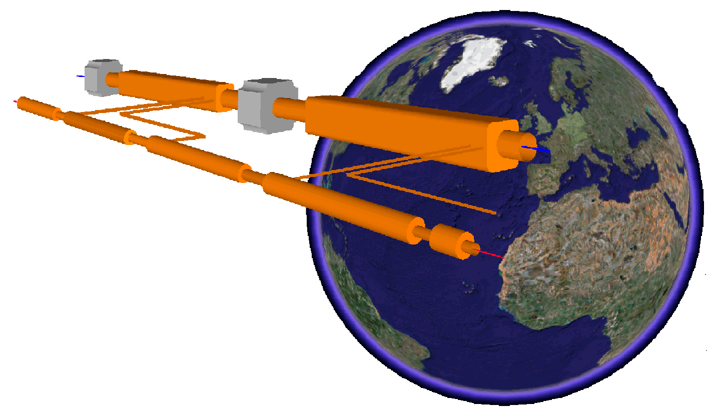
CLIC Status

D. Schulte for the CLIC study team



http://clic-study.web.cern.ch/CLIC-Study/

World-Wide CLIC&CTF3 Collaboration

http://clic-meeting.web.cern.ch/clic-meeting/CTF3_Coordination_Mtg/Table_MoU.htm

33 Institutes involving 22 funding agencies from 18 countries

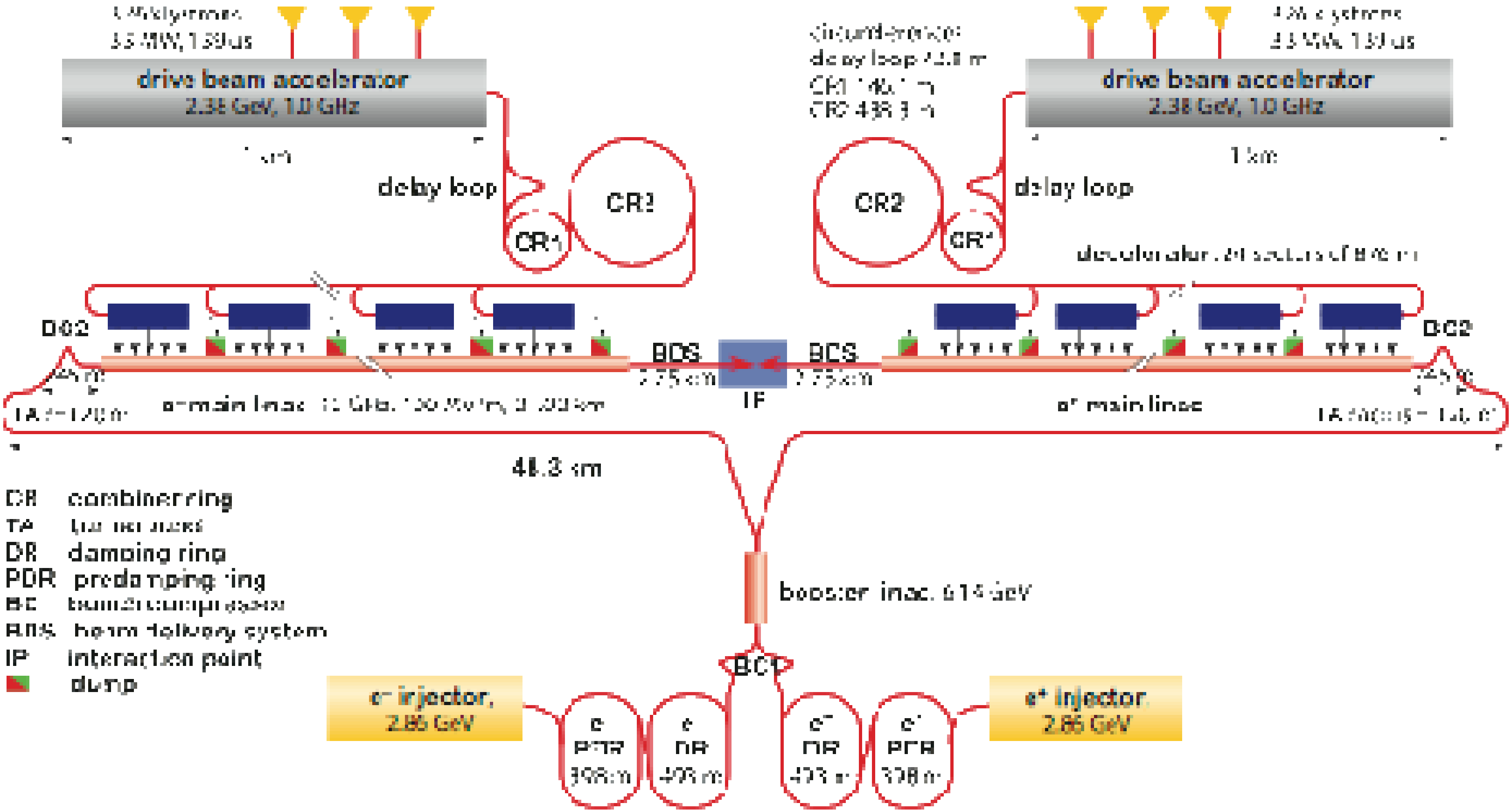
Aarhus University (Denmark)
Ankara University (Turkey)
Argonne National Laboratory (USA)
Athens University (Greece)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
Gazi Universities (Turkey)

Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
INFN / LNF (Italy)
Instituto de Fisica Corpuscular (Spain)
IRFU / Saclay (France)
Jefferson Lab (USA)
John Adams Institute (UK)

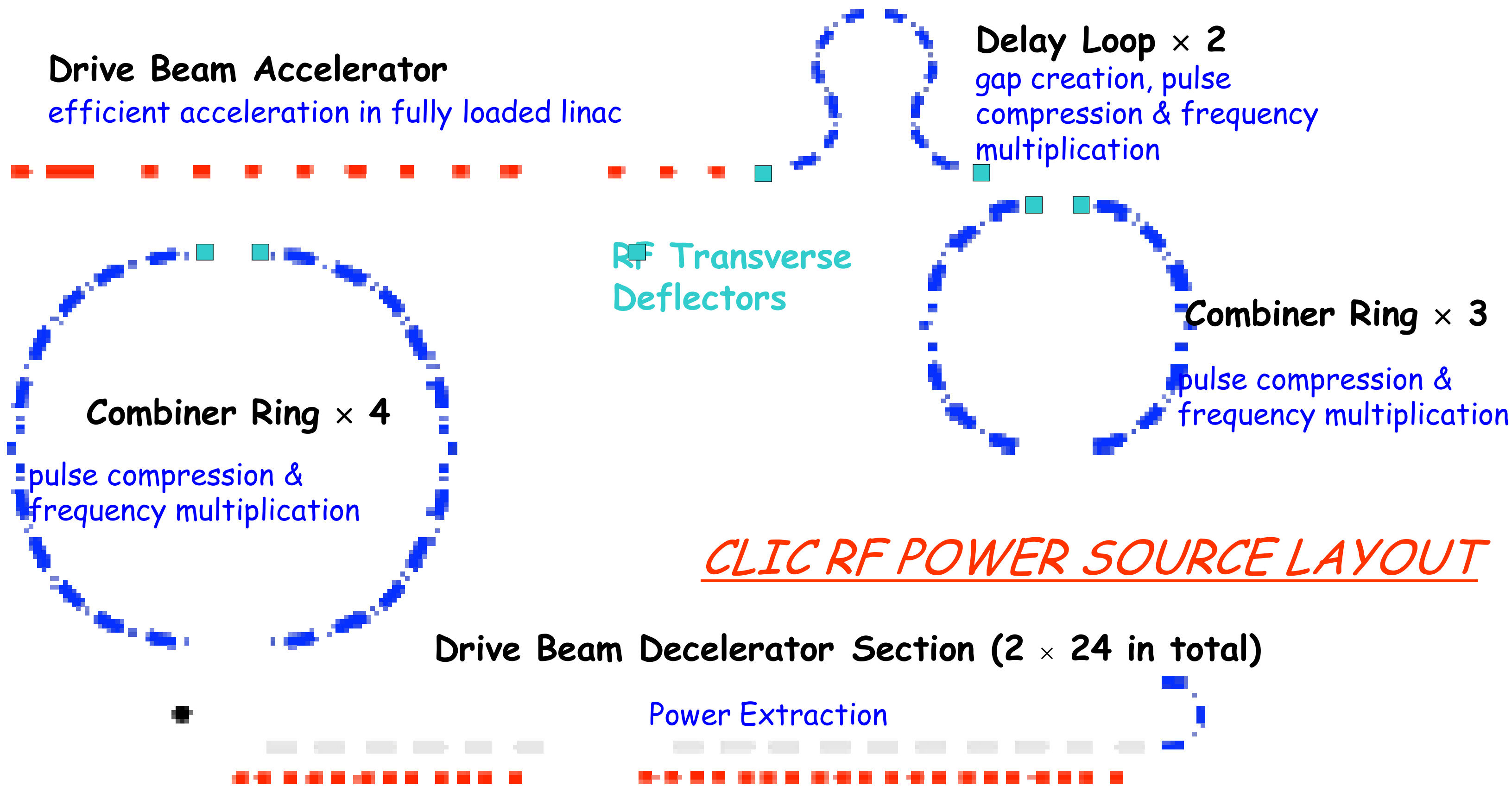
JINR (Russia)
Karlsruhre University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Patras University (Greece)

Polytech. University of Catalonia (Spain)
PSI (Switzerland)
RAL (UK)
RRCAT / Indore (India)
SLAC (USA)
Thrace University (Greece)
University of Oslo (Norway)
Uppsala University (Sweden)

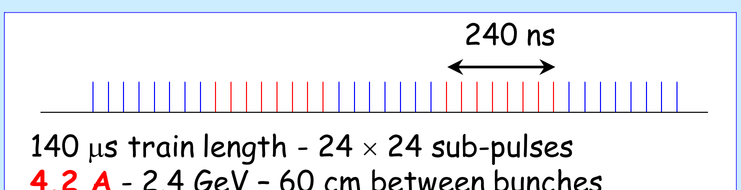
Reminder: The CLIC Layout



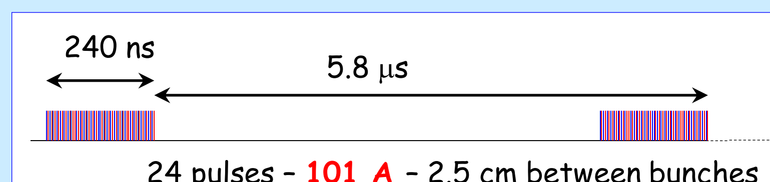
CLIC Power Source Concept



Drive beam time structure - initial



Drive beam time structure - final



CLIC Main Parameters

http://cdsweb.cern.ch/record/1132079?ln=fr http://clic-meeting.web.cern.ch/clic-meeting/clictable2007.html

High gradient to reduce cost

- Break down of structures at high fields and long pulses
  - Pushes to short pulses
  - and small iris radii (high wakefields)

High luminosity

- Improve wall plug to RF efficiency
- Push RF to beam efficiency
  - Push single bunch charge to beam dynamics limit
  - Reduce bunch distance to beam dynamics limit
- Push specific luminosity -> High beam quality
  - Beam-based alignment and tuning
  - Excellent pre-alignment
  - Component stabilisation

		CLIC	CLIC	ILC
E_{cms}	[TeV]	0.5	3.0	0.5
f_{rep}	[Hz]	50	50	5
f_{RF}	[GHz]	12	12	1.3
G_{RF}	[MV/m]	80	100	31.5
n_b		354	312	2625
Δt	[ns]	0.5	0.5	369
N	$[10^9]$	6.8	3.7	20
σ_x	[nm]	202	40	655
σ_y	[nm]	2.26	1	5.7
ϵ_x	[μm]	2.4	0.66	10
ϵ_y	[nm]	25	20	40
$\mathcal{L}_{total}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	2.3	5.9	2.0
$\mathcal{L}_{0.01}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	1.4	2.0	1.45

CLIC Plan

- Divided the identified critical issues into three categories (endorsed by ACE)
  - Failure to solve a feasibility issue implies that the CLIC technology is fundamentally not suited to build a machine of interest for high energy physics
  - Performance issues can compromise the performance
  - Cost issues have significant impact on cost

- For the CDR concentrate on addressing feasibility issues (mid 2011 to council)
  - Targeted conclusion: It is worth to make a technical design of such a machine
  - A baseline is being developed, involving many new experts
  - Will have turned the feasibility issues mostly into performance issues
    - Programme is in place and needs some continuation afterwards
  - A number of important performance issues addressed
  - A number of important cost issues addressed

- In the TDR phase more detail is needed (2016)
  - Targeted conclusion: One can propose this machine as a project
  - Something that is not a feasiblity issue could kill a project
  - Addressing the performance issues
  - Reducing cost
  - A workplan for the TDR phase is being finalised

10 CLIC Feasibility Issues

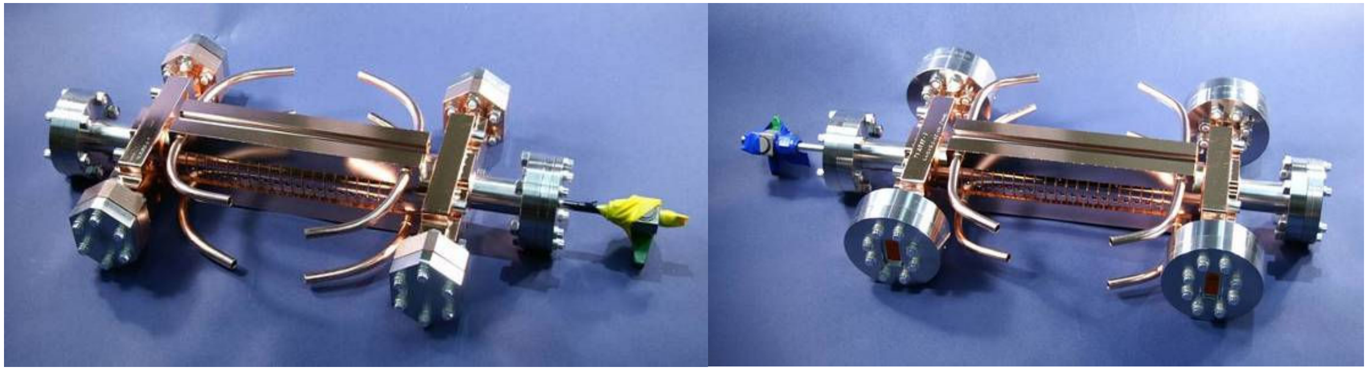
- RF Structures (gradient + power generation):
  - Accelerating Structures (CAS)
  - Power Production Structures (PETS)
- Two Beam Acceleration (power generation and machine concept):
  - Drive beam generation
  - Two beam module
  - Drive beam deceleration
- Ultra low beam emittance and beam sizes (luminosity):
  - Emittance preservation during generation, acceleration and focusing
  - Alignment and stabilisation
- Detector (experimental conditions):
  - Adaptation to short interval between bunches
  - Adaptation to large background at high beam collision energy
- Operation and Machine Protection System (robustness)

Gradient Limitations

- Structure gradients are limited by breakdowns, depending on
  - Surface electric field
  - Surface magnetic field
    - Pulsed surface heating
  - RF power flow
    - RF power flow through iris aperture
  - Have empiric limits for these values but no full theory
    - Experiments are vital
- Structures can generally achieve higher gradients if the aperture is reduced
  - But higher wakefields $\Rightarrow$ beam stability
  - Can focus the beam more $\Rightarrow$ tight tolerances on misalignments and jitters
  - Need to find a compromise $\Rightarrow$ performed full parameter optimisation

Results Obtained To Date

T18 and TD18 built and tested at SLAC and KEK
• real prototypes with improved design are TD24



