Drive Beam injector frond end developments

- DB injector introduction
- Beam dynamics design
- Hardware design, klystron, buncher, gun
- Conclusions and outlook

Steffen Döbert, BE-RF

Main activities and goal for 2018

Design and Implementation studies:

- Baseline design and staging strategy
- Solid cost basis and more optimized power/energy (aim for 20% energy reduction)
- Proof of industry basis for key components/units, in particular those specific for CLIC
- Comprehensive reliability/robustness/uptime analysis
- Pursue increased use of X-band for other machines/applications (hard to set concrete goal)
- CDR status: not optimized except at 3 TeV and not adjusted for Higgs discovery, not optimized cost, first power/energy estimates without time for reductions, limited industrial costing, very limited reliability studies

System-tests:

- Complete system-tests foreseen for next phase, and comprehensive documentation of the results at CERN (CTF3) and elsewhere
- Strategy for further system verification before construction (XFEL, connected to light-sources, further drive-beam verifications) or as part of initial machine strategy.
- CDR status: CTF3 results initial phase (as of early 2012), ATF and FACET very little, no convincing strategy for further system verification
- Demonstrator of drive beam FE and RF power unit based on industrial capacity – will open for larger facilities beyond 2018 if necessary
- CDR status: Nothing done beyond CTF3

X-band developments:

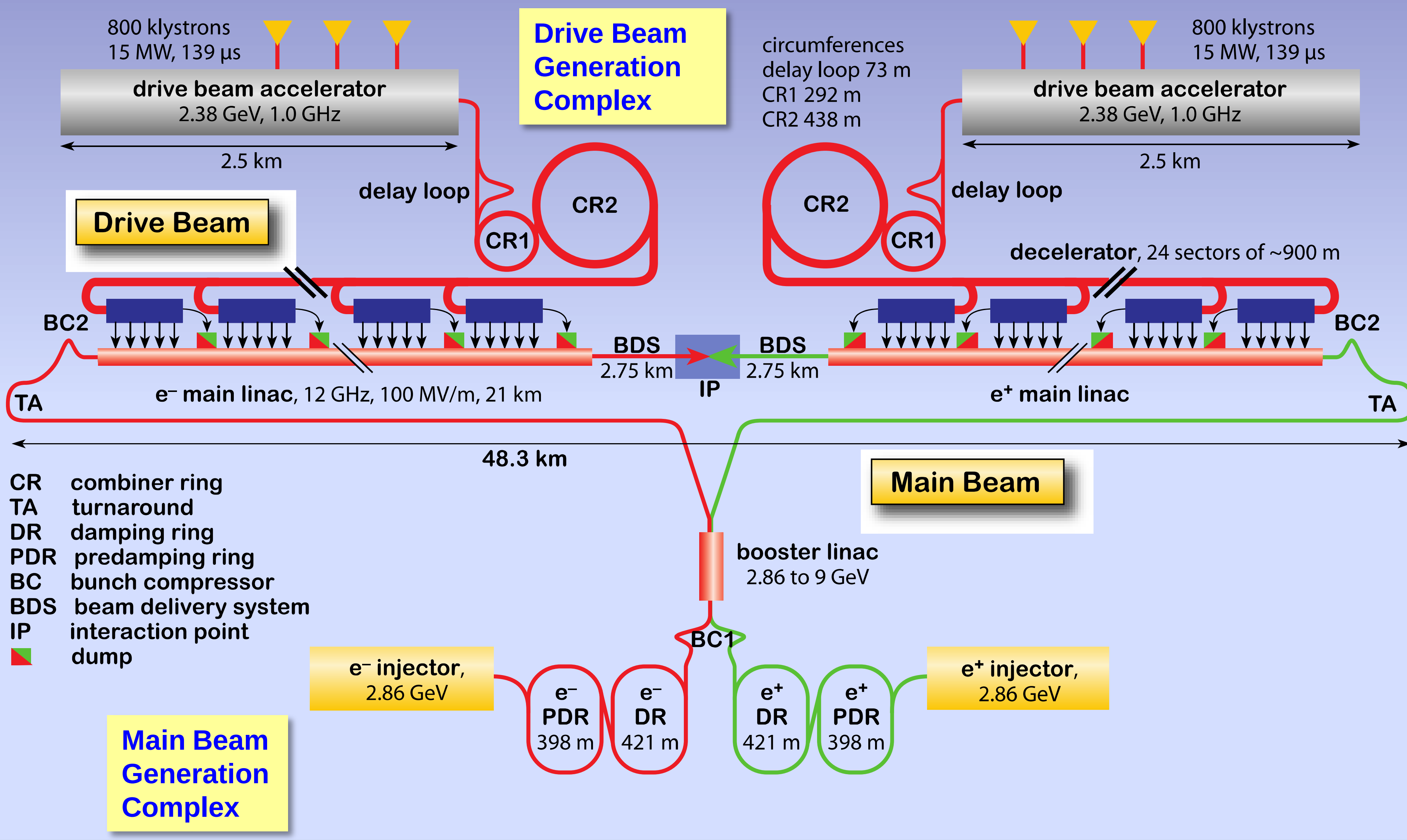
- Statistics for gradient and structure choice (energy reach) and other X-band elements
- CDR status: Single elements demonstrated – limited by test-capacity

Technology developments:

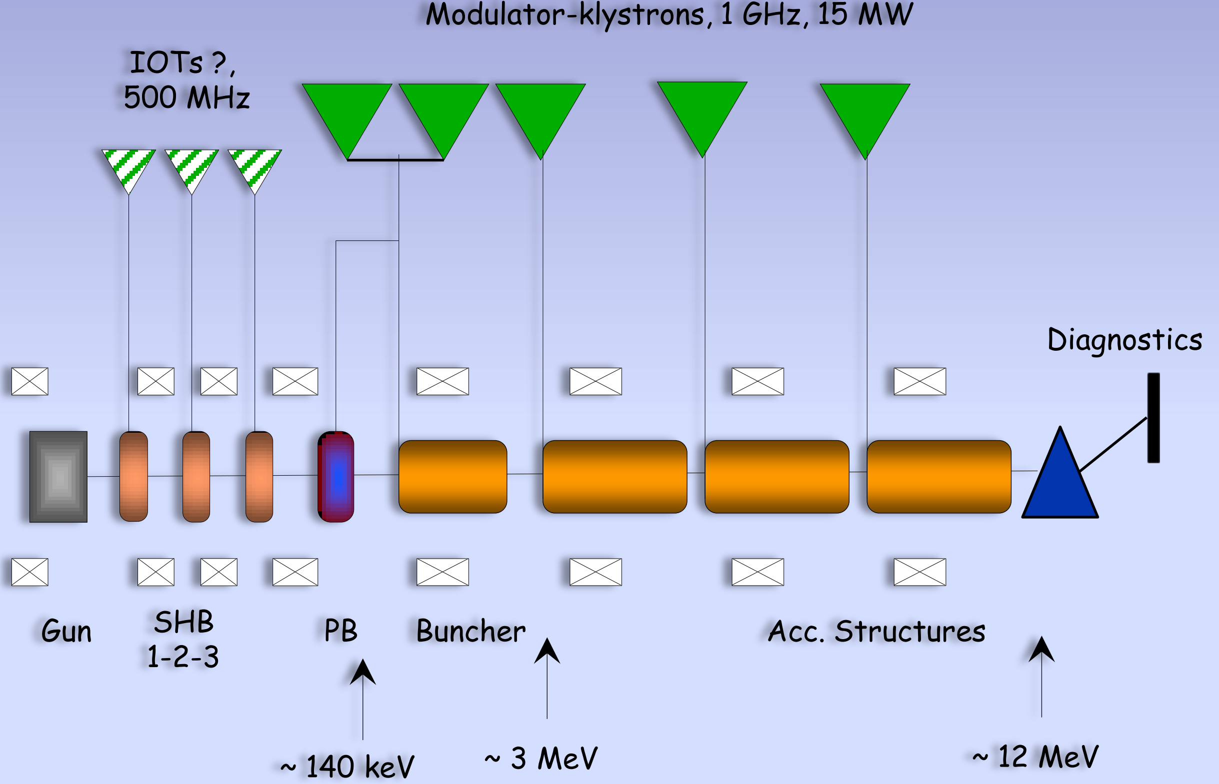
- Demonstration of critical elements and methods for the machine performance:
  - DR, main linac, BDS with associated instrumentation and correction methods (combination of design, simulation, system-tests and technologies)
  - Stability/alignment (locally and over distances)
  - Module including all parts
- CDR status: alignment/stability partly covered, BBA assumed, wakefield mon. perf. assumed, no complete module




CLIC Layout at 3 TeV



CLIC DB front end, Post CDR Project

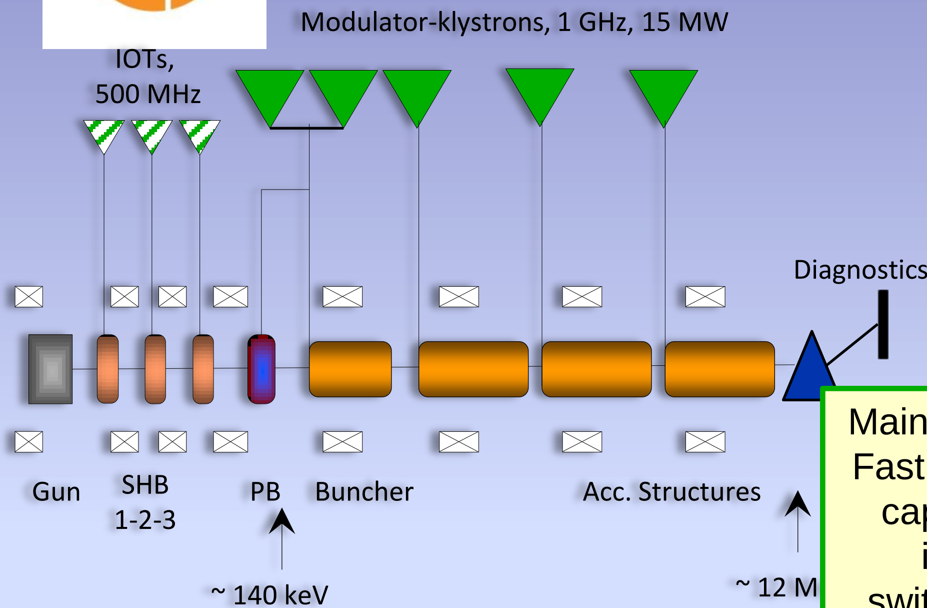


For time being only major component development:
GUN, SHB, high bandwidth 500 MHz source, 1 GHZ MBK, modulator and fully loaded accelerating structure

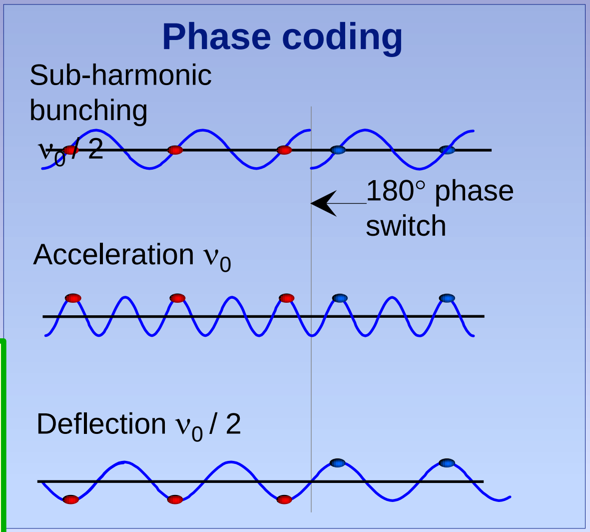
CLIC DB injector specifications

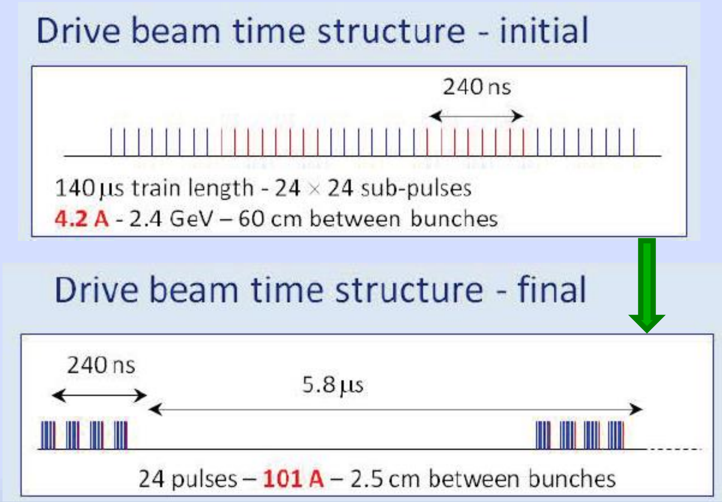
Parameter	Nominal value	Unit
Beam Energy	50	MeV
Pulse Length	**140.3** / 243.7	μs / ns
Beam current	4.2	A
Bunch charge	**8.4**	nC
Number of bunches	70128	
Total charge per pulse	**590**	μC
Bunch spacing	**1.992**	ns
Emittance at 50 MeV	100	mm mrad
Repetition rate	100	Hz
Energy spread at 50 MeV	1	% FWHM
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

