Status of the CLIC study and its main beam injectors

- CLIC status, CDR published
- Recent research highlights
- Future program
- Main beam injectors overview

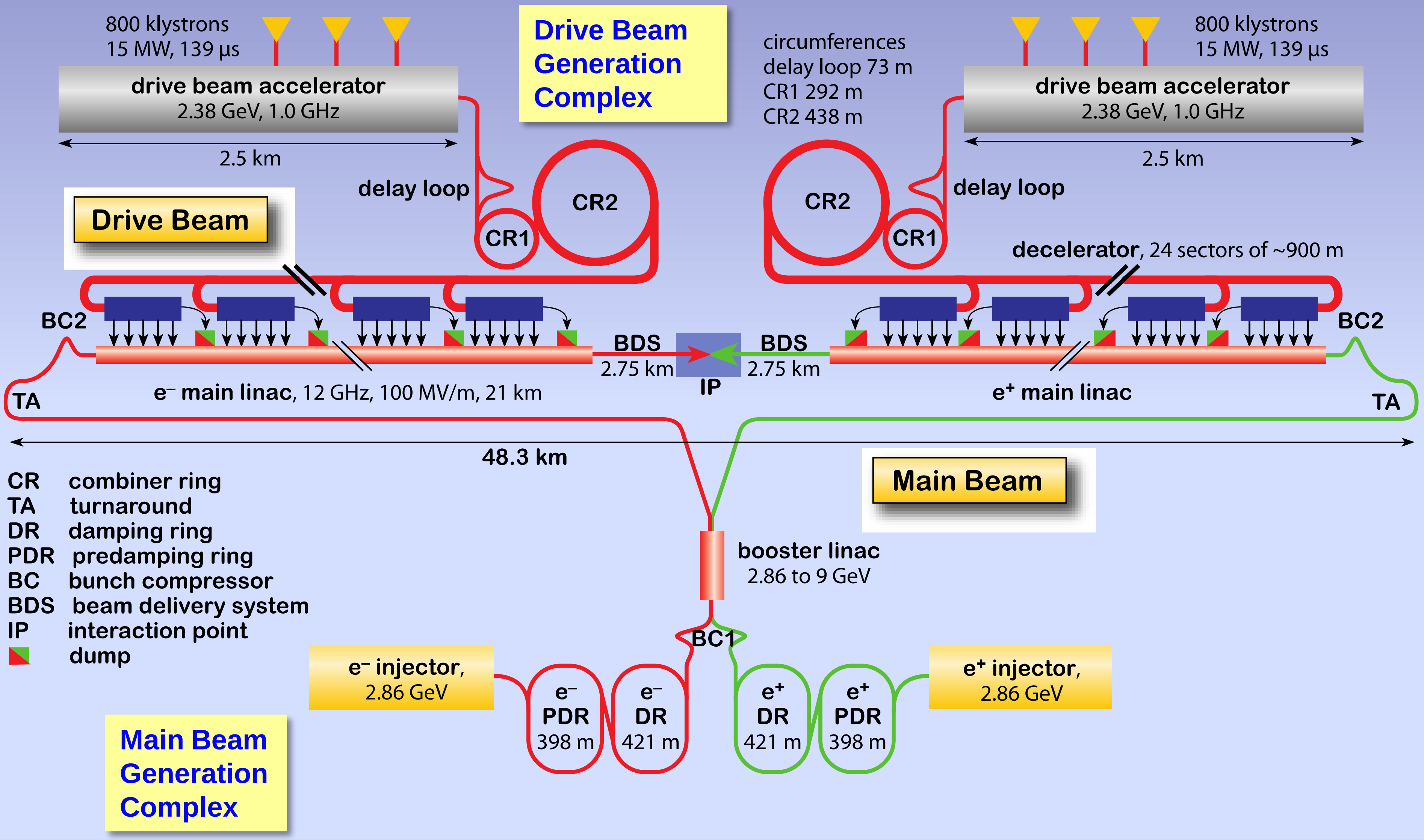
Many slides from S. Stapnes, D. Schulte, R. Corsini

Current CLIC&CTF3 Collaboration

CLIC multi-lateral collaboration - 44 Institutes from 22 countries

- ACAS (Australia)
- Aarhus University (Denmark)
- Ankara University (Turkey)
- Argonne National Laboratory (USA)
- Athens University (Greece)
- BINP (Russia)
- CERN
- CIEMAT (Spain)
- Cockcroft Institute (UK)
- ETH Zurich (Switzerland)
- FNAL (USA)
- 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)
- Joint Institute for Power and Nuclear Research SOSNY /Minsk (Belarus)
- John Adams Institute/RHUL (UK)
- JINR (Russia)
- Karlsruhe University (Germany)
- KEK (Japan)
- LAL / Orsay (France)
- LAPP / ESIA (France)
- NIKHEF/Amsterdam (Netherland)
- NCP (Pakistan)
- North-West. Univ. Illinois (USA)
- Patras University (Greece)
- Polytech. Univ. of Catalonia (Spain)
- PSI (Switzerland)
- RAL (UK)
- RRCAT / Indore (India)
- SLAC (USA)
- Sincrotrone Trieste/ELETTRA (Italy)
- Thrace University (Greece)
- Tsinghua University (China)
- University of Oslo (Norway)
- University of Vigo (Spain)
- Uppsala University (Sweden)
- UCSC SCIPP (USA)

CLIC Layout at 3 TeV



Drive Beam Generation Complex

800 klystrons
15 MW, 139 μs

drive beam accelerator
2.38 GeV, 1.0 GHz

2.5 km

delay loop

CR2

CR1

circumferences
delay loop 73 m
CR1 292 m
CR2 438 m

800 klystrons
15 MW, 139 μs

drive beam accelerator
2.38 GeV, 1.0 GHz

2.5 km

delay loop

CR2

CR1

Drive Beam

decelerator, 24 sectors of ~900 m

BC2

BDS
2.75 km

IP

BDS
2.75 km

BC2

TA

e⁻ main linac, 12 GHz, 100 MV/m, 21 km

e⁺ main linac

TA

48.3 km

Main Beam

booster linac
2.86 to 9 GeV

BC1

e⁻ injector,
2.86 GeV

e⁻ PDR
398 m

e⁻ DR
421 m

e⁺ DR
421 m

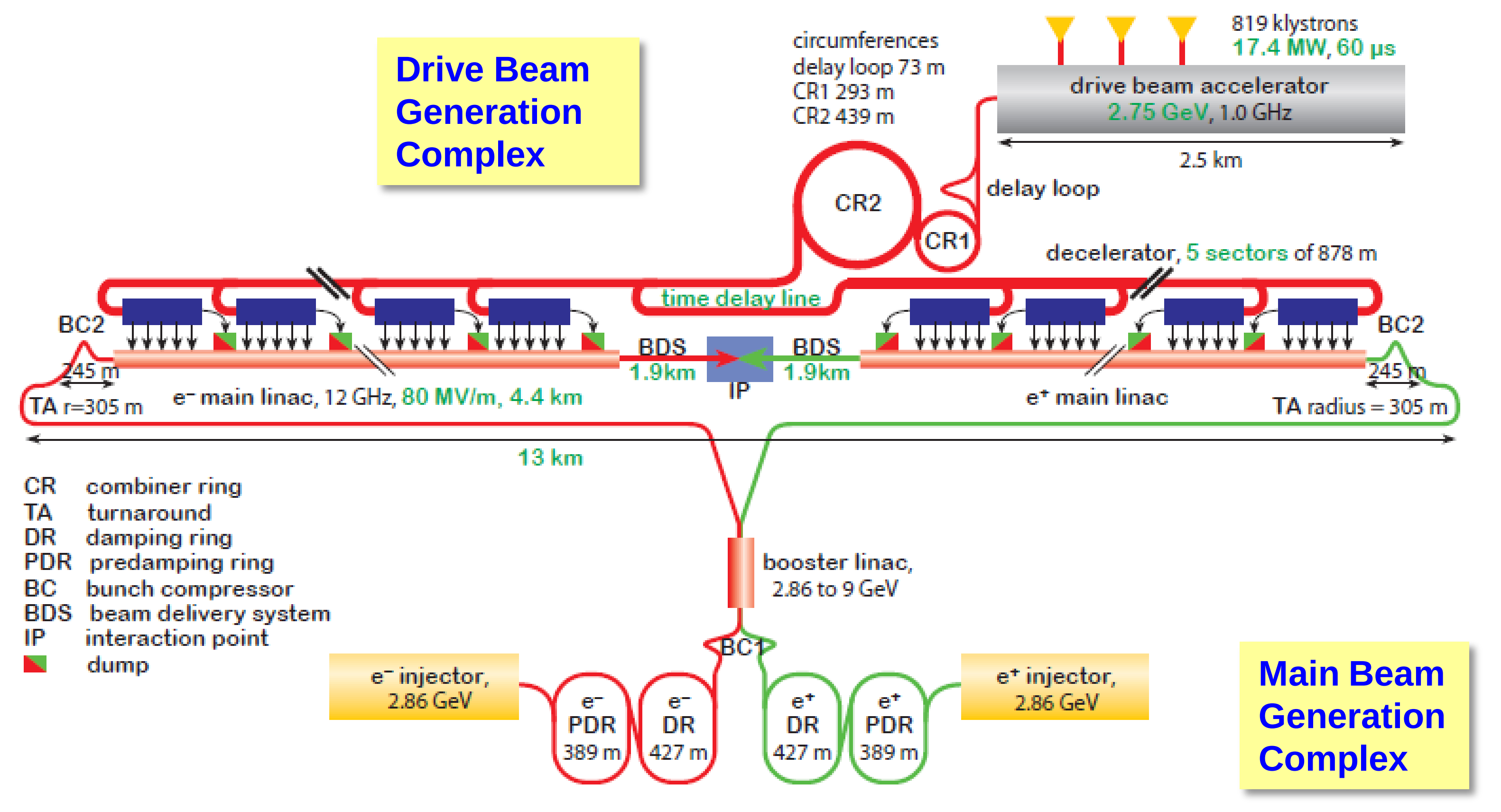
e⁺ PDR
398 m

e⁺ injector,
2.86 GeV

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

Main Beam Generation Complex

CLIC Layout at 500 GeV



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

Drive Beam Generation Complex

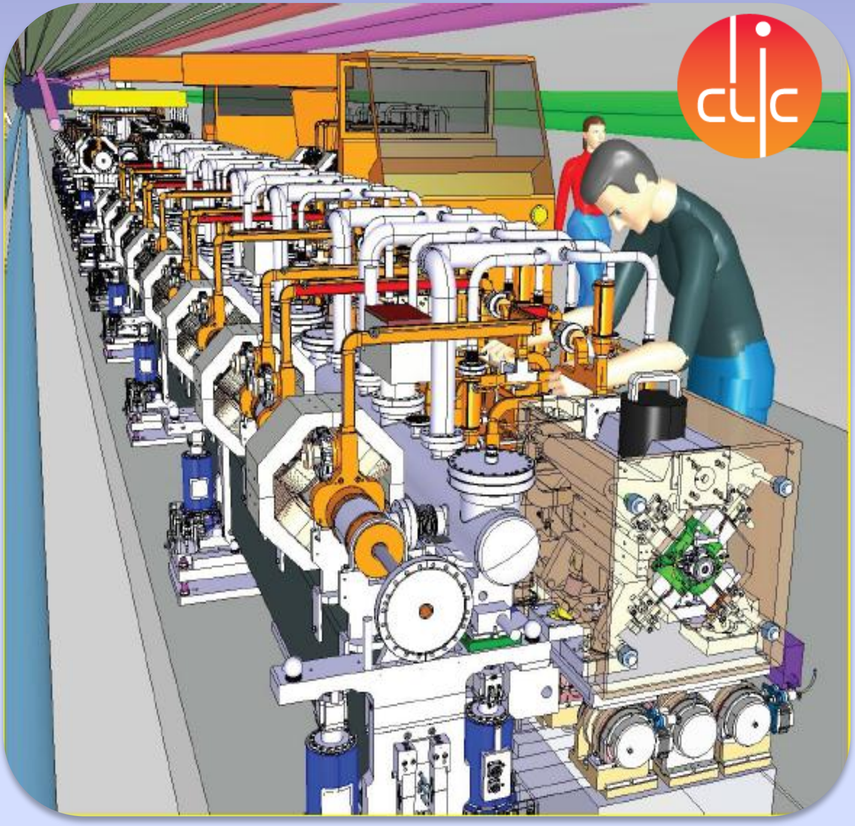
Main Beam Generation Complex

CLIC Main Parameters

parameter	symbol		
centre of mass energy	E_{cm} [GeV]	500	3000
luminosity	$\mathcal{L}$ $[10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}]$	2.3	5.9
luminosity in peak	$\mathcal{L}_{0.01}$ $[10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}]$	1.4	2
gradient	G [MV/m]	80	100
site length	[km]	13	48.3
charge per bunch	N $[10^9]$	6.8	3.72
bunch length	σ_z [μm]	72	44
IP beam size	σ_x/σ_y [nm]	200/2.26	40/1
norm. emittance	ϵ_x/ϵ_y [nm]	2400/25	660/20
bunches per pulse	n_b	354	312
distance between bunches	Δ_b [ns]	0.5	0.5
repetition rate	f_r [Hz]	50	50
est. power cons.	P_{wall} [MW]	271	582

The CLIC CDR finally published

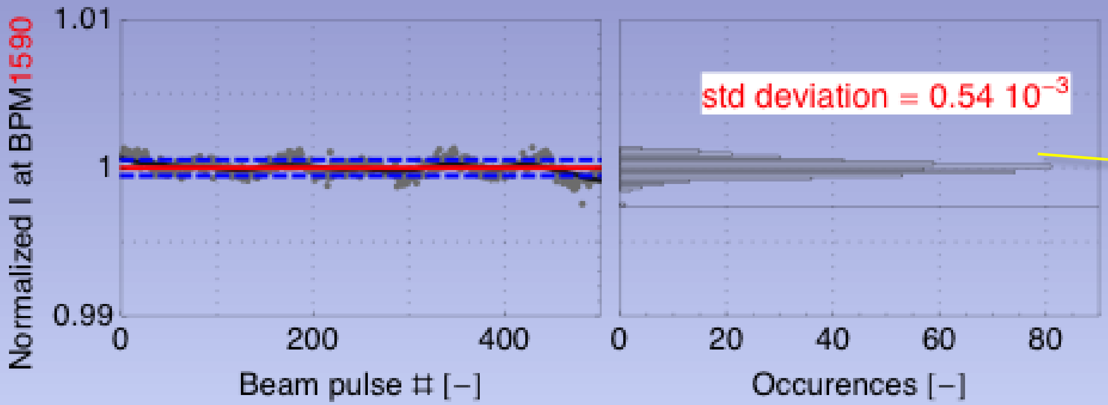
Vol 1: A Multi TeV Linear Collider based on CLIC Technology (H.Schmickler)



