Review of Results
WP9 - NCLinac

Erk JENSEN, CERN

June 2013

EuCARD'13

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WP9 – NCLinac: goals

- **Over 4 successful years, NCLinac focused on identified R&D issues for a future electron-positron linear collider:**
  - High gradient acceleration (here normal-conducting)
  - Nanometre (transverse) and femtosecond (longitudinal) beam stabilisation
- **NCLinac was well integrated in the CLIC R&D effort concentrated at CERN and the ILC GDE.**
- **Supported infrastructures: CTF3 at CERN, DAΦNE at LNF and ATF2 at KEK,**

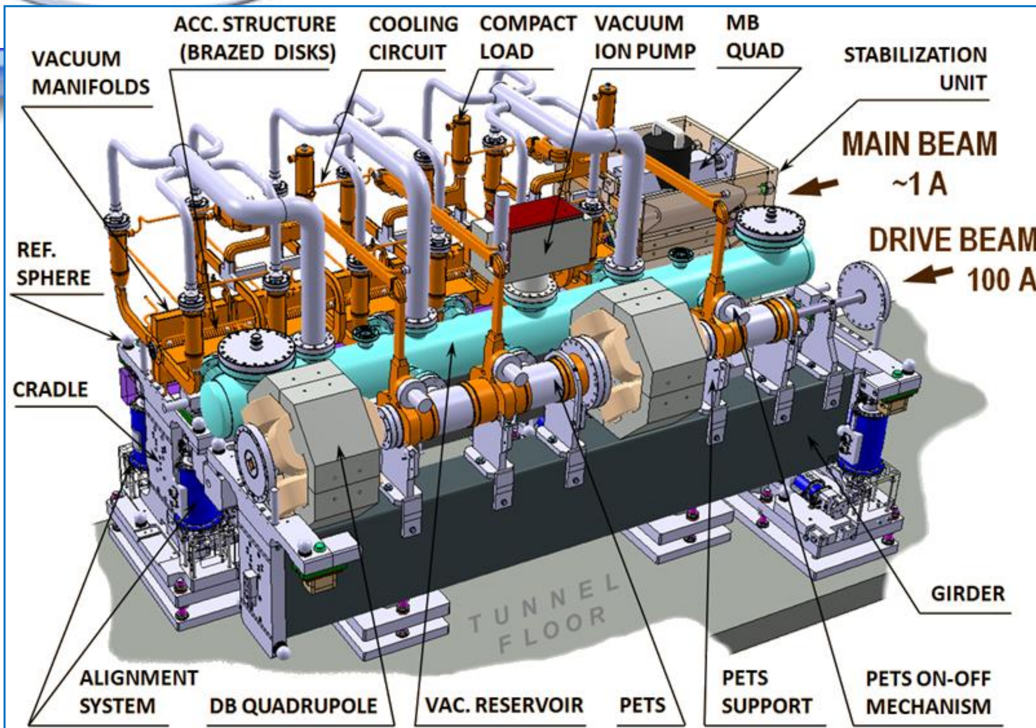
NCLinac – Tasks

- **9.2: Normal Conducting High Gradient Cavities (& module integration)**
  - Special PETS for CTF3
  - HOM damping
  - Breakdown simulation
  - Breakdown diagnostics
  - High precision assembly
- **9.3 Linac & FF Stabilisation**
  - 1 nm CLIC quadrupole stabilisation
  - 0.1 nm FF stabilisation
- **9.4 Beam Delivery System**
  - Test tuning procedures at ATF2
  - Precision BPM's
  - Laser-wire system
- **9.5 Drive Beam Phase Control**
  - RF phase monitor
  - electro-optical system

NCLinac People

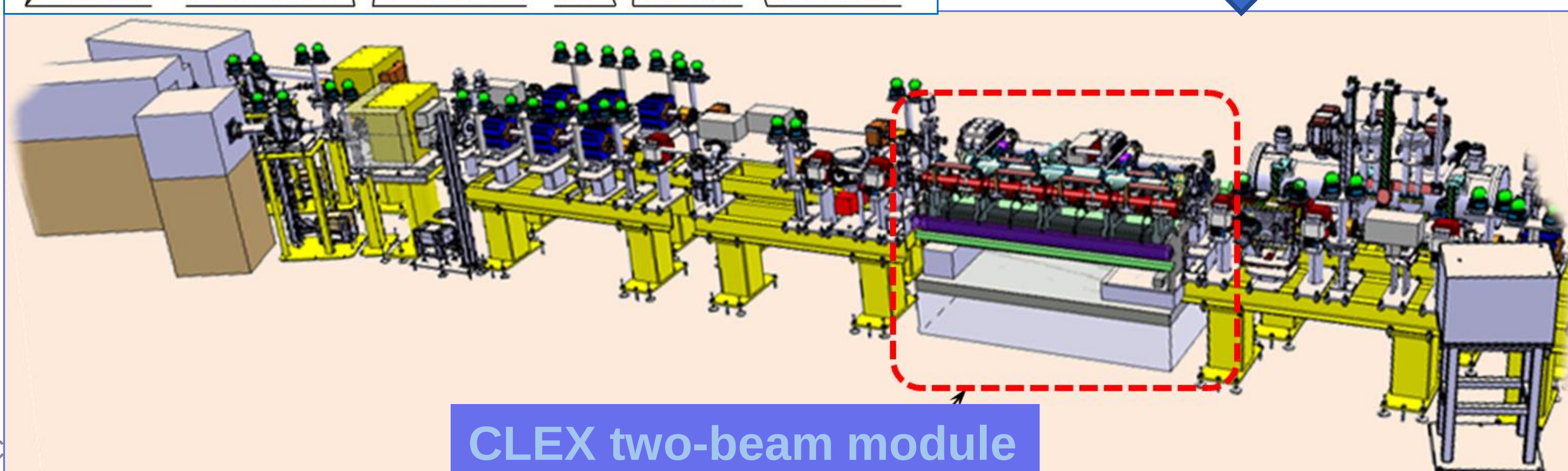
	Coordination	High Gradient	Stabilisation	BDS	Phase control
CERN	**Jensen**	**Riddone,** Kahn, Dubrovsky, Muranaka	Mainaud-Durand, Artoos, Esposito, Fernandez Carmona, Modena		Andersson
CIEMAT		Toral, Sánchez, Aragón, Calero, Gavela, Lara, Gutiérrez, Rodriguez			
CNRS/LAPP			**Jeremie**, Balik, Allibe, Deleglise, Brunetti,		
INFN/LNF					**Marcellini**
PSI					Dehler, Kaiser, Arsov
RHUL	**Boogert**			**Boogert**, Lyapin	
STFC/ASTEC				Angal-Kalinin, J. Jones, Scarfe	
UH		Österberg, Djurabekova, Raatikainen, Nordlund, Pohjonen, Parviainen			
UNIMAN		R. Jones, D'Elia		Appleby, Toader, Tygier	
UOXF-DL			Burrows, Christian		
UU		Ziemann, Ruber, Leifer, Palaia			

WP9.2 – High Gradient Acceleration



CLIC two-beam module

UH: High-precision assembly and breakdown studies
UNIMAN: HOM damping studies
UU: diagnostic equipment
CIEMAT: PETS design and fabrication

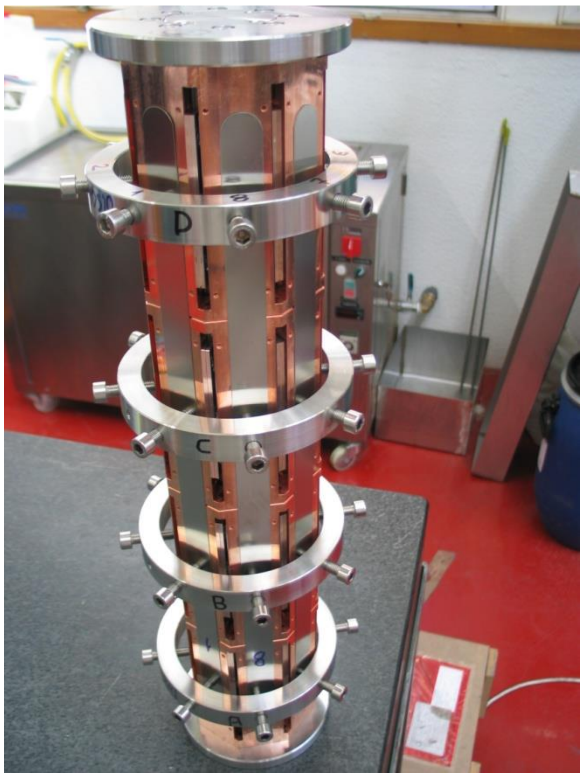


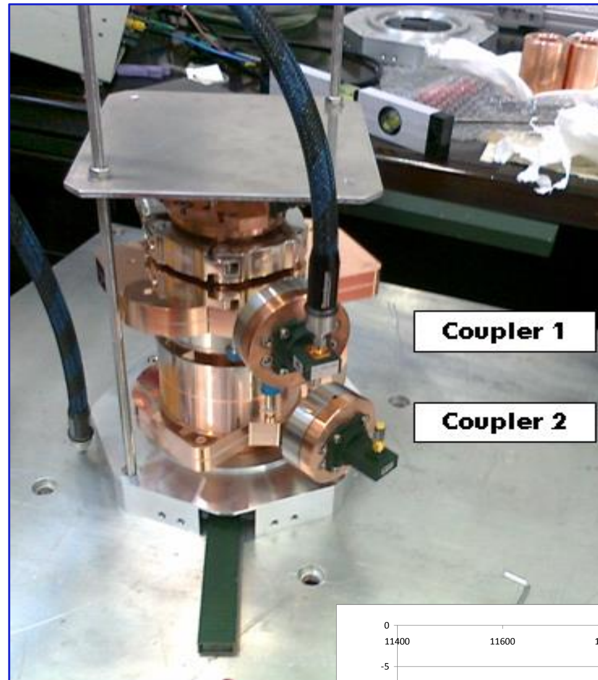
CLEX two-beam module

WP9.2 – Special PETS

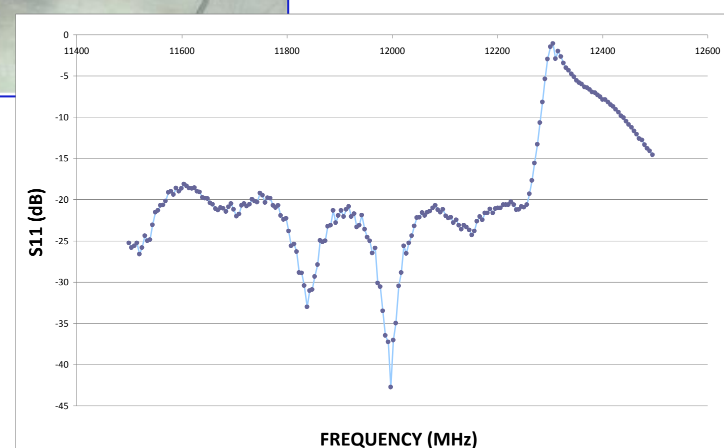
CIEMAT: PETS design and fabrication

Bars for the first double-length PETS successfully assembled. At current at CERN for EBW





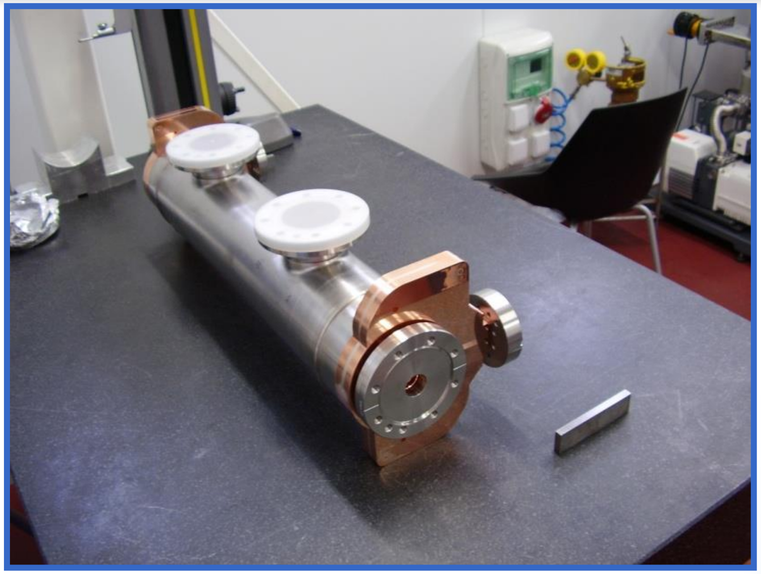
Coupler machining completed and couplers successfully tested

