The High Power RF Systems of MAMI and MESA

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on behalf of the accelerator group

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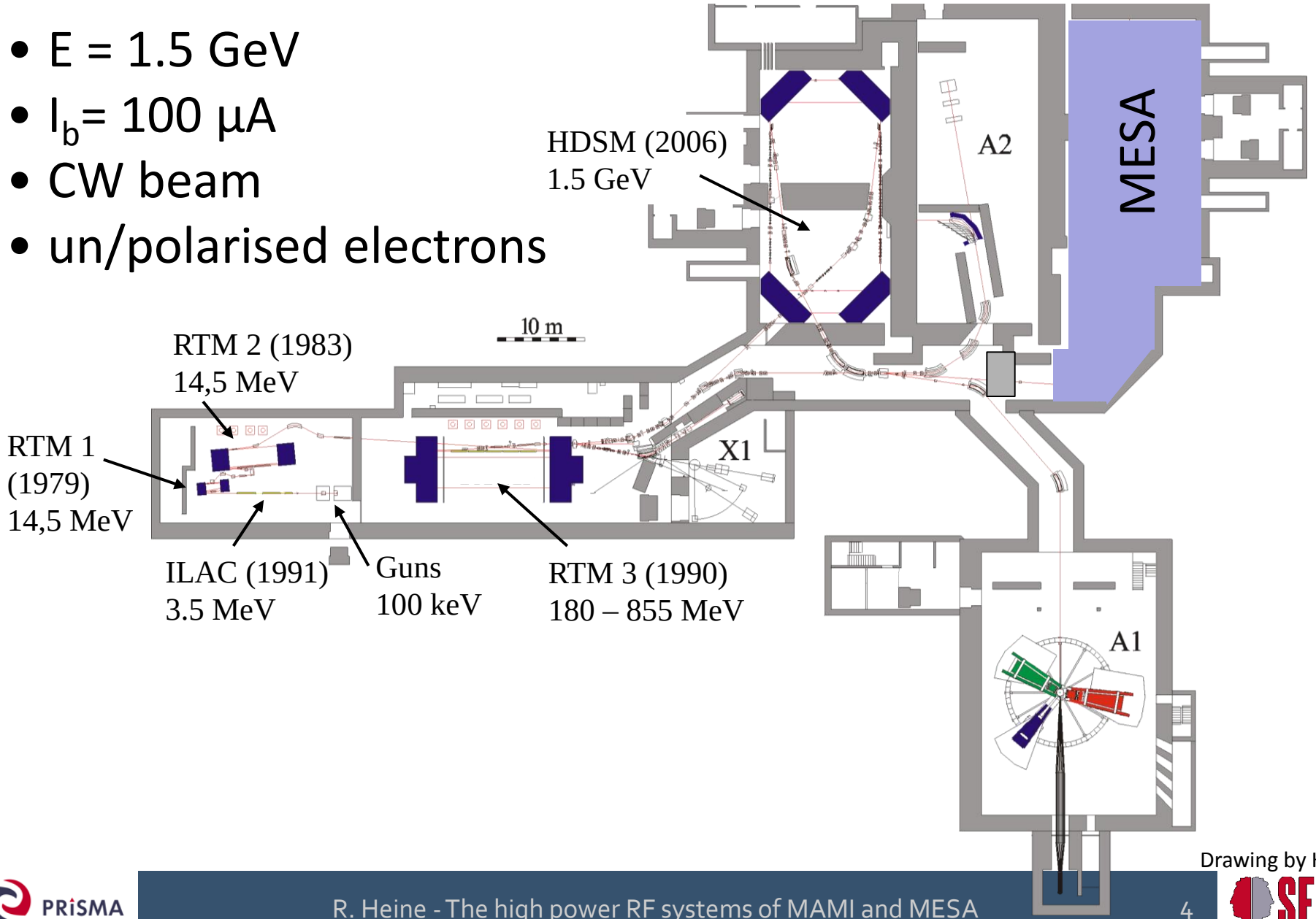
Outline

- MAMI
  - Introduction to the facility
  - Overview of the RF system
  - Operational experiences
- MESA
  - Introduction to the facility
  - Concept of the RF system

MAMI

Mainzer Mikrotron – MAMI

- E = 1.5 GeV
- I_b = 100 µA
- CW beam
- un/polarised electrons



Drawing by KPH

Mainzer Mikrotron – MAMI

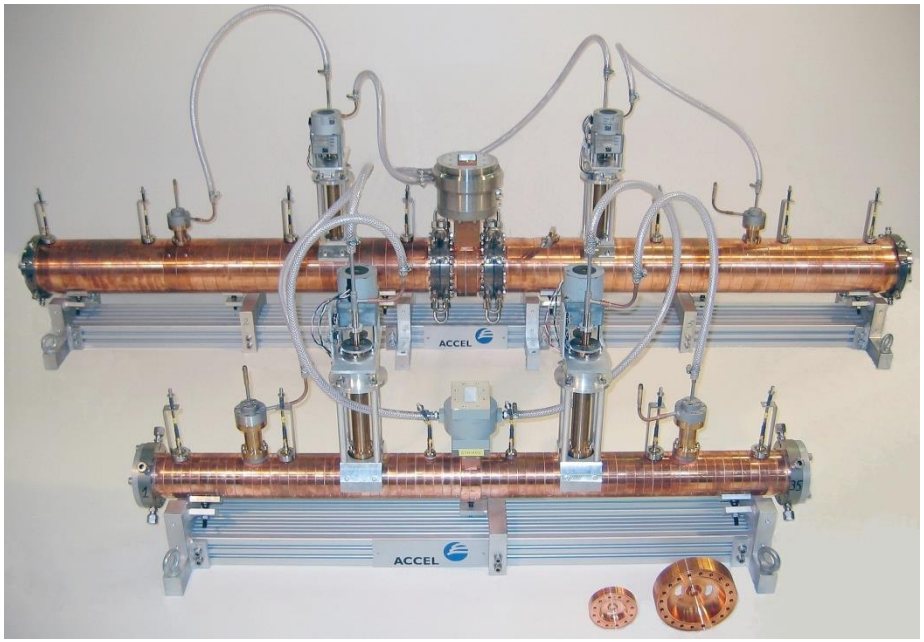
RTM 3 is the world largest microtron!

450 t per magnet! Magnetic field 1.28 T

picture by KPH

MAMI RF System

- RF frequency: 2.45 GHz and 4.9 GHz
- RF-structure:
  - standing wave $\pi/2$
  - on axis coupled bi-periodic structure
- Type of operation: CW, 100% duty cycle



pictures by KPH

MAMI RF System

- ILAC: 3 RF sections, graded β and const. $\beta<1$
- RTM1: 1 RF section, $\beta = 1$
- INT 2: 1 RF section
- RTM 2: 2 RF sections
- INT 3: 1 RF section
- RTM 3: 5 RF sections
- HDIN: 2 RF sections (4.90 GHz)
- HDSM: 5 RF sections (2.45 GHz)
  8 RF sections (4.90 GHz)

