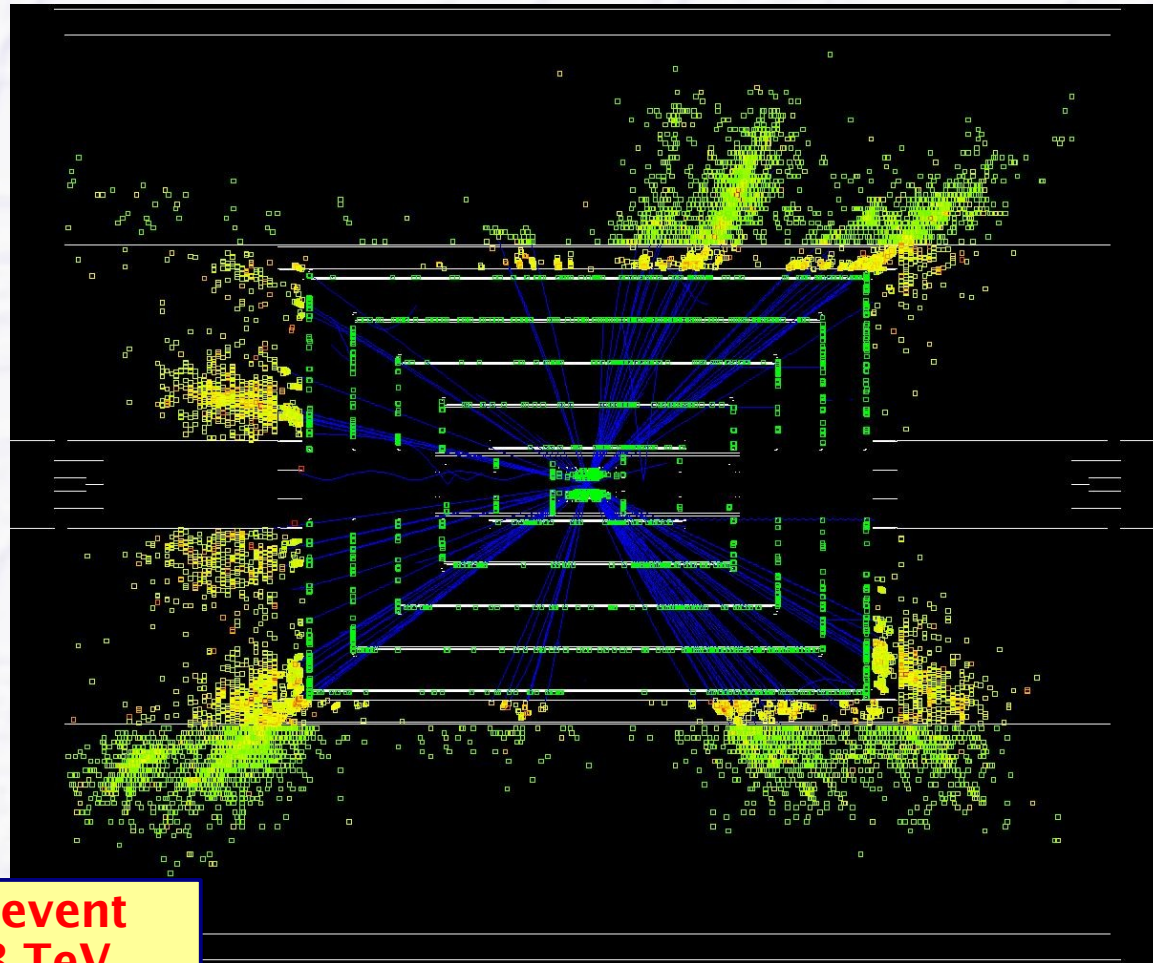


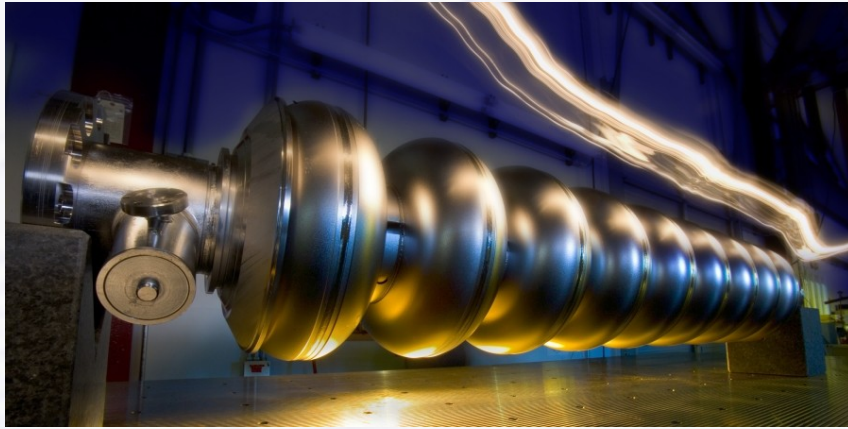
CLIC Status and Perspectives



**multi-jet event
at $\sqrt{s} = 3 \text{ TeV}$
 $e^+e^- \rightarrow WW \rightarrow qqqq$**

ILC and CLIC Technologies

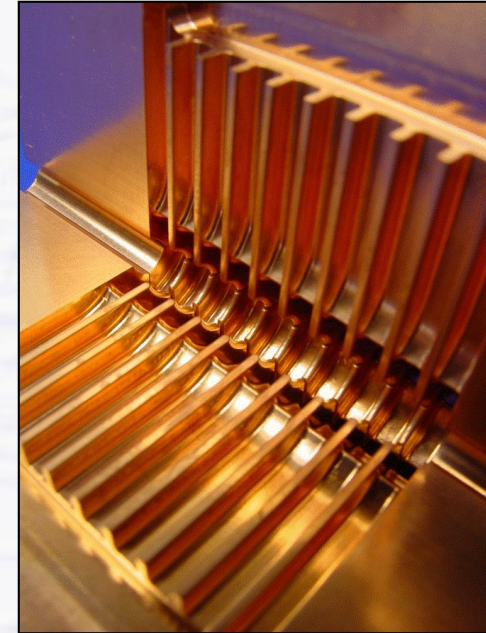
ILC



- Based on superconducting RF cavities (cold cavities)
- Gradient 32 MV/m
- Energy: 500 GeV, upgradeable to 1 TeV**
- Detector studies focus mostly on 500 GeV**

technology proven and available

CLIC



- Based on 2-beam acceleration scheme (warm cavities)
- Gradient 100 MV/m
- Energy: 3 TeV**, though will probably start at lower energy (~0.5 TeV)
- Detector study focuses on 3 TeV**

