Beam Instrumentation for CTF3

(excluding BPM's – see talk Lars Soby)

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Outline

- Overview of Instrumentation

  ➡ Transverse Profile; Longitudinal Profile; Bunch Frequency Measurements

- Where are we? (Installations, obtained performance, CTF3-CLIC extrapolation)

  ✓ Emittance

  ✓ Energy and energy spread

  ✓ Bunch frequency measurements

  ✓ Bunch length

  ✓ Form factor @ 12 GHz (depends on both phase and bunch length)

- Opportunities and future focus?

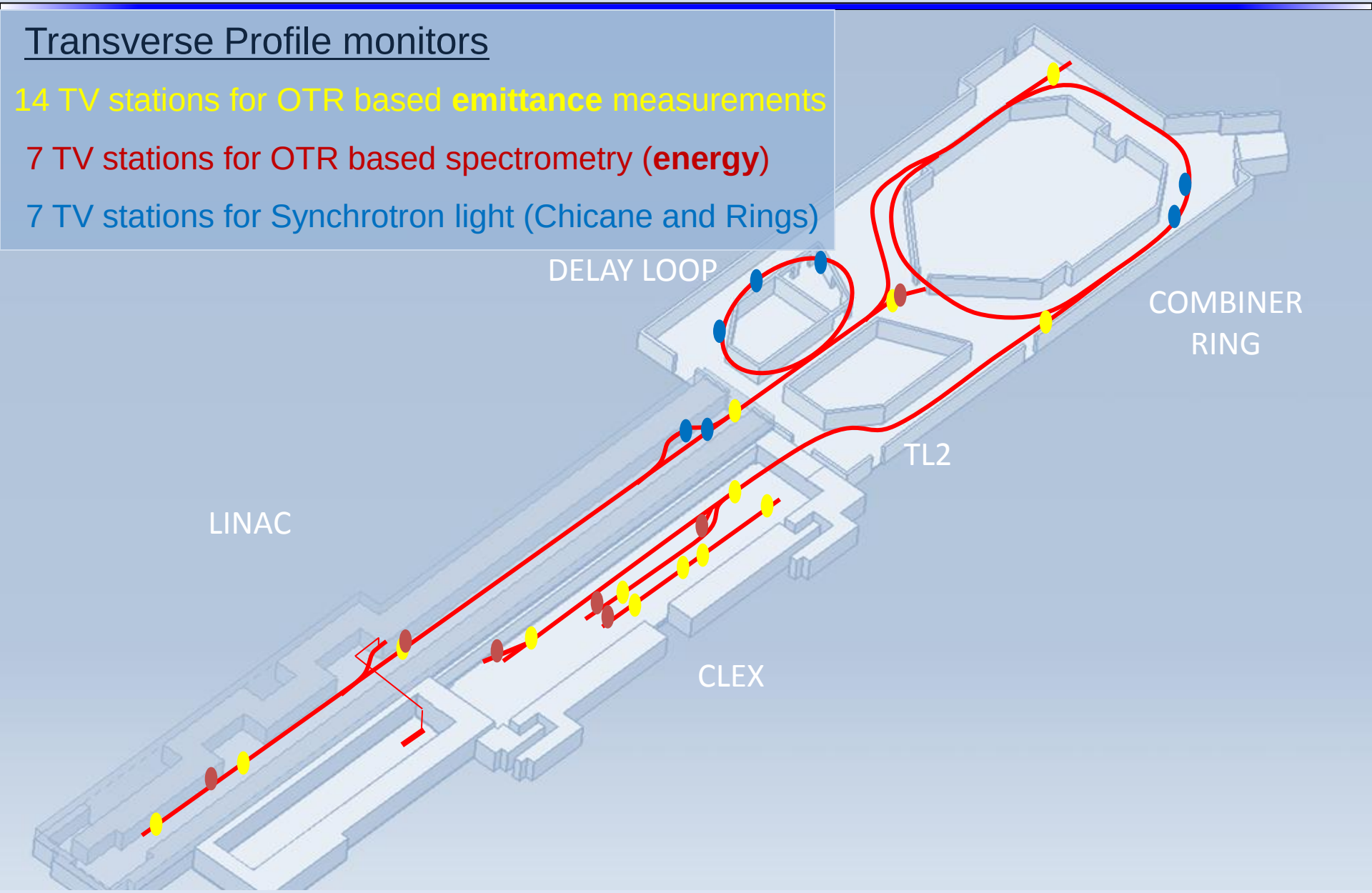
Overview of Instrumentation Installed (I)

Transverse Profile monitors

14 TV stations for OTR based **emittance** measurements

7 TV stations for OTR based spectrometry (**energy**)

7 TV stations for Synchrotron light (Chicane and Rings)

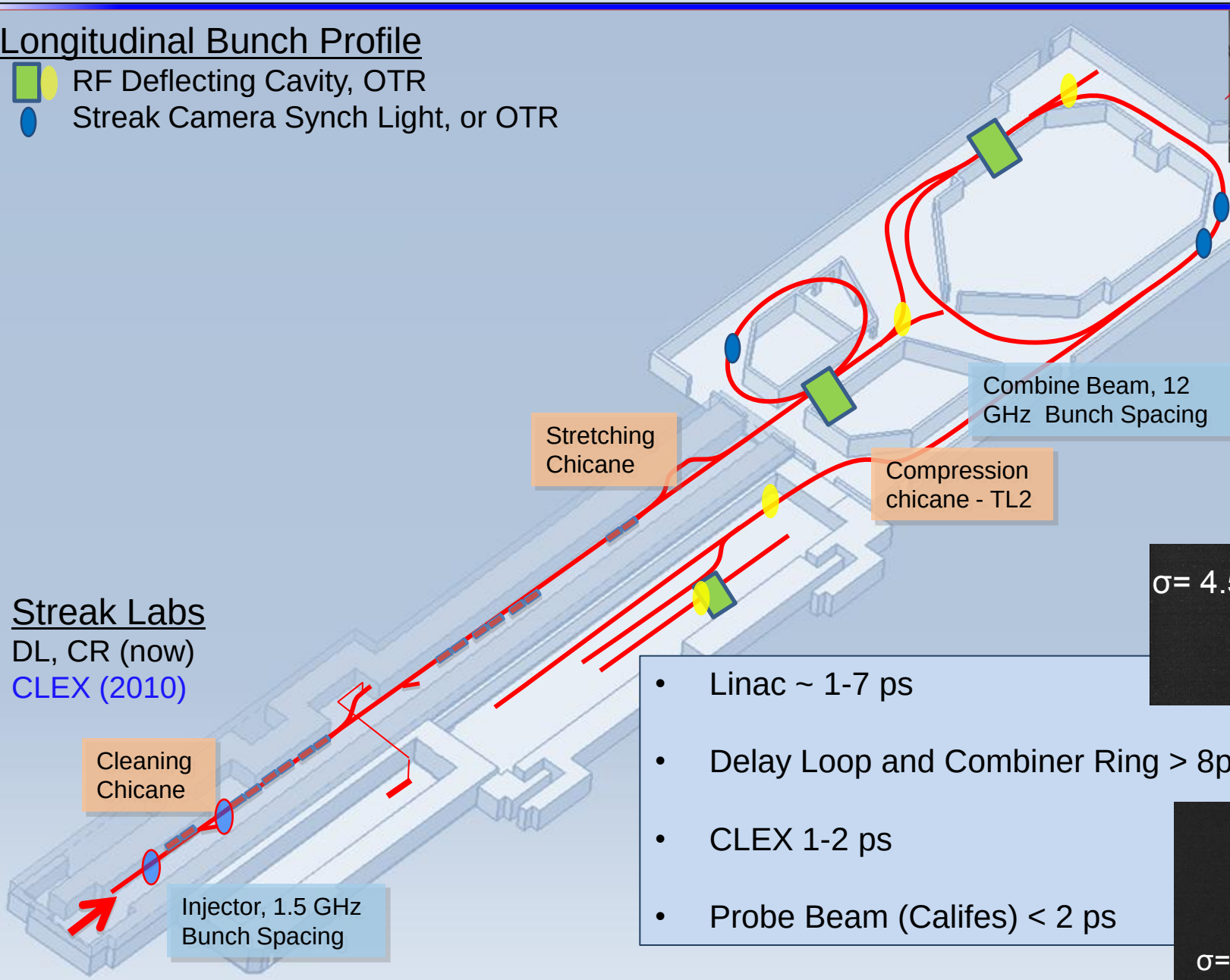


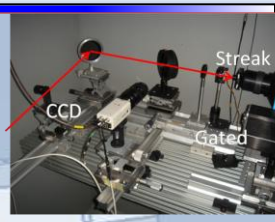
Overview of Instrumentation Installed (II)

Longitudinal Bunch Profile

RF Deflecting Cavity, OTR

Streak Camera Synch Light, or OTR



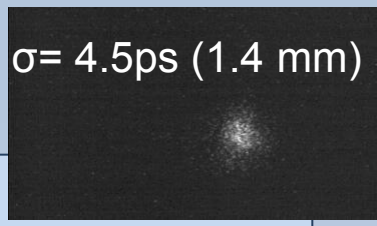


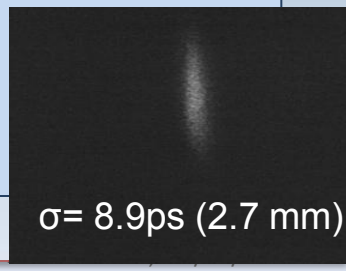
Streak Labs

DL, CR (now)

CLEX (2010)

- Linac ~ 1-7 ps
- Delay Loop and Combiner Ring > 8ps
- CLEX 1-2 ps
- Probe Beam (Califes) < 2 ps





Overview of Instrumentation Installed (III)

Longitudinal Bunch Profile

- RF Deflecting Cavity, OTR
- Streak Camera Synch Light, or OTR

Bunch Length Form Factor (r.m.s.)

- BPR-W (Power 26-40 GHz)
- RF-pickup (Power harmonics 30 – 170 GHz)
- CDR Experiment

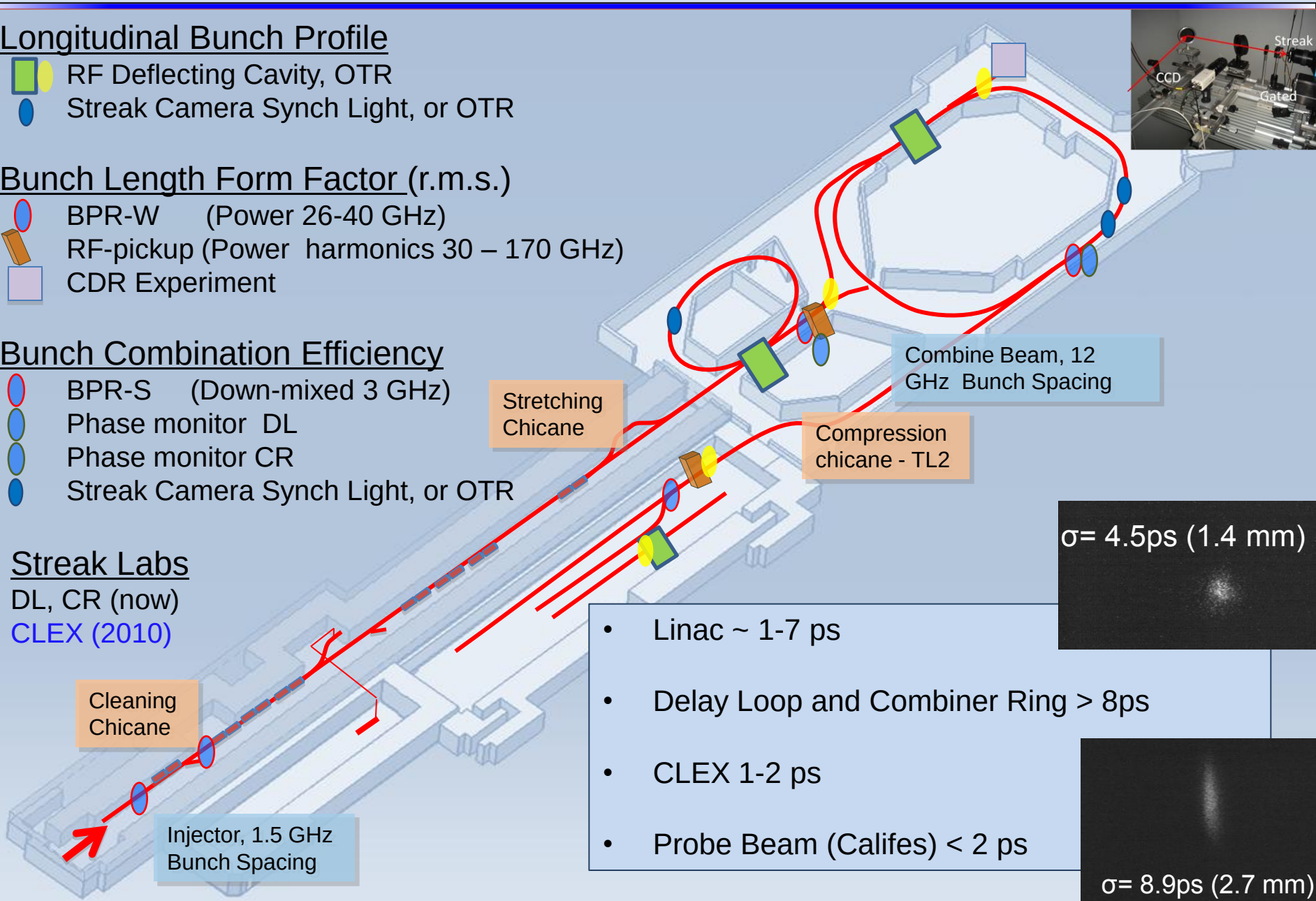
Bunch Combination Efficiency

- BPR-S (Down-mixed 3 GHz)
- Phase monitor DL
- Phase monitor CR
- Streak Camera Synch Light, or OTR

Streak Labs

DL, CR (now)

CLEX (2010)



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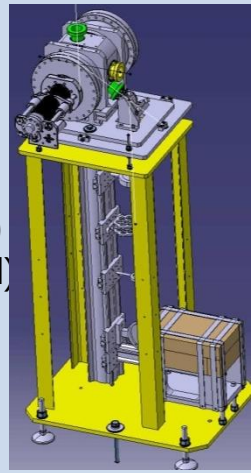
  - ✓ Energy and energy spread
  - ✓ Bunch frequency measurements
  - ✓ Bunch length
  - ✓ Form factor @ 12 GHz

- Opportunities and future focus?

OTR based emittance TL2 and CLEX (2010)

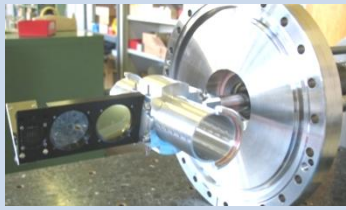
✓New Installations 6 Transverse Profile Monitors CTF3

TL2 emittance tank
TL2' emittance tank
TBL emittance tank
TBTs drive beam (Uppsala / Saclay mechanics & planning – CERN acquisition & control)
TBTs probe beam (Uppsala / Saclay mechanics & planning – CERN acquisition & control)

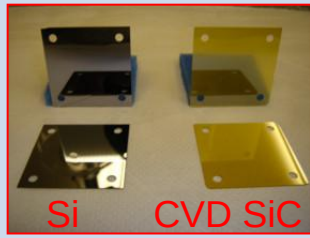


- 15º angle between OTR screen and the beam trajectory to minimize field depth errors

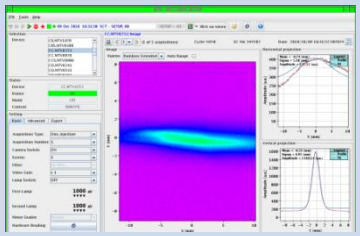
- Screens are mounted on a 4 positions remotely controlled support
  1. A replacement chamber to ensure the continuity of the beam line
  2. Low beam intensity operation (reflective silicon coated with thin aluminium)
  3. High intensity operation (CVD Silicon Carbide screen)
  4. A calibration plate can be inserted to quantify the resolution of the optical system



- Typical resolution in the machine at the moment:
  - 70-130 µm/pixel
  - Resolution gain possible (~20µm)
    ➔ sacrifice of total screen size



- Acquisition nominally at 0.8 Hz, camera integrates 20 ms
  new CPU tested in dctfmtv2 reduced acquisition time
  From about 350 ms to 60 ms. Other crates updated in 2011

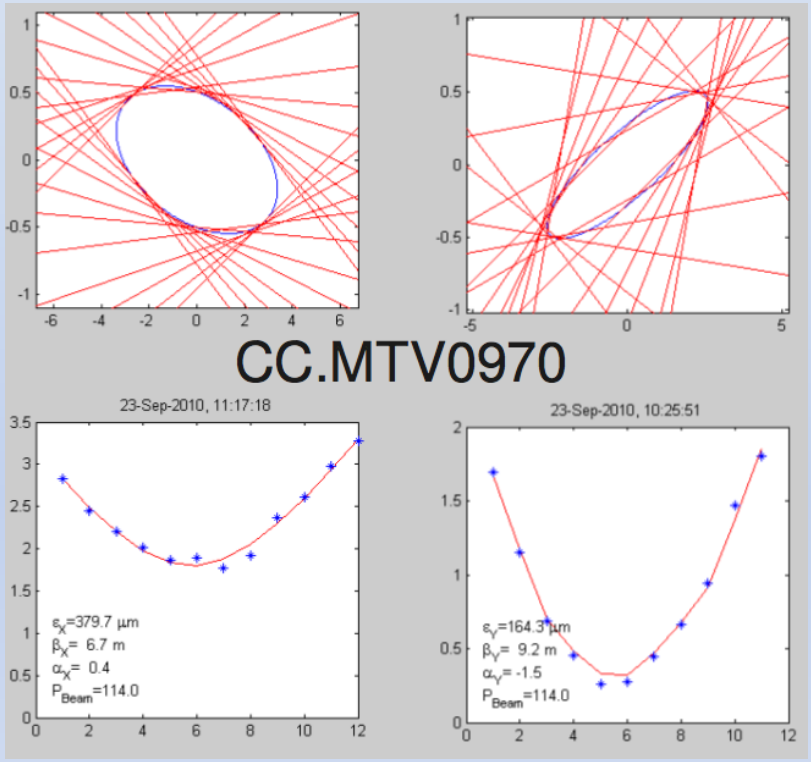


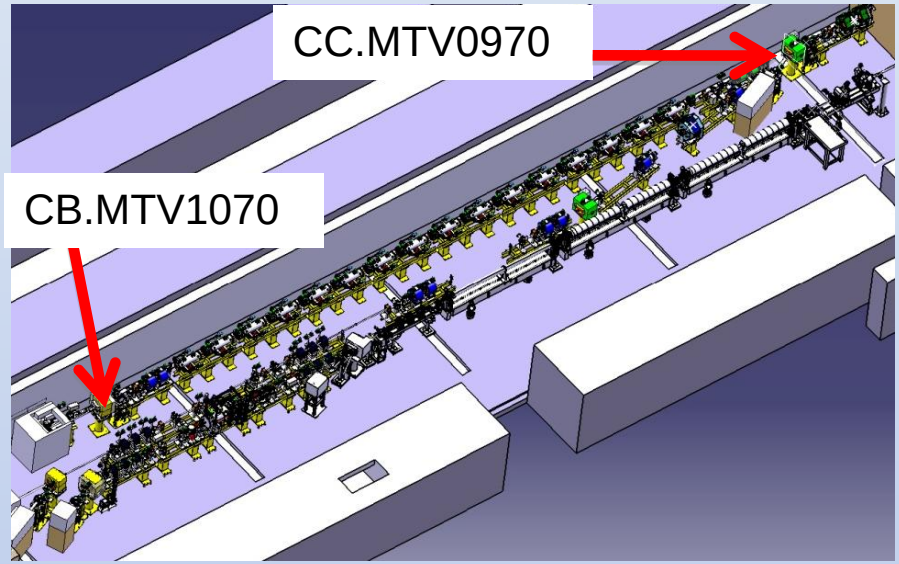
Reference: T Lefevre, "CTF3 Instrumentation", BIW08 conference.

