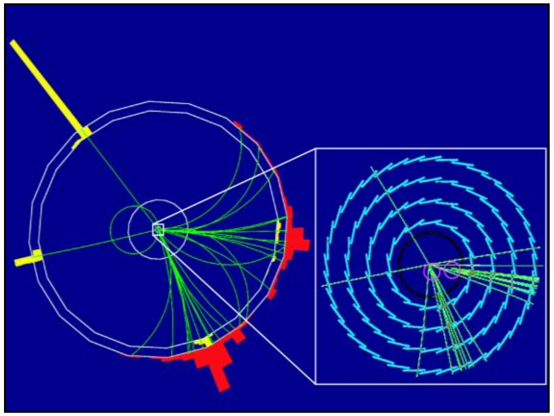
Compact Linear Collider Beam Instrumentation

T. Lefevre, CERN
for the CLIC BI team

- CLIC beam instrumentation requirements
- Status on Linear Collider beam instrumentation
- Status and plans for the coming years

Collider luminosity [$cm^{-2} s^{-1}$] is approximately given by

$$L = \frac{n_b N^2 f_{rep}}{4\pi\sigma_x^* \sigma_y^*} \times H_D$$

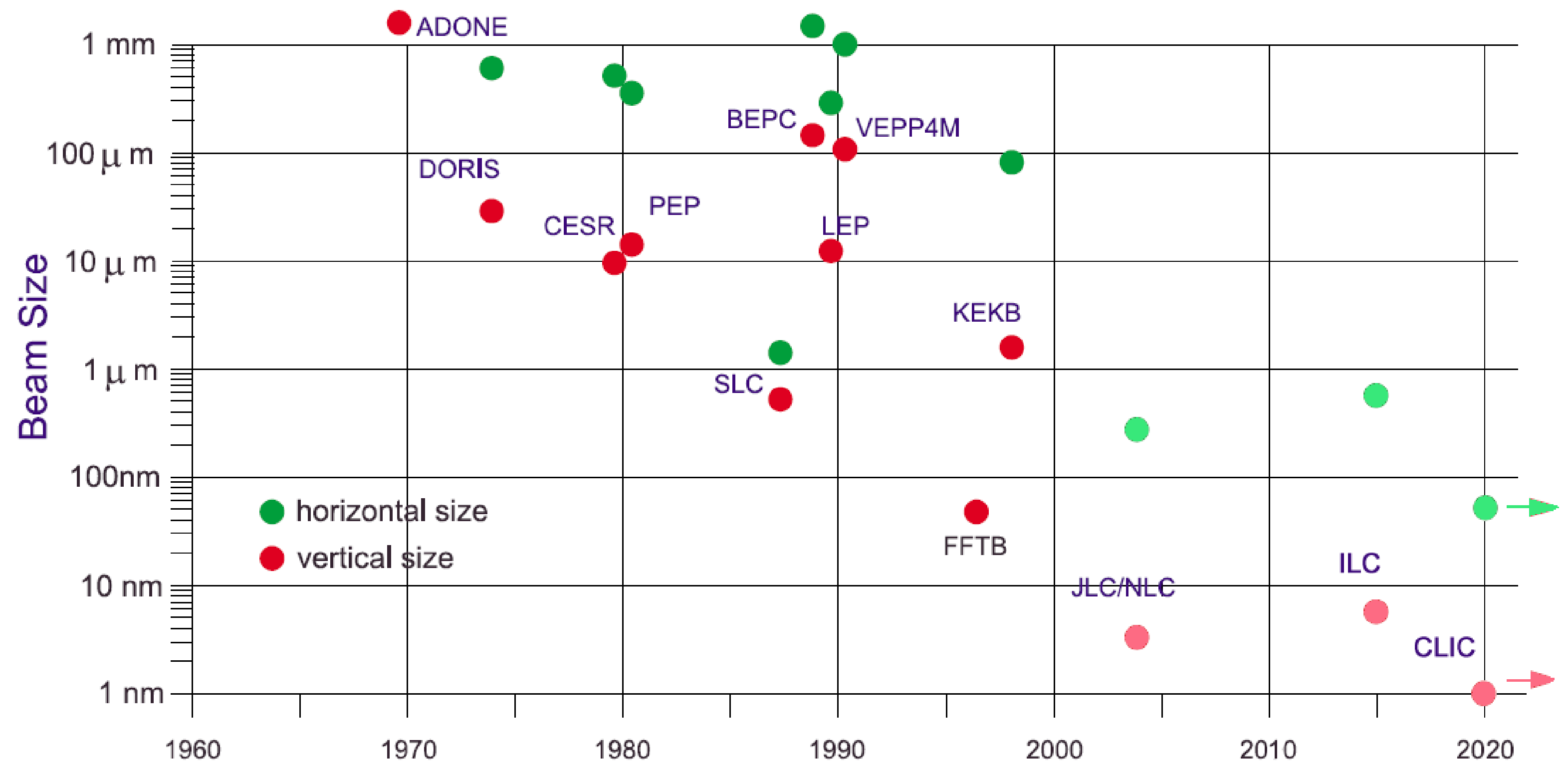


- n_b = bunches / train
- N = particles per bunch
- f_{rep} = repetition frequency
- $\sigma_{x,y}$ = beam size at IP
- H_D = beam-beam enhancement factor

A linear collider uses the beam pulses only once:

- Need to accelerate lots of particles
- Need very small beam sizes

The small beam size challenge



Adapded from S. Chattopadhyay, K. Yokoya, Proc. Nanobeam `02

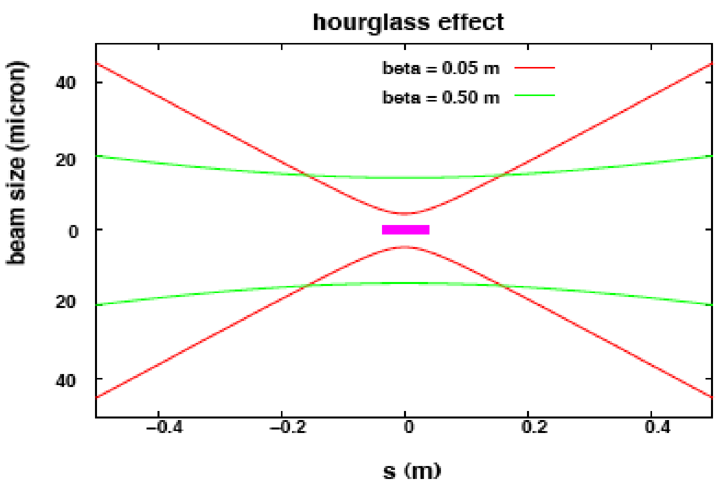
LEP: $\sigma_x \sigma_y \approx 130 \times 6\ \mu m^2$

