Recent R&D on RF systems for muon collider ionization cooling complex

Alexej Grudiev (CERN)
On behalf of the International Muon Collider Collaboration

Advanced Accelerator Concepts, 2026

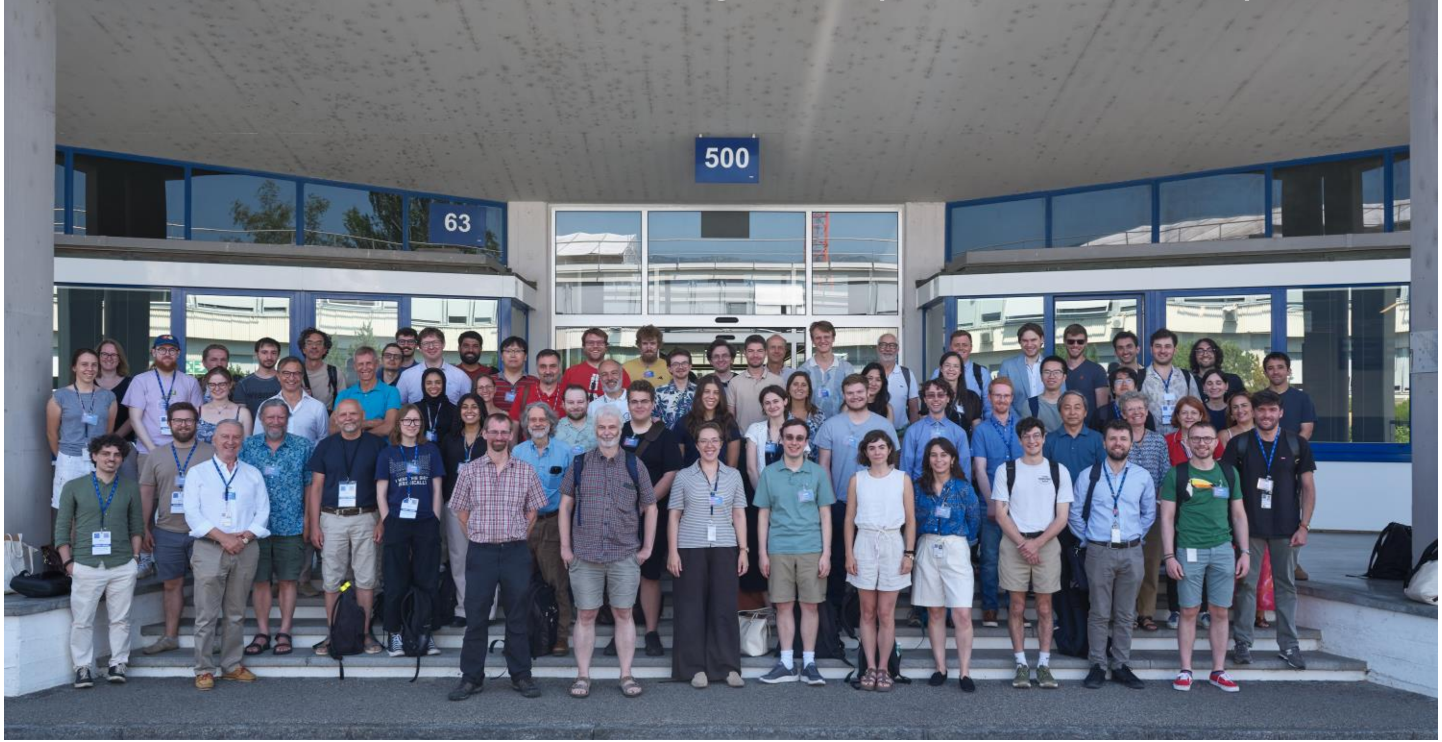
Funded by the European Union (EU). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the EU or European Research Executive Agency (REA). Neither the EU nor the REA can be held responsible for them.

Outline

- Introduction
  - IMCC
  - ESPPU 2026
  - MC R&D program
- High Gradient RF in strong Magnetic field
  - Reminder of the State-of-the-Art from US MAP
  - Some new ideas on the breakdown model
  - Recent plans on the RF test stands in strong magnetic field
- Design of RF cavities for Muon Cooling
  - Comparison of Be-window and Dielectric-loaded cavities for 6D-cooling
  - Very low frequency Dielectric-loaded cavities for the Final cooling
- Conclusions and Outlook

International Muon Collider Collaboration (IMCC)

IMCC and MuCol Annual Meeting 2026 (22-25 June 2026), CERN



IMCC:
68 institutes
from
18 countries
+
30 partners
from
4 countries

199 participants

European Strategy Particle Physics Update (ESPPU) 2026 Recommendation

- The full exploitation of the physics potential of the LHC and the **HL-LHC** [..] remain the highest priorities of European particle physics.

- The electron–positron Future Circular Collider (**FCC-ee**) is recommended as the preferred option for the next flagship collider at CERN.

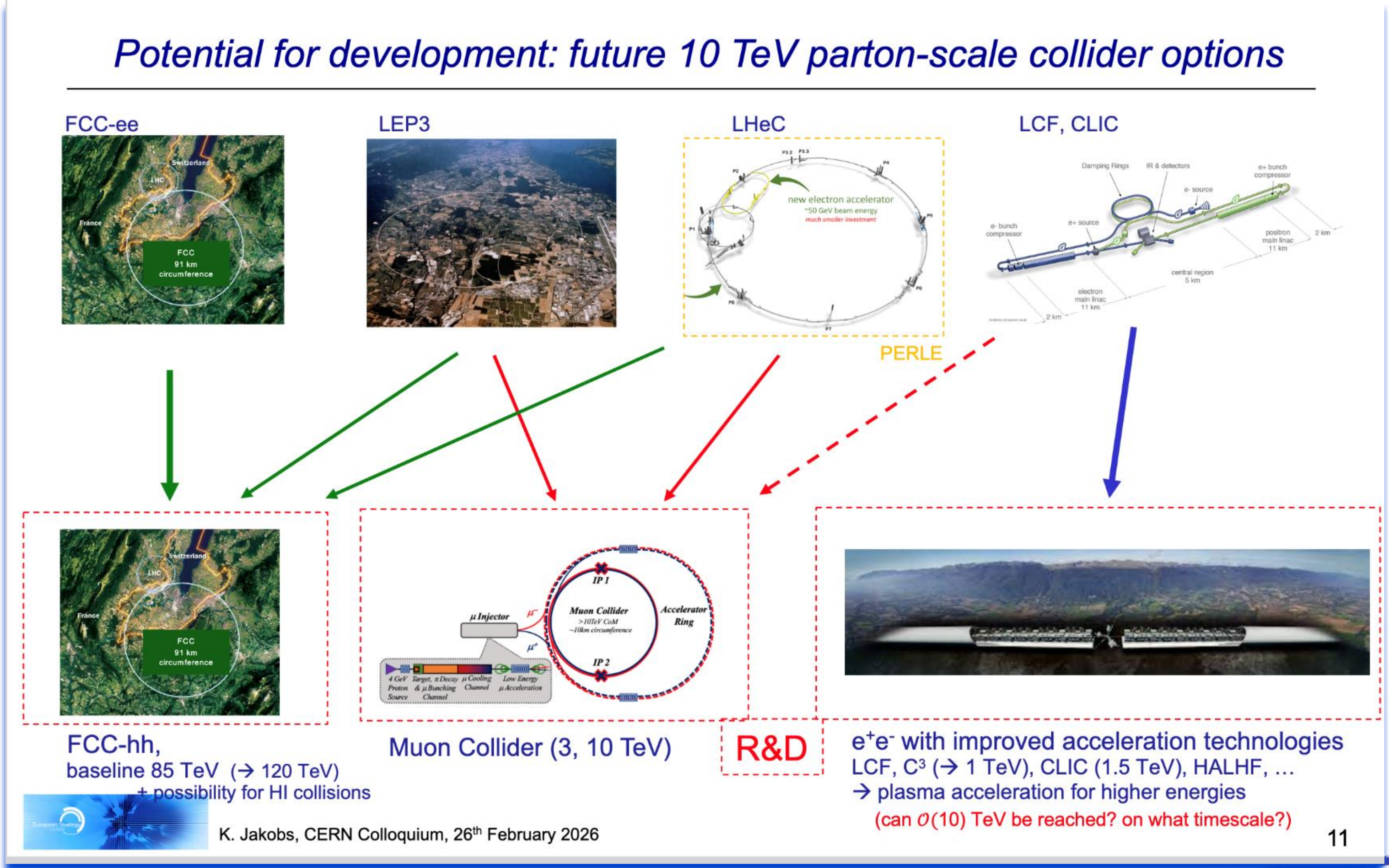
- A **descoped FCC-ee** is the preferred alternative option for the next flagship collider at CERN.

- *The longer-term development of advanced technologies, such as high-gradient wakefield acceleration and those underpinning bright muon beams, should be supported at an appropriate level. Synergies with the US initiative on muon collider R&D should be exploited.*

Note: CERN wants a **go/no-go decision on FCC-ee**
Documentation on **LEP3** and **LCF380** will also be provided

D. Schulte, CERN

Collider landscape in Europe. ESPPU view



~2045

~2065

International MUON Collider Collaboration

IMCC R&D Program

International MUON Collider Collaboration

Accelerator design

- Complete start-to-end design

Muon cooling technology

- Staged implementation
  - RF test stands
  - Cooling cell prototype
  - Demonstrator

RF

Detector

- Strong potential for further improve physics potential with technologies, AI and ML

Magnet programme

- Have conceptual designs, need hardware
- HTS solenoids have important synergy with society (also power converter)
  - Industry is ready to invest
  - Must not miss the opportunity

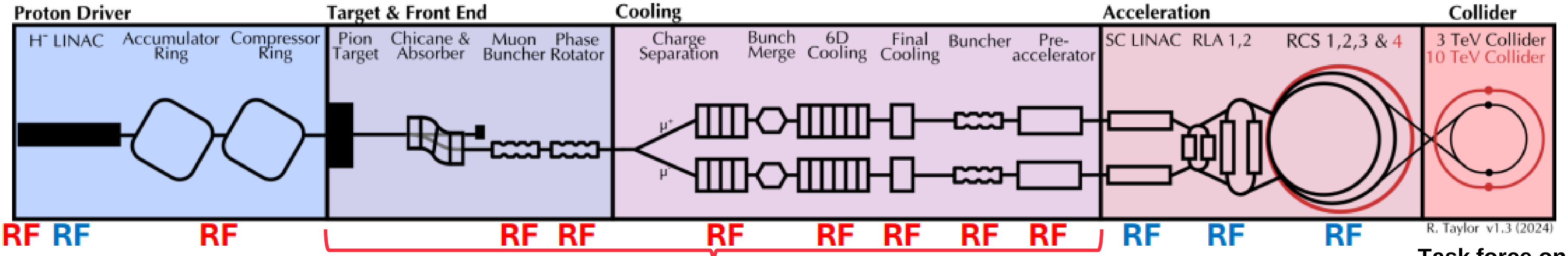
ESPPU: Accelerator WG2a concluded on the muon collider:
[…] the Muon Collider (MC), together with the FCC-hh, promises a potentially energy-efficient path toward high-luminosity collisions at a parton centre-of-momentum energy of 10 TeV. However, the MC has not yet reached the level of maturity of the other proposals discussed here. [..]

