Design of SRF cavities for muon accelerators status and plans – MuCol Task 6.1

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MuCol Design Study

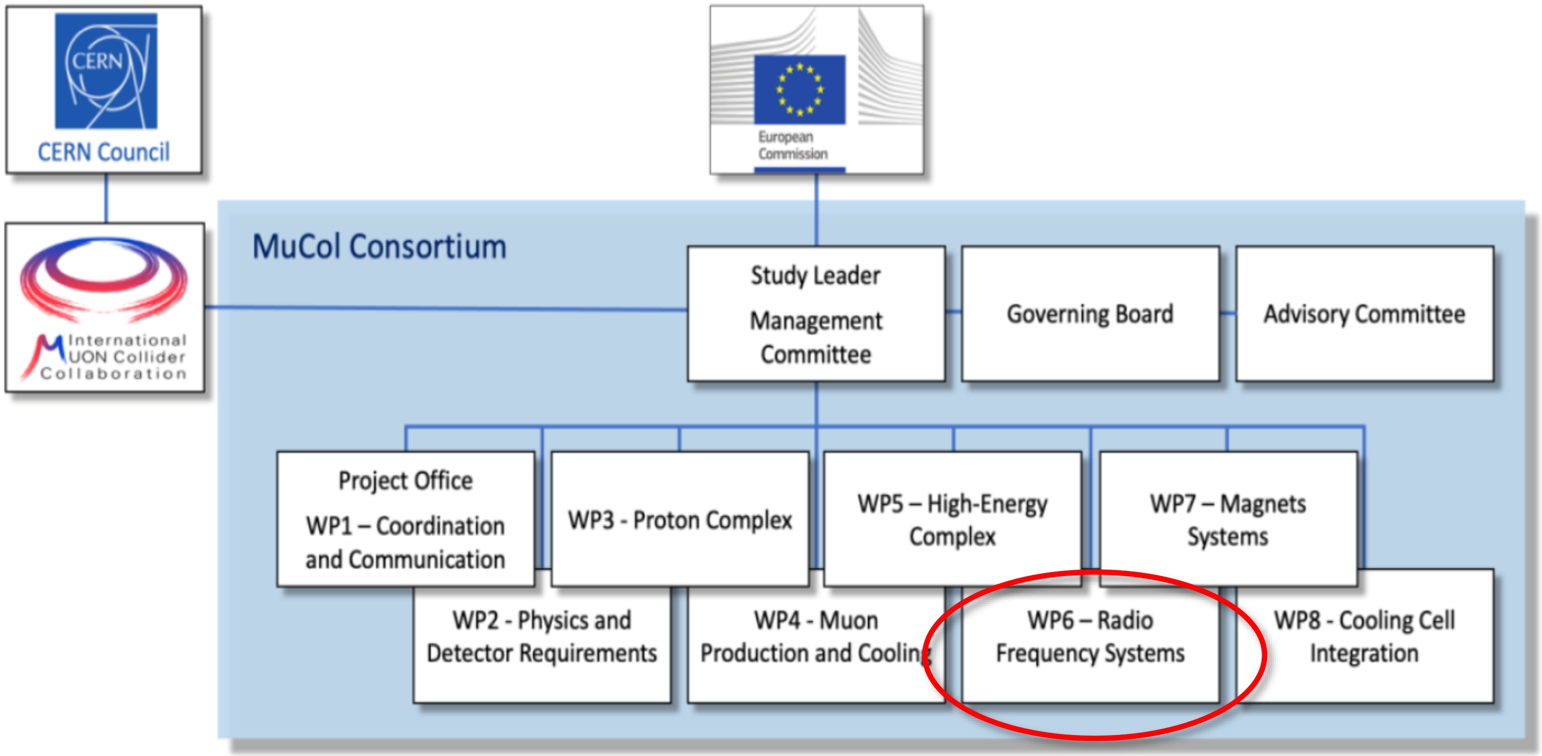


Fig. 5: Proposed organisation of MuCol

Illustration adapted from MuCol proposal

Task 6.1: Baseline concept of the RF system for acceleration to the High Energy Complex (HEC)

- Provide a preliminary design concept for the SRF cavities of the Rapid-Cycling Synchrotrons (RCS) of the HEC