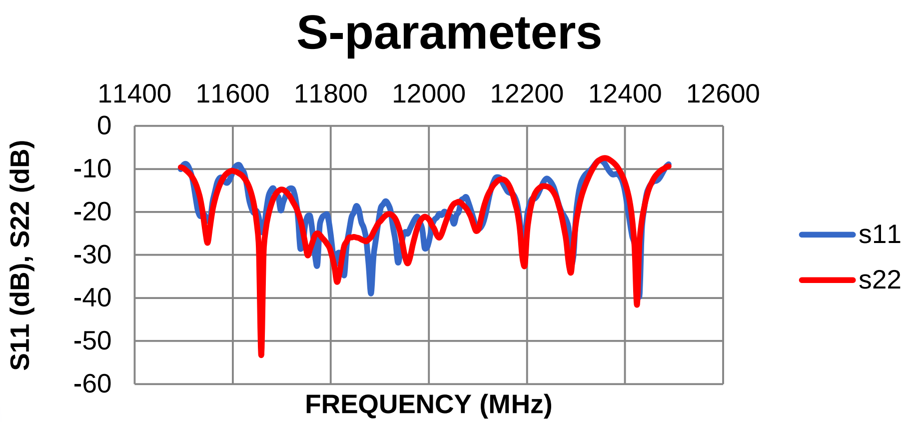


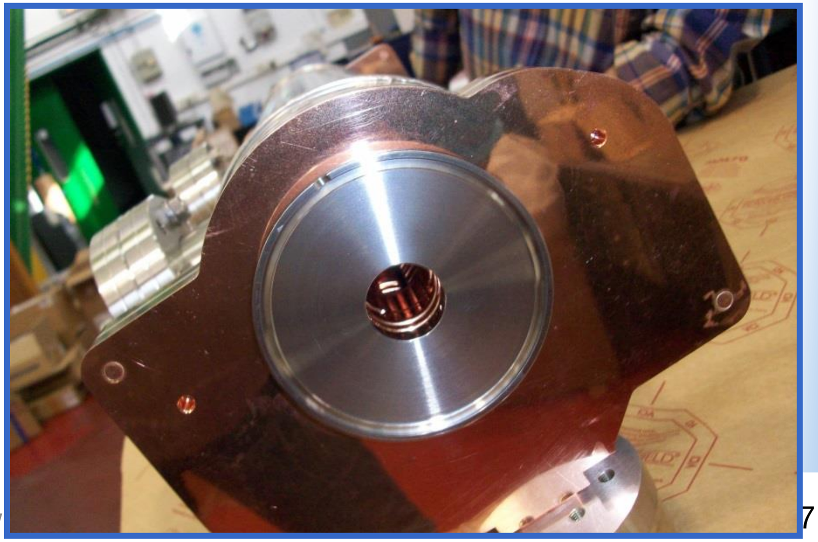
WP9.2 – Special PETS

CIEMAT: PETS design and fabrication

- **Readily assembled double length PETS:**



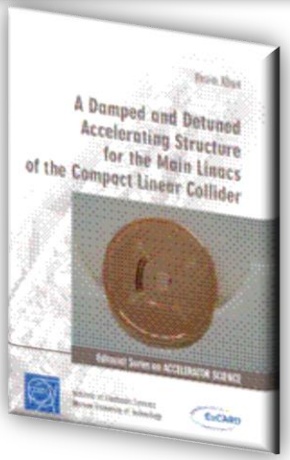


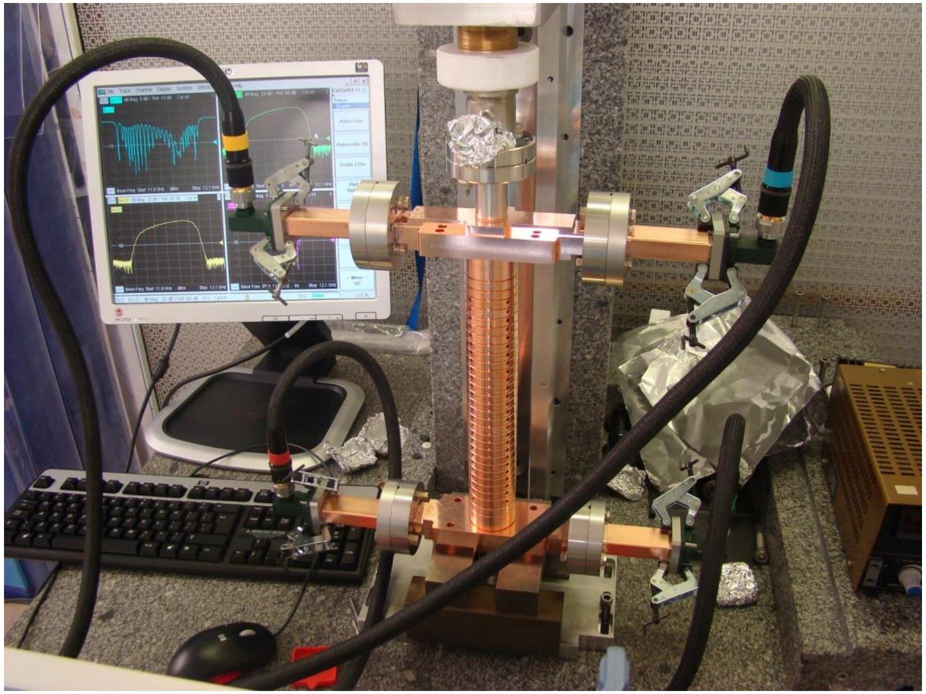


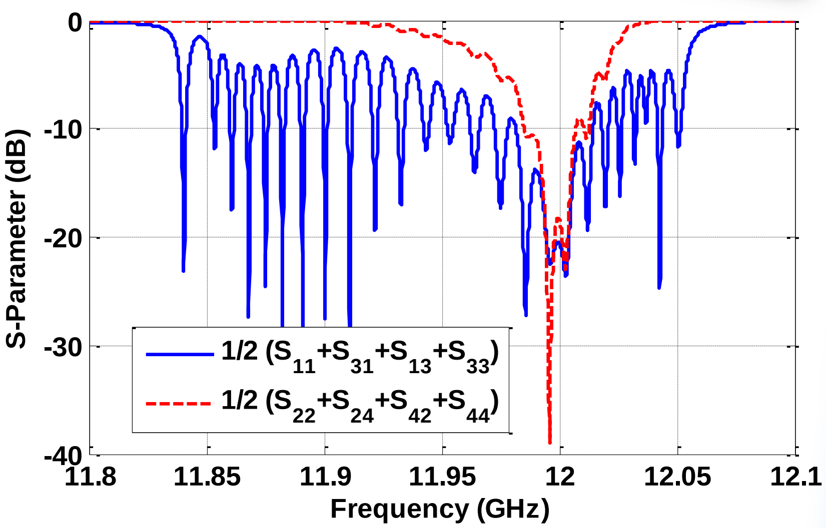
WP9.2 – HOM Damping

UNIMAN: HOM damping studies

- **DDS idea – combine damping and detuning; relax by using "interleaved" structures.**
- **Successfully finished (incl. PhD Khan)**
- **Structures successfully built, tuned and measured!**

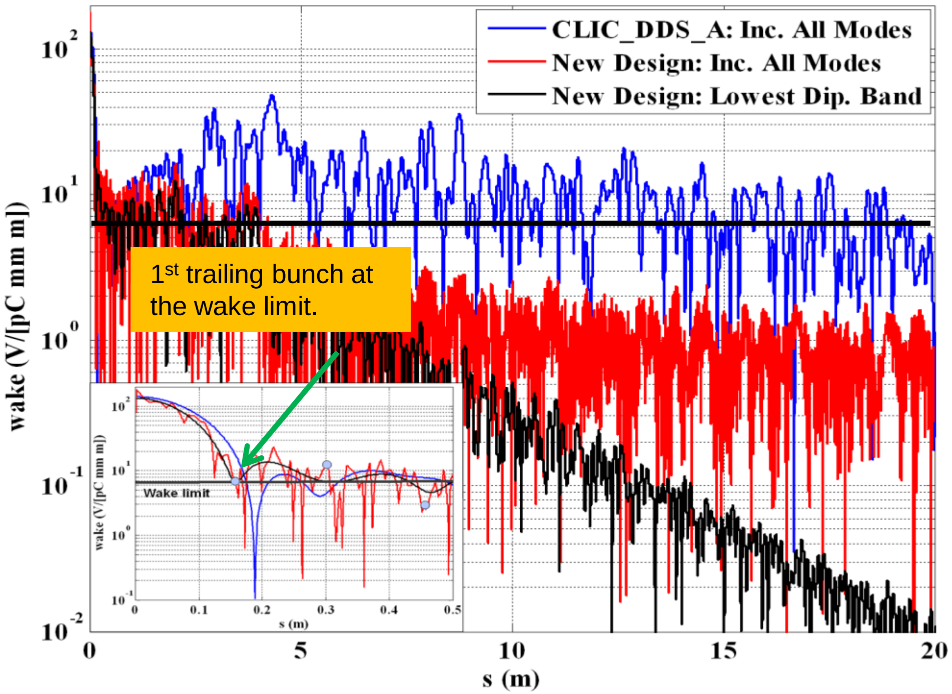


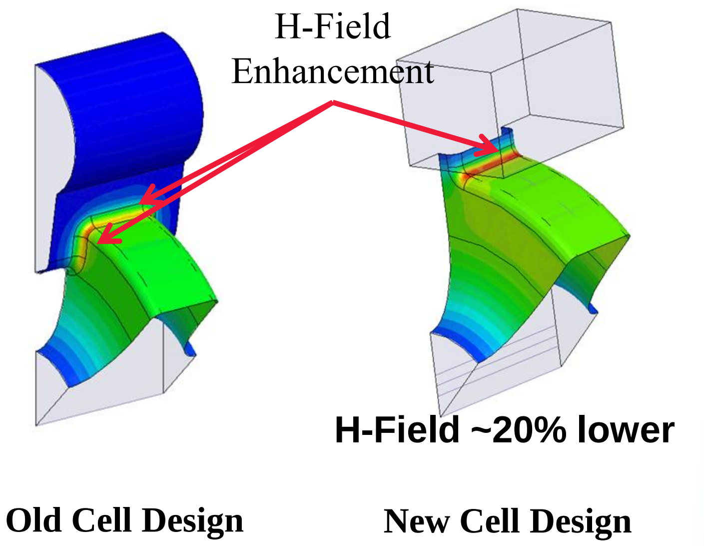




WP9.2 – HOM Damping

UNIMAN: HOM damping studies





A **new cell design** has been studied which:

- features improved overall wakefield suppression
- exhibits a larger 1st dipole bandwidth ➔ wakefield within acceptable limits after 6 RF periods
- improved HOM coupling from cell to manifolds
- reduced H-Field value on the cavity walls

WP9.2 – Breakdown Studies

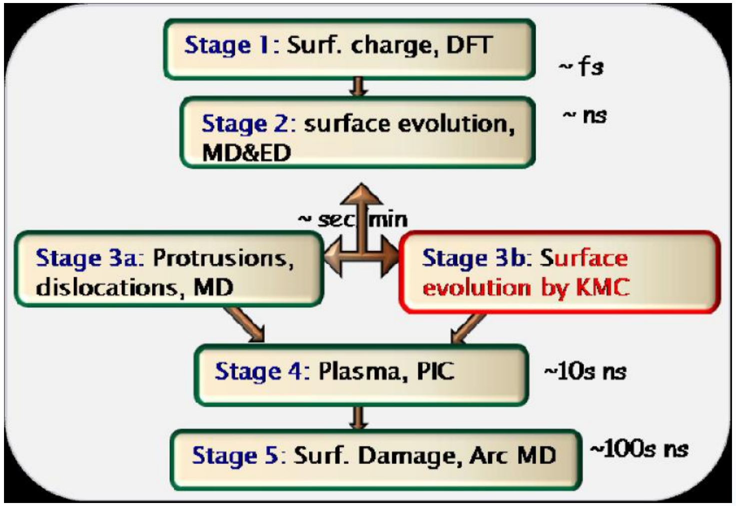
UH: breakdown studies

→ Highlight talk by Flyura Djurabekova (UH): "Understanding the breakdown: new prospects?" Wed. morning

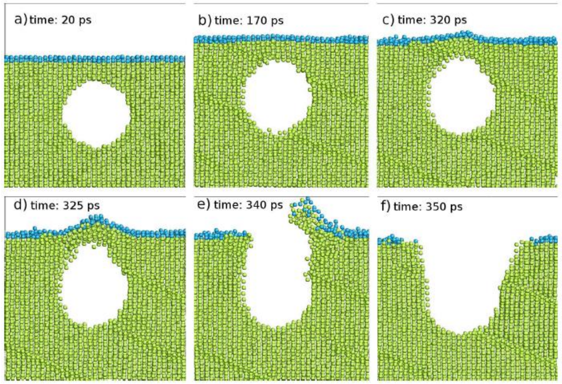
WP9.2 – Breakdown Studies

UH: breakdown studies

- **UH developed a powerful "multiscale" model, describing the motion of electrons and ions near a metal-vacuum transition in the presence of strong EM fields!**
- **Includes plasma formation and plastic deformations.**



- **Interesting finding: the influence of voids below the surface, their migration/deformation and subsequent effect on field limits. Simulations can explain observations!**
- **Very successful study, PhD Timkó, …**

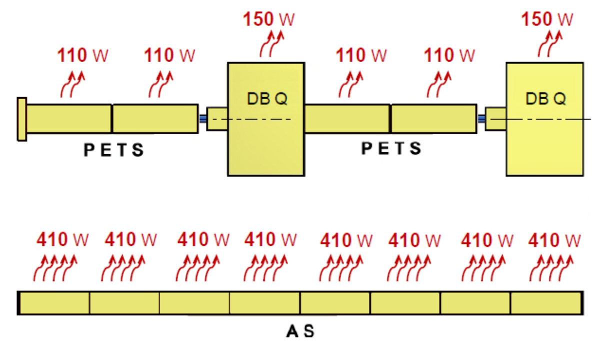


WP9.2 – Precise assembly

UH: high-precision assembly

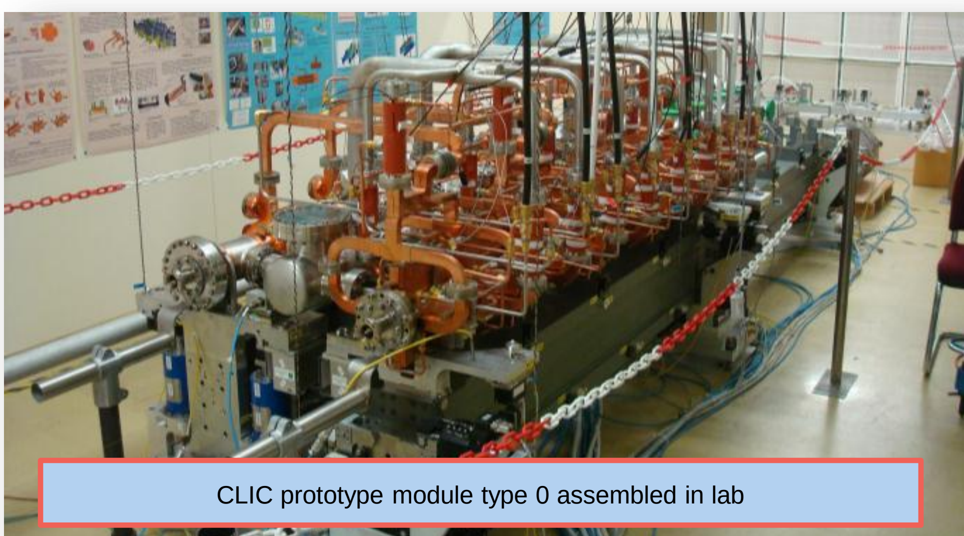
- CLIC luminosity target imposes micron-level stability requirement on the two-meter long CLIC modules
- High power dissipation during normal operation result in misalignments in & between different elements.
- Thermo-mechanical modeling of the CLIC modules needed to predict structural deformations affecting final alignment of modules due to internal heat dissipation.
- Numerical results used to compensate misalignments by re-adjustments of supporting system integrated linear actuators. Under validation by experimental tests with full-scale CLIC prototype modules.

