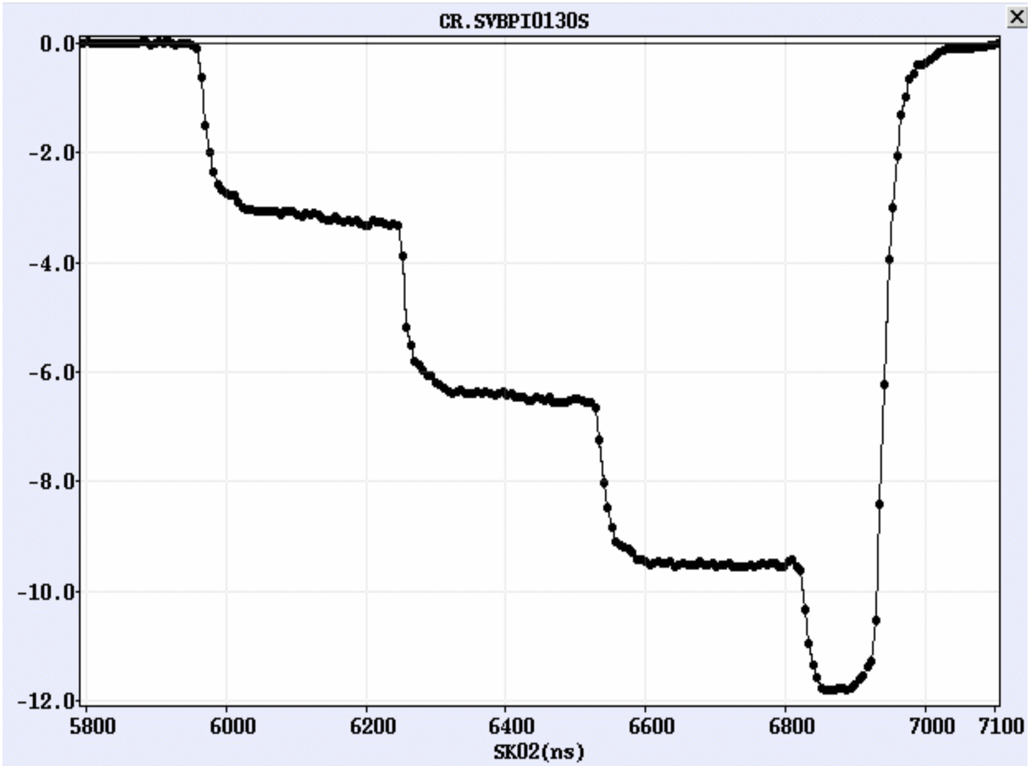
# CTF3 status + experimental program

## What can be expected by 2010 + possible improvements afterwards

Frank Tecker – CERN
for the CTF3 team

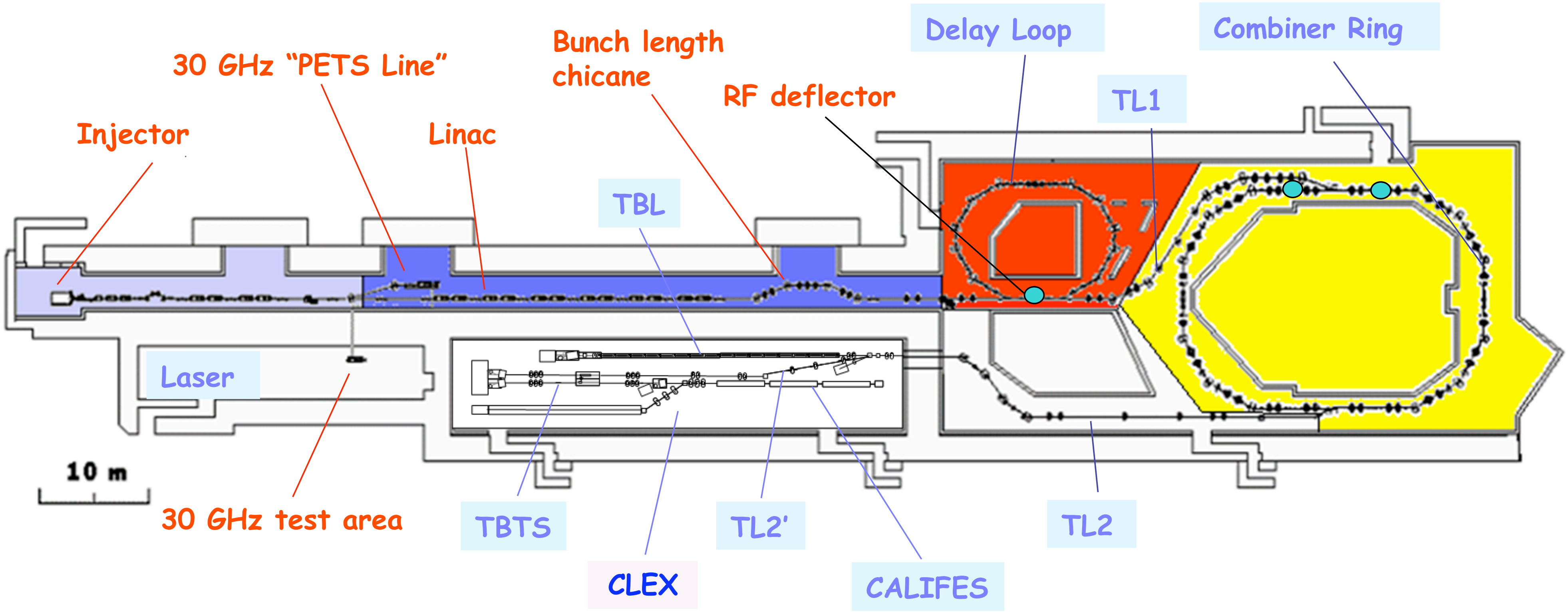
- Introduction
- CTF3 status + achievements
- CTF3 experimental program
- Conclusion



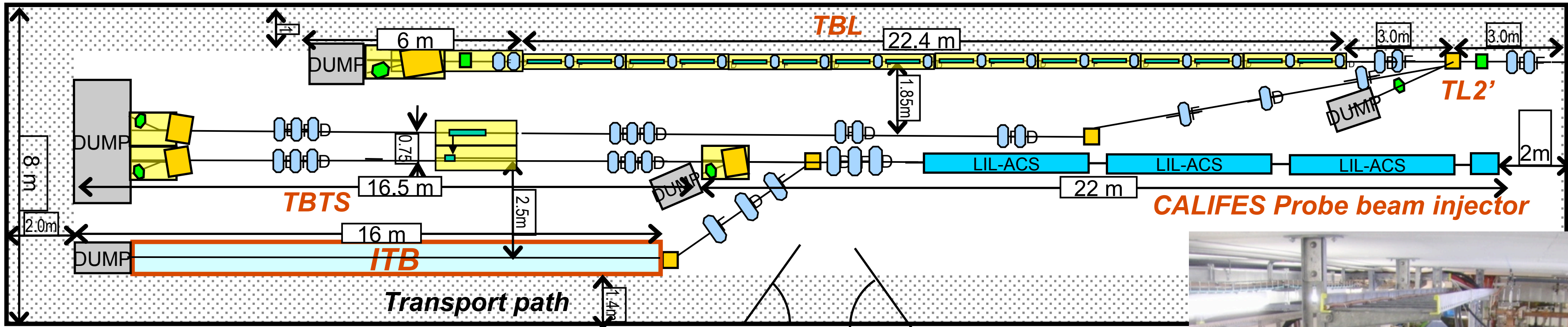
# CTF 3

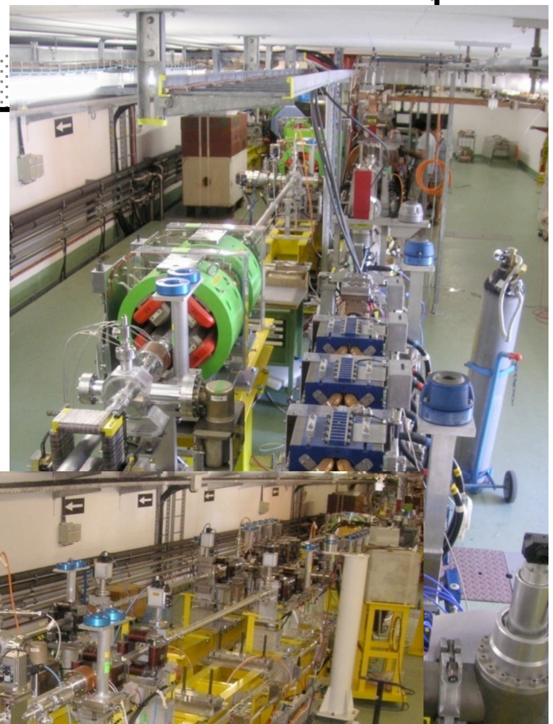
- demonstrate Drive Beam generation (fully loaded acceleration, bunch frequency multiplication 8x)
- Test CLIC accelerating structures
- Test power production structures (PETS)

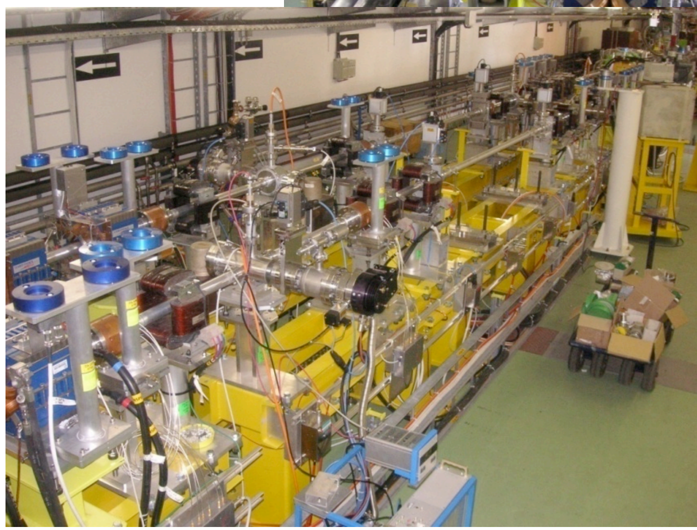
- 2003 Injector + part of linac
- 2004 Linac + 30 GHz test stand
- 2005 Delay Loop
- 2006/07 TL1 + Combiner Ring
- 2008/09 New photo-injector, TL2 + CLEX



# CLEX – Installation status



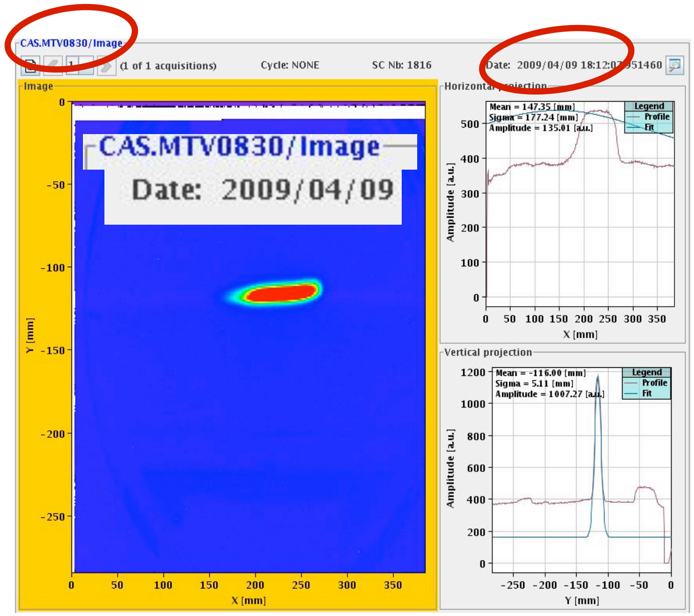


- TL2, TL2', CALIFES, and TBTS lines finished had first beam
- Shutdown 08/09:
  - Initial TBL installed
  - Tail Clipper in TL2
- Summer/Autumn 09
  - TBTS accelerating structure
  - continue TBL installation (see Steffen)

# Some Highlights since last ACE

- new RF deflectors allowed high current CR operation
- TBTS PETS produced RF power (as shown by Igor)