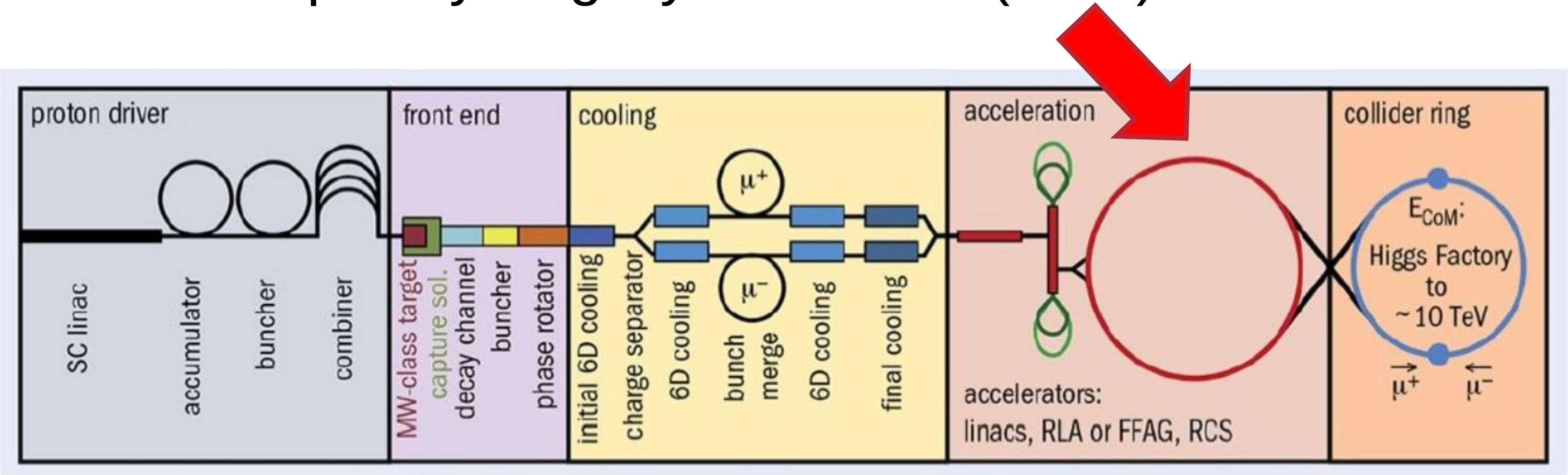


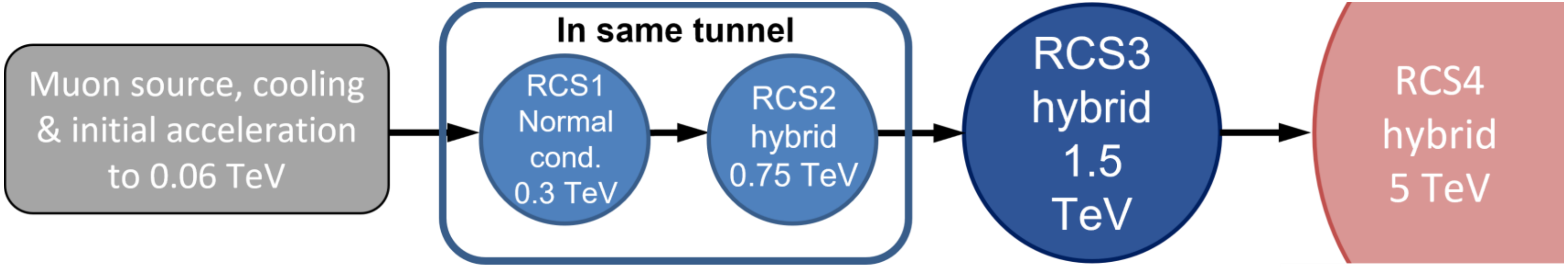
Fig. 2: Layout of the Muon Collider complex as elaborated by the MAP

Illustration from MuCol proposal

Task 6.1: Baseline concept of the RF system for acceleration to the High Energy Complex (HEC)

From Antoine Chancé`s presentation:

- Chain of rapid cycling synchrotrons, counter-rotating m+/m- beams
  → 60 GeV → 314 GeV → 750 GeV → 1.5 TeV → 5 TeV



Task 6.1: Baseline concept of the RF system for acceleration to the High Energy Complex (HEC)

