Drive Beam linac structures and RF power sources

Erk Jensen, BE-RF

with major contributions from:
Jean-Bernard Jeanneret, Rolf Wegner

CLIC Drive Beam RF System – issues:

- Reminder of the main issues for the Drive Beam RF system:
  - ***Very large total RF power*** (23 GW peak, 170 MW average)
  - ***Phase stability (jitter < 50 fs)***
  - ***Overall efficiency (corrected numbers for CLIC)!***
  - ***Cost!***

- Summary from last ACE: **Trends:**
  - **Accelerating structures** were optimized for
    - group delay = length of delay loop (≈ 245 ns)
    - aperture to meet beam dynamics requirements (was in work)
    - HOM damping efficiency was not yet verified.
  - **Phase jitter** requirements are manageable, feedback and feed forward alleviated problems! … still hard for the modulators (next talk!)
  - **Power sources**: MBK 15 … 20 MW, 150 μs, 50 Hz, η > 65 %, seems in reach. Higher efficiency RF sources required!

Accelerating Structures

Last years conclusion:

Conclusion accelerating structures:

- SICA structures were successfully redesigned and re-optimized for 1 GHz (thanks to Rolf Wegner!).
- Design includes:
  - Optimum aperture – to be finalized with BD simulations
  - Optimum RF efficiency
  - Optimum group delay (≈ 245 ns)
  - New idea for dipole mode damping verified
  - Moderate outer Ø < 300 mm

  - The coupler design is ongoing.

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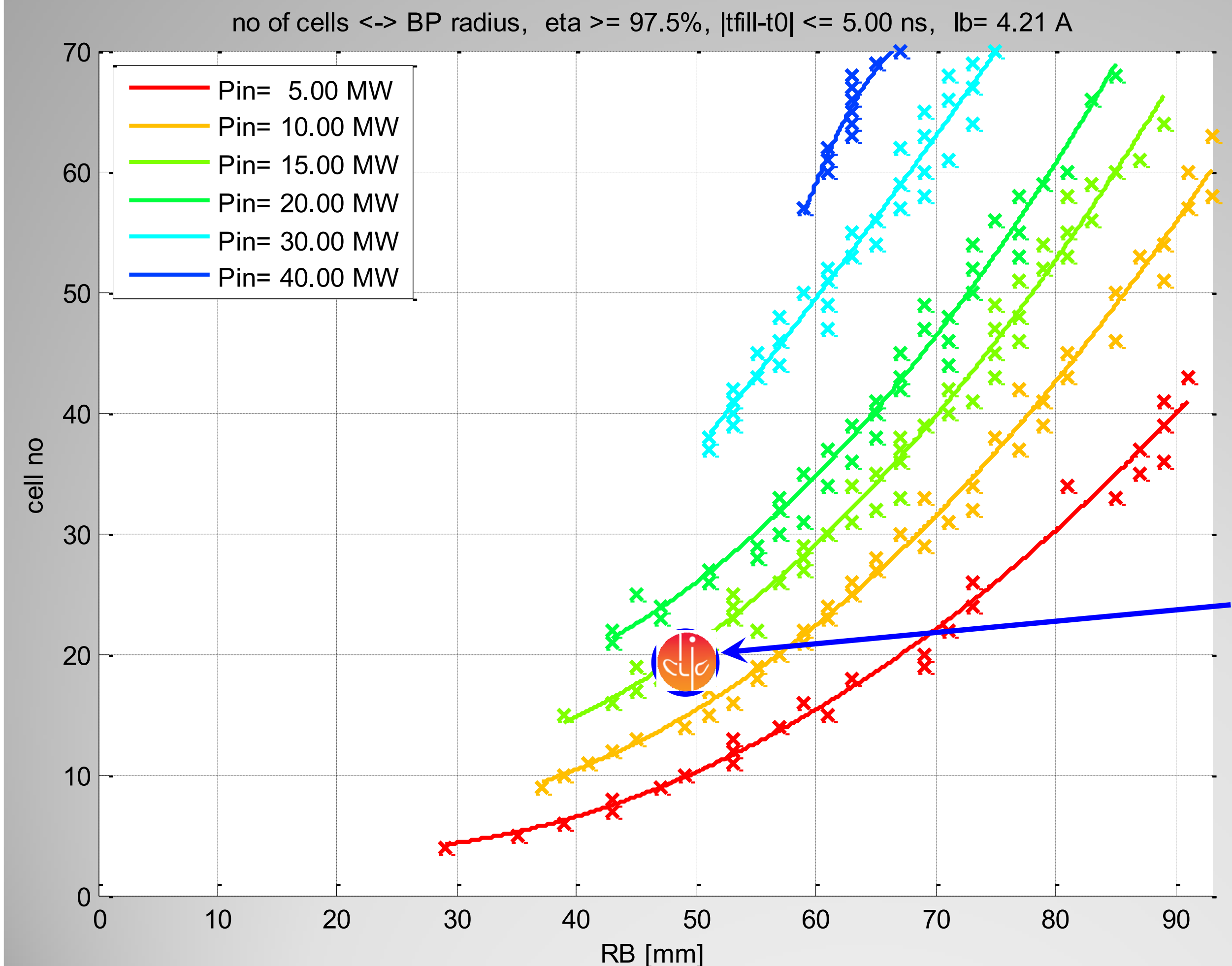
Optimum aperture found