feasibility still to be demonstrated

The CLIC Two Beam Scheme

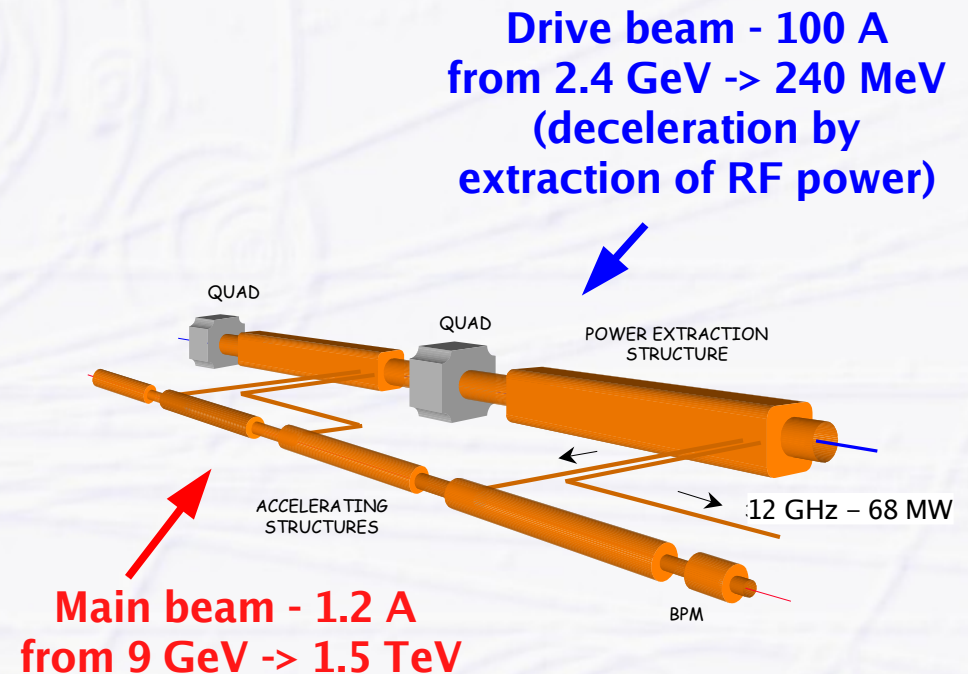
Two Beam Scheme

Drive Beam supplies RF power

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

Main beam for physics

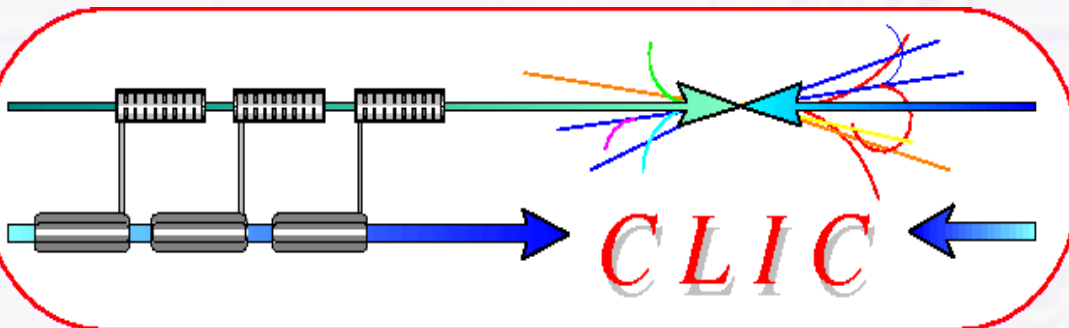
- high energy (9 GeV – 1.5 TeV)
- current 1.2 A



No individual RF power sources

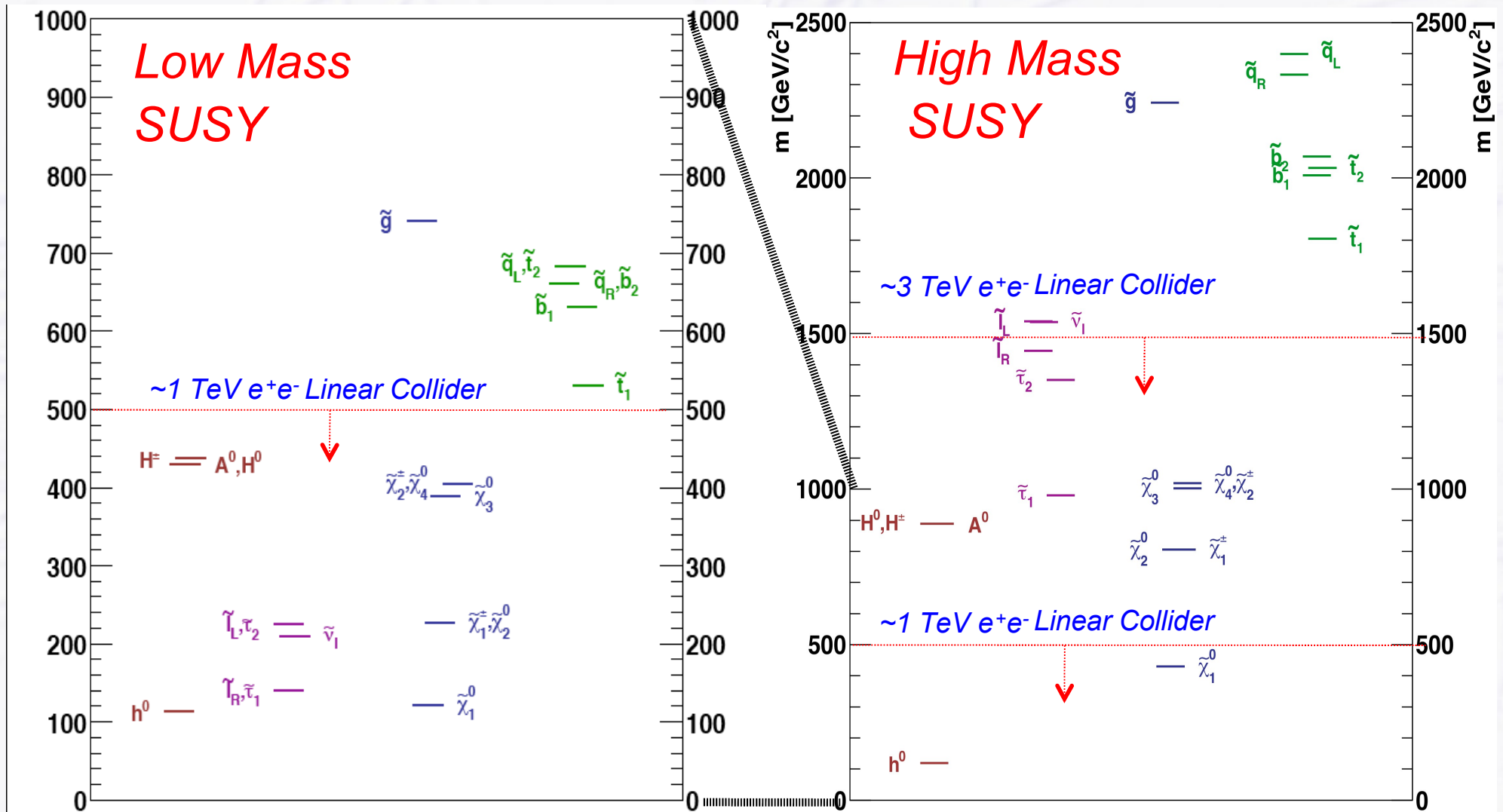
->

CLIC itself is basically
a ~50 km long klystron...



Physics Motivation for LC @ 3 TeV

- High Mass SUSY scenarios with masses at \sim TeV scale, e.g.



