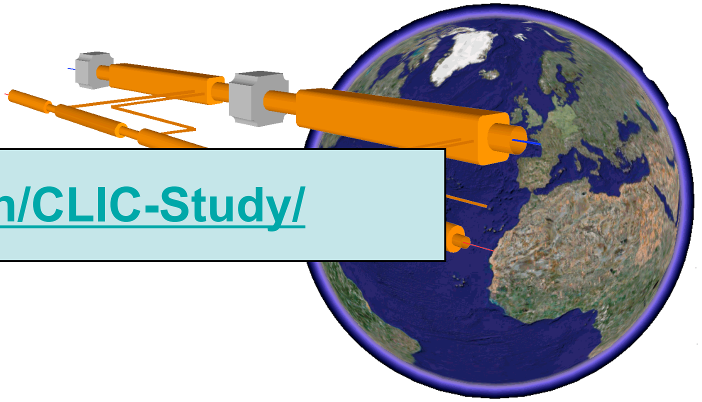
CLIC Overview and Status

D. Schulte for the CLIC team

Very short introduction to CLIC scheme

Feasibility issues

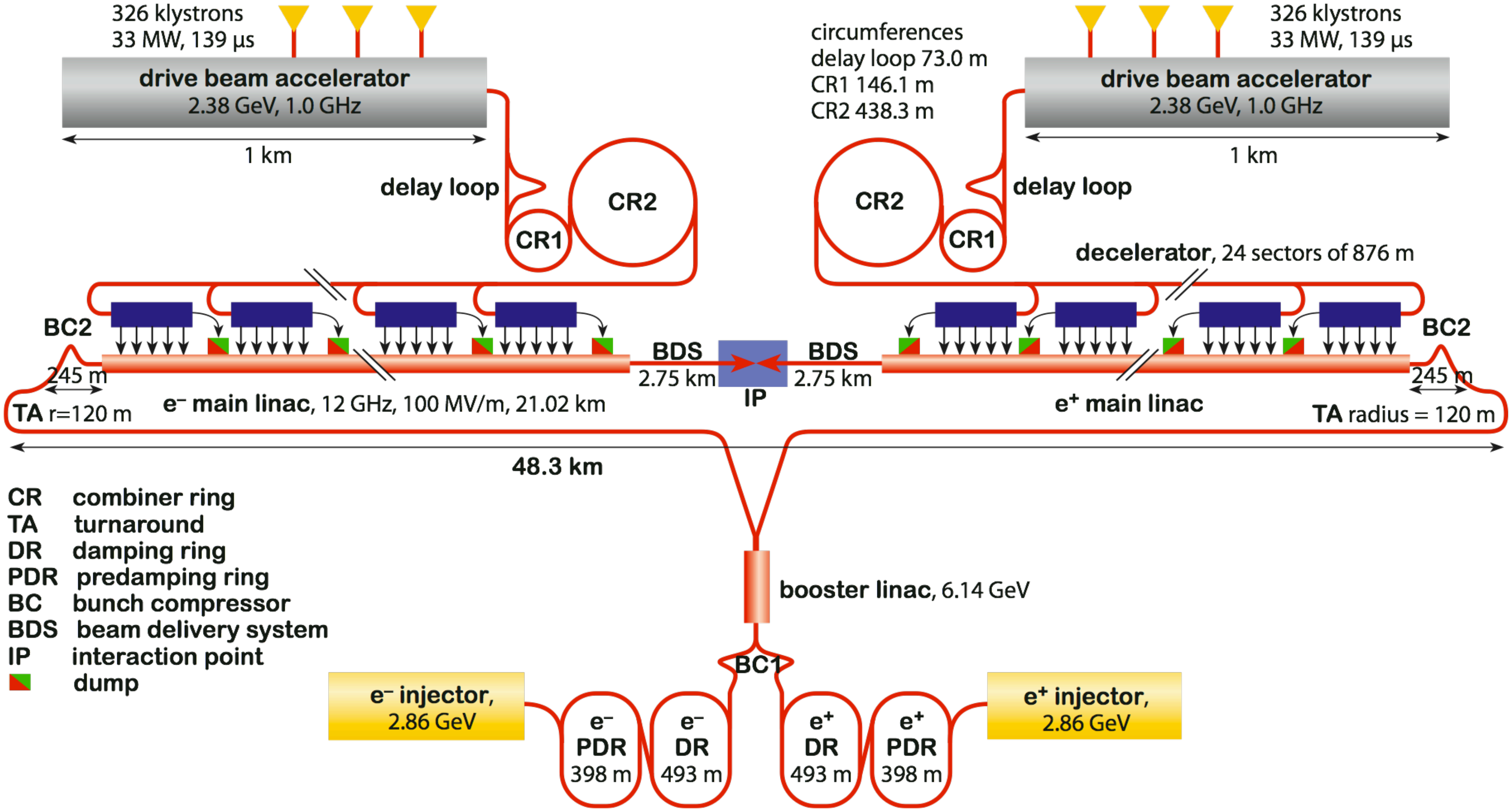
Conclusion



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

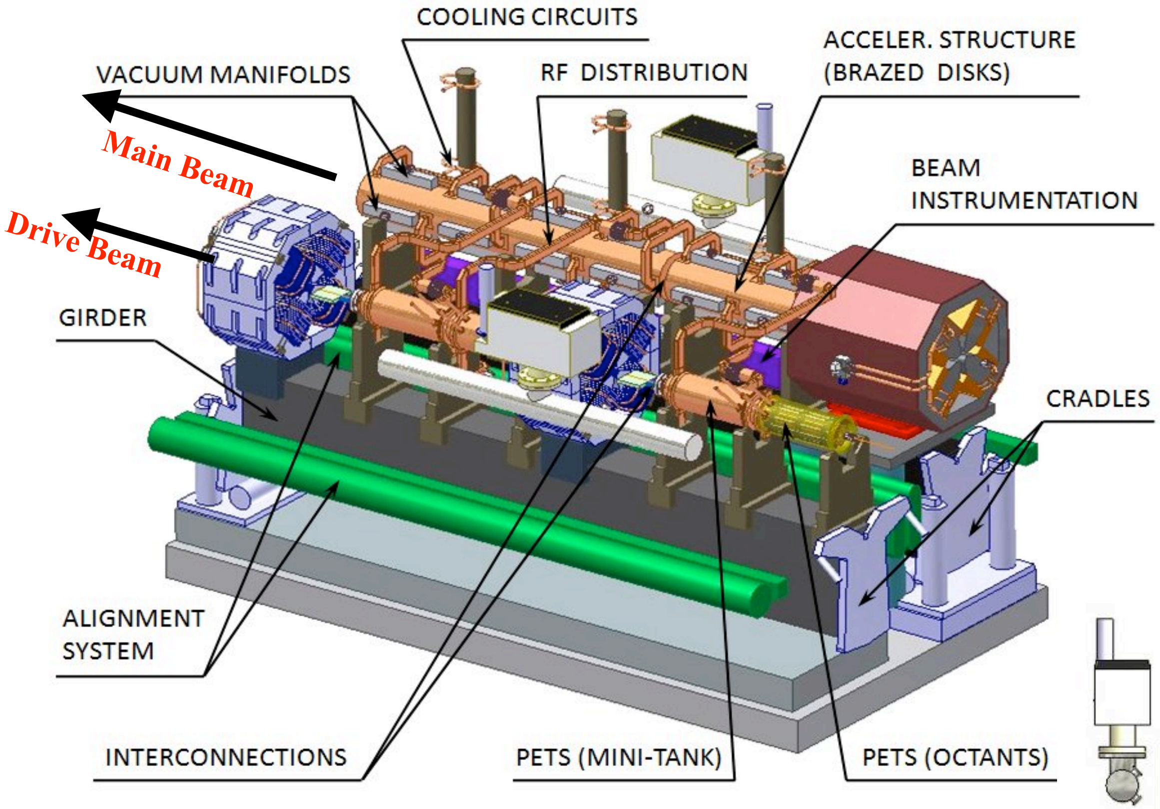
FNAL November 2009

The CLIC Layout



CR	combiner ring
TA	turnaround
DR	damping ring
PDR	predamping ring
BC	bunch compressor
BDS	beam delivery system
IP	interaction point
🟥	dump

CLIC Two Beam Acceleration Module



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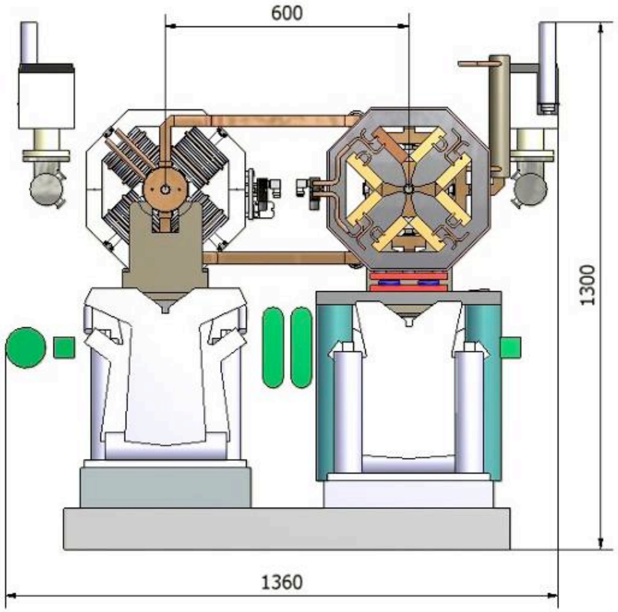


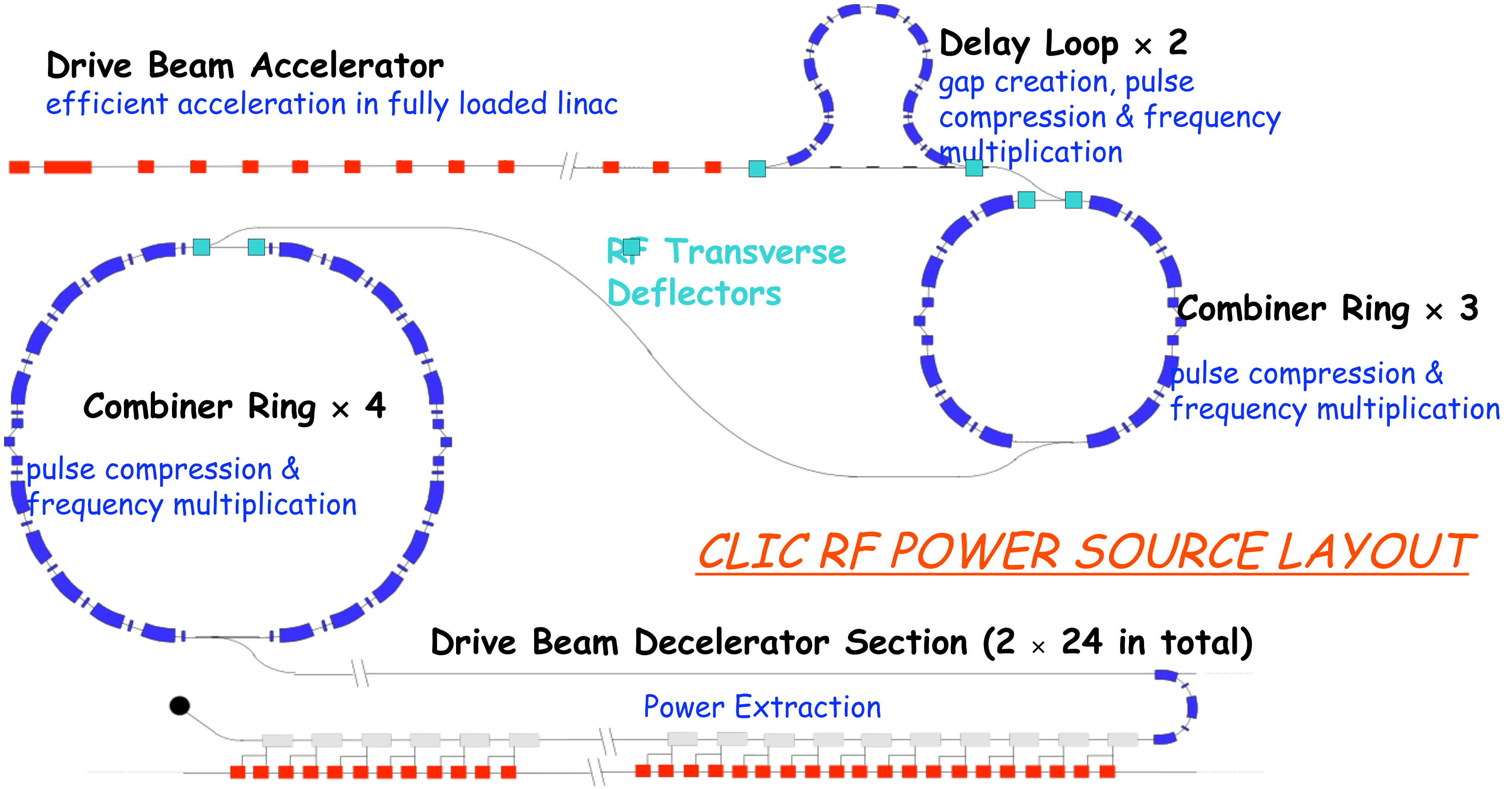
20760 modules (2 meters long)

71460 power production structures PETS (drive beam)

143010 accelerating structures

(main beam)

CLIC Power Source Concept



Drive Beam Accelerator
efficient acceleration in fully loaded linac

Delay Loop × 2
gap creation, pulse compression & frequency multiplication

RF Transverse Deflectors

Combiner Ring × 3
pulse compression & frequency multiplication

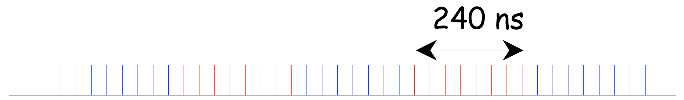
Combiner Ring × 4
pulse compression & frequency multiplication

CLIC RF POWER SOURCE LAYOUT

Drive Beam Decelerator Section (2 × 24 in total)

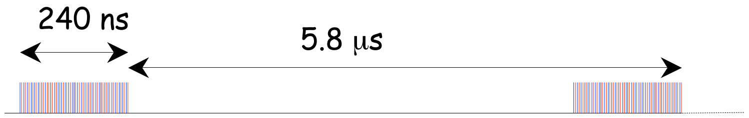
Power Extraction

Drive beam time structure - initial



140 µs train length - 24 × 24 sub-pulses
4.2 A - 2.4 GeV – 60 cm between bunches

Drive beam time structure - final

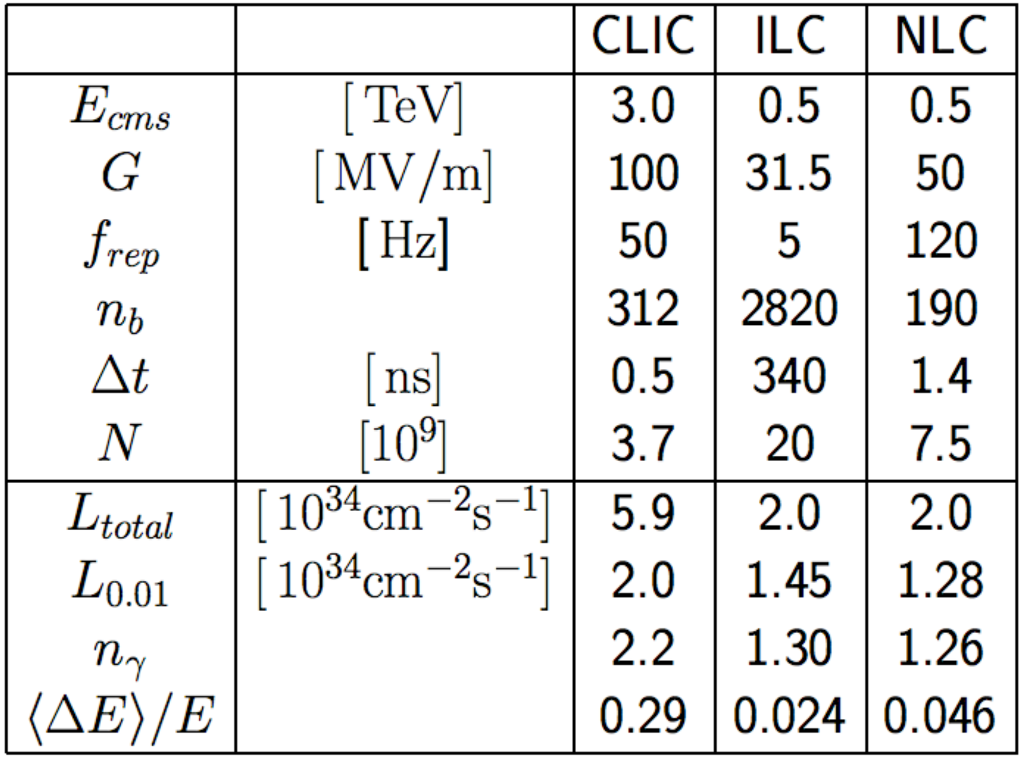


24 pulses – 101 A – 2.5 cm between bunches

The CLIC Rational

- Aim at high centre-of-mass energy at reasonable cost
  - Reduce machine size
    - high accelerating gradients -> structure design
  - Minimise cost per unit length
    - focus is on the main linac module and tunnel
  - Power source
- Aim at high luminosity
  - Push beam current -> push efficiency
  - Push specific luminosity -> high beam quality
  - Push effective run time -> operation and machine protection
- Aim at good experimental conditions
  - Detector design
  - Quality of luminosity spectrum
  - Background conditions

Basic Parameter Comparison



		CLIC	ILC	NLC
E_{cms}	$[\mathrm{TeV}]$	3.0	0.5	0.5
G	$[\mathrm{MV/m}]$	100	31.5	50
f_{rep}	$[\mathrm{Hz}]$	50	5	120
n_b		312	2820	190
Δt	$[\mathrm{ns}]$	0.5	340	1.4
N	$[10^9]$	3.7	20	7.5
L_{total}	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	5.9	2.0	2.0
$L_{0.01}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	2.0	1.45	1.28
n_γ		2.2	1.30	1.26
$\langle\Delta E\rangle/E$		0.29	0.024	0.046

ILC is based on superconducting cavities
NLC had been based on klystrons
500GeV and initial parameter sets for CLIC exist

Gradient Limitations

- Structure gradients are limited by breakdowns, depending on
  - Surface electric field
  - Pulsed surface heating
    - Surface magnetic field and pulse length
  - RF power flow
    - RF power flow through iris aperture, depends on pulse length
  - Have empiric model for limit 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

Luminosity

The luminosity is given by

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

Which can be written as

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

Note $\sigma_x >> \sigma_y$

Hence try to optimise
- efficiency (main linac)
- vertical beam size
- horizontal beam size

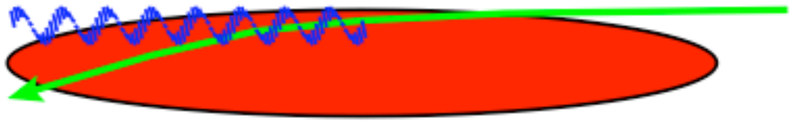
Use realistic assumptions about obtainable beam parameters

