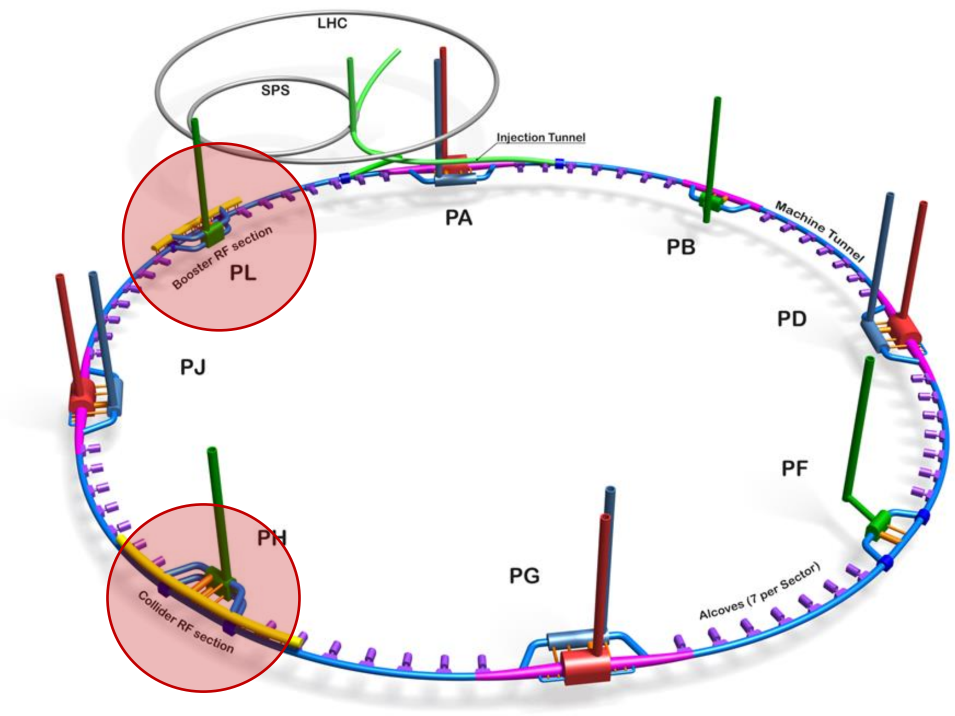
(S)RF for FCC, status and outlook



SY FCC Workshop
October, 2024

O. Brunner, on behalf of the FCC SRF WP

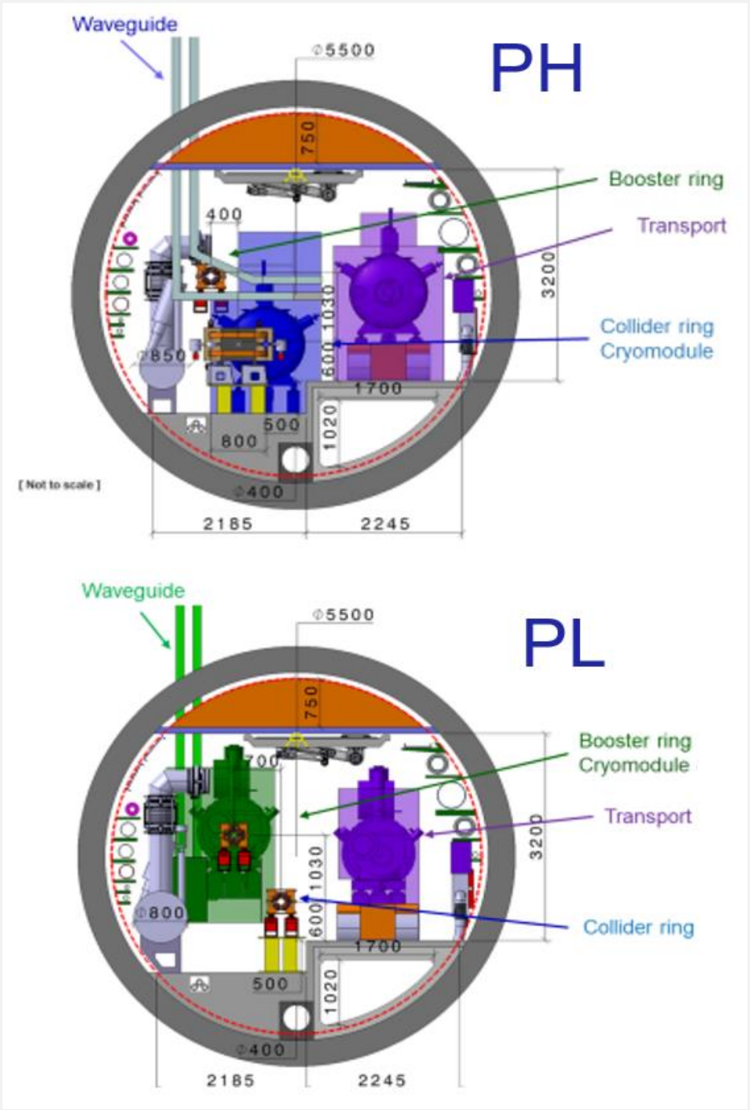
High level RF requirements

	Energy (GeV)	Current (mA)	RF voltage (GV)
Z	45.6	1280	0.080
W	80	135	1.05
H	120	26.7	2.1
ttb	182.5	5	11.3

