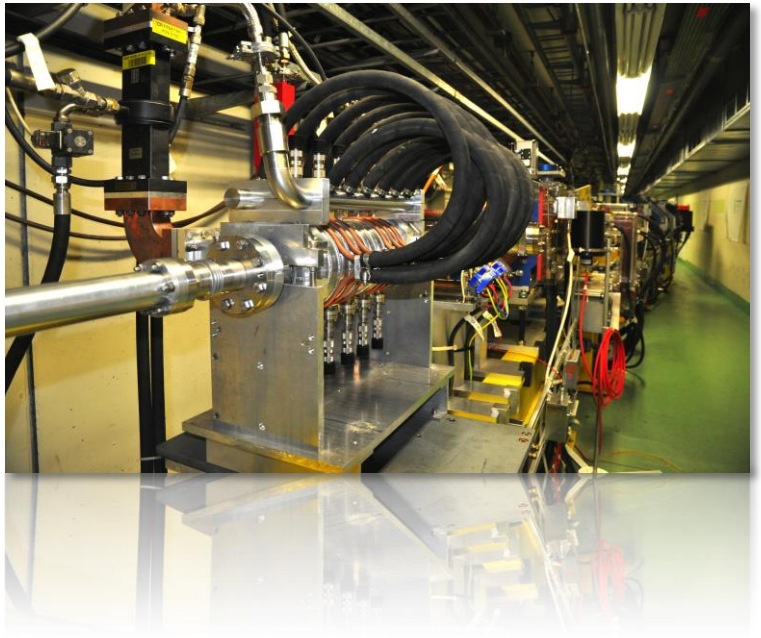
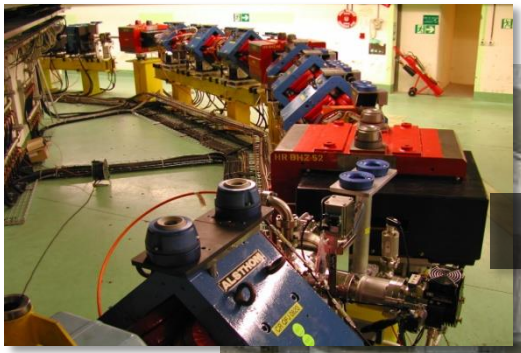
# Future tests beyond CTF3
## Overview of options & hardware

R. Corsini



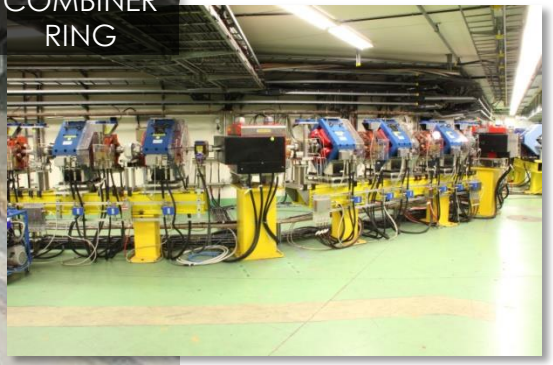
# CLIC Test Facility (CTF3)



DELAY LOOP


CERN

COMBINER RING

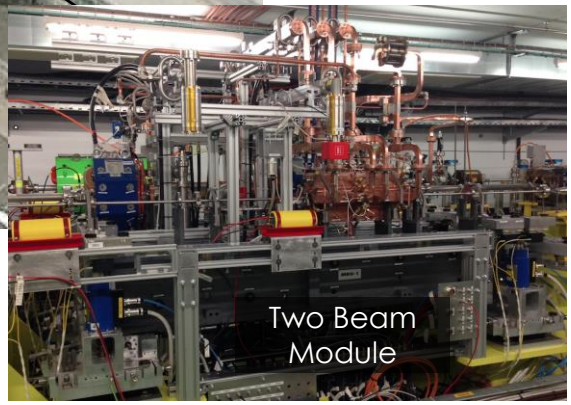


CLEX

DRIVE BEAM LINAC



TBL



Two Beam Module

# 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 next?*

- Discussions started in 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/

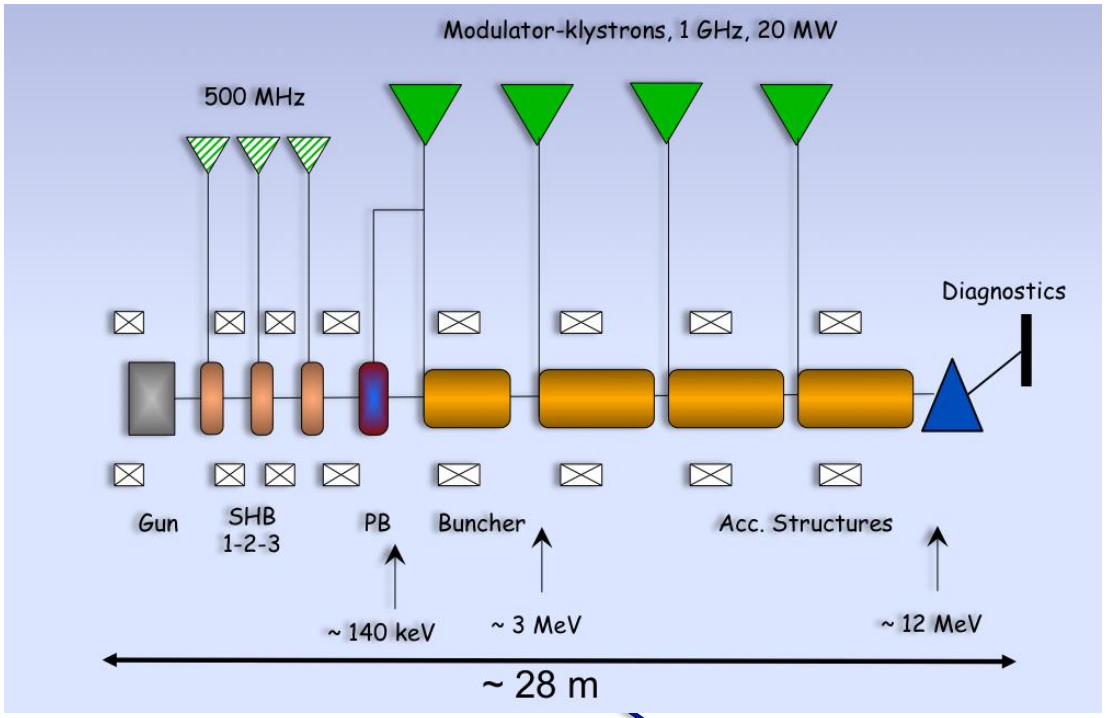

# Rationale for uses of CTF3 hardware beyond 2016

- CLIC Collaboration interest: keep beam test capability for CLIC (diagnostics, components…) locally at CERN after CTF3 stop
- Find synergies with other potential partners (project/groups within and outside CERN) in order to gather enough resources and get approval from CERN management
- 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


# Scope and aim of the session

- 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

# Drive Beam Front-End

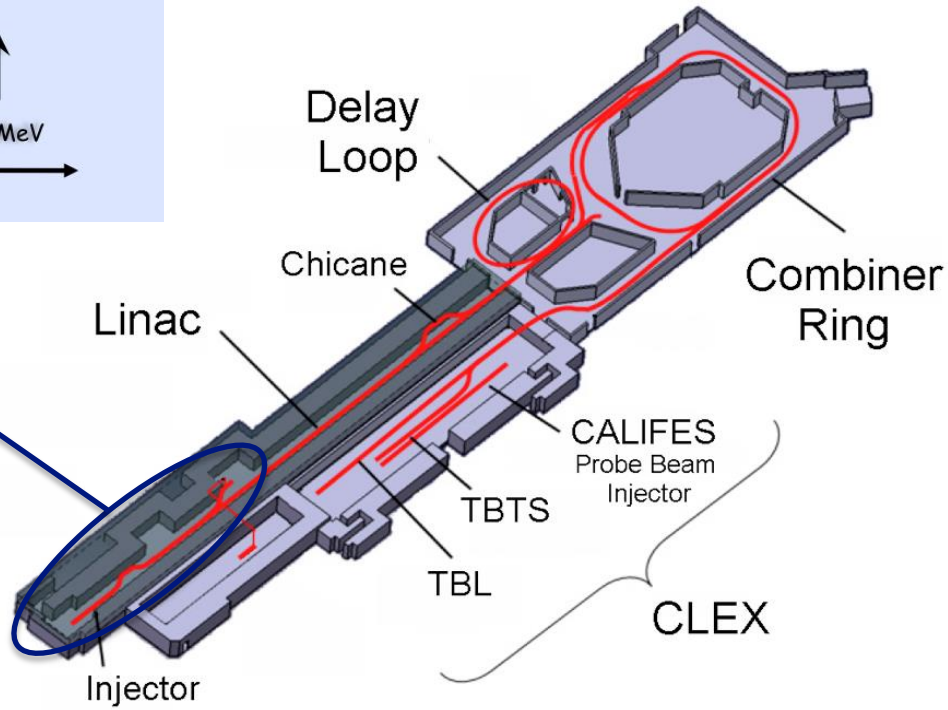



*The drive beam front-end in the CTF3 building – F. Tecker, LCWS2014*
http://agenda.linearcollider.org/event/6389/session/18/contribution/114/material/slides/0.pptx