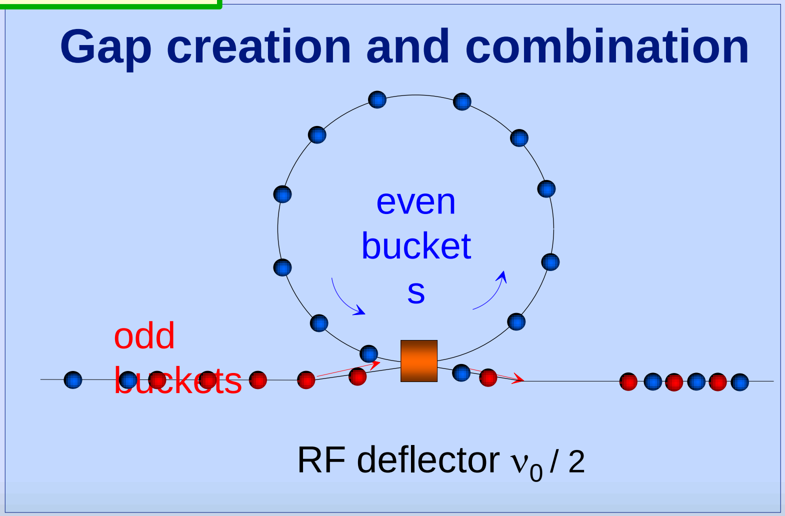
Sub Harmonic Bunchers (SHBs)



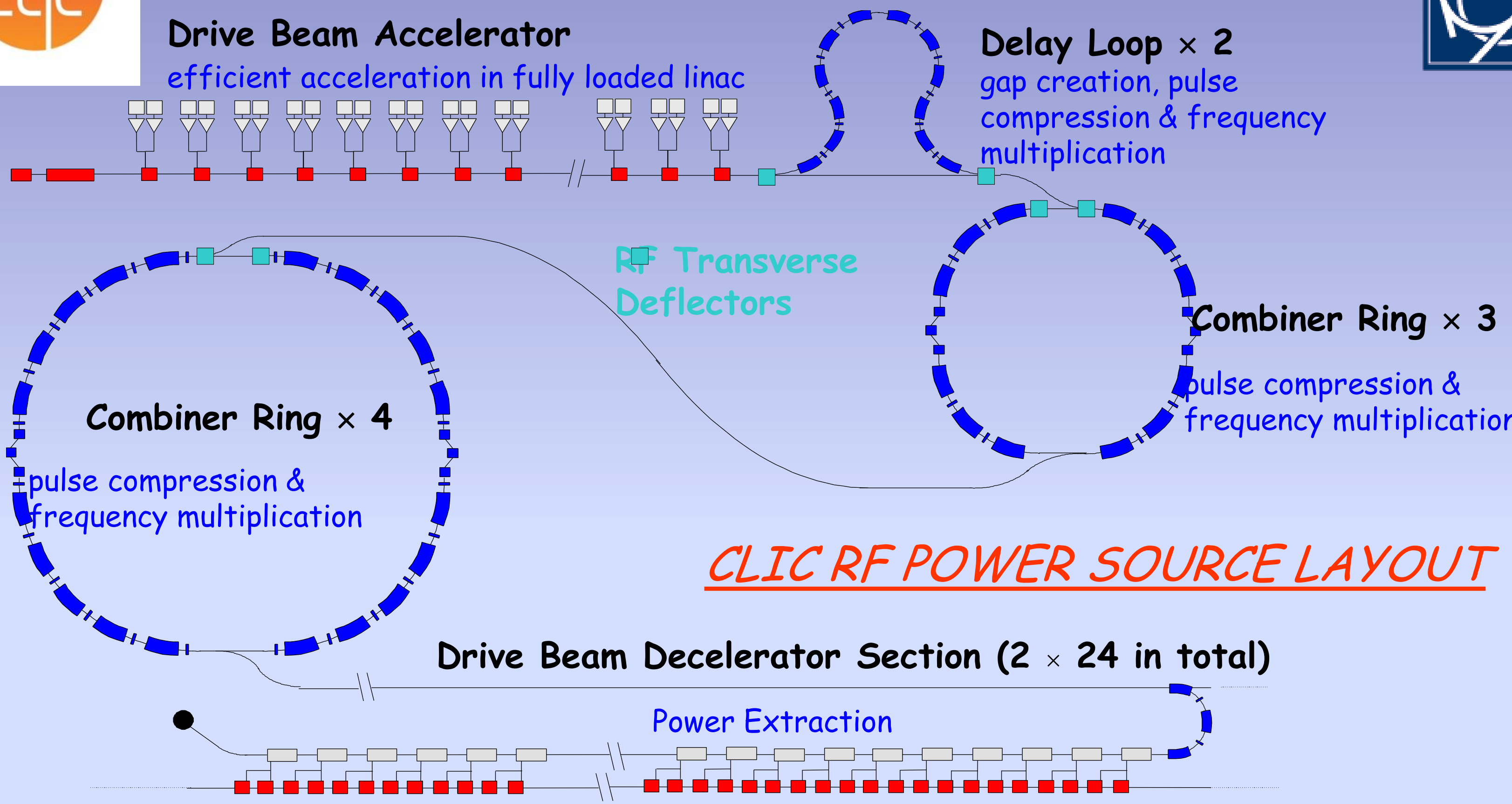
Main challenge of SHBs: Fast 180° phase flipping capability, simulation indicate < 18 ns switching time needed