High current machine

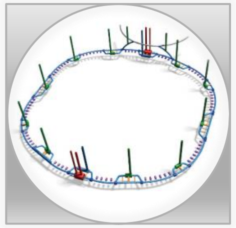
High gradient machine

- Collider (2 rings): 100 MW of RF power in CW (50 MW per ring) to compensate synchrotron radiation losses
- Booster (3rd ring) for top-up injection: to accelerate from 20 GeV to the final energy with 10% beam current and 15% average duty cycle
- *Injector complex (see A. Grudiev 's presentation)*
- Availability in operation of 80%



Courtesy, F. Valchkova, CERN

FCC SRF Program (phase 2)



Coordination, parameters and design

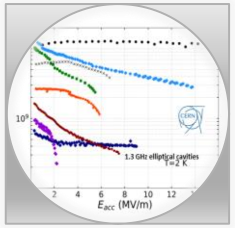
- Coordination and review
- Challenge the operational scenarios (timeline, cost,..)

Cavity Studies & Beam Dynamics

- Determine the cavity design for each FCC machines.
- Validate the HOM damping schemes
- Carry out the beam-cavity interactions studies
- Evaluate the cavity control system (LLRF) challenges

Cavity Engineering & Fabrication

- Push the limits of fabrication technologies: seamless, internal welding, precision machining, 3D printing (?)
- Built a cavity for Z machine



SRF & Substrate Preparation

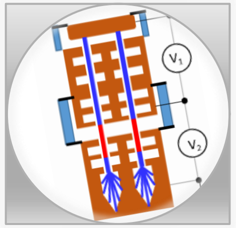
- Establish the limits of surface preparation and Nb coatings
- Optimize HIPIMS coatings using 1.3 GHz seamless cavities
- Pursue exploration of A15
- Prepare and validate a cavity for Z machine

Cryomodule Development

- Develop a test bed for new cavity, FPC and CM technologies
- re-assess generic CM challenges: thermal performances, magnetic shielding, cavity & FPC support,…
- study HOM power extraction schemes for Z machine
- define feasibility of 2K and 4.5 K operation (SWELL)
- built a CM mockup to validate cavity for Z machine

FPC & HOM Couplers

- Push the limits of FPC performances
- Towards 1 MW (baseline)
- Towards large adaptability (SWELL, baseline)
- HOMC mechanical design & production



High power RF Systems

- Challenge RF power systems and power distribution schemes
- Demonstrate HE two stage technology (baseline)
- Evaluate alternative technologies (SWELL, baseline)

-- modifications / upgrade underway for "phase 3" --

Main RF parameters and layout

	Z		W		H		ttb		
	collider	booster	collider	booster	collider	booster	collider	collider	booster
RF Frequency [MHz]	400.79	801.58	400.79	801.58	400.79	801.58	400.79	800.79	801.58
Cavity type	1-cell	5-cell	2-cell	5-cell	2-cell	5-cell	2-cell	5-cell	5-cell
Eacc [MV/m]	3.77	10.7	10.1	15.35	10.6	19.4	10.6	20.1	20.1
Q0	2.7E+09	3.0E+10	2.7E+09	3.0E+10	2.7E+09	3.0E+10	2.7E+09	3.0E+10	3.0E+10
Epk [MV/m]	8.3	22	20.2	31.5	21.2	39.8	21.3	41.3	41.3
Bpk [mT]	20.2	46.3	54	66.5	56.4	84.1	56.7	87.3	87.3
Beam current [mA]	1283	14.3	135	11.8	53.6	2	10	10	0.3
RF power [kW]	894	110	377	144	378	32	78	163	5
Optimum QL	2.5E+04	1.7E+06	8.4E+05	2.7E+06	9.2E+05	2E+07	4.5E+06	4.2E+06	1.3E+08
Optimum detuning [Hz]	13884	191	601	90	112	11	9	56	1.4
Operating temp. [K]	4.5	2	4.5	2	4.5	2	4.5	2	2
dyn losses/cav [W]	8	2.3	117	4	128	9	129	23	20
# CM (with 4 cav/CM)	14 per beam	2	33 per beam	7	66	27	66	122	135