- CALIFES probe beam studies
- transported to end of TBTS

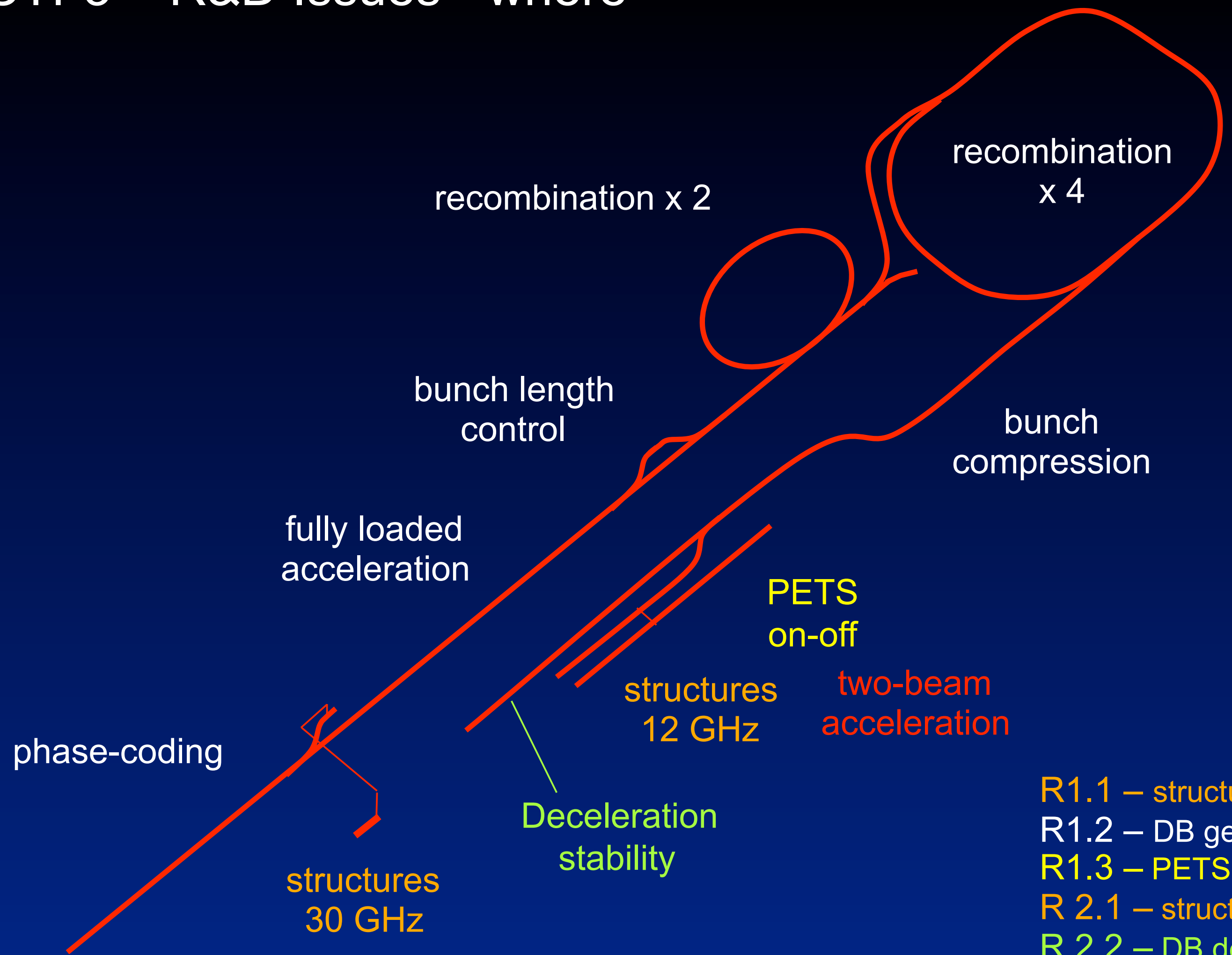



- PHIN photoinjector successful run

- careful RF setup for long pulses in view of DL/CR combination
- Delay loop beam reestablished

# CTF3 base line programme

## CTF3 – R&D Issues - where




R1.1 – structures
R1.2 – DB generation
R1.3 – PETS on-off
R 2.1 – structure materials
R 2.2 – DB decelerator
R 2.3 – CLIC sub-unit

R.Corsini

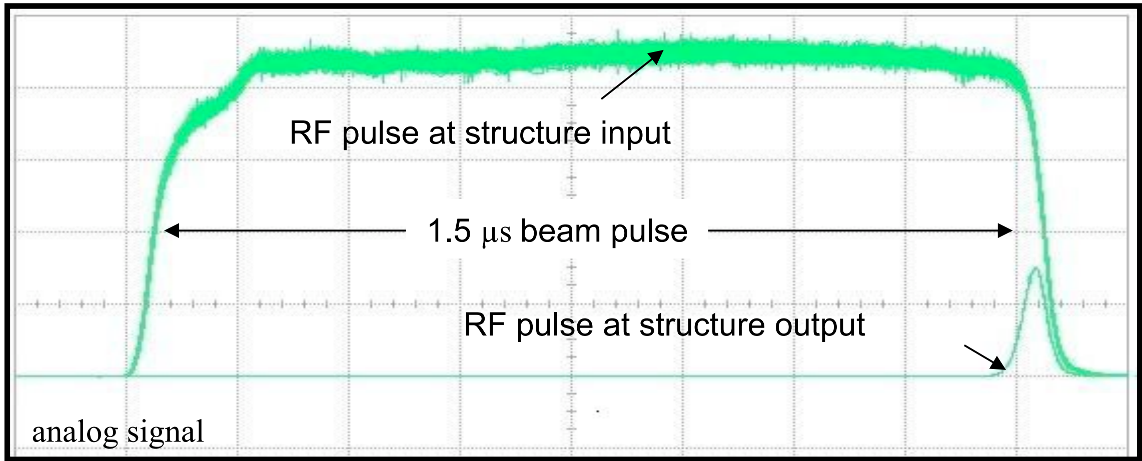
# Comparison CLIC - CTF3

| | CTF3 | CLIC |
|---|---|---|
| Energy | 0.150 GeV | 2.4 GeV |
| Pulse length | 1.2 μs | 140 μs |
| Multiplication factor | 2 x 4 = 8 | 2 x 3 x 4 = 24 |
| Linac current | 3.75 A | 4.2 A |
| Final current | 30 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 |

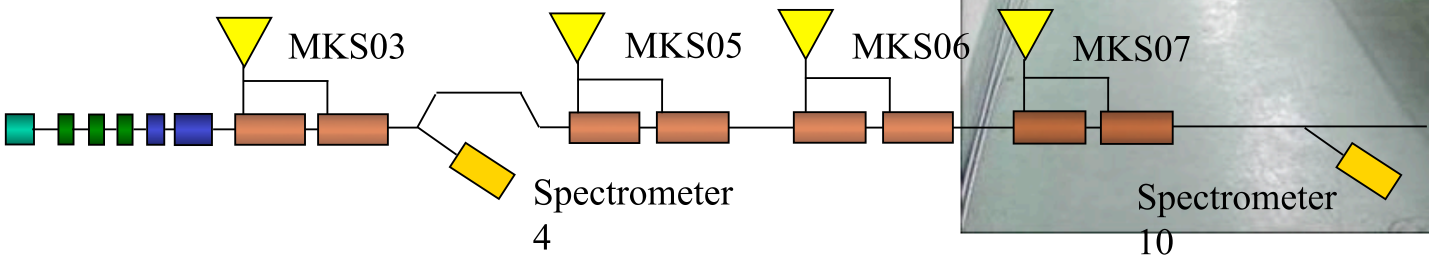
- Still considerable extrapolation to CLIC parameters
- Especially total beam power (loss management, machine protection)
- Good understanding of CTF3 and benchmarking needed

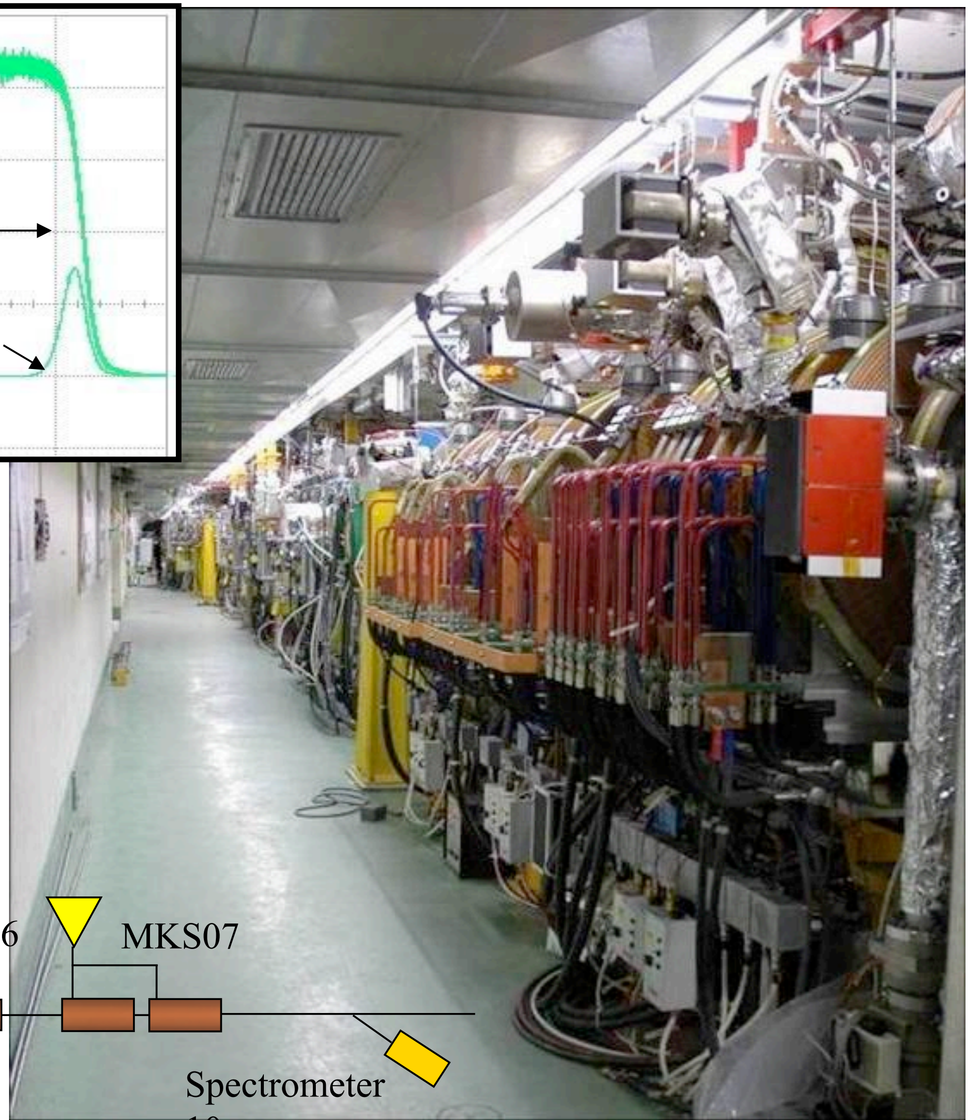
# Full beam-loading acceleration in CTF3

- high current **routine operation demonstrated**




- Measured RF-to-beam efficiency 95.3%
- Theory 96%
  (~ 4 % ohmic losses)



# Beam current stability

- operation sensitive to beam current variations
- instable, defective gun made commissioning very tedious
- repaired, much more stable this year
- stability ~ 0.1% end-of-linac, ~ 0.2% combiner ring

