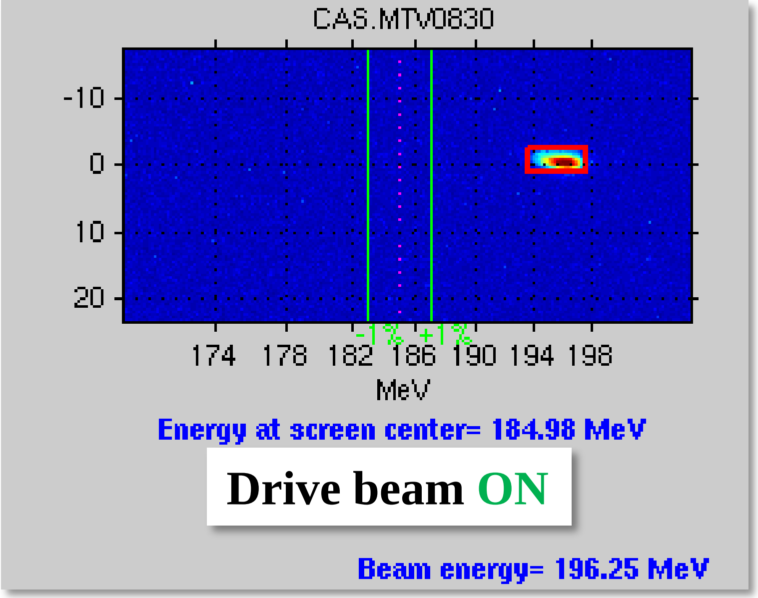
CTF3 results

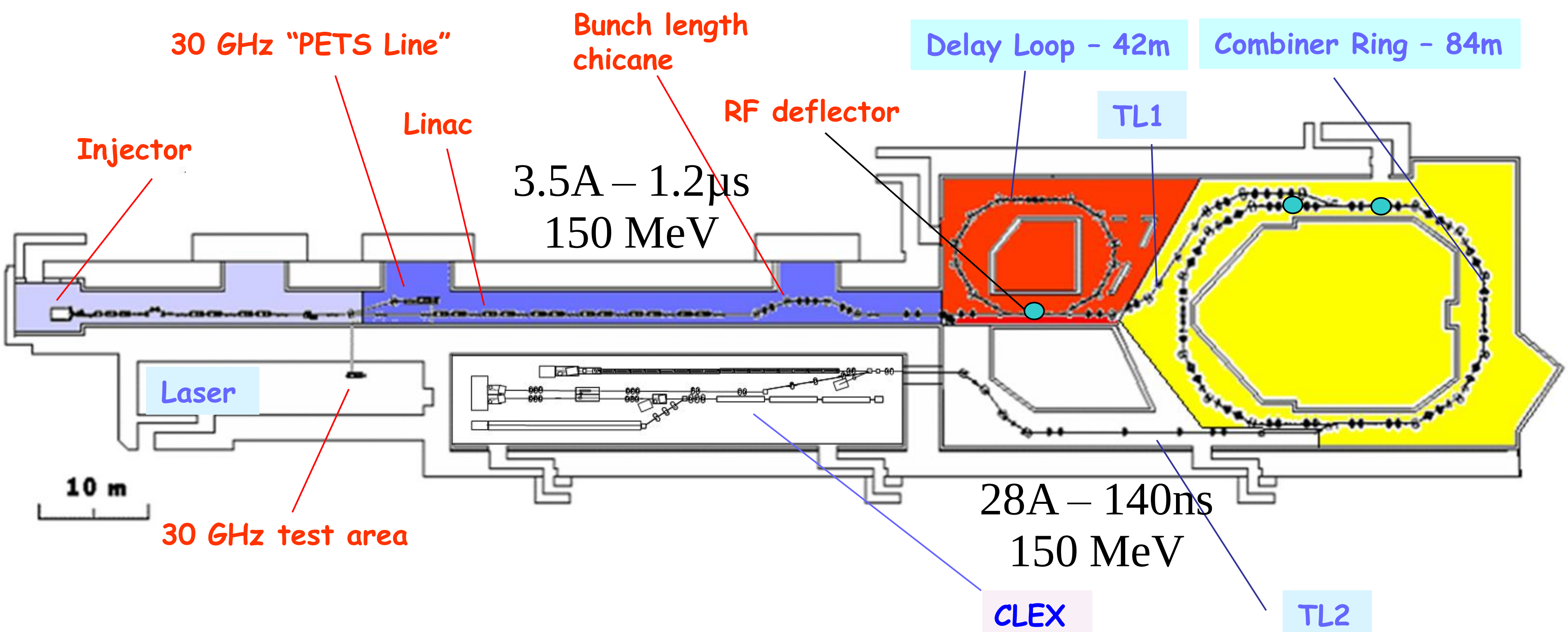
Frank Tecker - BE/OP
for the CTF3 Team

- Introduction
- Achievements in 2010
- Conclusion



CTF 3 – CLIC Test Facility

- demonstrate CLIC RF power source Drive Beam generation (fully loaded acceleration, bunch frequency multiplication 8x)
- Test CLIC accelerating structures
- Test power production structures (PETS)



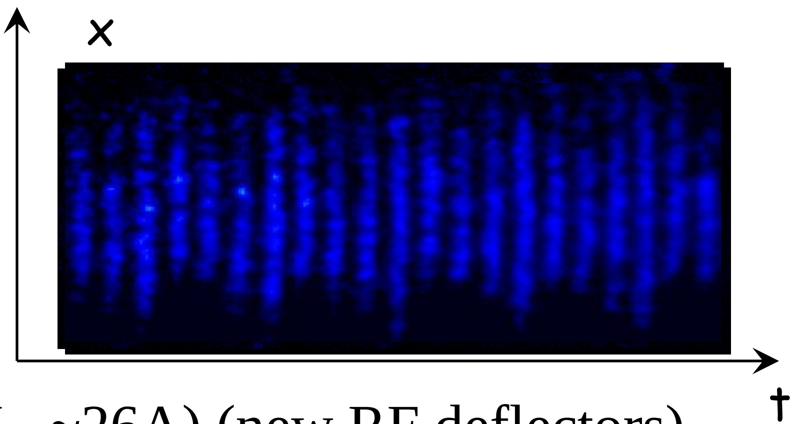
World-wide CLIC&CTF3 Collaboration

40 Institutes from 21 countries

ACAS (Australia)
Aarhus University (Denmark)
Ankara University (Turkey)
Argonne National Laboratory (USA)
Athens University (Greece)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
ETHZurich (Switzerland)
Gazi Universities (Turkey)
Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
IHEP (China)
INFN / LNF (Italy)
Instituto de Fisica Corpuscular (Spain)
IRFU / Saclay (France)
Jefferson Lab (USA)
John Adams Institute/Oxford (UK)
John Adams Institute/RHUL (UK)
JINR (Russia)
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NCP (Pakistan)
NIKHEF/Amsterdam (Netherlands)
North-West. Univ. Illinois (USA)
Patras University (Greece)
Polytech. University of Catalonia (Spain)
PSI (Switzerland)
RAL (UK)
RRCAT / Indore (India)
SLAC (USA)
Thrace University (Greece)
Tsinghua University (China)
University of Oslo (Norway)
Uppsala University (Sweden)
UCSC SCIPP (USA)

Previous demonstrations

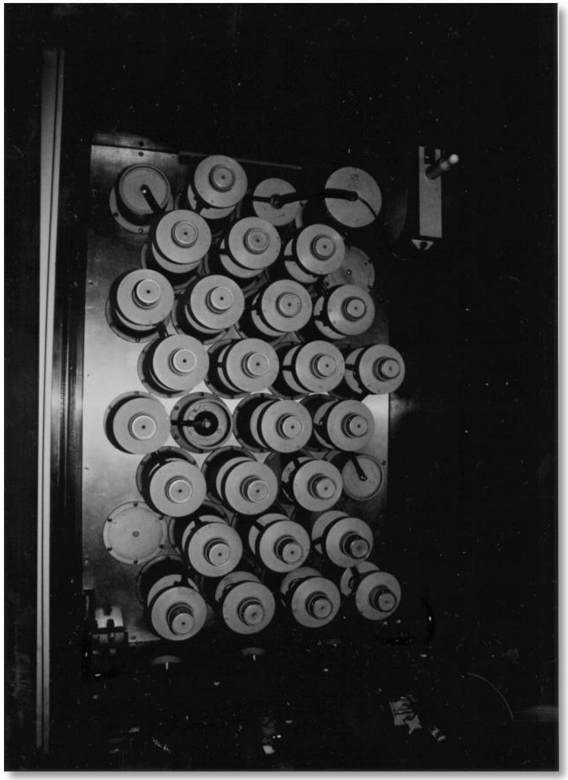
- Fully loaded acceleration: ~96% RF to beam efficiency!
- subharmonic bunching and phase coding: ~5 ns phase flip
- Delay Loop principle, factor 2 current multiplication
- Combiner Ring principle, CTF3 Preliminary Phase (low current)
  - factor 4 and 5 combination
  - combination setup
  - isochronicity tuning



- present Combiner Ring
  - high current 2x4 combination (with DL, ~26A) (new RF deflectors)
  - ring length control
- RF power generation (12 and 30 GHz)

Fire in CTF3 Klystron Gallery

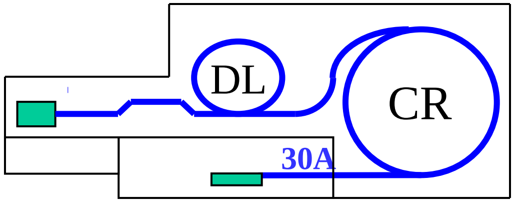
- On March 4 a fire destroyed the pulse forming network in the faraday cage of MKS13
- Cleaning of components was needed to prevent corrosion
- 400 cables repaired



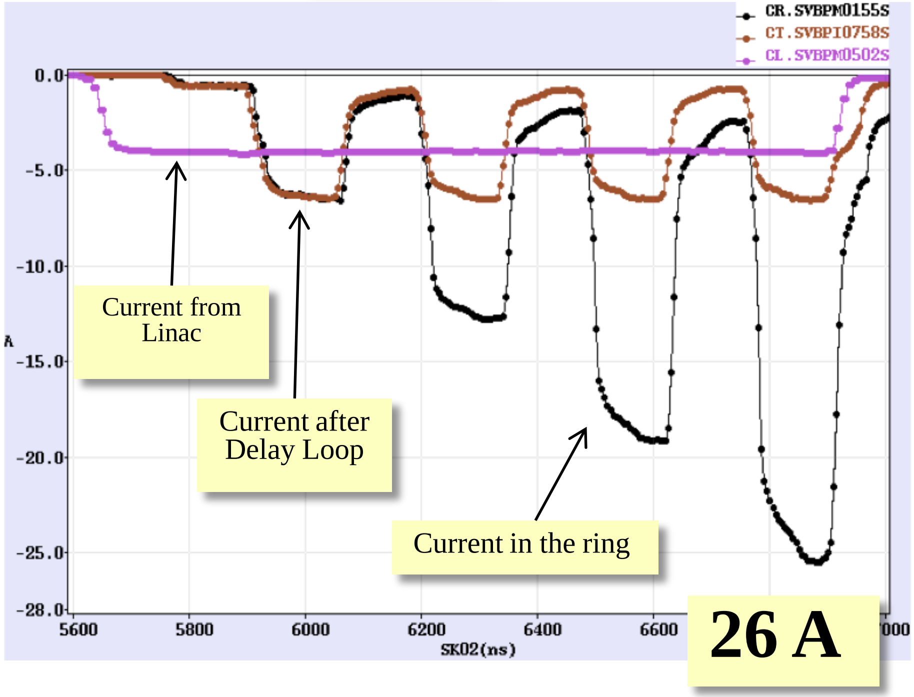
- => ~4 months delay, about half of operation time lost this year
- klystron missing, accelerating structures removed
  => lower beam energy or lower beam current => new setup needed
- restart went well without any major problems
- klystron will be rebuild for 2011 run

Evolution from previous CLIC-WS

- had ~26 A combination achieved, nominal 140 ns pulse length
- detailed studies still had to be done
- now lower linac current due to missing klystron
  => ~20 A combined current => progress ???



2009

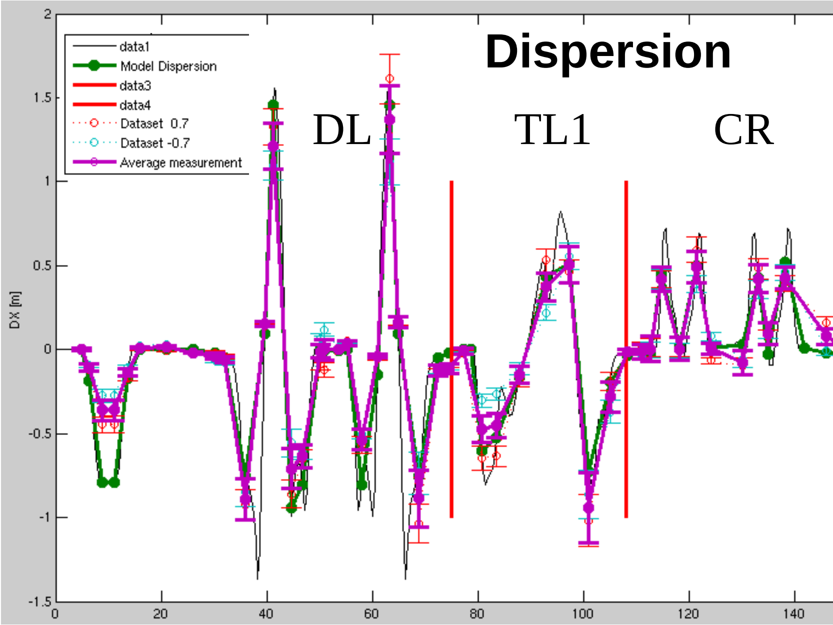


2010

Progress in Operation

Frank Tecker, WG6, Thu 16:10

- Lots of progress in the operation of the machine
  - careful setting up of RF pulses (minimize amplitude/phase variation)
  - hardware improvements in low-level and high-power RF
  - gun improvements (new heater power supply, …)
  - many optic checks, dispersion measurements, quad scans, response matrix studies, …
  - => optics model much better understood and adapted
    CTF3 runs based on design optics
  - => beam acceptance improved
  - shaped RF pulse to minimize ΔE/E
  - CCC supervision of klystrons at night/WE
- => better setup of the machine

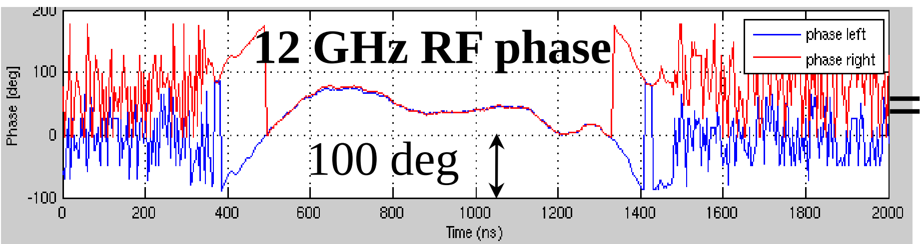


Simona Bettoni, Piotr Skowronski, et al.

