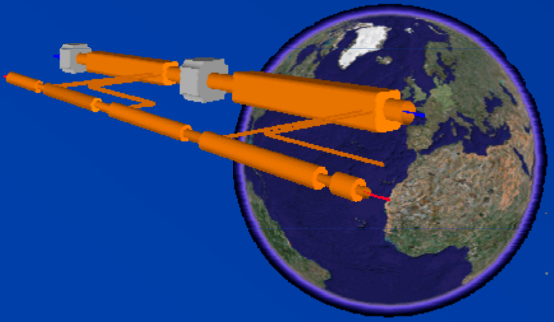
Report from the CLIC07 Workshop



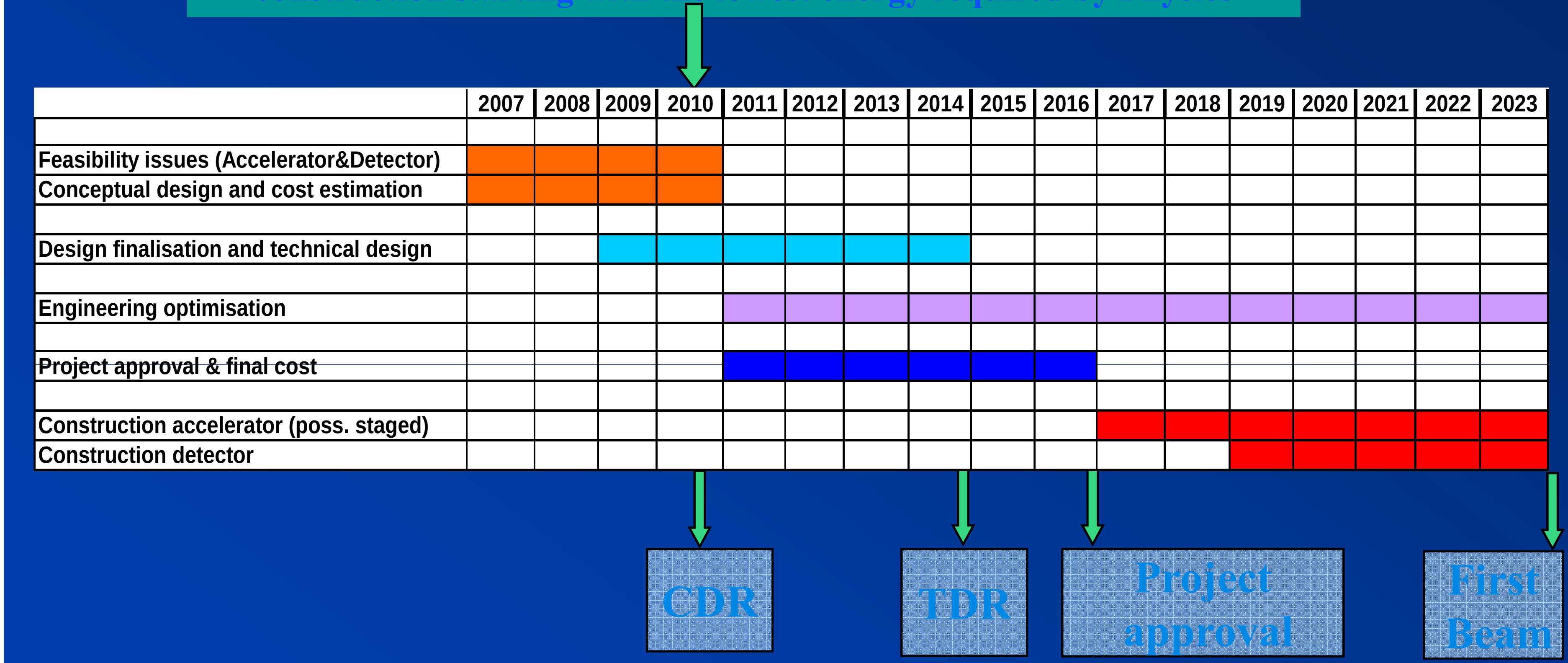
Markus Hüning
DESY
23.11.2007

The Workshop

- 200 registered participants from 49 institutions in 19 countries
- The workshop was supposed to address in particular:
  - Present status and future plans of the CLIC study
  - CLIC physics case and detector issues
  - The Test Facility CTF3 used to address major CLIC technology issues
  - The ongoing CLIC R&D, future plans (including FP7 proposals) and open issues
  - The CLIC related collaborative efforts

Linear Collider Roadmap from the CERN/CLIC point of view

Technology evaluation and Physics assessment based on LHC results for a possible decision on Linear Collider funding with staged construction starting with the lowest energy required by Physics



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Feasibility issues (Accelerator&Detector)	🟧	🟧	🟧	🟧													
Conceptual design and cost estimation	🟧	🟧	🟧	🟧													
Design finalisation and technical design			🟦	🟦	🟦	🟦	🟦	🟦									
Engineering optimisation					🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
Project approval & final cost					🟦	🟦	🟦	🟦	🟦	🟦							
Construction accelerator (poss. staged)											🟥	🟥	🟥	🟥	🟥	🟥	🟥
Construction detector													🟥	🟥	🟥	🟥	🟥