IP Beam Size Limitations at the IP

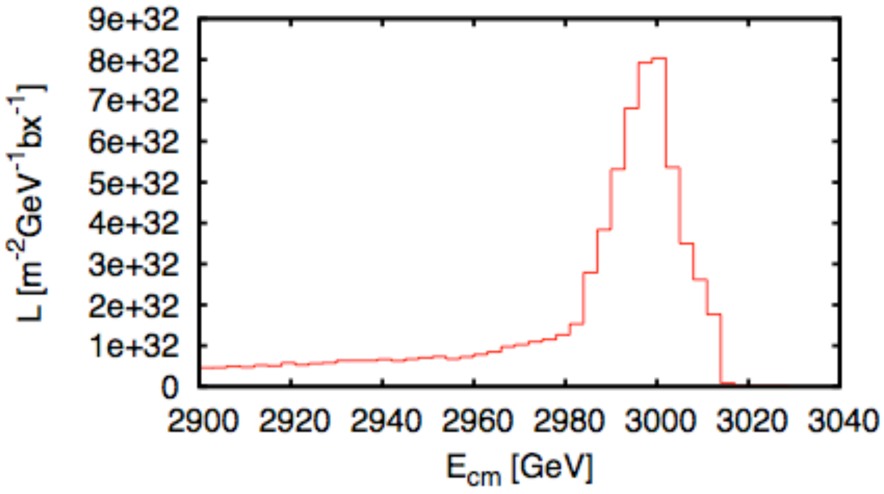
- Vertical beam size σ_y
  need to collide beams, beam delivery system, main linac, beam-beam effects, damping ring, bunch compressor

  $\Rightarrow$ 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



For our parameters 40nm x 1nm

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

Optimisation Results

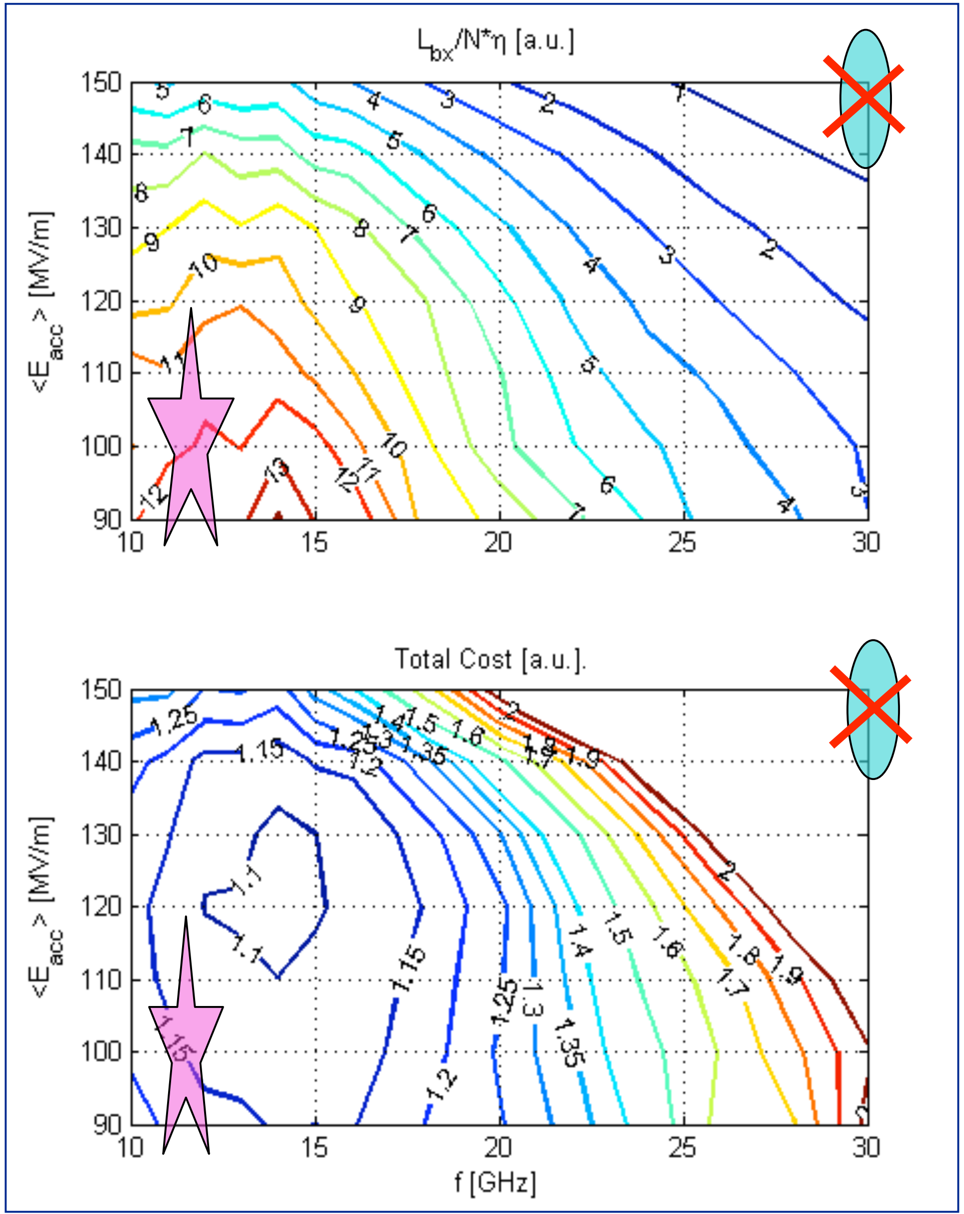
- Optimisation - figure of merit:
  - Luminosity per input power
  - Luminosity per cost

- Using
  - Structure limits:
  - Beam dynamics:

- Take into account cost model

- Once assumptions are defined, parameters drop out automatically

- Chose 100MV/m and 12GHz

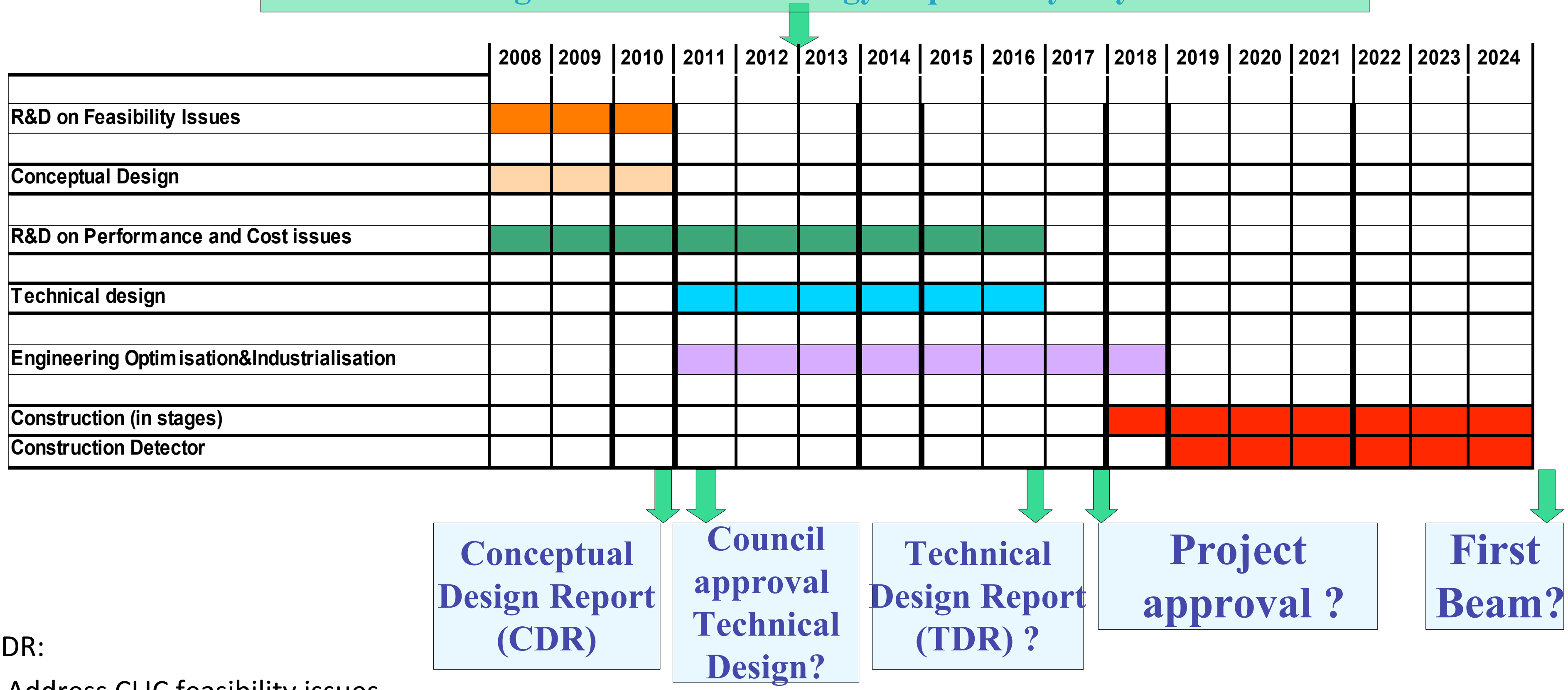


A.Grudiev et al.

Tentative long-term CLIC scenario

Shortest, Success Oriented, Technically Limited Schedule

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



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
R&D on Feasibility Issues	🟧	🟧	🟧														
Conceptual Design	🟨	🟨	🟨														
R&D on Performance and Cost issues	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩								
Technical design				🟦	🟦	🟦	🟦	🟦	🟦								
Engineering Optimisation&Industrialisation				🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪						
Construction (in stages)											🟥	🟥	🟥	🟥	🟥	🟥	🟥
Construction Detector												🟥	🟥	🟥	🟥	🟥	🟥

Conceptual Design Report (CDR)

Council approval Technical Design?

Technical Design Report (TDR) ?

Project approval ?

First Beam?

CDR:

- Address CLIC feasibility issues
  - And a part of performance and cost issues
- Conceptual design of a linear collider based on CLIC technology
- Estimation of its cost (capital investment & operation)
- CLIC Physics Study and detector development (L. Linssen et al.:

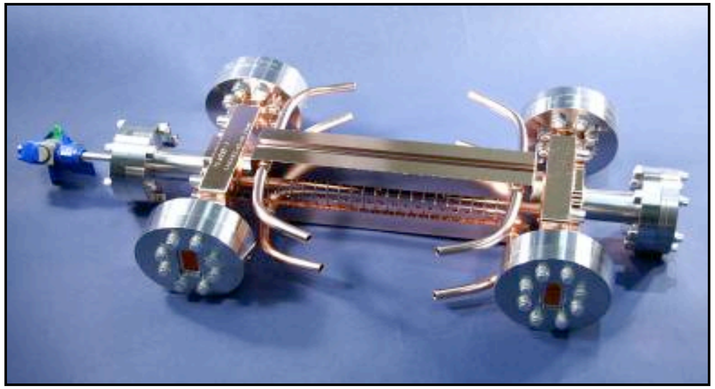
CLIC Feasibility Issues

System	Item	Parameter Issue	Test facility Common with ILC
Two Beam Acceleration	Drive beam generation	100 A peak current / 590 μC total charge 12 GHz bunch repetition freq. & 1 mm bunch length 0.2 degrees phase stability at 12 GHz (0.1 psec) $7.5\ 10^{-4}$ intensity stability	CTF3 CTF3/TBL Simulations X-FEL, LCLS
	Beam Driven RF power generation	90% conversion efficiency from drive beam to RF Large drive beam momentum RF pulse shape accuracy < 0.1%	CTF3/TBL Simulations
	Two beam module	Two Beam Acceleration at nominal parameters	CTF2&3/TBTS
RF Structures	Accelerating Structures (CAS)	100 MV/m 240 RF pulse length with flat top 160ns breakdown probability/pulse < 3·10-7 /m	CTF2&3 SLAC/NLCTA&NASTA KEK/NEXTEF
	Power Production Structures (PETS)	132 MW total flat-top pulse length 240/160 ns breakdown probability/pulse < 1·10-7 /m On/Off/adjust capability	CTF3 CTF3/TBTS & TBL SLAC/ASTA
Ultra low beam emittance & sizes	Emittance preservation	during generation, acceleration and focusing: Emittances (nm): H= 600, V=5 Absolute blow-up (nm): H=160, V=15	ATF, SLS, NSLSII Simulations LCLS, SCSS
	Alignment and stabilisation	Main Linac : 1 nm vert. above 1 Hz BDS: 0.3 nm beam-beam offset	CESRTA ATF2
Detector	Short interval between bunches	Time stamping: 0.5 nsec bunch interval	Simulations
	Background at high beam collision energy	Beam-Beam background: $3.8\ 10^{8}$ coherent/1e5 incoherent e+/e- pairs, Hadrons, High muon flux	Simulations
Operation and Machine Protection System (MPS)		drive beam power of 72 MW @ 2.4 GeV main beam power of 13 MW @ 1.5 TeV MTBF, MTTR	CTF3 Simulations

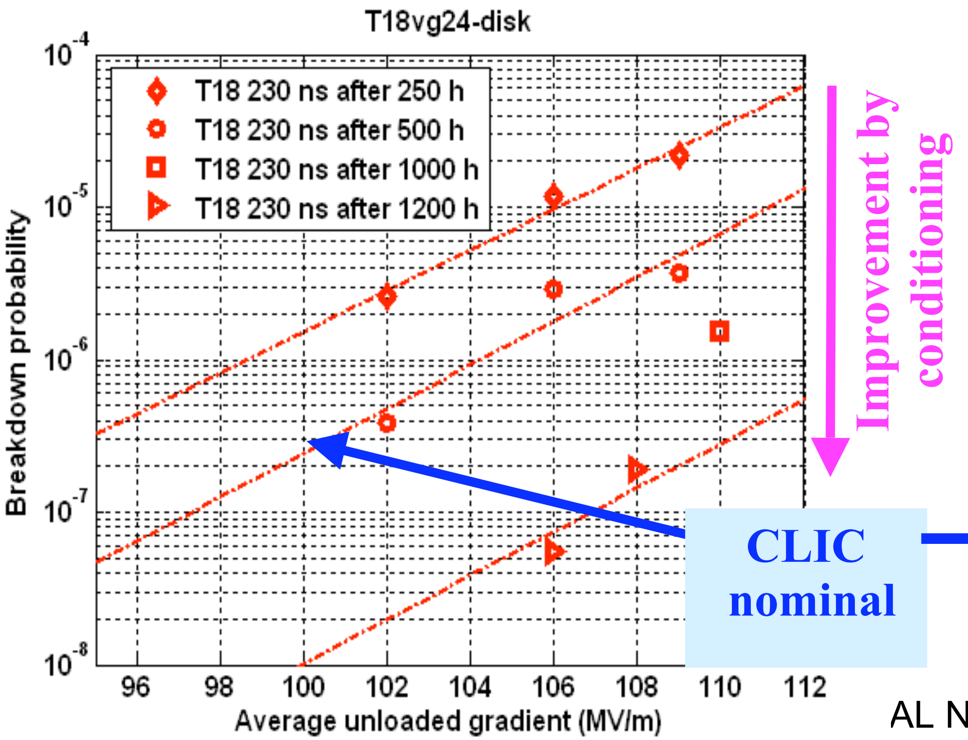
Accelerating Structure Performance

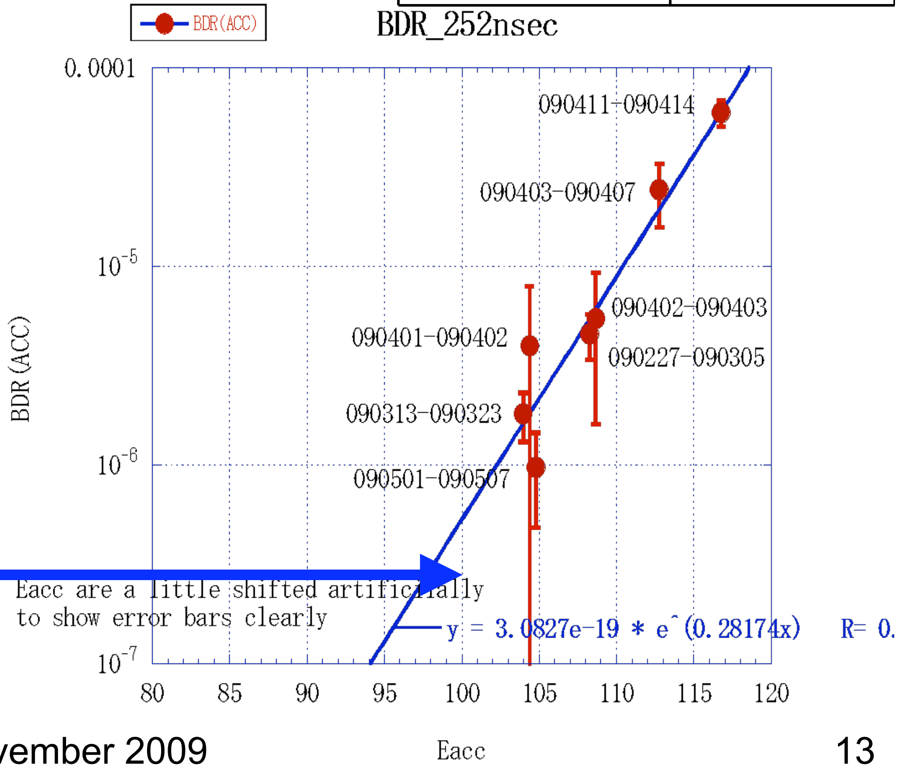
Excellent Collaboration: CERN-KEK-SLAC

- 3 structures *T18_VG2.4_disk (no damping)*
- RF design @ CERN Fabricated @ tested at SLAC and KEK
- Exceeded 100 MV/m at nominal breakdown rate

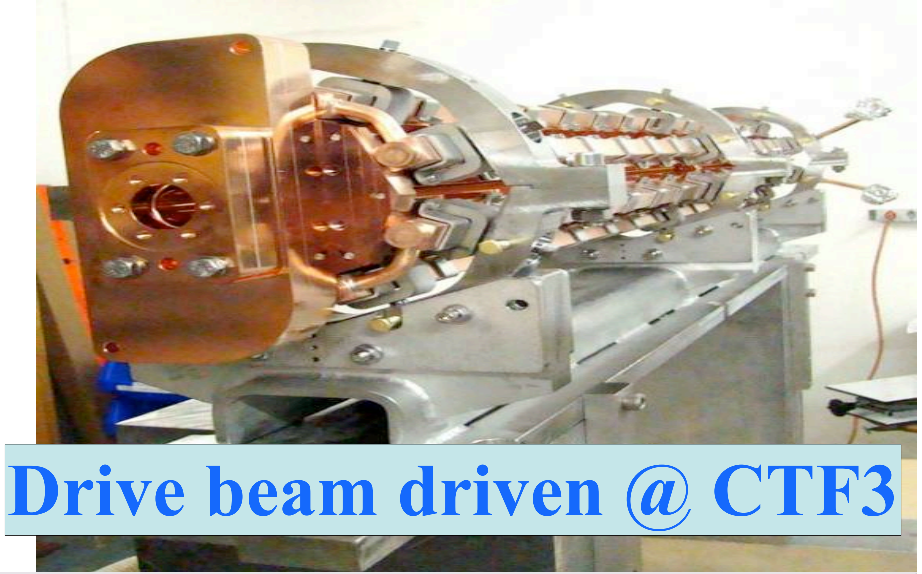


Frequency:	11.424 GHz
Cells:	18+2 matching cells
Filling Time:	36 ns
Length:active acceleration	18 cm
Iris Dia. a/λ	0.155~0.10
Group Velocity: vg/c	2.6-1.0 %
Phase Advace Per Cell	2π/3
Power for <Ea>=100MV/m	55.5 MW
Unloaded Ea(out)/Ea(in)	1.55
Es/Ea	2