Progress in Operation (cont.)

Guilio Morpurgo, WG6, Wed 14:40

- For 12 GHz power production, bunch phase along the pulse is crucial
  - => need stable beam energy, klystron phases, beam current
  - DL, CR ring length, orbit, closure carefully optimized
- detailed studies of bunch phase, variation understood and minimized



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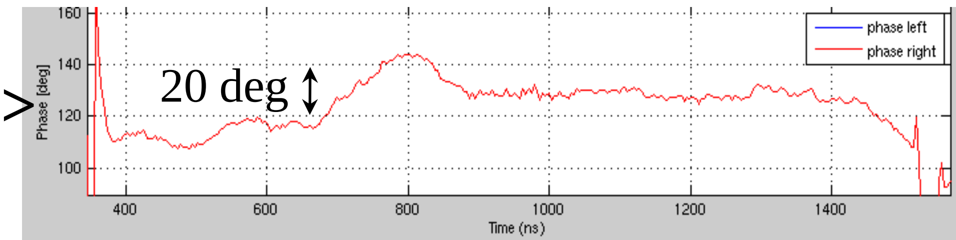
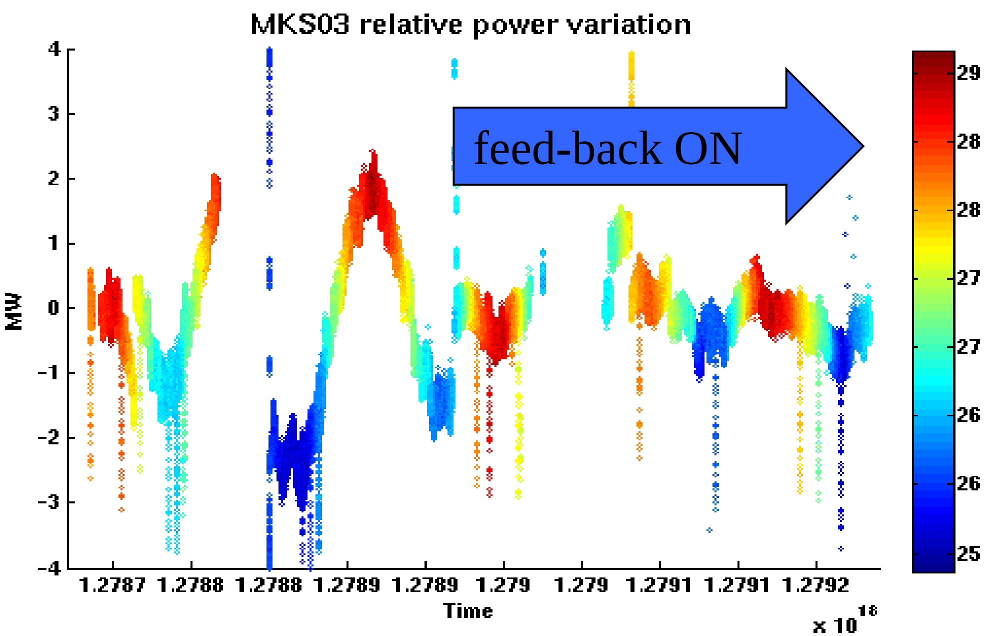


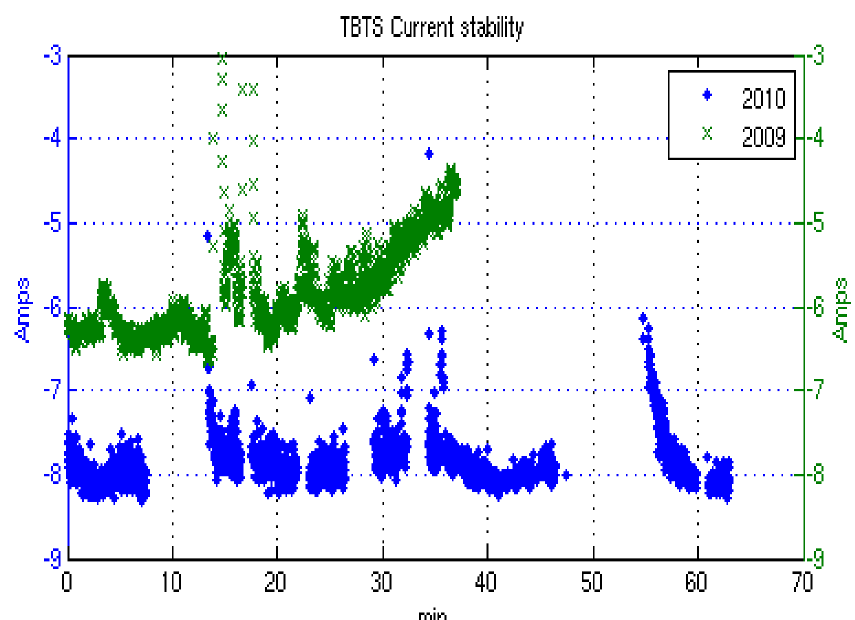
Erik Adli, Reidar Lillestøl

- => Operation more complex and more demanding
- Extensive use of reference signals (RF, BPMs, etc.)
- still jitter and slow drifts render operation difficult
- different feedbacks developed
  - klystron phase loops (implemented)
  - RF pulse compressor temperature feedback (implemented)
  - gun current feedback

RF compressor temp. feedback

- RF pulse compression cavities very sensitive to temperature variations
- Temperature sensors installed along the klystron gallery
- feed-back developed => significantly improved RF stability
- recovers quickly after klystron trip
  - => compressed RF flat top much more stable
  - together with operational improvements => current in TBL/TBTS more stable

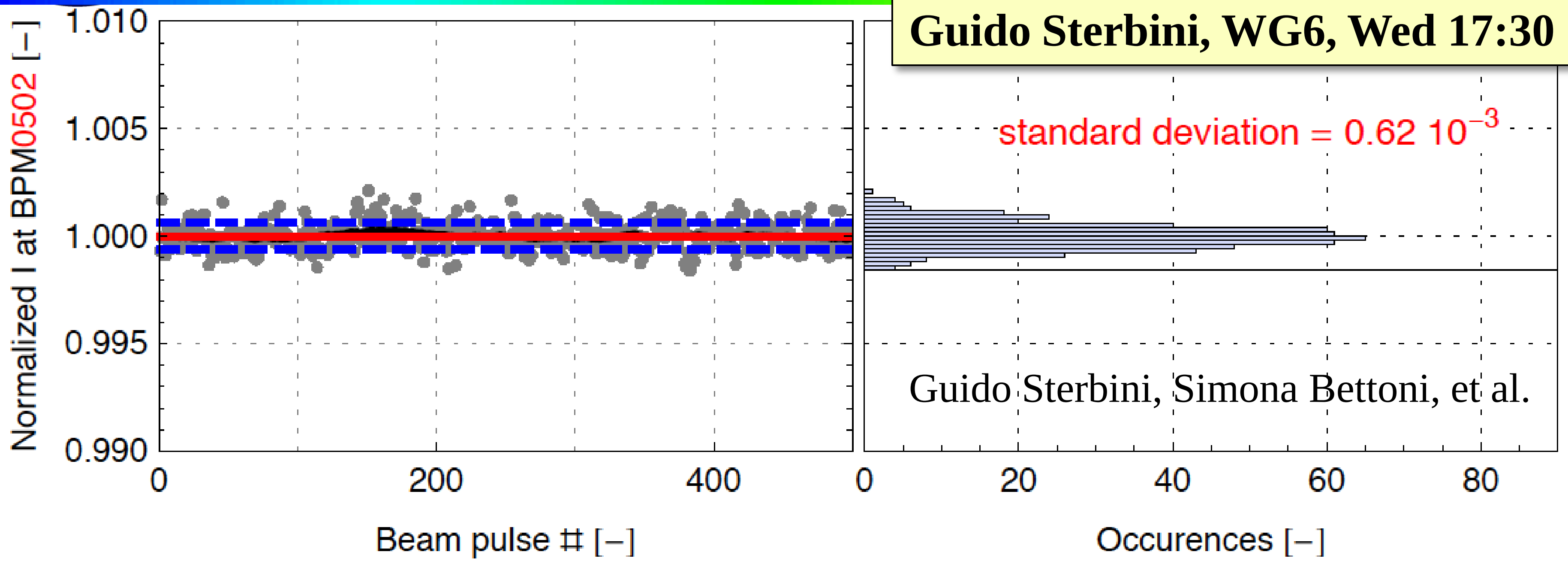




Alexey Dubrovskiy

Beam current stability

Guido Sterbini, WG6, Wed 17:30

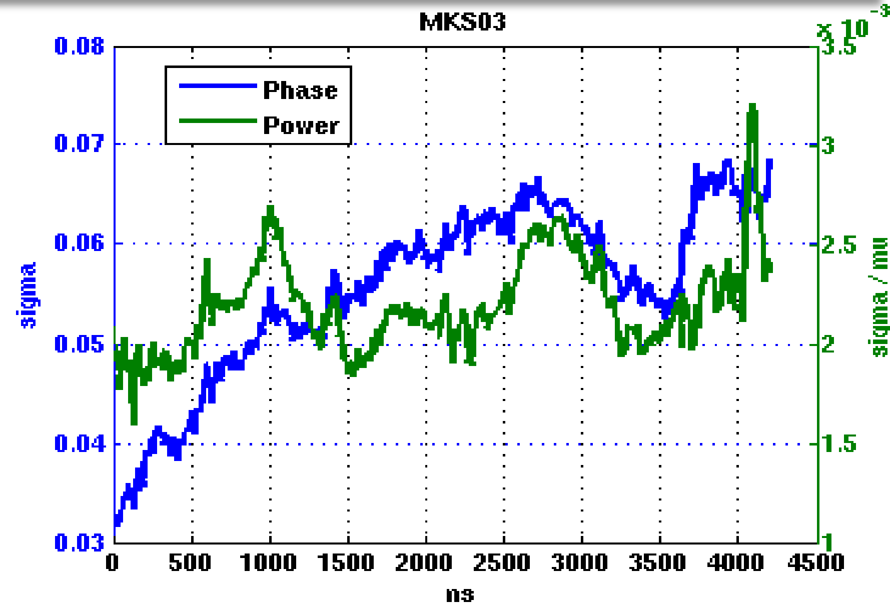


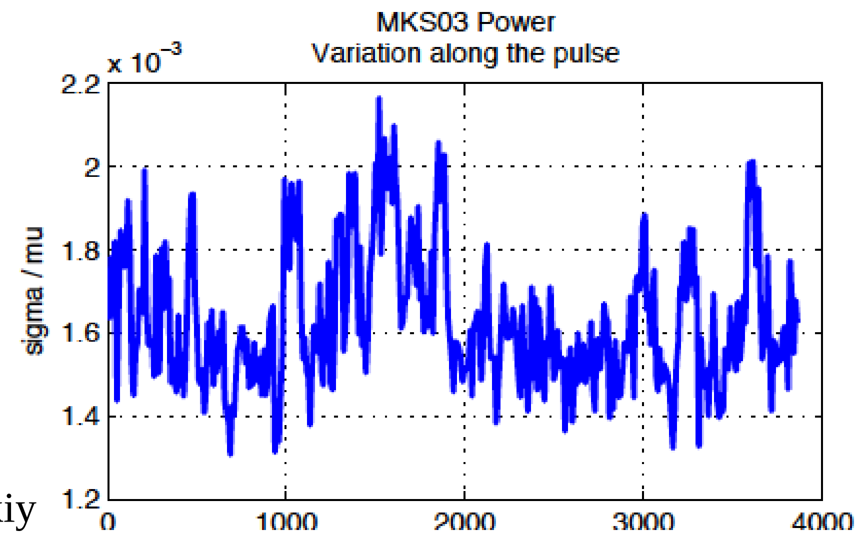
- stability already good without stabilization: $1.5\ 10^{-3}$ (linac)
- new gun heater power supply improved it to: $0.9\ 10^{-3}$
- pulse-to-pulse feedback test reduced it to: $0.6\ 10^{-3}$
- => current stability reaches the needs for CLIC ($1\text{-}2\ 10^{-3}$)

Klystron phase stability

Alexey Dubrovskiy, WG6, Wed 17:50

- Measurements of klystron phase and power indicate
  - pulse-to-pulse average phase stability with respect to local reference phase 0.035 ◦
  - for each 10 ns times slice the pulse to pulse jitter is 0.07 ◦
  - pulse-to-pulse power stability of < 0.2%
  - => gradient stability ≤ 0.1%
- => Corresponds to CLIC drive beam needs