Detailed R&D program proposal towards CDR with deliverables defined

Year	I	II	III	IV	V	VI	VII	VIII	IX	X
Accelerator Design and Technologies										
Material (MCHF)	1.6	3.2	4.8	6.4	9.6	10.8	12.0	12.0	12.0	12.0
FTE	47.1	60.6	75.0	85.0	100.0	120.0	150.0	174.6	177.2	185.1
Demonstrator										
Material (MCHF)	0.6	2.2	3.9	5.4	7.8	15.1	25.9	32.4	31.8	12.6
FTE	9.5	11.0	12.5	29.2	29.7	30.5	25.5	27.7	26.7	25.5
Detector										
Material (MCHF)	0.5	1.1	1.6	2.1	2.1	2.1	2.1	2.6	3.1	3.1
FTE	23.4	46.5	70.0	93.0	93.0	93.0	93.0	116.4	139.5	139.5
Magnets										
Material (MCHF)	3.0	4.9	10.1	10.0	11.0	13.4	11.7	7.2	6.6	4.7
FTE	23.3	28.4	36.4	40.9	44.3	47.1	46.2	37.7	36.1	29.4
TOTALS										
Material (MCHF)	5.7	11.4	20.3	23.9	30.6	41.4	51.7	54.2	53.5	32.4
FTE	103.3	146.5	194.0	248.1	267.0	290.6	314.8	356.3	379.4	379.6

D. Schulte, CERN

MC RF systems R&D Program



Moun cooling complex RF systems

Collaborators \ Tasks	1	2	3	4
CERN, CH	★		★	★
INFN, IT	★	★	★	
University of Rostock, DE			★	
University of Lancaster, UK		★		★
CEA, FR	★	★		
LBNL, USA	★	★		
FNAL, USA			★	
SLAC, USA		★		★
University of Helsinki, FI		★		

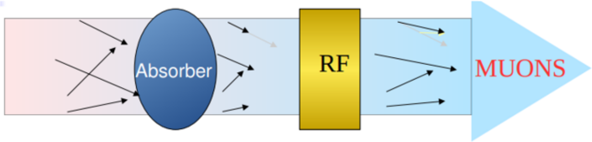
Detailed R&D program **partially** funded

	Tasks	year	1	2	3	4	5	6	7	8	9	10	All
1	**Muon Cooling Design Effort**												
	Staff	FTE/y	1	1	1	1	1	2	2	2	2	2	**15 FTE**
	Postdoc/Student	FTE/y	4	4	4	4	4	8	8	8	8	8	**60 FTE**
	Material	MCHF	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	**1.5**
2	**Muon Cooling RF Tests & Theory**												
	Staff	FTE/y	3	3.5	5.3	4.5	4	0	0	0	0	0	**20 FTE**
	Postdoc/Student	FTE/y	3.5	5	6	5	5	0	0	0	0	0	**25 FTE**
	Material	MCHF	0.2	0.4	0.8	0.2	0.5	0	0	0	0	0	**2.2**
3	**RF systems for Accelerators**												
	Staff	FTE/y	0.3	0.3	0.3	0.8	1	5.5	5.5	5.5	4.5	3.5	**27 FTE**
	Postdoc/Student	FTE/y	2	2	2	2	3	5	5	5	5	4	**35 FTE**
	Material	MCHF	0	0	0	0.3	0.5	0.6	0.6	0.8	0.5	0.4	**3.7**
4	**RF power sources**												
	Staff	FTE/y	0.3	0.3	3.05	3.05	2.7	0.45	0.45	3	3	2.5	**19 FTE**
	Postdoc/Student	FTE/y	1.1	2.2	3.6	4.1	4	2.1	3.1	4	4	3	**31 FTE**
	Material	MCHF	0	0.02	1.8	0.8	0.4	0.03	0.03	0.8	0.8	0.4	**5.1**
Tot	**Staff**	**FTE/y**	**4.5**	**5.1**	**9.6**	**9.3**	**8.7**	**8**	**8**	**10.5**	**9.5**	**8**	**81 FTE**
	Postdoc/Student	**FTE/y**	**11**	**13.2**	**15.6**	**15.1**	**16**	**15.1**	**16.1**	**17**	**17**	**15**	**151 FTE**
	Material	**MCHF**	**0.3**	**0.53**	**2.7**	**1.4**	**1.5**	**0.83**	**0.83**	**1.8**	**1.5**	**1**	**12.4**

Task force on R&D for MC RF systems:
S. Belomestnykh (FNAL),
G. Burt (ULAN),
R. Calaga (CERN),
D. Giove (INFN),
A. Grudiev (CERN),
T. Luo (LBNL),
E. Nanni (SLAC),
J. Plouin (CEA),
U. van Rienen (UROS),
I. Syratchev (CERN)

RF system for muon cooling

Region	Length [m]	Num. RF	RF Frequency [MHz]	Max. RF Gradient [MV/m]	Magnetic field [T]	Peak RF power [MW/cav.]
Buncher	21	54	490 - 366	0 - 15		1.3
Rotator	24	64	366 – 326	**20**		2.4
Rectilinear cooler A-type	**363**	**1605 x2**	**352, 704**	**26, 32**	**2-4, 5-7**	**4, 2**
Bunch merge	130	26 x2	108 - 1950	**~ 10**		
Rectilinear cooler B-type	**487**	**2057 x2**	**352, 704**	**21, 30**	**3-7, 9-17**	**4, 2**
Final Cooling	140	96 x2	~100 - 10			
Reacceleration			~100 - 10			
Total	1165	**7686**				**~20GW**



ESPPU Muon Collider Report – ACCELERATOR COMPLEX CONCEPTS – March 31, 2025

	RF Frequency (MHz)	Num. RF	RF Length (cm)	Max. RF Gradient (MV/m)	RF phase (deg)
A-Stage 1	352	6	19	27.4	18.5
A-Stage 2	352	4	19	26.4	23.2
A-Stage 3	704	5	9.5	31.5	23.7
A-Stage 4	704	4	9.5	31.7	25.7
B-Stage 1	352	6	25	21.2	29.9
B-Stage 2	352	5	22	21.7	27.2
B-Stage 3	352	4	19	24.9	29.8
B-Stage 4	352	3	22	24.3	31.3
B-Stage 5	704	5	9.5	22.5	24.3
B-Stage 6	704	4	9.5	28.2	22.1
B-Stage 7	704	4	9.5	28.5	18.4
B-Stage 8	704	4	9.5	27.1	14.5
B-Stage 9	704	4	9.5	29.7	11.9
B-Stage 10	704	4	9.5	24.9	12.2

Table 5.2.5: Rectilinear cooling cell RF parameters.

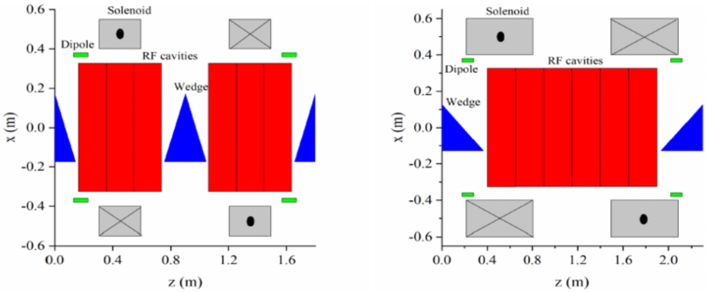


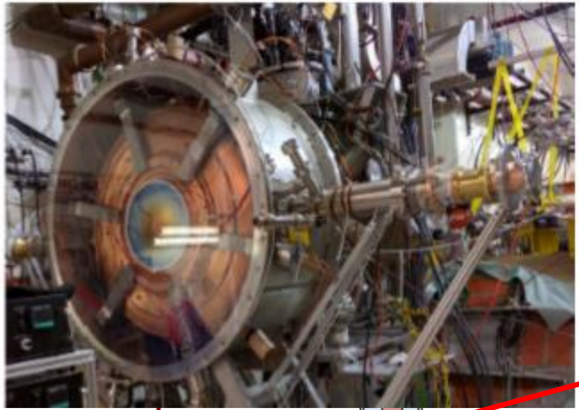
Figure 5.2.4: Schematic of the (left) A-type and (right) B-type cooling cell layout.