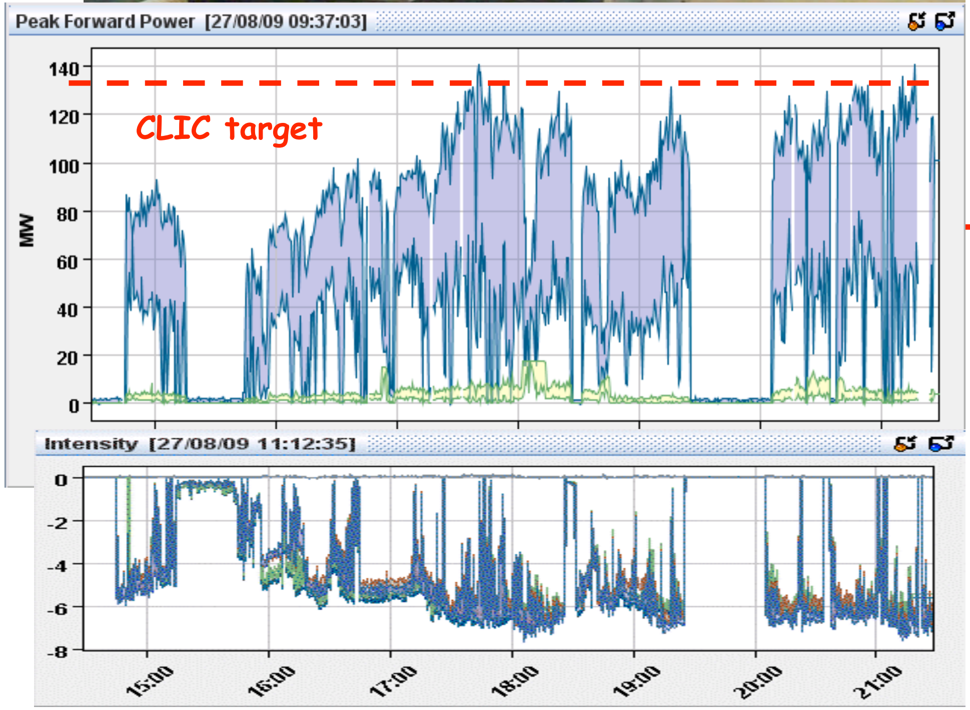


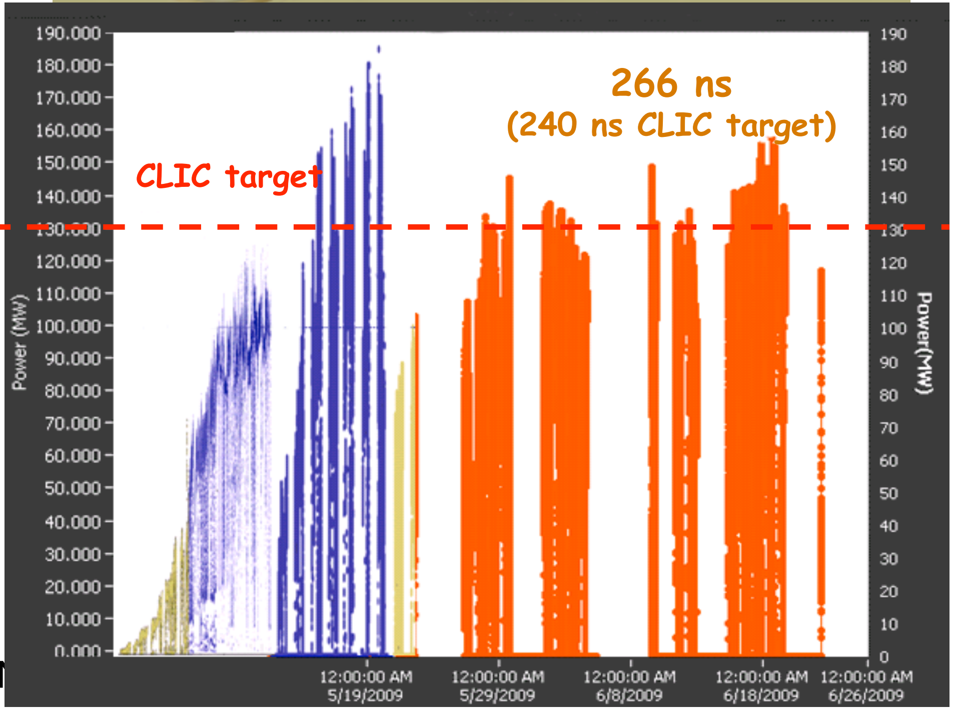
PETS Experimental Results



Drive beam driven @ CTF3

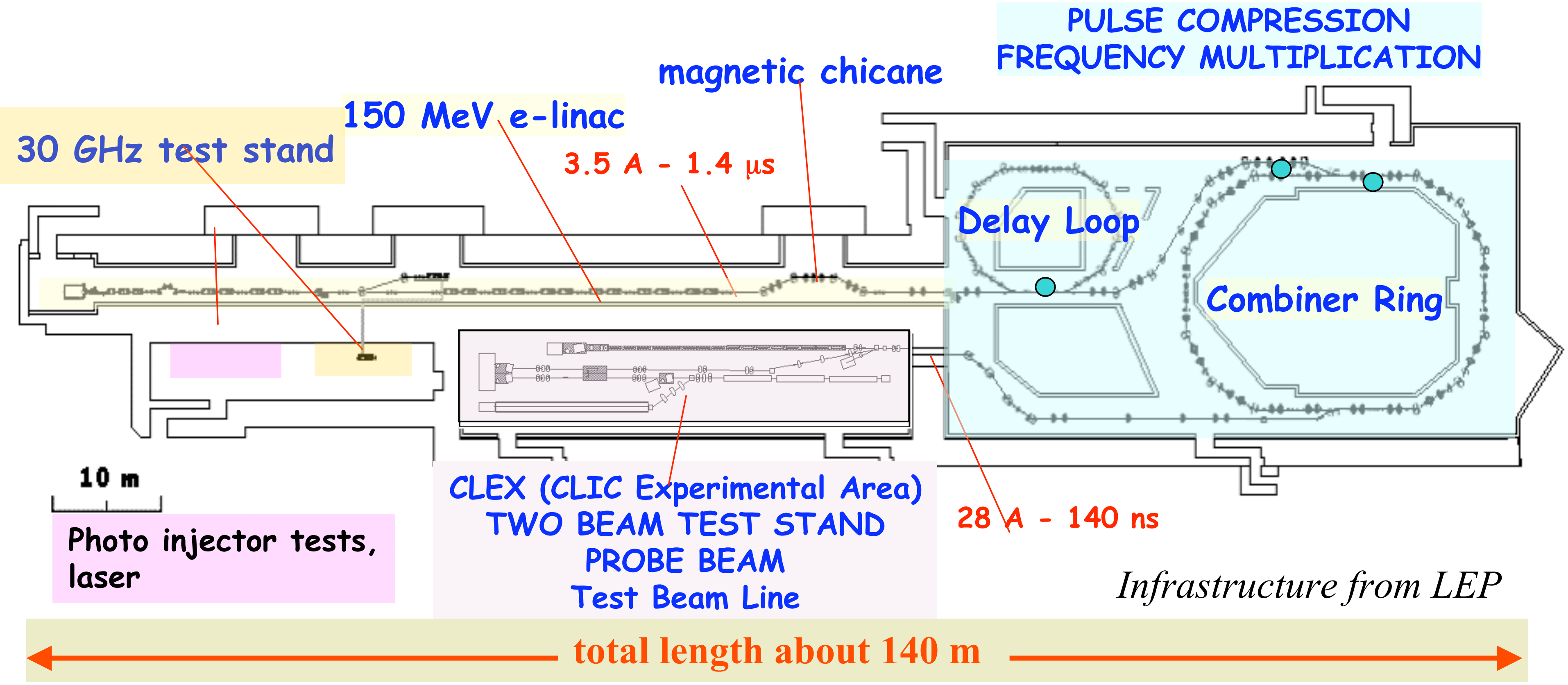
Klystron driven @ SLAC





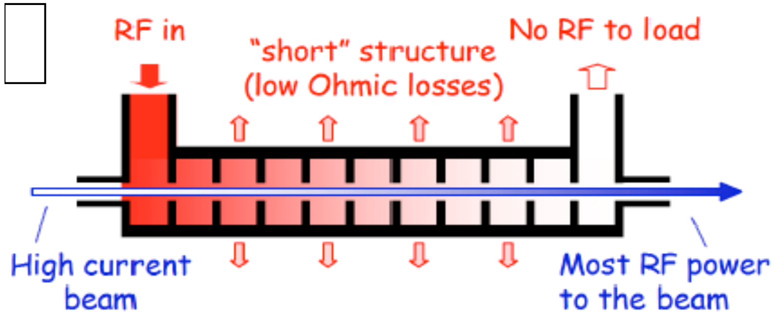
Two-Beam Acceleration: CLIC Test Facility (CTF3)

- 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

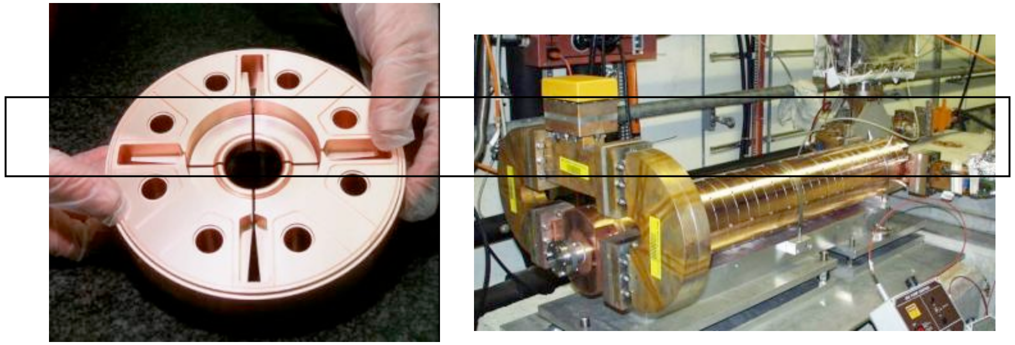


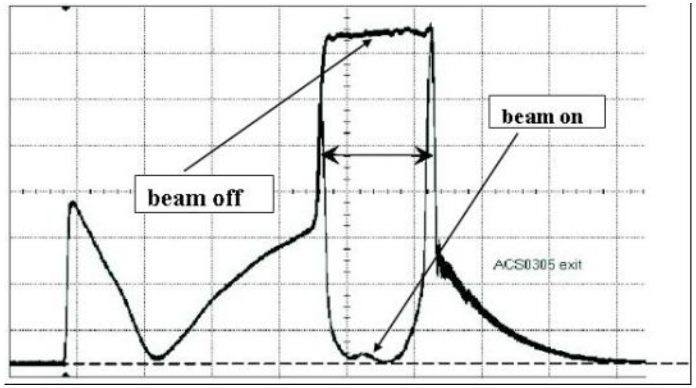
Drive Beam Generation: Full Beam Loading Acceleration in Drive Linac

Proof of one of the major CLIC features:
Full Beam Loading



Drive Beam accelerating structure:



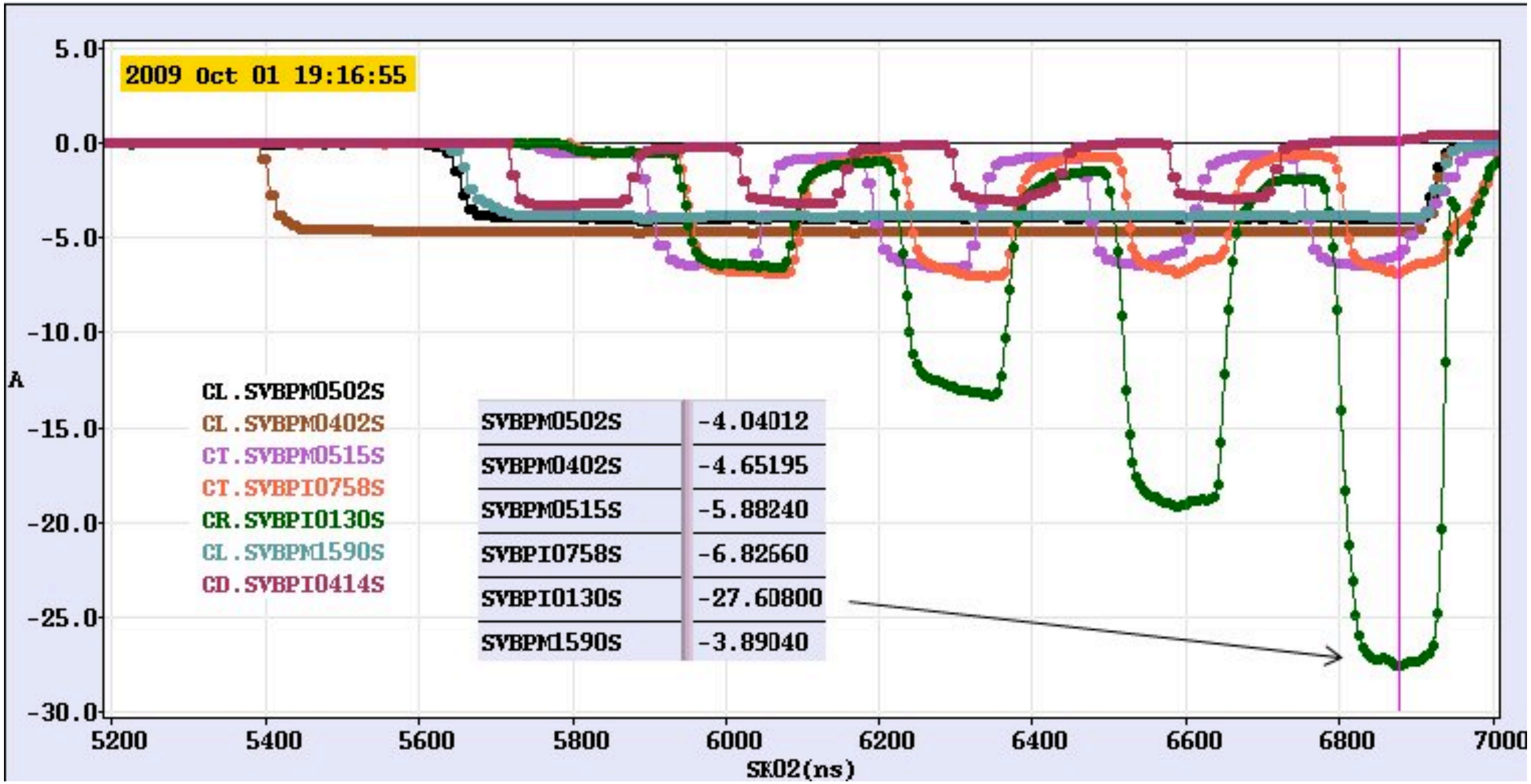


RF power at output of accelerating structure

RF to beam transfer:
95.3 % measured

Linac routinely operated with full beam loading

Drive Beam Generation:
Beam Pulse Compression in CTF3

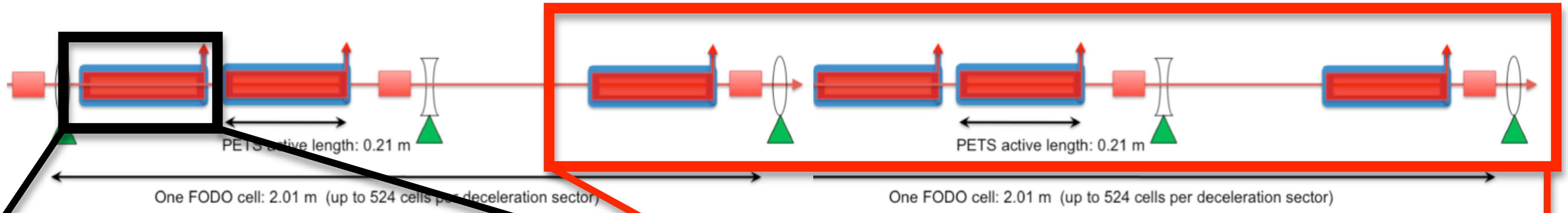


SVBPM0502S	-4.04012
SVBPM0402S	-4.65195
SVBPM0515S	-5.88240
SVBPI0758S	-6.82660
SVBPI0130S	-27.60800
SVBPM1590S	-3.89040

Remaining: some increase in intensity (10%), phase stability

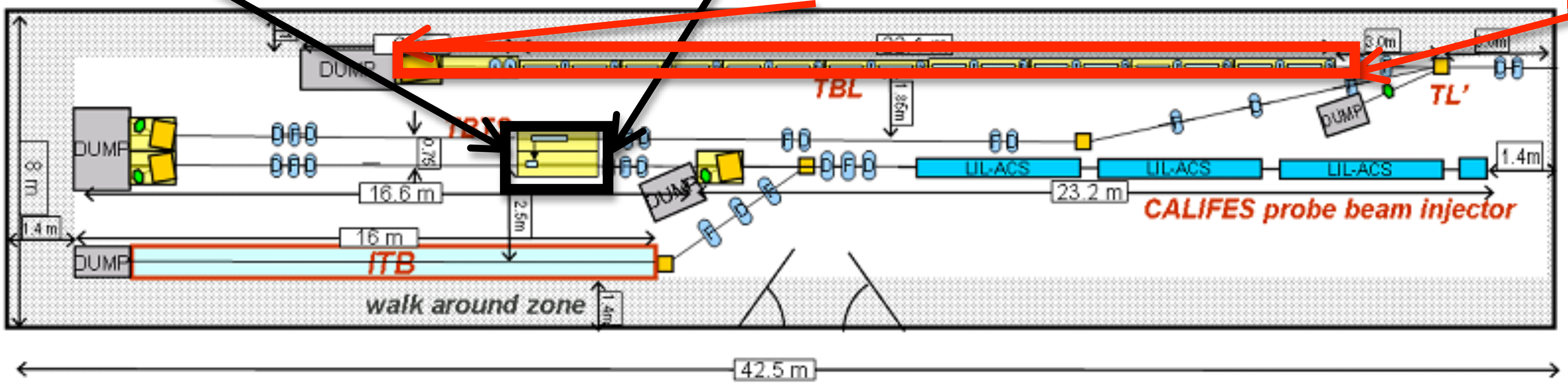
Drive Beam Deceleration and Module: CLEX

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



Two-beam Test Stand:
test the characteristics of a **single** PETS

Test Beam Line:
test of **beam transport** where a large fraction of the energy is extracted, under betatron motion (16 PETS)