$\eta_{RF} \geq 97.5$ %

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

P_{in} = 15 MW

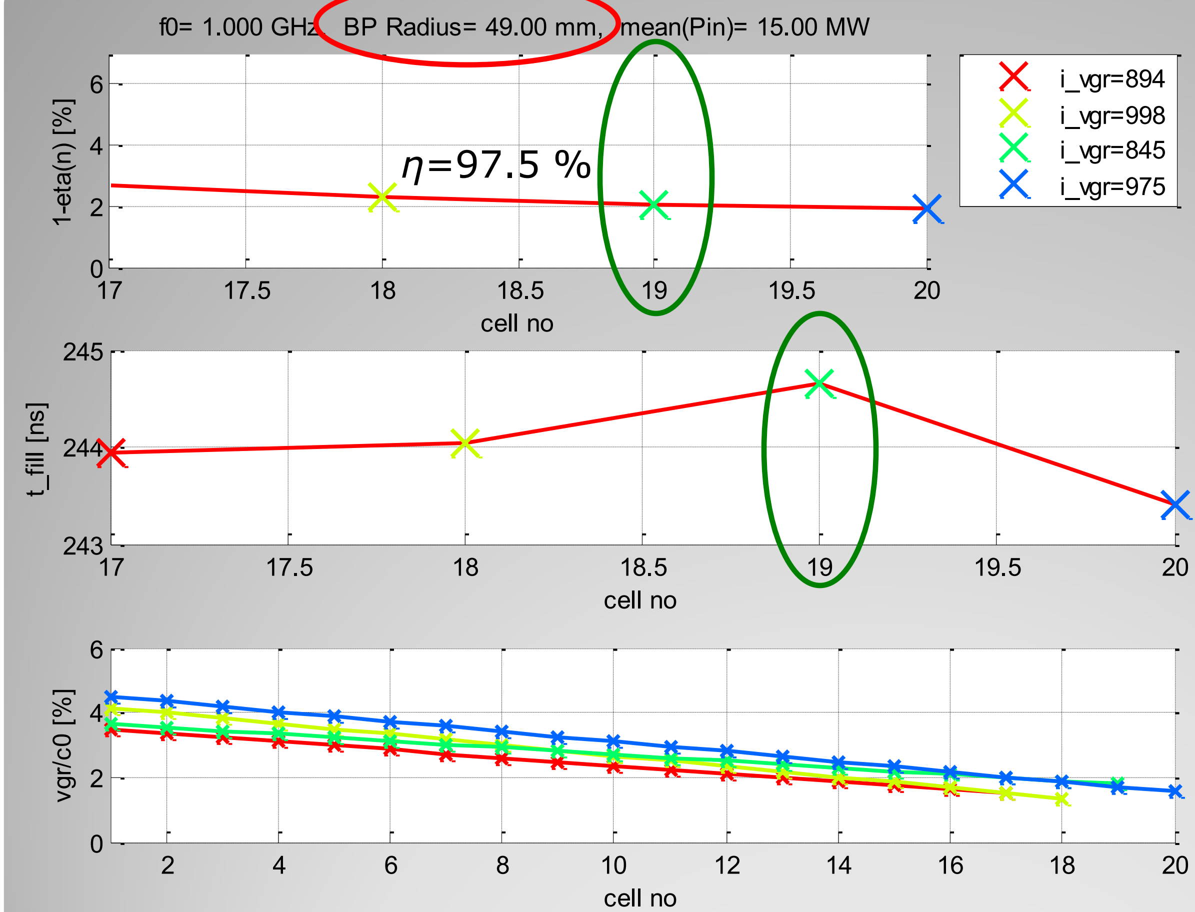
Beam dynamic (Avni Aksoy):

R_B = 49 mm,

N = 19 cells

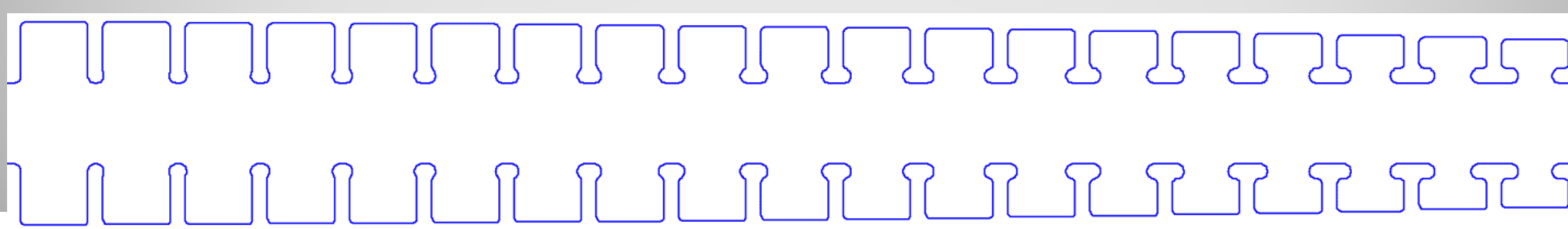
Rolf Wegner

Baseline structure



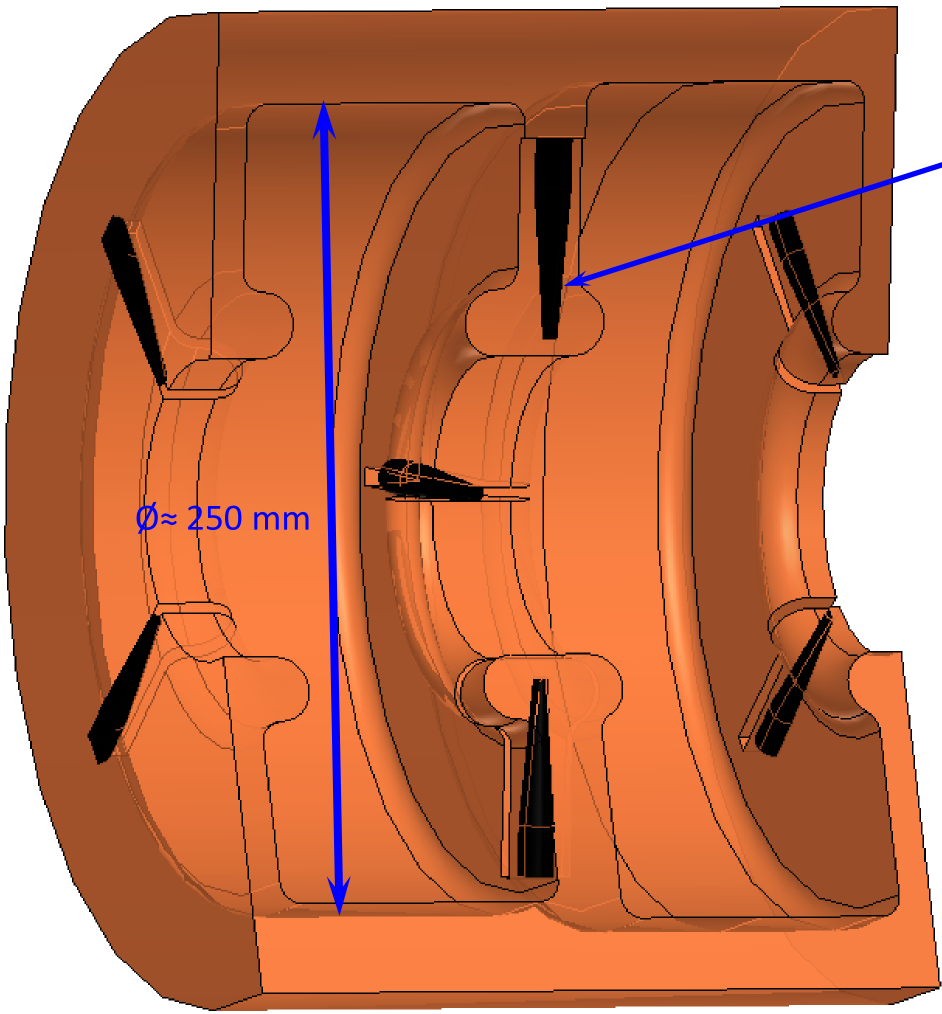
P_{in} = 15 MW
R_B = 49 mm,
N = 19 cells