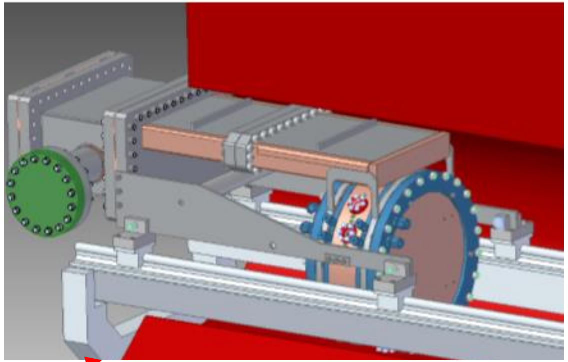
RF cavities for muon cooling from US MAP

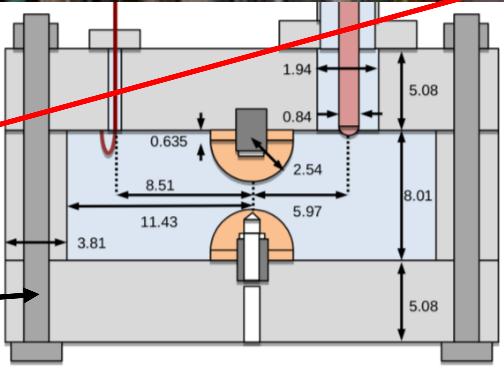
US MAP

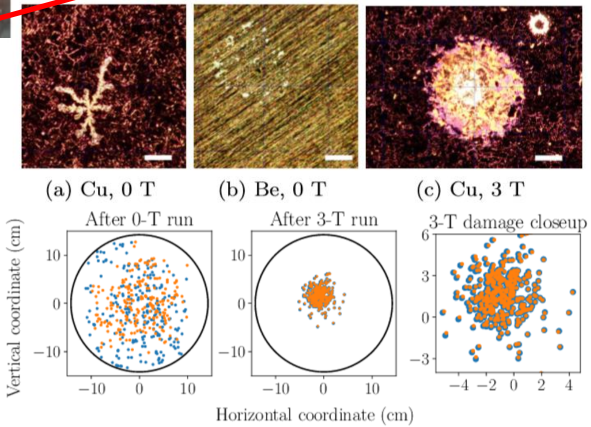
Challenges:
- High Gradient
- High magnetic field
- High radiation
- No synergy with other projects

State of the art (not complete):
- MICE 200 MHz RF module prototype: 4T, 10 MV/m, 1ms@1Hz
- 800 MHz **beryllium** cavity: 3T, **50 MV/m**, 30us@10Hz
- **Gas** filled RF cavity: Small gap, 800 MHz, >50 MV/m





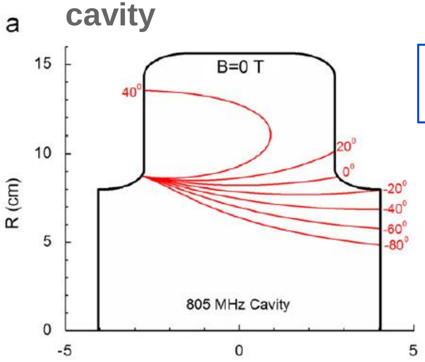


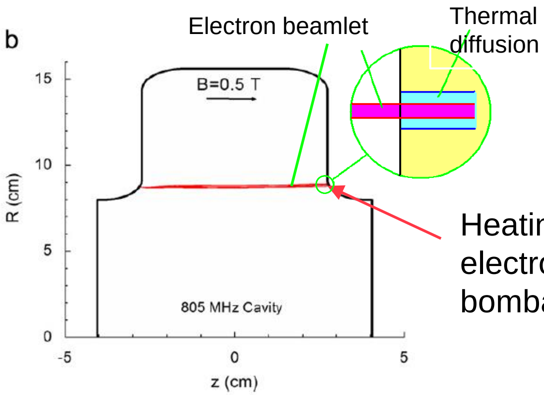


Breakdown model: beamlet focused by magnetic field

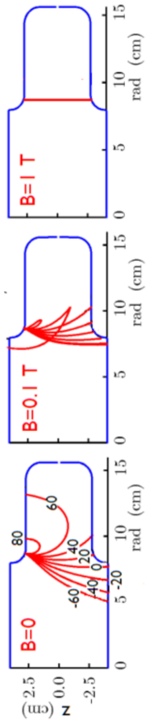
Numerical simulations showed trajectories of beamlets in the presence of the 805 MHz pillbox cavity

US MAP

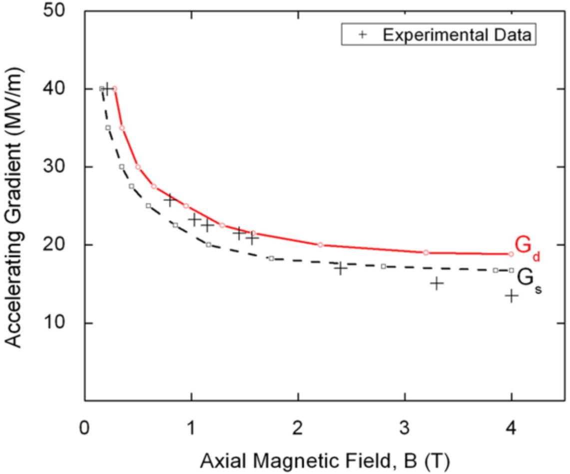




Heating due to electron bombardment



- Model developed by US labs, checked against measurements in high B. papers: Palmer et.al PRAB 2009, Stratakis et.al NIMPR 2010
- Model predicts local temperature rise ΔT due to electron bombardment
- Breakdown occurs when $\Delta T > \Delta T_{plastic}$

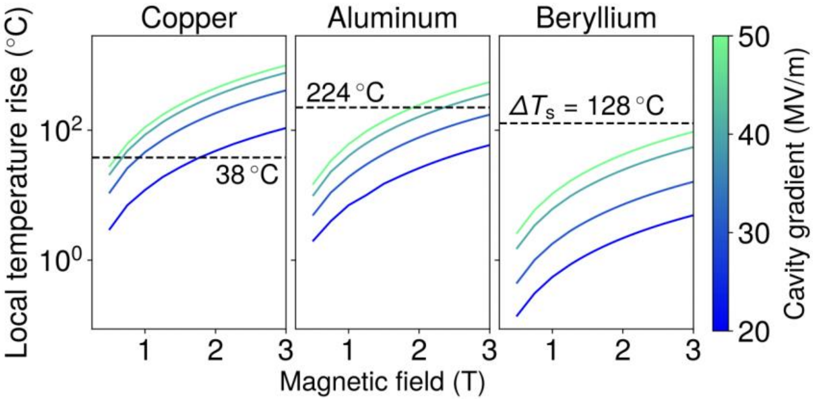


$$= \Delta T_{plastic} = \frac{2(1-\nu)\sigma_t}{E\alpha_{th}}$$

Poisson ratio; Yield strength; Elastic modulus; Linear expansion

$\Delta T_{plastic}$:
38 °C for Cu,
129 °C for Be,
224 °C for Al

MuCool 805 MHz cavity with modular plates



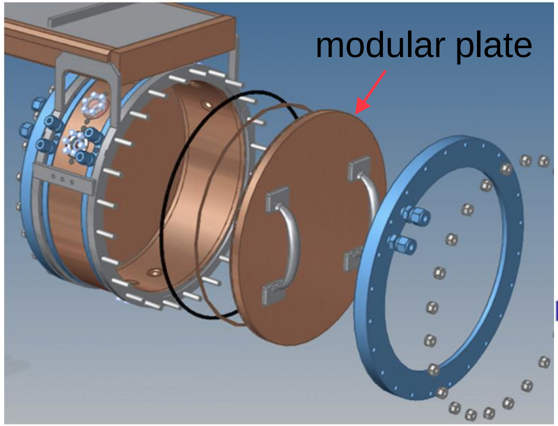
Operation of normal-conducting rf cavities in multi-Tesla magnetic fields for muon ionization cooling: A feasibility demonstration

D. Bowring, A. Bross, P. Lane, M. Leonova, A. Moretti, D. Neuffer, R. Pasquinelli, D. Peterson, M. Popovic, D. Stratakis, K. Yonehara, A. Kochemirovskiy, Y. Torun, C. Adolphsen, L. Ge, A. Haase, Z. Li, D. Martin, M. Chung, D. Li, T. Luo, B. Freemire, A. Liu, and M. Palmer

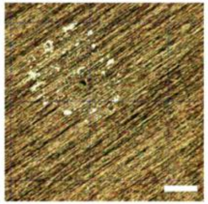
Phys. Rev. Accel. Beams **23**, 072001 – Published 2 July 2020

FIG. 2. Semi-log plot of local ΔT for Cu, Al, and Be cavities at various gradients and across a range of solenoidal magnetic field strengths. ΔT_s [Eq. (4)] is indicated in each plot by a horizontal, dashed line. Note that for Be, the local temperature rise is lower than ΔT_s for a broad range of gradients and magnetic fields.

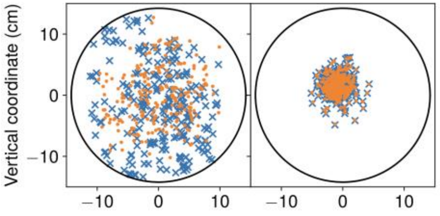
US MAP



Material	B-field (T)	SOG (MV/m)
Cu	0	24.4 ± 0.7
Cu	3	12.9 ± 0.4
Be	0	41.1 ± 2.1
Be	3	$> 49.8 \pm 2.5$
Be/Cu	0	43.9 ± 0.5
Be/Cu	3	10.1 ± 0.1

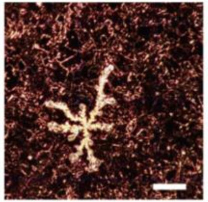


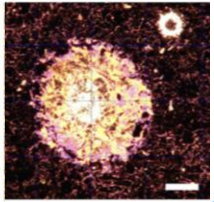
Be: 0 & 3 T



Cu: 0 T

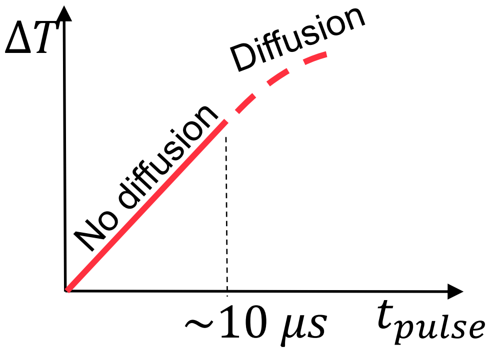
Cu: 3 T





- Strong indication that Al could be a good middle ground between safety of Cu and performance of Be.