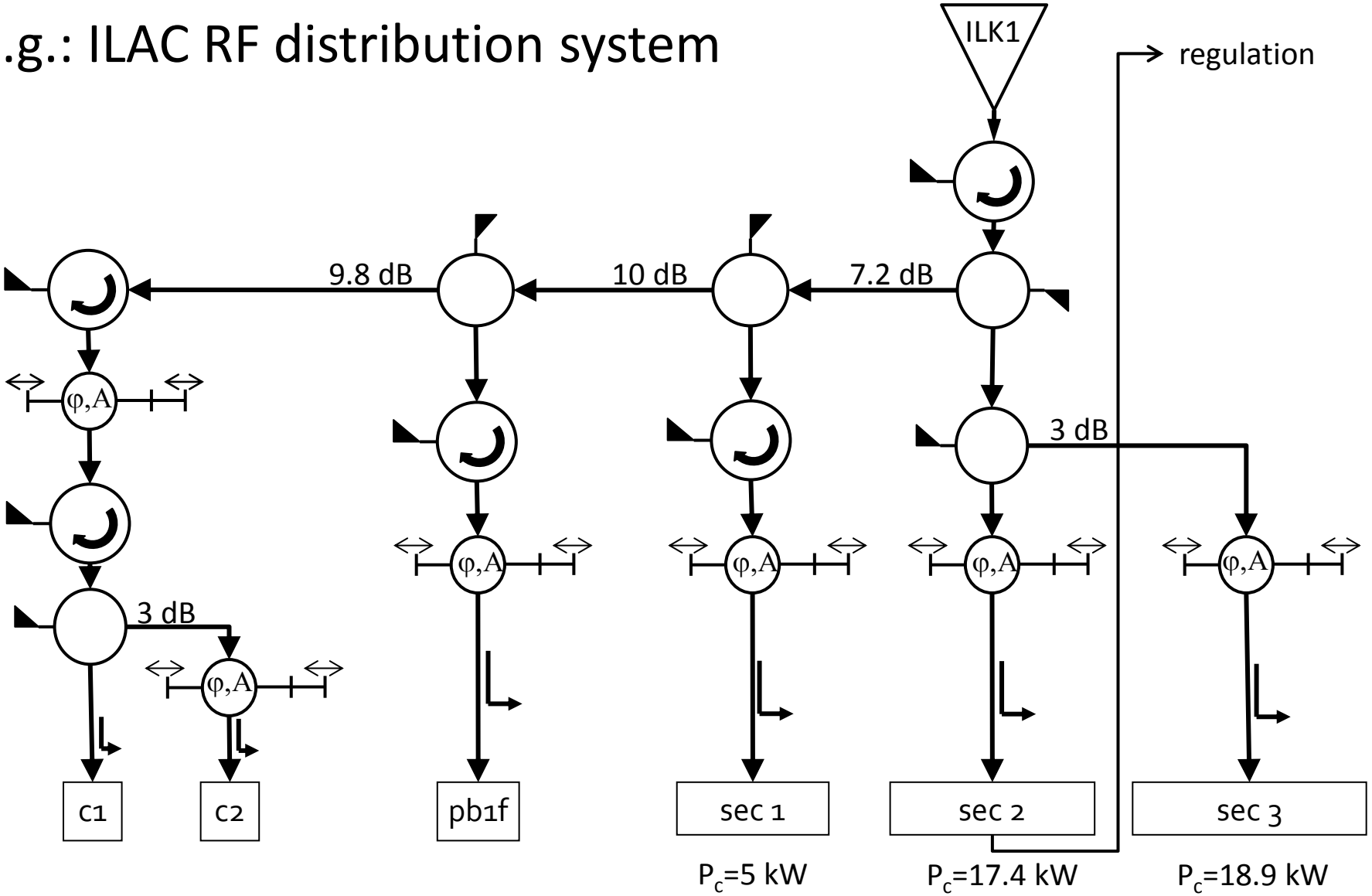
Total of 26 RF sections in operation

MAMI RF System

- MAMI A/B: 9x 2.45 GHz 50kW Klystrons in operation:
  - 1x ILAC: CPI VKS 7960 M
  - 1x RTM 1: TH 2075 (drives also INT2 + INT3)
  - 2x RTM 2: TH 2075
  - 5x RTM 3: 3x TH 2075, 2x VKS 7960 M
- MAMI C (HDSM)
  - 5x 2.45 GHz: TH 2174 (improved TH 2075)
  - 5x 4.90 GHz: TH 2166 (50 kW)