CDR

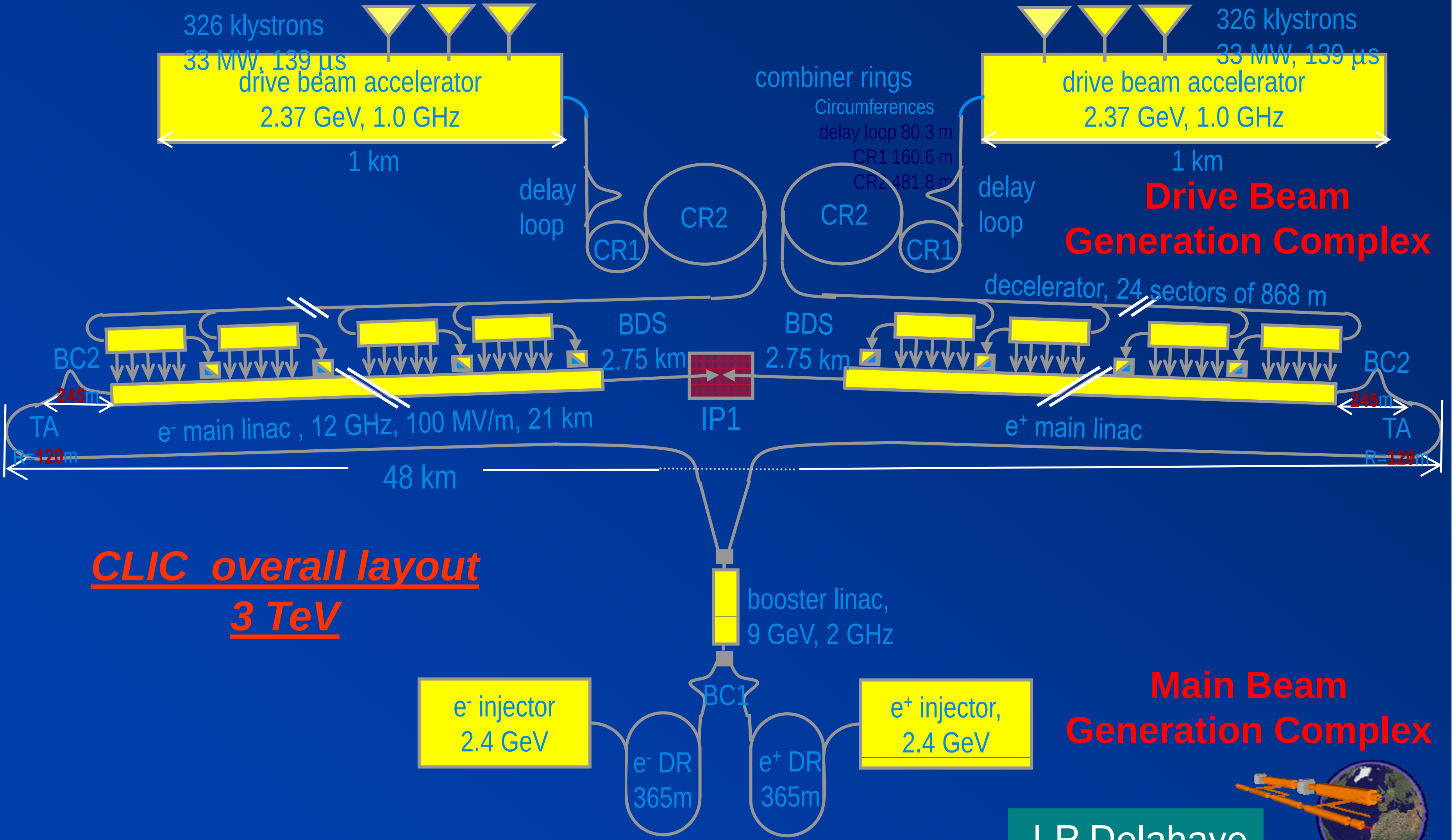
TDR

Project approval

First Beam

J-P Delahaye

The CLIC Layout



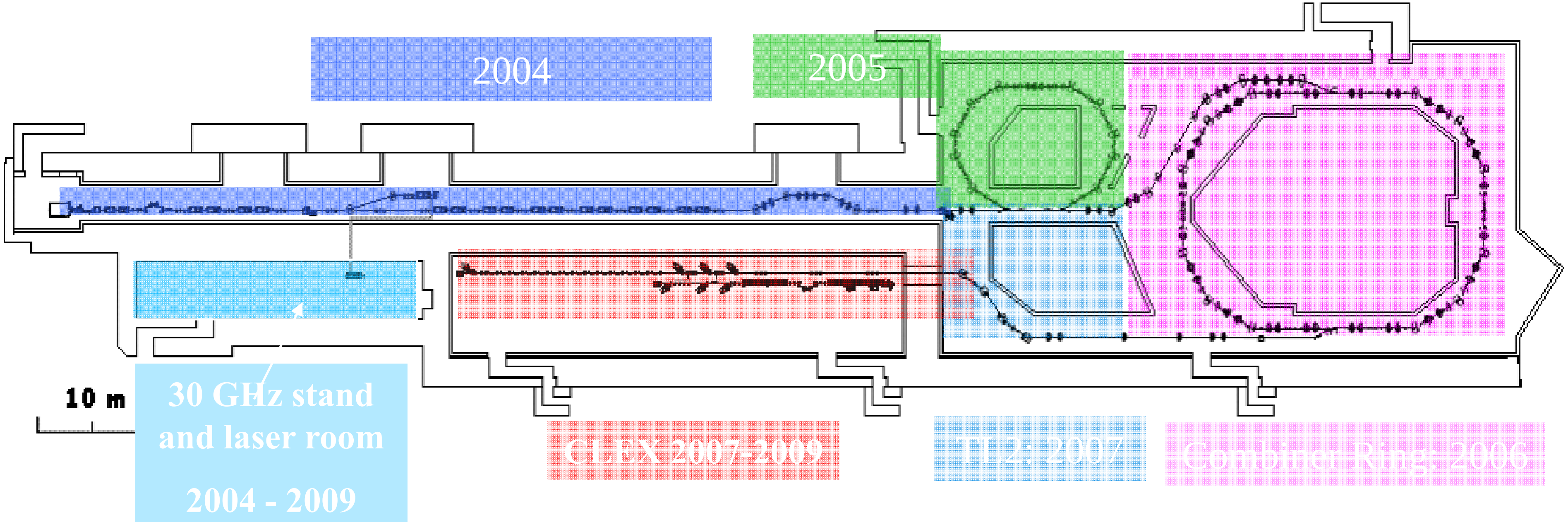
Drive Beam Generation Complex

CLIC overall layout
3 TeV

Main Beam Generation Complex

J-P Delahaye

The CTF 3



2004

2005

30 GHz stand and laser room

2004 - 2009

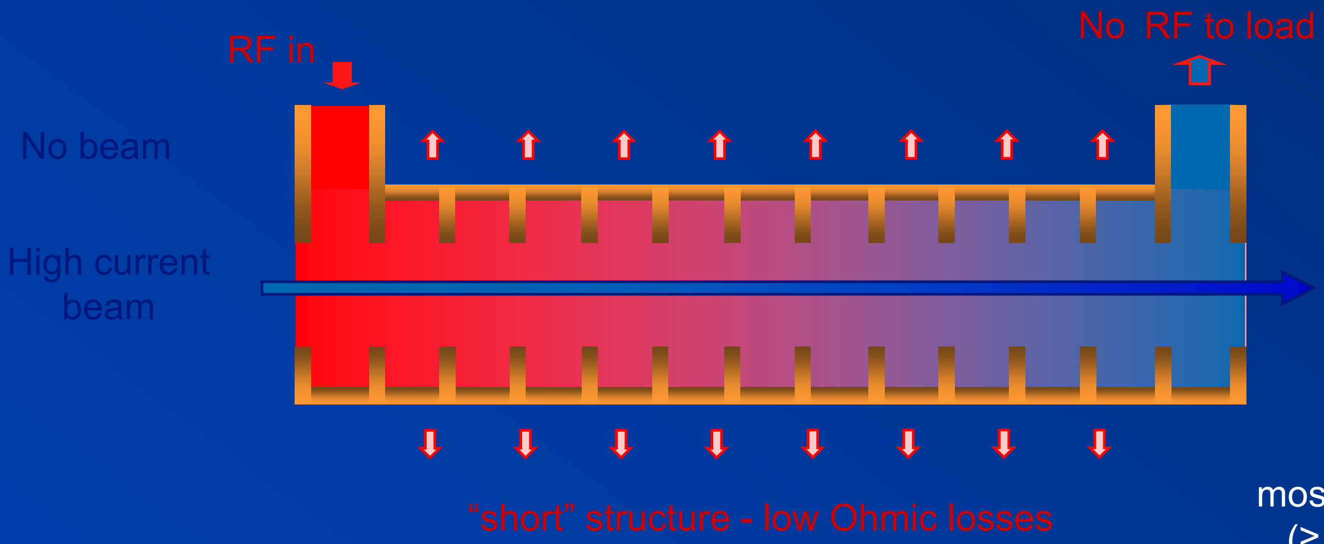
CLEX 2007-2009

TL2: 2007

Combiner Ring: 2006

Fully loaded Structures

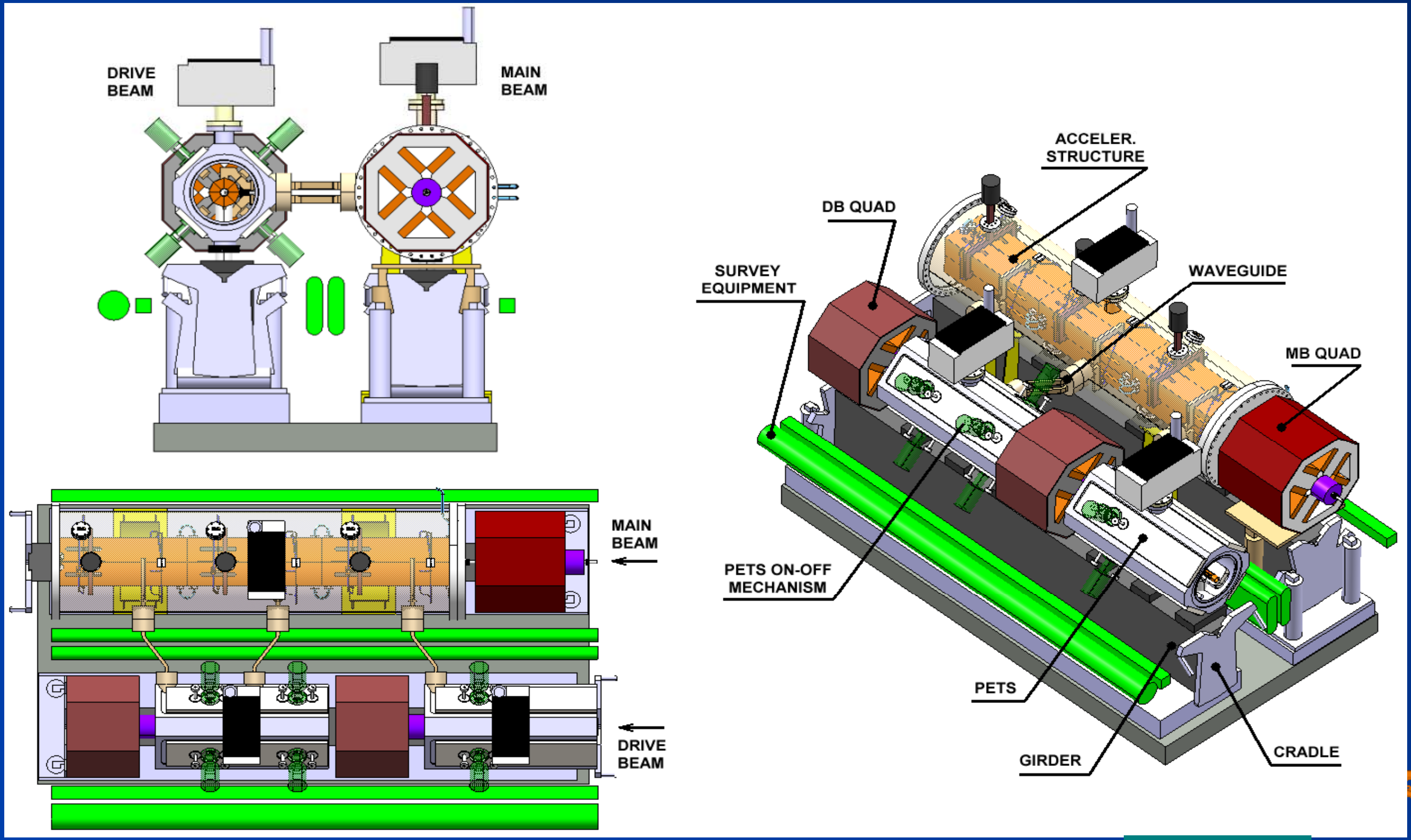
Full beam-loading acceleration in TW sections