Scaling using no-diffusion beamlet model



The breakdown model can be simplified: for short pulses ($t_{pulse} < 10\ \mu s$) we can neglect heat diffusion in the wall.
Then the breakdown condition $B(E_{acc})$ is given by (S. Arsenyev, 2021):

$$B^2 = \rho C_s \frac{2(1-\nu)\sigma_t}{E\alpha_{th}} \times \frac{e\pi\xi^2}{I_{em}^{\frac{1}{3}}\left(\frac{dE}{dz}\right)} \times \frac{1}{t_{pulse}}$$

$\Delta T_{plastic}$

Cavity-dependent constant

Pulse length

Magnetic field at breakdown

Wall material properties

Field Emission current $I(E_{acc})$

Electron energy loss

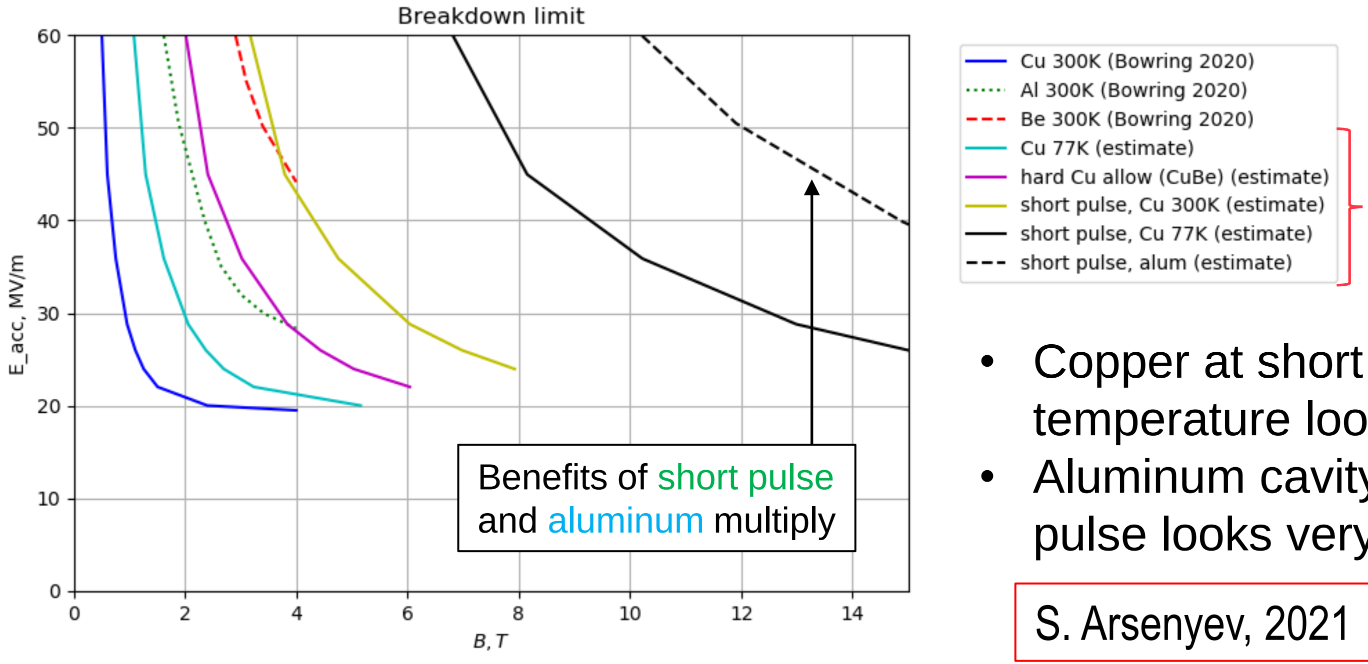
This equation provides scaling laws of $B(E_{acc})$ on different parameters. Mitigation solutions that follow from this equation:

- Very short pulse (sub μs)
- Different wall materials (Al, hard copper alloys)
- Low temperature (nitrogen cooling 70 K)
- Cavity shape optimization

When combined, benefits from different solutions would multiply

Comparing breakdown mitigation ideas

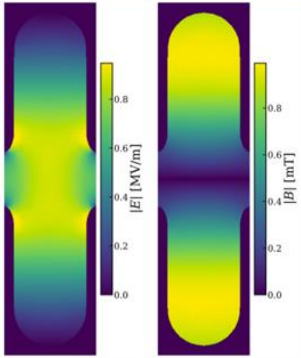
This plot is not intended to give absolute values for breakdown threshold, but only a feeling of which solutions can be more promising. We scale curves from MUCOOL cavity study ($t_{pulse} = 20\ \mu s > 10\ \mu s$ so the no-diffusion model applies only approximately)



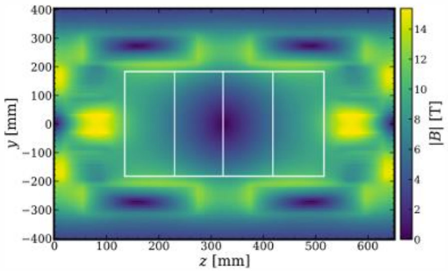
- Copper at short pulse and low temperature looks better
- Aluminum cavity with a short pulse looks very promising

S. Arsenyev, 2021

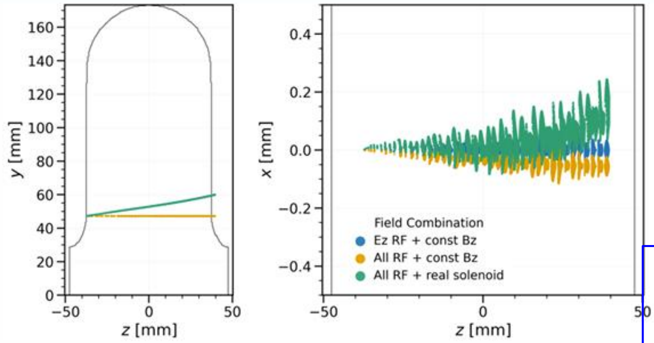
Breakdown Model in a Magnetic Field



Stage-B8 cavity fields



Lattice magnetic field

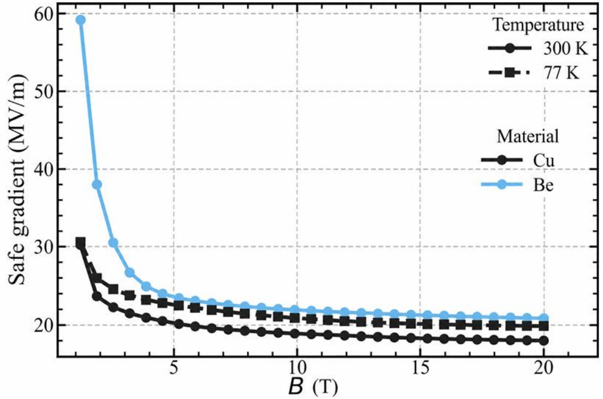


Electron trajectory comparison

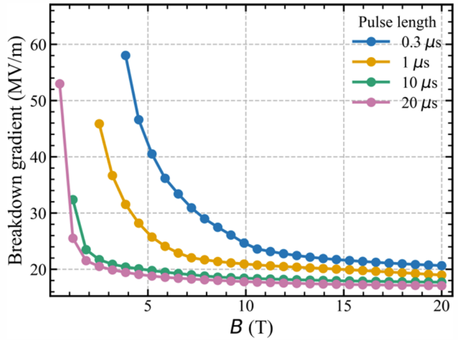
Realistic field maps used for “RF-track”ing