Radiation damaged ➔ pixelized cameras, decreases S/N ratio

Example Emittance Measurements

Quadrupole scan





- Reproducible TWISS parameter measurements for TBL used to match FODO lattice, *See Talk R. Lillestol (TBL) WG-6*

- Emittance can be overestimated due to overlapping of different beam trajectories in CLEX. Gaussian profile fits used in code at the moment.
- Filters for light attenuation to avoid saturation of camera and overestimation of beam width
- Quadrupole misalignment in TBL prevents a good measurement at the end of the line

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  ✓ Energy and energy spread

  ✓ Bunch length

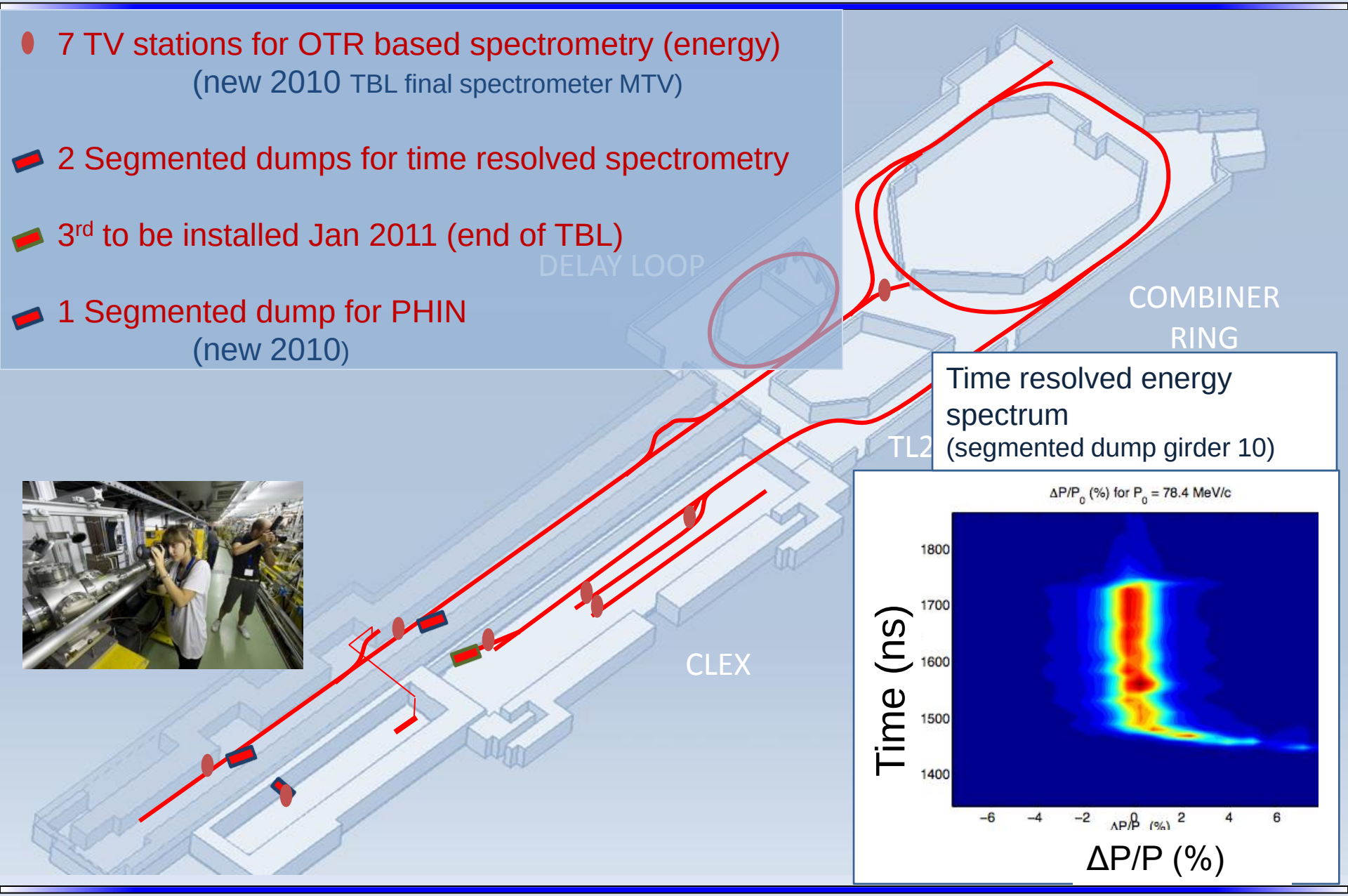
  ✓ Bunch frequency measurements

  ✓ Form factor

- Opportunities and future focus?

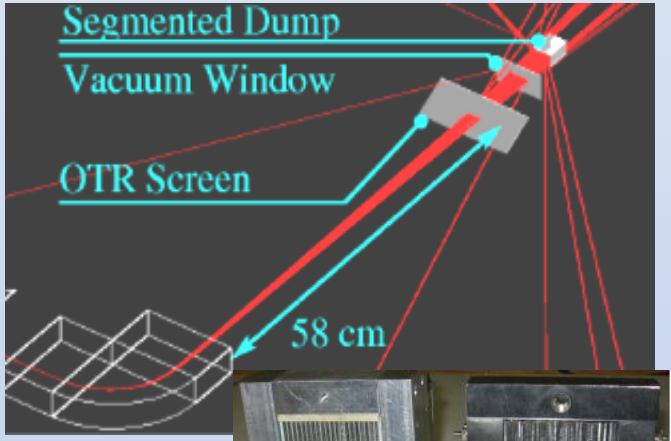
Spectrometry - Energy

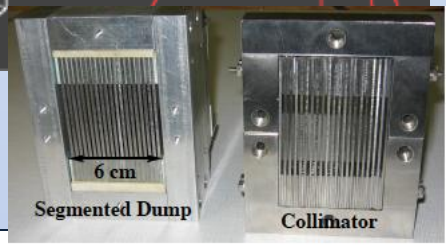
- 7 TV stations for OTR based spectrometry (energy)
  (new 2010 TBL final spectrometer MTV)
- 2 Segmented dumps for time resolved spectrometry
- 3rd to be installed Jan 2011 (end of TBL)
- 1 Segmented dump for PHIN
  (new 2010)

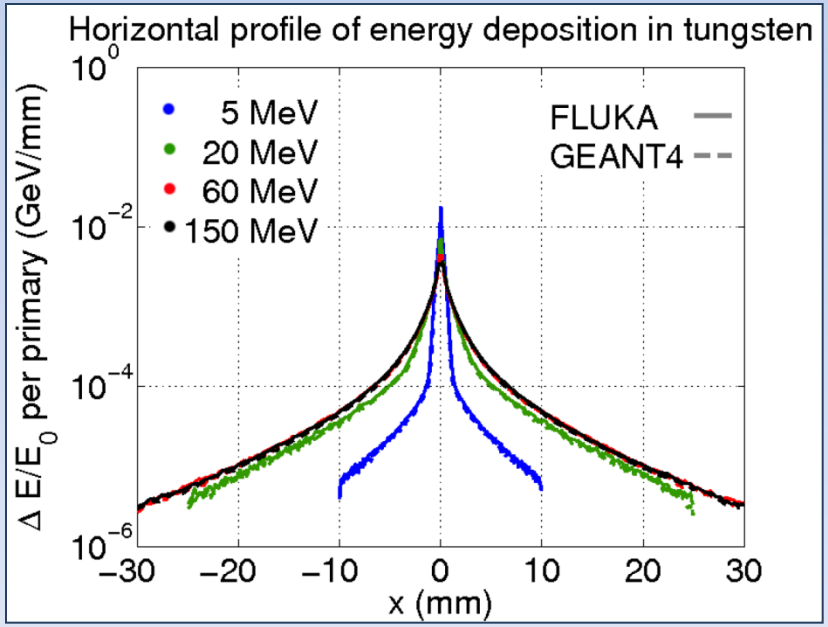


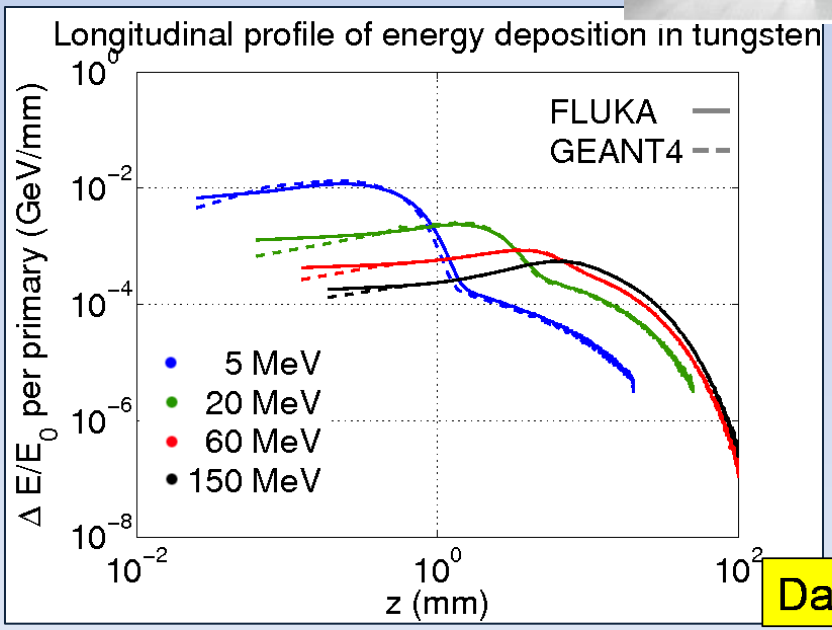
Spectrometery Design work 2009/2010

- Extensive Fluka and GEANT4 studies on 5-150 MeV electrons interacting with matter
- Necessary for optimizing detector resolution, thermal effects, material choices and radiation damage for **time resolved spectrometry**
- Transverse and longitudinal shower energy deposition







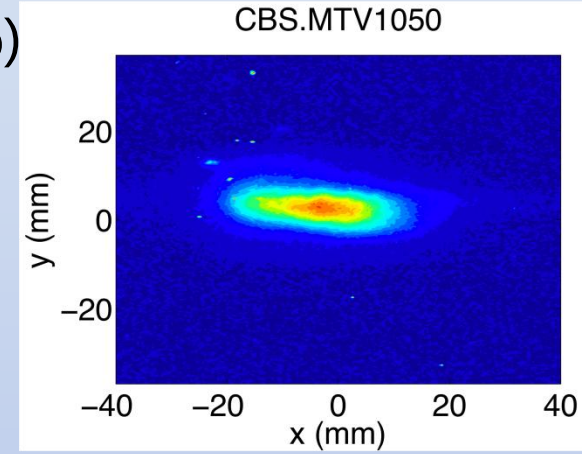


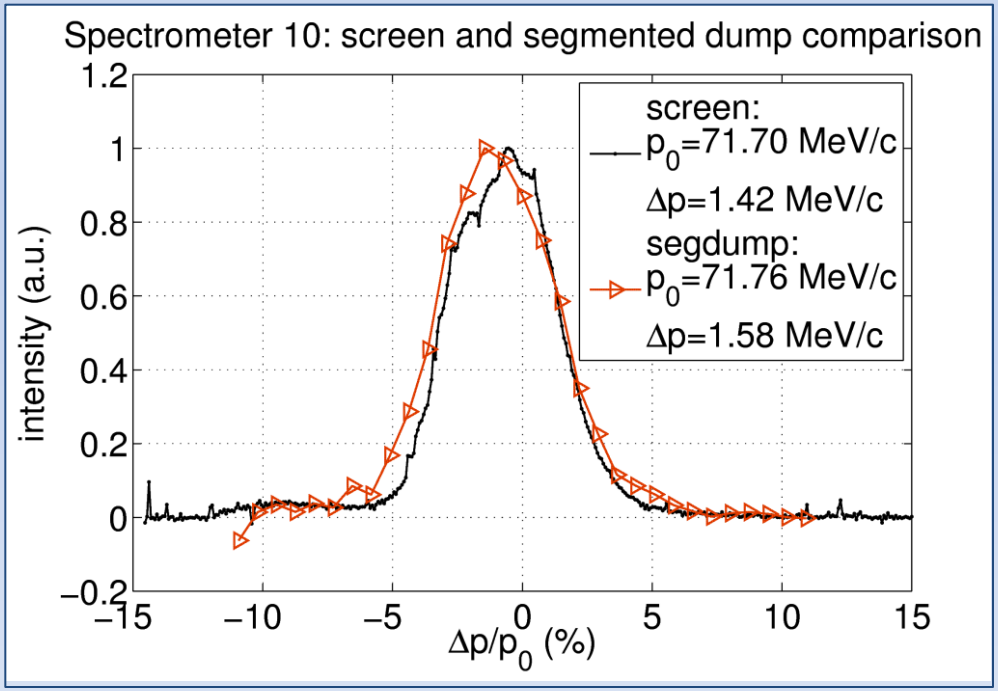
Daniel Egger

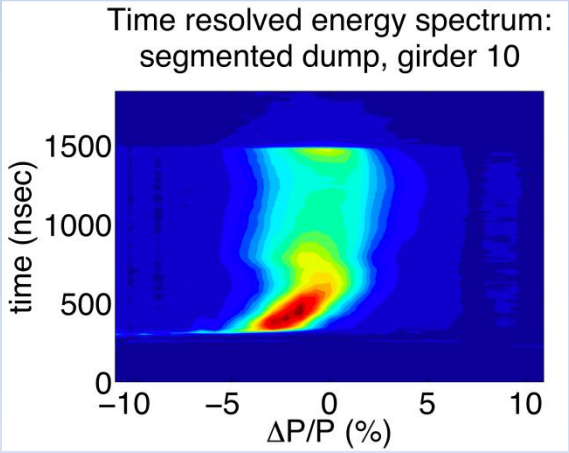
Maja Olvegaard

Consistency: OTR and integrated segmented dump:

- Energy (alignment)
- energy spread (resolution agreement to 10%)







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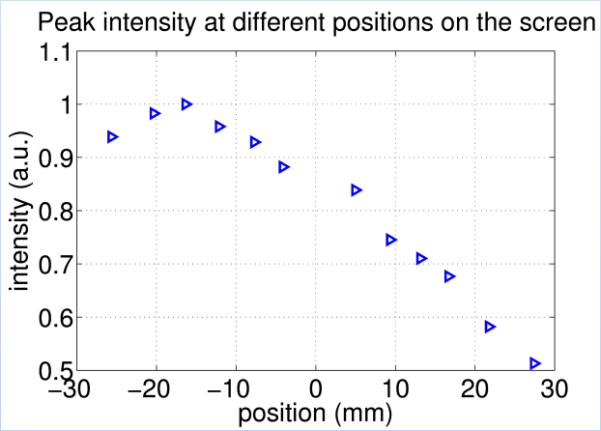
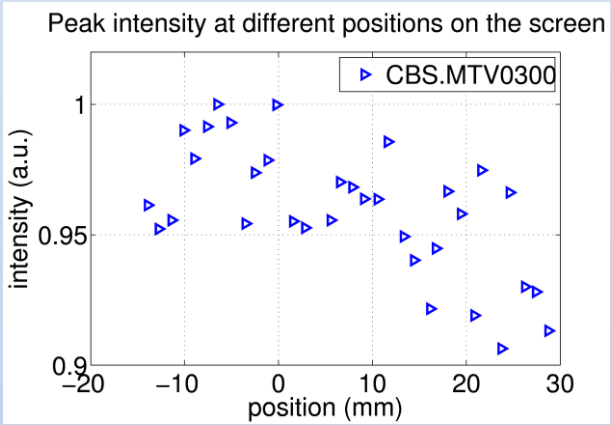
Impact of non-linearity of screen on profile measurements

CLS.MTV1050 (Spectrometer 10)

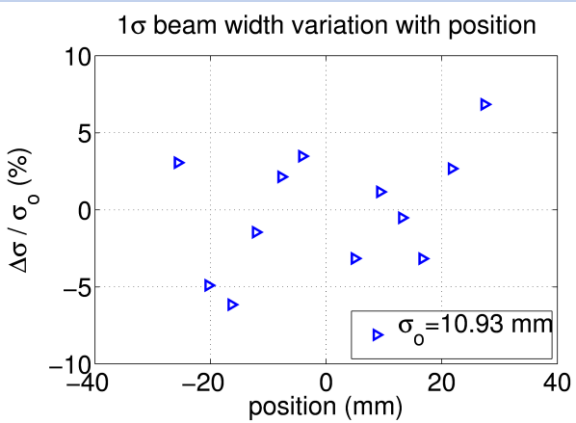
CBS.MTV0300 (TBL)

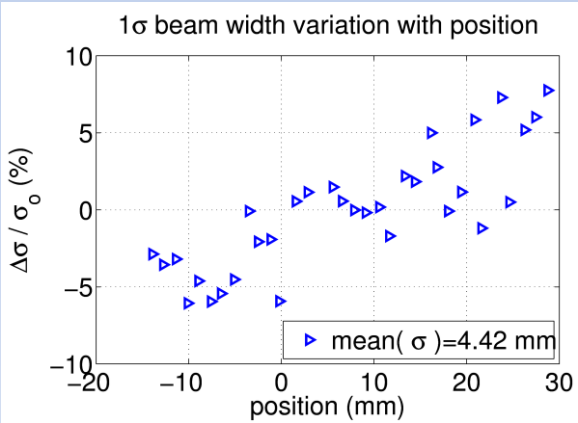
peak intensity





beam width





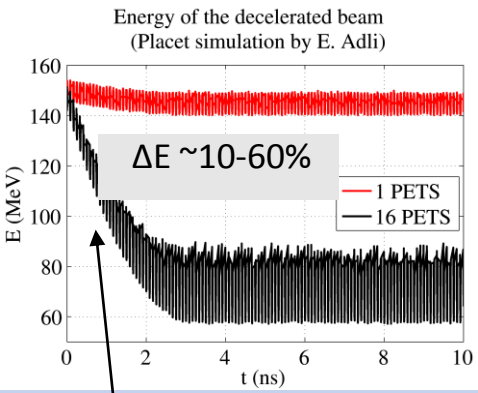
position

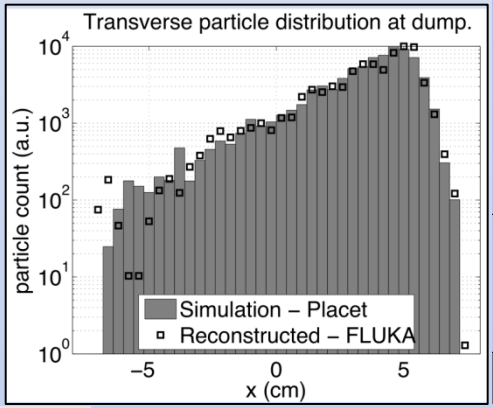
position

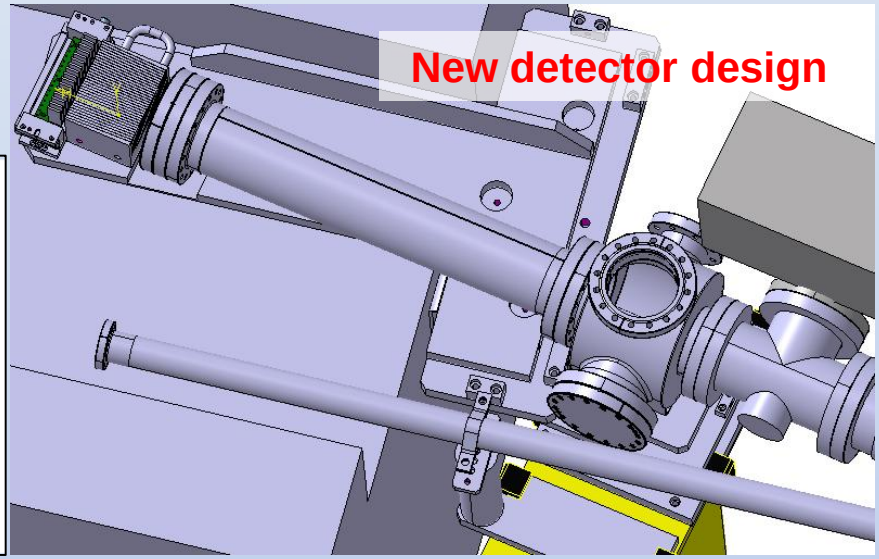
- residual non-linearity's of the OTR system, 5% impact on beam profile sigma
- further studies needed – goal calibrate out this small effect
- CLS.MTV1050 (parabolic) CBS.MTV0300 (diffusive) – both aluminium

Time resolved energy measurement TBL

High intensity (28 A) e⁻ beam of 150 MeV



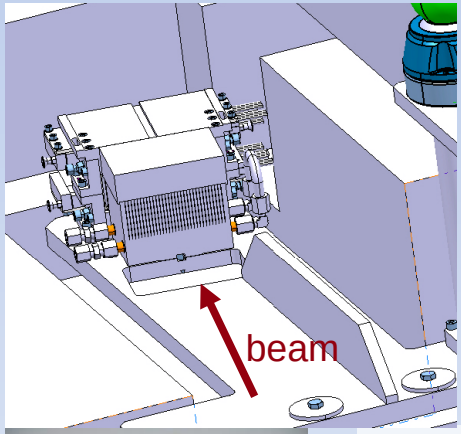


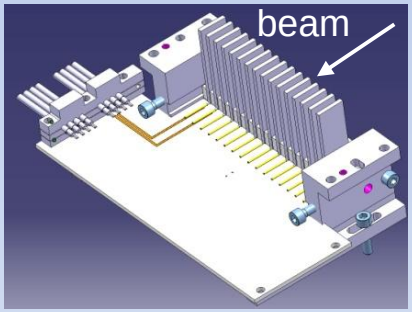


High energy transient

Nominal pulse length: 140 ns

- **Design:**
  - 32 channel transverse faraday cup
  - 10° spectrometer line
  - includes full FLUKA simulation
  - realistic beam profile from PLACET
  - 3 mm segments, 400 µm slits collimator –> 2% resolution
  - Single shot measurement of the steady state
- **Implement in Machine TBL Jan 2011**



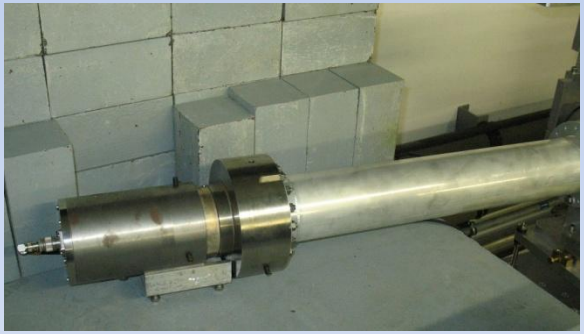


- **5% measurement on energy spread**
- **5ns time resolution (limited by ADC choice)**

