Summary of the high-efficiency (HEIKA) day

I. Syratchev, CERN

Some statistics

2015 HEIKA ½ day. 6 talks.

Klystrons development

Introduction to HEIKA. Tentative structure and objectives	160-1-009, CERN	09:00 - 09:30
Klystron simulations. Review/comparison of existing tools	160-1-009, CERN	09:30 - 10:00
Klystron with adiabatic bunching (Kladistron). Status and prospective	160-1-009, CERN	10:00 - 10:30
Bunch congregation and ultimate efficiency study	160-1-009, CERN	10:50 - 11:20
Towards klystrons with 90% efficiency of RF power extraction	160-1-009, CERN	11:20 - 11:50
6MW S-band MBK status/JSC	160-1-009, CERN	11:50 - 12:20

28 people attended

One year progress/evolution reports

2016 HEIKA day. 15(13) talks.

Klystrons development

Development of the new computers tool for the klystron simulation at SLAC	Sami TANTAWI	
Theoretical analysis of the delta-bunch deceleration in the klystron outpu...	Quentin VUILLEMIN	
Development of the high efficiency MBK klystron for FCC	Chris LINGWOOD	
Electrons bunching quality, special issues	Igor SYRATCHEV	
The klystron with multi-harmonic cavities	Victoria HILL	
Council Chamber, CERN		09:50 - 10:10
Kladistron – the klystron with adiabatic bunching		
Council Chamber, CERN	Antoine MOLLARD	

News from labs and industry

Status of the CLIC MBK klystron(s)	Steffen DOEBERT	
Council Chamber, CERN		11:00 - 11:20
Status of the SLAC S-band klystron retrofit activity	Jeff NEILSON	
Status of the S-band MBK development at VDBT	Igor GUZILOV	

New in 2016

IOT

Status of the L-band MBK IOT for ESS	Morten JENSEN
Very high efficiency IOT with 3 cavities	Vladislav TSAREV
Resotrode – RF amplifier with regene...	Andrey BAIKOV

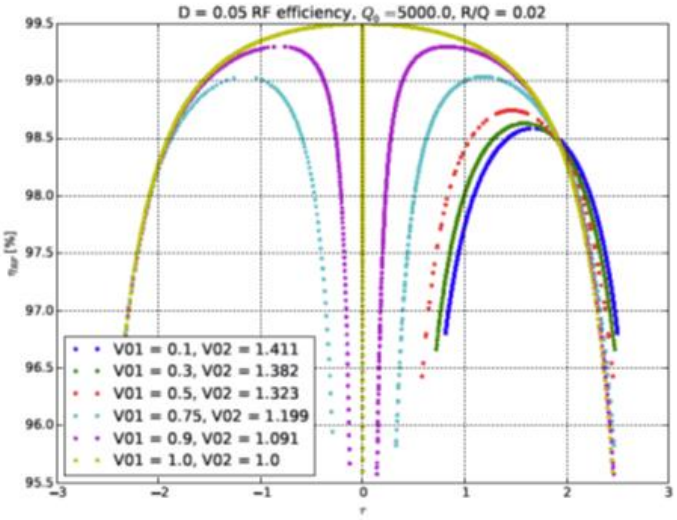
Modulators

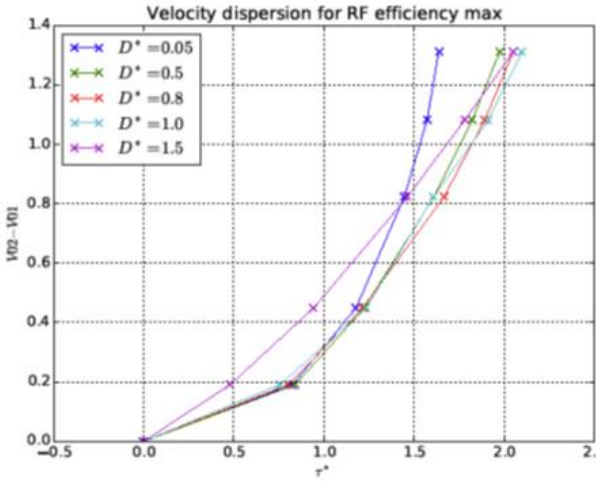
Status of the modulator for CLIC ...	Davide AGUGLIA
Energy recovery in depressed collector of ...	Jeff NEILSON
Optimised RF unit	Mikael LINDHOLM
Council Chamber, CERN	16:10 - 16:30

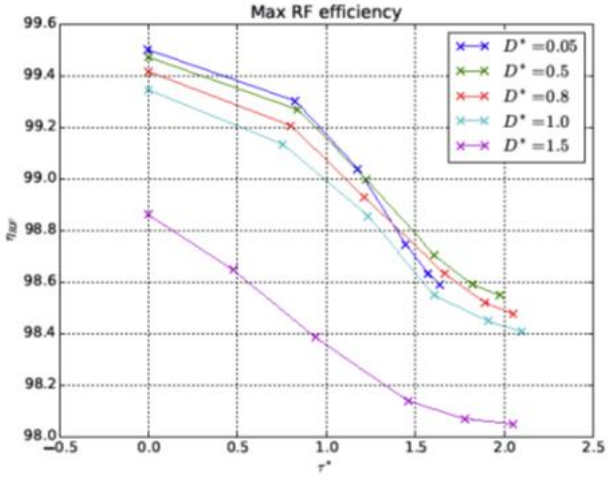
52 people attended

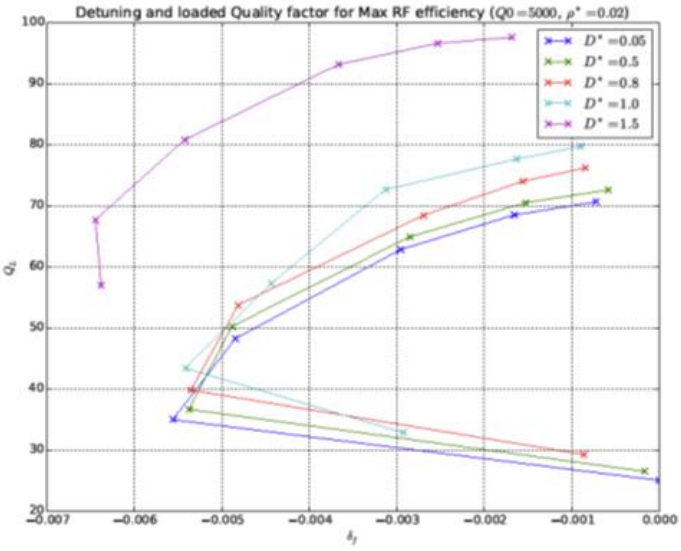
Theoretical analysis of the delta-bunch(es) deceleration in the klystron output cavity.