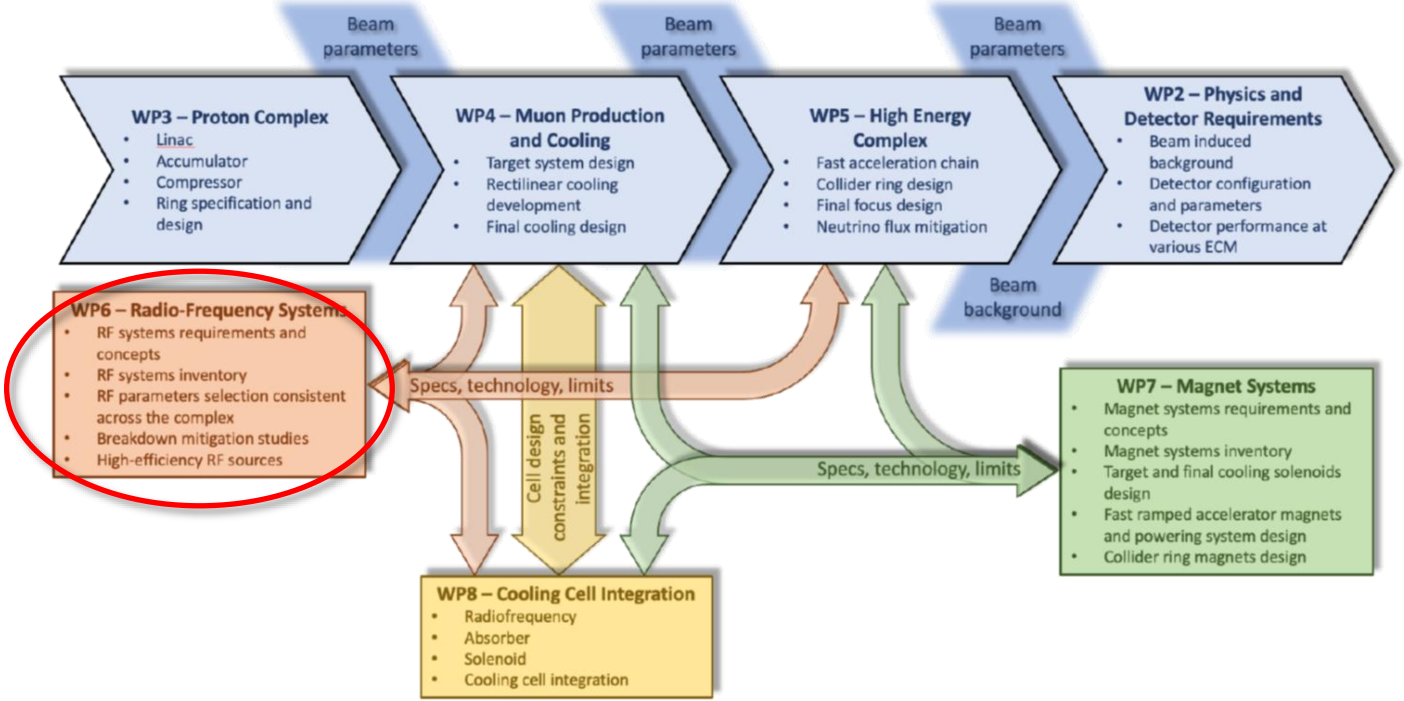


Fig. 6: Schematic diagram of interactions among workpackages

Illustration from MuCol proposal

Task 6.1: Baseline concept of the RF system for acceleration to the High Energy Complex (HEC)

- The short muon lifetime requires the highest possible acceleration rate to reach energy gains of $\mathcal{O}$(10 GeV) per turn
- Shall be provided by very high-voltage SRF cavities
- Thus, task 6.1 includes **determining a suitable cavity technology**, i.e. type, shape, material, main RF frequency
- During cavity optimisation, we need to consider the strong transient beam loading and wakefield effects
- In cooperation with WP5: Full set of parameters for the fundamental mode and Higher Order Modes' suppression

Task 6.1 Contributions

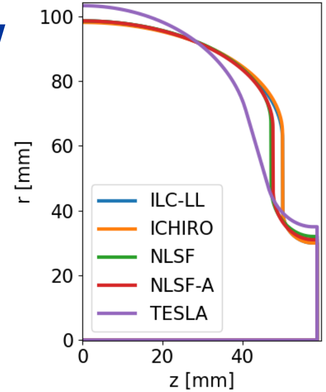
- MuCol participants contributing:
  - CEA – Beam loading & FPC study
  - CERN – Beam dynamics simulations for the RCSs
  - INFN LASA – Frequency sweep and HOMs
  - UROS* – SRF cavity design, incl. HOM couplers - so far:

    *Funded by EU with 12 person months; additionally: Gentner-funded PhD student started 06/23
- Open for further contributions from other IMCC members!

