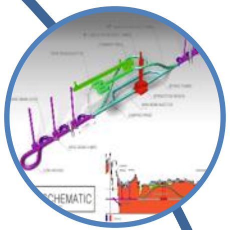
The Drive Beam front-end in the CTF3 building

- DB injector introduction
- Beam dynamics design
- Status and planning of hardware
  - gun
  - bunching system
  - klystron, accelerating structure
- Implementation in the CTF3 building
- Conclusions and outlook

Thanks to Steffen Döbert for the material!

LINEAR COLLIDER COLLABORATION

Main activities



Parameters, Design and Implementation

- Integrated Baseline Design and Parameters
- Feedback Design, Background, Polarization
- Machine Protection & Operational Scenarios
- Electron and positron sources
- Damping Rings
- Ring-To-Main-Linac
- Main Linac - Two-Beam Acceleration
- Beam Delivery System
- Machine-Detector Interface (MDI

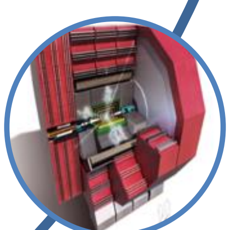
X-band Technologies

ng

Experimental verification

- Drive Beam phase feed-forward and feedbacks
- Two-Beam module string, test with beam
- Drive-beam front end including modulator development and injector
- Modulator development, magnet converters
- Drive Beam Photo Injector
- Low emittance ring tests
- Accelerator Beam System Tests (ATF and FACET, others)

- Two-Beam module development
- Beam Intercepting Devices
- Controls
- Vacuum Systems

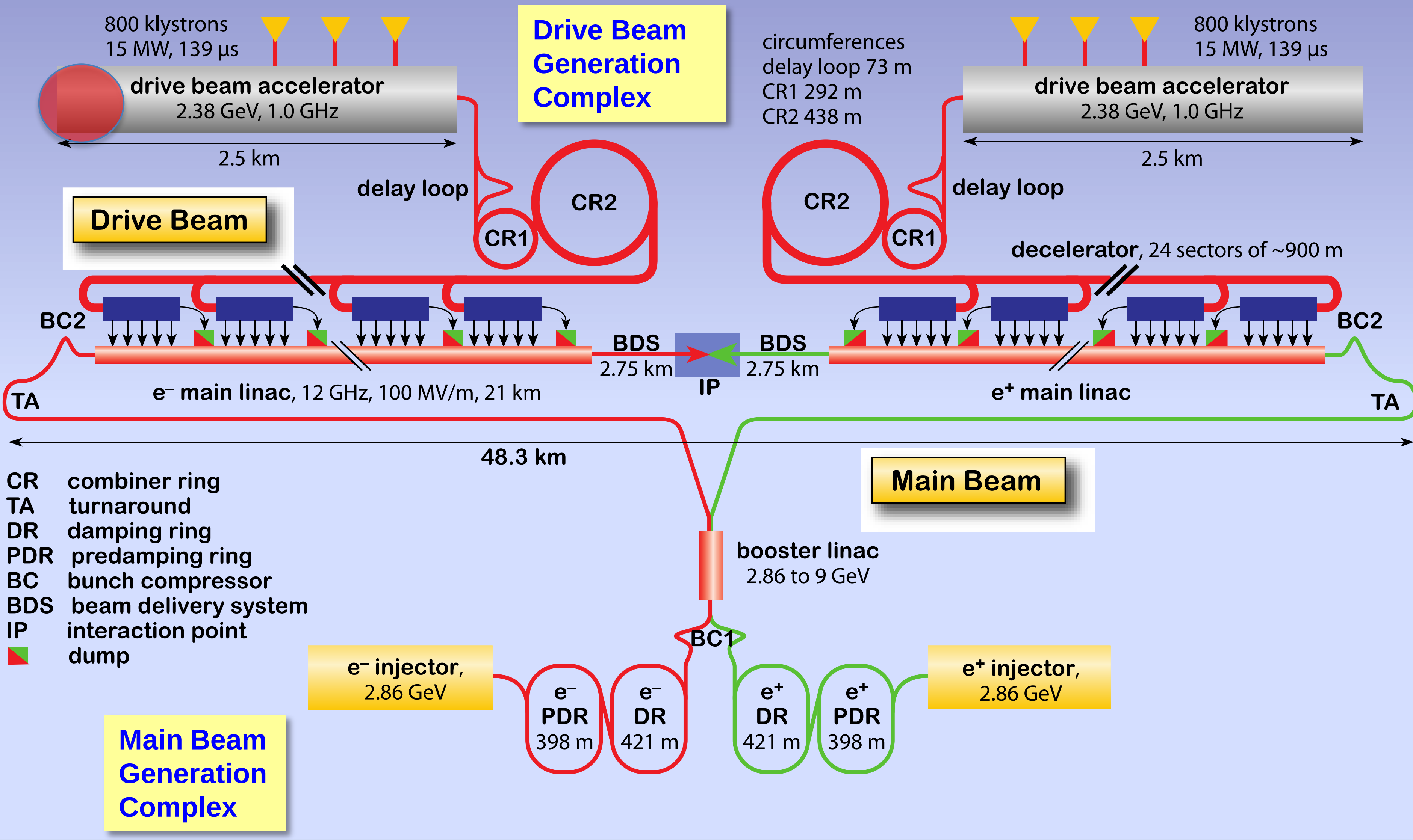


Detector and Physics

- Physics studies and benchmarking
- Detector optimisation
- Technical developments

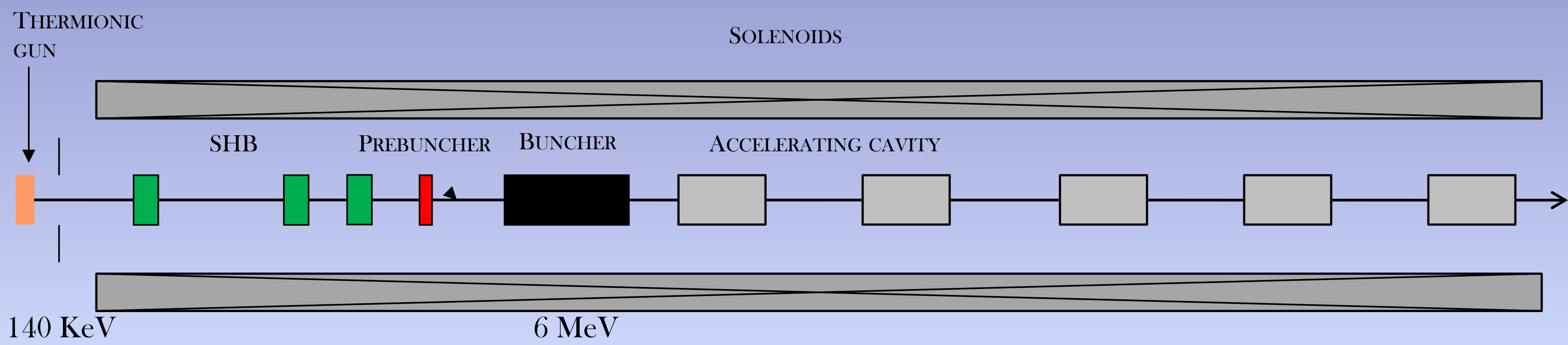
Steinar Stapnes

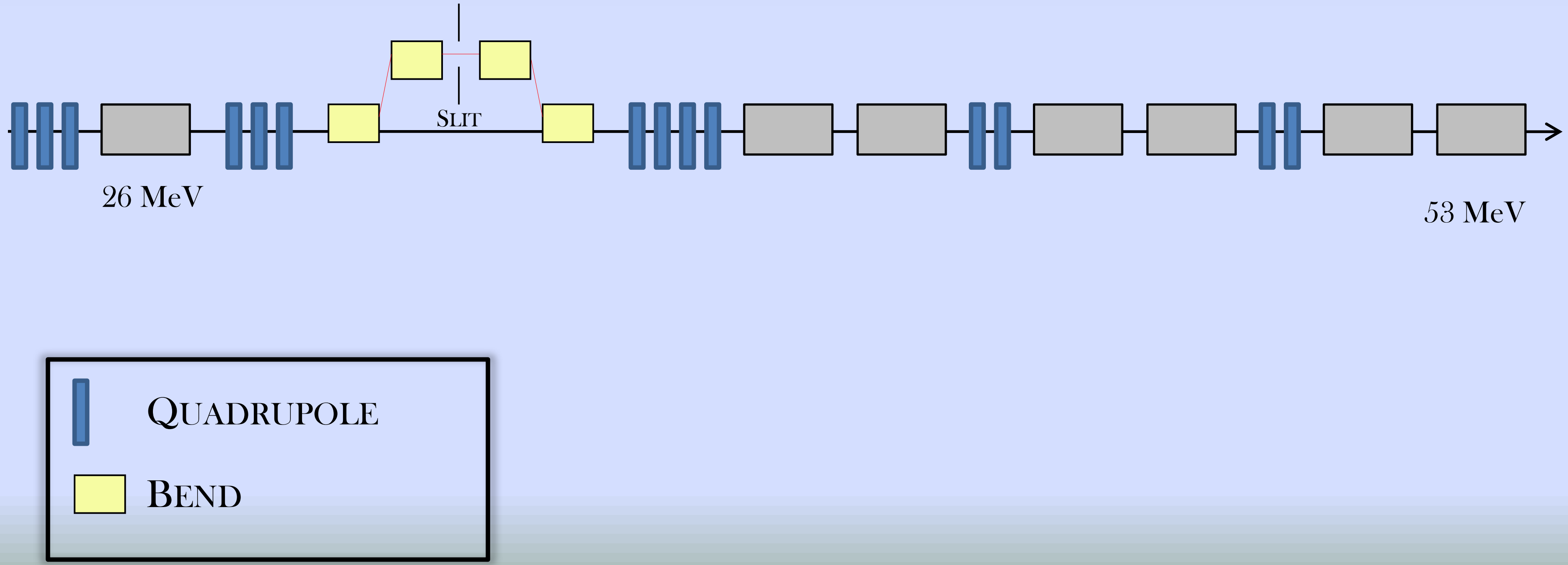
CLIC Layout at 3 TeV



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 injector layout



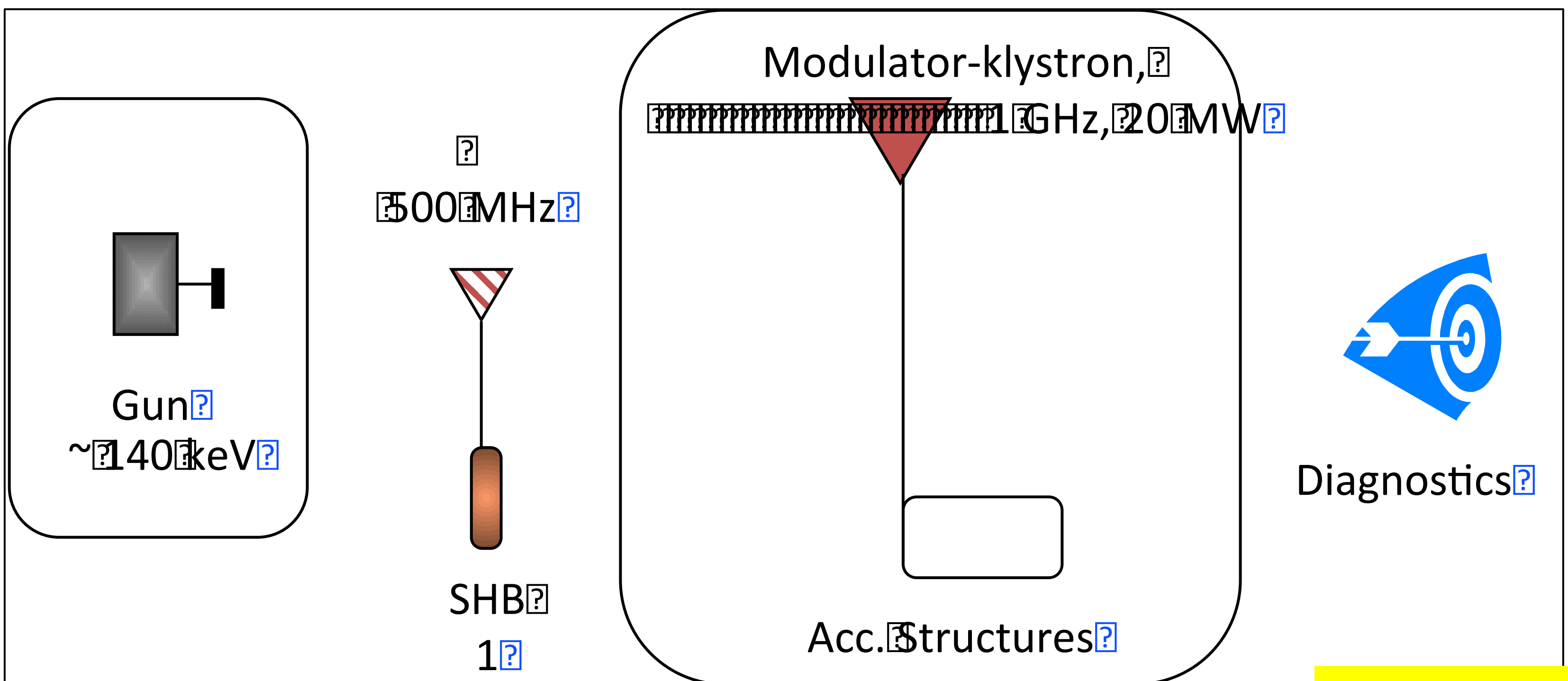


CLIC DB injector specifications

Parameter	Nominal value	Unit
Beam Energy	50	MeV
Pulse Length	**140.3** / 243.7	μs / ns
Beam current	4.2	A
Bunch charge	**8.4**	nC
Number of bunches	70128	
Total charge per pulse	**590**	μC
Bunch spacing	**1.992**	ns
Emittance at 50 MeV	100	mm mrad
Repetition rate	100	Hz
Energy spread at 50 MeV	1	% FWHM
Bunch length at 50 MeV	3	mm rms
Charge variation shot to shot	**0.1**	%
Charge flatness on flat top	**0.1**	%
Allowed satellite charge	< 7	%
Allowed switching time	5	ns

