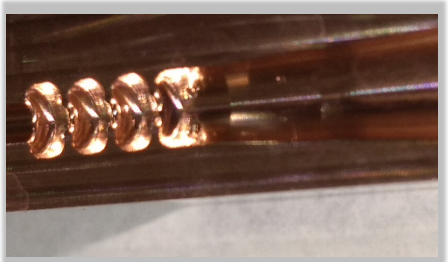
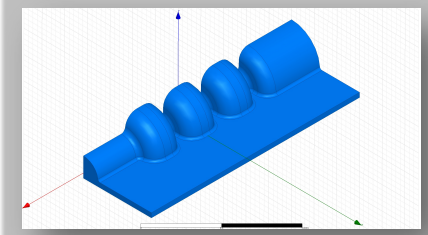
RF per Acceleratori ad alto gradiente e strutture dielettriche

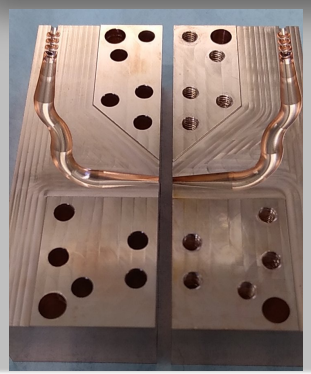
Giuseppe Torrisi

Giornata sulla radiofrequenza nell'INFN - 13 settembre 2021

W-band <u>metallic</u>
<u>open structures</u>





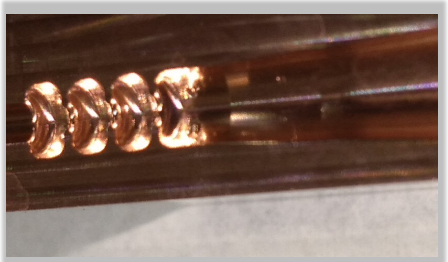


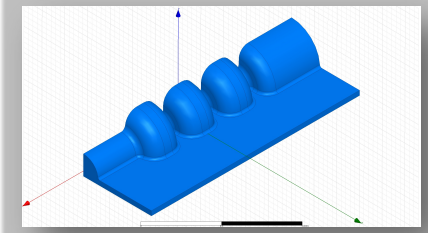
Strutture acceleranti ad alto gradiente:

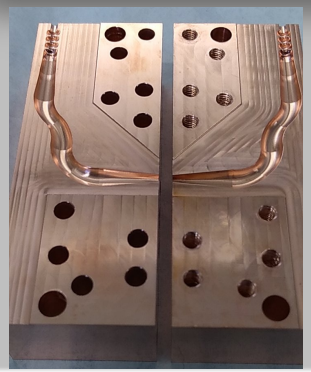
from ***mm-size Ka and W-band <u>metallic accelerating structures</u>***

new technologies promising gradients
from several **100 MV/m** to some **GV/m**

W-band metallic open structures





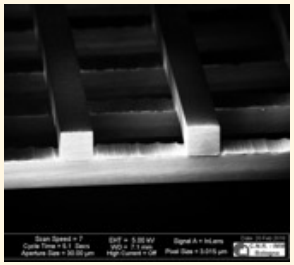


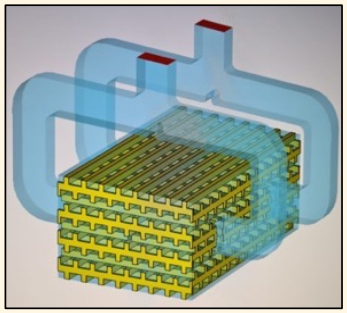
Strutture acceleranti ad alto gradiente:

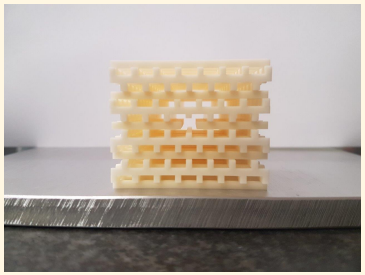
from ***mm-wave Ka and W-band metallic accelerating structures***
to infrared laser-driven dielectric "accelerator on a chip"

new technologies promising gradients
from several **100 MV/m** to some **GV/m**

laser-driven dielectric structures







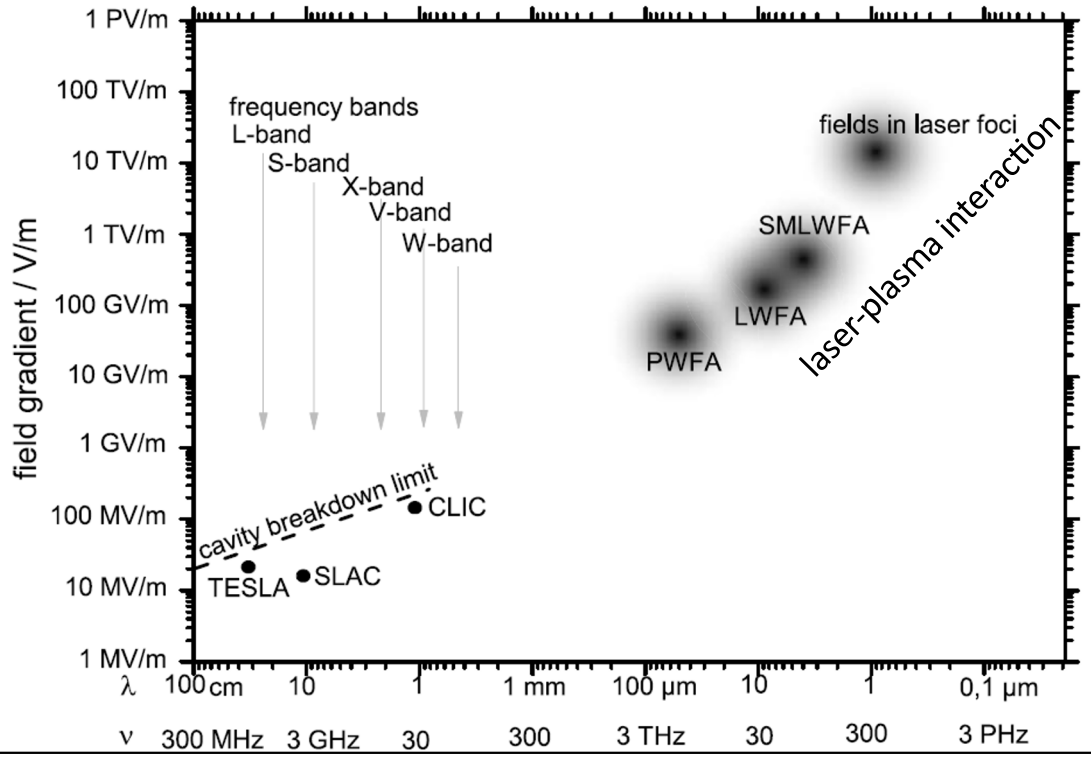
TARGET

Accelerating Gradient: ~ 100 MV/m - 2 GV/m

1) **Metallic Structure from Ka to W-band (35-200 GHz, mm-wavelength)**

2) **Dielectric Laser Accelerator (DLA) structures operating at optical wavelengths (~ 1- 5 µm)**

schematic overview of the accelerating gradient for different types of accelerators



