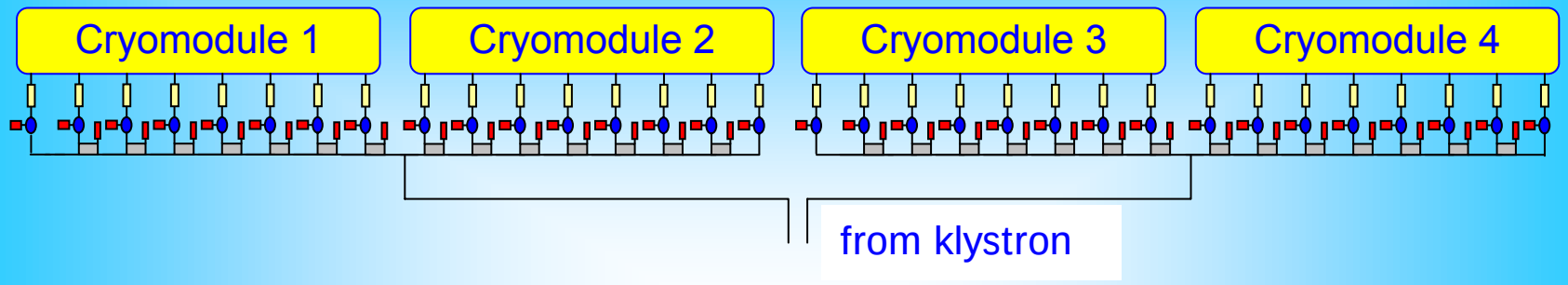
XFEL
X-Ray Free-Electron Laser

Waveguide system

V.Katalev, S.Choroba

Basic principles of RF power distribution

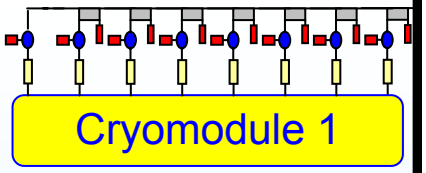
- Multibeam klystron feeds 4 cryomodules with 5.2 MW RF power



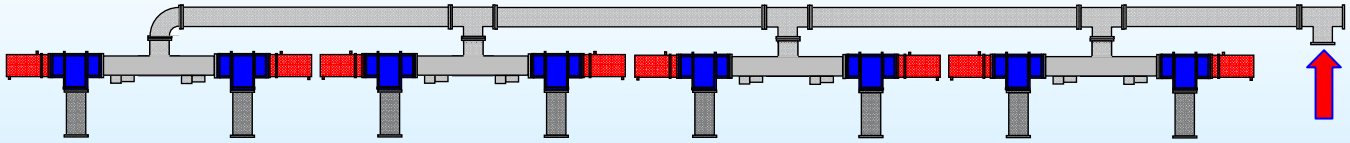
- A cryomodule consists of 8 sc cavities
- Each cavity receives 122 kW peak RF power for nominal gradient
- But 10 MW/32=312 kW + 10% (reserve for relibility)

  => 350 kW (pulse) and 5 kW (average)

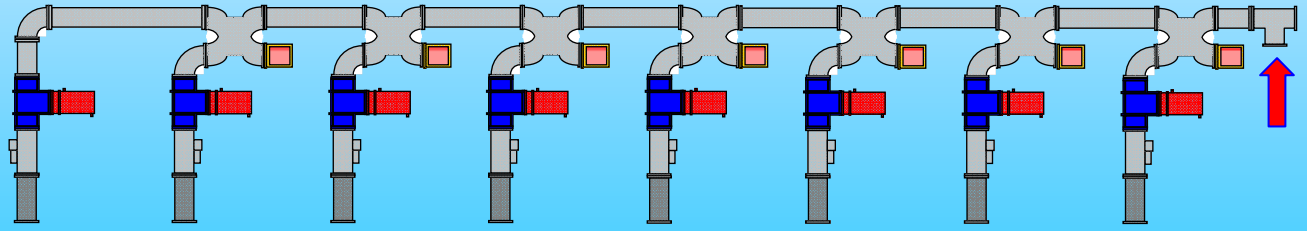
Waveguide distribution for cryomodule



Combined system with asymmetric shunt tees

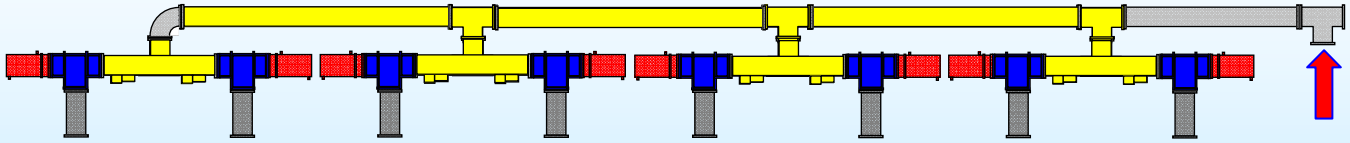


Linear system with hybrids - FLASH like



Waveguide distribution with shunt tees

New elements of waveguide distribution



Shunt tee with integrated phaseshifters

Asymmetric shunt tee 3.0 dB, 4.77 dB, 6.0 dB

Fixed phaseshifters

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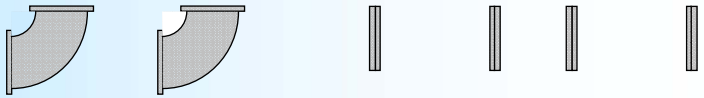
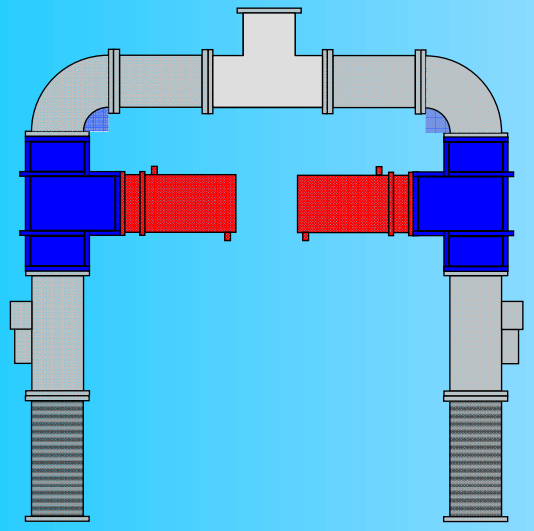
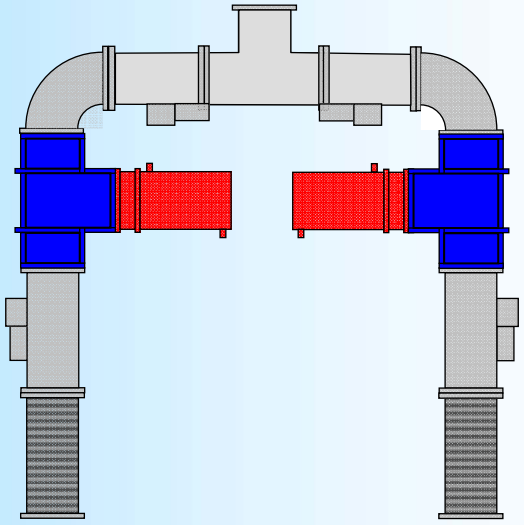
Waveguide distribution with shunt tees