Total of 19 klystrons in operation

e.g.: ILAC RF distribution system



MAMI RF System

e.g.: ILAC RF distribution system

- In house hybrids and phase shifters

from klystron ILK1

MAMI RF System

- MAMI A/B HVPS

ILAC: Heinzinger, 30 kV, 4 A

RTM 1:
Fischer, 20 kV, 3 A

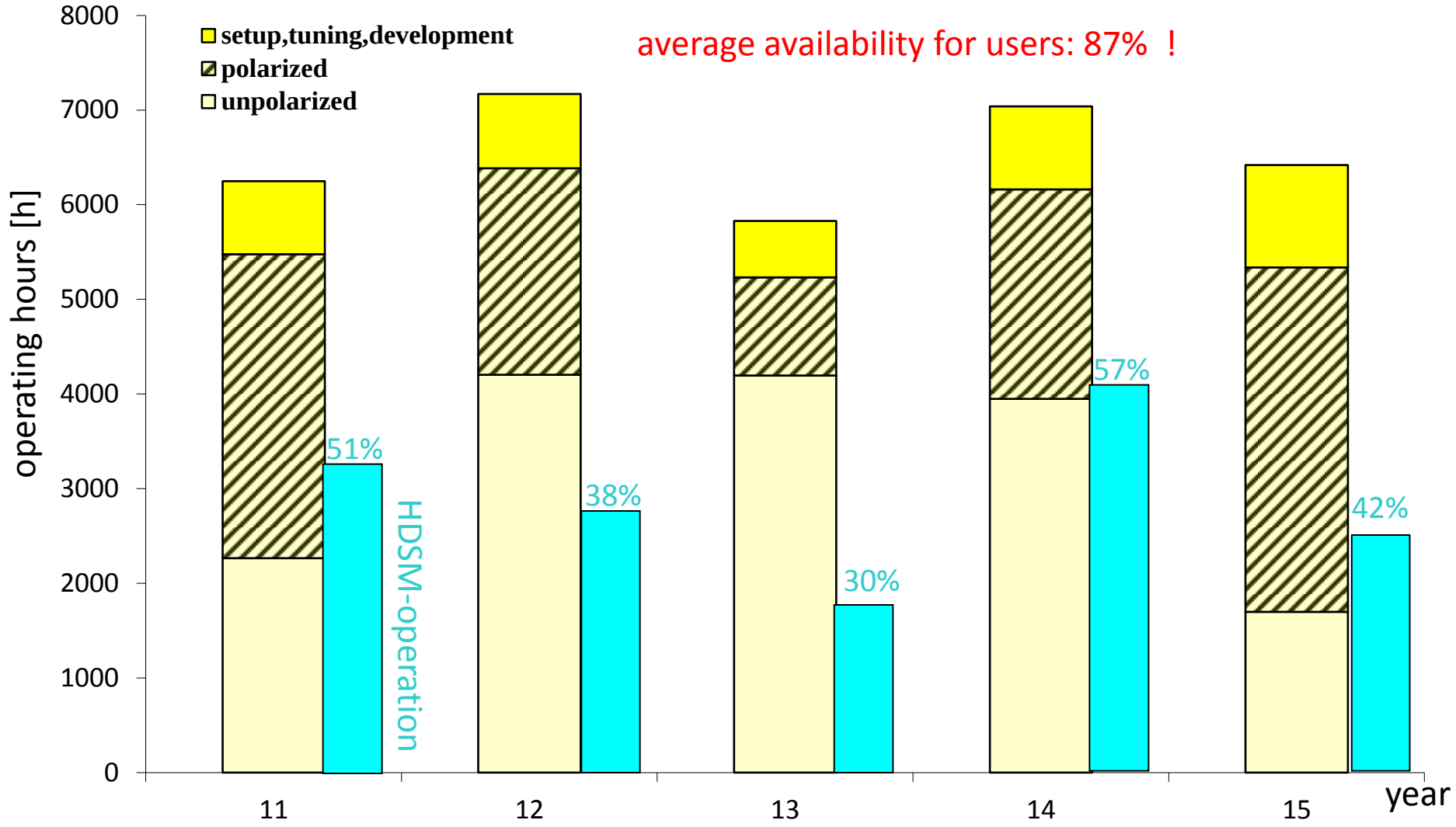
RTM 2&3:
ABB 26/30 kV, 28 A

MAMI RF System

- MAMI C modular HVPS

2x Bruker 30 kV, 27 A, 625 V/module

MAMI past 5 years operation statistics

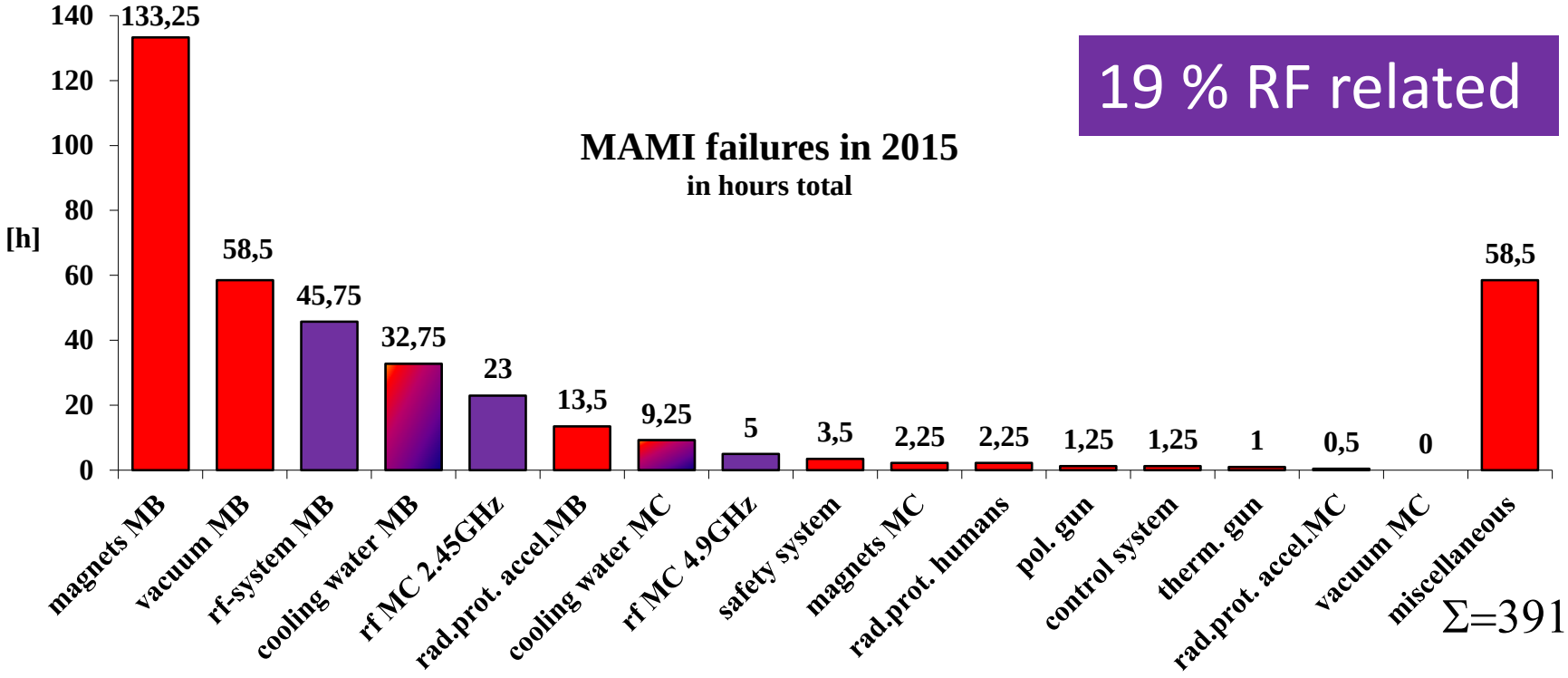


total (2011 – 2015): 32703 hours of operation = **6541 h avg. per year**

source: H.J. Kreidel, KPH

Statistics of downtimes

Downtime due to failure: **6.1%** of total beam time.



19 % RF related

Main causes of failure were

- Trips of the aging magnet power supplies of the RTMs
- Vacuum leakage in a bellow of the movable beam-stopper of the safety system
- Klystron trips (mostly due to aging components of auxiliaries)
- Water leaks in installations for cooling water of MAMI A and B

source: H.J. Kreidel, KPH

Failures of RF system

- Klystron interlocks:
  - aging components of auxiliaries (e.g. heater PS, foc. PS, etc.)
  - P_{refl} (e.g. after long beam pause → body temperature changes)
  - Arc detection
- Water Interlocks:
  - Cu piping of RF sections eroded → successive replacement with stainless steel pipes. (30 y old Cu pipes last longer, than todays pipes!)
  - plungers of 4.9 GHz: leakage to vacuum → design improved
  - Klystron cooling pipes and fittings eroded
  - Aging flowmeters
- HVPS:
  - no major problems, only aging components (capacitors, transistors, piping, etc.)

Klystrons: long-time experiences

Status of Jan. 04. 2016

- TH 2075:
  - Since 1978 thirteen tubes were set out of operation
  - Average age of “retired” tubes: (45000 ± 29000) h
  - Mainly because of vacuum leakage or multipactor (I_{body})
  - But all working tubes well above this average!
- VKS 7960 M:
  - In operation since 1995
  - Main problems: water leakages (collector, foc. magnets)
- TH 2174: ☺
- TH 2166:
  - 3x water leakages at different spots
  - 1x minor vacuum leakage, but still in operation (since 2013!)

Klystrons: long-time experiences

- Average hours of operation of operating klystrons:
  - MAMI A/B klystrons: 74400 h
  - MAMI C klystrons: 27000 h

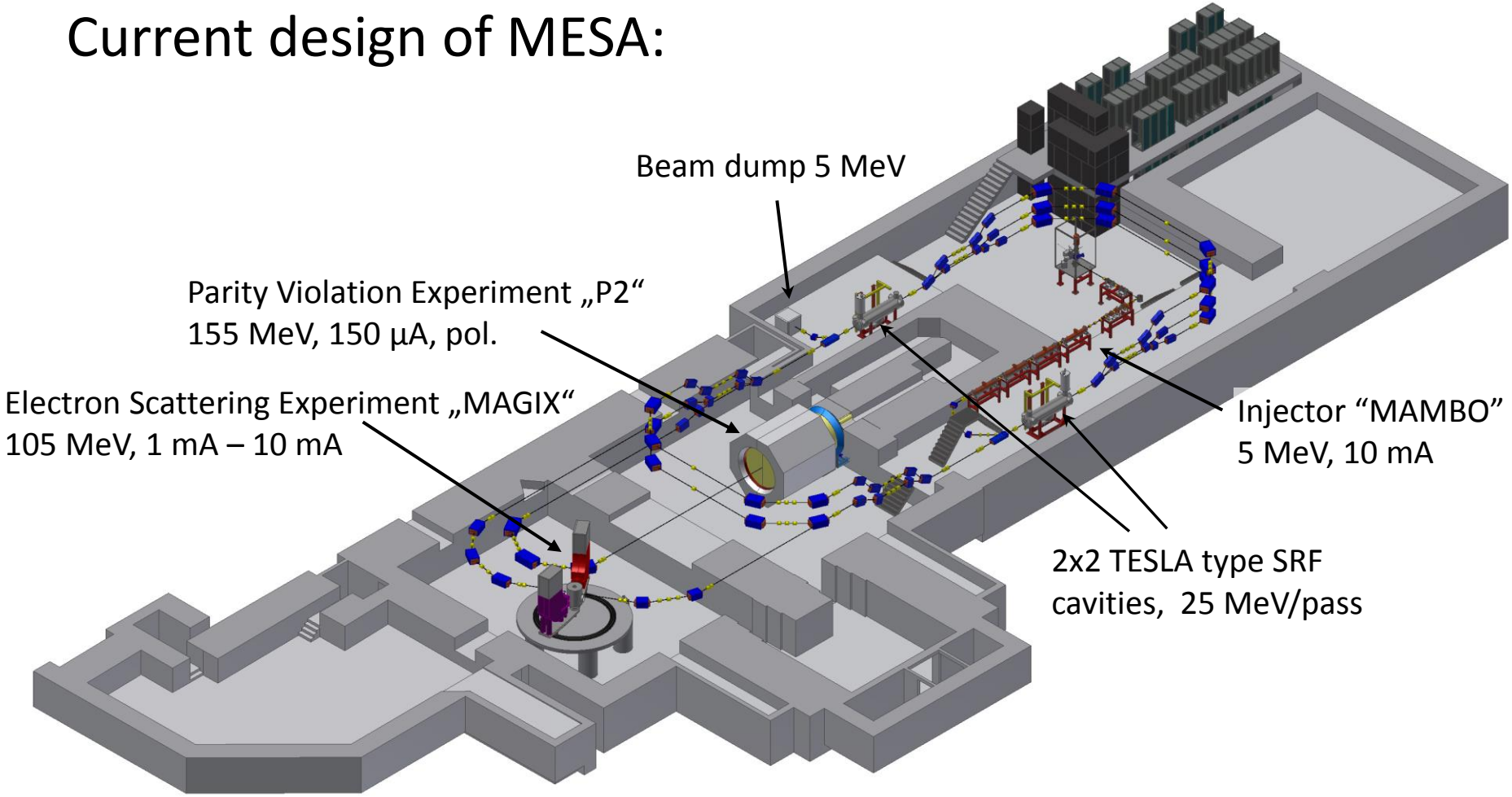
- Since 1978 four klystrons have overcome 100,000 h
  - 2x Thales, 2x CPI
  - Still in operation: 2
  - Back up: 1
  - Out of operation: 1
  - Record held by TH 2075-007: 151,750 h (RTM 1)

→ Durability of Thales and CPI tubes is comparable

Status of Jan. 04. 2016

MESA

Current design of MESA:



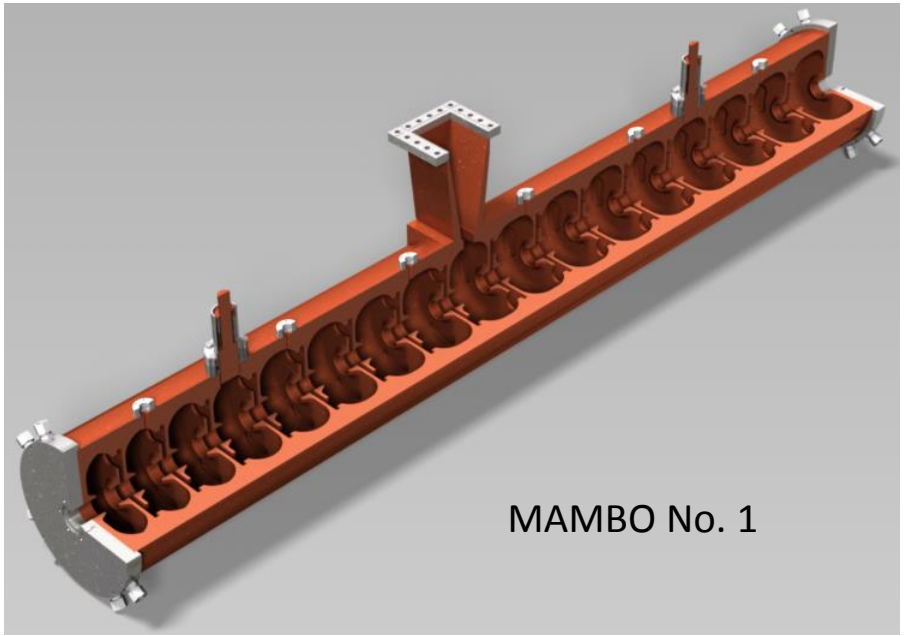
Drawing by D. Simon, KPH

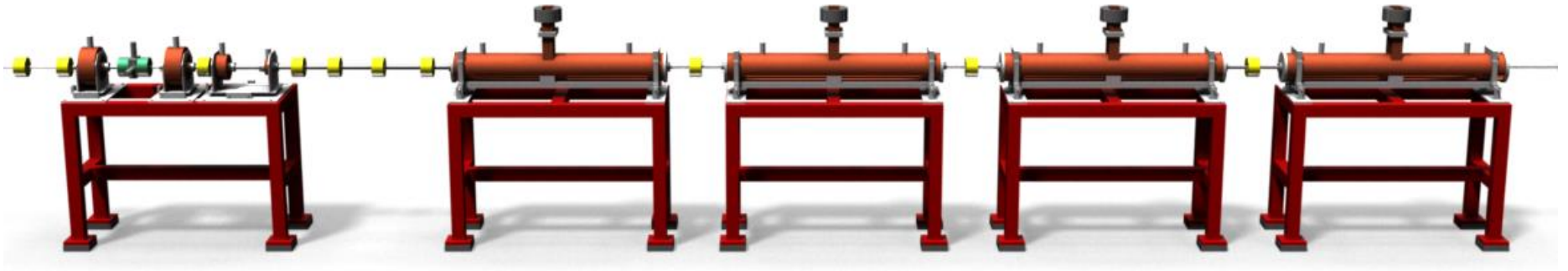
MESA RF system

- RF frequency: 1.3 GHz
- RF structures:
  - MAMBO (MilliAMpereBOoster):
    - standing wave $\pi/2$
    - on axis coupled bi-periodic
  - MEEC (MESA Enhanced ELBE Cryomodule)
    - standing wave π
    - TESLA type
- Type of operation: CW, 100% duty cycle

MAMBO

- MAMBO No. 1: graded β
- MAMBO No. 2: β=0.977
- MAMBO No. 3: β=1
- MAMBO No. 4: β=1

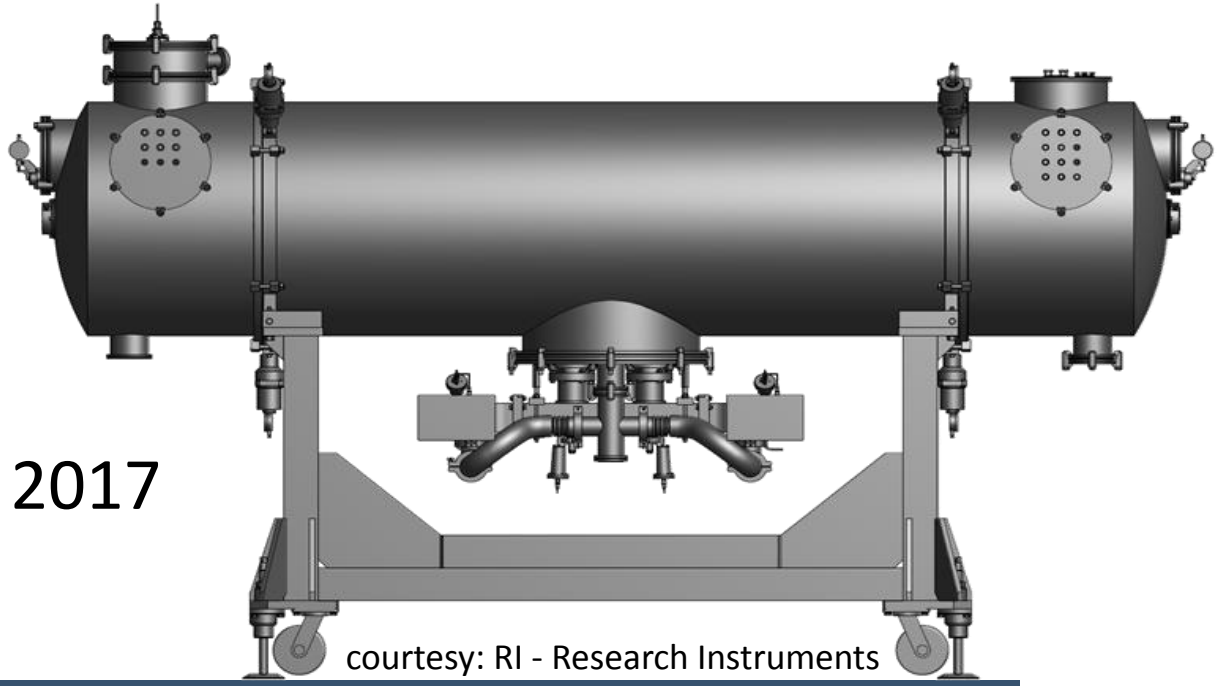




Chopper & Buncher | MAMBO No. 1 | MAMBO No. 2 | MAMBO No. 3 | MAMBO No. 4

2x ELBE Rossendorf type with some modifications to be delivered by RI :

- Tuners with piezo elements (XFEL/Saclay)
  → alteration of LHe tank and 2K phase separator
- Sapphire feedthrough at HOM damper
- 4K/2K cold box



courtesy: RI - Research Instruments

Expected delivery:
spring and summer 2017

MESA RF system

Estimated RF power consumption:

$$P_c + P_{beam} + P_{loss}$$

- MAMBO:
  - graded β section: 87 kW
  - const. β sections: 56 kW

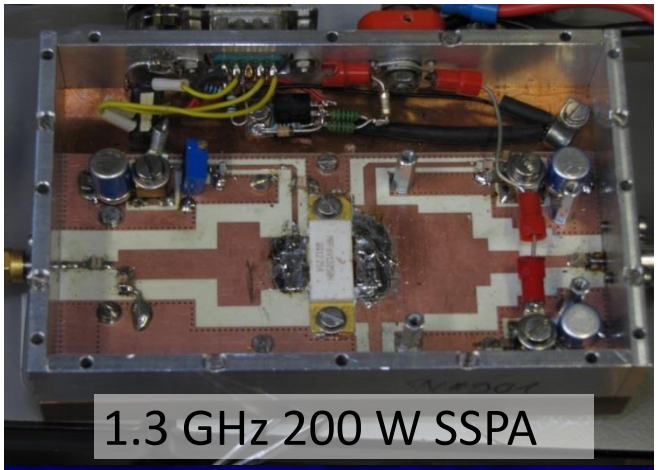
- MEEC:
  - external beam mode: 15 kW/cavity

Power generation: Why we choose SSPA?