Quentin VUILLEMIN





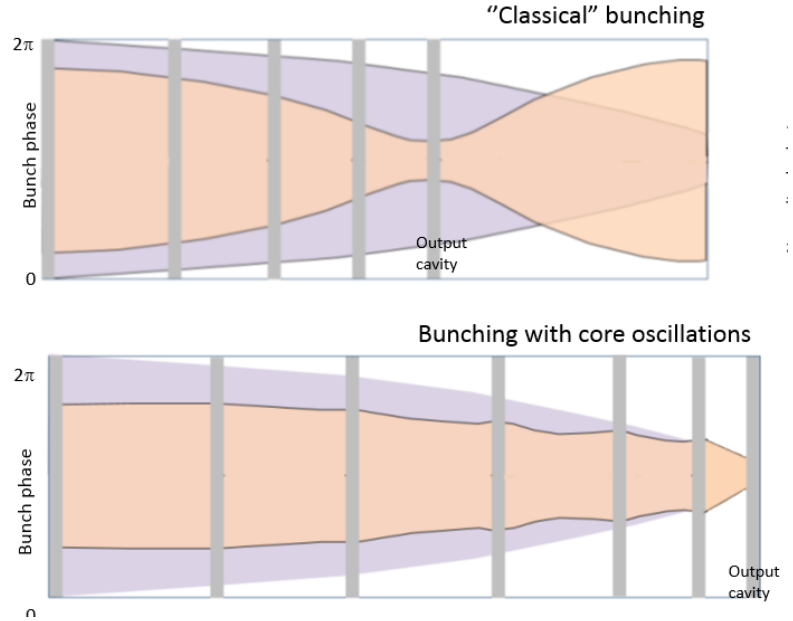


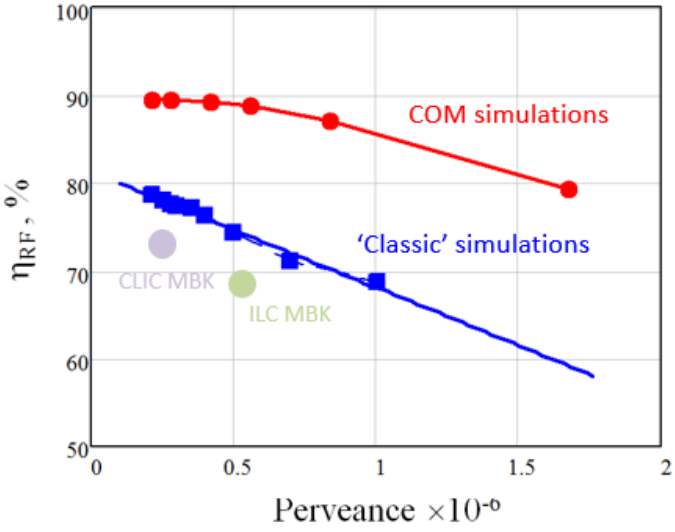


- The self-consistent analytical model of the infinitely short (delta) bunch(es) interaction with the output klystron cavity has been developed.
- Based on two bunches model approximation it was shown that in order to reach very efficiency the cavity needs to be tuned down in frequency and the bunch needs to be congregated (the head should be slower than the tail).

Development of the high efficiency MBK klystron for FCC.

Chris LINGWOOD

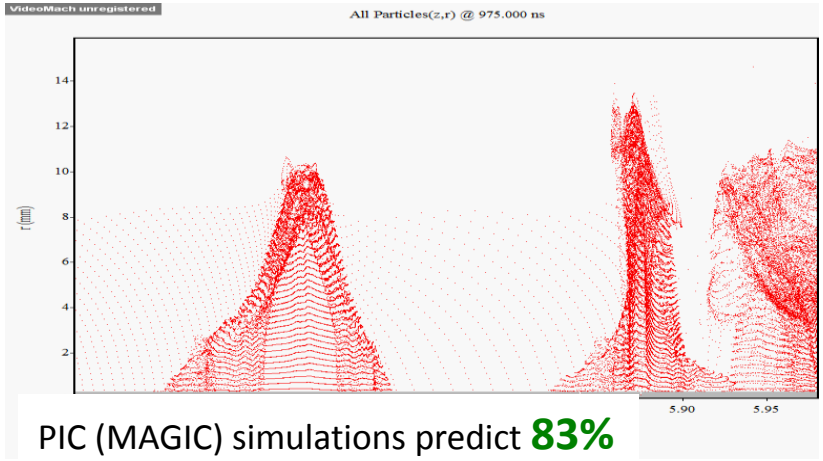




0.8 GHz, 1.5 MW, CW MBK FCC klystron in progress

Using new bunching theory 80%+ looks possible for FCC/CLIC/ESS/ILC klystrons

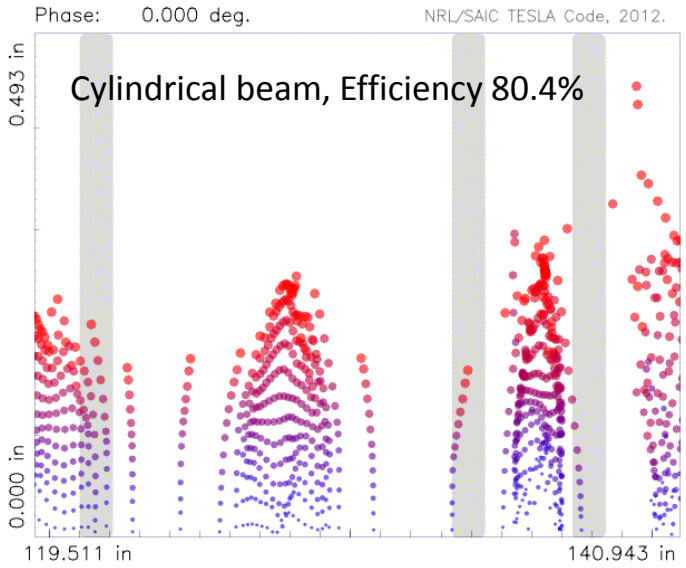
- No new materials or manufacturing techniques needed
- Little additional complexity. Simply existing technology reconfigured.
- Prototypes for proof of concept in progress.
- Lower voltages combined with high efficiency appears achievable.
- 83% and stable in PIC so far, and improving.
- International collaboration at work.

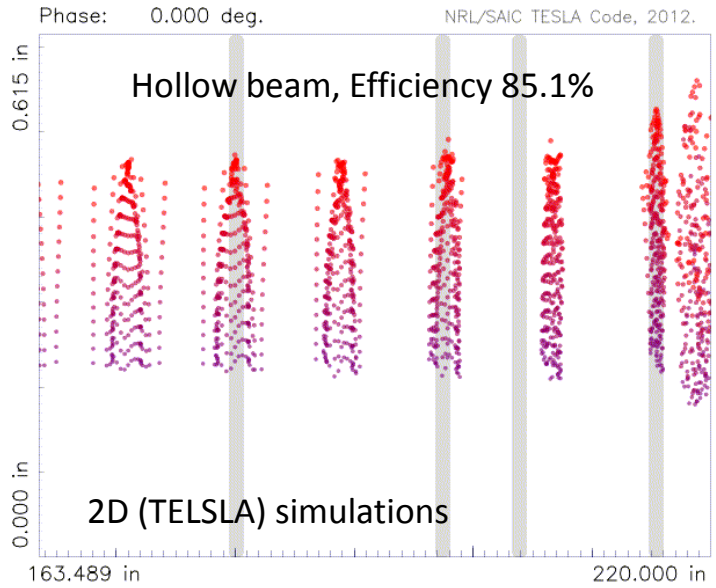


PIC (MAGIC) simulations predict **83%**

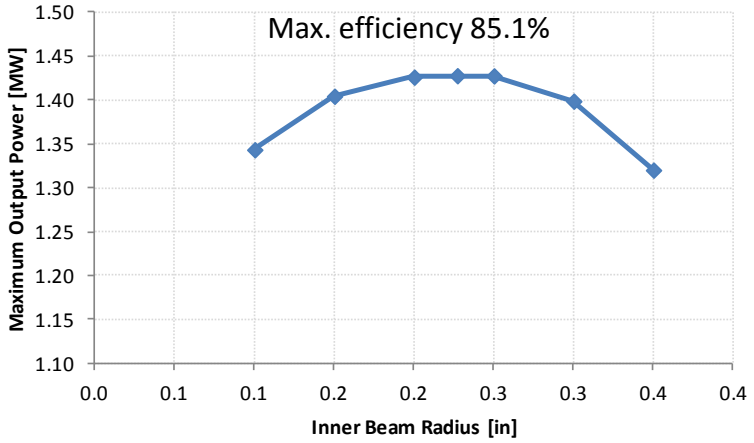
Electrons bunching quality, special issues.