SUSY Parameter Scan

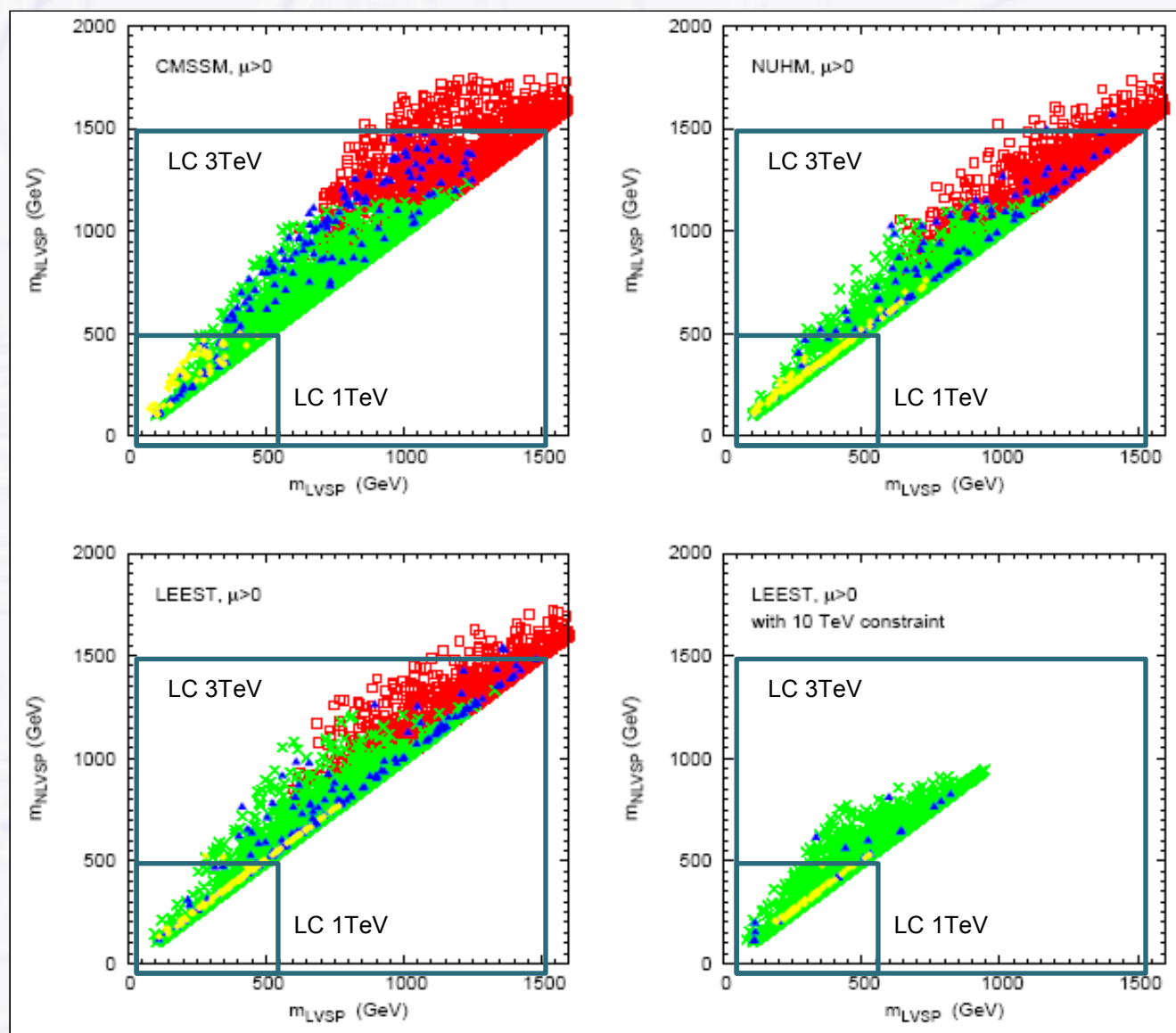
J.Ellis

all
samples

Detectable
@ LHC

Provide
Dark
Matter

Dark
Matter
Detectable
Directly



↑
Second lightest visible sparticle

Lightest visible sparticle →

ILC + CLIC Parameters

Luminosity at
500 GeV similar to ILC

Center-of-mass energy	ILC 500 GeV	CLIC 500 GeV	CLIC 3 TeV
Total (Peak 1%) luminosity [$\cdot 10^{34}$]	2(1.5)	2.3 (1.4)	5.9 (2.0)
Repetition rate (Hz)	5	50	
Loaded accel. gradient MV/m	32	80	100
Main linac RF frequency GHz	1.3	12	
Bunch charge [$\cdot 10^9$]	20	6.8	3.7
Bunch separation (ns)	370	0.5	
Beam pulse duration (ns)	950 μ s	177	156
Beam power/beam (MWatts)		4.9	14
Hor./vert. IP beam size (nm)	600 / 6	200 / 2.3	40 / 1.0
Hadronic events/crossing at IP	0.12	0.2	2.7
Incoherent pairs at IP	$1 \cdot 10^5$	$1.7 \cdot 10^5$	$3 \cdot 10^5$
BDS length (km)		1.87	2.75
Total site length km	31	13	48
Total power consumption MW	230	130	415

Crossing Angle 20 mrad (ILC 14 mrad)

Energy Scans at < 3 TeV

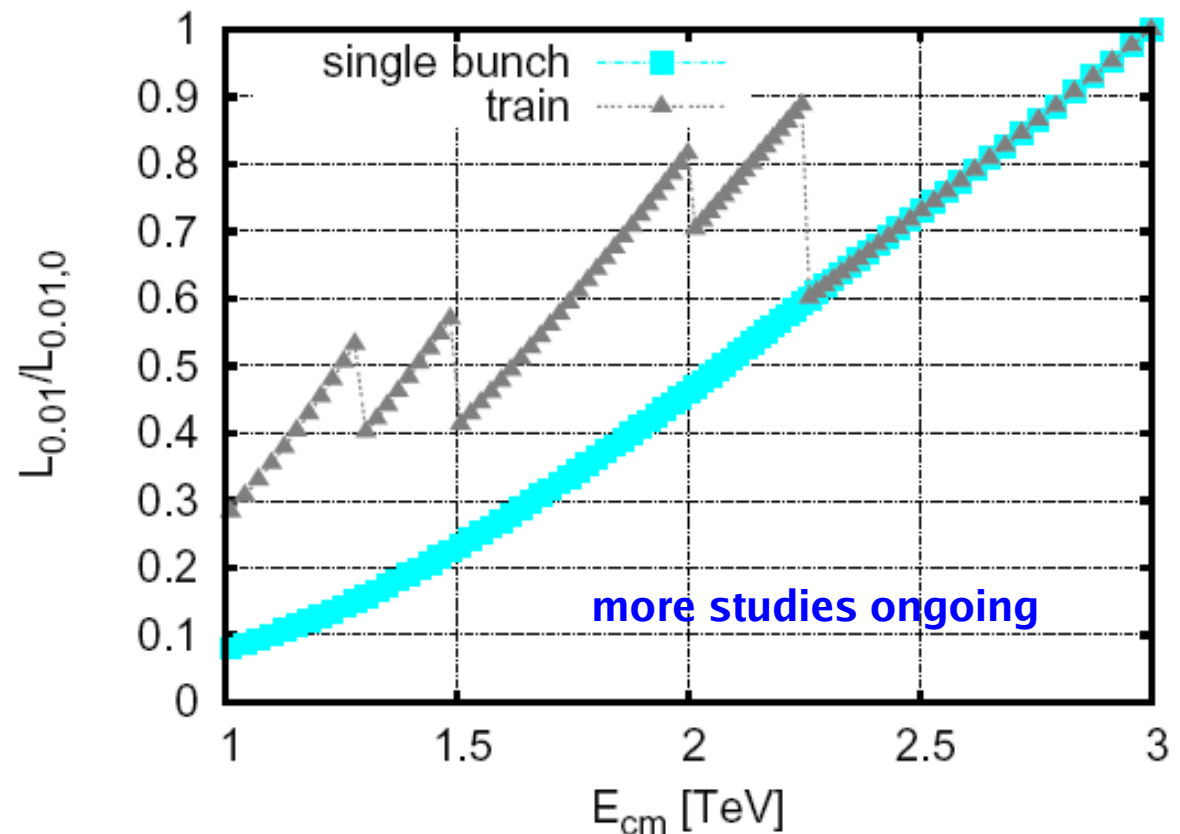
- **Threshold scan or peak scan of new resonances is a non-trivial operation mode at CLIC**

- machine optimized for 3 TeV (luminosity)
- running at lower energy -> significantly lower luminosity
- Bypass tunnel(s) costly and exact energy range likely unknown at construction time

- **Luminosity drop can be partially compensated by longer bunch trains**

E/E_0	n_b	n_L	$Q_p/Q_{p,0}$
1.0	312	1.0	1.0
0.75	472	1.5	1.12
0.667	552	1.77	1.18
0.5	792	2.54	1.27
0.375	1112	3.56	1.34
(0.333)	(1272)	(4.08)	(1.36)

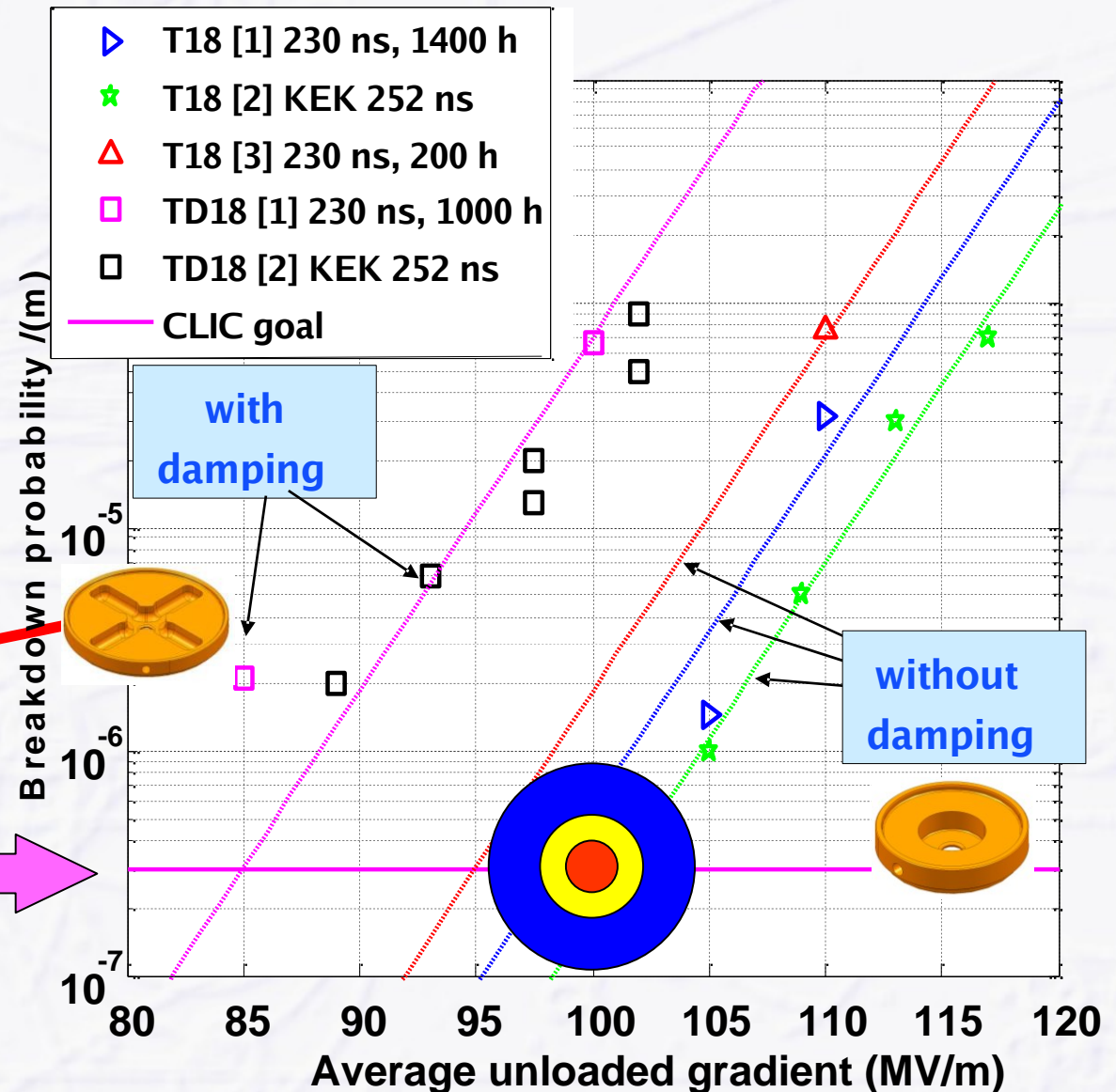
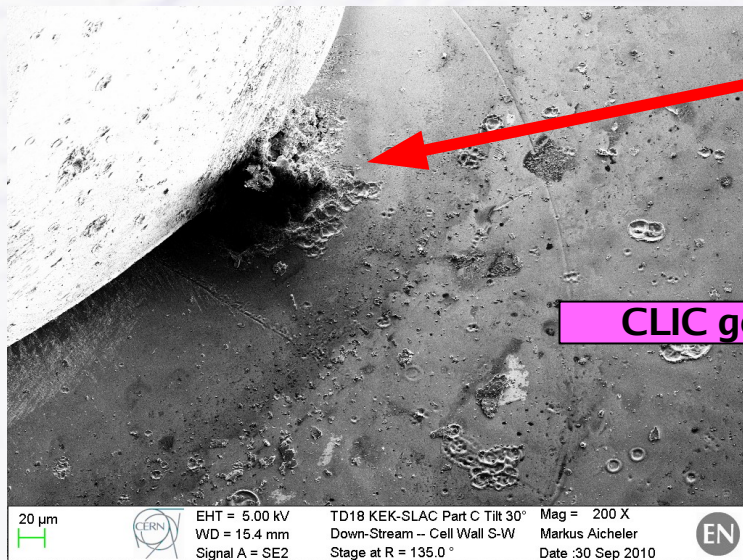
E maximum centre-of-mass energy for operation mode



