CLIC/CTF3
status, results and plans

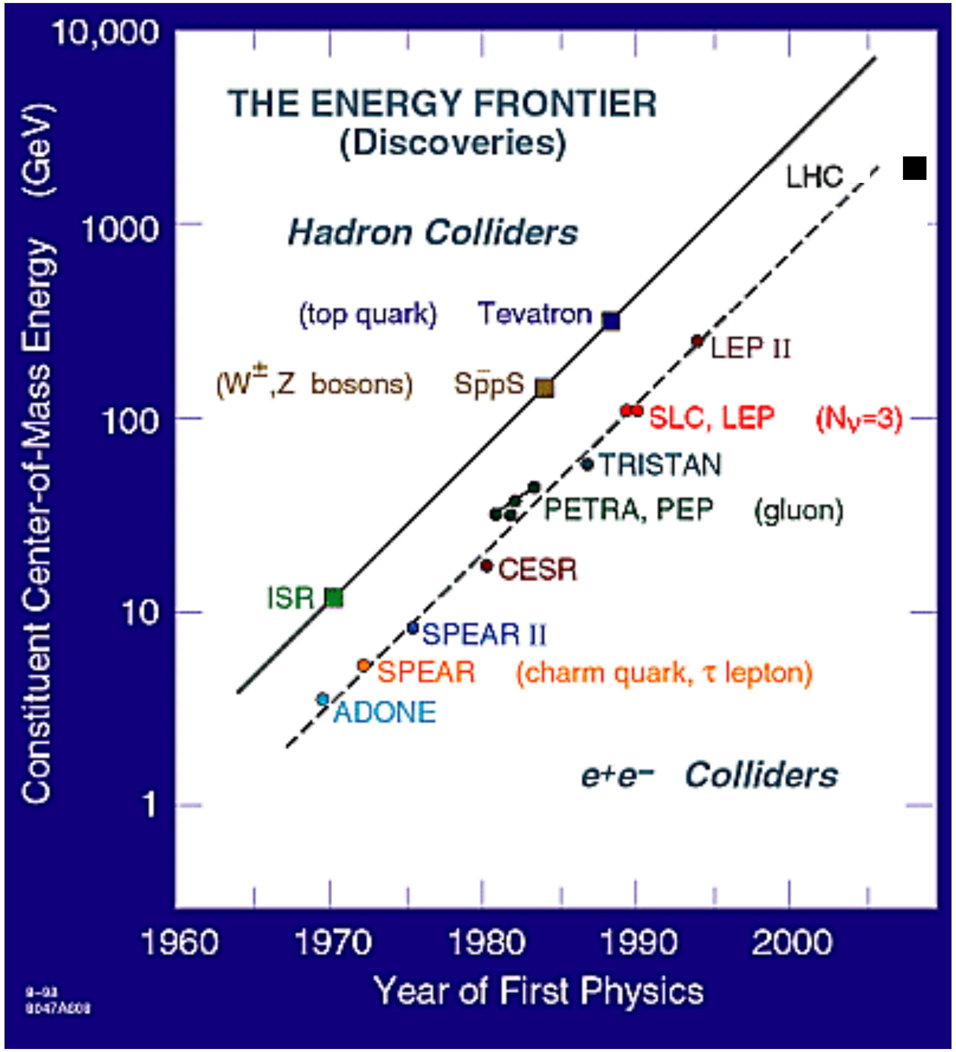
Frank Tecker

for the CLIC study team

- Introduction
- Status of feasibility demonstration
- Conclusion

http://cern.ch/CLIC-study

Path to higher energy



- Collider History:
  - Energy constantly increasing with time
  - Hadron Collider at the energy frontier
  - Lepton Collider for precision physics
- LHC online now
- e-/e+ storage ring excluded by synchrotron radiation
- Consensus to build Lin. Collider with E_{cm} > 500 GeV to complement LHC physics (*European strategy for particle physics* by CERN Council)

TeV e+e- physics

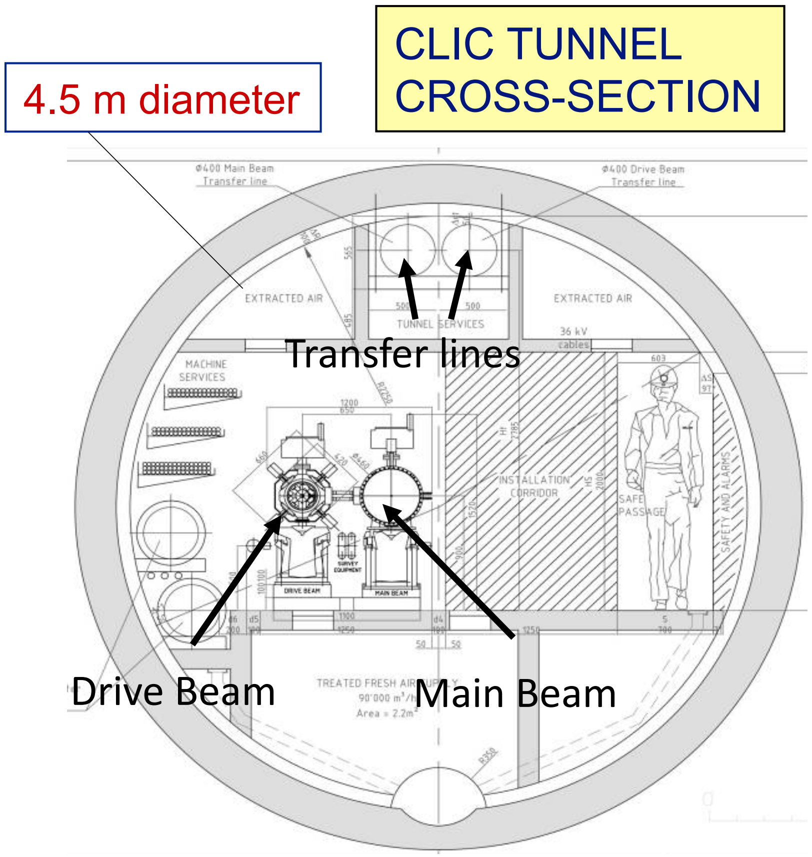
- Higgs physics
  - Tevatron/LHC should discover Higgs (or something else)
  - LC explore its properties in detail
- Supersymmetry
  - LC will complement the LHC particle spectrum
- Extra spatial dimensions
- New strong interactions
- . . .

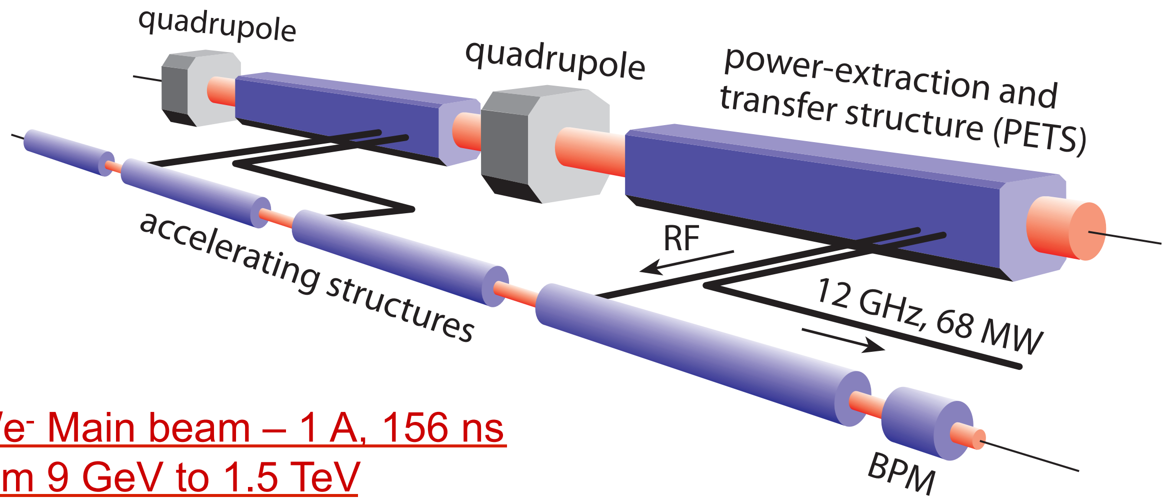
  => a lot of new territory to discover beyond the standard model

- "Physics at the CLIC Multi-TeV Linear Collider" CERN-2004-005
- "ILC Reference Design Report – Vol.2 – Physics at the ILC" www.linearcollider.org/rdr

CLIC – basic features

- e-/e+ collider up to 3 TeV collision energy
  Luminosity > few 10^{34} $cm^{-2}s^{-1}$
- High acceleration gradient (100 MV/m)
  - "Compact" collider – total length < 50 km
  - Normal conducting acceleration structures
  - High acceleration frequency (12 GHz)
- Two-Beam Acceleration Scheme
  - High charge e^- Drive Beam (low energy)
  - Low charge Main Beam (high collision energy)
  - => Simple tunnel, no active elements
  - => Modular, easy energy upgrade in stages





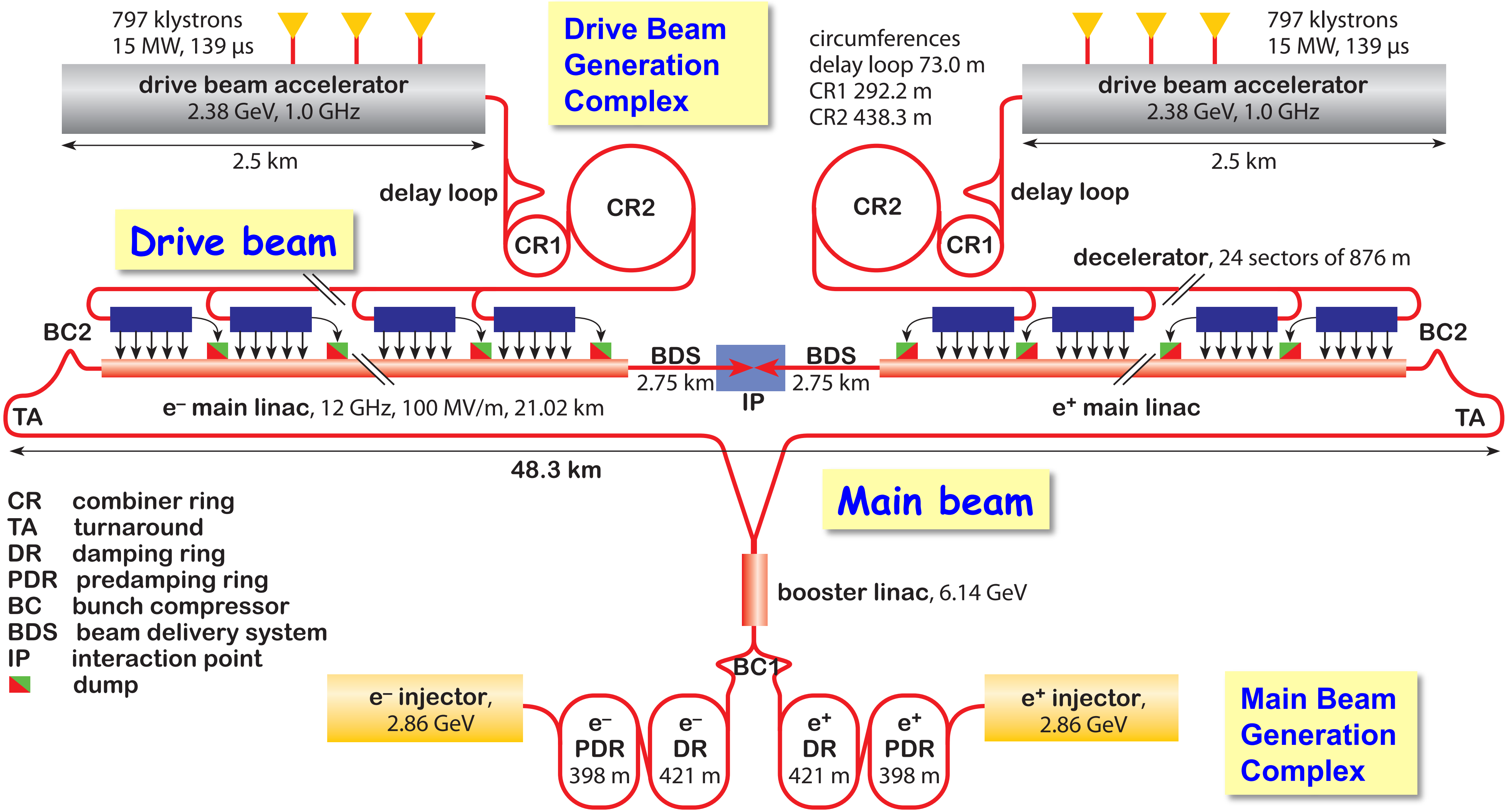
e^- Drive beam – 101 A, 240 ns
from 2.4 GeV to 240 MeV