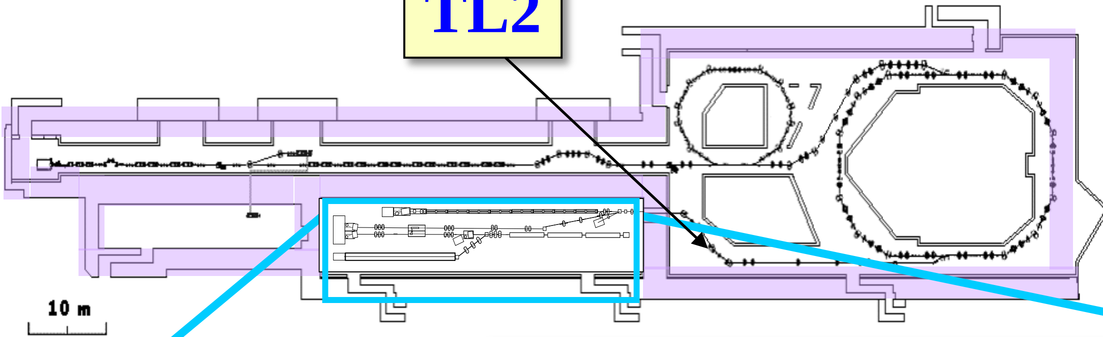


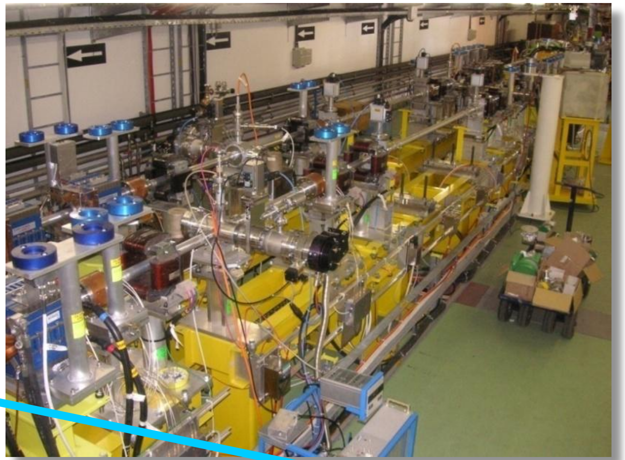


Alexey Dubrovskiy

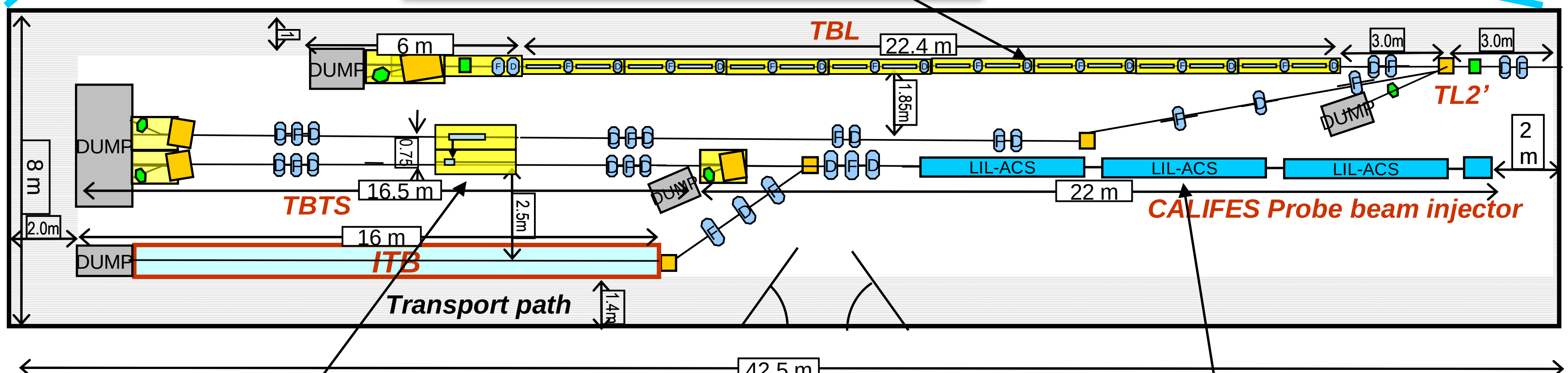
CLEX (CLIC Experimental Area)

TL2





Test Beam Line - TBL



Two Beam Test Stand - TBTS

Probe Beam - CALIFES

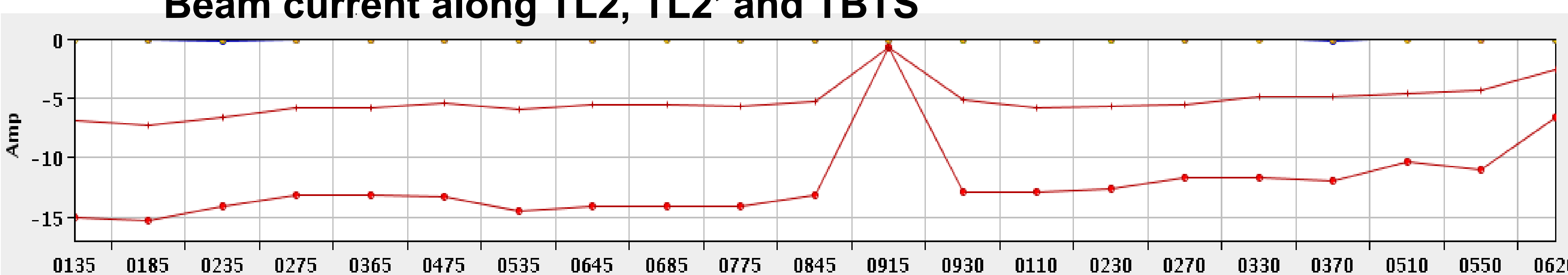
- tests for power production, deceleration and two-beam studies

TL2, TL2', TBTS beamlines

BPMs: Lars Soby, WG6, Wed 16:50

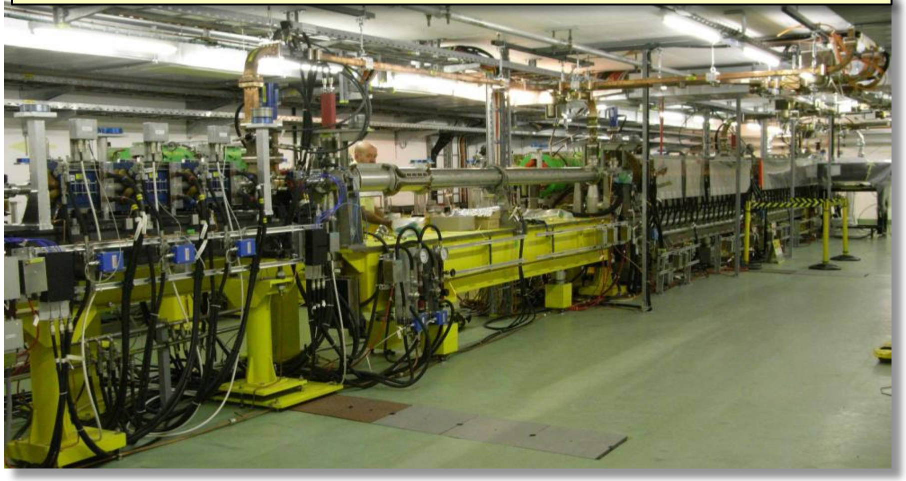
- previously difficult to transport the beam (BPM system problems)
- new BPM system works fine (except overloaded front-end crates)
- optics model better understood (from kick measurements)
- improved transport to TBTS and through PETS
  - Combined beam with some losses
    (from 15 A to ~12 A in PETS)

Beam current along TL2, TL2' and TBTS



CALIFES results

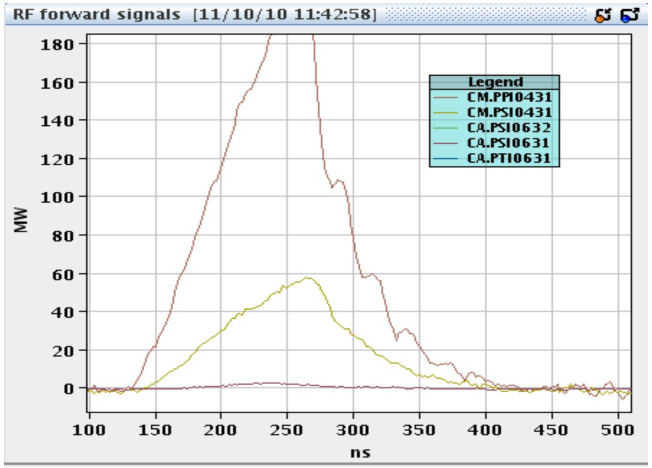
Wilfrid Farabolini, WG6, Thu 14:20



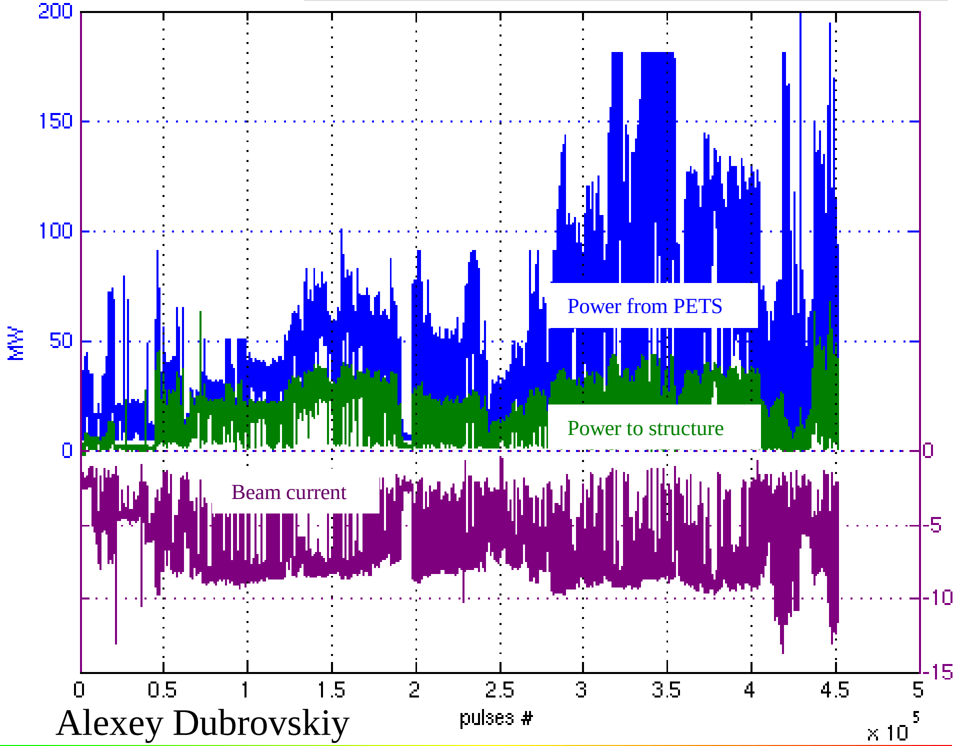
- newly installed 3 GHz high power phase shifter commissioned
- measured:
  - laser pulse and bunch length
  - Q_e, laser/beam stability
  - energy/energy spread
  - emittance
- bunch charge still small (<0.2 nC) in standard operation (low Q_e)
- CALIFES probe beam is now routinely used for the TBTS operations and provides useful data on ACS behaviour
- Good beam parameters reasonably easy to obtain and stable in time

TBTS, PETS conditioning

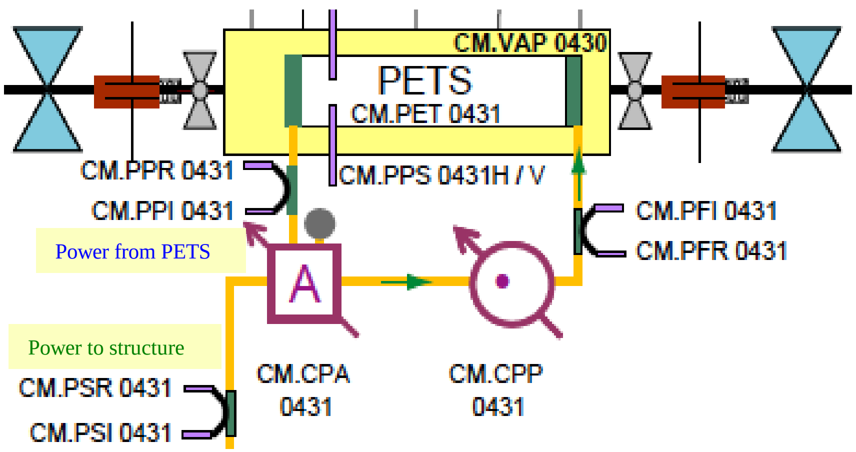
Igor Syratchev, WG4, Wed 11:10
Alessandro Cappelletti, WG6, Wed 10:30



- PETS operated with recirculation:
  part of generated power is re-injected into PETS
- last year limited by variable power splitter/phase shifter (outside PETS) – reworked now
- conditioned to higher power
- Max power reached 200 MW (peak)
  total pulse length ~200 ns – no flat top
  (135 MW nom.)