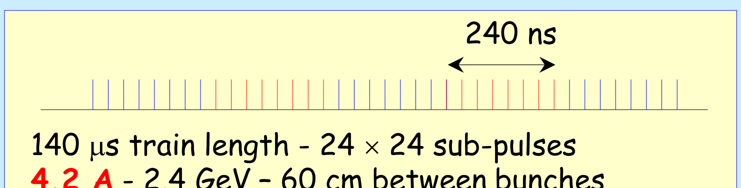




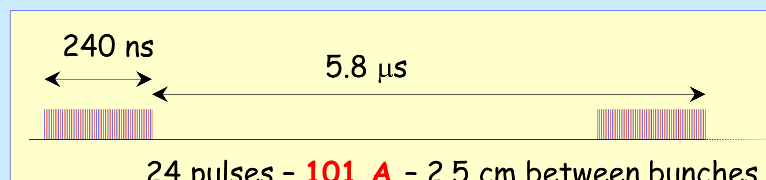
CLIC Power Source Concept



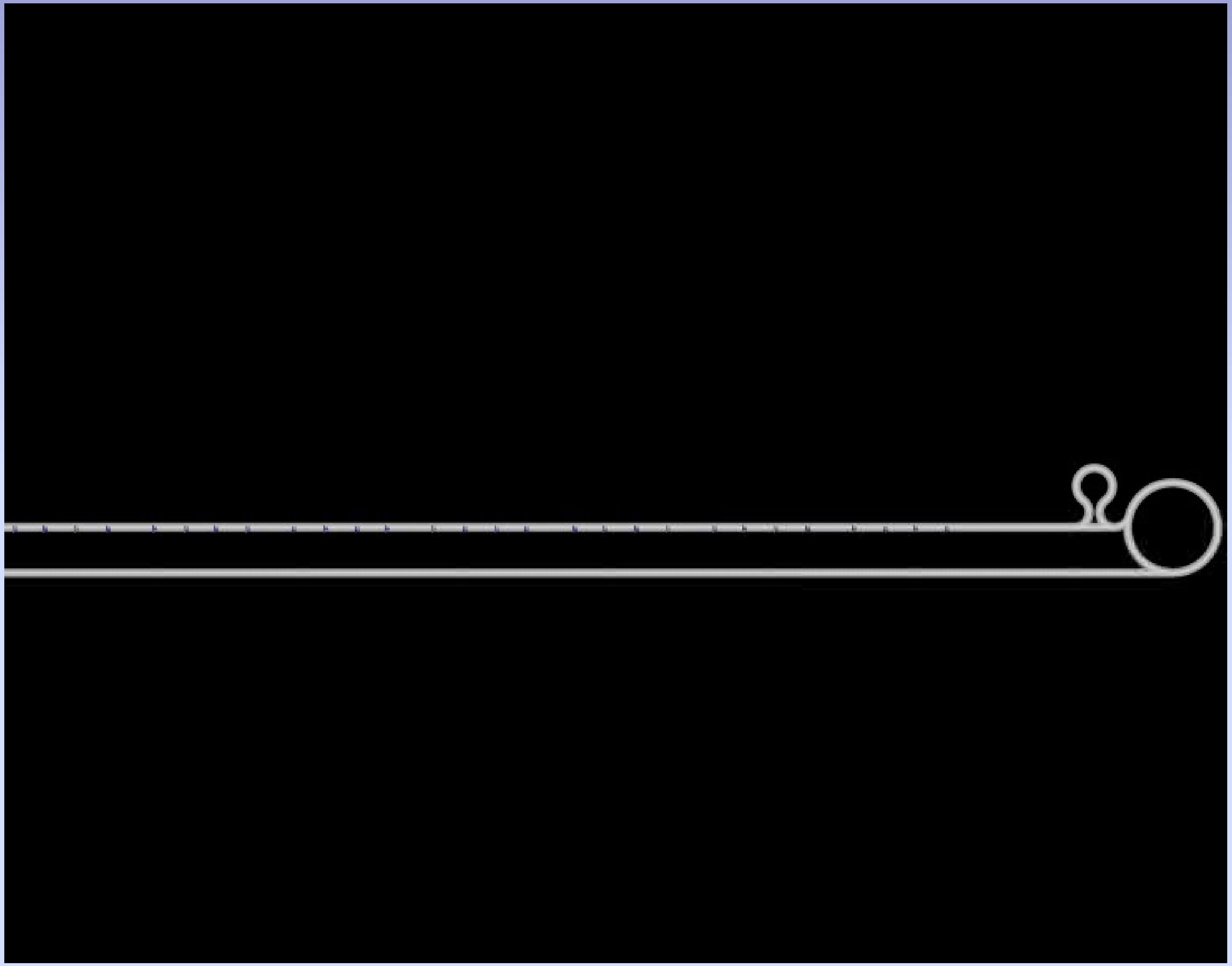
Drive beam time structure - initial



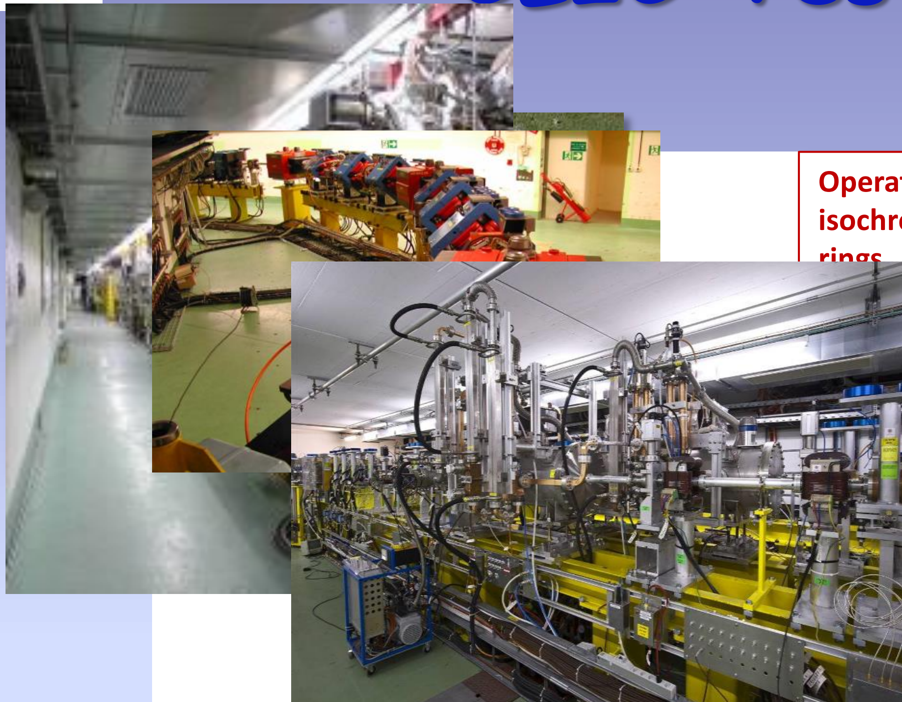
Drive beam time structure - final

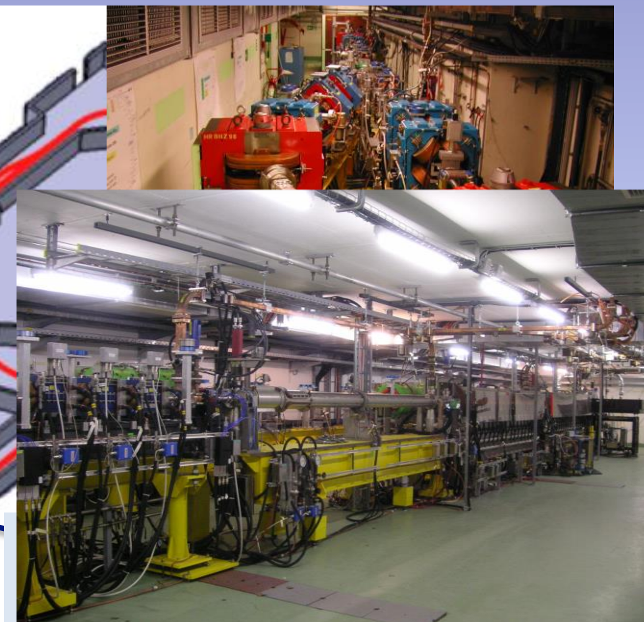


Beam combination animation

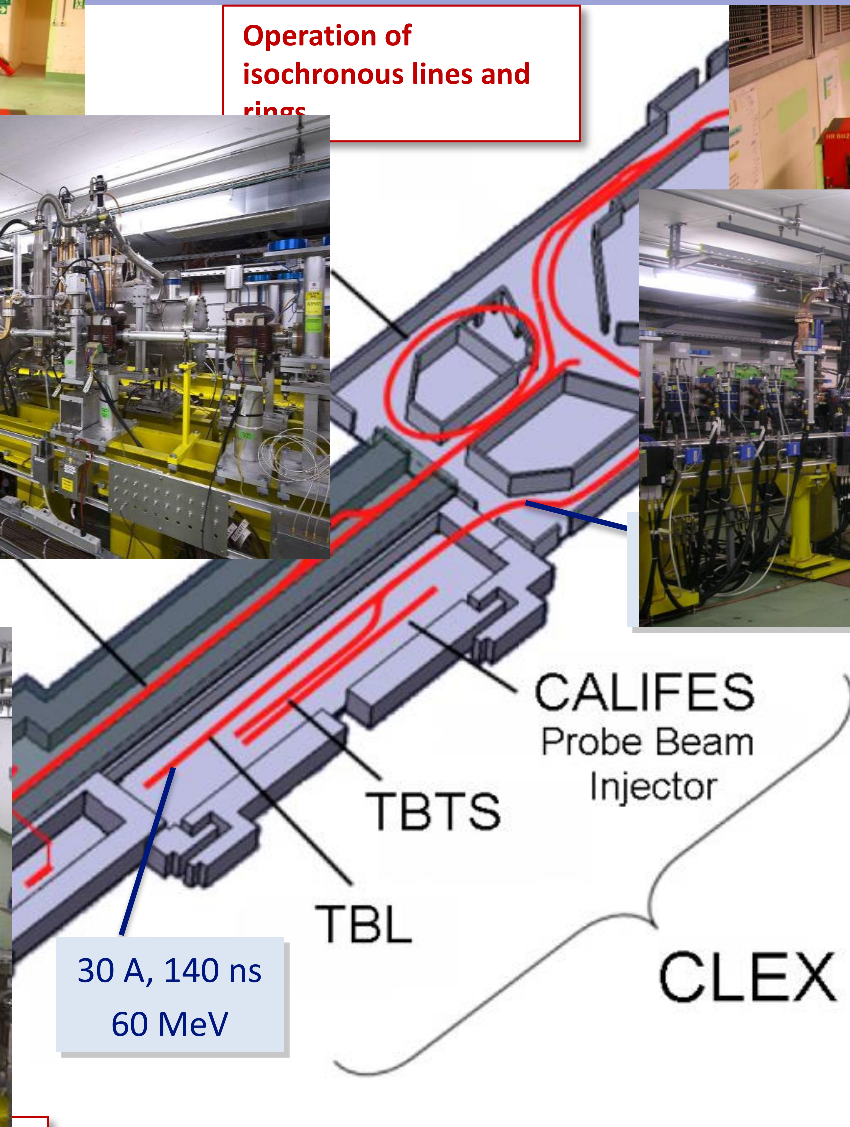


CLIC Test Facilities





Operation of
isochronous lines and
rings



30 A, 140 ns
60 MeV

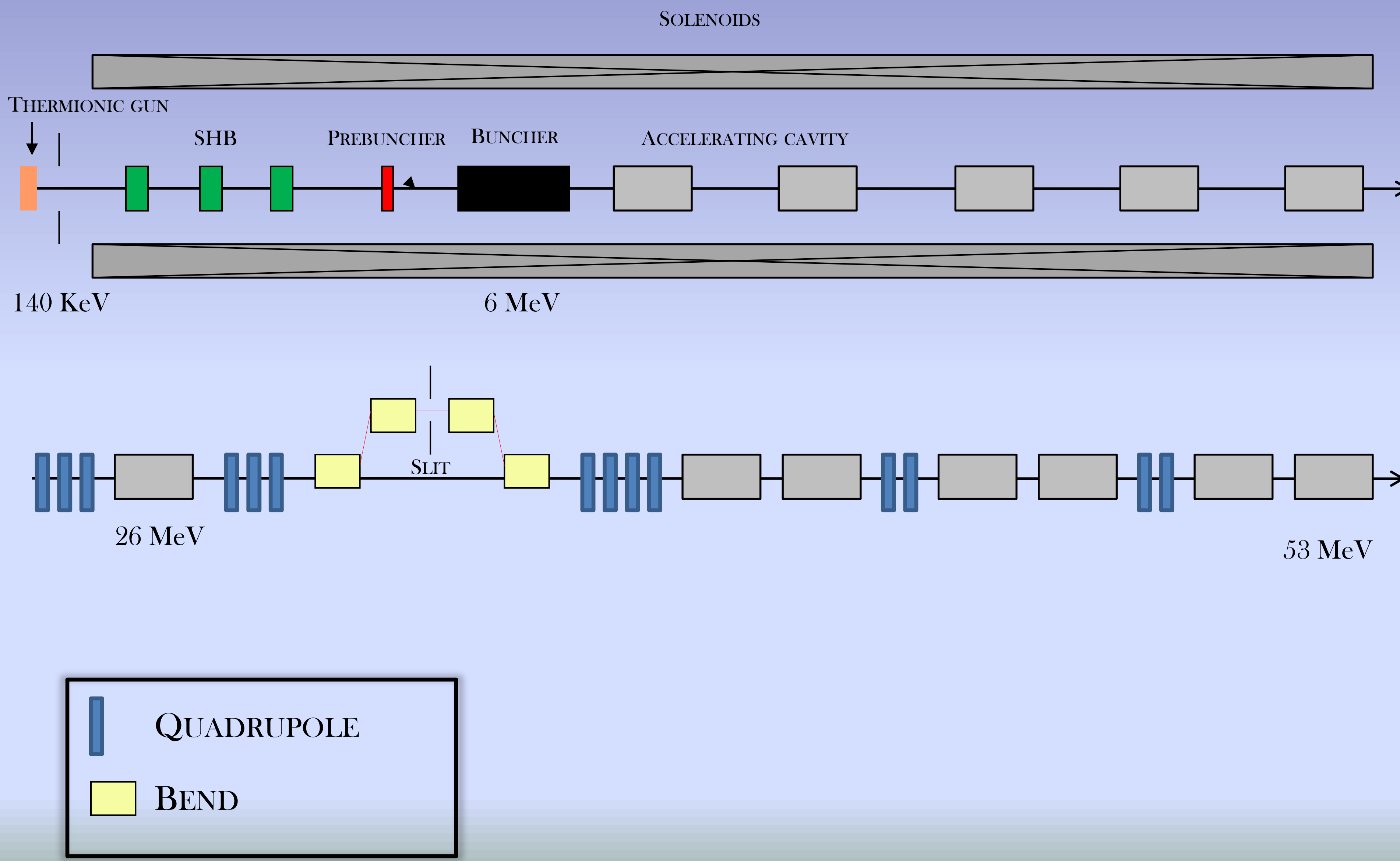
High current, full

and current
multiplication by RF
deflectors

12 GHz power
generation by drive
beam deceleration

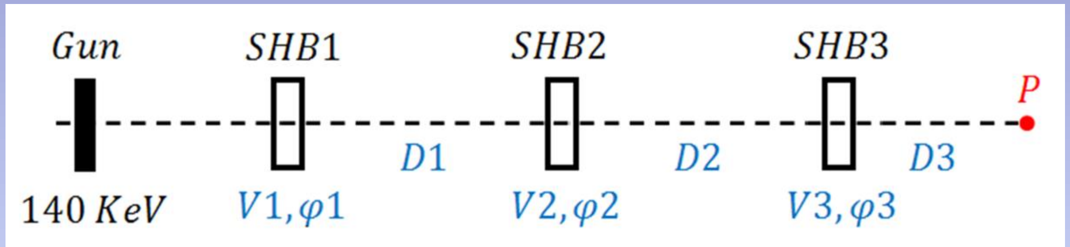
High-gradient two-
beam acceleration

CLIC drive beam injector layout



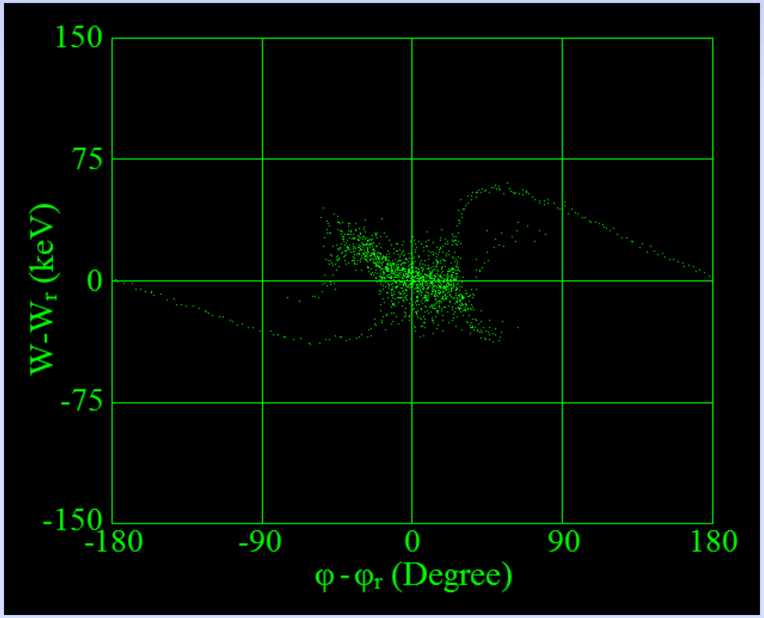
DB injector optimization

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%

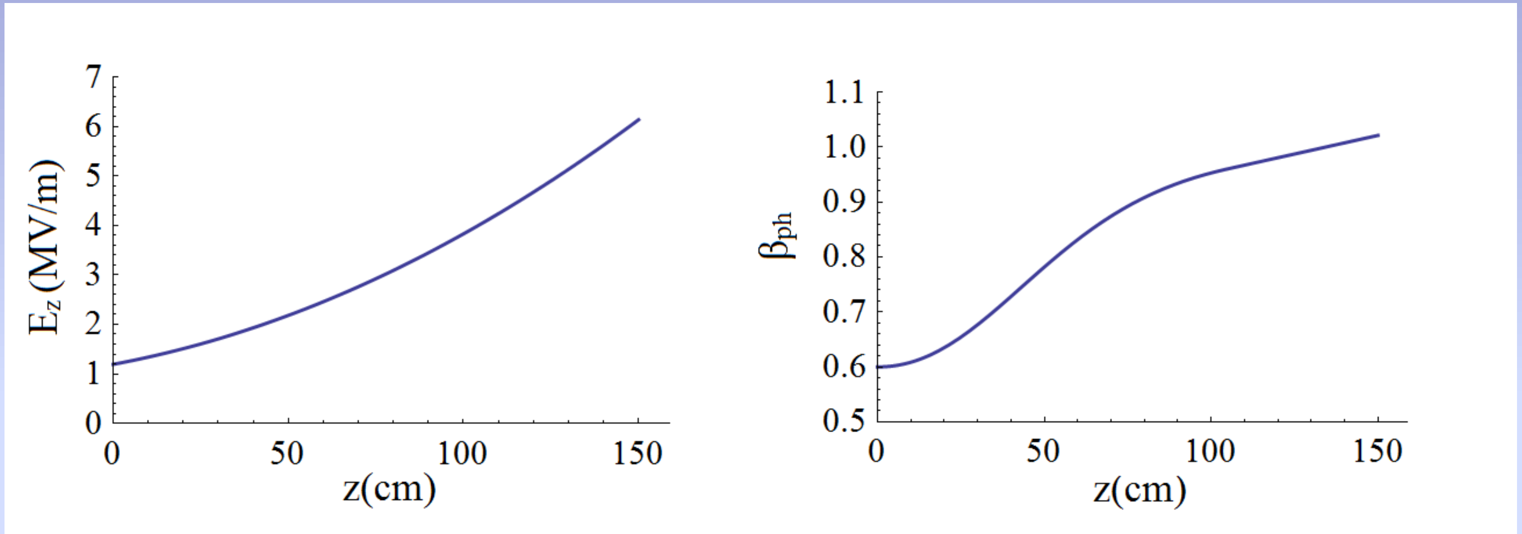


Additional 1 GHz pre-buncher for further optimization

Shahin Sanaye Hajari

DB injector optimization

Optimization of the TW buncher structure

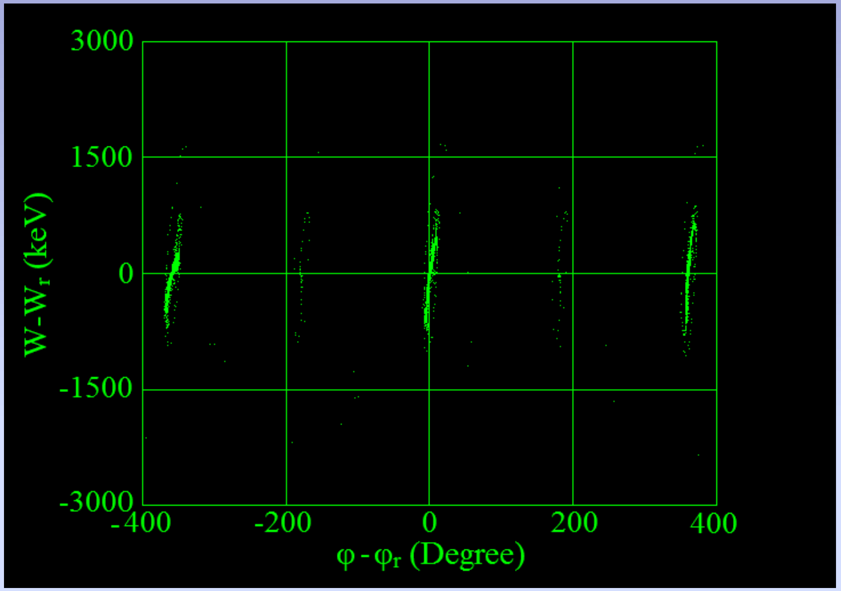


Parameter	Value
$E_{min}(MV/m)$	1.23
$E_{max}(MV/m)$	5.72
L(cm)	147
P(MW)	~20