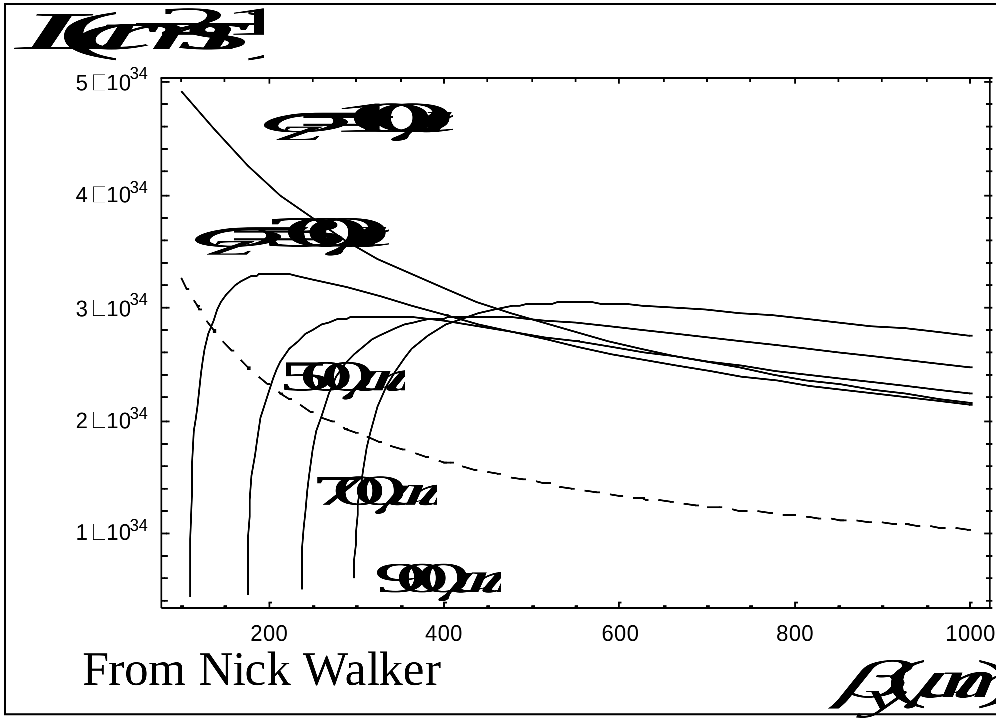
CLIC: $\sigma_x \sigma_y \approx 40 \times 1\ nm^2$

Hour glass effect – Bunch length

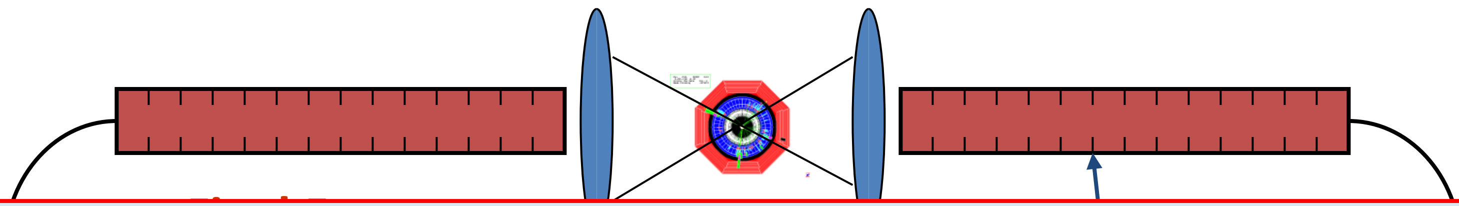
For achieving small beam size at IP, the beta function rapidly increases as the particle move away from the collision point

Variation of beam size along the bunch





Rule: ‘Keep $\beta_y \sim \sigma_z$’ ***45um for CLIC***



- Measuring small emittance and small beam size
  ~ 1um spatial resolution Transverse Profile Monitors
- Measuring Short bunch length
  ~ 20fs time resolution Longitudinal Profile Monitors
- Conservation of emittance over long distances relies on precise alignment
  high accuracy (5um) high resolution (50nm) Beam Position Monitor
- Dump the beam safely and properly
  Dealing with high beam power (tens of MW)