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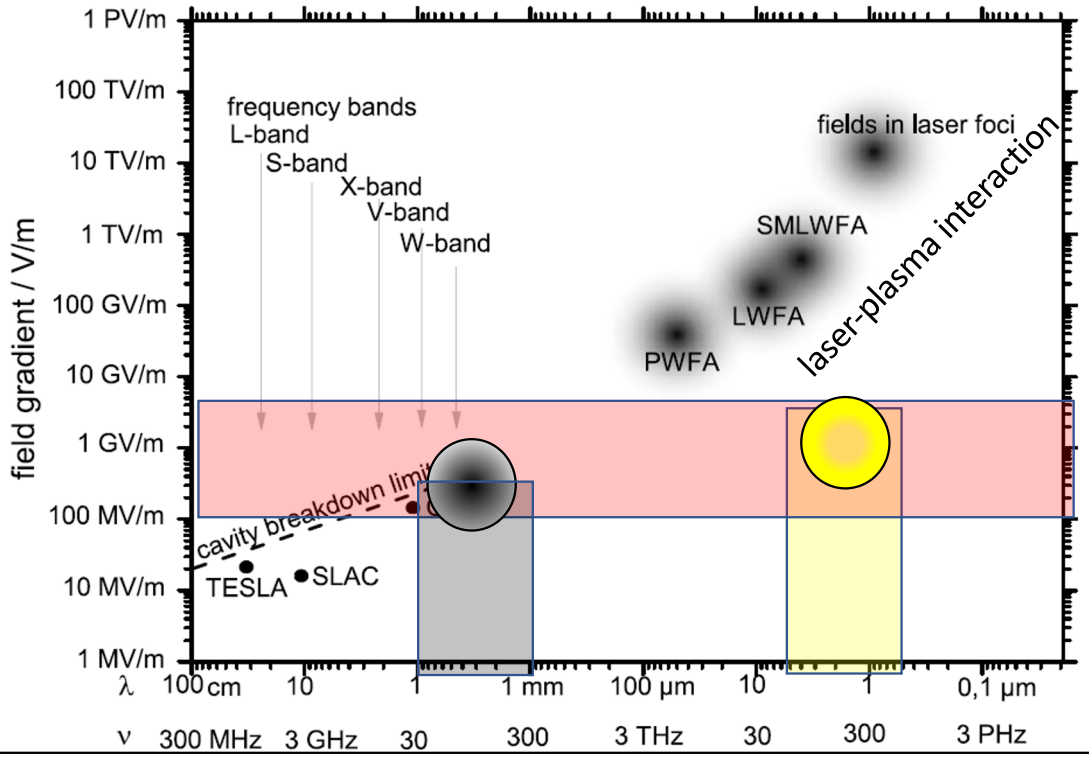

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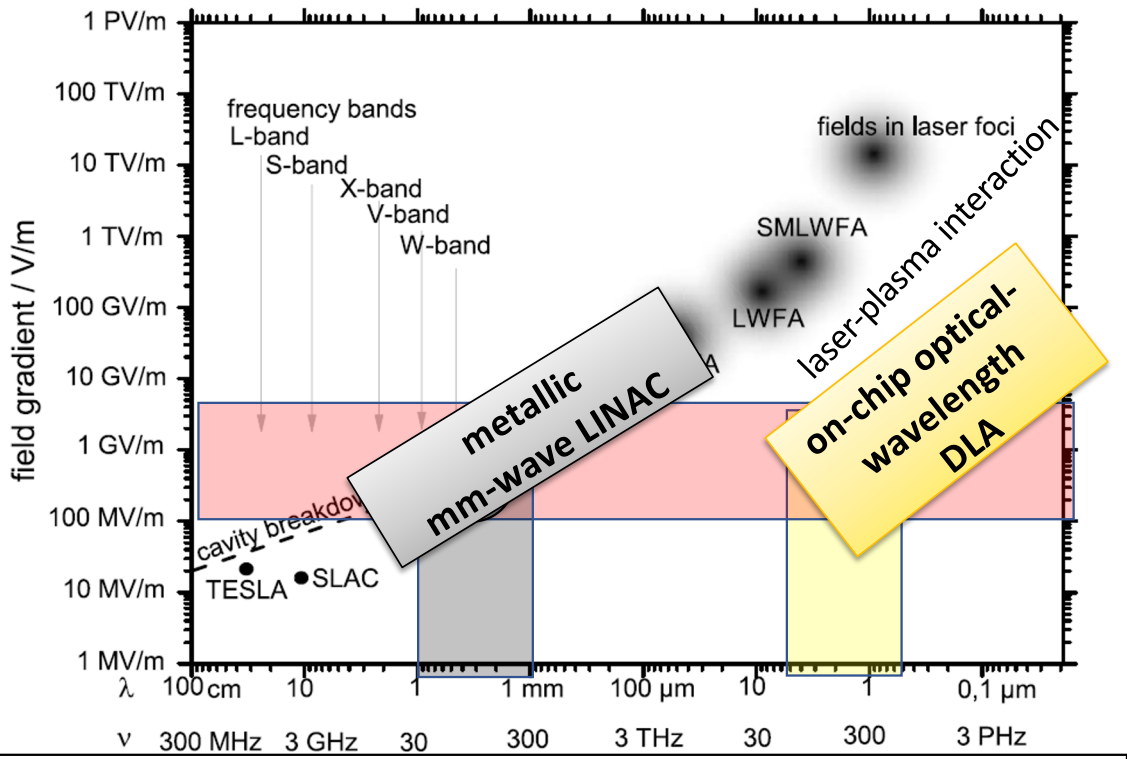


Expertise, Activities, Facilities

DIIEI

Expertise

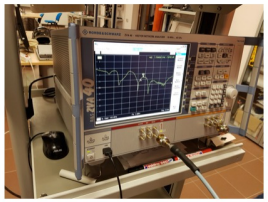
- EM simulation (COMSOL RF module, CST MW Studio, Ansys HFSS, package MIT Photonic–Bands (MPB))
- Inverse scattering EM optimization (design)
- Computational Electromagnetism
- Accelerating structure RF design
- Microwave Imaging Profilometry (diagnostics)
- Antenna Design

Activities/Interests

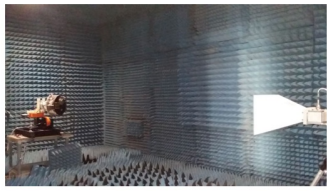
- **RF Power coupler/mode launcher** design
- Design of metallic mm-wave (W-band ~100 GHz) “open” structures for high-gradient study
- Design of **dielectric waveguide**, based on **photonic crystal structures**, for high-gradient Dielectric Laser Accelerators (DLAs).
- RF /Microwave “cold” characterization

Available Facilities

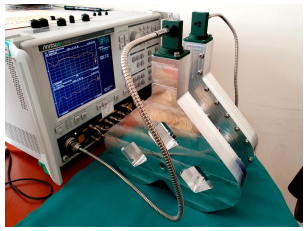
- Microwave laboratory (up to 50 GHz)
- Anechoical chamber
- Bead pull



