CLIC Beam Instrumentation Challenges

- Introduction
- Beam instrumentation Challenges

Update from CLIC Beam Instrumentation workshop in June 2009

- Perspective & Conclusion

Challenges for CLIC Instrumentation

- Manipulating high charge beams (Machine Protection issues, Radiation level, Non intercepting beam diagnostic, ..)
- Very strict tolerances on the beam phase stability (0.1º@12GHz)
- Reliability and availability : This is ‘just’ the RF Source !

- Producing and measuring **small beam emittance (1micron)**
- Producing and measuring **short Bunches (45microns)**
- Preserving small beam emittance (very strict tolerances/requirements on the **beam position monitor precision and resolution**)
- Dumping the beam correctly

CLIC CDR

1- Collect the beam instrumentation requirements for each CLIC sub-systems and identify Critical Items and the need for new R&D

2- Evaluate the performance of already-existing technologies

- **CLIC specific instruments**
  - Luminosity monitors

- **CTF3 beam diagnostics – importable to CLIC**

- **ILC instruments with similar requirements as for CLIC**
  - Laser Wire Scanner or Cavity BPM
  - Beam Delivery System instrumentation
    Ex: Polarization monitor, Beam Energy measurements
  - Damping ring instrumentation developed at ATF2

- **3rd and 4th generation light sources**
  - Damping ring instrumentation
  - Bunch Compressor instrumentation very similar to XFEL projects
  - Short bunch length and Timing synchronization

CLIC

CLIC vs ILC – Light sources

	CLIC@ 3TeV	CLIC [illegible]	ILC
Bunch Length in the Linac (fs)	[illegible]	[illegible]	900
Typical Beam Size in the Linac (u[illegible]	[illegible]	**1**	**5**
Beam Emittance H/V [illegible]	**660/20**	**2400/25**	**10^4/40**
Beam size at I[illegible] (nm)	40/1	202/2.3	640/5.7

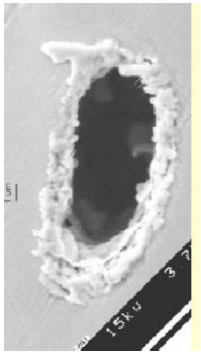
Requirements for CLIC are always tighter

	CLIC linac	XFEL	LCLS
Beam Energy (GeV)	3000	20	15
Linac RF Frequency (GHz)	12	1.3	2.856
Bunch charge (nC)	0.6	1	1
Bunch Length (fs)	150	80	73

	CLIC DR	SLS	Diamond	Soleil
Beam Energy (GeV)	2.86	2.4	3	2.75
Ring Circonfrence (m)	493	288	561.6	354
Bunch charge (nC)	0.6	1	1	0.5
Energy Spread (%)	0.134	0.09	0.1	0.1
Damping times (x,y,E) (ms)	2,2,1	9,9,4.5	-	6.5,6.5,3.3
Orbit stability (um)	1	1	1	1

CLIC vs CTF3

	CTF3	CLIC
Beam Energy (GeV)	0.15	2.4
RF Frequency (GHz)	3	1
Multiplication Factor	8	24
Initial Beam Current (A)	3.75	4.2
Final Beam Current (A)	30	100
Initial Pulse length (us)	**1.2**	**140**
Final Pulse Length (ns)	140	240
Total Beam Energy (kJ)	**0.7**	**1400**
Repetition Rate (Hz)	5	50
Average Beam Power (MW)	**0.0034**	**70**
Charge density (nC/cm^2)	**$0.4\ 10^6$**	**$2.3\ 10^{10}$**



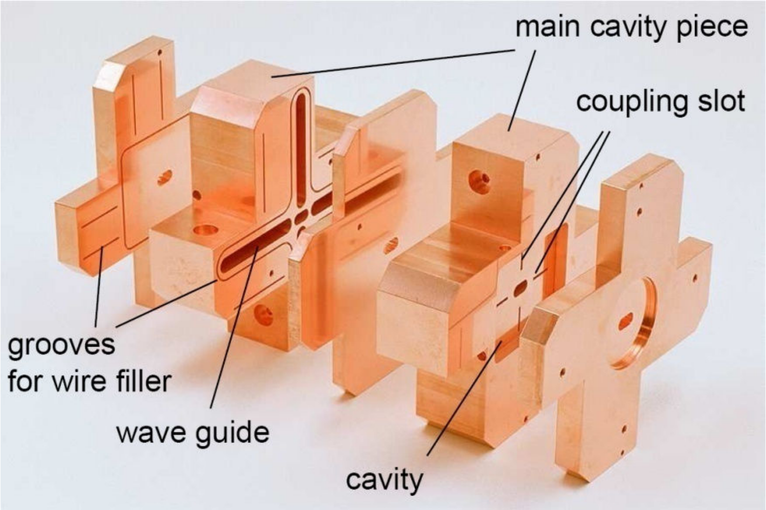
The thermal limit for ‘best’ material (C, Be, SiC) is 10^6 nC/cm^2

- Still considerable extrapolation to CLIC parameters
- Especially total beam power (loss management, machine protection)
- Development of non-destructive instruments
- Stability and reliability : CTF3 not designed to address these issues

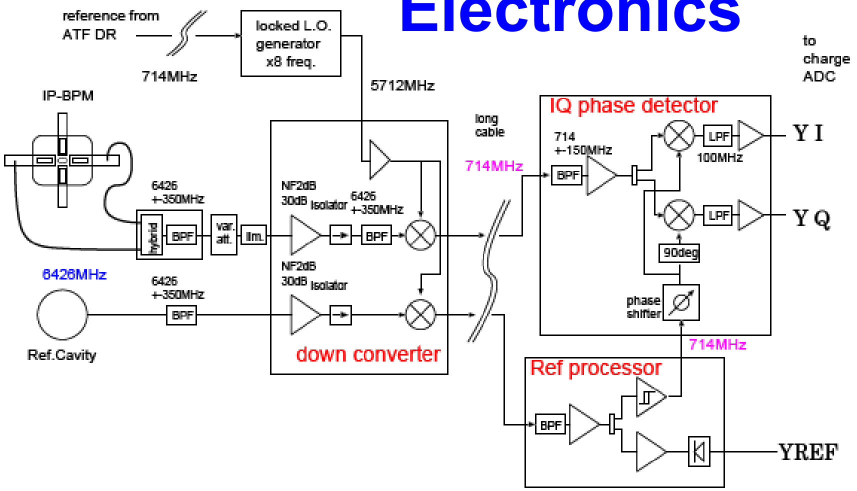
Beam Position Measurements with a 50nm resolution and adequate time resolution

Example: KEK C-Band IP-BPM

Model



Electronics



Characteristics

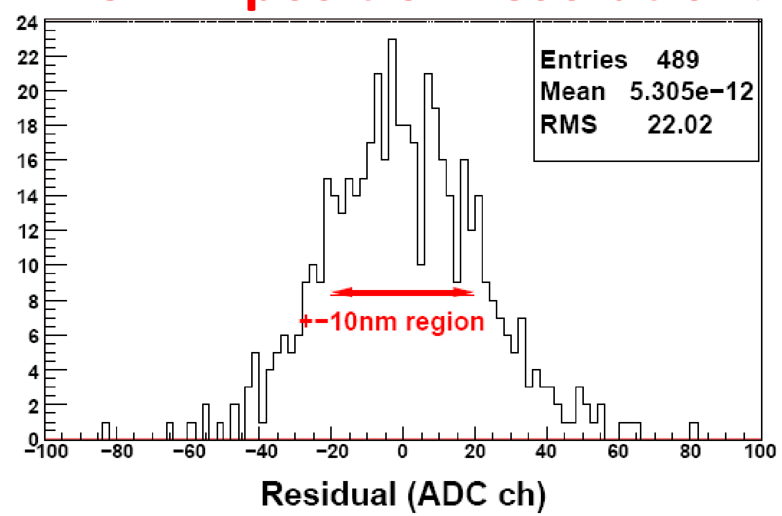
- Narrow gap to be insensitive to the beam angle.
- Small aperture (beam tube) to keep the sensitivity.
- Separation of x and y signal. (Rectangular cavity)
- Double stage homodyne down converter.

