CLIC
THE COMPACT LINEAR COLLIDER

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THE CLIC ACCELERATOR

Linear Collider Baseline

LEP: 209 GeV

next Electron-Positron Collider

- Centre-of-mass-energy:
- 0.5 - 3 TeV
- Luminosity: >2*10^{34}

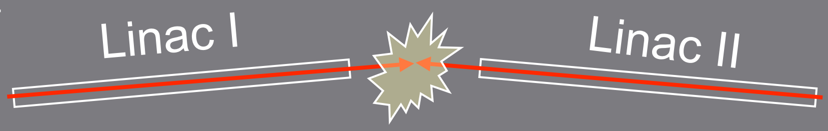
Physics motivation:

"Physics at the CLIC Multi-TeV Linear Collider: Report of the CLIC Physics Working Group,“

CERN Report 2004-5

Storage Ring not possible, energy loss $\Delta E \sim E^4$

➔ two linacs, experiment at centre



- total energy gain in one pass: **high acceleration gradient**
- beam can only be used once: **small beam dimensions at crossing point**

Boundary conditions: site length

Power consumption

High Energy Physics after LHC

In 1999 ICFA issued a statement on Linear Colliders, ... that there would be compelling and unique scientific opportunities at a linear electron-positron collider in the TeV energy range. Such a facility is a necessary complement to the LHC hadron collider.

Two options: ILC - CLIC

Collaboration on common issues

The European strategy *for particle physics*

Unanimously approved by the CERN Council at the special Session held in Lisbon on 14 July 2006

4. In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.*

5. It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientific opportunity at the precision frontier; *there should be a strong well-coordinated European activity, including CERN, through the Global Design Effort, for its design and technical preparation towards the construction decision, to be ready for a new assessment by Council around 2010.*

CERN/2685

Basic Differences ILC-CLIC

	ILC: Superconducting RF	CLIC: normal conducting copper RF
	500 GeV	3 TeV
Accelerating gradient:	31.5 MV/m (35 MV/m target)	100 MV/m
RF Peak power:	0.37 MW/m , 1.6 ms, 5 Hz	275 MW/m, 240 ns, 50 Hz
RF average power:	2.9 kW/m	3.7 kW/m
Total length:	31 km	48.4 km
Site power :	230 MW	392 MW

Beam structure:

	ILC	CLIC
Particles per bunch:	$20 * 10^9$	$3.7 * 10^9$
	2625 bunches / pulse of 0.96 ms	312 bunches / pulse of 156 ns
Bunch spacing	369 ns	0.5 ns

CLIC Acceleration System

CLIC = Compact Linear Collider
(length < 50 km)

CLIC parameters:

Accelerating gradient: 100 MV/m

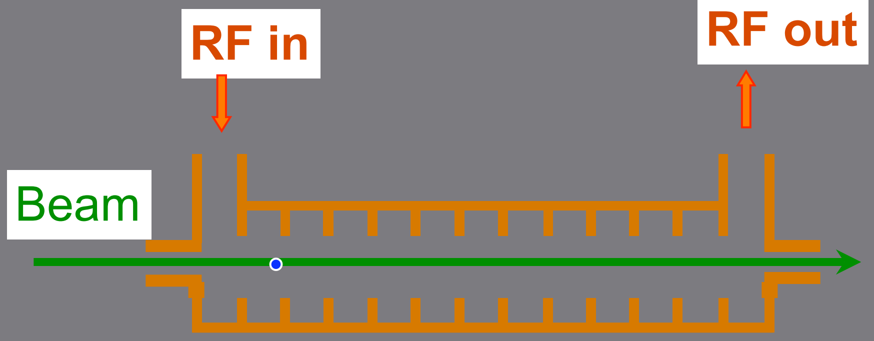
RF frequency: 12 GHz

64 MW RF power / accelerating structure
of 0.233m active length
➔ **275 MW/m**

total active length for 1.5 TeV: **15’000 m**

Pulse length 240 ns, 50 Hz

Acceleration in travelling wave structures:



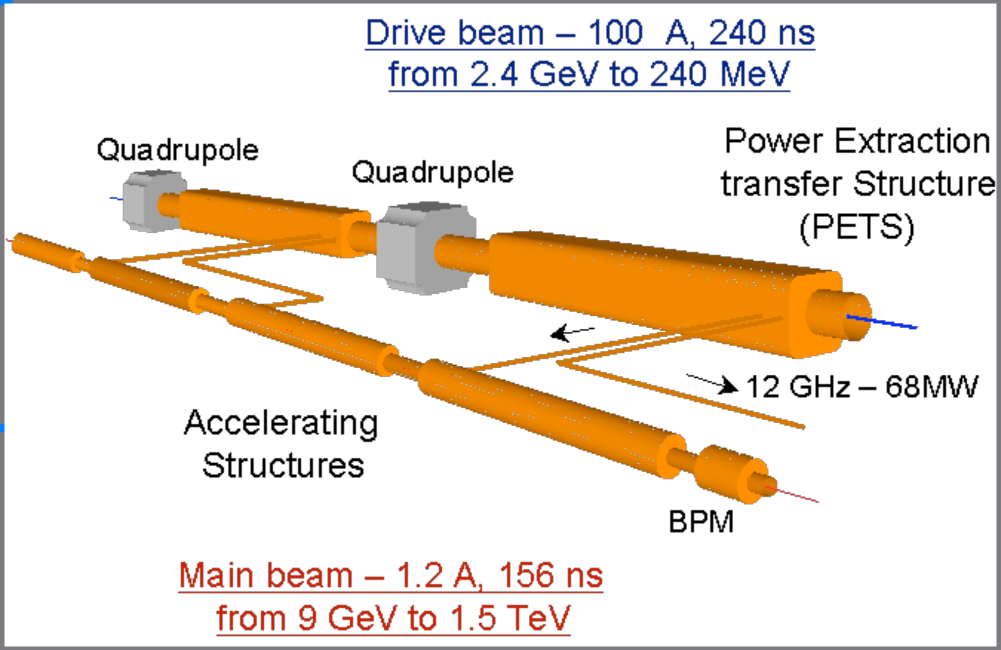
Efficient RF power production !!!!!

The CLIC Two Beam Scheme

Individual RF power sources ?
➔ Not for the 1.5 TeV linacs

Two Beam Scheme:
Drive Beam supplies RF power

- 12 GHz bunch structure
- low energy (2.4 GeV - 240 MeV)
- high current (100A)