e^+/e^- Main beam – 1 A, 156 ns
from 9 GeV to 1.5 TeV

Linear Collider main parameters

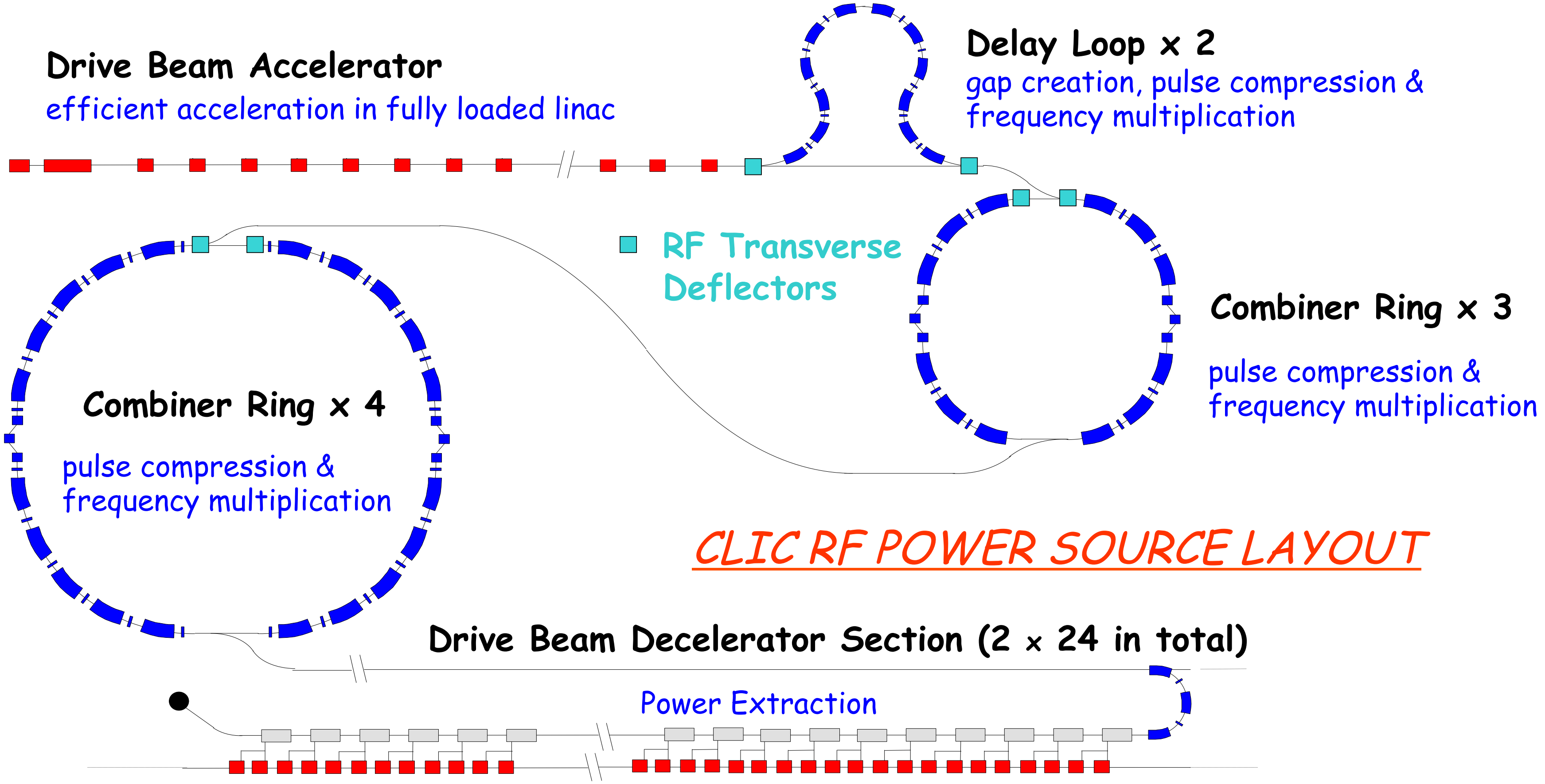
Technology	ILC	CLIC	
Centre-of-mass energy (GeV)	500	500	3000
Total (Peak 1%) luminosity (10^{34})	2.0(1.5)	2.3(1.4)	5.9(2.0)
Total site length (km)	31	13.0	48.3
Loaded accel. gradient (MV/m)	31.5	80	100
Main linac RF frequency (GHz)	1.3 (Super Cond.)	12 (Normal Conducting)	
Beam power/beam (MW)	20	4.9	14
Bunch charge (10^9 e+/-)	20	6.8	3.72
Bunch separation (ns)	176	0.5	
Beam pulse duration (ns)	1000	177	156
Repetition rate (Hz)	5	50	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)	10/40	4.8/25	0.66/20
Hor./vert. IP beam size (nm)	640/5.7	202 / 2.3	40 / 1
Hadronic events/crossing at IP	0.12	0.19	2.7
Coherent pairs at IP	10	100	$3.8\ 10^8$
Wall plug to beam transfer eff	9.4%	7.5%	6.8%
Total power consumption (MW)	216	129.4	415

CLIC – overall layout 3 TeV

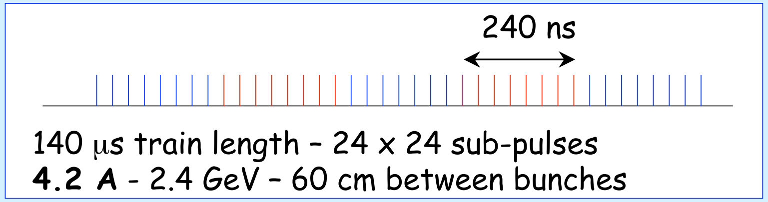


CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump

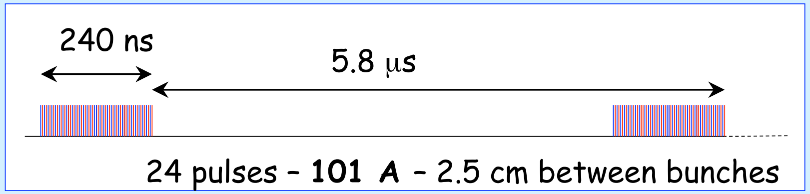
CLIC Drive Beam generation



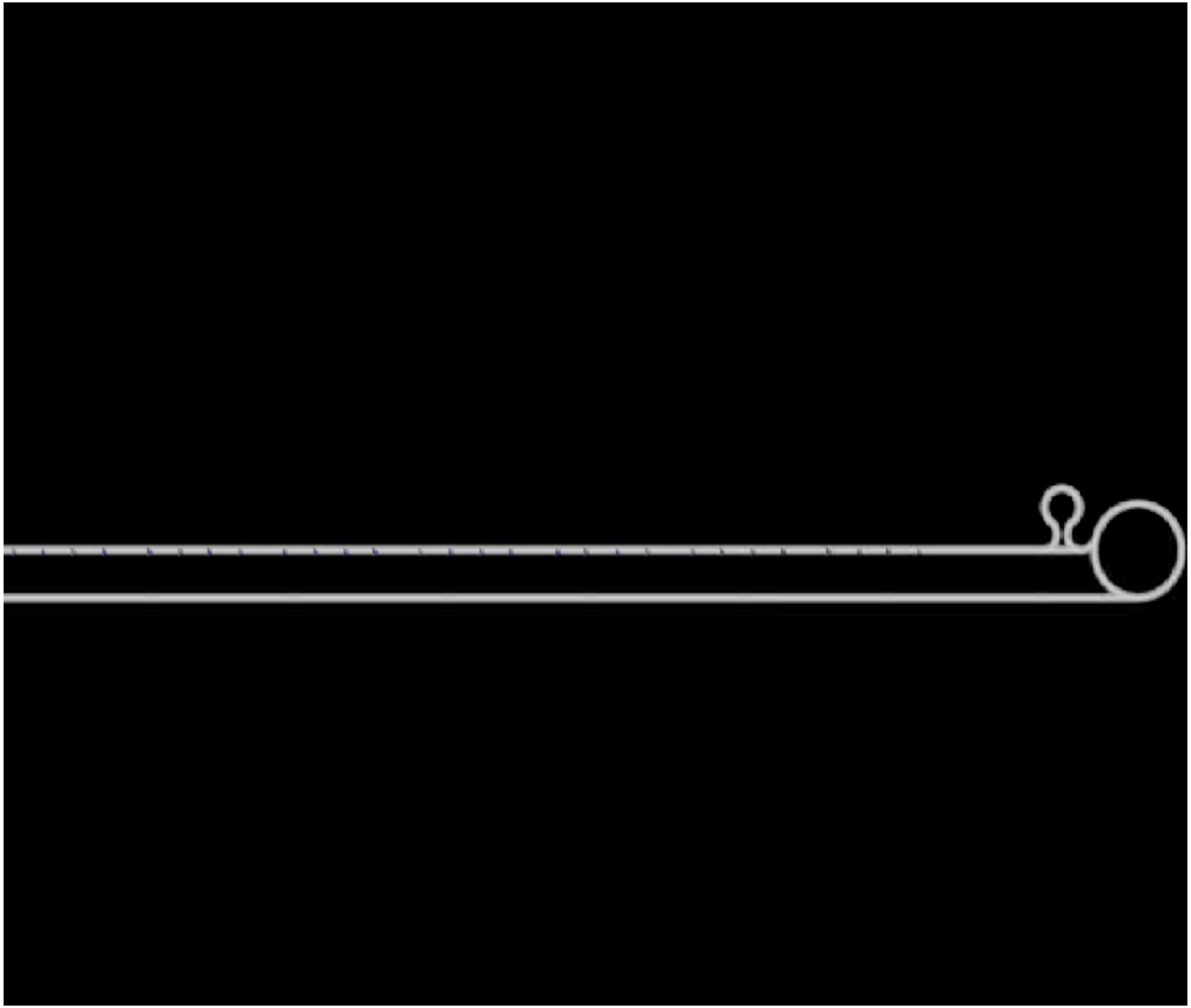
Drive beam time structure - initial



Drive beam time structure - final



Lemmings Drive Beam



Alexandra Andersson

World-wide CLIC&CTF3 Collaboration

39 Institutes from 20 countries

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

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

John Adams Institute/RHUL (UK)
JINR (Russia)
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NCP (Pakistan)
Nikhef (Netherlands)
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)
Tsinghua University (China)
University of Oslo (Norway)
Uppsala University (Sweden)
UCSC SCIPP (USA)

ILC – CLIC collaboration

- Extremely fruitful collaboration between CLIC and ILC
- Taking advantage of common issues and great synergies

- Common **International Workshop on Linear Colliders** IWLC2010
  for accelerator and detectors
  18-22/10/2010 @ CERN
  http://cern.ch/LC2010

- Towards single Linear Collider community and….