Design parameters

Port	f (GHz)	β	Q_0	Q_{ext}
X	5.712	1.4	5300	3901
Y	6.426	2	4900	2442

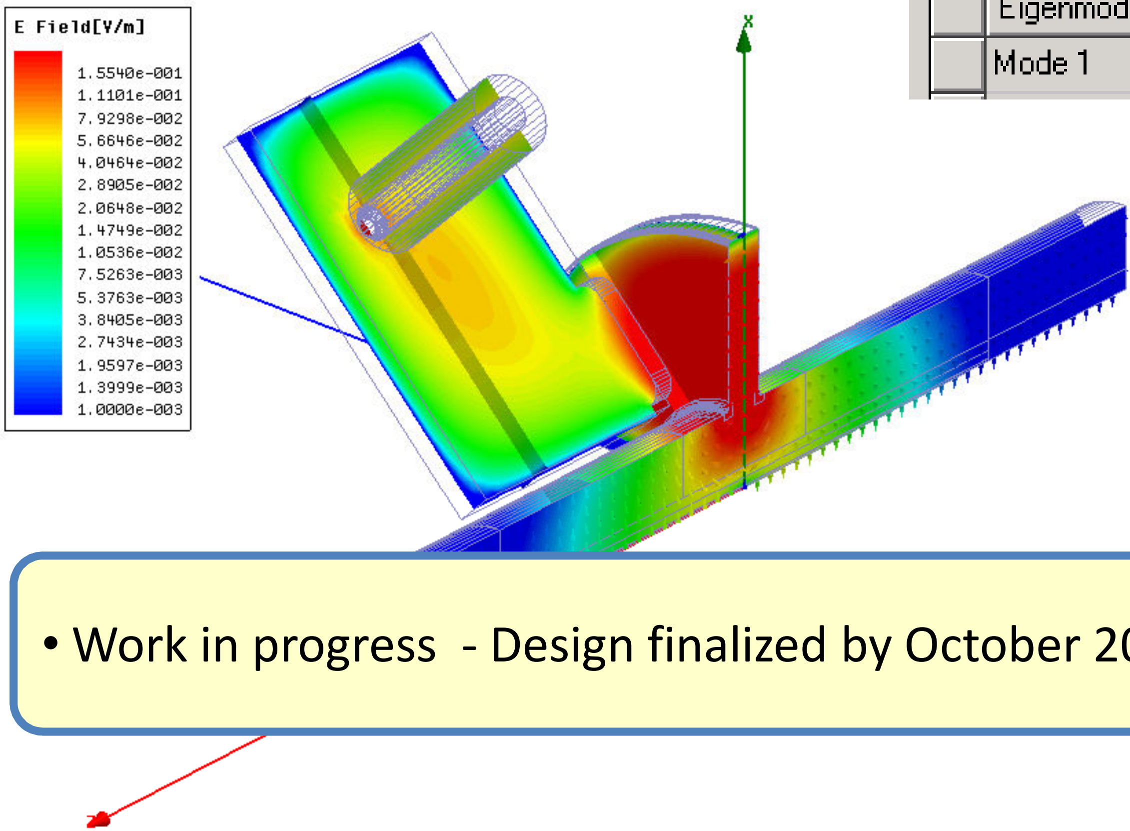
Results

15 nm position resolution!



Cavity BPM @ FERMILAB

Mode TM_{11}



	Eigenmode	Frequency (GHz)	Q
	Mode 1	13.9855 +j 0.0314875	222.081

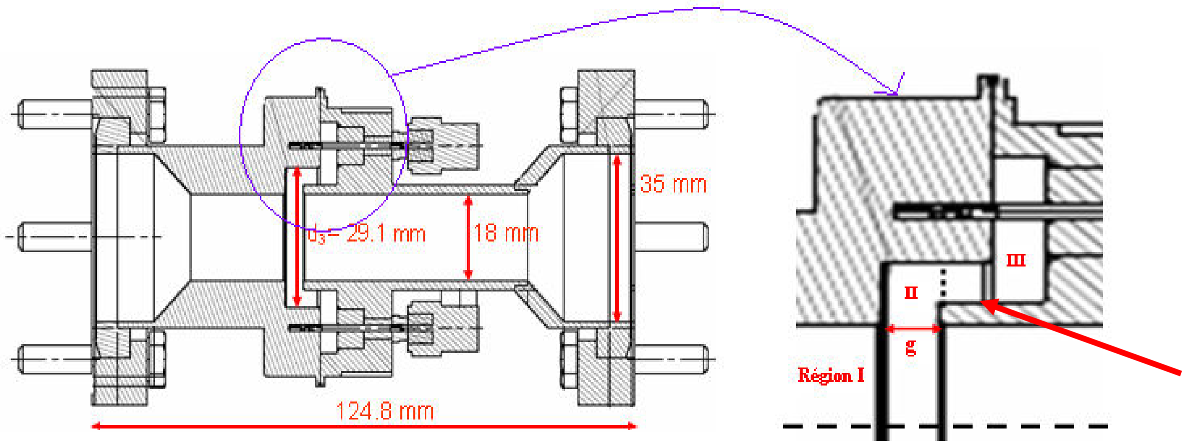
- Work in progress - Design finalized by October 2009 – Prototype 2010 ?

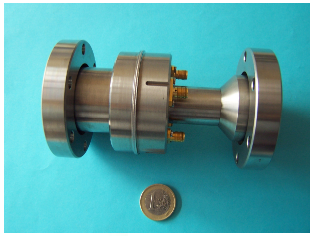
Design of Low-Q low cost cavity BPM (stainless steel)

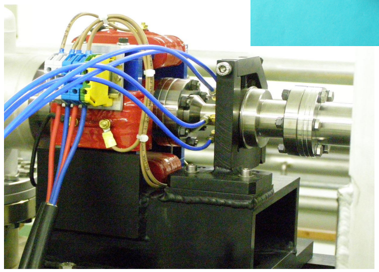
A. Lunin and M. Wendt

Reentrant Cavity BPM at CTF3/CALIFES

6 BPMs are installed on the CTF3 probe beam







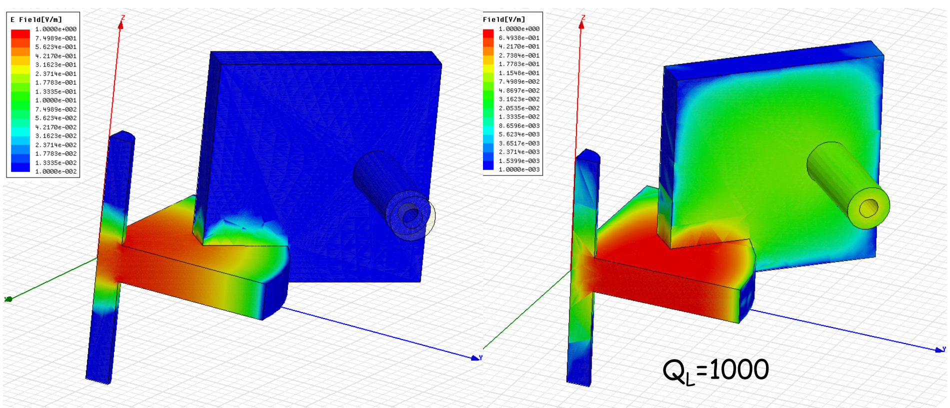
- Design for CLIC parameter and frequency

Eigen modes	F (MHz)			
	Measured			d
Monopole mode	3988	29.76	22.3	22.3
Dipole mode	5983	50.21	1.1	7

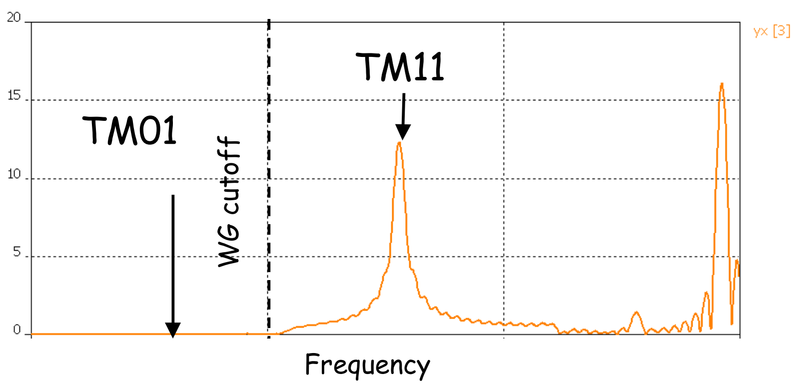
nch and multi-
nodes

- Single bunch resolution potential < 1 µm

‘yet another high resolution BPM’

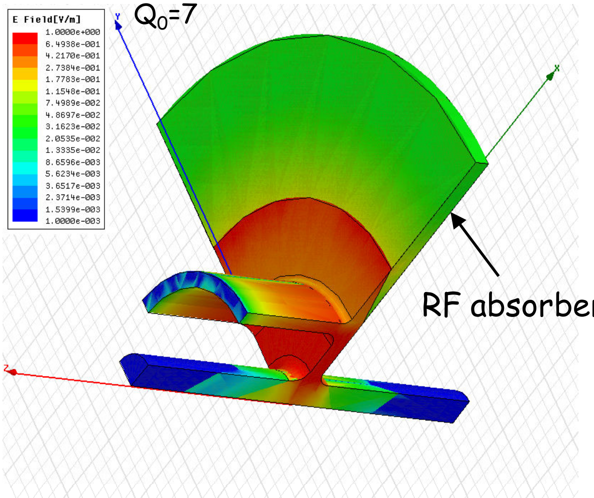


Spectrum of the port signal (single bunch)