most of RF power
(≥ 95%) to the
beam

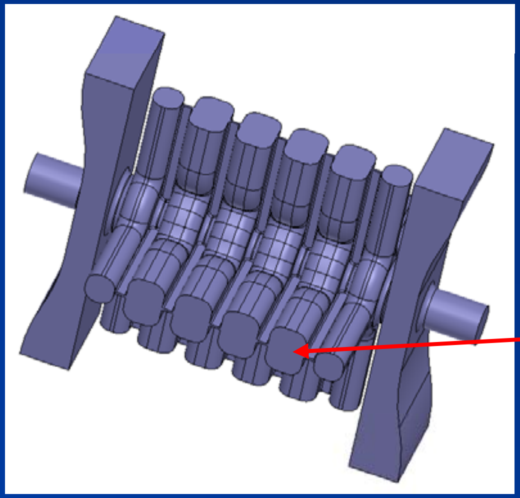
R Cosini

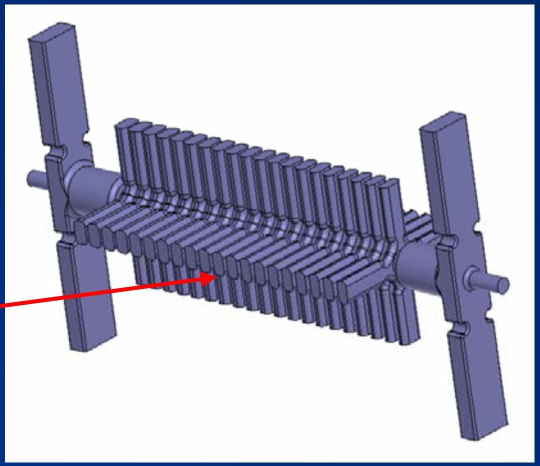
One CLIC Module



R Cosini

Geometry of CLIC accelerating structures

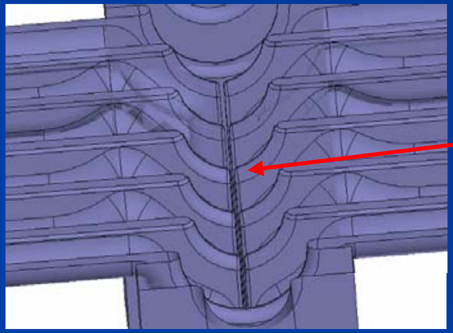




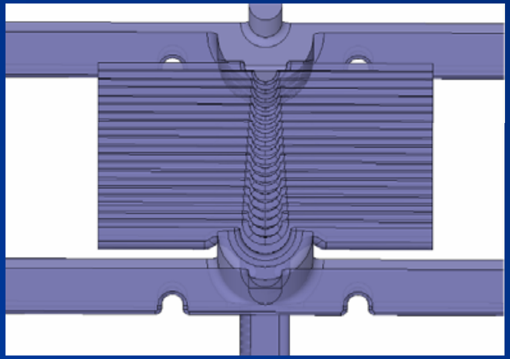
Higher order mode damping waveguides necessary for beam stability

HDS – slot and waveguide

WDS – waveguide only



damping slot for stronger damping



Must be milled quadrants. These can be clamped so exotic alloys, bimetallic possible.

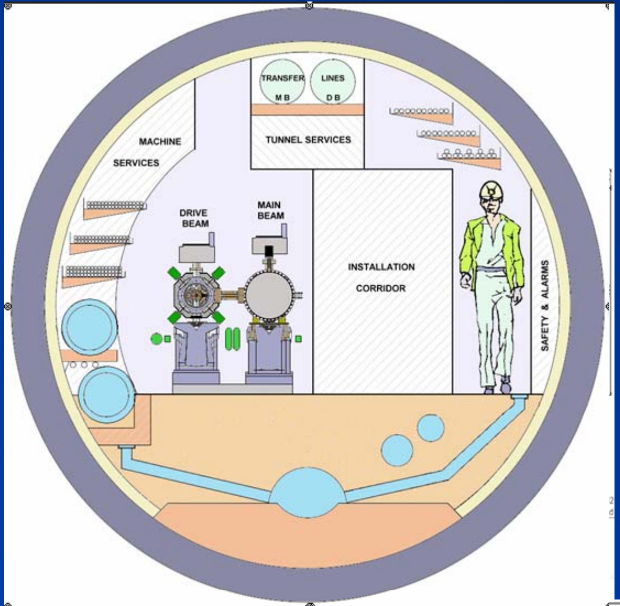
Technology

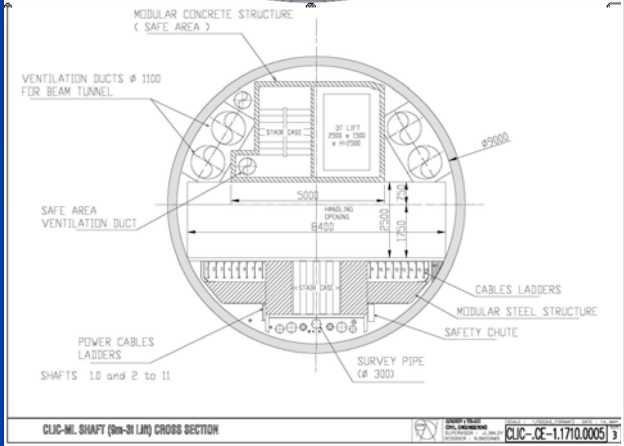
Can be milled quadrants or turned and milled disks. Disks must be brazed so are restricted to annealed copper.

W Wuensch

Single Tunnel Design

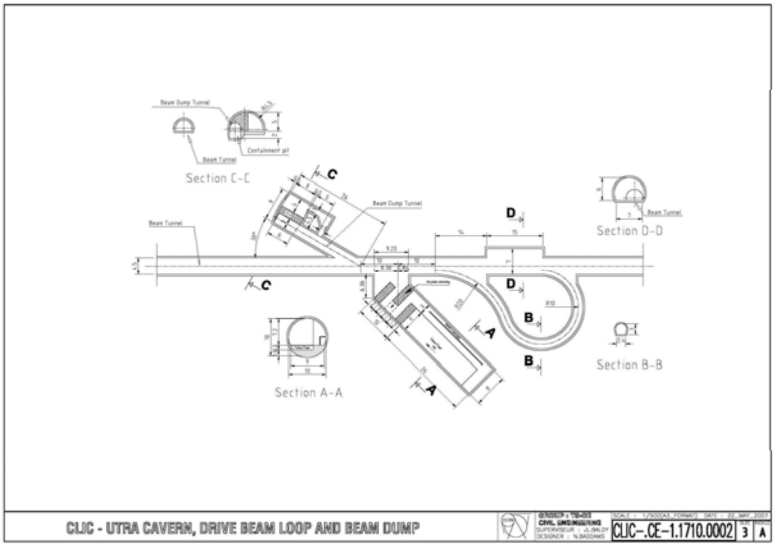
Single CLIC tunnel (4.5 m) with alcoves for drive beam return loops and dumps





CLIC-ML SHAFT (9m-3t Lift) CROSS SECTION

CLIC-.CE-1.1710.0005 3



CLIC - UTRA CAVERN, DRIVE BEAM LOOP AND BEAM DUMP

CLIC-.CE-1.1710.0002 3 A

The Key Issues (ILC-TRC)

Covered by CTF3

R1: Feasibility

- R1.2: Validation of drive beam generation scheme with fully loaded linac operation
- R1.1: Test of damped accelerating structure at design gradient and pulse length
- R1.3: Design and test of damped ON/OFF power extraction structure

R2: Design finalization

- R2.1: Developments of structures with hard-breaking materials (W, Mo…)
- R2.2: Validation of stability and losses of DB decelerator; Design of machine protection system
- R2.3: Test of relevant linac sub-unit with beam
- R2.4: Validation of drive beam 40 MW, 1 GHz Multi-Beam Klystron with long RF pulse
- R2.5: Effects of coherent synchrotron radiation in bunch compressors
- R2.6: Design of an extraction line for 3 TeV c.m.