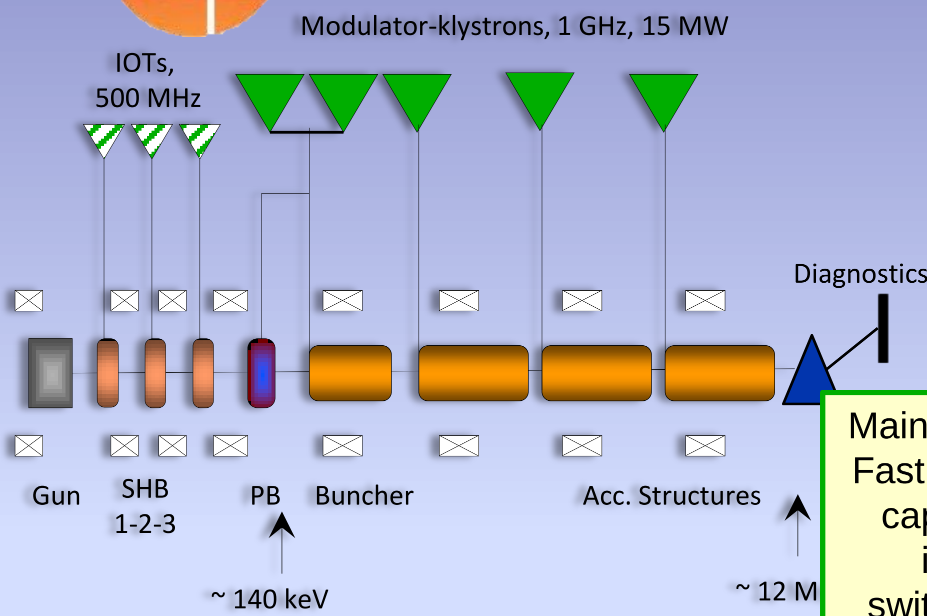
CLIC system tests beyond CTF3

- Drive beam development beyond CTF3
  - RF unit prototype with industry using CLIC frequency and parameters
  - Drive beam front-end (injector), to allow development into larger drive beam facility beyond 2018

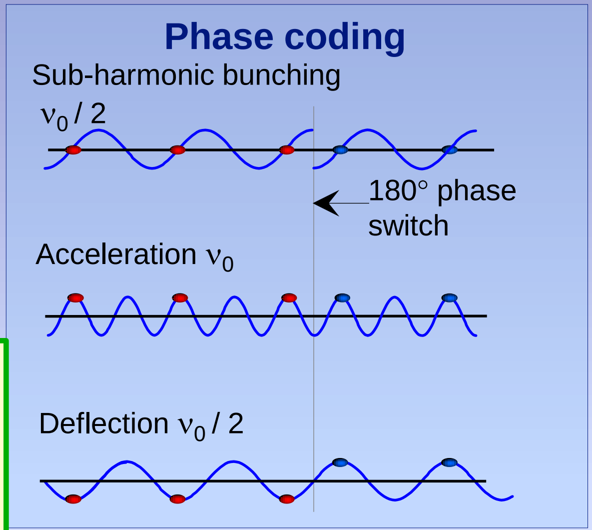


Steinar Stapnes

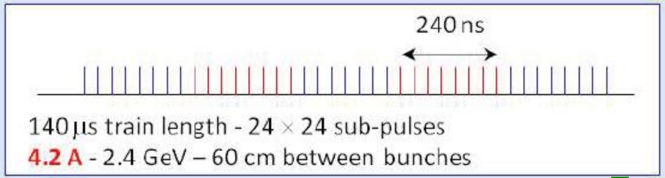
Sub Harmonic Bunchers (SHBs)



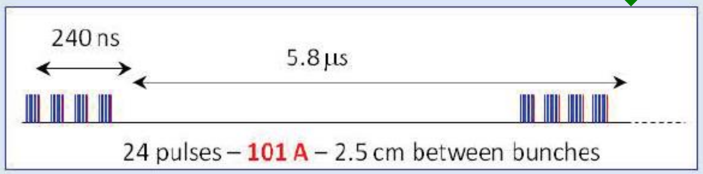
Main challenge of SHBs: Fast 180° phase flipping capability, simulation indicate < 18 ns switching time needed