Heat dissipation CLIC prototype module type 0



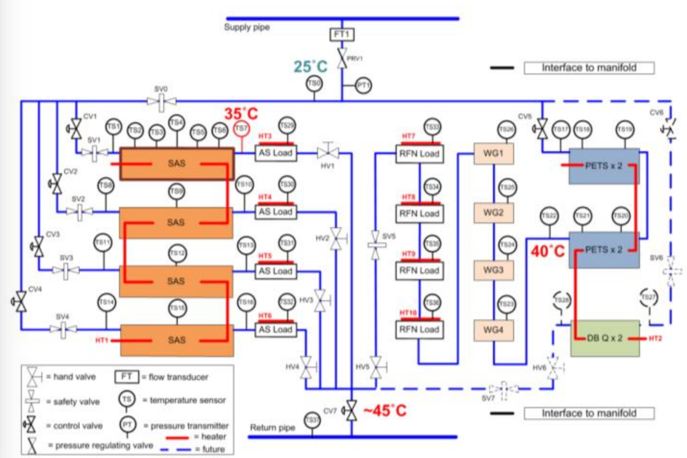
PETS → 440 W
DB Q → 300 W
AS → 3280 W

* *Technical Specification for the CLIC Two-Beam Module*
G. RIDDONE EDMS 1097388



CLIC prototype module type 0 assembled in lab

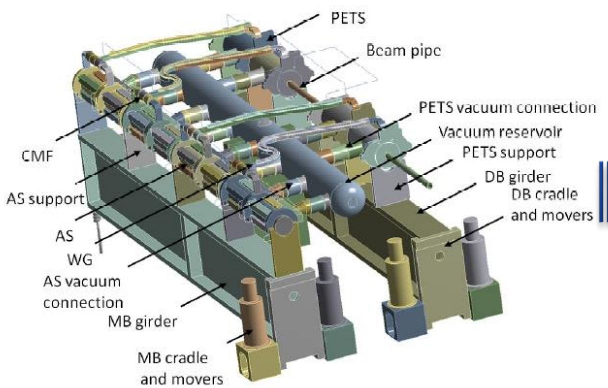
Cooling system CLIC prototype module type 0



WP9.2 – Precise assembly

UH: high-precision assembly

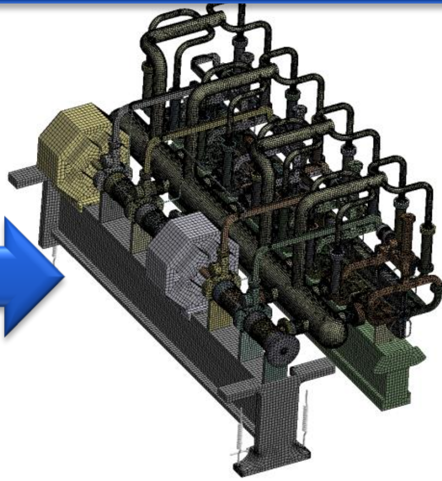
2009-2010 (R. Nousiainen)



- Geometry creation from CAD model
- Implementation of cooling channels using line bodies

R. Nousiainen et al., "Studies on the Thermo-Mechanical behaviour of the CLIC Two-Beam Module", MOP104, LINAC2010, Tsukuba, Japan, 2010.

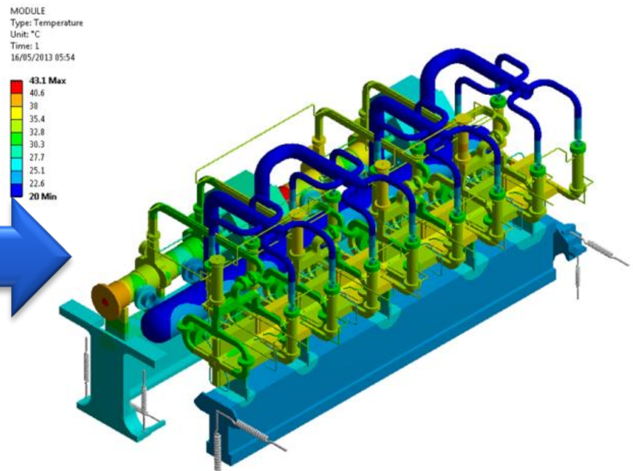
2011-2012 (R. Raatikainen)



- Update of the module geometry
- Modelling of bellows and actuators using equivalent stiffness elements

R. Raatikainen et al., "Improved Modeling of Thermo-mechanical Behavior of the CLIC Two-Beam Module", TUPPR033, IPAC2012, New Orleans, USA,2012.

2012-2013 (L. Kortelainen)

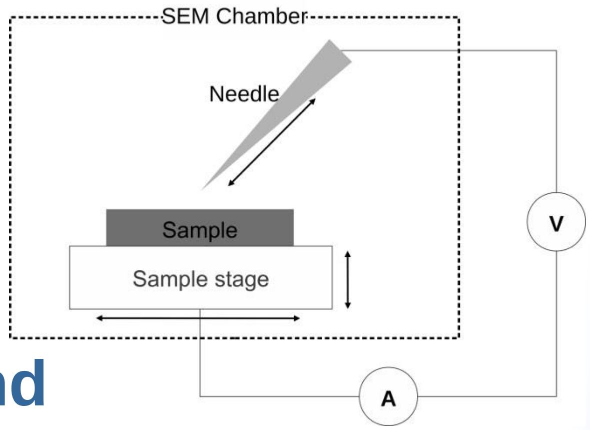


- Update of the geometry and boundary conditions to the current configuration
- Modelling of heat convection to air
- Parametrisation of model
- Reproduction of load conditions of the thermal tests program
- Comparison to experimental results and validation of modeling

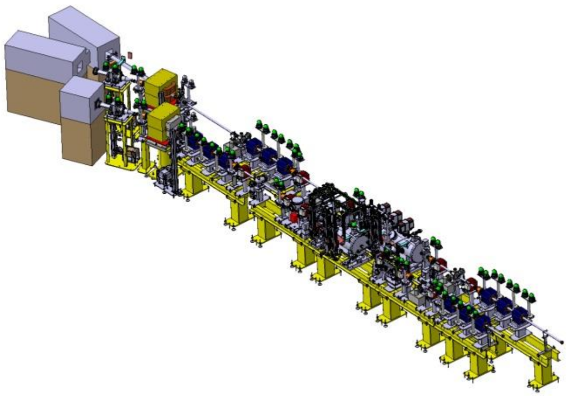
WP9.2 – Diagnostic equipment

UU: diagnostic equipment

- **In-situ discharge experiments inside an Electron-microscope**
  - Field emission probe
  - Simple scanning
  - Cut and Slice, voids

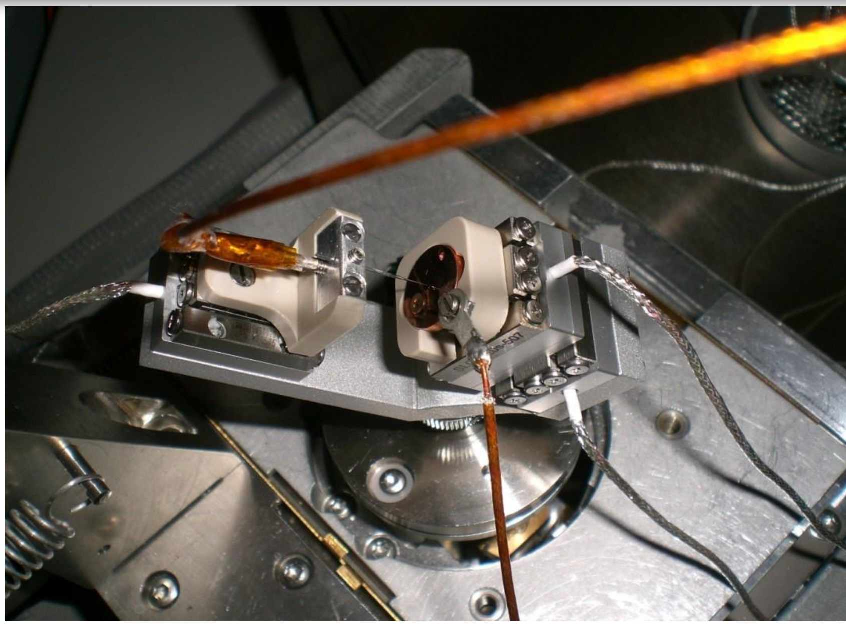


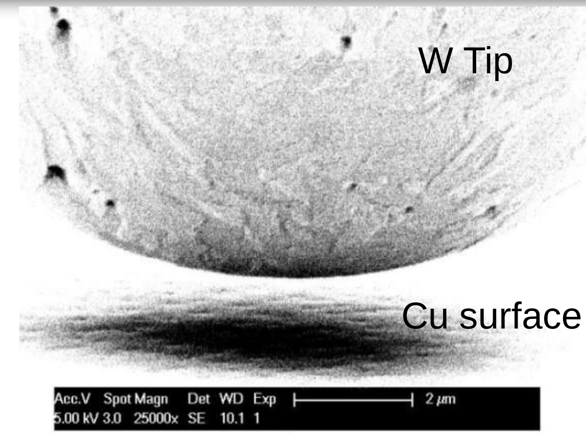
- **Upgrade of the Two-beam test stand in CTF3**
  - Upgrade diagnostics: positi[obscured by image] screens, and FlashBox
  - PETS based phase monitor

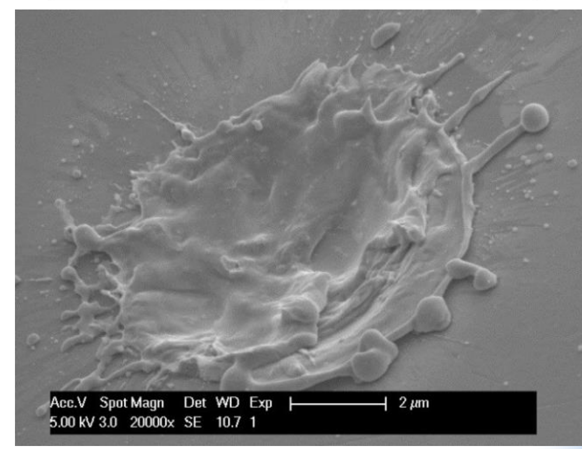


NCLinac – WP9.2

UU: diagnostic equipment







Piezo scanner (smaract) in SEM:

Anode tip diameter 5 µm, gap 1 µm, HV up to 1 kV, vacuum: 1 mPa

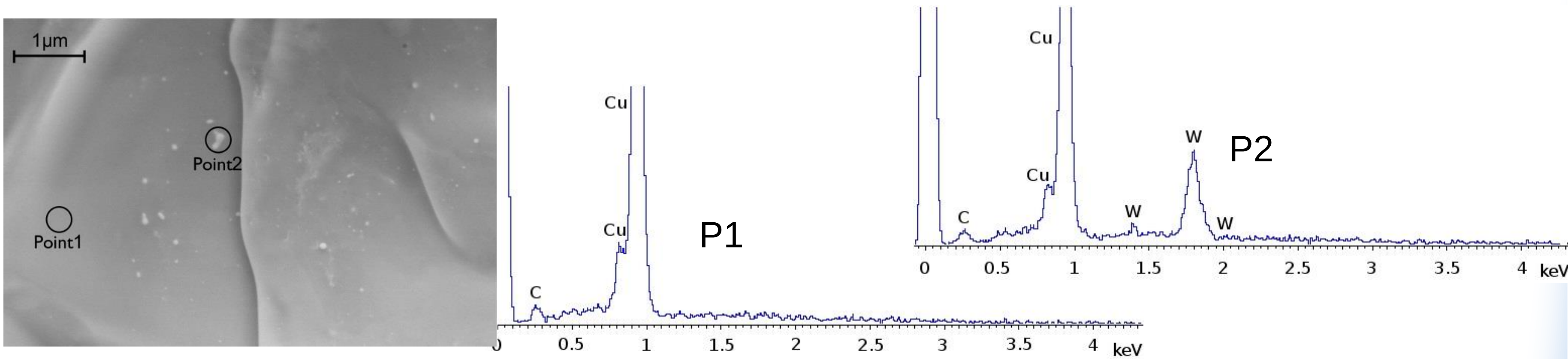
- Scanning capability in the piezo-motor probe stage
- Grains visible in optical and electron-microscope.
- Voltage at which 10 nA FE current is reached