Covered by EUROTeV

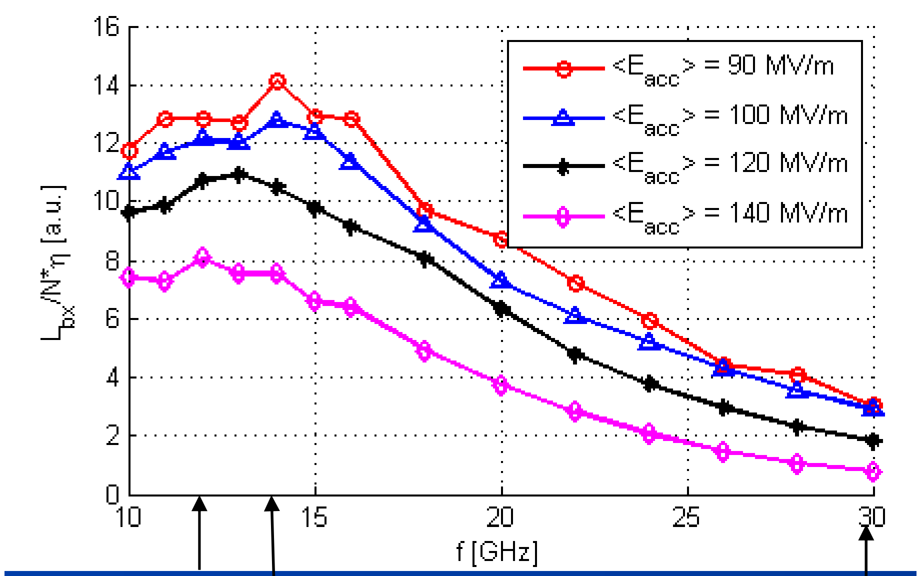
J-P Delahaye

Performance/Cost Optimization

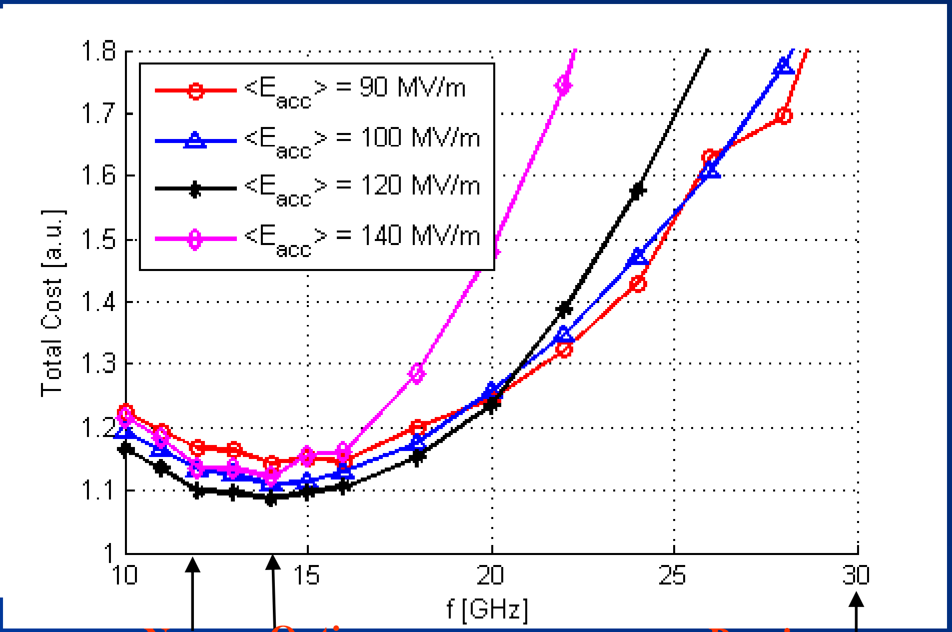
- Some lessons were learned:
  - High frequency (30 GHz) did not result in desired gradients and breakdown rates
  - Manufacture of 30 GHz structure difficult
  - Quadrant structure lacks performance
  - Optimal structures have very small aperture and group velocity
    - tight tolerances for manufacture
    - Wakefields increase even further
  - High gradient saves tunnel length but is less efficient

Performance/Cost Optimization

E_{cms} = 3 TeV $L_{(1\%)} = 2.0\ 10^{34}\ cm^{-2}s^{-1}$



New Optimum Previous

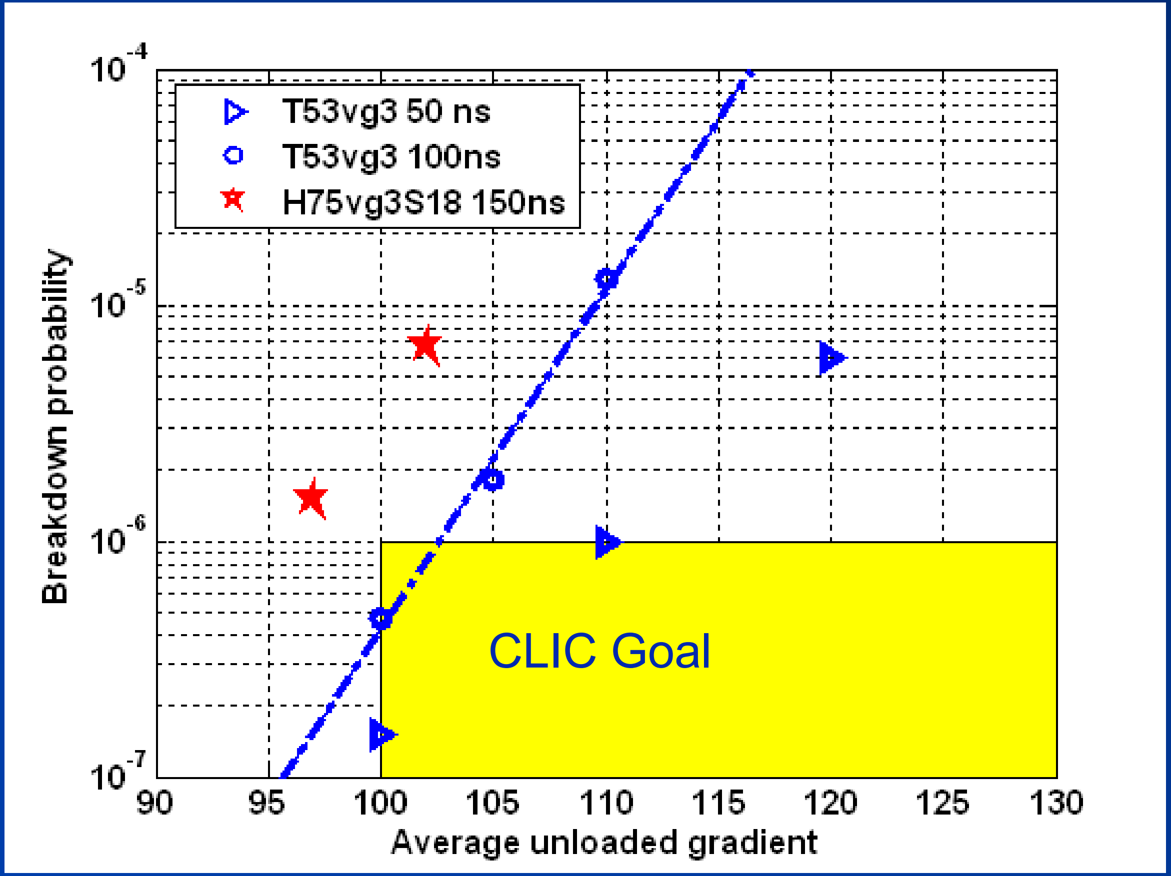


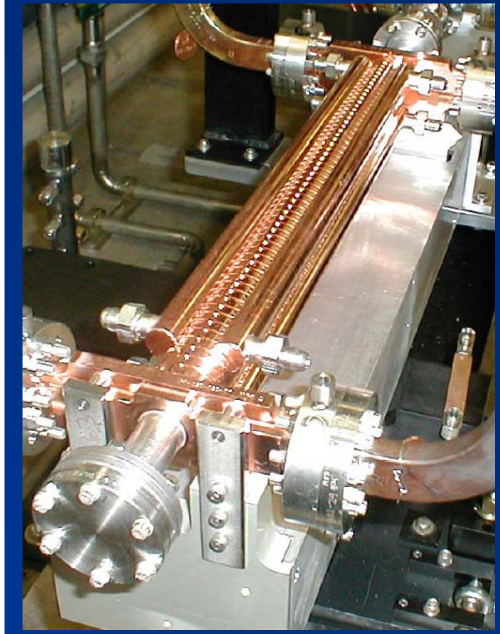
New Optimum Previous

- **Maximum Performance around 14 GHz**
- **Flat cost variation in 12 to 16 GHz frequency range with a minimum around 14 GHz**

J-P Delahaye

SLAC Results

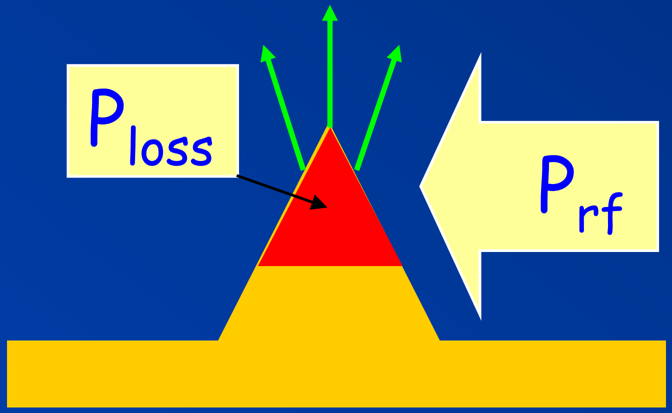




Remember: CLIC structure 23 cm long (2 Cavity Cells in ILC), need 130000!

J-P Delahaye

Model for RF Breakdown



$$\Delta T \approx P_{loss} < P_{rf}$$

$$P_{loss} = \int_V J_{FN} \cdot E \, dv$$

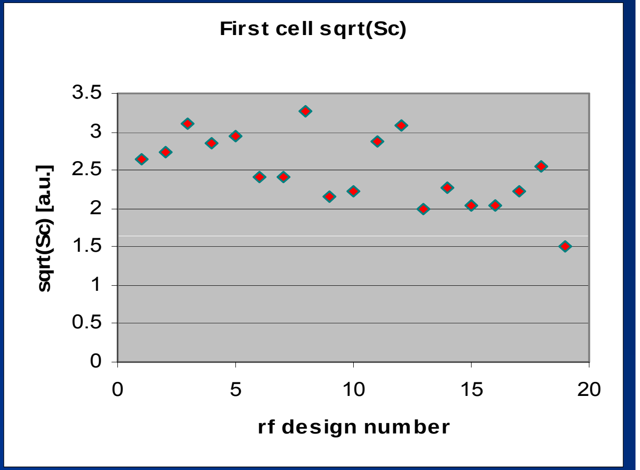
$$P_{rf} = \oint_S E \times H \, ds$$

There is no other source of energy in the cavity than rf energy.