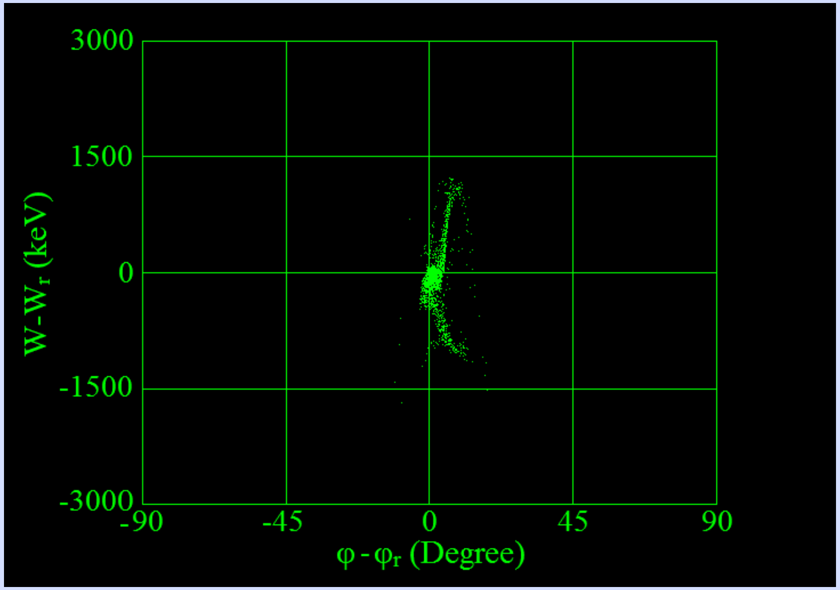
Shahin Sanaye Hajari

DB injector optimization

phase space after TW buncher



Final phase space at 50 MeV



Parameter	Value
$\sigma_L(mm)$	2.64
$\sigma_W(MeV)$	0.480
$W_{av}(MeV)$	50.0
Satellite(%)	2.2

Shahin Sanaye Hajari

Tentative klystron

Thales

Toshiba

CPI #a

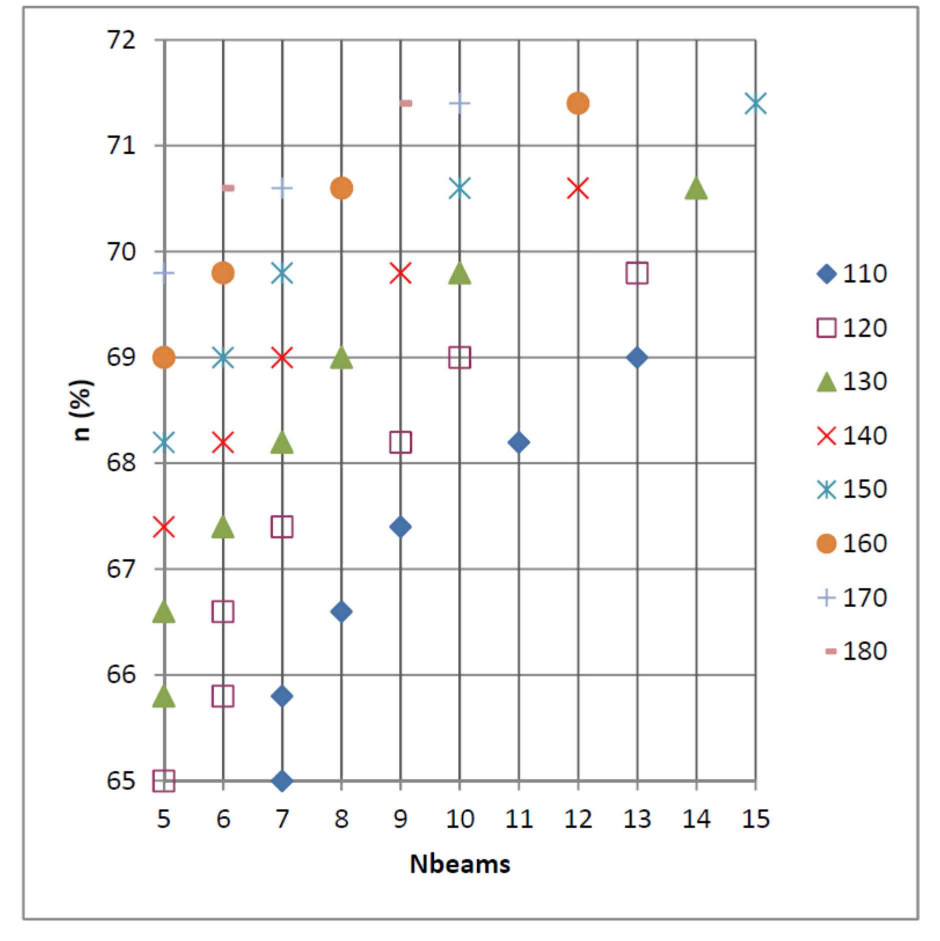
CPI #b

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/cm²	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



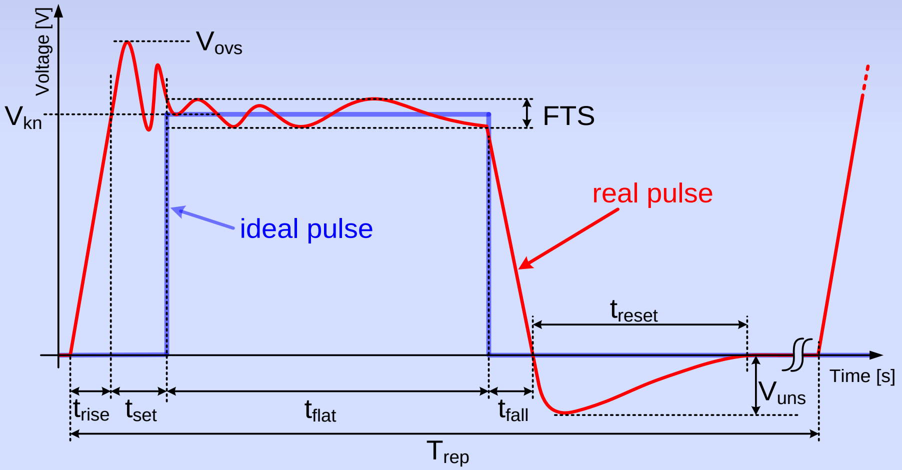
Efficiency for 20 MW for different voltages (Thales study)

Modulator design

– Main modulator specifications

Average power of 200kW per modulator R
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	$\mathbf{t_{rise}}$	**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**

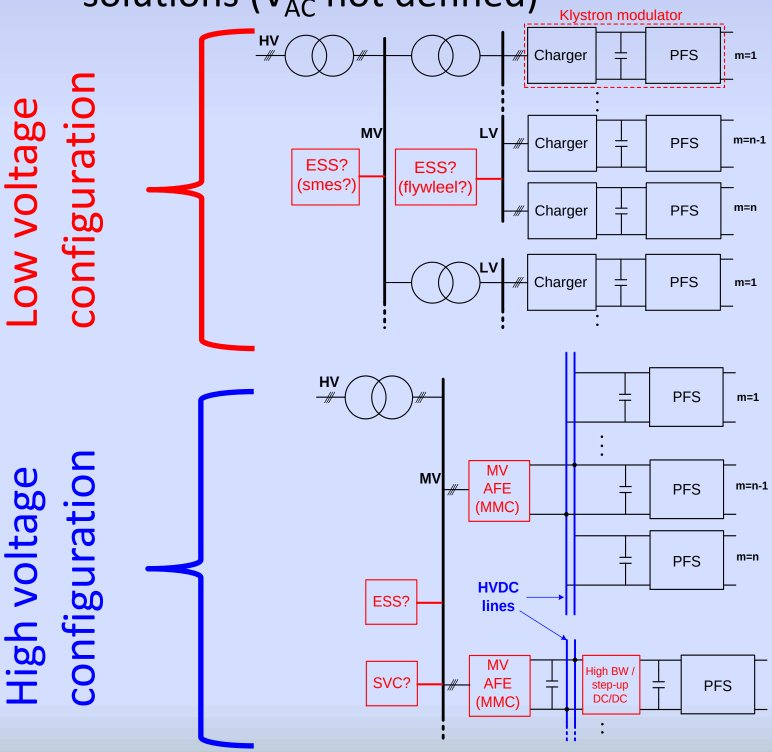


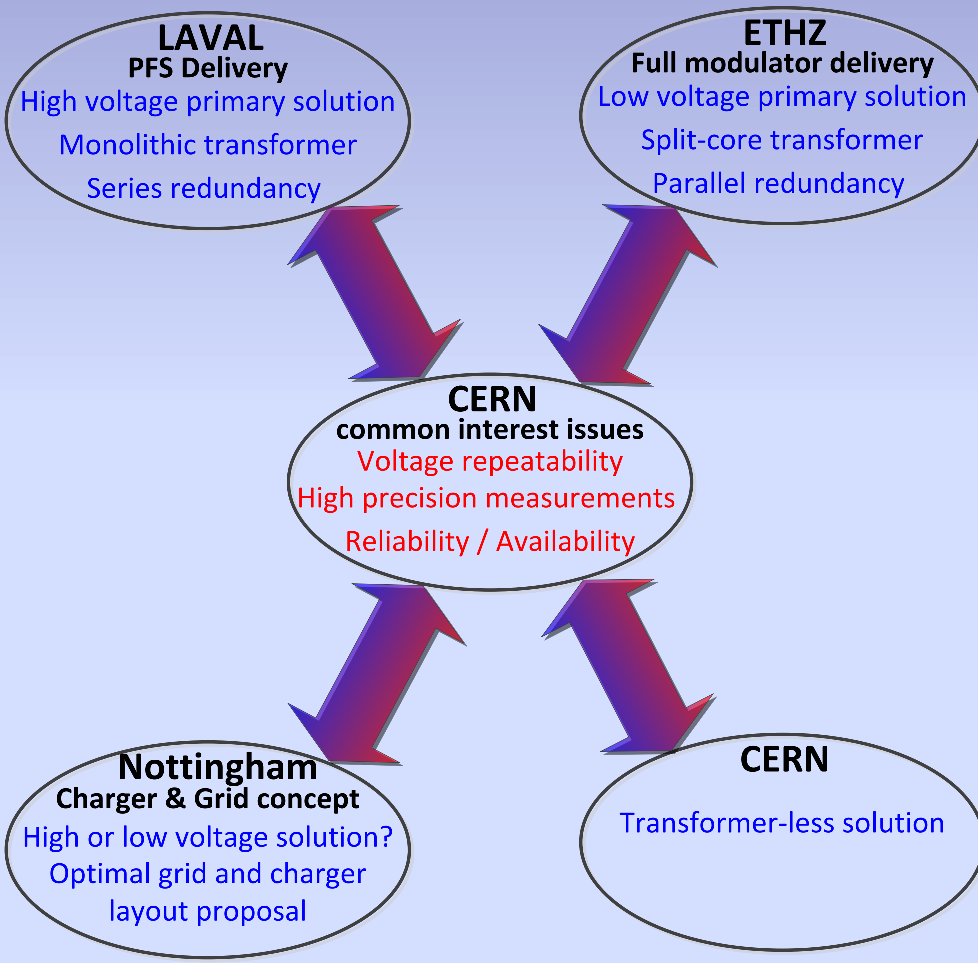
- Low AC power fluctuation
- High reliability / availability

R&D strategy and status

– General concept

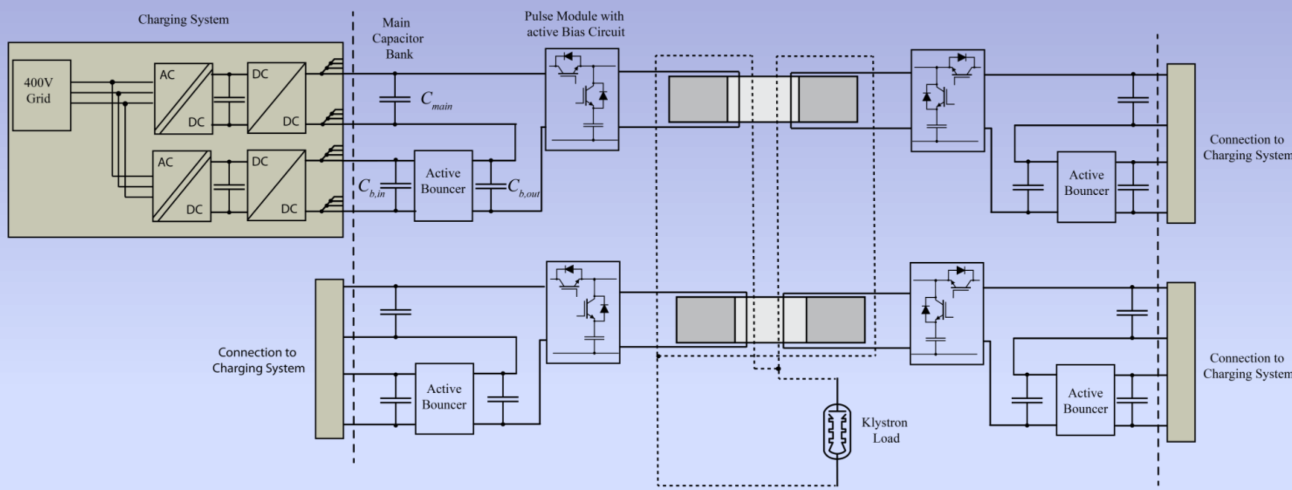
1. At CERN we study common issues to all R&D partners
2. Tasks allocation considering partner expertise
3. Obtain 2 topologically different solutions (V_{AC} not defined)