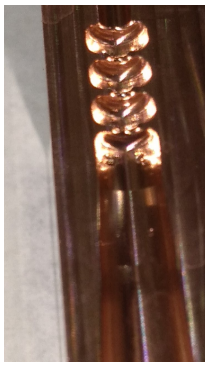
RF & Microwave

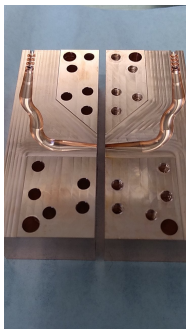


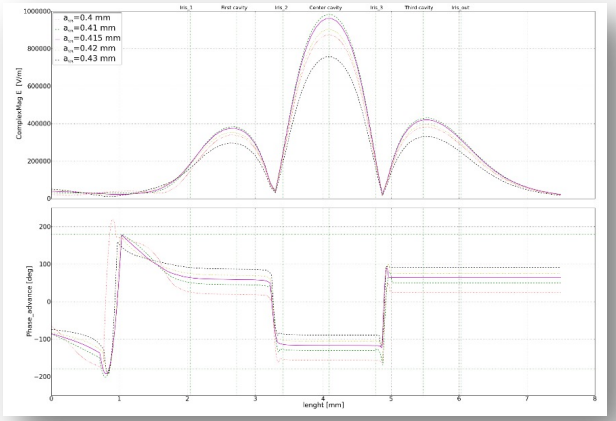
Antenna Test Range



100 GHz Open Accelerating Structure Experiments Show Possibility of ~ 0.5 - 1 GeV/m Accelerators

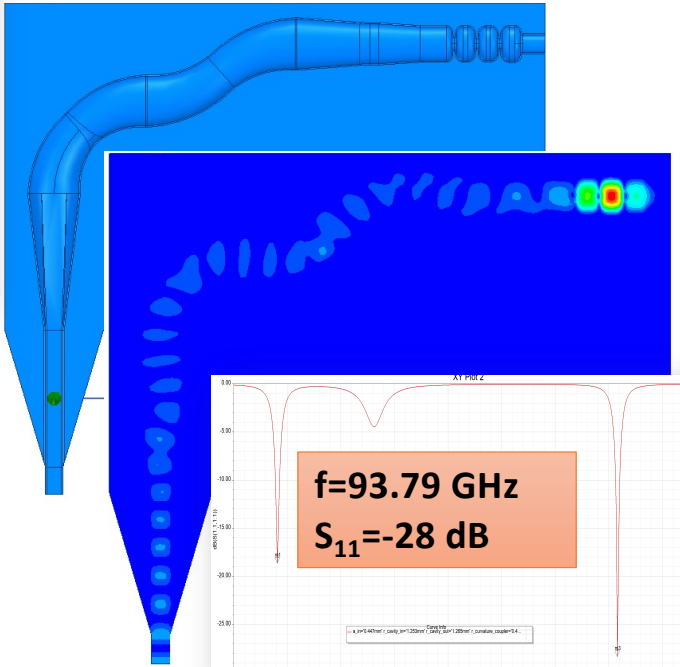


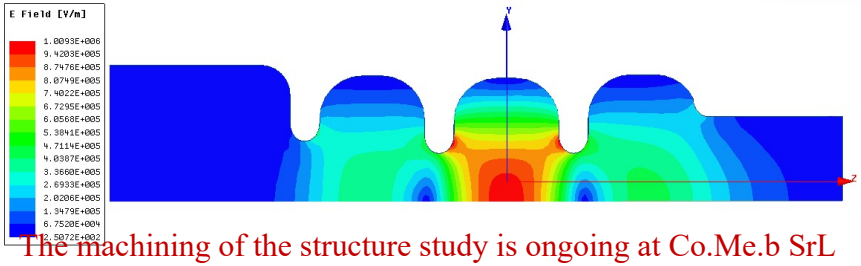




Open TE11-to-TM01 snake mode converter

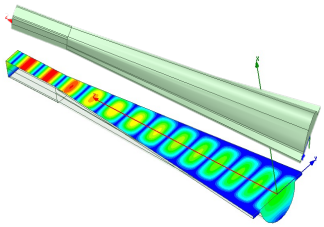
Open Standing wave cavities





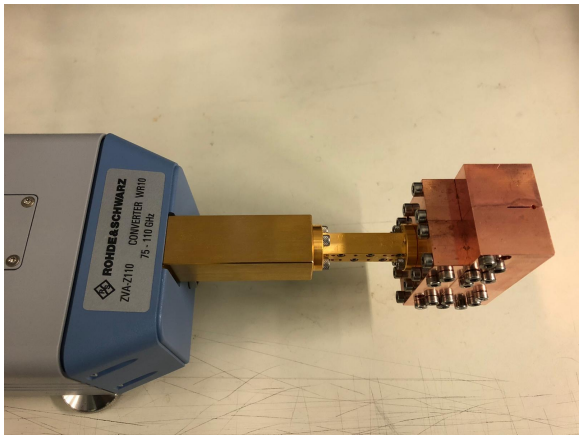
The machining of the structure study is ongoing at Co.Me.b SrL (Roma).

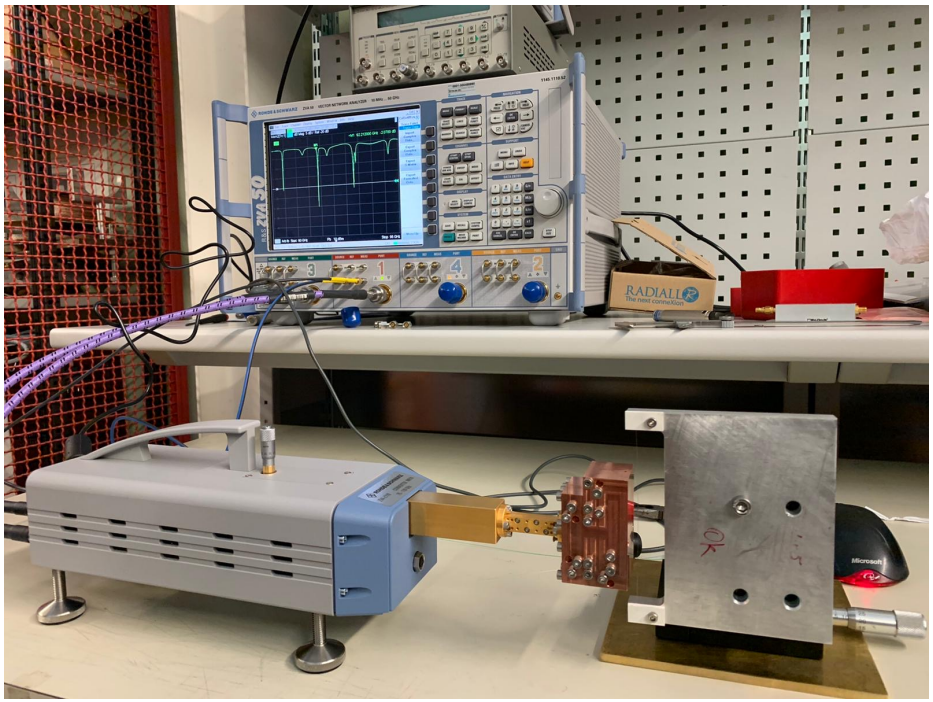
RF characterizations has been carried out @ LNF, LATINO