Binary cell – new type





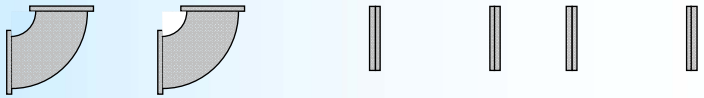
first proposal



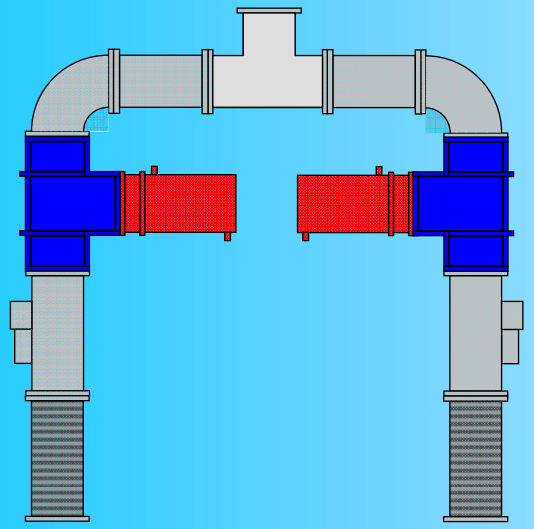
new

Waveguide distribution with shunt tees

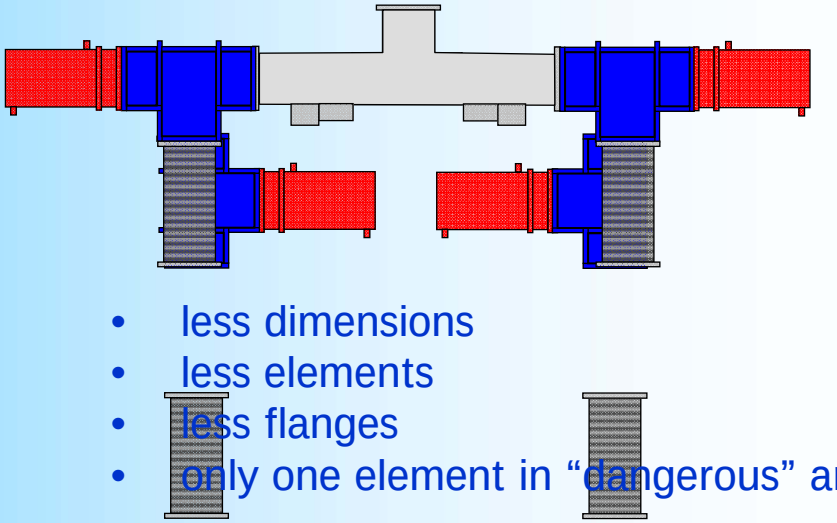
Binary cell – new type



x 490



first proposal



- less dimensions
- less elements
- less flanges
- only one element in “dangerous” area

new

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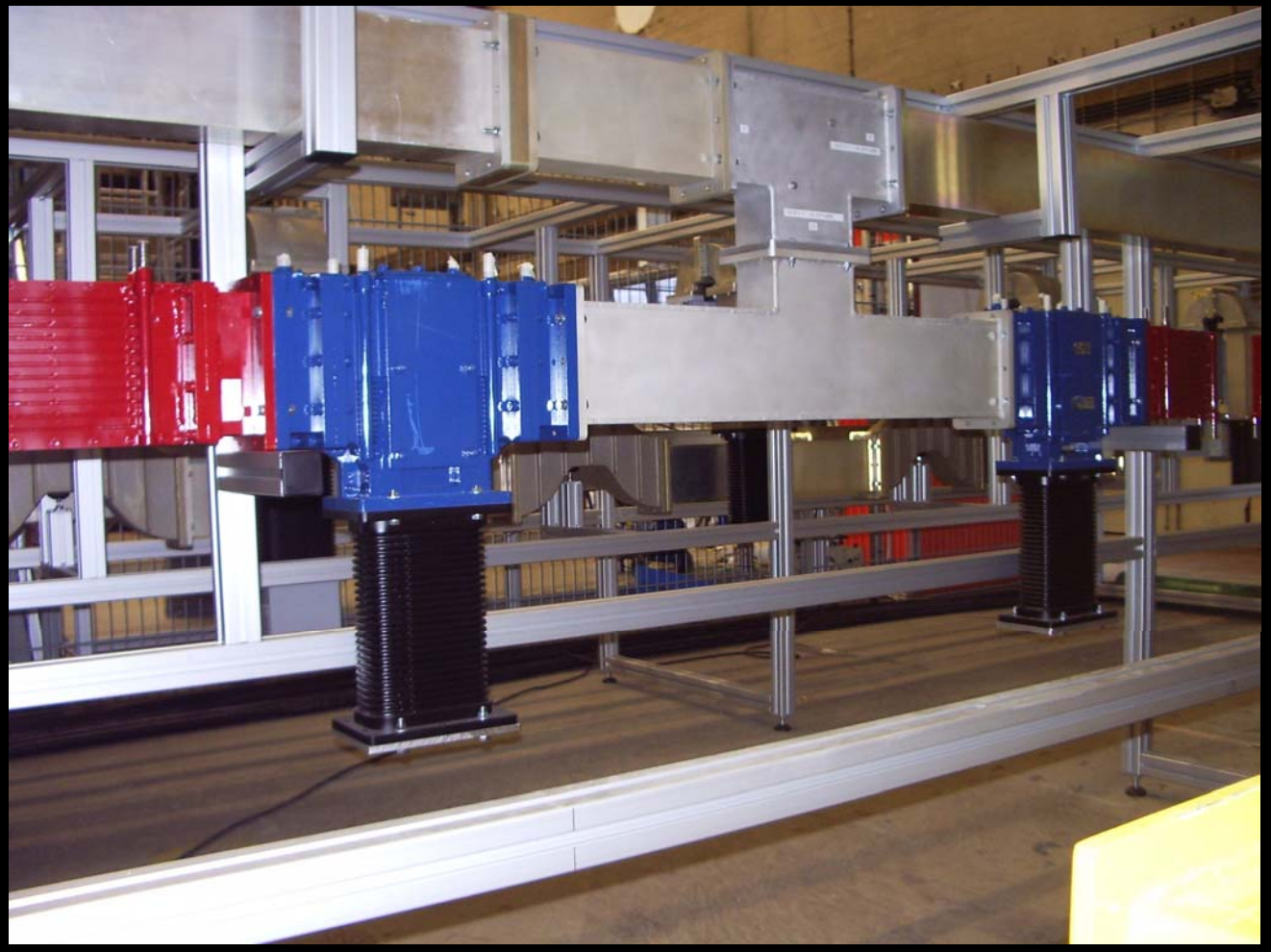
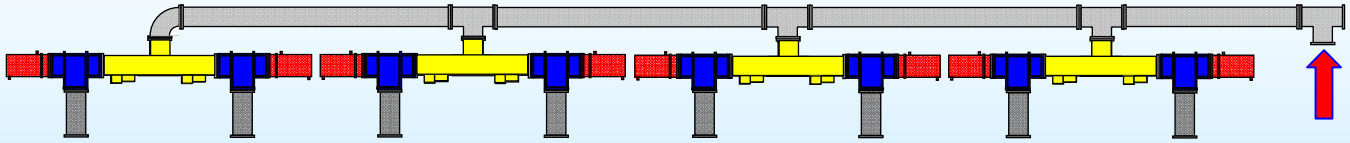
Waveguide distribution with shunt tees