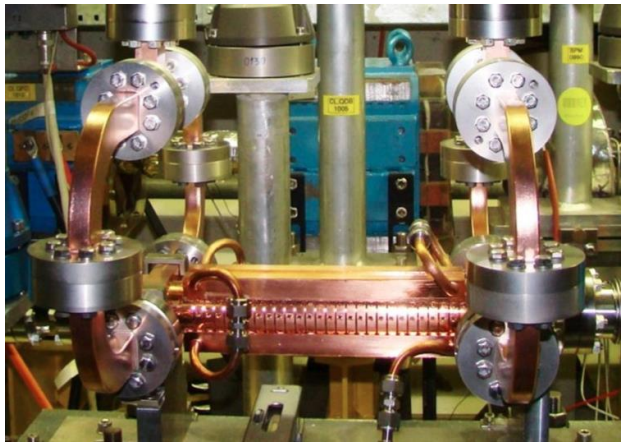
- Same peak current than present CTF3 injector (4 A)
- Longer pulse (140 us instead of 1.4 us)
- Higher rep rate possible (up to 50 Hz)

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

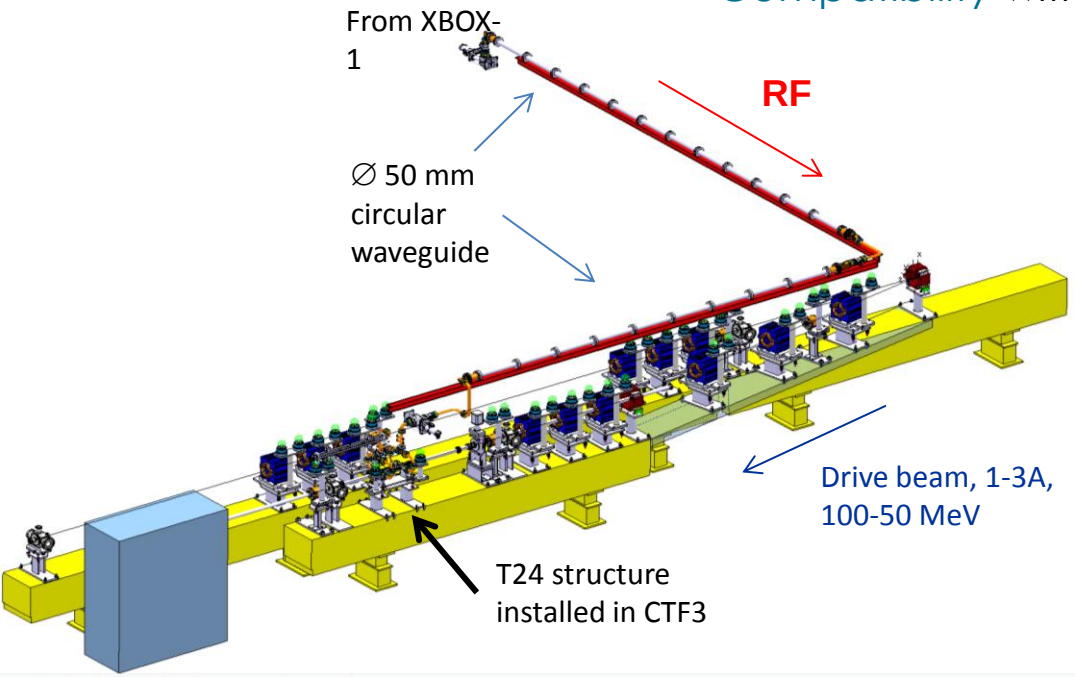
Will enable beam energies up to ~ 100 MeV with limited pulse length( ~ 4 us max).

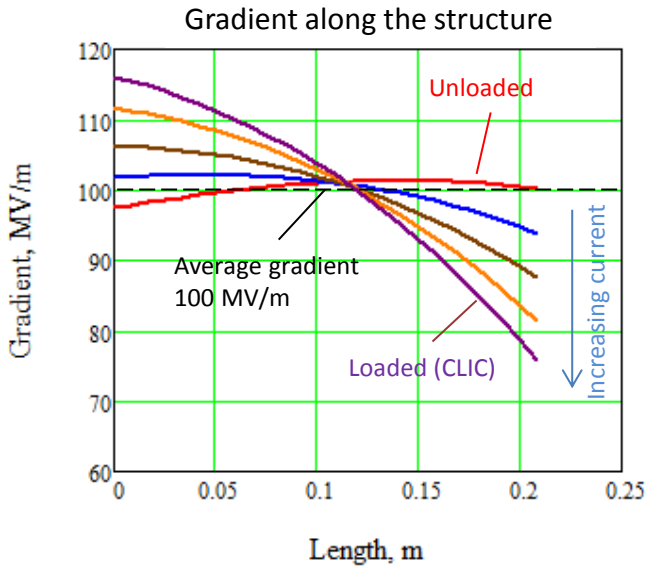


# Beam Loading experiment - run beyond 2016?



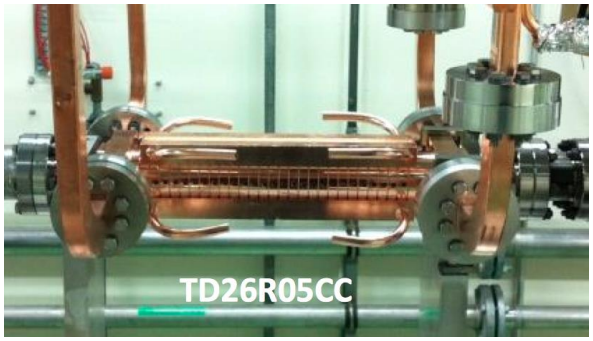
- From here to 2016 ~ 3 test slots (one per year) – not a large statistics
- In this time scale could have a new CLIC structure prototype from re-baselining, may want to test it
- May want to explore structures with different (tapered-up) gradient profile
- Need relative small infrastructure – 5 MKS,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

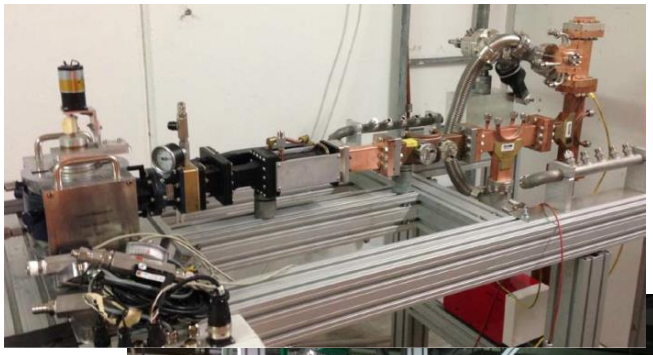


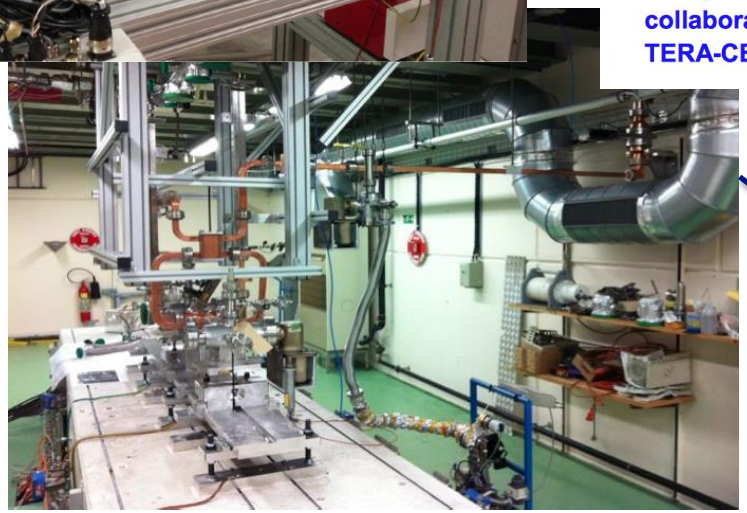



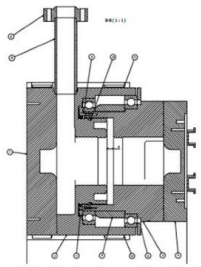
# Former CTF2 area, X-band and S-band RF testing