NCLinac – WP9.2

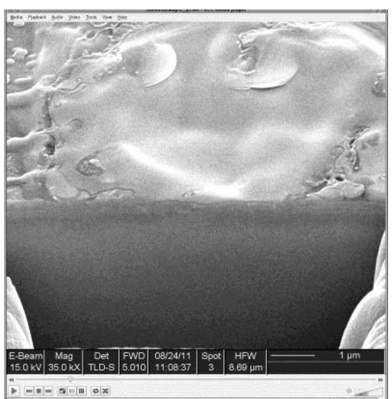
UU: diagnostic equipment

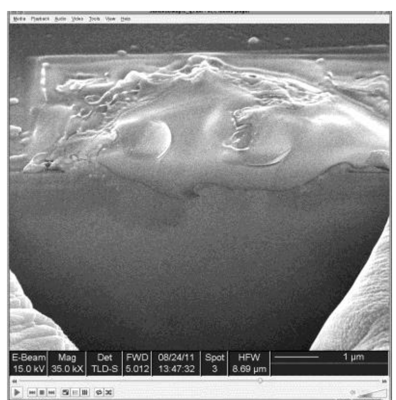
<u>Surface and underneath</u>

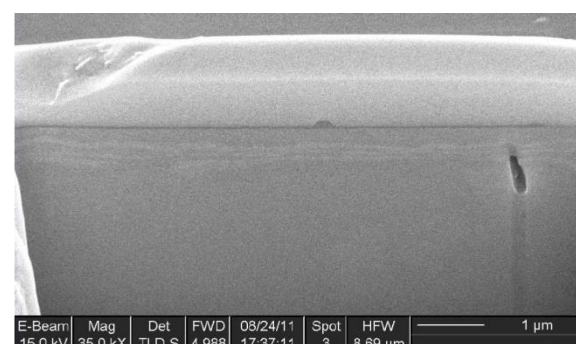
- **Initiate discharge with W tip on copper sample and analyze the discharge site with EDX**



- **Cut and slice, observed sub-surface voids**





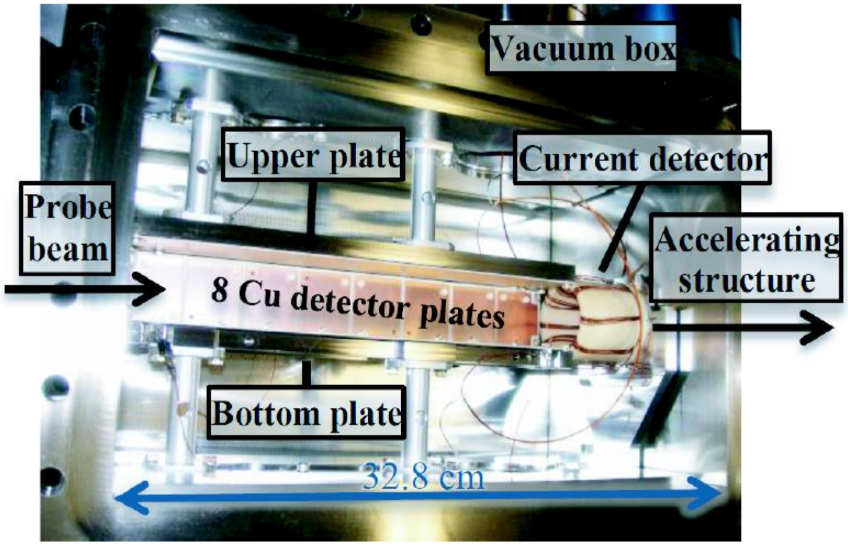


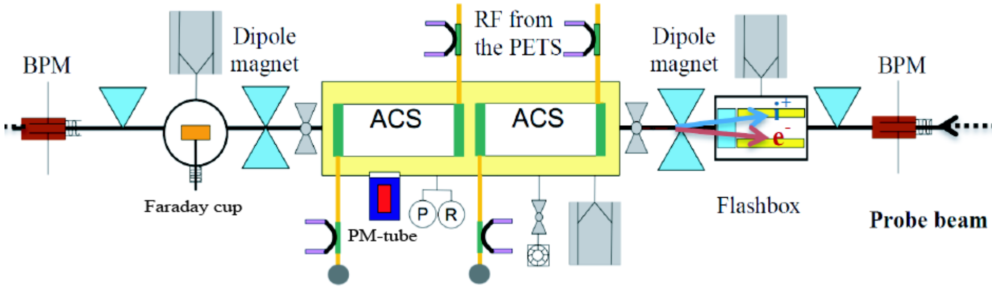
NCLinac – WP9.2

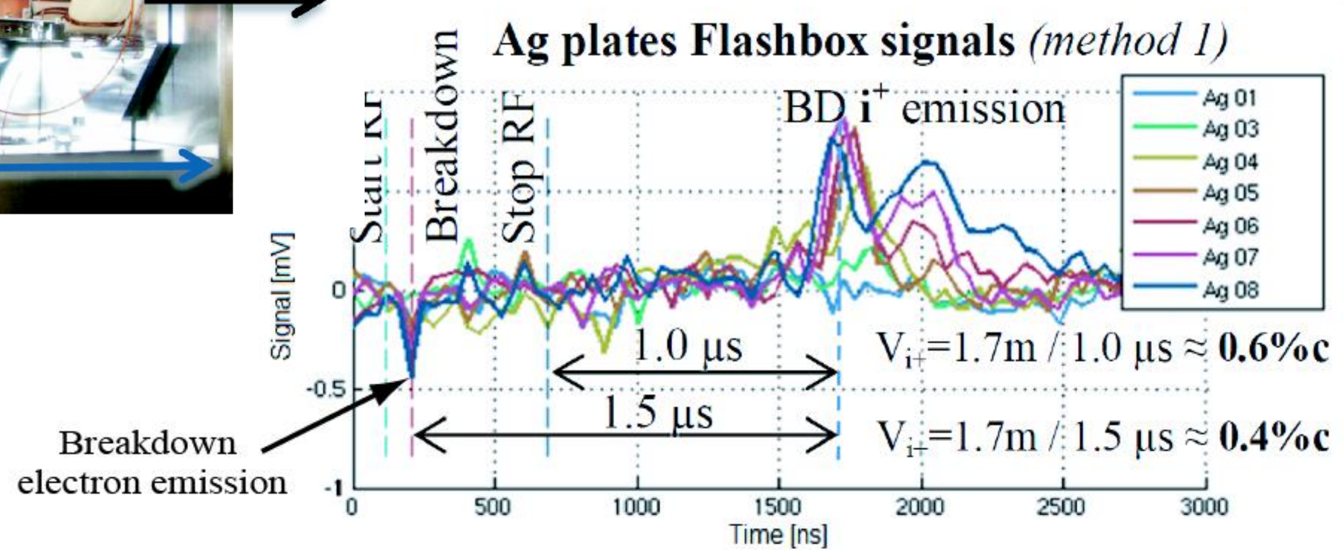
UU: diagnostic equipment

TBTS upgrade

Flashbox: Detector for electron and ions ejected during breakdown from the acceleration structures in the probe beam of CTF3 at CERN.





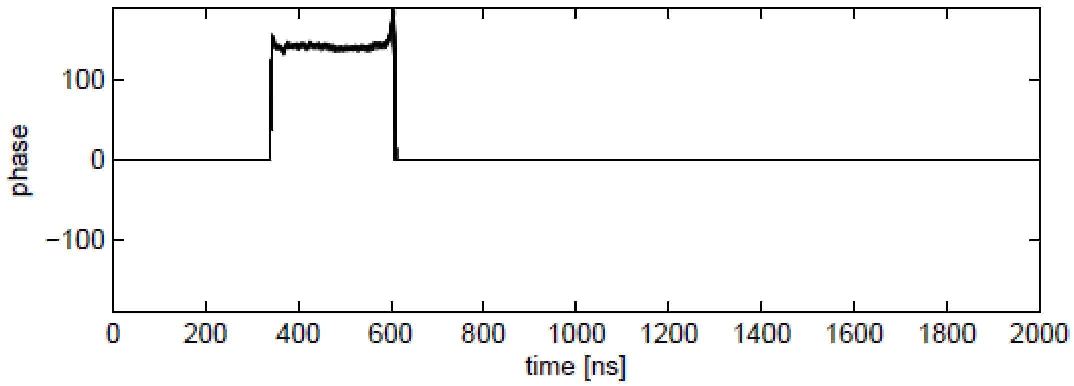


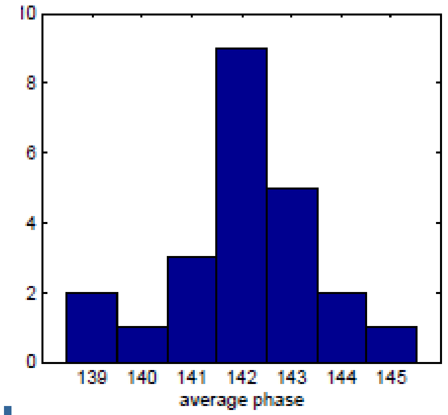
UU: diagnostic equipment

PETS as φ monitor

- **Idea: Use PETS with recirculation as phase monitor (link to 9.5)**
- **Electric field at sample *m* depends on field at time one round-trip time earlier and the driving current Im and its arrival phase α_m**

$$E_m = qE_{m-1} + ce^{i\alpha_m} I_m$$



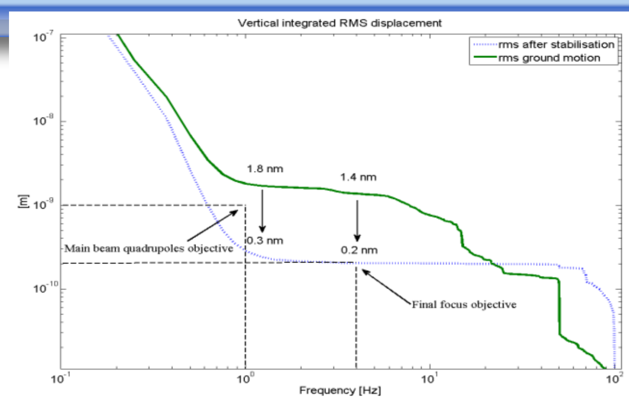


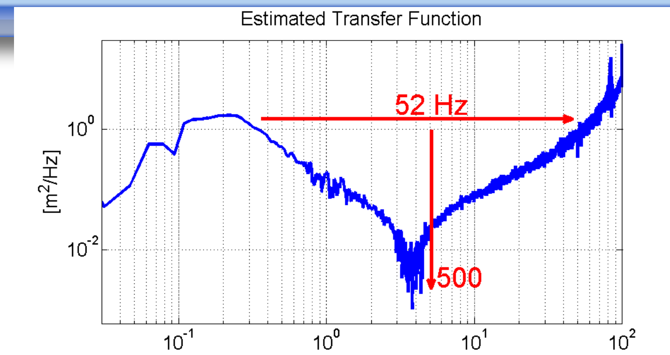
- **Phase for 23 different beam pulses are very similar**

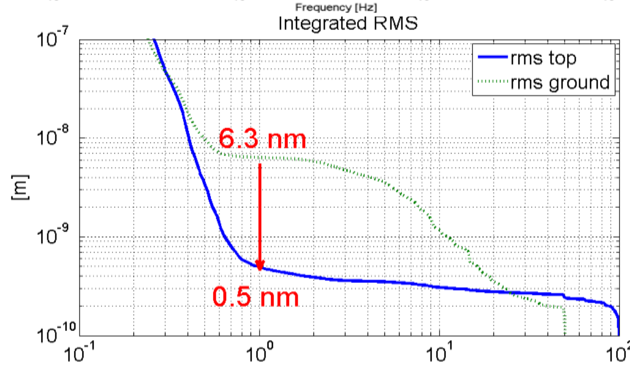
WP9.3 - Stabilization

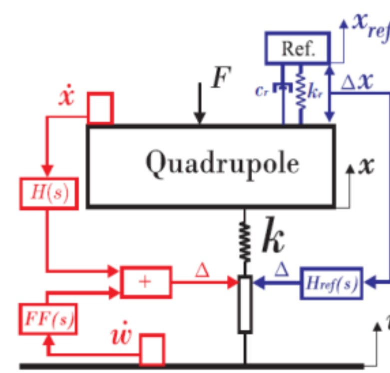
→ **Highlight talk by Kurt Artoos (CERN): "Linac Stabilisation", Wed afternoon**

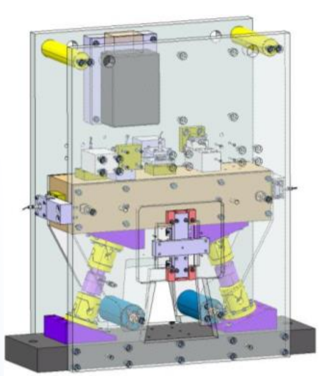
WP9.3 - Stabilization



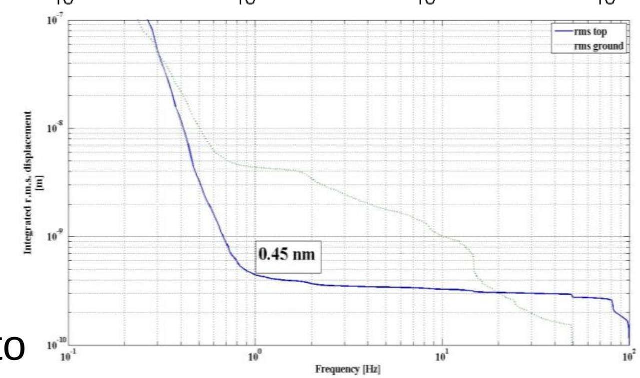








X-y proto



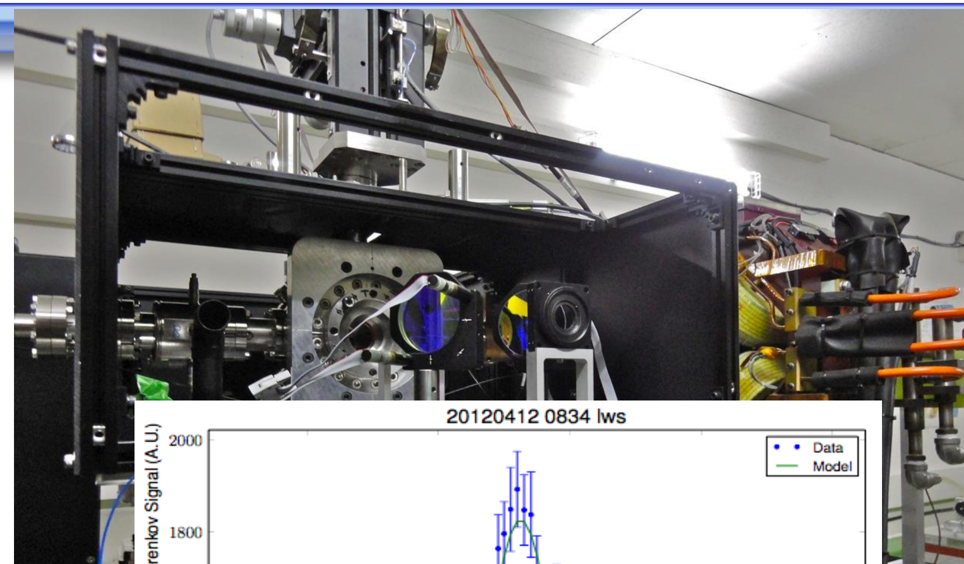
Seismometer FB max. gain +FF (FBFFV1mod): 7 % luminosity loss (no stabilisation 68 % loss)