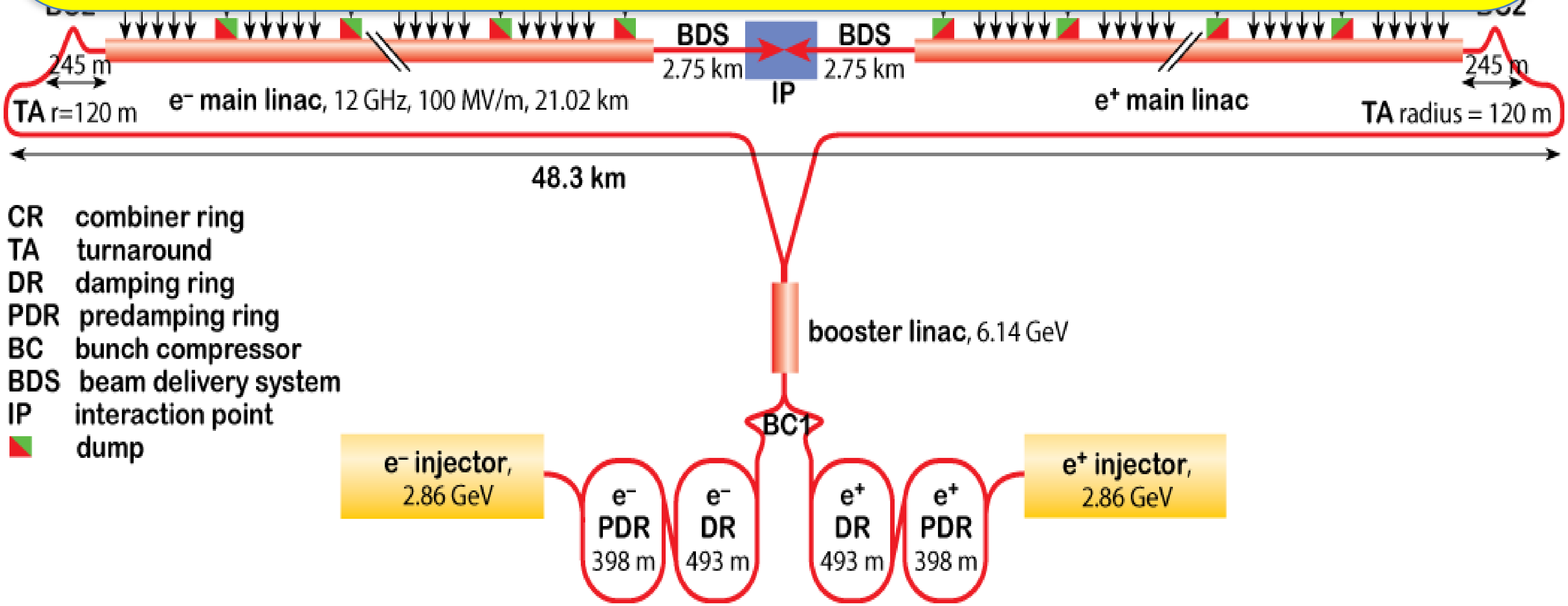
Deliver stable beam current

Use electrons to pair-produce positrons

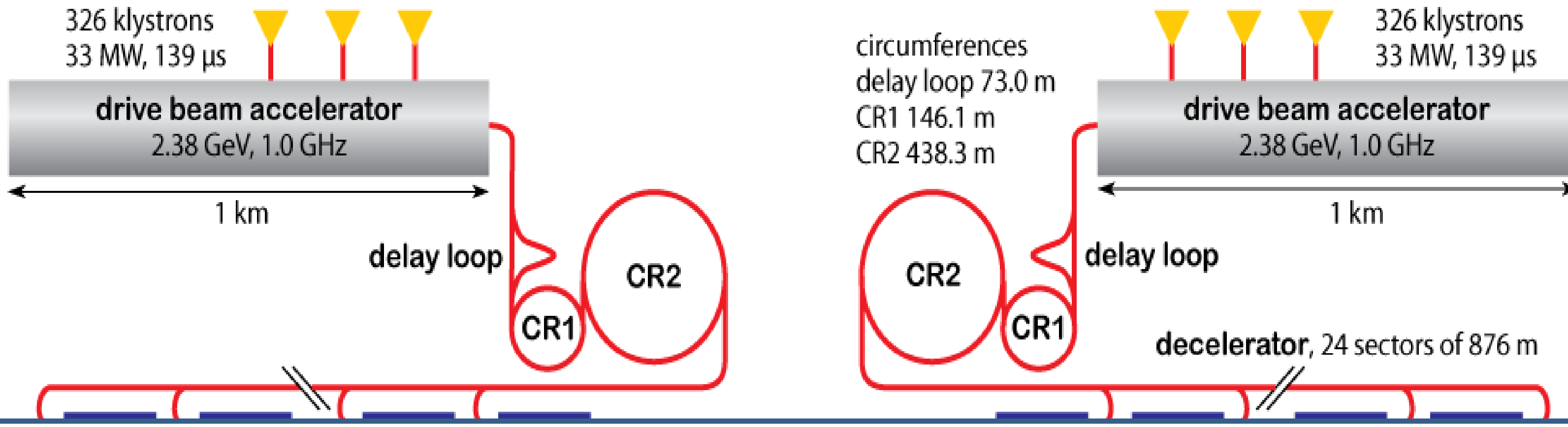
CLIC @ 3 TeV

CLIC RF source

How to power 142k Accel. Structures @ 12 GHz , 150MW over ~50kms



CLIC Power Source : Two-Beam concept



- Acceleration (94% RF to be efficiency) using fully loaded accelerating structures : **see the talk by Maja Olvegard later today**

- Innovative Bunch Multiplication Frequency scheme: **see Poster by Mathilde Favier**