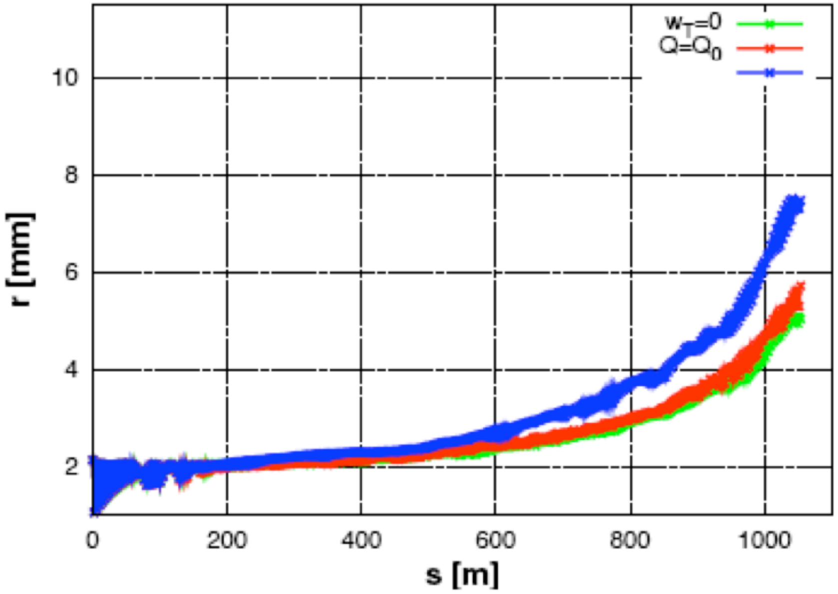


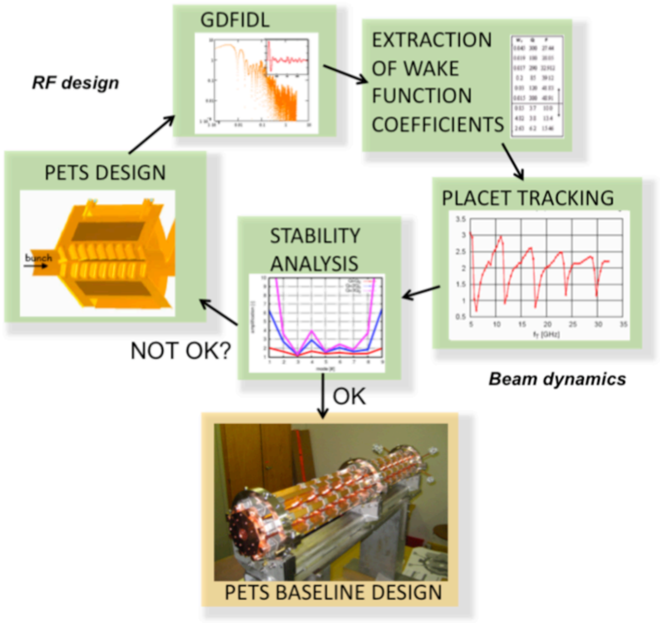
Two Beam Module:

- Principle of two-beam acceleration had been established in CTF and CTF2
- Test of new PETS and accelerating structure end 2009-2010
- Some tests after 2010 (wake monitors)

Drive Beam Deceleration

- Drive beam has high current (100A) and large energy spread (factor 10)
    - Simulations show that the beam is stable
    - Several iteration of PETS design
- Test Beam Line (TBL) under construction will increase confidence
    - first PETS installed
    - beam to the end




GDFIDL

RF design

EXTRACTION OF WAKE FUNCTION COEFFICIENTS

PETS DESIGN

PLACET TRACKING

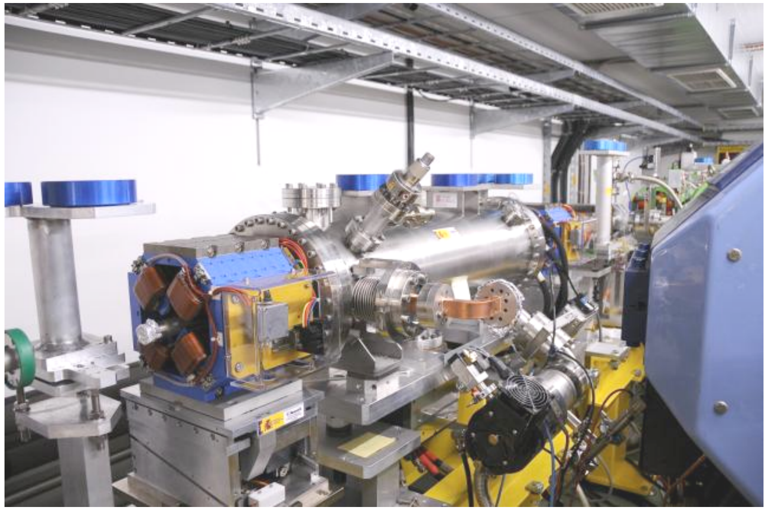
STABILITY ANALYSIS

NOT OK?

OK

Beam dynamics

PETS BASELINE DESIGN



Drive Beam Generation Feasibility

Feasibility Issue	Unit	Nominal @ 2 GeV	Feasibility Target @ 0.2Gev	Achieved @0.2 GeV	How	Feasibility
Fully loaded accel effic	%	96	95	95	CTF3	✓
Freq&Current multipl		2*3*4	2*4	2*4	CTF3	✓
12 GHz beam current	A	4.5*24=100	3.75*8=30	3.6*8=27	CTF3	✓
12 GHz pulse length	nsec	240	140	140	CTF3	✓
Bunch length	mm	1	1mm	?	CTF3	?
Timing stability	psec	0.1 psec	?	?	XFEL	-
Intensity stability	10^{-4}	7.5	30	30 @ * 4	CTF3	✓@*4

Drive beam generation feasibility demonstrated

- Intensity stability still to be improved
- Timing stability to be addressed (XFEL collab)

  a number of components exist or are being developed

J.-P. Delahaye et al.

Beam Driven RF Power Generation Feasibility

Feasibility Issue	Unit	Nominal	Feasibility Target	Achieved	How	Feasibility
PETS RF Power	MW	132	132	130	TBTS/	✓
PETS Pulse length	ns	240	240	>240	SLAC	✓
PETS Breakdown rate	/m	< 1·10-7	< 1·10-7	?	TBL	under cond.
PETS ON/OFF		@ 50Hz	@ low rep	-	CTF3	Being built
Drive beam to RF effic.	%	90%	50%	-	CTF3	TBL being installed
Drive mom. spread	%	90%	50%		CTF3	
Systematic RF pulse accuracy	%	< 0.1%	< 0.1%		CTF3	

- RF power generation by single PETS feasibility demonstrated except for breakdown rate.
- ON/OFF mechanism being built, still to be tested
- Efficient RF power extraction in multiple stages still to be addressed in TBL (being built for tests in 2010)

Two Beam Acceleration Feasibility

Feasibility Issue	Unit	Nominal	Feasibility Target	Achieved	How	Feasibility
Structure Acc field	MV/m	100	100	100	Test stand/	No Damping
Structure Pulse length	ns	240	240	240		
Structure Breakd . rate	/m	< 3·10-7	< 3·10-7	< 3·10-7		
Two Beam acceleration	MV/m	100	100	-	TBTS	Under constuction
module	ns	240	240	-		

Acceleration Structure with nominal parameters demonstrated without damping:

- RF to beam efficiency still to be improved.
- Structures with damping being built still to be tested.

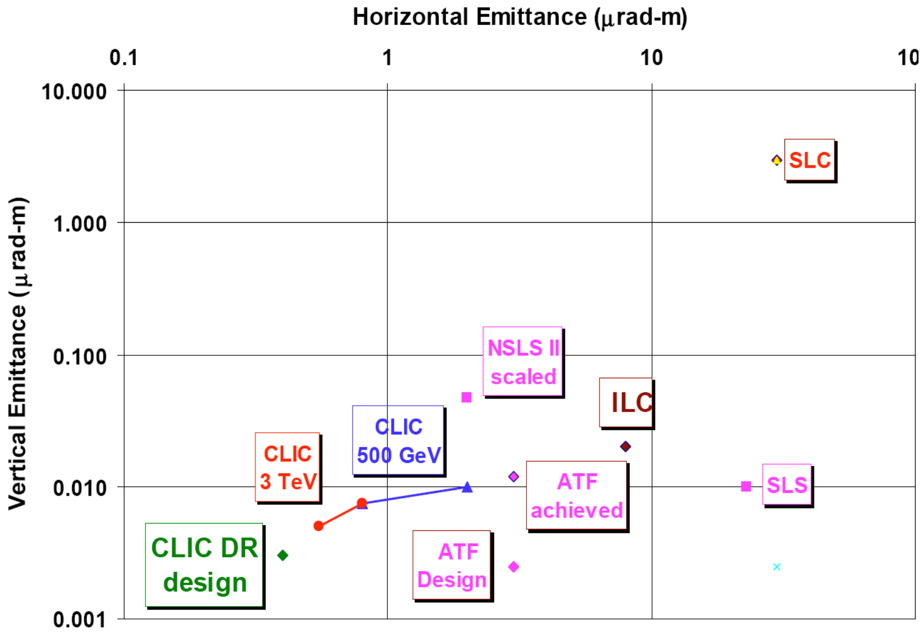
Two beam acceleration principle demonstrated in CTF2

- Two Beam Test Stand being built integrating (final) prototypes with power and beam tests in CTF3

Ultra Low Beam Emittances/Sizes

- Achievement of small emittances is based on
  - Advanced lattice designs
    - Damping ring, most important RTML lines, beam delivery system
  - Advanced component design
    - Instrumentation, e.g. wake monitors
    - Damping ring wigglers
    - Final focus magnets
  - Low level of imperfections
    - Alignment and stabilisation of beam line elements (ground motion etc)
    - Control of timing and drive beam phase and amplitude stability
    - Stray fields
  - Advanced strategies to deal with imperfections
    - Beam-based alignment, tuning and feedback
- On all items R&D is ongoing

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	312
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

Design achieves goals with 10-20% margin

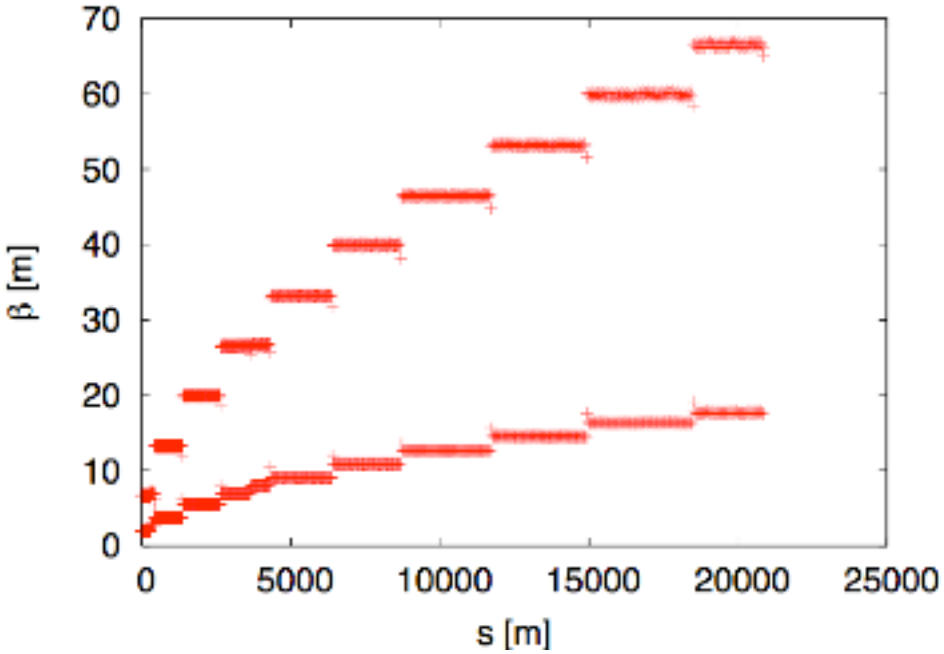
- intra-beam scattering is important (new detailed code available)
- electron cloud and FBII are relevant (global effort on mitigation)
- advanced wigglers are instrumental (first prototypes available)
- other issues

500GeV conservative parameters scaled from existing or approved rings

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)



imperfection	with respect to	symbol	value	emitt. growth
BPM offset	wire reference	σ_{BPM}	14 μm	$0.367\,\mathrm{nm}$
BPM resolution		σ_{res}	0.1 μm	$0.04\,\mathrm{nm}$
accelerating structure offset	girder axis	σ_4	10 μm	$0.03\,\mathrm{nm}$
accelerating structure tilt	girder axis	σ_t	200 μradian	$0.38\,\mathrm{nm}$
articulation point offset	wire reference	σ_5	12 μm	$0.1\,\mathrm{nm}$
girder end point	articulation point	σ_6	5 μm	$0.02\,\mathrm{nm}$
wake monitor	structure centre	σ_7	5 μm	$0.54\,\mathrm{nm}$
quadrupole roll	longitudinal axis	σ_r	100 μradian	$\approx 0.12\,\mathrm{nm}$

Beam Delivery System Design

The beam delivery system cleans the beams and squeezes them at the collision point

Challenge to squeeze the beam down to 40 nm x 1 nm and to maintain collision

- Optics design
- Stabilisation of beam line components against ground motion and technical noise
- Instrumentation
- Beam-based tuning, correction and feedback

Global effort at ATF2 is addressing the relevant issues

- Intra-pulse feedback, BPMs, wire monitors, stabilisation, tuning algorithms, ...

Challenge to ensure collimator survival

- Profit from ILC work and LHC developments

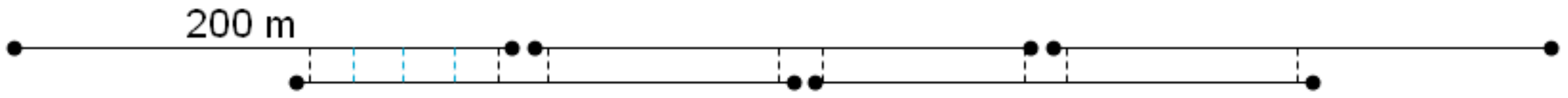
Final quadrupole (QD0) is inside the detector (L*=3.5m)

- Alternative option with longer L* but has some luminosity reduction

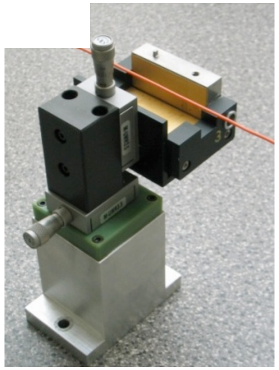
Additional effort is ongoing to develop stabilisation equipment

Pre-Alignment Concept

- Principle has been demonstrated in CTF2



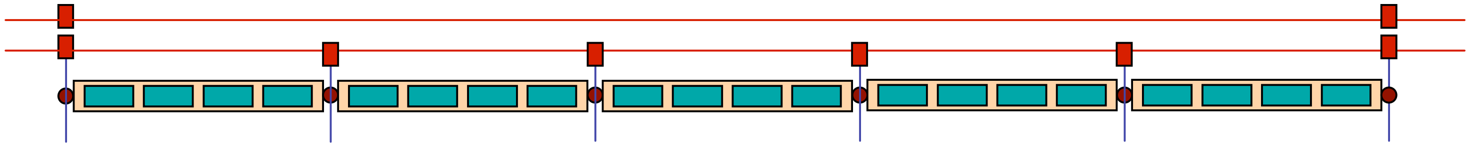
- Straight reference = stretched wire
- Vertical & transverse position measured with Wire Positioning Sensors (WPS)



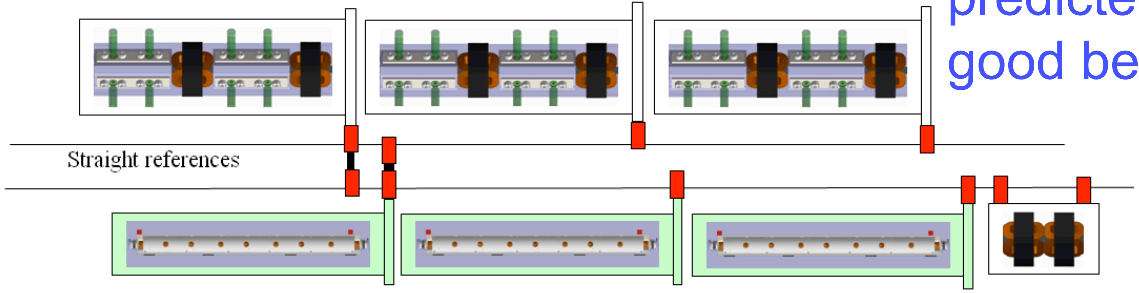
Accelerating structures
PETS + DB quad

pre-aligned on independent girders

- DB and MB girders pre-aligned with 3+1 DOF (« snake system » / "articulation point")



- MB quad pre-aligned independently with 5+1 DOF



Simulations with predicted errors show good beam quality

Stabilisation

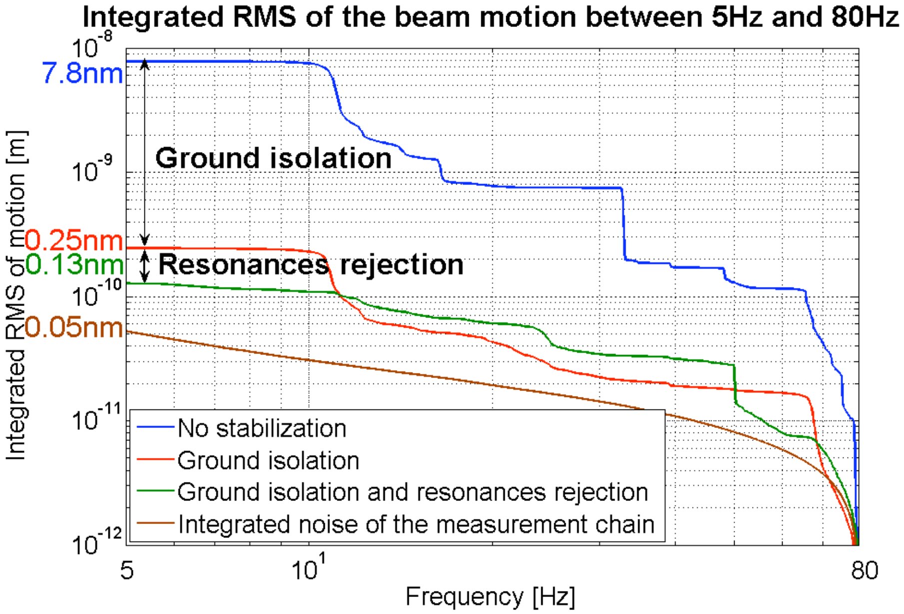
Protoype of ML quadrupole stabilisation in development, expected for 2010 (1nm at 1Hz)

Final doublet stabilisation is in study

- support concept in detector (sub-nm stability required)
- sensors
- integration with beam-based feedback (0.3nm beam-beam jitter)

All stabilisation depends on environnement

- have to continue of study technical noise sources



(L.Brunetti et al, 2007)

Beam Emittances Preservation Feasibility

Feasibility Issue	Unit	Nominal	Feasibility Target	Achieved	How	Feasibility
Emit blow-up H Emit blow-up H	Nm nm	H=160, V=15	H=160, V=15	H=160, V=15	Simulation	-
Pre-Alignment	microns	15	10	10 (principle)	Test bench	Module integration
Stabilisation Vert: Quad Main Linac Final doublet	 nm>1 Hz nm>4 Hz	1.3 0.15 to 0.5	1 1	0.5 (principle)	Test bench	Real quad and real environment

- Ultra low beam emittances addressed in ATF2, SLS & NSLS2
- Emittance preservation by simulation bench-marked in CTF3 and with other codes
- Principle of 10 micron Pre-Alignment demonstrated in CTF2 and wire test

  Feasibility by upgraded method integrated Module Test Bench
- Principle of sub-nanometer active stabilisation demonstrated

  nm stabilisation of main linac quad prototype (400 kGs) in lab and integration in Two Beam Module

  Application to realistic detector environment (adequate support)