Binary cell – new type



Waveguide distribution with shunt tees

New elements of waveguide distribution



Shunt tee with integrated phaseshifters

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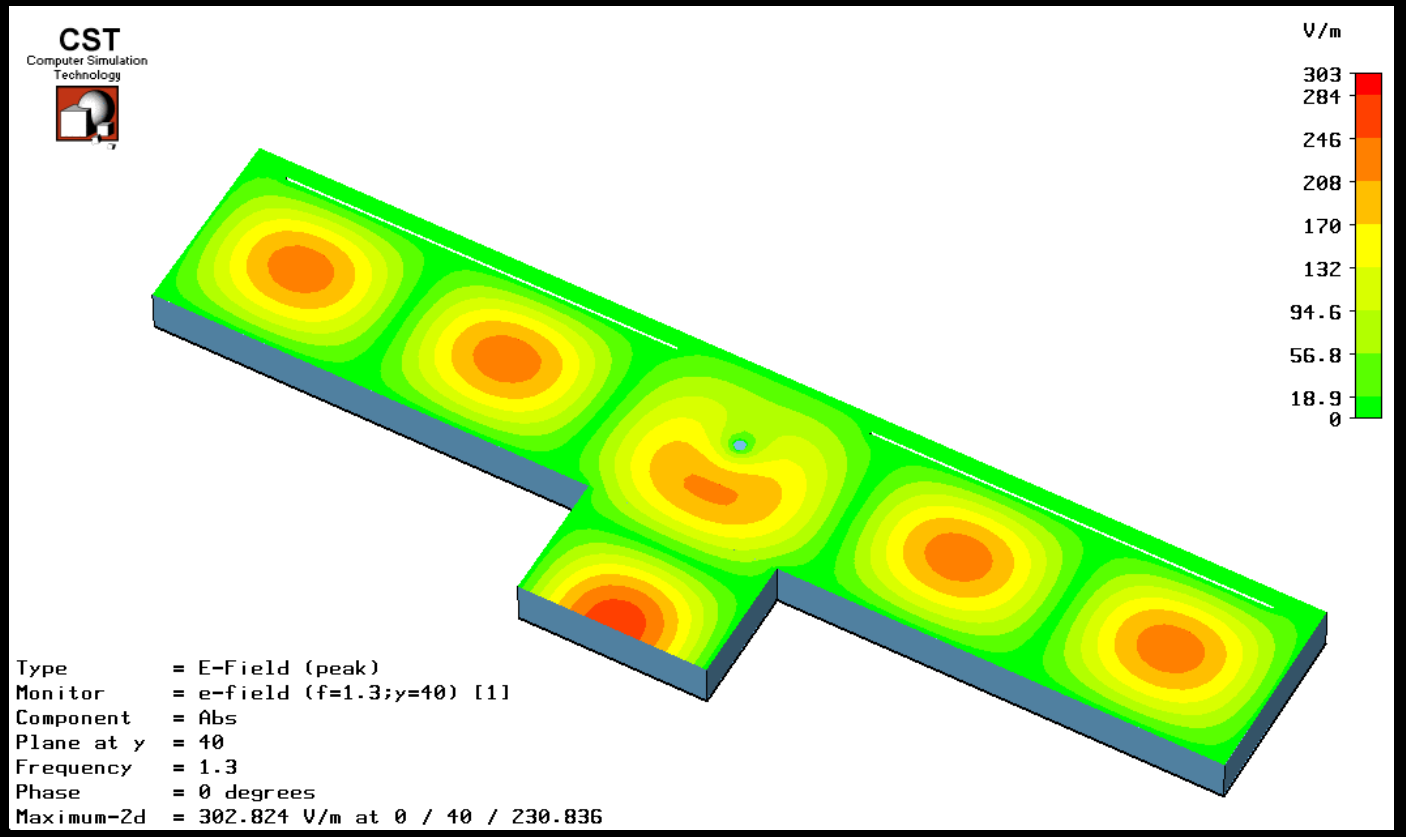
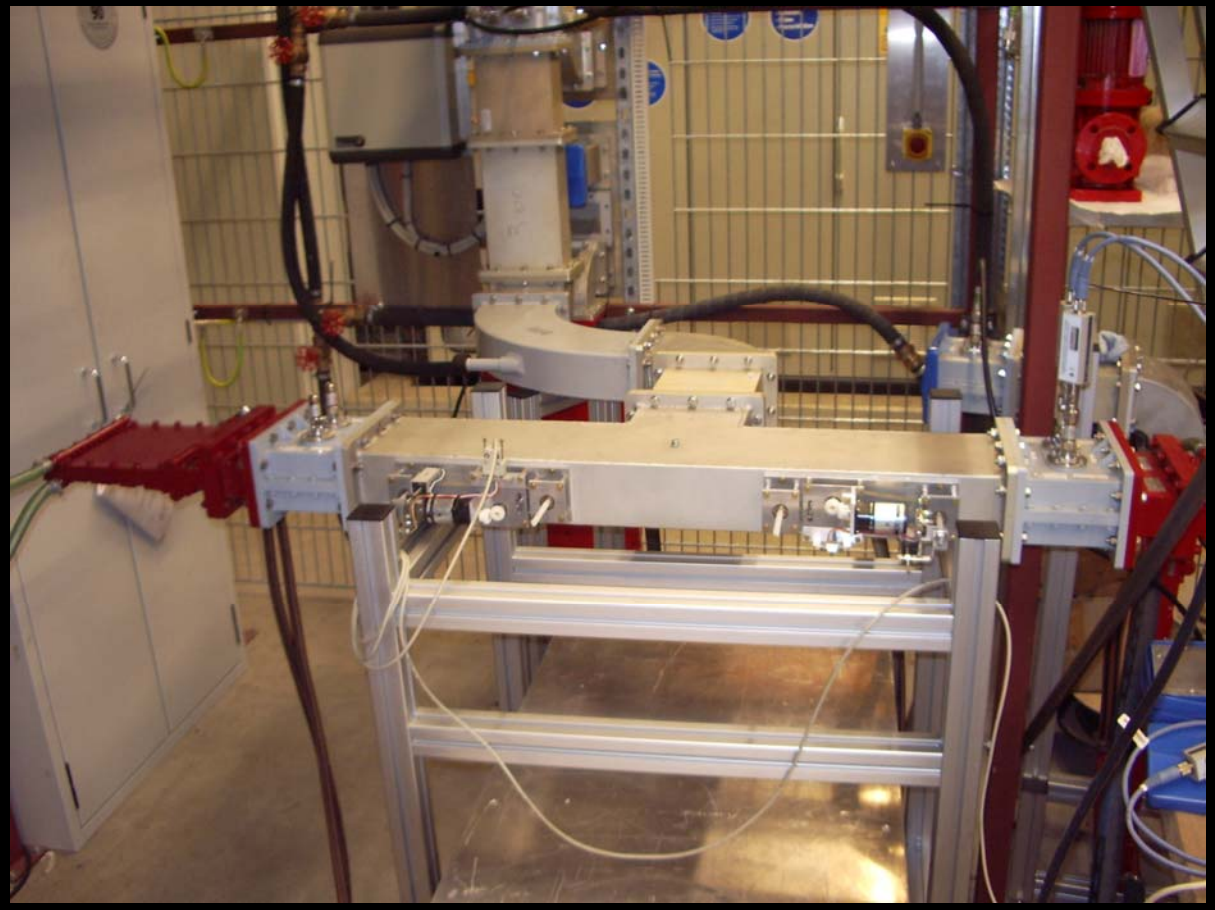
Shunt tee with integrated phaseshifters



Shunt tee with integrated phaseshifters

High power test (tested by J.Randhahn and F.Eints MHF-p)

