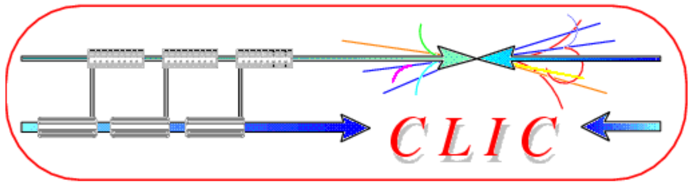
CLIC
A Multi-TeV e+e- Collider

Albert De Roeck CERN



A personal account of

- Status of the CLIC accelerator study
- Its physics potential
- CERN and Linear Colliders

Web Site http://clicphysics.web.cern.ch/CLICphysics/

CERN and Linear Colliders

- Priority of CERN: LHC (startup 2007)
  LHC financial constraints do not allow CERN to start/contribute to large new projects before 2011.
  If a TeV class LC (TESLA or NLC/JLC type) construction starts before that CERN (LAB) can not be a major contributer.

- The mandate of CERN allows it in principle to represent Europe in world wide discussions and committees on HEP/LC via CERN Council.
  Main proponents may have direct participation (Germany, UK,…)

- CERN has a LC accelerator R&D program: CLIC: Compact Linear Collider
  Aims for large accelerating gradients (150 MV/m)
  Active R&D program with several test facilities CTF1, CTF2 and now CTF3.
  CLIC/CERN budget 3.4 MCHF/Year, 30 FTE's involved

New: CERN DG will be requesting extra funding for CLIC/CTF3 such that before 2010 the full feasibility can be demonstrated (R1's and R2's)
Concerns: ~ 17 MCHF material and 15 MCHF manpower

CLIC

- An e^+e^- linear collider optimized for a c.m. energy of 3 TeV with $\mathcal{L} \cong 10^{35} cm^{-2} s^{-1}$

- Construction can be staged without major modifications, starting an experimental program at lower energies, if useful.

- Aim: 3 TeV collisions, complementing LHC/TeV class LC and breaking new ground, with a final stage up to 5 (10?)TeV

To achieve this within reasonable cost (length $\sim$ 35-40 km), and not too many active elements:

$\rightarrow$ Accelerating gradient $\boxed{\sim 150 \text{ MV/m:}}$ Two Beam Acceleration (TBA)

$\rightarrow$ High beamstrahlungs regime to reach luminosity

$\rightarrow$ Challenging beam parameters and machine requirements (nm stability, strong final focus, 30 GHz accelerating structures,...)

- Status CTF2: 150-193 MV/m (15 ns pulses)
  CTF3: Under construction: 2002-2006 (drive beam test)