Rolf Wegner



Damping and detuning

Reduction of transverse wakefields by damping and detuning



Alexej Grudiev's idea:
dampers in web (~18 mm tick)

acc. mode

Q_0= 2.2 ·10⁴, Q_{ext}= 3.7·10⁷

distorted, 0.1° <=> 0.1 mm @ nose

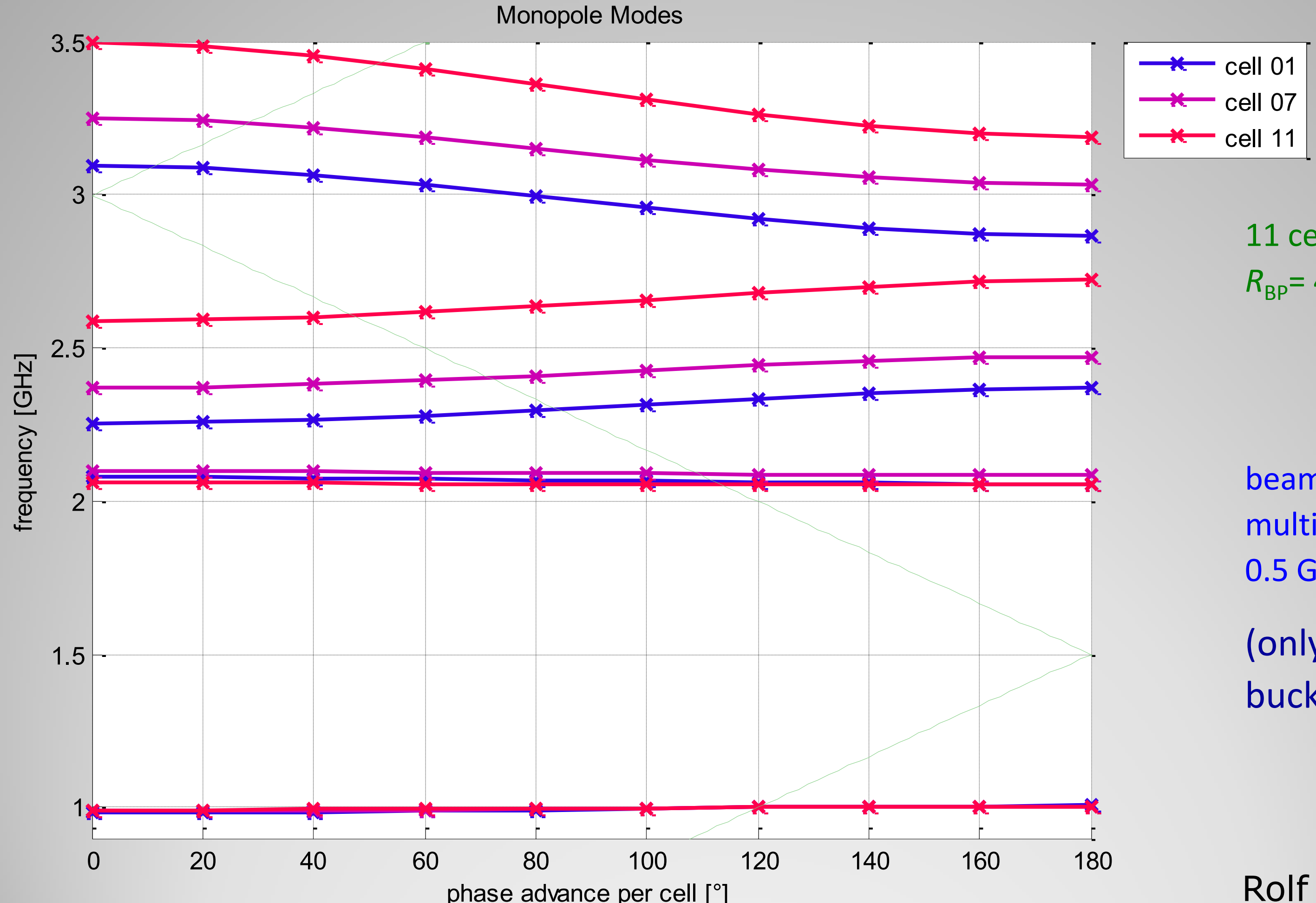
Q_{ext}= 1.5 ·10⁶

$P_{ext,peak}$= 110 W, $P_{ext,avg}$= 0.83 W

Rolf Wegner

Damping and detuning (m=0)

Reduction of transverse wakefields by damping and detuning



11 cell structure

R_{BP}= 41 mm

beam may excite multiples of 0.5 GHz

(only every other bucket filled)

