Introduction: potential for gradient, current, or energy increase

Frank Gerigk, CERN,
Upgrading Existing High Power Proton Linacs,
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Content

Increased power

can be obtained by:

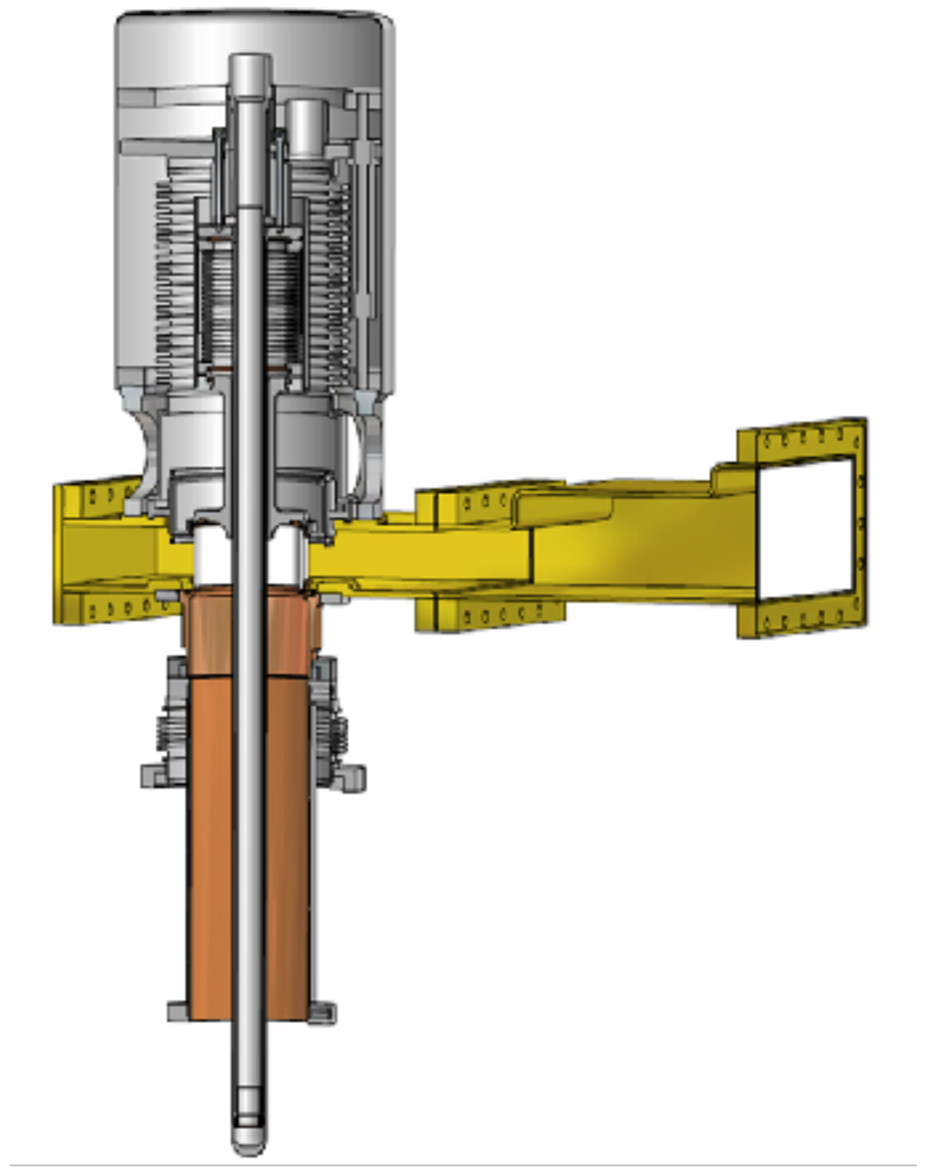
\# Raising the **current**