Igor SYRATCHEV





FCC 0.8 GHz 1.5 MW CW MBK klystron with hollow beams



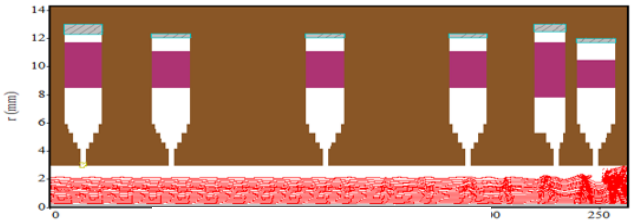
- The radial beam stratification (‘triangular’ bunch shape) prevents from achieving very high efficiency in the ‘classical’ klystron operation with cylindrical beam.
- We have now good indication that klystron with hollow beam can be very efficient. For the first time ever in 2D simulations we observed **85%** efficiency and stable tube operation.

Kladistron – the KLystron with ADIabatic bunching.

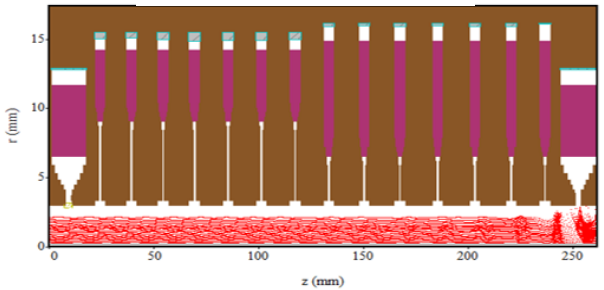
Antoine MOLLARD

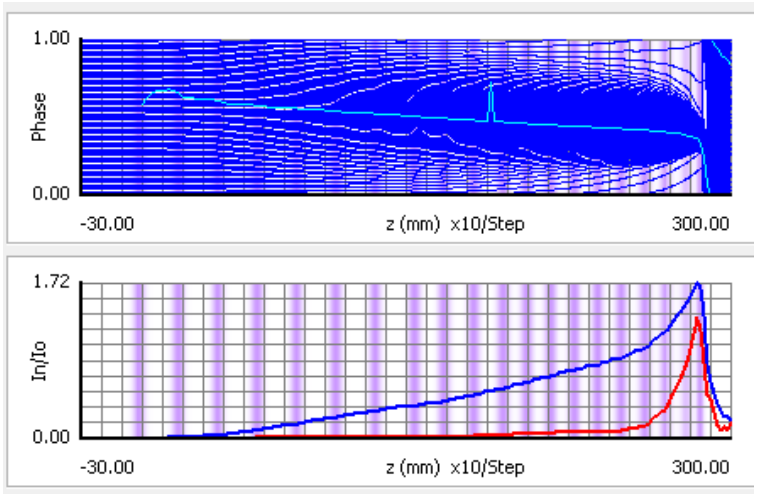
MAGIC 2D

Thales TH2166 Klystron

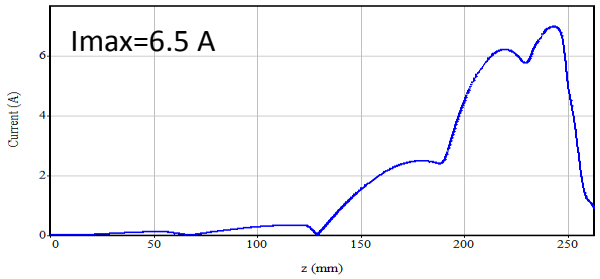


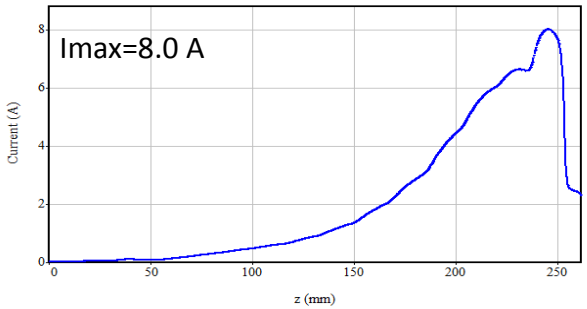
CEA TH2166 Kladistron





- 12 GHz Kladistron 1D simulations.
- 20 bunching cavities
- Efficiency 78%

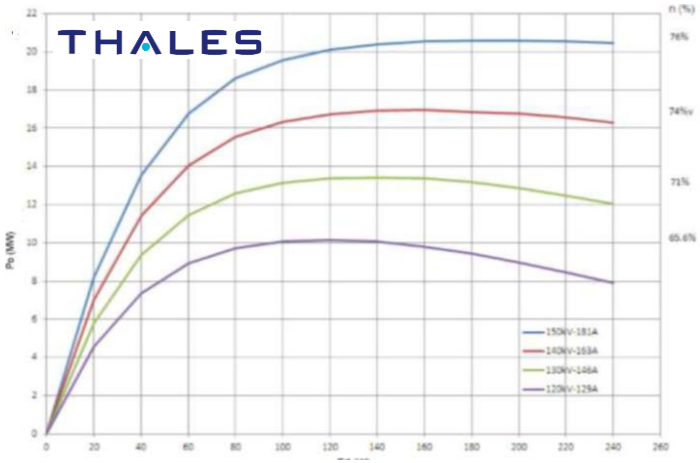




- Kladistron bunching unit comprise many low impedance cavities. It provides ‘gentle’ bunching with RF current exponential growth.
- This allow for high saturation of the bunch and thus high efficiency at a large perveance.
- It is an excellent candidate for the high frequency, high power and high efficiency RF power source.
- The retrofit design of existing TH2166 4.9 GHz tube is in progress, targeting the technology feasibility demonstration in 2016.

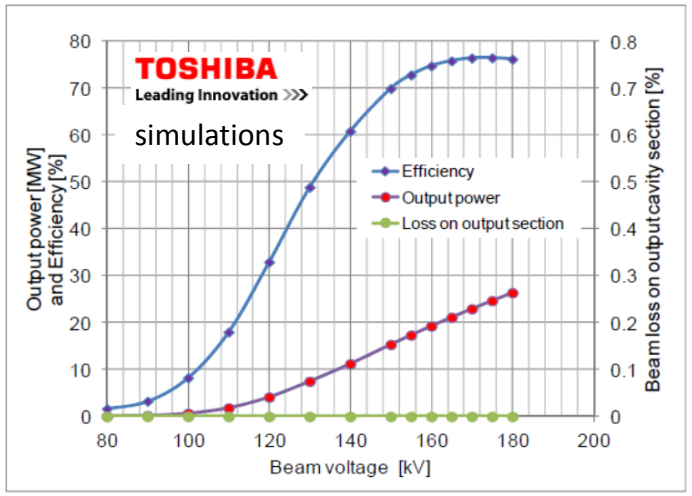
Status of the CLIC MBK klystron(s).