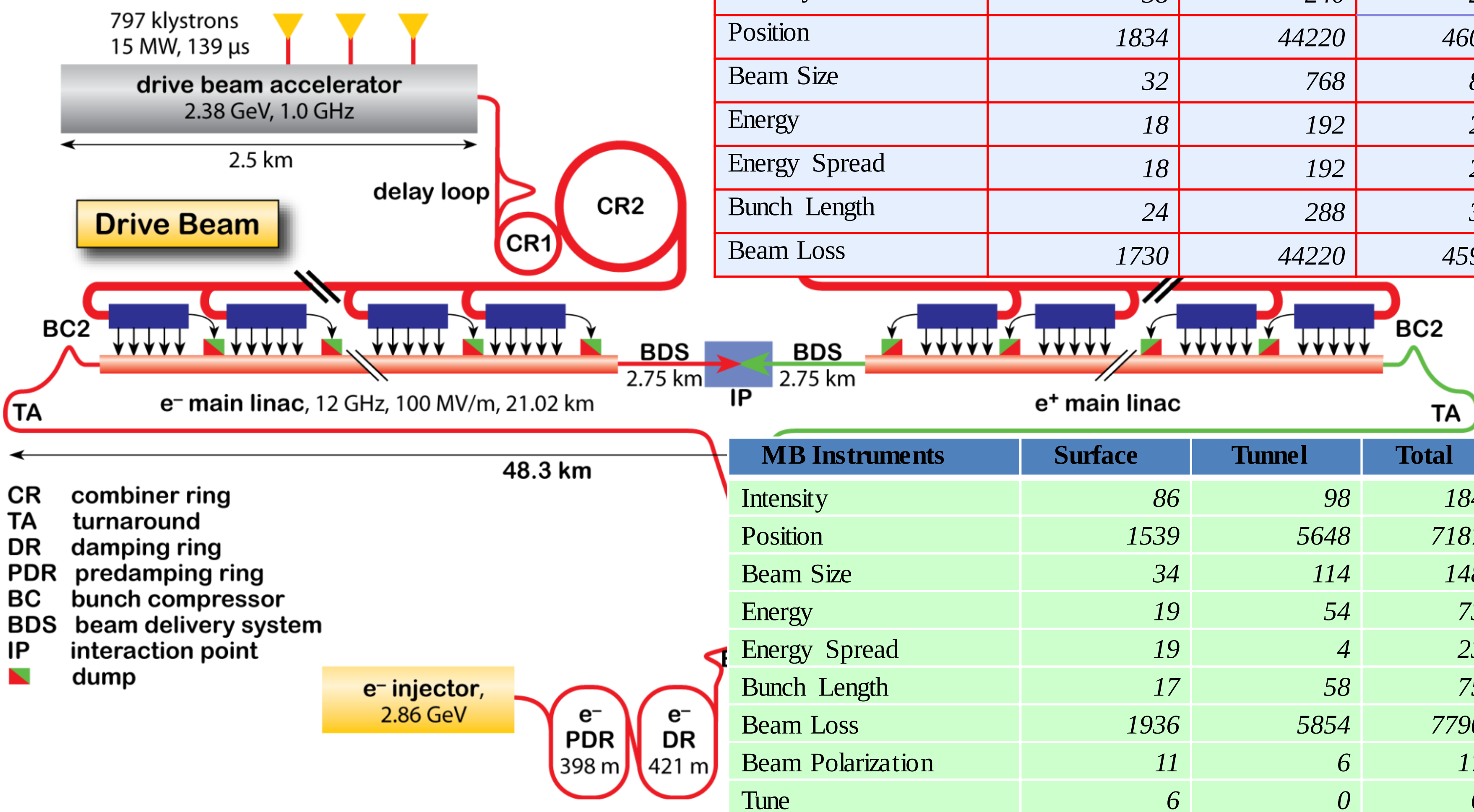
- Manipulating high charge beams (Machine Protection issues, Radiation level, Non intercepting beam diagnostic, ..) : **see poster by Sophie Mallows**

- In addition, there are very strict tolerances/requirements on the beam phase stability (0.1º@12GHz)

- Reliability and availability : This is 'just' the RF Source !

CLIC Instrumentation in Numbers

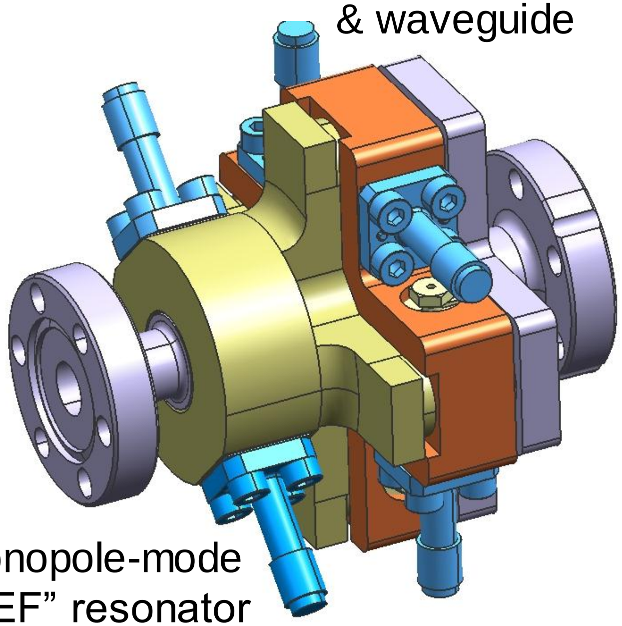
DB Instruments	Surface	Tunnel	Total
Intensity	*38*	*240*	*278*
Position	*1834*	*44220*	*46054*
Beam Size	*32*	*768*	*800*
Energy	*18*	*192*	*210*
Energy Spread	*18*	*192*	*210*
Bunch Length	*24*	*288*	*312*
Beam Loss	*1730*	*44220*	*45950*



MB Instruments	Surface	Tunnel	Total
Intensity	*86*	*98*	*184*
Position	*1539*	*5648*	*7187*
Beam Size	*34*	*114*	*148*
Energy	*19*	*54*	*73*
Energy Spread	*19*	*4*	*23*
Bunch Length	*17*	*58*	*75*
Beam Loss	*1936*	*5854*	*7790*
Beam Polarization	*11*	*6*	*17*
Tune	*6*	*0*	*6*
Luminosity		*2*	*2*

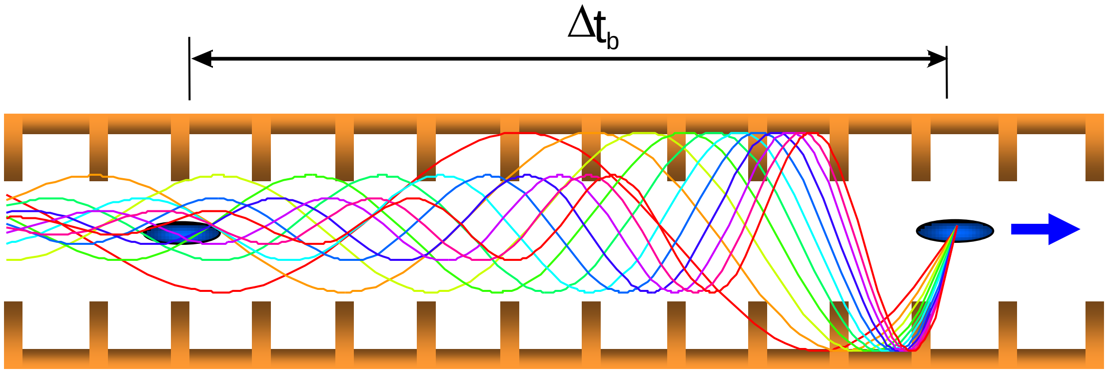
CLIC Cavity Beam Position Monitor

- Dispersive emittance dilutions along the main linac due to offset of quadrupoles
  - Beam based alignment to define a precise reference using ~4200 high resolution (50nm) cavity BPM
  - Quadrupoles on movers and stabilized in position using actuators and active feedback system