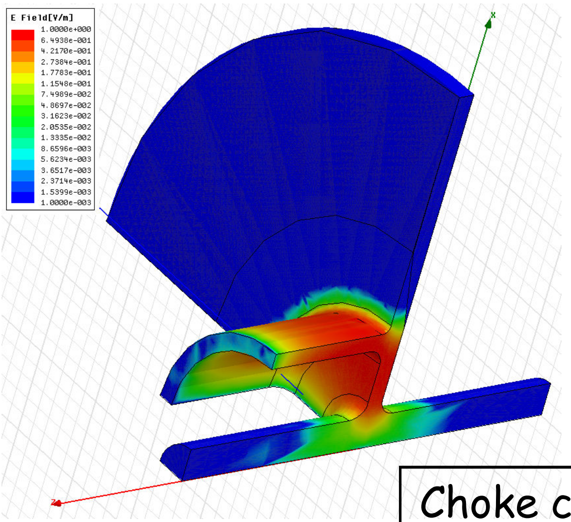


Slotted cavity

Monopole mode TM01
f=7.8GHz
Q_0=7



Dipole mode TM11
f=12GHz
Q_0=1600 (Copper)

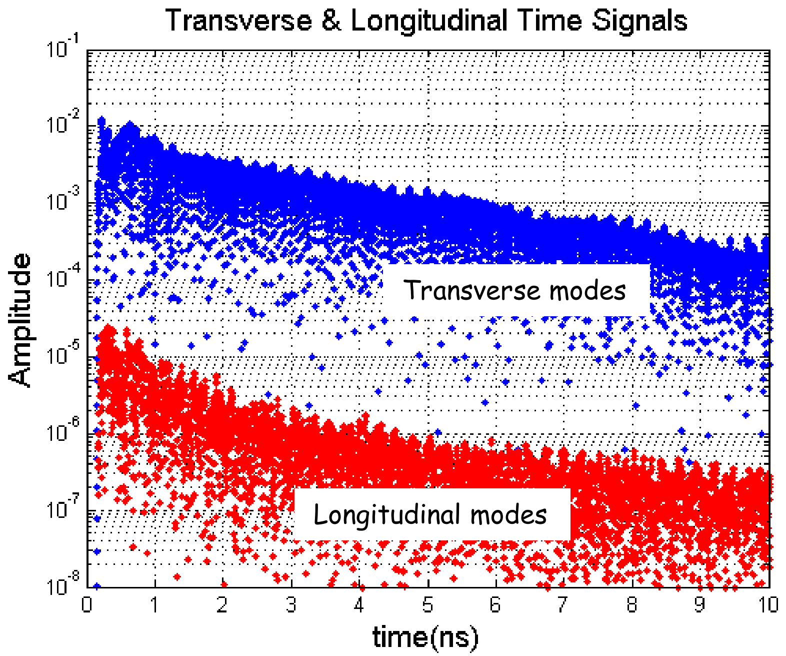


Choke cavity

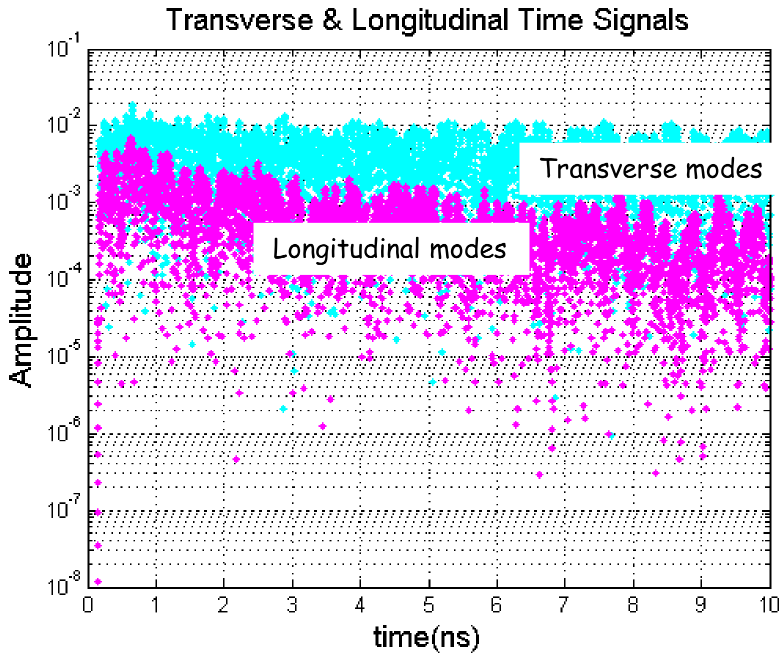
I. Syratchev – R. Fandos

‘yet another high resolution BPM’

Choke BPM



Slotted cavity BPM



~ 1 micron ⇐ Internal single bunch resolution ⇒ 500 micron

⇓

The two port pairs combination through the hybrid normally reduces the signals induced by the longitudinal modes by at least 20 dB

⇓

~ 10 nm ⇐ Single bunch resolution without post processing ⇒ 5 micron

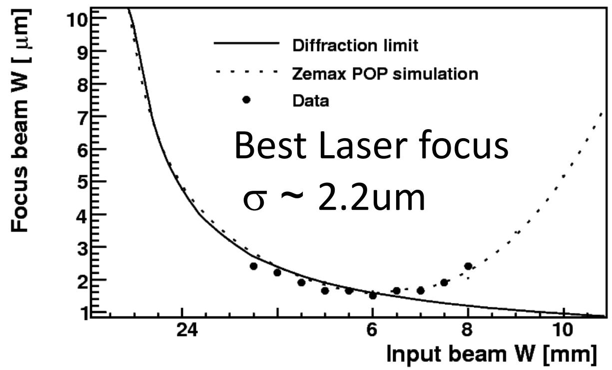
I. Syratchev – R. Fandos

Beam Size Measurement with a micron accuracy

Micron resolution with Laser Wire Scanner

Optimized to measure 20umx1um beam spot size

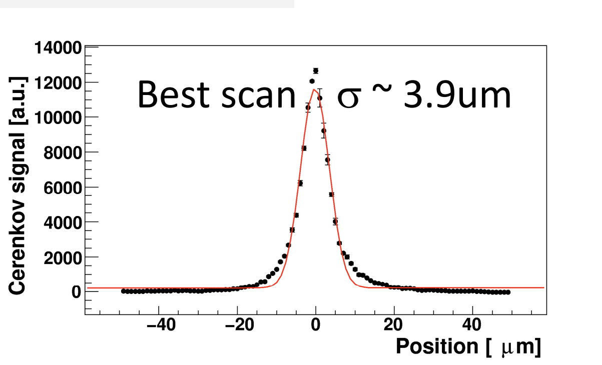
- High energy green (λ=532nm) laser pulses
- Amplify a single pulse from passively mode-locked seed laser
- Frequency locked to ATF RF distribution system at 357MHz
- Pulse duration ~150ps ; Pulse energy ~30mJ
- Laser light is transported collimated to extraction line by series of mirrors and aligned using irises