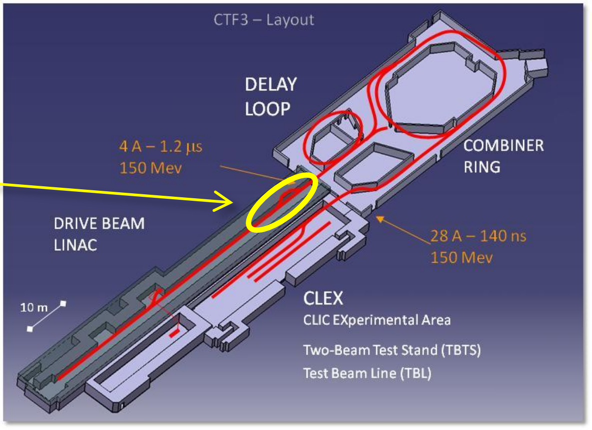
- CLIC concept with exploration over multi-TeV energy range up to 3 TeV
- Feasibility study of CLIC parameters optimized at 3 TeV (most demanding)
- Consider also 500 GeV, and intermediate energy range
- presented in the SPC In March 2012 (by Daniel Schulte)

http://project-clic-cdr.web.cern.ch/project-CLIC-CDR/

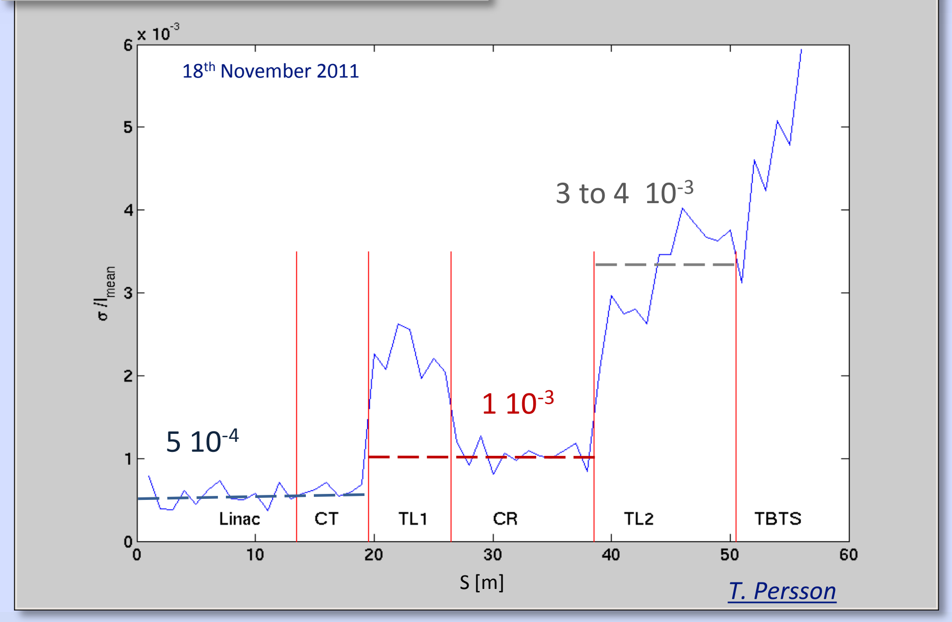
CTF3 Stability



std deviation = $0.54\ 10^{-3}$



Charge stability – Factor 4



18th November 2011

3 to $4\ \ 10^{-3}$

$1\ 10^{-3}$

$5\ 10^{-4}$

T. Persson

Repeatability and long term current stability improved

Pulse charge stability measured at end of the linac better than CLIC requirements

Several feed-back loops operational, for temperature, RF phase and power and gun current.

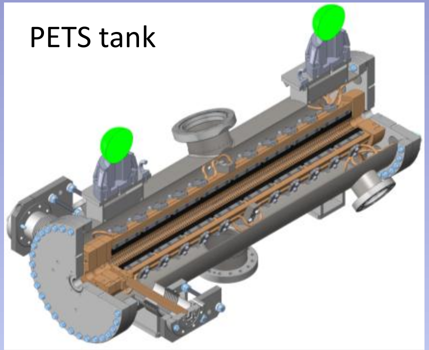
F. Tecker, P. Skowronski,T. Persson

CTF3 Test Beam Line (TBL)

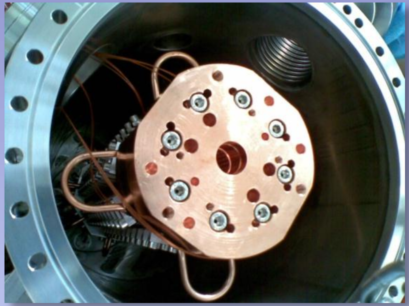
Thirteen PETS tanks installed and commissioned until now

Full beam transport to end-of-line spectrometer, stable beam

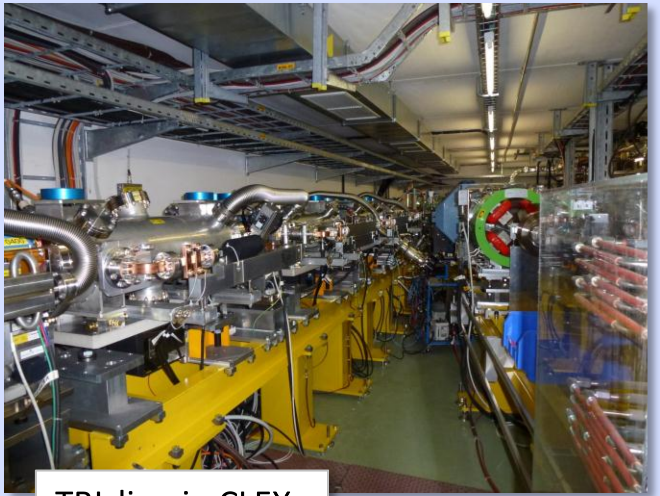
Power produced (70 MW/PETS) fully consistent with drive beam current (21 A) and measured deceleration.
Total power produced: 630 MW (9 PETS)

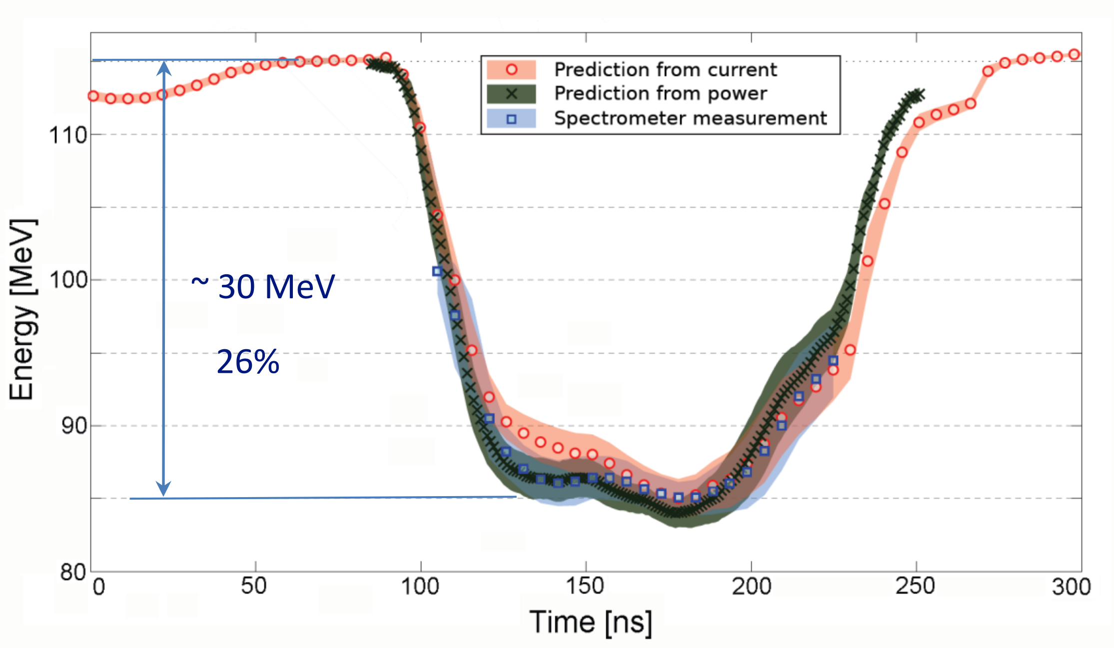

PETS tank

PETS tank
during
installation



Beam deceleration,
measured in spectrometer and compared with expectations


TBL line in CLEX



S. Doebert, R. Lillenstol

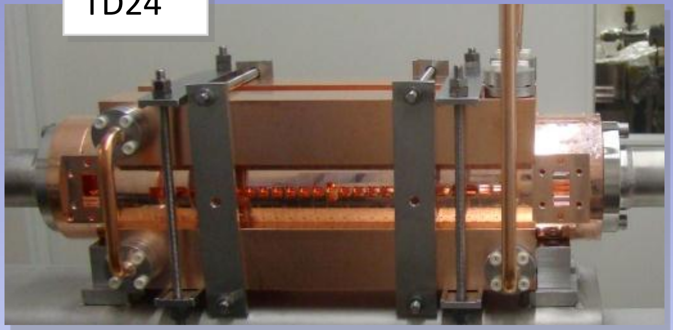
TBTS – Two-beam acceleration

Two-Beam Acceleration demonstration in TBTS

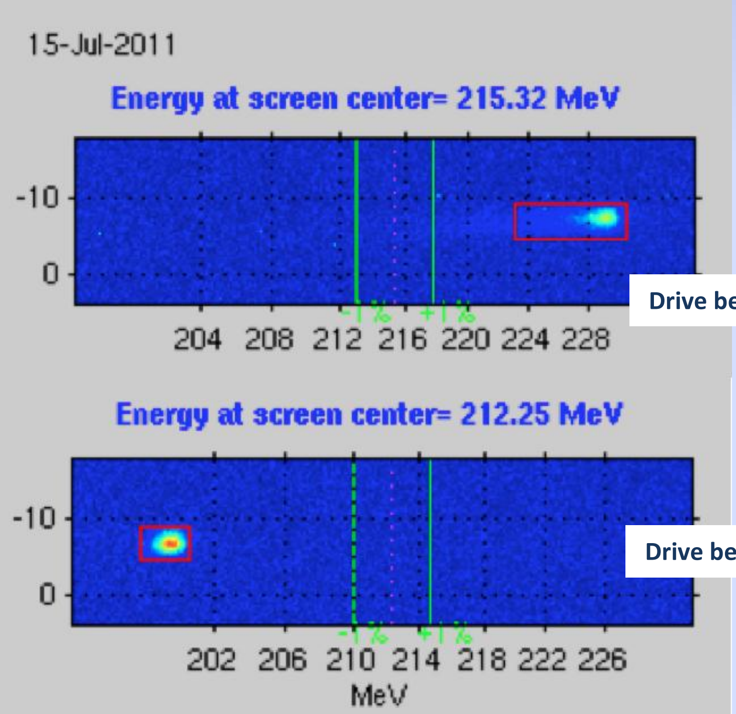
Up to **145 MV/m** measured gradient

Good agreement with expectations (power vs. gradient)

TD24

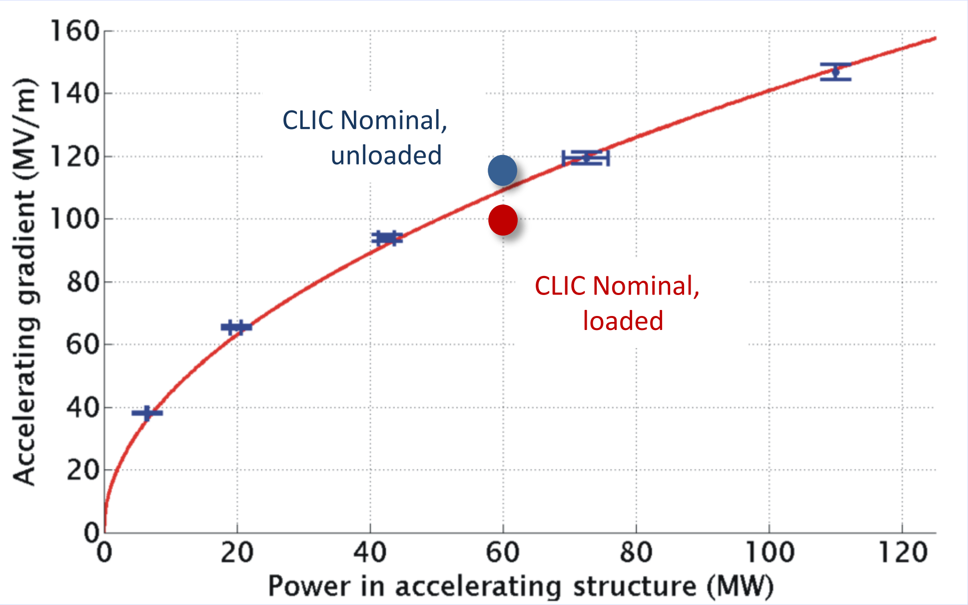


PETS operated routinely above **200 MW** peak RF power
Demonstration of PETS ON/OFF mechanism at high power