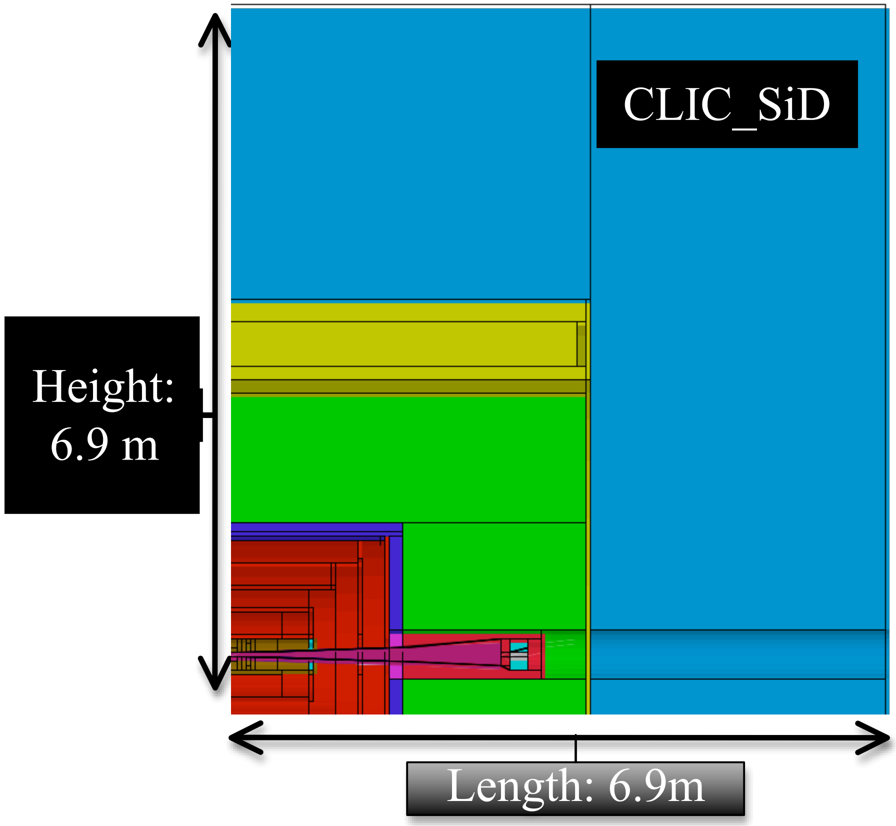
CLIC Detector Issues

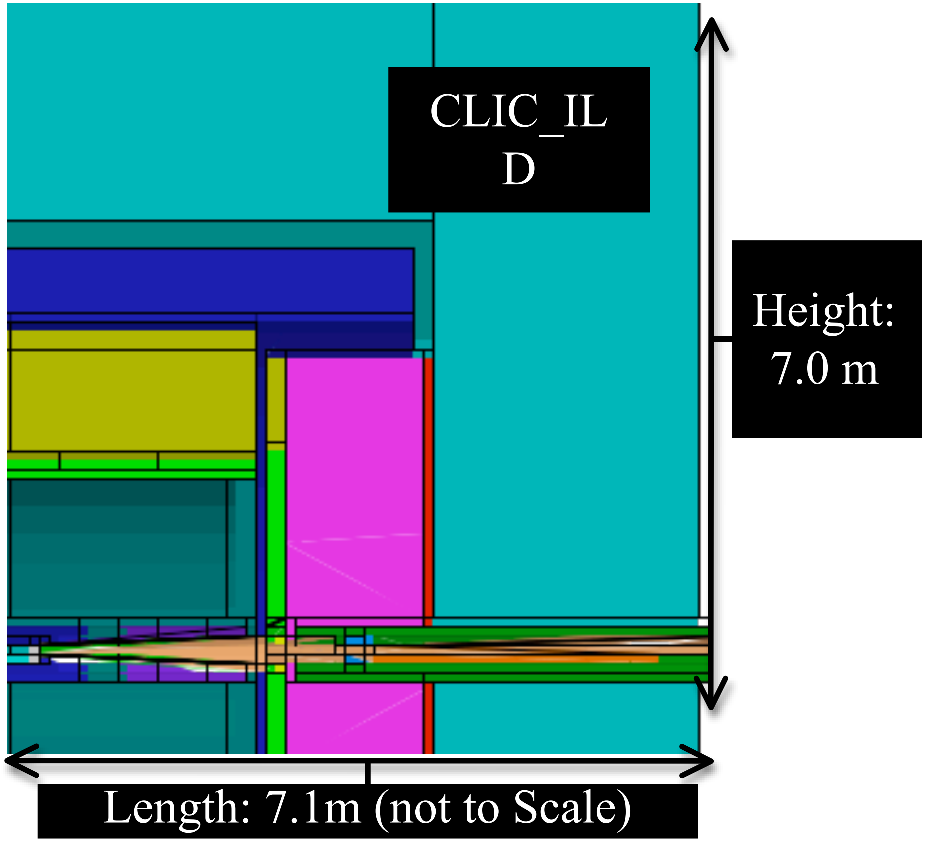
- Detector requirements are close to those for ILC detector
  - First studies indicate that ILC performances are sufficient and necessary
  - Adapt ILD and SID concepts for CLIC
- Differences to ILC
  - Larger beam energy loss
  - Time structure (0.5ns vs. ~300ns)
  - Higher background
    - High energy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

CLIC Detector Concepts

- Created CLIC 3 TeV detector models using SiD and ILD geometries and software tools

Andre Sailer





Luminosity Spectrum

- Four main sources of energy spread at the IP

  - initial state radiation

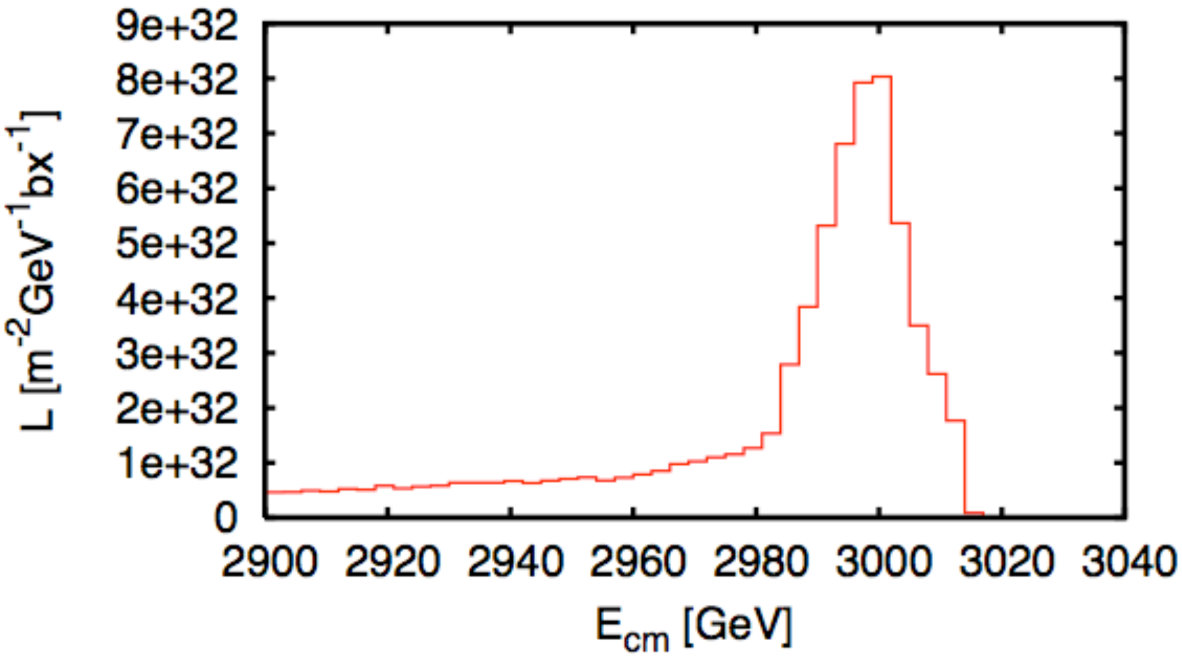
    ⇒ unavoidable

    ⇒ has sharp peak

  - beamstrahlung

    ⇒ similar shape as ISR

    ⇒ can be reduced by reducing luminosity



- single bunch energy spread

  due to single-bunch beam loading and RF curvature

⇒ part cannot be avoided

⇒ helps in stabilising the linac

⇒ $\mathcal{O}(0.35\,\%)$ (better for ILC)

Can be reduced for some luminosity loss

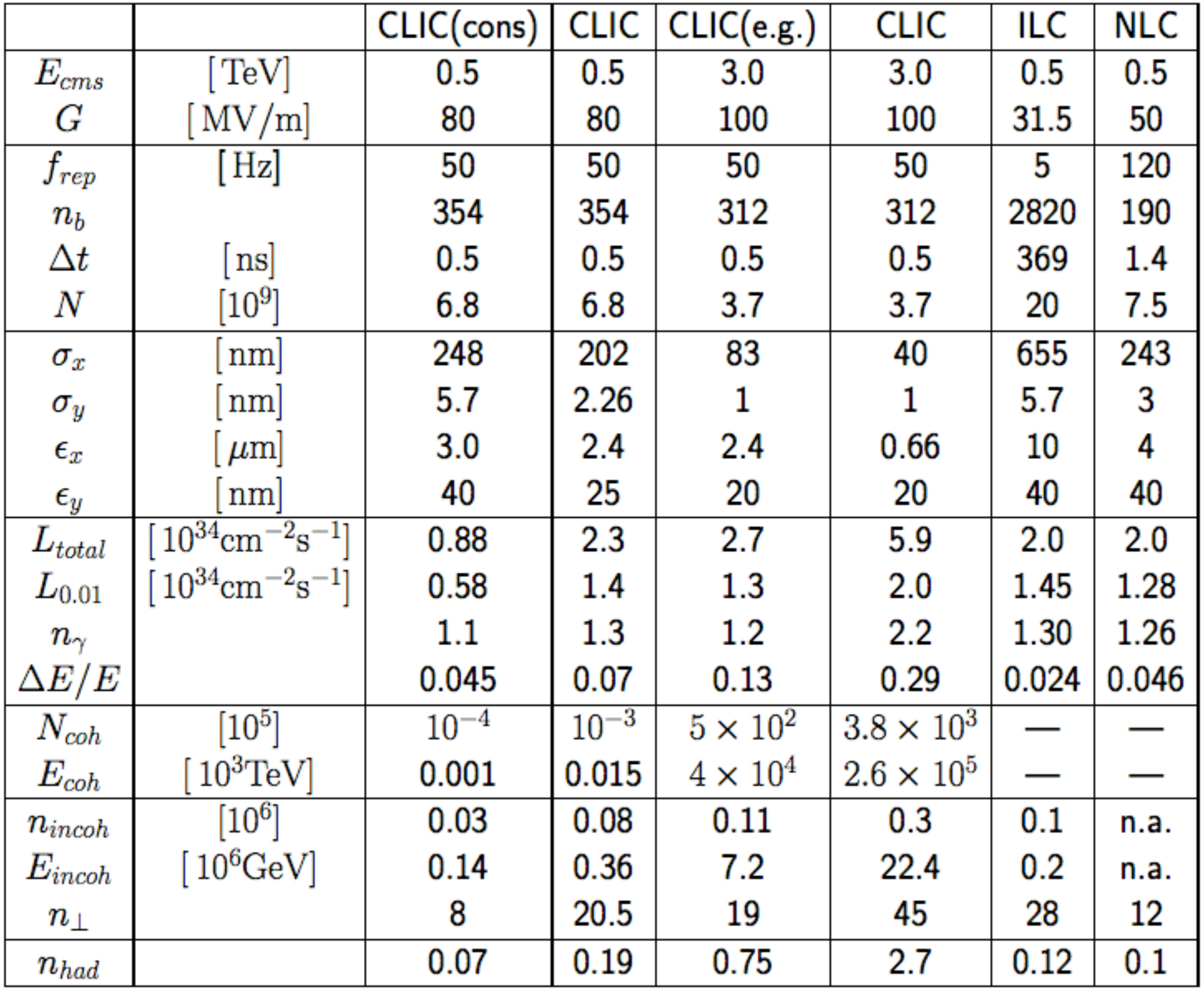
- bunch-to-bunch and pulse-to-pulse variations

  ⇒ $\mathcal{O}(0.1\,\%)$

Background

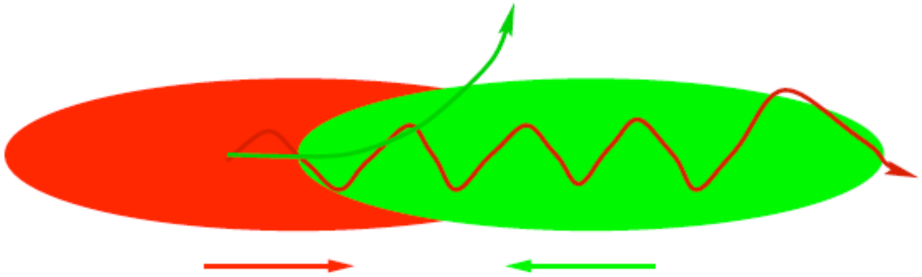
- A number of background sources exist
  - From the machine
    - Beam tail and halo (collimation)
    - Synchrotron radiation (partly by collimation)
    - Muons (magnetised iron spoilers, if needed)
  - From the beam collision
    - Beamstrahlung (exit hole)
    - Coherent pair production (exit hole)
    - Incoherent pair production (mask, vertex detector radius)
    - Hadronic events (time stamping)
  - From the spent beams
    - Backscattered pairs (shielding, soft material layers)
    - Neutrons (shielding, distance)
    - …
- Will only quickly touch the beam-beam background
  - Most fundamental background

CLIC Main Parameters



		CLIC(cons)	CLIC	CLIC(e.g.)	CLIC	ILC	NLC
E_{cms}	[TeV]	0.5	0.5	3.0	3.0	0.5	0.5
G	[MV/m]	80	80	100	100	31.5	50
f_{rep}	[Hz]	50	50	50	50	5	120
n_b		354	354	312	312	2820	190
Δt	[ns]	0.5	0.5	0.5	0.5	369	1.4
N	[10^9]	6.8	6.8	3.7	3.7	20	7.5
σ_x	[nm]	248	202	83	40	655	243
σ_y	[nm]	5.7	2.26	1	1	5.7	3
ϵ_x	[μm]	3.0	2.4	2.4	0.66	10	4
ϵ_y	[nm]	40	25	20	20	40	40
L_{total}	[$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	0.88	2.3	2.7	5.9	2.0	2.0
$L_{0.01}$	[$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	0.58	1.4	1.3	2.0	1.45	1.28
n_γ		1.1	1.3	1.2	2.2	1.30	1.26
$\Delta E/E$		0.045	0.07	0.13	0.29	0.024	0.046
N_{coh}	[10^5]	10^{-4}	10^{-3}	5×10^2	3.8×10^3	—	—
E_{coh}	[10^3TeV]	0.001	0.015	4×10^4	2.6×10^5	—	—
n_{incoh}	[10^6]	0.03	0.08	0.11	0.3	0.1	n.a.
E_{incoh}	[10^6GeV]	0.14	0.36	7.2	22.4	0.2	n.a.
$n_\perp$		8	20.5	19	45	28	12
n_{had}		0.07	0.19	0.75	2.7	0.12	0.1

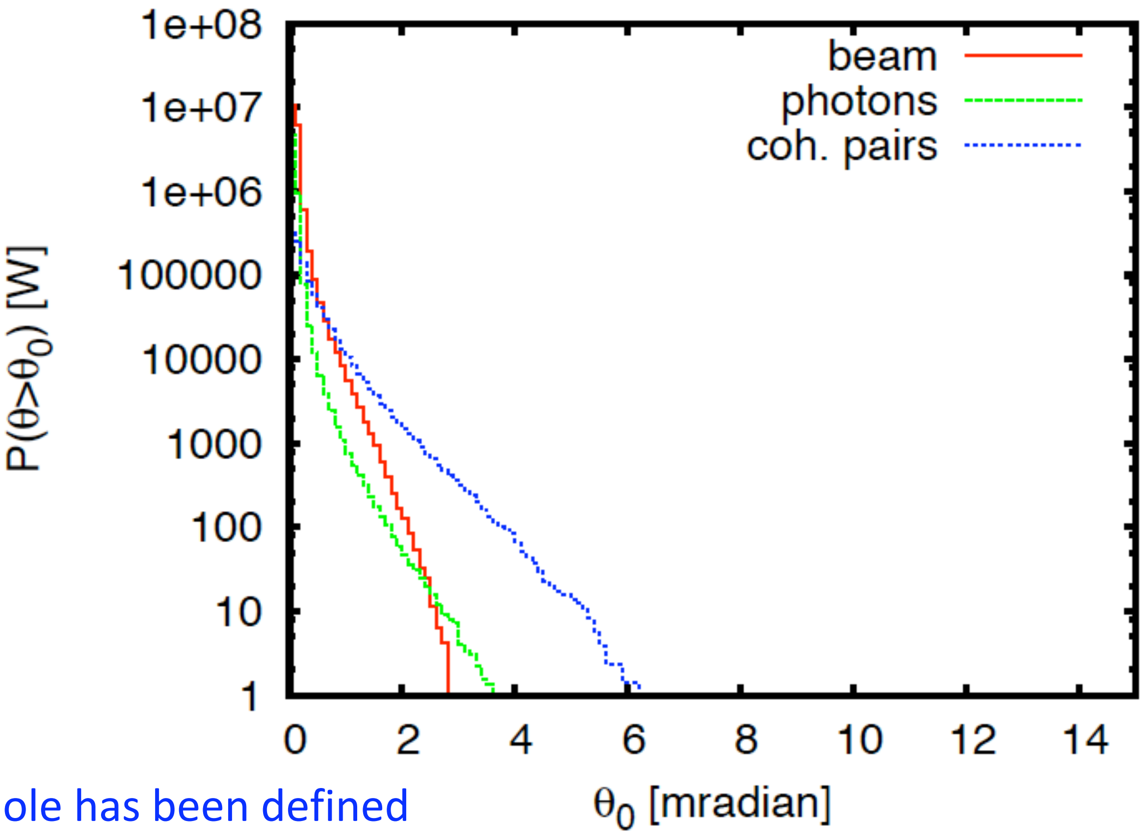
Extraction Hole Size



- Beam particles are focused by oncoming beam
- Photons are radiated into direction of beam particles
- Coherent pair particles can be focused or defocused by the beams