W Wuensch

What matters for the breakdown is the amount of rf power coupled to the field emission heating.

$$P_{coup} = \int_0^{T/4} P_{rf}\cdot P_{loss}\,dt \Big/ \int_0^{T/4} P_{loss}\,dt$$
$$= C^{TW}E_0H_0^{TW} + C^{SW}E_0H_0^{SW}$$


First cell sqrt(Sc)

Assuming that all breakdown sites have the same geometrical parameters the breakdown limit can be expressed in terms of modified Poynting vector S_c.

$$S_c = E_0H_0^{TW} + \frac{C^{SW}}{C^{TW}}E_0H_0^{SW} = \mathrm{Re}\{\mathbf{S}\} + g_c\cdot\mathrm{Im}\{\mathbf{S}\}$$

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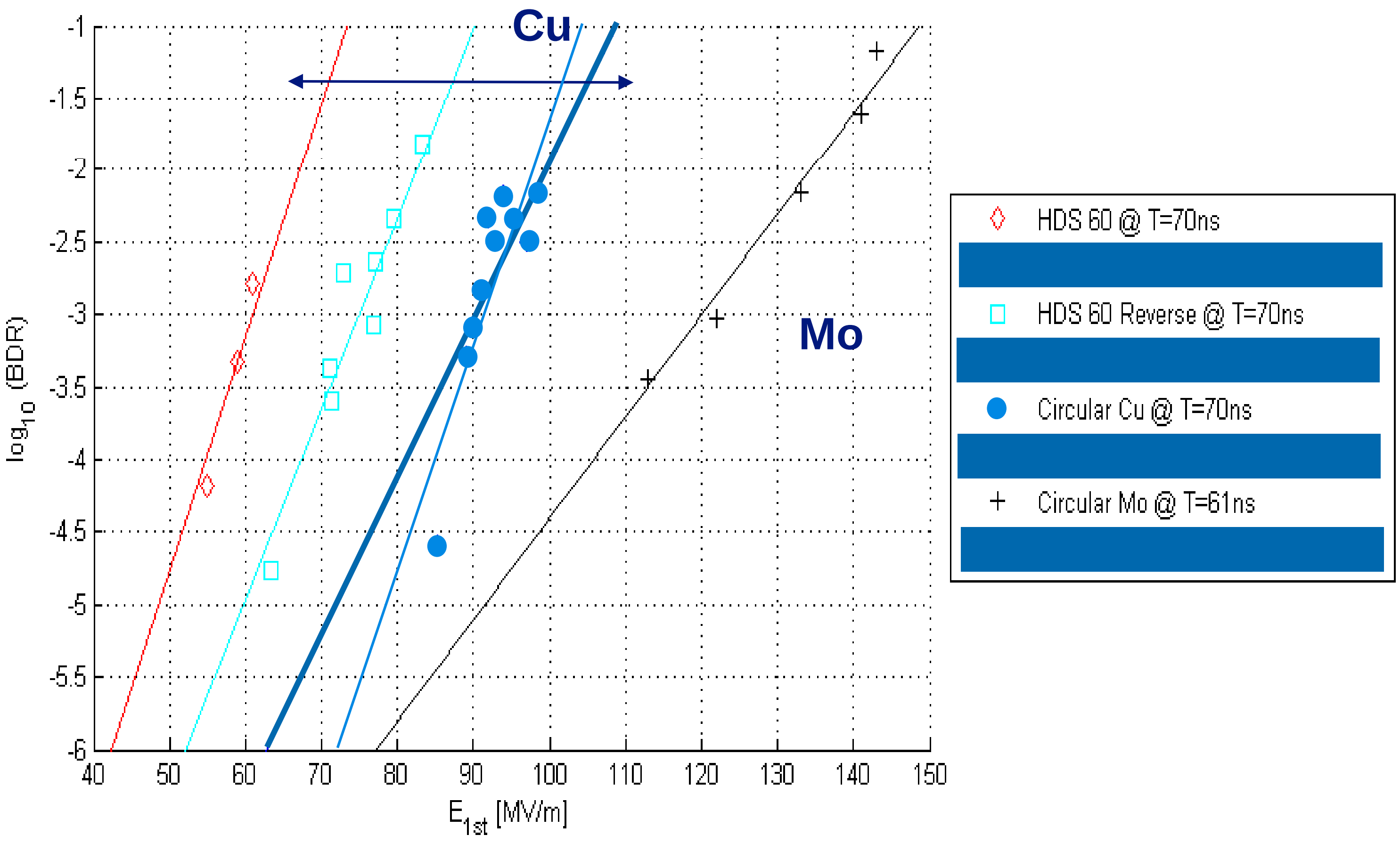
Material Selection



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Structure design

Structure	CLIC_G
Frequency: f [GHz]	12
Average iris radius/wavelength: $\langle a \rangle/\lambda$	0.11
Input/Output iris radii: $a_{1,2}$ [mm]	3.15, 2.35
Input/Output iris thickness: $d_{1,2}$ [mm]	1.67, 1.00
N. of reg. cells, str. length: N_c, l [mm]	24, 229
Bunch separation: N_s [rf cycles]	6
Luminosity per bunch X-ing: $L_{b\times}$ [m^{-2}]	1.22×10^{34}
Bunch population: N	3.72×10^{9}
Number of bunches in a train: N_b	312
Filling time, rise time: τ_f, τ_r [ns]	62.9, 22.4
Pulse length: τ_p [ns]	240.8
Input power: P_{in} [MW]	63.8
P_{in}/Ct$^{P}{}_{p}{}^{1/3}$[MW/mm ns$^{1/3}$]	18
Max. surface field: E_{surf}^{max} [MV/m]	245
Max. temperature rise: ΔT^{max} [K]	53
Efficiency: η [%]	27.7
Figure of merit: $\eta L_{b\times}/N$ [a.u.]	9.1

W Wuensch

New CLIC Design Parameters

CLIC 06 parameters: http://cdsweb.cern.ch/record/950185

Center-of-mass energy	3 TeV
Peak Luminosity	$7\cdot10^{34}$ cm^{-2} s^{-1}
Peak luminosity (in 1% of energy)	$2\cdot10^{34}$ cm^{-2} s^{-1}
Repetition rate	50 Hz
Loaded accelerating gradient	100 MV/m
Main linac RF frequency	12 GHz
Overall two-linac length	42 km
Bunch charge	$3.72\cdot10^{9}$
Bunch separation	0.5 ns
Beam pulse duration	156 ns
Beam power/beam	14 MWatts
Hor./vert. normalized emittance	660 / 20 nm rad
Hor./vert. IP beam size bef. pinch	40 / ~1 nm
Total site length	48 km
Total power consumption	322 MW

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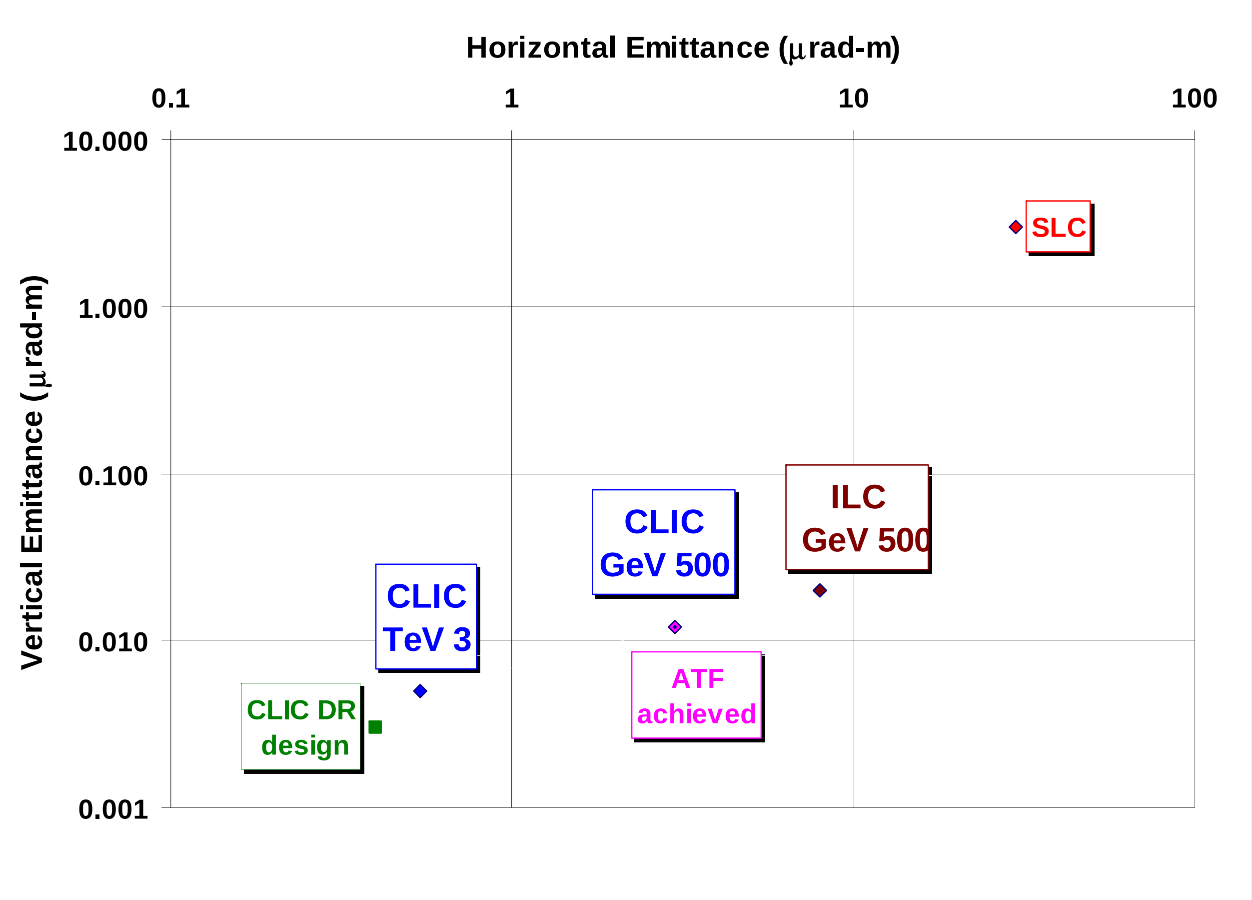
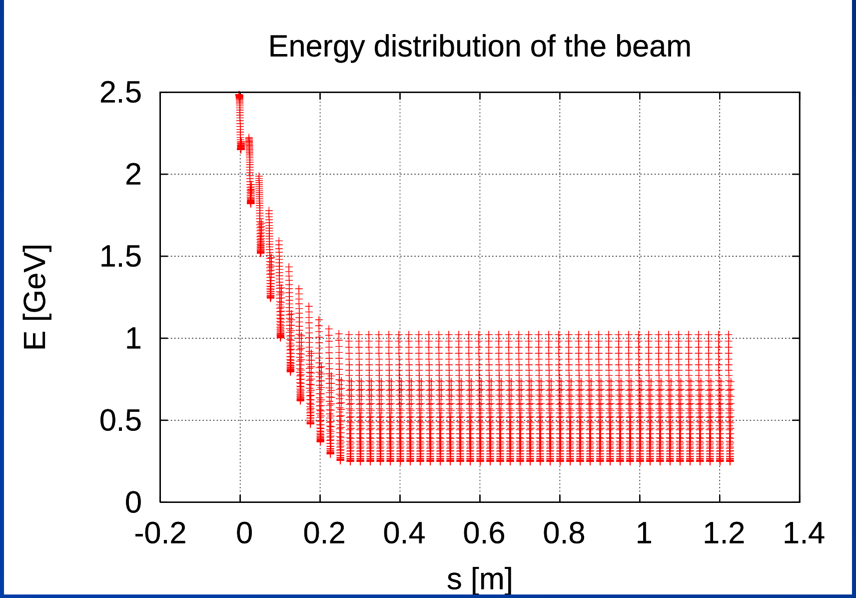
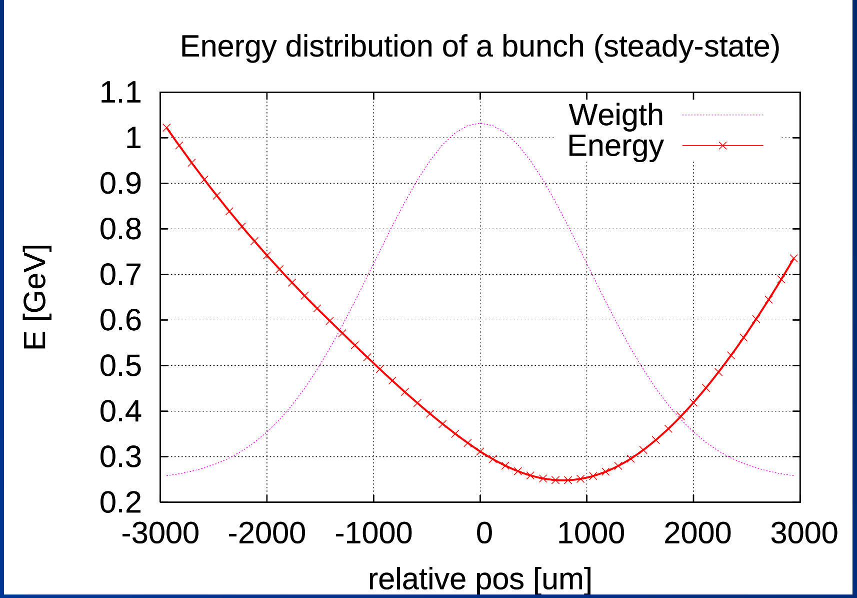
Emittance Goals