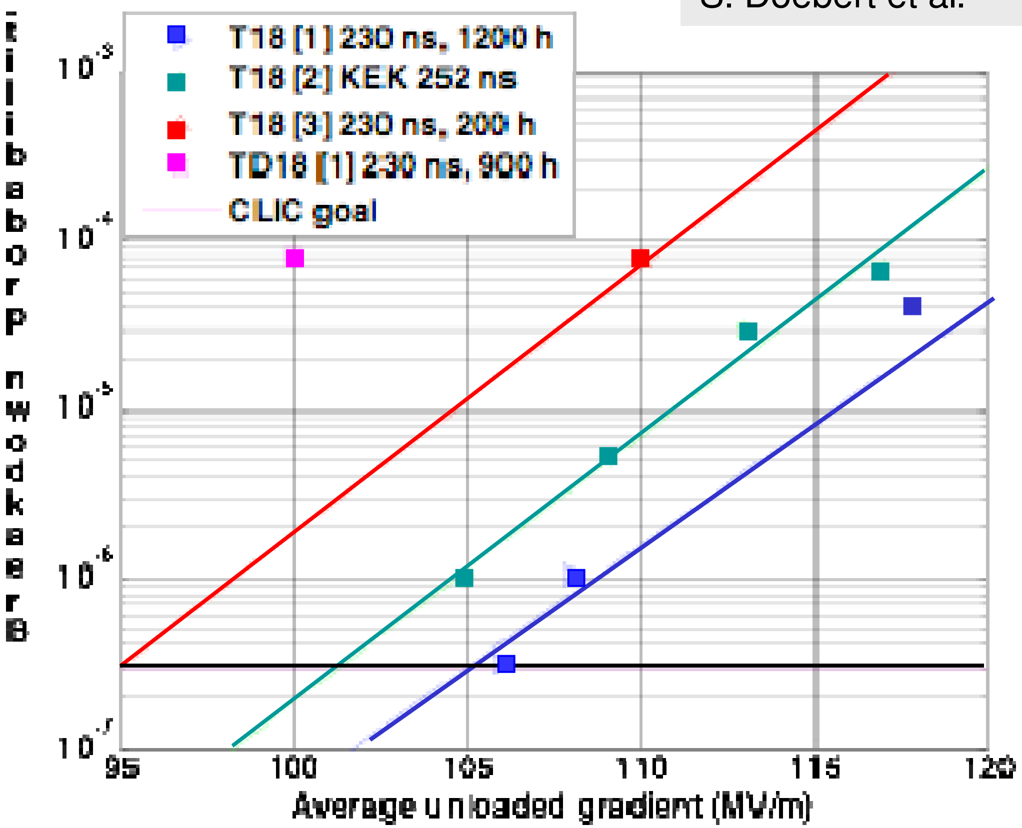
Goal: 3 10^{-7}/m at 100 MV/m loaded at 230 ns

T18 reaches 95-105 MV/m

Damped TD18 reaches an extrapolated 85MV/m
• Second TD18 under test at KEK
• Pulsed heating expected to be above limit

Will test TD24 this year
• expect similar or slightly better performance

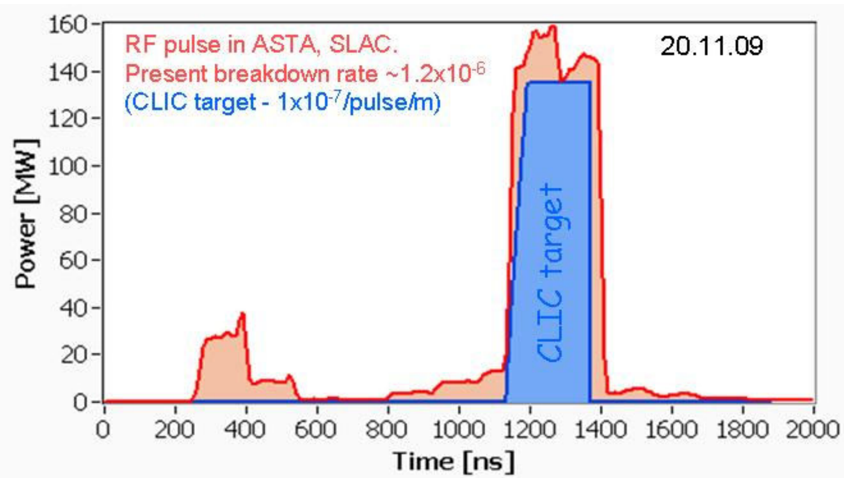
S. Doebert et al.

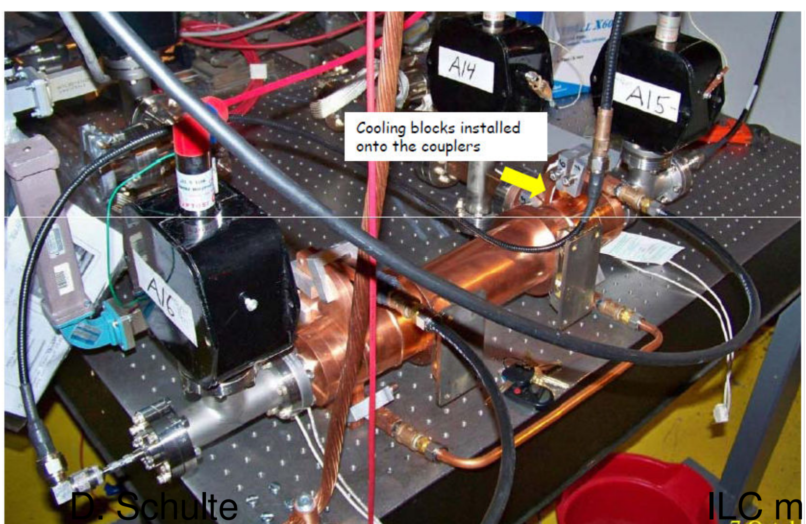


PETS Results

Klystron based (SLAC):

- achieved: 137 MW/266 ns/1.2 10^{-6}
- target: 132MW/240ns/10^{-7}





Beam based (with recirculation):

- Power
  - 130 MW peak at 150 ns
  - Limited by attenuator and phase shifter breakdowns
  - Power production according to predictions

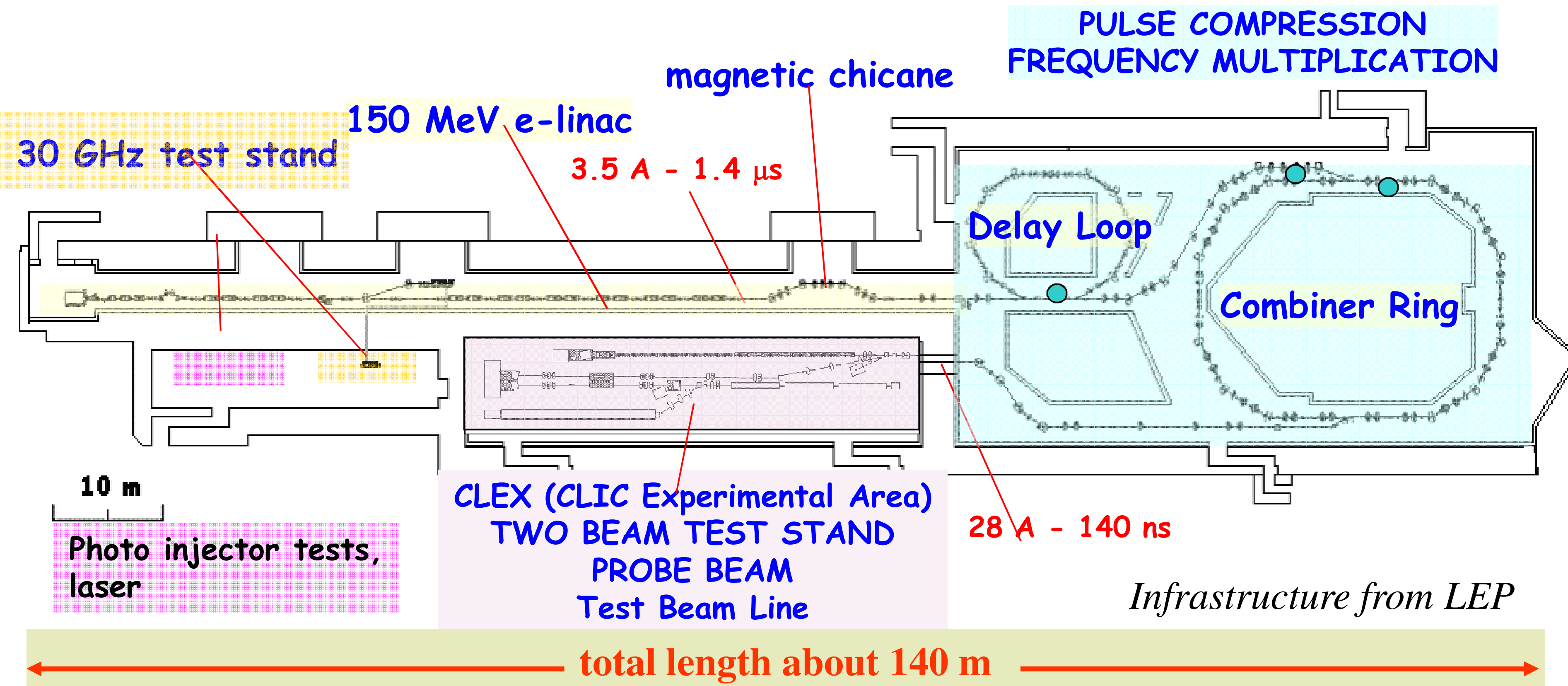
Structures had damping slots but no damping material

Novel design of on-off mechanism
- will be tested this year

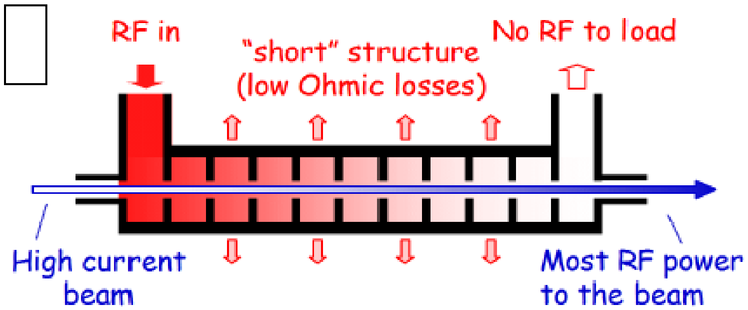
More testing is needed, conditions should be improved

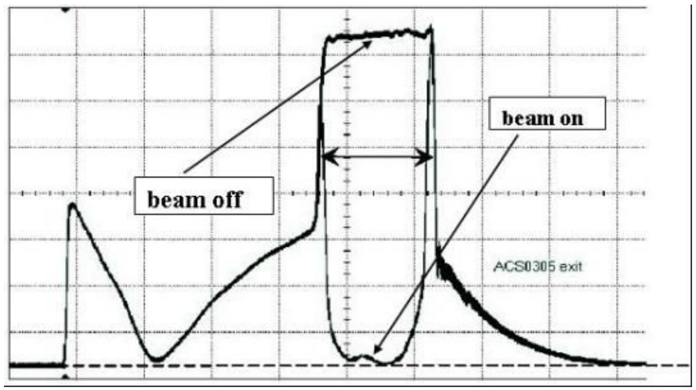
Two-Beam Acceleration: CLIC Test Facility (CTF3)

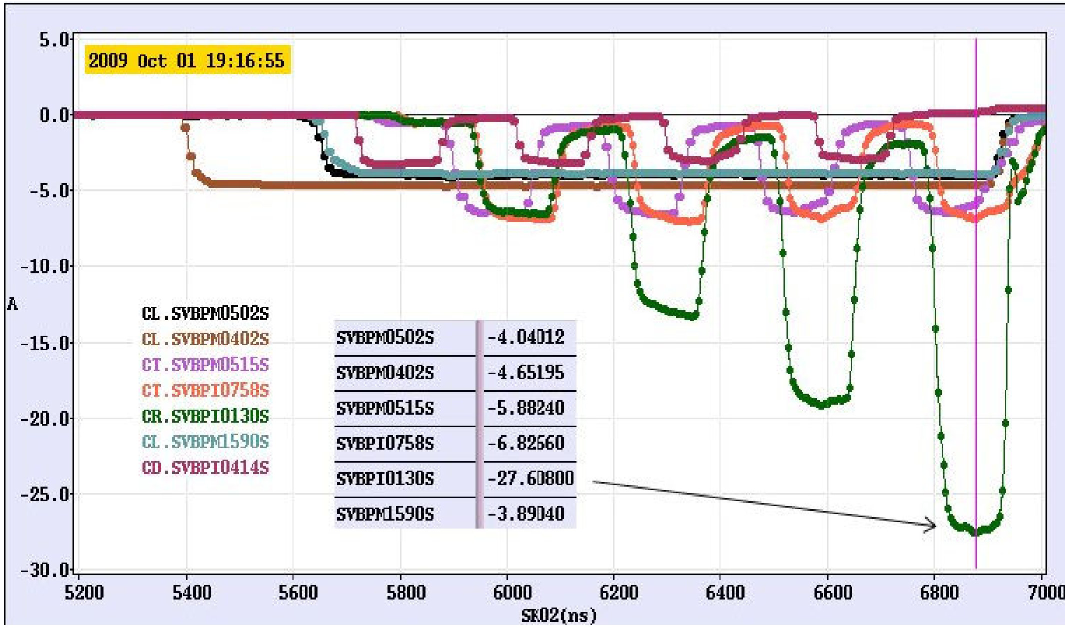
- Demonstrate Drive Beam generation (fully loaded acceleration, beam intensity and bunch frequency multiplication x8)
- Demonstrate RF Power Production and test Power Structures
- Demonstrate Two Beam Acceleration and test Accelerating Structures



Drive Beam Generation







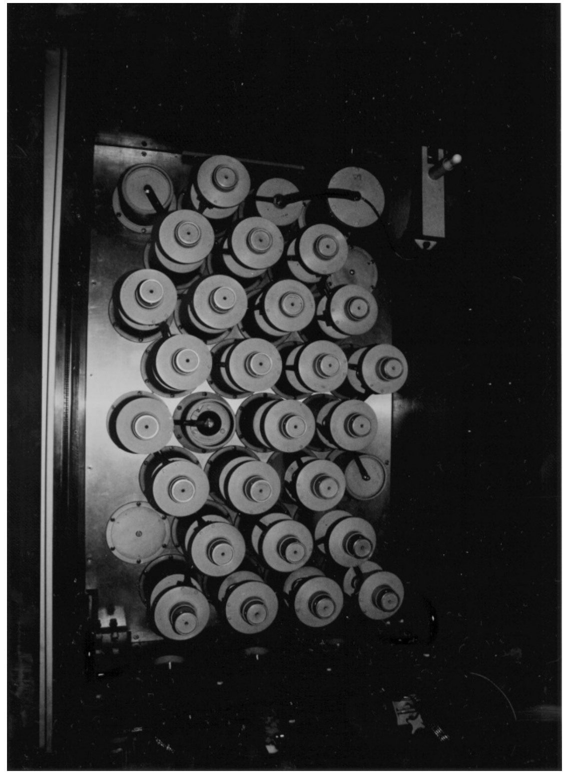
- Full beam loading operation demonstrated
- Current stability in drive beam accelerator close to target (1.5 10^{-3} vs. 0.75 10^{-3})
- Further improvement possible
  - simulated feedback: 0.6 10^{-3}

- Delay loop and combiner ring worked
- some improvements remain to be done
  - slight increase in current
  - optimisation of beam transport in combiner ring

S. Bettoni et al.
CERN

Fire in CTF3 Klystron Gallery

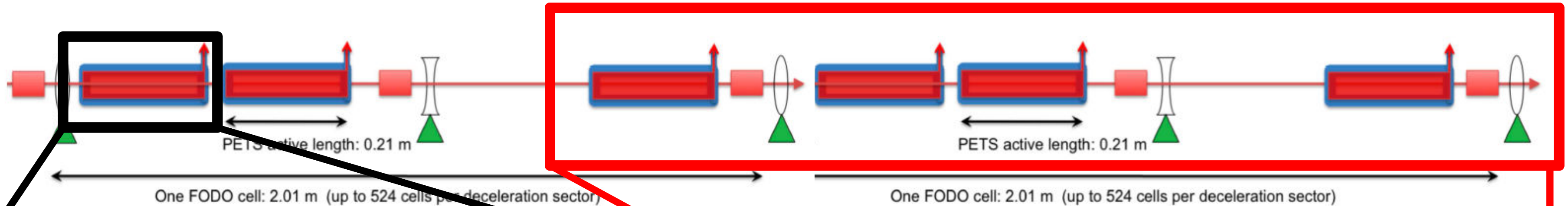
On March 4 a fire destroyed the pulse forming network in the faraday cage of MKS13



Cleaning of components is needed to prevent corrosion
=> a couple of months delay