3 cavity types

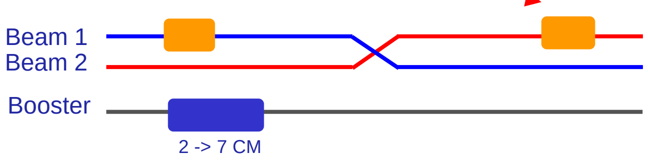
Very high -> low RF power

Large range of Q_{ext}

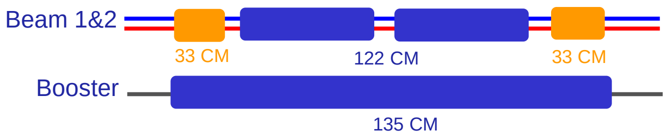
High gradients

Several hundreds of cavities and CM

Courtesy, F. Peauger



one RF system per beam

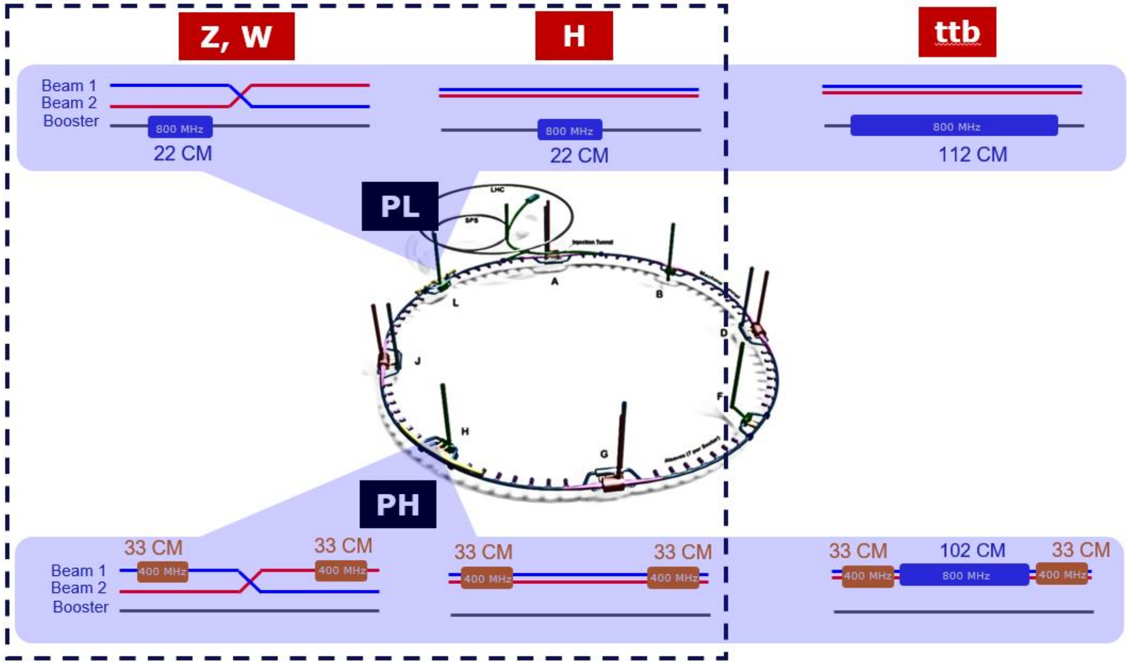


common RF system for both beams

-- Dedicated RF system for Z + massive upgrades (CM gymnastics + RF power distribution) --