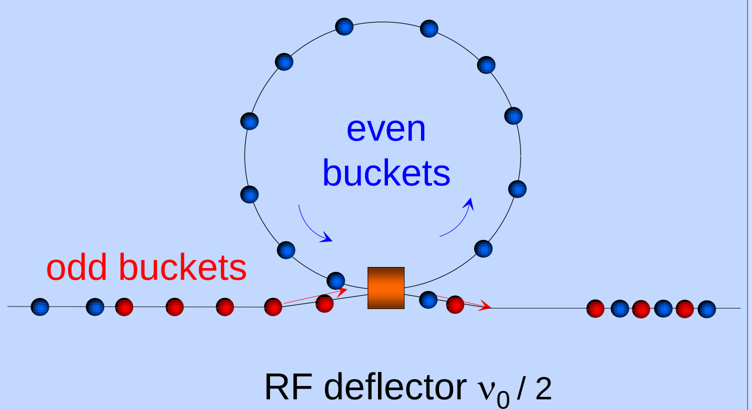
Drive beam time structure - initial



Drive beam time structure - final

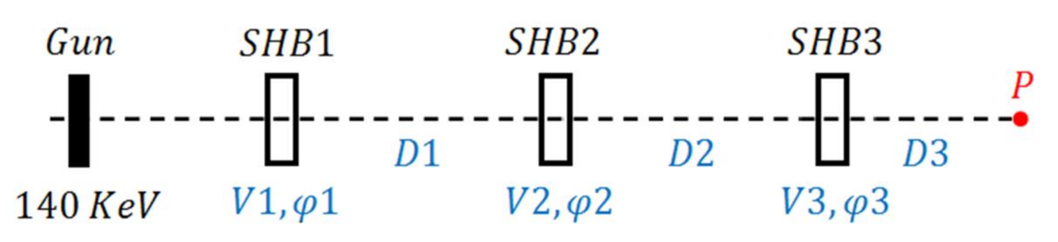


Gap creation and combination



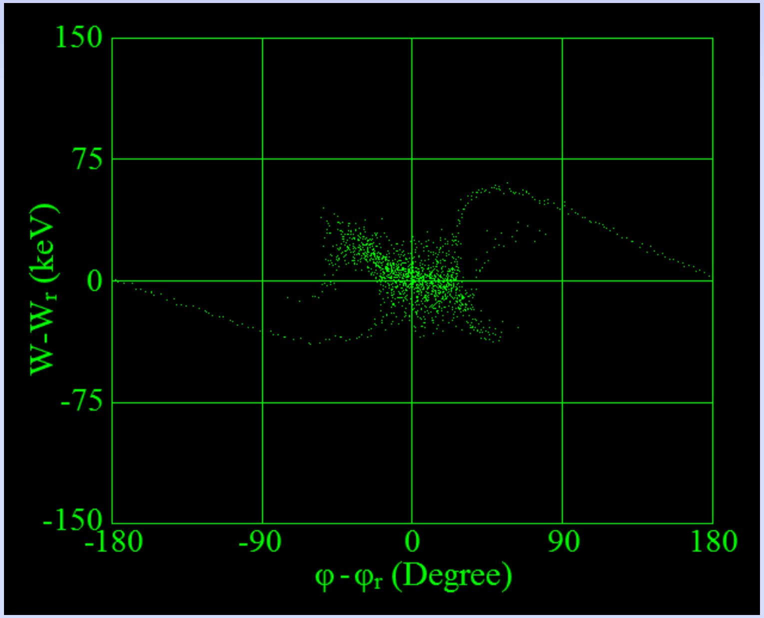
DB injector optimization

Optimization of the SHB system



SHB	V (kV)	D (cm)	Satellite (%)
1	15	220	25.8
2	30	95	10.6
3	45	50	3.9

Particle population in [-60, 60]: 93.3%

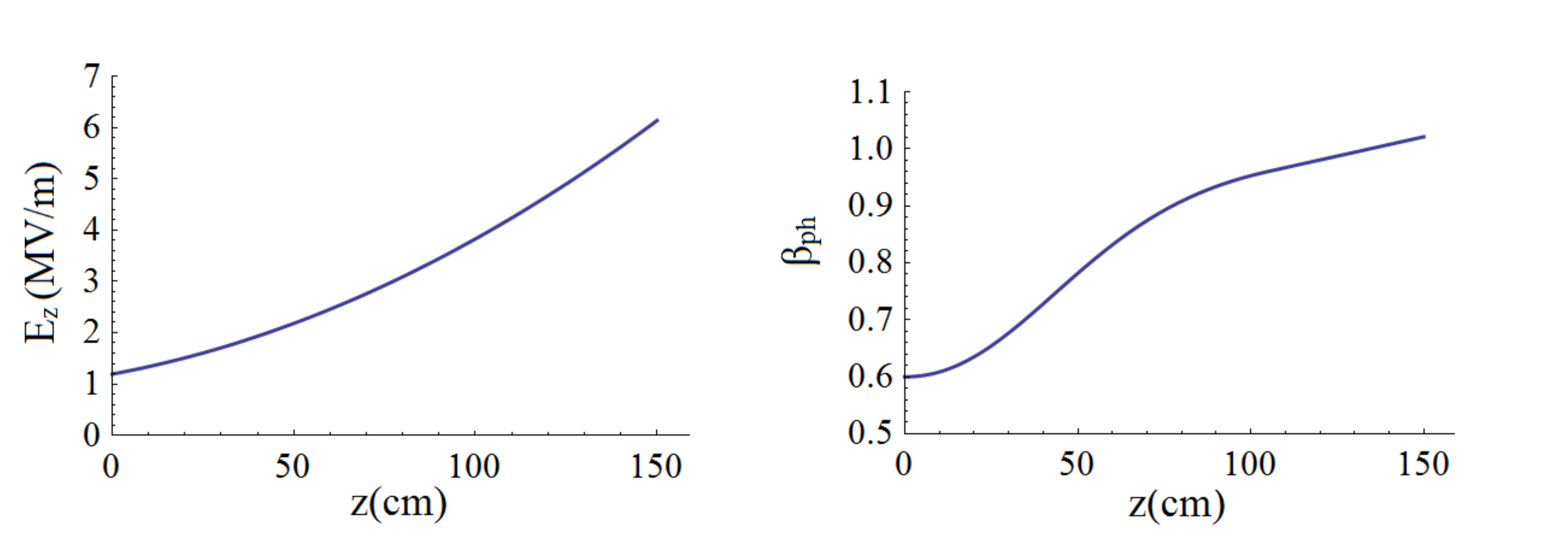


Additional 1 GHz pre-buncher for further optimization

Shahin Sanaye Hajari

DB injector optimization

Optimization of the TW buncher structure

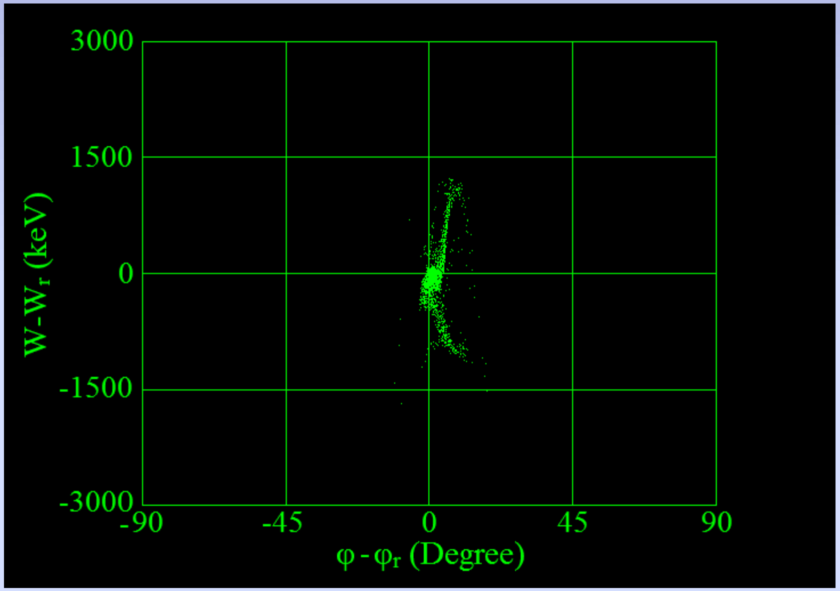


Parameter	Value
E_{min} [MV/m]	1.23
E_{max} [MV/m]	5.72
L [cm]	147
P [MW]	~20

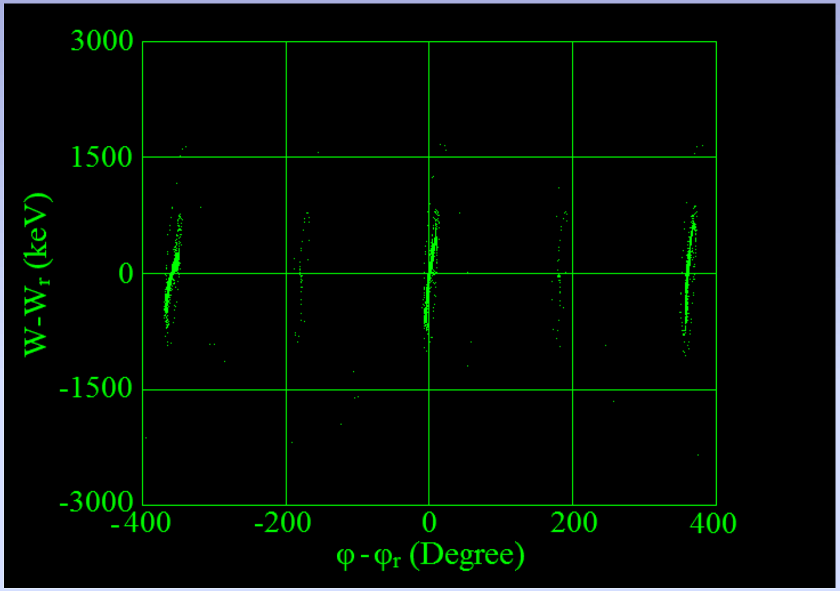
Shahin Sanaye Hajari

DB injector optimization

Final phase space at 50 MeV



phase space after TW buncher



Parameter	Value
σ_L [mm]	2.64
σ_W [MeV]	0.480
W_{av} [MeV]	50.0
Satellite [%]	**2.2**

Satellites and total losses significantly reduced !

Shahin Sanaye Hajari

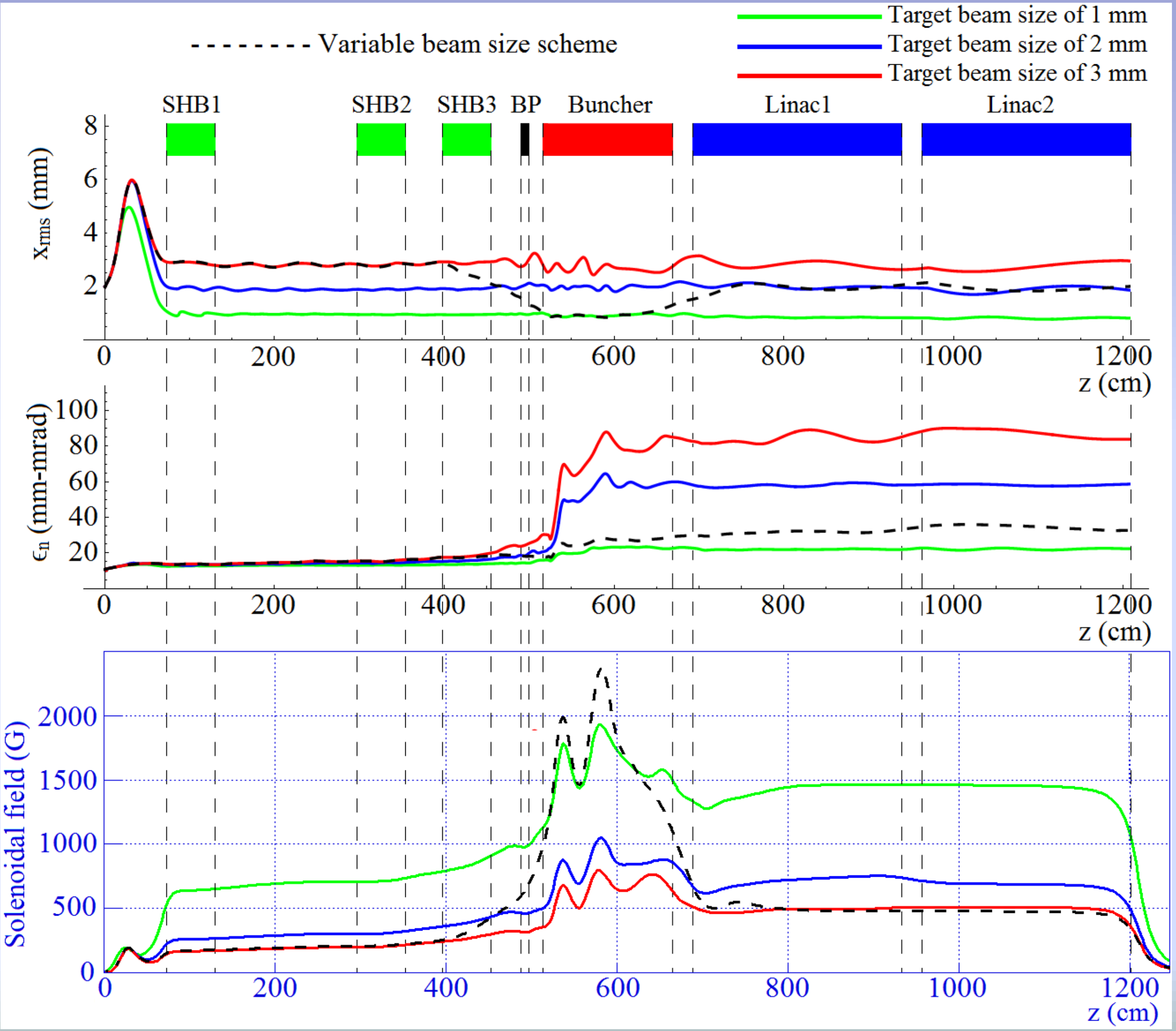
Solenoid focusing channel

Solenoid optimization:

- matched beam by envelope equation
- emittance growth at buncher entry for larger beam size
- smaller beam size needs larger field

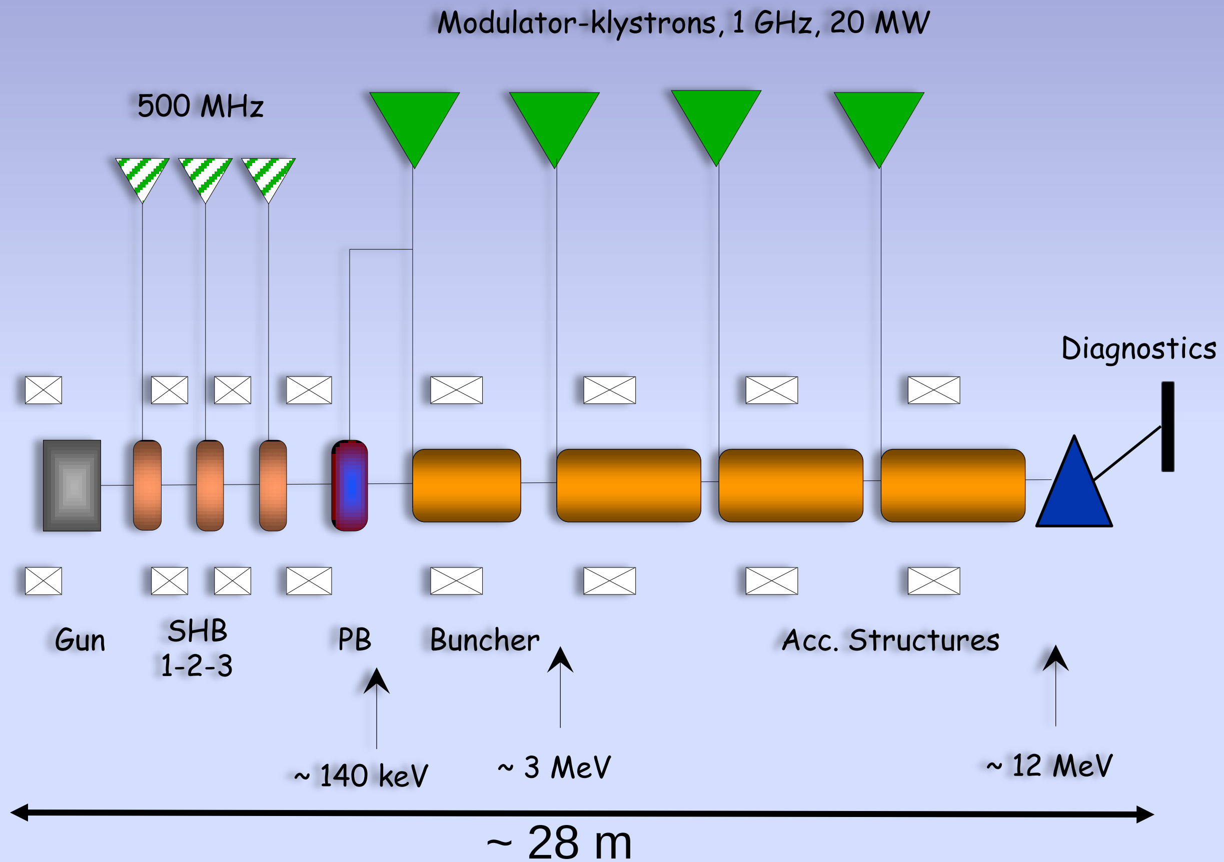
- variable beam size scheme:
- average field: 534G
- acceptable emittance growth 22.6μm

- quadrupole channel downstream



Shahin Sanaye Hajari

CLIC DB front end, Post CDR Project

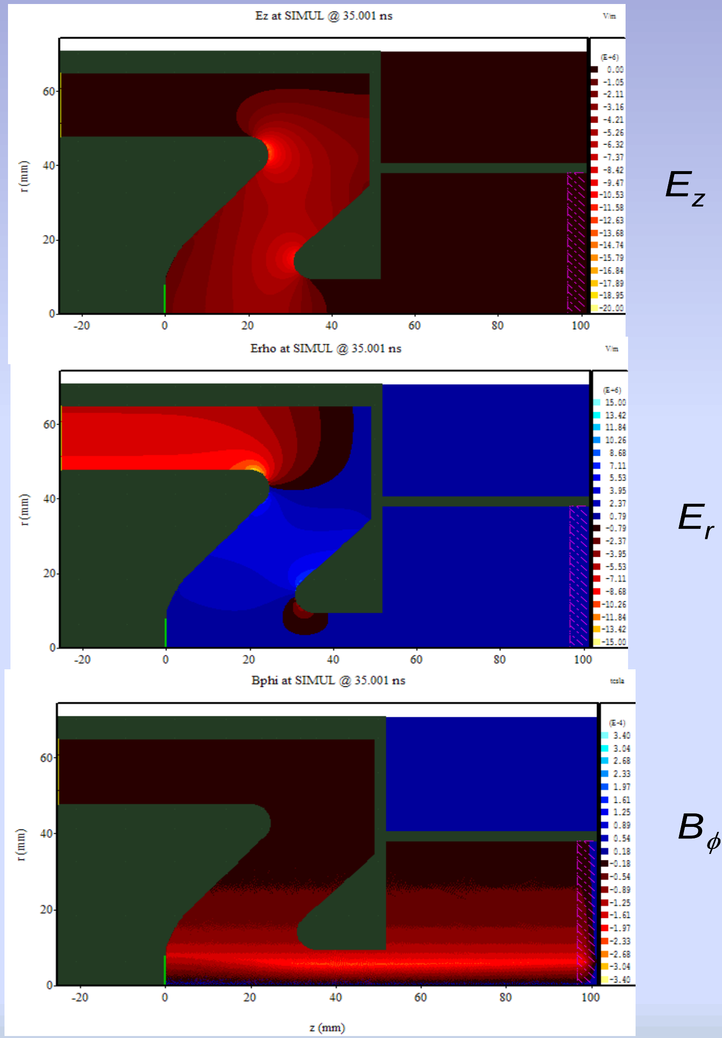


For time being only major component development:
Gun, SHB, high bandwidth 500 MHz source, 1 GHz MBK, modulator and fully loaded accelerating structure

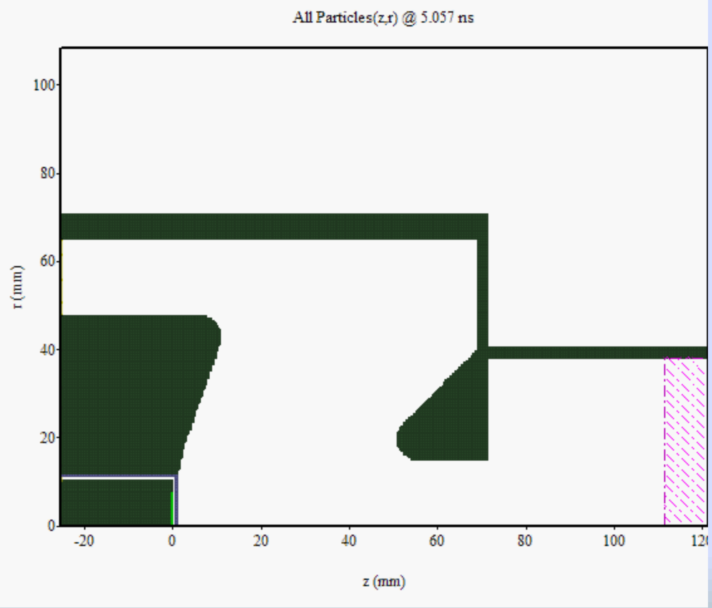
DB gun simulations

- done by CEA/CESTA Bordeaux
- Gun for **ADELE study**:
  - 20 MeV high current accelerator
  - 100μs, 4A, 50 Hz
  - X-ray production for material science