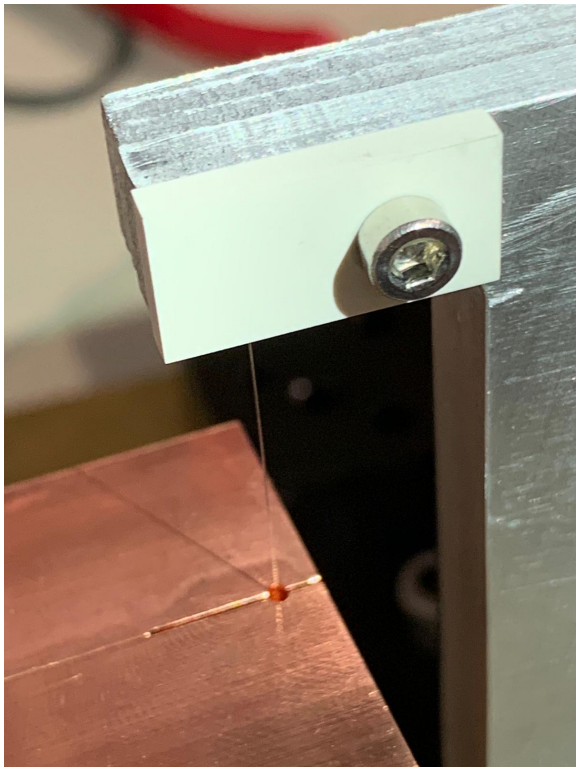


***Closed-open** adapter*

Measurements @ INFN-LNF, LATINO

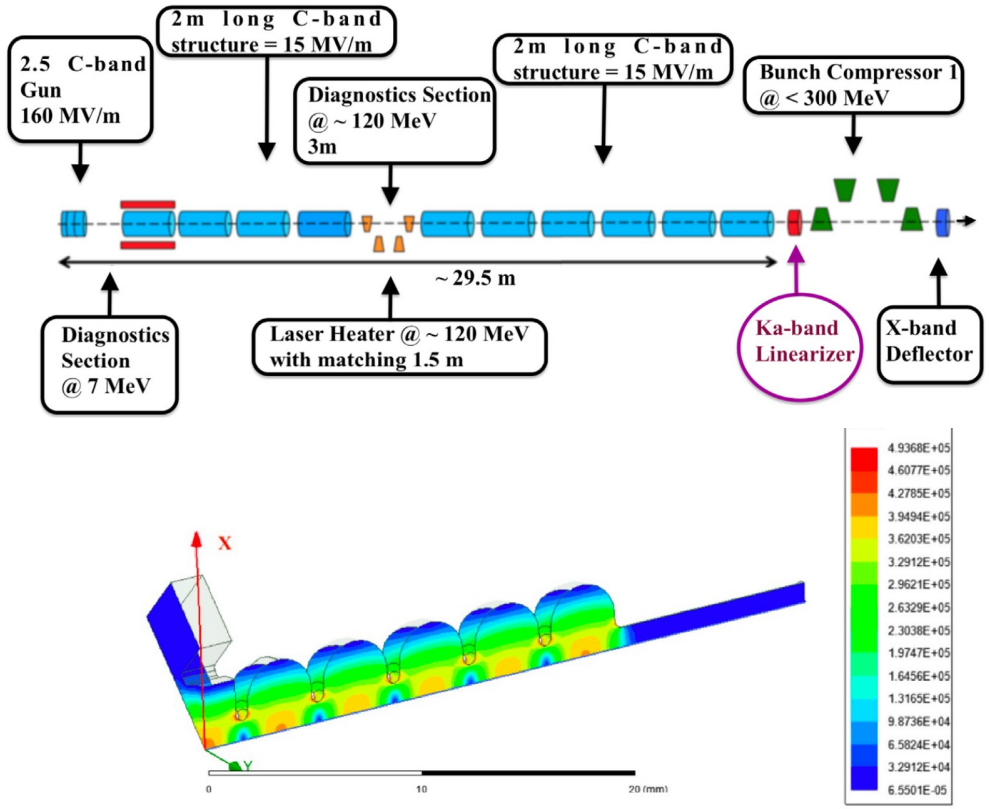






Design of a compact Ka-Band Mode Launcher for High gradien Accelerators

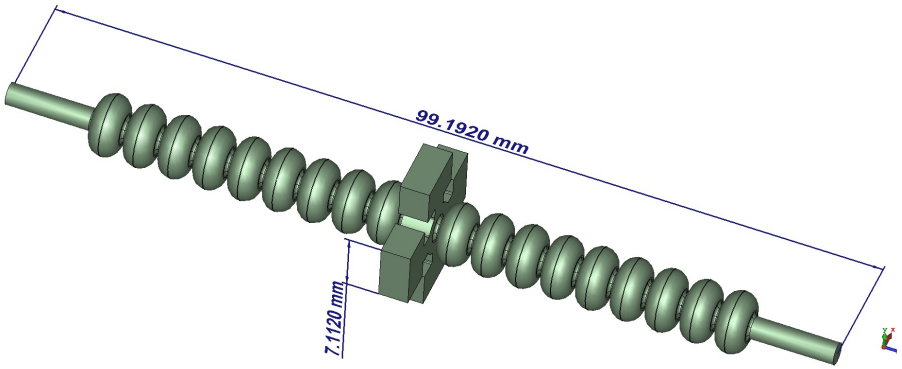
A Ka-Band accelerating structure as a linearizer for the UCXF project at UCLA



34 GHz cavity for the UCXF at UCLA

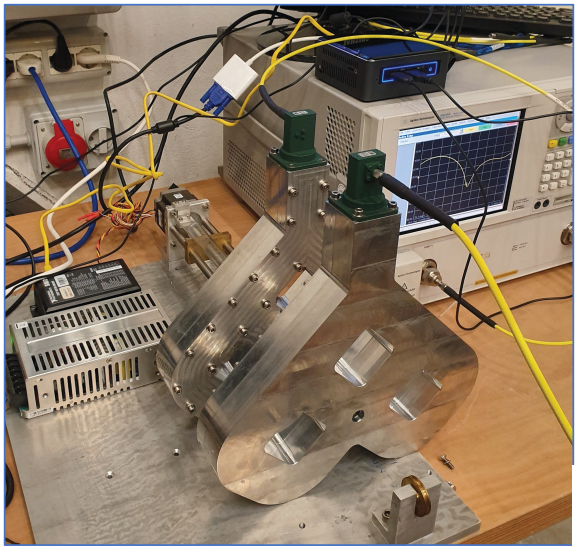
E_{acc}=125MV/m

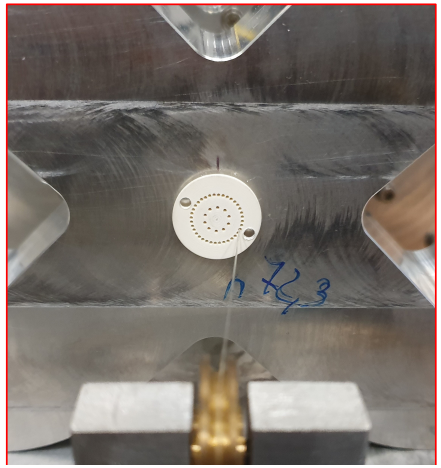
Main RF Parameters	
Frequency	35.982 GHz
Accelerating Gradient	100 MV/m
Shunt Impedance	158 MΩ/m
Quality Factor Q_0	4110

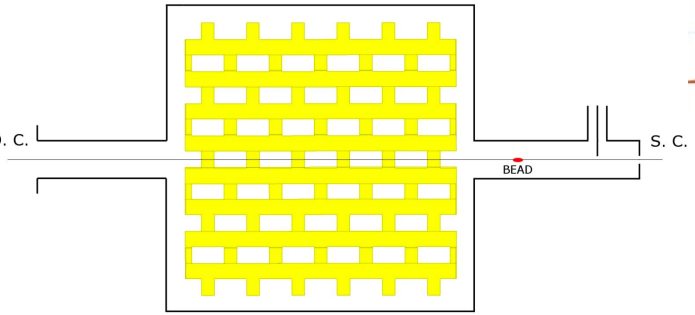


[M. Behtouei et al; NIM A: 984, 2020, 164653, https://doi.org/10.1016/j.nima.2020.164653.
G. S Mauro et al;" Design of a compact Ka-Band Mode Launcher for High gradient Accelerators ", IPAC21']

Measurement of local Electric Field profile

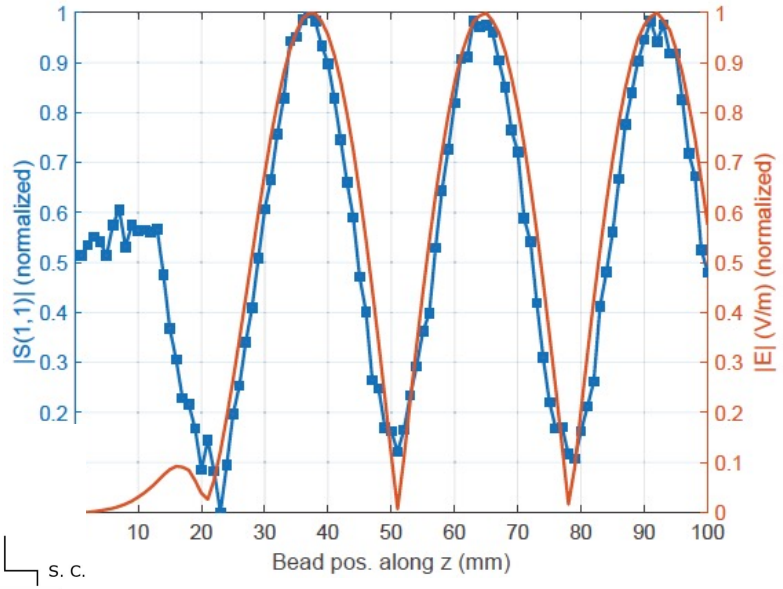






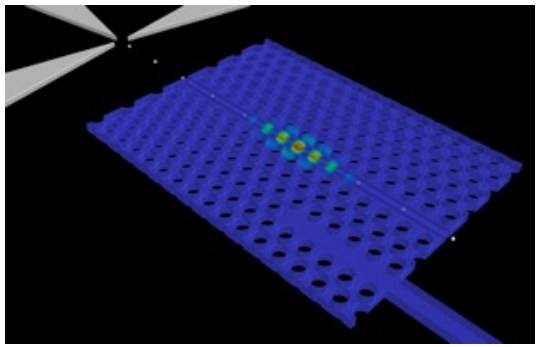
Bead-pull setup used for the E-fi mode launcher circular wavegu

TW Steele method
SW



Measured |S11| values VS bead position (blue curves) and comparison with HFSS electric field simulations (red curves)

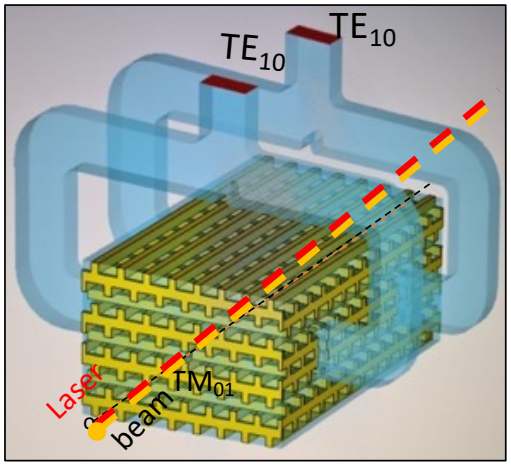
Photonic Crystal (PhC)-based Dielectric Laser Accelerator (DLA)



*DLA **high-Q photonic-crystal cavity***
[courtesy of C2N]