Breakdown Rate

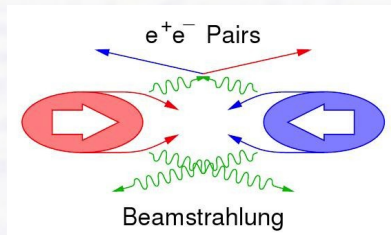
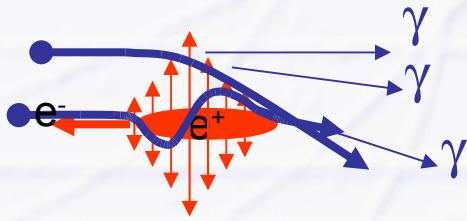
Major problem over last years

- breakdown and damage of accelerating structure at high gradients and long pulse length
- need to keep breakdown rate (damage) as low as possible

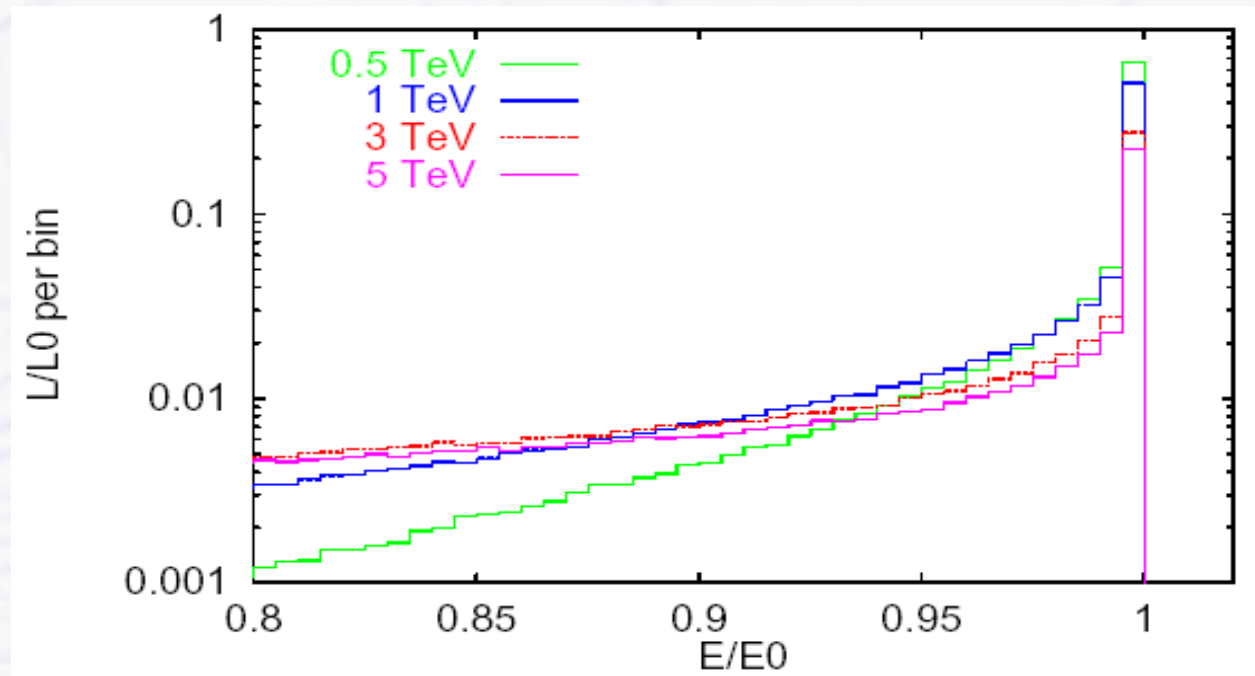


Beamstrahlung

unavoidable at Linear Colliders in general:
small beam sizes \rightarrow large beamstrahlung



more severe at CLIC
because of higher
energy and smaller
beamsizes



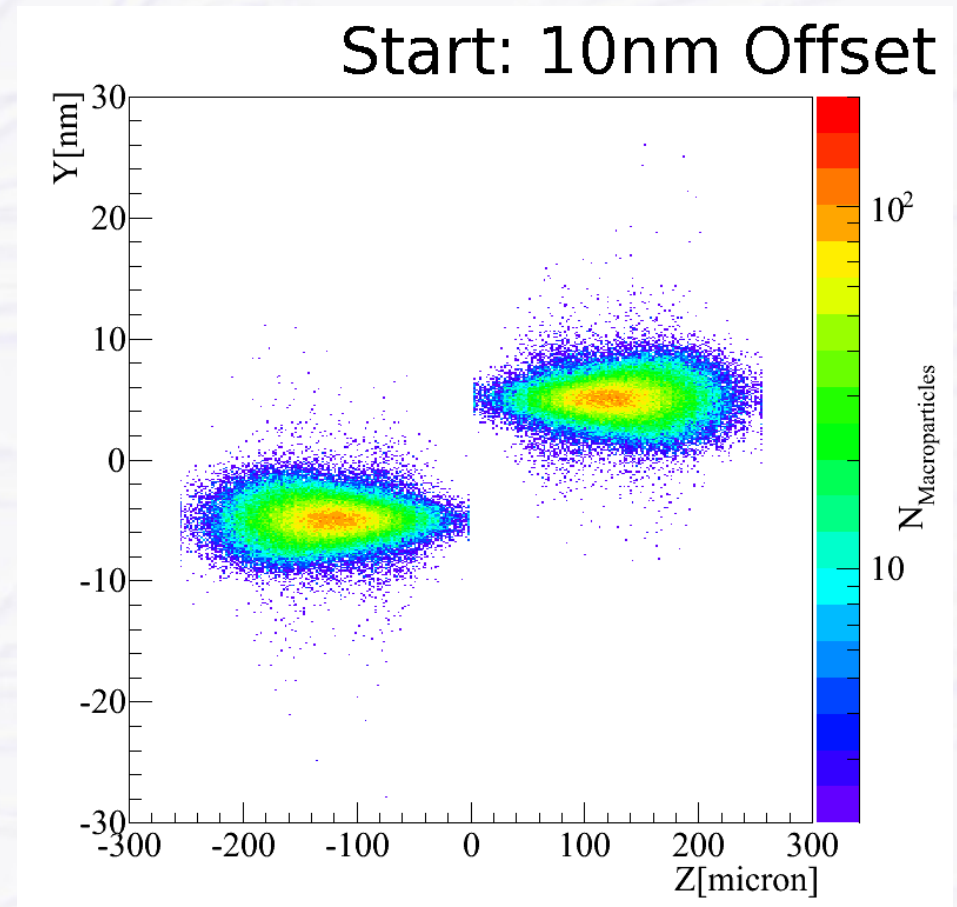
luminosity spectrum:
only 1/3 of luminosity in top 1%
centre-of-mass energy bin