- **WG-loaded, low-Q X-Band design (Fermilab-CERN)**
  - **$Q_\ell \approx 260$, resonator material: 304 stainless steel**
  - **~50 nsec time resolution, <50 nm spatial resolution**
- **First prototype under fabrication – Test with beam next year on CTF3**
- **Talk by Nirav Joshi (RHUL) on Wednesday**

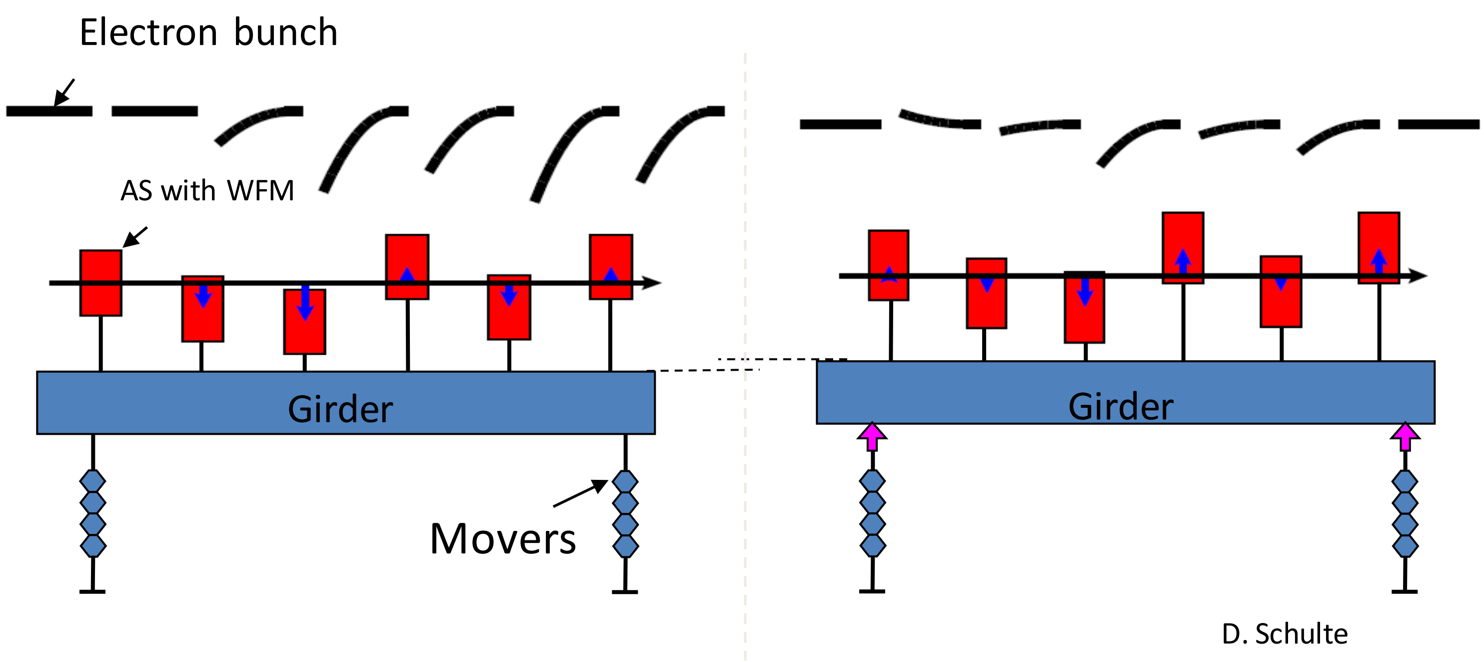
Wakefields in accelerating structures (damping of high order modes)



Bunches passing through an accelerating structure off-centre excite high order modes which perturbs later bunches

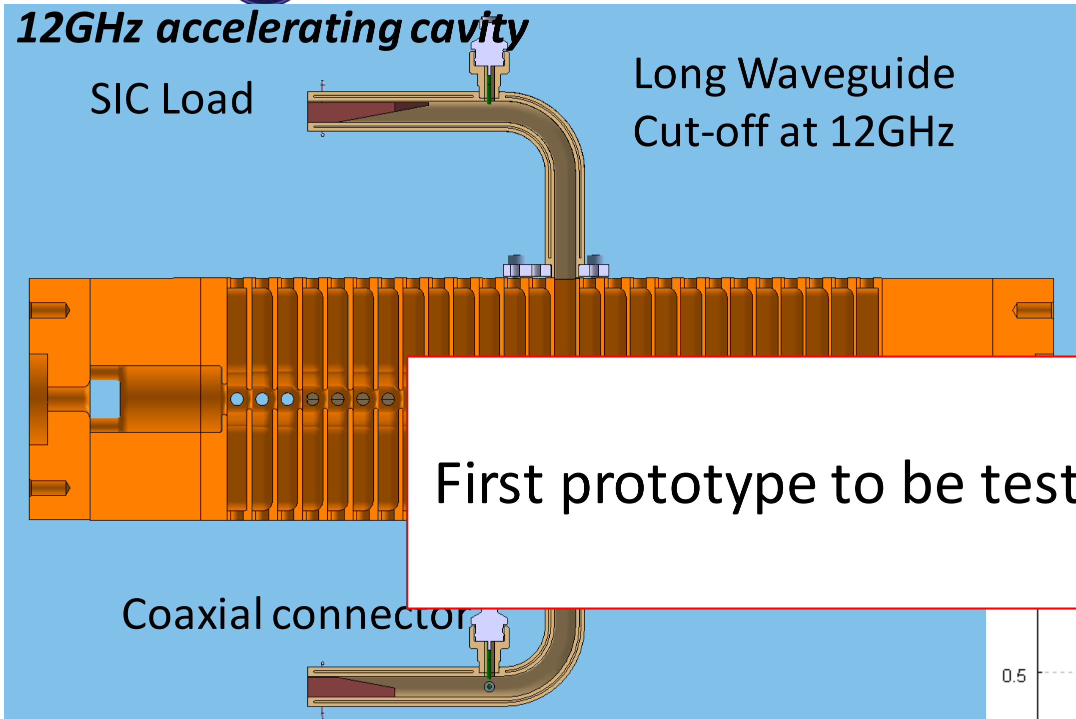
- Tolerances for acc. Structures alignment
- Cavity alignment at the 300 μm level 5 μm
- Need wakefield monitor to measure the relative position of a cavity with respect to the beam