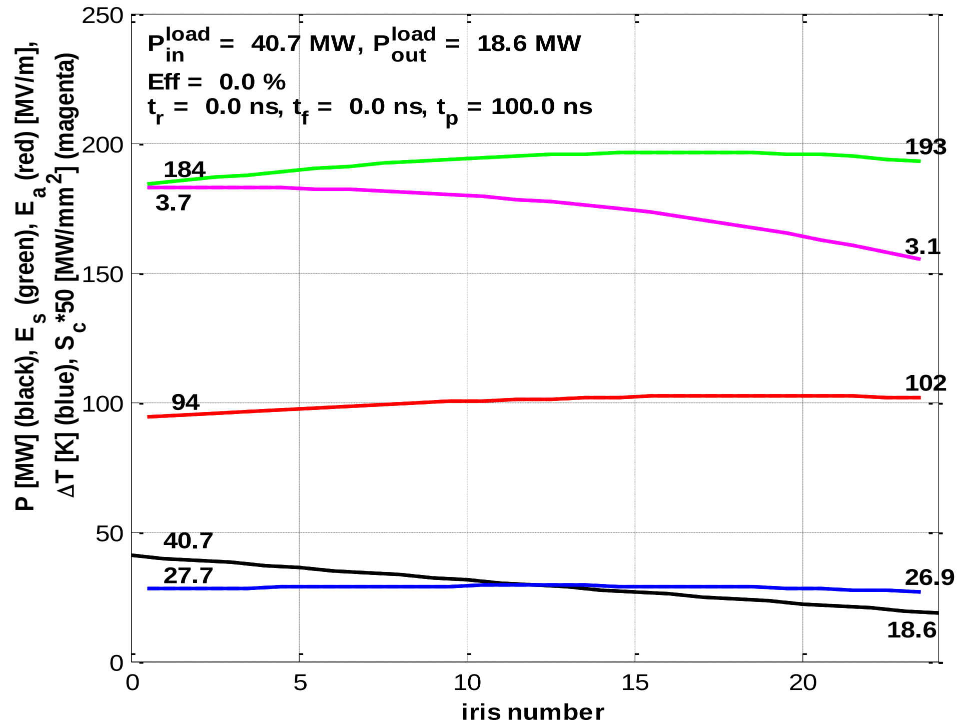
Alexey Dubrovskiy



Accelerating structure in CLEX

- TD24 accelerating structure installed during shutdown 2009/10
- 24 regular + 2 coupler cells with damping features
- L_{acc} = 200.0 mm (reg.cells)
- fill time t_f = 65 ns
- 42 MW input power for 100 MV/m (unloaded) (60 MW loaded)

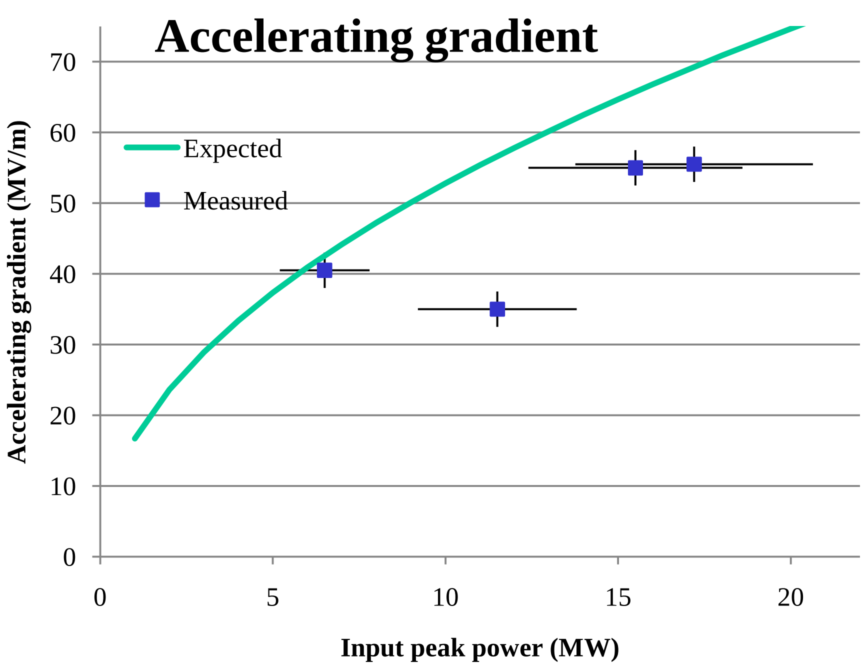
Average unloaded gradient of 100 MV/m

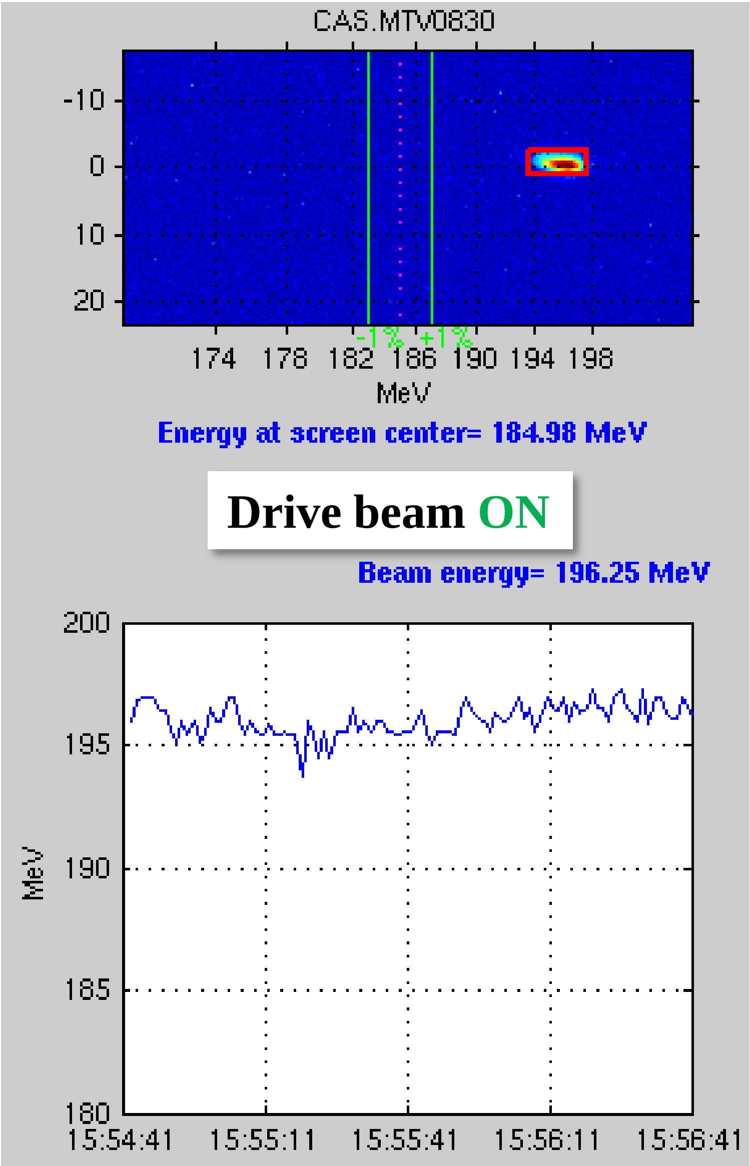


Alexey Grudiev

Two-beam acceleration in CTF3

- maximum probe beam acceleration of 11 MeV measured
- => **gradient ~55 MV/m**
- RF calibrations to be verified

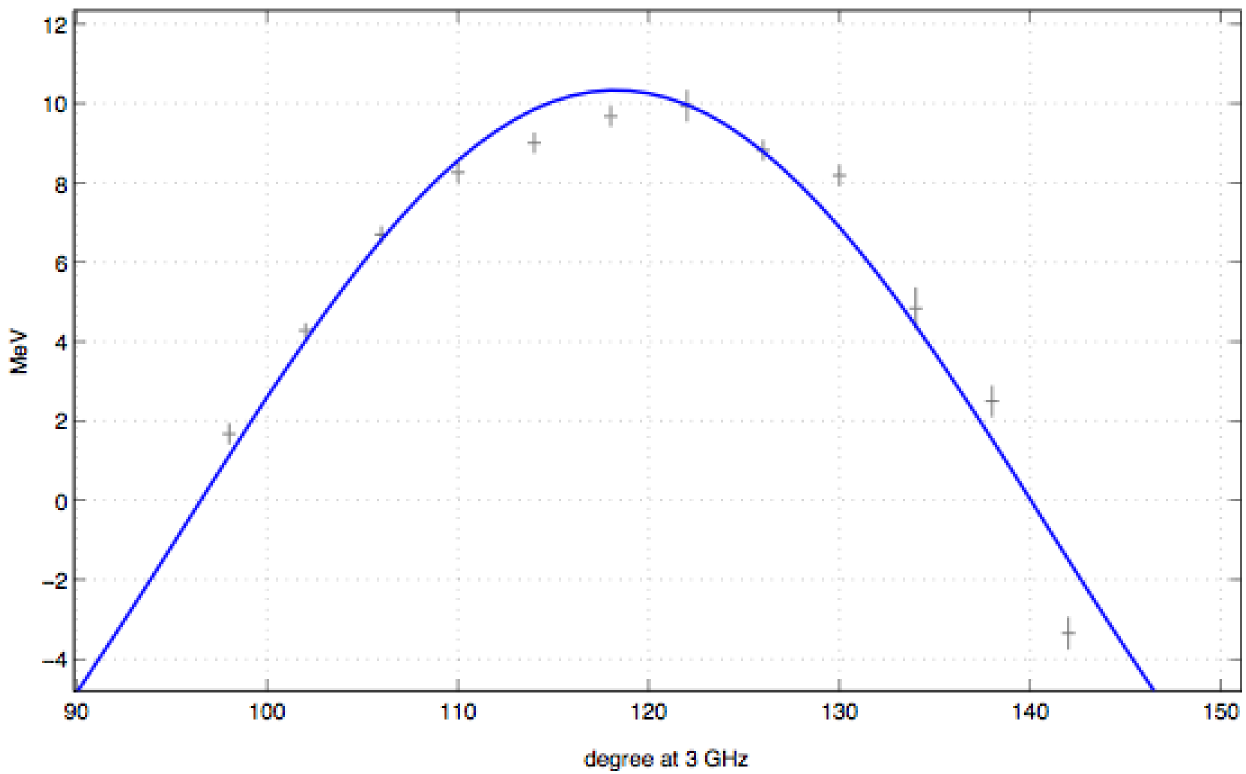




TBTS – Two Beam acceleration

Andrea Palaia, WG6, Thu 14:00

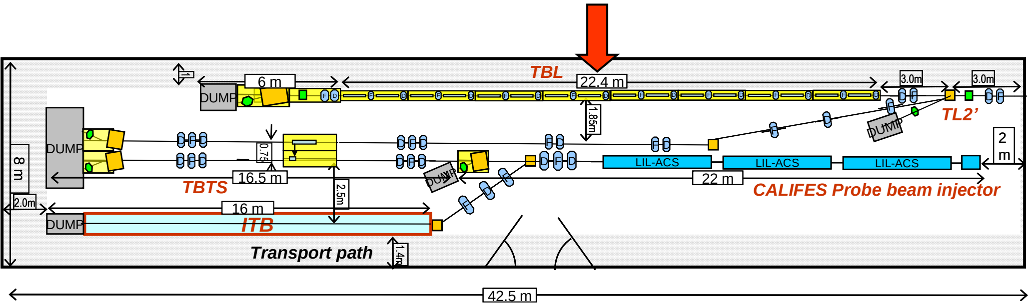
- phase scan of 3 GHz probe beam RF and Laser
- 10 MW acceleration (~50 MV/m)
- also deceleration studies done

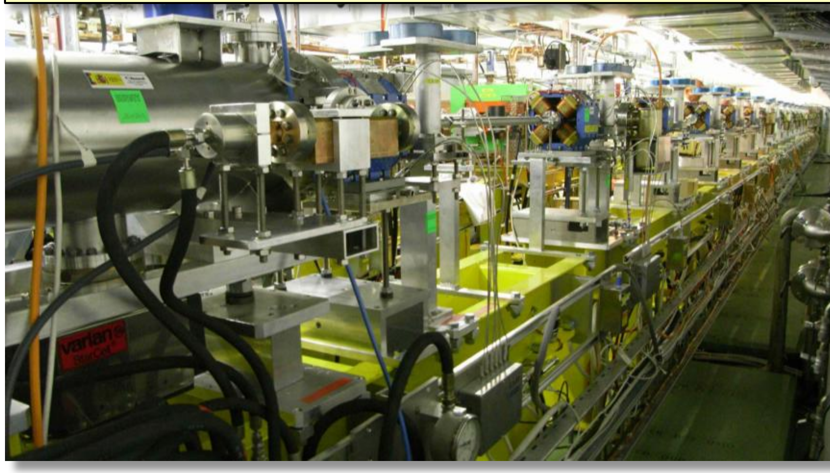


Andrea Palaia

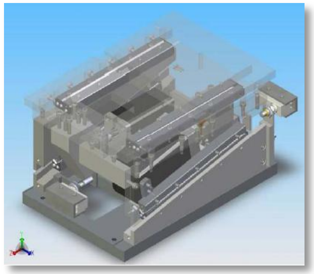
TBL - Test Beam Line

Steffen Doebert, WG4, Wed 11:40





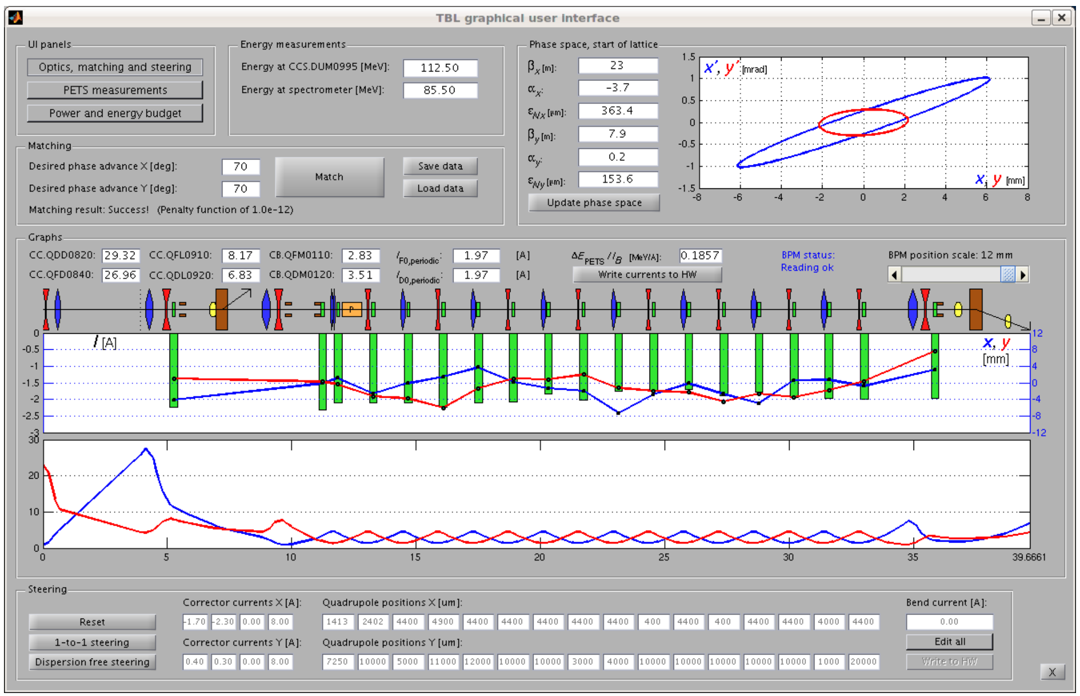
- all quadrupole movers (CIEMAT) installed and tested with remote control
- End-of-line spectrometer hardware and software installed
- New emittance screen at the end of the line
- 1 PETS will be installed in November
- Segmented dump will be installed in January
- A total of 4 PETS in January, then a total of 8 in summer 2011
- 8 last PETS in 2012