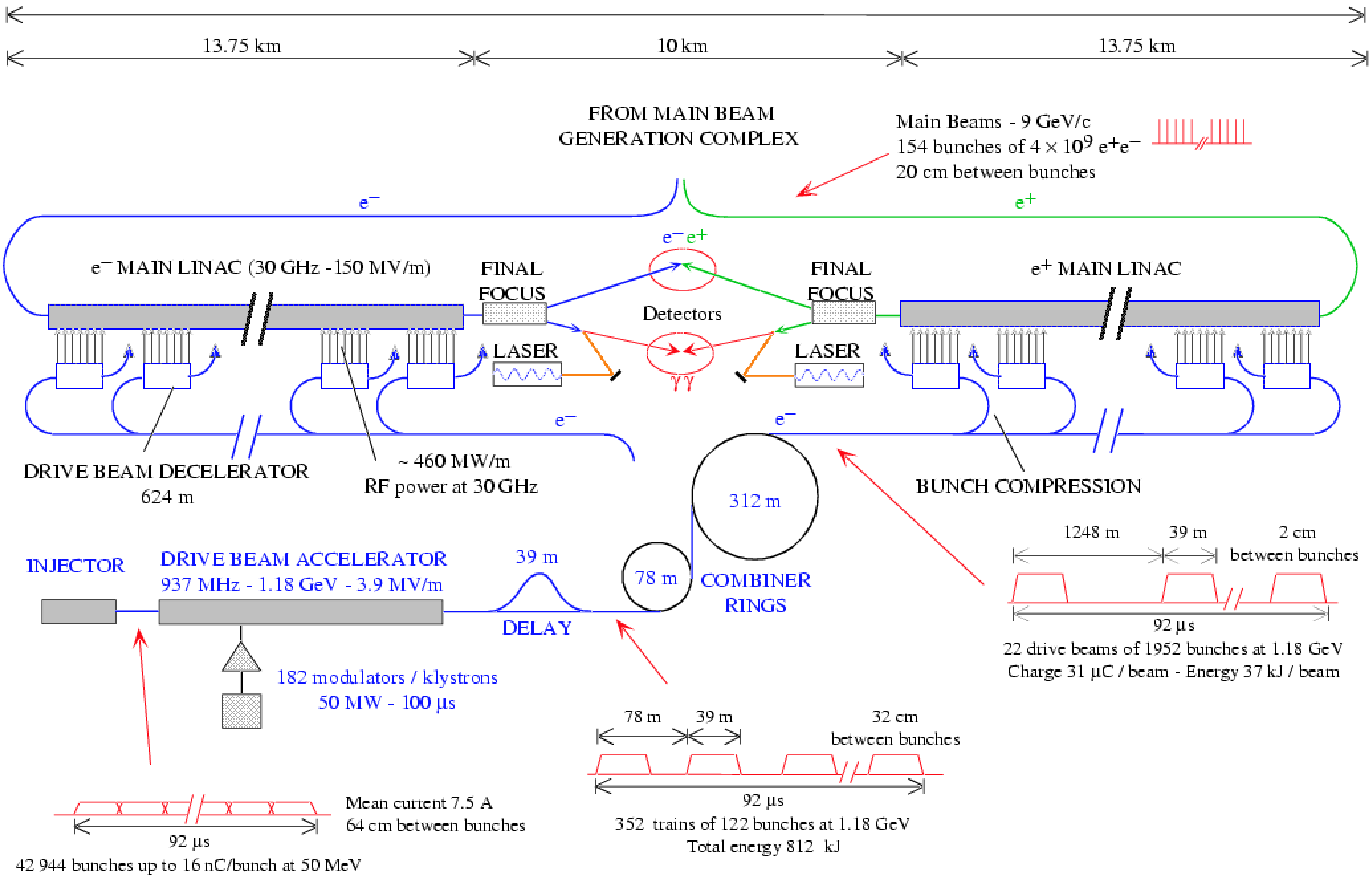
World Wide CLIC Collaboration

CLIC World Wide Collaboration: CERN +

- BERLIN Technical University (Germany) : Structure simulations GdfidL
- DESY (Germany): Ground motion studies, beam dynamics simulations
- INFN / LNF (Italy): Delay loop, transfer lines and RF deflectors for CTF3
- JINR and IAP (Russia): Surface heating tests using 30 GHz RF power source
- KEK (Japan): ATF and structure studies
- LAL (France): Electron guns and pre-buncher cavities for CTF3
- LLBL/LBL (USA): Laser-wire studies
- RAL (England): Lasers for CTF3 and CLIC photo-injectors
- SLAC (USA): HG testing, structure design, CTF3 drive beam injector design
- UPPSALA University (Sweden): Beam monitoring systems for CTF3
- North Western University (Illinois) Beam loss studies
- Finnish Industry Sponsorship of a mechanical engineer

CTF3 test facility collaboration: CERN +

- INFN, Frascati (Italy)
- LAL, Orsay (France)
- SLAC, San Francisco (USA)
- Uppsala University, Sweden
- North Western Univ, Chicago (USA)
- RAL (UK)