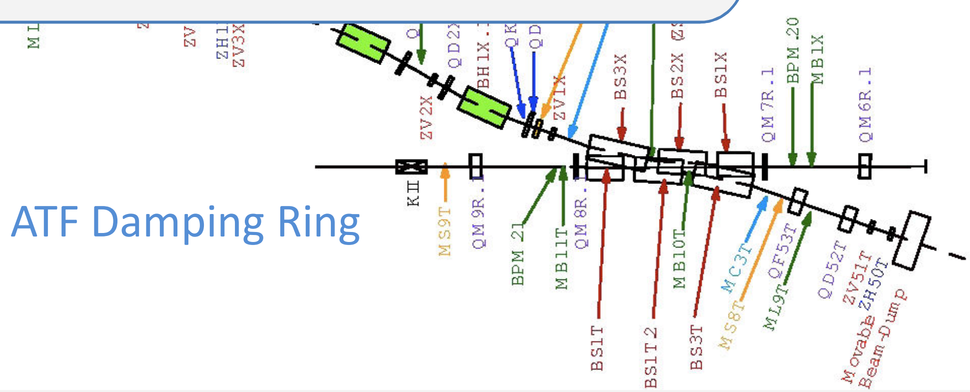


Dete

Need to improve the laser spot size by factor 2-3

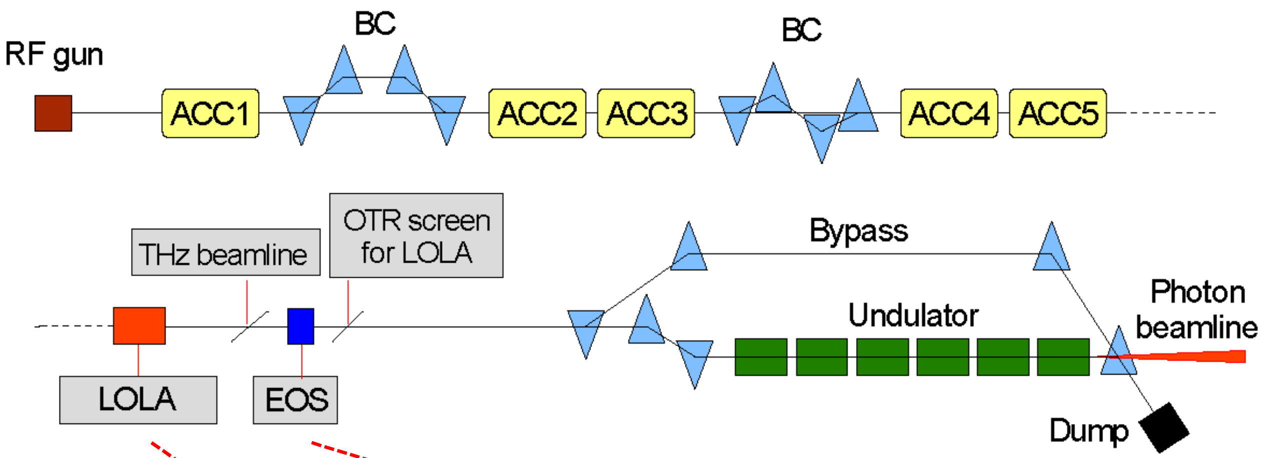
Improving the optic and laser quality





Bunch length Measurement with a 30 fs resolution

Benchmarking EO at FLASH against LOLA



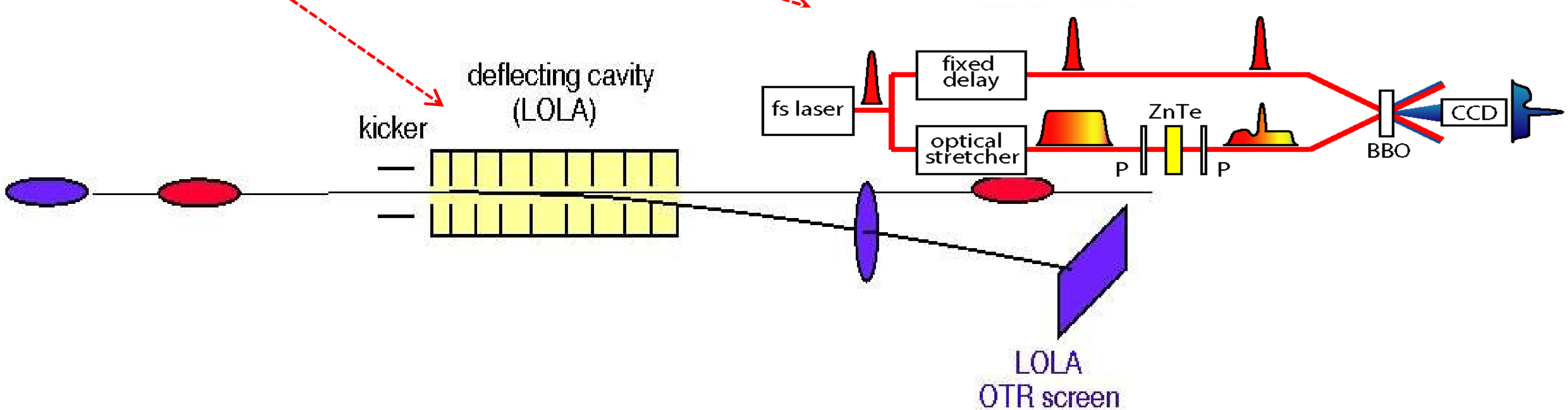
E = 450 MeV, q = 1nC

~20% charge in main peak

FLASH. Free-electron laser FLASH

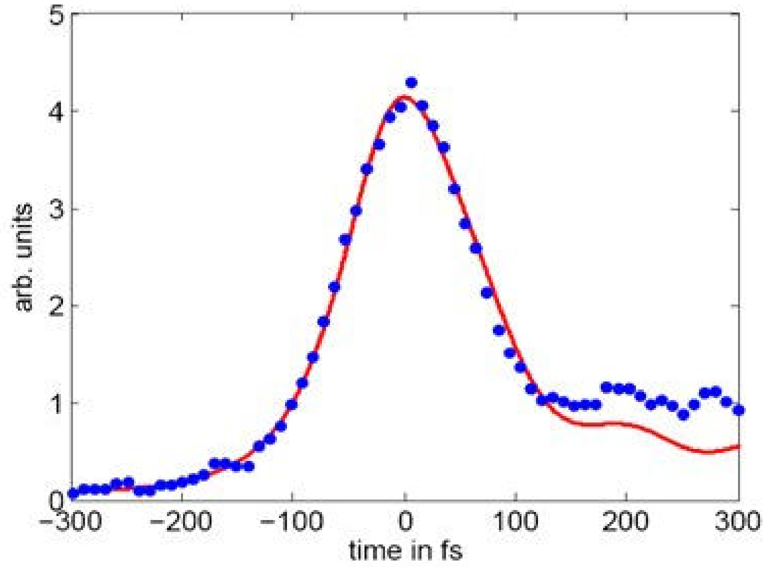
DESY

Single-shot Temporal Decoding (EOTD)

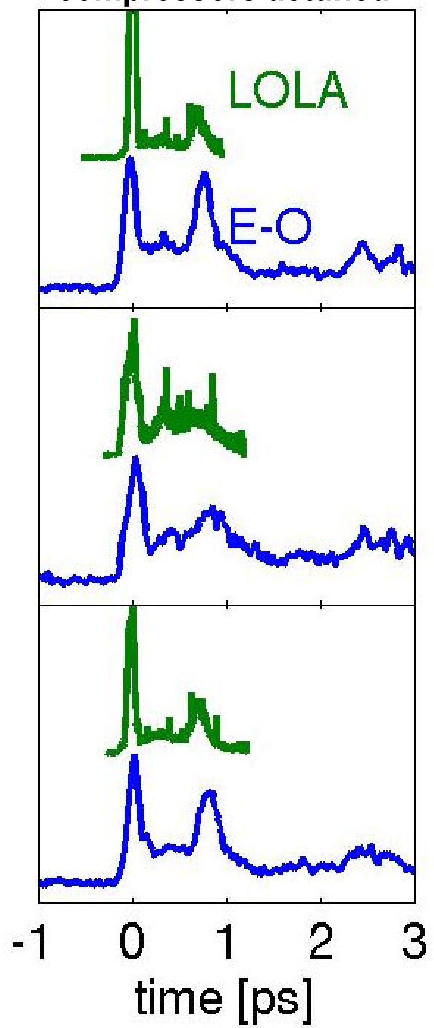


Benchmarking EO at FLASH against LOLA

Optimum compression
Fitted Gaussian curve
sigma = 79.3 ± 7.5 fs



with FLASH bunch compressors detuned

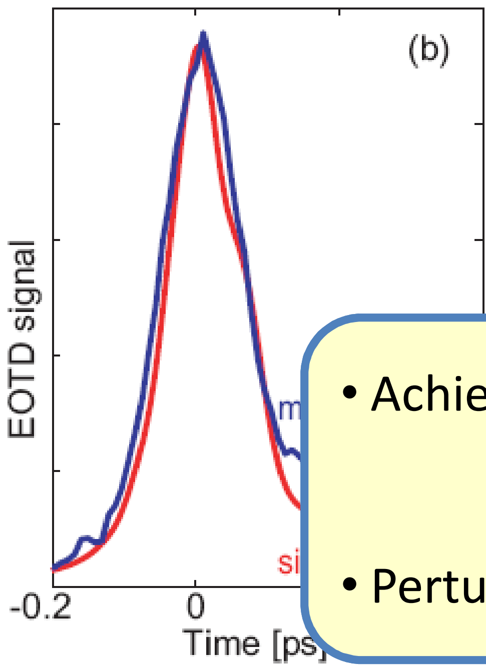


FLASH. Free-electron laser FLASH DESY

Physical Review Special Topics - Accelerators and Beams 12, 032802 (2009)

Benchmarking EO at FLASH against LOLA

FLASH. Free-electron laser FLASH



...se deflecting

...ive)

wakefields

...poral decoding

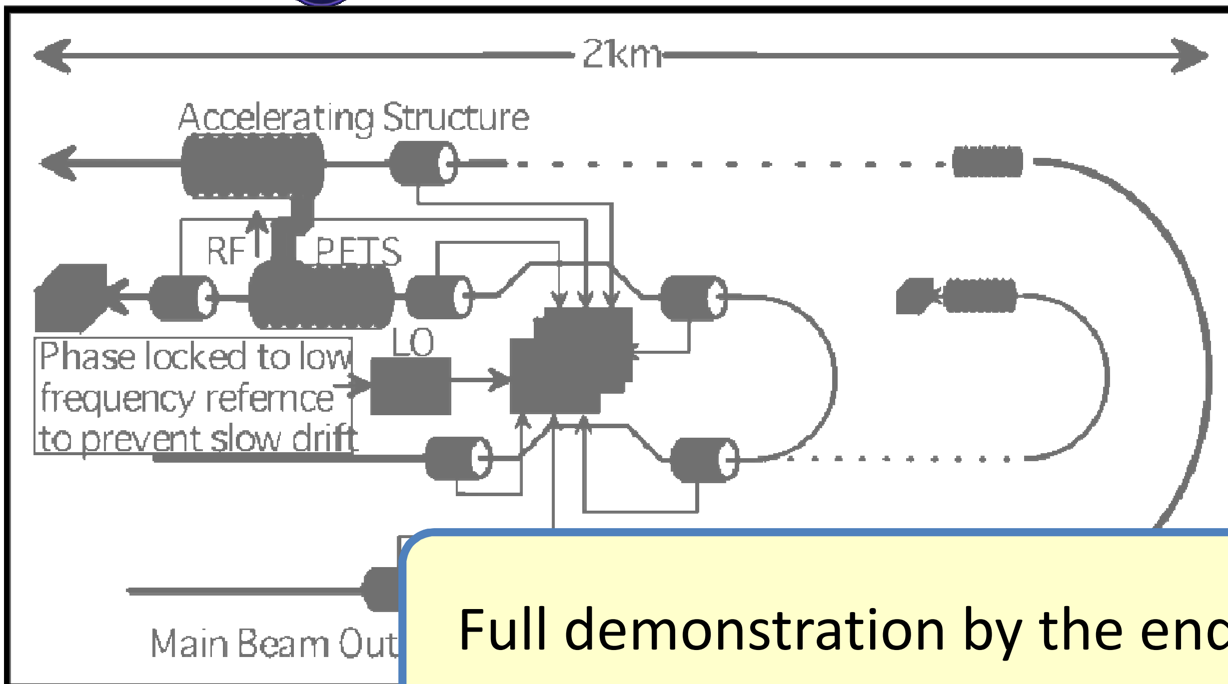
(non-destructive & compact)