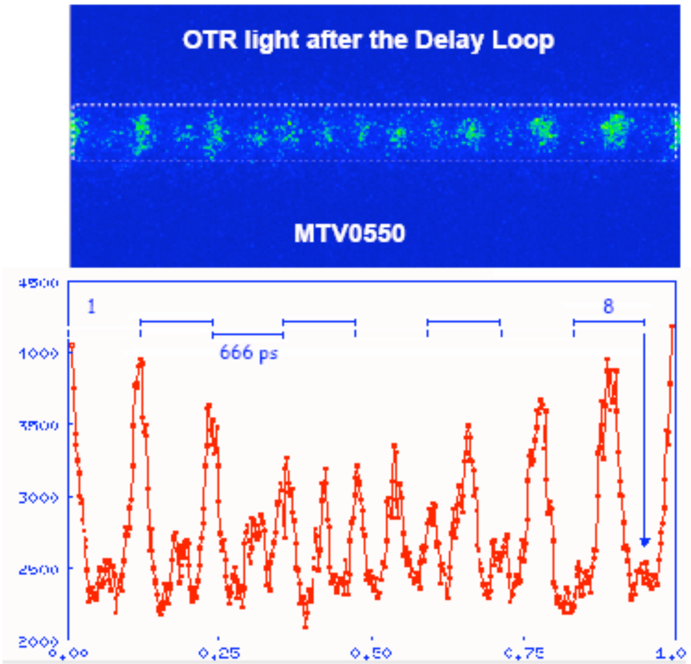
- we see current variation over the pulse => different energy
- => feed-forward needed
  foreseen in gun but not implemented
- Energy stability
  - RF phase stabilisation for klystrons put into operation
  - short term jitter presently ~ 0.5 $10^{-3}$

# SHB system – Phase coding

Key parameters for the SHB system:

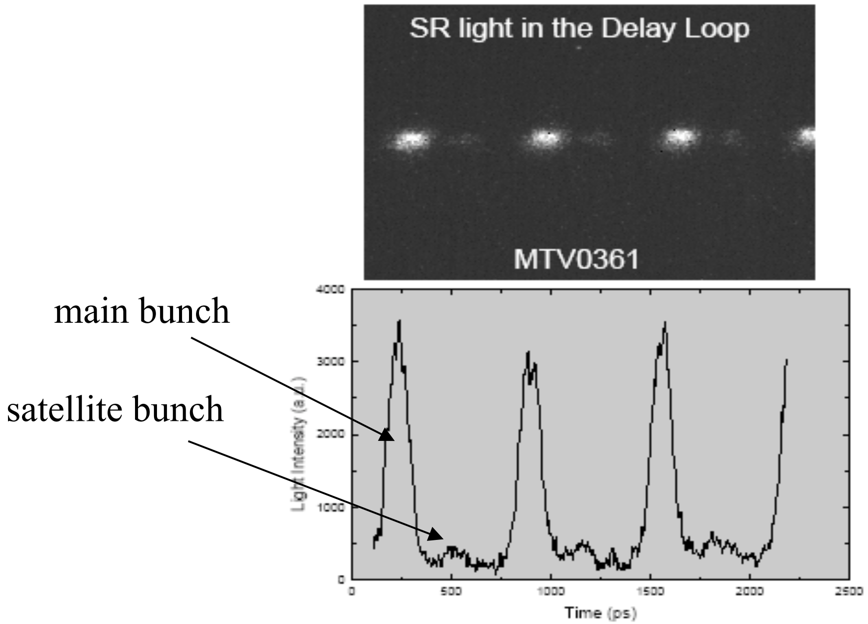
1) time for phase switch < 10 ns (15 1.5 GHz periods)
2) satellite bunch population < 7 %
   (particles captured in 3 GHz RF buckets)

**phase switch:**



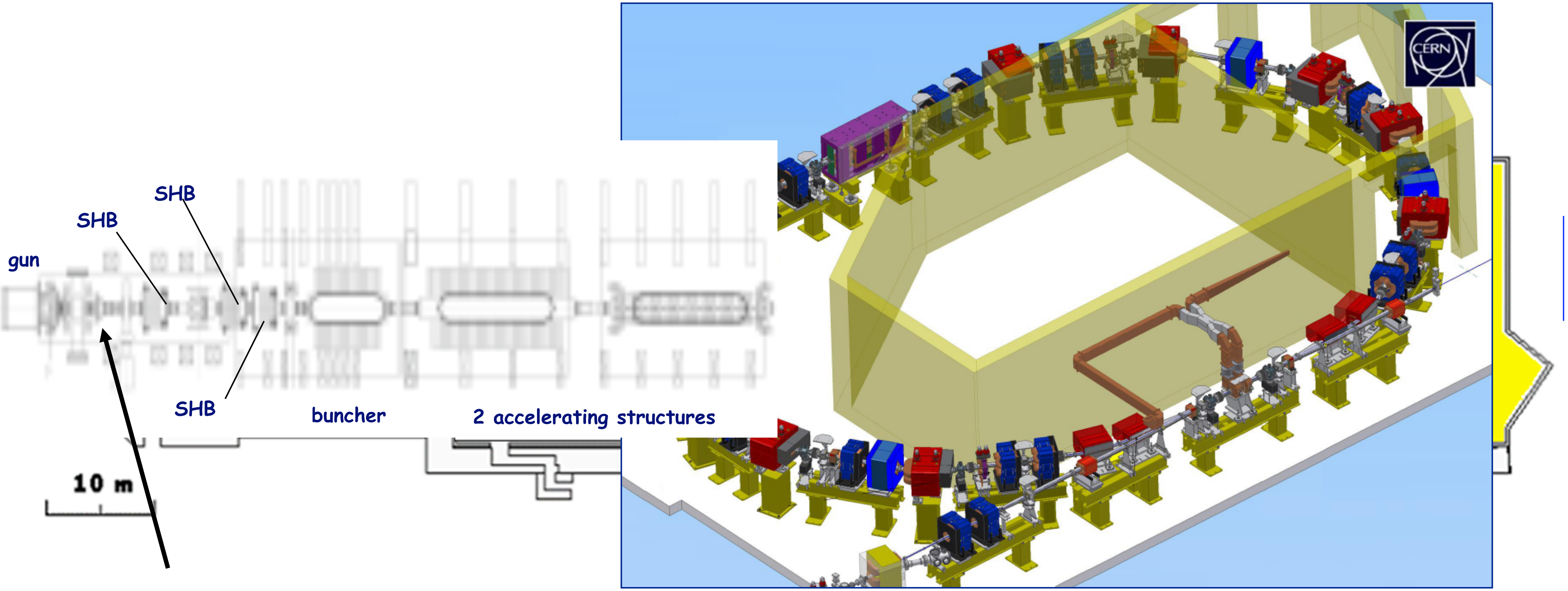

Phase switch is done within eight 1.5 GHz periods **(<6 ns).**

**satellite bunch population:**



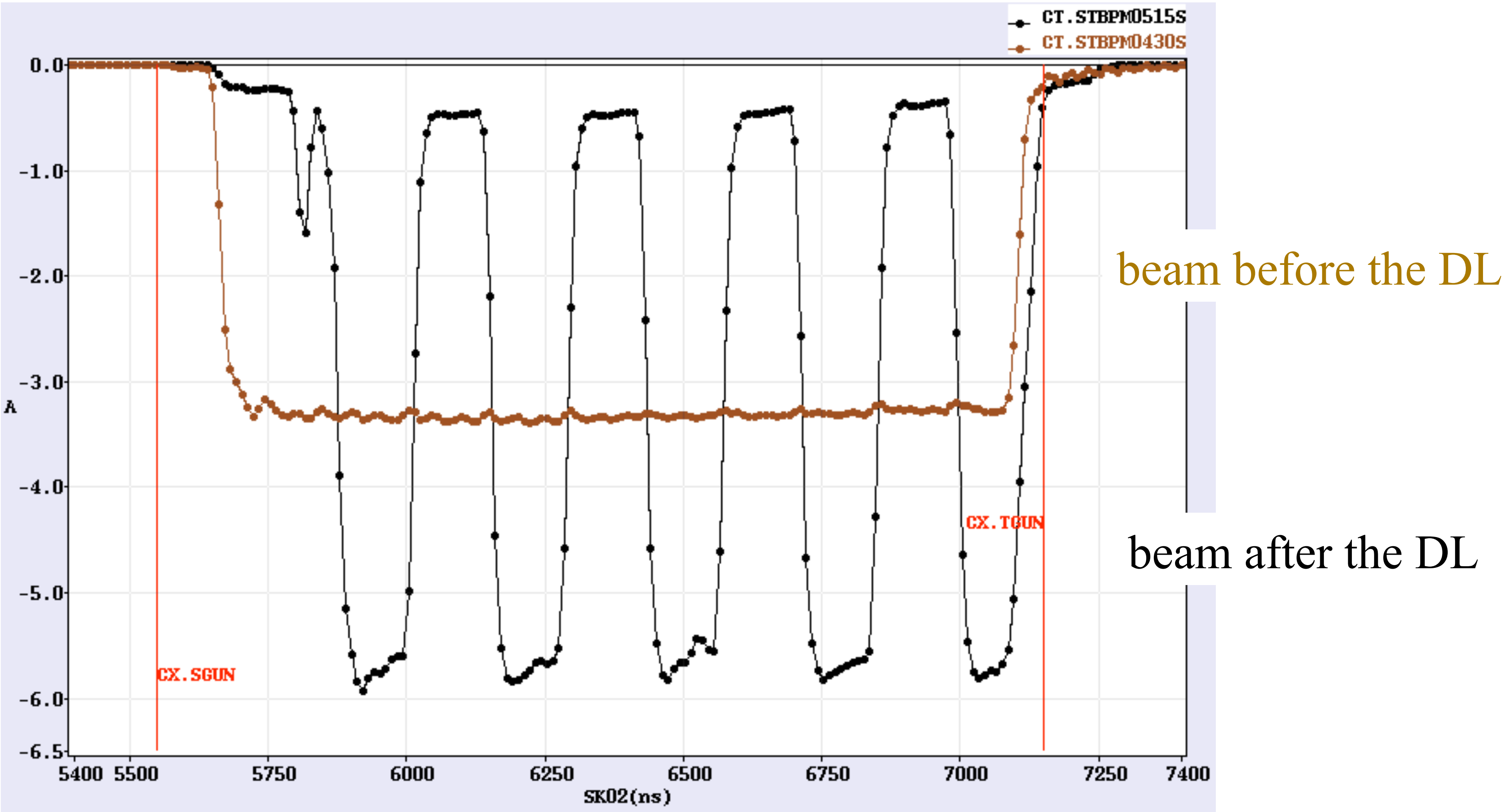

Satellite bunch population was estimated to **~8 %.**

# Delay Loop operation




- 1.5 GHz sub-harm. bunching system
- 1.5 GHz RF deflector

# Delay Loop – full recombination

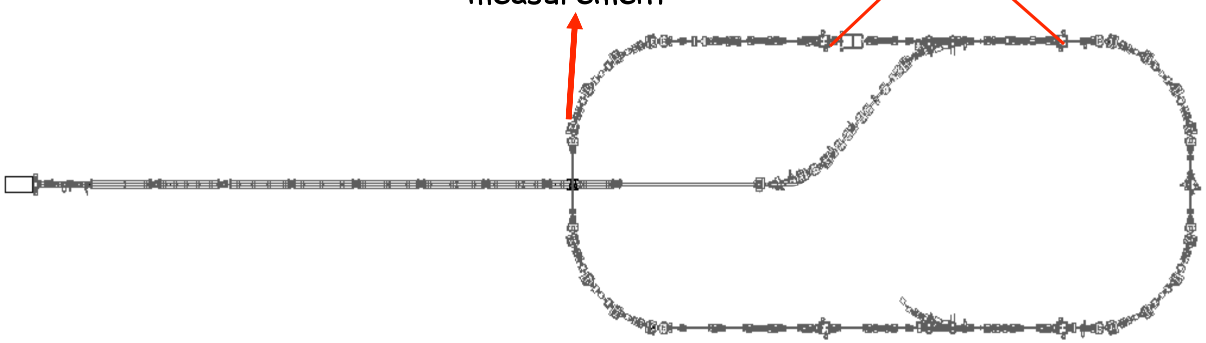



- 3.3 A after chicane => < 6 A after combination (satellites)