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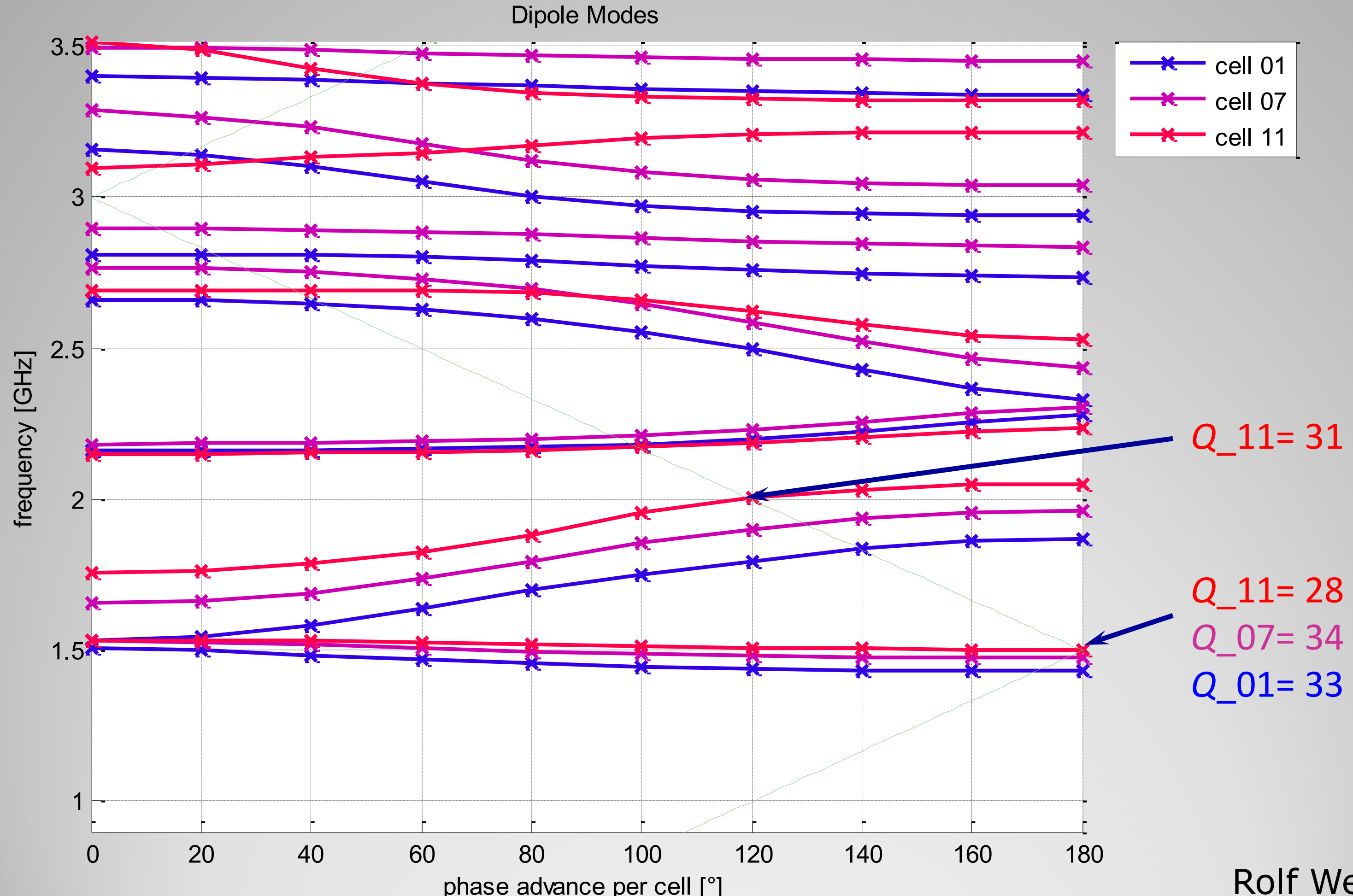
Damping and detuning (*m*=1)

Reduction of transverse wakefields by damping and detuning



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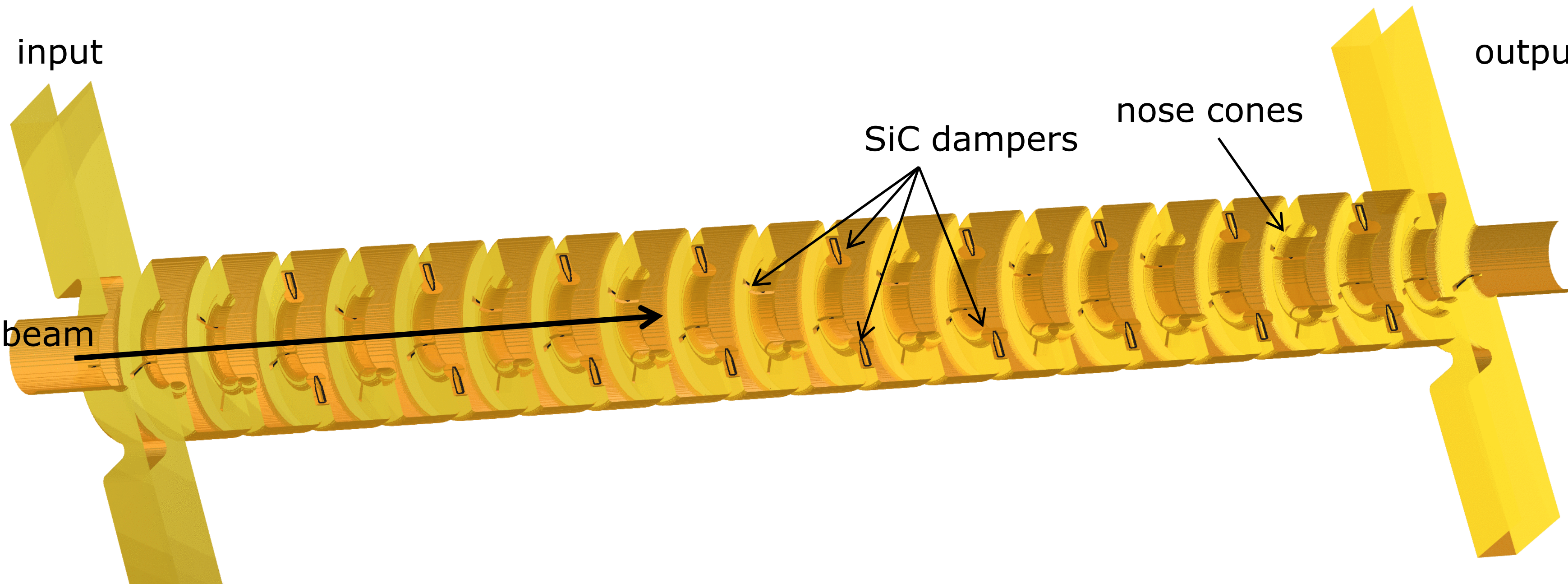
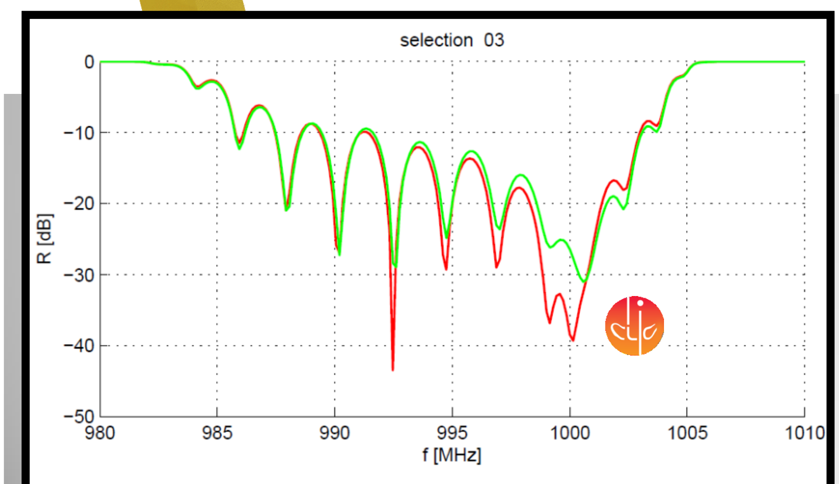
SICA – GdfidL simulations (1):