Contour plots of field components at t=35ns

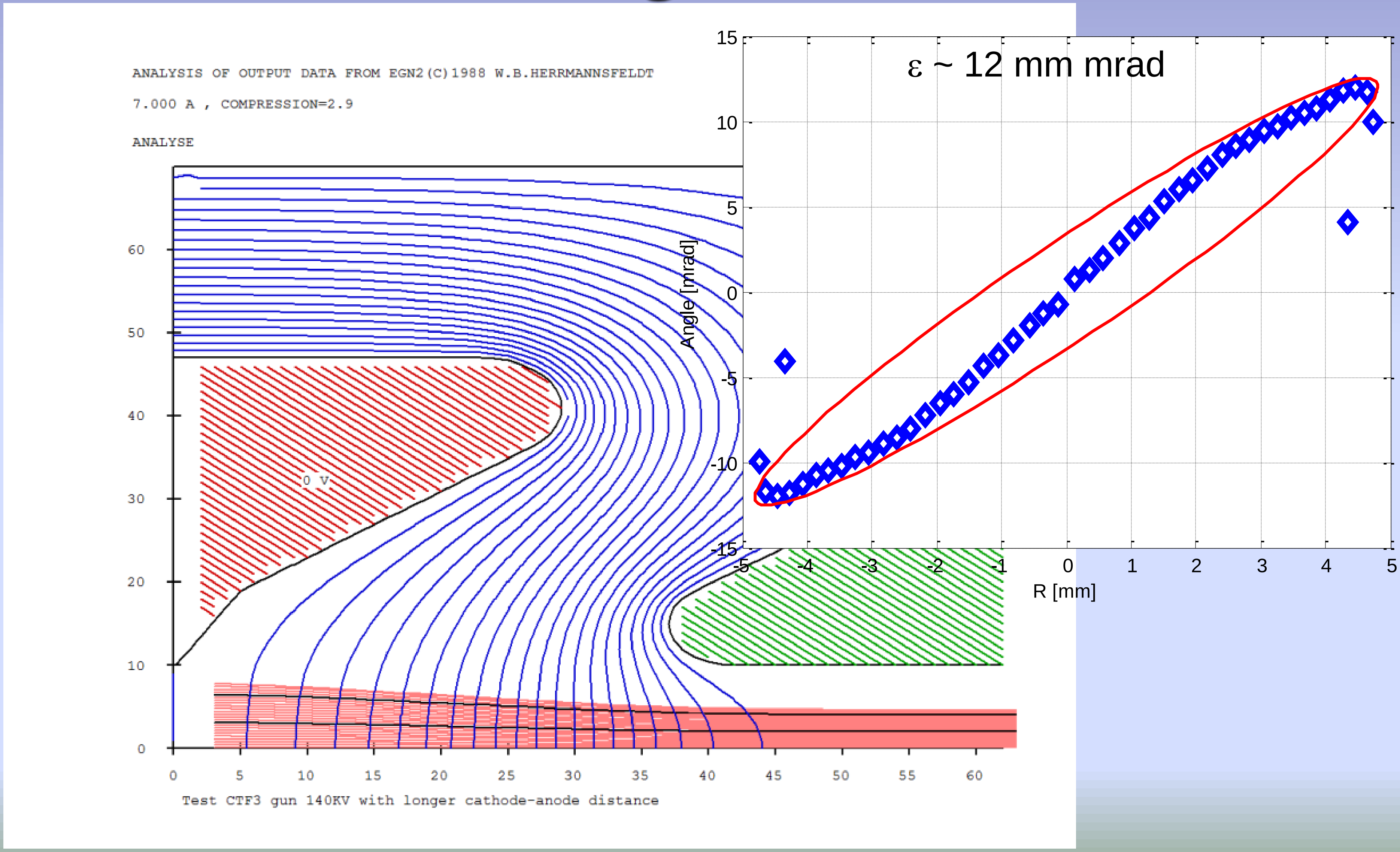


MAGIC simulation: particle positions in r-z

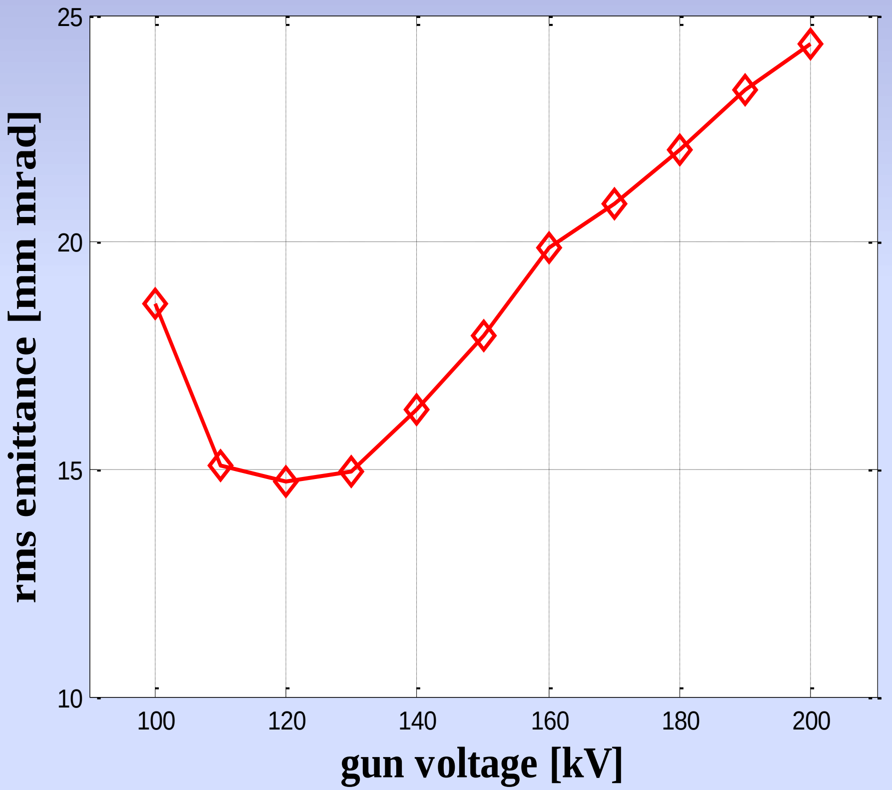


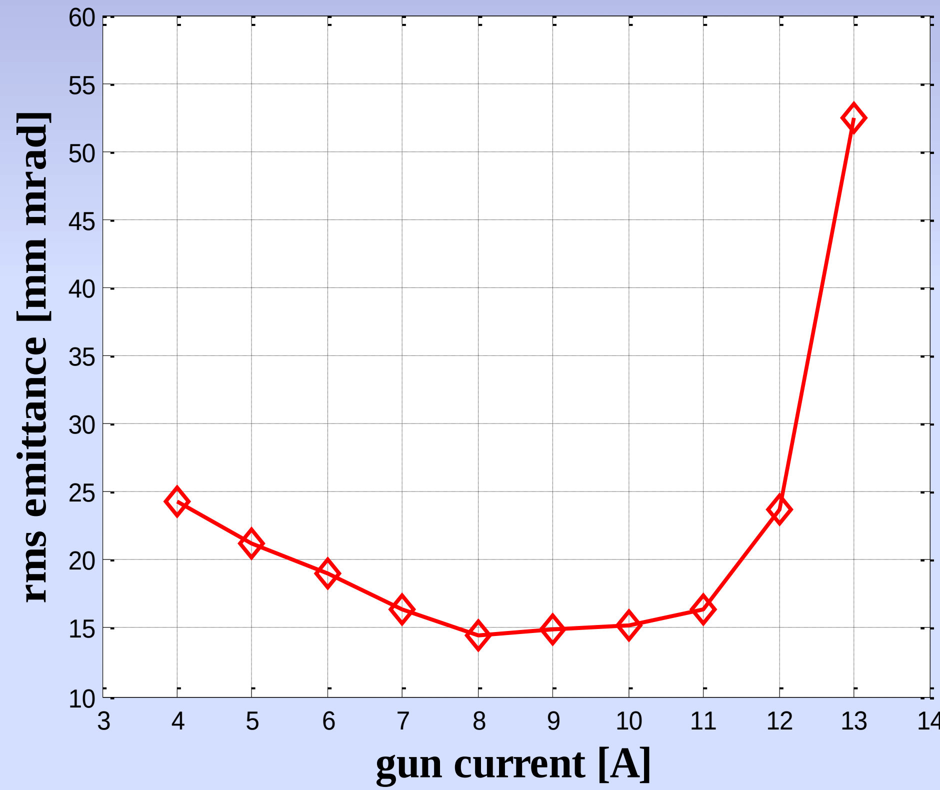
Jacques Gardelle, CEA-CESTA

Gun simulations Using EGUN

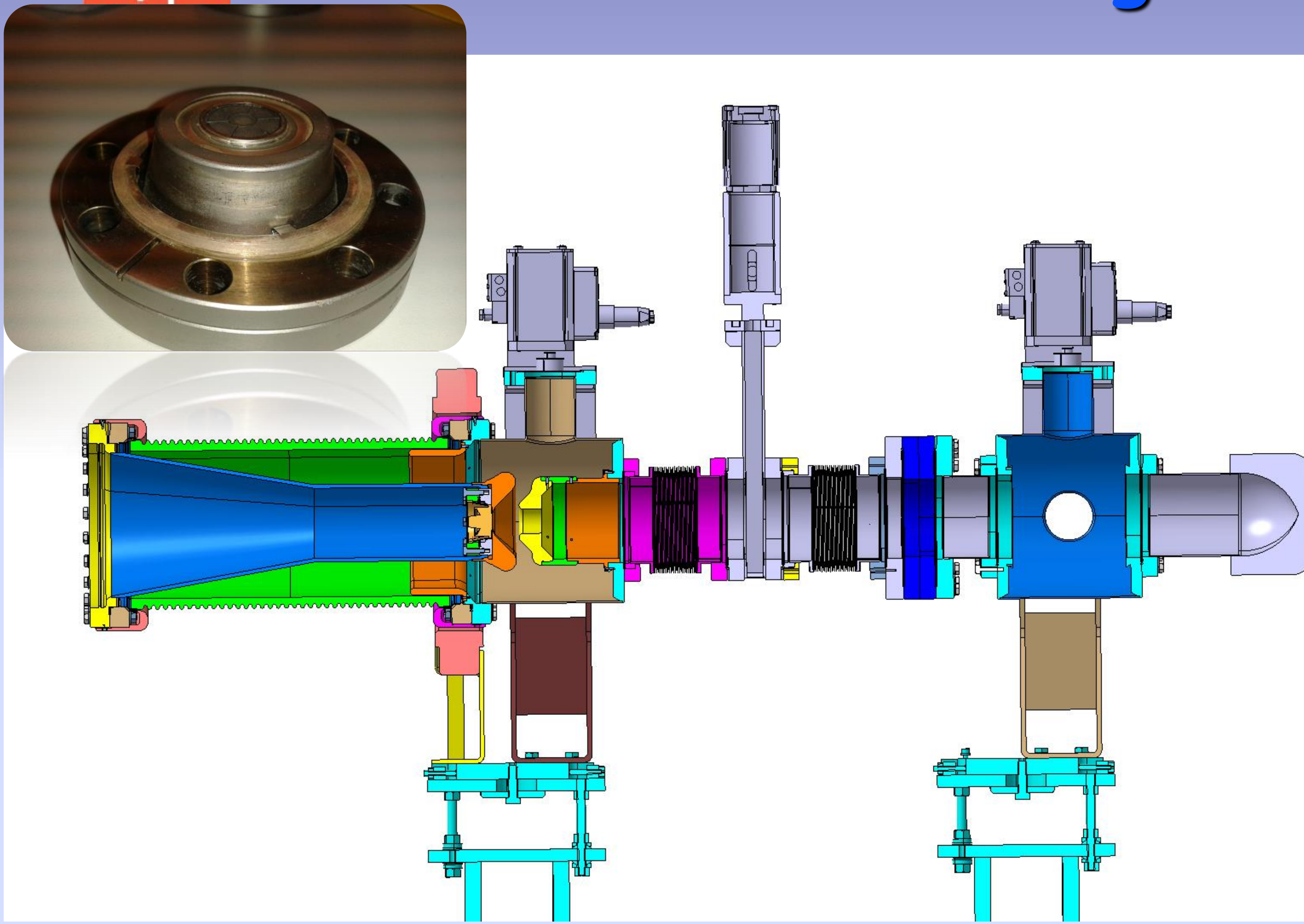


Gun simulations
Emittance vs voltage/current



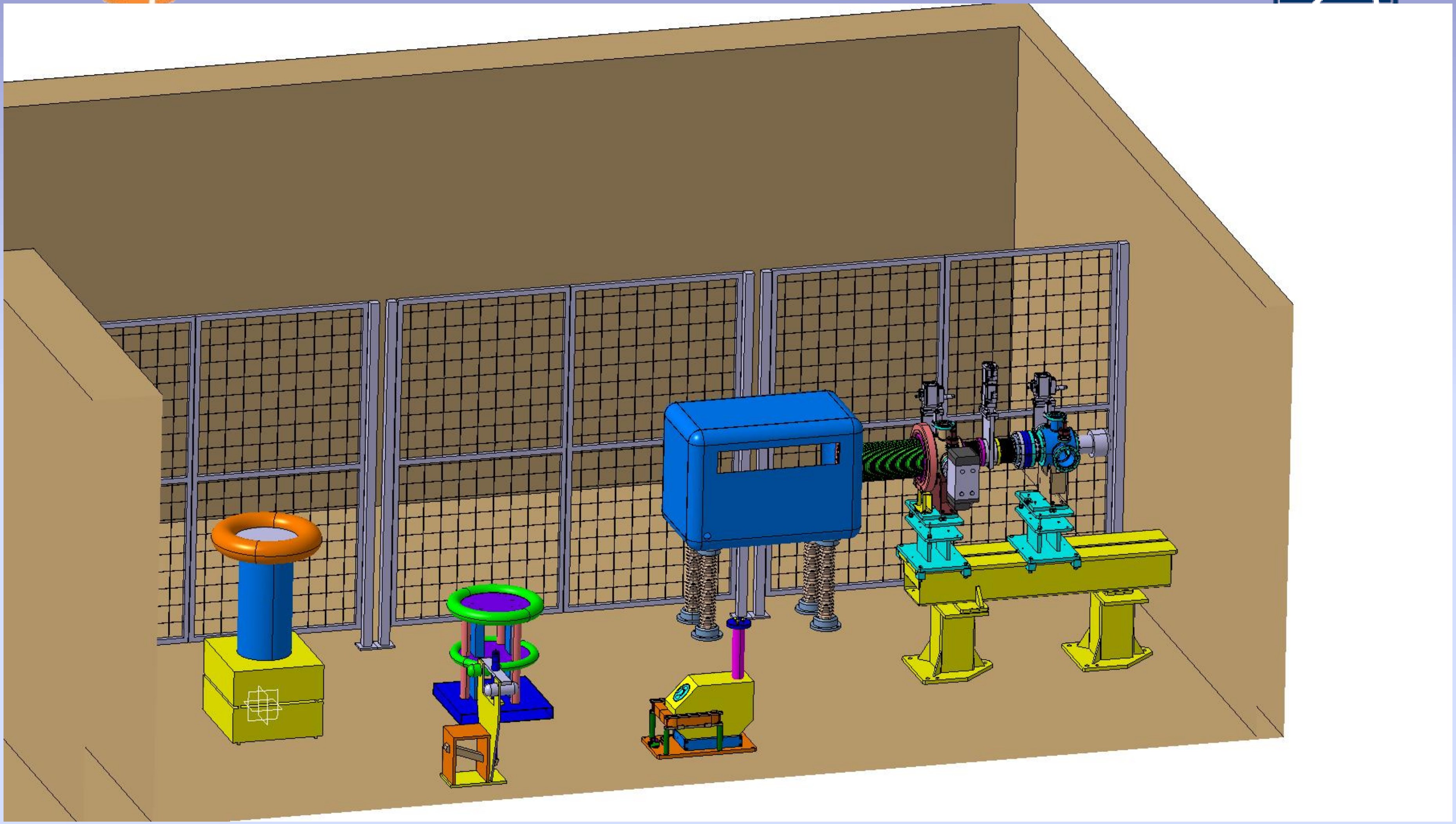


Thermionic Gun design



Thermionic Gun hardware
HV ceramics

Gun Test Facility



Gun status

- gun cage existing, interlocks in progress, gun HV deck cage end 2014

- **gun** in fabrication, foreseen for 2015

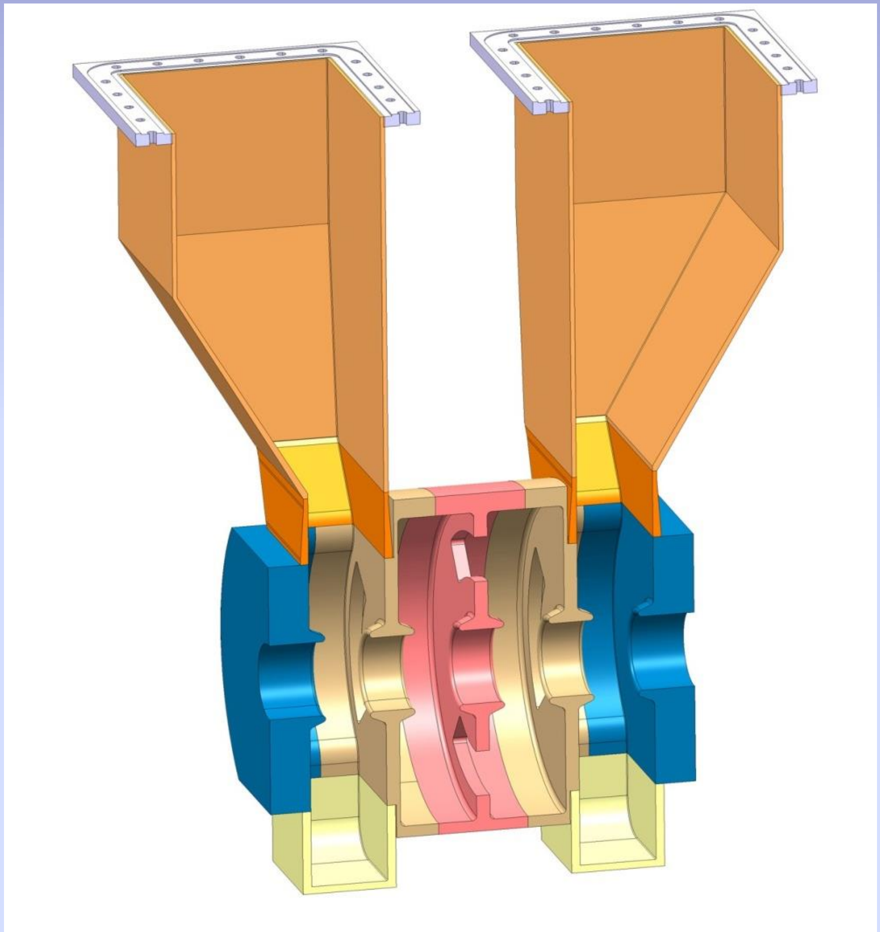
- existing spare **power supply** foreseen for initial tests at 140kV with limited pulse length, installed in gun test facility
- CEA/CESTA Bordeaux is working on a Marx generator type solid state modulator power supply for 150μs, 10A (with a 30kV setup at CESTA first)
- Foreseen for summer 2015
- **Collaboration agreement with CEA/CESTA signed last week!**

- **Dump** for the long beam pulse challenging due to thin absorption layer at 140kV => graphite
- design existing, FLUKA simulations done, foreseen for 2015

- Current **measurements** to check performance
- Emittance measurements planned by CEA/CESTA Bordeaux