- Achieved Resolution is fine
- Perturbation due to Wakefield to be investigated

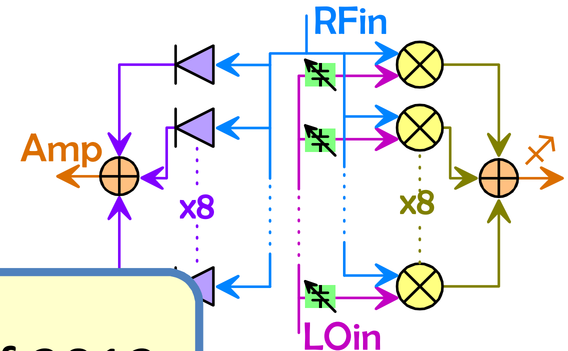
Physical Review Special Topics - Accelerators and Beams 12, 032802 (2009)

20-50fs timing synchronization

20-50fs timing synchronisation

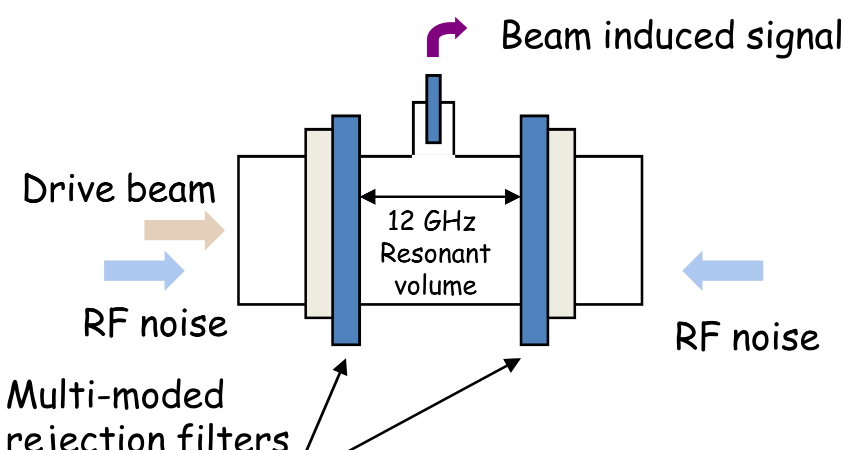


12 GHz electronics (A. Andersson)
- Use mixers directly at 12 GHz
- Use an array of many devices, sum their outputs for a reduction in noise



Full demonstration by the end of 2012

12 GHz low impedance noise-free pick-up concept by I. Syratchev, to be followed by M. Marcellini within FP7-EuCARD



Sapphire Loaded Cavity Oscillator with ~2 fs integrated phase noise.

- Stable distribution of low frequency reference for long term stability
- Low noise local oscillator at each turnaround

CLIC 3TeV – Numbers of devices

Instrument	N° Devices
Intensity	316
Position	**45242**
Beam Size	**902**
Energy	216
Energy Spread	27
Bunch Length	212
Beam Loss/Halo	0
Beam Phase	240

→ **Drive Beam**

47155 devices

No Beam Loss Monitors specified yet

Instrument	N° Devices
Intensity	311
Position	**7579**
Beam Size / Emittance	143
Energy	75
Energy Spread	23
Bunch Length	26
Beam Loss/Halo	4
Beam Polarization	23
Tune	8
Beam Phase	96
Luminosity	4
Wakefield monitor	**142812**

→ **Main Beam**

8292 devices

+ 142812 wakefield monitors

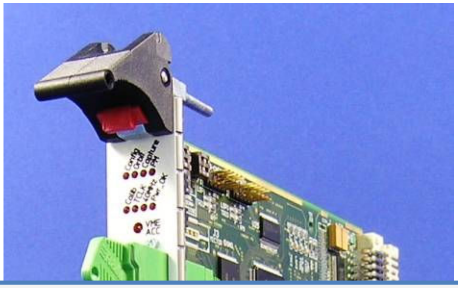
Numbers of devices

- For large scale distributed systems : > 100 (Position - Loss - Size)
  - Simplicity where possible and Standardisation
    - Cost effective
    - Maintainability
  - Robustness and Final working environment
    - Availability
    - Reliability

(LEP BPM reliability 99%, LHC Better ?)

Numbers of devices

- Electronic Standardisation
  - Single type of digital electronics acquisition card used for the majority of LHC



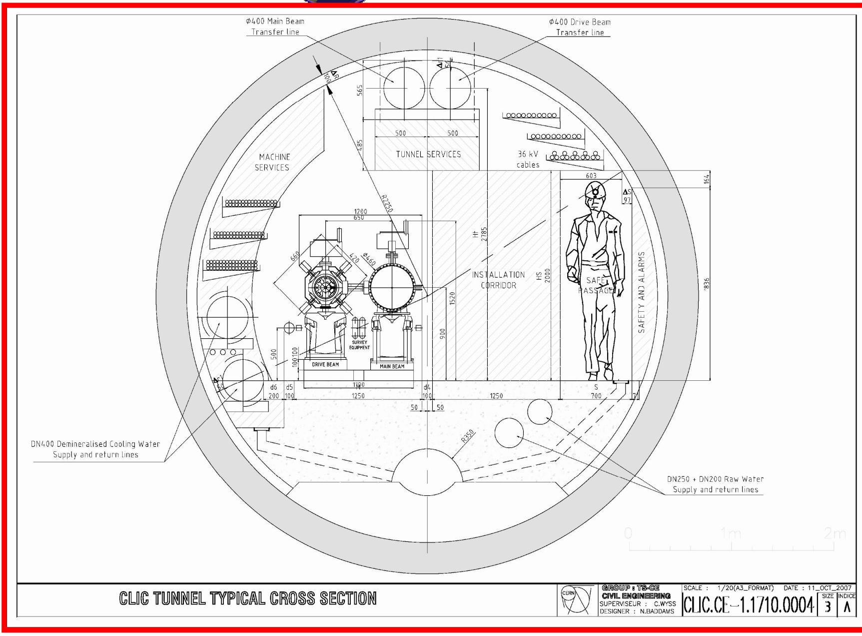
Follow similar concept for CLIC

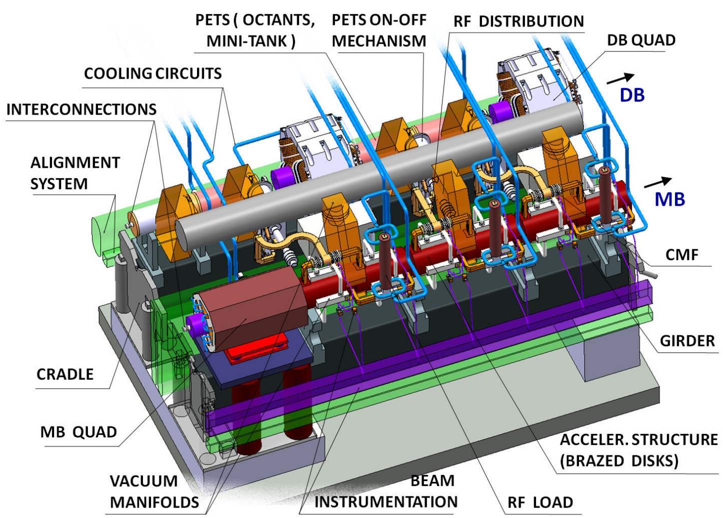
- *Elimination of cables*
- *Standardized Digital Acquisition on local crate with single connection via synchronous ethernet for timing/clock (White Rabbit – Javier Serrano)*
- *Radiation hardness ?*