Drive beam ON

Drive beam OFF

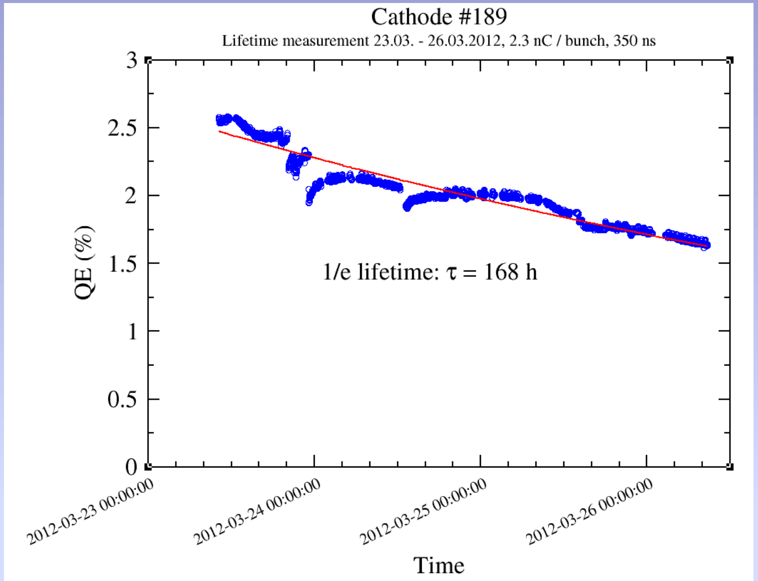


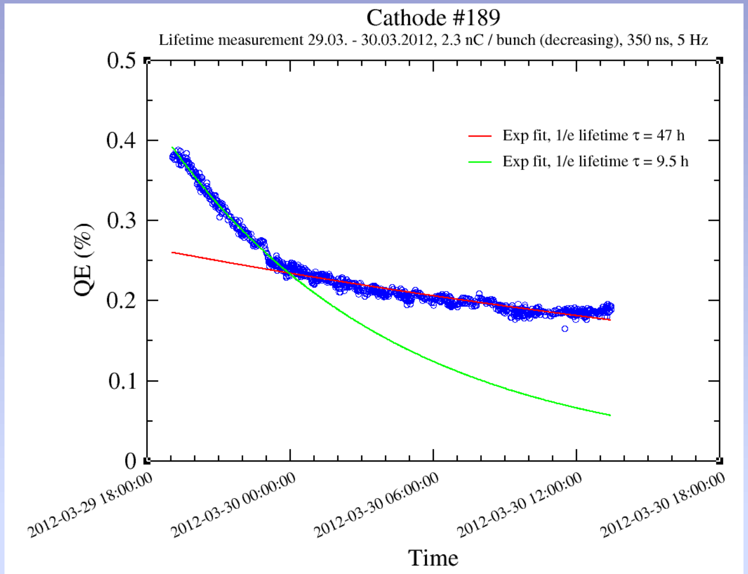
Demonstration of PETS of-off mechanism

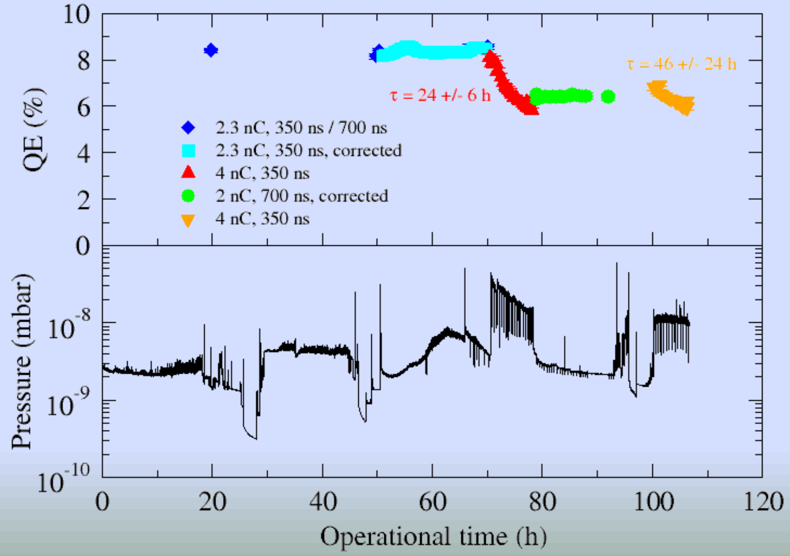
W. Farabolini, J. Barranco

PHIN run in March

March 2012: Lifetime studies of Cs_3Sb cathodes with green light, about 2 weeks



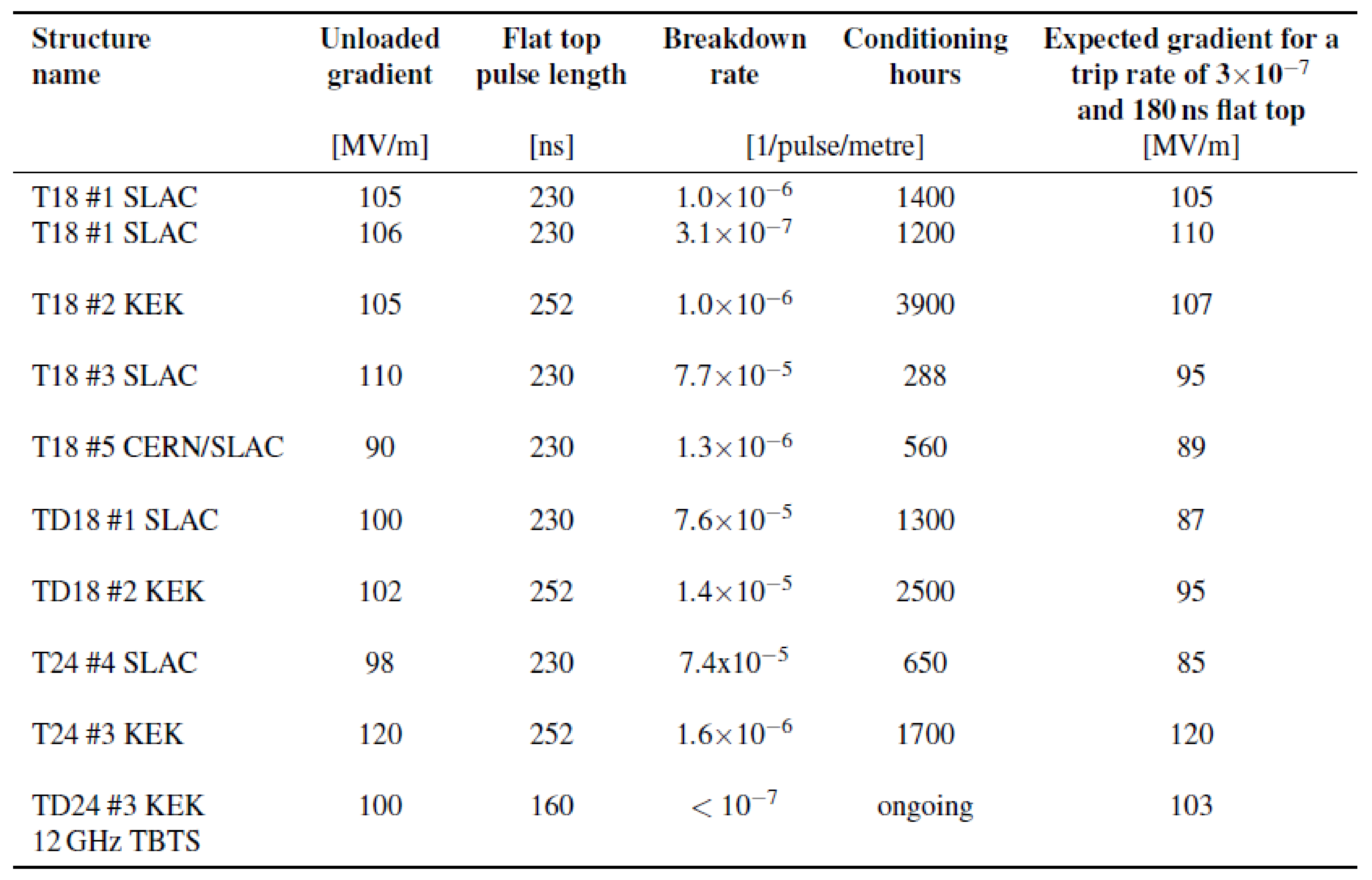




- Correlation between lifetime and vacuum.
- In high 10^{-9} mbar/ low 10^{-8} mbar < 50h lifetime was measured.
- When vacuum is kept at low 10^{-9} mbar lifetime is within specification.

C. Hessler, E. Chevallay, M. Csatari, S. Doebert, V. Fedosseev

Achieved Gradient

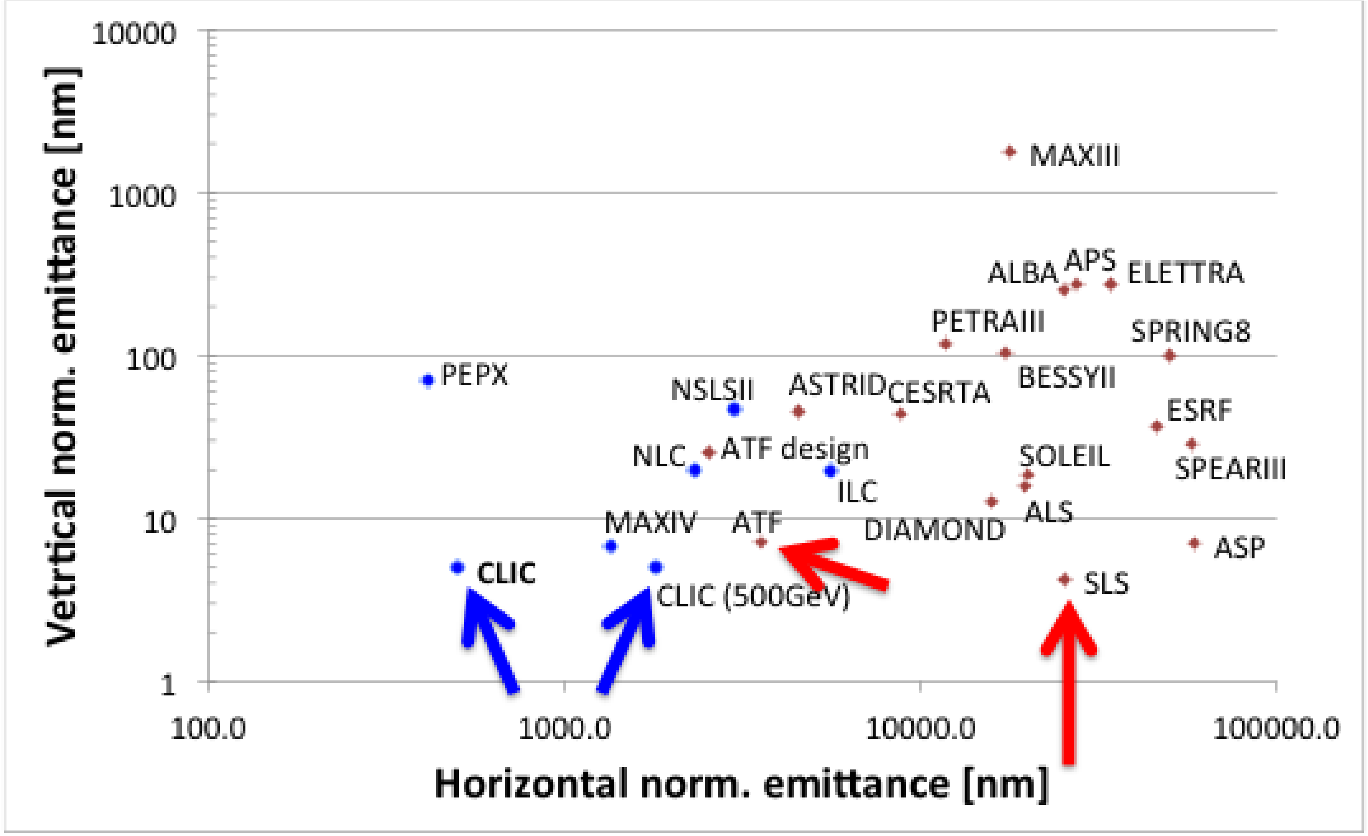


Structure name	Unloaded gradient [MV/m]	Flat top pulse length [ns]	Breakdown rate [1/pulse/metre]	Conditioning hours	Expected gradient for a trip rate of 3×10^{-7} and 180 ns flat top [MV/m]
T18 #1 SLAC	105	230	1.0×10^{-6}	1400	105
T18 #1 SLAC	106	230	3.1×10^{-7}	1200	110
T18 #2 KEK	105	252	1.0×10^{-6}	3900	107
T18 #3 SLAC	110	230	7.7×10^{-5}	288	95
T18 #5 CERN/SLAC	90	230	1.3×10^{-6}	560	89
TD18 #1 SLAC	100	230	7.6×10^{-5}	1300	87
TD18 #2 KEK	102	252	1.4×10^{-5}	2500	95
T24 #4 SLAC	98	230	$7.4\text{x}10^{-5}$	650	85
T24 #3 KEK	120	252	1.6×10^{-6}	1700	120
TD24 #3 KEK 12 GHz TBTS	100	160	$< 10^{-7}$	ongoing	103

Emittance Generation

Many design issues addressed

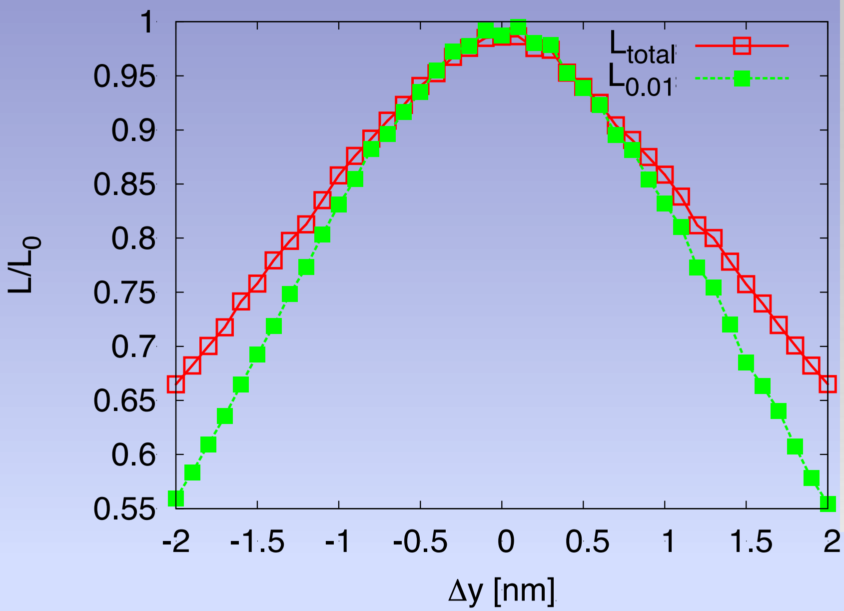
- lattice design
- dynamic aperture
- tolerances
- intra-beam scattering
- space charge
- wigglers
- RF system
- vacuum
- electron cloud
- kickers