  - short pulse of a few μs with a screen
  - longer pulse (~50μs) with graphite slits (as Linac 4)

Sub-harmonic bunching system

SHB Cavity Status:
- RF design existing
- mechanical design done
- 1 aluminum SHB in production in the CERN work shop
- only 1 foreseen for the moment



	SHB 1	SHB 2	SHB 3
Beam velocity	0.62 c	0.62 c	0.62 c
Current	5 A	5 A	5 A
Voltage	15 kV	30 kV	45 kV
Bunch form factor	0.058	0.57	0.73
Detuning	1.6 MHz	12.1 MHz	12.7 MHz

Hamed Shaker

Sub-harmonic bunching system

Power source:

- 500 MHz, 15-115 kW, wide band (60 MHz) sources needed for fast phase switching.
- Solid state favoured
- Foreseen to build 1 by the Indian collaboration
- also available in industry

	SHB 1	SHB 2	SHB 3
Beam velocity	0.62 c	0.62 c	0.62 c
Current	5 A	5 A	5 A
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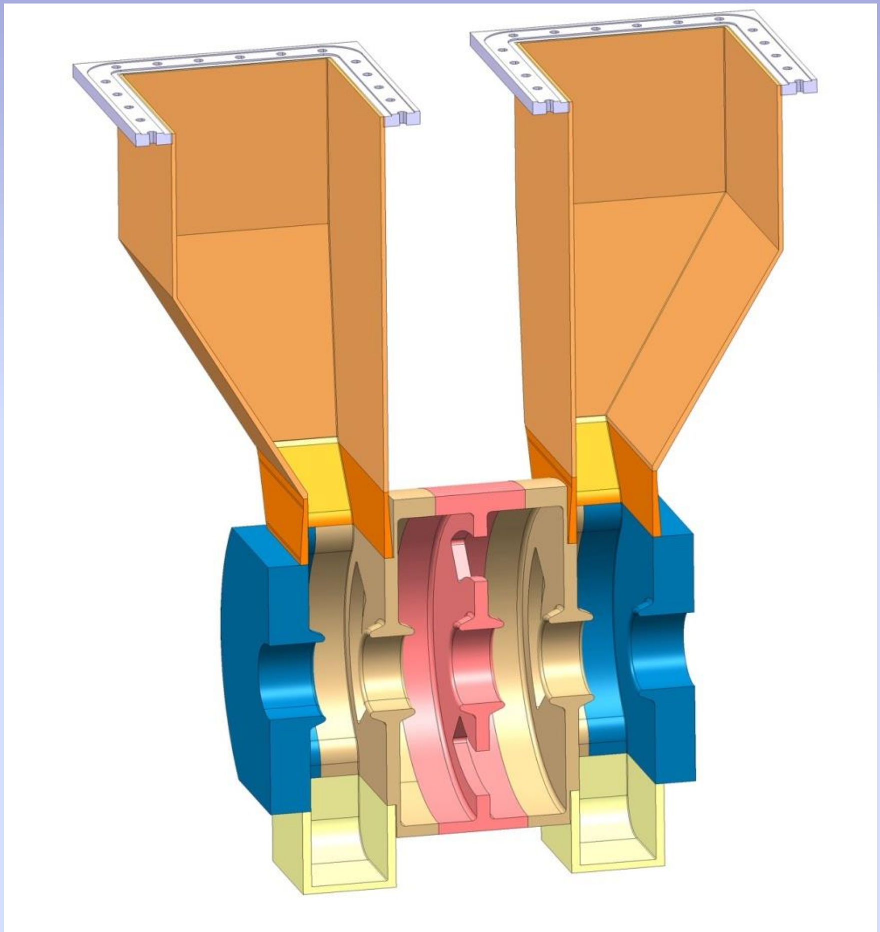


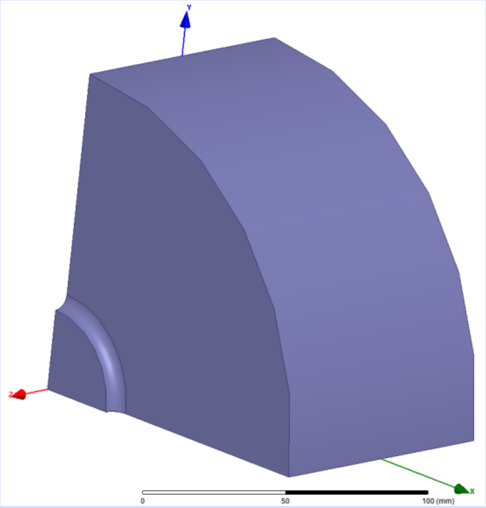
Prebuncher / Buncher

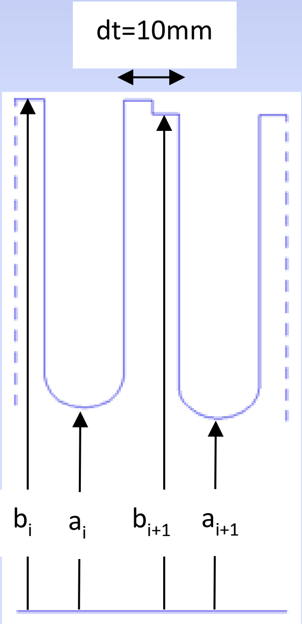
Prebuncher

- beam dynamics calculations done optimized for beam-loading
- RF design done
- improvement of bunching from 3.8% to 3.1% in satellites
- no mechanical design existing
- but straightforward to build

Buncher

- beam dynamics calculations done
- TW structure
- 1.5m long
- RF design ongoing
- not foreseen to be built in present plan