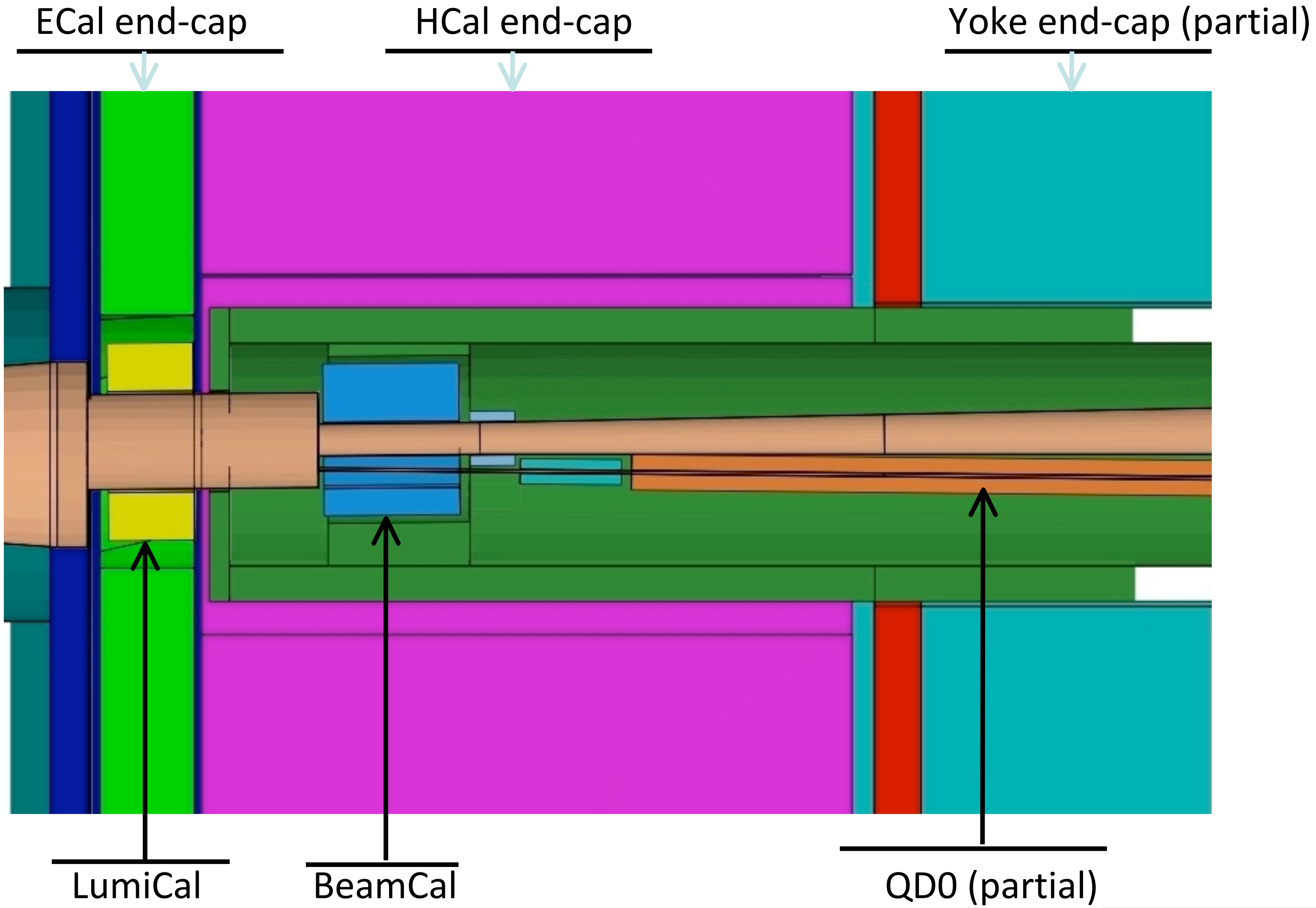
⇒ Extraction hole angle should be significantly larger than 6 mradian

$1\,\mathrm{W} \approx 400\,\mathrm{TeV/bx} \approx 300\,\mathrm{beamparticles/bx}$



Based on this 10mradian opening hole has been defined and 20mradian crossing angle

CLIC_ILD Detector Concept
Forward Region Version 3 Nov. 2009

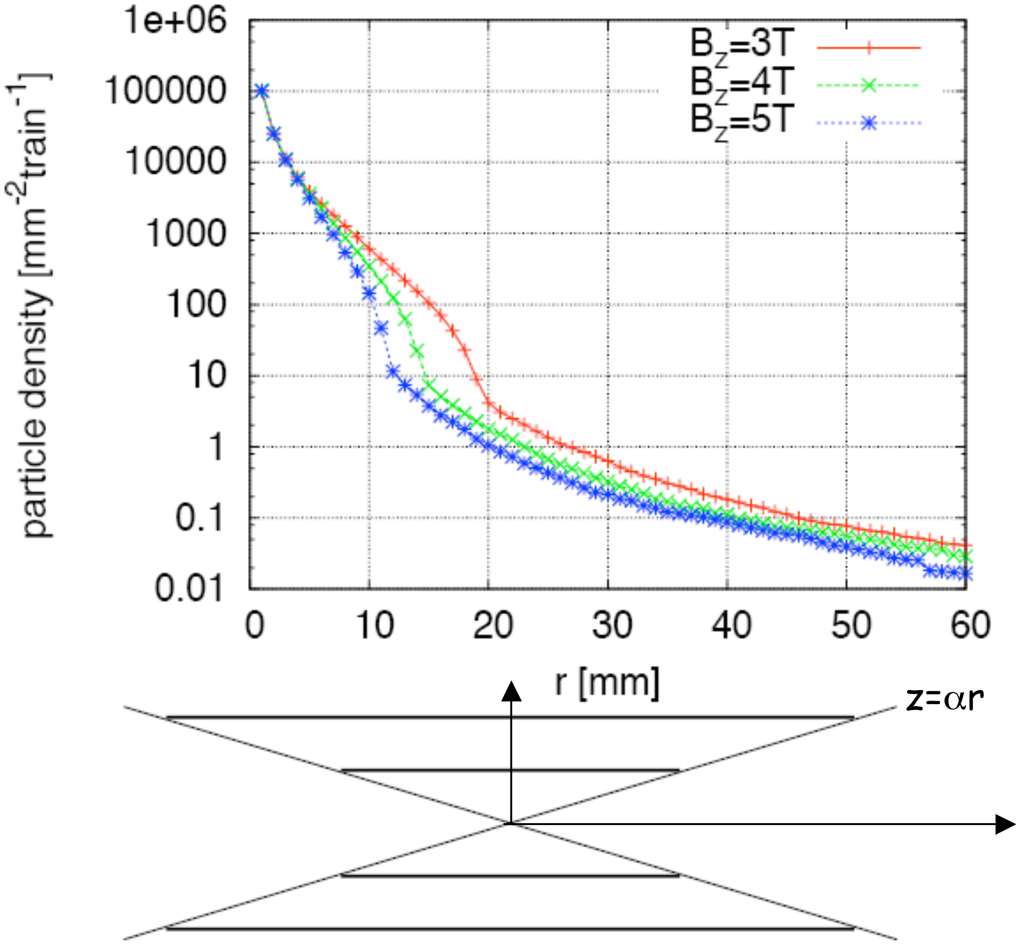


Andre Sailer

Vertex Detector Radius

- Simplified study using simple cylinder without mass
  - Coverage is down to 200 mrad
- Simulating number of particles that hit at least once
  - Experience indicates that number of hits is three per particle

$\Rightarrow$ At $r_1 \approx 30$ mm expected 1 hit per train and mm^2



Time stamping requirements

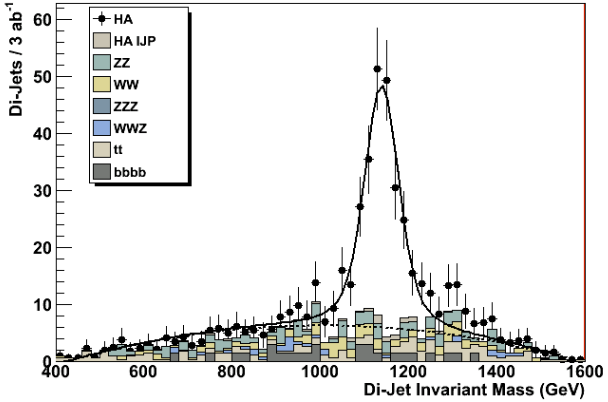
Simulation example of heavy Higgs doublet H^0A^0 at ~1.1 TeV mass (supersymmetry K’ point)

e+e- ➔ H^0A^0 ➔ bbbb

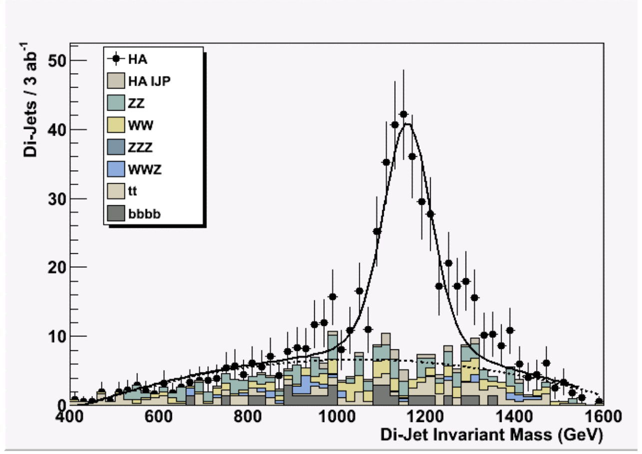
Signal + full standard model background + γγ=>hadron background

CLIC-ILD detector: Mokka+Marlin simulation, reconstruction + kinematic fit.

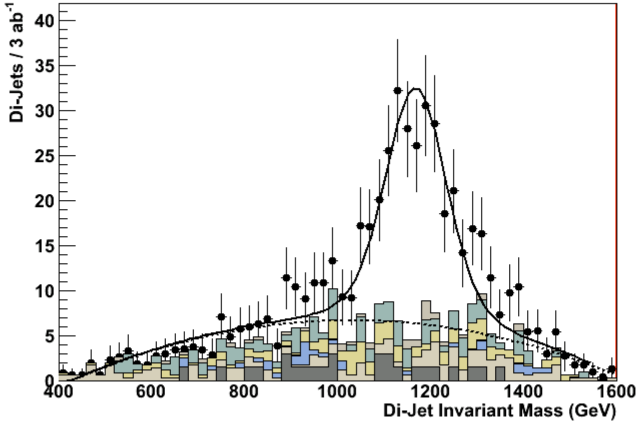
Marco Battaglia



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

Hardware/Engineering R&D

L. Linssen

Hardware/engineering R&D needed beyond present ILC developments:

- Time stamping
  - Needed for all sub-detectors; challenging in inner tracker/vertex region; trade-off between pixel size, amount of material and timing resolution
- Power pulsing and DAQ developments
  - In view of the CLIC time structure
- Hadron calorimetry
  - Dense HCAL absorbers to limit radial size (PFA calo based on tungsten)
- Solenoid coil
  - Reinforced conductor (building on CMS/ATLAS experience)
  - Large high-field solenoid concept
- Overall engineering design and integration studies
  - For heavier calorimeter, larger overall CLIC detector size etc.
  - In view of sub-nm precision required for FF quadrupoles

In addition: Core software development

Operation & Machine Protection System

- Beam power is high
    - damage potential as well

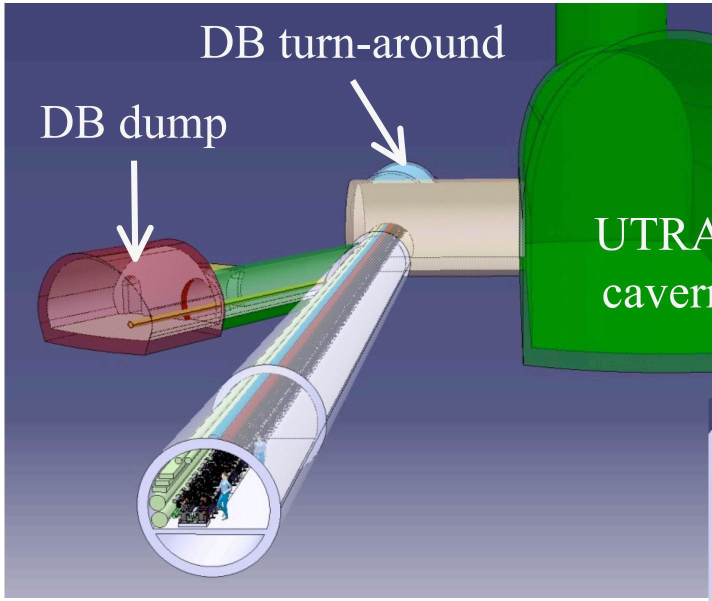
- Machine protection has been integrated into design
    - e.g. collimation in beam delivery system

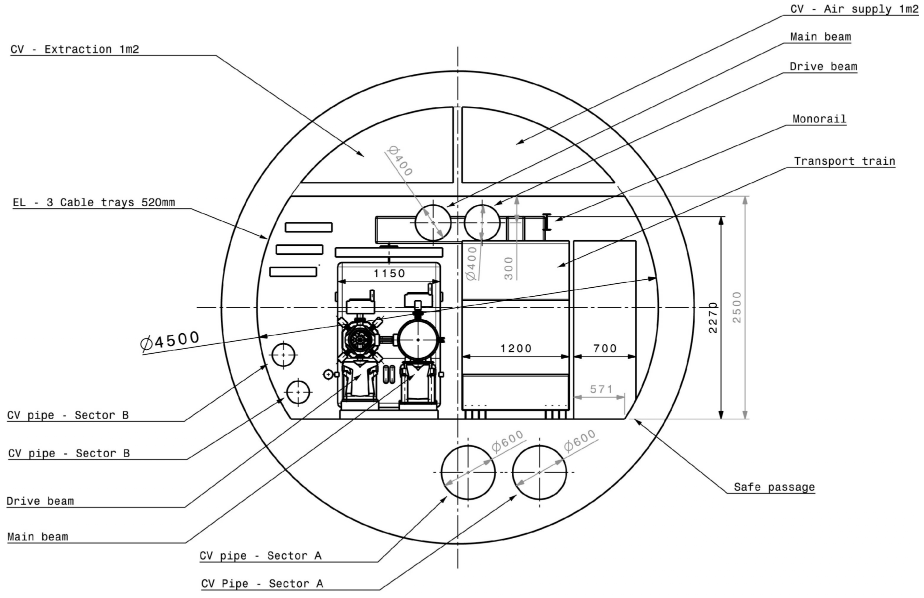
- Some studies have been already performed for most critical system, e.g.
    - impact of failures on collimation system
    - failures in drive beam decelerator

- But more work is needed

- Full concept is being developed based on LHC experience
    - Build system failsafe where possible
    - Get a confirmation that all system are working shortly before the beam pulse arrives
    - For drive beam at generation pulse is long so can react within pulse

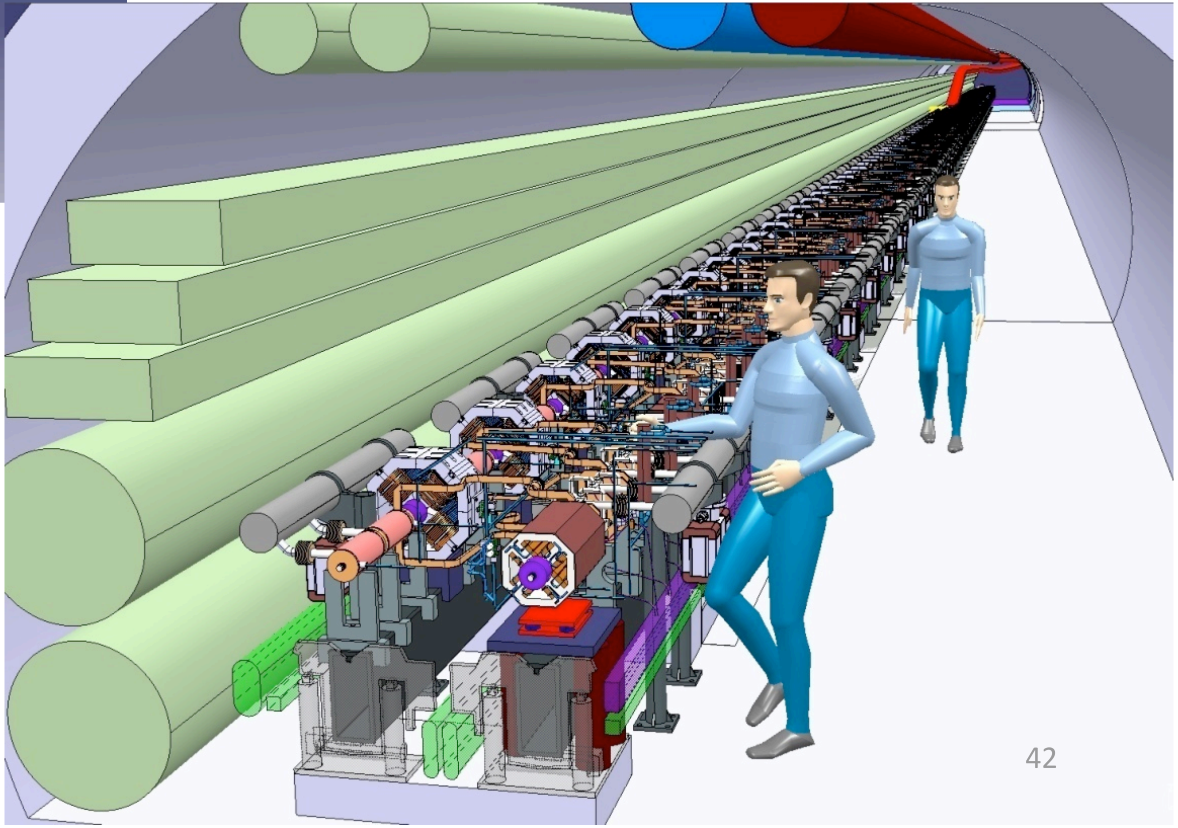
Tunnel Integration





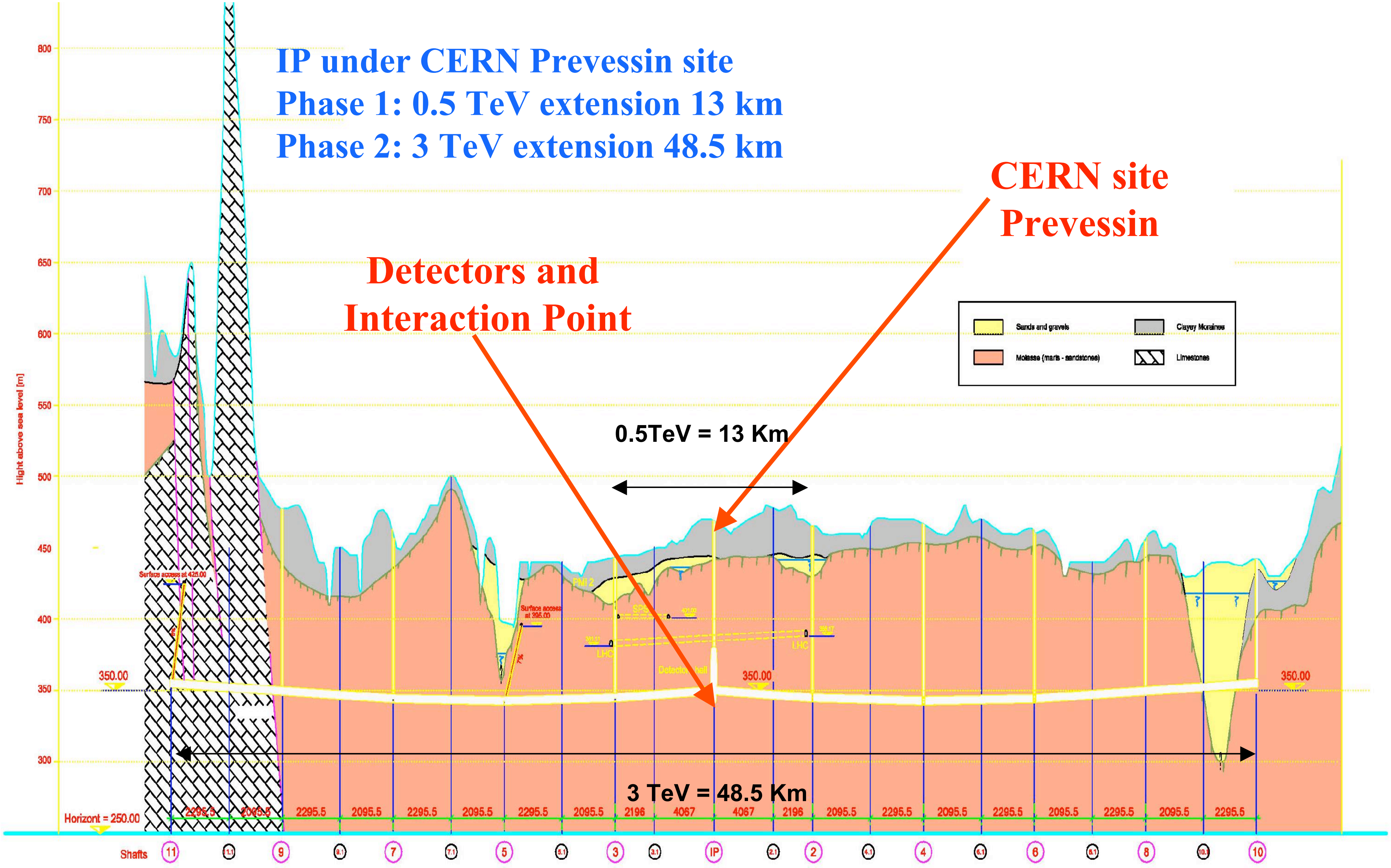
CLIC - Typical Cross Section - Diameter 4500mm
Draft - J.Osborne / A.Kosmicki - December 9th 2008