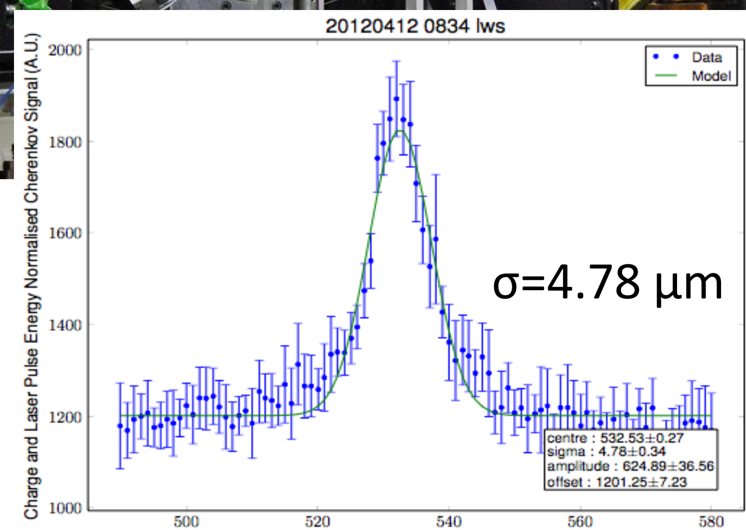
Courtesy J. Snuverink,
J. Pfingstner *et al.*

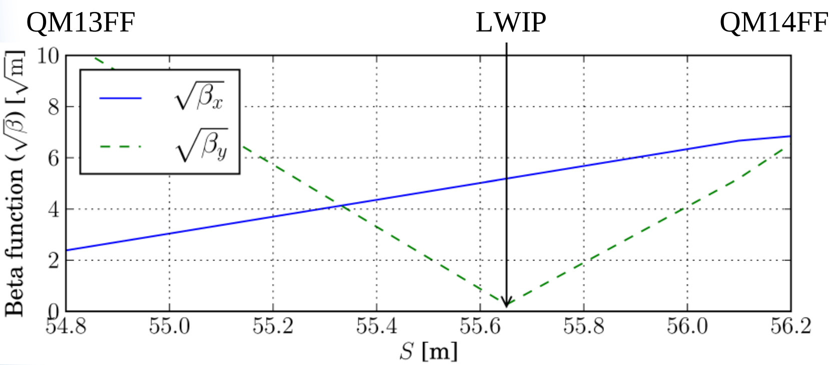
WP9.4 – Beam Delivery System

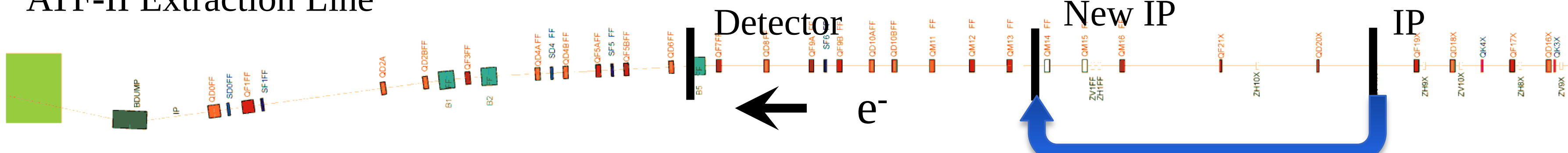
RHUL/UOXF-DL: ATF2 Laser wire

- LW moved post earthquake
- 1μm V x 100 μm H e^- beam
- Initial collisions found
- 4 μm vertical scan so far





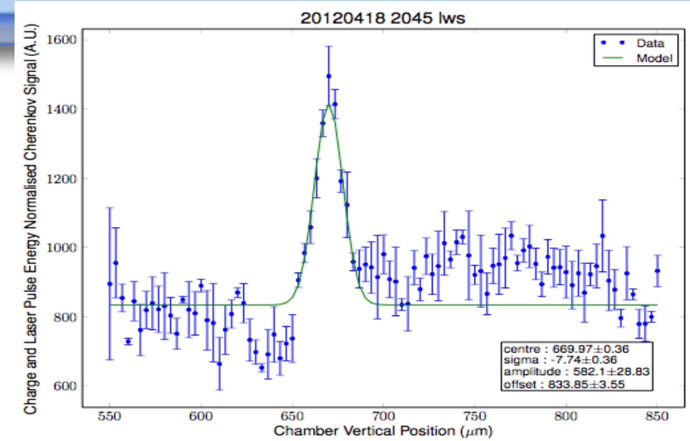


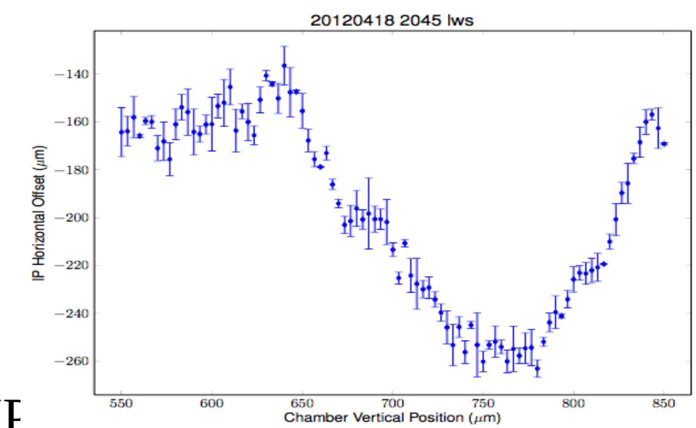


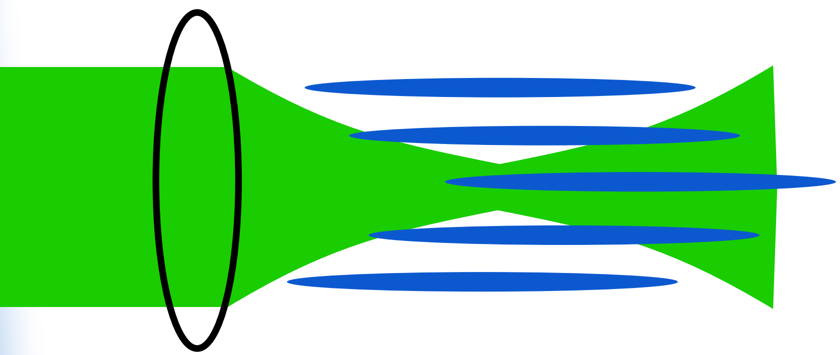
WP9.4 – Beam Delivery System

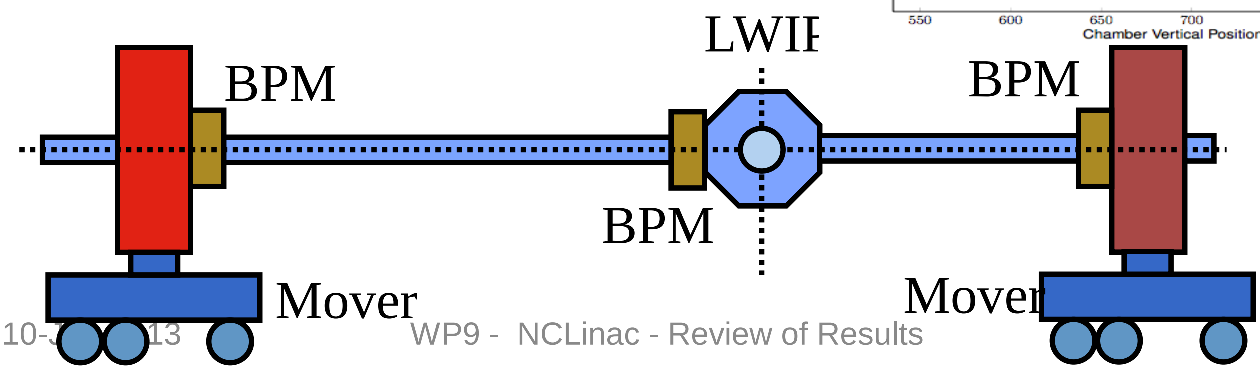
RHUL/UOXF-DL: ATF2 Laser wire with CBPMs

- Electron beam moves horizontally
- modulates Signal
- Use CBPMs to measure position
- LW follows electron beam







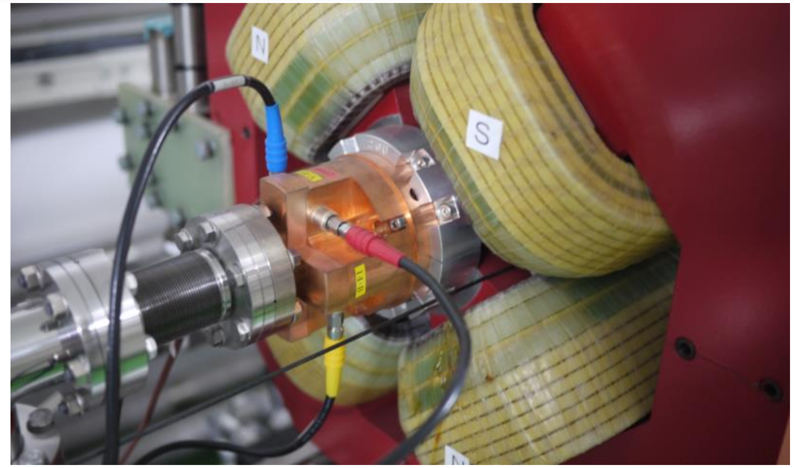


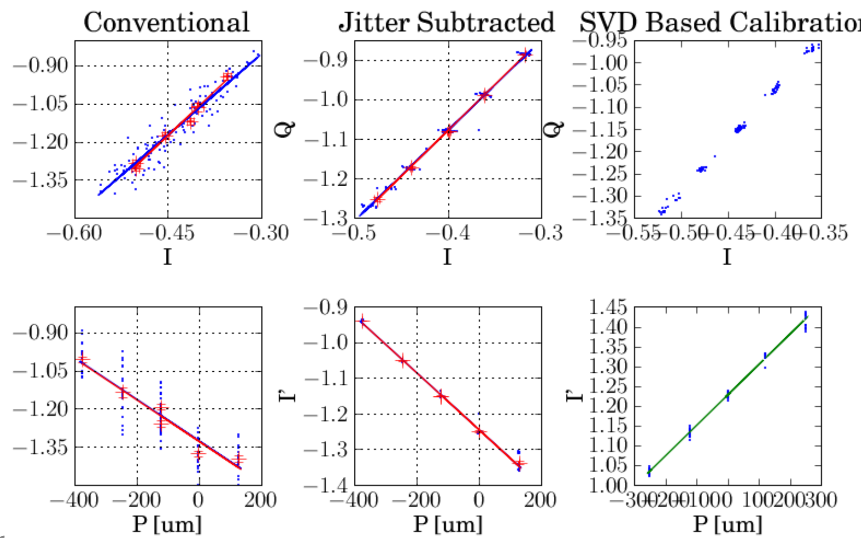
WP9.4 – Beam Delivery System

RHUL: Beam position monitors

ATF2 cavity BPM system:

- **44 BPM system operating well (36 c-band, 4 s-band, 4 IP)**
  - Average resolution 200 nm (with attenuation)
  - Best resolution 27 nm
  - Working on developing interaction point region (4 BPMs to monitor focus)
- **Calibration difficult due to large orbit changes**
  - Previously variation 20 % calibration scale change
  - Now less than 1 % with beam orbit subtraction