➔ **CLIC 3 TeV beamstrahlung $\Delta E/E = 29\%$ ($\sim 10 \times$ ILC at 500 GeV)**

- 3×10^5 incoherent pairs per BX (suppressed by strong solenoid field)
- 3.3 hadronic events per BX (from $\gamma\gamma \rightarrow$ hadrons)

Non Perfect Beam collisions

- Animation of colliding bunches with 10nm offset (note: different y- and z-scale)
- Due to jitter in accelerator, BDS, QD0 not all collision happen perfectly head on (though should be much smaller than 10nm)

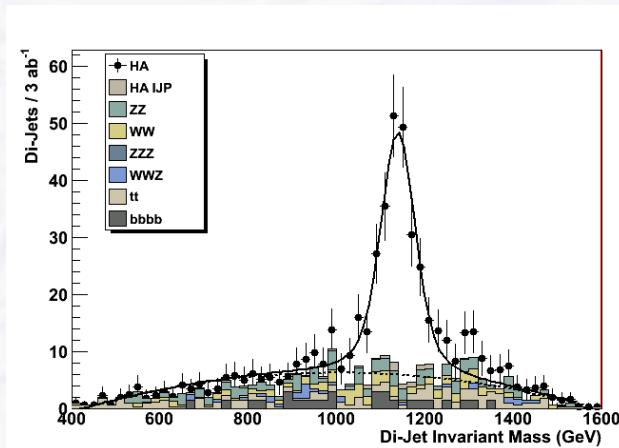


Main CLIC – ILC Detector differences

- **Higher energy -> more dense particle jets** (independent on machine concept)
 - ➔ need tracker with better double track resolution
 - TPC with good double hit resolution (GEMs, MicroMegas) reconsidered again as CLIC main tracker as alternative to full Si tracker
 - ➔ need calorimeters with larger thickness and higher granularity
 - Particle Flow concept requires to identify individual calorimeter EM and hadronic clusters
- **Much shorter bunch spacing: 0.5 ns (CLIC) vs 337 ns (ILC)**
 - ➔ need “time-stamping”: identification of tracks from individual bunch crossings
 - if no time-stamping -> overlay of physics events with hadronic background from beamstrahlung
 - ➔ general time structure also has consequences for pulsed electronics
- **Higher E (dominating) + Smaller beam sizes -> more (severe) background**
 - ➔ need to move innermost layers of Vertex Detector further out

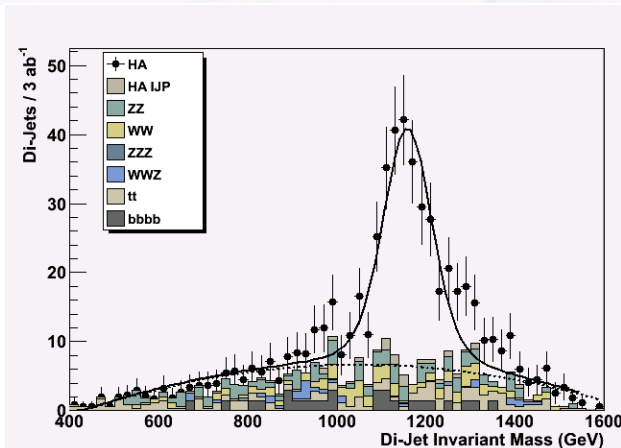
Time Stamping

- About 3 $\gamma\gamma \rightarrow$ hadrons per BX at CLIC
 - hadrons confuse particle flow + jet resolution if not resolved
- Study with heavy Higgs doublet $H^0 A^0$ at ~ 1.1 TeV mass
 - $e^+e^- \rightarrow H^0 A^0 \rightarrow bbbb$
- Signal + full standard model background + background from $\gamma\gamma \rightarrow$ hadrons



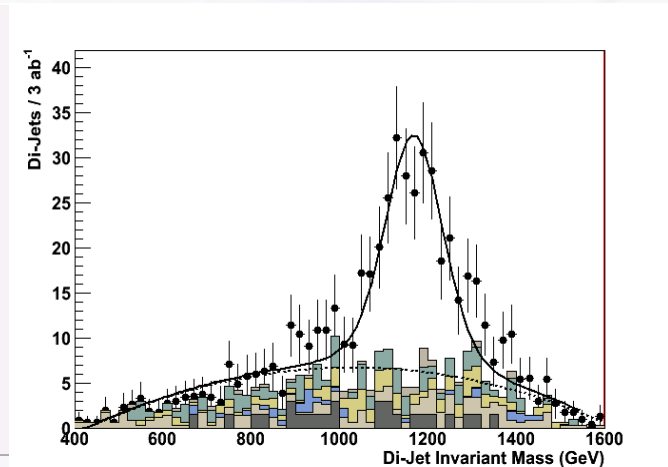
Zero bunch crossings
MA mass resol. 3.8 GeV

perfect BX resolution



20 bunch crossings
MA mass resol. 5.6 GeV

time resolution 10 ns

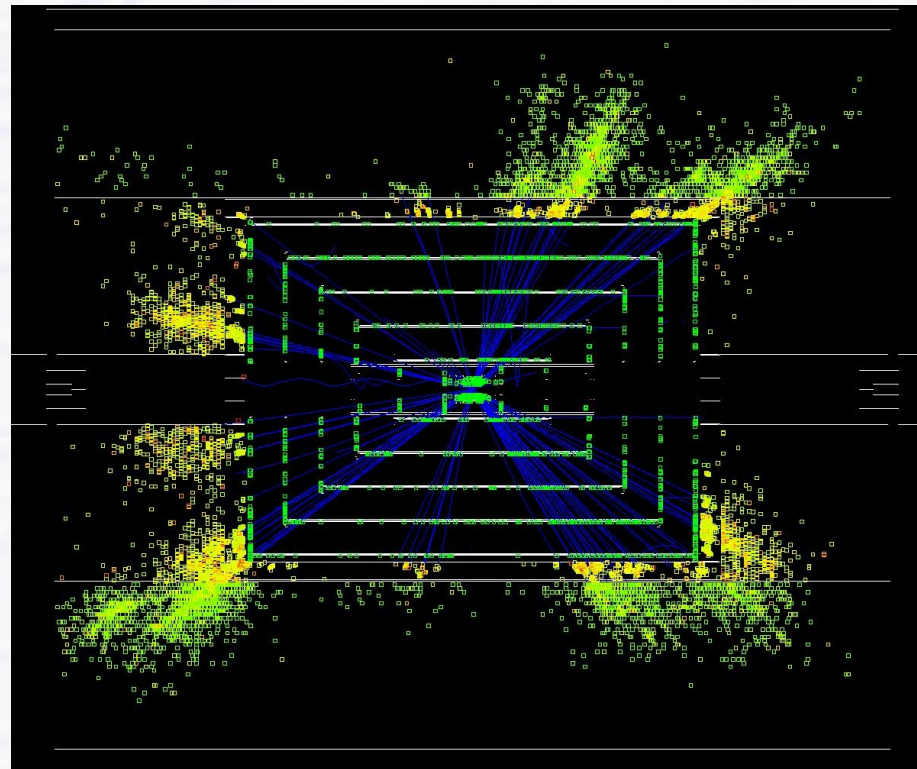


40 bunch crossings
MA mass resol. 8.2 GeV

time resolution 20 ns

Jet Multiplicities

Jet Multiplicity					
\sqrt{s} (TeV)	0.09	0.20	0.5	0.8	3.0
$\langle N_{Jets} \rangle$	2.8	4.2	4.8	5.3	6.4
	LEP1 90 GeV	LEP2 200 GeV	ILC 500 GeV	ILC 800 GeV	CLIC 3 TeV



multi-jet event
at $\sqrt{s} = 3$ TeV
 $e^+e^- \rightarrow WW \rightarrow qq\bar{q}\bar{q}$

Distance of Leading Particles in Jets

Spatial distance neutral – charged hadrons

(J.J. Blaising)