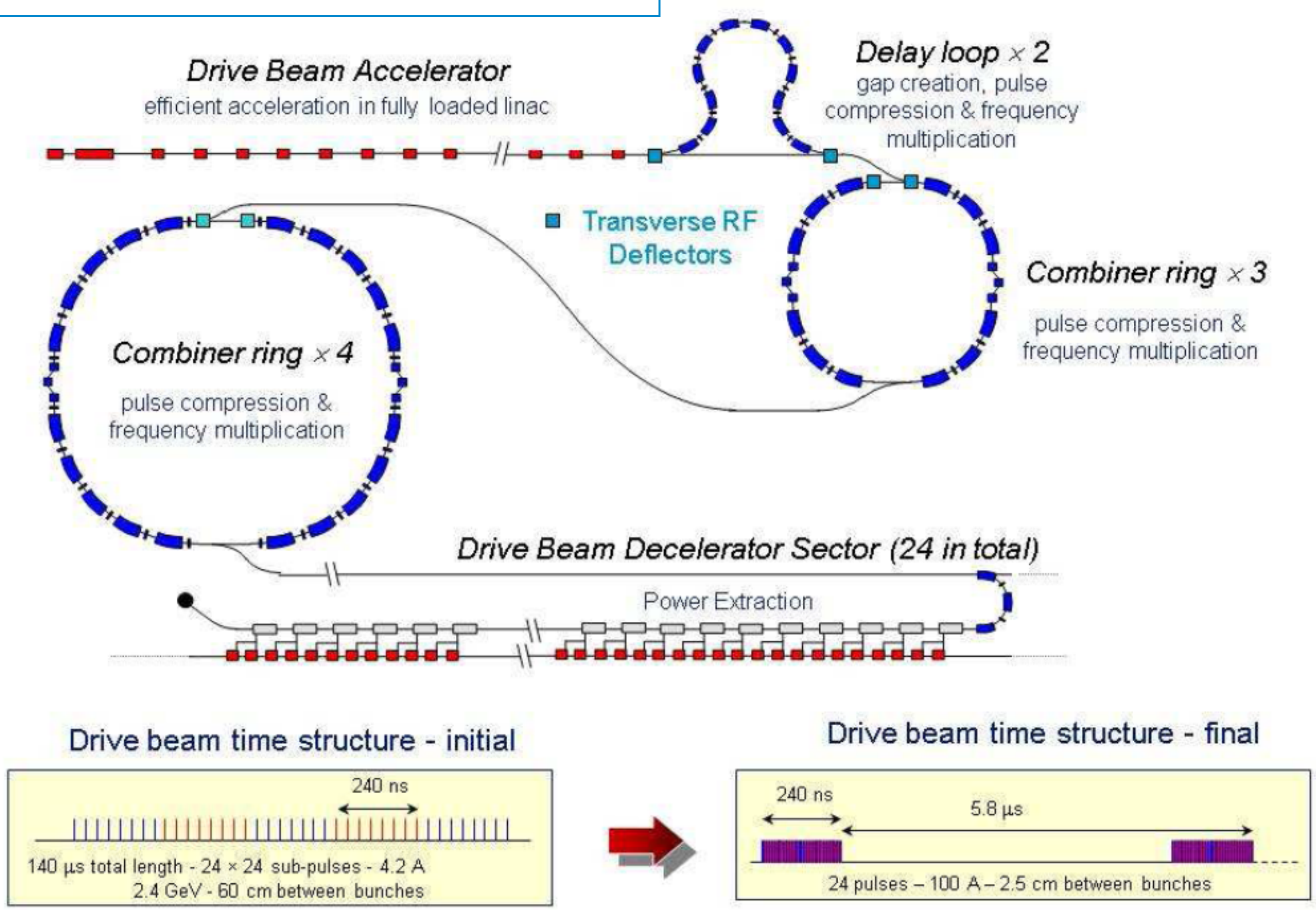


CLIC Drive Beam Generation

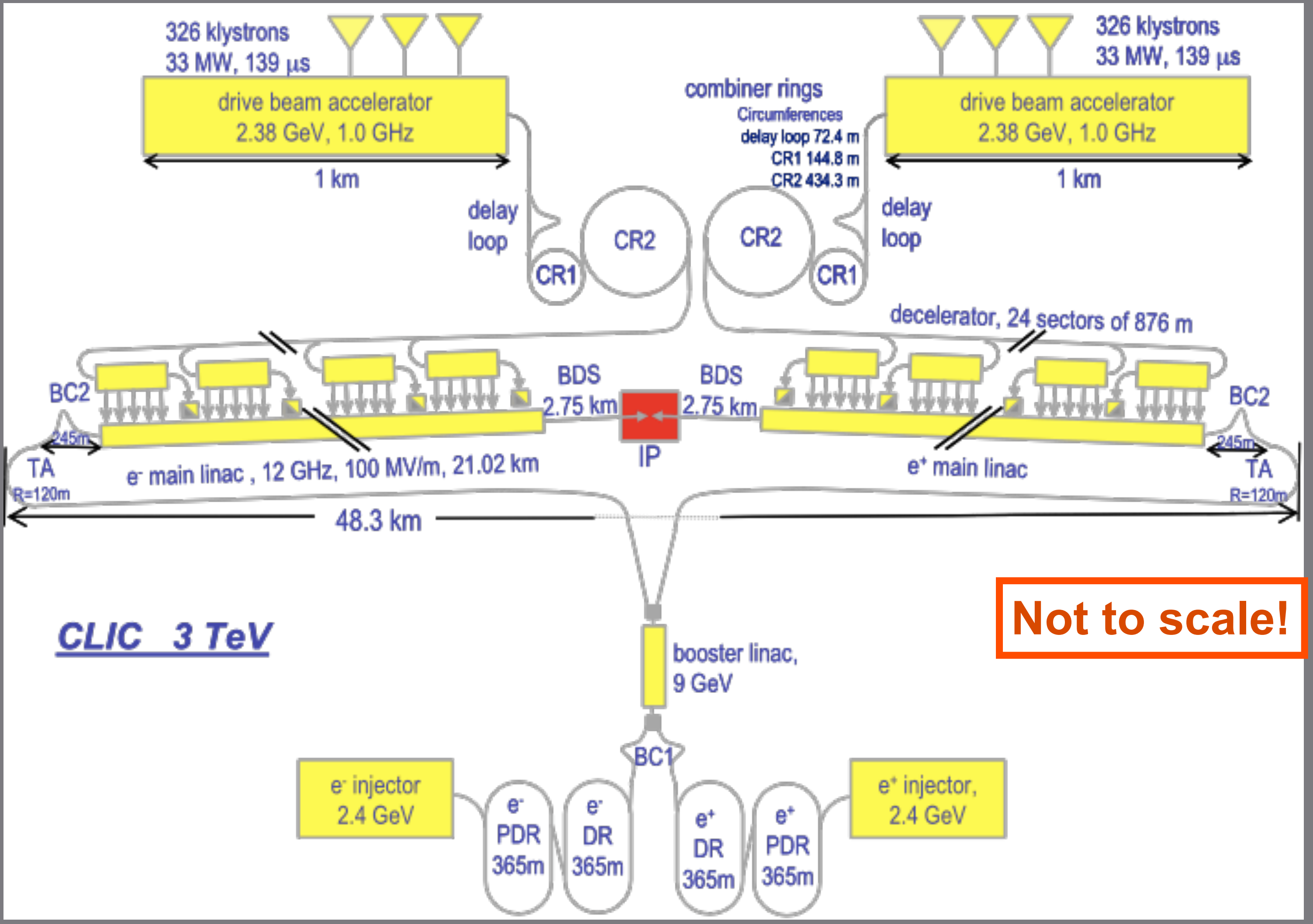
Accelerate long bunch train with low bunch rep rate (500 MHz)

⇨

interleave bunches between each other to generate short (280 ns) trains with high bunch rep rate (12 GHz)



The Full CLIC scheme



Why 100 MV/m and 12 GHz ?

Optimisation: (A.Grudiev)

Structure limits:

- RF breakdown – scaling
- RF pulse heating

Beam dynamics:

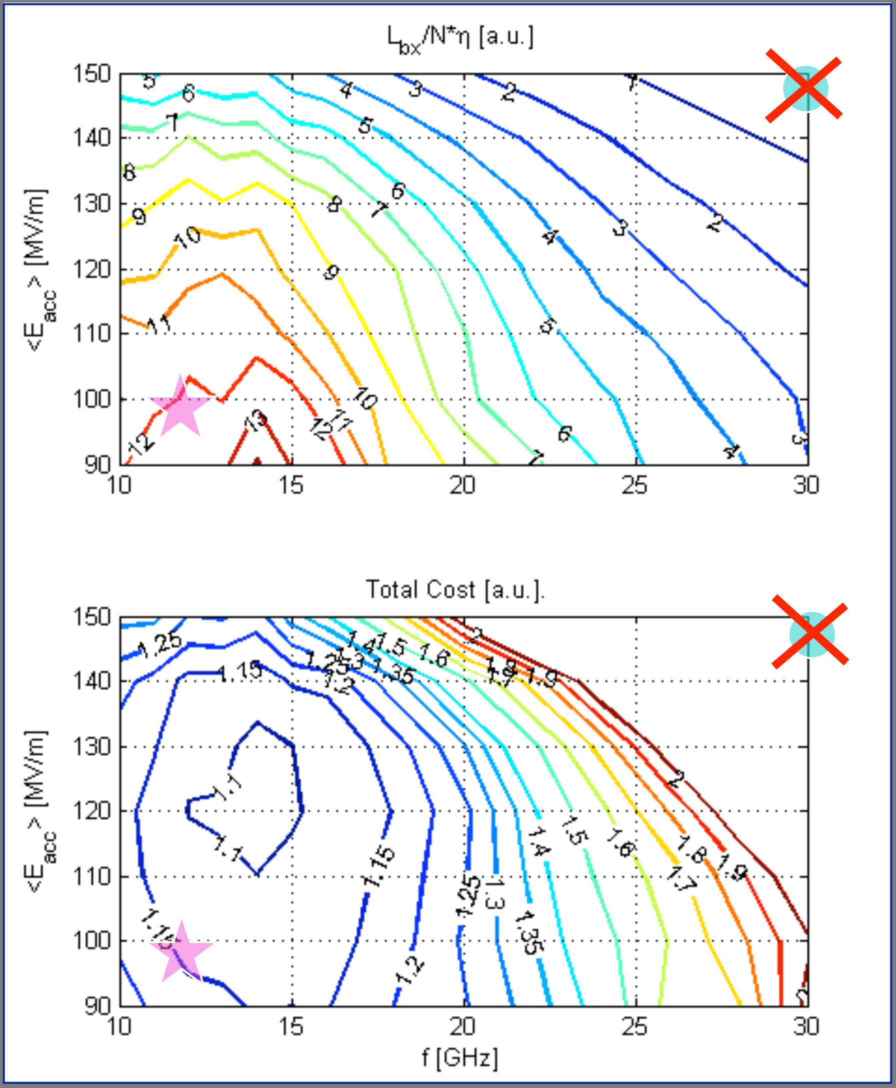
- emittance preservation – wake fields
- Luminosity, bunch population, bunch spacing
- efficiency – total power

