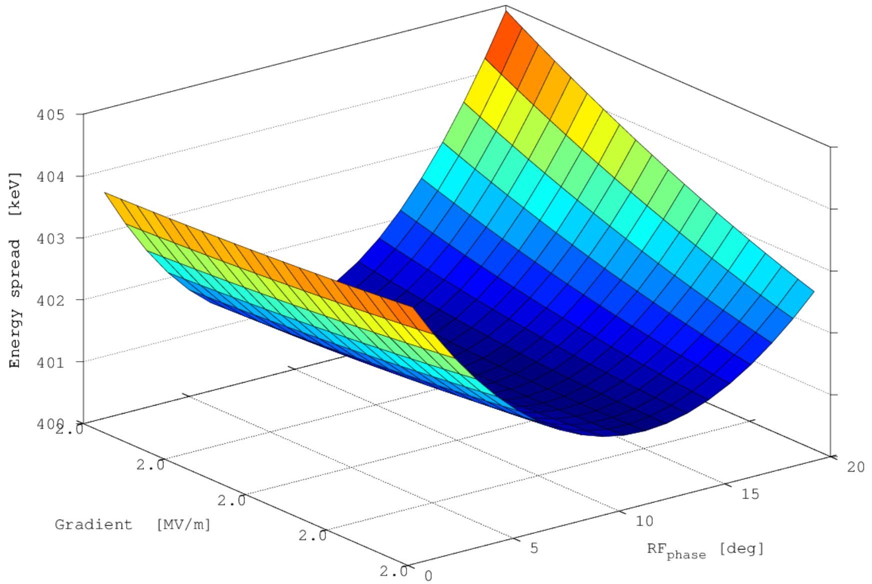
The plots show the result energy spread:





Dependence on voltage is much weaker

Example: 1.2 mm bunch length, 0.2% energy spread, two distributions

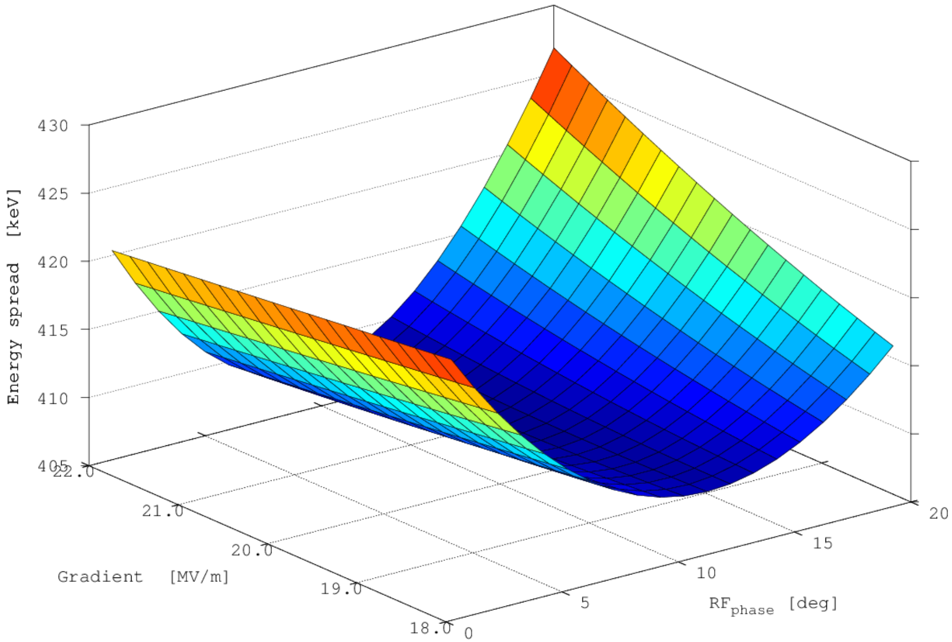


Gaussian:

- Resolution required ~ 1 keV

Uniform

Resolution required ~5 keV



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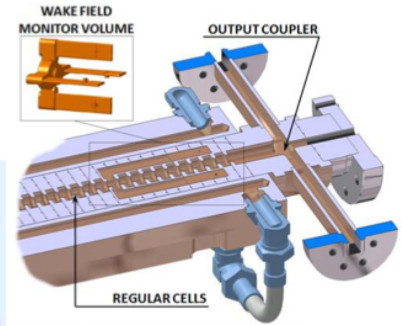
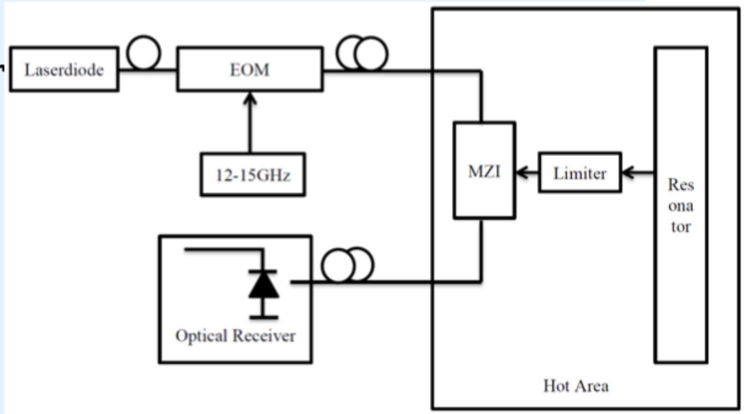
PSI

Perspectives: WFM characterization at CALIFES



- **Current Situation**
  - Within EuCARD 2, developing electro-optical front end for WFMs integrated in in X band phase space linearizer structure. First tests with in SwissFEL Test Injector Facility (SITF).
  - SITF stopped operation end of october '14, components to be transferred to SwissFEL injector planned to start operation end of 2015/beginning of 2016
  - No beam time for WFM front end characterization and tests in 2015, rather limited time later.
- **Using CALIFES as a test bed for WFM**
  - Using X band linearizer currently at CERN (which developed alignment kinks during brazing), active length 750mm, total 1000 mm
    - Do standard tests moving either structure or beam
    - Kinks in alignment ideal to test advanced measurement modes to determine the internal cell to cell alignment from signal spectra.
    - Open questions: Available space, necessary to condition structure before insertion into CALIFES?
  - Test WFM front end together with WFMs of CLIC accelerating structure: Interesting option due to other signal spectrum.
  - Synergies with CLIC related research (in discussion with Eric Adli and Reidar Lillestol)
  - Modest requirements on beam: orbit control with resolution ~ 5um, beam charge > 100 pC
  - Ideal scenario: having beam available from summer 2015



M. Dehler, M. Leich 12/2014

Additional considerations II

- Decommissioning ≠ zero resources !

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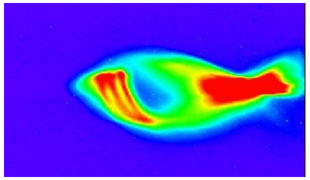
- It may be wise to "mothball" CTF3, also to keep open the possibility to re-start CTF3 after 2016 if needed (new module generation?) and according to CERN priorities
- Hovever, this clashes with requests to re-use CTF3 buildings and equipment…

- The shut-down paradox:

  "Given an accelerator facility, the cost of running it is in general lower or equal than the cost of a shut-down".

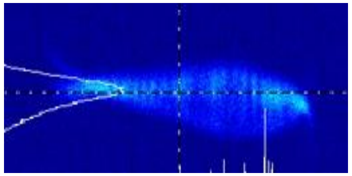
CALIFES

Parameters	Specified	Verified	Comment
Energy	200 MeV	205 MeV	Without bunch compression
Norm. emittance	< 20 π mm.mrad	4 π mm.mrad	With reduced bunch charge
Energy spread	< ± 2 %	± 0.5 %	
Bunch charge	0.6 nC	0.65 nC	With new photocathode
Bunch spacing	0.667 ns	0.667 ns	Laser driven
Nb of bunches	1-32-226	from 1 to 300	Limited by RF pulse length
rms. bunch length	< 0.75 ps	1-2 ps and above	
Repetition rate	0.8 – 5 Hz	0.8 – 5 Hz	Upgrade possibility to 10 Hz