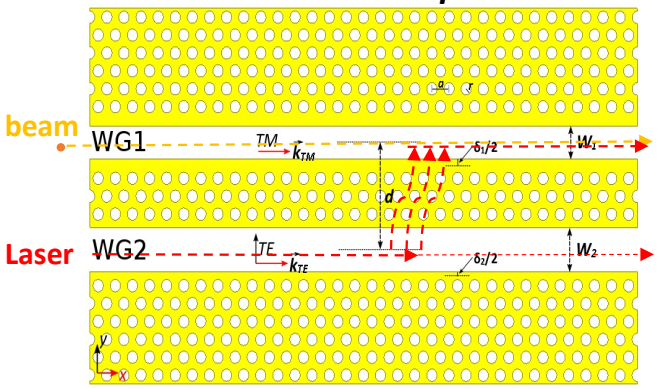
LoI Core Ideas:

- **Hollow-core waveguides** for high power handling
- **Collinear** co-propagating laser and particle beam
- **High interaction impedance** Z_c and accelerating gradient
- **Continuous wave** (CW) laser operation (1-5 μm)



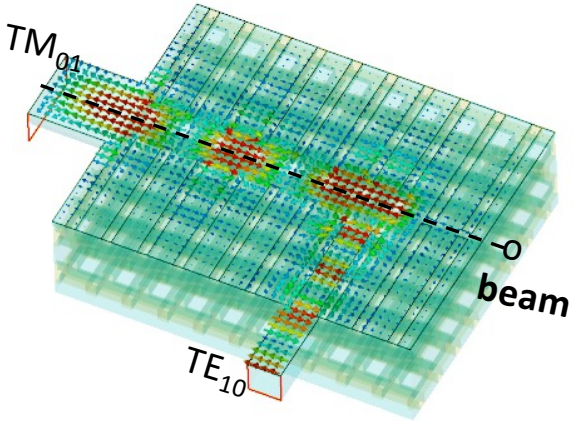
*3D Silicon **Woodpile mode launcher***

***2D** longitudinal Photonic Crystal*
Directional Coupler



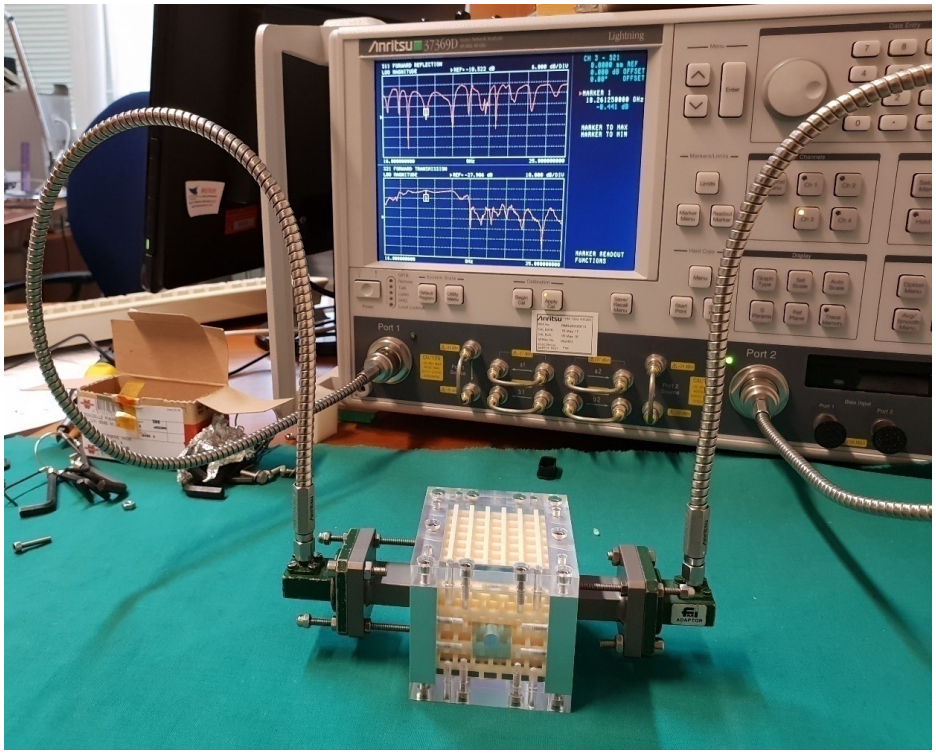
[G. Torrisi *et al* 2019 *J. Phys.: Conf. Ser.* **1350** 012060]

3D woodpile hollow-core mode converter

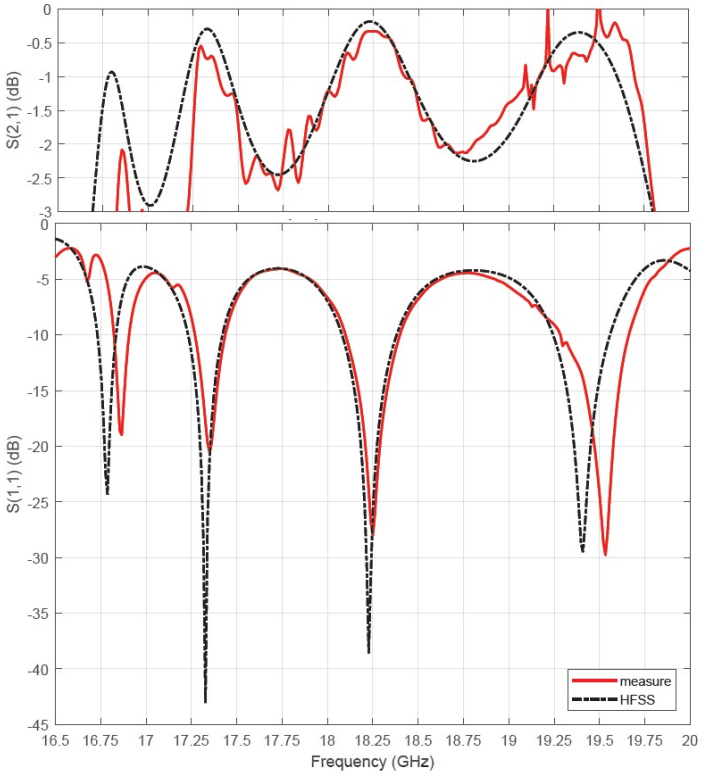


[G. S. Mauro et al;. submitted for 15th Metamaterials Conf. (Aug. 2021)]
[Ziran Wu et al; Phys. Rev. ST Accel. Beams 17, 081301

UniCT-LNS RF lab up to 40 GHz



EBG waveguide testbench.

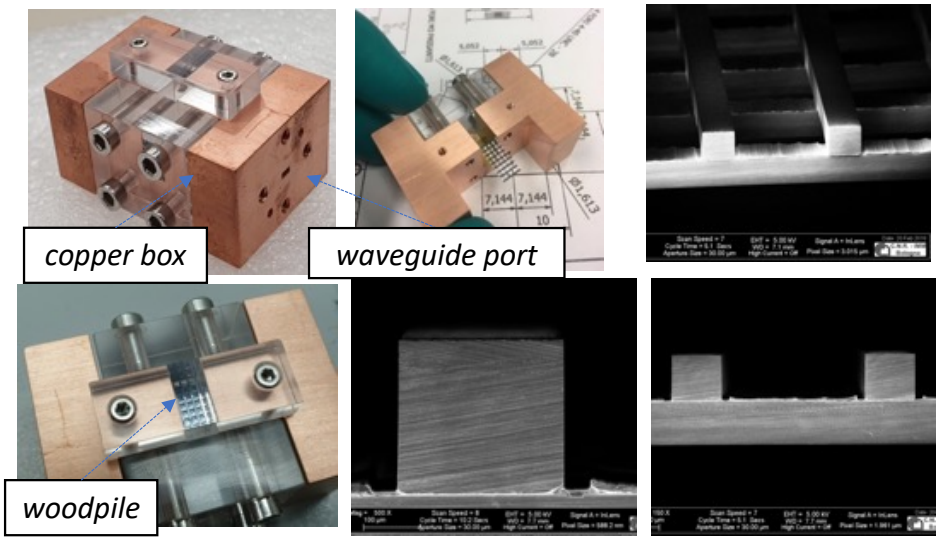


S(2,1) (top figure) and S(1,1) (bottom figure) of the realized woodpile EBG waveguide prototype vs HFSS results.