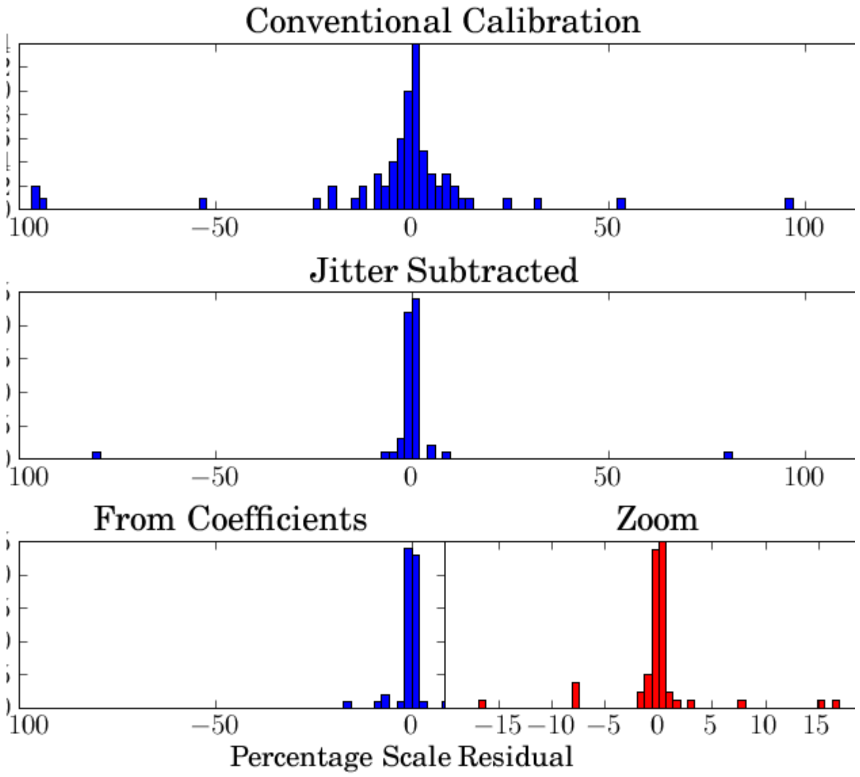




Cavity BPM long term stability

- **Calibration constant over weeks**
- **Two calibration constants required for each BPM**
  - Cavity output is single complex number
  - Calibration constant single complex number (magnitude and phase)
- **Monitor for 3 week period and conclude EuCARD deliverables with paper/report**

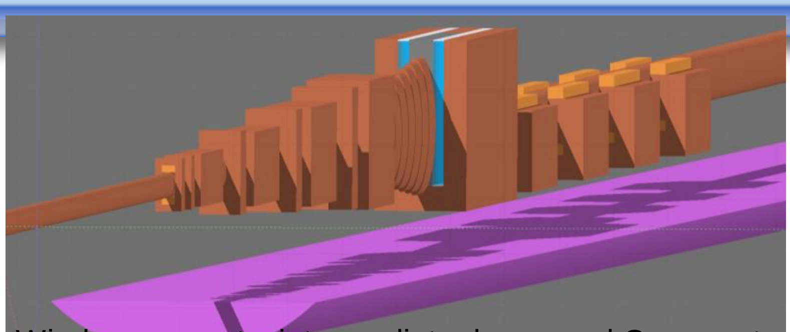
- **Calibration scale**



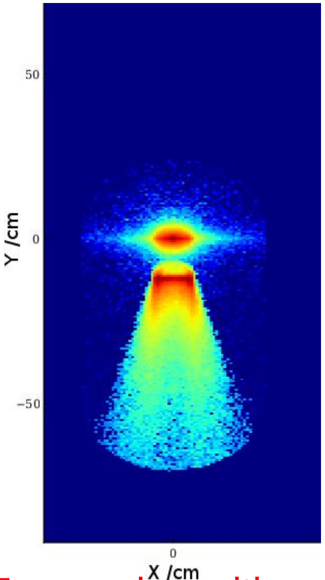
WP9.4 – Beam Delivery System

ASTEC/UNIMAN: Post-IP line modelling

CLIC post-IP line: ~10 MW of disrupted beam, ~3 MW beamstrahlung photons & other products. Opportunity to measure and optimise the collision luminosity through direct beam-beam products diagnostics.
EuCARD goal: model post-IP region in FLUKA & study backgrounds, diagnose & optimise luminosity



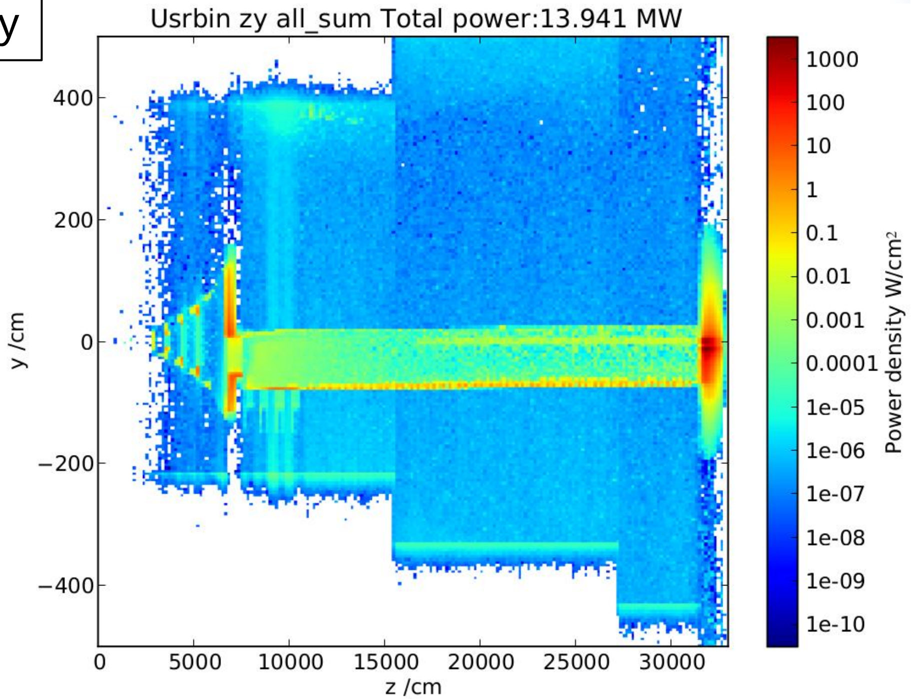
Window magnets, intermediate dump, and C magnets



Energy deposition on main dump

Model complete & validated, including tunnel and dump.
Used for P deposition & to measure particle fluxes @ candidate positions for lumi monitors.
This summer to be extended to IP beam offsets to map signals to beam collision parameters.

Appleby/Tygier



Energy deposition along beam line

WP9.4 – Beam Delivery System

Plus:

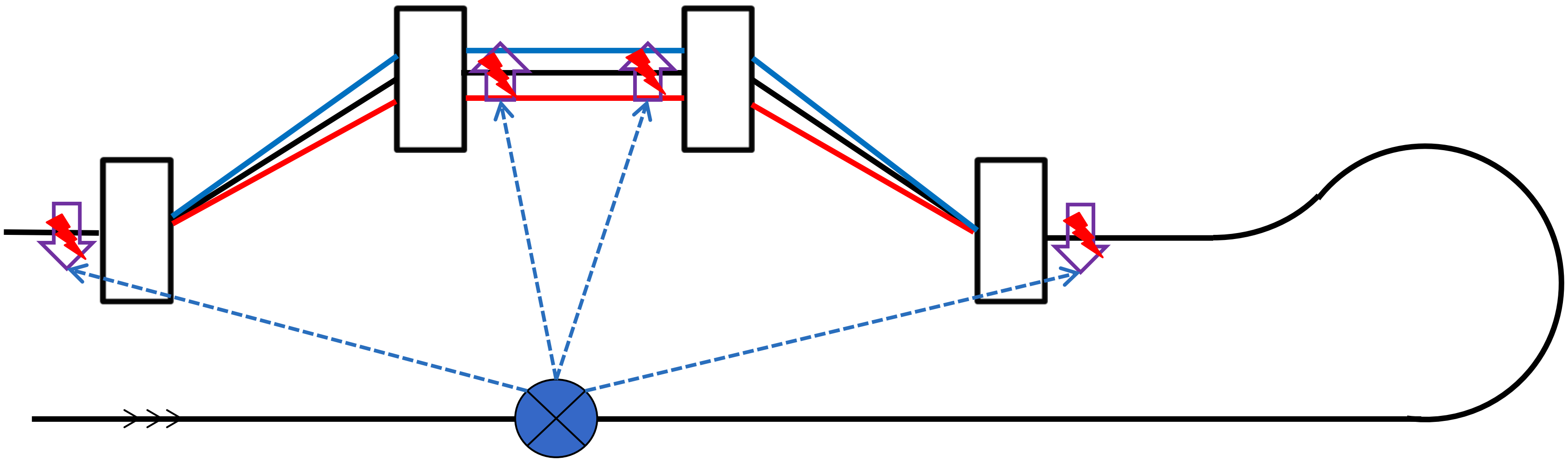
- **Simulations – linking with WP 10.4:**
  - The CLIC crab-cavity induces a higher order correlation in the beam dynamics at the IP, leading to luminosity loss within the CLIC BDS design. To compensate for this effect, simulation work was performed on re-optimising the non-linear elements in the CLIC BDS, between the crab-cavity and the Interaction Point, to minimise the luminosity loss and restore the design luminosity of the machine.
- **Need for non-linear optimizations of other areas was highlighted.**

WP9.5 – Drive Beam Phase Control

INFN/PSI/CERN: Phase PU, BAM

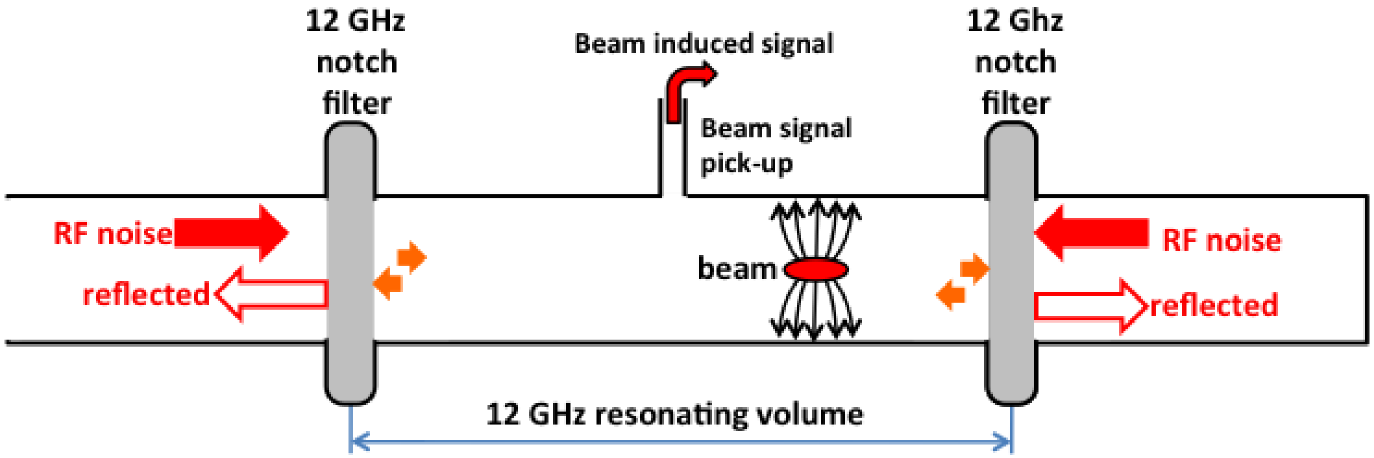
The idea of drive beam phase stabilization with feed forward:

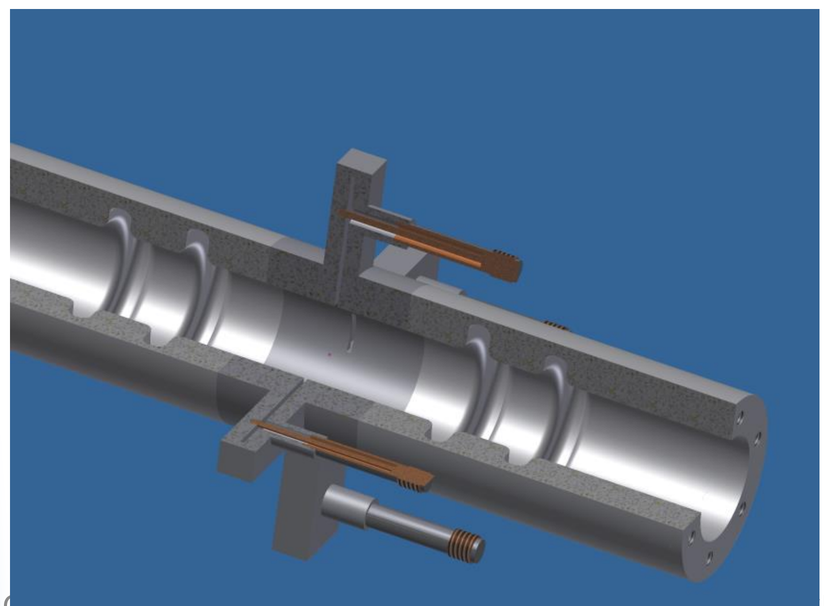
- **It will increase the drive beam stability and correct phase variation along pulse to the required 0.2° at 12 GHz (46 fs)**
  - Measure phase offset before the turn around
  - Correct it after the turn around
- **The current CLIC design based on a 4-bend chicane, each bend equipped with a fast kicker so the "height" of the chicane is changing, and thus the time of flight**