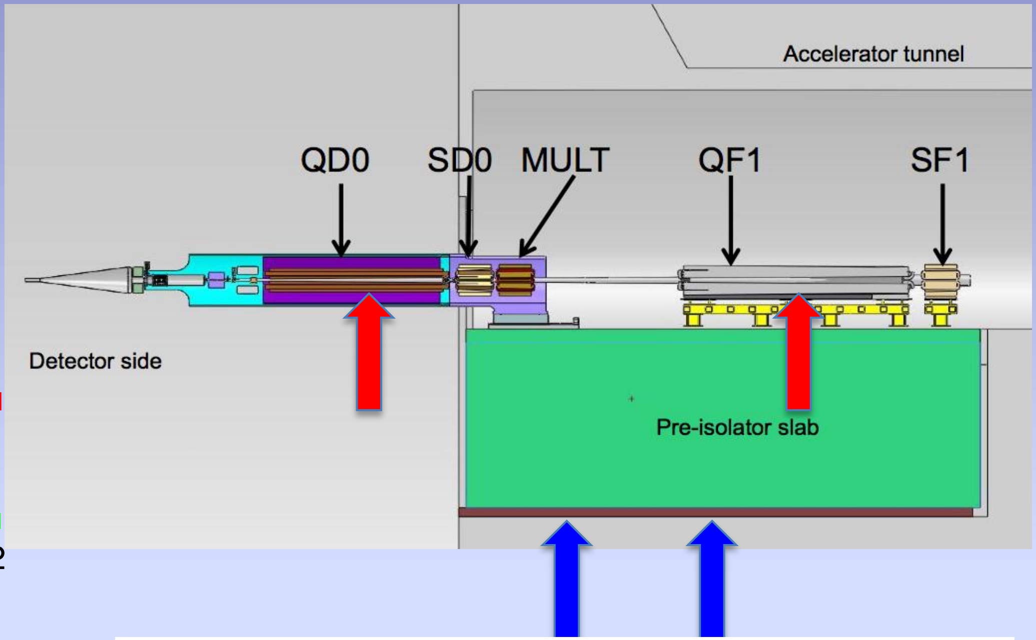


CLIC @3 TeV would achieve 1/3 of luminosity with ATF performance (3800nm/15nm@4e9)

Damping ring design is consistent with target performance

Ground Motion and Its Mitigation

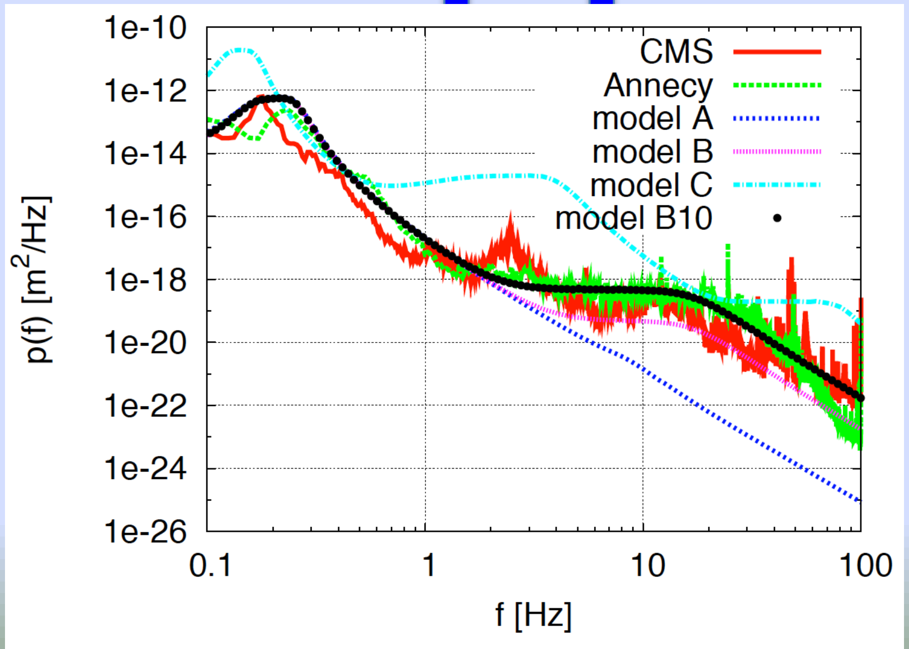




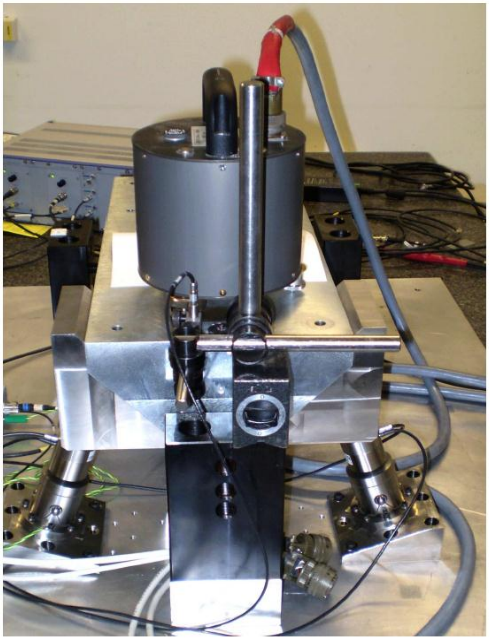
Natural ground motion can impact the luminosity

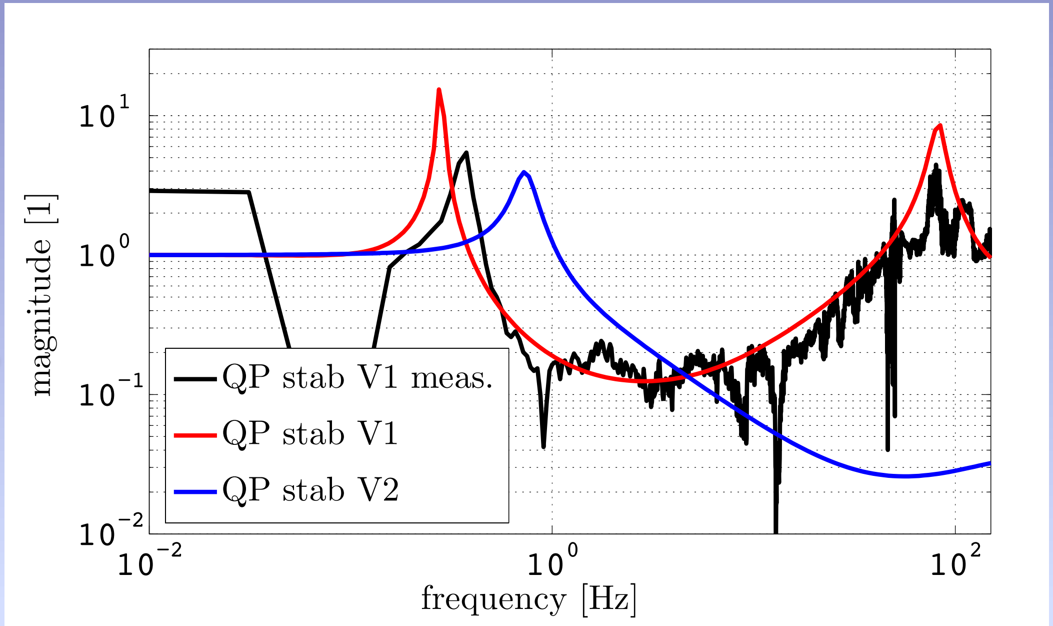
- typical quadrupole jitter tolerance O(1nm) in main linac and O(0.1nm) in final doublet

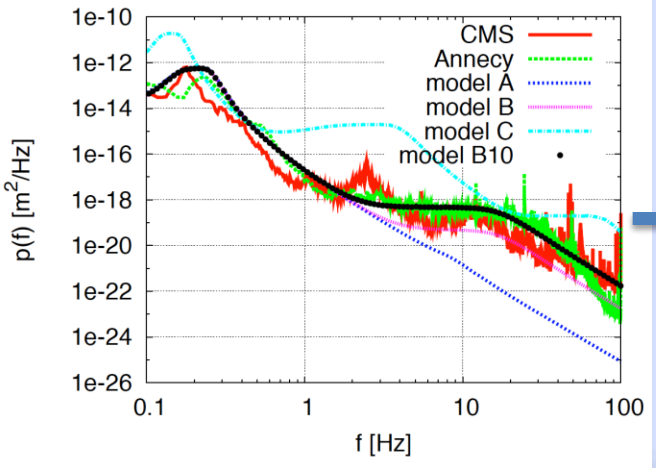
-> develop stabilization for beam guiding magnets



Active Stabilization Results







Code

Machine model
Beam-based feedback

Luminosity achieved/lost [%]

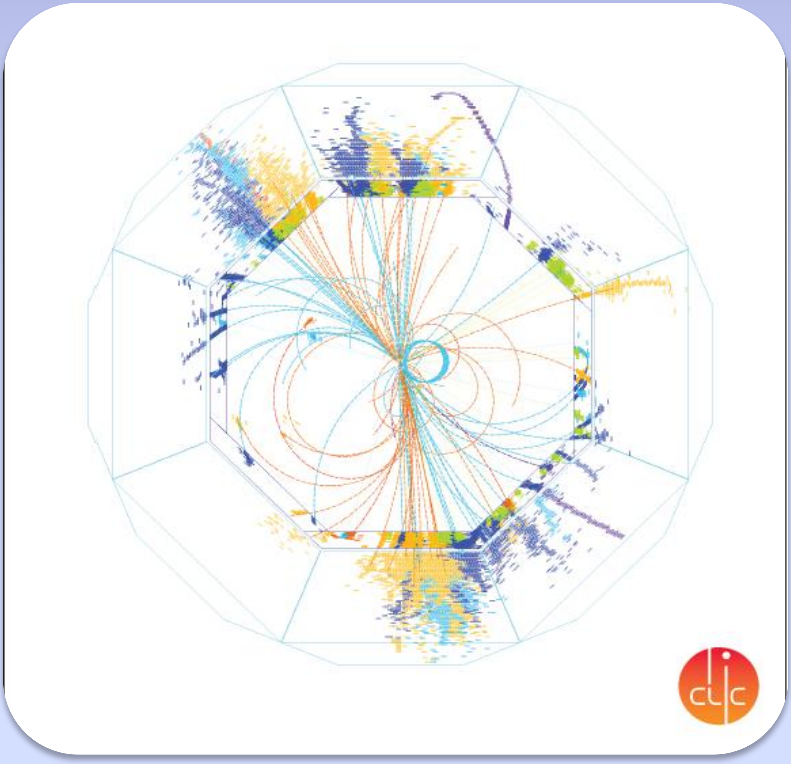
	B10
No stab.	53%/68%
Current stab.	108%/13%
Future stab.	118%/3%

Close to/better than target

The CLIC CDR finally published

Vol 2: Physics and detectors at CLIC

(L.Linssen)



- Physics at a multi-TeV CLIC machine can be measured with high precision, despite challenging background conditions
- External review procedure in October 2011
- Completed and ready for print end 2011, presented in SPC in December 2011 (by Lucie Linssen)

http://cdsweb.cern.ch/record/1425915/

CLIC physics potential

See CDR Volume 2

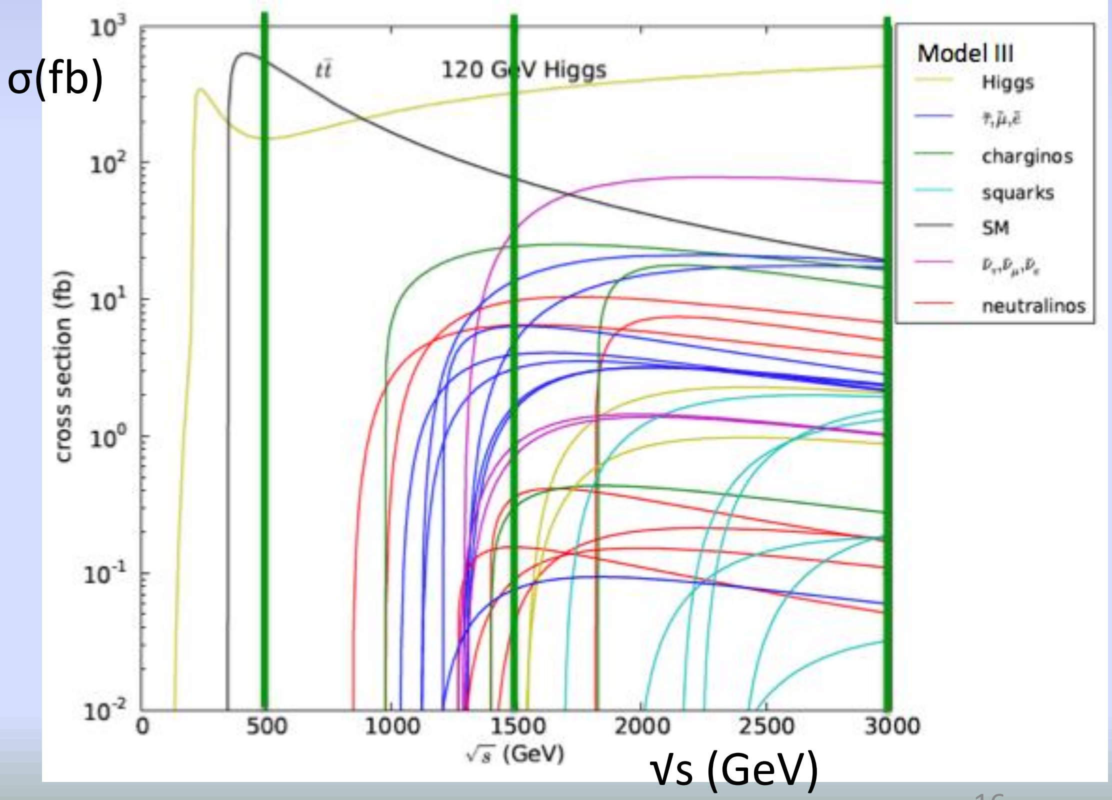
CLIC physics potential is complementary to LHC

Beyond LHC discovery reach:

- e+e- collisions give access to additional physics processes
  - weakly interacting states (e.g. slepton, chargino, neutralino searches)
  - more clean conditions than in LHC
- Defined initial state + more precise measurements

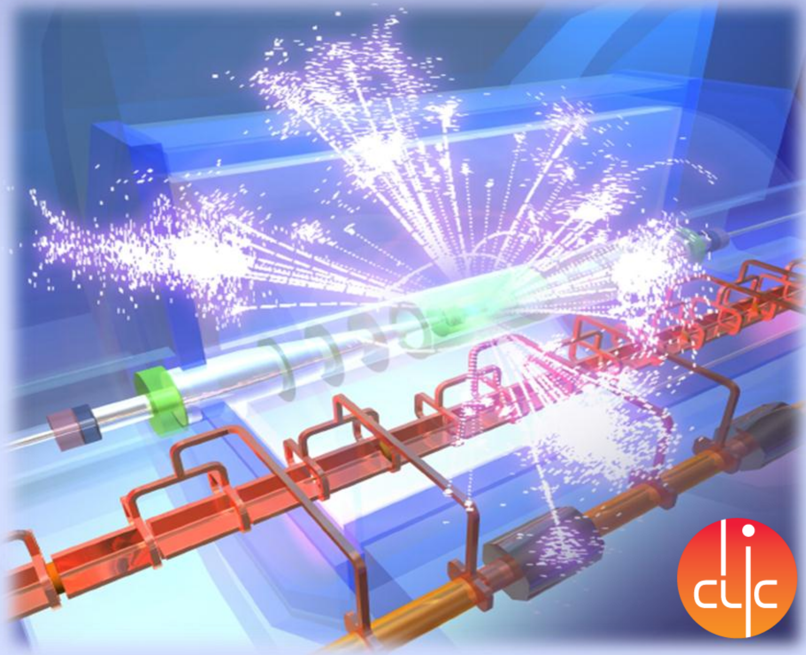
Examples highlighted in the CDR

- Higgs physics (SM and non-SM)
- Top
- SUSY
- Higgs strong interactions
- New Z’ sector
- Contact interactions
- Extra dimensions
- ….