Steffen DOEBERT



MBK contractual parameters:

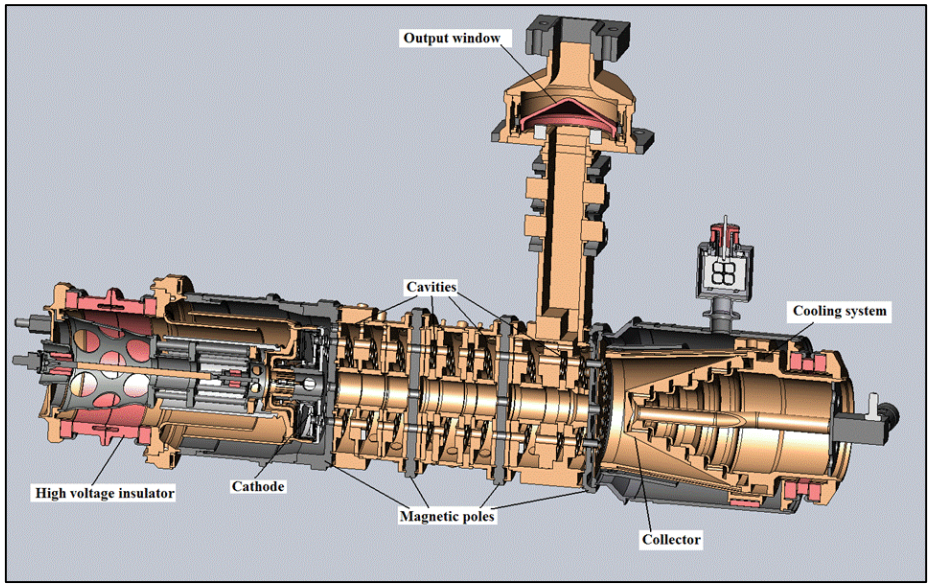
Frequency: 1. GHz
Peak power: 20 MW
Pulse length: 150 µsec
Rep. rate: 50 Hz
Efficiency: >67%



- Thales and Toshiba developing each a 1 GHz MBK to our specifications.
- Both design reports have been finished and accepted. Efficiencies >75% (in simulations) are predicted.
- Manufacturing ongoing with planned delivery this summer.
- We are looking forward to see these milestones for CLIC and other applications realized.
- Very pleasant collaboration with industry so far.

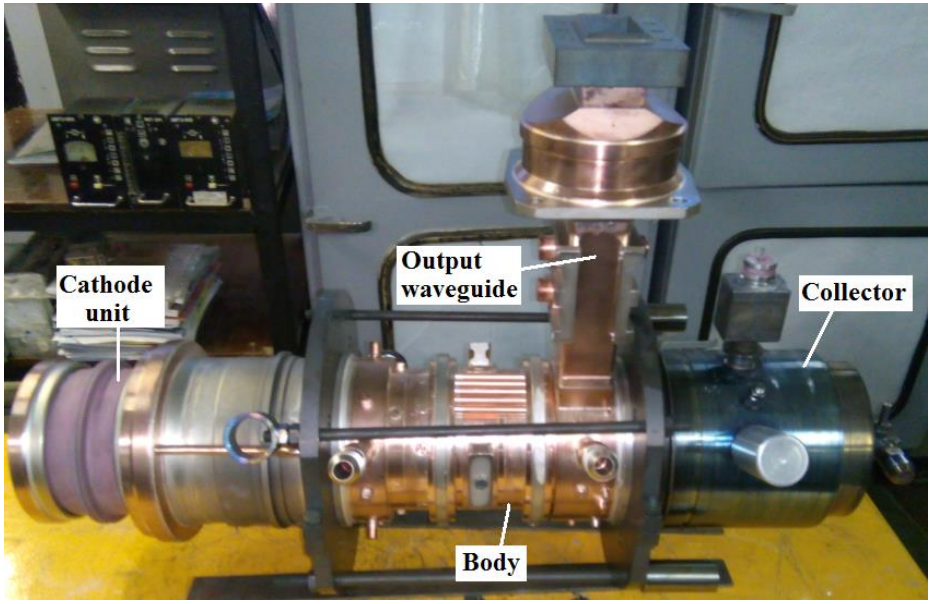
Status of the S-band MBK development at VDBT.

Igor GUZILOV

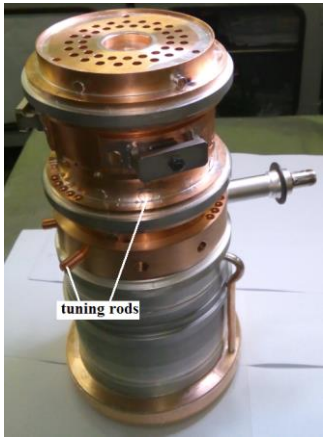


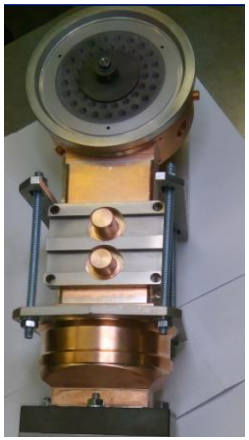
The first commercial S-band MB tube which employs the new bunching technology (BAC):

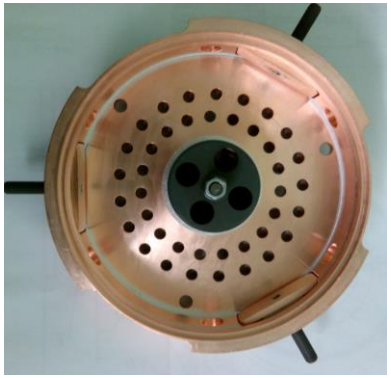
- 40 beams
- Permanent Magnets focusing system
- Low voltage: 52 kV
- Peak power: 7.5 MW
- Efficiency: 77% (in simulations)
- Pulse length: 5 microsecond
- Repetition rate: 300 Hz
- Average power: 30 kW



The tube has been built. Now undergoing installation of the focusing system. The first factory test will be done in February.



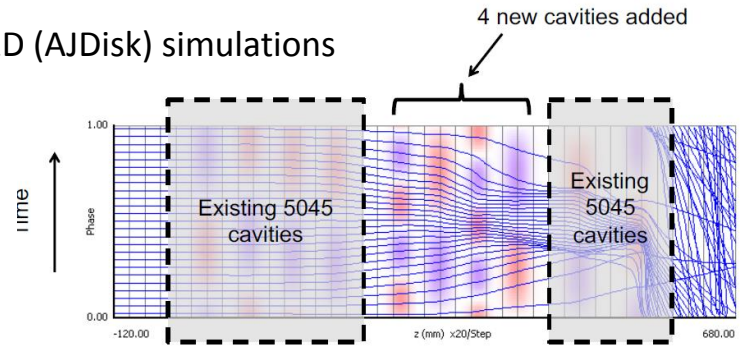




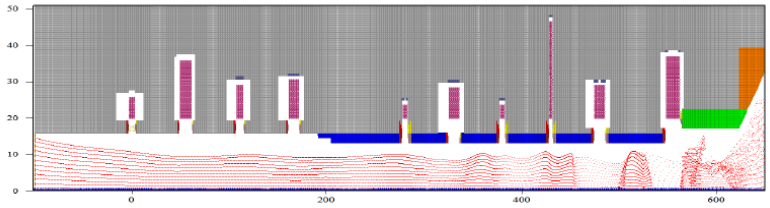
Status of the SLAC S-band klystron retrofit activity.