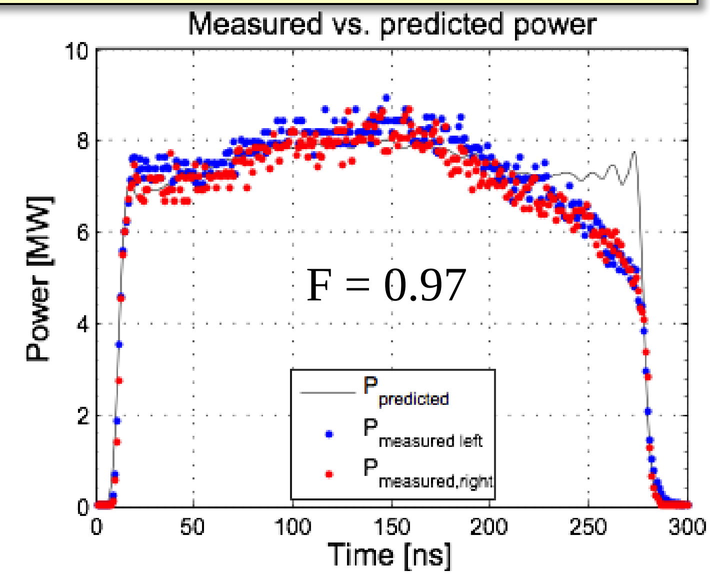


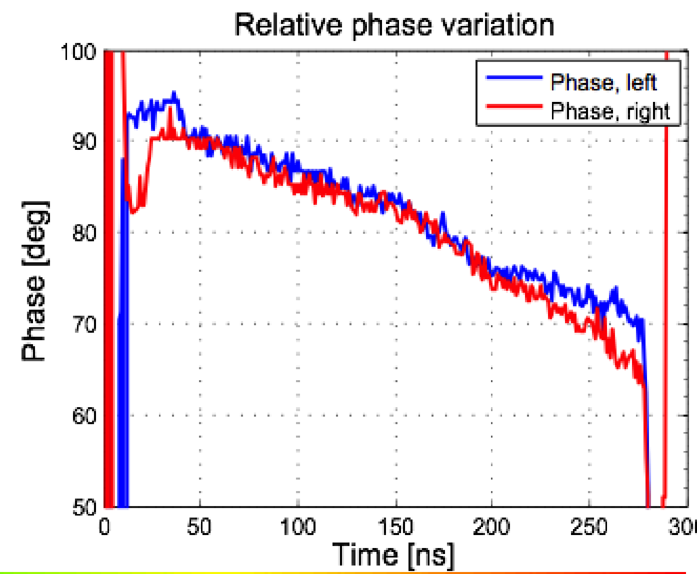
TBL Commissioning Status

Reidar Lunde Lillestøl, WG6, Wed 11:00

- new GUI used for commissioning and matching (MAD model)
- successful matching based on quad scans
- RF production consistent with expectations
- form factor and phase information used to optimize DB generation



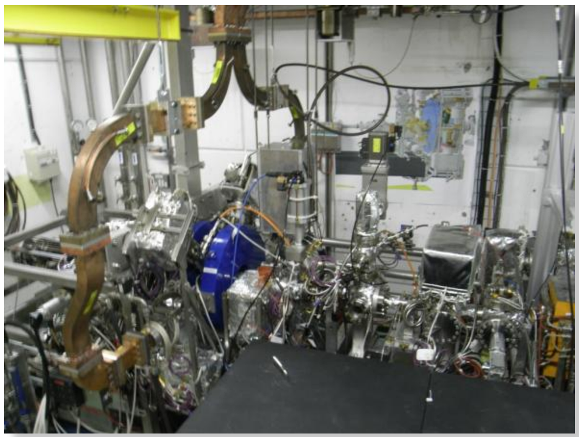


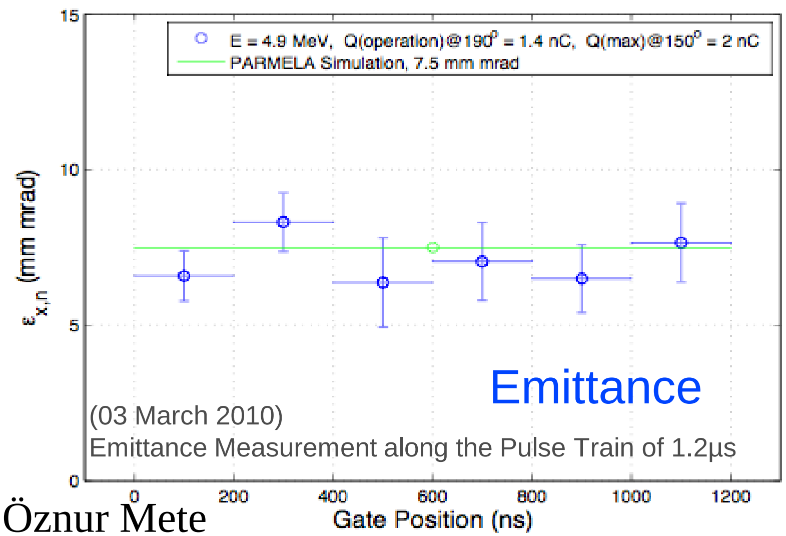


PHIN – DB Photoinjector test

- specifications successfully demonstrated during the June run
- measurements along pulse train

Öznur Mete, WG6, Thu 15:00





Öznur Mete

Parameter	Specification	Achieved
Charge per Bunch (nC)	2.33	4.4
Charge per Train (nC)	4446	>4446
Train Length (ns)	1273	1300
Current (A)	3.5	~3.4
Normalized Emittance (mm mrad)	<25	14
Energy Spread (%)	<1	0.7
Energy (MeV)	5.5	5.5
UV Laser Pulse Energy (nJ)	370	400
Charge Stability (%)	<0.25 rms	1-2
Cathode	Cs_2Te	Cs_2Te
Quantum Efficiency (%)	3	18 (peak)
RF Gradient (MV/m)	85	85
RF Frequency (GHz)	2.99855	2.99855
Micropulse Repetition Rate (GHz)	1.5	1.5
Macropulse Repetition Rate (Hz)	1-5	1-5

Laser Stability

Marta Csatari, WG6, Thu 14:40

Amplitude

In laser room

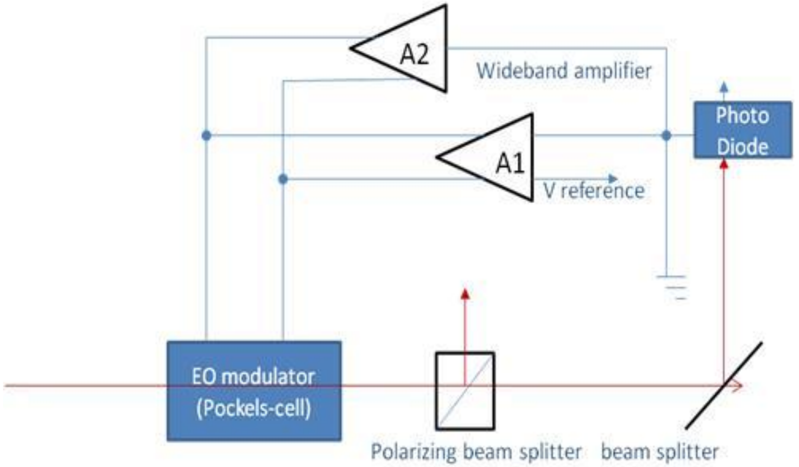
Macrop	IR	Green	UV
RMS stability	0.23%	0.8%	1.3%

Nonlinear conversion increases noise and causes amplitude variations along the train

In PHIN

Laser RMS	Current RMS	Train length(ns)	
1.3% RMS	0.8% RMS	1250	best
2.6%	2.4%	1300	worst

Feedback stabilization scheme

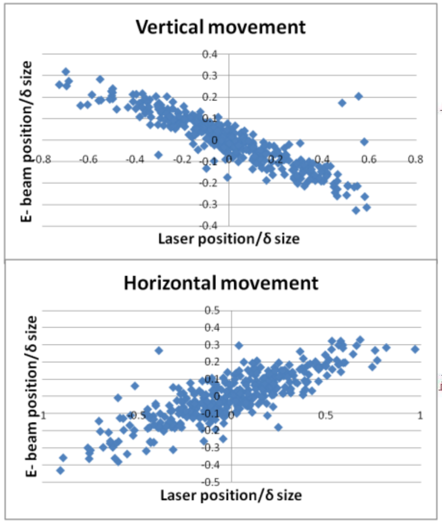


In TESLA this system was invented by I. Will and his group
0.7% rms stability was achieved from 3% with 70% transmission

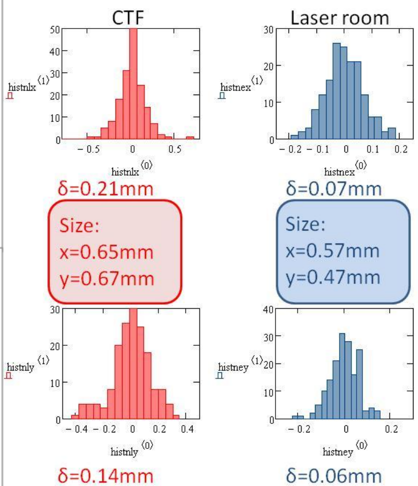
- Exceptional stability without feedback stabilization!
- Noise characterization ongoing
- **Fast feedback planned for Spring 2011**

Position

CLEX (CALIFES)



CTF2 (PHIN)



	RMS V movement /size	RMS H movement /size
Laser room Without laser cover	13%	12%
PHIN (11.4m transport)	32%	21%
Laser room With laser cover	7.5%	5%
CALIFES (70m transport)	25%	16%

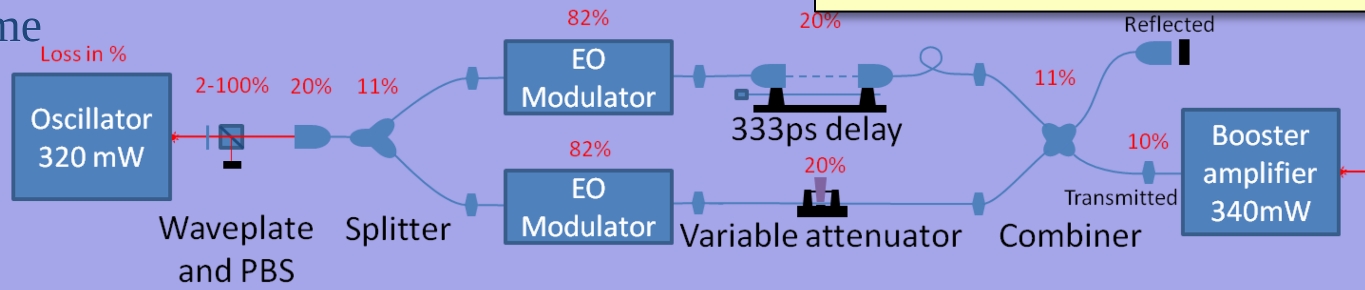
- **Pointing instabilities improved by laser cover**
- Windows will be installed on laser room floor to avoid airflow