\# Raising the **energy**

\# Raising the cavity **gradient**

\# Raising the repetition rate

\# Raising the pulse length

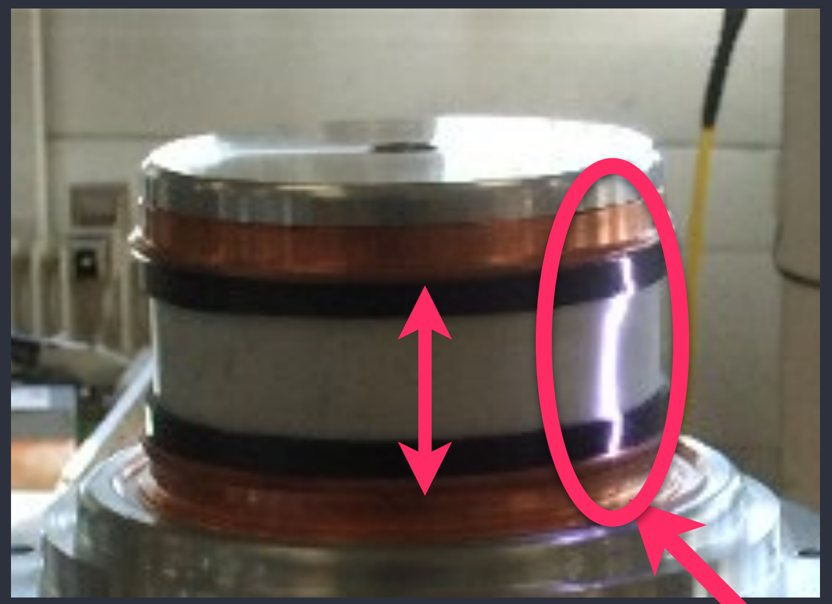


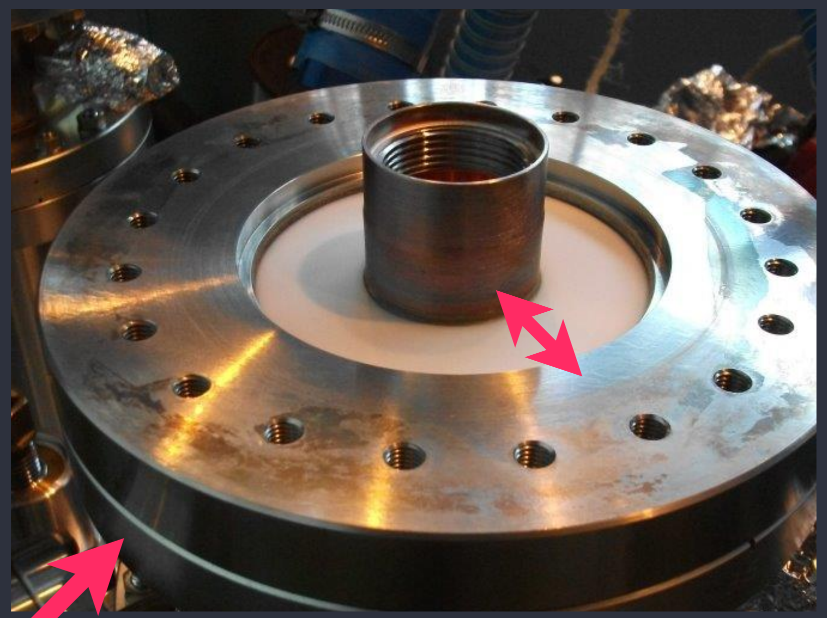
power coupler limitations

Power coupler

Peak power and average power