The CLIC CDR finally published

Vol 3: THE CLIC PROGRAMME: TOWARDS A STAGED e+e− LINEAR COLLIDER EXPLORING THE TERASCALE (S.Stapnes)



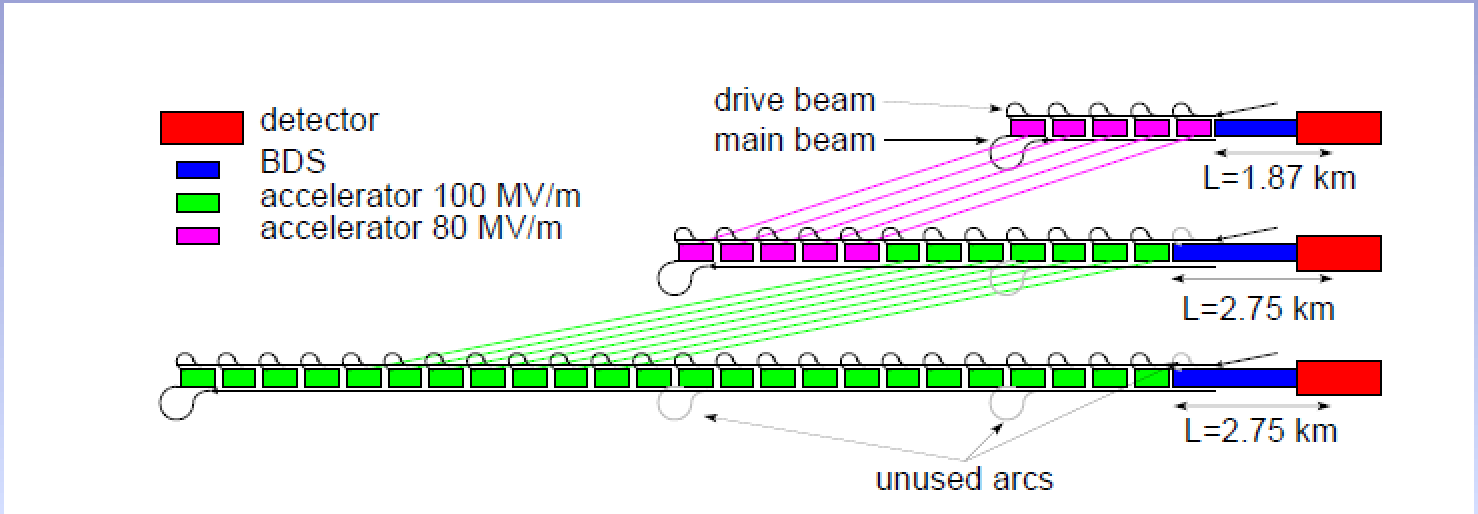
Summary and available for the European Strategy process, including possible implementation stages for a CLIC machine as well as costing and cost-drives
- Proposing objectives and work plan of post CDR phase (2012-16)

Link to the document:
- https://edms.cern.ch/document/1235960/

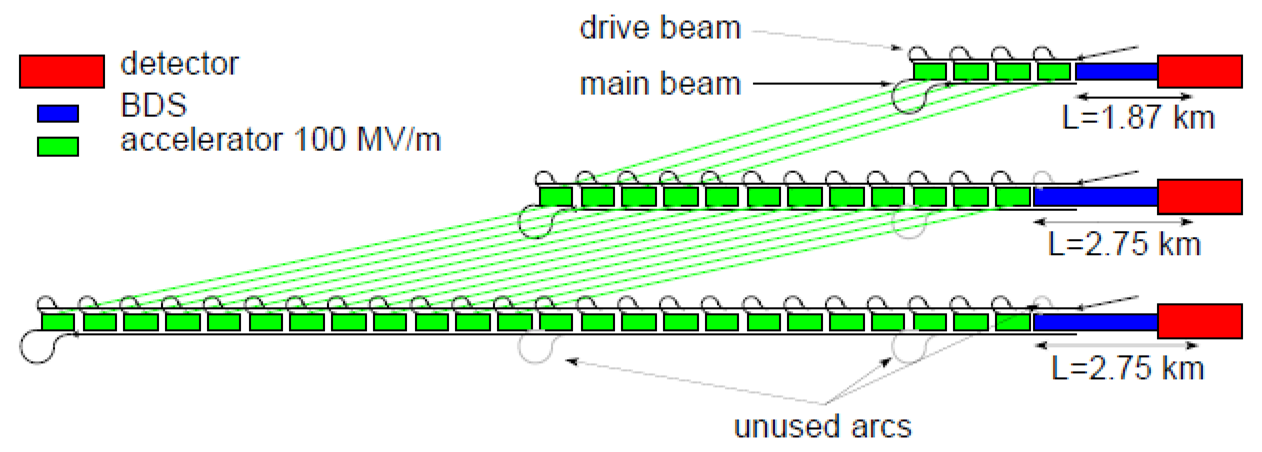
CLIC input to the Strategy Meeting:
- https://indico.cern.ch/abstractDisplay.py/getAttachedFile?abstractId=99&resId=0&confId=175067

CLIC Implementation – in stages?

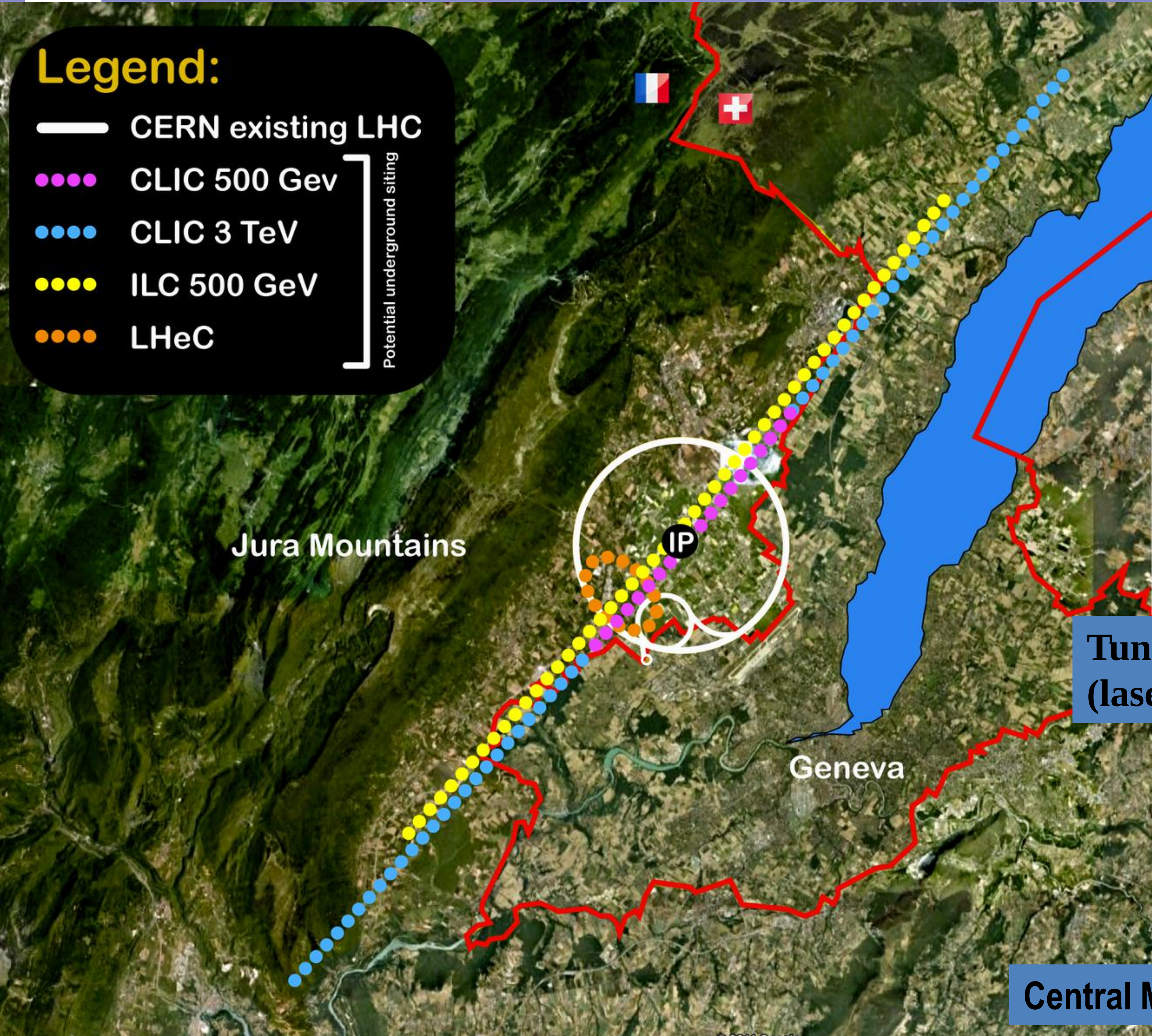
Scenario A, higher 500 GeV luminosity, lower gradient and larger emittance

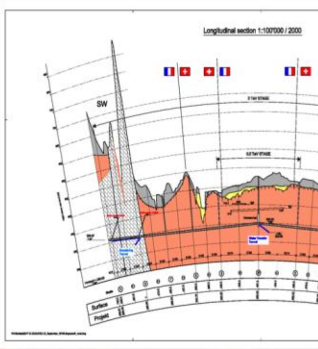


Scenario B, using CLIC 3 TeV design, straight forward and less expensive

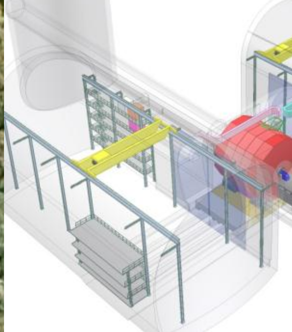


See CDR Volume 3



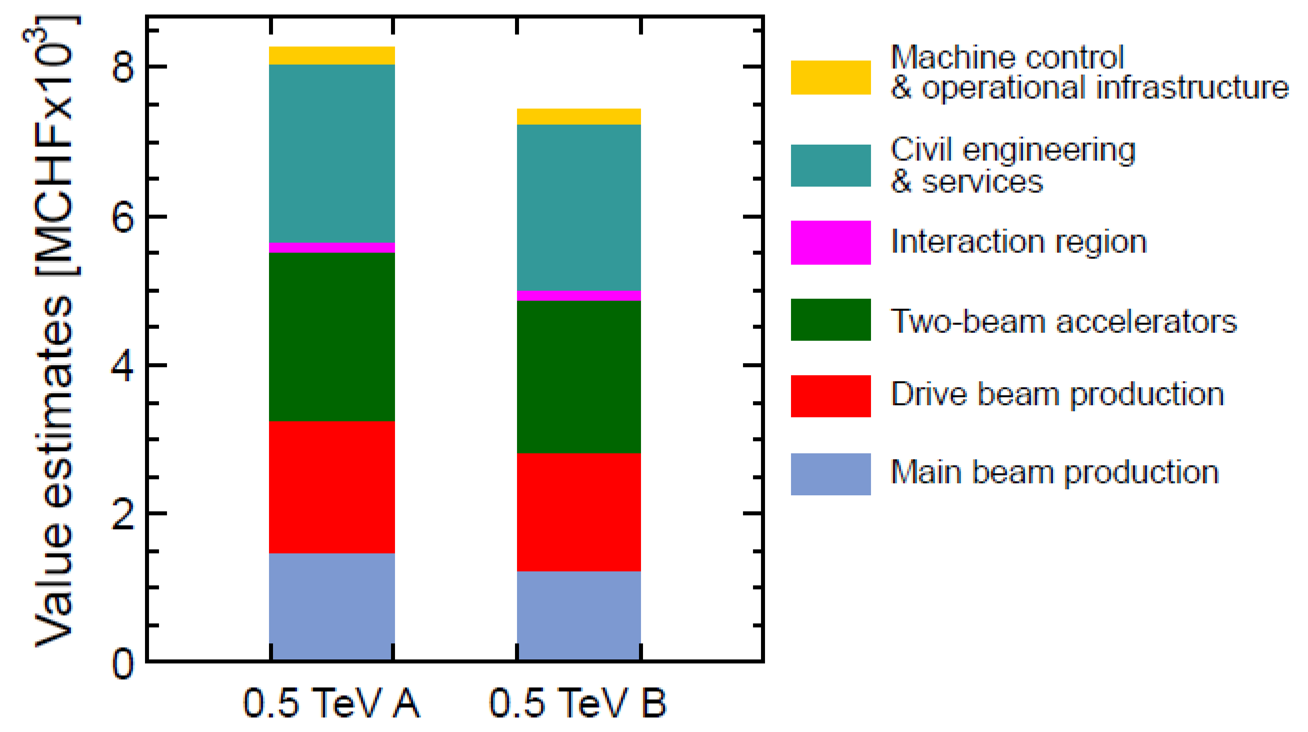


Tunnel implement
(laser straight)