Standard tunnel with modules



D. Schulte

Example Site at CERN



IP under CERN Prevessin site
Phase 1: 0.5 TeV extension 13 km
Phase 2: 3 TeV extension 48.5 km

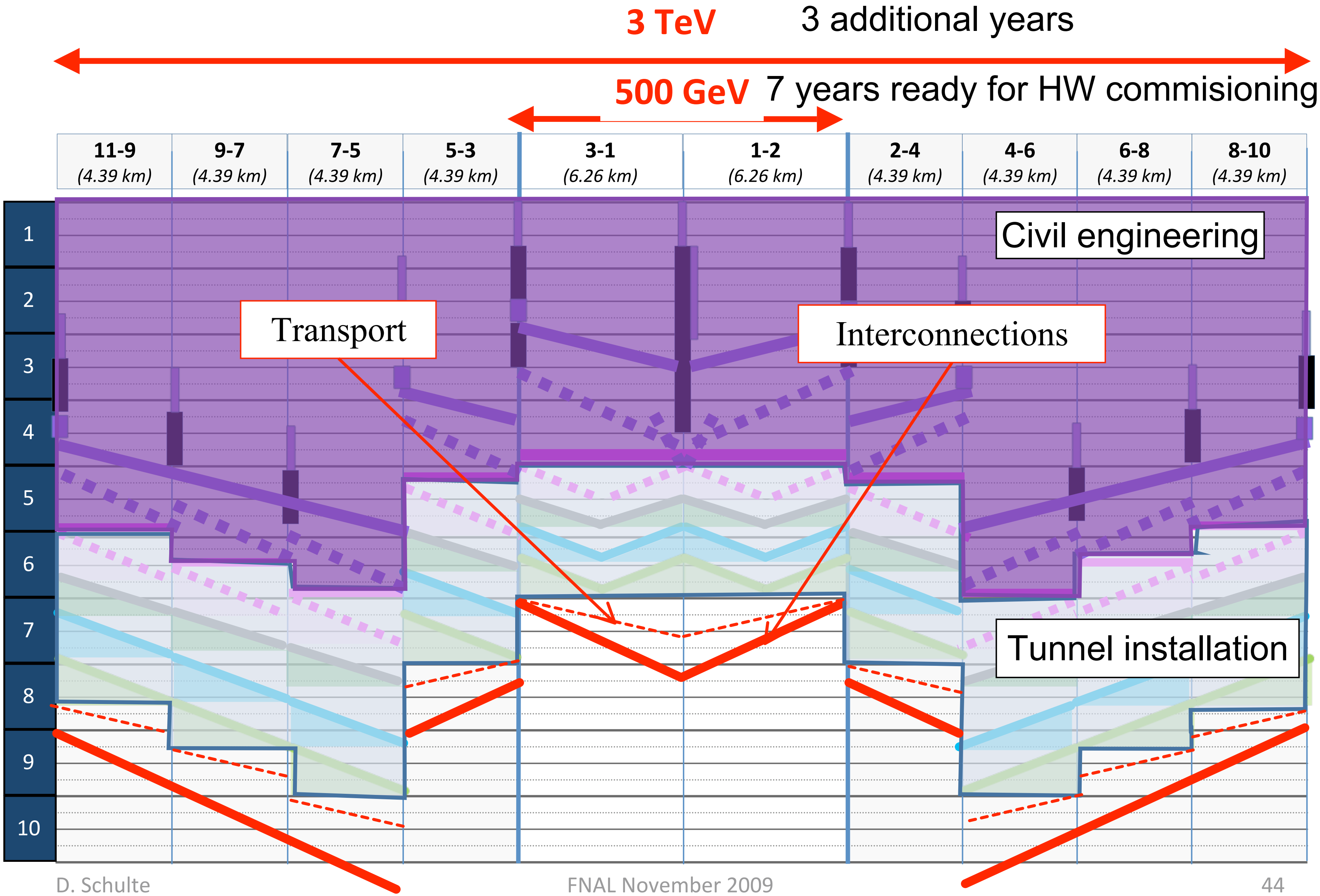
CERN site Prevessin

Detectors and Interaction Point

0.5TeV = 13 Km

3 TeV = 48.5 Km

CLIC Machine Installation (Based on LHC Experience)



Conclusion

- CLIC is moving foward to the CDR
  - many promising results
  - but more work is essential
  - feedback detector study is important
- The TDR phase is in preparation
- CLIC is supported by a strong collaboration
  - collaboration with ILC very useful

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)

Thanks

- To all the people from whom I stole slides, plots etc.
  - Jean-Pierre Delahaye, L.Linssen, K. Elsener, Alexej Grudiev, Frank Tecker, Walter Wuensch …

Reserve

ILC Detector Resolution

- ★ momentum:(1/10 x LEP)
  e.g. Muon momentum
  Higgs recoil mass

$$\boxed{\sigma_{1/p} < 5 \times 10^{-5}\,\mathrm{GeV}^{-1}}$$

- ★ jet energy: (1/3 x LEP/ZEUS)
  e.g. W/Z di-jet mass separation
  EWSB signals

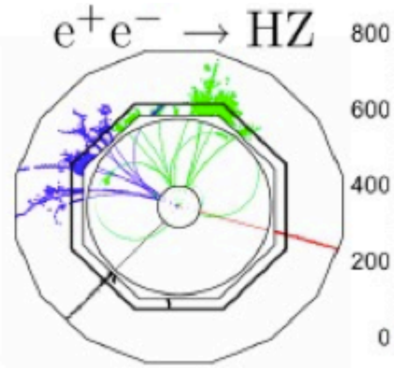
$$\boxed{\frac{\sigma_E}{E} \approx 3-4\,\%}$$

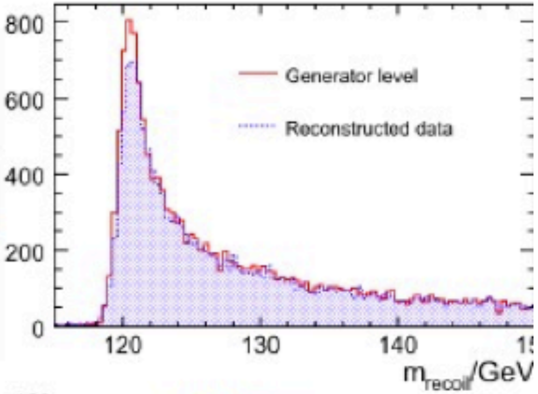
- ★ impact parameter:(1/3 x SLD)
  e.g. c/b-tagging Higgs BR

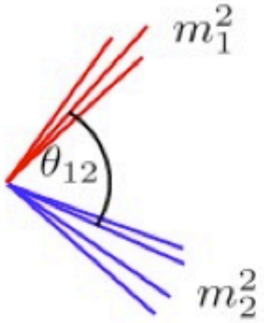
$$\boxed{\sigma_{r\phi} = 5 \oplus 10/(p\sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}}$$

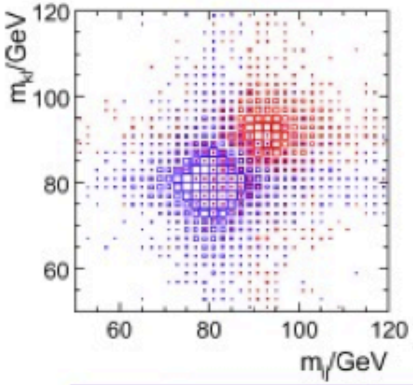
- ★ hermetic: down to θ = 5 mrad
  e.g. missing energy signatures in SUSY

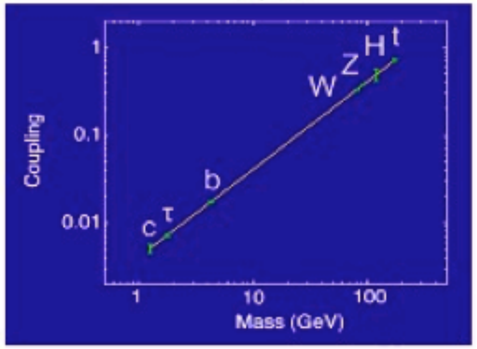
Dieter Schlatter - 21.10.09











M. Thomson

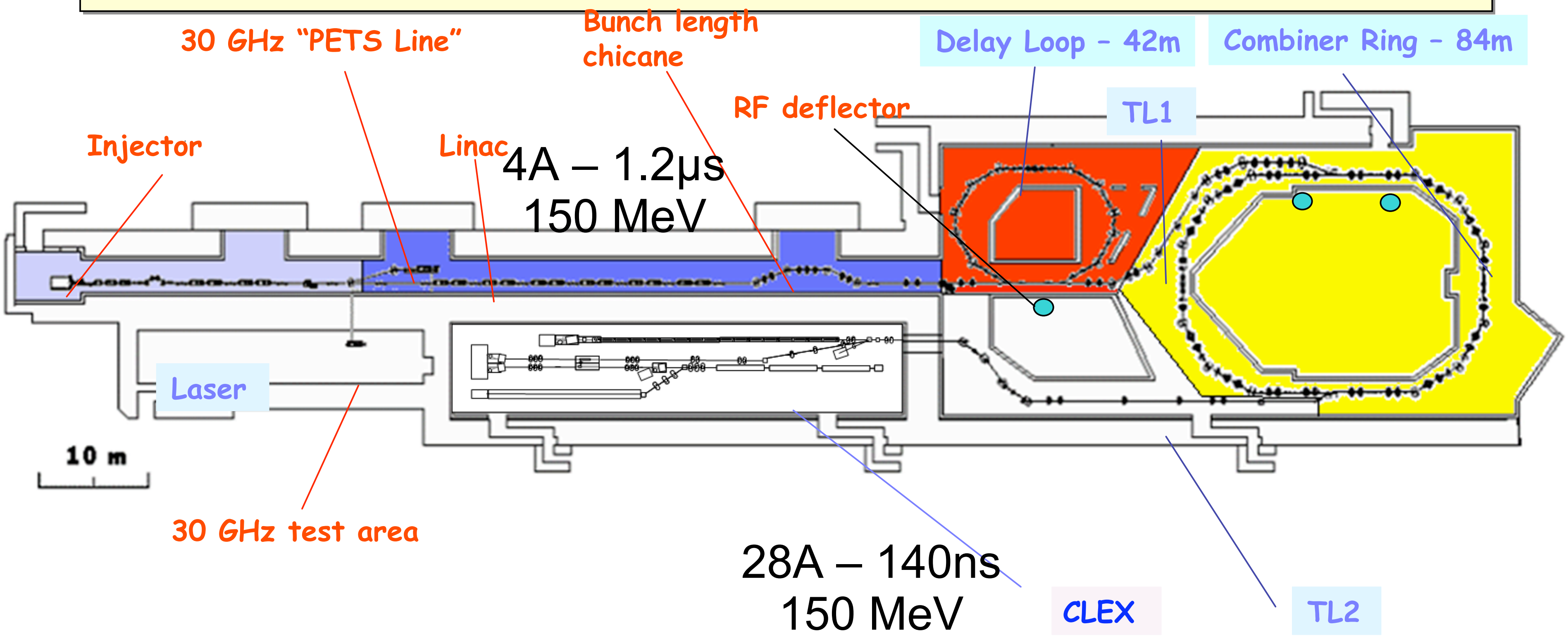
CLIC Main Parameters

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

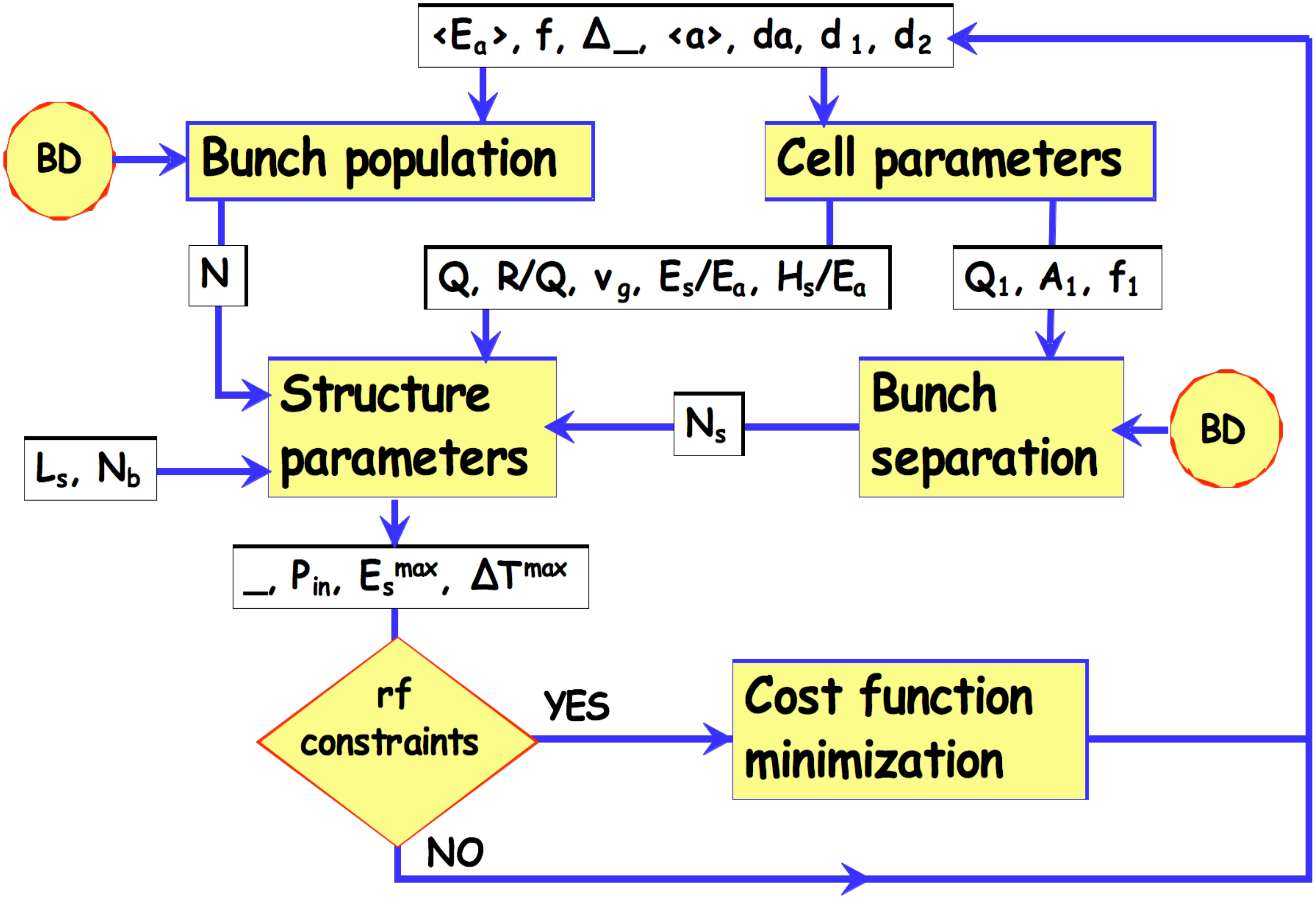
Center-of-mass energy	CLIC 500 G		CLIC 3 TeV	
Beam parameters	Conservative	Nominal	Conservative	Nominal
Accelerating structure	502		G	
Total (Peak 1%) luminosity	$0.9(0.6)\cdot10^{34}$	$2.3(1.4)\cdot10^{34}$	$1.5(0.73)\cdot10^{34}$	$5.9(2.0)\cdot10^{34}$
Repetition rate (Hz)	50			
Loaded accel. gradient MV/m	80		100	
Main linac RF frequency GHz	12			
Bunch charge10^9	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	

CLIC Test Facility (CTF 3)

- Demonstrate Drive Beam generation
  (fully loaded acceleration, bunch frequency multiplication 8x)
- Test CLIC accelerating structures
- Test power production structures (PETS)



Parameter Optimisation



$\langle E_a \rangle$, f, Δ_, $\langle a \rangle$, da, d_1, d_2

BD

Bunch population

Cell parameters

N

Q, R/Q, v_g, E_s/E_a, H_s/E_a

Q_1, A_1, f_1

Structure parameters

N_s

Bunch separation

BD

L_s, N_b

_, P_{in}, E_s^{max}, ΔT^{max}

rf constraints

YES

Cost function minimization

NO

A. Grudiev et al.

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

Beam-Beam Effect

- 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 $\Upsilon \gg 1$

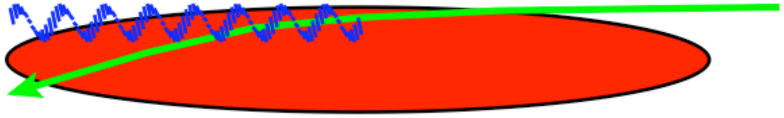
$$\mathcal{L} \propto \Upsilon\sigma_z/\gamma P\eta$$

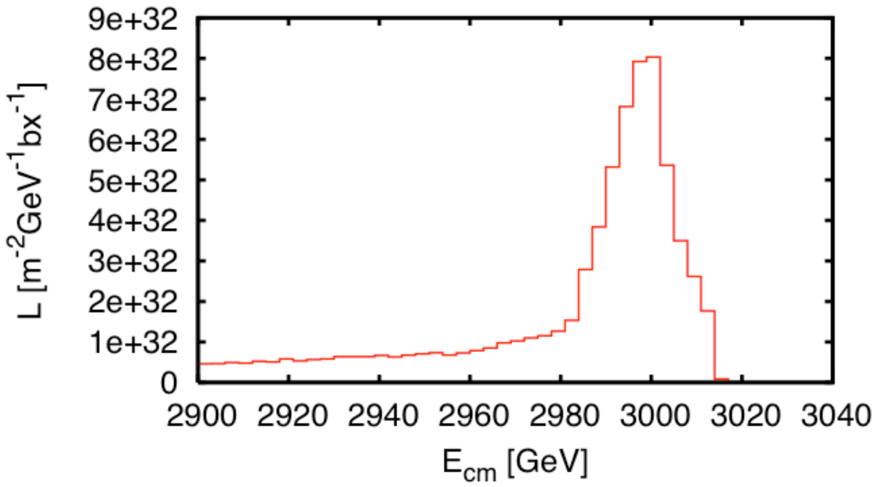
  $\Rightarrow$ partial suppression of beamstrahlung