- Possibly future joined project based on Physics requests (LHC results) and technology choice as best trade off between performance, maturity, risk, cost, etc….

CLIC Plan – CDR => TDR

- Identified critical issues divided into three categories (endorsed by ACE)
  - Feasibility issue: Failure to solve implies that CLIC technology is fundamentally not suited to build a machine of interest for high energy physics
  - Performance issue: can compromise the performance
  - Cost issue: has significant impact on cost
- CDR concentrating on addressing feasibility issues (mid 2011 to CERN council)
  - Targeted conclusion: worth to make a technical design of such a machine
  - A baseline is being developed, involving many new experts
  - Will have turned the feasibility issues mostly into performance issues
    - Programme is in place and needs some continuation afterwards
  - A number of important performance and cost issues addressed
- Technical design (TDR) phase with more details (2016/2020?)
  - Targeted conclusion: One can propose this very design as a project
  - Addressing the performance issues
  - Reducing cost
  - Work plan for the TDR phase is being finalised

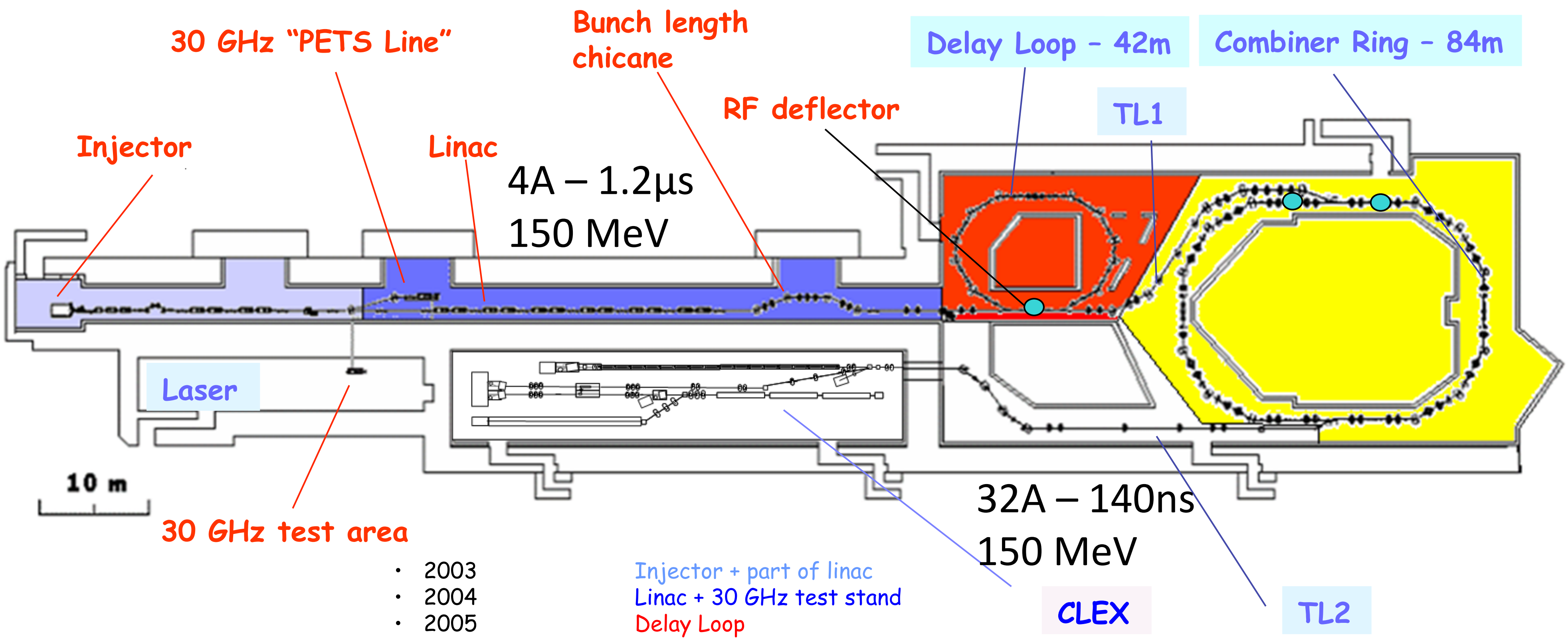
D. Schulte

10 CLIC Feasibility Issues

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

CLIC Test Facility - CTF 3

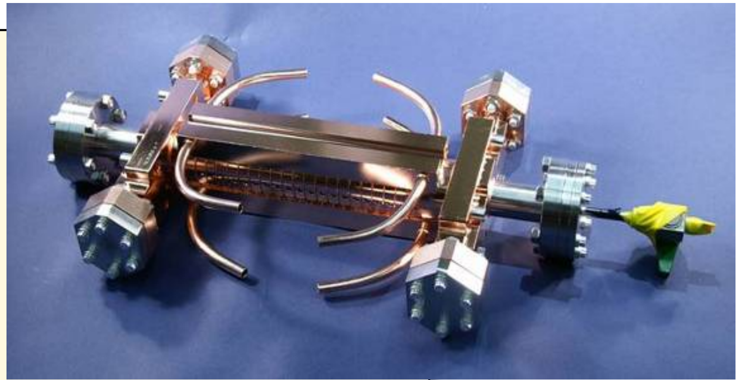
- demonstrate Drive Beam generation
  (fully loaded acceleration, bunch frequency multiplication 8x)
- Test CLIC accelerating structures
- Test power production structures (PETS)

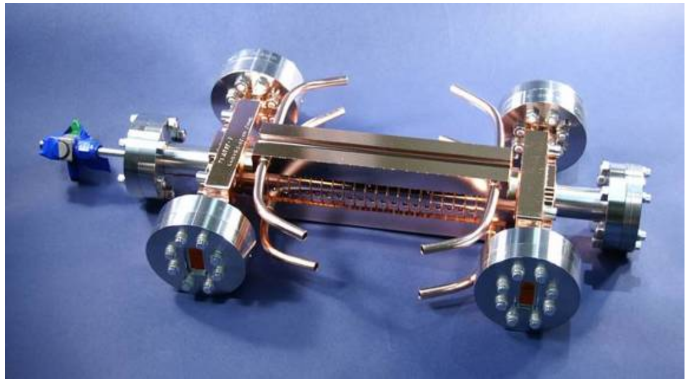


- 2003 Injector + part of linac
- 2004 Linac + 30 GHz test stand
- 2005 Delay Loop
- 2006/07 TL1 + Combiner Ring
- 2008/09 New photo-injector, TL2 + CLEX

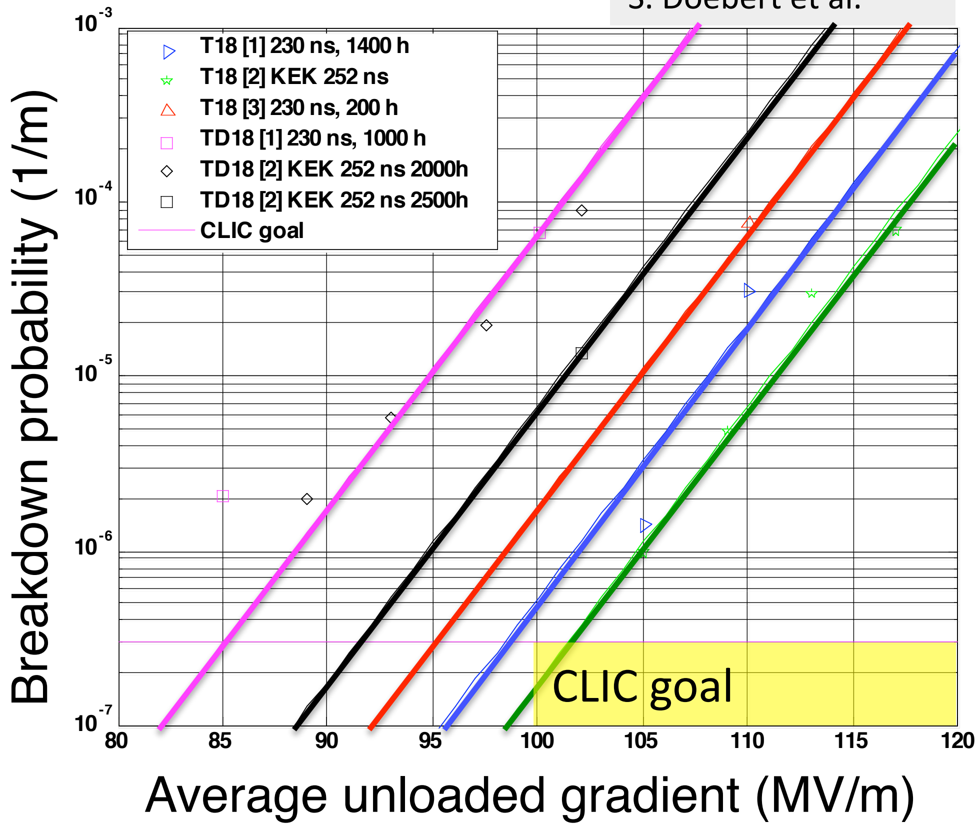
Accelerating Structure Results

- RF breakdowns can occur
  => no acceleration and deflection
- Goal: 3 10^{-7}/m breakdowns at 100 MV/m loaded at 230 ns
- T18 and TD18 structures built and tested at SLAC and KEK
- **T18 reached 95-105 MV/m**
- Damped TD18 reaches an extrapolated 85 MV/m
  - Second TD18 under test at KEK
  - Pulsed surface heating expected to be above limit
- CLIC prototypes with improved design (TD24) will be tested this year
  - expect similar or slightly better performances



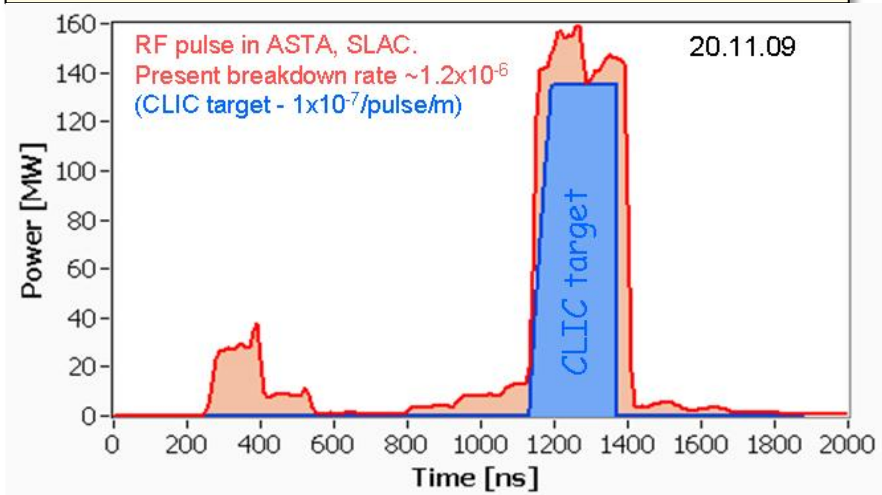


S. Doebert et al.



PETS Results

- Klystron based (SLAC):
  - achieved: 137 MW/266 ns/ 1.2 10^{-6} BDR
  - target: 132MW/240ns/10^{-7}