Figure of merit:

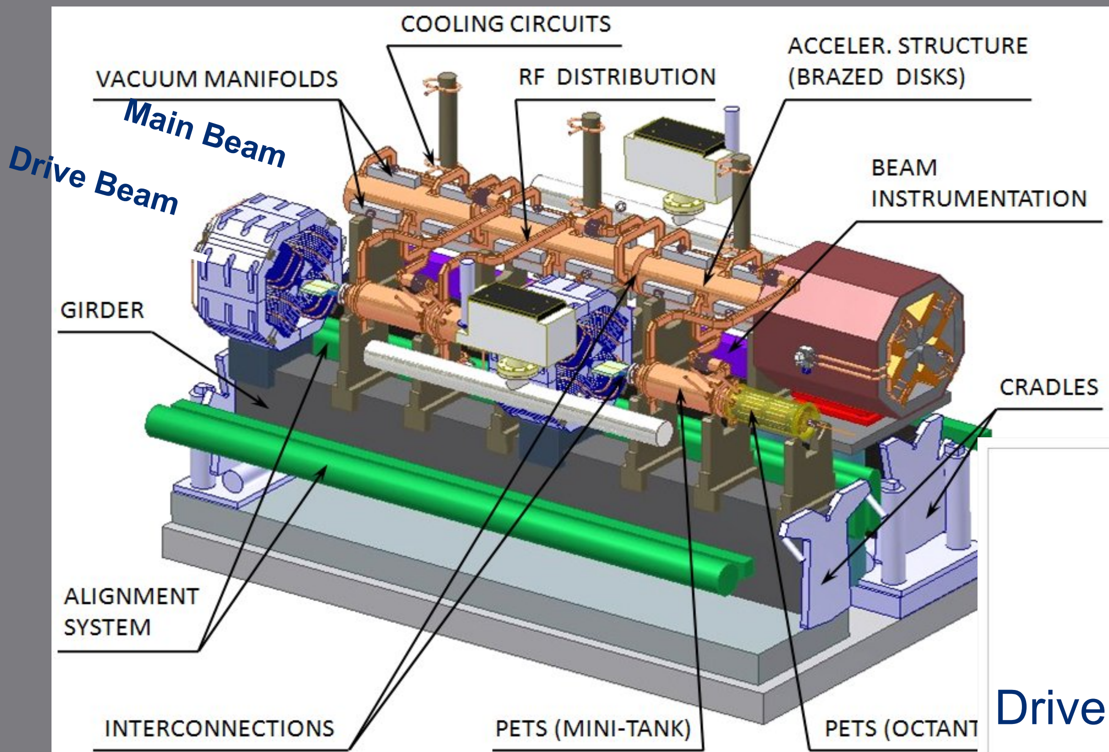
- Luminosity per linac input power

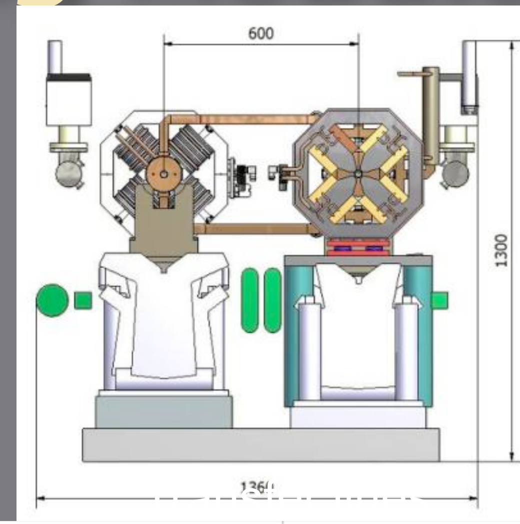
Take into account cost model

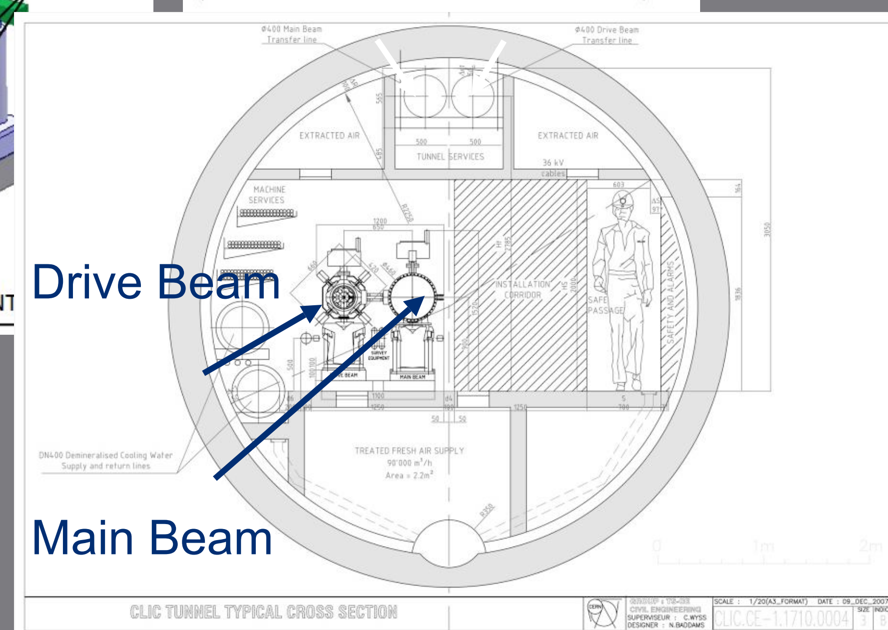
after > 60 * 10^6 structures:
100 MV/m 12 GHz chosen,
previously 150 MV/m, 30 GHz



CLIC Accelerating Module







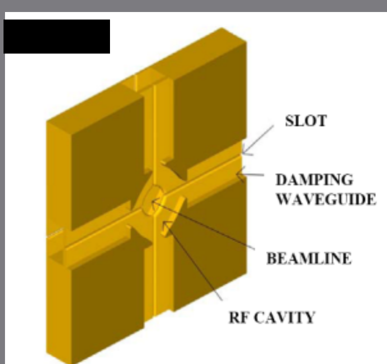
Accelerating Structures

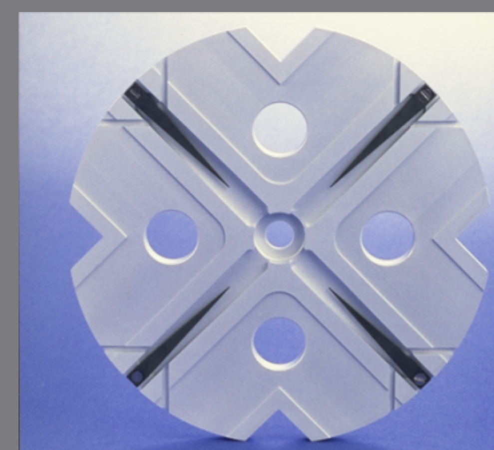
Objective:

- Withstand of 100 MV/m without damage
- breakdown rate < 10^{-7}
- Strong damping of HOMs

Technologies:

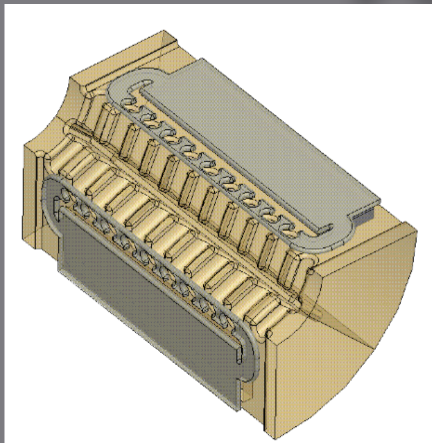
Brazed disks - milled quadrants





Collaboration: CERN, KEK, SLAC

Power Extraction : PETS



damped

on-off possibility

Special development for CLIC

- Travelling wave structures
- Small R/Q : 2.2 kΩ/m

  (accelerating structure: 15-18 kΩ/m)
- 100 A beam current

136 MW RF @ 240 ns per PETS

(2 accelerating structures)