See talk on Tue
D. Merenich, NIU

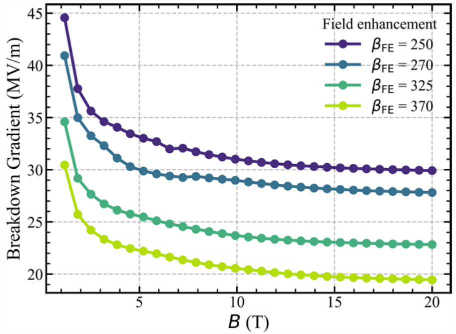
Copper and Beryllium Comparison



Sensitivity to RF Pulse and Field Enhancement



RF pulse length



Field-enhancement factor

Low temperature

Short pulse

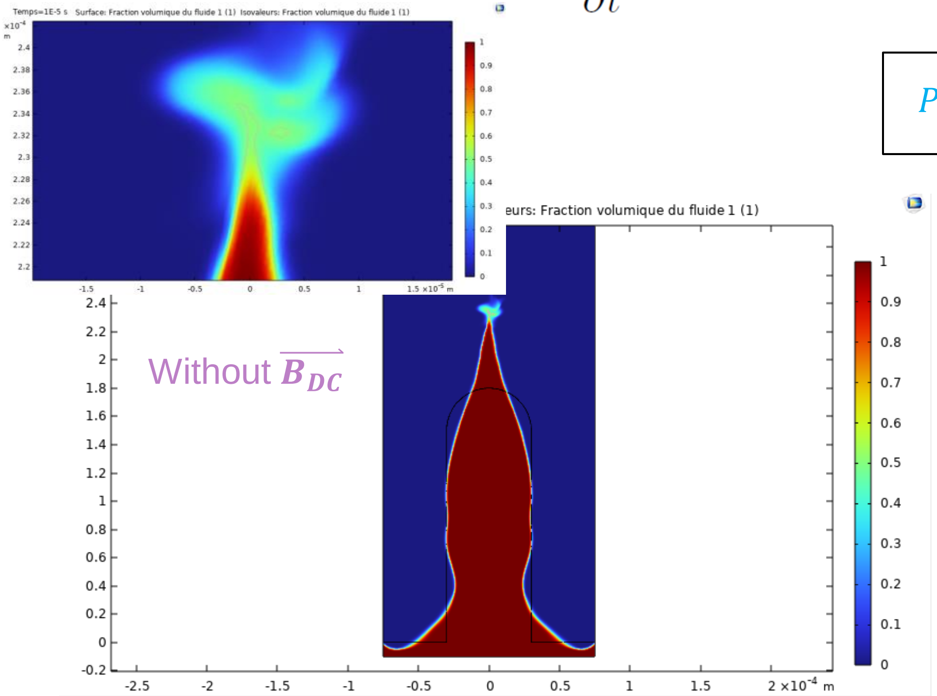
Different materials

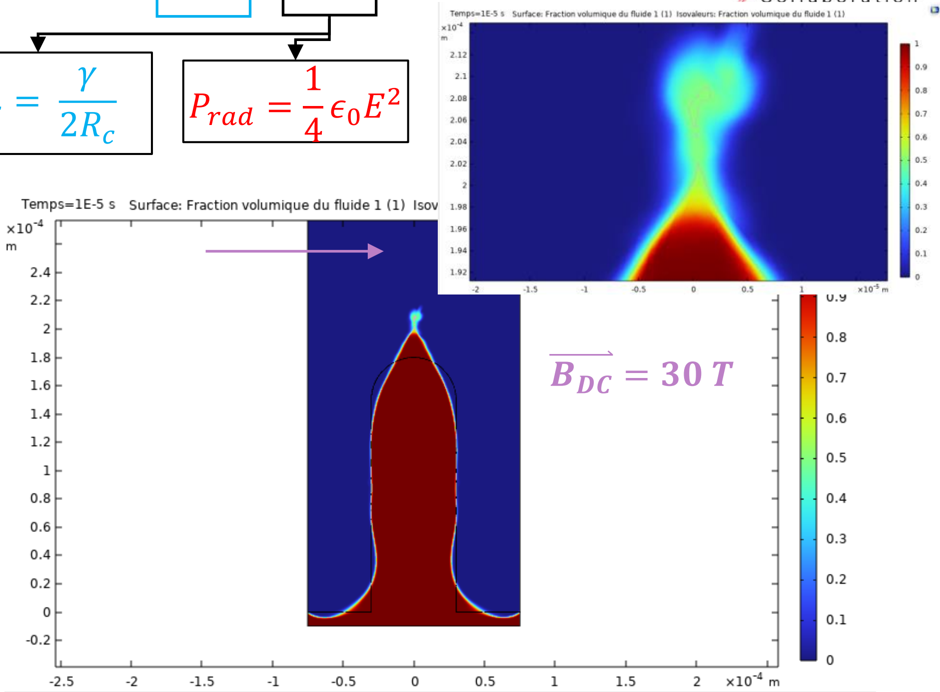
Magneto-hydrodynamic model of breakdown

Navier Stokes equation $$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}.\mathbf{grad})\mathbf{v}\right) = -\mathbf{grad}p + \tilde{\nu}\Delta\mathbf{v} + \mathbf{f}_{vol}$$

$$P_{ts} = \frac{\gamma}{2R_c}$$

$$P_{rad} = \frac{1}{4}\epsilon_0 E^2$$





$\overrightarrow{B_{DC}}$ will probably affect the amount and dynamics of copper detached

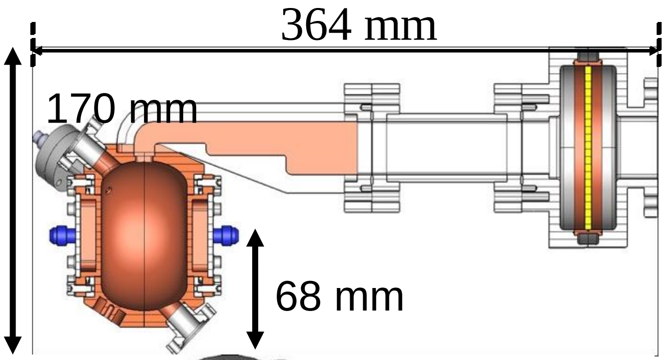
To this point : **no evidence of breakdown increase due to B field**

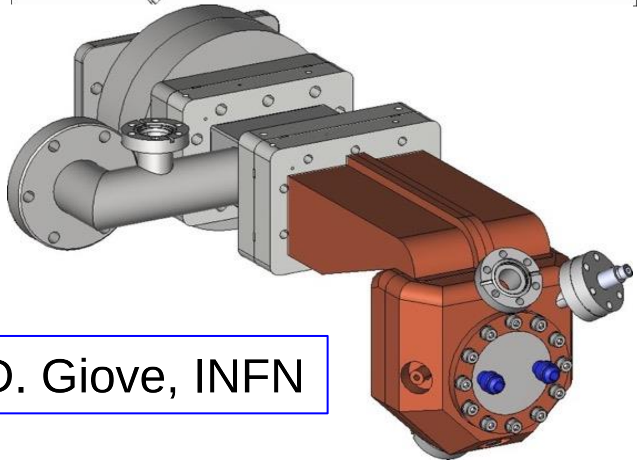
J. Plouin, CEA

R&D directions for cavity tests in high B field

- **Strong need of high gradient RF test stand(s) with strong B-field**
- Frequency: ideally 300 to 700 MHz range, but
- RF tests at higher RF frequency in **L, S, C and X-bands as well as DC** tests are very useful in studying and understanding the RF breakdown phenomena in **strong magnetic field**. They provides **important insights** on the achievable gradients and its dependence on the material, cavity geometry, RF pulse length, among others.
- **Gradients from 25 to 50 MV/m**
- **Magnetic field: ~10T, different field configurations**
- **Short RF pulses** (~10μs)
- Different materials and **Coatings**: Cu, Be, **Al**, Cu-alloys, **HTS(REBCO)**…
- Different temperatures: 300K -> **70K** ->…
- **Dielectric-loaded cavities**

INFN LASA RF in Magnetic Field Test Facility

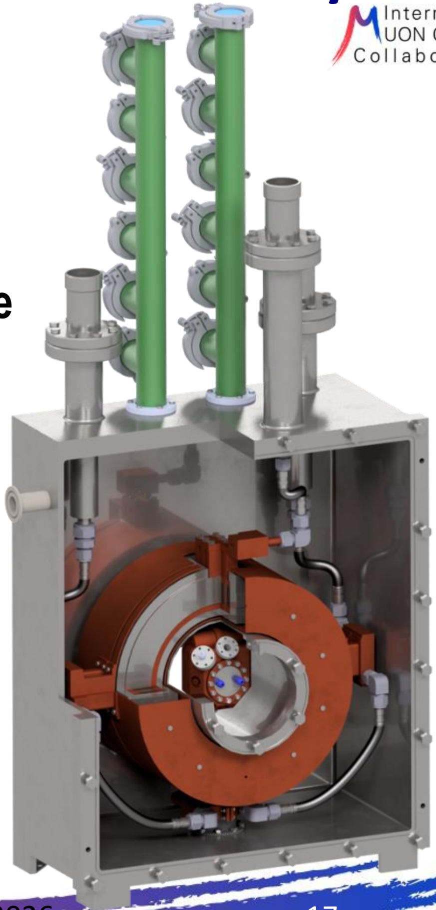




D. Giove, INFN

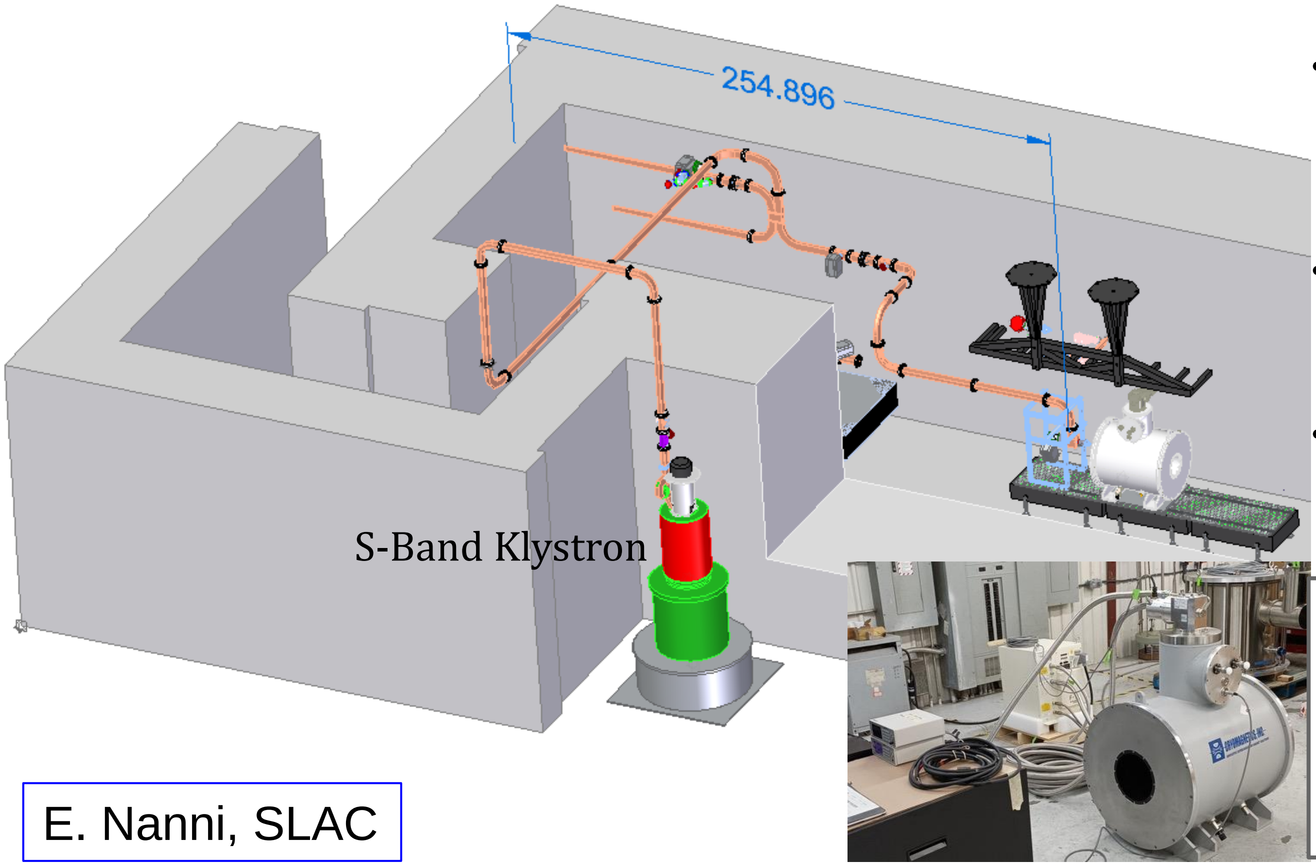
RFMFTF

- HTS split coils,
- 250 mm coil aperture,
- 170 mm room temperature free bore
- Axial B-field configuration: homogeneus + + or gradient + -
- Bz= 7 T to 10 T
- Gz = 68 T/m to 97 T/m
- S-band RF