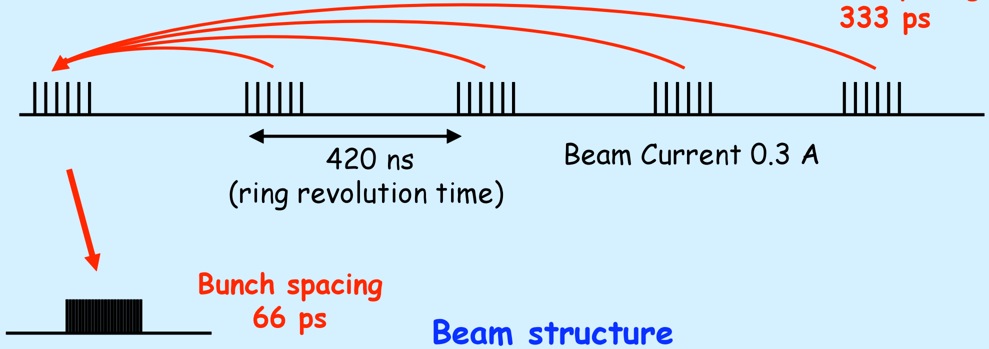
# Demonstration of frequency multiplication

## CTF3 - PRELIMINARY PHASE 2001/2002

**Successful low-charge demonstration of electron pulse combination and bunch frequency multiplication by up to factor 5**

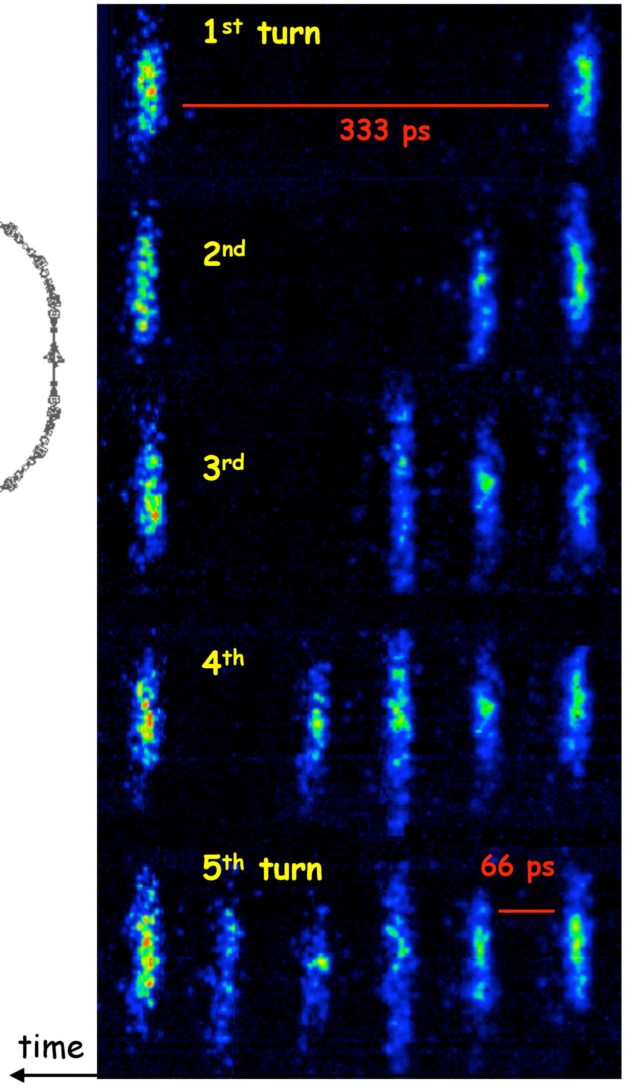



Beam time structure in linac




Beam structure after combination

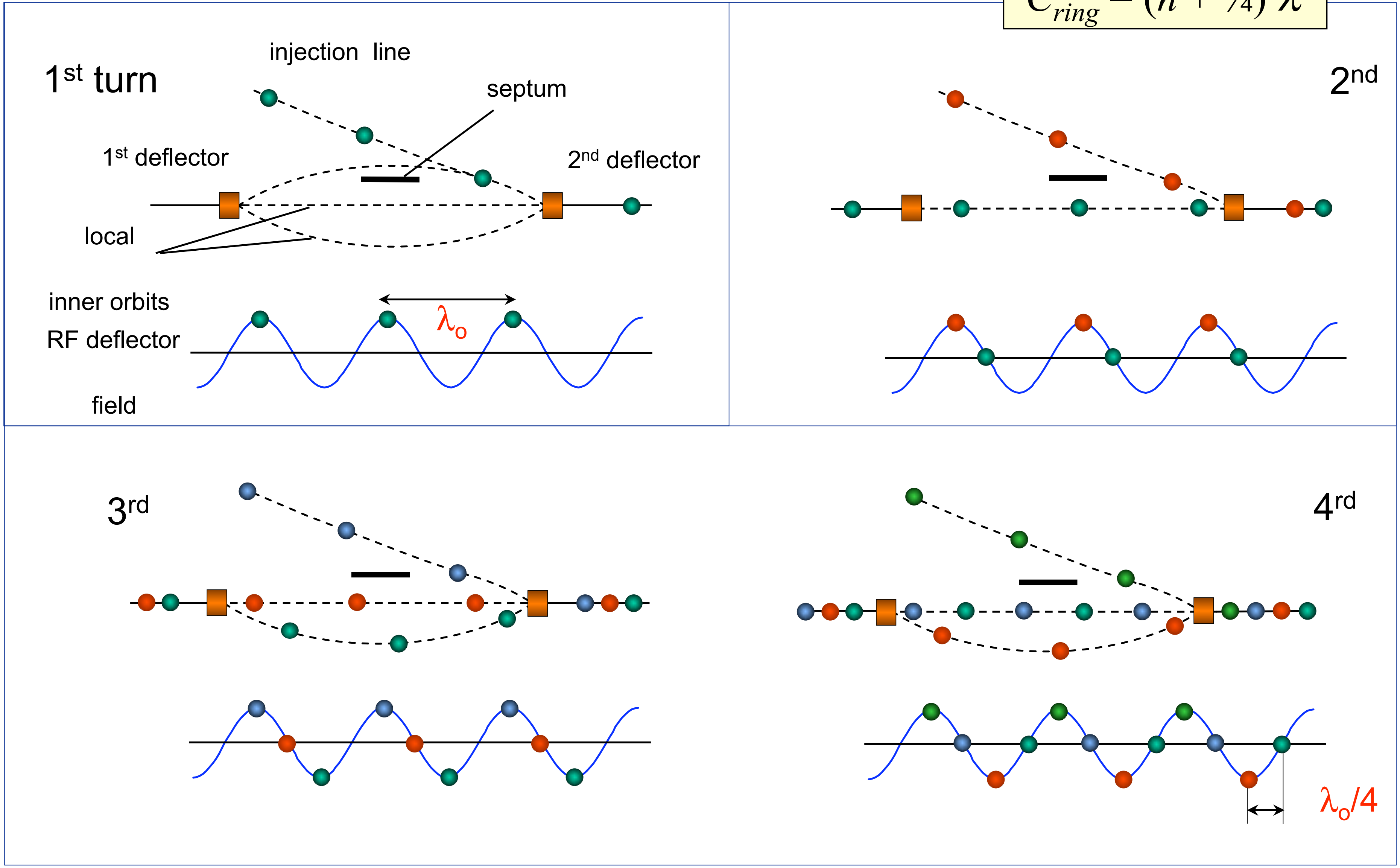
Streak camera image of beam time structure evolution



# RF injection in combiner ring

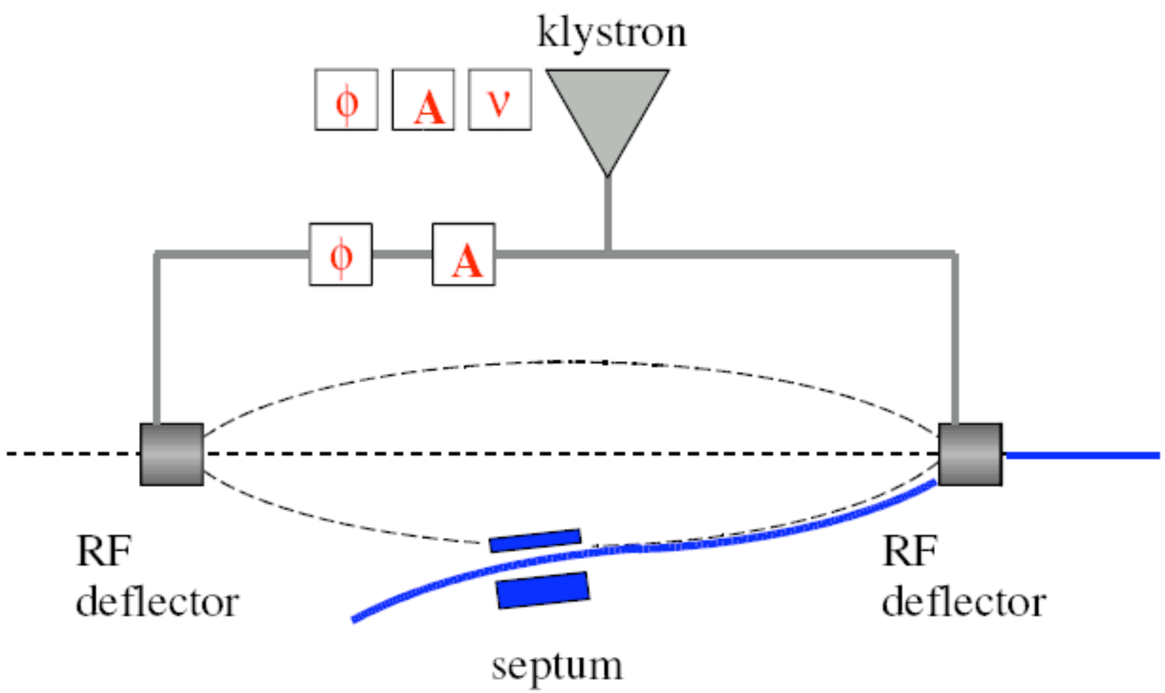
- combination factors up to 5 reachable in a ring

$$C_{ring} = (n + \tfrac{1}{4})\ \lambda$$



# Combination setup procedure

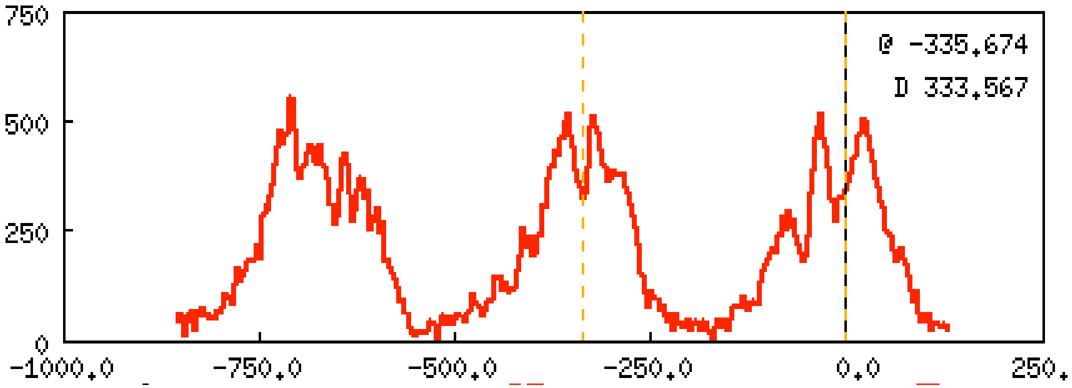
- Developed a setup procedure to optimize combination
- 5 parameters
  - Amplitude and phase in each deflector
  - RF frequency (no wiggler for path length tuning)
- Monitor trajectory differences over various turns