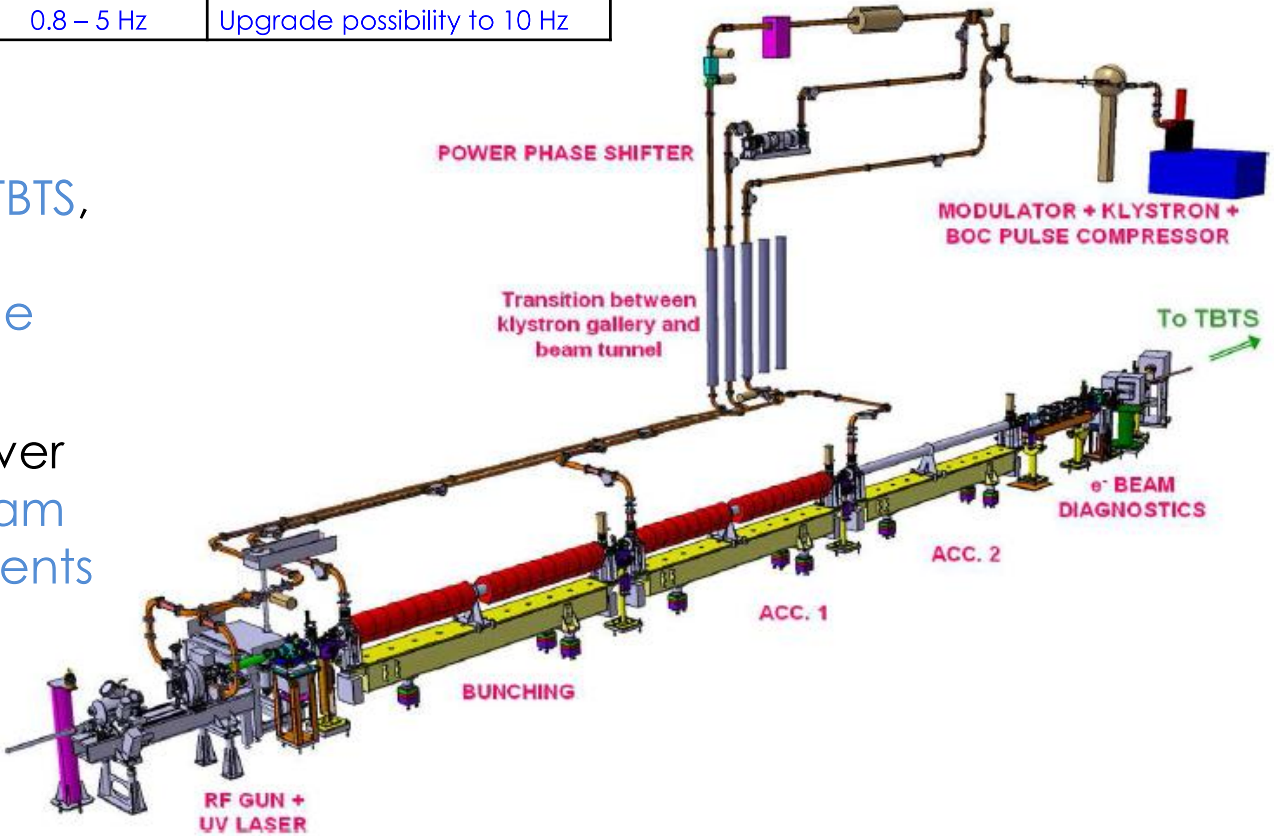
CALIFES

Swiss FEL injector (courtesy Simona Bettoni)