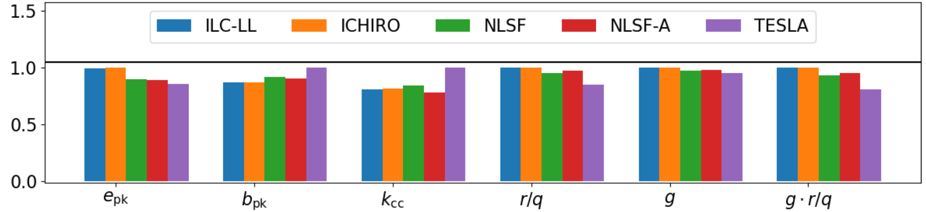
Low-loss cavity geometries from the literature

UROS Summary, Sosoho A. Udongwo, cf. talk today

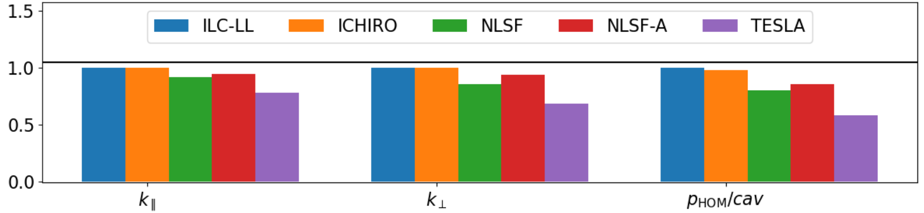
- Several low-loss cavities from the literature [1] were analysed
- There was no significant difference in the fundamental mode (FM) and higher-order mode (HOM) quantities of interest
- NLSF cavity was selected for further analysis; TESLA [2] and ERL [3] cavity geometries were also analysed for comparison



Analysed cavity geometry profiles



FM Figures of Merit: E_{peak}, B_{peak}, k_{cc}, R/Q, G factor, G·R/Q



HOM Figures of Merit: Normalised loss and kick factors, power per cavity

[1] N. Juntong, R.M. Jones, High-gradient SRF Cavity with minimized surface E.M. fields and superior bandwidth for the ILC, Proceedings of SRF2009, Berlin, Germany. https://accelconf.web.cern.ch/SRF2009/papers/thppo024.pdf

[2] B. Aune et al., Superconducting TESLA cavities, Physical Review Special Topics - Accelerators and Beams, Volume 3, 092001 (2000).

[3] V. Shemelin, Optimal choice of cell geometry for a multicell superconducting cavity, Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE), Ithaca, New York 14853, USA, 11 November 2009. https://journals.aps.org/prab/pdf/10.1103/PhysRevSTAB.12.114701

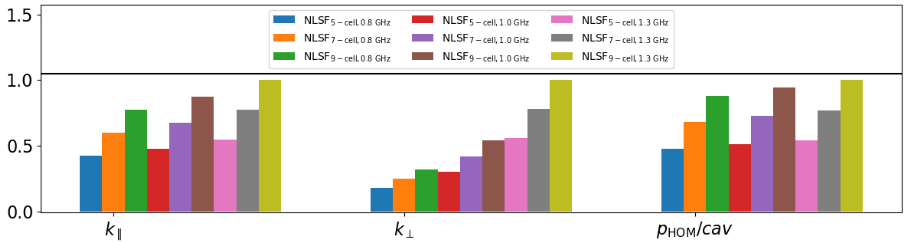
Study of the NLSF cavity considering different numbers of cells and operating frequencies

UROS Summary, Sosoho A. Udongwo, cf. talk today

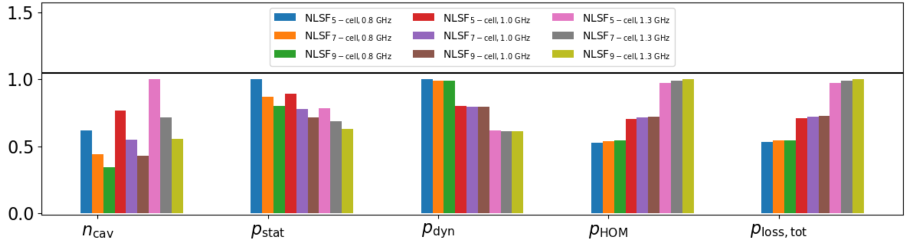
- HOM power for a 9-cell cavity (NLSF, TESLA, ERL-MA) is calculated to be about 10 kW