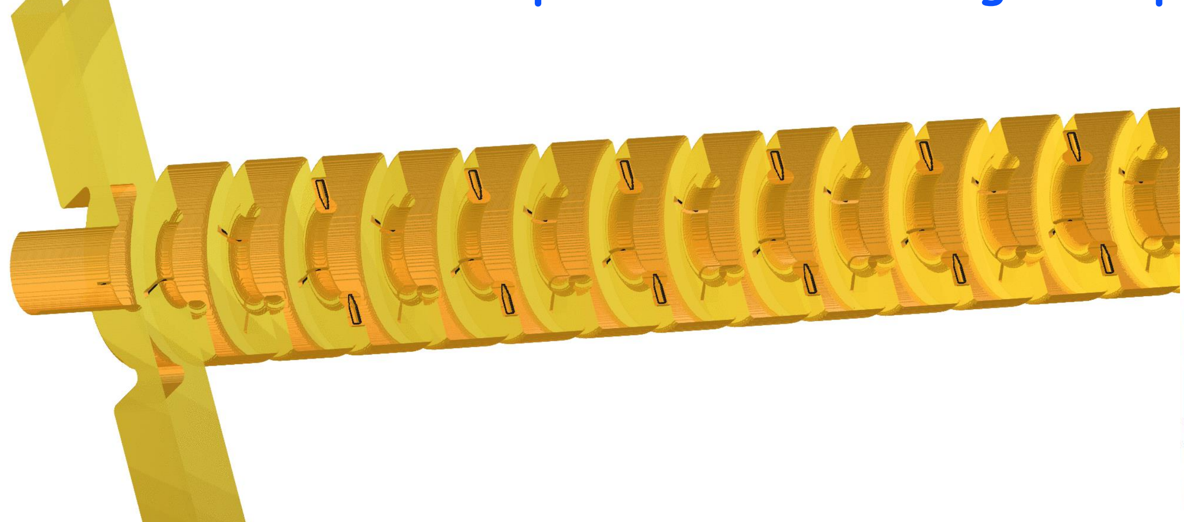


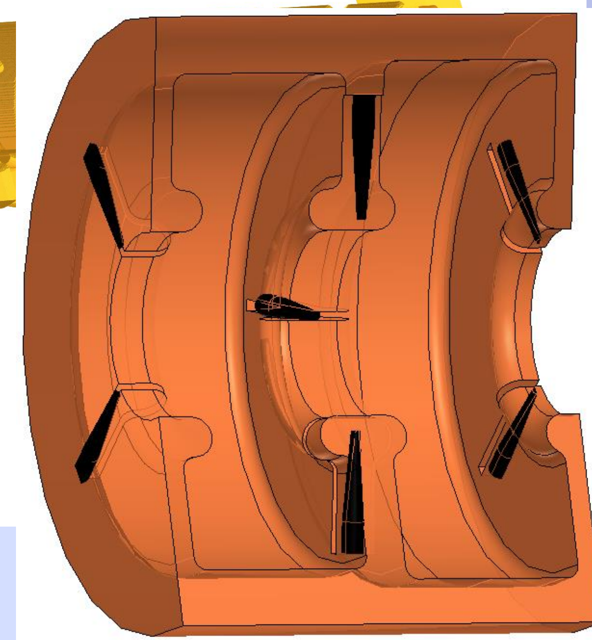
Hamed Shaker

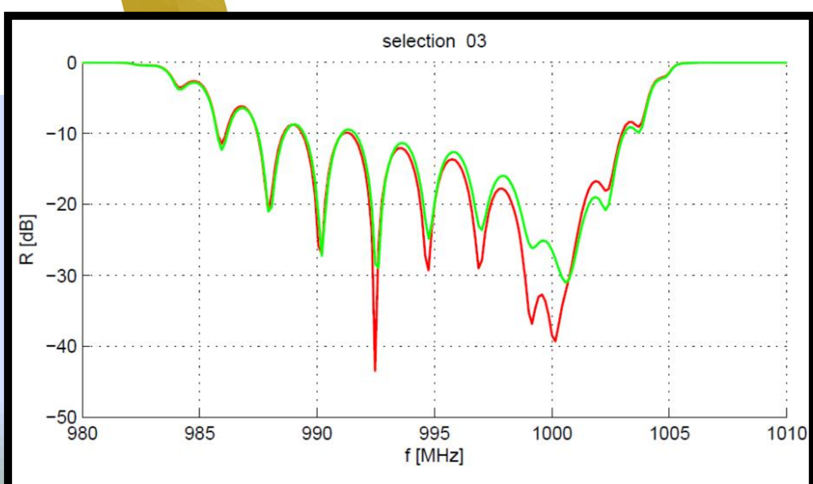
5 cells were designed
the rest was interpolated

DB-accelerator structure

RF-design existing,
next steps: mechanical design and prototype



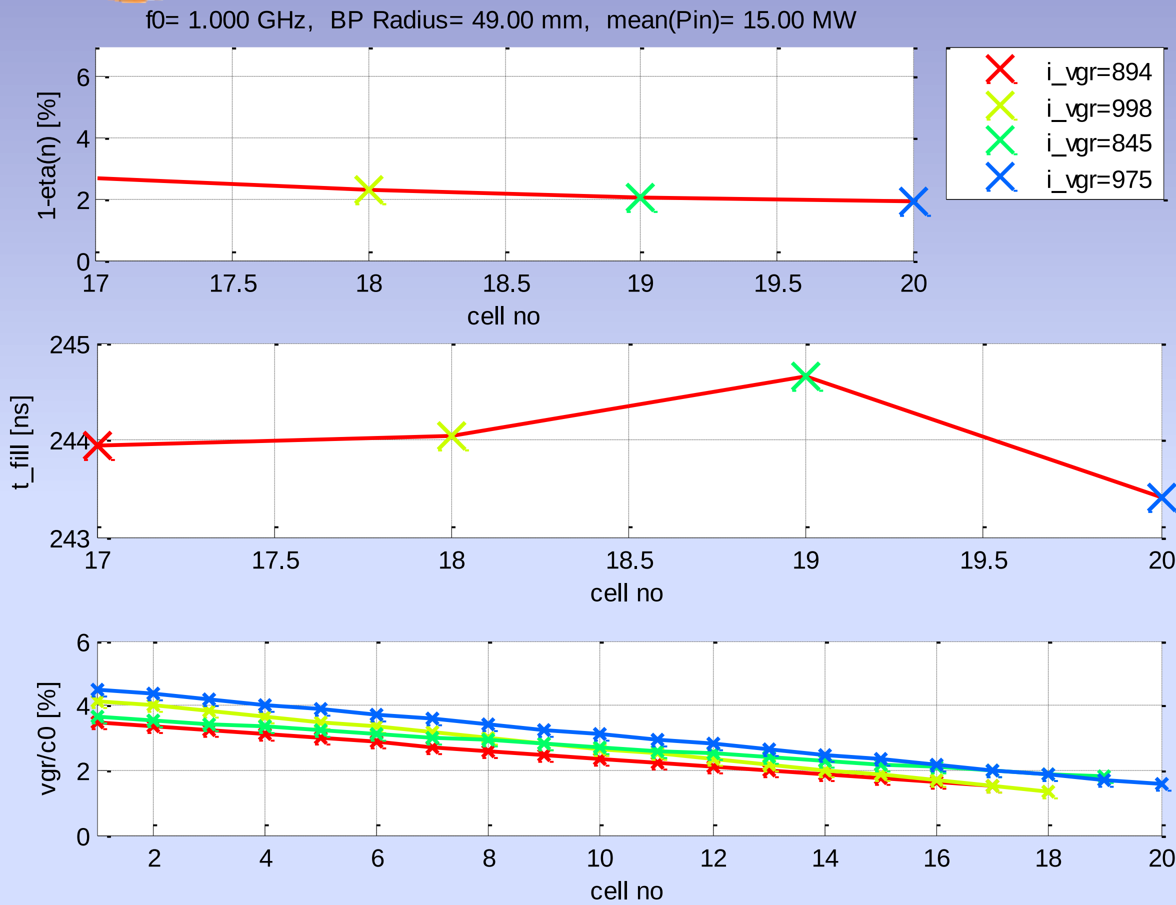




Input and output coupler design finished
Correct match, input reflection < 30 dB.
(red and green: two different geometries; red is final)

Rolf Wegener

DB-accelerator structure



Parameters:

f = 999.5 MHz

P_{in} = 15 MW

R_B = 49 mm

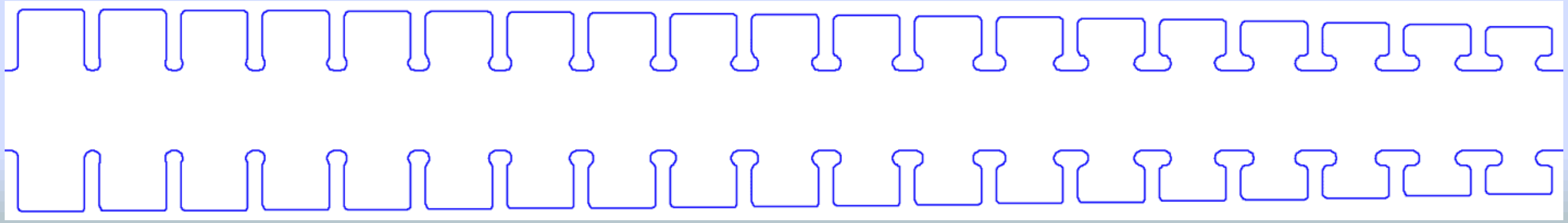
N = 19 cells

OD= 300 mm

L= 2.4 m

T_{fill} = 245 ns

$\eta_{RF\text{-}Beam}$= 97.5 %



Rolf Wegener

Accelerating structure

- 19 cells, with a $2\pi/3$ phase advance per cell,
- total structure length of 2.4 m
- RF design done (needs adaptation from 15->20 MW)
- no mechanical design existing
- one foreseen for the klystron test stand
- shorter prototype first
- discussion for a collaboration with Soltan Institute (Poland)

Tentative klystron

Thales

Toshiba

CPI #a

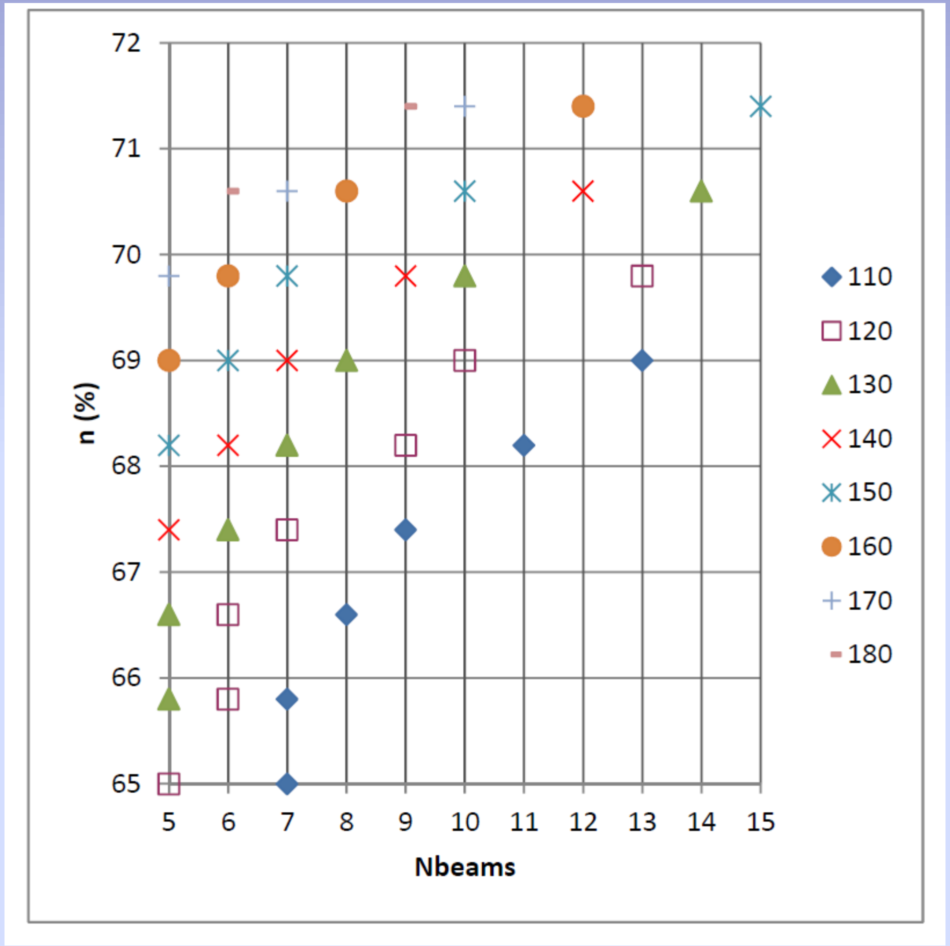
CPI #b

Tentative klystron parameters

Recommended parameters of the L-band klystron for CLIC

Parameter	
Frequency, GHz	1.0
N beams	6
Cathode diam., cm	4.94
Cathode loading A/cm^2	1.76-1.96
μ−perveance/beam	0.45
Peak power (max), MW	20-25
Cathode Voltage, kV	160 - 180
Cathode current, A	180-202
Efficiency, %	>70