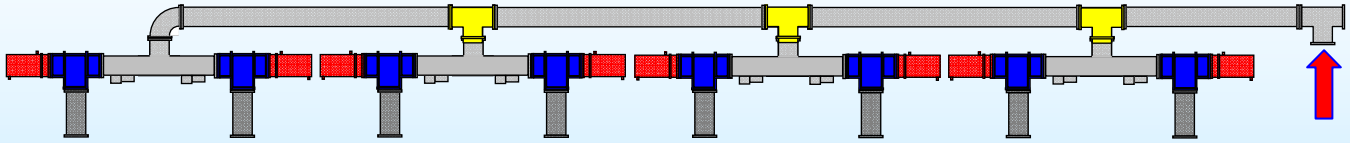


tested with 800 kW
10 Hz 1.5 ms

for XFEL -> 300 kW

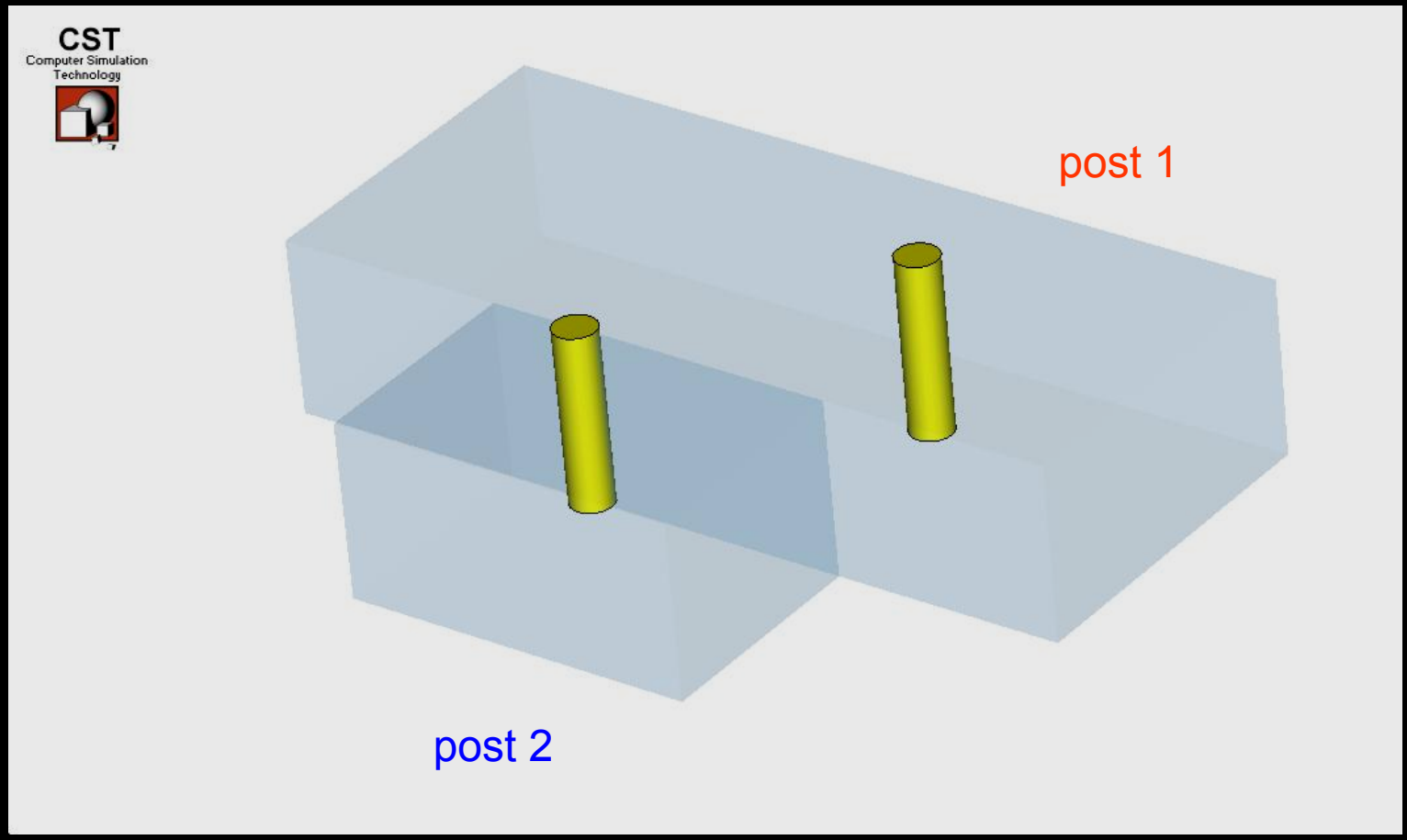
Waveguide distribution with shunt tees

New elements of waveguide distribution



Asymmetric shunt tee 3.0 dB, 4.77 dB, 6.0 dB

Asymmetric shunt tee



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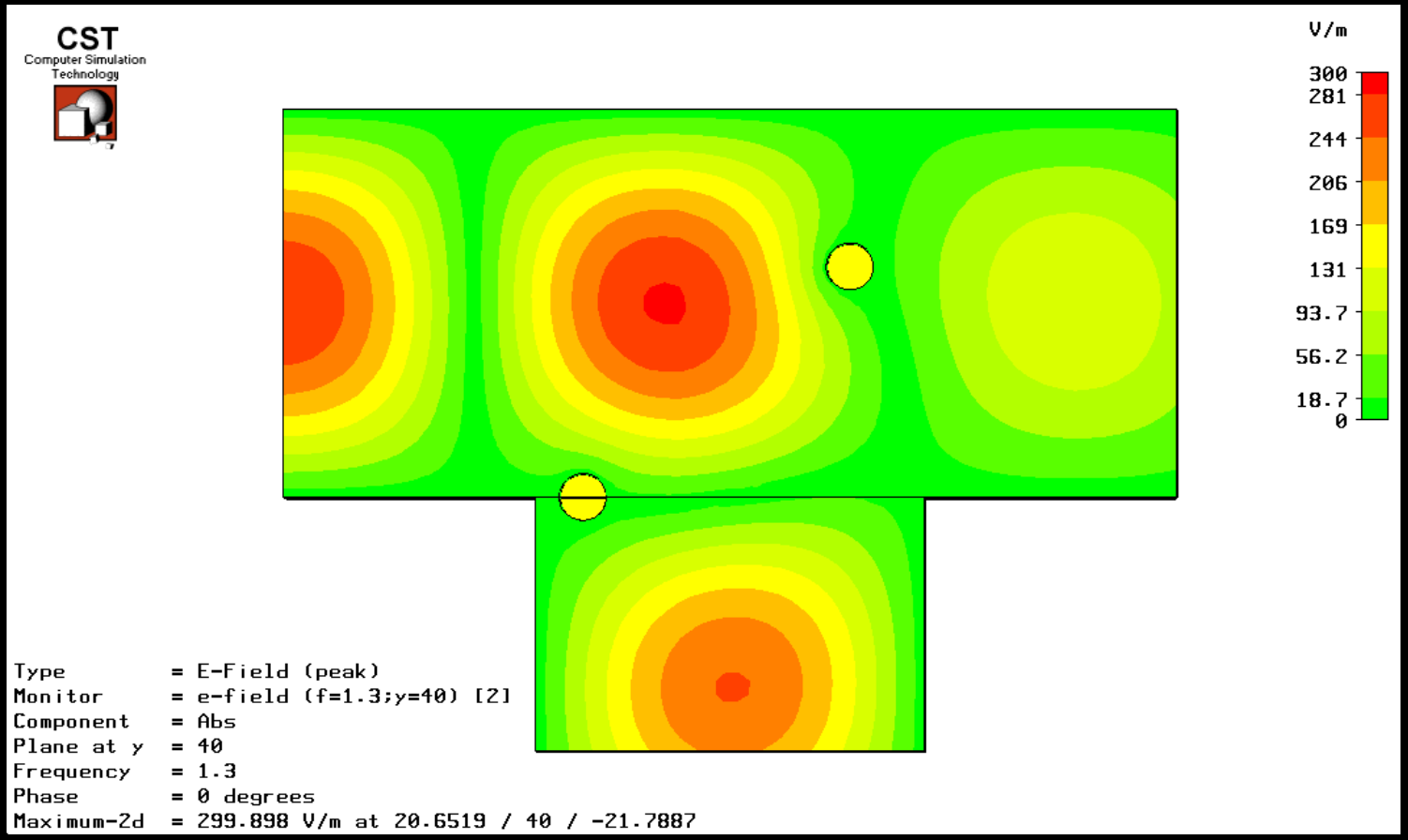
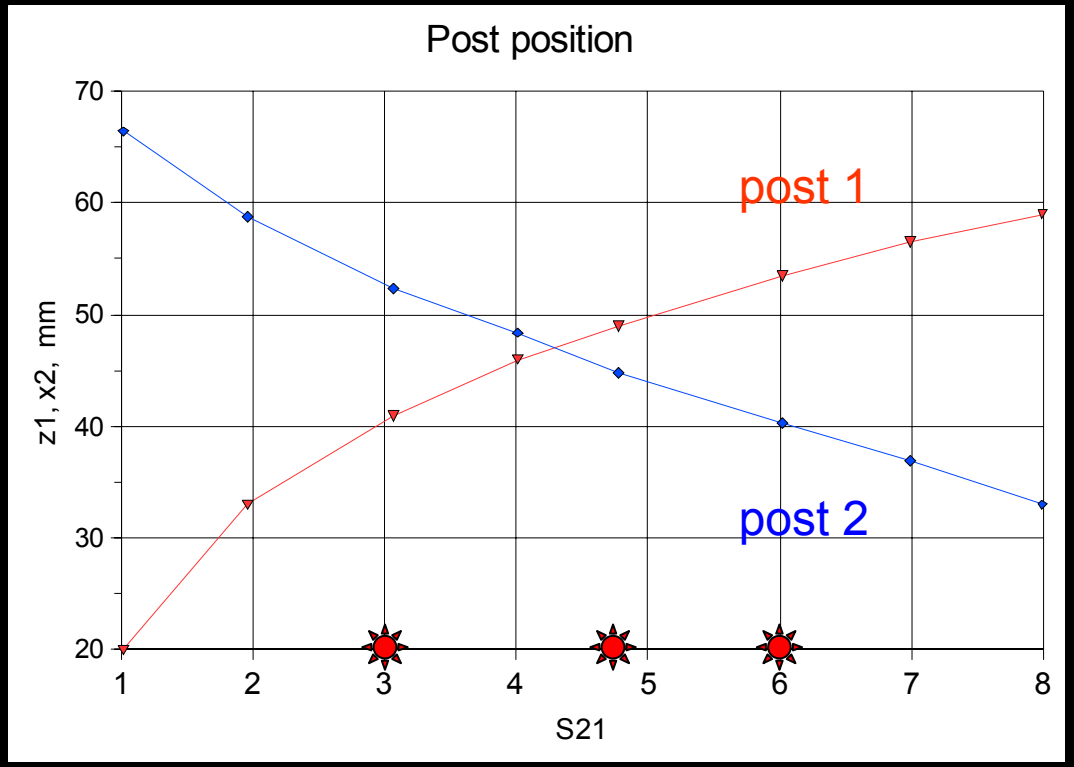
Asymmetric shunt tee