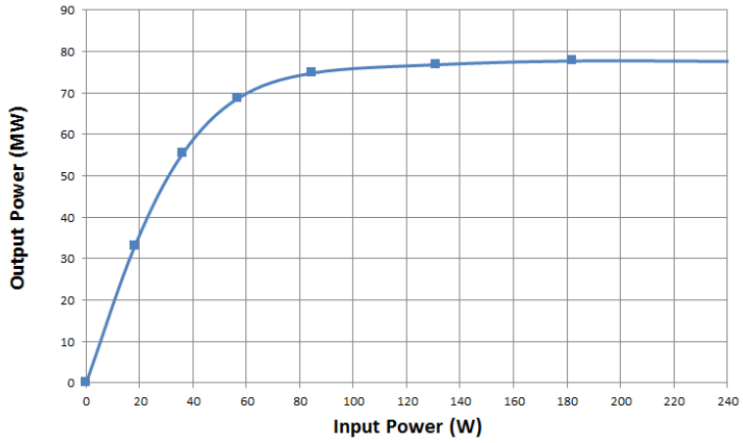
Jeff NEILSON

1D (AJDisk) simulations

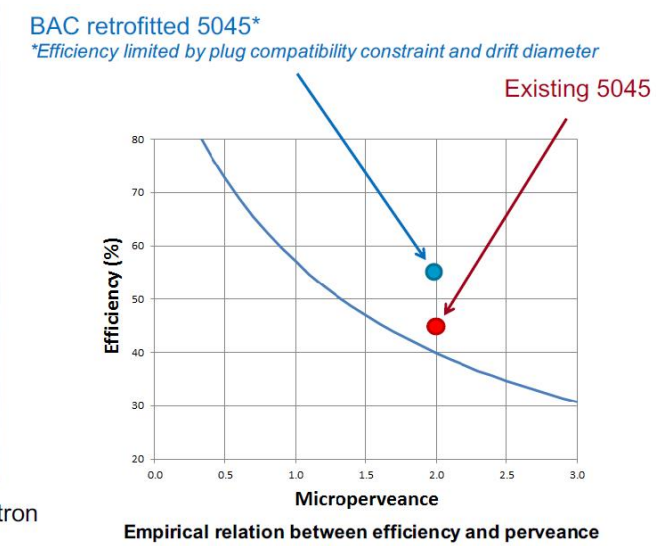


PIC (MAGIC) simulations





Conventional 5045 klystron



Empirical relation between efficiency and perveance

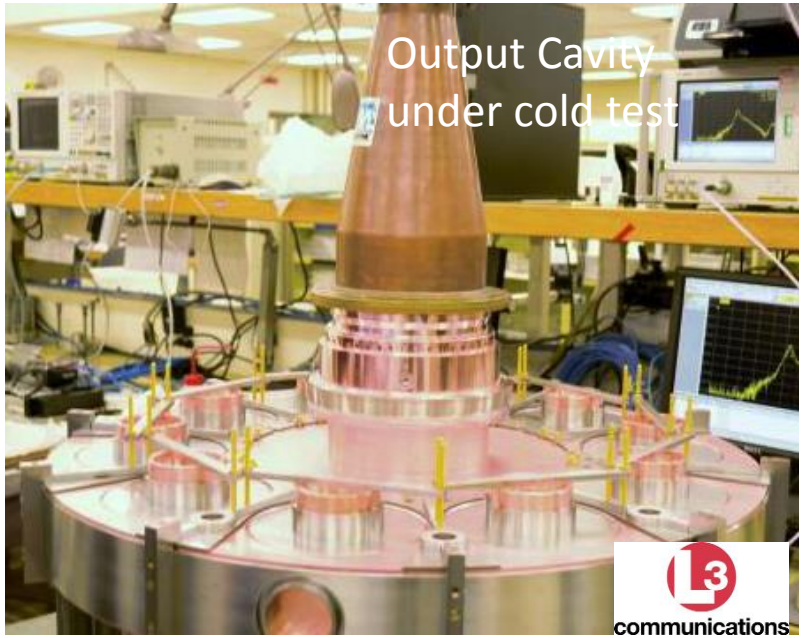
- SLAC is developing a BAC inspired retrofit of the 5045 linac klystron.
- Simulations predict the new design will achieve ~80MW a big improvement over the existing design and state of the art (~60MW).
- Mechanical design, drafting, and machining are presently underway.
- A new solenoid is being rewound by Stangenes.
- Results will be reported at IVEC in April, 2016

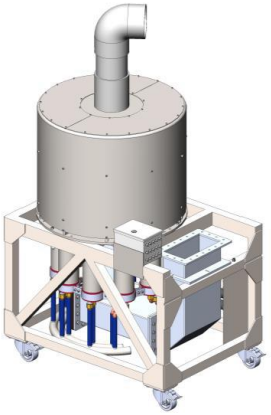
Aaron Jensen, Andy Haase, Erik Jongewaard, Mark Kemp and Jeff Neilson

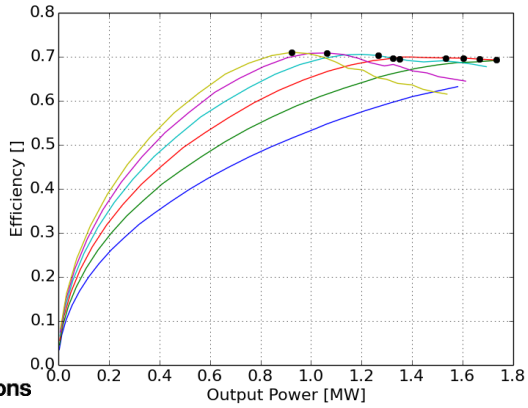
Status of the L-band MBK IOT for ESS.

Morten JENSEN

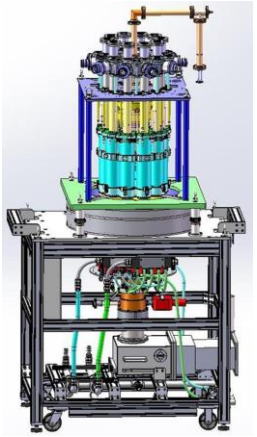
The new multi-beam IOT are now in fabrication in industry. This is very challenging device which should provide almost 10 times more RF power compared to existing commercial devices – 1.2 MW, and efficiency in excess of 70%. Two vendors – L 3 Communications and Thales/CPI consortium are on schedule and will deliver the first prototypes for testing in September 2016.