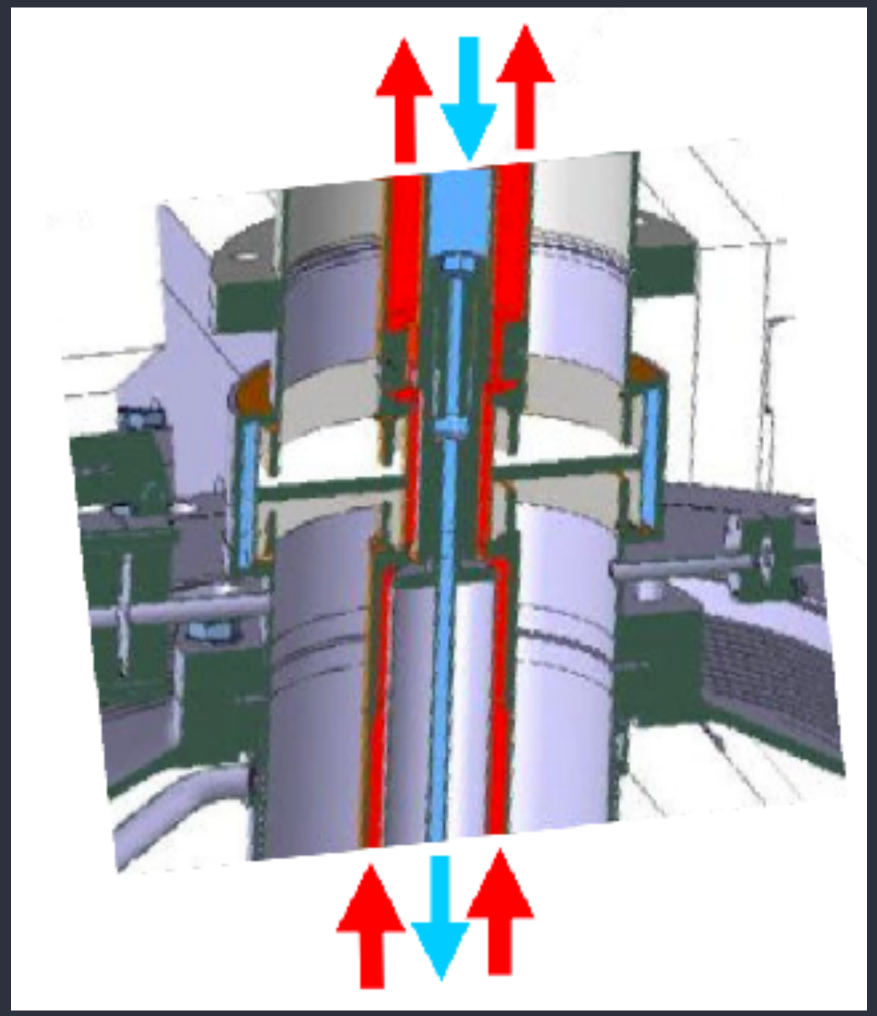
PEAK Power limit





Given by the distance between rings (coaxial couplers) or between inner and outer conductor due to surface flashover rating. Peak power of any given coupler design has a strict limit. Few couplers have exceeded 1 MW.