Coupling ratio 8 dB



Asymmetric shunt tee

Post position



3.01 dB
4.77 dB
6.02 dB

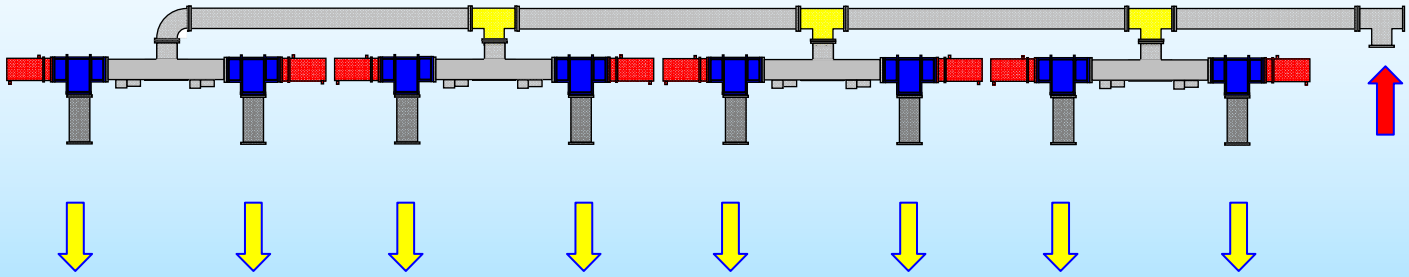
Impossible to tune so fast the slot hybrid!!!

Each pair of cavities with own gradient

Combined system with asymmetric shunt tees

is tunable waveguide system!

There is no more the “weak cavity” limit in cryomodule!



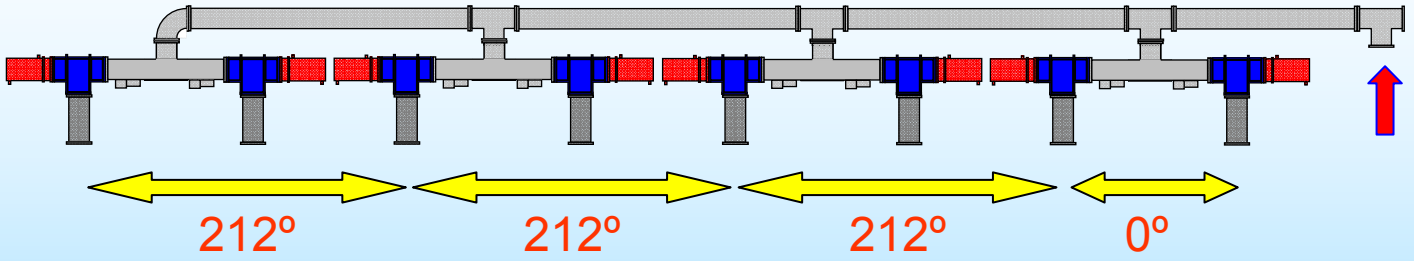
P_1, Q_1 E_1 | P_2, Q_2 E_2 | P_3, Q_3 E_3 | P_4, Q_4 E_4

Cavity gradient range from 18 to 35 MV/m

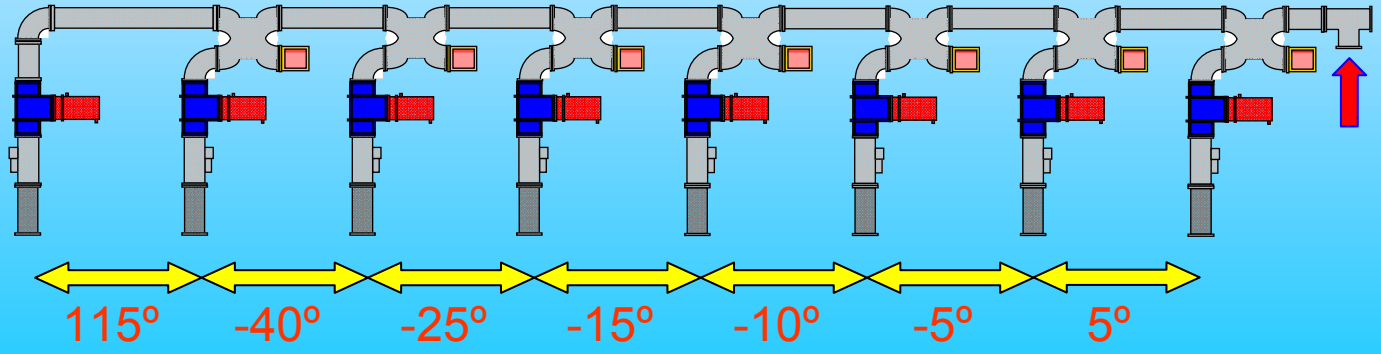
(from above limited by circulator only)