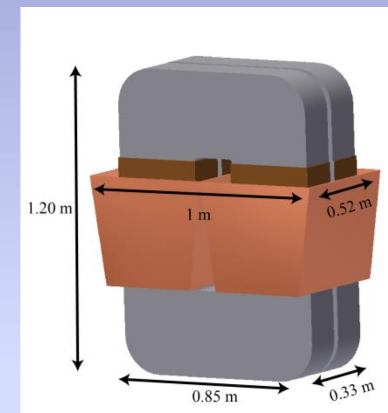




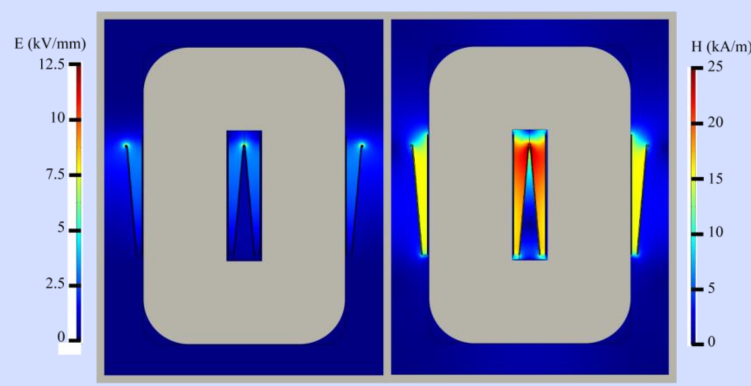
R&D strategy and status

- ETH: Topology defined-matrix transformer based





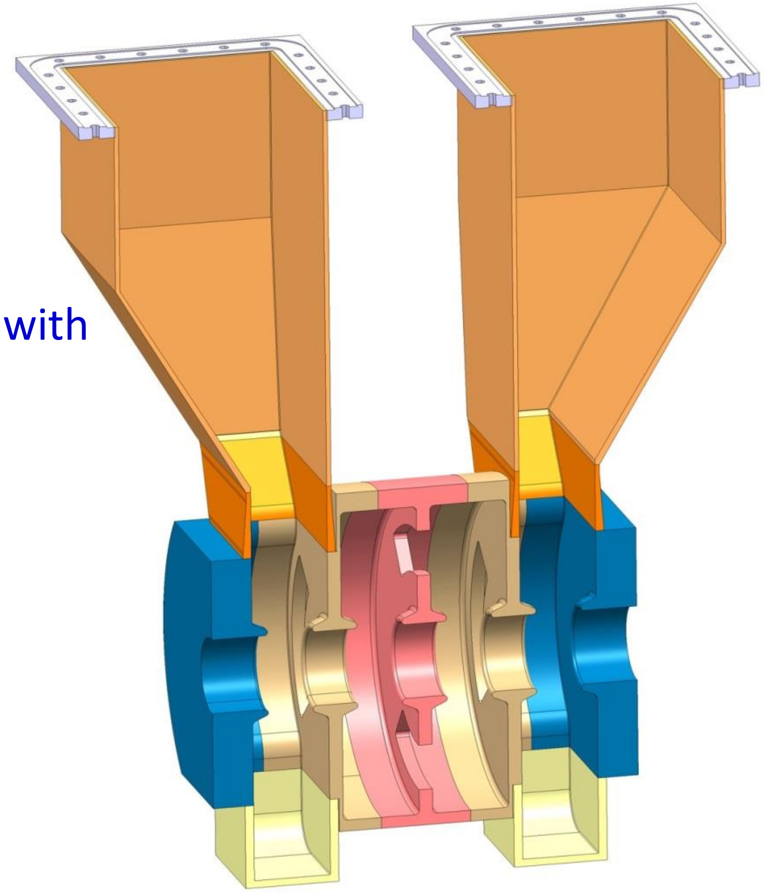
Pulse transformer design almost finished
Expected prototype beginning 2014
Active bouncer theoretical design almost finished – construction in 2014



Sub-harmonic bunching system

Status:
RF design existing, mechanical design advanced,
Next: launch prototype (in aluminum ?)

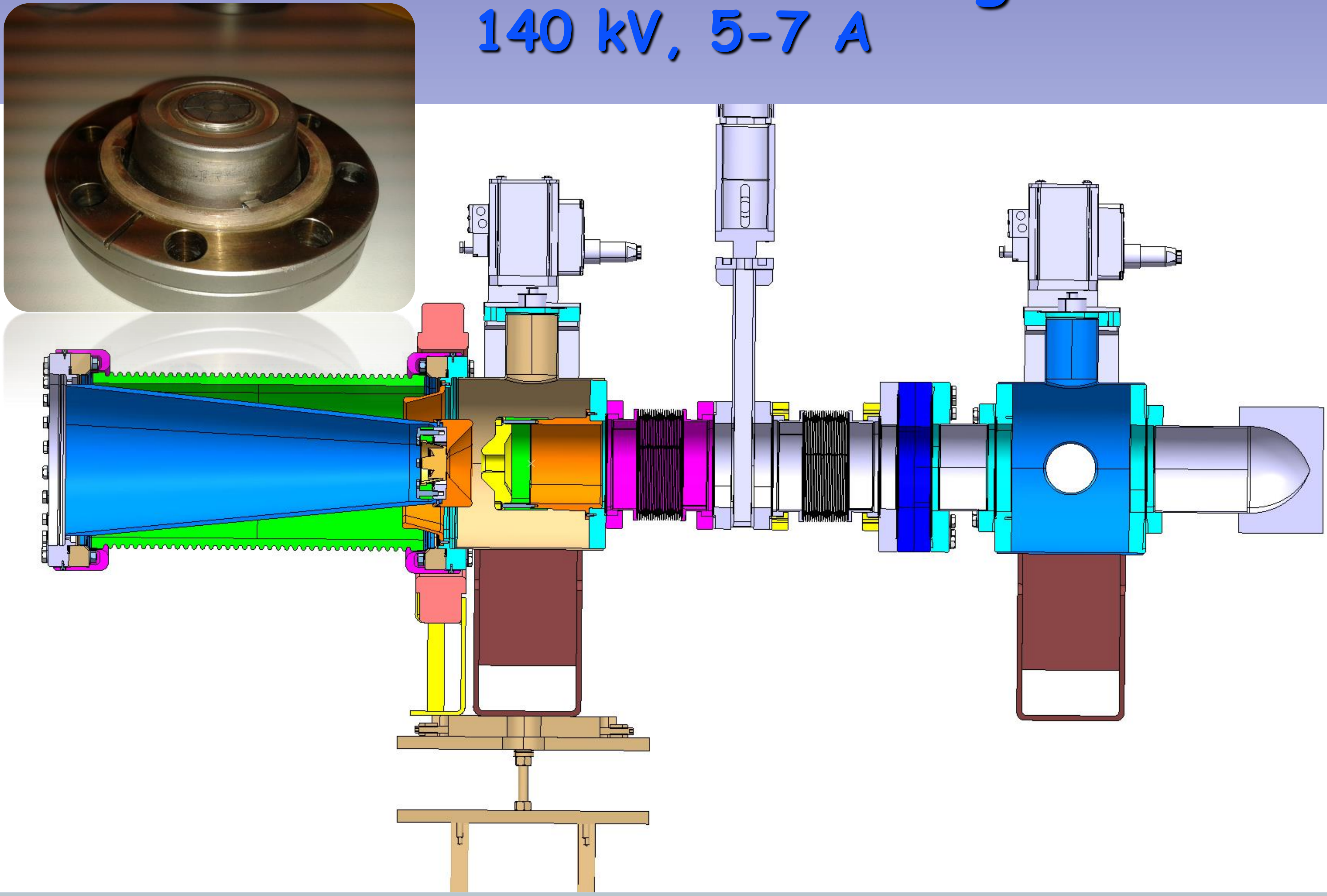
Power source:
500 MHz, 15-115 kW, wide band (60 MHz) sources needed for fast phase switching. Started to discuss with industry and collaborations.



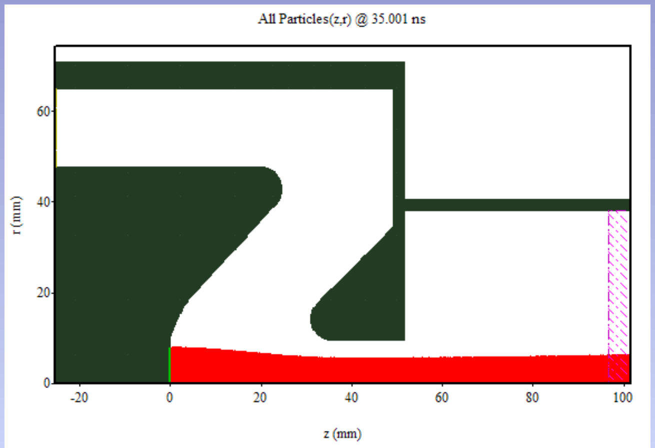
	SHB 1	SHB 2	SHB 3
Beam velocity	0.62 c	0.62 c	0.62 c
Current	5 A	5 A	5 A
Voltage	15 kV	30 kV	45 kV
Bunch form factor	0.058	0.57	0.73
Detuning	1.6 MHz	12.1 MHz	12.7 MHz