Central MDI & Interactio

Costs

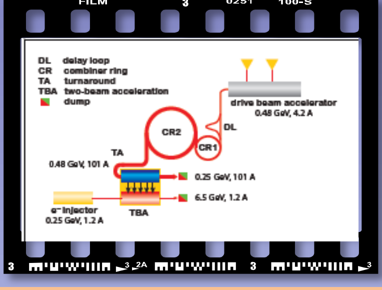


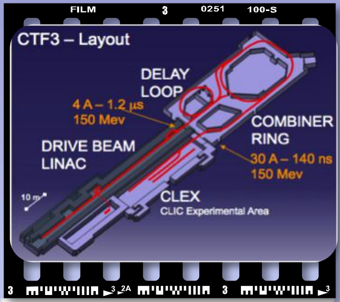
First to second stage: 4 MCHF/GeV (i.e. initial costs are very significant)

Remarks:

- Uncertainties 20-25%
- Possible savings around 10%
- However – first stage not optimised (work for next phase), parameters largely defined for 3 TeV final stage

CLIC project time-line





Final CLIC CDR and feasibility established, also input for the Eur. Strategy Update

From 2016 – Project Implementation phase, including an initial project to lay the grounds for full construction:

- 'CLIC 0' – a significant part of the drive beam facility: prototypes of hardware components at real frequency, final validation of drive beam quality/main beam emittance preservation, facility for reception tests – and part of the final project)
- Finalization of the CLIC technical design, taking into account the results of technical studies done in the previous phase, and final energy staging scenario based on the LHC Physics results, which should be fully available by the time
- Further industrialization and pre-series production of large series components for validation facilities
- Other system studies addressing luminosity issues (emittance conservation) …
- Environmental Impact Study

2004 - 2012

2012 - 2016

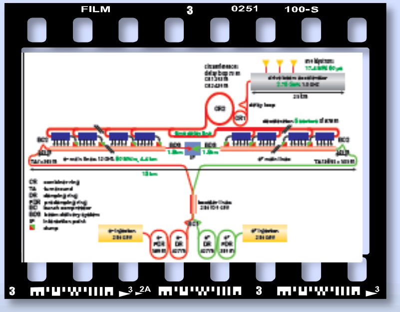
2016 – 2022

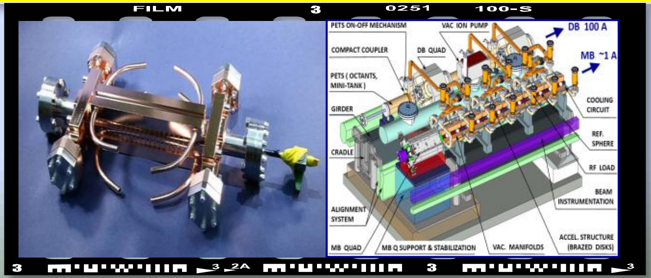
~ 2020 onwards

2011-2016 – Goal: Develop a project implementation plan for a Linear Collider:

- Addressing the key physics goals as emerging from the LHC data
- With a well-defined scope (i.e. technical implementation and operation model, energy and luminosity), cost and schedule
- With a solid technical basis for the key elements of the machine and detector
- Including the necessary preparation for siting the machine
- Within a project governance structure as defined with international partners

CLIC project construction – in stages, making use of CLIC 0

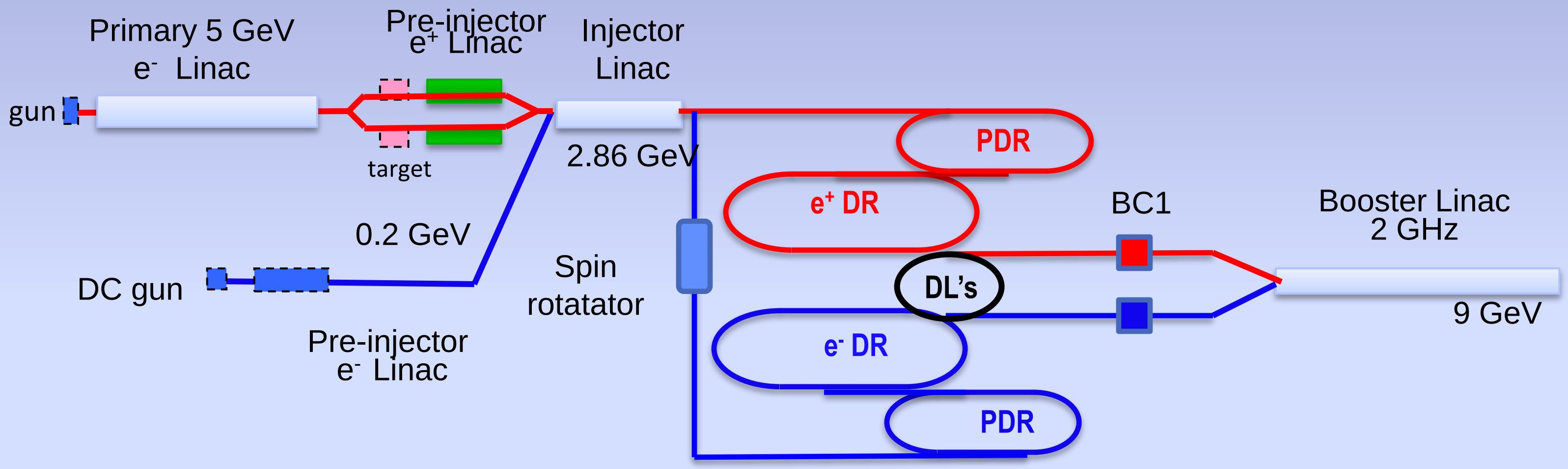




Work-packages and responsibilities

Activity	Workpackage	WP leader
Implementation studies	Civile engineering & services	J. Osborne
P. Lebrun	Project implemenation studies	P. Lebrun
Parameters and Design	Integrated baseline design and parameters	D. Schulte
D. Schulte	Integrated modelling and performance studies	A. Latina
	Feedback Design	D. Schulte
	Main beam electron source	S. Doebert
	Main beam positron source	
	Polarisation	
	Background	D. Schulte
	Damping rings	Y. Papaphilippou
	Ring-to-main linac	A. Latina
	Main linac - two-beam acceleration	D. Schulte
	Beam delivery system	R. Tomas
	Machine-detector interface	L. Gatignon
	Drive beam complex	B. Jeannaret
	Machine protection & operational scenarios	M. Jonker
Experimental Verification	CTF3 consolidation & upgrades	F. Tecker
R. Corsini	Drive Beam phase feed-forward and feed-backs	P. Skowronski
	TBL+, x-band high power RF testing	S. Doebert
	Drive beam source and injector system development	S. Doebert
	Two-beam module string beam tests	R. Corsini
	Drive Beam photo Injector	C. Hessler
	Accelerator Beam system tests (ATF,DR, FACET)	R. Tomas
	Sources beam test	
Technological developments & x-band technology	Damping rings sc wiggler	P.Ferracin
H. Schmickler	Survey & Alignment	H. Mainaud
	Quadrupole stability	K. Artoos
	Two-beam module development	G. Riddone
	Warm magnet prototypes	M. Modena
	Beam instrumentation	T. Lefevre
	Collimation, mask and beam dumps	
	Controls	M. Draper
	RF systems (1GHz klystron & DB cavities, DR RF)	S. Doebert
	Powering (modulators, magnet converters)	D.Nisbet
	Vacuum systems	C. Garion
	Magnetic stray fields	S. Russenschuck
	DR extraction sytems	M. Barnes
	Creation of an 'in house' technology center	F. Bertinelli
W. Wuensch	X-band structure design	A. Grudiev, I. Syratchev
	X-band rf structure production	G. Riddone
	X-band structure high power testing	S. Doebert
	Creation and operation of x-band high power testing facilities	I. Syratchev, G. McMonagle
	Basic high gradient R&D	S. Calatroni

CLIC Main Beam Injectors Layout



- Two hybrid positron sources (only one needed for 3 TeV)
- Common injector linac
- All linac's at 2 GHz , bunch spacing 1 GHz before the damping rings

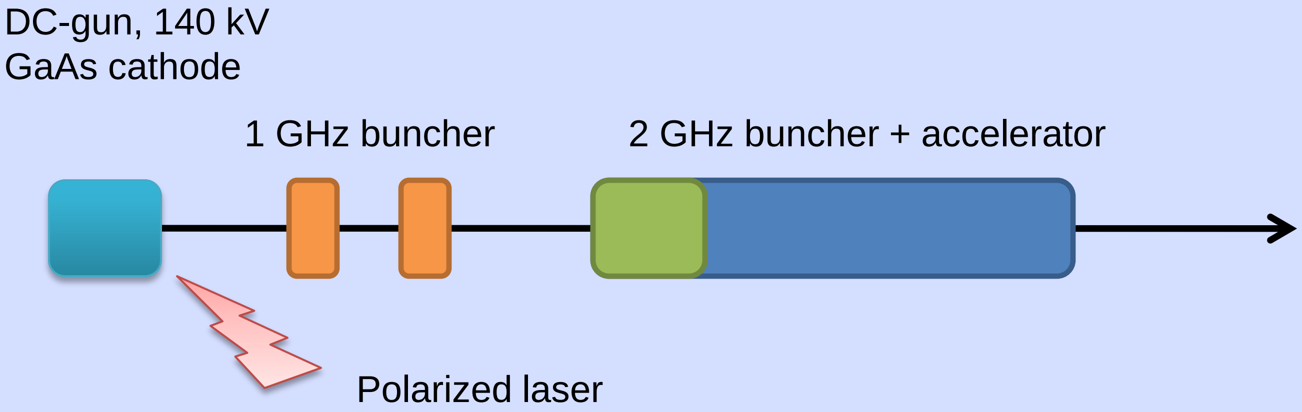
Injector Beam parameters

Parameter	Unit	CLIC polarized electrons	CLIC positrons	CLIC booster
E	GeV	2.86	2.86	9
N	10^9	4.3/7.8	4.3/7.8	3.75/6.8
n_b	-	312/354	312/354	312/354
Δt_b	ns	1	1	0.5
t_{pulse}	ns	312/354	312/354	156/354
$\varepsilon_{x,y}$	μm	< 100	7071, 7577	$600,10 \cdot 10^{-3}$
σ_z	mm	< 4	3.3	$44 \cdot 10^{-3}$
σ_E	%	< 1	1.63	1.7
Charge stability shot-to-shot	%	0.1	0.1	0.1
Charge stability flatness on flat top	%	0.1	0.1	0.1
f_{rep}	Hz	50	50	50
P	kW	29	29	85

500 GeV

Polarized electron source

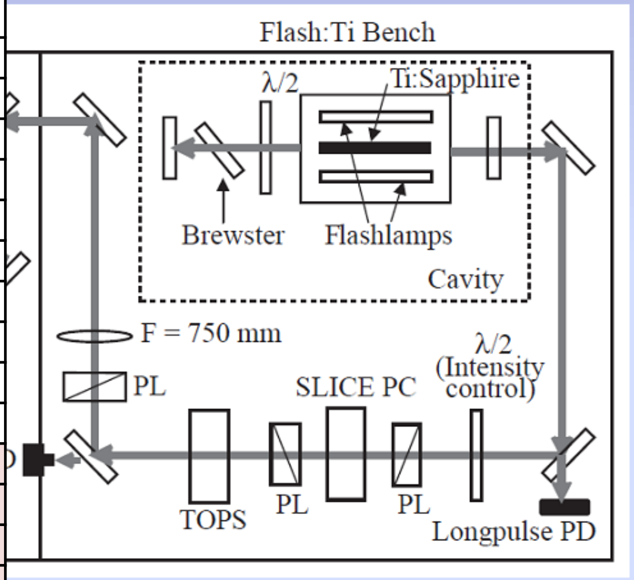
- Classical polarized source wit bunching system
- Charge production demonstrated by SLAC experiment
- Simulations showed 87 % capture efficiency (F. Zou, SLAC)