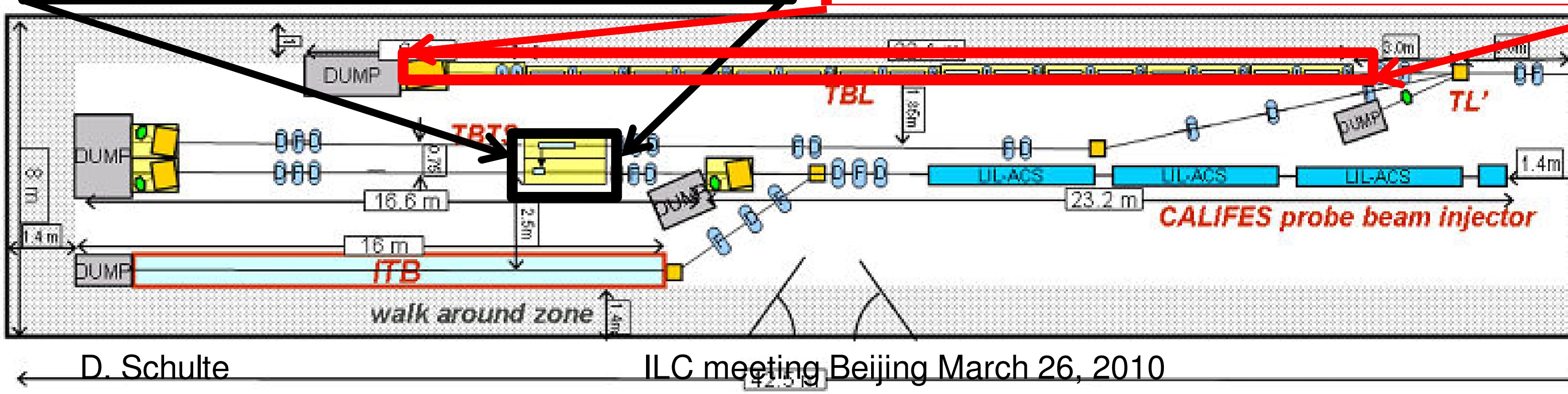
Drive Beam Deceleration and Module: CLEX

Decelerator sector: ~ 1 km, 90% of energy extracted



Two-beam Test Stand:
- **Single** PETS with beam
- Accelerating structure with beam
  - wake monitor
  - kick on beam from break down
- Integration

Test Beam Line:
- **Drive beam transport (16 PETS)**
  - beam energy extraction and dispersion
  - wakefield effects



Two Beam Module

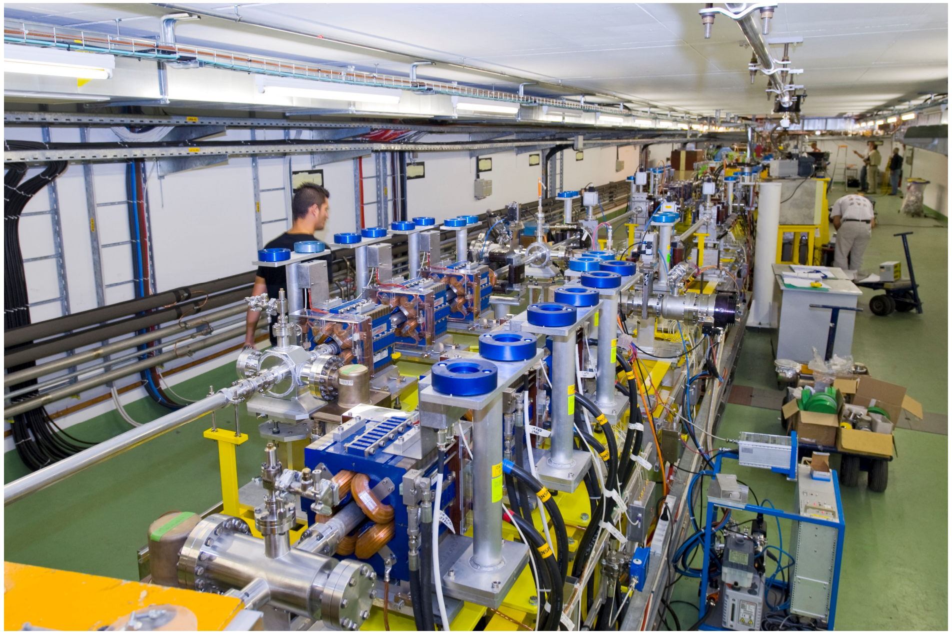
- Integration aspects are important
  - alignment
  - vacuum
  - transport
  - cabling
  - …

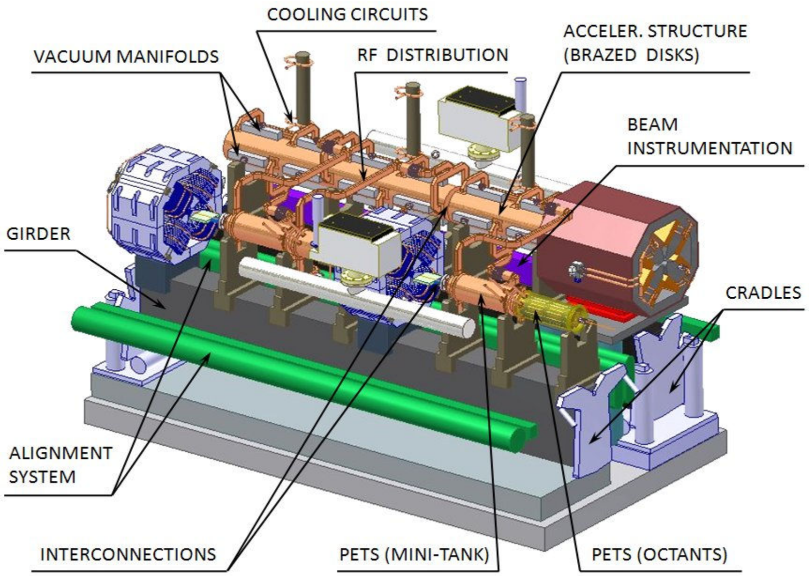
- Principle of two-beam acceleration had been established in CTF and CTF2

- Beam tests of PETS are ongoing
  - accelerating structure installed
  - wake kick measurements

- Some tests after 2010
  - e.g. wake monitors, design exists

- Later full modules will be tested

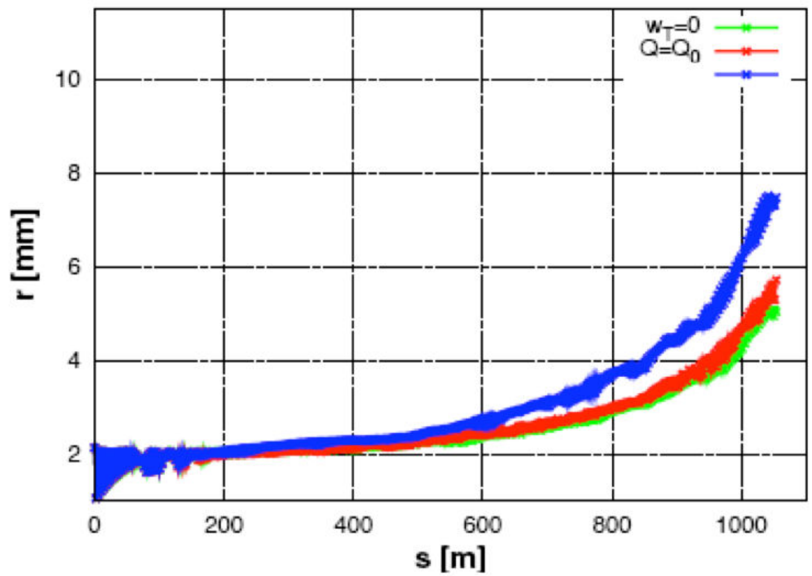


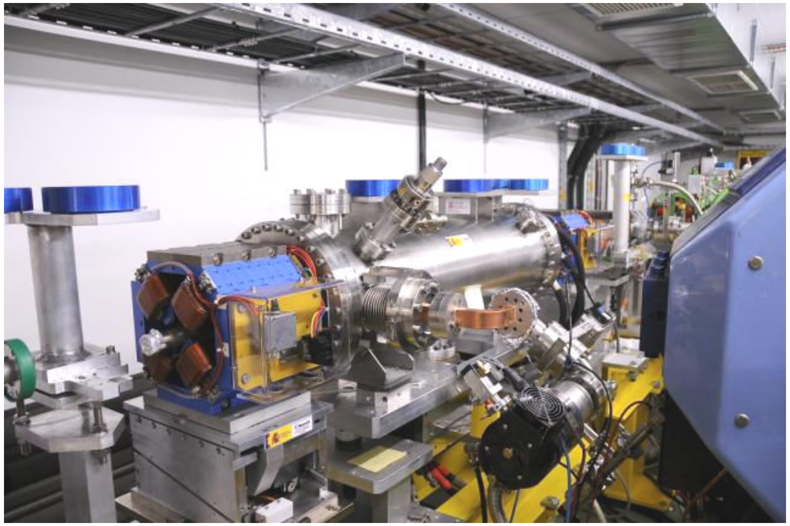


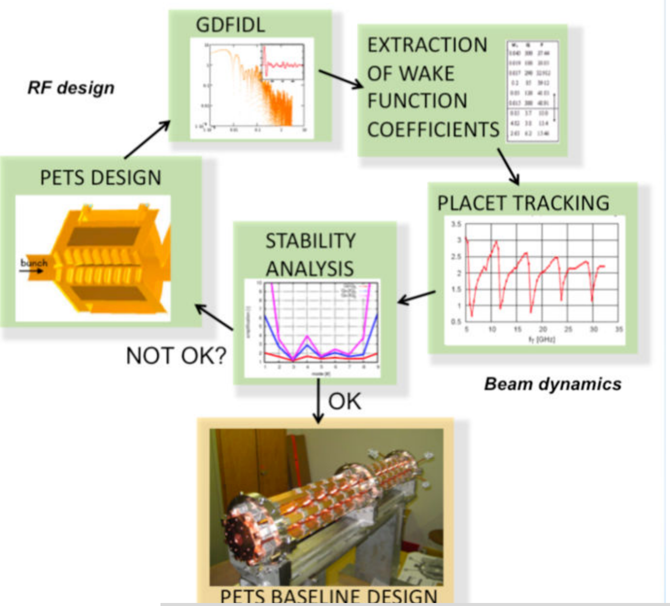
Drive Beam Deceleration

- Drive beam has high current (100A) and large energy spread (factor 10)
  - Simulations show that the beam is stable
  - Several iterations of PETS design

- Test Beam Line (TBL) under construction will increase confidence
  - the first PETS installed (8 for end 2010)
  - beam to the end







E. Adli et al.Oslo Univ. / CERN

Ultra Low Beam Emittances/Sizes

- Designs for critical lattices exist achieving target performances
  - Recent improvements
    - Predamping ring design (-> Y. Papaphilippou)
    - Improved damping ring design (-> Y. Papaphilippou)
    - RTML design, bunch compressors, turn-around loops, spin rotator (F. Stulle, -> A. Latina)
    - Beam delivery system with L*=6m as alternative (R. Tomas)
    - Drive beam phase stabilisation concept (-> D.S.)
    - Low energy running concept (-> D.S.)
    - …
  - Design and tests of key components are ongoing (DR wigglers, ML quadrupoles, final doublet, instrumentation …)
  - Main issue are imperfections
    - Beam-based alignment algorithms developed for main linac, BDS, key RTML components, which show good to satisfying performances
    - Integrated stability studies ongoing
    - Key issue are the hardware performances

Ultra Low Beam Emittances/Sizes

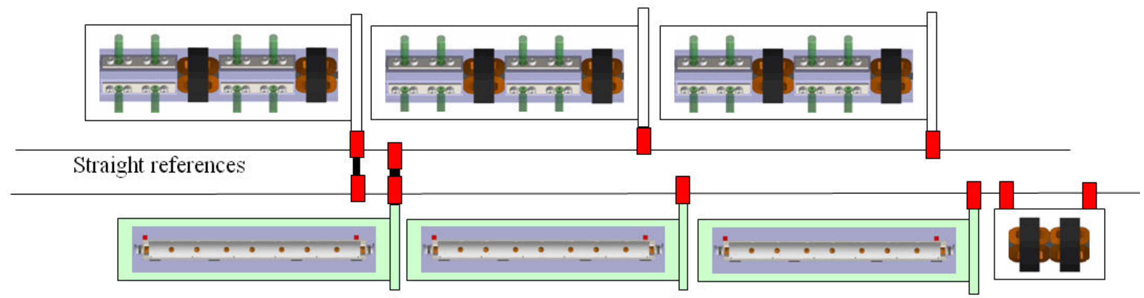
- A number of issues are being addressed by R&D
  - Electron cloud -> beam pipe design and other mitigation
  - Fast beam-ion instability -> excellent vacuum
  - RF stability -> phase stabilisation and feedforward
  - Pre-alignment imperfections -> beam-based alignment, wake monitors and precision pre-alignment
  - Dynamic imperfections -> feedback, feedforward, mechanical component stabilisation
  - ...

- Detailed design issues are also addressed
  - Baseline design needed
  - Cabling and power supplies
  - Magnets
  - Instrumentation
  - ...

Main Linac Alignment Concept

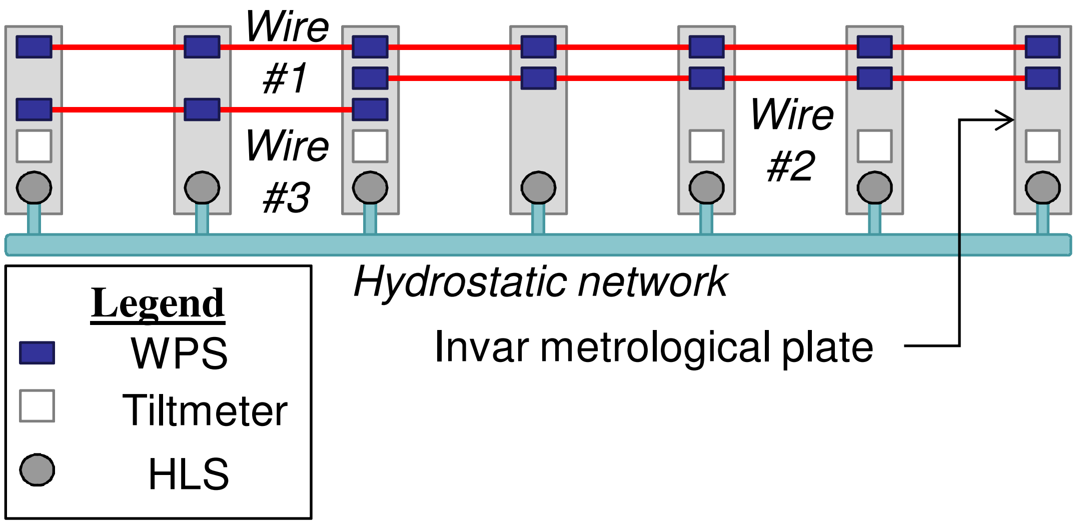
- Pre-alignment O(10um)
  - with wire system
  - detailed model in simulations
- Dispersion free steering
  - aligns BPMs and quadrupoles
- Move girders onto the beam
  - use wakemonitors
  - removes wakefield effects

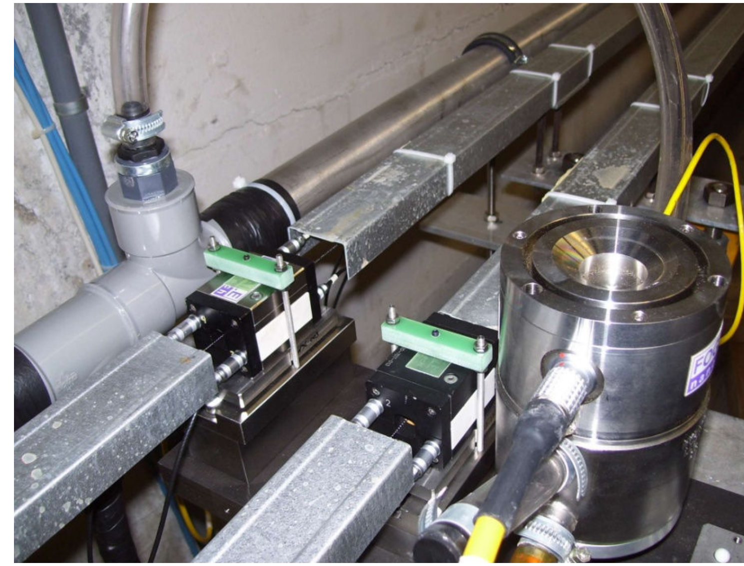
- Straight reference line defined by overlapping wires
- Girders are aligned to these wires
- Detailed work ongoing on module integration, mechanical alignment in module, wire system test, sensor cost reduction, use of laser system