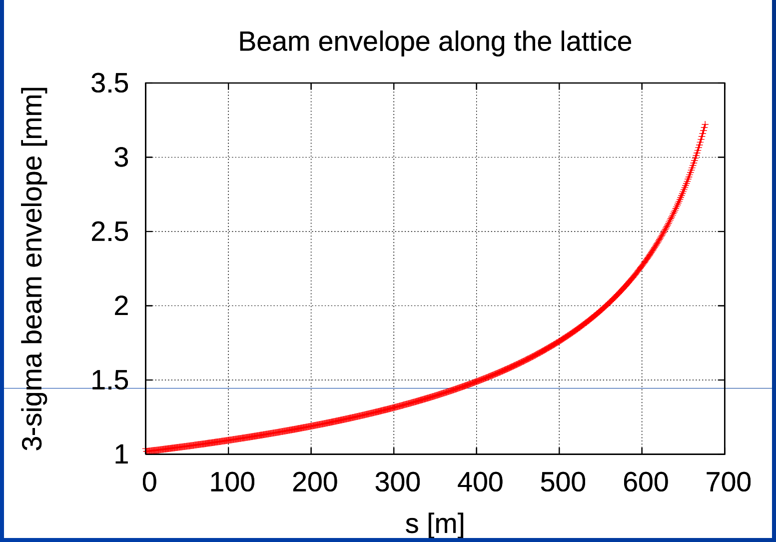


D Schulte

Drive Beam



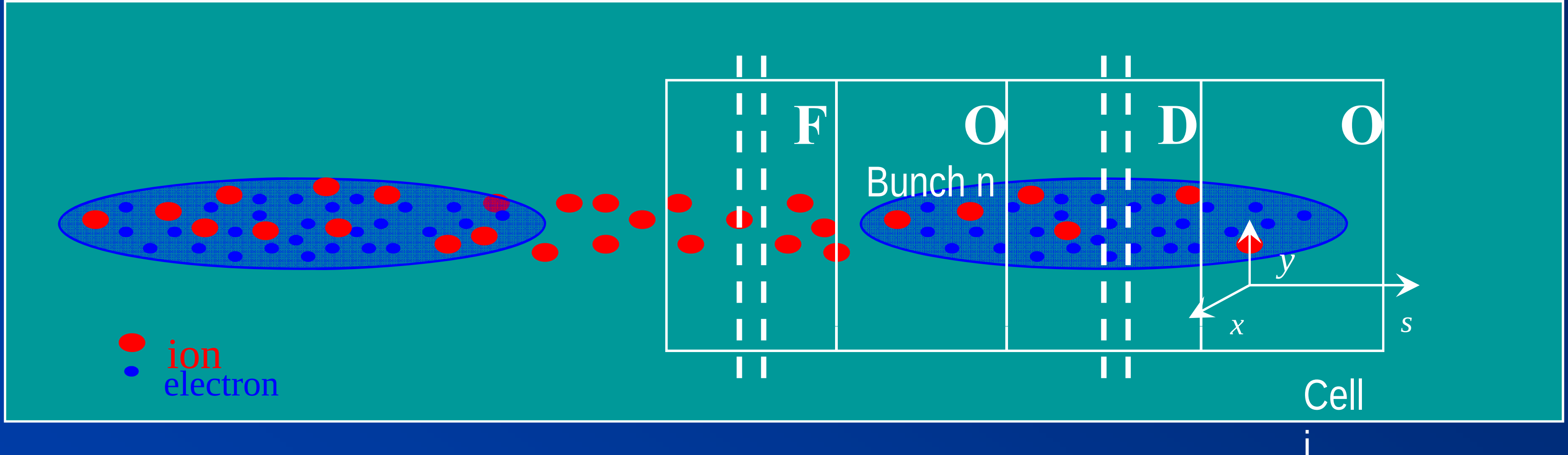




C Biscari

Fast Ion Instability

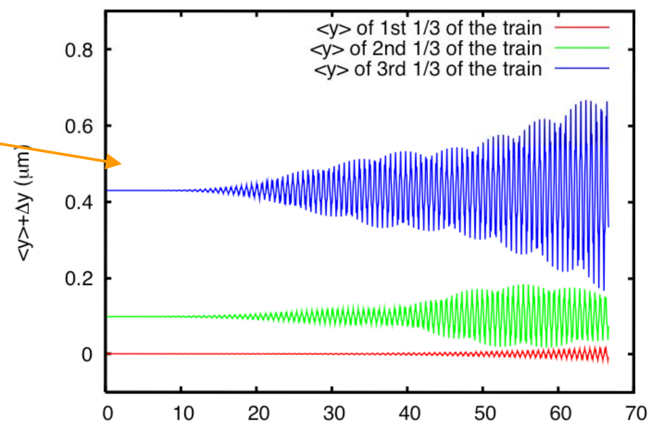
FASTION: new simulation code for FII in LInacs



ion effects in the CLIC Transport Line and Main Linac

1 nTorr is enough to have a fast instability in the Transfer Line

The threshold of instability lies between 1 and 10 nTorr in the Main Linac



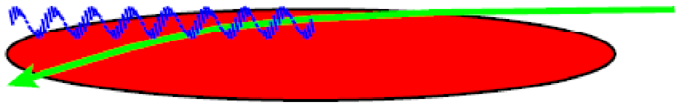
C Biscari

Beam Size Limit at IP

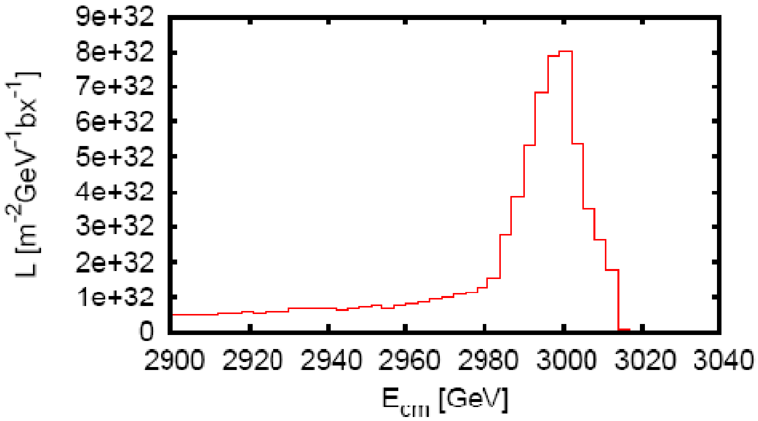
- Vertical beam size σ_y
  need to collide beams, beam delivery system, main linac, beam-beam effects, damping ring, bunch compressor