-- Solid but tedious scenario --
-- Is there any room for improvement ?? --

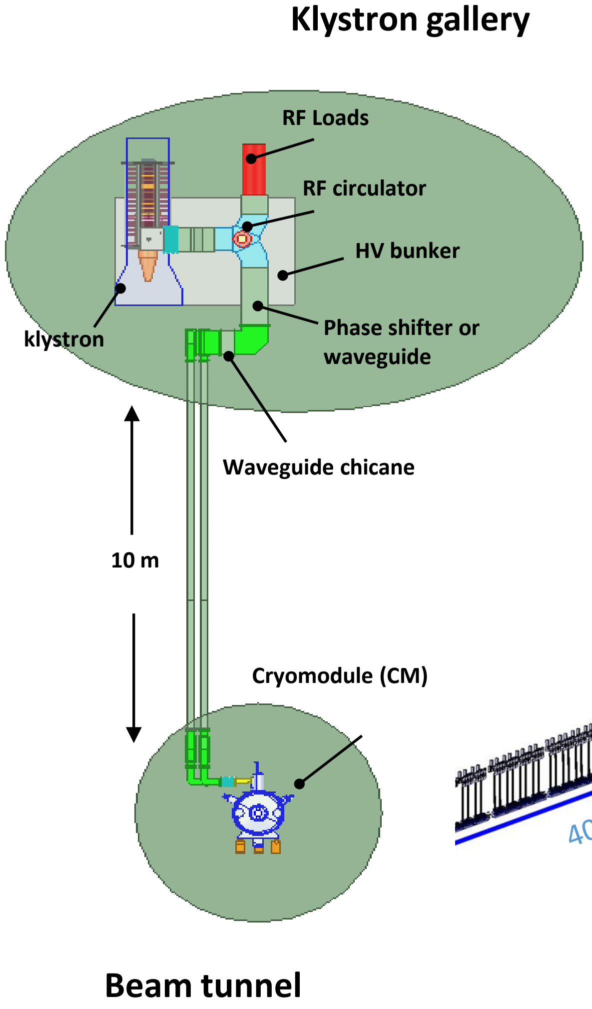
The dream scenario: (Z-W-ZH) - ttbar

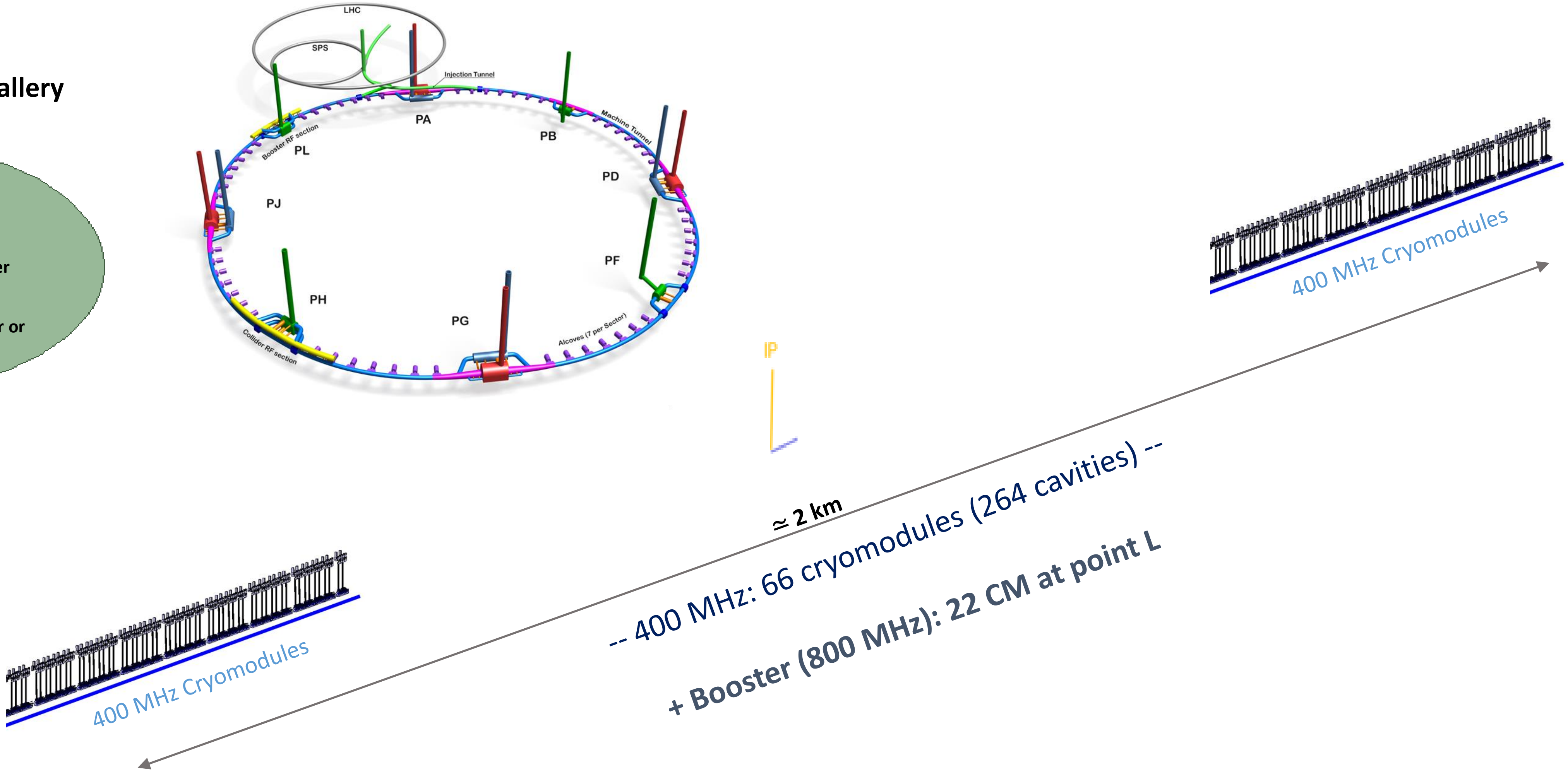


- **Increase the "real estate" gradient of the 800 MHz RF system (booster and ttbar)** → 5 to 6 cells per cavity ?
- **Optimize the design and the use of high efficiency (HE) RF power sources** → HE across a wide range of RF power levels ?
- **Single RF system for Z-W-ZH** → 400 MHz 2_cells cavities compatible with a common operating point ? → see I. Karpov / F. Peauger' s presentation

-- more operation time + more flexibility – reduced commissioning effort --

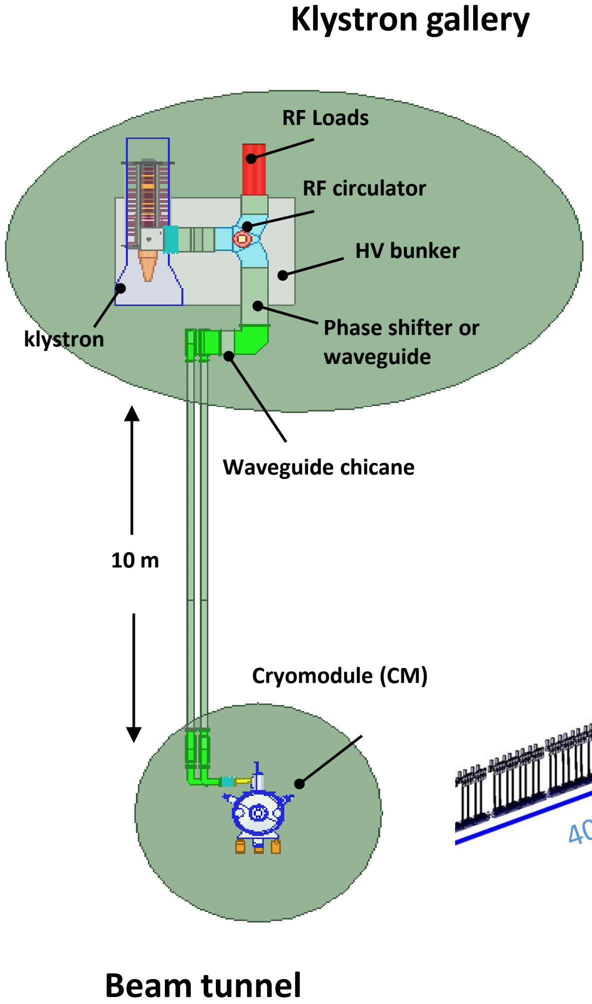
RF system integration (point H)