  $\Rightarrow$ coherent pair production

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

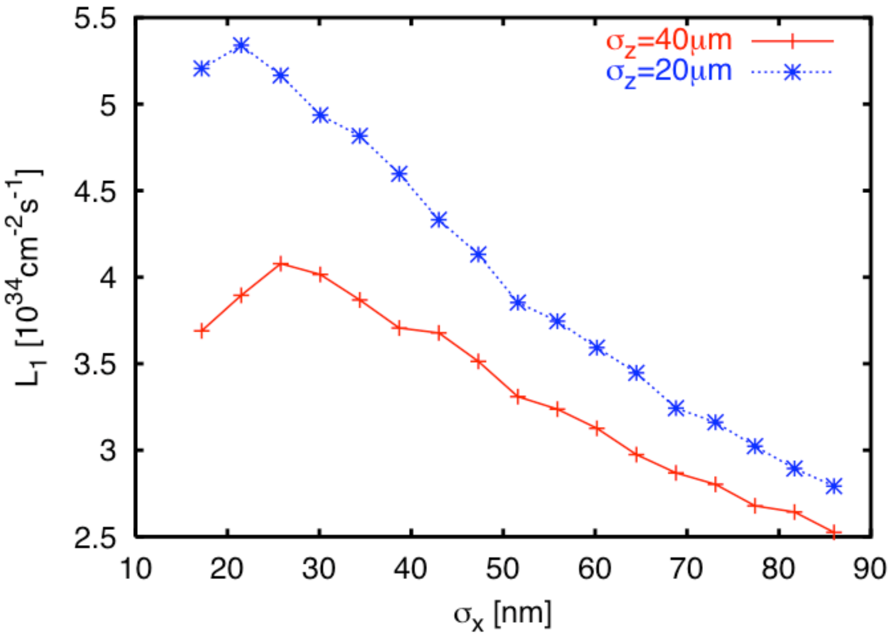
  $\Rightarrow$ somewhat in quantum regime





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

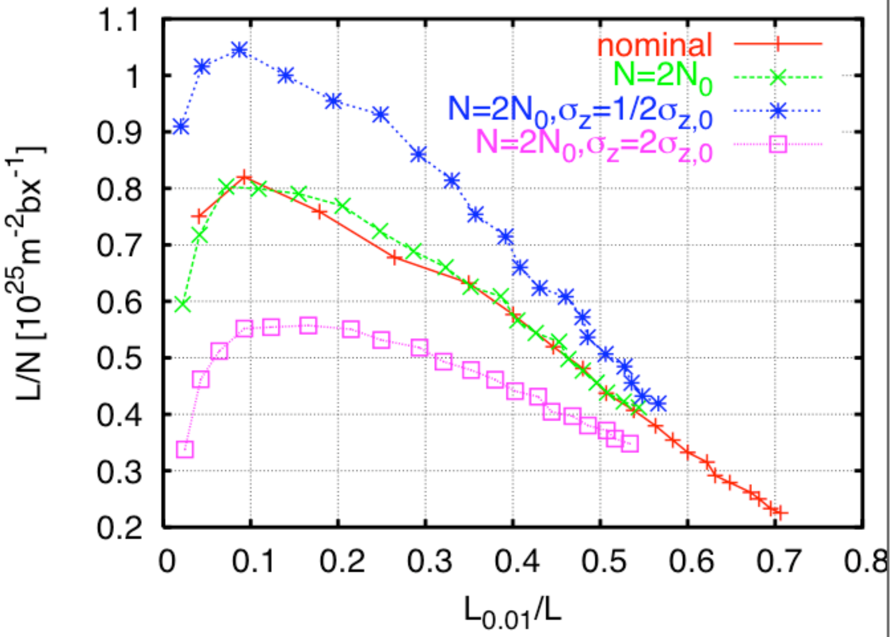
Horizontal Beam Size Optimisation



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 $n_\gamma \Rightarrow$ higher $\mathcal{L} \Rightarrow$ degraded spectrum



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

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

Beam Size Limitations

At the IP the horizontal beam size is much larger than the vertical

- also the horizontal emittance is much larger than the vertical

The minimum horizontal beam size is mainly given by

- damping ring
- ring to main linac transport
- beam delivery system

The minimum vertical beam size is mainly given by

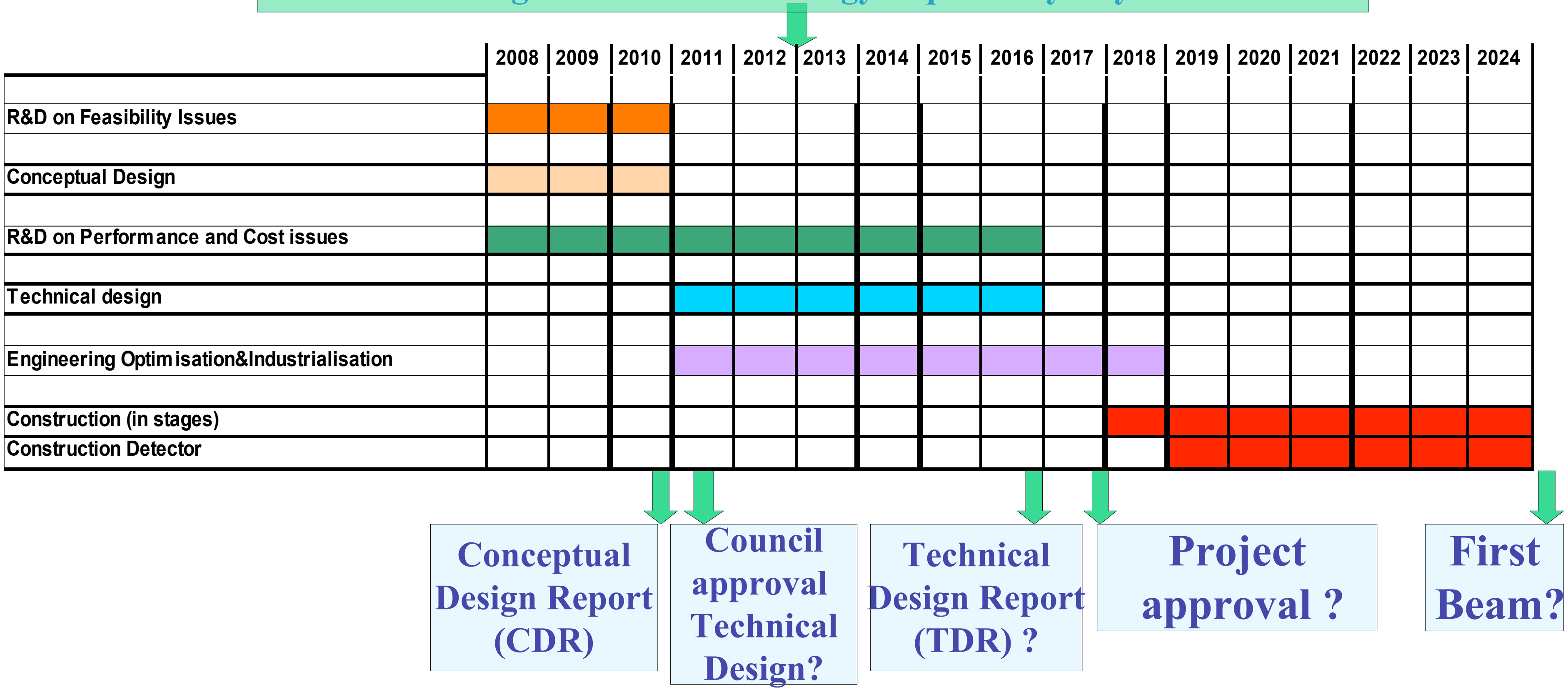
- damping ring
- ring to main linac transport
- main linac
- beam delivery system
- need to collide

With advanced damping ring and beam delivery system designs we find a 40nm horizontal beam size limitation

Tentative Long-Term CLIC Scenario

Shortest, Success Oriented, Technically Limited Schedule

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



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
R&D on Feasibility Issues	■	■	■														
Conceptual Design	■	■	■														
R&D on Performance and Cost issues	■	■	■	■	■	■	■	■	■								
Technical design				■	■	■	■	■	■								
Engineering Optimisation&Industrialisation				■	■	■	■	■	■	■	■						
Construction (in stages)											■	■	■	■	■	■	■
Construction Detector												■	■	■	■	■	■

Conceptual Design Report (CDR)

Council approval Technical Design?

Technical Design Report (TDR) ?

Project approval ?

First Beam?

EC supported programmes

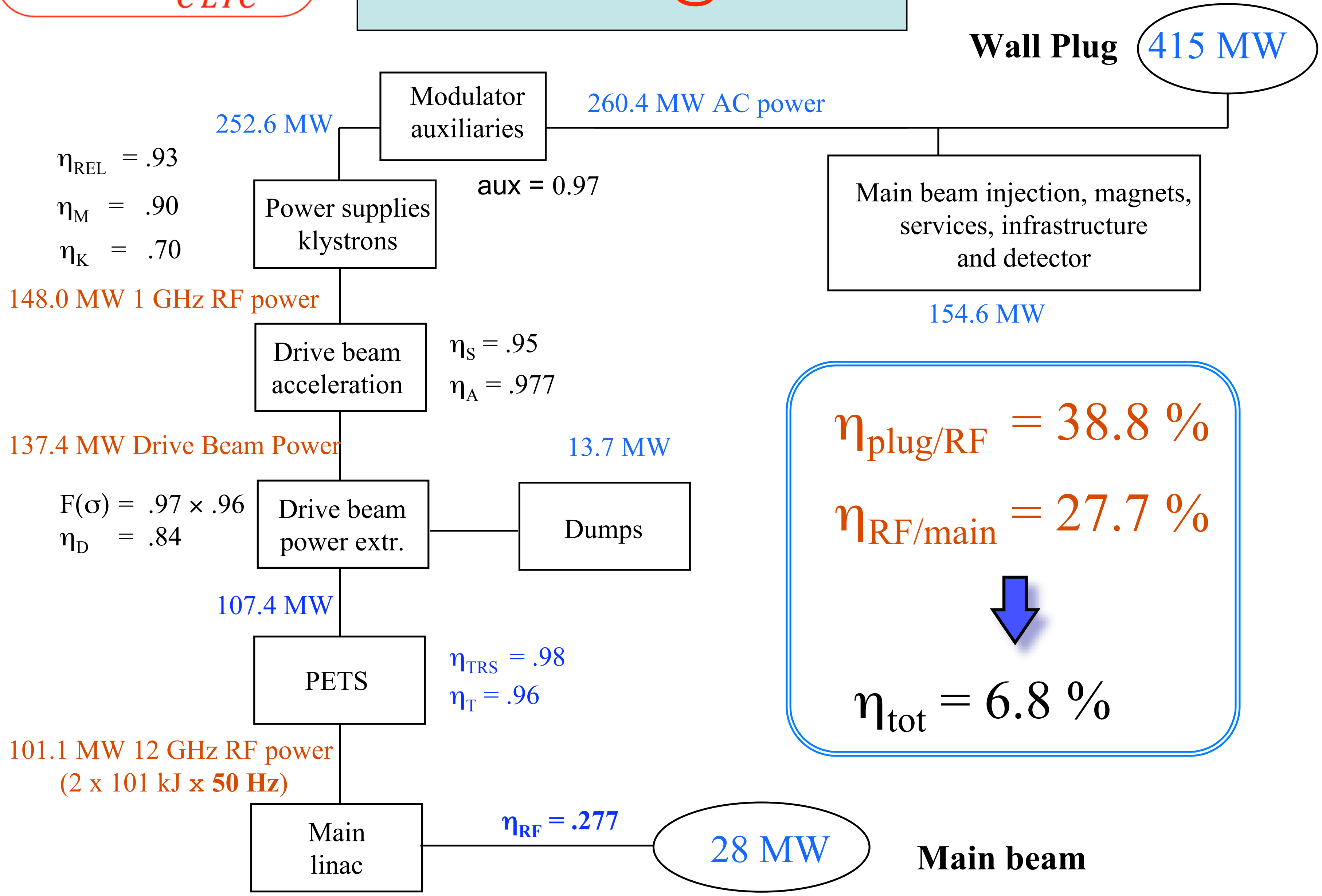
FP6 IA:CARE

FP7 IA:EUCARD

FP7 CNI:TIARA

FP7 CNI:CLIC?

Power flow @ 3 TeV



Wall Plug 415 MW

260.4 MW AC power

Modulator auxiliaries

aux = 0.97

252.6 MW

$\eta_{REL} = .93$

$\eta_M = .90$

$\eta_K = .70$

Power supplies klystrons

148.0 MW 1 GHz RF power

Drive beam acceleration

$\eta_S = .95$

$\eta_A = .977$

137.4 MW Drive Beam Power

$F(\sigma) = .97 \times .96$

$\eta_D = .84$

Drive beam power extr.

13.7 MW

Dumps

107.4 MW

PETS

$\eta_{TRS} = .98$

$\eta_T = .96$

101.1 MW 12 GHz RF power
(2 x 101 kJ **x 50 Hz**)

Main linac

$\eta_{RF} = .277$

28 MW **Main beam**

Main beam injection, magnets, services, infrastructure and detector

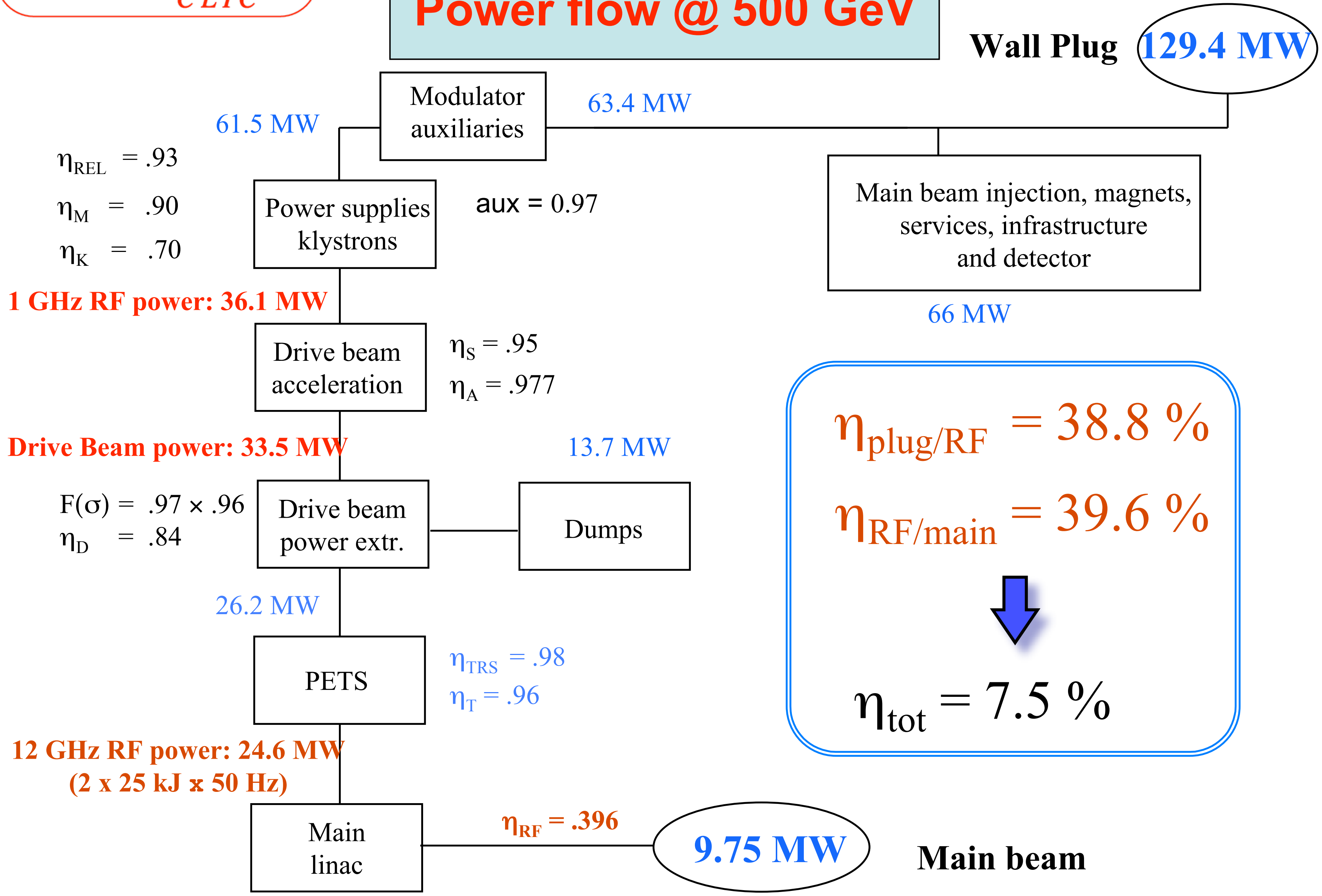
154.6 MW

$\eta_{plug/RF} = 38.8\ \%$

$\eta_{RF/main} = 27.7\ \%$

$\eta_{tot} = 6.8\ \%$

Power flow @ 500 GeV



Wall Plug 129.4 MW

63.4 MW

Modulator auxiliaries

61.5 MW

Main beam injection, magnets, services, infrastructure and detector

66 MW

$\eta_{REL} = .93$

$\eta_M = .90$

$\eta_K = .70$

Power supplies klystrons

aux = 0.97

1 GHz RF power: 36.1 MW

Drive beam acceleration

$\eta_S = .95$

$\eta_A = .977$

Drive Beam power: 33.5 MW

13.7 MW

$F(\sigma) = .97 \times .96$

$\eta_D = .84$

Drive beam power extr.

Dumps

26.2 MW

PETS

$\eta_{TRS} = .98$

$\eta_T = .96$

12 GHz RF power: 24.6 MW
(2 x 25 kJ x 50 Hz)

Main linac

$\eta_{RF} = .396$

9.75 MW

Main beam

$\eta_{plug/RF} = 38.8\ \%$

$\eta_{RF/main} = 39.6\ \%$

$\eta_{tot} = 7.5\ \%$

LC 500 GeV Main parameters

Center-of-mass energy	NLC 500 GeV	ILC 500 GeV	CLIC 500 G Relaxed	CLIC 500 G Nominal
Total (Peak 1%) luminosity	$2.0(1.3)\cdot 10^{34}$	$2.0(1.5)\cdot 10^{34}$	$0.9(0.6)\cdot 10^{34}$	$2.3(1.4)\cdot 10^{34}$
Repetition rate (Hz)	120	5	50	
Loaded accel. gradient MV/m	50	33.5	80	
Main linac RF frequency GHz	11.4	1.3 (SC)	12	
Bunch charge10^9	7.5	20	6.8	
Bunch separation ns	1.4	176	0.5	
Beam pulse duration (ns)	400	1000	177	
Beam power/linac (MWatts)	6.9	10.2	4.9	
Hor./vert. norm. emitt $(10^{-6}/10^{-9})$	3.6/40	10/40	7.5 / 40	4.8 / 25
Hor/Vert FF focusing (mm)	8/0.11	20/0.4	4/0.4	4/0.1
Bunch length (microns)	100	300	100	72
Hor./vert. IP beam size (nm)	243/3	640/5.7	248 / 5.7	202/ 2.3
Soft Hadronic event at IP	0.10	0.12	0.07	0.19
Coherent pairs/crossing at IP	10?	10?	10	100
BDS length (km)	3.5 (1 TeV)	2.23 (1 TeV)	1.87	
Total site length (km)	18	31	13.0	
Wall plug to beam transfer eff.	7.1%	9.4%	7.5%	
Total power consumption MW	195	216	129.4	