0.21 m active length

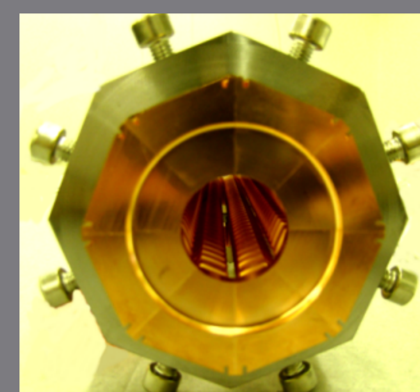
total number : 35’703 per linac

Status:

CTF3: up to 45 MW peak (3 A beam, recirculation)

SLAC: 125 MW @ 266 ns

ref: Igor Syratchev



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 transfert eff	7.5%		6.8%	
Total power consumption MW	129.4		415	

CLIC Test Facility CTF3

Provide answers for CLIC specific issues

➔ Write CDR in 2010

Two main missions:

Prove CLIC RF power source scheme:
- bunch manipulations, beam stability,
- Drive Beam generation
- 12 GHz extraction

Demonstration of “relevant” linac sub-unit:
- acceleration of test beam

Provide RF power for validation of CLIC components:

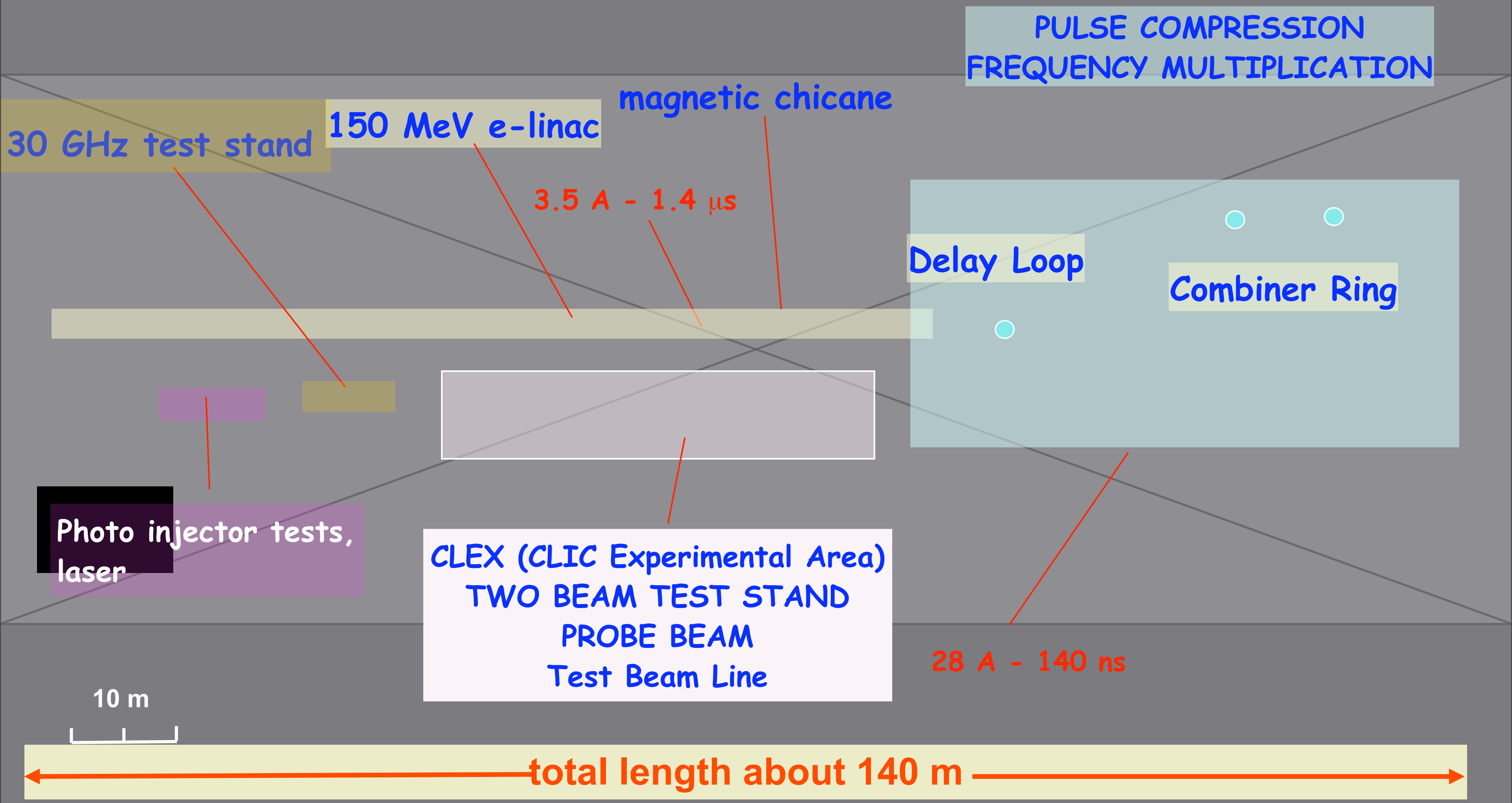
accelerating structures,

RF distribution,

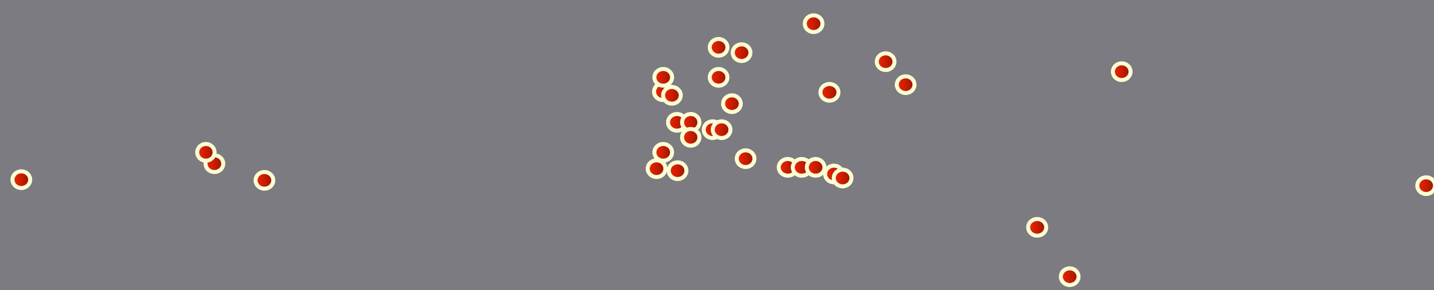
PETS (Power extraction and Transfer Structure)

CTF3 Building Blocks

Infrastructure from LEP



World-wide CLIC&CTF3 Collaboration



33 Institutes involving 21 funding agencies and 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)
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Oslo University (Norway)

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

DETECTORS & PHYSICS

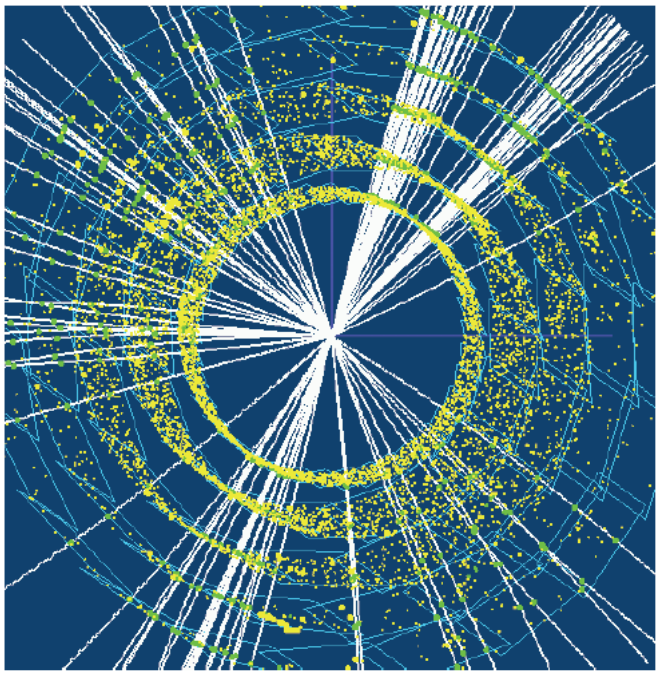
CLIC Physics

- New physics expected in the TeV energy range
  - Higgs, Supersymmetry, extra dimensions,…?
- LHC will indicate what physics and at which energy scale
  - Is 500 GeV enough or is there a need for a multi-TeV machine?
- Even if multi-TeV is the final goal, CLIC will most likely operate over a range of energies (e.g. 0.5 – 3.0 TeV)