Phasing of wavegude distribution

Combined system with asymmetric shunt tees

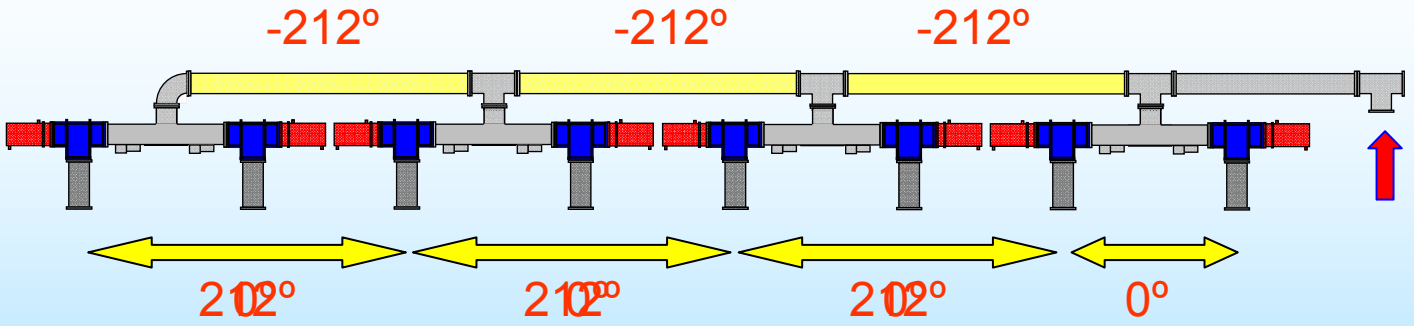


Linear system with hybrids - FLASH like

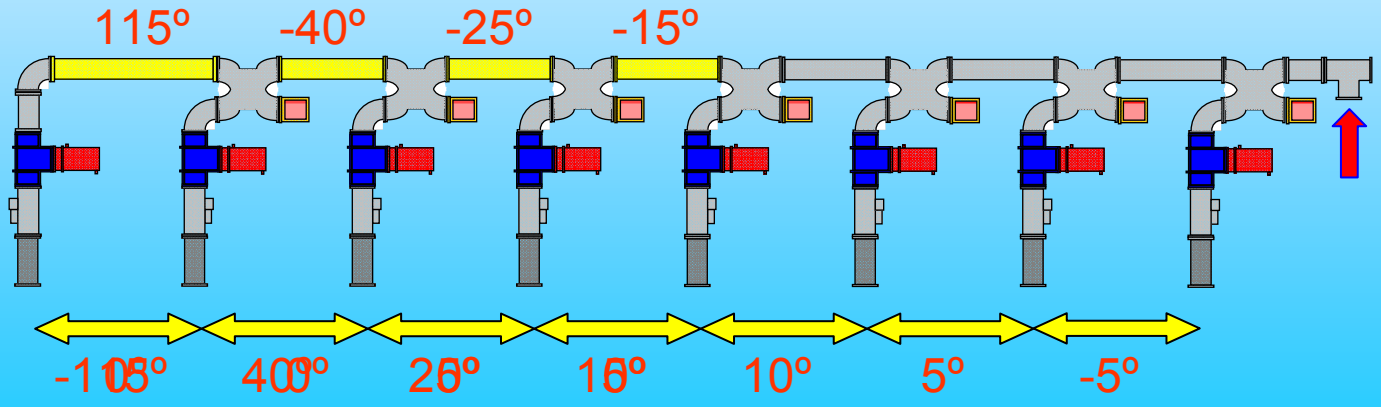


Phasing of wavegude distribution

Combined system with asymmetric shunt tees



Linear system with hybrids - FLASH like



Fixed phaseshifter

$$\Delta\varphi = 2\pi \times \frac{l}{\Lambda}$$

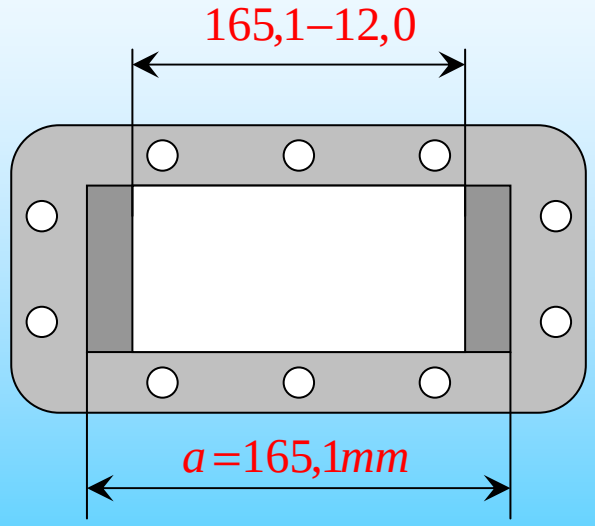
$$l \Rightarrow fixed$$

$$\Lambda = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{2a}\right)^2}}$$

Waveguide *165.1 × 88.55 × 2280 mm*

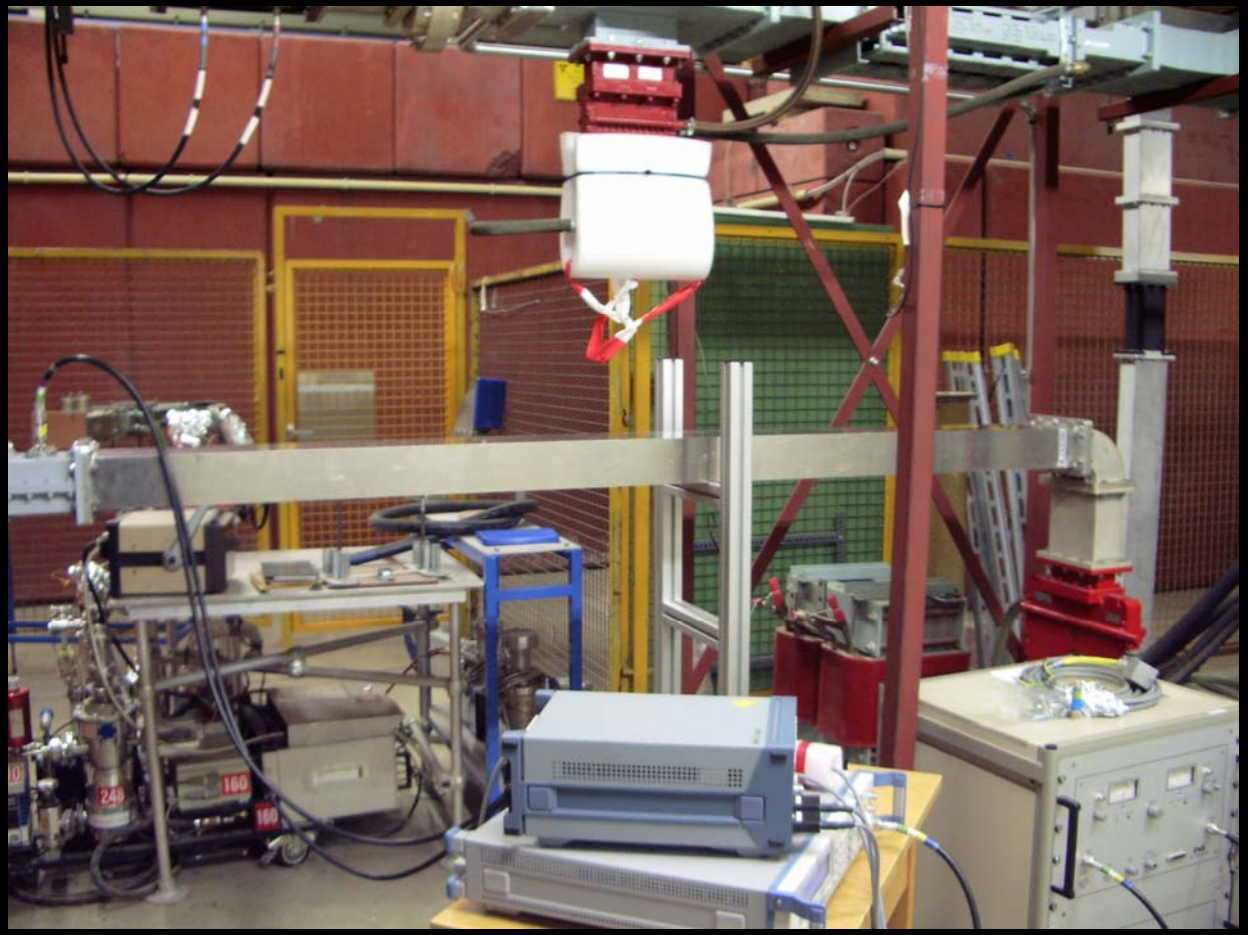
replaced by *153.1 × 88.55 × 2280 mm*

which has 212º phaseshift and SWR ≈ 1



Fixed phaseshifter

High power test (tested by F.Eints and I.Sandvoss MHF-p)



tested with 2.4 MW
5 Hz 1.5 ms

for XFEL -> 750 kW

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350 kW circulator with integrated dummy load

Produced by s.p.a. FERRITE Sankt Petersburg

not yet tested

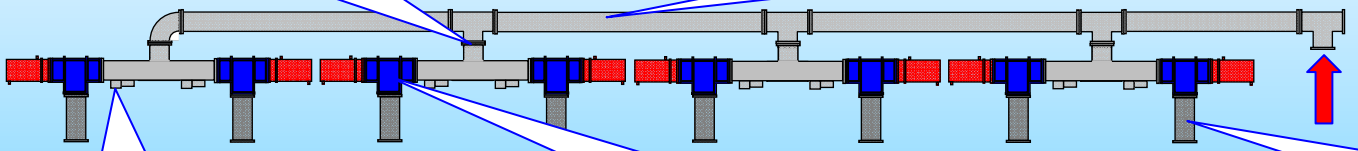
Waveguide RF losses for one RF station

estimation

32 cavity power ≈ 3.9 MW RF losses ≈ 370 kW (8.6%) *Klystron power* ≈ 4.3 MW

Average RF losses (10 Hz, 1,35ms) ≈ 5.1 kW

If RF losses = 100%, then…..