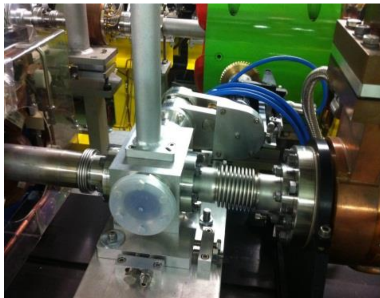


- Up to now used on TBTS, from November:
  ➔ Two-Beam module

- Growing activities over the last years on beam diagnostic/components testing

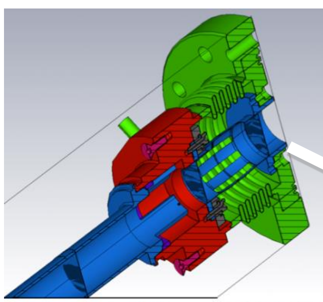


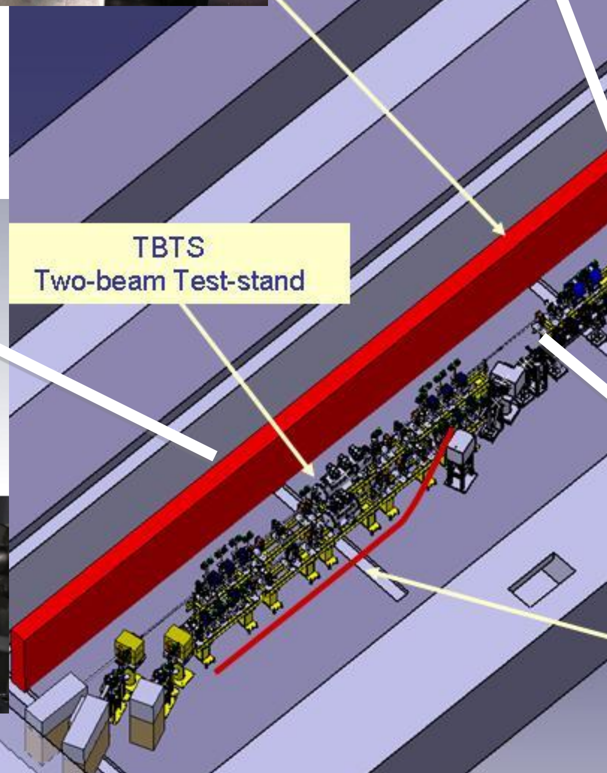
Beam Diagnostic Tests in CLEX



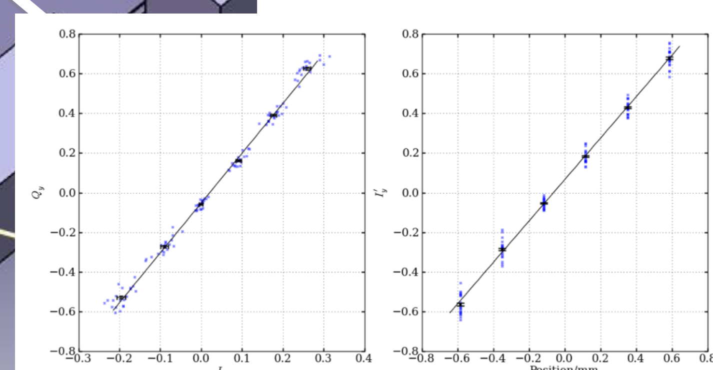
Electro-optic bunch profile monitor
in CALIFES
(CERN-Dundee University)

Stripline Drive Beam BPM in TBL
(CERN-LAPP)





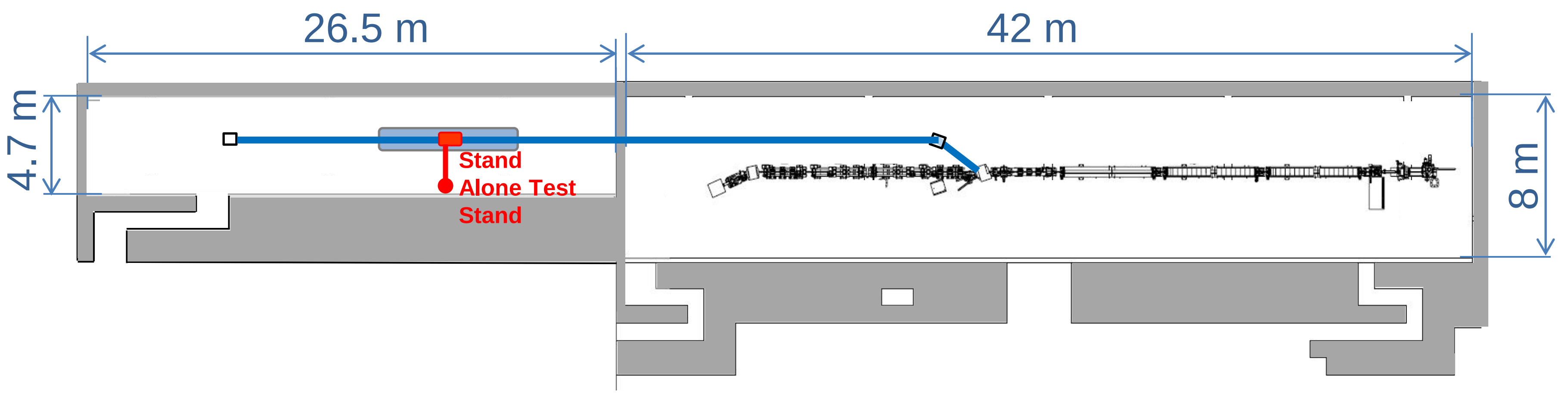
Cavity Main Beam BPM
in CALIFES/TBTS
(CERN-JAI at Royal Holloway)