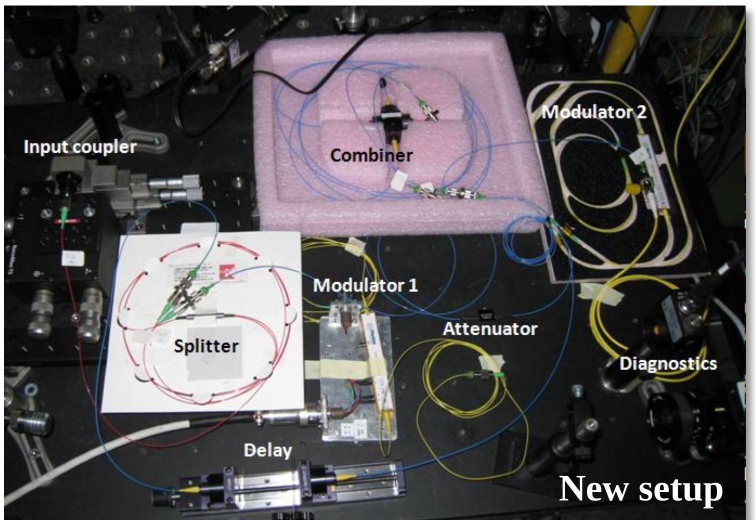
Laser Phase-coding

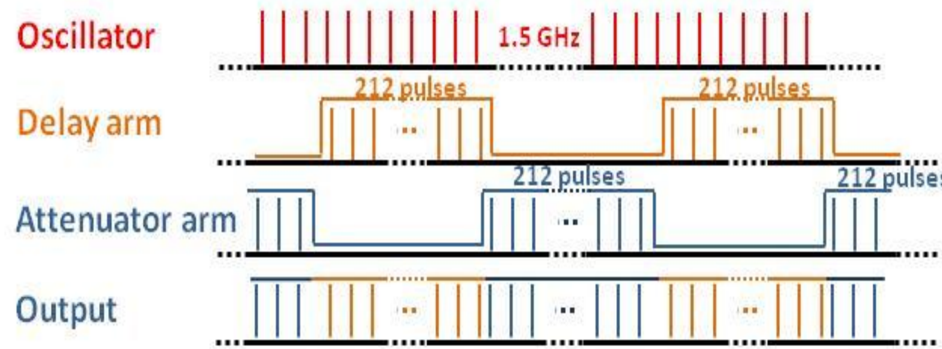
Marta Csatari Divall

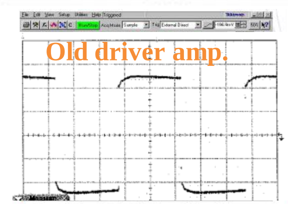
Marta Csatari, WG6, Thu 14:40

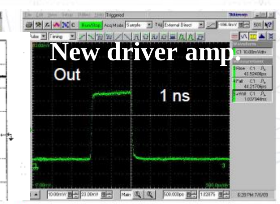
NEW scheme









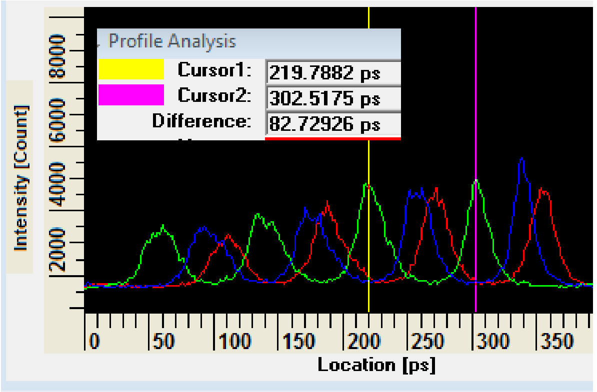


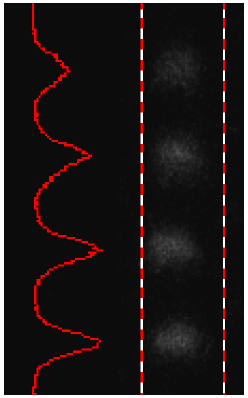
- all hardware components in place
- fully adjustable timing system for amplification window needed
- driver amplifier with flat output response ordered

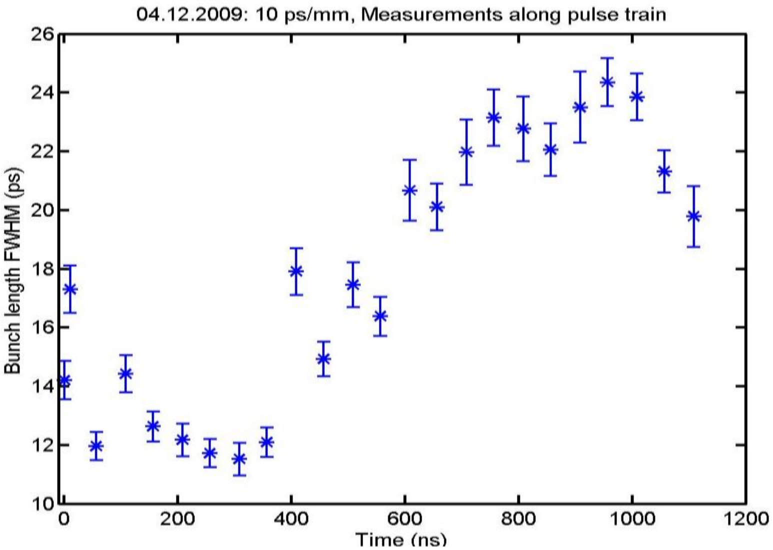
Beam Instrumentation/CDR Experiment

Anne Dabrowski, WG6, Wed 16:10

- the progress relies on various measurements
  - beam profile, emittance, energy and energy spread, bunch frequency, bunch length, form factor @ 12 GHz
- new Streak Camera (0.2 ps res.)

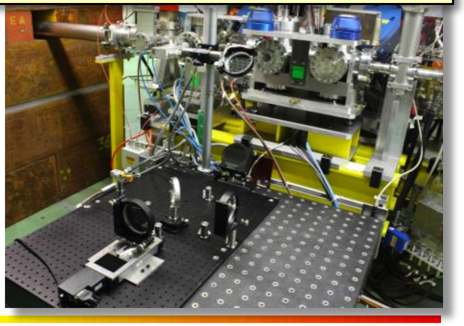






Konstantin Lekomtsev, WG6, Wed 17:10

- Coh. diffraction Radiation (CDR) experiment in the CR
- development continued
- studies performed, more sensitive detector needed



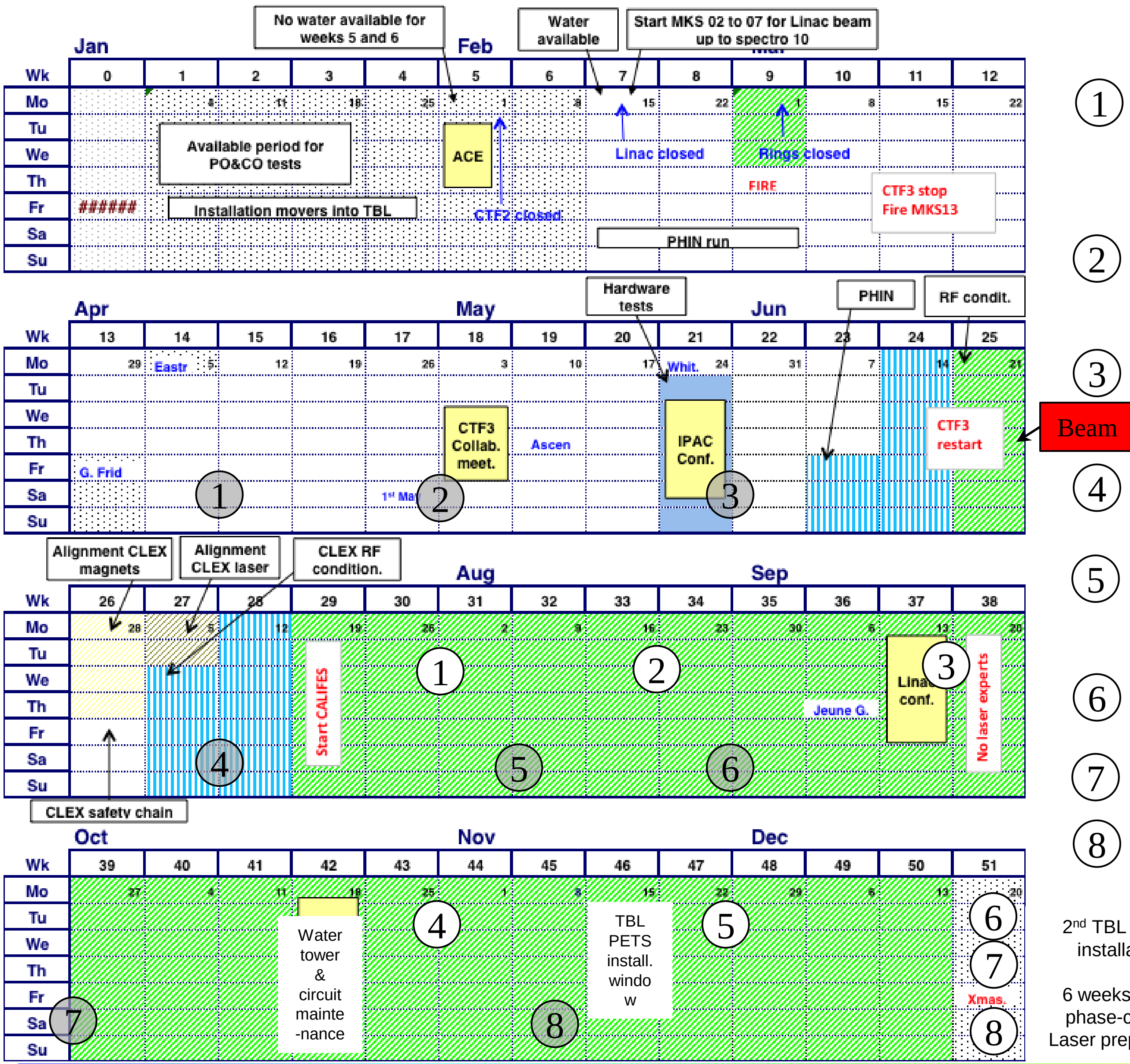
Conclusion

Roberto Corsini, WG6, Thu 16:40

- Important progress despite the fire
- operation with full Drive Beam generation consolidated
- stability issues addressed and stability improved
  - CLIC current stability needs reached
  - CLIC klystron stability demonstrated
- Beam Driven RF power generation as expected
  - up to 200 MW generated in PETS structure (CLIC 135 MW nom.)
  - bunch phase crucial
  - still optimizing the combined beam
- First two-beam acceleration with 55 MV/m
- Many other points well covered
- many more detailed presentations on Wednesday and Thursday in WG6 (Drive beam complex and CTF3)
- Many Thanks to everyone who made this possible!!!

Spares

Schedule (updated)



1. Optics improvements (DL dispersion)
   Full transport to CLEX
   Bunch length control (first tests)
   TBTS initial PETS tests
   CALIFES setup
   ~~new setup when MKS13 available?~~
2. PETS conditioned to nominal power/pulse length
   TBL PETS tests
3. Accelerating structure conditioned to nominal power/pulse length
   Two-Beam test power & energy gain, 100MV/m
4. TBL studies (limited)
   PETS breakdown rate measurements???
5. Measurement of breakdown kicks
   Beam Loading compensation experiment
6. Measurement of effect of beam loading on breakdown rate
7. Test of new PETS on-off scheme
8. TBL studies 30% deceleration ?

2nd TBL PETS installation

6 weeks PHIN phase-coding Laser preparation

- Stability studies & improvements
- PETS no recirculation
- Phase stability
- Operation at 5 Hz (or more)
- Control of beam losses
- Coherent Diffraction Radiation …

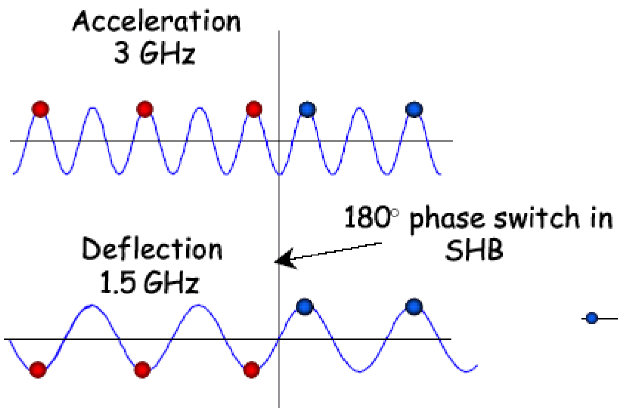
CTF3 Drive Beam generation

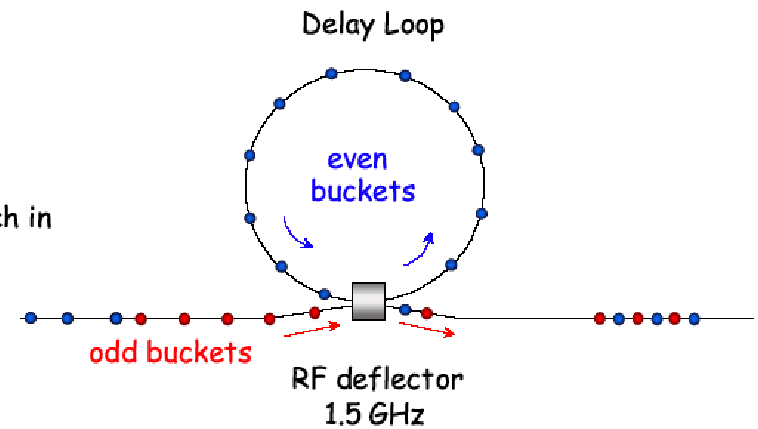
- Long, high-intensity bunch train (1.2µs) is accelerated with 3 GHz
- Bunch manipulations increase bunch repetition frequency and peak current