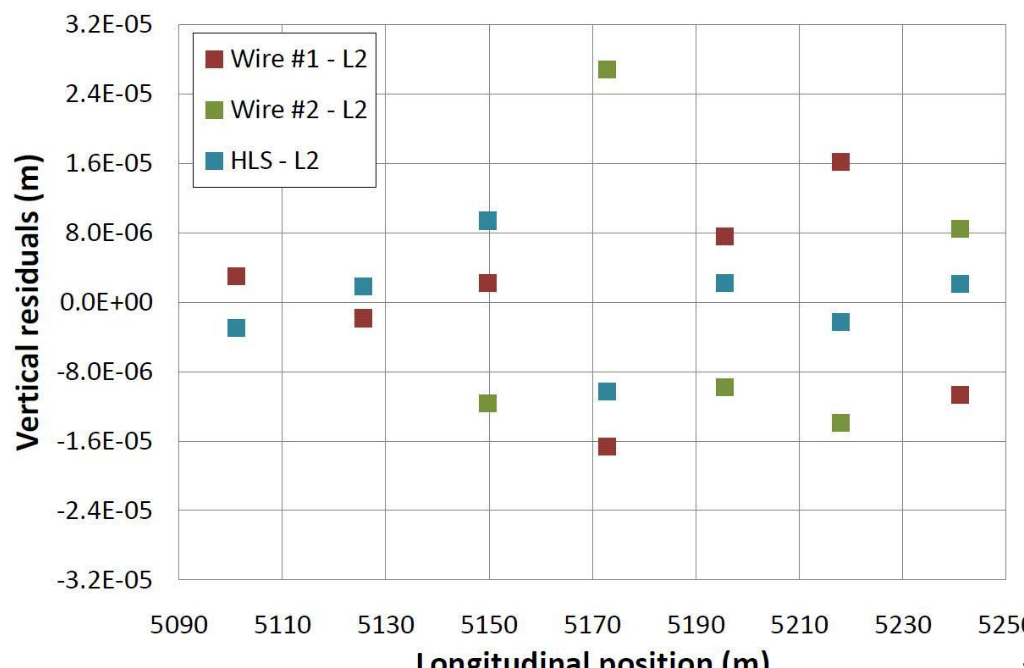
H. Mainaud-Durand et al. CERN

TT1 Alignment Results



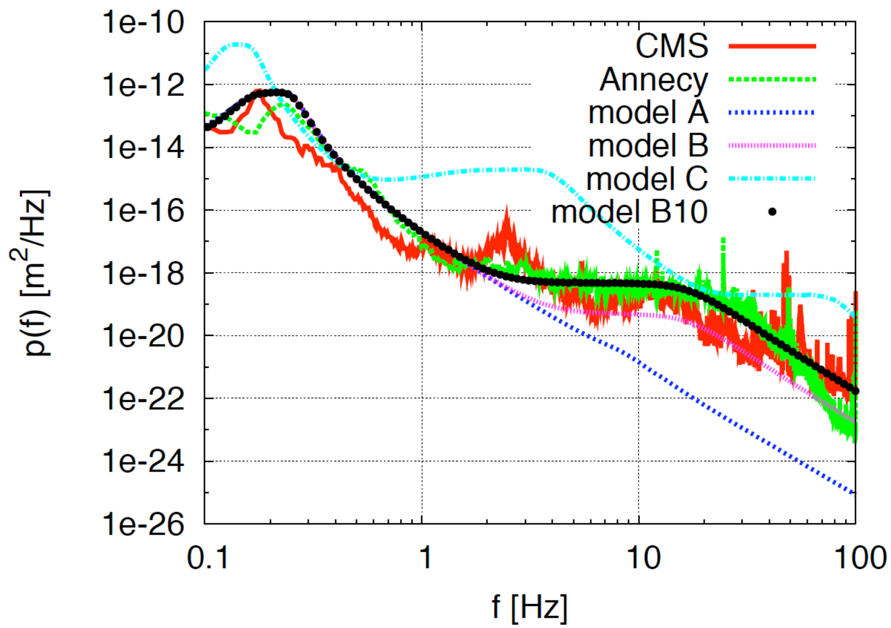


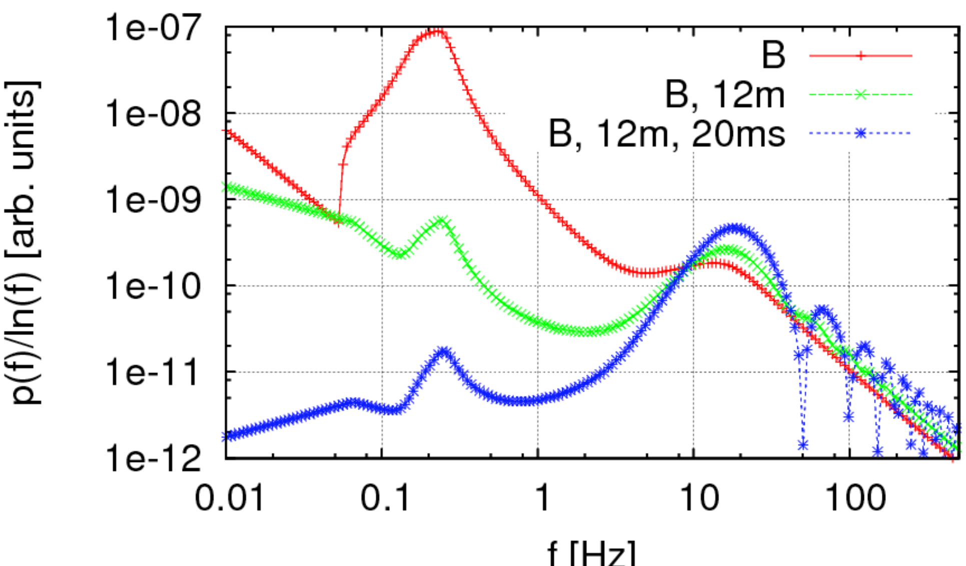
- RMS error of 11µm found
  - Target is 10µm
- More work remains to be done
  - Found two bad points due to mechanical problem
  - Stake-out error needs to be determined

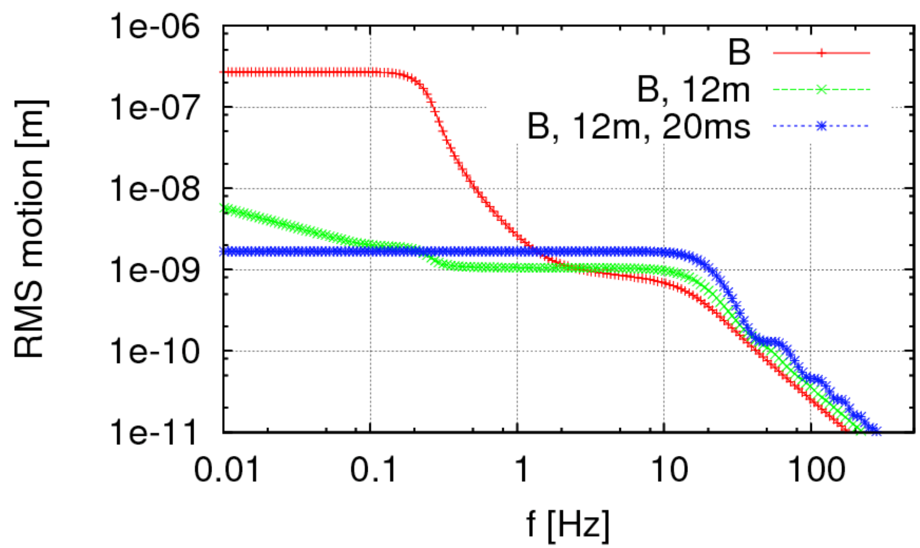


Element Stabilisation

- Elements move due to ground motion and technical noise
  - Two dimensional power spectrum P(f,s)
  - Focus on main linac (O(1nm)) and final doublet (O(0.2nm))
- Tolerances depend on correlation and frequency spectrum
  - Model A (LEP tunnel) would only need beam-based feedback
  - Beam-beam jitter tolerance 0.3nm





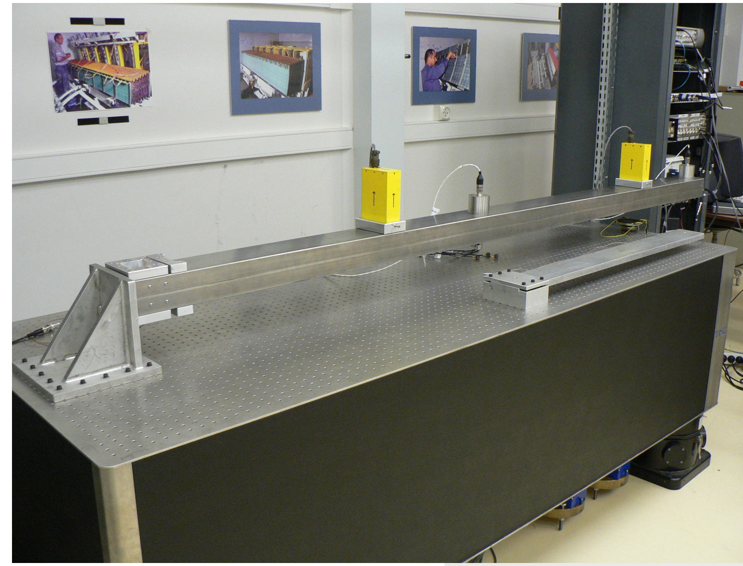


Element Stabilisation (cont.)

- Minimise impact of motion by
  - identification and minimisation of technical noise
  - mechanical support and component design
  - active mechanical stabilisation
  - motion sensor based feed-forward on the beam
  - beam-based orbit feedback
  - intra-pulse IP feedback

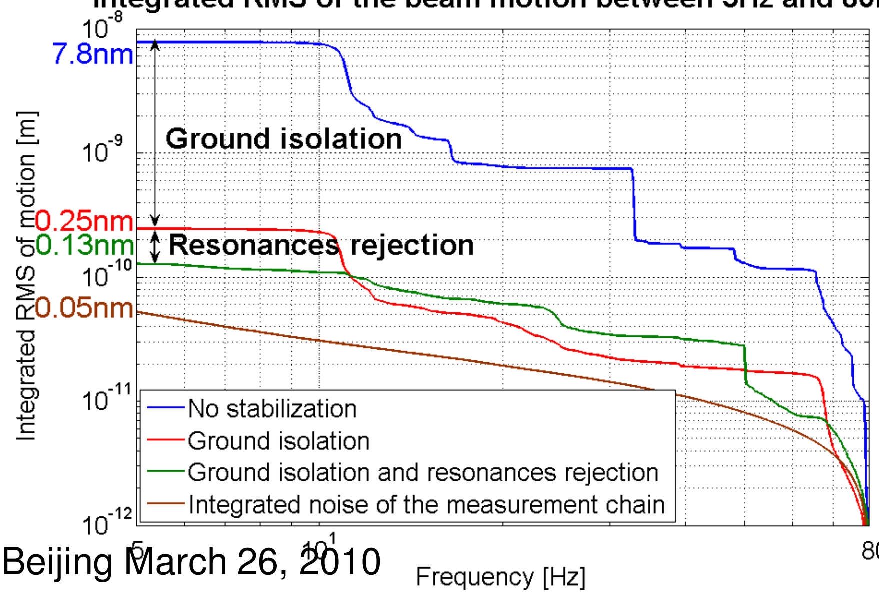
Main linac quadrupole support

K. Artoos et al



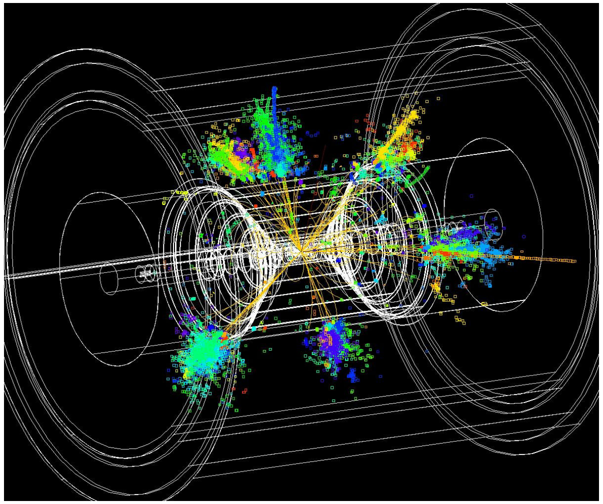
L.Brunetti et al

Integrated RMS of the beam motion between 5Hz and 80Hz

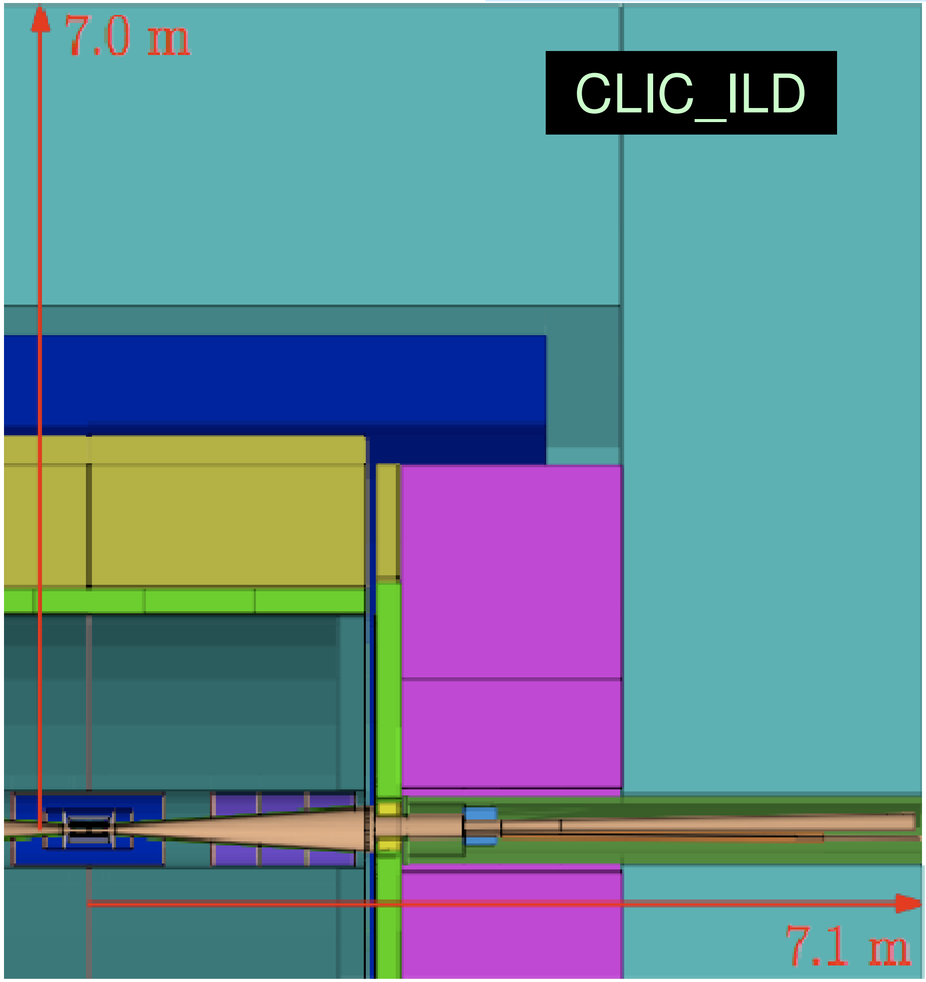


CLIC Detector Issues

- Detector requirements are close to those for ILC detectors
  - First studies indicate that ILC performances are sufficient
  - Adapt ILD and SID concepts for CLIC
  - Close collaboration with validated ILC designs
- Differences to ILC
  - Larger beam energy loss
  - Time structure (0.5ns vs. ~300ns)
  - Higher background
    - High energy
    - Small bunch spacing
  - Other parameters are slightly modified
    - Crossing angle of 20 mradian (ILC: 14 mradian)
  - Larger beam pipe radius in CLIC (30mm)
  - Slightly denser and deeper calorimetry
- Linear collider detector study has been established at CERN beginning of 2009 (led by L. Linssen, see **http://www.cern.ch/lcd)**



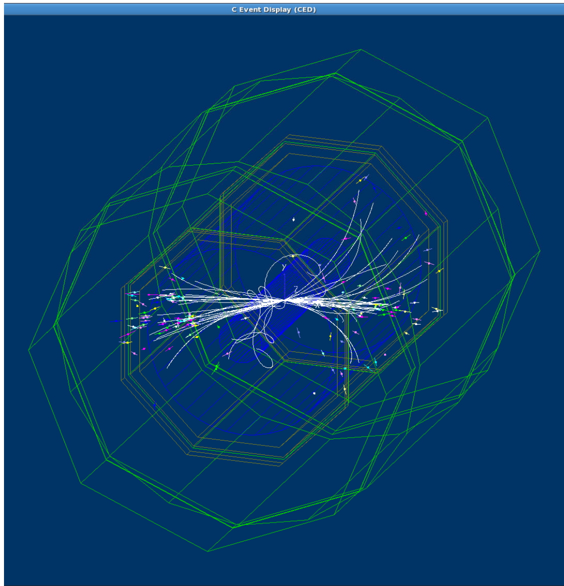
ILD concept adapted to CLIC



Changes to the ILD detector:

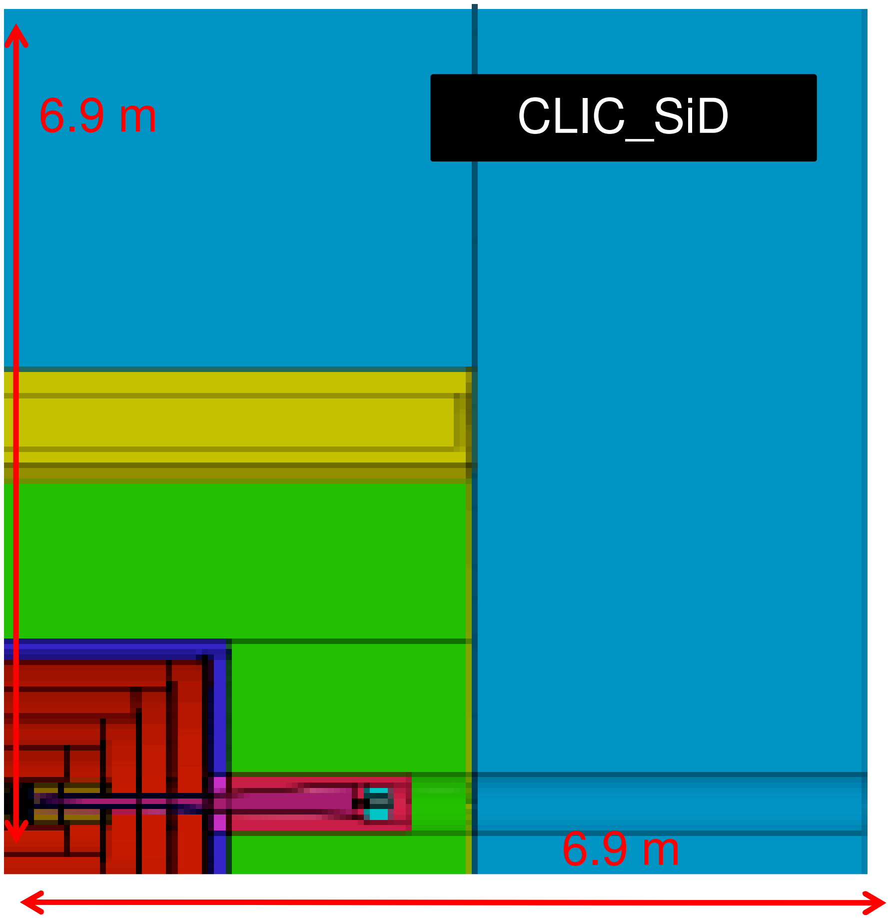
- 20 mrad crossing angle
- Vertex Detector to ~30 mm inner radius, due to Beam-Beam Background
- HCAL barrel with 77 layers of 1 cm tungsten
- HCAL endcap with 70 layers of 2 cm steel plates
- Forward (FCAL) region adaptations

Fully implemented in Mokka/Marlin



Andre Sailer
Berlin Humboldt /CERN

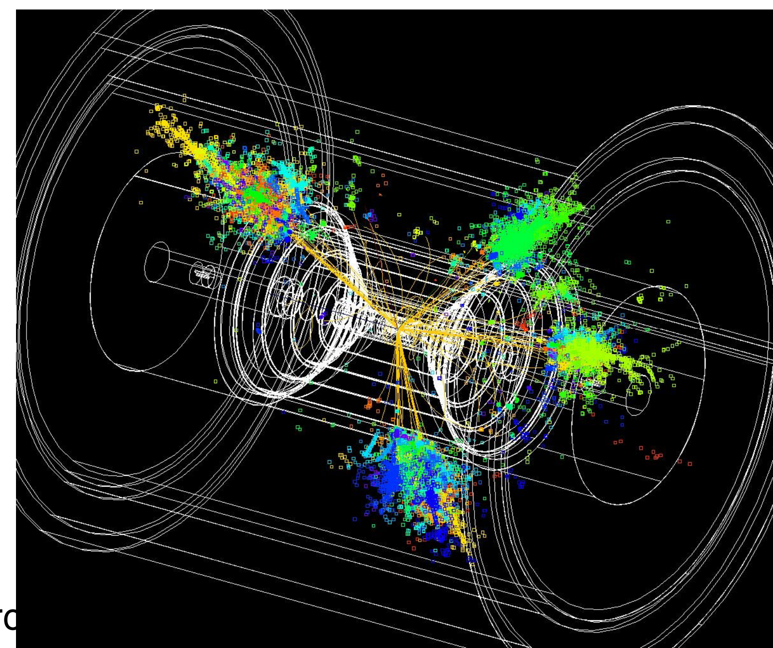
SiD concept adapted to CLIC



Changes to the SiD detector:

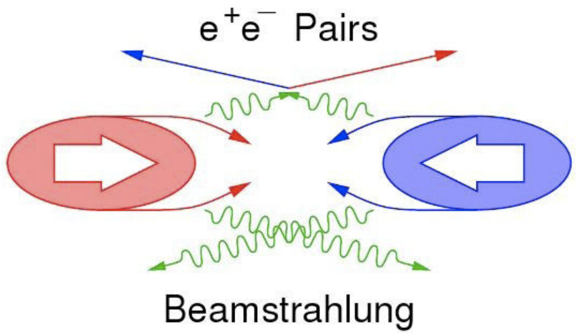
- 20 mrad crossing angle
- Vertex Detector to ~30 mm inner radius, due to Beam-Beam Background
- HCAL barrel with 77 layers of 1 cm tungsten
- HCAL endcap with 70 layers of 2 cm steel
- Inner bore of cryostat moved to 2.9 m radius
- Forward (FCAL) region adaptations

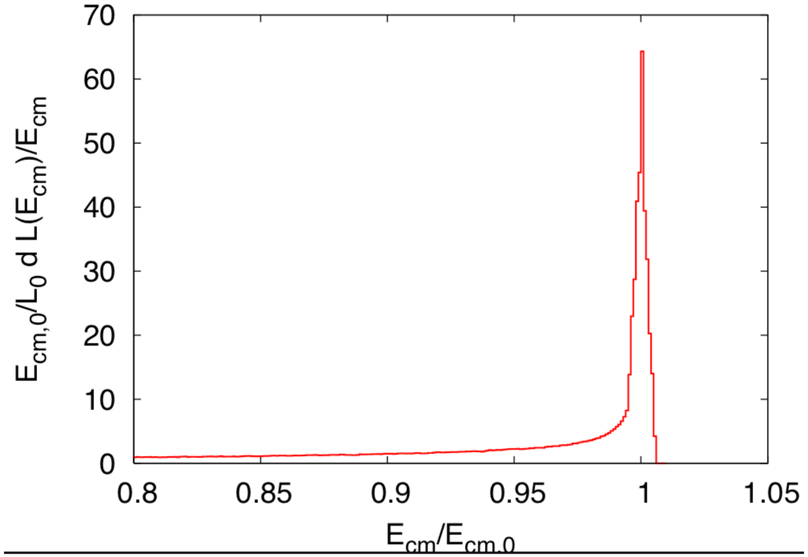
Fully implemented in SiD SLiC software



Christian Grefe
Bonn Univ. / CERN

Beam-Induced Background





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n_b		354	312	2625
Δt	[ns]	0.5	0.5	369
$\mathcal{L}_{total}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	2.3	5.9	2.0
$\mathcal{L}_{0.01}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	1.4	2.0	1.45
n_γ		1.3	2.2	1.3
$\Delta E/E$		0.07	0.29	0.024
N_{coh}	$[10^5]$	10^{-3}	3.8×10^3	—
E_{coh}	$[10^3\mathrm{TeV}]$	0.015	2.6×10^5	—
n_{incoh}	$[10^6]$	0.08	0.3	0.1
E_{incoh}	$[10^6\mathrm{GeV}]$	0.36	22.4	0.2
$n_\perp$		20.5	45	28
n_{had}		0.19	2.7	0.12

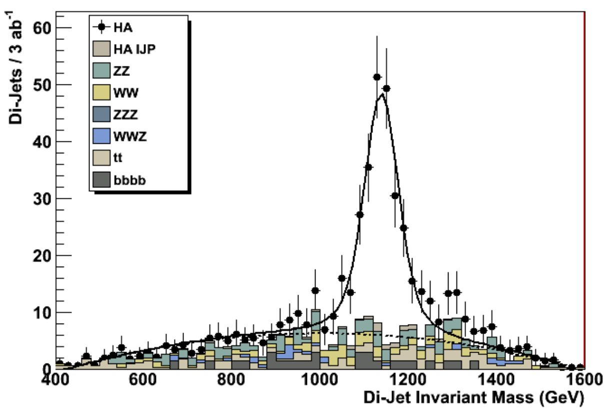
- Beamstrahlung
  - Disappear in the beam pipe
- Coherent pairs
  - Disappear in beam pipe
- Incoherent pairs
  - Suppressed by strong solenoid-field
- Hadronic events
  - Impact reduced by time stamping
- Muon background from upstream linac

About 3 γγ=> hadron events per bunch crossing
• energy goes mostly in the forward region

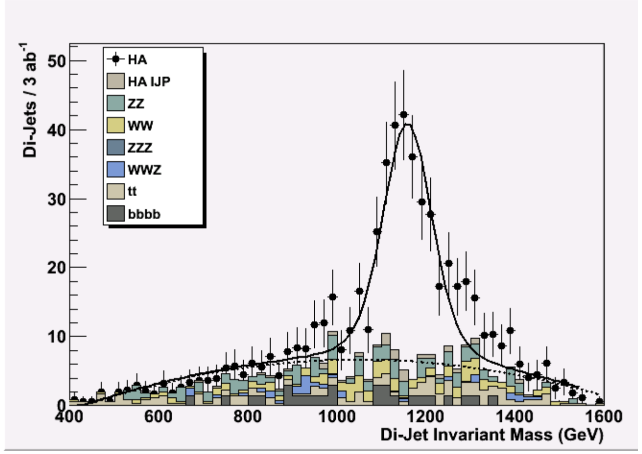
Simulation example of heavy Higgs doublet H^0A^0 at ~1.1 TeV mass (supersymmetry K' point)

e+e- ➔ H^0A^0 ➔ bbbb

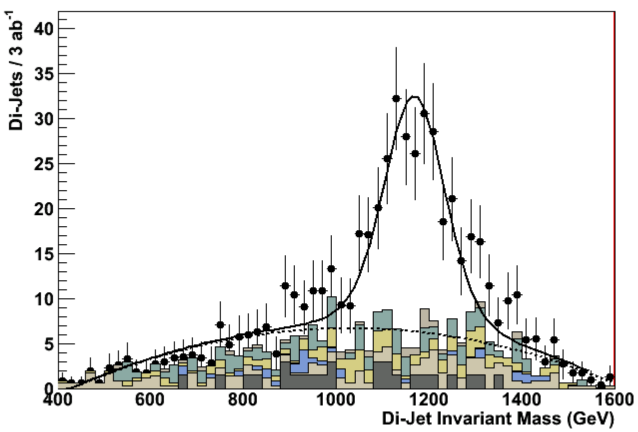
- Signal + full standard model background + γγ=>hadron background
- CLIC-ILD detector: Mokka+Marlin simulation, reconstruction + kinematic fit.



Zero bunch crossings
M_A mass resol. 3.8 GeV



20 bunch crossings
M_A mass resol. 5.6 GeV



40 bunch crossings
M_A mass resol. 8.2 GeV

Marco Battaglia
UCSC / CERN

Jet Energy Resolution and PFA

- Is an ILD-sized detector based on PFA suitable for CLIC ?
- Defined modified ILD+ model:
  - B = 4.0 T (ILD = 3.5 T)
  - HCAL = 8 Λ_I (ILD = 6 Λ_I)
- Jet energy resolution
  - using unmodified algorithm

PFA

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	25.2 %	3.7 %
100 GeV	28.7 %	2.9 %
180 GeV	37.5 %	2.8 %
250 GeV	44.7 %	2.8 %
375 GeV	71.7 %	3.2 %
500 GeV	78.0 %	3.5 %

Mark Thomson
Cambridge

- Meet “LC jet energy resolution goal [~3.5%]” for 500 GeV jets

Engineering Issues

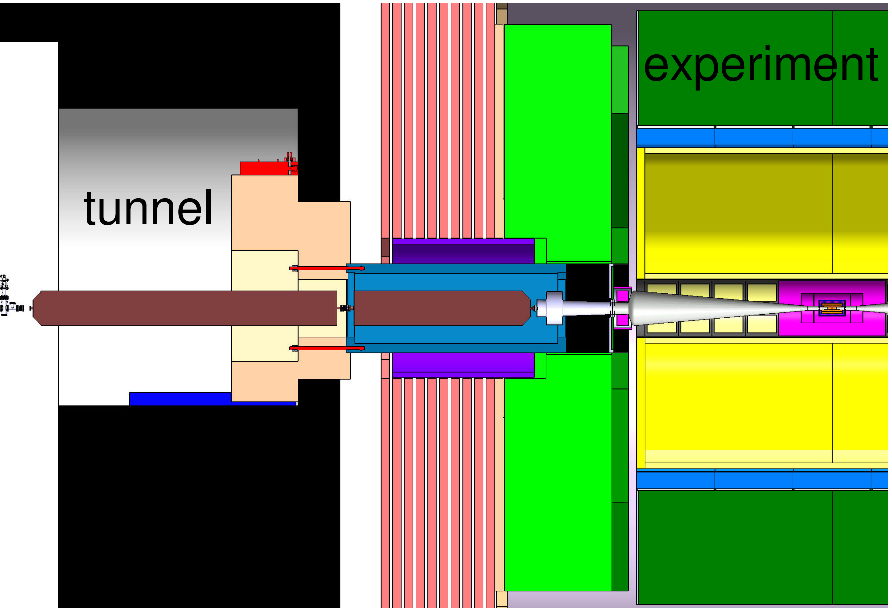
Focus on critical issue of providing a stable environment for QD0.

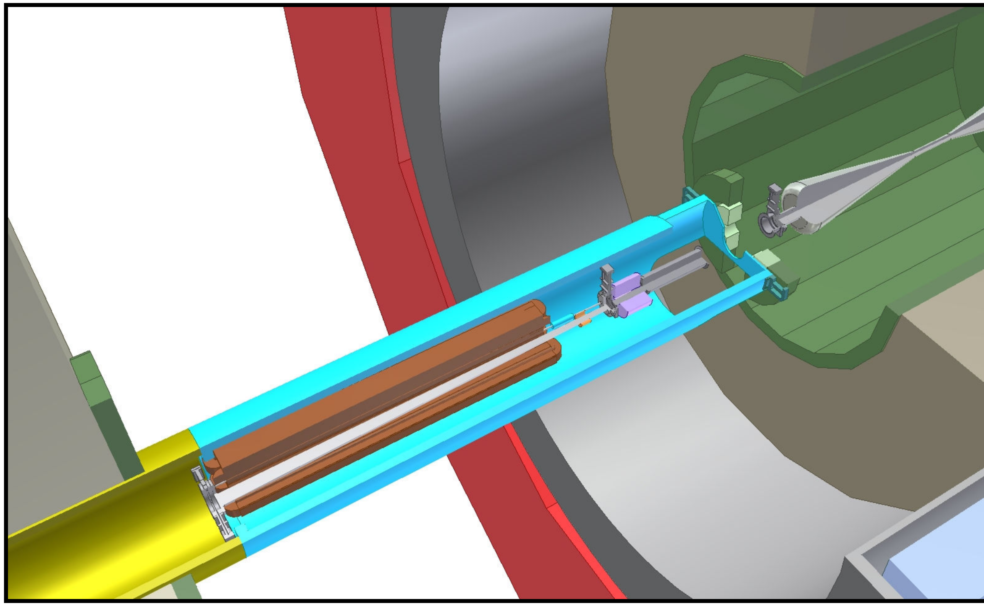
- Support QD0 from tunnel with cantilever (A. Herve et al.)
  first studies indicate small jitter amplification
- QD0 design exists (M. Modena et al.)
- Intra-pulse interaction point feedback integration worked out (Ph. Burrows et al.)
- Feedback and stability under study

Alain Herve (ETHZ), Hubert Gerwig (CERN)

Other practical issues are also studied

- profit from LHC experience

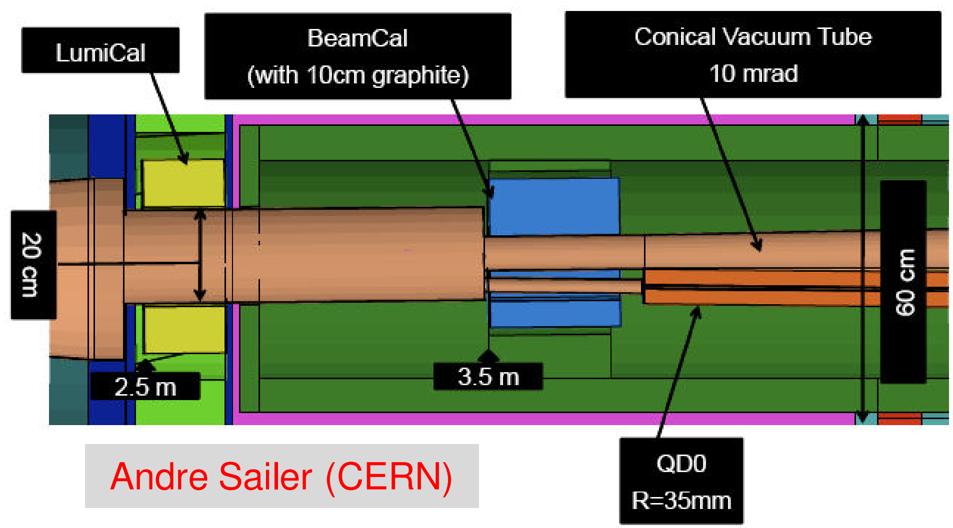




Current LCD Activities

Current activities: preparation for physics/detector CDR, due April 2011

- Mostly simulation studies:
  - Demonstrate that CLIC physics potential can be extracted from detector
  - Propose ILD-like and SiD-like detectors that can do the job
- Concentrate on critical issues
  - Propose ways to reduce impact of background on the performance
  - Redesign of the very forward region
  - Take engineering aspects, cost etc into account
- Preparing a targeted
  hardware R&D plan