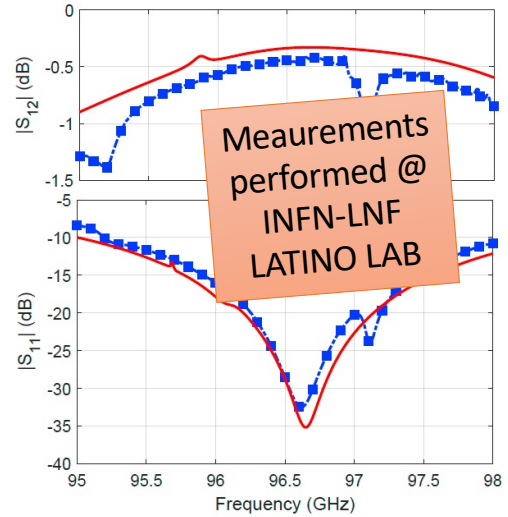
Silicon woodpile waveguide: fabrication & cold test at scaled at mm-wave frequencies

- high speed and **precision dicing saws**
- **silicon wafers** 850 µm thick with resistivity > 3 kΩcm
- **stacking together 9 silicon** layers
- **geometrical tolerance of 10 µm**

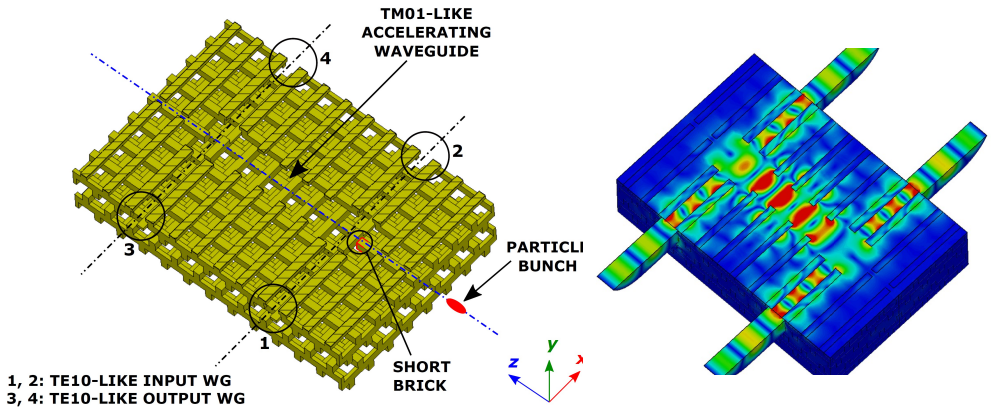
Design is frequency independent and valid at any working wavelength.



Manufactured dielectric PhC woodpile structure



Simulated vs Experimental S-parameters



[G. Torrisi *et al.*, *IEEE Microwave and Wireless Components Letters*, vol. 30, no. 4, pp. 347-350, 2020]

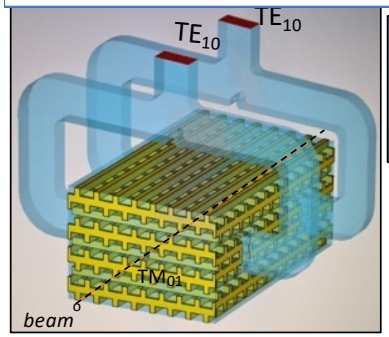
manpower

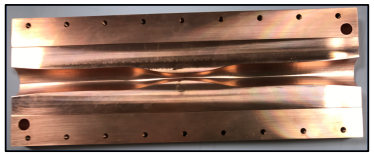
	LNS	
	NOME	FTE
INFN-LNS	Giuseppe Torrisi	50
	David Mascali	10
	Giorgio S. Mauro	50
UniCT	Gino Sorbello	40
	Loreto Di Donato	30
	Santi Pavone	25
UniRC	Nunzio Salerno	60
	Tommaso Isernia	30
	TOT	295

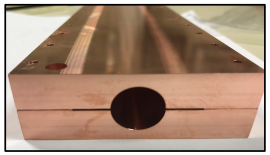
RF breakdown of accelerating-structure (more “fundamental” challenge)

Geometrical effect

- **Photonic band gap**
- **Open/jointless structures (**Novel geometry: open structure – no RF currents through the joint**)**



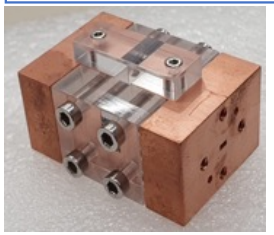


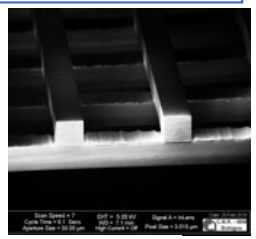


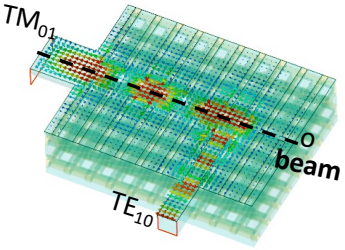
*3D Silicon **Woodpile mode launcher***

Advanced concepts

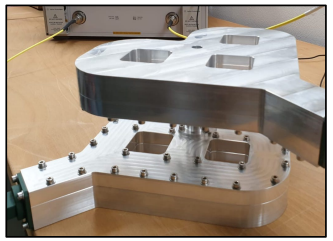
- **Photonic band gap**
- **all dielectric structures for DLA (Dielectric Laser Accelerators) at optical wavelengths (infrared)**

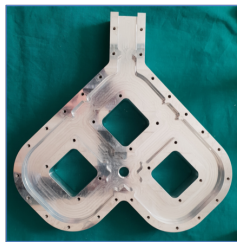




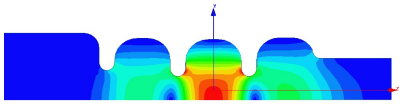


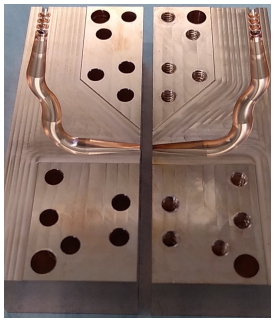
Efficient coupler/mode launcher





Frequency Scaling up to mm-wave





LNS **outputs** from **DEMETRA project** (*INFN Comm. V 2015-18, Resp. Nazionale: Prof. G. Sorbello*)

Geometrical effect

- **Photonic band gap**
- **Open/jointless structures**

- [G. Torrisi et al; “Synthesis of open structures starting from closed-cross-section waveguide devices’, IET Microwaves, Antennas & Propagation, 2020, 14, (13)]
- [G Torrisi .et al; ”Closed-to-open conversion of a mm-wave Gaussian Horn Antenna”, IET Conference Proceedings, 2018]

Advanced concepts

- **Photonic band gap**
- **all dielectric structures for DLA (Dielectric Laser Accelerators) at optical wavelengths (infrared)**

- [G. Torrisi *et al*., "Design and Characterization of a Silicon W-Band Woodpile Photonic Crystal Waveguide," in *IEEE Microwave and Wireless Components Letters*, 30, 4, 2020]
- [G. S. Mauro *et al*., "Fabrication and Characterization of Woodpile Waveguides for Microwave Injection in Ion Sources," in *IEEE Transactions on Microwave Theory and Techniques*, 68, 5, 2020]
  [G. Torrisi *et al* 2019 *J. Phys.: Conf. Ser.* **1350** 012060]
- [A. Locatelli, G. Sorbello, G. Torrisi, L. Celona and C. De Angelis, "Photonic crystal waveguides for particle acceleration," 2017 Progress In Electromagnetics Research Symposium - Spring (PIERS), St. Petersburg, Russia, 2017]