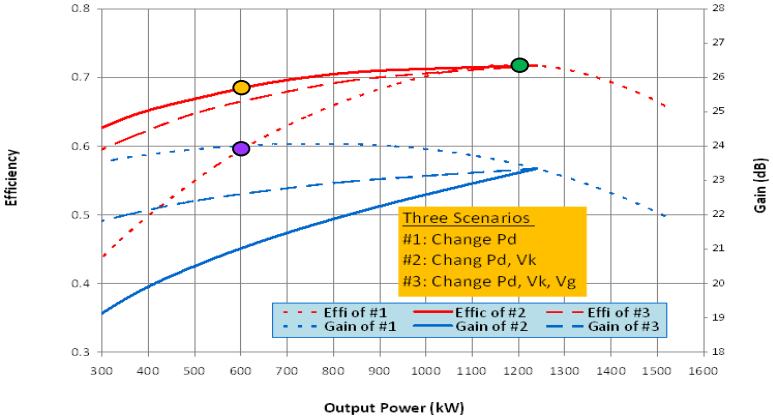






L3 communications

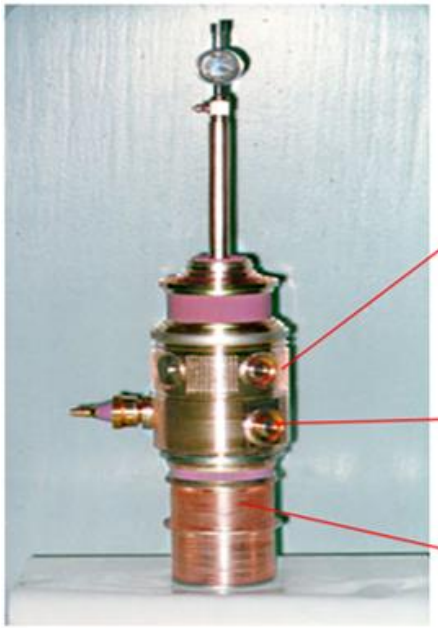




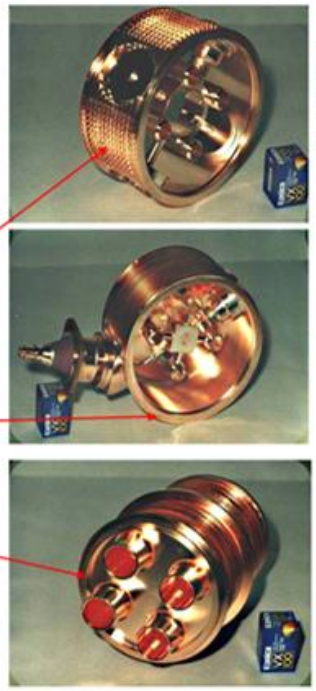
CPI THALES

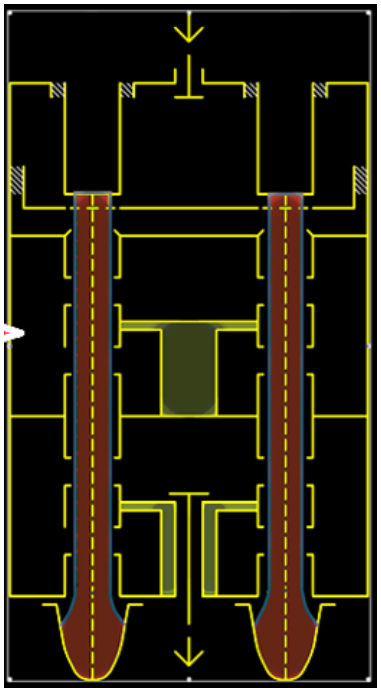
High efficiency Multi-beam IOT with 3 cavities.

Vladislav TSAREV

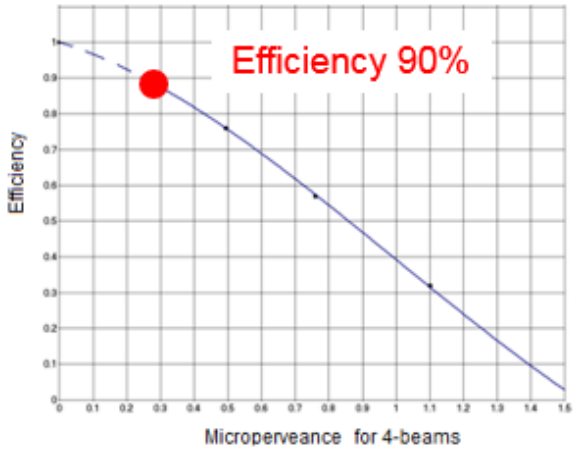


10 kW tube

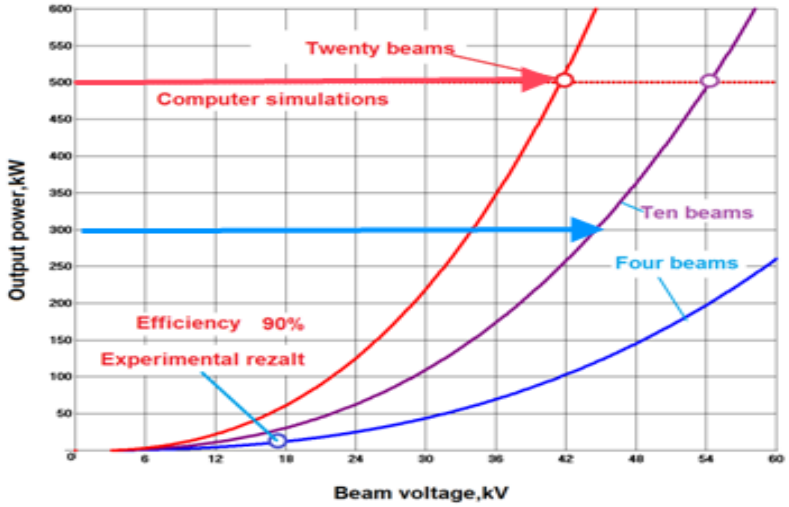




Measured performance:

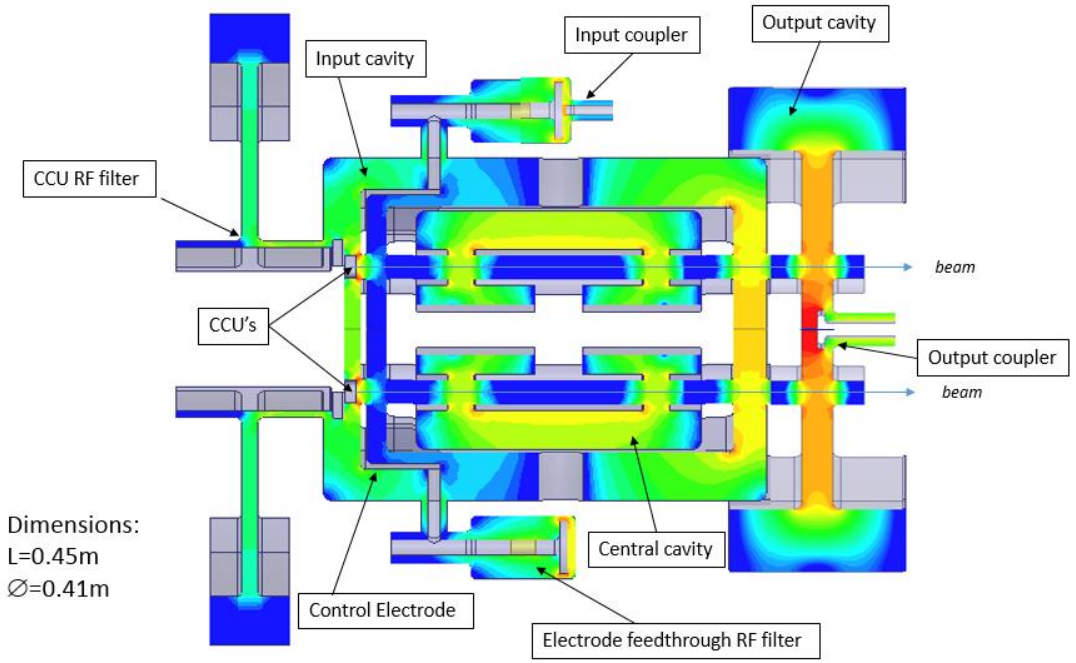


- The IOT with 3 cavities has demonstrated very high efficiency (90%) back in 1997.
- It has good potential for scaling towards CW RF power source for LHC and FCC at 0.4 GHz.

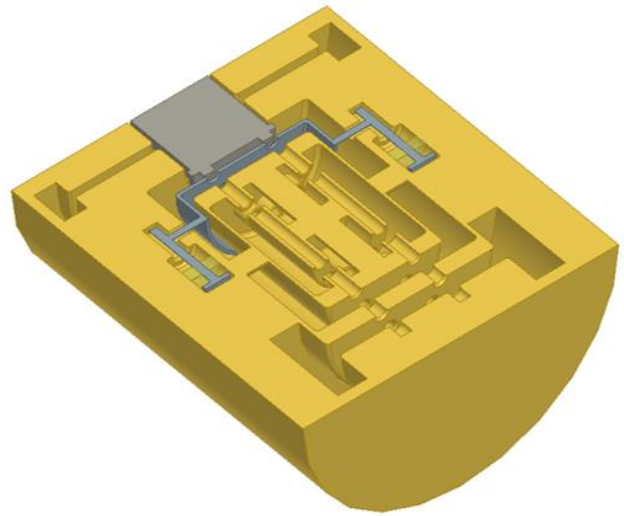


Resotrode, concept of the new type of RF amplifier.