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

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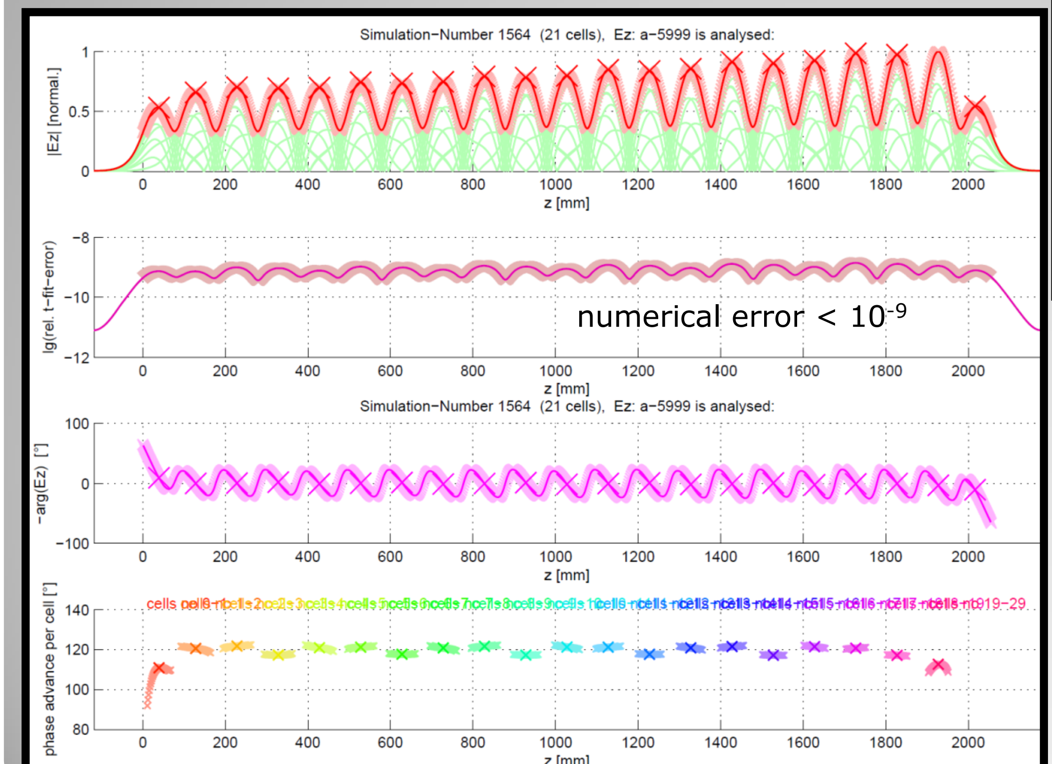
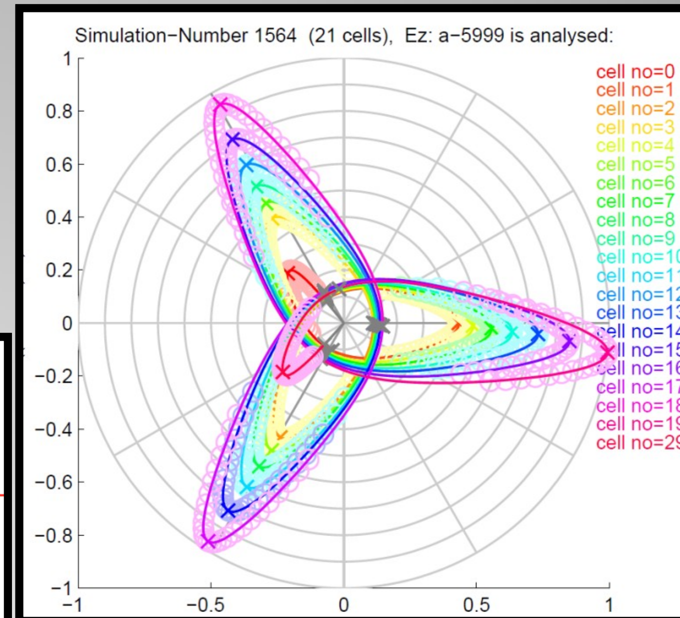
SICA – GdfidL simulations (2):

Results for field distribution,
phase advance per cell,
bead pull result simulation (E_z^2)





GdfidL time domain simulations to verify dipole mode damping and detuning are ongoing.

Rolf Wegner

Conclusion accelerating structures

- Structures finalized with
  - compact design (outer diameter 300 mm, length 2.4 m),
  - 19 cells (OK for input peak $P \approx 15$ MW),
  - aperture radius 49 mm (OK for BD),
  - group delay 245 ns (OK for φ-noise filtering),
  - $\eta > 97.5$ % RF to beam with full beam loading,
  - strong wakefield damping and detuning (OK for BD, verification in time domain are in progress)

  were obtained as a flat optimum.