Polarized electron source parameters

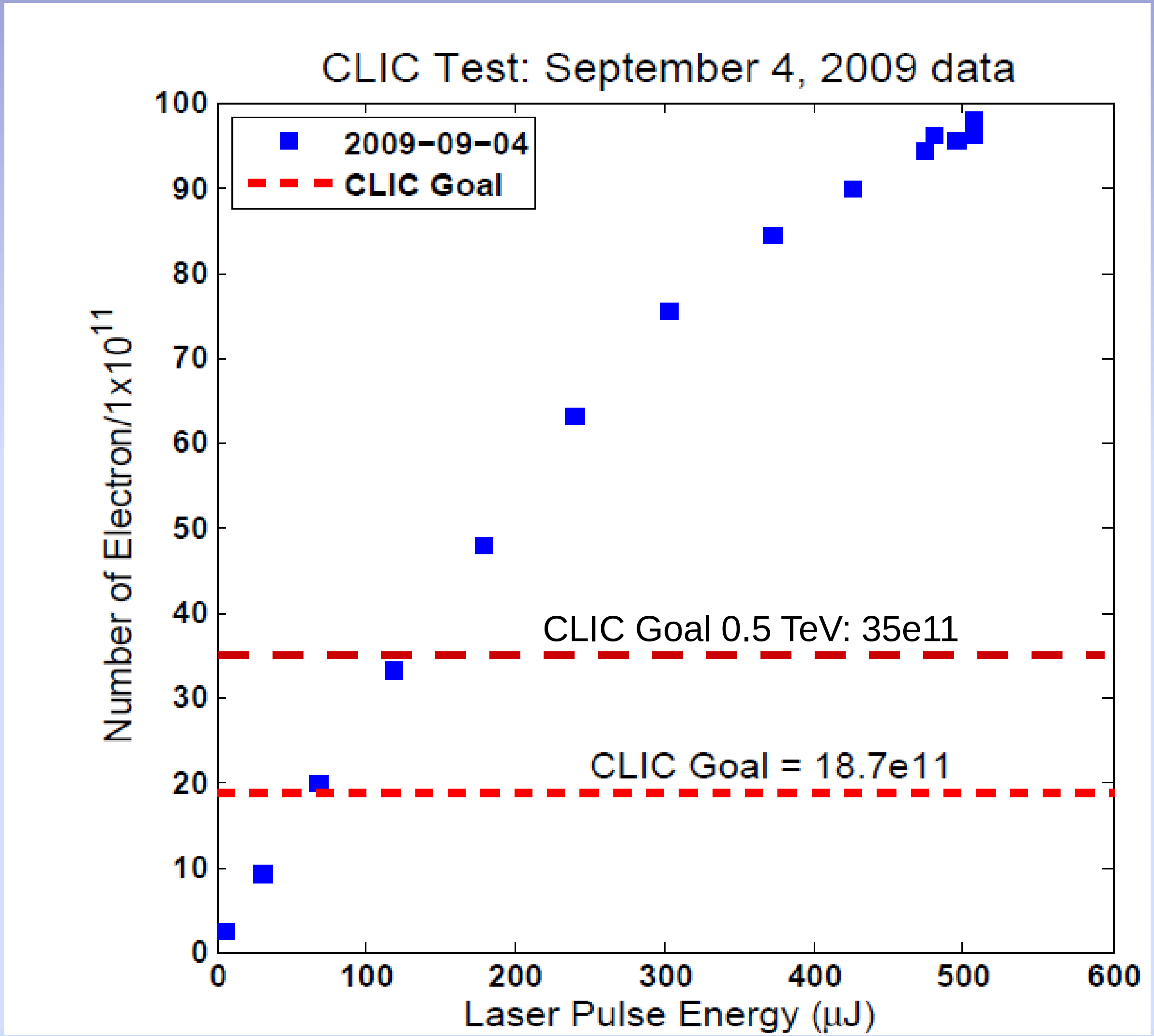
		POLARIZED SOURCE FOR CLIC	
		CLIC 1 GHz	CLIC DC/ SLAC Demo
Number of electrons per bunch (*10^9)	**Electrons**	3.72	1365
Charge/single bunch (nC)		0.96	NA
Charge/macrobunch (nC)		300	300
Bunch spacing(ns)		1	DC
RF frequeny (GHz)		1	DC
Bunch length at cathode (ps)		100	DC
Number of bunches		312	NA
Repetition rate (Hz)		50	50
QE(%)		0.3	0.3
Polarization		>80%	>80%
Circular polarization		>99%	>99%
Laser wavelength (nm)	**Laser**	780-880	865
Energy/micropulse on cathode (nJ)		509	NA
Energy/macropulse on cathode (μJ)		159	190
Energy/micropulse laser room (nJ)		1526	NA
Energy/macrop. Laser room (μJ)		476	633
Mean power per pulse (kW)		1.5	2
Average power at cathode wavelength(mW)		8	9.5

Laser scheme



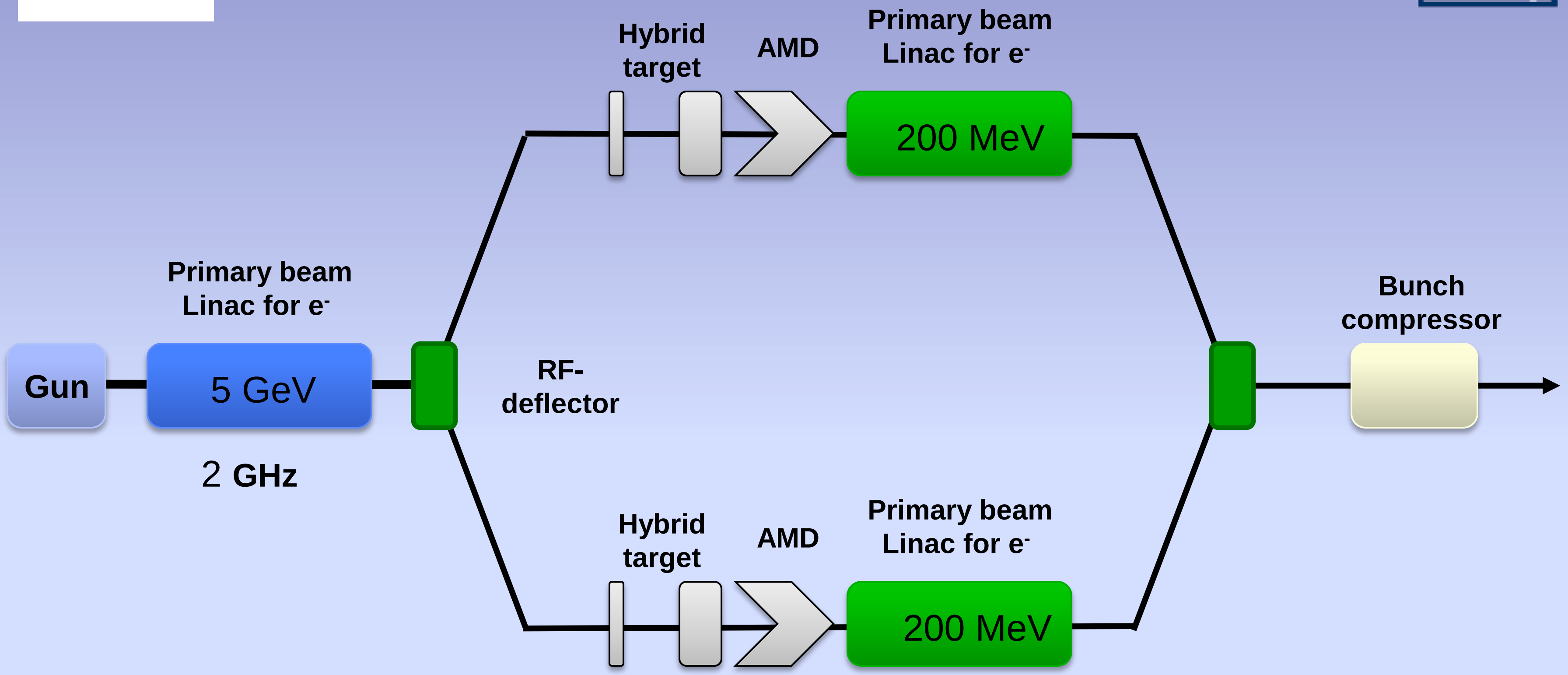
For the 1 GHz approach cathode current densities of 3-6 A/cm^2 would be needed, the dc approach uses < 1 A/cm^2

Polarized electron source



J. Shepard

Positron source conventional ?



AMD: 200 mm long, 20 mm radius, 6T field

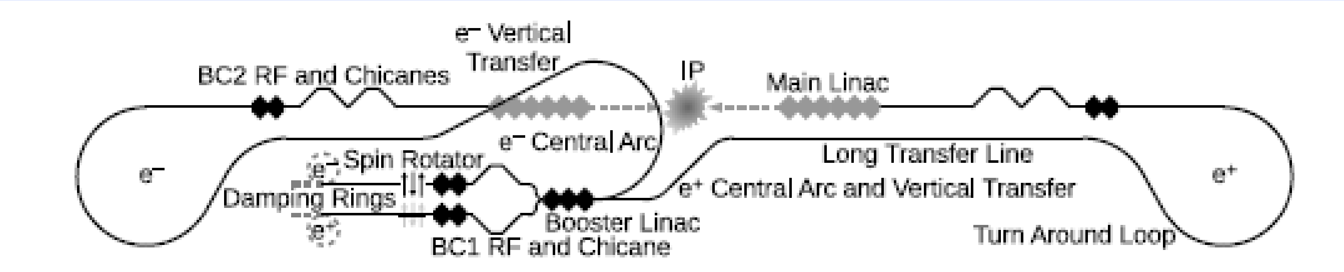
Target Parameters Crystal		
Material	**Tungsten**	**W**
Thickness (radiation length)	**0.4**	χ_0
Thickness (length)	**1.40**	**mm**
Energy deposited	**~1**	**kW**

Target Parameters Amorphous		
Material	**Tungsten**	**W**
Thickness (Radiation length)	**3**	χ_0
Thickness (length)	**10**	**mm**
PEDD	**30**	**J/g**
Distance to the crystal	**2**	**m**

Bunch compressors

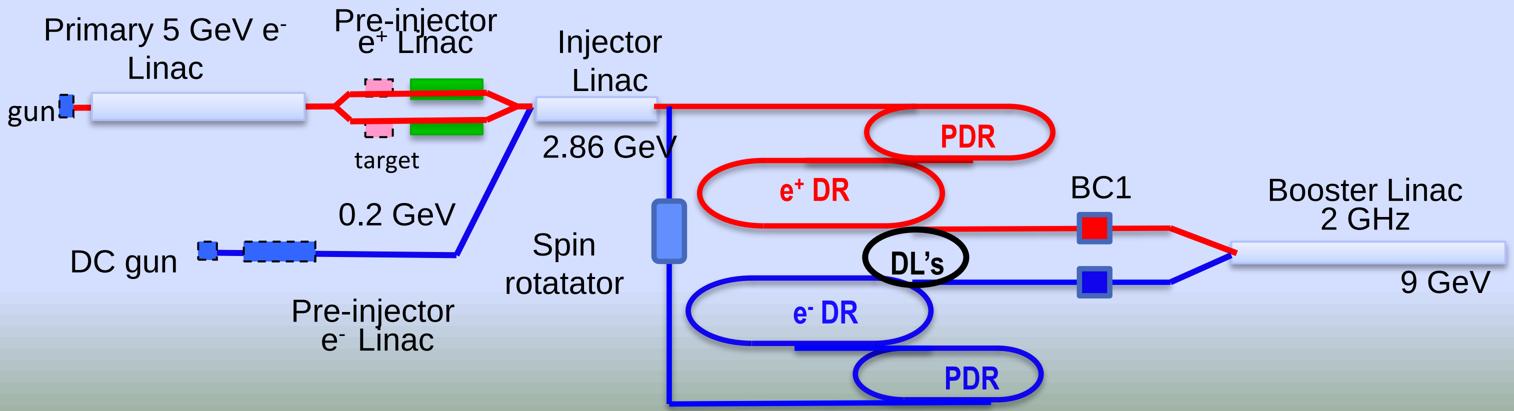
Two stages of bunch compressors, CSR, wake fields and tolerances have been studied

	BC1, 2.86 GeV	BC2, 9 GeV
Rf frequency	2 GHz, 15 MV/m	12 GHz, 74 MV/m
Phase tolerance	0.1 deg	0.1 deg
Bunch length after compression	300 μm factor 5.3	44 μm factor 6.8
Enegy spread after compression	0.25 %	1.7 %
Voltage	447 MV	1776 MV



Linac Parameters and cost

LINAC	Energy Gain (MeV)	Bunch charge (10^9)	rf pulse length (ns)	Power per structure (MW)	Loaded gradient (MV/m)	Configuration (structure/2 klystrons)	No of rf modules	pulse compressor gain	No of structures	Length (m)	Energy gain per module (MeV)	Cost
e- pre-injector	200	4.3	1300-1700	54	18	4	2	2.3-2.5	8.0	30	108	5830
e+ pre-injector	200	11	1300-1700	56	15	4	3	2.3-2.5	9.0	40	90	8745
injector linac	2660	6	3600-4000	44	15	2	60	1	119.0	300	45	127950
positron drive linac	5000	11	1300-1700	56	15	4	56	2.3-2.5	223.0	400	90	163240
booster linac	6140	4	1700-2000	53	16	4	64	2-2.3	256.0	473	96	186560



Conclusion

- Big milestone for CLIC, CDR finally published
- Developed interesting research program with the collaboration for next phase
- Unfortunately not much news beyond the conceptual design on the main beam injectors due to limited resources

  Your help is welcome !

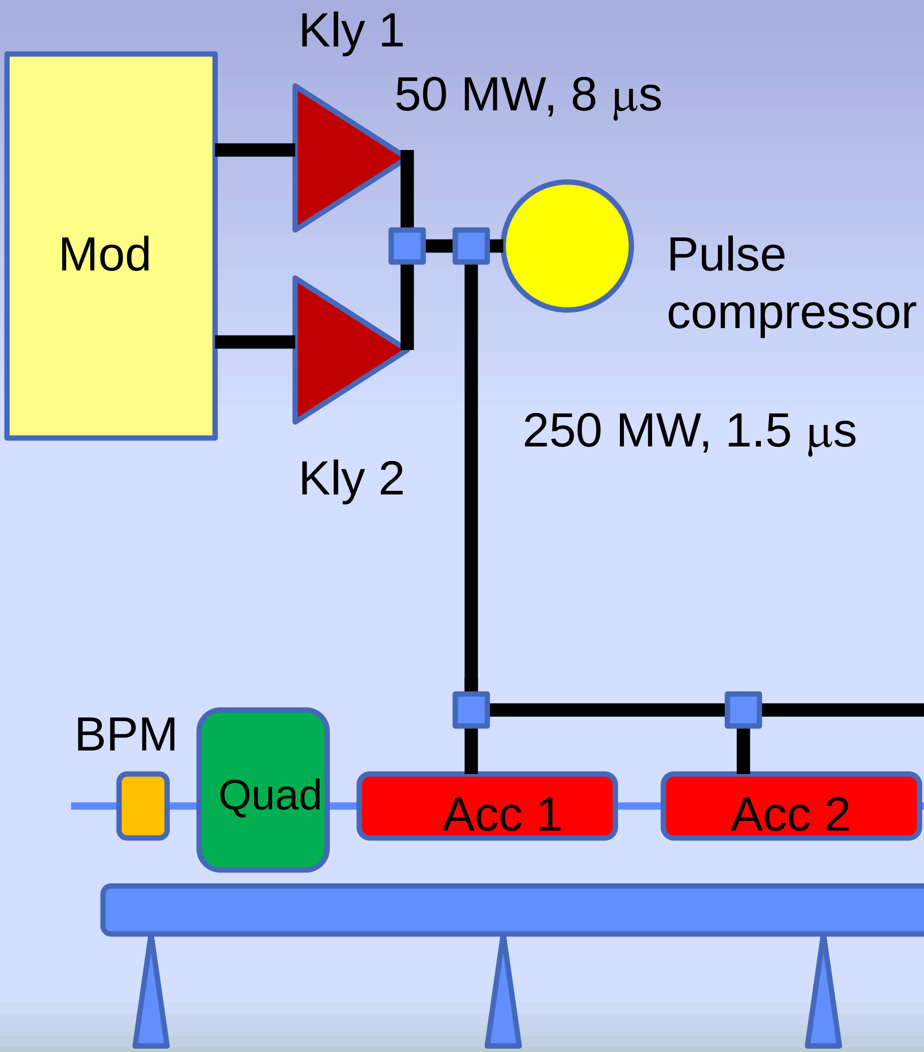
End

Primary electron beam and linac

Parameters		
Energy	5	GeV
Number of e^- / bunch	1.1×10^{10}	
Charge / bunch	1.8	nC
Bunches per pulse	312	
Pulse repetition rate	50	Hz
Beam radius (rms)	2.5	mm
Bunch length (rms)	1	ps
Beam power	140	kW