	NLSF	ERL-MA	TESLA
N_{cav}	671	671	671
P_{stat}[kW]	4.99	4.99	4.99
P_{dyn}[kW]	60.19	72.72	70.65
$P_{\mathrm{HOM}}/\mathrm{cav}(\sigma = 13.0\ \mathrm{mm})$[kW]	10.67	9.88	9.04
$P_{\mathrm{HOM}}(\sigma = 13.0\ \mathrm{mm})$[kW]	7162.29	6626.27	6066.59

RCS Stage 1
Beam current – 20.38 mA
Bunch length – 13 mm



From left to right: Bar plots of normalised loss and kick factors, and HOM power per cavity



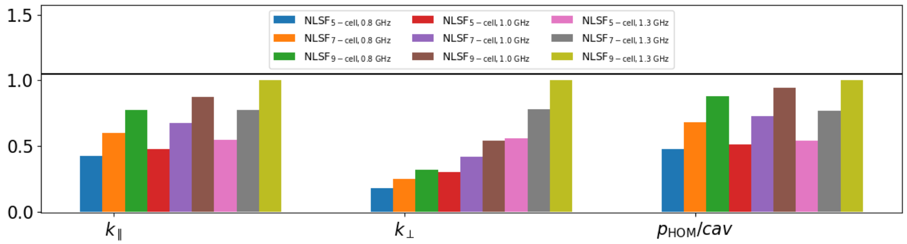
From left to right: Bar plots of the normalised number of cavities, static power loss, dynamic power loss, HOM power loss and total power loss

Study of the NLSF cavity considering different numbers of cells and operating frequencies

UROS Summary, Sosoho A. Udongwo, cf. talk today

International MUON Collider Collaboration

- Reducing the number of cells does not substantially reduce the HOM power, but operating at a lower frequency does
- This, however, comes at the cost of increasing the dynamic power loss



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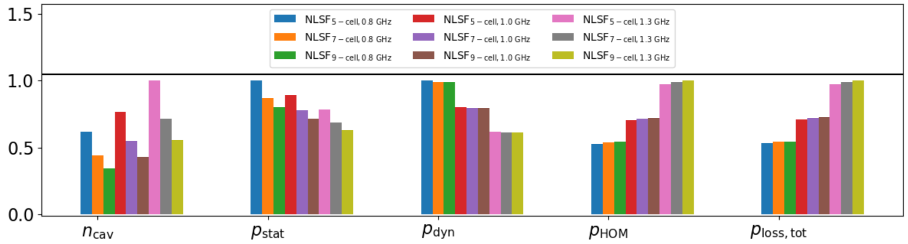

From left to right: Bar plots of the normalised number of cavities, static power loss, dynamic power loss, HOM power loss and total power loss

HOM impedance outlook for NLSF, ERL-MA and TESLA cavity geometries

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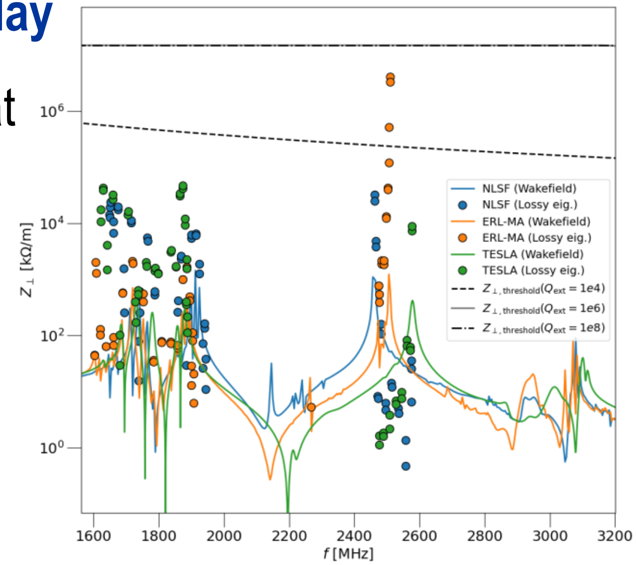
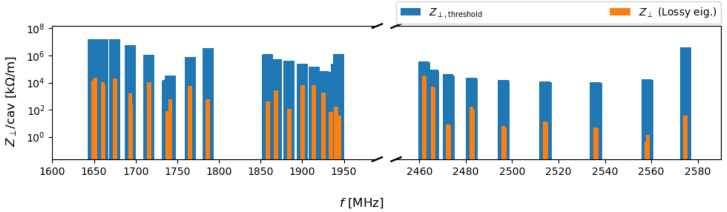
UROS Summary, Sosoho A. Udingwo, cf. talk today