- 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

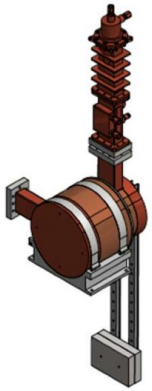


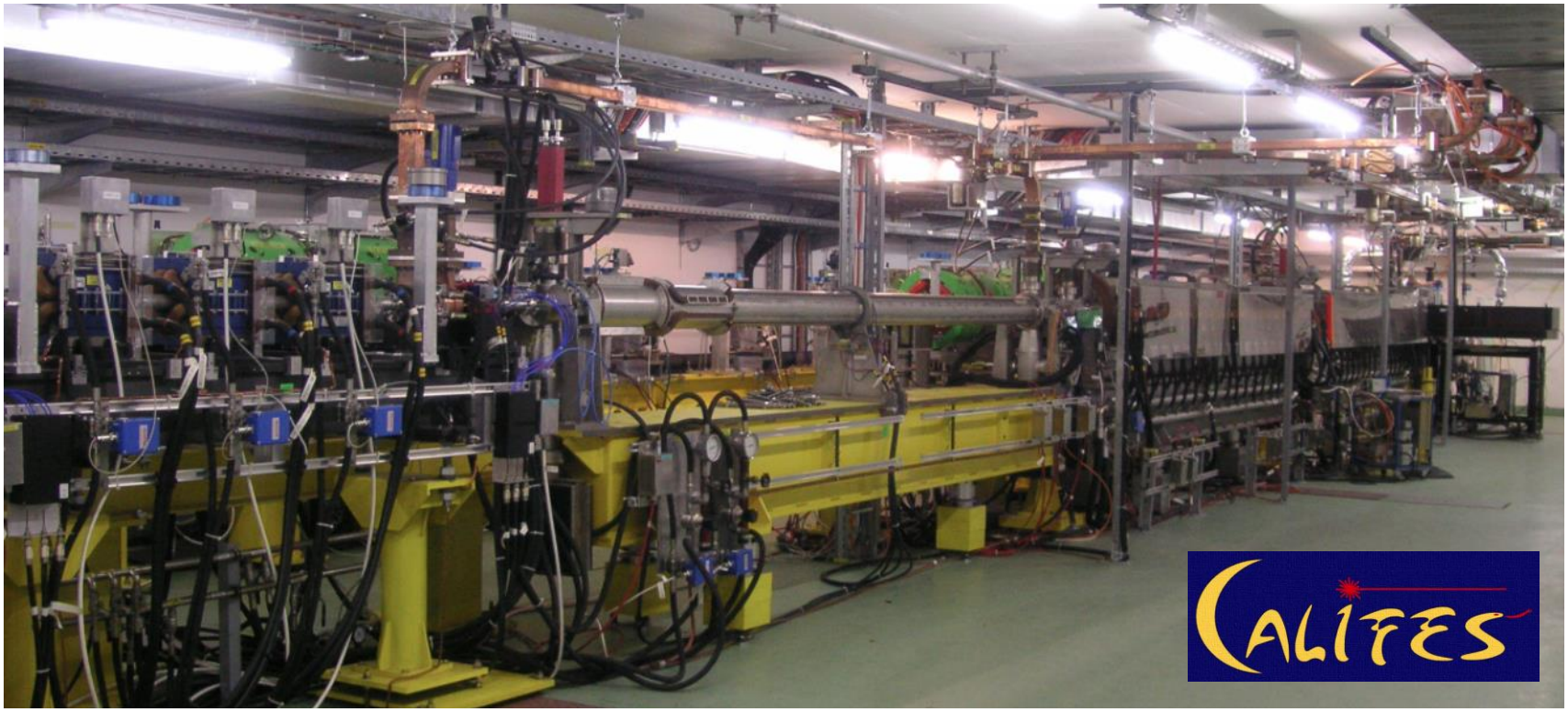


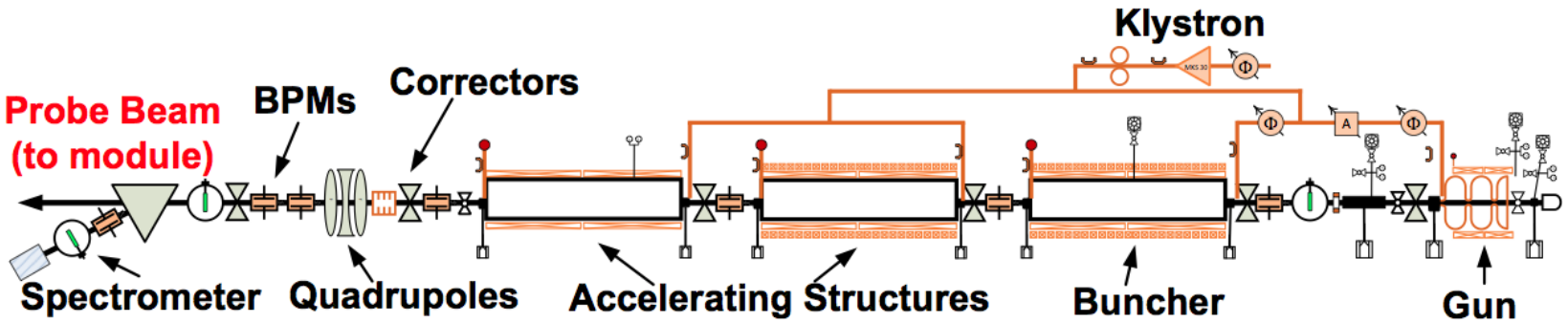


Design collaboration TERA-CERN



# CALIFES


CALIFES


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


# Potential interests for CALIFES based test facility

- R&D on diagnostics with beam tests (for CLIC, LHC & injectors, AWAKE…)

- X-band structure testing with beam (X-FEL, medical applications, Wake-Field monitors, deflecting cavities…)
- Irradiation tests (ESA/JUICE Mission, CERN?, others…)
- Impedance and wake-field measurements of components (LHC, CERN Injectors, CLIC… for: Cavities, diagnostics equipment, collimators, kickers…)

- 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
- …

| | | |
|---|---|---|
| 14:00 | **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* |
| 15:00 | *Council Chamber, CERN* | 14:50 - 15:10 |
| | **Use of Electro-Optics Sampling for Impedance measurements** | *steven JAMISON* |
| | **Coffee break** | |
| | *Council Chamber, CERN* | 15:30 - 16:00 |
| 16:00 | **Radiation testing with CALIFES** | *Markus BRUGGER* |
| | *Council Chamber, CERN* | 16:00 - 16:20 |
| | **Plasma wake-field acceleration possibilities in CTF3** | *Erik ADLI* |
| | **X-FEL requirements** | *Dr. Andrea LATINA* |
| | *Council Chamber, CERN* | 16:40 - 17:00 |
| 17:00 | **CTF3 controls renovation** | *Dr. Mick DRAPER* |
| | *Council Chamber, CERN* | 17:00 - 17:20 |
| | **Discussion** | |
| | *Council Chamber, CERN* | 17:20 - 18:00 |
| 18:00 | | |

# Overview of the session

# Beam parameters

- CALIFES beam
  - 0.01-1 nC bunches, 1.5 GHz spacing, from single bunch to 100 ns train
  - rep rate 1-50 Hz
  - 150-200 MeV
  - May provide lower energy (>10 MeV), need to study transport
  - Typical beam sizes 0.5 × 0.5 mm, uniform beam sizes obtained up to now 5 mm × 5 mm, up to few cm surely feasible.