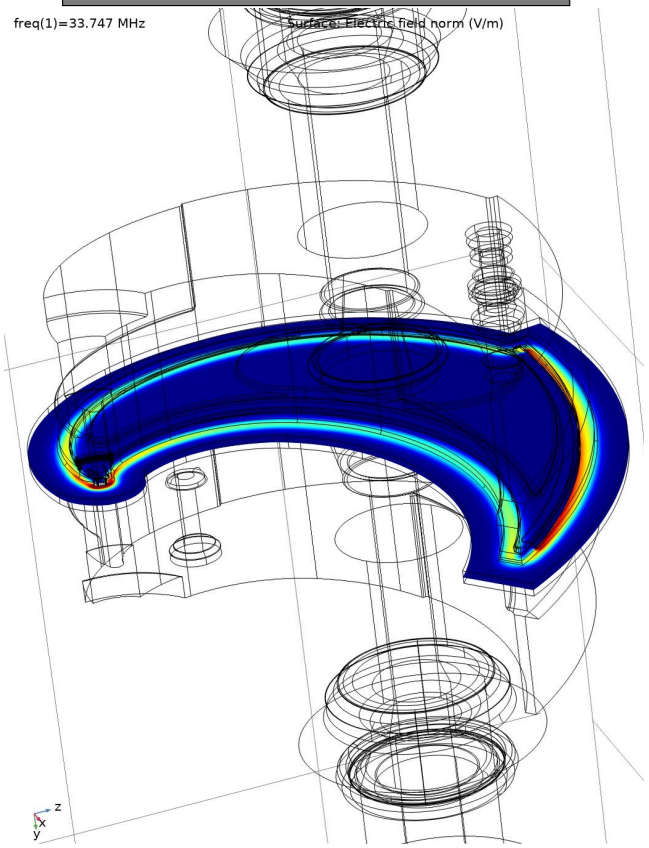
Efficient coupler/mode launcher

Frequency Scaling up to mm-wave

- [G. Torrisi et al 2019 J. Phys.: Conf. Ser. 1350 012188]
- [G. Torrisi et al., "RF design and experimental test of a quadrupole-free X-band TM01 mode launcher," in URSI Radio Science Bulletin, 2020, 373, 2020]
- [G Castorina et al 2018 J. Phys.: Conf. Ser. 1067 082025]

3D electromagnetic RF simulations with CST and Comsol software

Fully 3 D simulation of the **entire cavity geometry**

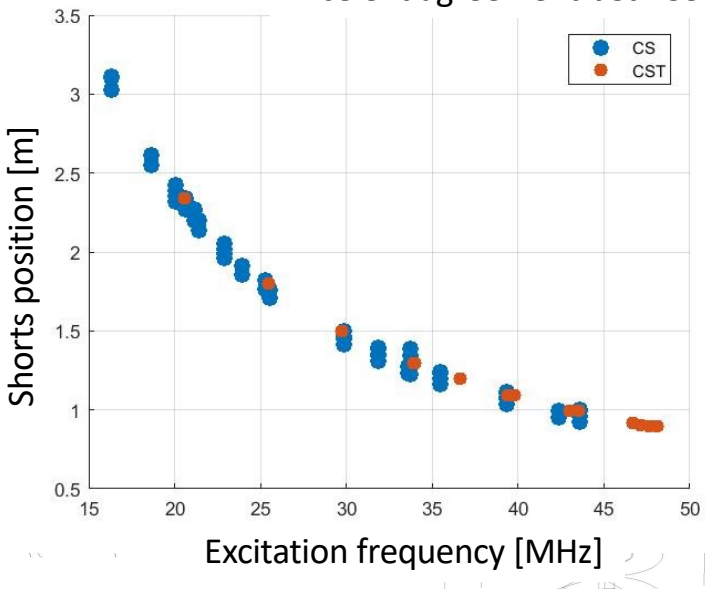


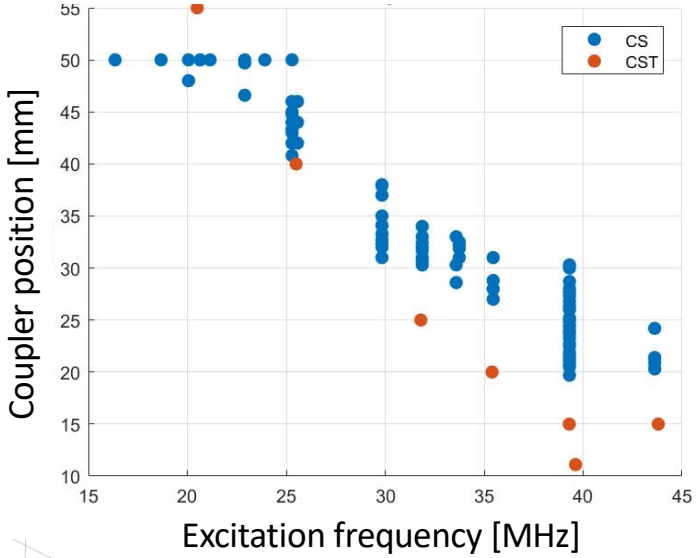
Experimental tuning parameters of cavities for different beams

Date	Frequency [MHz]	Energy [MeV/amu]	Beam	CAVITIES																	
				Sliding Shorts [mm]			Coupling Capacitors [mm]			Trimming Capacitors [mm]			SWR (Network Analyzer)			SWR (from ZPV)			V_{ref} [mV]		
				S_s1	S_s2	S_s3	C_c1	C_c2	C_c3	T_c1	T_c2	T_c3	1	2	3	1	2	3	1	2	3
18/05/2016	35,4568	50,0	^{16}O	300,8	300,5	262,0	27,0	28,0	31,0	26,4	17,8	14,2									465
08/06/2016	20,0600	15,3	^{18}O	1488,0	1488,0	1422,0	50,0	50,0	48,0												123
27/06/2016	22,9002	20,0	^{16}O	1118,5	1118,0	1060,5	50,0										1,04	133	139	210	
29/06/2016	39,3112	62,0	$^{1}H, ^{12}C$	175,3											1,01	1,11	1,10	1,10	349	312	458
11/07/2016	29,8350	35,0	^{40}Ar										1,01	1,01	1,08	1,10	1,06	1,16	245	253	402
14/07/2016	22,9002	20,0								11,3	19,6	20,6	1,02	1,05	1,08	1,03	1,20	1,04	133	142	214
18/07/2016	16,3500						50,0	50,0	50,0	15,1	16,5	17,8	1,80	1,70	2,00	1,63	1,53	1,71	92	114	182
31/10/201					206,8	170,5	27,7	23,7	24,4	14,0	24,8	29,0	1,06	1,13	1,07	1,16	1,13	1,08	346	327	488
05/11/2																1,17	1,16	1,11	347	321	490
14/11/2			^{20}Ne	1523,0	1522,0	1454,7	50,0	50,0	50,0	16,0	17,3	15,0	1,27	1,17	1,36	1,19	1,18	1,25	79	92	123
17/11/20		15,3	^{20}Ne																77	86	124
07/12/2016	39,3112	62,0	$^{1}H, ^{12}C$	209,0	206,8	169,8	30,0	21,6	22,5	16,8	15,5	14,7	1,04	1,01	1,03	1,20	1,10	1,25	348	303	476
16/12/2016	31,8707	40,0	^{84}Kr	490,0	487,5	442,7	34,0	30,3	31,7	19,6	26,4	26,6	n.p.	n.p.	n.p.	1,13			272	268	420
23/12/2016	39,3112	62,0	$^{1}H, ^{12}C$	209,0	206,8	170,0	30,3	20,5	25,2	30,2	24,8	33,3				1,19	1,18	1,09	348	303	476