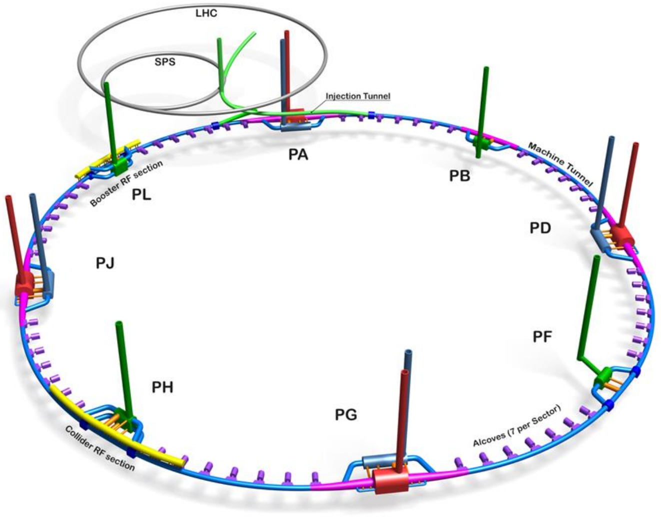


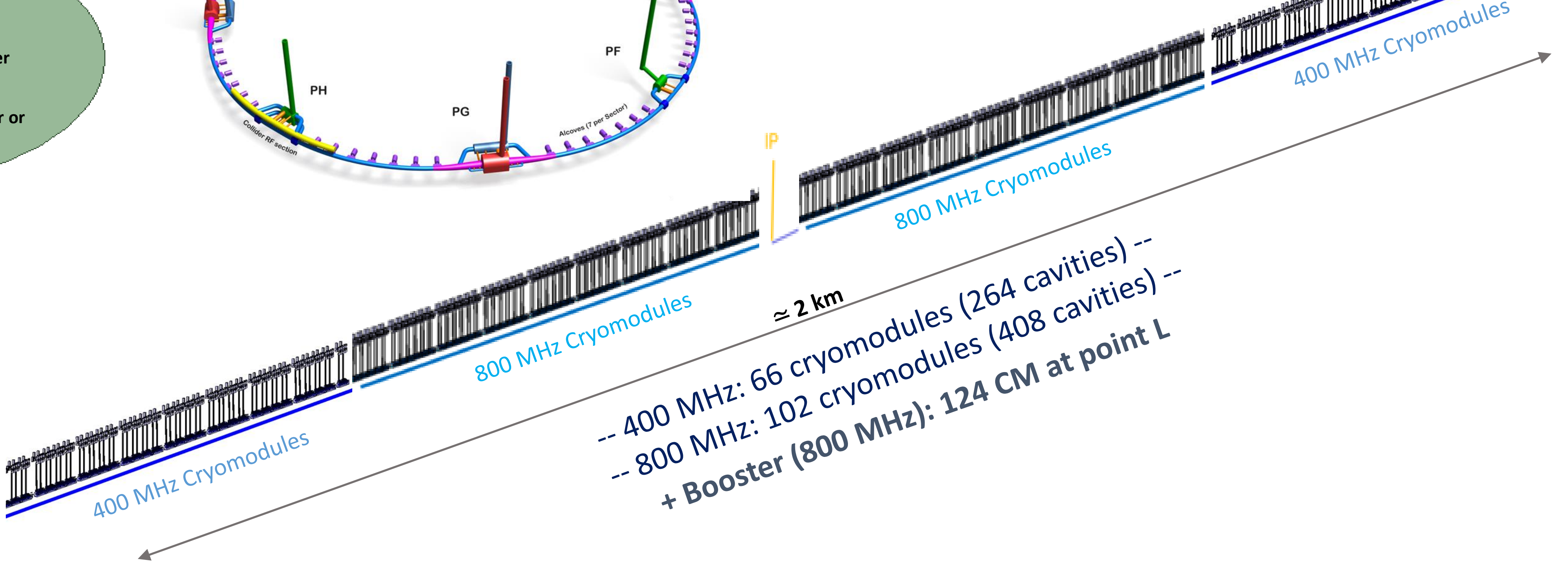


-- complex integration work --

RF system integration (point H)