Rolf Wegner

Power Sources

The two-pronged strategy (1)

- **(1)** On the short term (~3 years), we need a working installation (not necessarily final), based on existing (ILC/X-FEL) technology & modest extension (one may hope for $\eta \approx 70\%$)
  - Establish an International Review Panel, composed of independent experts. The aim would be to participate in establishing the qualification criteria as well as in identifying potential firms to be contacted for the Market Survey (MS).

  The ACE is kindly invited to propose potential panel members!
  - With the help of the panel, establish Qualification Criteria. The ability to perform the requested R&D will be very important.
  - The Review panel will assess the replies to the MS. The technical content replies will be treated confidentially (NDA's ...)
  - Invitation to Tender (IT) to deliver
    - the necessary R&D,
    - a prototype,
    - a small pre-series of 3 for validation.
  - In this we will ask a ceiling price for a series of 20.
  - If needed, based on a separate IT, acquisition of 20 MBK's.
  - The specification are consistent with the present Conceptual Design (>16 MW, 150 μs, 50 Hz, η > 66 %, V≈150 kV)

  This may however not lead to *the* CLIC power source ...

The two-pronged strategy (2)

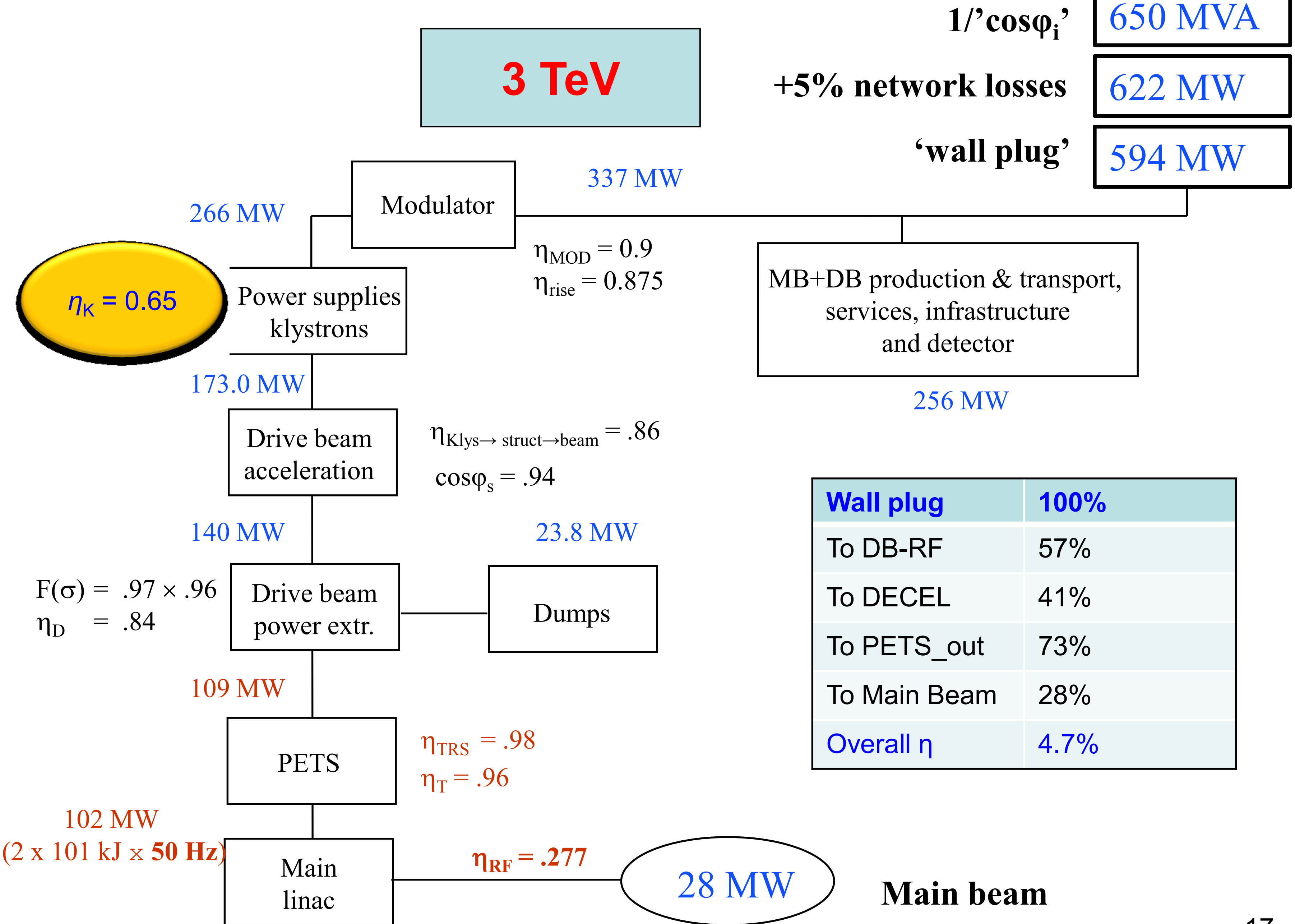
- **(2)** The optimum power source for CLIC may be different from what is in reach when extrapolating the existing ILC/X-FEL MBK.
- A more fundamental R&D should look for alternative solutions (see also my Linac10 paper http://silver.j-parc.jp/linac10/TH103.PDF).
- New ideas, lateral thinking and unconventional approaches are required.
- Compared to (1), this is a higher risk, but also higher potential R&D!
- The target: maximum efficiency, scalable to the required power levels, reliable, cost-effective, compatible with modulators and φ-noise!
- Candidates: klystrons (single- and multi-beam, sheet beam), magnetrons, IOT's, electron devices with depressed collectors, ...
- Received positive feedback and much interest – planning to implement Scientific Network in FP7 "EuCARD2".
- There is a clear interest in the community beyond CLIC (ILC, proton drivers, ADS, ...)
- A CERN fellow (C. Marrelli) has started to work with us on a high efficiency klystron; U. Lancaster is interested to contribute; Thales will hire and train a PhD student to work on this subject with us.