# Beam parameters

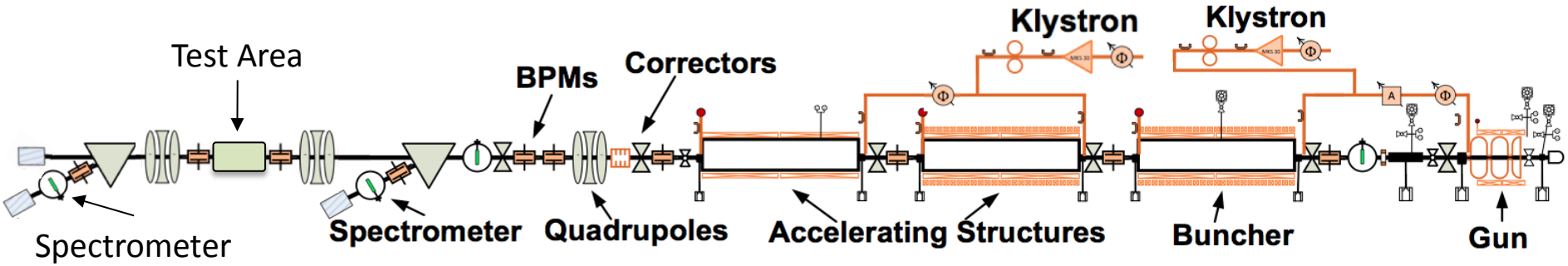
- CTF3 Drive beam (present)
  - 4 A, 1 us pulses (trains of 1-3 nC bunches, 1.5/3 GHz spacing)
  - rep rate 1-50 Hz
  - 50 – 125 MeV
  - May provide lower energy (>10 MeV), need to study transport
  - Typical beam sizes 1 × 1 mm, may easily fill round chamber, 4 cm diameter.

- 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.

# Future CALIFES – minimum configuration

Present

Future: CALIFES for beam instrumentation test



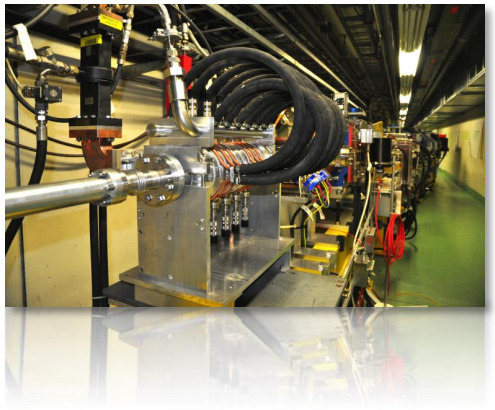

- Add an available S-band klystron + modulator
- More RF power (beam energy), more flexibility (power in 1st structure, phase in structures 2 and 3), possibility of running without RF pulse compression
- Reconfigure present TBM area as test area
- Most (all) hardware already existing

*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*

# 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

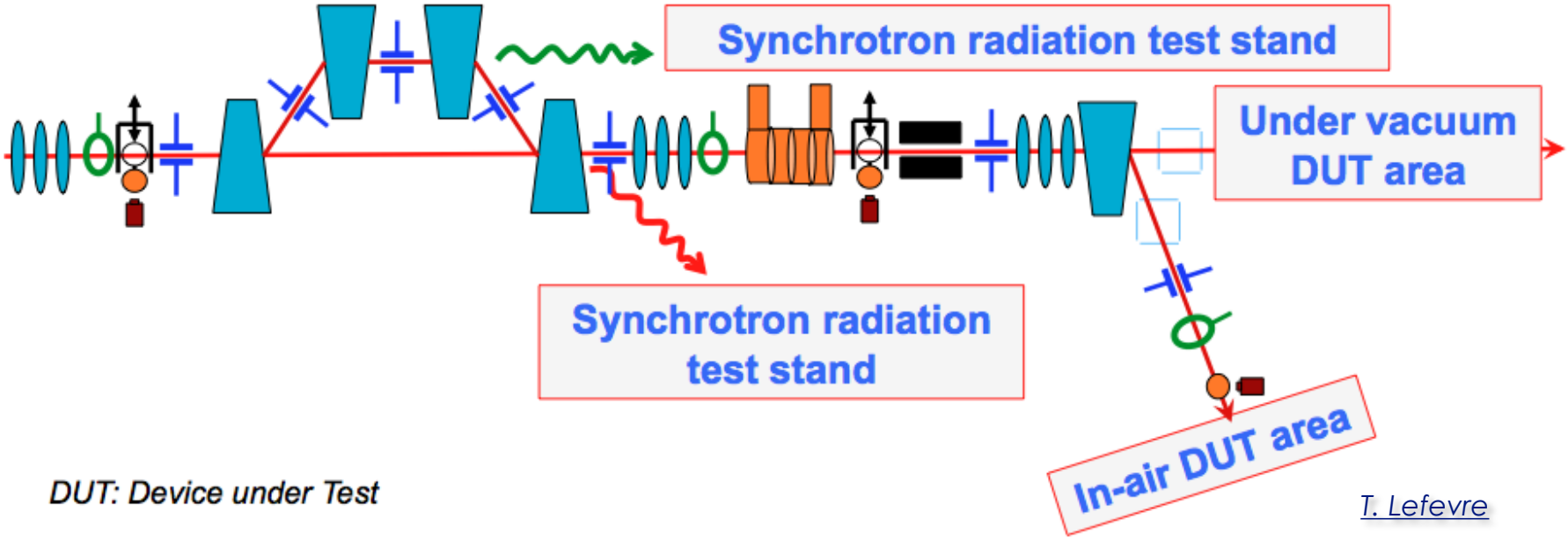
- Flexibility for single bunch / multibunch operation
- Flexibility in bunch charge – if high charge is needed, a switch between CALIFES gun and PHIN is still possible?
- Need of double pulse (drive + probe) for impedance/wake-fields measurements (and possibly plasma applications?). Flexibility in drive/probe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

# "Ultimate" test area layout to cover BI needs

**Magnetic chicane**
Shorten or lenghthen
100fs up to 200ps

**RF deflector**
for crabbing

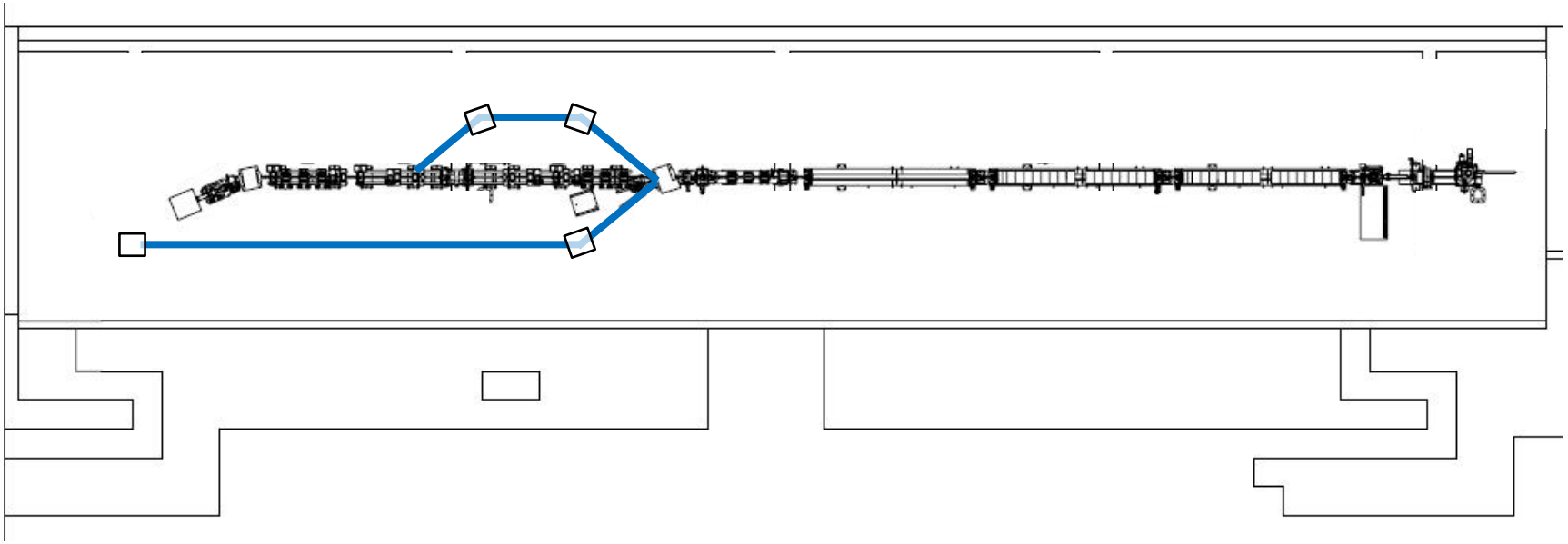
**Collimator**
- Reduce the bunch intensity before the DUT zones
- Reduce bunch length further in combination with RF deflector