  $\Rightarrow$ vertical size $\sigma_y = 1\,\mathrm{nm}$ is reasonable

  $\Rightarrow$ $\epsilon_y = 20\,\mathrm{nm}$ is practical



- Horizontal beam size σ_x
  beam-beam effects, final focus system, damping ring, bunch compressors
- Fundamental limit on horizontal beam size arises from beamstrahlung (limits N/σ_x as function of σ_z)
- Other lower limit for σ_x is given by finite damping ring emittance and difficulty to yield very small β_x/σ_x in BDS



$\Rightarrow$ Use luminosity in peak as figure of merit

D Schulte

Main Beam Emittance Budgets and Luminosity

- For the vertical emittance a budget has been established
  - $\epsilon_y \leq 5\,\mathrm{nm}$ after damping ring extraction
  - $\Delta\epsilon_y \leq 5\,\mathrm{nm}$ during transport to main linac
  - $\Delta\epsilon_y \leq 10\,\mathrm{nm}$ in main linac
- For the horizontal emittance the old design gave
  - $\epsilon_x = 550\,\mathrm{nm}$ after damping ring extraction
  - $\epsilon_x = 660\,\mathrm{nm}$ before the beam delivery system with the growth mainly in the RTML
- The emittance budget
  - includes design, static and dynamic effects
  - requires 90% of the machines to perform better than the target
- The luminosity is calculated
  - using $\epsilon_x \leq 660\,\mathrm{nm}$, $\epsilon_y \leq 20\,\mathrm{nm}$ before the beam delivery system
  - tracking the beam through a perfect beam delivery system ($L^* = 4.3\,\mathrm{m}$, $L^* = 3.5\,\mathrm{m}$ needs optimisation)
  - simulating the beam-beam effects
  - dividing the found luminosity by 1.2

D Schulte

Main Linac

- Specific challenges are
  - single and multi-bunch wakefields, transverse kicks
  - dynamic and static imperfections of quadrupoles and BPMs
  - RF stability
- The main linac limits the charge per bunch and the bunch-to-bunch distance

  ⇒ has been one of the optimisation drivers
- Goal is to keep static emittance growth below $5\,\mathrm{nm}$ for 90% of the machines
- Average dynamic growth should stay below $5\,\mathrm{nm}$

Element	error	with respect to	tolerance	
			CLIC	NLC
Structure	offset	beam	$5.8\,\mu\mathrm{m}$	$5.0\,\mu\mathrm{m}$
Structure	tilt	beam	$220\,\mu\mathrm{radian}$	$135\,\mu\mathrm{radian}$
Quadrupole	roll	axis	$240\,\mu\mathrm{radian}$	$280\,\mu\mathrm{radian}$
BPM	offset	straight line	$0.44\,\mu\mathrm{m}$	$1.3\,\mu\mathrm{m}$
BPM	resolution	BPM center	$0.44\,\mu\mathrm{m}$	$1.3\,\mu\mathrm{m}$

- Most relevant tolerances for 1nm growth after one-to-one steering
- Using DFS relaxes BPM position but constrains BPM resolution (example case $57\,\mu\mathrm{m}$ and $0.18\,\mu\mathrm{m}$), bumps help

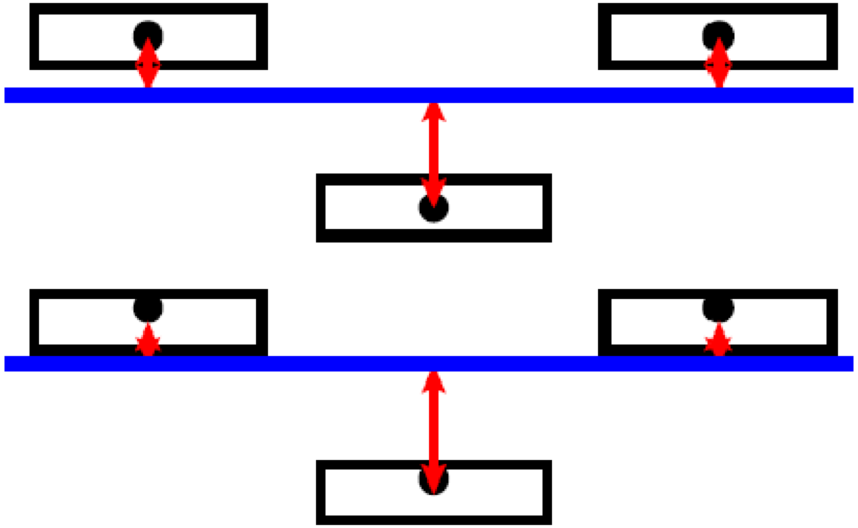
D Schulte

Beam-Based Structure Alignment

- Each structure is equipped with a wakefield monitor (RMS position error $5\ \mu\mathrm{m}$)
- Up to eight structures are mounted on movable girders

⇒ Align structures to the beam

- For identical wakefields:
  - wakefield monitor errors are relevant
- For differeing wakefields
  - structure to beam offset is relevant
- Structure precision is relevant parameter for tilt
  - upper and lower half must be aligned to $\mu\mathrm{m}$ precision



- Tolerance and performance prediction are similar for CLIC and NLC
  - $5.8\ \mu\mathrm{m}/\sqrt{2}$ vs. $5\ \mu\mathrm{m}$
  - $5\ \mu\mathrm{m}$ vs. $5\ \mu\mathrm{m}$

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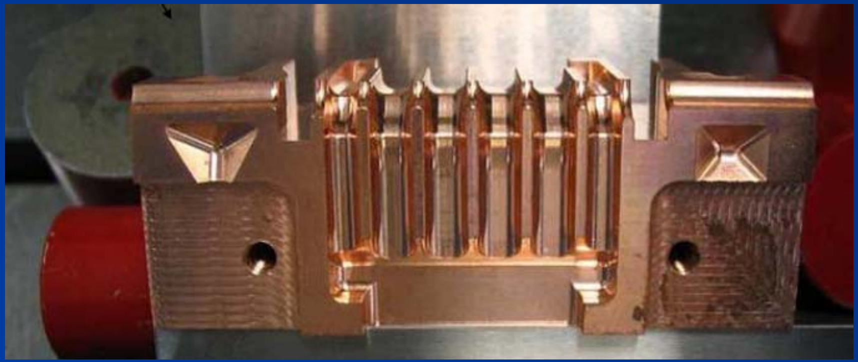
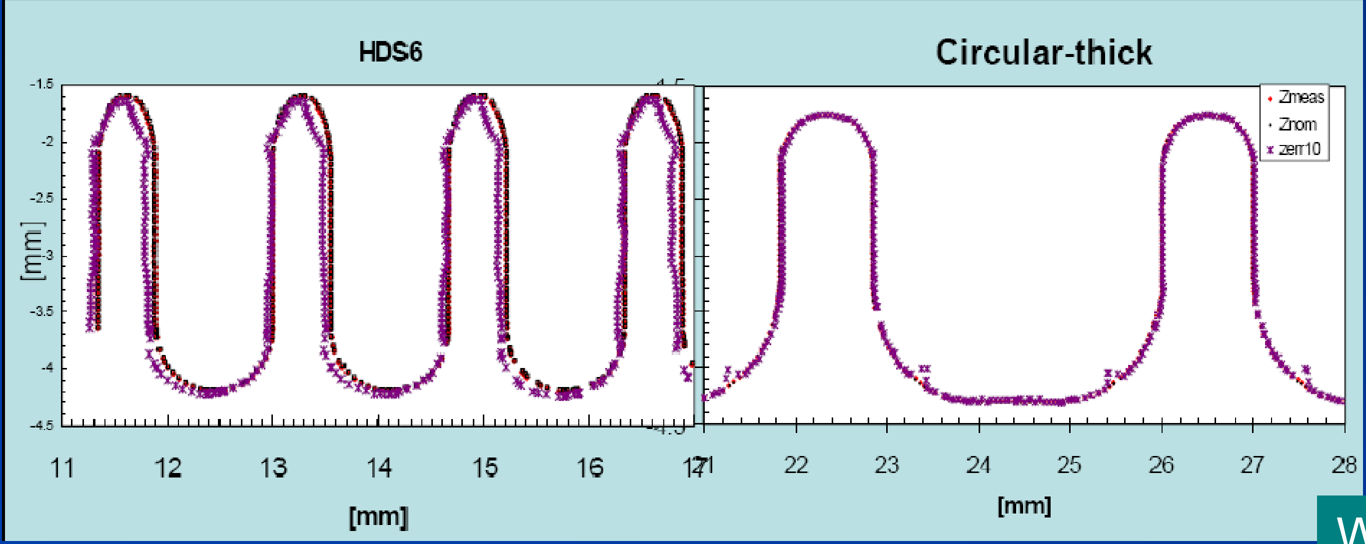
Shape Tolerances



Machining tolerances down to 5 µm (cutting edge)

Measurement: coordinate measuring machine, contact with 0.1N force, accuracy +/-3 µm (at CERN), scan pt. by pt. on the surface ………in parallel with RF low power control