Power needs for future Linacs:

	ESS	SPL II	ILC .5 TeV	CLIC .5 TeV	CLIC 3 TeV
Frequency	704 MHz	704 MHz	1300 MHz	1000 MHz	1000 MHz
Technology	klystrons	klystrons	MBK	MBK	MBK
Total AC power	38 MW	40 MW	230 MW	249 MW	594 MW
Modulator output	17.8 MW	26.5 MW	135 MW	64 MW	266 MW
Power source output	8.9 MW	10.7 MW	88 MW	41.6 MW	173 MW
Drive beam power				33.6 MW	140 MW
Acc. structure input	6.5 MW	7.8 MW	67 MW	24.6 MW	102 MW
Total beam(s) power	5 MW	4 MW	21.6 MW	9.75 MW	28 MW
Efficiency	13.5 %	10 %	9.4 %	3.9 %	4.7 %

Table from Linac10 talk “TH103”, CLIC numbers adjusted to present preliminary numbers.

From Bernard Jeanneret – PRELIMINARY!



Wall plug	**100%**
To DB-RF	57%
To DECEL	41%
To PETS_out	73%
To Main Beam	28%
Overall η	4.7%

Increased efficiency would …

- reduce the environmental impact,
- reduce the size of the installed power,
- reduce the size of the necessary cooling,
- decrease the electricity bill:

> Example CLIC @ 3 TeV, 594 MW AC consumption, 5,000 h operation per year, 40 $/MWh:
> Annual electricity bill of **120 M$!**
> If this number is for a klystron efficiency of 65 %, a klystron efficiency increase by 1 % (66 %) would save 1 M$ every year in electricity alone.

… this alone could already pay for some modest R&D!

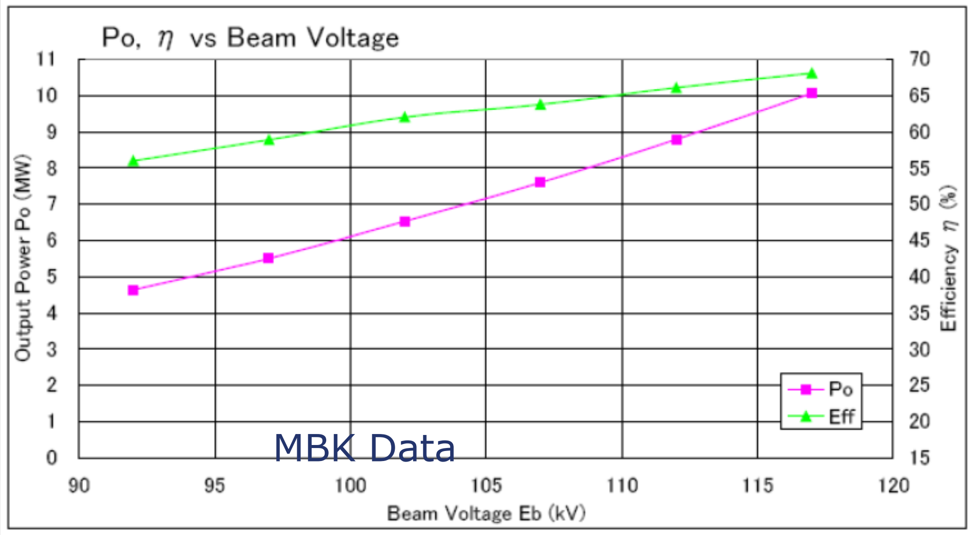
The same argument holds for other systems (next talk)!

My demand: Instead of buying more electricity later, invest now!
Well invested to cut cost, advance science and protect the planet!

… from Linac10 talk “TH103”, CLIC numbers adjusted to present preliminary numbers.

Present: the ILC/X-FEL klystrons

Item	Unit	TH1801 Thales	E3736 Toshiba	VKL-8301 CPI
Frequency	MHz	1300	1300	1300
Output Peak Power (max)	MW	10	10	10
Output Average Power (ma	kW	150	150	150
Beam Voltage	kV	110	115	114
Beam Current	A	130	132	131
Pulse width	ms	1.5	1.5	1.5
Efficiency	%	65	>65	65-67
Gain	dB	48	47	47
Number of beam		7	6	6
Beam micro-perveance	uA/V^3/2	3.5	3.38	3.4
Single beam micro-perv.	uA/V^3/2	0.50	0.56	0.57
Cavity numbers		6	6	6
Cathode loading	A/cm^2	<2	<2.1	<2.1



... from S. Fukuda's IWLC10 talk, CLIC numbers adjusted to present preliminary numbers.

Replies from industry:

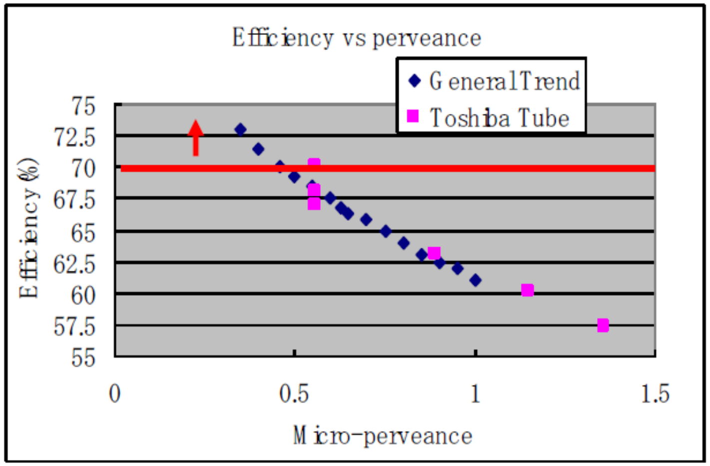
- CPI:
  - 20 MW, 150 µs, 50 Hz, 65 % ... feasible (≈ 8 beams),
  - design & proto estimate: 2 M$ and 2 years.
- Thales:
  - Existing Thales L-band MBK cannot directly be extrapolated to a device 20 MW.
  - 20 MW can be obtained with 3 A/cm^2, 0.56 µP, 8 beamlets (coaxial fundamental), 136.5 kV, 225 A.
  - no cost estimate yet.
- Toshiba:
  - see next slides from Fukuda-san!