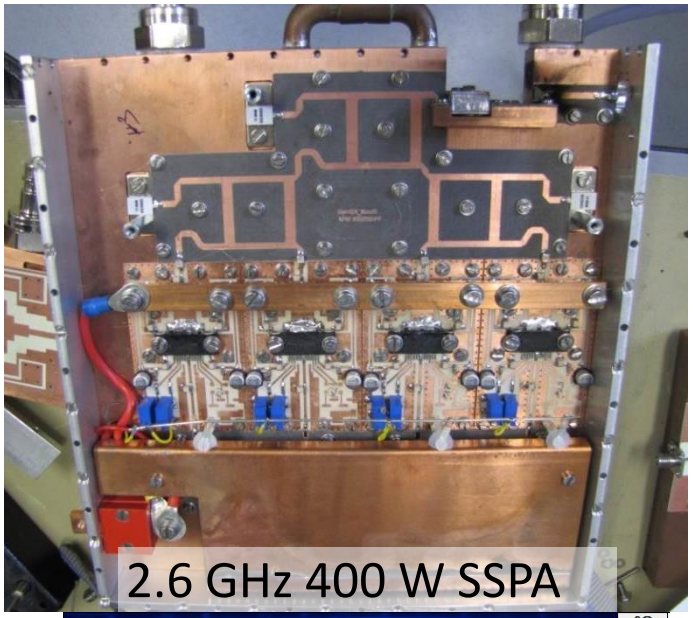
- High availability of beam is needed
  - a broken klystron means 1-2 days downtime
  - modular SSPA are more tolerant to a transistor failure
- No more tubes in 10 kW range on the market
- No “fitting” tubes for MAMBO
  - either too much power per section
  - or ILAC like power splitting (not desirable)
- SSPA is scalable → use of same technology for MAMBO and MEECs sensible.
- Cheapest solution according to total invest (for us)

MESA RF system

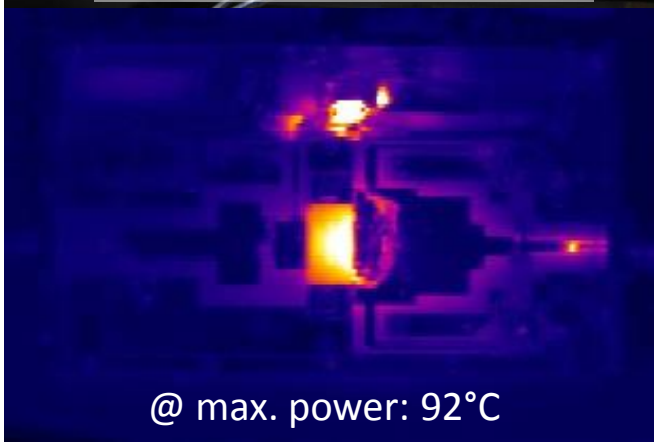
SSPA for low power applications (chopper & buncher) made in house



1.3 GHz 200 W SSPA

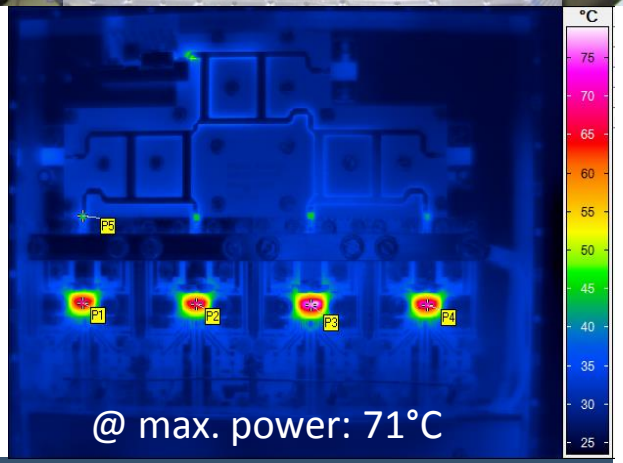


2.6 GHz 400 W SSPA



@ max. power: 92°C

F. Fichtner



@ max. power: 71°C

15 kW RF SSPA prototype

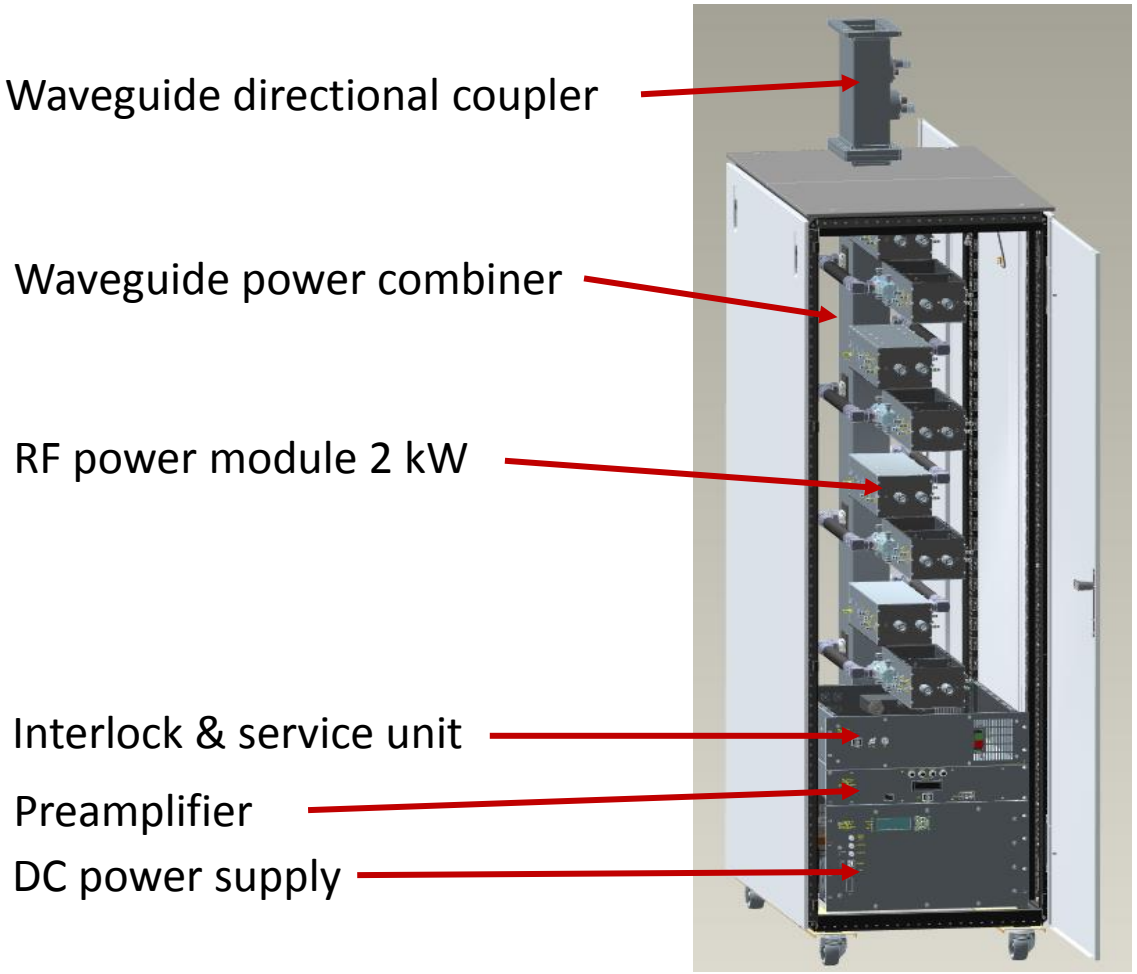
- 10.11.2015 Call for tender
- 05.01.2016 Deadline for bids
- 01.02.2016 Awarded to SigmaPhi, Haguenau

Mile stones of development:

- 24.02.2016 Kick off meeting at Mainz ✓
- April 2016 Preliminary Design Review (pending)
- July 2016 Final Design Review
- 10/2016 Factory acceptance test
- 12/2016 Shipment to Mainz