*DUT: Device under Test*

T. Lefevre

# 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…)

# 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


# Some consideration on resources

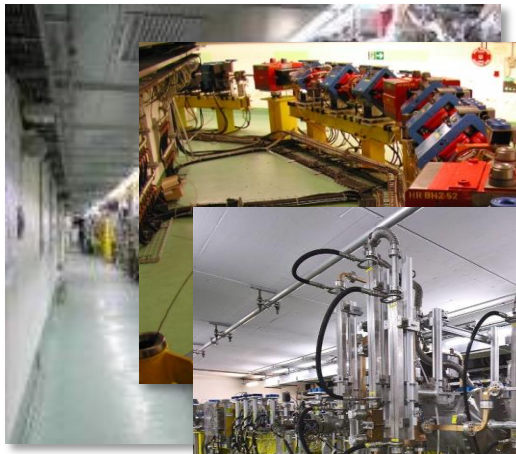
- Given the present CTF3 material budget/manpower, one may roughly evaluate the resources needed to keep CALIFES running after 2016 to about:
  - 200-300 kCHF/year (including M to P – students and PJAS)
  - About 5 FTEs (staff and fellows)
- The above would include a minimum upgrade (1 ½ additional klystron,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

# Outlook

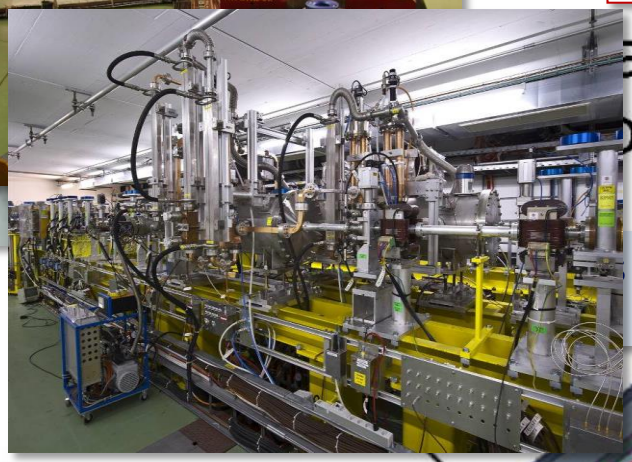
- CALIFES may be a reasonably cheap multi-purpose test facility
  - Useful within the CLIC study – potentially much wider interest
  - (Would help if enough support should come from outside the CLIC study or/and outside CERN)
- Minimum to medium upgrades will enhance flexibility/usefulness
- Connection to XBox1 seems a logical step
  - Possibilities of further upgrades
- Need full cost/resource assessment and evaluation of scientific case of the different options
- Develop an integrated proposal.


# THANKS
# for your attention

# CLIC Test Facility (CTF3)







Operation of isochronous lines and rings

High current, full beam-loading operation

Beam recombination & current multiplication by RF deflectors

CALIFES
Probe Beam
Injector

TBTS

TBL

CLEX

30 A, 140 ns
60 MeV

Injector

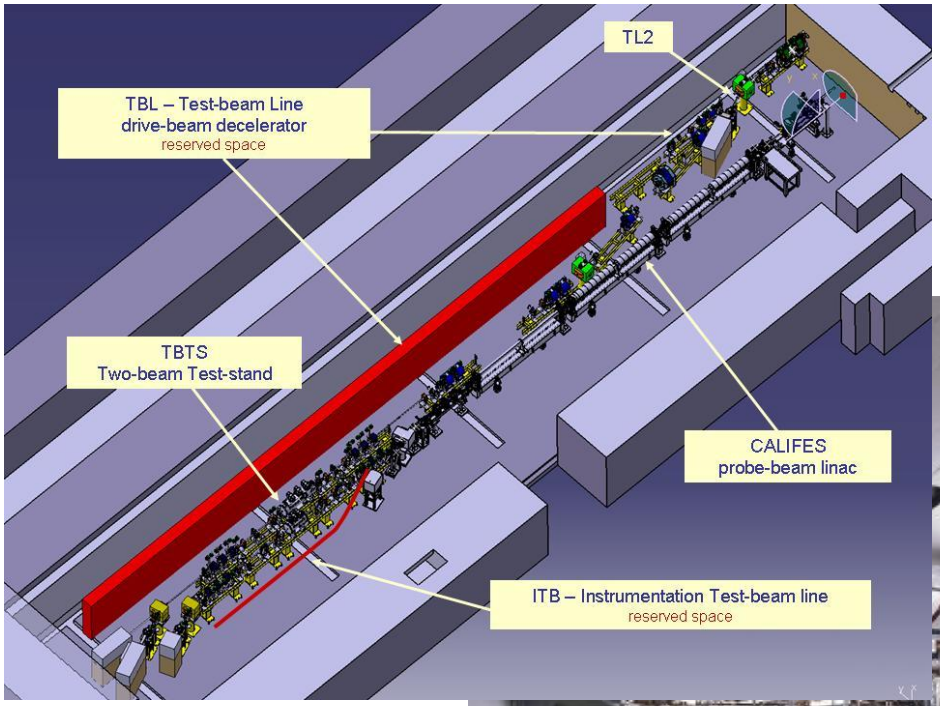
Bunch phase coding

12 GHz power generation by drive beam deceleration

High-gradient two-beam acceleration

PETS ON/OFF

# 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/*

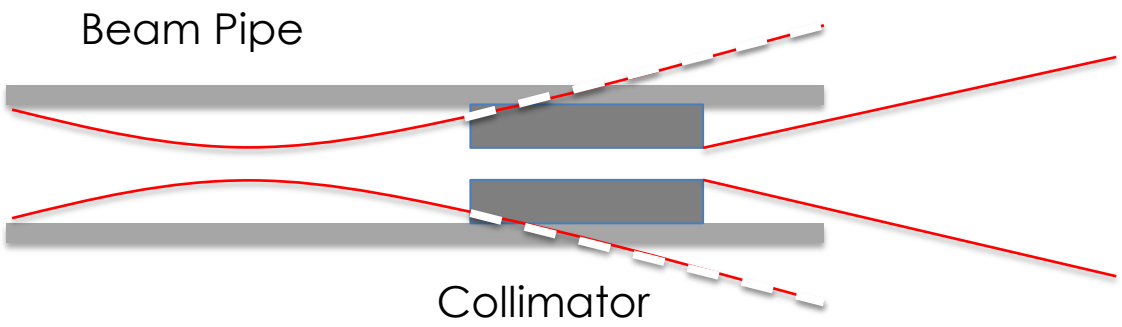
## Challenges for CALIFES

- 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*

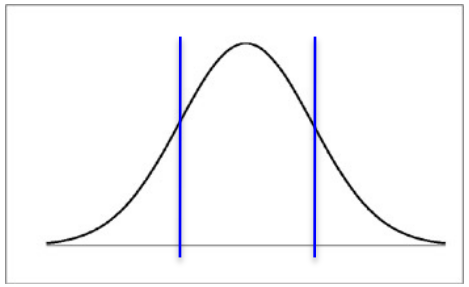
# Open issues/questions

- 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)
- …

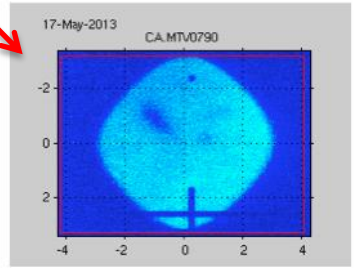
# Uniform beam - Filling the aperture



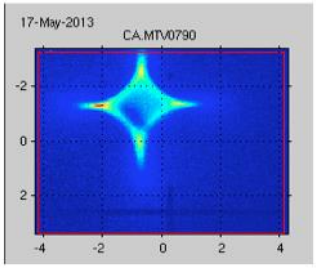

Test area



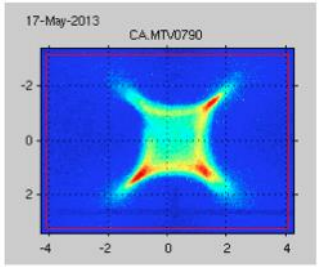
## Octupolar field study




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

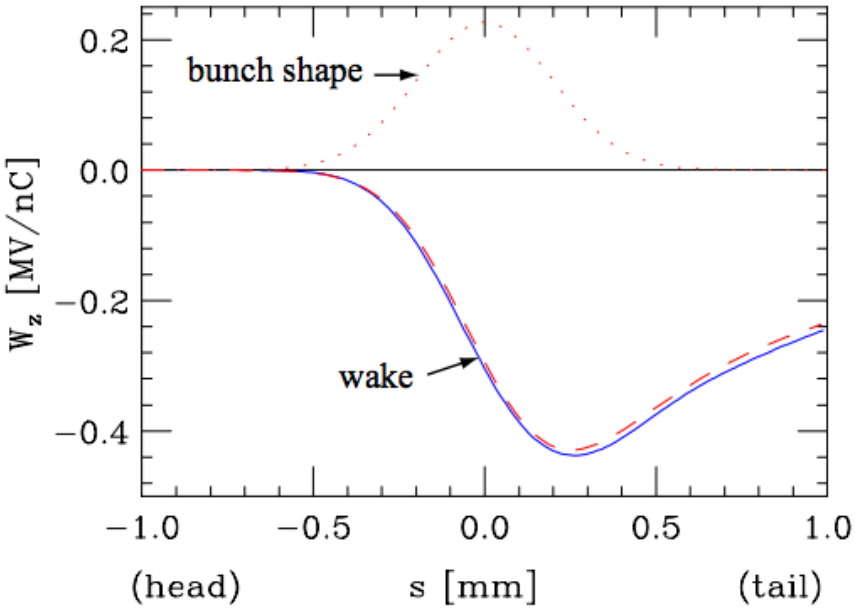
Longitudinal wakes cause energy loss and correlated energy spread (chirp)