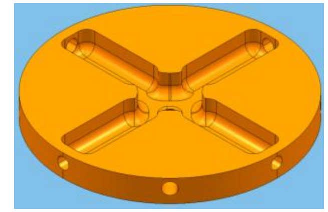
CLIC Cavity Beam Position Monitor



- Wakefield kicks from misaligned AS can be cancelled by another AS
- One WFM per structure (142k monitors) and mean offset of the 8 AS computed
- WFM is a cavity BPM with 5um resolution
- Need to get rid of the 100MW of RF power at 12GHz present in the structures

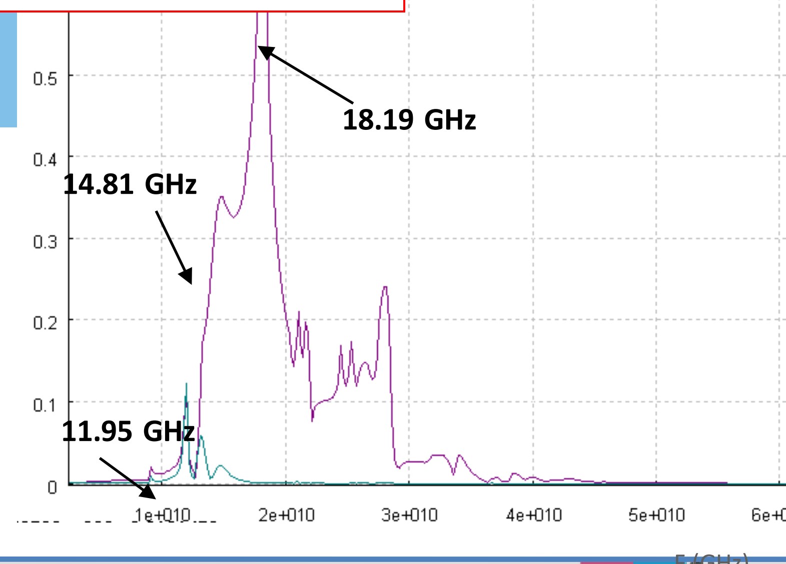
CLIC Cavity Beam Position Monitor



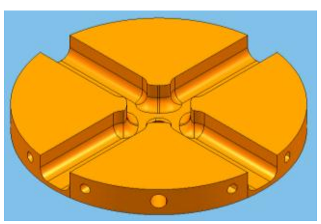


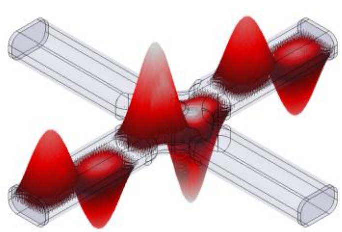
Regular cells with SIC load

First prototype to be tested in 2012



Middle cell with WFM



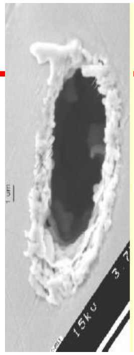


Courtesy of F. Peauger, CEA

CLIC Transverse Profile Monitors

- **Critical Issue on micron resolution beam profile measurements (> 100 monitors)**

- Charge density limitation problems in many places / **Strong need for non-interceptive devices** : two systems required to cover the total dynamic range



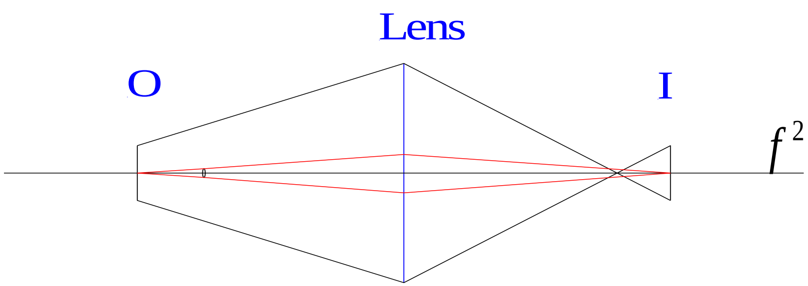
Combine Optical Transition screens and Laser Wire Scanners

- OTR used almost everywhere for commissioning (and more)
- LWS 1um resolution required for the Main beam
- LWS used in the Drive Beam injector complex for high charge beams (full charge)

Talk on LWS by T. Aumeyr this afternoon

High resolution OTR

At the diffraction limit (beam size ~ λ/Δθ with Δθ the angular acceptance of the optical system), the image of a point source (radiating a ring pattern) is defined by the OTR point spread function (PSF):

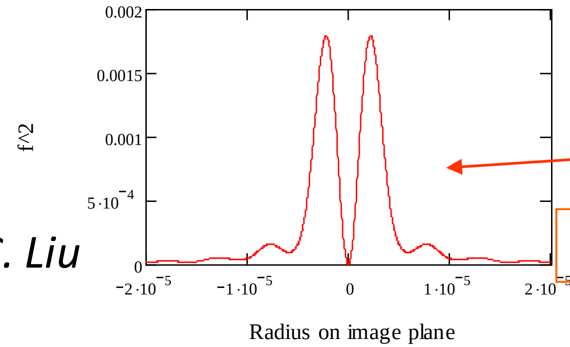


PSF: convolution integral of

$$f^2(\theta_m,\gamma,\varsigma)=\left[\int_0^{\theta_m}\frac{\theta^2}{\theta^2+\gamma^{-2}}J_1(\varsigma\theta)\,d\theta\right]^2$$