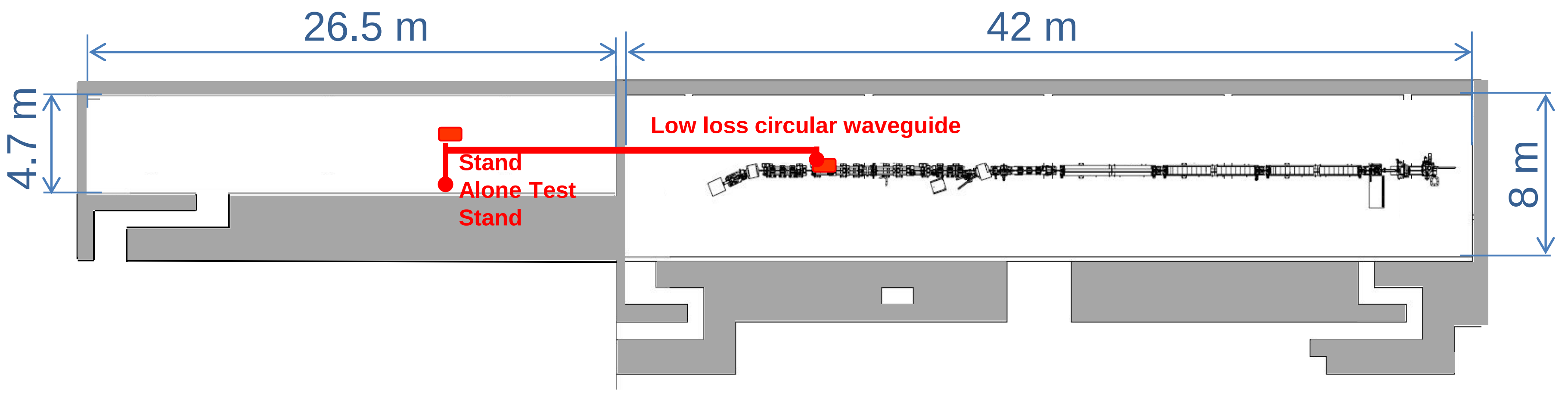


X-band

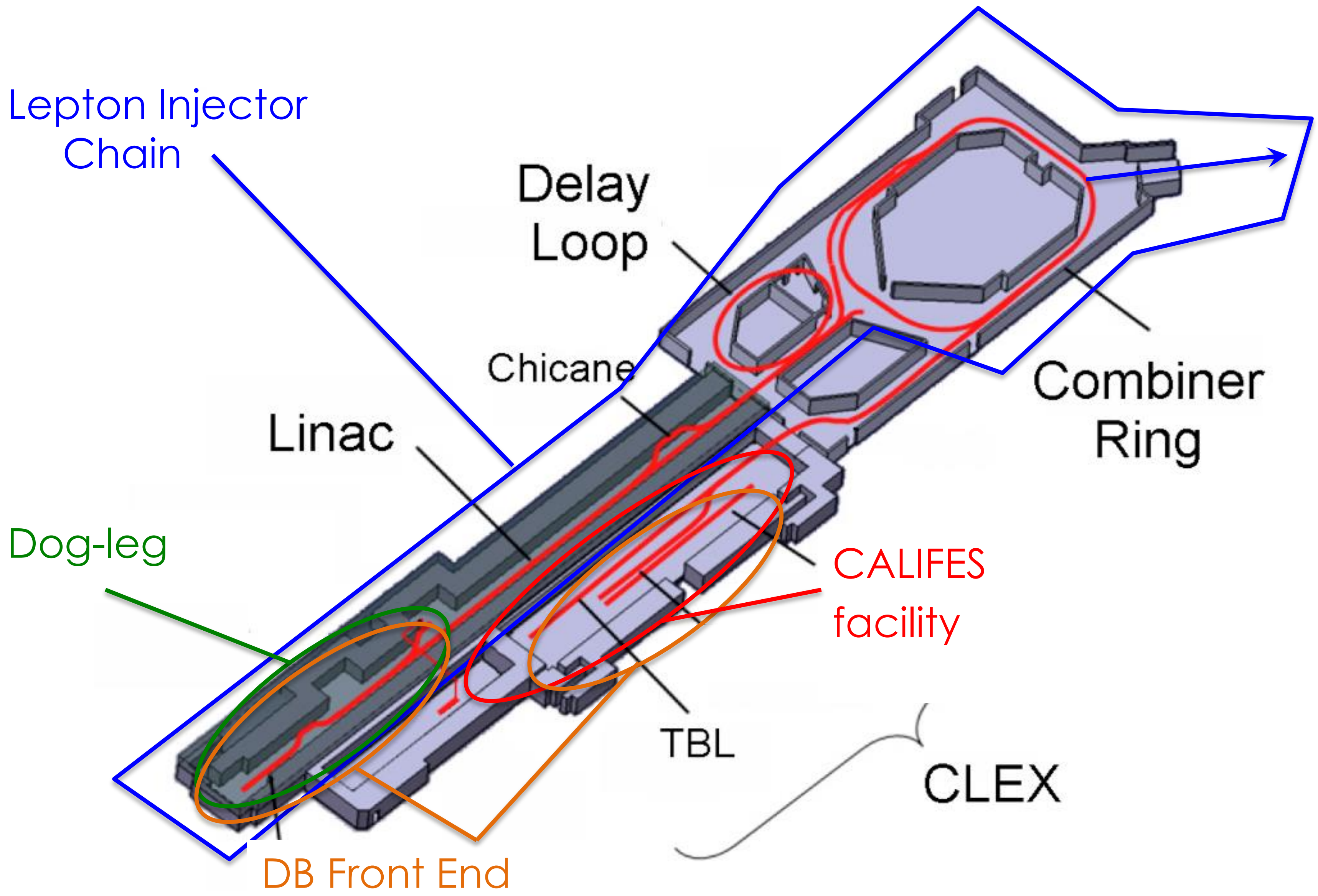
- CALIFES may provide an unique opportunity to test X-band structures/modules with beam
- XBOX1 located very close (distance comparable to present low-loss line for dog-leg beam loading experiment)
- Straight-forward solution: connect to XBOX1 for beam testing in CLEX
- An upgraded CALIFES beam may be not too far from what is needed for FELs: "Playing ground" for X-band FEL beam studies and developments