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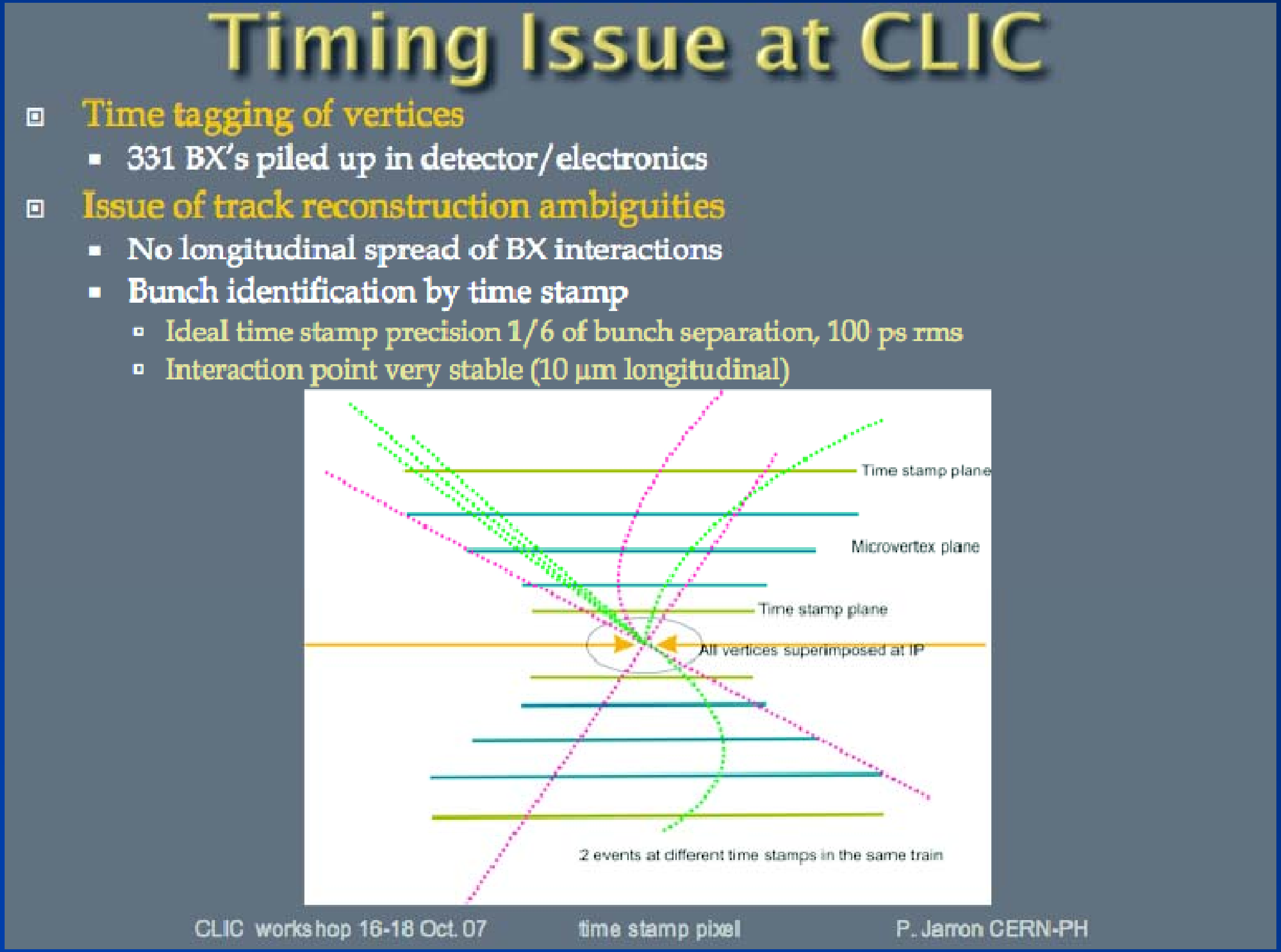
Physics and Detectors



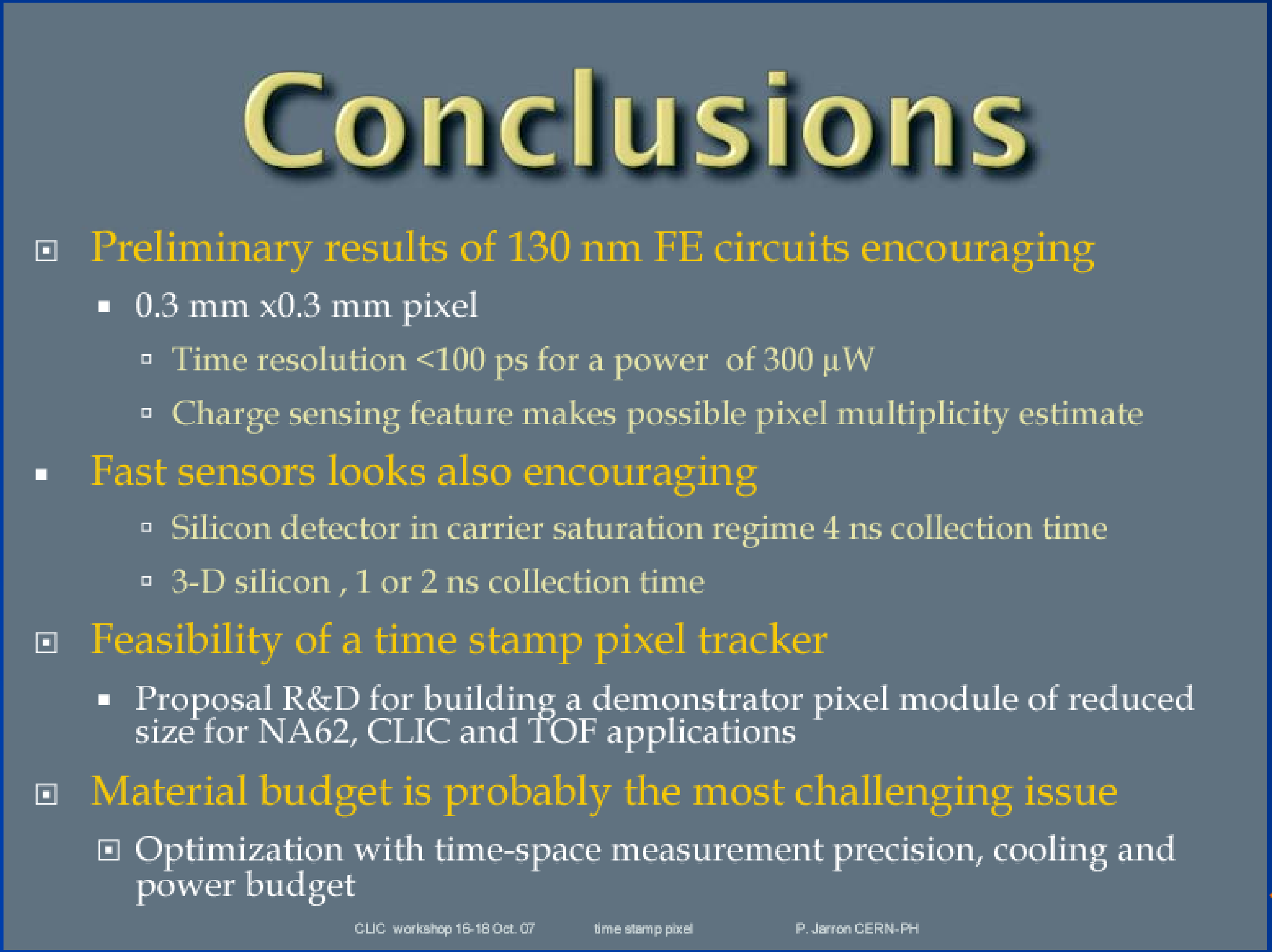
Timing Issue at CLIC

- Time tagging of vertices
  - 331 BX's piled up in detector/electronics
- Issue of track reconstruction ambiguities
  - No longitudinal spread of BX interactions
  - Bunch identification by time stamp
    - Ideal time stamp precision 1/6 of bunch separation, 100 ps rms
    - Interaction point very stable (10 µm longitudinal)

CLIC workshop 16-18 Oct. 07 time stamp pixel P. Jarron CERN-PH

M Hauschild

Physics and Detectors



Conclusions

- Preliminary results of 130 nm FE circuits encouraging
  - 0.3 mm x0.3 mm pixel
    - Time resolution <100 ps for a power of 300 μW
    - Charge sensing feature makes possible pixel multiplicity estimate
- Fast sensors looks also encouraging
    - Silicon detector in carrier saturation regime 4 ns collection time
    - 3-D silicon , 1 or 2 ns collection time
- Feasibility of a time stamp pixel tracker
  - Proposal R&D for building a demonstrator pixel module of reduced size for NA62, CLIC and TOF applications
- Material budget is probably the most challenging issue
  - Optimization with time-space measurement precision, cooling and power budget

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Physics and Detectors

- Dense program, perhaps too limited time for discussion on some topics
- Good exchange with ILC experts/possible basis for future collaborations?
  - There are certainly communalities with the ILC detectors
  - ILC detector studies: R&D and discussions/optimization still ongoing
- Remind that physics wants to keep options, such as polarization
- Work is needed for the CLIC on detector studies
  - Some benchmark channels started (taking SiD)
  - Need to discuss MDI with machine group (e.g.Mask upgrade/forward region instrumentation)
  - How well does particle flow (Energy flow) work at CLIC?
- R&D detector proposals being prepared
  - Good prospects for adequate time stamping at CLIC
  - Novel calorimeter concepts
- Include specific detector R &D in FP7? (February 2008)

M Hauschild

Remarks

- The CLIC study aims at proving the feasibility by 2010 (The expected time of decision on the Linear Collider)
- The Frequency choice caused a few former NLC collaborators (and FEL projects) to join in on the project
- It seemed (to me) that the main goal of the workshop was to convince people that CLIC can be built
- A model for cost and performance was used to find new parameter set – the details are not public yet, during the workshop it was mentioned only once
- According to CERN whatever the results of LHC – CLIC is needed