Presented IPAC10

Maja Olvegaard

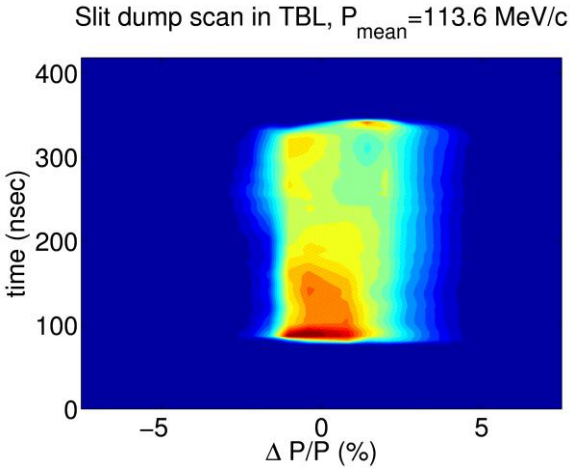
Time resolved energy measurement end TBL

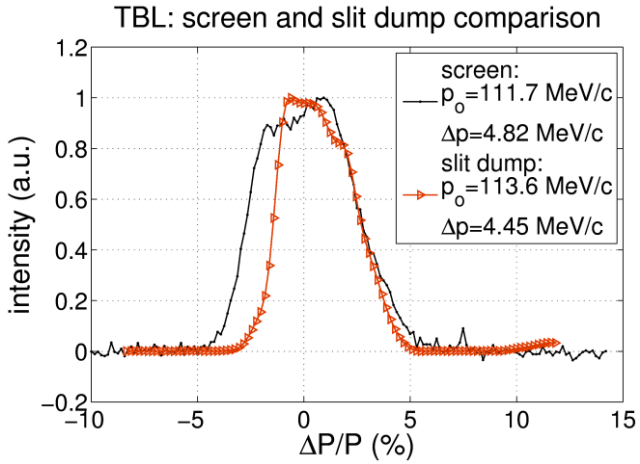


Installed single slit segmented dump (2009)

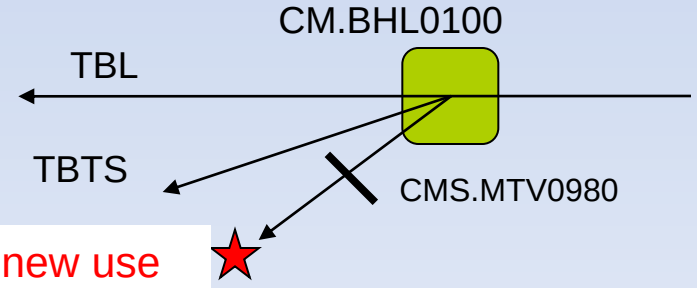
- Slit dump already used to understand TBL
- slit 1mm wide
- length 100 mm
- iron

Full transmission in TBL (September 2010)





Plan to install slit dump in TL2/TL2' (2011)



- Time resolved energy measurement before and after PETS

Maja Olvegaard

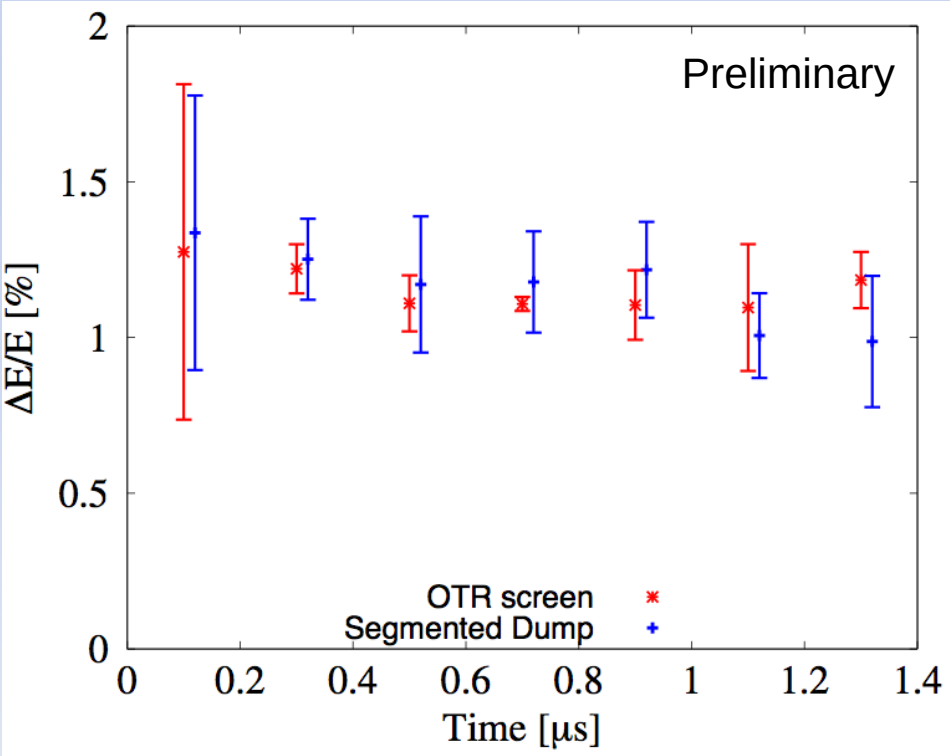
PHIN Energy Measurement

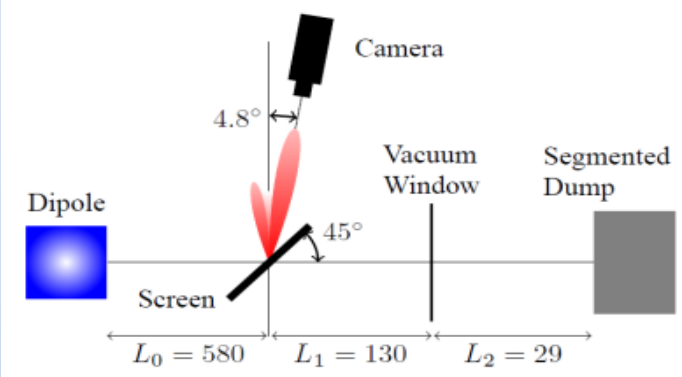
For PHIN beam measurements at nominal performance, see talk O. Mete

Diagnostics Studies

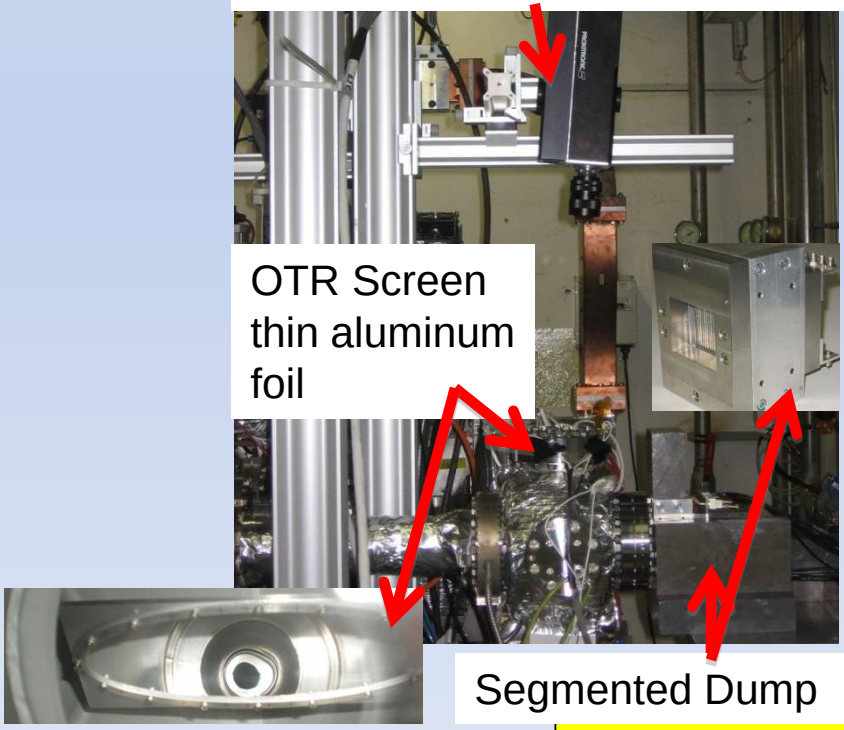
✓ Comparison between gated OTR measurement and segmented dump

✓ Agreement to within 7.8±4.6%





Gated Intensified Camera



OTR Screen thin aluminum foil

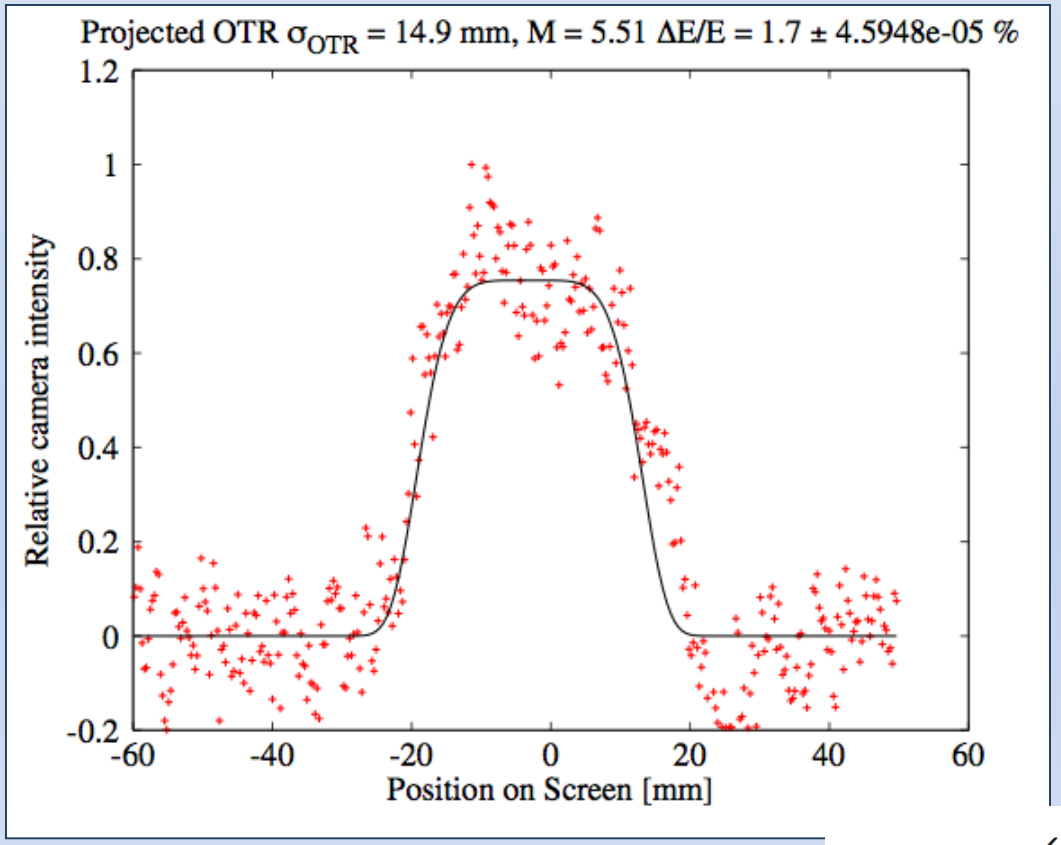
Segmented Dump

Daniel Egger

Presented IPAC10

PHIN – Gated OTR in spectrometer line

OTR measurement with 5 ns gate (beam conditions 0.1 nC / bunch – nominal 2.3 nC / bunch)
MCP Gain 76%



$$I \propto \exp\left(-\frac{|x|^m}{2\sigma^m}\right)$$

Super-Gaussian best fit best the distribution

Nominal conditions, X20 more light ➔ reduce gain and single shot noise.

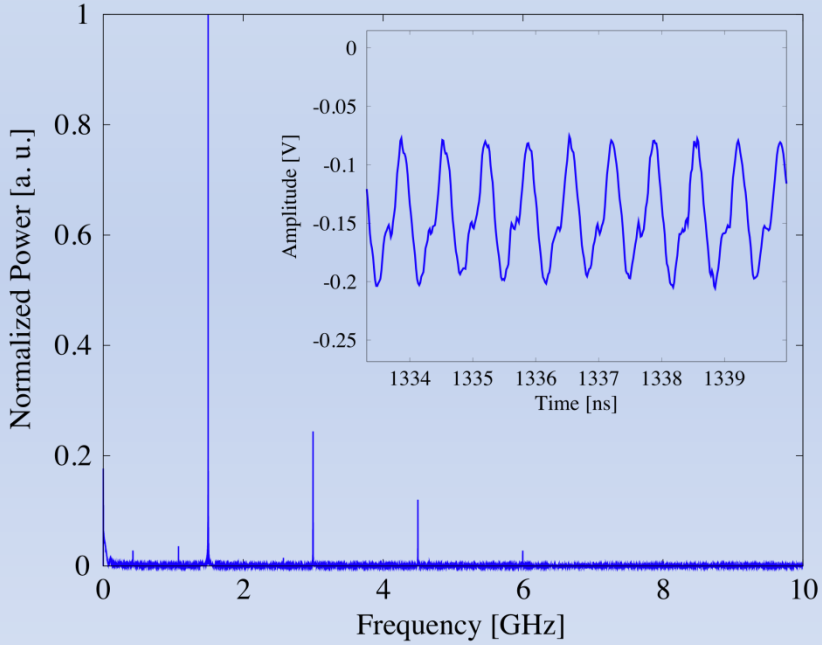
Daniel Egger

PHIN - Time response segmented dump

Connected the output of a detector channel to a fast 12 GHz analog bandwidth scope

Time response of **segmented dump**

- lemo and BNC connectors, 100 m N-type cable



Resolving individual bunches possible, here limited by cables and connectors

Time response of matched **faraday cup**

- N-type connectors and 100m of N-type cable

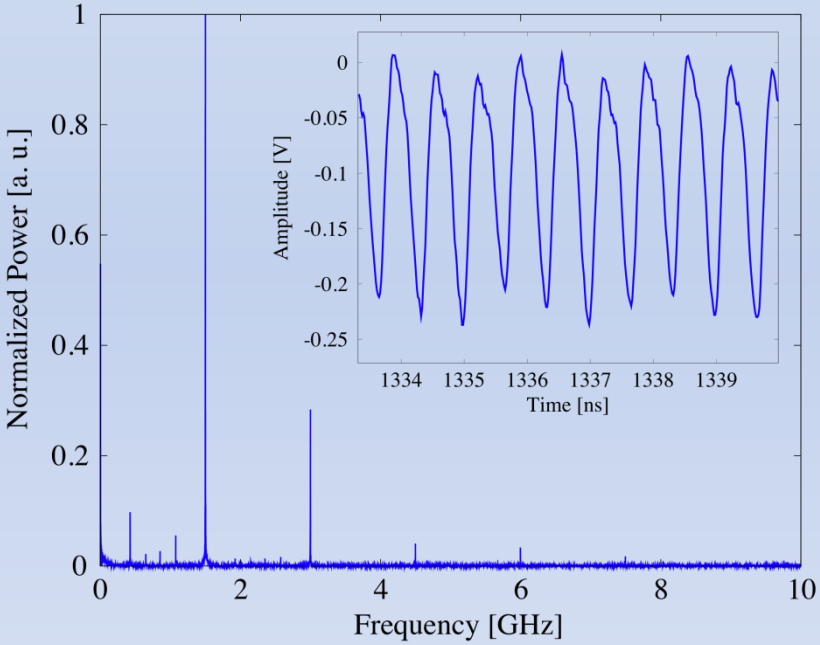


Figure of merit for timing resolution is given by 266 ps (FWHM) of bunch signal

Daniel Egger

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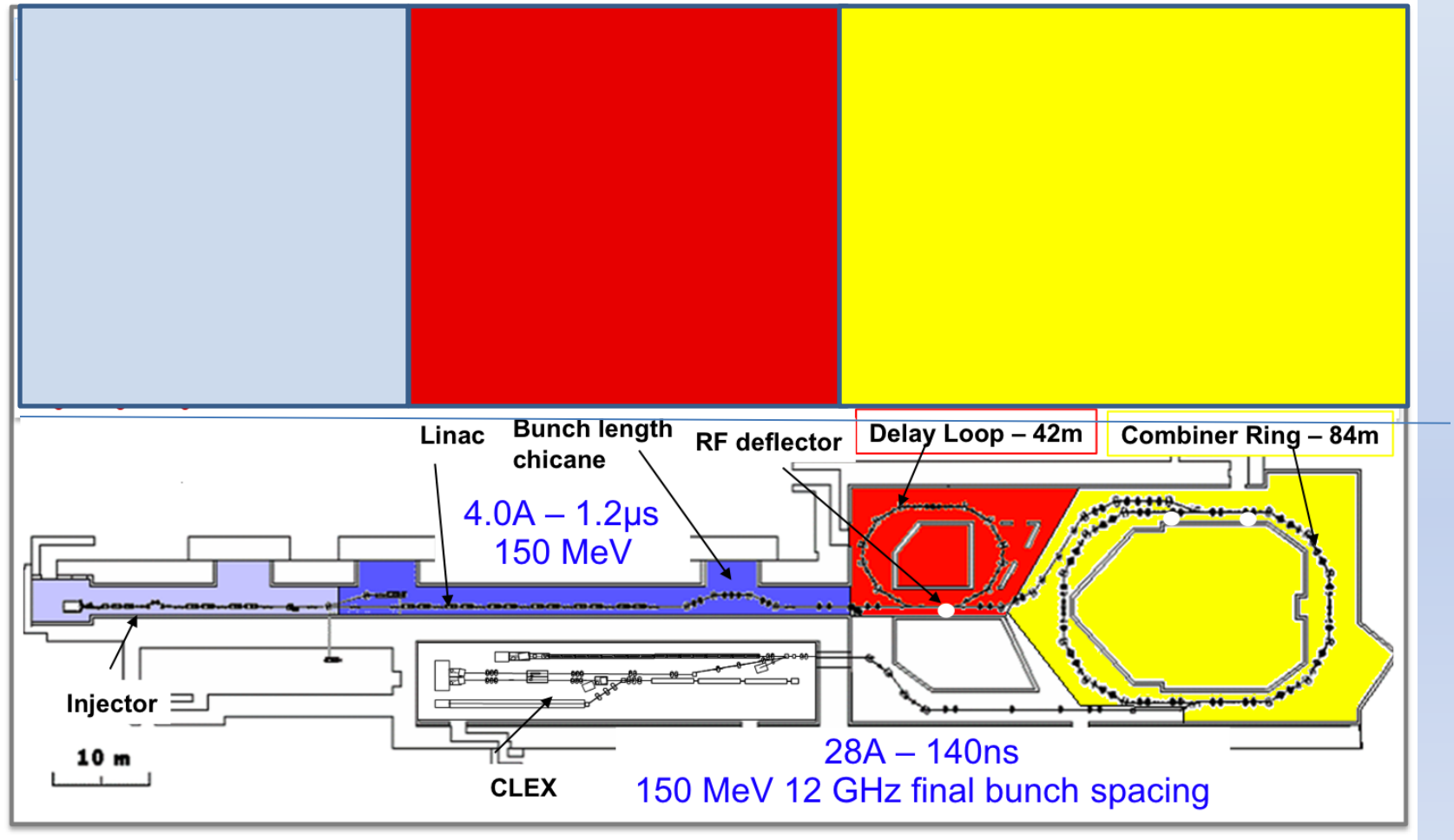
  ✓ Bunch length

  ✓ Form factor

- Opportunities and future focus?