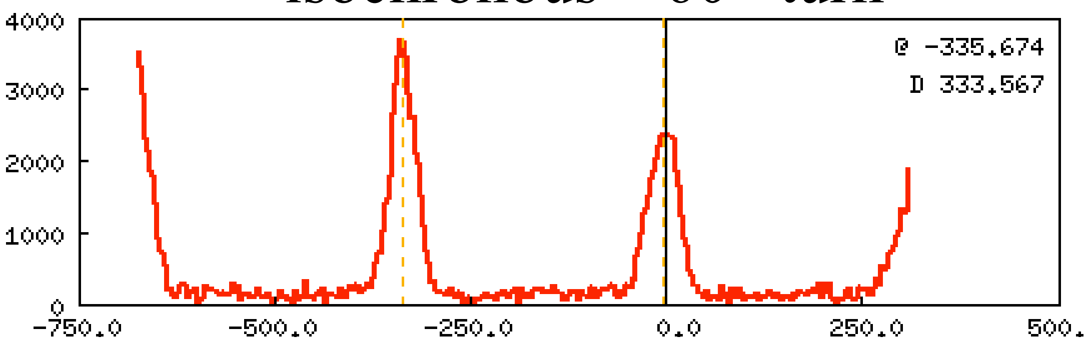
# Isochronicity Tuning

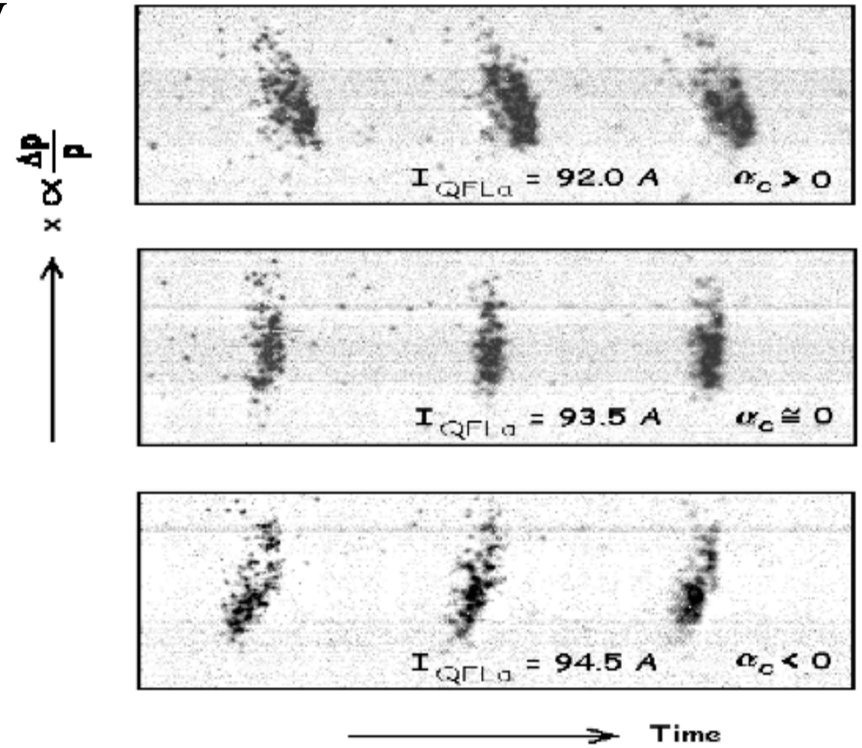
- ring optics needs to be isochronous to keep short bunch length
  => high power extraction efficiency
- Streak Camera observations

non-isochronous – 2nd turn




isochronous – 60th turn

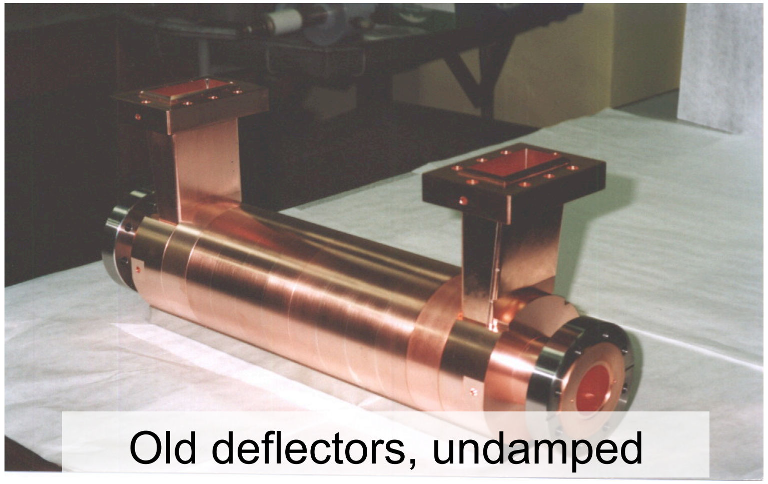


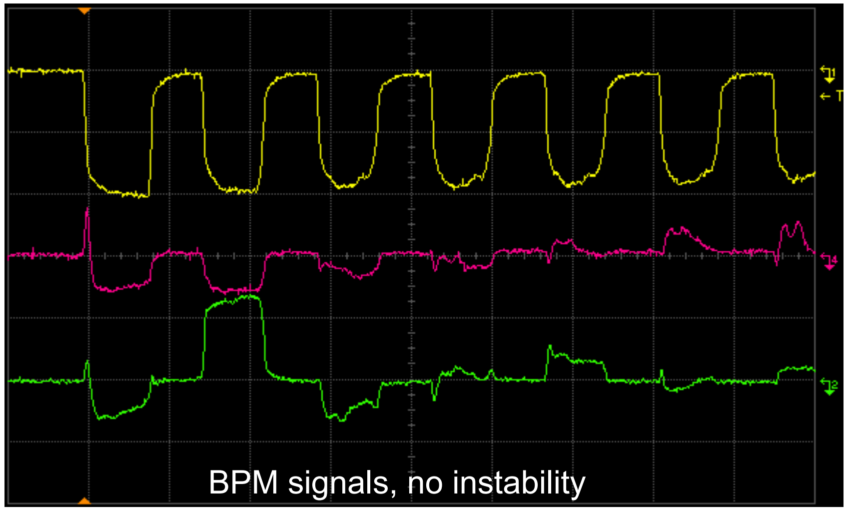

- **momentum compaction**
  **$\alpha_p < 10^{-4}$**

# CR RF deflectors => Instability

- RF deflectors had a vertical mode that deflects the beam
- Could be minimized by proper phase advance – not done