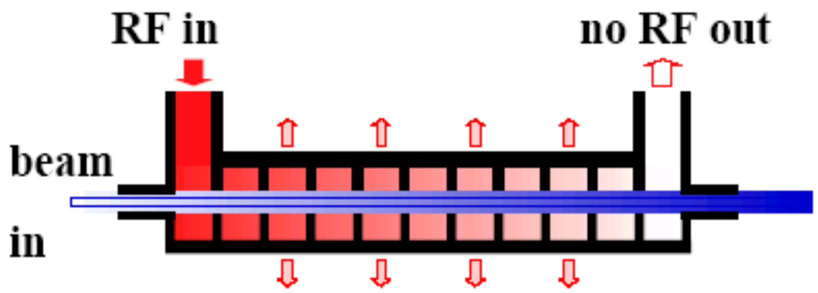


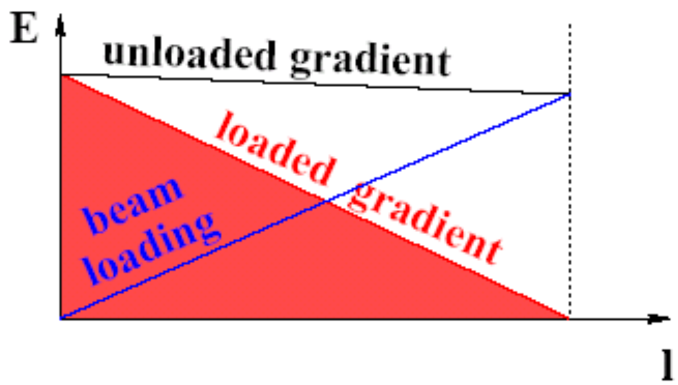
- Beam based (with recirculation):
  - Power >130 MW peak at 150 ns
  - Limited by attenuator and phase shifter breakdowns (cleaned for this run)
  - Power production according to predictions

- Structures had damping slots but no damping material
- Novel design on-off mechanism will be tested this year
- More testing is needed

Drive Beam generation (1)

- efficient acceleration needed
- => fully loaded operation



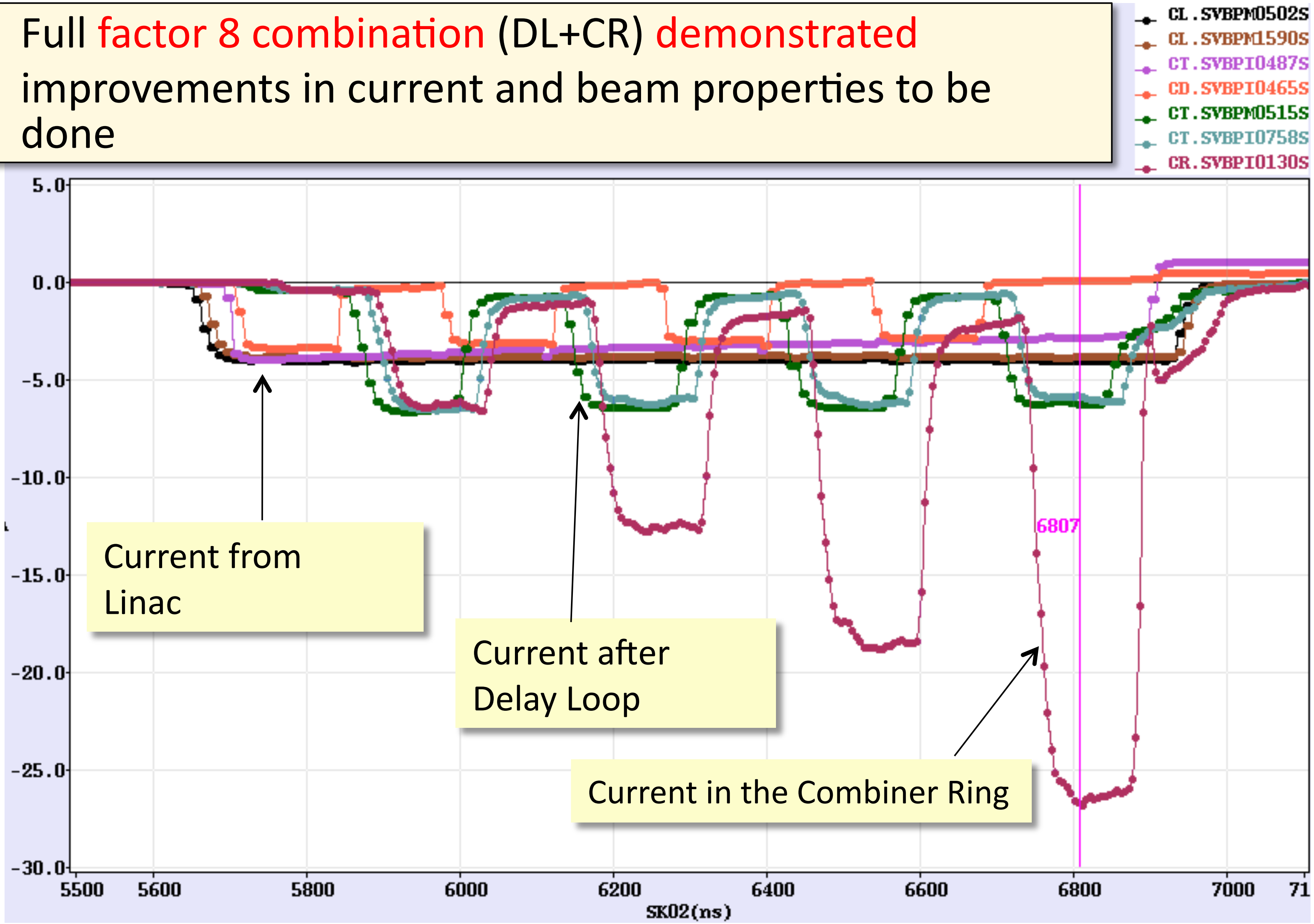


- Full beam loading operation routinely demonstrated
- Current stability in drive beam accelerator close to target ($1.5\ 10^{-3}$ vs. $0.75\ 10^{-3}$)
- Further improvement possible
- simulated feedback: $0.6\ 10^{-3}$

- Measured RF-to-beam efficiency 95.3%
- Theory 96% (~ 4 % ohmic losses)

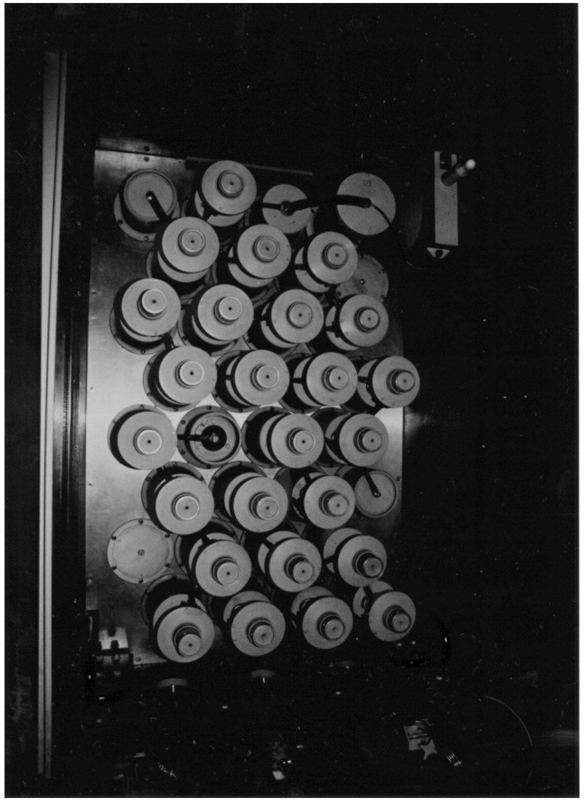
Drive Beam generation (2)

- Full factor 8 combination (DL+CR) demonstrated
- improvements in current and beam properties to be done



Fire in CTF3 Klystron Gallery

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



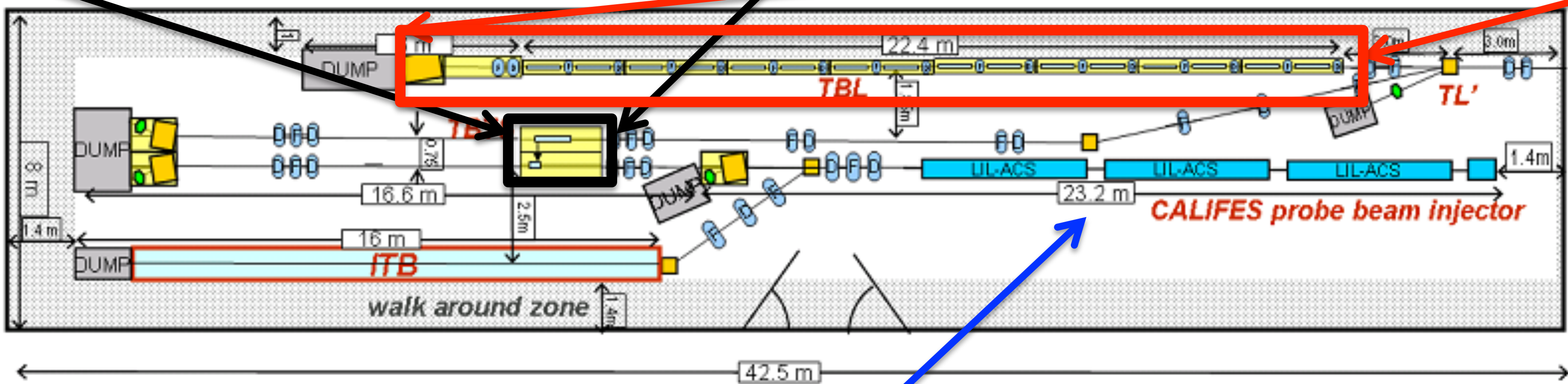
- Cleaning of components was needed to prevent corrosion
- => ~4 months delay
- klystron missing => lower beam energy or lower beam current
- restart went well without any major problems

Drive Beam Deceleration and Module: CLEX

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

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

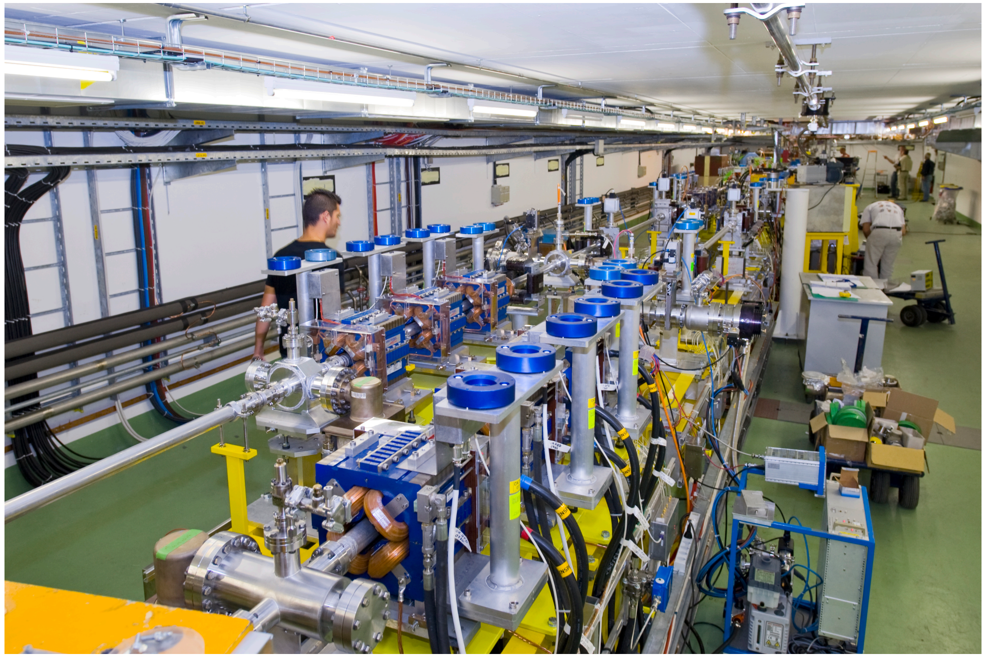
Test Beam Line (TBL):
- **Drive beam transport (16 PETS)**
  - beam energy extraction and dispersion
  - wakefield effects