Hamed Shaker

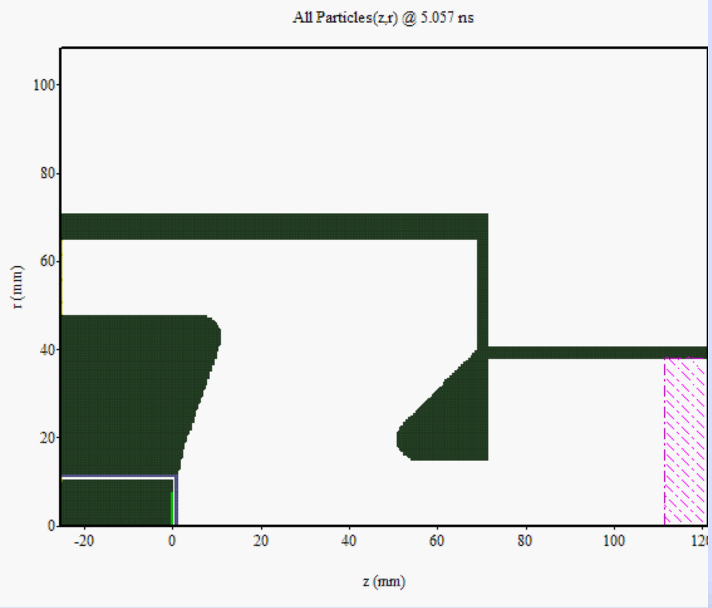
Thermionic Gun design
140 kV, 5-7 A



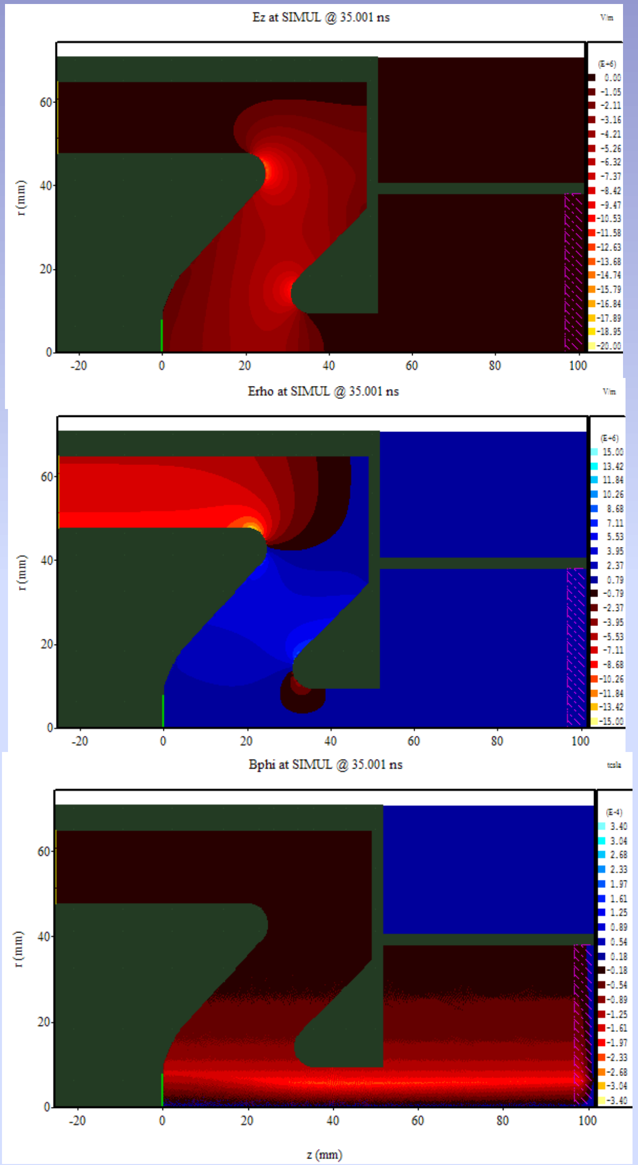
Jacques Gardelle, CEA-CESTA



Typical MAGIC snapshot: particle positions in r-z



Contour plots of field components at t=35ns

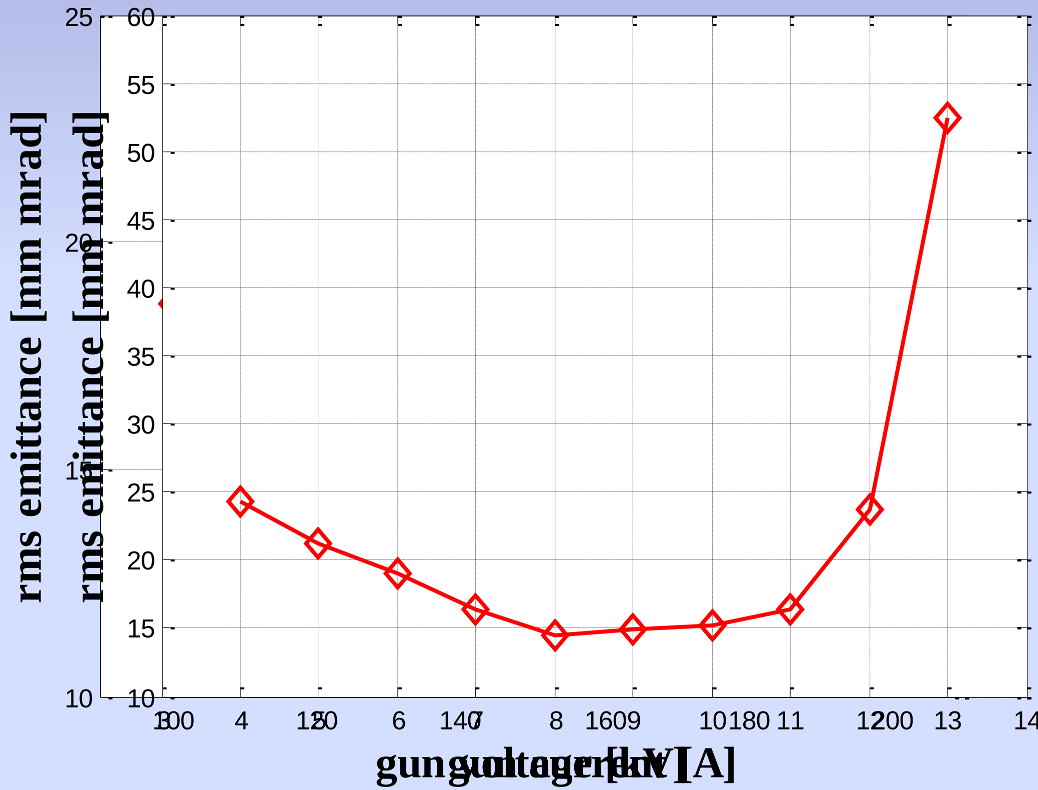


E_z

E_r

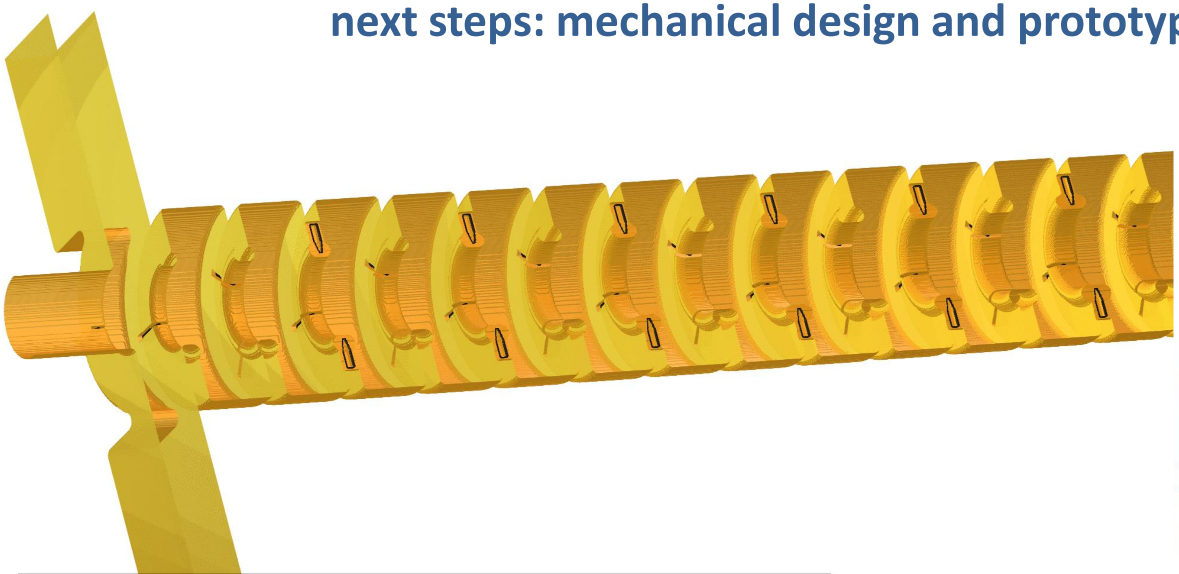
B_ϕ

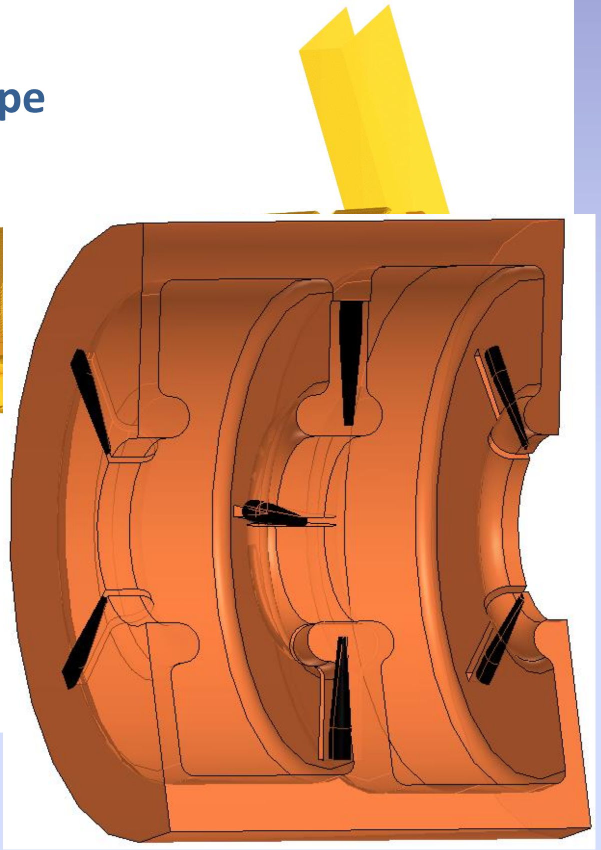
Gun simulations
Emittance vs voltage

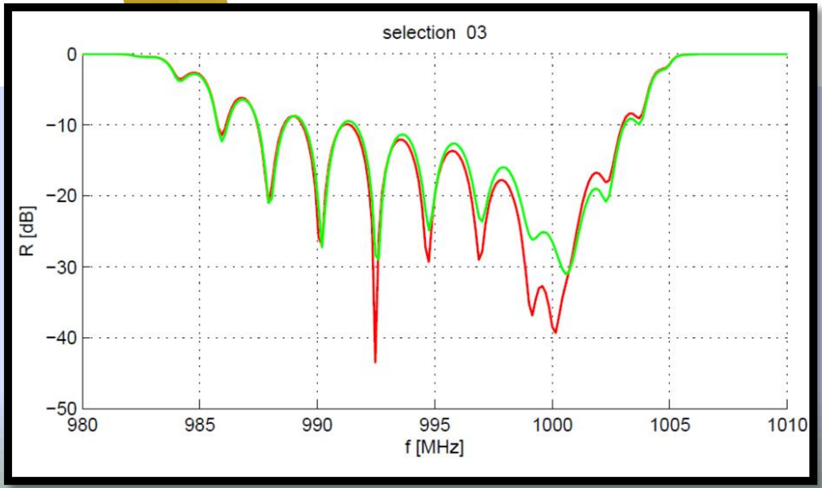


DB-accelerator structure

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



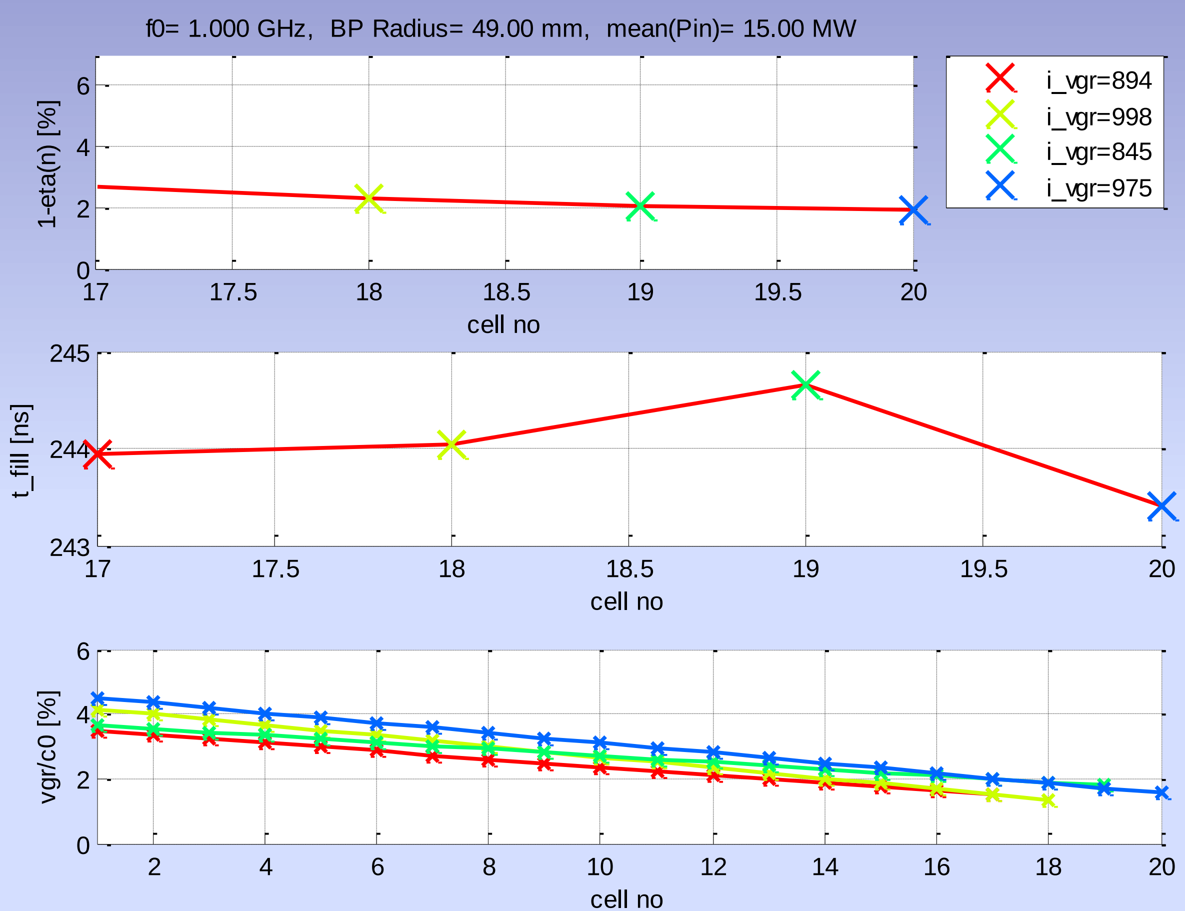




Input and output coupler design finished
Correct match, input reflection < 30 dB.
(red and green: two different geometries; red is final)

Rolf Wegener

DB-accelerator structure



Parameters:

f = 999.5 MHz

P_{in} = 15 MW

R_B = 49 mm

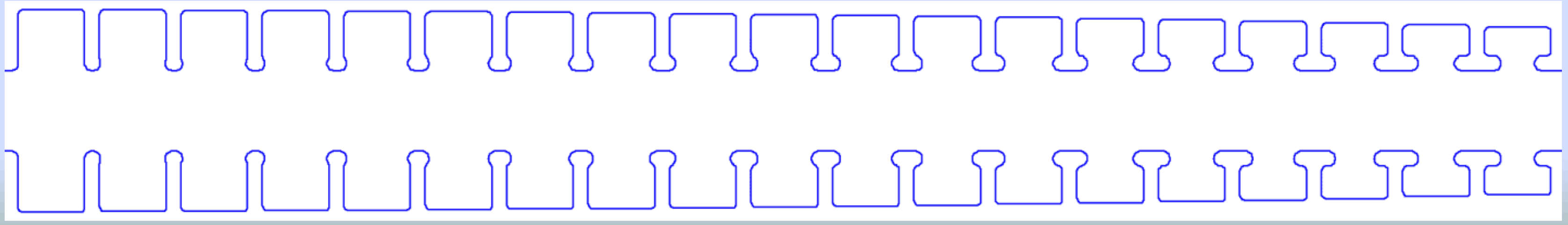
***N* = 19 cells**

OD= 300 mm

L= 2.4 m

T_{fill} = 245 ns

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



Rolf Wegener

Conclusion and Outlook

- Challenging Drive beam frond project
- Key elements under design or manufacturing
- Large collaborative effort

- Hope to get some 'real' CLIC drive beam hardware to test in 2014
- CLIC collaboration workshop, February 2014

End

Gun Test Facility

Gun test area:
former GTF available, Bldg. 162-R-004/008, needs some refurbishment