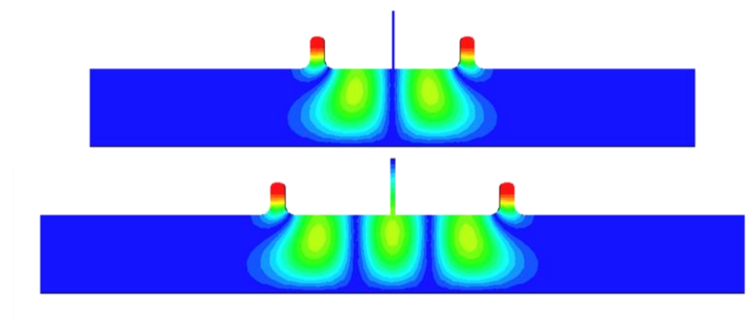


WP9.5 – Phase monitors

INFN/PSI/CERN: Phase PU, BAM

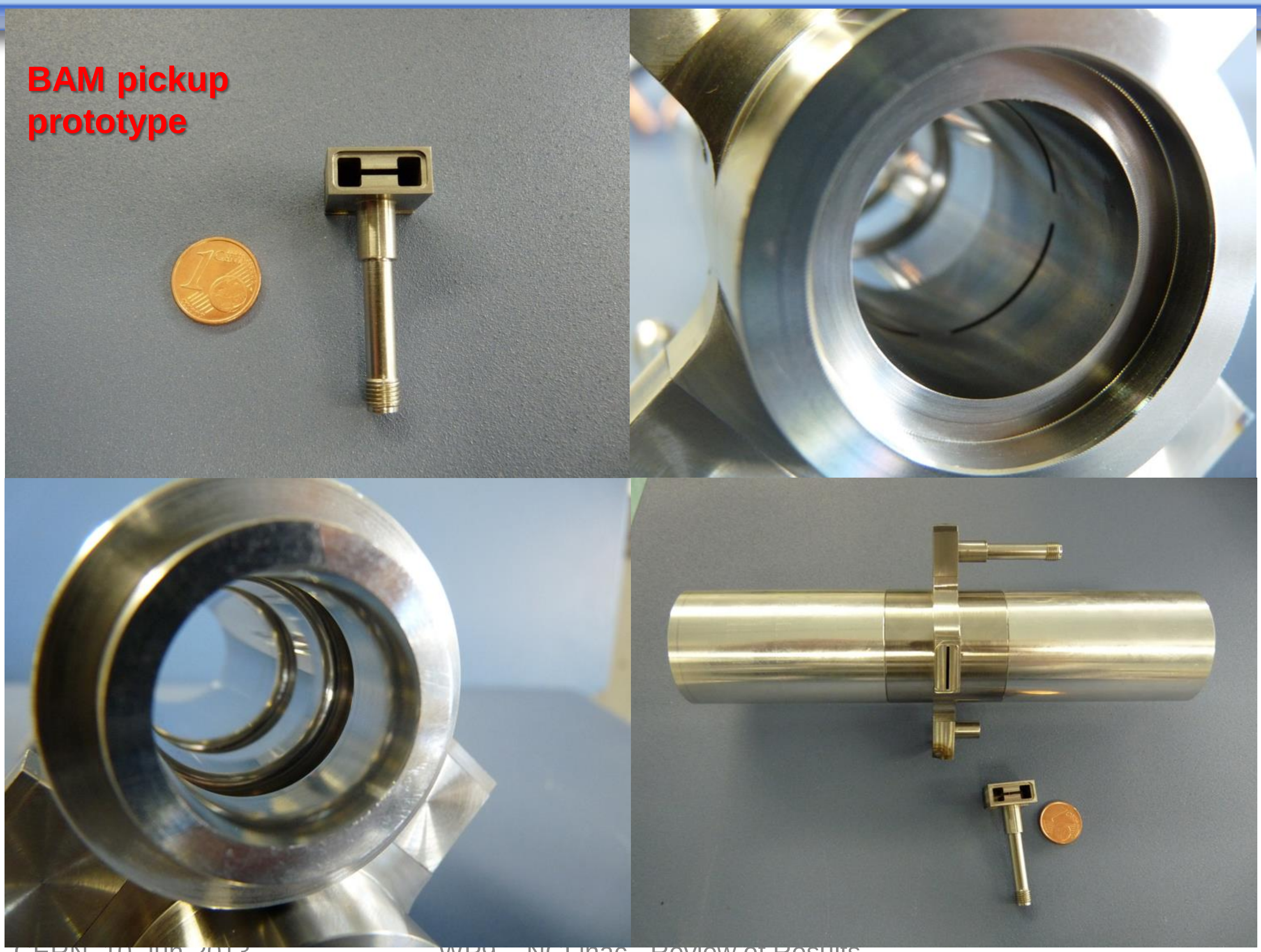






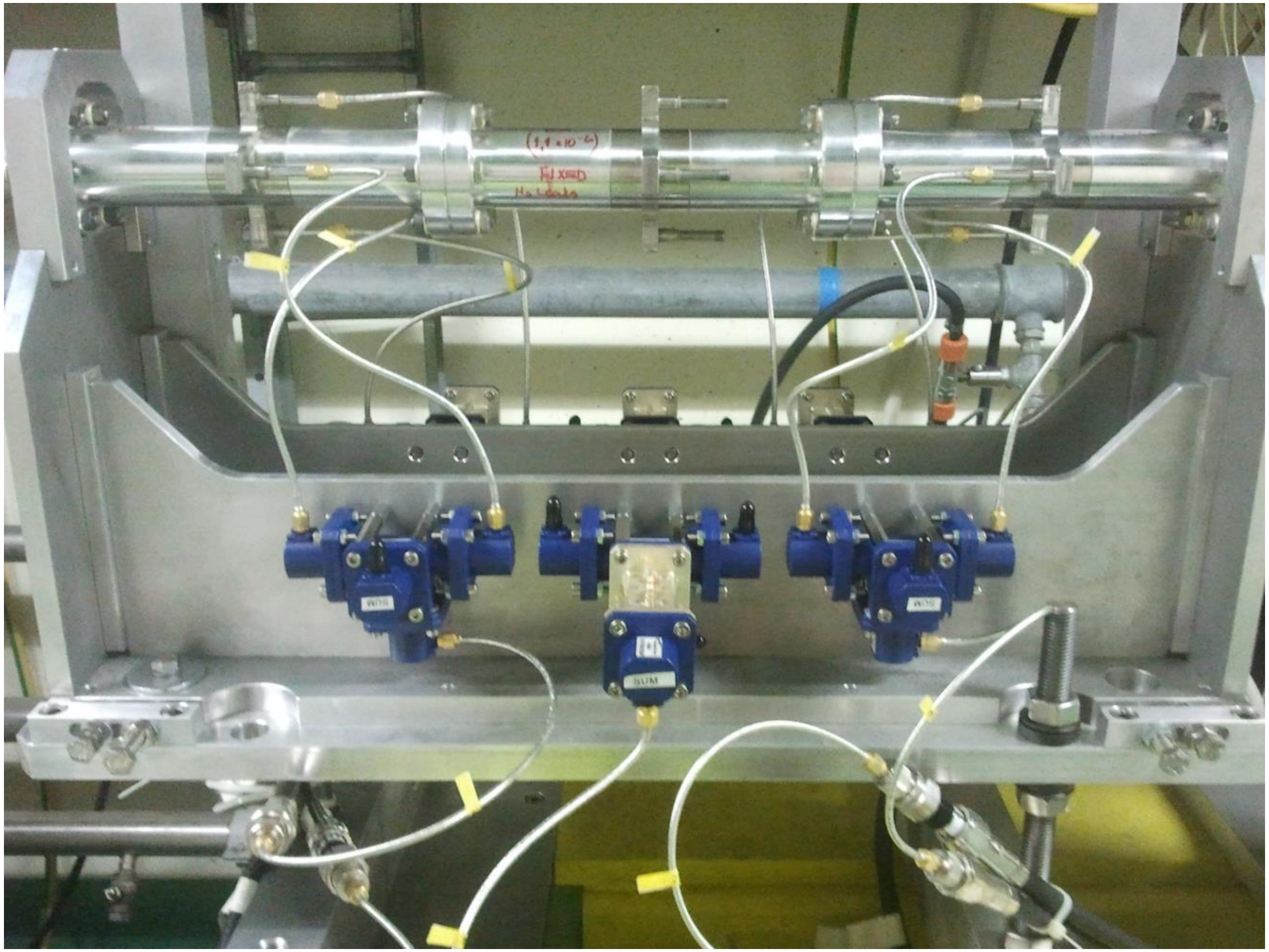
WP9.5 – Phase monitors

INFN/PSI/CERN: Phase PU, BAM



WP9.5 – Phase monitors

INFN/PSI/CERN: Phase PU, BAM

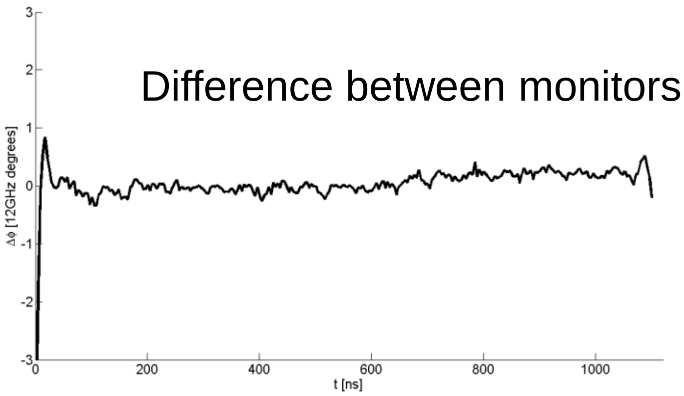


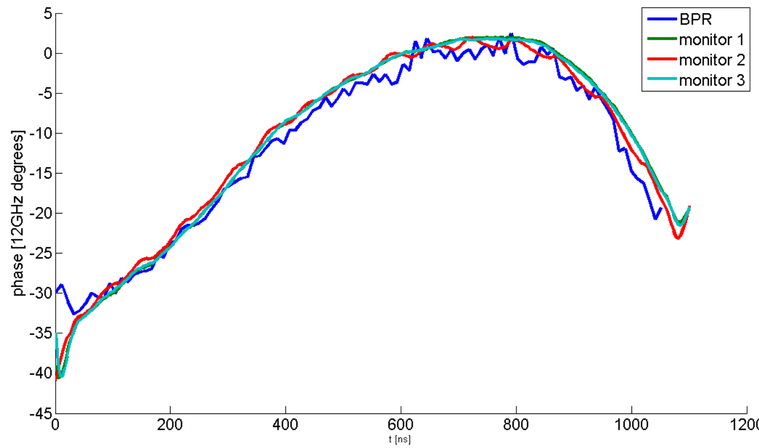
The 3 monitors were installed in a string

WP9.5 – Phase monitors

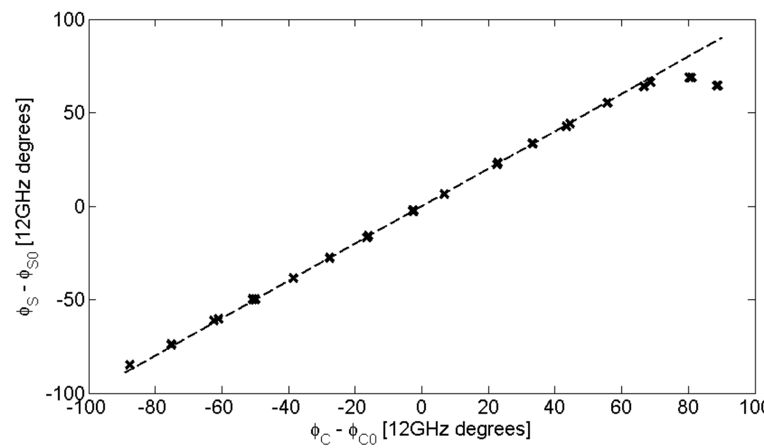
INFN/PSI/CERN: Phase PU, BAM

- **Drive beam phase measurements**
- **Read-out electronics presently limits resolution to 0.2° (46 fs).**
- **2 of the 3 monitors are OK and equal to within 0.3°.**





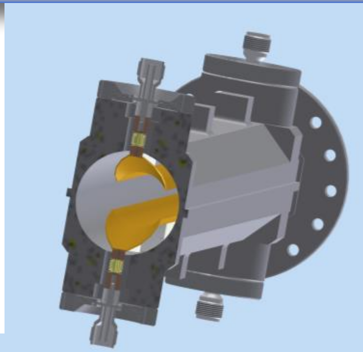
- **Linearity measured – OK up to ±70°**

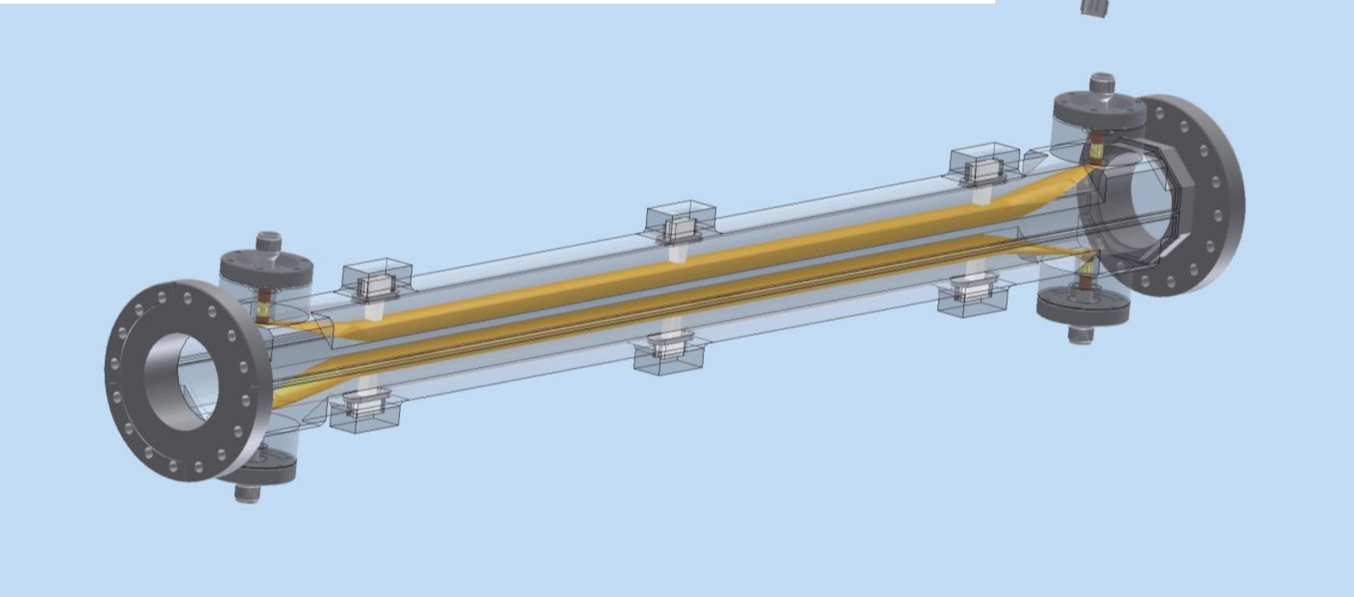


WP9.5 – Kickers (extra!)