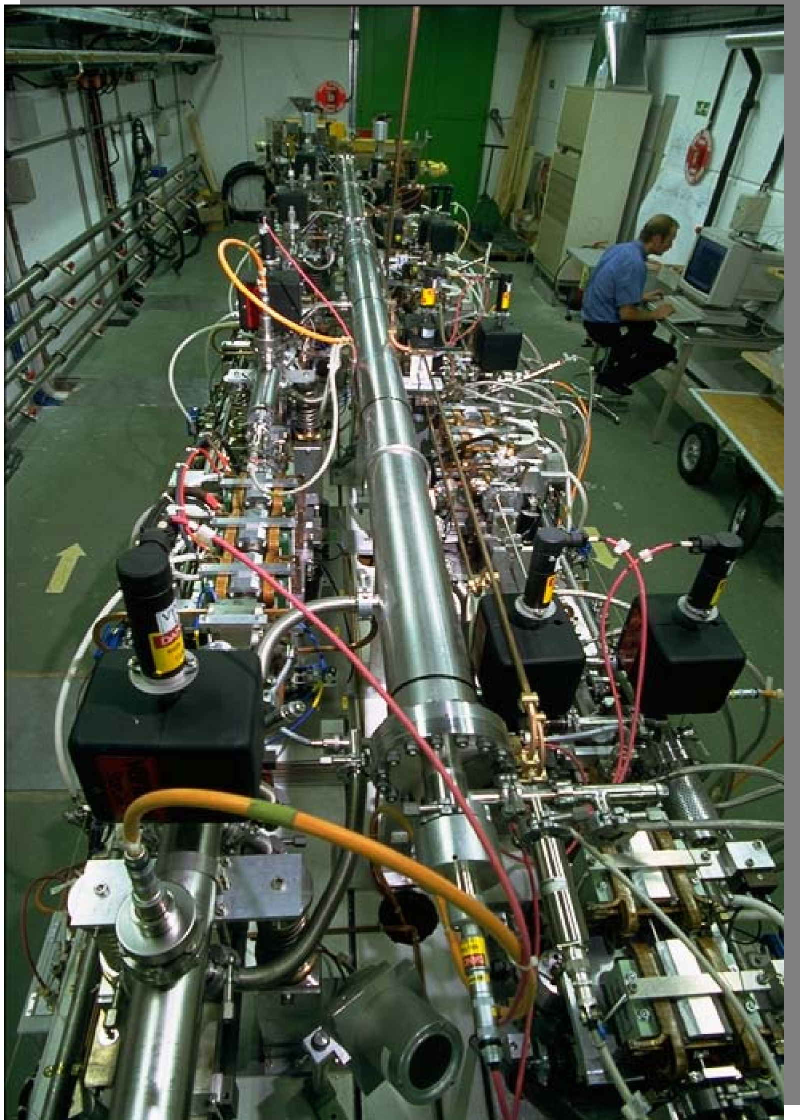

13.75 km
10 km
13.75 km
FROM MAIN BEAM
GENERATION COMPLEX
Main Beams - 9 GeV/c
154 bunches of 4 × 10^9 e+e−
20 cm between bunches
e−
e+
e− e+
e− MAIN LINAC (30 GHz - 150 MV/m)
FINAL FOCUS
FINAL FOCUS
e+ MAIN LINAC
Detectors
LASER
LASER
γγ
e−
e−
DRIVE BEAM DECELERATOR
624 m
~ 460 MW/m
RF power at 30 GHz
312 m
BUNCH COMPRESSION
1248 m
39 m
2 cm
between bunches
INJECTOR
DRIVE BEAM ACCELERATOR
937 MHz - 1.18 GeV - 3.9 MV/m
39 m
78 m
COMBINER
RINGS
DELAY
92 μs
22 drive beams of 1952 bunches at 1.18 GeV
Charge 31 μC / beam - Energy 37 kJ / beam
182 modulators / klystrons
50 MW - 100 μs
78 m
39 m
32 cm
between bunches
92 μs
352 trains of 122 bunches at 1.18 GeV
Total energy 812 kJ
Mean current 7.5 A
64 cm between bunches
92 μs
42 944 bunches up to 16 nC/bunch at 50 MeV

The CLIC Test Facitilty II

RF photo-injector
3 GHz linac
Three 35 MW klystrons

Achieved performances:
25 A
50 MV 1.25 GW
16 ns 2 J
200 MW, 30 GHz RF
Two-beam demonstration
RF breakdown studies:
⇒110-193 MV/m (peak)

Switched off at the end of 2002



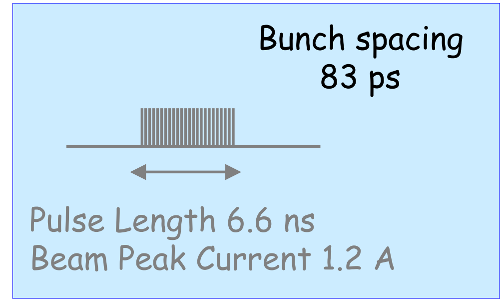
CTF3

Construction CTF3 started in 2002
First tests started October 2003

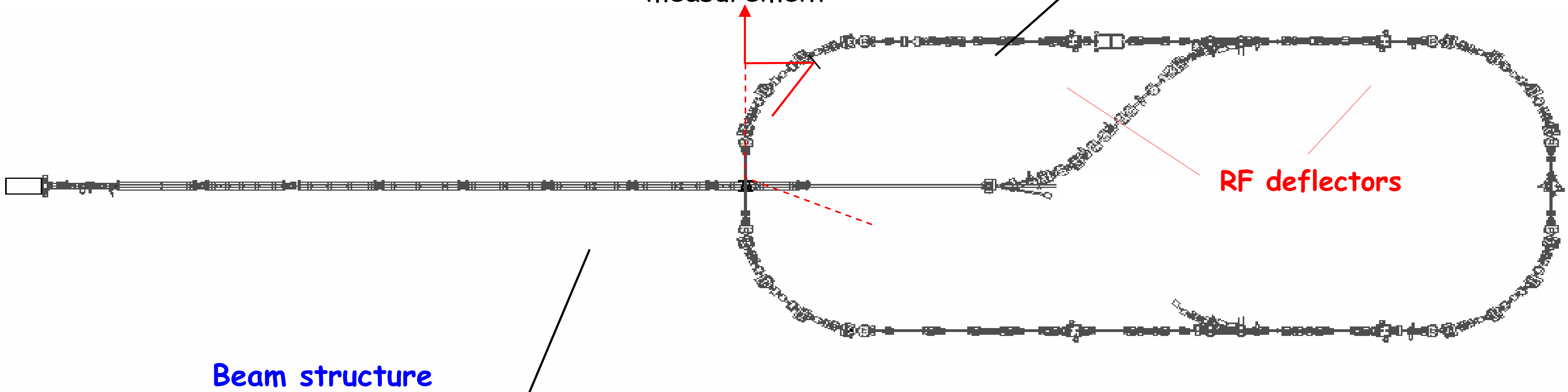
PRELIMINARY PHASE

low-charge demonstration of the electron pulse compression and frequency multiplication