OTR response — **Point charge diffraction**

Example:
M=1, E=4GeV, λ=500nm
courtesy of A. Lumpkin & *C. Liu*



Cross section

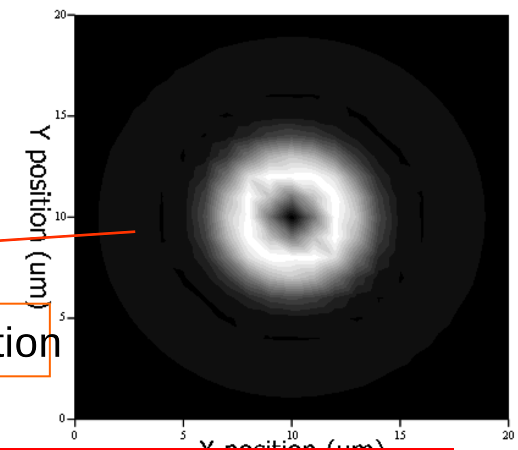
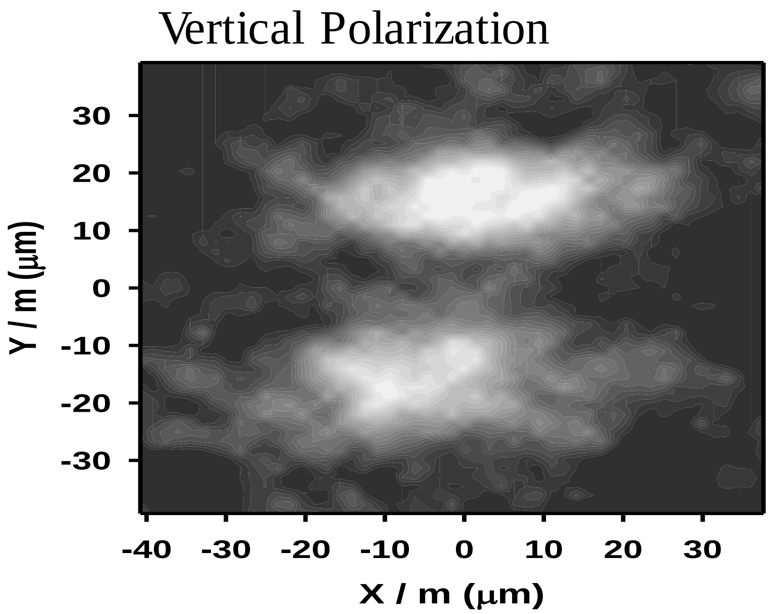


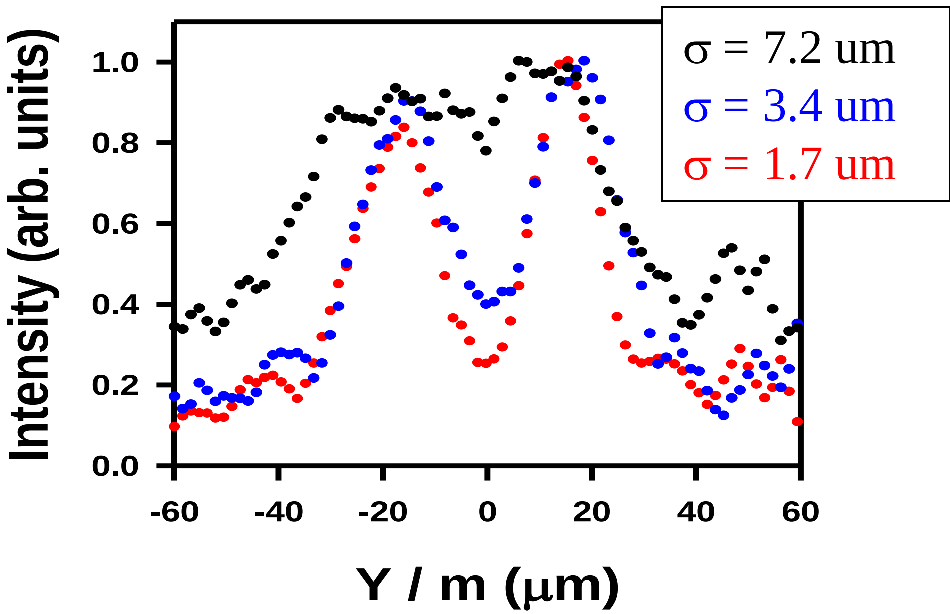
Image on the camera is the convolution of this function with the beam size

High resolution OTR

Measurements performed on ATF2 @ KEK

Courtesy of P. Karataev Royal Holloway University of London



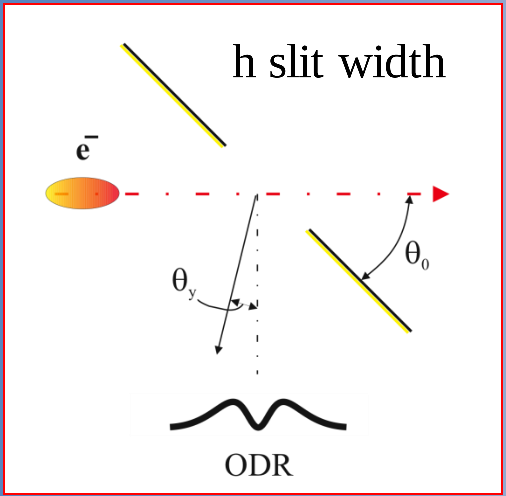


The limit for the use of screen is not the resolution but the thermal resistance of the screen

Similar system by Ake Andersson (maxlab) using the vertical polarization of Synchrotron radiation

Non-interceptive beam size monitors using DR

- Beam size monitoring using Diffraction Radiation



Photon yield:

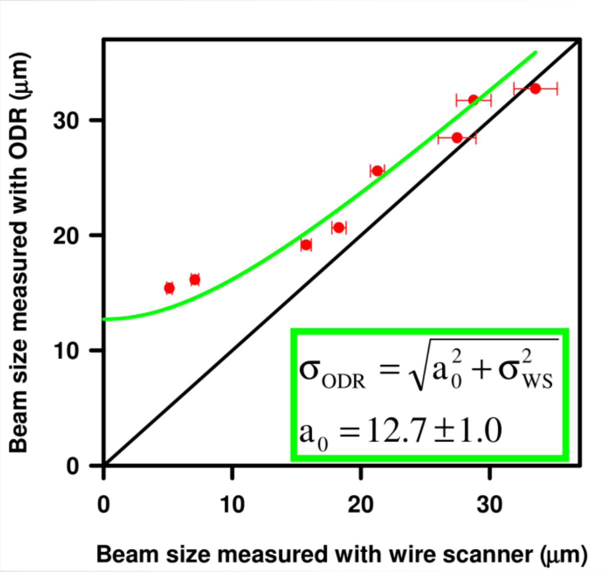
$$Z = \frac{\omega}{\omega_c} = \frac{2\pi h}{\gamma\lambda} < 1$$