Estimations from Igor Syratchev



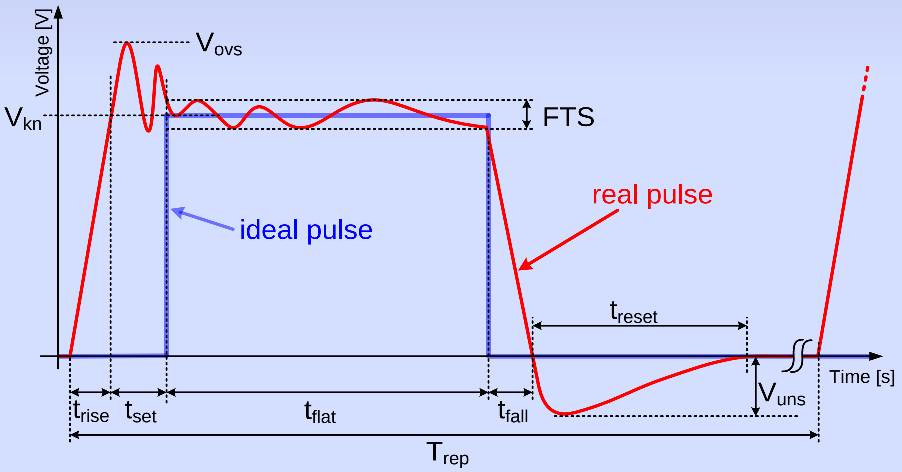
Efficiency for 20 MW for different voltages (Thales study)

Modulator design

Main modulator specifications

Average power of 200kW per modulator
Reproducibility of the peak pulse amplitude is about 10^-5 (frequency range between 6 kHz and 4 MHz).
At lower frequencies, feedbacks compensates
Higher frequencies are naturally filtered by the machine

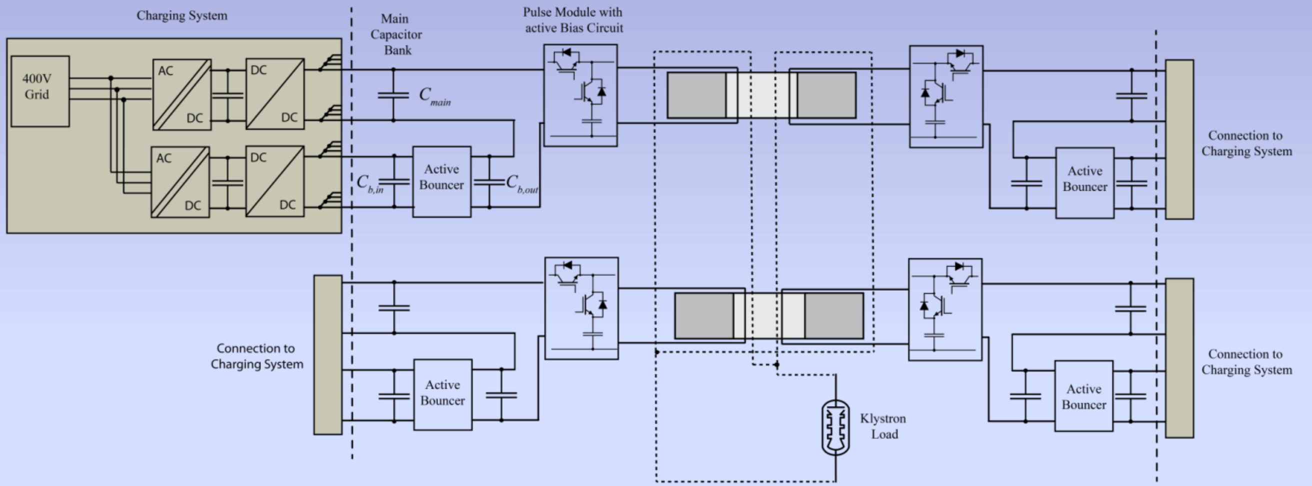
Modulator main specifications			
Pulse voltage	V_{kn}	150	kV
Pulse current	I_{kn}	160	A
Peak power	P_{out}	24	MW
Overall efficiency	Eff_{glob}.	>90	%
Rise & fall times	**t_{rise}**	**3**	**μs**
Flat-top lenght	t_{flat}	140	μs
Repetition rate	Rep_r	50	Hz
Flat-top stability	FTS	0.85	%
Pulse repeatability	**PPR**	**10-100**	**ppm**

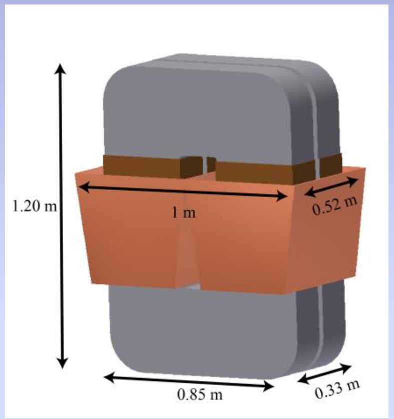


- Low AC power fluctuation
- High reliability / availability

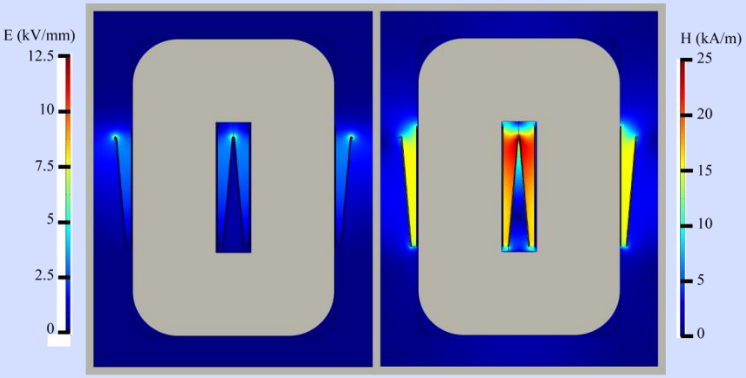
R&D strategy and status

ETH: Topology defined-matrix transformer based





Pulse transformer ordered, expected for tests in Zürich end 2015
on schedule



Davide Aguglia

Klystron/Modulator status

Klystron

- 2 vertical prototypes ordered from two suppliers – 3m high
- foreseen for 2016
- option for a 3rd one (after acceptance of the first prototype)
- to arrive in 2018

Modulator

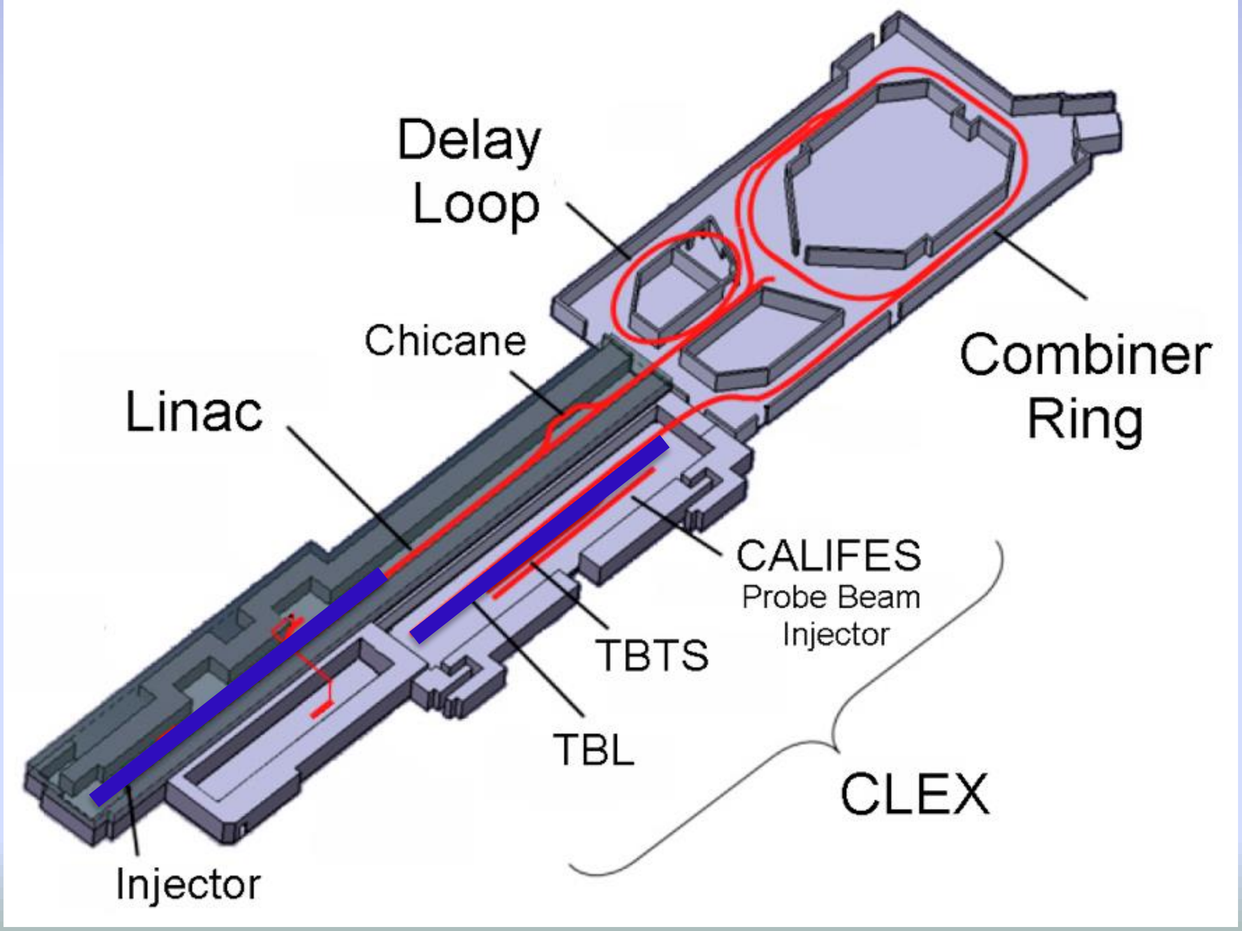
- one foreseen for 2016 by ETH Zürich
    - on schedule
- 2nd for 2017 by Laval University

Test stand

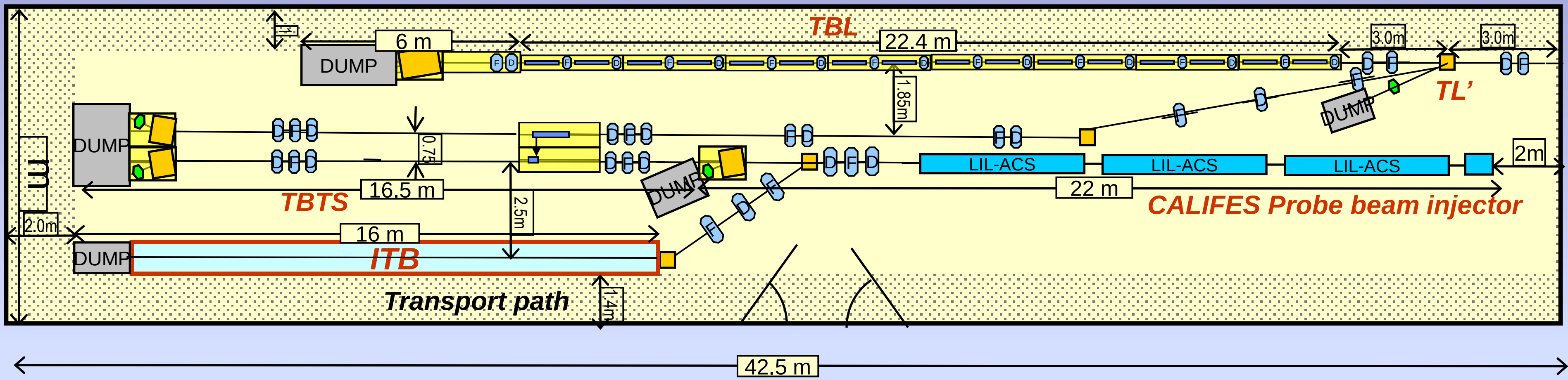
- planned in building 112
- testing of modulators, klystrons and the accelerating structure

Drive Beam Front End in CTF3

- CTF3 running foreseen until end 2016
- use the building to install the DBFE
  - infrastructure (electricity, cooling water, access system, …) existing