Distance, Δ , at the 1. layer of HCAL

	Njet, Ecm, B	Δ (cm) MPV barrel	Δ (cm) RMS barrel	Δ (cm) MPV endcap	Δ (cm) RMS endcap
$\nu\nu H^0$	2J, 0.5 GeV, 4T	8.0	3.6	9.7	4.4
$t\bar{t}$	4/6J, 0.5 GeV, 4T	6.4	2.8	8.6	6.7
$\nu\nu H^0$	2J, 3.0 TeV, 4T	3.8	2.6	2.6	2.4
$t\bar{t}$	4/6J, 3.0 TeV, 4T	1.0	1.1	1.7	0.9
$t\bar{t}$	4/6J, 3.0 TeV, 5T	1.4	1.2	1.9	1.0

- at 3 TeV neutral - charged particle separation only ~ 1 cm
- cluster of neutral and charged hadrons will overlap in HCAL
- neutral hadron reconstruction (with PFA) only by subtraction

Summary of (some) CLIC Challenges

● Accelerator

- ➡ **high gradient 100 MV/m**
 - damage of accelerating structures, break down
- ➡ **small accelerating structures (due to 12 GHz RF)**
 - machining of many parts down to μm level, adjustment at μm level
- ➡ **final focus (very small beam size)**
 - beam size 40 nm x 1 nm, stabilization issues, fast feedback

● Detector

- ➡ **“time stamping” at 0.5 ns bunch crossing rate**
 - resolve correct bunch crossing of an event or of tracks, reject $\gamma\gamma \rightarrow$ hadrons
- ➡ **Hadron calorimetry + particle flow**
 - need dense absorbers to limit radial size (e.g. tungsten), particle flow at high energies
- ➡ **machine background**
 - innermost layer of vertex detector needs to move out further, forward calorimeter, shielding against muon background more difficult at higher E

CLIC Detector Study

- **Early CLIC Detector Study finished in 2004**
 - ➔ very basic detector studies only (Toy MC)
 - ➔ not much progress until ~2008
- **Study relaunched to deliver the CLIC Conceptual Design Report in 2011**
 - ➔ starting point: use existing ILD and SiD software
 - ➔ create “CLIC flavours” of both ILC detector concepts
 - “ILD-like detector” @ CLIC @ 3 TeV = CLIC_ILD
 - “SiD-like detector” @ CLIC @ 3 TeV = CLIC_SiD
- **CLIC detector = “90% ILC detector” + “10% CLIC specifics”**
 - ➔ CLIC is profiting a lot from ongoing ILC detector R&D and design studies
 - ➔ but ILC also profits from CLIC studies
 - **CLIC detector = “extreme” ILC detector** -> win – win situation for both communities
 - e.g. common work on Particle Flow Algorithms
 - W-HCAL, test beams, TPC hit splitting, engineering studies (push – pull)

LCD Group at CERN

- **Established January 2009**

- ➔ <http://cern.ch/LCD>

- **Mandate**

- ➔ “The Linear Collider Detector project at CERN **focuses on physics and detector issues** for a future e+e- collider at the TeV-scale. The work is carried out in collaboration with several study groups from across the globe, addressing physics and detectors **at either the International Linear Collider (ILC) or the Compact Linear Collider (CLIC).**”



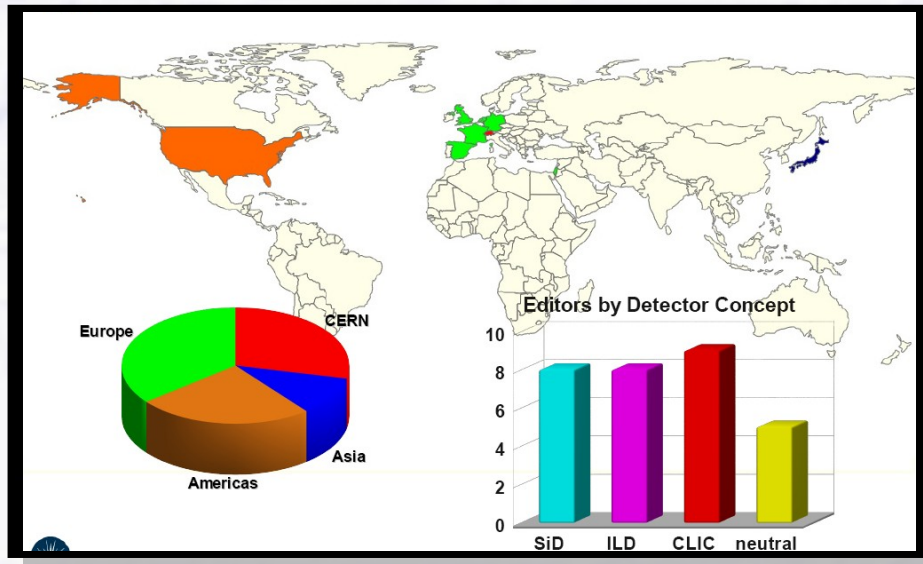
The CERN-LCD group is NOT limited to only CLIC.
However, present focus are preparations on physics and detectors for the CLIC-CDR in 2011.

- **Leading the CLIC Physics and Detector Study and CDR effort**

- ➔ contributing people ~50% CERN staff+fellows, ~50% from outside CERN

CLIC Conceptual Design Report

- **CLIC-CDR to be delivered in second half of 2011**
- **3 Volumes**
 - ➔ **Executive Summary**
 - ➔ **Accelerator and site facilities**
 - ➔ **Physics and Detectors**
 - 4 main editors, representing 3 regions + CERN
 - chapter editors representing ILD, SiD, CLIC



CDR Benchmarks

● 5 benchmarks at 3 TeV

→ to study and optimize detector performance

→ Higgs + SUSY

- $e^+e^- \rightarrow H \nu_e \nu_e$ $H \rightarrow bb, \mu\mu$ ($m_H = 120$ GeV)
- $e^+e^- \rightarrow H^+H^- \rightarrow tbtb$ $e^+e^- \rightarrow HA \rightarrow bbbb$ ($m_{H,H^+,A} = 900$ GeV)
- $e^+e^- \rightarrow \tilde{q}_R \tilde{q}_R$ $m_{\tilde{q}_R} = 1.1$ TeV
- $e^+e^- \rightarrow \tilde{l}^+ \tilde{l}^-$ $m_{\tilde{l}} = 423,696$ GeV
- $e^+e^- \rightarrow \chi^+ \chi^-, \chi^0 \chi^0$ $m_{\chi^0} = 340$ GeV