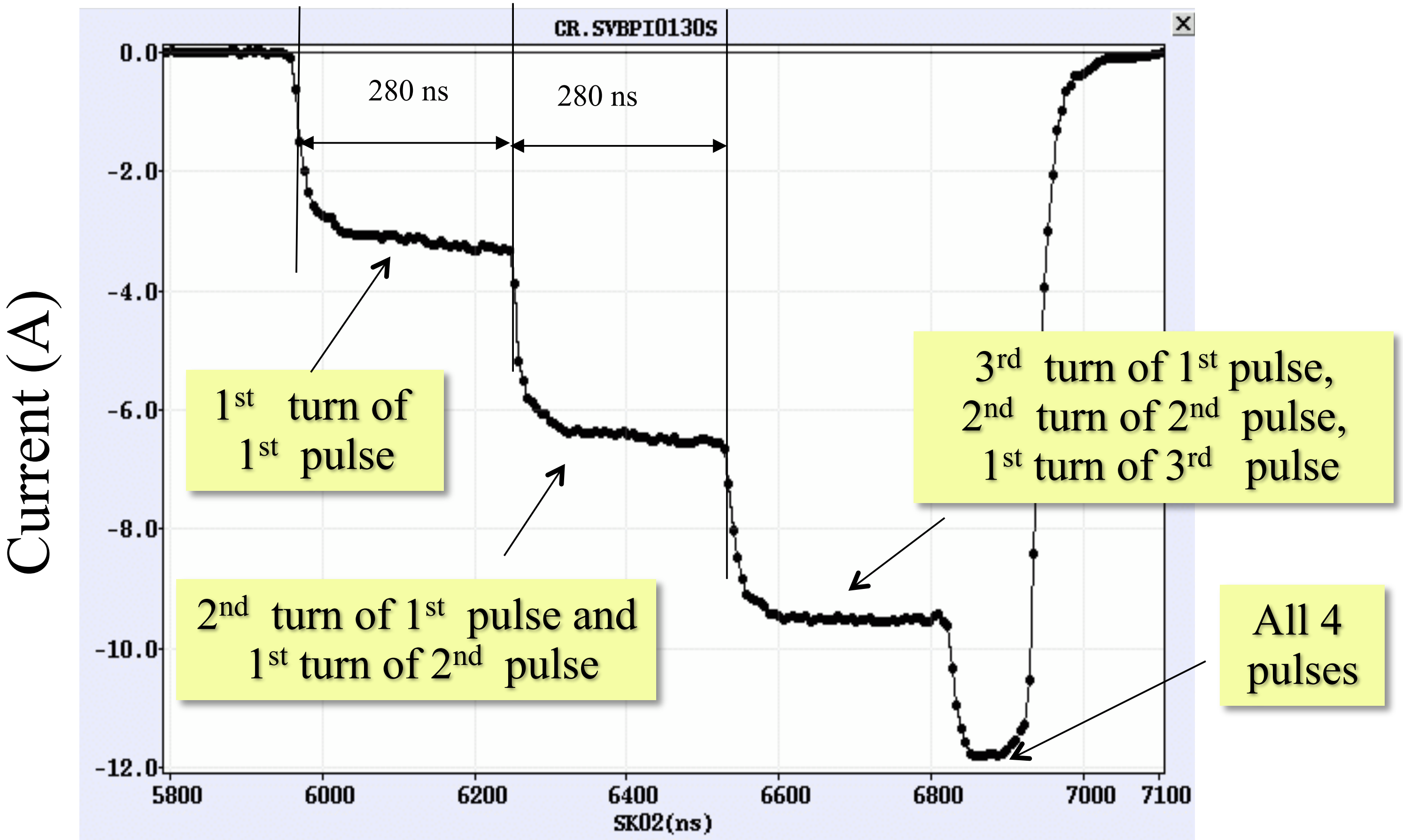




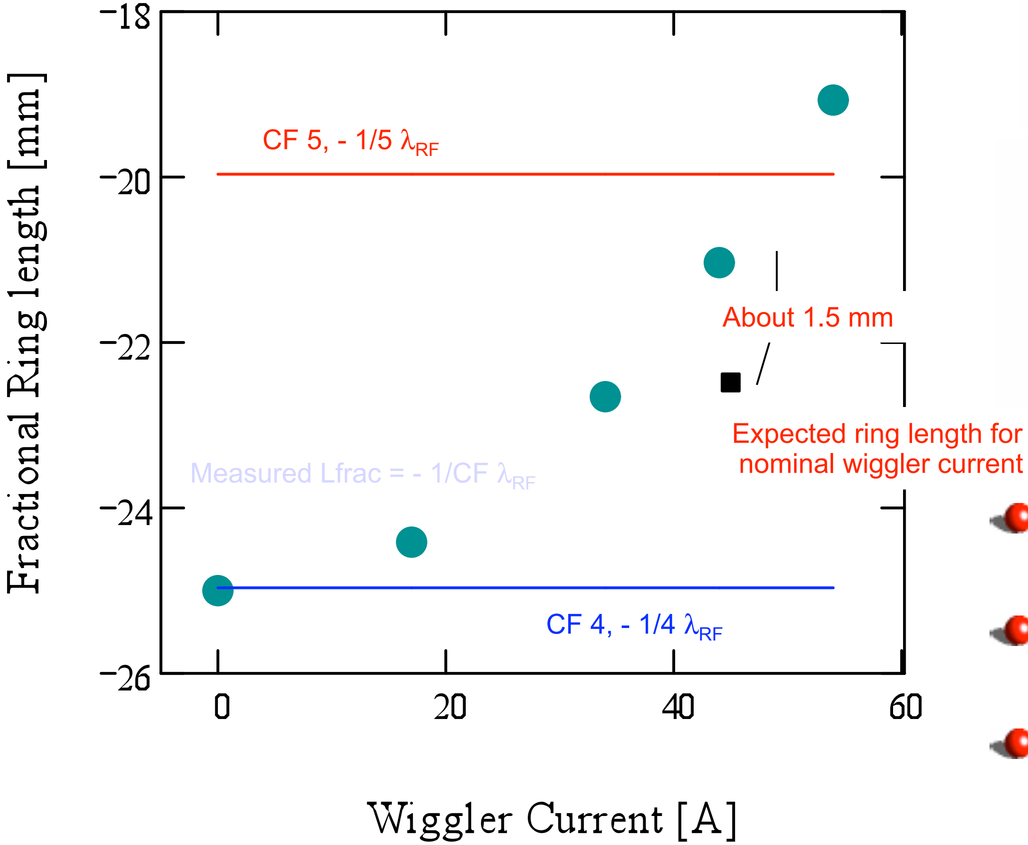
# CTF3 combiner ring - latest status

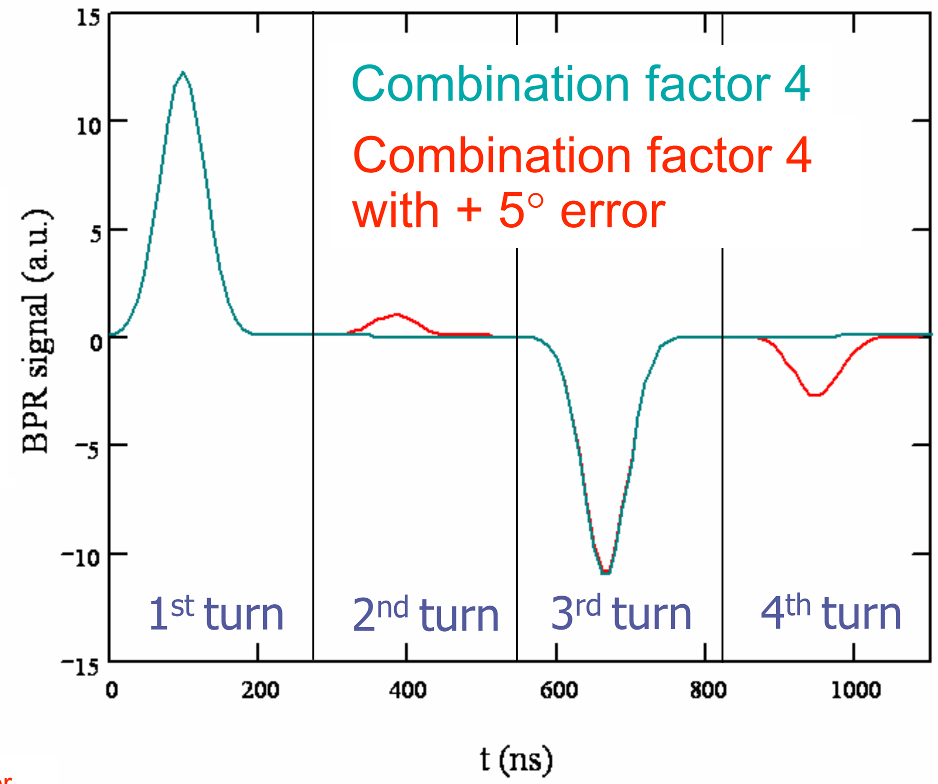
- Recombination at higher current achieved
  - DL bypassed (no holes, missing factor 2)



# Measurement of the ring length

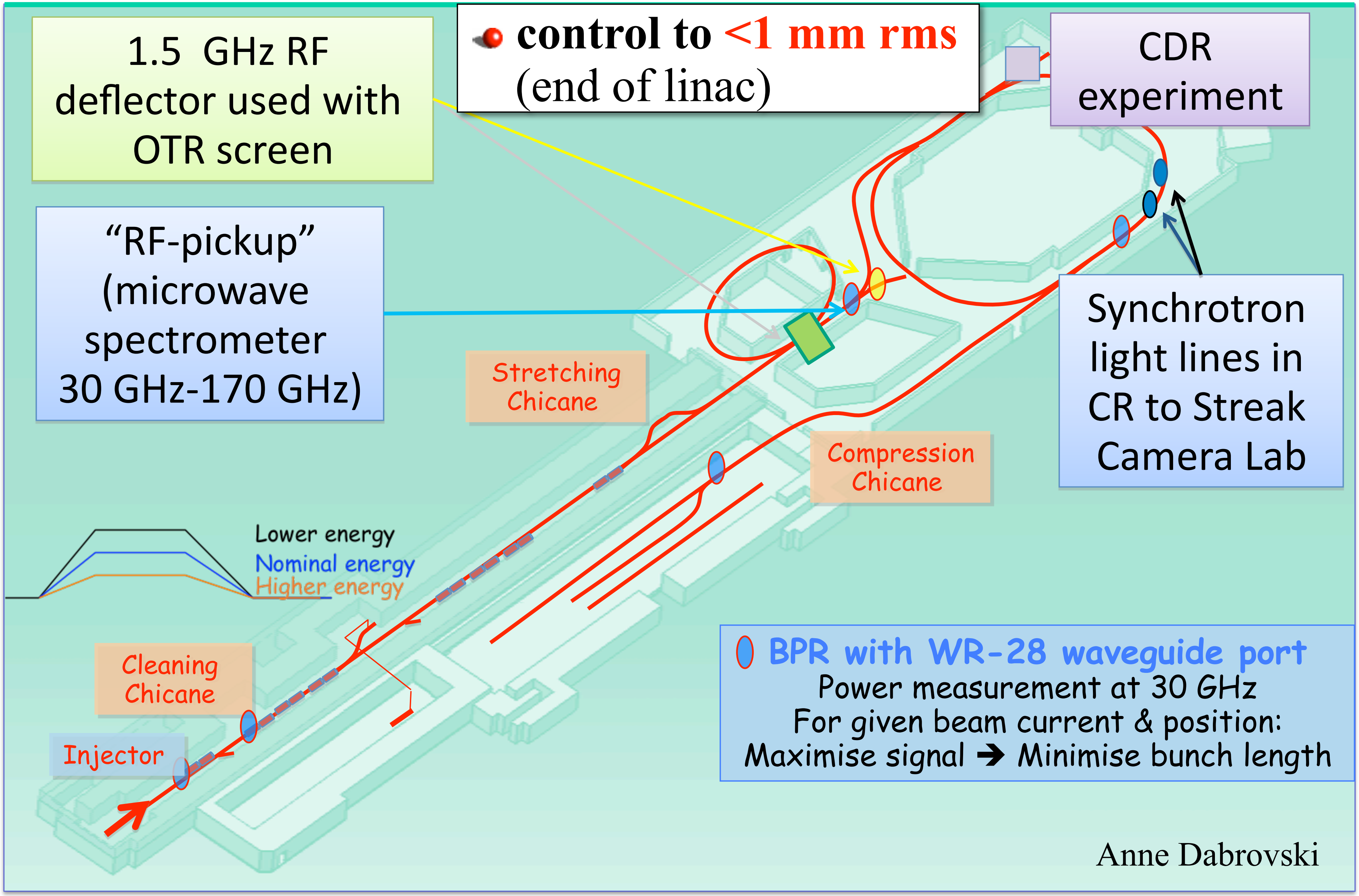
- BPR: RF Phase Monitor
- Mix of the beam induced signal and internal frequency (3 GHz)
- FFT of the signal




- Wiggler behaviour as expected
- About 1.5 mm difference only
- **control to better than 0.5 mm**

# Bunch length measurements

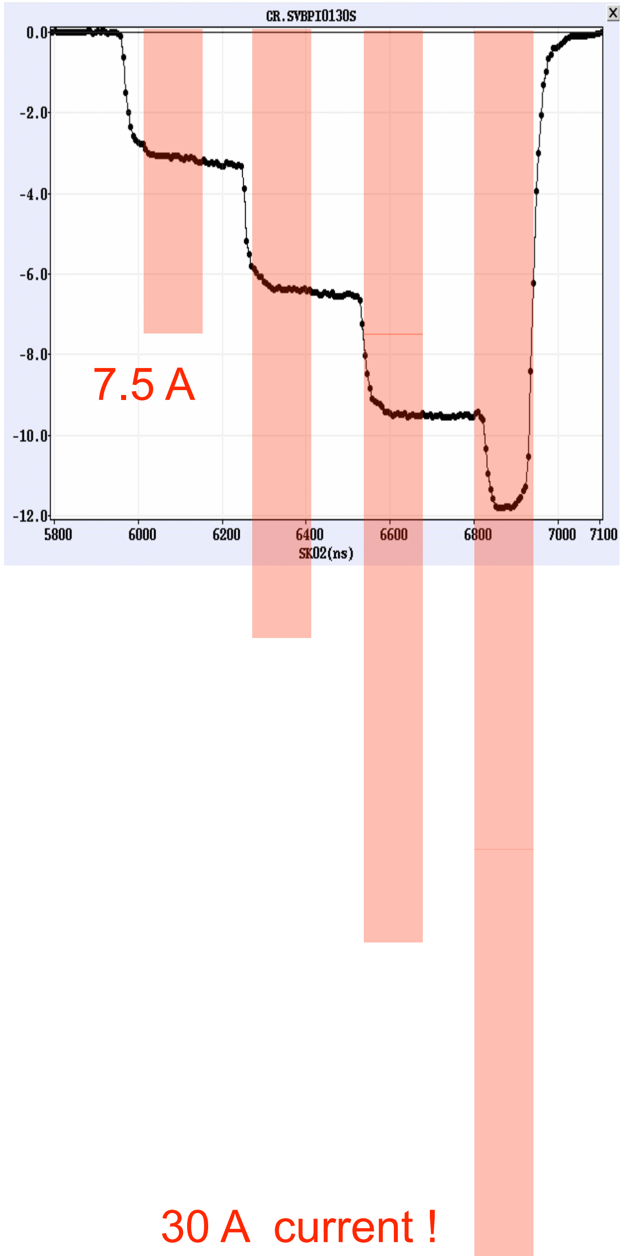


# State of the art today

- ongoing Drive Beam generation demonstration in CTF3.
  - Full beam loading (95% transfer), high current operation (up to 5A) of drive beam linac
  - Sub-Harmonic bunching, phase coding (8.5% satellites)
  - Bunch train recombination factor 2 in Delay Loop (from 3.5 to 7 A)
  - Bunch train recombination factor 4 in Combiner Ring (3 to 12 A)
  - Isochronous operation of ring, $\alpha_p < 10^{-4}$
  - Transverse rms emittance 100 $\pi$ mm mrad (end of linac only)
  - Bunch length control to < 1 mm rms (end of linac only)
  - Control of ring length to better than 0.5 mm
  - Beam current stability ~ 0.1% end-of-linac, ~0.2% combiner ring

# The final combination…

- Delay Loop and Combiner Ring combination simultaneously
- Operation becomes more demanding
- Stability + reproducibility
- current fluctuations over the pulse
- (RF phase variation over the pulse - not for CLIC)
- Isochronicity
- Emittance in combination
- Bunch length control
- …



# To be addressed …

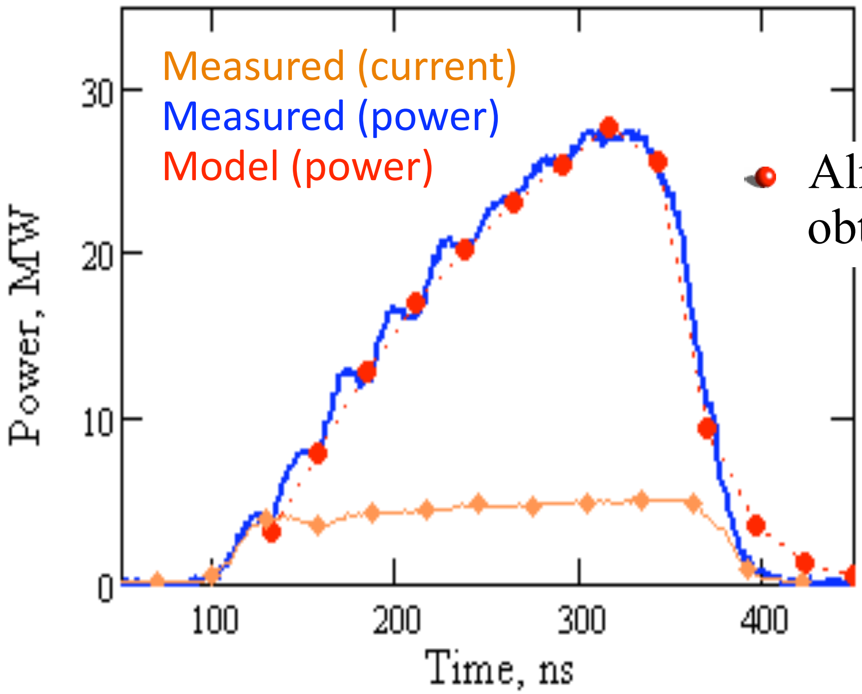
- Full bunch length manipulations in TL2 after combination
- RF power production in CLEX
- Two-beam operation in TBTS (relevant CLIC sub-unit)
- Deceleration stability
- Loss management, machine protection system
- Satellite bunches
- Photo injector option
- …