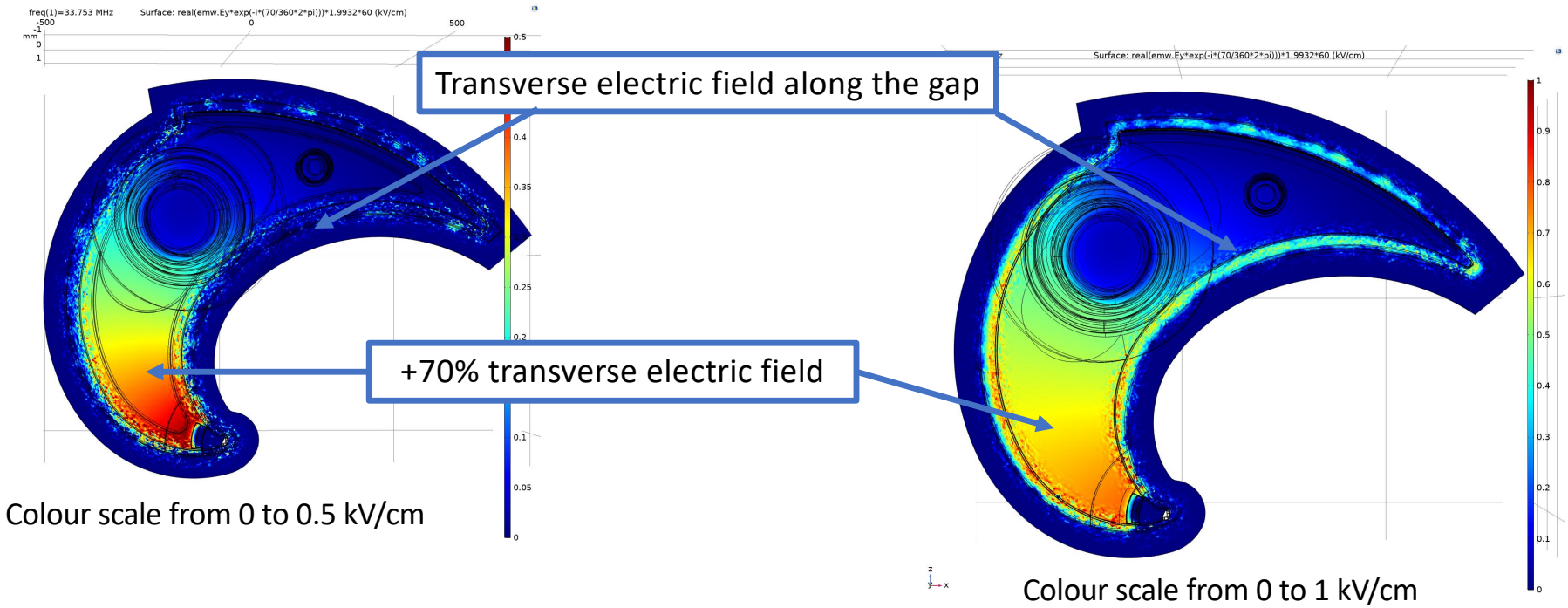
Coupler

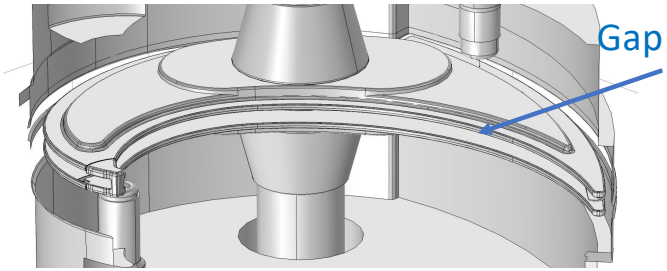
Excelent agreement between simulation and experimental data

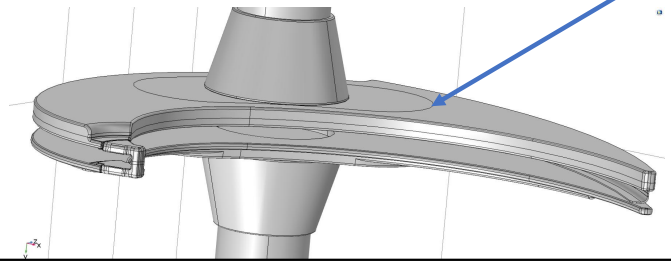




30 mm symmetric gap vs 30 mm asymmetric gap

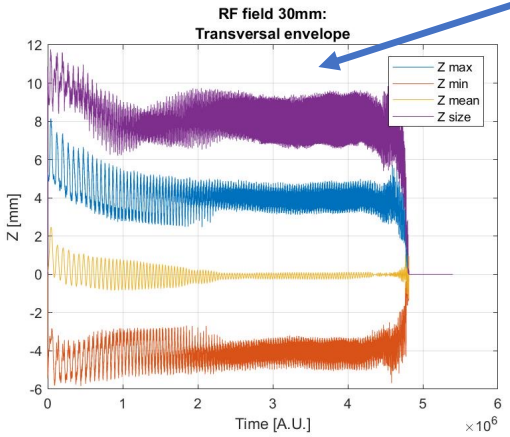


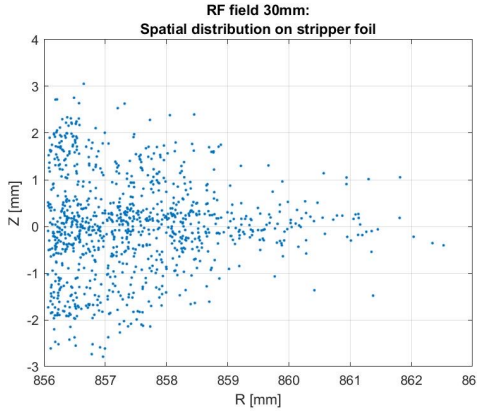


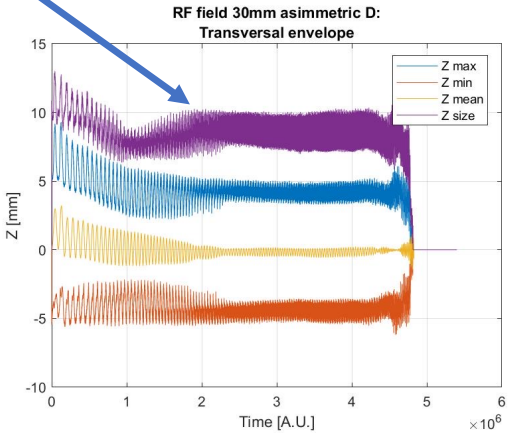


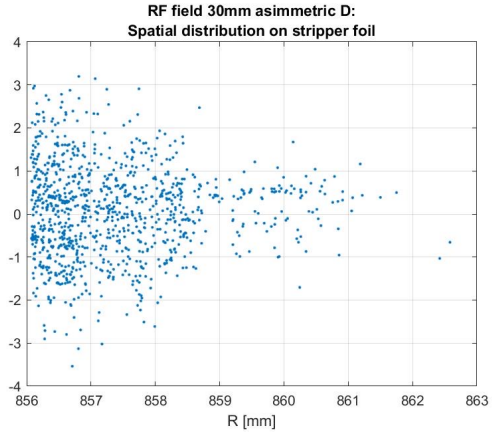
30 mm symmetric gap vs 30 mm asymmetric gap

Small increase of vertical size









[Torrisi, G; Mauro, G.S.; Neri, L.; Allegra, L.; Caruso, A.; Gallo, G.; Longhitano, A.; Maggiore, M.; Rifuggiato, D.; Spartà, A. "Electromagnetic Simulations and Measurements of the K-800 Superconducting Cyclotron RF Cavity at INFN-LNS". *Appl. Sci.* **2021**, *11*,5995. https://doi.org/10.3390/ app11135995]

PROJECTS

- **DEMETRA (DiElectric and METallic Radiofrequency Accelerator)** 2016-2018 **funded by** INFN Comm. V

Submitted Proposals under evaluation:

- **MICRON** (**MI**niaturised a**C**cele**R**at**O**rs **N**etwork) INFN V Comm. [requested budget: ~200 k€ in 3 years]
- **FRIDA** (**F**LASH **R**adiotherapy with h**I**gh **D**ose-rate particle be**A**ms) INFN CSN5 Call 2021 [requested budget: ~1 M€]
- **Micro Optical Dielectric AcceLerator (MODAL)**, *EIC Pathfinder Open* - European Innovation Council – OPEN-PATHFINDER [date of submission:24-01-2021, requested budget: 3 M€]
- **Electromagnetic PhotonIc Crystal Accelerators (EPICA)**, Relevant Researches of National Interest (in Italian: *PRIN,* Progetti di Ricerca di Interesse Nazionale), Italian Ministry of Education, University and Research (MIUR) h PRIN [date of submission: 26-01-2021, requested budget: ~1 M€]

"Rete della Radiofrequenza nell'INFN"

TAVOLA ROTONDA - PUNTI PER UNA DISCUSSIONE

- quali competenze mi mancano che ho visto potrebbero esserci altrove?
- quali tra le attività presentate oggi hanno suscitato il mio interesse e sulle cui non escludo di (o vorrei) collaborare?
- ho individuato competenze/persone/strumentazioni che potrebbero risolvere attuali carenze o criticità del mio gruppo? quali?

BD (-->LASA)

- vedo delle opportunità di partecipare a progetti nazionali/internazionali, ma mi servirebbero delle competenze che ho visto oggi esserci in altre strutture?
- vedo competenze strategiche totalmente assenti che potrebbero penalizzare la comunità come insieme? Ci sono azioni che si possono mettere in campo per colmare eventuali gap nei confronti dei grandi laboratori internazionali?

nanosorgenti-nanofasci --> (TuWien), beam-->(Candle)