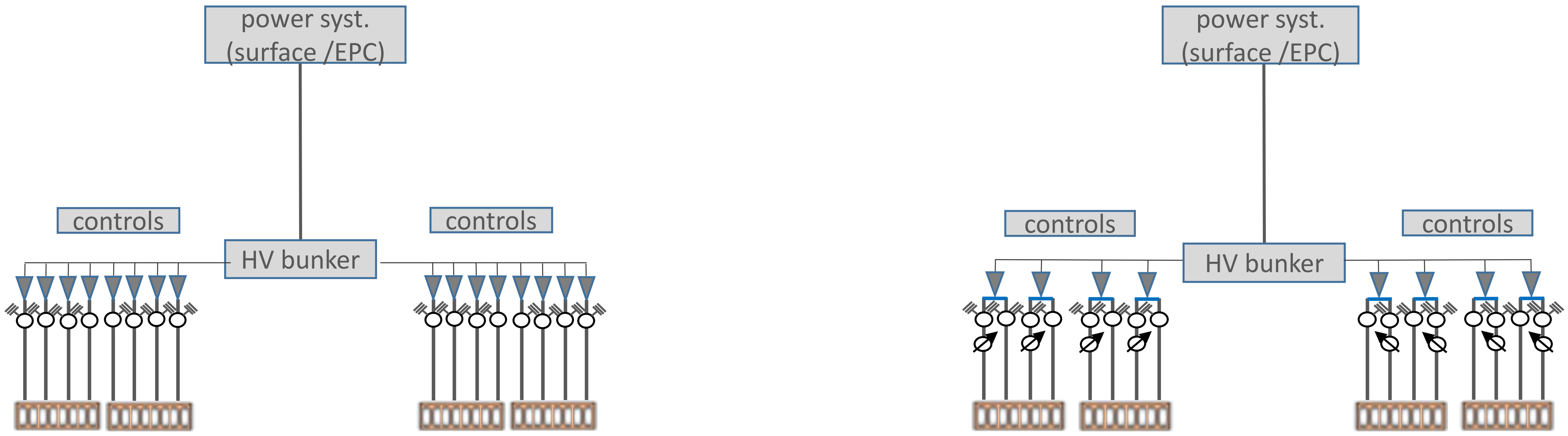






-- RF system length ~ LLS → effort on CM length and E_{acc} --

400 MHz RF units' principle: (Z, W, ZH -- ttbar)



Z, W & ZH

- **~400 kW per cavity**
- 500 KW TS klystrons
- 1 cavities per klystron + strong feedback per cavity