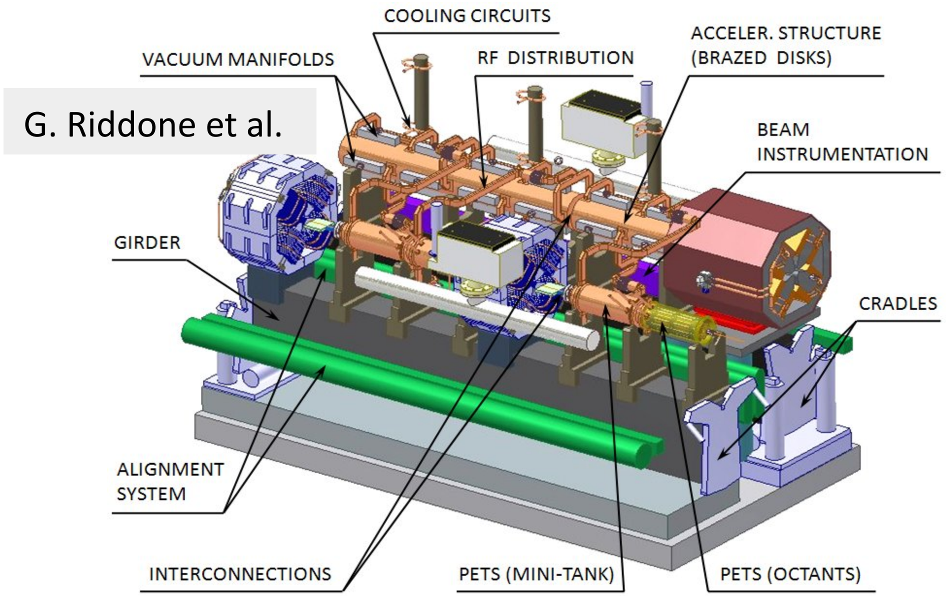
- **Califes**: Probe beam photo-injector
- Beam energy 175 MeV

Two Beam Module

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



- Beam tests of PETS are ongoing
- accelerating structure installed
- important goal 2010: two-beam acceleration with 100 MV/m
- Some tests after 2010
  e.g. wake monitors, design exists
- Later full modules will be tested

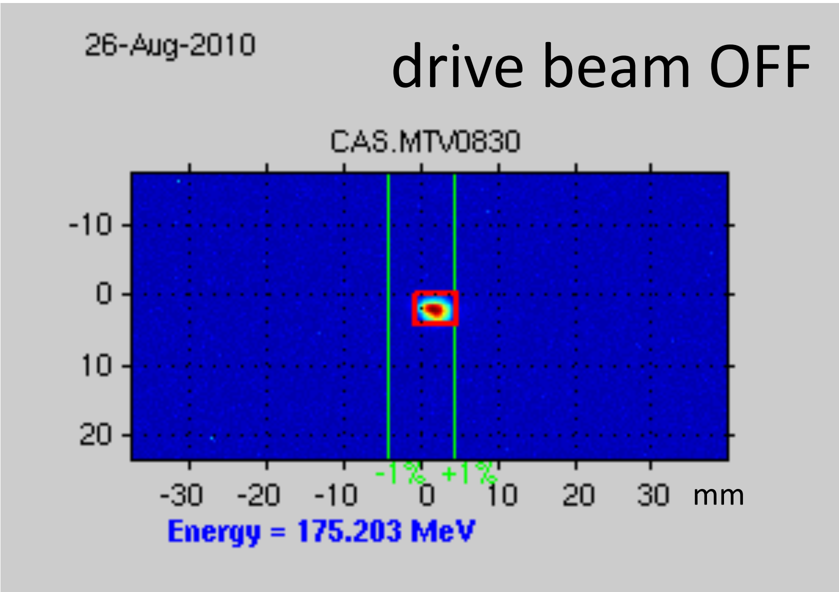


First two-beam acceleration in CTF3

- Principle had been established in CTF and CTF2

- probe beam initial energy = 175.2 MeV
- Energy gain provided by ACS = 4.3 MeV
- Power entering in the ACS is about 3.5 MW
- just the beginning of conditioning of the accelerating structure

Spectrometer line screen



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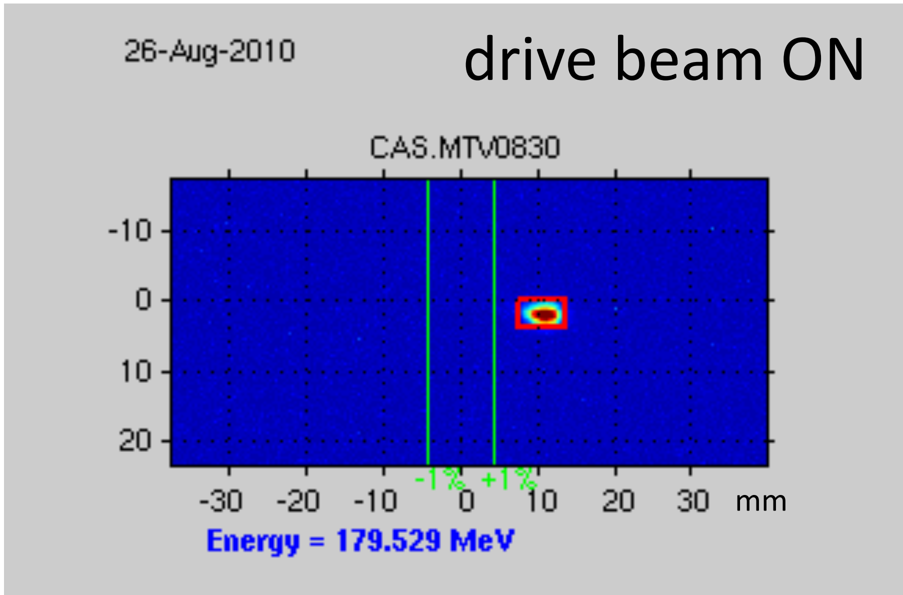
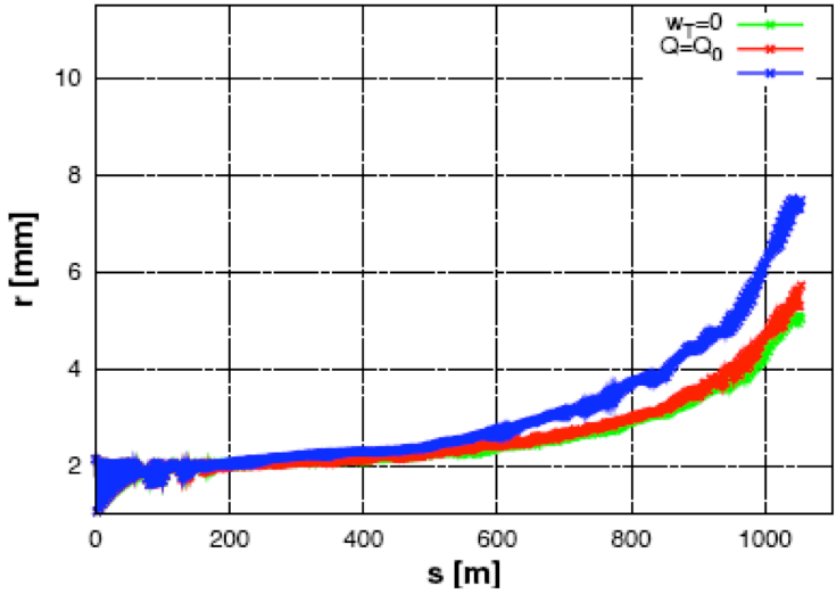
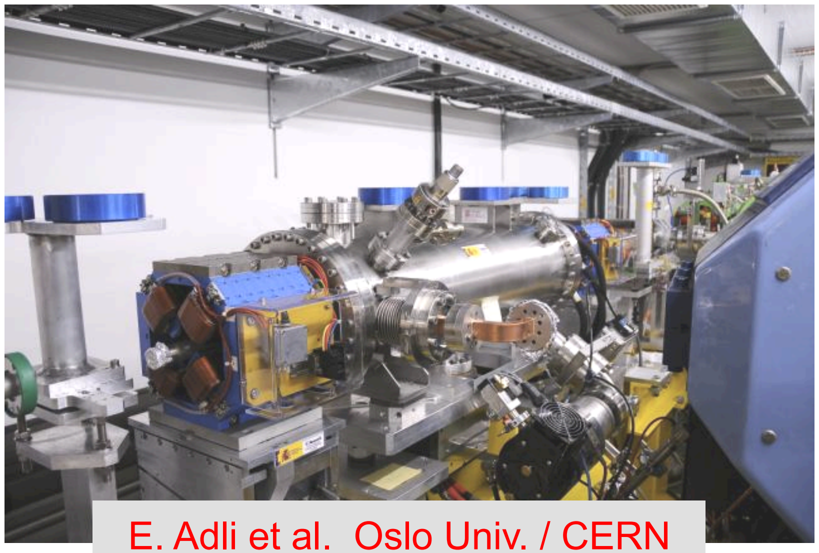
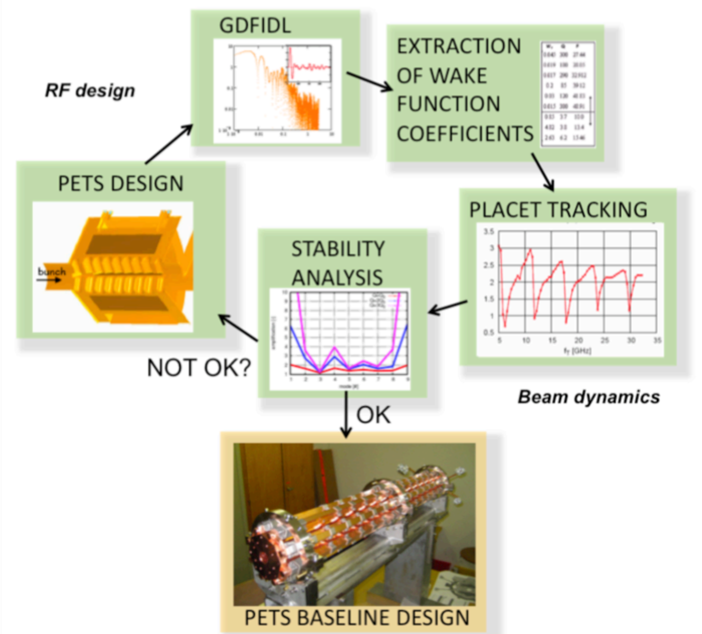


Drive Beam Deceleration

- Drive beam has high current (100A) and large energy spread
- Simulations show that the beam is stable
- Several iterations of PETS design
- Test Beam Line (TBL) under construction will increase confidence
  - the first PETS installed (3 for end 2010)
  - beam to the end