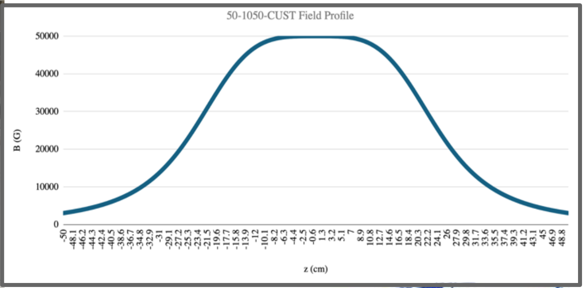


Courtesy M. Statera and E. De Matteis

NLCTA-SLAC Test Facility

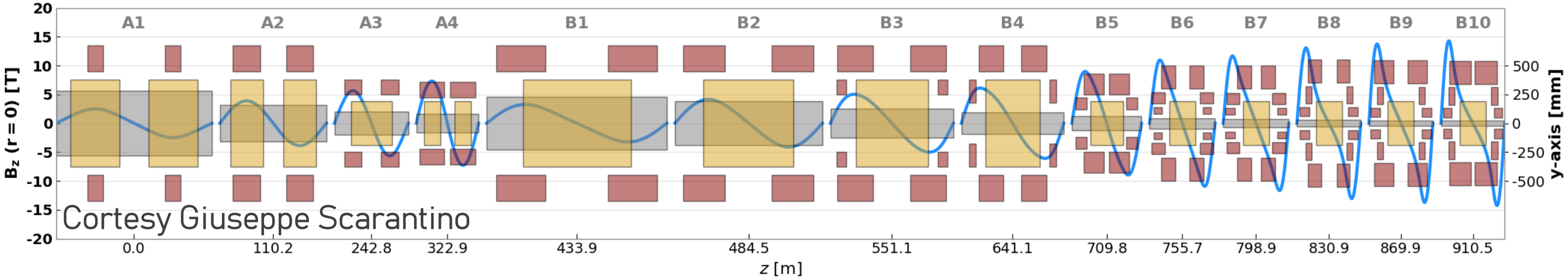


- 5 T Solenoid from Cryomagnetics with 9.5” diameter horizontal bore at room temperature
- First measurements planned with a single-cell S-band cavity in the fringe field
- Benchmark high gradient results for frequency scaling with measurements at S-band and L-band



E. Nanni, SLAC

RF cavities for 6D-cooling



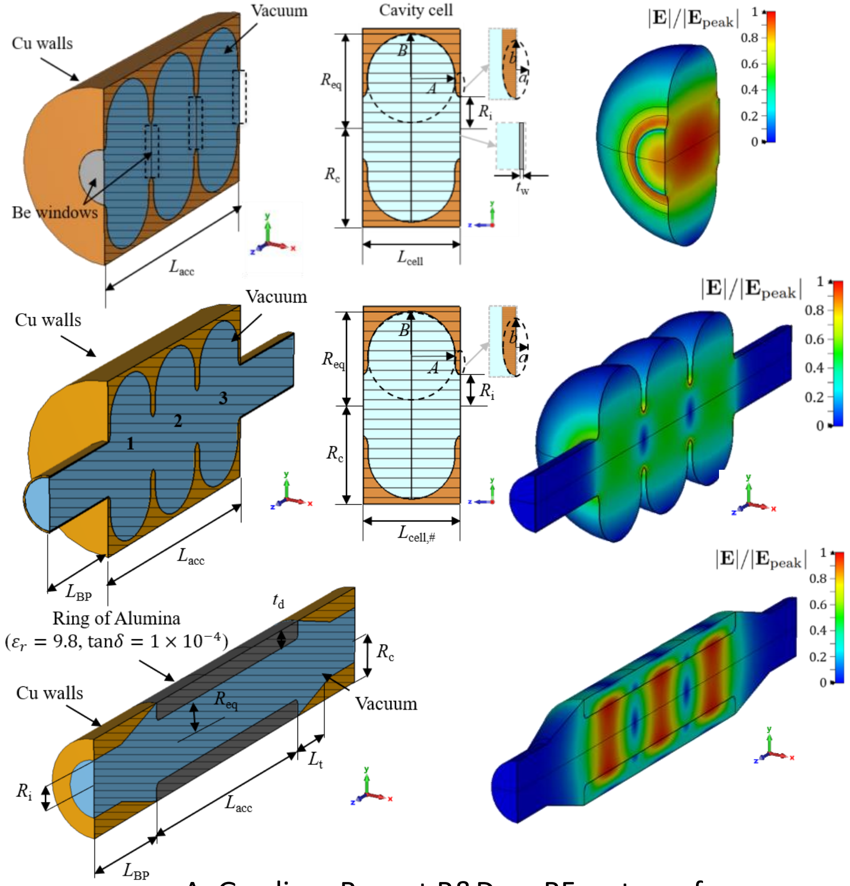
- Several cavity designs. Different parameters for each stage
- High gradient in strong B-field. Current baseline is Be-window closing each RF cell
- RF cavities are inside solenoids. Strong motivation for compact cavities

R. Zhu, https://doi.org/10.1103/PhysRevAccelBeams.28.041003

	Cell length (m)	Stage length (m)	Pipe radius (cm)	Max. on-axis B_z (T)	Integrated B_y (T·m)	Transverse beta (cm)	Dispersion (mm)	On-axis wedge length (cm)	Wedge apex angle (deg)	RF frequency (MHz)	Number of RFs	RF length (cm)	Max. RF gradient (MV/m)	RF phase (deg)
A-Stage 1	1.8	104.4	28	2.5	0.102	70	-60	14.5	45	352	6	19	27.4	18.5
A-Stage 2	1.2	106.8	16	3.7	0.147	45	-57	10.5	60	352	4	19	26.4	23.2
A-Stage 3	0.8	64.8	10	5.7	0.154	30	-40	15	100	704	5	9.5	31.5	23.7
A-Stage 4	0.7	86.8	8	7.2	0.186	23	-30	6.5	70	704	4	9.5	31.7	25.7
B-Stage 1	2.3	55.2	23	3.1	0.106	35	-51.8	37	110	352	6	25	21.6	28.2
B-Stage 2	1.8	61.2	19	3.9	0.138	30	-52.4	32	120	352	5	22	23.3	30.9
B-Stage 3	1.4	75.6	12.5	5.1	0.144	20	-40.6	24	115	352	4	19	24.9	29.8
B-Stage 4	1.1	67.1	9.5	6.6	0.163	15	-35.1	20	110	352	3	22	24.3	31.3
B-Stage 5	0.8	44	6	9.1	0.116	10	-17.7	12	120	704	5	9.5	22.5	24.3
B-Stage 6	0.7	38.5	4.5	11.5	0.0868	6	-10.6	11	130	704	4	9.5	31.2	19.8
B-Stage 7	0.7	35.7	3.7	13	0.0882	5	-9.8	10	130	704	4	9.5	29.5	17.8
B-Stage 8	0.65	44.85	2.65	15.8	0.0726	3.8	-7.0	7	140	704	4	9.5	28.1	14.0
B-Stage 9	0.65	34.45	2.25	16.6	0.0694	3	-6.1	7.5	140	704	4	9.5	29.7	11.9
B-Stage 10	0.63	30.87	2.1	17.2	0.0691	2.7	-5.7	6.8	140	704	4	9.5	24.9	12.2

Comparison of different cavities: FM

International MUON Collider Collaboration



Parameter	Unit	*Cavity with windows*	*Cavity without windows*	*Dielectric cavity*
f_0	MHz	704	704	704
L_{acc}	mm	567.86	551.07	567.79
R_i	mm	60	60	60
R_c	mm	192.63	195.59	**103.53**
β	-	0.8889	0.8889	0.8889
t_w	um	30	-	-
t_d	mm	-	-	36.28
E_{nom}	MV/m	22.50	22.50	22.50
Q_0	-	3.84E+04	3.92E+04	**6.98E+03**
t_f	us	19.63	20.02	3.57
DF	-	7.41E-05	7.57E-05	1.39E-05
TTF	-	0.65	0.68	0.60
R/Q (β)	Ω	**478.00**	**294.42**	**113.97**
P_{diss}	MW	**3.76**	6.14	**73**
$P_{diss,Be/Diel}$	MW	0.08	-	43.87
E_{peak}/E_{acc}	-	1.63	3.82	2.34
$E_{peak,Cu}$	MV/m	**23.80**	**58.34**	**7.10**
$E_{peak,Be/Diel}$	MV/m	**20.79**	-	**31.44**
P_g	MW	**4.51**	7.37	**87.60**
DFg	-	9.88E-05	1.01E-04	1.84E-05
$P_{ave,g}$	W	**445.99**	**740.50**	**2297.29**
$P_{plug,} = P_{ave,g}/\eta_G\eta_M$	W	707.92	1175.40	2552.54