AVERAGE Power limit

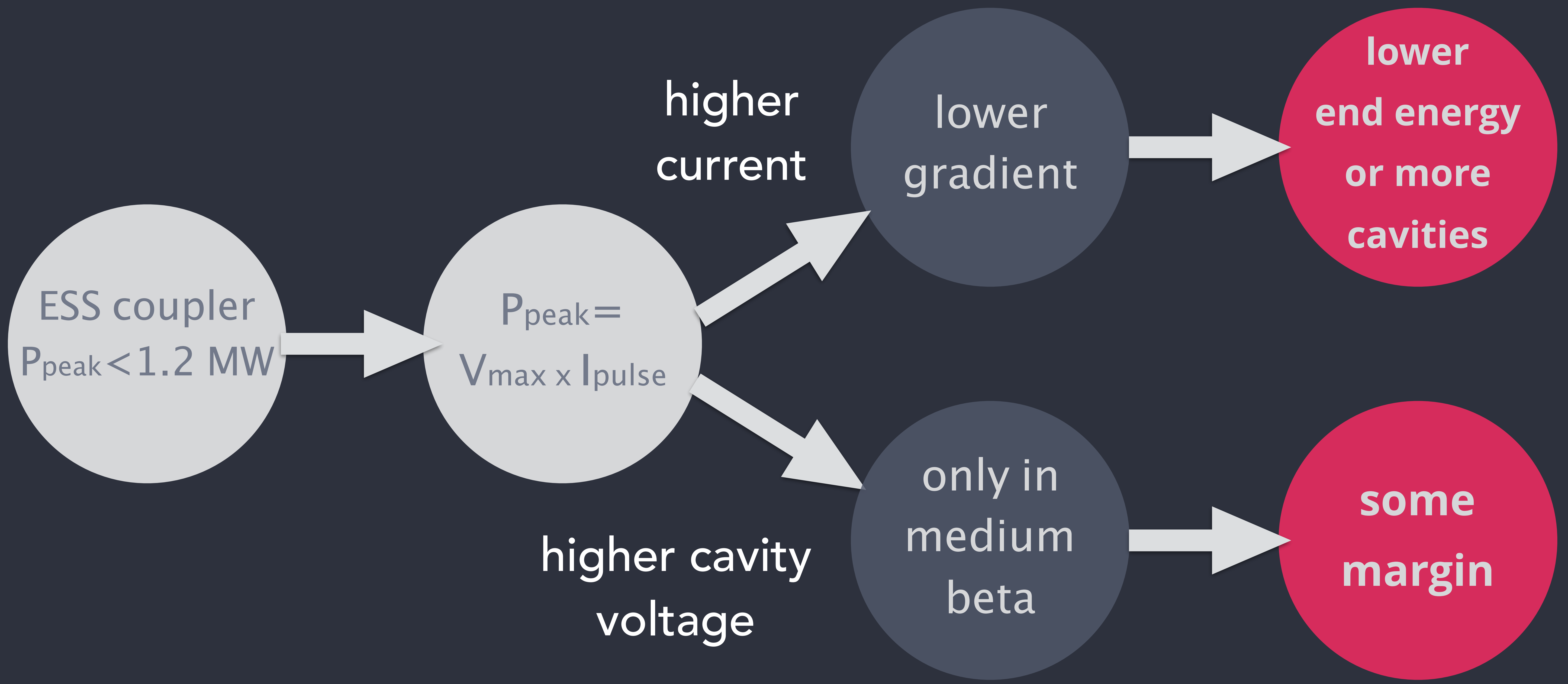


E.g: water flow through inner conductor of ESS coupler

Given by the cooling capacity of the coupler and is in general more flexible. Average power of up to 1 MW (APT) has been demonstrated. ESS coupler designed for up to 120 kW

Power coupler

Peak power



ESS coupler	E_{acc}	beta	cells	P_{peak}	margin
high beta	19.9 MV/m	0.86	5	1.14 MW	5%
medium beta	16.7 MV/m	0.67	6	0.9 MW	25%

close to design limit!