CTF3 complex and Bunch manipulation



RF power Generation

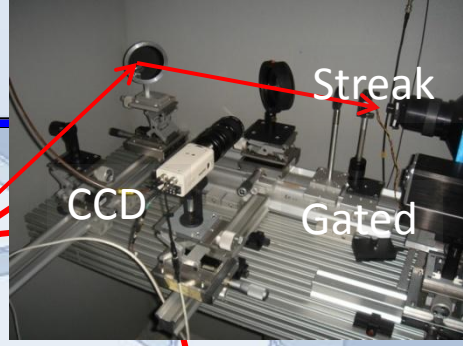
$$P = I^2 L^2 F_b^{\,2} \omega_0 \frac{R/Q}{V_g 4}$$

Diagnostics to tune the "ring lengths"

Form factor diagnostics @ 12GHz optimize power

- bunch length
- bunch spacing (phase)

Streak cameras in CTF3



4 Long Optical lines

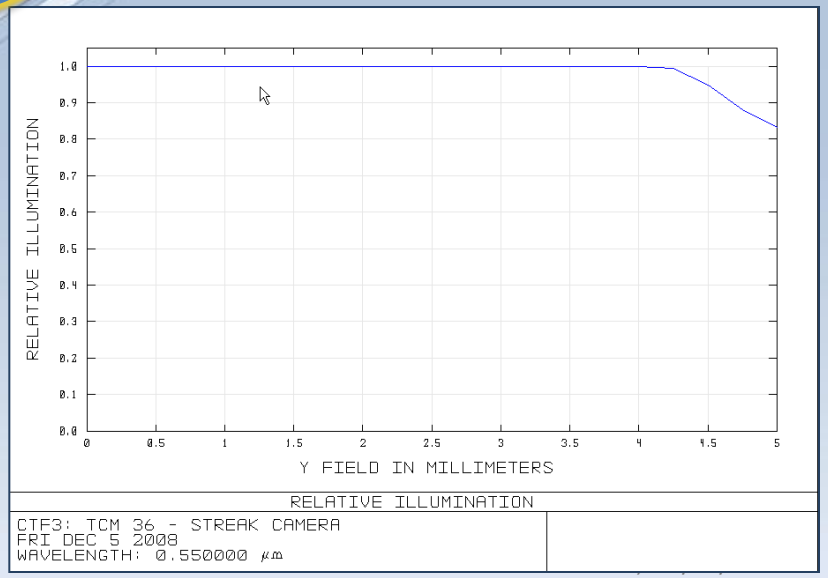
- 3 Synchrotron Radiation in the DL, CR (zero and non-zero dispersion points)
- OTR at the end of linac CT line

Optical lines simulated with Zemax

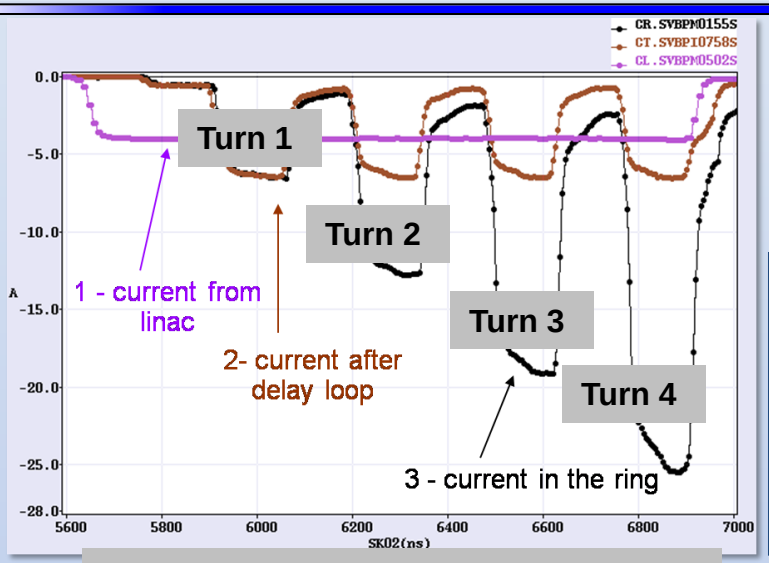
- ✓ high transmission
- ✓ Min aberration (good for transverse imaging too) and min. chromatic effects

Future Optical Line CLEX & New Optics Lab

- ~ 20m optical line to new Optics Lab.
- Special attention to longitudinal dispersion through lenses and air.
- ✓ Optical lab construction starting this week!
- ✓ Optical line to be installed Jan/Feb 2011



Frequency Multiplication



Current Multiplication Measured with BPMS

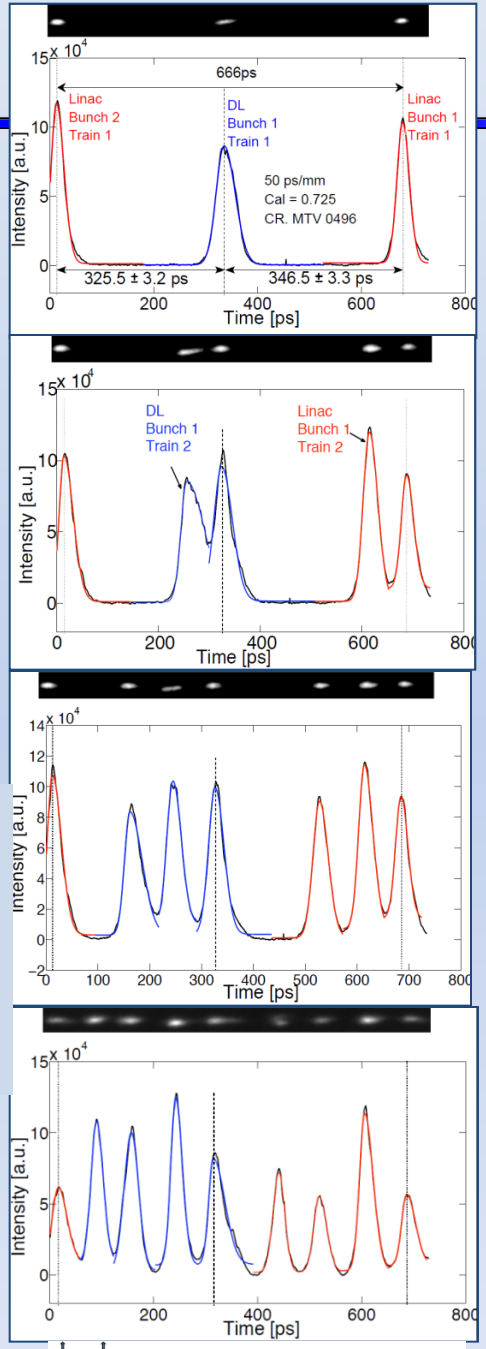
Train	Bunch Spacing error (ps)
1	13.0 ± 3.3
2	25.3 ± 3.4
3	32.4 ± 3.5
4	16.9 ± 3.4

For single shot, trade off between duration along the pulse and time resolution

➔Need to scan with Streak trigger to measure bunch spacing along the full pulse train

➔Automatic scan not possible with older streak cameras

Streak cameras	LEP double sweep	LEP single sweep	FESCA200
Time window	16 ns – 400 ps	14 ns – 120 ps	1 ns – 20 ps

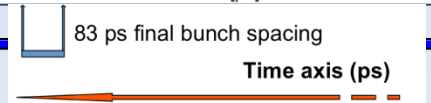


Turn 1

Turn 2

Turn 3

Turn 4

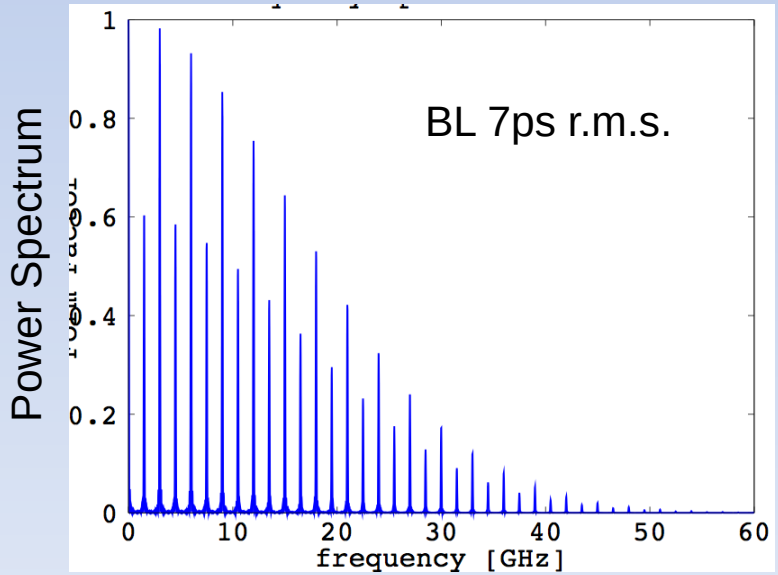


Example Beam induced Power Spectrum

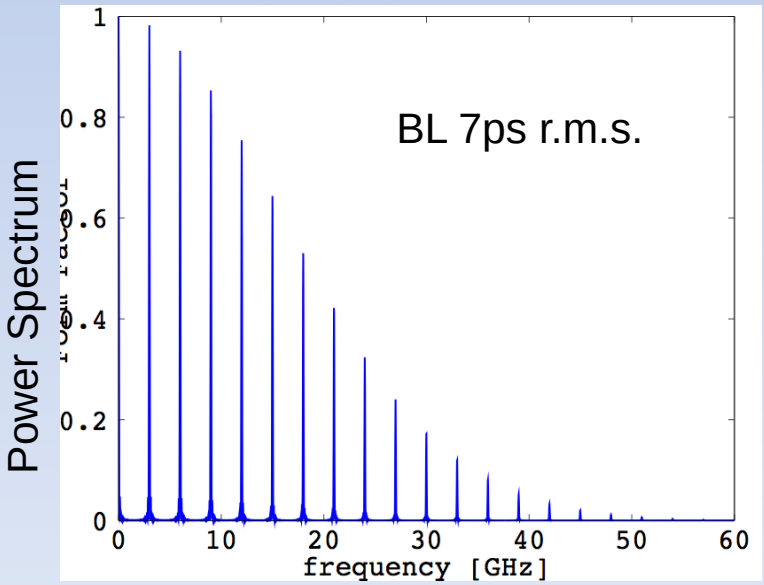
Power Spectrum

$$P(f,t) \propto I^2(t) \left(\frac{\sigma_- e^{-2\pi^2\sigma_-^2 f^2} + \sigma_+ e^{-2\pi^2\sigma_+^2 f^2}}{\sigma_+ + \sigma_-} \right)^2 \times \left[\left(\sum_{i=1}^{N} \cos(2\pi\tau_i f) \right)^2 + \left(\sum_{i=1}^{N} \sin(2\pi\tau_i f) \right)^2 \right],$$

1.5 GHz beam CTF3 linac, 12% satallites

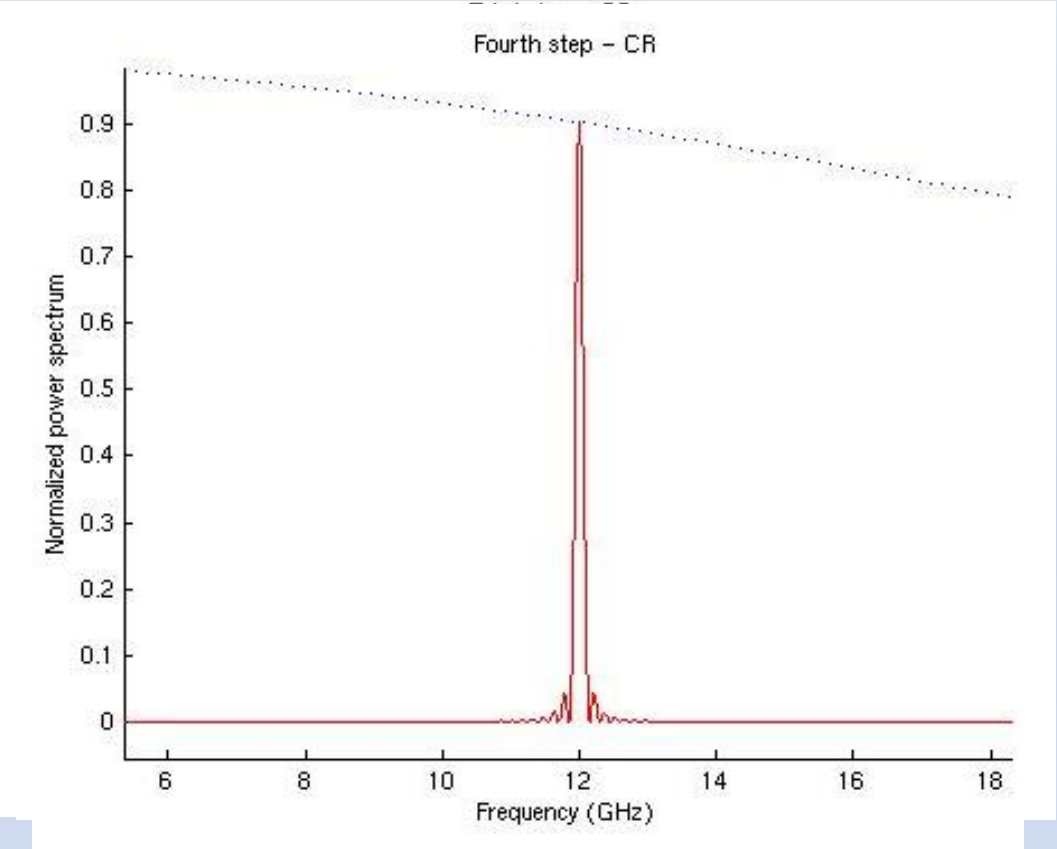


3 GHz beam CTF3 linac, 0% satallites

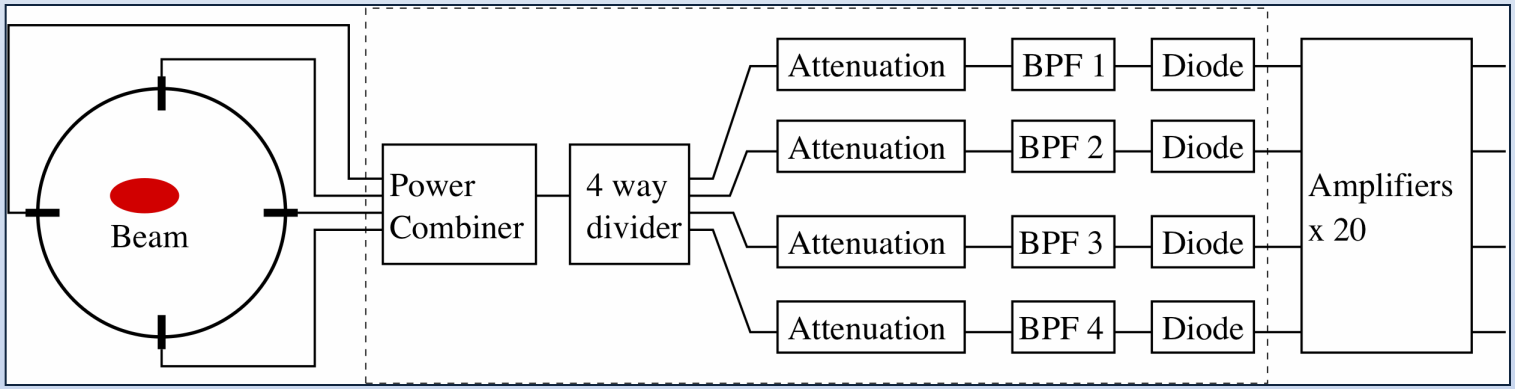


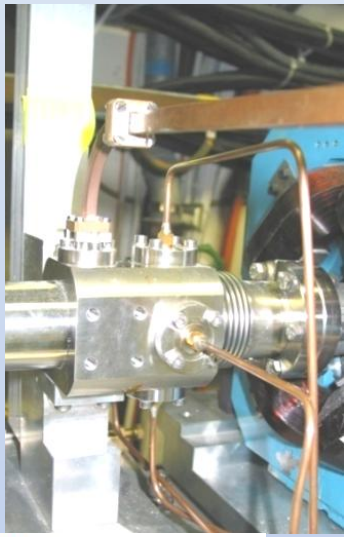
Simplified – frequency space during combination

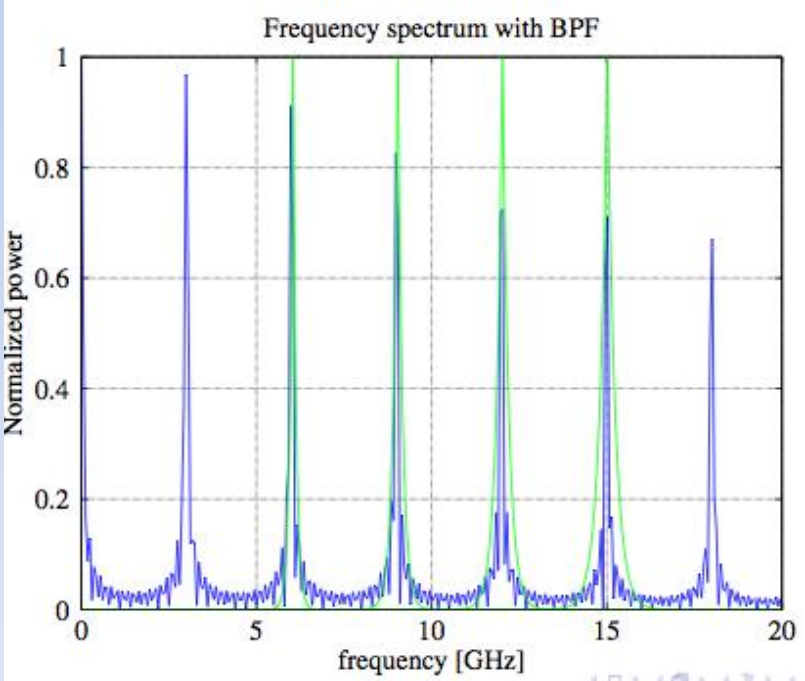
- No satellites
- No phase switches
- No phase errors
- No losses
- Uniform bunch length along the pulse train



Tune Combination Efficiency - Phase Monitor

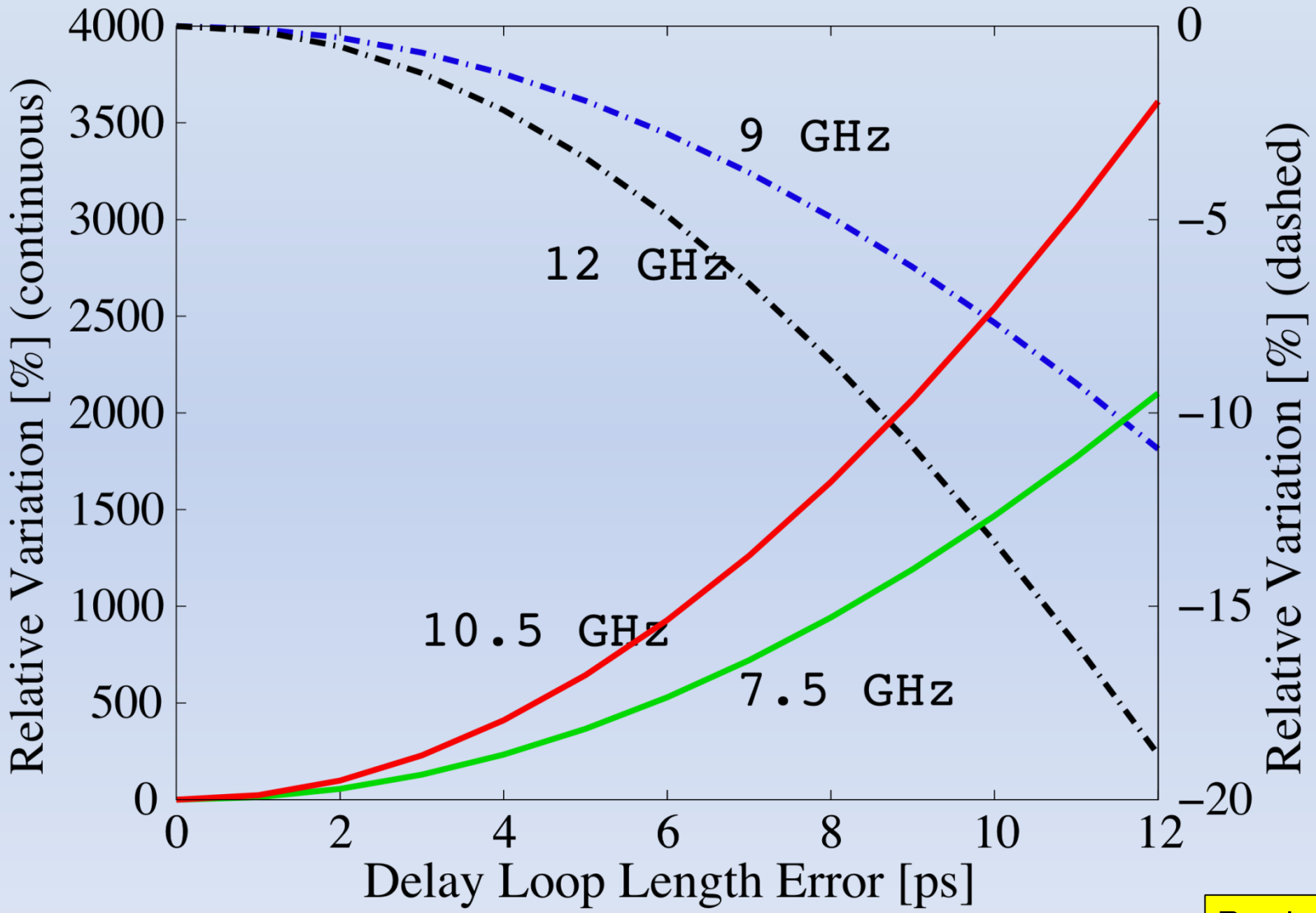






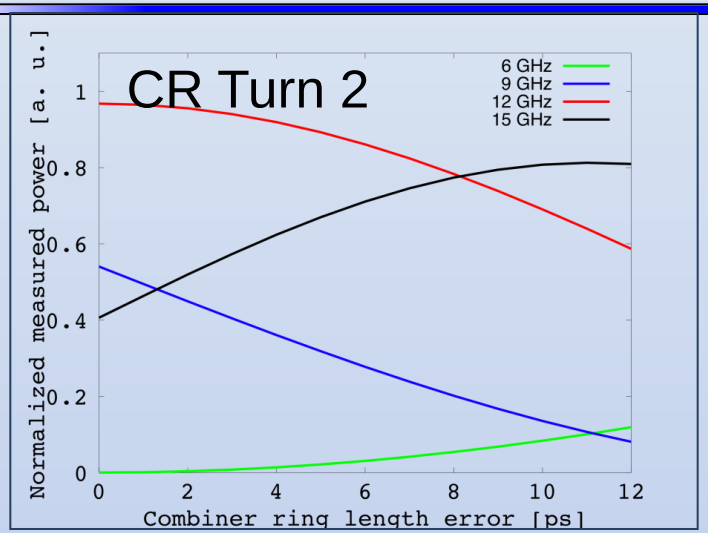
Delay loop	(1.5 GHz – 3 GHz): 7.5, 9.0, 10.5 & 12 GHz
Combiner ring:	(3 GHz – 12 GHz): 6.0, 9.0, 12.0 & 15 GHz