28 tees ≈ 2.5%

12 fixed phaseshifters ≈ 9%

32 bellows ≈ 2%

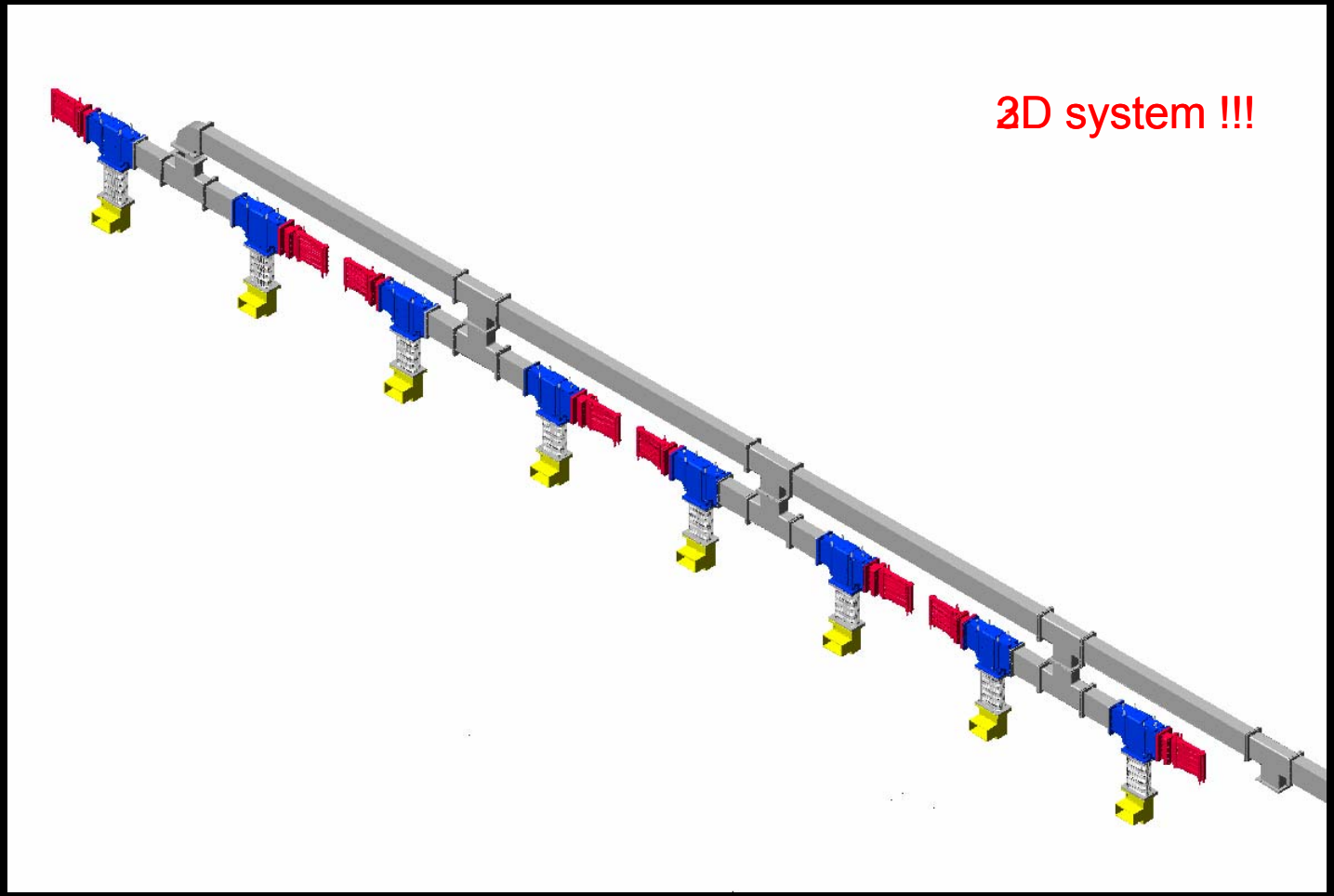
32 circulators ≈ 40%

32 phaseshifters ≈ 1.5%

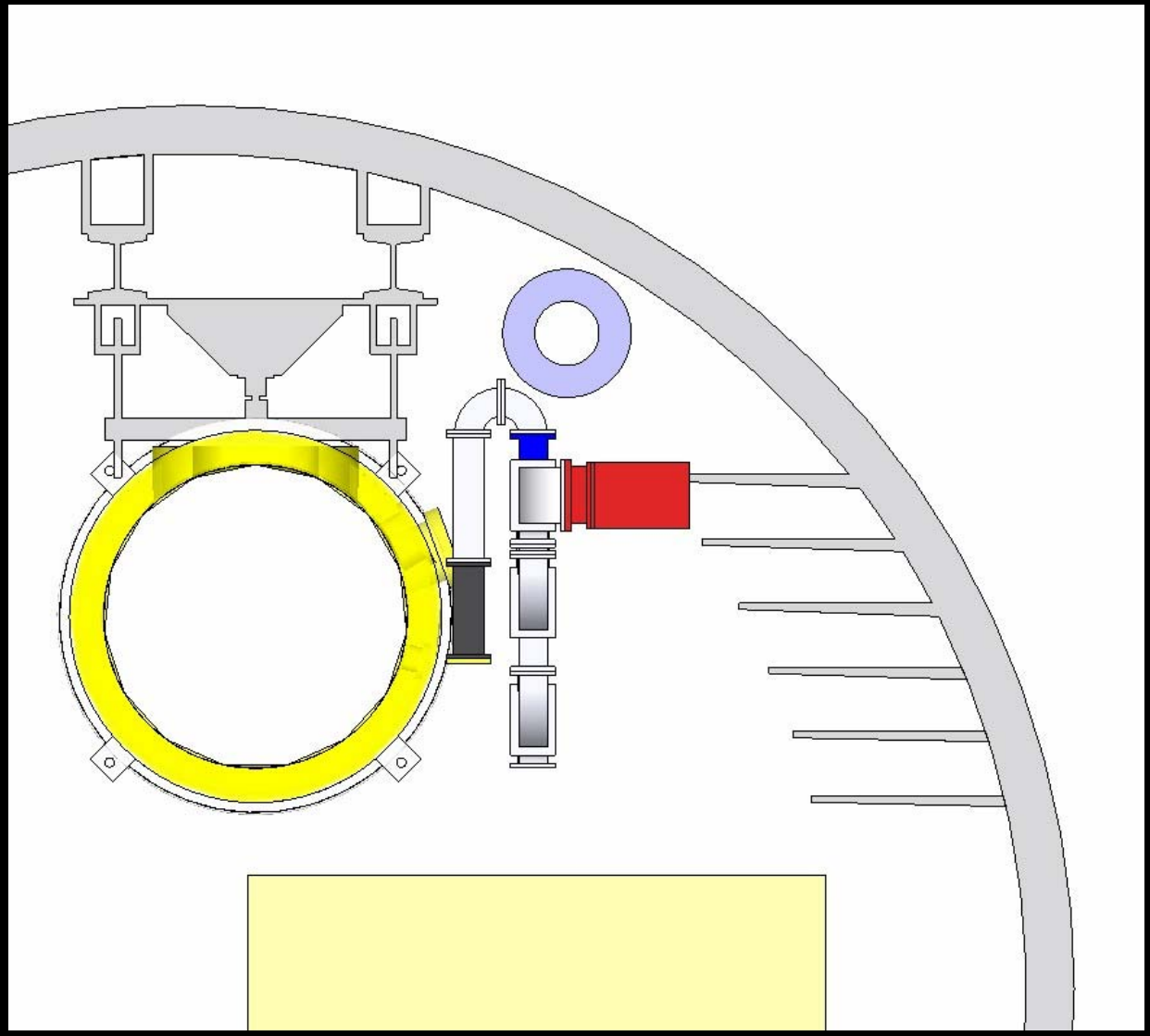
40 m straigth wavegude ≈ 45%

Power distribution for cryomodule

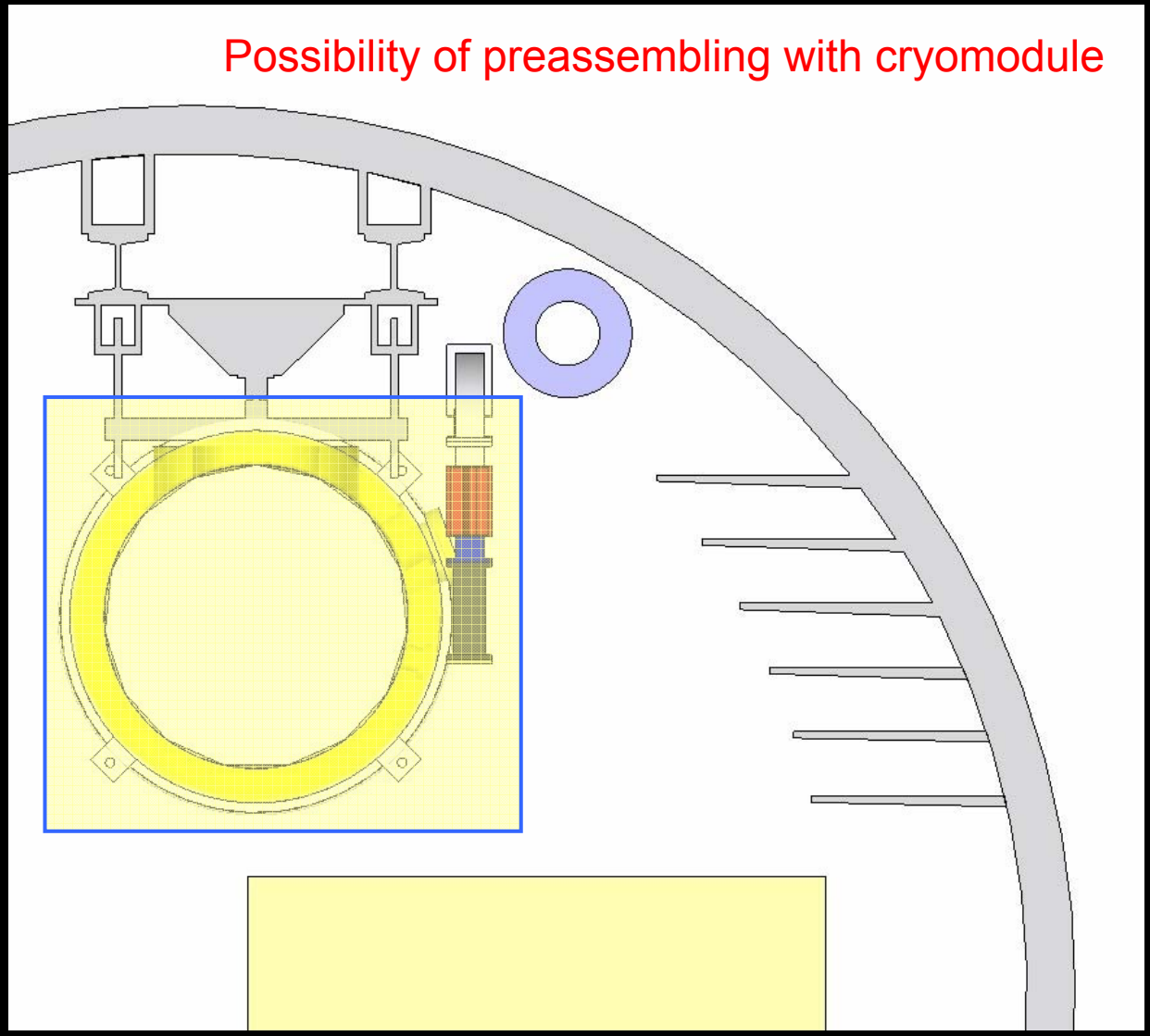
Combine system with hybrids and FLASH-like tees



Linear distribution into tunnel



Combined distribution into tunnel



Waveguide distribution in Halle II

FLASH like

Combined system

Comparison of waveguide systems

Component	wg for one cryomodule	
	TTF like	Combined
Circulator & dummy	8	8
Bellows	8	8
Hybrid (7 types)	7	-
Dummy load 200 W	7	-
Phaseshifter	8	-
Shunt tee with phaseshifters	-	4
Asymmetric shunt tee (3 types)	-	3
E-bend	24	-
H-bend	2	1
Straight wg 880 mm	7 (6160 mm)	-
Straight wg 2280 mm	-	3 (6840 mm)
Flanges	79x2	27x2
Weight, kg	600	450
Possibility of power tuning for cavity	no	yes
Cost estimation, %	100	89

Comparison of waveguide systems