Andre Sailer (CERN)

D. Schulte

Hardware/Engineering/Software Development

LCD hardware/engineering R&D (for CLIC, beyond ILC developments):

- Time stamping
  - Most challenging in vertex detector: trade-off between pixel size, amount of material and timing resolution
- Hadron calorimetry
  - Tungsten-based HCAL (PFA calo, beam tests in preparation, within CALICE)
- Solenoid coil
  - Large high-field solenoid concept and reinforced conductor R&D
- Power pulsing
  - In view of the 50 Hz CLIC time structure => allows for low-mass detectors
- Engineering developments
  - For tungsten-based HCAL calorimeter
  - For sub-nm stability for FF quadrupoles within experiment volume

In addition: Collaboration with ILC on Core Software Development

Operation & Machine Protection System

- Basic concept is being developed (M. Jonker et al.)
  - based on LHC experience
- Loss monitoring/control
- Startup scenarios
- Accidental beam losses
  - Slow drifts
    - e.g. temperature
    - Next pulse permit (if pulse is OK next pulse is allowed otherwise safe beam operation)
  - Slow trips
    - e.g. magnet failure
    - interlock 2ms before pulse
  - Fast trips
    - e.g. RF or kickers
    - reduce incidence frequency and impact
    - protective masks

Project Preparation

Project cost, schedule, site, integration aspects and many technical details are critical part of a project

- Analytic cost estimate is being prepared (Ph. Lebrun et al.)
  - To verify previous synthetic cost estimate
  - To identify cost drivers
  - In collaboration with ILC to exploit synergy and provided comparable basis for cost estimate
- Schedule is being developed (K. Foraz et al.)
- Other technical issues are being addressed
  - To provide base line for conceptual design
    - A number of changes have been implemented
  - To make sure that we did not overlook an issue
  - To prepare for the TDR phase
- Potential sites are being explored (-> J. Osborn et al.)
  - Strong synergy with ILC site studies and common ILC-CLIC working group
- Close collaboration with ILC

Conclusion

- Conceptual design is advancing well
  - Last baseline choices are being finalised
  - Strong involvement of expert groups
- Feasibility issues are being addressed
  - Overall good progress but will have to continue after CDR
- Cost study is ongoing
  - Feedback on design issues
- The TDR phase is being prepared

- Thanks to all the people from whom I stole slides
  - Jean-Pierre Delahaye, L.Linssen, Alexej Grudiev, Frank Tecker, Walter Wuensch …

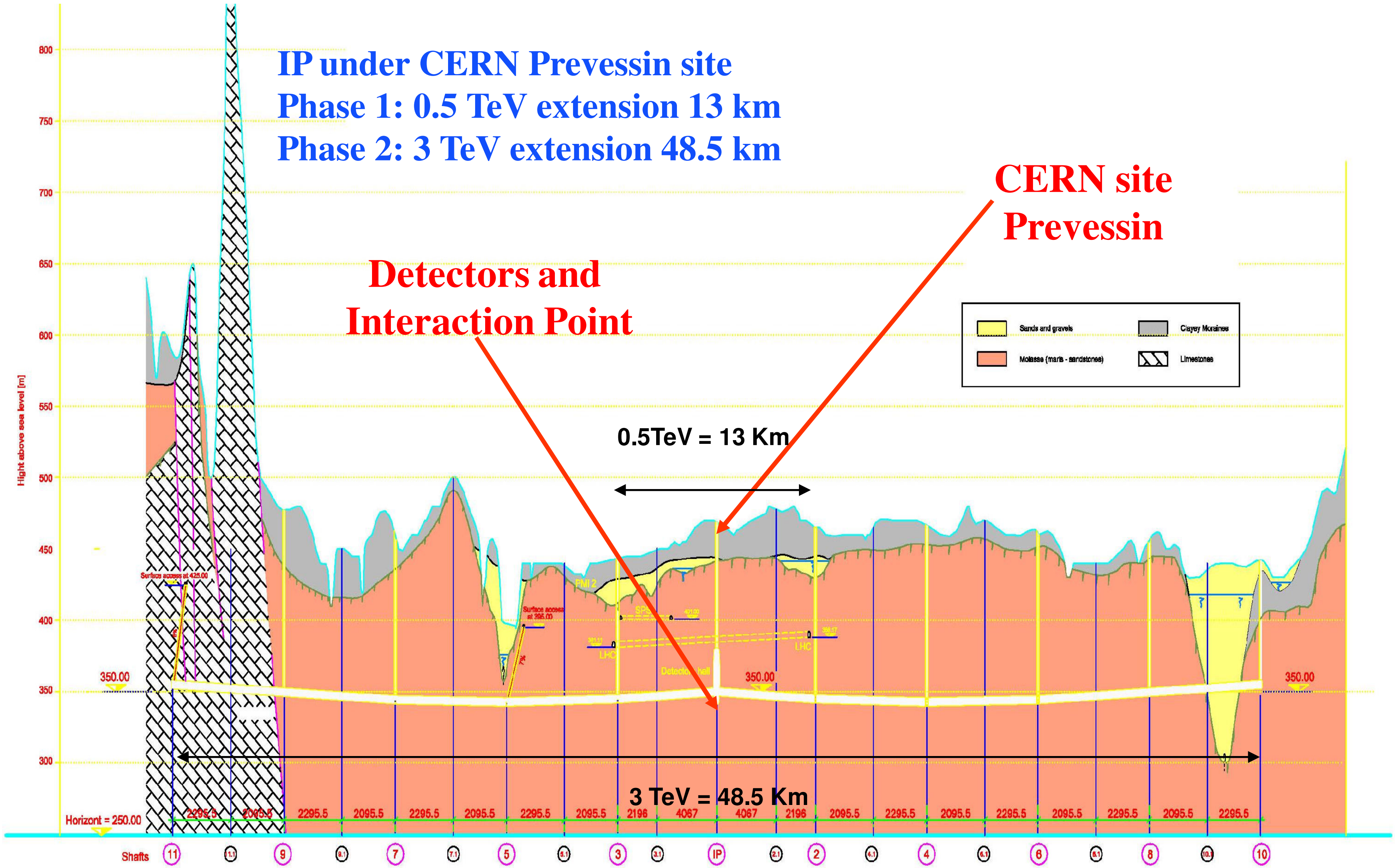
Reserve

CLIC Main Parameters

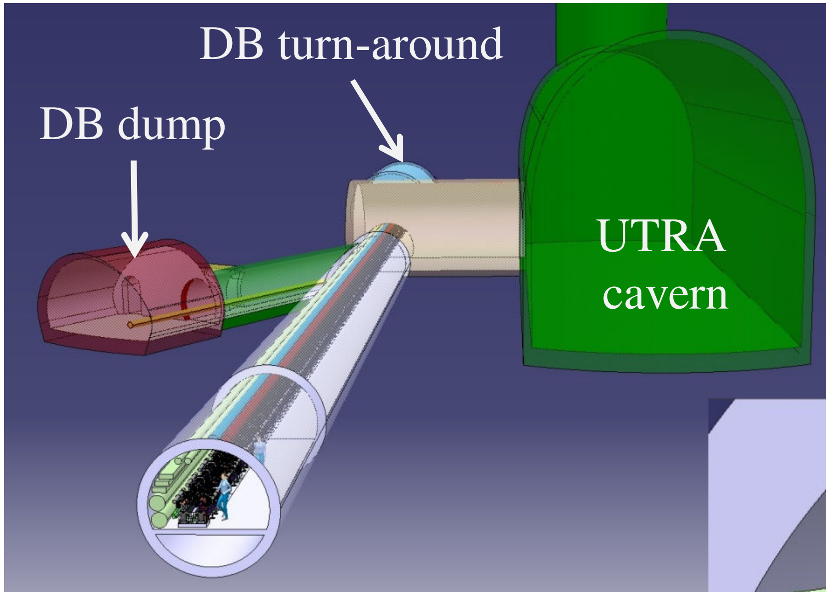
http://cdsweb.cern.ch/record/1132079?ln=fr http://clic-meeting.web.cern.ch/clic-meeting/clictable2007.html

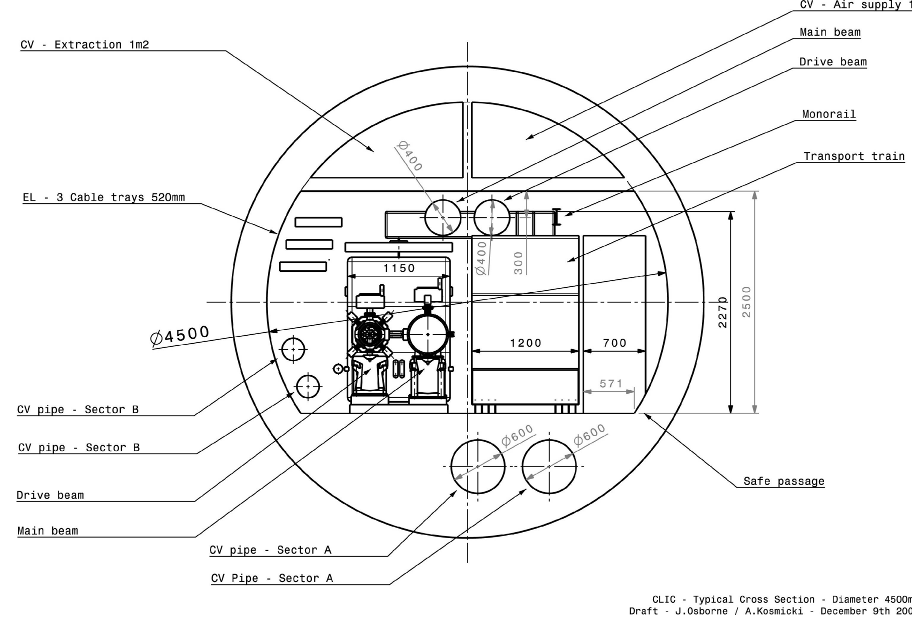
Center-of-mass energy	CLIC 500 G		CLIC 3 TeV	
Beam parameters	Conservative	Nominal	Conservative	Nominal
Accelerating structure	502		G	
Total (Peak 1%) luminosity	$0.9(0.6)\cdot10^{34}$	$2.3(1.4)\cdot10^{34}$	$1.5(0.73)\cdot10^{34}$	$5.9(2.0)\cdot10^{34}$
Repetition rate (Hz)	50			
Loaded accel. gradient MV/m	80		100	
Main linac RF frequency GHz	12			
Bunch charge 10^9	6.8		3.72	
Bunch separation (ns)	0.5			
Beam pulse duration (ns)	177		156	
Beam power/beam (MWatts)	4.9		14	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)	3/40	2.4/25	2.4/20	0.66/20
Hor/Vert FF focusing (mm)	10/0.4	8 / 0.1	8 / 0.3	4 / 0.07
Hor./vert. IP beam size (nm)	248 / 5.7	202 / 2.3	83 / 2.0	40 / 1.0
Hadronic events/crossing at IP	0.07	0.19	0.57	2.7
Coherent pairs at IP	10	100	$5\ 10^7$	$3.8\ 10^8$
BDS length (km)	1.87		2.75	
Total site length km	13.0		48.3	
Wall plug to beam transfer eff	7.5%		6.8%	
Total power consumption MW	129.4		415	