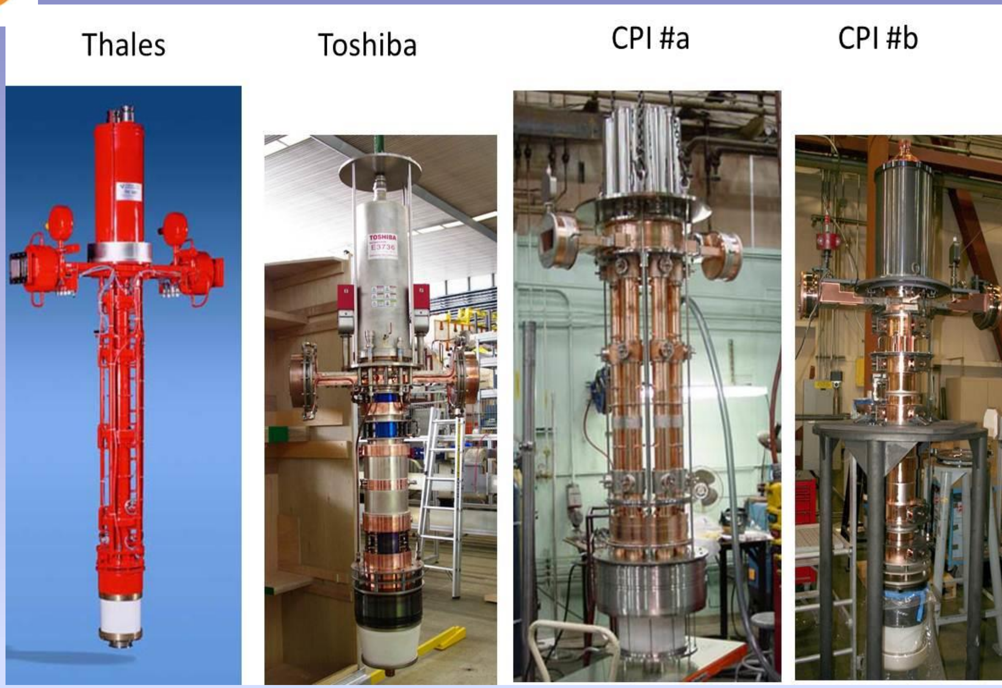
What do we plan to do until 2016

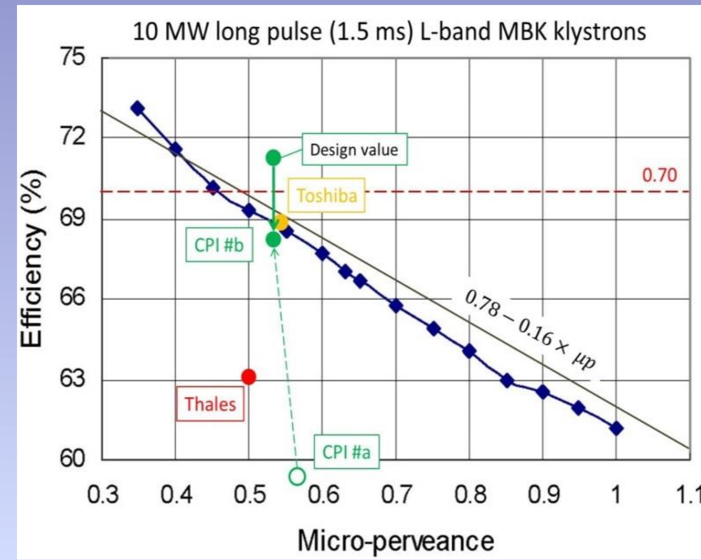
Optimistic and rough planning

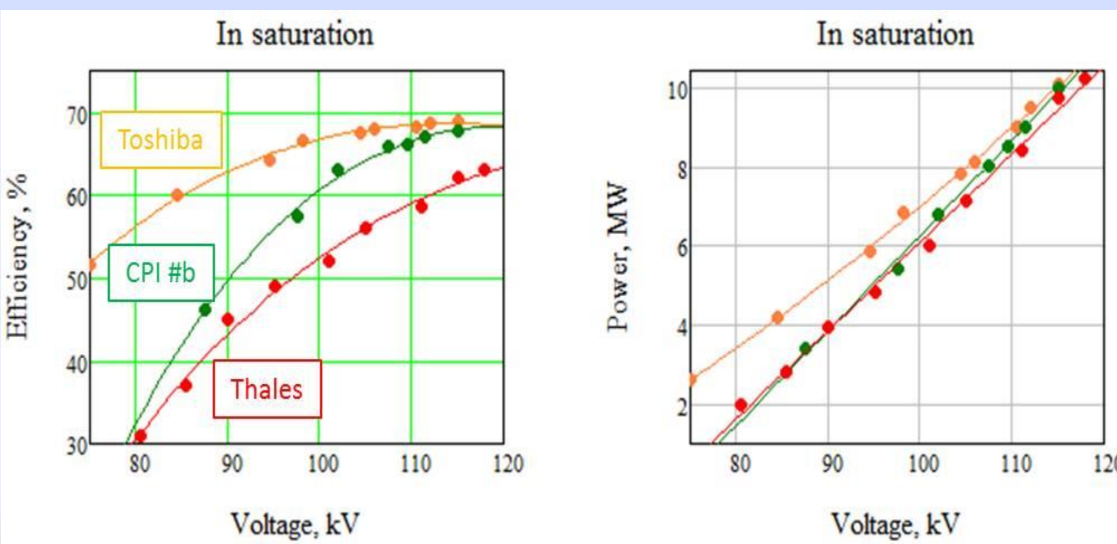
Task	2012	2013	2014	2015	2016
Space needed		prepare gun test facility	prepare Klystron test sand	prepare injectot building	injector building
Gun	conceptunal design	design	GUN test facility	GUN test facility	
SHB Buncher	design	fabrication	testing		
500 MHz power source	specification		Purchase, testing		
Buncher	specification		design		
1 GHz structure	specification	design	mechanical design	manufacturing	high power test
Diagnostis	specification, purchase		IC in gun test		
LLRF		specification	fabrication+test	ready for klystron test	
1 GHz klystrons		Tender, design	fabrication of prototype	Receive Klystron 1	Klystron 2
1 GHz Modulator		R&D	R&D	Receive first MDK	MDK2
Injector integration, vacuum, controls, magnets, diagnostics	on hold	on hold	design		

Create a gun test facility to test the source
and a high power test stand to test the klystron, modulator and rf structures

10 MW L-band klystrons for ILC







In terms of achieved RF efficiency, the klystrons with RF circuit adopted by Toshiba and CPI provides values very close to the 70%, as is specified in CLIC CDR (67.8% for CPI and 68.8% for Toshiba. These values validate the feasibility of a slightly higher efficiency with minimised design/fabrication efforts, when scaled in frequency down to 1.0 GHz.

Igor Syratchev

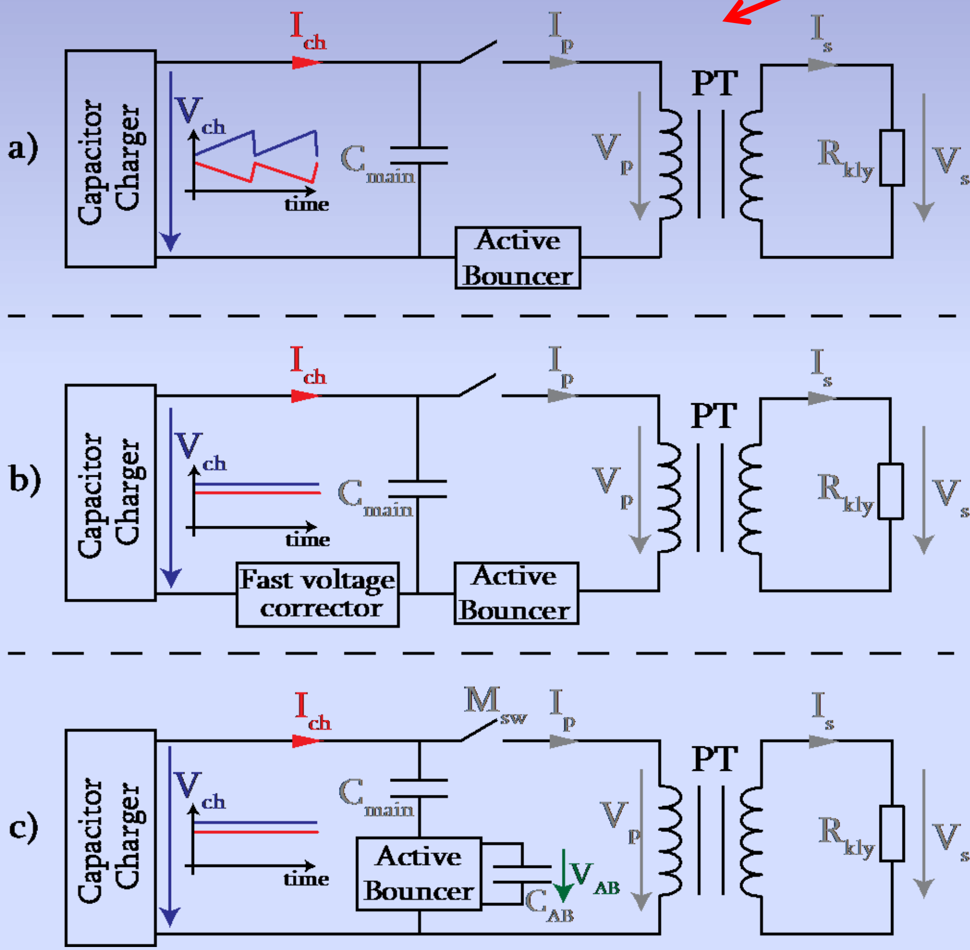
DB-Gun strategy and planning

1-2/2013	3-4/2013	1-2/2014	3-4/2014
SLAC design study based on YU156	SLAC mechanical design with YU156	Fabrication	Test
Concept for GTF	Prepare local and purchase equipment	HV-test for PS ready install equipment	Gun test
Design GUN CERN-CESTA based on YU796 and YU156 modular ?	Mechanical design based on YU796	Fabrication	Test
	Modulator design CESTA	Prototype	Prototype at CERN
Concepts for HV deck electronics	Design of pulser electronics	Fabrication and tests	Ready for use

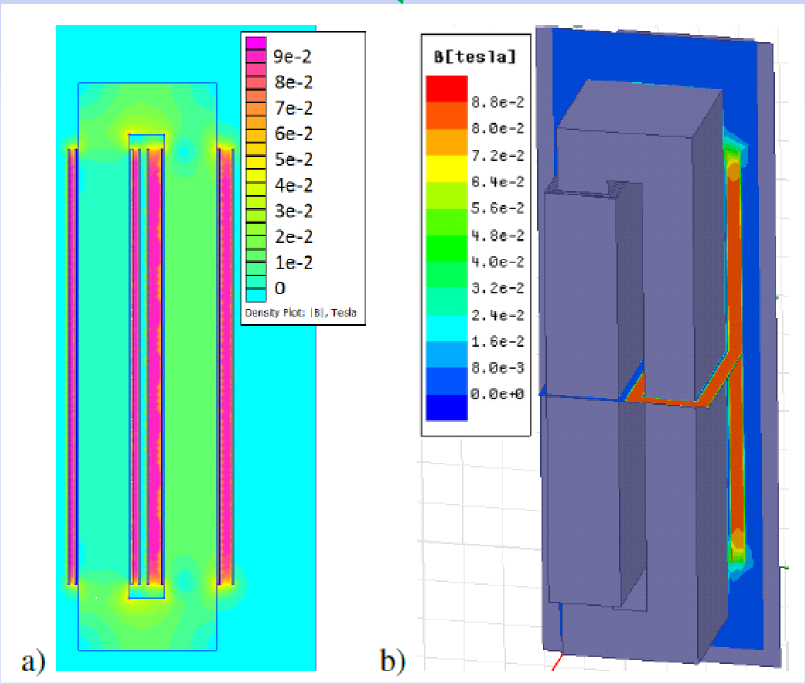
R&D strategy and status

- LAVAL University

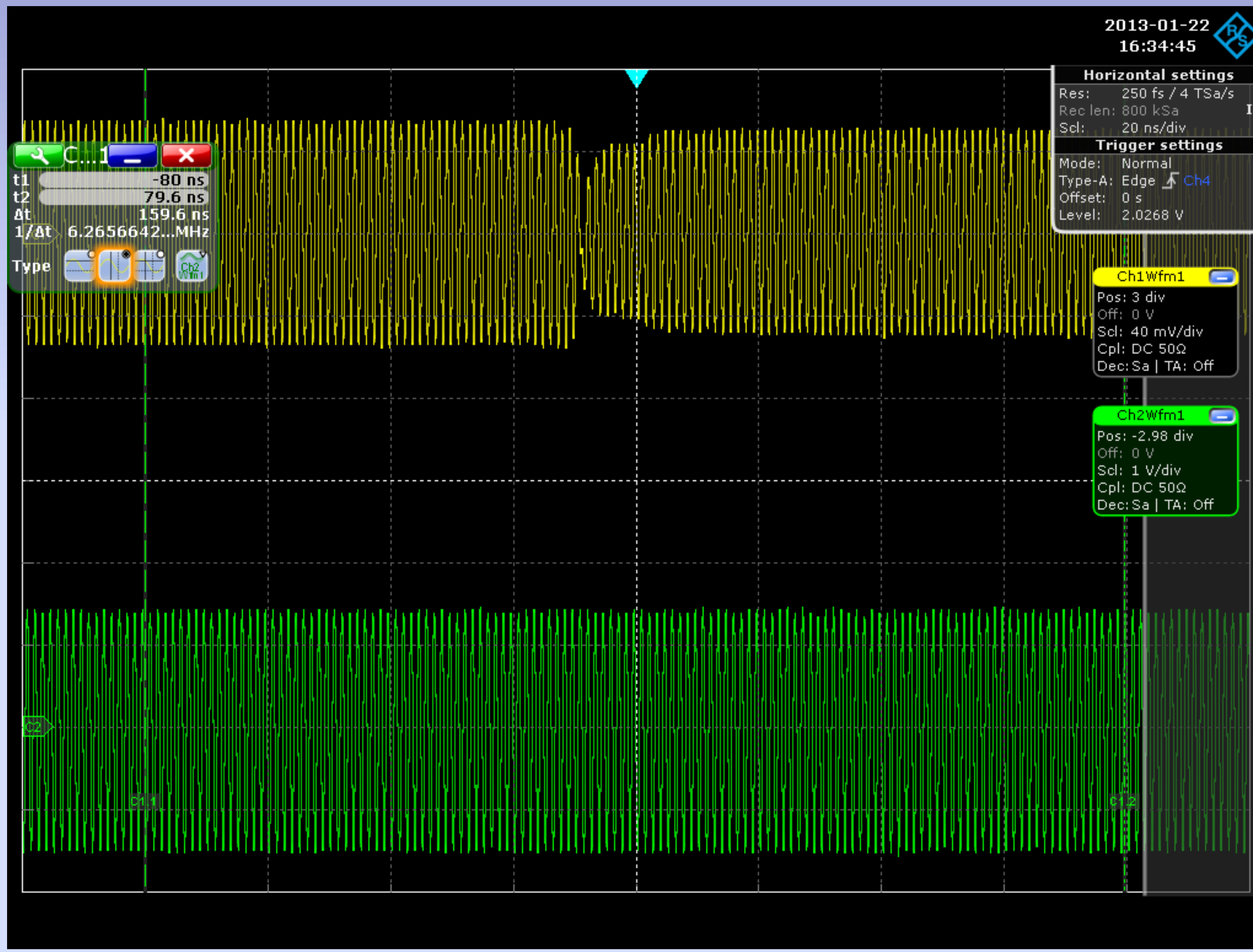
Two novel active bouncer topologies under evaluation (small scale protos beginning 2014)