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

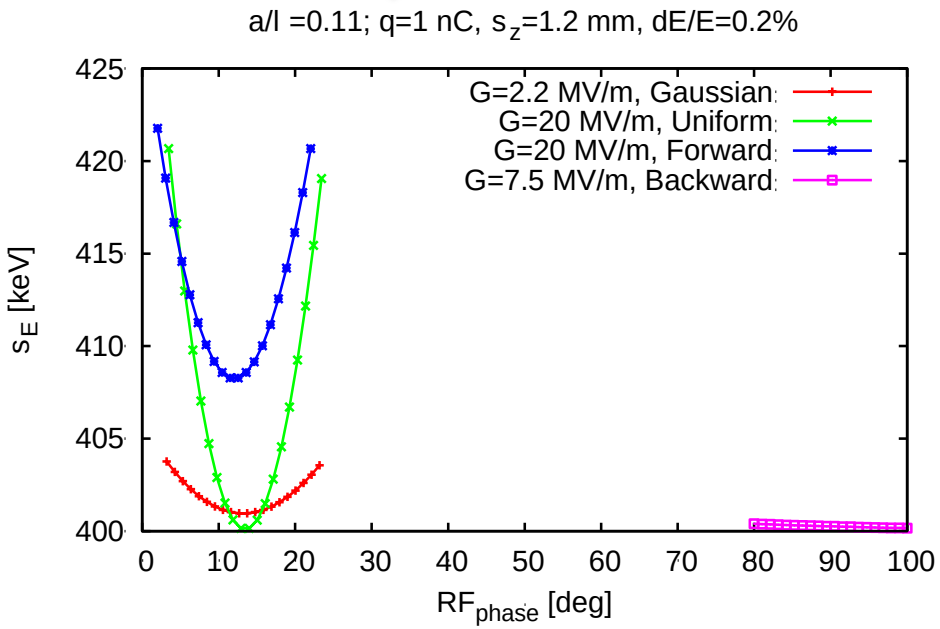
CALIFES-like parameters:
- Two CLIC AS with a/λ = 0.11
- Bunch charge = 1 nC
- Average energy = 200 MeV

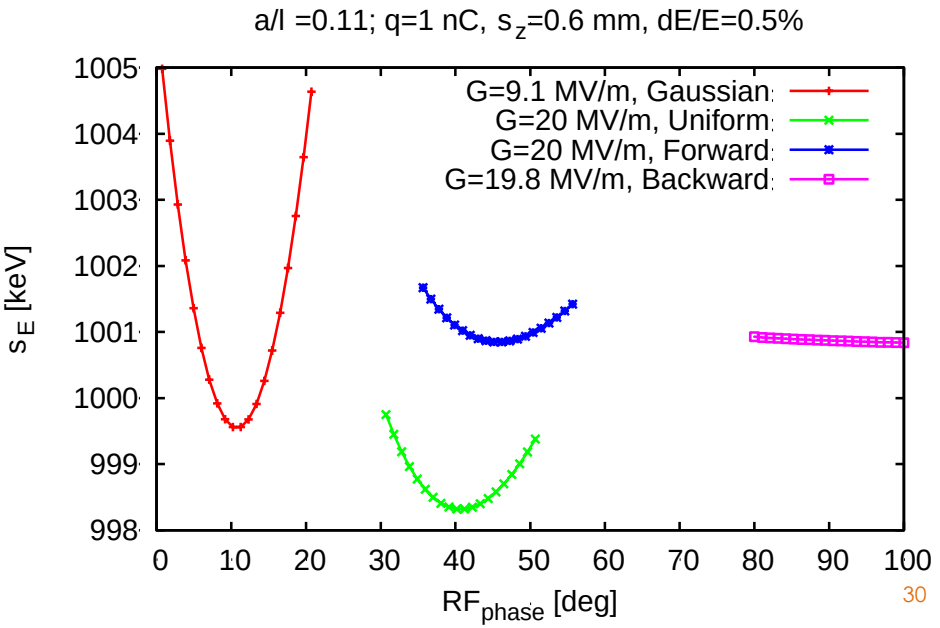
Two bunch configurations considered:
- Bunch uncorrelated espread = 0.25 %
- Bunch length = 1200 um

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

Four different longitudinal distributions
- Gaussian
- Uniform
- Forward
- Backward

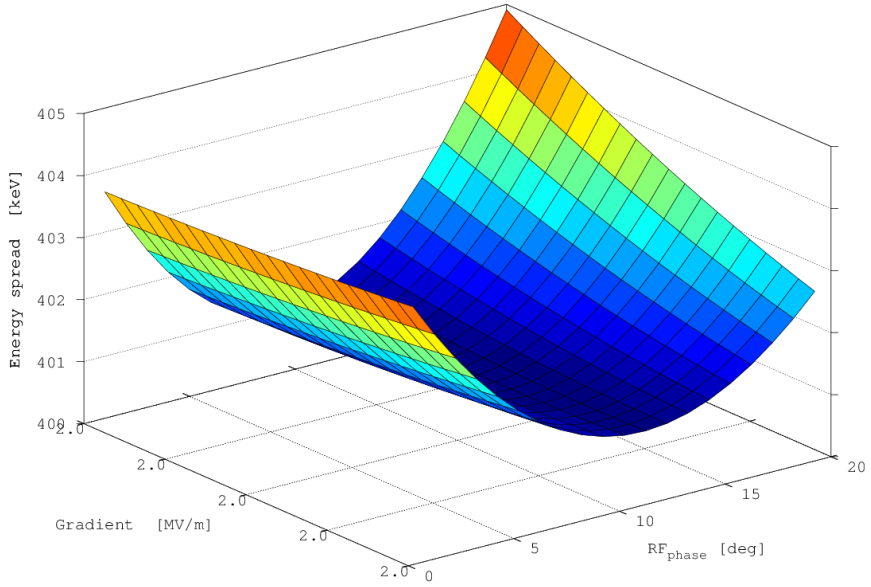
The plots show the result energy spread:



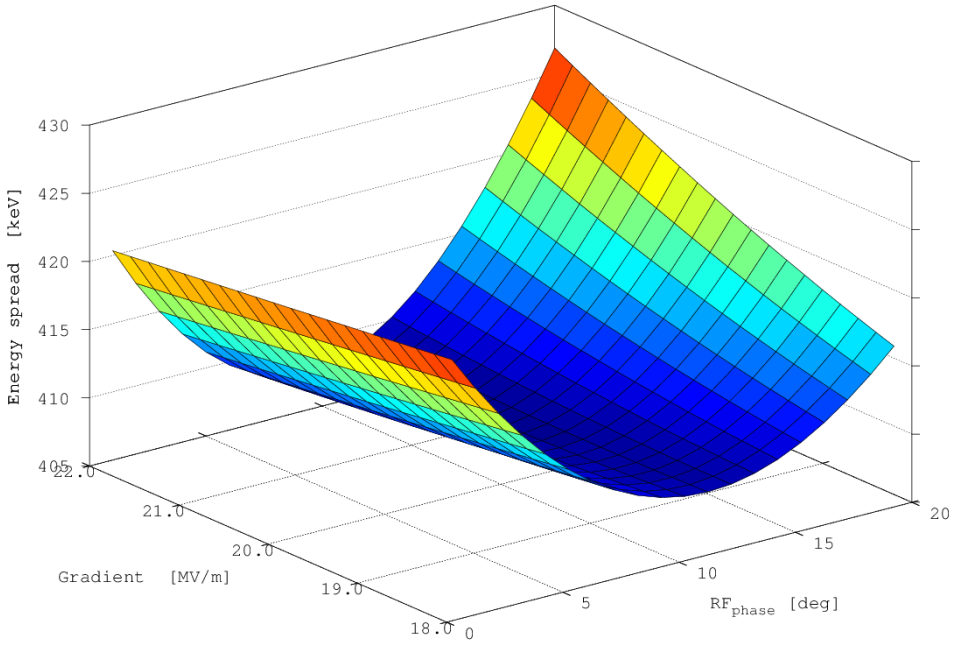
# Dependence on voltage is much weaker

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



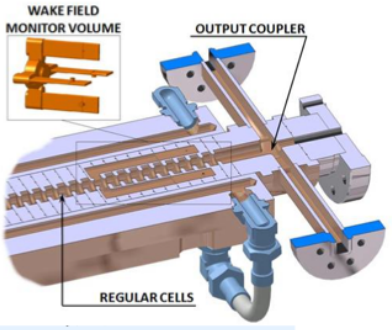

Gaussian:
- Resolution required ~ 1 keV

Uniform
Resolution required ~5 keV

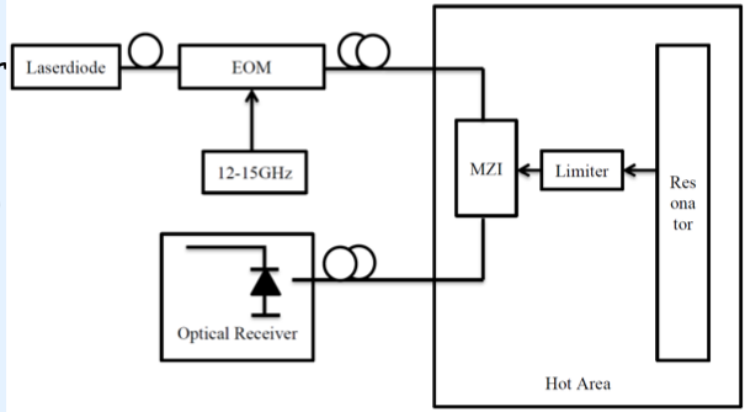


PAUL SCHERRER INSTITUT

# 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 !

*G. McMonagle*

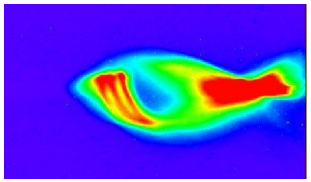
- It may be wise to "mothball" CTF3, also to keep open the possibility to re-start CTF3 after 2016 if needed (new module generation?) and according to CERN priorities
- Hovever, this clashes with requests to re-use CTF3 buildings and equipment…

- 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".

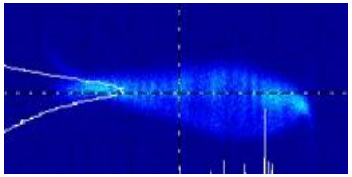
# CALIFES

| 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 |

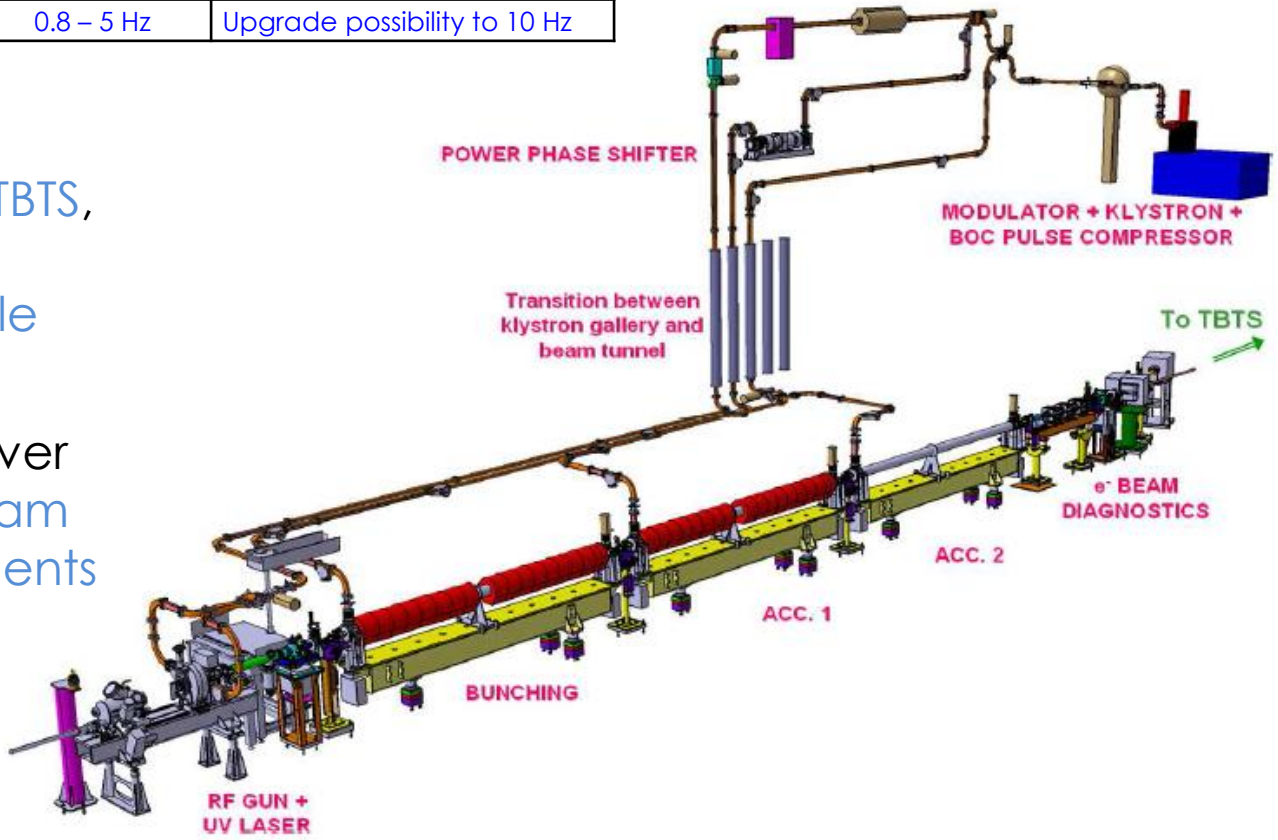


CALIFES

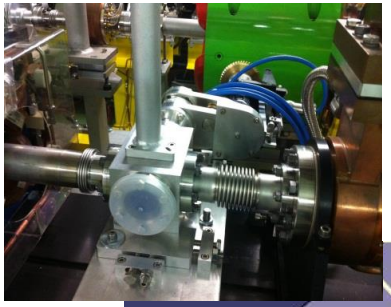
Swiss FEL injector (courtesy Simona Bettoni)



- Up to now used on TBTS, from November:
  ➔ Two-Beam module
- Growing activities over the last years on beam diagnostic/components testing