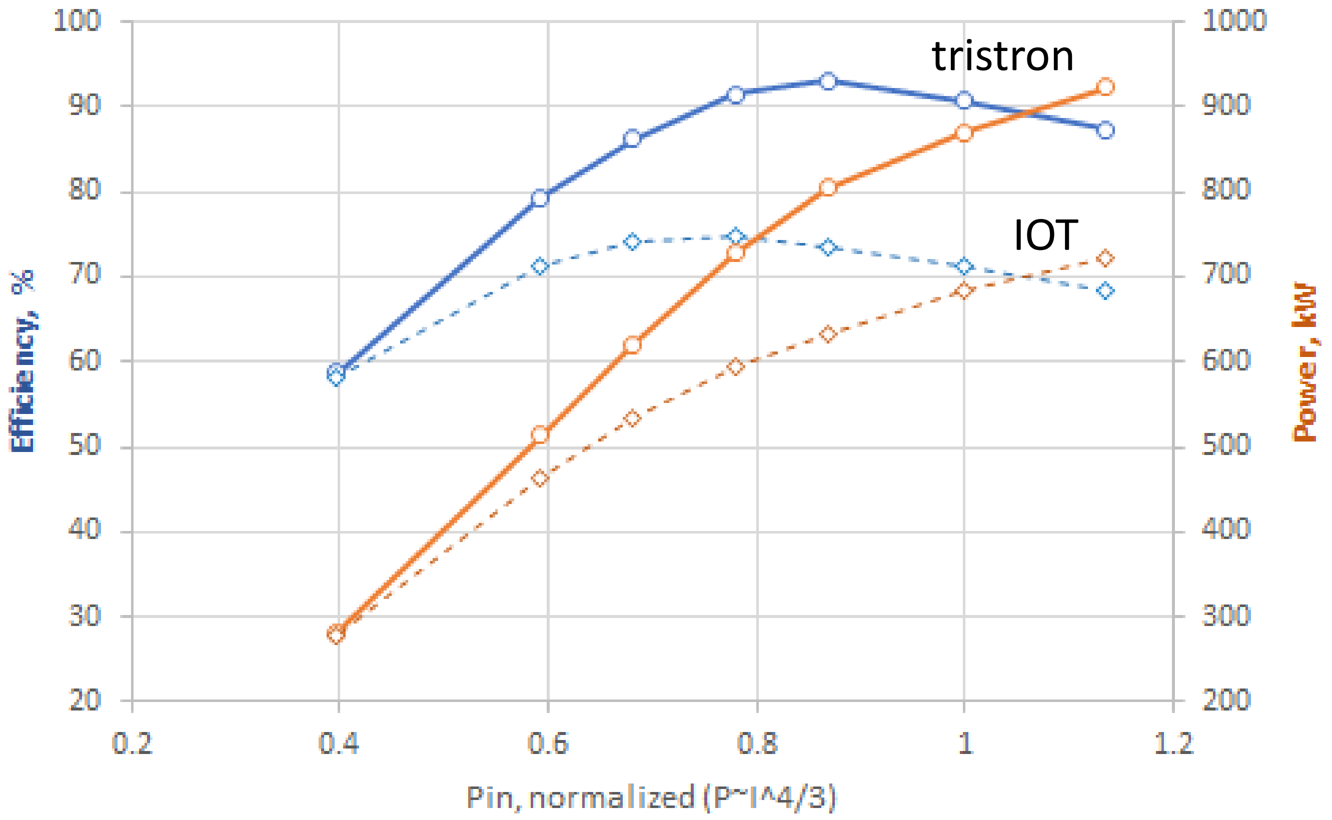
ttbar

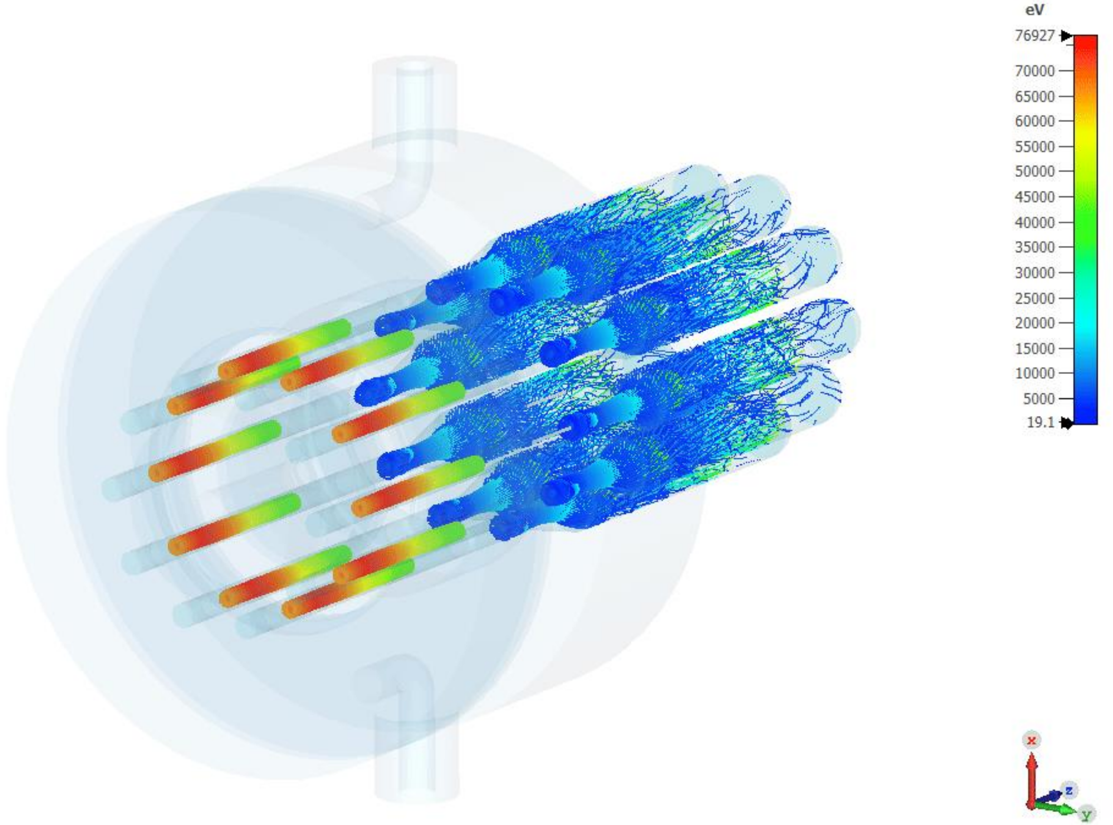
- **~ 80 kW per cavity**
- 500 kW TS klystron → 132 spare klystrons
- 2 cavities per klystron
- + magic T + phase shifters

-- high-efficiency RF source across a wide power range would avoid any modification for ttbar --
(also highly desired for the 800 MHz system)

Tristron: the ultimate RF power source !(?)