Optimal Sensitivity

$$\sigma > 0.05\frac{\gamma\lambda}{2\pi}$$

Royal Holloway University of London

P. Karataev *et al*, PRSTAB 11 (2008) 032804

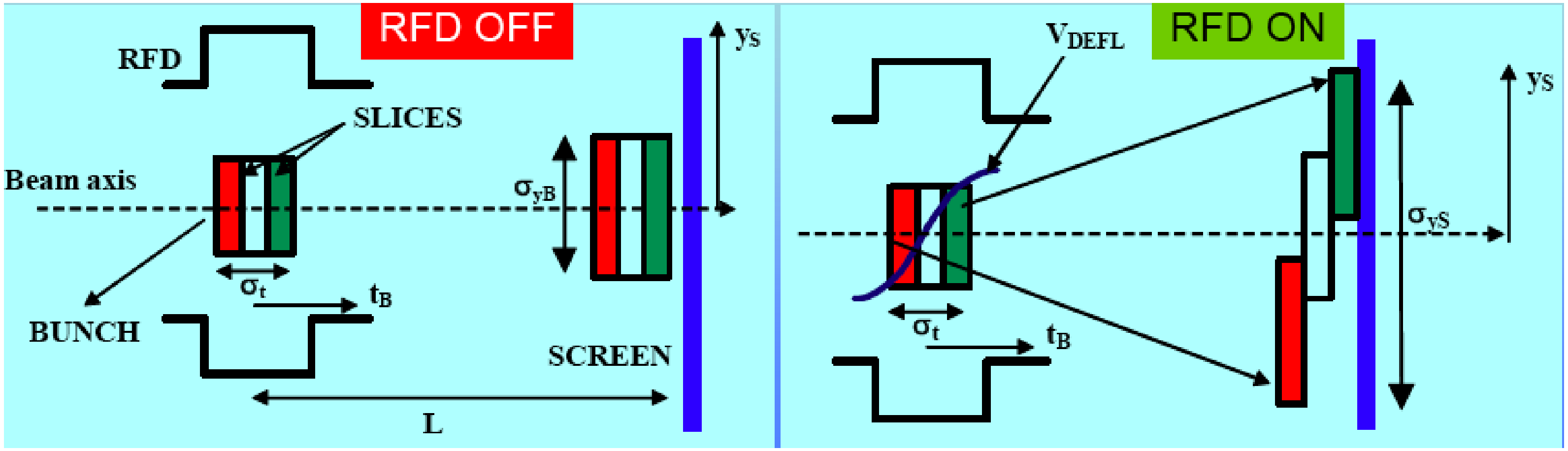


- Already few existing prototypes in IR and visible range

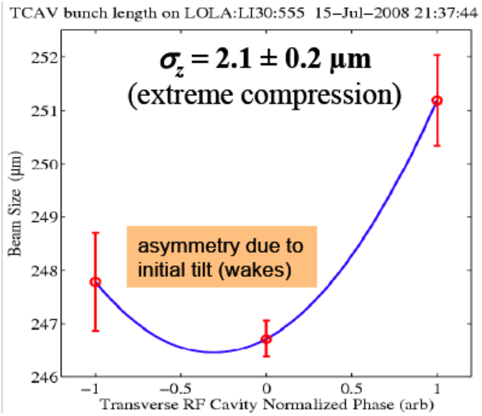
E. Chiadroni et al, PAC 2007 pp3982 and A.H. Lumpkin *et al*, *PRST-AB* **10** (2007) 022802

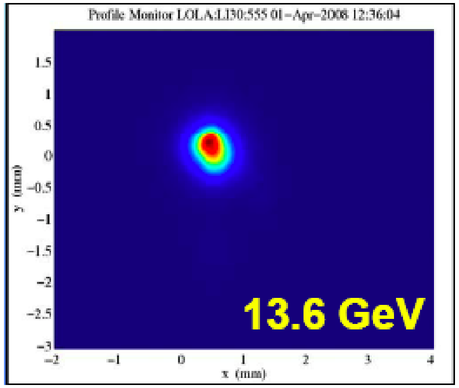
- Alternative technology for both Drive and Main Beams
  - Drive Beam Injector Complex (2.4GeV) – typical beam size of 50-100um
  - Ring To Main Linac (RTML) complex (2-9GeV) – Typical beam size of 5-10um
  - >100 of devices in total
  - Push the resolution to the micron range using DR in extreme UV
  - Experimental validation foreseen on CESRTA @ Cornell – first stage (10um resolution in 2012)

- **Critical Issue on 20fs resolution bunch profile monitor**
- **Resolution already obtained by radio-frequency deflecting cavity …**



Courtesy of D. Alesini





Courtesy of P. Emma

- **But …… RF deflector's resolution can be expressed as**

$$\sigma_{t_B\_RES} = \frac{\sigma_{y_B}}{\frac{V_{DEFL}}{E/e}\,\omega_{RF} L}$$

Requiring high RF power at high frequency and long deflecting structures

Getting worse at high beam energies

- **Need non-interceptive instruments which can work up to very high beam energy**

Two talks by S. Jamison and Rui Pan on **Electro-optical techniques**

Two talks by L. Sukhikh and K. Lekomtsev on **Coherent radiation monitors**

CLIC BI Today

- R&D on Critical issues known since long time already…
  50nm precision BPM – 20fs precision bunch length monitor – 1um transverse profile monitor

- Conceptual Design Report
  - Collect requirements for the whole CLIC complex (started in 2008)
    - 200kms of beam line, more than 10^5 instruments
  - Defined Baseline CLIC instrumentation with appropriate technology choice
  - Propose Alternative solutions which would impact either on cost or performance

BI Chapter is completed (waiting for publication) !
Many Thanks to the all of the 26 co-authors,
mainly from collaborating institutes

What comes next ?

- CLIC goes in the Project Preparation Phase (2012-16)
  - Testing of CLIC prototypes
  - Integration of CLIC instruments in the machine layout
  - Operational issues: reliability study and maintenance strategy
  - Cost optimization
    - Simplicity if applicable (not always compatible with tight tolerances)
    - Standardization (detectors, electronics) is a key concept
    - Gain in Mass production ?