MESA RF system

- Mechanical construction and power combining of 15 kW RF power amplifier



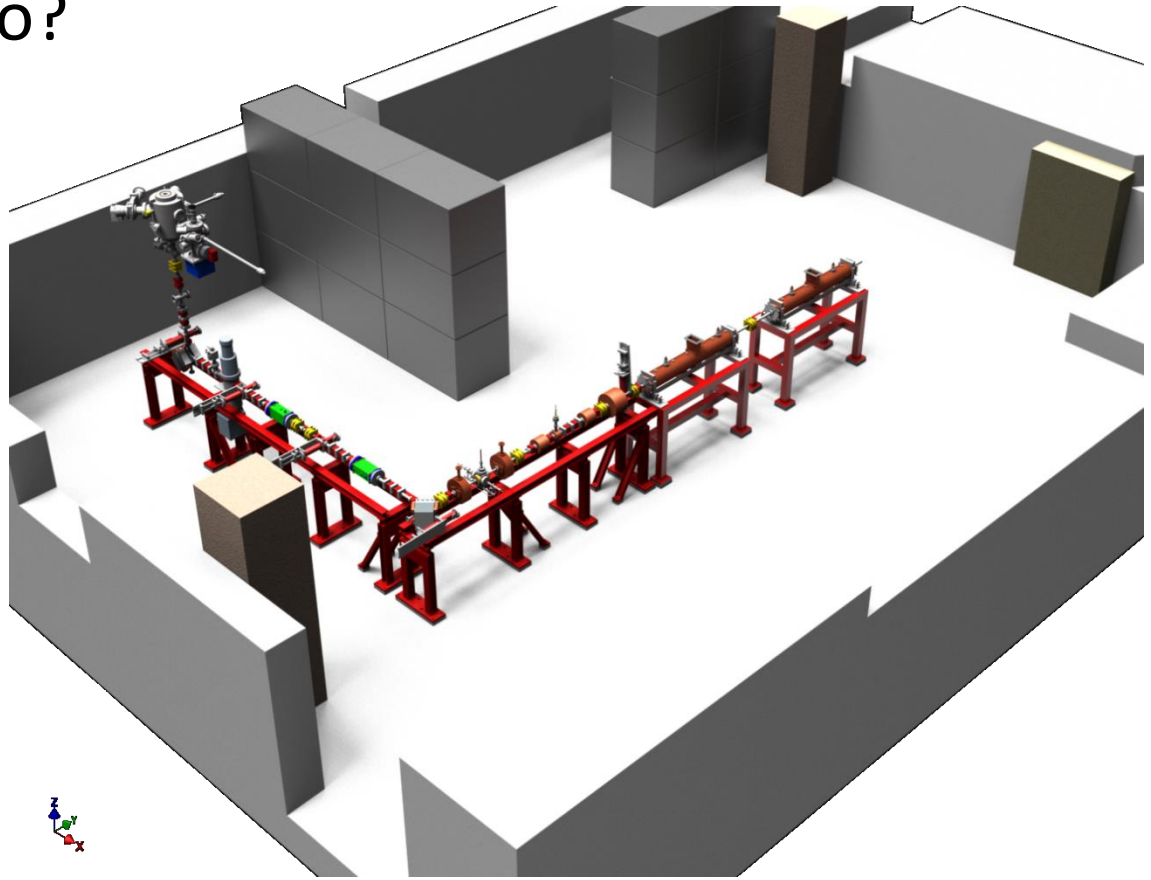
courtesy: SigmaPhi

Plans for the future?

Civil construction works for MESA will not be finished before 2020, what to do?

Build a test facility for:

- Gun
- Spin rotator
- Chopper & Buncher
- MAMBO No. 1&2

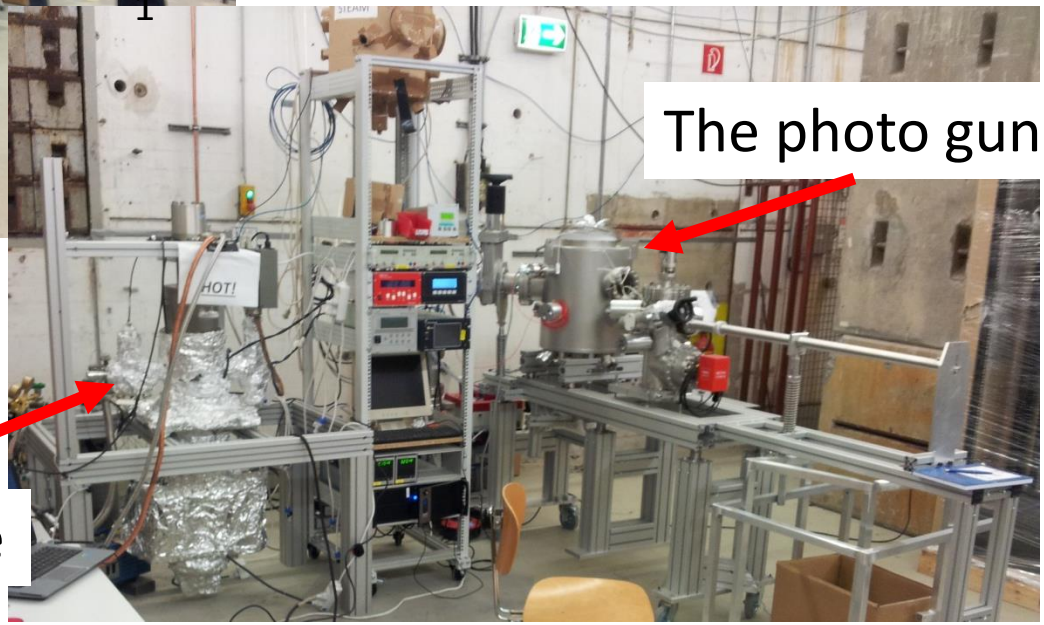


Gun is currently set up,

start of testing planned for July.

In the making...

Status of June 16th 2016



The photo gun

Differential pumping stage

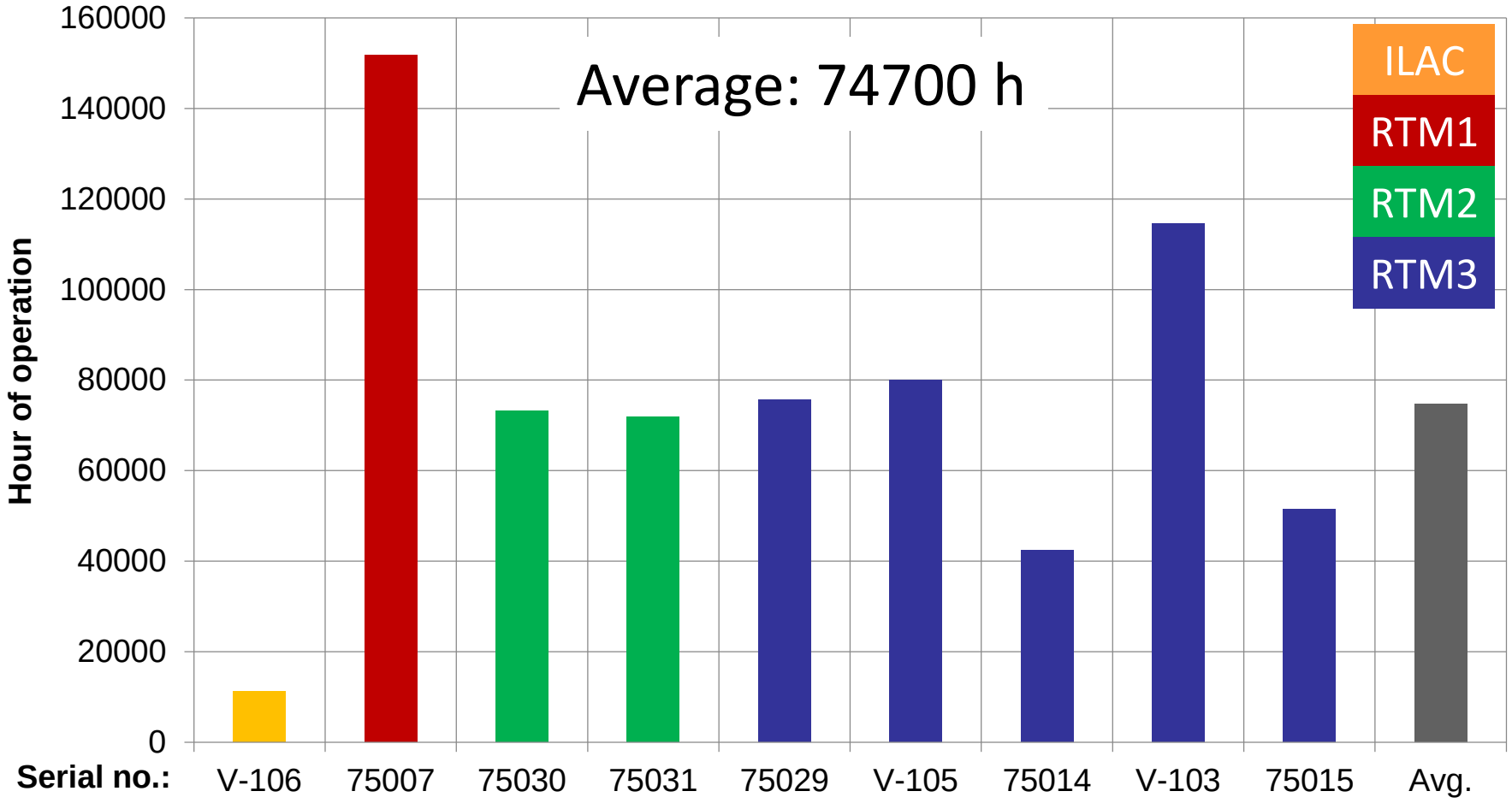
Summary

- MAMI is in parts older than 30 years, but still very reliable
- Besides some aging effects the RF system is without problems
- The experience gained is transferred to MESA
- MESA is introducing new technologies to KPH such as SRF and solid state RF amplifiers
- Key components of MESA are ordered/in production
- A test facility is currently set up