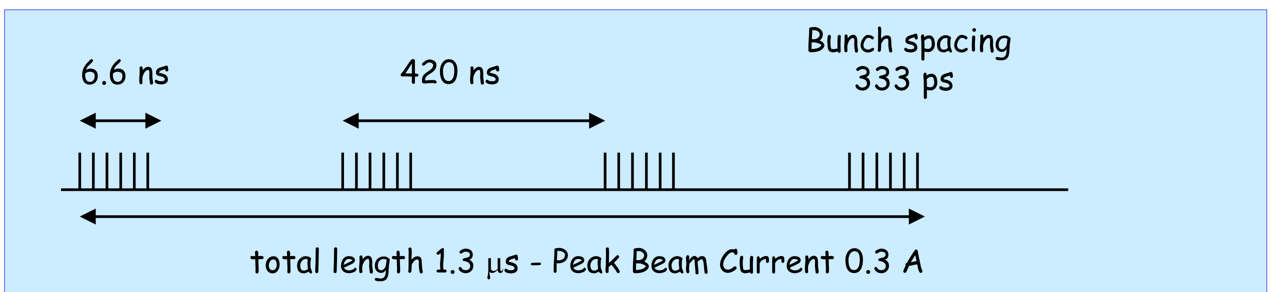
Beam structure after combination (factor 4)



streak camera measurement



Beam structure in linac – 4 pulses



Bunch charge	0.1 nC
Beam energy	350 MeV
$\gamma\varepsilon_{x,y}$	25 π mm mrad
σ_t	< 7 ps
σ_E	~ 0.5 %

CLIC LIST OF CRUCIAL CLIC-TECHNOLOGY-RELATED FEASIBILITY ITEMS

1. Test of damped accelerating structure at design gradient and pulse length (TRC R1)

2. Validation of drive beam generation scheme (TRC R1)

3. Design and test of damped ON/OFF power extraction structure (TRC R1)

4. Validation of stability and losses of drive beam decelerator, and design of machine protection system (TRC R2)

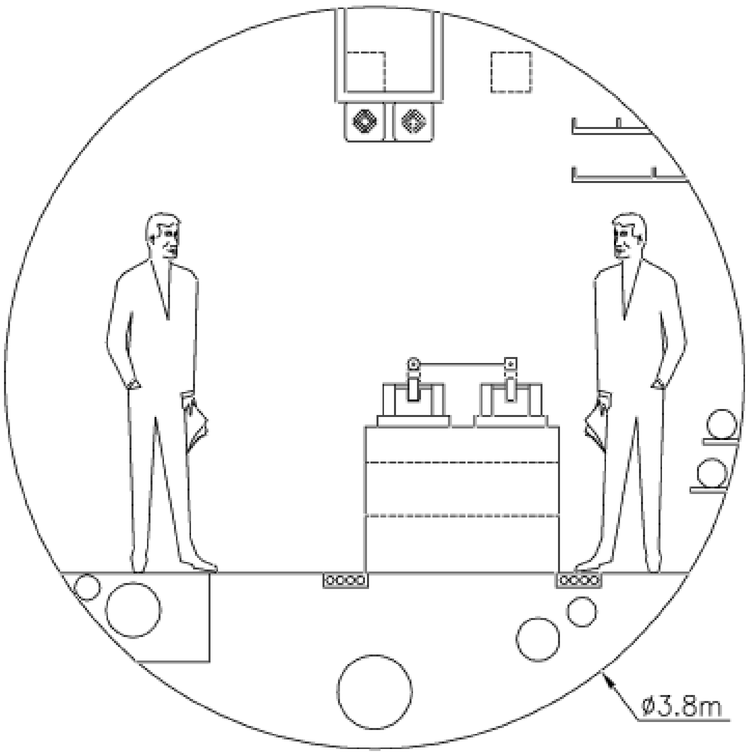
5. Test of relevant linac sub-unit with beam (TRC R2)

+ R2 which are in common with other technologies

These will be addressed with CTF3

.