B class (180 degrees bunches)
V beam=60kV

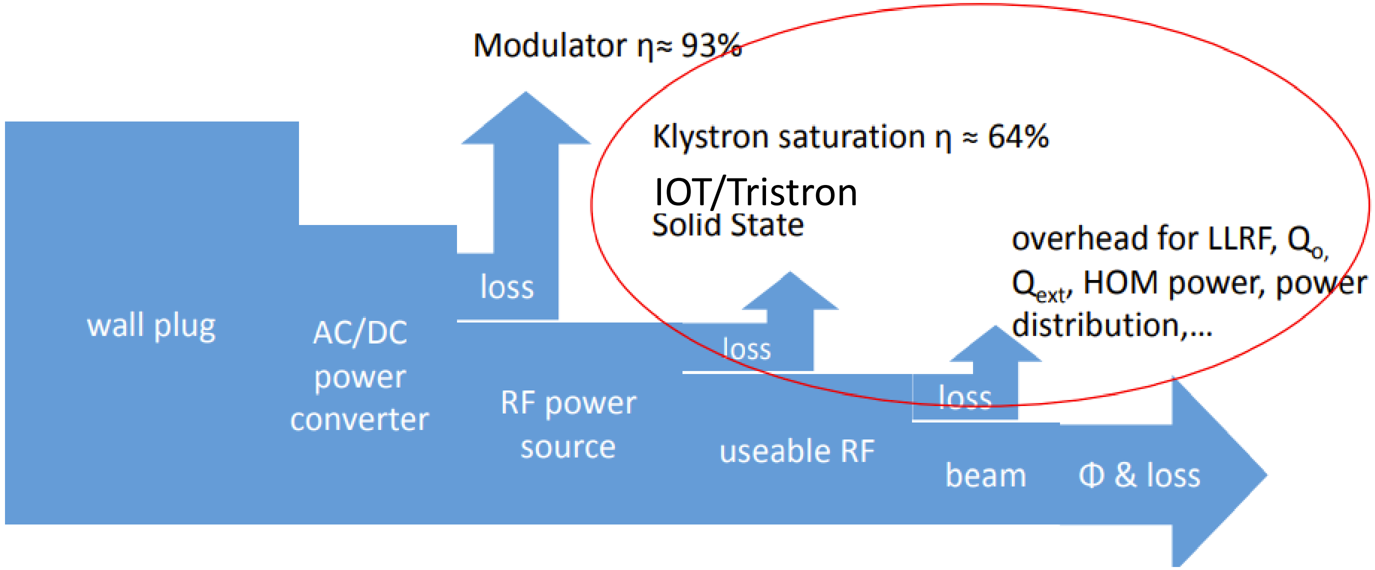




See I. Syratchev 's presentation

-- compact, highly efficient, reliable, low power consumption in standby, large power range, *'low' cost*--

The whole system must be optimized – not one efficiency alone

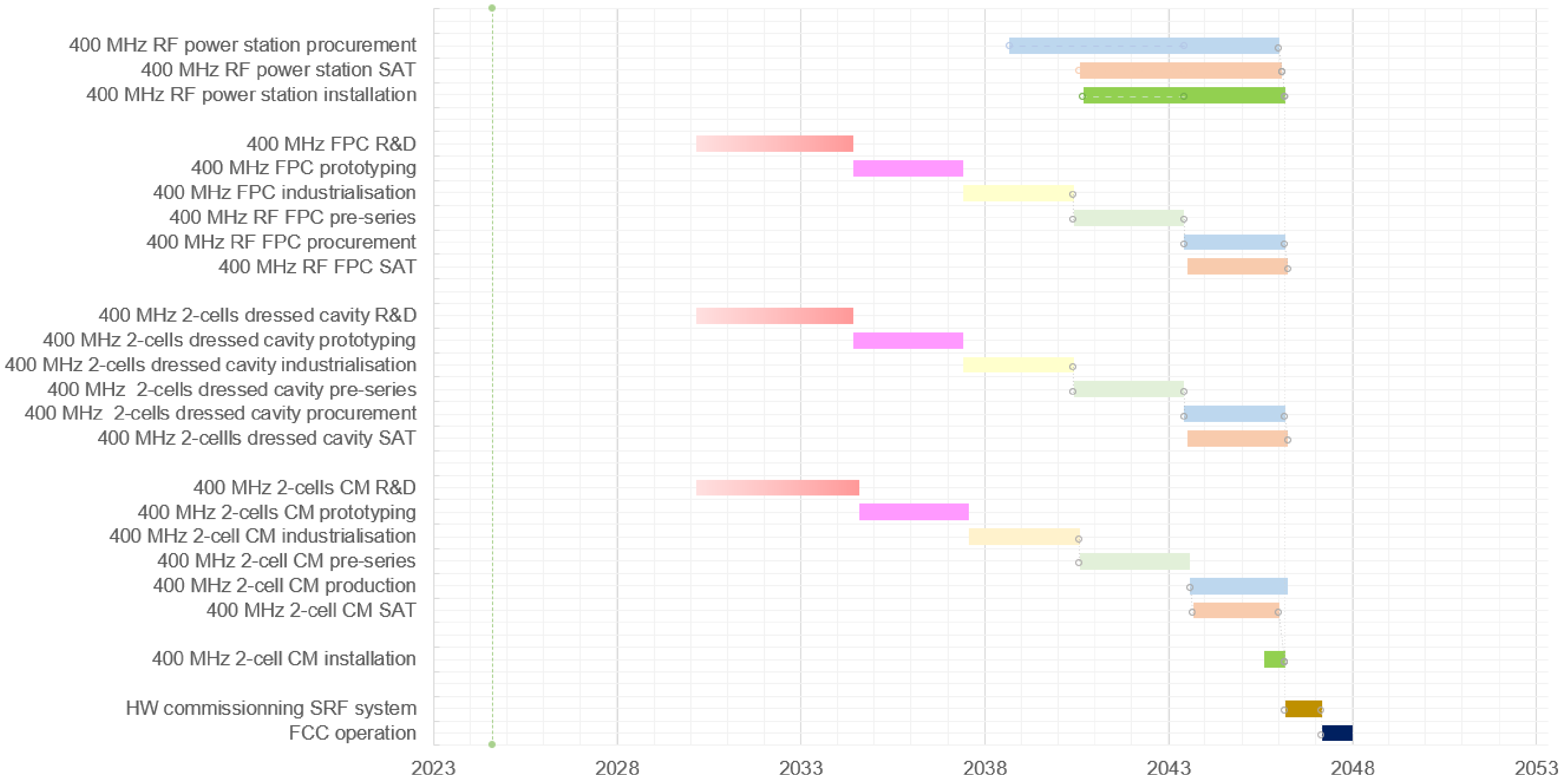


From E. Jensen -EnEfficient RF Sources, The Cockcroft Institute, 3-4 June 2014

- Beam dynamics / controls
- RF power generation / distribution
- Accelerating cavities performances
- Cryomodule design
- RF couplers (HOM, FPC)
- Production, logistics
- Operational aspects (reliability, ..)

-- FCC_ee opens a broad range of R&D challenges in RF --

Top-down plan (here 400 MHz only)



-- tight schedule + “short” R&D period --

Thank you for your attention!