Cavity radius

Q-factor

Peak power

E-fields

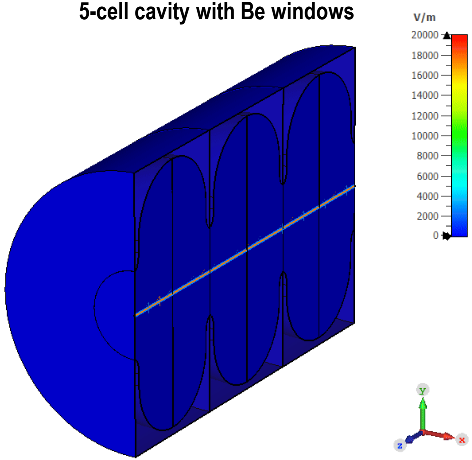
Peak power

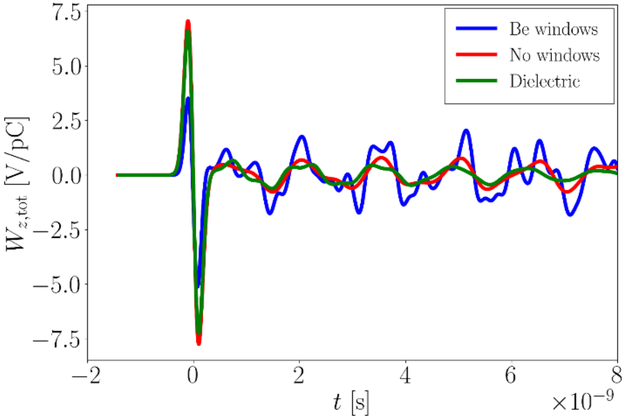
Average power

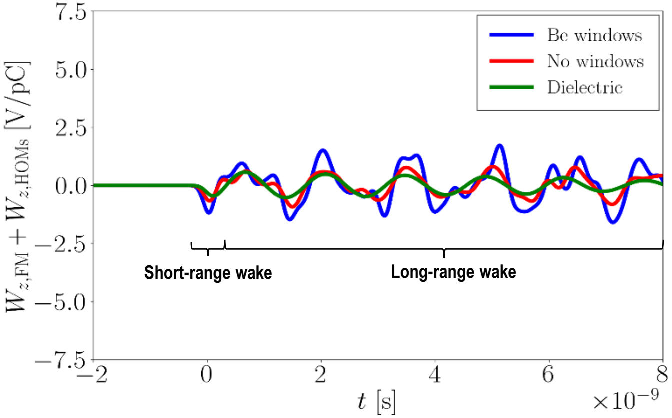
C. Barbagallo, CERN

Comparison of different cavities: Wakefields

5-cell cavity with Be windows







Total longitudinal wake potential (CST wakefield solver)*

$$W_{z,\mathrm{tot}}(t) = \underbrace{W_{z,\mathrm{FM}}(t) + W_{z,\mathrm{HOMs}}(t)}_{W^{\mathrm{finite}}_{z,\mathrm{eig}}(t,\sigma_t)} + W_{z,\mathrm{SC}}(t)$$

Finite-beam eigenmode wake potential (CST eigenmode solver)

$$W^{\mathrm{finite}}_{z,\mathrm{eig}}(t,\sigma_t) = \frac{1}{Q_b}\int_{-\infty}^{t} F_{n,\perp}(\sigma_t) W^{0}_{z,\mathrm{eig}}(t-t')\lambda(t')\,dt' \qquad W^{0}_{z,\mathrm{eig}}(t) = H(t)\sum_n \frac{\omega_n}{2}(R/Q)_n\, e^{-t/\tau_n}\cos(\omega_n t)$$

Transverse form factor

$$F_{n,\perp}(\sigma_t) = \int_0^{R_i} 2\pi r_s\,\rho_r(r_s)\sqrt{(R/Q)_n(r_s)}\,dr_s$$

Normalized transverse charge density

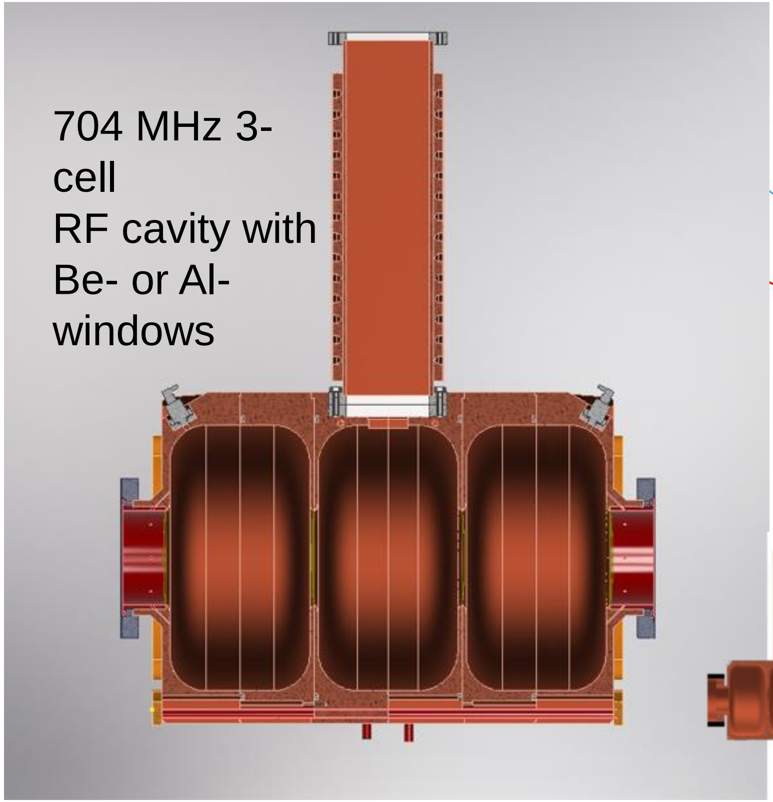
$$\rho_r(r_s) = \frac{1}{2\pi\int_0^{R_i} r'\exp\left(-\frac{r'^2}{2\sigma_t^2}\right)dr'}\exp\left(-\frac{r_s^2}{2\sigma_t^2}\right)$$

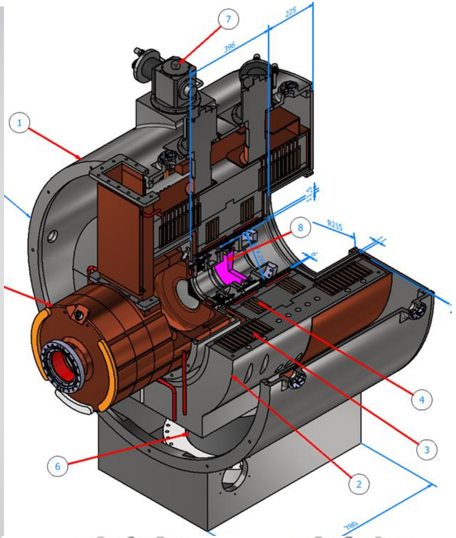
- **Be-windowed design:** Exhibits the highest mode excitation. This is due to the high field confinement introduced by Be windows
- **Windowless design:** Shows reduced wakefield excitation compared to the Be-windowed version, as the open iris allows a large fraction of long-range wakefields to escape the cavity
- **Dielectric cavities:** Achieves the lowest overall wakefield due to the lowest R/Q

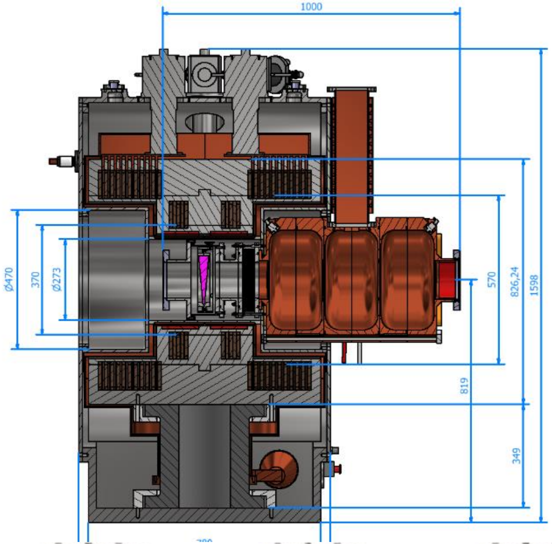
C. Barbagallo, CERN

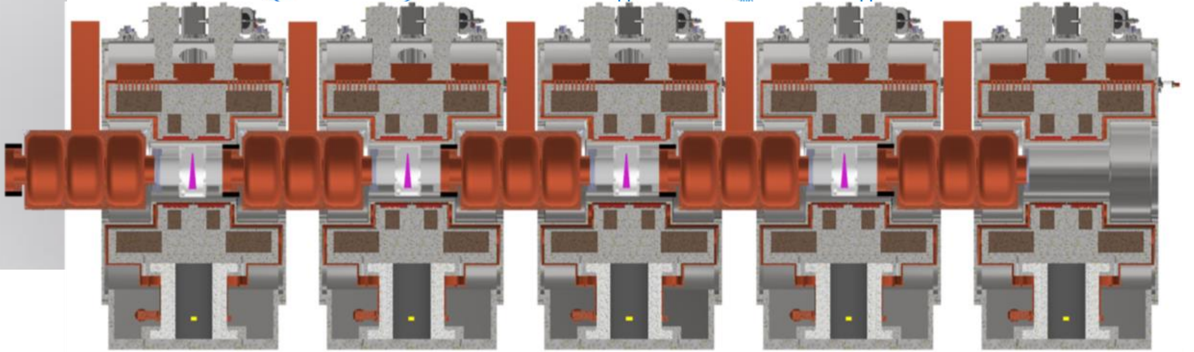
Integration study for 6D-cooling demonstrator