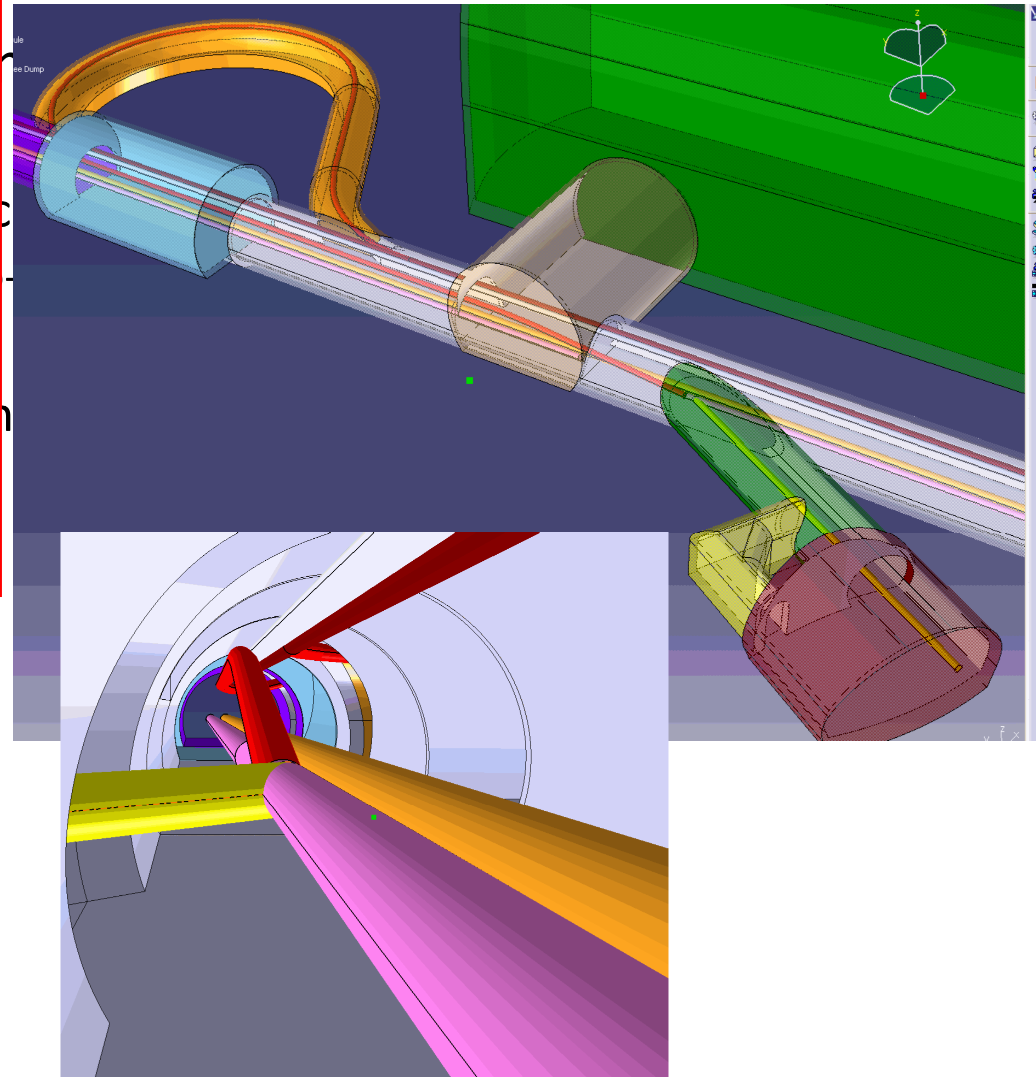
lapp S. Vilalte, J. Jacquemier, Y. Karyotakis, J. Nappa, P. Poulier, J. Tassan

- Cheaper production

Numbers of devices



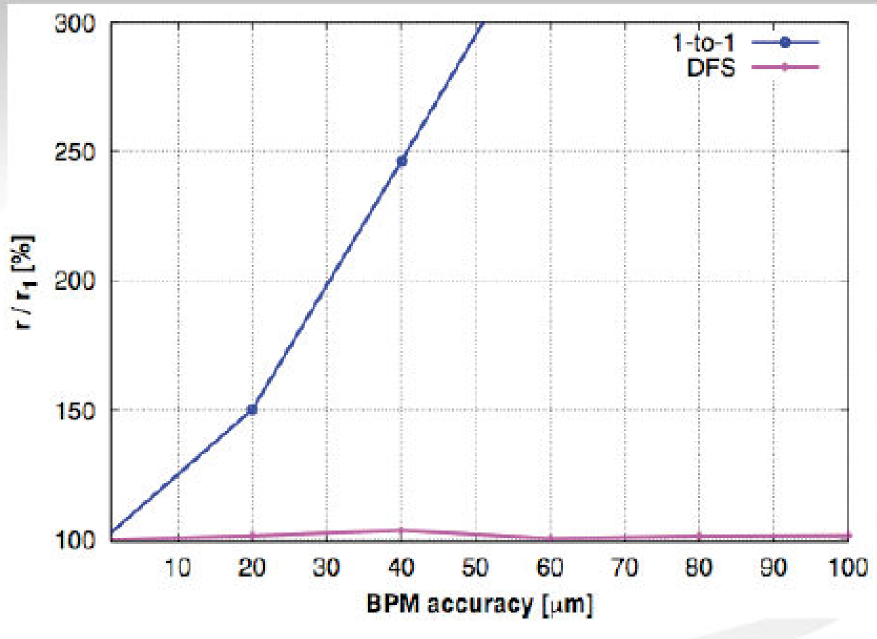


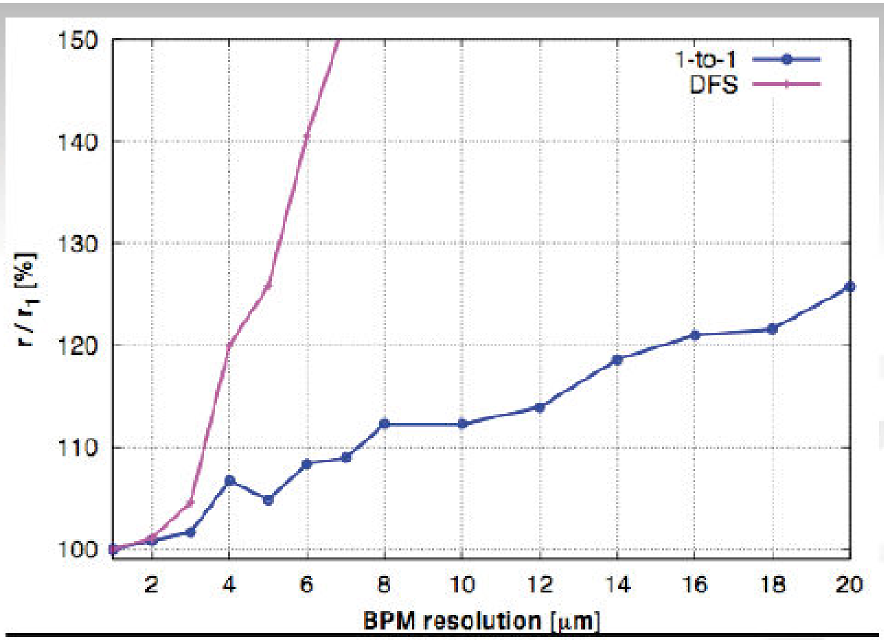


Courtesy of J. Osborne and A. Samoshkin

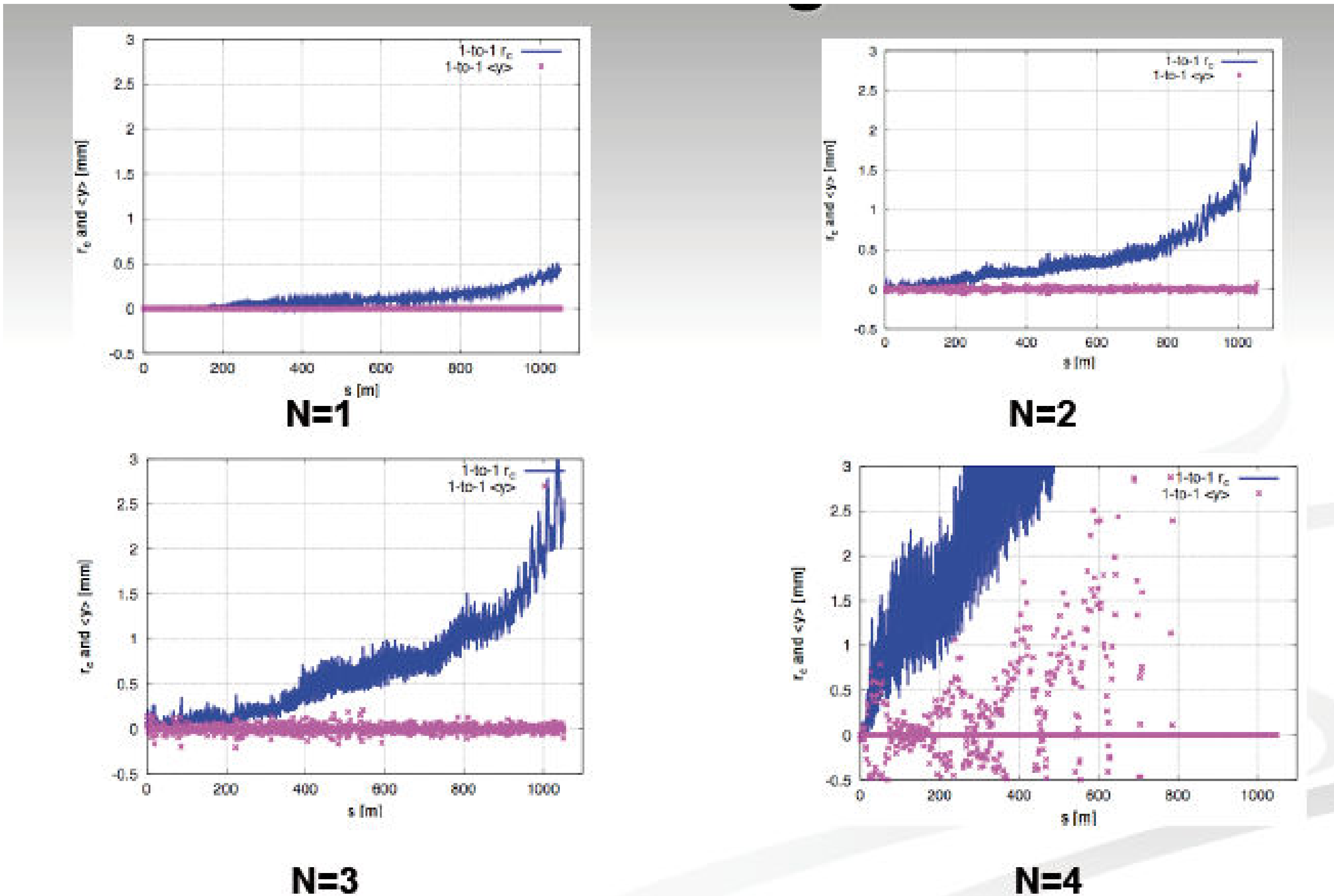
Reducing the Performance ?