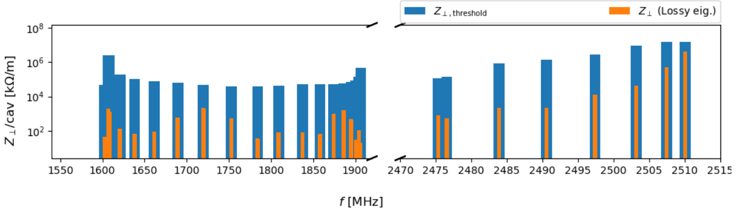
- Trapped dipole mode at around 2500 MHz, but
- Transverse impedance of dipole modes below the threshold value for HOM-damped cavities



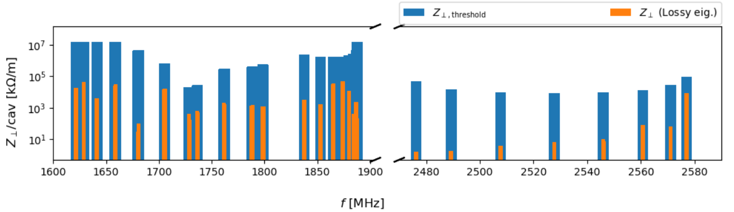
Lossy eigenmode and wakefield analysis transverse HOM impedance plot for analysed cavities



NLSF: Comparision of $Z_\perp$ and $Z_{\perp,\mathrm{threshold}}$



ERL-MA: Comparision of $Z_\perp$ and $Z_{\perp,\mathrm{threshold}}$



TESLA: Comparision of $Z_\perp$ and $Z_{\perp,\mathrm{threshold}}$

Longitudinal dynamics – HOM power losses

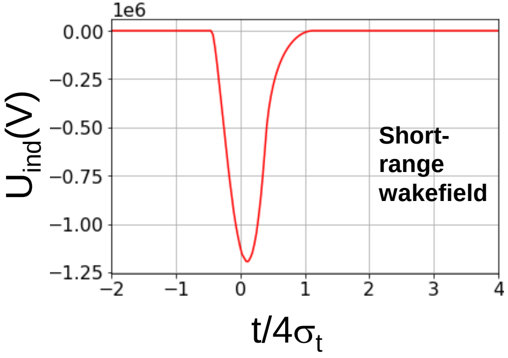
CERN Summary, Fabian Batsch, cf. talk today

The results from S.-A. Udongwo are compared with:

- Calculation of HOM power in TESLA / ILC 1.3 GHz cavity in macro-particle tracking simulations (using the BLonD code):
- Obtain power loss through loss factor $k_{||}$ from approximated wake potentials containing the information about all HOM:
- $k_{||} = \int \lambda(t)\, W_{||,SR}(t) dt$, with $W_{||,SR}$ short-range wake potential

↓

- $P_{HOM} = k_{||} * Q_2 / T_B$, with bunch charge Q, b. spacing $T_B = T_{rev}$



Longitudinal dynamics – HOM power losses

CERN Summary, Fabian Batsch, cf. talk today

- Further comparison with ABCI simulations that use the approximated loss factor for short Gaussian bunches:
- $k_{||}=|R/Q|\omega_r/2$ ($\omega_r/4$ for Linac norm)
- → HOM loss factor is summed up over all HOMs: $k_{||}=\sum k_{||,i}$

MODE	FREQ.	R/Q	2 welded couplers on asymmetric cavity Qext	2 demount. couplers on asymmetric cavity Qext	2 demount. couplers on symmetric cavity Qext
	[MHz]	[Ω]	[1.0E+3]	[1.0E+3]	[1.0E+3]
TM011 1	2379,6	0,00	350,0	1150	1600
2	2384,4	0,17	72,4	360	460
3	2392,3	0,65	49,5	140	220
4	2402,0	0,65	84,0	68	110
5	2414,4	2,05	32,0	70	97
6	2427,1	2,93	29,1	81	59
7	2438,7	6,93	20,4	66	49
8	2448,4	67,04	27,4	58	51
9	2454,1	79,50	58,6	110	100