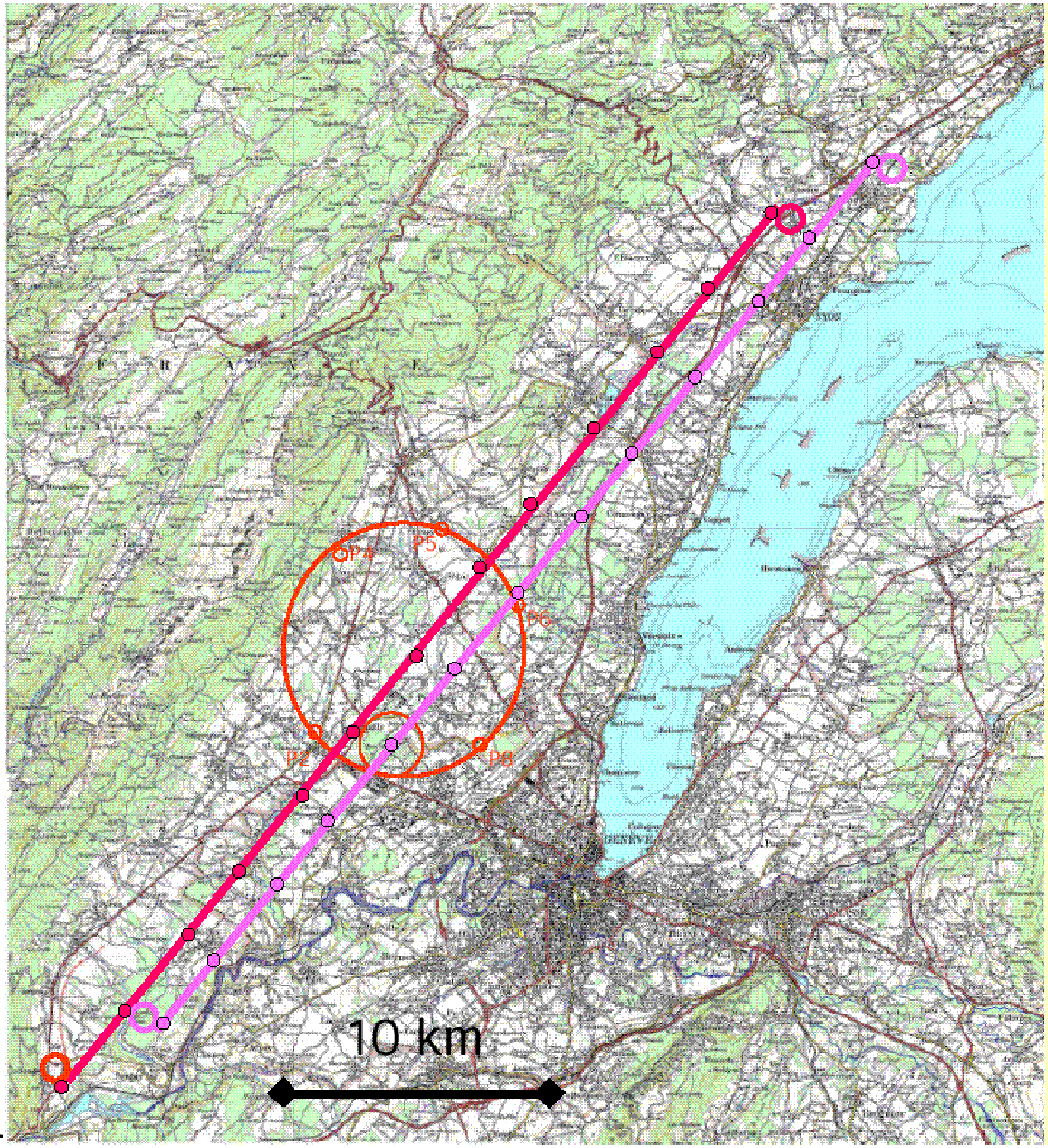
CLIC Tunnel & Parameters



E_{cm}	[TeV]	0.5	3	3
$\mathcal{L}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	2.1	10.0	8.0
$\mathcal{L}_{0.99}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	1.5	3.0	3.1
f_r	[Hz]	200	100	100
N_b		154	154	154
Δ_b	[ns]	0.67	0.67	0.67
N	$[10^{10}]$	0.4	0.4	0.4
σ_z	[μm]	35	30	35
ϵ_x	[μm]	2	0.68	0.68
ϵ_y	[μm]	0.01	0.02	0.01
σ_x^*	[nm]	202	43	≈ 60
σ_y^*	[nm]	≈ 1.2	1	≈ 0.7
δ	[%]	4.4	31	21
n_γ		0.7	2.3	1.5
$N_\perp$		7.2	60	43
N_{Hadr}		0.07	4.05	2.3
N_{MJ}		0.003	4.05	1.5

CLIC tunnel… not much material

Building CLIC at CERN?



It is possible!

Geological analyses show that there is a contineous stretch of 40 km parallel to the Jura and the lake, with good geological conditions.

Of course no budget till at least 2011

Physics Menu at CLIC

- Higgs sector: light and heavy Higgses, Higgs potential
- Supersymmetry: if exists, will be discovered at a hadron collider

  Role of CLIC: completing the particle spectra with precision measurements (masses < $\sqrt{s}/2$)
- Particle Factory: if new particles have been detected/predicted at the LHC/LC-500 in the range of 1-5 TeV (New Gauge bosons, Kaluza-Klein resonances, resonances in WW scattering…): CLIC will produce them directly, provide an accurate determination of their couplings and establish their Nature. Also exotic decays (such as $Z' \rightarrow$ heavy Majorana Neutrinos) can be detected.
- If NO new particles are observed directly, probe scales up to the O(100-800) TeV indirectly via precision measurements
- QCD measurements: BFKL, photon structure, α_s,…
- The unexpected???

e+e- at $\sqrt{s} \approx$ 3-5 TeV: Expect to break new grounds

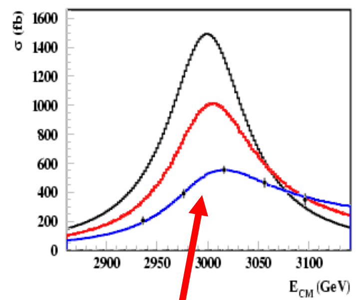
Examples/overview of Physics Reach

Measurements at CLIC (5 TeV / 1 ab^{-1})