only 30% of the elliptical cavities

Power coupler

Peak power

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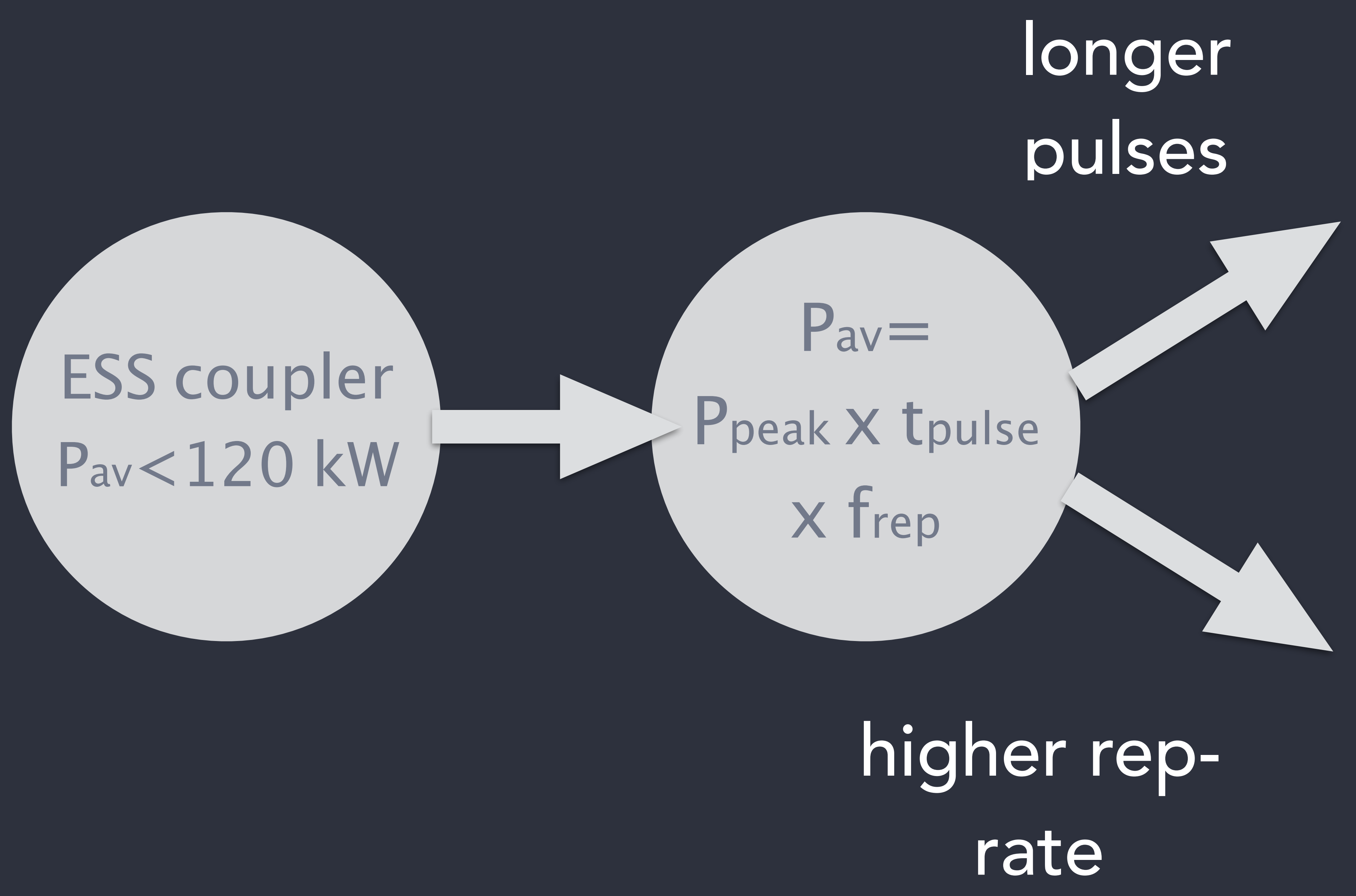
- Current increase increases peak power in both section
- Gradient increase in medium beta section would be possible from the coupler point of view but is likely limited by peak cavity surface fields (quenches)

If the ESS medium beta cavities could stand a 25% increase in accelerating gradient, and if the RF system can supply the needed power, then:

- the energy of the medium beta might be increased by ~80 to 85 MeV,
- resulting in a potential ESS beam power increase of 0.2 MW **(limited potential)**

Power coupler

average power



Higher energy or longer pulses and higher rep-rate have the potential to increase beam power significantly.

ESS	E_{acc}	beta	cells	P_{peak}	$P_{average}$
high beta	19.9 MV/m	0.86	5	1.14 MW	46 kW
low beta	16.7 MV/m	0.67	6	0.9 MV	36 kW

$P_{average}$ (max) :
120 kW,
still margin

Cavity gradient & current

In the real world:

SOME CAVITIES WILL UNDERPERFORM:

- so we need means to recuperate the nominal performance.
- not all linacs are limited by their power couplers.