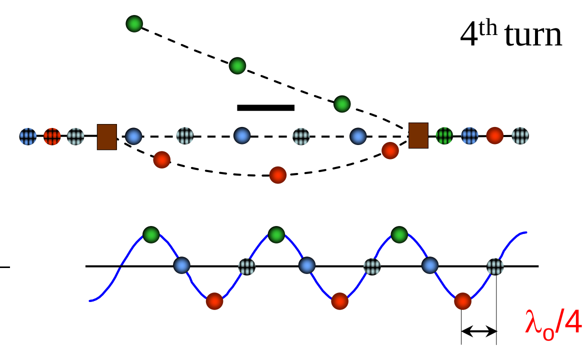
"phase-coding" of bunches

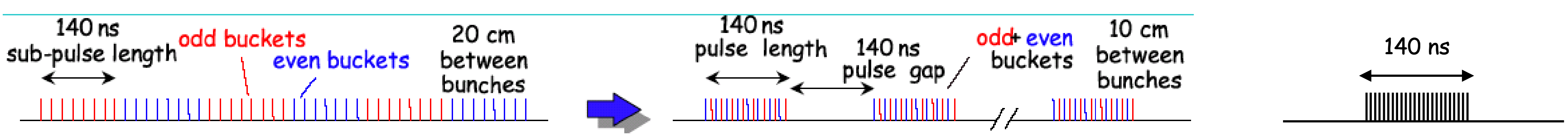
bunch interleaving with **Delay Loop**

successive injection of 4 bunch trains into **Combiner Ring**





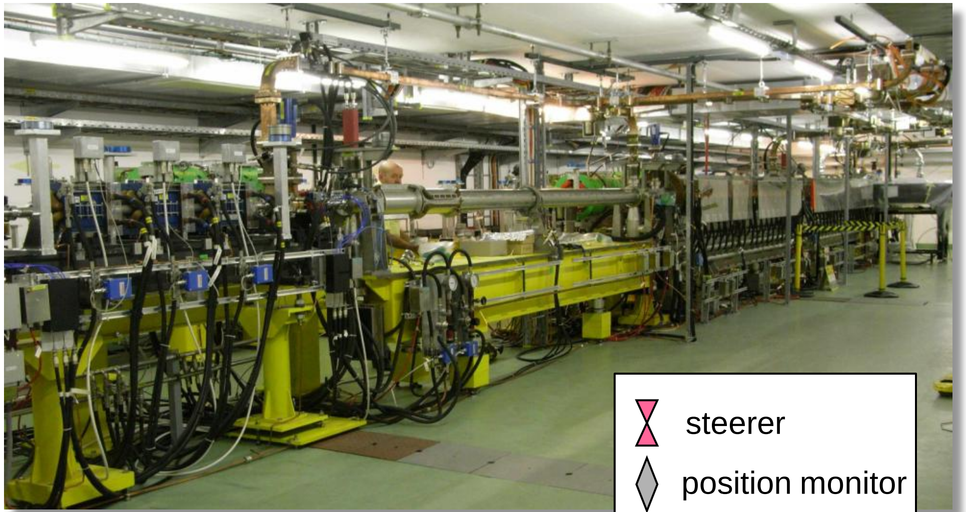


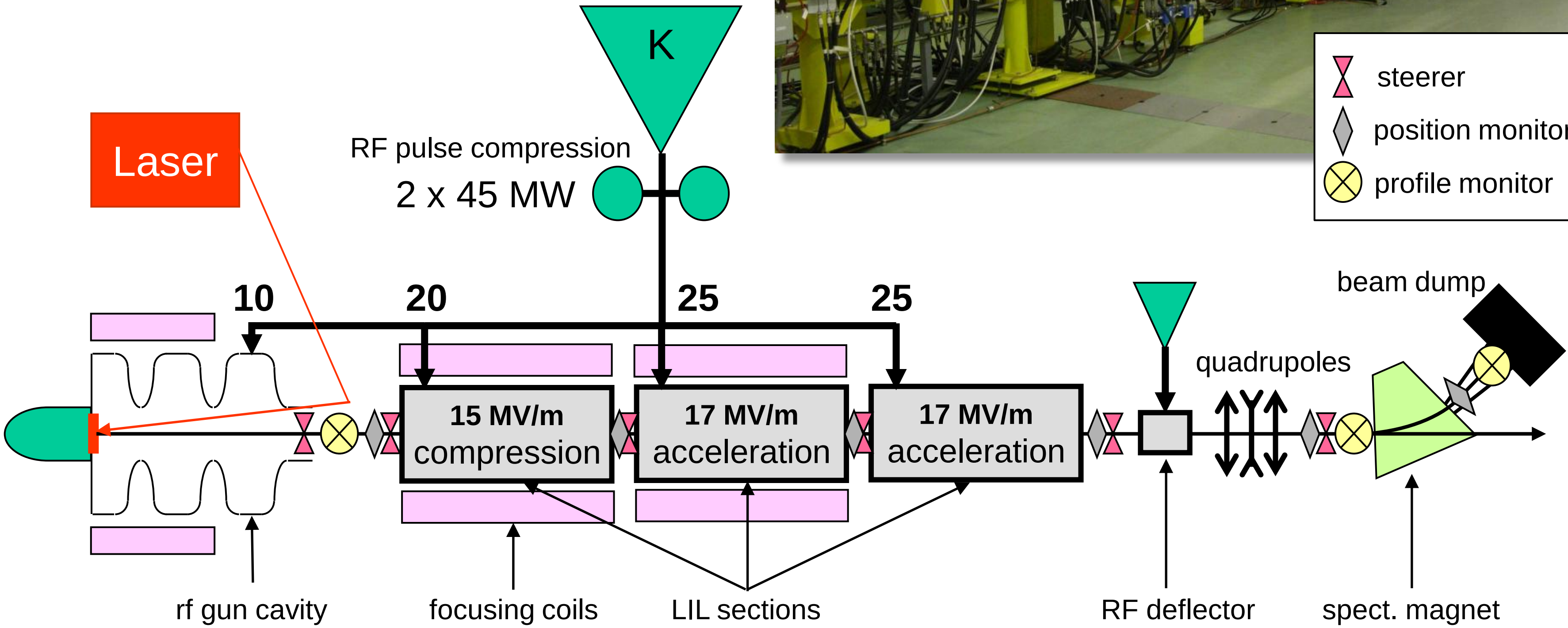


Probe Beam - CALIFES

Responsibility of IRFU (DAPNIA), CEA, Saclay, France

180 MeV
bunch charge 0.6 nC
number of bunches 1 – 32, 226

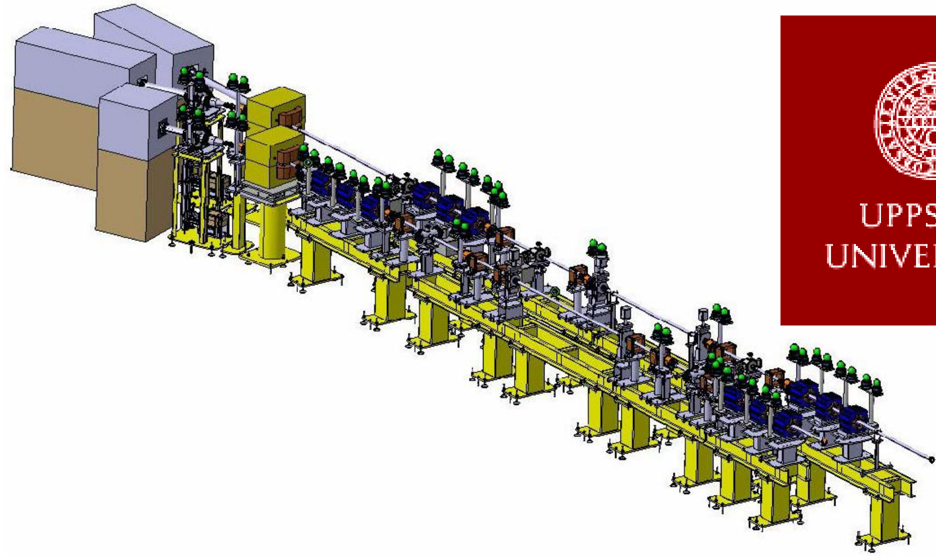




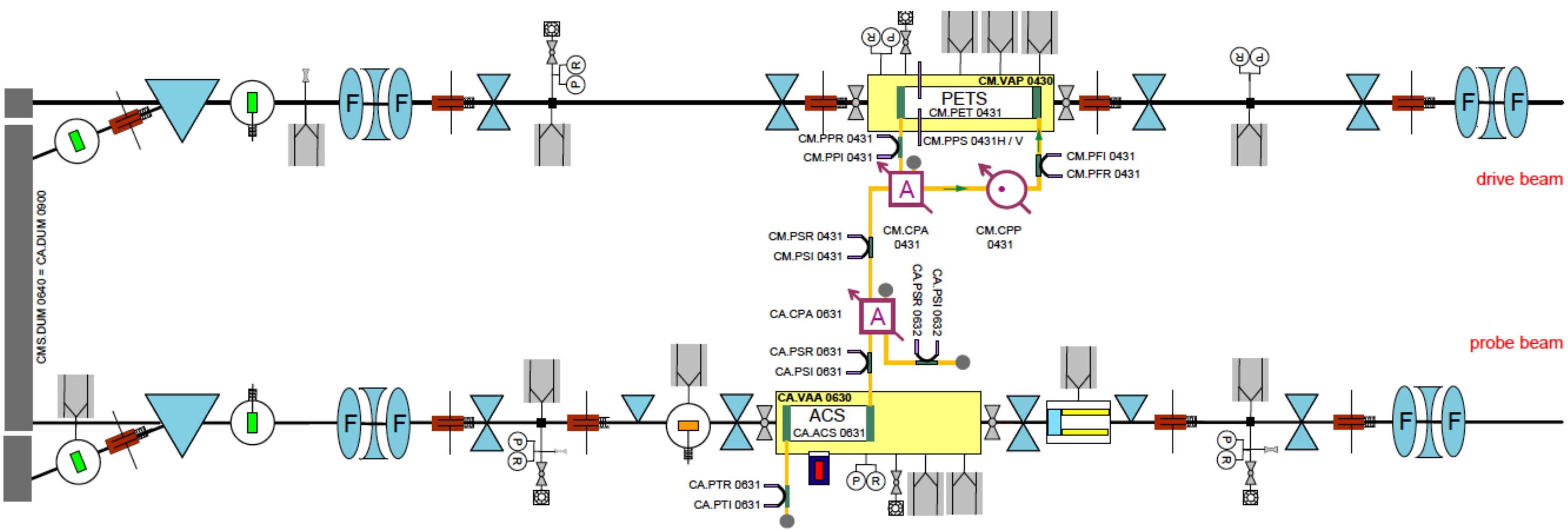
CALIFES

A. Mosnier, CEA Dapnia

Two-Beam Test Stand - TBTS

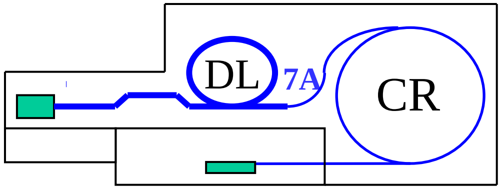


UPPSALA
UNIVERSITET

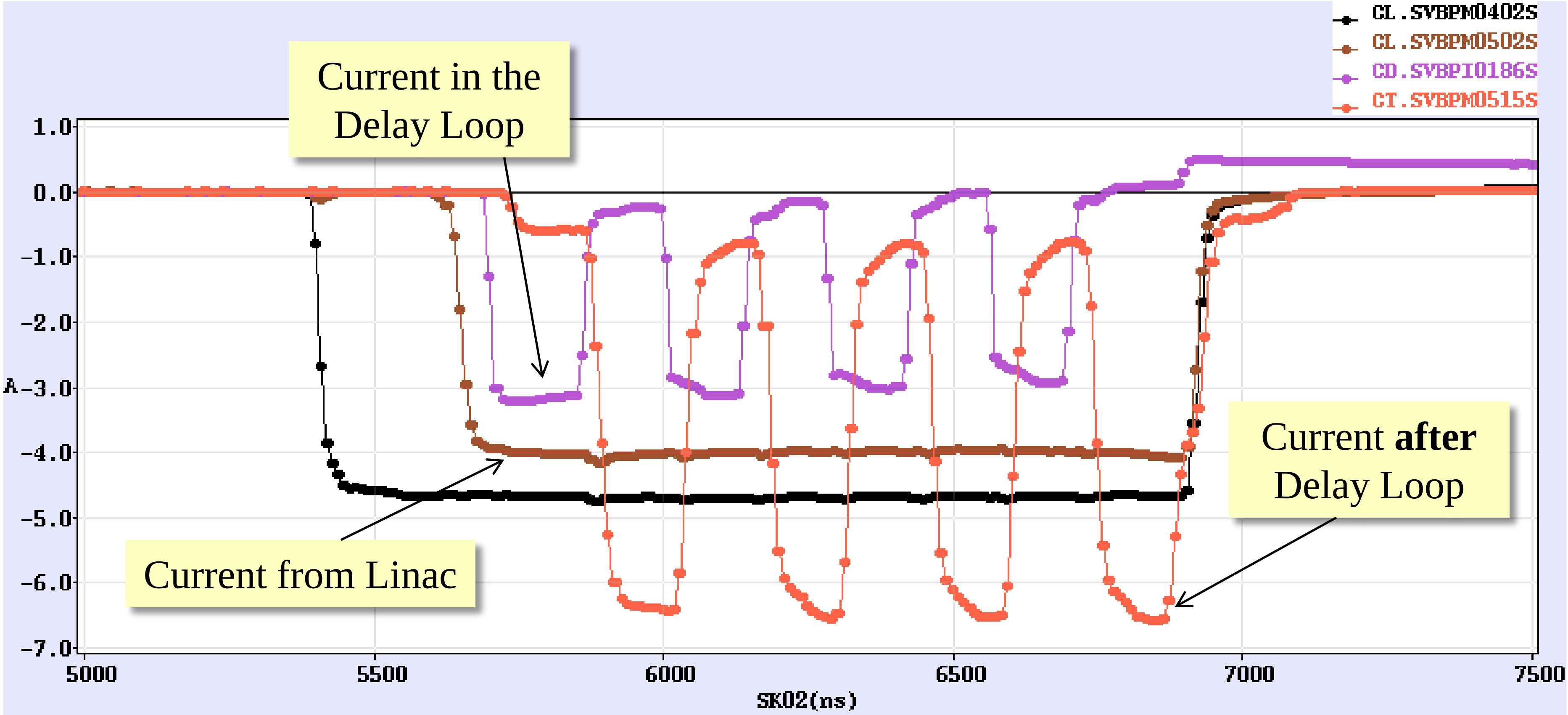


Delay loop status

- factor 2 combination re-established after 2 years

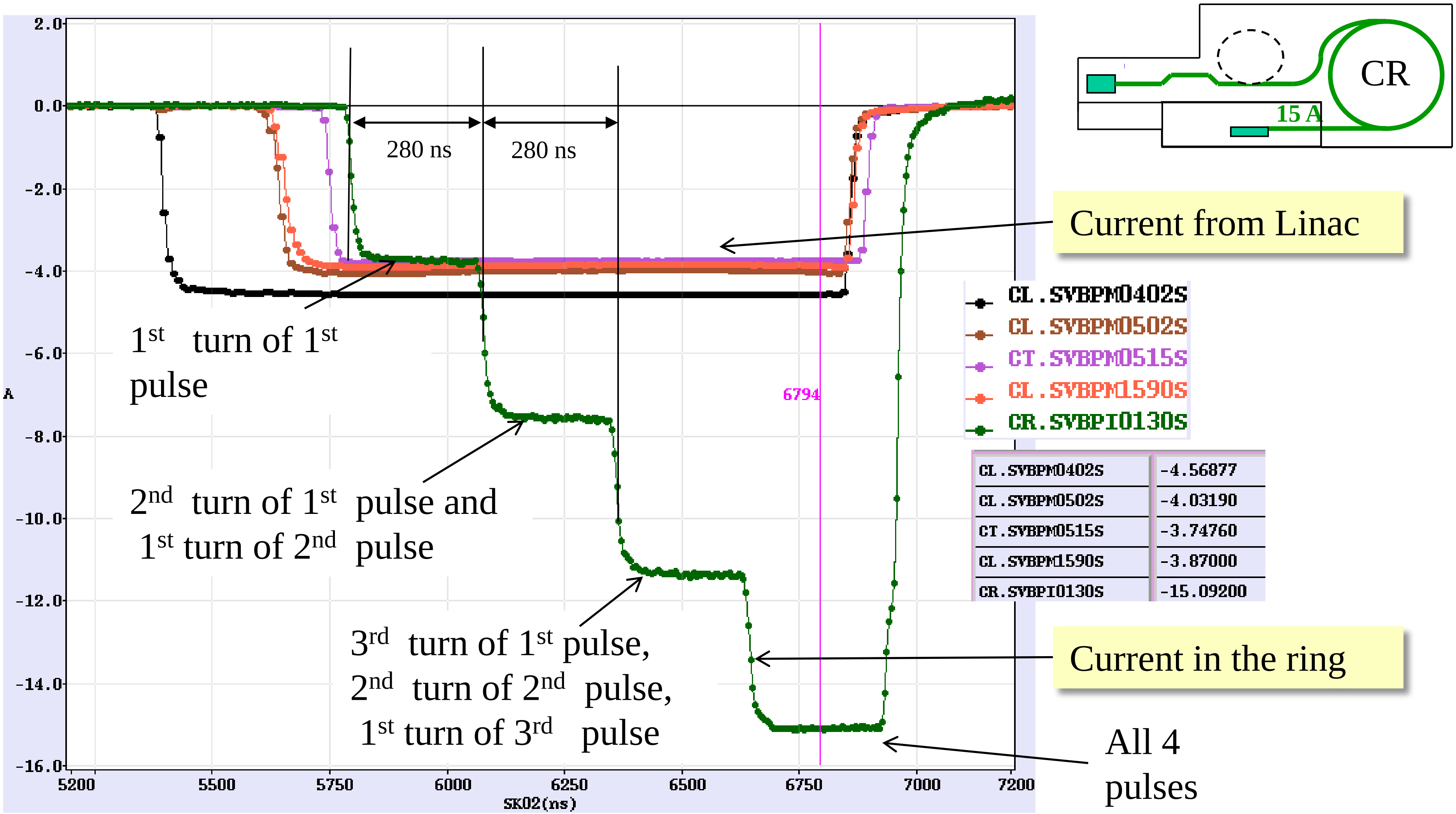


- current about doubled, from ~3.5 A to ~6.5A (0.5 A in satellites)



Combiner ring status

- factor 4 combination achieved with 15 A, 280 ns (without Delay Loop)



CL.SVBPM0402S	-4.56877
CL.SVBPM0502S	-4.03190
CT.SVBPM0515S	-3.74760
CL.SVBPM1590S	-3.87000