# 2009 experimental program

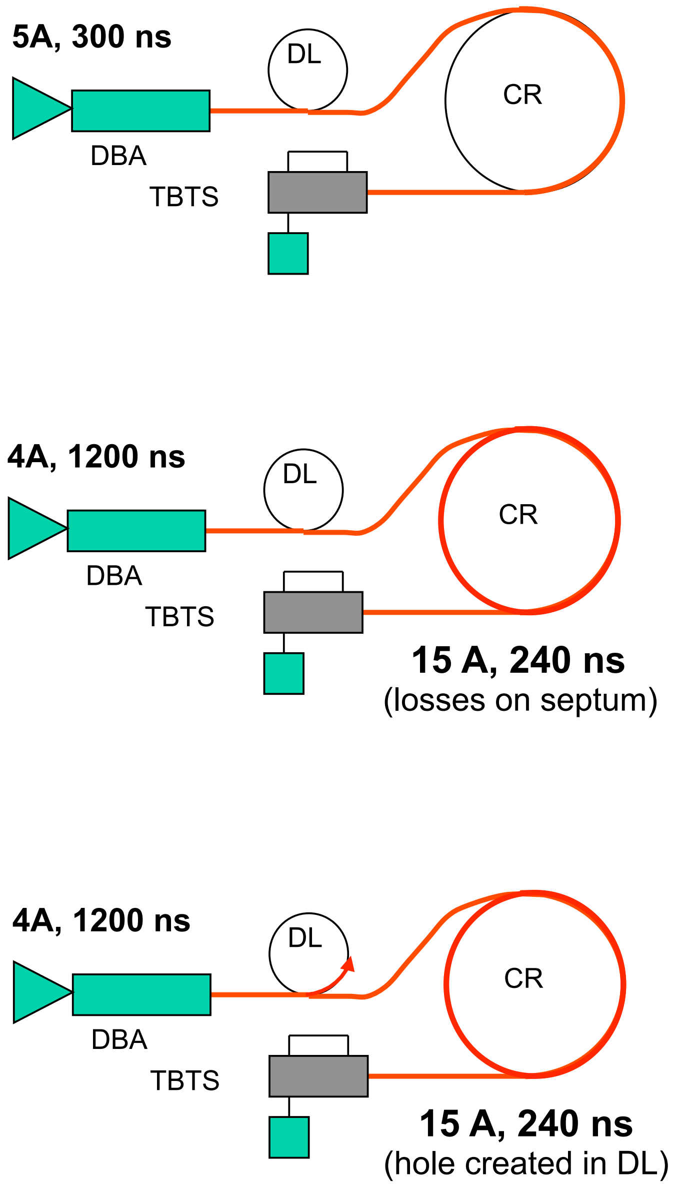
| | |
|---|---|
| 30 GHz: | One structure test (TM02) + breakdown studies ✓ |
| PHIN | Beam characterization, reach ½ of nominal bunch charge ✓ |
| CALIFES | Beam characterization, beam to TBTS (most likely reduced current) |
| Delay Loop | Back in operation, retrieve combination x 2 (~ 7 A) |
| Comb.Ring | Final optics checks, isochronicity, put together with DL (> 24 A) |
| TL2 | Complete commissioning (tail clipper), bunch length control<br>> 20 A to users |
| TBTS | PETS to nominal power/pulse length (15 A, recirculation)<br>Beam commissioning of probe beam line<br>First accelerating structure tests (one structure – CLIC G)<br>Two-beam studies (de-/acceleration), initial breakdown kick studies |
| TBL | PETS validation (100 MW, need > 20 A)<br>beam line studies (2-3 PETS ?) |
| Others | CDR studies in CRM, beam dynamics benchmarking,<br>stability studies, control of beam losses |

# Long DB pulses in CTF3

- DL length limits to 140 ns
- Longer pulses at the expense of lower current
- use recirculation in the TBTS PETS
- model well understood




- Almost 30MW obtained

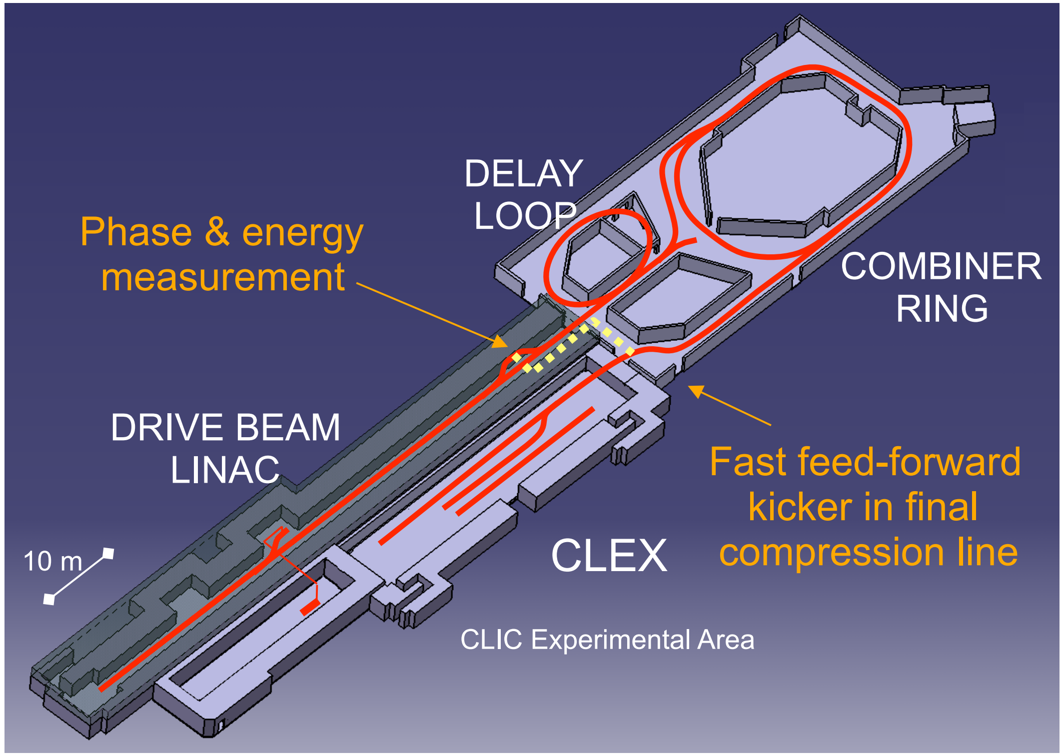


# Goals for 2010

- DB Linac — current + energy stability ~$10^{-3}$
- Comb.Ring — Final combination together with DL (> 28 A)
  combined emittance < 150 π mm mrad
- TL2 — Complete bunch length control (< 1 mm)
  > 28 A to users
- TBTS — PETS to nominal power/pulse length (15 A, recirculation)
  Accelerating structure tests
  Two-beam studies (de-/acceleration), breakdown kick studies
- TBL — beam line studies (8 PETS)
  deceleration studies (by ~33%)
- Others — Beam loading compensation of probe beam,
  phase stability, …

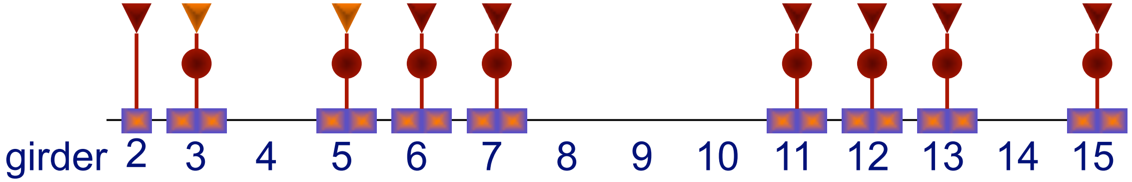
# Phase measurement & feed-forward

- phase stability 0.2°@12 GHz (46fs) required
- electronics tested in CTF3 and demonstrated sub-10 fs resolution
- FP7 Task 9.5: Drive Beam Phase Control (F. Marcellini/LNF)
  - RF monitor (INFN/CERN) – final tests in CTF3
  - Electro-optical monitor (design, prototype, tests PSI)
- Common characteristics:
  - Very low coupling impedance
  - Filters to reject wake fields and RF noise
  - Application also in other machines where precise high frequency beam phase detection is necessary