Backup slides

ILAC and RTM klystrons

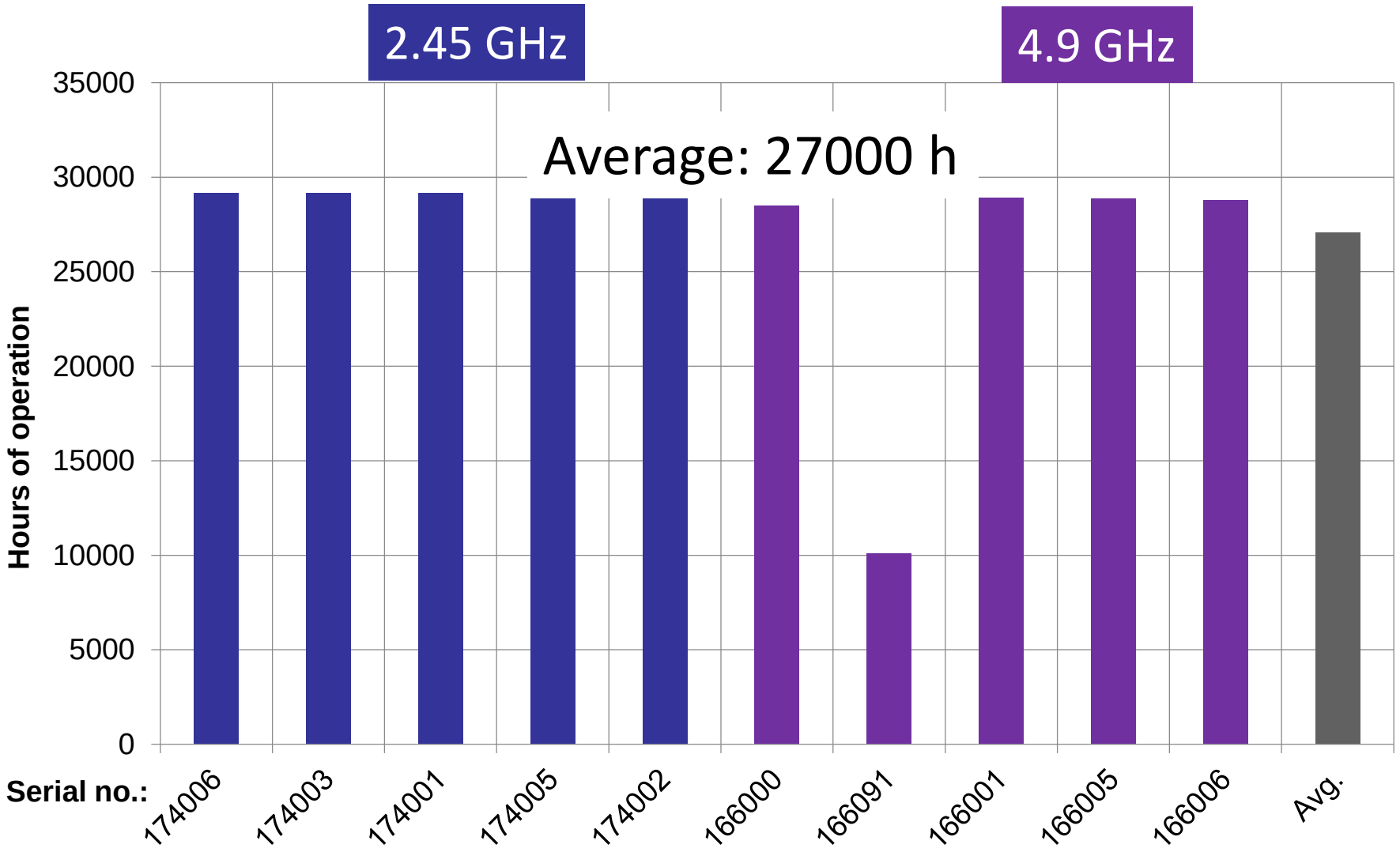
MAMI A/B: 9x 2.45 GHz klystrons in operation



Serial no.: V-1nn= CPI VKS 7960 M, 75nnn= TH 2075

Status of Jan. 04. 2016
source: A. Nuck, KPH

HDSM klystrons

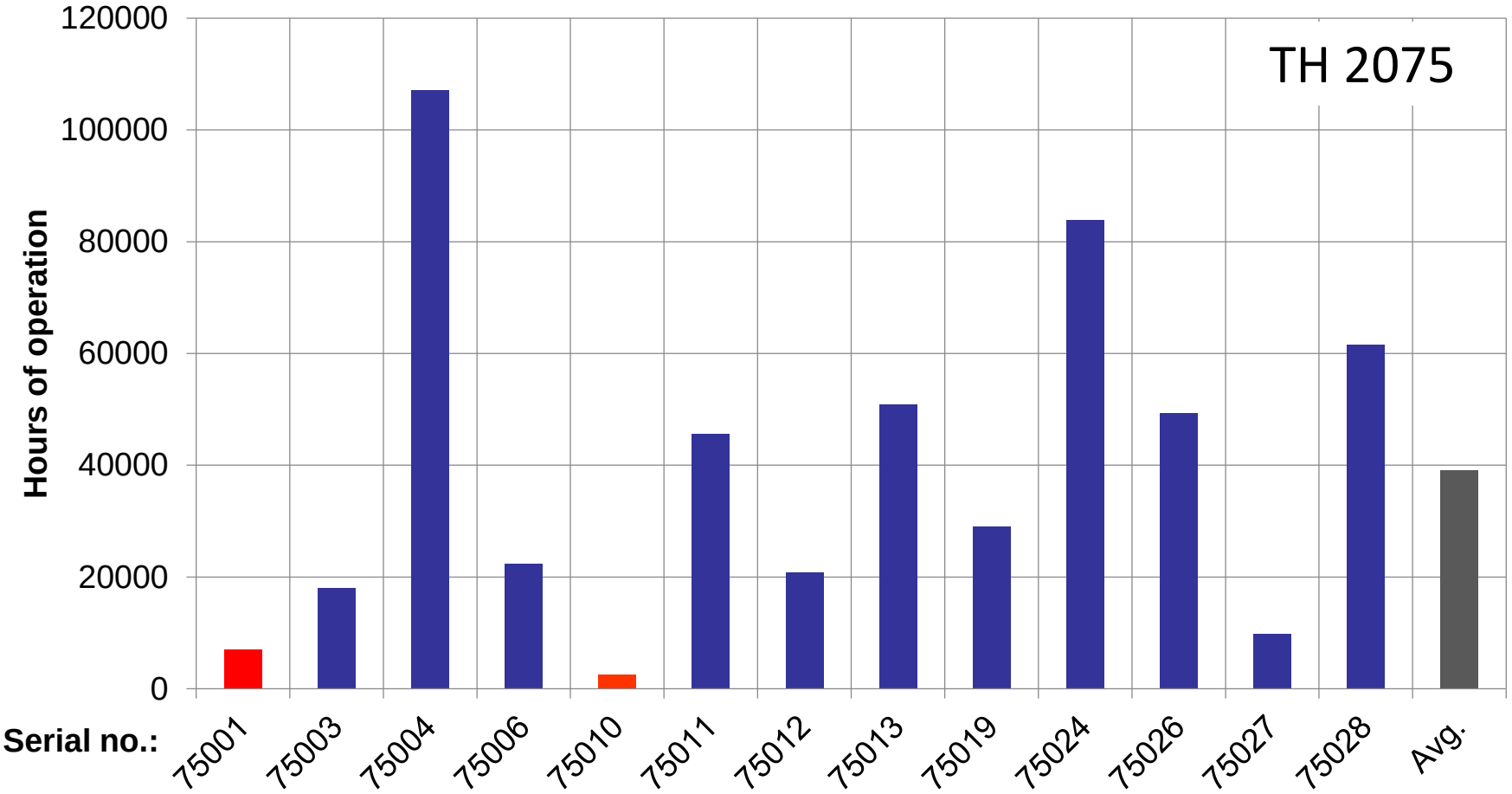


174nnn= TH 2174, 166nnn= TH 2166

Status of Jan. 04. 2016
source: A. Nuck, KPH

End of life of klystrons

- Average EOL: (45326 ±28628) h (1978-2009)
- Main reason for EOL: multipacting and vacuum leakage



red: tubes destroyed by a malfunction of RTM1 HVPS in 1991

Status of Jan. 04. 2016
source: A. Nuck, KPH

MAMBO section data

RF – section	L [mm]	$\langle R_s \rangle$ [MΩ]	$\langle R_s/L \rangle$ [MΩ/m]	Q_0	P_{diss} @ 1MV/m [kW]
1	1658	49.5	28.86	21500	55.5
2	1689.5	90.2	53.39	23600	31.6
3 & 4	1729.5	93.3	53.95	24000	32.1