Higgs (Light)	λ_{HHH} to $\sim 5-10\%$ (5 ab^{-1})
Higgs (Light)	$g_{H\mu\mu}$ to $\sim 3.5-10\%$ (5 ab^{-1})
Higgs (Heavy)	2.0 TeV (e^+e^-) 3.5 TeV ($\gamma\gamma$)
squarks	2.5 TeV
sleptons	2.5 TeV
Z' (direct)	5 TeV
Z' (indirect)	30 TeV
l^*, q^*	5 TeV
TGC (95%)	0.00008
Λ compos.	400 TeV
$W_L W_L$	>5 TeV
ED (ADD)	30 TeV (e^+e^-)
	55 TeV ($\gamma\gamma$)
ED (RS)	18 TeV (c=0.2)
ED (TeV^{-1})	80 TeV
Resonances	$\delta M/M, \delta\Gamma/\Gamma \sim 10^{-3}$
Black Holes	5 TeV

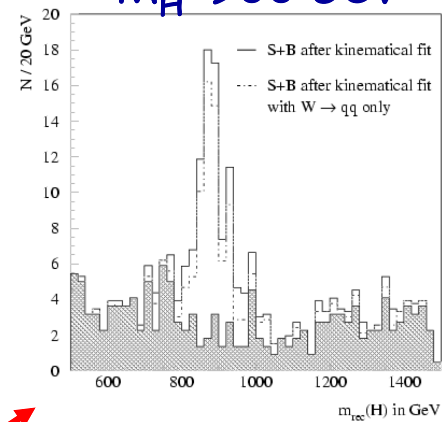
CLIC physics study
CERN Yellow Report to appear

Assume $M_{Z'} = 3.0$ TeV and
$\Gamma(Z')/M_{Z'} \simeq \Gamma(Z^0)/M_{Z^0}$



$\Rightarrow$ FIT ACCURACY (1AB^{-1})
$\delta M'_Z/M'_Z \sim 10^{-4}$ $\delta\Gamma'_Z/\Gamma'_Z \sim 3\cdot 10^{-3}$

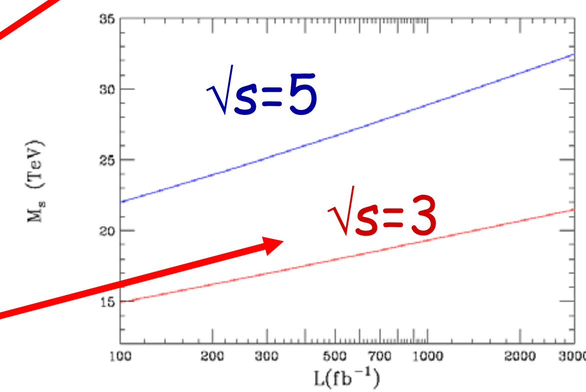
M_H=900 GeV



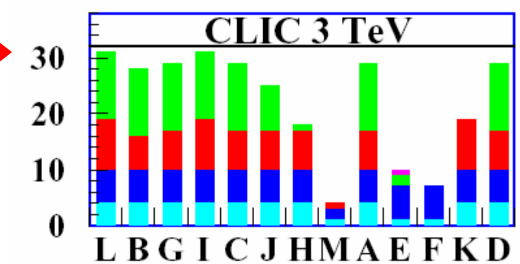
New Z' resonance

Heavy Higgs

ADD Extra Dimensions



Supersymmetric particles:
# of higgses, sleptons
gauginos, squarks
detected for benchmark
scenarios (hep-ph/0306219)