From Shigeki Fukuda (1):

Requirements for the CLIC L-band Tube

From Toshiba Quotation,

- High Efficiency of More than 70%
- High Power of more than 40MW
- Long pulse width around 150 us
- Frequency near to ILC Frequency, but need to change a bit (1.3->1.0 GHz))
- Reliability



Technical Difficulty

- High Power and High Efficiency

  High Efficiency → Low perveance, and High applied voltage

  In order to avoid difficulty, approach MBK like ILC.

  High Power → More many –beam MBK, or Distributed MBK System

  Still need study about, cathode loading, minimize gun arching, RF window study

From Shigeki Fukuda (2):

Simple survey of CLIC-L

- Constraint: Output power of 40MW, efficiency of 70%, and cathode loading of 2A/cm^2. Search of MBK direction.
  Pulse width of about 150us is not short, and cares to cathode loading, allowable field gradient and window capability are necessary.

No. of Beam		1	6	8	12	16	24	36
P0 Total	MW	40	40	40	40	40	40	40
Power/beam	MW	40	6.67	5.00	3.33	2.50	1.67	1.11
Voltage	kV	438.0	213.9	190.7	162.1	144.5	122.9	104.5
Current	A	130.5	44.5	37.5	29.4	24.7	19.4	15.2
Beamlet power/beai	MW	57.14	9.52	7.14	4.76	3.57	2.38	1.59
Perveance	uP	4.5E-07	4.5E-07	4.5E-07	4.5E-07	4.5E-07	4.5E-07	4.5E-07
Efficiency	%	70	70	70	70	70	70	70
Cathode loading	A/cm^2	2	2	2	2	2	2	2
Cathode Diametr	cm	9.1	5.3	4.9	4.3	4.0	3.5	3.1

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S.Fukuda-L-band Klystron

From Shigeki Fukuda (3):

Another Example
(Eff. of 70% and 75%)

Eff. of 70% needs uP=0.45.
Cathode loading of 3A/cm^2 in this case.

No. of Beam		1	6	8	12	16	24	36
P0 Total	MW	40	40	40	40	40	40	40
Power/beam	MW	40	6.67	5.00	3.33	2.50	1.67	1.11
Voltage	kV	438.0	213.9	190.7	162.1	144.5	122.9	104.5
Current	A	130.5	44.5	37.5	29.4	24.7	19.4	15.2
Beamlet power/bea	MW	57.14	9.52	7.14	4.76	3.57	2.38	1.59
Perveance	uP	4.5E-07	4.5E-07	4.5E-07	4.5E-07	4.5E-07	4.5E-07	4.5E-07
Efficiency	%	70	70	70	70	70	70	70
Cathode loading	A/cm^2	3	3	3	3	3	3	3
Cathode Diametr	cm	7.4	4.3	4.0	3.5	3.2	2.9	2.5

Eff. of 75% needs uP=0.3.
Cathode loading of 3A/cm^2 in this case.

No. of Beam		1	6	8	12	16	24	36
P0 Total	MW	40	40	40	40	40	40	40
Power/beam	MW	40	6.67	5.00	3.33	2.50	1.67	1.11
Voltage	kV	501.1	244.7	218.1	185.5	165.3	140.6	119.5
Current	A	106.4	36.3	30.6	24.0	20.2	15.8	12.4
Beamlet power/bea	MW	53.33	8.89	6.67	4.44	3.33	2.22	1.48
Perveance	uP	3E-07	3E-07	3E-07	3E-07	3E-07	3E-07	3E-07
Efficiency	%	75	75	75	75	75	75	75
Cathode loading	A/cm^2	3	3	3	3	3	3	3
Cathode Diametr	cm	6.7	3.9	3.6	3.2	2.9	2.6	2.3

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Planned work with Thales

Searching for the keyword "klystron" on the Thales Web-site: http://jobs.thalesgroup.com//pid39/E-staffing.com.html, you'll find:


THALES

Change site language

START YOUR THALES ADVENTURE

Discover Our Group | Working with us | Your career | Thales social networks | Search and Apply

Description de poste

Envoyer à un ami

Poser ma candidature

INFORMATION GENERALE

Titre de l'offre : Stage Design d'une optique de Klystrons
Référence : D3S4053
Date : 15/12/10

Région ou pays: Vélizy

Division: Security Solutions & Services

Famille professionnelle : 0506 - Etudes et Développement en Techniques Spécifiques (optique, tubes, satellites &)
Contrat: Stage

DESCRIPTION

L'activité Microwave & Imaging Sub-Systems de Thales (2700 personnes, dans 7 pays) est un des leaders mondiaux de composants et de sous-systèmes d'hyperfréquences et d'imagerie médicale, pour applications professionnelles. Ses produits, sources de puissance radio et hyperfréquences, et détecteurs rayons X, se trouvent au coeur de systèmes de haute technologie parmi lesquels les satellites de télécommunications et de navigation, les systèmes de défense, les grands instruments scientifiques, ainsi que dans les équipements de radiologie.

Dans le cadre de notre développement nous recherchons un(e) :
Stagiaire en Design d'une optique de Klystrons

La mission du stage est la conception d'une optique de klystron comportant 20 faisceaux d'électrons compatible d'une structure d'interaction de MBK coaxiale déjà développée.
Le stagiaire sera intégré aux équipes R&D Composants Hyper Scientifique et Calcul Numérique en contact direct avec les besoins techniques.

Les différentes étapes du travail sont les suivantes :

This "stage" (course) is meant to prepare the applicant for a subsequent PhD work at CERN.

Conclusion power sources

- Industry (CPI, Thales, Toshiba) confirm our belief that a MBK with 20 MW peak, η>65%, 50 Hz, 150 µs is in reach.

- A two-pronged strategy aims at
  1. getting a suitable tube (MBK) with the above characteristic in ≈ 3 years from industry,
  2. investigating better, alternative solutions for high η RF power sources in a wider scope R&D on the longer term (synergy with other large projects)

Overall conclusions

- The accelerating structures are well studied – there are no remaining “issues”.
- The CLIC overall power needs are huge – special attention is given to overall **efficiency**; this includes (amongst other things) the RF power source, where we have a two-pronged approach (short term & long term).
- ACE is invited to propose experts for a MBK development review panel.