From
“Higher order mode coupler for TESLA”,
J. Sekutowisz

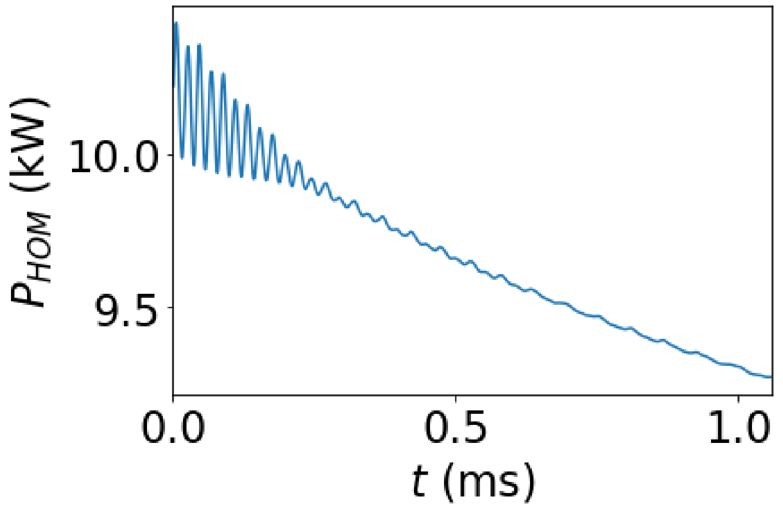
See here (TESLA) & paper (ILC LL)

HOM power losses

CERN Summary, Fabian Batsch, cf. talk today

- From BLonD, for the induced voltage of 1.1 MV/m per cavity, we obtain up to 10 kW per bunch and cavity

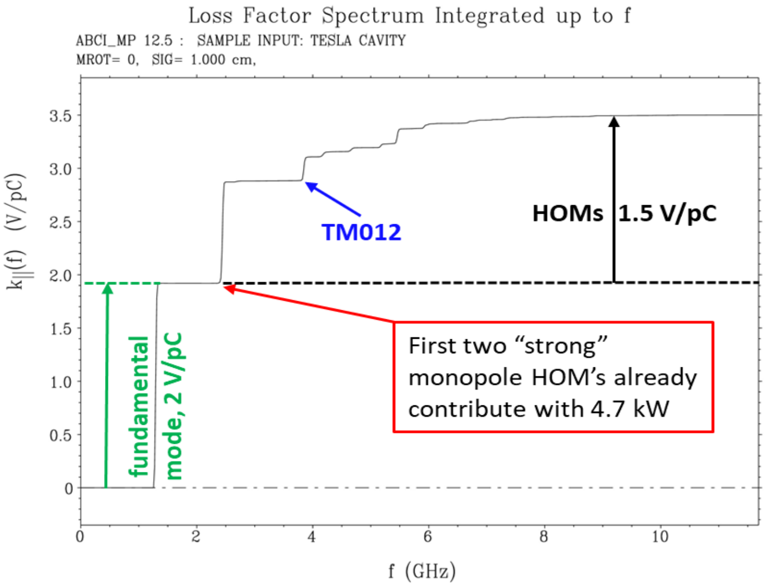
(Bunch population 2.54×10^{12}, T_{rev} = 20 μs → I = 20.4 mA)



HOM power losses

CERN Summary, Fabian Batsch, cf. talk today

- From HOMs from ABCI: (ABCI file from S.-A. Udongwo):
  1.5 V/pC results in 7.9 kW → Consistent with BLonD



→ Large values up to 10 kW HOM power per bunch within t_{acc}

→ Bunch crossings in cavities must be avoided

→ High-capacity HOM coupler development required

→ Discussion of which is the corresponding CW power loss

→ Further benchmarking with CST to be continued

Summary

- MuCol Task 6.1 just started its work
- First results on impedances, HOM power, etc., achieved for various elliptical multicell cavity profiles

- Main contributions so far by a few young researchers
- A PhD candidate just joined

- About monthly meetings https://indico.cern.ch/category/15522/
- More manpower is highly welcome to join and support in achieving our aims

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Thank you for your attention