Example Site at CERN

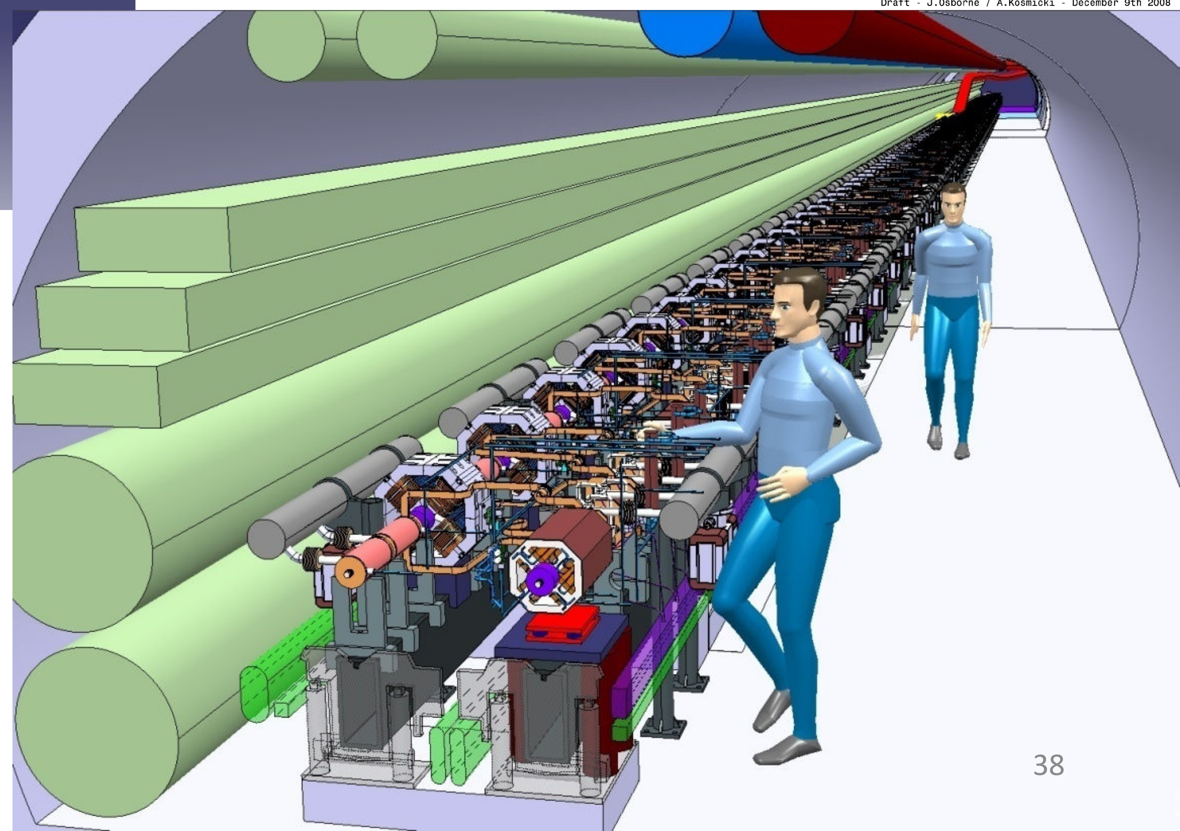


Tunnel Integration



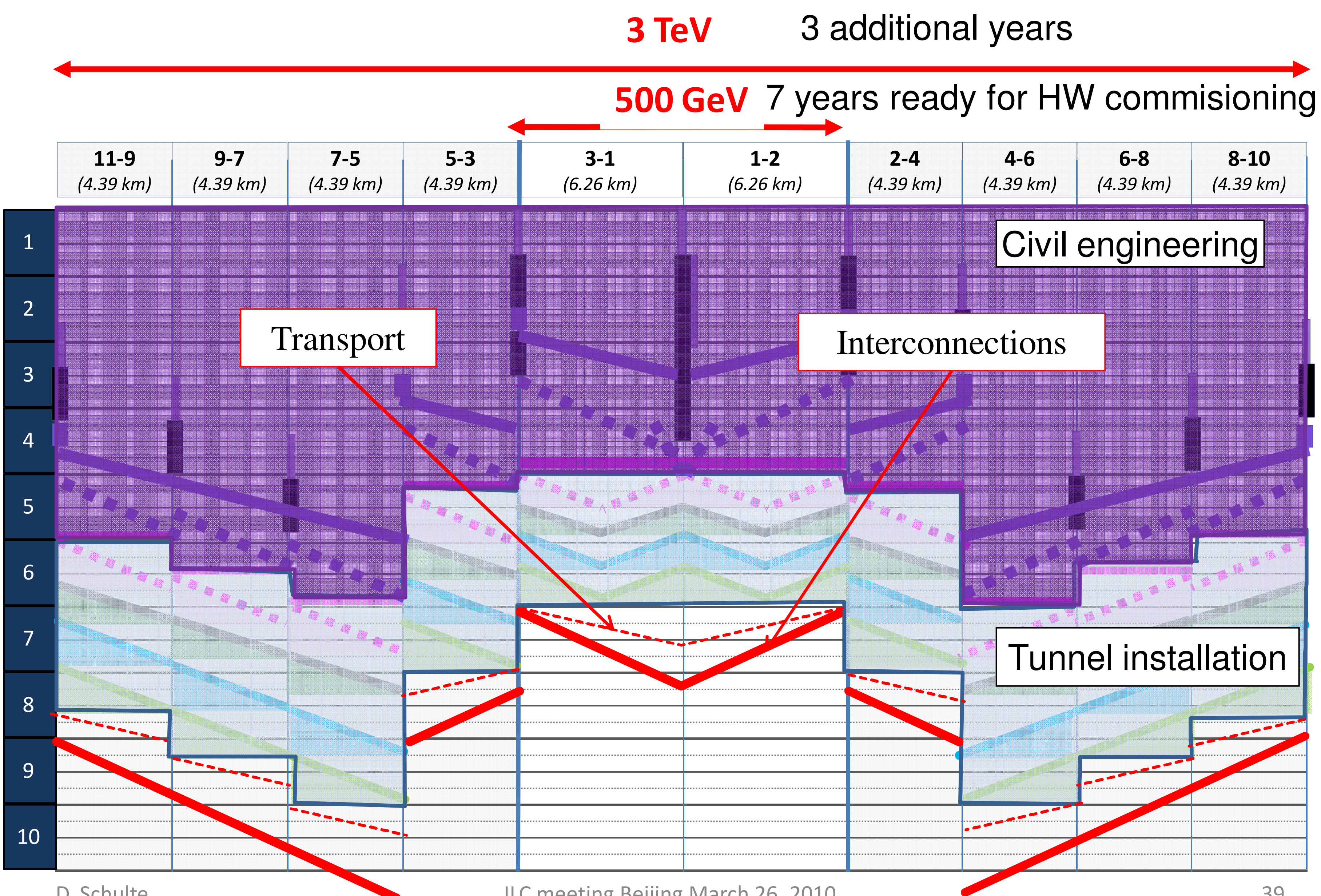


Standard tunnel with modules

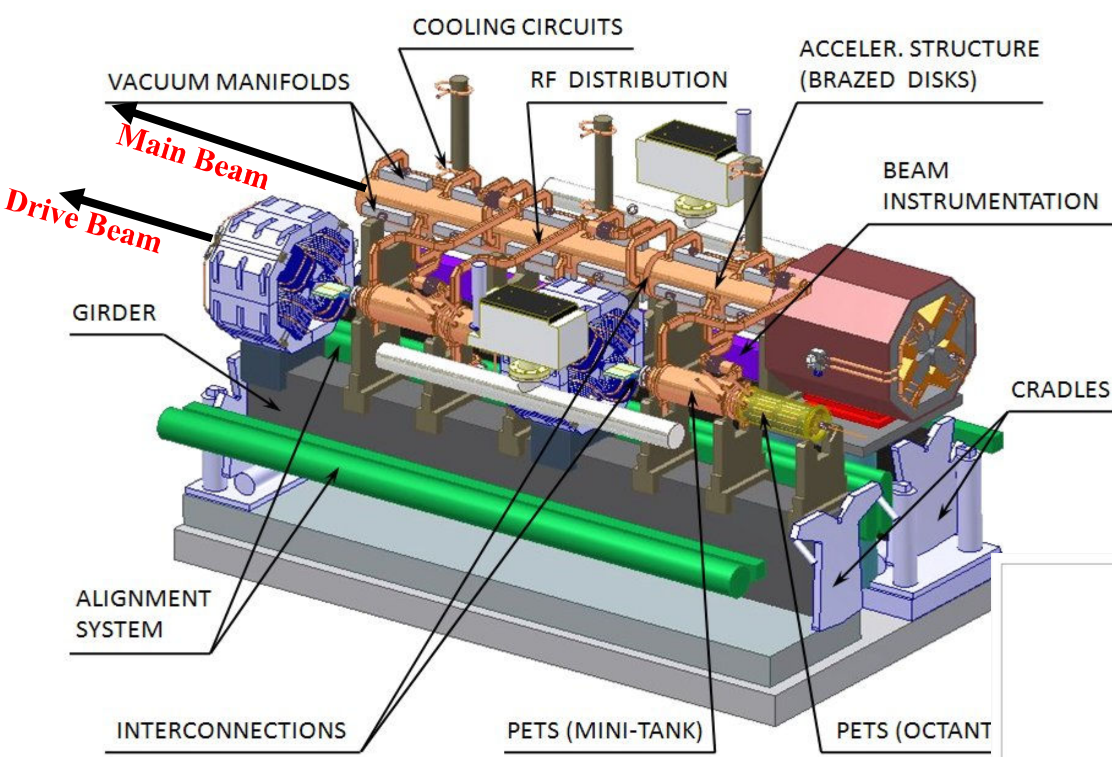


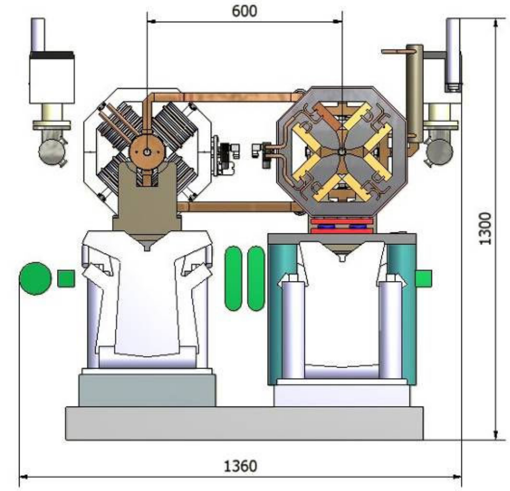
D. Schulte

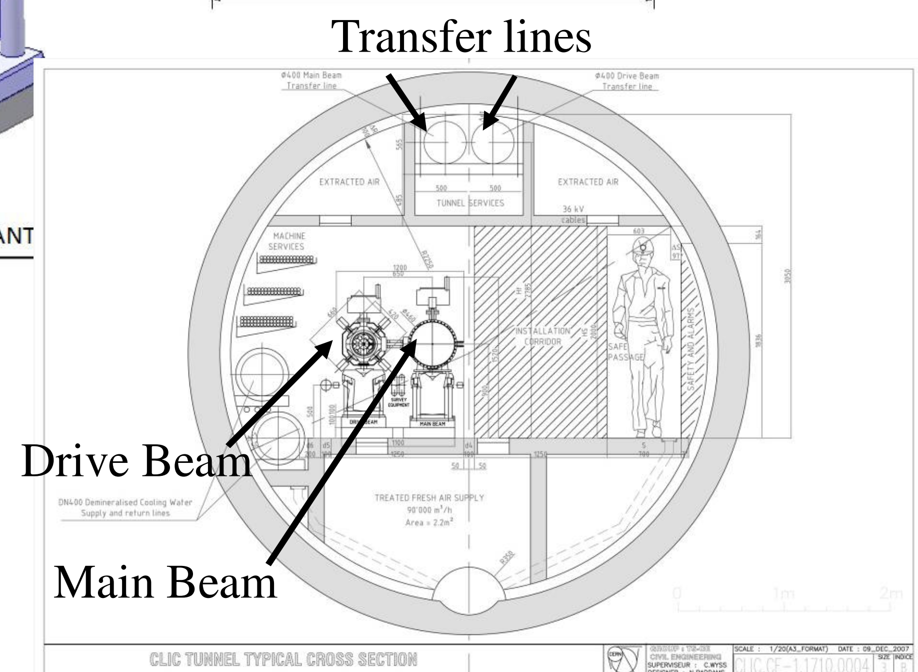
CLIC Machine Installation (based on LHC experience)



CLIC Two Beam Acceleration Module

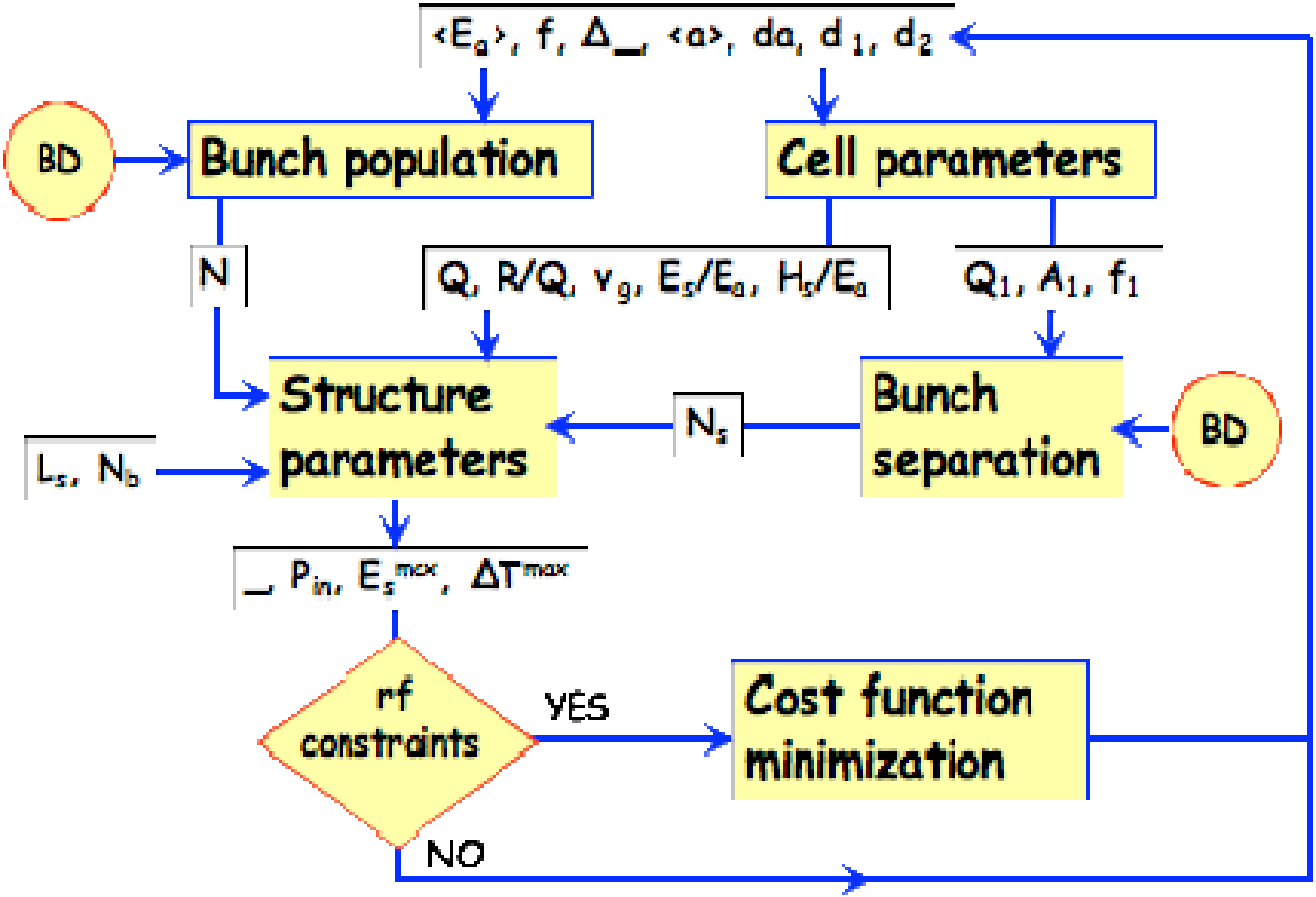






RF power is generated by 100A drive beam

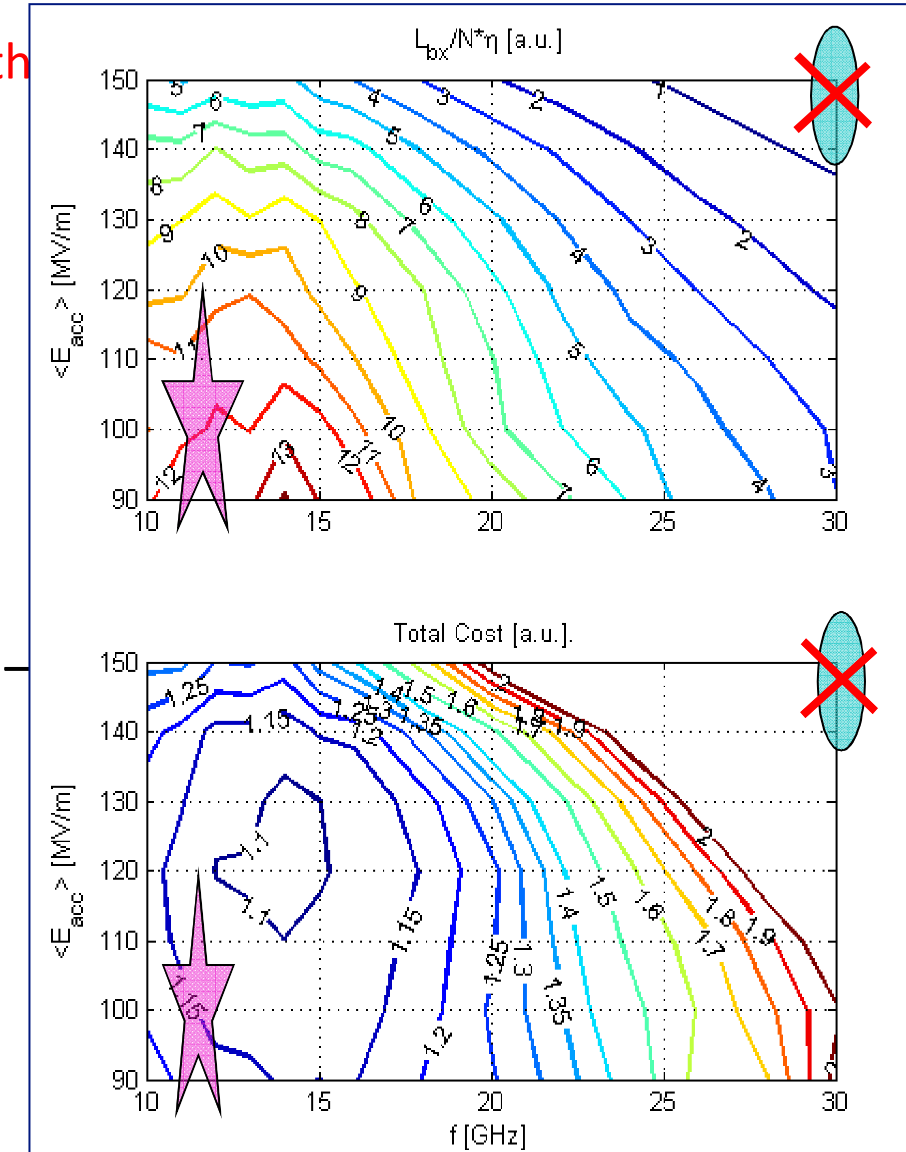
Parameter Optimisation



A. Grudiev et al.

Optimisation Results

- Optimisation - figure of merit:
  - Minimum project cost for 3TeV with $L_{0.01}=2\ 10^{34}cm^{-2}s^{-1}$
- Structure limits
  - RF breakdown – scaling (E_{surf}<260MV/m , $P/C\tau^{1/3}$ limited)
  - RF pulse heating (ΔT<56°K)
- Beam dynamics
  - Beam-beam effects
  - Damping rings, BDS
  - Main linac emittance preservation – wake fields
- Cost model
- Merged into one big model
- Chose 100MV/m and 12GHz



A.Grudiev, H. Braun, D. Schulte, W. Wuensch.