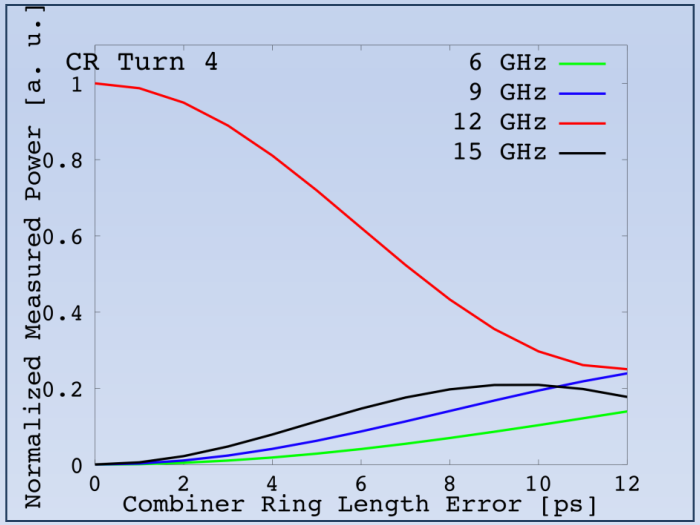
Phase Monitor – sensitivity to DL ring length errors



Daniel Egger

Phase Monitor – sensitivity to CR ring length errors



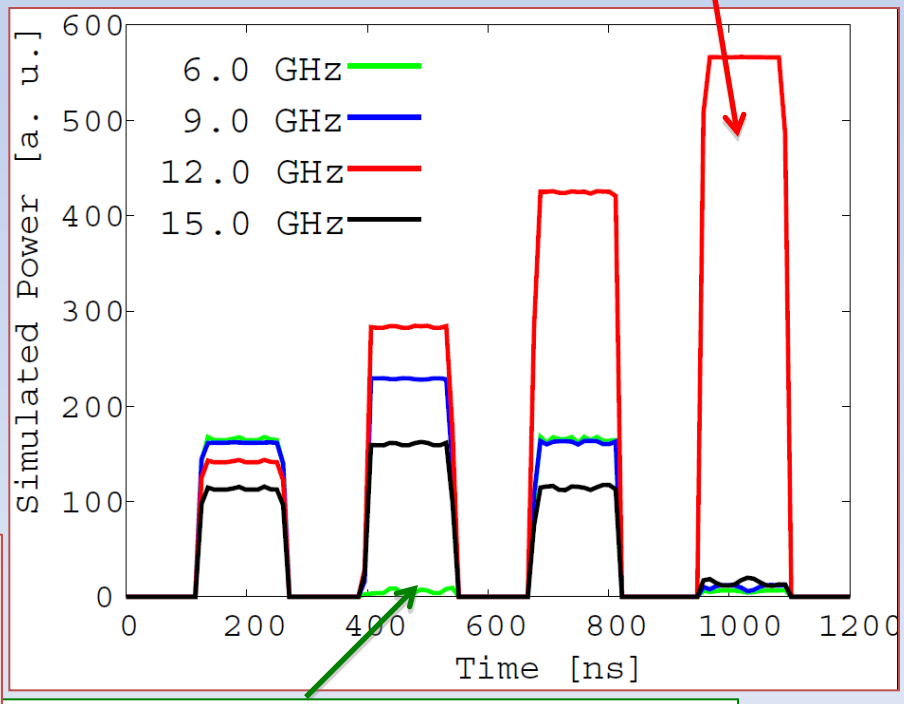


Operation tuning schema

Daniel Egger

- Bench-mark the phase monitor signals against a perfect combination as measured with the streak camera (2-3 ps bunch spacing precision)
- Monitor changes in this perfect combination with the phase monitor signals
- Note: Signals also bunch length dependent!

4th turn – all power in 12 GHz



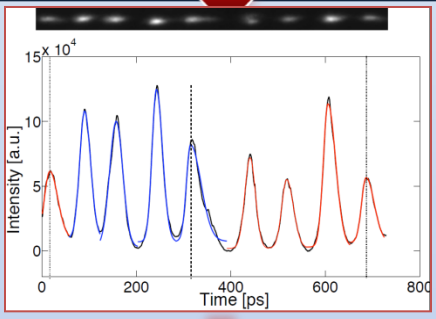
2nd turn – no power in 6 GHz

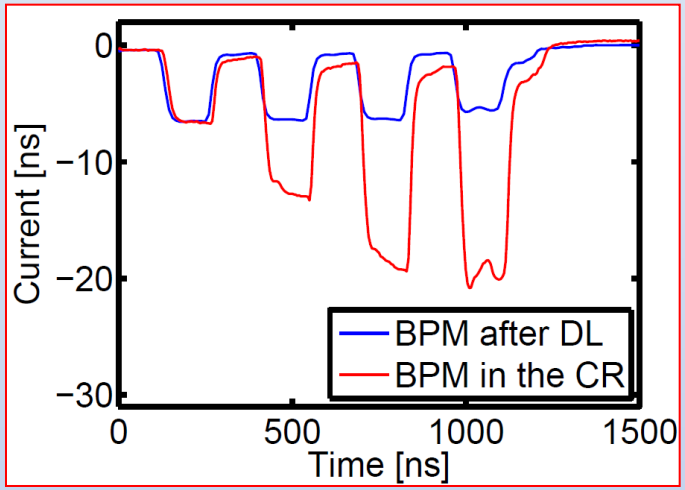
Simulation Assumptions:

perfect combination, uniform bunch length (15 ps FWHM) along the train and uniform current, measured response and band pass filtering included

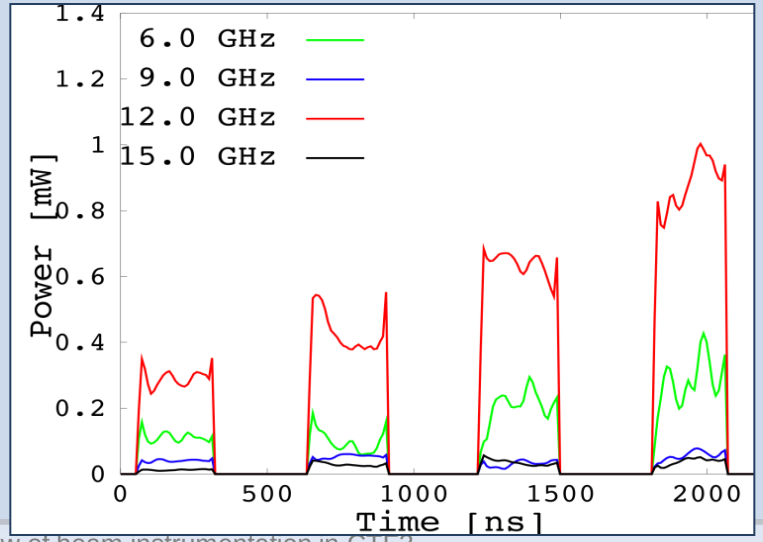
Phase Monitor – measurement example

- Example of measurement 18 Nov 2009, Factor x8 combination current
- DL ~ 20 ps late





- Factoring out: Electronics gain + Bunch length (BPRW) + current (BPM) variation corrected along the pulse



Combination efficiency measurement with phase monitor in combiner ring

… **new improved measurements to come soon**

… but normalizations needed for good phase measurement incl. slow phase drift profile in the linac

D. Egger and M. Favier

Outline

- Overview of Instrumentation

  ➡ Transverse Profile; Longitudinal Profile; Bunch Frequency Measurements

- Where are we? (Installations, obtained performance, CTF3-CLIC extrapolation)

  ✓ Emittance

  ✓ Energy and energy spread

  ✓ Bunch length

  ✓ Bunch frequency measurements

  ✓ Form factor

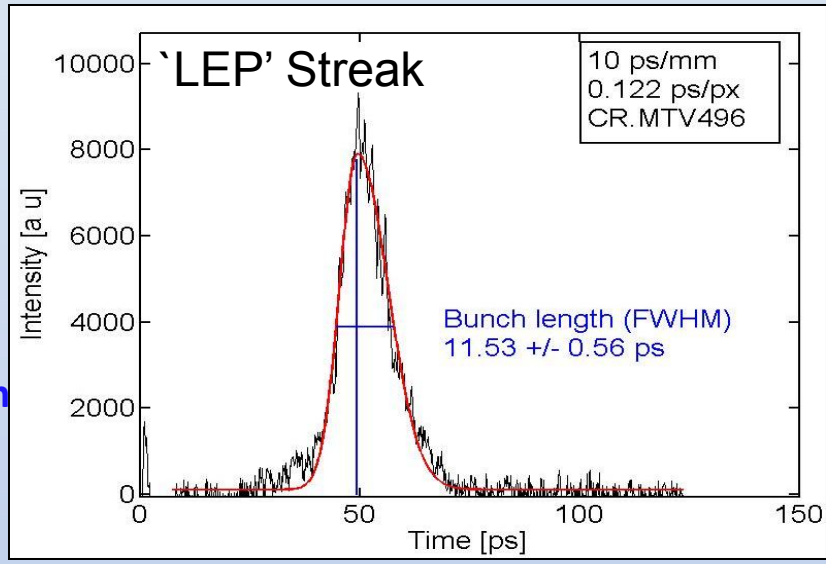
- Where is near - future focus?

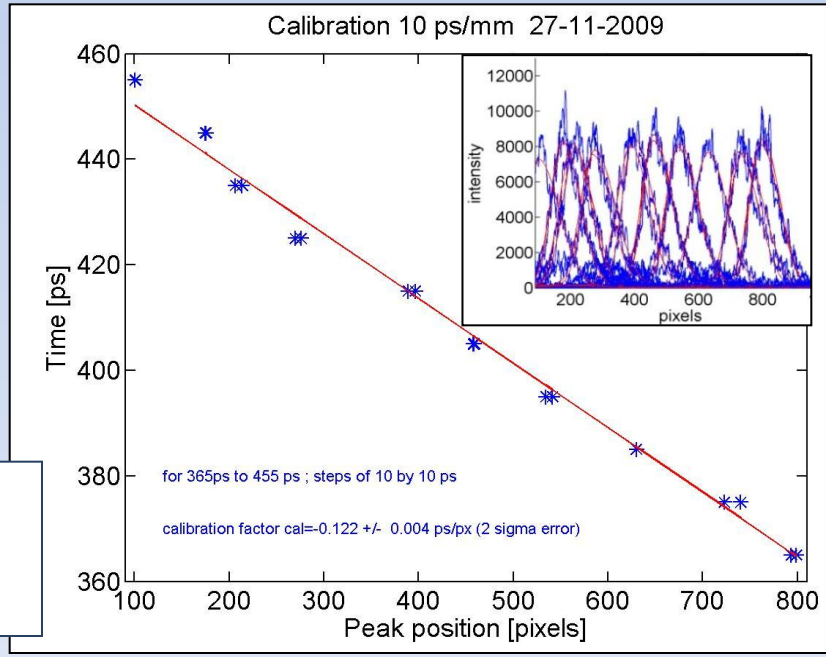
‘LEP’ Streak Camera – Bunch Length Measurement

- **Bunch Shape**
  - A **Skew Gaussian bunch shape**

$$y = ae^{-\frac{(x-\mu)^2}{2\sigma^2(1+\alpha\cdot sgn(x-\mu))}} + off$$

- **Measure calibration factors**
  - Result **0.122 ± 0.004 ps/pixel (2 sigma) for 10ps/mm**
- **Measurement of the jitter**
  - Eg, Jitter in the peak measured **5.5 ps ± 0.2 (2 sigma)**
  - Contribution from trigger and beam
- **Slit size contribution to measurement**
  - **FWHM in focus 14.8±0.9 pixels (2 sigma)**



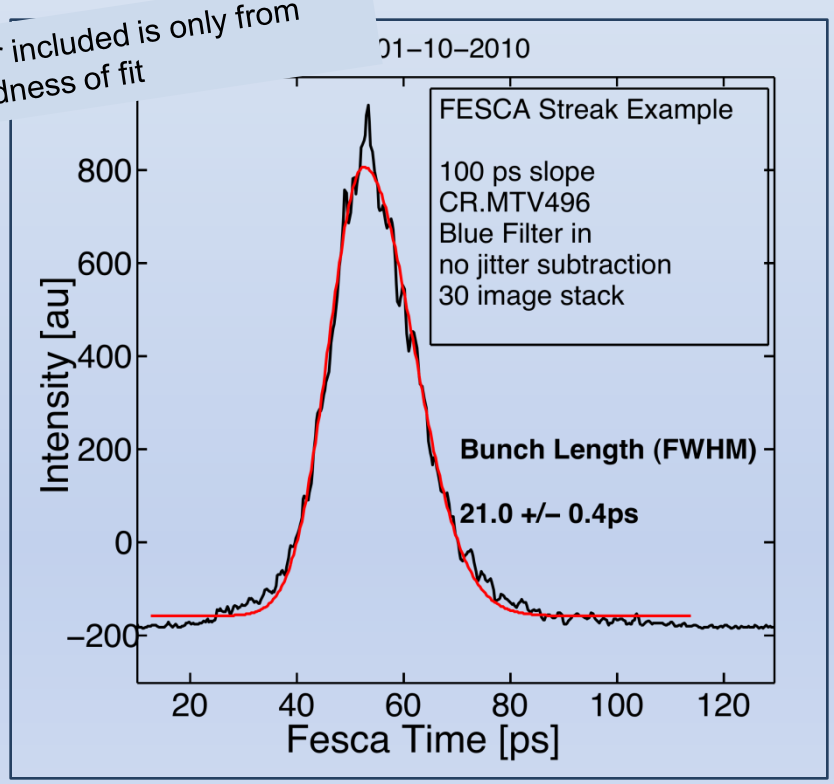


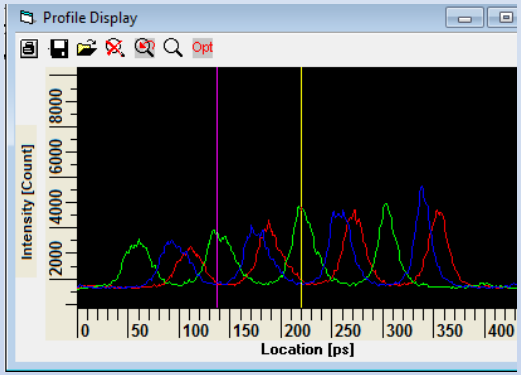
Propagate all error contributions …

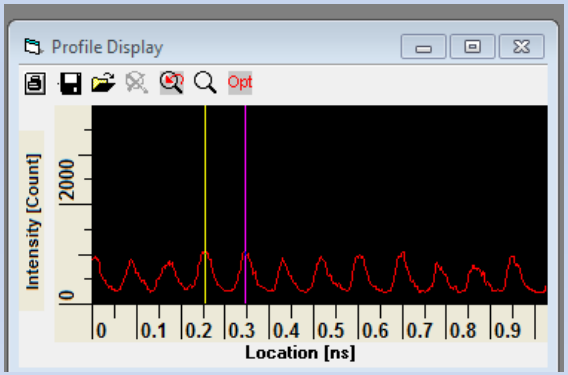
Typical **measurement error on FWHM is 4% (2 sigma)**

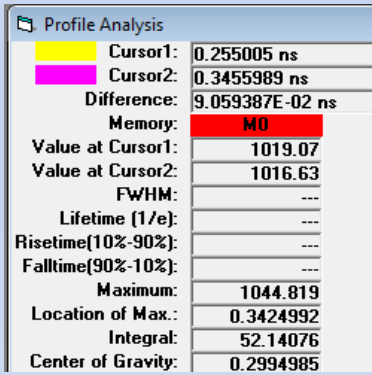
FESCA Streak Camera – Bunch Length / Spacing Measurements

Error included is only from goodness of fit







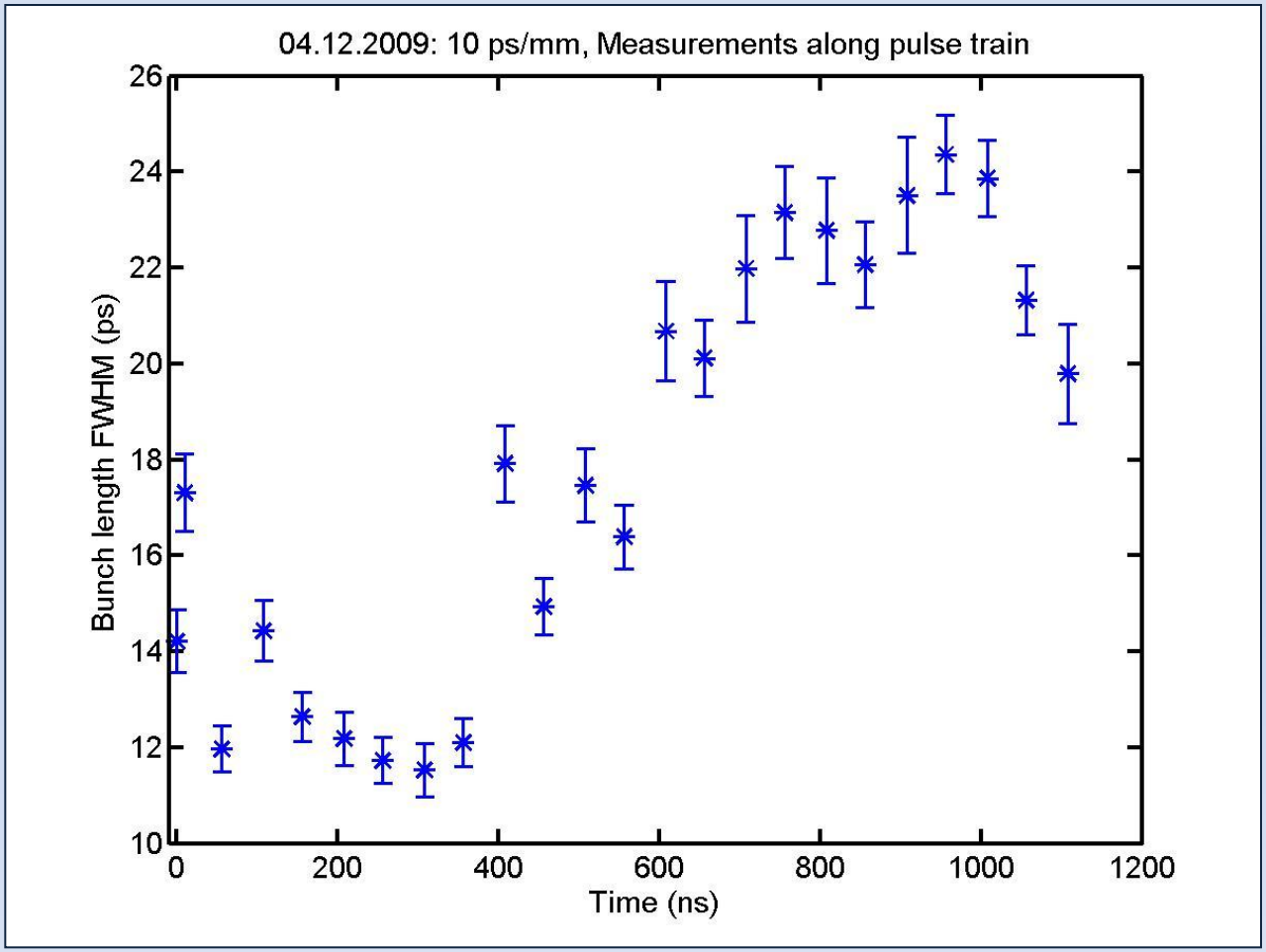


Studies ongoing to fully understand/optimize the resolution for the CTF3 environment

- Time calibration
  - 1% resolution on calibration for all sweep speeds from Hamamatsu,
  - Except 10% for 20 ps (highest time resolution)
- Jitter contribution
- Photocathode response

Bunch Length measurement along pulse train

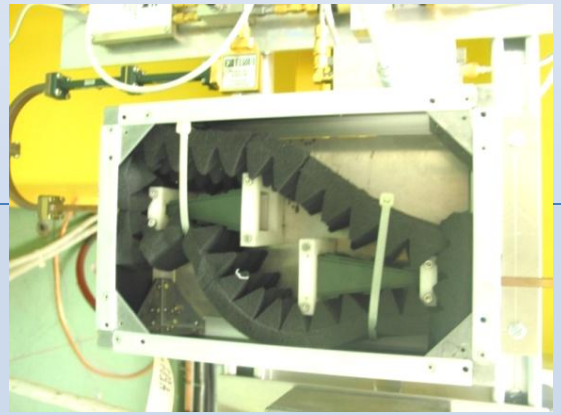
- Streak Camera in Combiner Ring using MTV 0496 (zero dispersion point)
- 3 GHz uncombined beam, by-passing the delay loop
- 50 ns sampling
- 2 sigma error bars