Andrey BAIKOV, Igor SYRATCHEV



Dimensions:
L=0.45m
∅=0.41m

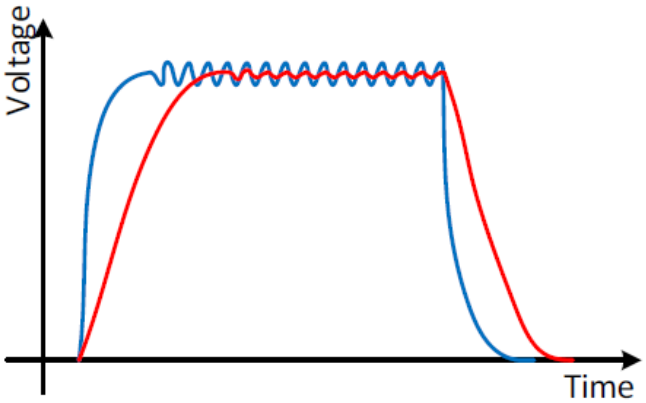


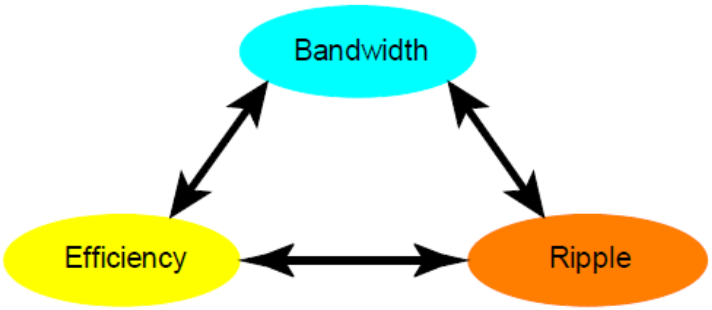
- The new resonant RF power amplifier with regeneration (Resotrode) has been proposed and evaluated.
- Resotrode is a MW class device, with very high efficiency (~90%) and high RF power gain (30-50 dB). It is best optimised to operate at the frequencies transition region between UHF and L-band.
- Resotrode is compact (about 0.5 m long) device and its length practically does not depend on the operating frequency in the range between 0.2 GHz and 0.4 GHz.
- Resotrode can be considered as an excellent candidate to be used in RF power plants of LHC, FCC, electron synchrotrons, proton linear accelerators and cyclotrons.

Status of the modulator for CLIC MBK.

Davide AGUGLIA

The modulator performance: efficiency, stability and cost are all linked together





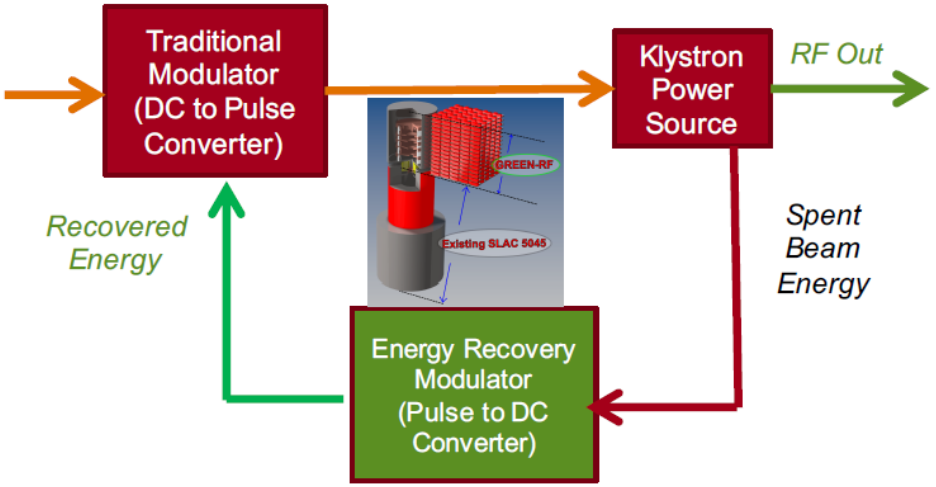
Modulator's Specs			
Pulsed voltage	V_{kn}	160-180	kV
Pulsed current	I_{kn}	160	A
Peak power	P_{out}	29	MW
Rise/fall time	t_{rise}	**3**	**µs**
Flat top length	t_{flat}	140	µs
Repetition rate	Rep_r	50	Hz
Flat top stability	FTS	0.85	%
Pulse repeatability	**PPR**	**10-50**	**ppm**

- Efficiency directly linked to dynamic performances
- Modulators topology choice is a global/complex process, no best topology - optimal solution for each specific application
- Modulator global optimization methodology is mandatory: collaboration of designers from different domains is essential to achieve global efficiency
- Two topologies under study (one in construction) considering CLIC accelerator specificities
- Grid layout drives the input voltage range (thus topology) for the modulators – optimal value 20kV DC
- For power fluctuation control on grid & pulse repeatability, the accelerator operation shall be synchronized with the utility grid's 50Hz

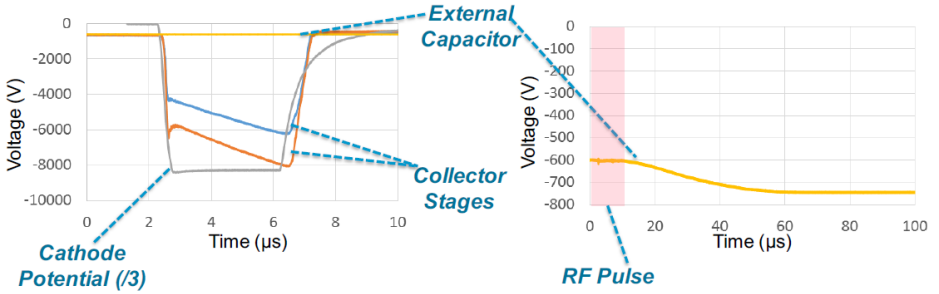
Energy recovery in depressed collector of the klystron operating in pulsed mode.

Jeff NEILSON

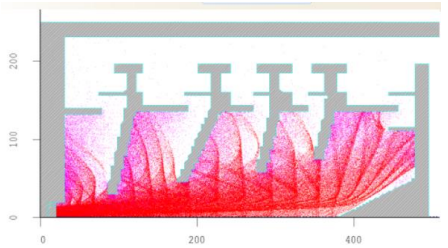
Spent beam energy recovery concept:

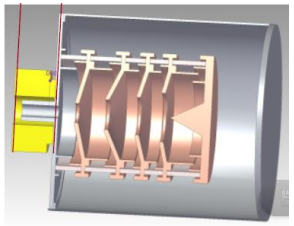


Generation 3: Inverse Marx (with recovery). Used inductors as isolating elements. Recovered energy to external capacitor

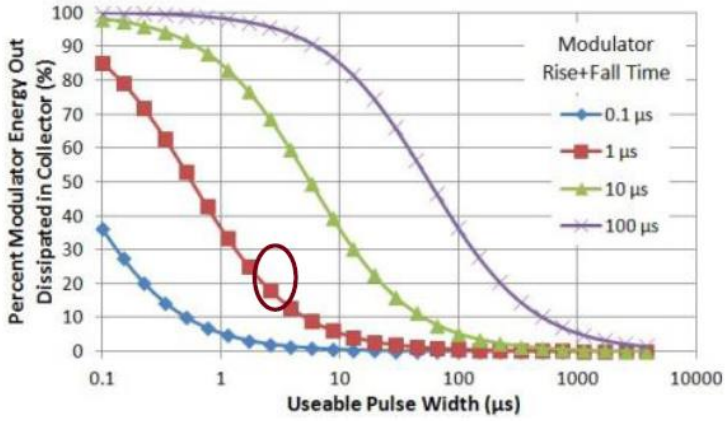


Full-scale optimisation:





Ability to Recover Rise and Fall of Pulse is important



- Pulsed energy recovery concept has been experimentally proven with excellent agreement.
- The energy recovery technology is ideally suited for ultrashort pulse (<300ns) RF sources.
- Accelerator stewardship funding will make technology commercially available within two years

Mark Kemp, Aaron Jensen, Gordon Bowdon, Erik Jongewaard, Andy Haase and Jeff Neilson

Optimised RF unit.