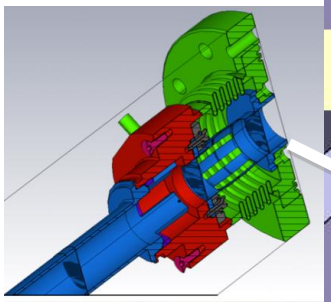


# Beam Diagnostic Tests in CLEX



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

Stripline Drive Beam BPM in TBL
*(CERN-LAPP)*



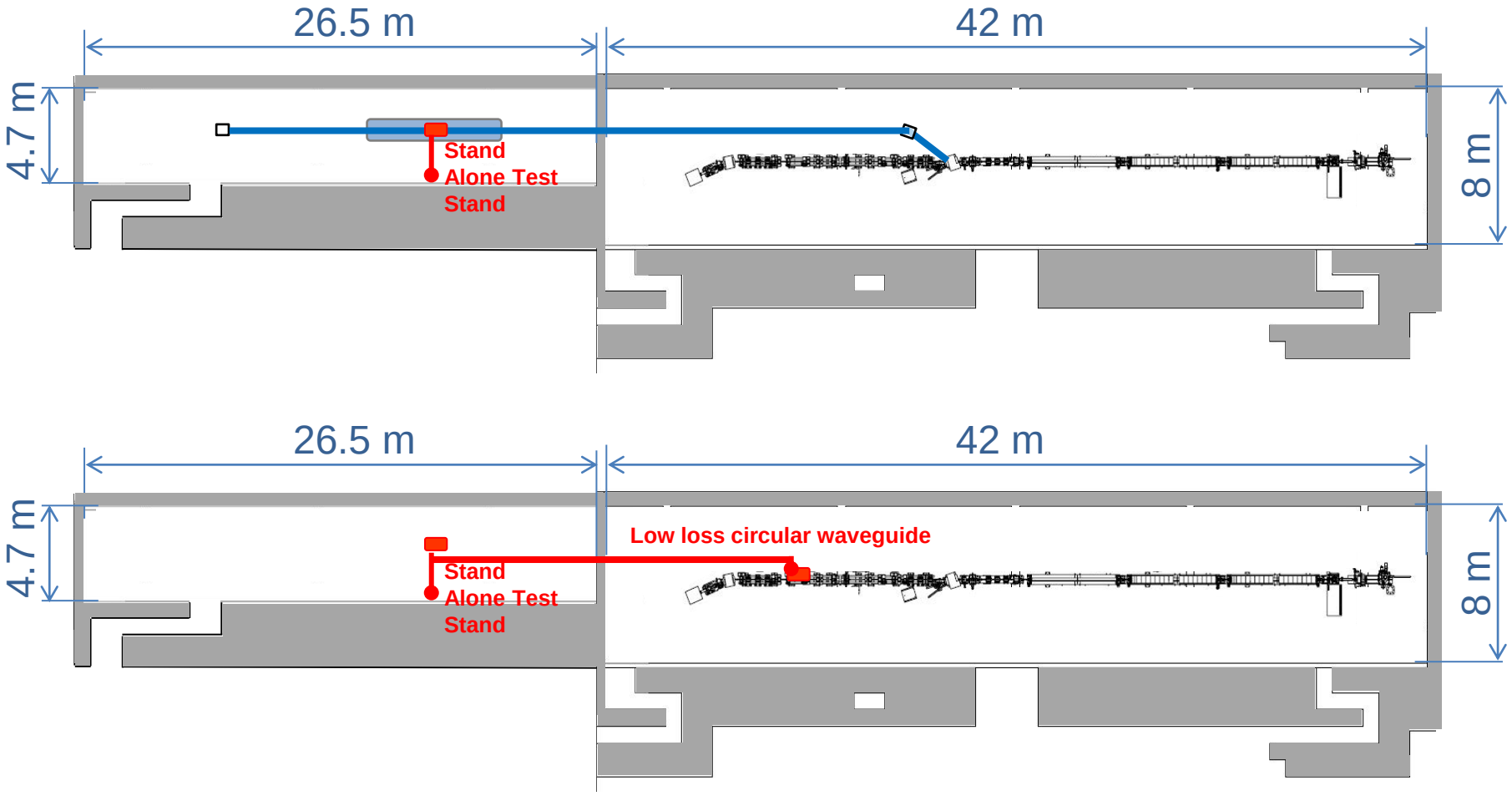



Cavity Main Beam BPM in CALIFES/TBTS
*(CERN-JAI at Royal Holloway)*

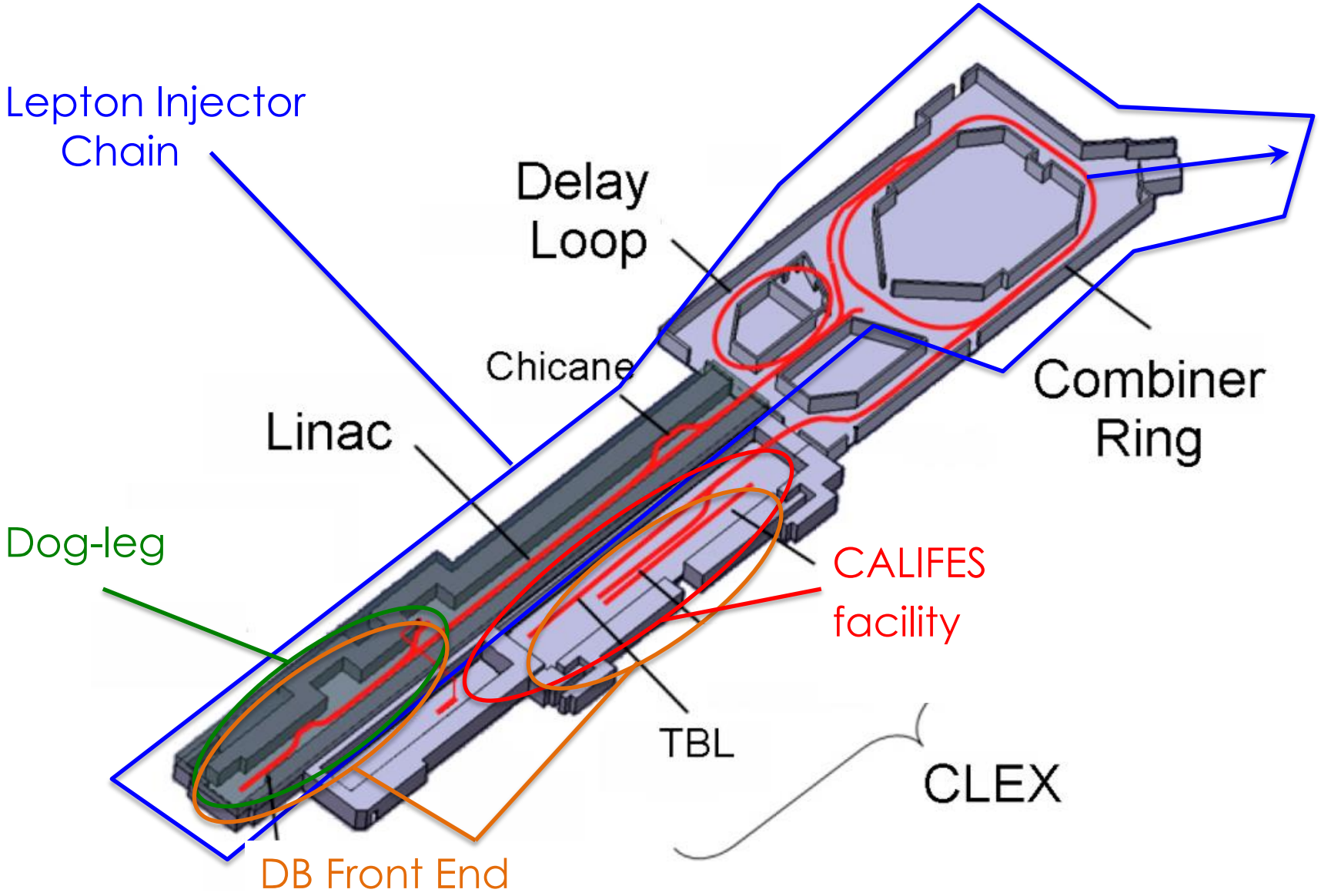
# X-band

- 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

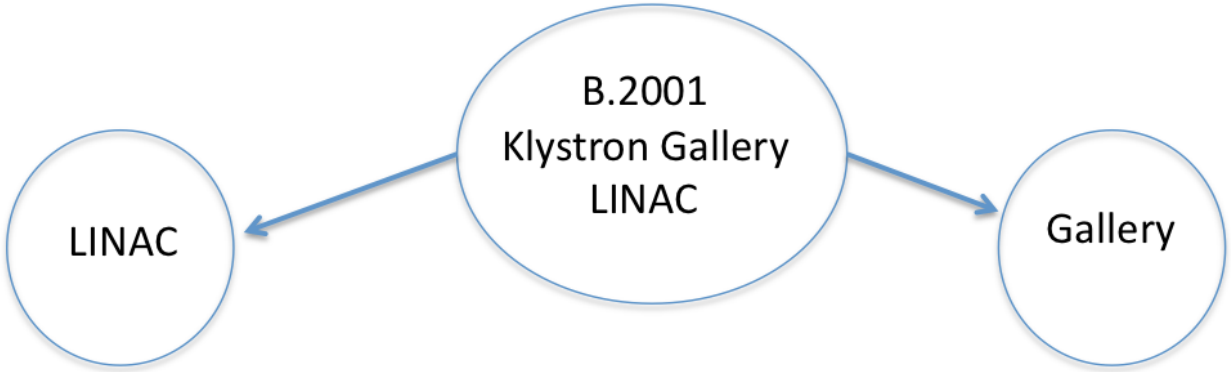
# Options


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

# CTF3 Decommissioning issues

*G. McMonagle*

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

*G. McMonagle*

- 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 | |
| | Klystrons | 550 | | 890 (1200) |
| | 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?