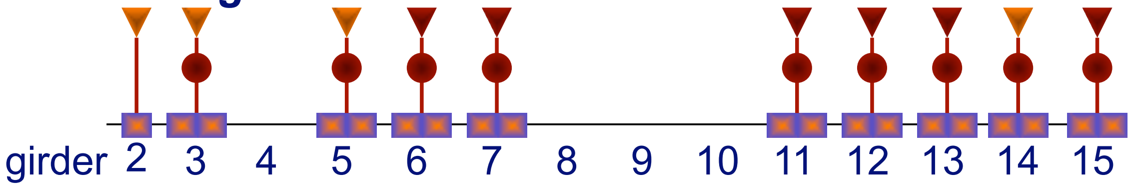


- Increase power to increase current/energy

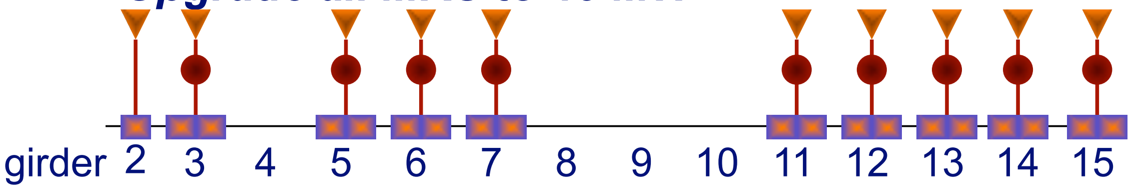
***Present***



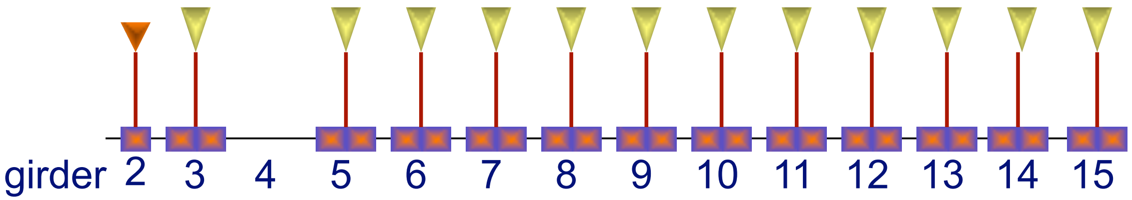

***Add girder 14***




***Upgrade all MKS to 45 MW***

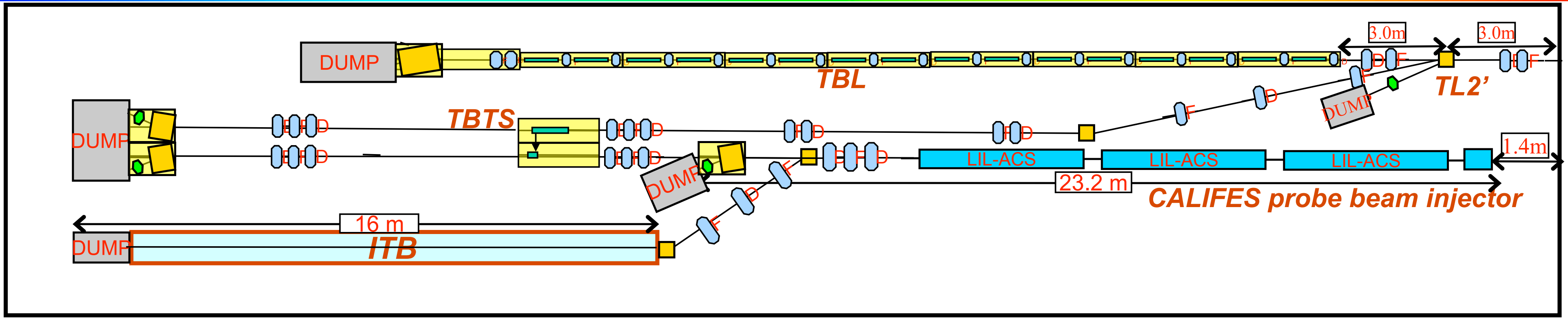



***Add RF on girders 8,9,10 and upgrade all MKS to 100 MW, 1.5μs tubes, no pulse compression***



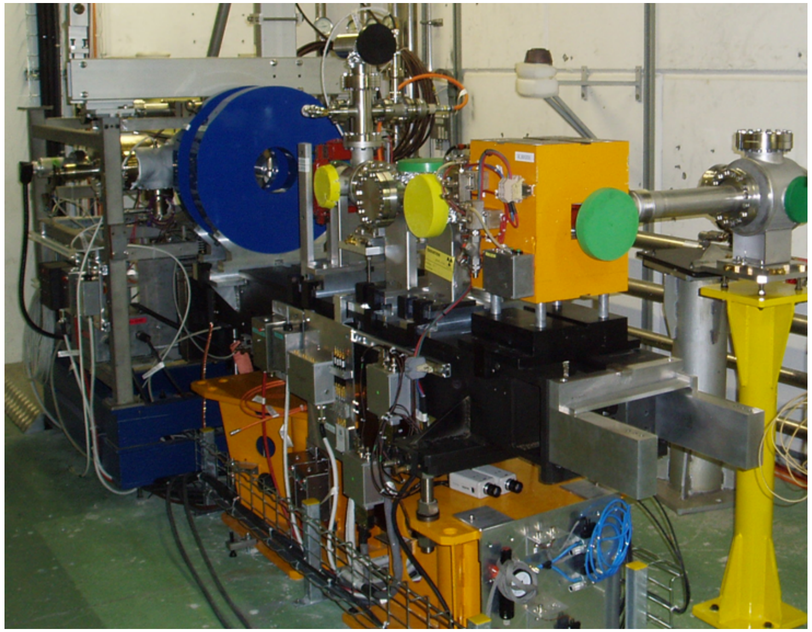

| $I_{Linac}$[A] | $I_{CLEX}$[A] | T [MeV] |
|---|---|---|
| 0.1 | 0.72 | 246 |
| 3.6 | 25.9 | 156 |
| 4.9 | 34.9 | 125 |
| 0.1 | 0.72 | 279 |
| 3.6 | 25.9 | 179 |
| 4.9 | 34.9 | 143 |
| 0.1 | 0.72 | 303 |
| 3.6 | 25.9 | 203 |
| 5.3 | 38.2 | 154 |
| 0.1 | 0.72 | 402 |
| 3.6 | 25.9 | 270 |
| 5.3 | 38.2 | 206 |

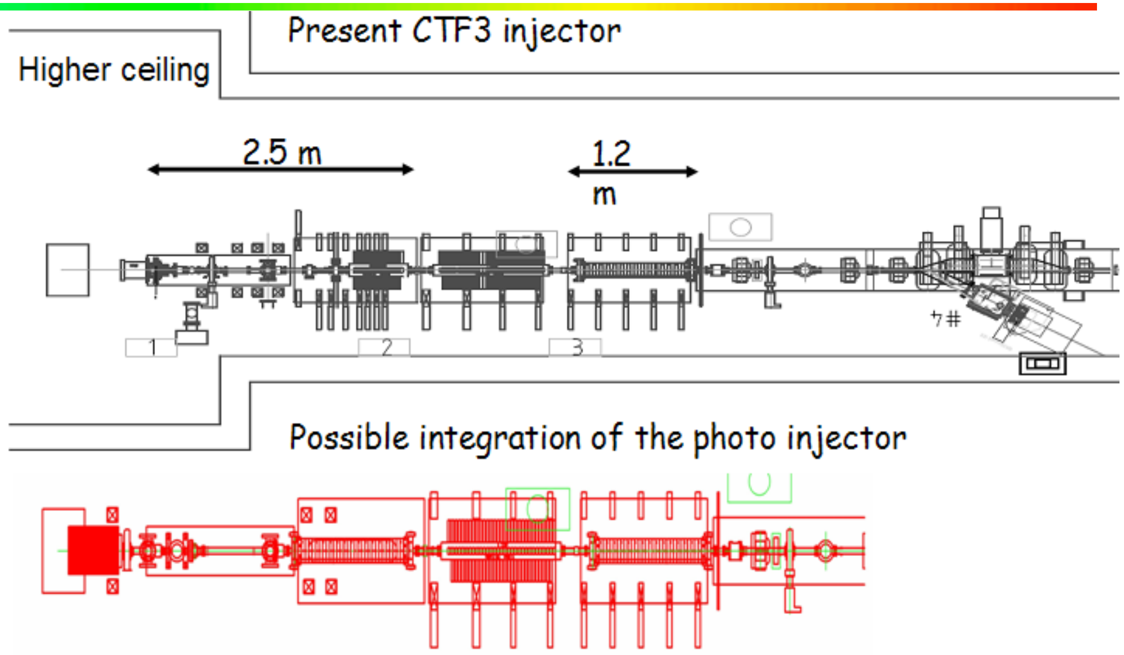
# Instr. Test Beam Line, ITB




- Dedicated beam line for beam diagnostics R&D using CALIFES beam
  - low ε beam well known and characterised at location of test device
  - possibility to achieve very short bunch length, variable time structure
  - Independent of drive beam operation
- Test & experiments which could be performed in ITB
  - BPM & WCM developments
  - Coherent diffraction radiation monitors
  - Longitudinal profile monitors
  - Halo monitors
  - …
  - Beam loss monitors
  - Single shot emittance measurements
  - Test of CLIC X-band crab cavities
  - Wakefield measurements (i.e. collimators)

# Photo-injector option

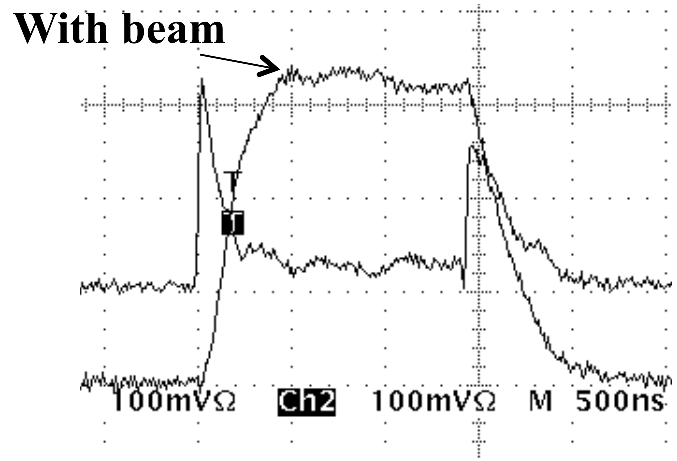




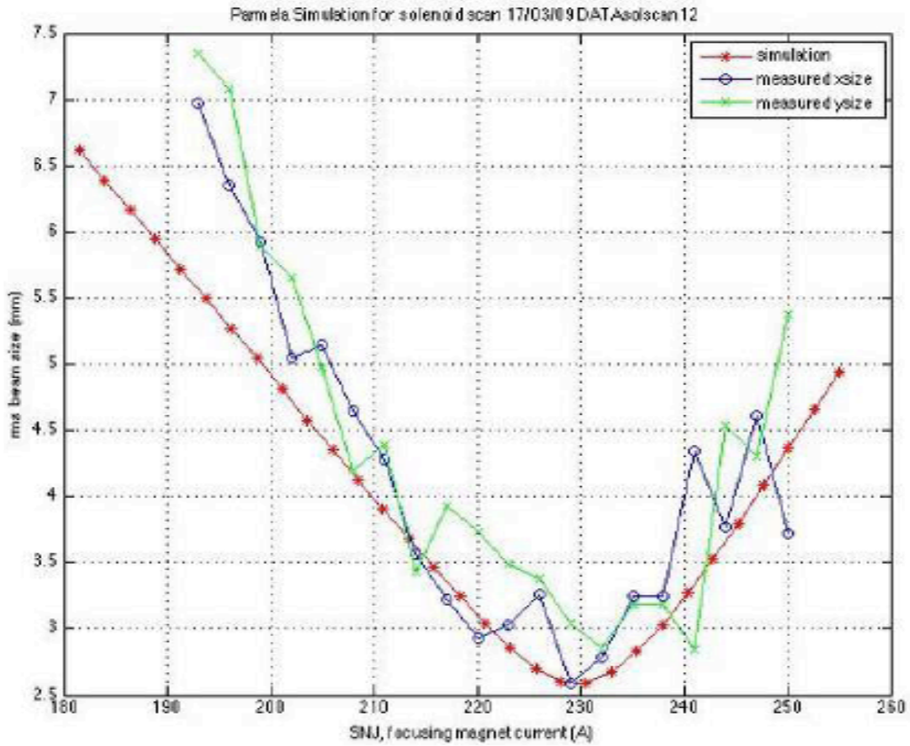

- Smaller transverse emittance, shorter bunches, no energy tails, no satellites
- Lower current
- Single bunch option will allow:
  - high precision beam optics check and correction
  - high precision CSR measurements in DL, CR and TL2 bunch compressor.
  - δ response of PETS and beam instrumentation

# Photoinjector PHIN

- very successful runs end 2008/2009
- transverse optics + beam-loading studies
- long-term behaviour ($Q_e$) to be studied
- Phase coding to be demonstrated




| | PHIN design | achieved Apr. 2009 |
|---|---|---|
| RF power [MW] unloaded | 13 | 13 |
| beam energy [MeV] | 5-6 | 5.3 |
| number of bunches | 1908 | 3000 |
| bunch spacing [ps] | 666.7 | 666.7 |
| charge per bunch [nC] | 2.3 | ~2.3 (@500ns)<br>1.5 (@1270ns) |
| repetition rate [Hz] | 5 | 0.8 |
| bunch length FWHM [ps] | < 10 | < 10 ? |
| rms. energy spread [%] | < 2 | 0.5 |
| n. emittance [$\pi$ mm mrad] | < 25 | 5-7 |
| vacuum pressure [mbar] | < 2 x $10^{-10}$ | < 4 x $10^{9}$ (no NEC) |



# Validation of DB scheme

| Parameter | Unit | CLIC nominal | Present state | Objective 2010 | Objective 2012 |
|---|---|---|---|---|---|
| I initial | A | 7 | 5 | 5 | 5 |
| I final | A | 100 | 12 | 30 | 30 |
| $Q_b$ | nC | 8.4 | 4 | 2.5 | 2.5 |
| Emittance, norm rms | π mm mrad | ≤ 150 | 100 (end of linac) | ≤ 150 (comb. beam) | ≤ 150 (comb. beam) |
| Bunch length | mm | ≤ 1 | ≤ 1 (end of linac) | ≤ 1 (comb. beam) | ≤ 1 (comb. beam) |
| E | GeV | 2.4 | 120 | 120 | 150 |
| $T_{pulse}$ initial | μs | 140 | 1.4 | 1.4 | 1.4 |
| $T_{pulse}$ final | ns | 240 | 140 (240) | 140 (240) | 140 (240) |
| Beam Load. Eff. | % | 97 | 95 | 95 | 95 |
| Deceleration | % | 90 | - | 50 | 50 |
| Phase stability @ 12 GHz | degrees | 0.2 | - | ? | |
| Intensity stability | | $7.5 10^{-4}$ to few $10^{-5}$ | $10^{-3}$ | ? | |

# CTF3 operation

- 1 staff + 1 fellow + 1 Research Associate operate routinely the machine
- + support from other staff partially + 1 fellow for stability/feed-back studies
- 1 white paper post to be opened now
- maximize run time by 2 ‘shifts’ per day presently not done any more
- Supervision of linac by shift operators foreseen and starting
- Weekly supervisor to coordinate activity
- Daily commissioning meeting

- Remarks:
  - Work concentrated on commissioning of new components
  - Increased complexity
  - Higher demand for availability of components
  - Full recombination (DL + CR) to be demonstrated
  - Operation becomes more demanding in terms of stability
  - Review the performance and identify bottlenecks

# Conclusion

- Drive Beam generation very well covered
  - fully loaded operation demonstrated and routinely used
  - bunch train combination principle shown (DL/CR)
  - optimization procedures developed
  - full current DL/CR combination will be done soon
  - performance and stability still to be addressed
- next major steps:
  - two beam tests in TBTS
  - drive beam deceleration in TBL

- Many options for the TDR phase => see Roberto's talk
- Many THANKS to all collaborators!