E. Adli et al. Oslo Univ. / CERN

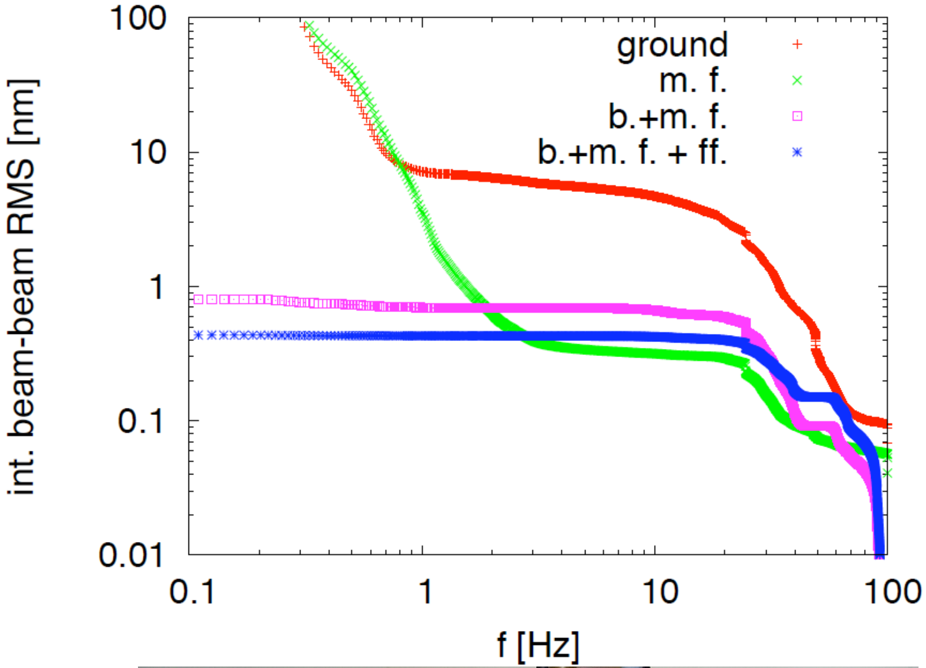


Ultra Low Beam Emittances/Sizes

- Designs for critical lattices exist achieving target performances
  - Critical beam physics issues are being addressed in time for CDR
    - E.g. electron cloud, intra-beam scattering, fast beam ion instability, RF stability, beam-based alignment, stability and feedback
  - Specification for critical hardware exists
    - Design exist of key components and tests are ongoing/planned (alignment system, mechanical stabilisation systems, phase stabilisation systems, DR wigglers, ML quadrupoles, final doublet, instrumentation …)
    - Also detailed studies for baseline design, e.g. cabling and power supplies
  - Very important issue are imperfections
    - Key issue are the alignment and stabilisation hardware performances

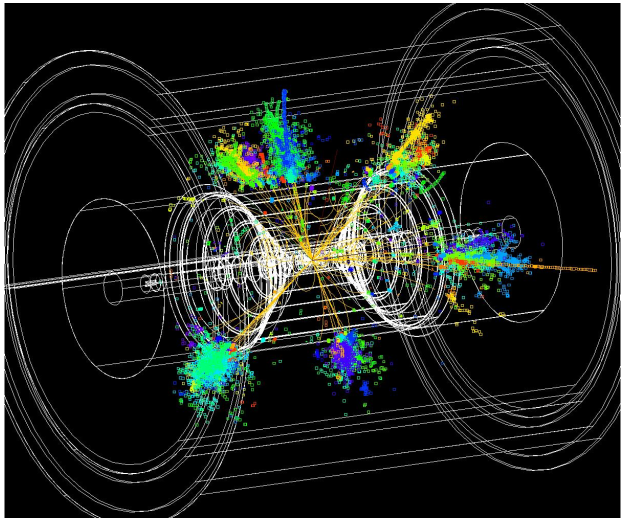
Important Example: Element Stabilisation

- Tight tolerances on magnet mechanical stability
  - main linac ~1nm
  - final doublet ~0.2nm
  - correlations matter
- Beamline elements move
  - ground motion (site dependent)
  - technical noise
- Minimise impact of motion by
  - technical noise identification/minimisation
  - support/component design
  - active mechanical stabilisation (m.f.)
  - beam-based orbit feedback (b.)
  - motion sensor based feed-forward (ff.) on beam
  - intra-pulse IP feedback
- Chose tools according to needs
  - LEP tunnel without technical noise would only need beam-based feedback



CLIC Detector Issues

- Detector requirements close to those for ILC detectors
  - First studies indicate that ILC performances are sufficient
  - Adapt ILD and SID concepts for CLIC
  - Close collaboration with validated ILC designs
- Differences to ILC
  - Time structure (0.5ns vs. 370ns)
  - Larger beam energy loss
  - Higher background
    - High energy
    - Small bunch spacing
  - Other parameters are slightly modified
    - Crossing angle of 20 mrad (ILC: 14 mrad)
  - Larger beam pipe radius in CLIC (30mm)
  - Slightly denser and deeper calorimetry



More in the following talk …

- Linear collider detector study has been established at CERN beginning of 2009 (led by L. Linssen, see http://cern.ch/lcd)

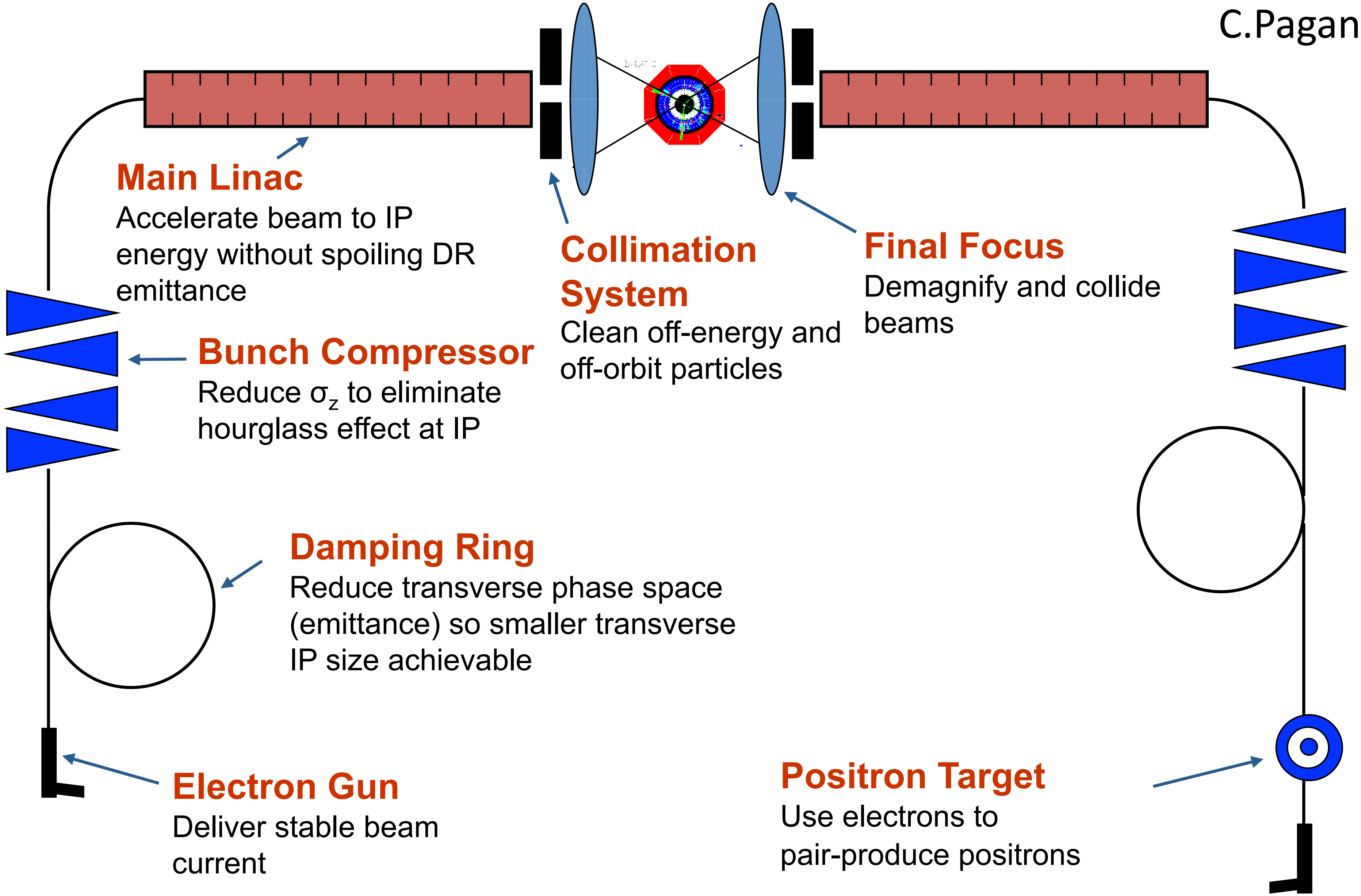
Conclusion

- CLIC Conceptual design is advancing well
  - Baseline choices have been finalised
- Feasibility issues are being addressed
  - Overall good progress but will have to continue after CDR in 2011
    - Verify conceptual design with experiments
- Project preparation is ongoing -> feedback on design
  - Cost study
  - Schedule
  - Site studies
- The TDR phase is being prepared
- Future decision on linear collider based on LHC results
  - Hope for exciting discoveries at LHC
- Thanks to everyone I used some material from