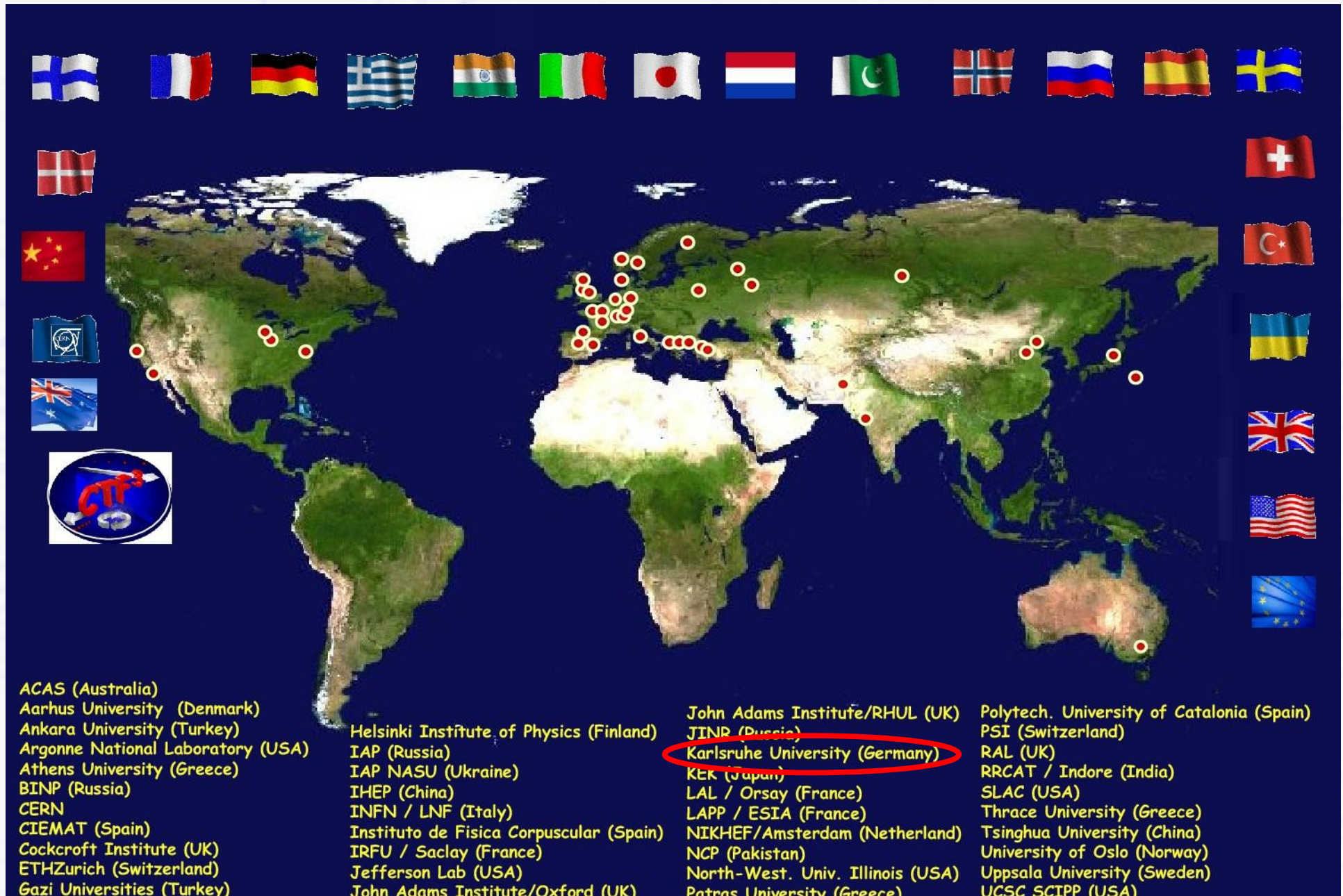
● 1 benchmark at 500 TeV

→ same as ILC for comparison

- $e^+e^- \rightarrow tt$

CLIC Collaboration

40 institutes, 21 countries



German CLIC Activities

● CTF3 Collaboration (U Karlsruhe)

- development and test of mock-ups for CLIC SC damping wigglers
- halo simulations for CLIC drive beam

● Physics and Detector Study

➡ Detector simulations including machine background studies

- U Bonn, HU Berlin (both through Gentner PhD students)

➡ W-HCAL + beam tests (in collaboration with CALICE)

- DESY Hamburg, U Heidelberg, U Wuppertal, MPI Munich

➡ Forward Calorimetry

- DESY Zeuthen

➡ Polarization

- U Hamburg, DESY Hamburg + Zeuthen

➡ 5 German financed CDR Chapter Editors

● CLIC has profited enormously from work done for ILC

➡ large synergies in BOTH directions

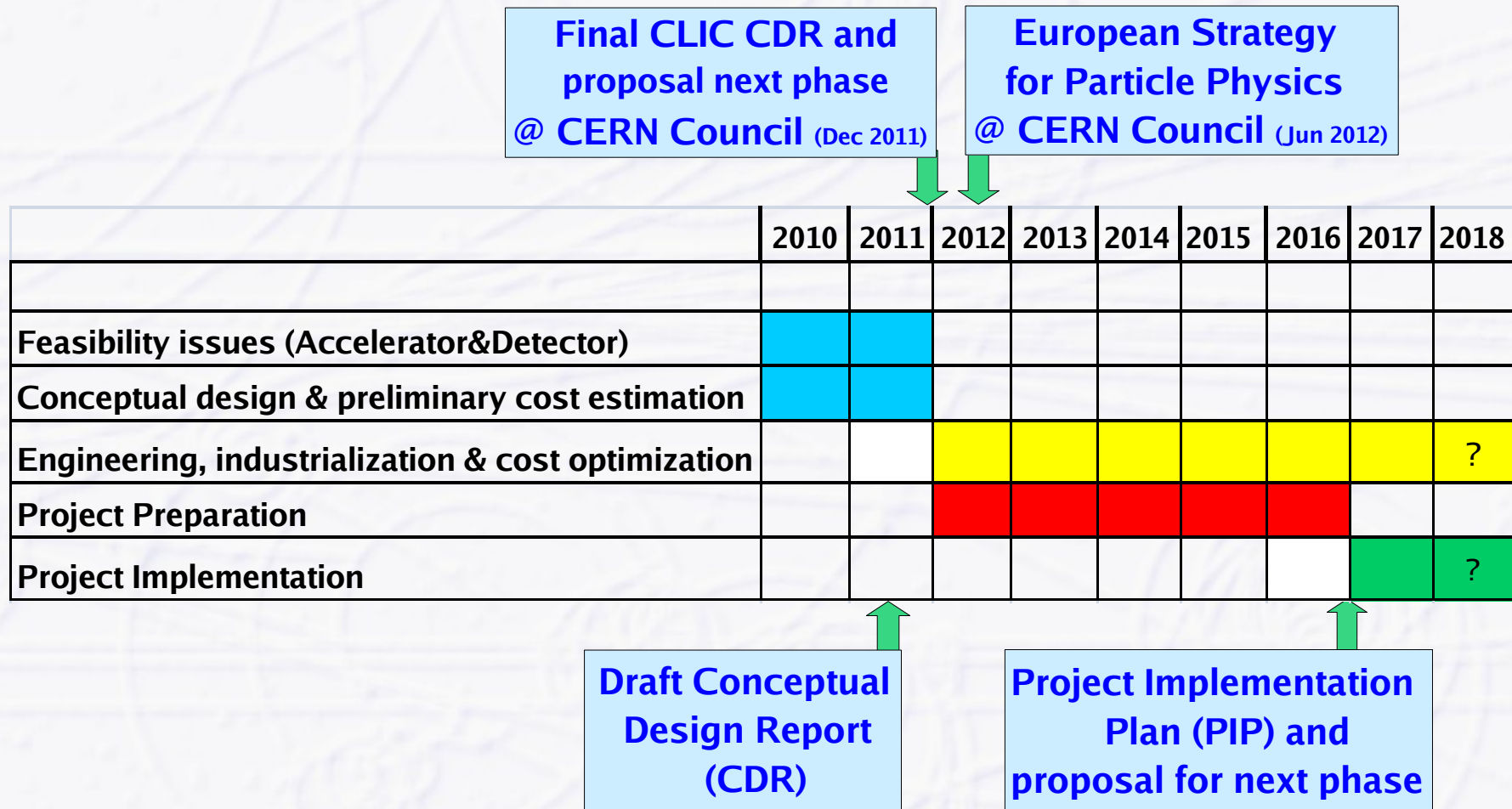
CLIC Feasibility Status

- Plan to solve missing individual feasibility issues (w.r.t. design parameters) until 2012

System	Item	Feasibility Issue	Unit	Nominal	Achieved	How	Feasibility
Two Beam Acceleration	Drive beam generation	Fully loaded accel effc	%	97	95	CTF3	✓
		Freq&Current multipl	-	2*3*4	2*4	CTF3	✓
		12 GHz beam current	A	4.5*24=100	3.5*8=28	CTF3	✓
		12 GHz pulse length	nsec	240	240	CTF3	✓
		Intensity stability	1.E-03	0.75	0.6	CTF3	✓
		Drive beam linac RF phase stability	Deg (1GHZ)	0.05	0.035	CTF3, XFEL	✓
	Beam Driven RF power generation	PETS RF Power	MW	130	130	TBTS/SLAC	✓
		PETS Pulse length	ns	170	>170	TBTS/SLAC	✓
		PETS Breakdown rate	/m	< 1·10 ⁻⁷	>1.2 10 ⁻⁶	TBTS/SLAC	✓
		PETS ON/OFF	-	@ 50Hz	-	CTF3/TBTS	2011
		Drive beam to RF efficiency	%	90%	-	CTF3/TBL	2010-11
		RF pulse shape control	%	< 0.1%	-	CTF3/TBTS	2010-11
	Accelerating Structures (CAS)	Structure Acc field	MV/m	100	100	CTF3 Test Stand, SLAC, KEK	✓
		Structure Flat Top Pulse length	ns	170	170		✓
		Structure Breakdown rate	/m MV/m.ns	< 3·10 ⁻⁷	5·10 ⁻⁵ (D)		2010-11
		Rf to beam transfer efficiency	%	27	15		2010-11
	Two Beam Acceleration	Power production and probe beam acceleration in Two beam module	MV/m - ns	100 - 170	55 - 170	TBTS	2011-12
		Drive to main beam timing stability	psec	0.05	-	CTF3	2012
		Main to main beam timing stability	psec	0.07	-	CTF3	2012
Ultra low beam emittance & sizes	Ultra low Emittances	Emittance generation H/V	nm	500/5	3000/12	ATF, NSLS/SLS	✓
		Emittance preservation: Blow-up	nm	160/15	160/15	+ simulation	2010-12
	Alignment	Main Linac components	microns	15	10 (princ.)	Alignment & Mod.Test Bench	2010
		Final-Doublet	microns	2 to 8			2010
	Vertical stabilisation	Quad Main Linac	nm>1 Hz	1.5	0.13	Stabilisation Test Bench	2010-12
		Final Doublet (assuming feedbacks)	nm>4 Hz	0.2	(principle)		