Monolithic transformer design almost finished – small scale proto in 2014



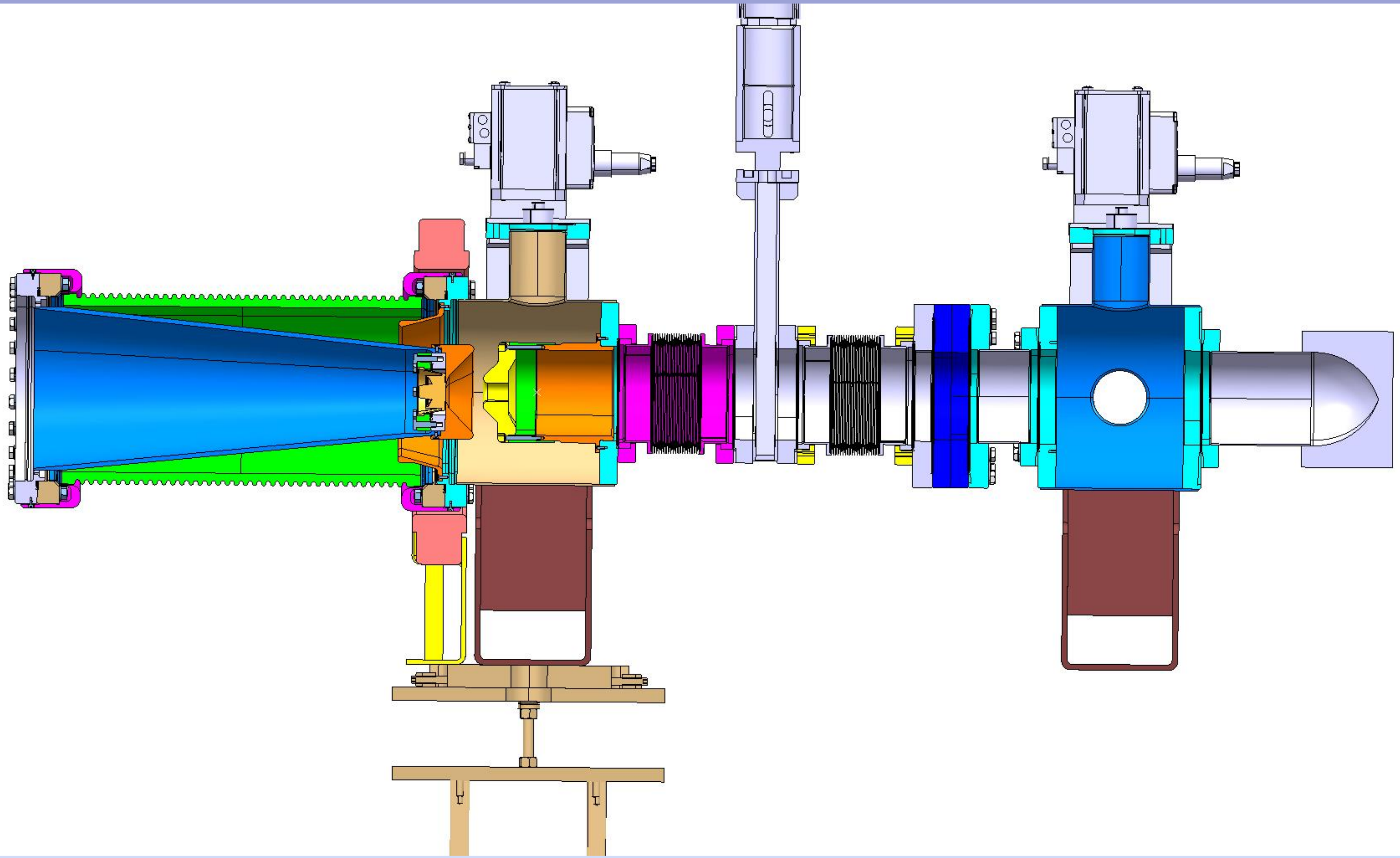
800 MHz SPS IOT switching test



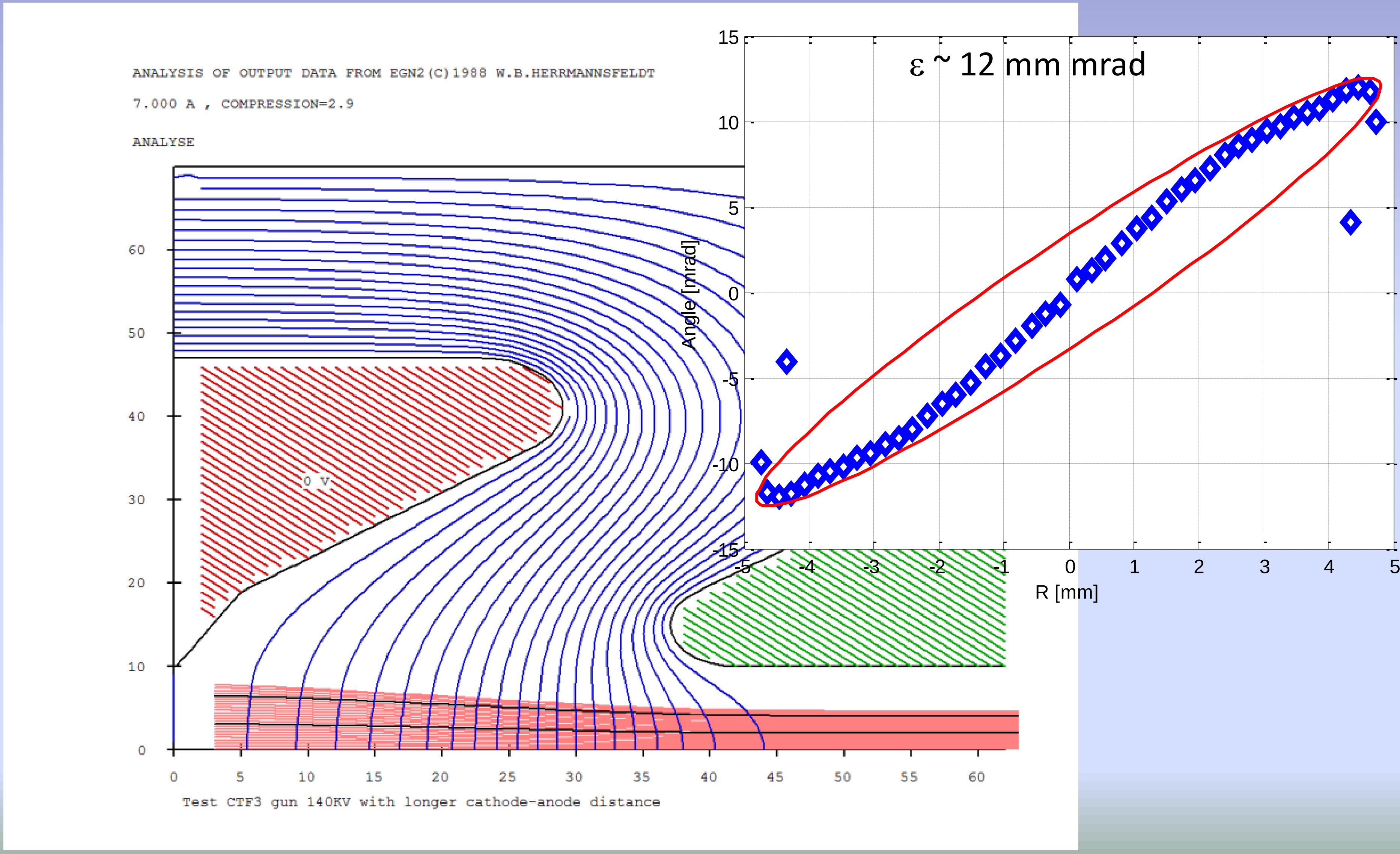
~80 ns switching time → BW 6.25 MHz

~100 ns switching time → BW 5 MHz

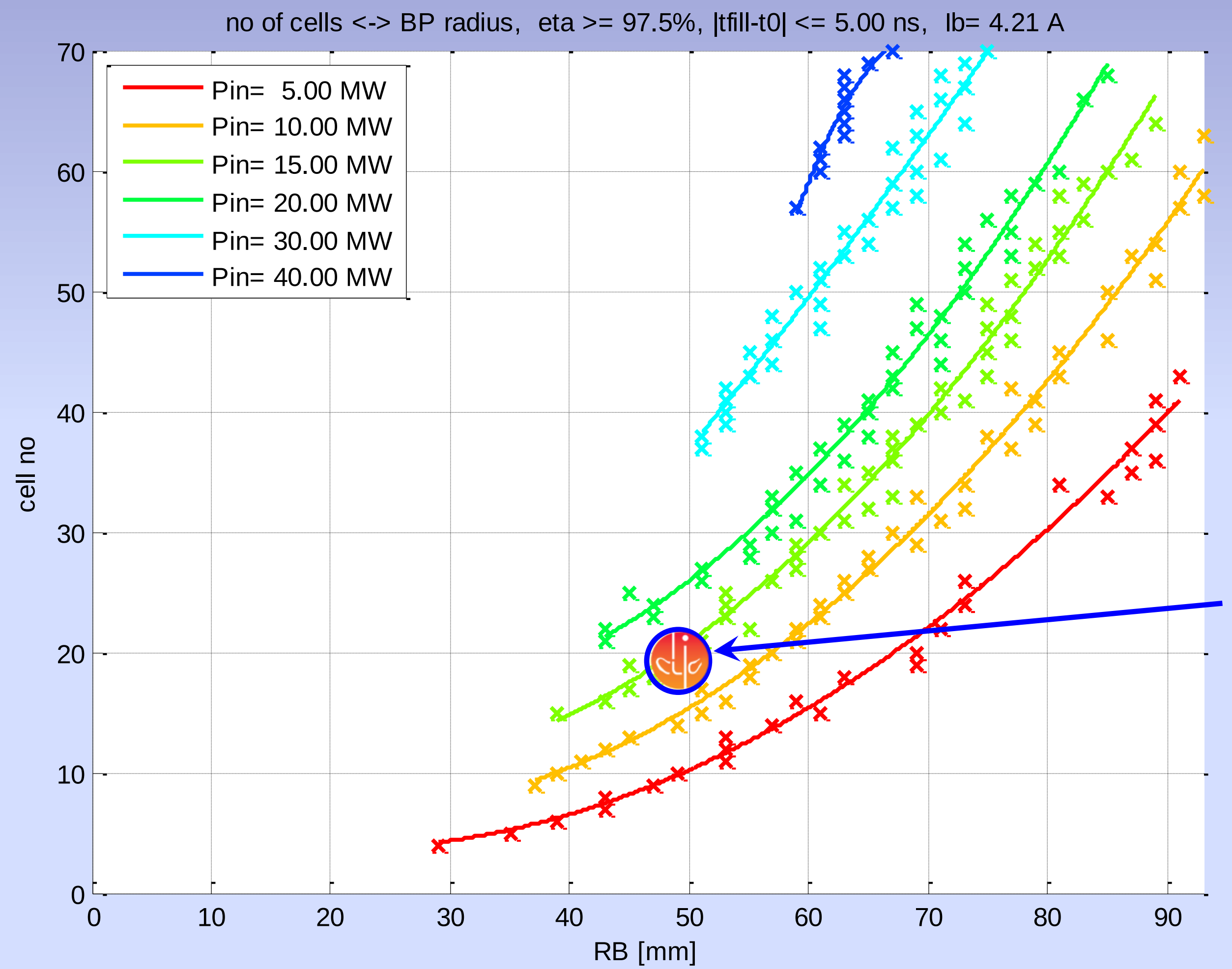
Thermionic Gun design



Gun simulations
Using EGUN



Optimum aperture found



$\eta_{RF} \geq 97.5\ \%$

$|t_{fill} - 245\ \text{ns}| \leq 5\ \text{ns}$

P_{in} = 15 MW

Beam dynamic (Avni Aksoy):

R_B = 49 mm,

N = 19 cells

Rolf Wegner