Spares

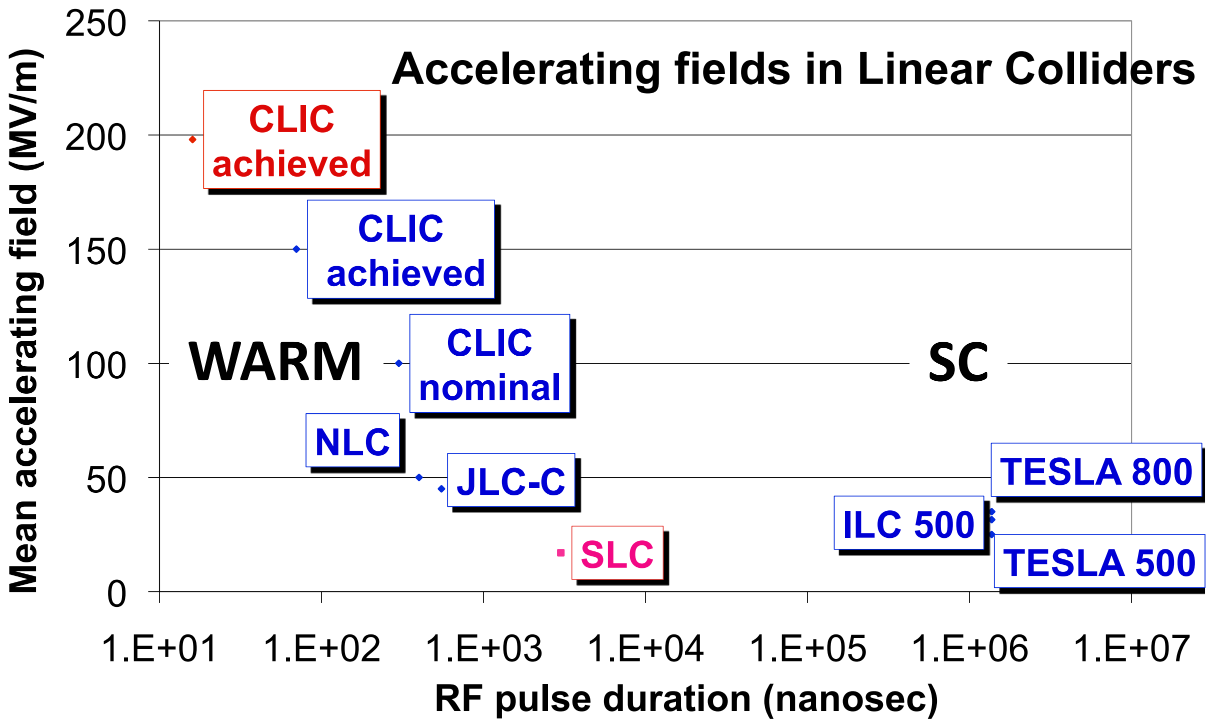
Generic Linear Collider

C.Pagani



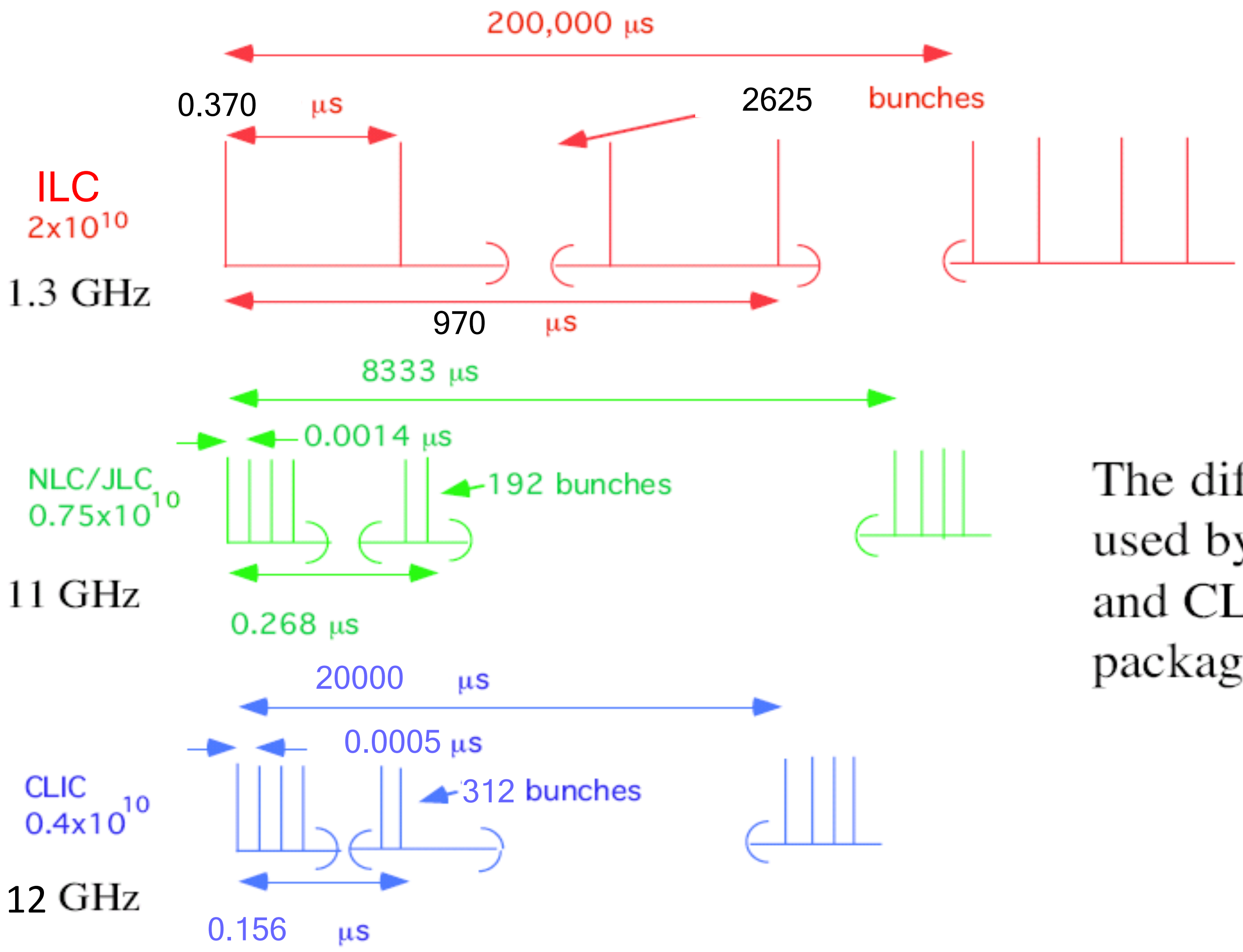
Accelerating gradient

- Superconducting cavities fundamentally limited in gradient by critical magnetic field => become normal conducting above
- Normal conducting cavities limited in pulse length + gradient by
  - "Pulsed surface heating" => can lead to fatigue
  - RF breakdowns (field collapses => no acceleration, deflection of beam)
- Normal conducting cavities: higher gradient with shorter RF pulse length
- Superconducting cavities: lower gradient with long RF pulse



Bunch structure

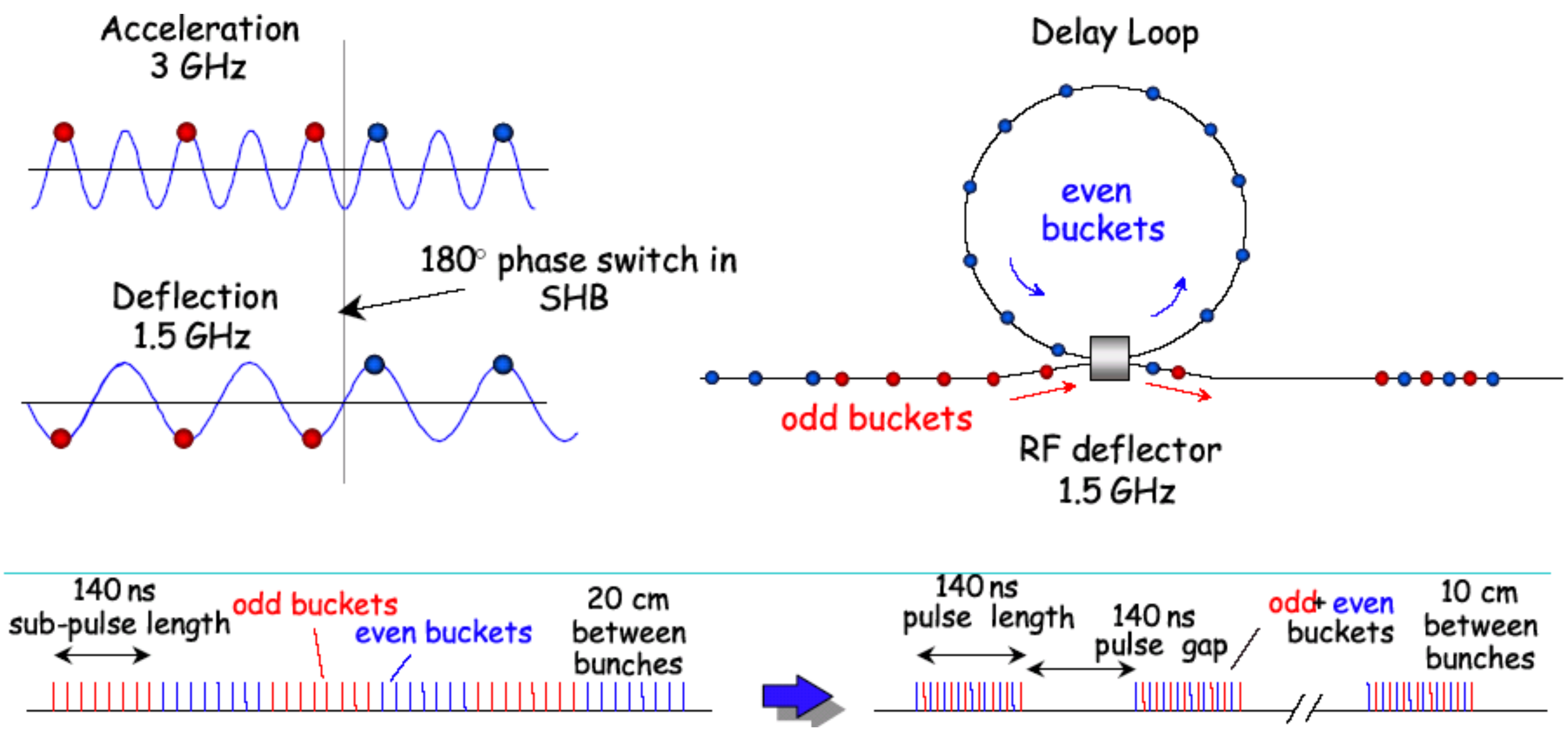
- SC allows long pulse, NC needs short pulse with smaller bunch charge



The different RF technologies used by ILC, NLC/JLC and CLIC require different packaging for the beam power

Delay Loop Principle

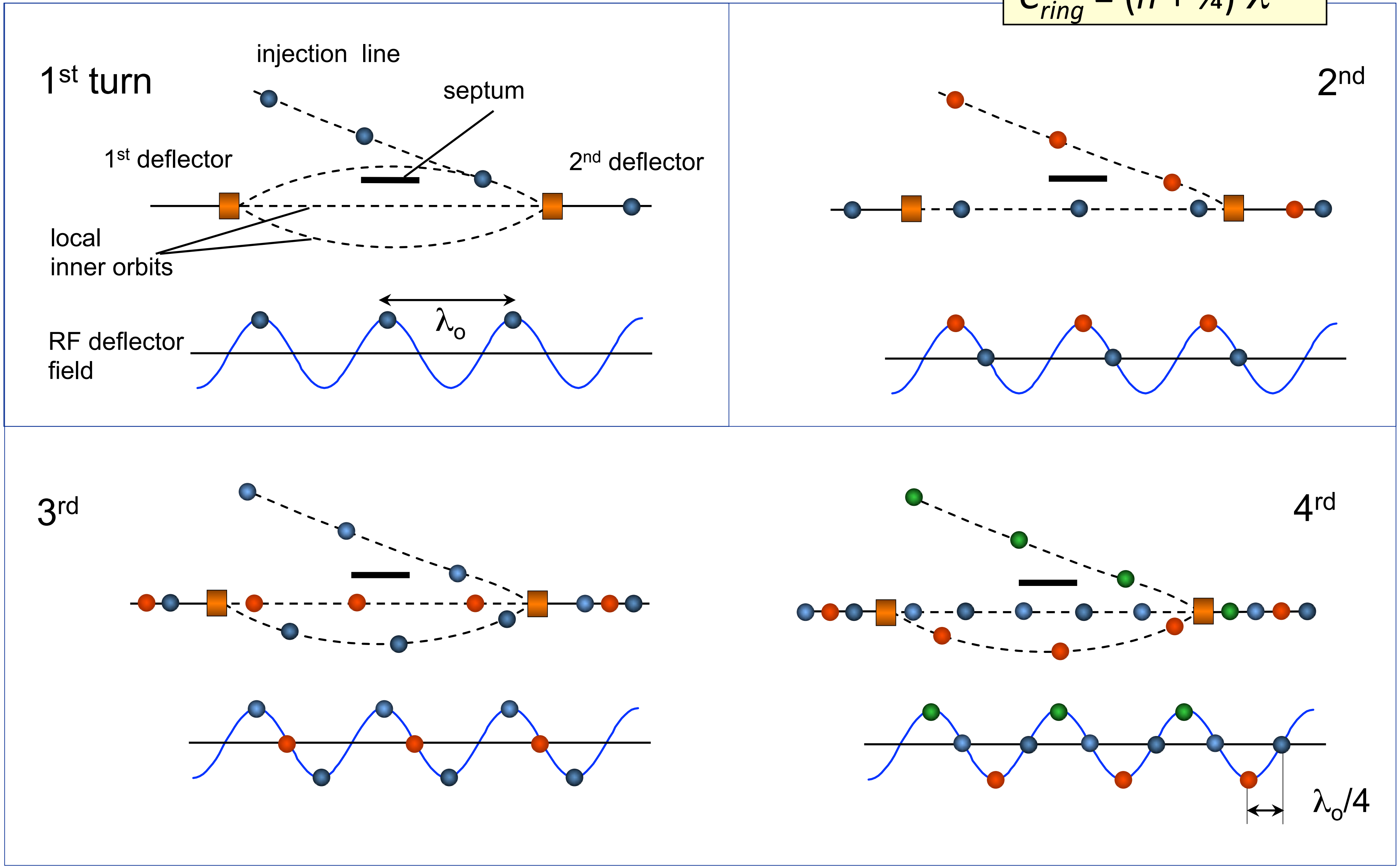
- **double repetition frequency and current**
- parts of bunch train delayed in loop
- RF deflector combines the bunches