- Future possibility: test a full X-band module (for X-band FEL or klystron-based CLIC) – may need an additional modulator/klystron
- Add more? …

Layouts?


26.5 m
42 m
4.7 m
8 m
Stand Alone Test Stand


26.5 m
42 m
4.7 m
8 m
Low loss circular waveguide
Stand Alone Test Stand

Options


Lepton Injector Chain
Delay Loop
Chicane
Linac
Combiner Ring
Dog-leg
CALIFES facility
TBL
CLEX
DB Front End

CTF3 Decommissioning issues

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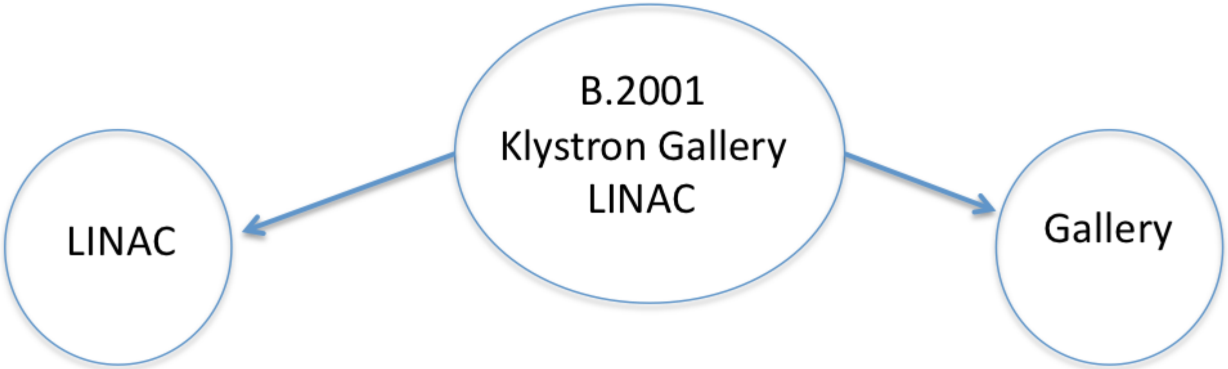
Example of clearing out an area