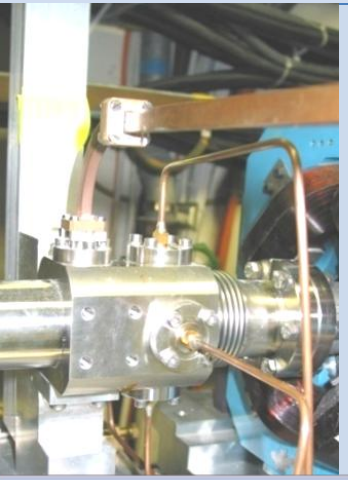


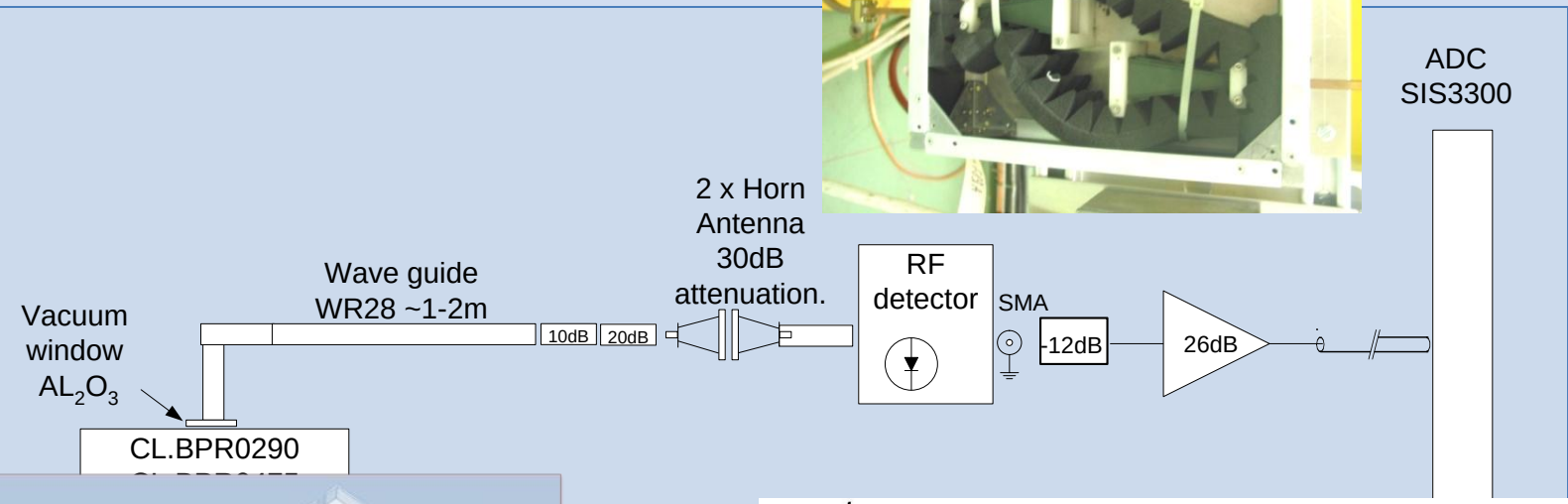
Use Streak Camera measurement and this bunch length variation to **cross calibrate other bunch length instruments**

RF Techniques – r.m.s. bunch length - BPRW

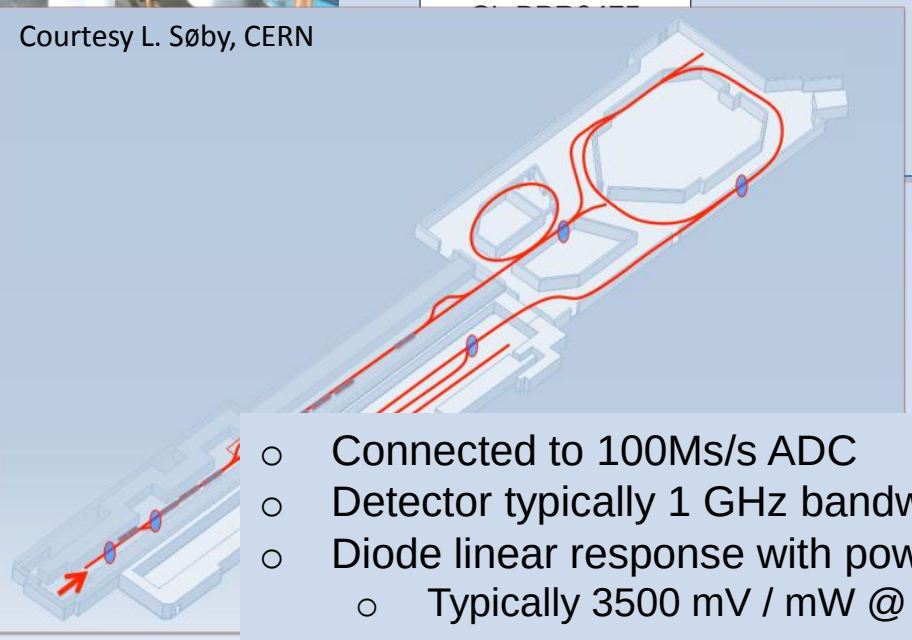
$$P \propto \frac{r^2}{r_o^2} q^2 e^{-\frac{\varpi^2 \sigma_t^2}{c^2}} \text{ (example Gaussian bunch shape)}$$

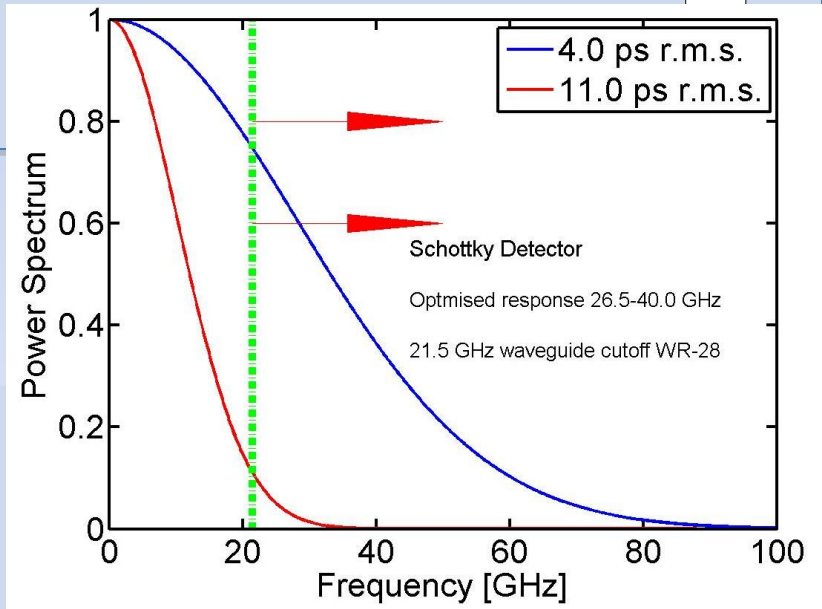






Courtesy L. Søby, CERN

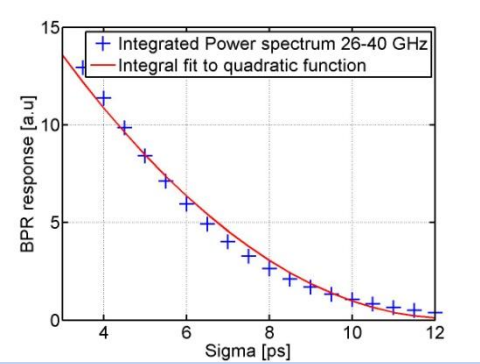


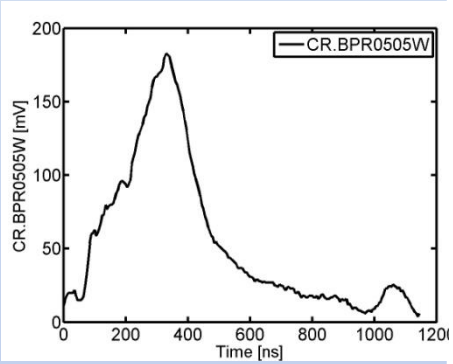


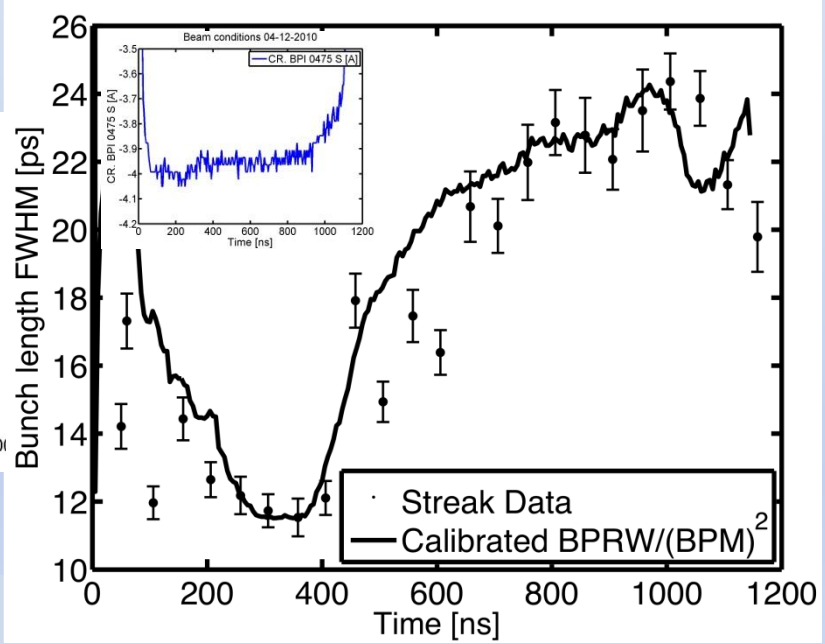
- Connected to 100Ms/s ADC
- Detector typically 1 GHz bandwidth
- Diode linear response with power
  - Typically 3500 mV / mW @ -20 dbm

BPRW Power measurement compared to streak Camera

- Data used: 04-12-2010
- Beam conditions: 3 GHz 4 Amp beam
- Use time resolved bunch length from Streak
- Assume quadratic function for fit







Application of Calibration:

- BPR and Streak in good agreement
- Exercise should be repeated with different beams to study systematics and verify current and position normalization
- Error in calibration large (40% error 2 sigma)
- Measurement of BPM, BPR and Streak relevant for a good calibration

Suitable Drive Beam Complex, and main beam injector complex, bunches 2 ps < BL < 8ps r.m.s.

✓ BPR's used as Online bunch length measurement available today!

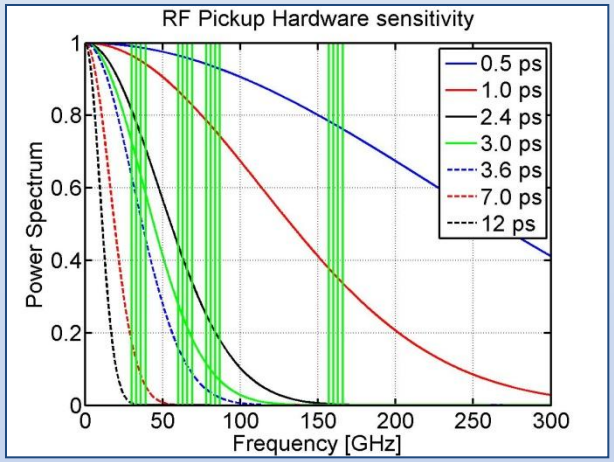
An improved calibration requires more beam based measurement

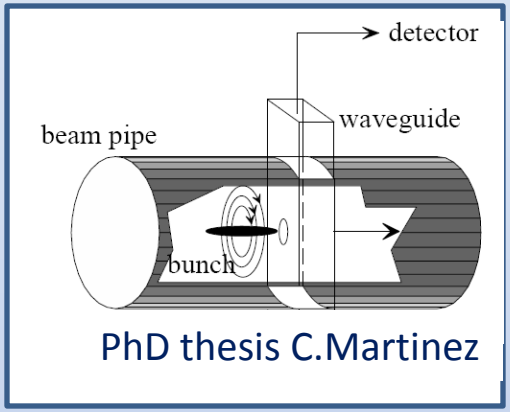
CTF3 Microwave Spectroscopy – “RF pickup”

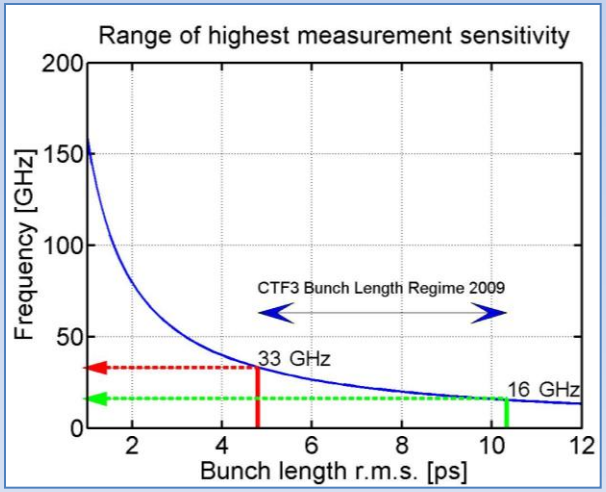
$$i_b(t) = \frac{q_b}{\sqrt{2\pi}\sigma_b} \exp\left(\frac{-t^2}{2\sigma_b^{\,2}}\right)$$

$$F_b(\omega) = \frac{q_b \sigma_b}{\sqrt{2\pi}} \exp\left(\frac{-\omega^2 \sigma_b^{\,2}}{2}\right)$$

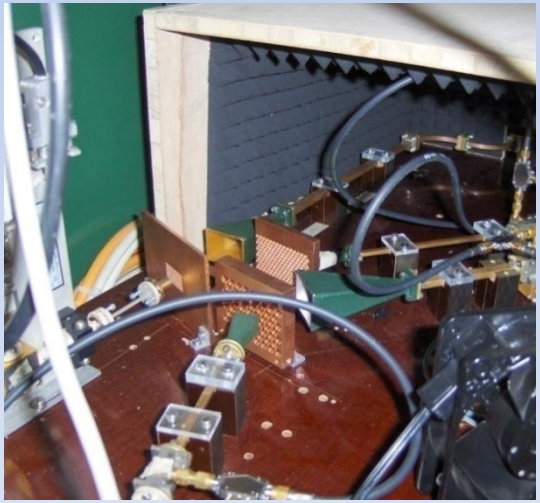
$$\frac{d^2 F_b(\omega)}{d\omega^2} = 0 \quad \Rightarrow \quad \omega_{opt} = \frac{1}{\sigma_b}$$





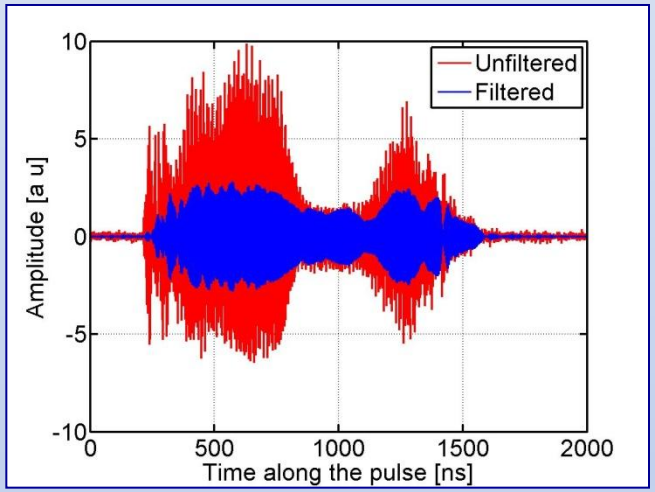


- Measure the power of frequency harmonics
- Self – calibrating if bunch length scan is performed
- Sensitive to bunch envelope **and** the relative position of bunches with the bunch train (down-mixing)



Similarly Compare RF pickup (waveguide down mixing) to Streak

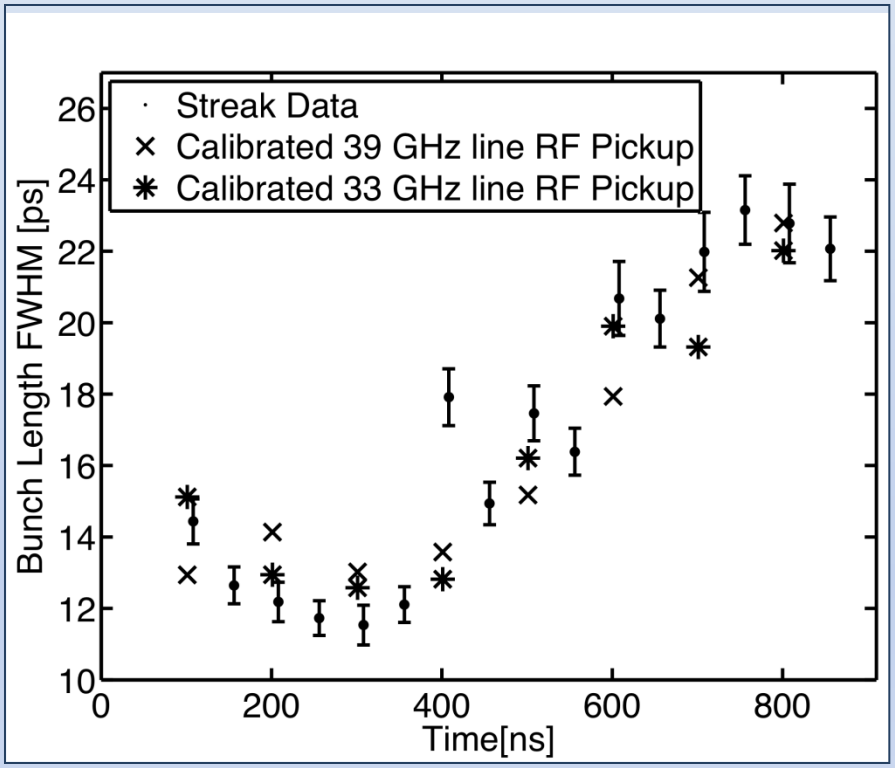
Power measurement in time domain



Corresponding Frequency domain

Apply Band pass filter to isolate beam signal

Correspond power (33 GHz) to bunch length Streak



✓ Good agreement between RF pickup and Streak in the Steady state part of the pulse

The first 50 ns and final 100 ns suffered because of strong phase variation along the pulse train

Suitable Drive Beam Complex, and main beam injector complex, bunches > 300 fs

Outline

- Overview of Instrumentation

  ➡ Transverse Profile; Longitudinal Profile; Bunch Frequency Measurements

- Where are we? (Installations, obtained performance, CTF3-CLIC extrapolation)

  ✓ Emittance

  ✓ Energy and energy spread

  ✓ Bunch length

  ✓ Bunch frequency measurements

  ✓ Form factor

- Where is near - future focus?

Opportunities and future focus? - CTF3

- Turn by turn beam size measurement with gated intensified camera
  - CERN, Collaboration started with Abant Izzet Baysal University, Turkey

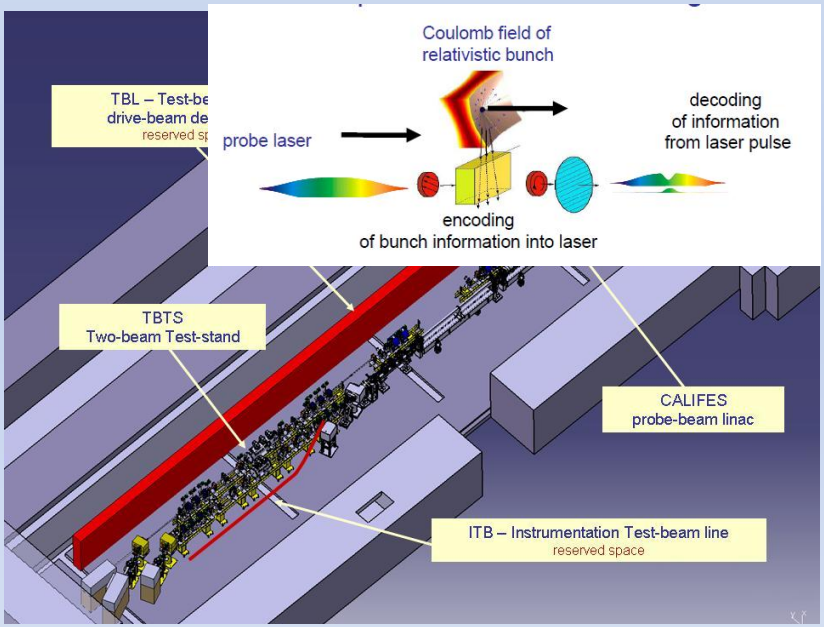
- RF bunch length, form factor and phase measurements in CLEX
  - CERN, Collaboration with Northwestern University
  - Clarify the requirements from OP

- New phase monitor concept to work at lower frequencies (less sensitive to bunch length variations), to monitor residual path length errors coming from the DL – see extra slides
  - CERN, S. Smith SLAC
  - Clarify the requirements from OP – would this be useful? Used in a feedback? Only longitudinal phase information, also transverse trajectory errors of neighboring bunches interesting? Is this already covered by other activities? E.g. work of G. Morpurgo

Instrumentation R&D for CLIC

- Exploit CLEX and potential ITBL for instrumentation development in beam loss, energy spread, beam position and bunch length
- Possible Electro-optics measurement in Califes Test Beam Line?
  - CERN, Collaboration with Steven Jamison (ASTEC, STFC Daresbury) and Allan Gillespie (Univ. Dundee)

	CALIFES specifications
Bunch charge	0.6 nC
Energy	170 MeV
Energy dispersion	± 2%
Emittance	<20 π mm.mrad
Bunch train	1 – 32 – 226
Bunch length	0.75 ps



- Investigate Energy Measurement concept for CLIC

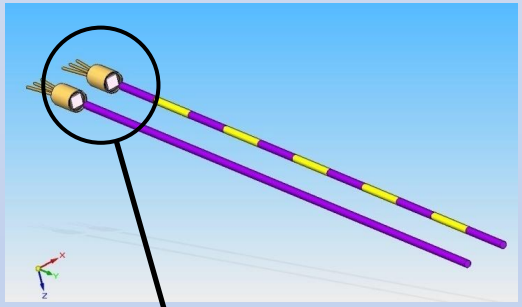
  Energy measurement at the end of TBL or Califes, using Cherenkov photons (perhaps in air) coupled to streak camera or fast photomultiplier, CERN & Uppsala University

Instrumentation R&D for CLIC

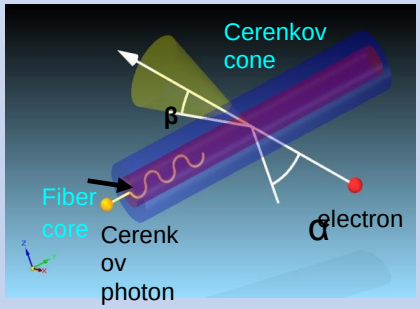
- Beam Loss monitor test, using silicon photomultipliers and optical fibers in CLEX
  - Collaboration **A. Intermite**, C Welsch (Cockcroft Inst.)