BEAM LOSS MAY ALREADY PREVENT TO REACH NOMINAL PERFORMANCE:

- need to understand how to reduce the losses, and how to increase currents if the couplers and RF system support it

Gradient increase in SC cavities via plasma processing, Marc Doleans, SNS

Gradient limitations in pulsed SC cavities imposed by power couplers, RF systems, Lorentz Force detuning compensation, Franck Peauger, CEA

Beam current limitations in high-power proton linacs, Tomofumi Maruta, J-PARC

Cavity gradient & current

See how other people do it:

Linac upgrade scenarios for the RAL neutron source, Ciprian Plostinar, STFC

Upgrades to the Spallation Neutron Source Linac to support the second target station limitations, Mark Middendorf, SNS

The ESSnuSB case:

Outcome of a review by F. Gerigk and E. Montesinos (June 2016), on behalf of the ESSnuSB study.

The ESSnuSB example

summary table

Scenario: ESS linac provides 5 MW for neutrons and injects 5 MW H- into an accumulator to create short pulses for neutrinos

- Accumulator injector is asking for H- injection (or maybe not, see C. Priors talk) —> a 2nd front-end with an H- source is needed and pulses need to be interleaved.

	baseline	**ESSnuSB #1**	**ESSnuSB #2**
beam power	5 MW	5 **+ 5 MW**	5 **+ 5 MW**
beam energy	2.0 GeV	2.**5** GeV	2.**5** GeV
beam current	62.5 mA	**50** mA	**50** mA
repetition rate	14 Hz	**28** Hz	**56** Hz
pulse length	2.86 ms	2.86 **+ 2.86 ms**	2.86 **+ 3 x 0.95ms**
particles	protons	protons **+ H^-**	protons **+ H^-**
accumulator	-	**3 rings**	**1 ring**

The ESSnuSB example

Reasoning to combine a doubling of the duty cycle with an energy upgrade and a lower current:

- A 100% increase of average power would be difficult within the existing RF gallery space and needs:
    - new cooling water supplies,
    - new high voltage cabling between HV substations and modulators,
    - upgraded Heating Ventilation Air Conditioning (HVAC),
- With the energy increase and smaller current, the increase of average power from the existing RF stations is ~60% (instead of 100%).
- **Scenario #1 (2 pulses of 2.86 ms)**: yields a total RF duty cycle of 8.4%
- **Scenario #2 (2.86 ms + 3 x 0.95 ms)**: yields a RF duty cycle of 9.45% because of the cavity filling time (~0.3 ms).