Simulation by E. Adli on DB decelerator performance





Simulation by E. Adli on DB decelerator performance



Perspectives & Conclusions

- Still a lot to demonstrate but None of the devices looks unfeasible
  - Study of Beam loss monitoring just started
  - Complex and non standard Post-collision beam line

- Huge amount of devices (well-beyond what was already achieved in our field)
  - Still need input from Machine Protection/Operation to define the BI architecture
  - Dependability analysis needs to be performed

    Reliability, Availability, Maintainability and Safety

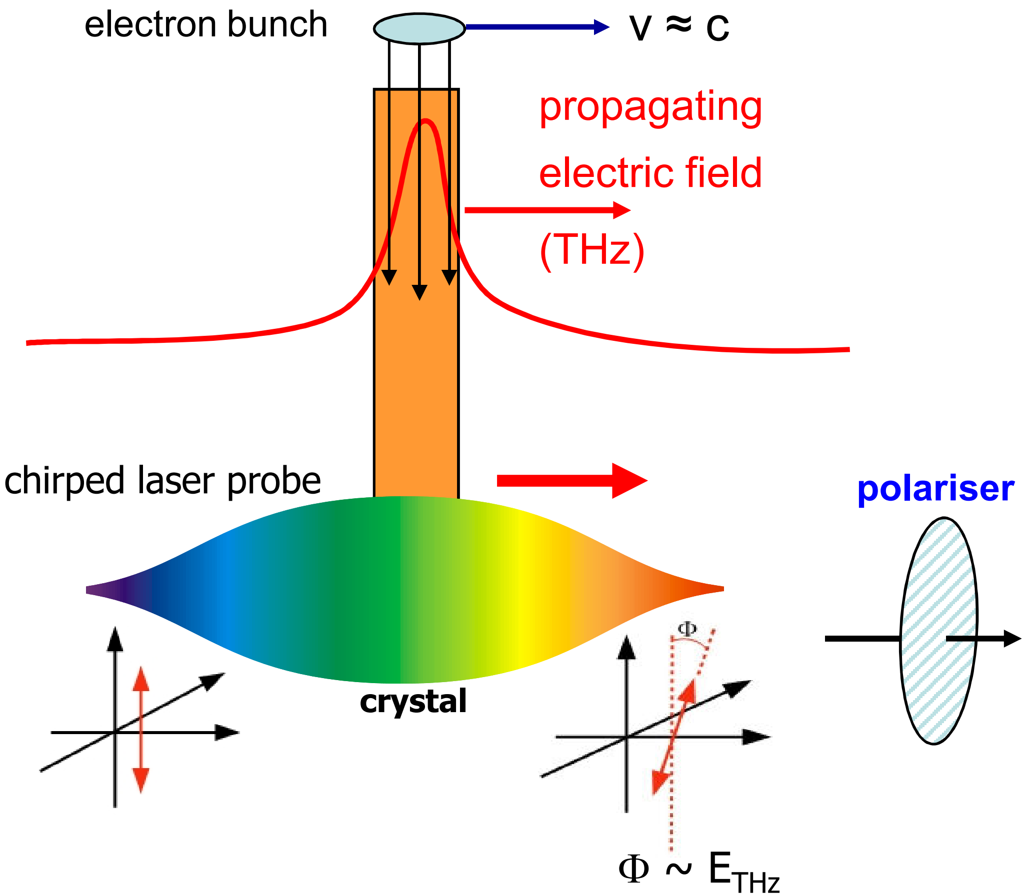
- Cost estimate and optimisation
  - Simplicity if applicable (not always compatible with tigh tolerances)
  - Standardization is a key concept
  - Gain in Mass production ?

Thanks for your attention

E-O longitudinal bunch profile measurements

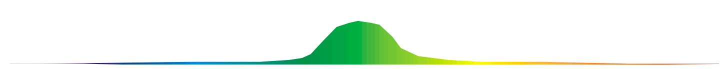
Principle: Convert Coulomb field of e-bunch into an optical intensity variation

Encode Coulomb field on to an optical probe pulse - from Ti:Sa or fibre laser



Decoding: via single-shot cross correlation in a BBO crystal

yields the temporal intensity variations in a single laser pulse

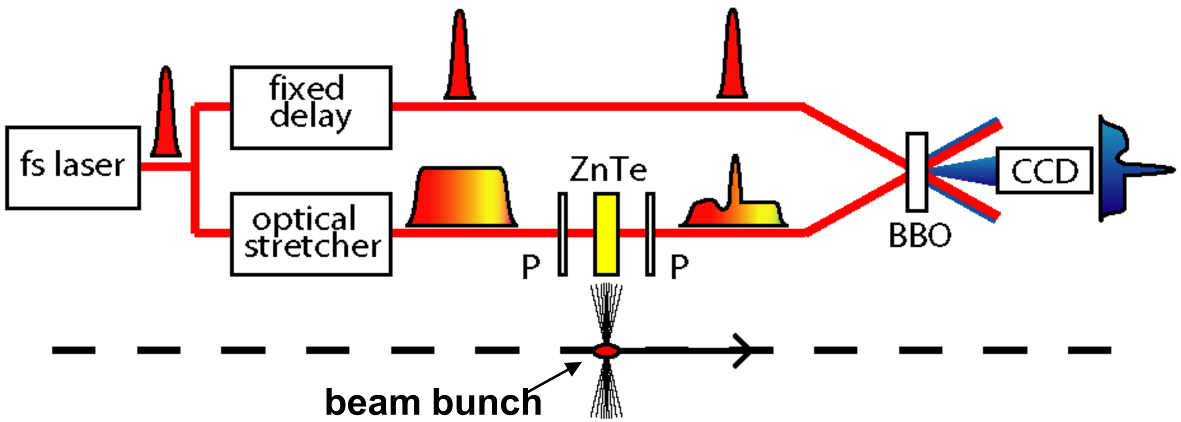


(FELIX & FLASH)

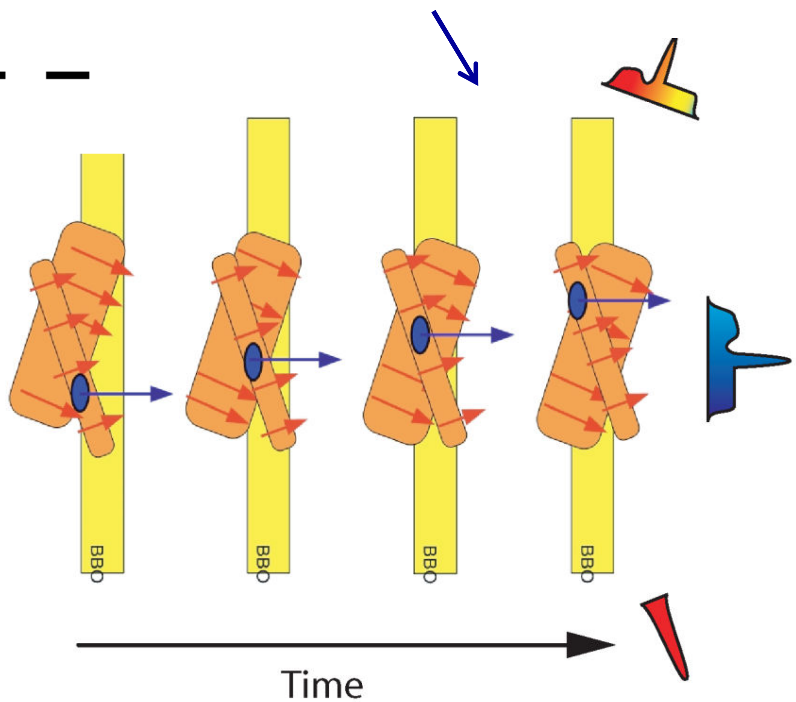
Detect polarisation rotation proportional to E or E^2, depending on set-up