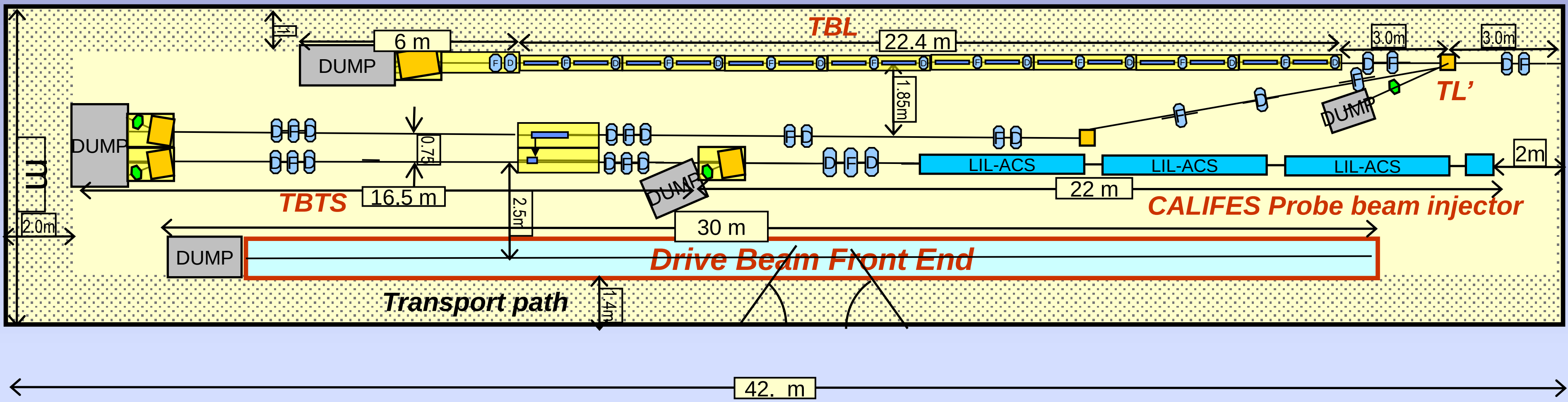
present CLEX building



Space reservations

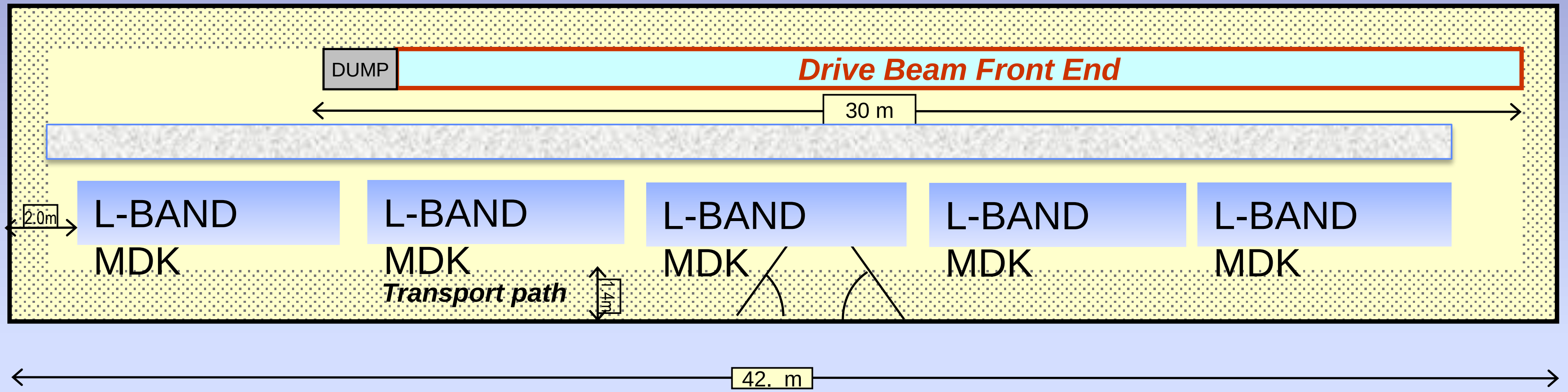
CALIFES	**22.0 m from cathode preparation chamber to end of spectrometer**
TBTS	**16.5 m from output spectrometer to end of beam dump**
TBL	**31.4 m from dogleg bend to end of beam dump**
ITB	**16.0 m from 2nd dogleg magnet to end of beam dump**

DB front end in CLEX



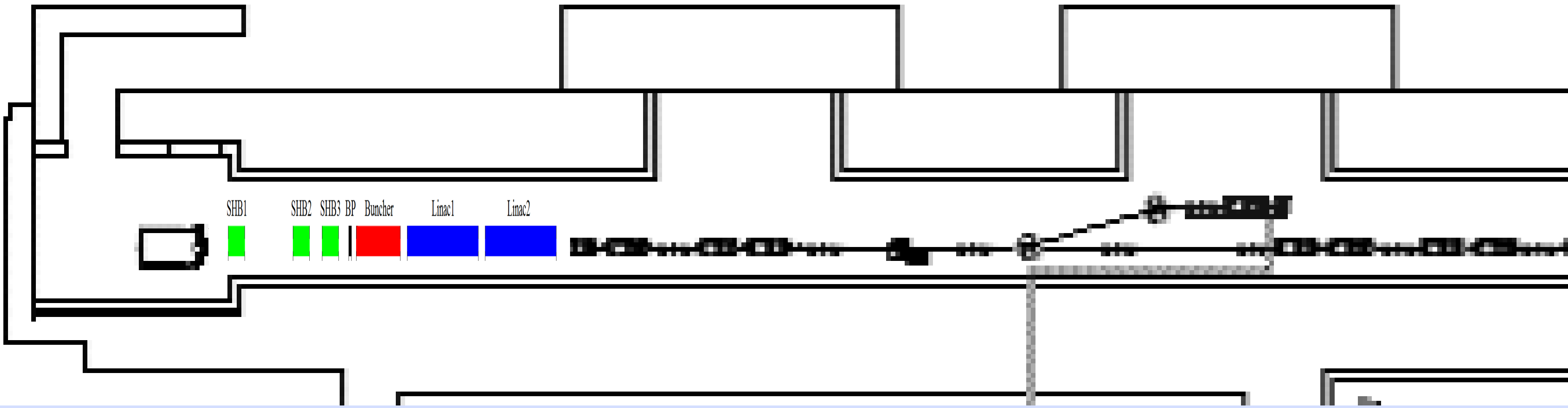
- Drive Beam Front End: ~ 30 m
- Concerns:
  - Shielding likely not sufficient for full beam power operation (350 KW)
  - Extra Space for modulators and klystrons needed if not exclusively used for the front end
  - cohabitation with CALIFES imposes many installation/operation constraints

DB front end in CLEX



- Drive Beam Front End: ~ 30 m
- Concerns:
  - Shielding likely not sufficient for full beam power operation (350 KW)
  - Extra Space for modulators and klystrons needed if not exclusively used for the front end
  - cohabitation with CALIFES imposes many installation/operation constraints

DB front end in CTF3 linac



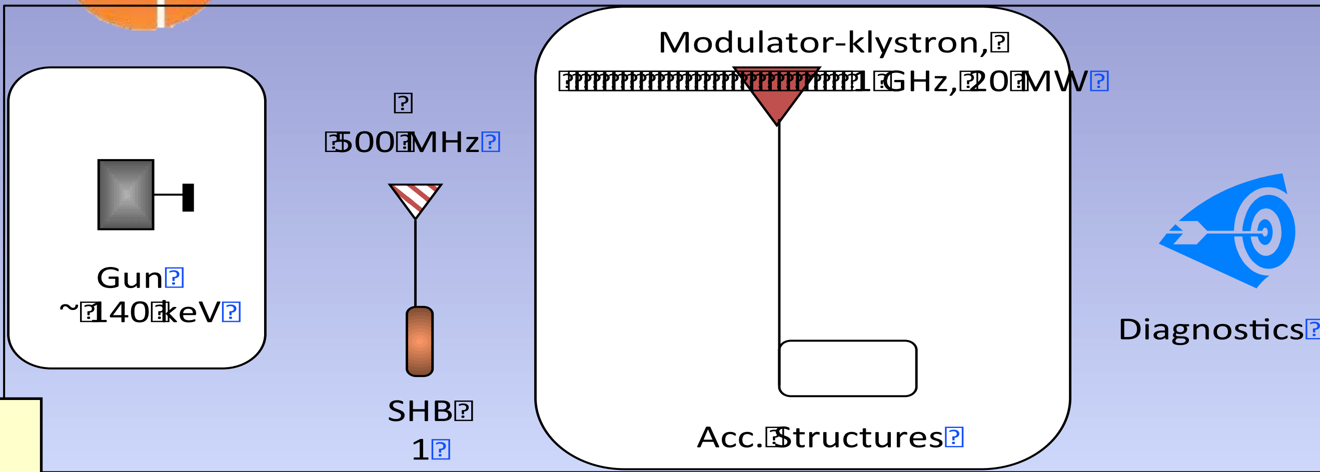
- no conflicts with other installations
- 'old' CTF3 equipment can be taken out (in 2017)
- space in the klystron gallery available
- modification needed to accommodate the 3m high vertical 1 GHz klystrons
- part of existing equipment (compression chicane, 3 GHz RF) could be used to post-accelerate the 1 GHz beam to girder 10 for better diagnostics
- The linac tunnel could house the entire CLIC0 injector

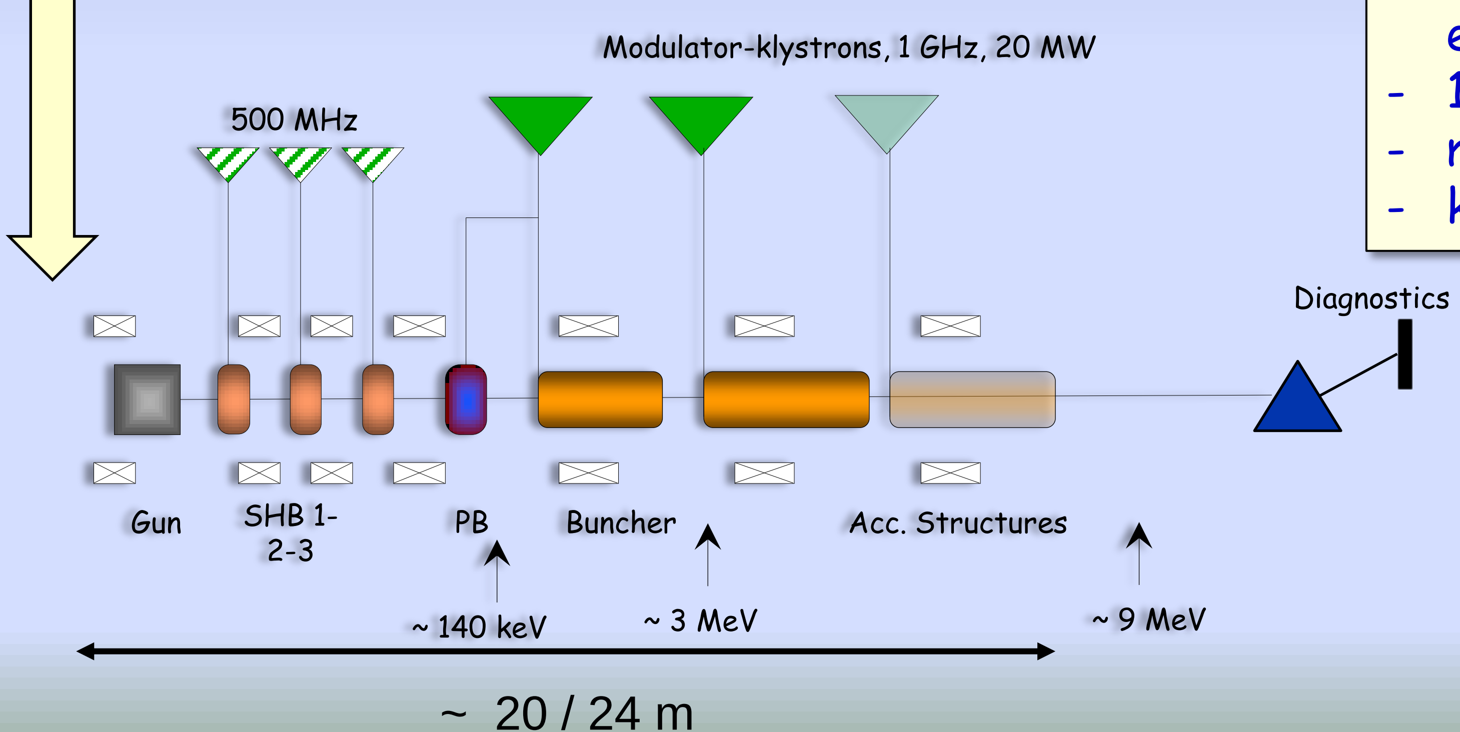
Dump / Radiation considerations

	Pulse length [µs]	Repetition rate [Hz]	Current [A]	Energy [MeV]	Average Power [kW]
CTF3 (end linac)	1.2	5	4.2	120	3 (4.7 design)
DB FE (full)	140	50	4.2	9/12	260/350
DB FE (low rate)	140	0.8	4.2	9	4.2
DB FE (short pulse)	2.5	50	4.2	9	4.5

- low repetition rate for full pulse length results in average power like CTF3
- shorter pulse length at full repetition rate
- additional shielding/blocking off area for longer pulse tests

minimal DB front end





Shopping List:

- 2 SHBs
- 2 500 MHz sources
- Pre-buncher
- buncher
- solenoids (many existing)
- 1 acc. structure
- modulator
- klystron

What do we plan to do until 2018

Optimistic and rough planning

Task	2014	2015	2016	2017	2018
Space needed		prepare Klystron test stand		prepare injector building	injector building
Gun	fabrication	GUN test facility	GUN test facility	move to injector building	injector building
SHB Buncher	fabrication	testing			
500 MHz power source	fabrication	testing			
Buncher	specification	fabrication	testing		
1 GHz structure	design	mechanical design	manufacturing	high power test	
Diagnostis	specification, purchase		in gun test		
LLRF	specification	fabrication+test	ready for klystron test		
1 GHz klystrons	Tender	fabrication of prototypes	Receive 2 Klystrons	high power test	optional 3rd Klystron
1 GHz Modulator	R&D	R&D	Receive first MDK	MDK2	
Injector integration, vacuum, controls, magnets, diagnostics	on hold	on hold	design		

- gun test facility to test the source
- high power test stand to test the klystron, modulator and rf structures
- Could be assembled from 2017/18 in CTF3

Conclusion and Outlook

- Drive beam front end key elements under design or manufacturing
- Gun and klystron test stands in preparation
- Large collaborative effort

- Could assemble components in CTF3 in 2017/2018 with some additional resources
- Opens possibility to test the real CLIC DB injector

THANK YOU!