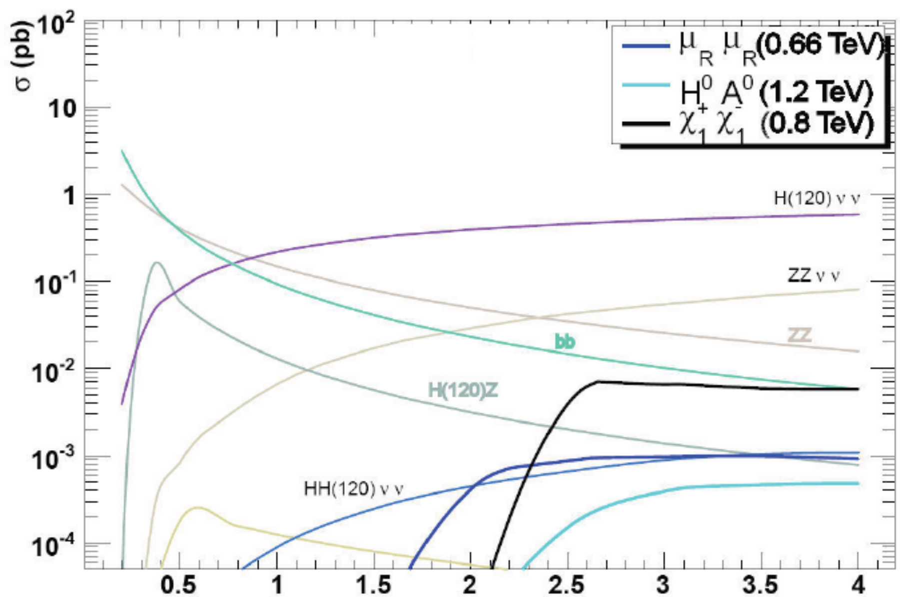
Heavy Mass SUSY Particles

e.g. $e^+e^- \to H^0A^0$ production

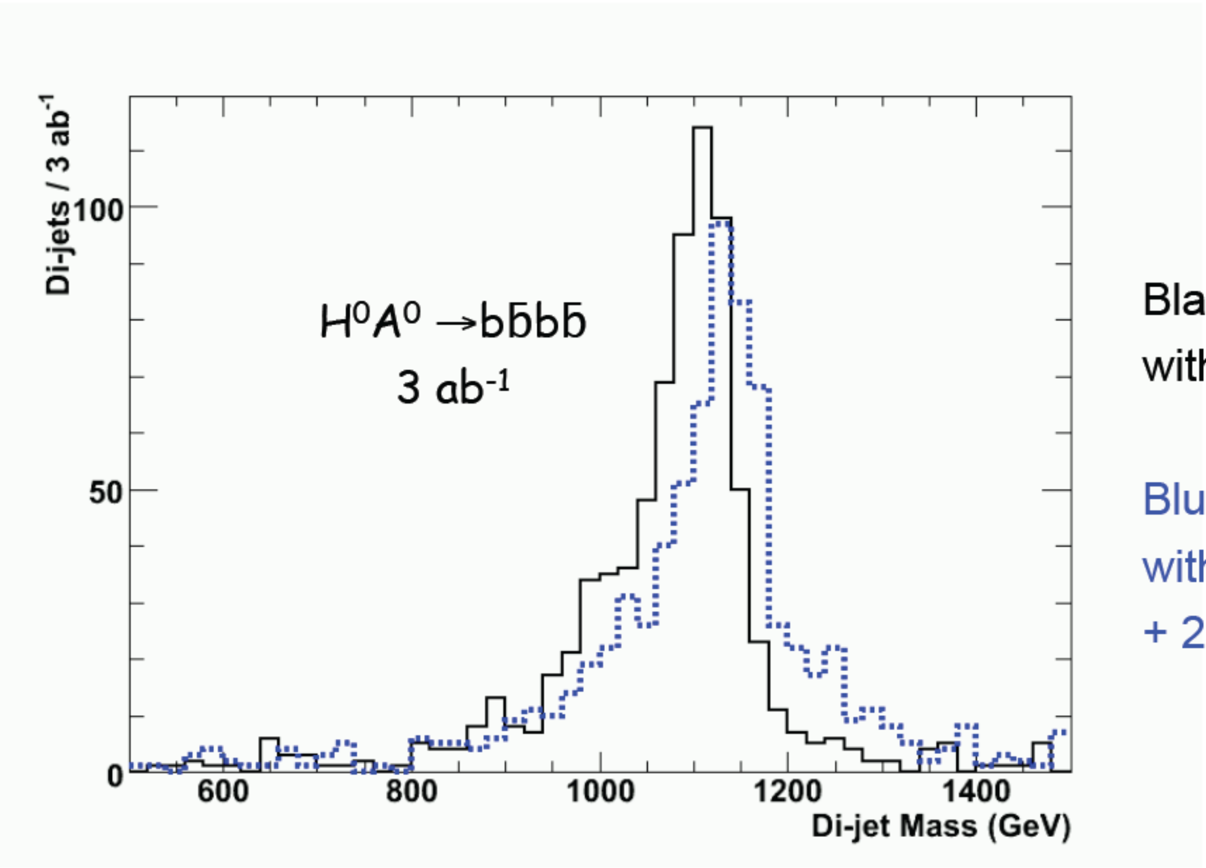
$e^+e^- \to H^0A^0 \to b\bar{b}b\bar{b}$