E-O longitudinal bunch profile measurements

Single-shot Temporal Decoding (EOTD)



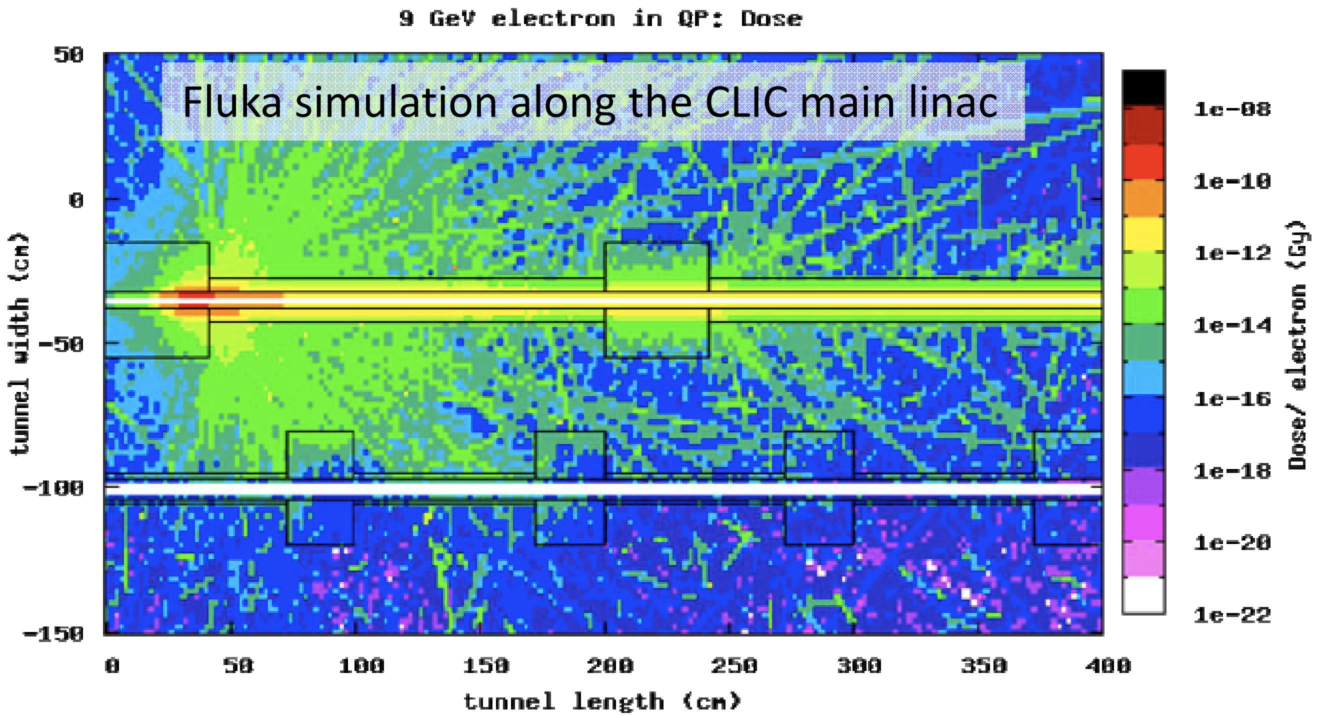
Temporal profile of probe pulse → Spatial image of SHG pulse



- *stretched & chirped* laser pulse leaving EO crystal assembly measured by short laser pulse via single-shot cross correlation in BBO
- ~1mJ laser pulse energy required (Ti:Sa amplifier)

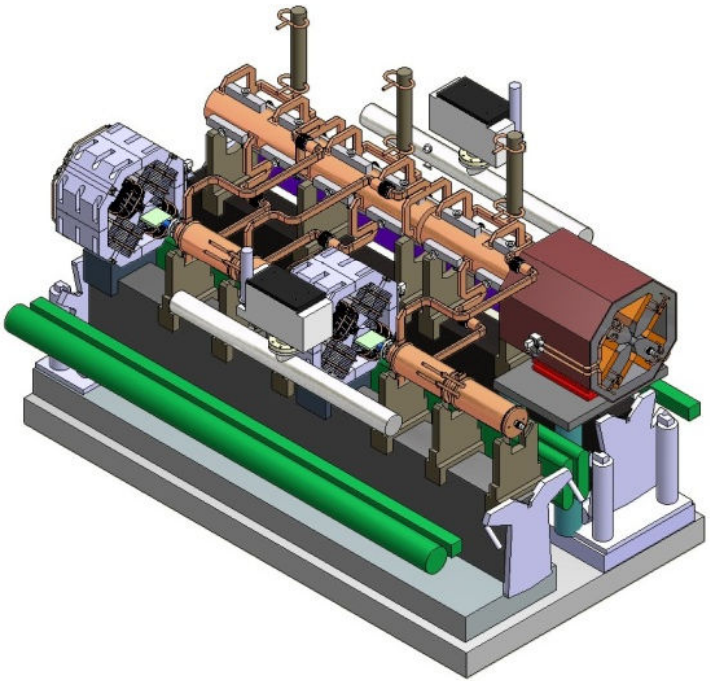
Beam loss monitors : Simulations

- Work as just started
- Plan to have functional specifications for the CDR by 2010
- For the Cost estimate
  - Choice of Technology (Cerenkov emission in Optical fiber, Ionization chambers, …)
  - Investigation of Safety Integrity Level (Need for redundancy ?)



Beam loss monitors : Hardware development

Major complication: Two beams & Long train!



Exploitation of Cerenkov-radiation in optical fibres

- Based on DESY-Flash work
- 4ˣ2 fibres around vacuum chamber
- Short individual fibres for true 3D analysis

Fast time response

Transverse and longitudinal information

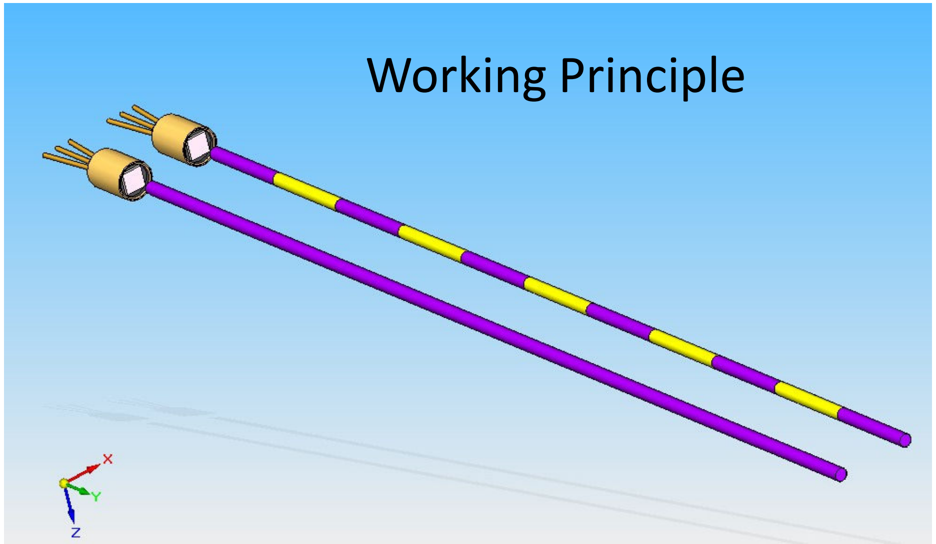
Insensitive against E and B fields

Quite Radiation hard

Limited space requirement of monitor

Beam loss monitors : Hardware development

- Optical Fiber Sensor based on SiPM composed of SPAD Array.
- Two arms:
  - Reference fiber
  - Composite fiber with different losses (~0.45dB)



Features:

- Optical fiber diameter: 1mm^2 as the dimensions of SiPM active surface.
- Numerical aperture of fibers between 0.22 and 0.63.
- Pure silica and PMMA multimode step index fibers with n = 1.46.
- SiPM recovery time ca. 4 ns. (~ better than PMT)
- SiPM quantum efficiency 15 % in the blue wavelength range

Post collision line

Post collision line

A. Ferrari, V. Ziemann – ?

E. Gschwendtner – K. Elsener

Complex and non-standard beam line

- Luminosity monitors based on beamstrahlung photons detection
- Intensity monitors
- Interferometric dump thermometer
- Tails monitors and/or instrumented collimators

Intro: ILC Beam Instruments

- ~ 2000 Button/stripline BPM's (10-30 / 0.5 μm resolution)
- … m, 0.1 …
- … part …
- … s (0 …
- … tion …
- 15 Deflecting Mode Cavities (bunch length)
- ~ 1600 BLM's
- Other beam monitors, e.g. toroids, bunch arrival / beam phase monitors, wall current monitors, faraday cups, OTR & other screen monitors, sync light monitors, streak cameras, feedback systems, etc.
- Read-out & control electronics for all beam monitors

ILC
~ 6000 Devices

CLIC@500GeV
~32000 Devices