1 fiber coupled to a detector will be installed in CLEX in Dec 2010 for a test

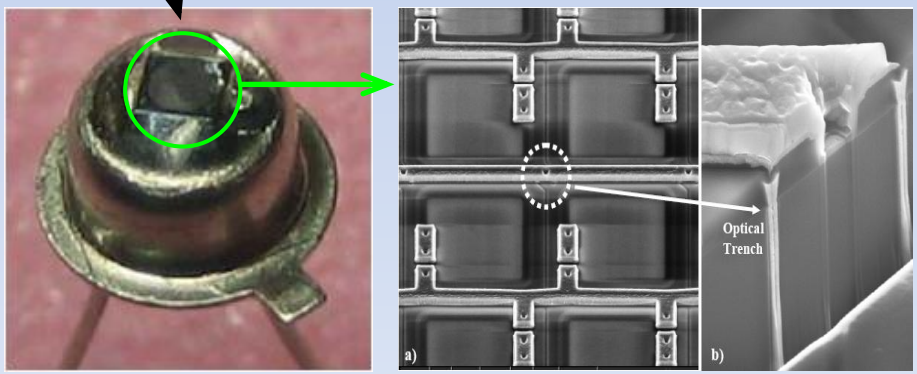
400 x 400 SPAD array
Active surface 1mm^2
Recovery time ca. 4 ns
1 photon detection
CMOS technology
Low cost detector
Quantum efficiency 20% in blue range
Immunity to external magnetic fields



BLM general layout



Physical principle



Silicon Photomultiplier

Conclusion

- **All MTVs** for transverse profile measurements have been commissioned
- Full diagnostics spectrometer line for PHIN has been designed, installed commissioned
- **Robust Bunch Length Measurement** with Streak Camera and calibration **of non-destructive RF bunch length measurements** using Streak Results
  - “BPRW” ; RF pickup
- **Measuring of the bunch spacing** with the Streak and Phase monitor well mature
  - Systematic corrections due to bunch length variation & long bunches add additional complications to phase monitor measurement
  - Proposal to use 1.5 GHz down mixing technique (See extra slides Steve Smith) – need input from beam dynamics and RF w.r.t. combination phase & form factor tolerance @ 12 GHz
- **Design** for time resolved spectrometry for **TBL mature** –manufacturing started
- **Design** of bunch length measurement for CLEX **has started**
  - Long Optical lines to New Streak Camera Lab
  - Non destructive RF based bunch length measurement techniques
- Starting to think about extrapolating to CLIC parameters
  - Non-interceptive Cherenkov-based energy detector ? End spectrometer TBTs
  - EOS bunch length detector possibly in ITBL; Beam loss detector study in CLEX
- Bunch spacing measurement for PHIN (**phase coding**)
  - BI will give support where possible (manpower/BI priorities)

Conclusion & Outlook

Improved calibrations of RF based Bunch Length & phase monitor measurements require in house calibration time and studies, in collaboration with CTF3 control room crew.

Perhaps revisit the specification needs for CTF3 BI from beam physics point of view

- Emittance – non Gaussian beams, errors in Twiss parameters?
- Energy spread?
- Bunch Length?
- Phase errors of combined beam?
- Trajectory errors of combined beams?

Man-powered limited from CERN BI point of view

- Should identify and focus time on needs that can have the biggest impact for the project.

EXTRA SLIDES

Form factor requirements CLIC

$$P = I^2 L^2 F_b^{\,2} \omega_0 \frac{R/Q}{V_g 4}$$

- CLIC Main beam requires a gradient shot to shot stability of 0.7×10^{-3}.
- Hence, the form factor (contributions from bunch length and phase), should be monitored to level 0.7×10^{-3}.
- Knowledge of variations in bunch length only level 1% for CLIC

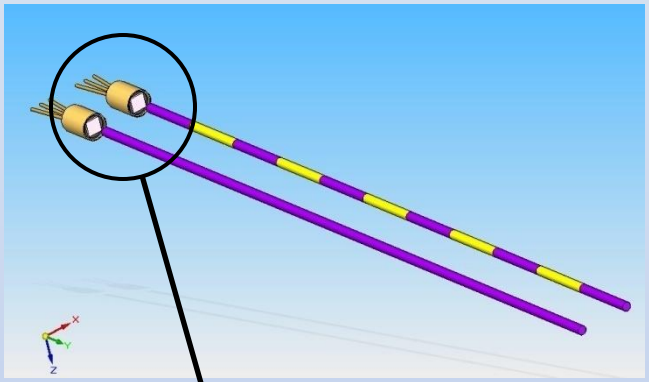
@ CTF3 ….

- Typical bunch length measurement with “LEP” streak camera typically FWHM is 4% (2sigma)
- Expect less with the FESCA streak camera once system is fully understood
- RF techniques require careful studies in terms of calibration and bunch shape dependency … calibration method relies on good streak camera measurement, current measurement. Good streak calibration relies on a stable, adjustable fast timing system. More beam measurements needed to understand limitations of RF devices.

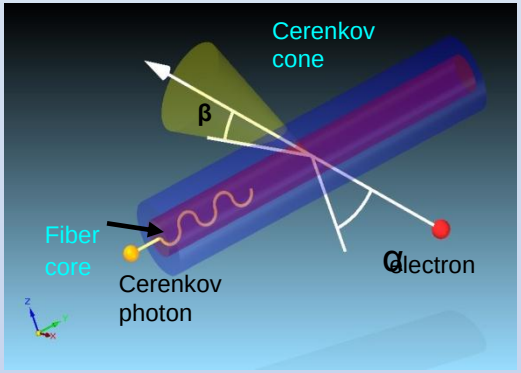
- Beam Loss

Beam Loss Monitor for TBL: a general layout

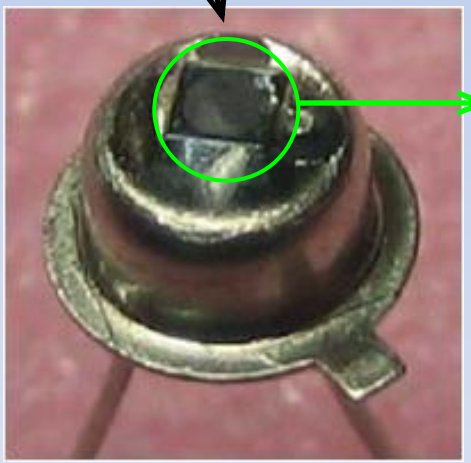
- 400 x 400 SPAD array
- Active surface 1mm^2
- Recovery time ca. 4 ns
- 1 photon detection
- CMOS technology
- Low cost detector
- Quantum efficiency 20% in blue range
- Immunity to external magnetic fields

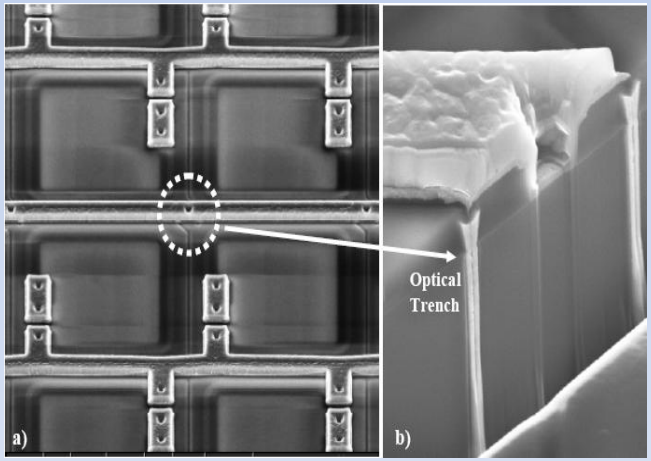


BLM general layout



Physical principle





Silicon Photomultiplier

Beam Loss Monitor for TBL: SiPM Dark Noise Characterization

<u>Goal</u>: Identification of best sensor for detection of Cerenkov Light generated by particle losses.

Investigation into:

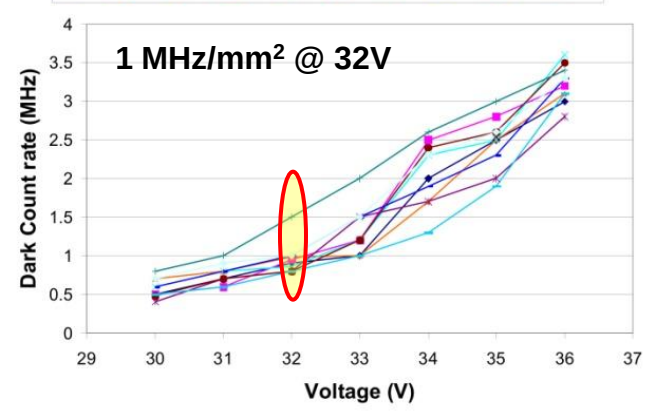
- Dark noise
- Optical cross talk
- Dynamic range of noise

As a function of:

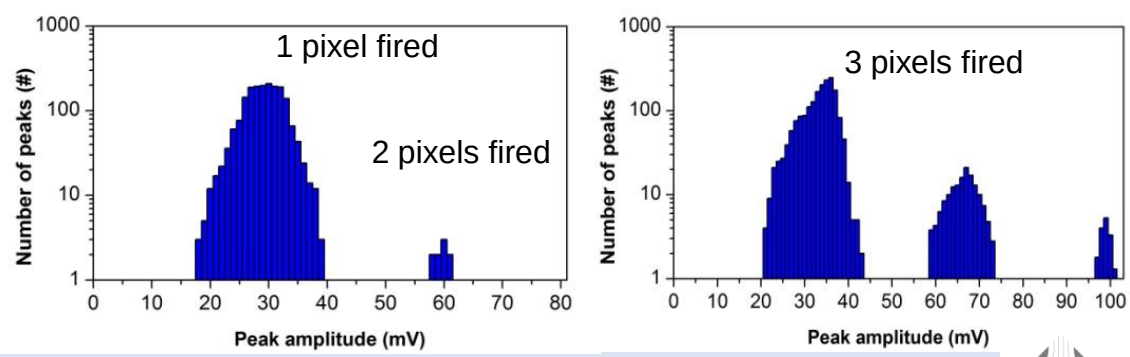
- Overvoltage
- Temperature
- Number of pixels
- Pixel arrangement
- Optical trench between pixels

Installation at CTF3 in 2010.

Dark count rate as a function of the overvoltage



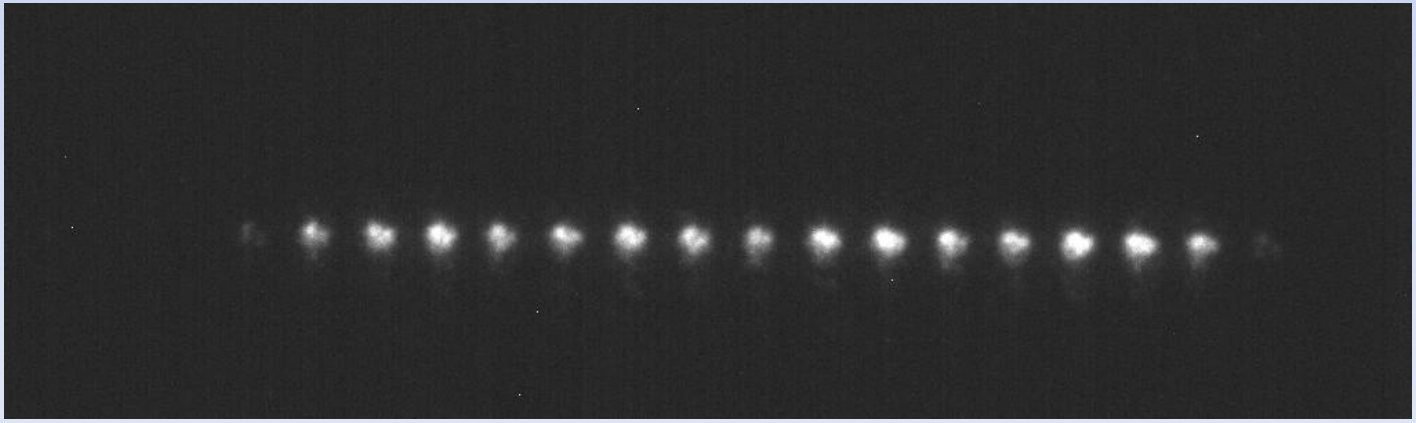
Dark count rate for different samples



- Support Phase coding for PHIN laser

Measurement of the Phase Coding in PHIN

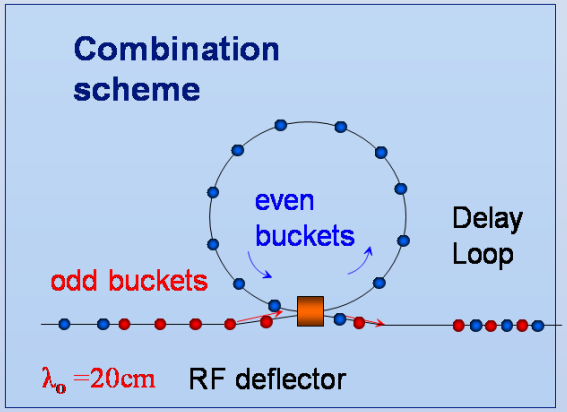
- Phase coding for the PHIN laser will be implemented & tested late 2010/2011
- Phase coding of the Laser verified with the Streak Camera
  - BI/PM support will provide support (depending on other priorities)
  - Design optical line with only a small fraction of laser photons
- Measurement phase switch on the electron beam to be designed
  - Proposal
    - Generate Cherenkov photons with a sapphire Chrystal
    - Hardware exists from CTF2 –compatibility with PHIN beam parameters (beam size, bunch charge) to be checked
    - Build an optical line to transport photons from PHIN to the laser room
    - Image these photons with the Streak Camera



- Phase diagnostics

Proposal for phase monitor for the DL based on 1.5 GHz signal (S. Smith)

- To remove the bunch length dependency from phase measurement → propose a phase measurement based on a lower frequency
- For DL Loop 1.5 GHz rate in → 3.0 GHz rate out
- Ideal output is periodic at 3.0 GHz
- Path length error yields signal periodic at 1.5 GHz
  - gives rise to 1.5 GHz component in signal
  - So does slow intensity modulation in input beam



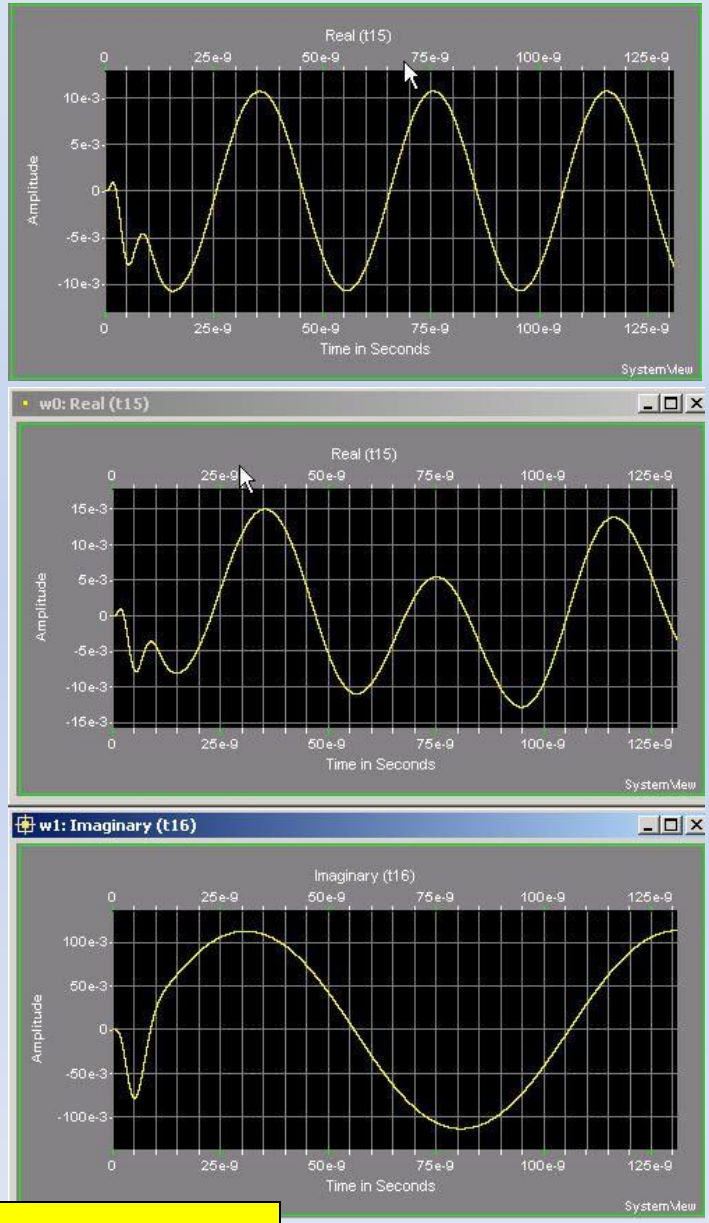
- For the DL, S. Smith proposes to use a reference 1.5 GHz signal, and to downmix it with the beam signal → hence measuring directly any residual 1.5 GHz beam component that indicate a poor combination after the Delay Loop
- Simulations show sensitivity to < 1ps shown in his simulations
- Much of the BPR-S pickup and electronics can be reused, only We need an (unlocked) RF source for the 1.425 MHz LO signal needed and 1.5 GHz mixer
  - Block Schema – see extra slides

- For measuring the bunch combination efficiency in the combiner ring, no simple schema available
  - Needs more work to find a bunch length independent schemea

Steve Smith

Simulation of 1.5 GHz down-mixing phase monitor

- Simulate ±1ps delay loop timing error.
  - Modulated at 25 MHz to make it stand out in the simulation,
- Add ±10% charge variation in alternating (3 GHz) buckets.
  - modulated at 10 MHz (for visibility)
  - expect errors quasi-static in real machine
- The simulated LO is phased to make the timing error show up as (almost) purely real.
- find a scale of 10 mV/ps timing error.
- demodulate the 1.5 GHz to:
  - real component (timing error)
  - imaginary component (amplitude mis-match)
- The amplitude of the 1.5 GHz signal is completely dominated by the amplitude mis-match signal
  - one can still cleanly extract the timing error signal.
  - The timing error signal contaminated ~0.5ps level by the charge variation



Steve Smith

Systematic: 1.5 GHz phase monitor

- Resolution is not limited by the signal strength
  - but by systematic like charge variation present on drive beam.
- Expect that to get the timing correct to 1 degree of 3 GHz (1ps) one needs the current the same to 1% over the delay of the delay loop
- However at 1.5 GHz this signal is in quadrature to the timing error signal
  - can in principle be separated.
- The charge difference signal is in phase with the 1.5 GHz bunches, where the time error signal is 90 degrees out of phase,
  - that is it comes from the alternating short and long gaps between bunches and is phased with the center of the short gap.
- Guess: reduces sensitivity to charge variation by x100
- ➔Could probably tolerate 10% charge variation over the train and still measure delay loop timing errors of <1 ps.

Steve Smith

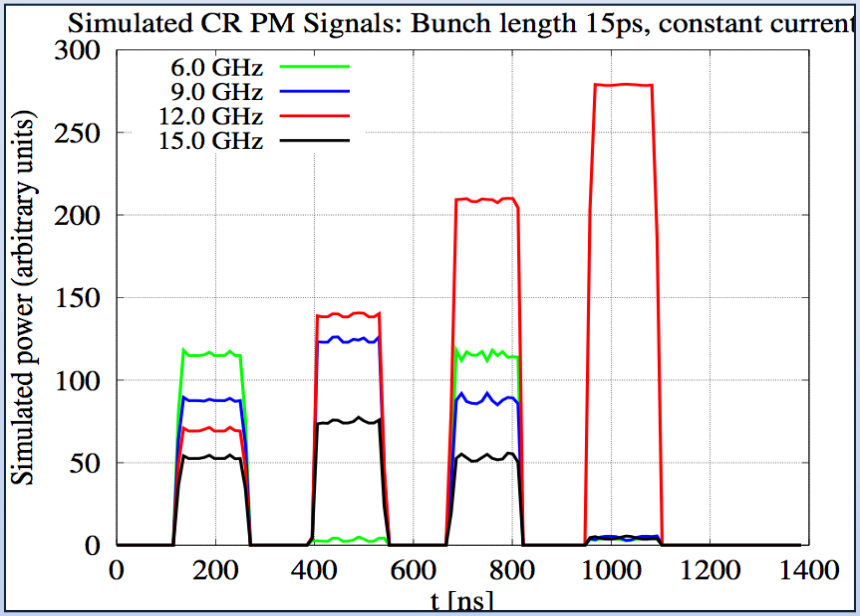
Path-Lenth Diagnostics Conclusion

- Looks straightforward to measure timing to <1ps. Most of the hardware already exists.
- We need a mixer, a couple of filters and possibly an amplifier or two and probably a couple of pads.
- We need an (unlocked) RF source for the 1.425 MHz LO.
- And software!