$m_{H,A} \approx 1$ TeV
Yellow dots mostly from $\gamma\gamma$



$e^+e^- \to H^0A^0$ at 3 TeV



Black

without γγ background

Blue

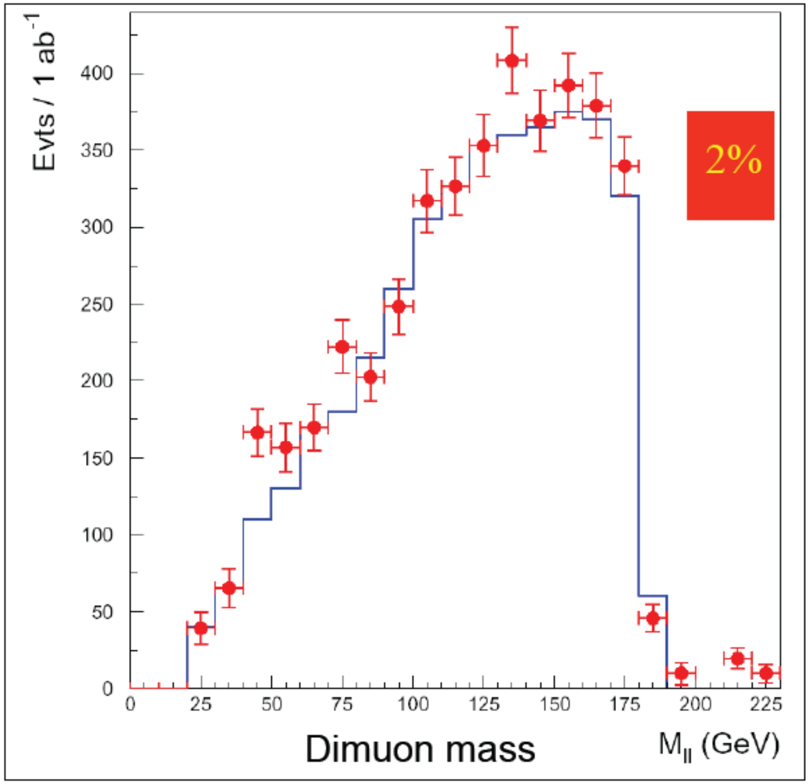
with γγ background

+ 25 ns time stamping

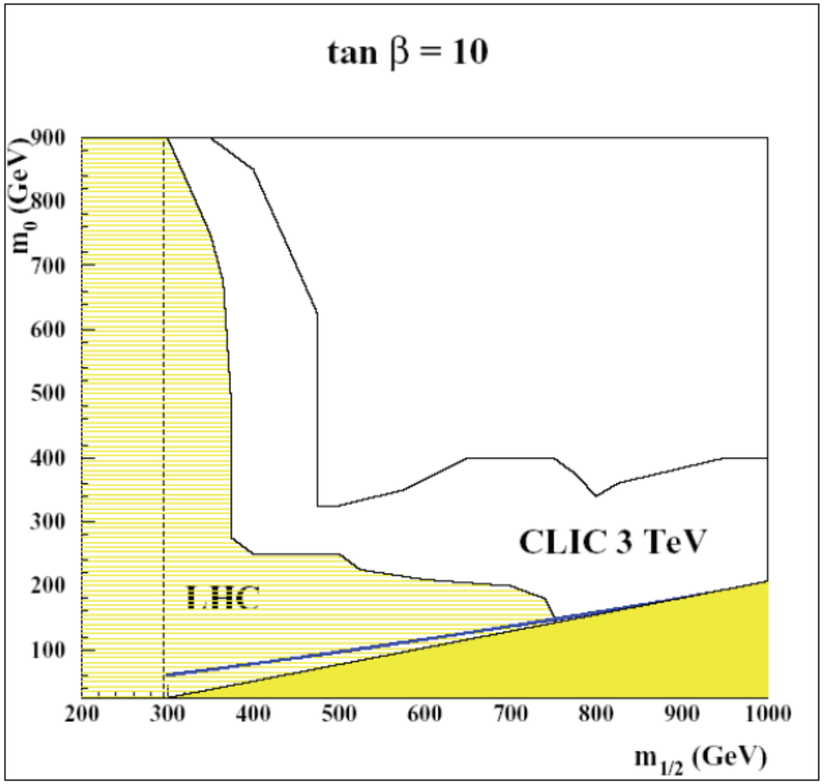
Example of CLIC SUSY Search

Dilepton spectrum in neutralino decay

$$\tilde{\chi}_j^0 \to \ell^\pm \tilde{\ell}^\mp \to \ell^+ \ell^- \tilde{\chi}_1^0 \;+\; \tilde{\chi}_j^0 \to \tilde{\chi}_i^0 Z^0 \to \tilde{\chi}_i^0 \ell^+ \ell^-$$



Reach in parameter space



Universal Extra Dimensions

Extra Dimensions and SUSY have rather similar signatures at LHC.

Clean final states and control of CM energy at CLIC allows separation.

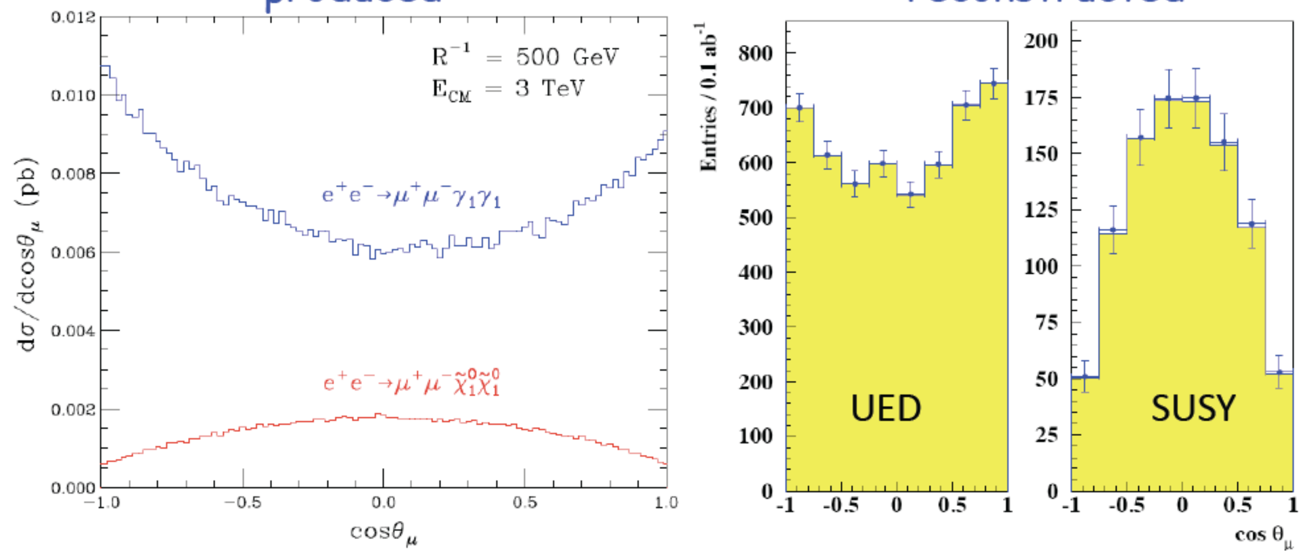
Example: pair produced KK muons and SUSY smuons: $\rightarrow \mu^+\mu^- \not{E}$

$e^+e^- \rightarrow \mu_1^+\mu_1^- \rightarrow \mu^+\mu^-\gamma_1\gamma_1$

$e^+e^- \rightarrow \tilde{\mu}^+\tilde{\mu}^- \rightarrow \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$

produced

reconstructed

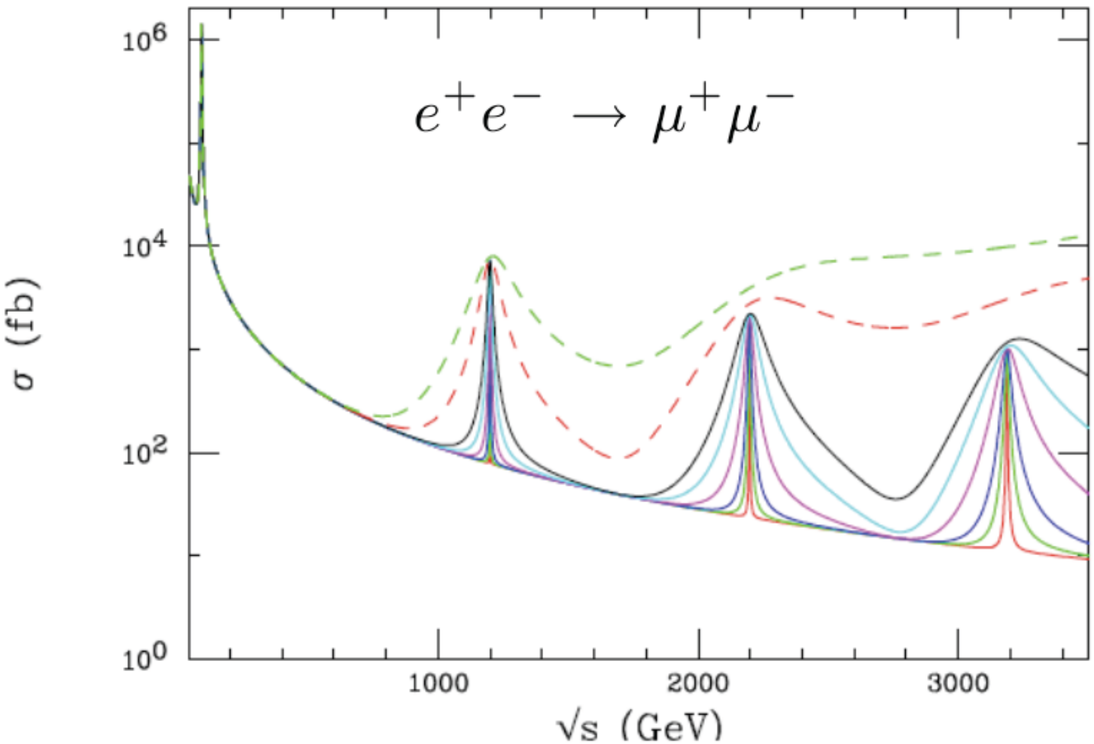


Angular distribution of muon

M. Battaglia, AK Datta, A dRoeck, K Kong, K Matchev

Extra Dimensions Graviton Production

In UED theories, TeV-scale Graviton resonances are predicted, decaying into γγ, *gg* or ffbar pairs. Cross sections are large.