Mikael LINDHOLM

- **RF QUALITY**
  - Frequency stability
  - Phase stability
  - Power Stability
  - Time jitter
  - Efficiency
- **COMPACTNESS**
- **LOW COST**

ScandiNova SUMMARY & CONCLUSIONS

June 16, 2015 I 18

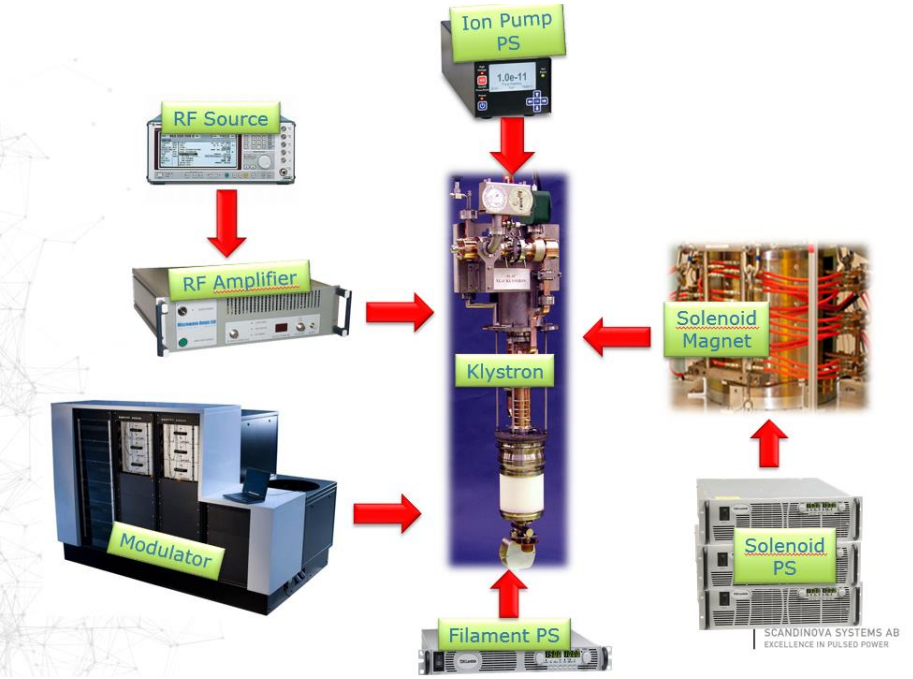
- Example: Optimised Design RF Unit

RF Peak Power:	8.5MW
RF Average Power	14kW
RF efficiency:	75%
Klystron Voltage:	0 – 54kV
Klystron current:	0 – 209 A
Impedance:	258 Ω
RF pulse width:	1 - 5μs
Pulse Repetition Rates:	1 – 1000Hz
Pulse Flatness:	0.5%
Pulse to Pulse stability:	70 ppm
Mod. Pulse jitter:	5ns

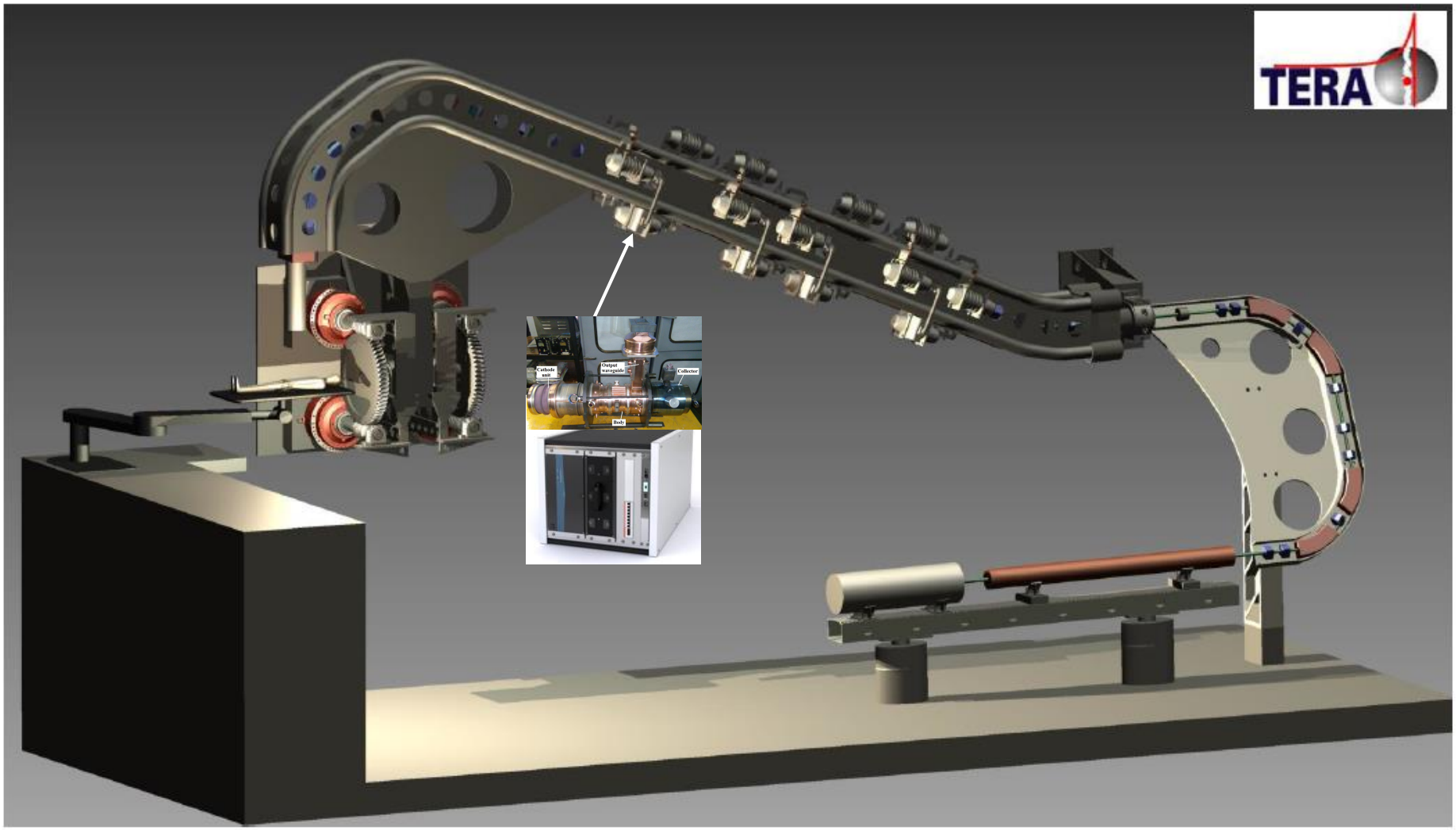
Size: 1.1m x 0.6m x 0.6m

13 MW/m^2

SCANDINOVA SYSTEMS AB
EXCELLENCE IN PULSED POWER



TULIP- high gradient compact proton linac for cancer therapy



Courtesy of M. Vaziri, TERA Foundation

Summary (of the summary)

- The High Efficiency International Klystron Activity (HEIKA) has matured and became now a truly international and efficient team of experts.
- We had a lot of progress during last year and gained much more confidence that beam based RF power amplifiers can be as efficient as 90%.
- Our progress is a good example that close collaboration between Labs and industry from the very start is a very efficient way to proceed.