INFN/PSI/CERN: Phase PU, BAM

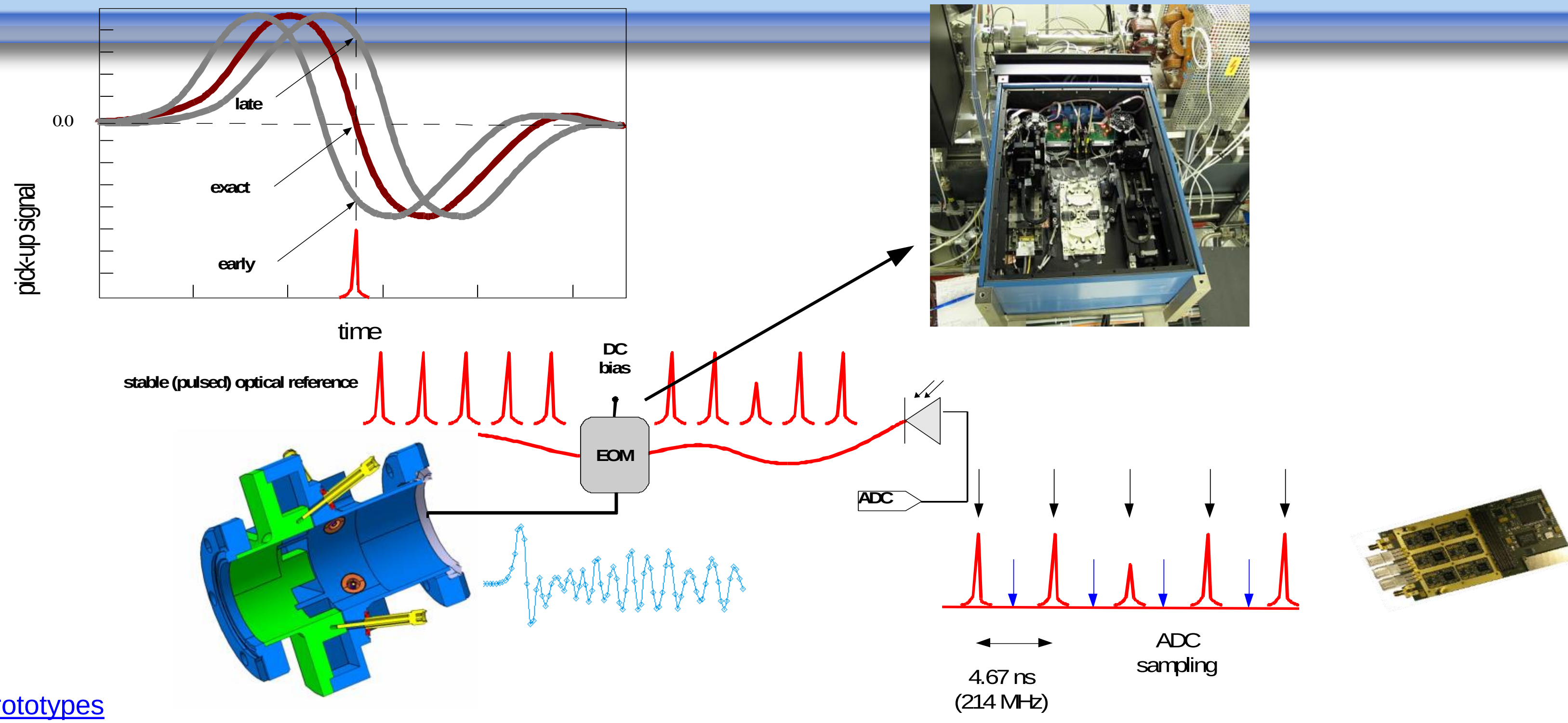
- **Strip-line kickers based on the Dafne design**
- **1.1 kV for 1 mrad deflection @125 MeV**
  - 100 Ω differential impedance
  - At least 50 kW drive needed





WP9.5 – BAM Principle

INFN/PSI/CERN: Phase PU, BAM



SITF Pickup Prototypes

I. Button (38 mm chamber):
- **80 GHz design BW,**
- **good resolution and sensitivity:**
  - **200pc – 60 pc: 20 fs**
  - **60 pC-10pC: 30fs -170 fs**

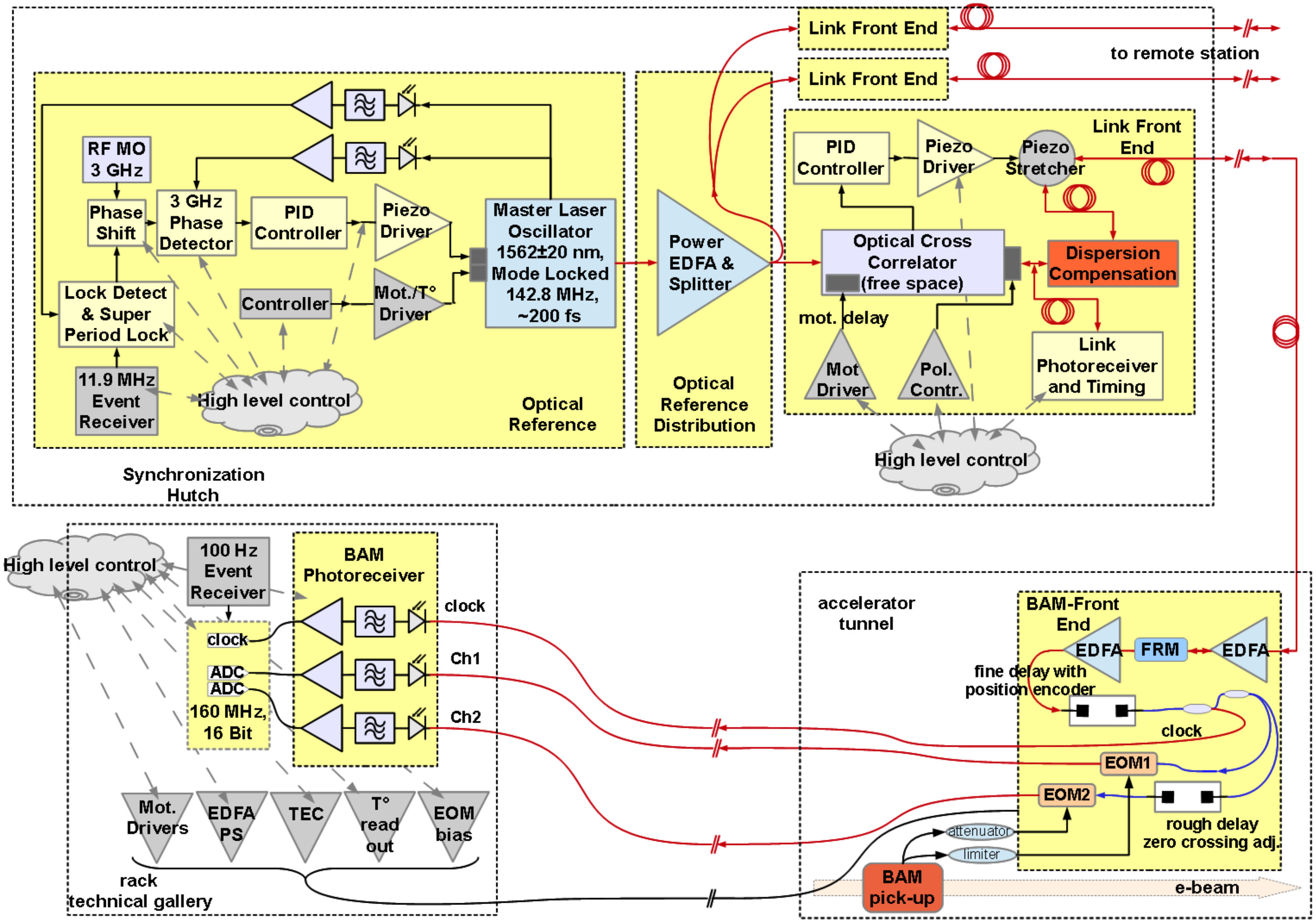
II. Ridge waveguide (RWG) (38 mm chamber):
- **strong signal, but in combination with the RF-front end: non linear**
- **insufficient resolution, ringing,**

SITF BAM-Data Acquisition (GPAC ADC12FL)
- **The ADC clock is generated by the laser pulses and is shifted simultaneously with them**
- **The laser pulse amplitude is normalized pulse-to-pulse**
- **The laser amplitude jitter is monitored online**

* **Florian Löhl, DESY-THESIS-2009-031, March 2009**

WP9.5 – BAM Layout

INFN/PSI/CERN: Phase PU, BAM

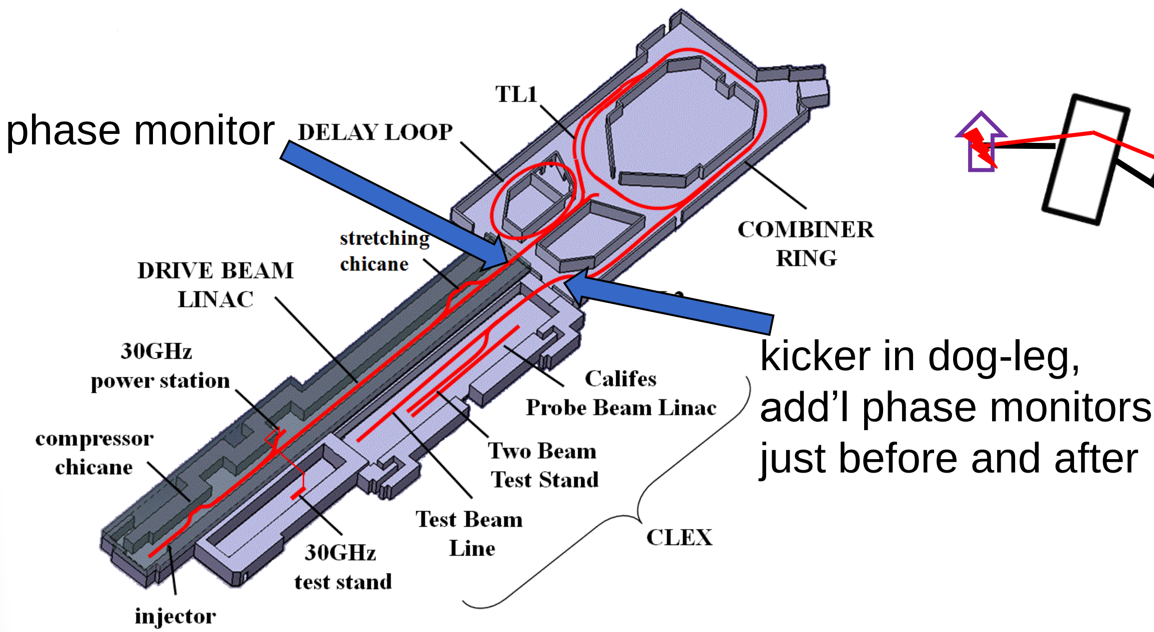


WP9.5 – Phase Feed-forward (extra)

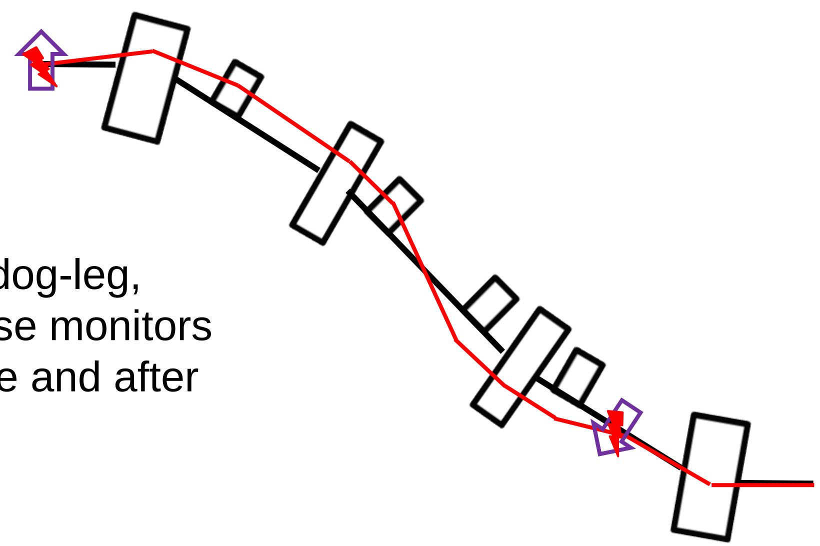
INFN/PSI/CERN/UOXF-DL

- This goes on after EuCARD: UOXF-DL have engaged on wide-band SS amplifiers to drive the kickers and a LLRF system with the feed-forward algorithm implemented.
- Phase feed-forward will be installed and tested in CTF3 this summer.

CTF3



Dog-leg after CR



NCLinac – Conclusions

- **NCLinac can look back on 4 very successful years. Achieved everything we intended and some more!**
- **Found additional connections/synergies:**
  - Uppsala saw voids “predicted” by Helsinki,
  - PETS used as phase monitor
  - Royal Holloway simulated nonlinear effects of crab cavities (10.4)
  - Oxford helps with the wide-band amplifiers for 9.5
- **Education: Excellent sourcing of future experts from NCLinac student collaborators (e.g. D’Elia, Timkó, Khan, Muranaka …)**

NCLinac

A big THANK YOU to all colleagues participating in NCLinac and thus contributing to its good success.