Beam loading:

- No. 1: 11.5 kW
- No. 2-4: 12.5 kW

Transmission line losses approx. 1 dB

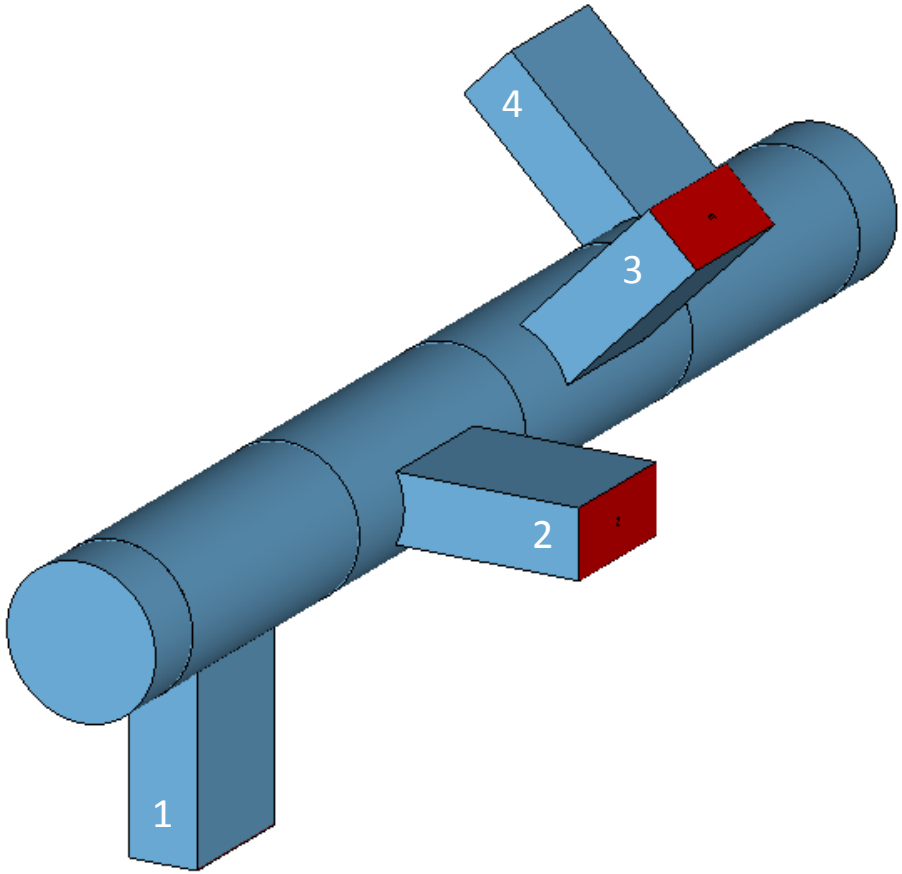
→ P_{gen} (No. 1) = 87 kW

→ P_{gen} (No. 2-4)= 56 kW

RF budget estimation & comparison

RF – solution:	Klystron 270 kW	IOT 4x 100 kW	SSPA 258 kW
Amplifier	470 k€	920 k€	1720 k€
HVPS	520 k€	1000 k€	included
Drive PA	-	175 k€	-
Foc. magnet PS	40 k€	40 k€	-
Spare	470 k€	230 k€	25 k€
Waveguide & components	912 k€	632 k€	632 k€
Sum	2412 k€	2997 k€	2377 k€
overall costs:	8,93 €/W	7,49 €/W	9,21 €/W
costs w/o spares and WG:	3,67 €/W	5,20 €/W	6,67 €/W

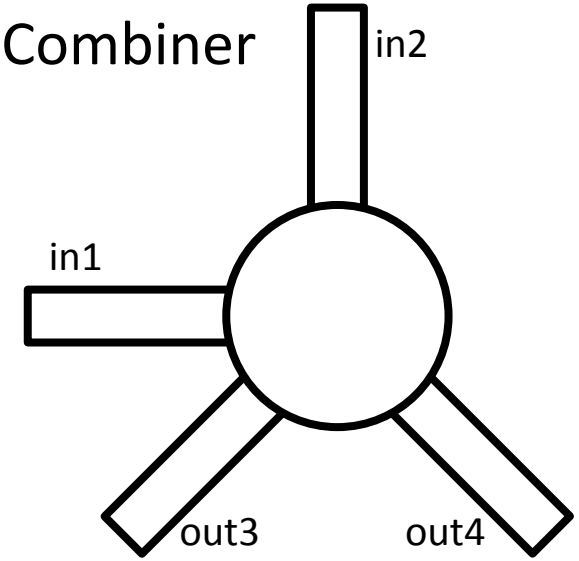
ILAC Combining



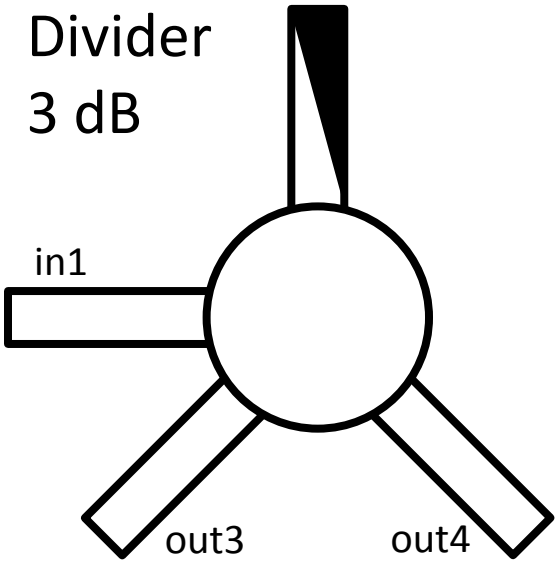
according to: CMT Segment, drawing no. 612, U. Reiss, KPH, 1986

ILAC Combining

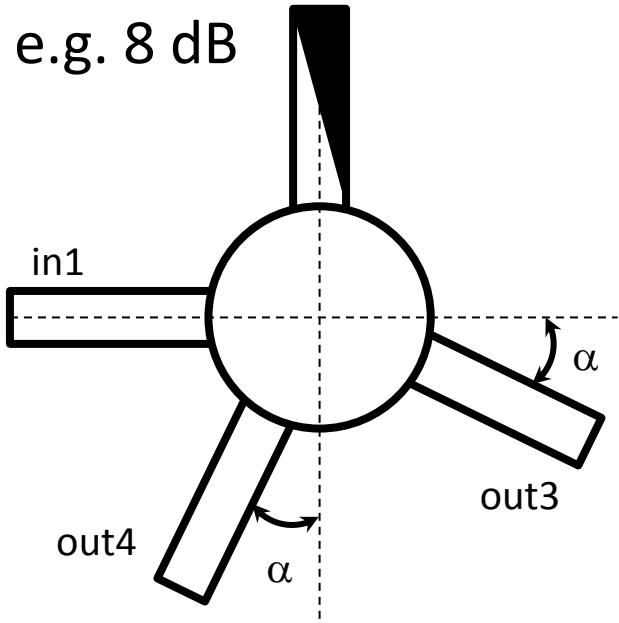
Combiner



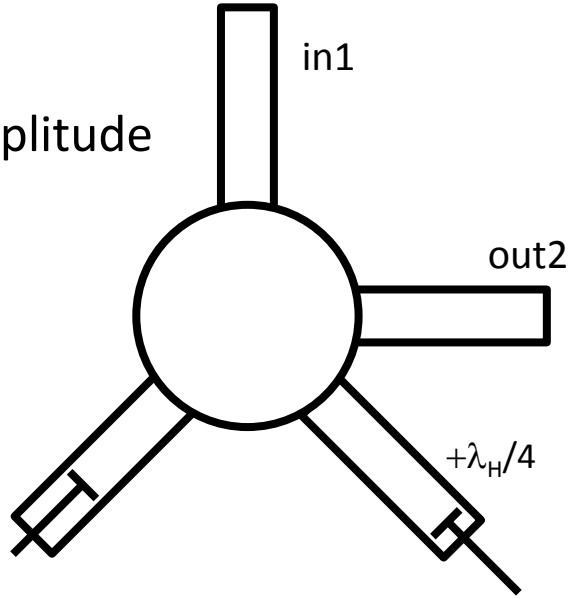
Divider
3 dB



e.g. 8 dB



Phase/Amplitude shifter



$\kappa = in/out4 = 10^{-0.8} = 0.158$

$\kappa = \sin^2 \alpha$

$\Rightarrow \alpha = 23.5°$

Internal Report MAMI 7/88

ILAC Combining