The ESSnuSB example

upgrade measures

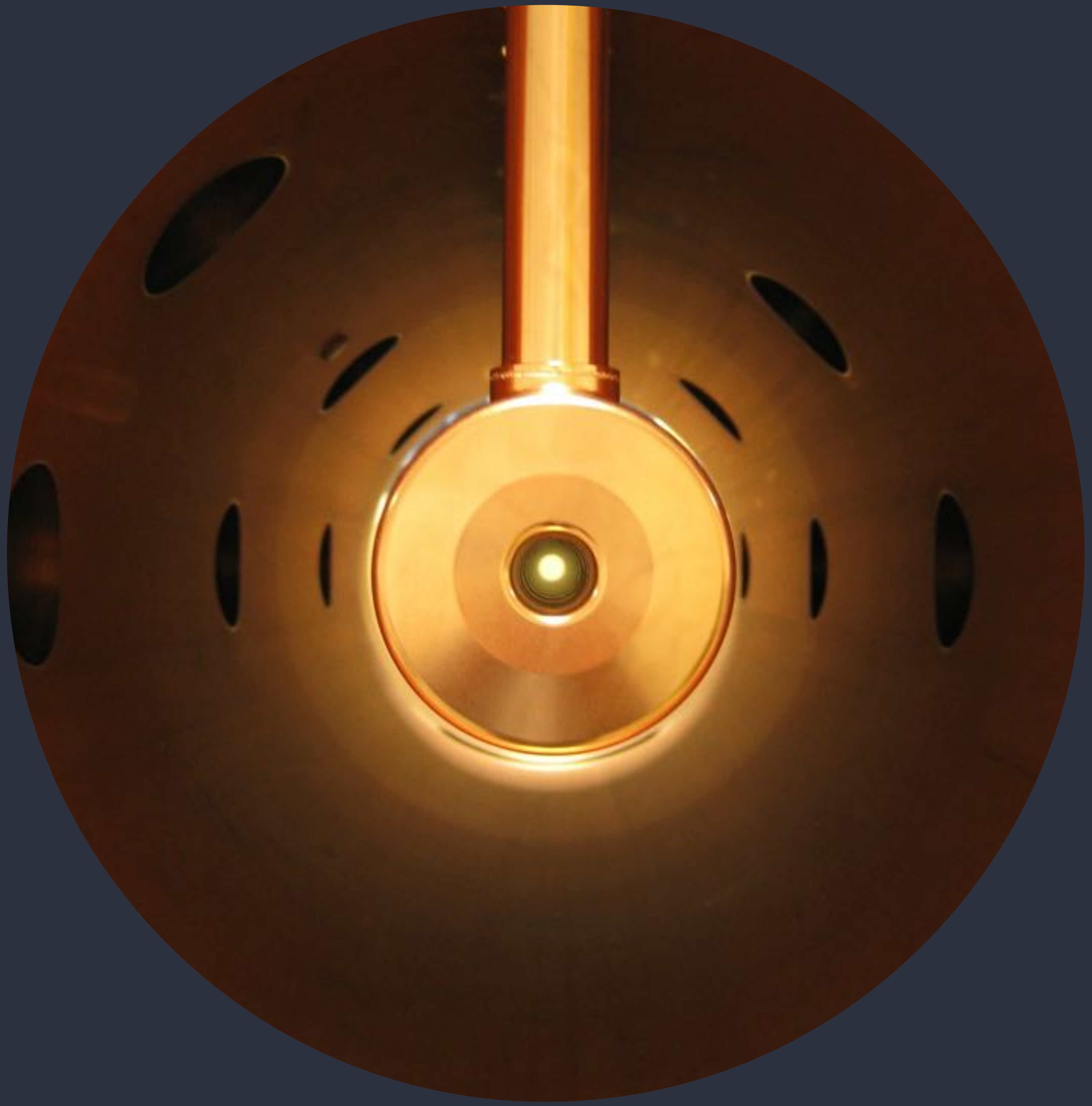
Both scenarios need the following upgrade measures:

1. Three new electrical substations along the RF gallery.
2. A third main electrical station, alongside the 2 existing ones.
3. HV cable trenches and pulling of additional HV cables from the main station towards the new substations. New HV cables between the substations and the modulators in the RF gallery.
4. Installation of 8 new cryo modules and associated RF stations.
5. Change of klystron collectors, so that 60% more average power can be produced. If klystrons are at the end of their lifetime, they could be exchanged against more powerful models.
6. Installation of additional capacitor chargers to allow faster pulsing of the modulators. This is only possible if the modular in-house developed modulator design is adopted.
7. Installation of a H- source + RFQ + MEBT + beam funnel alongside the existing protons source.
8. Exchange trim magnets and associated power supplies against pulsed versions.

Summary

- Power coupler limitations in peak or average power often determine the upgrade options.
- The margins and upgrade potentials of existing cavities, RF systems, HVAC, cooling water systems, cryogenics, electrical stations will determine which parameters (energy, current, gradient, duty cycle) will be changed. Some margins may only become clear once the systems are operating.
- One will try to use the existing cryo-modules with existing couplers and cavities.
- Beam loss can only be judged once a machine is operational and may pose serious limitation on current increases, or additional H^- operation.
- The most efficient upgrade path will always depend on the specifics of the existing linac and conventional facilities.

References



- O. Brunner et al., Assessment of the basic parameters of the CERN Superconducting Proton Linac, PRSTAB 12 (2009) 070402
- F. Gerigk et al., Working group on accelerator components and beam dynamics, ESS-Bilbao initiative workshop, 2009
- F. Gerigk and E. Montesinos, Recommended modifications of the ESS baseline architecture for ESSnuSB, CERN-ACC-NOTE-2015-040
- F. Gerigk and E. Montesinos, Required modifications of the ESS accelerator architecture for ESSnuSB, CERN-ACC-NOTE-2016-0050

THANKS

FOR

Listening