Measuring the bunch spacing with Phase Monitor (CR)

Simulation

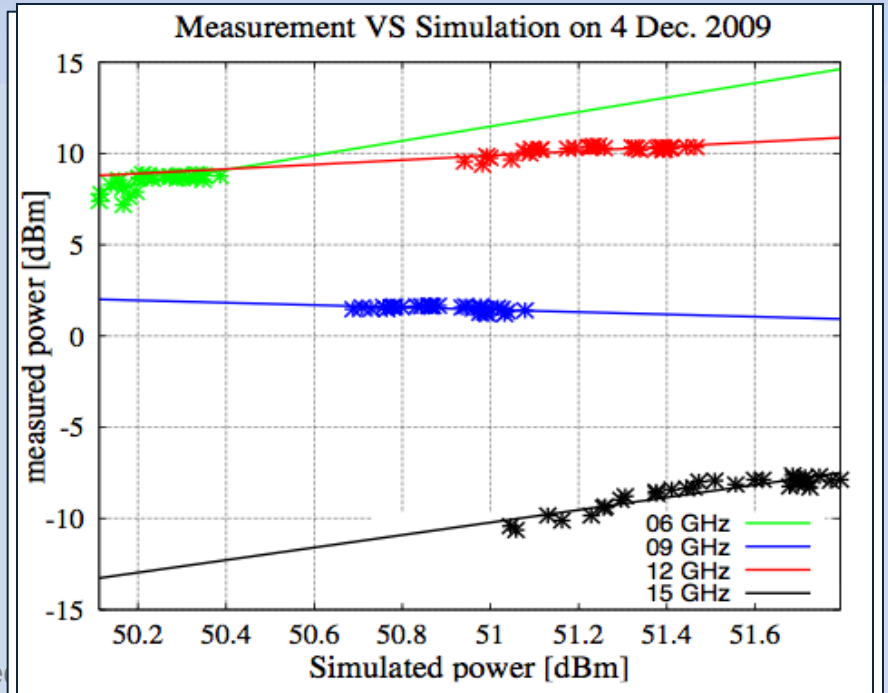
- beam with uniform current
- 15 ps FWHM Gaussian Bunch length uniform along the pulse
- Turn 1, shows effect of bunch length



Data compared to simulation

- 3 GHz uncombined beam for hardware test (04-12-2010)
- Raw signal corrected for electronic gains
- Simulation includes the bunch length dependence along the pulse measured with the BPRW

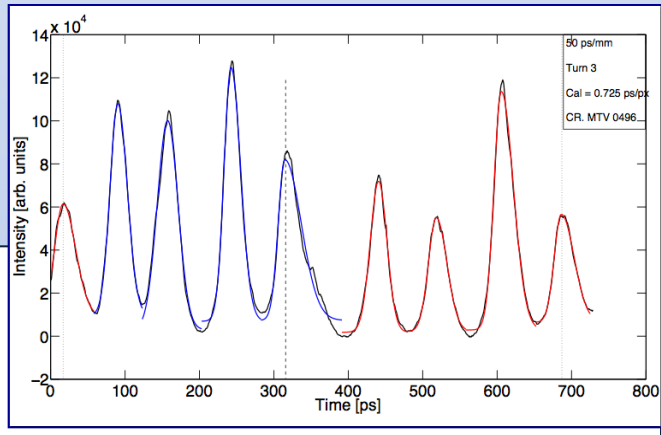
➢ **Data compared to simulation, shows strong correlation**

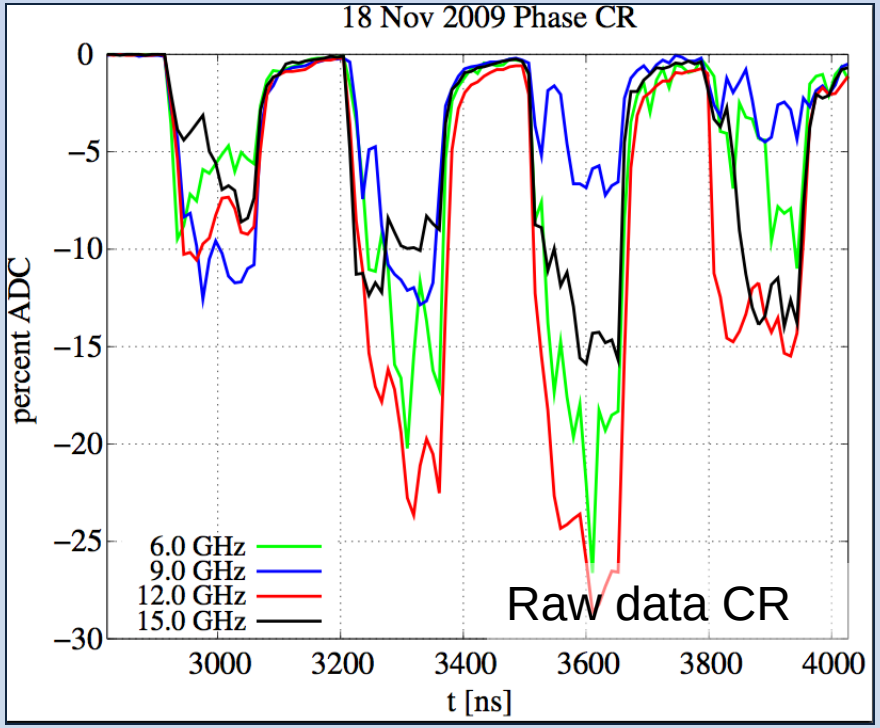


Monitor bunch spacing with the Phase Monitor

- Example of measurement 18 Nov 2009, Factor x8 combination current
- DL ~ 20 ps late
- Bunch length variation along the pulse train

Measurement difficult to interpret because of bunch length and bunch spacing variations





The way forward?

Instrumentation:

- Use BPRW in CT line to measure bunch length along pulse train & normalize
- Produce feedback for the operators
- Re-design phase monitor to work at lower frequencies – less sensitive to bunch length variations ?? (see extra slides for potential upgrade)

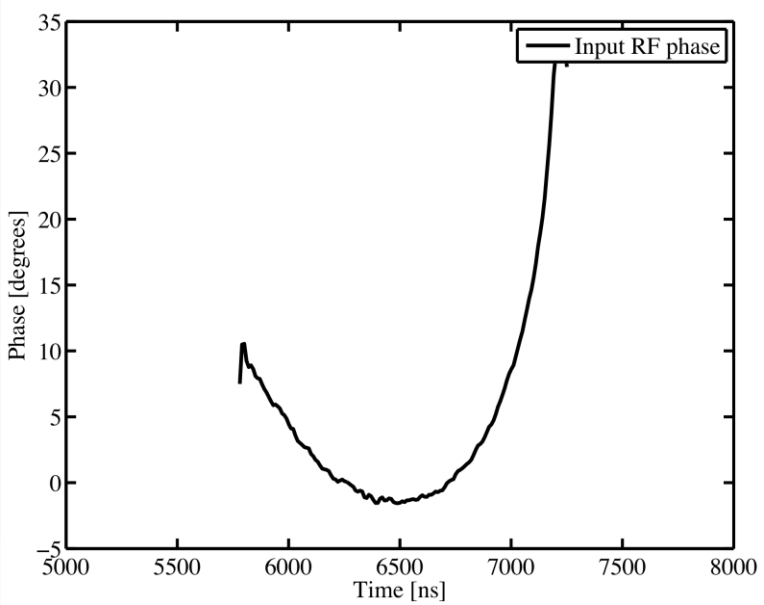
- Bunch Length extra slides

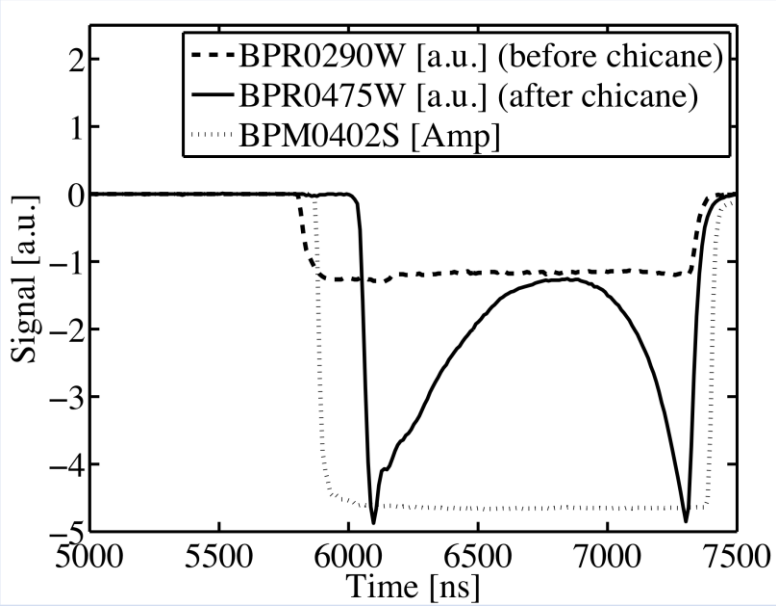
Energy gain and Bunch Lengthening

Due to the pulse compression system, phase sag along the Klystron pulse ~ 5-15° (see talk CTF3 Collaboration meeting of A. Dubrovskiy)

- not all bunches see same RF phase
  - Difference energy gain of one bunch with respect to another
  - Within a single bunch, the head and tail of bunches to have different energy

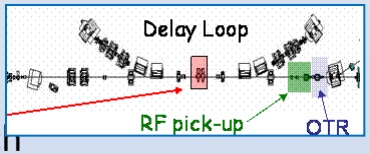
Example of RF phase for MKS03





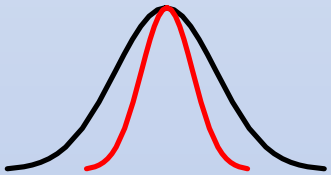
- Bunch length variation along the pulse train is a feature in CTF3 (to a greater / lesser extent depending on RF)
- Time resolved bunch length diagnostics essential

Extension of same principle to RF-pickup



Measurement principle:

1. Measure the amplitude of the beam harmonic (30-172 GHz) of interest
2. The correlation between amplitude and bunch length depends on the bunch shape
3. Normalize the power to changes in the charge and the position squared in the cavity



$$P \propto \frac{r^2}{r_o^2} q^2 e^{-\frac{\varpi^2 \sigma_t^2}{c^2}} \text{ (example Gaussian bunch shape)}$$

Example for Talk:

1. 33 GHz beam harmonic (since bunches rather long during calibration)
2. ADC is 2 GS/s, typically use 4000 points, 2 micro second time window, delta t = 0.5 ns (X10 faster than BPRW sampling)
3. LO can be chosen to have an IF that gives the best sampling of the bunch length variation

Beam acceleration	Beam harmonic #	Beam harmonic	Fixed first Mixing	Variable Mixing	IF	IF (measured)
2.99855 GHz	11	32.984 GHz	26.5 GHz	7.2 GHz	716 MHz	735 MHz

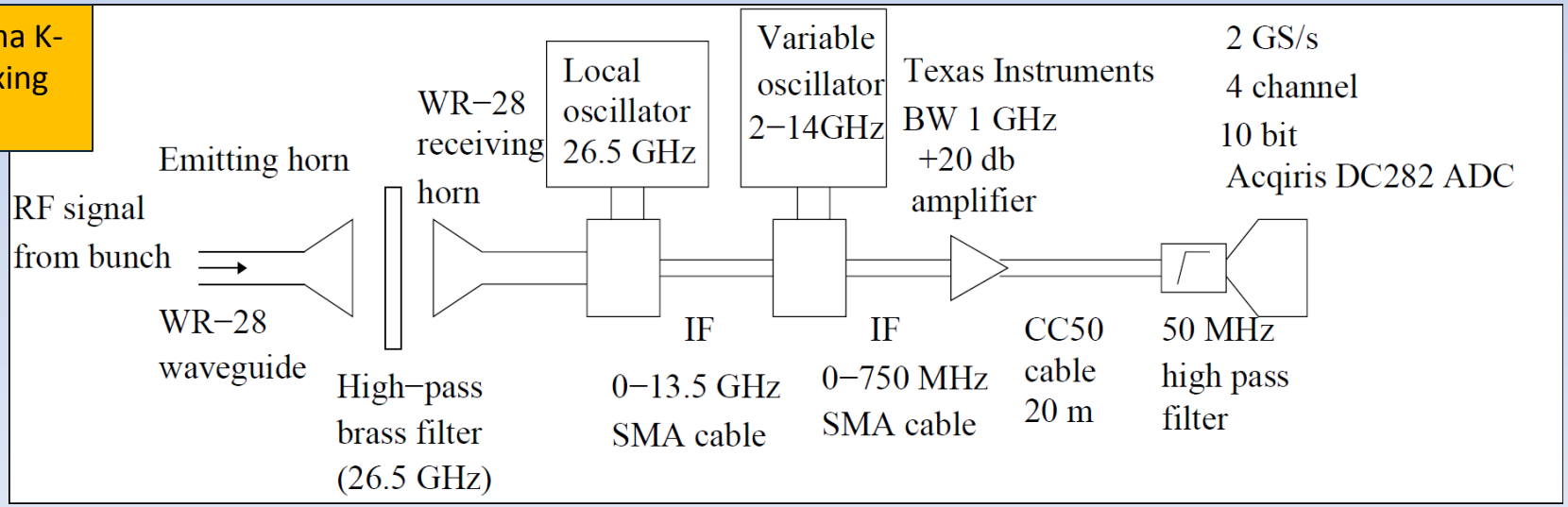
Example of one down mixing stage - RF-pickup

Example:

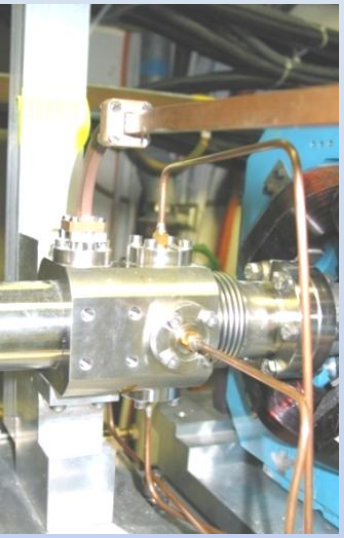
1. 33 GHz beam harmonic (11th of 3 GHz)
2. ADC is 2 GS/s, typically use 4000 points, 2 micro second time window, delta t = 0.5 ns
3. Depending on the period of the bunch length variations along the pulse & parasitic noise optimize the choice of the second LO mixing stage
4. choose to down mix to a high frequency LO signal, choose 716 MHz

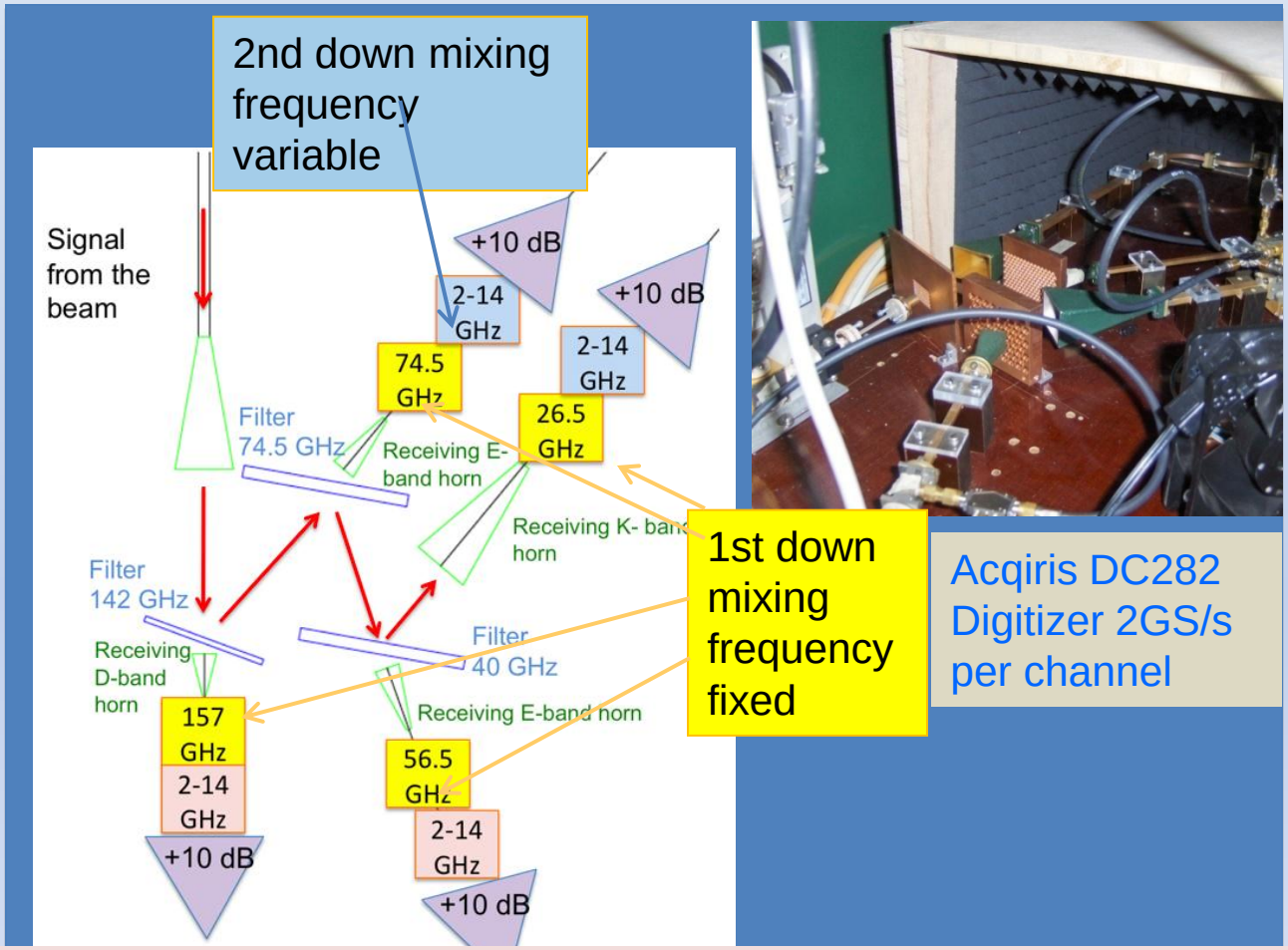
Beam acceleration	Beam harmonic #	Beam harmonic	Fixed first Mixing	Variable Mixing	IF	IF (measured)
2.99855 GHz	11	32.984 GHz	26.5 GHz	7.2 GHz	716 MHz	735 MHz

Example Schema K-band down mixing scheme



CTF3 Bunch Length Measurement – “RF pickup”





Transmission transparent for high Freq < 170 GHz, very thin 0.150 +- 0.005 mm thick diamond window (ε_r~6 at 30 GHz) designed and successfully brazed by S Mathot @ CERN EN/MME on a Test Titanium sample

Thinnest window ever brazed at CERN

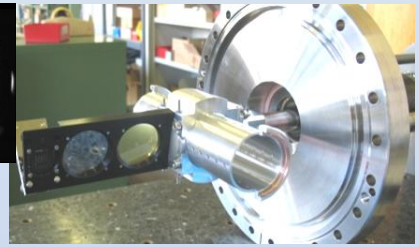
➔Window has been installed since 2009, and holds good vacuum

Thanks to the FULL PHIN Team!
Especially thanks to Steffen Doebert for
– allowing us a little fun with our instrumentation @ end of run

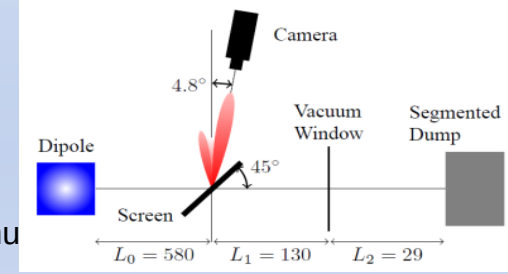
- Profile Monitor extra slides

Transverse profile hardware activity in 2009 / 2010

✓ New Installations



- 6 Transverse Profile Monitors CTF3
  - TL2 emittance tank
  - TL2' emittance tank
  - TBL emittance tank
  - TBTs drive beam (Uppsala / Saclay mechanics & planning – CERN acquisition & control)
  - TBTs probe beam (Uppsala / Saclay mechanics & planning – CERN acquisition & control)
  - TBL final spectrometer line (energy and energy spread)



- 2 Transverse Profile Monitor PHIN
  - Emittance / beam size:
    - Gated (100 ns) Intensified Triggered Camera
    - OTR based measurement, 4.8 degrees to the spectral reflection, for maximu
    - ~ 0.1 micron / pixel optical resolution
  - Energy / energy spread
    - Gated (5 ns) Intensified Triggered Camera
    - OTR based measurement, 4.8 degrees to the spectral reflection, for maximum light acceptance
    - ~0.3 micron / pixel optical resolution
    - 20 Channel Segmented Dump for Time Resolved Profile Measurements designed, built and commissioned

✓ Maintenance and Improvements

- Replacement of 2 damaged screens
- Replacement of CCD box (radiation damage)
- Replacement of pixelized cameras