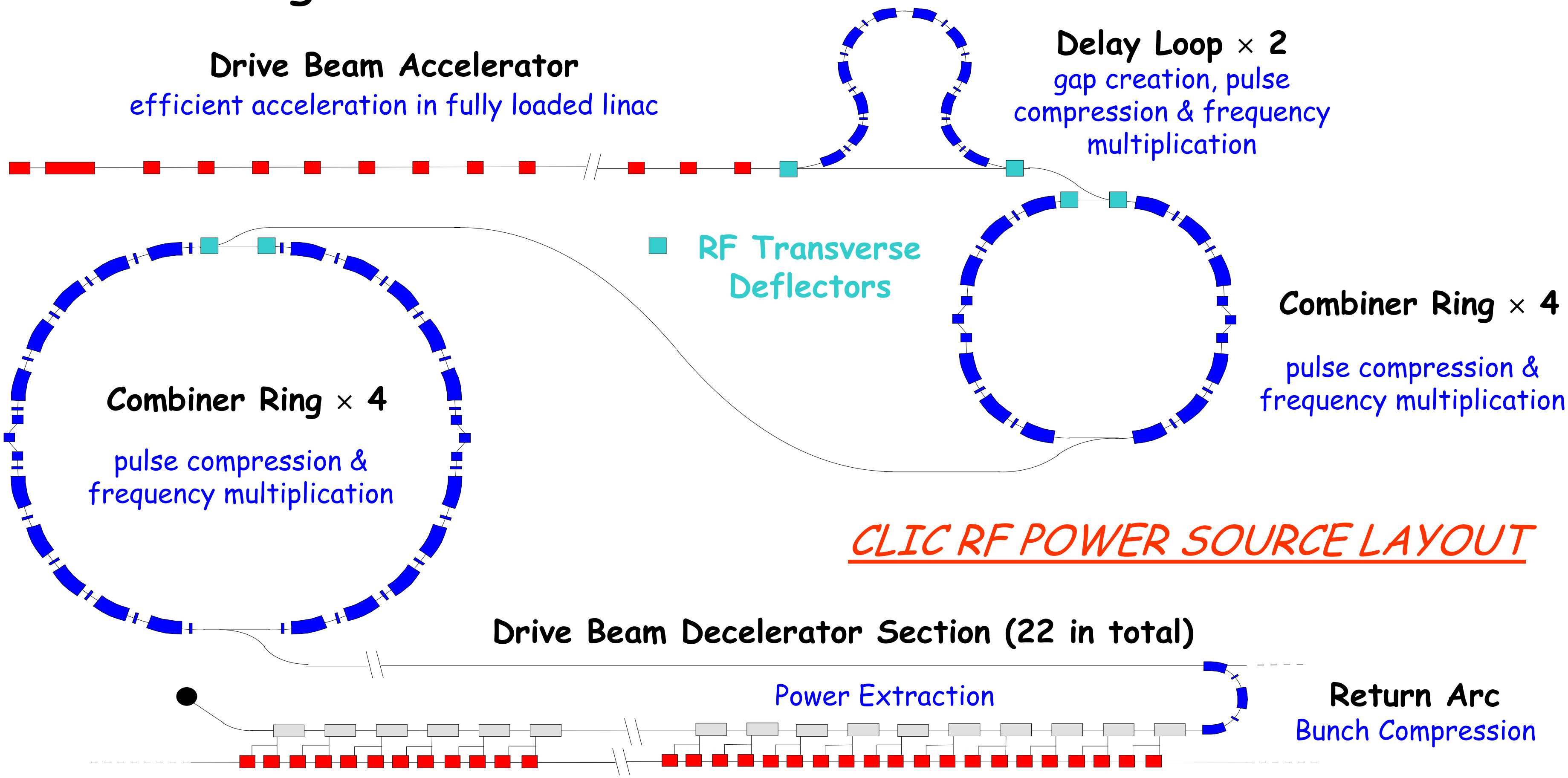
Questions by the Organizers

- Young people sufficiently interested?
  - Yes, even if we talk about 2015-2020
- Importance of the location
  - Generally: Infrastructure→ opt for existing lab/site
  - Location important mostly for instalation phase.
  - LHC/CMS experience:
    - meetings basically all via VRVS (time zone problems…)
    - There will be regional analysis centers (e.g. at FNAL)
    - There may be virtual control rooms (e.g at FNAL). Some components such as the HLT farm can be controlled from anywhere.
  - Future detector designs will be even more adapted to this option
- Accelerators: GAN?

Studies with new materials for the iris (15 ns tests)

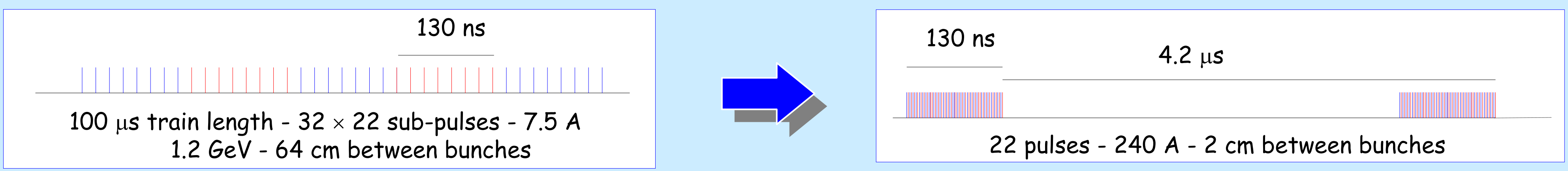
Structure	Peak accelerating	Average accelerating	Peak surface
Copper	110 MV/m	100 MV/m	260 MV/m
Tungsten	150 MV/m	125 MV/m	340 MV/m
Molybdenum	193 MV/m	153 MV/m	426 MV/m