CR.SVBPI0130S	-15.09200

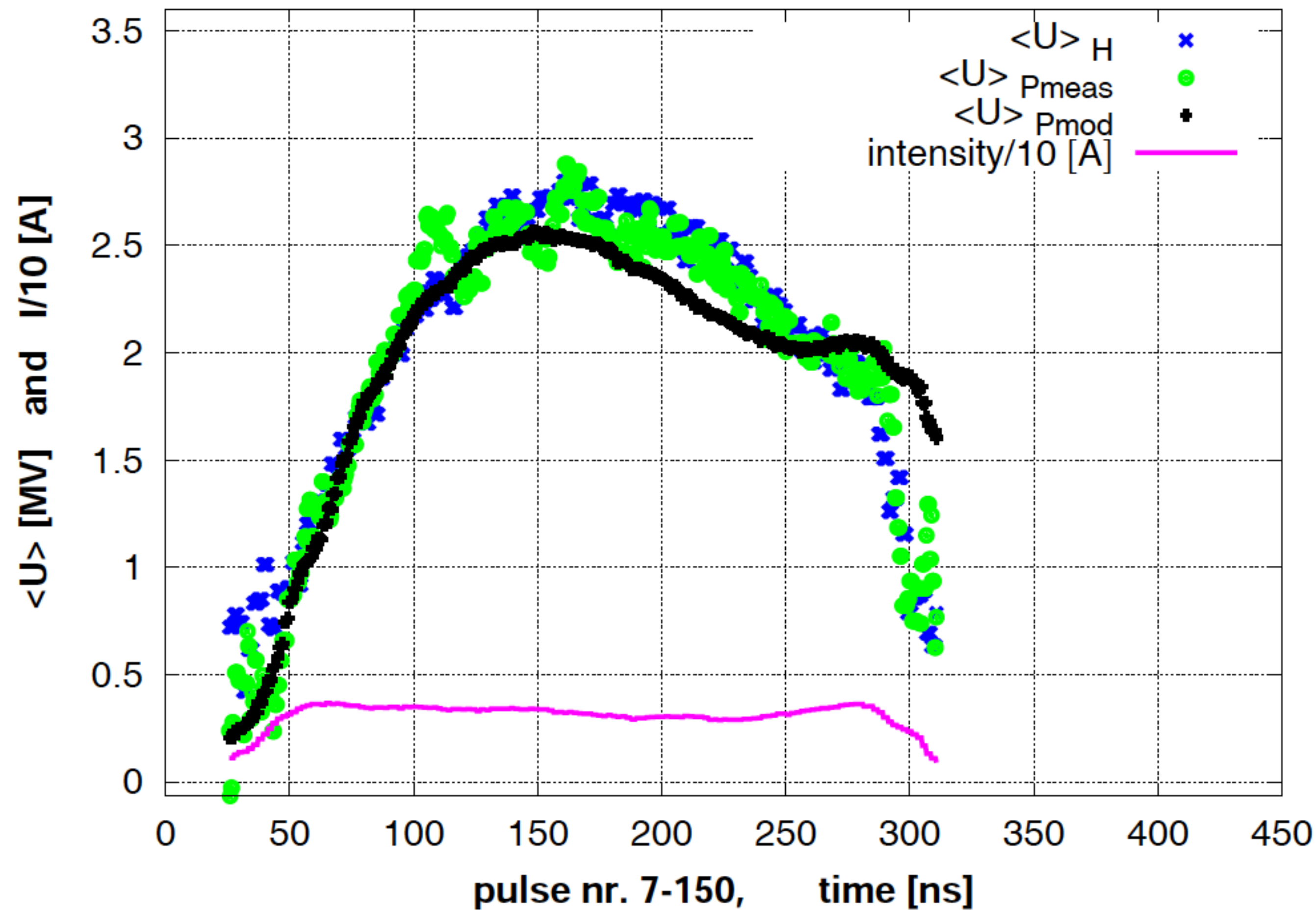
Comparison CLIC - CTF3

	CTF3	CLIC
Energy	0.150 GeV	2.4 GeV
Pulse length	1.2 μs	140 μs
Multiplication factor	2 x 4 = 8 (DL + 1 CR)	2 x 3 x 4 = 24 (DL + 2 CR)
Linac current	3.5 A	4.2 A
Final current	28 A	100 A
RF frequency	3 GHz	1 GHz
Deceleration	to ~50% energy	to 10% energy
Repetition rate	up to 5 Hz	50 Hz
Energy per beam pulse	0.7 kJ	1400 kJ
Average beam power	3.4 kW	70 MW

- CTF3 covers well the CLIC drive beam generation scheme
- Still considerable extrapolation to CLIC parameters
- Especially total beam power (loss management, machine protection)

TBTS deceleration

- deceleration in PETS structure as expected
- different models agree, slight difference (phase variation)

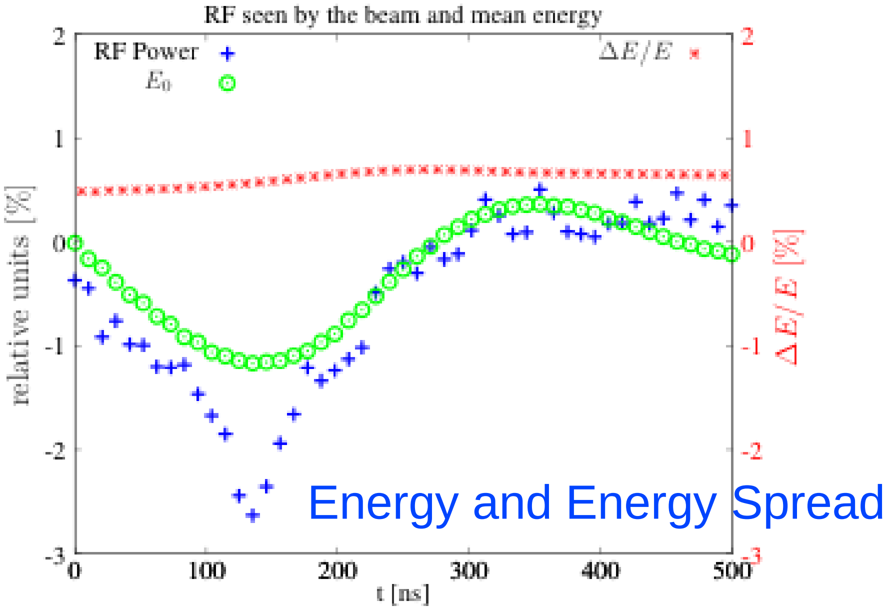


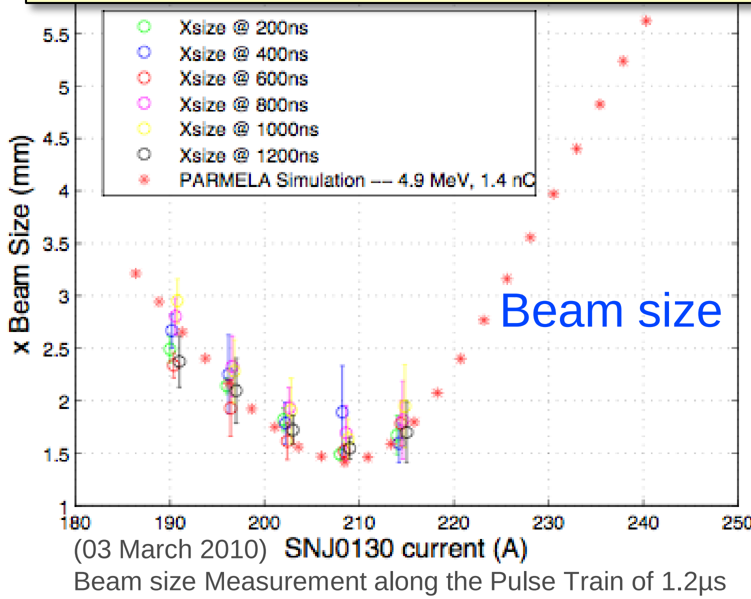
Erik Adli

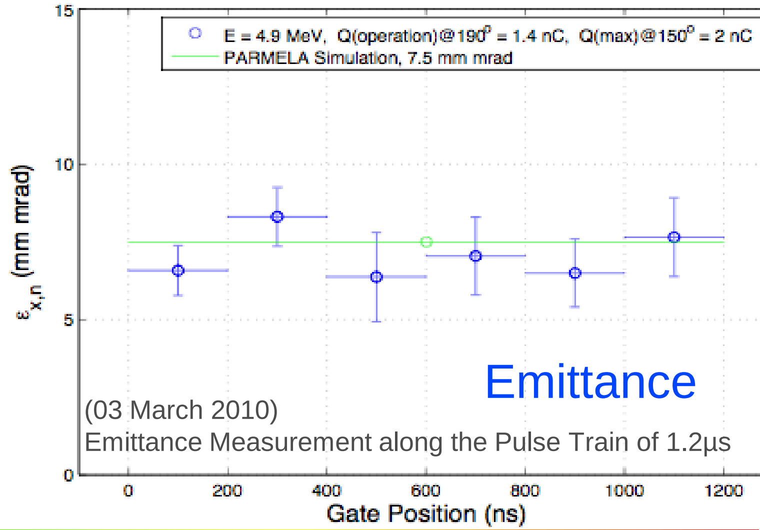
PHIN Measurements

Öznur Mete, WG6, Thu 15:00

- stability along pulse train crucial for DB power production
- measurements along PHIN pulse train performed







Öznur Mete