Controlled area
Not INB .. No INB paperwork needed ☺
Each item that is removed needs RP control
(full time RP technician in situe necessary)
Timescale …… some weeks maybe months
Storage area needed for activated items
Storage area needed for non activated items

No radiation issues as installation is not activated
Mainly klystron modulators
Magnet Power supplies
Control racks
Any requests for reusing components?
Significant manpower needed for removal and reinstallation

CTF3 Decommissioning & re-use issues

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- Simplest solution close the complex and lock the doors
- Continue running CTF3
  - Costs
    - New access control system needed
    - Upgrade of modulator controls (get rid of non supported CAMAC)
    - manpower
- Reuse the Linac and rings for electron injector to PS
  - Costs
    - New access control system needed
    - Upgrade of modulator controls (get rid of non supported CAMAC)
    - manpower
- CLEX
  - Keep CALIFES operational
    - New access control system needed SOLVED
- New DB injector test area
    - Use LINAC area but probably need civil engineering work in CTF2 area to allow modulators and klystrons to be installed (too large for gallery)
- CTF2
  - Continued PHIN tests, X band test area
    - New access system needed SOLVED

Yearly cost of CTF3 running

2012 running, relevant budget codes in blue

CLIC -EV		Budget Code Description	Charged to Budget Code (kCHF)	Annual Open Commitment (kCHF)
ABP	61440	CLIC-EV Drive Beam Phase Feed-forward and feedbacks	56	10
	61441	CLIC-EV Two-Beam module string	23	0
	61442	CLIC-EV Accelerator Beam System Tests	0	0
	61725	CLIC-EV General	480	23
	Total of ABP:		559	33
ABT	65776	CLIC-EV Kickers and Septas	2	0
	Total of ABT:		2	0
BI	64778	CLIC-EV Instrumentation	180	14
	Total of BI:		180	14
EPC	68725	CLIC-EV Power Converters	39	2
	68727	CLIC-EV Drive Beam Front-End (Modulators)	2	0
	Total of EPC:		41	2
OP	67700	CLIC-EV Operation, Consolidation & Upgrades	105	76
	Total of OP:		105	76
RF	69727	CLIC-EV RF	1433	149
	69792	CLIC-EV TBL+	67	3
	69793	CLIC-EV CLIC0 Drive Beam	0	38
	Total of RF:		1500	190
STI	63736	CLIC-EV CLIC0 Photoinjector & Laser	247	16
	Total of STI:		247	16
VSC	86756	CLIC-EV Vacuum	51	17
	Total of VSC:		51	17
Total of CLIC-EV:			2686	350

Include some consolidation and upgrade	2053	273

Yearly cost of CTF3 running

Codes	Equipment	Charged 2012 (kCHF)	Planned 2013 (kCHF)	Spent 2013 (kCHF)
67700+	Operation and Manpower (PhDs, PJAS)	200	380	340
65776	Kickers and Septas	2	4	13
64778	Instrumentation	180	230	170
68725	Power Converters	39	35	26
69727	Modulators	260	1323	890 (1200)
	Klystrons	550		
	Waveguides, networks, various manpower …	350		
	TWTs	100		
86756	Vacuum	51	44	58
63763	CLIC0 Photoinjector & Laser	80	50	50
TOTAL		1812	2066	

Taking out upgrades, divided by sub-systems

1550 (1860)

+ Manpower: about 15 FTE, including M to P

Contribution to AWAKE

- Awake needs 20 MeV electron source with low charge, small emittance and possibly short bunches
- One CTF3-type Klystron-Modulator would be needed to power the injector
- PHIN (Califes) type gun could be used
- Some diagnostics, vacuum equipment and magnets might be useful
- CTF-team experience would be likely helpful as well
- Test facility and pre-commissioning in CTF2 area?