Indicative Physics Reach

Ellis, Gianotti, de Roeck
Hep-ex/0112004 + updates

Units : TeV (except $W_L W_L$ reach)

PROCESS	LHC 14 TeV 100 fb^{-1}	sLHC 14 TeV 1000 fb^{-1}	LC 0.8 TeV 500 fb^{-1}	LC 5 TeV 1000 fb^{-1}
Squarks	2.5	3	0.4	2.5
$W_L W_L$	2σ	4σ	6σ	30σ
Z'	5	6	8†	30†
Extra-dim (δ=2)	9	12	5-8.5†	30-55†
q*	6.5	7.5	0.8	5
Λcompositeness	30	40	100	400
TGC (λ_γ)	0.0014	0.0006	0.0004	0.00008

† indirect search (from precision measurements)

Linear Collider Detector Project at CERN

Motivation:

• Substantial CLIC accelerator effort towards Conceptual Design Report (CDR) for end 2010

• Include CDR chapters on the CLIC physics potential, CLIC detector concepts and their related technological issues

CLIC detector concept will be very similar to ILC concepts

A few challenging differences:

- **Higher energy**
- Increased **background conditions**
- Difference in **time structure**

Profit from many years of investment in ILC e^+e^- physics/detector simulations, hardware R&D and detector concepts

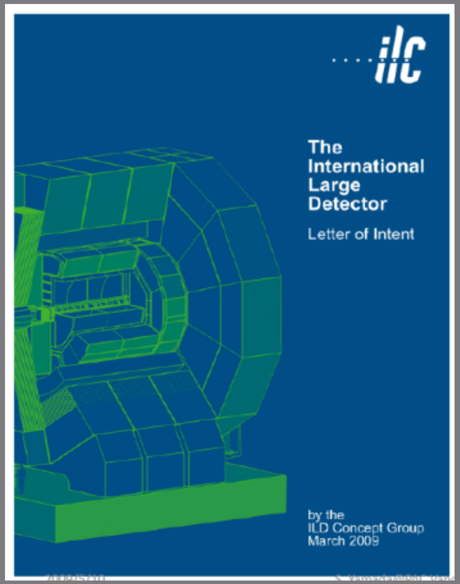
LCD@CERN: Working together with the **ILC detector concepts** and with the linear collider detector **technology collaborations** to study **modifications to the ILC concepts for CLIC energies and beam conditions.**

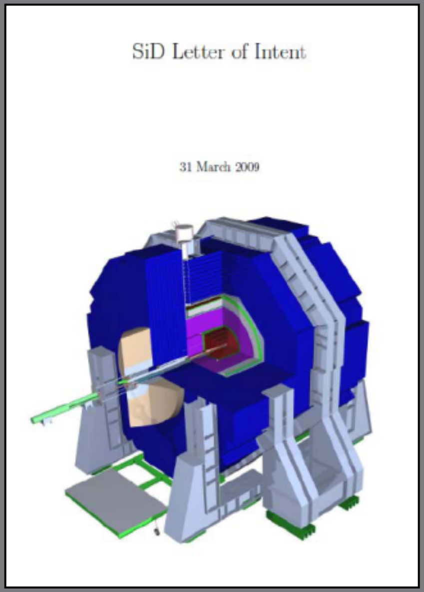
Detectors

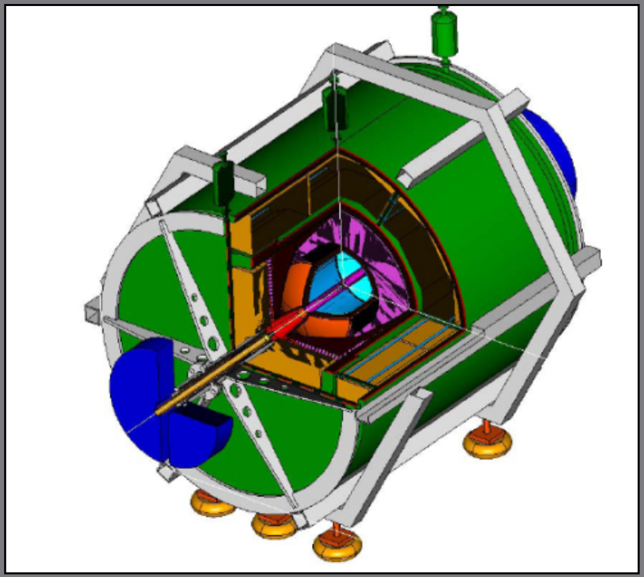
ILC: IDAG (International Detector Advisory Group

Physics and Experiments Board

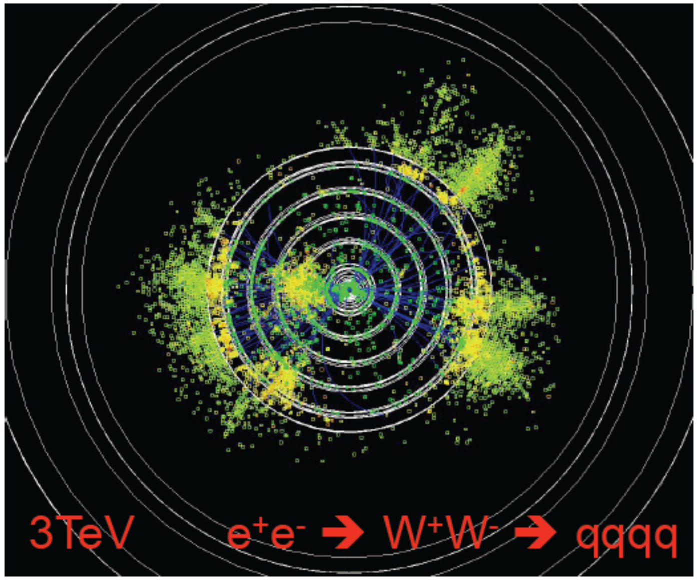
LOI's







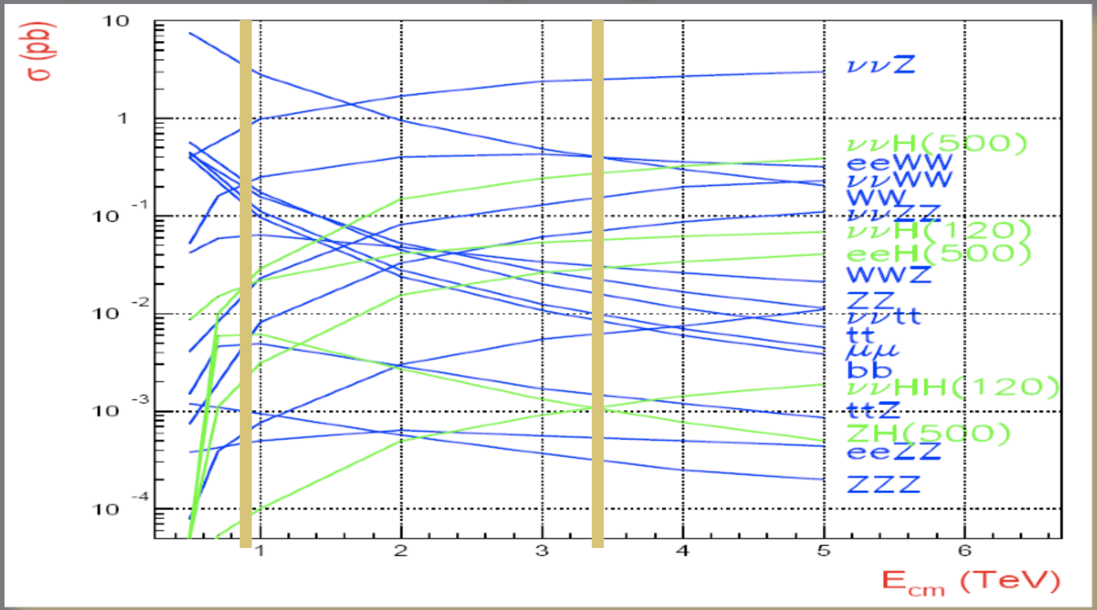
CLIC Detector Issues

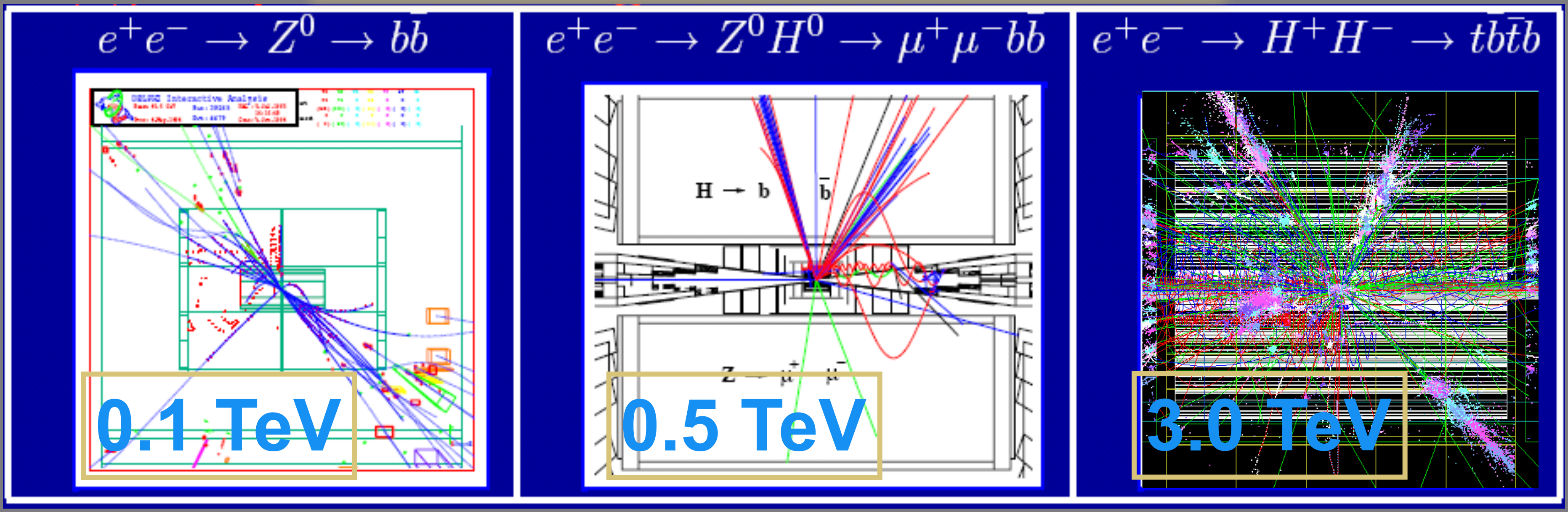


3 main differences with ILC:

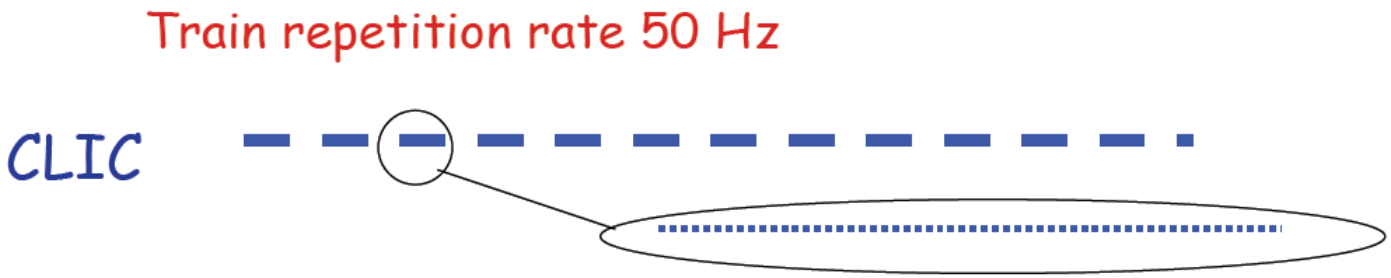
- Energy 500 GeV => 3 TeV
- More severe background conditions
  - Due to higher energy
  - Due to smaller beam sizes
- Time structure of the accelerator

How is physics changing from LEP to CLIC ?





CLIC Time Structure



CLIC:	1 train = 312 bunches	0.5 ns apart	50 Hz
ILC:	1 train = 2820 bunches	308 ns apart	5 Hz

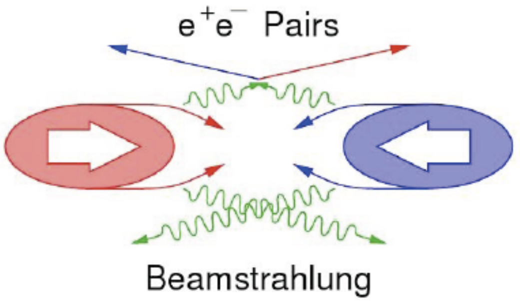
Consequences for CLIC detector:

- Need for detection layers with **time-stamping**
  - Innermost tracker layer with ~ns resolution
  - or …. all-detector time stamping at the 10 ns level
- Readout/DAQ electronics will be different from ILC
  - Power pulsing has to work at 50 Hz instead of 5 Hz

Beam-induced Background

Background sources: CLIC and ILC similar

Due to the higher beam energy and small bunch sizes they are significantly more severe at CLIC.

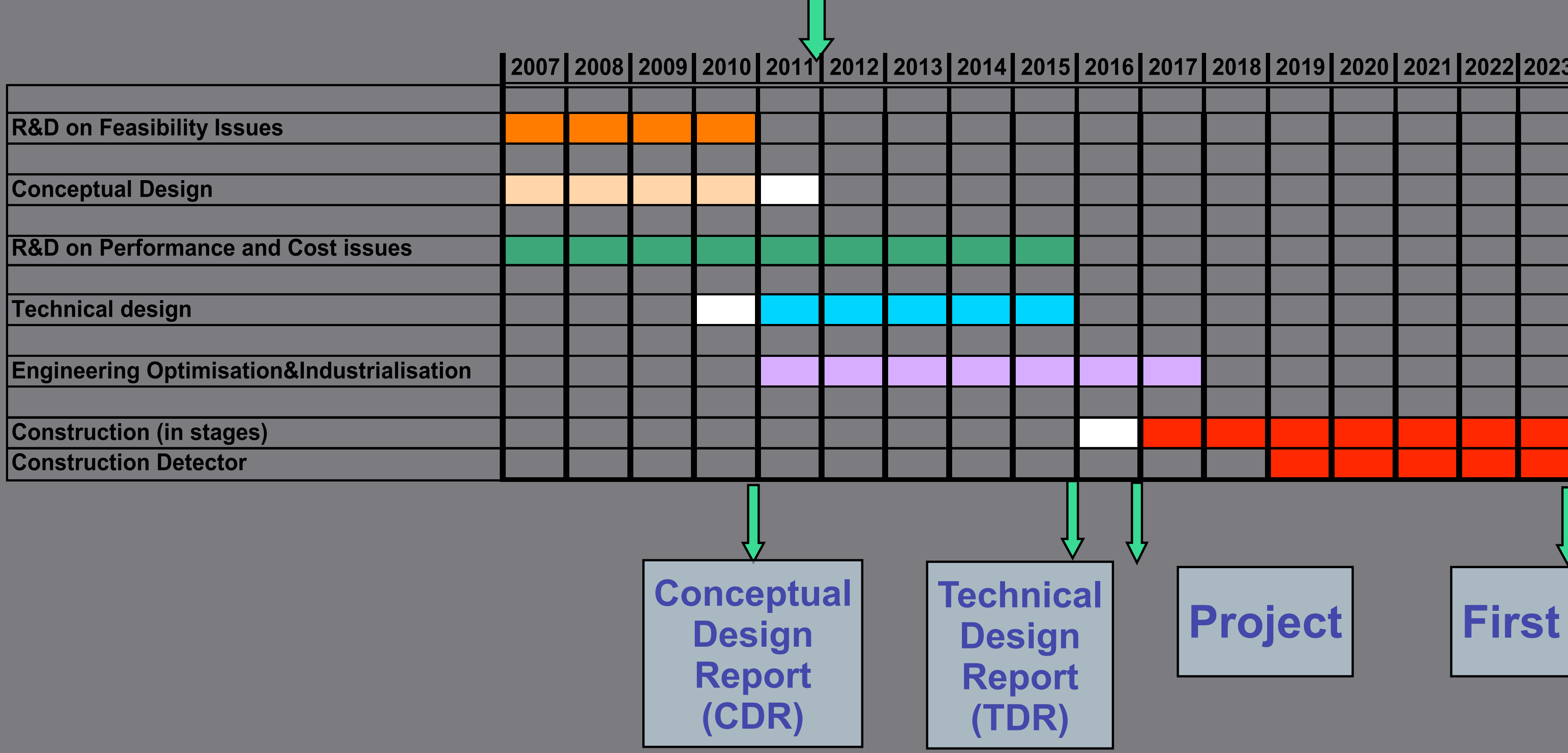


Main backgrounds:

- CLIC 3TeV beamstrahlung $\Delta E/E$ = 29% ($10\times ILC_{value}$)
  - **Coherent pairs** (3.8×10^8 per bunch crossing) <= disappear in beam pipe
  - **Incoherent pairs** (3.0×10^5 per bunch crossing) <= suppressed by strong solenoid-field
  - $\gamma\gamma$ interactions => hadrons (**2.7 hadron events per bunch crossing**)
- Muon background from upstream linac
  - More difficult to stop due to higher CLIC energy (active muon shield)

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



Conclusion

- Future course of high-energy physics to be determined by results from LHC.
- Although we do not yet know what the LHC will (or will not) find, many of the physics scenarios that have been studied would best be explored further with a high-energy e+e- collider.
- CLIC will provide unique, high-precision physics at the energy frontier up to 3 TeV centre-of-mass energy.
  - Provide access to heavy Higgs boson, supersymmetry and extra dimensions.
- Prudent to have the widest possible technology available (CLIC and ILC) to make a choice when LHC results appear.
  - In the meantime, CLIC and ILC teams are working together in studies of positron sources, damping rings, beam dynamics, beam delivery, interaction regions, detectors and costing.