Two-Beam Concept

- The drive-beam concept is important because it provides the necessary flexibility in parameter space
  - For optimum cost and gradient CLIC needs short RF pulses with very high power
    - 240ns long 64MW pulse for each 23cm long structure
- X-Band klystrons
  - Less than 100MW
  - Need one klystron per structure (140,000 klystrons) or pulse compression
  - Klystrons are vital for structure tests
- Drive beam scheme
  - 140us long 1GHz RF pulses are transformed into 240ns long 12GHz RF pulses
    - Very efficient klystrons can be used
    - No need to have klystrons in main linac tunnel (or to use long over-moded waveguides)

CLIC Main Parameters

http://cdsweb.cern.ch/record/1132079?ln=fr http://clic-meeting.web.cern.ch/clic-meeting/clictable2007.html

High gradient to reduce cost

- Break down of structures at high fields and long pulses
  - Pushes to short pulses
  - and small iris radii (high wakefields)

High luminosity

- Improve wall plug to RF efficiency
- Push RF to beam efficiency
  - Push single bunch charge to beam dynamics limit
  - Reduce bunch distance to beam dynamics limit
- Push specific luminosity -> High beam quality
  - Beam-based alignment and tuning
  - Excellent pre-alignment
  - Component stabilisation

		CLIC	CLIC	ILC
E_{cms}	[TeV]	0.5	3.0	0.5
f_{rep}	[Hz]	50	50	5
n_b		354	312	2625
Δt	[ns]	0.5	0.5	369
N	$[10^9]$	6.8	3.7	20
σ_x	[nm]	202	40	655
σ_y	[nm]	2.26	1	5.7
ϵ_x	[μm]	2.4	0.66	10
ϵ_y	[nm]	25	20	40
$\mathcal{L}_{total}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	2.3	5.9	2.0
$\mathcal{L}_{0.01}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	1.4	2.0	1.45
n_γ		1.3	2.2	1.3
$\Delta E/E$		0.07	0.29	0.024
N_{coh}	$[10^5]$	10^{-3}	3.8×10^3	—
E_{coh}	$[10^3\mathrm{TeV}]$	0.015	2.6×10^5	—
n_{incoh}	$[10^6]$	0.08	0.3	0.1
E_{incoh}	$[10^6\mathrm{GeV}]$	0.36	22.4	0.2
$n_\perp$		20.5	45	28
n_{had}		0.19	2.7	0.12

Luminosity Limitations

Goal is to provide $L_{bx}(f, a, \sigma_a, G)$, $N(f, a, \sigma_a, G)$ and criterium for Δz

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

$$\mathcal{L} \propto H_D \frac{N}{\sqrt{\beta_x\epsilon_x}\sqrt{\beta_y\epsilon_y}} \eta P$$

- Efficiency η depends on beam current that can be transported

  $\Rightarrow$ decrease bunch distance $\Rightarrow$ long-range transverse wakefields in main linac

  $\Rightarrow$ increase bunch charge $\Rightarrow$ short-range transverse and longitudinal wakefields in main linac, other effects

- Horizontal beam size σ_x
  beam-beam effects, final focus system, damping ring, bunch compressors

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

- Will start at IP and try to explain limitations at new parameter set

Experimental Condition Limitations

- The vertical beam size had been $\sigma_y = 1\,\mathrm{nm}$ (BDS)

  $\Rightarrow$ challenging enough, so keep it $\Rightarrow \epsilon_y = 10\,\mathrm{nm}$

- Fundamental limit on horizontal beam size arises from beamstrahlung

  Two regimes exist depending on beamstrahlung parameter

$$\Upsilon = \frac{2}{3}\frac{\hbar\omega_c}{E_0} \propto \frac{N\gamma}{(\sigma_x + \sigma_y)\sigma_z}$$

  $\Upsilon \ll 1$: classical regime, $\Upsilon \gg 1$: quantum regime

  At high energy and high luminosity $\Upsilon \gg 1$

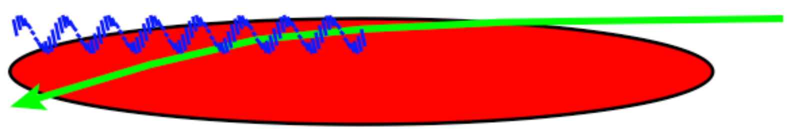
$$\mathcal{L} \propto \Upsilon\sigma_z/\gamma P\eta$$

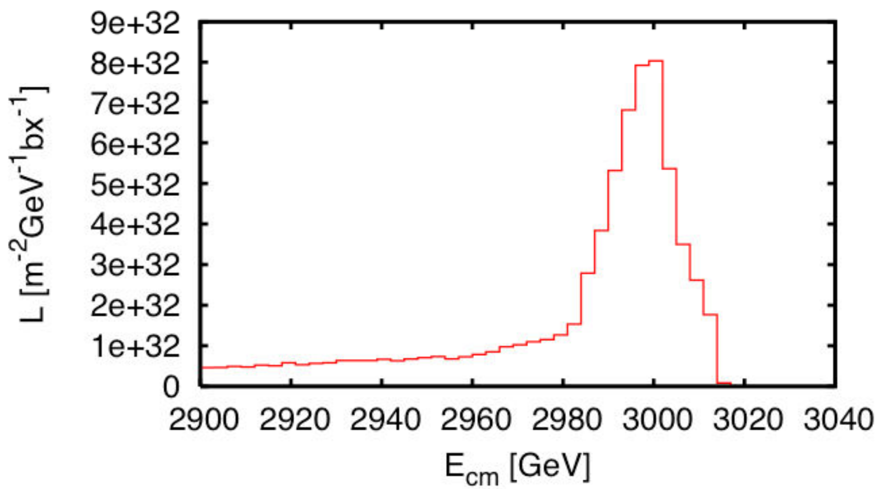
  $\Rightarrow$ partial suppression of beamstrahlung

  $\Rightarrow$ coherent pair production

  In CLIC $\langle\Upsilon\rangle \approx 6$, $N_{coh} \approx 0.1N$

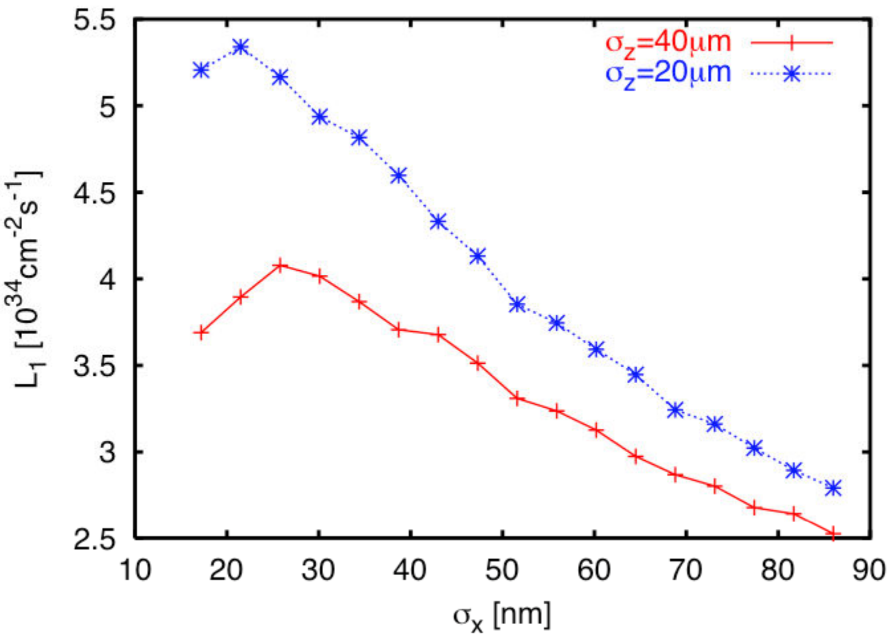
  $\Rightarrow$ somewhat in quantum regime

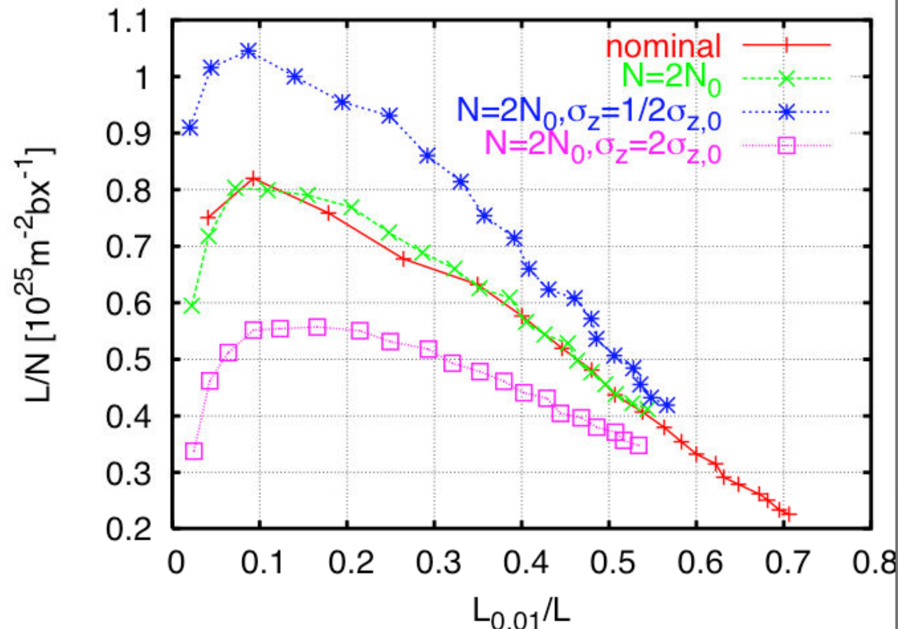




$\Rightarrow$ Use luminosity in peak as figure of merit

Horizontal Beam Size Optimisation





Total luminosity for $\Upsilon \gg 1$

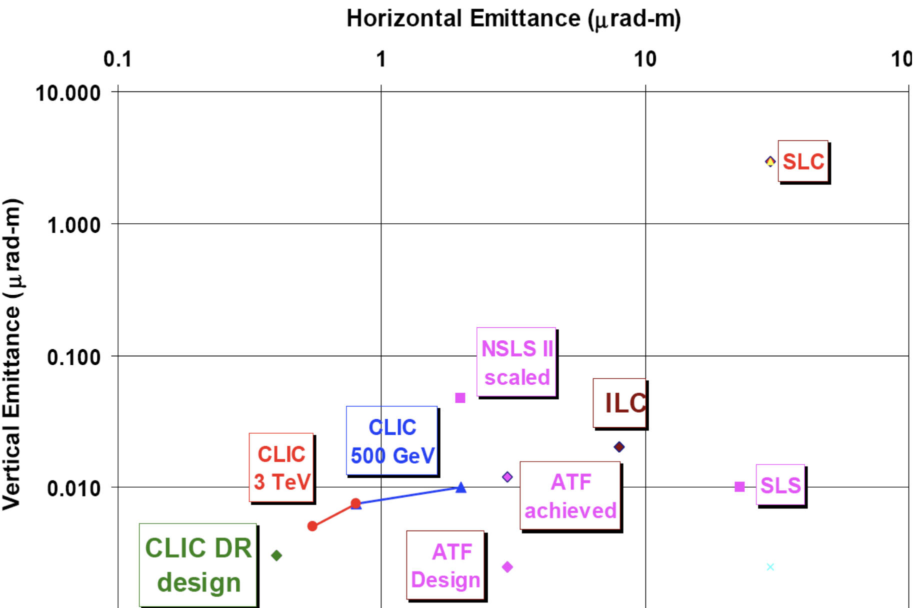
$$\mathcal{L} \propto \frac{N}{\sigma_x}\frac{\eta}{\sigma_y} \propto \frac{n_\gamma^{3/2}}{\sqrt{\sigma_z}}\frac{\eta}{\sigma_y}$$

large n_γ $\Rightarrow$ higher $\mathcal{L}$ $\Rightarrow$ degraded spectrum

chose n_γ, e.g. maximum $L_{0.01}$ or $L_{0.01}/L = 0.4$ or ...

$$\mathcal{L}_{0.01} \propto \frac{\eta}{\sqrt{\sigma_z}\sigma_y}$$

Damping Ring Design



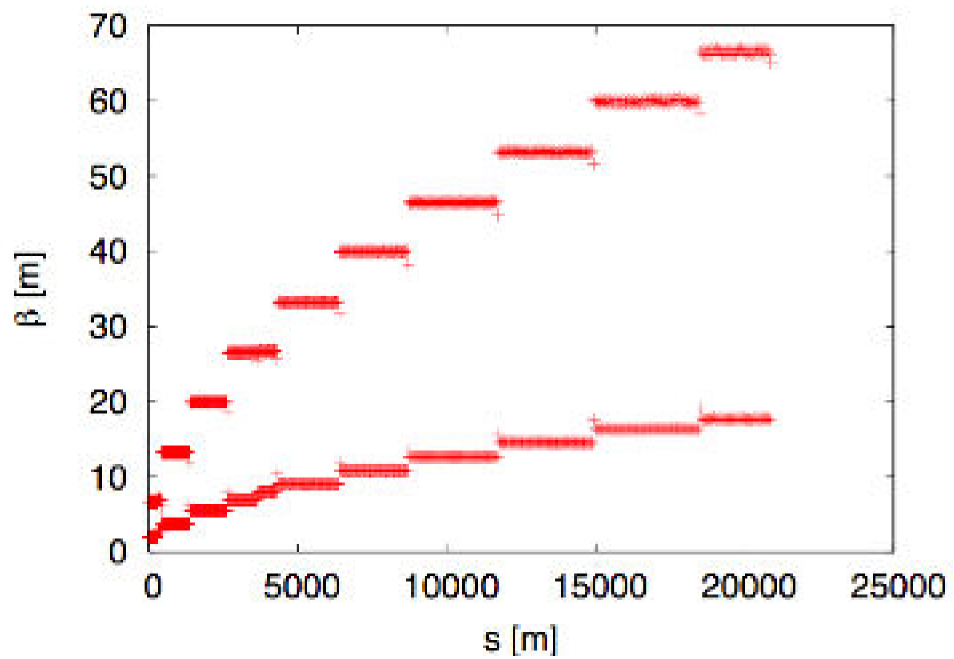
PARAMETER	NLC	CLIC (3TeV)
bunch population (10^9)	7.5	4.1
bunch spacing [ns]	1.4	0.5
number of bunches/train	192	316
number of trains	3	1
Repetition rate [Hz]	120	50
Extracted hor. normalized emittance [nm]	2370	<500
Extracted ver. normalized emittance [nm]	<30	<5
Extracted long. normalized emittance [keV.m]	10.9	<5
Injected hor. normalized emittance [μm]	150	63
Injected ver. normalized emittance [μm]	150	1.5
Injected long. normalized emittance [keV.m]	13.18	1240

- Present CLIC DR design for 3TeV achieves goals for transverse emittances with a 20%-30% margin (380nm horizontal and 4.1nm vertical)
- Conservative DR output emittances (2.4μm horizontal, 10nm vertical) for CLIC @ 500GeV scaled from operational or approved light source projects (NSLSII, SLS)
- Route to lower emittances to be defined

Main Linac Design

Main linac uses strong focusing to maximise bunch charge that can be transported in stable fashion

- About 10% of the linac are magnets
- Leads to tight alignment tolerances (O(10μm))
- Leads to tight stability tolerances (O(1nm) for quadrupoles)



CLIC Physics up to 3 TeV

What can CLIC provide in the 0.5-3 TeV range?
In a nutshell…

Higgs physics:

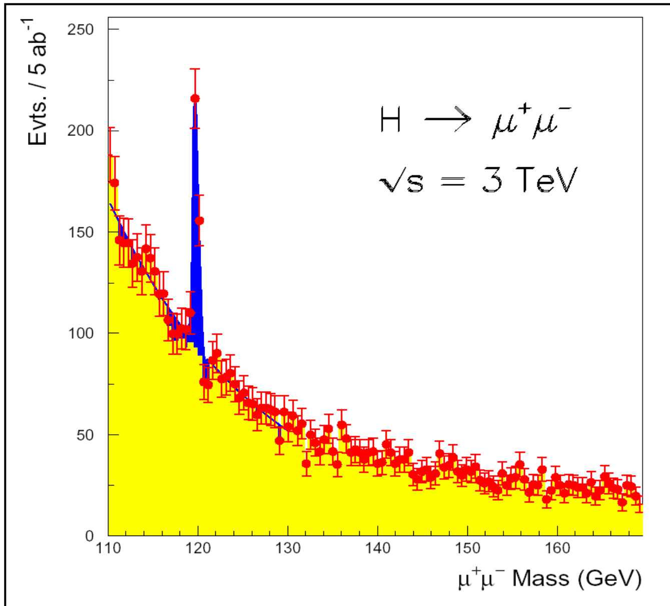
- Complete study of the light standard-model Higgs boson, including rare decay modes (rates factor ~5 higher at 3 TeV than at 500 GeV)
  - Higgs coupling to leptons
  - Study of triple Higgs coupling using double Higgs production
- Study of heavy Higgs bosons (supersymmetry models)

Supersymmetry:

- Extensive reach to measure SUSY particles

And in addition:

- Probe for theories of extra dimensions
- New heavy gauge bosons (e.g. Z')
- Excited quarks or leptons



(S)LHC, ILC, CLIC reach

	LHC 100 fb^{-1}	ILC 800 GeV 500 fb^{-1}	SLHC 1000 fb^{-1}	CLIC 3 TeV 1000 fb^{-1}
Squarks [TeV]	2.5	0.4	3	1.5
Sleptons [TeV]	0.34	0.4		1.5
New gauge boson Z′ [TeV]	5	8	6	22
Excited quark q* [TeV]	6.5	0.8	7.5	3
Excited lepton l* [TeV]	3.4	0.8		3
Two extra space dimensions [TeV]	9	5–8.5	12	20-35
Strong $W_L W_L$ scattering	2σ	-	4σ	70σ
Triple-gauge Coupling (95%)	.0014	0.0004	0.0006	0.00013

Gian Giudice CLIC09