- Can be done with thermionic gun or photo injector (CTF3 and Phin are nice references)
- 2 GHz rf system as used for other injector linac's

Injector linac rf system

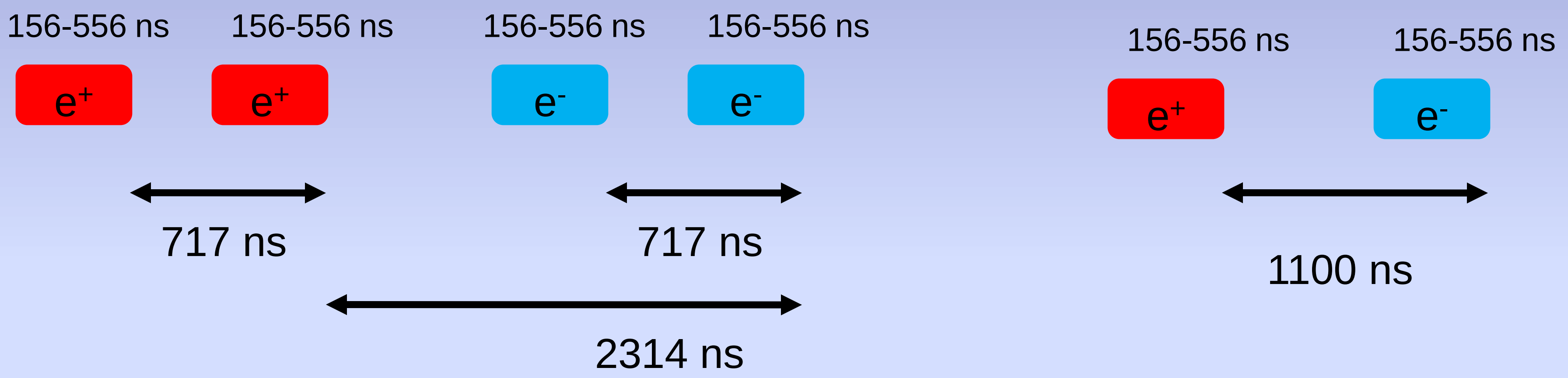


Structure Parameter	Value
Frequency	1998 MHz
Structure length (30 cells)	1.5 m
Filling time	389 ns
Cell length and iris thickness	50 mm, 8 mm
Shunt impedance	54.3 – 43.3 MΩ/m
Aperture a	20 – 14 mm
Cell size b	64.3 – 62.9
Group velocity vg/c	2.54 -0.7 %
Phase advance per cell	2π/3

Beam timing and operational modes

Before damping ring
(1 GHz bunch spacing)

After damping ring
(2 GHz bunch spacing)



156-556 ns 156-556 ns 156-556 ns 156-556 ns

e^+ e^+ e^- e^-

717 ns

717 ns

2314 ns

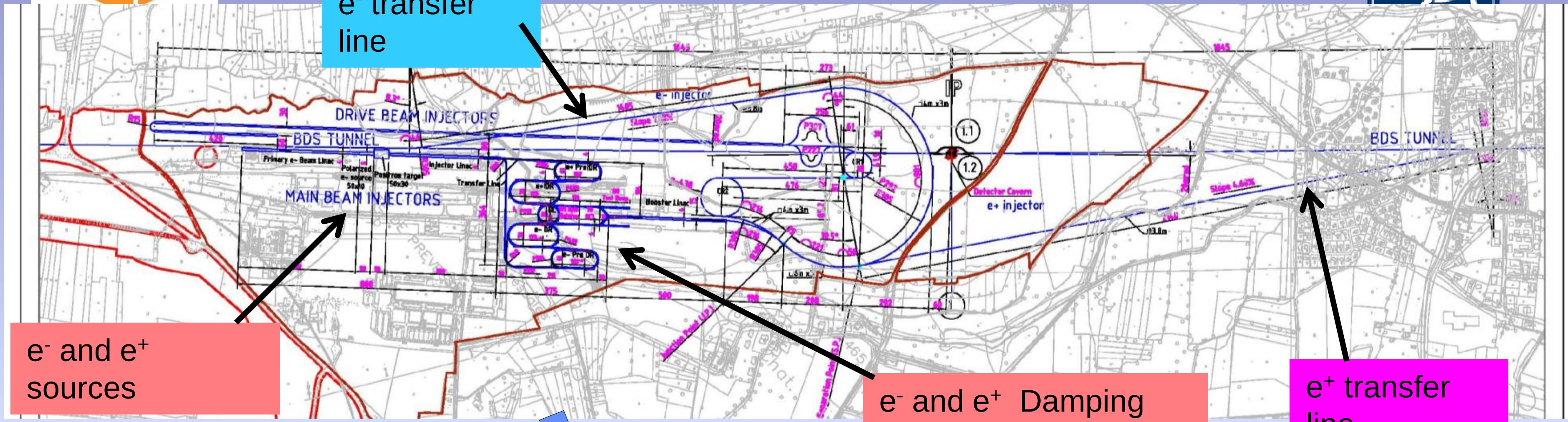
156-556 ns 156-556 ns

e^+ e^-

1100 ns

Operational mode	Charge per bunch (nC)	Number of bunches
Nominal	0.6	312
500 GeV	1.2	312
Low energy scans	0.6, 0.45, 0.4, 0.3, 0.23	312, 472, 552, 792, 1112

CLIC Main Beam complex



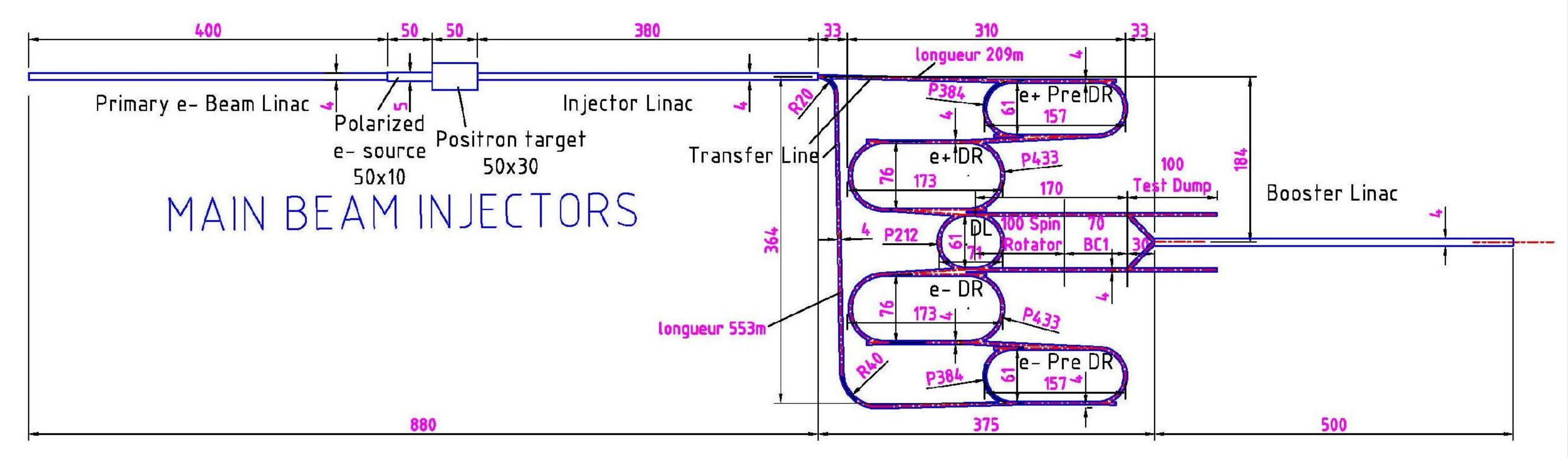
e$^-$ transfer line

e$^-$ and e$^+$ sources

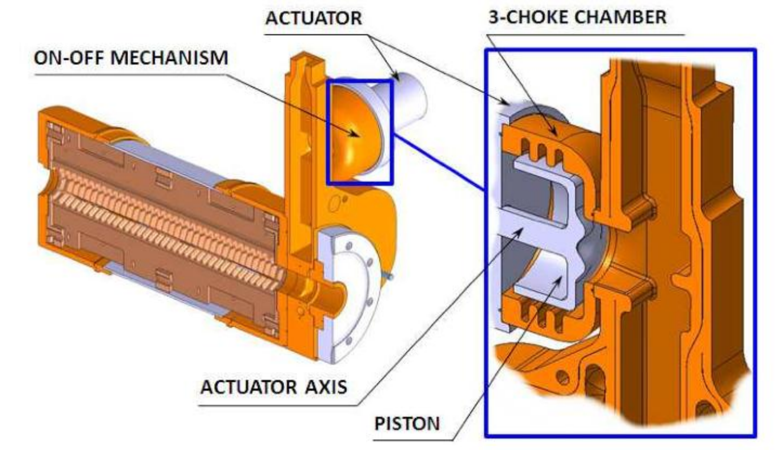
e$^-$ and e$^+$ Damping Rings

e$^+$ transfer line

Zoom



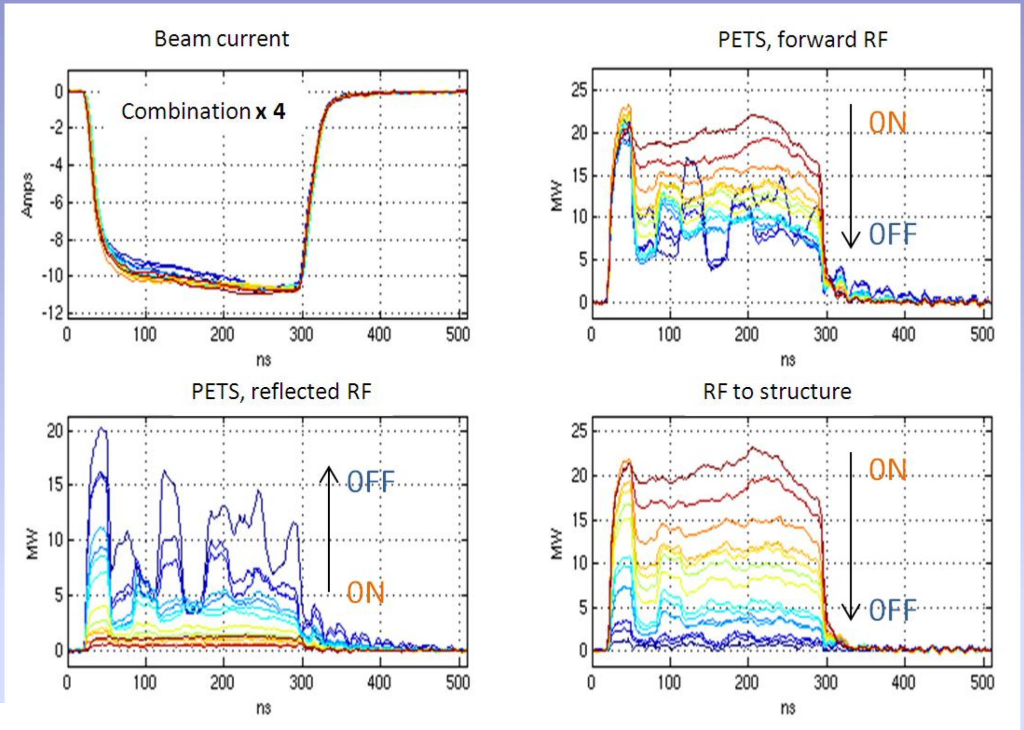
TBTS – PETS On-off mechanism

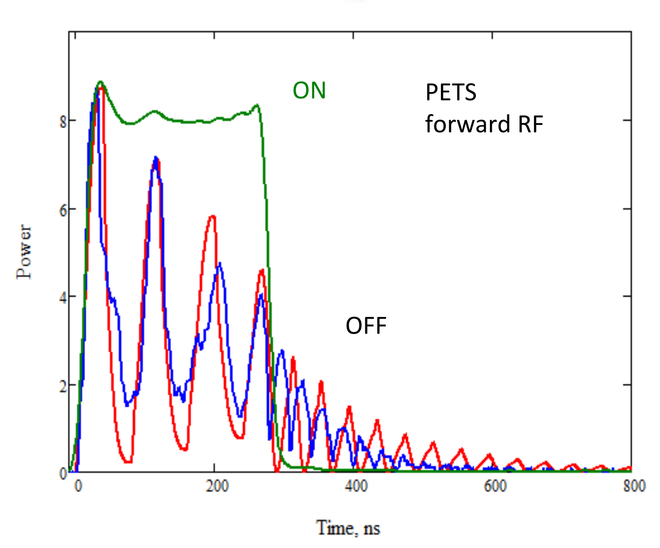


I. Syratchev,
A. Dubrowski

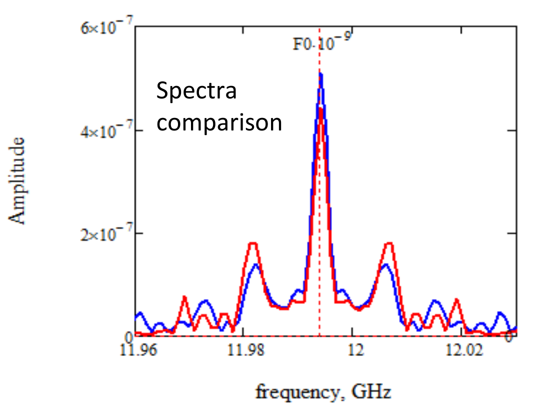
Demonstration of PETS of-off mechanism

- Considered a feasibility issue
- Ability to:
  - Switch off power from individual PETS to accelerating structure in case of breakdown
  - Reduce substantially power in PETS, to cope with PETS breakdowns
- PETS on-off principle fully tested
- Conditioned at high power (135 MW - nominal) by recirculation





Simulation vs. experiment



Possible luminosity scenarios