Drive beam generation

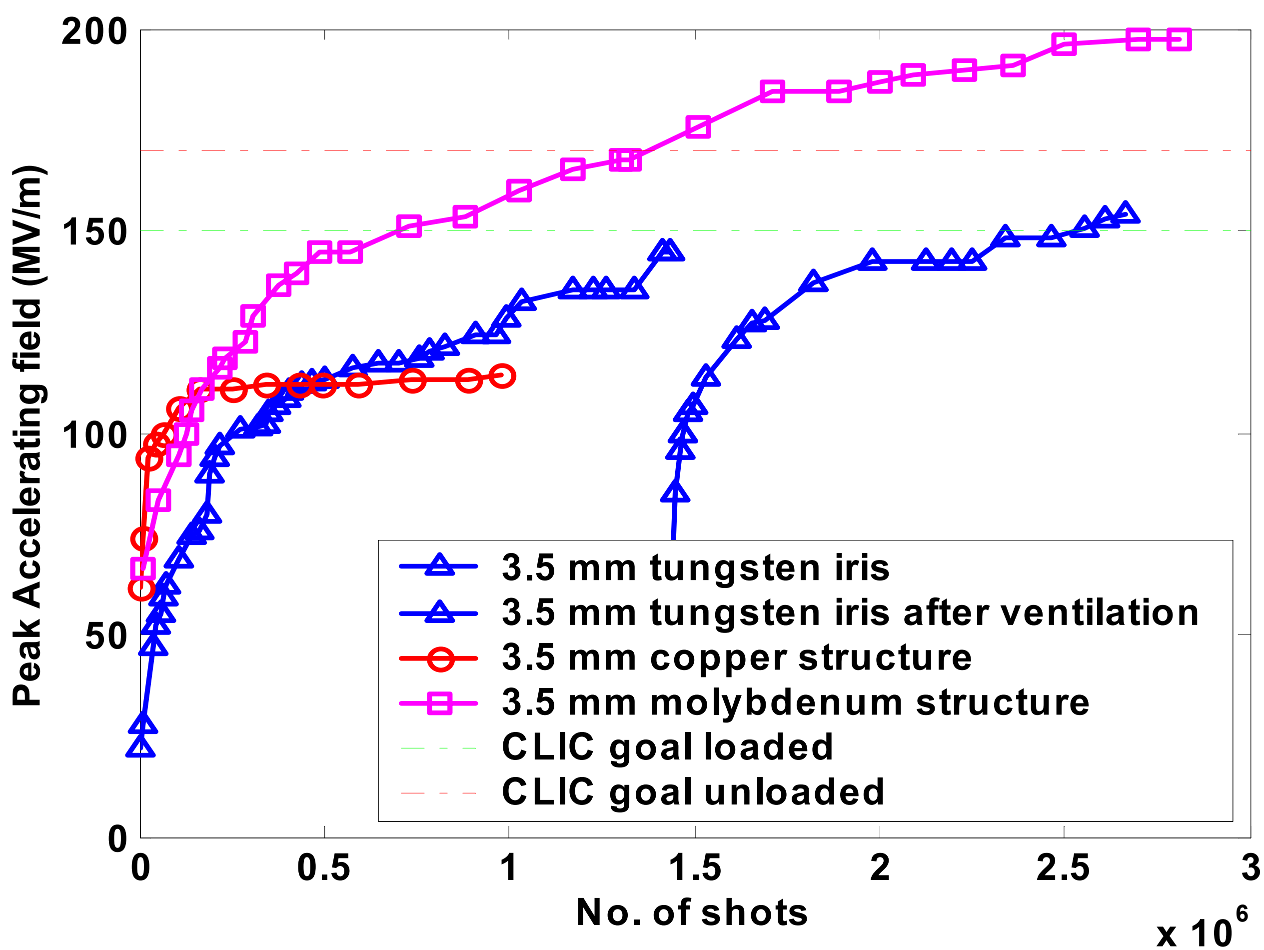


Drive beam time structure - initial

Drive beam time structure - final



Accelerating Gradient tests (CTF2)



Several weeks of running the structures: looks ok!!

Indicative Physics Reach

Ellis, Gianotti, ADR
hep-ex/0112004+ updates

Units are TeV (except $W_L W_L$ reach)
☜Ldt correspond to <u>1 year of running</u> at nominal luminosity for <u>1 experiment</u>

PROCESS	LHC 14 TeV 100 fb^{-1}	SLHC 14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	VLHC 40 TeV 100 fb^{-1}	VLHC 200 TeV 100 fb^{-1}	LC 0.8 TeV 500 fb^{-1}	LC 5 TeV 1000 fb^{-1}
Squarks	2.5	3	4	5	20	0.4	2.5
$W_L W_L$	2σ	4σ	4.5σ	7σ	18σ		90σ
Z'	5	6	8	11	35	8†	30†
Extra-dim (δ=2)	9	12	15	25	65	5-8.5†	30-55†
q*	6.5	7.5	9.5	13	75	0.8	5
Λcompositeness	30	40	40	50	100	100	400
TGC (λ_γ)	0.0014	0.0006	0.0008		0.0003	0.0004	0.00008

† indirect reach
(from precision measurements)

Approximate mass reach machines:
$\sqrt{s}$ = 14 TeV, L=10^{34} (LHC) : up to ≈ 6.5 TeV
$\sqrt{s}$ = 14 TeV, L=10^{35} (SLHC) : up to ≈ 8 TeV
$\sqrt{s}$ = 28 TeV, L=10^{34} : up to ≈ 10 TeV