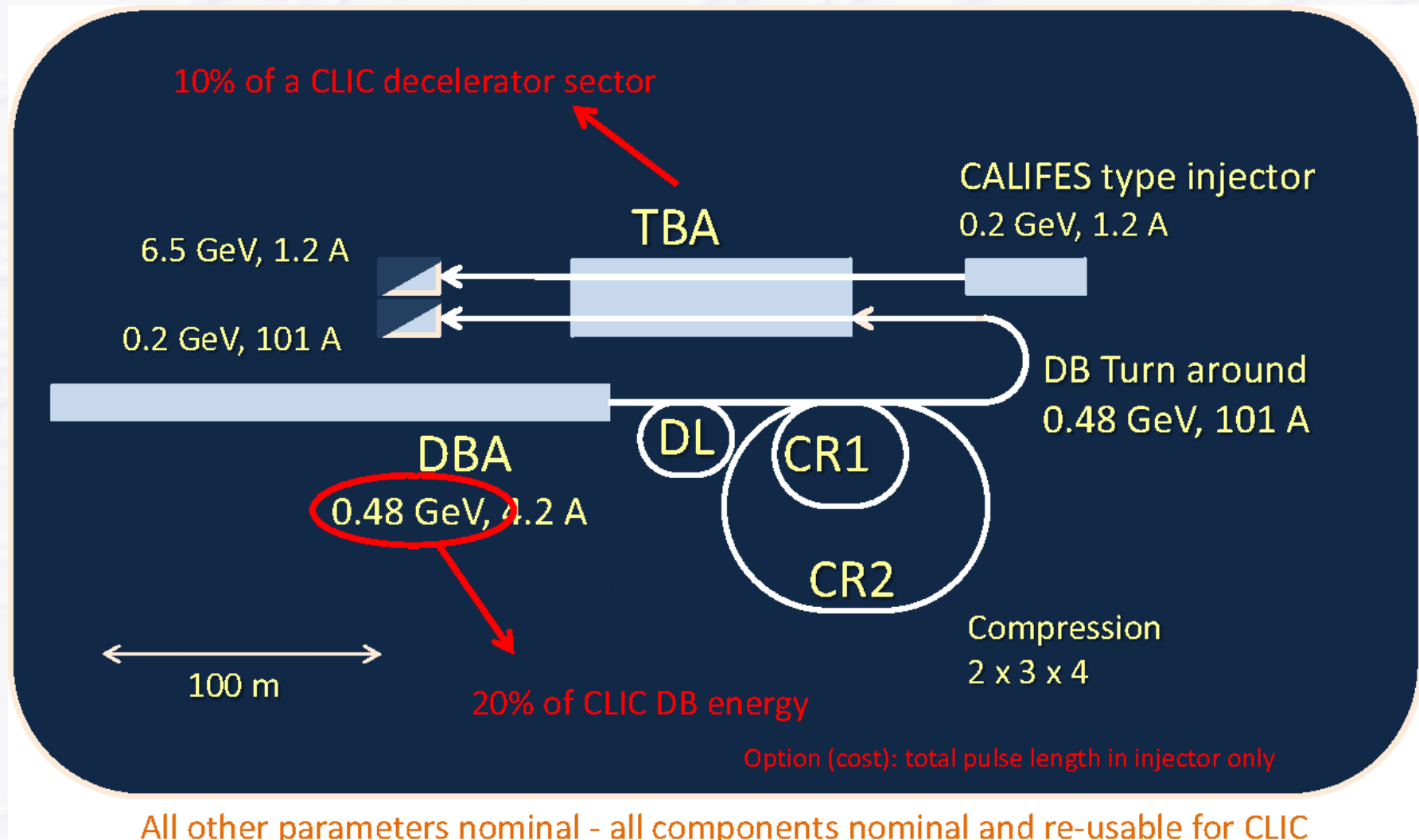
55 MV/m achieved in 2-beam acceleration

CLIC Tentative Schedule until 2016



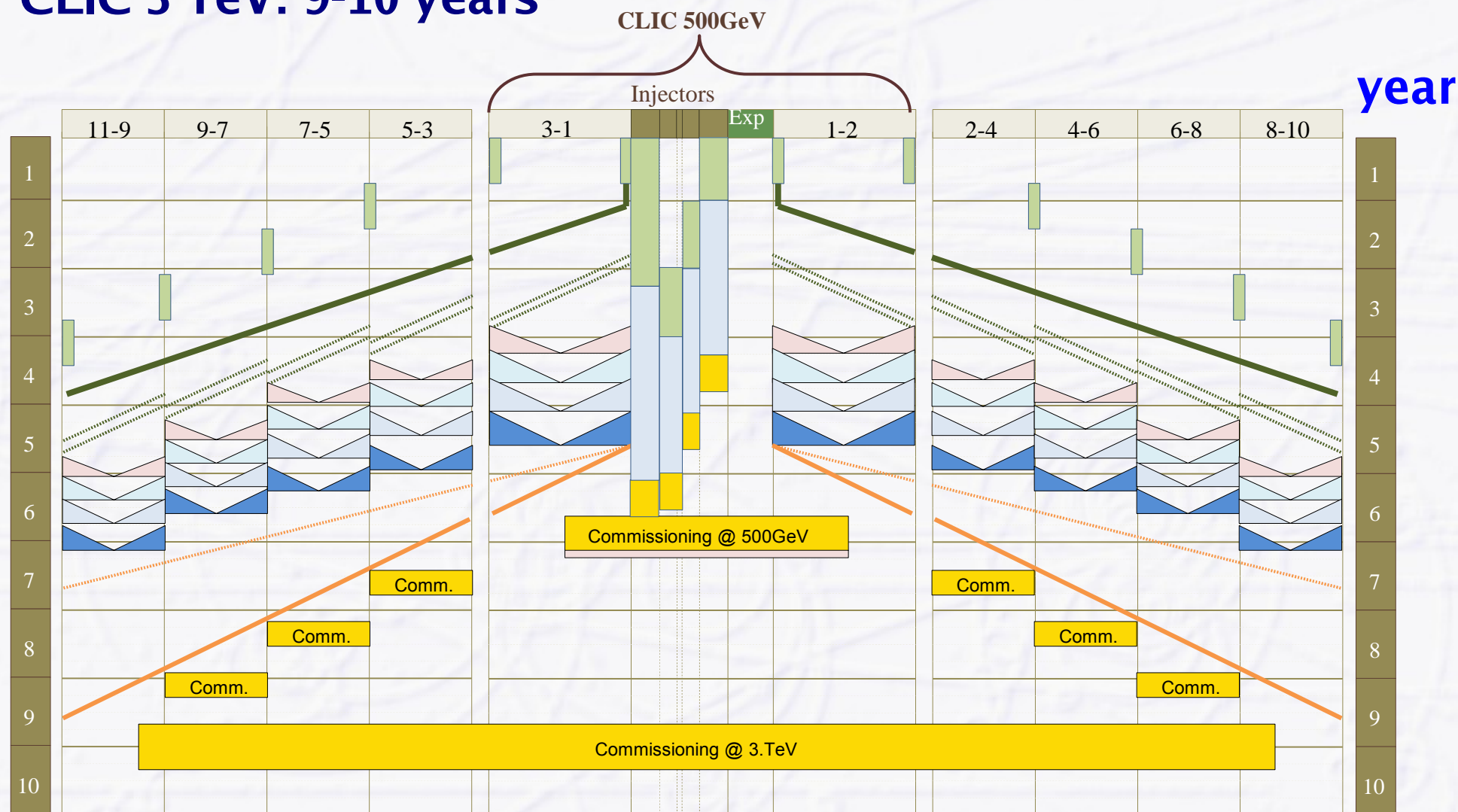
CLIC zero

- Possible injector for CLIC drive beam generation complex after 2016



General Construction Schedule

- CLIC 500 GeV (1st stage): 6-7 years
- CLIC 3 TeV: 9-10 years



CLIC Tentative Time Scale

- **CDR on accelerator, physics and detector end of 2011**
- **Solve remaining feasibility issues until 2012**
- **2011 – 2016: project preparation phase**
 - ➔ **project implementation plan in 2016**
- **After 2016: project implementation (several years)**
 - ➔ **finalization of CLIC technical design**
 - ➔ **possible construction of “CLIC zero”**
 - ➔ **produce all documents for CLIC construction start-up**
 - **will be basis for staged or full approval**
- **Time between approval and start of construction?**
- **9-10 years construction time**

First collisions at 3 TeV not before ~2030 at the earliest