Combined waveguide distribution with shunt tees has:

- smaller dimensions → *2D system*
  → *more suitable for XFEL tunnel*
- less quantity of waveguide components
  → *less flanges* → *increasing of reliability*
  → *easier and faster assembling*
- less weight → *25%*
  → *possibility of preassembling with cryomodule*
- possibility of the power tuning for each pair of cavities
  → *no limit of the lowest cavity gradient*
- it is more convenient to phase
- less range of waveguide components
  → *more maintainability*
- cost should be less about 10-15%

But it is necessary to complete the RF power test
for new waveguide components and we have no experience of running

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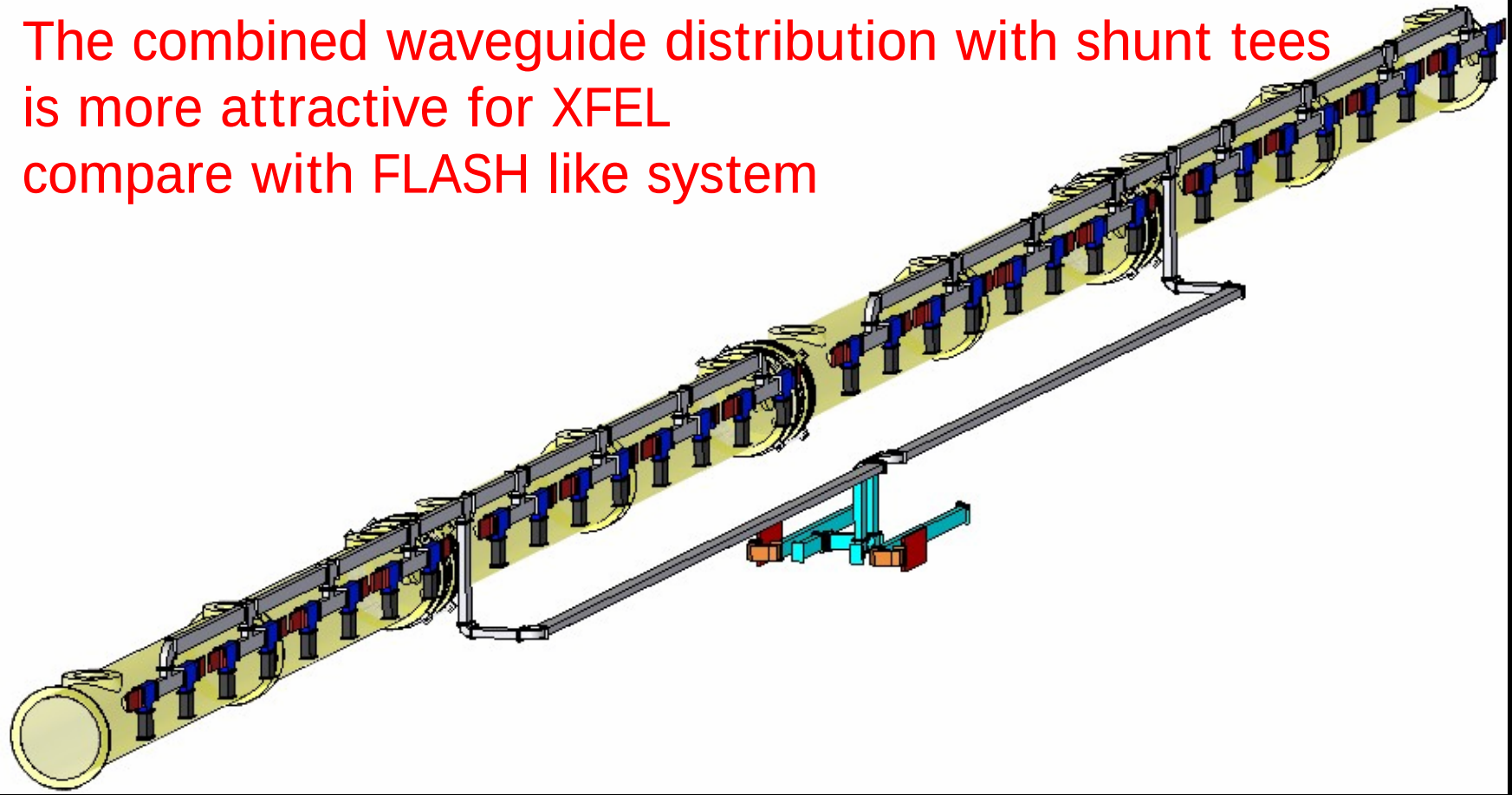
Waveguide distribution for one RF station

The combined waveguide distribution with shunt tees
is more attractive for XFEL
compare with FLASH like system



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Thank you for attention!