704 MHz 3-cell
RF cavity with
Be- or Al-
windows









L. Rossi, Uni. Milan & INFN

The ultimate cavity for 6D-cooling

70K

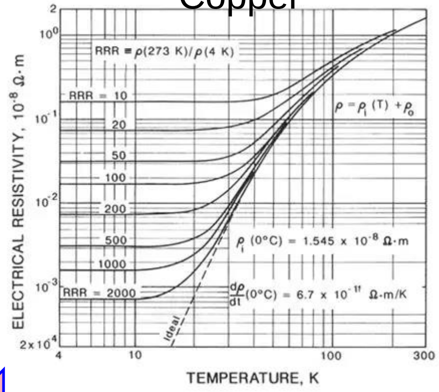
Sapphire(tanD=1e-8): 4 kW

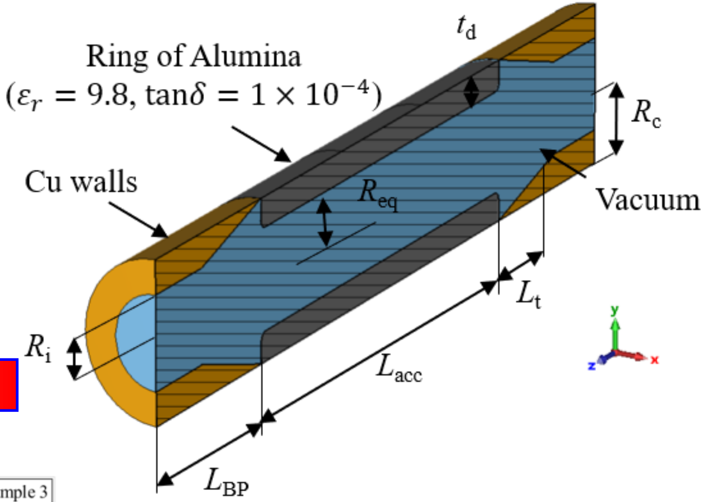
Copper walls: 10 MW

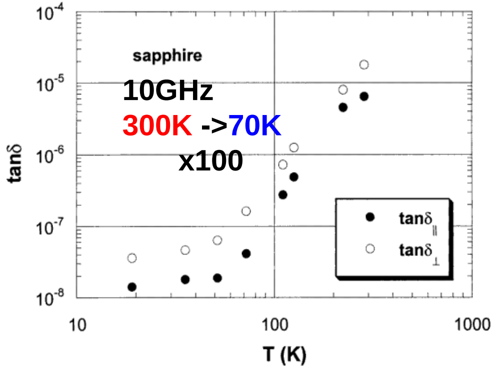
HTS walls: **~1 MW**

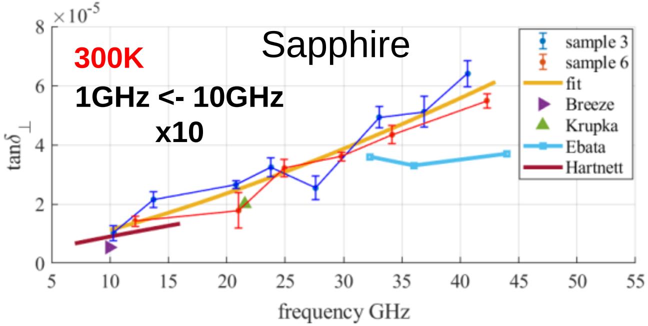
Sapphire-loaded cavity with HTS walls in common cryostat with HTS solenoid

Copper









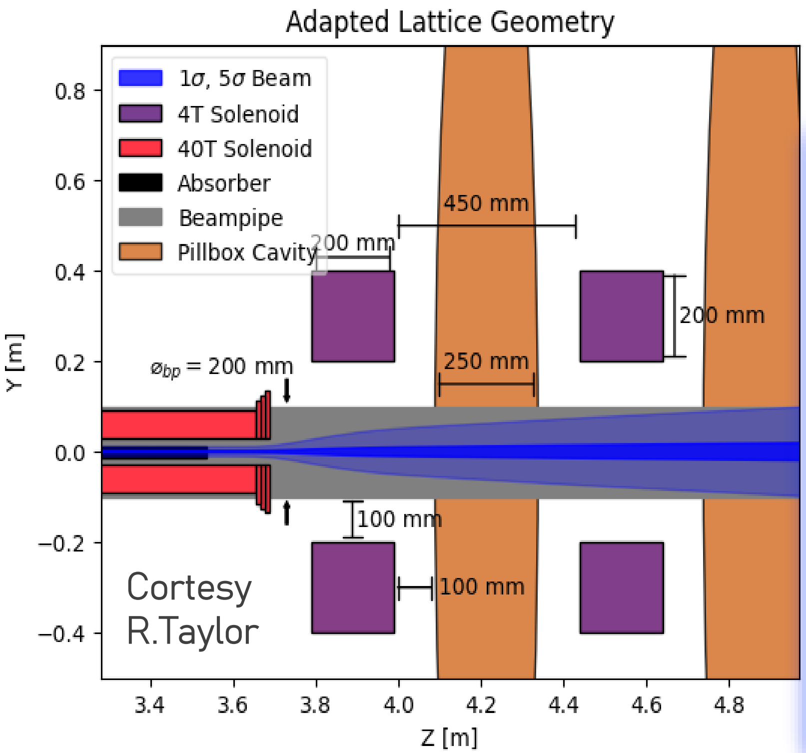
300K

Peak power loss: **73 MW**

Al2O3(tanD=1e-4): 44 MW

Copper walls: 29 MW

RF cavities for Final Cooling



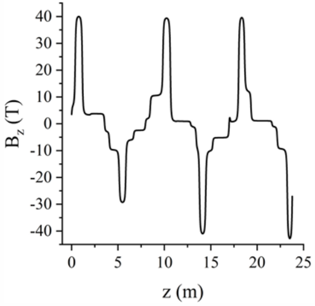
- Very long bunches result in the use of very low RF frequencies

Parameters of final cooling lattice

☐ Key parameters

	Stage length (cm)	Peak on-axis B_z (T)	Absorber length (cm)	RF frequency (MHz)	RF gradient (MV/m)	RF phase (°)	RF length (cm)
Stage 0	203.5	40	18.3				
Stage 1	465.6	-29.3	25.5	131.8	6.6	14.5	150
Stage 2	462.8	39.4	5.5	56.3	4.4	31.4	125
Stage 3	389	-41	2	25.5	2.9	17.4	150
Stage 4	412.4	39.6	1.5	14.8	1.7	45.6	175
Stage 5	506.8	-42.7	0.92	11.5	1.3	41.3	225

☐ On-axis field



- Non-periodic Bz field. Maximum on-axis Bz is around **40 T**.
- The cooling channel consists of 6 stages with **length of ~24.4 m**.
- RF frequency reduces from **131.8 MHz to 11.5 MHz**. (probably need induction linacs for stage 4 and 5, f_{RF}<20 MHz)

Cortesy R.Zhu

“Compact” cavities for final cooling at 100, 30 and 10 MHz, Rcav<1m

Parameter	Unit	100 MHz Reentrant - Cu	30 MHz AL_2O_3 insert - Cu Reentrant - water	10 MHz Al_2O_3 2.5cm ring /water loaded Reentrant	Description
R_{cav}	[mm]	880.00	880.00	889.7	Cavity radius

Accelerating fields

Parameter	Unit	100 MHz	30 MHz	10 MHz
E_{nom}	[MV/m]	10	6.4	3.71
E_{acc}	[MV/m]	9.7	6.4	3.71
V_{acc}	[MV]	2.42	1.6	0.927
E_{peak}/E_{acc}	[-]	1.41	1.50	1.56

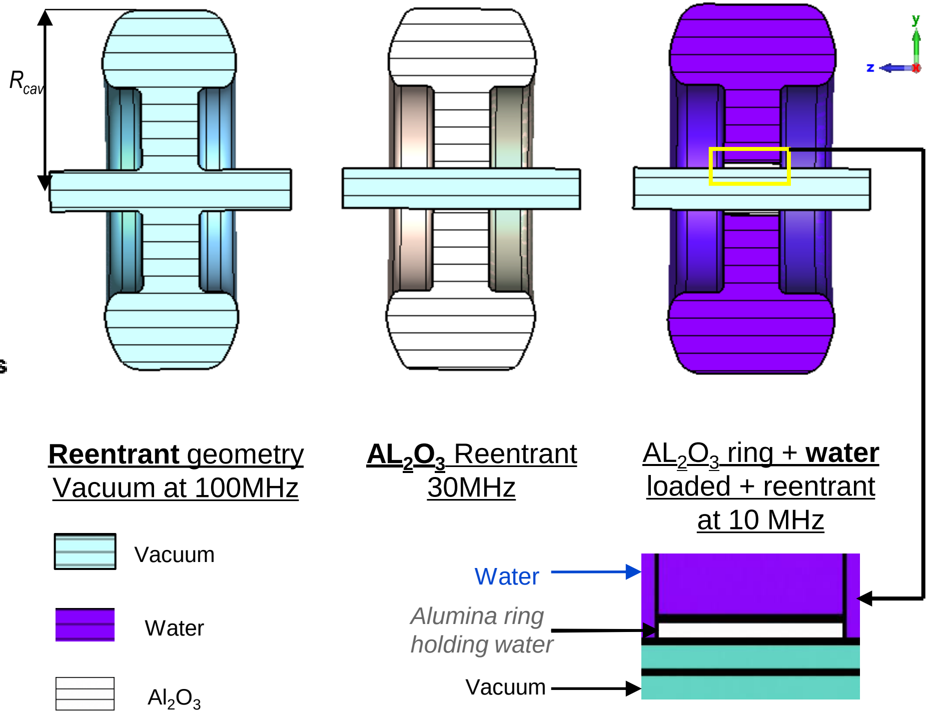
RF figures of merits

Parameter	Unit	100 MHz	30 MHz	10 MHz
R_{cav}	[mm]	880.00	880.00	889.7
Q_0	[-]	4.09e4	7293	1742
t_f	[µs]	147.12	87.40	62.64
DF	[-]	55.30e-5	32.87e-5	23.58e-5
TTF	[-]	0.970	0.999	0.999
R/Q	[Ω]	111.78	36.47	13.13
$P_{diss,tot}$	[MW]	1.29	9.6	37.3
$P_{ave,tot}$	[W]	713	3146	8798
$P_{loss\%dielectric}$	[-]	[-]	68%	87%

Very high peak power due to loss in dielectric

Generator power

Parameter	Unit	100 MHz	30 MHz	10 MHz
Pg	MW	1.55	11.52	44.76
DFg	-	7.36e-4	4.37e-4	3.13e-4
Pave,g	kW	1.14	5.03	14.0



E. Mortreuil, CERN

Conclusions and Outlook

- The MC promises a potentially energy-efficient path toward high-luminosity collisions at a parton centre-of-momentum energy of 10 TeV
- 10-year resource loaded R&D plan towards CDR developed by IMCC
- High gradient RF in strong magnetic field test stand are extremely important to understand the limitations and develop RF technology for muon cooling
- Dielectric-loaded RF cavities for muon cooling offer several advantages: compactness, no Beryllium, high gradient potential
- Low loss dielectric materials and low temperature operation are promising directions to mitigate the high peak power required by dielectric loaded cavities
- R&D on high gradient RF and dielectric cavities has synergies between MC and AA communities

International
MUON Collider
Collaboration

CERN

Thank you
for your attention

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