RF injection in combiner ring

- combination factors up to 5 reachable in a ring

$C_{ring} = (n + ¼)\ \lambda$

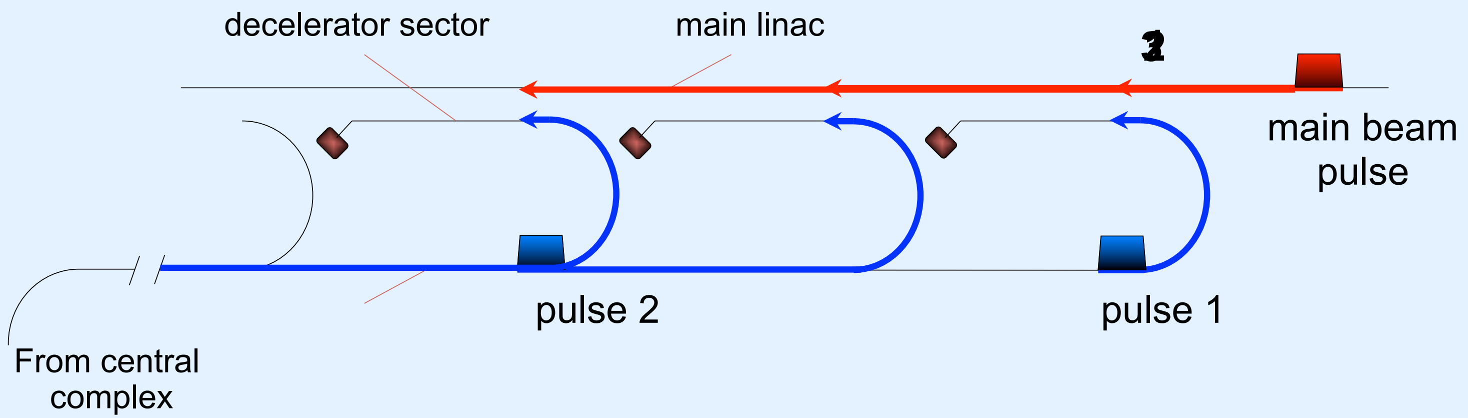


Two-beam acceleration

Counter propagation from central complex

Instead of using a single drive beam pulse for the whole main linac, several (N_S = 24) short drive beam pulses are used

Each one feed a ~880 m long sector of two-beam acceleration (TBA)



Counter flow distribution allows to power different sectors of the main linac with different time bins of a single long electron drive beam pulse

The distance between the pulses is $2\ L_s = 2\ L_{main}/N_S$ (L_{main}= single side linac length)

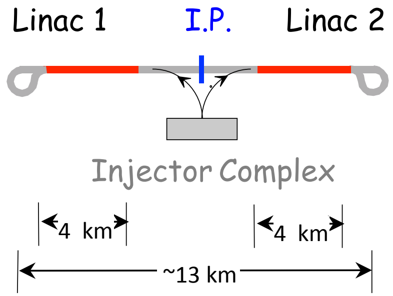
Initial drive beam pulse length t_{DB} is given by twice the time of flight through one single linac

so $t_{DB} = 2\ L_{main} / c$, 140 μs for the 3 TeV CLIC

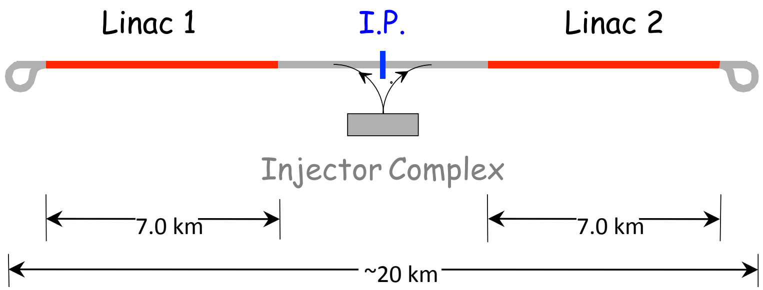
R.Corsini

CLIC Layout at various energies

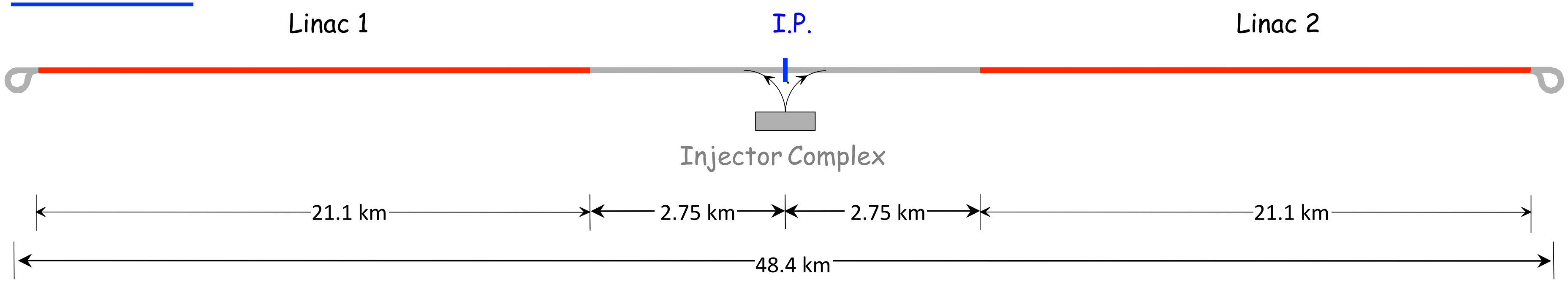
0.5 TeV Stage



1 TeV Stage

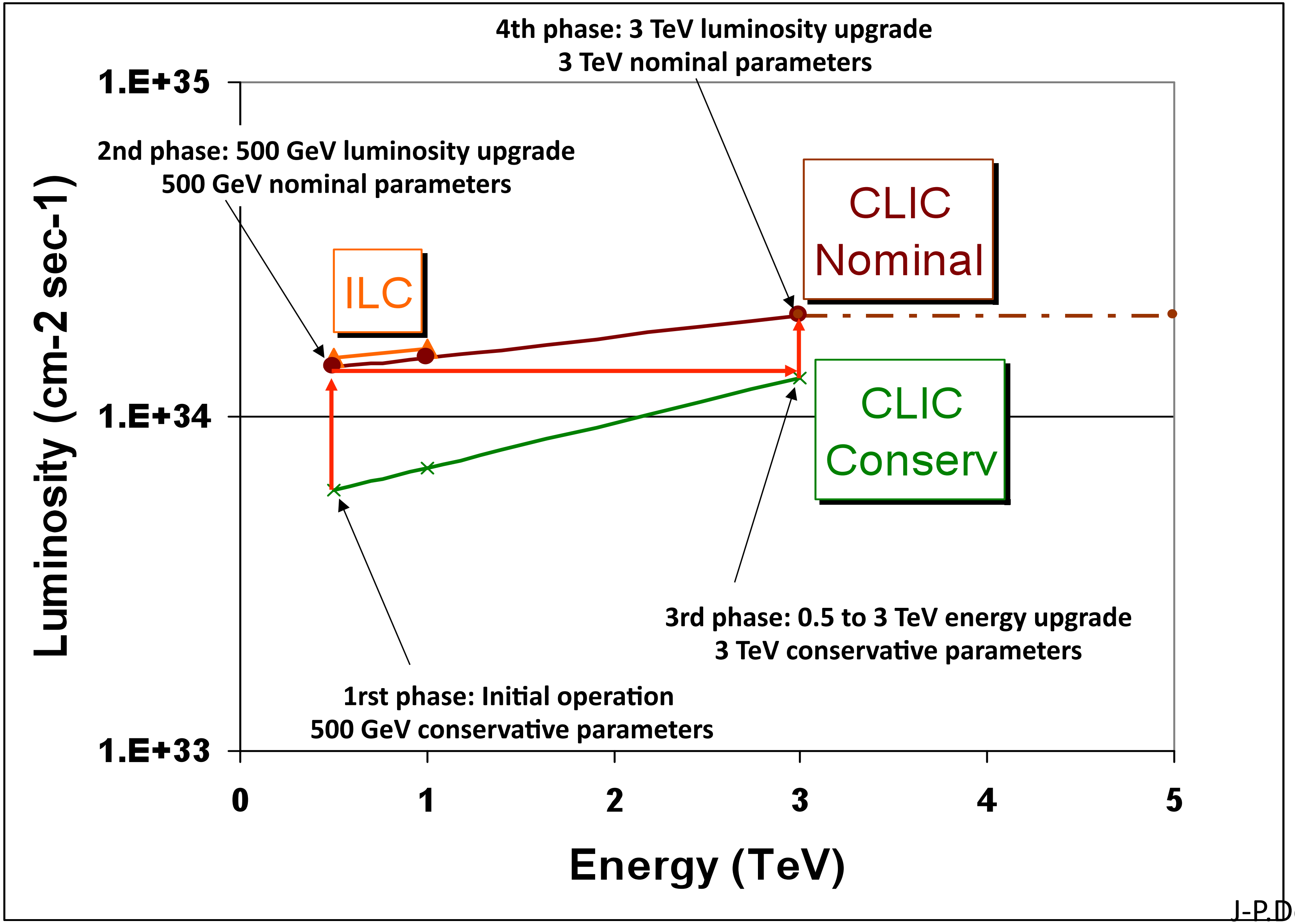


3 TeV Stage



CLIC Parameters and upgrade scenario

http://cdsweb.cern.ch/record/1132079/files/CERN-OPEN-2008-021.pdf



J-P.Delahaye

CLIC main parameters

Center-of-mass energy	CLIC 500 G		CLIC 3 TeV	
Beam parameters	Conservative	Nominal	Conservative	Nominal
Accelerating structure	502		G	
Total (Peak 1%) luminosity	$0.9 (0.6)\cdot 10^{34}$	$2.3 (1.4)\cdot 10^{34}$	$2.7 (1.3)\cdot 10^{34}$	$5.9 (2.0)\cdot 10^{34}$
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		4 / 0.1
Hor./vert. IP beam size (nm)	248 / 5.7	202 / 2.3	83 / 1.1	40 / 1
Hadronic events/crossing at IP	0.07	0.19	0.75	2.7
Coherent pairs at IP	<<1	<<1	500	3800
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	